ATLAS experiment status and perspectives

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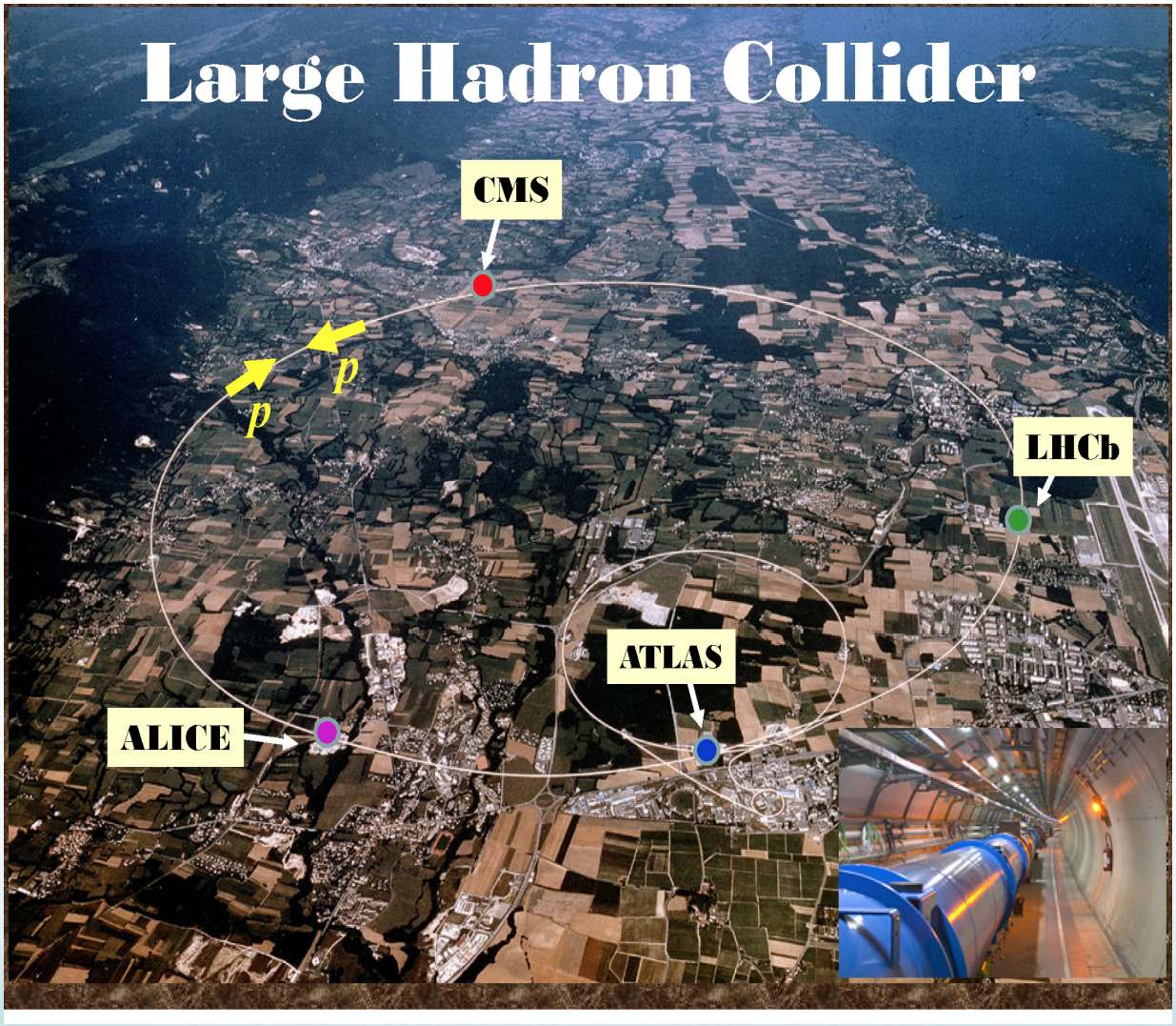
Outline

- ✓ The LHC and ATLAS
- ✓ Standard Model measurements
- ✓ Top quark results
- ✓ Higgs Physics
- ✓ Beyond Standard Model
- ✓ Run 3 perspectives
- ✓ Summary

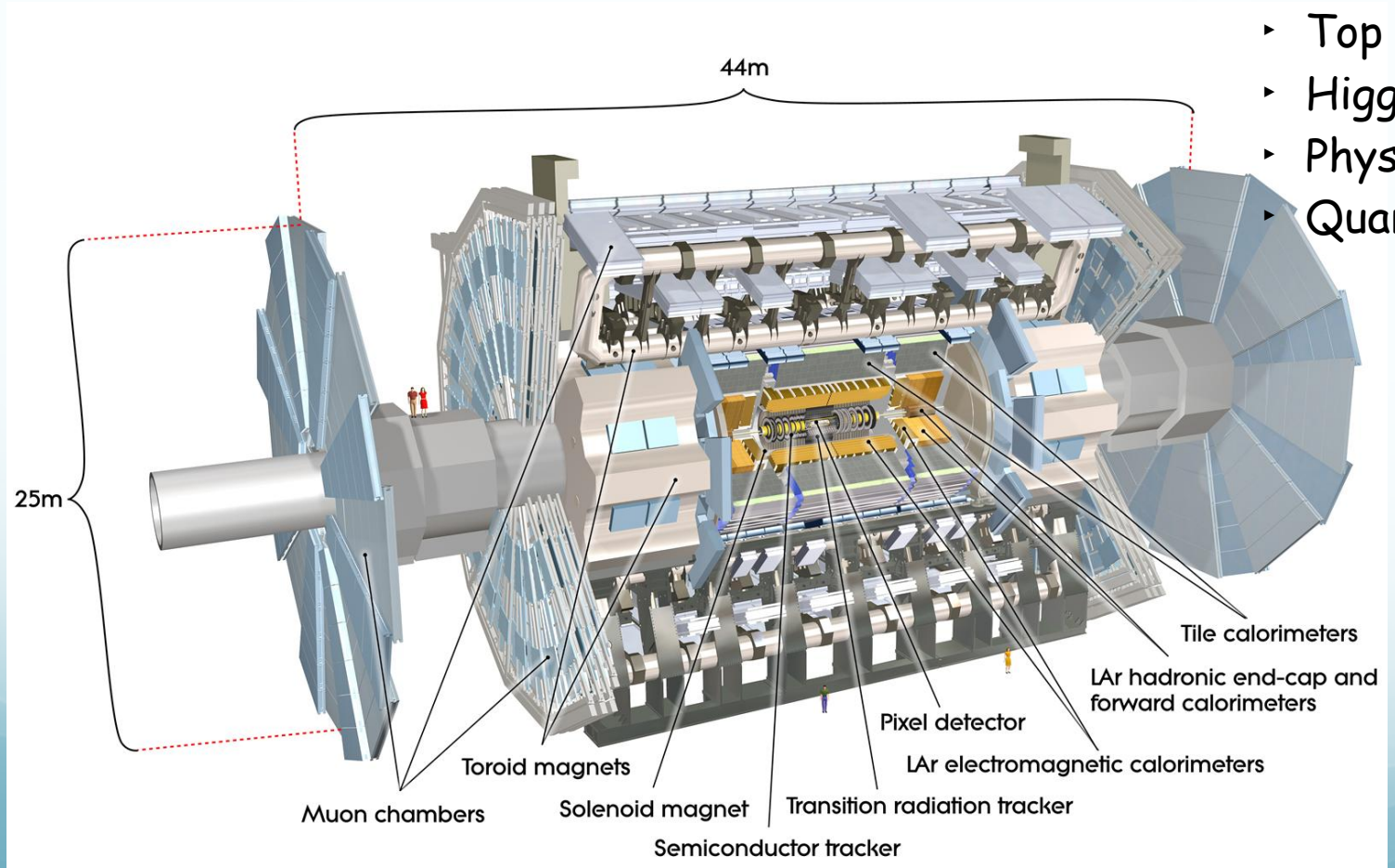
The LHC



With 13.6 TeV energy in the c.m. , the LHC offers the best scenario for searching a large variety of signals.

The ATLAS detector

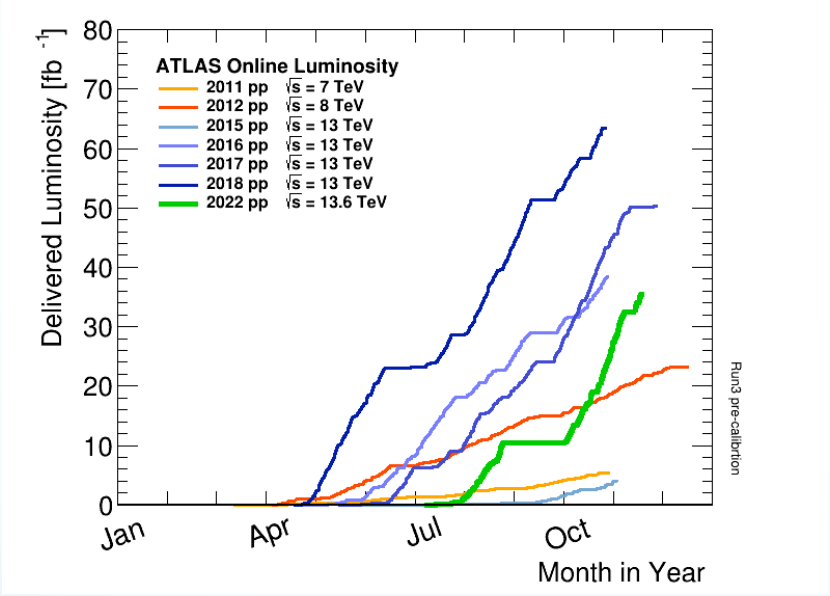
- Multipurpose detector
- Rich physics program:
  - EW measurements
  - QCD processes
  - Top and b-physics
  - Higgs physics
  - Physics BSM
  - Quark-gluon plasma

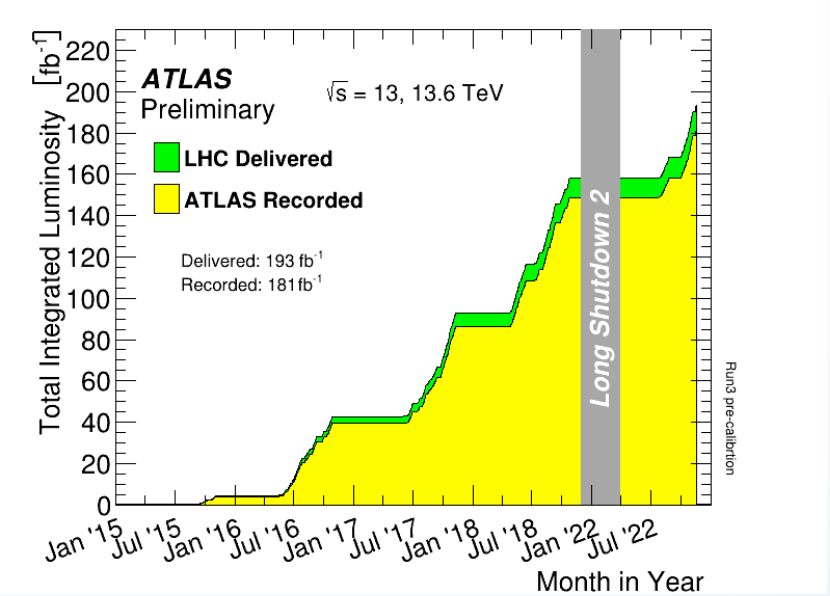


ATLAS in Run 1, 2 and 3

✓ Excellent performance of the LHC and in particular the ATLAS detector in Run 1 (2009-2012) and Run 2 (2015-2018)

✓ Run 3 already started (June 2022) and incredible amount of data collected





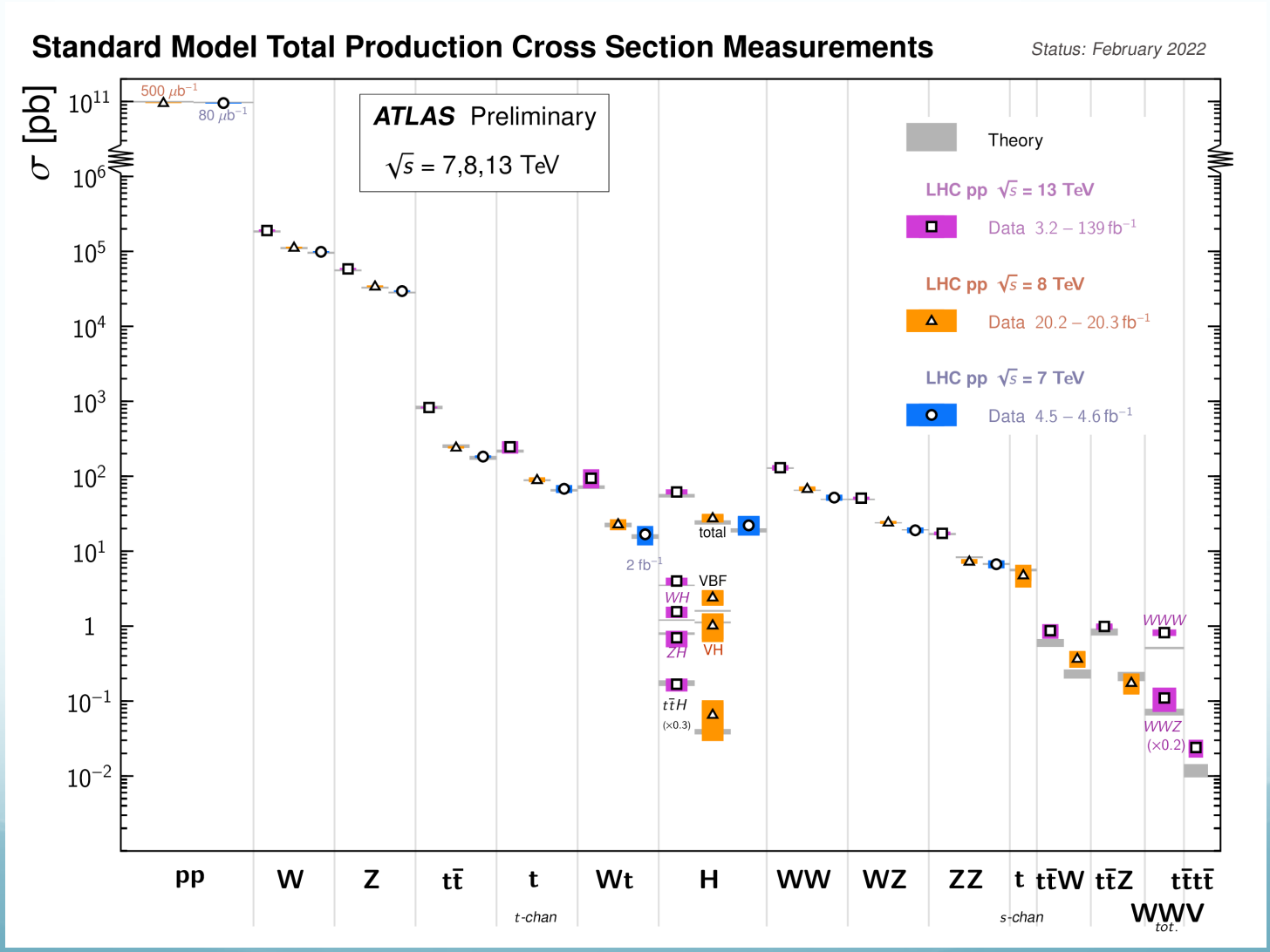
✓ More than 1 k results published in all these years.

Analysis	# papers
SM	215
Top + b-physics	187
Higgs	196
BSM	488
Heavy Ions	79

Standard Model results

Physics processes involving :

✓ W bosons, Z bosons, photons, jets and low energy QCD phenomena predicted and described within the SM.



