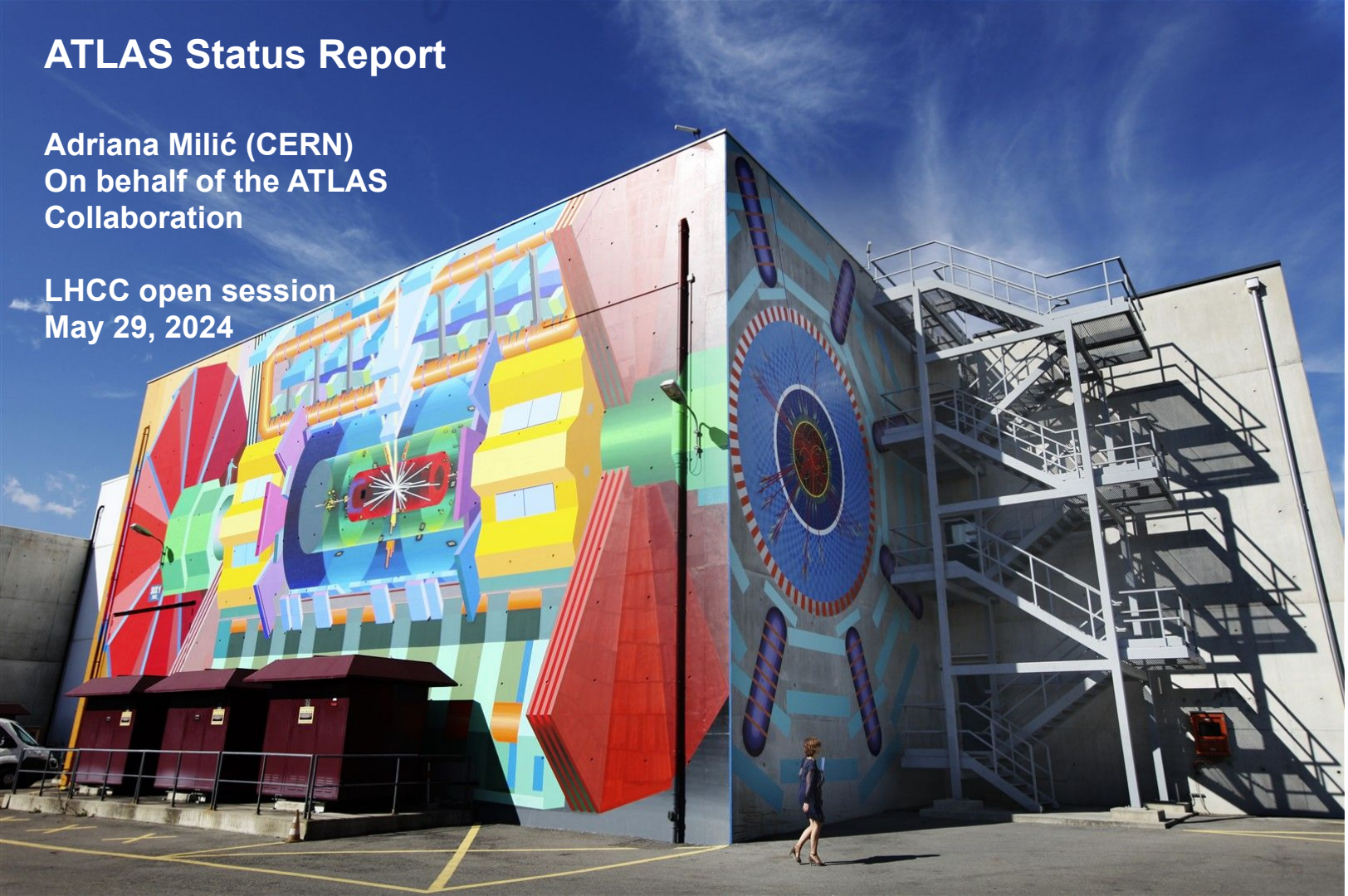
ATLAS Status Report

Adriana Milić (CERN)
On behalf of the ATLAS Collaboration

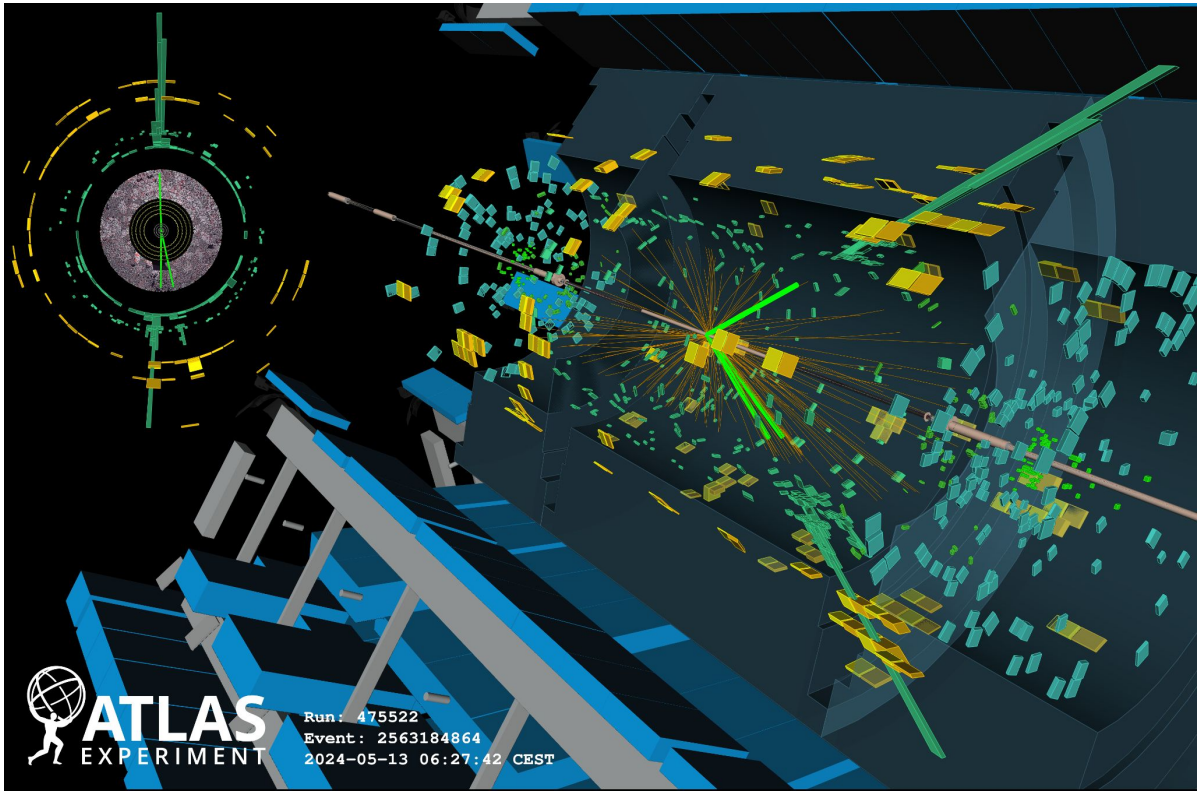
LHCC open session
May 29, 2024



Outline

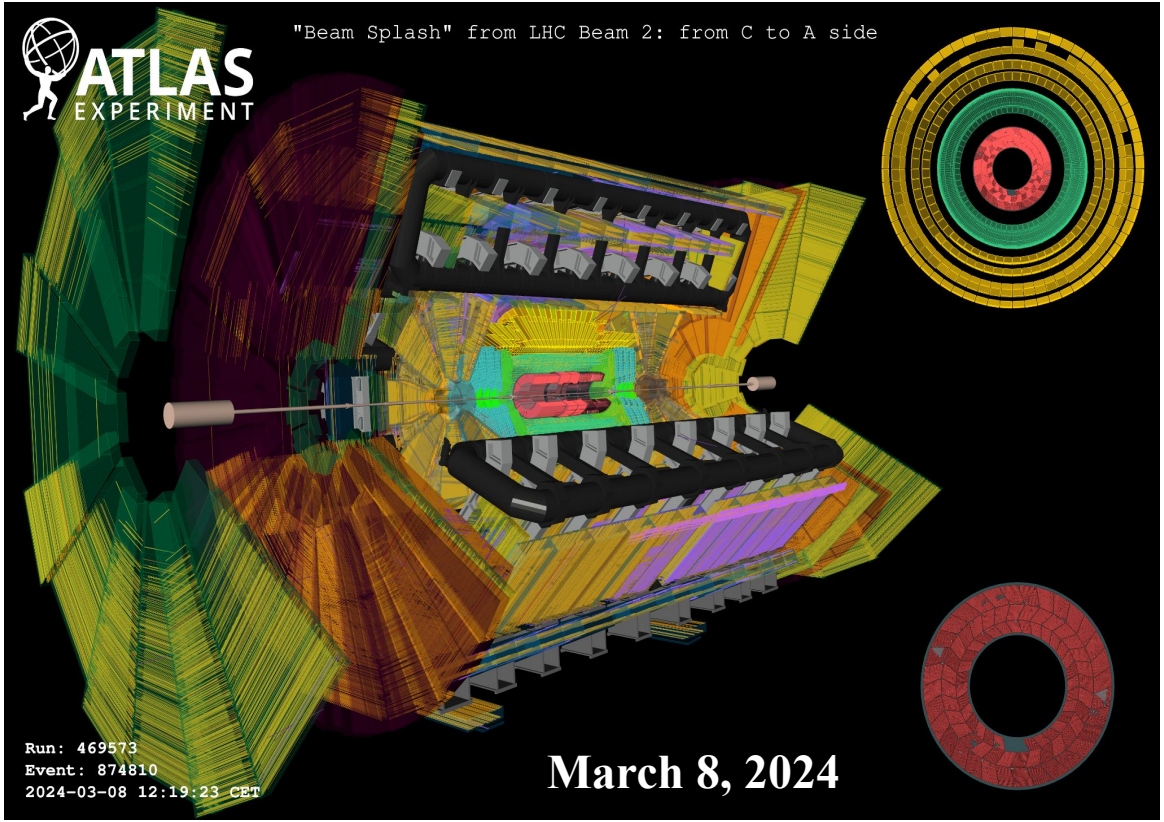
Highlights from

- Data taking and performance
- Physics analysis
- Phase-II

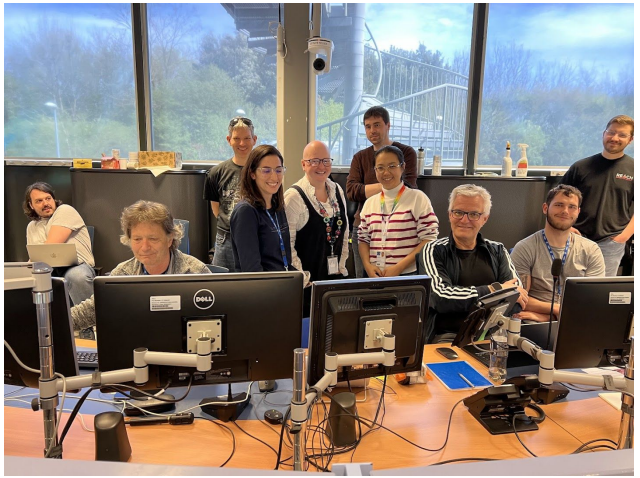


Highlights from Operations

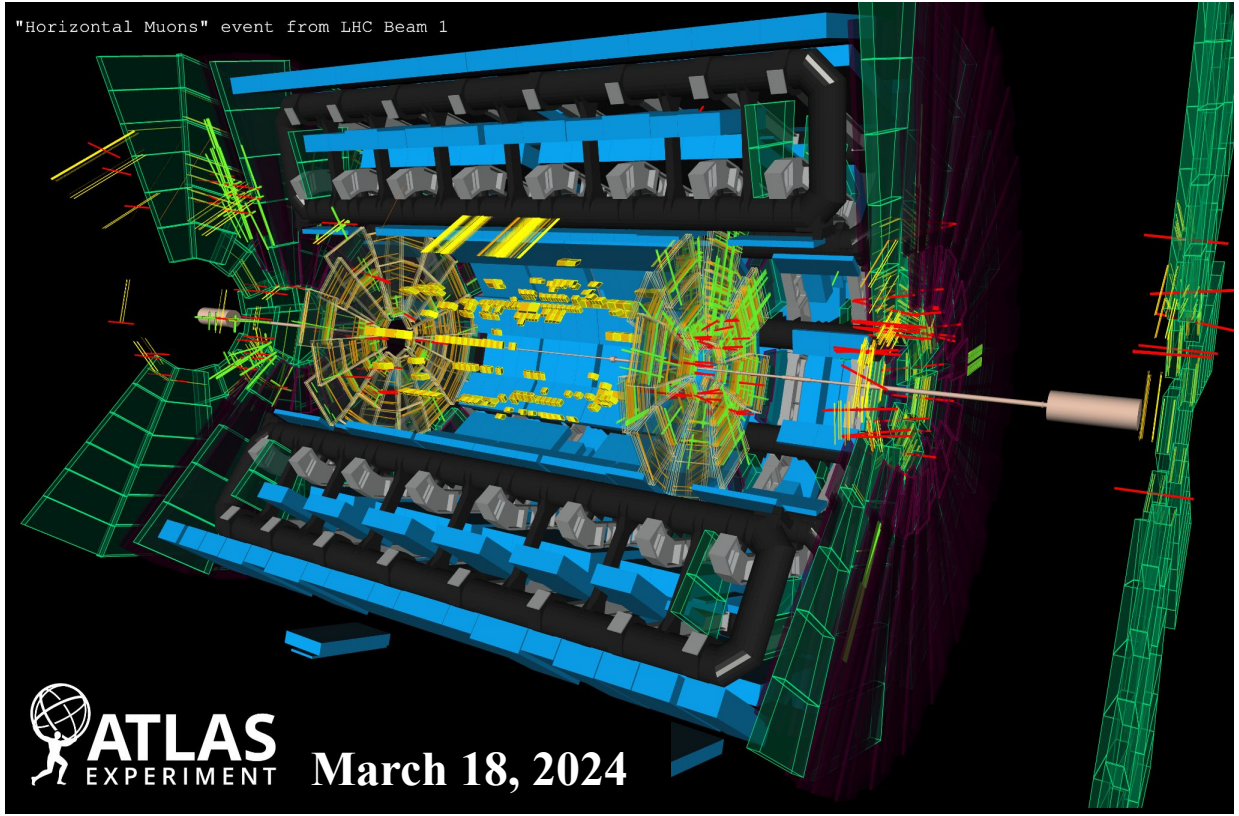
2024 beam commissioning



- **Splash event triggered** for the **first time by Phase-I** system
- Great for **timing in detector**!



2024 beam commissioning

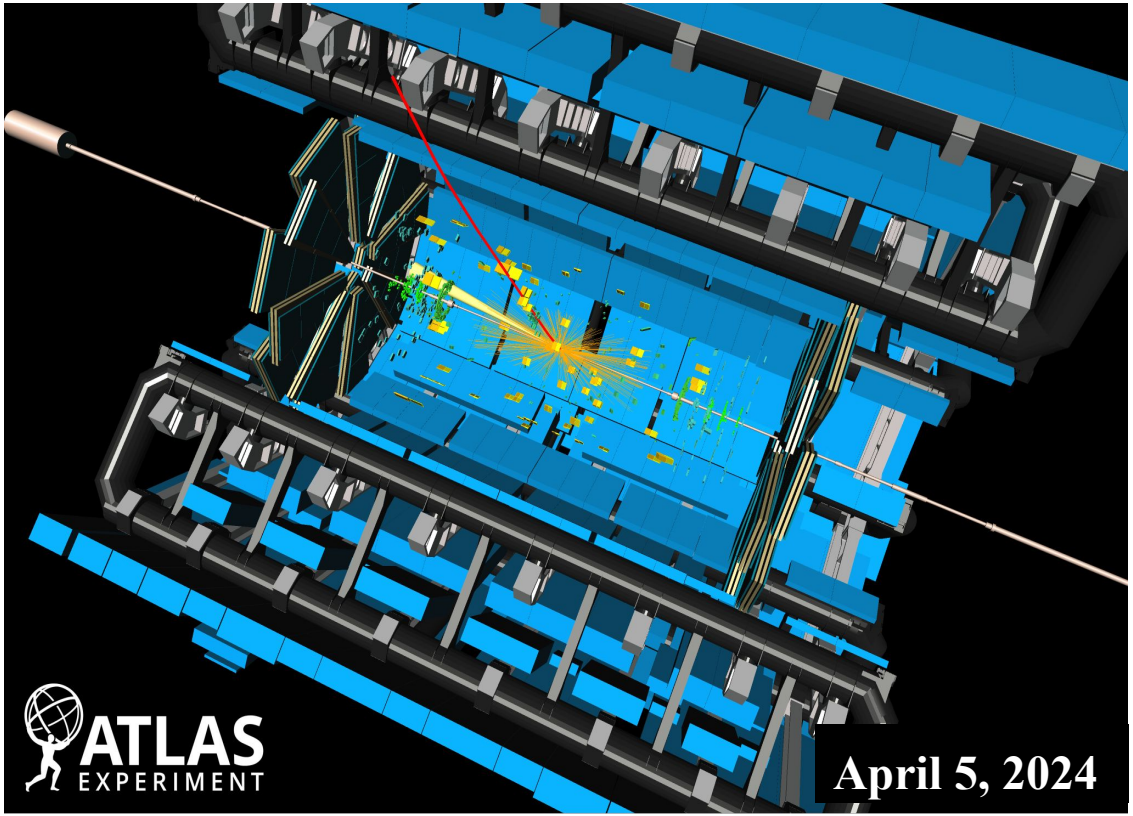


Horizontal muon event from special run provided for ATLAS for

- **Timing in detector**
- **Calibrate**

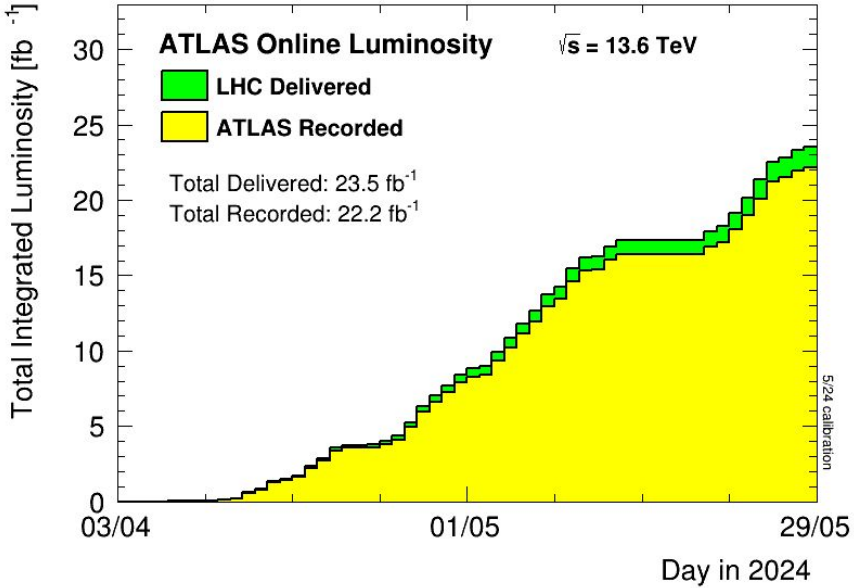
Big thank you to the LHC team!

