Highlights from pp collisions at ATLAS

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on behalf of the ATLAS collaboration

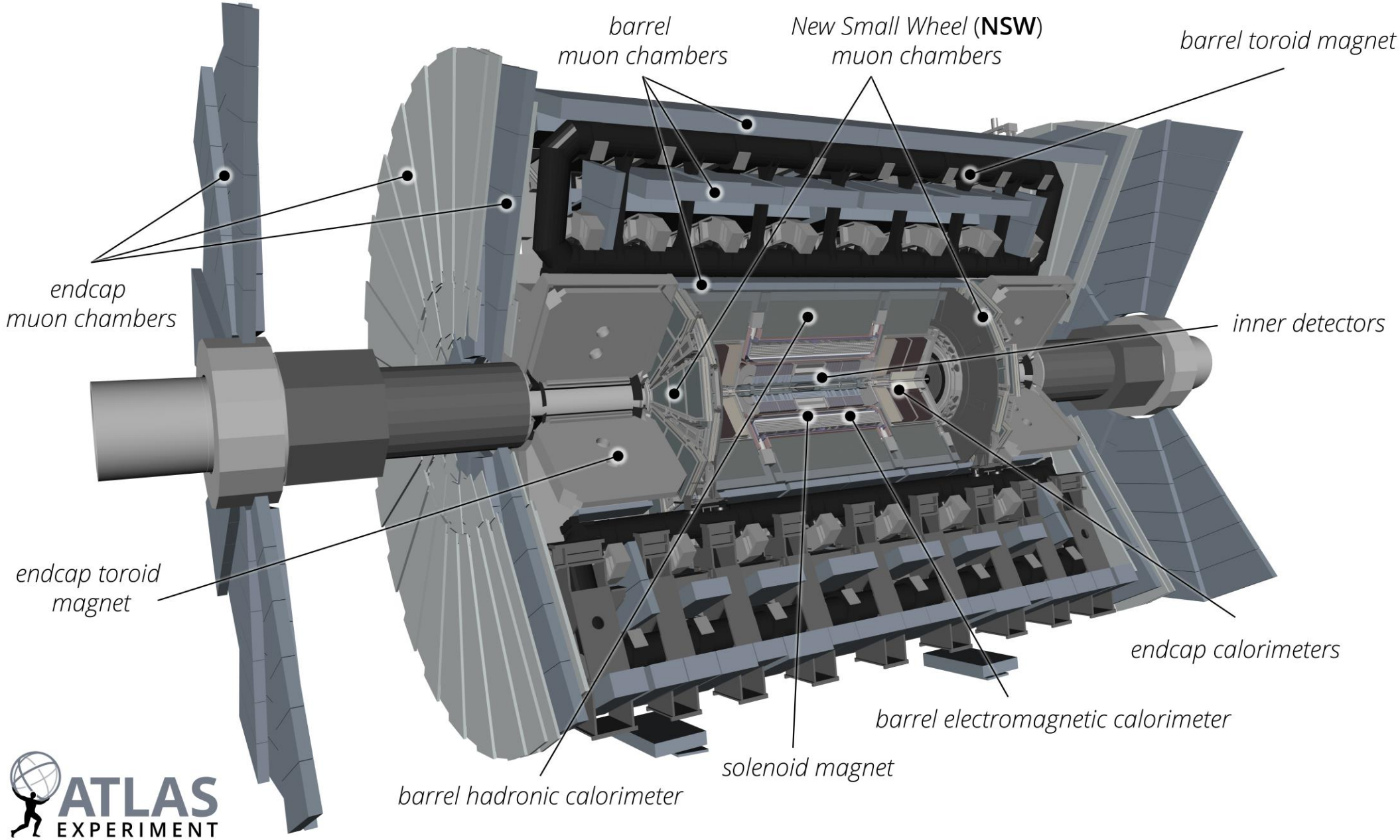
INFN GENOVA

ATLAS EXPERIMENT

Outline

- **ATLAS**
- **SM: furthering the precision frontier**
- **HIGGS: sharpening the precision, seek for rare processes**
- **HIGGS: explore enlarged scenarios**
- **BSM1: desperately seeking SUSY**
- **BSM2: the quest for Exotica**
- **Outlook**

- Disclaimer
  - Hard choice, given the wealth of the harvest
  - Focus on recent results, and on breadth of fields
  - Many additional extremely interesting results available (older, but also fresh): see topical ATLAS talks at this Conference

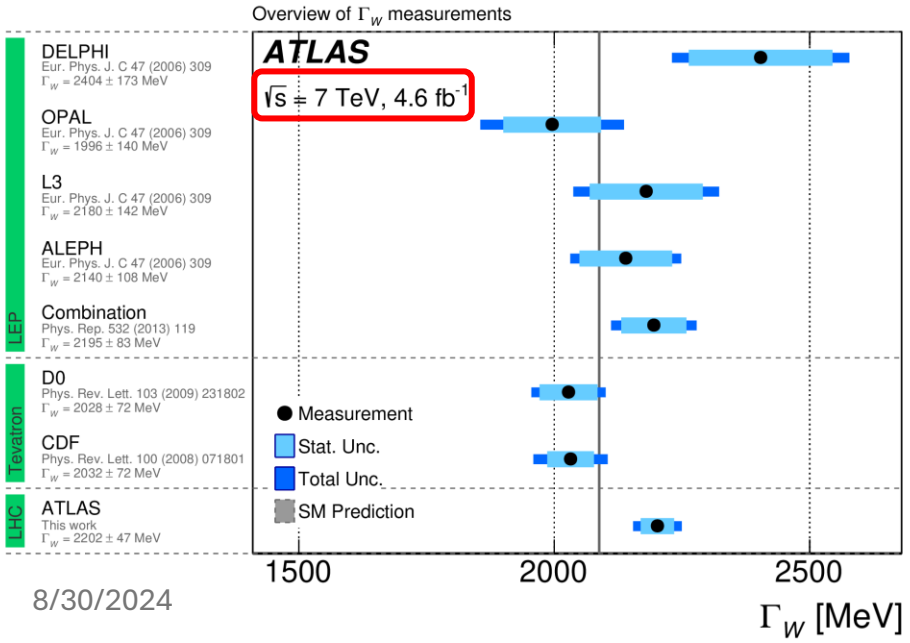

barrel
muon chambers
New Small Wheel (NSW)
muon chambers
barrel toroid magnet
endcap
muon chambers
inner detectors
endcap toroid
magnet
endcap calorimeters
barrel electromagnetic calorimeter
solenoid magnet
barrel hadronic calorimeter
ATLAS
EXPERIMENT

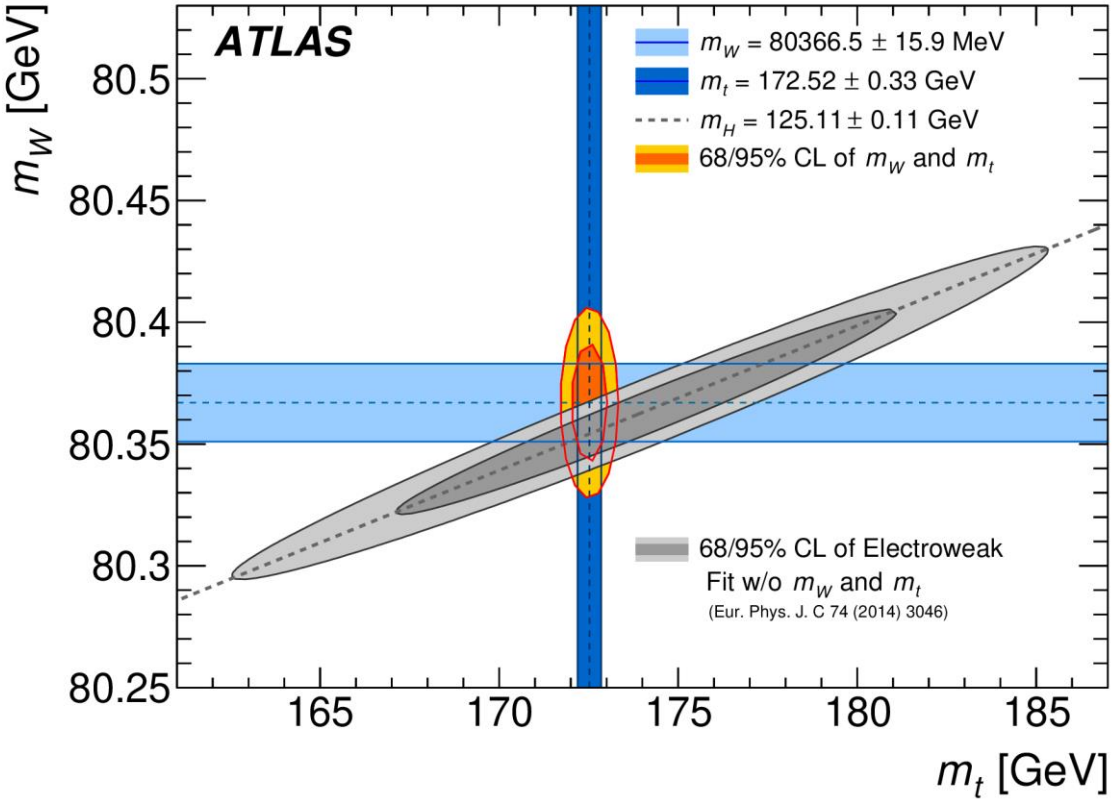
Standard Model
Furthering the precision frontier

arXiv:2403.15085

Improving the understanding of fundamental parameters

- First measurement of the W width at the LHC, together with an improved W mass
  - Largest systematics from the calibration, the theoretical modeling and the parton density functions





Dedicated measurements under optimal running conditions can play a key role to improve these limitations

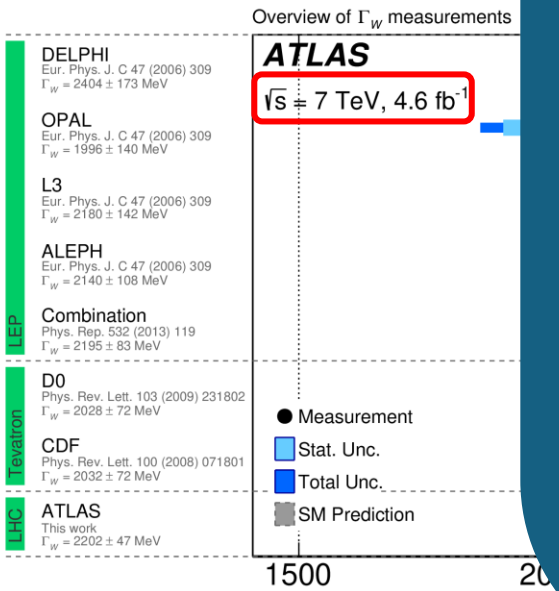
arXiv:2403.15085

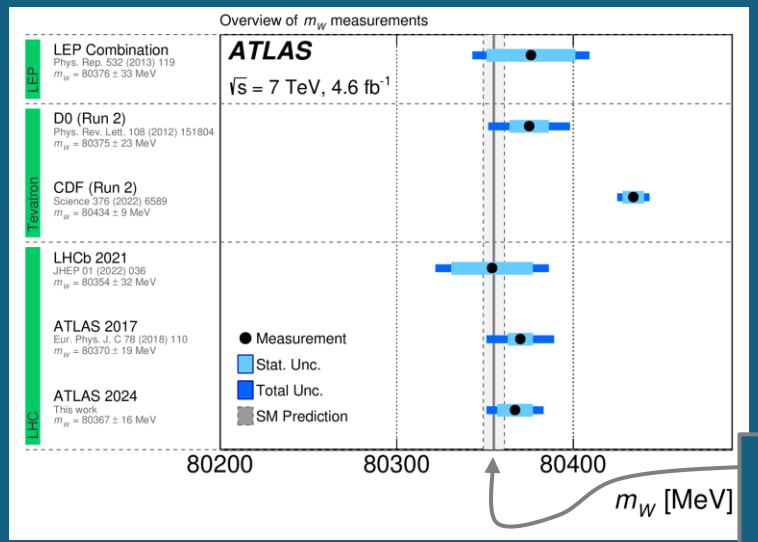
Improving the understanding of fundamental parameters

