ATLAS Highlights

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IFIN-HH, Bucharest, Romania

2026, November 16th

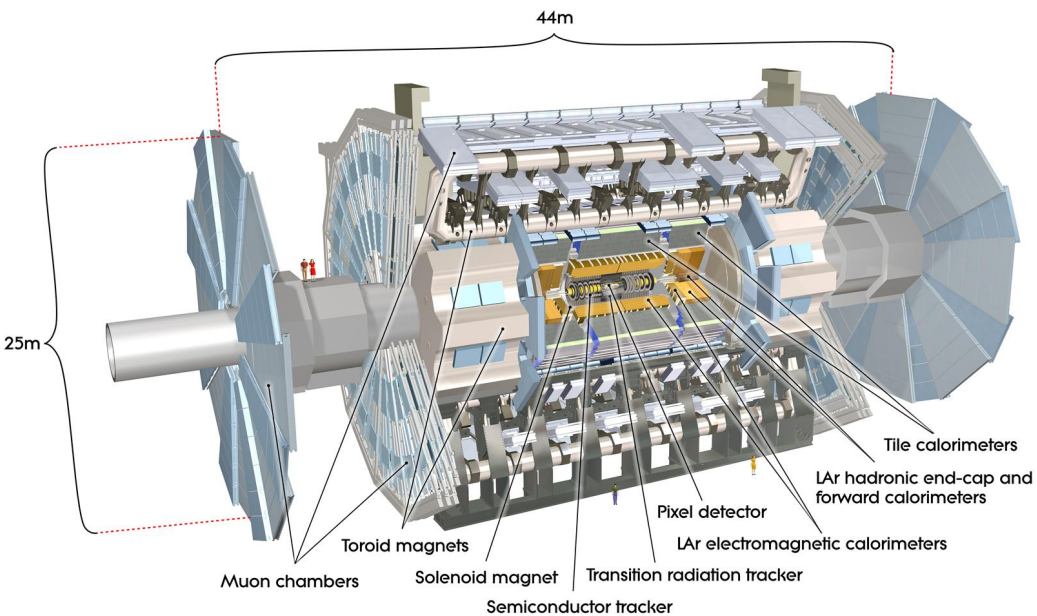
DISCRETE 2026, Bratislava, Slovakia

ATLAS public page

ATLAS detector

General-purpose detector with excellent reconstruction, identification, and energy/momentum resolution for e, γ, μ, τ, and jets, complemented by powerful flavour-tagging capabilities:

- γ energy calibration to 0.2% at 60 GeV, $e^{\pm}$ energy calibration to 0.05% at 45 GeV
- $\mu^{\pm}$ momentum calibration to 0.1-0.05%
- jet energy calibration to 1% above 60 GeV
- τ energy calibration to $\sim 1\%$



New for LHC Run-3 (2022-2026):

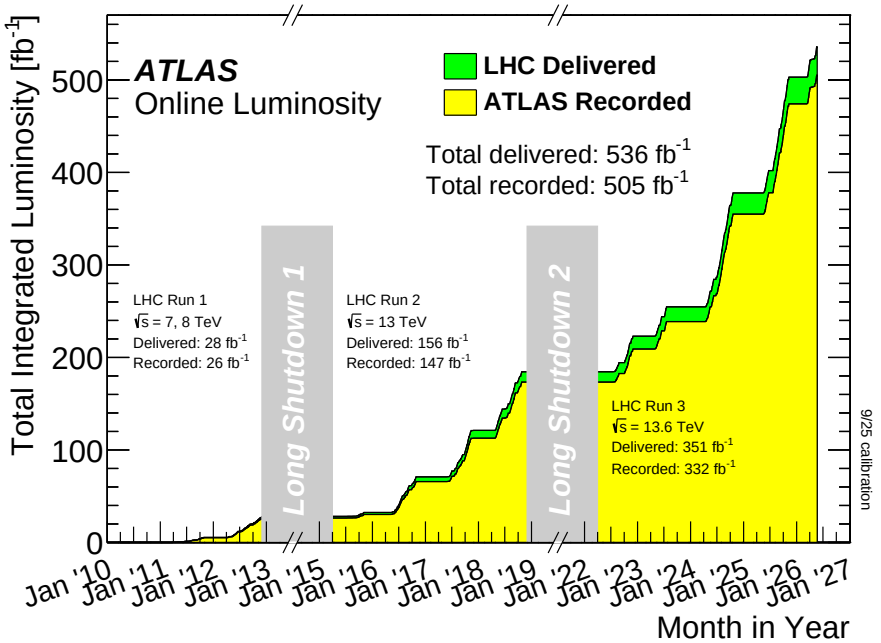
- Muon New Small Wheel (reduce trigger fakes)
- Energy LAr calorimeter electronics with higher granularity for trigger
- L1 endcap muon and calorimeter triggers

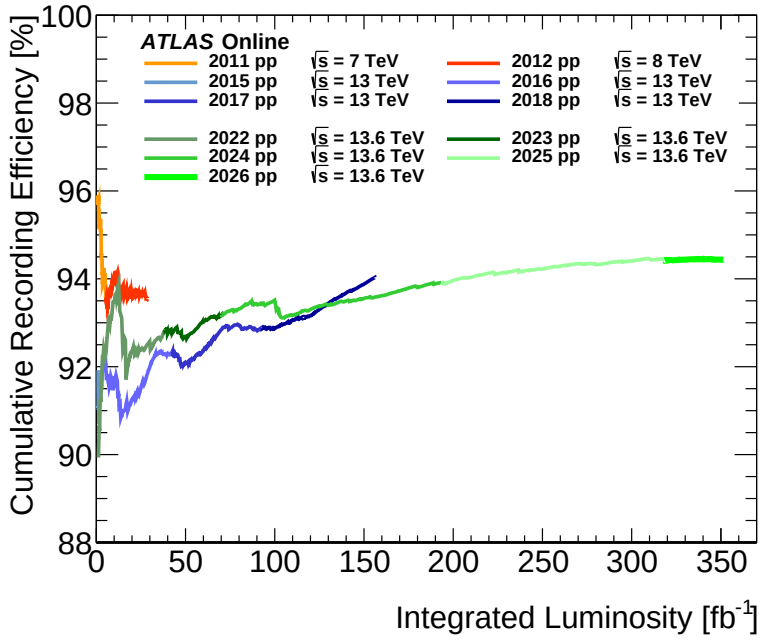


LHC Run-1 + Run-2 + Run-3: more than 500 fb^{-1} recorded lumi by ATLAS

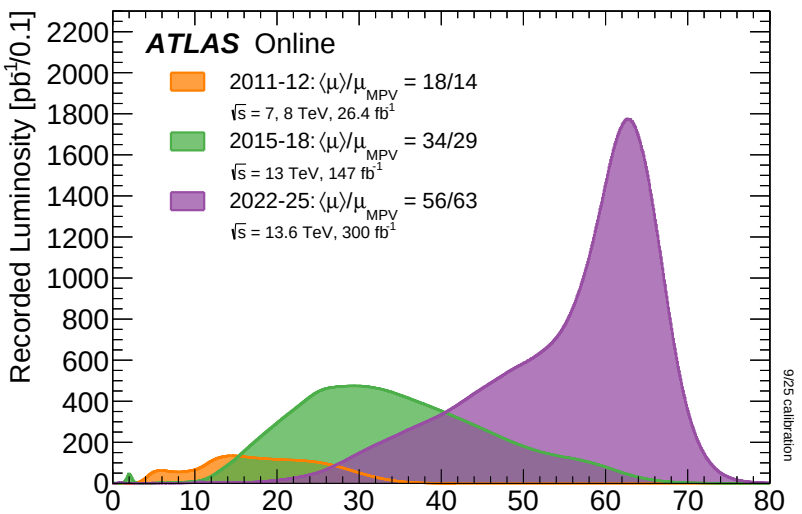
- Excellent achievement by the accelerator & detector teams

ATLAS data

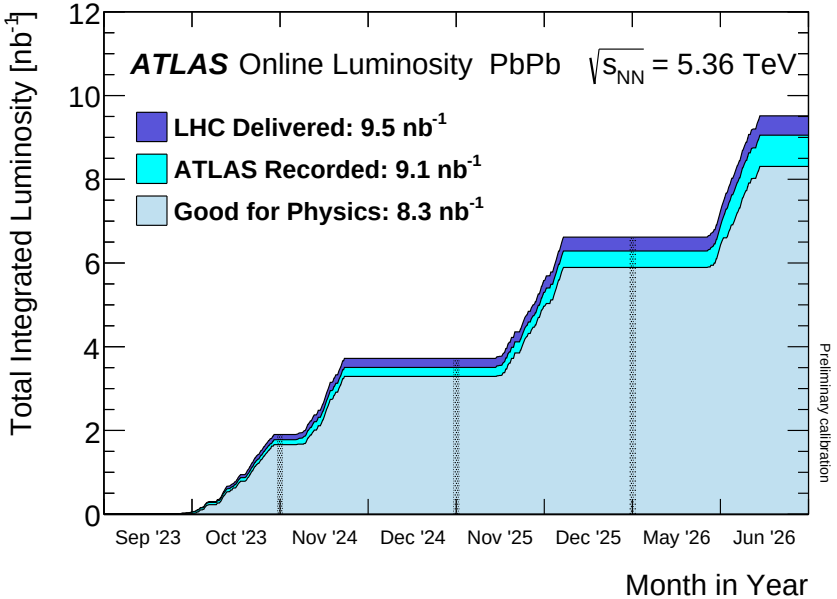


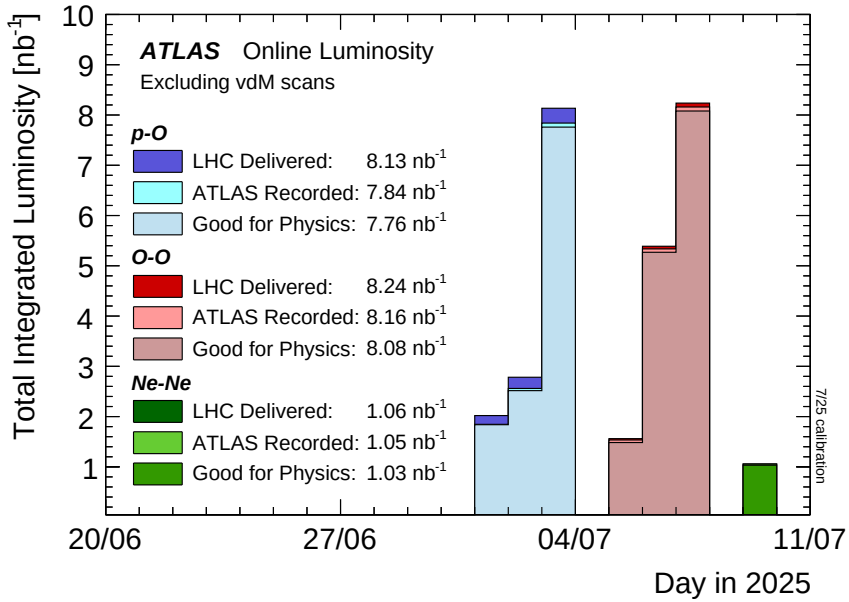


- ATLAS records $\sim 95\%$ of delivered *pp* data, with $\sim 94\%$ good for physics
- Special 2026 low-μ run ($\langle\mu\rangle = 3$): 1.3 fb^{-1} recorded at 96% efficiency, more than doubling the Run-2 low-μ dataset
- *See Lumi public plots for additional details*



In addition to *pp* collisions, ATLAS has an extensive heavy- and light-ion programme:



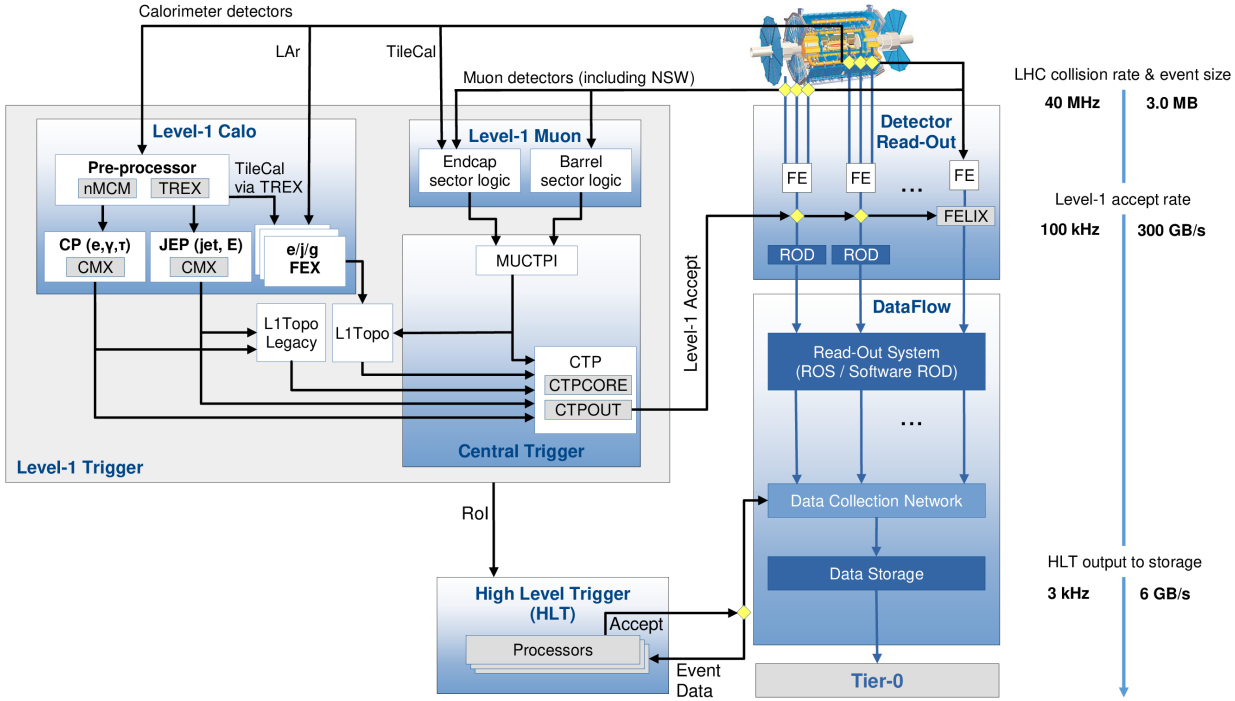


- (Left) Pb-Pb collisions at $\sqrt{s} = 5.36$ TeV/NN centre-of-mass energy in LHC Run-3
- (Right) Proton-Oxygen, Oxygen-Oxygen, and Neon-Neon collisions in 2025
- *See public plots for additional details*

