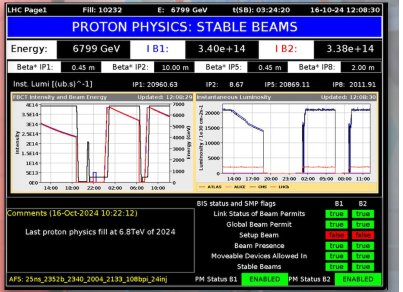
ATLAS Status Report

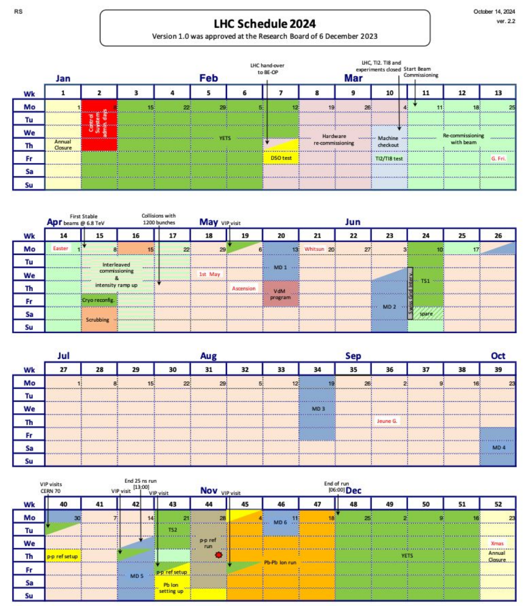
Catrin Bernius (SLAC)
on behalf of the ATLAS Collaboration

LHCC Open Session
18. November 2024

Outline

- 2024 data-taking and performance results
- Phase-II upgrade progress
- Physics highlights

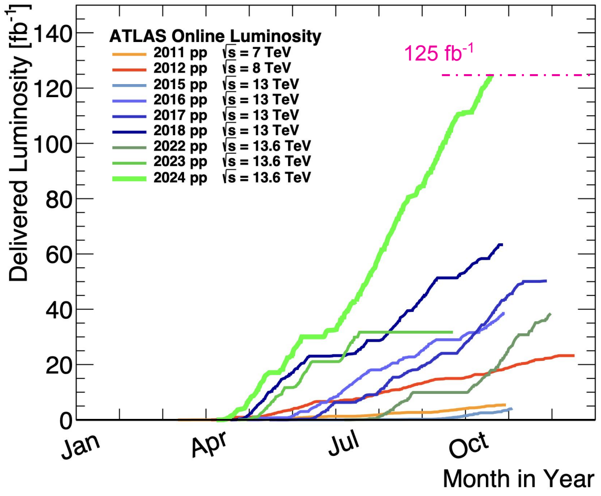


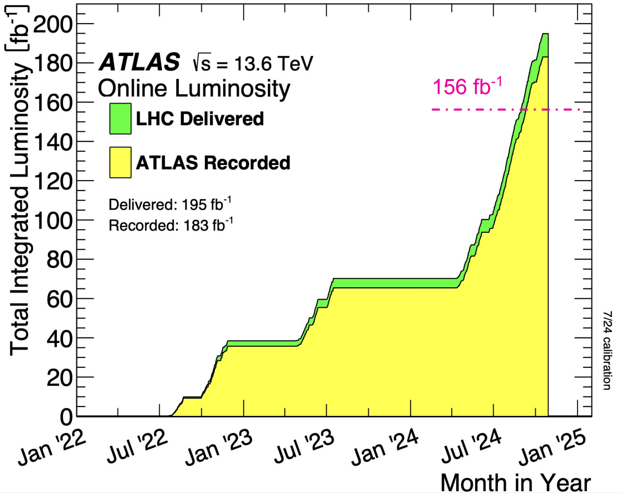


13.6 TeV pp data-taking in 2024

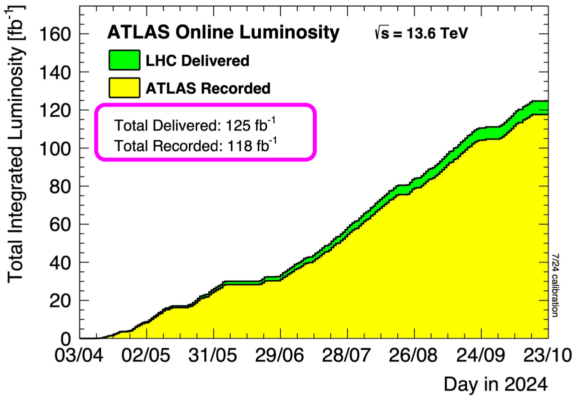
2024 has been an extremely impressive year for pp data-taking!
Congratulations and a huge thank you to the LHC and injector complex for the excellent performance in 2024!!

- Exceeded predictions: **Delivered an integrated luminosity of 125 fb^{-1}**
- Surpassed the Run-2 data-set (156 fb^{-1}) in Run 3 (195 fb^{-1})



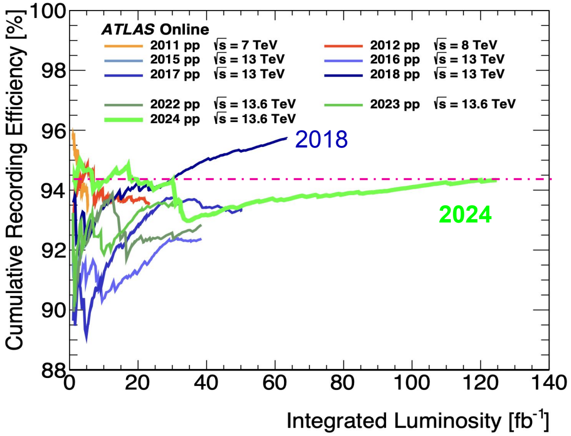


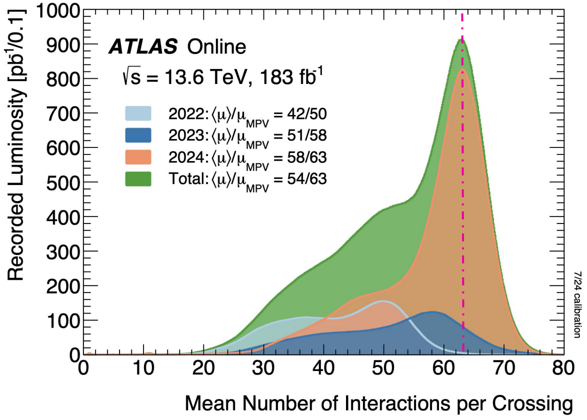
ATLAS operation performance in 2024

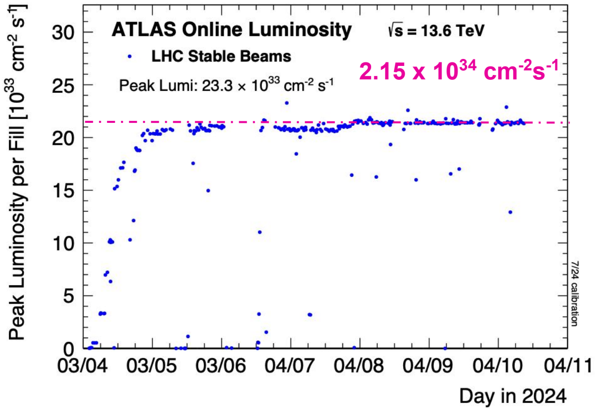


Data-taking efficiency of 94.3%, on the rise throughout 2024 (and Run 3)

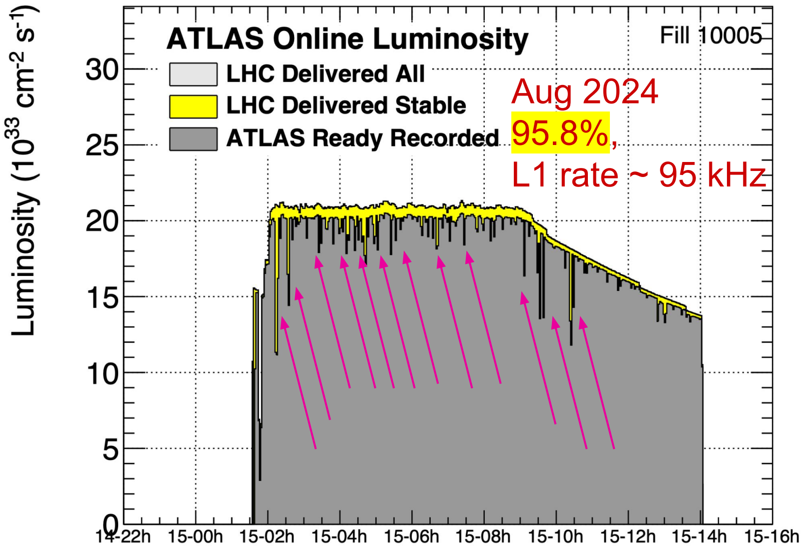
- 2nd best data-taking year so far (at higher pileup / luminosity with levelling)
- Levelled at **pileup of 64** and **luminosity** of **2.15×10^{34} cm^{-2}s^{-1}**
- Thanks to:
  - Phase-I upgrades
  - Experience and expertise gained in operating our detector
  - Addressing also the smaller inefficiencies causing data loss

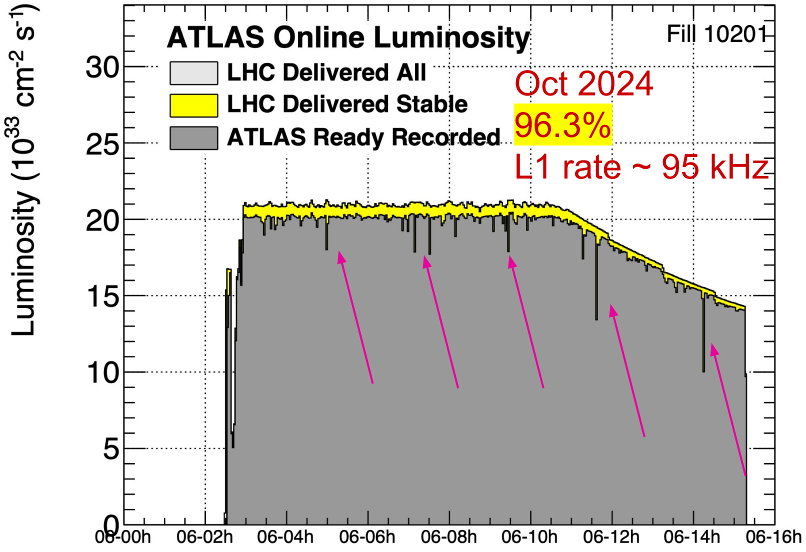






Detector system improvements in 2024





Across the ATLAS detector subsystems:

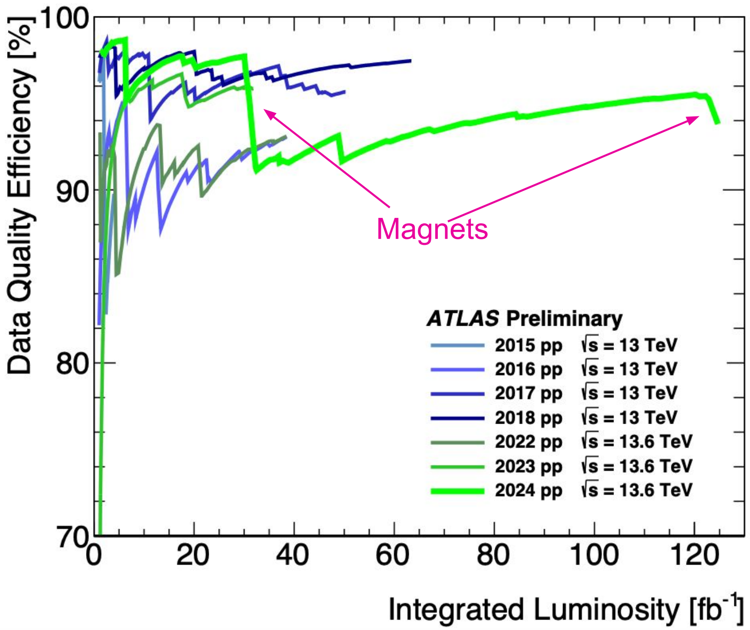
Improvements of operational robustness and reduction of inefficiencies during data-taking

⇒ visible in the reduction of the small dips that indicate a brief interruption of data-taking

ATLAS operation performance in 2024

Data quality efficiency is an equally important measure of our performance and operating conditions

- 110 fb^{-1} are considered good for physics
- Largest inefficiencies in data recording and quality assessment due to downtimes of magnets



ATLAS pp Run-3: 2024

Trigger	Inner Tracker			Calorimeters		Muon Spectrometer			Magnets		Global	
L1+HLT	Pixel	SCT	TRT	LAr	Tile	MDT	RPC	TGC	Solenoid	Toroid	Lumi. calib.	Other
99.7	99.7	99.8	99.9	99.8	99.3	100	99.8	99.8	98.3	96.6	99.6	99.9

Good for physics: 93.8% (110 fb^{-1})

Luminosity weighted good data quality efficiencies (in %) in 2024 during stable beam operations of *pp* physics runs at $\sqrt{s} = 13.6$ TeV, corresponding to an integrated luminosity of 110 fb^{-1}, for 118 fb^{-1} *pp* data recorded. Technical runs such as luminosity calibration scans totalling 0.6 fb^{-1} recorded are not accounted for in the efficiencies.

When the stable beam flag is raised, the tracking detectors initiate a "warm start", which involves ramping up the high-voltage and activating the pre-amplifiers for the Pixel and SCT systems. The inefficiency due to this, as well as the DAQ inefficiency, are not included in the table above, but accounted for in the ATLAS recording efficiency.

The good-for-physics luminosity is 110 fb^{-1} for all analyses, except those relying on *b*-jet triggers, where the data quality efficiency is slightly lower (93.5%) due to the brief time needed to measure the online beamspot at the start of a run.

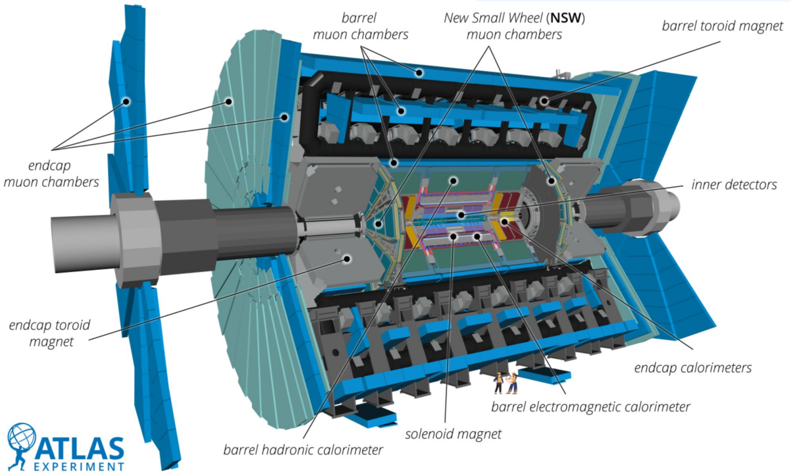
Detector status 2024

Inner Detector (Pixel, SCT, TRT):
Good status
No limitation to operating ATLAS in 2026; updated projections to ~ 550 fb^{-1} indicate that radiation damage effects can be mitigated

Forward: AFP suffers from backgrounds / increased radiation, ToF had to be removed from the tunnel; LUCID good; ZDC installed in TS2 for HI programme

TDAQ: No limitations with DAQ system; Trigger: Phase-I L1 systems in operation, better efficiency with reduced background trigger rates; L1 & HLT deal well with higher lumi and pileup; HLT CPU sufficient

Calorimeters:
LAr: Good status
Tile: FE electronics cooling leaks at limit but stable so far; 3.5 modules switched off (1.4%)



Muons:
MDT, TGC: Good status
RPC: Inlet repairs and resin application during last EYETS did not reduce leak rate significantly; increase effort to consolidate during upcoming YETS (145 person-weeks)
NSW: DAQ stable; sTGC pad & MM triggers operating, sTGC strips under work; Rising number of sTGC HV failures at inner radius (105/256 (41%), in total 180/1024 (18%))
Mitigations: lowering HV reduces failure rate; tests with spare sectors underway (irradiation, HV stress)

Magnets: 7 solenoid and 8 toroid slow dumps; Efforts to enhance magnet operational resilience ongoing (water cooling, electrical perturbation, cryo system)

Offline computing:
Tier0 reconstruction operating smoothly (~8 GB/s)

Detector status: Phase-I Trigger

Inner Detector (Pixel, SCT, TRT): Good status
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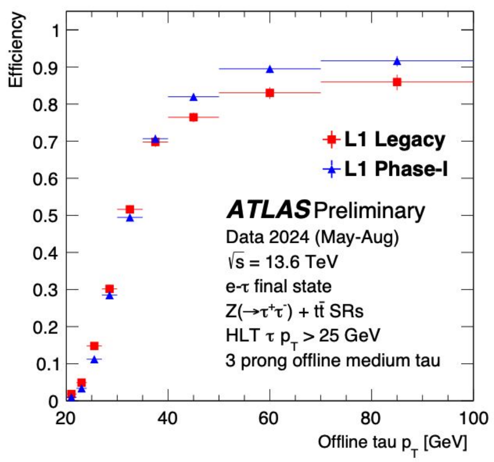
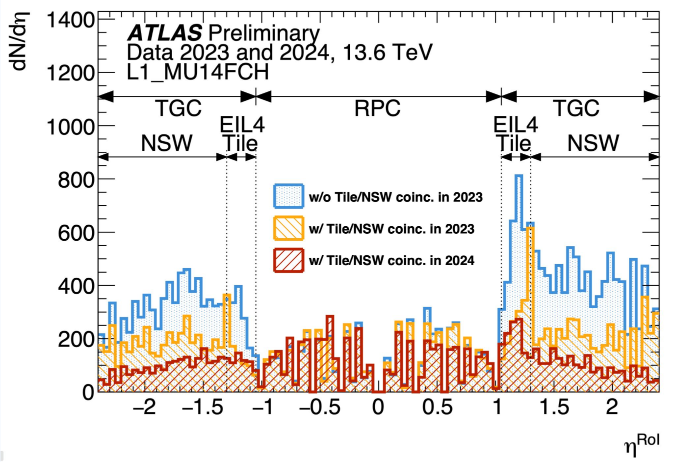
Phase-I trigger **shows excellent performance**

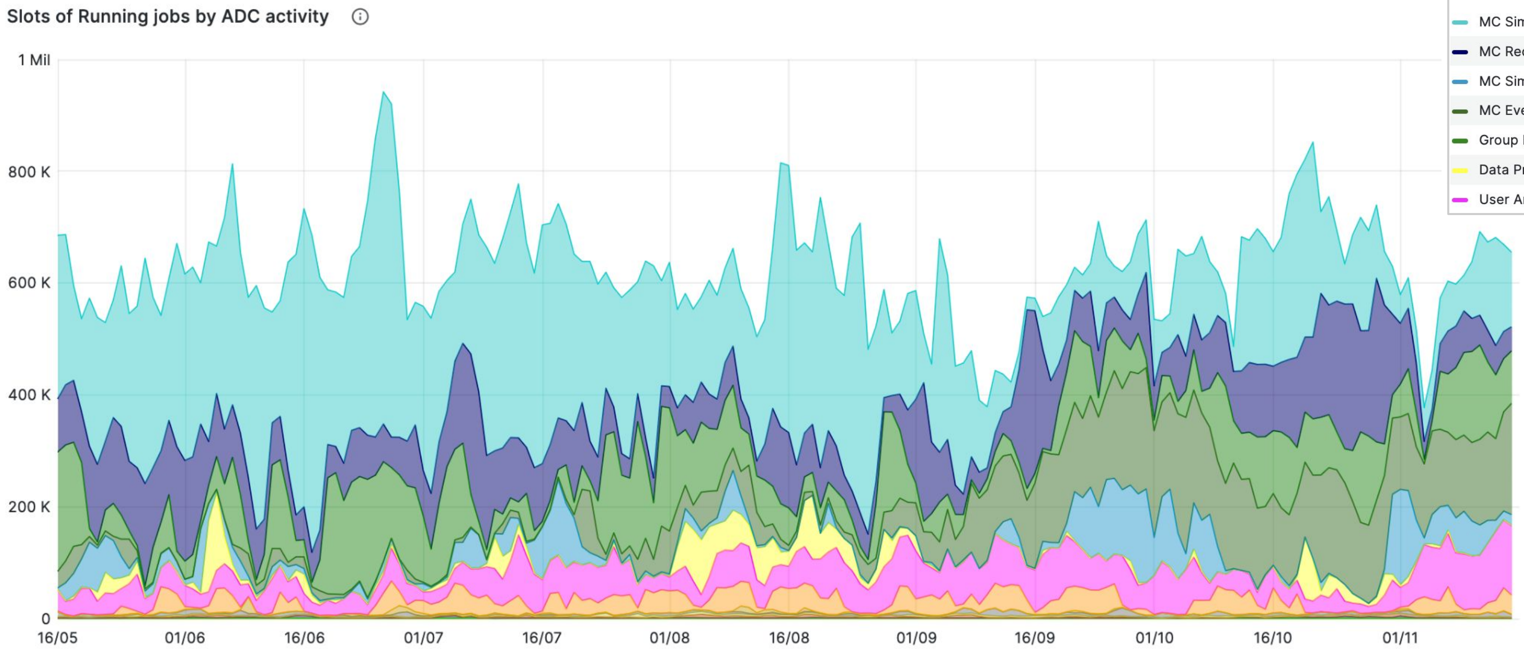
- **Phase-I L1Calo + LAr system** with sharper turn-on, better efficiency, purer selection and lower rate compared to legacy system
- **L1Muon endcap trigger** with inner coincidence included both **sTGC PAD and MicroMegas** in coincidence with the Big Wheel
  - All sectors with > 95% efficiency, overall L1 rate reduction of 15 kHz (including also contribution from Tile-Muon coincidence)





