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Physics and Society

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Hans Peter Beck [1], Ivan Melo [2], Thomas Naumann [3]
[1] Albert Einstein Center for Fundamental Physics, Laboratory for High Energy Physics, University of Bern, Switzerland
[2] Department of Physics, Faculty of Electrical Engineering, University of Zilina, Slovakia
[3] Deutsches Elektronen-Synchrotron DESY, Zeuthen, Germany

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Hans Peter Beck [1], Ivan Melo [2], Thomas Naumann [3]
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1. Introduction

Nowadays we are witnesses of increasing distrust of governments and political system in society. Some groups question democracy itself. To make things worse, it appears that science is not an exception and a growing number of people look upon it either with suspicion or find it less and less relevant for their lives. As a result, many fill the empty space with cheap substitutes and fall prey to conspiracy theories, superstition and dubious alternative healing methods, to name just a few.

When looking for reasons within science domain, we find that there is an objective barrier between complex language and methods used by modern science on the one side and the public on the other side which requires more and more effort to get through. For us scientists it can be a grueling task among all our research obligations. Nevertheless, the questions, suspicion, doubts and fears we face are understandable and it is our duty to address them in an honest way. In fact, communicating our results to the public and sharing the beauty of our discoveries with the young generation should be considered an intrinsic part of research work within the scientific community. In this contribution we will describe how particle physicists deal with some of these ethical issues.

2. Demystifying the Universe

Particle physics probes the basic building blocks of matter and their interactions, which determine the structure and properties of the extreme diversity of matter in the universe. It aims at explaining what holds the world together in its most fundamental constituents.

Modern physics relies on an elegant «Standard Model of particle physics», a quantum field theory based on three symmetries and a symmetry breaking. This theory describes and explains magnificently all experimental results obtained so far. With the discovery of the Higgs particle in 2012 at the Large Hadron Collider at CERN, the last missing piece of the Standard Model has been experimentally confirmed. Experiments at CERN and at other international laboratories now continue to test the validity and limits of the Standard Model in ever widening scope. However, for a comprehensive understanding of the laws of nature a theory beyond the Standard Model is needed, which should include gravity and explain the presence of dark matter and dark energy in the universe.

The quest for deeper and deeper understanding is therefore pushed in all thinkable and affordable manners at laboratories and universities worldwide. With the scale, complexity and costs of modern experiments ever increasing, physicists have learned that only when concentrating in international, large-scale collaborations, involving thousands of physicists from hundreds of institutions, from many tens of countries and all continents worldwide, ground-breaking advancements can be achieved. Examples are the above-mentioned discovery of the Higgs boson at CERN by the A Toroidal LHC ApparatuS (ATLAS) and Compact Myon Solenoid Spectrometer (CMS) Collaborations in 2012 [1 and 2], the detection of gravitational waves by the Laser Interferometer Gravitational-Wave Observatory (LIGO) Collaboration in the US [3], the detection of the highest energies of cosmic ray particles by the Icecube Collaboration at the South pole in 2015 [4], the new upper limits on Darkmatter candidates by the Large Underground Xenon experiment (LUX) Collaboration in 2016 [5], to name just a few.

As a reaction to such fundamental large-scale experiments, which often make head-lines in the public press, questions arise on the usefulness of fundamental research, whether money should better be spent otherwise, e.g. to cure world hunger, or to invest in cancer research instead. Often fears and potential dangers from such experiments are expressed along-side such critics. Applications based on new knowledge gained from fundamental research may not only be used for the better of mankind, but can indeed be life threatening, which, as often is argued, should be reason enough for not pursuing fundamental research any more. Further, some people may question whether mankind should even address scientifically a deeper understanding of the Universe, its coming to existence, evolution and possible fate.

Only when addressing openly these questions, emphasizing the relevance of fundamental research, its benefits to society and mankind worldwide, by leading an open dialogue, such perceived fears can be recognized as irrational or at least be lingered. Furthermore, the costs can be explained, put in relation with other state expenses, and be recognized as dwindling when compared with medical, educational, or infrastructure costs, and be understood as well placed investments for a flourishing future.

