The ATLAS detector evolution towards the High Luminosity era

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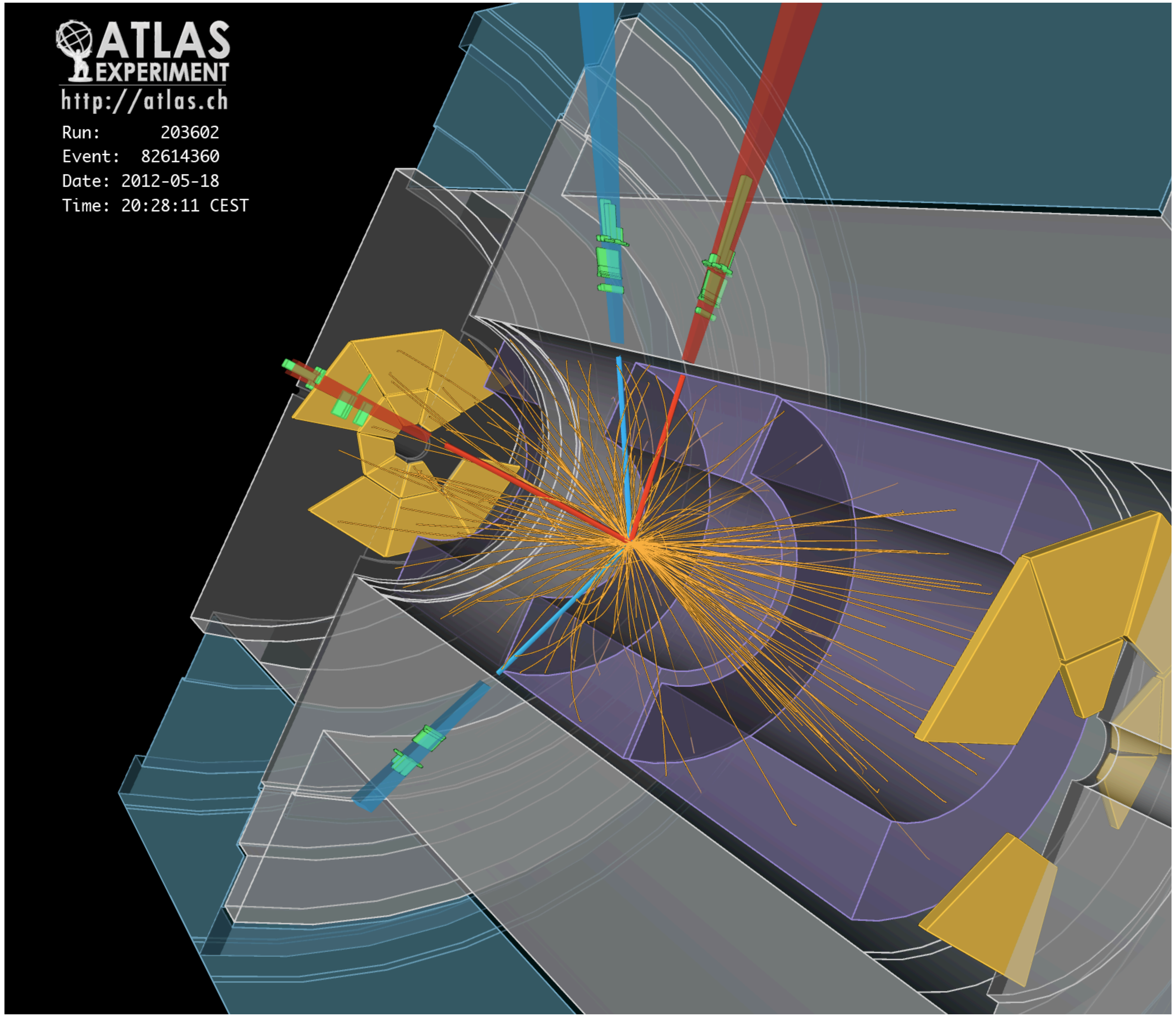
International Conference on Technology and Instrumentation in Particle Physics
25 May 2021

Physics motivation for High Luminosity LHC

Extend the reach of LHC physics program

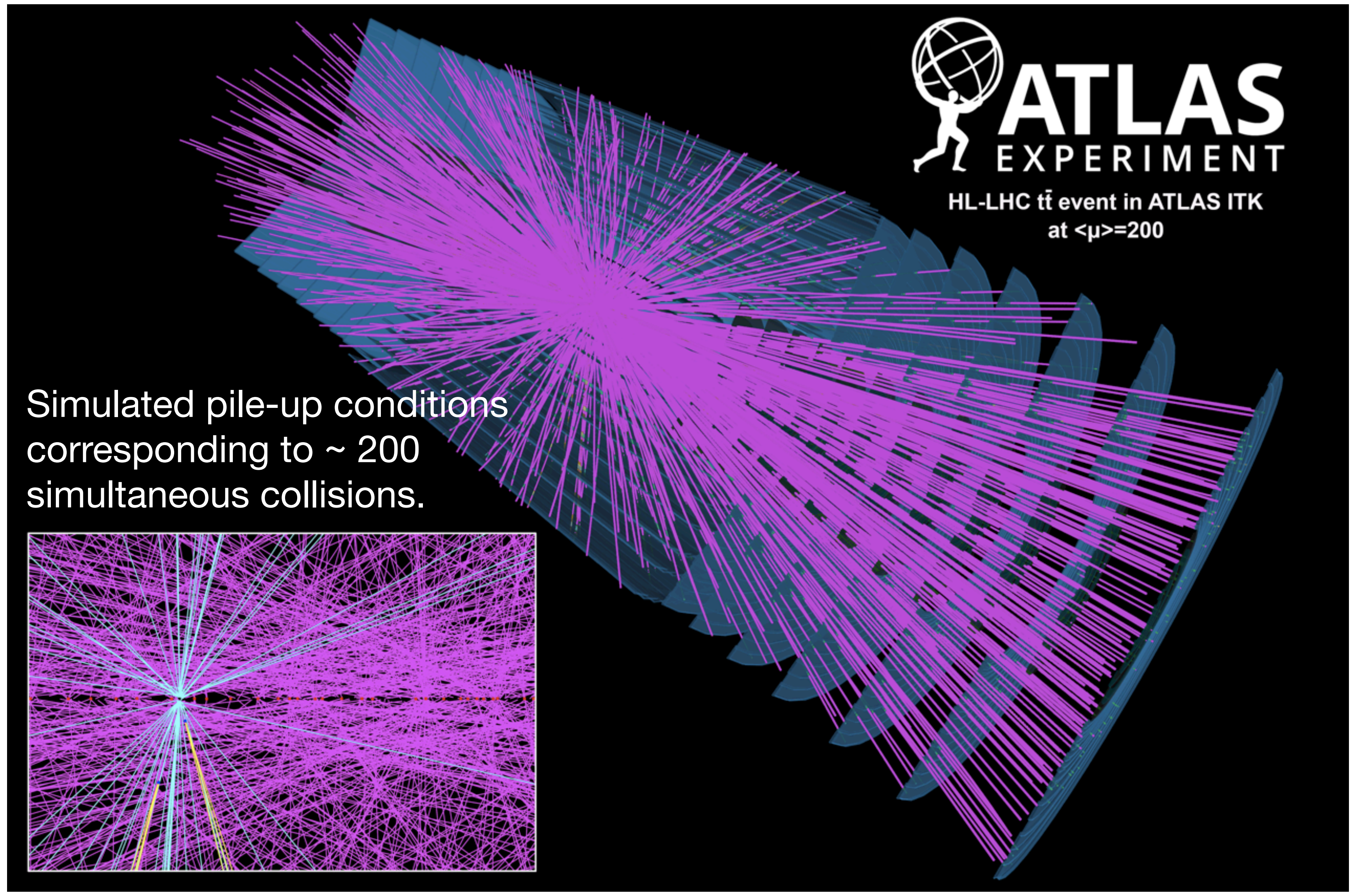
- Pursue exploration of Electroweak Symmetry Breaking in the Standard Model
    - Precision measurements (e.g. Higgs couplings, gauge boson cross-sections)
    - Search for SM rare processes (e.g. $H \to \mu\mu$, weak boson scattering, etc.)
- Search for new physics in new regions of phase space
    - Rare processes
    - Challenging experimental signatures



