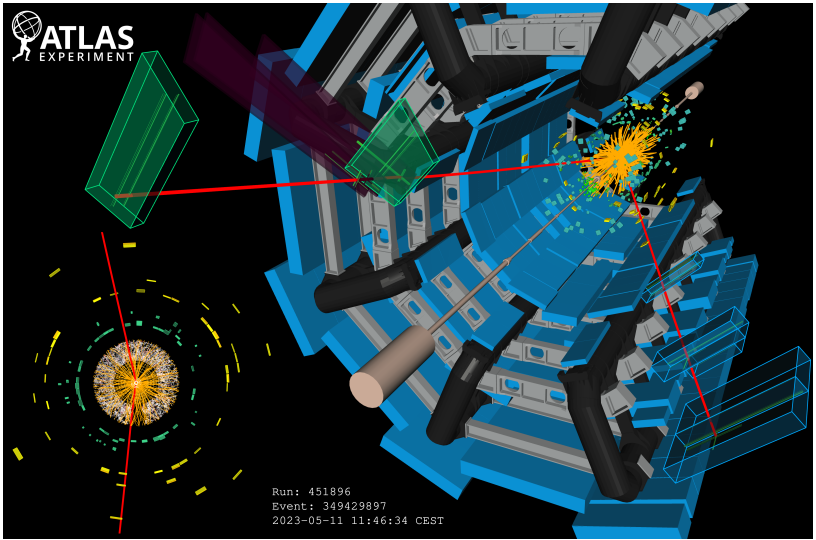
ATLAS Status Report

Rhys Owen[1] on behalf of the ATLAS collaboration

STFC - Rutherford Appleton Laboratory[1]
LHCC Open Session - 07.06.23

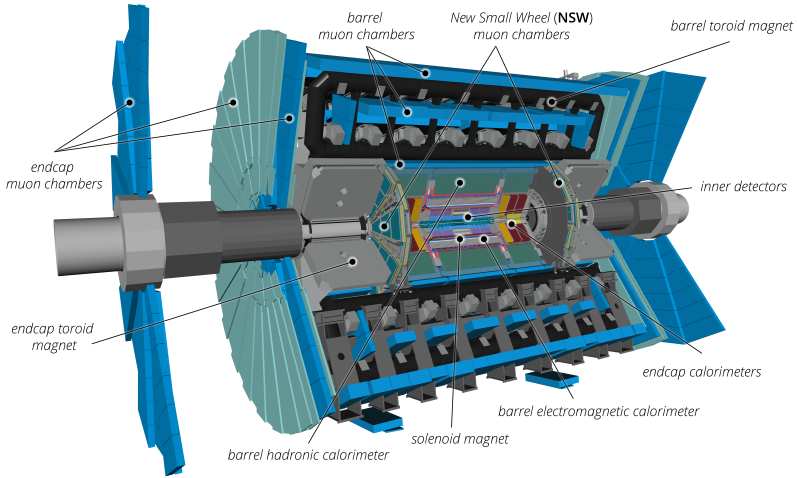
Run-3 Data taking well under way



$Z \rightarrow \mu\mu$ event from the first 2023 2400b Fill

Detector Configuration for Run 3

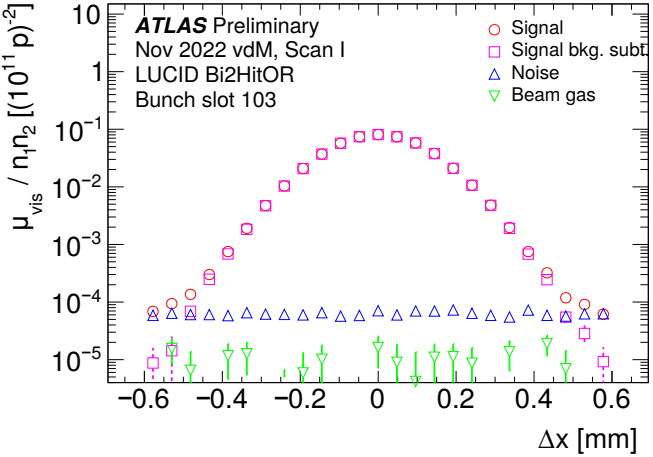
[arXiv:2305.16623]



New Publication consolidating the description of configuration in LHC Run-3

Initial Luminosity determination at 13.6 TeV

[ATL-DAPR-PUB-2023-001]



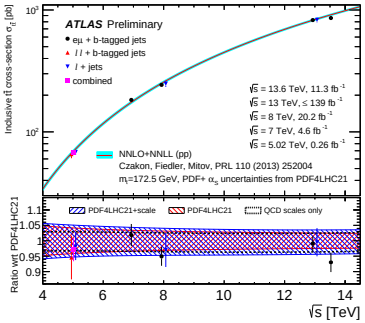
First luminosity calibration for Run-3, $31.4 \pm 0.7\,\mathrm{fb}^{-1}$
Good for Physics!

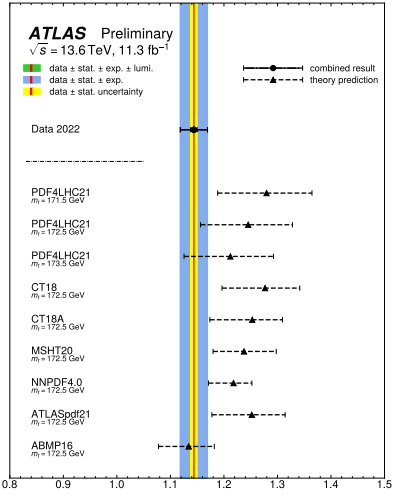
- Already with an impressive 2.2% uncertainty

Data sample	2022
Uncertainty contributions [%]:	
Statistical uncertainty	0.01
Fit model	0.24
Background subtraction	0.06
FBCT bunch-by-bunch fractions	0.01
Ghost-charge and satellite bunches	0.17
DCCT calibration	0.20
Orbit-drift correction	0.06
Beam position jitter	<0.01
Non-factorisation effects	1.07
Beam–beam effects	0.35
Emittance damping correction	0.21
Length scale calibration	0.03
Inner detector length scale	0.24
Magnetic non-linearity	0.32
Bunch-by-bunch σ_{vis} consistency	0.50
Scan-to-scan reproducibility	0.27
Reference specific luminosity	0.43
Subtotal vdM calibration	1.45
Calibration transfer	1.50
Calibration anchoring	0.53
Long-term stability	0.41
Total uncertainty [%]	2.19

Z and $t\bar{t}$ cross-sections at 13.6 TeV (2022 Data!)

[ATLAS-CONF-2023-006]



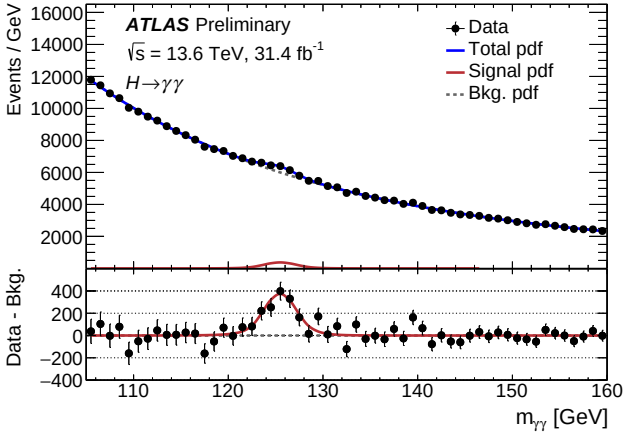


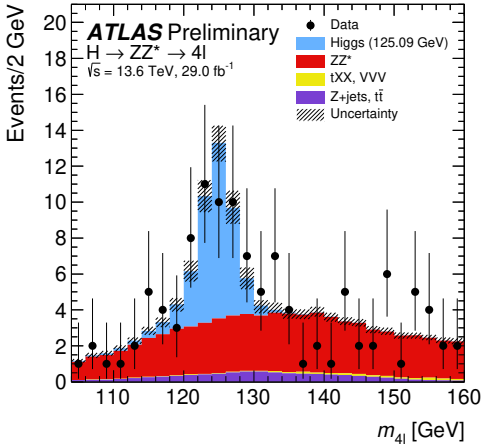
Measurement of Z and $t\bar{t}$ cross-section

- Absolute cross-sections uncertainty already at 2.2% and 2.3% for Z and $t\bar{t}$
- Ratio of Z and $t\bar{t}$ consistent with SM (1.9% uncertainty)

$H \to \gamma\gamma$ and $H \to ZZ$ cross-section at 13.6 TeV

[ATLAS-CONF-2023-032]





Both Higgs boson discovery channels now re-observed at 13.6 TeV

$H \to \gamma\gamma$ and $H \to ZZ$ cross-section at 13.6 TeV

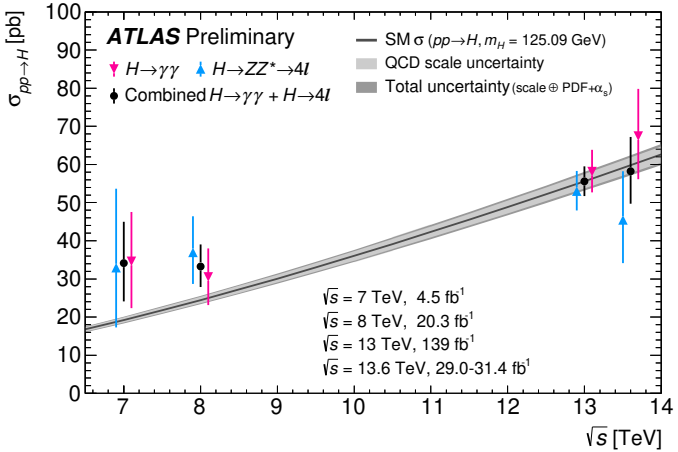
[ATLAS-CONF-2023-032]