Standard Model results

Elastic cross section measurement

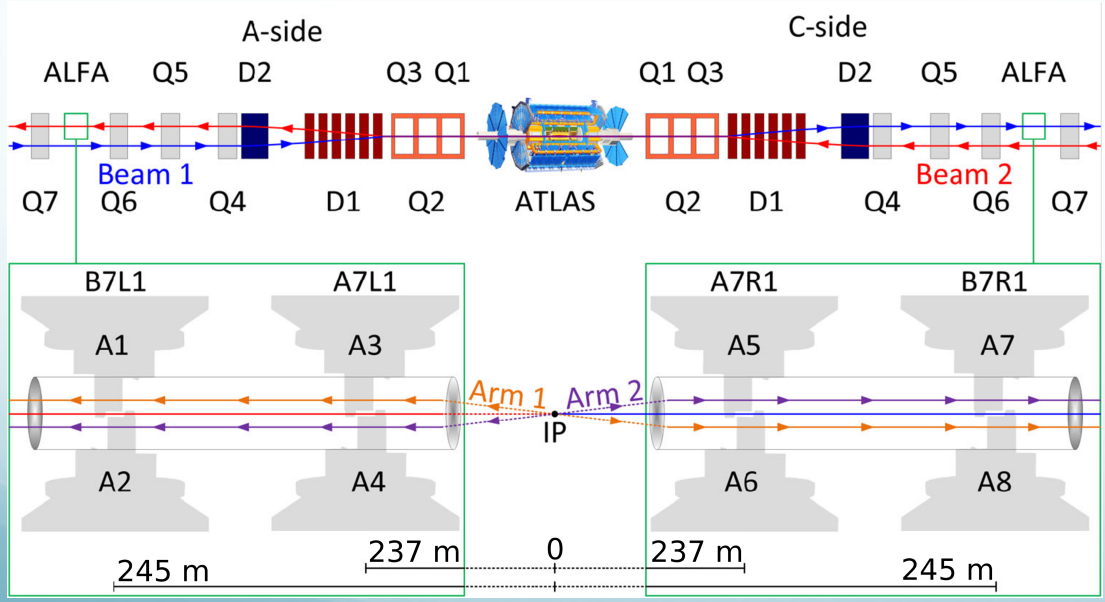
arXiv:2207.12246
Accepted by EPJC

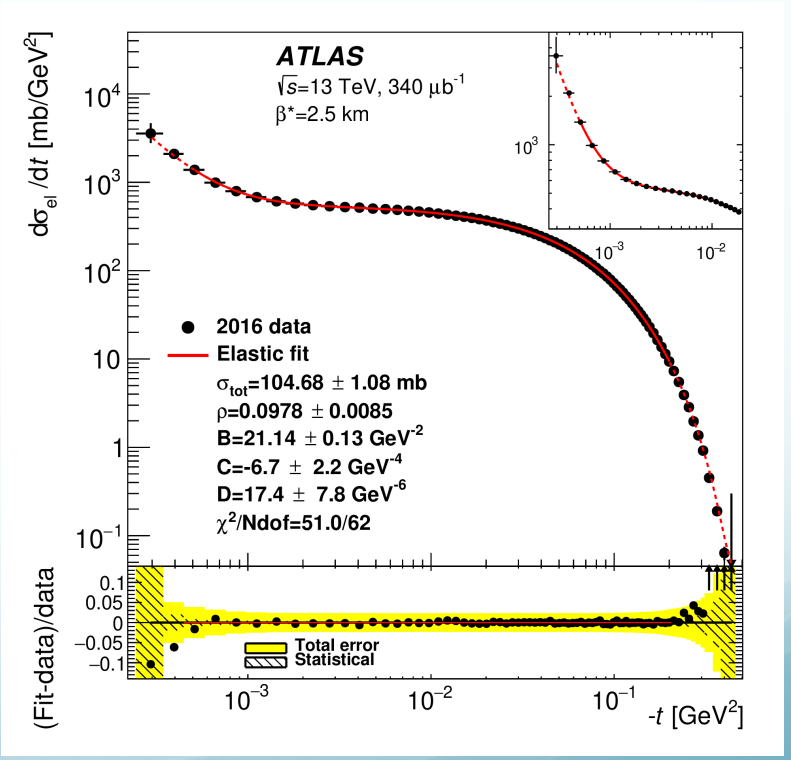
- Different kind of collisions, among them, protons bounce off each other and change their direction and momenta -> elastic scattering interactions

- proton proton elastic-scattering events recorded at $\sqrt{s} = 13\ TeV$ using the alpha sub detector of ATLAS.

- Special run with

  $\beta * = 2.5$ km





Standard Model results

arXiv:2207.12246
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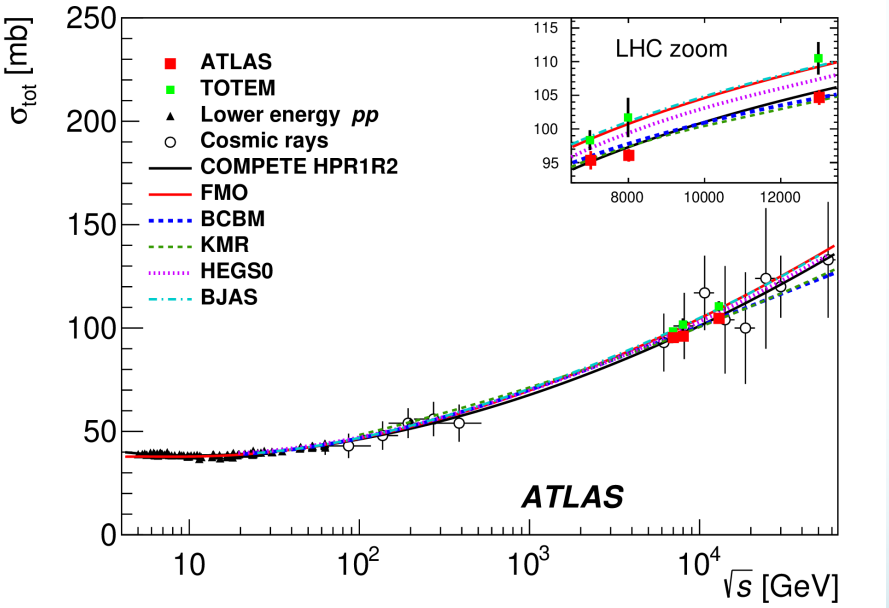
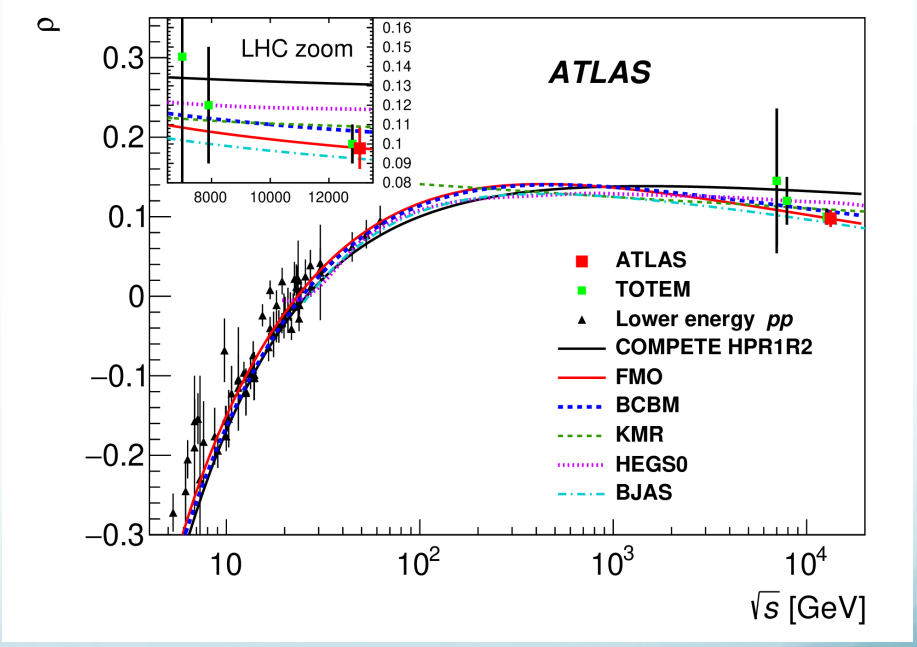
Elastic cross section measurement

- Total cross-section: 104.68±108 mb
- $\rho = 0.0975 \pm 0.0106$ (real and imaginary part of the elastic amplitud for t->0)





Standard Model results: WZ polarization

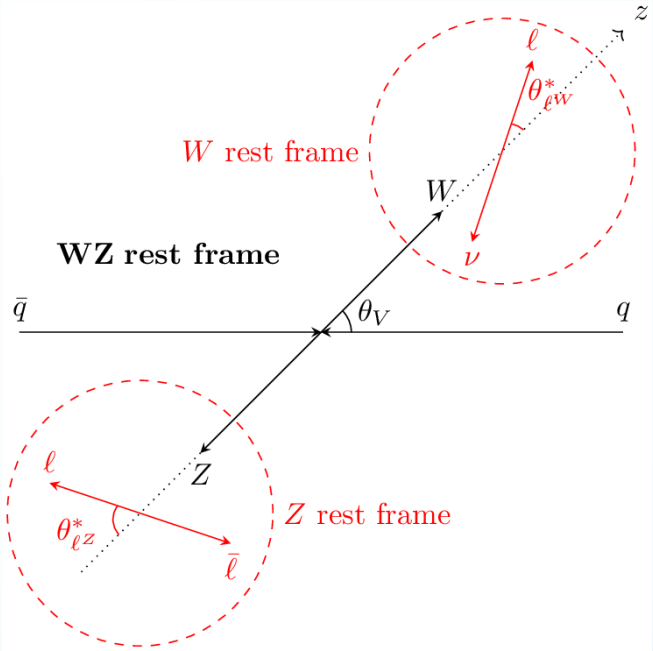
New

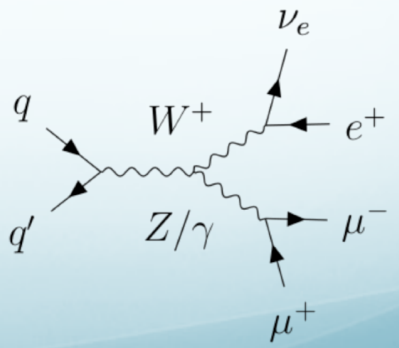
arXiv:2211.09435

Submitted to PLB

Observation of joint polarization states in WZ bosons production

- ✓ The W and Z bosons have a spin of 1 and can be longitudinally polarized as a direct consequence of their being massive -> their spin is oriented perpendicular to their direction of motion.
- ✓ ATLAS has been able to observe events with both a W and Z boson simultaneously polarised longitudinally for the very first time.
- ✓ Data set used corresponds to an integrated luminosity of 139 fb^{-1} of proton-proton collisions at $\sqrt{s} = 13$ TeV.
- ✓ $W^{\pm}Z$ candidate events are reconstructed using leptonic decay modes of the gauge bosons into electrons and muons.
- ✓ Measuarement of the fraction of such events with a longitudinal-longitudinal (f_{00}) joint-polarisation along with the longitudinal-transverse (f_{0T}), transverse-longitudinal (f_{T0}) and transverse-transverse (f_{TT}) joint-polarisations.





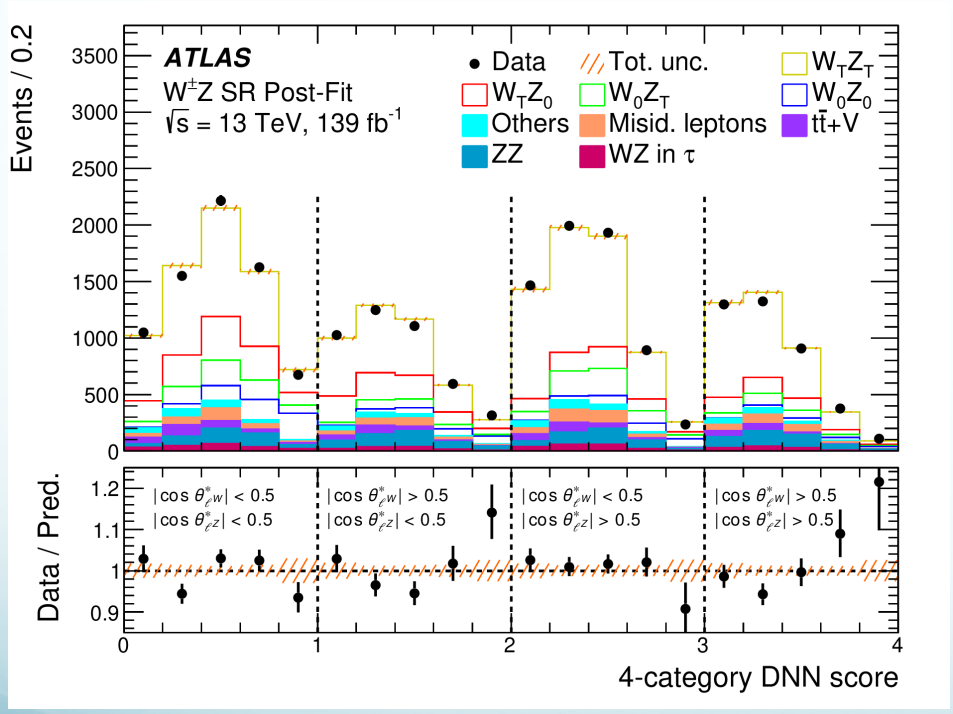
Standard Model results: WZ polarization

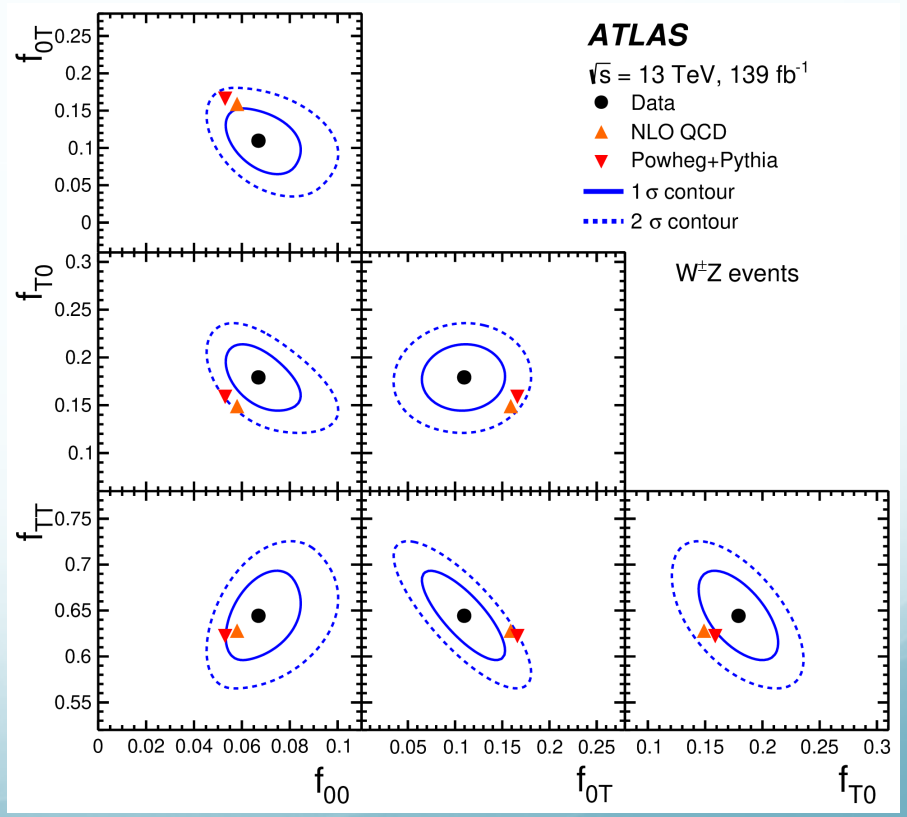
New
arXiv:2211.09435
Submitted to PLB

Observation of joint polarization states in WZ bosons production

- ✓ First observation with a significance of 7.1 σ
- ✓ Measured joint helicity fractions in agreement with NLO SM predictions.

$$f_{00} = 0.067 \pm 0.010,\ f_{0T} = 0.110 \pm 0.029,\ f_{T0} = 0.179 \pm 0.023,\ f_{TT} = 0.644 \pm 0.032$$





A multivariate discriminant is used to better separate the four joint helicity states. A deep neural network (DNN) classifier is implemented to exploit kinematic differences between polarisation states in different observables

Top quark results

✓ Motivations for detailed studies of the top quark are numerous:

- Within the SM an accurate measurement of the top quark mass helps to constrain the mass of the SM Higgs boson.
- Measurements of the total and differential cross-section for top pair production are sensitive to physics beyond the SM. Studying the top quark properties (decays and couplings) would probe the existence of physics beyond the SM.
- Detailed studies of single top production mechanisms should be possible since more than 2 million single top events every year are expected, even during the low luminosity phase.
- Enormous cross-section for top quark pair production -> top events will be one of the main tools for the commissioning and calibration of the ATLAS detector, e.g. b-tagging calibration, determination of jet energy scale..etc.

