Performance and upgrades of ATLAS

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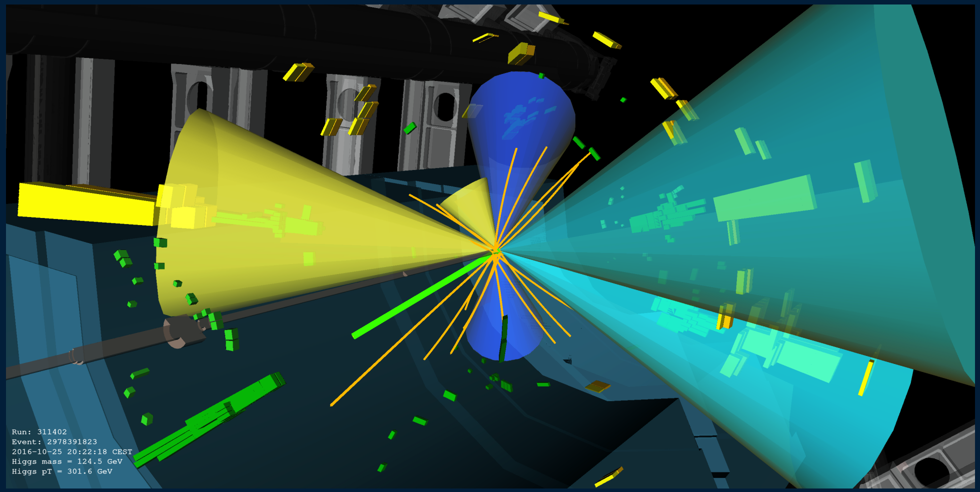
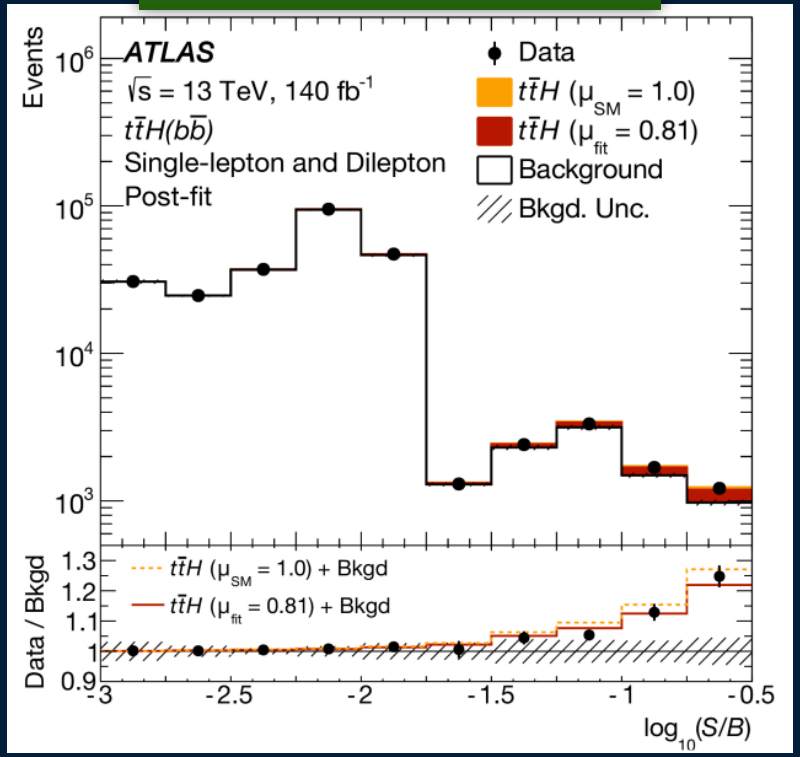
LHC Days 2024
Hvar, Croatia, Sep. 30th - Oct. 4th 2024

Introduction

- Vast physics programme spanned by ATLAS, now and in the HL-LHC era
  - Heavy Ion, B-physics, Standard Model measurements, search for BSM physics…
- All final physics analyses rely on many pillars
  - One key pillar : performance, *i.e.* reconstruction, identification and calibration of physics objects
    - Continuous efforts to improve over the years
  - Some other pillars : building, maintenance and operation of the detector
    - Detector needs upgrade for future data taking
- Presentation focuses on
  - Latest developments in Performance
  - Upgraded detector for HL-LHC



arXiv:2407.10904

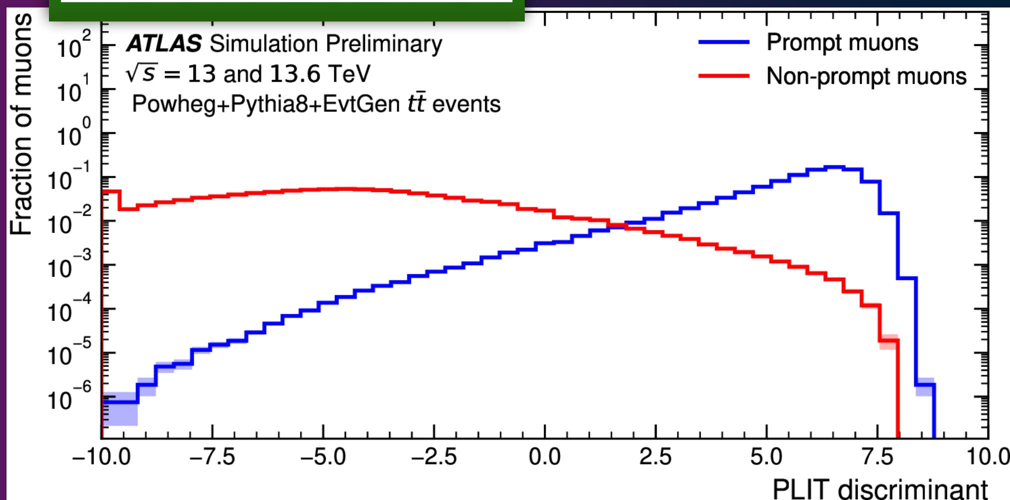


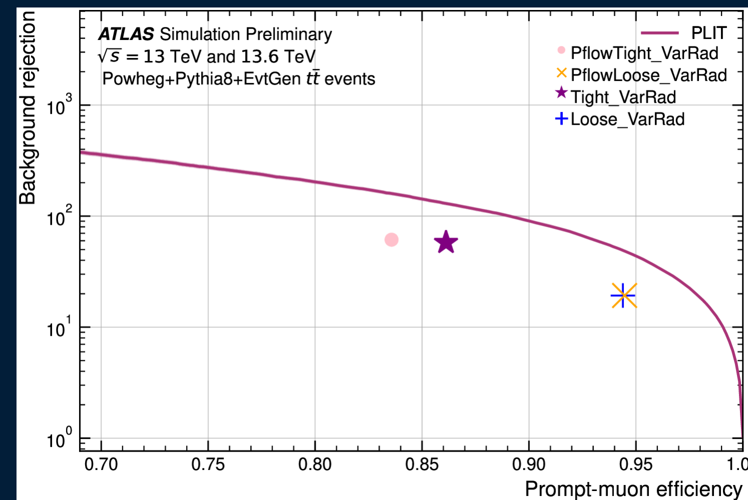
most precise individual measurement of ttH
Observed significance 4.6 σ

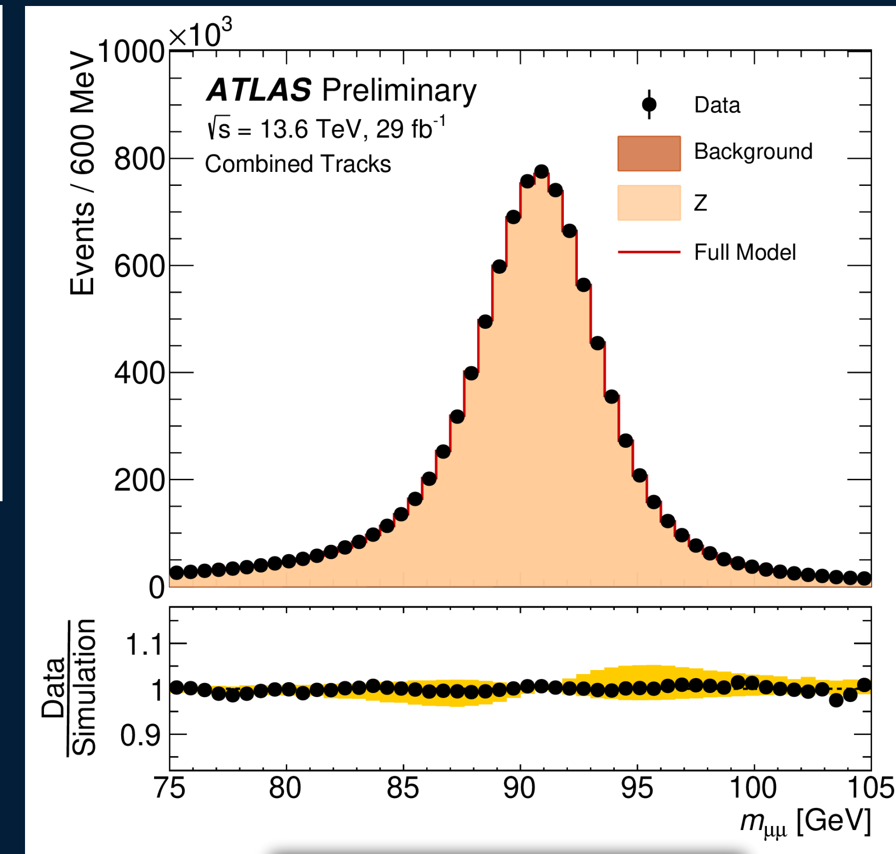
Performance

Performance : muons

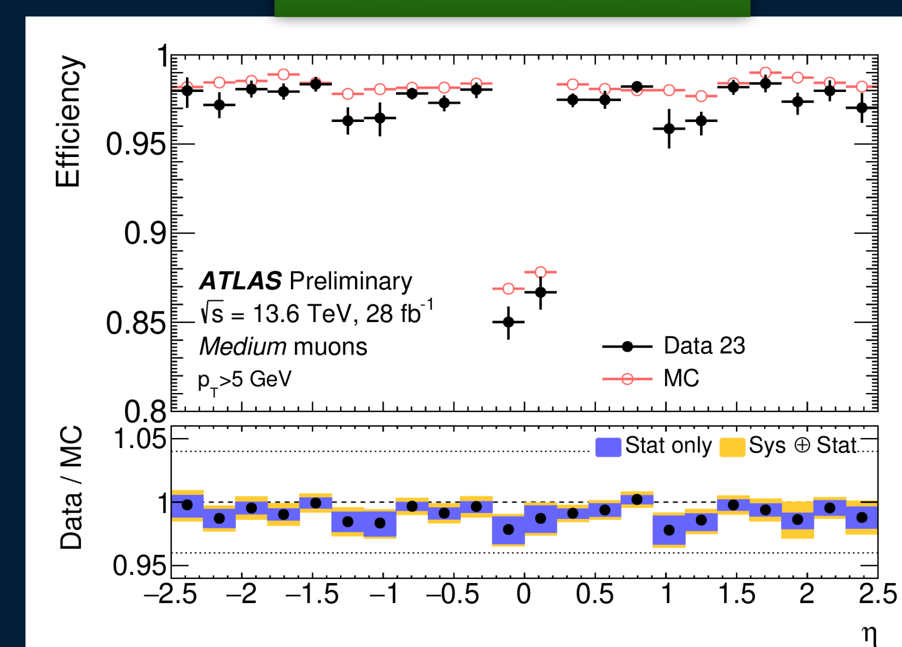
MUON-2024-01







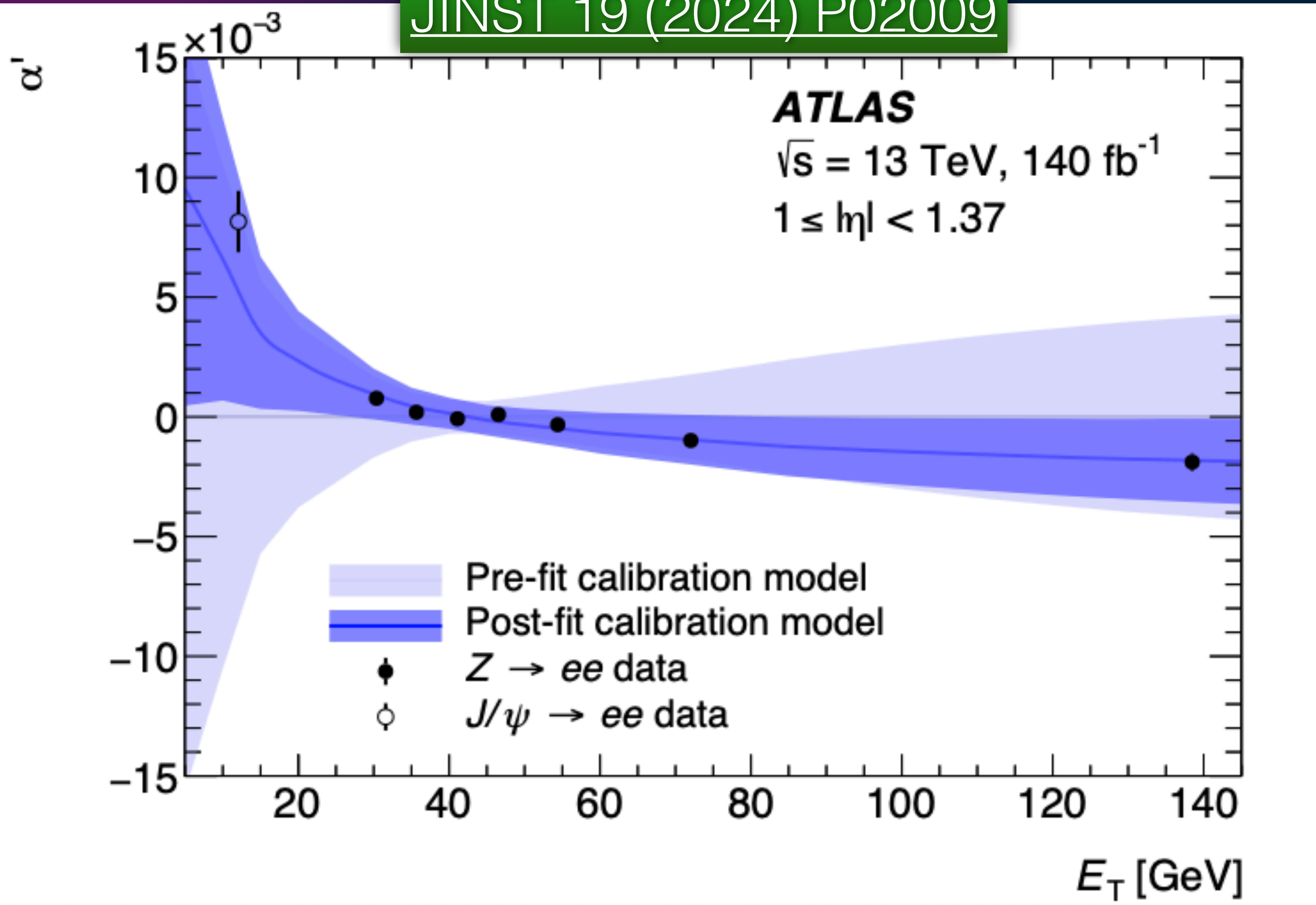
MUON-2023-02



- Development of new Prompt Lepton Isolation Tagger (PLIT)
  - Standard isolation algorithm to separate prompt from non-prompt leptons uses the sum of track momenta in a cone around the muon
  - **NEW** algorithm using a transformer neural network architecture that takes these tracks' moments as input features !
    - Highly surpasses the previous algorithms based on simple cuts
- Preliminary muon momentum calibration and efficiency scale factors available for Run3
  - NSW commissioned and included in data taking, resulting in significantly increased efficiency in 2023

Performance : electrons/photons

JINST 19 (2024) P02009



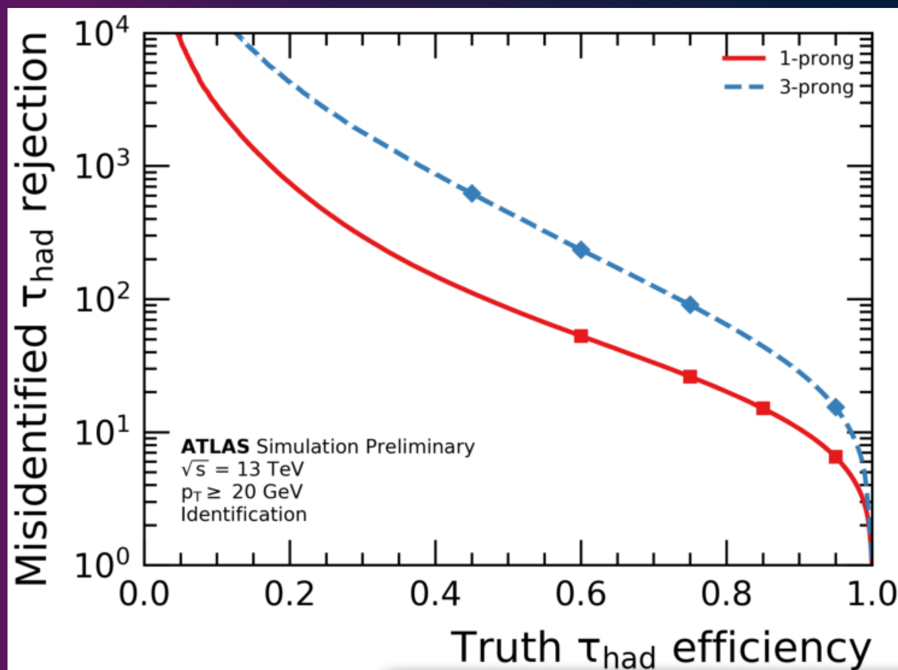
- Improved measurement of lateral energy leakage from reconstructed electron and photon energy
- Precise measurement of energy linearity with Z—>ee
  - improvement of overall uncertainty by a factor 2-3, <0.5% uncertainty above 25 GeV
  - Keep systematic on H—>ɣɣ mass below the statistical uncertainty