Why heavy and light ions collisions? (more info here)

- Characterizing microscopic properties of QGP
- Investigating initial state effects in ion collisions
- Direct probe of nuclear structure
- New testing ground for jet quenching when light ions

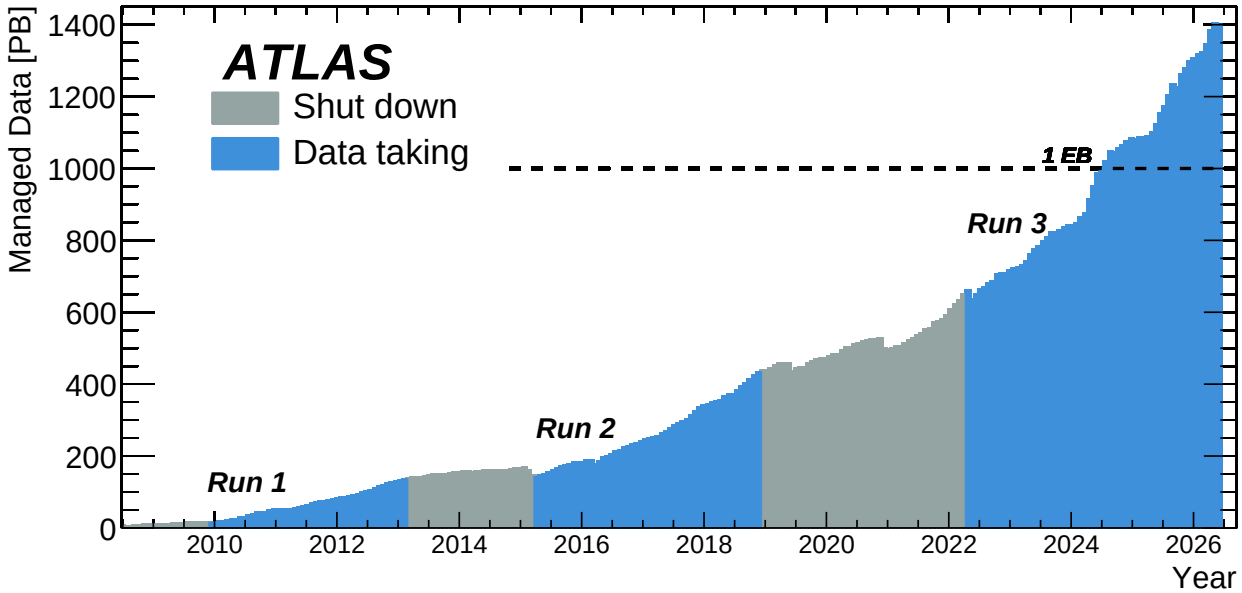
ATLAS trigger system in Run-3



- Phase-I upgrade during LS2 → TDAQ and NSW
  - LAr readout system: traditional trigger towers replaced by finer-granularity Super Cells, providing layer-by-layer calorimeter information with up to four times finer segmentation
- Inclusion of ML at all levels
- New triggers for measurements and searches
- *See paper for additional details*

Trigger Selection offline threshold (GeV)	Run 1	Run 2	Run 3
isolated single e	25	27	27
Isolated single μ	25	27	**25**
di-γ	25,25	20,20	20,20
di-τ	40,30	40,30	**35,25**
four-jet w/ b-jets	4x45	4x45	4x45 + asymmetric
HT	700	700	700
MET	150	200	200

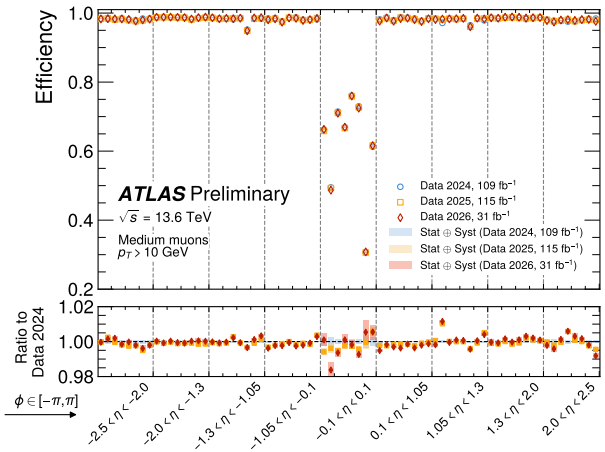
ATLAS computing in Run-3

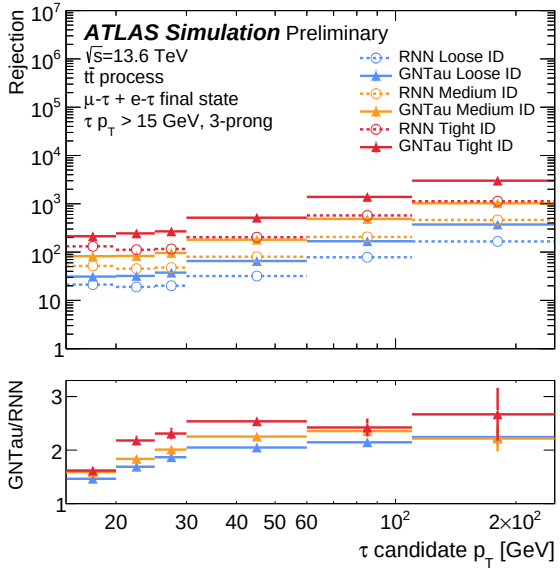


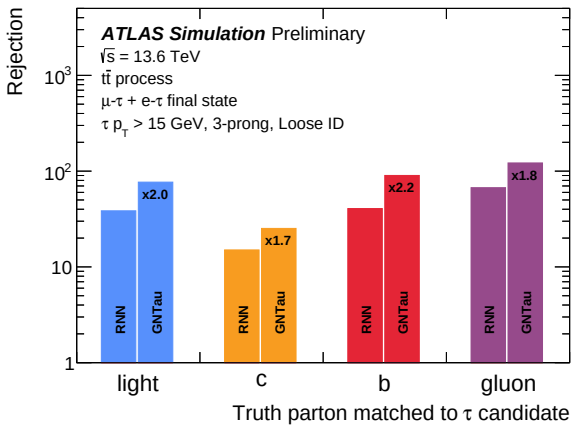
- ATLAS records over 10,000 TB of data per year!
- ATLAS software and computing system processes and stores this vast amounts of collision data collected by the detector
  - After, the data are distributed to over 130 computing centers worldwide – located on every inhabited continent – and filtered according to the needs of individual physics analyses (link)
  - As part of these analyses, ATLAS processes 25,000 TB of data every week
- Detector simulation dominates CPU usage: AtlFast3 a great success!
- *See link and paper for additional details*

ATLAS OBJECTS PERFORMANCE

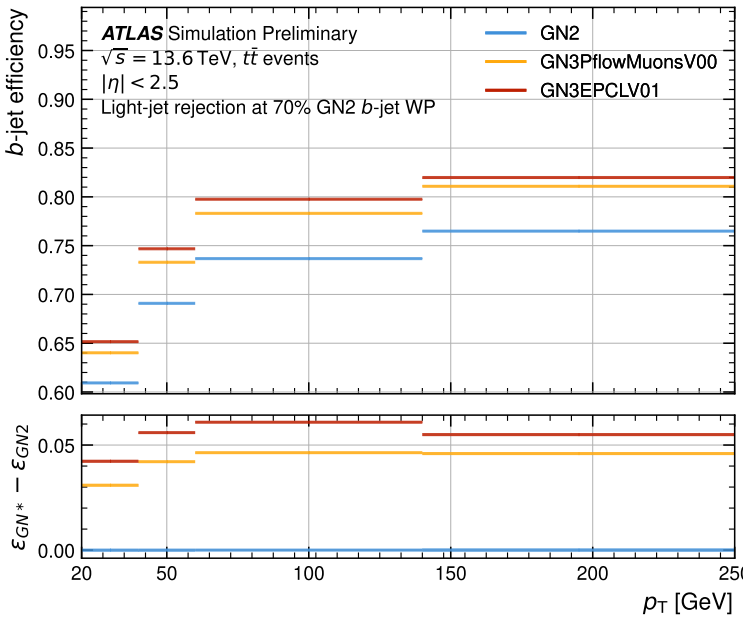
Advanced ML algorithms plus lots of data: significant improvements in the object reconstruction, identification, tagging, etc.

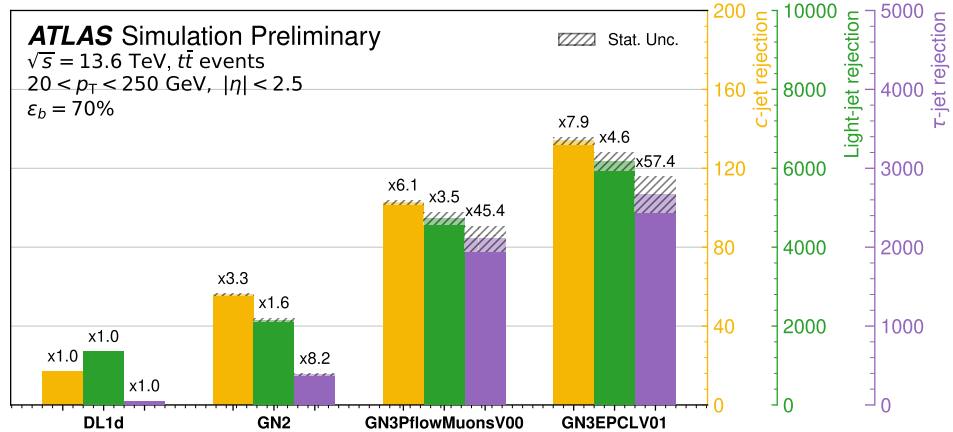






- (Left) Excellent muon reco and identification also in Run-3
- Comparison of RNN and GNTau jet rejection versus tau p_T $\rightarrow$ recurrent neural network vs. the new transformer architecture
- *See twiki and twiki for additional details*



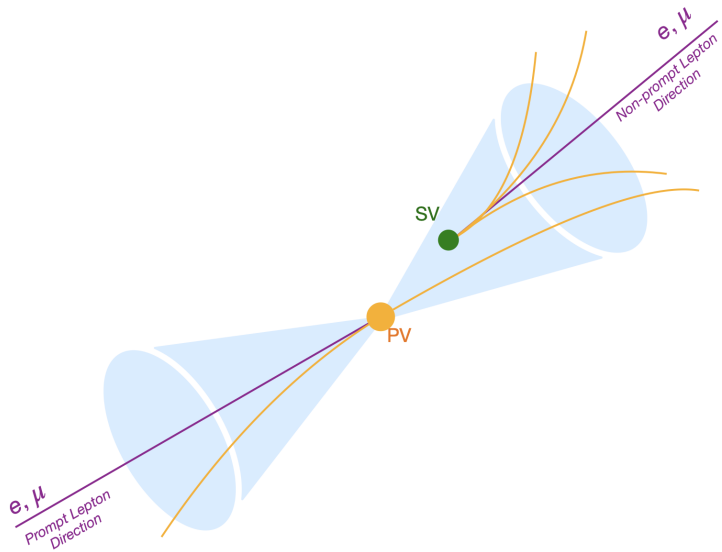


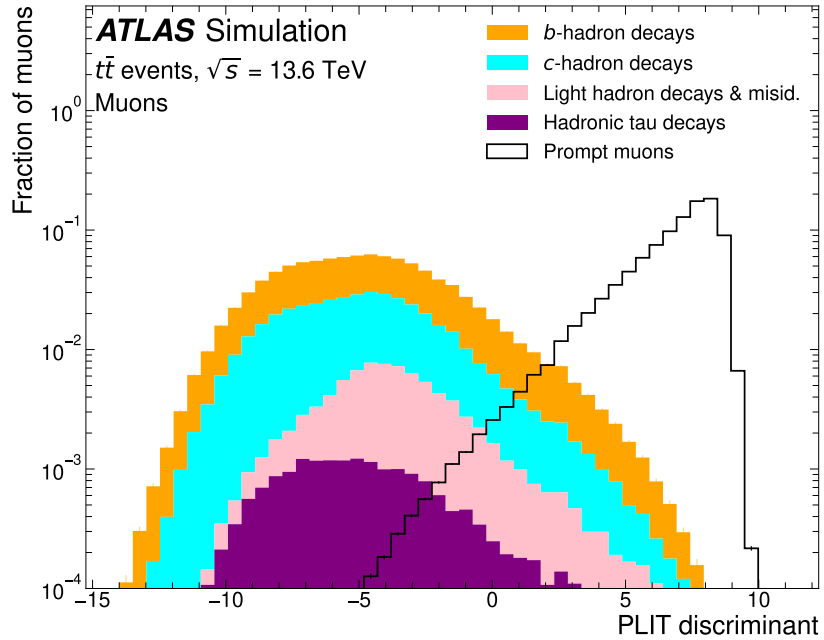
- (Left) Jet Flavor tagging with GN3: Multi-task, Multi-modal Transformers

→ GN2→GN3: continued improvement incorporating new object association algorithm, soft-lepton info, charged and neutral particle-flow objects, etc.