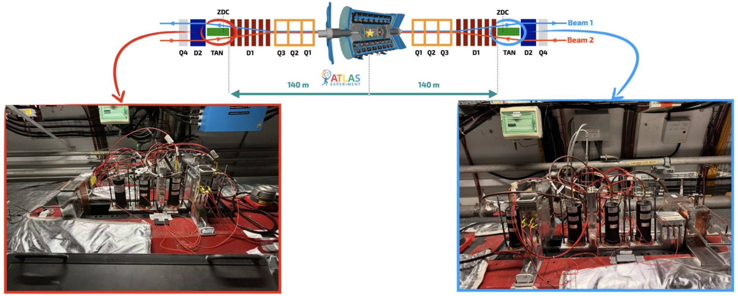
ATLAS Computing and Software

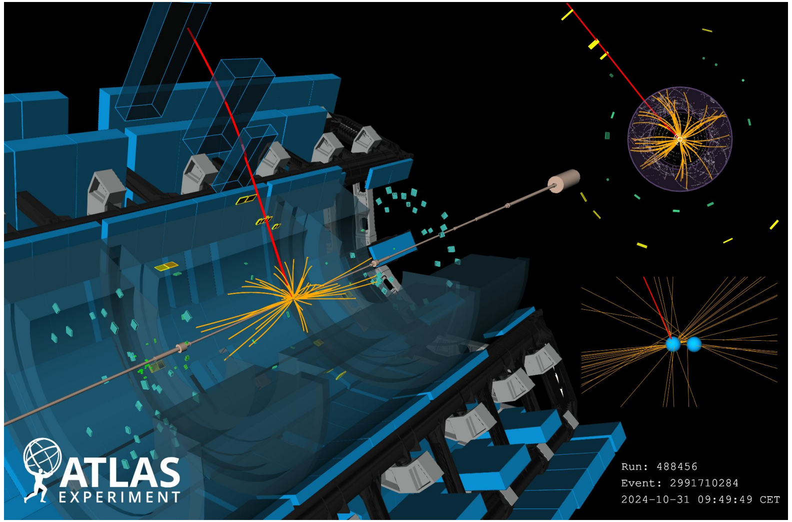
- Generally smooth running in the last 6 months, with a wide variety of activities
  - Recent focus on Monte Carlo for 2024, now running reconstruction at large scale
- Significant beyond-pledge CPU from Tier-2 and HPC centres
  - ATLAS accepts resource-saving ARM as pledge, validated majority of our workflows

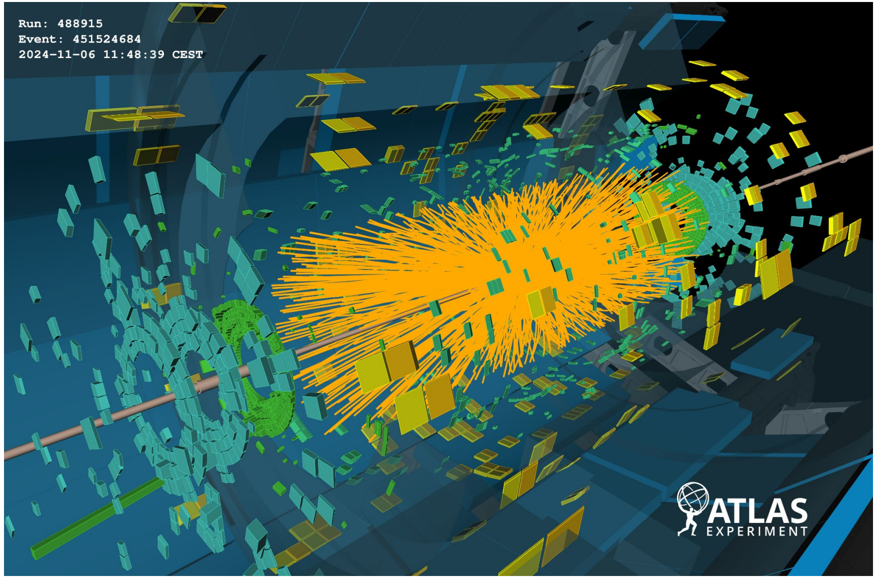


	max	avg
MC Simulation Full	600 K	238 K
MC Reconstruction	385 K	107 K
MC Simulation Fast	274 K	29.5 K
MC Event Generation	269 K	69.9 K
Group Production	218 K	77.2 K
Data Processing	197 K	15.4 K
User Analysis	105 K	48.5 K

Heavy Ion program



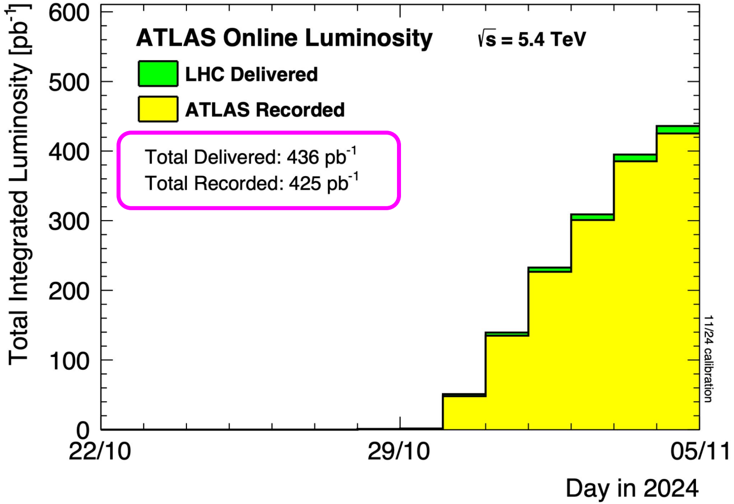


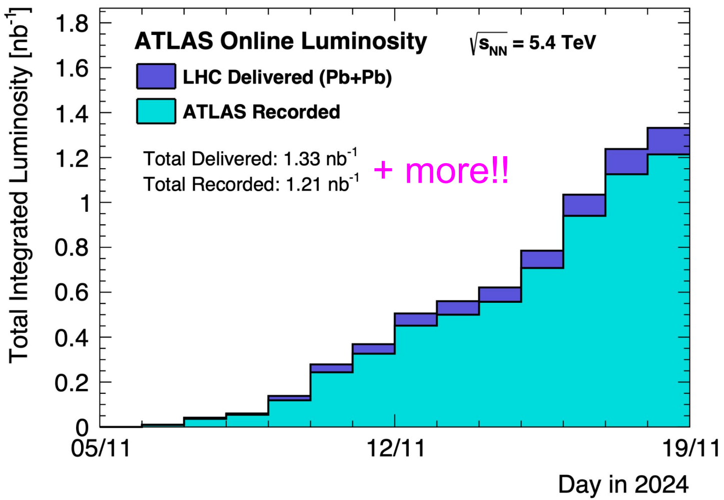


Preparation & program

- During TS2: Zero Degree Calorimeter (ZDC) installation
- First pp ref run since 2017, including vdM program
- PbPb data-taking, including vdM program

pp reference & PbPb





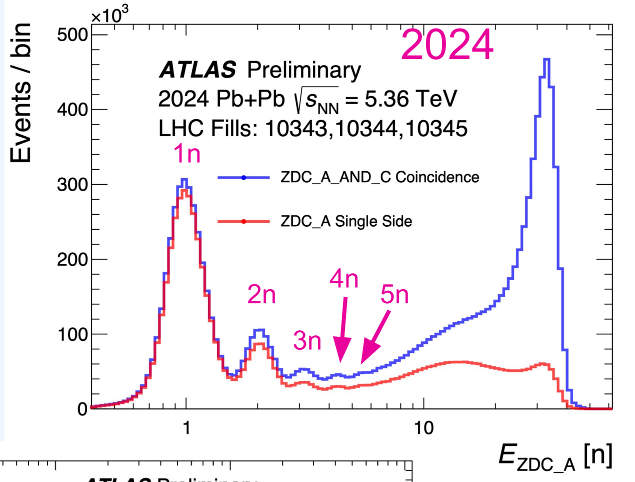
pp reference run:

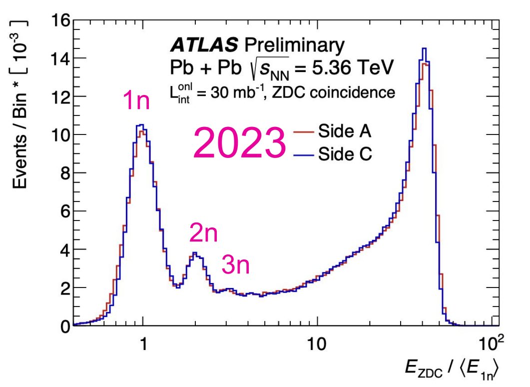
- Total delivered integrated luminosity of 436 pb^{-1}, recorded 425 pb^{-1}, exceeding the desired target of 300 pb^{-1}
- Levelled at pileup target ~4 with data-taking efficiency of 97.5 %