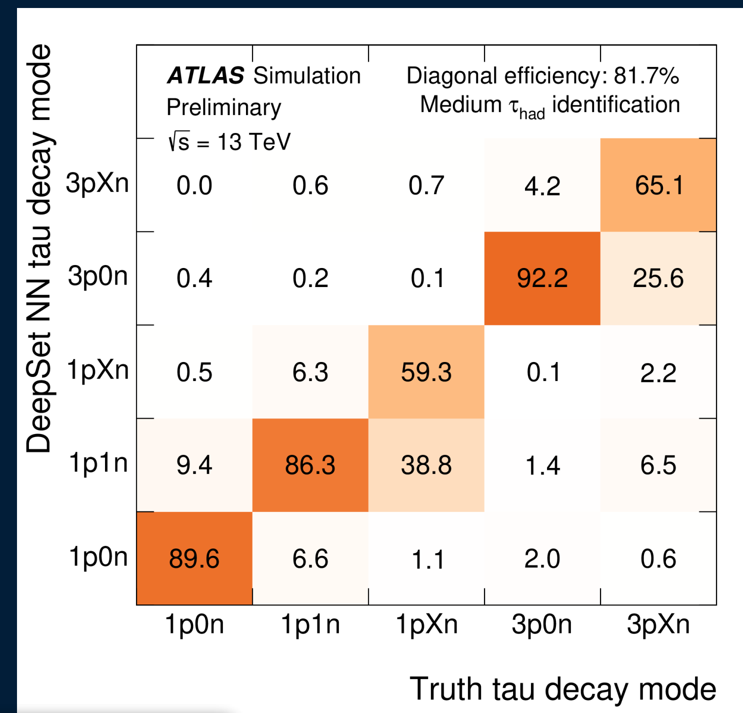
mγγ = 124.93 ± 0.21 (stat) ± 0.34 (syst) GeV
Phys. Lett. B 784 (2018) 345, partial Run2

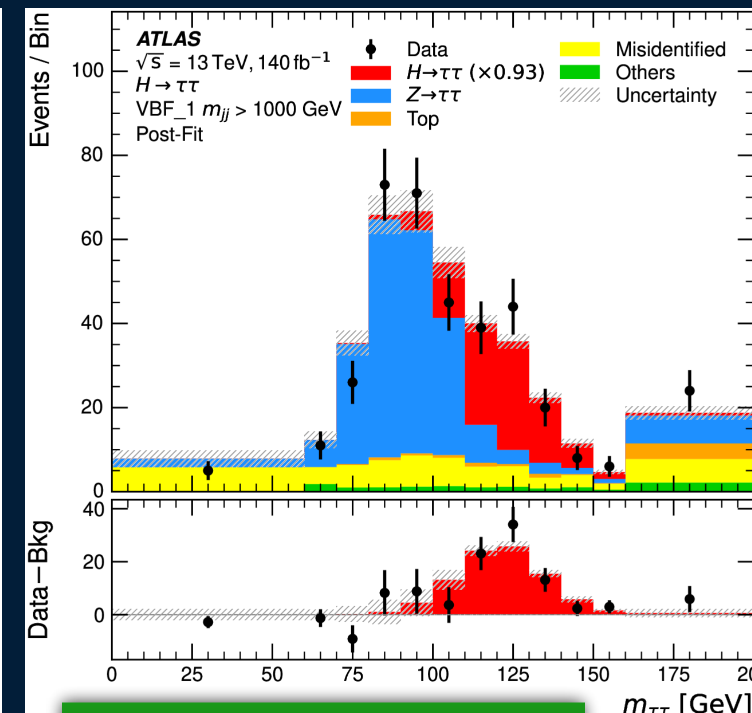
—> mγγ = 124.93 ± 0.11 (stat) ± **0.09 (syst)** GeV
Phys. Lett. B 847 (2023) 138315, full Run2

- Run3: preliminary energy calibration and efficiencies ready
  - Comparable efficiencies as in Run2
- New DNN/CNN based approaches for electron identification being developed

Performance : tau







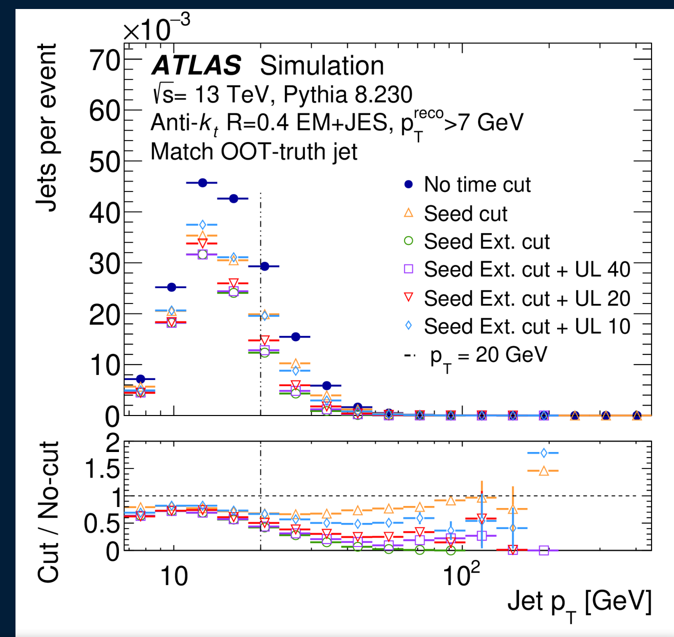
ATL-PHYS-PUB-2022-044

arXiv:2407.16320

- Improved and optimized algorithms for Run3 and reprocessed Run2 data
  - Track association and classification efficiency for 1-prong (3-prong) improved from ~70% to > 90% (from 65% to about 75%) for 1-prong (3-prong) taus, comparing to algorithm at the start of Run2 !
- Reconstruction seeded by jets reconstructed using the anti-k_T LCTopo R=0.4 jets
  - use of Recurrent Neural Network for reconstruction, as well as jet and electron rejection
- Energy calibration with Boosted Regression Tree
- Decay mode classification based on DeepSet Neural Network - differentiates between 5 decay topologies

Performance : jets

- Recent developments:
  - Use of Calorimeter time information to reject contributions from pileup to topo-clusters in Run 3
    - Cell timing cut: |t| < 12.5 ns for any cell that has |E| > 4σ



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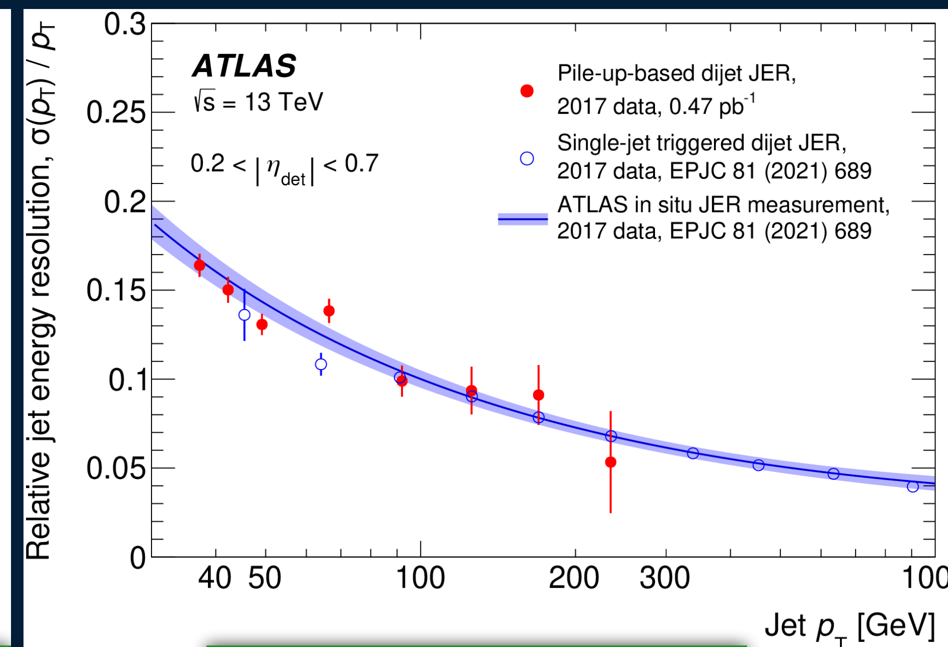
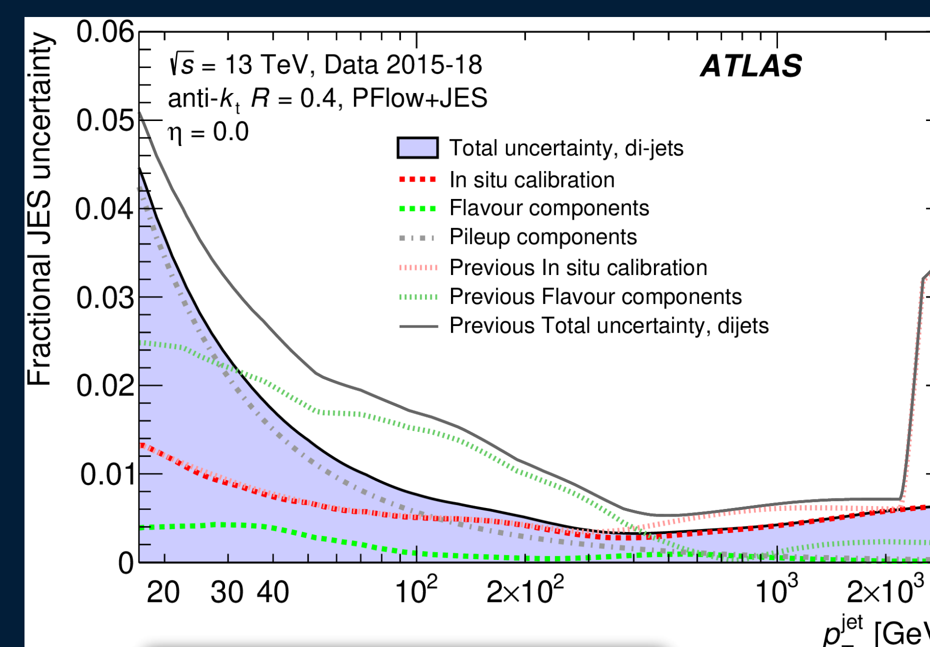


arXiv:2407.10819

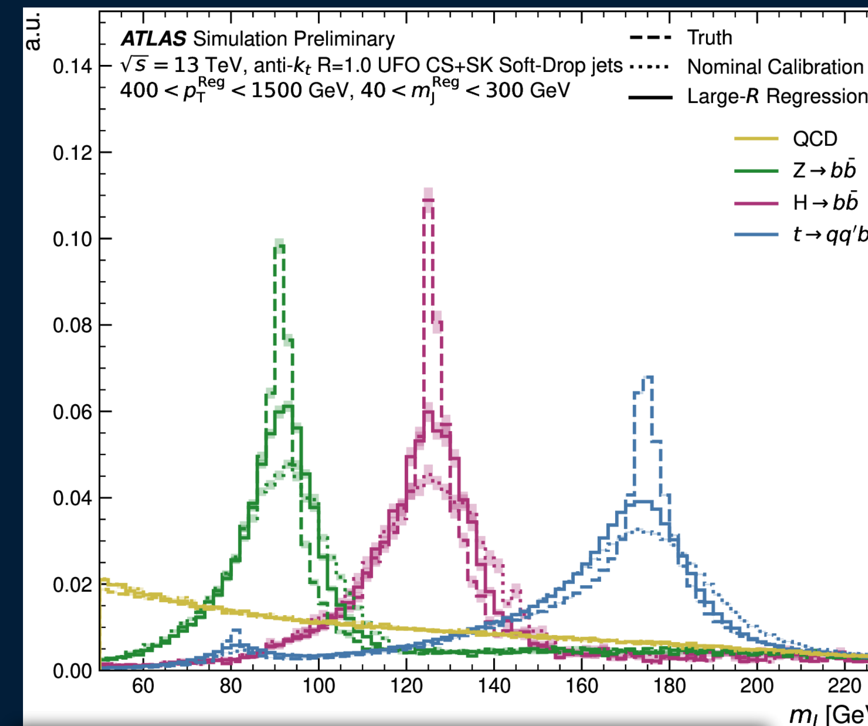
- Significant improvement on the Jet Energy Scale (JES) uncertainty by studying the baryon fraction in various generators and using a deconvolution technique together with single particle E/p measurements
- Use of pileup jets to measure the Jet Energy Resolution (JER) (in development)



arXiv:2407.15627

Performance: Machine-Learning for jets and pTMiss

- Latest techniques of Machine-Learning (ML) entering all stages of the reconstruction/calibration chains, e.g. Transformers!
  - Developing ML-topocluster calibration that improves resolution at the input level
  - Jet energy calibration
  - Reconstruction of pTMiss
  - Huge improvements in Jet Tagging (boosted Tops, Higgs, Ws, Zs, quark-gluon discrimination, b/c tagging)
    - Comes together with more questions and exciting challenges to solve: modeling dependence, calibration, etc…



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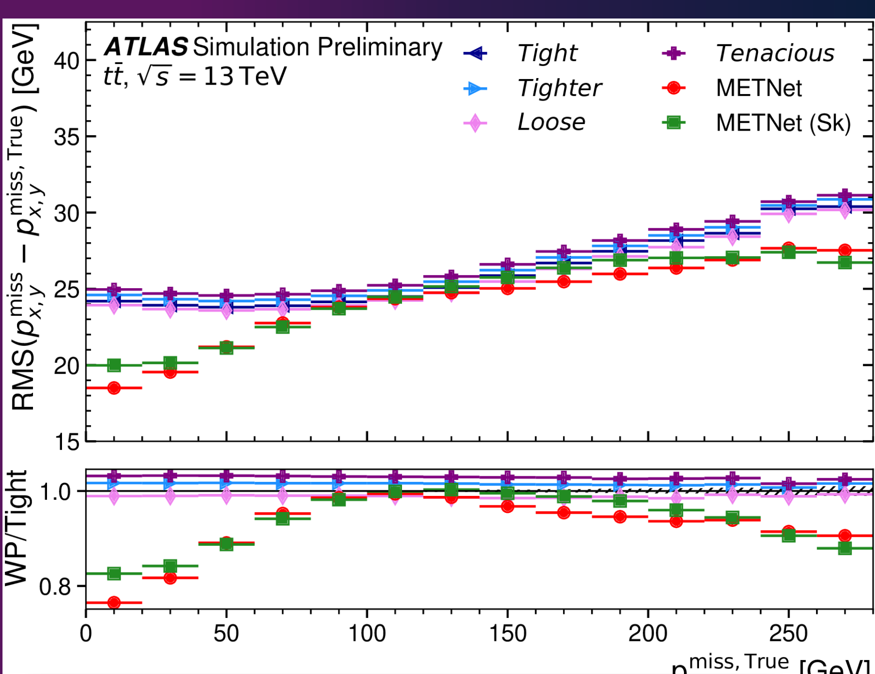

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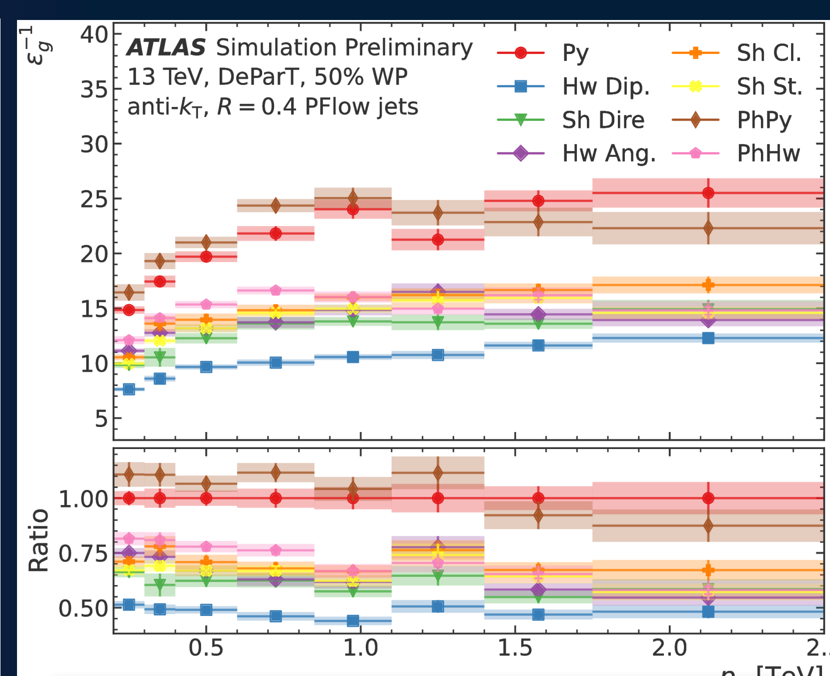