  - GN3EPCLV01: first model with heavy flavour quark charge identification capabilities

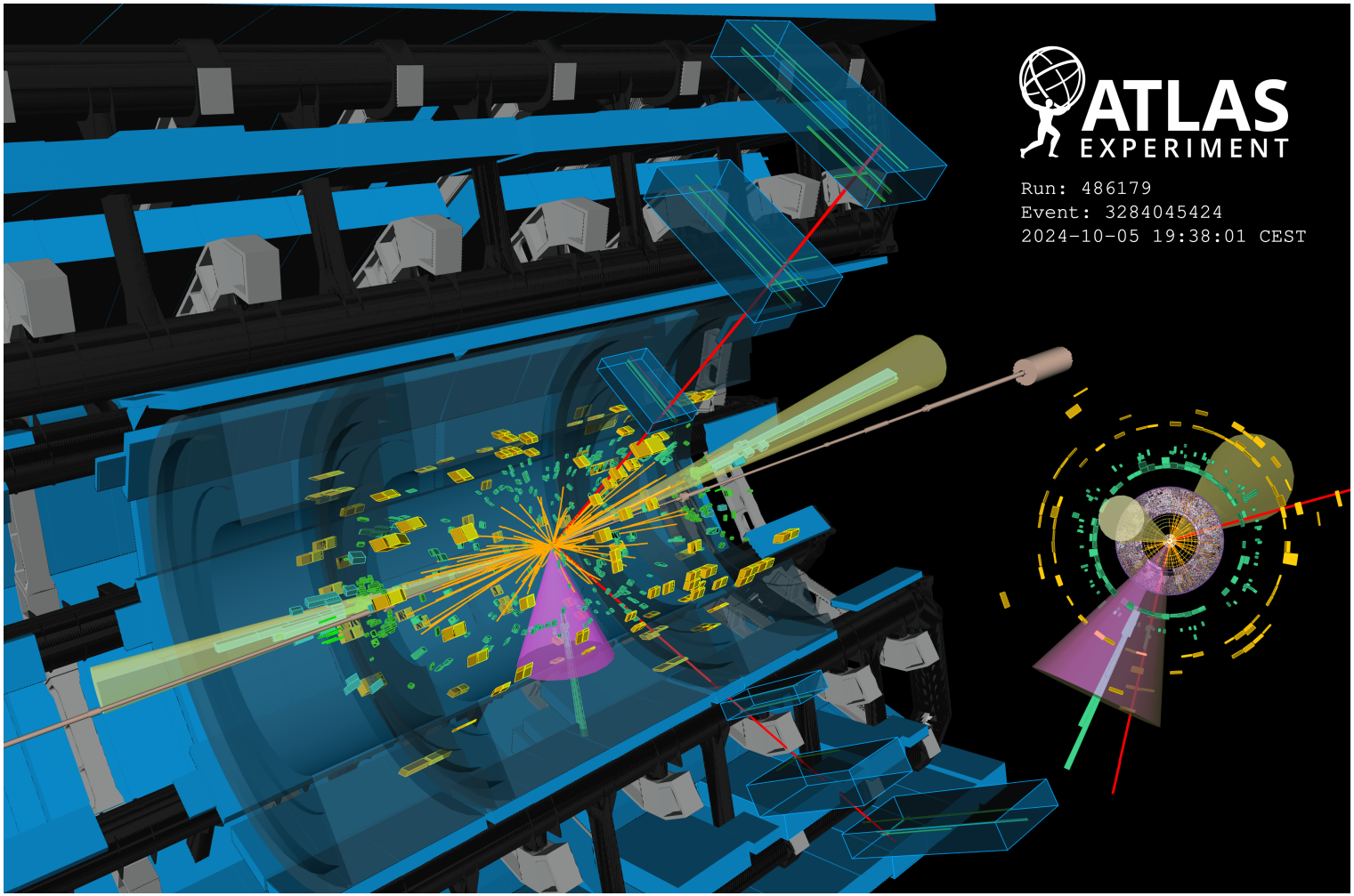
- *See paper, paper, figures and figures for additional details*



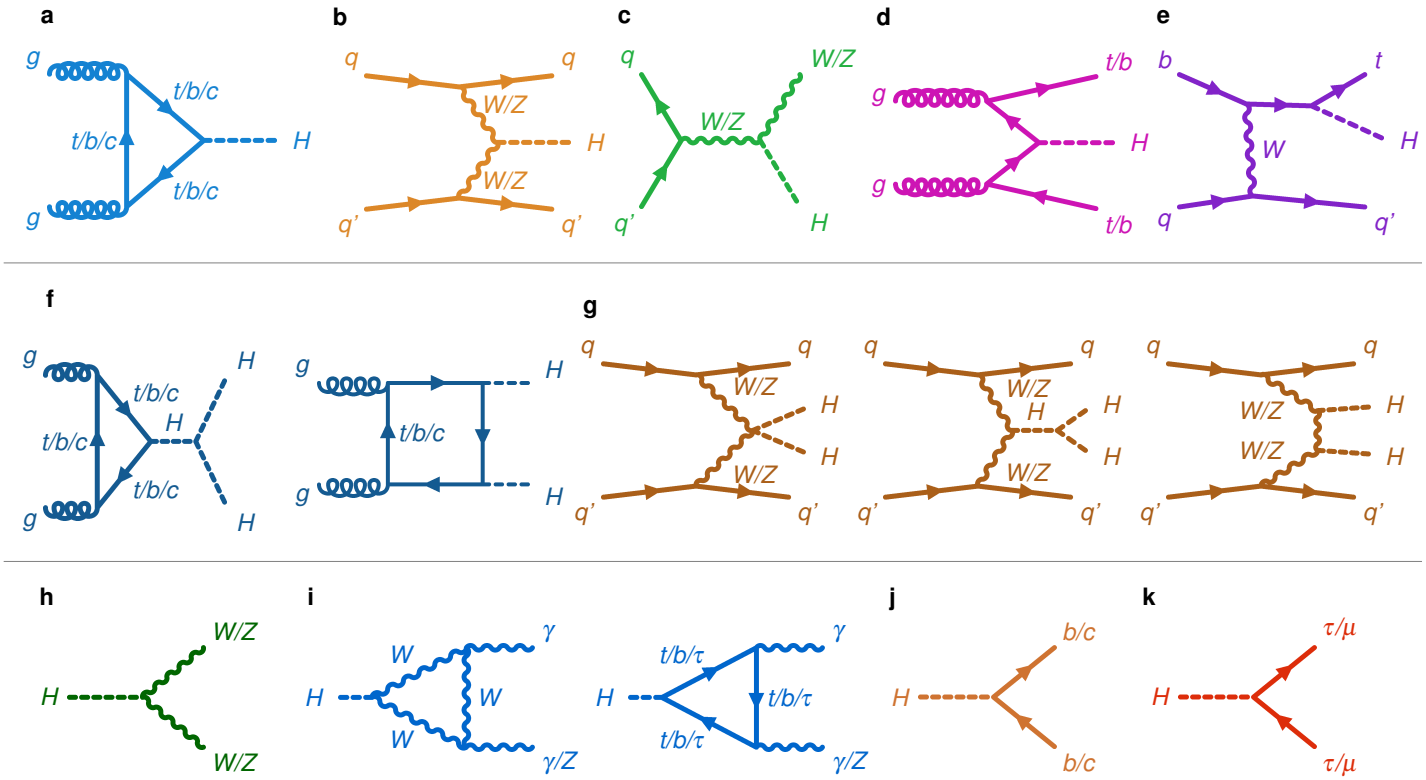


- Transformer-based lepton isolation → algorithm based on the GN2 transformer architecture developed for the heavy-flavour jet tagging!
  - Trained to distinguish prompt light leptons produced in electroweak boson decays, from non-prompt leptons produced predominantly in heavy-flavour hadron decays
  - Combines conventional isolation observables with detailed track-level information sensitive to displaced heavy-flavour decays
- *See paper and figures for additional details*

The Higgs boson



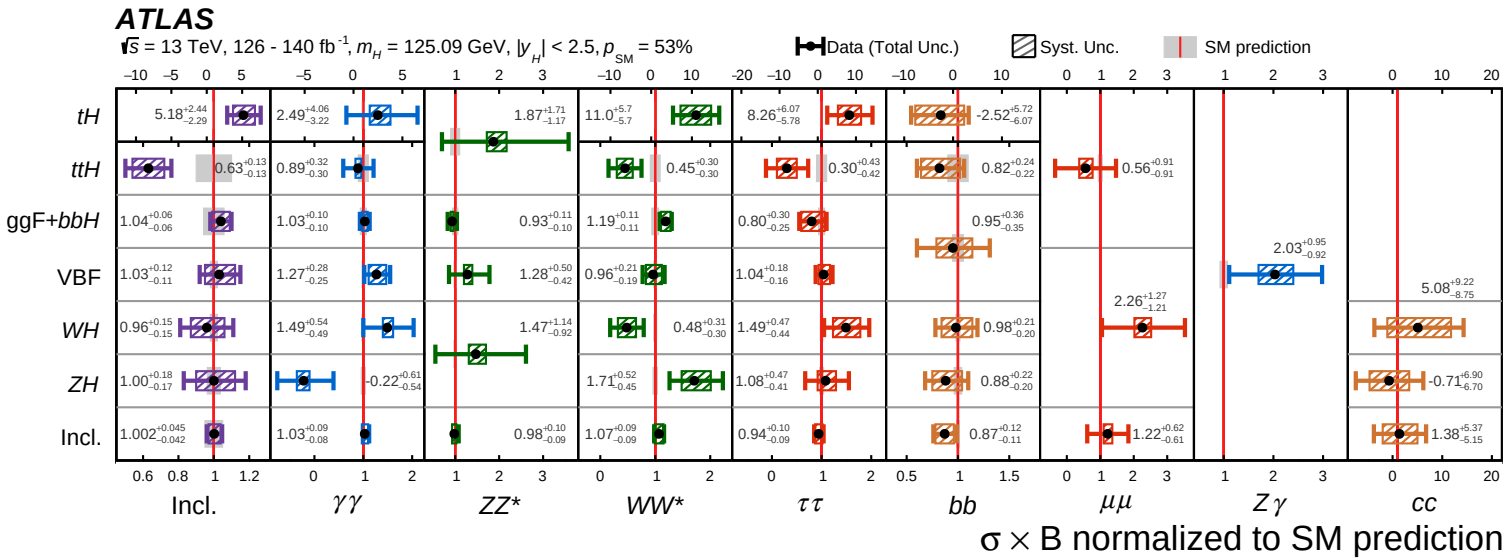
$H \to Z\gamma \to \mu\mu\ \gamma +$ two forward jets (*ATLAS event displays*)



- Higgs boson mass: $m_H = 125.09 \pm 0.21$ (stat.) ± 0.11 (syst.) GeV from ATLAS+CMS combination
- Inclusive Higgs boson signal strength relative to its SM expectation: $0.990^{+0.053}_{-0.051} = 0.990 \pm 0.027(\text{stat.}) \pm 0.024(\text{exp.})^{+0.037}_{-0.035}(\text{sig. theo.})^{+0.016}_{-0.015}(\text{bkg. theo.})$, in agreement with SM predictions
- *See paper and paper for additional details*

Latest paper presenting the combination of Higgs boson measurements: arXiv:2608.07332

- Provides the most precise and comprehensive ATLAS measurements of Higgs boson production, decays, and couplings, combining 26 Run 2 single- and di-Higgs analyses



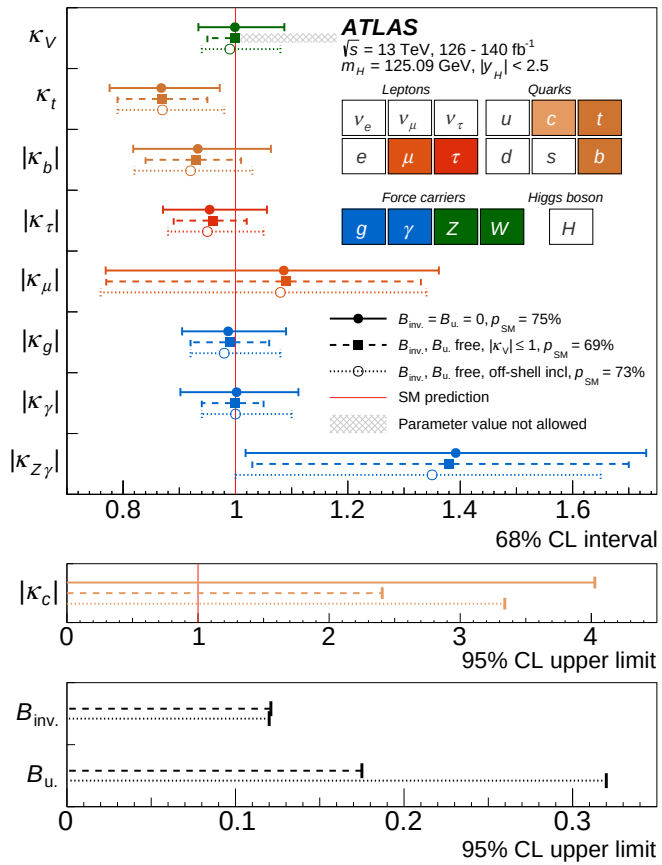
Measured values of ($\sigma_i \times B_i$) for the measured combinations of production cross-sections and branching ratios, relative to their SM predictions.