On the costs of Big Science projects:

It is true that e.g. building the Large Hadron Collider at CERN and the associated experiments, ALICE, ATLAS, CMS, and LHCb, meant an investment in the order of 10 billion Euros. A cost factor that at first sight seems extremely high, when not be put in relation. The overall project of the LHC has a life-span of the order of four decades, from the initial ideas, the research and development phase on how to build the accelerator and the experiments, their construction and commissioning, it already took two decades [6]. Adding the data-taking, the detector and machine upgrades, and the data analysis time scales to this, which takes another two decades, explains the long time span of such projects, during which generations of young people get trained and are working at the forefront of knowledge in a demanding truly international environment. Further, the overall funding is shared among the CERN 21 member states and additional 43 countries directly contributing to the experiments at CERN. The costs have therefore to be understood as split over many countries and over four decades. The overall cost-sharing scheme is further taking into account the economic strength of each participating member, such that rich and poor countries can equally participate and contribute. Indeed, physicists do not receive more funding for their research than scientists in other areas of research. Physicists however manage to concentrate resources to big common goals and structure their research worldwide in a coordinated effort. Costs are therefore being minimized and unnecessary parallelism otherwise occurring in many competing small-scale research teams is avoided.

Fundamental research has led to many applications, now being thought of as given in modern society. Prominent examples come from medical diagnostics and cures. Many scanning and imaging devices find their roots in particle detector technologies, also radiotherapy, hadron therapy, or even the production of special isotopes would not be thinkable without accelerator technologies – this forms a direct answer regarding the use of money in cancer treatment. Indeed, particle physics provides new tools and methods for medical treatment of cancer and more.

Many of the everyday materials, such as e.g. ordinary shrink-wrap used for packing food before placing it in an ordinary refrigerator, car tyres, cable isolations, etc., etc. need to undergo special treatment to obtain their needed structures, hardness, or softness depending on specific requirements and use cases. Such special treatment means that materials undergo radiation with electrons and sometimes also other particles accelerated using particle accelerators. Indeed, many tens of thousands of particle accelerators are operating almost unnoticed continuously for industrial purposes worldwide, whereas only a handful of pure research accelerators exist in the world. With better food storage, and in general with better materials available, an important contribution to curb world hunger is made. Sure in cases of urgent needs such as draughts, wars, and other catastrophes, resources must be made available for immediate help. For creating longer-term improvements of the overall situation, new applications and spin-offs from fundamental research activities will provide tools and methods to linger and help.

On applications based on new knowledge gained from fundamental research that may not only be used for the better of mankind:

Fundamental science and gaining new insights in the understanding of the Universe is per se free from qualifying it as good or bad. Knowledge and understanding in general can however be used in different ways, and here, a deep ethical question arises that needs broad discussion in society. Such questions, however, are not new to mankind, but are part of its entire history. This started probably when first tools were created and is nicely shown e.g. with the mastering of fire in prehistoric times. Indeed, fire can be used to warm up sheltering places, to prepare food, to treat materials and can also be misused to do harm to others. Nowadays, threats from misuse of applications can have global dimensions. With e.g. the construction of atomic bombs, that were only possible when applying new knowledge from fundamental research, a worldwide threat was created that clearly showcases where limits need to be set in the building and construction of applications – but not in the quest of fundamental research itself. We may miss new insights in the understanding of the Universe as a whole, and will prevent new applications in the benefit of society.

On whether mankind should even address scientifically a deeper understanding of the Universe:

Asking deep questions is paramount to mankind. It is part of humanity to try to know where we are coming from, what our world constitutes of, what the future will be, why the sky is blue, or why the grass is green. With a lack of understanding, and with a lack of tools and methods to address such deep questions, superstition and bad answers prevail in order to satisfy, and therefore also muzzle, curiosity. Without curiosity, however, no advances in society are possible. This may be seen as non-problematic, and indeed is seen as best solution in some societies. Indeed, inside small, isolated groups such a scheme can work well. On a global scale, however, only a global understanding of the world, and not superstition, can lead to societies that collaborate and are addressing global issues together.

Fundamental research activities, with their large-scale projects, are showcasing that common, complex goals can indeed be addressed across national, ethical, or religious boundaries, and showcasing a pathway leading to open societies that freely interact without borders.

3. Mini Black Holes, Apocalypse and CERN's honest response

The history of black holes at the European Centre of Nuclear Physics CERN in Geneva shows how particle physics reacted to the fears of the public initiated by a discussion on a possible universal doomsday in the media in an honest and transparent way. The starting point was the fact that the Large Hadron Collider LHC at CERN amongst many other topics seeks after microscopic black holes. They are predicted by some theories of quantum gravity to be possibly produced at the high energy densities reached in the particle collisions at the LHC and to decay immediately due to Hawking radiation predicted in the same context.

