Recent results from ATLAS and CMS

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CHIPP annual meeting

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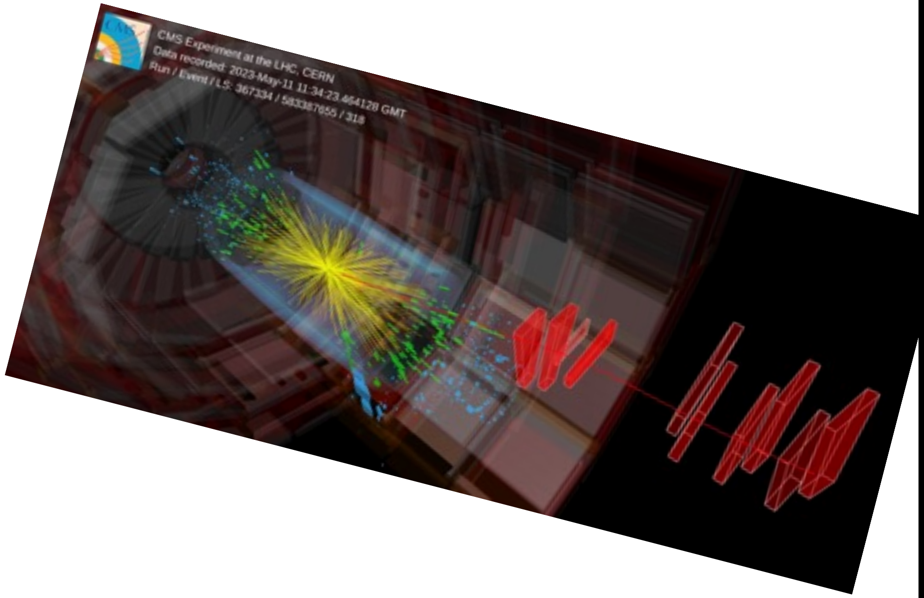
Compilation of results from conference Summary talks at Moriond EW (M. Kado,) Moriond QCD (A. Rizzi) and LHCP (R. Hawkins)

13 years of LHC physics

- LHC experiments continue to explore the new energy frontier
  - Discovery of a / the(?) **Higgs boson**
    - ➔ A new precision measurement program
  - Deepening the **study of the SM**
    - ➔ Increasing precision of many SM parameters
    - ➔ Exploring QCD in new environments
  - Plethora of searches for **new physics**
    - The Standard Model reigns supreme
    - Many models/parameter space ruled out
    - But new ideas are developing
    - 3σ effects come and go (and come and go)



Everything everywhere all at once

- ATLAS and CMS have a clean and well calibrated dataset of ~140 fb^{-1}
  - Still numerous results from Run 2 expected

- Run 3 started on 5th July 2022
  - Significant upgrades for both machine and detectors (esp. triggers)
    - Expect ~250 fb^{-1} for ATLAS/CMS, 25-30 fb^{-1} for LHCb and 7 nb^{-1} PbPb for ALICE
    - More than doubling the Run-2 dataset
    - Injector/LHC improvements (e.g. lumi-levelling)
    - New detector capabilities bring new possibilities
    - Starting to see first results from Run3 data

- HL-LHC upgrade is coming (Run-4 ++)
  - Operation from 2029-2041, ~3 ab-1
  - Major upgrades of ATLAS+CMS for Run-4
  - LHCb and ALICE scoping their phase2b upgrades for Run-5 (2035 onwards)

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In this talk:
Recent = Winter to LHCP
No flavor results since our colleagues from LHCb are not here

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  - Operation from 2029-2041, ~3 ab-1
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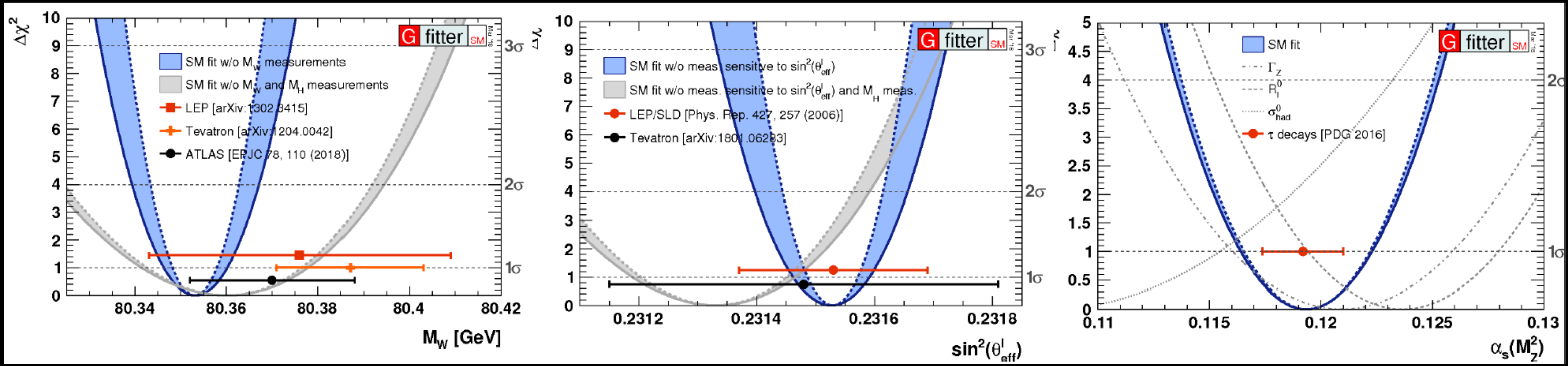
- Challenges everywhere – data analysis, operations and construction

The precision frontier at LHC

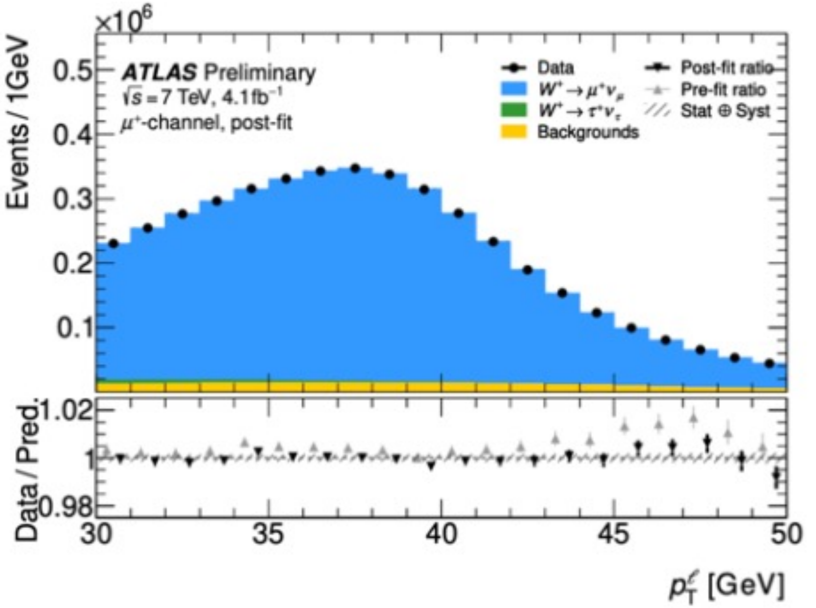


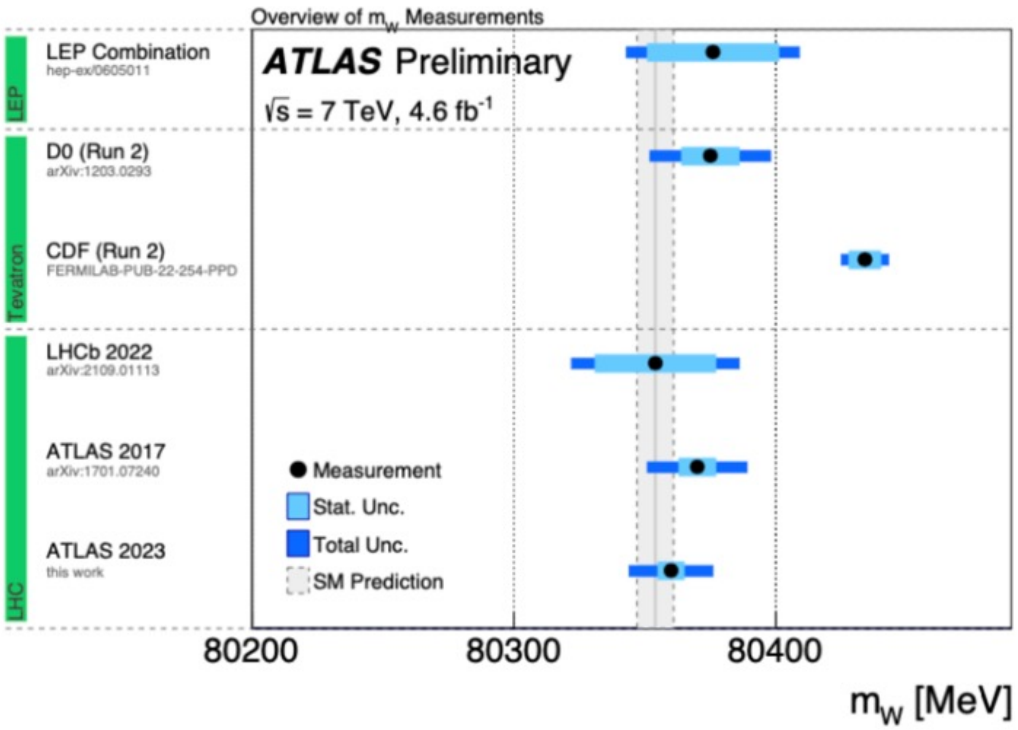
W boson mass

Update of the ATLAS analysis with 7 TeV data

New re-measurement includes several small

Improvements mainly relies on profiling paradigm





m_W = 80360±5(stat.) ±15(syst.) = 80360 ±16 MeV

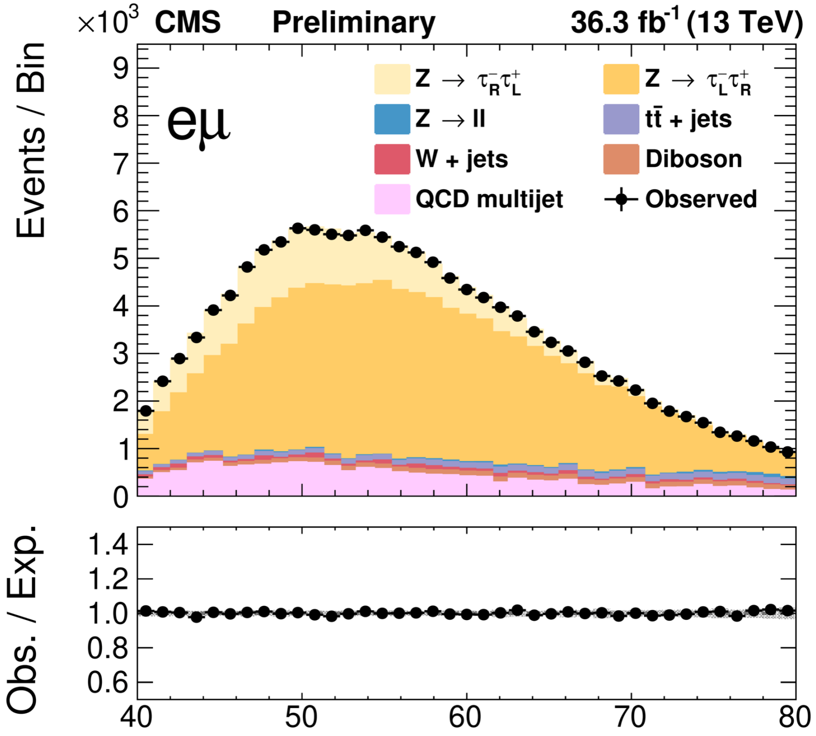
m_W = 80370 ±19 MeV

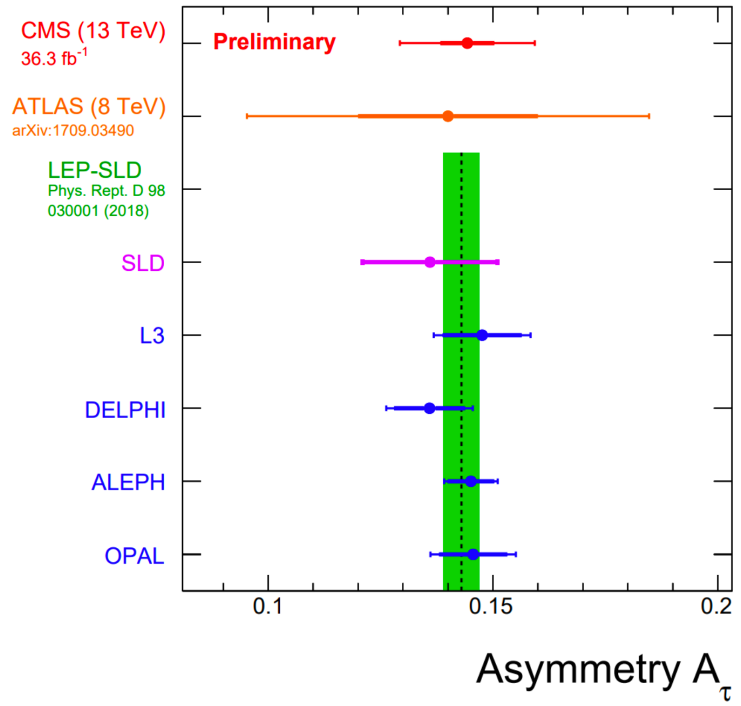
Reduced uncertainty from 19 to 16 GeV

Tension w/ CDF larger from 3.4σ now 4σ (Tension of CDF w/ the SM 7σ)