2024 data taking



Collision event from first stable beam run of 2024 at 13.6 TeV

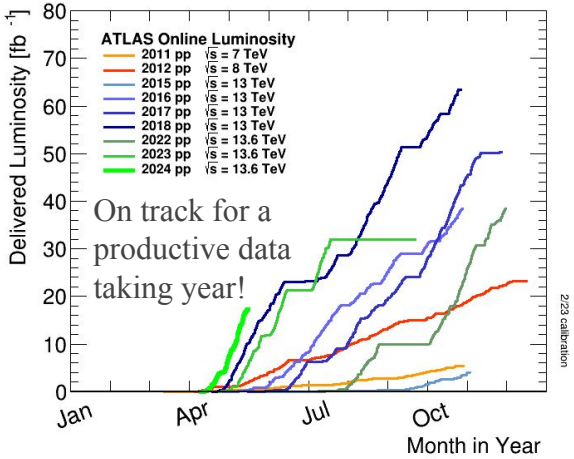
2024 data taking

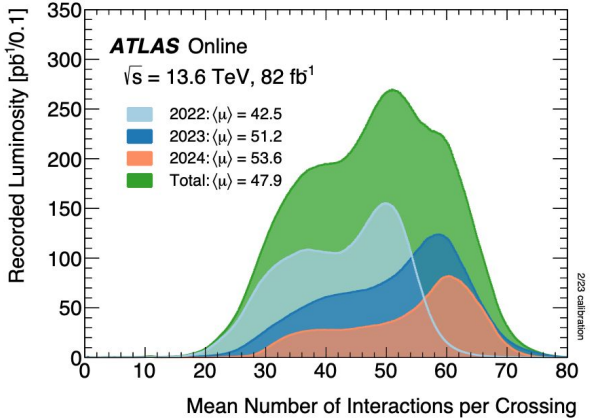


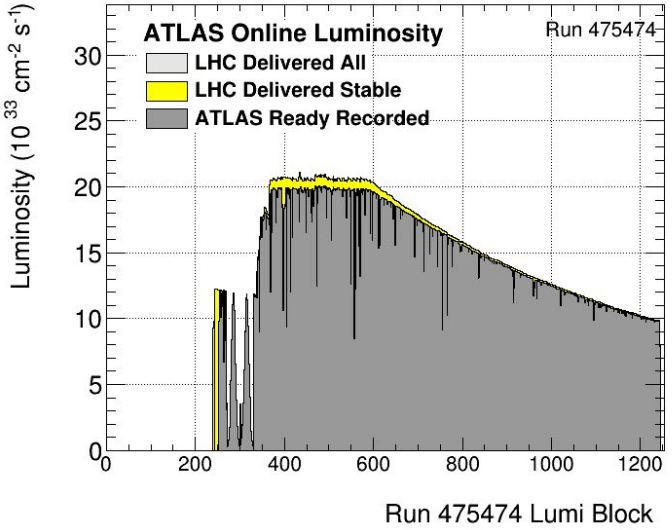
- Data taking efficiency at ~ **94.5%**
- Detector operational fraction in most systems **close to 100%**

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	92 M	95.1%
SCT Silicon Strips	6.3 M	98.4%
TRT Transition Radiation Tracker	350 k	95.6%
LAr EM Calorimeter	170 k	100%
Tile Calorimeter	5200	98.8%
Hadronic End-Cap LAr Calorimeter	5600	99.9%
Forward LAr Calorimeter	3500	99.8%
LVL1 Calo Trigger Fibers	7500	100%
LVL1 Calo Trigger Channels (LAr)	34 k	99.7%
LVL1 Calo Trigger Channels (Tile)	1920	98.4%
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	95.8%
STGC NSW	358 k	93.3%
RPC Barrel Muon Chambers	383 k	94.2%
TGC End-Cap Muon Chambers	312 k	99.2%
AFP	430 k	90%
AFP TOF	2x16	94%
LUCID	2x12+8	100%
ZDC	2x(4+16)	100%

2024 data taking



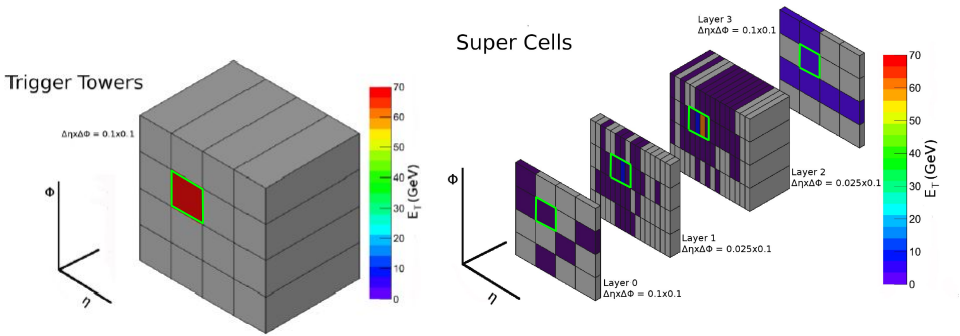




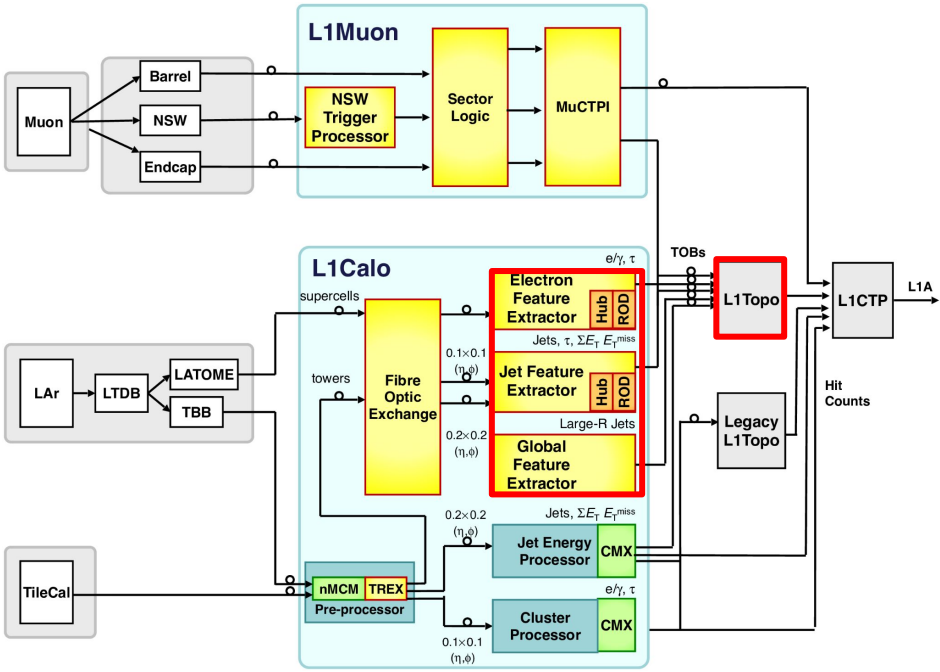
- Currently running at a L1A rate of ~95 kHz at $\mathcal{L}$ = 2.1e34 cm^{-2}s^{-1} at a peak $\langle\mu\rangle$ = 63
- **Higher beam background rates** seen this year
  - Might be due to changed optics

Phase-I: Liquid Argon digital trigger + L1Calo system

Primary goal is to reduce L1 rate while keeping p_T thresholds low



Liquid Argon digital trigger providing higher granularity and resolution E_T to Feature EXtractors (**FEXes)** with preapplied baseline correction

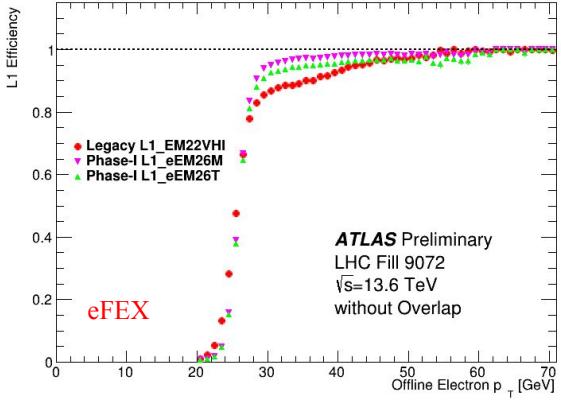


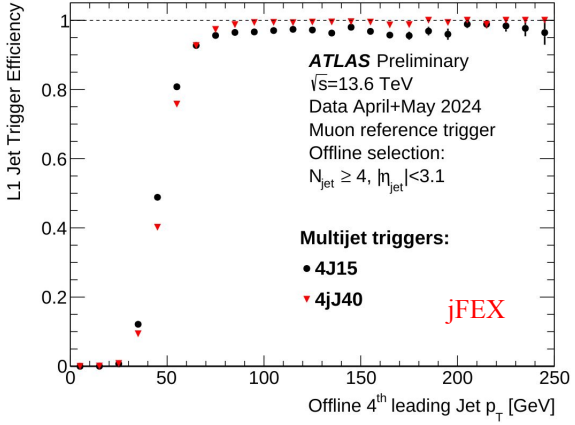
arXiv:2401.06630

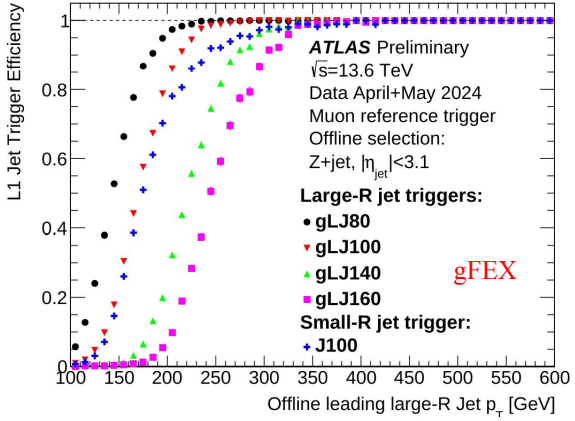
Phase-I: Liquid Argon digital trigger + L1Calo system

Commissioning progress

- All **primary triggers seeded from Phase-I FEXes**
- Small number of **legacy triggers kept for validation comparisons**
  - **electron (e)-FEX** fully enabled in 2023 (L1 rate reduction of 10%)
  - **jet (j)-FEX and global (g)-FEX** commissioning being finalized
  - Trigger items in the progress of being unprescaled for small-R jets, large-R jets, energy sums, MET
  - Disabling of legacy items in parallel with Phase-I validation

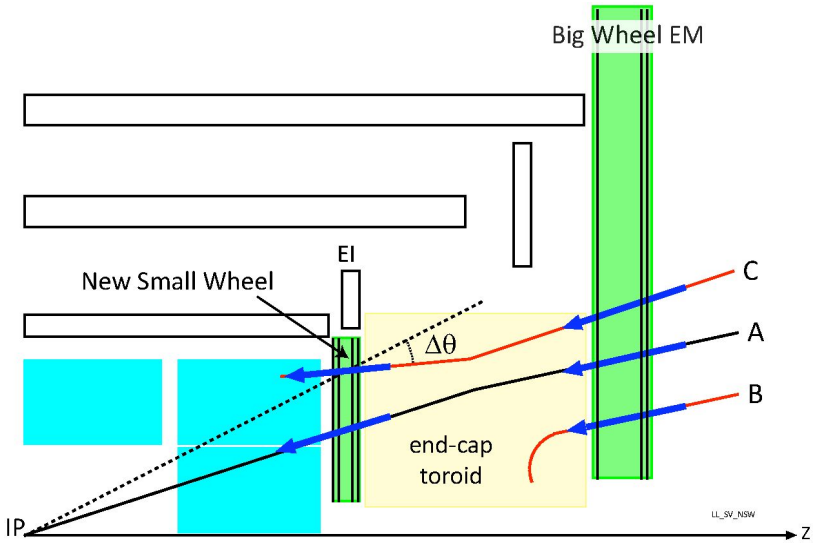


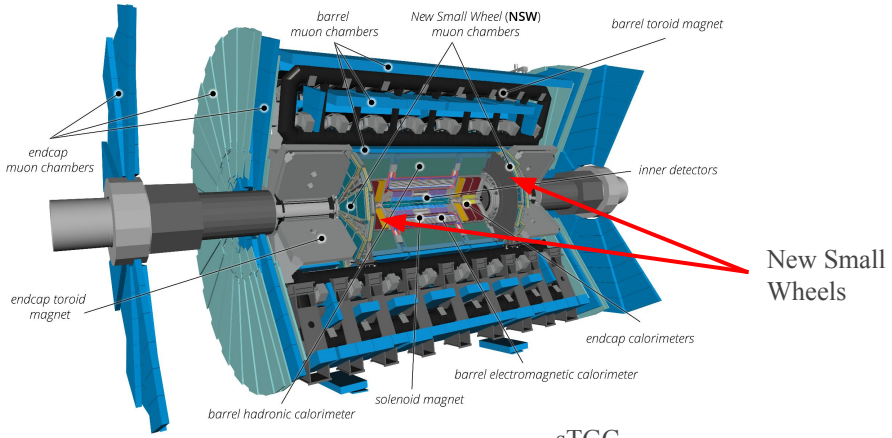


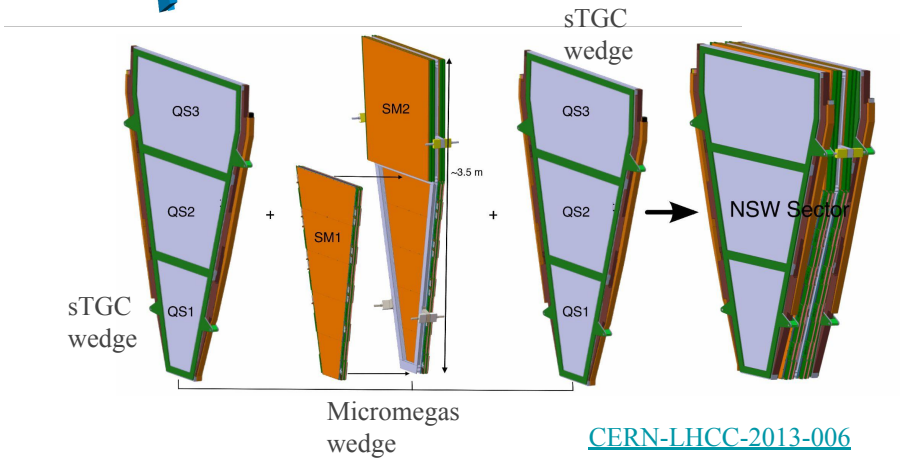


Phase-I: Muon New Small Wheel (NSW)

- **Primary goals**
  - **Reduce muon fake rate using trigger coincidence between NSW and Big Wheel**
  - **Increase muon efficiency**