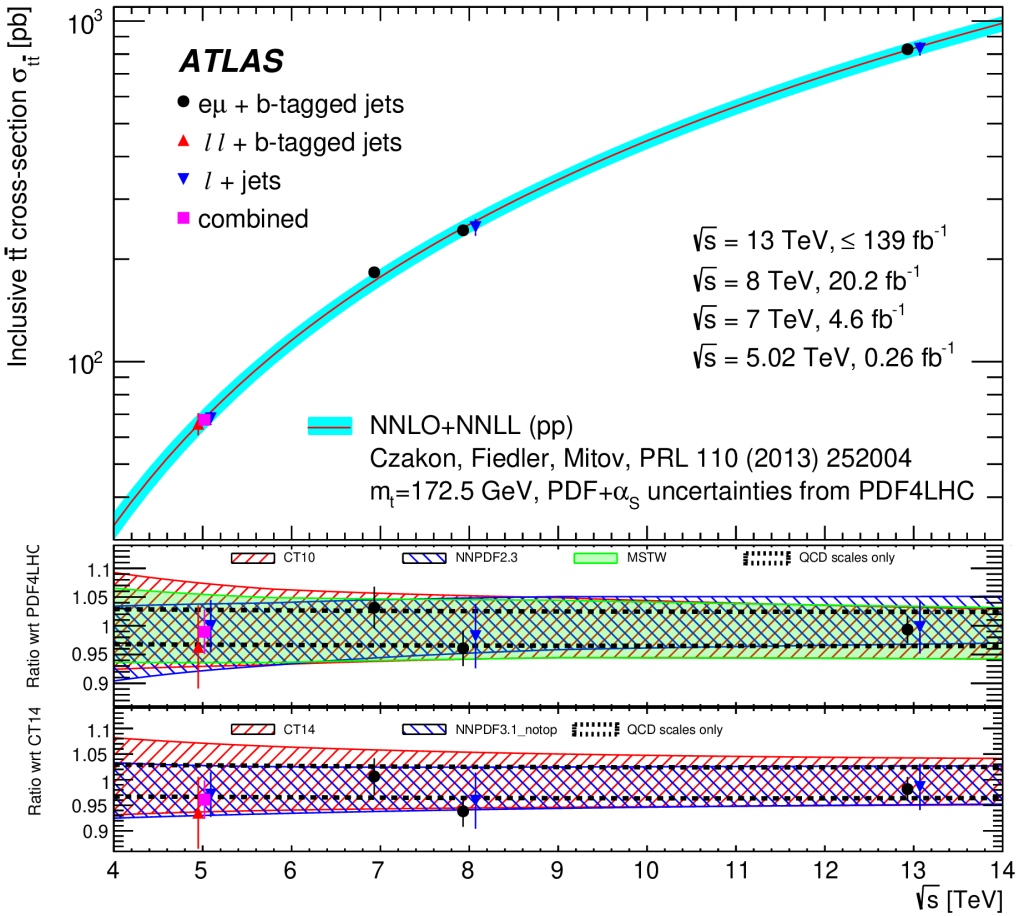
Top Quark results: inclusive cross-section

arXiv:220701354, Accepted by JHEP

Inclusive top quark cross-section

$$\sigma_{t\bar{t}} = 67.5 \pm 0.9(stat) \pm 2.3(syst) \pm 1.1(lumi) \pm 0.2(beam)pb$$

- ✓ Measurement of the inclusive top quark pair production cross-section with pp collisions at $\sqrt{s} = 5.02$ TeV
- ✓ $t\bar{t}$ XS measured in both channels dilepton and single-lepton final states and then combined:
- ✓ Total uncertainty of about 4%
- ✓ Result in agreement with theoretical calculations at NNLO in α_s

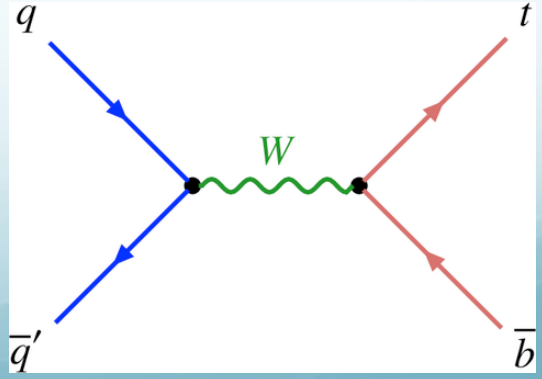


Top quark results: single-top

arXiv:220908990, Submitted to JHEP

Single top production

- ✓ In proton-proton collisions, top quarks are produced predominantly in pairs via the strong interaction, but also singly via the electroweak interaction through a Wtb vertex.
- ✓ Single top-quark production is therefore a powerful probe for the top quark electroweak couplings.
- ✓ In the SM -> three different production mechanisms possible at LO: an exchange of a virtual W boson either in the t-channel or in the s-channel, or the associated production of a top quark and a W boson (tW)
- ✓ Measurement of the single top quark production in the s-channel at $\sqrt{s} =$ 13 TeV and with a luminosity of 139 fb^{-1}.

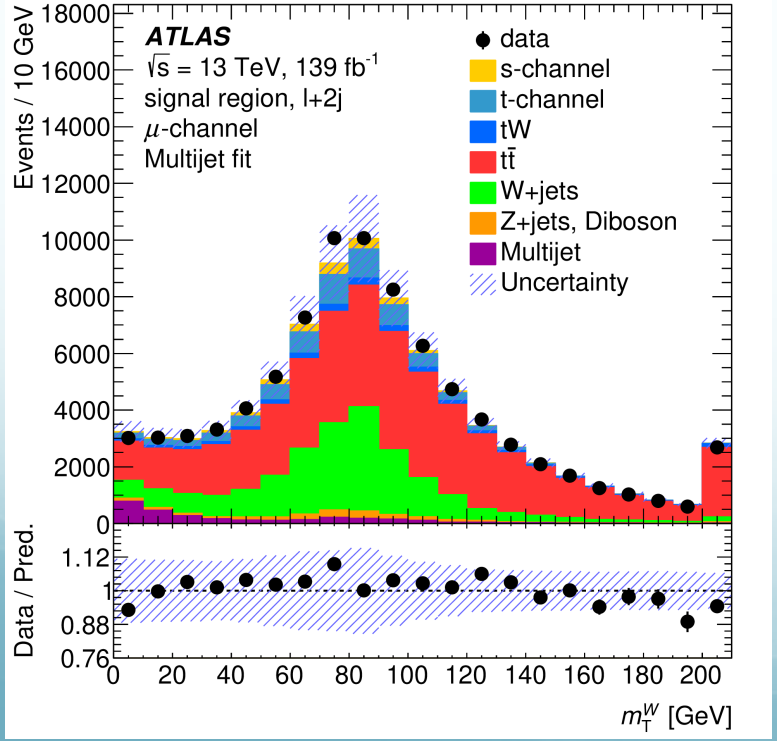


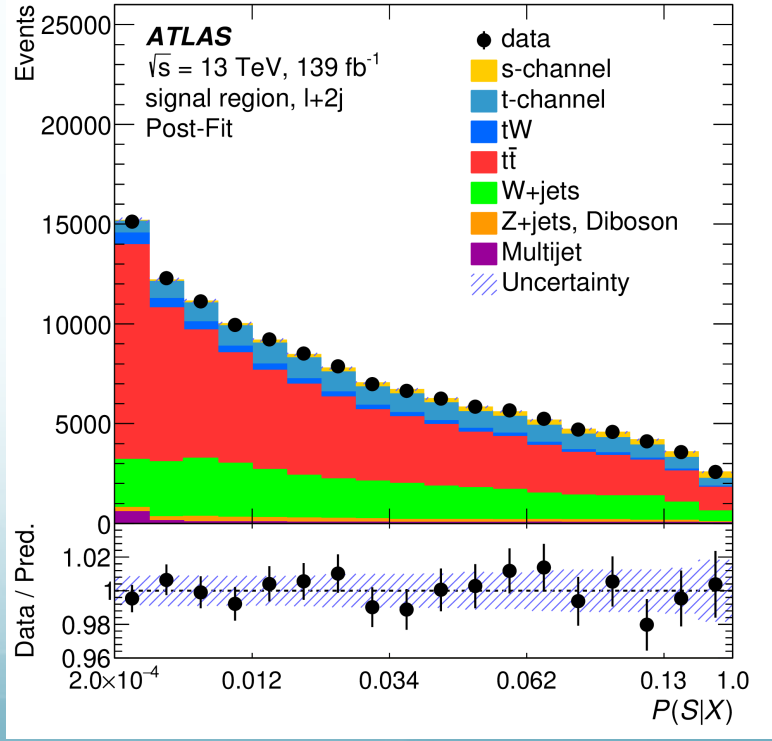
Top quark results: single-top

arXiv:220908990, Submitted to JHEP

Single top production

- ✓ Top quark decays almost exclusively into a W boson and a b-quark
- ✓ Leptonic decay of W and some events where the W decays into τ-leptons (decaying in b-jets)
- ✓ Matrix Element Method (MEM) used to discriminate signal from background.
- ✓ Measured cross-section: $\sigma = 8.2^{+3.5}_{-2.9}$ pb consistent with SM prediction.





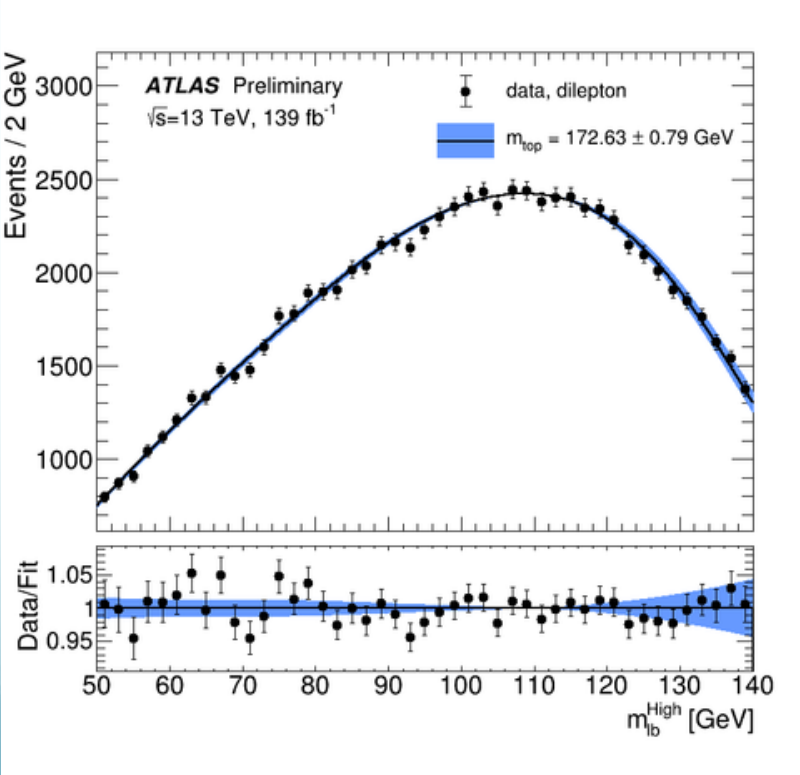
Top quark results: top mass

ATLAS-CONF-2022-058,

Top quark mass

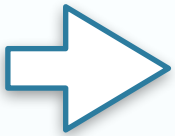
- ✓ Top quark mass measurement using the full Run 2 dataset (139 fb^{-1}), in the dilepton channel.
- ✓ The top-quark mass is extracted from the observed invariant mass distribution of the pair of a charged lepton and a b-tagged jet with the largest transverse momentum.

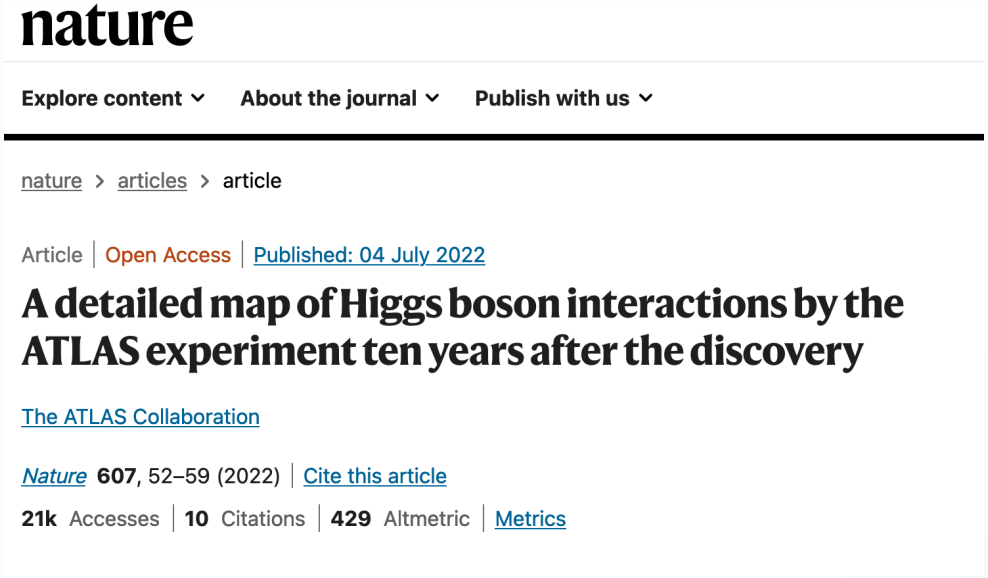
$$m_{top}^{dil} = 172.63 \pm 0.20(stat) \pm 0.67(syst) \pm 0.37(recoil)\ \text{GeV}$$



Higgs measurements: 10 years of the Higgs Boson

✓ Ten years since ATLAS and CMS discovered the Higgs Boson!