PbPb run:

- Current status: delivered integrated luminosity of 1.3 nb^{-1}
- First time triggering with Phase-I LAr + L1Calo system

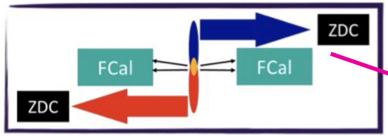
Zero Degree Calorimeter (ZDC)





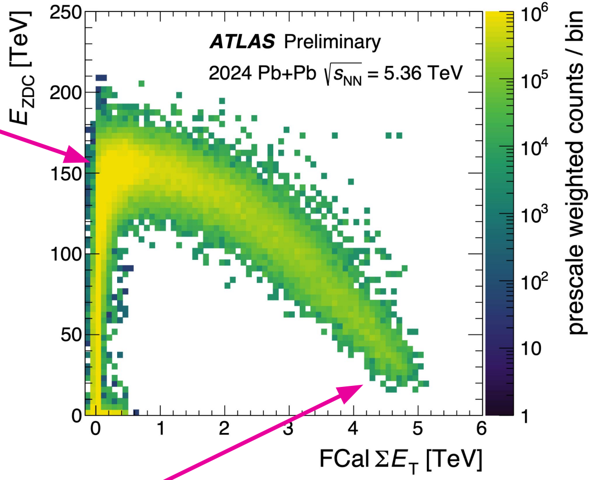
ZDC Energy distribution for events with at least 1 neutron:

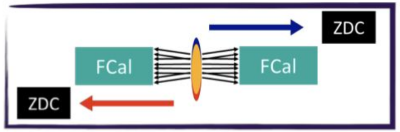
- Up to 5 neutron peaks visible
- Also visible enhancement in detector resolution compared to 2023 ⇒ thanks to shift of LHC BRAN luminosity detector behind ZDC in 2024



Peripheral events (low FCal activity, several spectator neutrons with high energy deposits in ZDC)

ZDC total energy vs FCal E_T

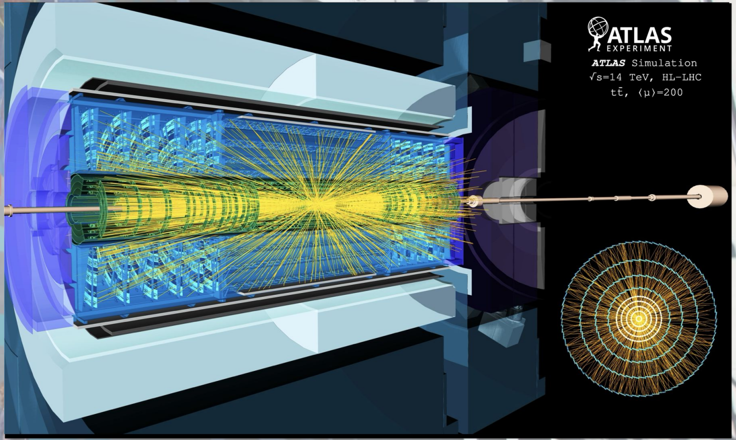




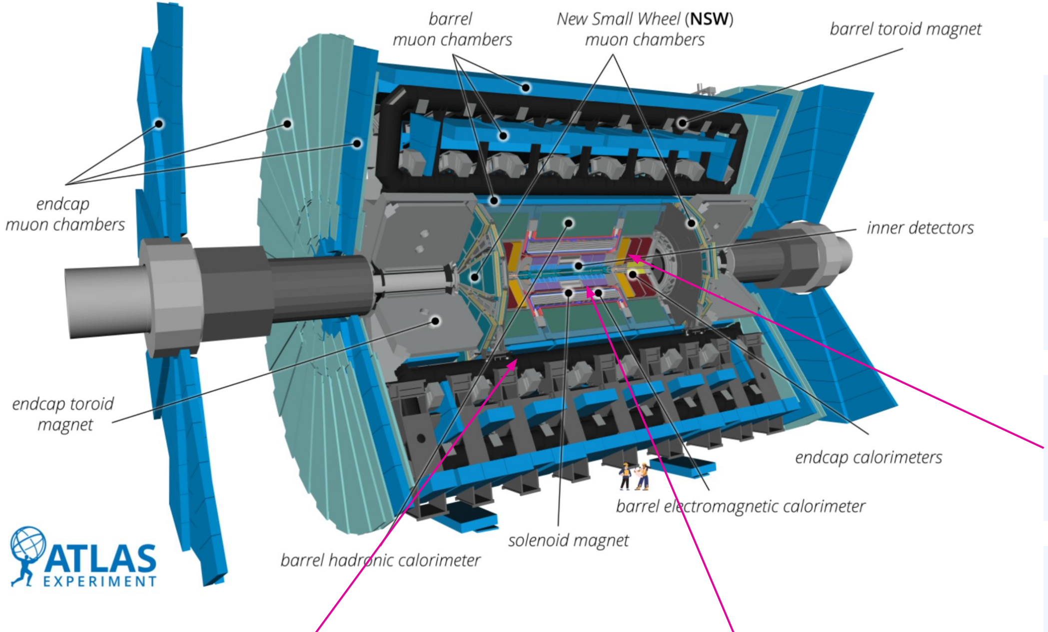
Central events: high activity in FCAL, low number of spectator neutrons

Outline

- 2024 data-taking and performance results
- Phase-II upgrade progress
- Physics highlights



ATLAS Phase-II upgrade overview



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

Additional upgrades

Luminosity detectors (1% precision goal)

HL-ZDC

New Muon Chambers

Inner barrel region with new RPC and sMDT detectors

New Inner Tracking Detector (ITk)

All silicon, up to $|\eta| = 4$

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


Installation of large ITk barrel structures in SR1 at CERN

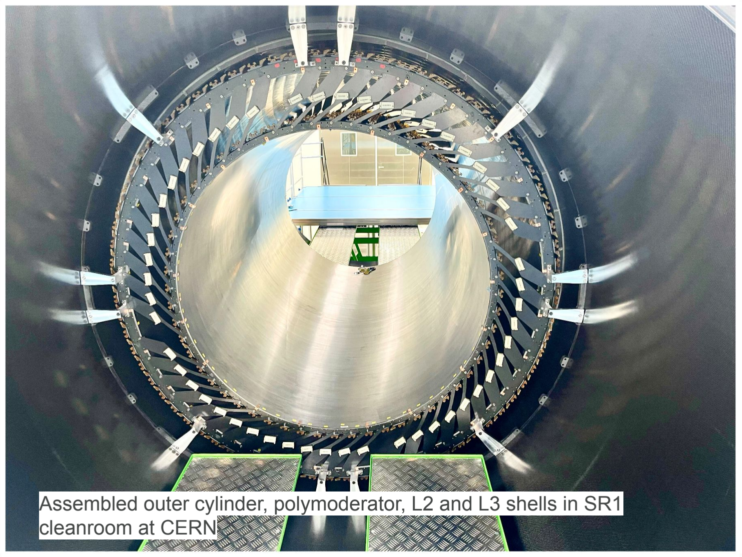

Polymoderator installed in Outer Cylinder


Preparation of L3 shell

Overall status

- **Huge progress across the board**, many components in production, some completing
- **ITk Pixel and Strip define critical path** of the schedule due to technical challenges, but **good progress in addressing them**; expect start of ITk module assembly (production) this year (Pixel), Jan 2025 (Strip)


Transport of Strip L3 shell to SR1


Assembled outer cylinder, polymoderator, L2 and L3 shells in SR1 cleanroom at CERN

Recent ITk highlights

ITk Pixel

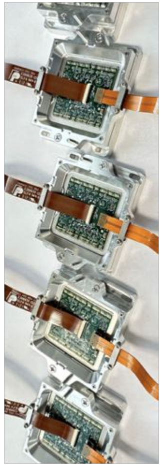
- Pixel production progresses well with sensors and FE ASIC; hybridisation has started with 2 (of 4) vendors (hope to qualify 3rd soon), some bare local supports & services in production
- Many areas close to critical path, tightly following up

ITk Strip

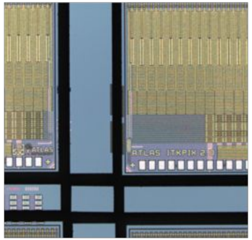
- Many areas (sensors, ASICs, EOS, bus-tapes, cores, etc.) in production; sites ready for production
- Module site qualification well advanced (94% completed)
- **Strip sensor fracturing of cold mounted modules under intense follow up**
  - Solution with 50 µm kapton interposer developed and successfully tested for the barrel down to –70 °C
  - Initial test on an endcap ½ petal shows no evidence of cracks down to –65 °C
  - Final reviews this year, module production start Jan 2025

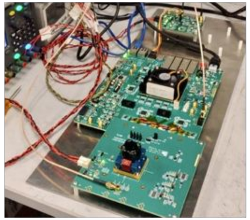
Production of ITk common items and structures proceeds well

ITk Pixel quad modules

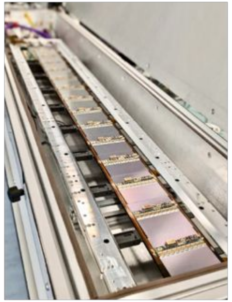


ITkPixV2 wafer





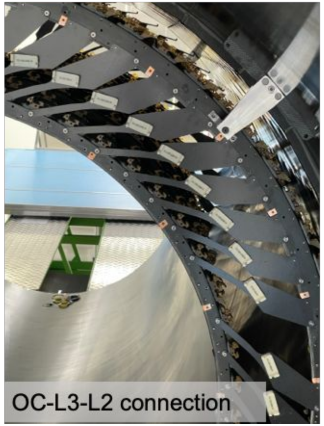
FEB2 mass testing board

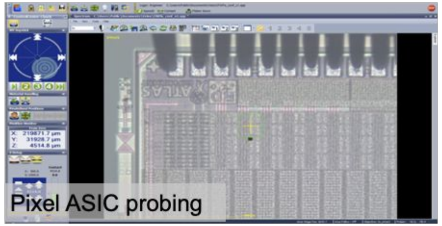


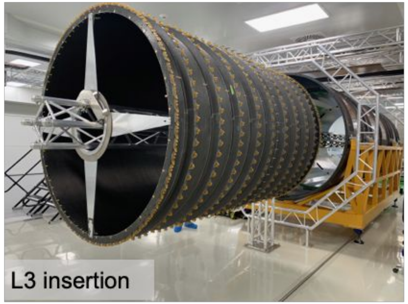
Strip Half-stave in climate chamber at RAL