Tau polarization

Measurement relies in measuring the fraction of tau helicity states using polarisation sensitive variables - as the polar emission angle of the τ lepton and its sign are only very poorly known and cannot be used in the analysis





$$\mathcal{P}_\tau(Z^0) = -0.144 \pm 0.015 = -0.144 \pm 0.006\,(\text{stat}) \pm 0.014\,(\text{syst}).$$

$$\sin^2\theta_W^{\text{eff}} = 0.2319 \pm 0.0019 = 0.2319 \pm 0.0008\,(\text{stat}) \pm 0.0018\,(\text{syst}).$$

[LEP 1 and SLD at Z pole: 0.23152 ± 0.00016]

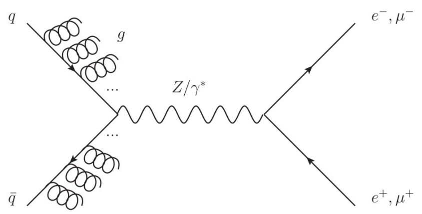
Determination of α_s

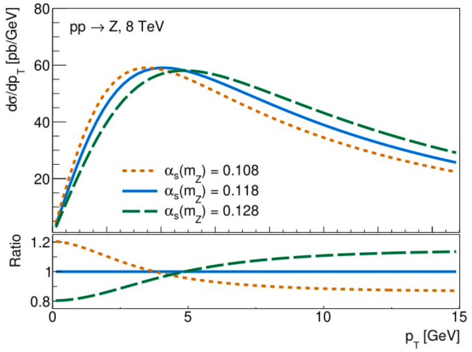
Measurement of the differential full-lepton phase space Z cross section!

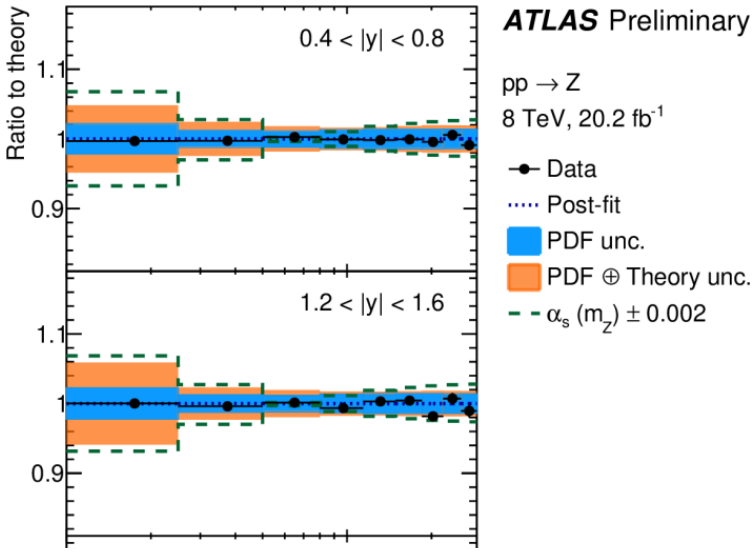
Current **most precise measurement**

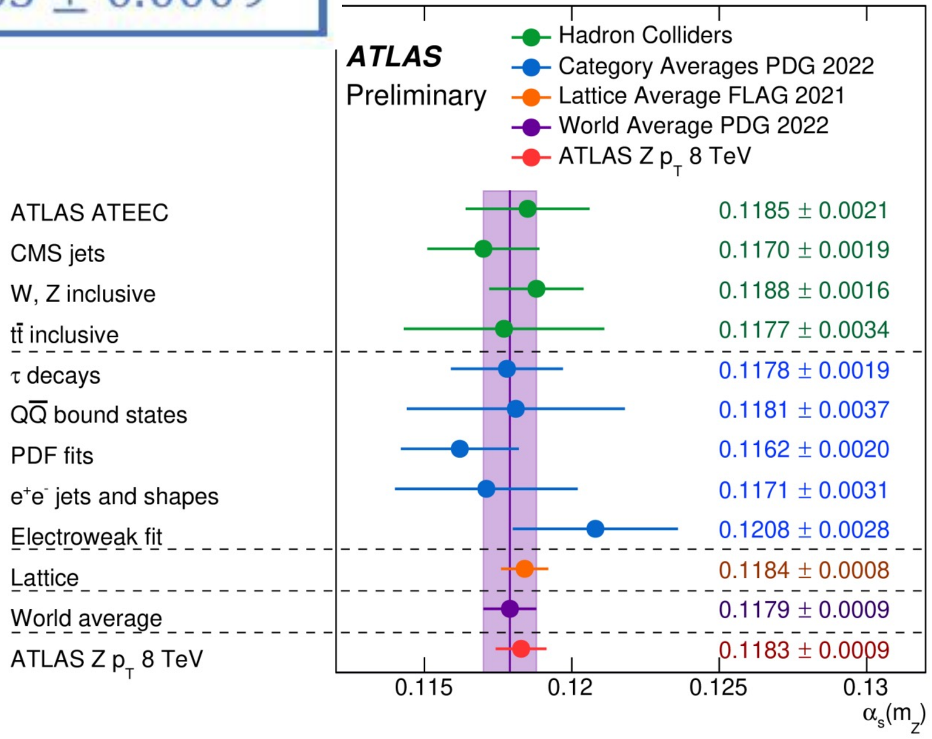
$$\alpha_S(m_Z) = 0.1183 \pm 0.0009$$

Dominated by theory uncertainties





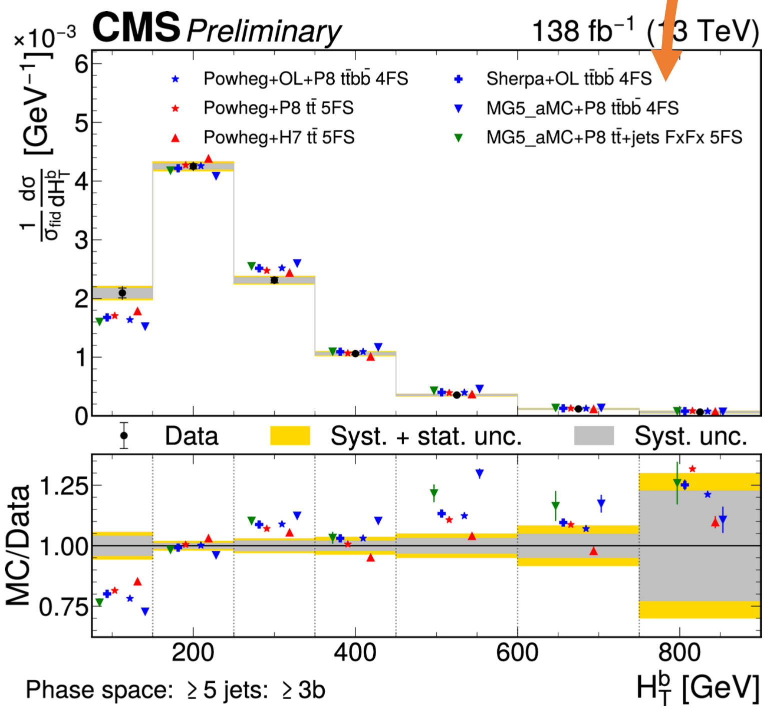


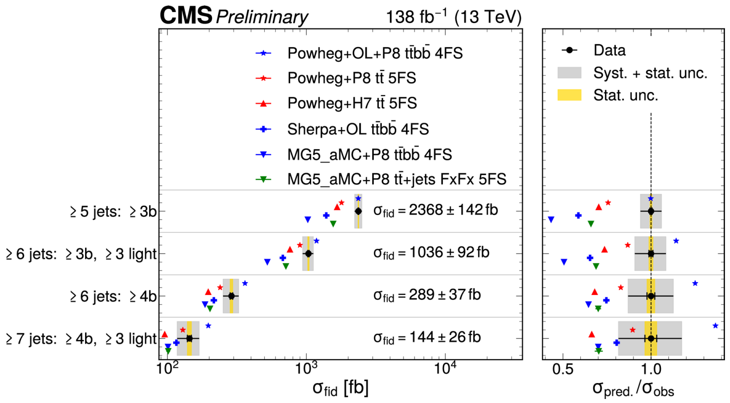


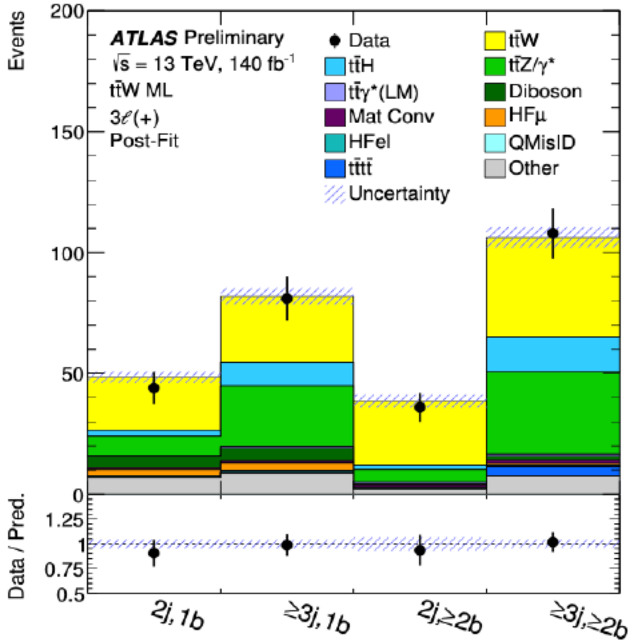
- New measurement from ZEUS from jet production $\alpha_s(M_Z^2) = 0.1138 \pm 0.0014$ (exp/fit)