Cross-section with 2022 data exploring the $\sqrt{s}$ scaling of the H cross-section

- Combination of $H \to \gamma\gamma$ and $H \to ZZ$ channels

$$\sigma_{(pp\to H)} = 58.2 \pm 7.5\ (\text{stat.}) \pm 4.5\ (\text{syst.})\ \text{pb}$$

- Compatible with SM 59.9 ± 2.6 pb



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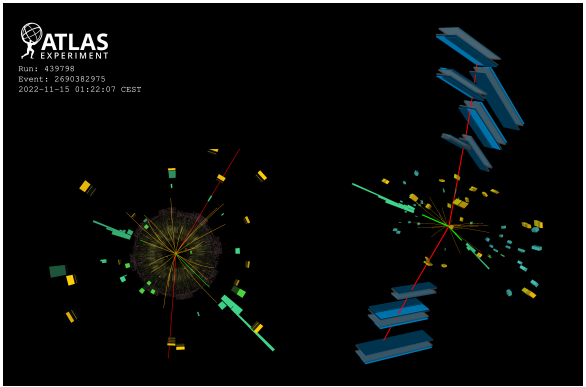
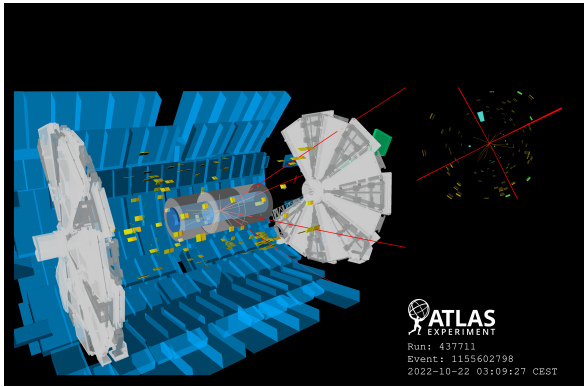
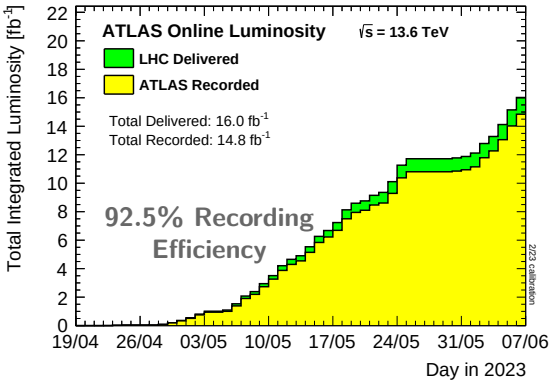
[ATLAS-CONF-2023-032]





Two nice $H \to ZZ^{\star} \to 4\ell$ events from last year

Detector Status



The detector is operating well with most sub detectors above 95% operational fraction and remaining stable

Sub detector	Number of Channels	Approximate Operational Fraction
Pixels	92 M	95.3%
SCT Silicon Strips	6.3 M	98.4%
TRT Transition Radiation Tracker	350 k	94.9%
LAr EM Calorimeter	170 k	100%
Tile Calorimeter	5200	99.4%
Hadronic End-Cap LAr Calorimeter	5600	99.9%
Forward LAr Calorimeter	3500	99.8%
LVL1 Calo Trigger Legacy	7160	99.9%
LVL1 Calo Trigger Channels Phase I	34 k	99.9%
LVL1 Muon RPC Trigger	383 k	99.8%
LVL1 Muon TGC Trigger	312 k	100%
MDT Muon Drift Tubes	344 k	99.7%
MicroMegas NSW	2.1 M	98.0%
STGC NSW	358 k	95.0%
RPC Barrel Muon Chambers	383 k	90.1%
TGC End-Cap Muon Chambers	312 k	99.3%
ALFA	10 k	100%
AFP	430 k	98.1%
AFP TOF	2x16	100%
LUCID	2x12+8	100%
ZDC	2x(4+16)	100%

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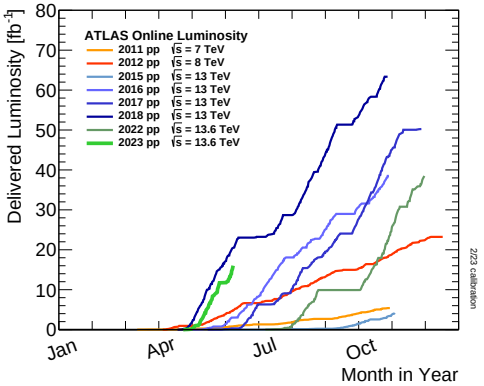

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On track for a very productive data taking year

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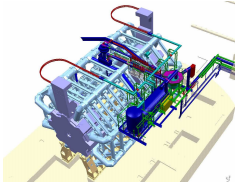
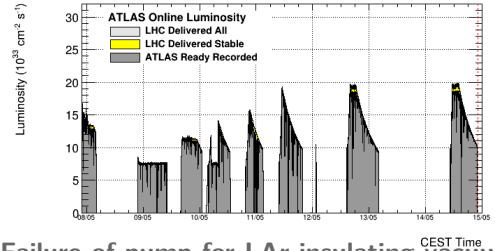
Cryogenic Challenges

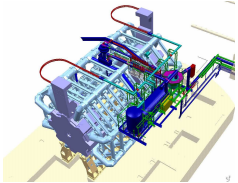


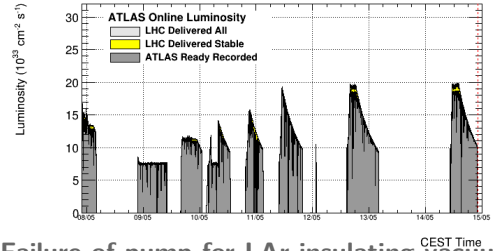
Clogging of the ATLAS Magnet system cooling Shield Refrigerator Cold Box



Failure of pump for LAr insulating vacuum

Cryogenic Challenges





Clogging of the ATLAS Magnet system cooling Shield Refrigerator Cold Box

- No oil contamination in the system ✓
- Dryer regenerated and system now performing well but kept under close observation

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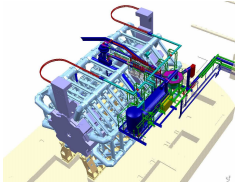

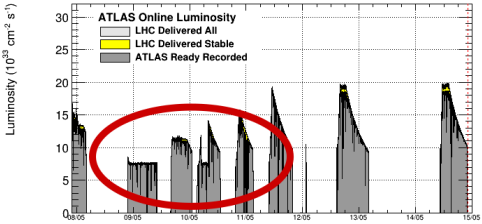

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- found strong correlation between the degradation of the insulation vacuum and the beam activity
- Caution about possible condensation on the external part of cryostat due to bad vacuum, so requested low mu for some fills
- Remote turbo pump installed in an access and vacuum returned to nominal levels

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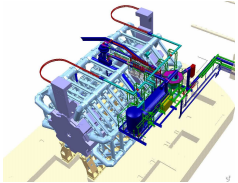

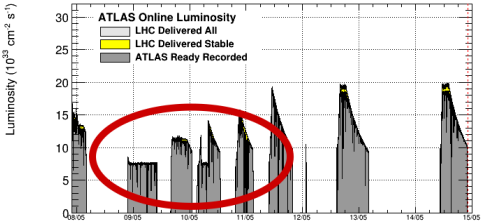

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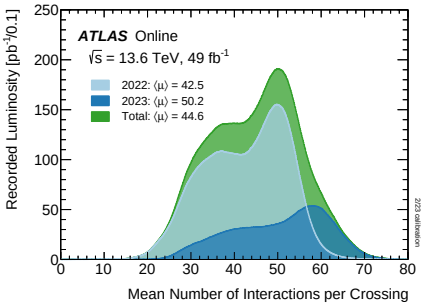
Prompt mitigation for both issues, now operating normally. Many thanks to the expert support from the CERN cryo and vacuum teams and the flexibility for the access from LHC community

High intensity / $\langle\mu\rangle$ Challenges

Pushing the limits of the detector to make the most of high intensity beams delivered by LHC

- High level-1 rate, as the LVL1 rate pushes towards 100 kHz protective deadtime for detector readout increases sharply
  - Optimisation of filters and noise cuts for Calorimeter trigger signal in response to 8b4e filling schemes
  - Bringing online Phase-1 items has already saved some rate (details in next slides) but more to gain
  - Alongside other menu optimisations
- High CPU usage causing some back-pressure from the software trigger
  - Costly items already identified and optimisations applied



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currently operating up to $\langle\mu\rangle = 61$ with plans to optimise to $\langle\mu\rangle = 65$

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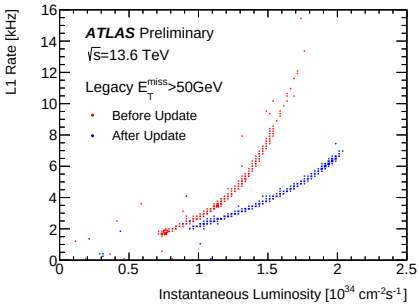

