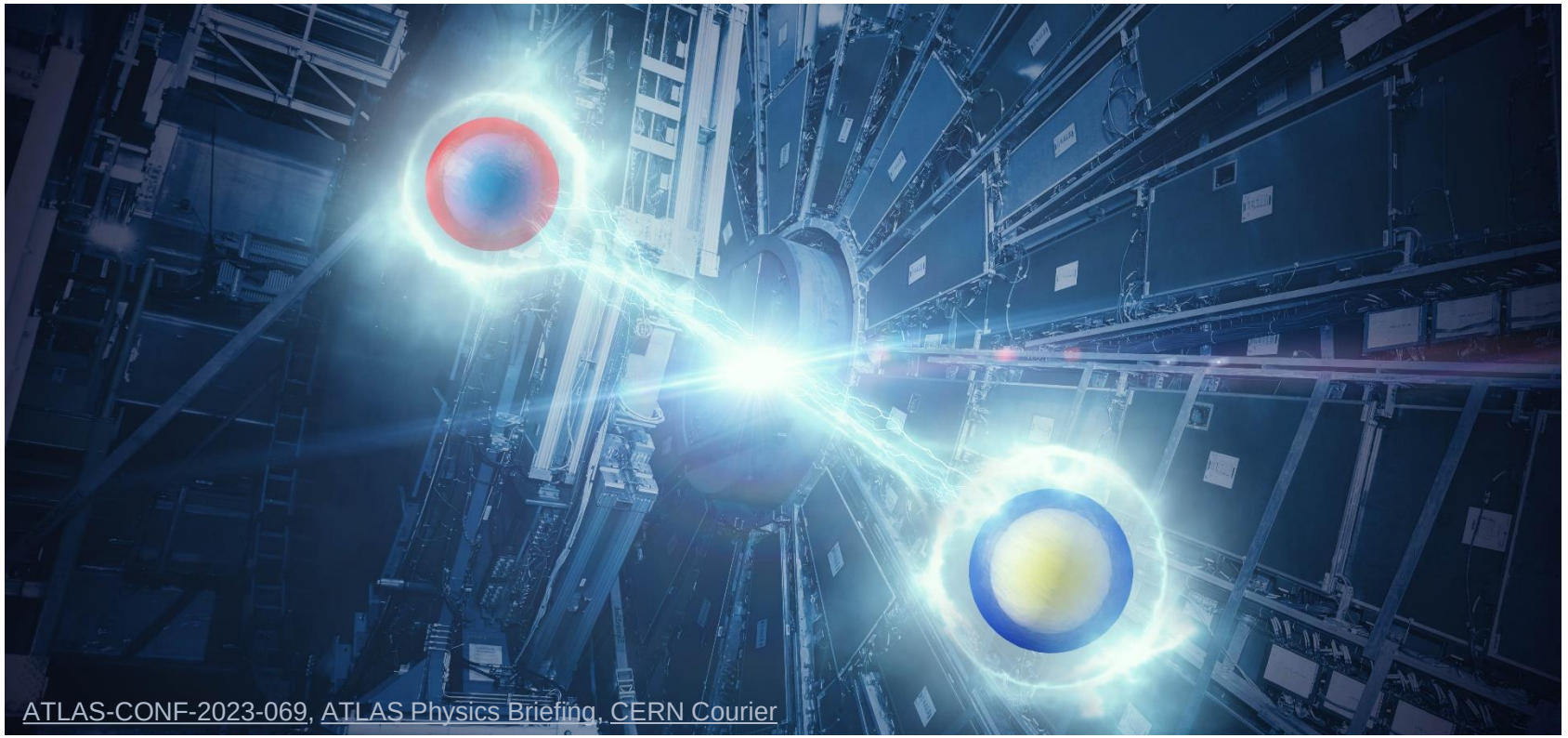


ATLAS status report

Silvia Franchino (CERN/Heidelberg University)

On behalf of the ATLAS collaboration

LHCC Open session, 29.11.23 CERN

Outline

- Run3 Data taking and performance results
- Phase-II upgrade progress
- Physics highlights

Recap on 2023

2023 data recorded by ATLAS:

- **pp 13.6 TeV**: 29.9 fb^{-1}
- **pp high beta*** run at 13.6 TeV: ~ 0.3 nb^{-1}
- **PbPb 5.36 TeV**: 1.75 nb^{-1}

(ppReference postponed to 2024)

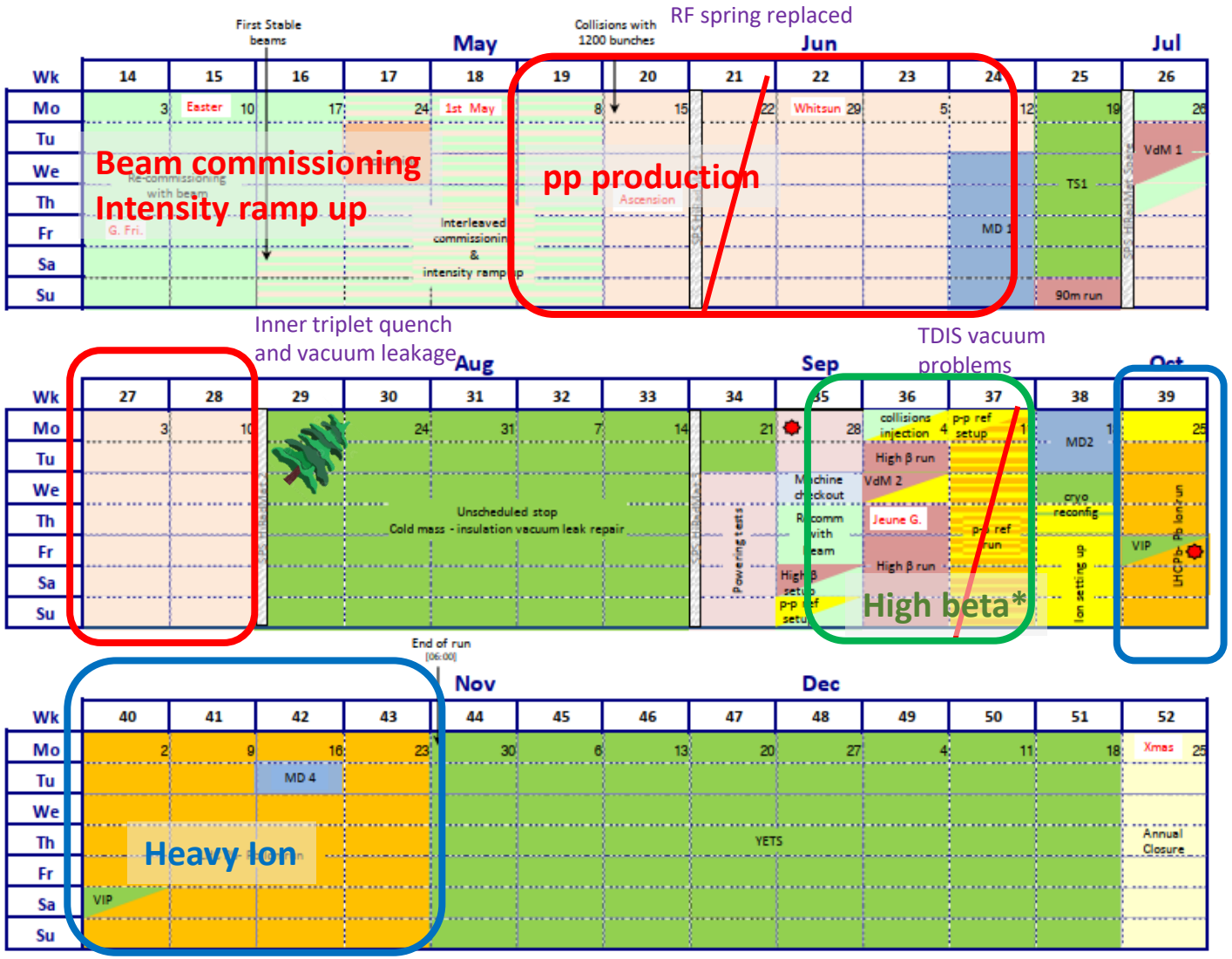
2022:

- pp 13.6 TeV: 35.7 fb^{-1}

Shortened run because of energy crisis
Ambitious goals (pushing detector and LHC limits)

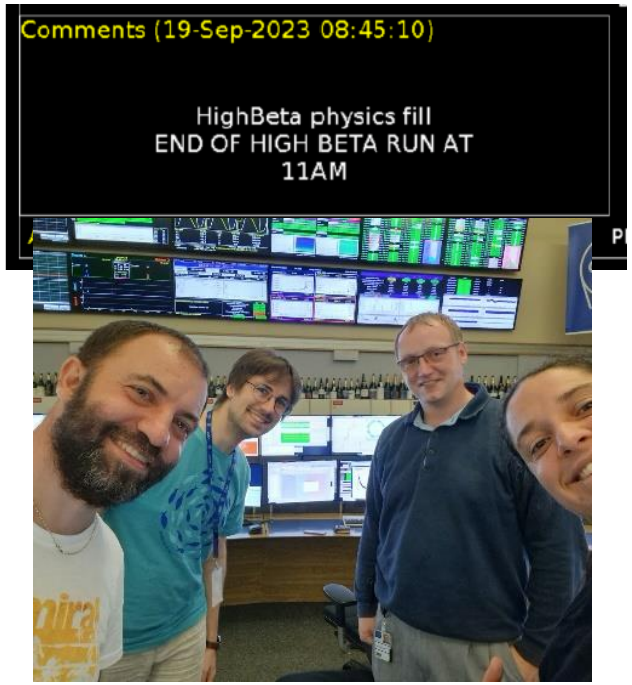
First Run3 papers released:
ZZ -> 4l arXiv:2311.09715
tt, tt/Z cross section arXiv:2308.09529
H→γγ, H→ZZ*→4l arXiv:2306.11379
b tagging at HLT arXiv:2306.09738

More data needed for most of the analyses



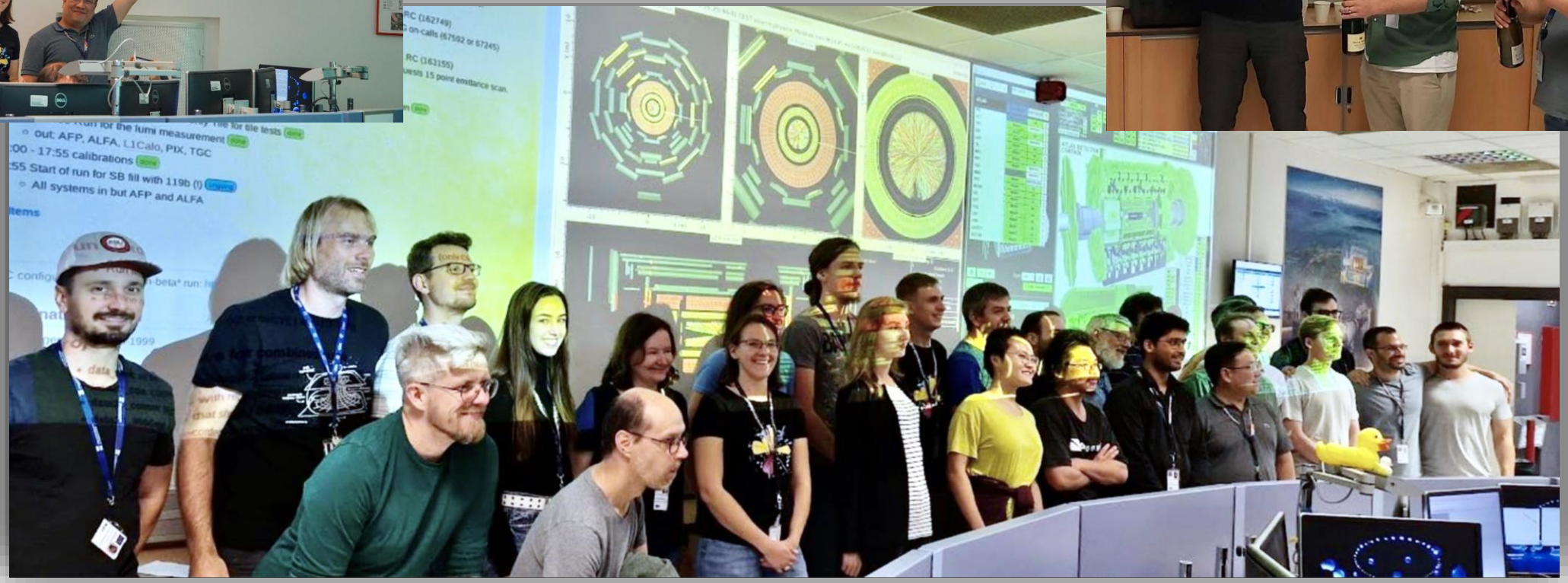
3/6 km beta* run with ALFA/TOTEM

Physics goals: **measure the total cross-section and ρ-parameter from elastic scattering**



- ALFA detector in good shape in terms of radiation damage after the LHC “summer break”
- **Difficult background conditions**, intense work to adjust **new crystal collimators** (thanks to the CERN collimation team!)
- Some fills acquired with **ATLAS Inner Detector** (+ ALFA) **for luminosity measurement**
- ATLAS magnets dump + 2nd TDIS leak causing 2.5 days of interruptions
- **Luminosity target > 0.3 nb^{-1} reached!**
- **Last run for ALFA detector, two stations decommissioned on C side** (donated to TWOCRYST project)

Heavy Ion data taking



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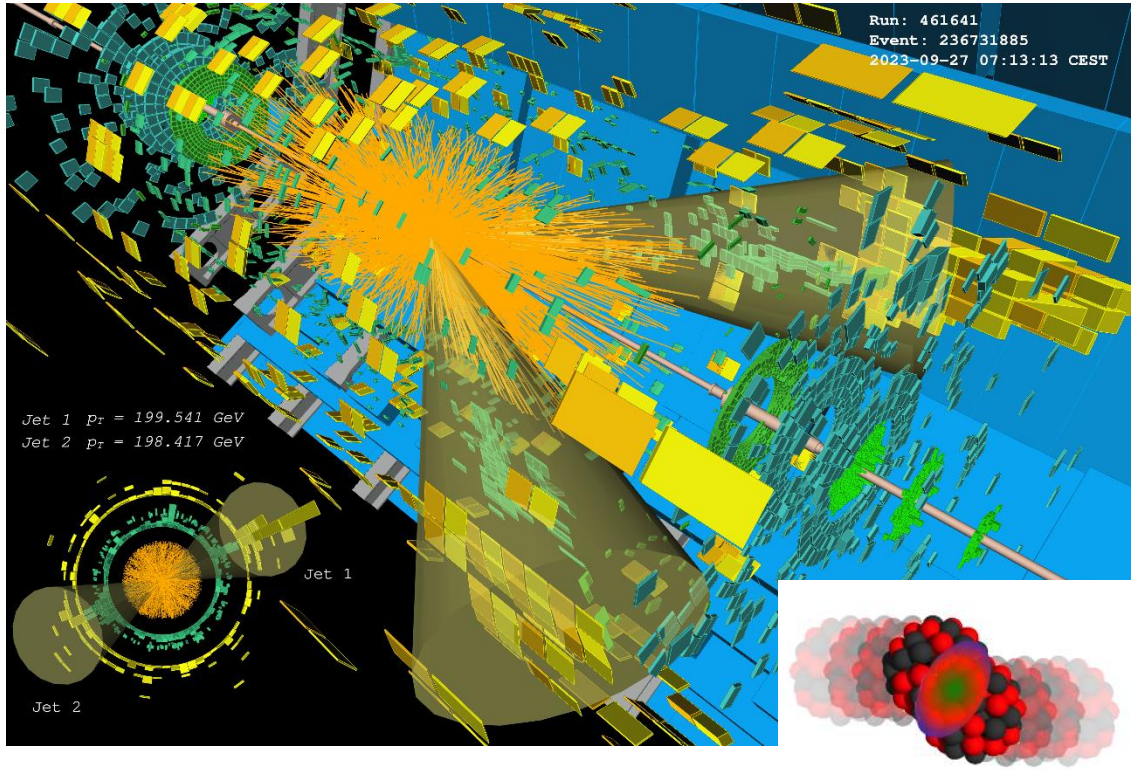
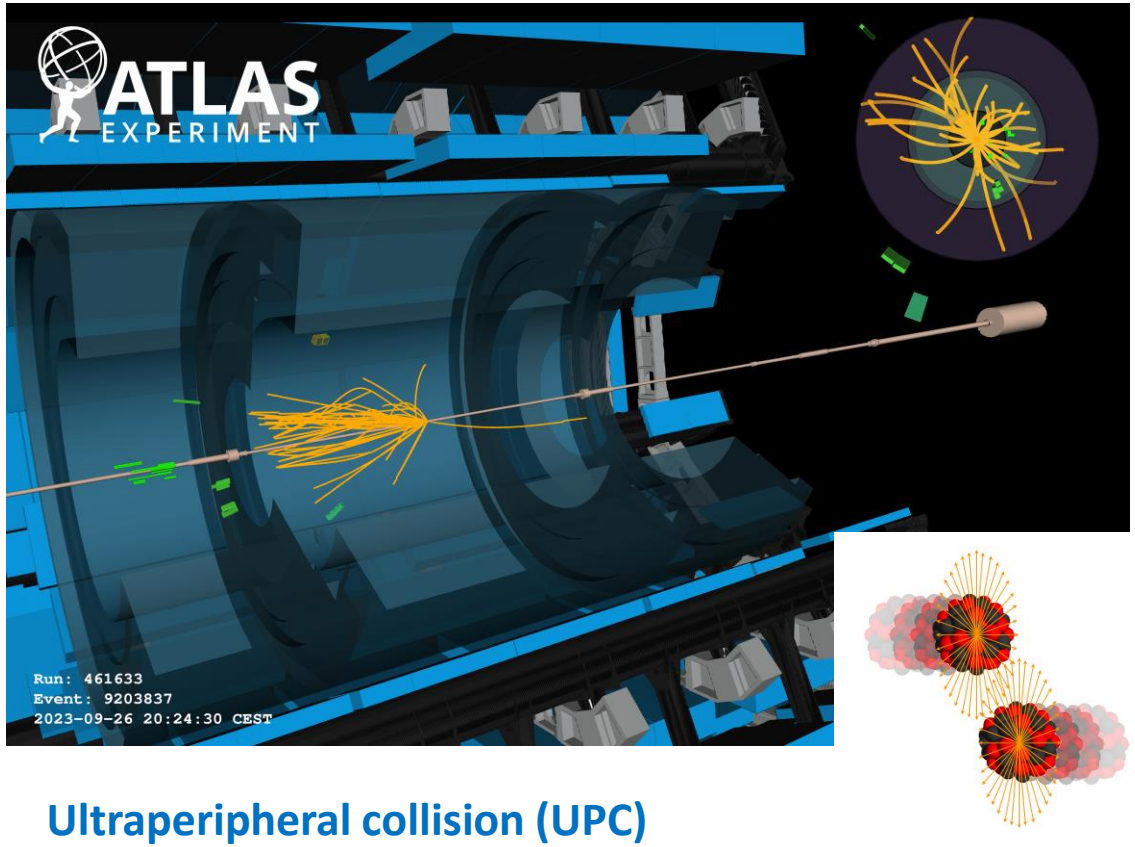


Central collision

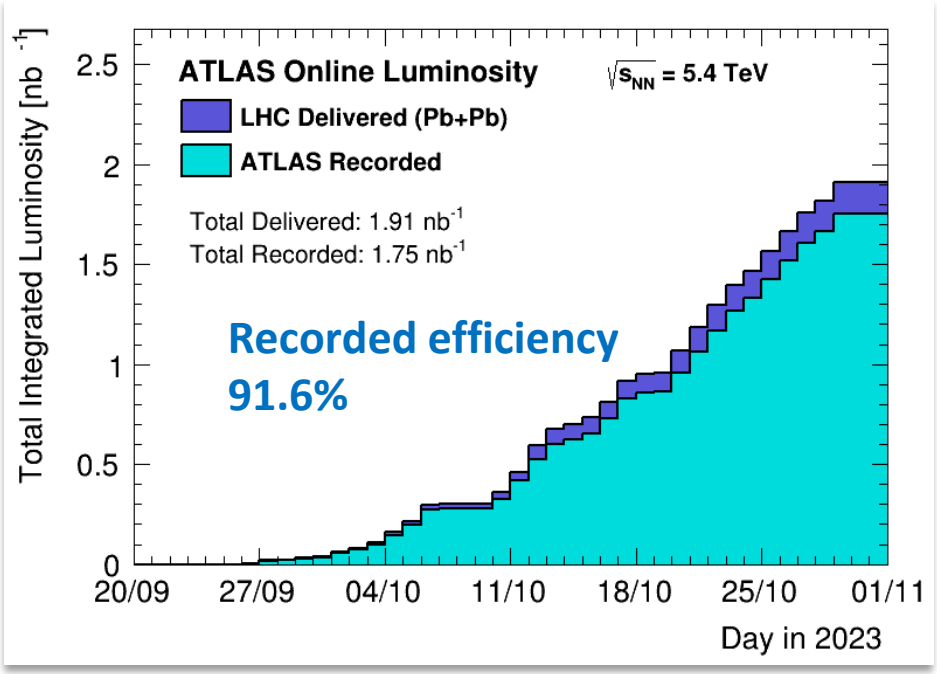
Strong interaction between the colliding nuclei