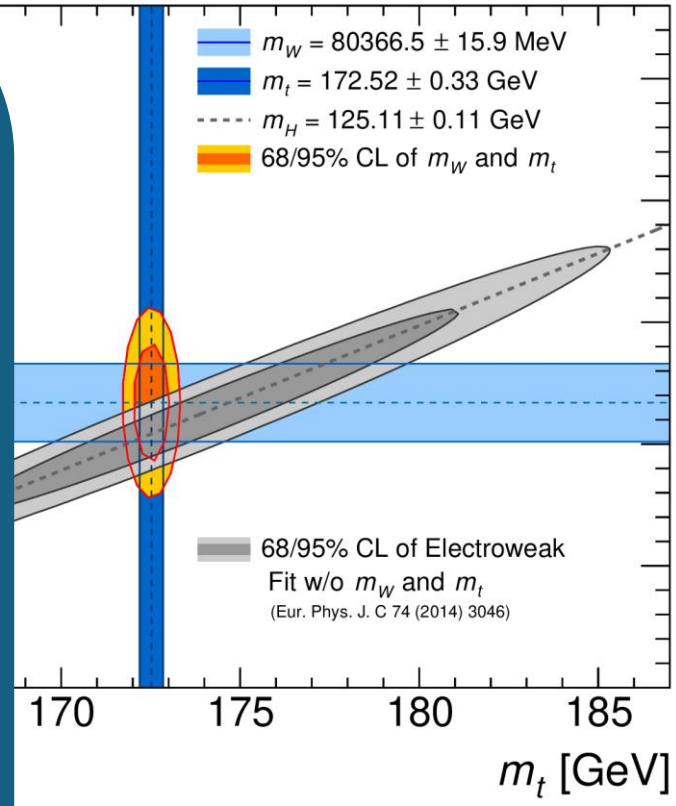
- First measuremen
  at the LHC, toget
  improved W mass
  - Largest systemat
    calibration, the t
    and the parton d

ATLAS precision on m_W exceeding that on other SM heavy particles by ~1/10

0.02% on m_W
0.2% on m_t
0.09% on m_h







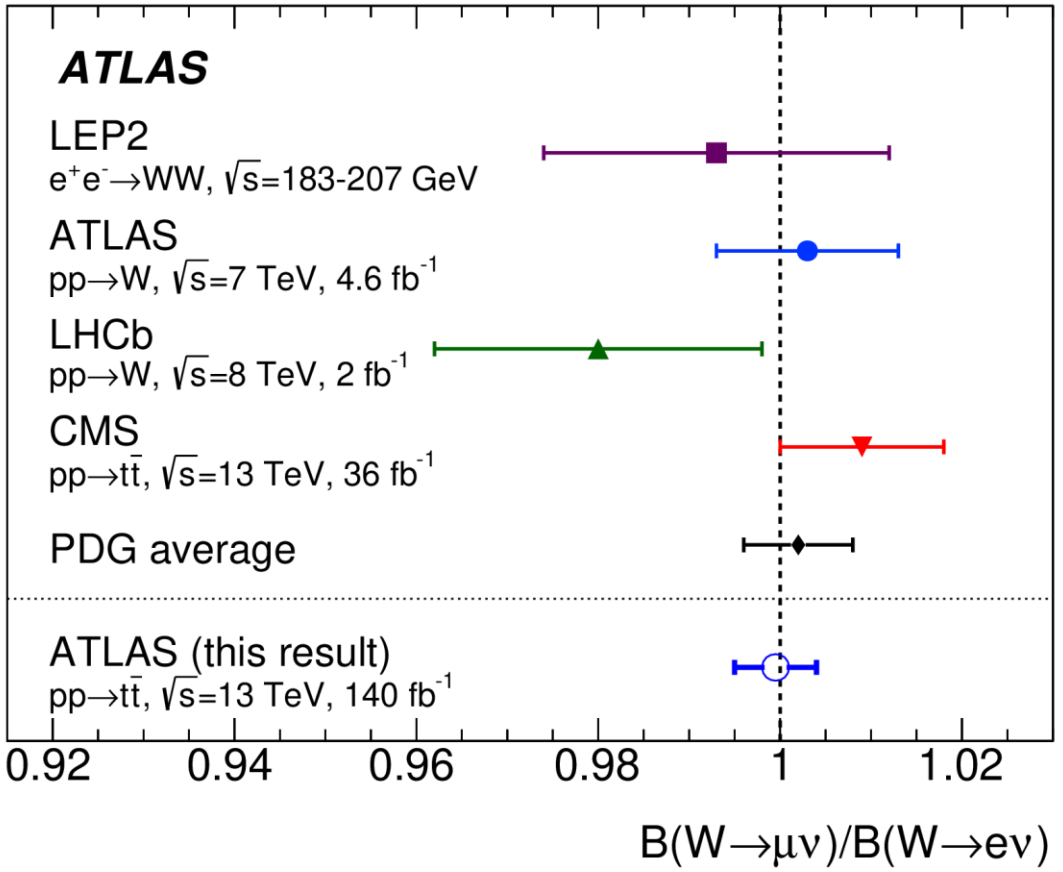
…nents under optimal
…an play a key role to
…e limitations

SM prediction for m_W based on m_Z (measured much more precisely elsewhere)

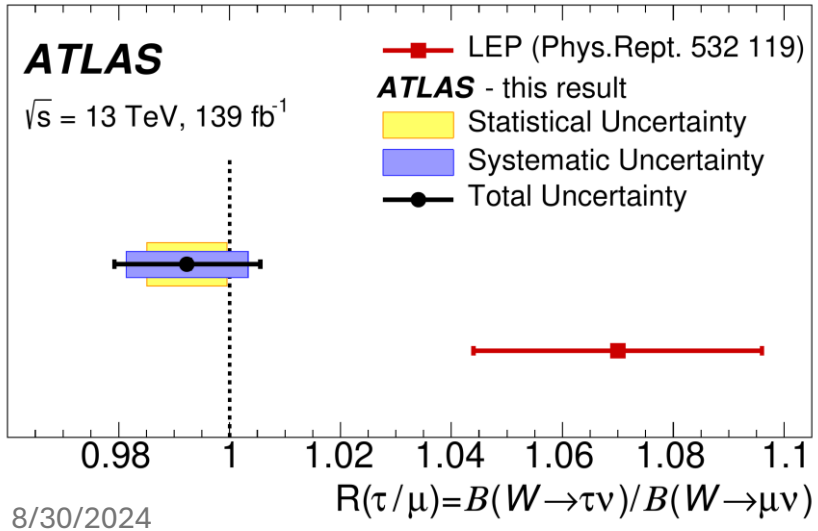
arXiv:2403.02133

Check of lepton universality in W decays

- Exploits clean W bosons from top-pair decays
- Higher precision than current world average
  - $R_W^{\mu/e} = 0.9995 \pm 0.0045$



Nature Phys 17 (2021) 813



This adds to a previous result with taus, solving a decade old puzzle from LEP

Higgs Boson Sharpening the precision and seek for rare

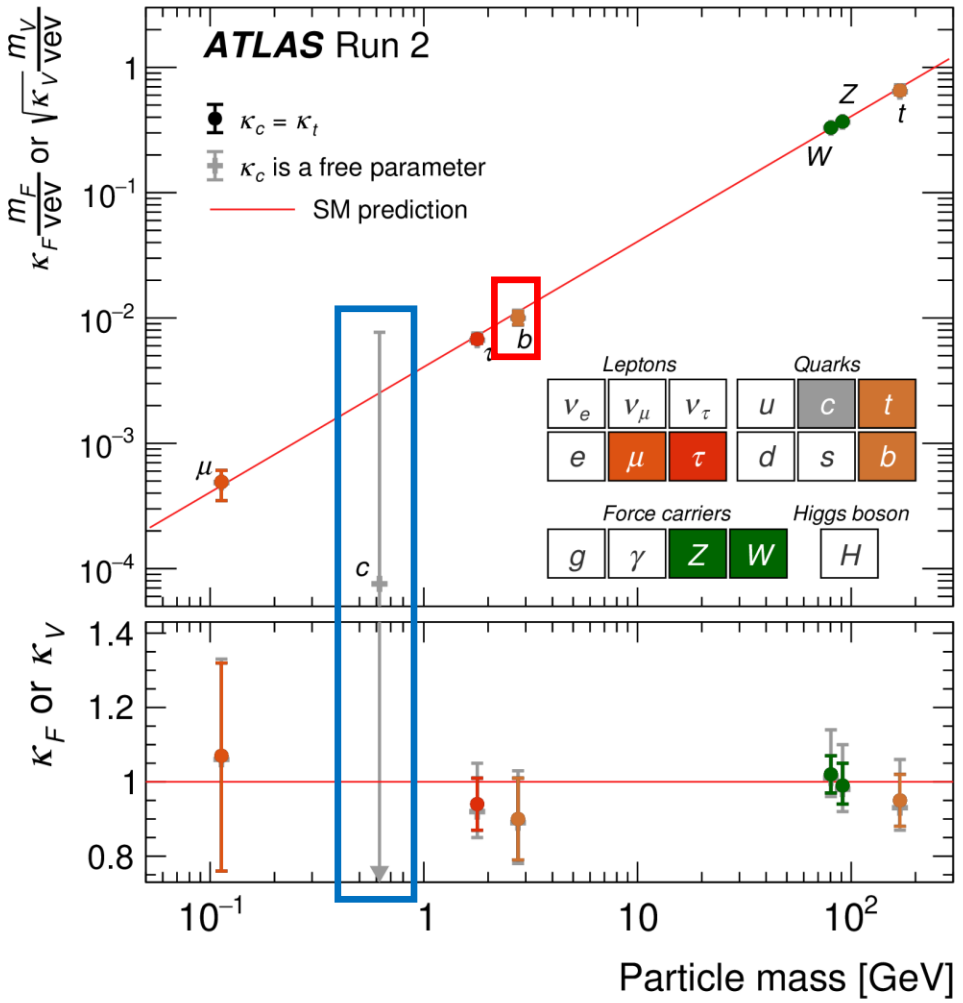
The beauty and the charm of the Higgs boson

- Probing Yukawa couplings in the quark sector is a cornerstone of the experimental program of LHC
- Goals
  - measurements of VH Higgs production with decays into bottom quarks
  - **direct constraints on the charm Yukawa coupling**

with full Run2 statistics

The only accessible second-generation quark Yukawa coupling

Important check of the Higgs mechanism
but currently
very large uncertainties



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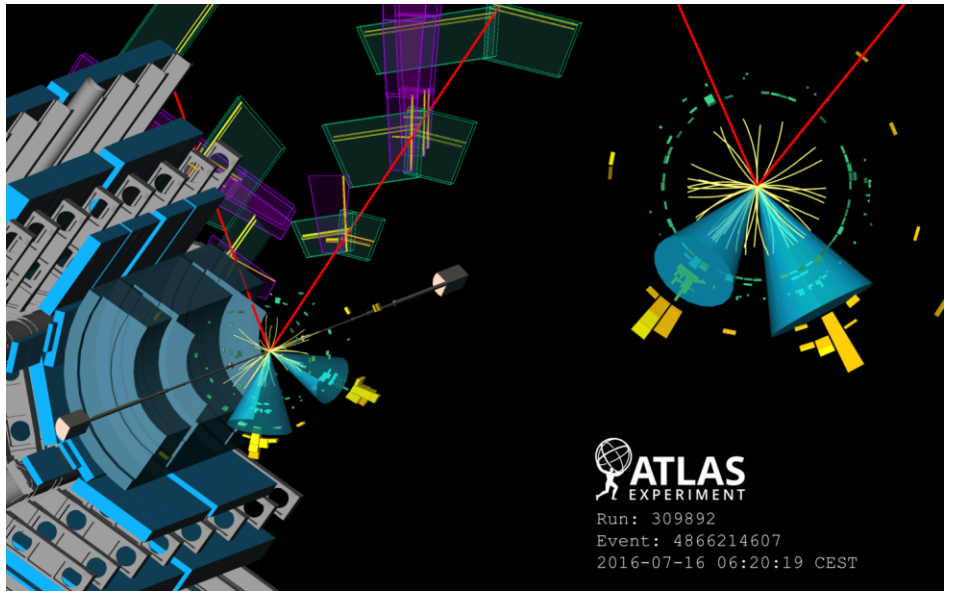
- Goals
  - measurements of VH Higgs production with decays into bottom quarks
  - **direct constraints on the charm Yukawa coupling**

  with full Run2 statistics
- Individual production of WH and ZH with $H \to b\bar{b}$ is established with observed (expected) significances of **5.3** (5.5) and **4.9** (5.7)