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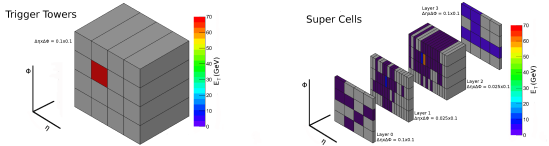
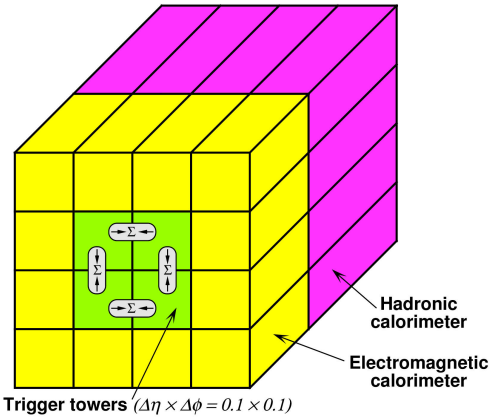
Bringing online Phase-1 upgrades

Liquid Argon digital trigger provides higher resolution and granularity E_T to Level-1 with baseline correction pre-applied



eFEX system uses that information to identify electron and photon like clusters



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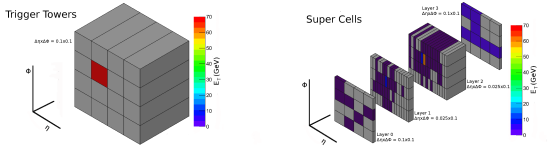

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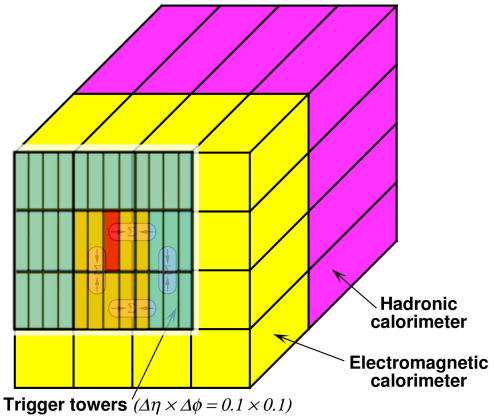
- Optimised seed and cluster size, using η and depth dependant energy corrections



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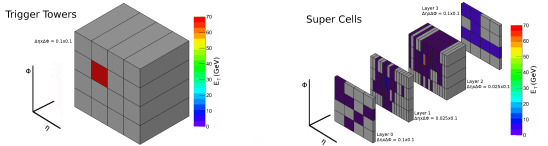
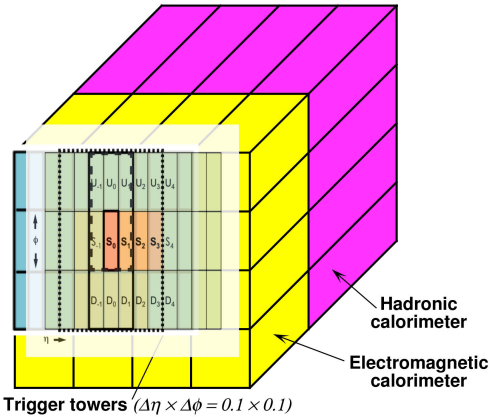


eFEX system uses that information to identify electron and photon like clusters

- Optimised seed and cluster size, using η and depth dependant energy corrections
- Isolation→Shower shape variables, also exploiting granularity and depth information



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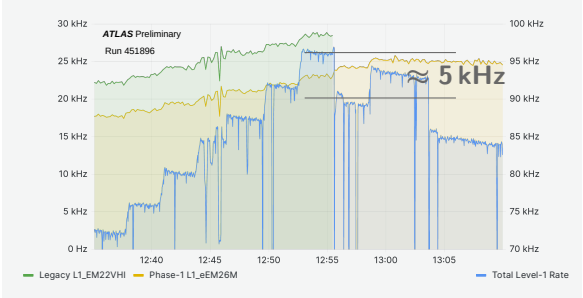
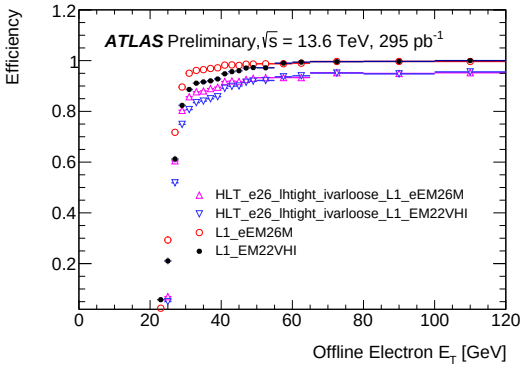
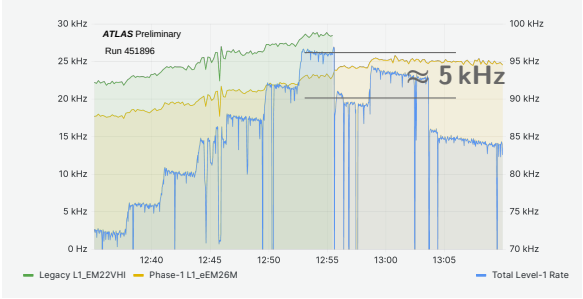


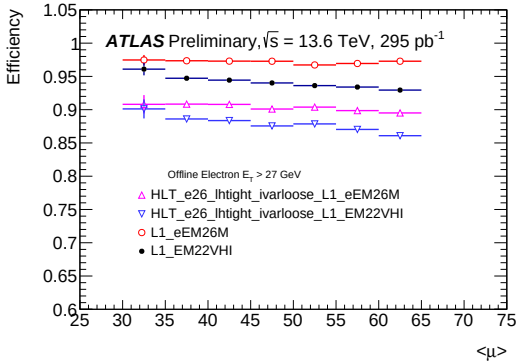


Filled circle = legacy Level-1, Empty circle = new Level-1

After running existing and phase-1 e/γ triggers in parallel during ramp up pre-existing system now deactivated, eFEX is providing primary electron triggers for ATLAS

Bringing online Phase-1 upgrades





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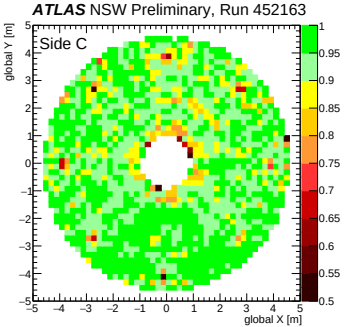
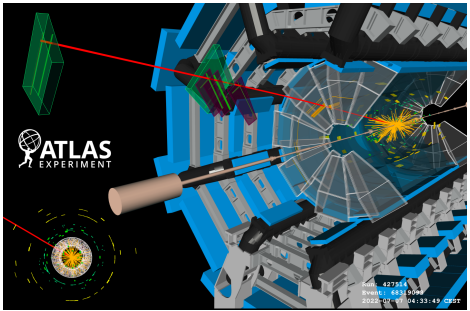
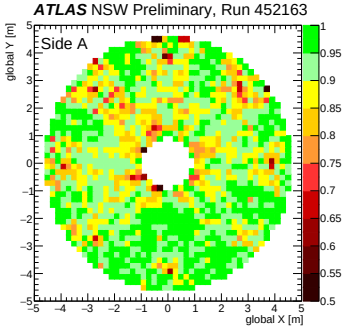
Muon New Small Wheel

Area of intense commissioning, operational and DAQ stability improved significantly



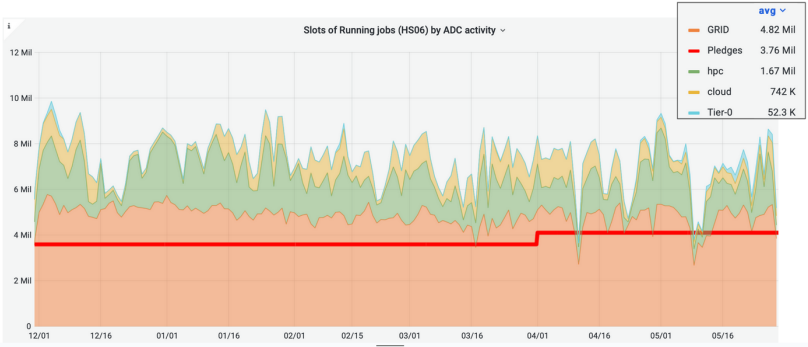




Now leveraging more stable data taking to understand remaining DAQ inefficiencies

Trigger path also under heavy development, hope to start activating the coincidence from the first sectors in the coming weeks

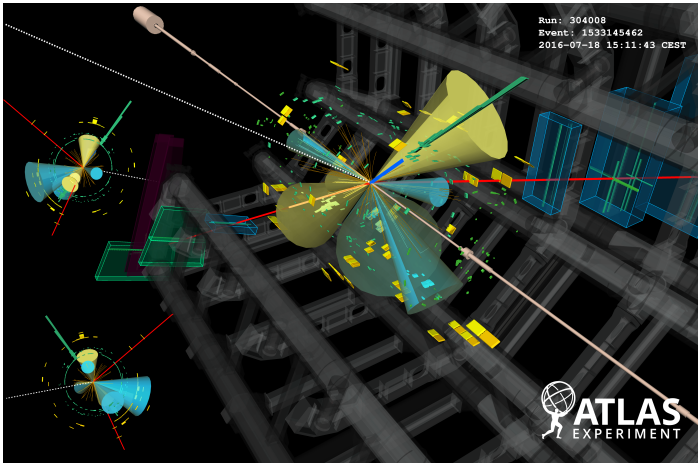
Software and Computing Activities



Wonderful performance of our computing centres world-wide, including T1s and T2s; significant opportunistic resources (HPCs and HLT farm)

- Great showing at CHEP 2023 — 65 ATLAS contributions, including 15 posters; several additional joint contributions (e.g. ATLAS+ROOT)
- New detector simulation campaigns modelling 2022 and 2023 data conditions now underway; operations otherwise stable