Ultraperipheral collision (UPC)

Photon-induced interactions

Heavy Ion data taking



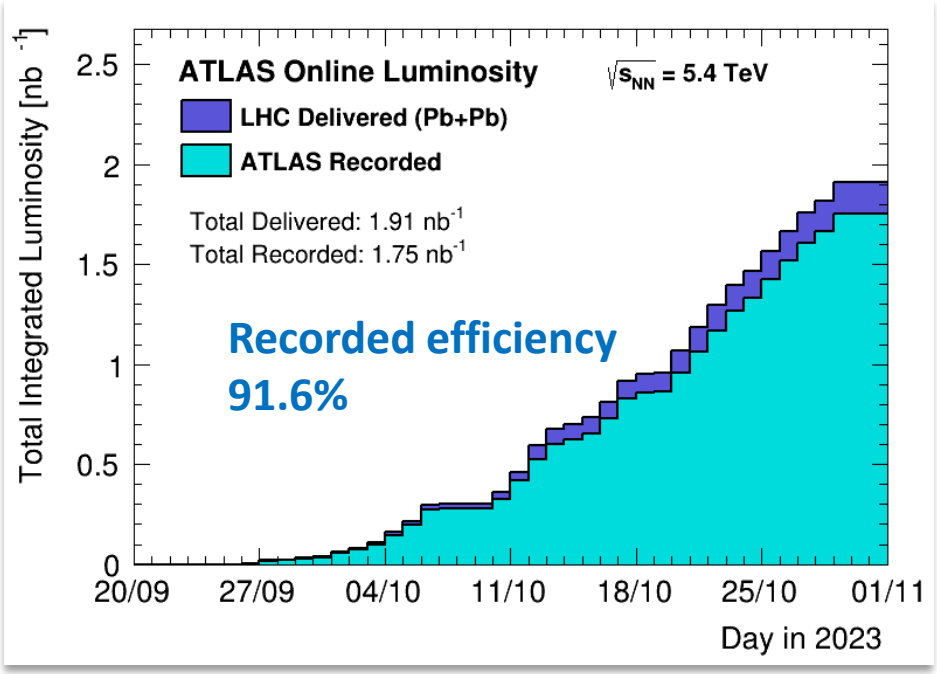
Total delivered luminosity of 1.91 nb^{-1}, recorded 1.75 nb^{-1} (in 2018: 1.76 nb^{-1}), **recorded efficiency 91.6%**

- Successful vdM scans, luminosity correction applied ~1 week later

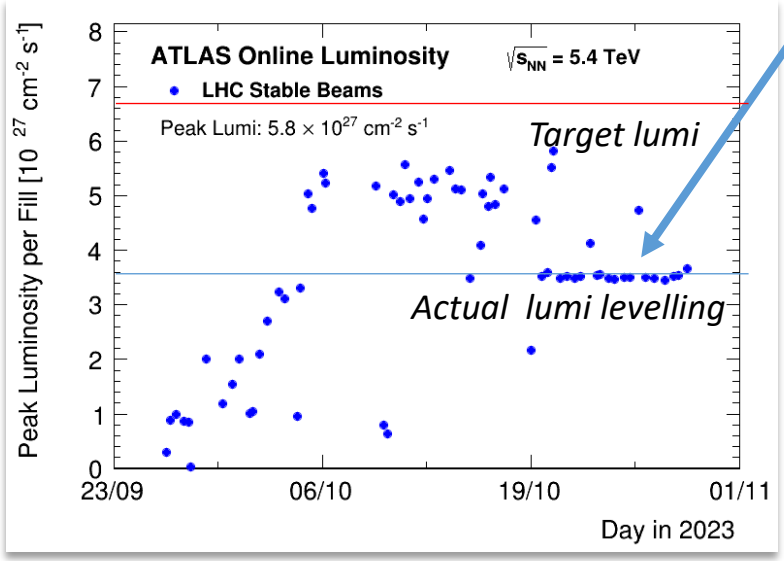
50 ns bunch spacing (wrt 75ns in 2018) challenging

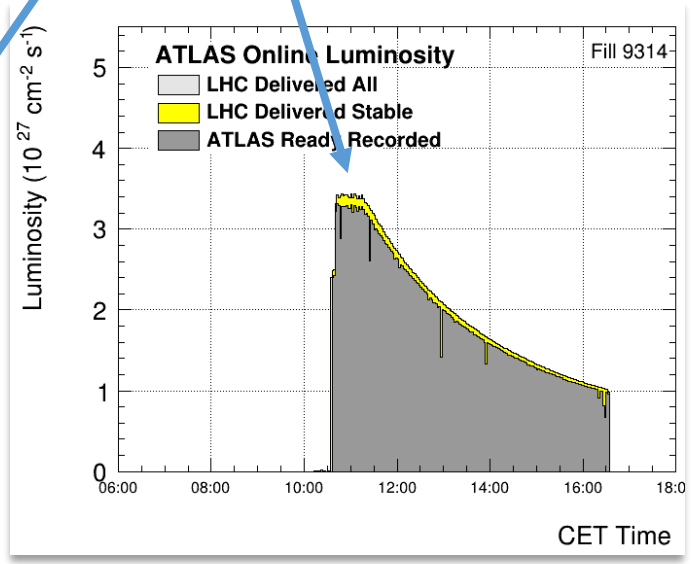
- Detector and trigger deadtimes caused lower recording efficiency due to **out of time pileup effects**
- Data Quality assessment ongoing

Heavy Ion data taking



Low luminosity levelling to minimise not understood quenches





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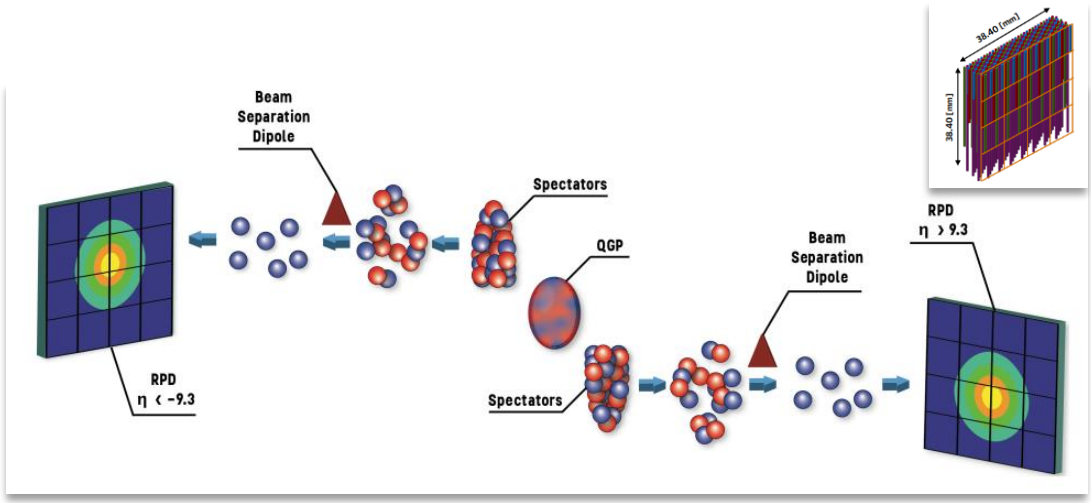
LHC levelled at a **lower luminosity** (3.5 vs foreseen 6.5 10^{27} cm^{-2}s^{-1}) to reduce number of not understood quenches

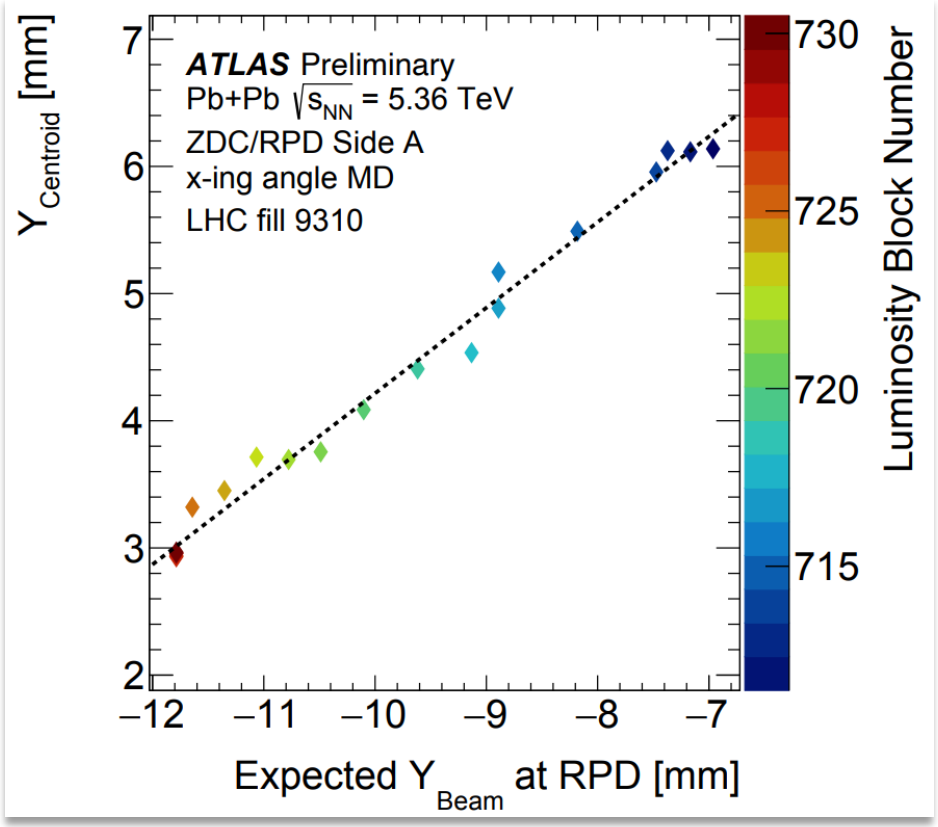
First time running with Phase-I L1Calo triggers in HI (many more low energy triggers used for HI physics than pp physics)

- Very low ET L1 triggers pushing the boundaries of LAr digital trigger specs, more tuning for future HI runs needed

Zero Degree Calorimeter (ZDC)

- Key part of the HI program [UPC triggering + offline analysis]
- **Improvements during LS2** (now fully digital trigger with new electronics)
- **New Reaction Plane Detector (RPD)** image the location of collisions via spectator neutrons
  - New set of flow measurements possible for ATLAS in Run 3

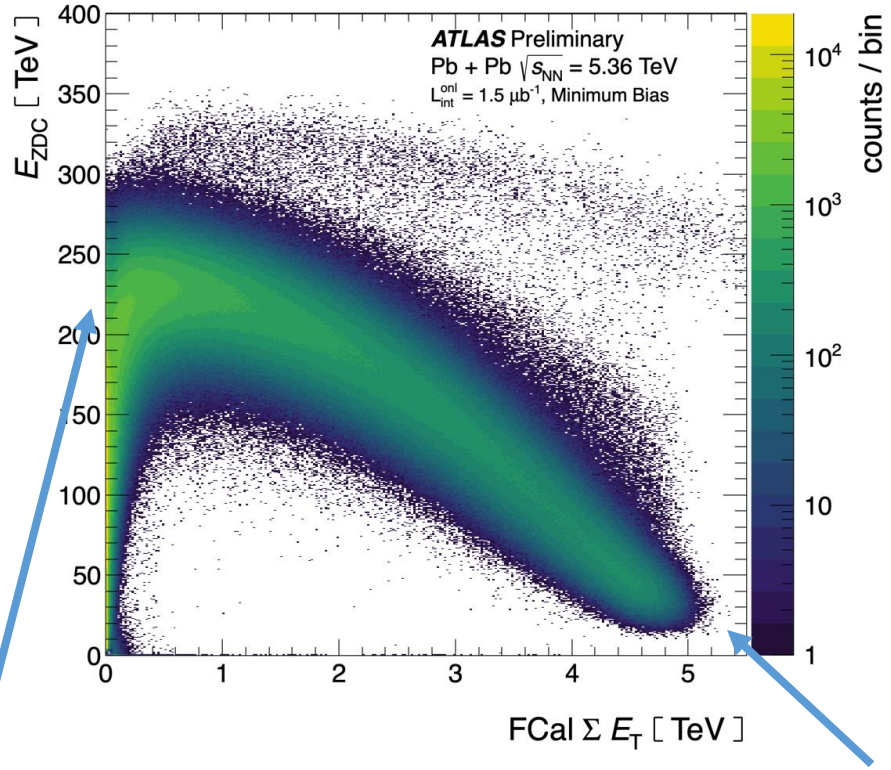


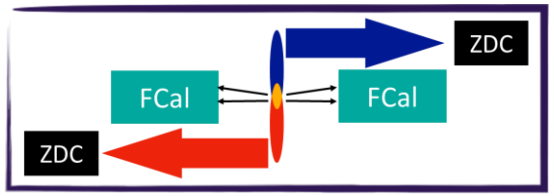


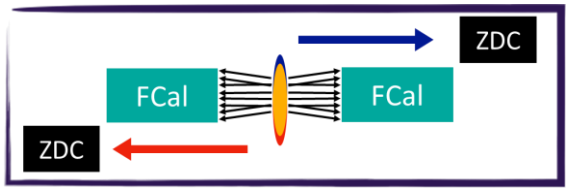
Measured shower centroid with RPD and expected beam position (machine development with change crossing angle)

Zero Degree Calorimeter (ZDC)

ZDC total energy vs FCal E_T



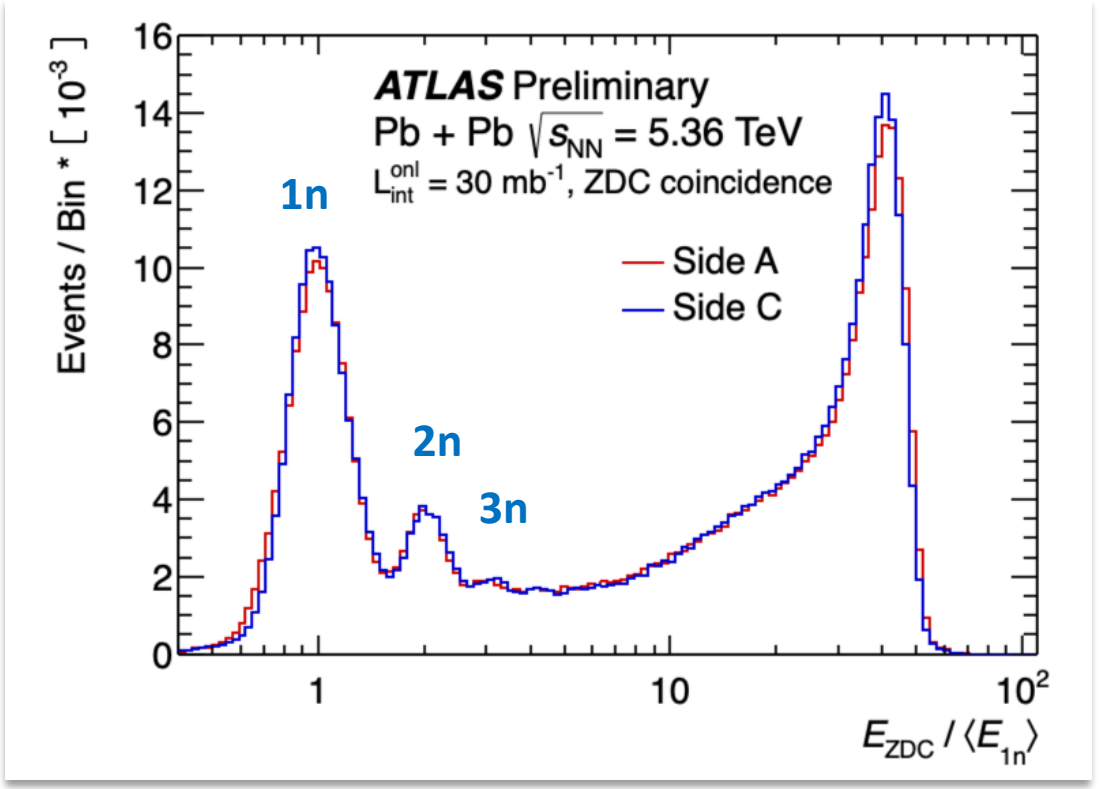




Peripheral events: low activity in the FCal, several spectator neutrons (high energy deposit in the ZDC)

Energy distribution for events passing L1 ZDC trigger

- *Performance of both ZDC sides agrees*
- *1,2,3 neutron peaks visible*
- *Expected resolution for 1n peak*

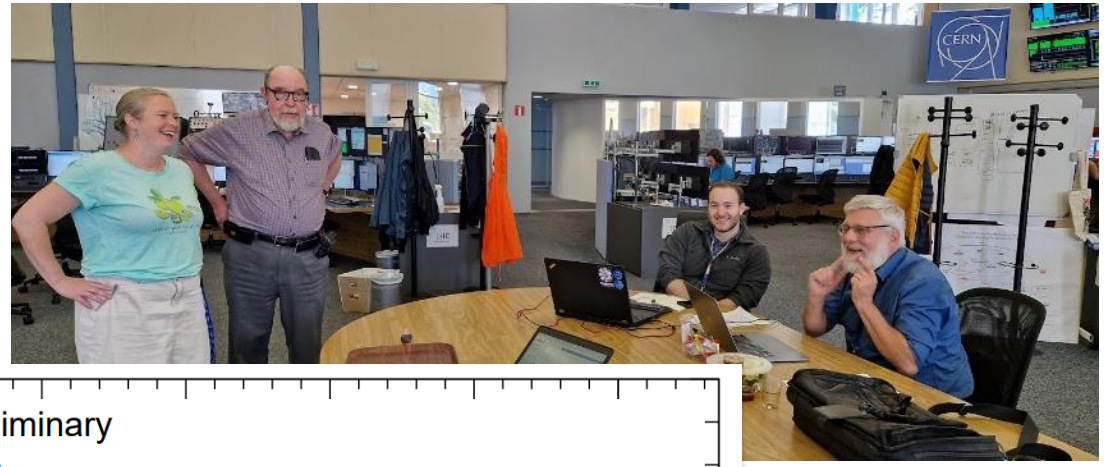


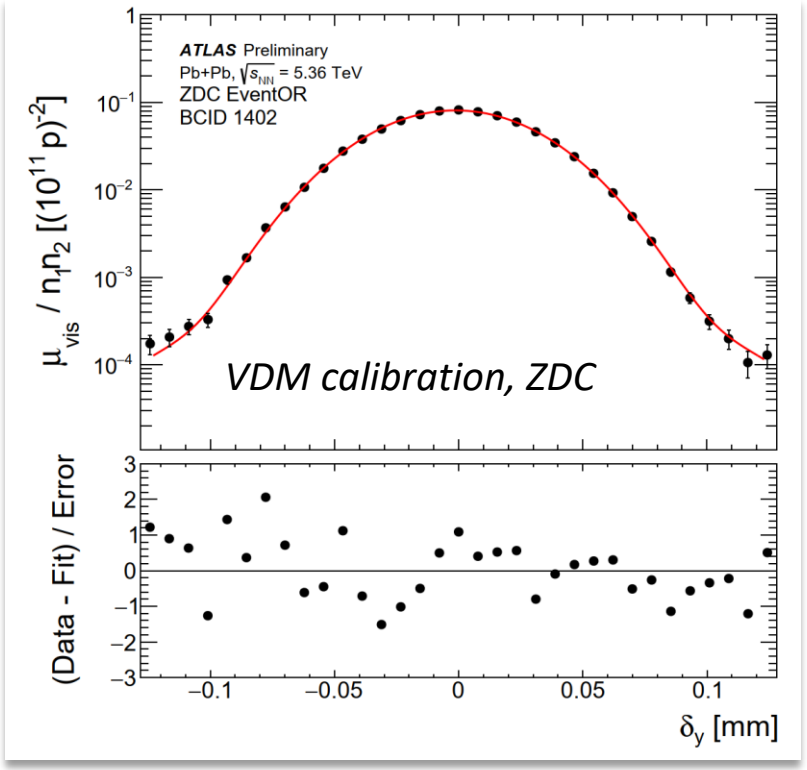
Central events: high activity in the FCal, low number of spectator neutrons (low energy deposit in the ZDC)

