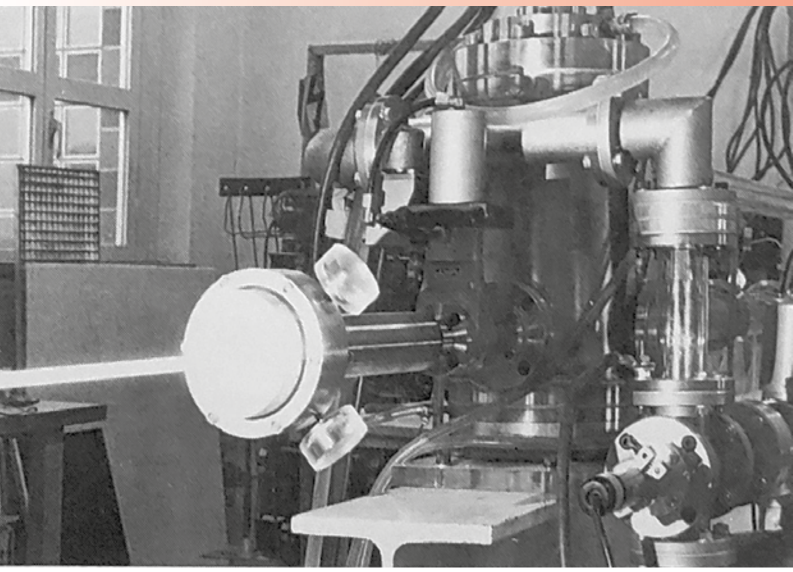
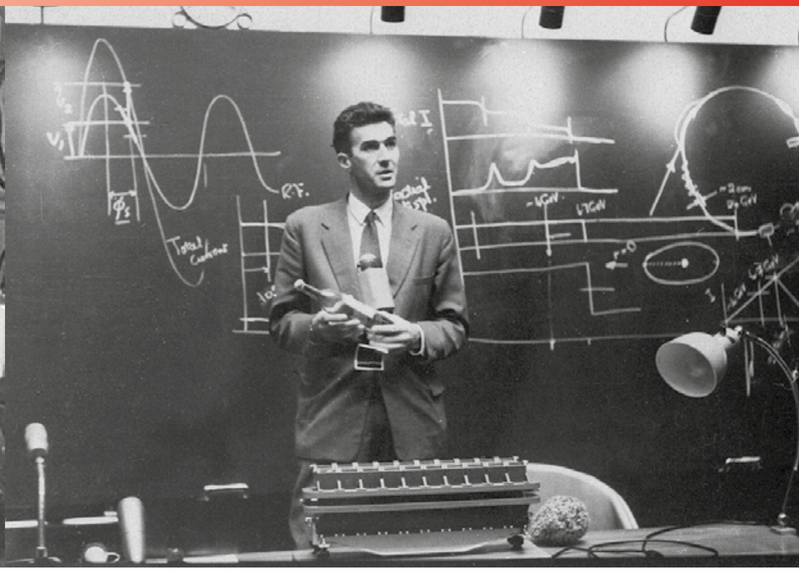
swiss physical society

Nr. 61
Juni 2020

SPG MITTEILUNGEN
COMMUNICATIONS DE LA SSP



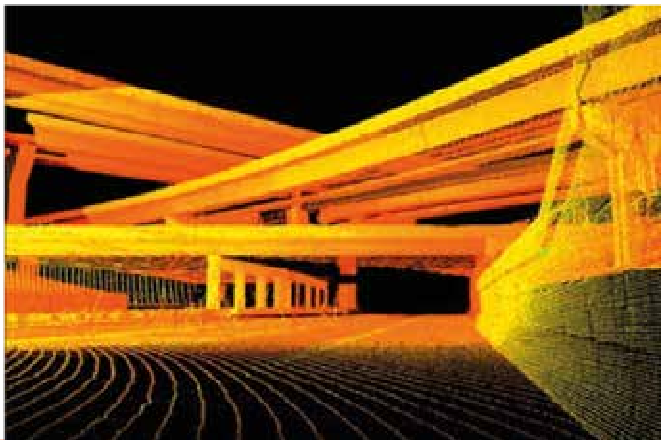
150 Watt Argon-Ion Laser Operation in Bern. The full story on p. 22. Reprinted from Laser Focus August 1970, courtesy of Endeavor Business Media, LLC.



John Adams, leader of the construction team, during the celebration of the first acceleration of particles in the Proton Synchrotron (PS) to 24 GeV in 1959 (CERN-HI-5901881-1). More on the PS's 60th anniversary on p. 32. Picture: © CERN

Left: View from 4000 m asl with the muon telescope inclined by 45°. More on "Cosmic Rays at the 42nd Hot-Air Balloon Festival in Château-d'Oex" on p. 40.

Right: 3D-Lidar Scan to assist autonomous driving, see p. 44.



Annual Meeting of the
Swiss Physical Society
29 June - 3 July 2020, Université de Fribourg

CANCELLED

in collaboration with

CHIPP, SGN, PGZ, SCNAT, Département de Physique - Université de Fribourg

Details on p. 4.

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Editorial

Physics in the time of the Corona virus (2020)

Giovanni Dietler, EPFL

By paraphrasing Gabriel Garcia Marquez's novel "Love in the time of cholera" (1985) I just wanted to state that we, physicists, have a role to play when it comes to understand living matter or conversely when living matter is challenging us like today.

This requires that physics considers living matter at the same level of importance as the other branches of physics. Ignoring living matter is like ignoring ourselves, we are made out of living matter !

Actually, living matter is a part of physics that has peculiar properties not found in "dead" matter. The list of special properties of living matter is rather astonishing: namely it has the ability to reproduce autonomously (means without the need of an external machinery) with the help of solely an energy input. It has the ability to evolve in time and it can rapidly adapt to external stimuli. It can go up the scale of complexity and of order against entropy due its energy input and also output. Across time and length scales it can perform complex functions, from the nanomachines inside a cell, to a flying insect or to the functional complexity of the brain. Another property of living matter is the huge complexity and its compositional heterogeneity on a wide range of length and time scales, and still there is an organization across these scales. For example, in the brain the basic modules (~ 10^{12} neurons) are assembled in a 3-dimensional network of about thousand connections per neuron leading to complex functions like learning, memory, decision making pathways, image and sound recognition, etc. Living matter is dynamic, it can change in time. Speaking of time, there is a wide range of time scales involved in living matter, from the picosecond scale of electronic phenomena at the molecular level up to the hours, days, months or years of the life of a biological organism. Also think of the fate of a fertilized ovule which undergoes cell division from one single cell up to billions of cells (~ 10^{13}) in an adult organism over a time span of years. Inside a single cell (diameter 10-100 μm), there are 10'000 different proteins that seamlessly work together to perform all the needed tasks of a living organism.

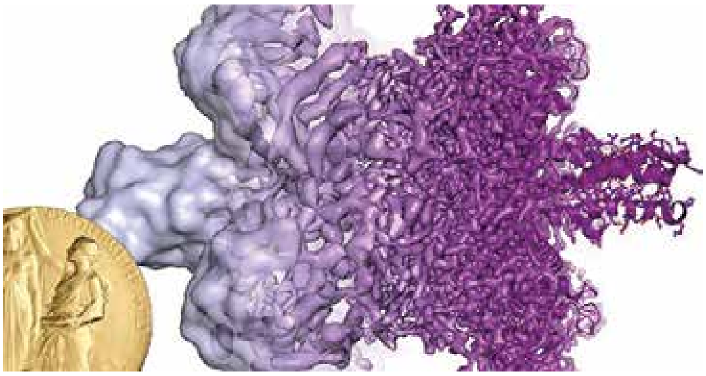
The "plasticity" of living matter on length and time scales is a real challenge for physics.

Why I am speaking of this? It needs a quantitative understanding and a conceptual framework in order to understand this special matter. What are the laws governing all this complex machinery? Often, I think in terms of the present situation in condensed matter: simply speaking, given Coulomb interaction (described in 1785) and the fine structure constant, one can derive "everything" about condensed matter starting at the scale of the atom up to the solid state. We get all the electronic properties of matter, all the phenomena of "dead" matter. Of course, I strongly simplify by neglecting the other essential ingredients needed that came along the twisty path of physics like quantum physics, relativity and the rest of the theories that followed Coulomb's initial discovery.

For living matter, we need something similar, that allows to construct its properties and derive its properties from few basic principles or laws. How molecules in thermal bath can go from simple few molecules up to an organism with billions of cells working all together to have a living organism? This is not a simple task given the constraints of thermodynamics. There is an urgent need of developing out-of-equilibrium theories for these complex systems.

To reach this goal, biophysics has to go deeper into the complexity and heterogeneity of living matter and develop the tools (theoretical, numerical and experimental) needed for this endeavor.

We have in the past years heard about the experimental tools by physicists and biophysicists with the attribution of Nobel prizes (Binnig & Rohrer, Wüthrich, Betzig & Hell & Moerner, Dubochet, etc), but the theoretical and experimental efforts should be as strong if we want to understand living matter.



Cryo-Electronmicroscopy has become the tool of choice to elucidate the structure of biomolecules. (J. Dubochet, Nobel Prize 2017)

In the present societal situation, a deeper understanding of the physics of living matter would have had an impact on the management of the strategy to fight the infection. But as an old saying states "Do not start to feed the dogs before hunting", physics should now take up the challenge and advance in the understanding of living matter and be prepared for the next challenge.

Jahrestagung der SPG in Fribourg, 29. Juni- 03. Juli 2020
Réunion annuelle de la SSP à Fribourg, 29 juin - 3 juillet 2020

abgesagt - annulée

Vorwort

Die diesjährige Jahrestagung der SPG, mit Beteiligung von CHIPP, SGN, PGZ und SCNAT, muss leider aufgrund der Corona Situation abgesagt werden.

Nach Prüfung verschiedener Szenarien hat der Vorstand entschieden, am **1. Juli** nur ein Notprogramm, bestehend aus Generalversammlung und Preisverleihung, durchzuführen. Diese Veranstaltungen werden auch nur in Form einer Videokonferenz stattfinden.

Der Vorstand war sich auch einig, dass das im Rahmen der Jahrestagung geplante Symposium zum Röntgen-Doppeljubiläum (125 Jahre Röntgenstrahlen und 175. Geburtstag von Wilhelm Conrad Röntgen) in einer Videokonferenz nicht gebührend gefeiert werden kann. Wegen der Bedeutung dieser Erfindung, zum Beispiel in der modernen Medizin, aber auch wegen der Tatsache, dass Röntgen in Zürich diplomiert und 1869 promoviert hatte, soll das Symposium wie geplant, jedoch zu einem späteren Zeitpunkt nachgeholt werden. Wir werden rechtzeitig informieren, sobald der neue Termin bekannt ist.

Zwei andere Jubiläen, ebenfalls mit direktem Bezug zur Schweiz, können wir aber in dieser Ausgabe in der Reihe "Meilensteine der Physik" feiern. So begeht die UNESCO am 16. Juni 2020 den 60. Jahrestag der Einführung des Lasers, der unsere heutige Zeit in vielen Bereichen der Wissenschaft und des Alltags nachdrücklich geprägt hat. In Bern erkannte man frühzeitig das Potential der Erfindung und trug mit wichtigen wissenschaftlichen Arbeiten zum heutigen Erfolg massgebend bei. Daran erinnern sich direkt Involvierte in einem Artikel auf Seite 22. Ebenfalls vor 60 Jahren wurde das Protonensynchrotron PS am CERN in Betrieb genommen, das in seiner technischen Komplexität bereits alle Schwierigkeiten der nachfolgenden Ausbaustufen vorwegnahm. Wie all die Herausforderungen damals gemeistert wurden, so dass das PS auch zum Ausgangsinstrument heutiger Grossanlagen wurde, darüber berichten Kollegen aus erster Hand auf Seite 32.

Im Folgenden finden Sie die Informationen für die SPG Mitglieder sowie die Angaben, um an der Generalversammlung teilnehmen zu können.

Trotz der aussergewöhnlichen Umstände hoffen wir auf eine rege Beteiligung an der diesjährigen "geschrumpften" Tagung und freuen uns, Sie im nächsten Jahr gesund und munter wieder an einer vollständigen Konferenz begrüssen zu dürfen.

Avant-propos

La réunion annuelle de la SSP, avec la participation de CHIPP, SSSN, PGZ et SCNAT, doit malheureusement être annulée cette année en raison de la situation sanitaire.

Après avoir examiné différents scénarios, le comité a décidé de ne lancer qu'un seul événement urgent le **1er juillet**, consistant en l'Assemblée générale et la cérémonie de remise des prix. Ces événements ne seront organisés que sous forme de visioconférence.

Le comité a également convenu que le symposium pour le double anniversaire Röntgen (125 ans de rayons X et 175ème anniversaire de Wilhelm Conrad Röntgen) planifié dans le cadre de la réunion annuelle ne pouvait pas être célébré comme il se doit en visioconférence. En raison de la portée de cette invention, par exemple en médecine moderne, mais aussi parce que Röntgen a obtenu son diplôme à Zurich et y a obtenu le doctorat en 1869, le symposium aura lieu comme prévu, mais à une date ultérieure. Nous vous informerons en temps utile, dès que le la nouvelle date sera connue.

Il y a deux autres anniversaires, également en relation directe avec la Suisse, que nous présentons dans ce numéro sous la rubrique "Evénements clés de la physique". Ainsi l'UNESCO fête le 16 juin 2020 le 60e anniversaire de l'introduction du laser, qui a marqué notre époque dans de nombreux domaines de la science et de la vie de tous les jours. À Berne, on a reconnu très tôt le potentiel de cette invention et contribué avec d'importants travaux scientifiques au succès actuel. Des chercheurs directement impliqués s'en souviennent dans un article à la page 22. Il y a également 60 ans que le synchrotron à protons PS a été construit et mis en service au CERN et qui, dans sa complexité technique, a déjà résolu nombre de difficultés des étapes d'expansion suivantes. Un rapport de collègues de première main fait le point à la page 32 et montre comment toutes les difficultés maîtrisées font du PS l'instrument à l'origine des grandes installations actuelles.

Vous trouverez ci-dessous les informations s'adressant aux membres de la SSP et les données pour participer à l'assemblée générale.

Malgré les circonstances exceptionnelle, nous espérons avoir une participation soutenue à cette réunion "rétrécie" et nous nous réjouissons de vous souhaiter la bienvenue en bonne santé l'année prochaine à une conférence complète.

Generalversammlung 2020 - Assemblée Générale 2020

Mittwoch 1. Juli 2020, 14:00h - Mercredi 1er juillet 2020, 14:00h
Videokonferenz - Visioconférence

	Traktanden	**Ordre du jour**
1.	Protokoll der Generalversammlung vom 27. August 2019	Procès-verbal de l'assemblée générale du 27 août 2019
2.	Bericht des Präsidenten	Rapport du président
3.	Projekte	Projets
4.	Rechnung 2019, Revisorenbericht	Bilan 2019, rapport des vérificateurs des comptes
5.	Wahlen	Elections
6.	Neues Ehrenmitglied	Nouveau membre d'honneur
7.	Diverses	Divers

Die Generalversammlung ist nur für Mitglieder der SPG zugänglich. Dazu ist eine Anmeldung auf https://indico.cern.ch/e/SPS_GA2020 erforderlich. Nach erfolgreicher Prüfung erhalten Sie eine Bestätigung. Weitere Details finden Sie unter obigem Link.

L'assemblée générale n'est accessible qu'aux membres de la SSP. Pour y participer, il faut s'inscrire sur https://indico.cern.ch/e/SPS_GA2020. Vous recevrez une confirmation après une vérification de vos droits de vote. Veuillez trouver toutes les informations nécessaires sous le lien ci-dessus.

Preisverleihung - Cérémonie de remise des prix

SPG Preise und Charpak-Ritz Preis - Prix de la SSP et prix Charpak-Ritz

Mittwoch 01. Juli 2020, 15:30h - Mercredi 1er juillet 2020, 15:30h
Videokonferenz - Visioconférence

Die Preisverleihung ist öffentlich. Der Link zur Videokonferenz wird rechtzeitig auf https://indico.cern.ch/e/SPS_GA2020 bekanntgegeben.

La cérémonie de remise des prix est ouverte au public. Le lien vers la visioconférence sera publié en temps voulu sur https://indico.cern.ch/e/SPS_GA2020.

Für beide Videokonferenzen wird die Software "Zoom" verwendet. Der Client kann kostenlos unter https://zoom.us/support/download heruntergeladen werden.

Le logiciel utilisé pour les deux visioconférences sera "Zoom". Le client gratuit peut être téléchargé sur https://zoom.us/support/download .

A note from the President

What has the corona crisis to do with physics, or even the Swiss Physical Society? Not much, one could think, other than the fact that this year's annual meeting had to be cancelled, following health and hygiene measures that for good reasons need to be observed. This thinking, however, goes way too short.

The corona pandemic is a global thread and what affects one person anywhere affects everyone everywhere. For this simple reason, we need to think and act globally, rather than compartmenting, dividing nations, race, ethnicity, or economic status.

Science in general and physics in particular have paved the way on how to collaborate globally, exchanging ideas with a free flow of information, advancing understanding and explaining the world at the microscopic and macroscopic scale, developing tools, technologies and methods. Often, these find their way into everyone's life, for instance via start-up companies of which some grow up to become global actors.

To address the corona pandemic, knowledge, methods and tools are needed that we have only at hand because of basic research done in the past. And here, I am not only talking about medical research, or more specifically virology, which these days is in the spotlight, but I explicitly mean physics, and to be inclusive again, I mean all branches, applied and fundamental. Where would we be without a basic understanding of matter at the quantum level, or the sophisticated infrastructure and tools developed in the quest to understand matter this deep? Understanding the inner workings of a virus without the tools provided by fundamental physics research is unthinkable. From sophisticated laser setups to whole particle accelerator chains, understanding the biochemistry of viruses needs high-tech infrastructure, that would not exist without the long history of physical research made. In the crisis of today, many physics labs engage in building tools to fight corona directly.

It's not only about tools and infrastructure, it is also about the way complex problems are being attacked. In physics, we learned long ago to effectively build large-scale collaborations and a free and open exchange of ideas. A good example is arXiv.org, a pre-print server allowing for free and broad access to latest developments. Sharing (preliminary) results is allowing for fast turn-around and swift advancing. I am more than happy to see that successful schemes find their way into other fields. So have bioRxiv.org for biology and medRxiv.org for medical research emerged for good reason. Typing 'covid' into the search field of medRxiv.org yields over 2000 preprints at the time of writing this text.

With the urgent need to find a solution to fight SARS-CoV-2, the virus causing COVID-19, we realize again the reason for publishing papers. It is not about satisfying publishers economic desires, and it is not about advancing one's own career or the ranking of one's institute. The true reason is about advancing science and with it, providing ideas, understanding, methods, tools, infrastructure, … to society. With global crises to be solved, like the current pandemic, it becomes also clear that what is meant with society, implies to mankind at the global scale.

Trust in Science and scientific reasoning has always been good in Switzerland and this is one of the reasons of its success. At the global scale however, mistrust and even denial of scientific reasoning and its capabilities in solving problems of utmost urgencies are often seen and even powerful nations seem to prioritize short-term profits over finding of long-term solutions. Conspiracy theories and fake news find their fast and unstoppable way through large fractions of society.

Where fake news prevail, science and scientific reasoning is the only answer that exists. Even if hard, there is no way that fake news could be fought with more fake news.

What has been positive about the current crisis is too see how fast politics and stakeholders can act, once a problem is accepted to be tackled. This is of utmost importance, as once the corona pandemic will be behind us, other threats to society at the global scale will emerge back to the daily agenda. I mean climate and energy first, but there are more to tackle. Common to these is that they pose a global threat that need to be addressed globally, asking again for a free exchange of ideas, methods, tools, etc. Physics, and with it, the big-science projects and large-scale collaborations, have paved the way on how to address and find solutions to complex and fundamental questions – not only for the good of physics, but for society at the global scale.

Hans Peter Beck

Protokoll der Generalversammlung vom 27. August 2019 in Zürich
Protocole de l'assemblée générale du 27 août 2019 à Zürich

Agenda

1. Approval of the Minutes of the General Assembly held at EPFL on 28 August 2018
2. Brief Report from the President
3. Projects
4. 2018 Finances and Auditors Report
5. Elections
6. Delegates
7. Varia

The President opens the General Assembly 2019 at 11:30.

1. Approval of the Minutes of the General Assembly held at EPFL, Lausanne on 28 August 2018

The protocol of the last General Assembly, published in the *SPG Mitteilungen* Nr. 58 on p. 6 is unanimously approved.

2. Brief Report from the President

The President welcomes the 60 new members to the Society, which now counts 1141 members, thereof 18 honorary members and 24 associate members. With 67 members leaving, this marks again a slight decrease with respect to last year's count. The President states that the Society is healthy and but it can be more effective, create bigger impact and enable a stronger network with increased membership.

3. Projects

The President then reports on the main goals of the Society and the activities organized and/or supported in 2018. Besides the organization of the main annual event, the Society is organizing smaller, regional seminars and symposia, often together with the help of regionally embedded associations. Examples are the Richard Feynman centennial Symposium (together with the History and Philosophy of Science Unit of the Geneva University) or the Jost Bürgi Symposium (together with the Jost Bürgi foundation).

Promoting the youth is one of the key activities of the Society, which it does via sponsoring various events targeted to young talents like the *Swiss Physics Olympiad*, the *Swiss Young Physicists' Tournament*, the *International Physicists' Tournament*, etc. Further by supporting the Swiss *Young Physicists Forum*, the EPS *Young Minds*, and without forgetting the very young where the *Physics in Advent* is exemplary for inspiring and raising interest of the next generation. A novum in this year's annual meeting is for young talents who were winning national and excelling in international competitions to have the chance to participate in a young talents day. They are awarded with a diploma and guided through the physics institute and laboratories of the organizing host university, whereby they not only get acquainted with how physics works in institutes and laboratories, but also can build up their own local network among themselves, with the offerings SPS holds for them, and any other physicists they have a chance to meet at the event.

The Society is further promoting individual physicists by giving awards to young and gifted minds. Five young physicists are awarded this year with SPS Prizes sponsored by ABB, IBM, Oerlikon Surface Solutions, METAS, and COMSOL, respectively.

Confirmed physicists are awarded with the Charpak-Ritz Prize which is bestowed jointly by the French Physical Society and the Swiss Physical Society. In 2019, the Charpak-Ritz award was given to Benoît Deveaud "for pioneering optical spectroscopy studies dedicated to the ultrafast and quantum optical properties of semiconductor nanostructures".

The High Altitude Research Station Jungfraujoch HFSJG (https://www.hfsjg.ch/en/home/) received the prestigious award as "EPS Historic Site" from the European Physical Society. The inauguration and the unveiling of the commemorative plaque took place on 8 February 2018, which is reported on page 8 of the *SPG Mitteilungen* Nr. 57.

The Society is informing its members with three issues of the *SPG Mitteilungen* per year and the meanwhile well-established monthly newsletter.

4. 2018 Finances and Auditors Report

The 2018 annual financial report is presented by the treasurer, Dr. Dirk Hegemann (see page 9 of the *SPG Mitteilungen* Nr. 58). Prof. Dr. Philipp Aebi and Dr. Pierangelo Gröning, the auditors of this report, have approved the numbers and their statement can be found on page 10.

A net income of 18'308.69 Swiss Francs is accounted for. The treasurer explains that the benefits or losses depend mostly on the success of our annual meetings. Most of the surplus of 2018, however, follows from contribution pledges from SCNAT, which are booked as income, although the money will only be received upon effective spending made in Spring of the coming year. In particular, a deficit guarantee over CHF 10'000.- for the annual meeting 2018 is accounted for as income. As the deficit guarantee was not used, SPS will also not receive it from SCNAT.

The annual financial report is approved unanimously by the General Assembly which gives discharge to the Board.

5. Elections

The following committee members have reached the end of their current mandate and can be re-elected for a further term according to our statutes, and are re-elected unanimously by the General Assembly:

- President: Prof. Hans Peter Beck (for 2 years)
- Vice-president: Dr. Bernhard Braunecker (for 1 year)
- Atomic Physics and Quantum Optics: Prof. Philipp Treutlein (for 2 years)

Stéphane Goyette (Earth, Atmosphere and Environmental Physics) has reached the end of his extended mandate (see General Assembly 2018). Unfortunately still no successor could have been found for him so the position will remain vacant for now.

Prof. Dr. Philipp Aebi and Dr. Pierangelo Gröning have been unanimously reappointed to their roles of auditing the SPS finances.

6. Delegates

The SPS maintains relations with other scientific societies and international organizations. The executive board appoints delegates to these who act as link-persons, assuring for good relations and flow of information. The following persons have been appointed:

• AHP Editorial board	Prof. Gian-Michele Graf
• AHP Editorial board	Prof. Thomas Jung
• IUPAP	Prof. Hans Peter Beck
• EPS Council	Prof. Hans Peter Beck
• SATW	Dr. Kai Hencken
• SCNAT	Dr. Christophe Rossel

7. Varia

The President states that the Swiss Physical Society is a 'learned society' with goals and interests to link and interlink physicists in Switzerland and beyond. He stresses that physicists are: professionals, teachers, undergraduate and graduate students, postdocs who are directly active in physics in academia, at research institutes, in industry, at schools, or anyone with a deeper interest in physics.

The President also repeats a statement he made in the *SPG Mitteilungen* Nr. 58:

> *SPS is actively supporting young talents for enabling a next generation of physicists who can contribute tackling the challenges society faces. With what we can do today, and with what an educated and savvy next generation of talents will be able of doing, climate change, energy strategy 2050, artificial intelligence, quantum computing, and many more challenges can all be mastered. It needs, however, an environment which allows these talents to flourish. SPS is taking its share in contributing exactly here, but it needs your help by being a Member, an Associate Member or a SPS Prize sponsor to allow SPS fulfilling its mission.*

Upon request by the president whether there is any other business to be discussed, Peter Wolff makes a statement that *physics articles should not only be allowed to be published in English, but also articles in German, French, or Italian should be readily accepted. Otherwise, a non-ideal monoculture would emerge.*

The president replies that English is the 'lingua franca' in physics and all disciplines of natural sciences. Publishing in English guarantees that the widest possible audience is reached and can contribute scientifically. The *SPG Mitteilungen* feature articles in all Swiss languages, but mostly English is used to guarantee for wide audience.

The President closes the meeting at 12:30.