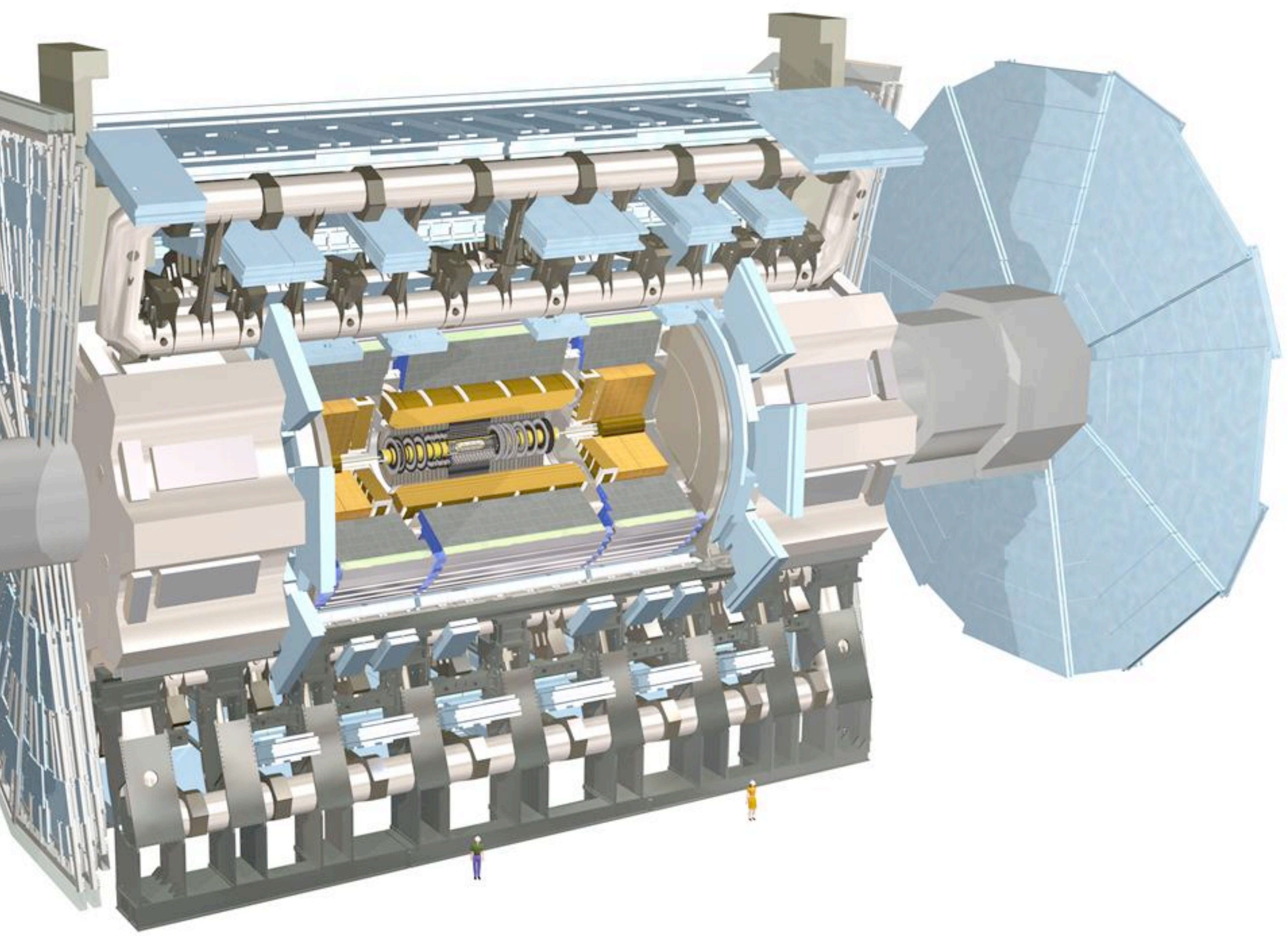
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplaysFromHiggsSearches

The road to High Luminosity LHC

- **HL-LHC design targets**
  - Center-of-mass energy: 14 TeV
  - Peak levelled instantaneous luminosity of $7.5 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - Total integrated luminosity of up to $4000\ \mathrm{fb}^{-1}$
- **High Luminosity Challenges**
  - High pile-up up to ~ 200 collisions/bunch crossing
  - High radiation levels: $\sim 10^{16}\ \mathrm{n_{eq}/cm^2}$ and 10 MGy
- **Major upgrades to the ATLAS detector necessary to maintain good physics performance under HL-LHC conditions**
  - Upgrades designed to be carried out in two phases



ATLAS detector evolution

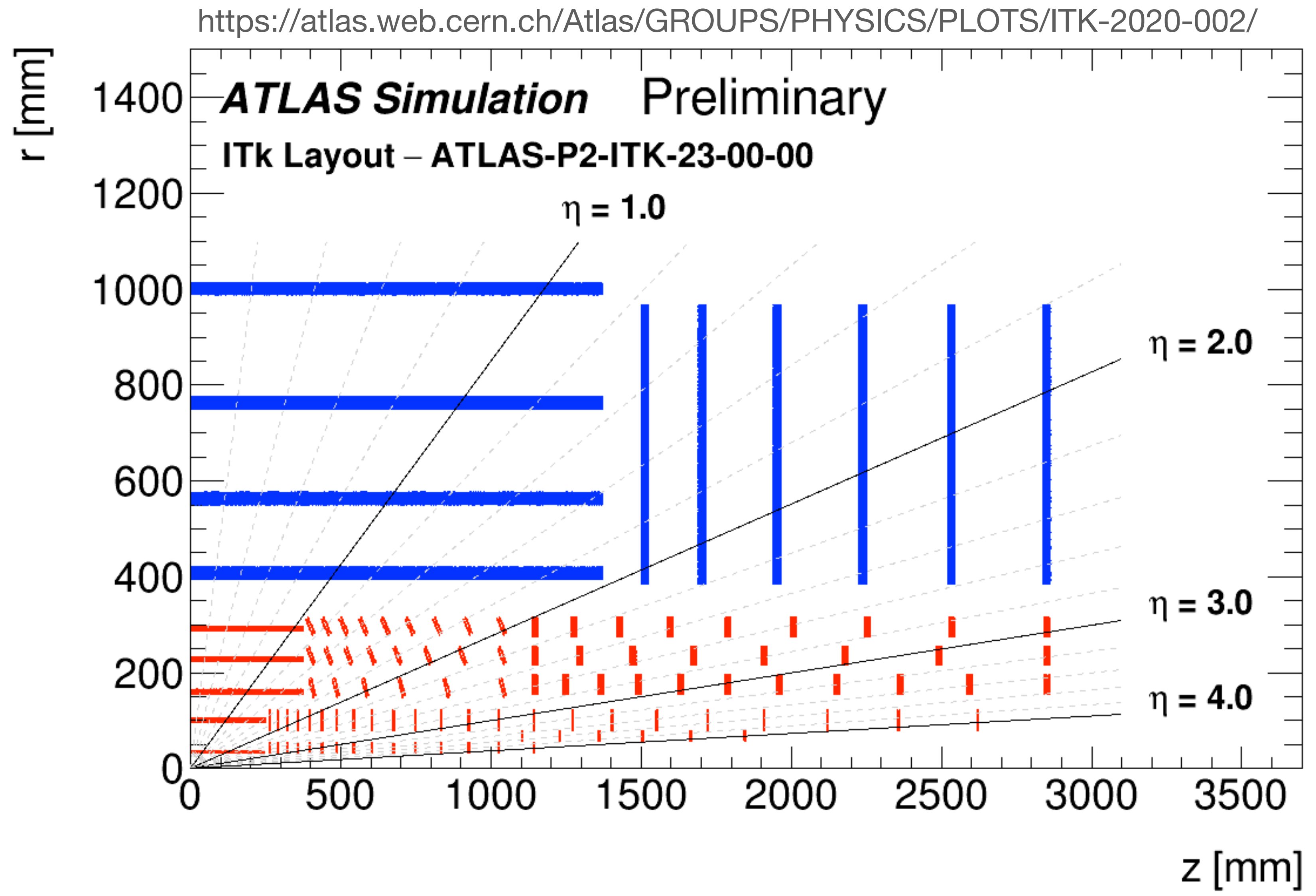


Other systems also being upgraded, e.g. LUCID-3 and BCM' used for luminosity measurements.