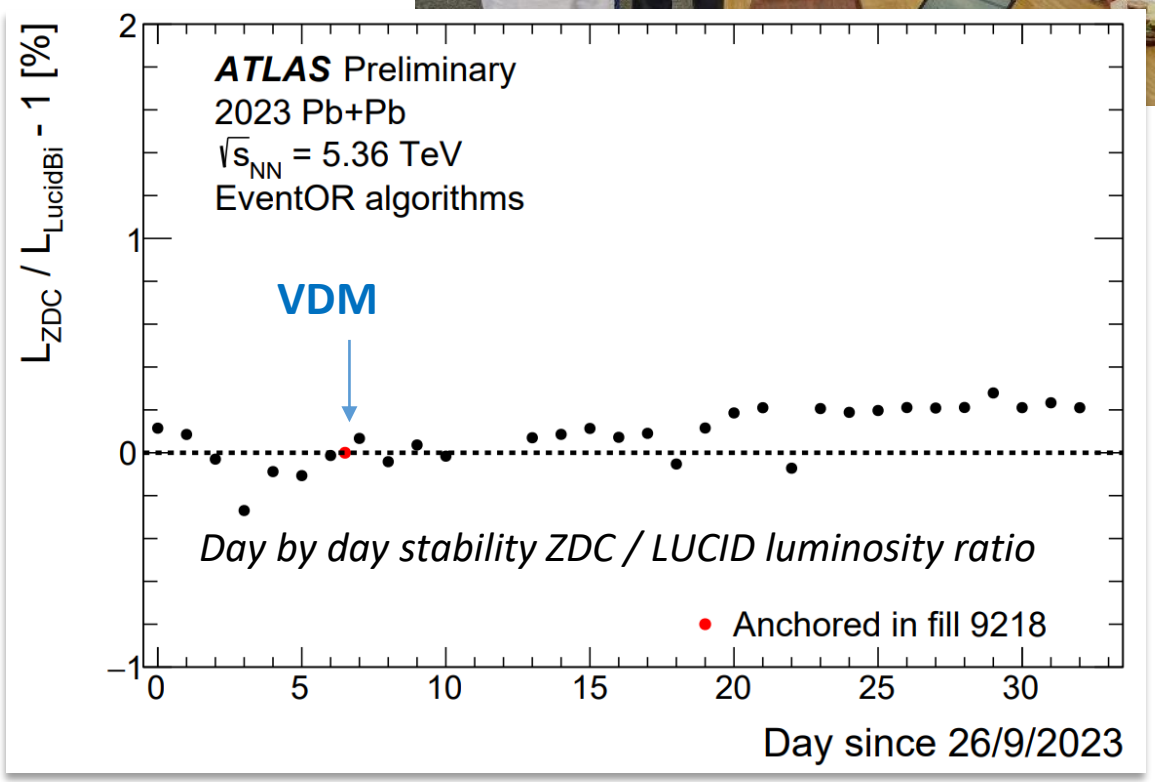
ZDC luminosity measurement

New luminosity algorithm based on ZDC trigger with high statistics

- Allows to **cross-check results** obtained with LUCID (agreement less than 1% found)
- Can **significantly improve long term stability uncertainties** wrt Run2







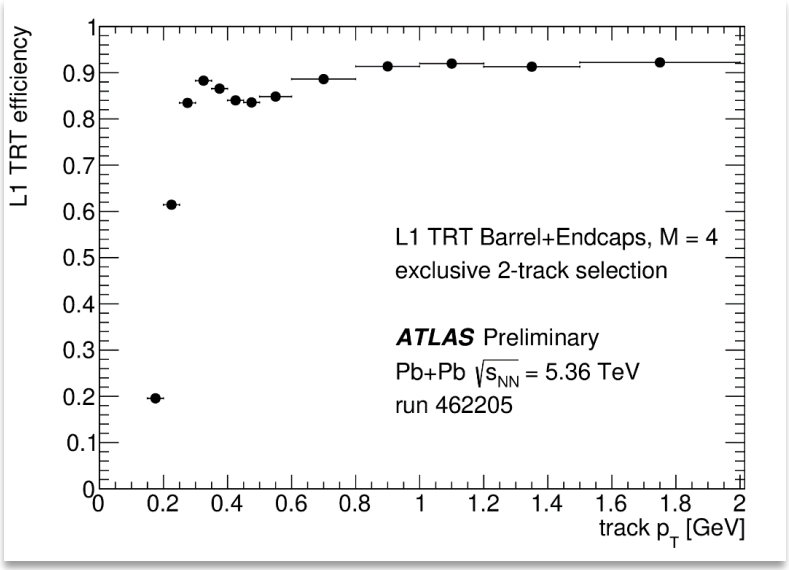
< 1% agreement

New L1 TRT track trigger for UPC events

New L1 track trigger using Transition Radiation Tracker (TRT) focussing on Ultra peripherical collisions (combined with energy veto)

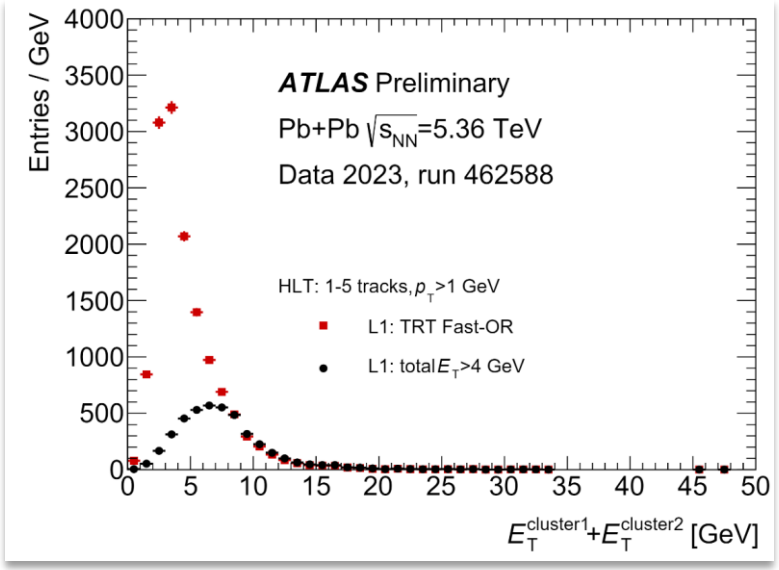
- **High efficiency and cleaner sample even at impressively low track p_T** (clean L1 triggers for low pT dileptons)
- **Great step forward compared to Run 2**
- Commissioning in parallel with data taking: a 2023 year-long effort

High efficiency from ~ 300 MeV tracks



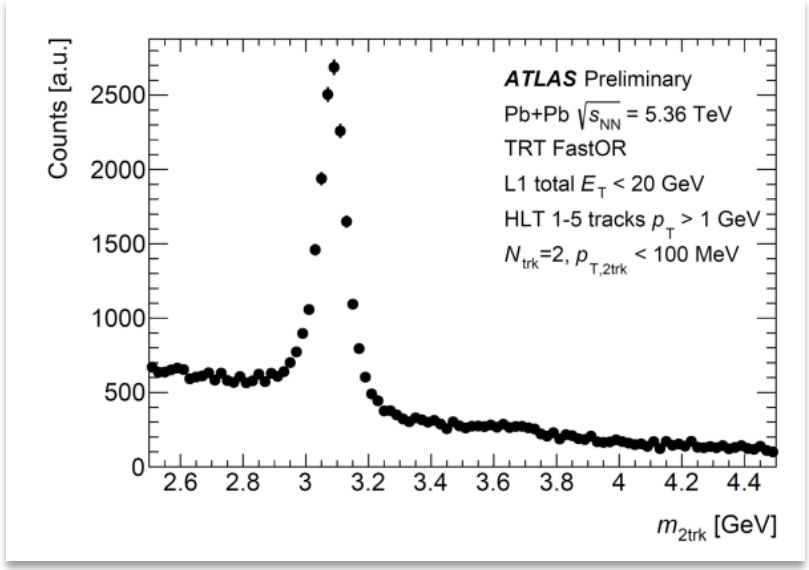
Measured L1 TRT trigger efficiency for exclusive 2-track events as a function of leading track transverse momentum

Improvement statistics for low p_T objects



E_T sum of two e^+e^- clusters

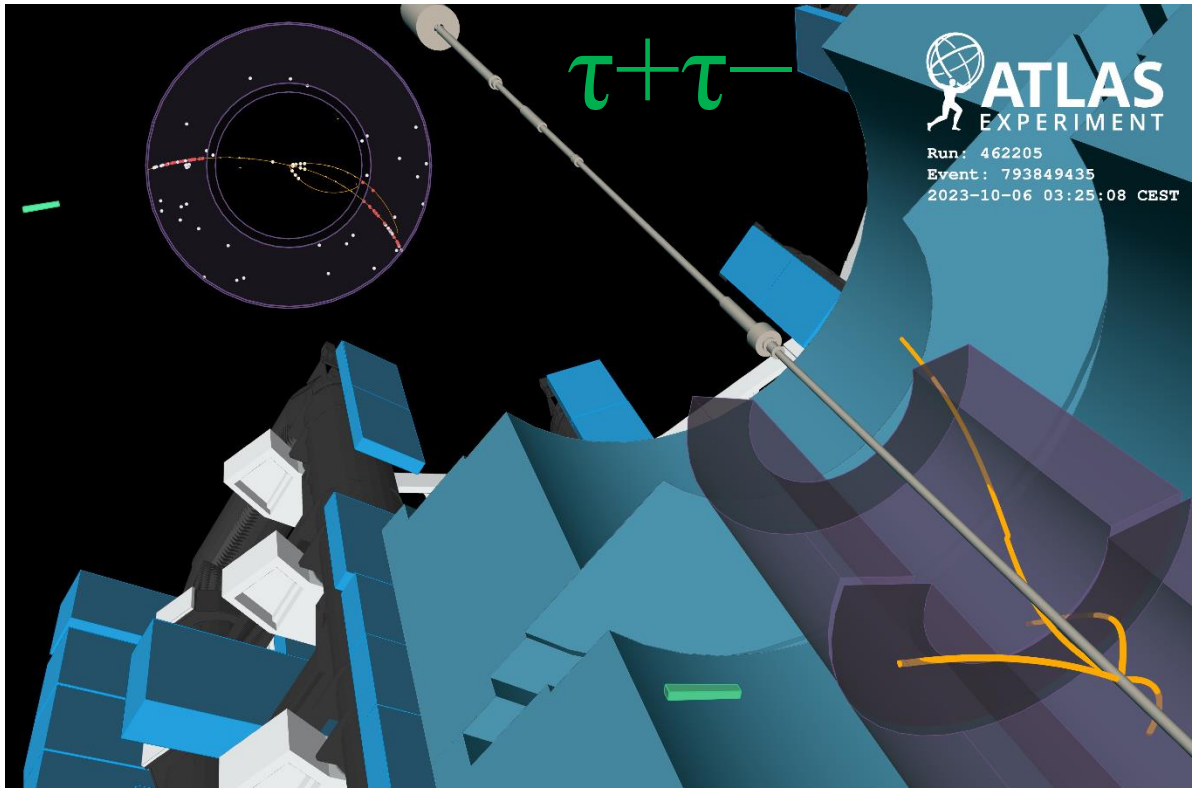
new type of measurement in HI Run3



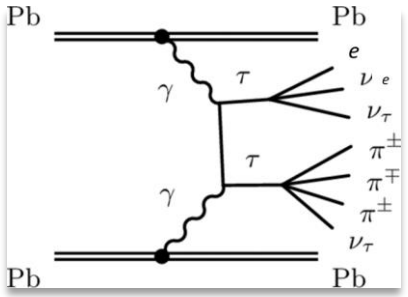
Two-track invariant mass in the J/ψ region for events selected by the L1 TRT trigger

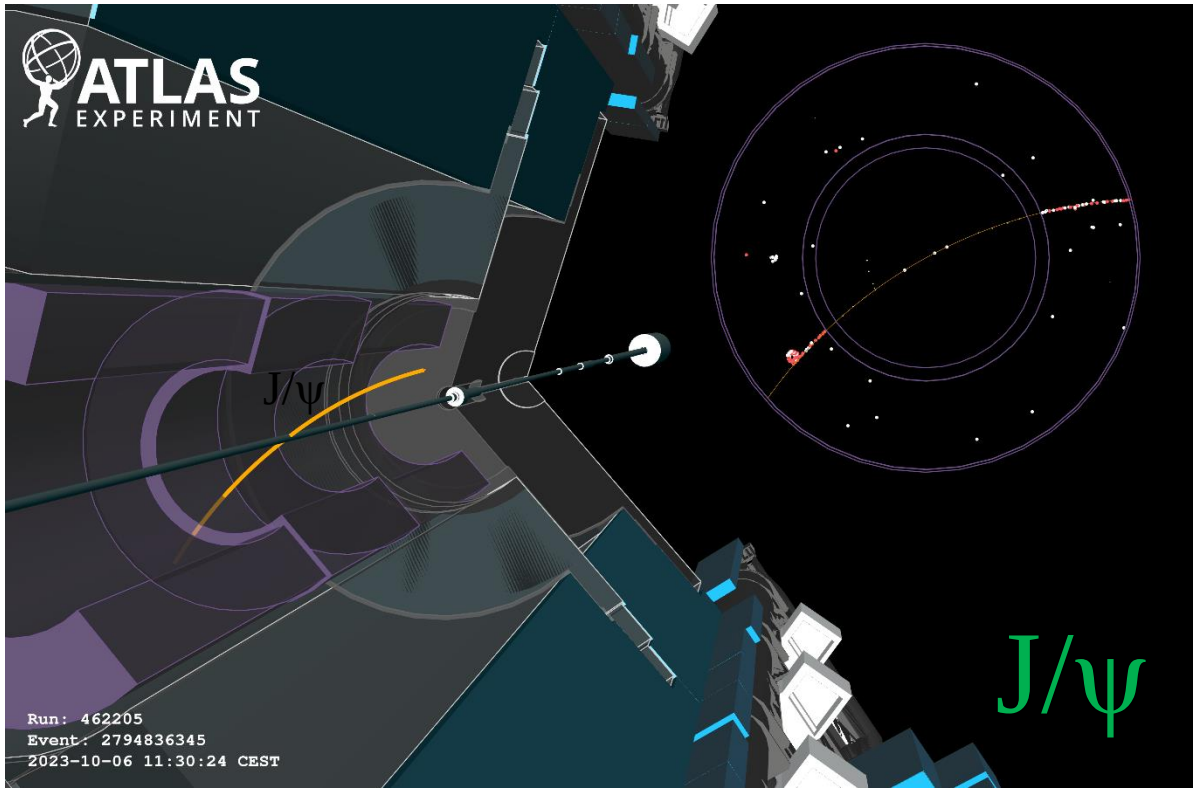
New L1 TRT track trigger for UPC events

HI event displays for events **triggered with TRT detector at L1** (no other ways to trigger them)

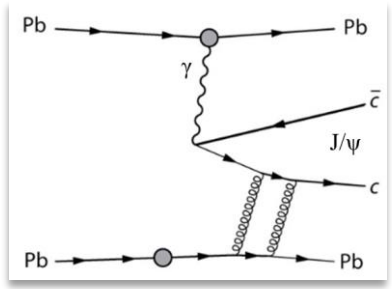


γγ→ττ candidate -> e,3π,2ν





J/ψ candidate -> 2l

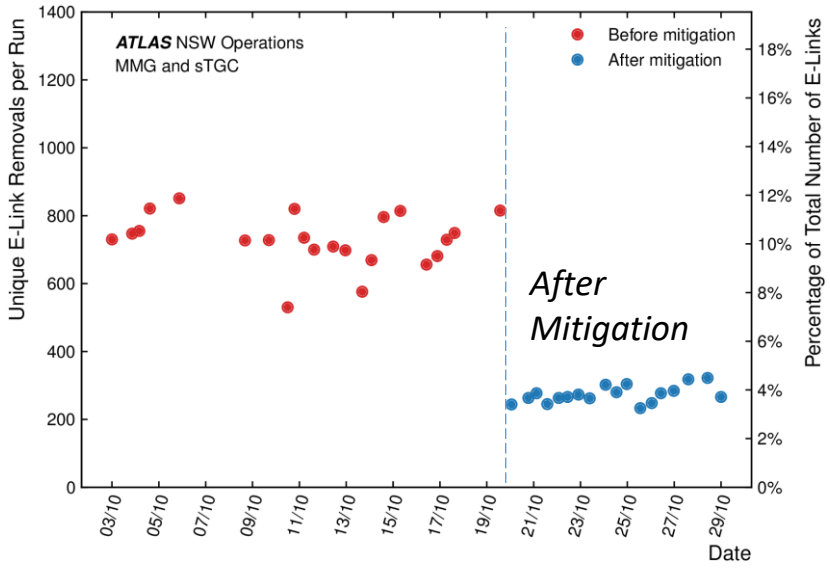


New Small Wheel readout and performance

NSW DAQ stability studies and possible improvements tested during HI runs

- Mitigated DAQ stability issues by **increasing number of transitions in TTC stream to GBTx**
- Investigations to understand the underlying cause ongoing

Number of NSW e-links removed from acquisition



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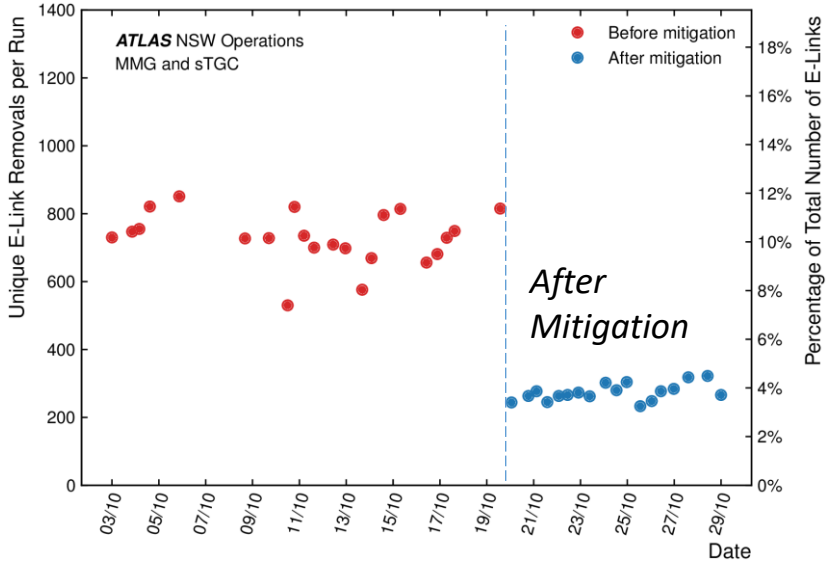
- Investigations to understand the underlying cause ongoing

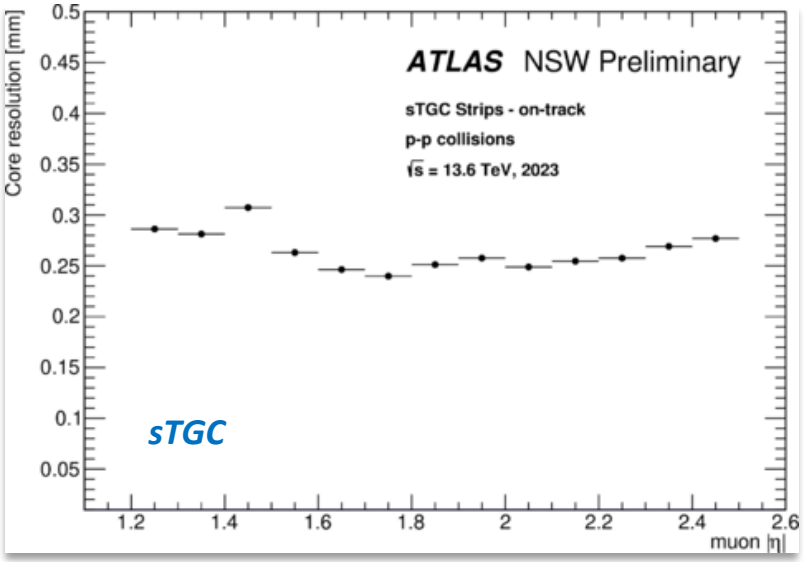
Studies on detector performances and working point optimization

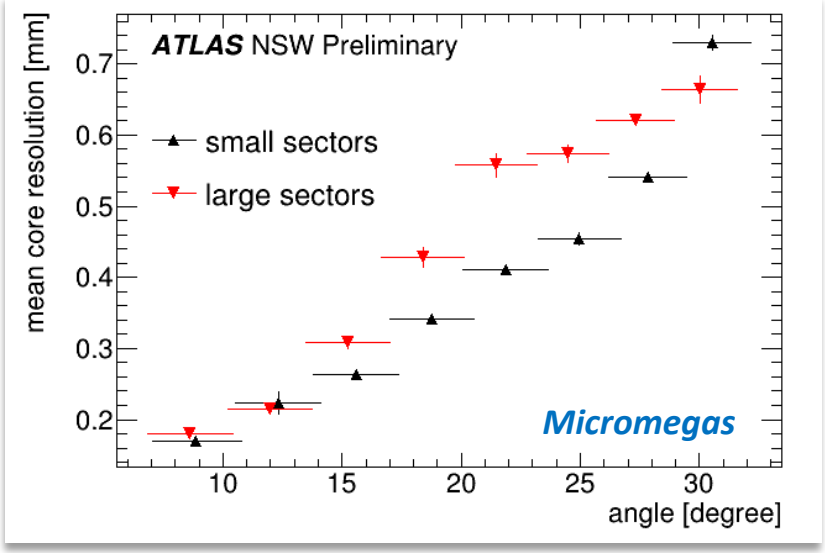
- new technology, first time applied at such a large scale, detector performance still under study
- Position resolution will be improved with further corrections for geometry, alignment and magnetic field

Number of NSW e-links removed from acquisition



Position resolution (per layer). 12 points in total (sTGC + MM)