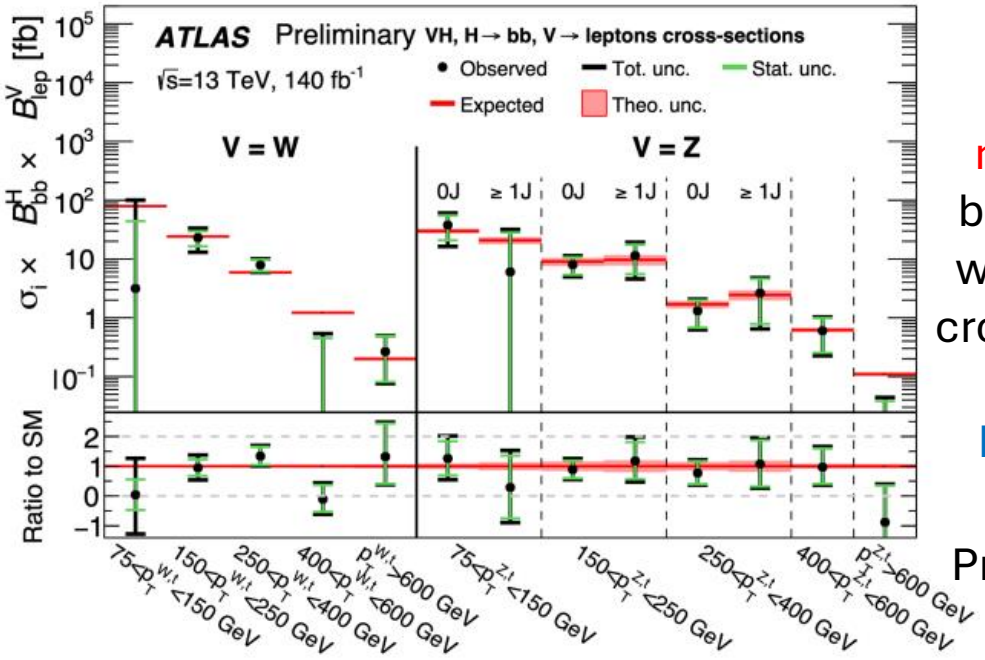


1st Obs!

This new legacy V(lep)/H(bb,cc) improves and combines previous results:
V(lep)/H(cc), V(lep)/H(bb), boosted V(lep)/H(bb)

- Better Flavor Tagging (MV2 to DLr1: EPJC 63 (2023) 681) and dedicated WP optimizations
- Introduced BDT discriminant for VH(cc) and VH(bb) boosted
- New MC samples (JHEP 08 (2022) 89) with much higher stat and dedicated treatment of "truth-tagging"
- Increased statistics of alternative generators using CARL (arxiv:1506.02169)
- Inclusion of additional analysis regions (e.g. 75-150 pTV in 1L), improved mass resolution

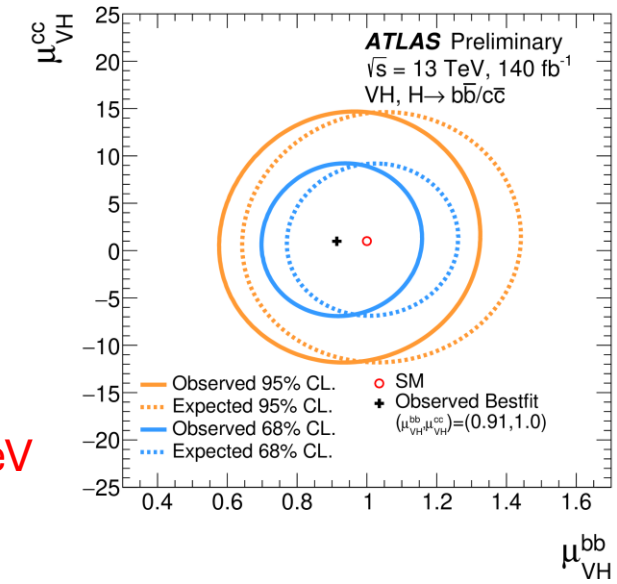
ATLAS-CONF-2024-010



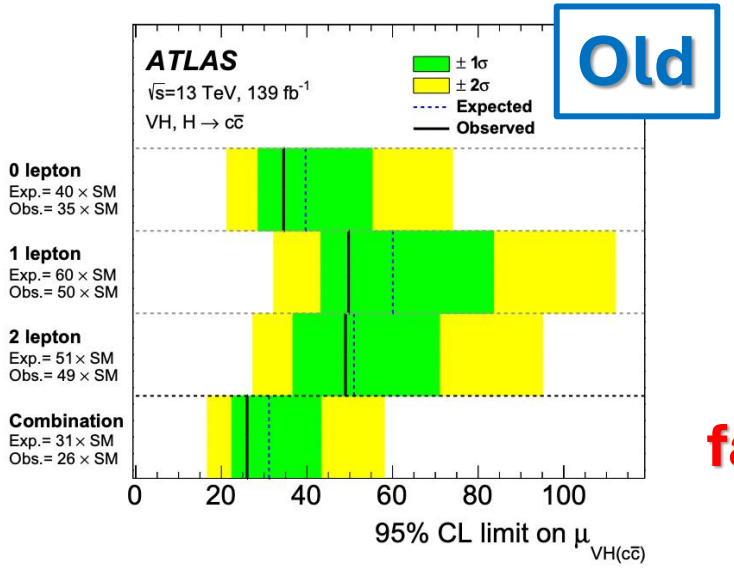
Differential cross-section measurements of the gauge boson transverse momentum within the simplified template cross-section (STXS) framework performed in a total of 13 kinematical fiducial regions

Probe p_T V spectrum up to 600 GeV for both WH and ZH

Obs and exp 68% and 95% CL contours of the VH signal strengths, with $H \to b\bar{b}$ and $H \to c\bar{c}$ and their best fit values



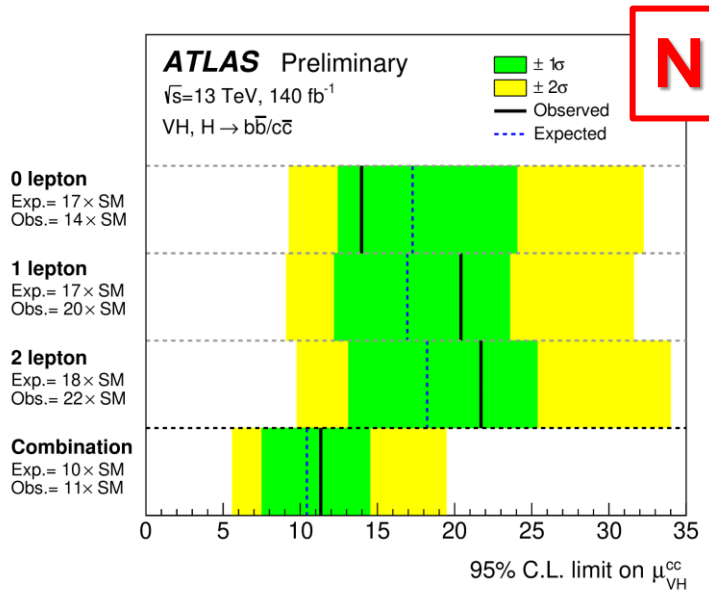
Old



95% CL UL on $\mu_{VH(c\bar{c})}$

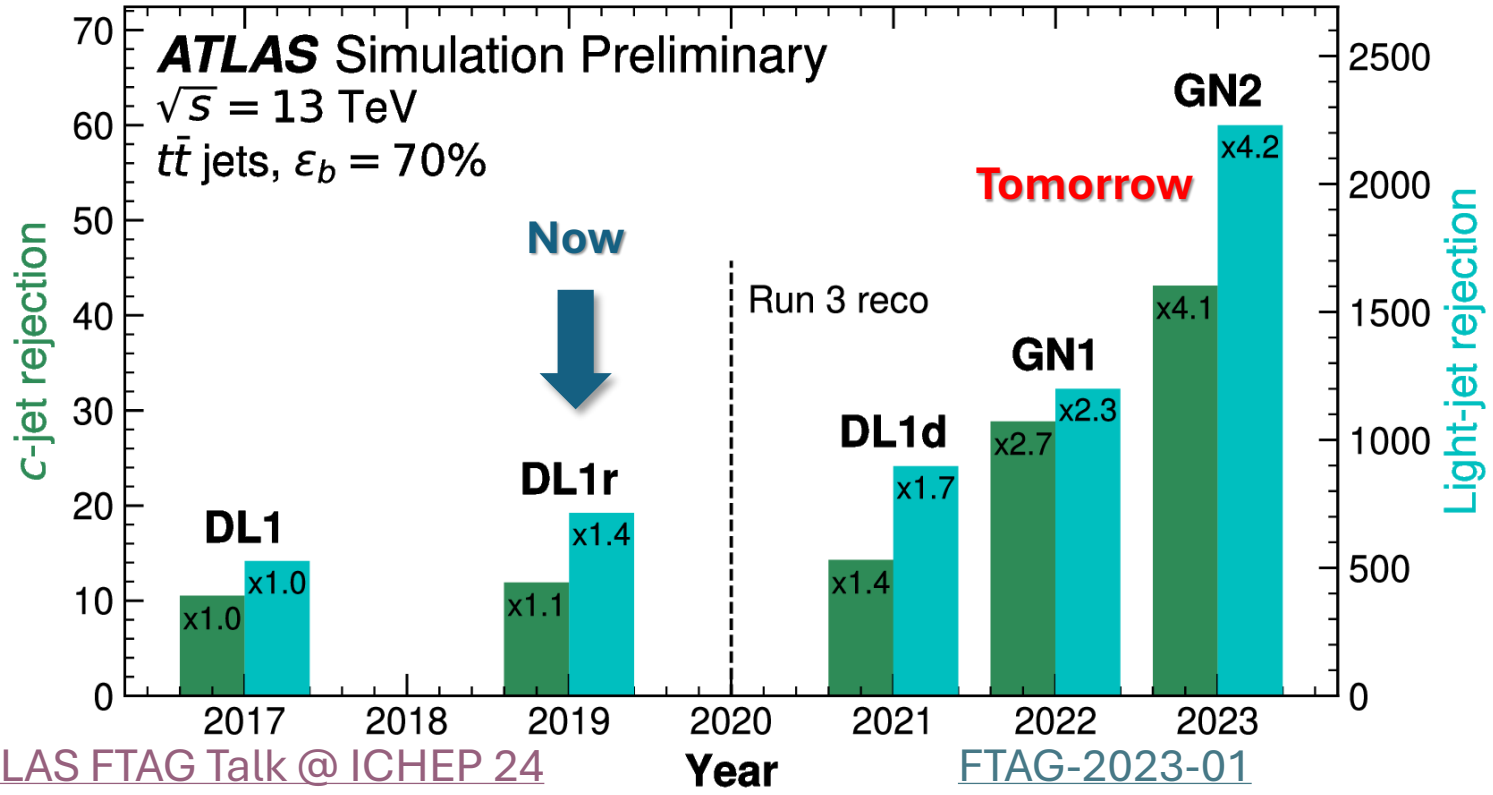
More than factor 2 improvement!

New



Best limit to date

Will we be able to find evidence of the charm Yukawa coupling during the lifetime of LHC?