Runs 1 & 2 still providing analysis gold



Four Top event from Run-2

Fruitful analysis of data at $\sqrt{s} = 5.02, 7, 8$ and 13 TeV continuing exploiting the strengths of those datasets

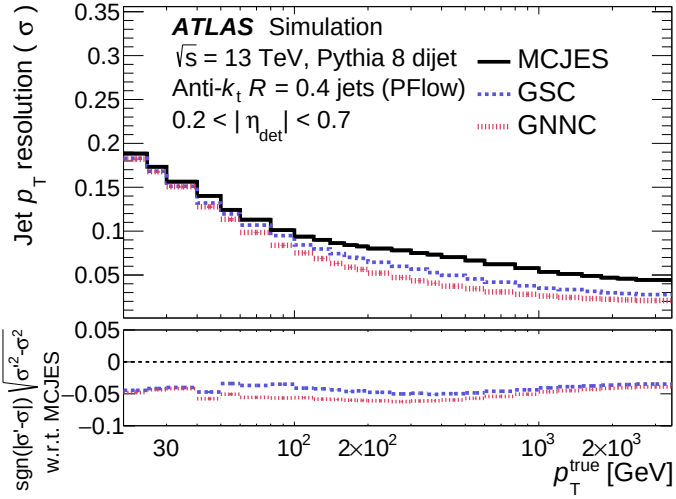
- 73 new results (33 new papers, 30 conference notes and 10 public notes) since last LHCC meeting
- And many more in the pipeline

New techniques for jet calibration

[arXiv:2303.17312]

State of the art methods to improve jet calibration

- Jets fundamental to many ATLAS analyses
- Improvements to pile-up stability at high p_T, closure, energy resolution and uncertainties
- Average improvement of 15% to jet energy resolution



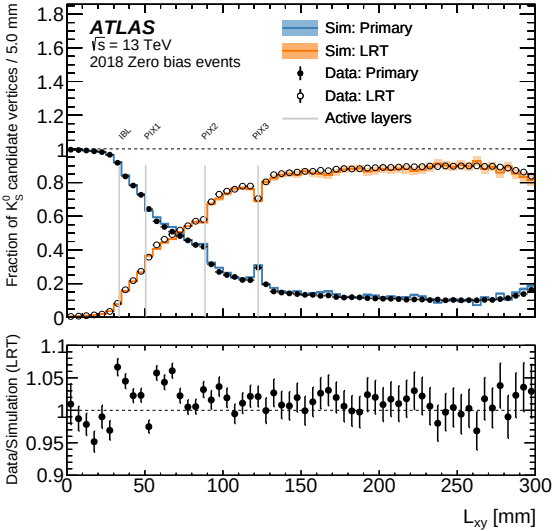
Improved Large Radius Tracking deployed for Run 3

[arXiv:2304.12867]

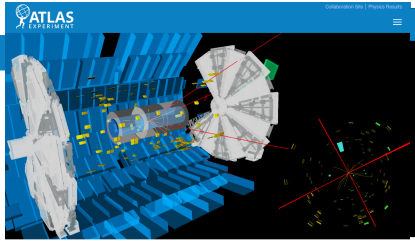
Large radius tracking available in standard Run-3 reconstruction allowing more searches for long lived particles

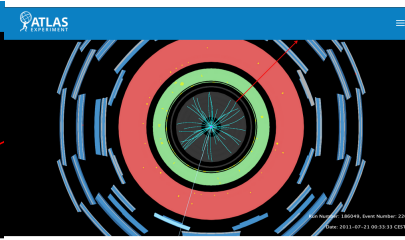
- 10× improvement in CPU usage and 50× improvement in disk usage, compare to previous LRT

Compliments Trigger improvements meaning LRT selections also available in the HLT



Physics briefings for conferences

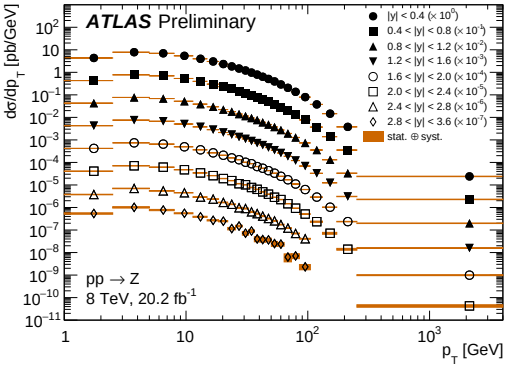


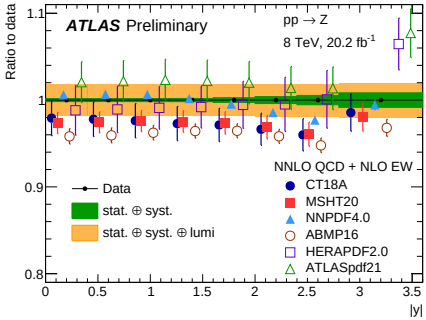


Many results and conference summaries also presented as physics briefings for a more general audience

Precise measurements of the Z boson at $\sqrt{s} = 8\,\text{TeV}$

[ATLAS-CONF-2023-013]

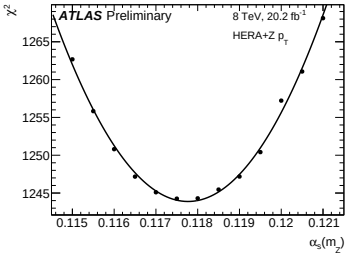




Double differential cross-section in $|y|$ and P_T

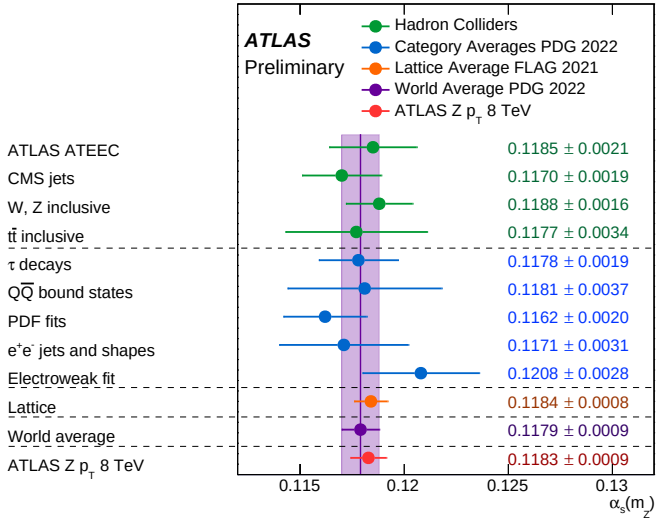
- Strong constraints on higher order QCD and electroweak calculations as well as PDFs

Determination of α_s from Z boson recoils at $\sqrt{s} = 8$TeV [ATLAS-CONF-2023-015]



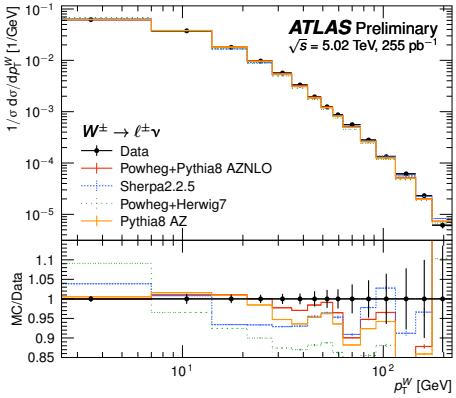
The most precise experimental determination of α_s

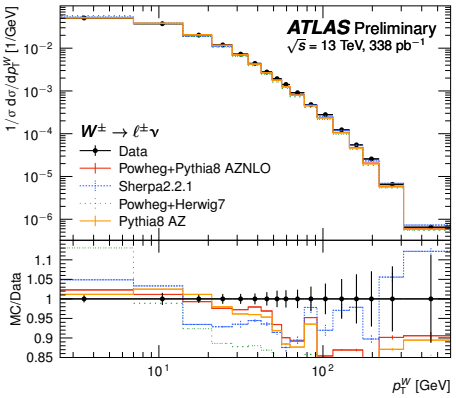
- Using the precise double differential cross-section results from [ATLAS-CONF-2023-013]
- And latest N^{4}LLa + N^{3}LO predictions



Precise measurement of W and Z P_T spectra at $\sqrt{s} = 5.02\,\text{TeV}$ and $\sqrt{s} = 13\,\text{TeV}$

[ATLAS-CONF-2023-028]





Use special low pile-up ($\langle\mu\rangle \approx 2$) data set to accurately measure W boson P_T

- Probe of parton distribution functions and MC generators

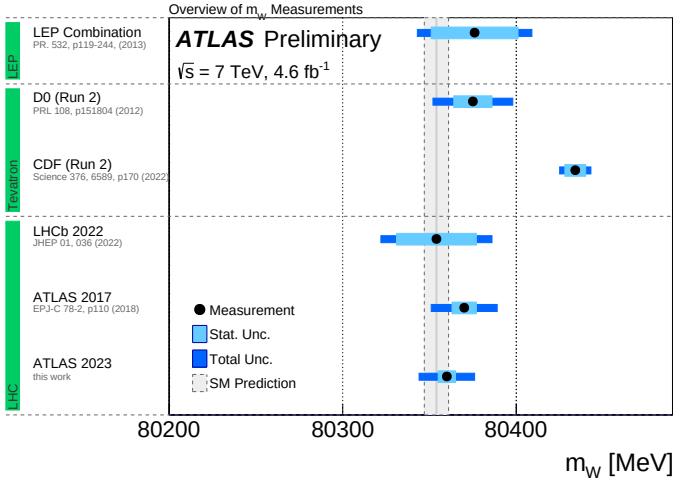
Improved W boson Mass Measurement

[ATLAS-CONF-2023-004]