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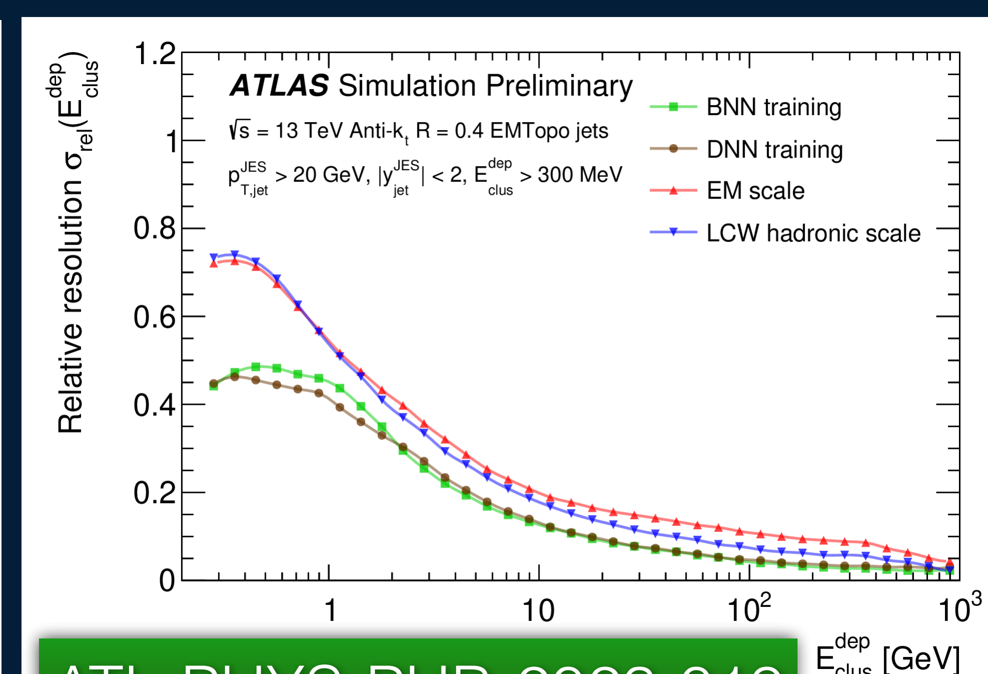
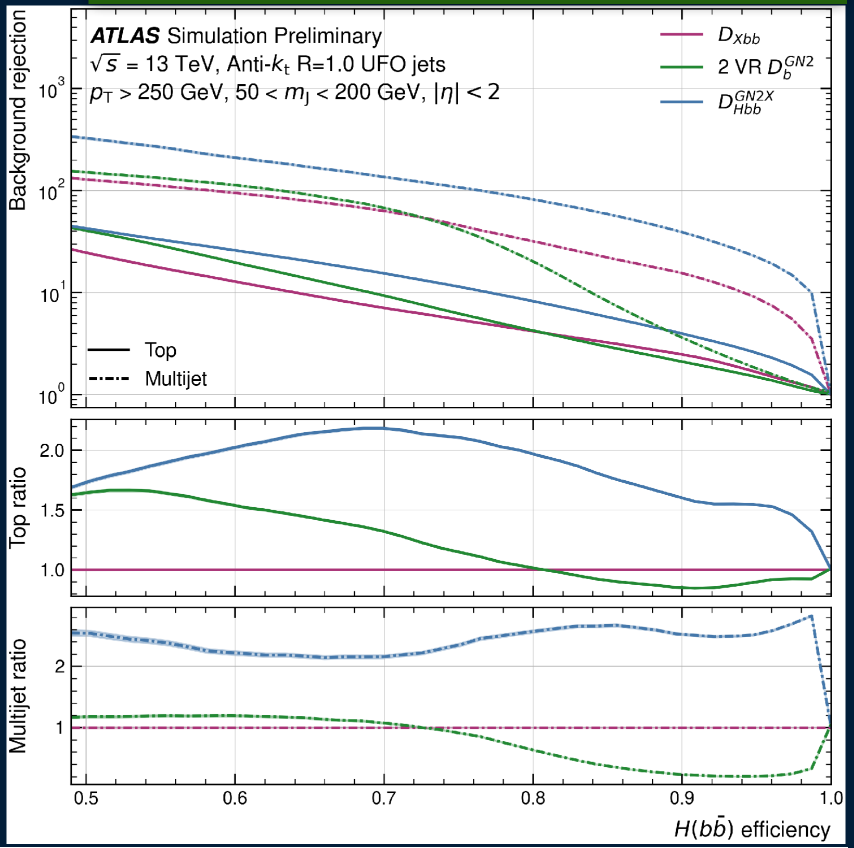


ATL-PHYS-PUB-2023-019

Performance: Flavour tagging

- Development of a GN2 discriminant using improved training procedure and optimised architecture to identify jets coming from b-hadrons
  - Jet flavour, vertexing & track origin task inferred simultaneously using Transformer networks
  - > 2x improvement in small-R and boosted jet b-tagging over previous taggers
- First look at in Run3 performance looks healthy

ATL-PHYS-PUB-2023-021



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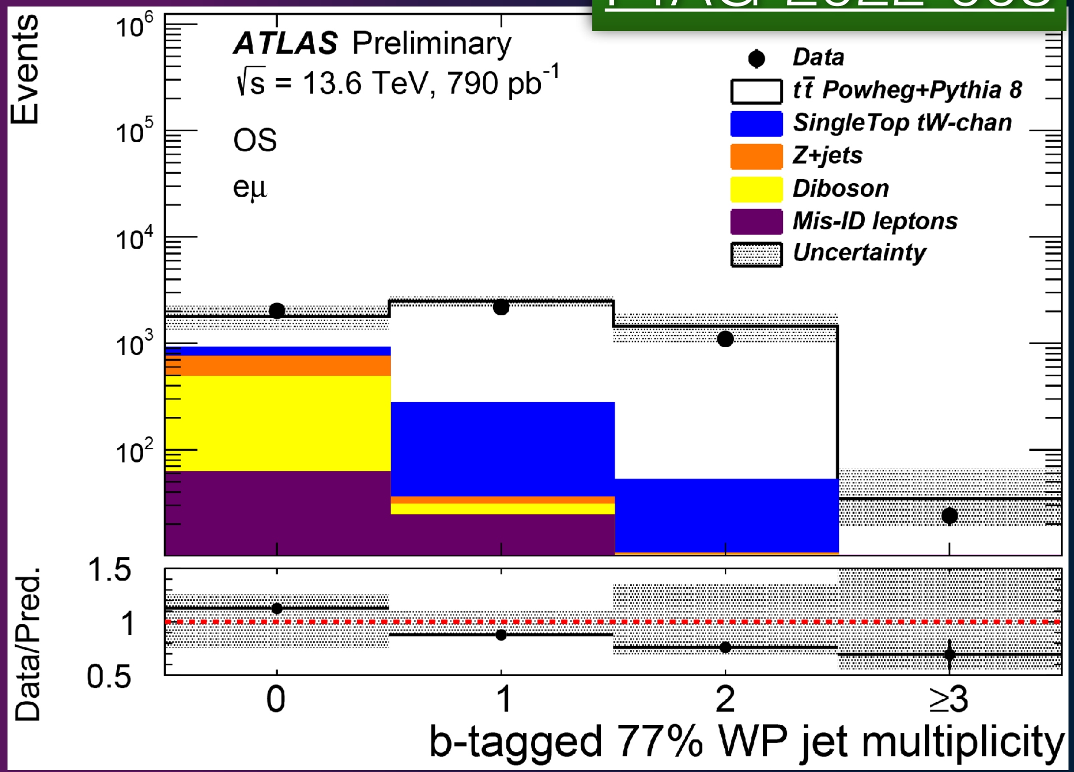

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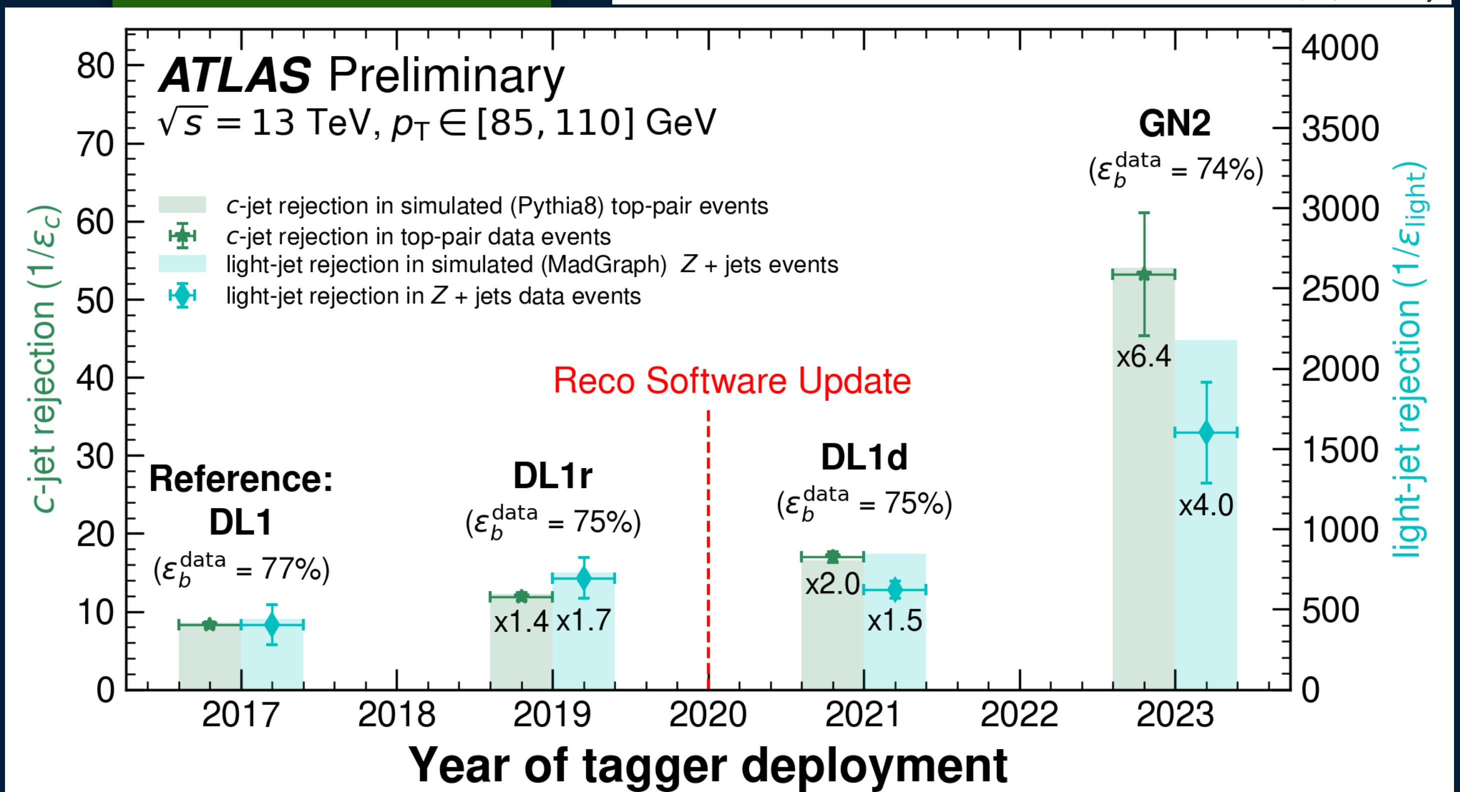
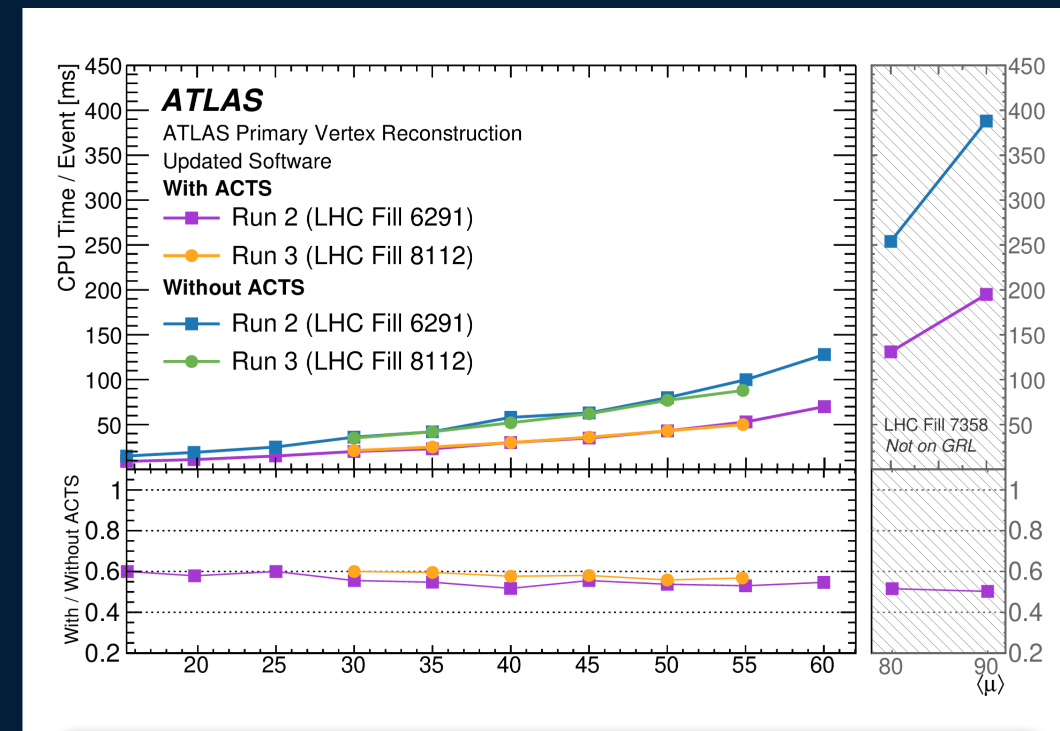
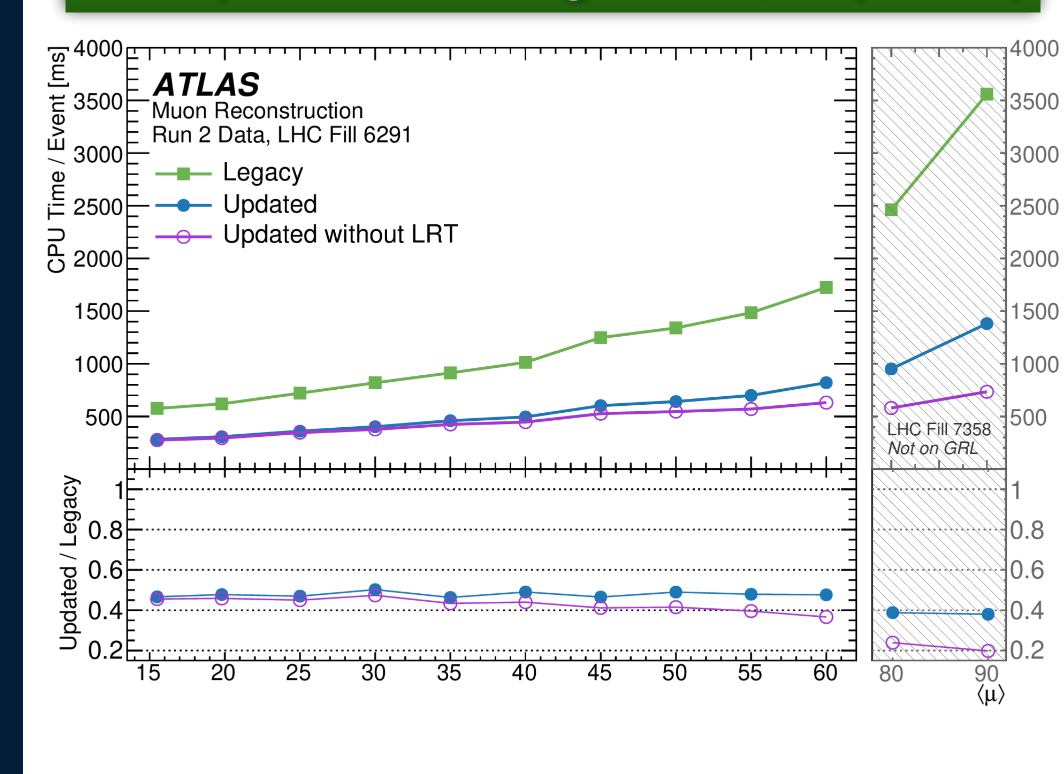


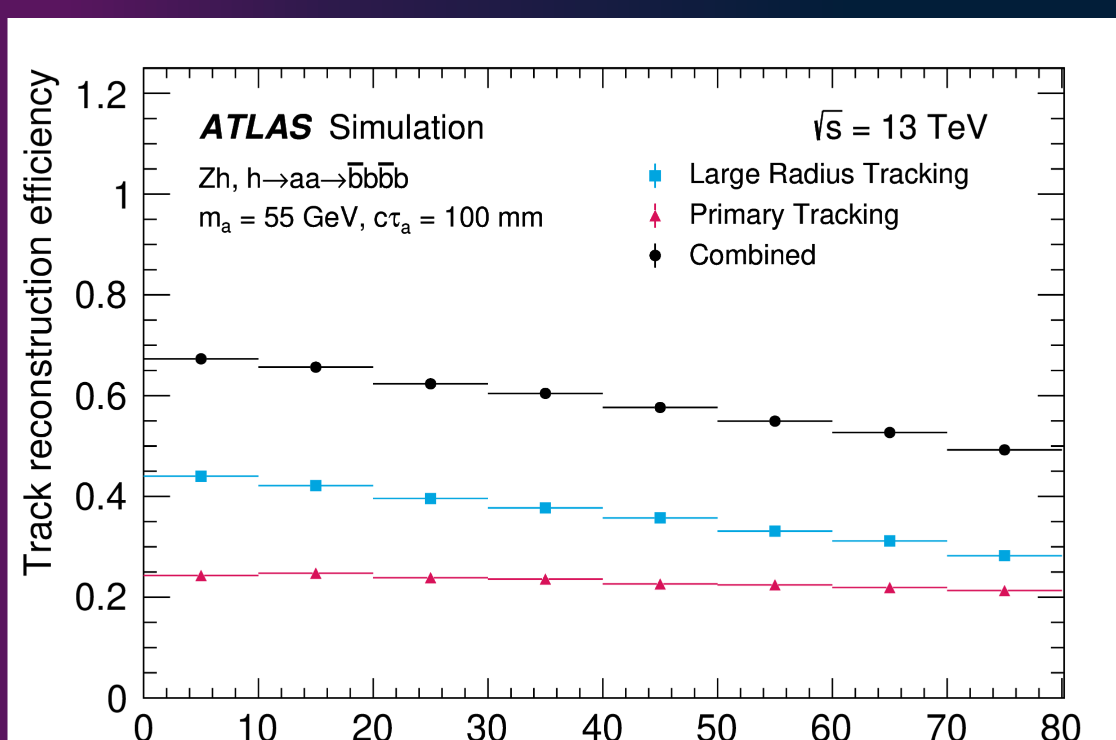
Performance: Tracking

- Updated track reconstruction in Run 3 (ID and muon track reconstruction software) with faster decision making algorithms
  - Vertex reconstruction using A Common Tracking Software Project (ACTS), Comput Softw Big Sci 6, 8 (2022), Link to project), experiment-independent and framework-independent toolkit for tracking
  - 2x as fast as before for mu=60 events and 2x combinatorial fake rate reduction, without significant reduction in reconstruction efficiency
- Improved Large Radius Tracking (LRT) for Run 3
  - Important for LLP searches