- Higgs boson production cross-sections are consistent with the SM predictions, with relative uncertainties of 6–21% across observed processes
- *tH* process remains unobserved
- Significant improvements in the measured rates of associated Higgs production: observed uncertainties reduced by 30% (WH), 20% (ZH), and 40% (ttH), with expected uncertainties reduced by up to 35% compared to the previous analysis

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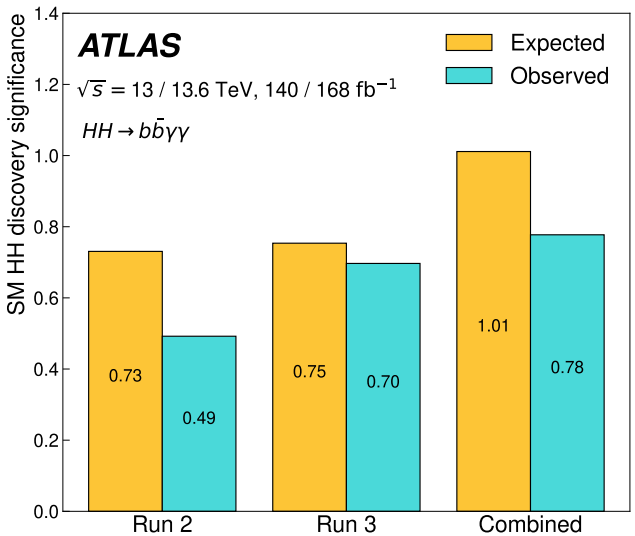
- Couplings to W, Z, t, b, τ measured with 5-12% precision
- Charm Yukawa coupling constrained to $|\kappa_c| < 4.1$ (95% CL)
- $\mathscr{B}(H \to \text{inv}) < 12\%$ (95% CL)
- Higgs boson width $\Gamma_H = 3.6^{+2.1}_{-1.6}$ MeV
- Self-coupling constrained to $-1.5 < |\kappa_\lambda| < 6.5$ at 95% CL based on single and di-Higgs analyses

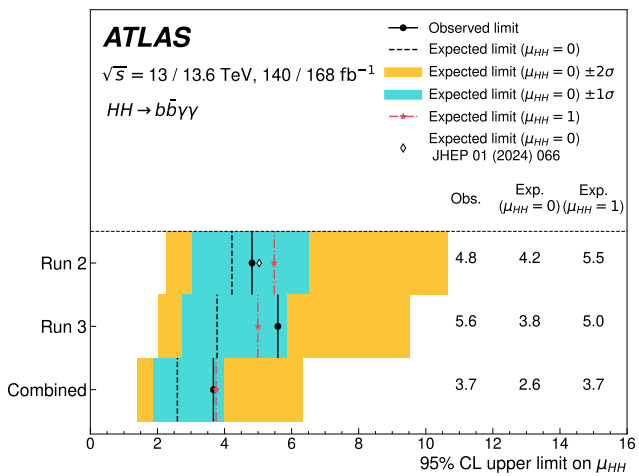


Search for double-Higgs production

Higgs boson pair production (di-Higgs) is one of the rarest processes at the LHC

- Predicted to occur once in a trillion proton-proton collisions
- Probe of Higgs self-coupling: crucial to understand the nature of the EW phase transition and the stability of the EW vacuum
- $HH \to b\bar{b}\gamma\gamma$ channel, using 308 fb^{-1} of 2015–2024 Run-2 + Run-3 data
- Signal strength: $\mu_{HH} = 0.9^{+1.4}_{-1.1}$ ($\mu_{HH} = 1^{+1.3}_{-1.}$ expected)
- Background-only hypothesis (no HH production): an upper limit of 2.6σ





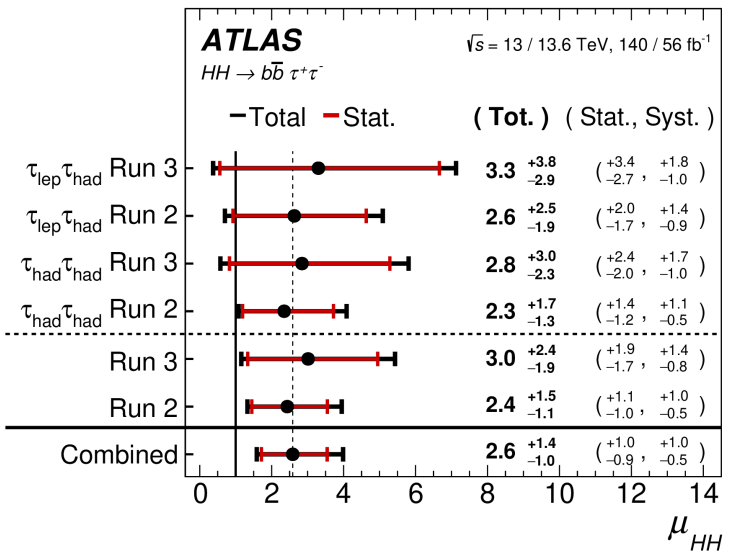
- The magnitude of the Higgs boson self-coupling normalised to its SM prediction (κ_λ), limited to be between -1.6 and 6.6 (95% CL)
- *See link and paper for additional details*

Search for double-Higgs production

- $HH \to b\bar{b}\tau\tau$ channel, using the 196 fb^{-1} of 2015–2023 Run-2 + Run-3 data

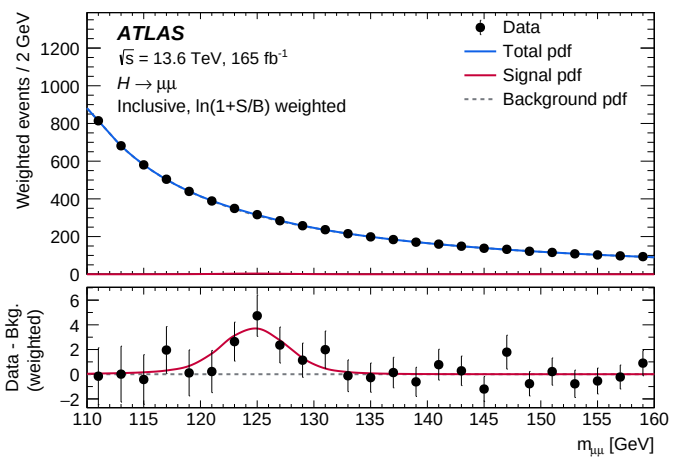
→ **Two complementary tau signatures: $\tau_{\text{had}}\tau_{\text{had}}$ and $\tau_{\text{lep}}\tau_{\text{had}}$**

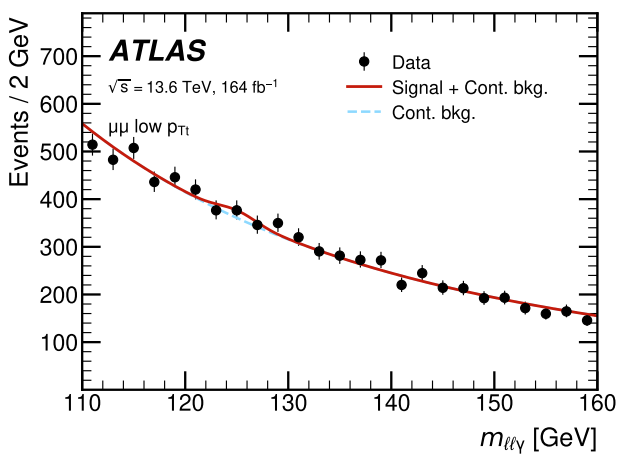
- Signal strength: $\mu_{HH} = 2.6^{+1.4}_{-1.0}$, compatible with the SM prediction ($\mu_{HH} = 1$) within 1.65σ
- Background-only hypothesis (no HH production): observed excess signif. of 2.6σ (expected: 1.2σ)
- Improvements compared to previous HH search:
  - Transformer-based machine-learning classifier
  - Took advantage of the improved jet flavor tagger
  - Counted on the additional trigger chains introduced during Run-3
  - More data
- *See link and paper for additional details*



Hunting some of the rarest Higgs decays

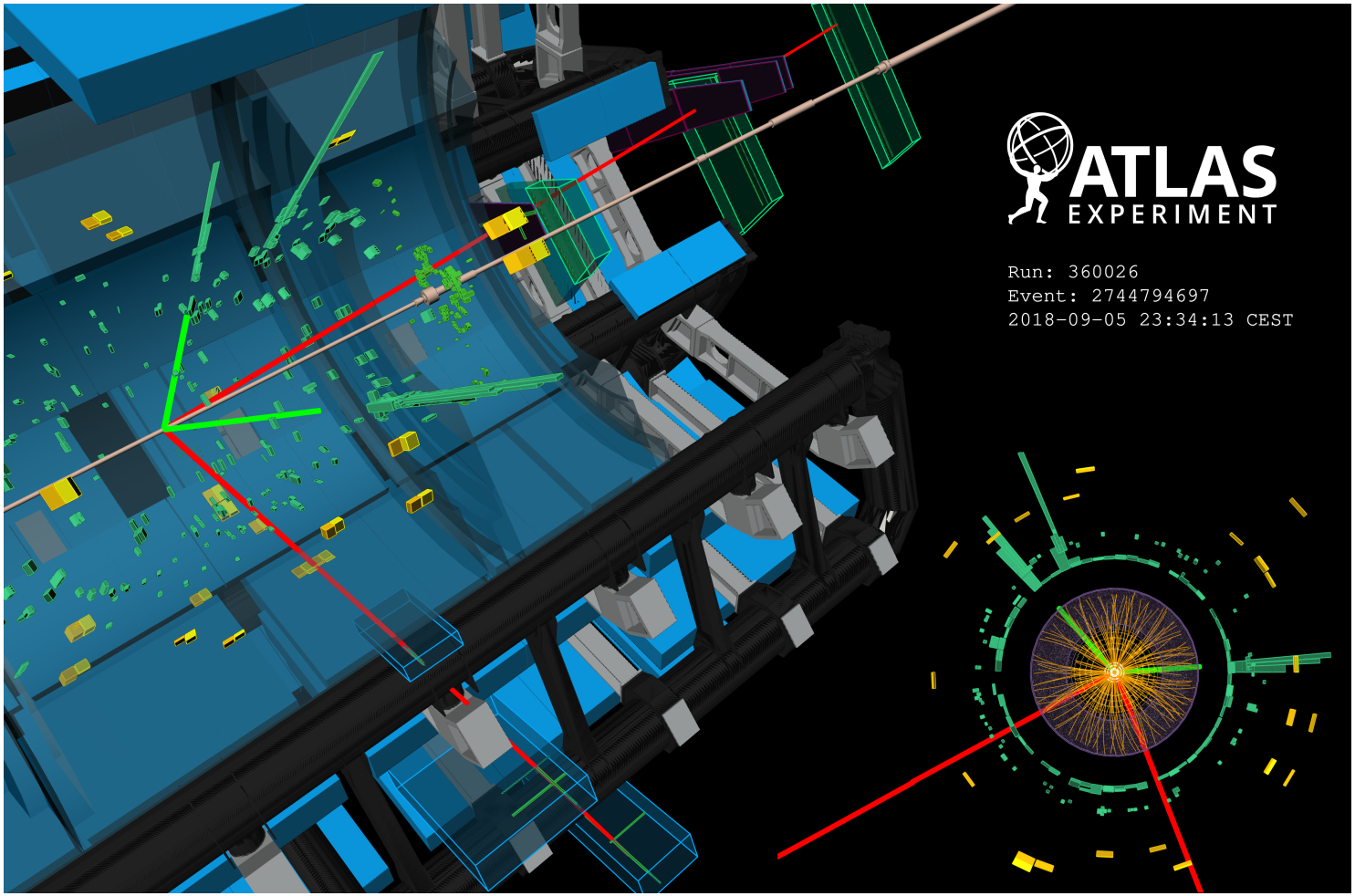
- $H \to \mu\mu$: direct probe of the Higgs Yukawa coupling to 2nd generation fermions
  - Latest analysis performed with Run-3 data, using 165 fb^{-1}
  - Run-3 results combined with the Run-2 measurement
  - Evidence for the $H \to \mu\mu$ rare decay with an observed (expected) significance over the bkg-only hypothesis of 3.4σ (2.5σ)
- $H \to Z\gamma$: Loop-induced decay, sensitive to BSM contrib. that can modify $\mathscr{B}(H \to Z\gamma)$
  - Evidence reported by the ATLAS and CMS combo with Run-2 data (3.4σ observed)
  - Latest ATLAS results combining Run-2 and Run-3 data: observed (expected) excess over the bkg-only hypothesis of 2.5σ (1.9σ)
- $H \to \gamma^*\gamma \to \ell\ell\gamma$: sensitive to coupling modifications introduced by possible SM extensions
  - Event selection targeting $m_{\ell\ell} < 30$ GeV (Run-3, 164 fb^{-1})
  - Evidence for this decay with an observed (expected) significance of 3.4σ (3.3σ)