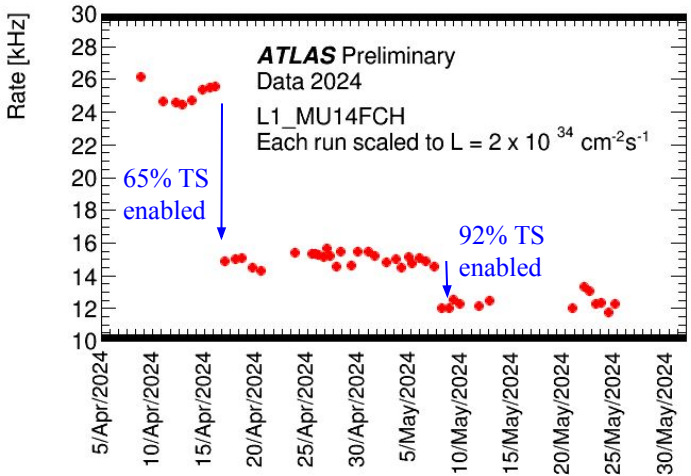


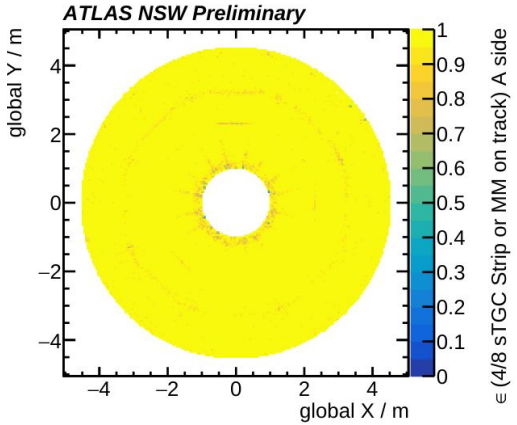
CERN-LHCC-2013-006

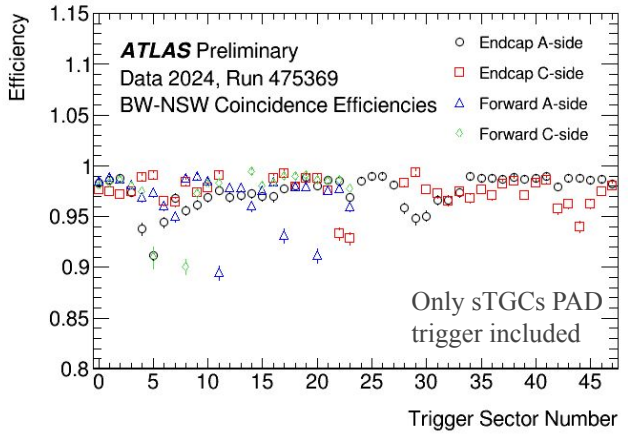
Phase-I: Muon New Small Wheel (NSW)

Commissioning progress

- **sTGC trigger coincidence** already enabled in 2023 and yielded 7-8 kHz rate savings (70% of trigger sectors (TS) enabled)
- In 2024 rejection increased to ~14 kHz (92% of sectors enabled)
  - Rate from real muons also higher due to higher efficiency
- Progressive enabling of **Micromegas trigger coincidence** is in progress
  - Showing even better efficiency (> 95%)!







HLT improvements

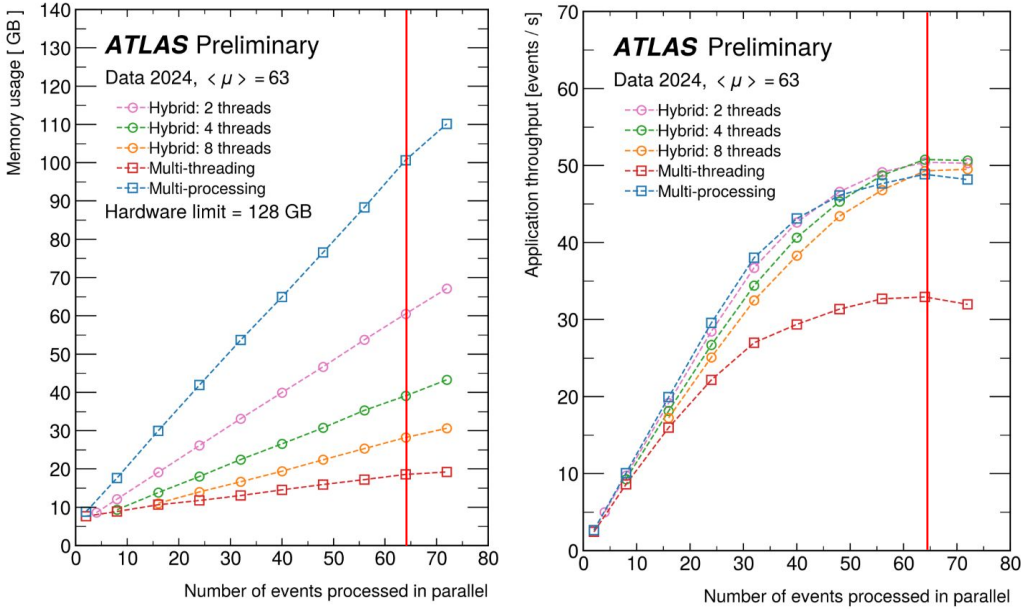
HLT in good shape

- HLT output bandwidth at ~ 7.5 GB/s, nominal limit at 8 GB/s
  - Plans to reduce ATLAS event size once Phase-I fully commissioned
- HLT CPU, readout system, and DAQ network non-limiting

- **CPU performance**
  - Aided by trigger algorithmic optimisations, gain in throughput from OS change to Alma 9 and HLT multithreaded framework improvements

- **B-tagging**
  - New **Graph Neural Network tagger** (GN2) further improved rejection for same efficiency

Running 16 forks * 4 threads →64 events in parallel



With currently used processing approach (Hybrid: 4 threads) **high throughput maintained while lowering memory consumption** with respect to previously used scheme (Hybrid: 2 threads).

HLT improvements

HLT in good shape

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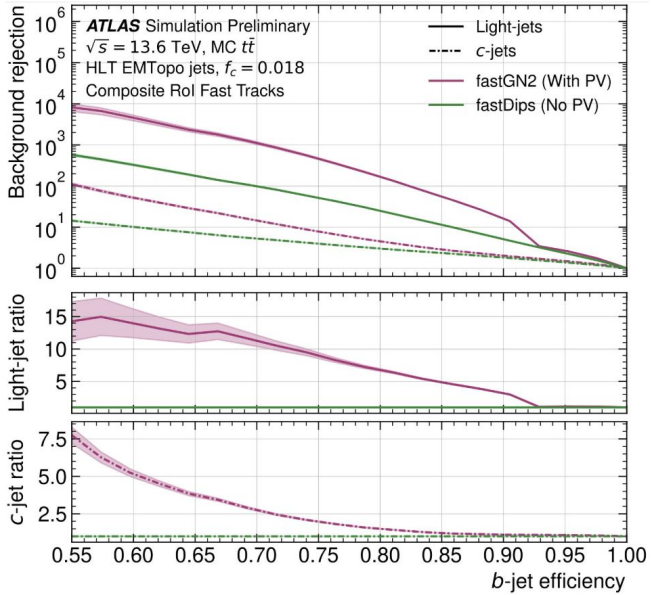
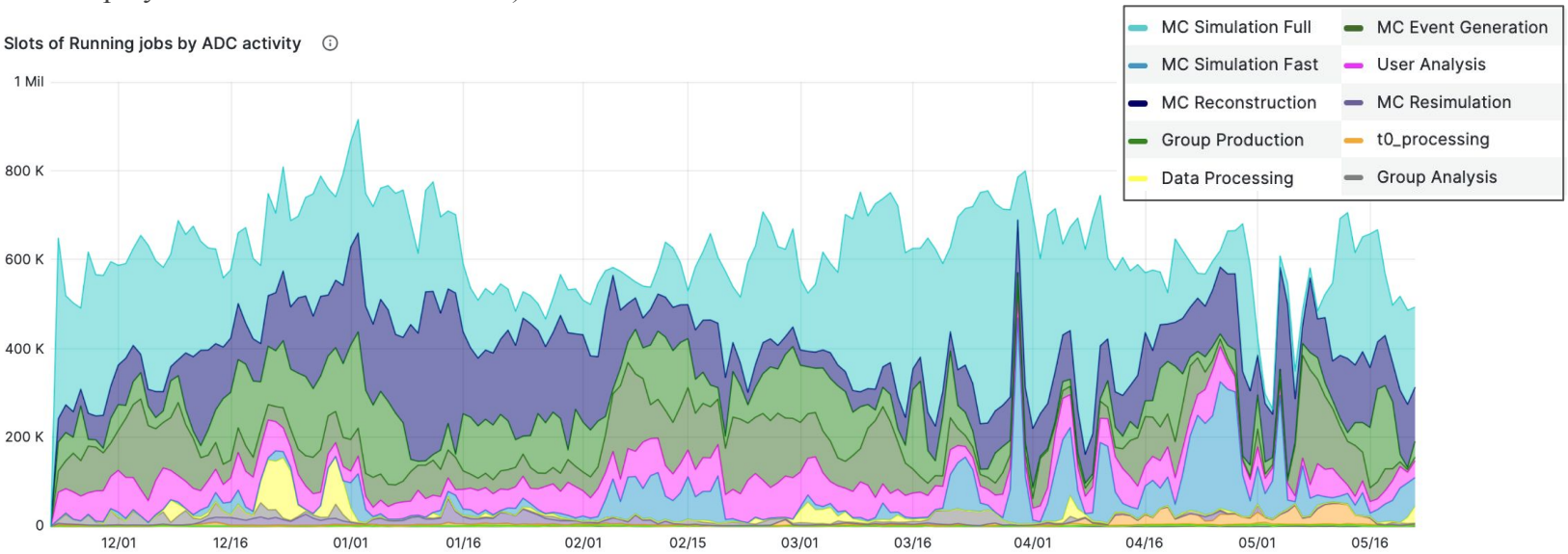


New tagging algorithm (*fastGN2)* utilizes **primary-vertex information**, while old algorithm (*fastDIPS)* does not
→ much **better performing c-jet and light-jet rejection** for all working points!

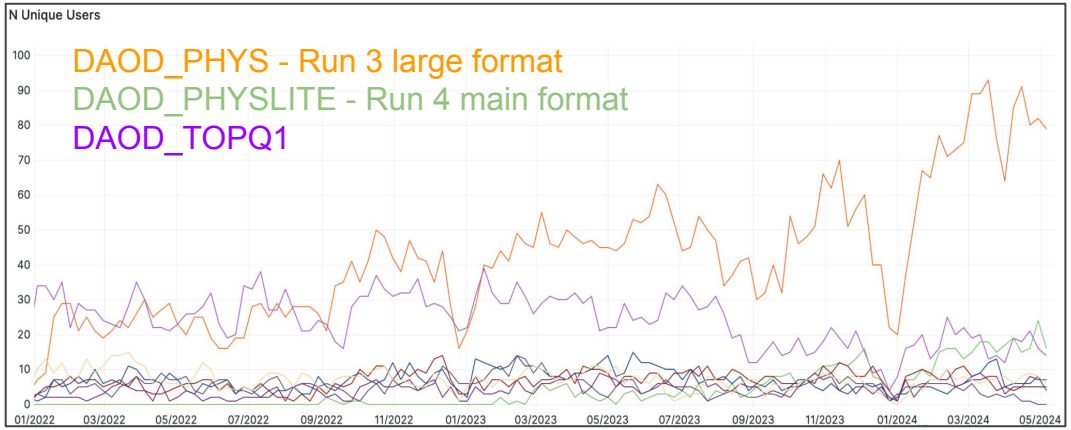
Software and Computing Activities

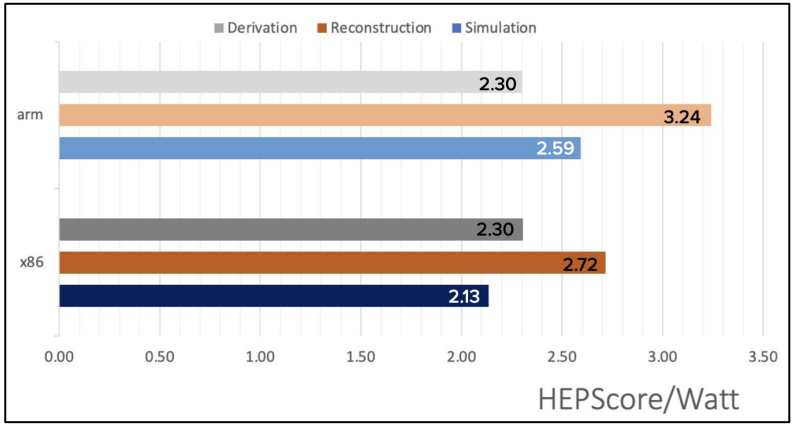
- **Smooth distributed computing operations**
  - Grid sites continuously providing reliable resources, significant opportunistic resources available (HPC centers)
  - First significant Grid-based-GPU test data reprocessing campaigns ran in the last month!
- **Two papers submitted**
  - Run 3 Software and Computing paper (ATLAS SW design, workloads, DBs, distributed computing, analysis tools…)
  - Total Cost of Ownership evaluation of Google resources (project with Google to evaluate how ATLAS can best employ commercial cloud resources)



Software and Computing Activities

- Adoption of **small data formats** proceeding at a good pace
  - Many groups moving to smaller derivation format.
- Added about **8k cores of ARM processors** to several sites worldwide
  - More power efficient than processors used so far
  - Plots from recent HEPix reports on ARM studies





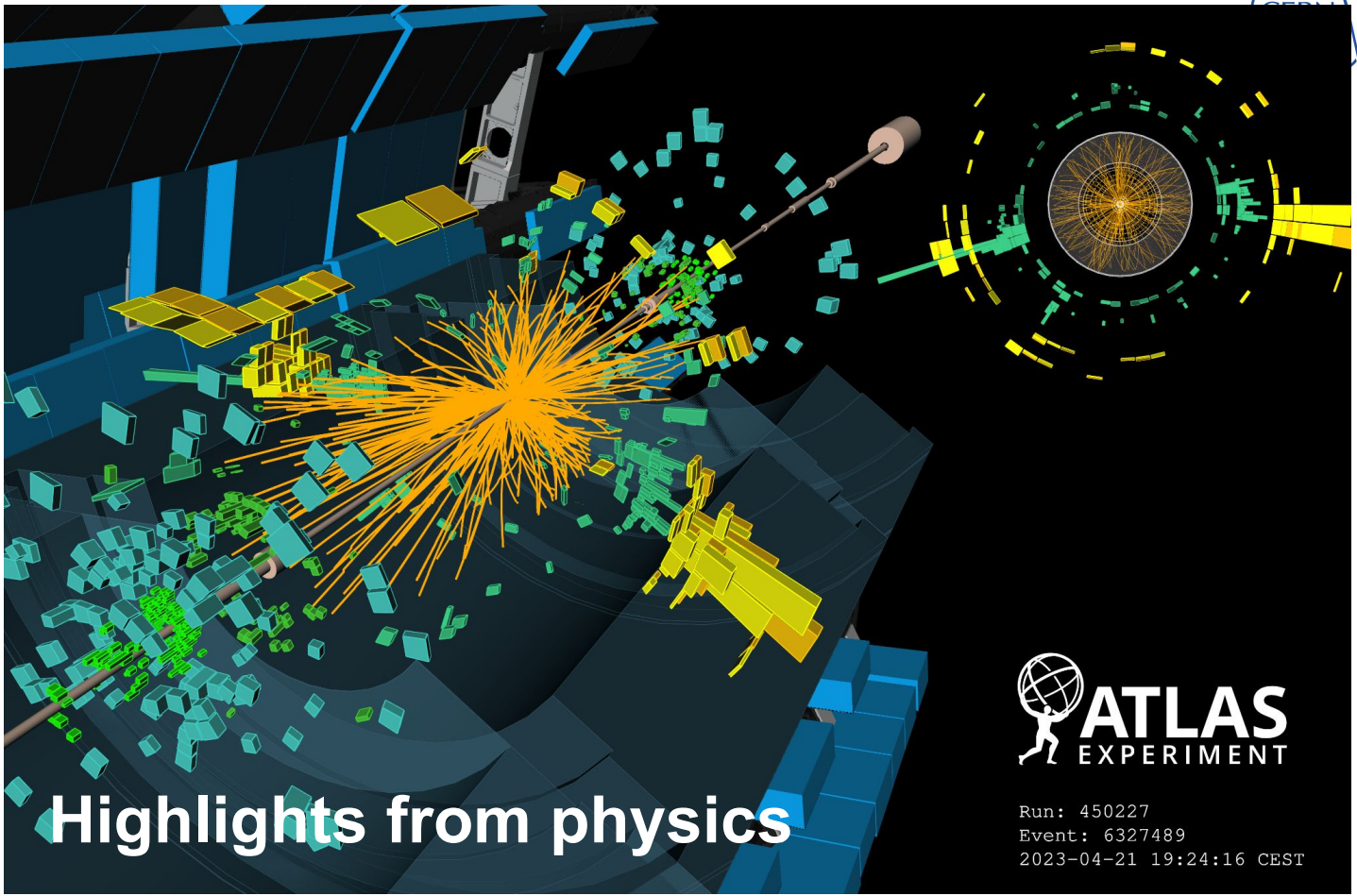
Since last LHCC on February 28

- 35 Papers
- 4 Conference notes
- 2 PubNote
- 7 Physics Briefings

In this talk:
A selection of new results with data from Run 1, 2, and 3!