Statistik - Statistique

Neue Mitglieder 2019 - Nouveaux membres en 2019

Aguiar Maceira Ivo, Allenspach Stephan, Almat Nil, Arbet-Engels Axel, Ayres Nicholas, Backhaus Malte, Bardyn Charles-Edouard, Boselli Margherita, Brown Adam, Brülisauer Manuel, Businger Moritz, Cabrera Cifuentes Hugo Leonel, Celani Sara, Chanel Estelle, Chatterjee Meghranjana, Chiu Pin-Jung, Colonna Francesco, Conconi Luca, Däster Simon, De Simone Dario, Dumont Elisabeth, Ek-In Surapat, Falletta Stefano, Ferreira Lopes Lino, Ferrillo Martina, Frahm Kolja, Franke Andrew, Friedel Sven, Gaina Roxana, Galloway Michelle, García Pardiñas Julian, Gisler Tanja, Guguchia Zurab, He Qi, Herger Roger, Holzäpfel Adrian, Ilie Ioana-Măriuca, Jandke Jasmin, Janoschek Marc, Klein Yannick Maximilian, Korosec Lukas, Kutbay Ümit, Leuenberger Markus, Lyzwa Fryderyk, Ma Keyuan, Marsch Guido, Mergenthaler Matthias, Molignini Paolo, Müller Katharina, Müller Clemens, Musso Maurizio E., Nayak Mithilesh, Nuber Jonas, Ochs Markus, Offeddu Nicola, Pan Fei, Patzke Greta Ricarda, Pietrzyk Guillaume, Puphal Pascal, Redi Federico Leo, Römer Niklas, Sanchez Nieto Federico, Sarkar Subhrangsu, Schäfer Max, Schneider Johannes, Schulte Sebastian, Sheveleva Evgeniia, Shlykov Aleksandr, Soter Anna, Stefko Pavol, Strobl Markus, Tenasini Giulia, Thorne Jacob, Tseng Yi, Tully Alison Maria, Vicente Pais Duarte Alexandre, Vieites Díaz María, Visuri Anne-Maria, von Rohr Fabian O., Waelchli Adrien, Walicka Dorota, Witteveen Catherine, Yin Zhong, Yu Le, Zeyen Manuel

Ehrenmitglieder - Membres d'honneur

Prof. Hans Beck (2010)
Dr. J. Georg Bednorz (2011)
Prof. Jean-Pierre Borel (2001)
Prof. Maurice Bourquin (2018)
Prof. Jean-Pierre Eckmann (2011)
Prof. Charles P. Enz (2005)
Prof. Hans Frauenfelder (2001)
Prof. Jürg Fröhlich (2011)
Prof. Hermann Grunder (2001)
Prof. Martin C. E. Huber (2011)
Prof. Piero Martinoli (2016)
Prof. K. Alex Müller (1991)
Prof. Hans Rudolf Ott (2005)
Prof. T. Maurice Rice (2010)
Prof. Louis Schlapbach (2010)
Prof. Herwig Schopper (2015)
Prof. Norbert Straumann (2016)

Assoziierte Mitglieder - Membres associés

A) Firmen
- ABB Schweiz AG, 5405 Baden
- COMSOL Multiphysics GmbH, 8005 Zürich
- IBM Research GmbH, Forschungslabor, 8803 Rüschlikon
- METAS, 3003 Bern-Wabern
- Oerlikon Surface Solutions AG, LI-9496 Balzers

B) Universitäten, Forschungseinrichtungen
- Albert-Einstein-Center for Fundamental Physics, Universität Bern, 3012 Bern
- CERN, 1211 Genève 23
- Swiss Plasma Center (SPC), EPFL, 1015 Lausanne
- Département de Physique, Université de Fribourg, 1700 Fribourg
- Departement Physik, Universität Basel, 4056 Basel
- Departement Physik, ETH Zürich, 8093 Zürich
- EMPA, 8600 Dübendorf
- Lab. de Physique des Hautes Energies (LPHE), EPFL, 1015 Lausanne
- Paul Scherrer Institut, 5332 Villigen PSI
- Physik-Institut, Universität Zürich, 8057 Zürich
- Section de Physique, Université de Genève, 1211 Genève 4
- Section de Physique, EPFL, 1015 Lausanne

C) Studentenfachvereine
- AEP - Association des Etudiant(e)s en Physique, Université de Genève, 1211 Genève 4
- Fachschaft Physik und Astronomie, Universität Bern, 3012 Bern
- Fachschaft Physique, Université de Fribourg, 1700 Fribourg
- Fachverein Physik der Universität Zürich (FPU), 8057 Zürich
- Fachgruppe Physik Universität Basel, 4056 Basel
- Les Irrotationnels, EPFL, 1015 Lausanne
- Verein der Mathematik- und Physikstudierenden an der ETH Zürich (VMP), 8092 Zürich

Verteilung der Mitgliedskategorien - Répartition des catégories de membres (31.12.2019)

Ordentliche Mitglieder	653
Doktoranden	74
Studenten	34
Doppelmitglieder DPG, ÖPG, APS oder VSMP	164
Doppelmitglieder PGZ	65
Mitglieder auf Lebenszeit	115
Assoziierte Mitglieder	24
Bibliotheksmitglieder	2
Ehrenmitglieder	17
Beitragsfreie (Korrespondenz)	6
Total	**1154**

Jahresrechnung 2019 - Bilan annuel 2019

Bilanz per 31.12.2019	Aktiven	Passiven
Umlaufsvermögen		
Postscheckkonto	75878,69	
Bank - UBS 230-627945.M1U	35847,82	
Debitoren - Mitglieder	1780,00	
Debitoren - SCNAT/SATW u.a.m.	59902,35	
Transitorische Aktiven	2500,00	
Anlagevermögen		
Beteiligung EP Letters	15840,00	
Mobilien	1,00	
Fremdkapital		
Mobiliar		1,00
Mitglieder Lebenszeit		72883,25
Transitorische Passiven		14405,59
Eigenkapital		
Vefügbares Vermögen		108932,31
Total Aktiven/Passiven	**191749,86**	**196222,15**
Verlust	**4472,29**	
Summe	**196222,15**	**196222,15**
Verfügbares Vermögen per 31.12.19 nach Verlustzuweisung:		104460,02

Erfolgsrechnung per 31.12.2019	Aufwand		Ertrag
Gesellschaftsaufwand		**Ertrag**	
EPS - Membership	12694,62	Mitgliederbeiträge	95013,70
SCNAT - Membership	7637,00	Sponsorbeiträge	5000,00
SATW-Mitgliederbeitrag	1750,00	Inserate / Flyerbeilagen SPG Mitteilungen	5170,00
		Aussteller	14373,01
SCNAT Verpflichtungskredite		Zinsertrag	0,95
SPG Jahrestagung	29683,24	Ertrag aus EP Letters Beteiligung	6684,28
Schweizer Physik Olympiade	4000,00		
Übrige Tagungen SPG / SCNAT	1061,80	**SCNAT Verpflichtungskredite**	
Delegierte NuPECC, EPS, IUPAP	2791,65	SPG Jahrestagung (SCNAT)	15000,00
SPG Young Physicists Forum	4910,09	Schweizer Physik Olympiade	3500,00
Lehrerfortbildungsevent 2014 ff.	10840,60	Übrige Tagungen SPG / SCNAT	1700,00
International Physics Tournament	6500,00	Delegierte EPS, NuPECC, IUPAP (SCNAT)	2500,00
SPG Bulletin / Tagungsband (SCNAT)	11725,45	SPG Young Physicists Forum	3500,00
SCNAT Periodika (SPG Mitteilungen, Druckkosten)	20564,10	Lehrerfortbildungsevent 2014 ff.	13000,00
SCNAT Internationale Zusammenarbeit	2114,11	International Physics Tournament	6500,00
SCNAT Swiss Young Phys. Tournament	5000,00	SPG Bulletin / Tagungsband (SCNAT)	5000,00
		Periodika (SPG Mitteilungen, Druckkosten) (SCNAT)	5000,00
Betriebsaufwand		Internationale Zusammenarbeit (SCNAT)	2000,00
Löhne	30845,00	SCNAT Swiss Young Phys. Tournament	5000,00
Sozialleistungen, berufliche Vorsorge, Versicherung	19963,75		
Porti / Telefonspesen / WWW- und PC-Spesen	1117,56		
Versand (Porti Massensendungen)	7240,95		
Unkosten	3611,81		
Büromaterial	3805,50		
Bankspesen	181,90		
Debitorenverluste Mitglieder	2577,50		
Debitorenverlust SCNAT / SATW u.a.m.	2797,60		
Total Aufwand / Ertrag	**193414,23**		**188941,94**
Verlust			**4472,29**
Summe	**193414,23**		**193414,23**

Revisorenbericht zur Jahresrechnung 2019

Die Jahresrechnung 2019 der SPG wurde von den unterzeichneten Revisoren geprüft und mit den Belegen in Übereinstimmung befunden.
Die Revisoren empfehlen der Generalversammlung der SPG, die Jahresrechnung zu genehmigen und den Kassier mit bestem Dank für die gute Rechnungsführung zu entlasten.

Die Revisoren der SPG:

Prof. Dr. Philipp Aebi

Dr. Pierangelo Gröning

Dübendorf, 13.05.2020

Wahlen - Elections

An der diesjährigen Generalversammlung sind mehrere Ämter neu zu besetzen. Folgende Kandidaten stehen zur Wahl (ausführliche Präsentation während der GV):

Vizepräsident - Vice Président:
Prof. Johan Chang, Uni Zürich
Kondensierte Materie - Matière condensée (KOND):
Dr. Maria Luisa Medarde Barragan, Paul Scherrer Institut, Villigen
Atomphysik und Quantenoptik - Physique Atomique et Optique Quantique:
Prof. Guillermo Pedro Acuna, Uni Fribourg

Lors de l'Assemblée générale de cette année, plusieurs nouveaux postes doivent être pourvus. Les candidats suivants sont en lice (présentation détaillée lors de l'AG) :

Biophysik, Weiche Materie und Medizinische Physik - Biophysique, Matière molle et Physique médicale:
Prof. Christof Aegerter, Uni Zürich;
Dr. Christof Fattinger, ex F. Hoffmann-La Roche, Basel

Neues Ehrenmitglied - Nouveau membre d'honneur

Der Vorstand hat dieses Jahr einen Vorschlag für ein neues Ehrenmitglied erhalten. Die Ernennung findet im Rahmen der virtuellen Generalversammlung am 01. Juli 2020 statt.
Le comité a reçu une proposition pour un nouveau membre d'honneur cette année. La nomination aura lieu le 1er juillet 2020 lors de l'Assemblée Générale virtuelle.

Ralph Eichler

Ralph was born in 1947 in the UK and started his scientific career in high-school in Basel. Already very early on, his talents for experimental physics emerged, when he won the first prize in "Schweizer Jugend forscht", building his first micro-computer. University studies at ETH Zurich followed that culminated with a PhD at PSI in the field of muon-physics.

A post-doctoral position with Robert Hofstadter (Nobel Laureate 1961) at Stanford Univ. provided a most welcome opportunity to earn recognition abroad and to become involved in high-precision rare decay experiments at the "Anderson Meson Physics Facility" in Los Alamos. Then, Ralph moved on to lepton collisions at the e^+/e^- collider PETRA in the JADE experiment at the Deutsche Elektronen-Synchrotron (DESY) in Hamburg. At PETRA, the force carrier particles of the strong force, the gluons, were discovered. Ralph returned back to ETH in 1982 and became professor of physics at ETH in 1989. His career continued with research at DESY, in the H1 experiment, an electron-proton collider designated to study the structure of the proton. As spokesman of the experiment from 1995-1997, he led the H1 collaboration during very productive (e.g. precision measurements of the gluon distribution as an important input to LHC physics) and exciting times (Lepto-quark candidate anomaly).

In 2002 he became director of the Paul-Scherrer-Institut, honing his leadership skills at the helm of this large and complex national scientific research center in Villigen before taking over the presidency of ETH Zurich in 2007 in difficult times. His reliable, decisive and steady hand approach gained him the trust and admiration of this colleagues and staff, and he managed to highly successfully reinvigorate ETH Zurich.

His personal leadership style was characterized by scientific based argumentation and excellence in judgement, honesty, trust and integrity, recognizing that "a maze of regulations is not the right tool for getting the best out of ETH". His many accomplishments as president include the foundation of the Department of Health Sciences and Technology (D-HEST), the establishment of the Institute for Theoretical Studies (ETH-ITS) and the initiation of the "Gender Action Plan" to achieve an equal balance between genders. He served on numerous scientific research and governing boards, such as in the Governing Board Singapore ETH-Centre (SEC) or Scientific Advisory panels at DESY and CERN, as well as highly appreciated member of various International Advisory Committees.

Ralph Eichler always showed a strong commitment to high-quality teaching and pushed for outstanding research on any scale, be it on the small scale of research groups all the way up to developing a full university level strategy. He realized that a close connection between research and technical innovation is essential for progress, and that the gained knowledge should be transferred to society. This approach he consistently pursued both as group leader as well as ETH president. In the words of NZZ, " ... during Ralph Eichler's tenure, ETH Zurich has strengthened its role as an initiator and innovation driver for the Swiss economy and society...."

That research is a way to search for solutions to the major social problems, was one of Ralph Eichler's deepest convictions and he set new strategic priorities for ETH Zurich which is evidenced by this quote: "Climate change, energy, risk, nutrition and health are challenging tasks for which our university can make substantial contributions with its variety of disciplines." After his retirement, Ralph Eichler was elected president of the foundation council of "Schweizer Jugend forscht", closing his outstanding scientific career full circle.

The proposed laudatio reads as follows:

The Swiss Physical Society awards honorary membership to Professor Ralph Eichler for his numerous scientific achievements, his outstanding leadership in large-scale scientific collaborations and as head of PSI and ETH, and his engagement in supporting young talents, in particular his commitment for "Schweizer Jugend forscht."

The winners of the SPS Awards 2020

The SPS Award committee chaired by Professor Minh Quang Tran selected the winners for 2020 out of many submissions. The winners will be presented during the virtual award ceremony on 1 July (see p. 5). Below are the brief summaries directly provided by the winners.

SPS Award in General Physics, sponsored by ABB

The SPS Award in General Physics is given to **Hiske Overweg** for her work on "*Electrostatically induced nanostructures in bilayer graphene*".

Electrostatically induced nanostructures in bilayer graphene

Soon after the discovery of graphene, the idea was put forward that this material could be an attractive host for spin qubits. Because of the low atomic weight of carbon, spin-orbit interactions in graphene are small. On top of that, the material mostly consists of nuclear spin-free carbon-12 isotope, which leads to a small hyperfine interaction. These facts should lead to a long coherence time of electron spins, which is an important criterion for a quantum computation platform.

A first step towards the creation of a spin qubit in graphene is the implementation of confinement of charge carriers on the nanoscale. Single layer graphene has a gapless band structure, which makes it hard to realize controlled confinement. The tunable band structure of bilayer graphene provides a solution. By applying a vertical electric field to this material, a band gap is opened. When the Fermi level is locally tuned into the band gap, confinement can be realized.

We investigated the confinement of charge carriers in bilayer graphene by electrostatic gating. We fabricated samples consisting of exfoliated bilayer graphene encapsulated in hexagonal boron nitride, a good insulator. This “sandwich” was placed on a doped silicon substrate, which functions as a back gate. After evaporating metallic gates on top, electric fields could be applied.

Despite the observation of various interesting physical phenomena in dual-gated devices, the maximal resistance in these devices usually stayed in the range of tens of kiloohms, which is insufficient for electrostatic definition of nanostructures. We demonstrated that the incorporation of a graphite back gate into the device structure reproducibly leads to induced resistances in the megaohm or even gigaohm regime, paving the path for electrostatically defined nanostructures.

With a graphite back gate in place, we measured quantized conductance in a device, thereby demonstrating the formation of a quantum point contact. We investigated the magnetic field dependence of the conductance through the constriction, which shows a fascinating pattern of level crossings [1].

The introduction of a graphite back gate in bilayer graphene devices has opened doors to explore various quantum dot arrangements in this material [2].

[1] Hiske Overweg, Angelika Knothe, Thomas Fabian, Lukas Linhart, Peter Rickhaus, Lucien Wernli, Kenji Watanabe, Takashi Taniguchi, David Sánchez, Joachim Burgdörfer, Florian Libisch, Vladimir I. Fal'ko, Klaus Ensslin and Thomas Ihn, Phys. Rev. Lett. 121, 257702 (2018)
[2] Annika Kurzmann, Hiske Overweg, Marius Eich, Alessia Pally, Peter Rickhaus, Riccardo Pisoni, Yongjin Lee, Kenji Watanabe, Takashi Taniguchi, Thomas Ihn and Klaus Ensslin, Nano Lett. 19, 8, 5216-5221 (2019)

SPS Award in Condensed Matter Physics, sponsored by IBM

Shantanu Mishra receives the SPS Award in Condensed Matter Physics for his work on "*Atomic-scale investigations of carbon magnetism*".

Engineering intrinsic π-magnetism in carbon

Magnetism is ordinarily thought of in terms of the d- and f-block elements of the periodic table, which form the basis for modern magnetic technologies. In this context, magnetism in light elements, in particular carbon, may hold several advantages over current inorganic materials. The low atomic mass of carbon, combined with the zero nuclear spin of the ^{12}C isotope implies weak spin-orbit and hyperfine couplings, which are the major sources of spin relaxation and decoherence. This makes carbon nanomaterials ideal for transport of spin polarized currents with high fidelity, or toward realization of fault-tolerant qubits for quantum computation. In addition, carbon nanomaterials offer the intriguing prospect of electric field control of spin transport, which remains difficult to achieve in inorganic materials.

The electronic structure of polycyclic aromatic hydrocarbons (or, nanographenes) critically depends on the topology of the underlying π-electron network, which provides a tunable platform to realize all-carbon magnetism at the nanoscale. Combining rational design principles with on-surface chemistry, we engineer elusive magnetic nanographenes, and probe their structural, electronic and magnetic properties at submolecular resolution with scanning tunneling microscopy. The simplest route toward inducing magnetism in nanographenes involves inducing a sublattice imbalance in the bipartite honeycomb lattice, which translates to a net spin imbalance. As an experimental verification of this concept, we synthesize π-extended triangulene, a nanographene consisting of ten benzenoid rings fused in a triangular fashion [1]. An inherent sublattice imbalance in π-extended triangulene leads to the appearance of non-bonding states in the electronic energy spectrum, which become spin polarized due to electron-electron interactions, leading to a spin-quartet ground state. Moreover, we show for the first time that nanographenes without a sublattice imbalance may also host non-bonding states. Herein, we demonstrate the experimental realization of an elusive spin-singlet nanographene known as Clar's goblet, after its first prediction almost fifty years ago [2]. The magnetic exchange coupling in Clar's goblet is found to exceed the thermodynamic threshold, which, in principle, enables room temperature spintronic applications.

[1] S. Mishra et al., *Synthesis and characterization of π-extended triangulenes*, J. Am. Chem. Soc. **141**, 10621 (2019).
[2] S. Mishra et al., *Topological frustration induces unconventional magnetism in a nanographene*, Nat. Nanotechnol. **15**, 22 (2020).

SPS Award in Applied Physics, sponsored by Oerlikon Surface Solutions AG

The SPS Award in Applied Physics is given to **Michael A. Becker** for his work on "*Exciton dynamics and light-matter interactions of colloidal semiconductor nanocrystals*".

Exciton dynamics and light-matter interactions of colloidal perovskite quantum dots

Colloidal quantum dots are tiny semiconductor crystals, whose size is in the order of only few nanometers. At these length scales quantum effects within the nanocrystal become apparent that alter its optical and electronic properties. Colloidal quantum dots possess a broad range of applications ranging from bio-imaging applications to photovoltaic devices and displays. Recently, the synthesis of a novel type of colloidal semiconductor quantum dot with a perovskite crystal structure was developed. These cesium lead halide perovskite quantum dots exhibit outstanding optical properties compared to conventional quantum dots such as a high photoluminescence quantum yield, a fast photoluminescence decay and a broad tunability of the emission energy.

We investigated their optical properties at cryogenic temperature and demonstrated that these nanocrystals possess a bright triplet exciton state with a typical fine-structure splitting in the millielectronvolt range. The bright triplet exciton state is responsible for their ultrafast radiative decay, which is roughly 1000 times faster at cryogenic temperature compared to other conventional nanocrystals [1]. Using transient three-beam four-wave mixing we measured the characteristic dephasing time T_2, which is in the range of several tens of picoseconds. The low dephasing rate together with the ultrafast radiative decay enable coherent coupling phenomena among nanocrystals. By investigating perovskite quantum-dot superlattices, that are long-range-ordered three-dimensional lattices consisting of well-separated individual quantum dots, we demonstrated a collective emission effect known as superfluorescence. Using excitation-power dependent streak camera measurements, we observed all key signatures of superfluorescence, such as a shortening of the radiative decay time, a superlinear increase of the initial intensity in time-correlated decay measurements, a shortening of the so-called delay time and Rabi-type oscillations of the intensity [2].

[1] Becker, M. A.; Vaxenburg, R.; Nedelcu, G.; Sercel, P. C.; Shabaev, A.; Mehl, M. J.; Michopoulos, J. G., Lambrakos, S. G.; Bernstein, N.; Lyons, J. L.; Stöferle, T.; Mahrt, R. F.; Kovalenko, M. V.; Norris, D. J.; Rainò, G.; Efros, A. L., *Nature*, **553**, 187-193 (2018)
[2] Rainò, G.; Becker, M. A.; Bodnarchuk, M. I.; Mahrt, R. F.; Kovalenko, M. V.; Stöferle, T., *Nature*, **563**, 671-675, (2018)

SPS Award related to Metrology, sponsored by METAS

Katharina Schmeing is honored with the SPS Award related to Metrology for her work on "*Integrated Gallium Phosphide Photonics*".

Integrated nanophotonics with gallium phosphide

Gallium phosphide (GaP) is an intriguing but mostly unexplored material for integrated photonics. It possesses an attractive combination of a large refractive index ($n_0 > 3$) and a large electronic bandgap (2.26 eV). These values offer the possibility of creating devices with strong light confinement and enhanced light-matter interaction, while simultaneously providing transparency into the visible as well as weak two-photon absorption at typical data communication wavelengths in the infrared. GaP also has large second- and third-order non-linear optical coefficients and is piezoelectrically active. This uncommon confluence of properties has led to numerous proposals utilizing GaP as a platform for solid-state cavity-quantum electrodynamics, optomechanics, solar cell technology, and even cold-atom physics, in addition to non-linear photonics.

The main challenge has been the development of methods for fabricating GaP structures on a low-refractive-index substrate. To address this problem, we employed a direct wafer-bonding approach for scalable integration of high quality, epitaxially-grown GaP onto silicon dioxide. Exploiting new techniques for patterning GaP into high-aspect-ratio structures with nanometer precision while maintaining good material quality, we realized a catalog of low-loss photonic devices, including free-standing photonic crystal cavities exhibiting optomechanical coupling in the resolved-sideband regime [1] and grating-coupled waveguide resonators with loaded quality factors of 3×10^5 [2]. The photonic crystal cavities had optical quality factors as high as 1.1×10^5 and were optimized to couple an optical mode at ~ 200 THz via radiation pressure to a co-localized mechanical mode with a frequency of 2.9 GHz. Notably, the large vacuum optomechanical coupling rate (400 kHz) permitted amplification of the mechanical mode into the so-called mechanical lasing regime with input power as low as ~ 20 µW. For non-linear optics, we used waveguide resonators pumped at 1550 nm to generate second- and third-harmonic light as well as Kerr frequency combs. Parametric threshold powers as low as 3 mW were realized, followed by broadband (> 100 nm) frequency combs with sub-THz spacing, frequency-doubled combs and, in a separate device, efficient Raman lasing.

Taken together, our results herald the emergence of GaP as a new platform for integrated nonlinear photonics.

[1] K. Schneider, Y. Baumgartner, S. Hönl, P. Welter, H. Hahn, D. J. Wilson, L. Czornomaz, and P. Seidler, "Optomechanics with one-dimensional gallium phosphide photonic crystal cavities," *Optica* **6**, 577–584 (2019).
[2] D. J. Wilson*, K. Schneider*, S. Hönl*, M. Anderson, T. J. Kippenberg, and P. Seidler, "Integrated gallium phosphide nonlinear photonics," *Nature Photonics* **14**, 57–62 (2020).

SPS Award in Computational Physics, sponsored by COMSOL Multiphysics GmbH

The SPS Award in Computational Physics is given to **Frank Schindler** for his work on "*Higher-order topological insulators*".

Higher-order topological insulators

The mathematical field of topology has become a framework in which to describe the low-energy electronic structure of crystalline solids. Typical of a bulk insulating three-dimensional topological crystal are conducting two-dimensional surface states. This constitutes the topological bulk–boundary correspondence. We extend the notion of three-dimensional topological insulators to systems that host no gapless surface states but exhibit topologically protected gapless hinge states [1]. We numerically predict tin telluride as a material candidate realizing this kind of higher-order topology. The hinge states discussed by us may be used for lossless electronic transport, spintronics, or — when proximitized with superconductivity — for topological quantum computation.

Furthermore, we establish that the electronic structure of bismuth, an element consistently described as bulk topologically trivial, is in fact topological and follows a generalized bulk–boundary correspondence of higher-order [2]. Its hinge states are protected against localization by time-reversal symmetry locally, and globally by the three-fold rotational symmetry and inversion symmetry of the bismuth crystal. In addition to extensive first-principles and tight-binding calculations, we provide supporting evidence from two complementary experimental techniques.

[1] Schindler, Frank, et al. "Higher-order topological insulators." *Science advances* **4**.6 (2018): eaat0346.
[2] Schindler, Frank, et al. "Higher-order topology in bismuth." *Nature physics* **14**.9 (2018): 918-924.

Johannes Geiss, ein Pionier der Weltraumforschung und prominenter Wissenschaftler auf dem Gebiet der Sonnensystemforschung

Johannes Geiss, geboren am 4. September 1926 in Vorpommern, verstarb am 30. Januar 2020 im Alter von 93 Jahren. Er hinterlässt seine geliebte Frau Carmen, die Tochter Janka und zwei Enkel. Er hinterlässt aber auch tiefe Spuren in der Wissenschaft auf dem Gebiet der Weltraumforschung, insbesondere des Sonnensystems.

Johannes Geiss studierte in der Nachkriegszeit Experimentalphysik in Göttingen bei Max von Laue und dissertierte 1953 am selben Ort bei Wolfgang Paul. Sein Forschungsgebiet war die Anwendung der Massenspektrometrie auf Isotope, insbesondere von Blei. Diese Methode wollte der damalige Leiter des Physikalischen Instituts der Universität Bern, Fritz Houtermanns in der Meteoritenforschung zur Altersbestimmung anwenden, und so holte er den jungen Geiss samt seines gläsernen Massenspektrometers nach Bern. Forschungsaufenthalte in Chicago beim Chemie-Nobelpreisträger Harold C. Urey komplementierten seine Ausbildung und weckten sein Interesse für die chemische Entwicklung des Universums. 1957 habilitierte er in Bern. Nach einem weiteren Auslandsaufenthalt in Miami als junger Professor kehrte er nach Bern zurück, wo er 1960 zum Extraordinarius und vier Jahre später zum Ordinarius ernannt wurde. Nach dem Tod von Fritz Houtermanns übernahm er die Leitung des physikalischen Instituts, das er bis zu seiner Emeritierung 1990 leitete. 1970/71 war er Dekan der naturwissenschaftlichen Fakultät und 1982/83 amtete er als Rektor der Universität.

Seine wissenschaftlichen Verdienste aufzuzählen, würde den Rahmen dieses Nachrufs sprengen. Am bekanntesten ist sicher das Sonnenwindsegel auf dem Mond, das einzige nicht-amerikanische Experiment, das auf Apollo 11 und auf späteren Apollo Missionen zum Einsatz kam. Zusammen mit Kollegen und mit grossem diplomatischem Geschick gelang es Geiss, ein auf den ersten Blick verblüffend einfaches Experiment der NASA schmackhaft zu machen. Das ganze Experiment wog 1 amerikanisches Pfund und enthielt keinerlei Elektronik. Eine einfache Aluminiumfolie sollte auf dem Mond Sonnenwindteilchen sammeln, die dann später im Labor mit den gläsernen Massenspektrometern namens Susanne, Evelyn, Helen, Anna und Bäbi analysiert wurden. Dank dieser Folie gelangten so erstmals Teilchen der Sonne auf die Erde. Ein guter Draht zu den Astronauten machte es möglich, dass das Berner Segel vor der amerikanischen Flagge auf dem Mond gehisst wurde, entgegen den Instruktionen der offiziellen NASA. Das Experiment war ein voller Erfolg. Diese Messungen waren für mehrere Dekaden die zuverlässigsten Messungen der Edelgase im Sonnenwind und wurden erst von der Genesis Mission 2004 in ähnlicher Qualität bestätigt.

Johannes Geiss beim Prüfen der Aluminiumfolie des Sonnenwindsegels, bevor es von Apollo 11 zum Mond gebracht wurde.