ML techniques for FTAG are in full blossom

See also: ATLAS FTAG Talk @ ICHEP 24 FTAG-2023-01

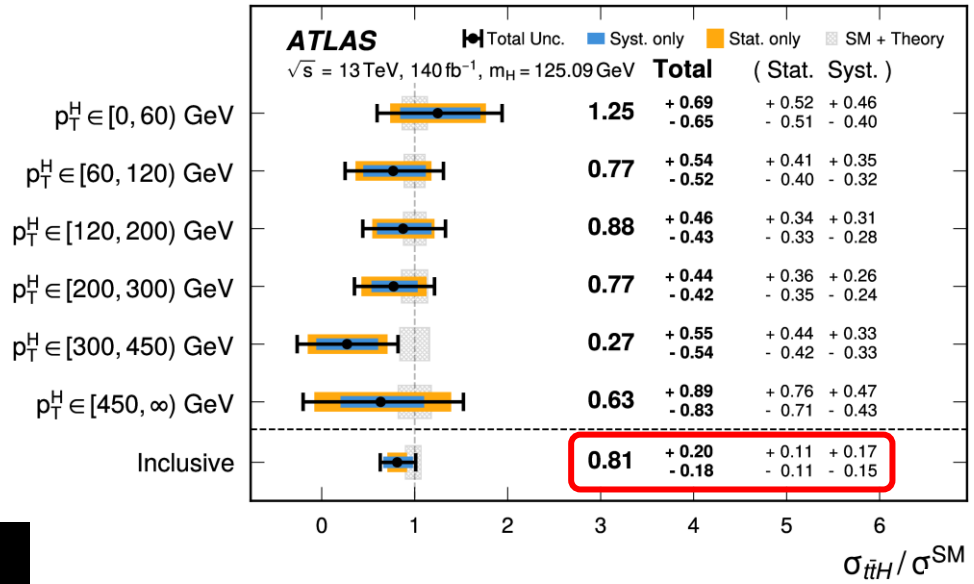
Rapid progress in techniques: major driver of sensitivity increases

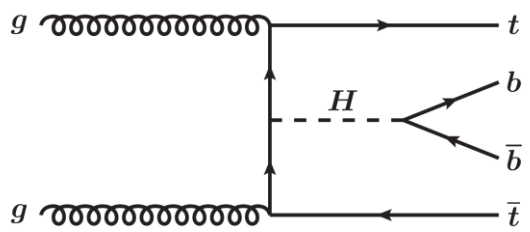
BDTs → **feed-forward DNNs** → **Graph NNs**, **transformer networks**...

arXiv:2407.10904

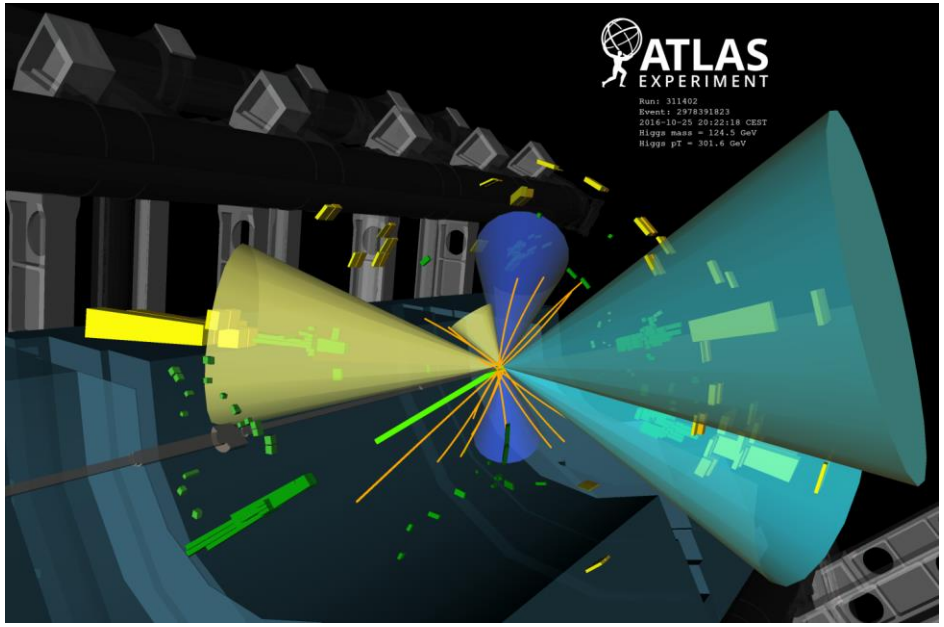
Higgs production in association with top quarks

- Direct probe of top Yukawa coupling
- Refined reconstruction and calibration of physics objects (in particular: b-jets)
- Improved description of top-quark background processes
- Advanced neural network used to classify the selected collision events





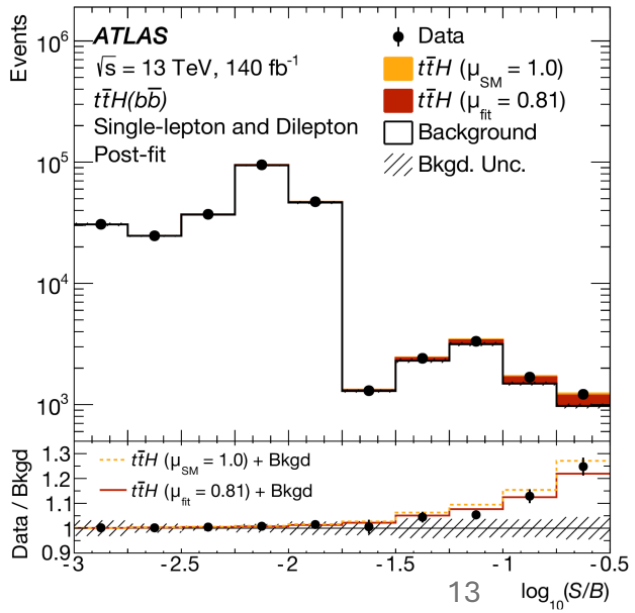
Observed and expected event yields as function of the ratio of post-fit signal (S) and total bkg (B) yields



Total uncertainty improved by ~40%

4.6 σ observed
(2x previous meas)

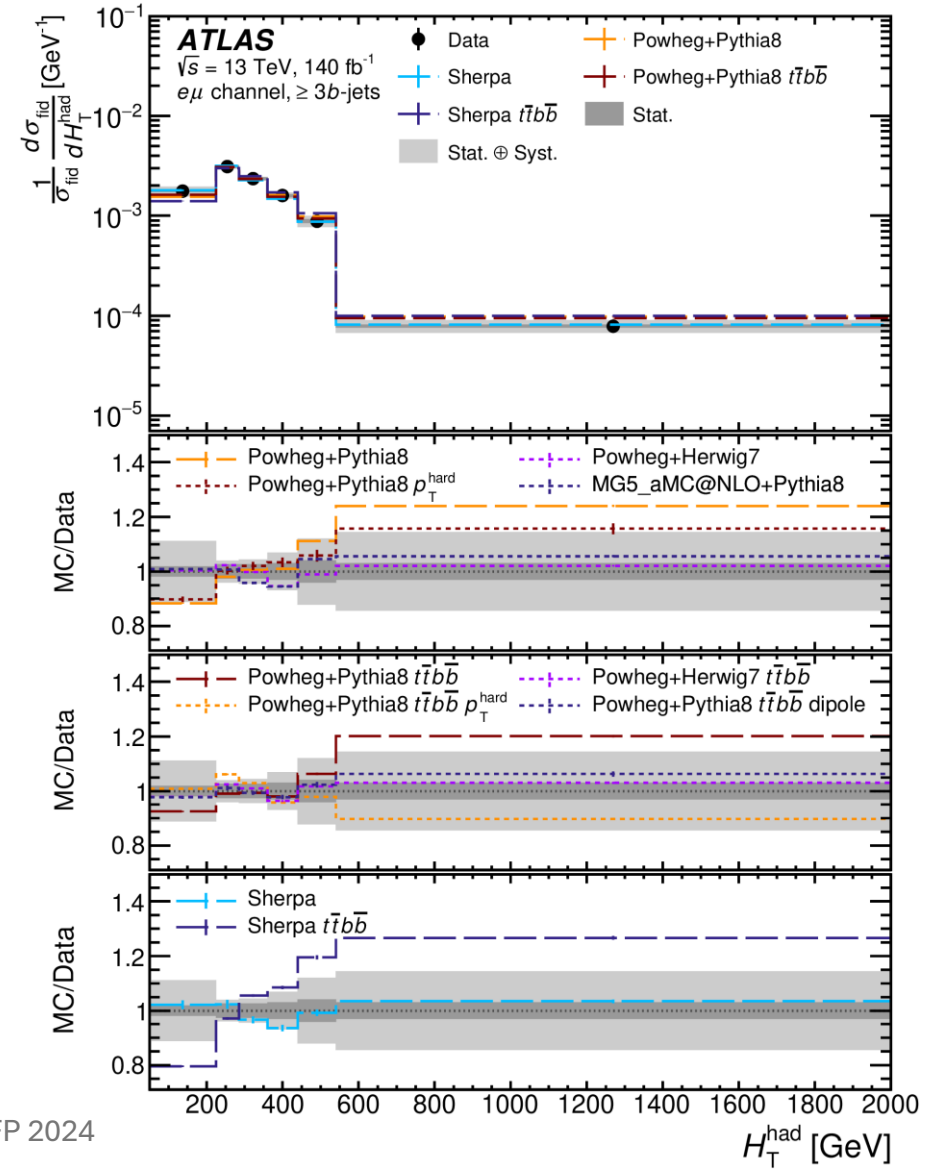
Inclusive and differential in p^H_T via STXS formalism
(only ttH channel to reach p^H_T above 450 GeV)



arXiv:2407.13473

Where can we go: Precision Top for precision Higgs

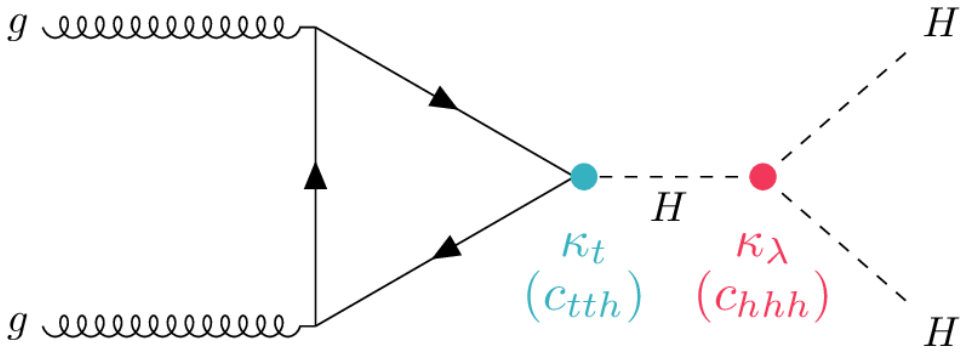
- Measurement of $t\bar{t}$ + heavy flavor
  - extensive measurements for improved theory modeling
- Precision 10% achieved on several observables
- Good agreement with $t\bar{t}b\bar{b}$ MC
- Huge amount of precious information for MC authors
- Important result to help further improve measurement like $t\bar{t}H$



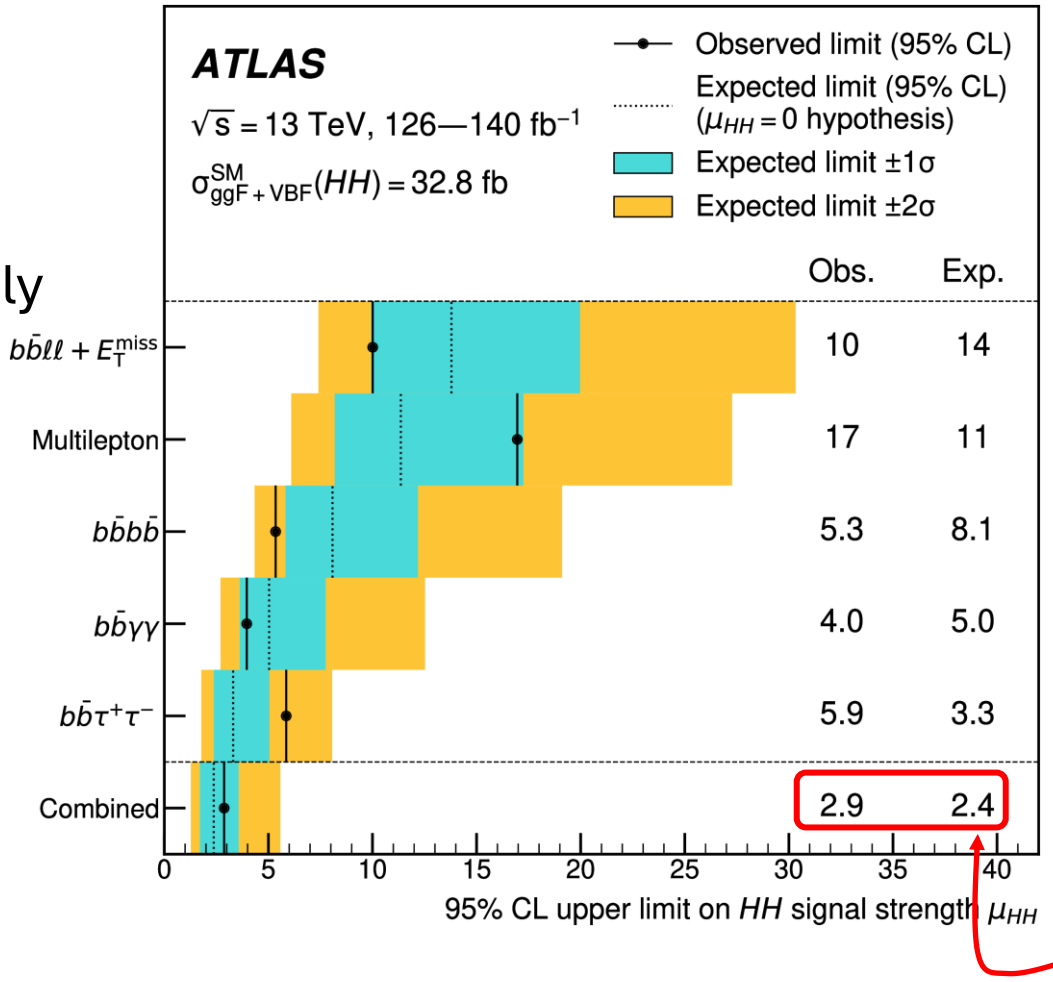
arXiv:2406.09971

New combined search for di-Higgs production

- **Approaching SM prediction for HH production cross section**
- Many production (ggF + VBF) and decay channels explored
  - Some new
  - Significant improvements in previously explored ones
- Best expected sensitivity on HH cross section, self-coupling, κ_λ