ITk Progress Highlights

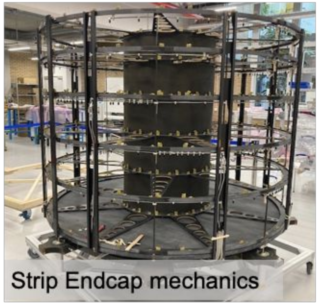

CO2 plant SR1

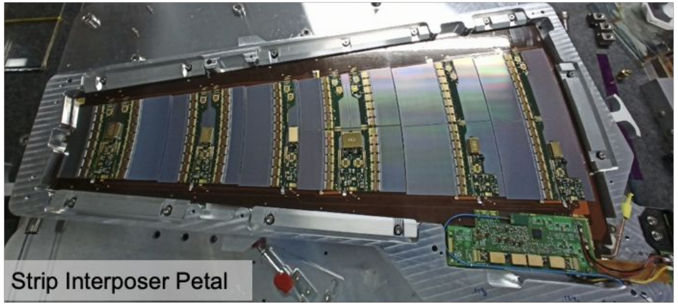

OC-L3-L2 connection

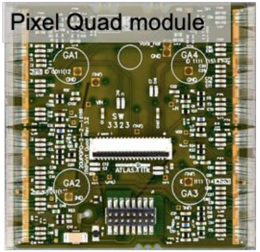

Pixel ASIC probing


L3 insertion


Fiber Optic Sensors on L3

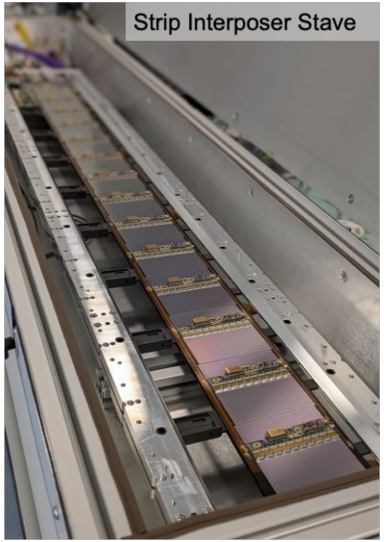

Strip Endcap mechanics


Strip Interposer Petal


Pixel Quad module


Pixel Inclined Half-rings

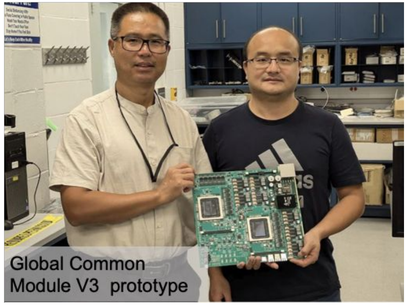

Strip Interlock in SR1


Strip Interposer Stave

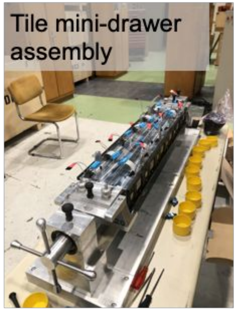
Recent other Phase-II project highlights

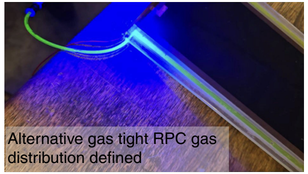
Other systems progressing well, no critical issues

- **LAr**: ASICs in production with excellent test results, completing design of electronics boards (FEB2, LASP)
- **Tile**: good overall progress, comfortable contingency
- **HGTD**: pre-production LGAD and ALTIROC hybrids under test; Demonstrator with 54 modules being tested in clean room with CO_2 cooling
- **Muon**: good progress on sMDT, finalise RPC readout electronics, started RPC readout chain tests with prototypes/emulators, fixing gas-gap leaks
- **TDAQ**: good progress in many areas (online software, dataflow, EF Tracking technology choice, …), more effort identified for delayed NSW trigger processor

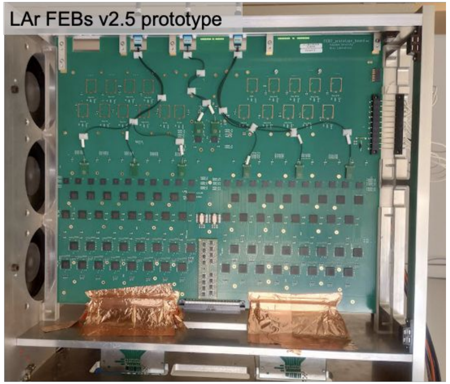

Global Common Module V3 prototype


Tile PMT block tests

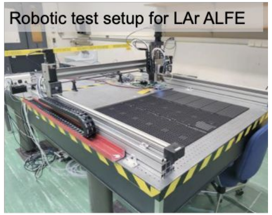

Tile mini-drawer assembly


Alternative gas tight RPC gas distribution defined

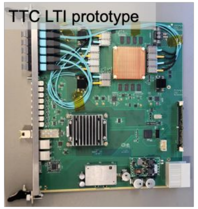

First batch of FELIX FLX-182 boards


LAr FEBs v2.5 prototype


HGTD demonstrator


Robotic test setup for LAr ALFE

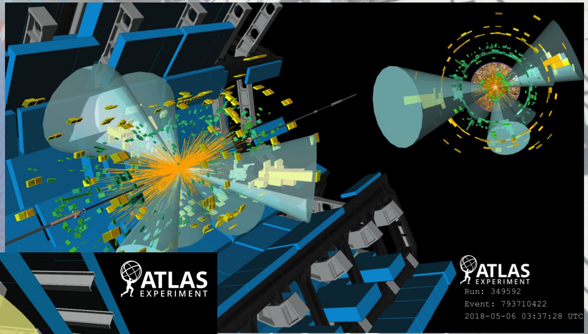

RPC Gas Gap production


TTC LTI prototype

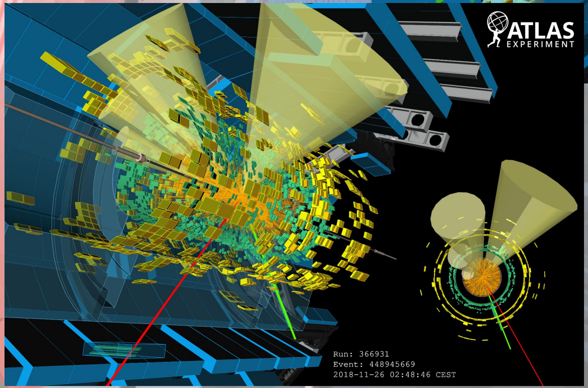
During October ATLAS Week we organised visits to various upgrade sites at CERN (150 participants)

Outline

- 2024 data-taking and performance results
- Phase-II upgrade progress
- **Physics highlights**



Candidate HHH → 6b event recorded in 2018



Candidate top quark pair production event produced in a lead-lead collision at 5.02 TeV(2018)

Publications & Physics results

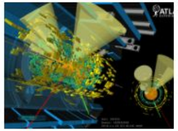
Publication status in 2024: 113 papers released so far

- In total: 385 on full Run-2 and 13 papers on Run-3 data-set

Since the last LHCC meeting in September, quite some new ATLAS results

- 16 papers
- 4 conference notes and 3 public notes
- 5 new physics briefings

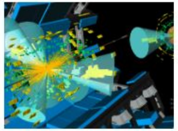
Briefings



ATLAS observes top quarks in lead-lead collisions

The ATLAS Collaboration at CERN has observed top-quark pair production in lead-lead ion collisions, marking the first observation of this process in nucleus-nucleus interactions.

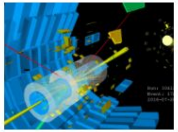
Physics Briefing | 12 November 2024



Why stop at two? ATLAS hunts for the production of three Higgs bosons

At this week's Higgs2024 conference, the ATLAS Collaboration unveiled the first LHC search for tri-Higgs production – a process over 60,000 times rarer than the production of a single Higgs boson.

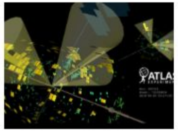
Physics Briefing | 8 November 2024



Cracking open the Higgs shell

ATLAS researchers are using innovative new techniques in their analysis of off-shell Higgs-boson production.

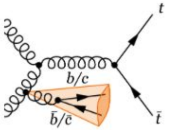
Physics Briefing | 6 November 2024



Advancements in particle tagging accelerate the search for new particles

The ATLAS Collaboration has released three major searches for new-physics phenomena, all utilising new advancements in particle tagging.

Physics Briefing | 5 November 2024

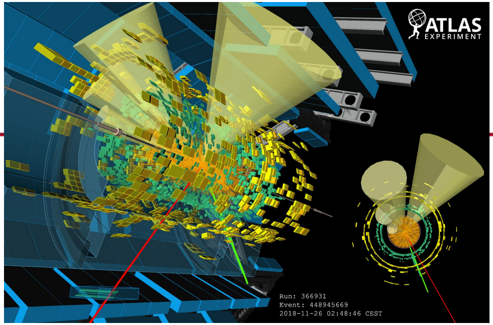


Decoding top quarks: Precision in heavy-flavour partner production

Two new studies from the ATLAS Collaboration explore how top-quark pairs are produced alongside heavy-flavour quarks, like bottom and charm.