New Small Wheel trigger

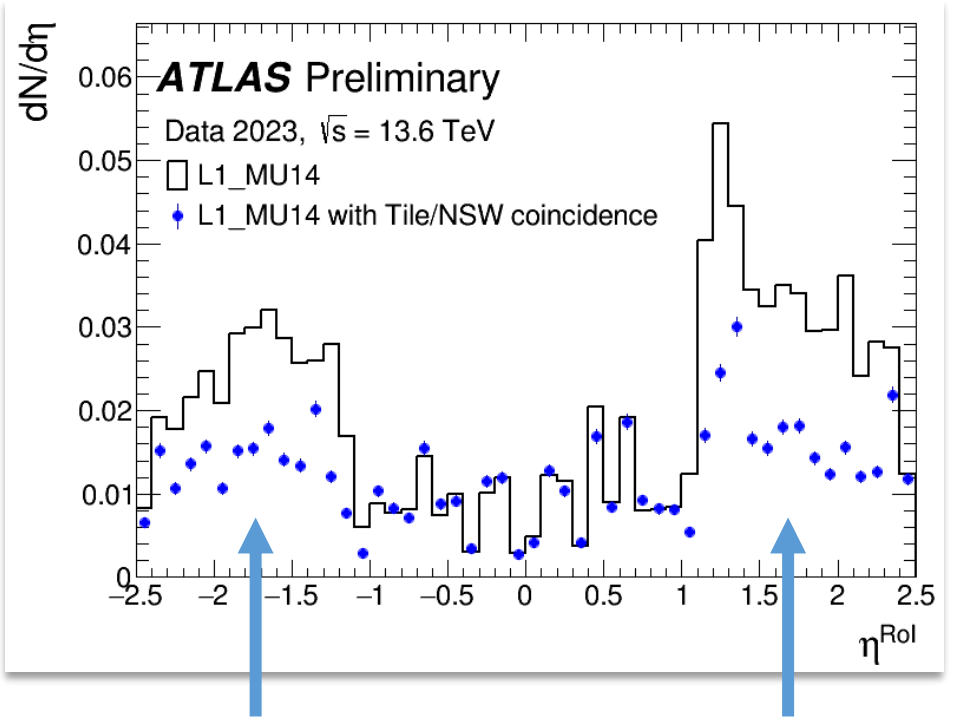
NSW trigger commissioning ongoing during Heavy Ion data taking

sTGC pad trigger improvements:

- Protection against Single Event Upset
- More **loose coincidence schemes** implemented to further **improve the matching efficiency**
  - Preliminary tests with HI bring efficiency to ~97-98%
- Timing optimization

Micromegas trigger:

- FW development
- Good progress in latency adjustment
- **MM Trigger processor enabled in last HI runs**, merged MM with Pad segments in several sectors (ongoing analysis)

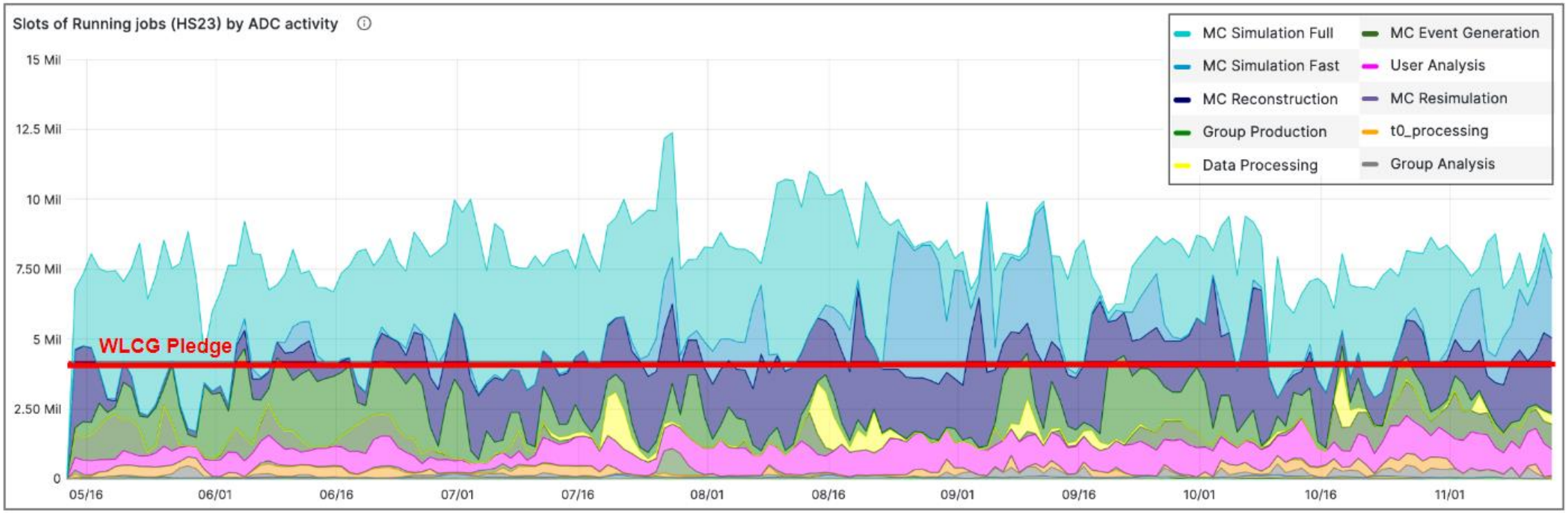


*NSW **sTGC pad trigger**, rejection of fake muons in July pp data, **95% efficiency, 75% sectors included***

Plans for start of Run 2024

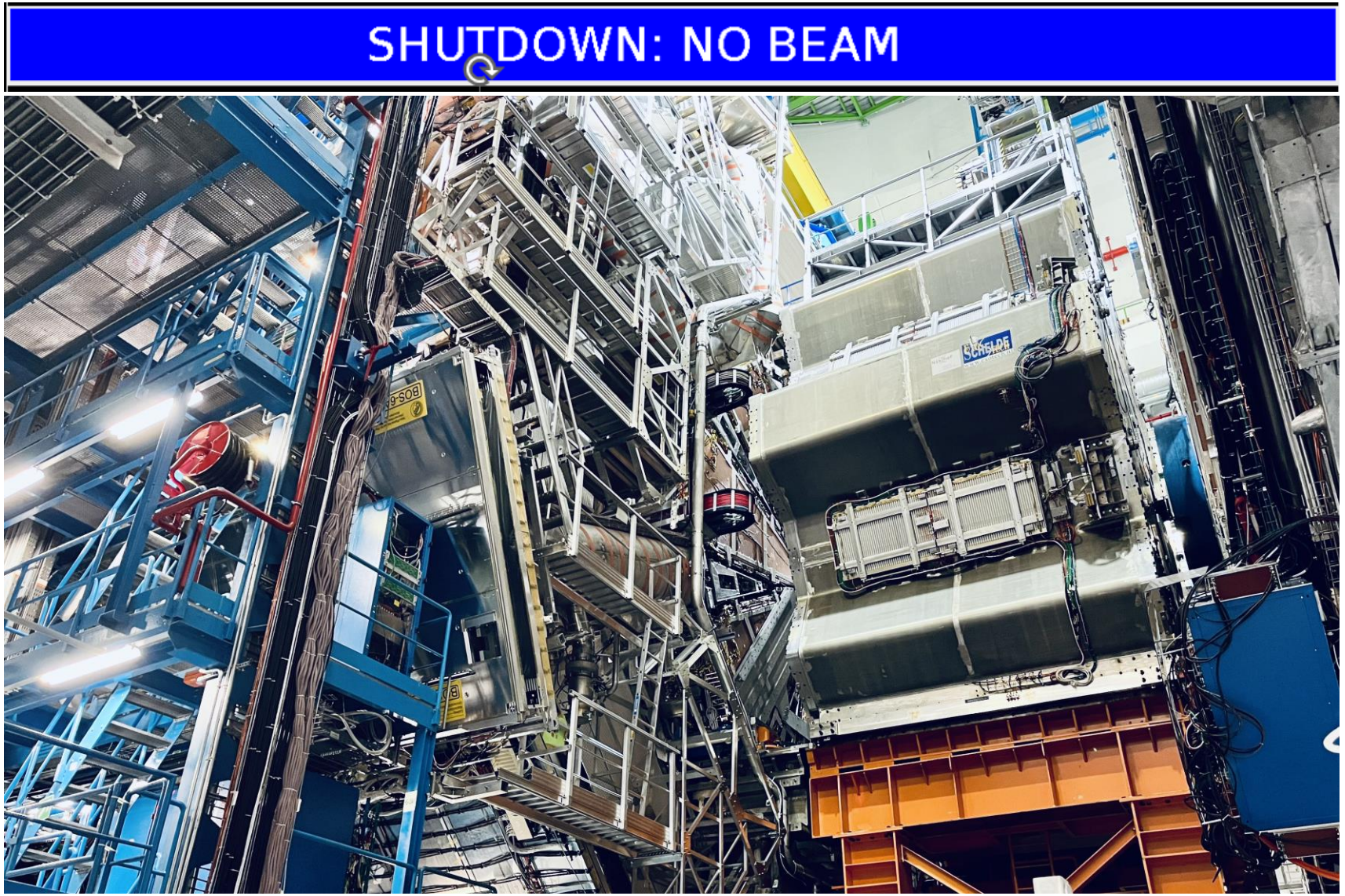
- Both **sTGC Pad + MM merged** to provide triggers with the start of the run at least for some sectors, gradually include all sectors.
  - Reduce L1 trigger rate (and allow ATLAS to run at maximum luminosity) with maximum efficiency (sTGC OR MM)
- Include the sTGC strip trigger to have full NSW trigger deployment

Software and Computing Activities



- Excellent performance of **grid computing**, significant use of **opportunistic resources** from High Performance Computing (HPC) and the High Level Trigger farm
- All **Run3 data now reprocessed**, corresponding MC available; **2024 MC campaign will start shortly**
- Migration of all ATLAS computing, trigger and data acquisition infrastructure to **AlmaLinux9 underway**, expected to take several months for completion
- Power-efficient ARM resources examined at scale and validated for most production workflows

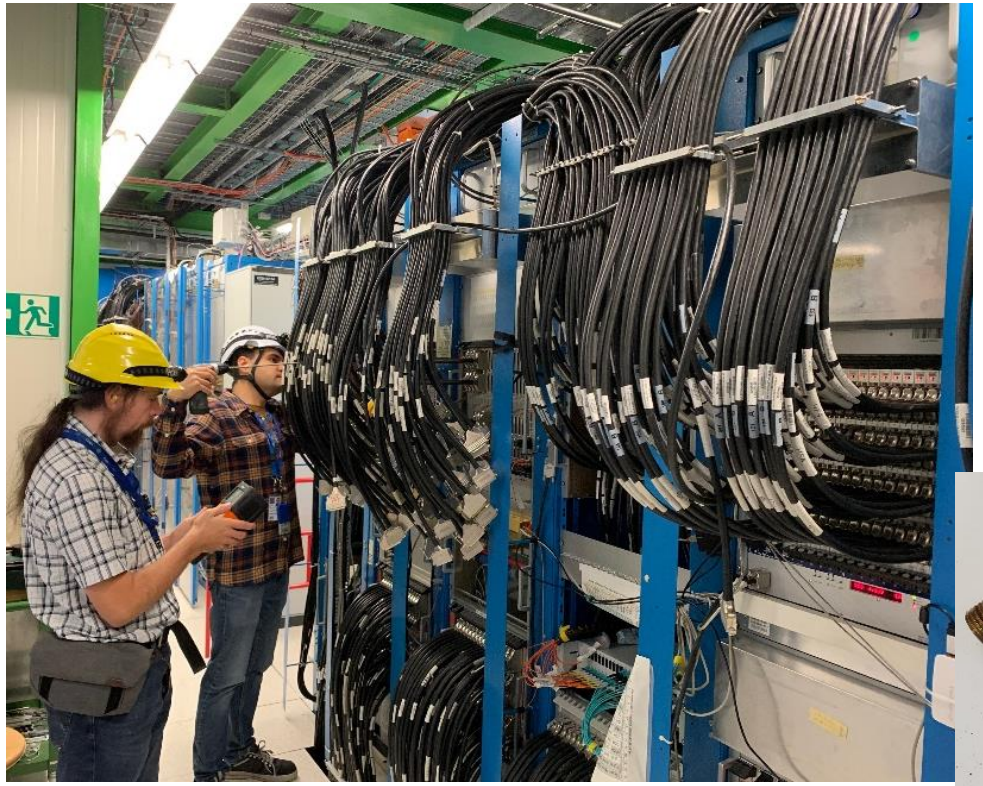
EYETS ongoing activities



EYETS ongoing activities

- Standard detector maintenance
- **Heat exchanger replacements** (heavily affected by pipe clogging and risk or water leaks)

Hoses and Heat exchanger replacement



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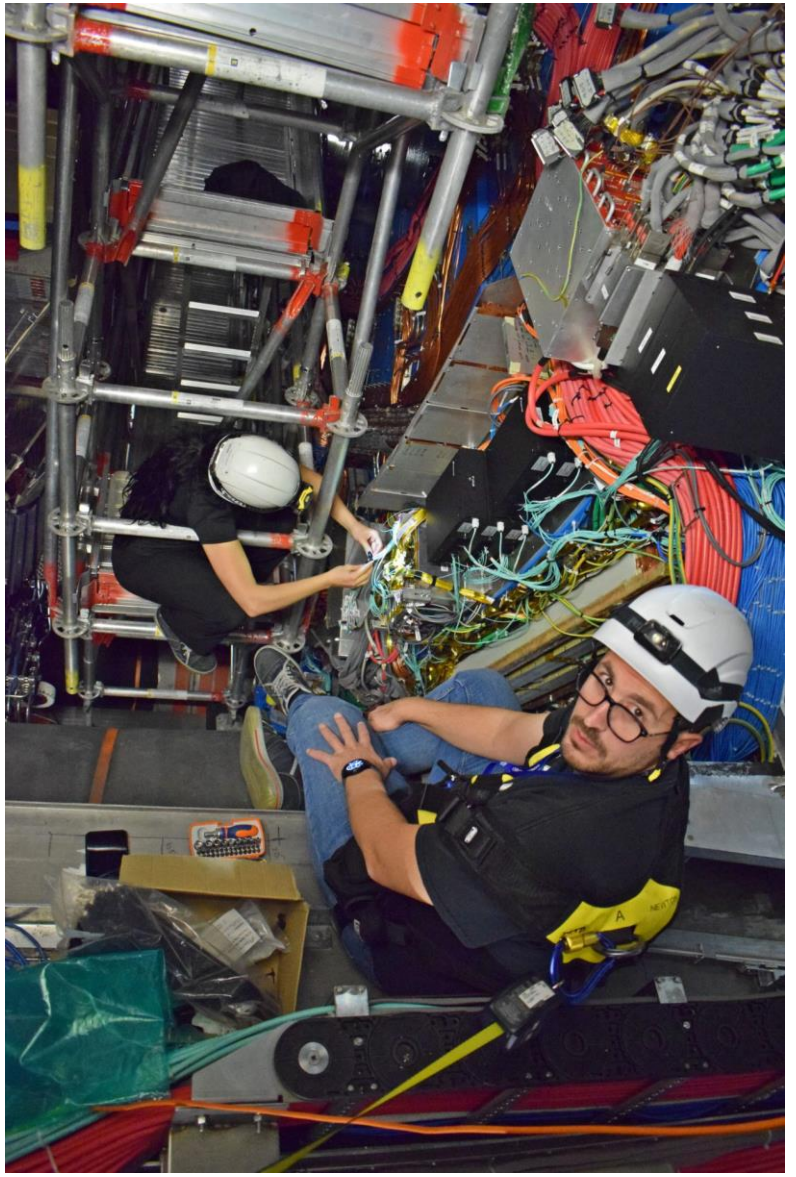
- **TRT frontend cooling leaks** improvements
- **NSW ICS and VTRX** refurbishment

NSW refurbishment



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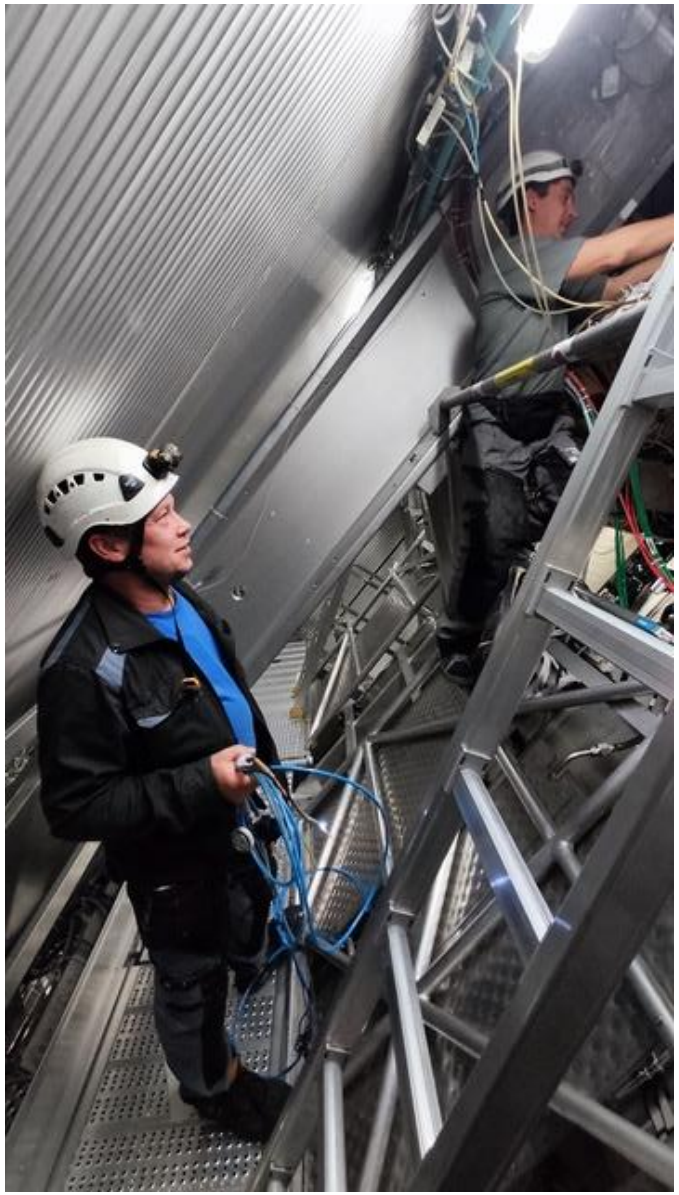
- **RPC gas leak** repairs and gas inlet consolidation

RPC gas leak repairs



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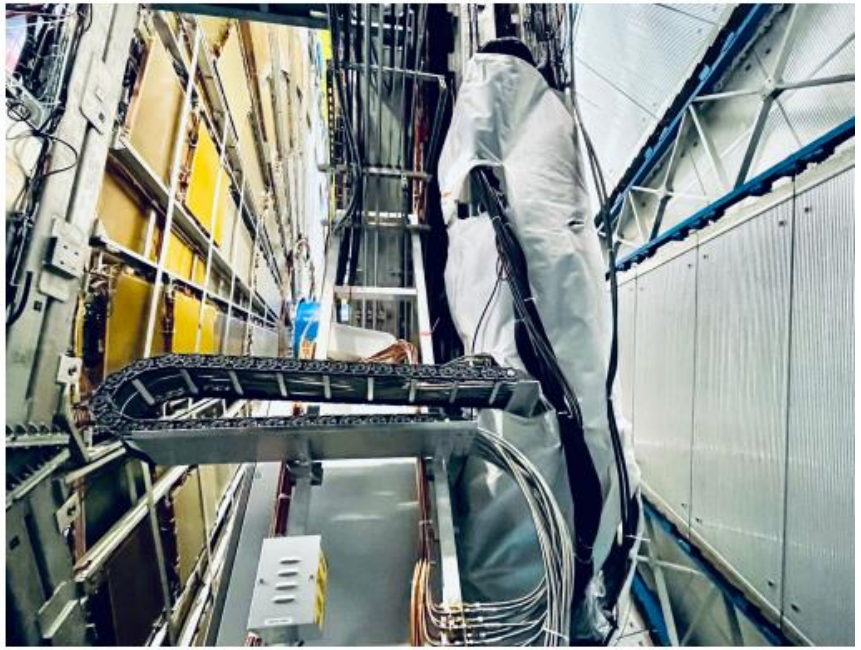
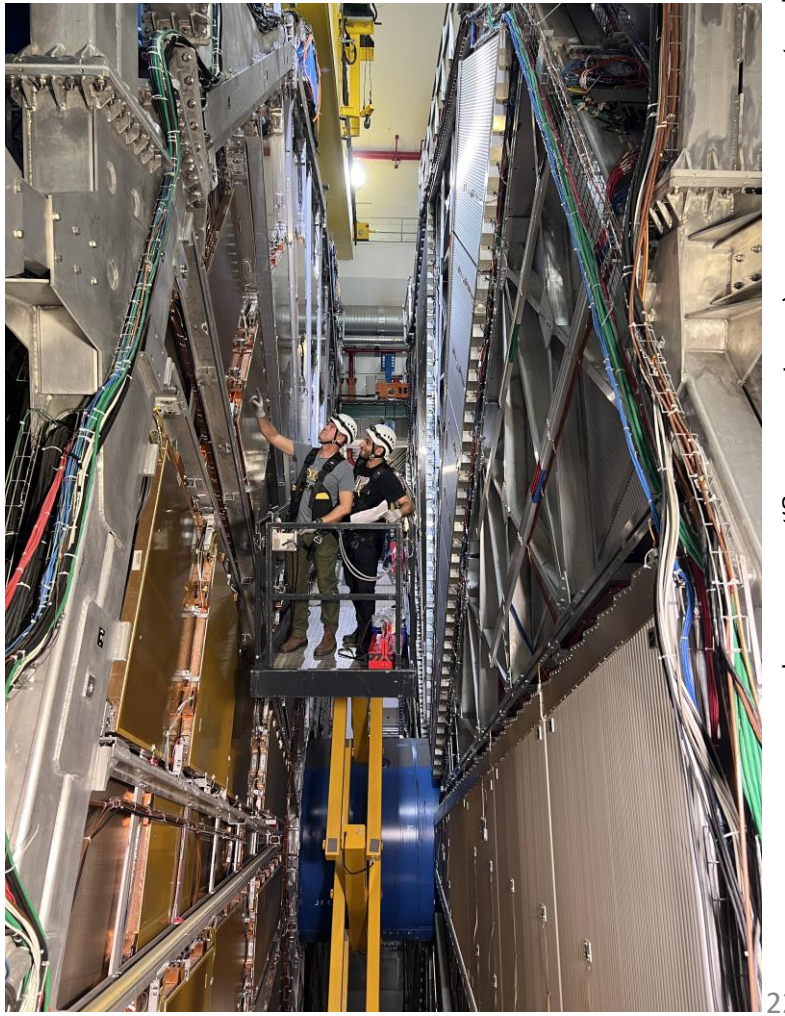
- **TGC replacements** on side C