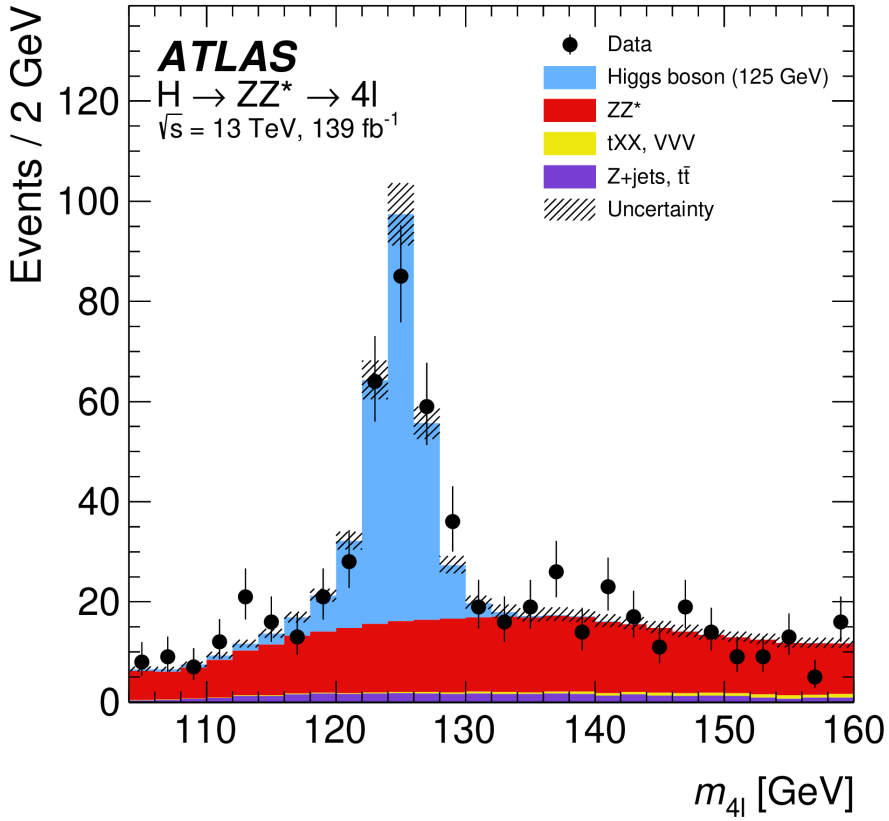
CERN event

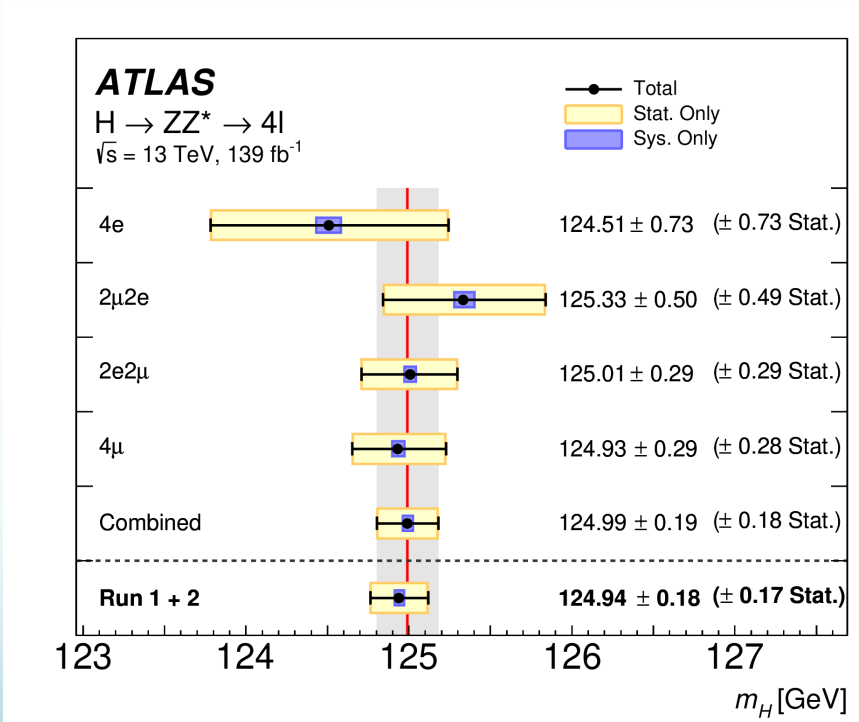
Photo Credit: C. Sandoval

Higgs measurements: $H \rightarrow ZZ^* \rightarrow 4l$

- ✓ Measurement of the Higgs Boson mass in $H \rightarrow ZZ^* \rightarrow 4l$ decay channel
- ✓ Data recorded during Run 2: 139 fb^{-1}.
- ✓ $m_H = 124.99 \pm 0.18(stat) \pm 0.04(sys)$ GeV

arXiv:2207.00320, Submitted to PLB

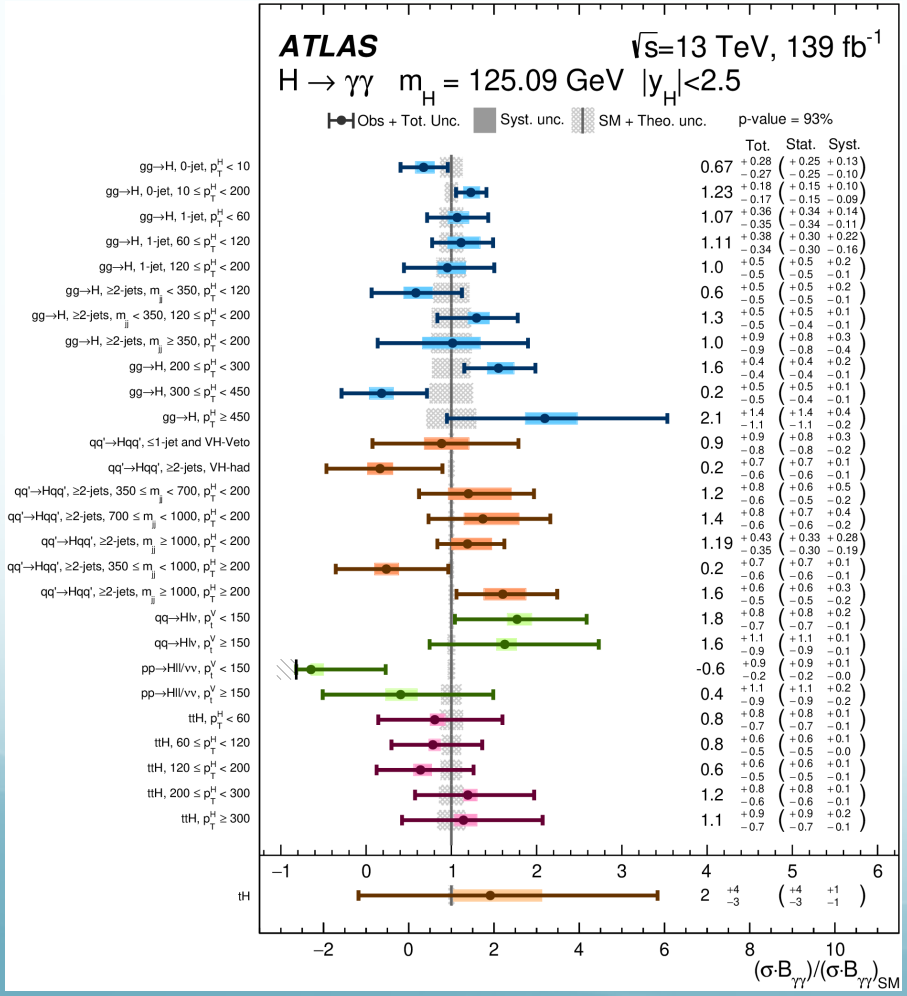


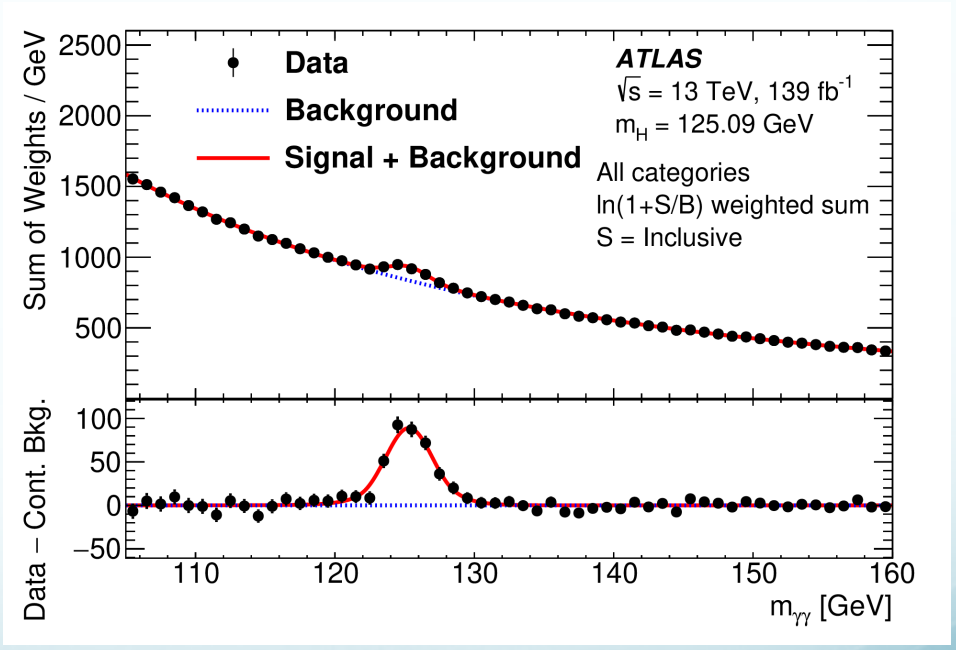


Higgs measurements: $H \to \gamma\gamma$

- ✓ Measurement of the Higgs Boson mass in $H \to \gamma\gamma$ decay channel
- ✓ Data recorded during Run 2: 139 fb^{-1}.
- ✓ Different production modes considered.

arXiv:2207.00348, Submitted to JHEP

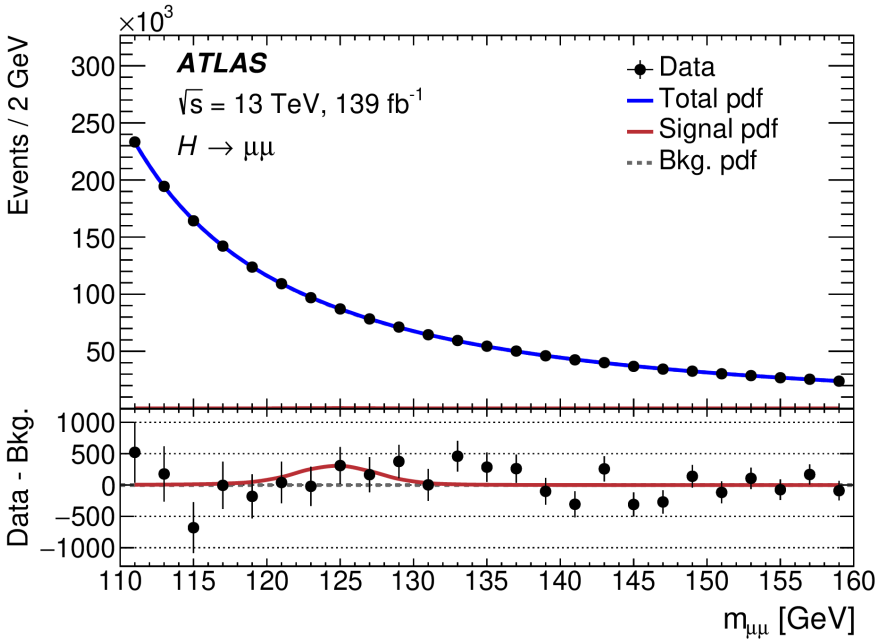


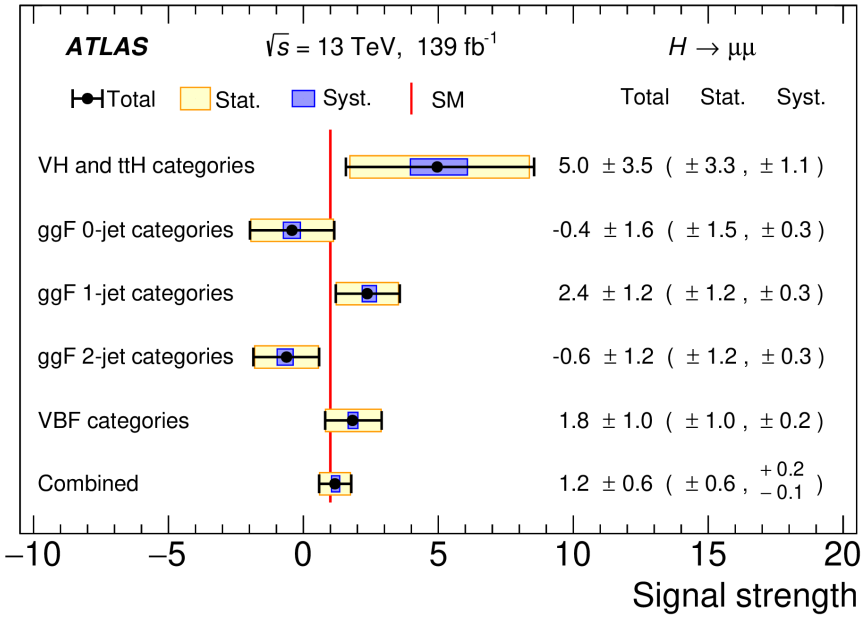


Higgs measurements: $H \to \mu\mu$

- ✓ Search for the rare $H \to \mu\mu$ decay channel.
- ✓ Data recorded during Run 2: 139 fb^{-1}.
- ✓ Search for a bump.
- ✓ Events classified in 20 different mutually exclusive categories.
- ✓ Background dominated by DY process.

[Phys. Lett. B 812 (2021) 135980]

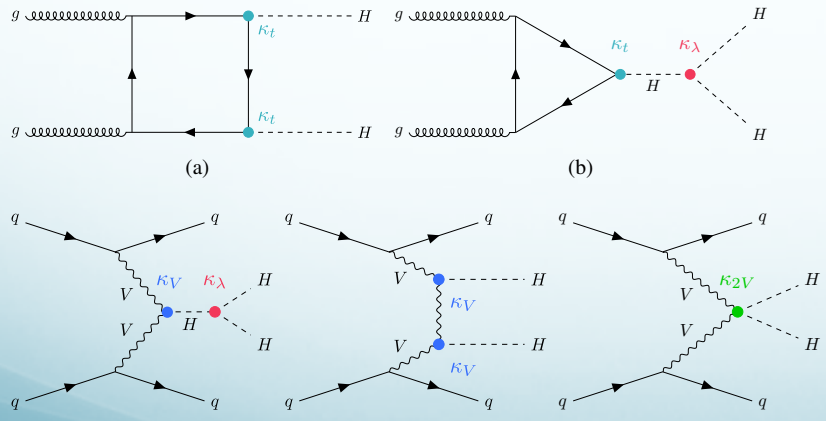


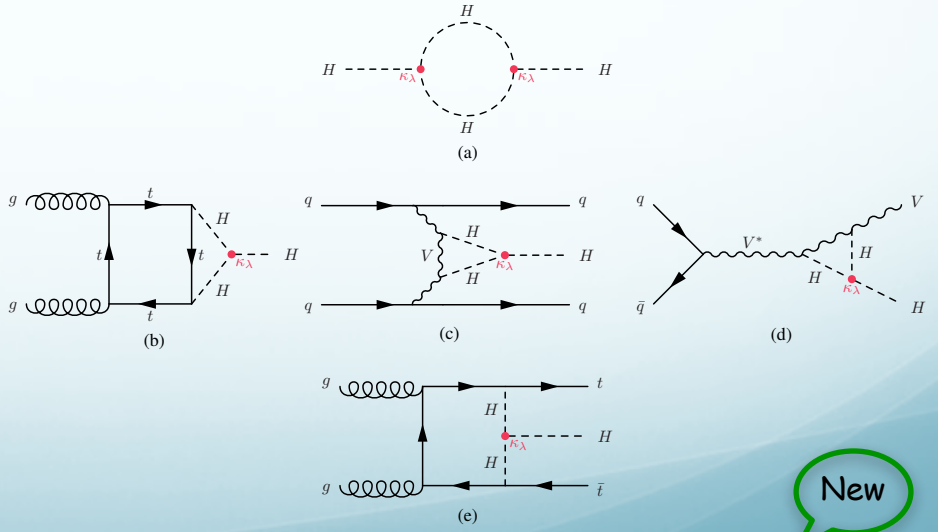


Best-fit values of the signal strength parameters for the five major groups of categories