Re-analysis of the $\sqrt{s} = 7$ TeV data set using profile likelihood based approach

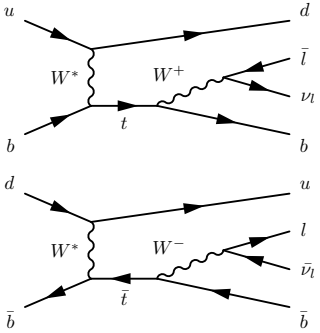
- Reduces systematic uncertainties by 15%
- Also includes latest PDF updates
- Compatible with SM prediction

$$m_W = 80360 \pm 5(\text{stat.}) \pm 15(\text{syst.}) = 80360 \pm 16\ \text{MeV}$$



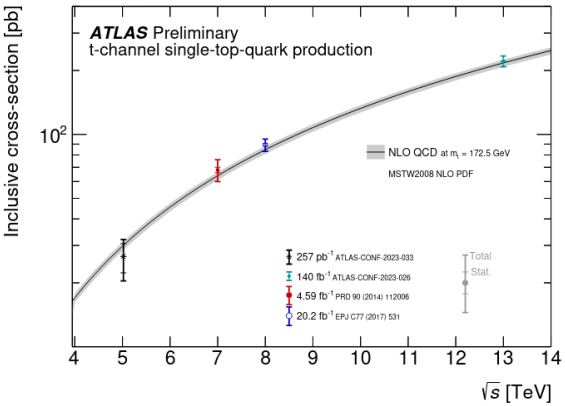
Single Top production at $\sqrt{s} = 5$ and 13 TeV

[ATLAS-CONF-2023-026][ATLAS-CONF-2023-040]



First measurement at $\sqrt{s} = 5$ TeV and updated result with the full dataset at $\sqrt{s} = 13$ TeV

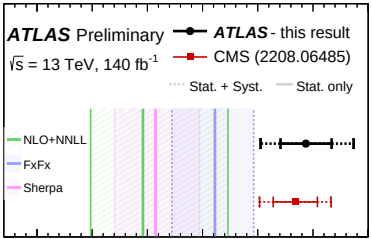
- Good agreement with the standard model for total cross-section and ratio $R_t = \sigma(tq)/\sigma(\bar{t}q)$

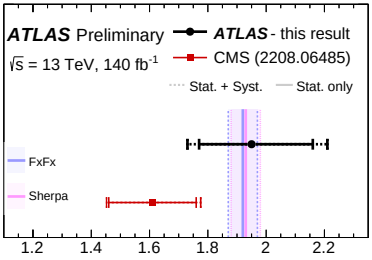


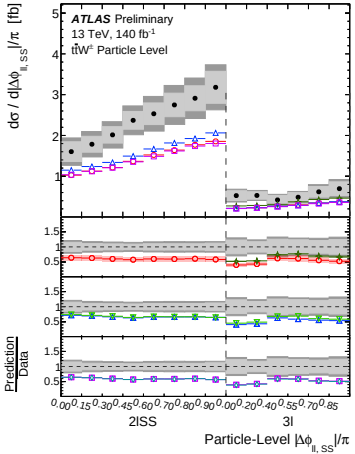
$\sigma(tq + \bar{t}q) = 221 \pm 13\,\text{pb}$ @ 13 TeV

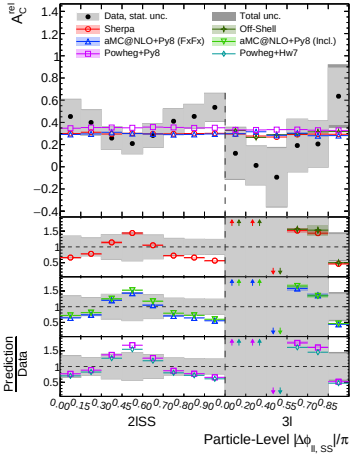
Total and differential cross-sections of $t\bar{t}W$

[ATLAS-CONF-2023-019]









First Differential cross-sections for this channel at the LHC

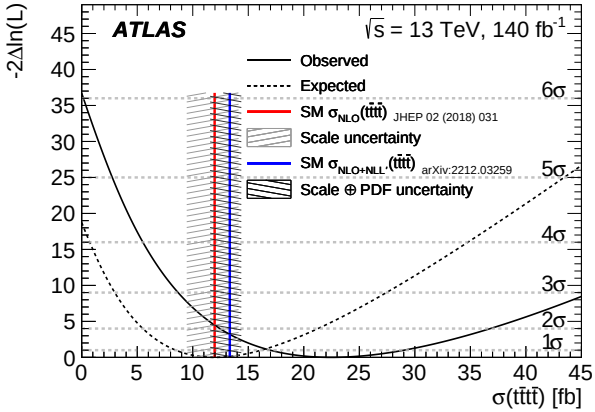
- Especially important as an irreducible background in many searches!

Observation of $t\bar{t}t\bar{t}$ production

[arXiv:2303.15061 (accepted by EPJ-C)]

Observation of four-top production in multi lepton final states

- 6.1(4.3)σ overved (expected) significance
- Compatible with the SM prediction within 1.8σ
- Measured cross section $22.5^{+6.6}_{-5.5}$ fb
- Results also used to set limits on several new physics scenarios
- ATLAS Physics Briefing



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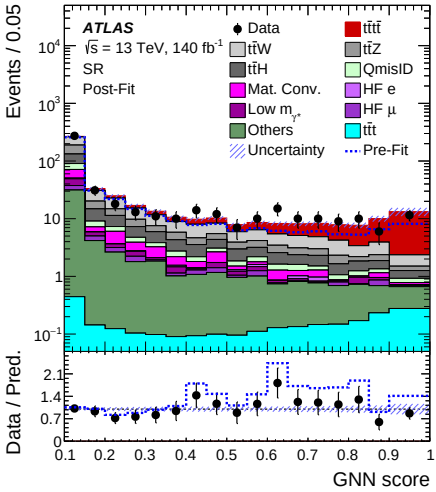
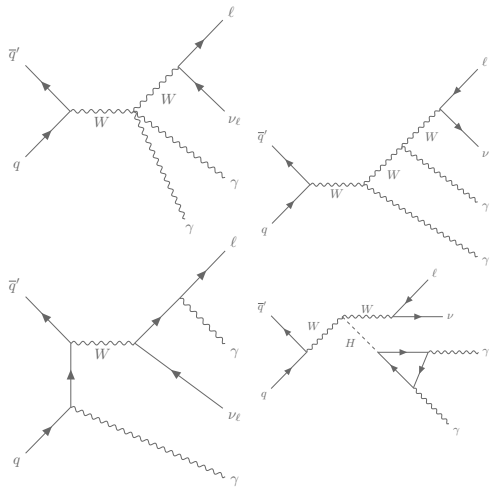
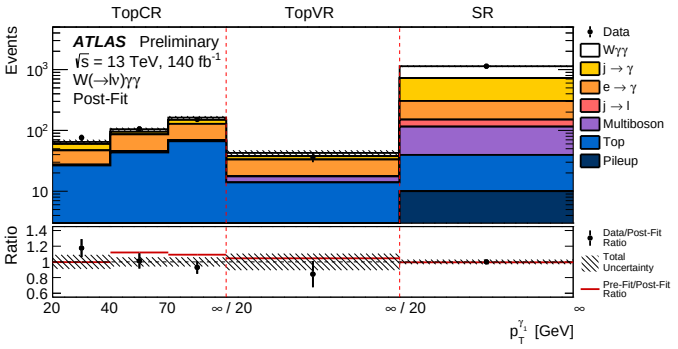


Observation of $W(\ell\nu)\gamma\gamma$ production

[ATLAS-CONF-2023-005]





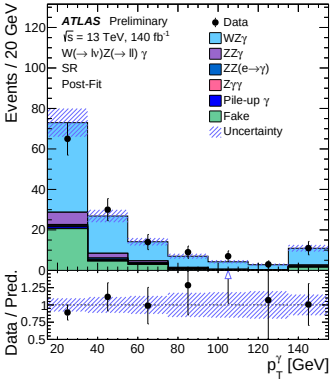
Observation of this process with $5.6(5.6)\sigma$ Observed (expected) significance

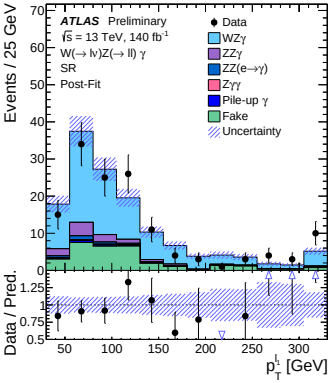
Observation of $WZ\gamma$ production

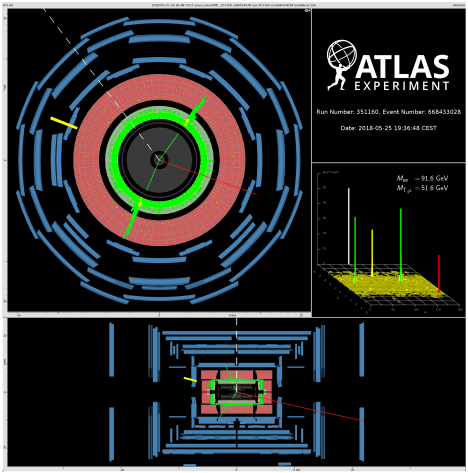
[ATLAS-CONF-2023-014]