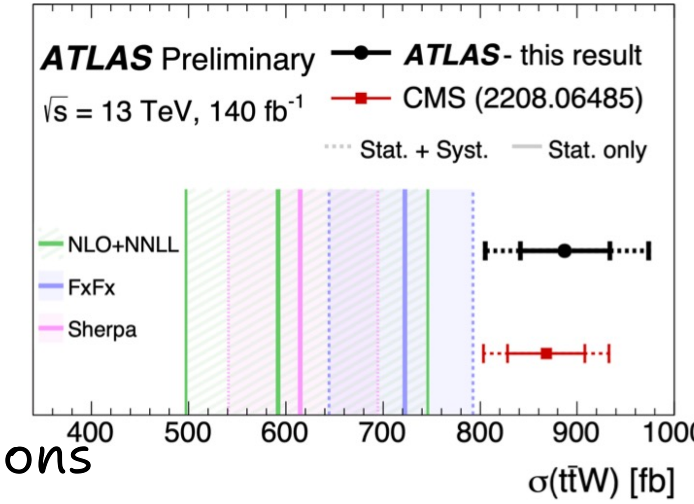
Ancilliary measurements

Inclusive and differential tt+bb and tt+W









Varying degrees of compatibility with the theoretical predictions

Consitent with SM predition at 1.5σ

New production processes

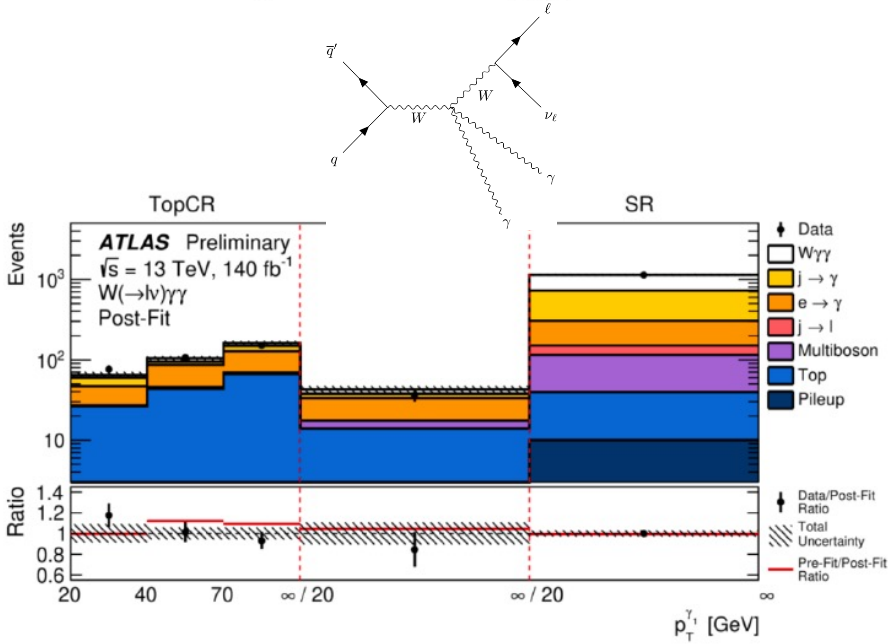
New multibosons

Mature field with many inclusive and differential measurements

Investigate triple and quartic gauge couplings and more and more EFT limits

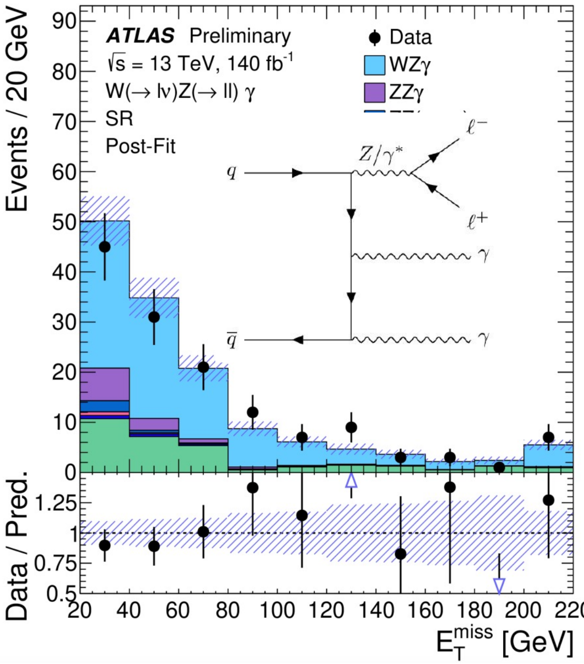
Wγγ observed with 5.6σ

$$\sigma_{fid} = 12.1^{+2.5}_{-2.2}\ \text{fb}^{-1}$$



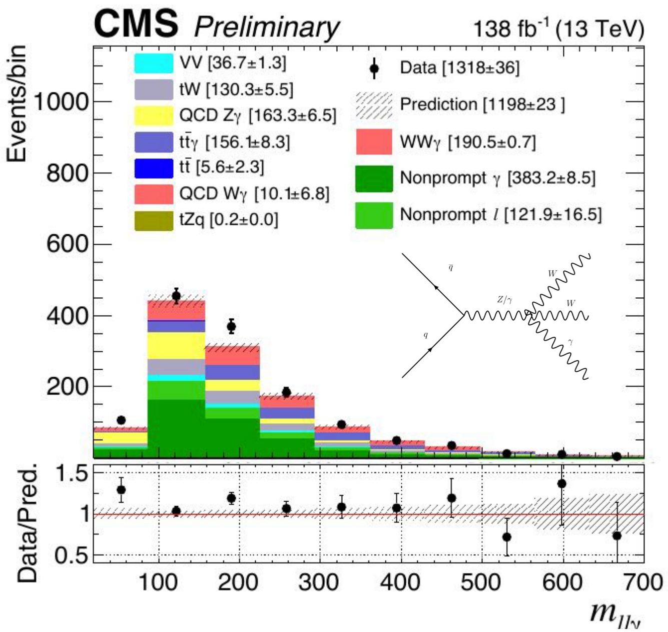
WZγ observed with 6.3σ

$$\sigma^{\text{fid}}_{\text{obs}} = 2.01 \pm 0.30\,(\text{stat}) \pm 0.16\,(\text{syst})\ \text{fb}$$



WWγ observed with 5.6σ

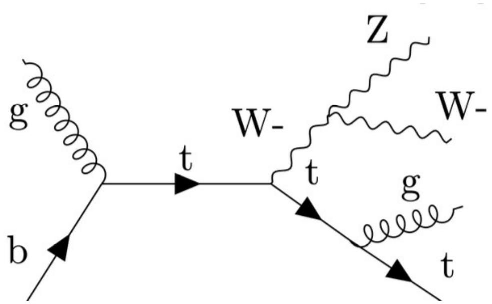
$$\sigma_{\text{fid}} = 6.0 \pm 1.7\ \text{fb}$$



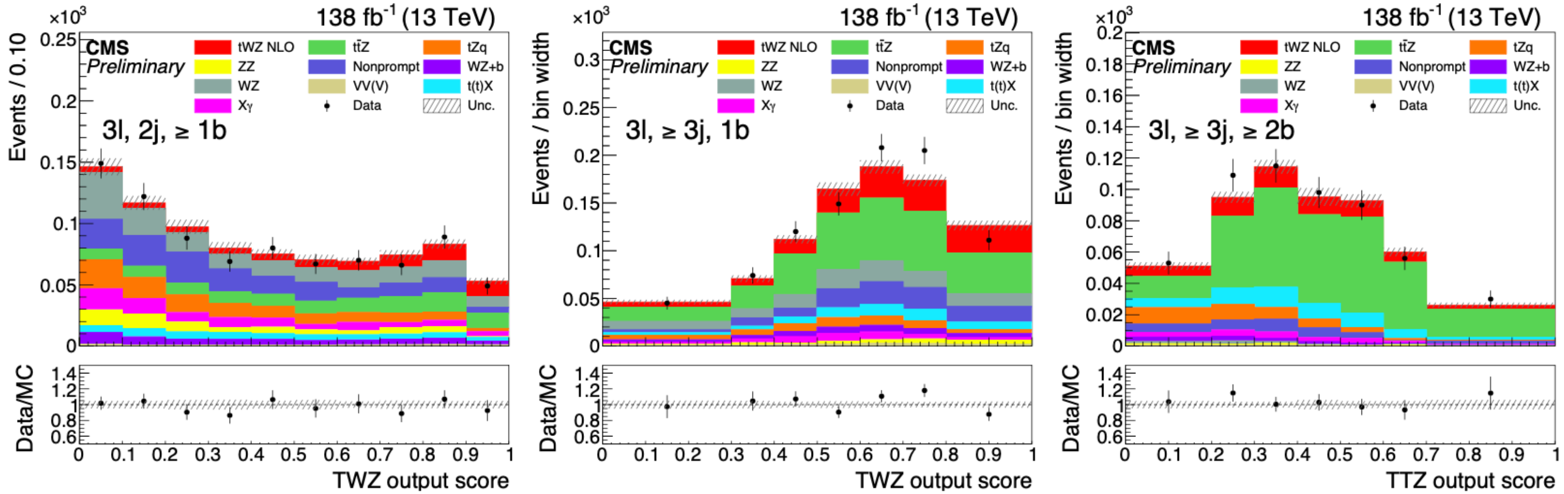
Stat. dominated, main syst. from non-prompt photons/ leptons

New top + multibosons

Evidence of tWZ production



in multileptons channels

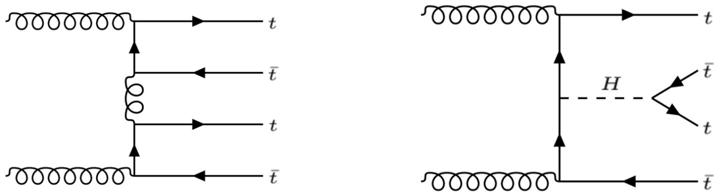


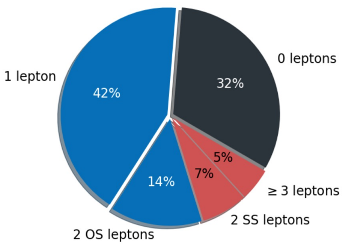
Measured cross section
0.37 ± 0.05 (stat) ± 0.10 (syst) pb

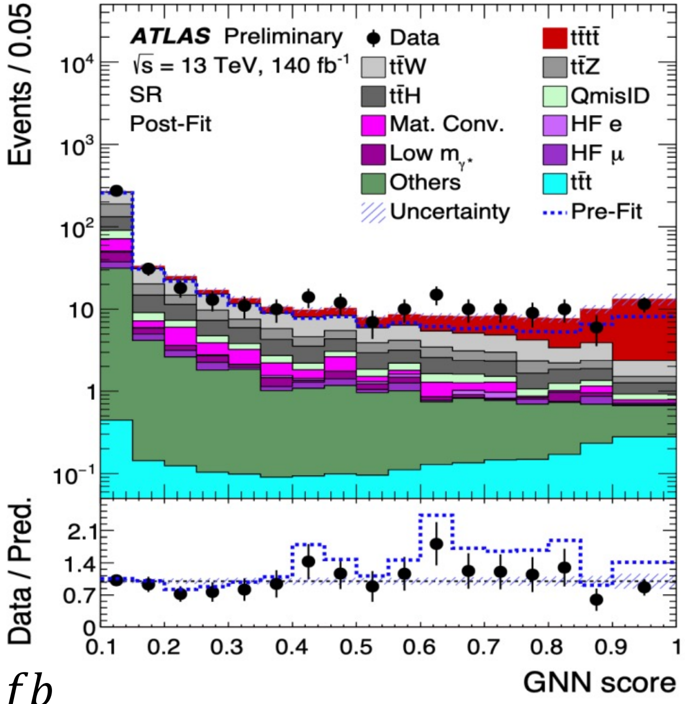
Observes a signal with **3.5σ** significance (expected **1.3σ**)

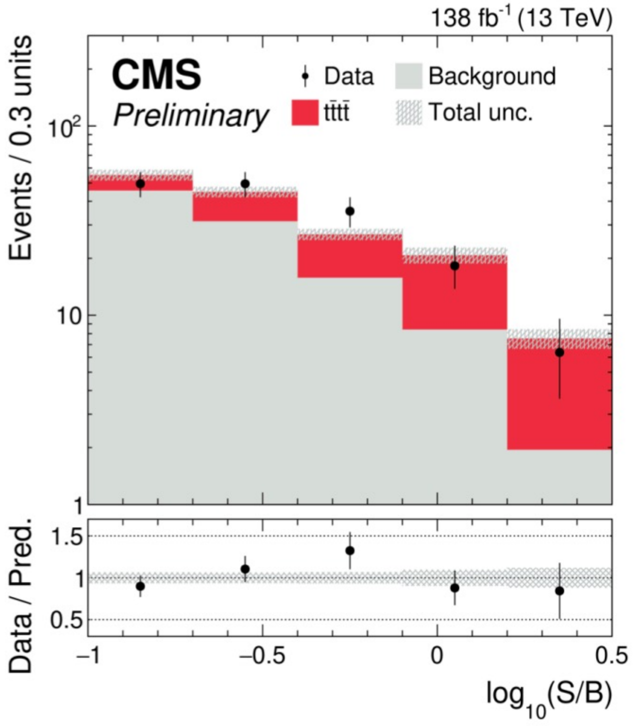
New multitops

- (Independent) Observation by ATLAS and CMS of 4 top production!