Comput Softw Big Sci 8, 9 (2024)



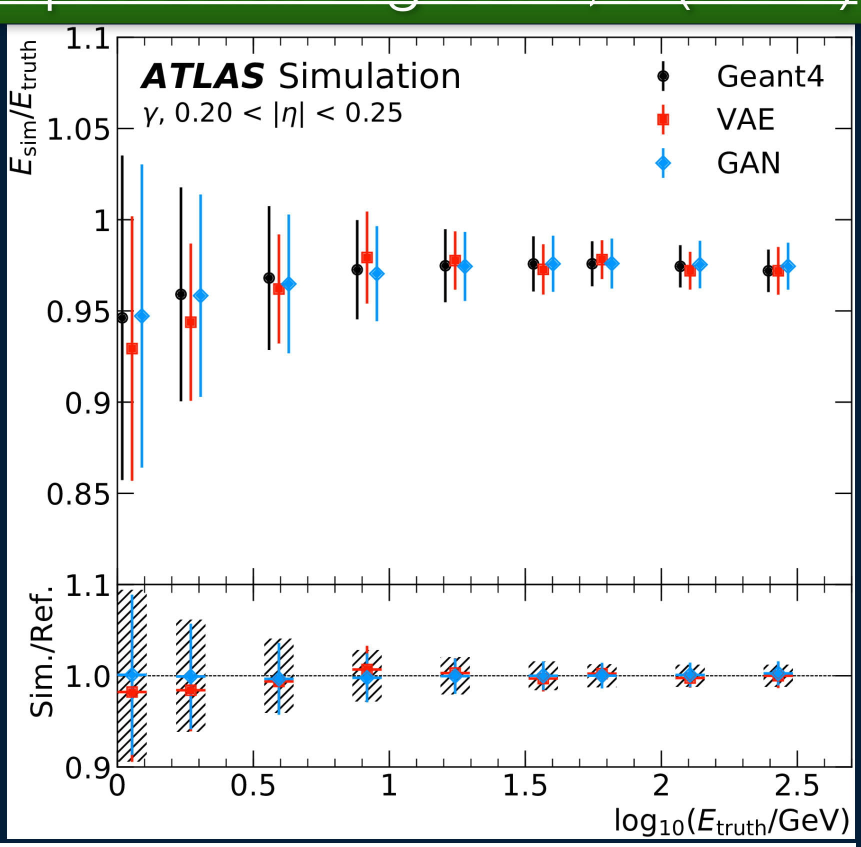


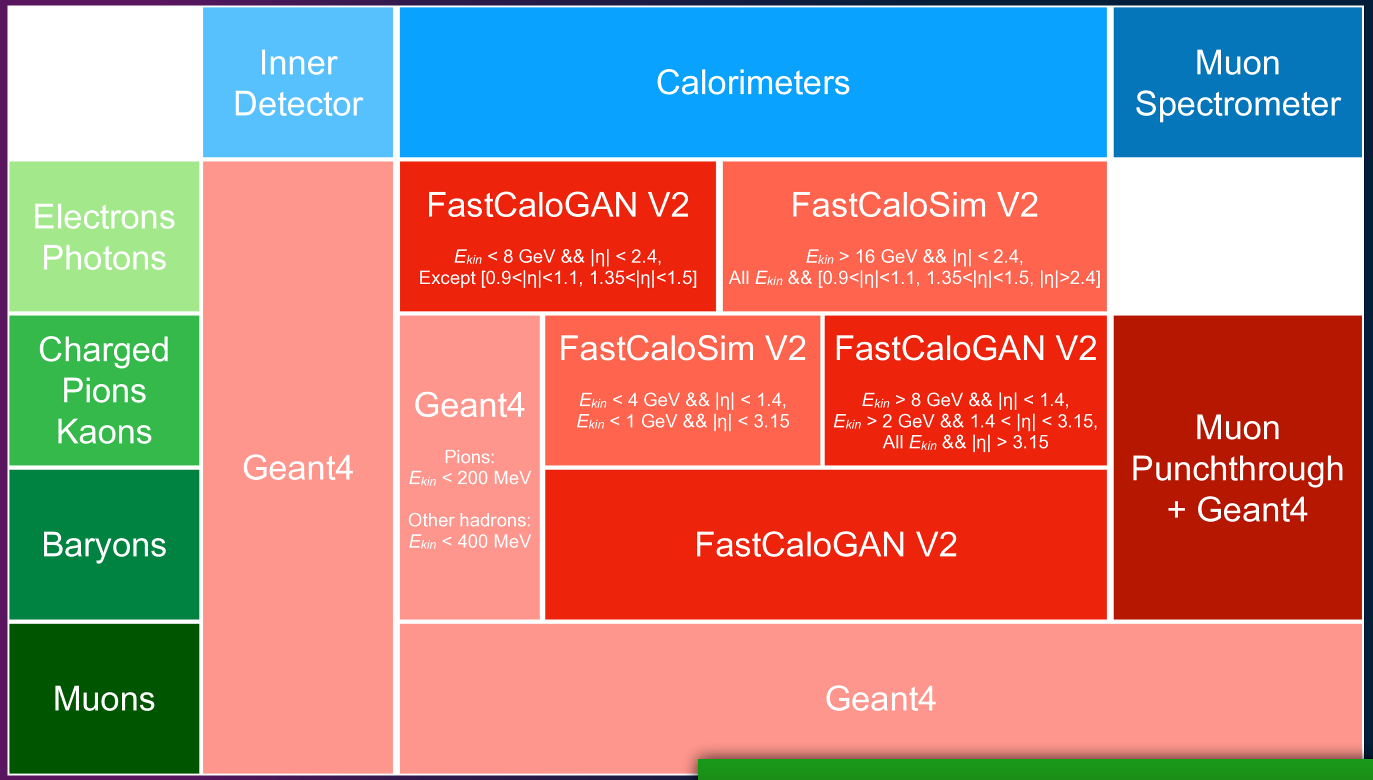
Eur. Phys. J. C 83 (2023) 1081

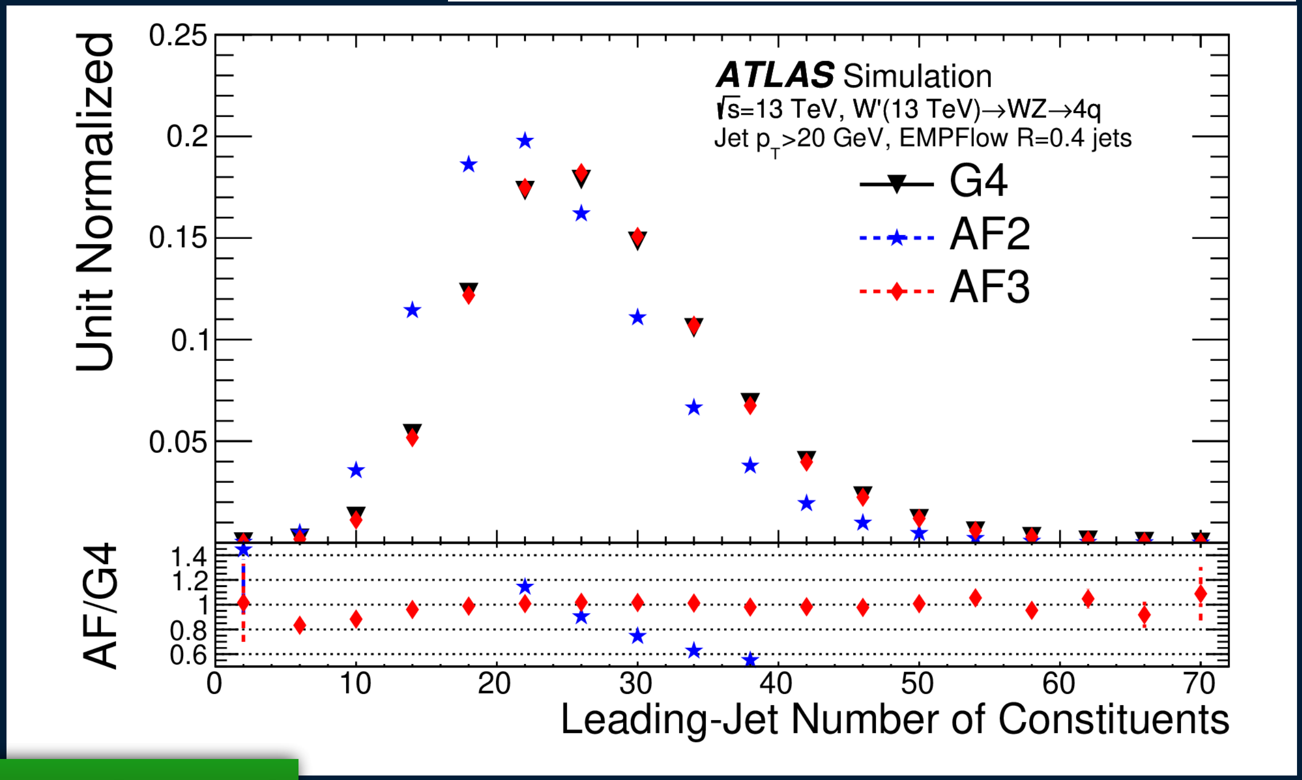
Performance: Simulation

- Latest developments:
  - Speed improvement in standard full simulation by a factor ~2 in Run3, as compared to Run2
  - Deep generative models for fast photon shower simulation in ATLAS
    - Up to 2 orders of magnitude faster than Full simulation (for single photons hitting the calorimeter), and small memory footprint
  - Fast Simulation (AtlFast3, AF3)
    - Plan extensive use in future physics analyses
- Full details of Run3 Software and Computing: arXiv:2404.06335

Comput Softw Big Sci 8, 7 (2024)



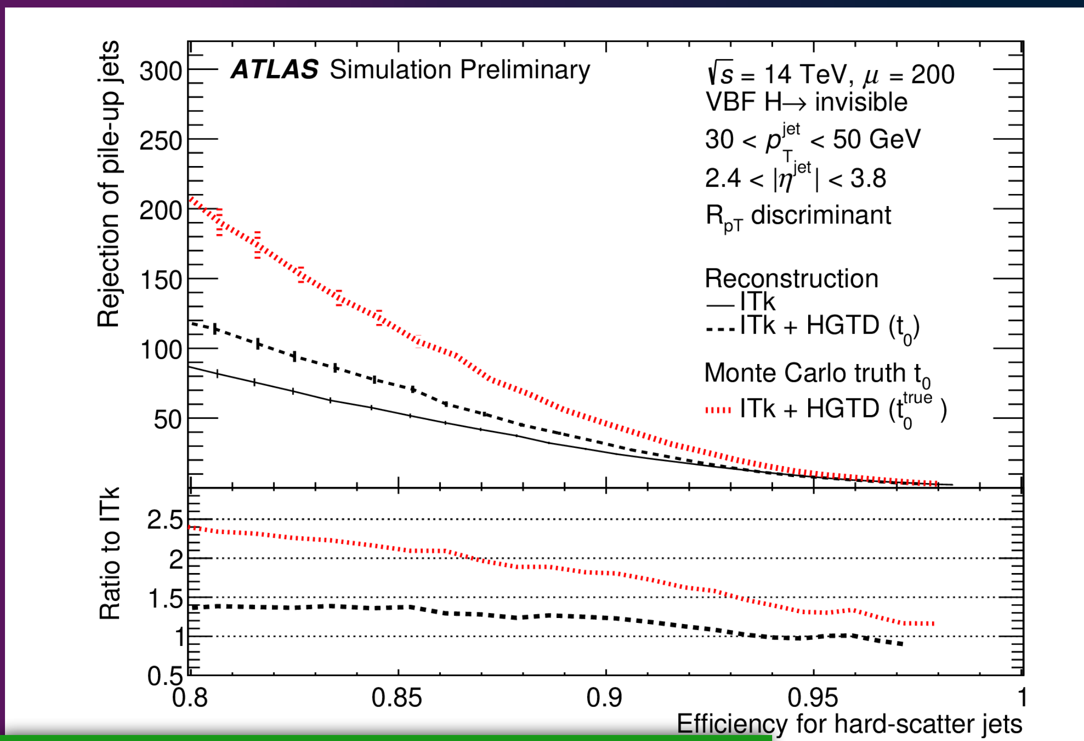




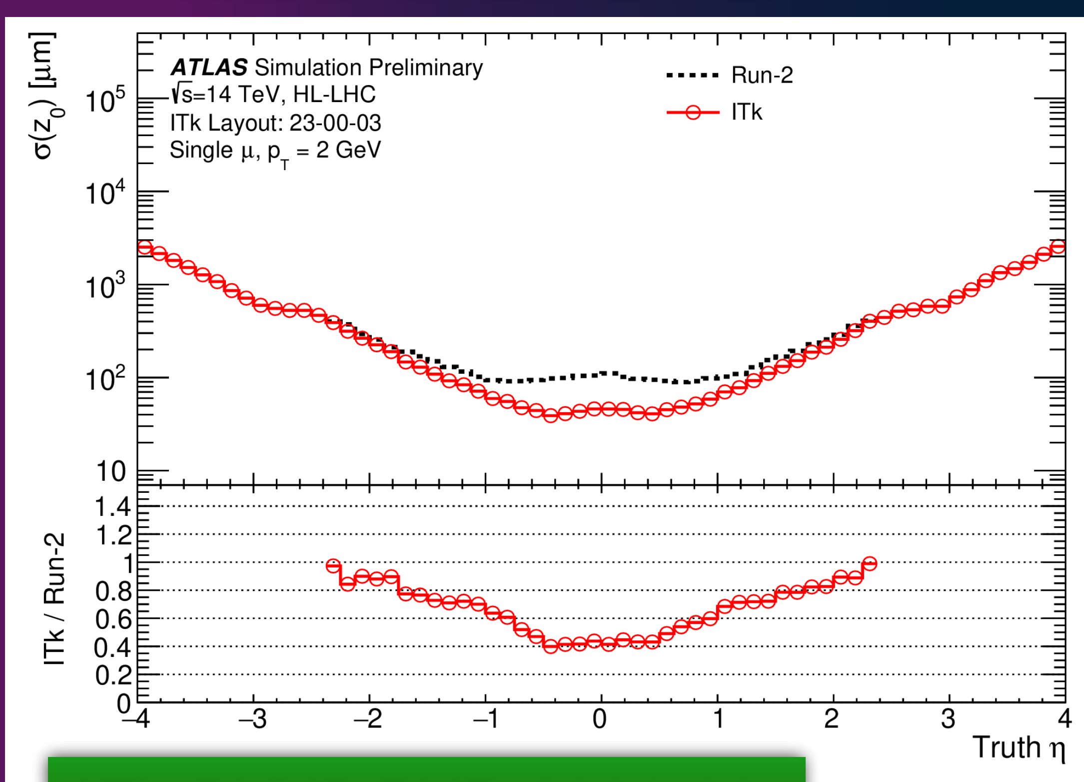
Comput Softw Big Sci 6, 7 (2022)

Performance: preparing for HL-LHC

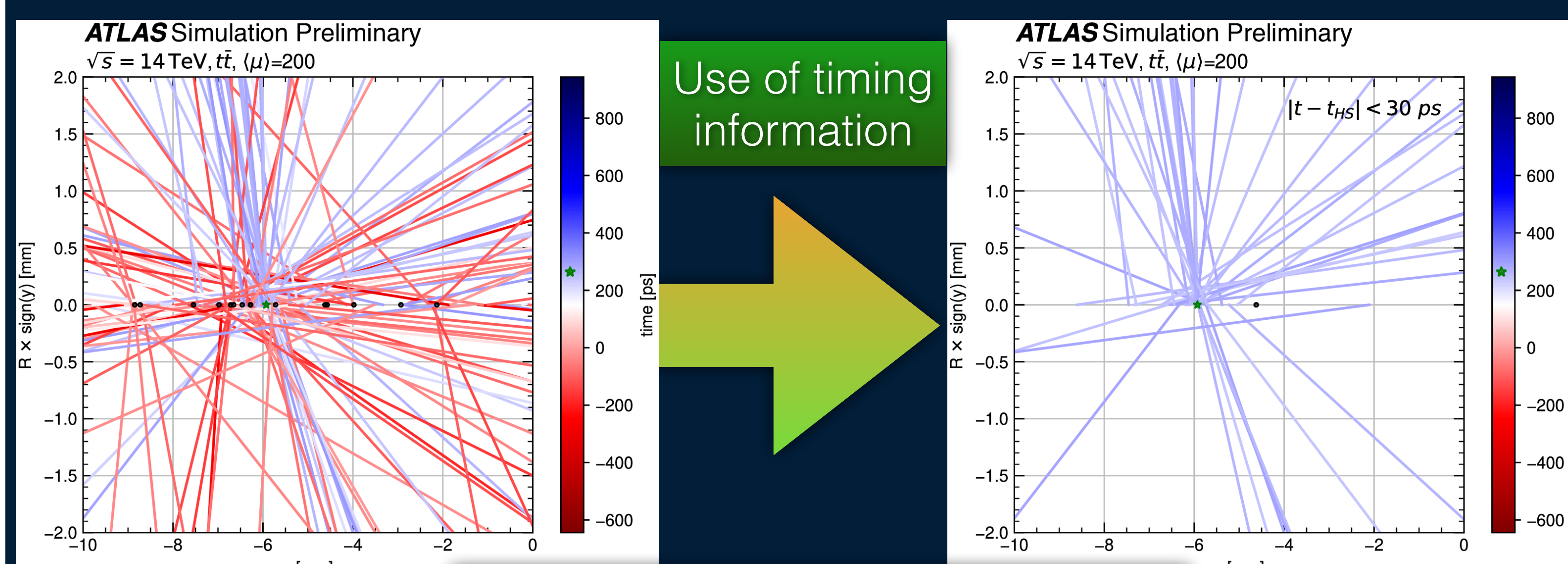
- Preparing for Run 4 conditions, with <mu>=200 !
- Improvements in tracking/timing (ITk, HGTD)
  - Track z0 resolution ~40 um for a 2GeV muon in the central region
  - Time resolution from HGTD ~30ps
- Rejection of pileup at jet level thanks to timing information