Separation of big wheel C to allow for TGC chamber replacements

TGC replacement on Big Wheel C (16 chambers, finished this week)



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- **RPC gas leak** repairs and gas inlet consolidation
- **TGC replacements** on side C (17 chambers)
- **AFP** electronics refurbishment
- **ALFA** detector and its roman pot (one side only) **decommissioning**

ALFA station side C deinstallation

EYETS ongoing activities

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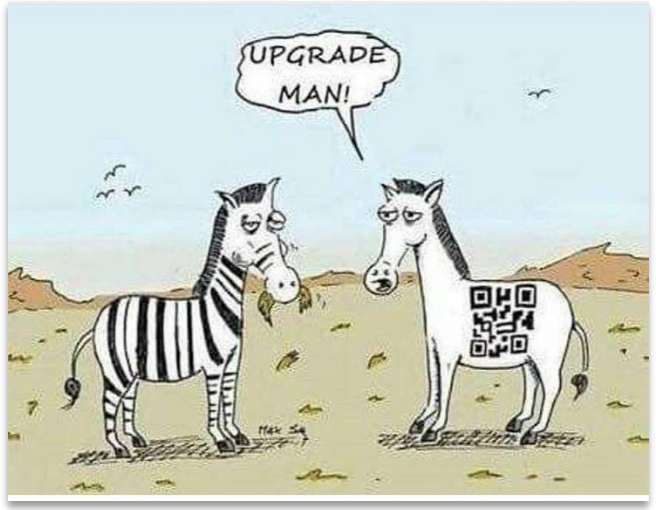
Magnets:

- OFF in EYETS, ran smoothly after the last solenoid fast dump (September)
- shield refrigerator do not show any sign of clogging yet, plan to improve stability

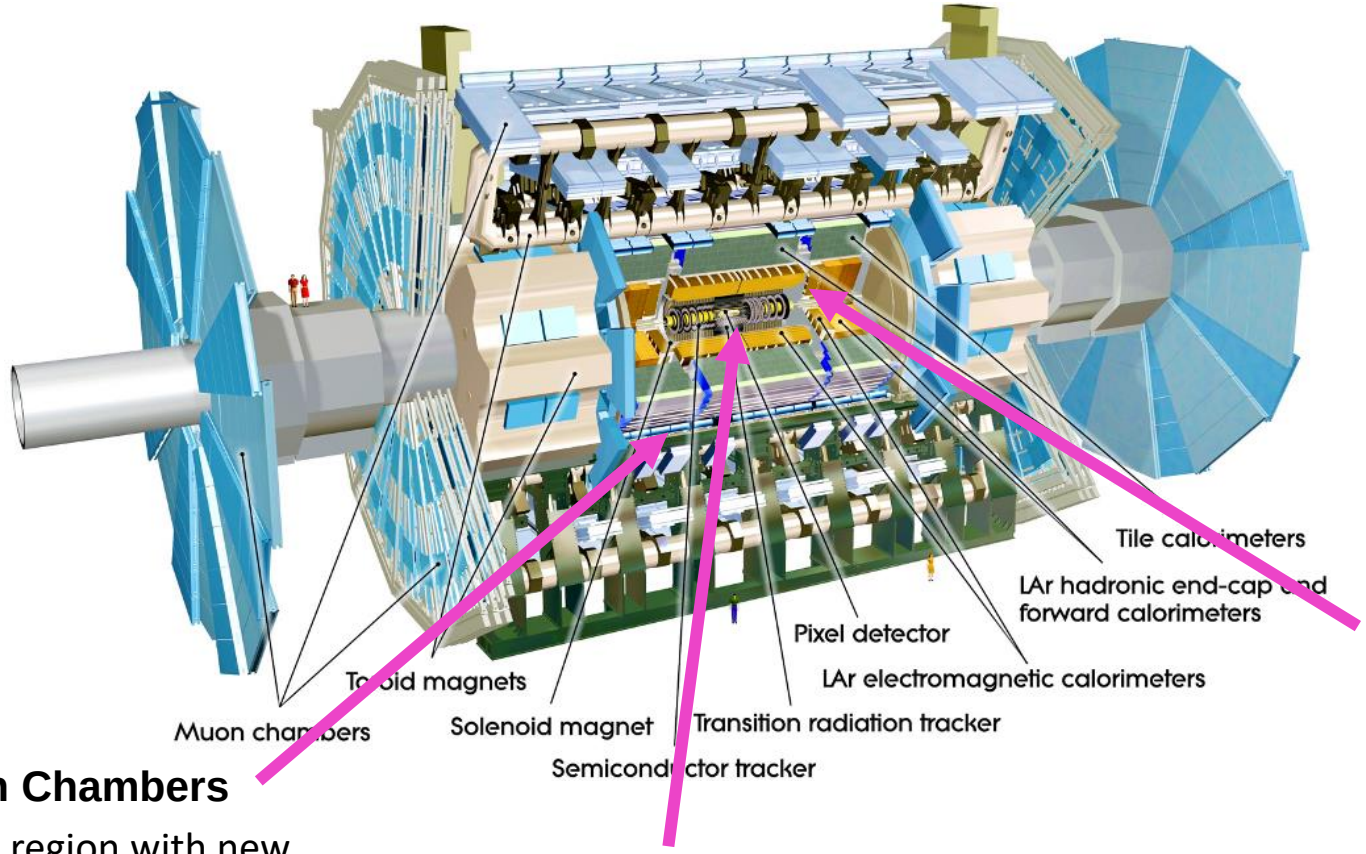
- Piping work in for **CO2 cooling**, anticipating work for LS3

CO2 cooling pipes, Phase II preparation

- Run3 Data taking and performance results
- Phase-II upgrade progress
- Physics highlights



Phase-II upgrade programme



New Muon Chambers

Inner barrel region with new RPC and sMDT detectors

Additional small upgrades

Luminosity detectors (1% precision goal)

HL-ZDC, BCM'

New Inner Tracking Detector (ITk)

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

Upgraded Trigger and Data Acquisition system

Level-0 Trigger at 1 MHz

Improved High-Level Trigger (150 kHz full-scan tracking)

Electronics Upgrades

LAr, Tile Calorimeters

Muon system

High Granularity Timing Detector (HGTD)

Forward region ($2.4 < |\eta| < 4.0$)

Low-Gain Avalanche Detectors (LGAD) with 30 ps track resolution

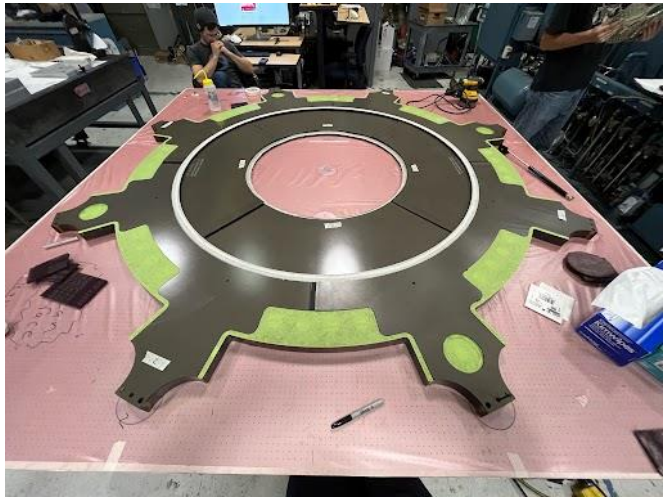
Detailed scope described in 7 TDRs approved by the CERN Research Board in 2017, 2018, 2020

Upgrade Recent achievements

ATLAS Upgrade projects are **moving into production**

Essential technical and procurement achievements:

- **ASIC design** almost completed for all projects
- Various **vendor delays**, largely due to the pandemic and geopolitical instabilities **have been addressed**
- The ITk **support structures are being completed** (see pictures)



Bulkhead

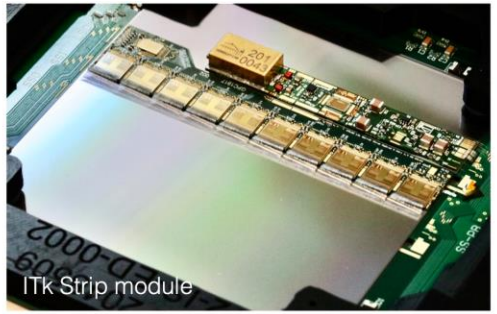
Outer Cylinder

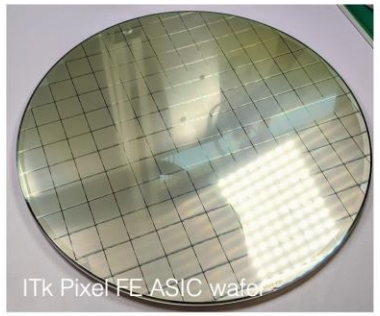
L3 Shell

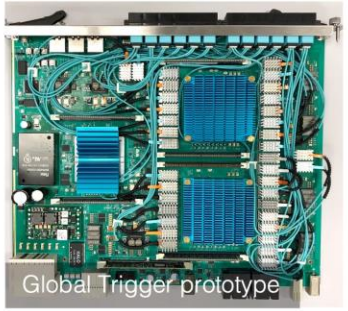
L2 Shell

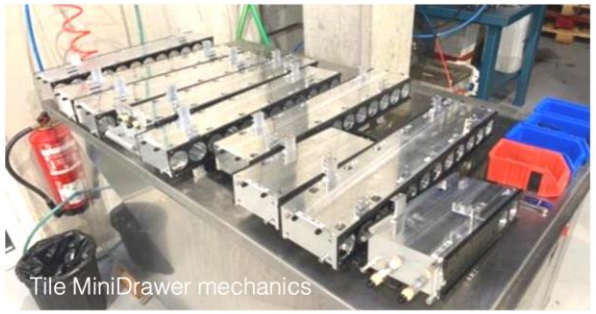
Impressive Progress in all Areas

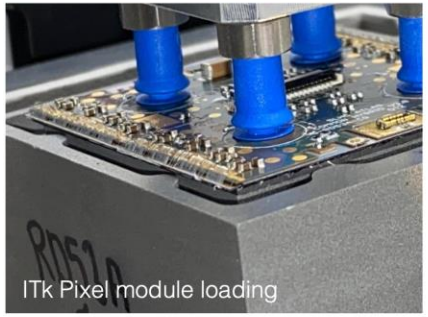

HGTD LGAD wafer under testing


ITk Strip module


ITk Pixel FE ASIC wafer


Global Trigger prototype


Tile MiniDrawer mechanics


ITk Pixel module loading


Tony Weidberg and Georg Viehhauser with Strip L3 structure and

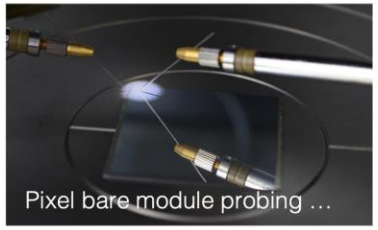

ITk Strip endcap petal


sMDT geometry measurements


HGTD testbeam at DESY


ITk Pixel Inner System ring with modules


LAr ALFEv2 tests


Pixel bare module probing …


… and module metrology


sMDT chamber measurements

Upgrade challenges and next steps

… but a very intense 2024 is awaiting

- A few remaining **technical issues** are being intensively studied
  The **most critical is the observed cracking of mounted ITk Strip barrel modules**
- We are planning to complete all remaining Final Design Reports/Production Readiness Reviews
  ~30 reviews just for ITk
- A long list of **crucial procurement processes** is in the pipeline
  Many thanks to CERN procurement and CERN management for their proactive support!

The schedule continues to be very tight for many projects

- We are striving to find **ways to gain contingency** and increase robustness
  - Some success already with ITk Pixel schedule
    Splitting reviews and parallelizing production tasks as main ingredients
    A follow-up with the Fraunhofer Institute is scheduled to run few ambitious case studies for ITk
- The **hybridisation** process qualification needs to be completed
  - ITk pixel: two out of four vendors are fully qualified - the other 2 are progressing
  - HGTD: technical issues are being investigated - initial results with ALTIROC3-based hybrids are encouraging

Outline

- Run3 Data taking and performance results
- Phase-II upgrade progress
- Physics highlights

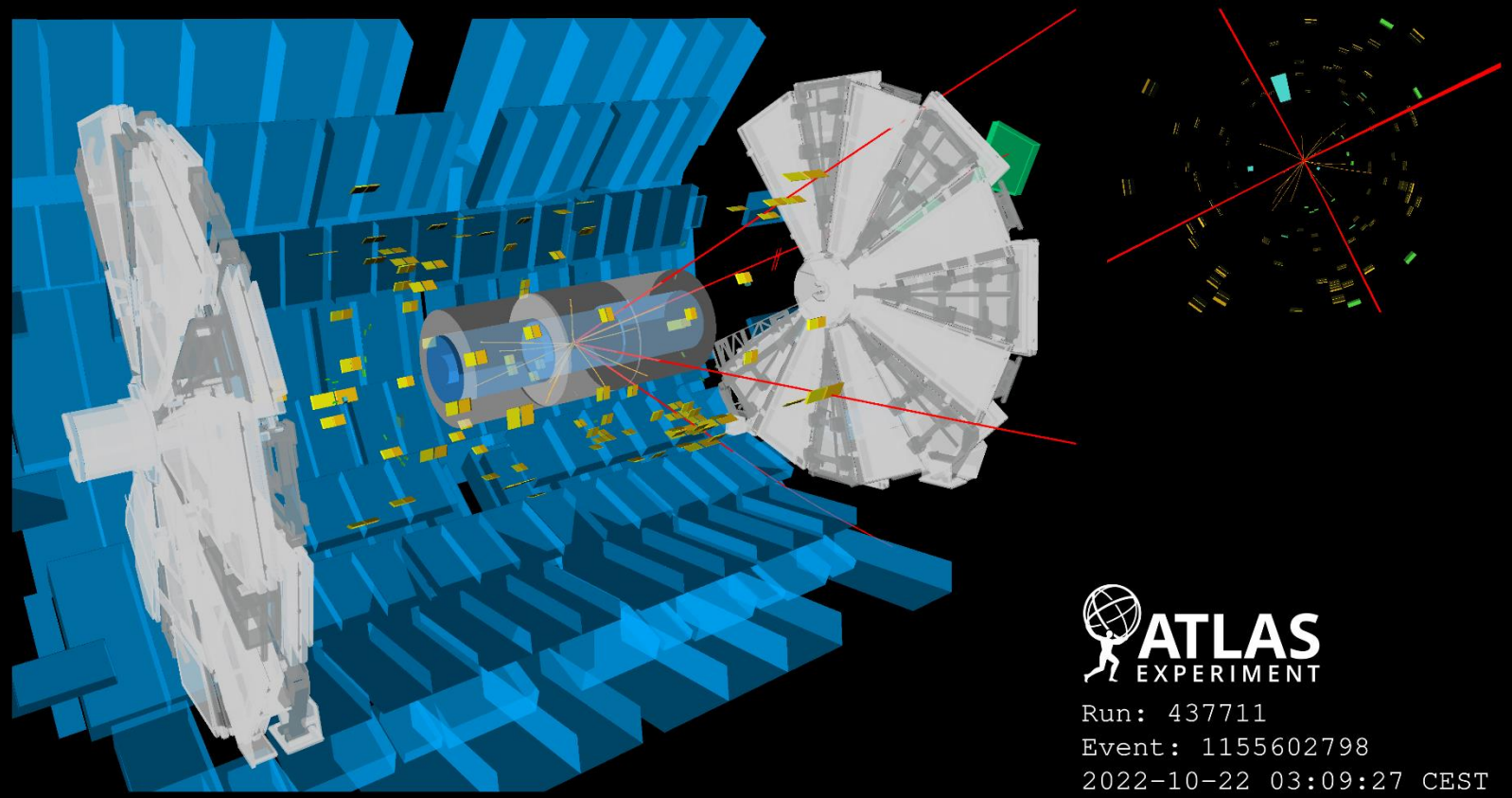
Physics analysis

Since September LHCC:

- **18 Papers**
- **6 Conference notes**
- **7 Public notes**
- **5 Physics Briefings**