Measured cross section (CMS)
17.9 +3.7 -3.5 (*stat*) +2.4-2.1 (syst) *fb*

[for reference σ_{tt}= 791 ± 25 pb]

Observed (expected) significance measured at **6.1σ** (**4.3σ**)

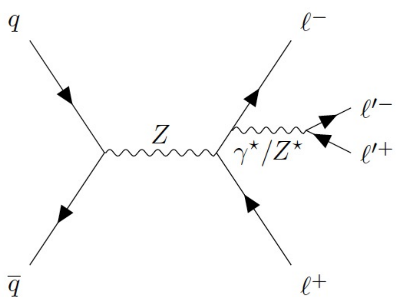
Observed (expected) significance is **5.5σ** (**4.9σ**)

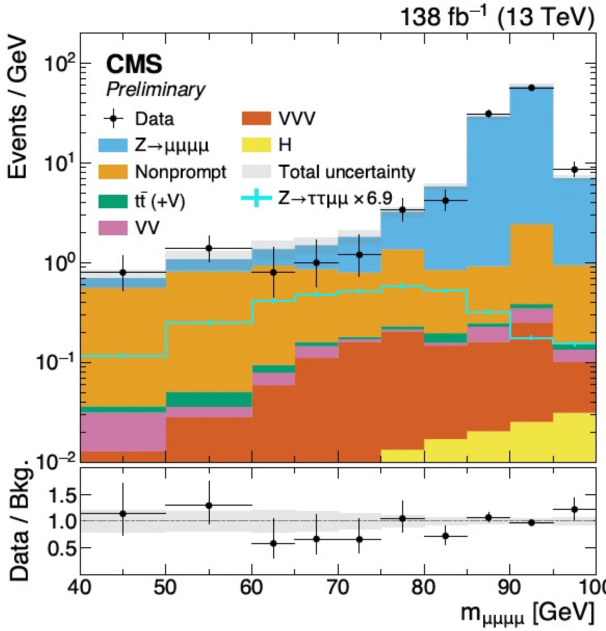
Searches for rare decays

In old particles

First ever searches for these decays

Z→2μ2τ: Using tau lepton decays to muons and neutrinos, events with two pairs of oppositely charged muons

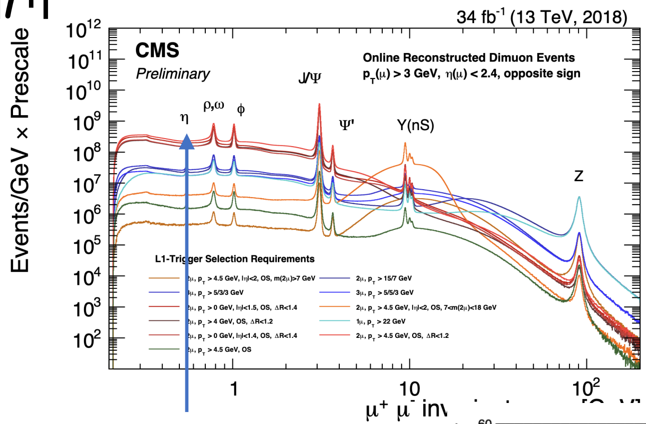




Upper limit of 6.2

Excludes values above 6.9 times the SM expectation

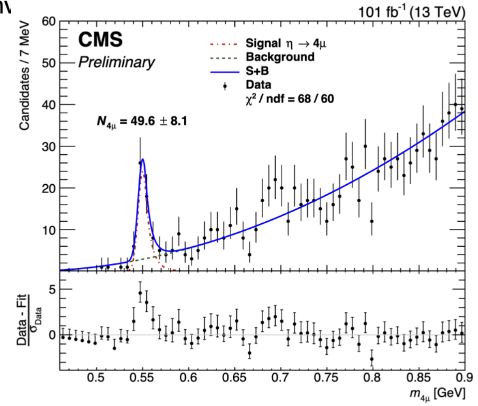
η→4μ: Using scouting triggers to measure leptonic radiative decays of the η/η'



10^{12} η mesons

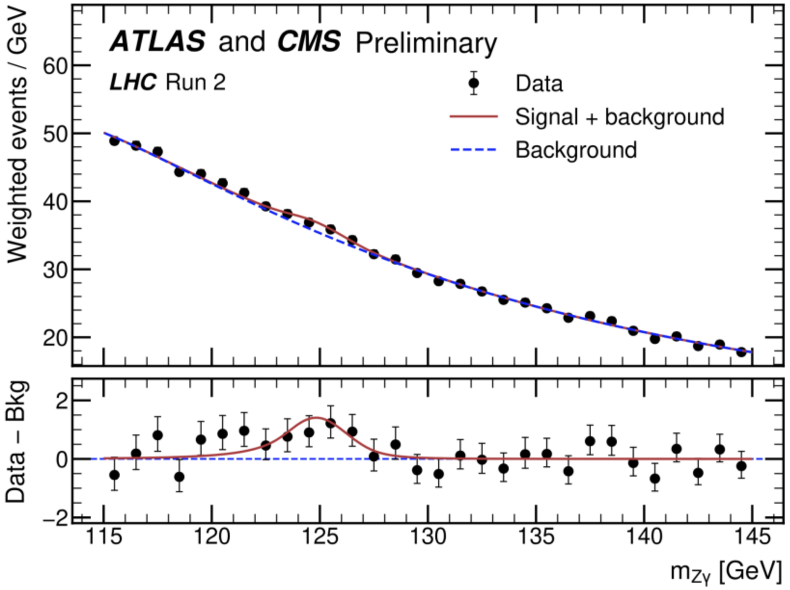
First observation of η→4μ

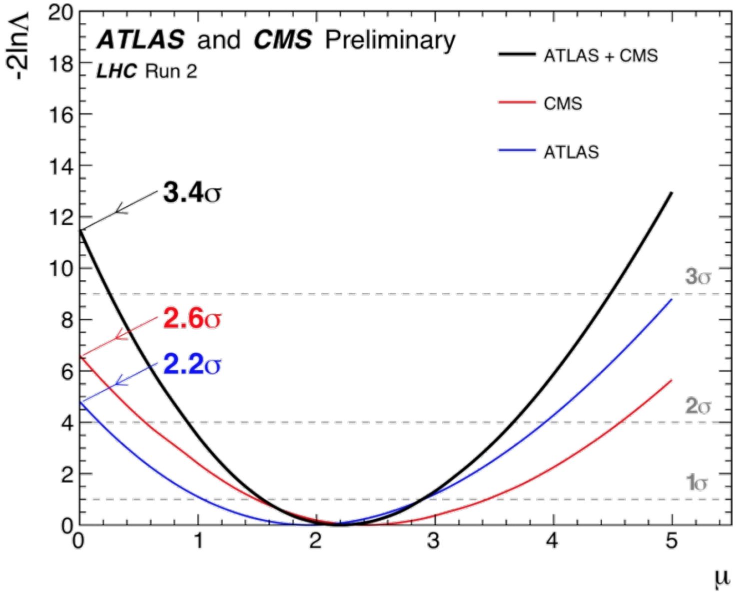
Well above 5σ



In Higgs

- $H \to Z\gamma$ decay studied by ATLAS+CMS (both published)
  - BR in SM is ~1.5 10^{-3}, 0.3% per $Z \to ll$ flavor
- Existing analyses have now been combined at the likelihood level





- Evidence for a signal with **3.4σ** significance (expected **1.6σ**):
  - Observed signal cross section corresponds to 2.2±0.7 times the SM cross section
  - 1.9σ compatibility with SM prediction

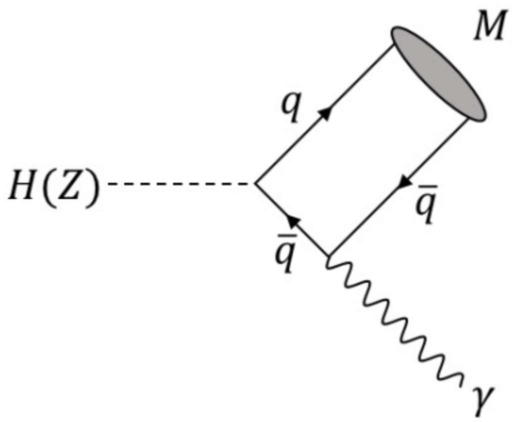
In Higgs

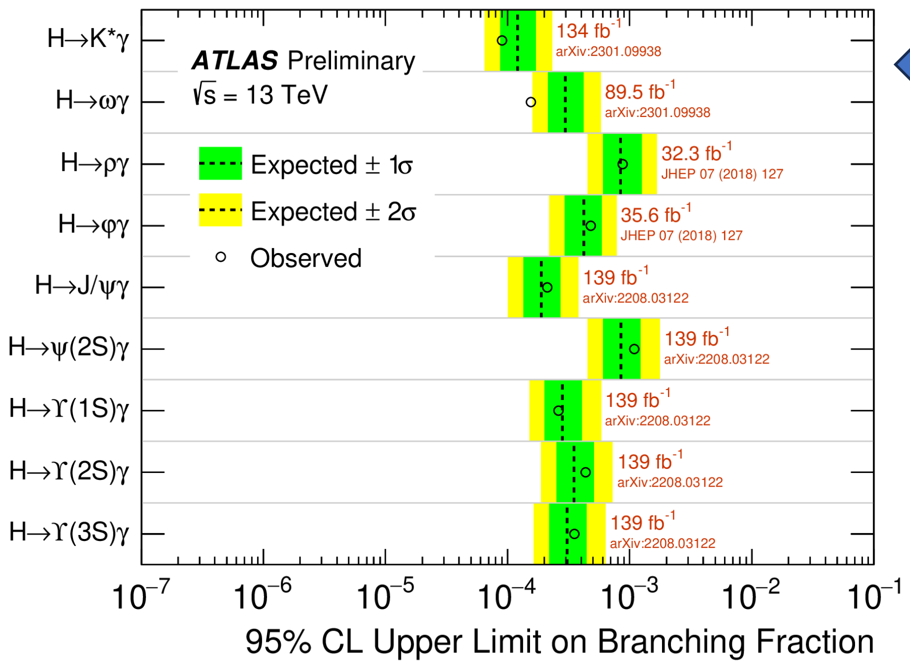
New searches for H (or Z) to meson + photon and new summary

Can probe couplings of the **Higgs boson to light quarks**

And can probe **charm and bottom couplings** when with

Heavy quarkonia (J/ψ, $\psi(2S)$ and $\Upsilon(nS)$ with n = 1, 2, 3,)