ATL-HGTD-PUB-2022-001



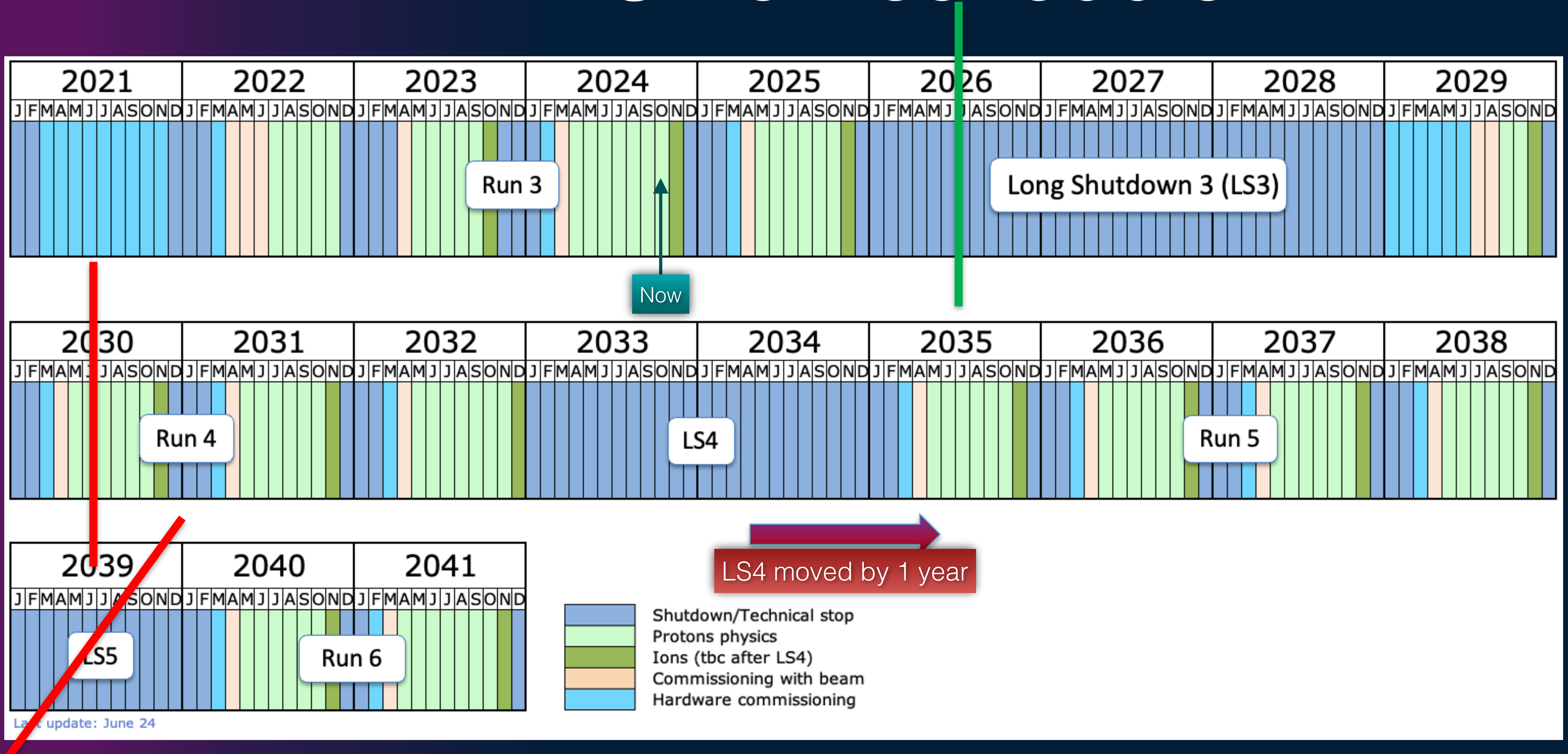
ATL-PHYS-PUB-2021-024



ATL-PHYS-PUB-2023-023

Upgrade

HL-LHC new schedule



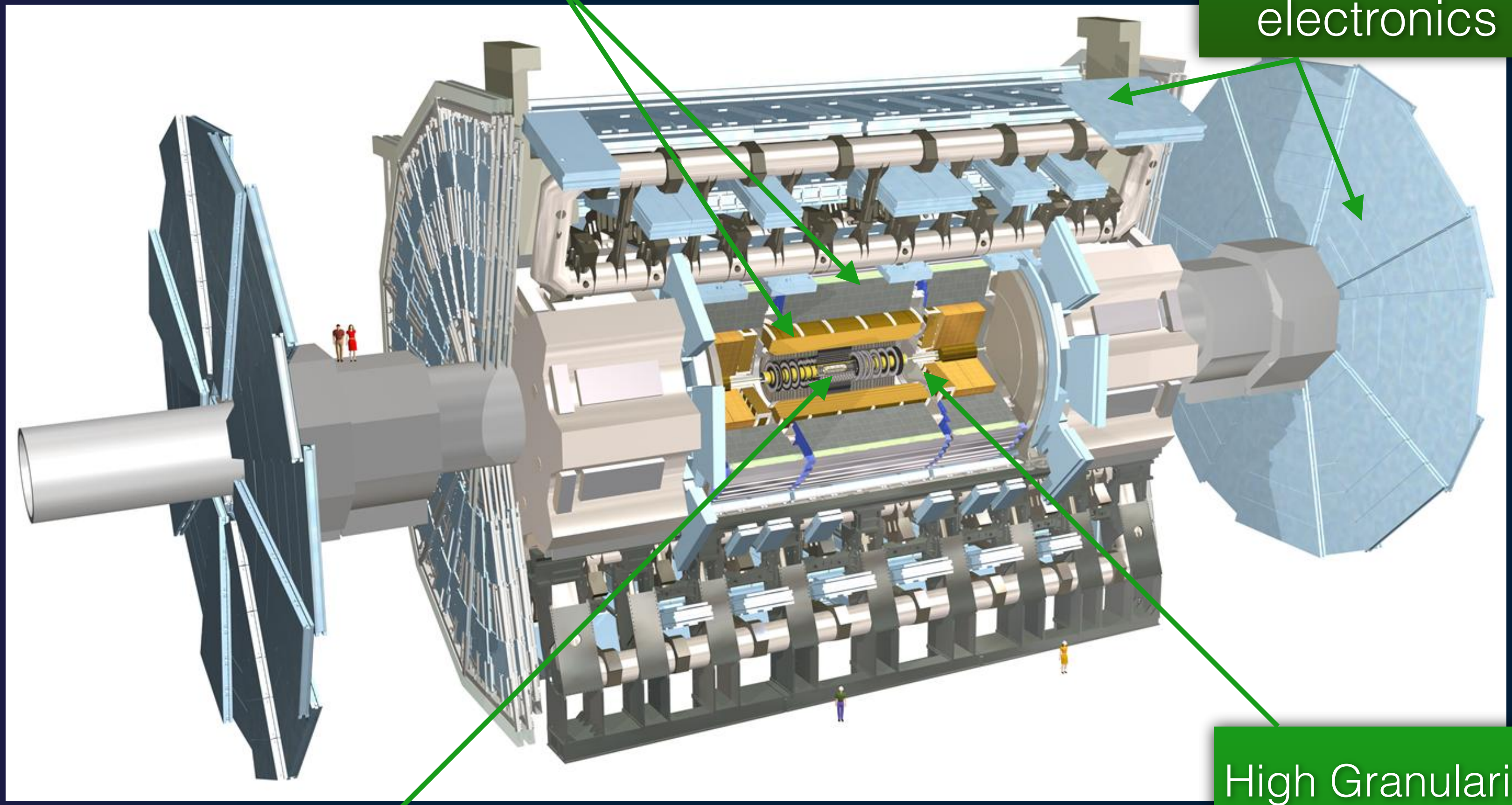
- The LHC upgrade to the HL-LHC is the main motivation for the Phase II upgrade of ATLAS
  - Luminosity Increase: peak ~ $7x10^{34}$ $cm^{-2}s^{-1}$, integrated ~ 3000 fb^{-1}
  - 200 pile up events (~65 peak in current run)
  - Radiation fluence: ϕ(HL-LHC) ~ 10 x ϕ(LHC) = 2 x 10^{16} neq/cm^2 around the interaction point
- Rich physics programme, see talk from Bjarne!

Overview of Phase-II upgrades

Calorimeters readout electronics
- 40 MHz for triggering
- Both LAr and Tile calorimeters

Muon system:
- New Inner Barrel chambers with improved trigger efficiency and resolution
- Upgrade of readout/trigger electronics

Trigger and Data Acquisition (TDAQ)
- Single-level trigger, 1 MHz output (x10 current)
- Faster, with generalized use of Front-End Link eXchange (FELIX)

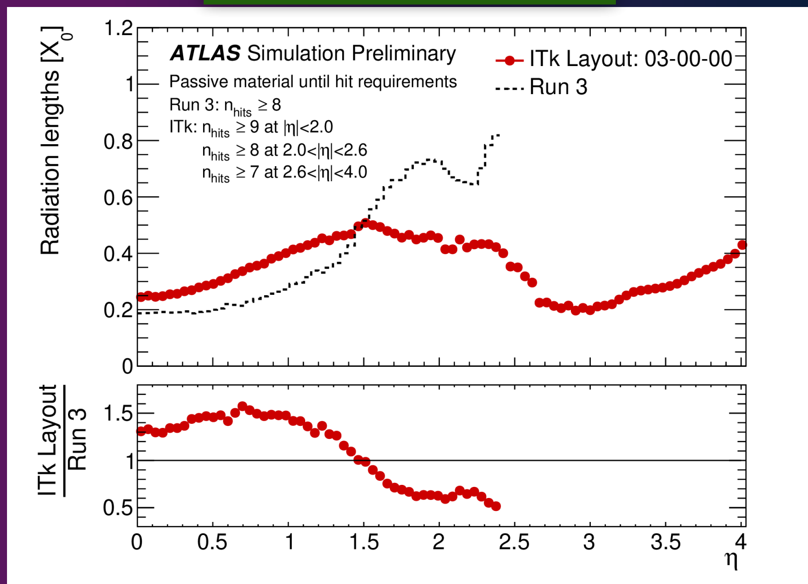


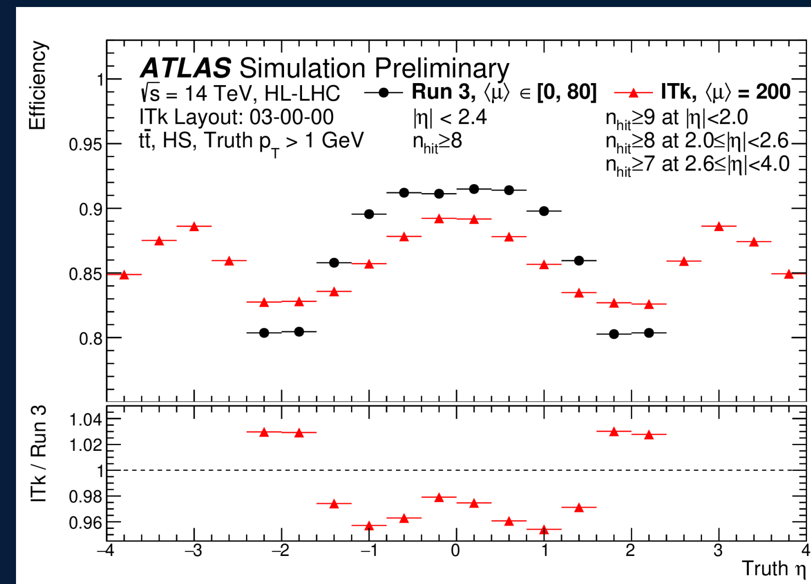
Inner Tracker (ITk)
- Silicon, 9 layers up to |η|=4
- Will replace the entire current tracking system
- improved vertexing, tracking, b-tagging
- 2 technologies : strips and pixels

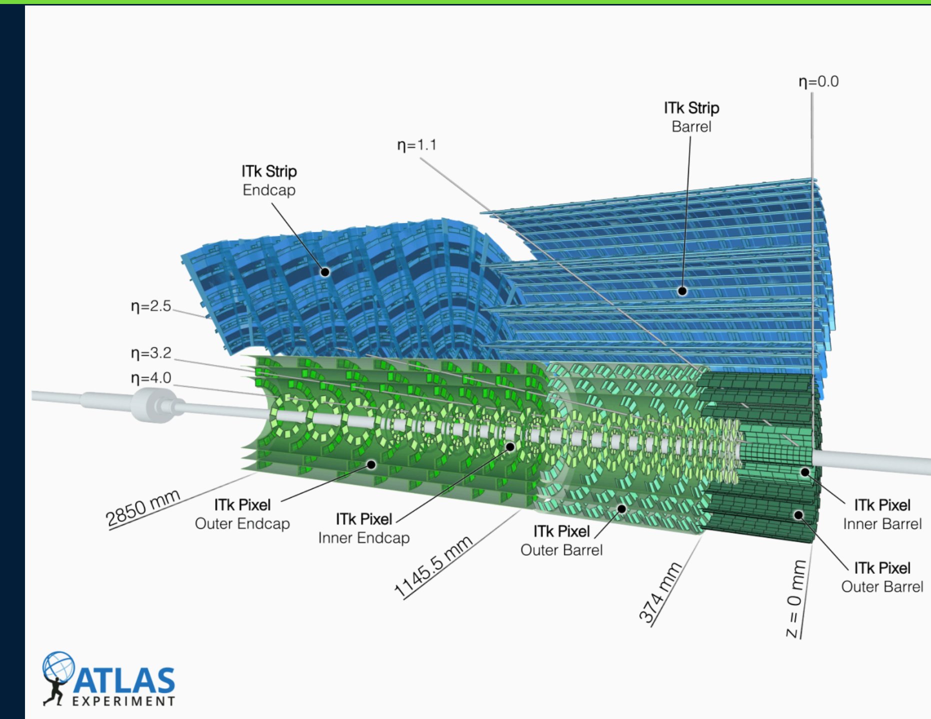
High Granularity Timing Detector (HGTD)
- Precision time resolution (30ps) with Low-Gain Avalanche Detector (LGAD) pixels
- Improved pile-up jet rejection in the forward region
- Also allows to measure bunch-by-bunch luminosity