Using the leptonic decays of both Z and W bosons

- Observed (expected) significance of $6.3(5.0)\sigma$







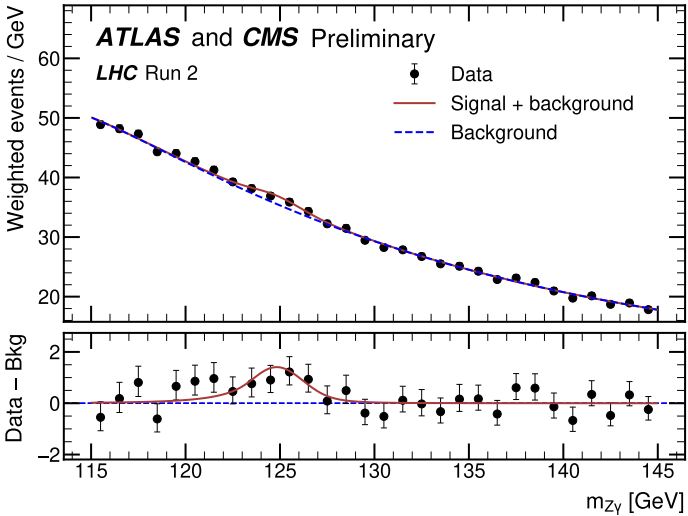
Green: electrons, Red: Muon,
Dashed: $E_{\mathrm{T}}^{\mathrm{miss}}$, Yellow: Photon

Evidence for $H \to Z\gamma$

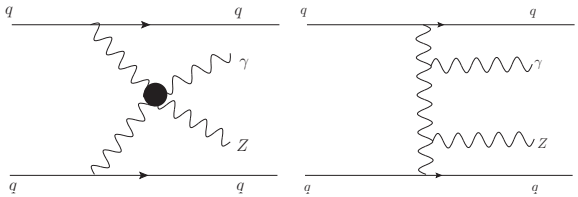
[ATLAS-CONF-2023-025]

First evidence in combination with CMS using full Run-2 dataset

- 3.4σ observation from combination of independent 2.2σ ATLAS and 2.6σ CMS observations
- Observed signal is 2.2 ± 0.7 times the SM prediction (1.9σ)

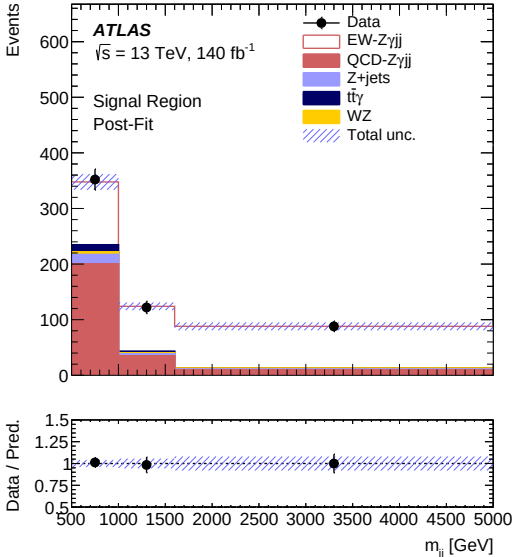


Cross-sections of the electroweak and total production of a $Z\gamma$ [arXiv:2305.19142]



Measurement of the total and Electroweak production

- Good agreement with the standard model



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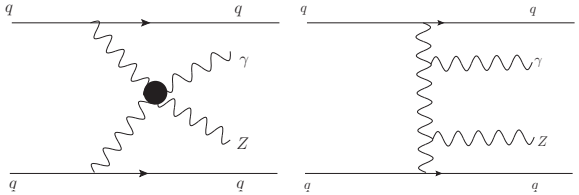
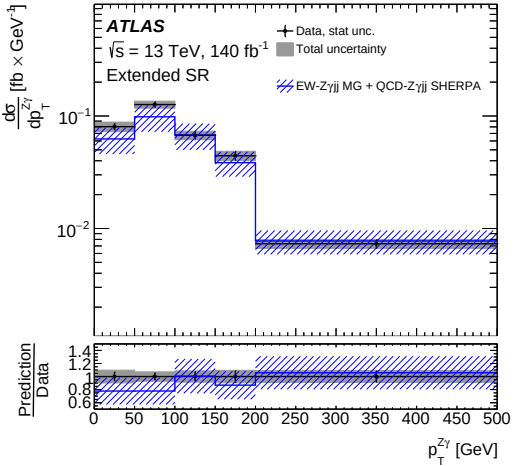


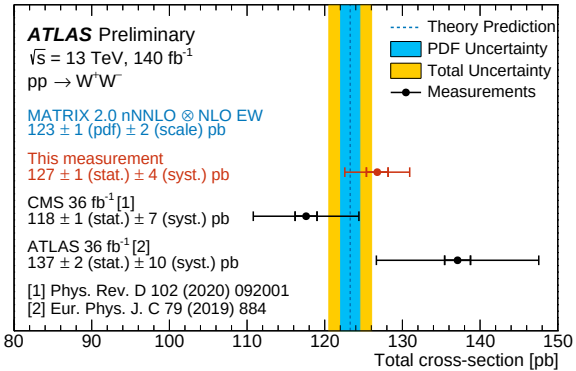
Measurement of the total and Electroweak production

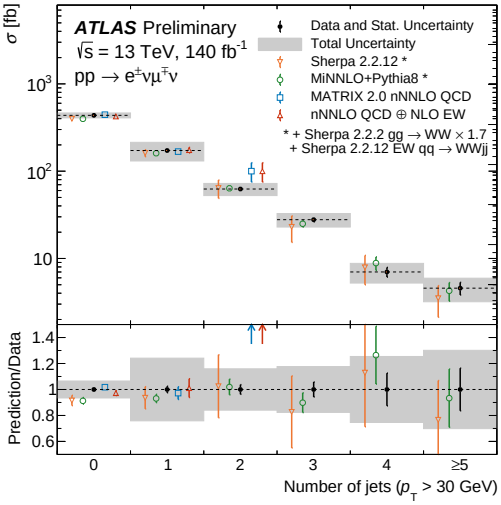
- Good agreement with the standard model
- Also differential measurement comparisons with predictions



Measurement of W^+W^- production at $\sqrt{s} = 13\,\text{TeV}$

[ATLAS-CONF-2023-012]





Fiducial, Total and Differential Cross-sections with the full Run-2 dataset

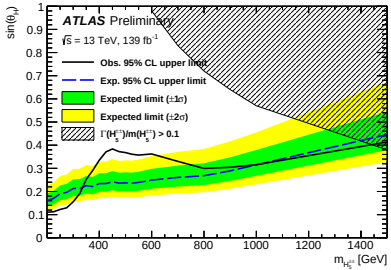
- Experimental measurements approaching the uncertainty of theory predictions

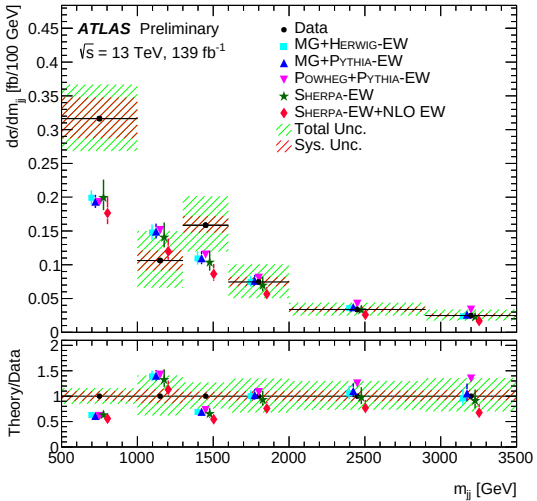
Differential cross-section for $W^{\pm}W^{\pm}jj$

[ATLAS-CONF-2023-023]

ATLAS's first differential measurement for this process

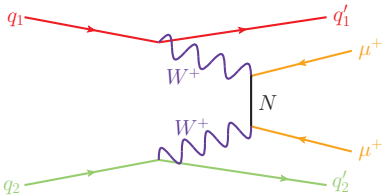
- Vector boson scattering sensitive to electroweak symmetry breaking
- This channel in particular sensitive to gauge boson self coupling
- Model independent limits on doubly charged Higgs boson production





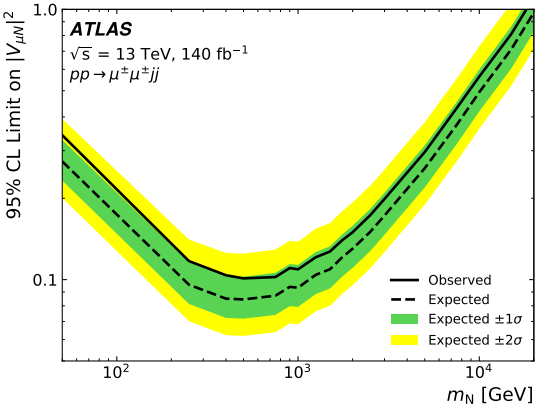
Search for Majorana neutrinos in $W^{\pm}W^{\pm}$ scattering events

[arXiv:2305.14931]



A new search using this channel to search for Majorana neutrinos

- Signal expected to lead to boost muon P_T
- Limits extended up to higher m_N than resonant searches

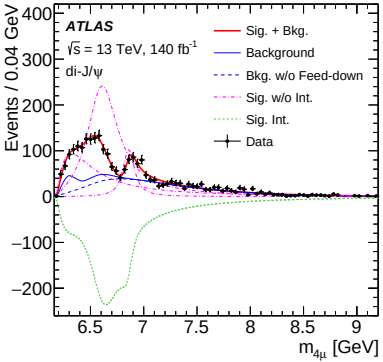


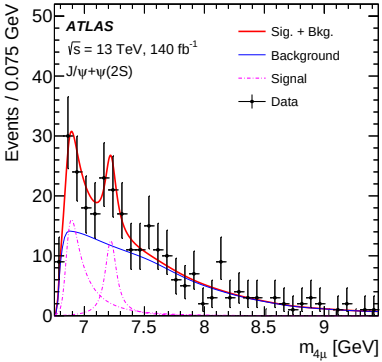
Excess of di-charmonium events

[arXiv:2304.08962]