Higgs measurements: self-interaction

- ✓ One of the most intriguing and interesting characteristics of the SM is that the gauge EW symmetry is broken spontaneously by the non-trivial structure of H potential, related to its self-interaction.
- ✓ H self-interactions are characterized by the trilinear self-coupling λ_{HHH}
- ✓ At the LHC -> the self-interaction is accessible via the production of HH.
- ✓ Measurement combined 3 most sensitive decay channels of HH for constraining the HH xs and Higgs self-coupling.
- ✓ Results in terms of the coupling modifier $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM}$



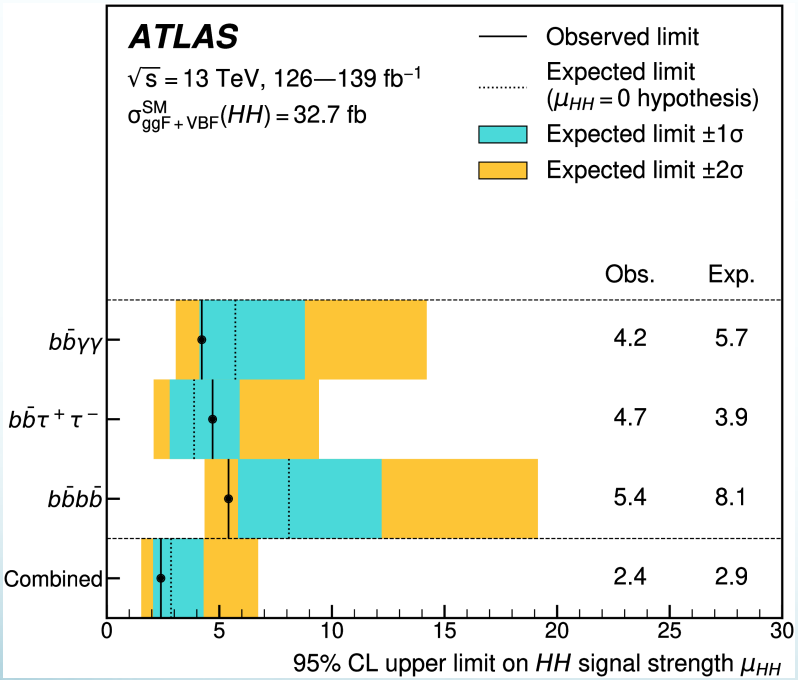


New

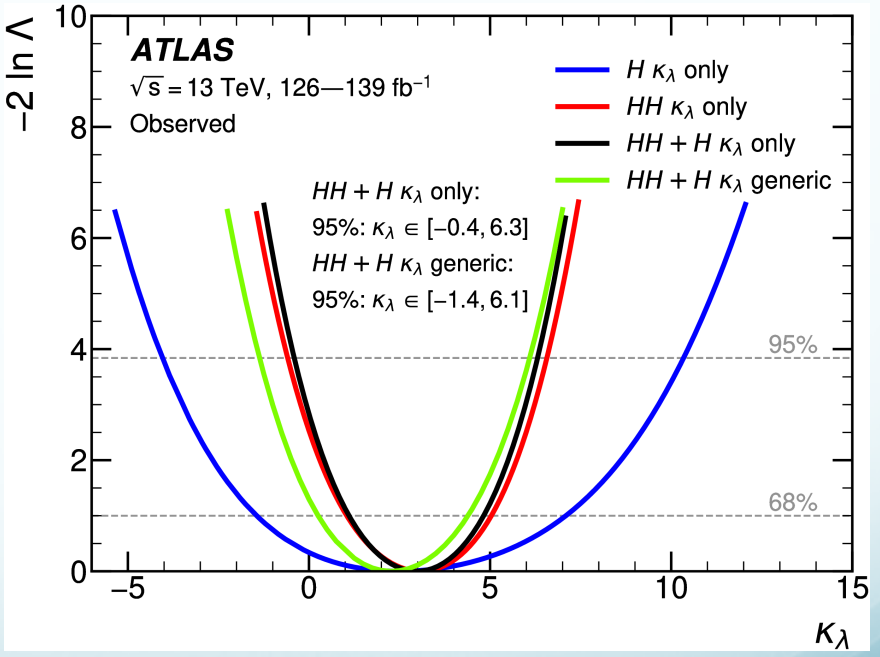
arXiv:2211.01216
Submitted to PLB

Higgs measurements: self-interaction

- ✓ Double H combination results
- ✓ Determination of the signal strength μ_{HH} including only the ggF and VBF HH processes.



- ✓ Single and double H combination results
- ✓ Double-H and single-H analyses are combined to derive constraints on κ_λ
- ✓ Observed values of the test statistic as a function of κ_λ



New

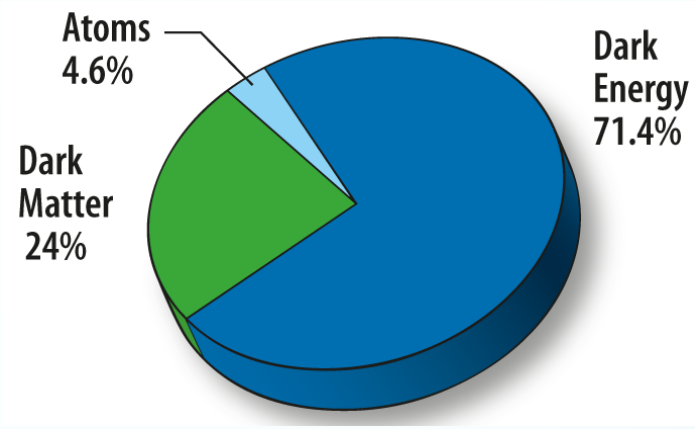
arXiv:2211.01216

Submitted to PLB

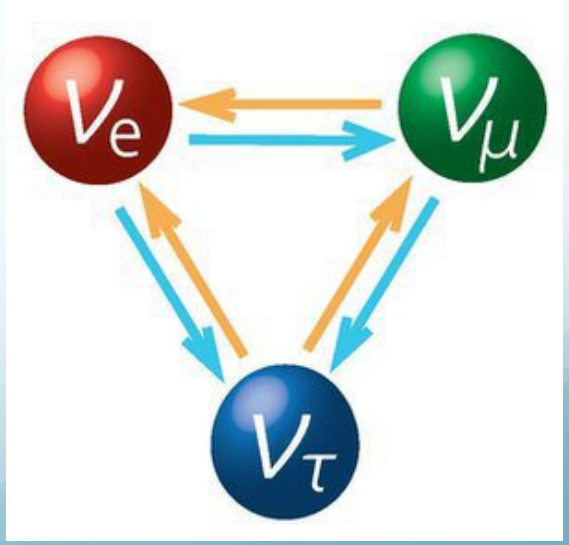
Beyond Standard Model

Standard Model: provides a very successful description of some known phenomena.
But there exist some unsolved questions:

- Presence of dark matter (DM)



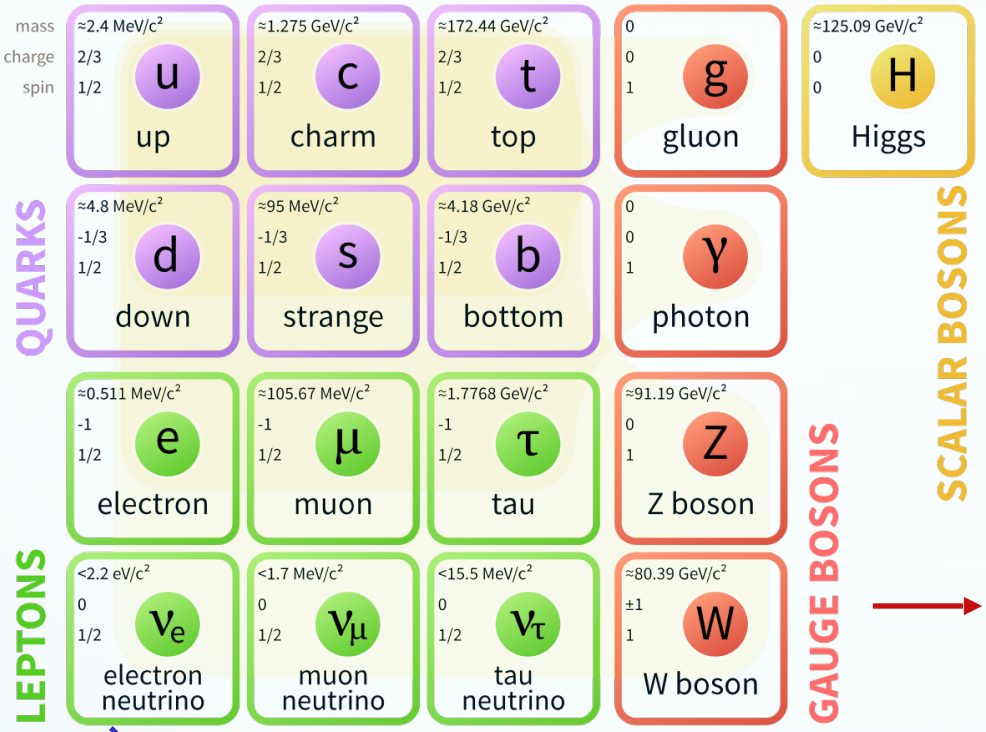
- Neutrino's oscillations.



- It doesn't include a description of gravity.

- ...

Beyond Standard Model results

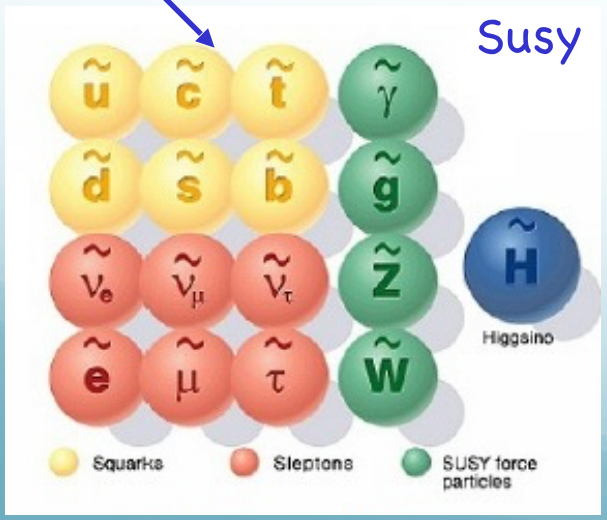


→ Non-minimal Higgs sector
Invisible decays
Higgs as DM portal
Extended models: 2HDM, MSSM …
Charged scalars …

→ "Exótics" signals: large variety of models and theories.

- Heavy vector Bosons (Z', W')
- Vector-like quarks, excited quarks
- No SUSY DM models
- Lepto-quarks
- …

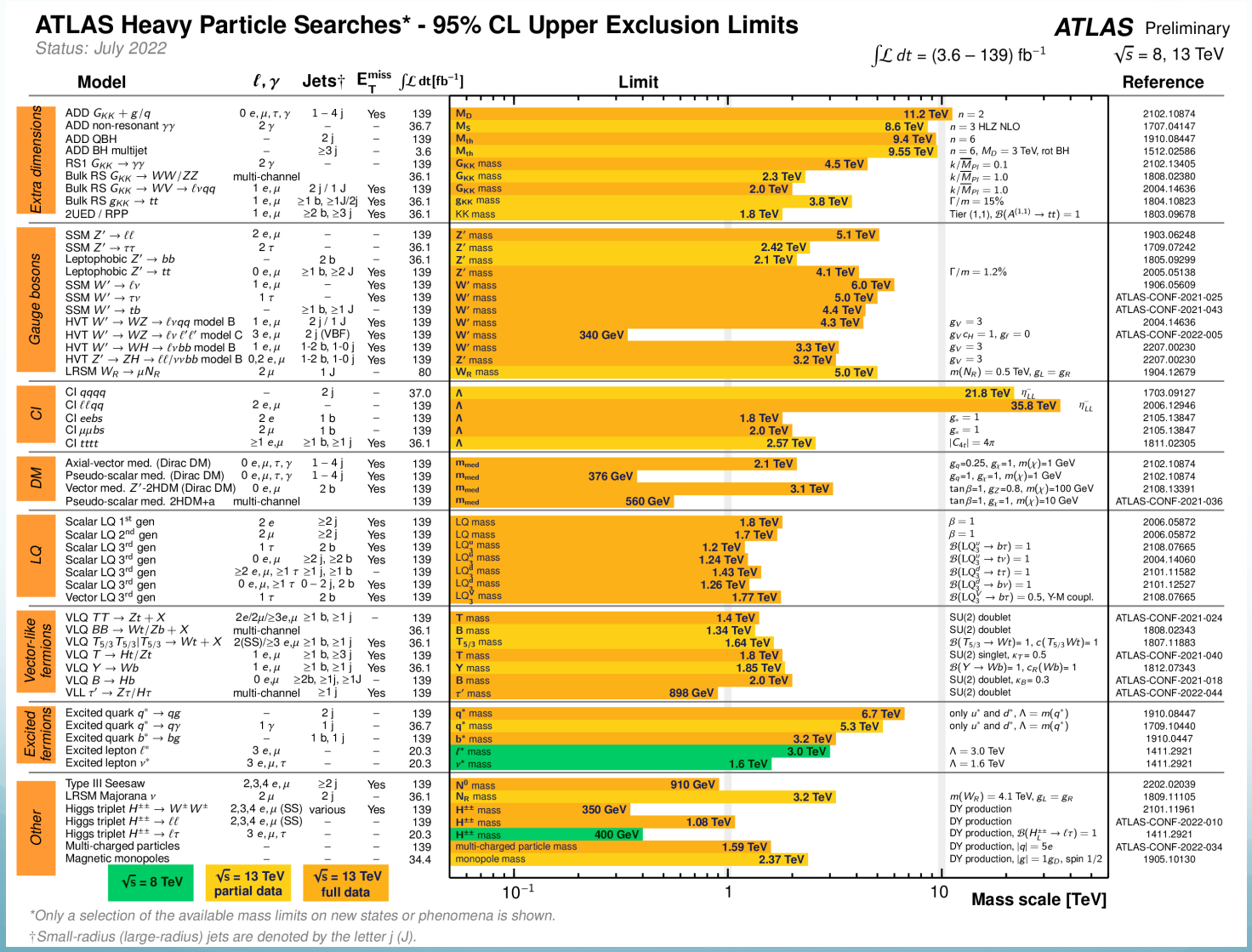
Susy



- Introduce new particles superpartners of the SM ones.
- Provides a candidate for DM.
- Unifies the interactions at a heavy scale (10^{16} GeV)

Exotic searches: Resonances

✓ Search for heavy resonances is an important part of the physics program at the Large Hadron Collider (LHC) -> focus of an intense effort to uncover physics beyond the Standard Model (SM)

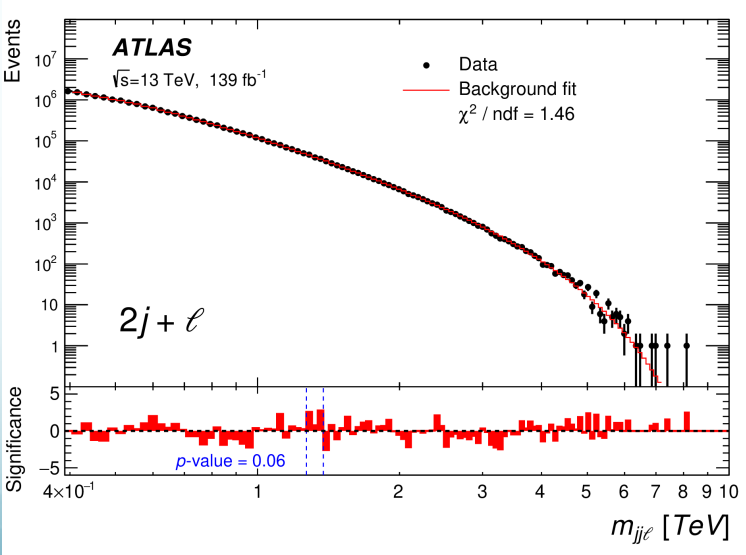


No significant excess has been observed to date.