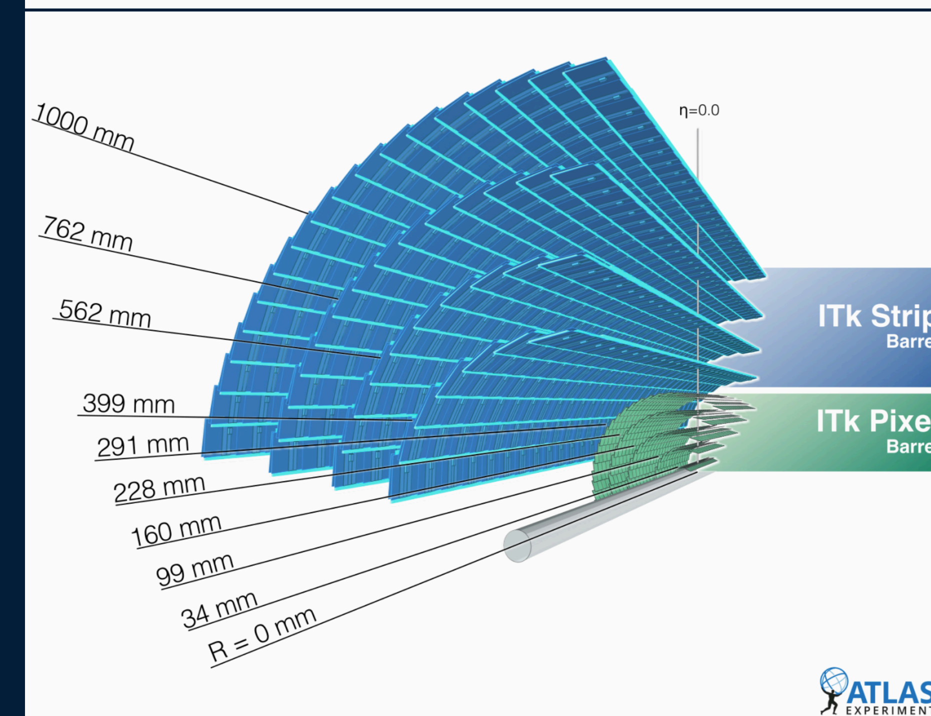
ITk

ITK-2023-001







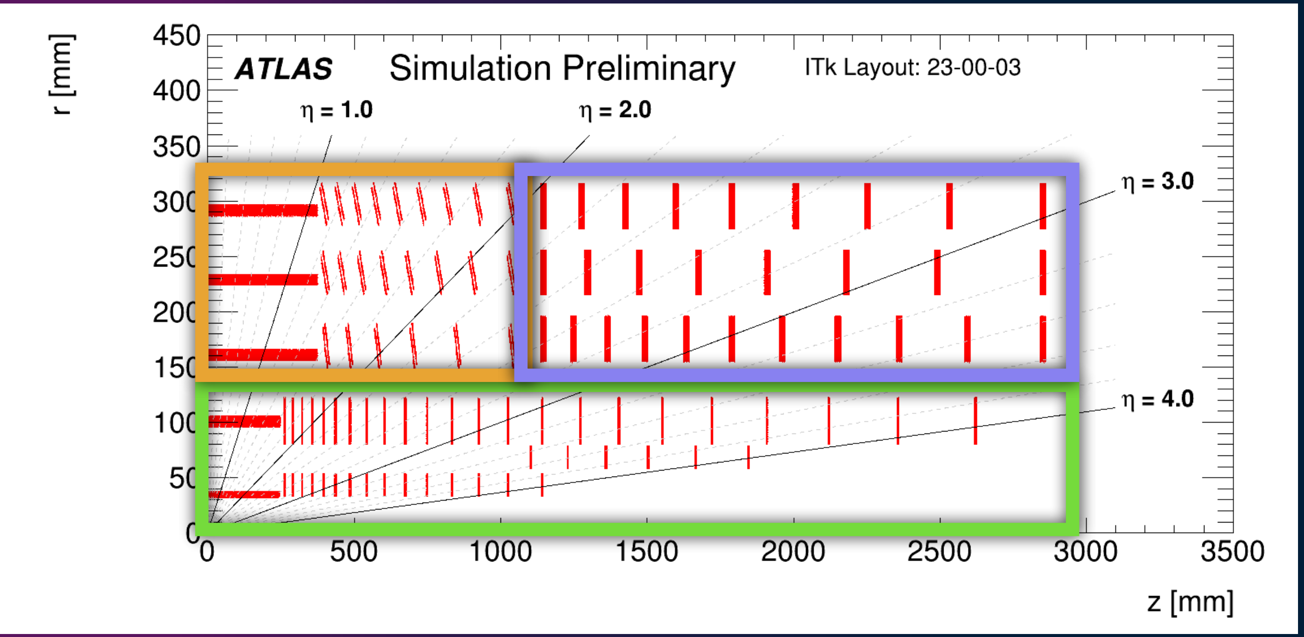


- Full replacement of current tracking system, extending coverage up to |η|=4
- All-silicon: 168 m² of strips, 13 m² of pixels
- Radiation-hard design up to 10^{16} neq/cm² on innermost layers
- Reduced material budget, higher granularity, data rate capability

- Components made worldwide, final assembly being made at CERN
    - Outer Cylinder is at the ATLAS site, polymoderator (neutron shielding) has been installed
    - Two Strips supporting cylinders are currently being integrated

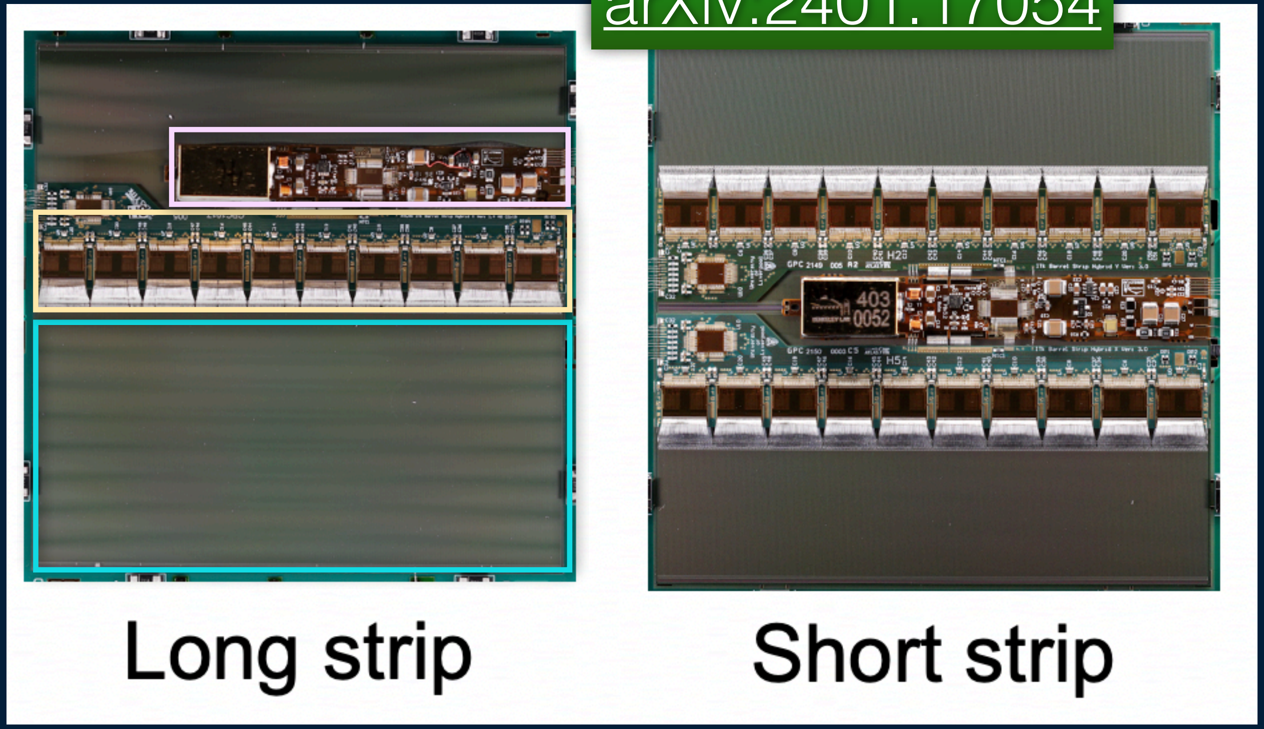
ITk

- ITk Pixel:
  - Divided in three sub-detectors:
    - Inner system, to be replaced after 2000 fb^{-1}
    - Outer Barrel
    - 2 Outer endcaps
  - Hybrid modules using radiation hard silicon sensor technologies: thin planar and 3D sensors
    - Production in progress
  - Readout chip ITkPixV2 developed by RD53 Collaboration
    - Production started



- ITk Strips: Barrel and end caps
- n^+-in-p sensors, in production since 2021
- ASICs for readout and control based on 130 nm CMOS technology, hosted on flexible PCBs (hybrids)
- Assembled in modules comprising Silicon sensors + hybrids + power board
- To be loaded on local supports
- On the verge of full production!

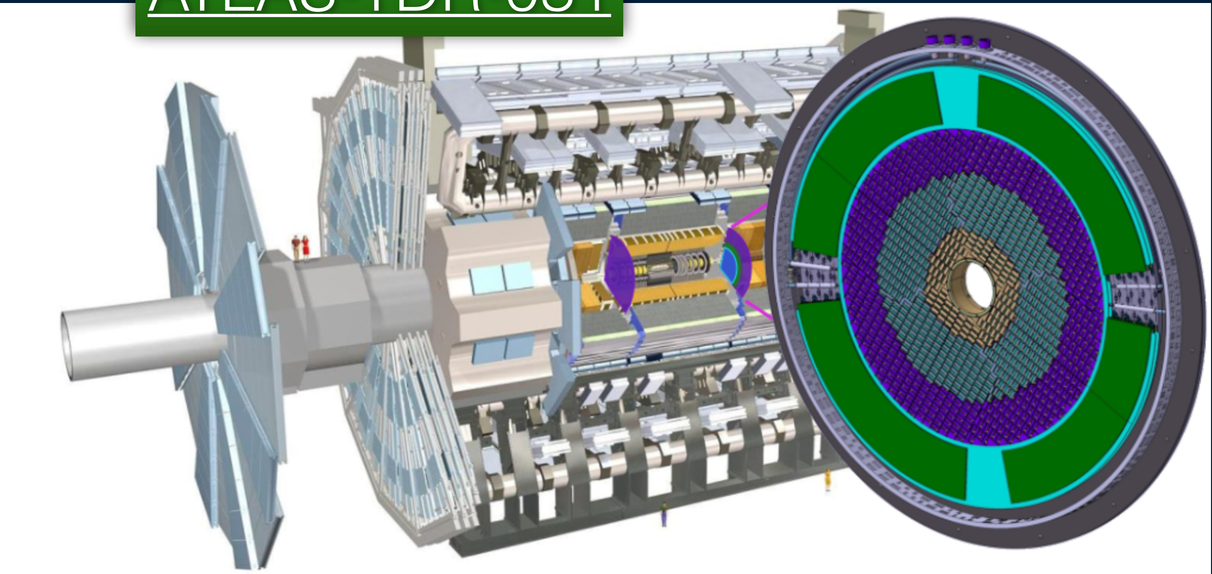
arXiv:2401.17054

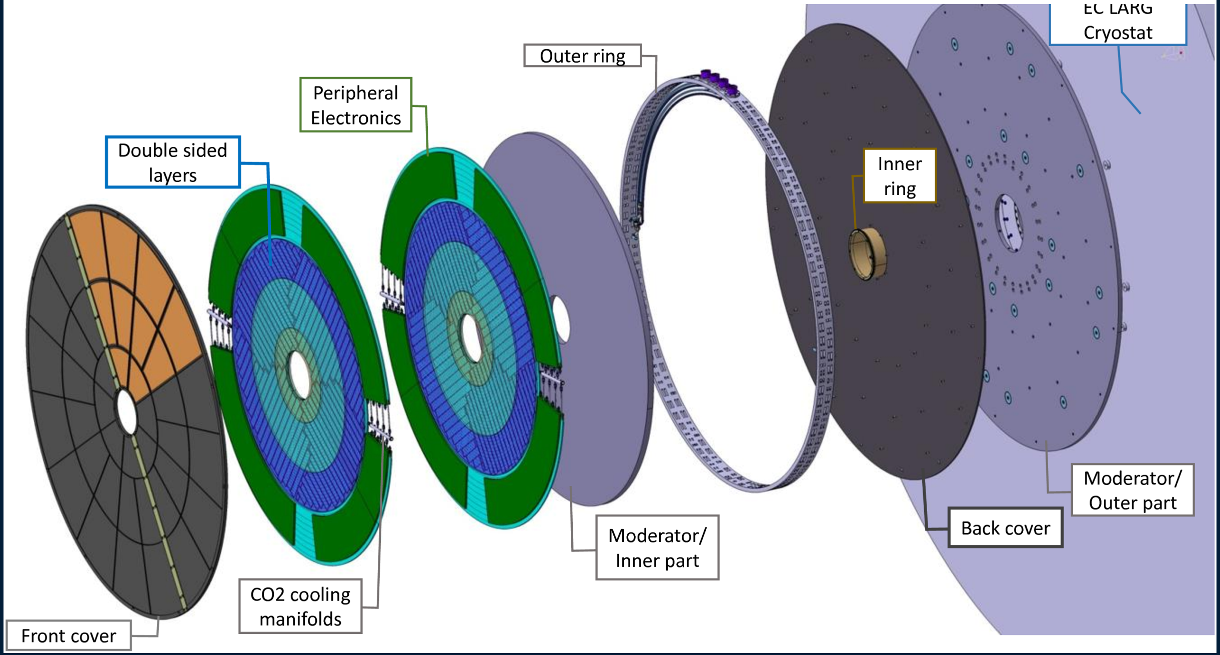


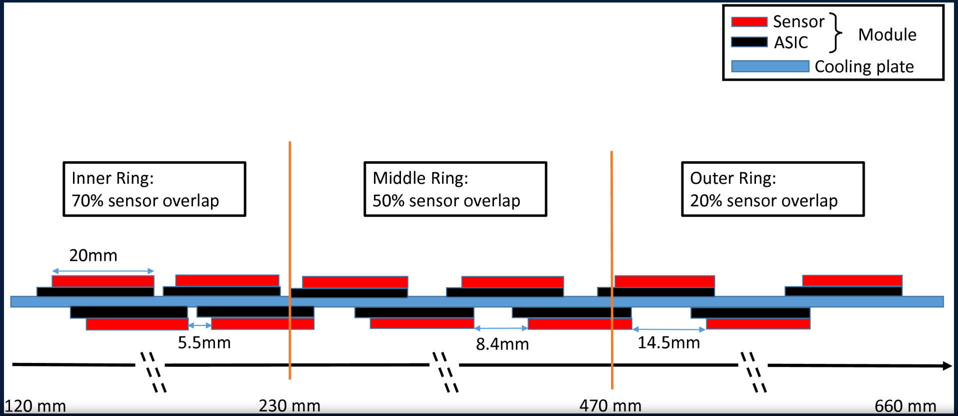
High Granularity Timing Detector

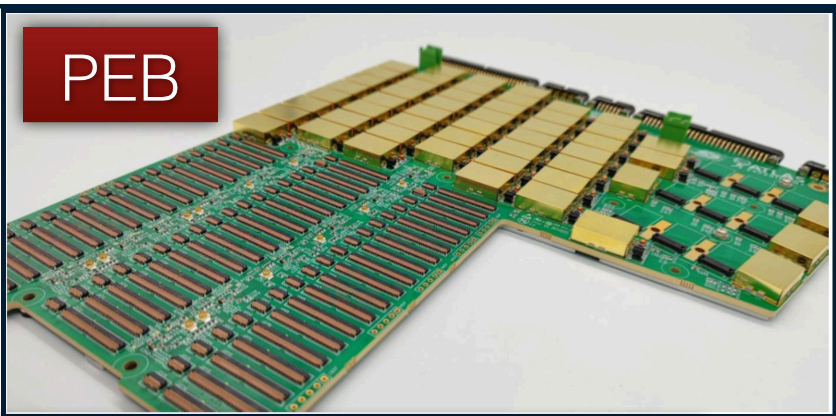
ATLAS-TDR-031

- New detector between ITk and endcap calorimeter will provide timing information (2.4<|η|<4.0), critical to reject pileup and improve vertex reconstruction
  - Timing resolution: 70 ps per hit, 30-50 ps per track
- Also provides precision bunch-by-bunch luminosity measurements
- Each end-cap: two double-sided disks, in total 8032 modules (3.6M readout channels)
- Required to be radiation hard up to 2.5 x 10^{15} neq/cm^2
- Low-Gain Avalanche Detector (LGAD) arrays with 1.3x1.3 mm^2 pixels (50 um thick), bump-bonded to ATLAS LGAD Timing Integrated ReadOut Chip (ALTIROC) ASICs
  - ALTIROC : Small jitter: 25 ps at 10 fC
- Peripheral electronics board (PEB) : on-detector electronics responsible for control, monitoring, data aggregation and transmission, as well as power distribution







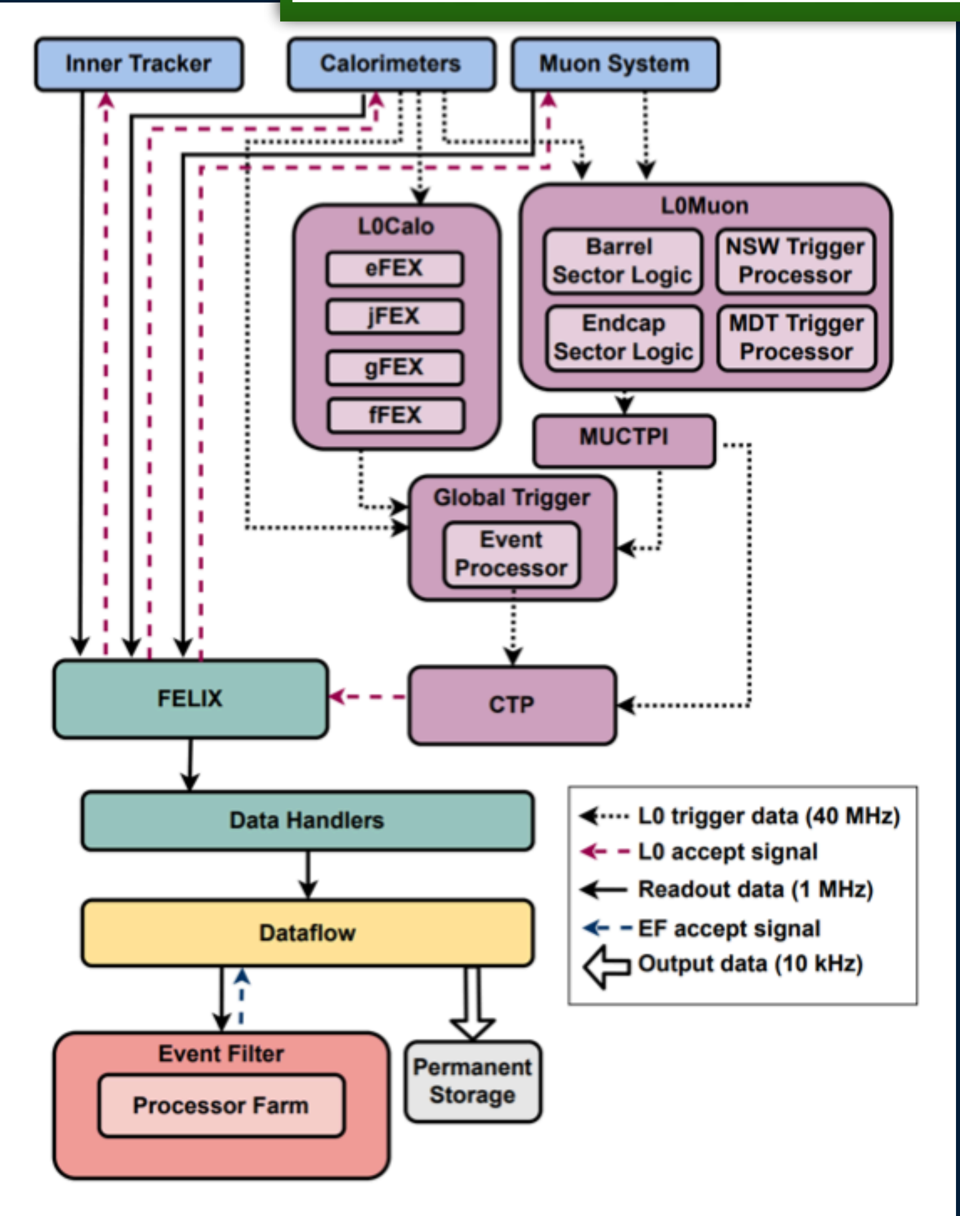


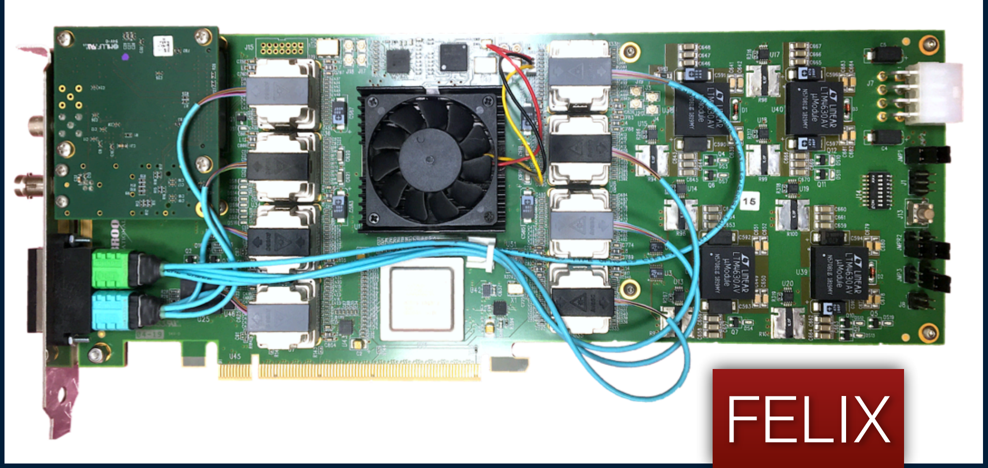
R&D coming to an end, moving towards mass production and construction of HGTD