Als Resultat dieser Messungen publizierte Johannes Geiss zusammen mit Hugh Reeves unter anderem eine Arbeit zur Bestimmung von Helium Isotopen, insbesondere ^{3}He im Sonnenwind, woraus sich die fundamentale Grösse der Dichte des Universums herleiten lässt. Dafür und für seine bahnbrechenden Arbeiten auf dem Gebiet des Sonnenwindes erhielt er mehrere prestigeträchtige internationale Preise, wie z. B. eine Ernennung zum Foreign Associate of the National Academy of Sciences der USA (1978), die Ehrendoktorwürde der University of Chicago (1986), die Einstein Medaille (2001) und die Bowie Medal, die höchste Auszeichnung der American Geophysical Union (2005).

Der Schritt von Labormassenspektrometern zu Fluginstrumenten wurde von Johannes Geiss und seinem Team bereits in den 60er Jahren an die Hand genommen. Dazu brauchte es entsprechende Missionen. Johannes Geiss war einer der massgebenden Wissenschaftler, die das Europäische Weltraumprogramm der ESA mitbestimmten, zuerst im Rahmen der ESRO, später der ESA. So flog das 1. Berner Massenspektrometer auf den GEOS Sonden Mitte der 70er Jahre. Bald folgten Massenspektrometer mit Hardware von Bern auf Ulysses um die Pole der Sonne und später auf SOHO. Johannes Geiss hat auch früh die Bedeutung von Kometen für die Erforschung der Geschichte des Sonnensystems erkannt, und so setzte er mit Kollegen bei ESA die verrückte, höchst erfolgreiche Giotto Mission zum Kometen Halley durch. Er darf auch ruhig als „Grossvater" der Rosetta Mission bezeichnet werden, hat er doch bei ESA schon in den 80er Jahren darauf gedrängt, eine Kometenmission als einen der Eckpfeiler ins ESA Horizon 2000 Programm aufzunehmen, was mit Rosetta dann auch erfolgreich gelang.

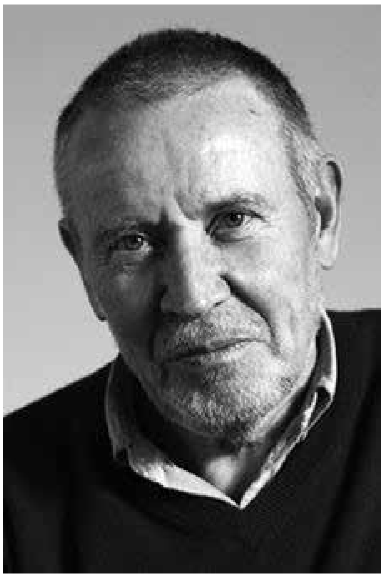
Mit viel diplomatischem Geschick und dank seines profunden Wissens legte er die Grundlagen für den Erfolg der Schweiz bei internationalen Weltraummissionen, der bis heute andauert. Diese Erfolge hatte er sicher auch der Tatsache zu verdanken, dass er wissenschaftlich sehr aktiv war. Dies wiederum gab ihm den nötigen Rückhalt, um das physikalische Institut in Bern punkto Professoren-, Mittelbaustellen und Infrastruktur hervorragend aufzustellen. Aber auch auf Bundesebene gelang es ihm, Weltraumforschung zu fördern. Er kann durchaus als der Erfinder des Prodex Programms bezeichnet werden, ein finanzielles Programm des Bundes in Zusammenarbeit mit der Industrie, das auch kleinen Ländern wie der Schweiz erlaubt, Hardware für Missionen zu entwickeln und zu bauen.

1990 wurde Johannes Geiss emeritiert. Wer meinte, er würde sich zur Ruhe setzen, hatte sich gewaltig getäuscht. Das war keinesfalls das Ende seiner wissenschaftlichen und diplomatischen Tätigkeit. Mit Beharrlichkeit und Begeisterungsfähigkeit gelang ihm die Gründung des International Space Science Institute (ISSI) in Bern. Dazu musste er ESA, den Bund und den Kanton Bern von seiner Idee eines interdisziplinären und weltumspannenden Instituts überzeugen. ISSI bringt Wissenschaftler aus der ganzen Welt zusammen, bis jetzt weit über 1000, die sich mit interdisziplinäre Analysen, Auswertungen und Interpretationen von Weltraumdaten befassen, unterstützt von sämtlichen Weltraumagenturen wie NASA, Roskosmos, Jaxa und der chinesischen Weltraumagentur. In den ersten acht Jahren war Johannes Geiss dessen geschäftsführender Direktor. Seit seiner Gründung ist ISSI ein führendes Institut für die internationale Zusammenarbeit auf dem Gebiet der Weltraumforschung, klein aber fein!

Was aber Johannes Geiss vor allem auszeichnete, war seine Persönlichkeit. Er war nicht nur ein aussergewöhnlicher Wissenschaftler, sondern auch ein begnadeter Lehrer und ein hervorragender Kommunikator. Noch heute trifft man Mediziner, die von den Physikvorlesungen von Geiss beeindruckt waren. Johannes Geiss nahm sich immer Zeit für den physikalischen Nachwuchs, den er auch entsprechend förderte. Mehrere später erfolgreiche Nachwuchsleute verdanken ihre Karriere und vor allem ihr Wissen der Person Geiss. Mit ihm zu diskutieren, ihm zuzuhören, war immer eine grosse Bereicherung. Diskussionsthemen waren aber nicht auf Wissenschaft beschränkt, sondern umfassten ein breites Interessensgebiet. Johannes Geiss war eine der ganz grossen Persönlichkeiten, die man nicht mehr vergisst. Es war ein Privileg, ihn zu kennen und von ihm zu lernen. Danke für alles, was Du, Johannes uns mitgegeben hast.

Prof. em. Kathrin Altwegg, Universität Bern

In memoriam Peter Truöl



Peter Truöl, Professor Emeritus for Elementary Particle Physics at the University of Zurich, died after a short serious illness on March 22th at the age of 80 years.

From 1971 to 2006 Peter Truöl was Professor for Elementary Particle Physics at the Physik-Institut of the University of Zurich (UZH). From here, he strongly shaped the new field of experimental meson physics at PSI. Later he initiated the university's involvement in high-energy accelerator physics. With his research group he participated in various experiments at PSI, DESY, and CERN and also in Berkeley, Los Alamos, and Brookhaven.

After studying physics, mathematics and chemistry in Göttingen and Zurich, Peter Truöl received his PhD under the supervision of Prof. Verena Meyer at UZH in 1967 with a thesis on the properties of the ^{10}B nucleus that he investigated through scattering α-particles on ^{6}Li. A two-year research fellowship from ETH Zurich subsequently allowed him to work at the Bevatron and at the 184" cyclotron in Berkeley to experiment with pion beams. In 1969, at the age of only 30 years, he became assistant professor at the University of California, Los Angeles.

In 1971, Peter returned to UZH for his habilitation. He experimented with precise pion beams, first at CERN and starting in 1974 at the newly created Swiss Institute for Nuclear Research (now PSI-West). In collaboration with groups from the Universities of Lausanne and Munich he initiated important experiments to study nuclear resonances, to measure the neutron scattering length and other important reactions in what we now call low-energy particle physics. The large pair spectrometer that he helped to develop made a significant impact in the progress of this field. Some results of Peter's experiments later played a major role in the chiral perturbation theory of the strong interaction.

In 1979 Peter Truöl embarked in experiments at LEAR at CERN, where at that time antiprotons could be generated at large rates and very low momentum, allowing to stop antiprotons in a target. The ASTERIX spectrometer has been used to study the formation and the ground state of the proton-antiproton system and allowed to analyse exclusive final states of proton-antiproton annihilation at rest to a large variety of mesons. Under Peter's supervision, large multi-wire proportional chambers were built for this experiment at the Physik-Institut of the UZH for the first time.

In 1985 Peter joined the H1 collaboration and significantly contributed with his group to the detector, the trigger, the software and various analyses. Under the leadership of Peter a cylindrical multiwire chamber and a drift chamber were built in Zurich, and a trigger concept for the H1 experiment was developed and implemented. In addition Peter coordinated the construction of the superconducting compensation magnet for H1, a project performed in collaboration with PSI, ETH and the industry financed on his initiative by Kanton Zurich.

The next stage of his research work took Peter to Brookhaven. Here he took part in various measurements to study rare kaon decays, the most important result of which was to clarify the strength of the coupling of the strange quarks to the weak interaction. For this experiment too, he built large multi-wire proportional chambers at the Physik-Institut.

In his scientific work, Peter Truöl was equally interested in the experimental aspects, the theoretical understanding and last but not least the linguistic quality of the publications. To convey the latter was a particular concern of his when supervising his PhD students. Building huge precise detector systems at the university was a constant challenge for and stimulated the development of the infrastructure of the Physik-Institut, especially the mechanical workshop.

At UZH Peter Truöl introduced elementary particle physics to the curriculum of physics. He taught physics students in elementary particle physics for many years and gave the basic lectures for students of medicine and biology countless times. In doing so, he succeeded in conveying to his audience the fascination of research in fundamental physics questions and in making physics a basic subject for future scientists.

From 1993 to 2000 Peter Truöl chaired the Program Review Committee at the PSI, where his broad experience helped to identify many possible and even impossible experiments. Peter Truöl was Director of the Physik-Institut from 1999 to 2003 and served as Dean of the Faculty of Mathematics and Natural Sciences from 2003 to 2006. After his retirement, he remained closely associated with current research projects in physics and with the University of Zurich. From 2007 to 2012, he served on the Board of Science Alumni.

In Peter Truöl, the University of Zurich, his colleagues and former students are losing a person and a teacher to whom they owe a lot.

Katharina Müller, Ueli Straumann and Peter Robmann

Exploring quantum correlations experimentally on quantum computers

Leonid Leiva Ariosa, IBM Research, Communications

A team of EPFL researchers was recently awarded the second prize in the Best Paper category of the IBM Quantum Awards for experimental work related to the generation and study of Bell-diagonal states.

In May of 2016 IBM became the first organization in the world to make quantum computers available in the cloud to anyone who wants to use them, free of charge.

Ever since making its superconducting qubit devices available to the public in the IBM Quantum Experience, IBM has been undertaking efforts to build a strong community of students, researchers and developers with activities such as hackathons, developer camps, or the publication of quantum computing textbooks and tutorials. These community building activities are grounded in the realization that fostering such an ecosystem is crucial in order to fully exploit the groundbreaking potential of quantum computing.

As an essential component of its community engagement efforts, IBM introduced the IBM Quantum Awards in 2018. The awards recognize outstanding scientific and educational work on IBM quantum computers. In its second edition, that of 2019, a team from EPFL won the second place in the Best Paper Award category.

Photo of the EPFL team taken during a recent teleconference. Three of the paper's coauthors (Javier Naya Hernandez, Samuel Bosch and Xinyu Si) are missing in the picture.

The EPFL researchers were recognized for their paper *Bell Diagonal and Werner state generation: entanglement, non-locality, steering and discord on the IBM quantum computer*. In it, they performed an in-depth study of quantum states called Bell-diagonal states, which they were able to generate with high fidelity on IBM Quantum devices. Bell states are archetypal examples of entangled two-qubit pure quantum states. Statistical mixtures of Bell states are called Bell-diagonal states (BDS). They form a very interesting restricted class of states which, despite their relative simplicity, display a rich variety of correlations, and have played a crucial role in the theory of quantum information. Because they form a representative three-dimensional subspace of the full 15-dimensional space of two-qubit mixed states, they are often used as a testing ground for measures of quantum correlation that go beyond entanglement, such as entropic measures or quantum discord. “In our paper, we focused on the understanding of the quantum correlations between these Bell-diagonal states, confronting for the first time to such an extent the theory with the experiment”, said EPFL researcher Nicolas Schwaller, one of the paper’s coauthors.

Quantum correlations: Complexity beyond entanglement

Quantum correlations are a key to the power of quantum technologies. Combined with superposition, they help to generate the asymptotic speedup that quantum computers can achieve in certain sets of problems with respect to their classical counterparts. Therefore, in recent years a lot of research has been conducted on this topic. “We believe that any progress in the field of quantum correlations is relevant to quantum information”, Schwaller added.

A prominent example is quantum entanglement, which is necessary in many quantum protocols. However, entanglement has been recently found to be more complex than expected, and other quantum correlations have been identified, which also are useful in quantum protocols, and allow to classify more precisely how much a state is non-classical.

While it isn’t still clear whether all Bell-diagonal states (which are all states written in a diagonal form in the Bell basis) are useful for applications, they still have an elegant graphic representation given by three independent parameters. Thanks to their mathematical form, theoretical expressions of various correlations are available for these states. Schwaller believes that visualizing those quantities, as well as understanding their behavior and links for the whole set of BDS could be useful in identifying important correlations, which could then help in the concrete application realm. “Our work provided quantum circuits to generate Bell-diagonal states. We tested them on IBM Quantum and came up with hints at possible improvements of the hardware which would give a more efficient way to generate such states”, Schwaller summarizes. “In particular, we pointed out that the now lacking possibility of performing non-unitary operations on the qubits would be useful for our experiment.”

Schwaller also notes that similar experiments have been performed on a quantum computer before. In particular, measurements of the different correlations of some states, and even attempts to generate Bell-diagonal states (BDS) had been carried out by other groups. “However, we think that the quantum circuit we came up with in our study is the first which is able to generate all possible Bell-diagonal states.”

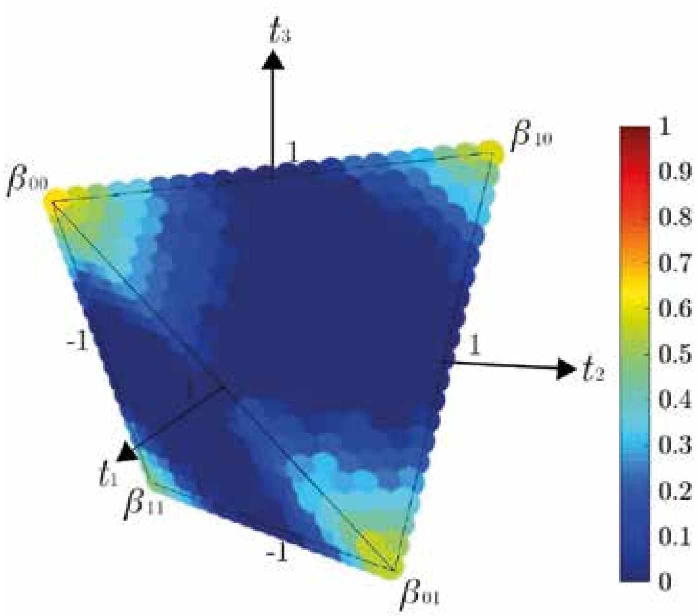
The advantages of using quantum computers

To experimentally measure the correlations in a quantum state, researchers need to generate it and then perform a set of measurements on the state to retrieve the quantity of interest. So, in principle this experiment could be performed with various setups and physical systems, including photonic qubits for example, that one is able to generate, manipulate and measure.

In particular, such experiments require the generation of entangled states. “I think that the fact these experiments haven’t been performed before highlights the new power that quantum computers put at our disposal in terms of their universality”, said Schwaller.

Schwaller points out that the circuits the EPFL team proposed are in fact quite simple. “Once we have built the circuit, the quantum computer will do the rest of the job. Doing the same with optical photons for example would be much more challenging. In particular, controlled gates are themselves a challenge because photons interact very weakly”. In contrast, Schwaller notes, a quantum computer makes it much easier to create any Bell-diagonal state. With our circuit, all the researchers need to do is to input the three corresponding circuit parameters.

Schwaller doesn’t see truly “experimental” challenges in what the EPFL team did. “A big part of the work was the theoretical analysis, to check that the mathematical descriptions of BDS are right, and that their defining parameters are correctly mapped to the ones we use in our circuit”. A big task was also to find the right modifications to correct the original circuit that the EPFL scientists used as the basis for their own proposal. The team also had to run their experiment on IBM Quantum devices for days to finally get nice experimental results.



Plot of the concurrence, one of the measures of the degree of entanglement of a state. In the EPFL experiments, the Bell states only reach 0.7 of concurrence, while theory predicts the maximal value, 1. The deviation from theory can be attributed to decoherence due to imperfecions in the qubits. The experimental results do reflect, however, the fact that the Bell states are the most strongly entangled ones.

But Schwaller also cautions that there’s still a long way to go: “There is still work to be done in order to comprehend the subtleties of the correlations, and the main difficulty we faced was to identify and understand very precisely the differences between these, formulate them clearly and then apply that in our context of Bell-diagonal states.”

Teaching quantum physics with quantum computers

Quantum computers constitute not only a great experimental tool but can also be used for didactic purposes. This is reflected in the fact that the IBM Quantum Awards comprise one category dedicated to educational work. In the 2019 edition of the awards, a team of theoretical physicists from the University of Turku in Finland earned the $8,000 first-place Teach Me Quantum prize for its Open Quantum Systems with Qiskit tutorial. The researchers derived their winning entry from a course that postdoctoral researchers Guillermo Garcia-Pérez and Matteo Rossi taught to masters and PhD students in the spring of 2019. The hands-on course required students to use Qiskit and an actual quantum computer to write and execute code simulating open quantum systems dynamics, which includes noise and other environmental factors. “We realized that the IBM Quantum computers offer a versatile platform for the simulation of open quantum systems when working on a research paper [García-Pérez, Rossi, Maniscalco, npj Quantum Inf. 6, 1 (2020)]”, Matteo Rossi from the Turku team said. For physicists, it’s important to be able to simulate quantum systems if they are to understand how they evolve in noisy environments. While the models presented in the paper above can be worked out analytically and simulated easily on a regular computer, when increasing the size of the system the complexity grows exponentially. “Unlike classical computers, quantum computers are naturally suited to perform these simulations when the size of the systems increase”, Rossi explains. He adds that in the future, he and his team are eager to see the evolution of the IBM Quantum devices and in particular to explore even more detail control of the qubits with OpenPulse.

A team of students and researchers develops quantum computer programs at the Qiskit Camp Europe on Schilthorn (September 2019).

Looking to the future, Schwaller is optimistic about the potential of quantum computers to add new experimental capabilities. In the short term, Schwaller predicts, quantum computers will especially show their usefulness in improving and developing implementations of the generation of particular quantum states, as well as developing more efficient ways to perform various quantum protocols.

Thanks to the universality and accessibility of quantum computers, Schwaller adds, anyone can easily perform the counterpart of fundamental and historical experiments. "The playground for experimental quantum physics is already being considerably broadened by quantum computers and this will probably continue with further improvements. Quantum computers may become the essential tool for cutting-edge experimentation."

Progress in Physics (74)

The corona crisis hit the world completely unprepared, and this although one could have expected it. The unanimous worldwide political measures of reducing all social contacts and economic processes on the one hand, and of raising gigantic funds on the other hand, are methods without any sustainability and reflect the helplessness of public decision makers. Since pandemics are also to be expected in the future, science is challenged in three ways: in explaining the causes, in providing real-time measurement methods that can be applied universally and without social acceptance problems, and in physically proved modelling of the propagation of the pandemic. Therefore many institutes but also big research facilities have started initiatives to support involved health institutions with the necessary scientific and technical expertise of physicists.
The first article summarises a selection of running activities at PSI in cooperation with Swiss universities. Following this one we mention some research studies performed by and/or coordinated at large international research institutions, The random selection should underline the broad scientific field that physicists have to cover in cooperation with colleagues from other disciplines in order to understand the pandemic. https://www.interactions.org/interactions-members-fight-covid-19 and https://naturalsciences.ch/organisations/chipp/activities/covid_19_task_force .

BB, HPB

What physics in Switzerland is doing to meet the COVID-19 challenge

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The COVID-19 pandemic is redefining the political and economic landscape of the world and also challenges physicists to contribute to its resolution. We describe here how as in physics, the identification, measurement and management of key features and variables allows progress towards a solution of the problem presented. The features and variables range from the structures of the implicated proteins through the lung damage caused by the disease to the infection rates at the core of the epidemiology of the pandemic. The problems to which solutions are needed include that of low-cost and reliable testing for both the virus itself as well as antibodies, the development of vaccines and other pharmacological countermeasures, medical imaging, and optimal timing of control measures imposed on the general population. It should come as no surprise to the general readership of this journal that physical scientists in Switzerland are contributing on all of these fronts, and the purpose of this article is to provide an overview of activities.

We start with the underpinning molecular biology, where the reproduction of the virus in mammalian cells is an elaborately choreographed sequence of protein interactions, whose success and kinetics depend on structural matches during docking events. For this reason, determining the

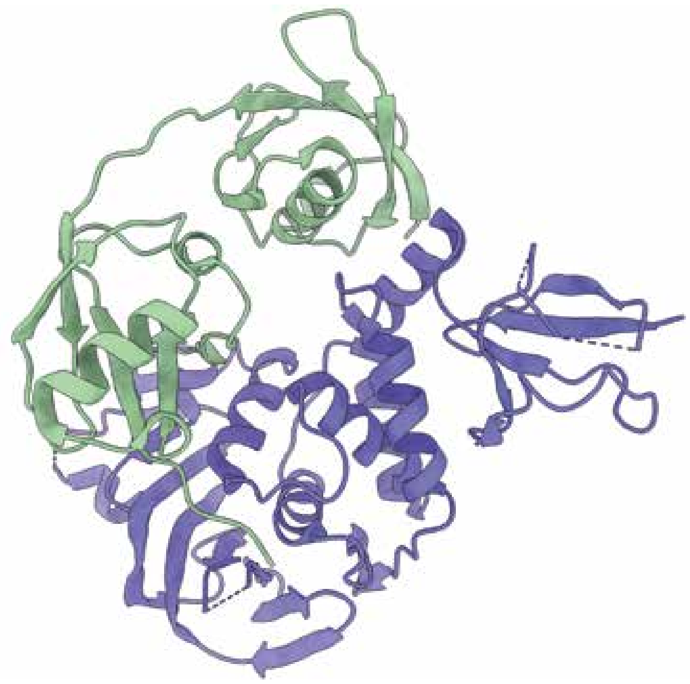

Fig. 1: Crystal structure of SARS-CoV-2 papain-like protease PLpro (violet) in complex with ubiquitin-like protein ISG15 (green) presented as cartoon model (PDB ID 6YVA).

atomic-level structure of the relevant proteins when docked and released opens the door to fundamental understanding. In addition, candidate drug molecules can be introduced to frustrate docking. A key probe here is X-ray diffraction, where atomic positions, for both the proteins as well as drug molecules, can be determined with exquisite precision. In response to the current pandemic, the Swiss Light Source of the Paul Scherrer Institute has already contributed several new COVID-19-related structures to the Protein Data Base which is the standard repository. Among them is the crystal structure (Fig. 1) of SARS-CoV-2 papain-like protease PLpro in complex with ubiquitin-like protein ISG15 from the Dikic's group at the Goethe University in Frankfurt am Main, Germany [1]. Required for the assembly of new viral particles, PLpro represents an important drug target to block the virus spread within human cells.

X-rays are useful not just for imaging atoms via diffraction, but are also a powerful tool for tomographic microscopy of biomedical samples. A particular challenge though is to go well beyond clinical routines, and to perform high-sensitivity tomographic (3D) imaging at the micro- and nanoscale. In a recent article [2] published by the TOMCAT team lead by Prof. Marco Stampanoni from ETHZ and PSI, multiscale tomographic microscopy has been used to generate a high-precision map of the inner structure of an entire rat lung, as shown in Fig. 2. This imaging technique will allow detecting COVID19-induced damages to the alveolar structure and will provide a quantitative assessment of its impact on pulmonary performance.

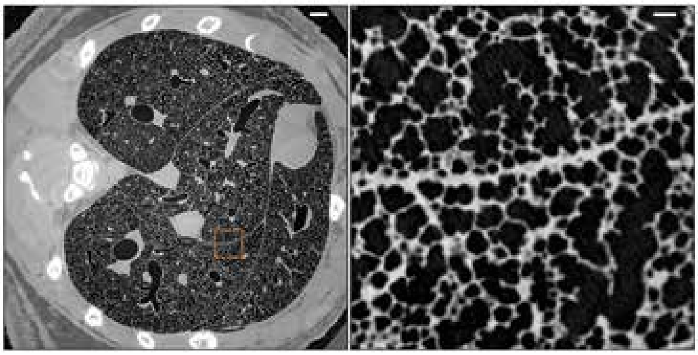

Fig. 2: Left: A 20 × 20 mm^2 horizontal slice through a rat lung under immediate post-mortem conditions. The full volume contains the entire pulmonary structure from the trachea down to the parenchyma in a single dataset. The isotropic voxel size is 2.5 µm^3, which allows to clearly distinguish single alveoli, as shown on the right panel. Scale bars: 1 mm (left), 100 µm (right). Full dataset available at https://doi.org/10.16907/7eb141d3-11f1-47a6-9d0e-76f8832ed1b2 .

Let us now turn to epidemiology and economics. The systems of equations characterizing population dynamics or the evolution of epidemics are very familiar to physicists, and indeed many epidemiologists started their careers by studying mathematics and physics. Out of the many parameters that enter epidemiological evolution equations, a key quantity, the reproduction number *R*, is often referred to in the media. It captures the average number of additional infections that each infected person induces.

The value of *R* is affected by the boundary conditions implemented by policies. The number *R* has to be determined from fitting observables such as the number of reported cases, hospitalizations, or deaths to a given epidemiological model. Theorists at PSI are exploring how the acquisition of different data, namely the prevalence of asymptomatic but infectious persons in a random sample or specific subgroups of the population, may help to measure the value of *R* more rapidly and/or more reliably.

In the absence of a vaccine or a cure, two strategies have been used to limit the scope of a pandemic such as the one that we are currently facing with COVID-19. One strategy consists in imposing socio-economic restrictions, as were put in place in Switzerland from March until May of 2020. What is accomplished here is a tuning of *R* from a dangerous value well above unity (estimated to be 3 for a typical developed country with no social distancing or mask regime), to a value which is hoped to lie below unity. Because of their severe economic consequences, such lock-downs must almost inevitably end before the virus has completely disappeared.

If relaxed too quickly, *R* can grow back to a value above unity, entailing a "second wave". The "management" of the pandemic thus reduces to managing *R* in such a way that no waves of infection numbers become too large to challenge the capacity of the health care system to cope with the fraction of infected people with severe symptoms. The interested reader can visit www.covidsim.org (created in a collaboration between Imperial College and a company co-founded by one of the authors of this article) to play the policymaker who modulates disease transmission rates over time in an effort to minimize mortality and prevent overloading of hospitals.

Another strategy, which is effective if infection numbers are sufficiently low, consists in tracking transmission pathways and isolating the infected people detected via contact tracing. This has been done successfully in South Korea and could also be a model for countries such as Switzerland where prevalence has been sufficiently reduced by physical distancing. Unfortunately, this approach requires symptomatic individuals to already have emerged, which delays the response to sudden growths in prevalence.

The authors of this contribution have produced a manuscript [3] which details how sampling the population or specific subgroups for active virus could function as an efficient "thermometer" with a shorter delay time than standard approaches. This allows to regulate physical distancing measures during the lengthy lead time until a vaccine is produced in sufficient quantity to administer to an entire population. A shorter delay time, will allow to react more rapidly if the reproduction number happens to increase relatively suddenly to a higher value upon a release of restrictive measures. This in turn reduces the increase of the prevalence and the ensuing health damage, including the death rate. To illustrate the economic benefit of shortening the delay time, let us estimate the economic cost of detecting a jump of *R* to a value 1.3 with an extra delay of 4 days (during which the prevalence increases by a factor of *R*). This undoes a reduction by 30 % of the case numbers that had been achieved over about 3 days during the lock-down. The latter has been estimated to amount to about 1.5 billion CHF in lost economic value generation. Thus gaining even just a few days in measuring the value of *R* may have a large effect, both for public health and for the economy.

In summary, physicists in Switzerland are making various important contributions to meet the challenge of COVID-19. In particular, the Swiss Light Source is contributing crucial structural information on length scales from centimeters to Ångstroms, while the type of thinking about time-dependent collective phenomena that physicists have developed over centuries is producing useful insights into epidemiology and pandemic management.