Strong constraints have been placed on the production of such new heavy particles.

Exotic searches: Resonances

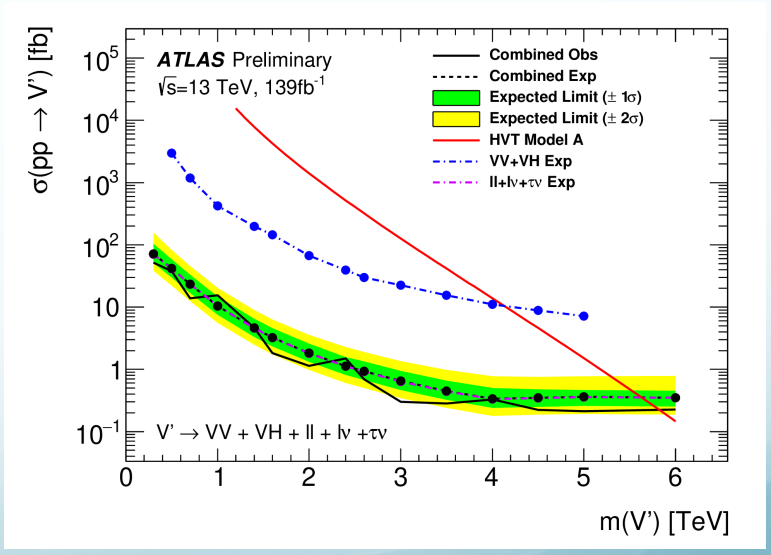
- ✓ Search for resonances in dijet invariant mass distributions provide a means to investigate a wide range of BSM theories.
- ✓ Sensitive to heavy particles that decay into two partons (quarks or gluons) which, following hadronisation, form jets.
- ✓ A search for resonances in events with at least one isolated lepton (e or μ) and two jets -> 139 fb^{-1} Run 2 dataset.



Combination of searches

- ✓ Strategy:
  - consider orthogonal ATLAS analyses which are independently searching for specific final states of new physics.
  - combine them together in a statistical interpretation.

- ✓ 95% CL upper observed and expected limits on the V' XS versus pole mass assuming HVT-A



arXiv:2211.08945
Submitted to JHEP

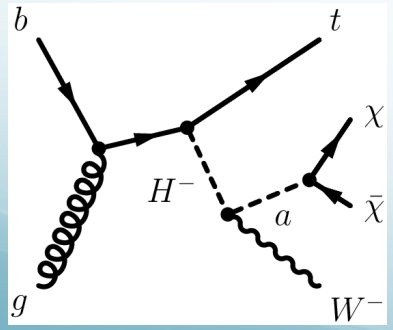
New

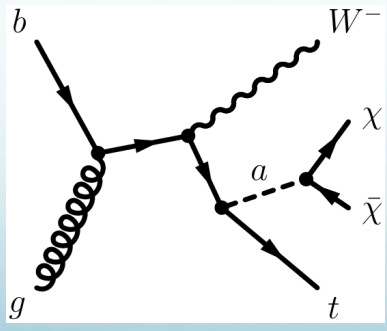
ATLAS-CONF-2022-028

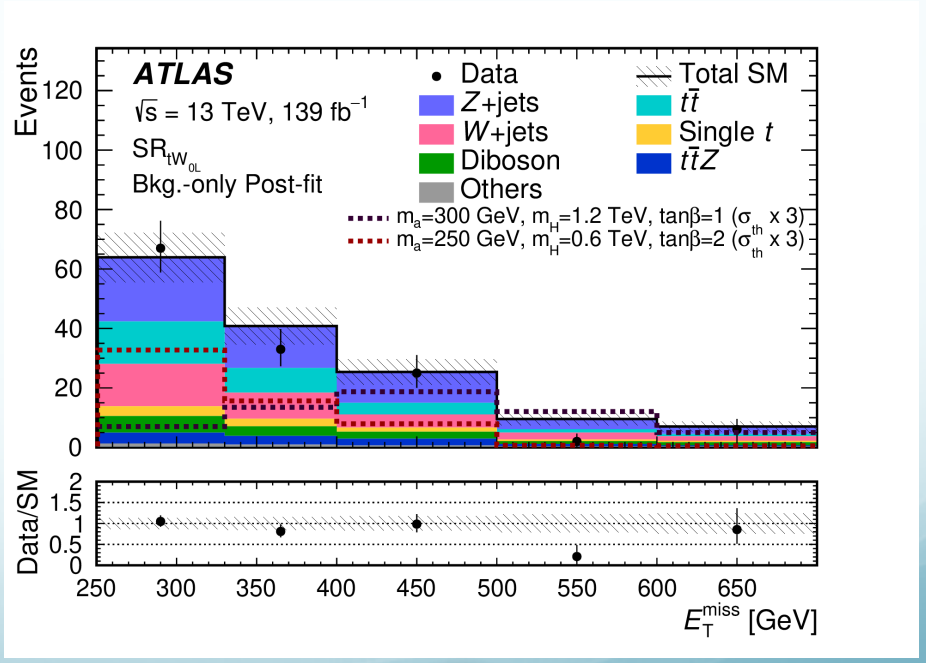
DM searches

- ✓ Several extensions of the SM postulate a DM candidate χ that is a stable, electrically neutral, and weakly interacting massive particle (WIMP).
- ✓ WIMPs can potentially be produced in high-energy collisions at LHC.
- ✓ A wide class of DM models probed at the LHC postulate processes where one or more SM particles X are produced recoiling against DM particles, resulting in an '$X + E_T^{MISS}$' signature.
- ✓ Searches at the LHC have considered X to be a hadronic jet, top or bottom quarks, a photon, a W or Z boson, or a Higgs boson.

- Search for dark matter, χ using events with a single top quark and an energetic W boson
- Final states with zero or one charged lepton (electron or muon), at least one b-jet and large missing transverse momentum.







arXiv:2211.13138
Submitted to EPJC

New

SUSY searches

Searches for SUSY particles in different scenarios:

✓**Inclusive production of squarks and gluinos:**

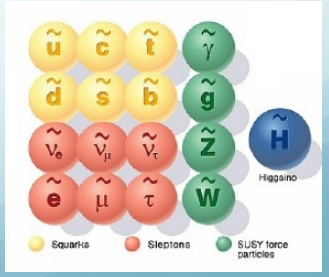
Searches for all strongly produced R-parity conserving SUSY.

✓**Electroweak production of sparticles**

Searches for direct pair production of sleptons of the 1st, 2nd and 3rd generation (staus), as well as charginos and/or neutralinos, considering all possible R-parity conserving decays.

✓**RPV and long-lived signatures**

Searches for signatures with R parity violation

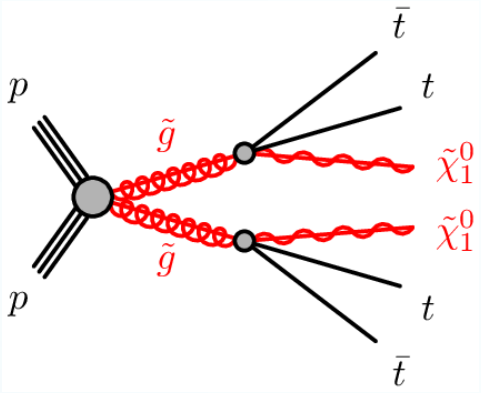


SUSY searches

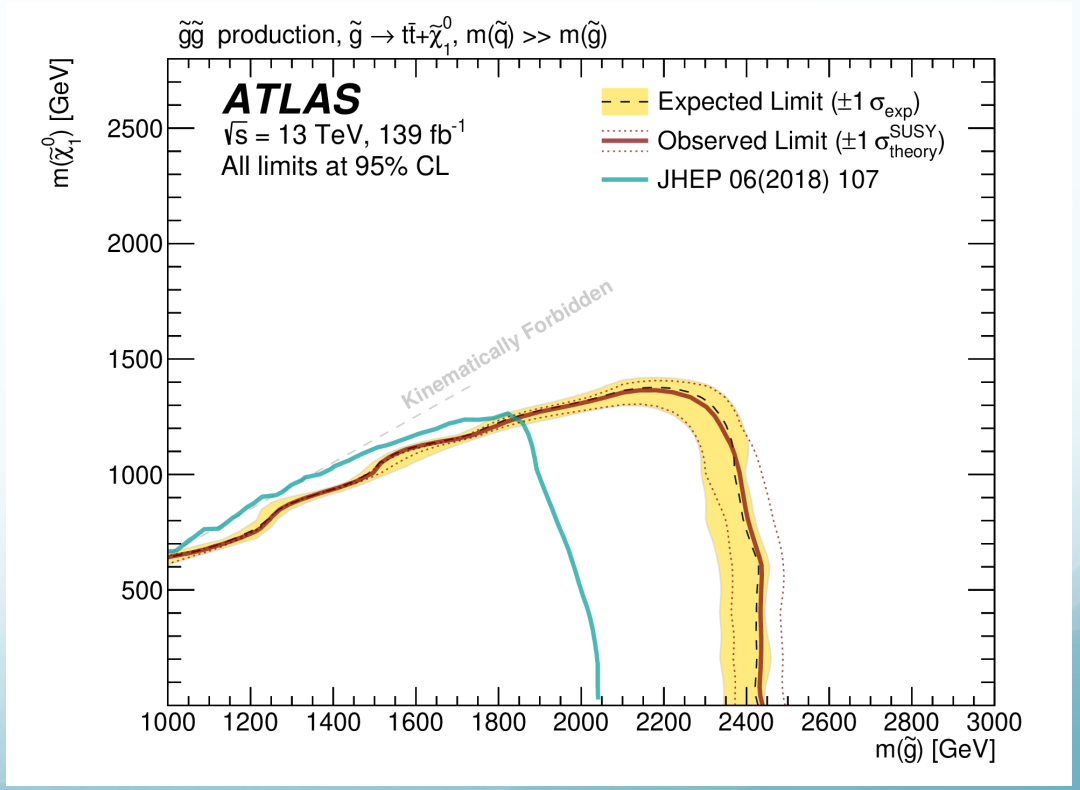
- ✓ Search for SUSY in final status with E_{MISS}^{T} and b-jets.
- ✓ Involve pair production of gluinos decaying into the lightest $\tilde{\chi}_1^0$

New

arXiv:2211.0828
Submitted to EPJC



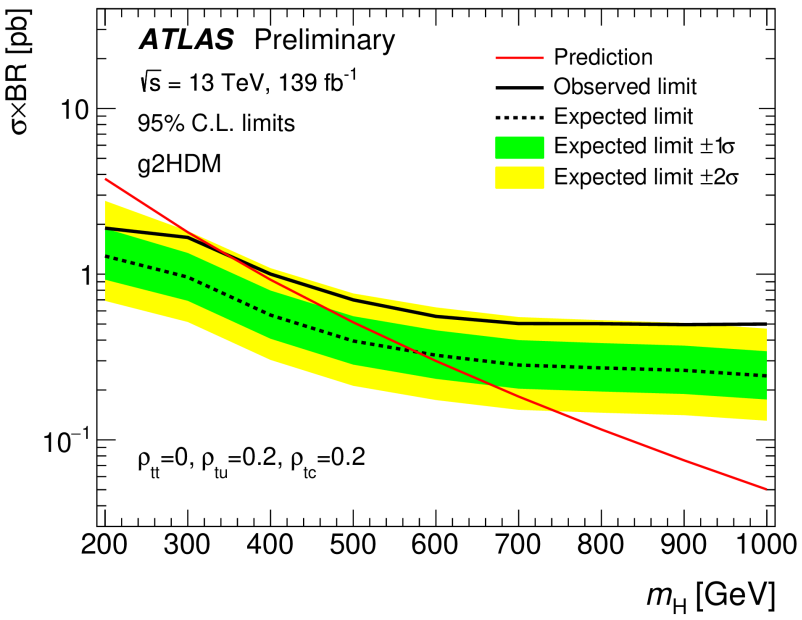
- ✓ **No significant excess from SM expectations.**
- ✓ 95% CL observed and expected exclusion limits for the Gtt for the NN analysis.
- ✓ Most stringent exclusion limits on the neutralino mass is approximately 1.35 TeV obtained for a gluino mass of approximately 2.20 TeV



Searches for extended Higgs sector

- ✓ Several extensions of the Standard Model propose the augmentation of the Higgs sector by the addition of a second complex Higgs doublet (2HDM)
- ✓ Five Higgs bosons:
  - two CP-even scalar fields h and H,
  - one CP-odd pseudo-scalar A,
  - two charged fields $H^{\pm}$
- ✓ Search for new heavy scalars with flavour-violating decays in final states with multiple leptons and b-tagged jets.