Trigger and Data Acquisition

ATLAS-TDR-029-ADD-1

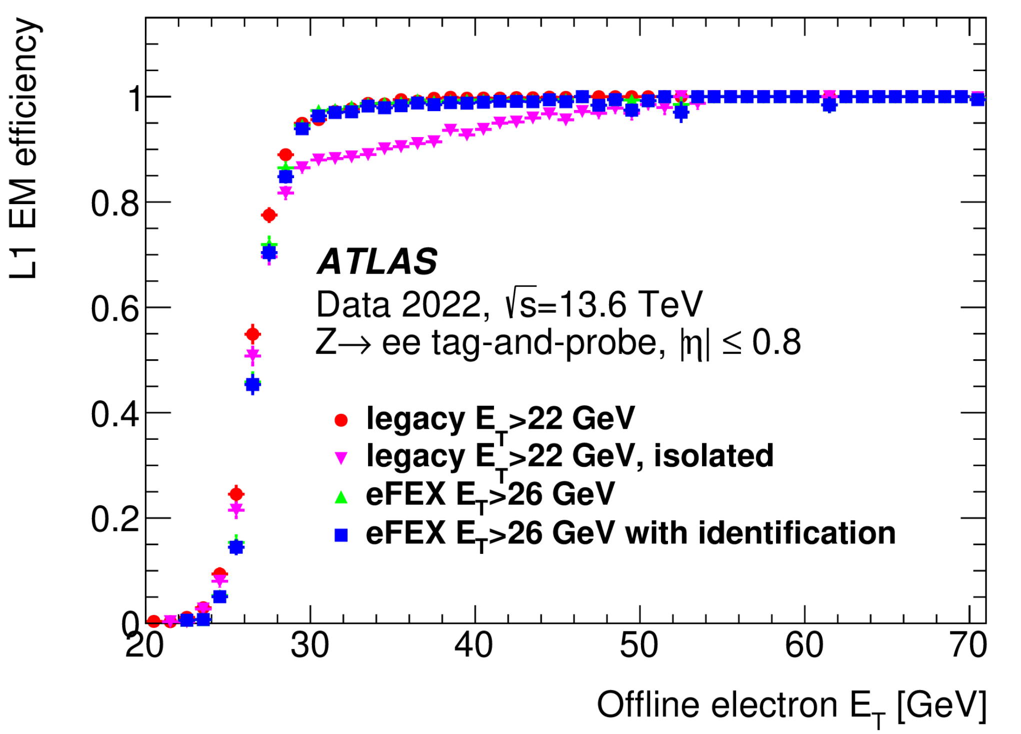
- The hardware trigger (L0) running at 40 MHz will be improved
  - decision rate will increase from 100 kHz to 1 MHz, latency 10 us
  - Full event-building at the L0 rate
  - Exploits improved detector granularity and coverage
- Software trigger (Event Filter) will reduce the final data collection rate to 10 kHz (~5x Run 3 output rate)
  - Accelerators (GPU), Machine Learning (ML) and Neural Networks (NN) for online reconstruction
- Increased detector readout rate will force a renewal of all the Front-End electronics
  - All linked via FELIX (custom FPGA cards) readout to DAQ – Replaces VME-based readout boards
- System currently in prototype and testing phase, with system-level integration tests ramping up



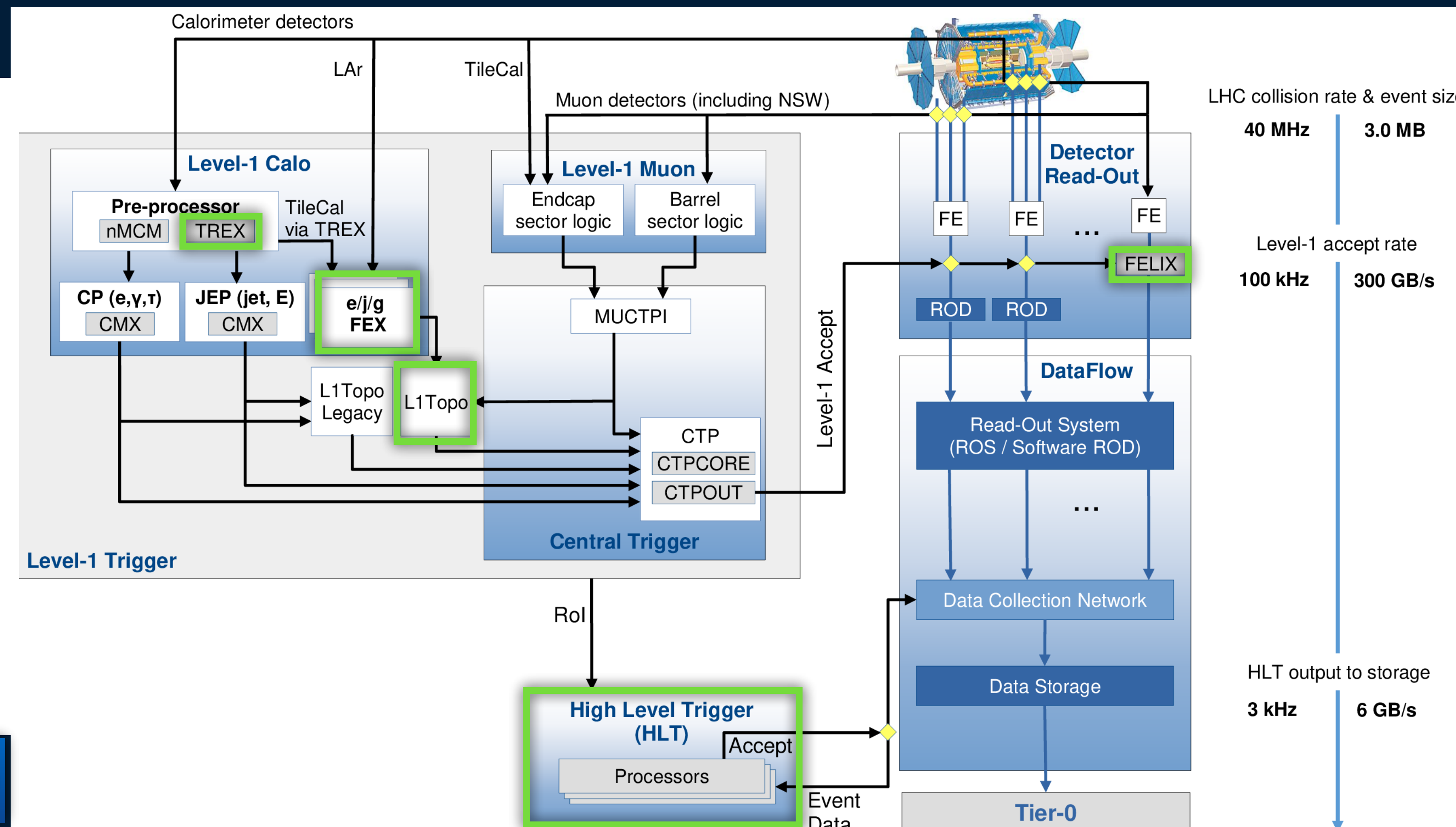


FELIX

Calorimeters: L1Calo (phase-1 upgrade)



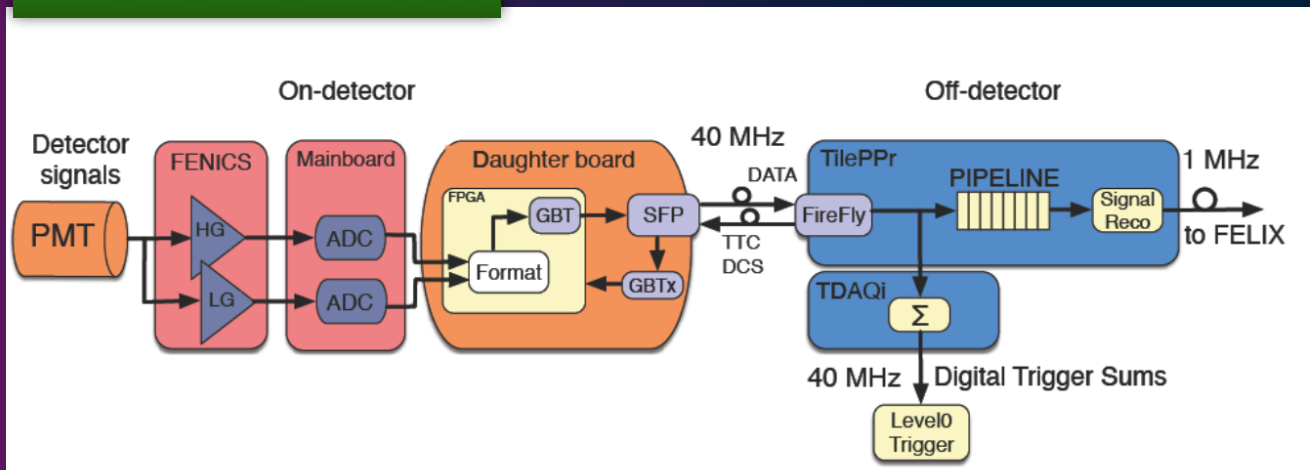
[JINST 19 (2024) P06029]



- New L1Calo hardware: higher granularity, digital calorimeter inputs —> greater background rejection via cuts on shower shapes & use of ML techniques
- High-Level Trigger algorithms were re-written to run as a Multi-Threaded (MT) environment with positive impact in memory footprint.
- Being commissioned in steps during 2022 (eFex/jFex) and 2023 (gFex) data taking

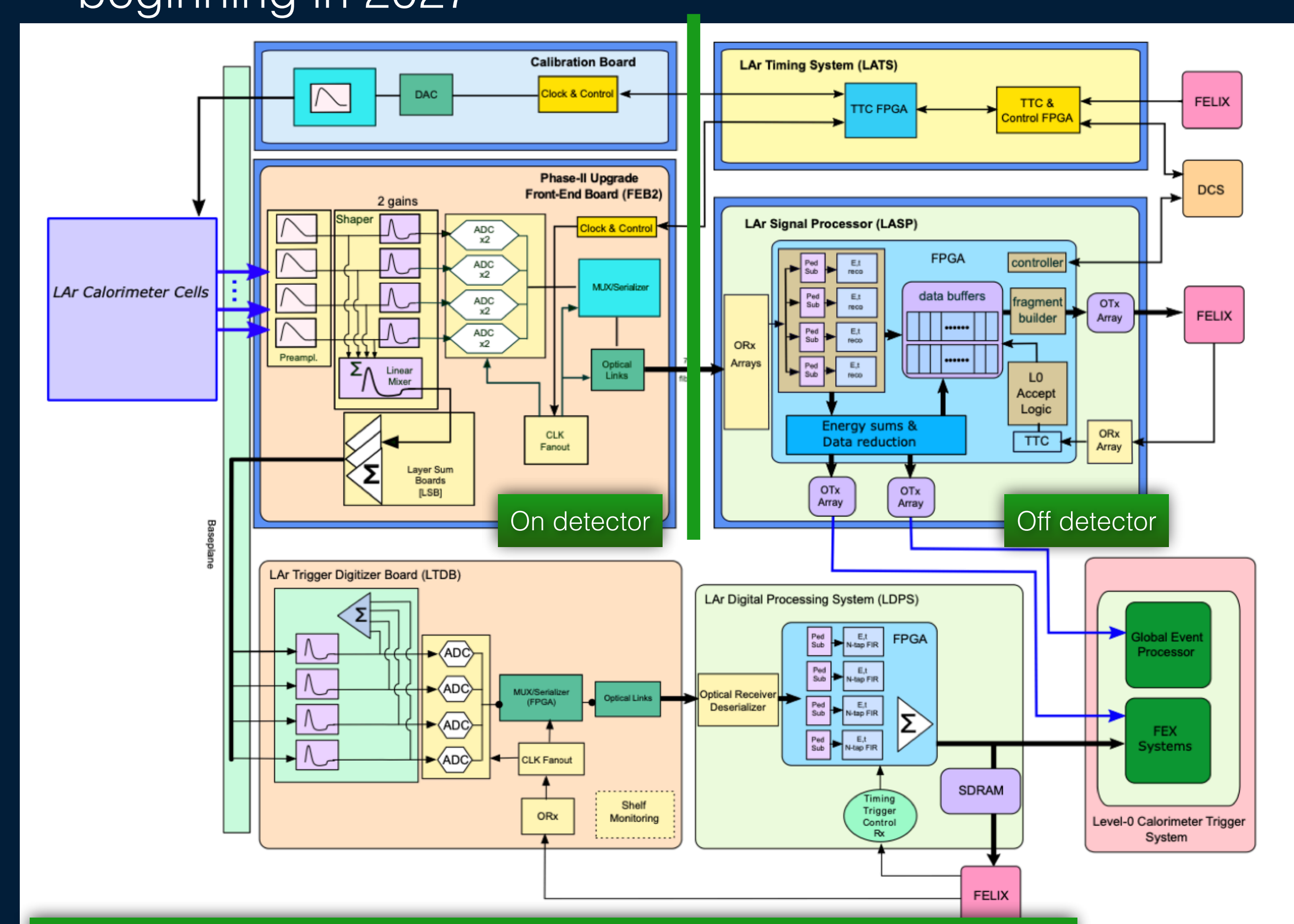
Calorimeters

ATLAS-TDR-028



- Tile Calorimeter, improve redundancy and reliability, need to cope with higher radiation
  - Replacement of on and off detector readout electronics
    - Make readout architecture compatible with new fully digital Trigger and DAQ architecture: 40 Tb/s over 6000 optical fibres
      - Replacement of LV and HV systems
      - Upgrade of calibration systems
  - Replacement of 10% of the PMTs
  - New super-drawer mechanics that house the electronics

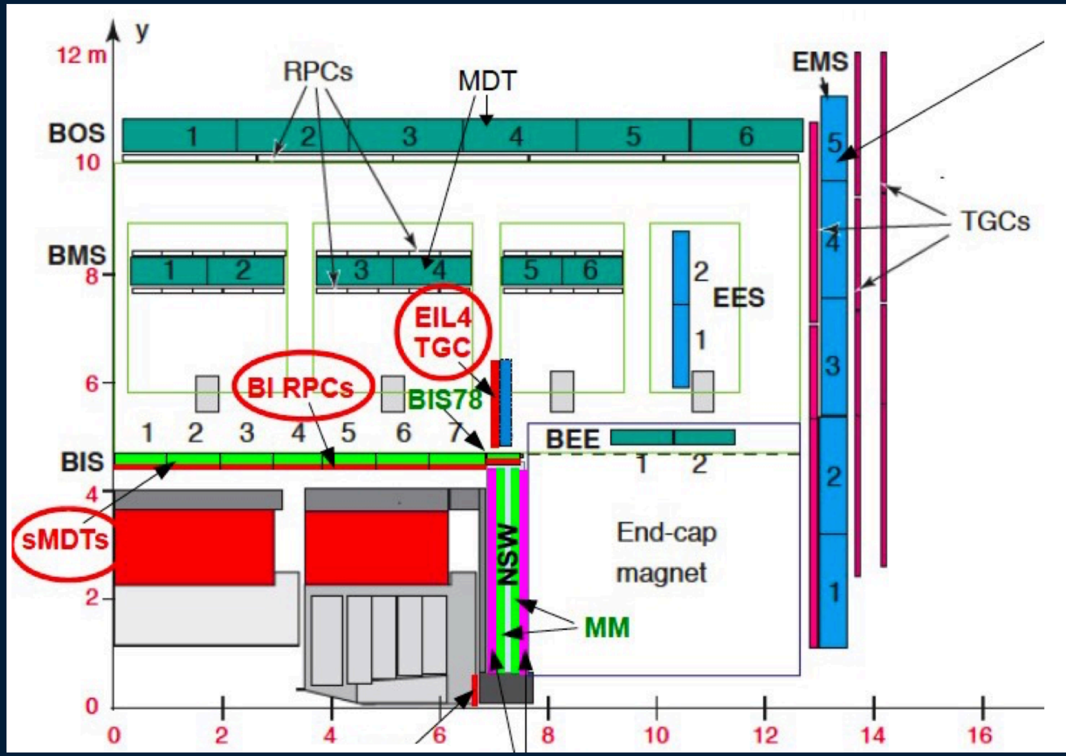
- LAr (electromagnetic calorimeter) : read-out electronics being re-designed to cope with the harsher data-taking conditions expected at the HL-LHC
  - On-detector: New high-precision front-end electronics
  - Off-detector: ATCA boards for waveform feature extraction (energy, time)
- Final designs for the off-detector boards and firmware are underway
- On schedule for installation into ATLAS cavern beginning in 2027