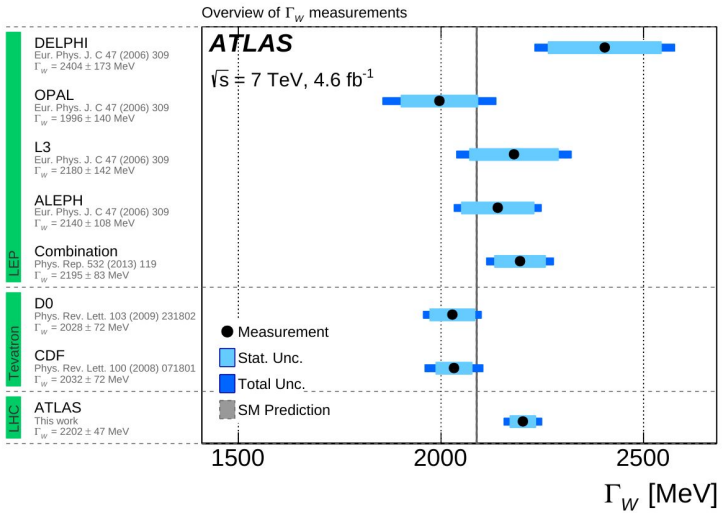
Impressive paper output of the collaboration**:**

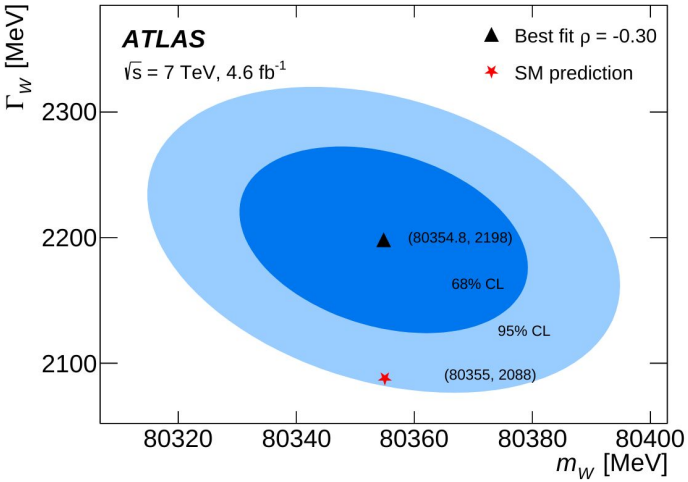
- **340 papers with full Run 2 dataset**
- **9 Run 3 papers**



Measurement of the W boson mass and width

- **First measurement of the W width** at the LHC in combined fit with W mass
- Result achieved by analysing kinematic spectra of W decays into electrons and muons
- Most precise single-experiment Γ_W measurement to date!



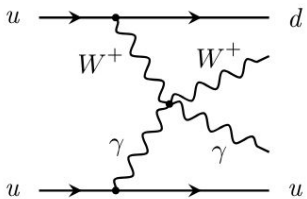


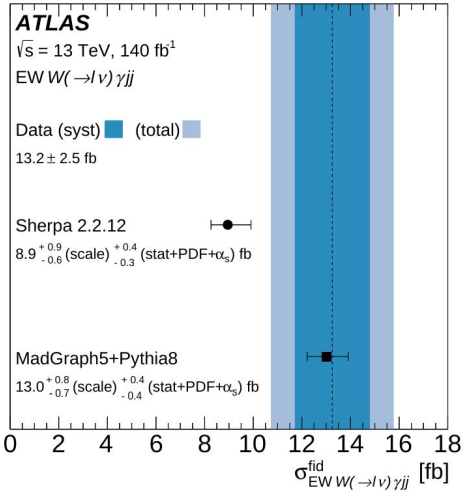
- Result consistent with SM predictions within 2σ
- $\Gamma_W = 2202 \pm 32 \pm 34$ MeV (SM: 2088 ± 1 MeV)

arXiv:2403.15085, Physics briefing

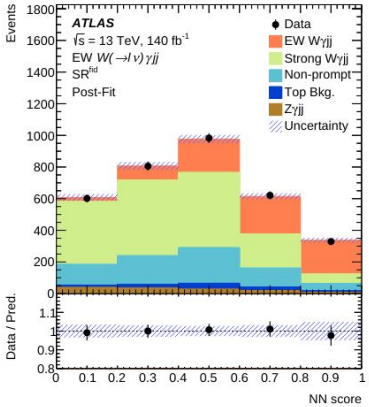
Electroweak $W\gamma jj$ production

- Observation of the electroweak production of a W boson and a photon in association with two jets
  - Sensitive to the quartic gauge boson couplings via VBS!
- Fiducial and differential cross section measurement

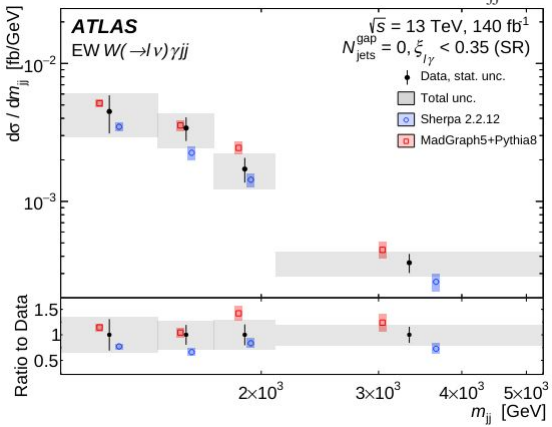




Neural networks deployed to separate especially strong from EW Wγjj production



Differential cross section as function of invariant mass m_{jj}

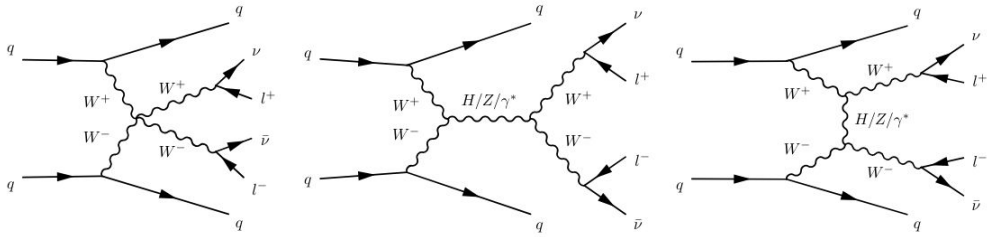


- Observed significance of the electroweak $W\gamma jj$ process > 6σ
- Measured fiducial cross section σ_{EW} = 13.2 ± 2.5 fb consistent with LO predictions
- Differential cross sections measured as function of six kinematic variables

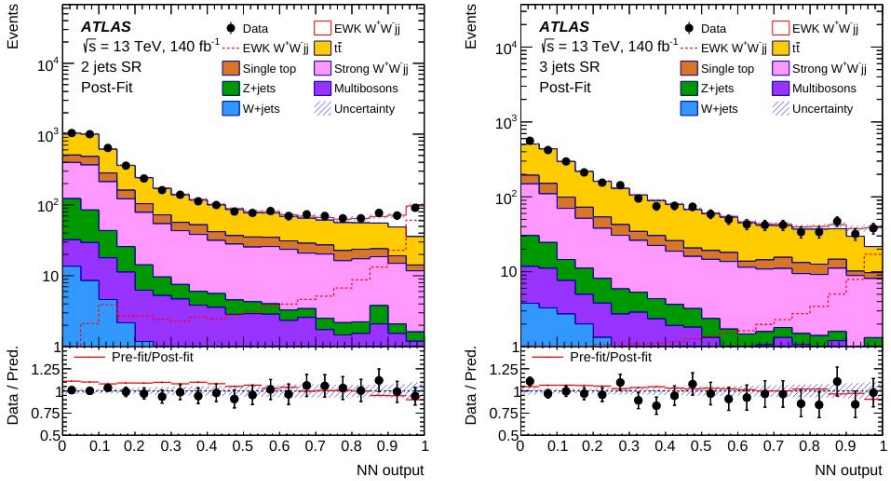
arXiv:2403.02809

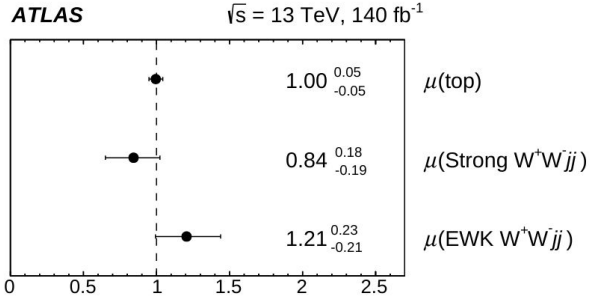
Electroweak W^+W^-jj production

- Observation of W^+W^- in association with jets
- Fiducial cross section measurement
- Different lepton flavor final states selected



A neural network is used to separate the signal from top quark and strong W^+W^-jj production



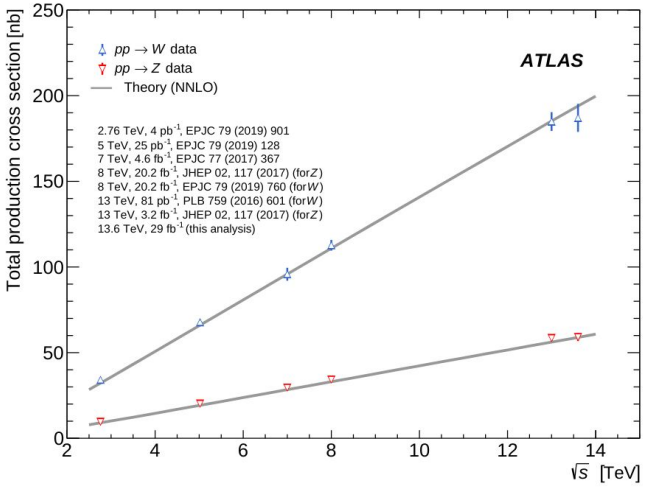


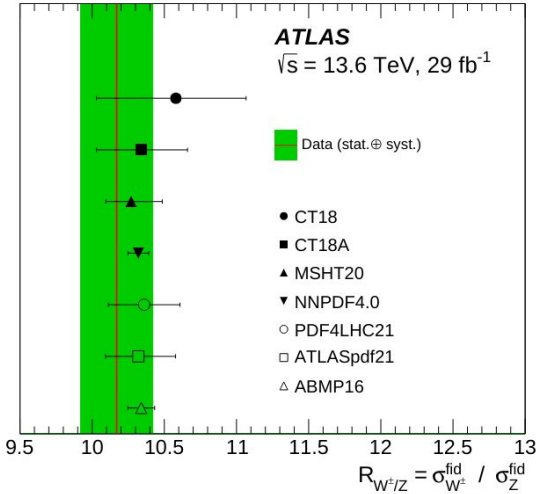
- Significance of 7.1σ observed
- Measured cross section 2.7 ± 0.5 fb consistent with theoretical prediction
- Dominant uncertainty from limited data sample

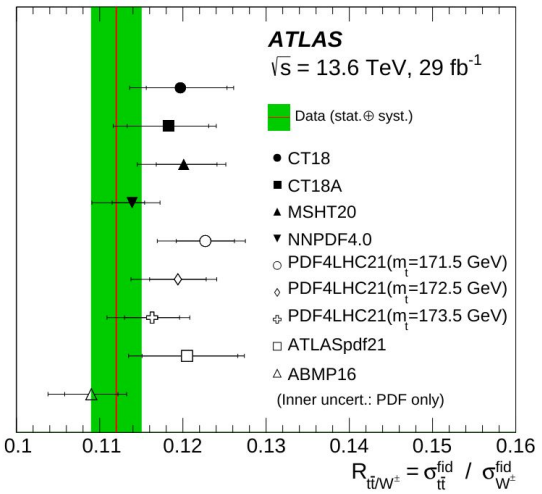
arXiv:2403.04869

W and Z production cross section measurement (Run 3 data!)

- Fiducial and total $W^{\pm}$ and Z boson cross sections measurement
- …and their ratios and the ratio of top-antitop pair and W boson fiducial cross sections







- W and Z boson cross sections are **in good agreement with the SM predictions**
- top-antitop over W boson fiducial cross section ratios slightly overestimated by some theoretical predictions
  - Consistent with Run 3 top-antitop cross-section measurement

Measured fiducial cross section values

- $W^{+} \to \ell^{+} \nu = 4250 \pm 150$ pb
- $W^{-} \to \ell^{-} \bar{\nu} = 3310 \pm 120$ pb
- $Z \to \ell^{+} \ell^{-} = 744 \pm 20$ pb

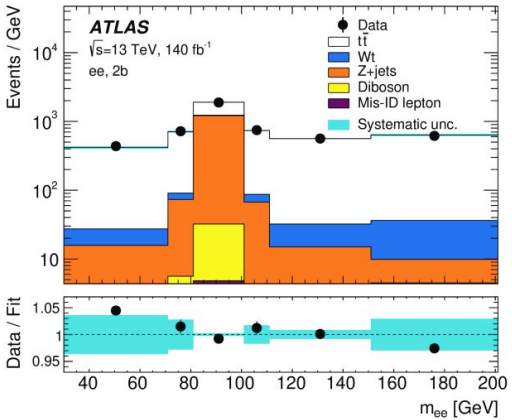
arXiv:2403.12902, Physics Briefing

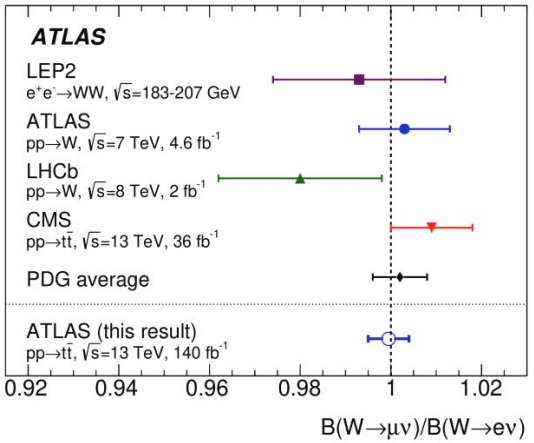
Probing lepton universality

- Lepton universality from W bosons from top-antitop pair decays measured by evaluating ratio $R_W^{\mu/e}$
- **Challenge**: Collect unbiased W sample
  - Systematic uncertainty be reduced by making a simultaneous measurement of the analogous ratio $R_Z^{\mu\mu/ee}$

$$R_{WZ}^{\mu/e} = \frac{R_W^{\mu/e}}{\sqrt{R_Z^{\mu\mu/ee}}} = \frac{\mathcal{B}(W \to \mu\nu)}{\mathcal{B}(W \to e\nu)} \cdot \sqrt{\frac{\mathcal{B}(Z \to ee)}{\mathcal{B}(Z \to \mu\mu)}}$$

Fit performed using double ratio. Uncertainties on electron and muon efficiencies cancel!