[1] D. Shin et al., To be published, *http://doi.org/10.21203/rs.3.rs-27134/v1*
[2] E. Borisova et al., Histochemistry and Cell Biology (2020), *https://link.springer.com/article/10.1007/s00418-020-01868-8*
[3] Using random testing to manage a safe exit from the COVID-19 lockdown. M. Müller, P. M. Derlet, Ch. Mudry, and G. Aeppli, *arXiv:2004.04614*.

Selected International Studies

1 Argonne National Laboratory

New drug target found for COVID-19 *(March 20, 2020)*

Scientists discover critical protein that lets virus hide from immune system. A new potential drug target has been identified in SARS CoV-2 — the virus that causes COVID-19 — by scientists who say multiple drugs will be needed to treat the pandemic. Scientists from Northwestern University Feinberg School of Medicine have mapped the atomic structure of two critical proteins in a complex, nsp10/16. These proteins modify the genetic material of the virus to make it look more like the host (human) cell RNA. This allows the virus to hide from the cells, giving it time to multiply. If a drug can be developed to inhibit nsp10/nsp16, the immune system should be able to detect the virus and eradicate it faster. (*https://www.anl.gov/article/new-drug-target-found-for-covid19en*)

2 Brookhaven National Laboratory

Researchers Working on Computational Models to Design Ways to Treat COVID-19 *(April 6, 2020)*

Project will sift through 1 billion drug-like molecules and 60 sites on virus to find most promising options for targeted drug development. A team of Stony Brook University (SBU) researchers is working on computer models that could help speed the discovery of drugs to combat the novel coronavirus responsible for COVID-19. They are doing this work in collaboration with scientists at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory and Argonne National Laboratory, and will be leveraging those laboratories' computational resources and expertise. The researchers are working on models to better understand how the "spike" protein on the surface of the COVID-19 virus interacts with the cells it infects. (*https://www.bnl.gov/newsroom/news.php?a=117161*)

3 CERN

CERN established the ***CERN against COVID-19*** task force to collect and coordinate ideas and contributions from the CERN community of over 18 000 people worldwide. These initiatives draw on scientific and technical expertise and facilities at CERN, in the Member State countries and beyond, and in close contact with the medical community and the WHO.

These include the high-energy physics community ventilator, **HEV** (*https://arxiv.org/pdf/2004.00534.pdf*), the **Mechanical Ventilator Milano**, MVM (*https://arxiv.org/abs/2003.10405*) project spearheaded by the INFN in Italy and involving physicists from around the world, and **Openbreath** (*https://www.openbreath.it/en/*) to develop and produce scalable low-cost lung ventilators. The designs will be published using the CERN Open Hardware License, so that they can be reproduced wherever there is a need and freely adapted to comply with local regulatory frameworks.
CERN is the hub of a vast global computing resource, the Worldwide LHC Computing Grid, WLCG, and is also home to the CERN openlab collaboration with key players in the IT industry. This represents a considerable potential resource for fighting the pandemic, with potential applications ranging from the support of therapy and vaccine research, to the deployment of the data-sharing platform Zenodo, and epidemic modelling.

4 GSI Darmstadt

In order to develop vaccines, inactivated viruses are needed with as little damage to the virus' structure as possible. In past years, the inactivation of viruses for vaccine development has been carried out with gamma radiation. In a new project at GSI influenza and SARS-CoV-2 viruses are irradiated with high-energy heavy ions. Energetic ions are able to inactivate the virus by inducing breaks in the viral RNA with only a few passages in the envelope, thus minimizing membrane damage. The resulting viruses will then be examined at the HZI in Braunschweig for their ability to promote the formation of virus-binding and neutralizing antibodies after vaccination.
Pneumonia caused by SARS-CoV-2 may be treated with low-dose radiation. The anti-inflammatory effects in the lung are studied and compared in cases where a low-dose X-ray radiation is applied or an increased radon activity is administered.
Polymer foils are irradiated with individual ions for chemical etching to create single nanopores whose geometry and diameter can be adjusted very precisely. The nanopores are specifically functionalized to monitor the transport of specific particles, molecules or even viruses, which opens opportunities the detection of viruses such as SARS-CoV-2.
https://www.gsi.de/en/start/news/details/2020/04/16/gsi_fair_forschung_unterstuetzt_den_kampf_gegen_corona0.htm

Milestones in Physics (19)

Laser Research in Bern

René Salathé, EPFL

Introduction

The first report on laser emission in ruby by Maiman in 1960 [1] encouraged many laboratories around the world to start research on this entirely new light source. In Switzerland, first activities had been reported in 1964 by Hugentobler [2] on the application of a pulsed ruby laser in a bubble chamber and by Huber [3] on a new laser transition in NO. The University of Bern was able to establish in short time a prominent research group covering the most important topics in the new field. The group became the most important research center in this field in Switzerland at that time with international reputation. In this introduction we describe the background of this evolution and in the subsequent sections we recount the major events and achievements in the different fields of activities from the beginning until early 1980ies.

The University inaugurated in 1962 a new building adjacent to the main edifice above the main railway station, the "Institut für exakte Wissenschaften", after a long and painful planning and construction period. The new building hosted the mathematics, physics, and astronomy institutes. In advance to this event, the head of the Institute of Experimental Physics at that time, Fritz Houtermans, together with Hans König, Director of the "Eidgenösische Amt für Mass und Gewicht" and part time professor in the Experimental Physics wrote a letter to the Bernese government suggesting to create an Institute of Applied Physics in analogy to a similar institute at the University of Basel. The new institute should cover the more industry related research with respect to activity of the Institute of Experimental Physics. The Bernese government accepted these plans in 1961. Klaus Peter (KP-) Meyer, a physicist from the group in Basel, moved in 1961 to Bern and became the first director of this institute. He and his wife who worked for a long time as secretary of the institute are shown in Fig. 1.

Fig. 1: Prof. K. P. Meyer and his wife at the15th IAP anniversary in 1976 [4]

K. P. Meyer had been active in measuring the strengths of radioactive sources in absolute units using a coincidence method. In addition to his own activity, he looked out for new research topics. He couldn't find sponsors for his first idea to start research in superconductors. But the first demonstrations of generating laser radiation in crystals, gases, and semiconductors and the many potential applications - at that time speculative - of this new light sources convinced industry and government that research in this field could become important for Switzerland. K. P. Meyer was able to build up a research group consisting of two physicists (Hans-Peter Brändli, René Dändliker) and an electrical engineer (Jörg Hatz), all graduated with their diploma from ETH Zürich and financed on external funds. He convinced the general directorate of the Swiss PTT and 16 industrial companies [1] to sponsor an international conference in order to assess the status in laser research and applications. The newly formed laser group was involved in the preparation and organization of the conference that was announced in spring 1964 and took place in Bern in October 1964. After a conference focusing on laser physics organized in 1963 in Paris [5], the meeting in Bern was the second international event organized in Europe. It covered all scientific laser topics: General laser physics, nonlinear optics and Raman scattering, solid state lasers, gas lasers, injection lasers, chemical lasers. In addition, it included presentation on all emerging laser applications known at that time: be it in the fields of physics, in testing and measurements, in material processing, in optical communication, in medicine, or in biology [2]. Therefore, the most important academic, industrial, and governmental research laboratories from all around the world sent collaborators to present their latest work and more than 250 participants from 22 countries participated.

The proceedings of the conference were published 5 months later in a special issue of the "Zeitschrift für angewandte Physik und Mathematik" [6]. The new laser group was completed the same year with other physicists from ETHZ, Heinz P. Weber and Christian Deutsch, as well as Max Keller, Ernst Mathieu, and Alfred Roulier, physics students from Bern. The edition of the conference proceedings and the discussion of the results presented at the conference helped the members of the laser group to consolidate their know-how and to strengthen (or start) activities in the fields of gas lasers, solid-state lasers, non-linear optics, diode lasers, laser ranging, and drilling holes in ruby, topics that will be discussed in the following sections.

Some of the conference sponsors together with the Swiss Armaments Services Group were convinced of the need to have a permanent group of specialists available informed about the latest laser developments. K. P. Meyer formed a core group that financially supported the laser group. The latter delivered quid pro quo regularly reports to them and – on request – analyzed particular developments. This additional support allowed hiring more PhD students so that veritable research groups could be formed to cover the most important fields.

1 Albiswerk AG, Zürich; Balzers AG, Balzers; Brown-Boveri AG, Baden; Buhrle & Co., Zürich; Ciba AG, Basel; Djievahlrdjian SA, Monthey; Geigy AG, Basel; Generaldirektion der PTT, Bern; Hasler AG, Bern; Hoffmann-La Roche AG, Basel; IBM Forschungslaboratorium, Zürich; Impulsphysik AG, Zürich; Kontron AG, Zürich; Paillard SA, Yverdon; Philips AG, Zürich; Sandoz AG, Basel; Siemens AG, Zürich; Turlabor AG, Zumikon

2 Comprehensive conferences covering all laser topics didn't yet exist, e.g. the very first CLEO conference, then called CLEA Conference on Laser Engineering and Applications), took place in 1969.

When the first research generation finished their PhD works and gradually left the Institute for working in industrial laboratories, K. P. Meyer looked out for experienced laser researchers in the field for guiding and managing the increasing number of diploma and doctoral students. He hired Gerd Herziger and then Horst Weber, both students of Hans Boersch, the former director of the "1. Physikalische Institut" at the Technical University of Berlin. They graduated there in 1965 and were engaged in Bern 1969 as lecturers (Privatdozent). Gerd Herziger supervised the gas laser and laser processing activities, in particular the drilling of holes in watch stones. He became associate professor in 1970, full professor in 1974 but left the Institute in 1975 with an appointment as full professor at the Technical University of Darmstadt [3]. Horst Weber supervised the non-linear optics-, the solid state-, dye- and diode-laser activities and was promoted associate professor in 1972. He left the Institute also in 1975 with an appointment of full professor at the University of Kaiserslautern [4].

Heinz P. Weber, another physicist from ETHZ hired shortly after the laser conference by K. P. Meyer, finished his PhD at the IAP in 1968. When he presented his work on the measurement of picosecond pulses in the US (c.f. below), he received immediately an offer to work as staff member with the Bell Telephone Laboratory in Holmdel. He worked there until 1975, when K. P. Meyer invited him to come back to head the orphaned laser group. He was appointed associate professor in 1975, full professor in 1983, and he successfully increased the international reputation of the laser group once more [5].

Solid State Lasers

Ruby Lasers

Pulsed ruby lasers were one of the most advanced systems with respect to applications at the time of the laser conference in Bern. In the early 1960ties, optics was a stepchild among the fields of physics; some universities had even removed this topic from their physics curriculum. Optical rail systems with triangular cross-section developed in 1912/1913 by Carl Zeiss in Jena ("Zeisssschiene") were used for experiments. Optical components were mounted on stands that were shifted along the length of the rail and bolted down at the desired position. The possibilities of adjusting the lateral position and angular direction of the component were very limited and the adjustment precision was unsatisfactory for laser experiments. New optical mounts had to be designed and fabricated in the workshop of the institute. The first free running ruby laser was constructed at the IAP by René Dändliker in 1964 (Fig. 2). This laser became then the workhorse of Heinz P. Weber in 1964 for the experiments in non-linear optics.

3 Gerd Herziger moved in 1985 to the Technical University of Aachen, where he founded the Fraunhofer Institute for Laser Technology (ILT) in the same year. This institute focused on industrial research grew rapidly under Herziger's leadership to become the largest European laser research center.

4 Horst Weber returned to the Technical University of Berlin in 1987 and worked as full professor for Applied Laser Physics and Head of the Institute for Solid State Lasers until his retirement in 2003.

5 Heinz P. Weber stayed in Bern and co-directed the Institute of Applied Physics until his retirement in 2004.

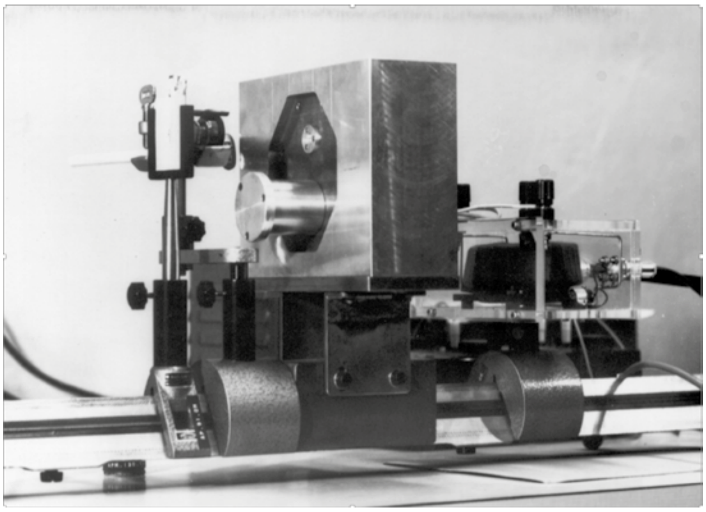

Fig. 2: IAP Ruby laser in 1964 [4]

The ruby crystals were procured from Djeva SA in Monthey, Switzerland. This company also delivered the first ruby laser crystals to the United States in 1960. Their crystals were fabricated by flame fusion ("Verneuil" process) and had not yet the optical quality of today's crystals drawn with the Czochralski process. The crystals were excited by a helical flash lamp placed inside a cylindric metal reflector (Fig. 3).

Fig. 3: Ruby laser cavity [7]

Ruby lasers emit in the red (694 nm). The active ion (Cr^{3+}) has a very long fluorescence lifetime (3 milliseconds) that allows for high energy pumping and for generating light pulses useful for demonstrating the material processing potential of such lasers, by e.g., drilling holes into razor blades (Fig. 4) and coins.

Fig. 4: Impact of ruby laser pulse on razor blade [7]

Using a variable attenuator within the laser cavity such as, e.g. a dye cell or a rotating prism, the energy stocked in the crystal can be released in one single light pulse. The technique, called Q-switching, allows generating light pulses with Megawatt peak powers (at the time called "giant" light pulses). It was investigated in parallel to the explorations on the spatial and temporal emissions of "free running"

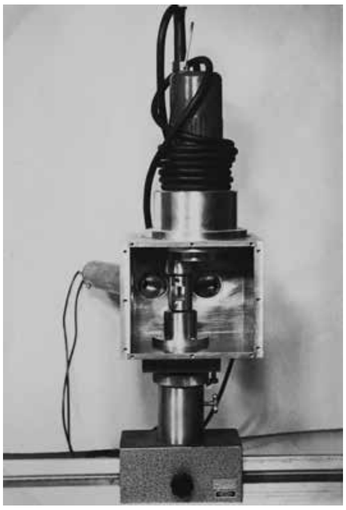

Fig. 5: Rotating prism [7]

ruby laser. An idea of the experimental technique back in 1964 is illustrated in the following figures. Fig. 5 shows a rotating prism mounted on a Zeiss rail. Fig. 6 illustrates the experimental set-up for a Q-witched laser with the home built high voltage electric supply and condenser bank on the left and the laser set-up on the right.

Q-switched lasers allowed generating air breakdowns (Fig. 7), but they also created problems when working with such intensities: The layers of dielectric mirrors had too much residual absorption and could not withstand high light intensities (Fig. 8). This problem was investigated in a collaboration with Balzers AG in Lichtenstein and in the framework of a diploma work at the IAP that allowed to fabricate dielectric mirrors with very high reflectivity and damage threshold [8].

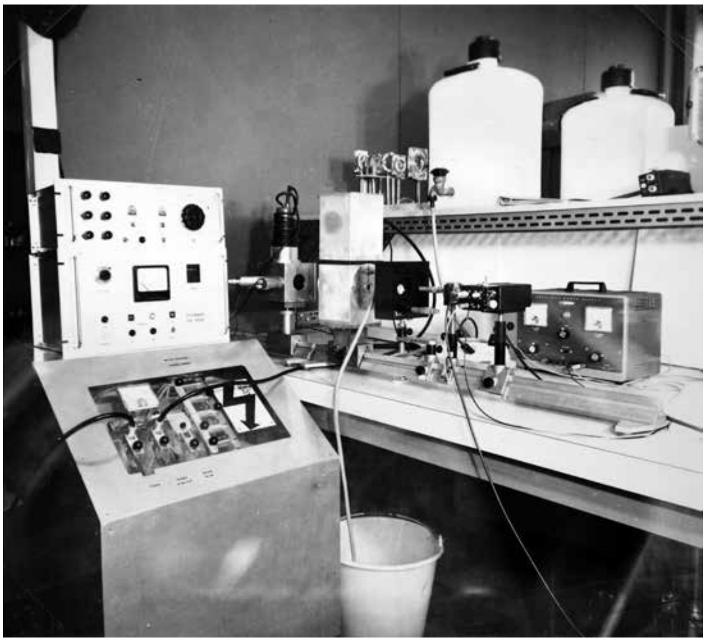

Fig. 6: Q-switched Ruby laser [7]

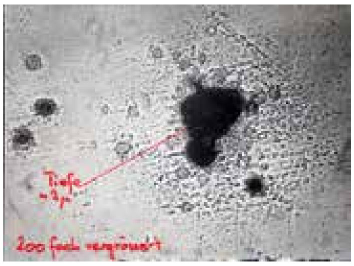

Fig. 7: Air breakdown [7]; Fig. 8: Damaged dielectric mirror [7]

ND:YAG Lasers

Ruby lasers were fine for demonstrations and Q-switching at low repetition rates. But, the underlying three-level energy scheme required high pump intensities for reaching the laser threshold. Continuous working (cw-) operation or high-average pulsed laser operation necessary for industrial laser application could not be achieved. Nd:YAG lasers (Neodymium-doped Yttrium-Aluminium-Granat crystal) don't have these problems. This type of laser had been developed in 1964 at the Bell Laboratories by LeGrand Van Uitert and Joseph E. Geusic [9]. The laser active ion, Nd^{3+}, absorbs light in the near infrared, at 730 - 760 nm and 790 - 820 nm respectively. The laser emission line is at 1060 nm. Nd:YAG has a 4-level energy scheme, i.e. the lower energy level of the laser transition is situated above the ground level so that the threshold for laser emission is attaint much easier. The laser was also pumped by flashlamps in the same configuration as for ruby lasers. The solid-state laser team procured Nd:YAG crystals and glass rods right away when the first publications appeared in 1964 and developed this type of laser further for research in mode-locking experiments, in non-linear optics, generation of plasma, and for industrial applications, particularly for drilling holes into watch stones (cf. below).

Nonlinear Optics

The high intensities that could be achieved with Nd:YAG lasers were used already in 1966 by Heinz P. Weber and Ernst Mathieu for frequency doubling (conversion to green light) in crystals whose structure does not show inversion symmetry, e.g. Potassium Dihydrogen Phosphate (KDP) and Lithiumniobate ($LiNbO_3$) [10]. Theoretical studies and investigations on the symmetry, on the optical dispersion, and on the birefringence had to be considered for achieving synchronization of the various participating optical beams [10, 11]. This research lead Heinz P. Weber subsequently to the development of a novel correlation technique for measuring the pulse duration of ultra-short pulses [12-14]. Such pulses had been generated and reported by A. J. DeMaria in 1967 [15]. But their duration could not be measured since no photo-detection system existed at that time with a time resolution below a nanosecond. The new technique was then applied to study the asymmetry and the behavior of ultrashort pulses. Fig. 9 shows the optical set-up used in 1968 in the framework of the diploma work of Bruno Hausherr [16]. Heinz P. Weber's correlation method was quickly adopted by the laser community and became for a long time a standard technique for characterizing ultrashort laser pulses. The method is presently still used routinely to study f-sec pulses.

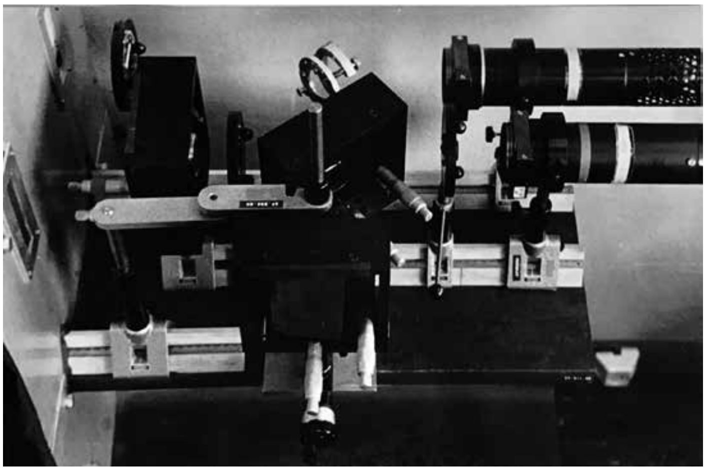

Fig. 9: Experimental arrangement for intensity correlation measurements [16]

Laser Plasma

The generation of plasma with high-power lasers played a crucial role in the interaction of radiation with metals, in particular for drilling holes. This was investigated at the IAP in the thesis work of Martin von Allmen [17, 18]. After his thesis Martin stayed at the IAP and headed a research group investigating in detail the new possibilities that arose by the rapid heating and cooling down in the interaction of laser pulses at the surface of solids, in particular silicium (Si). With his collaborators Willy Lüthy, Klaus Affolter, and Markus Wittmer, he investigated, e.g., the laser assisted doping of Si [19], the epitaxial growth of deposited Si-layers on Si [20], or the laser induced reaction of magnesium on Si [21]. Many of the results he elaborated during his work at the IAP had been published later in a book [22].

The possibility of generating shock waves in hot plasma with mode-locked lasers let people dream that this technology could be scaled up to such an extent that one day nuclear fusion could be initiated by symmetrically irradiating, heating up, and compressing pellets of the size of a pinhead containing a mixture of deuterium and tritium. According to work performed in the U.S. at the Lawrence Livermore National Laboratory (LLNL) and published by Nuckolls et al. [23], pulses with energy above one kilojoule at the target would be needed for ignition, and hundreds of kilojoules for sufficiently high energy gain. For comparison, short-pulse (picosecond) energies of at most a few joules were available in the early seventies [24]. So many research groups started work in scaling up the pulse energy of mode-locked lasers. When Horst Weber arrived in Bern in 1972, he hired a PostDoc collaborator from Euratom (European Space Research Institute, ESRIN) in Frascati/Italy, Wolfgang Seka, with experience in laser generation of plasma and plasma diagnostics. Because of the shutdown of the laser-plasma activity in Frascati, Wolf Seka arrived in Bern with a truck filled with Nd:YAG/glass amplifiers, power supplies, control electronics, fast oscilloscopes, and other state-of-the-art laser equipment. Together with PhD students, a research group was formed at the IAP, which soon was able to contribute in the fields of pulse amplification and plasma generation and -spectroscopy. A modest Nd:YAG/glass laser source delivering pulses of 1 J in 30 ps, mostly based on the "ESRIN components", was developed and used for the experiments (Figs. 10, 11) [25-28].

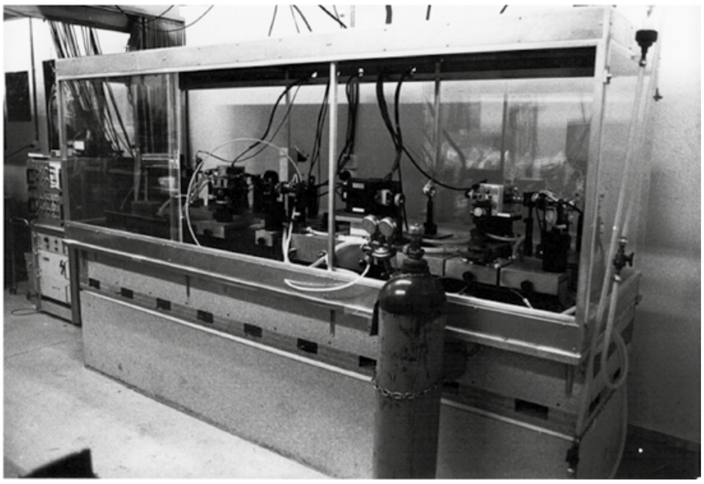

Fig. 10: "IAP Plasma" Laser ca. 1976. Nd:YAG oscillator and discrimination amplifier table. The nitrogen bottle in front of the table served to pressurize a laser-triggered spark gap used to select a single pulse from the train of mode-locked pulses [29].

Fig. 11: Nd:glass amplifier table. Two 20 mm diameter rods pumped by helical flashlamps (KORAD Laser Systems) boosted the pulse energy to ~1 J [29].

HE-NE

In 1961 the first laser emission at an infrared wavelength of 1.15 μm was demonstrated in a He-Ne gas discharge by Javan et al. [30]. Emission in the visible at 0.63 μm by White et al. [31] and a systematic study on the optimal discharge conditions at both wavelength by Boersch et al. [32] were reported shortly afterwards. At the IAP Hans Peter Brändli, René Dändliker and new diploma students, Peter Blaser and Theo Tschudi started working in this field. Discharge tubes were prepared at the IAP with the help of the glassblower and vacuum equipment at the Institute for Experimental Physics and the first home built He-Ne lasers were operated in 1964 (Fig. 12).

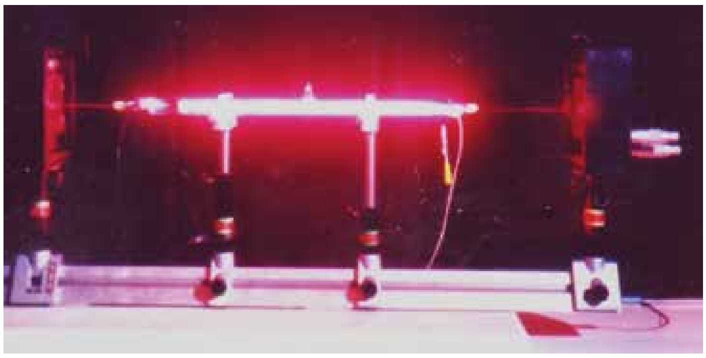

Fig. 12: He-Ne laser in 1964 [4]

New ideas for absolute frequency stabilization of He-Ne-lasers [33-35], for measuring small losses [36], on the polarization of gas lasers [37-39], and on coupled resonators were successively published [40]. When reliable He-Ne lasers became commercially available around 1969, the IAP group focused on developing measurement techniques and applications in interferometry [41-43] and holographic techniques [44]. With the arrival of Gerd Herziger in 1969 the activities included also more application oriented research such as, e.g. light scattering and particle size measurements [45-47], optical correlation techniques and quality control [48-53], Moiré techniques [54, 55], and spatial light modulation [56].

ION LASERS

The transition (decay) from the lower laser level in a He-Ne laser is not fast enough and has to be accelerated by collisions with the tube walls. Because the number of collisions with the tube walls increase as the tube becomes narrow, the laser gain is inversely proportional to the tube radius. Laser gain, tube radius and tube length being limited, the output power of He-Ne laser is limited typically below 100 mW and cannot be scaled up. Gerd Herziger and Horst Weber started to work on Argon ion laser in 1967 while they were still with the Boersch group at Berlin [57]. Ar^{2+} is the laser active ion in the discharge and its lower laser level decays by radiation. However, the excitation efficiency in this system is very poor, typically 6.7% for the quantum efficiency and 0.1% for the wall plug efficiency. Energy efficiency or saving was not yet an issue at these times and this system was an ideal candidate for scaling up the output power of visible lasers. But the poor thermal conductivity of quartz glass limited the evacuation of the enormous heat load from the plasma through the tube walls. The group developed tubes composed of anodized aluminum rings (Fig. 13) screwed together [58].

Fig. 13: Ar-ion laser discharge tube segment with 32 mm inner diameter [59].

The good thermal conductivity of aluminum evacuated the heat, the oxide layer between the rings prevented from short circuiting anode and cathode. When Gerd Herziger moved to Bern, he had soon Wolfgang Seelig and Karlheinz Banse, the key Ar-laser people, follow him. Together with a technician, Jürg Steinger, and later a diploma/PhD student, Hansruedi Lüthi, the team built the most powerful visible and UV laser at the time with an output power of 150 W at the 514 nm line (Fig. 14).