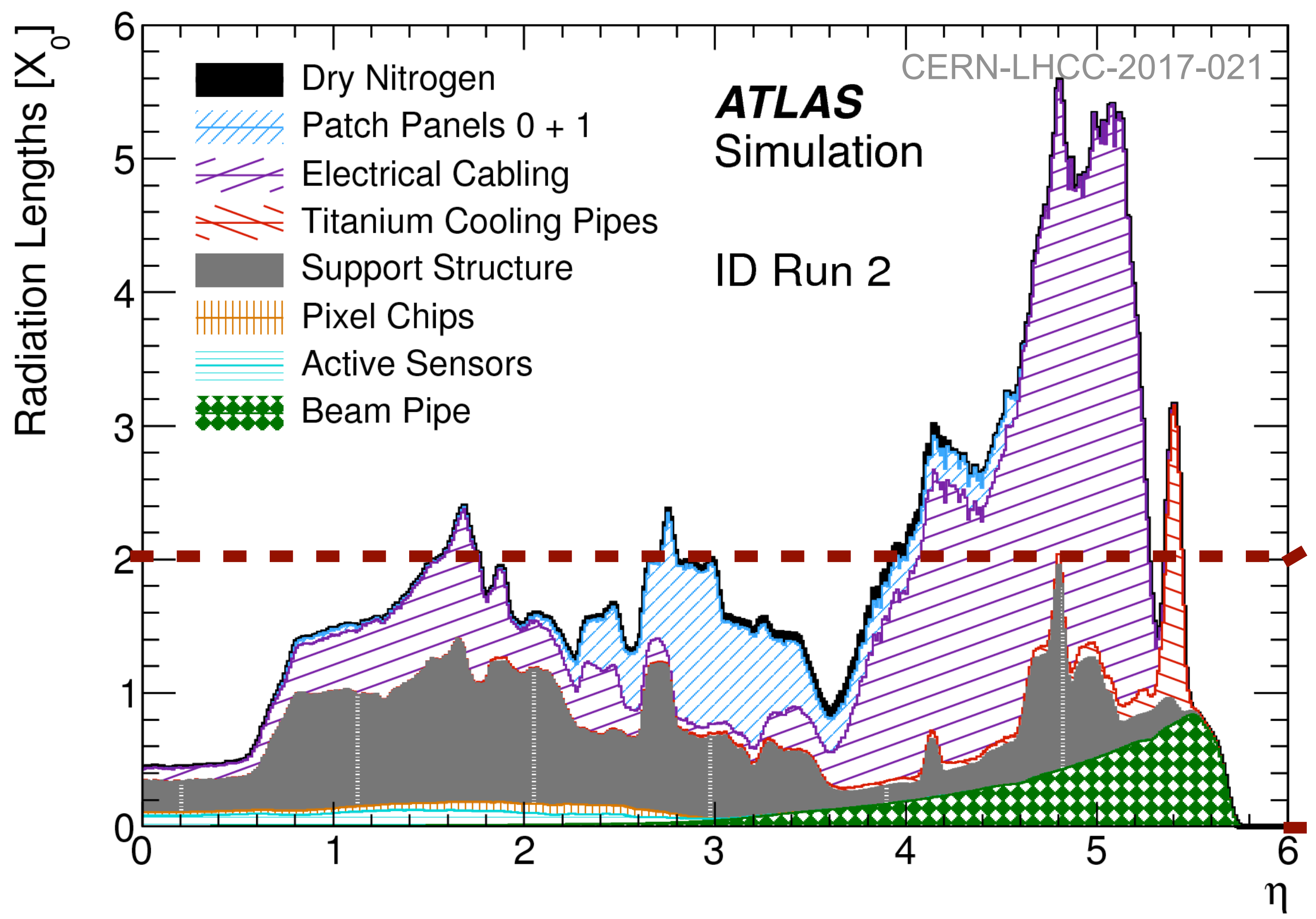
	Phase-1 Upgrade Improved trigger capabilities (granularity, new functionalities)	Phase-2 Upgrade Full detector capability for HL-LHC
Tracking		• New **all-silicon inner tracker** with $\lvert\eta\rvert < 4$
Timing		• New **high-granularity timing detector**
Calorimeter	• LAr: New L1 trigger electronics	• LAr: New continuous readout • Tile: New continuous readout
Muon	• **New Small Wheels**	• New **muon chambers** in barrel inner region. • New continuous readout
TDAQ	• New trigger hardware - Increase purity of e/γ triggers - Reduce muon trigger fake rate in forward regions	• New trigger hardware - Achieve first level trigger rate of 1 MHz with 10 μs latency. - Increase final trigger output rate to 10 kHz - New "hardware track trigger" used in Event Filter.

Tracking Upgrade (Phase-2)

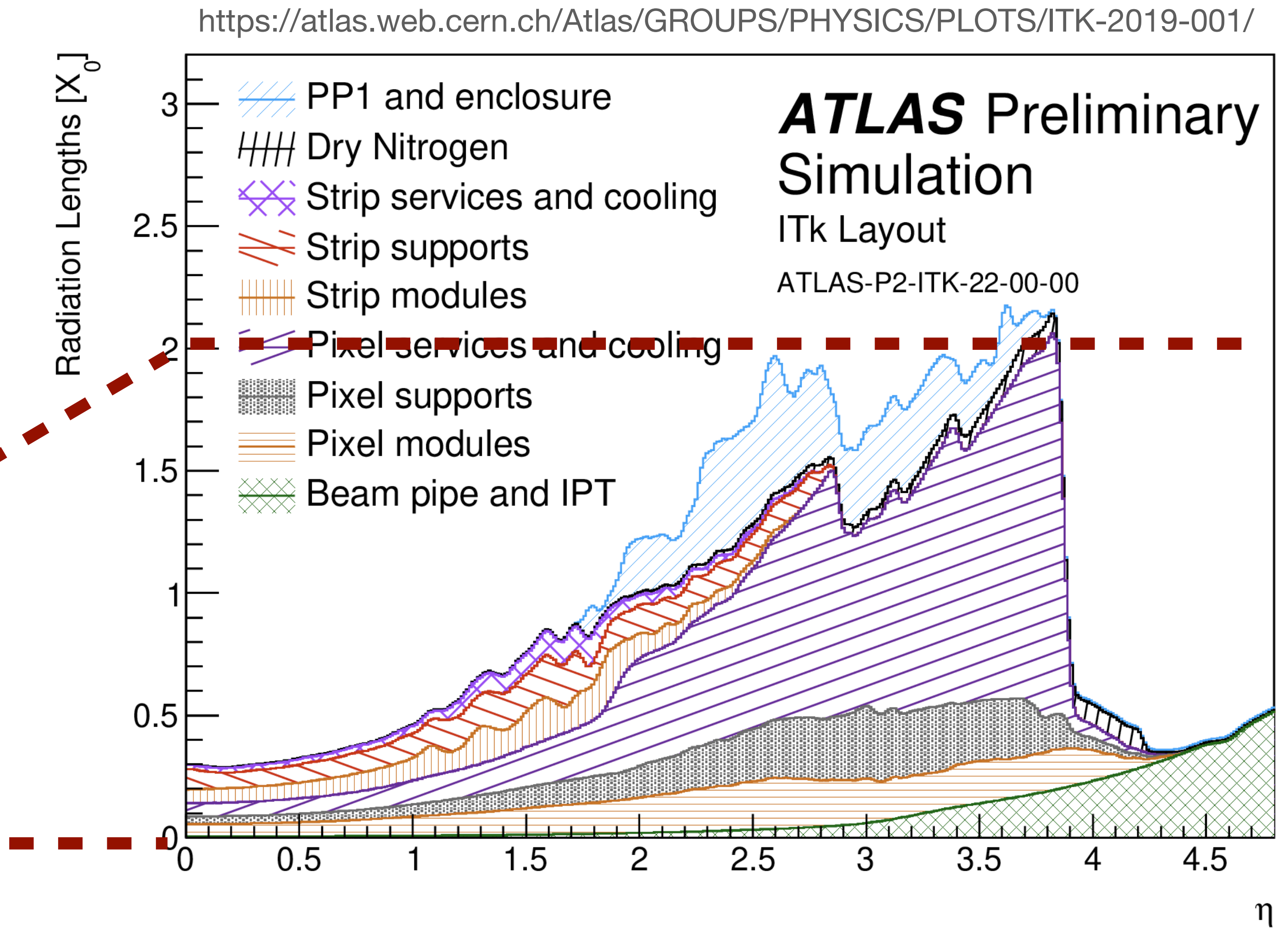
- New **all-silicon inner tracker** (ITk)
  - **Pixel** + **Strips** sensors
    - Planar and 3D Pixels: $50 \times 50\mu m^2$ ($25 \times 100\ \mu m^2$ in flat pixel barrel)
    - Strips width: $\sim 75\ \mu m$
    - 4 double-strip + 5 pixel layers = minimum of **13 hits in barrel (9 hits in forward) region.**
  - Large pseudo rapidity coverage $|\eta| < 4.0$
  - Total ~ 178 m^2 of silicon
  - Innovative pixel support structures to position modules at an angle.



- ITk has less material than current Inner Detector (despite increase in channels, data rates, …)