Observed and expected 95% CL UL's on HH signal strength μ_{HH}



New

New

Improved boosted part

Improved

Improved

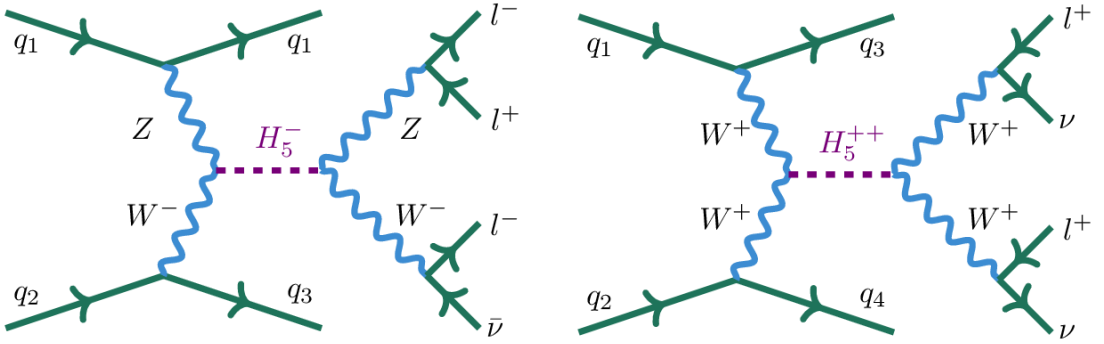
17% lower than previous combination

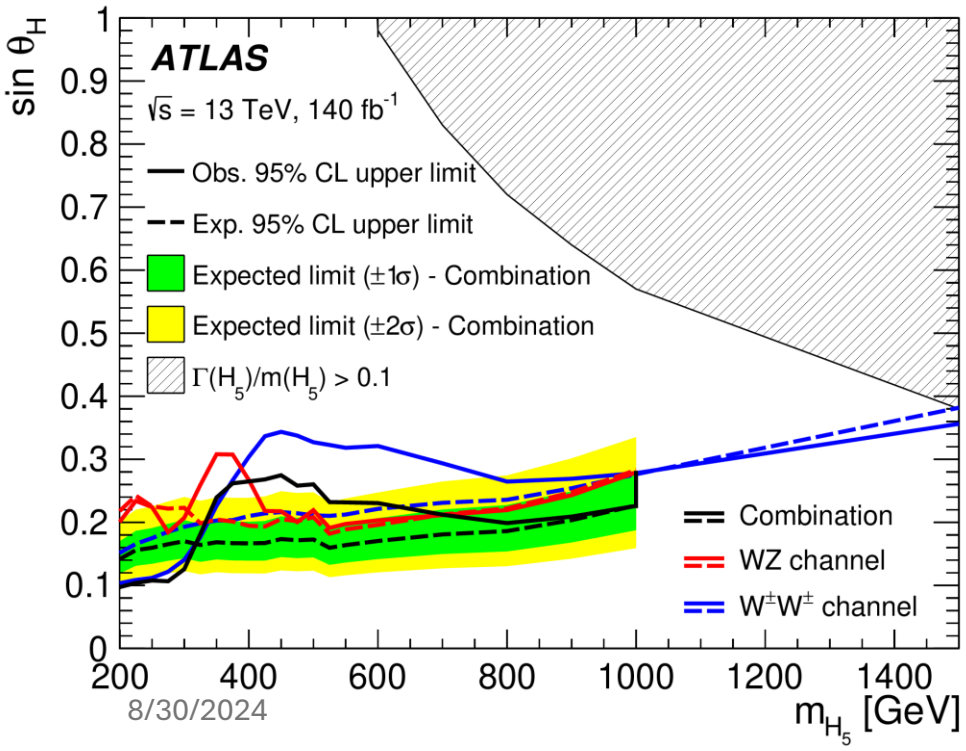
Higgs Boson / Looking beyond
Search for extended Higgs sectors

arXiv:2407.10798

Search for singly and doubly charged Higgs in VBF

- Charged Higgs bosons predicted in extended Higgs sectors with additional complex doublets or higher-isospin scalar fields
- H^+/H^{++} produced in VBF and decaying into a WZ/WW boson pair (forbidden at tree level in the generic two Higgs doublet model due to CP conservation)
- Benchmark: Georgi–Machacek (GM) model





- Physical scalar states are organised into custodial multiplets (a quintuplet, a triplet and two singlets [including the observed 125 GeV neutral h])
- Focus on the fermiophobic quintuplet, assumed mass degenerate (m_{H_5}), which couples to vector boson pairs
- A parameter, $\sin(\theta_H)$, characterises the contribution of the isotriplet scalar fields to the masses of the W and Z bosons
- Upper Limit on $\sin(\theta_H)$ as a function of m_{H_5} both for singly and for doubly charged state (and their combination)
- The largest observed excess is for 375 GeV mass point, where the local (global) significance amounts to 3.3 (2.5) σ

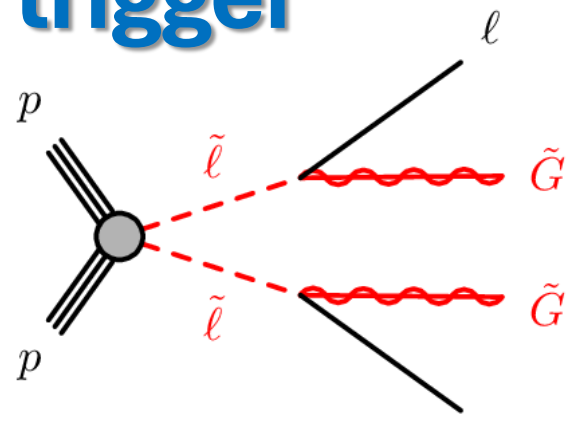
Looking beyond:
Desperately seeking SUSY

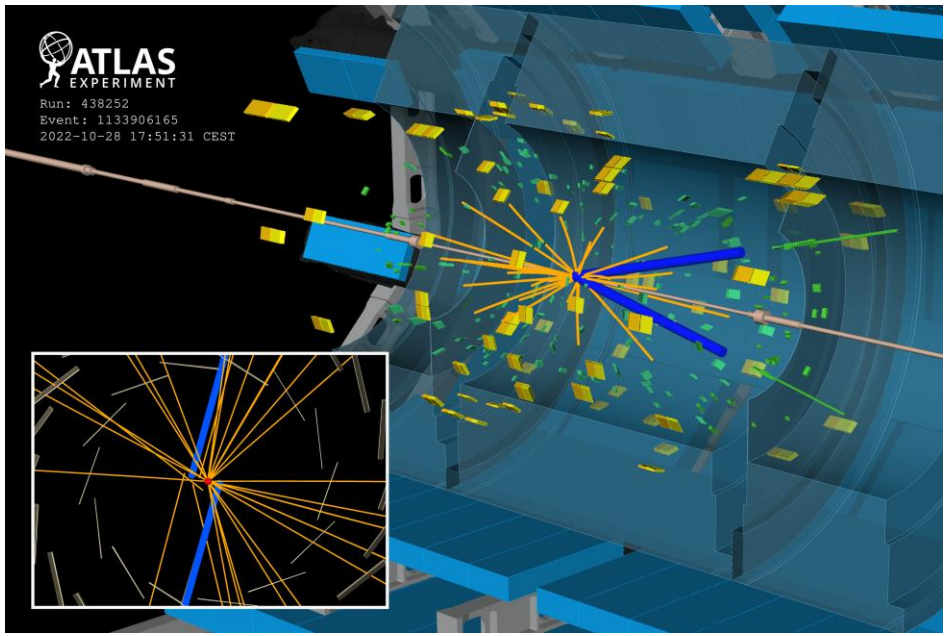
New Run3!

ATLAS-CONF-2024-011

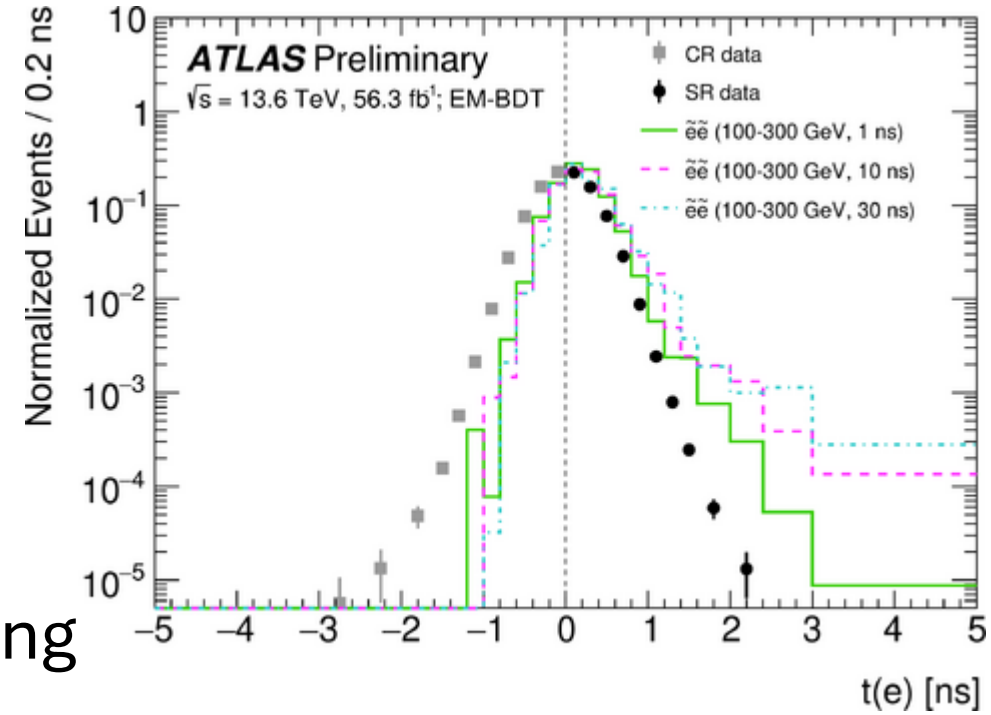
Probing uncharted territory with improved trigger

- Targeting Long-Lived slepton production
- Using Run-3 data (combined with Run2) and Large Radius Track Trigger at HLT (improved low-pT acceptance)