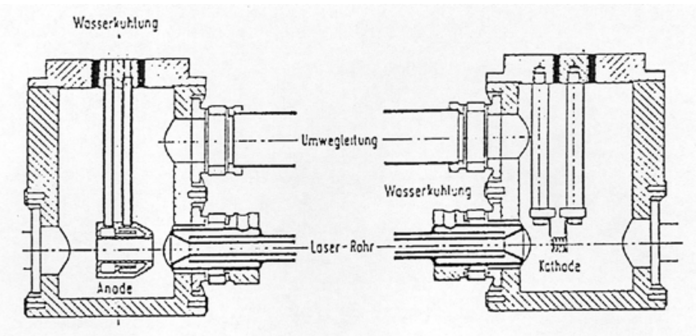

Fig. 14: Schema of the Ar-ion laser in Bern

The operation of this laser was quite impressive: The laser was mounted on a long granite table, with the electric supply consisting of transformer, rectifier, and solid cables, the howling of turbo vacuum pumps and the noise of the water pumps used for cooling the tube. Jealous colleagues jokingly claimed that in Bern the tram operation had to stop, when the laser was in operation.

The Ar-ion laser had a major problem: During starting-up, operation, and shutting down the laser tube was subjected to mechanical and thermal stress that lead to the formation of cracks in the oxide layers of the Al rings. The surrounding cooling water penetrated into these cracks, damaged the isolation between individual rings producing short circuits between anode and cathode. The damaged rings had to be found, the tube was unscrewed, the damaged rings replaced, and then the tube was reassembled. Maintenance time for the laser was orders of magnitude longer than the operating time and this was one of the main reasons, the laser tube could never be commercialized. However, the operation of this laser was spectacular for the public. Wolfgang Seelig used to light a cigarette for demonstrating the intensity of the parallel and unfocussed beam. But one day, in a public demonstration, his finger with wedding ring slid into the beam and a reflex hit the eye of a spectator. The ophthalmologist, Franz Fankhauser, was consulted. He found a small retinal coagulation outside of the field of vision, which fortunately had no consequences. The director of the institute, alerted about the security of his collaborators, asked Franz Fankhauser to check the retina of all collaborators when they started working in the laser group and when they left the institute. Fortunately, Fankhauser never found a damage, and the systematic controls were stopped about a decade later.

Dye Lasers

Dye lasers were discovered in 1966 by two groups, Sorokin and Lankard [60] at IBM research laboratories, and Schaefer et al. [61] in Göttingen. Here, fluorescent dyes are used as lasing medium, e.g. rhodamine 6G (emitting in the orange), fluorescein (green), coumarin (blue). They are usually dissolved in liquid solution (e.g. water, ethanol, ethylene glycol, or dimethylsulfoxide). They are excited by optical pumping with a flash lamp or another laser with optical conversion efficiency between 10% and 30%. The optical gain per unit length and the gain profile are much larger as compared to gas or solid-state lasers. Because of the high gain, pulsed dye lasers were easily set up: A glass cuvette with the solution, a discharge lamp for excitation and an alumina paper wrapped around the lamp and the cuvette. The reflection on two parallel walls of the cuvette was sufficiently high to achieve laser emission. A visible parallel light beam and interference pattern from the cuvette walls emerged perpendicular to the cuvette walls and convinced the audience that it was laser radiation. Contacts with the Schaefer laboratory facilitated knowhow transfer and from the late sixties on variation of this experiment had been one of the standard laser demonstrations in Bern.

In contrast to solid state laser materials dye molecules have very short fluorescence lifetimes (typically a few nanoseconds). This requires very powerful pump sources for excitation. In 1972 Peter Anliker and Michael Gassmann realized a flashlamp pumped rhodamine 6G dye laser with a maximum output energy of 12 J in a 5 μs pulse at 1 kJ electrical input energy [62].

Organic dye molecules have the tendency to become trapped in triplet states, in which they cannot participate in the lasing process. Moreover, during operation, laser dyes tend to be chemically degraded. These problems made it difficult to achieve continuous operation. In Bern, the high power Ar-ion laser was used to pump dye lasers [63]. Three PhD students, Michael Gassmann, Hansruedi Lüthy, and Peter Anliker, investigated dye lasers [64]. Anliker looked into the homogeneity of rhodamine 6G jets, an important parameter for achieving high power outputs. In collaboration with three colleagues from the Institute of Inorganic chemistry, Anliker et al. achieved with rhodamine 6G at the beginning of 1977 a conversion efficieny of 30% and a record cw output powers of 33 W [65]. After submission of the manuscript they achieved in March 1977 even 52 W of cw power in the red with an Ar-ion pumping power of 175 W !

CO_2 Lasers

The carbon dioxide (CO_2) laser emits infrared light at wavelength bands centered at 9.4 and 10.6 μm. It can be operated under cw- or pulsed condition and is characterized by quite high quantum efficiency (~30 %) and overall efficiencies (ratio of output power to pump power) of up to 20 %. In 1964 when the laser was first described in the scientific literature by Kumar Patel from Bell Laboratories [66], Robert A. Kaplan from the US company TRG in Melville N.Y. demonstrated already laser welding with a pulsed laser. The gas laser team at the IAP had acquired over the years a detailed know-how on the excitation of the gases by electric discharges at all pressure levels. Two PhD students, Michel Dufour and Hans Egger started to investigate CO_2-Lasers with transverse excitation, i.e. the gas discharge occurs perpendicular to the optical axes. These so called TEA-(Transversely Excited Atmospheric-) lasers can be operated in a pulsed mode at atmospheric pressure or above and are particularly simple to build: They consist of an isolating tube, e.g. plexiglass, filled with a mixture of N_2, He, and CO_2, sealed with two mirrors (one semi-transparent). Along the inner tube wall, an anode and cathode in form of metal strips, e.g. alumina, are placed on opposite sides. Alternatively, the cathode can also be formed by a series of evenly spaced nails that penetrate the tube wall opposite to the anode. The gas is excited by a discharge from a capacitor and the infrared beam emerges through the semi-transparent mirror. The discharge occurs in a myriad of filaments from the cathode to the anode. This results in a strongly non-uniform gain profile and a highly multimode laser emission. Two PhD students, Michel Dufour and Hans Egger started to investigate the homogeneity of various types of self-sustained TEA laser discharges in CO_2-N_2-He mixtures by analytical methods and experiments [67]. They added volatile organometallic gas molecules with a low ionization potential (ocenes) and used flash lamps to pre-ionize the whole volume immediately before the main gas discharge. This new technique allowed achieving a more uniform gas discharge and gain profile [68]. Emission under controlled transversal mode and uniform laser pulse conditions could be achieved. The technique worked in CO_2–N_2–He mixtures between 1 and 5 atm and offers a large scalability [69].

Diode Lasers

The first laser emissions from gallium arsenide (GaAs) p-n junctions were reported in 1962 by three groups in the USA [70-72]. The work in Bern started, when K. P. Meyer hired in 1964 the PhD student Jörg Hatz and shortly afterwards Christian Deutsch, Eugen Mohn, and later Ronald F. Broom. At that time GaAs was an exotic semiconductor material. Monocrystalline n-doped boules of ~1 inch diameter were grown by Czochralski and cut into 500 μm thick wafers. At that time the Batelle Institute in Geneva was active in this domain and the group in Bern could obtain wafers from them. A small fraction from a boule is shown in Fig. 15.

Fig. 15: lower part of GaAs ingot

Diodes were prepared by zinc diffusion at 850° in a hydrogen atmosphere, by grinding and polishing the wafer on one side to a thickness of 150 μm, applying gold contacts, sawing and cleaving the wafer into diodes of 400 μm length and 125 μm width, and mounting individual diodes on a modified TO-5 transistor head. The first diodes could only be operated at liquid helium (4°K) or liquid nitrogen temperature (77°K) because the laser threshold increased dramatically with temperature. The diodes were mounted at the bottom of a copper rod in a small vacuum chamber with two optical windows. The top of the rod was cooled in a Dewar bottle filled with liquid nitrogen. The arrow in Fig. 16 indicates the position of the diode.

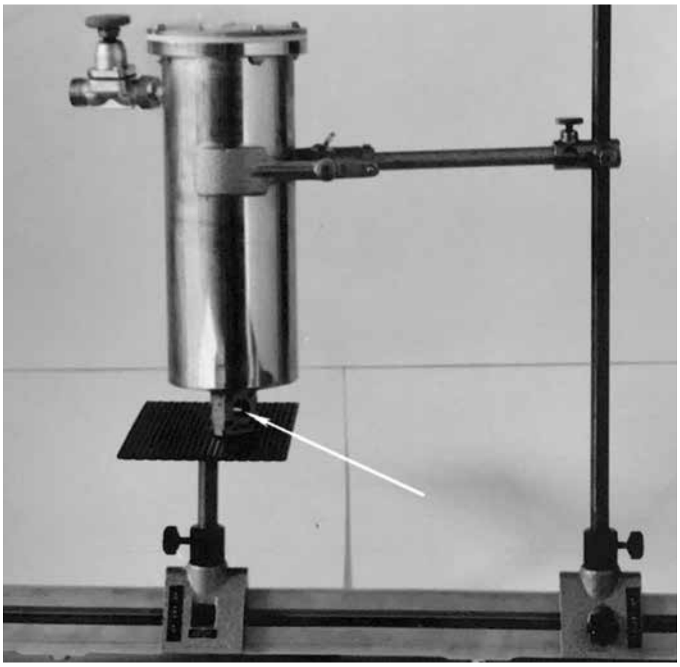

Fig. 16: Early experiments with Gallium Arsenide laser diodes [73]

Within 2 years the group managed organizing or buying and put into operation the necessary equipment for the semiconductor technology, for working at cryogenic temperatures and for optical diagnostics. First scientific results were reported in 1966/67 [74-77].

The first generation of PhD students was gradually replaced from 1967 on by a physicist from ETHZ (Christian Risch) and new diploma students (René Salathé, René Keller, Claude Voumard). From 1968 on the p-n diodes were prepared by liquid phase epitaxy, a method originally proposed by H. Nelson [78]. P-layers with higher doping concentrations and a steeper gradient at the p-n junction could be fabricated leading to lower threshold currents. A GaAs wafer was fixed at one end of a graphite boat, Ga with pieces of GaAs and Zn on the other end. The boat was loaded in a tube under oblique angle with the wafer at the upper position, heated up under hydrogen to 750°C. The liquid and saturated Ga solution was brought into contact with the wafer by tilting the oven and an epitaxial layer of some ten μm was grown on the wafer by slowly cooling down the melt. The equipment is shown in Fig. 17.

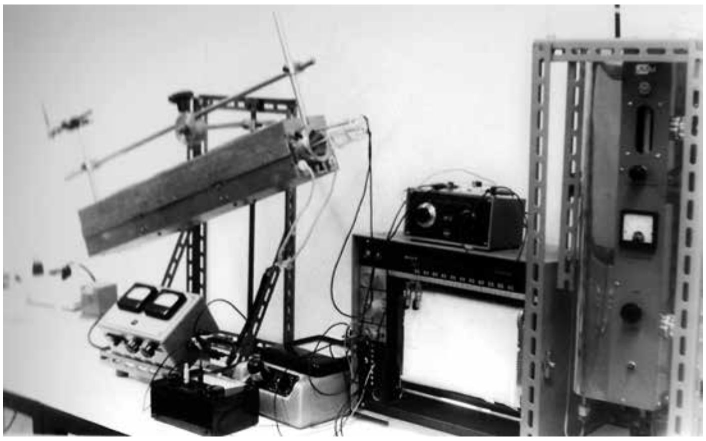

Fig. 17: Tilting oven (left) for GaAs liquid phase epitaxy with hydrogen purifier (right)

In the 1970ties the technique has been improved by inserting a glider with bins containing Ga-solutions in the graphite boat, that were in the cooling down phase successively moved over the GaAs substrate fixed at the bottom. This allowed to grow layers with different compositions of GaAlAs and doping material. This key technique, originally proposed by Zh. I. Alferov [79] and M. B. Panish [80], allowed to grow hetero-structures that confined carriers and photons to a thin layer at the p-n junction and reduced the laser threshold current to levels that made continuous operation at room temperature possible. The group, now under the direction of Horst Weber, was forced to reproduce this technology in order to have diode lasers available because they were not yet available commercially.

A technician, Jean-Marie Kuenzi, assisted the group in preparing and mounting individual diodes on specially designed copper mounts that allowed optical access on both mirror facets. René Keller was able to perform interferometric measurements on the deformation of the tiny diode mirrors during pulsed operation of the diodes at room temperature [41, 43]. René Salathé investigated the optical coupling of two laser diodes [81, 82]. Claude Voumard and Christian Risch looked into the properties of diode lasers coupled to external resonators [83-85].

After the first demonstration of continuous working diodes at room temperature based on double hetero-structure diodes [86, 87] many industrial research laboratories got involved with fabricating diode lasers. The group started a collaboration with the laboratories of Marcoussis near Paris in France, the research center of the "Compagnie générale d'électricité". In exchange to technological know-how transfer they received professionally fabricated laser diodes. The time-consuming production of own laser diodes was no longer necessary. In 1975/76, Franz-Karl Reinhart spent half a year of his sabbatical from Bell Telephone Laboratories as invited professor at the IAP. The collaboration with him and his collaborators in Murray Hill enabled the group to work with advanced material used for integrated optics. Yolande Rytz-Roidevaux, a PhD student from the Ecole Polytechnique in Lausanne, and two diploma students, Gerhard Badertscher and Heinz Gilgen, joined the group and the focus of research activity turned to laser processing of semiconductor laser material [88, 89].

Laser Applications

Ophthalmology

The ophthalmologist Franz Fankhauser was interested in performing systematic studies on retina coagulations with lasers. In search for a reliable industrial ruby laser he visited together with Alfred Roulier the Siemens laboratories in Munich, where they performed coagulation experiments on the retina of a rabbit. They returned to Switzerland not without some difficulties in bringing rabbit and laser through the customs. Franz Fankhauser, Alfred Roulier, and an optics expert from the Federal Office of Weights and Measures, W. Lotmar, conducted systematic studies from 1967 onwards on retina coagulation with patients at the ophthalmologic clinic of the University Hospital ("Inselspital") in Bern. The experimental studies were backed up by Alfred Roulier who calculated in the framework of his thesis the temperature increase in the eye produced by intense light [90]. The experiments represent the first medical applications of lasers in Switzerland and paved the way in establishing lasers mounted on slit lamps as efficient medical treatment for circumventing retinal detachment [91-94].

In 1968 Franz Fankhauser came up with the idea to clot blood vessels in the choroid (bloodshot eye) with the newly available argon laser light. A small fraction of the light was decoupled with a beam splitter and transferred to an ophthalmoscope that was mounted aside of the laser. The patient, a robust truck driver, was sedated with copious amounts of cognac before starting the laser machine. The attempt was successful but remained an episode. The more than bizarre scene was re-enacted after the operation with Alfred Roulier mimicking the ophthalmologist and the secretary of the institute as patient (Fig. 18). Jürg Steinger, the technician of the Argon laser group operated the laser.

Fig. 18: Medical Application of Ar-ion laser [95]

Satellite Telemetry

A proposal to use Q-switched Ruby-lasers for satellite telemetry has been elaborated in 1967 by Max Keller [96]. He estimated to achieve an accuracy in distance measurements of 0.5 m for satellites equipped with reflectors for costs of about 300'000 CHF. A project proposal was submitted to the Swiss National Science Foundation in collaboration with the Astronomy Institute (Prof. M. Scheurer). The accepted project allowed to equip the 60-cm telescope at the Observatory of Zimmerwald with a Q-switched ruby laser system (Fig.

19). First measurement could be performed in spring 1971. An accuracy of 0.5 m was reported in 1972 for distances of 1000 - 3000 km [97].

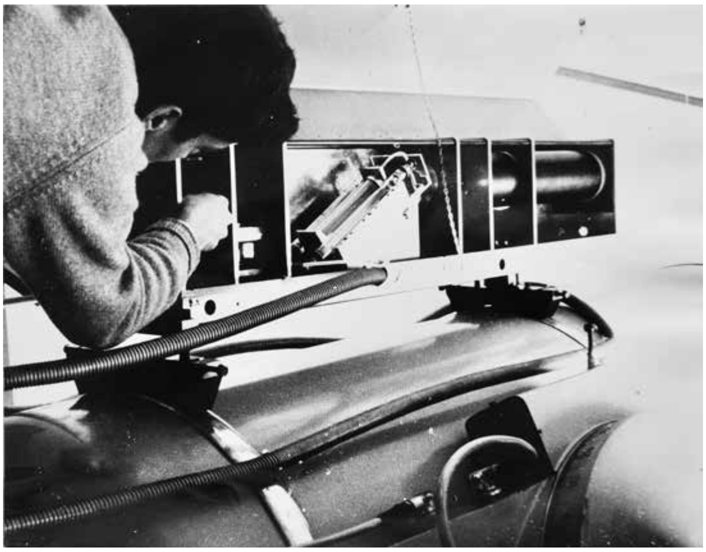

Fig. 19: Mounting of the ruby laser on the telescope in Zimmerwald [7]

Drilling Of Watch Stones

In the early 1960ties the Swiss Watch Industries produced 50 million ruby watch bearings per month (17 – 21 jewels per watch) and drilled for that 50 μm diam. cylindrical holes in ruby discs (1 mm diam. 0.3 mm thick). The drilling was realized with rotating steel wires using diamond paste, which took 3 – 5 minutes per hole. Drilling a hole in less than a thousandth of a second with a laser would be a real revolution in the watch stones community. In 1965 Hans Räz, director of the Watch Stones Company in Thun, was intrigued by publications on drilling of small holes into metals and crystals with ruby lasers. He mandated the Hughes company in the US to drill holes into ruby platelets, but the laser drilled holes were characterized by irregular diameters and showed craters, material ejections, and cracks. He asked Prof. K. P. Meyer to perform drilling tests at his institute. The free running ruby laser shown in Figs 2 & 3 was used end of 1965 by Hans-Peter Brändli, Max Keller, Alfred Roulier, and Michel Seehof for this purpose. The feasibility of drilling watch stones with diameters in the 50 - 70 μm range in a single shot could be demonstrated (Fig. 20), but the drilled holes were unusable for further processing.

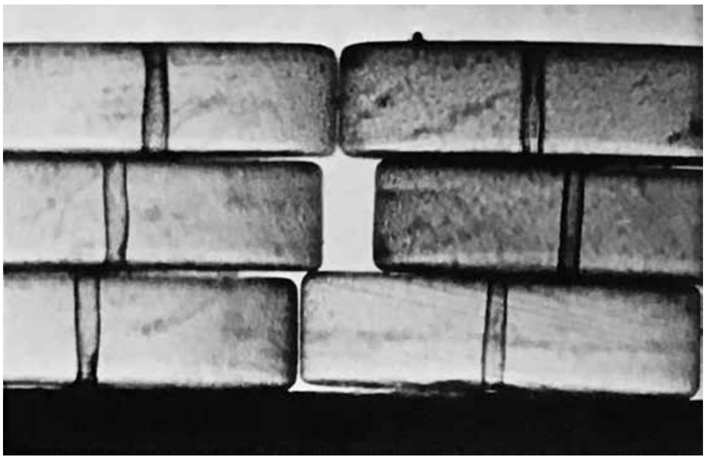

Fig. 20: 1966 experiments in drilling watch stones with ruby laser [98]

For improving the hole-quality the drilling process had to be investigated in detail. K. P. Meyer recruited Jürg Steffen, who just finished his diploma thesis on submillimetre wave gas lasers at ETH Zürich, to reinforce the project team. By observing the drilling process with a high speed camera and measuring simultaneously the input and transmitted laser light [99], it could be demonstrated that the mediocre quality and reproducibility of the drilling process was related to the poor time and mode behaviour (spatial intensity distribution) of the ruby laser pulses.

The group started investigating hole drilling with Nd:YAG-lasers. These lasers showed a TEM00-Mode intensity distribution and regular spiking (Fig. 21).

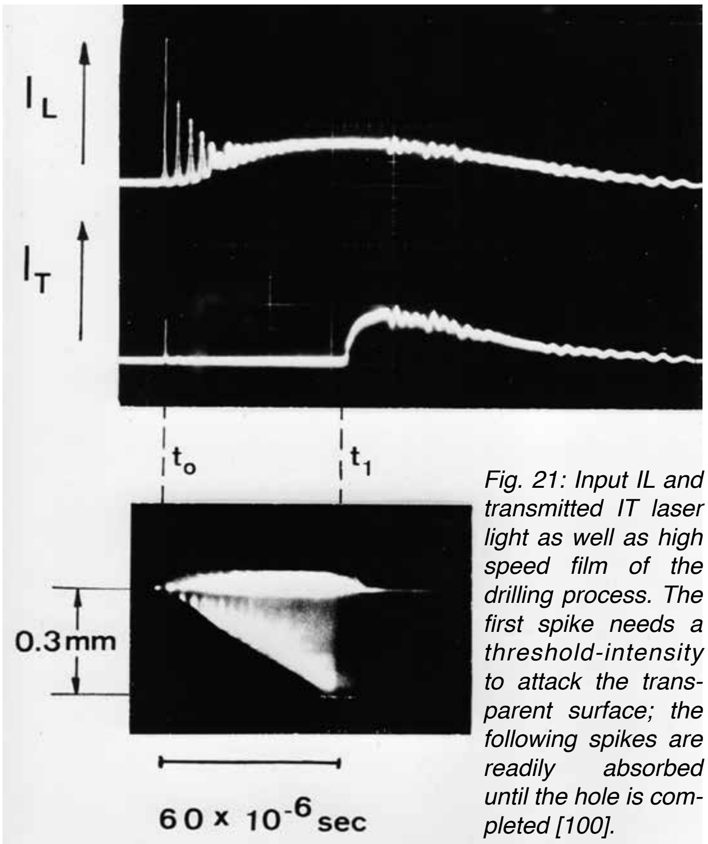

Fig. 21: Input IL and transmitted IT laser light as well as high speed film of the drilling process. The first spike needs a threshold-intensity to attack the transparent surface; the following spikes are readily absorbed until the hole is completed [100].

Drilling experiments with this laser resulted in a reproducible process (Fig. 22). Clean cylindrical holes could now be generated suitable for further processing into watch bearings (Fig. 23).

The feasibility experiments on hole drilling had been undertaken by researchers working in parallel for their thesis devoted to other topics in the laser field. They had to focus on finishing their thesis. New diploma and PhD students (Ernst Kocher, Hans-Peter Lörtscher, Lorenz Tschudi, Hans-Ulrich Leuenberger, and Lorenz Scheidegger) were hired and Jürg Steffen took over the lead of the research group. They investigated the absorption in transparent materials [101] and the design of the laser pumping unit [102]. The shape of laser drilled holes was studied in detail [103].

The development towards an industrial machine was further reinforced when Gerd Herziger took the direction of this part of the IAP and hired more personnel. New engineers and technicians (Reiner Stemme, Jürg Pulfer, Hans-Jakob Weber, and Hans Bühlmann) together with Watch Stones col-

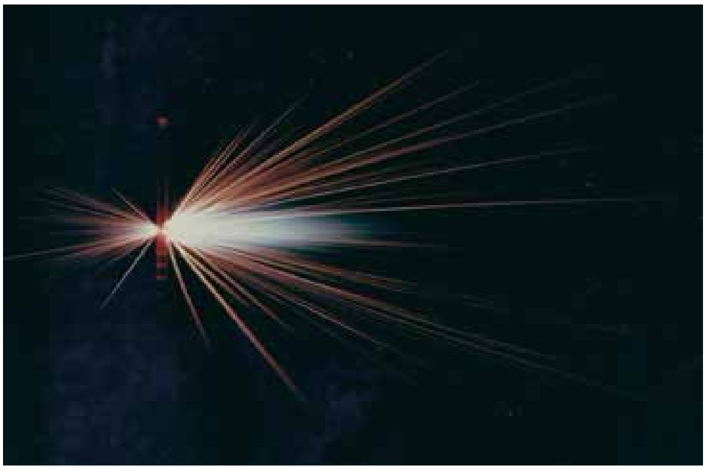

Fig. 22: Drilling process of a ruby disc viewed perpendicular to the laser beam through a polished edge of the ruby disc. Laser beam comes from right side [100].

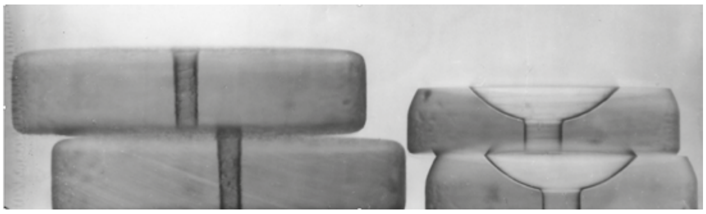

Fig. 23: Nd:YAG drilled holes (diam. 50 µm) in 0.3 mm thick ruby discs (diam. 10 mm) and finished watch bearings [100].

laborators developed a feeding machine for the ruby discs to enable series production. But new problems arose: the automatically fed discs were not drilled reproducibly, many of the discs had not been drilled at all. Up to now the discs, inserted piece by piece by hand into a chucking tool, were slightly greased on the surface. By automatic feeding this absorbing layer was missing. Such a layer had to be added before the ruby discs were ready for drilling. The beam properties emerging from the laser head and the laser resonator configuration had to be investigated in detail as function of the average power [104-106] in order to keep the thermal beam deformation at higher pulse repetition rates under control. In addition, the pump cavity [106] and the disc-feeding device had to be improved. Finally, the automatic series production at higher repetition rates became possible: In 1968 twelve discs/second could be drilled and were finished as bearings at Watch Stones Ltd. In Thun. Two years later, four laser machines had been installed drilling 50 million pieces a month (Fig. 24).

In 1972 Watch Stones Ltd, in the meantime part of the Pierres Holding group, decided to take on the original project team led by J. Steffen. The group was transferred from Bern to Thun into the "Research Institute Pierres Holding SA". Other materials processing tasks in the watch industry and associated micro-technical industries, such as, e.g., drilling of conical holes for sapphire bearings, tuning of the oscillation frequency of the quartz for the electronic watches, were investigated. In 1974 the research institute was transformed into an autonomous company named LASAG SA, led by Reiner Stemme, providing laser-based solutions for production problems in the micro-technical industries and to build and market application-specific laser equipment. Finally, LASAG AG had been integrated via Rofin-Sinar into the globally active COHERENT-Group. It's hard to believe, but in 2019, the laser-system, set up for drilling watch stones

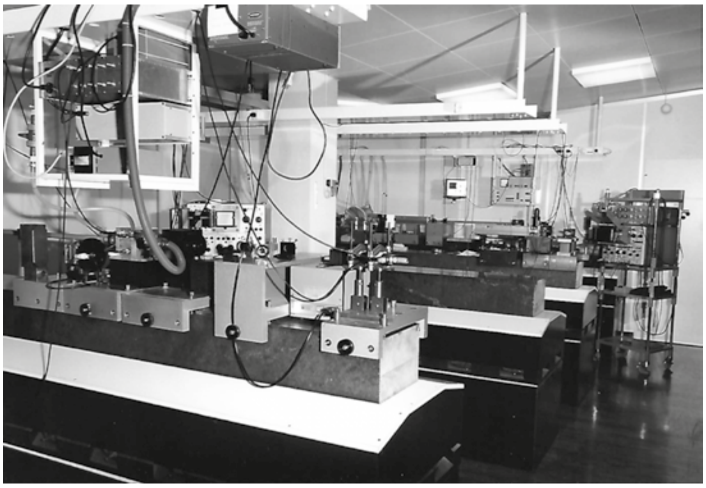

Fig. 24: Four laser installations to drill 50 Mio. ruby discs per month for watch bearings [100].

in 1970, has still been in operation in the old Watch Stones building in Thun.