Link here

Event display for a H → 4μ candidate event

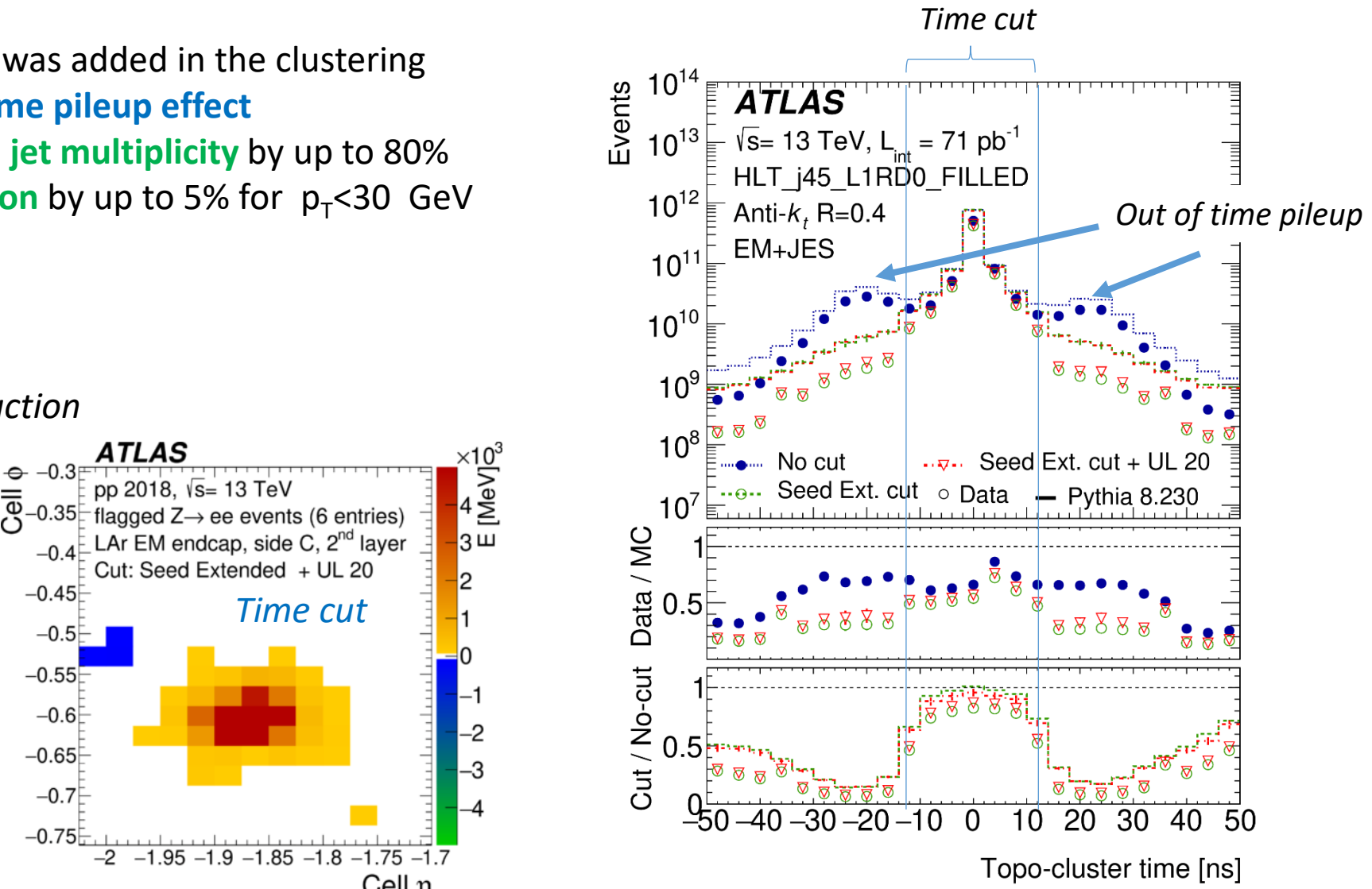


Improved topological cluster reconstruction using calorimeter cell timing

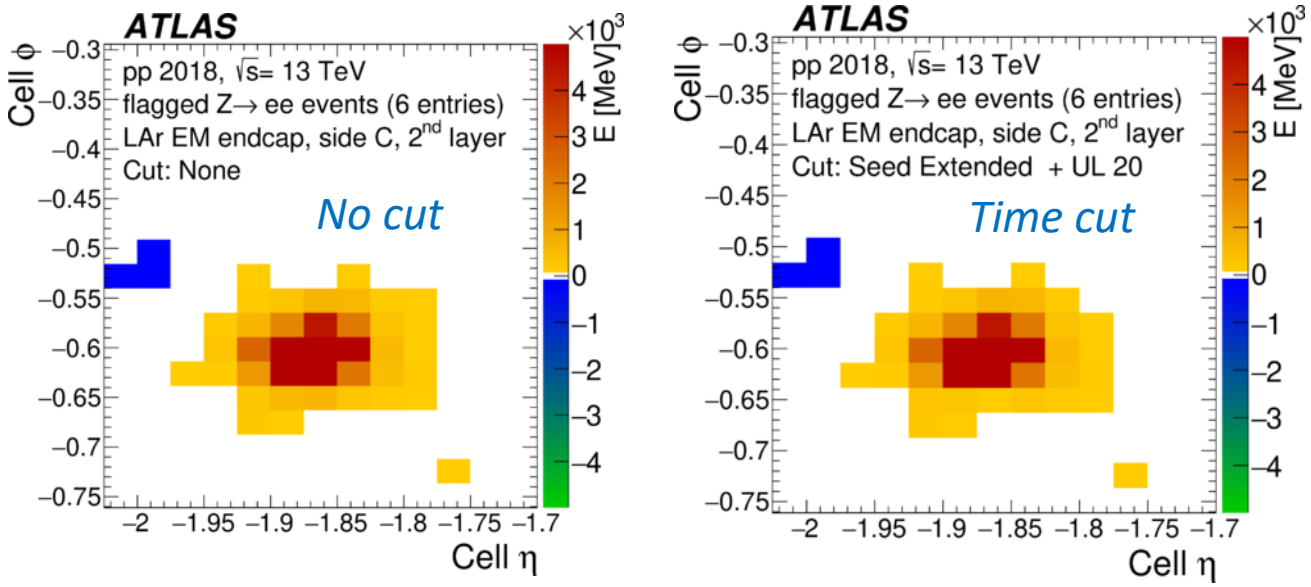
Jets performance

Submitted to EPJC

- **Calorimeter-cell timing criterion** was added in the clustering algorithm **to reduce the out of time pileup effect**
- **Reduction of out-of-time pile-up jet multiplicity** by up to 80%
- **Improved the jet energy resolution** by up to 5% for p_T<30 GeV
- **RAW Event size reduced** by ~ 6%
- **Used for Run 3 reconstruction**



No disruption on signals reconstruction



Unconventional track triggers, new for Run3

Trigger Performance

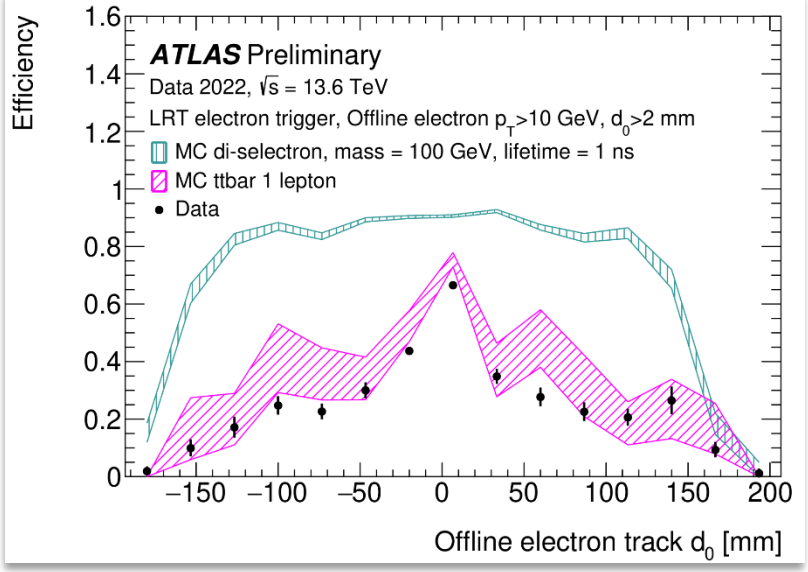
Extended trigger capabilities with new triggers in Run 3

HLT tracking Public Results
ATL-DAQ-PUB-2023-002

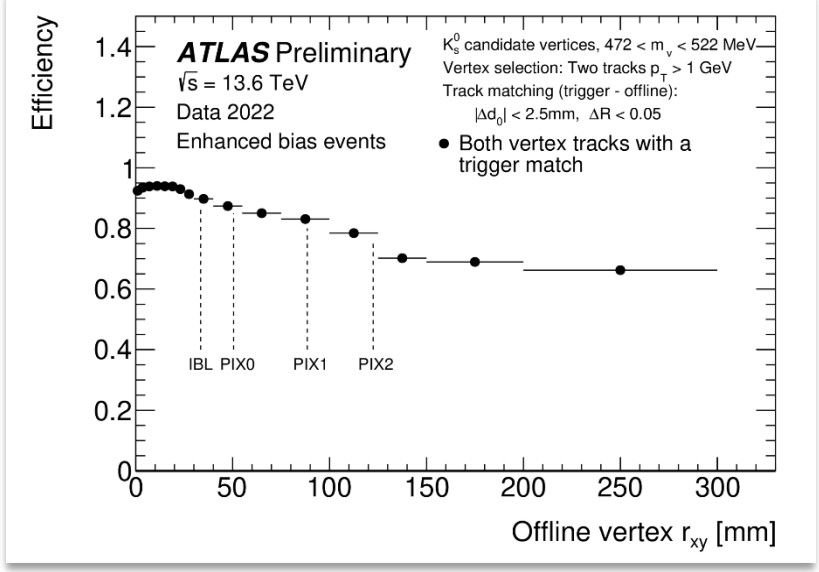
General ID trigger improvements used for pileup robustness in all hadronic signatures (jets, MET)
New triggers enabled: **Large Radius Tracking** for **Long-Lived Particle** searches. Specifically:

- **Displaced leptons**, sensitive to displaced sparticle decays
- **Displaced vertex**, efficiency even past Pixel detector layers
- **Emerging jet** triggers, detect unusual showers from dark hadrons

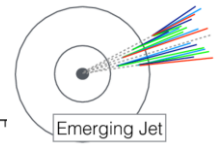
Electron Large Radius Tracking

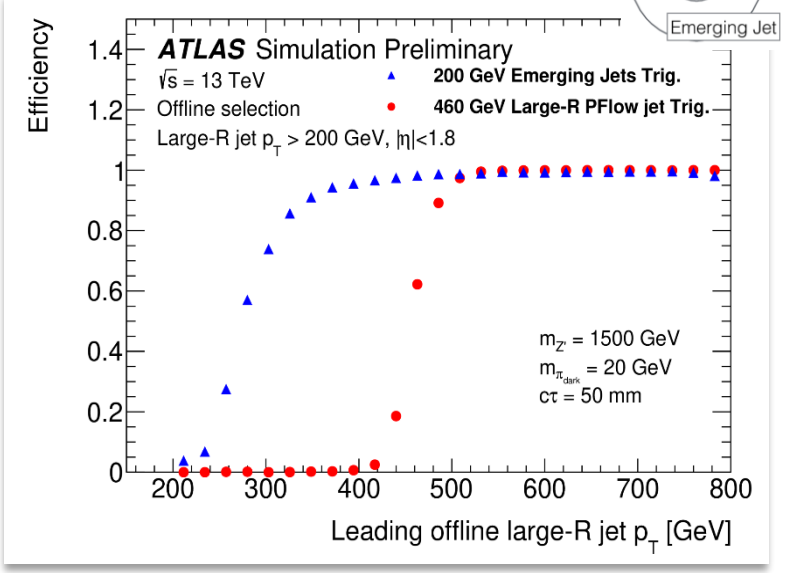


***Displaced vertex** efficiency measured by reconstruction Kshort vertices*



***Emerging jet** wrt standard Large-R jet*
Model used: 1.5 TeV Z' -> two 20GeV dark pions, 50mm decay length



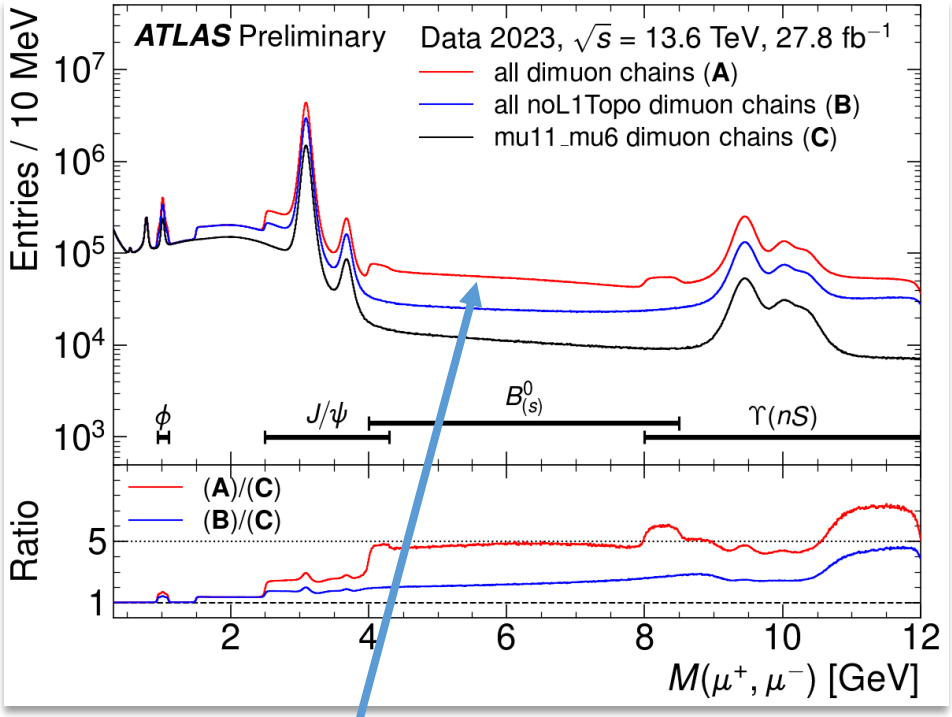


2023 new trigger data

B physics trigger performance

L1Topo algorithms (on new L1Topo Phase-I hardware) in production for muon triggers for all 2023

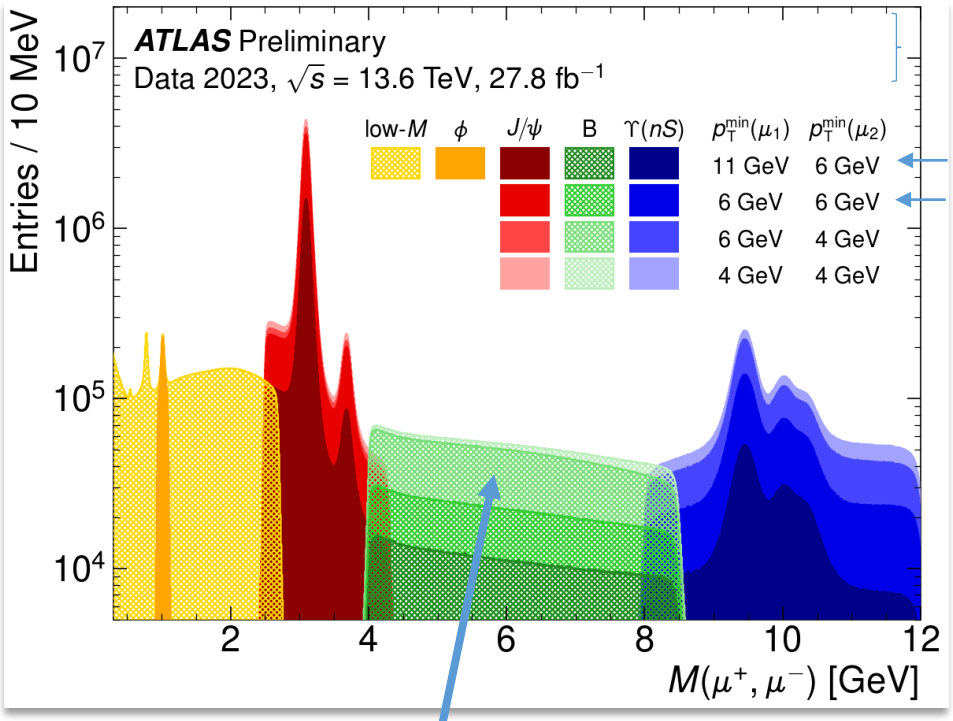
[B Physics Trigger Public Results]



Visible impact from inclusion of L1Topo triggers

C: Unprescaled, higher threshold dimuon chains only
B: Addition of prescaled, lower threshold dimuon chains
A: ***Addition of L1Topo triggers***

Dimuon mass spectrum from B Physics triggers (2023 data)



Unprescaled
Prescaled

L1Topo based triggers with mass cuts, big impact on B meson

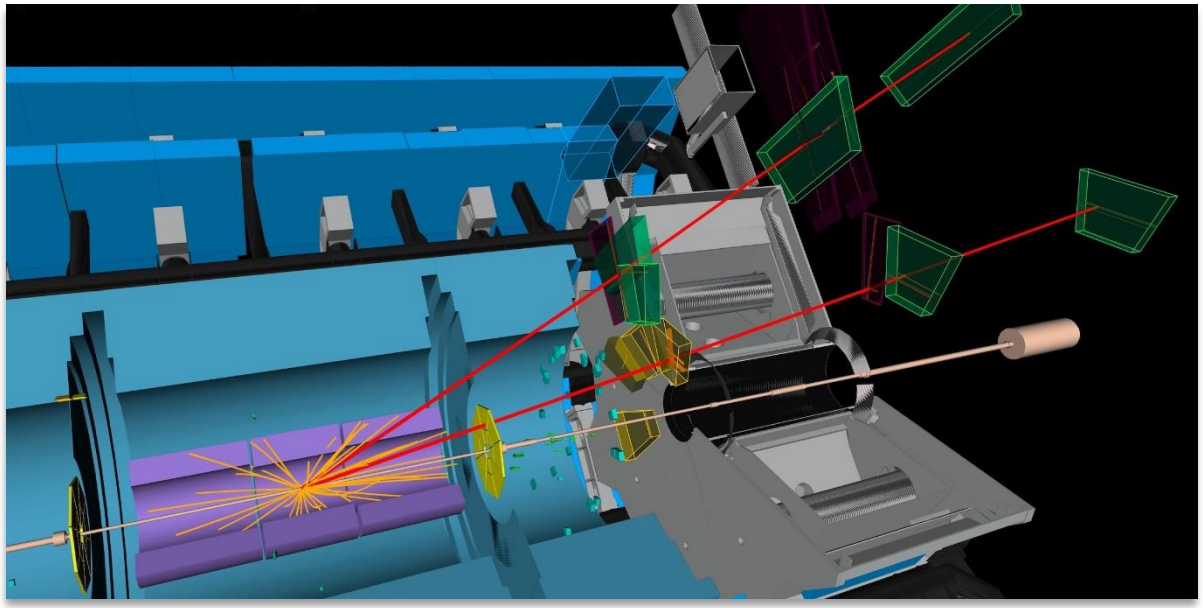
J/ψ and ψ (2S) differential cross-sections

B Physics

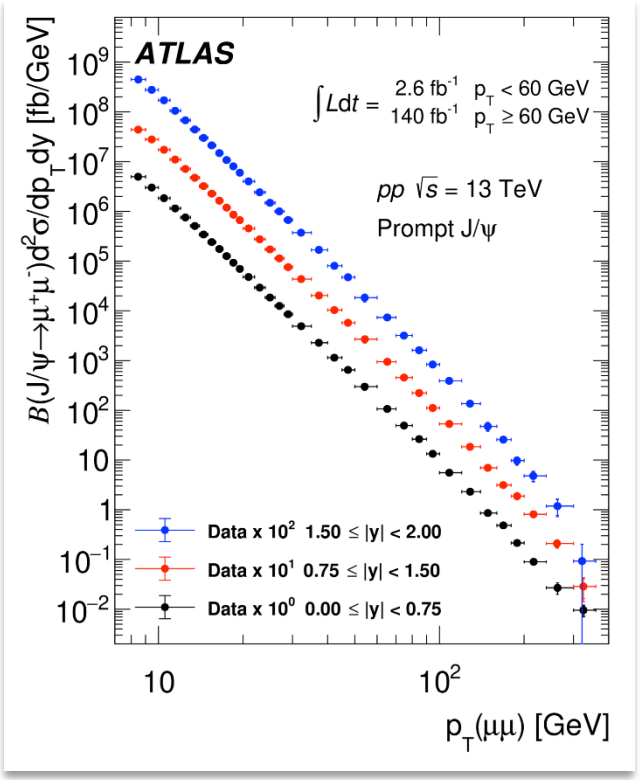
Measured the production cross section of the J/ψ and ψ(2S) with **widest range of transverse momentum so far** (J/ψ : 8 - 360 GeV, ψ(2S) 8-140 GeV),

Submitted to EPJC
Physics Briefing

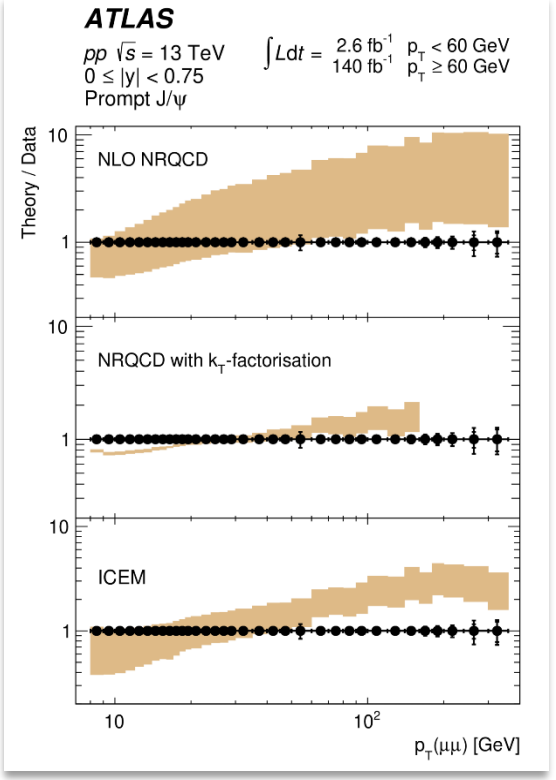
New input for **tuning of theoretical models, Enhancement of our QCD understanding**



*Event with **two muons** with invariant mass consistent with that of a J/ψ meson.*



Differential cross-sections for prompt J/ψ production



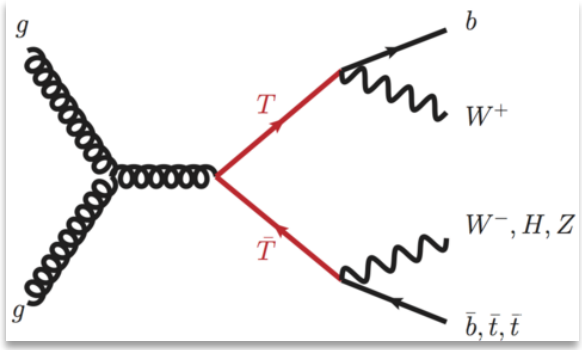
Ratios of various theoretical predictions to the data points from this measurement

Vector-like quarks pair production search in the Wb+X final state

Exotics

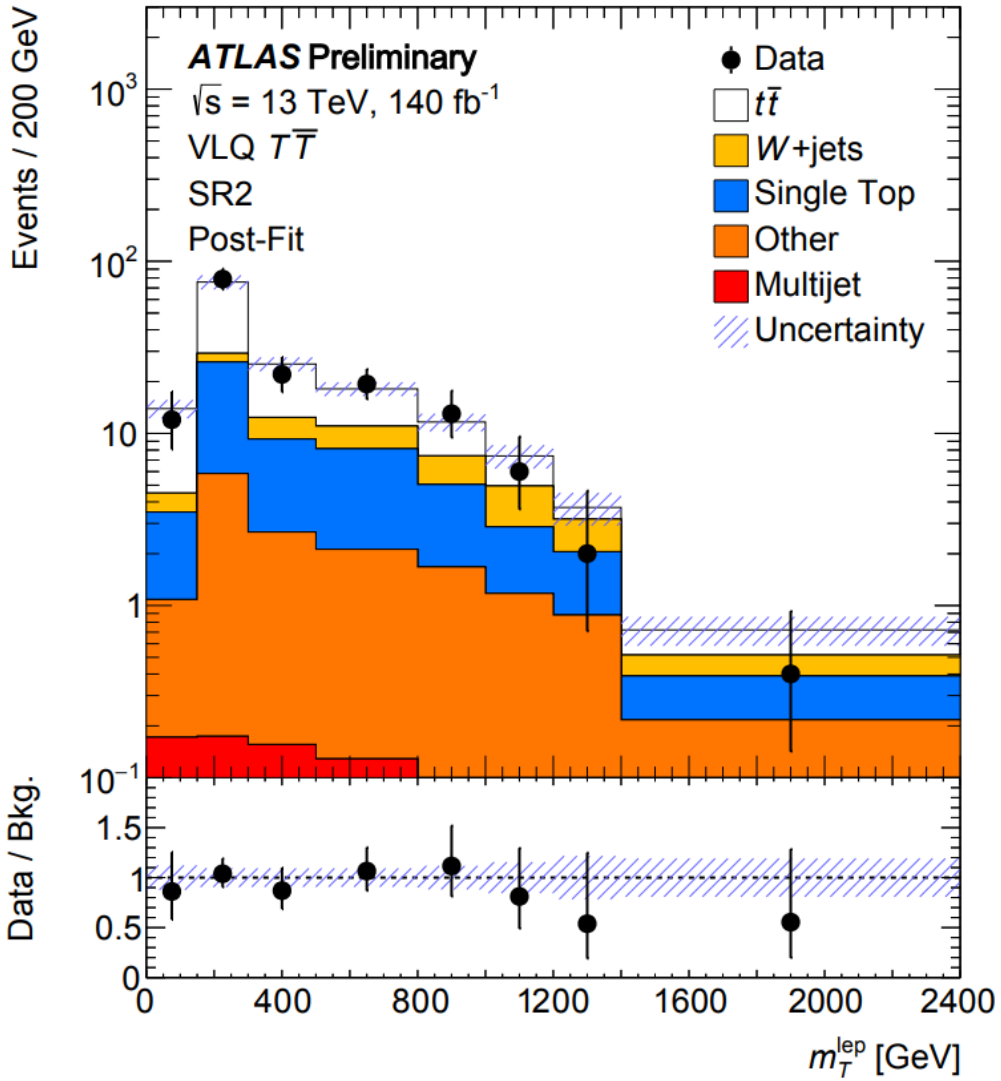
(VLQ) **vector-like top quarks** (T) → **Wb**, one W decay leptonically and the other hadronically.