Current Inner Detector

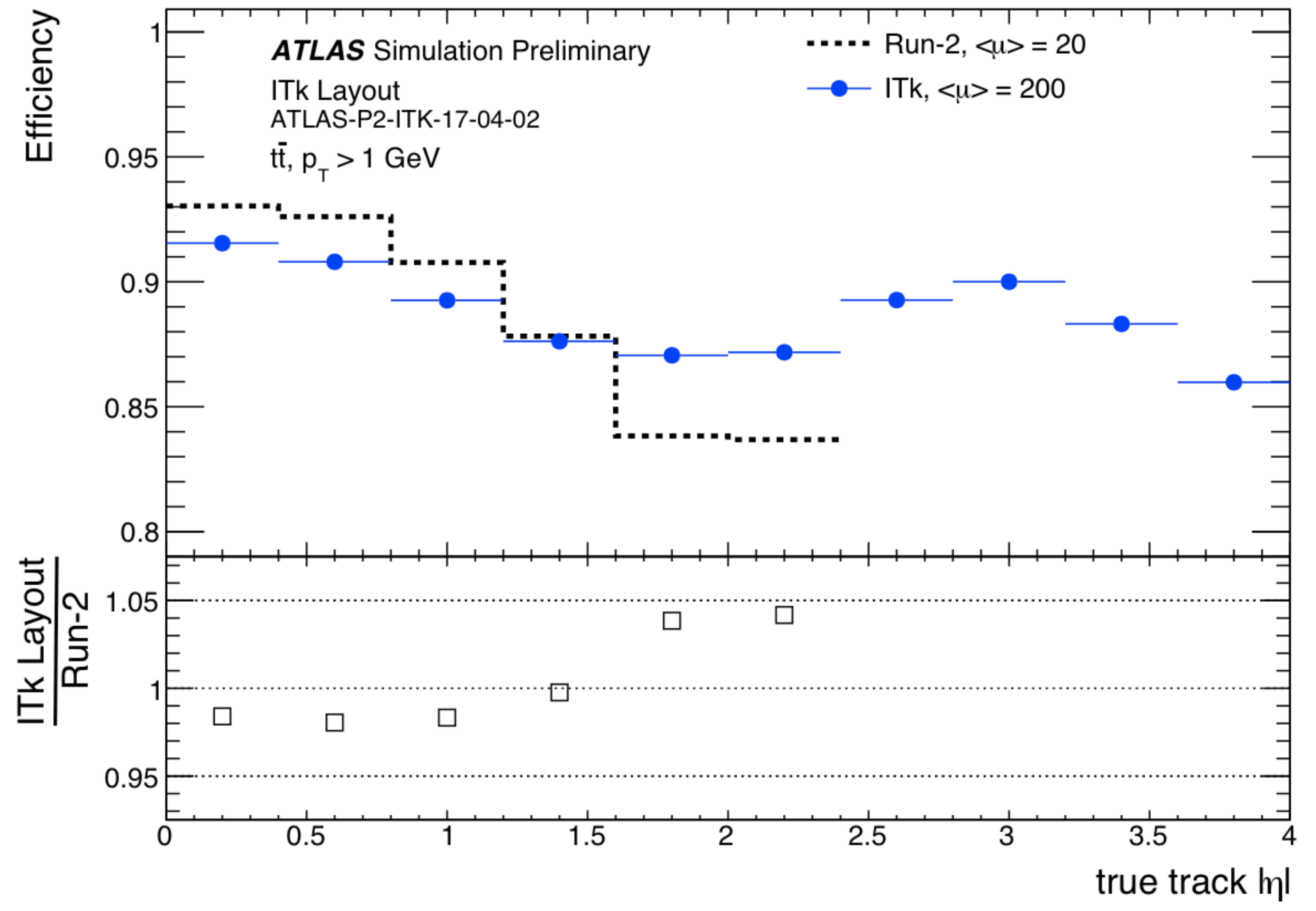


New ITk

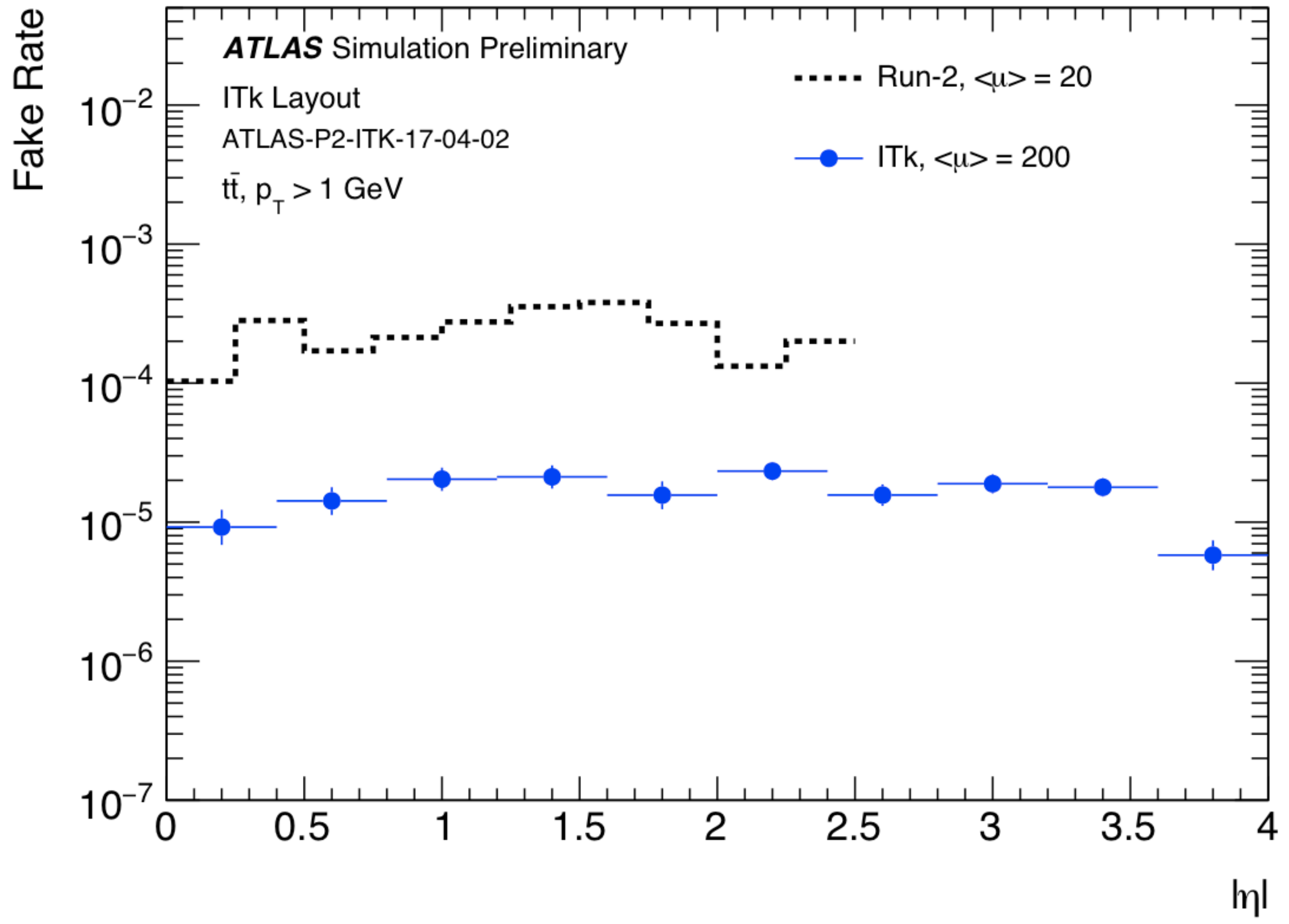
Tracking Upgrade: Expected performance

- Track reconstruction efficiency
  - Comparable to current inner detector (ID).
  - Track efficiency ~ uniform down to $|\eta|$ of 4, despite pile-up of 200.

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/IDTR-2019-009/



- Fake rate
  - Order of magnitude reduction in fake rate with ITk compared to current ID.
  - Achieve high purity tracking even with pile-up of 200.