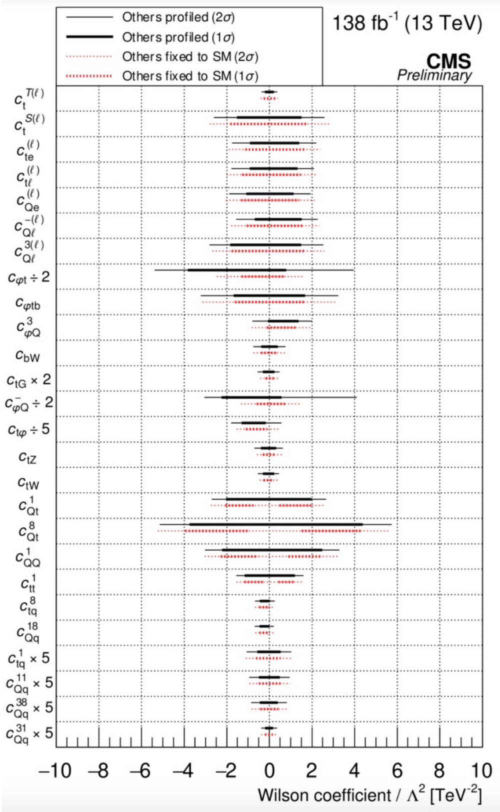


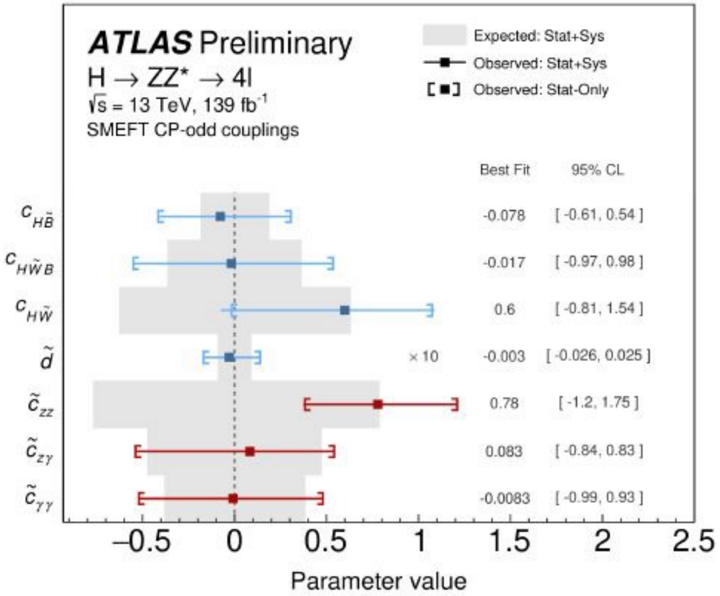


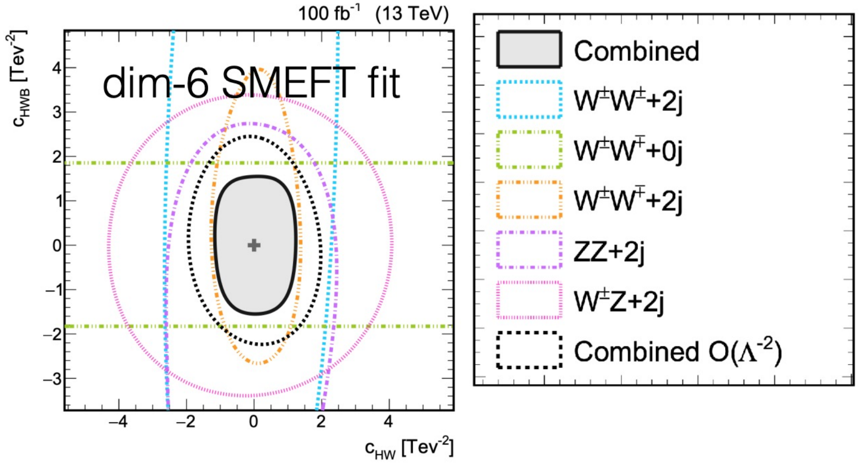
SM expectation for w ~ 10^{-6} and K* 10^{-11}

EFT instead of going model by model

EFT interpretation can be used to combine several processes and analysis and derive a single picture on the presence of new physics.





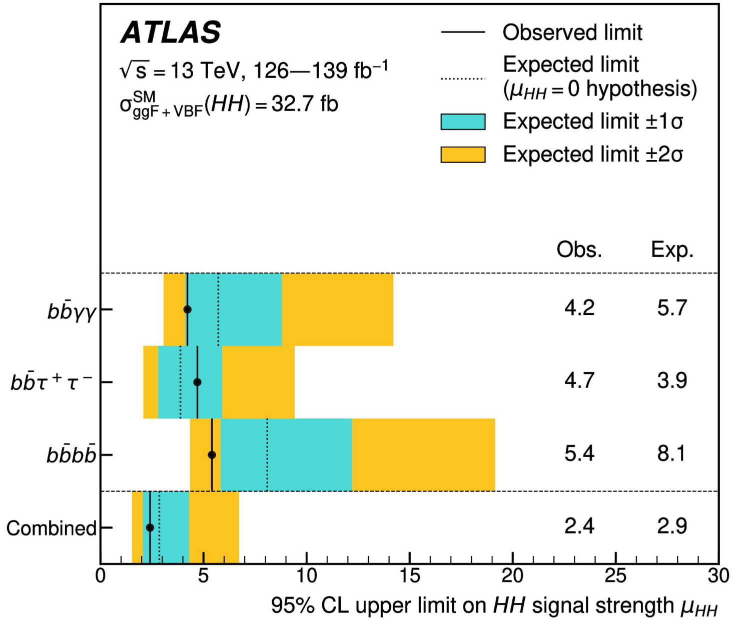


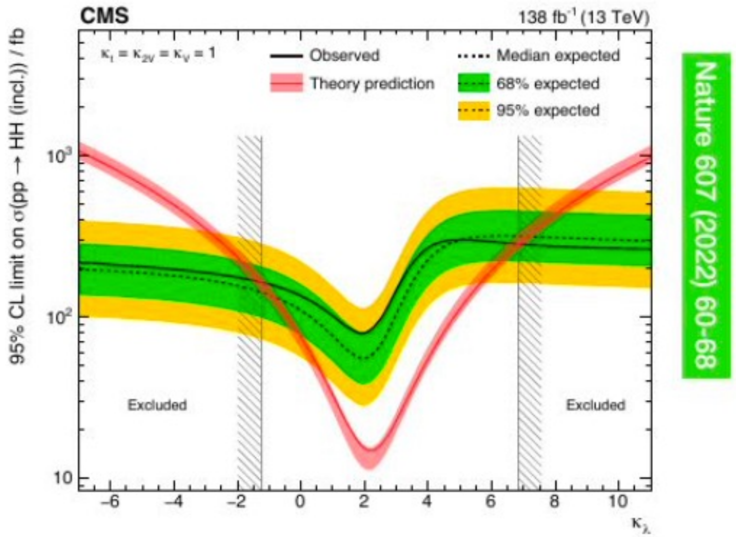
Many results sensitive to EFT operators: t-V coupling, four fermions' operators, etc.

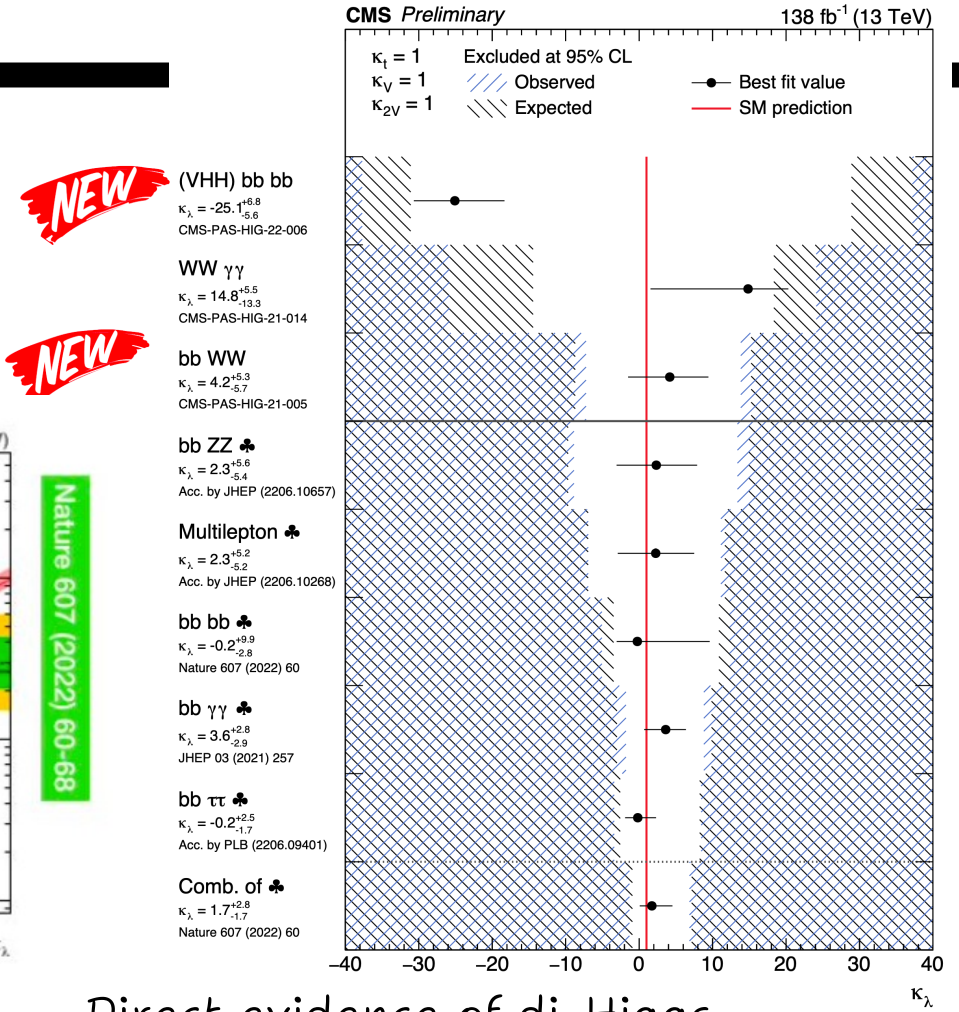
Higgs self coupling

Production of di-Higgs sensitive Higgs self-coupling

κ_λ and VVHH κ_{2V}







2.4 Obs (2.9 Exp)
[CMS 3.4 Obs (2.5 Exp)]

$-1.24 < \kappa_\lambda < 6.49$

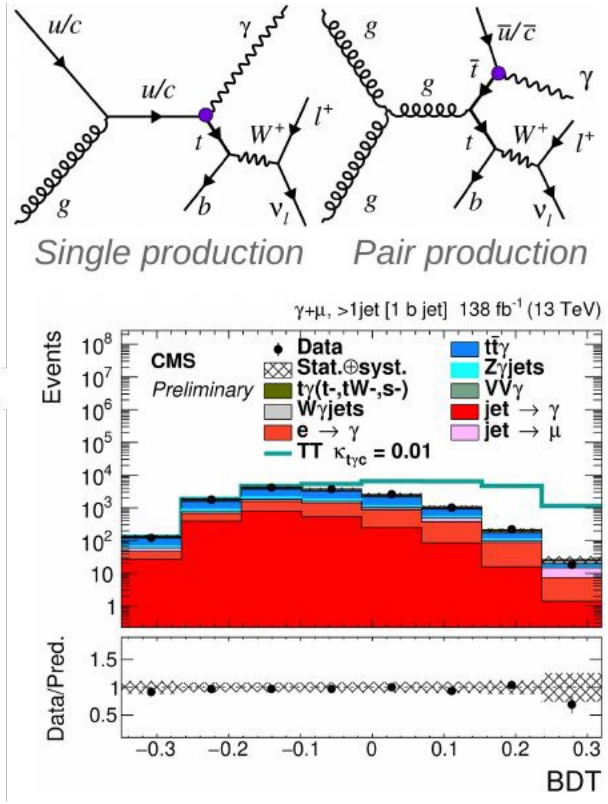
[ATLAS $-0.6 < \kappa_\lambda < 6.6$]

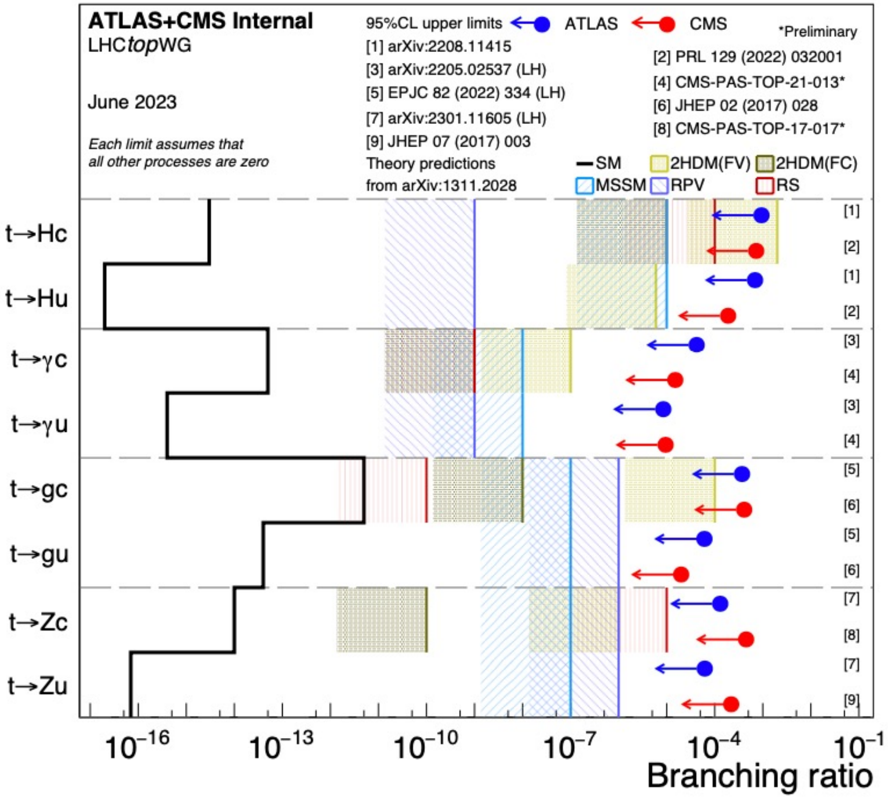
Direct evidence of di-Higgs production by both ATLAS and CMS should be achievable at the HL-LHC!