Observed and expected exclusion limits at 95% confidence level on the heavy Higgs boson mass for the g2HDM signal model

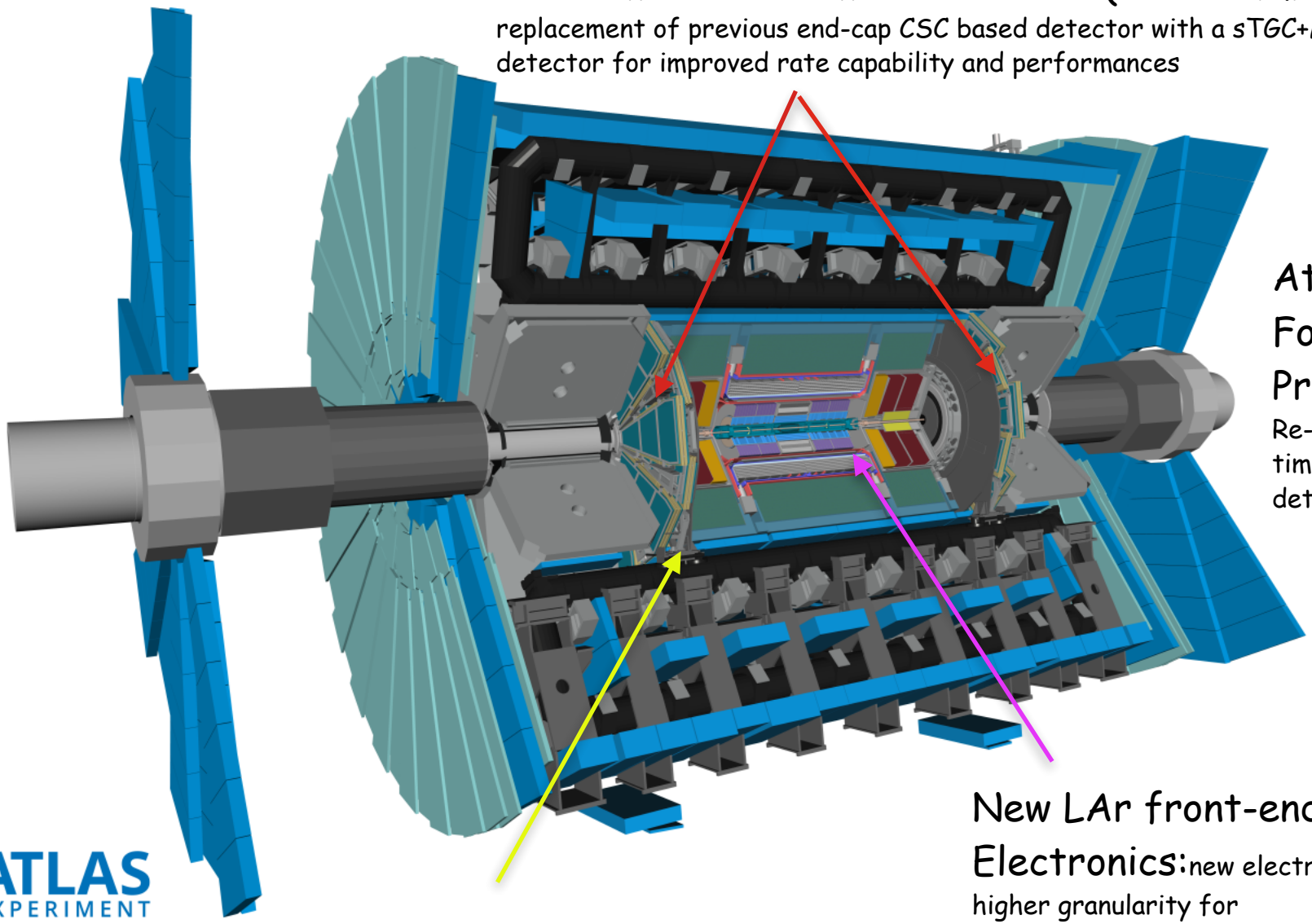


ATLAS-CONF-2022-039

Run 3: ATLAS upgrades

New Small Wheel muon detector (sTGC + MM):

replacement of previous end-cap CSC based detector with a sTGC+MicroMega detector for improved rate capability and performances



Atlas Forward Proton:

Re-design of time-of-flight detector

New LAr front-end Electronics:

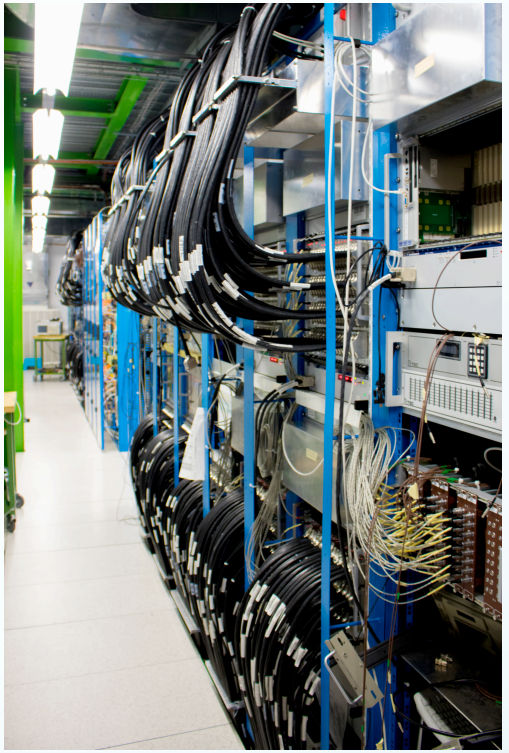
new electronics with higher granularity for improved performances of the detector and of the Level-1 Calorimeter electromagnetic trigger.

New RPC muon detectors in the BIS78 region

new RPCs in the barrel to improve the rejection rate of theL1 trigger in the barrel-endcap transition region

Run 3: ATLAS upgrades

Upgrades in the TDAQ off-detector electronics:



- Level-1 hardware trigger: new L1 electronics for calorimeter, topological, NSW, end-cap, MuCTPi

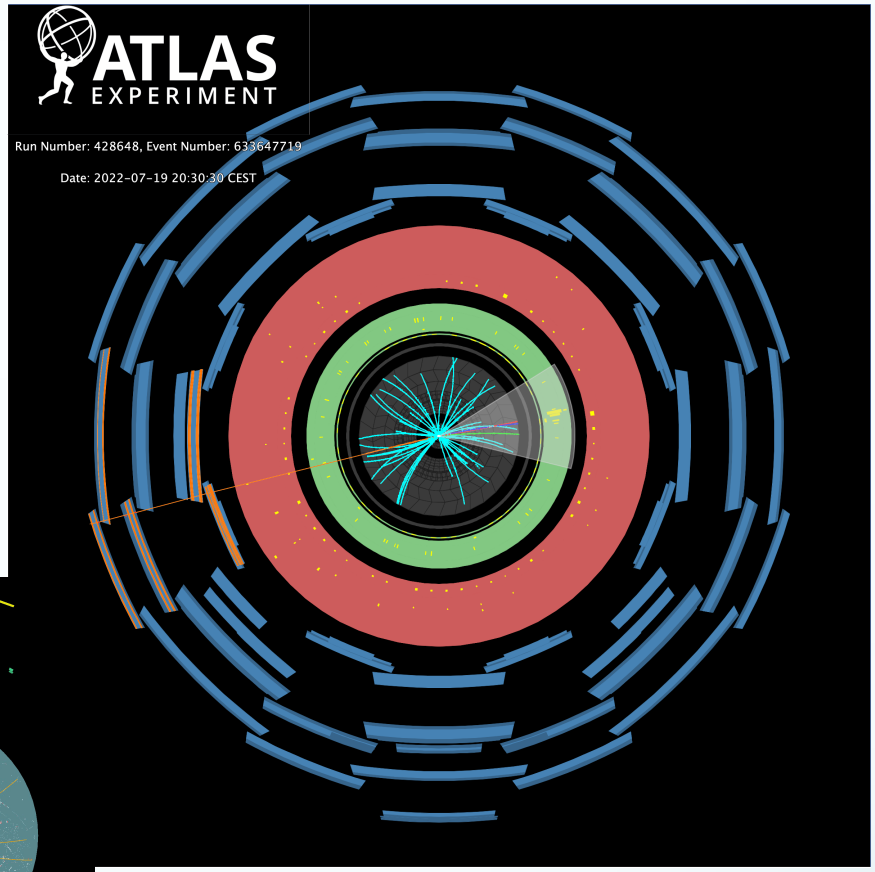
- Readout: new FELIX system for NSW, BIS78, LAr, L1Calo. Hardware data router between front-end and commodity network connected to SW-RODs, DCS, TTC, busy

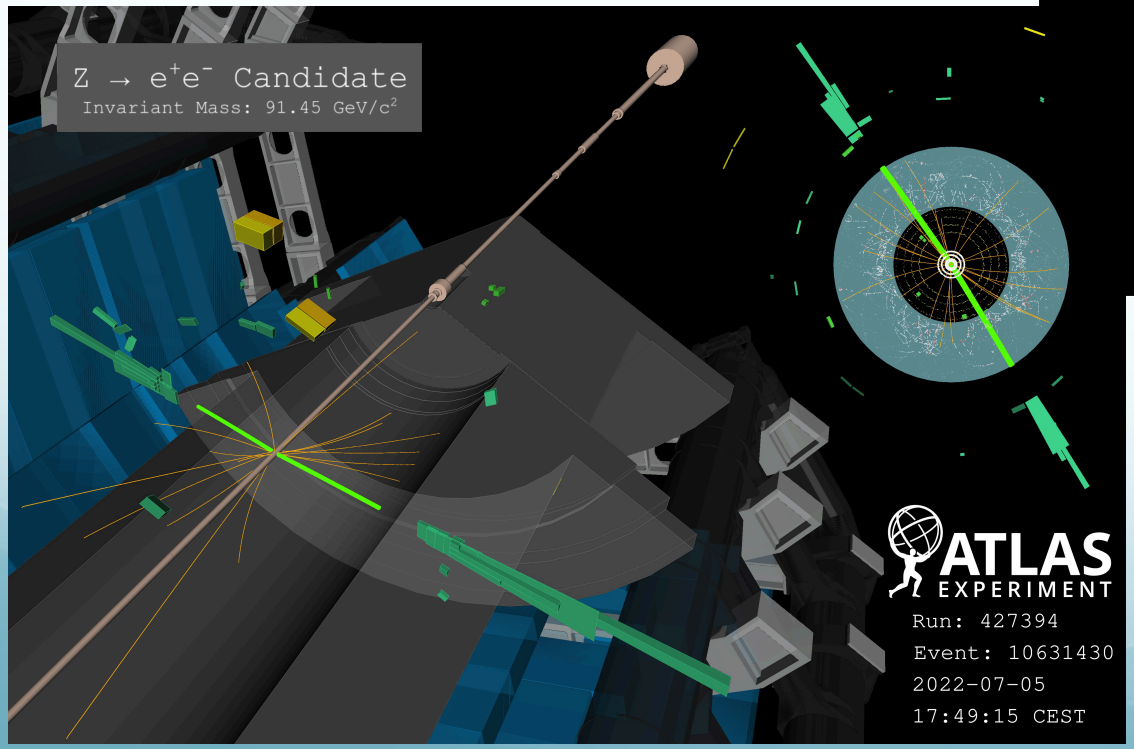
- High Level Trigger: new processor cluster, improved off-line algorithms and track reconstruction, 1.5 kHz output rate

Run 3: 13.6 TeV collisions

Event displays

Z->tautau candidate in a final state with a muon and the visible products of a hadronically-decaying tau lepton

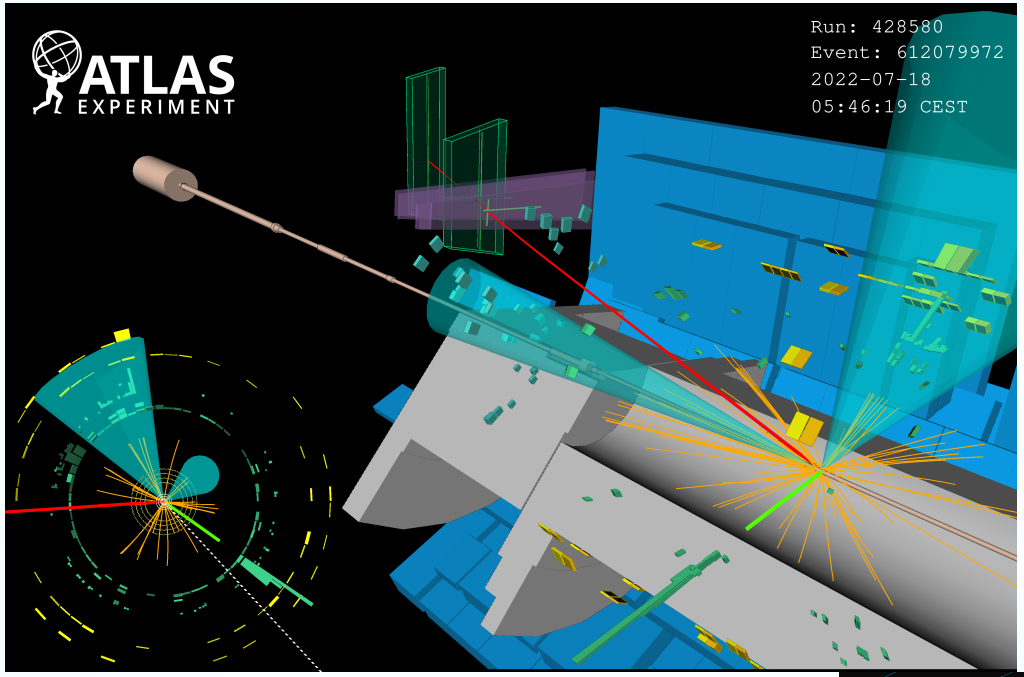




Z to e+ e- candidate recorded in ATLAS on 5 July 2022, when stable beams of protons at the energy of 6.8 TeV per beam were delivered to ATLAS for the first time by the LHC

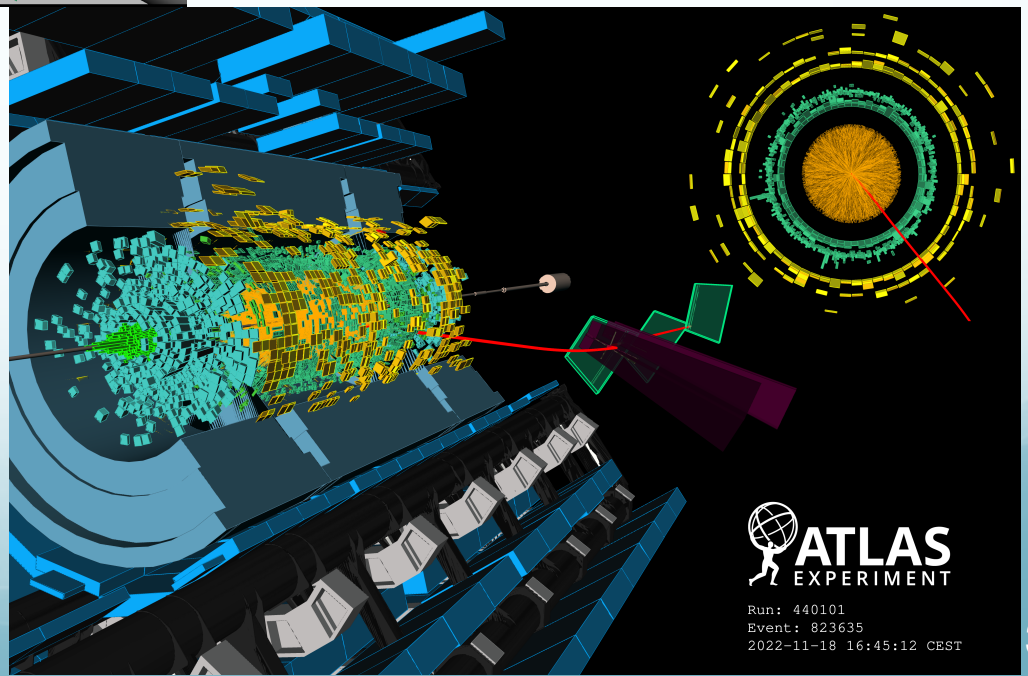
Run 3: 13.6 TeV collisions

Event displays

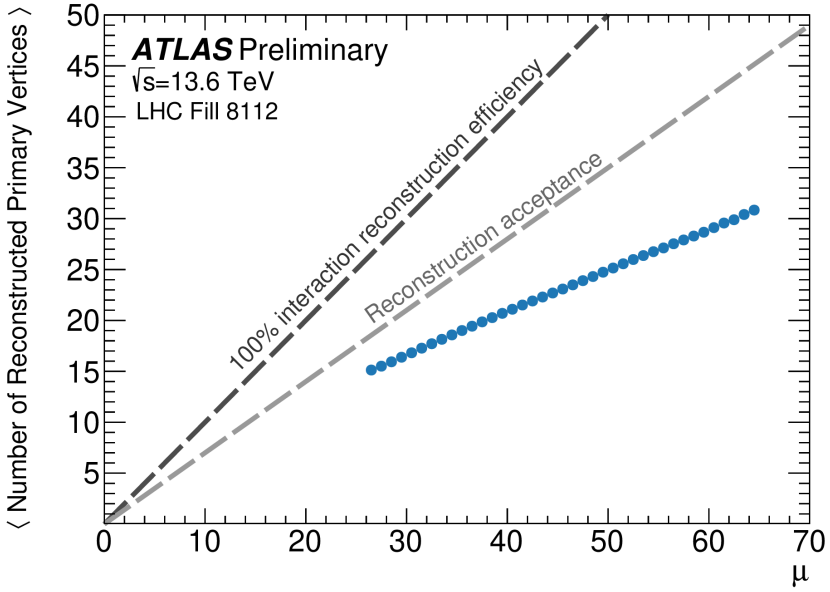


Dilepton ttbar candidate recorded in ATLAS on 18 July 2022 when stable beams of protons at the energy of 6.8 TeV per beam were delivered by the LHC