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Milestones in Physics (20)

The CERN 25 GeV Proton Synchrotron
The backbone of CERN celebrated its 60th Anniversary

Klaus Hanke, Kurt Hübner, CERN

On 24 November 1959 the first proton beam was accelerated to 24 GeV. This event 60 years ago was duly celebrated in a colloquium at CERN in November 2019. This article summarizes the conception, design, construction and evolution of this unique physics instrument, which became the tireless workhorse and the unflagging backbone of the accelerator-based research programme of CERN [1, 2].

From the idea to decision

After World War II common action was considered a prerequisite for re-establishing Europe's science position as for example suggested in a declaration by Louis de Broglie at the "Conference Européenne de la Culture" at Lausanne in 1949. Isisdor Rabi's declaration at the General Conference of UNESCO in 1950 at Florence lent American support to this idea to pool European resources for nuclear research. Pierre Auger, a physicist active in cosmic ray research, assembled a Group of Experts in 1951 which finally proposed the construction of two accelerators: a very ambitious one which could not be "easily overtaken elsewhere" and a more conventional one for early operation. Obviously, the first one had to be a synchrotron and for the second one a synchro-cyclotron was chosen. After the first meeting of government representatives at the end of 1951, a convention was agreed provisionally establishing CERN in a second meeting in February 1952.

After ratification of this provisional convention, the CERN Council decided in its first meeting in May 1952 to establish four study groups. One of them, led by Odd Dahl, was formed for the Proton Synchrotron (PS). This Group presented already in June a first proposal for the construction of a 10 to 15 GeV proton synchrotron obtained from scaling up the 3 GeV weak-focusing Cosmotron at Brookhaven (BNL), which had reached 1 GeV. Three members of the study group, Dahl, Goward and Widerøe, visited Brookhaven in August and were acquainted there with a new idea, the Alternating-Gradient (AG) or "strong" focusing principle of particle beams which held the potential to substantially reduce the size of the vacuum chamber und hence the magnets producing the guide field. Odd Dahl presented two options to the 3rd Council meeting in October: a 10 GeV weak-focusing (estimated magnet weight 6000 t) and a 30 GeV strong-focusing synchrotron (700 t) with identical cost within the error margins. Council boldly entrusted the group with a study of the 2nd option, strongly advocated by O. Dahl, though in untried and new, risky territory. The site of Geneva was selected at the same Council meeting. In June 1953, a referendum against this choice was successfully passed in the Canton and Republic of Geneva and the final CERN convention was signed by the then twelve member states.

A more detailed study discovered serious beam stability problems brought about by sensitivity to inevitable magnet misalignments and field inhomogeneities enhanced by the too strong magnet field gradient in the combined-function magnets which provide the dipole guide field and the focusing quadrupole field gradient. A concerted theoretical effort leading to a number of parameter iterations and friendly help from colleagues from Brookhaven provided understanding and a satisfactory parameter set so that the 7th Council meeting in October 1953 could take the decision to aim at a strong-focusing synchrotron which would reach 25 GeV with a magnetic dipole field of 12 kG.

Construction of the PS

The preliminary design of the main components had started in institutes spread all over Europe, in Bergen, Paris, Heidelberg and Harwell. However, the design team reached its efficiency only until its transfer to Geneva in the course of 1954. John B. Adams became the project leader after resignation of O. Dahl and the final parameters were adopted in December 1954.

The strong-focusing magnet lattice with 2π 100 m orbit length contained 100 combined-function magnet units of 4.4 m nominal length with a field index n = 288 and a total steel mass of 3400 t. The magnet unit was assembled from 10 blocks consisting of 1.5 mm thick steel sheets glued together.

Each magnet was equipped with pole-face windings to correct i) for the remanent field at the injection energy of 50 MeV where the field level is as low as 140 G and ii) for saturation effects at high fields. Sixteen out of the twenty 3 m long straight section were reserved for the accelerating cavities and the eighty 1.6 m long short straight sections housed auxiliary magnets as quadrupole correction lenses, sextupole and octupole lenses. The width of the vacuum chamber in the main units was 14 cm and its height is 7 cm.

The rise time was set to 1.0 to 1.2 s and the pulse rate

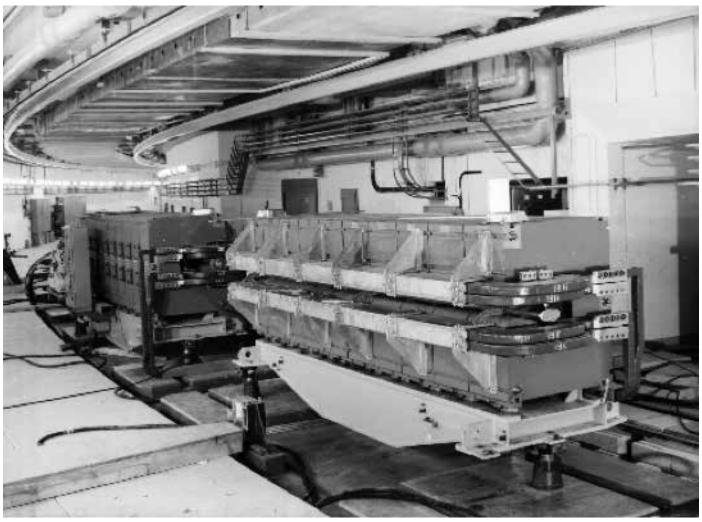

Figure 1: The first magnets in the PS tunnel [3].

10 to 12 per min depending on the final energy of 25 resp. 28 GeV corresponding to a maximum magnetic field of 12 resp. 14 kG. The maximum required peak electrical power of 32 MW was provided by a motor-generator set with a fly-wheel as energy storage. Sixteen ferrite-loaded accelerating cavities tune-able between 3 to 10 MHz supplied 54 keV per turn.

Civil engineering had started in May 1954 even before the ratification of the convention in September. Exploration of the subsoil showed that the machine could be based on a concrete ring-shaped beam of 2 × 2 m^2 cross-section supported by pillars founded on the competent deeper molasse rock under the moraine. The PS tunnel building was finished by mid-1957 and the magnet installation was complete in June 1959 (Fig. 1).

Running-in and first operation

Despite the choice of a hitherto unknown technology and an inexperienced team the running-in took a surprisingly short time. The first turn of a proton beam at 50 MeV was obtained in middle of September 1959 and, after the RF system was complete in October, the acceleration tests started. A few GeV were quickly reached and the beam reached a kinetic energy of 24 GeV on 24 November after a modification of the low-level RF control system. The pulse intensity was 3 × 10^{10} protons, beyond the design intensity of 10^{10}. By the way, the sister accelerator at BNL in Brookhaven, the Alternating-Gradient Synchrotron (AGS) developed in friendly competition with the PS, started operation in summer 1960 after having reached 31 GeV in July.

The next years saw an intense effort to better understand the accelerator, improvement of the beam observation, an increase of the available RF voltage and expansion of the experimental facilities. The main power supply was modified in 1960 to provide a flat top so that two bursts from the internal targets could be produced in the same acceleration cycle: a short one (hundreds of ms) for the bubble chambers and a long one (up to 400 ms) for counter experiments.

After a first neutrino experiment had failed in 1961, a unique neutrino beam was constructed based two novel technologies: a fast-ejected beam (Fig. 2) produced by fast kicker magnet and a pulsed magnetic horn for efficient focusing of the parent mesons and, therefore, of the neutrinos produced in the reaction p → external target → π → $\mu\nu_\mu$. However, the experiment taking data in 1963/1964 came too late to compete with BNL where the discovery of the existence of at least two neutrinos was made in 1962, which understandably led to some deception.

Figure 2: Fast-extracted proton beam in PS 1963 [4].

Although fast extraction was also used later for the short spill needed for the bubble chambers and, therefore, mitigated somewhat the radiation damage brought about by the use of internal targets, the development of the so-called slow extraction serving external targets and already proposed in 1961 was intensified. In this extraction mode, the beam is slowly "peeled" at top energy during the so-called flat top by means of a non-linear resonance with a thin electrostatic septum magnet deflecting the beam out of the vacuum chamber. The first tests took place in 1964 and the refinement of this technique continued over the years beyond the elimination of the internal targets in 1980 and is still in use.

Consolidation and operation as injector

By end of 1965, 10^{12} protons per pulse had been reached and the protons were shared between nine experiments by means of four internal targets, one slow-extraction and a fast extraction. However, new demands for the PS were coming up: operating as injector for the Intersecting Storage Rings (ISR), a new neutrino beam line for the new heavy liquid bubble chamber Gargamelle, and feeding protons to the planned West Hall earmarked to house the large hydrogen bubble chamber BEBC and the Omega experiment. Hence, a comprehensive and long-term improvement programme was decided by the CERN Council in December 1965, where also the ISR programme was approved.

A new, performing main magnet power supply was foreseen and came in operation in 1968, which provided e.g. two flat tops at different energies in the same magnet cycle. The injection energy was raised to 800 MeV by interleaving between the 50 MeV linear accelerator (Linac 1), a fast-cycling four-ring synchrotron, the PS Booster (PSB), which became operational in 1972 and boosted indeed the number of protons in the PS pulse to 5 × 10^{12} and, in consequence, the neutrino flux to Gargamelle by a factor three, which was essential for the discovery of the neutral currents by this experiment.

The increasing intensity and the inevitable losses implied and implies a relentless effort to replace radiation damaged and ageing components: e.g., all vacuum seals made from organic material were replaced by 1972. Magnets had to be replaced from 1967 onwards and the damaged units became spares after having been refurbished with new coils; all pole-face windings very exposed to radiation by their position close to the vacuum chamber were completely replaced by 1979; the ageing original Linac 1 was superseded by Linac 2 of CERN design authorised in 1973 and coming on line in 1978.

For the ISR, a new fast-extraction system and new beam lines were constructed and beam was delivered to the ISR from late 1970 onwards. The 450 GeV Super Proton Synchrotron (SPS), approved in 1971 and entering the scene in 1975, required a novel extraction technique, called somewhat obscurely Continuous Transfer (CT), to cope with its circumference of 11 times the one of the PS. Each PS pulse was cut into five beamlets in betatron phase space prior to extraction by means of a combination of a fast kicker, fast beam bumpers, and a thin septum in order to fill with two PS pulses 10/11th of the SPS circumference by boxcar stacking. Obviously, this crude cutting of the beam resulted in intolerable particle losses with increasing intensity and had to make way for the novel and much more efficient Multi-Turn Ejection (MTE) commissioned in 2008 (see section "New challenges").

Antiparticles enter the scene

After failing to discover the J/Ψ and the Υ in the ISR for lack of performing 4π detectors in the early 70's, the attention of CERN turned to two new projects having a substantial impact on the PS: i) conversion of the SPS into an proton-antiproton collider in the medium term; ii) construction of a Large Electron Positron collider (LEP).

Since the antiproton phase space density was crucial for the luminosity of the SPS collider and this density was too low in the secondary beam created by the primary proton beam hitting the target, it was imperative to increase this density by beam cooling both in the transverse and longitudinal phase space. This was performed in the new large-acceptance Antiproton Accumulator (AA), accumulating secondary antiprotons at 3.5 GeV/c for hours and simultaneously increasing the 6-dimensional phase space density of the accumulated coasting beam by means of stochastic cooling which had been pioneered in the ISR. In order to increase the rate of antiproton production by a factor 10, a second ring, the Antiproton Collector (AC), was installed in 1987 around the AA, the latter being in operation since 1980. Stochastic cooling also in the AC increased this phase space density by up to 4 x 10^9 before the beam was extracted to the AA, where the beam was accumulated over hours or days continuing cooling until transfer.

The PS provided every 2.4 s a primary beam of up to 1.4 × 10^{13} 25 GeV protons per pulse, which had to be grouped in one quarter of the PS circumference to match the circumference of the AA. This challenge ushered in a new chapter in treating bunched beams in longitudinal phase space. This RF technique reached its culmination in the complex manipulation of the PS bunches to prepare the beam for LHC (see section "New challenges"). After a number of trials, a two-step process was adopted taking place on the flat top of the PS cycle at ejection energy where initially the proton bunches occupy 20 equidistant positions around the circumference. In the first step, each group of 10 consecutive bunches are merged into five bunches which produces a beam filling half of the circumference. In the second step, the distance between the bunches is progressively halved yielding a beam in a quarter of the circumference as required.

Since the momentum of the accumulated antiproton beam was too low for direct injection into the SPS, the beam was injected into the PS and accelerated to 26 GeV/c before transfer to the SPS. Weak pilot bunches of antiprotons taken from the stack in the AA were used to check the correct functioning of the whole chain from AA to SPS in order to avoid the loss of the whole stack painstakingly collected over some 24 hours. Even with this precaution, the cliff-hanging operation created daily anxiety for the PS team and their clients in the SPS.

The PS was thus a key player in the successful SPS proton-antiproton programme pursued from 1980 onwards and terminated in 1991, which established the existence of the heavy bosons $W^{\pm}$ and Z^0. However, this programme had not been the only user of antiprotons. The strong interest in low-energy physics with antiprotons had led to the construction of a small Low-Energy Antiproton storage Ring (LEAR), which provided from 1982 to 1996 a constant flux of antiprotons over spill times of several hours after filling of the ring. A single bunch, of usually 10^9 antiprotons, was skimmed off the AA stack and, after deceleration in the PS to 609 MeV/c, transferred to LEAR where it could be either decelerated to as low as 100 MeV/c (5.3 MeV kinetic energy) or accelerated up to 2000 MeV/c. For most of the experiments, ultra-slow extraction provided a continuous spill until the next fill. In order to simplify the costly operation involving four accelerators (AC, AA, PS, LEAR), the AA was dismantled in 1997 and the AC was converted into the 3.5 GeV/c Antiproton Decelerator (AD) now in operation since 2000 providing decelerated antiprotons down to 100 MeV/c (5.3 MeV). In order to increase the antiproton flux at lowest energy by decelerating the particles from AD even further to down to 100 keV, the Extra Low ENergy Antiproton (ELENA) ring is under commissioning. It has only 30 m circumference and is fitted inside the AD. To eliminate the blow-up of the beam during deceleration, stochastic and electron cooling are used in the AD, whereas the latter cooling technique suffices for ELENA.

Studies for the long-term LEP project started in 1975 and they had shown that the electrons and positrons could be accelerated in the two existing synchrotrons PS and SPS without fundamental modifications. This was an overwhelming argument to choose a site in close vicinity to the existing CERN site when the project was authorized in 1981. Hence, the PS had to shoulder this additional task, which implied the construction of a 600 MeV lepton Linac and of a small accumulation ring sequentially providing electron and positrons to the PS, and the addition of injection and extraction systems. The acceleration to 3.5 GeV within 1.2 s of two consecutive pulses of positrons followed by two pulses of electrons was accomplished by the existing 10 MHz RF system tuned to 3.8 MHz, but two new cavities operating at 114 MHz were installed to prepare the PS bunches for proper injection into the SPS and trapping by its 200 MHz RF system. Since the PS ring is composed of combined-function magnets, the horizontal betatron oscillations would be excited by the synchrotron radiation at higher energies whereas the energy oscillations would be strongly damped. Hence, the damping of the horizontal oscillations had to be established by the addition of two short so-called Robinson gradient wiggler magnets each consisting of four blocks of a total magnetic length of 46 cm so that they could be easily housed in the existing straight sections. In order to limit the synchrotron radiation induced gas desorption from the vacuum chamber, a vacuum improvement programme was carried out in the mid-80s. All 100 magnets received a new vacuum chamber made out of vacuum-fired stainless steel and the total pumping capacity was substantially augmented reaching 80 × 200 l/s and 40 × 400 l/s yielding a static pressure of 1 × 10^{-6} Pascal in static conditions. After these modifications, the PS beam was ready for the first injection tests of LEP in 1988 and the new challenge of regular operation of LEP between 1989 and 2000.

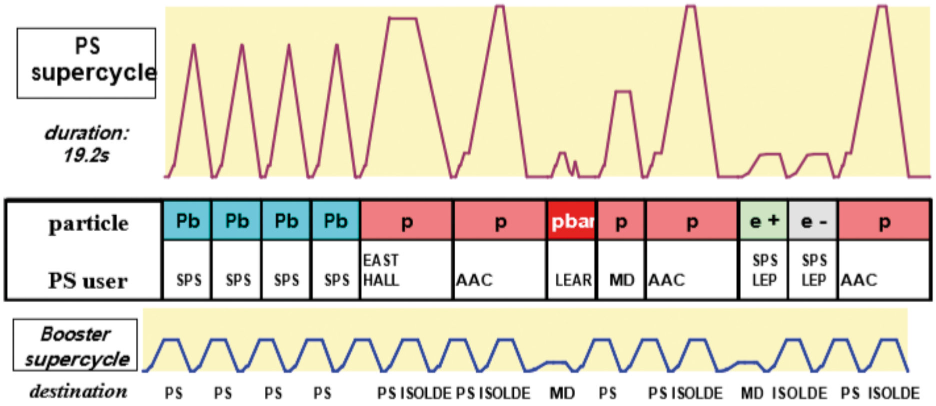

Figure 3: Typical PS super-cycle in 1995 of 19.2 s. The upper graph shows the PS magnetic field and the lower graph the field of the PSB as a function of time [5].

The versatile particle factory

The backbone of the operation of the PS was, of course, the flexible, continuously upgraded beam instrumentation and control system, which handled the timing and the sequencing. The first computer was installed in 1967 to assist the operators and the PS was proud of a memory upgrade to 16 k words (sic) in 1968. By 1981, a network of computers has taken over not only the monitoring and operation of the main ring but also of the injectors and AA. The whole dispatching of the beams was computer-driven. The various cycles providing very different beams had become the substructure of a super-cycle. The super-cycles were composed on the basis of the agreed schedule with the users and, once established, could be executed at will with high precision and reproducibility without tedious retuning. As illustration of the astonishing PS versatility, Fig. 3 gives an example of such a 19.2 s long super-cycle used in fall 1995 which was an especially demanding year with 6800 h operation. Nevertheless, the availability for SPS and LEP was 92%. The shown super-cycle was composed of four cycles delivering 3.5 GeV/c/u Pb beams to the SPS for fixed-target physics; a 24 GeV proton beam for similar experiments in the East Hall; 25 GeV protons for antiproton production for AC; deceleration of 3.5 GeV/c antiprotons for LEAR; protons for machine development; 3.5 GeV positrons and electrons for LEP via SPS, and a 2nd cycle for the AC. The PSB super-cycle reveals that the PSB was providing a 1 GeV proton beam for a nuclear physics programme (ISOLDE) in its spare time when not needed for the PS. Obviously, when the PS celebrated its 40th anniversary in 1999, it had become the heart of a vast system of accelerators serving a large physics community and executing multiple tasks not dreamt of in 1953 when the decision for its construction was made.

New challenges

In the 1990s and early 2000s, the PS faced two major challenges: the request for even higher intensity beams on one side, and the request for very dense ("high brightness", defined as the intensity divided by the transverse emittances) beams for the Large Hadron Collider (LHC), approved in 1994 and constructed at CERN 1998 – 2008 in the former LEP tunnel.

The request for higher beam intensity was mainly pushed by the neutrino appearance experiments installed in the INFN Gran Sasso Laboratory in Italy and deserved by the CERN neutrino beam named CERN Neutrinos to Gran Sasso (CNGS), operating between 2006 – 2012. In order to deliver a sufficiently high neutrino flux to the experiment, a maximum proton beam intensity was required culminating in an intensity record of 3.5×10^{13} reached in 2004.

With the quest for higher and higher intensities, the beam loss brought about by the extraction using the continuous transfer technique became unacceptably high and a new extraction mode was devised: the Multi-Turn Extraction (MTE). It consists in a resonant extraction process based on beam splitting in the horizontal phase space. Non-linear elements (sextupoles and octupoles) are used to excite a fourth-order resonance (Fig. 4). By a controlled adiabatic crossing of this resonance, the beam is split into four islands and one core, with essentially no particles in between. The beam is then extracted in two consecutive 5-PS turn long pulses towards the SPS to uniformly fill 10/11th of the SPS circumference.

The other, very different new client for beams from the PS was the LHC. The LHC requires beams with a high proton density ("brightness"), as well as a certain time structure which the PS generates using its different RF systems. A whole variety of beam types for the LHC can be produced by the injector complex, underlining its flexibility. The main type of beam used by the LHC is the beam with 25 ns bunch spacing. For this beam, the PSB produces six bunches at 1.4 GeV energy, which are then transferred in two extractions (4 + 2 bunches) to the PS. In the PS the beam is accelerated to a top energy of 26 GeV and at the same time the bunches are longitudinally split at an intermediate and final energy. This scheme employs consecutively the RF harmonics 7, 21, 42 and 84, which leads to a 12-fold splitting of each bunch. The resulting number of bunches produced from the six bunches coming from the PSB is hence 72. The

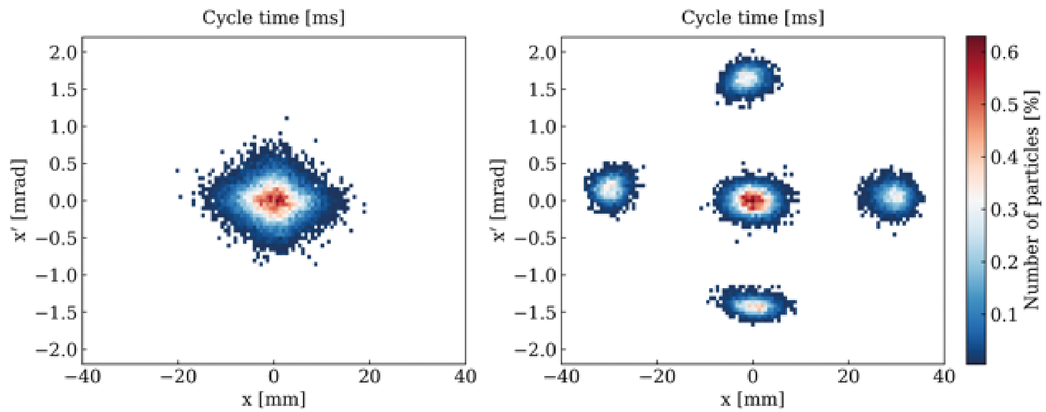

Figure 4: Principle of multiturn extraction. The uniform beam distribution (left) is split in horizontal transverse phase space into four beamlets and a core (right) which are then consecutively extracted with essentially vanishing beam loss [6].

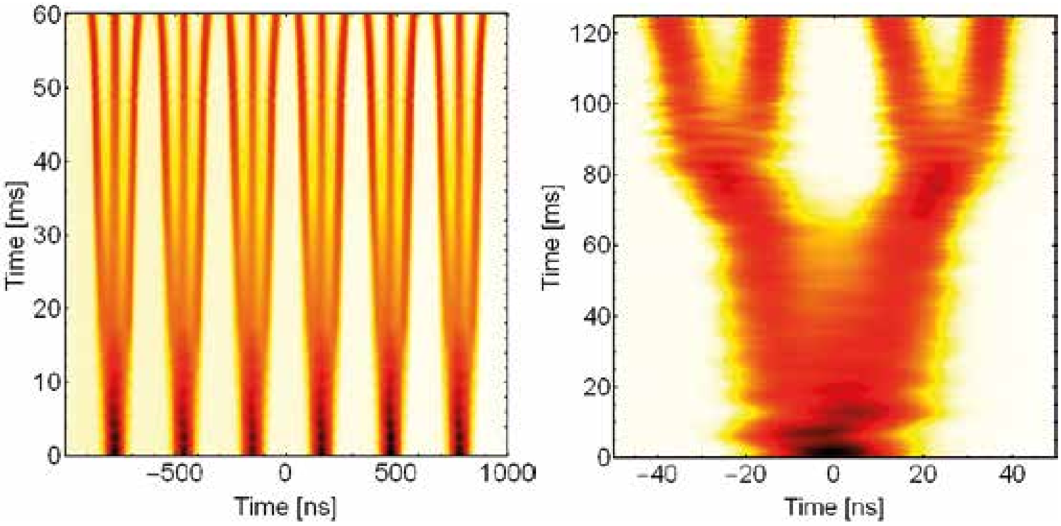

Figure 5: Evolution of the longitudinal structure of the LHC 25 ns beam in the PS as a result of the bunch splitting at 2.5 GeV and 26 GeV. The position of the bunches along the circumference is plotted horizontally and the time increases along the vertical axis. See for example [7, 8].

evolution of the bunch distribution as a function of time as a result of complex RF manipulations is shown in figure 5. In a first step triple splitting of each bunch coming from the PS Booster is performed at 2.5 GeV (left figure); in a second step, two consecutive double splittings are performed at 26 GeV, yielding 72 bunches to be injected into the SPS.

A word on ions

After the ISR runs with deuterons and alphas supplied by the PS in the 1970s, the demand increased at CERN for heavier ions to be delivered as a primary beam to the SPS North experimental hall. The installation of a new ECR (Electron Cyclotron Source) along with a dedicated RFQ and a number of upgrades in the PS enabled delivery of a total of around 2×10^9 oxygen ions per SPS shot to a variety of experiments in 1986. One year later, up to 9×10^9 sulphur ions were accelerated at CERN to a world-record energy of 6.4 TeV (200 GeV/u). The success of the oxygen and sulphur runs in the SPS pushed the users to request heavier ions. Since this was out of reach of CERN's Linac 1, a new ion injector chain was constructed in collaboration with Czech, French, German, Indian and Italian institutes consisting of a new ECR source and a new Linac ("Linac 3") based on a novel compact, high-gradient Interdigital H-type structure suggested and built by GSI. Linac 3 injected ions first into the PS Booster, where they were pre-accelerated before being injected into the PS. During this transfer, the charge state of the ions was progressively increased by stripping, first at the exit of Linac 3 to an intermediate charge state (Pb^{53+}), followed by full stripping in the PS-SPS transfer line. Between 1995 and 2002 the PS complex delivered lead ions to the SPS, followed by an Indium run in 2003. While the intensities and brightness delivered was sufficient for the fixed-target program, the upcoming LHC ion program requested intensities orders of magnitudes beyond what could be delivered by this injection scheme. This led to the decision to convert the low-energy ion ring (LEAR) to and ion accumulator and cooler, called Low Energy Ion Ring (LEIR), operating as buffer between the fast-cycling linac and the slow cycling PS. The PSB stopped injecting ions into the PS in 2004, and LEIR operation started in 2005, injecting into the PS, where the new Pb ion beam was commissioned in 2006. In this configuration, the PS is today delivering Pb ion beams for the LHC ion program as well as for the fixed target ion program.

Upgrades and future

While the injector complex is delivering beams to the LHC well within and beyond the original specifications, the High-Luminosity LHC program (HL-LHC) is aiming at beam parameters well out of reach of the present injectors. Figure 6 shows the beam emittance versus beam intensity, indicating the values presently achieved and the one requested by the HL-LHC program. In order to enable the injector chain to deliver high-brightness beams in the High-Luminosity LHC era, CERN has put in place the LHC Injectors Upgrade (LIU) project. This project comprises the replacement of CERN's proton Linac (Linac 2) by a new H^- Linac (Linac 4) with an increased injection energy in the PSB, the increase of the top energy of the PSB from 1.4 GeV to 2.0 GeV and upgrades of the PS and SPS synchrotrons [9, 10].