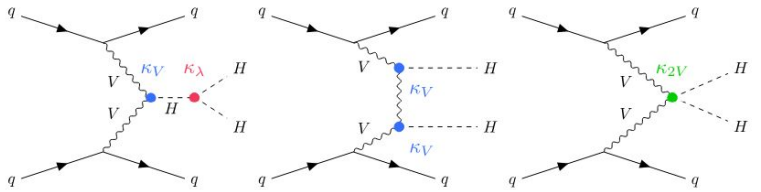
$R(\mu/e) = 0.9995 \pm 0.0045$

- Confirming SM at 0.5% level!
  - Improves single-experiment precision by factor of two!
- Adds to previous ATLAS $R(W \to \tau/\mu)$ result (Nature Physics 17, 813 (2021))

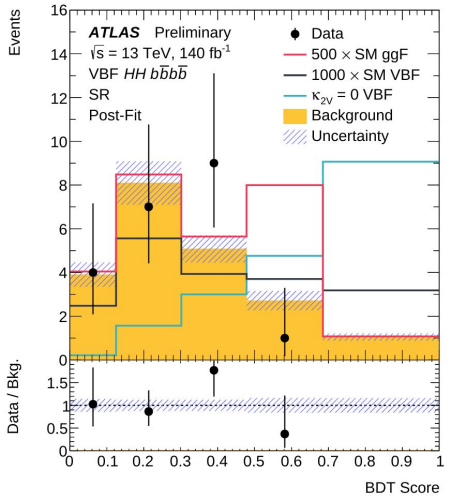
arXiv:2403.02133, Physics Briefing

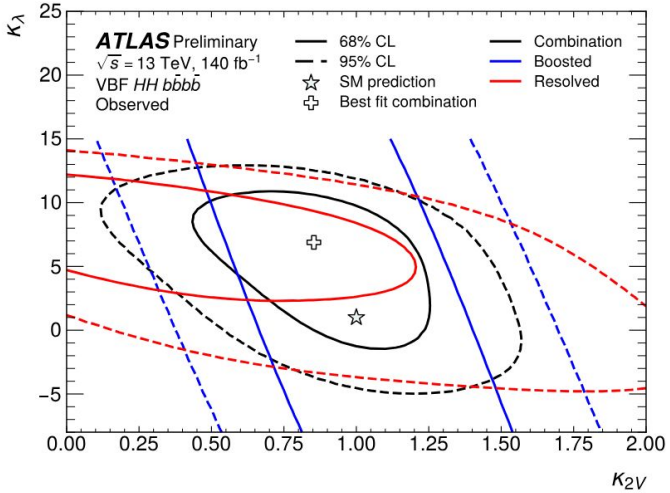
DiHiggs searches

- Search for boosted Higgs pair production via VBF in the *bbbb* final state
- Search sensitive to the **anomalous quartic couplings κ_{2v}** between two vector bosons and two Higgs bosons



BDT score used to separate signal from background



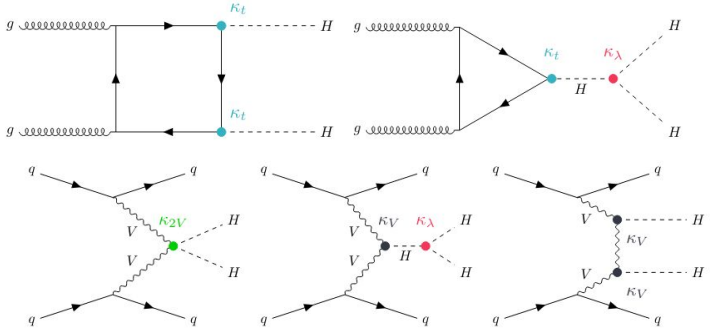


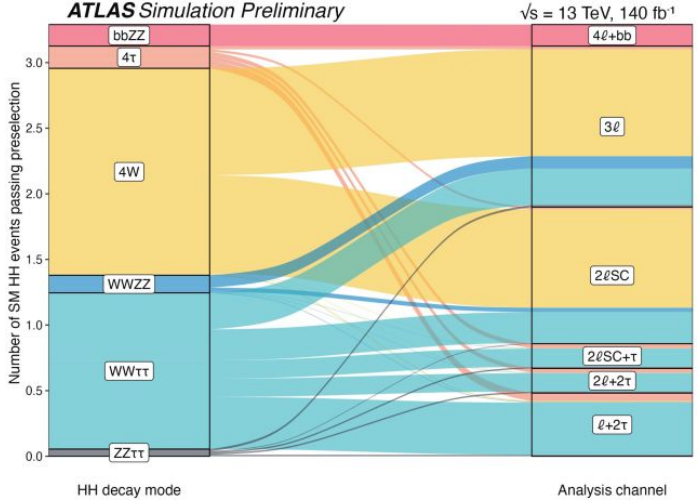
- Data agree with background only hypothesis
- Constraints when combining boosted and resolved results $0.55 < \kappa_{2V} < 1.49$
- $\kappa_{2V} = 0$ excluded with an observed significance of 3.8σ
- Statistically limited analysis

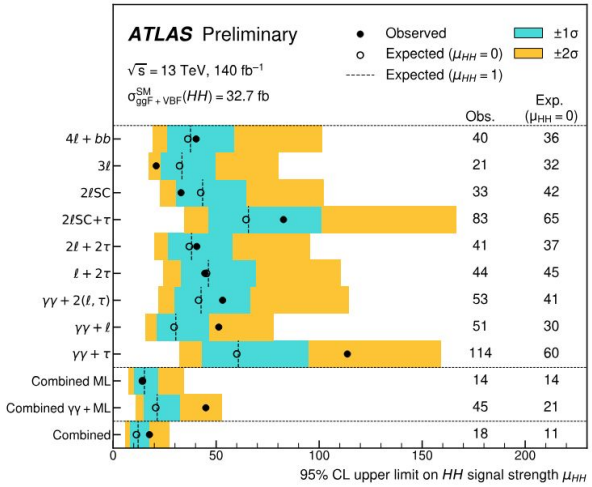
ATLAS-CONF-2024-003

DiHiggs searches

- Search for Higgs pair production in final states with leptons, taus and photons
  HH→ bbZZ, 4V, VVττ, 4τ, γγVV, γγττ
  - **Explored for the first time in ATLAS!**
- BDT scores are used to separate signal from background



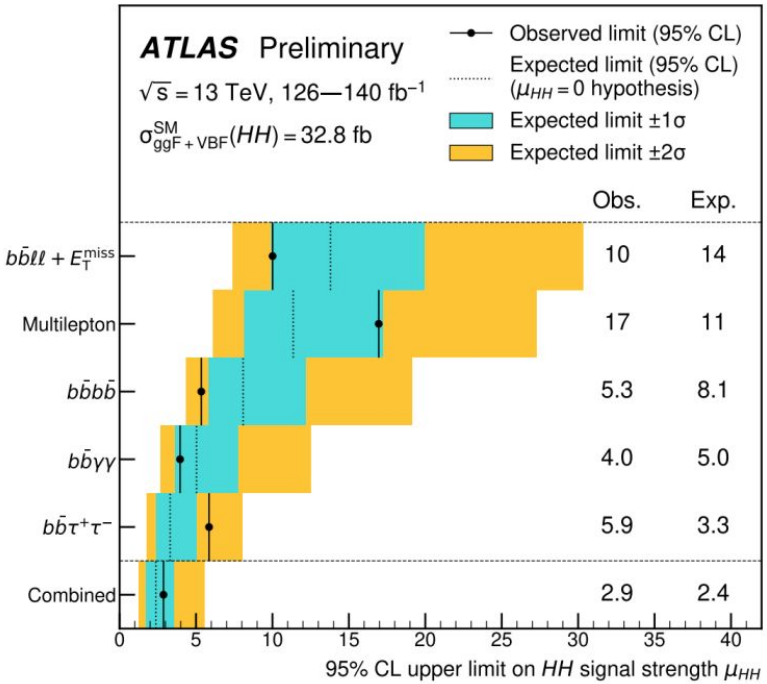




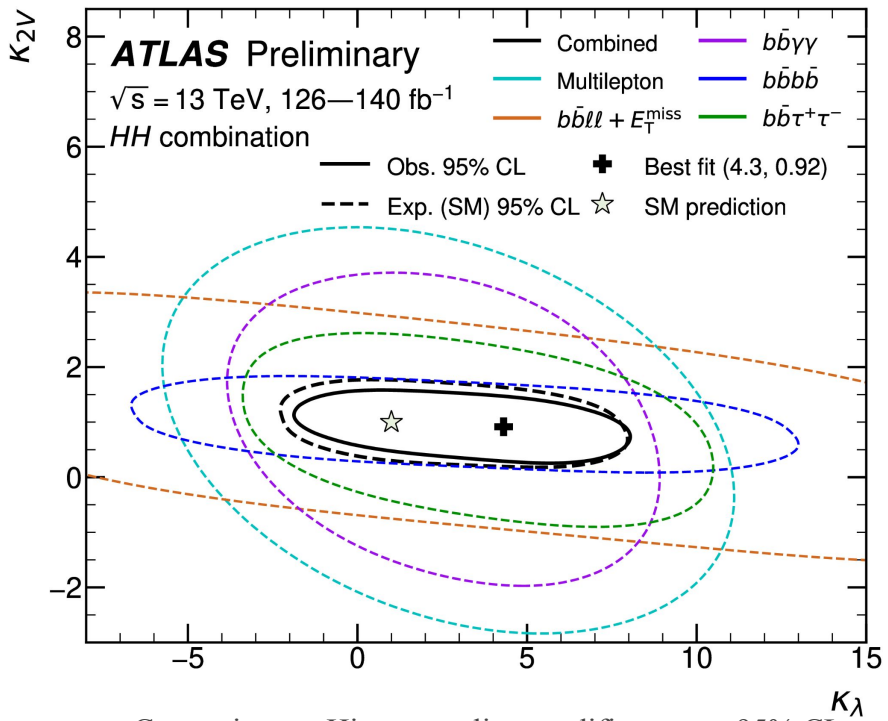
- Observed limits of 18 times the SM prediction are set on the *HH* signal strength μ
- Statistically limited analysis

ATLAS-CONF-2024-005, Physics Briefing

Legacy Run 2 *HH* combination



New combination of updated **diHiggs** searches using full Run 2 dataset



Constraints on Higgs coupling modifiers set at 95% CL

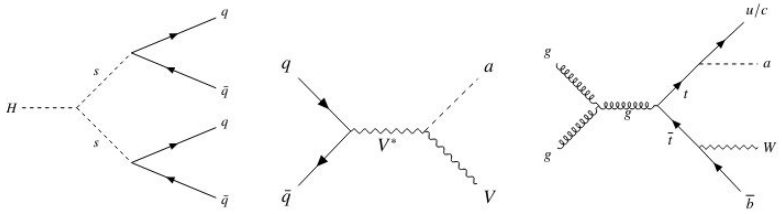
$-1.2 < \kappa_\lambda < 7.2$

$0.57 < \kappa_{2V} < 1.48$

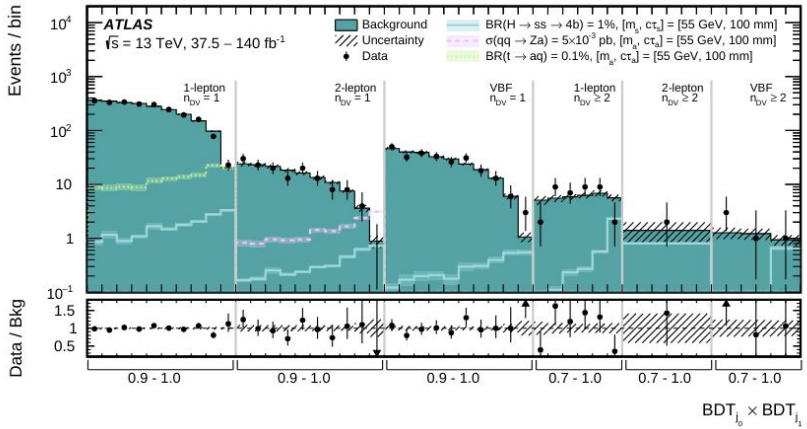
ATLAS-CONF-2024-006

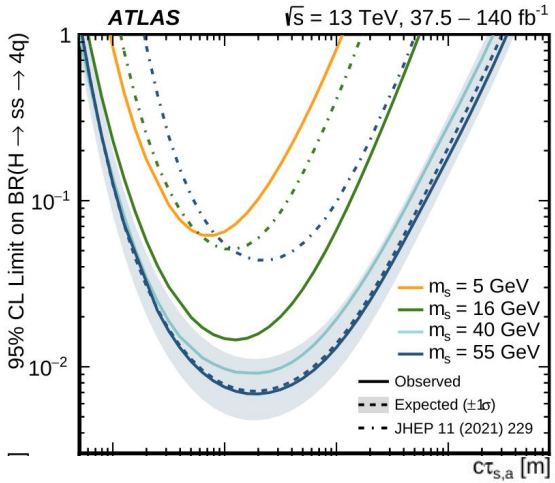
Light long-lived particles (LLPs) using displaced vertices

- LLPs ($c\tau \gtrsim 100\,\mu$m) with 5 GeV < m_s < 55 GeV that decay hadronically targeted
  - Possible with **improved track reconstruction pass** for large impact parameter tracks!
- All Higgs production modes included!
- Benchmark models from exotic Higgs decays to axion-like particles (ALPs) considered



Product of two BDT discriminants used to distinguish events with displaced from those with prompt jets





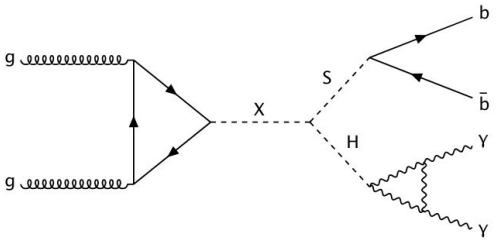
- No significant excess beyond the SM is observed
- Most stringent constraints to date on Higgs BR for $m_s < 40$ GeV and $1 < c\tau_s < 100$ mm!

arXiv:2403.15332

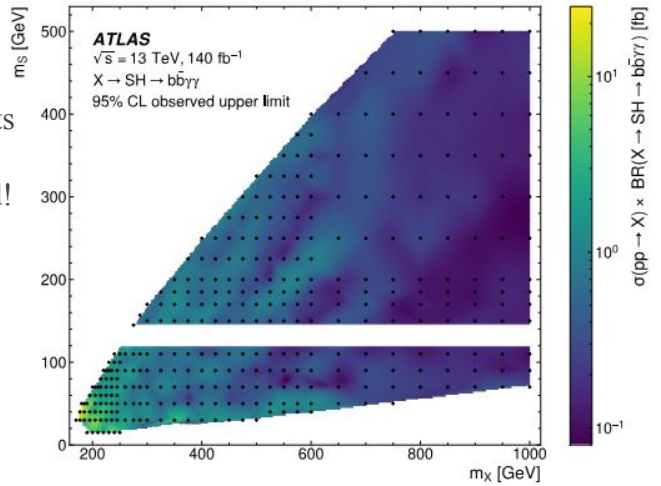
Heavy Higgs

Search for a heavy scalar X decaying into another scalar S and a Higgs boson H

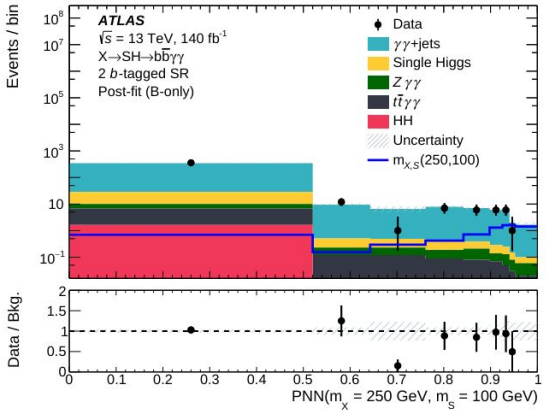
$X \rightarrow S(\rightarrow bb)H(\rightarrow \gamma\gamma)$

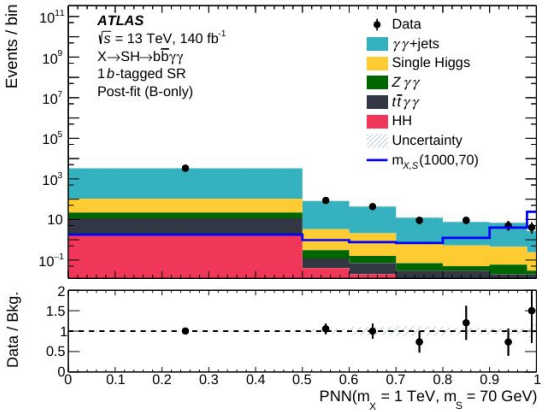


For setting limits 359 (m_X, m_S) pairs are probed!