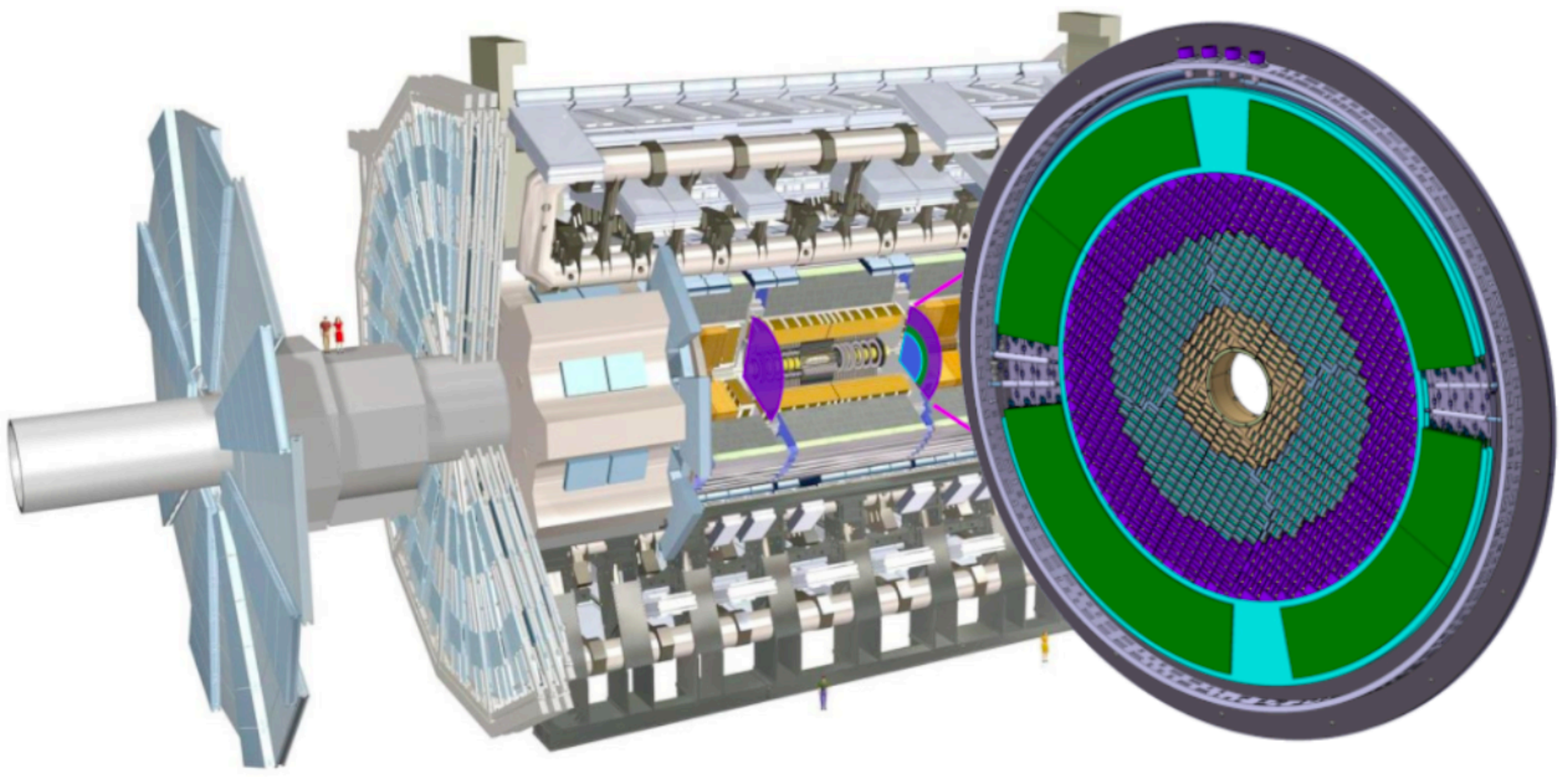


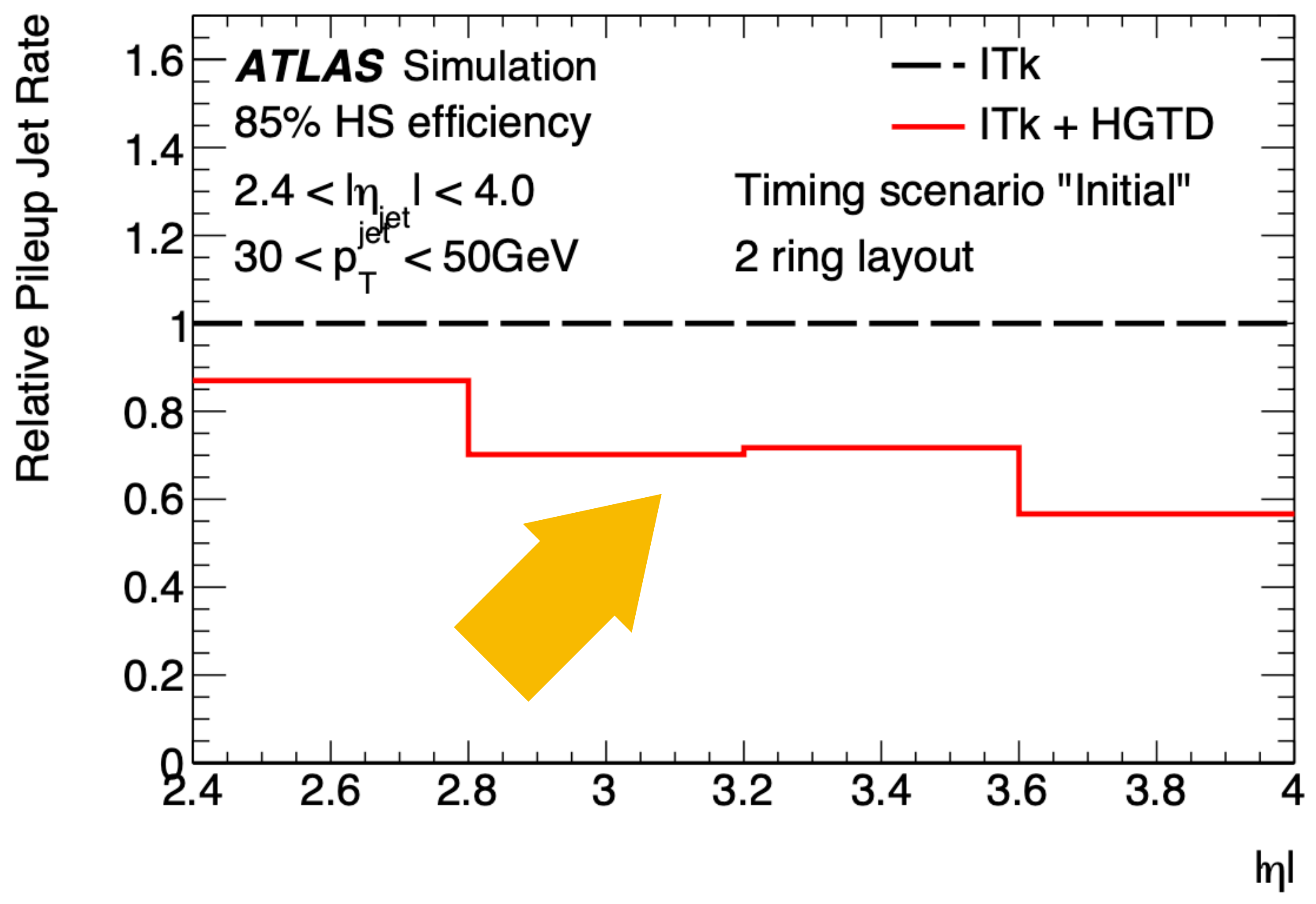
ITk expected to outperform current Inner Detector in all relevant parameters.

High-Granularity Timing Detector (Phase-2)

ATLAS-TDR-031

- HGTD designed to improve ATLAS performance in the forward region under increasing pile-up using timing information.
  - Use high-precision timing information to distinguish between collisions occurring close in space but well-separated in time.
- Challenges:
  - New detector system constrained by limited available space.
    - Thickness of 12.5 cm
  - Require time resolution: 30-50 ps/track
  - Radiation hardness
    - Expect fluence > $5.6 \times 10^{15}\ \mathrm{n_{eq}/cm^2}$
    - Total ionizing dose ~ 3.3 MGy
- HGTD design:
  - **Silicon Low Gain Avalanche Detector** (LGAD) technology
  - Located between barrel and endcap calorimeters, covering $2.4 < |\eta| < 4.0$.
  - Two disk/side and two sensor layers/disk.
  - Detector segmented into replaceable rings.