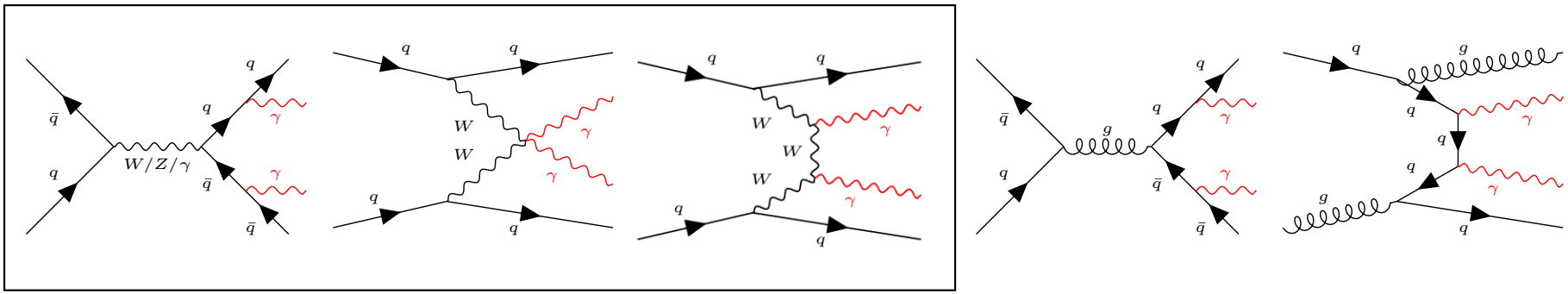
- *See link, link, paper and paper for additional details*

$ZZ\gamma \to \ell\ell\ell'\ell'\gamma$



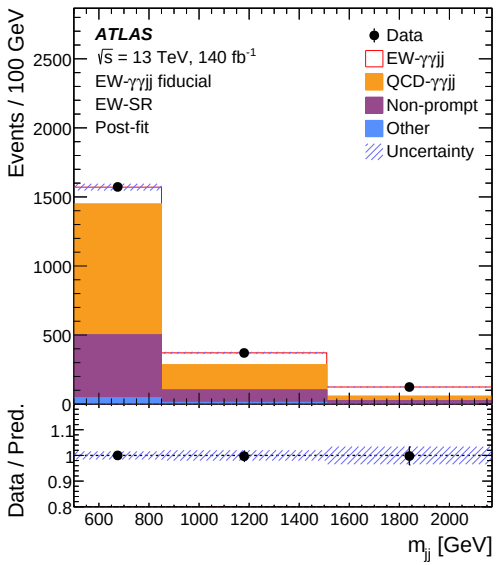
- Using the Run-2 dataset, ATLAS reported the first evidence of $ZZ\gamma$ production (paper)
  - Eight events selected, with 0.92 ± 0.15 estimated background events
  - Observed significance of the $ZZ\gamma$ final state of 4.4σ

VECTOR BOSON SCATTERING: ELECTROWEAK PRODUCTION OF $\gamma\gamma jj$

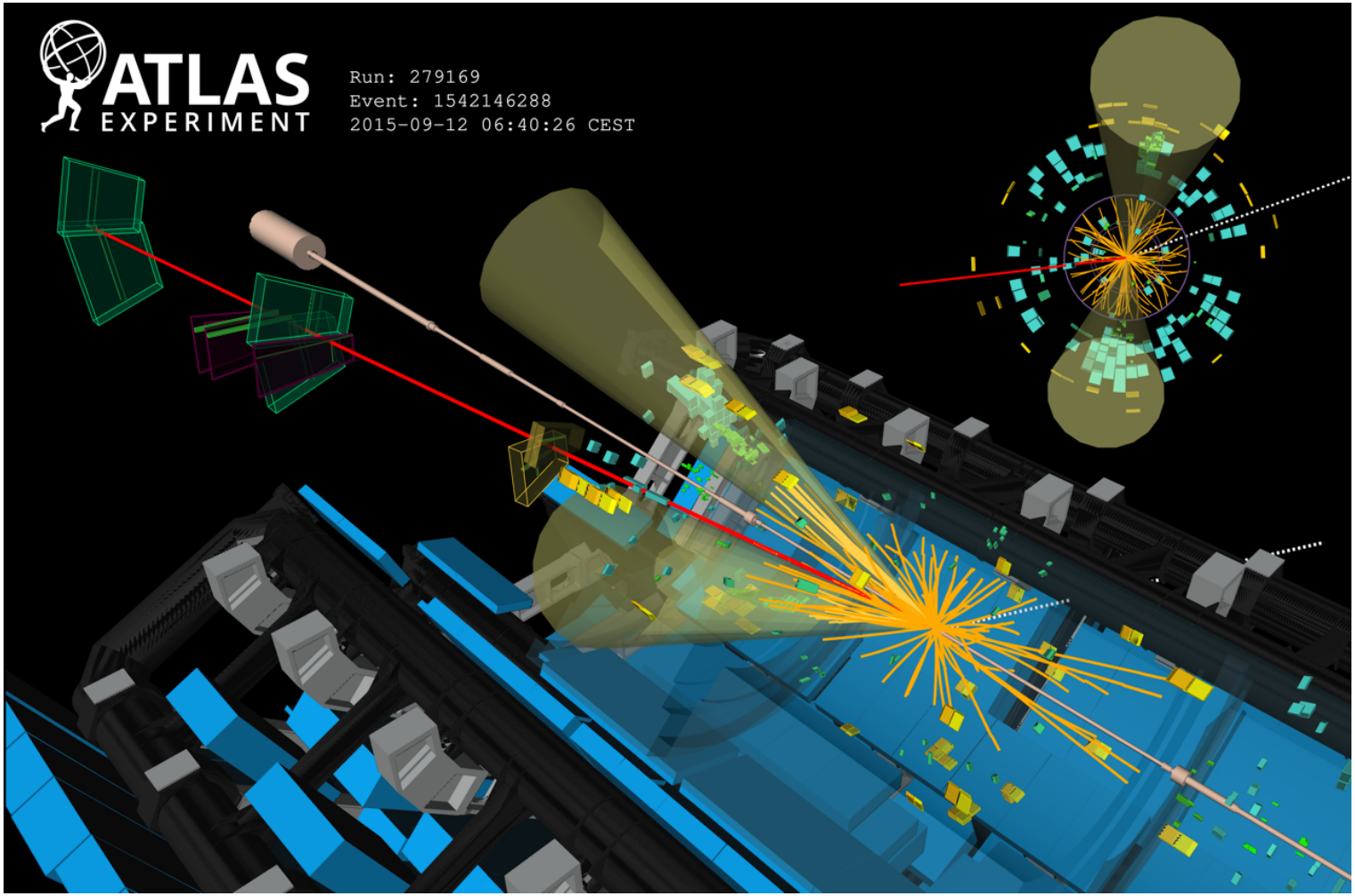


- Distinctive experimental signature: two high-energy and well separated jets, and two photons
- Very high background (around 1000 times more likely): two photons and two or more jets produced via strong interaction (QCD-$\gamma\gamma jj$)

- First observation of the electroweak production $\gamma\gamma jj$, with an observed significance of 6.2σ
- Measured fiducial cross-section: $\sigma_{\text{obs}}^{\text{EW}} = 13.8^{+3.0}_{-2.6}$ fb ($\sigma_{\text{SM}}^{\text{EW}} = 17.1^{+2.4}_{-2.4}$ fb)
- *See link and paper for additional details*



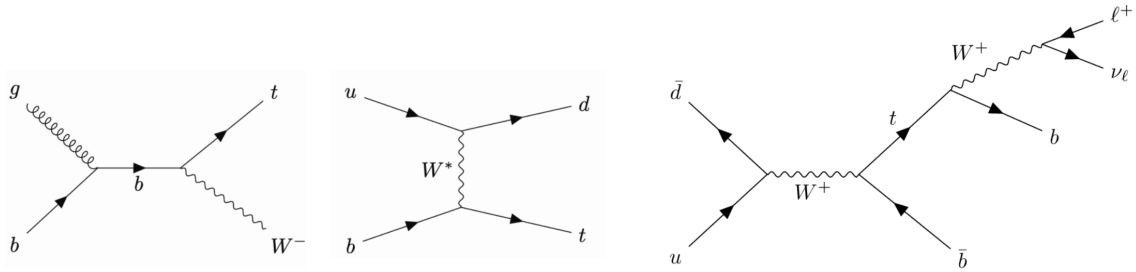
Top quark



s-channel single top-quark production in a muon with (two) jets topology (*link*)

Single top

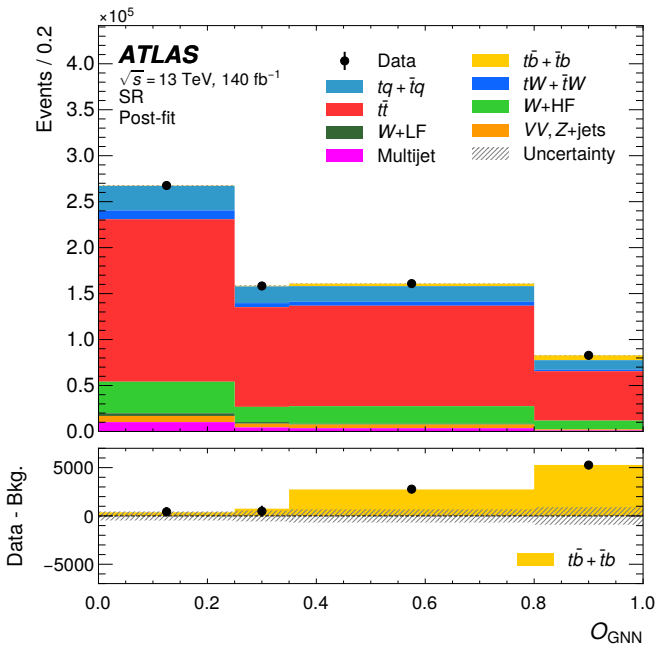
LO Feynman diagrams of single top-quark production in the tW-channel, t-channel and s-channel



- t-channel and tW production studied extensively in ATLAS
- s-channel first observed in 2014 at Tevatron (CDF + D0 combination)

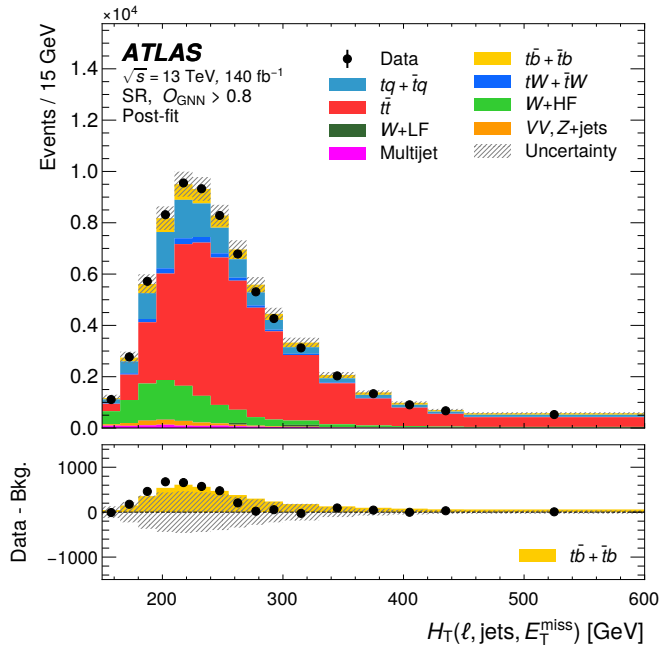
- In ATLAS, its study is very challenging → very rare signal events among huge backgrounds
  - Signal over backgorund more favourable for Tevatron than at LHC!