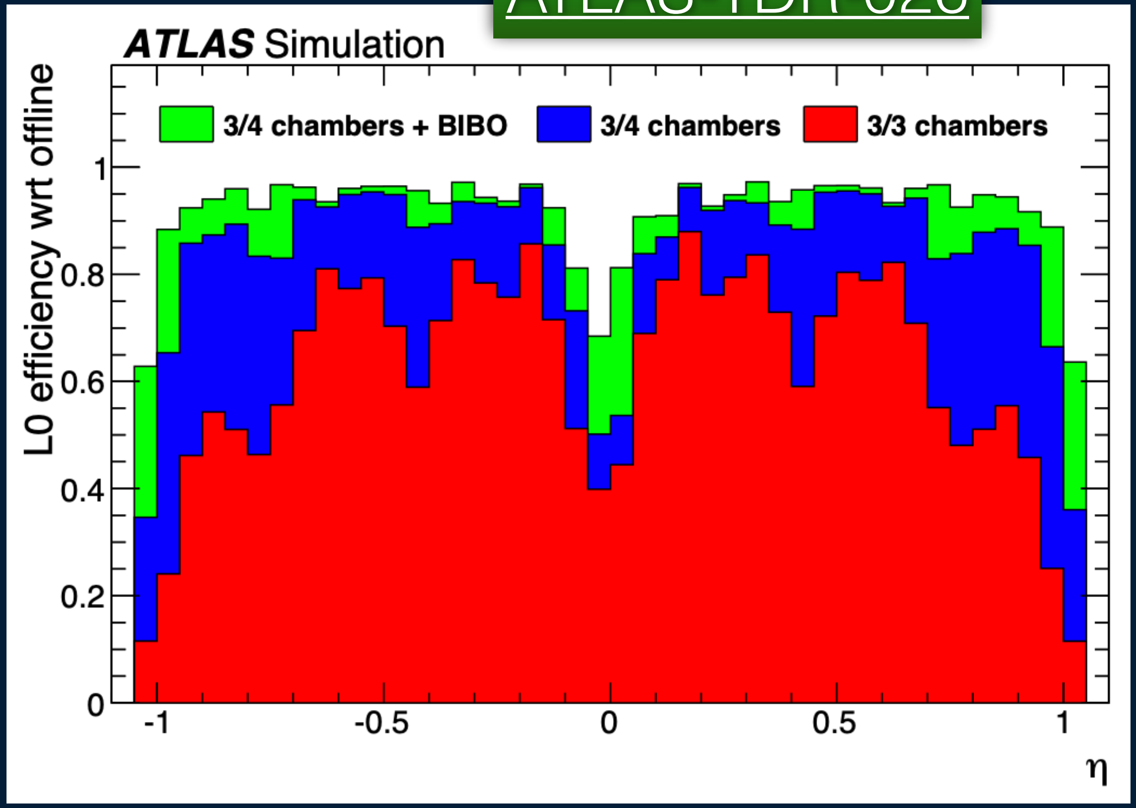
Nucl.Instrum.Meth.A 936 (2019) 274

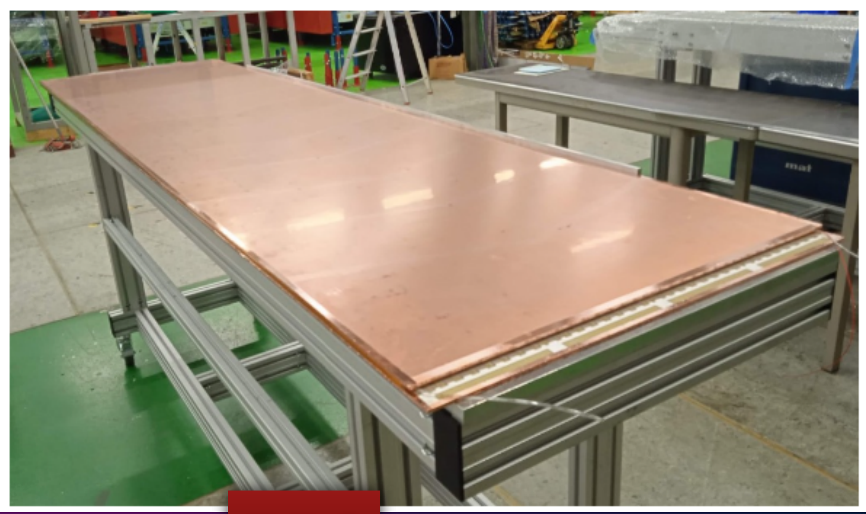
Muon systems

- Addition of layers of sMDT, TGC, RPC
  - In production, many chambers finished
- MDT will provide L0 trigger information
- Readout/trigger electronics upgrade to fit in the new TDAQ upgrade
- Chamber production status: about to start for RPC, ongoing for TGC, complete for sMDT
- Improved coverage, trigger uniformity, momentum resolution, fake rates



ATLAS-TDR-026





RPC

sMDT

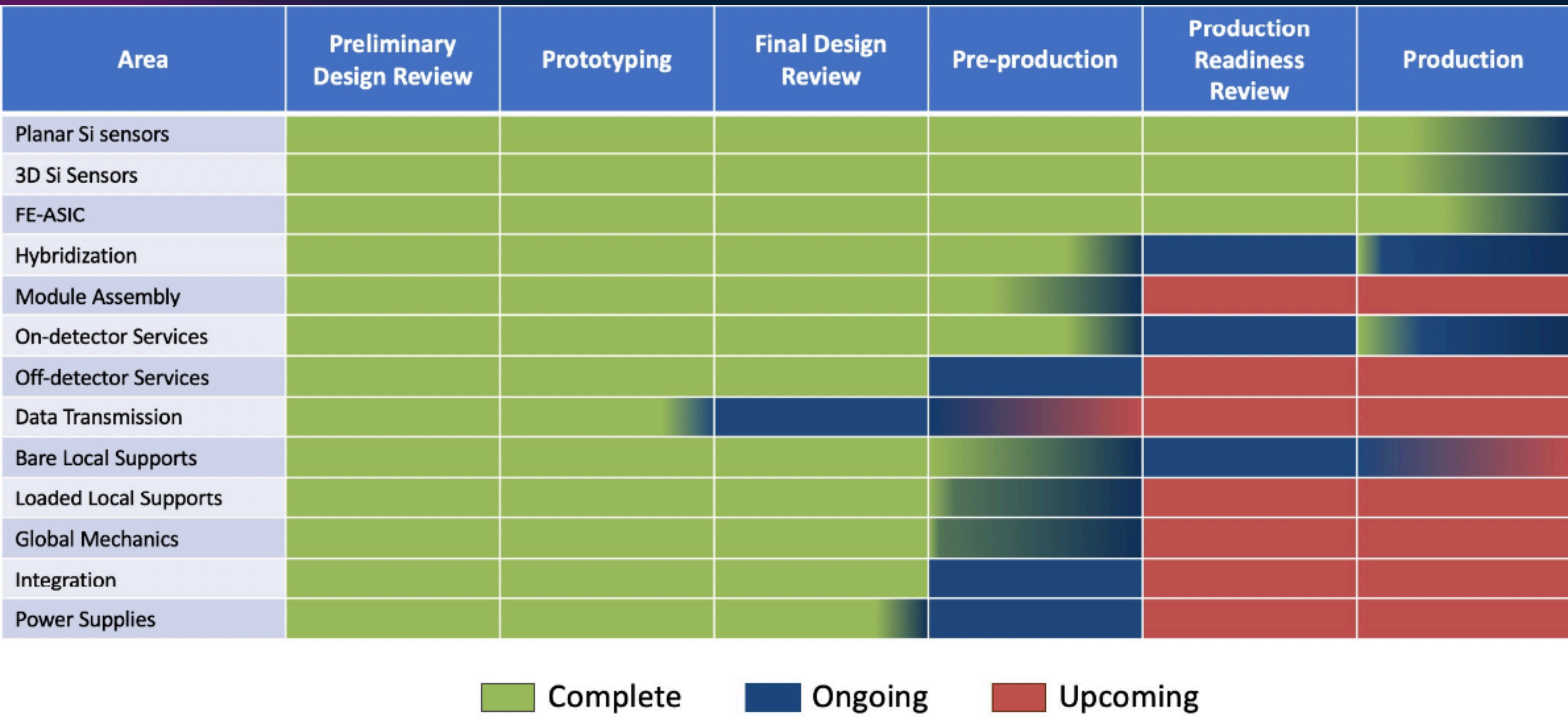
Summary

- Hard efforts to improve performance as pileup conditions increase at LHC, and will become even harsher at HL-LHC
  - Machine-Learning is a key player for the future, in almost all areas
- Ambitious upgrade programme to cope with HL-LHC new conditions strongly relies on new hardware aspects
  - New tracker, use of timing, renewed electronics…
  - Schedule might need to adapt to LHC running plans for the coming 2 years

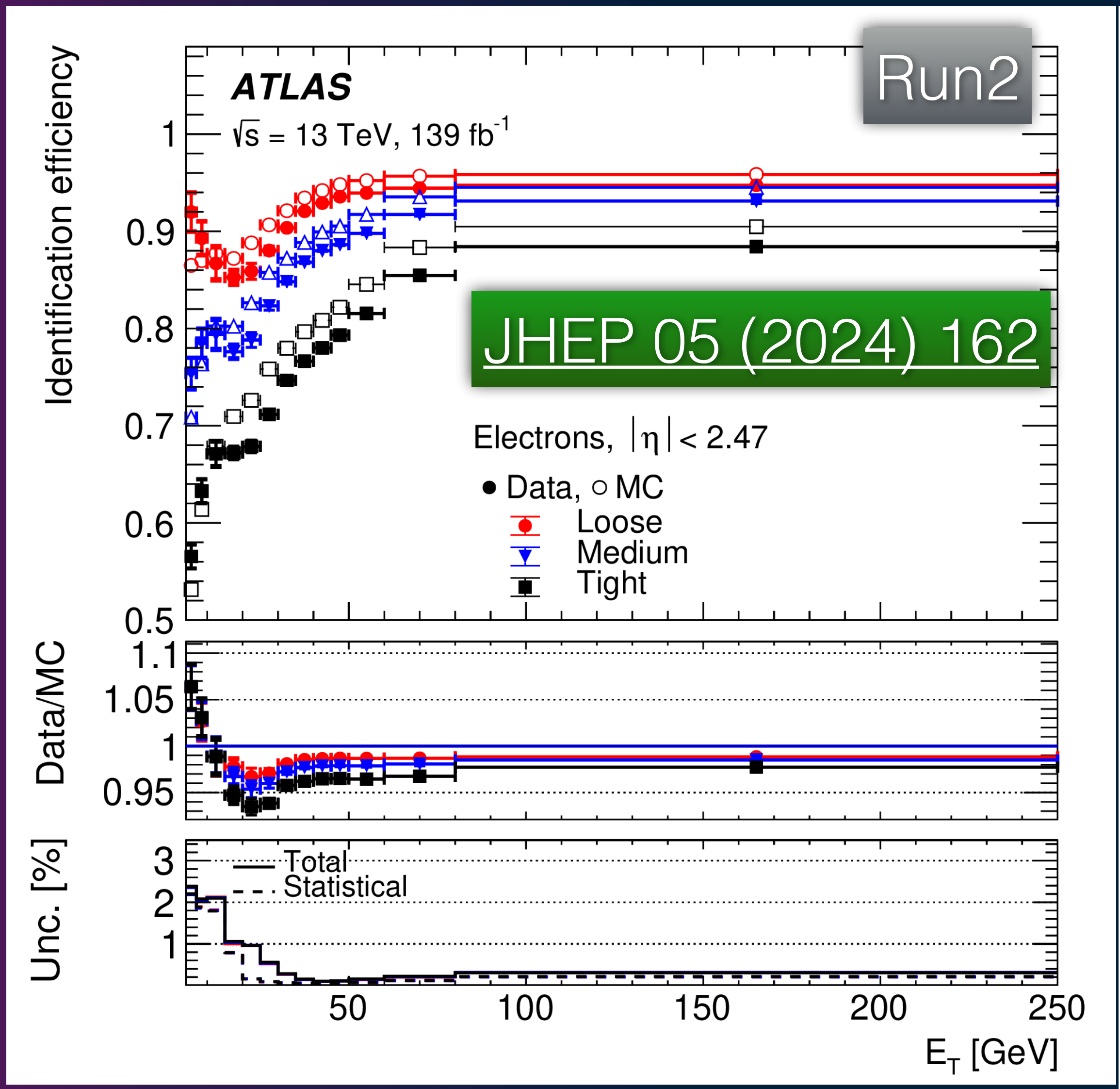
BACKUP

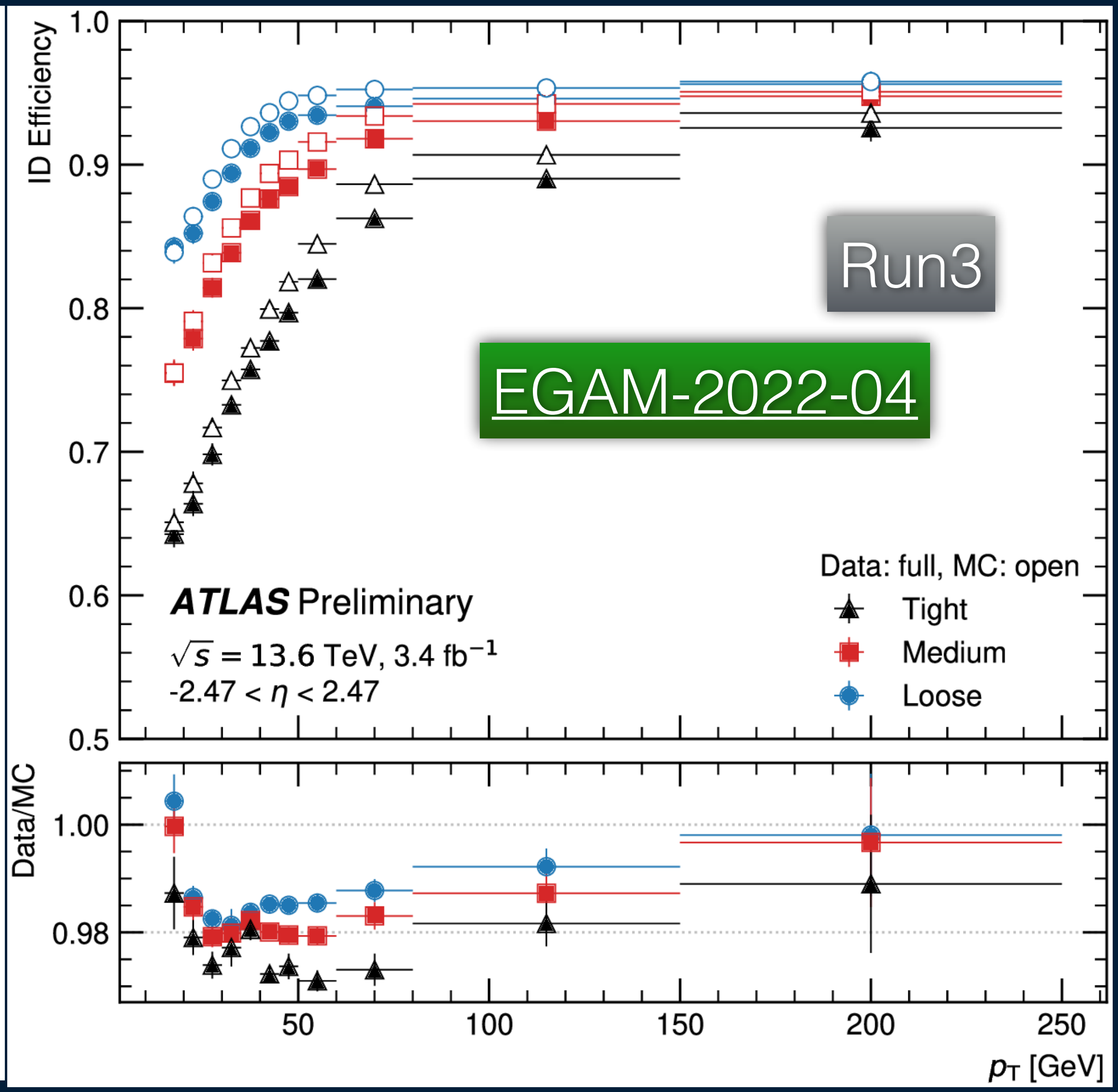
ITk Pixel: project status

Taken from F. Muñoz Sánchez



Performance : electrons/photons





- Preliminary energy calibration and efficiencies ready for Run3
  - Comparable efficiencies as in Run2
  - Larger uncertainties, expected to be reduced in the future