Significant excess of events in data above expected background

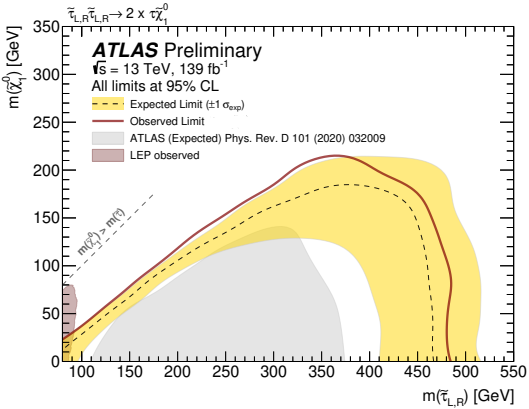
- Considers the four-muon final state
- Excess seen in di-J/ψ and J/$\psi + \psi$(2s) channels
- Analogous to LHCb, a broad structure at lower mass and a resonance at around 6.9 GeV are observed

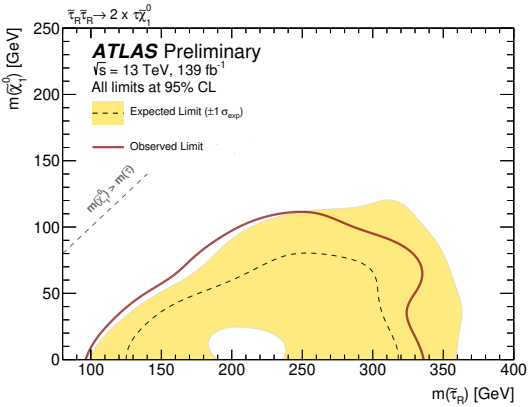




Search for direct stau ($\tilde{\tau}$) production

[ATLAS-CONF-2023-029]





First LHC limits on only right handed stau ($\tilde{\tau}_R\tilde{\tau}_R$) production!

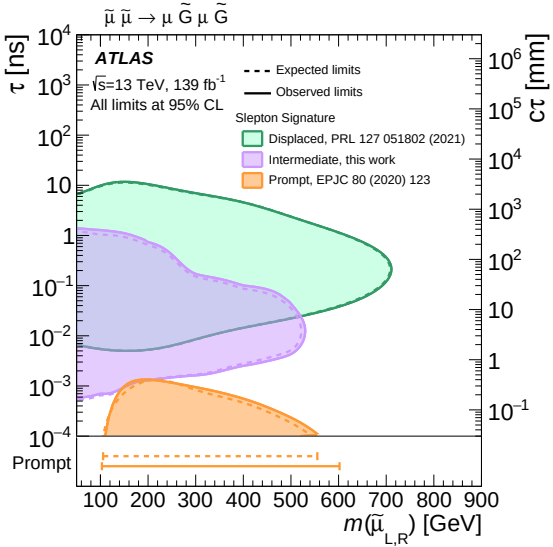
- Improved limits on existing channels, largely driven by improved τ identification

Search for muons with small displacements

[arXiv:2305.02005]

Search for decays in the phase space between prompt and displaced muons

- Search interpreted in terms of Smuon production excluding lifetimes down to 1 ps and masses up to 520 GeV
- But analysis designed to be reasonably model-independent

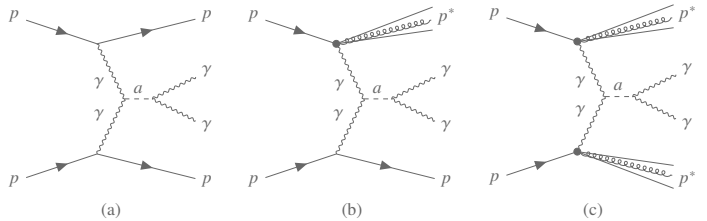


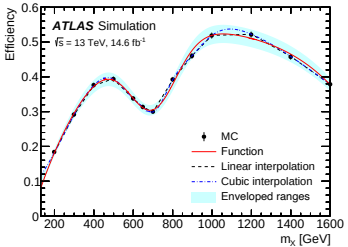
Search for axion-like particles with AFP

[arXiv:2304.10953]

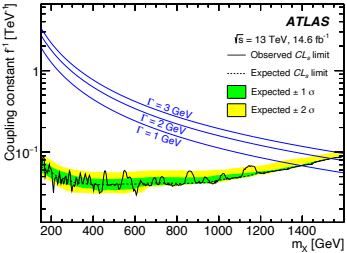
Use ATLAS Forward Proton detector (AFP) to tag protons from exclusive (a) and single-dissociative (b) events

- inferred upper limit on ALP coupling constant in the range $0.04 \rightarrow 0.09$ TeV at 95% confidence level
- Assuming 100% decay into two photons





Exclusive signal efficiency



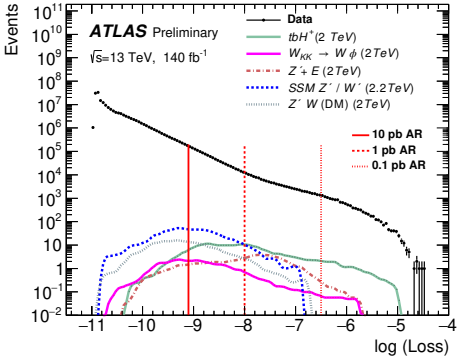
Limits on ALP coupling

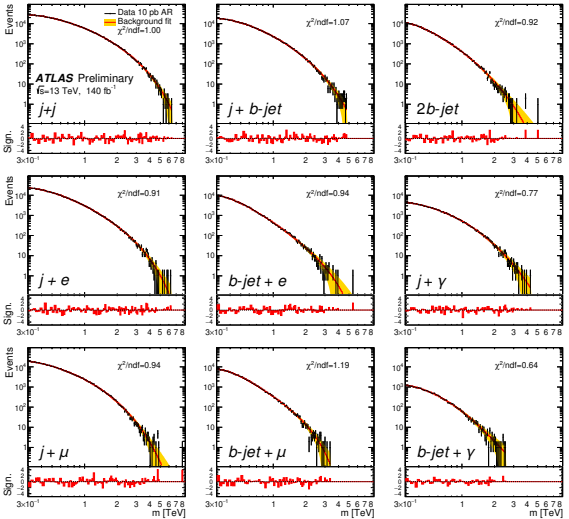
Searches with unsupervised learning

[ATLAS-CONF-2023-022]

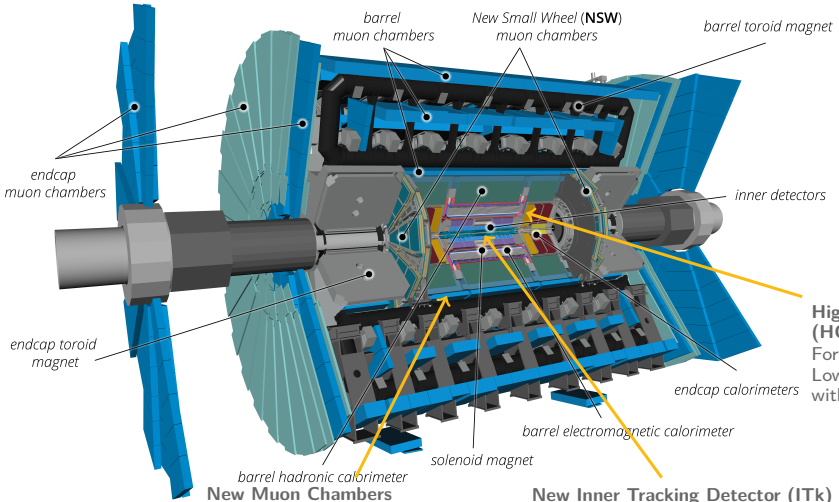
Auto encoder used to classify anomalous events

- Trained 1% of events with isolated leptons
- Bump hunt in di-object invariant mass





Phase-II upgrade program



Upgraded Trigger and Data Acquisition system
Level-0 Trigger at 1 MHz,
Improved High-Level Trigger
(150 kHz full-scan tracking)

Electronics Upgrades
LAr Calorimeter
Tile Calorimeter
Muon System

High Granularity Timing Detector (HGTD)
Forward region ($2.4 < |\eta| < 4.0$)
Low-Gain Avalanche Detectors (LGAD)
with 30 ps track resolution

New Muon Chambers
Inner barrel region with new
RPC and sMDT detectors

New Inner Tracking Detector (ITk)
All silicon up to $|\eta| = 4$

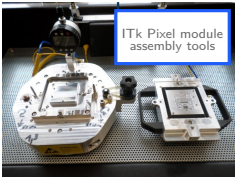
Additional small upgrades
Luminosity detectors (1% precision goal), HL-ZDC

Detailed scope described in 7 TDRs approved by the CERN Research Board in 2017, 2018, 2020

Upgrade status overview

Upgrade projects are steadily moving into production

- We completed essential steps in critical technical developments ✓
  - FE ASIC designs are close to completion
    - ITk Pixel's submitted, HGTD's and RPC's final prototype in testing
  - ITk Strip noise issues are understood and pre-production has resumed ✓
- Some early procurement concerns have been addressed ✓
  - e.g. slow Strip sensor delivery rate, carbon foam availability
- Infrastructure work is advancing ✓
  - e.g. passed Production Readiness Review for CO_2 cooling system
- A few designs need to be finalised **!**
  - Flexes, power-boards, data cables ... (devil is always in the details)
- Production processes are being validated and key players qualified **!**
- A few late technical issues require attention **!**
  - e.g. HGTD prototype modules bump breaking after thermal cycles
- We have to address missing effort in certain areas **!**
  - Including but not limited to lost Russian contributions