Physics Briefing | 26 September 2024

tt production in PbPb collisions

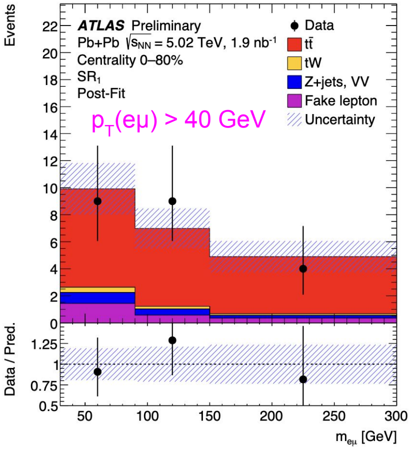


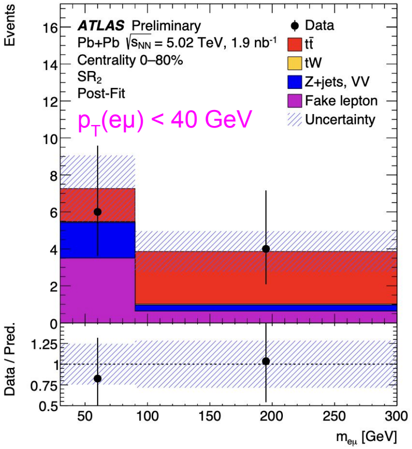
arXiv:2411.10186
Physics Briefing

- First observation of top quark pair production in PbPb collisions
  - Sensitivity to time structure of QGP and to nuclear parton density functions
- Measured inclusive cross section in PbPb collisions is

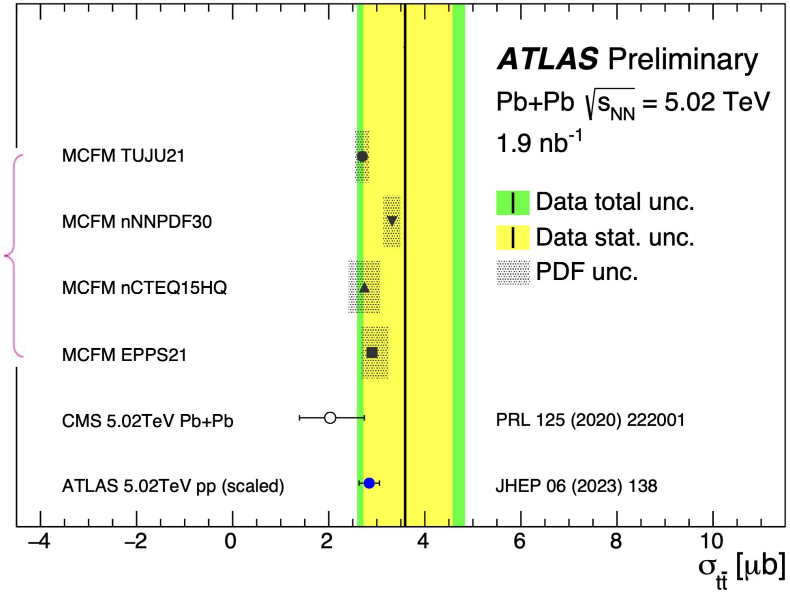
$$\sigma_{t\bar{t}} = 3.6 \ {}^{+1.0}_{-0.9} \ (\text{stat.}) \ {}^{+0.8}_{-0.5} \ (\text{syst.}) \ \mu\text{b}$$

- Significance of observed (expected) signal is 5.0 (4.1) σ

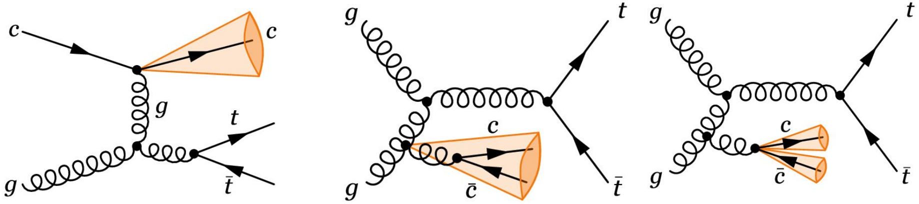




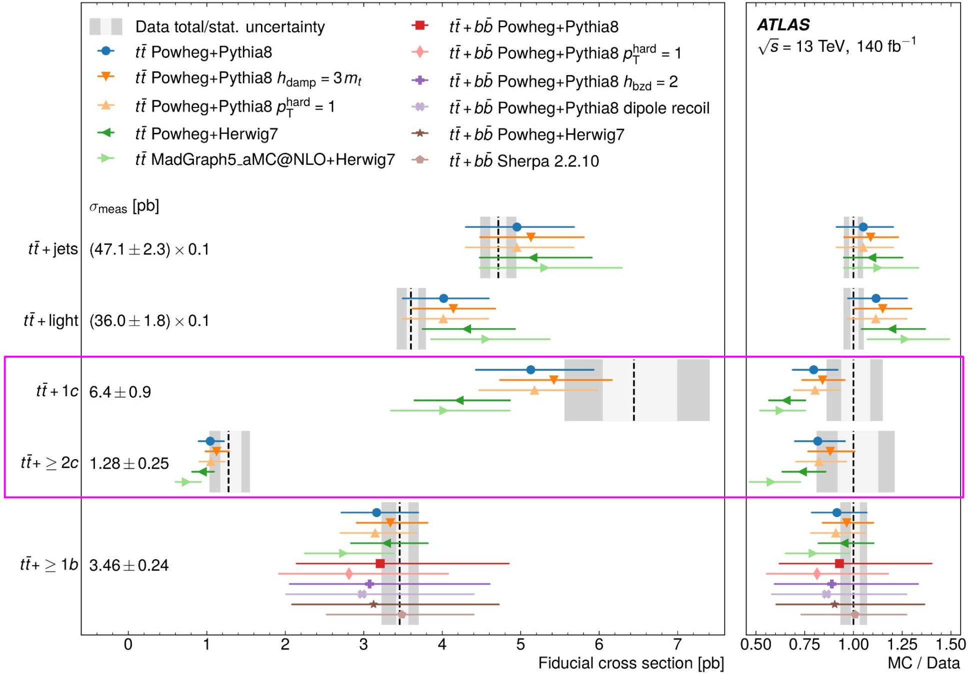
SM predictions with nuclear modifications to PDFs



tt+charm jets production cross section



arXiv:2409.11305
Briefing: Decoding top quarks



- First dedicated ATLAS measurement of top-quark-pair production with additional jets originating from c-quarks
  - Complements tt+bb measurement (arXiv:2407.13473)
- All MC setups **underpredict** the production rates of c-jets by 0.5 - 2σ
- **Powheg+Pythia8** show the best agreement, while others under-predict the cross sections by up to 40%

⇒ Need for refined simulations to improve background estimations to further improve future measurements (ttH, 4-top production)

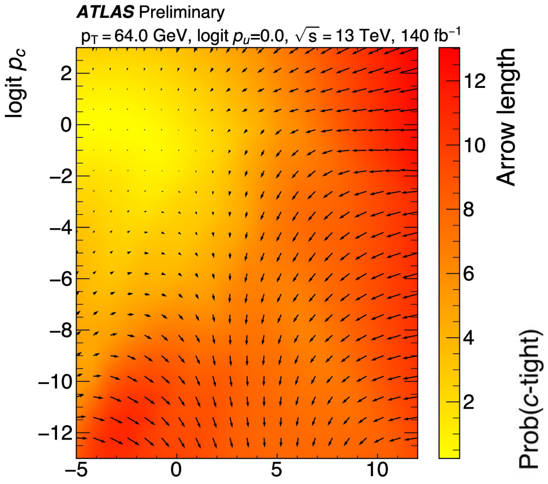
Flavor-tagging advancements

New strategy providing detector calibrations with optimal transport

- Directly calibrate the discriminant distributions by correcting the 3 correlated flavour probabilities (p_b, p_c, p_u), instead of calibrating the efficiency in fixed discriminant bins

- First time using ML to derive high-dimensional corrections to simulation
- Optimal transport solvers find the minimal altering of the simulation resulting in closure with data

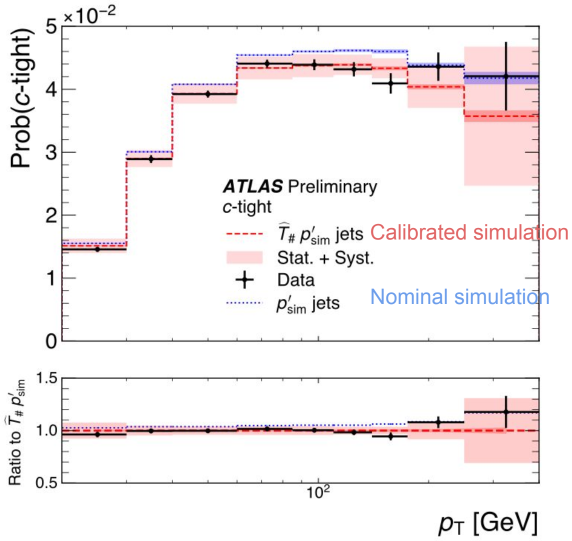
- Sophisticated use of jet flavor information crucial for our physics programs
  - Could provide breakthrough for using jet flavor information in analysis (e.g. H → cc)



logit p_b = log (p_b/(1-p_b)) (flavor classification score)

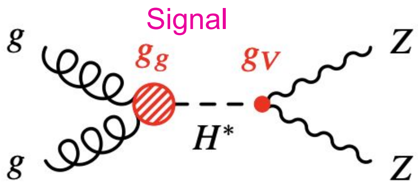
2 flavor projection of 3 flavor calibration

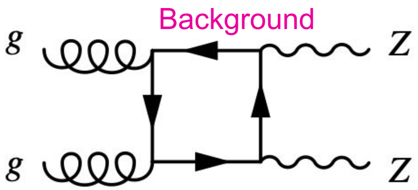
ATLAS-CONF-2024-014



Probability of jet passing c-tagging selection in VH, H → cc

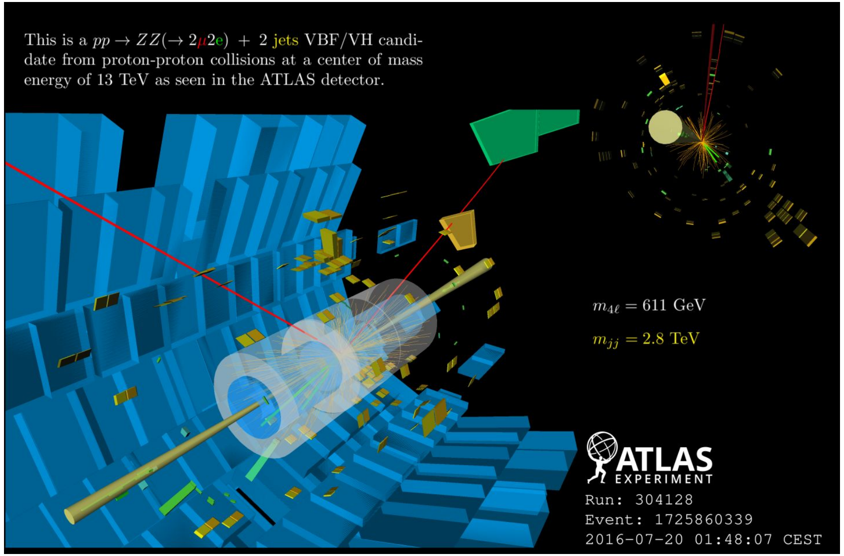
Higgs boson width via off-shell coupling