The upgrade program of the PS focuses on issues both in the transverse and longitudinal plane. In the transverse plane, the direct space-charge tune spread pushes the beam on betatron resonances causing beam loss and transverse emittance blow up. The upgrade of the injection energy to 2 GeV will help to overcome this limitation. The transverse damper was also upgraded to cope with transverse instabilities and to reduce injection errors. Concerning the

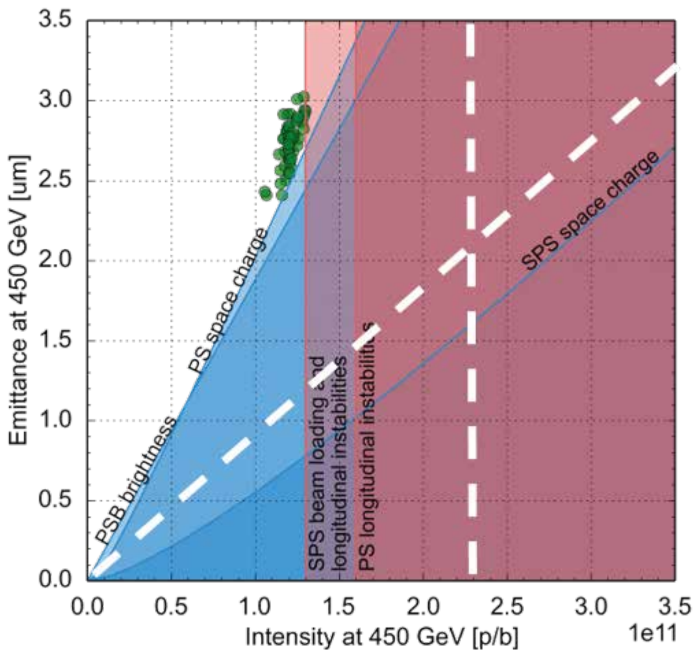

Figure 6: Bunch emittance versus intensity for LHC beam at SPS extraction. The green circles are measured data before LIU upgrade, the intersection of the dashed white lines is the target to be reached for the HL-LHC era. The main limitations to be overcome are space charge effects and instabilities in the injector synchrotrons. See for example [11, 12].

longitudinal plane, coupled bunch instabilities appearing after the transition energy would limit the maximum intensity per bunch well below the 2.6 × 10^{11} p+ per bunch of the future HL-LHC type beam if no countermeasures were taken. A new dedicated longitudinal damper, based on a Finemet® cavity and a new low-level RF have been installed to stabilise the beam. The electronics of the 1-turn delay feedback was also renovated with a new digital system for the main accelerating cavities. The high-frequency cavities are being equipped with additional multi-harmonic feedbacks. Beyond these main upgrade items, new hardware items are being constructed, as for example beam instrumentation, RF components and beam dumps.

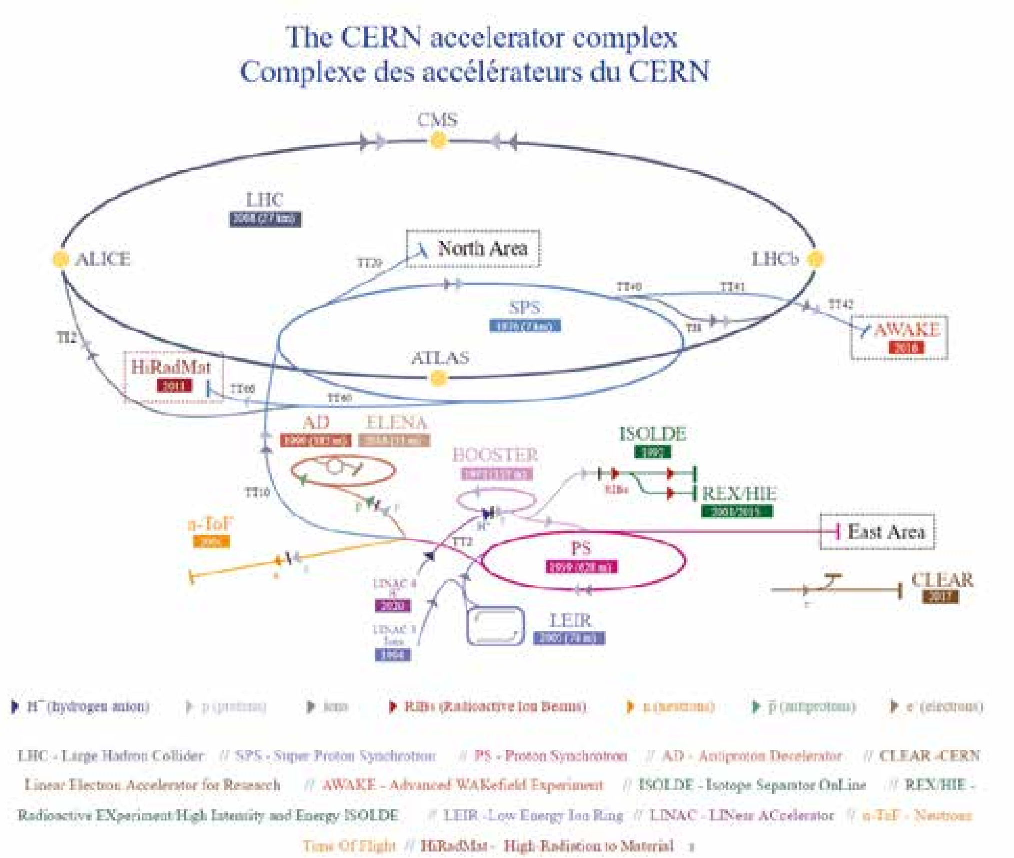

Figure 7: An overview on the various accelerators and experiments at CERN. The years of their start of operation as well as their circumferences (where appropriate) are also shown.

Summary

Sixty years after its commissioning the PS, one of the two oldest synchrotrons still in operation, is today the hub for CERN's entire physics program as shown in Fig. 7. Accelerating protons and heavy ions for the fixed target physics and the LHC, the PS keeps on evolving and ramping up its performance, exceeding by orders of magnitude the original specifications. Multiple consolidation and upgrade programs have been performed over the years, culminating in the presently ongoing LIU project. During the upcoming run 3 of the LHC, the whole injector chain will ramp up its performance in order to satisfy the needs of the upgraded High-Luminosity LHC. For the foreseeable future, the PS will remain the heart of CERN's accelerator complex serving both CERN's collider and fixed-target physics program.

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Kurt Hübner (*1937) promovierte in technischer Physik an der Technischen Hochschule Wien. Ab 1964 Mitglied der Division für Beschleunigerforschung im CERN. Arbeit am Speicherringmodel für die ISR (CESAR), an den Intersecting Storage Rings (ISR), der LEP-Injektorkette und der CLIC-Studie. Forschungsaufenthalte im Budkerinstitut Novosibirsk, SLAC und DESY. Leiter der CERN PS-Division 1991-1993, Direktor für Beschleuniger 1994 bis Mitte 2001. Fellow der Europäischen Physikalischen Gesellschaft.

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Planck and the Extraterrestrials or what the new SI means for astronomy

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In 1899, during his struggle to understand blackbody radiation but about a year before he found the key, Planck proposed a curious set of units [1]. In these natural units, as he called them, the unit of mass m is $\sqrt{hc/G}$ which comes to about 55 μg. The length unit is $h/(mc)$, the time unit is $h/(mc^2)$, while the temperature unit is mc^2/k. (Reading the original today, one needs to substitute $f \rightarrow G$, $b \rightarrow h$, $a \rightarrow h/k$.) Planck then declared that these units would be recognized by all cultures as fundamental, even extraterrestrial or non-human ones ("ausserirdische und aussermenschliche Culturen").

Planck was not the only one to propose a system of units based on fundamental constants [2], but he was the most prescient. In Planck's system there is no prototype mass, length, time, or temperature. Instead there are dimensional coefficients that appear in multiple equations of physics, which define the units implicitly. In the 21st century the International System of units concluded that implicit definition of units is not a bug, it's a feature. In 2018 the SI decided that only the second shall be defined by a particular physical process (a spectral line in Cs). All other units are defined implicitly, through defined values of physical constants, including (but of course) Planck's constant. Any applicable equation of physics can be used for the realization of units [3].

The reforms in the SI were not especially designed to communicate with extraterrestrials. The decision to adopt implicit definitions was pragmatic, in that explicit definitions were sometimes overtaken by technology. In particular, the kilogram is best realized as a derived electrical unit, with mass measured by way of the quantum Hall effect and the Josephson effect. That would be sternly frowned upon by the old SI, but the new SI is cheerfully agnostic about it. The new SI also removes conflicts with some common scientific usages. For example, the electronvolt is not an SI unit. However, if we understand mass in electronvolts as a shorthand for the value of mass times c^2/e in volts, there is no conflict with the new SI.

Planckian units can be useful useful for theoretical work, provided one changes to standard units for comparing with observable quantities [4]. Meanwhile, the community of scientists engaged with extraterrestrial things have steadfastly resisted adopting SI units. Even the proponents of SI units among astronomers [5] have not advocated a complete change to the SI. Why is that? The answer may lie to some extent in sociological factors, but there has been a scientific reason. The key is the constant that Planck included but the new SI does not: G. The gravitational constant is uniquely weak and uniquely hard to measure, and even now is known to only four significant digits [6]. The so-called solar mass parameter $GM_\odot$ is known to eight significant digits in Newtonian gravity, two more with general relativity. But if you split that product into G and $M_\odot$, in order to write the mass of the Sun in kilograms, your value of the gravitational field will be only good to four significant digits. You cannot navigate a spacecraft on four significant digits. End of story for SI in astronomy. Or so it used to be.

After the reforms, however, the SI no longer requires you to express the solar mass in kg — but we'll get to that. We remark first that distances in light-seconds are compliant with the new SI. Like the electronvolt, a light-second can be understood as not itself a unit, but an abbreviated way of referring to the equivalent light travel time. On the other hand, which astronomer would wish to lose the cultural legacies of the astronomical unit of length (au), and the parsec? Fortunately, metrology and cultural legacies can be reconciled. To see how, we need only to see how modern German has kept the old unit of a Pfund, but has rounded its meaning to exactly 500 g. The au and parsec have serendipitously round values: 1 au $\simeq$ $c \times 500$ s to better than 1 %, while a parsec is just 3 % over $c \times 10^8$ s. Many astronomical applications do not require 1 % precision, and there "rounded" au and parsecs would work just fine.

In the astronomy literature one finds many further units (Ångström, Gauss, Jansky) that are simply powers of 10 times SI units, and need not detain us here. There are also parody units such as gallons Mpc^{-1} for cross-sections (it depends on the type of gallon, but is about a kilobarn), which would need an article to themselves. The only remaining unit that needs discussing is the optical magnitude scale. Optical magnitudes are a measure of brightness going back to classical times, but like other units they have been progressively redefined, and are now considered SI-traceable. A zero-magnitude source (such as the star Vega) corresponds to a flux of roughly 10^{10} photons m^{-2} s in a typical spectral band. More precisely, zero magnitude is 5.480×10^{10} photons m^{-2} s per logarithmic spectral interval, with each 5 mag being 100 times fainter. Since modern optical cameras are invariably counters of photons, it makes sense to simply use photon fluxes rather than optical magnitudes, with "rounded" magnitudes used for historical comprehension.

Now we come to the kilogram, or avoiding the kilogram when necessary. Spacecraft dynamics has long used $GM_\odot$ in m^3 s^{-2}. In pulsar timing, $GM_\odot/c^3$ in seconds is usual. In the new SI, by analogy with electronvolts, we can meaningfully measure mass as GM/c^3 in "gravity-seconds". The solar mass is about 5 micro-(gravity)-seconds. This does not mean that kilograms are to be avoided in astrophysics. Rather, gravity-seconds can be useful where kilograms would needlessly propagate the uncertainty in G, which is typically the case for orbital processes. Together with distances in light-seconds and dimensionless velocities, gravity-seconds allow for some elegant simplifications in the description of all kinds of orbital processes, classical and relativistic [7]. Some constructions arise that seem very strange at first: in particular density in gravity-seconds per cubic light-seconds, or power in gravity-seconds per second. But these are not really unphysical at all. In gravitational phenomena, a density ρ is always associated with a time scale $(G\rho)^{-1/2}$, so density as frequency squared does make sense. As for dimensionless power in gravity-seconds per second, this is just power in units of the well-known Planck power c^5/G, which is the luminosity scale in gravitational waves for merging black holes, irrespective of their mass.

To illustrate working with the new SI in astronomy, let us consider an example that sounds like science fiction, but is in fact a serious design study: the solar gravity lens mission [8]. It envisions a telescope larger than the solar system with the sun's gravitational field as its main lens, for mapping the surfaces of extra-solar planets. The essential physical effect is that light rays going past the sun with impact parameter R are gravitationally deflected by an angle $4GM_\odot/(c^2R)$. In particular, the deflection of light from a star that is barely covered by the sun will make that star appear to be just outside the rim of the sun. The deflection at the rim of the sun is well known to be 1.75 arcsec and its first measurement a century ago is the stuff of legend [9]. Knowing the solar mass in gravity-seconds and approximating the solar radius as $R_\odot \approx c \times 2$ s, we can trivially work out the gravitational deflection angle $\alpha = 4GM_\odot/(c^2R_\odot) \approx 10^{-5}$ radians, which is indeed a little under 2 arcsec. If we go far enough from the sun that its apparent radius on the sky becomes smaller than the deflection angle, a remarkable phenomenon will present itself: light sources precisely behind the sun will appear as luminous rings (known as Einstein rings) around the sun. The threshold distance to see an Einstein ring is $R_\odot/\alpha \approx c \times 2 \times 10^5$ s or $\approx$ 400 au. (Actually about 550 au with less drastic approximations.) The advantage of an Einstein ring is that it enormously magnifies the source, so much so that a 1 m telescope located at the right place in deep space could resolve features down to 10 km on an exoplanet at 30 parsecs. That level of detail is comparable to what the Hubble Space Telescope can see on Mars. The image-reconstruction problem involved would be a major challenge in its own right, because the magnification produced by Einstein rings is highly anisotropic, but simulations indicate that it is solvable and that images could indeed be obtained. The task that remains, then, is to fly a fleet of space telescopes to appropriate locations beyond 500 au. And within one lifetime, if possible, please. The currently most promising strategy for doing this turns out to be (who would have guessed?) solar sails. Solar sails also provide a nice example of how kilograms and gravity-seconds can co-exist. Radiation pressure from the sun is, like gravity, inverse squared in the distance. Hence the acceleration on a spacecraft with a solar sail will take the form

$$\frac{SF_\odot}{r^2} - \frac{GM_\odot}{r^2}$$

where r is the distance from the sun, $F_\odot/r^2$ is the radiation pressure from the sun, and S is the effective sail area per unit mass. For simplicity we are neglecting the gravity of the planets and further non-gravitational perturbations. The solar-sail term in effect reduces the gravitating mass of the sun, and could even reverse its sign if S is large enough. Let us consider both terms at $r = r_\oplus = 1$ au. Knowing the solar mass in gravity-seconds we easily get $GM_\odot/r_\oplus^2 \approx 6$ mm s^{-2}. To estimate $F_\odot/r_\oplus^2$ a convenient way is to recall the solar constant, which is the energy flux from the Sun at the top of the Earth's atmosphere. This energy flux is, of course, in photons, and the energy of a photon is c times its momentum. Holding up a mirror normal to sunlight reflects the photons and imparts twice their momentum to the mirror. Hence, multiplying the solar constant by $2/c$ gives the pressure on an optimally-aligned solar sail 1 au from the sun. The value of the solar constant is 1361 W m^{-2} with small variations which we will disregard here, and the corresponding pressure will be a little under 10^{-5} Pa. Comparing the terms, we see that we would need $S \approx 600$ m^2 kg^{-1} to make the sun a net repeller. This may or may not be technologically feasible, but it is actually not necessary, thanks to a further cunning plan. This is to first plunge the spacecraft in a very eccentric orbit close to the sun, and then at perihelion deploy the solar sail. Without the solar sail, the spacecraft would simply have returned to repeat the orbit, but now it can sail out of the solar system on its mission to the focal region of the solar gravity lens.

Even with such a daring space mission, it will probably be some time before we make contact with non-human or extraterrestrial cultures, so that we can ask them if they indeed share Planck's views on units. Yet in the 120 years since Planck drew special attention to physical constants, they have turned out to have meanings not even Planck in 1899 had imagined. As we all know, the following year Planck himself discovered that h (formerly known as b) was about quantization. A few years later the formal relation between mass and energy through c^2 turned out to be real. Starting in the 1920s $(hc/G)^{3/2} \times$ (proton mass)$^{-2}$ was discovered to be the mass scale of stars. Later in the 20th century, $2e/h$ and h/e^2 turned out to be macroscopically observable as Josephson's constant and von Klitzing's constant. And just in the last few years, c^5/G has been observed to be the power-output scale for merging black holes. We can only wonder what more surprises await us.

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[8] S. G. Turyshev, M. Shao, V. T. Toth, L. D. Friedman, L. Alkalai, D. Mawet, J. Shen, M. R. Swain, H. Zhou, H. Helvajian, T. Heinsheimer, S. Janson, Z. Leszczynski, J. McVey, D. Garber, A. Davoyan, S. Redfield, and J. R. Males, arXiv e-prints, arXiv:2002.11871 (2020), arXiv:2002.11871 [astro-ph.IM].
[9] D. Kennefick, "Not only because of theory: Dyson, Eddington, and the competing myths of the 1919 eclipse expedition," in *Einstein and the Changing Worldviews of Physics*, edited by C. Lehner, J. Renn, and M. Schemmel (Birkhäuser Boston, Boston, 2012) pp. 201–232.

Cosmic Rays at the 42nd Hot-Air Balloon Festival in Château-d'Oex

Hans Peter Beck

The Hot Air Balloon Festival in Château-d'Oex is a well-known established event in the Swiss mountainous regions between Gstaad and Gruyère. Aeronauts from around the globe meet there every winter for their special week since 1979. It is well-known for Bertrand Piccard and Brian Jones' ascent in 1999 for their three-weeks lasting, non-stop tour around the globe, in a balloon, the Breitling Orbiter 3. In its 42nd edition, the physics of cosmic rays entered the stage of the Hot-Air Balloon Festival, end of January 2020. This is no coincidence and preparatory work was needed for it to hap-

Figure 1: Balloon museum Château-d'Oex

pen. The balloon museum in Château-d'Oex [1] is featuring historic balloon material, equipment, measuring devices, as well as modern equipment and illustrates the difficulties that needed to be mastered for the Breitling Orbiter endeavor to be a success. Keeping museums alive and attracting visitors means adding temporary exhibitions. General science topics, not even to speak physics, is rarely on the screen of museums curators. For the 2019 temporary exhibition, however, the theme was a mixture of art and science, as Figures 1, 2, and 7 show. In particular, it was the museum's curator, Jacqueline Trenta, who was first attracted by the art works of Michael Hoch, physicist and member of the CMS collaboration at CERN. Hoch became internationally renowned for his specific art works, rendering particle physics into art

Figure 3: Photos of the CMS experiment by Michael Hoch

Figure 2: Pioneers of cosmic rays. A large-scale poster, inviting the visitors in the balloon museum to dive into a topic they wouldn't have expected at first. The historic balloon flights of Albert Gockel, Victor Hess and Werner Kolhörster are put in context as the pioneers of a new field of research that is continued still today with actual experiments carried on in space on the International Space Station (AMS), in high altitudes (Jungfraujoch), on ground in Argentine (Auger), La Palma (MAGIC), and below ground in Japan (Super Kamiokande) and the South Pole (IceCube).

for everybody to grasp and be indulged, for which he has been bestowed the 2017 Outreach Prize of the European Physical Society for *initiatives highlighting the conceptual and physical beauty of high-energy physics, and the inspirational qualities that are common to both art and science*.

Upon Hoch's invitation to expose his work in the balloon museum in Château-d'Oex, he contacted the author of this article, who is member of the ATLAS collaboration at CERN, telling about his invitation. With this connection, the idea was born to add the physics of cosmic rays to the exhibition. Cosmic rays were detected in the beginning of the last century in balloon flights, measuring conductivity of air with electrometers in function of altitude. The exhibition, as it stands today, is adding the narrative of cosmic ray detection in balloon flights, where the conductivity of air was measured in function of altitude by Albert Gockel in 1909, reaching 4500 m asl, followed by Victor Hess in 1912 up to 5300 m asl, and by Kolhörster in 1914 ascending as high as 9300 m asl.

Figure 4: Albert Gockel, only known photograph. Courtesy of Uni Fribourg.

Albert Gockel, professor of physics at the University of Fribourg, Switzerland, concluded that the number of ion's measured per volume of air doesn't decrease at high altitude as one would expect if radiation primarily would come from the ground [2]. He couldn't conclude on his findings as he did not get the needed hydrogen gas to reach higher altitudes of up to 7000 m asl [3,4], but it was Albert Gockel to coin the term *Kosmische Strahlung* [5]. Victor Hess' ascent to 5300 m asl, with an improved electrometer, was conclusive and it was him to be awarded the Nobel Prize in Physics 1936 for the *discovery of cosmic radiation*, together with Carl David Anderson for the *discovery of the positron*. Gockel, who died in 1927, could not be considered, and for this reason, he is almost forgotten in the history of physics. With an original electrometer from Gockel's legacy in Fribourg and now a showcase element at the balloon museum (see Figure 5), Gockel's achievement can be grasped with admiration.

Certainly, a story that reads well by a general audience visiting the balloon museum and taken in by surprise, but this is not where it ends. Measuring cosmic rays became a hot topic of research in the decades to follow and still is today. Because of its relevance to the topic, both geographically and scientifically, the High-Altitude Research Station Jungfraujoch at 3500 m asl, was ideal to add into the narrative. Especially the emulsionplates that were exposed on the Jungfraujoch in the 1950ies, and that we received on loan, are of special value (Figure 6). These are showing the breaking up of nuclei as they were hit by a cosmic ray particle, denoted as star events. Such star events are often source where new particles emerge, in one case, the path of an antiproton

Figure 5: Electrometer from Albert Gockel's legacy, on loan from Uni Fribourg. From the Société Centrale de Produits Chimiques, 44 Rue des Ecoles Paris, ca. 1910. In the back, reprint from the original vending catalogue, featuring the device.

is clearly visible. A spark-chamber, on loan from Uni Bern, is operating continuously, showing how particles can be visualized and that indeed cosmic rays, in this case secondary muon tracks, are real and penetrating.

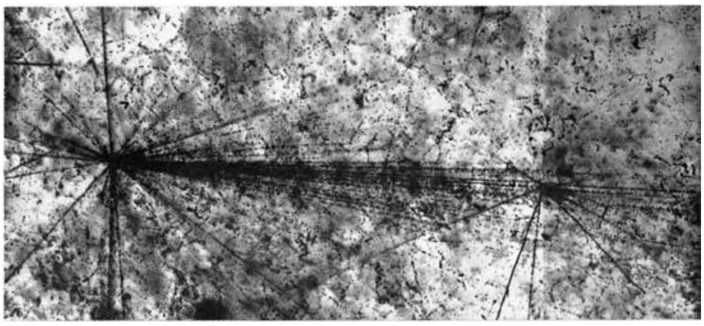


*Figure 6: Star event identified at the physics institute of Uni Bern in an emulsion plate that was exposed at the Jungfraujoch, on loan from Uni Bern. A Br or Ag nucleus in the emulsion interacts with a high-energetic oxygen nucleus from cosmic radiation, where over 200 ionizing particle tracks were produced. The event was published in Suppl. Nuovo Cimento **12** (1954) 361.*

The general audience, now fully engaged in a new world of cosmos and particles, can now be guided further to the world of accelerators, where cosmic rays are quasi-created under laboratory conditions and to the world of detectors, as particles also need to be measured. Showing Lawrence's palm-size cyclotron from 1931, and over a few steps of larger and larger-scale accelerators, guiding the audience up to the Large Hadron Collider at CERN, renders the scope and purpose of this machine in new light for most of the visitors. In parallel, the history and development of particle detectors, from early-day Geiger counters and cloud chambers up to modern devices and big detectors like ATLAS or CMS is also presented. Applications and spin-offs have not been forgotten and the link to medical diagnostic and treatment is made with PET scan and hadron therapy. The story finalizes with the Standard Model of particle physics, and Big Bang cosmology, closing the circle of what is known today about the Universe, starting from its smallest constituents.

Setting up this narrative into a balloon museum was in a certain way adventurous. It was not clear whether it will work out, or fail. The artwork of Michael Hoch being shown in parallel, lingered this fear and is adding an emotional touch to the physics shown that pleased many.

In the end, the exhibition was counted a big success, as a substantial increase of the flow of people visiting the museum showed, and where visitors also significantly spent more time in the museum. As a result, the temporary Art & Science exhibition being planned to be open for one year from May 2019 to end of March 2020, was prolonged for another year to end in March 2021 [1].

Figure 7: Art & Science exhibition at the balloon museum in Château-d'Oex. The temporary exhibition, originally planned to be open to the public from May 2019 to end of March 2020 was prolonged till end of March 2021, due its success - however, the corona outbreak dictated an untimely end.

The director of the balloon festival, Fred Paulin-Getaz, excited by the exhibition, decided to make the physics of cosmic rays as a lead theme of the 42nd balloon festival, 25 January to 2 February 2020 – not without initial resistance from his local staff that he needed to overcome first. A highlight of the festival was a commemorative balloon flight on the footsteps of Albert Gockel and Victor Hess, where cosmic rays were measured with modern equipment in function of altitude over the Swiss alps.

The modern equipment used, came in form of a muon telescope that was built with two scintillating-fibre tiles of 15 cm^2 each and separated by 15 cm. Cosmic rays, or to be more

1 However, due to the Corona outbreak, the museum had to be closed and it was decided to use this extra time of closure for a reorientation – dictating an unexpected early end of the Art & Science exhibition.

Figure 8: Group photo before ascending. The muon telescope inside its insulating box is mounted to the balloon basket. From left to right: Pierre Adatte, Augustin Muster, Nicolas Bruder, Frédéric Chassot, Hans Peter Beck, Michael Hoch, Baptiste Hildebrand.

Figure 9: Ascent of the balloon with the muon telescope attached. Hans Peter Beck (centre) and Nicolas Tièche (right), while two more students, Nicolas Bruder and Frédéric Chassot, also on board, can't be seen from this perspective. Image credit: Jean Claude Dubé

precise, mostly muons in the low atmosphere, that traverse the two tiles, cause simultaneous flashes of light in the fibres of each of the two tiles. After converting the light yield into electrical signals, the coincidence rate of both tiles firing, is obtained. The flux of muons can be measured this way in function of altitude and also in the direction in which the telescope is pointing. The CAEN Cosmic Hunter [6] was used and packed inside an insulating container, such to stabilize it from temperature drifts, avoiding condensation and freezing. A team from the University of Fribourg was readily formed, consisting of four students that all followed the author's course on particle physics and included also local staff from the physics department in Fribourg, where already Albert Gockel prepared his flights a century earlier. The insulating container was built by the Fribourg team with active heating, feedback-loop and energy supply. Further, exact GPS data and other environmental data points needed to be measured and integrated. An ideal task for young students finishing up their bachelor degree that culminated in a balloon flight up to 4000 m asl measuring cosmic rays. Figure 8 shows the students with their supervisors in the moments before the eagerly awaited ascent. Figure 9 shows an impression of the flight from Château-d'Oex to Giffers, a small village near Fribourg, reaching slightly above 4000 m asl. An increase of the cosmic ray flux by a factor of three was obtained in both configurations of the muon telescope, pointing straight to the zenith during the first half of the flight and tilted by 45° away from the zenith during the remaining half, as can be seen in Figure 10. With a successful flight and measured data available, their next task is to analyze and write up their report.

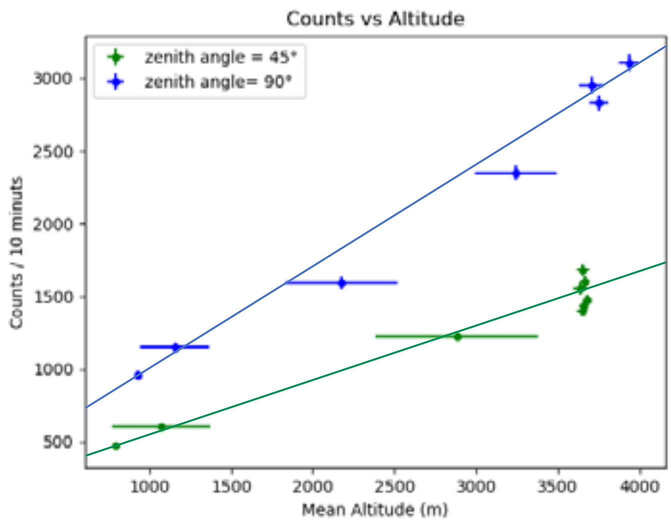


Figure 10: Coincidence rate in counts per 10 minutes interval, in function of altitude above Château-d'Oex. The rate increases by a factor of three when ascending from 1000 m to 4000 m asl, for fluxes measured under 90° and under 45°. The slopes with which the count rates increase differ by a factor of two for the two configurations measured, following a $\cos^2 \Theta$ decrease of flux rates with the zenith angle Θ.