- Sensitive signal regions obtained using:
  - A Graph NN to separate the signal from bkg
  - GN2 for the Jet Flavor tagging → three times more signal events selected compared to the previous analysis
  - Precise theoretical modelling



In ATLAS, the s-channel signal observed for the first time in 2026 with a statistical significance of 5.1σ (compared to an expected 5.2)

- Measured cross section: 10.8 ± 1.5 (stat.) ± 1.6 (syst.) pb, in agreement with the SM prediction of 11.07 ± 0.19 pb
  - The most precise cross-section measurement of this process to date, with an unc of 20%
- For comparison: $\sigma(tq + \bar{t}q) = 221^{+13}_{-13}$ pb t-channel cross section, 75^{+15}_{-14} pb tW production cross-section

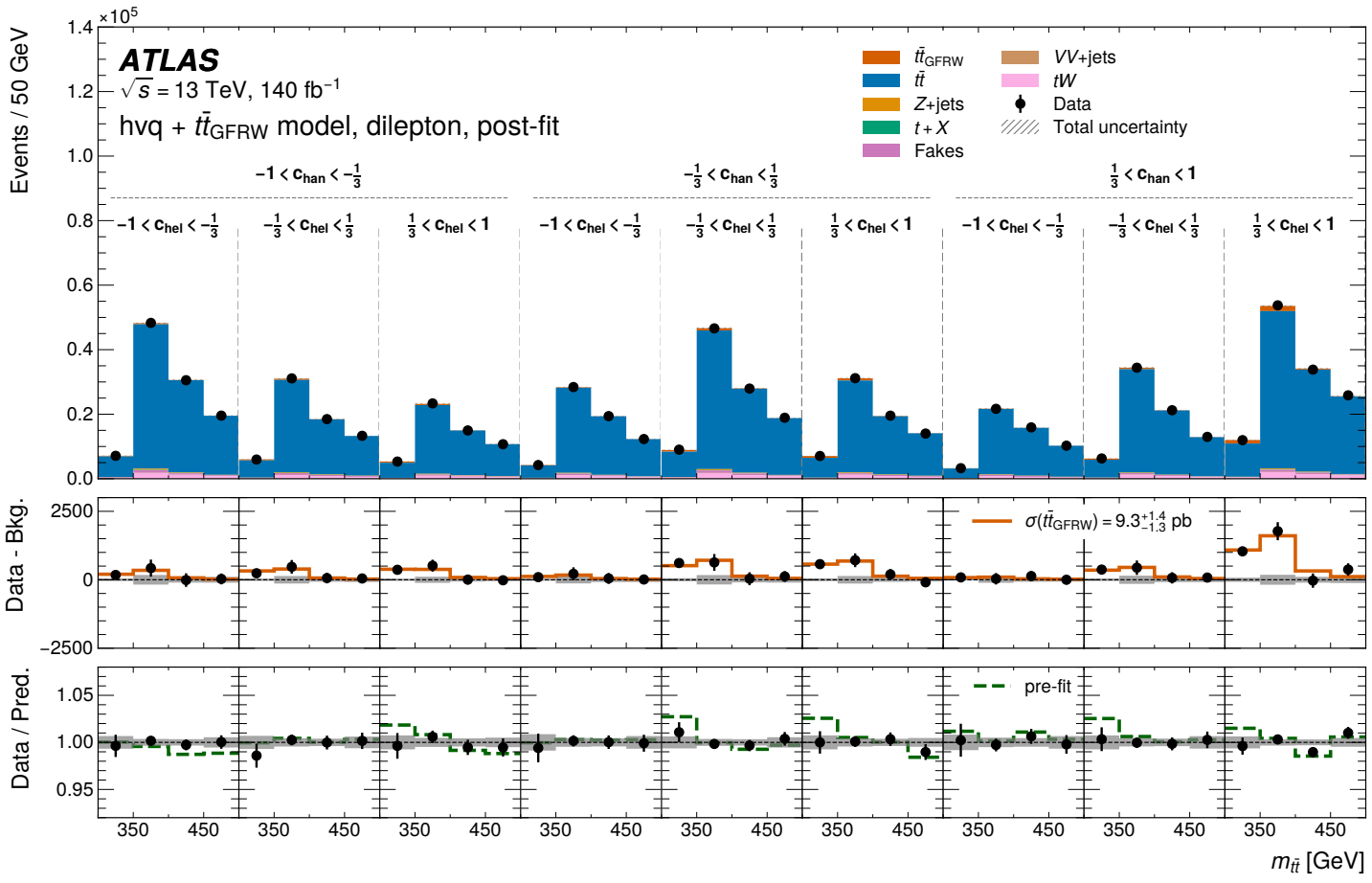


- *See link and paper for additional details*

Observation of a $t\bar{t}$ cross-section enhancement at threshold

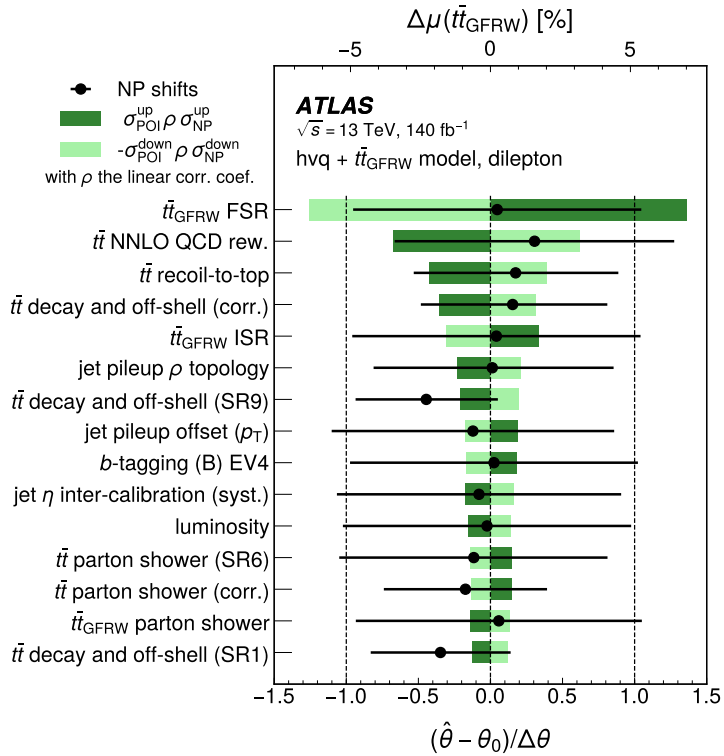
Near the $t\bar{t}$ production threshold ($m_{t\bar{t}} \approx 2m_t \approx 345$ GeV), non-relativistic QCD predicts the formation of quasi-bound states (toponium)

- Extremely difficult to look for such enhancement: small effect (1% of total x-section)
- ATLAS search done using $t\bar{t} \to \ell\nu b\ell\nu b$ decays, at 13 TeV and 140 fb^{-1}
- Main variables: $m_{t\bar{t}}$, and angular observables sensitive to $t\bar{t}$ spin correlations (c_{hel} and c_{han})



- Nine signal regions defined
- $t\bar{t}$ bkg model: baseline perturbative QCD (pQCD)
- Signal model: non-relativistic QCD (NRQCD)

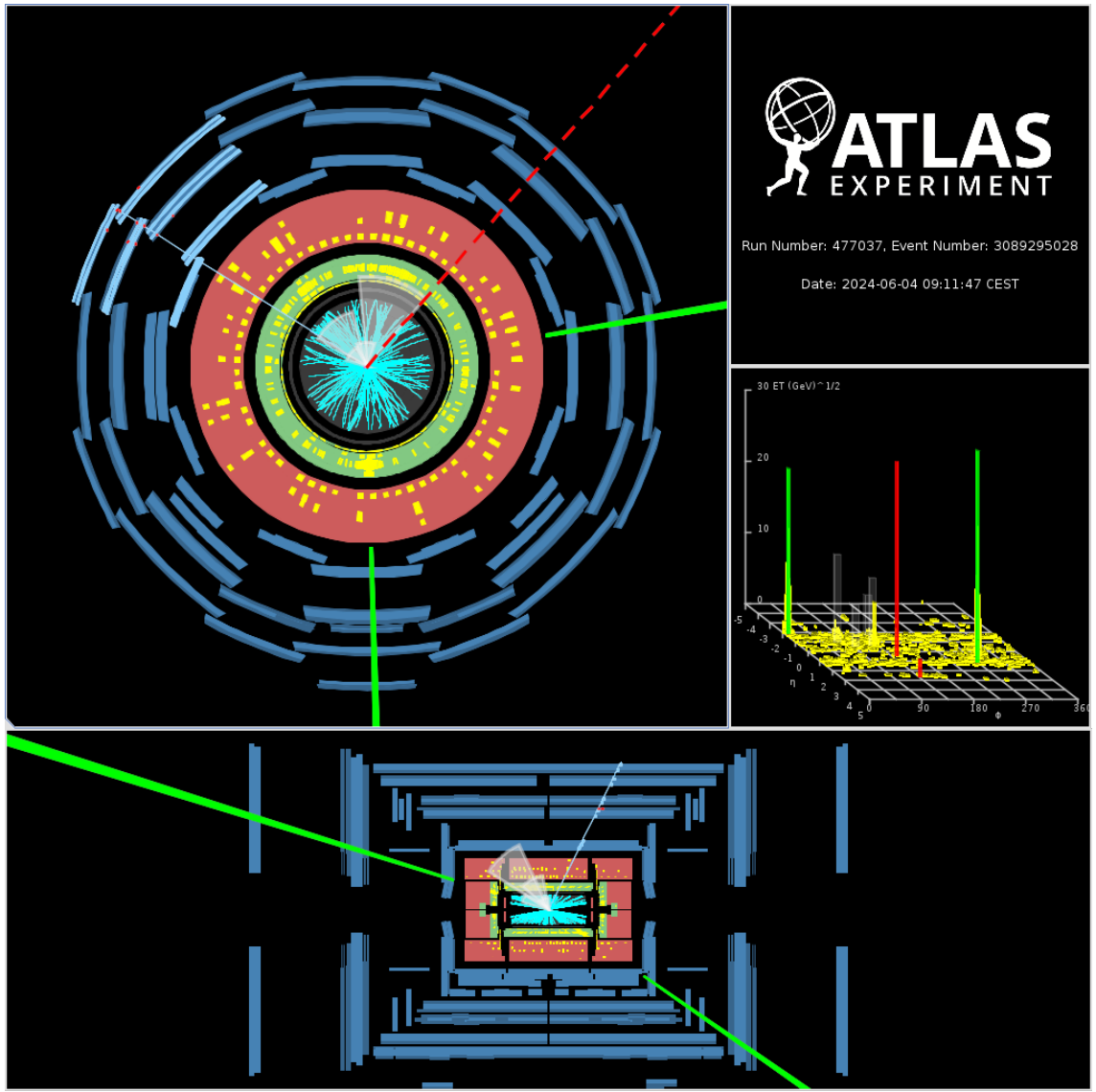
- Significant evidence for non-relativistic effects: the model without these effects rejected at an observed significance of 8σ
- Quasi-bound state production cross section: measured to be $9.3^{+1.1}_{-1.0}$ (stat) ± 0.8 (syst) pb



- Future improvements needed to understand the properties of this signal: off-shell effects, matching pQCD and NRQCD, other NRQCD effects, etc.

- *See link, link and paper for additional details*

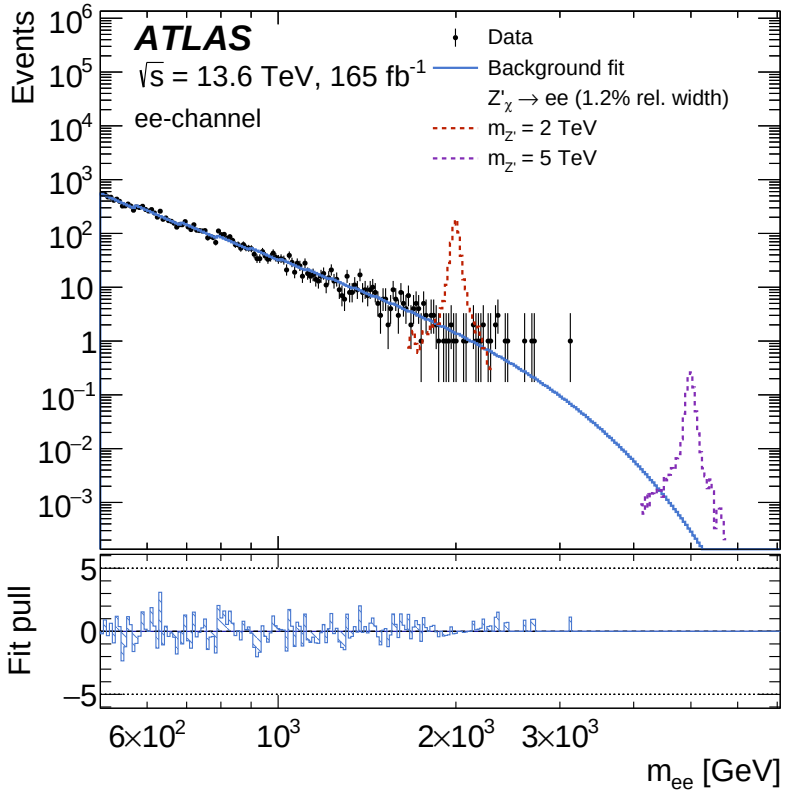
Direct searches for BSM physics

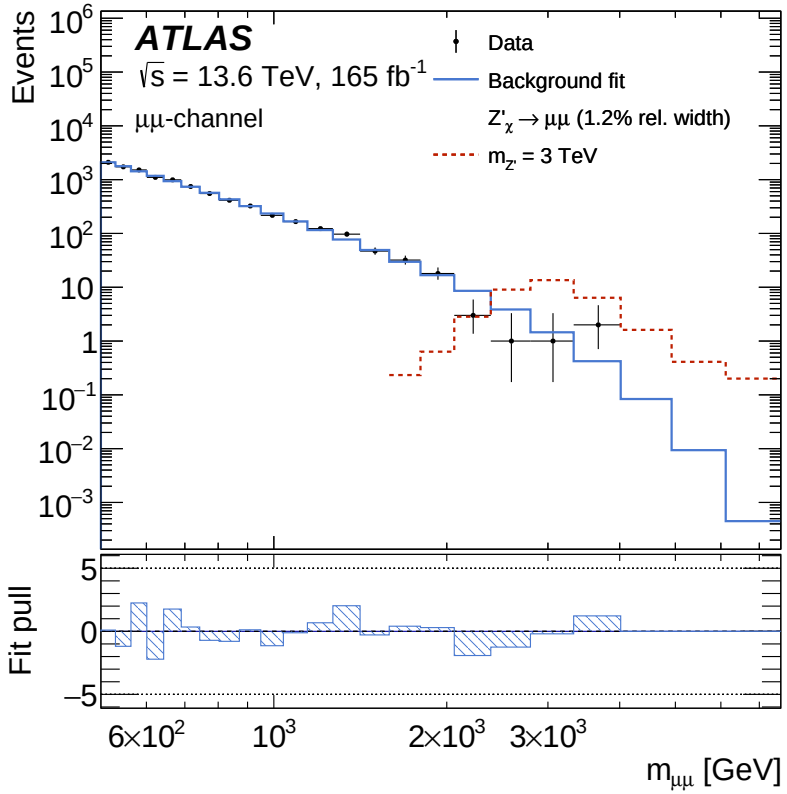


High-mass dilepton resonances search: highest invariant mass dielectron event (3.13 TeV!). (*link*)