Parameterised neural networks for signal discrimination in resolved and boosted decays



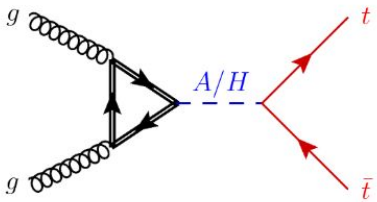


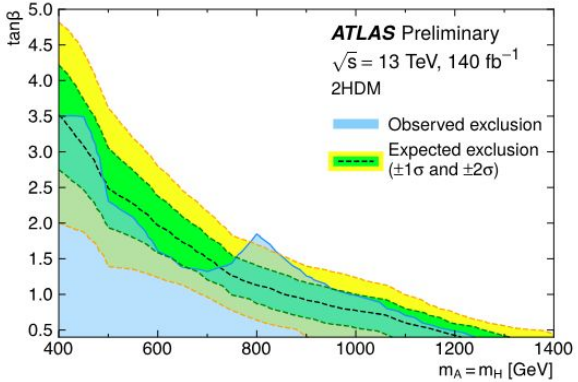
- No significant excess above the expected background is found
- Earlier LHC searches expanded to lower masses m_S and m_X
- Upper limits range from 39 fb to 0.09 fb
  - Excluding small CMS excess at (m_X, m_S) = (650,90) GeV

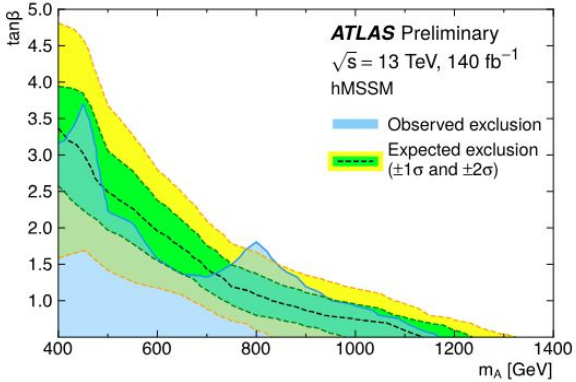
arXiv:2404.12915, Physics Briefing

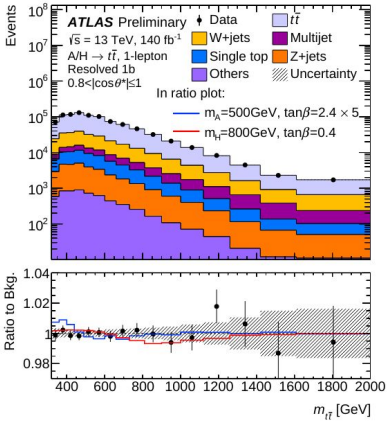
Heavy Higgs

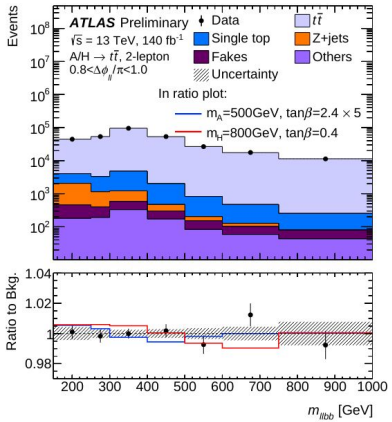
Search for heavy scalar H or pseudo-scalar A decaying into a top pair in a semi- or fully leptonic final state







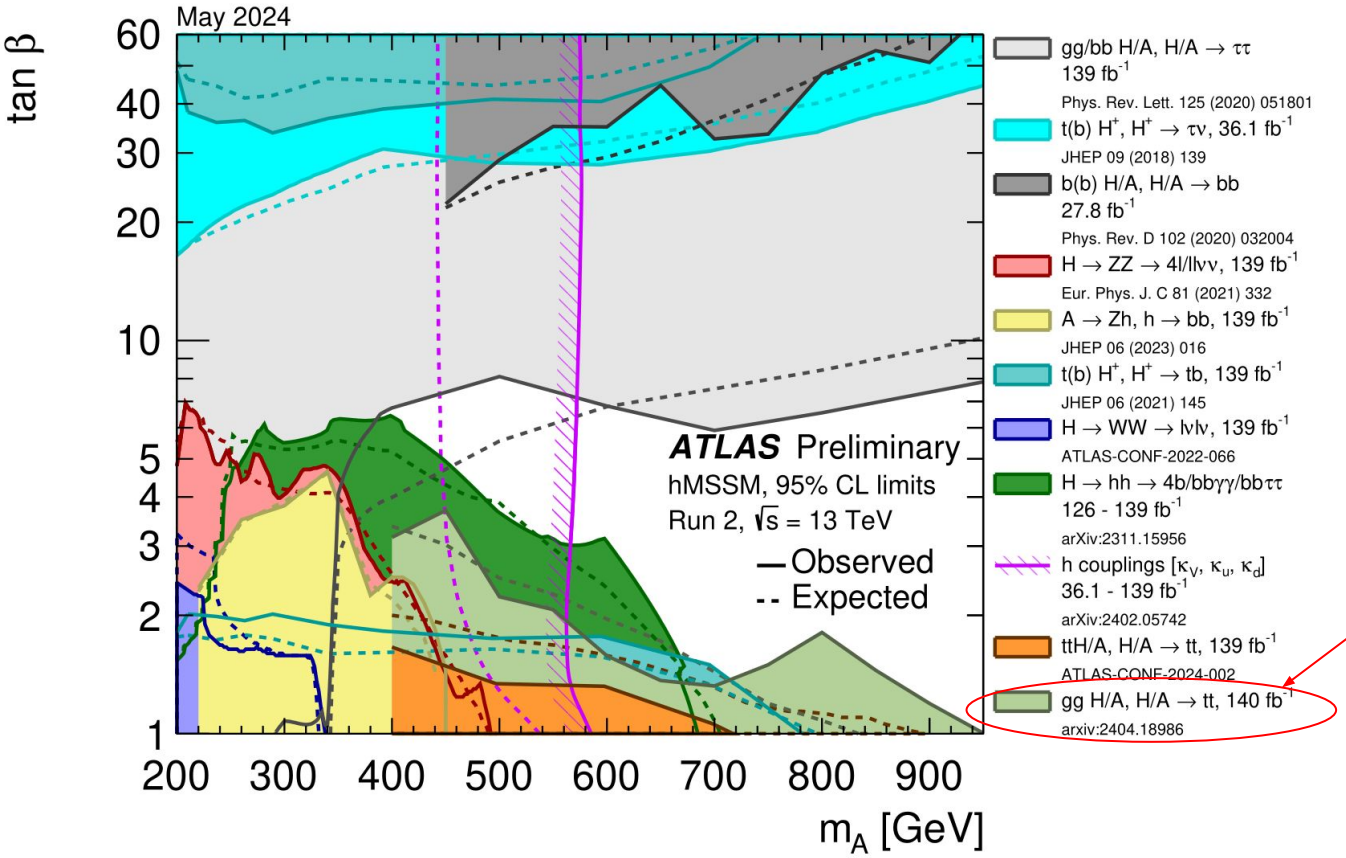




- No significant deviation from SM is observed
- **Most stringent constraints on the 2HDM** and **hMSSM** parameter space **for high m_A and low tanβ** to date

arXiv:2404.18986

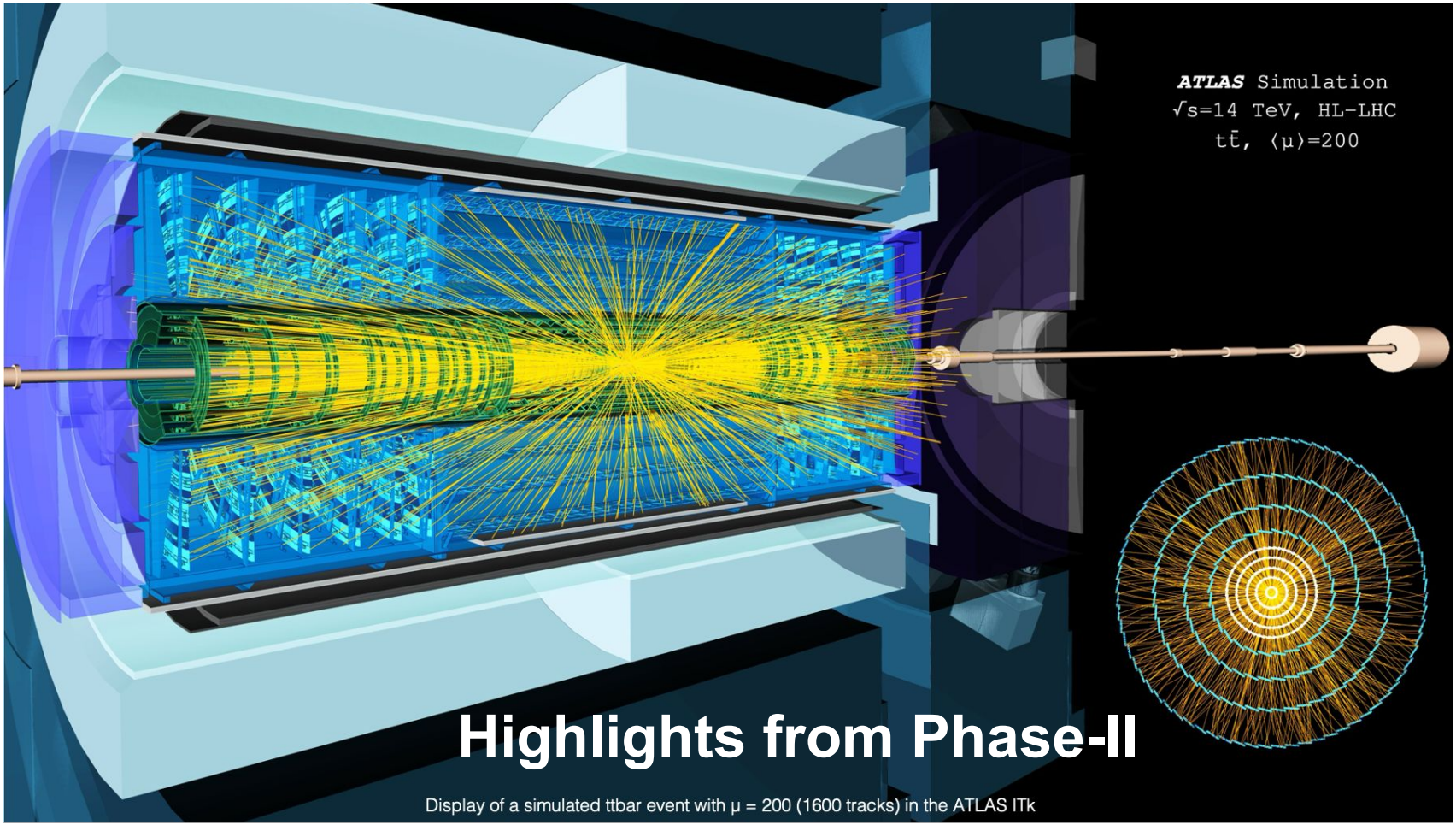
Heavy Higgs summary plot



Excluded regions of [m_A, tanβ] plane excluded in the hMSSM via direct searches for heavy Higgs bosons

- *gg H/A , H/A→ tt* adds to exclusion at low tanβ!

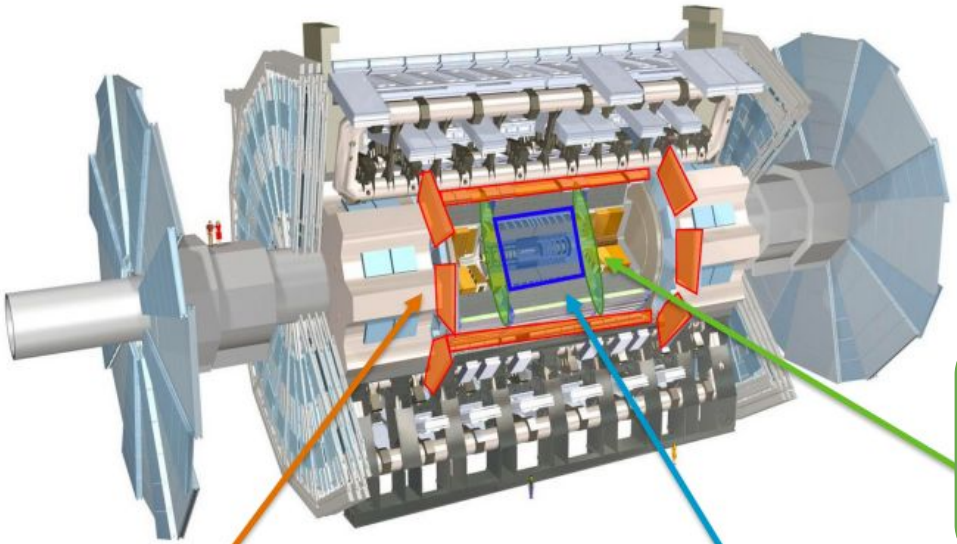
ATL-COM-PHYS-2024-195



Highlights from Phase-II

Display of a simulated ttbar event with μ = 200 (1600 tracks) in the ATLAS ITk

ATLAS Phase-II Upgrade overview



Upgrade of trigger and DAQ system
- L0 trigger at 1 MHz
- Improved High Level Trigger

Electronics upgrades
- Replacement of on/off detector electronics for LAr, Tile, and Muon detectors
- 40 MHz continuous readout with finer segmentation

High Granularity Timing Detector (HGTD)
- Forward region ($2.4 < |\eta| < 4.0$)
- Precision time reconstruction (30 ps) with Low Gain Avalanche Diodes (LGADs)
- Improved pileup separation and bunch-by-bunch luminosity

New Muon Chambers
- Inner barrel region with new RPC and sMDT detectors
- Improved trigger efficiency/resolution and reduced fake rate

New Inner Tracking Detector (ITk)
- All silicon, coverage up to $|\eta| = 4$
- Less material and finer segmentation

Additional upgrades
- Luminosity detectors
- HL-ZDC for heavy ion physics

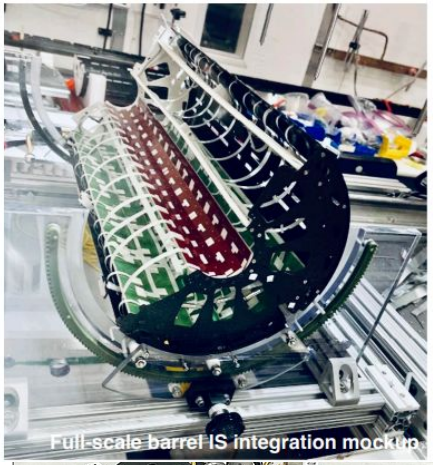
Most upgrades moved into production!

Inner Tracker (ITk)

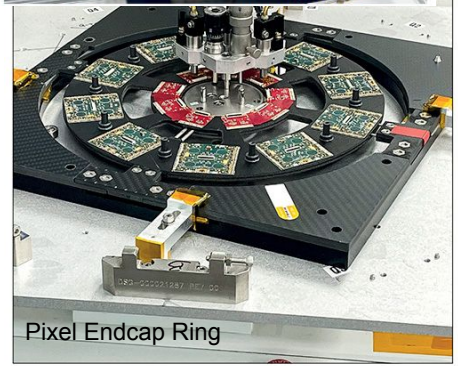
- **All ASICs in production**
- Good progress on services work (out of critical paths)
- Production of **ITk common structures** proceeds well

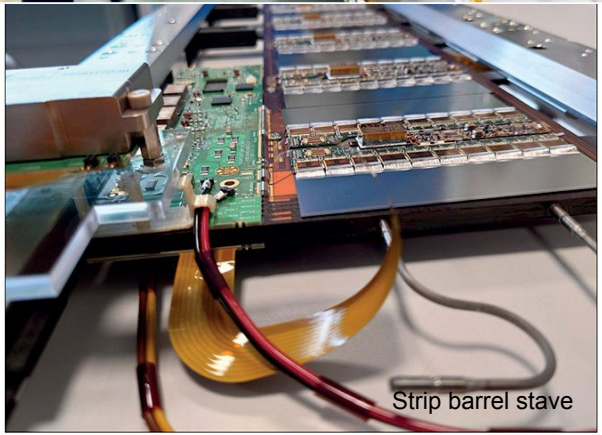
- **Pixel**
  - **Qualification** of 2 out of 4 **hybridisation vendors** completed
  - Module production started

- **Strips**
  - **Sites ready for production**
  - **Strip cold noise** mostly understood & mitigated
  - **Strip sensor cracking** of glued modules on staves after thermocycling
    - Under intense follow up (critical path of Phase-II upgrade)


Full-scale barrel IS integration mockup


SR1 ITk surface assembly cleanroom at CERN


Pixel Endcap Ring


Strip barrel stave

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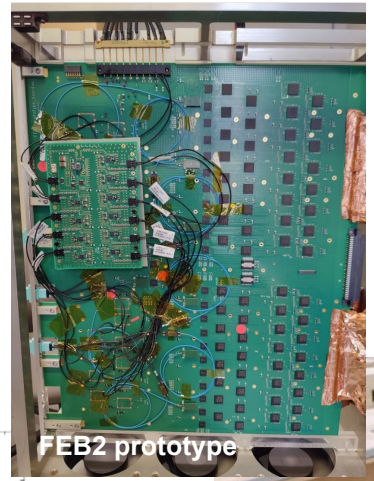
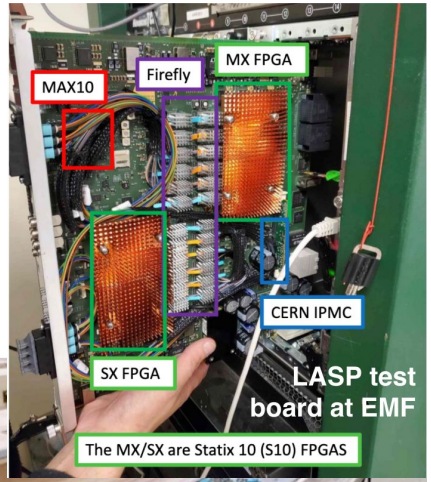
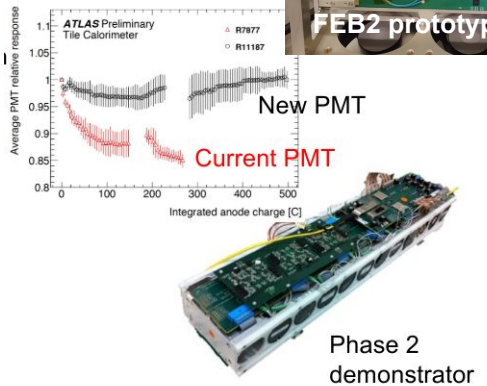
Calorimeter electronics upgrades

- **LAr Calorimeter**
  - New prototype of the **front-end board (FEB2)** tested successfully
  - **LAr Signal Processing (LASP) prototype** being tested at P1