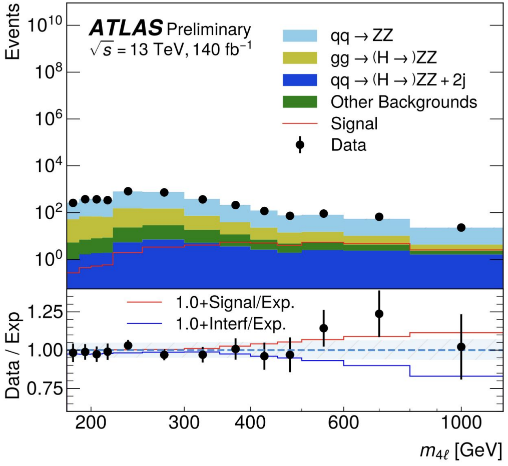


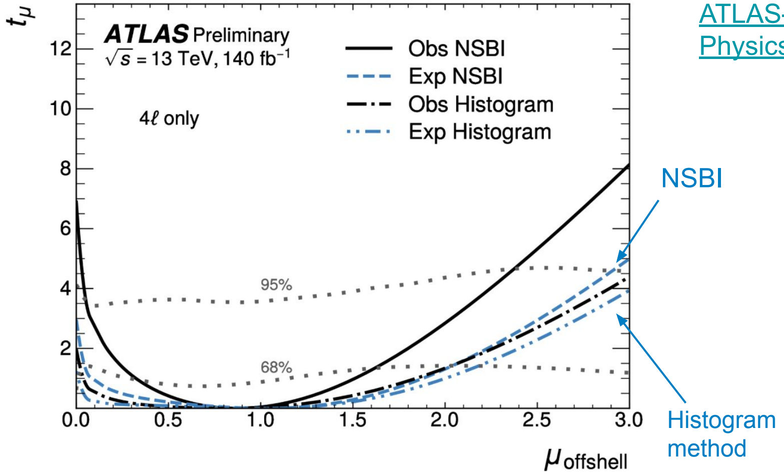
ATLAS-CONF-2024-016
Physics Briefing

- First ATLAS evidence of off-shell H* → ZZ → 4ℓ production (Phys. Lett. B 846 (2023) 138223)
- Updated measurement with new innovative technique (ATLAS-CONF-2024-015):
  Neural Simulation-Based Inference (NSBI)
  - Continuous ML-based approximation of full matrix elements at detector level
  - Better sensitivity to off-shell Higgs production



Higgs boson width via off-shell coupling





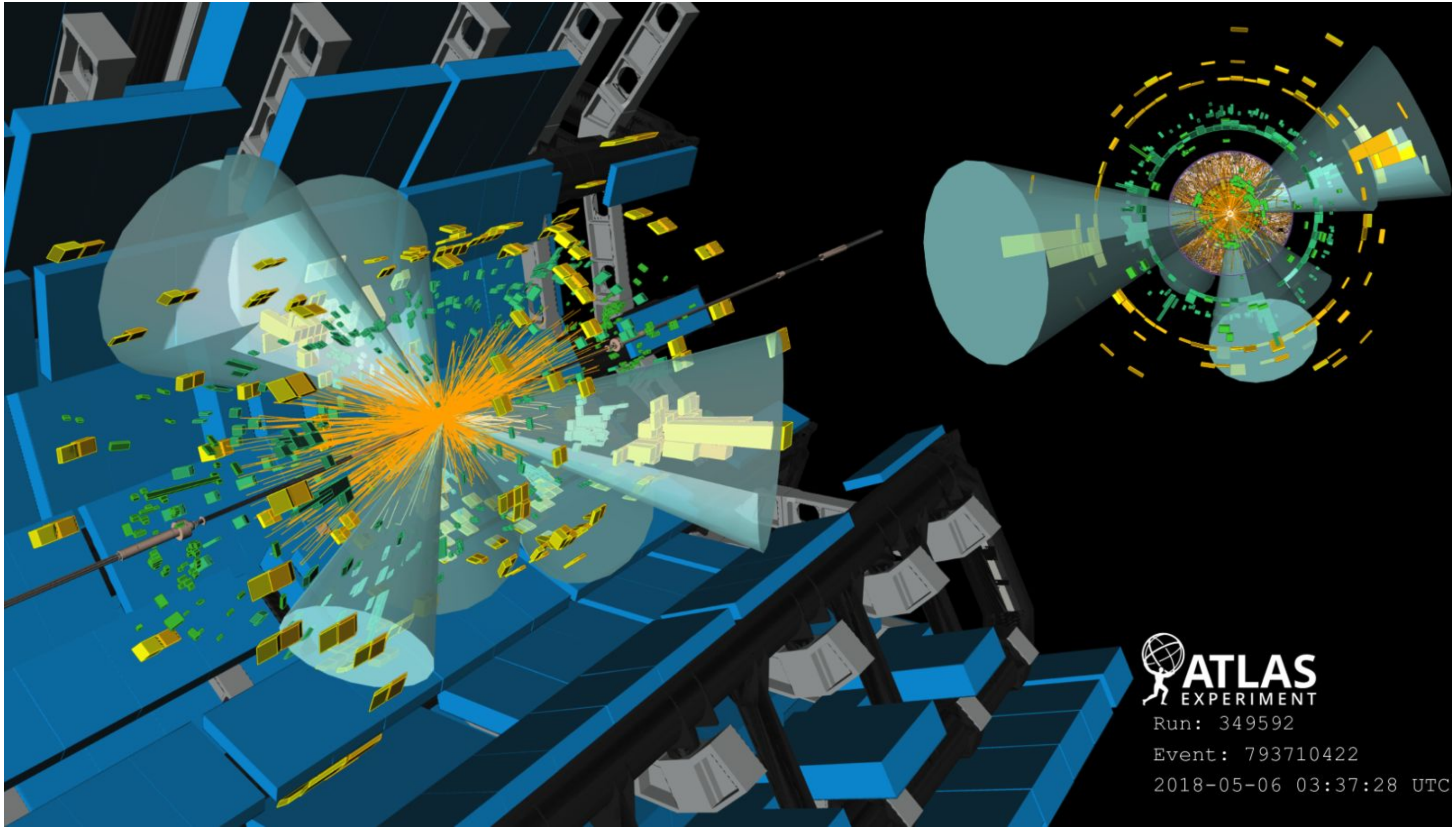
ATLAS-CONF-2024-016
Physics Briefing

- Comparison with previous result shows improved sensitivity
- Combining with H* → ZZ → 2ℓ2v, hypothesis of no off-shell Higgs boson production is excluded with a observed (expected) significance of 3.7σ (2.4σ)
- Combining with on-shell H → ZZ → 4ℓ allows to constrain total Higgs boson width at 68% CL to

$$4.3^{+2.7}_{-1.9}\ (4.1^{+3.5}_{-3.4})\ \text{MeV}$$

- Great potential of NSBI for complex analyses, particularly those dealing with quantum interference

Search for HHH → 6b

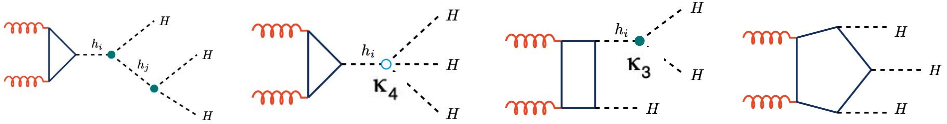


arXiv:2411.02040
Physics Briefing

Search for HHH → 6b

arXiv:2411.02040
Physics Briefing

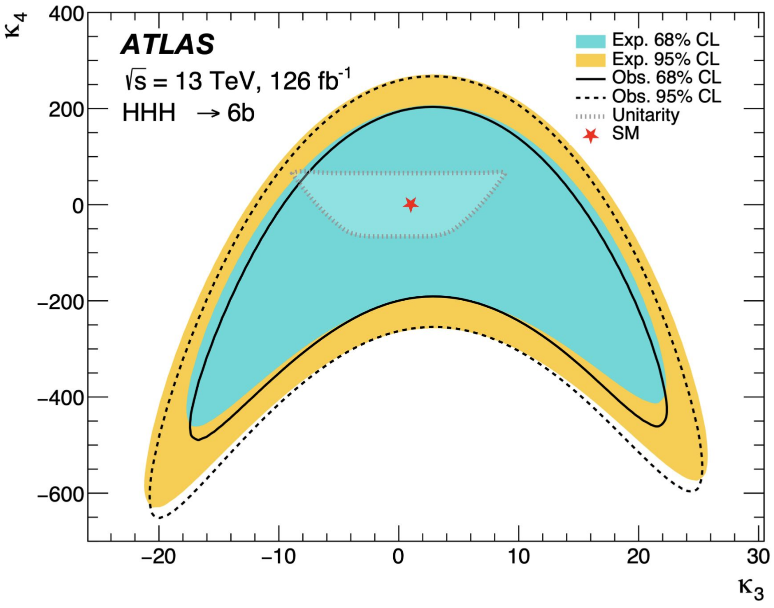
- First LHC search for tri-Higgs production with 6b final state
  - Very rare process, suppressed by a factor of ~ 400 compared to SM HH production



- Studying resonant and non-resonant production:
  - Resonant: extended scalar sectors can produce cascade decays and appear in this channel first
  - Non-resonant: probe Higgs quartic coupling as well as cross section / signal strength

- No evidence of tri-Higgs production observed ⇒ 95% CL upper limit on cross section (for SM kinematic shape): 59.4 fb (SM prediction 0.08 fb)
- Additionally: probing of Higgs self-coupling strengths with first experimental constraints on κ_4