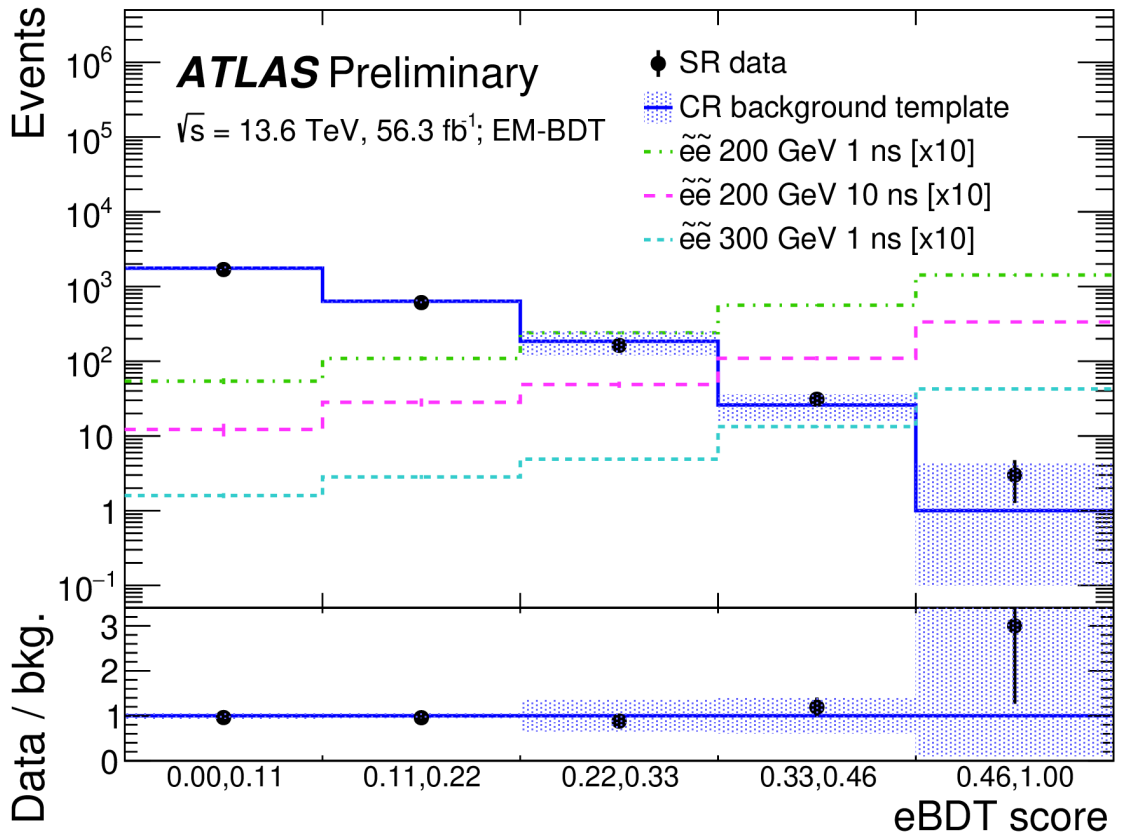
Precision timing information from calorimeter to complement tracking

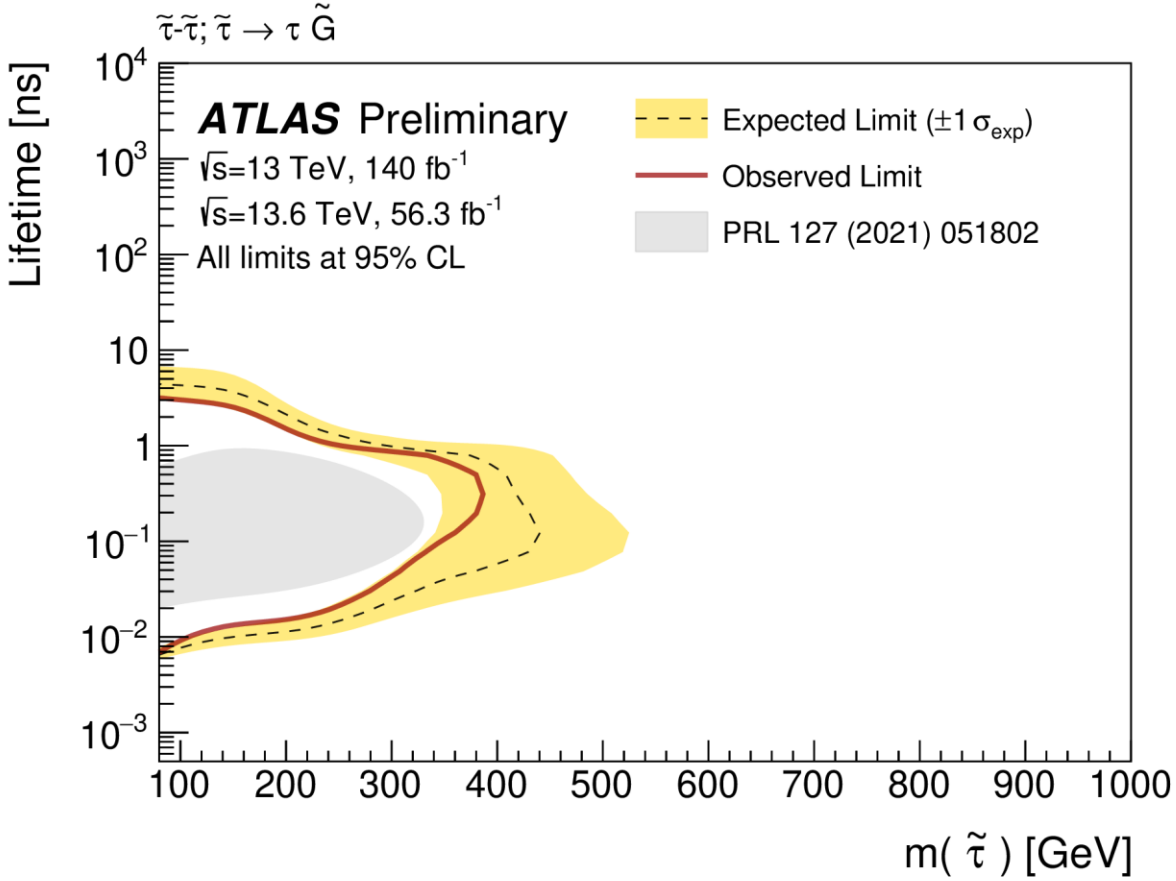


New Run3!

ATLAS-CONF-2024-011

2 Set of signal regions (one optimized with a BDT for displaced EM clusters)



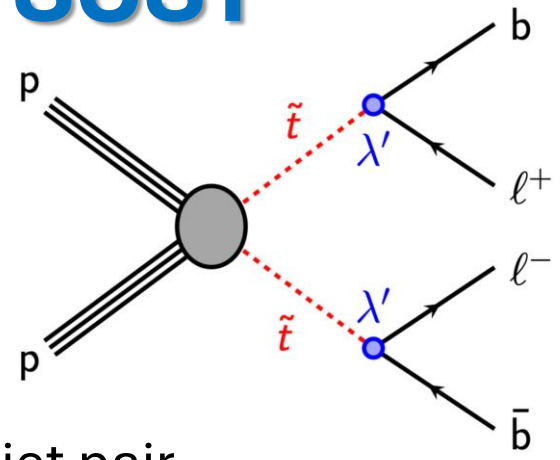


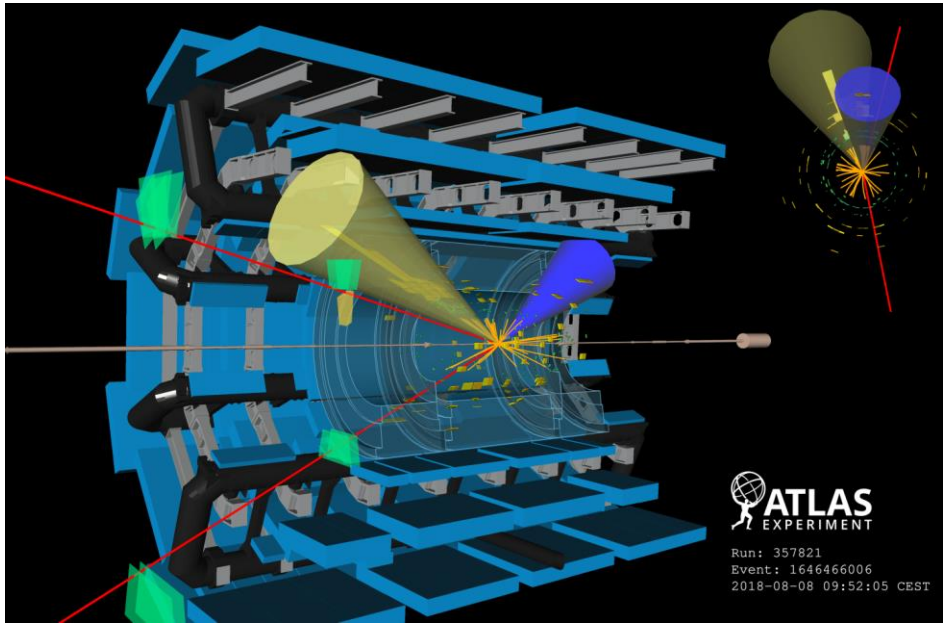
Vast improvement in sensitivity relative to Run 2 analysis

arXiv:2406.18367

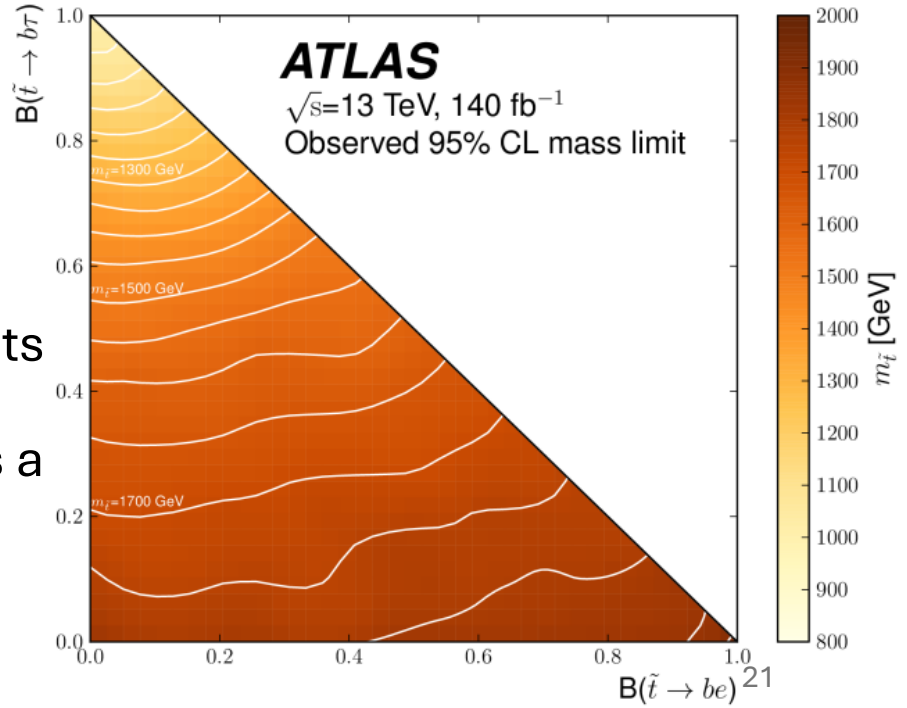
Breaking "R-parity" in new searches for SUSY

- Searching for heavy stops, decaying to a b-quark and a lepton (muon or electron)
  - Signature: two oppositely charged leptons and at least two jets (one of which must come from a b-quark)
  - Enhanced background estimation strategies
  - Optimized fit to the distribution of the mass of the leading lepton-jet pair

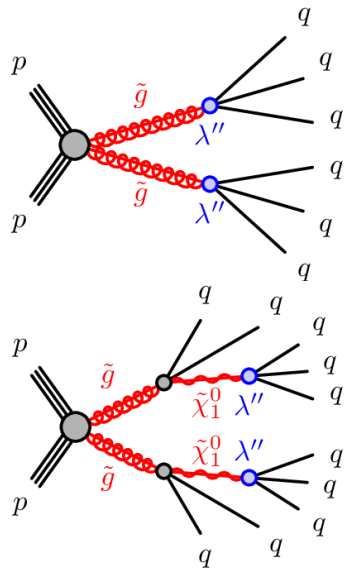


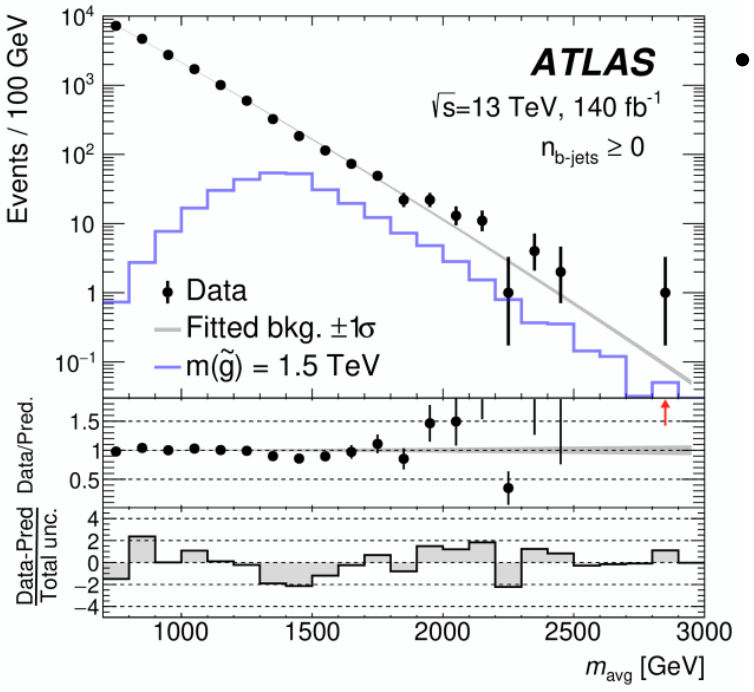


Observed lower limits on $m_{\tilde{t}}$ at 95% CL confidence level, as a function of $\tilde{t}$ branching ratios