- **Tile Calorimeter**
  - **Phase-II demonstrator** installed in ATLAS and taking data
  - Good overall progress in all areas
    - Main Board production
    - LVPS preproduction
    - Calibration system design
    - …

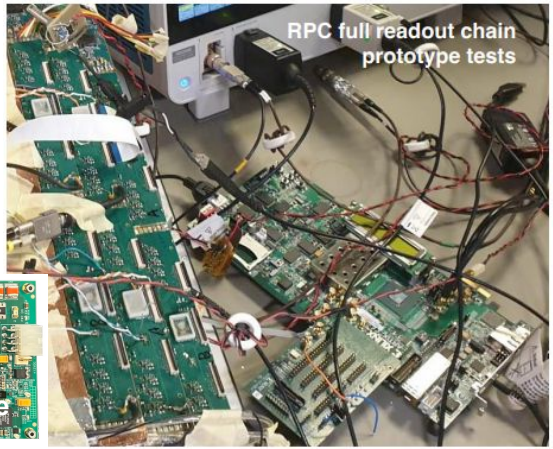


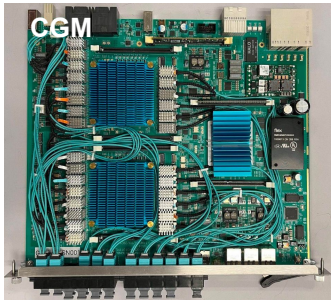


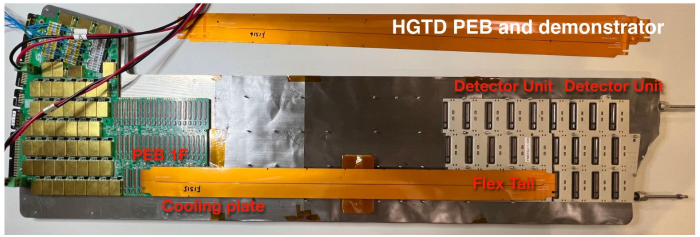


Muons, TDAQ, HGTD

- **Muon detector**
  - All **sMDT** at CERN
  - RPC chambers in production
  - Full **RPC readout chain prototype** being tested
- **TDAQ**
  - **Common module of Global Trigger (CGM)** under intense testing
  - Designing new **FELIX board** with a more powerful FPGA
- **High Granularity Timing Detector (HGTD)**
  - First **complete prototype of the most challenging board (PEB)** produced







Conclusions

- **2024 data taking in full swing**
  - Detector in good shape, Phase-I systems in last phase of commissioning
  - Trigger, data acquisition as well as reconstruction chains and offline computing working well

- **Sustained rich physics production**
  - Continued paper output and high-profile results
  - Several Run 3 results already released!

- **Substantial progress on Phase-II upgrade**
  - Mass production has started in many areas
  - Remaining technical challenges being addressed

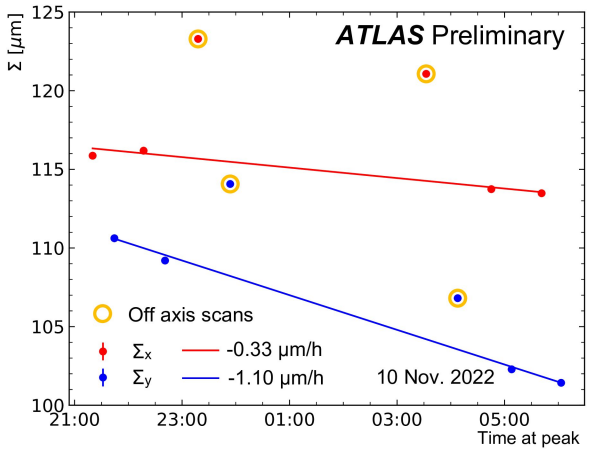
Thanks to the LHC team for efficient ramp up and continuous collaboration!

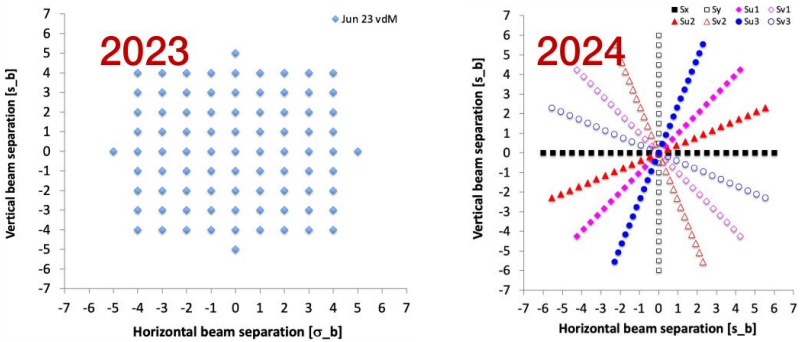
Back up

Luminosity calibration 2024

Full program completed May 14 - 20

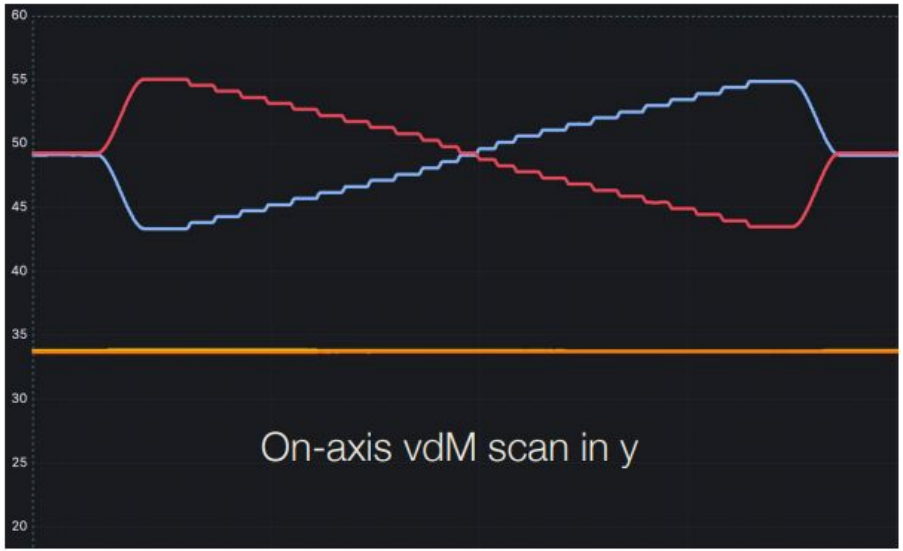
- **Non-Factorization (NF) measurement in collision**
  - Non-factorization = non Gaussian shape of luminous region
  - Increased in Run 3 wrt Run 2
  - Added scanning pattern also used by CMS to better evaluate and reduce NF
- **vdM scans + Length scale calibration**
  - Determine the visible cross section via beam separation scans
- **Calibration transfer fills**
  - Calibrate non-linear response of LUCID to luminosity and ⟨μ⟩ using offline algorithms that are linear (tracks and calorimeter)
  - Scan from low ⟨μ⟩ to high ⟨μ⟩ and from individual bunches to trains

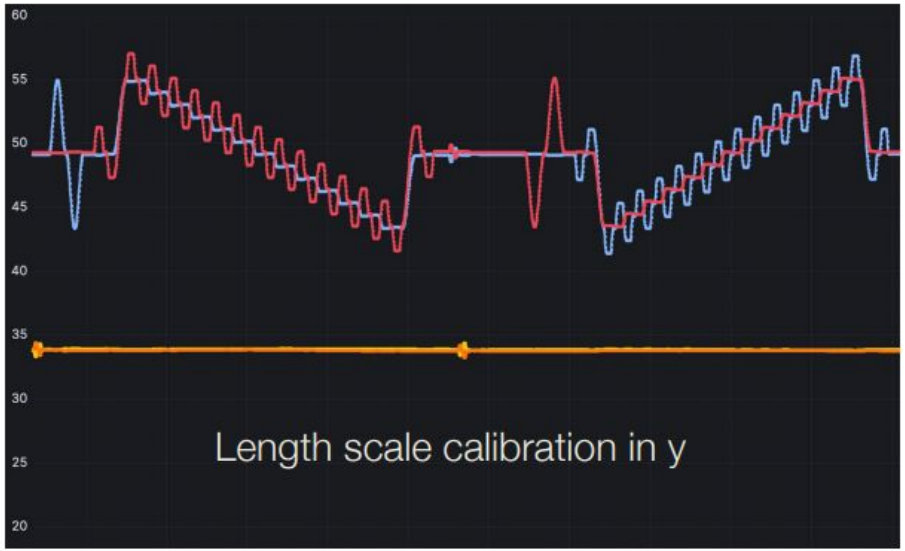




New scan pattern for improved sensitivity to NF

vdM vs LSC





Calibrate visible x-sec using various separation points
2D-scans, where the other dimension is off-axis allows us to measure non-factorizing components

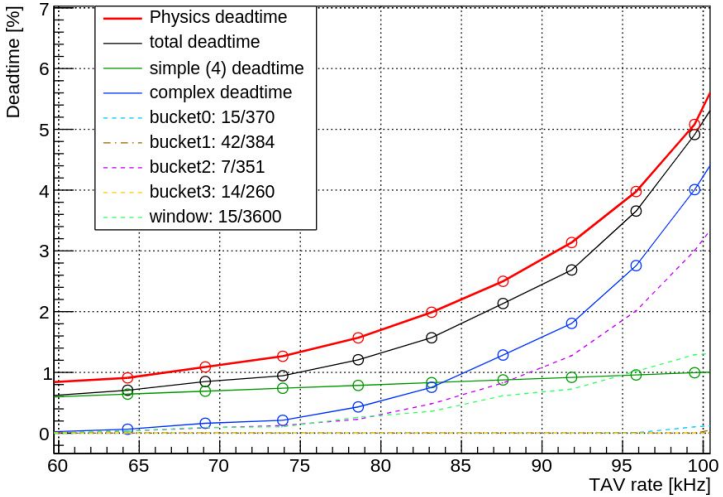
Position of one beam is used as reference, the other (test) beam is steered around that. Measured is the response of the position change as a function of the beam steering input, the "length scale"

Challenges at high pileup ⟨μ⟩

L1 rate main limiting factor

- 95 kHz when leveling at ⟨μ⟩ = 64 at ℒ=2.1e34
  - Beyond that L1 rate complex deadtime starts diverging
- L1 rate reduction thanks to Phase-I systems

L1A rate with 2352 bunches

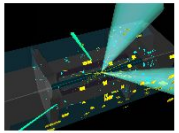


HLT in good shape

- HLT output bandwidth at ~ 7.5 GB/s, nominal limit at 8 GB/s
  - Plans to reduce ATLAS event size once Phase-I fully commissioned
- HLT CPU, readout system, and DAQ network non-limiting

Physics briefings

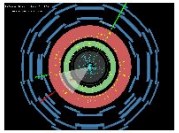
Briefings



Looking for the extended family of the Higgs boson

The ATLAS Collaboration has just published a search for two new Higgs bosons, X and S, that would interact with the Standard-Model Higgs boson.

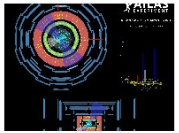
Physics Briefing | 26 April 2024



Menu of the day: Di-Higgs soup!

If spotting one Higgs boson is interesting, what happens when you spot two? ATLAS researchers are looking for the production of two Higgs bosons using a new technique.

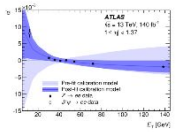
Physics Briefing | 19 April 2024



ATLAS explores Z boson production with heavy-flavour quarks

Using the full LHC Run-2 dataset, the ATLAS Collaboration measured Z boson production in association with both bottom (b) and charm (c) quarks, the latter for the first time in ATLAS.

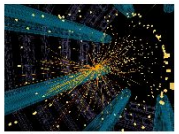
Physics Briefing | 15 April 2024



ATLAS detects electrons and photons with greater clarity

New results released by the ATLAS Collaboration describe the significant advancements made in identifying electrons and photons.

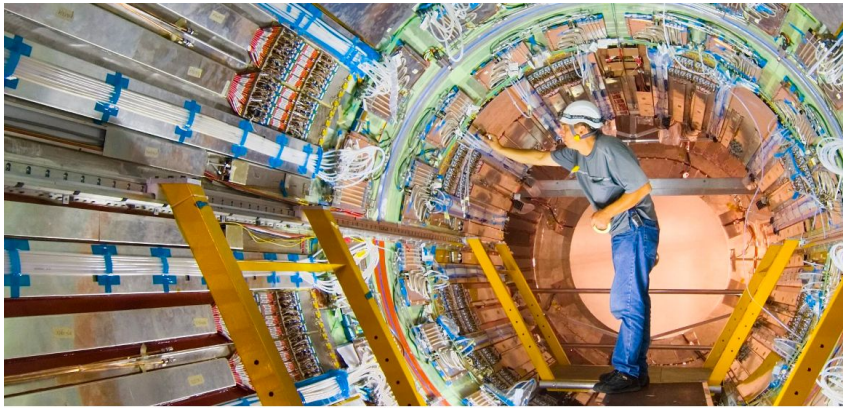
Physics Briefing | 12 April 2024



ATLAS provides first measurement of the W-boson width at the LHC

In a groundbreaking new result, the ATLAS Collaboration has measured the W-boson width for the first time at the Large Hadron Collider (LHC).

Physics Briefing | 5 April 2024



Updates > Briefing > ATLAS detects electrons and photons with greater clarity

Physics Briefing

Tags:
physics results,
calorimeter

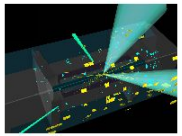
ATLAS detects electrons and photons with greater clarity

12 April 2024 | By ATLAS Collaboration

Several results presented in physics briefings for a more general public.

Physics briefings

Briefings



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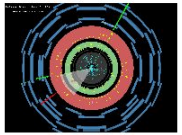

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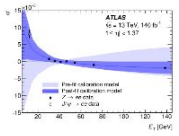

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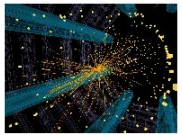

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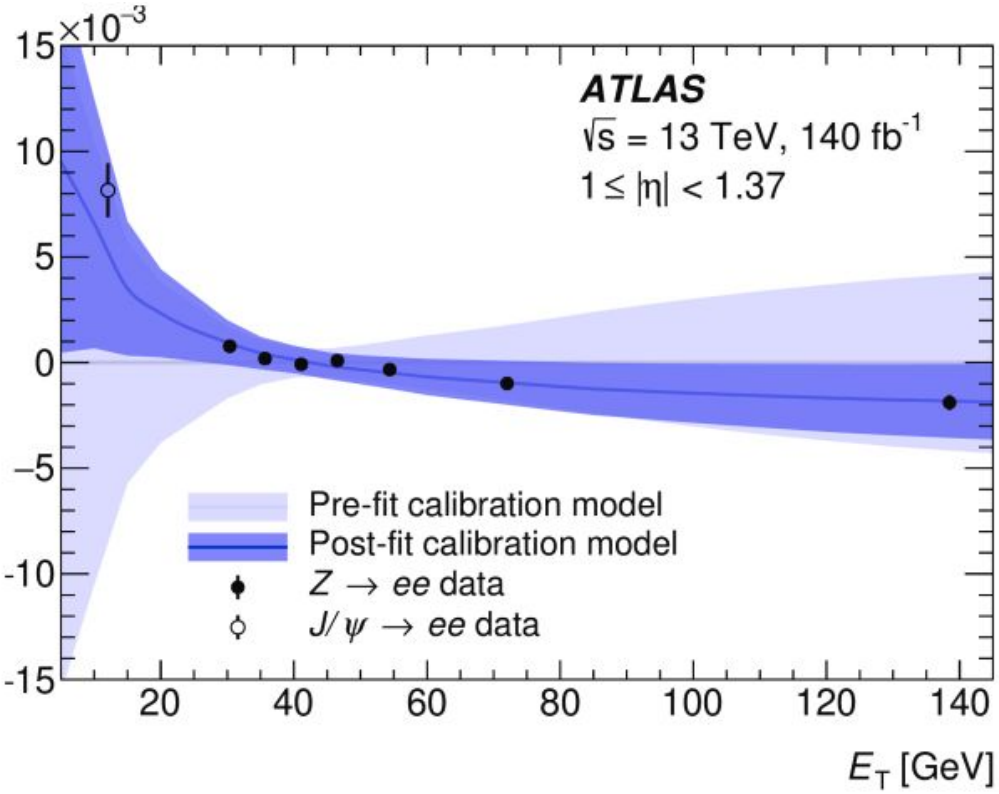

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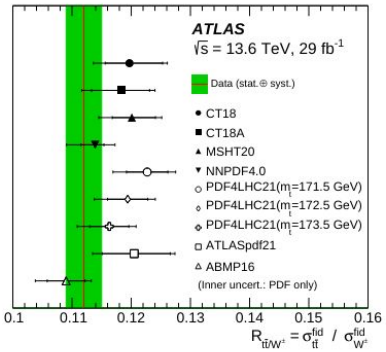
Physics Briefing about
Electron-Photon calibration

W and *Z* production cross section measurement (2022 data!)