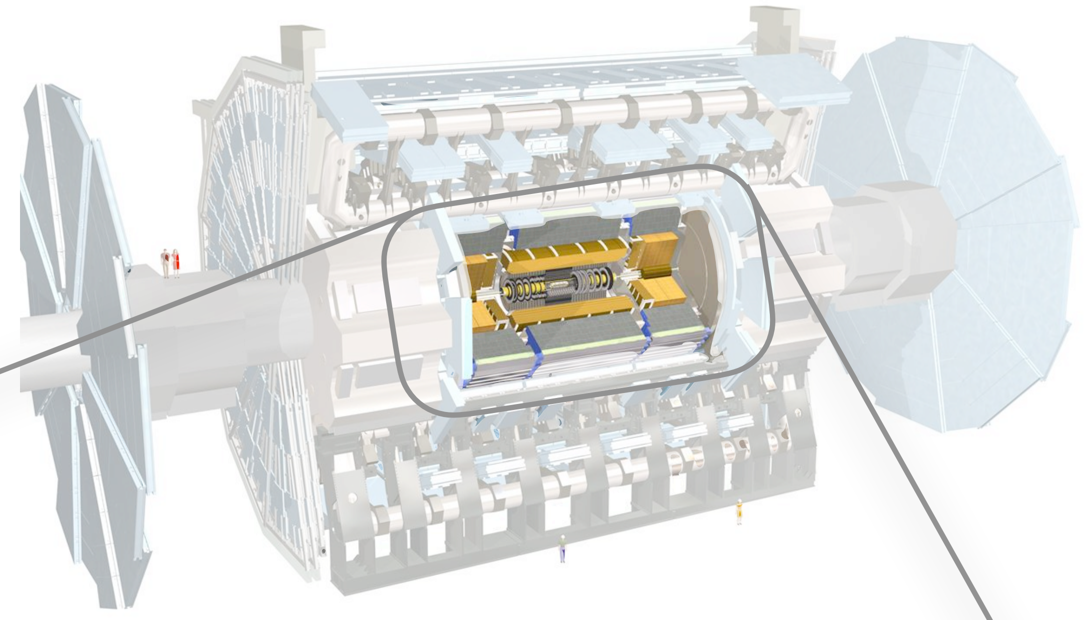


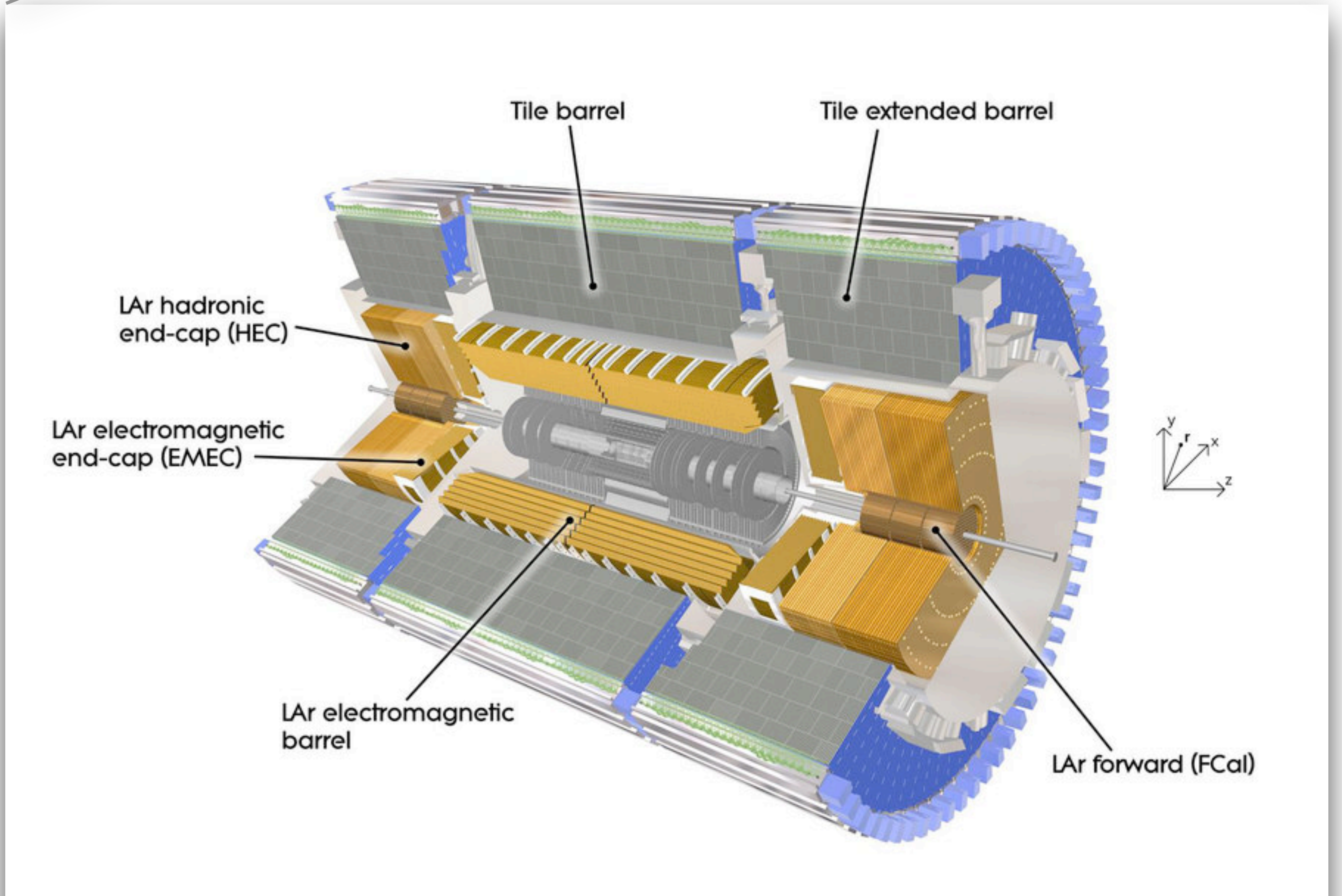
Calorimeters Upgrade

- ATLAS calorimeters expected to continue to operate reliably during HL-LHC data taking.

- **Phase-1 Upgrade** (see next slide)
  - New trigger electronics.
  - Improve trigger energy resolution and efficiency for electrons, photons, τ leptons, jets, and missing transverse momentum.

- **Phase-2 Upgrade**
  - New readout electronics enabling data streaming at 40 MHz for LAr and Tile calorimeters.
    - Radiation tolerance requirements at HL-LHC beyond existing electronics.