Higgs trilinear & quartic self-coupling limits



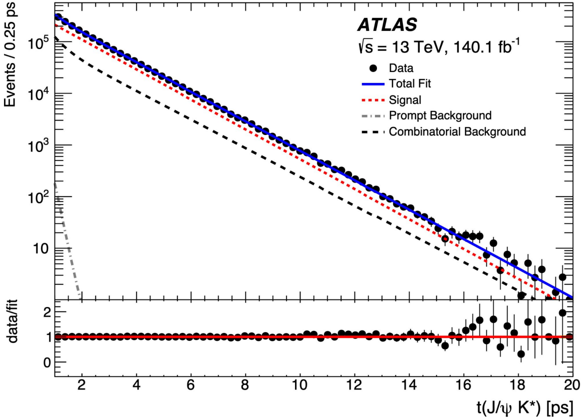
B^0 meson lifetime measurement

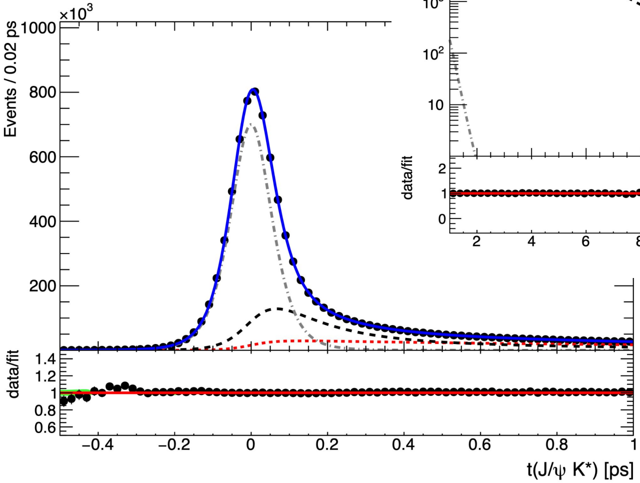
[CERN seminar, 19. Nov, M. Smizanska](#)

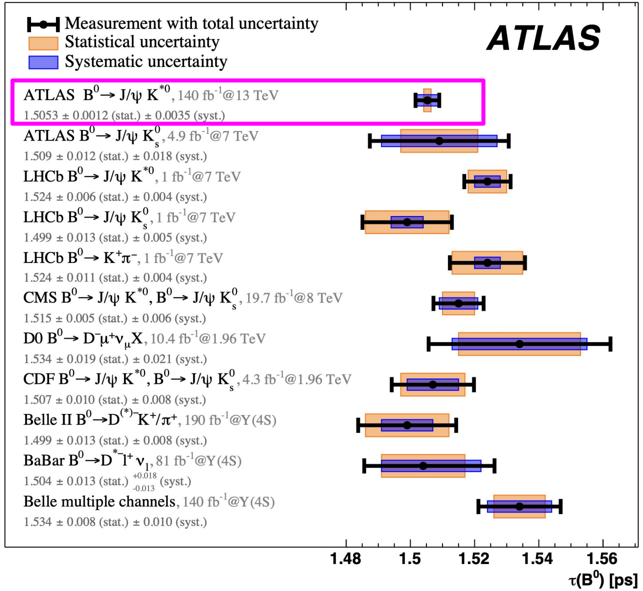
[arXiv:2411.09962](#)

Most precise $B^0 \to J/\psi K^{*0}$ measurements of lifetime and decay width

- τ = 1.5053 ± 0.0012 (stat.) ± 0.0035 (syst.) ps
- Γ_d = 0.6639 ± 0.0005 (stat.) ± 0.0016 (syst.) ± 0.0038 (ext.) ps^{-1}
- Dominating systematic errors: mass-lifetime correlation and fit model variation





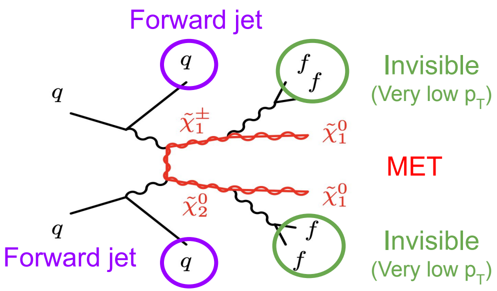


- Comparison with previous ATLAS measurements (Run 1, based on $B^0 \to J/\psi K_s^0$)
  - Improvement of systematic error by factor of 7 (IBL, ID alignment)
- Ratio Γ_d / Γ_s measured to be compatible with one, in agreement with theoretical predictions

Small mass-splitting SUSY with VBF

Search for compressed electroweak SUSY using VBF topology

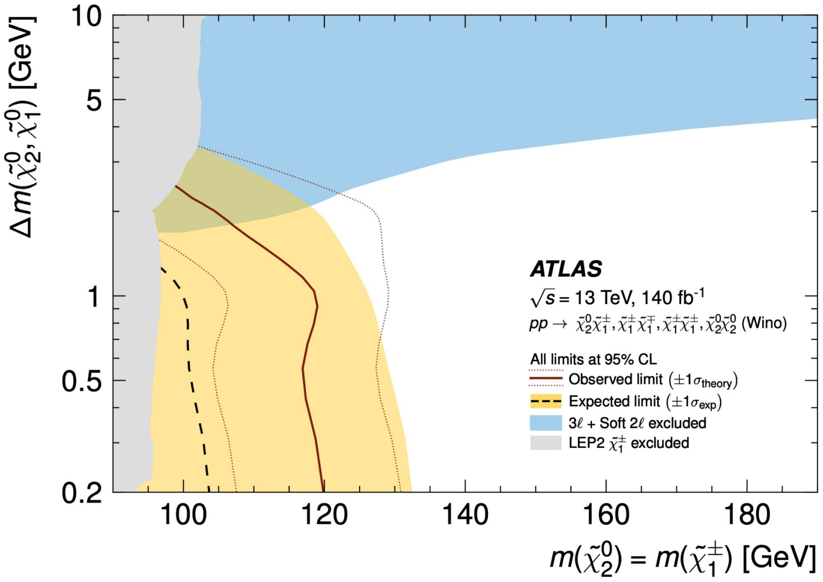
- Final state is MET + forward jets



- Very small mass-splitting
  - Chargino and neutralino decay still prompt ⇒ complementary to disappearing track search
  - Search is independent of the decay products of the chargino / neutralino; in case of e / μ, below threshold (p_T < 4.5 / 3 GeV) ⇒ complementary to dilepton and soft lepton searches

arXiv:2409.18762

Limits on compressed SUSY simplified model with a bino-like LSP and wino-like NLSPs

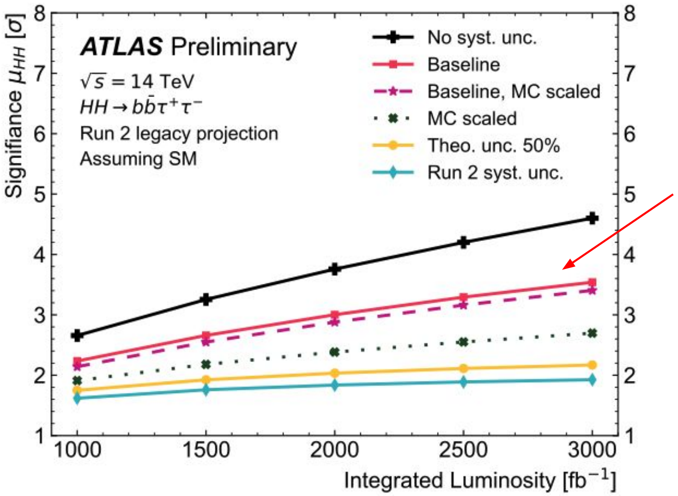


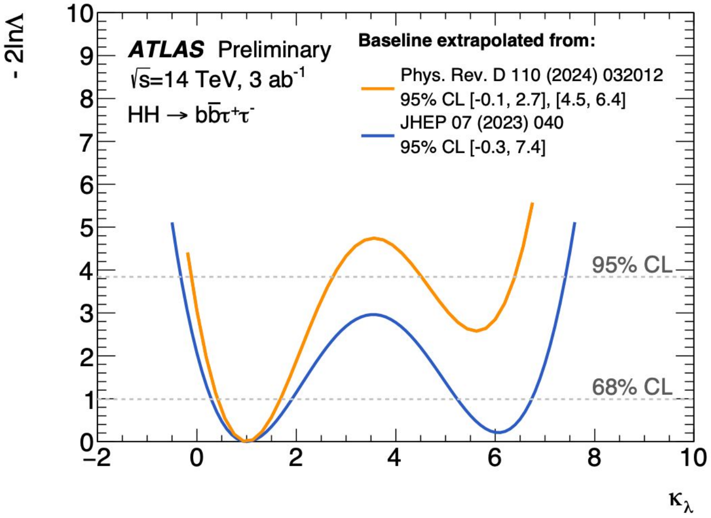
- Extension of sensitivity beyond LEP in the wino scenario (larger cross-section), while not yet for higgsinos (lower cross-section)

HL-LHC projection: HH → bbττ

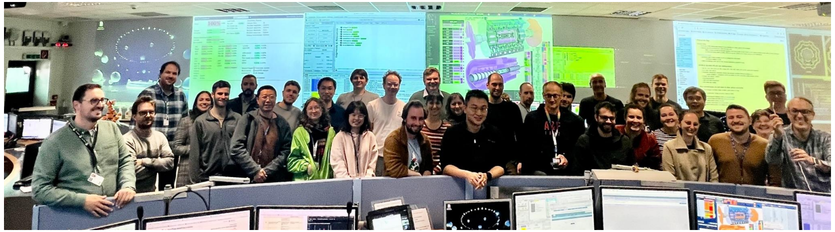
ATL-PHYS-PUB-2024-016

- Measurement of **Higgs self-coupling** is one of the physics drivers for HL-LHC
  - One of the most sensitive single channels: **HH → bb$\tau\tau$**
- Updated projection includes significant updates to analysis techniques
  - Improved multivariate classifiers, updated MC simulation for top and Z backgrounds
- Potential to reach significance of almost 3.5σ for HH production by the end of the HL-LHC in this channel alone, and significant improvement for constraint on κ_λ





Conclusions



Run-3 status

- Excellent LHC and ATLAS performance so far this year
- Phase-I triggers enabling ATLAS to operate at high luminosity and pileup

Phase-II upgrade for the HL-LHC - our highest priority

- Design completed, series production has started for many components, remaining technical challenges being addressed, launch ITk module assembly imminent

Sustaining rich physics production

- Continuing high-pace paper output across a wide range of areas with new and improved results