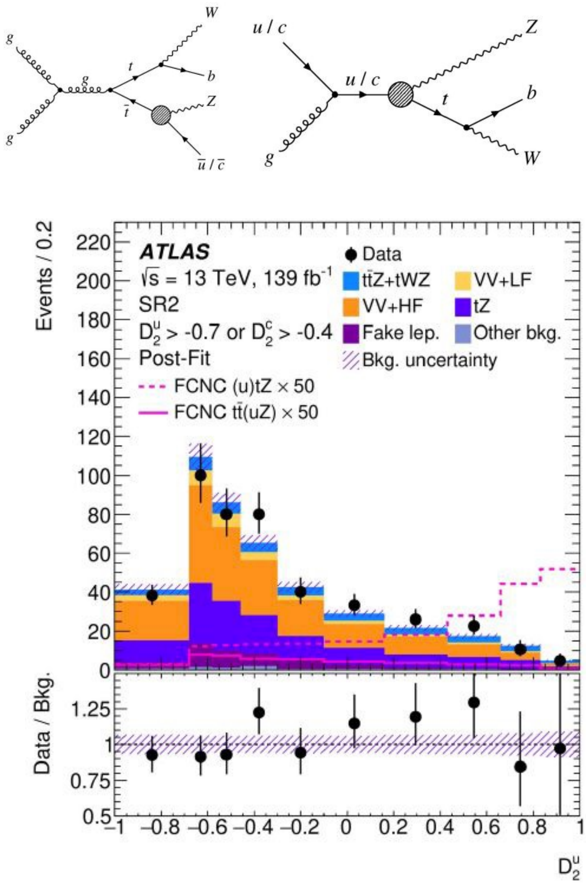
Beyond what we know

New interactions

Top quark Flavor Changing Neutral Currents in SM heavily suppressed in decays with BFs < $O(10^{-12})$





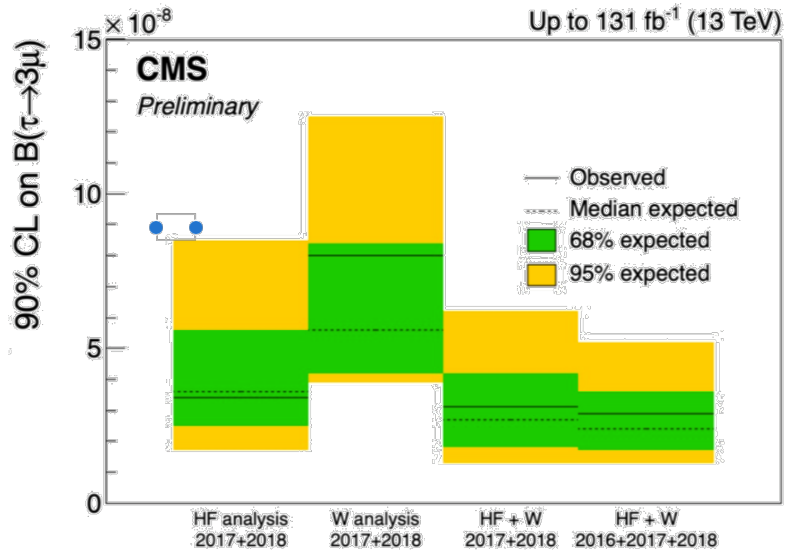


2 new results + summary

Lepton Flavor Violation

Search for $\tau \rightarrow 3\mu$

- Using taus from heavy flavor (low p_T) and W (high p_T)

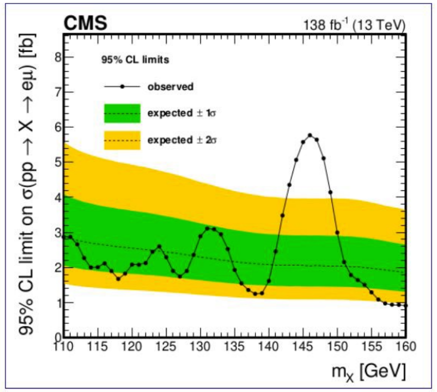


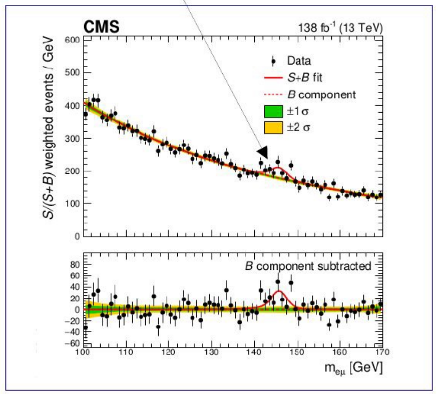
Limit $Br(\tau \rightarrow 3\mu) < 2.9\ 10^{-8}$ at 90% CL

- Approaching $2.1\ 10^{-8}$ limit set by Belle

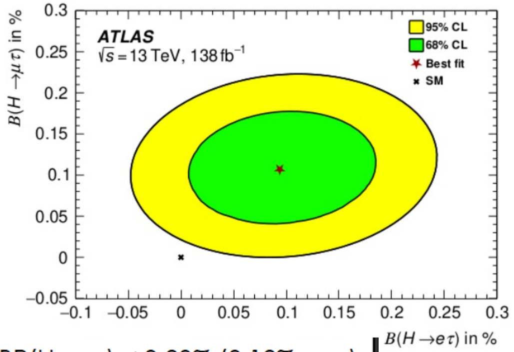
Search for **H→eμ**

Result: Global (local) Significance of 2.8(3.8)σ

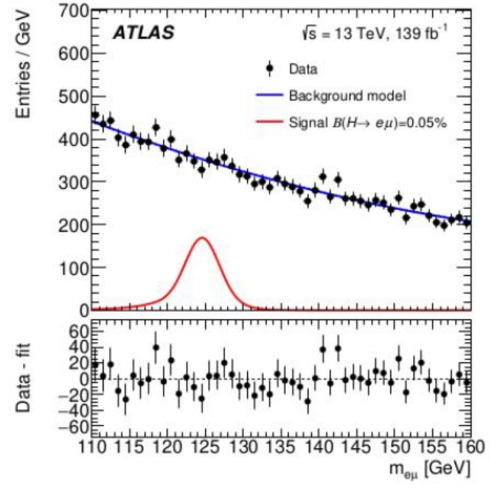




Search for H→τe and H→τμ

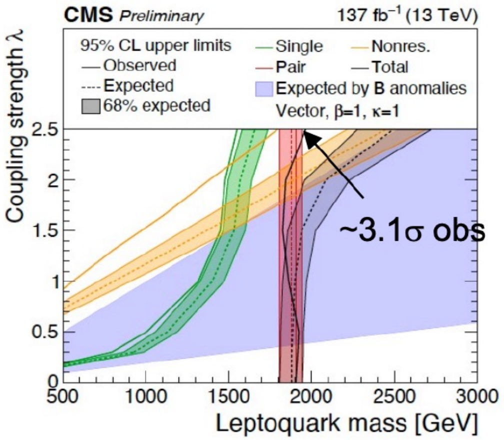


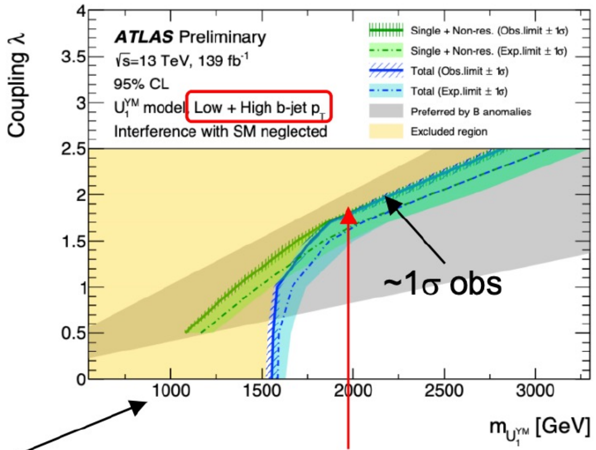
BR(H→eτ) < 0.20% (0.12% exp)
BR(H→μτ) < 0.18% (0.09% exp)
Compatible w/ SM in 2.1 sigma



Lepton Flavor Universality Violation

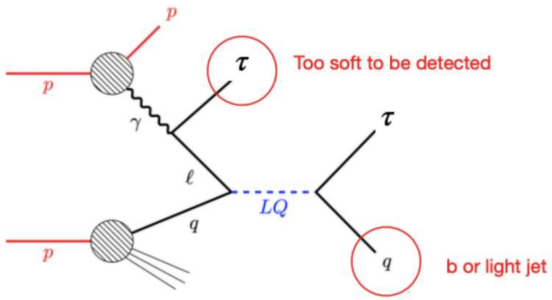
- LFUV anomalies claimed by LHCb can be explained in several NP scenarios with particles coupling preferentially to first or second generation
- Broad program of searches for leptoquarks single and pair-production
- Increasing focus on non-resonant production to reach highest masses
- New searches:
    - LQ decaying to b and taus in single and and pair production (in s- and t-channels
    - LQ produced in lepton-quark collision (first time this mechanism is probed)
    - Z' search produced in association with b-jets (not shown)