ATLAS-CONF-2023-070



- **No significant excess** over the background expectation
- **VLQ excluded for masses below 1.7 TeV**.

- **Improvement over previous result:**
  - Observed mass limits extended by 350 GeV
  - Improvements due to more statistics, better W boson tagging

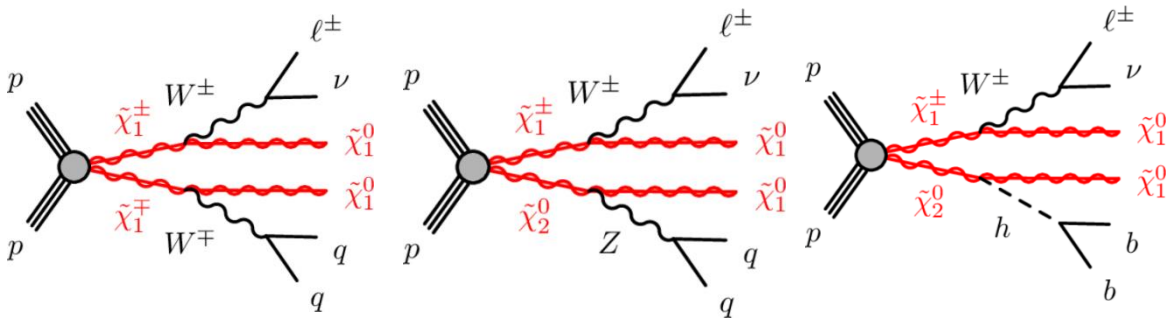


Search for electroweakinos in final states with one lepton and MET and boosted topology

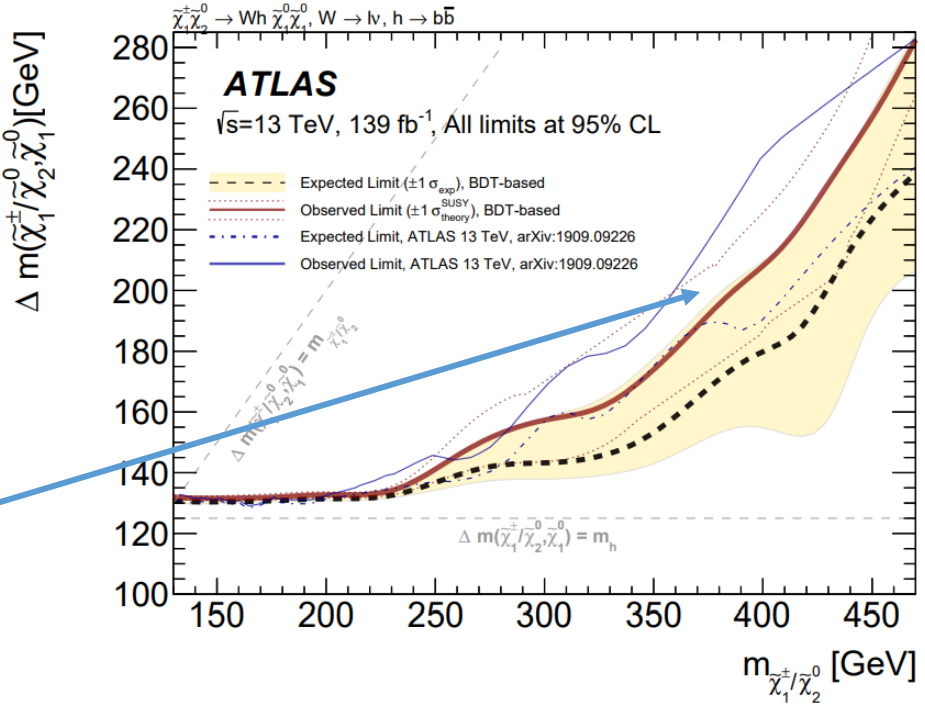
Supersymmetry

Searches for electroweak production of chargino pairs and of chargino and next-to-lightest neutralino.
Final decay products: **one isolated lepton**, **jets** and **missing transverse momentum**

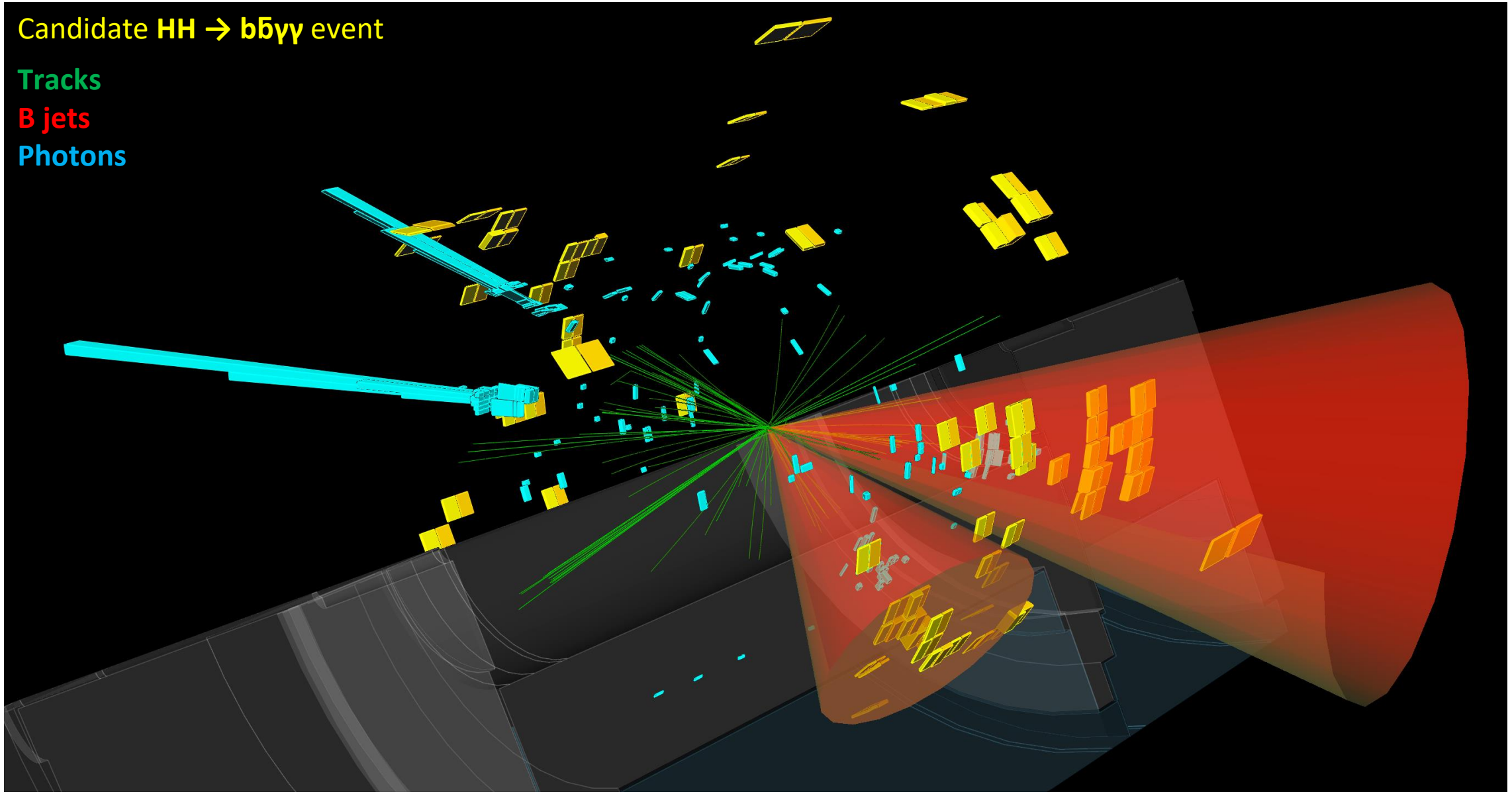
Submitted to JHEP



- **No deviations from the Standard Model** expectations are found
- **Exclusion range extended**, compared to previous ATLAS result, by **up to 40 GeV** in mass limits
  - Background reduced by using **boosted W,Z decay products**



Higgs-boson self-interactions



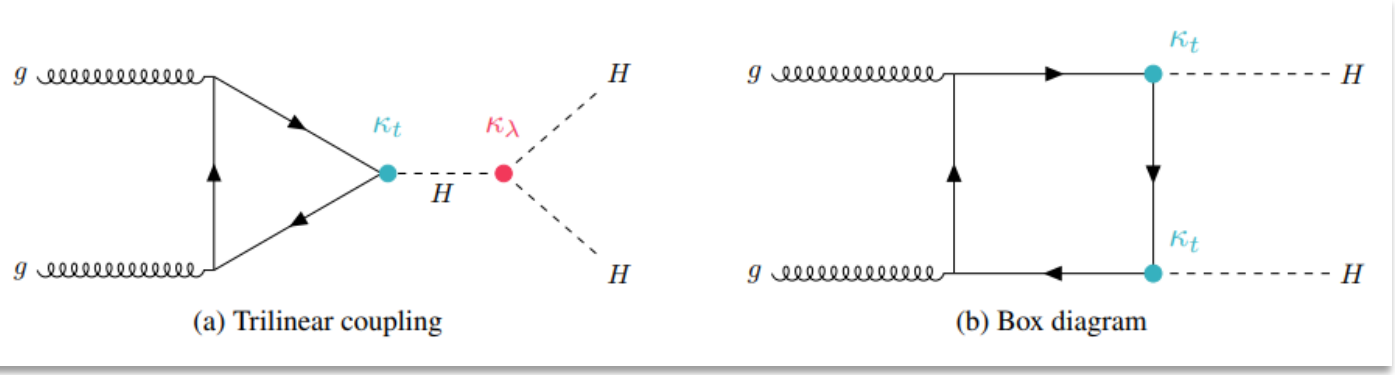
HH →2b2γ , HH → 2b+2l+$E^{t}_{miss,}$ H → 2b2τ

Higgs, Diboson

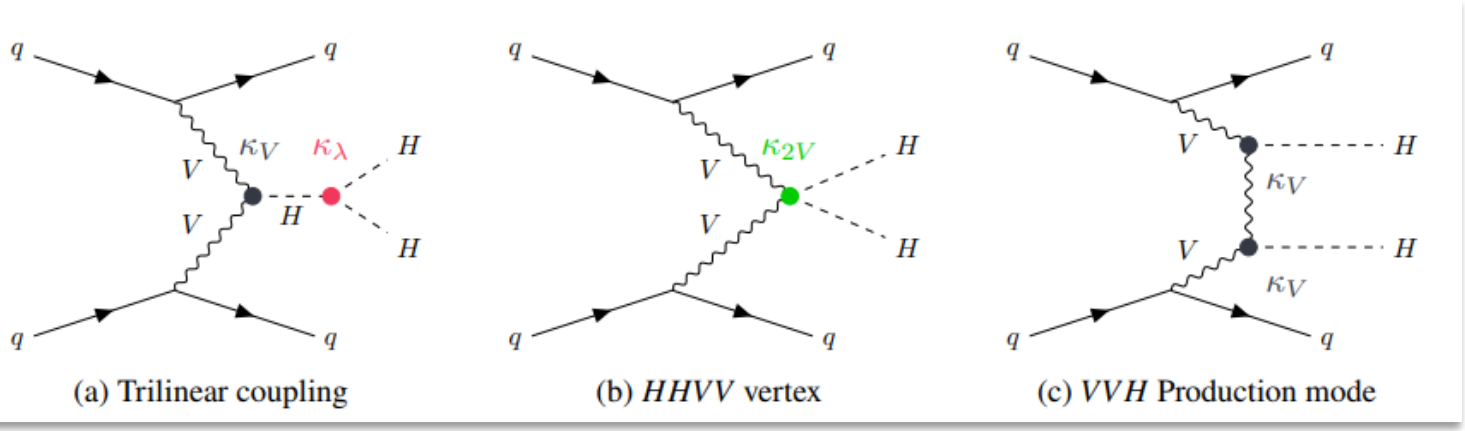
Refined analyses optimised towards self-coupling constraints

arxiv:2310.12301
arxiv:2310.11286
ATLAS-CONF-2023-071
Physics briefing

HH production **very rare**, **new physics processes** beyond SM could greatly increase this probability
Different decay channels studied, work in progress with combination.
HH production **studied using both gg fusion** and **vector boson fusion** (new result)



dominant **gluon--gluon fusion**



Vector Boson fusion (VBF)
Distinctive signature: two forward high p_T jets

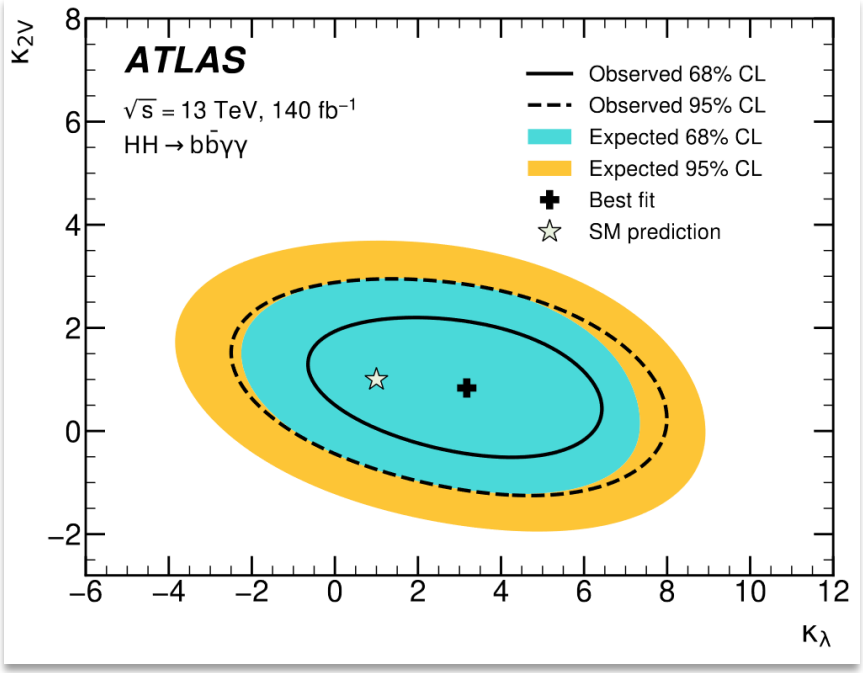
Used algorithms trained to look for this topology for background rejection

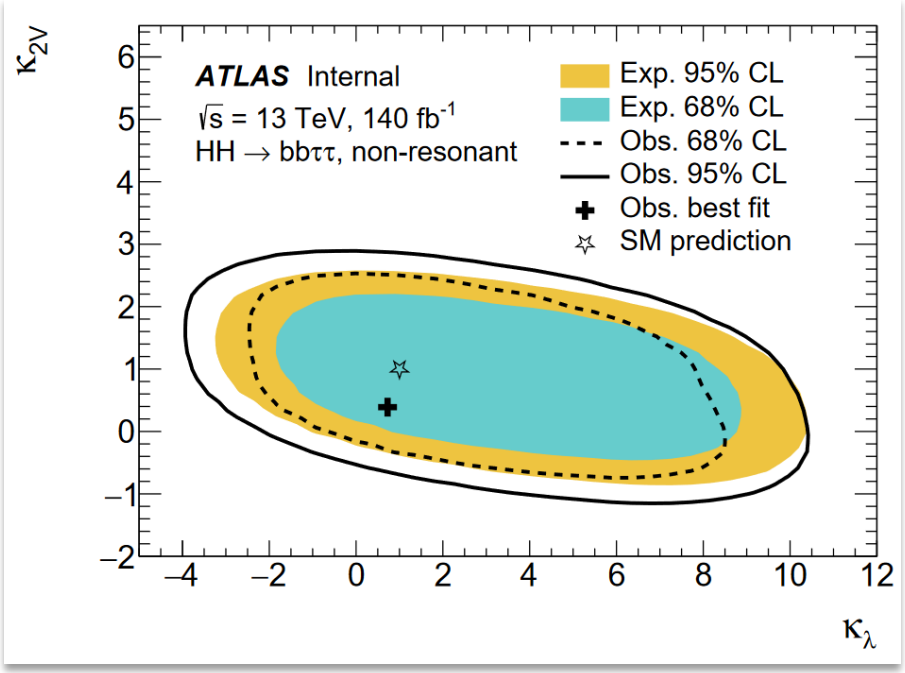
HH →2b2γ , HH → 2b+2l+$E^{t}_{miss,}$ H → 2b2τ

Higgs, Diboson

- **No deviations from SM expectations, coupling modifiers constrained**

arxiv:2310.12301
arxiv:2310.11286
ATLAS-CONF-2023-071
Physics briefing





- **Upper limit placed on HH production cross section wrt SM predictions,**
  - **Sensitivity improved wrt previous results**

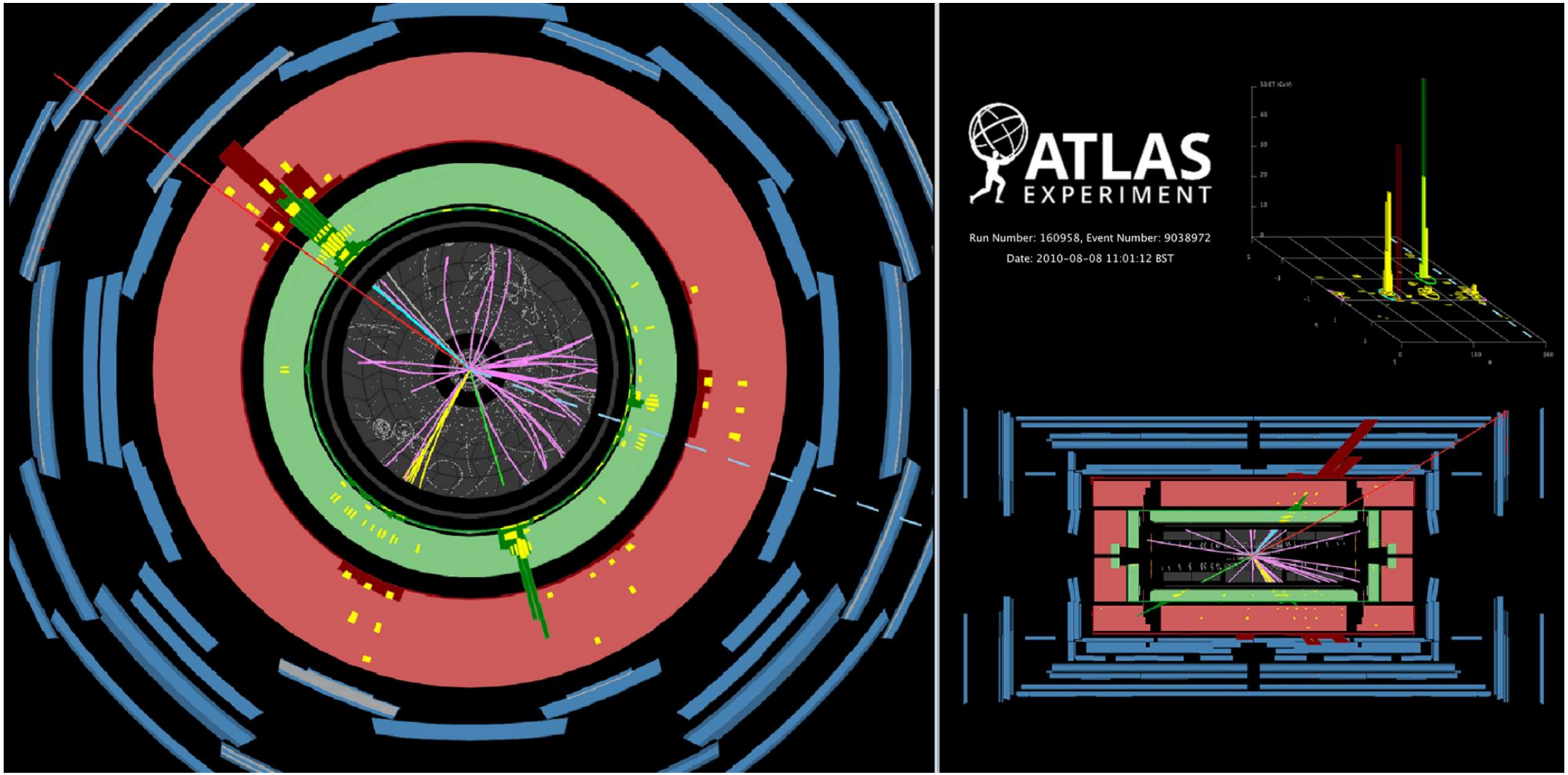
	observed	(expected)
2b2lEtmiss:	9.7	(16.2)
2b2γ:	4.0	(5.0)
2b2τ:	5.9	(3.1)

Effective Field Theory (EFT) used in **to constrain the anomalous interactions** that might affect HH production cross section and kinematics

Precision top quark physics

Top pair e-mu dilepton candidate with two b-tagged jets.