High-mass dilepton resonances search

Search for high-mass vector bosons decaying into electron or muon pairs using 2022 → 2024 data

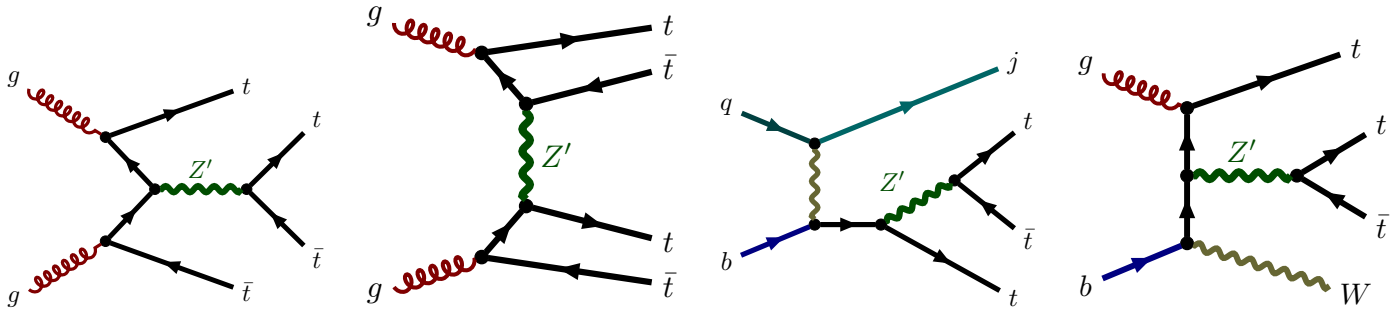




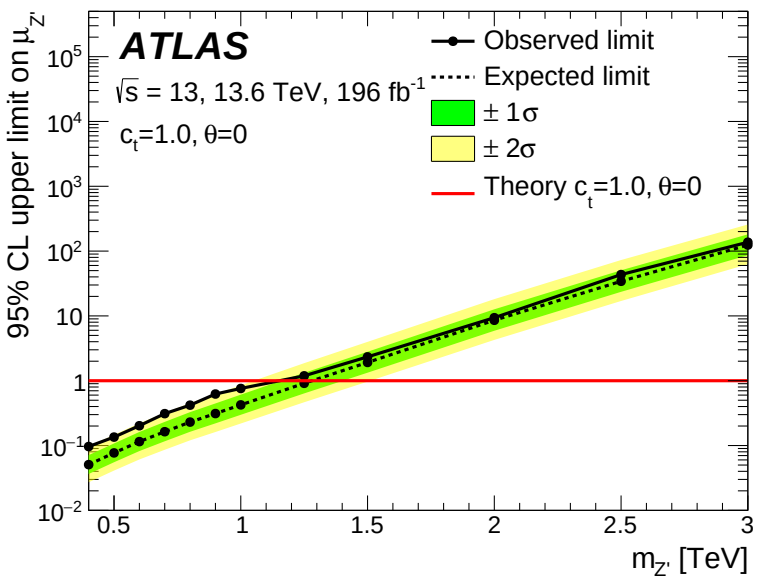
- No significant deviation from the background-only hypothesis found
- Depending on the model, Z' masses up to 5.5 TeV are excluded
  - Improvement between 25% and 50% obtained by combining the Run-3 results with the Run-2 ones! (paper)

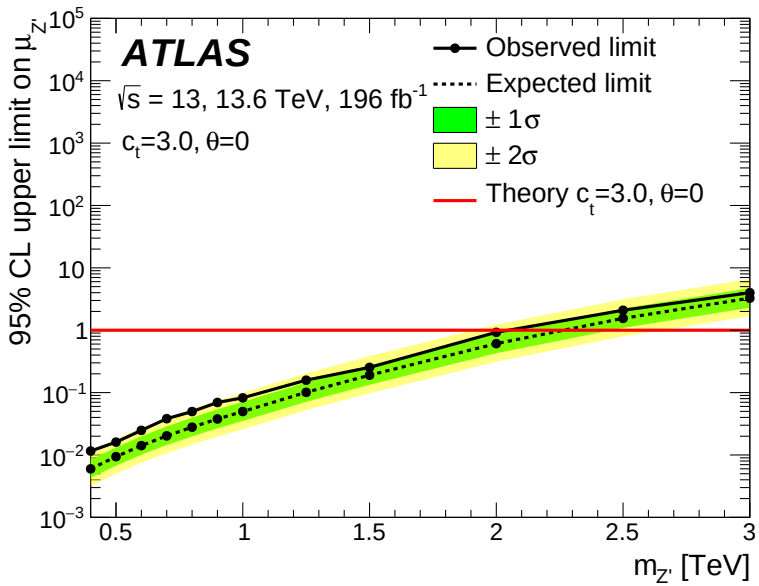
Top-philic heavy resonance in association with top quarks

Search for a top-philic vector boson Z' produced in assoc. with a top or a pair of tops (paper)



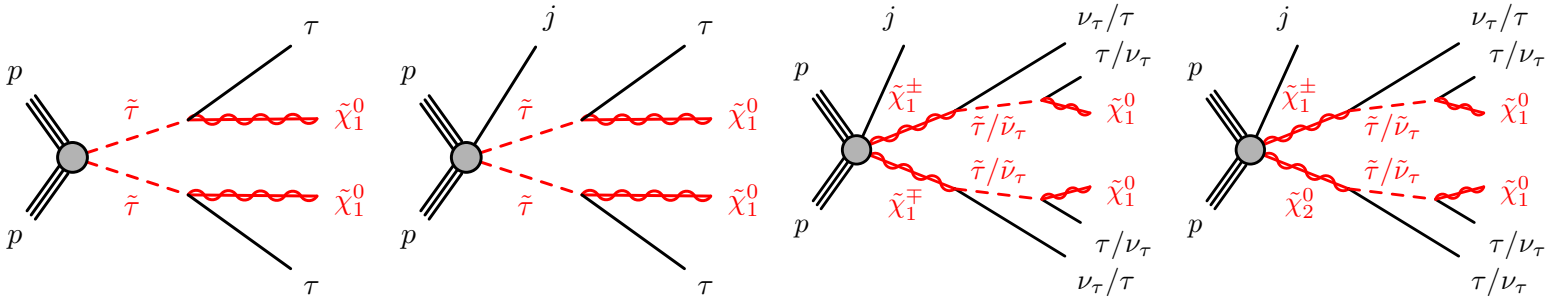
- Event selection: exactly two same-sign leptons or at least three light leptons
- Transformer-based classifier parameterised as a function of the Z' mass used to optimize the signal-to-background discrimination



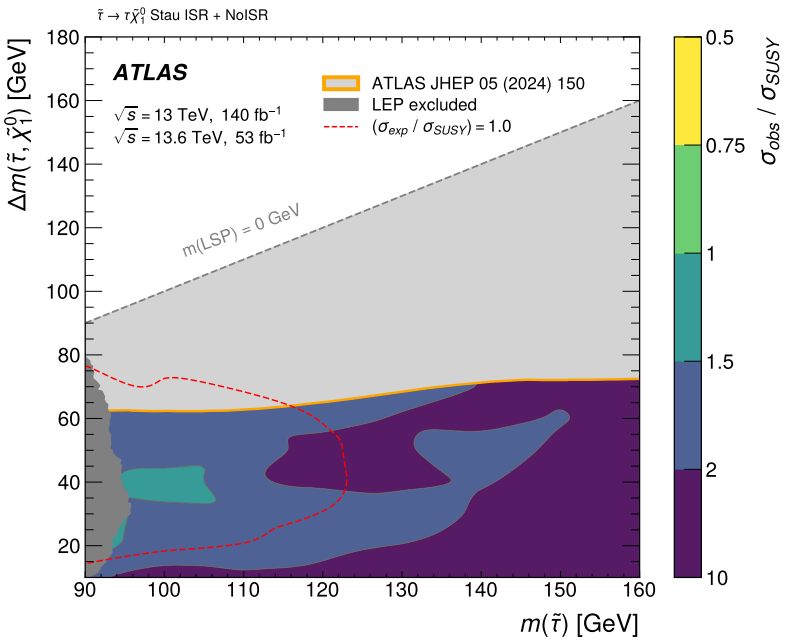


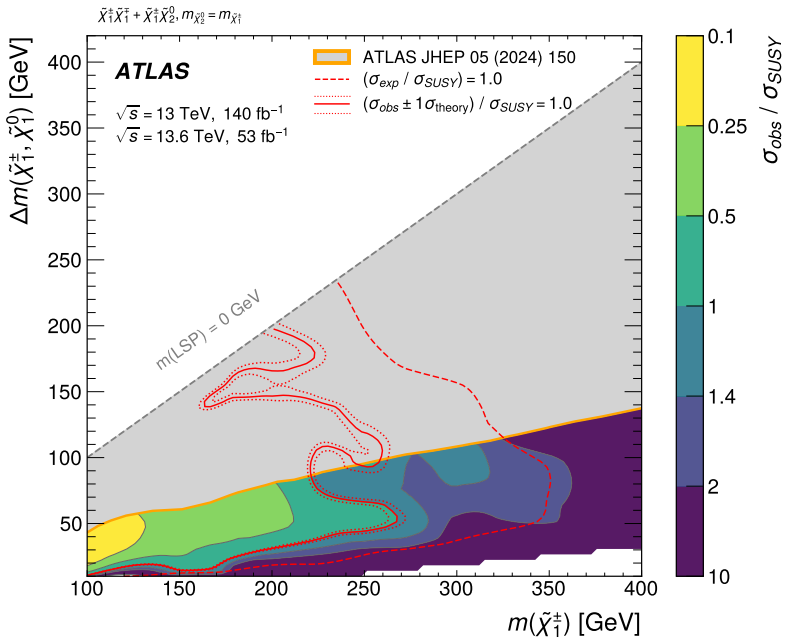
Compressed electroweak SUSY search

Search for $\tilde{\tau}$, $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ with at least one hadronically decaying τ (paper)

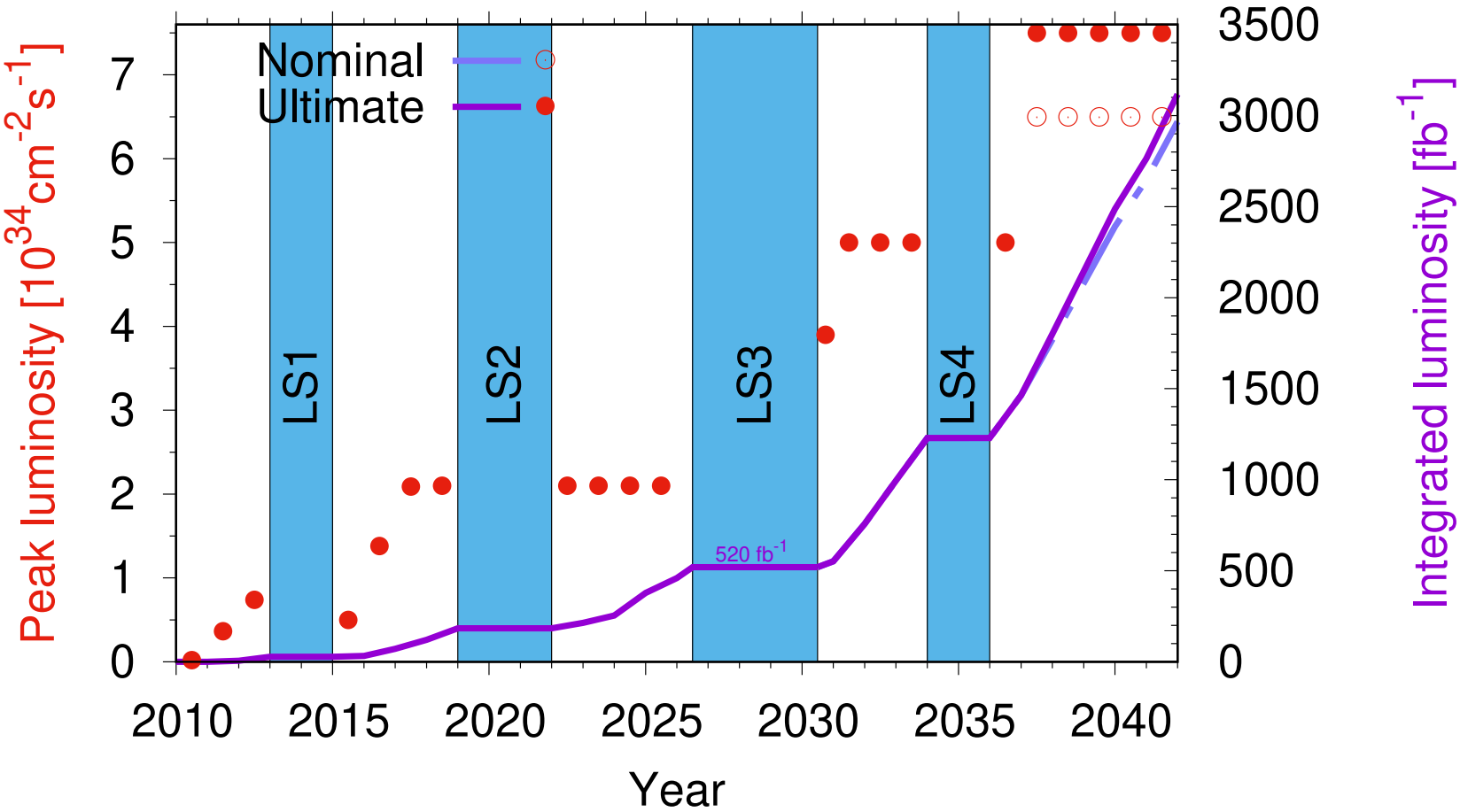


- Two final selections: one τ_{had} + 1 lepton, two or more τ_{had}
- DNNs and BDTs are used to define the signal regions