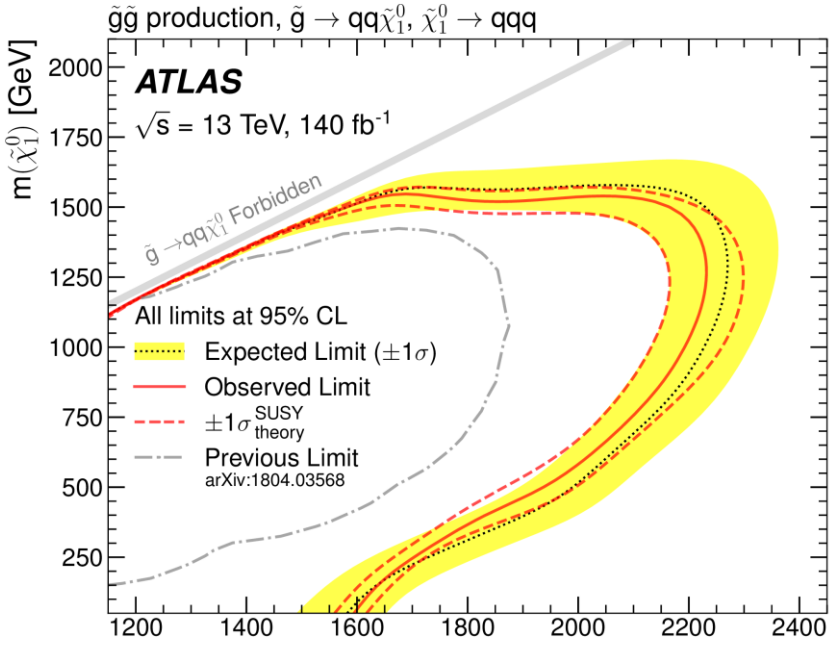


- Searching for pair-produced gluinos, decaying into multiple quarks either directly or through an intermediate neutralino
  - Signature: multiple jets (6j for direct, 10j for $\tilde{\chi}_1^0$ mediated)
  - Challenges:
    - SM background processes are poorly modeled
    - High number of jets creates a complex combinatorial background
    - Use standard as well as ML-based approaches





- No excess above SM found
  - Direct gluino decay: excluded up to 1800 GeV
  - Cascade gluino decay: excluded up to 2340 GeV for a neutralino with 1250 GeV mass
  - Mass resonance method extends limits compared to jet counting method by ~200 GeV

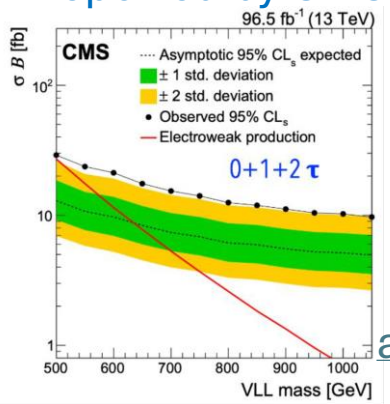


Looking beyond:
The Quest for Exotica

Search for Vector Like Leptons

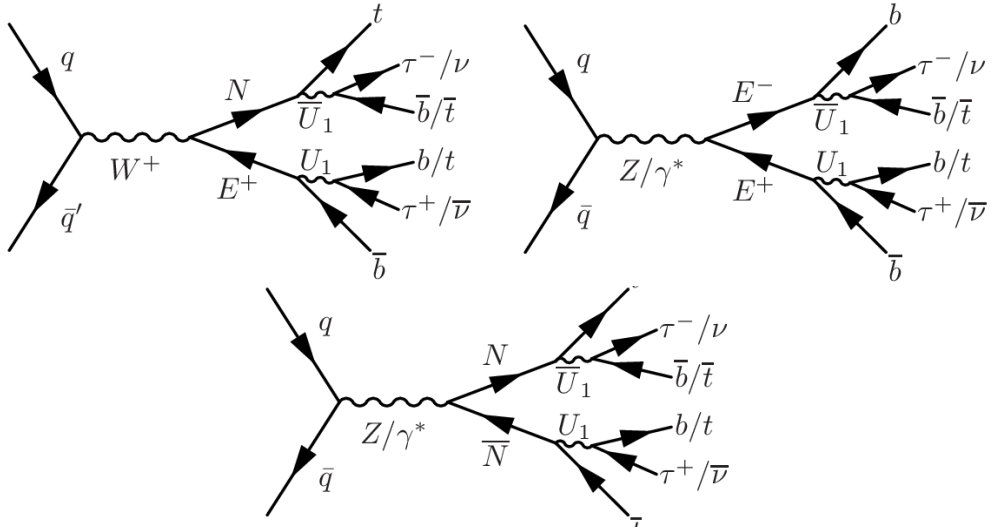
- Vector like leptons - UV-complete 4321 model
  - VLL favour decays via vector LQ into third generation quarks and leptons
- Signature with multiple τ, b-jets, jets, leptons and EtMiss ⇒Trigger Buckets strategy
- First time that ATLAS probes this model
- Signal regions characterised by the presence of b-jets and hadronically decaying tau leptons
- Using neural networks parameterised in the generated mass of the VLL signal

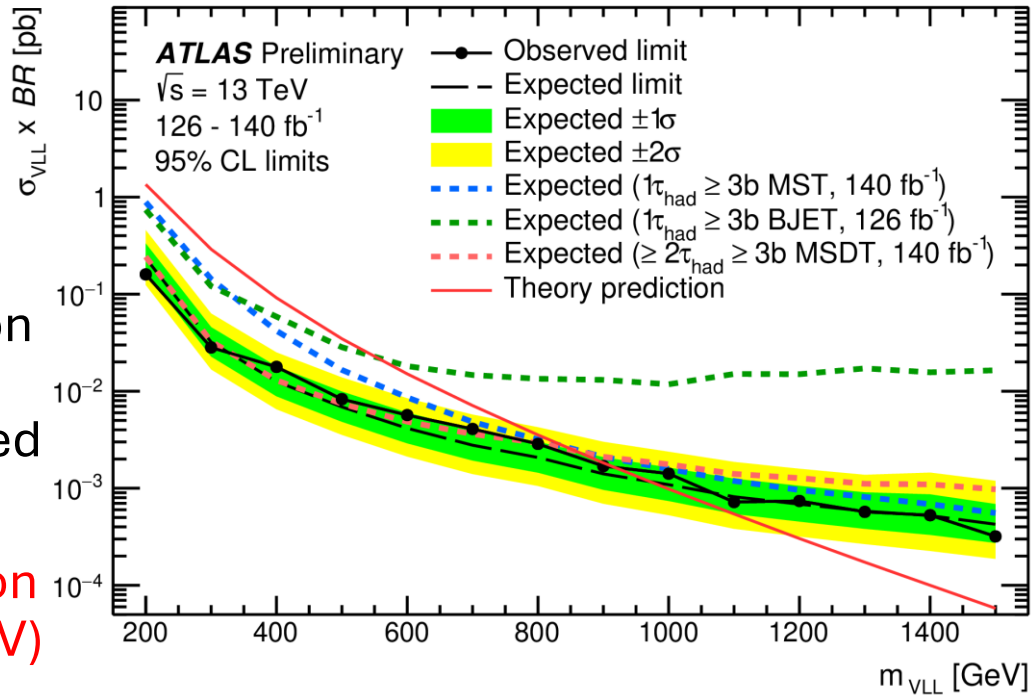
This ATLAS result rules out a 2.8σ excess previously reported by CMS



The 95% CL ULs on the production x-section times BR into 3rd generation SM fermions are derived as a function of VLL mass

Lower observed (expected) limit on the VLL mass at 910 GeV (970 GeV)

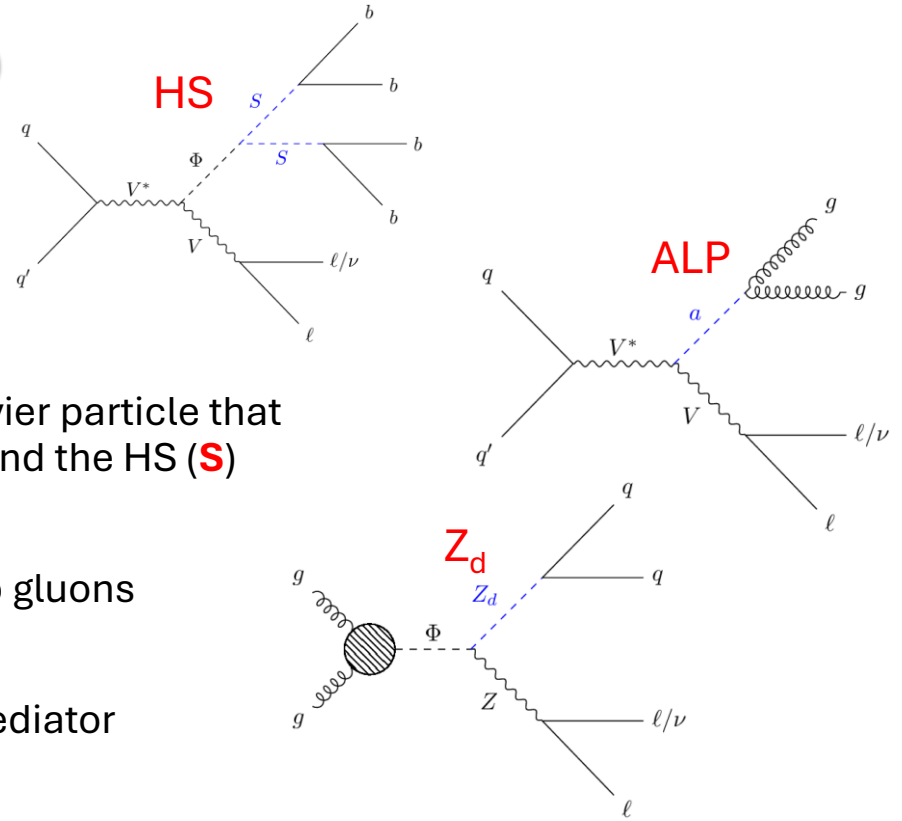




arXiv:2208.09700

2407.09183

Neutral LLPs decaying into displaced jets

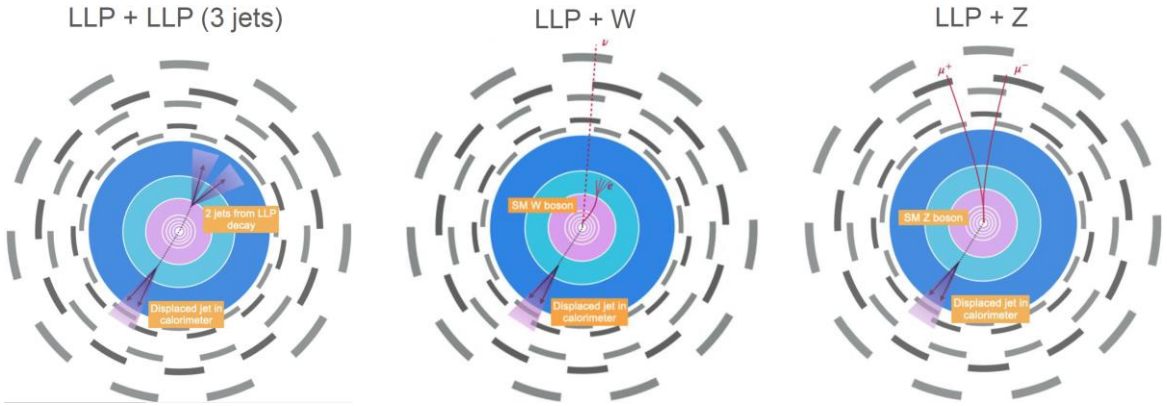


- Three benchmark models
  - Hidden Sector (HS) Model
    - A scalar boson Φ (the Higgs boson, or a lighter or heavier particle that behaves similarly) acts as mediator between the SM and the HS (**S**)
  - Photo-phobic Axion-Like Particle (ALP) Model
    - ALP (**a**) radiated from vector bosons and decaying into gluons
  - Long-lived Dark Photon (Z_d) Model
    - The $\mathbf{Z_d}$ is produced with a Z in the decay of a scalar mediator