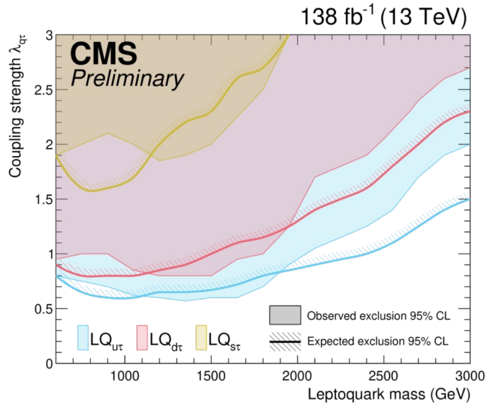




Large improvement in sensitivity when adding low b-jet p_T category

Excludes CMS' excess

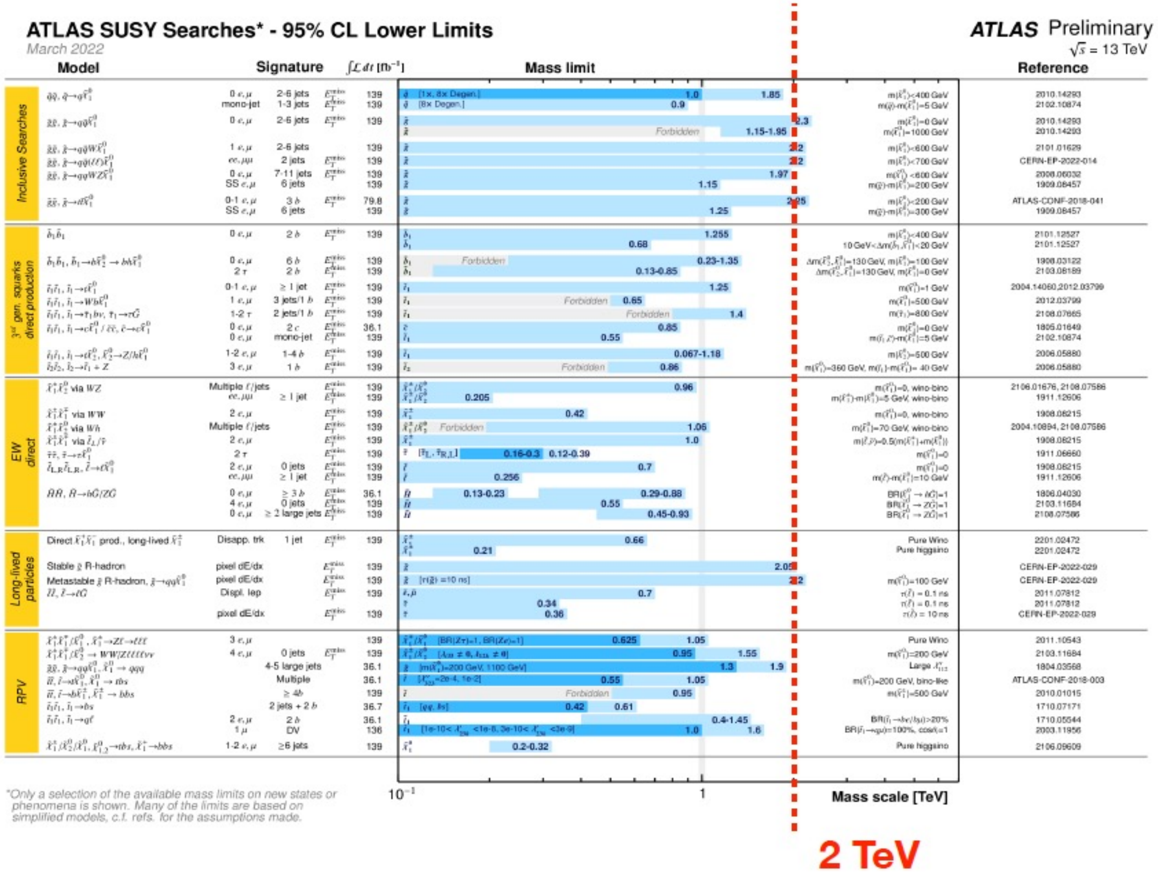


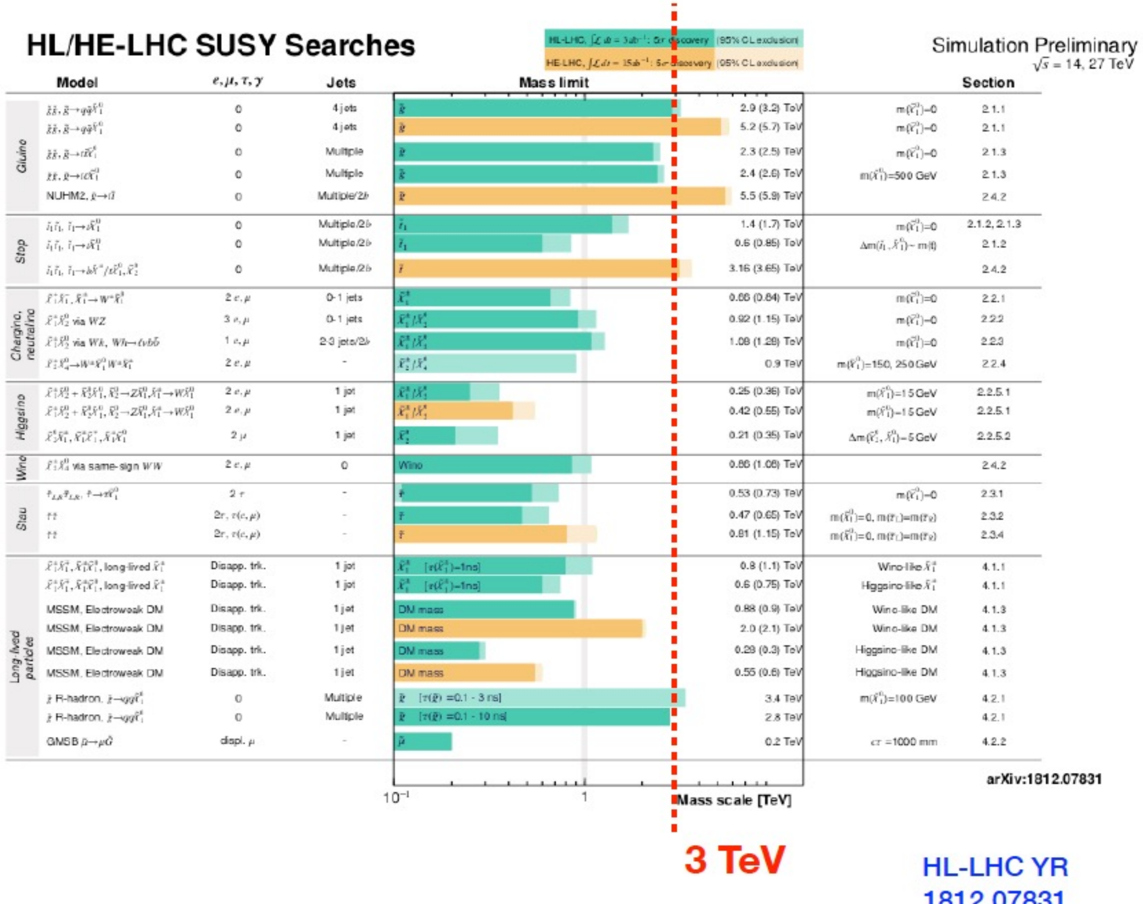


Numerous SUSY searches

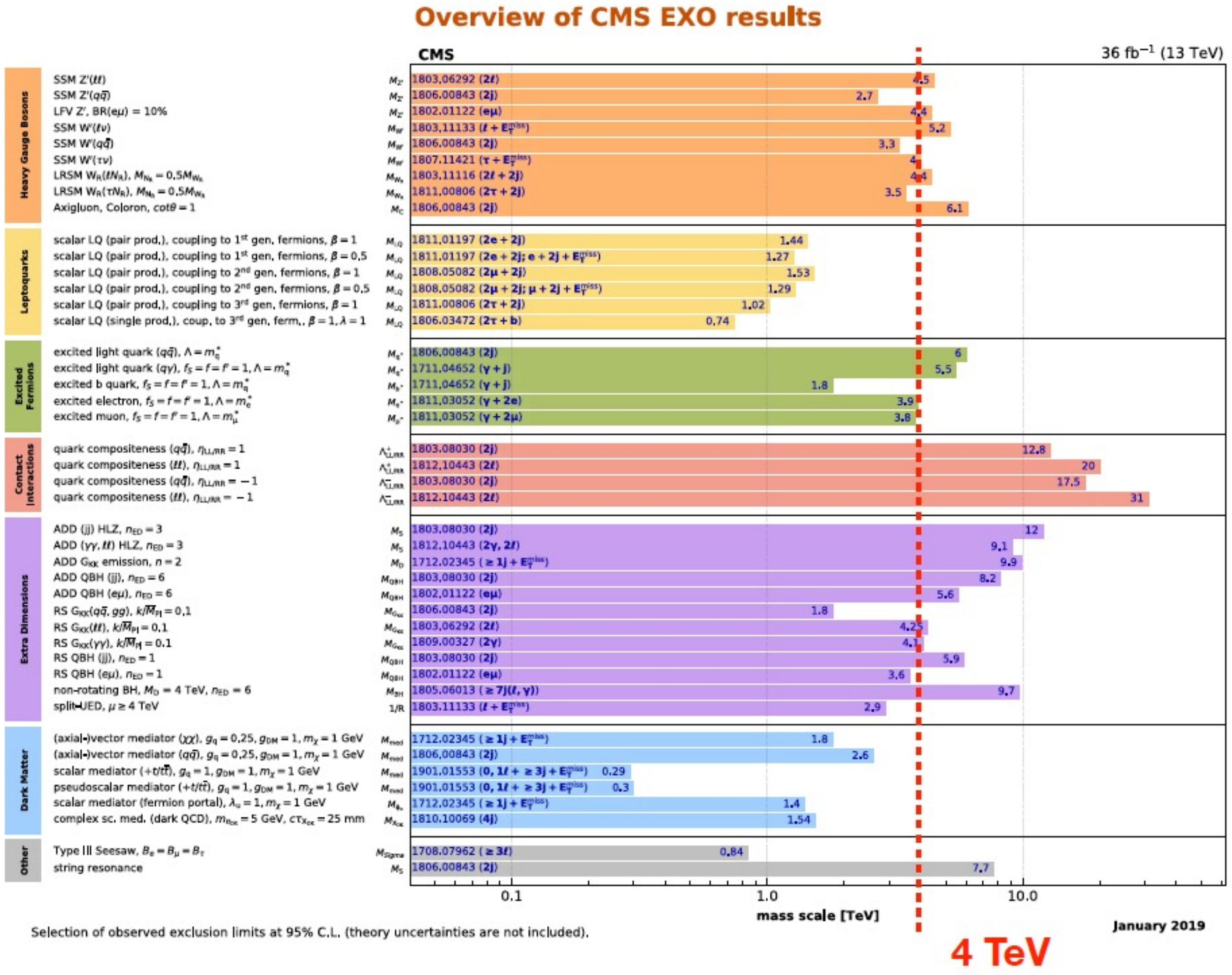
"Typical" SUSY searches: multiple SM objects, large MET

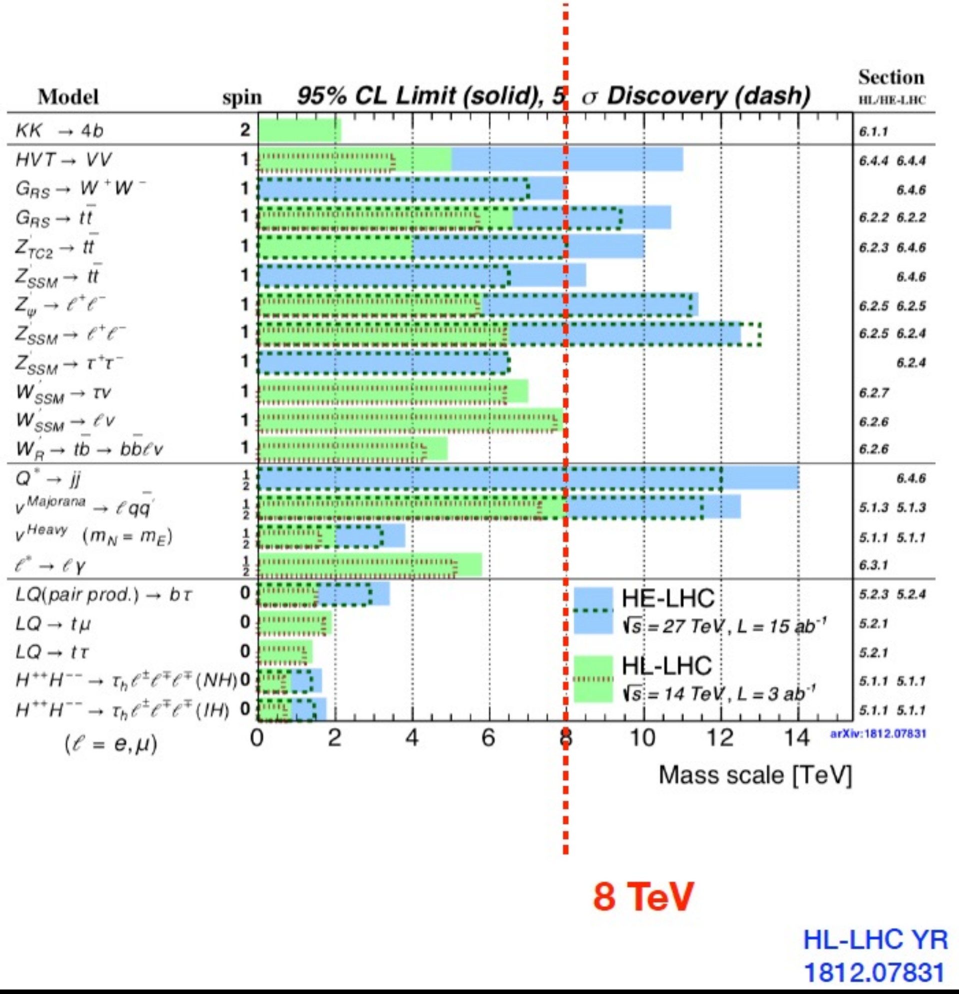
More exploration: **Challenging signatures** (e.g. stealth SUSY sector) and previously uncovered corners • **Compressed scenarios** (small amount of visible energy) • Sleptons (extremely **low cross sections**) • **Combine SUSY searches** to be more powerful together