In the years before the commissioning of the LHC the worry came up in parts of the public and among interested laymen that microscopic black holes similar to massive macroscopic black holes could attract matter, swallow our Earth and finally the whole Universe. So in February 2008 a threatening simulation appeared on YouTube [7] in which a black hole created at CERN swallows the Earth. The video immediately found millions of watchers (more than 5 million till 2014) and was also shown in television. Concerned laymen in the United States and Switzerland raised lawsuits against CERN because of destruction of the whole world and tried to get the commissioning of the LHC prohibited by a court.

As a reaction to this accuse CERN before the LHC start-up in 2008 called its "LHC Safety Assessment Group" which updated an existing safety study [8] from 2003. CERN developed a clear chain of arguments:

- The energies of cosmic rays are billion times higher than the LHC energy.
- Nature performed at least one million LHC experiments with Earth.

- The Universe in total does a billion LHC experiments per second.

Nevertheless stars collapsed to black holes do not dominate the Universe. From this the CERN study clearly concluded: The LHC is safe [9]. CERN started a further campaign [10] in May 2009 at the premiere of the film „Illuminati" produced after Dan Brown´s novel which partially takes place at CERN.
Also in Germany, a lawsuit was filed before the Federal Constitutional Court. Fortunately, the court dismissed it arguing that the applicant could not demonstrate conclusively why the Earth was threatened with destruction [11]. The judges declared in their verdict that basic research cannot be stopped just because some individuals do not believe in the established laws of physics.
This judgment was greeted in the press with much humour and relief:
"Who is afraid of a Black Hole? Karlsruhe rejects doomsday lawsuit", the *Spiegel* [12] joked. The *Frankfurter Allgemeine Zeitung* on its title page commented the judgment of the court with two small black holes and the remark: "Apocalypse ad acta".
Outside Germany the *German Angst* [13] was ridiculed: "Une Allemande craignant la fin du monde échoue à paralyser le CERN".
However, on the day of the LHC start-up the *Frankfurter Allgemeine* presented on its title page a gigantic black hole with the question: "Do we disappear in a Black Hole?" and the moderator of the second German TV said good-bye forever to its viewers.
On the day of the first LHC collisions the *FOCUS* [14] asked: "Doomsday now?", and *Die Welt* stated with relief [15]: "Big Bang experiment without Doomsday".
The online edition of the *Scientific American* announced the fifth anniversary of the LHC start-up in September 2013 with the headline: "LHC celebrates 5 years of not destroying the world" [16].
So thanks to an open and professional reaction to the fears of the public CERN and the world-wide LHC communication could avoid a severe damage both to its research and to its reputation.
However, a few years later doomsday fears reappeared. In a brilliant popular article on the inflationary universe the Russian-American cosmologist Andrei Linde in 1994 had developed the idea how to initiate from a tiny amount of extremely dense matter an eternally self-reproducing inflationary universe:
"*Instead of watching the universe at the screen of a computer, one may try to create the universe in a laboratory. Such a notion is highly speculative, to say the least. But some people (including Alan H. Guth and me) do not want to discard this possibility completely out of hand. One would have to compress some matter in such a way as to allow quantum fluctuations to trigger inflation. Simple estimates in the context of the chaotic inflation scenario suggest that less than one milligram of matter may initiate an eternal, self-reproducing universe. We still do not know whether this process is possible*"[17].
Linde finally asked: "*Is it conceivable that our own universe was created by a physicist-hacker?*"
Linde did not discuss how far the possibility of such a phase transition endangers the existence of our Universe. This left room for deep fears. The nuclear age also began with an estimation of the energy released from nuclear fission by Lise Meitner and her nephew Otto Frisch.
Based on such scenarios and by a statement by Stephen Hawking in September 2014 worries spread in the media that the Higgs boson could cause the end of the Universe [18]: "Stephen Hawking Believes Higgs Boson Particle May Destroy Universe". The *Berliner Kurier* reported [19]: "Stephen Hawking: Stay away from God particle ... it could trigger the doomsday", and *Focus Online* warned [20]: "Hawking warns of space-time collapse: God Particle could destroy the Universe".
Now, the US-American particle physics reacted properly and published a rectification in its online magazine *symmetry* [21]: "If you're a science enthusiast, this week you have likely encountered headlines claiming that physicist Stephen Hawking thinks the Higgs boson will cause the end of the universe. This is a jaw-dropping misrepresentation of science. The universe is safe and will be for a very long time - for trillions of years. To understand how abominably Hawking's words have been twisted, first we need to understand his statement". Having clarified the facts it concludes: "Returning to the original, overly hyped media stories, you can see that there was a kernel of truth and a barrel full of hysteria..."