CERN Seminar Baptiste Ravina 24.10.23



Electron
Muon
E^{T}_{miss}

Inclusive and differential ttZ cross-section

Top Physics ttZ **rare process** (~1000 more rare than tt). Multi lepton final states (2,3,4L).

ATLAS-CONF-2023-065

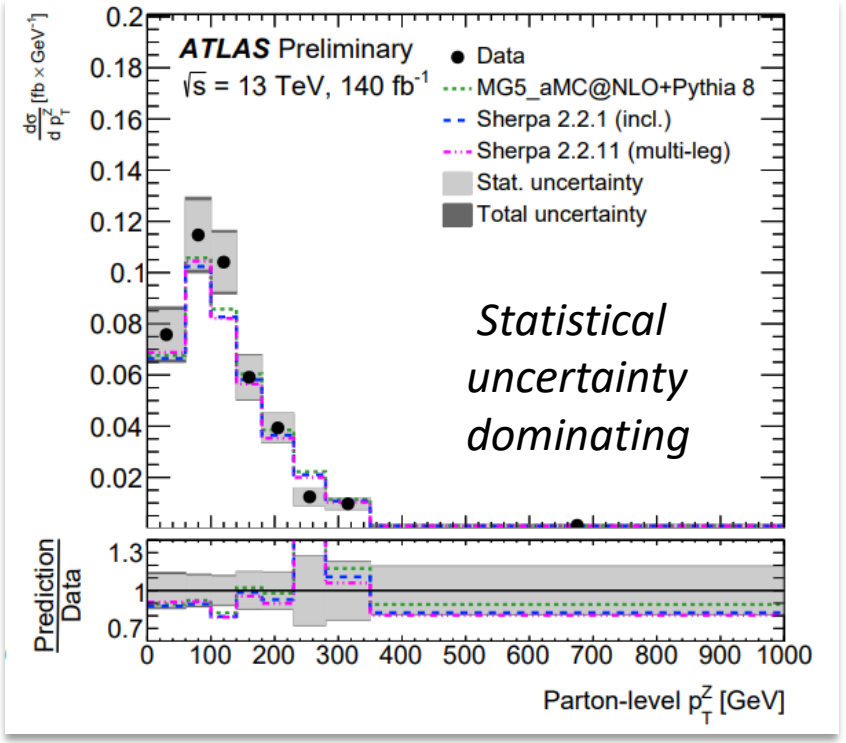
Key background to many analysis.
Top-Z coupling can be significantly altered by beyond the SM physics.

Significantly improve the precision of previous result
(Eur.Phys.J.C81(2021)737)
35% improvement on the inclusive cross section,
50% reduction of systematics!

- new analysis techniques,
- smaller uncertainty on integrated luminosity,
- improved calibrations of physics objects,
- better signal vs. background separation,
- more accurate MC modelling

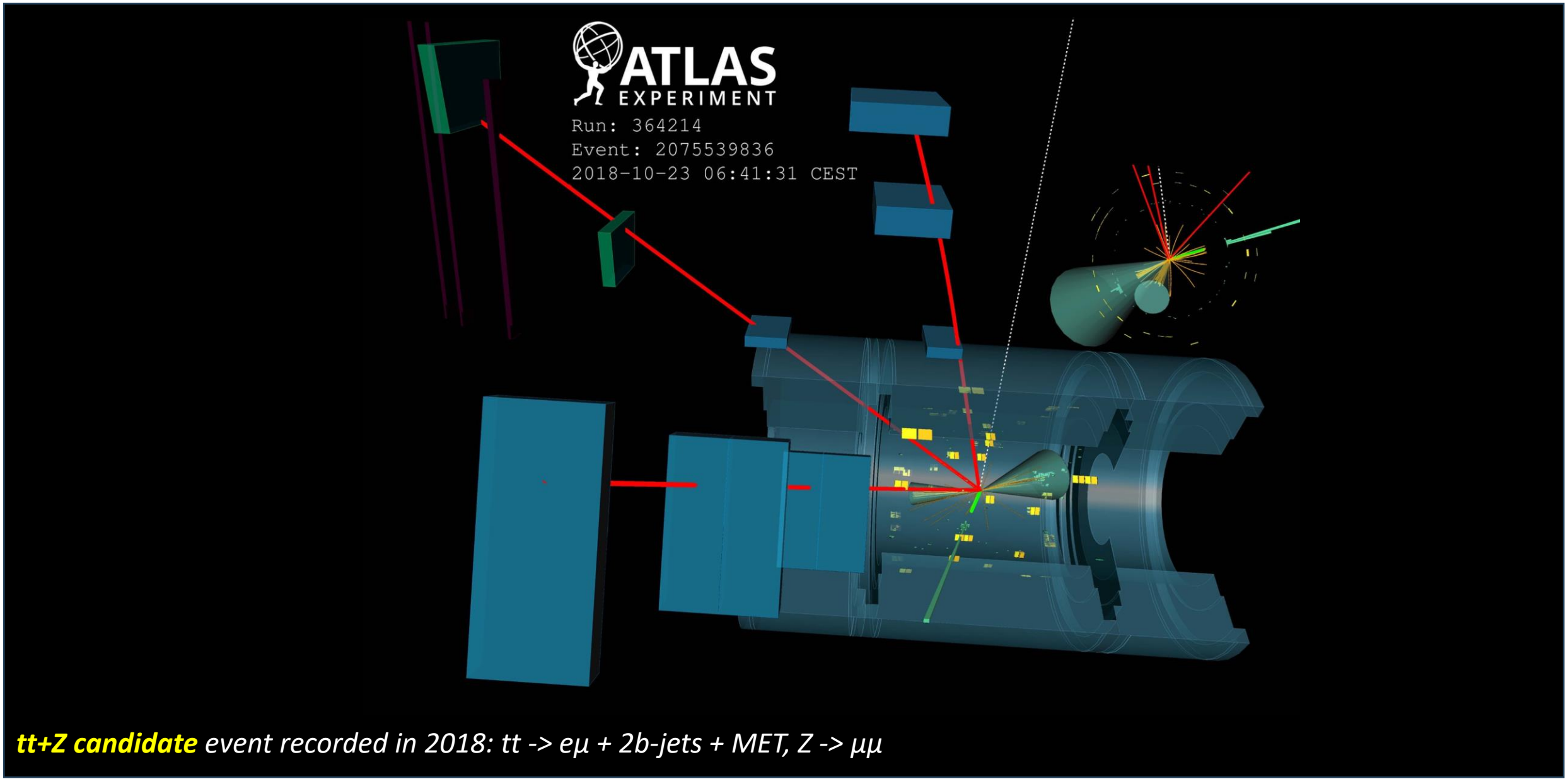
Inclusive cross section consistent with the SM:

- **σ(ttZ) = 0.86 ± 0.04 (stat.) ± 0.04 (syst.) pb** → **6.5%** uncertainty
- best theory prediction and previous measurement: 10% uncertainty



Differential measurements compared with theoretical predictions (measurement done for 17 kinematic observables)

Inclusive and differential ttZ cross-section



tt+Z candidate *event recorded in 2018: tt -> eμ + 2b-jets + MET, Z -> μμ*

ATLAS/CMS top mass combination

Top Physics

Combination of fifteen top quark mass measurements **by ATLAS and CMS** (Run1)

ATLAS-CONF-2023-066
Physics Briefing

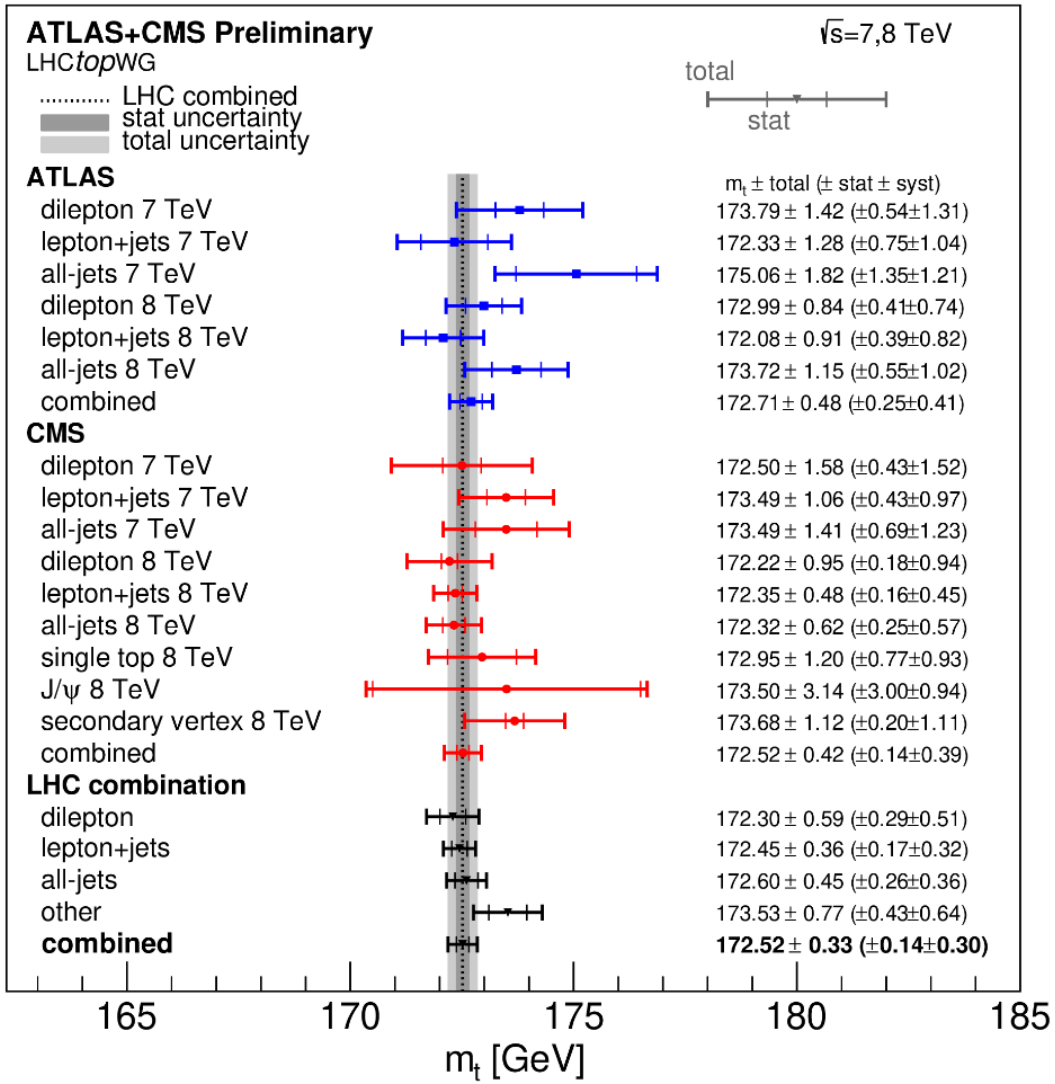
- $t\bar{t} \rightarrow$ semileptonic and hadronic decays,
- single top quark production via the electroweak t-channel.

m_{top} = 172.52 ± 0.14 (stat) ± 0.30 (syst) GeV,

total uncertainty of 0.33 GeV (<2 permil!)

Most precise m_{top} measurement to date thanks to the combination

Measurements are consistent between ATLAS and CMS and between top-pair decay channels



Observation of quantum entanglement in top-quark pair production

Top Physics First observation of **quantum entanglement in quarks** and at relativistic energies

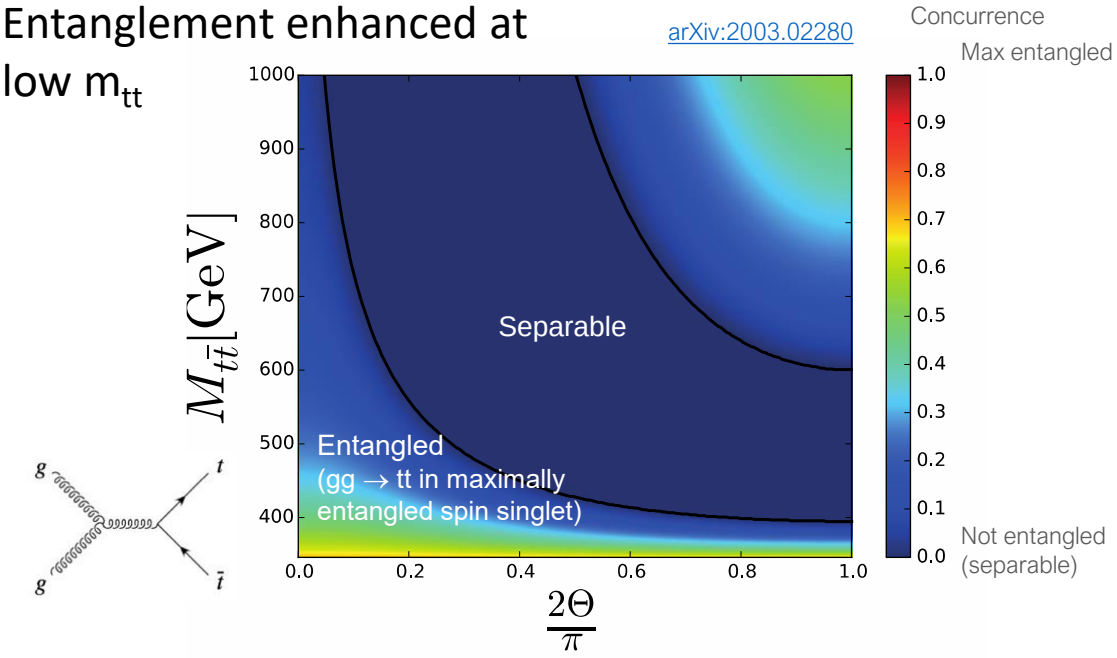
Physics Briefing
CERN Courier
Submitted to Nature

Fast decay transfers spin information to decay products -> allows tt spin correlation measurements
Entanglement: non-separable state -> test with tt → eμ + X events
Observable D (**degree of entanglement)** depends on tt kinematics

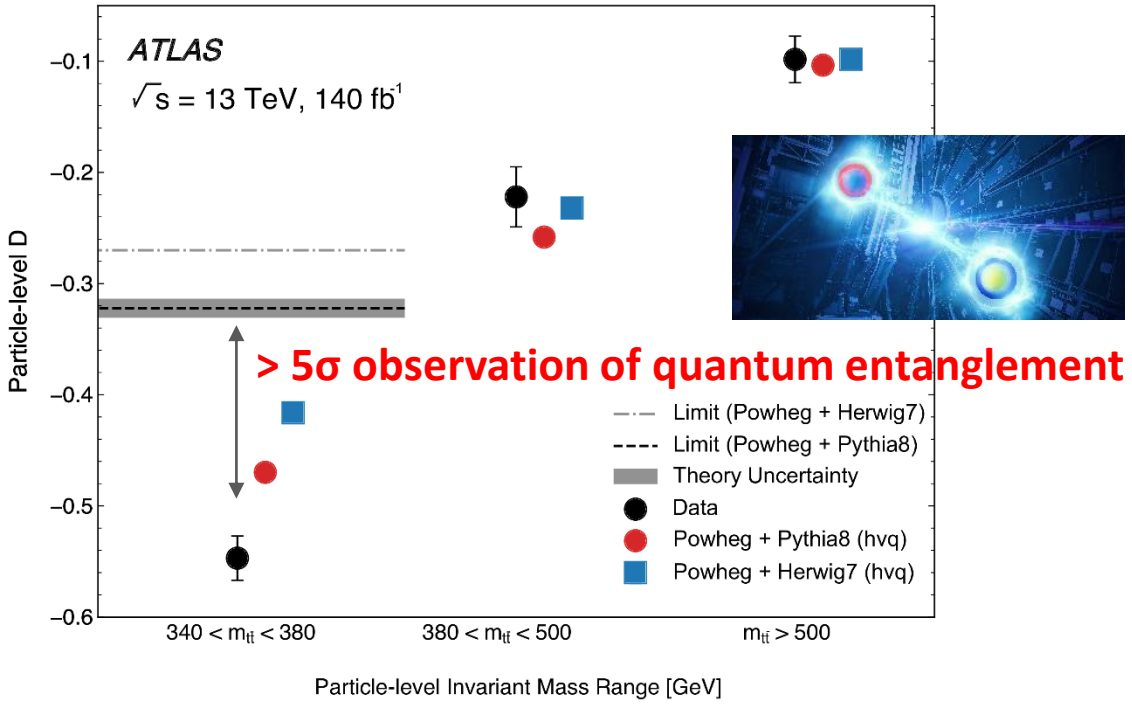
- **5σ entanglement observation at low m_{tt}** where the top quarks are expected to be maximally entangled

Entanglement enhanced at low m_{tt}

arXiv:2003.02280



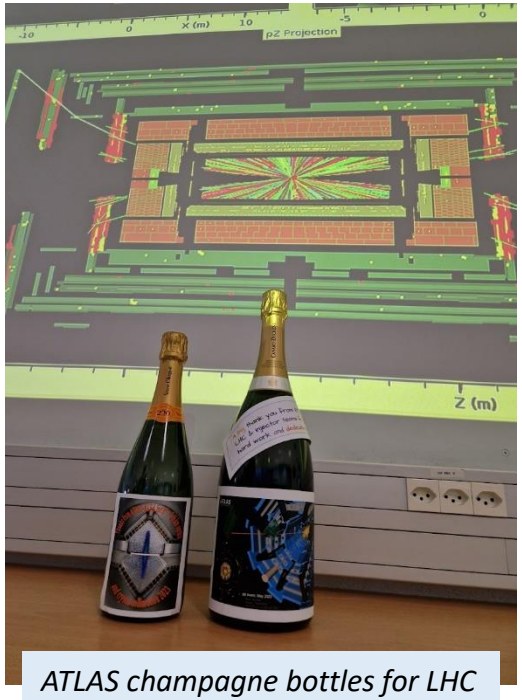
Entanglement versus m_{tt} and top angle wrt beam



Observed and expected D at particle level for different m_{tt} regions

Conclusions

- **ATLAS detector performed well** in Run3 proton and heavy ion physics, including the majority of critical Phase-I systems.
- Currently performing the **annual maintenance** activities and other interventions to make the most of the EYETS
- **Phase-II** continues to progress towards production
- First **Run 3 results** released, excellent detector and reconstruction performance, but **majority of physics analyses require more data**. To improve these results and motivate further Run 3 studies we need larger 13.6 TeV pp data set (ATLAS priority). ***Looking forward for productive 2024 and 2025 data taking***
- Continue to produce important **physics results from Run 2**, big effort to conclude.



ATLAS champagne bottles for LHC

Experiments Run Coordinators to give bottles to LHC teams


All empty bottles!!

2023 was a challenging year for LHC performance, thanks to the CERN accelerator teams for all the effort