    - Current readout electronics incompatible with planned upgrade of T/DAQ system.





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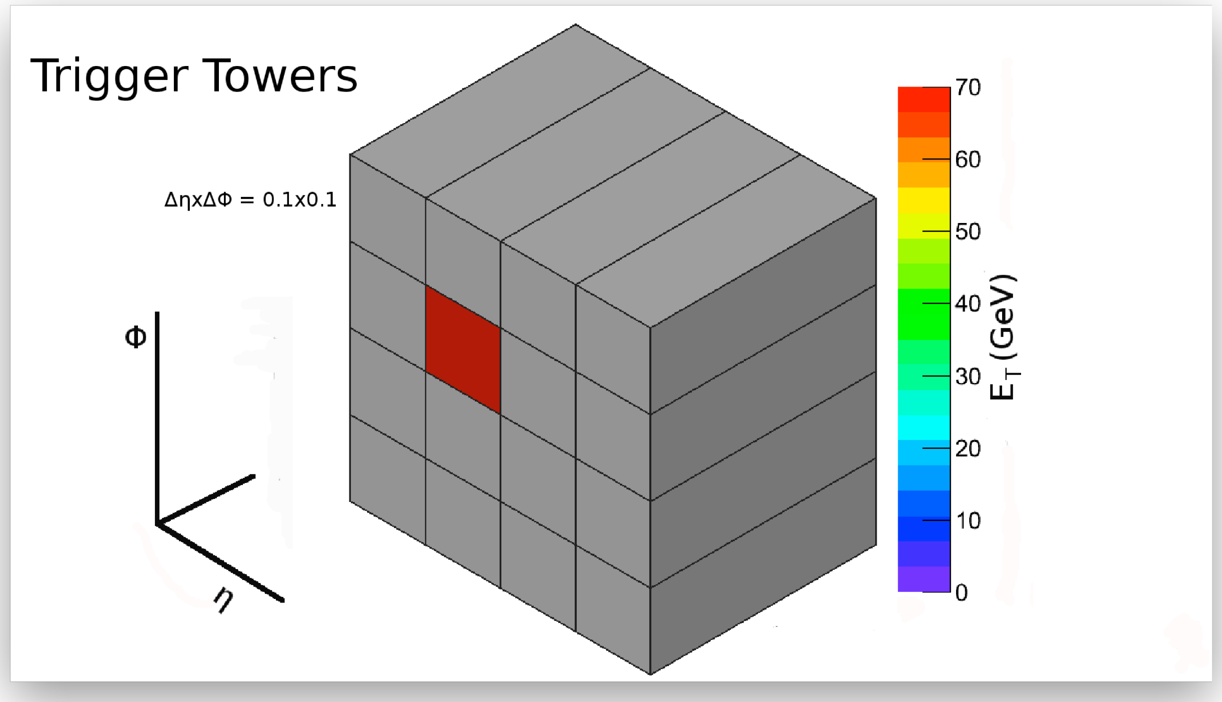
Calorimeters Upgrade: Run-3 Performance

Run-2



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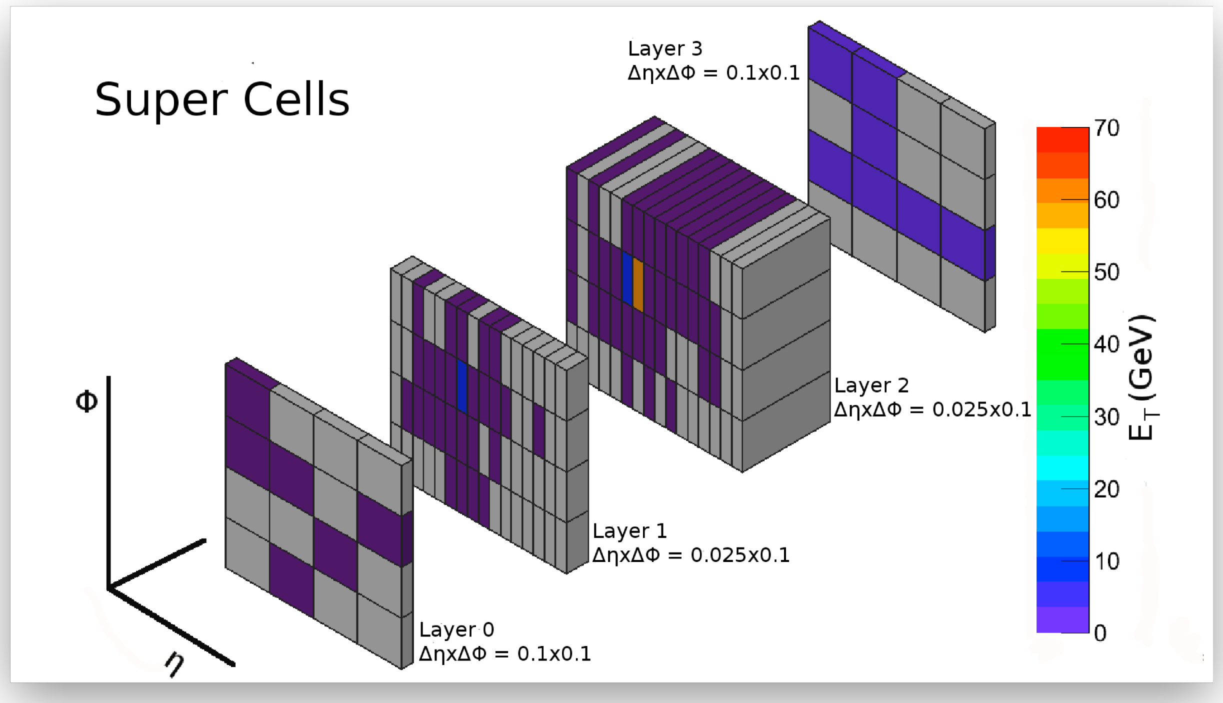
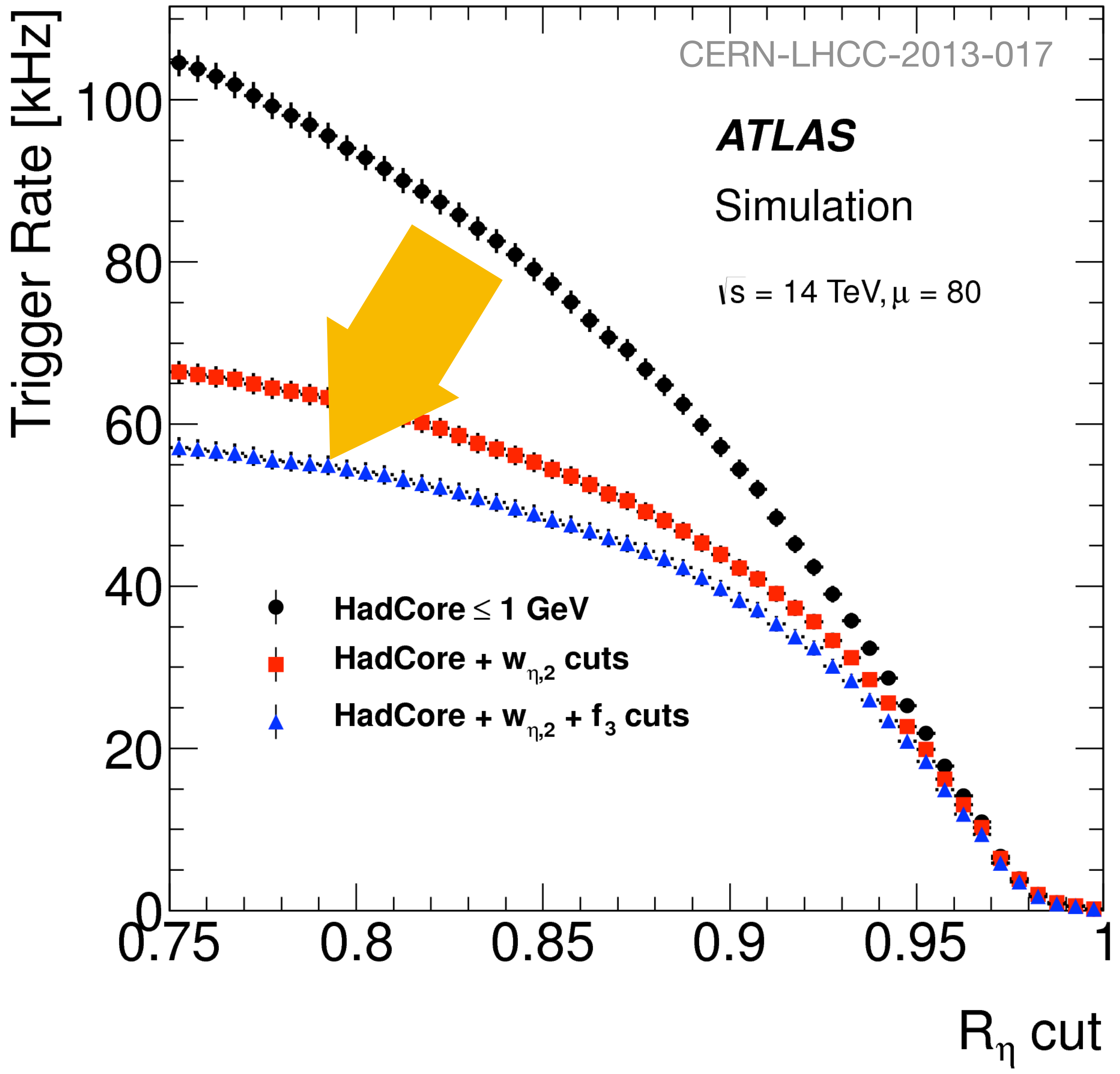
Higher-granularity, higher-resolution and longitudinal shower information from the LAr calorimeter to the first level trigger processors.