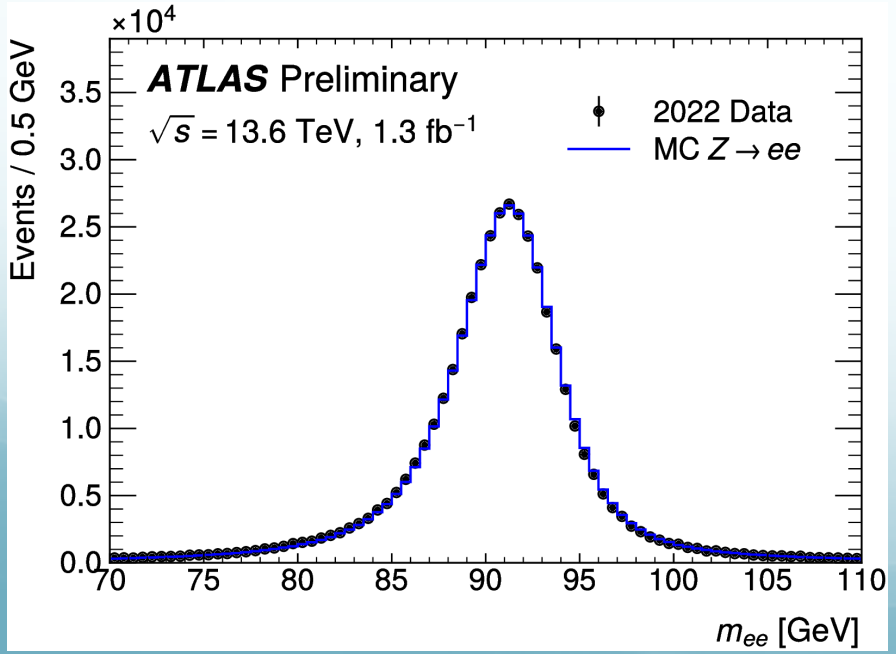
Heavy ion collision event recorded in ATLAS on 18 Nov 2022, when stable beams of lead ions colliding at a centre-of-mass energy per nucleon pair of 5.36 TeV were delivered to ATLAS by the LHC



Run 3: Some detector performance results

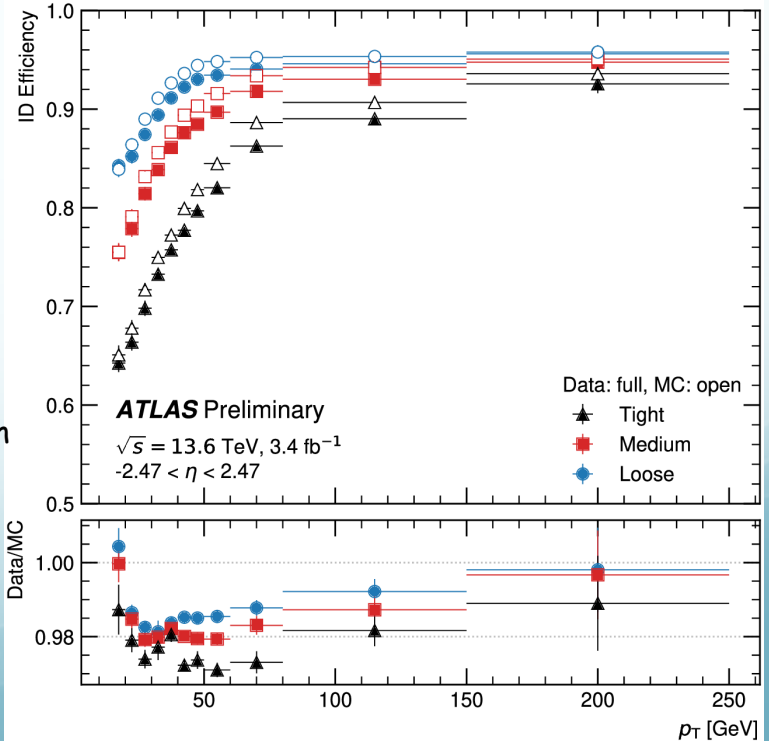


Average number of reconstructed primary vertices per event as a function of the number of interactions per bunch crossing measured in 13.6 TeV collisions in one Run 3 LHC fill. T



Distribution of the invariant mass of opposite-sign electron candidates pairs The data have been recorded in 2022 from pp collisions at s √ =13.6 TeV and correspond to about 1.3 fb −1

Electron identification efficiencies in Z→ee events as a function of transverse momentum pT



Summary

- ✓ ATLAS has a broad physics program and has been releasing many physics results during Run 1 and Run 2 of the LHC (more than 1 k papers):
  - Precision measurements of the SM processes
  - Higgs properties results
  - Wide program for BSM searches.
- ✓ Many analyses still ongoing with the full Run 2 dataset.
- ✓ Run 3 is starting now:
  - Commissioning of the detector
  - Many planned physics analyses (already some early analyses ongoing)

Stay tuned …

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Publications

Gracias!!

Backup Slides

ATLAS physics plans for Run3 and Run4

Higgs boson and SM processes precision measurements

- SM rare processes measurements (H -> μμ, self-coupling Higgs from double Higgs events, …)

- High density QCD measurements (from heavy-ion and pp collisions)

- Forward physics (from exclusive production processes tagging

- Beyond SM physics (SUSY, dark matter, long lived particles, …)

ATLAS physics plans for Run3 and Run4

High luminosity is needed to achieve physics goals

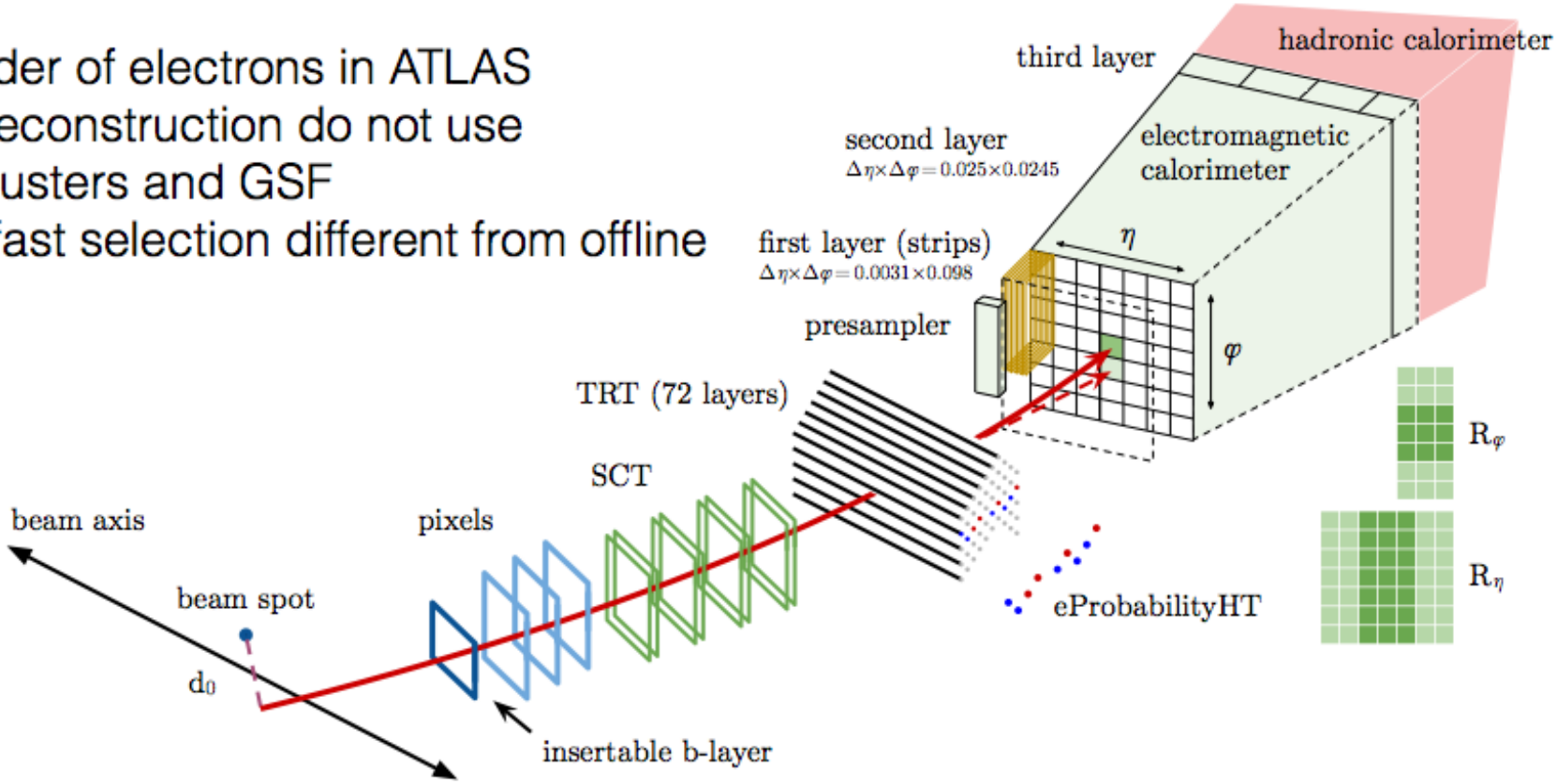
- The experiment has to stand the Run4 foreseen peak luminosity of 7.5 x 1034 cm-2 s-1
- high pile-up ~200 collisions/crossing
- high radiation levels, up to ~1016 neq/cm 2, 10 MGy

Requirements:

- maintain good physics performances in the challenging environment
- keep acceptable trigger rate for low pT threshold
- mitigate pile-up up to high η

Calorimeter towers

- A reminder of electrons in ATLAS
- Online reconstruction do not use SuperClusters and GSF
- L1 and fast selection different from offline

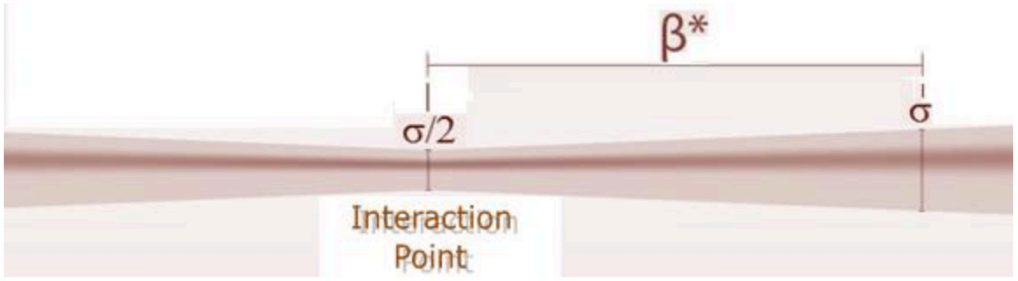


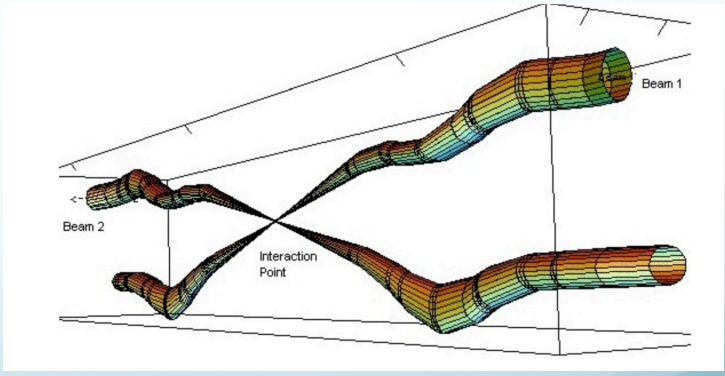
Luminosity

$$N_{exp} = \sigma_{exp} \times \int \mathscr{L}(t)dt$$

$$\mathscr{L} = f_{coll} \frac{n_1 n_2}{4\pi\sigma_x^* \sigma_y^*}$$

Beta*





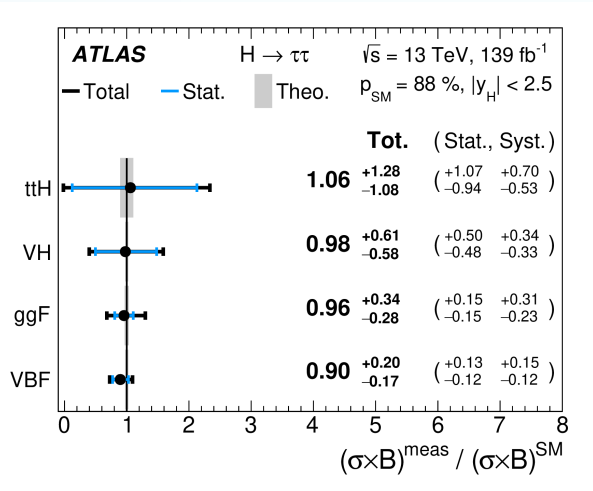
Higgs measurements: $H \to \tau\tau$

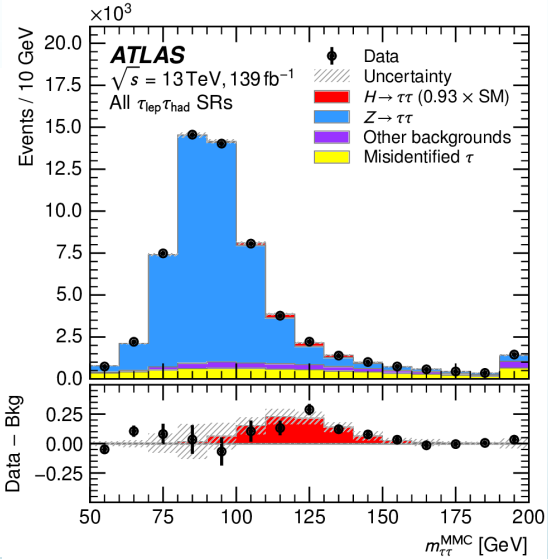
- ✓ Measurement of the Higgs Boson mass in $H \to \tau\tau$ decay channel
- ✓ Data recorded during Run 2: 139 fb^{-1}.
- ✓ Cross section of the process:

$$\sigma(pp \to H \to \tau\tau) = 2.94 \pm 0.21(stat)^{+0.37}_{0.32}(syst)pb$$

in agreement with the SM prediction.

- ✓ Inclusive cross-sections determined separately for 4 dominant process ggF, VBF, VH, ttH productions.





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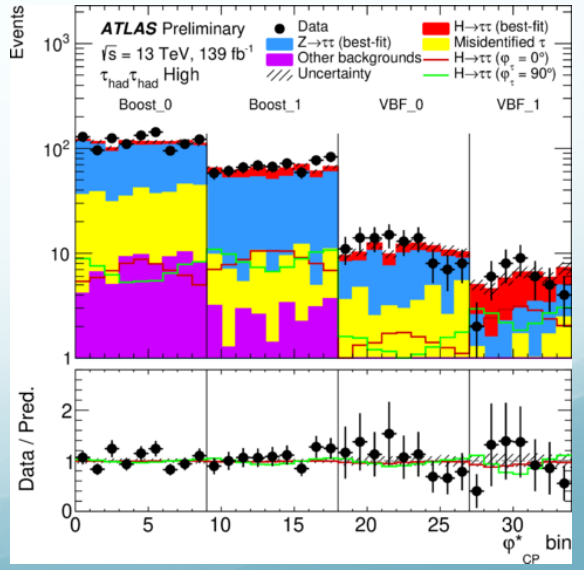
- ✓ Study of CP properties of the interaction between H and τ
- ✓ Data recorded during Run 2: 139 fb^{-1}.
- ✓ Measurement of CP-sensitive angular observables.
- ✓ The contributions from CP-violating interactions between H and τ are described by a single mixing angle ϕ_τ



[ATLAS-CONF-2022-032]