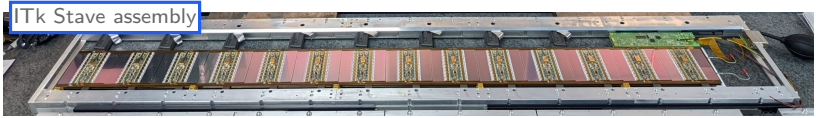
Upgrade status overview

The recent rate of loss of schedule contingency is not sustainable

- The limited remaining contingency (3 months) in ITk Pixel and Muons is worrisome
  - We are reviewing schedules to recover internal slack or possibly even global contingency (mostly during production)

The latest P2UG review praised the project's advancement but also underlined "the tensions [. . .] between understanding everything to perfection and getting into production"

- Critical judgement calls are ahead of us



Summary

ATLAS detector is taking good data at $\sqrt{s} = 13.6$ TeV

- Phase-1 upgrades moving from commissioning to operation helping keep pace with the LHC
- First analyses available exploiting new centre of mass and making important checks of data quality

A plethora of exciting results published since last LHCC using existing data sets

- Precision measurements of W and Z bosons
- Measurements of multiboson processes
- Observation of $t\bar{t}t\bar{t}$ production
- Wide range of BSM searches

And much more to come, from existing data, new data and HL-LHC data!

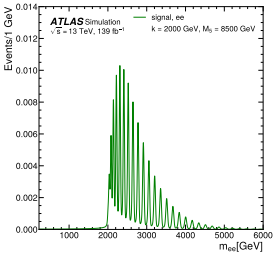
Backup

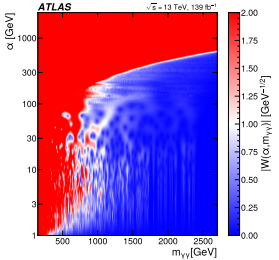
Periodic signals

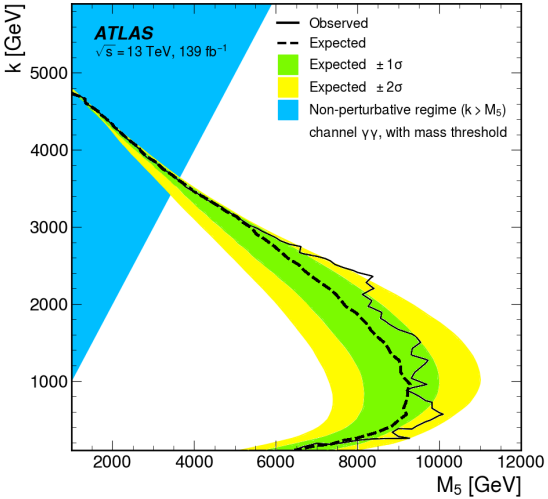
[arXiv:2305.10894]

Search optimised for spin-2 periodic resonances in clockwork/linear-dilaton model

- excludes values of M_5 in the range 11 TeV to 1TeV for k in the range 100 GeV to 5 TeV





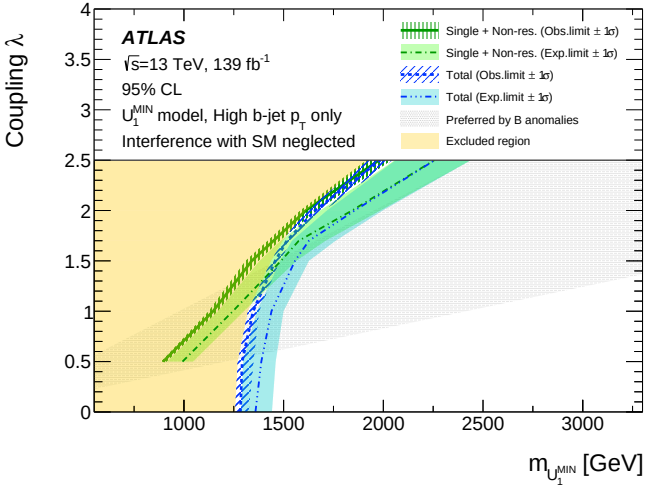


Leptoquark Search for decays to bτ

[arXiv:2305.15962]

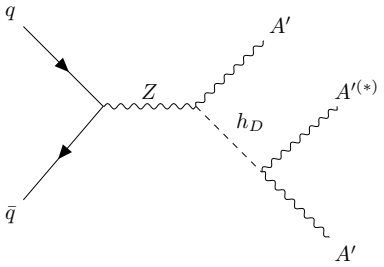
Search for leptoquarks decaying into the bτ final state in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

- Model dependant limits set for Yang-Mills and Minimal coupling scenarios
- as well as model-independent limits in terms of the scalar p_T sum of the visible decay products S_T



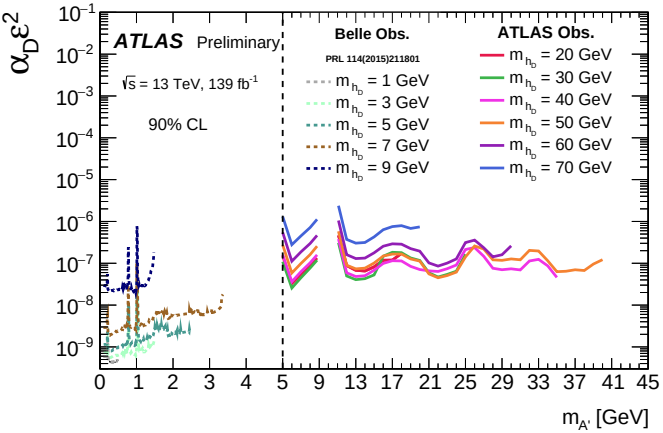
Search dark photons and dark Higgs boson in rare Z boson decays

[ATLAS-CONF-2023-016]



First search of its kind using dark Higgs-strahlung processes at the LHC

- limits are set in broad mass ranges for both the dark photon $5\,\text{GeV} < m_{A'} < 40\,\text{GeV}$ and the dark Higgs boson $20\,\text{GeV} < m_{h_D} < 70\,\text{GeV}$

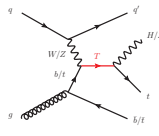


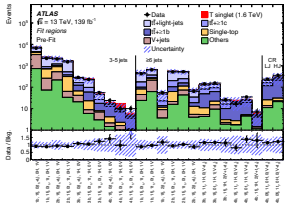
Search for vector like T quarks decaying to Ht or Zt

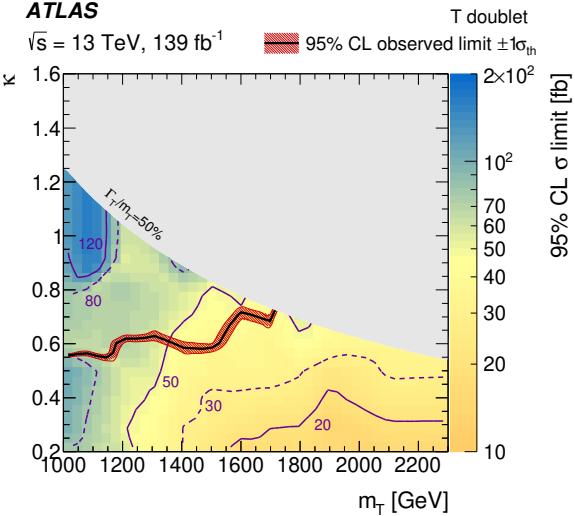
[arXiv:2305.03401]

Exclusion limits set for a wide range of T masses and couplings (κ) for both singlet and doublet scenarios

- Quarks recoiling from heavy vector like quark likely to be very high η used to tag events
- Scalar sum of central jets then used as m_{eff} used as final discriminant

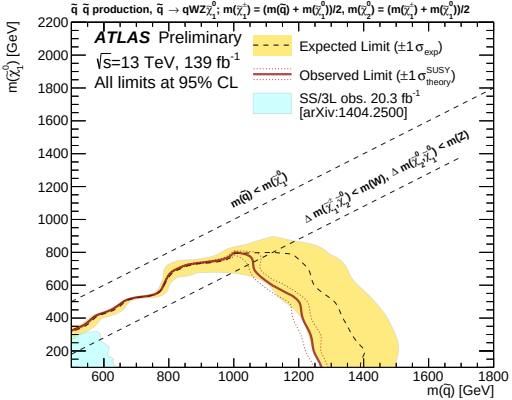


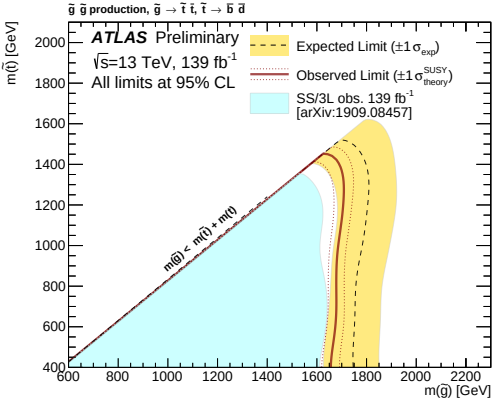




pair production of squarks or gluinos in final states with two same-sign or three leptons

[ATLAS-CONF-2023-017]





Analysis is interpreted in several supersymmetric simplified models improving previous ATLAS exclusion limits