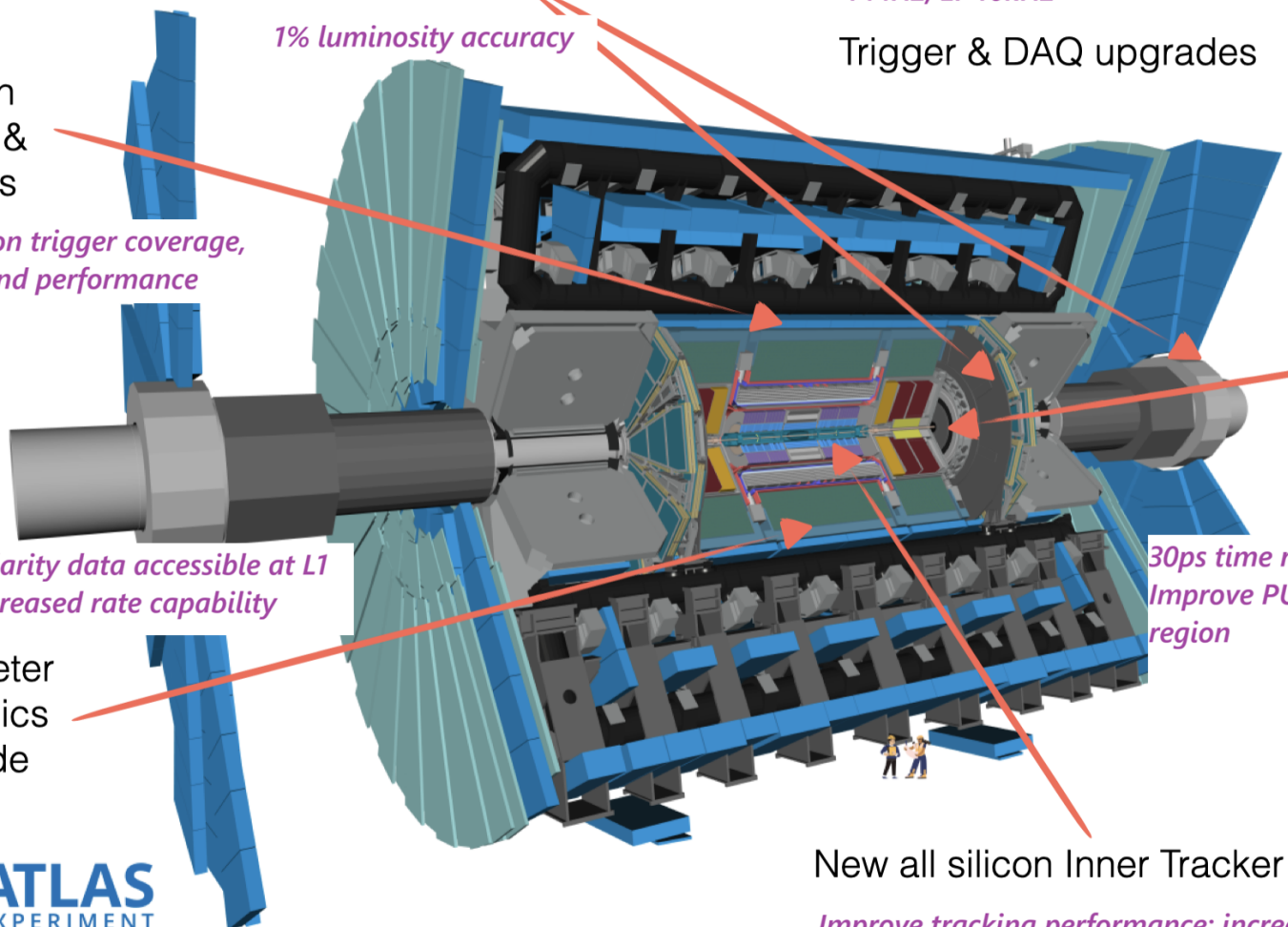


A peek into the future: HL-LHC



- HL-LHC data taking scheduled to start in 2030, running until 2041
- Expected to collect up to 3000 fb^{-1} of data (including around 500 fb^{-1} of Run-1→3 data)
- Interactions / BC (pileup, PU): 140 - 200
- **Crucial: detector upgrades to cope with high occupancy and harsh radiation**

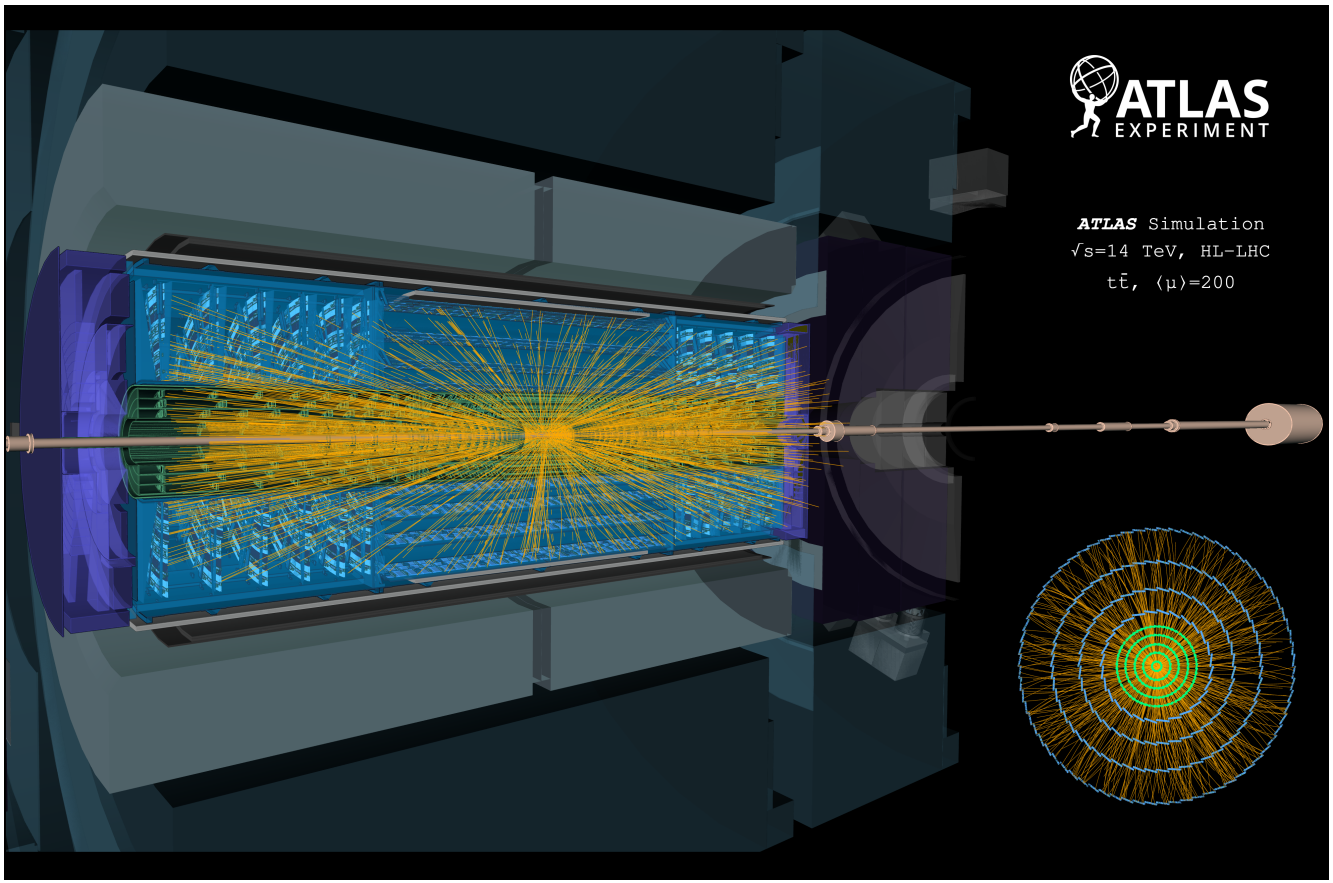
Major ATLAS upgrades

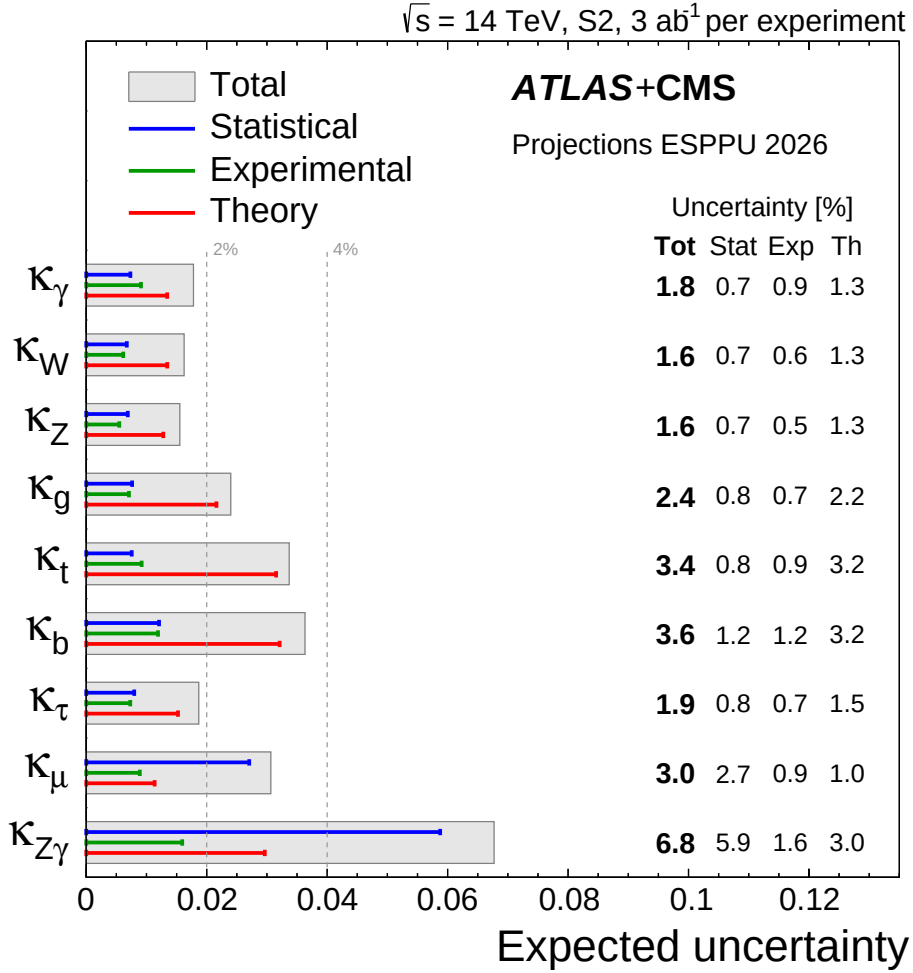


See also link this talk, and this paper for additional details

What do we expect from this heavy-particle factory?

- 180 million Higgs bosons produced in ATLAS
- 120,000 Higgs boson pairs, offering opportunities to study Higgs self-coupling
- 6.7 billion top quarks produced
- 130 billion (12 billion) W (Z) bosons decaying to electrons or muons
- 360 million W-boson pairs produced





- Higgs boson couplings to SM particles expected to be measured with an experimental precision ranging from 0.9% to 1.2%/1.7%
  - Measurements limited by theoretical uncs, currently projected between 1.3% and 3.2%
  - Theoretical developments to match the experimental precision also needed!
- Triple Higgs coupling expected to achieve better than 30% precision
- *See also link this talk, and this paper for additional details*

Conclusions

ATLAS experiment and collaboration continue to make outstanding contributions to our understanding of elementary particle physics!

- Building on the remarkable performance of the ATLAS detector in Run-3
- Supported by the outstanding efforts of the ATLAS computing team
- Impressive advances in object performance: ML transformers deliver significant gains in object tagging, reconstruction, and identification
- Precision measurements to fully characterize the properties of the Higgs boson
- Broad program of searches for BSM phenomena, probing challenging regions of phase space

More to come! The HL-LHC is on its way!

Thank you!