2407.09183

Neutral LLPs decaying into displaced jets

- Three topological targets
  - Pair production in which one of the LLPs is resolved into two jets (three jets total)
    - Probes shorter lifetimes and lower boosts wrt previous analysis (arXiv:2203.01009)
  - Production in association with a W or Z boson
    - Can take advantage of higher-efficiency lepton triggers and search for new models such as axion-like particles (ALPs)



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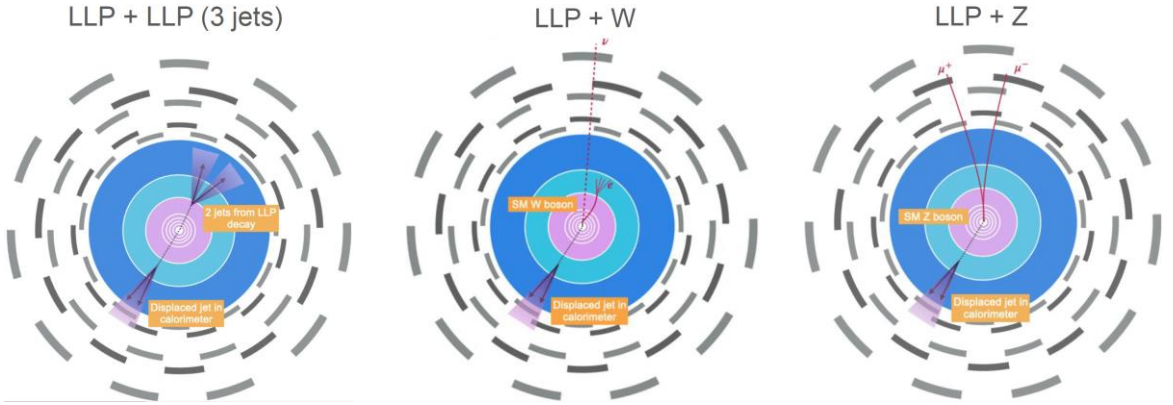
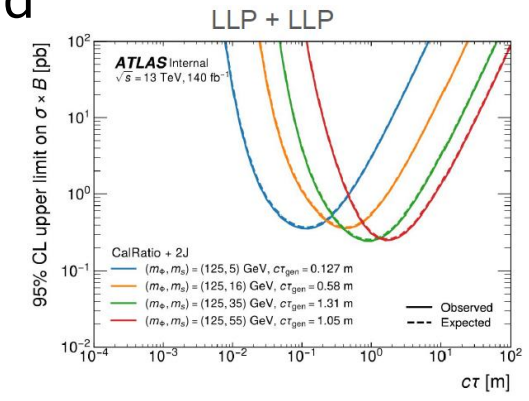
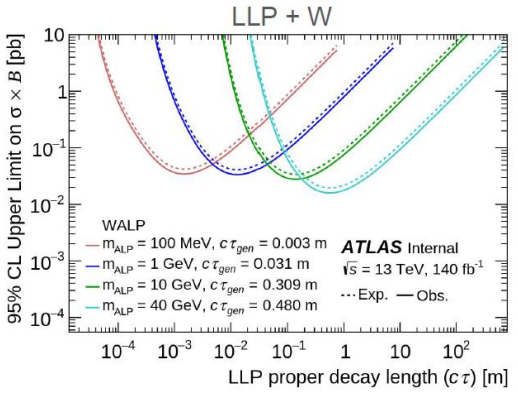
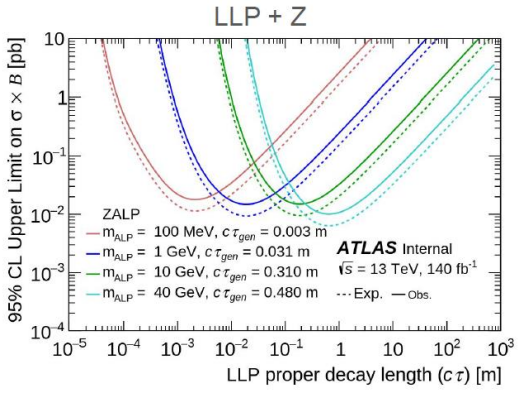
  - Production in association with a W or Z boson
    - Can take advantage of higher-efficiency lepton triggers and search for new models such as axion-like particles (ALPs)



- Trigger on either narrow, trackless jets with low ECal energy or leptons
- Data-driven bkg using ABCD method
- Per-jet NN to distinguish signal-like jets from SM jets or beam-induced backgrounds
- No significant excess found
  - New or improved upper limits set in each channel







Outlook

With its R1*-R2-R3** datasets ATLAS is working full steam toward…

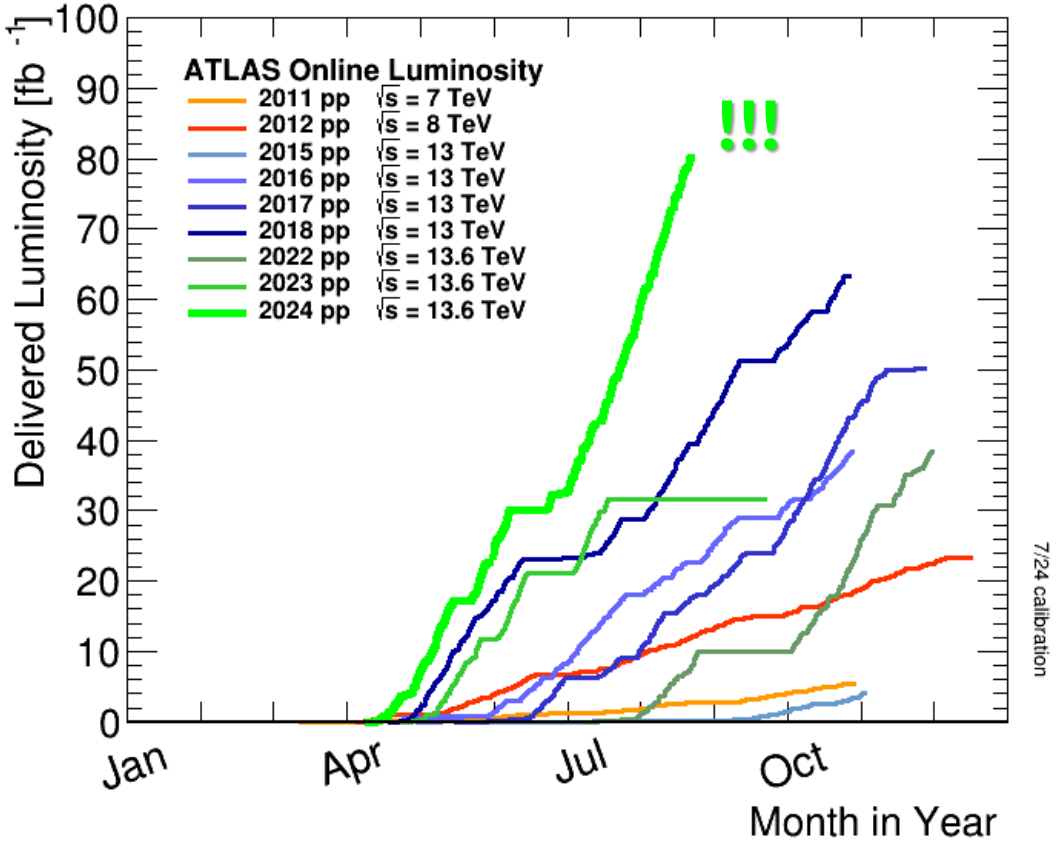
- … deepening and sharpening our knowledge of SM's fundamental parameters (precision frontier)
- … contributing to ever improving the control on systematics
  - not only on the experimental side
- … furthering our knowledge of the Higgs boson sector
  - both on the production and on the decay sides
- … turning every stone in the quest for BSM physics (search frontier)
  - in SUSY, but also in Exotic scenarios
- … significantly improving the performance of reconstruction and analysis tools

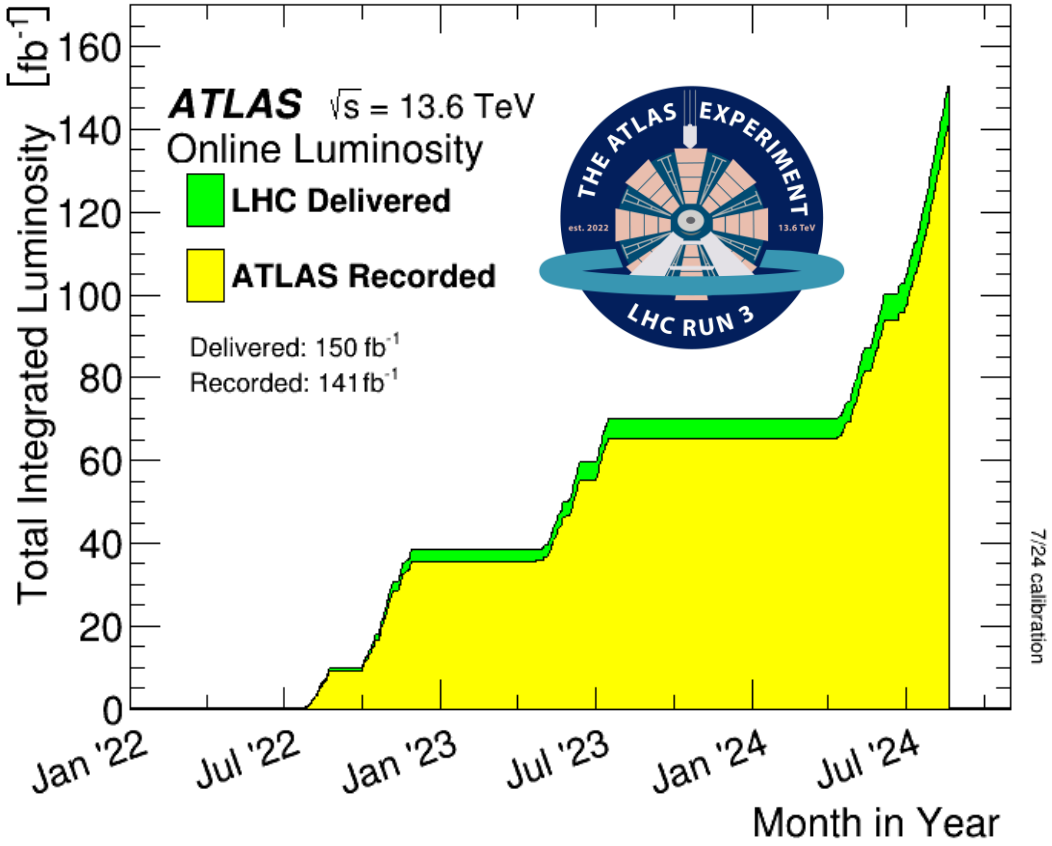
* Still ripe of cutting edge results

** Already producing amazing results, while still fast growing in size (see next slide)

And the future is at the same time promising...

- keep exploiting the “older” (but far from stale) datasets, while **enlarging the breadth of analyses making use of Run3**
  - which is growing fast:





… and challenging (but also ambitious): HL-LHC

- Turn LHC into a **veritable Higgs factory**
  - 400M Higgs bosons in ATLAS & CMS
  - precise Higgs coupling measurements
  - access to Higgs self interaction
  - longitudinal vector boson scattering
- While significantly increase the overall **sensitivity to rare & new physics**
- **ATLAS HL upgrades**
  - high-granularity, high-coverage **tracker**
  - high-granularity **timing detector**
  - **muon** chambers
  - improved **trigger**
  - high-performance **software & computing**
  - deeply embedded **machine learning**

ITk

Full silicon tracker upgrade
with
improved granularity, extended coverage,
better performance
(under much harsher conditions)