4. International Particle Physics Masterclasses

This event for high school students is a good example of care and zeal which particle physicists put into bringing the excitement of cutting-edge particle physics research into classrooms. Particle Physics Masterclasses [22] started in Great Britain in 1996 and turned international in 2005 under the coordination of International Particle Physics Outreach Group [23]. It became a very popular activity for students who come each year in the spring to nearby universities or research centers to become "scientists for a day" [24]. Masterclasses [1] is a truly global undertaking. In 2016, more than 10 000 students in 47 countries took part in the event at one of 200 universities (Fig. 1) over 5 weeks.
The format of the day includes three key elements:
i) lectures from active scientists give insight on topics and methods of fundamental research on the building blocks of matter and the forces between them, ii) active participation of students in measurements on real data from LHC

Fig. 1: Masterclass participants at University of Zilina

1 In Switzerland Masterclasse for young pupils (ca. 17 - 19 years) take place every year in Zürich (ETHZ + Uni ZH jointly), Bern (Uni BE) and Geneva (Uni GE and CERN). The next edition will be in Spring 2018, detailed information will become available in January 2018.

experiments ALICE, ATLAS and CMS and iii) international video-conference moderated from CERN or Fermilab during which students compare and combine results with their peers in other countries and discuss physics with the moderators. The main purpose of Masterclasses is to expose students to the scientific process and share our excitement about physics with them.

In the key measurement part students learn to use event display programs and analysis methods used by experimental particle physicists. They first practice particle identification by exploiting the characteristic signals left by particles in various parts of the detector; electrons, muons, photons and jets of particles are then recognized. From here students reconstruct some known particles, such as the weak gauge bosons W and Z and a number of hadrons (J/ψ, Y, Λ, Ks). As a highlight of the day, they learn how to use the technique of invariant mass to search for the Higgs bosons and other so far hypothetical particles.

As our survey shows, about 50% of participants are interested to pursue career in natural science or engineering programs, the other half is interested in social sciences and humanities. We feel that it is of paramount importance that these future opinion makers in their field of interest take from our program a better appreciation and understanding of the role of science in modern society.

5. Cascade projects competition for high school teams

International Particle Physics Masterclasses are successful in motivating high school students. However, some students are ready for further adventure. Cascade projects competition is aimed at those who would like to spend some more time discovering the realm of particle physics. The format was developed at the University of Birmingham in 2006/2007. Teams of 3 - 6 high school students work for several weeks on projects from particle physics and cosmology and then make 15 to 20 minute long presentations in their schools. The teams are helped by mentors (volunteers from the high energy physics community) and their teachers. Teams then send videos of their presentations to the Cascade organizers and the jury selects the best teams.

Fig. 2: Cascade team in the Great Final

The best team wins a trip to CERN or similar prize. The format is a success. Students enjoy working in teams and presenting in public (Fig. 2). In Slovakia about 15 teams enrol in the competition every year. Masterclasses is a good springboard for Cascade. Most of the teams are formed from former Masterclass participants.

The competition is relatively easy to organize. The first round (presentations at schools) does not require presence of the organizers which is very important given their tight work schedule. The best Cascade projects have the qualities we had hoped for: a solid scientific content and fresh, entertaining presentations which are fun to watch. Team members are often interested in pursuing a scientific career. Students effectively become our ambassadors in their schools – disseminating / cascading what they learned to many more young people than physicists could on their own. For more details see [25].

6. Conclusion

Particle physics probes nature at its most fundamental level often requiring large scale infrastructure and experiments invented, constructed and operated by large international collaborations involving thousands of physicists and concentration of large funds. With such large-scale endeavours, public interest arises and critics questioning the pros and cons are natural in democratic societies that can be addressed in an open dialogue to the benefit of society of which science is an integral part.

Scientists should respond to fears, worries and ambiguities of the public on the cost and results of their research in a proactive, honest, transparent and enlightening way. In this spirit reaching out to the broad public, to teachers, policy makers, science communicators, and in particular to the young generation is important to keep the light of science shining brightly in the world.

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