- Fiducial and total *W*± and *Z* boson cross sections, their ratios and the ratio of top-antitop quark pair and *W*-boson fiducial cross sections are measured in proton–proton collisions
  - *ttbar* over *W*-boson fiducial cross-section ratios are slightly overestimated by some of the theoretical predictions



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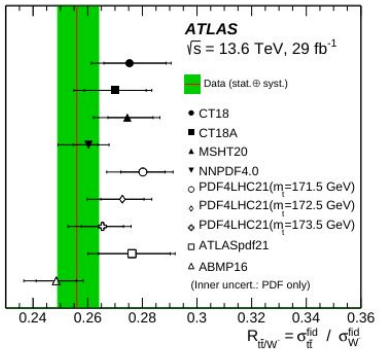

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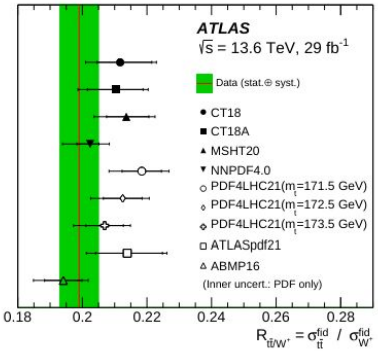
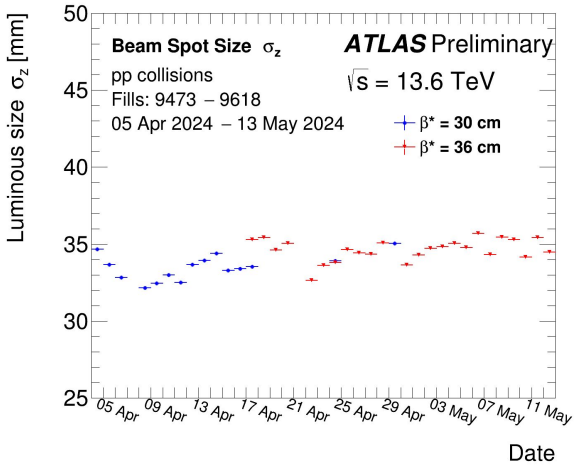


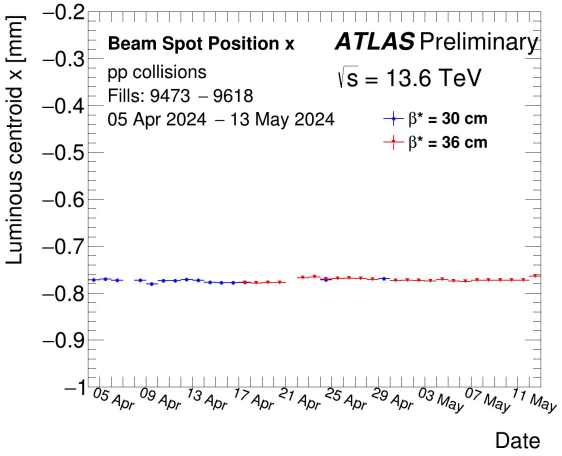
arXiv:2403.12902

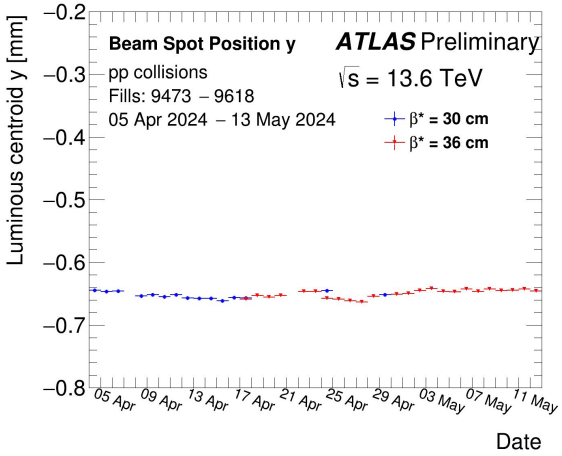
BeamSpotPublicResults

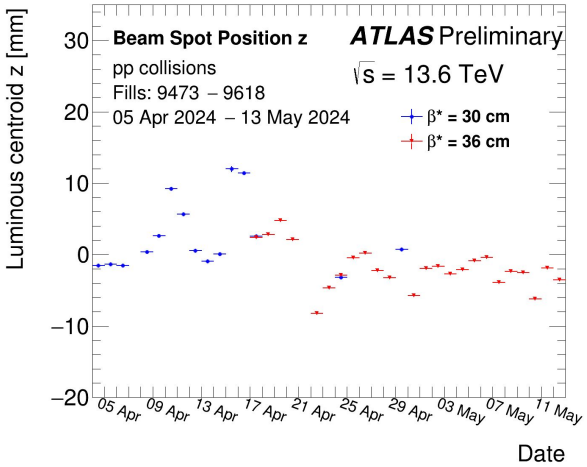
Beamspot

- Shift of approx. 0.2 mm in x- and y-direction observed compared to 2023 and larger variations in z-direction
  - No impact on physics expected: transparent to tracking algorithms



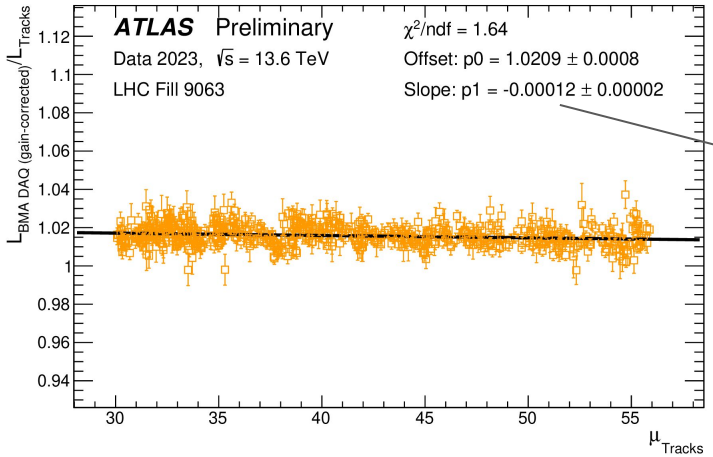


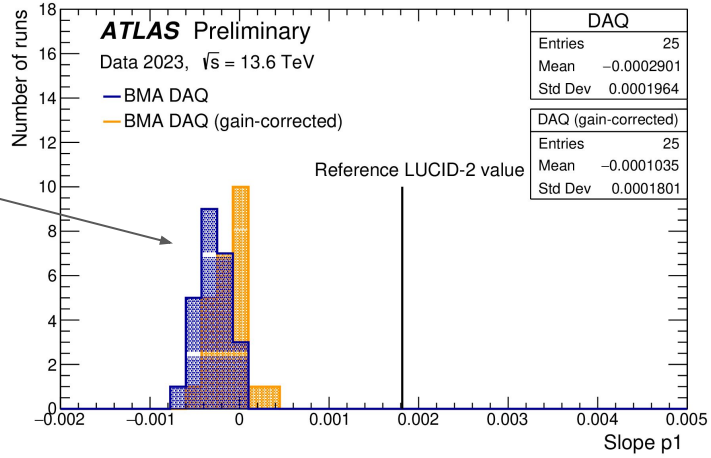




Luminosity

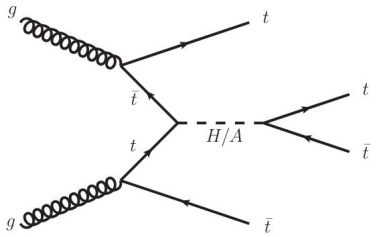
- Beam Monitor for ATLAS
  - Prototype for an additional ATLAS luminosity monitor for the HL-LHC with low geometrical acceptance
    - Modifications for 2023 data-taking to enhance detector's durability
    - Different types of configurations with varying thresholds: DAQ, DAQ (gain-corrected)
  - Lower mu dependence observed compared to LUCID



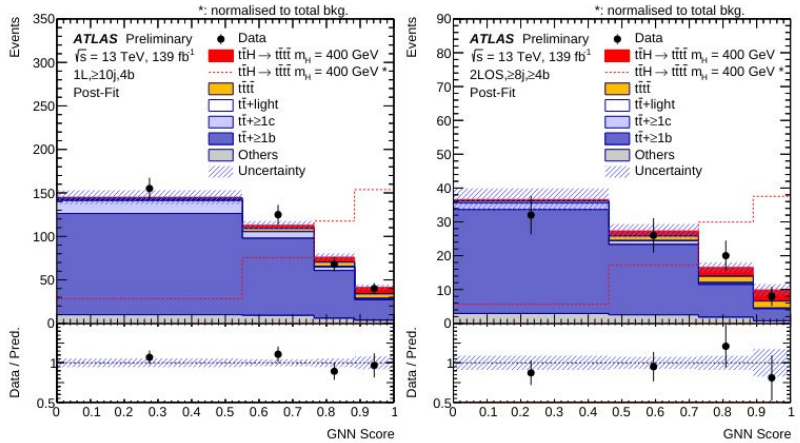


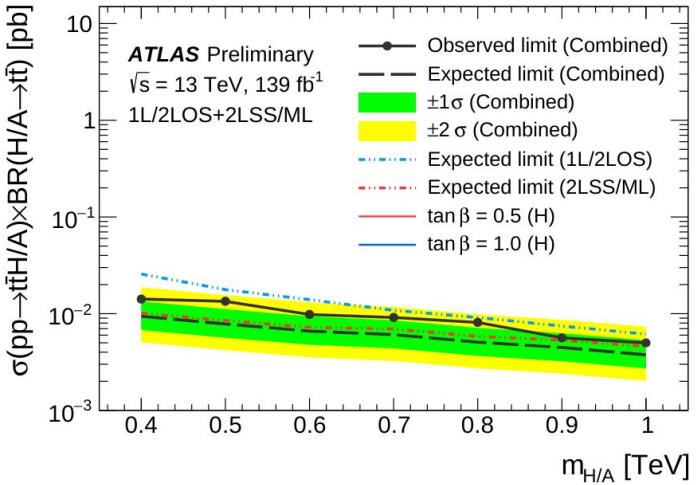
Heavy Higgs

Search for a heavy scalar H or pseudo-scalar A predicted by 2HDM in association with a top pair, with the H/A decaying to a top pair and opposite sign leptons in the final state



GNN is used to optimise the signal-background discrimination

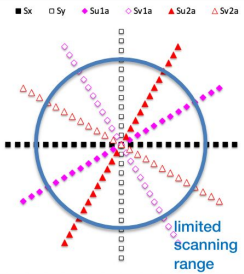


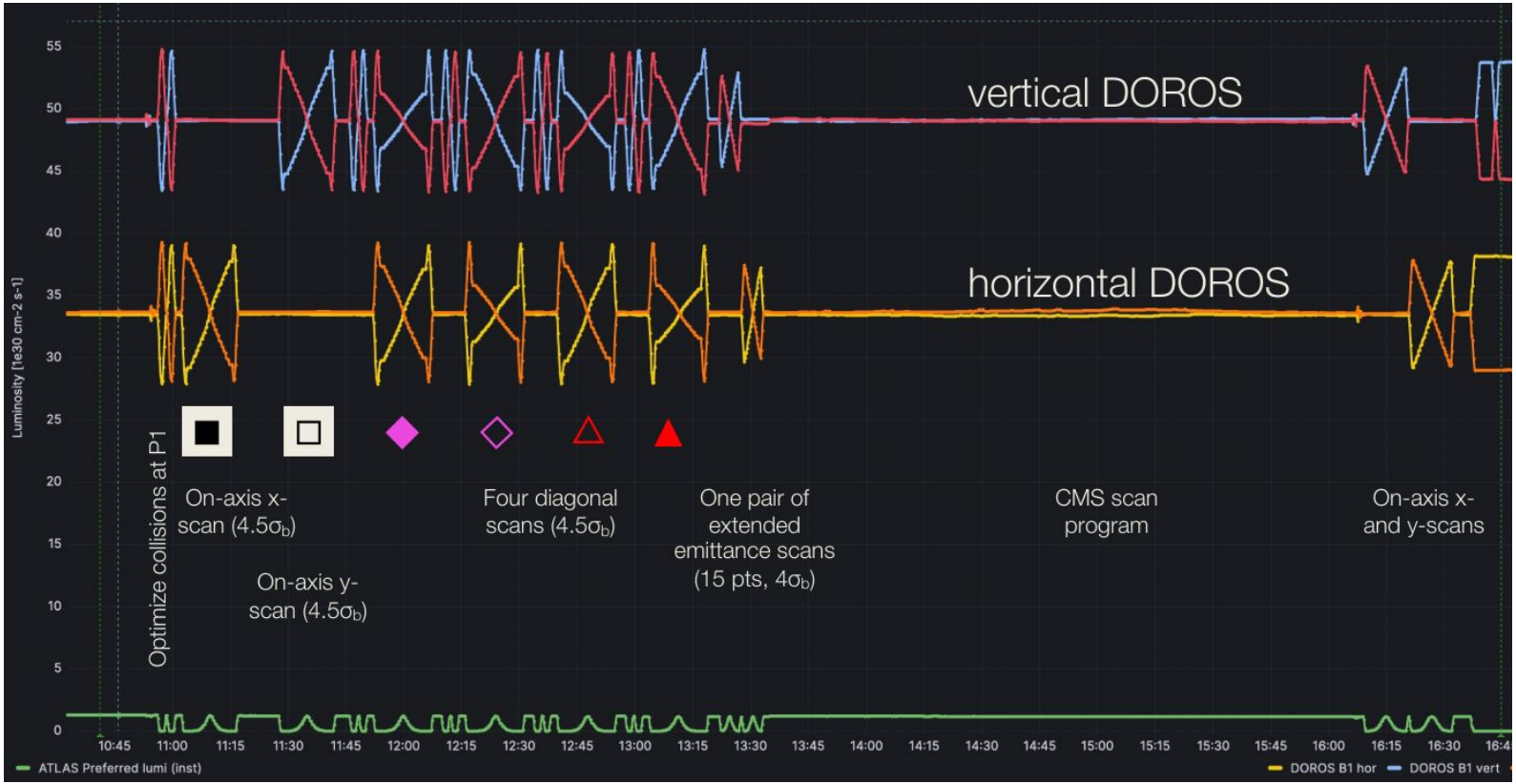


- Results combined with previous search from ATLAS with multilepton final states
- Combined observed limit ranges from 14.2 fb at $m_{A/H}$ of 400 GeV and 5.0 fb at 1000 GeV

Length scale calibration in pictures

vdM scan in pictures

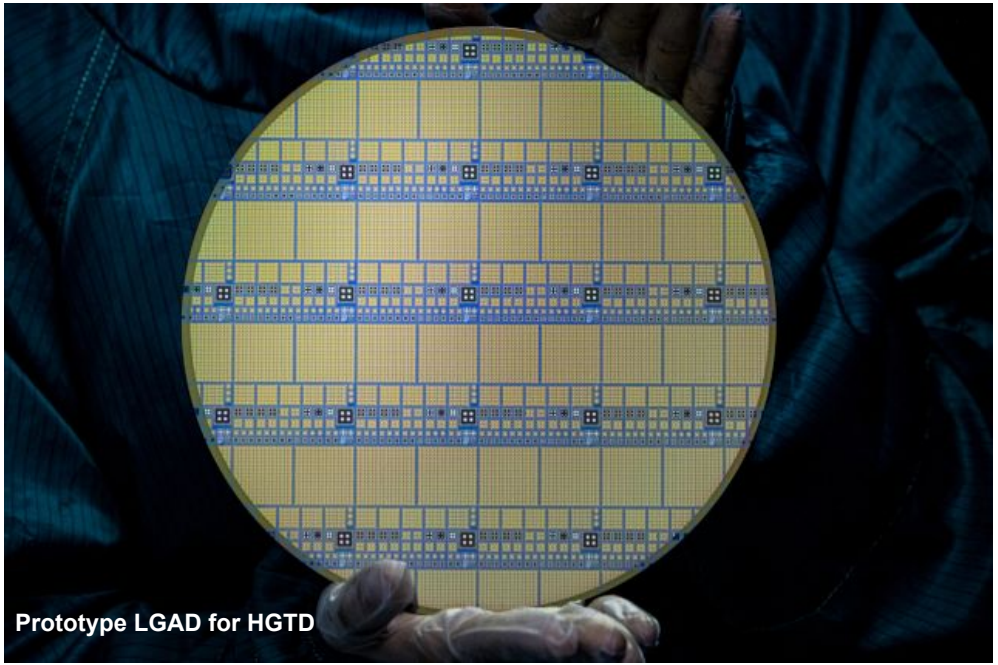




Phase-II points of attention

- The **schedule remains critical**
  - **ITk Pixel hybridisation process**
    - Managed to stabilise schedule lately
  - **ITk Sensor cracking in the ITk Strip**
    - Start of production will be delayed until reliable solution is found
    - Production process will need to be accelerated to recover time afterwards
  - **TDAQ FELIX board development**
    - Needed to adopt a higher-end FPGA than originally assumed

- **Additional resources will likely be needed** to
  - Address the technical issues
  - Speed up the production


Prototype LGAD for HGTD