Numerous searches for exotica

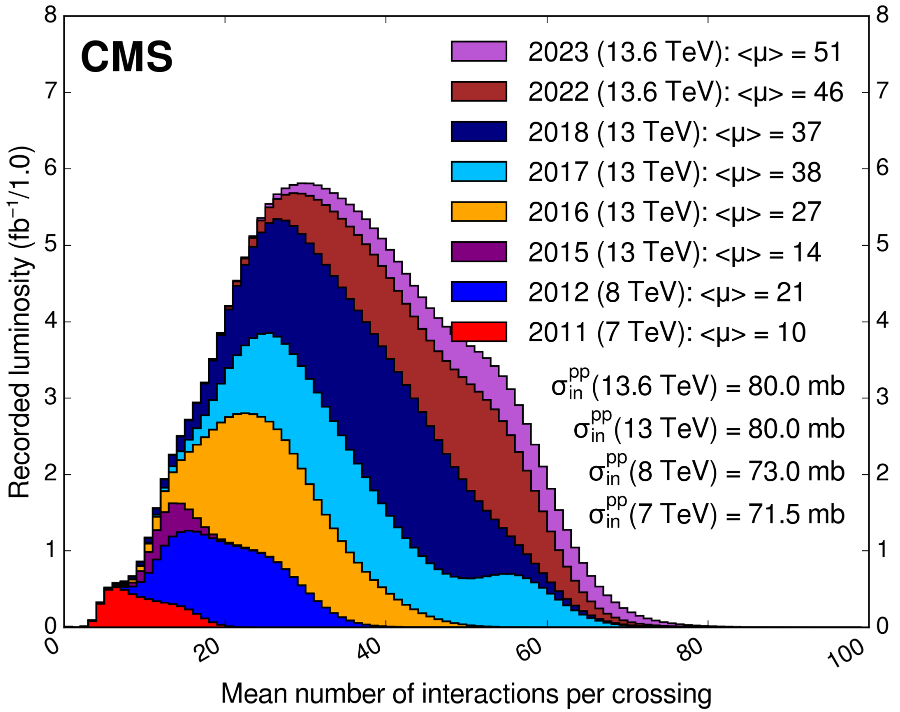




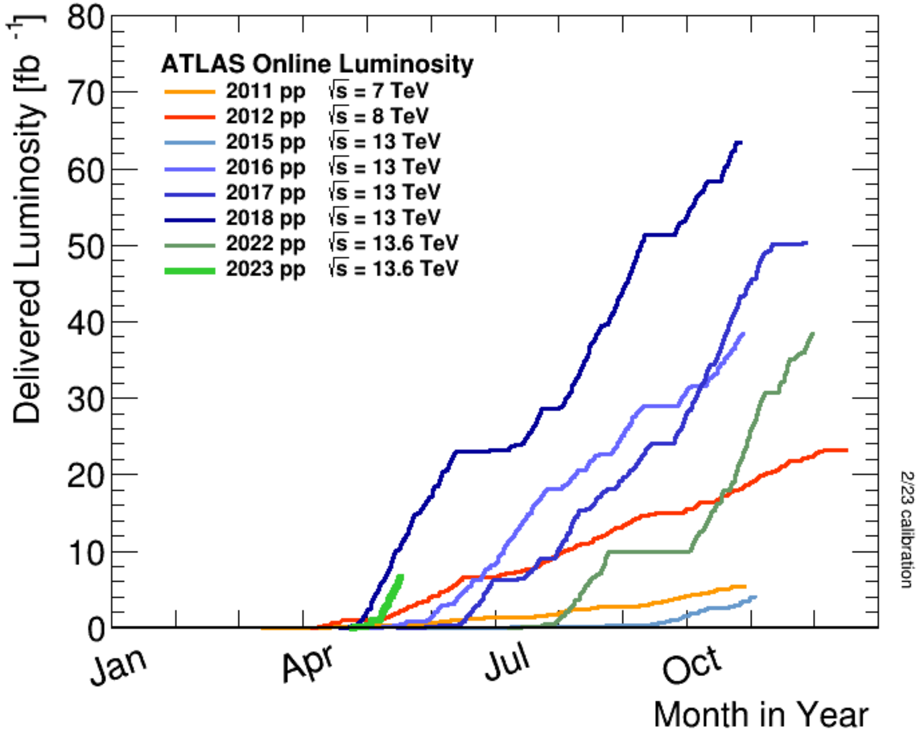
Example from CMS (similar for ATLAS) - latest plot in the backup!

Run 3

Run 3 is underway

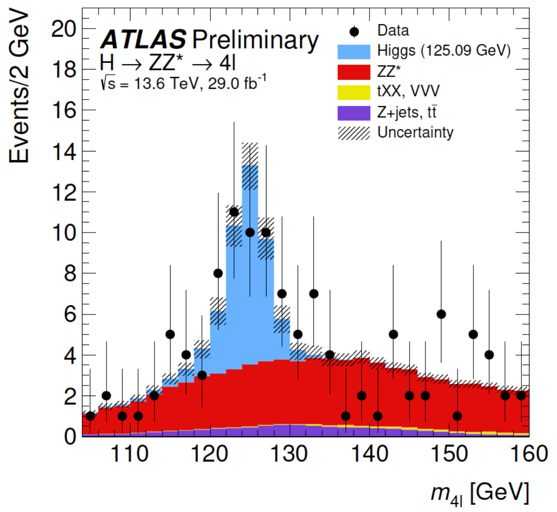


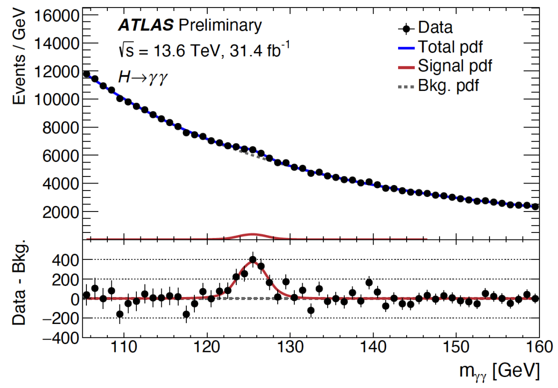
- 2022 was about 46
- 2023 is expected to be 60

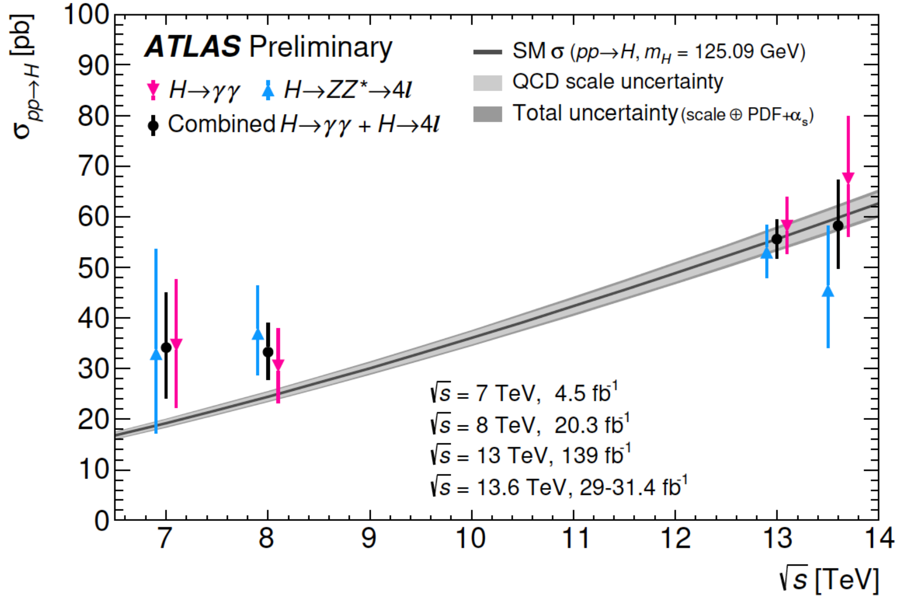


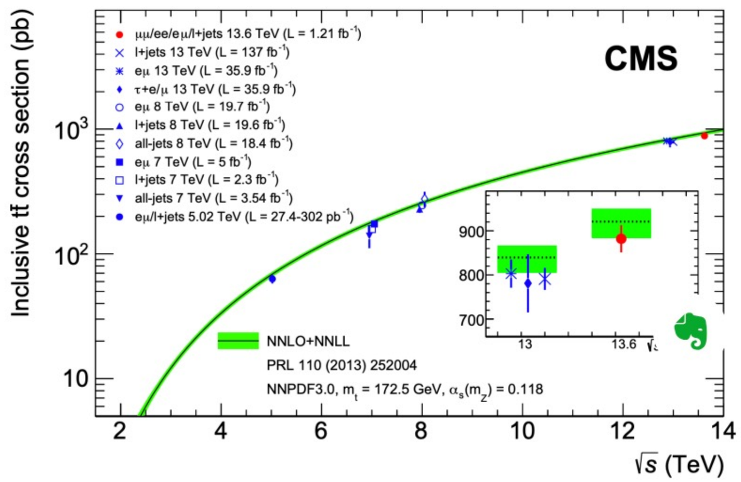
The slope of delivered luminosity in 2023 is impressively steep, with an early start in the calendar year.

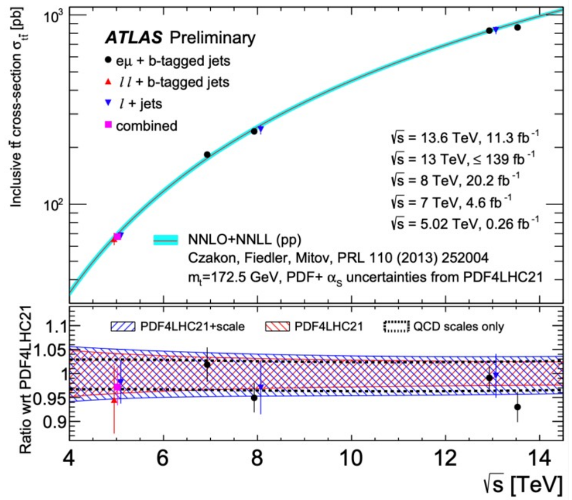
Results from Run 3: physics at 13.6 TeV







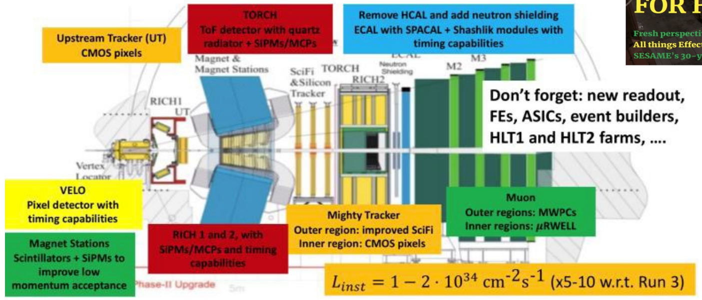


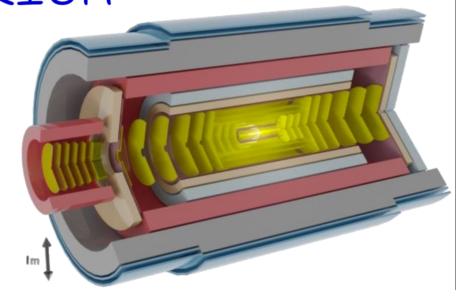


Run 4 and beyond

Detector upgrades for HL-LHC phase

- Upgrades for Run-3 now being commissioned
  - Trigger/rate capability, pre-Run4 upgrades
  - Challenging to commission/exploit for physics
- ATLAS+CMS phase 2 upgrades for Run4
  - New tracking detectors, timing layers, muons
  - CMS HGCal endcap 'digital' calorimeter
  - New state-of the art TDAQ/trigger systems
- LHCb and ALICE intermediate upgrades
  - E.g. RICH electronics; ITS3/FoCal
  - Phase2b upgrades for Run5-6
  - LHCb sub-ps precision timing everywhere, SciFitracker, SiPM-based RICH
  - ALICE3 with superconducting solenoid and all-silicon tracker
- Effort/cost like building new experiments …
  - Ambitious programme for next decade(s)





Conclusions

- Somehow incomplete list of results from the past 6 months from CMS and ATLAS
  - Leaving flavour out (and LHCb! as explained)
  - Heavy ions results – some of our community working in this area
- Increasing the precision of SM parameters and studies, deepening our understanding of the SM
  - Reaching new processes and decays
- New ideas and methods are improving are sharpening the exploration of SM and BM
  - Expanding the phase space
  - Improving uncertainties
- An exciting and intense few years ahead
  - Still lots to do with Run 2
  - Run 3 is her
  - Upgrades for Run 4 in progress