[1] https://www.espace-ballon.ch
[2] A. Gockel, Luftelektrische Beobachtungen bei einer Ballonfahrt, Phys. Zeit. 11 (1910) 280-282.
[3] H. Völkle, "Albert Gockel und die kosmische Strahlung", *SPG Mitteilungen* Nr. 28 (2009) 29
[4] J. Lacki, "Albert Gockel: from atmospheric electricity to cosmic radiation", *SPG Mitteilungen* Nr. 38 (2012) 25
[5] A. Gockel, Th. Wulf, Beobachtungen über die Radioaktivität der Atmosphäre im Hochgebirge, Phys. Zeit. **9** (1908) 907–911.
[6] https://www.caen.it/products/sp5620ch/

Cern Courier featured the commemorative balloon flight in its Mar/Apr 2020 edition, of which a shorted version is re-printed here with kind permission. Full text available at *https://cerncourier.com/wp-content/uploads/2020/03/CERNCourier2020MarApr-digitaledition.pdf*

Ascent commemorates cosmic-ray pioneers
Matthew Chalmers (CERN)

On 25 January, a muon detector, a particle physicist and a prizewinning pilot ascended 4000 m above the Swiss countryside in a hot-air balloon to commemorate the discovery of cosmic rays. The event was the highlight of the opening ceremony of the 42nd Château-d'Oex International Balloon Festival, attended by an estimated 30,000 people, and attracted significant media coverage.

ATLAS experimentalist Hans Peter Beck of the University of Bern, and a visiting professor at the University of Fribourg, along with two students from the University of Fribourg, reenacted Gockel's and Hess's pioneering flights using 21st-century technology: a muon telescope verified that the flux of cosmic rays increases as a function of altitude. Within two hours of landing, including a one-hour drive back to the starting point, Beck was able to present the data plots during a public talk attended by more than 250 people. A second flight up to 6000 m is planned, with oxygen supplies for passengers, when weather conditions permit.

"Relating balloons with particle physics was an easy task, given the role balloons played in the early days for the discovery of cosmic rays," says Beck. "It is a narrative that works and that touches people enormously, as the many reactions at the festival have shown."

The event – a collaboration with the universities of Bern and Fribourg, the Swiss Physical Society, and the Jungfraujoch research station – ran in parallel to a special exhibition about cosmic rays at the local balloon museum, organised by Beck and Michael Hoch from CMS, which was the inspiration for the festival organisers to make physics a focus of the event, says Beck: "Without this, the festival would never have had the idea to bring 'adventure, science and freedom' as this year's theme. It's really exceptional."

Cyberphysische Systeme und Autonome Mobilität

Bernhard Braunecker

Einleitung

Als Mitgliedsgesellschaft der SATW bringen wir in unregelmässigen Abständen Kurzberichte über Veranstaltungen oder Publikationen der Akademie, die auch Physiker interessieren könnten. Diesmal ist es ein Faktenblatt der Themenplattform "Autonome Mobilität" [1].

Abbildung 1: Faktenblatt. © SATW

Faktenblatt

Darin geht es um die Zukunft des vollautomatischen Fahrens mit dem Auto. Von vielen bereits euphorisch als wichtiger Meilenstein in der Geschichte der Menschheit gefeiert, wird es aber auch von vielen als unnötige und teure Beschäftigung einschlägiger Industrien gesehen, die von den wahren Problemen unserer Zeit nur ablenken und Ressourcen unnötig binden würde. Aber es gibt auch viele Pro-Argumente, die für ein autonomes Fahren sprechen wie ein Sinken der Unfallzahlen und ein Mobilitätsgewinn für Behinderte, Betagte und Kinder.

Doch wo steht man heute und wohin geht die Entwicklung? Das Faktenblatt kommentiert in tabellarischer Form die Ausbaustufen autonomen Fahrens (3 = bedingte Automatisierung; 4 = Hochautomatisierung und 5 = Vollautomatisierung) an Hand von Kriterien wie *Technische Herausforderungen, Individueller und gesellschaftlicher Nutzen, Risiken, gesellschaftliche Akzeptanz, rechtliche Aspekte* und schätzt *Zeithorizonte* ab.

Kernaussagen

Die Studie geht davon aus, dass ungeachtet aller Bedenken die Entwicklung des autonomen Fahrens weiterhin weltweit und mit grossem finanziellen Aufwand vorangetrieben werden wird, und dies schlichtweg aus dem Grund, weil eine Phalanx aus gigantischen Technologie- und Servicekonzernen dies als zukünftiges Kerngeschäftsfeld des Schwerpunkts Mobility sieht. Die rasant wachsenden technologischen Möglichkeiten in der Digitalisierung, bei den Algorithmen, bei der Vernetzung und Kommunikation lassen sich hier bündeln und zu anspruchsvollen Industrietätigkeiten ausbauen; eine Chance, die sich keine moderne Nation entgehen lassen kann.

Andererseits wird in der SATW-Studie auch nicht verhehlt, dass die Komplexität der Aufgabe so hoch ist, dass eine Marktdurchdringung mit teil- oder hochautomatisierten Fahrzeugen frühestens in zwanzig Jahren, mit vollautomatisierten sogar erst in vierzig Jahren zu erwarten ist. Die Schwierigkeiten sind unter anderem deshalb so hoch, weil Sicherheitsfragen an erster Stelle stehen und Konfliktsituation zwischen Passanten und Fahrzeugen von sehr vielen Parametern abhängen – seien sie technischer, umweltbedingter, aber auch psychologischer Art – die bislang nur unzureichend charakterisiert und bewertet werden können.

Hohe Komplexität

Um eine Gefühl für die enorme Komplexität zu bekommen, sei aus einem Vortrag am 12.6.2018 am Technologietag des NTB in Buchs zitiert [2]. Dort referierte ein Vertreter einer Grossfirma für modernes Auto-Engineering über "Neue und integrierte aktive Chassis Systeme für zukünftige Fahrzeugkonzepte" und erwähnte, dass die gegenwärtig in einem Auto installierte Software von 100 Millionen Codelines auf 200 Milliarden Codelines im Jahre 2030 steigen wird. Das würde dann immer erst noch der Stufe 4 entsprechen! Da die Gesamtsoftware in sehr viele Submodule aufgeteilt sein wird, muss die Widerspruchsfreiheit ihrer Schnittstellen garantiert sein, eine sehr anspruchsvolle Aufgabe.

Ebenso nachdenklich stimmt der Testaufwand (Zitat: '… *to prove safety with 95% confidence (needs) eight billion km of road testing (with) 100 vehicles 24/7 for 225 years*'). Das ist eine irritierende Aussage in einer Zeit, wo Sicherheitsmargen in vielen Bereichen wie der Raumfahrt von mindestens acht Sigma verlangt werden. Kann die (Cyber-) Physik hier helfend eingreifen?

Mini-Trams

Das Hauptproblem ist die unüberschaubare Vielfalt an möglichen Wechselwirkungen zwischen Fahrzeug und Fahrzeug, aber auch zwischen Fahrzeug und Passanten. Wie würde man als Physiker vorgehen? Man würde zuerst sinnvolle Randbedingungen setzen, dann messen, messen und nochmals messen und schliesslich mit physikalisch fundierten Modellen die Relevanz der Aussagen erhöhen, also deterministische und stochastische Fehler minimieren.

Abbildung 2: Trackless Tram Zhuzhou.
Quelle: https://commons.wikimedia.org/w/index.php?curid=79705921

Sinnvolle Randbedingungen sind solche, die die Möglichkeiten in akzeptabler Weise einschränken. Beim autonomen Fahren zählt primär die permanente Verfügbarkeit von Fahrzeugen, die individuell, sicher und komfortabel bis zur Haustüre fahren sollen, aber nicht zum Beispiel die Höchstgeschwindigkeit oder ein

1 https://www.satw.ch/fileadmin/user_upload/documents/02_Themen/01_Frueherkennung/SATW_Factsheet_AutonomMobilitaet_DE.pdf

2 https://www.ntb.ch/fue/ntb-technologietag-2018/tagungsprogramm/

Minimalabstand zwischen Fahrzeugen. Somit könnte man im Individualverkehr autonome Mini-Trams auf vorgegebenen Bahnen mit konstanter Geschwindigkeit in Betracht ziehen. Das klingt zwar reichlich weltfremd, aber in der Stadt Zhuzhou in China fahren bereits ganze Tramzüge auf normalen Hauptstrassen ohne verlegte Schienen, nur geleitet von Markierungslinien und stationären Sensoren am Strassenrand.

Stationäre Sensoren sind jedoch keine brauchbare Lösung für den Individualverkehr, bei dem das Fahren in weitverästelte Nebenstrassen oberste Priorität hat. Allein schon aus Kostengründen kommen daher nur im Fahrzeug montierte Sensoren zum Zuge, allerdings im Verbund mit stationären globalen Systemen wie die der Satellitennavigation. Aber auch sie sollten nur eine assistierende Rolle spielen, denn die nahe liegendste und sicherste Lösung wäre, die üblichen Strassenmarkierungen mit wetterfesten und physikalisch optimierten Spezialfarben durchzuführen, auf denen das Fahrzeug mittels geeigneter Optik- und Magnetsensoren spurgetreu geführt wird. Magnetleitlinien kennt man bereits aus Fabriken, aber sie im Strassenverkehr einzusetzen wäre vermutlich neu. Die Markierung von Strassen ist einfach, kostengünstig, erprobt und erschlösse in bewährter Weise alle Strassen einer Stadt einschliesslich die aller Vororte ohne den traditionellen nicht-autonomen Verkehr einzuschränken.

Die Führung durch intelligente Leitlinien müsste noch unterstützt werden durch mitfahrende GNSS-, INS-, Lidar- und Bildverarbeitungssensoren, die wir kurz beschreiben. Eine gute und kurze Zusammenfassung findet man unter [3].

GNSS (Global Navigation Satellite Systems)

Verschiedene Satellitensysteme können zur Navigation verwendet werden: GPS (USA), Glonass (Russland), Galileo (EU), Beidou (China), IRNSS (Indien) und QZSS (Japan). Die direkte Ortsbestimmung wäre wegen Satellitenfehlern (Uhren, Orbitschwankungen), Dispersionseffekten in Iono- und Troposphäre sowie Multireflexen an Gebäuden und Bäumen nur auf etwa ± 10 m genau. Neben technischer Massnahmen wie die der Aussendung der Satellitensignale in verschiedenen Frequenzbändern zur Erkennung der frequenzabhängigen Dispersionsfehler reduzieren vor allem aufwändige Konfigurationskonzepte wie DGNSS, SBAS und RTK die Fehlerraten, so dass man heutzutage auf beachtliche Genauigkeiten von nur wenigen cm kommt. Gleichzeitig konnten in jüngster Zeit die Stabilität und Robustheit der Positionsmessung sehr verbessert werden, ebenso wie die Akquisitionszeit, bis Messungen mit cm Genauigkeit vorliegen. Musste man vor einigen Jahren manchmal bis zu einer Stunde warten, bis die höchste Genauigkeitsstufe vorlag, so beträgt sie heutzutage nur noch wenige Sekunden. Um die genannten cm Genauigkeiten eines bewegten Fahrzeugs, genannt Rover, zu erreichen, benutzt man folgende Ansätze:

- ***Differential GNSS (DGNSS)***

  Eine ortsfeste GNSS Station (Base) berechnet aus den Satellitendaten ihre Position und vergleicht sie mit ihrer Ist-Position, die mittels Theodolit vorher sehr genau eingemessen wurde. Die Abweichungen, hervorgerufen durch die oben erwähnten Fehler, werden via Radio Link an die mobilen Rover gesendet, die damit ihre Positionsberechnungen korrigieren. Die Positionsbestimmung beruht auf der Korrelation der ausgesendeten Codesequenzen der gerade benutzten Satelliten.
- ***Satellite Based Augmentation Systems (SBAS)***

  Kostengünstiger ist es, wenn innerhalb einer grösseren Region die individuelle Basisstation durch ein Netz stationärer und genau vermessener GNSS Empfänger ersetzt wird. Diese senden laufend ihre berechneten Positionsdaten an eine Zentralstation. Dort werden für jeden Punkt in der Region die aktuellen Korrekturdaten berechnet und zu speziellen geostationären SBAS-Satelliten gesendet, die sie über der Region reemittieren. Jeder Rover in der Region kann so die für seinen Standort gültigen Korrekturdaten online beziehen.
- ***Real Time Kinematic (RTK)***

  Ähnlich wie bei DGNSS wird auch hier wieder eine stationäre Basisstation benutzt, die per Radio Link jedem Rover die von ihr berechneten Korrekturdaten sendet. Der Unterschied zu DGNSS ist, dass bei der Positionsbestimmung anstatt der Codekorrelationen nunmehr rechenaufwendigere Analysen der Codephasen durchgeführt werden. Damit erreicht man dann Positionsgenauigkeiten von ± 1-2 cm.

INS (Inertial Navigation Systems)

Während aus den Positionsmessungen eines GNSS Sensors durch Differenzierung die Geschwindigkeits- und Beschleunigungsvektoren mit hoher Genauigkeit abgeleitet werden können, ist die Bestimmung von Kippwinkeln schlecht konditioniert. Es ist besser, sie deshalb direkt zu messen, besonders wenn man bestimmte Neigungen einstellen will (Neigezüge) oder stochastische Neigungsfehler ausregeln oder dämpfen will wie bei Schiffen oder Flugzeugen.

INS Sensoren messen die linearen Beschleunigungen und mittels Gyros auch die Winkelbeschleunigungen in den drei Hauptachsen. Da aus den gemessenen Beschleunigungen durch zweimalige Integration die Orts- und Winkellage (Pitch, Yaw und Roll) erhalten wird, kann bei einem zeitweiligen Ausfall der GNSS Sensoren das INS System dessen Funktion übernehmen. Andererseits können die absolut messenden GNSS Sensoren die Konstanz der beiden Integrationskonstanten des INS Systems überwachen. Bei der photogrammetrischen Erfassung der Erdoberfläche durch luftgestützte Kameras und Lidar Systeme wird die sensible Lage des Flugzeugs von INS Sensoren mit hoher Taktrate von 200 Hz erfasst, wobei deren Nullpunktsdrift durch GNSS Systeme mit niederer Taktrate korrigiert wird.

Lidar

Bei Lidar Systemen werden Laserstrahlen ähnlich den GNSS Signalen so in Amplitude und Phase moduliert, dass man Distanzen messen kann. Das 3D-Erfassen einer Szene kann durch Abscannen oder auch durch Aussenden eines Laserbündel Arrays erfolgen (Image Ranger). In den Scheinwerfern von Fahrzeugen eingebaute Lidar Systeme können sowohl Objekte im Fahrfeld erkennen als auch ihre eigene Position und Orientierung durch Abtasten der Um-

3 https://www.novatel.com/#latestNews Download: 'An Introduction to GNSS'

gebung bestimmen. Diese oft als LOPS (Local Optical Positioning System) [4] bezeichnete Selbstreferenzierung wird nach jeder Einzelfahrt angepasst. Die Abb. 3 zeigt ein modernes Lidar System von Leica Geosystems, bei dem ein augensicherer Laserscanner Objekte von 0.5 m bis 25 m oder sogar bis 60 m Abstand mit etwa 8 mm Auflösung bei Taktraten von etwa 400 kHz erfasst. Integrierte Weitwinkel- und IR-Kameras, sowie INS-Module unterstützen das Lidar System.

Abbildung 3: Handheld Laserscanner BLK2G. © Leica Geosystems

Linemarking

Wie gut die Fahrzeugführung durch markierte Spuren und GNSS erfolgen kann, wird durch eine umgekehrte Variante gezeigt, nämlich der Linienmarkierung von Strassen und (Sport-) Plätzen mittels GNSS- und INS Sensoren sowie der Verwendung stochastischer Schätzalgorithmen. Bei dem in Abb. 4 gezeigten Linemarker sitzt die Spritzdüse auf einer motorisch bewegten Spindel, deren Lage quer zur Fahrtrichtung so geregelt wird, dass die Linie trotz Fahrfehler und Geländeunregelmässigkeiten ohne störenden ‚Wobble' gespritzt wird [5]. Im Verbund mit einer stationären RTK Basisstation lassen sich Linienkurven beliebiger Art über Gebiete von mehreren 100 m Seitenlänge markieren, wobei gleichzeitig mehrere halb- oder vollautomatisierte Rover im Einsatz sein können.

Abbildung 4: GNSS gesteuerter Linemarker. © Fleet Line Markers Ltd

Die Abb. 5 zeigt eine aktuelle Feldmarkierung, bei der die RTK-GNSS Signale zusammen mit den Messwerten eines INS-Sensors einem Kalman Algorithmus zugeführt werden, dessen Prädiktionswerte zur Steuerung der Düsenposition verwendet werden.

Algorithmen

Die im Beispiel gezeigte hohe Leistungsfähigkeit algorithmischer Schätzmethoden könnte auch helfen, das Problem des erratischen Verhaltens von Passanten zu entspannen. Es genügt sicher nicht, vom Fahrzeug aus zu erkennen, dass eine Person die Strasse überqueren könnte, sondern wie würde sie sich danach verhalten? Ein Kind spränge eher spontan auf die Strasse, käme aber genauso schnell wieder retour, während ein älterer Mensch nur zögerlich die Fahrbahn beträte, dann aber im Gefahrfalle auch nur langsam reagieren würde. Man kann davon ausgehen, dass es in den kommenden Jahren möglich sein wird, Bewegungsprofile eines Menschen am Strassenrand via Handy, Smartwatch oder Gesundheitsarmband anonym für einige Sekunden vom Fahrzeug aus abzufragen, um den nächsten Schritt vorherzusagen. Man müsste allerdings der Bevölkerung glaubhaft vermitteln, dass die Daten auch sofort wieder gelöscht würden.

Cyberphysische Systeme: Digitalisierung, Nutzung künstlicher Intelligenz und neuartiger Vernetzung und ihre physikalische Modellierung

Wie im SATW-Faktenblatt erwähnt, werden diese modernen Technologieansätze immer leistungsstärker. Ihre geschickte Kombination wird ermöglichen, das Spektrum möglicher Konfliktsituationen für autonome Fahrzeuge im Individualverkehr einzuengen und sie in einer Art der Katalogisierung zu charakterisieren. Sinnvolle Randbedingungen wie die Verwendung von Führungslinien mit physikalisch optimierten Farbeigenschaften, sowie Sensorfusion verbunden mit leistungsstarken adaptiven Algorithmen reduzieren erheblich den Grad der Komplexität. Anstatt ausgedehnter und letzten Endes irrelevanter Testfahrten über viele Dörfer liessen sich dann potentielle Konfliktsituationen verlässlich modellieren, simulieren und in lokalen Testanlagen verifizieren, so dass die Ergebnisse überall und zu jeder Zeit anwendbar sind. Die Verlässlichkeit der Erfassung und Zuordnung erlaubt dann geeignete Gegenmassnahmen wie Warnung, Abbremsung, Ausweichen, etc. in der Realität vorzunehmen.

4 United States Patent US 7,742,176 B2 (Jun. 22, 2010), Braunecker *et al.*

5 https://www.fleetlinemarkers.co.uk/satellite-guided-line-marking-machines.html

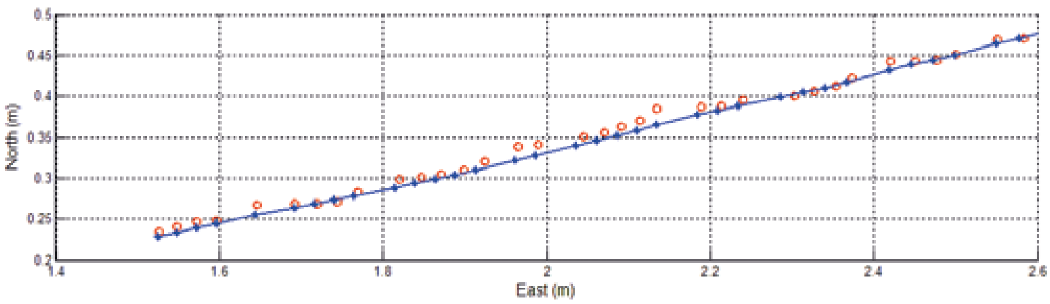


Abbildung 5: Links: Prototyp des in Abb. 4 gezeigten Linemarkers mit RTK GNSS Antenne (links), INS–Sensor (rechts) und Spritzdüse (unten). Zwischen beiden Sensoren sieht man die WIFI Antenne für den Datenaustausch mit der RTK-Basisstation. Oben: Auszug aus einer Messreihe für eine gerade Linie. Die Messwerte, aufgetragen in Ost- und Nordrichtung, zeigen die Bewegung des Linemarkers bei einer bewusst langsamen Fahrgeschwindigkeit von etwa 1 m/s. Die roten Punkte sind die GNSS Positionen (Taktrate 20 Hz) mit einer Streuung von etwa ± 1-2 cm , mit denen die Linie markiert werden kann. Führt man sie jedoch zusammen mit den INS Messwerten einem Kalman-Algorithmus zu, wird die Lage der Spritzdüse gemäss der blauen Kurve geregelt mit einer Genauigkeit von nur wenigen mm. © Bild und Messdaten: Braunecker Engineering GmbH

Bücherecke - Le coin aux livres

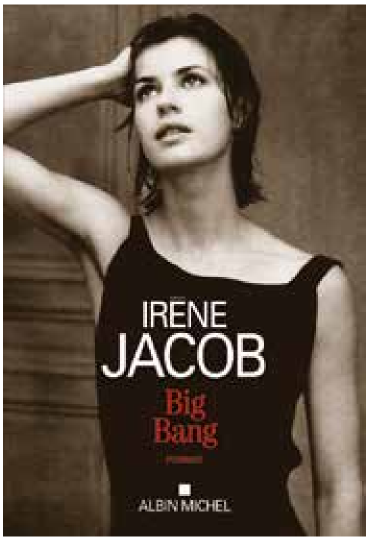
Irène Jacob

Big Bang, roman

Albin Michel 2019, ISBN 9782226442703

Ça se passait au CERN le 20 février dernier. La comédienne et actrice de cinéma Irène Jacob, fille du physicien des particules Maurice Jacob se présentait là, non comme comédienne, mais pour nous parler de sa propre vie… et nous invitait, souriante, à nous asseoir tous autour de la grande table de la bibliothèque. Elle était à vrai dire presque chez elle, dans les lieux familiers qu'elle arpentait dans son enfance, pour nous présenter son premier roman *Big Bang*, entourée d'anciens collègues de son père, en présence de sa mère et de ses frères… Et il s'agit bel et bien d'une biographie familiale, dont elle nous lit des extraits :

> *Ici, devant le deuil et la promesse de la vie, je me tiens et j'avance...*



Irène Jacob, l'inoubliable interprète de « La Double Vie de Véronique », rapproche deux évènements simultanés et essentiels de sa vie : la disparition de son père - Maurice Jacob, qui a travaillé au département de physique théorique du CERN de 1968 à 2002, qu'il a dirigé de 82 à 88 - et la naissance de son enfant.

Elle raconte l'histoire de la vie naissante, de la gestation de son second fils, sur arrière-fonds du mystère d'une autre naissance majeure, celle de l'univers, dont son père a instillé l'imaginaire familial. Cette conscience du physicien qu'a son père, interrogateur de la nature, Irène Jacob l'a saisie avec beaucoup de justesse, d'amour, parfois même d'espièglerie, lorsqu'elle décrit la communication entre le monde de sa famille et celui de la physique. Elle interroge, avec la même curiosité que son père, ces passages essentiels du non-être vers la forme qui émerge : l'origine de la vie et cet enfant en elle qui la convie à la grande fête cosmique de la vie. Curiosité bien sûr chez le père, mais aussi pointe de nostalgie en pensant aux limites de notre connaissance, lorsque son père, au cours d'un repas entre amis s'explique sur les moments initiaux de l'univers : « avant 10^{-43} s, on ne sait plus très bien ».

Irène Jacob avec une belle sensibilité d'écriture exprime les choses subtiles de la vie, avec une apparente légèreté de langage et joie de vivre. Elle parle aussi d'un autre langage qu'elle connaît bien, celui du cinéma. Elle mentionne celui du cinéaste et ami Krzysztof Kieslowski qui s'ingénie à faire des coupes dans le scénario pour laisser le spectateur libre d'interpréter son histoire et d'y projeter sa propre compréhension. Son père, tirant un lien avec l'indétermination quantique, expliquait à Kieslowski « que le monde quantique était également une quête sans explications exhaustives et que, quand on croyait s'approcher d'un but, la porte s'ouvrait à d'autres questions nouvelles. Une partie du mystère s'échappait toujours avec sa révérence ».

Et sur le langage des physiciens ? Elle cite des moments savoureux où son langage à elle et celui de l'écriture de son roman, se confrontent, s'entrechoquent avec le langage écrit du physicien, en principe rigoureux et sans ambiguïté. Comme lorsqu'elle convie un collègue de son père, Bertrand, à scruter la justesse physique de son texte qui relate une visite au CERN qu'elle rendait, alors enfant, à son père :

> - *Et papa, **avant** le Big Bang ? Il y a quoi ?*
> - *Eh bien… peut-être qu'il n'y a plus de temps ?*
>
> *Bertrand m'écoute, le torse maintenant presque couché sur son bureau. Il se redresse brusquement dans le silence, comme si le téléphone venait de sonner, mais non, ce n'est pas ça, il regarde mon texte.*
>
> - *Pourquoi tu as mis un point d'interrogation ?*
> - *Où ?*
> - *Ici : « Peut-être qu'il n'y a plus de temps – point d'interrogation. »*
> - *Ah oui. Tu veux que je l'enlève ?*
> - *Oui. « Peut-être qu'il n'y a plus de temps – Point. »*
> - *Point ?*
> - *Point.*
>
> *Des lumières roses explosent à seize heures trente par les fenêtres. Plus de temps, point. La page est soulevée d'une audace que jamais je n'aurais osé prendre… Ainsi il n'y aurait plus de temps – point ? Aussi simple et affirmé que ça. Point.*

Il y a dans ce livre de l'émerveillement qui rappelle celui de François d'Assise lorsqu'il célèbre la vie et la création et tutoie l'univers : « frère Soleil… frère Vent… sœur Eau… … ». Mais dans *Big Bang*, cet émerveillement s'appuie sur les connaissances de la science d'aujourd'hui, qui à sa façon enchante aussi le monde. La physique, le firmament à perte de vue, le big bang, les surprises de la physique quantique, l'évolution darwinienne, tout ceci vient habiter l'espace familial. Ce roman cherche aussi à comprendre les motivations profondes, les questions de psychanalyse et d'empreinte familiale… la perception du temps, la brume des souvenirs ou les images à vif, les émotions, leurs manifestations explosives, le sommeil et les rêves ...

Il s'agit donc d'un roman biographique, sincère, lumineux, émouvant de tendresse : une introspection familiale où le miracle de la vie et de l'infiniment grand se mêlent. Ce livre résulte bien sûr d'une relation forte entre un père et une fille, entre lesquels le courant passait bien, passe toujours d'ailleurs, tant son père y est vivant. Maurice Jacob a donné des contributions décisives au formalisme d'amplitude d'hélicité pour la diffusion de particules élémentaires et a été président des Sociétés Française et Européenne de Physique. Un témoignage passionnant.

A. Pochelon