Run-3



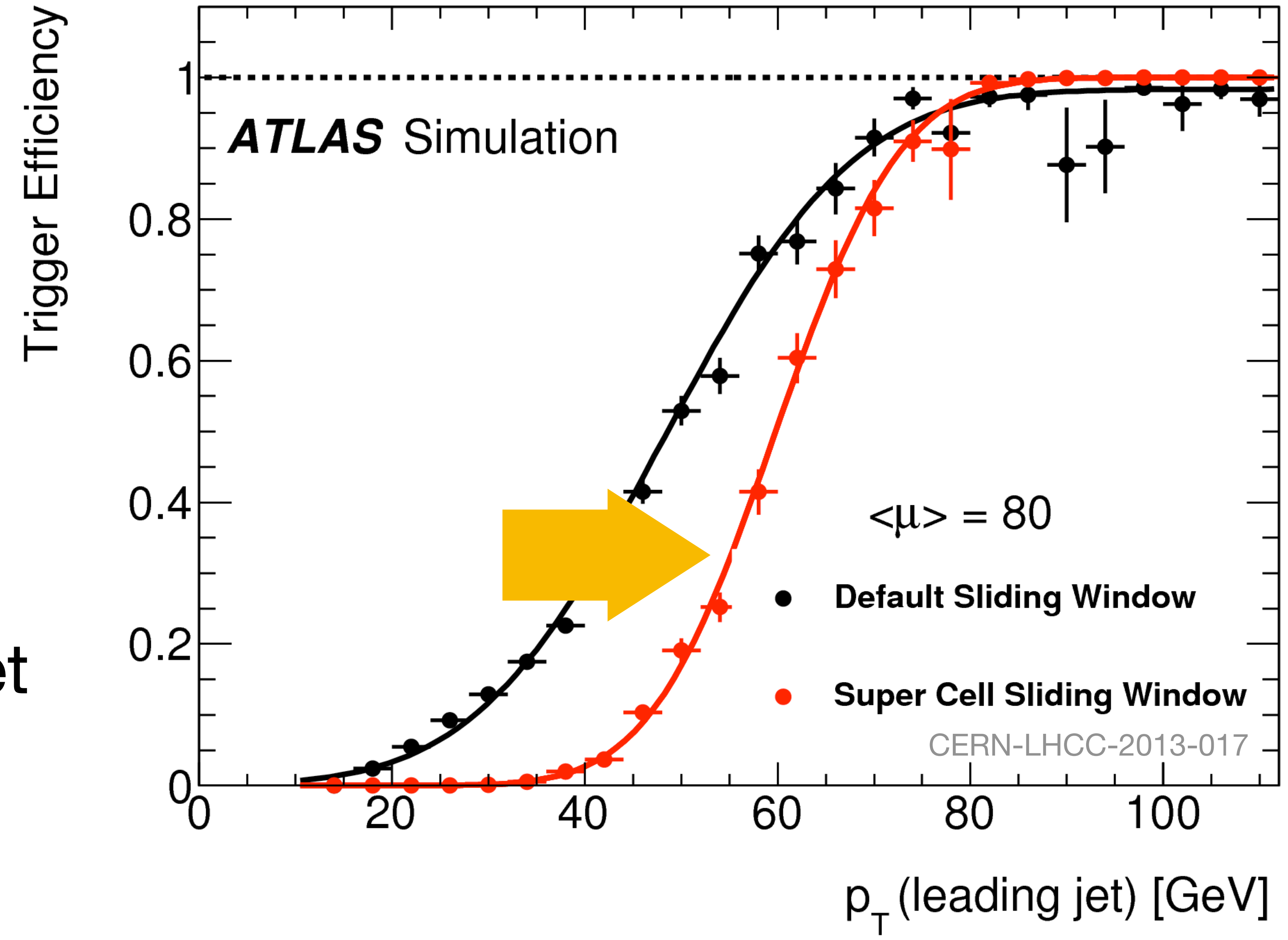
Electron



Trigger electron fake rate reduction

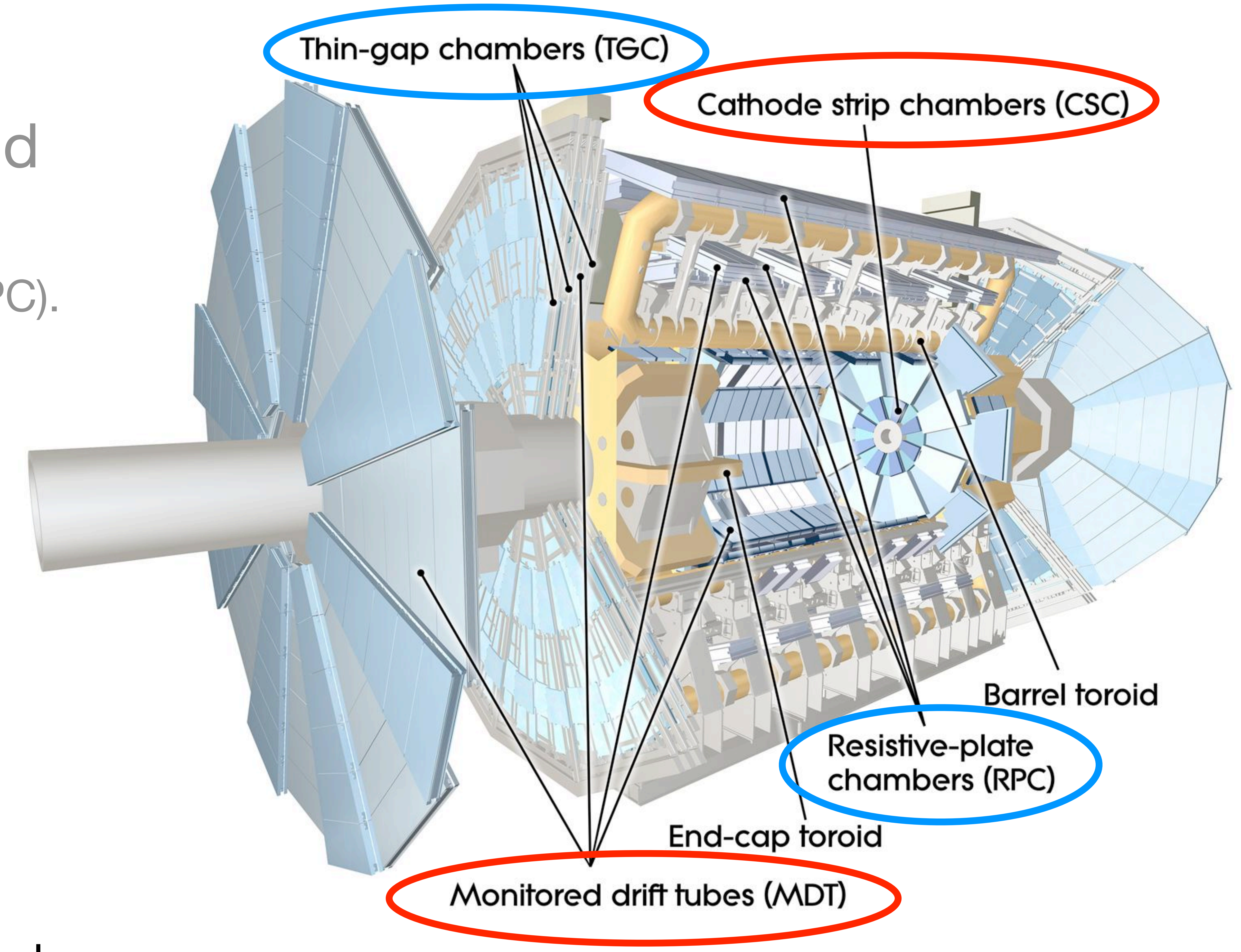
Jet

Improved trigger jet energy resolution



Muon System Upgrade

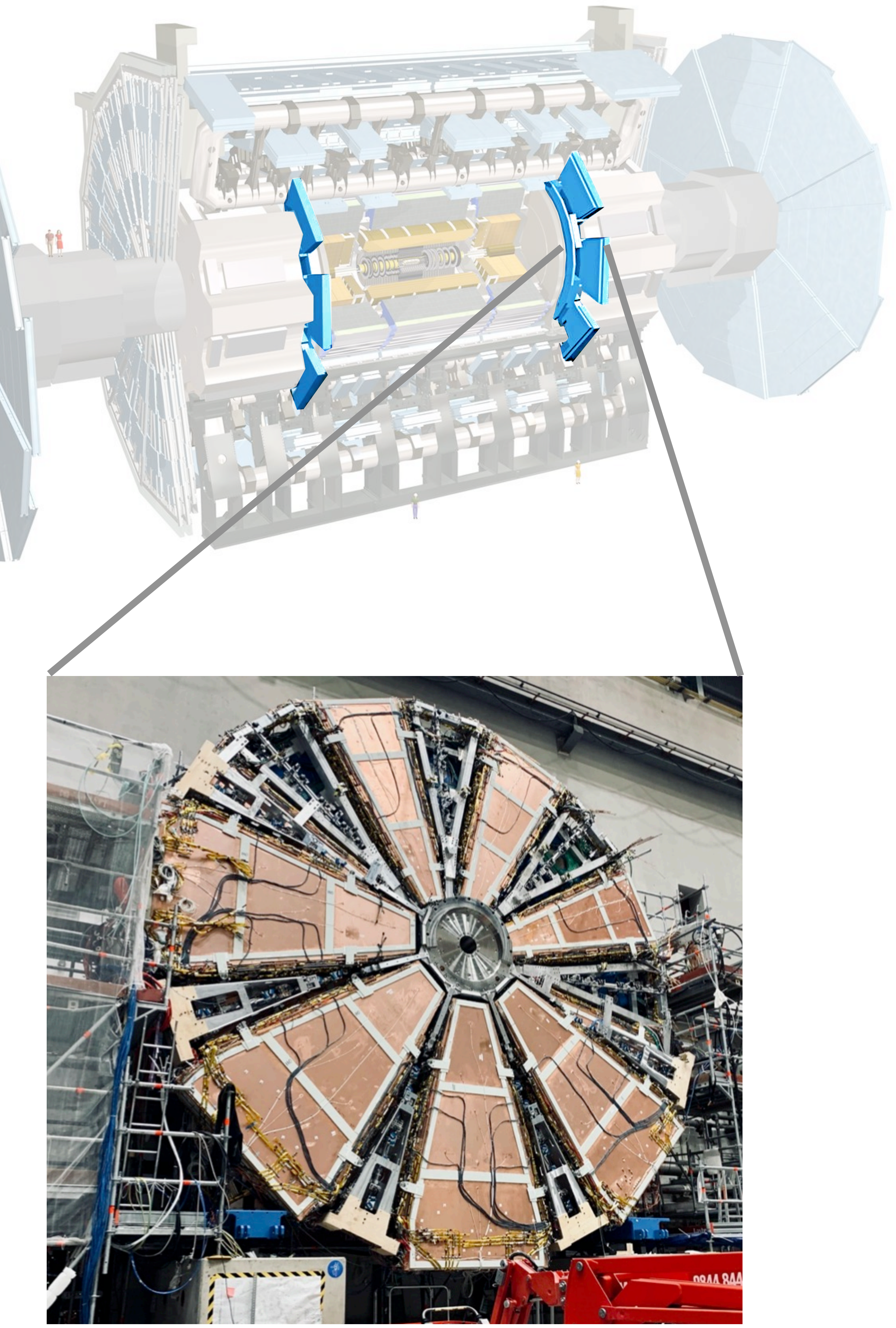
- Muon system made of different types of gas ionization chambers interspersed around toroid magnets.
  - HL-LHC environment challenging for some chambers (e.g RPC).



Trigger chambers
Precision coordinate measurement

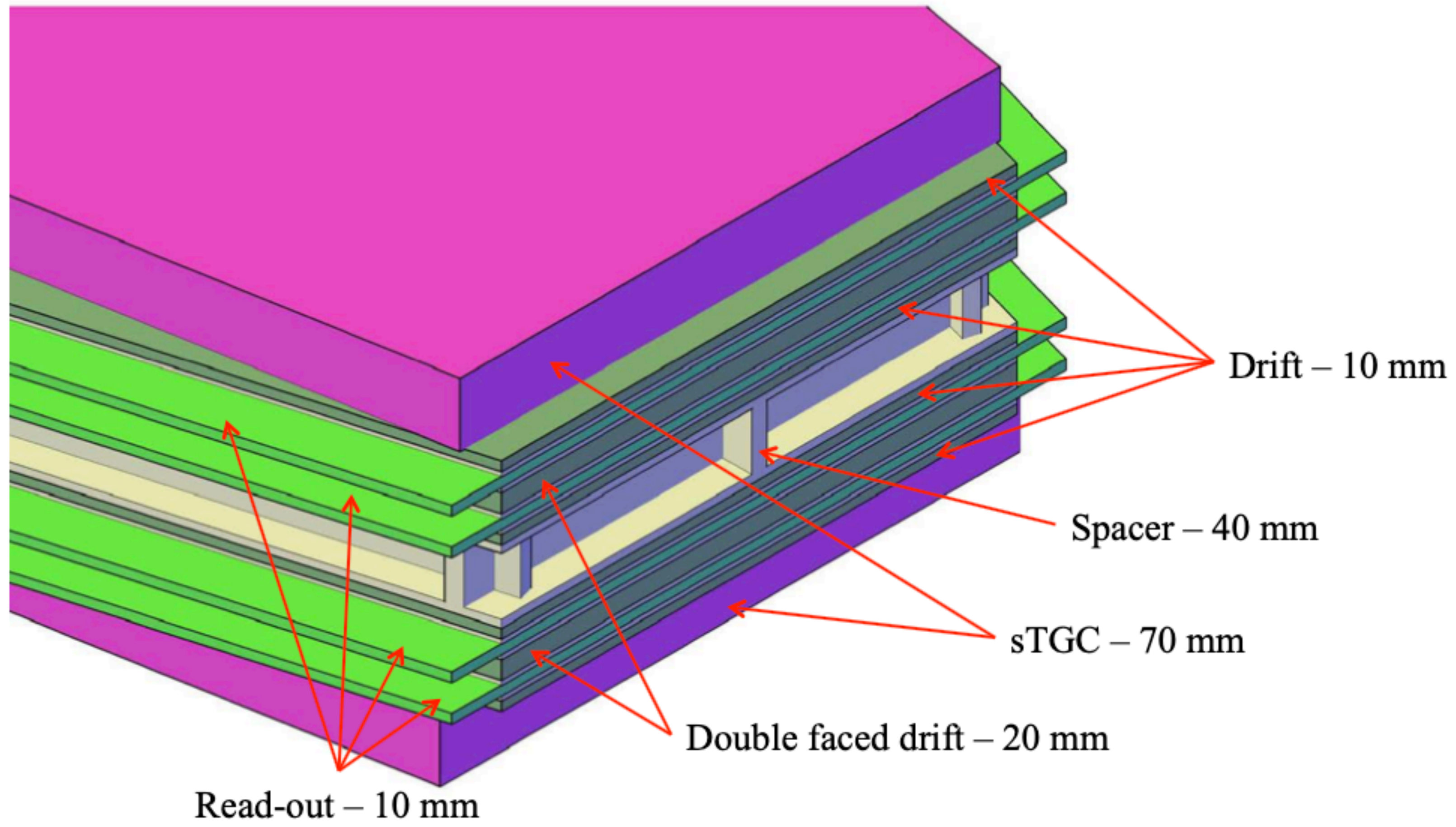
- **Phase-1 Upgrade**
  - Reduce L1 muon trigger fake rate in forward region.
  - Improve L1 muon trigger momentum resolution.
- **Phase-2 Upgrade**
  - Increase RPC and TGC trigger coverage in barrel and endcap.
  - Further reduce trigger fake rate in barrel and end-cap regions.
  - Further improve muon trigger momentum resolution.

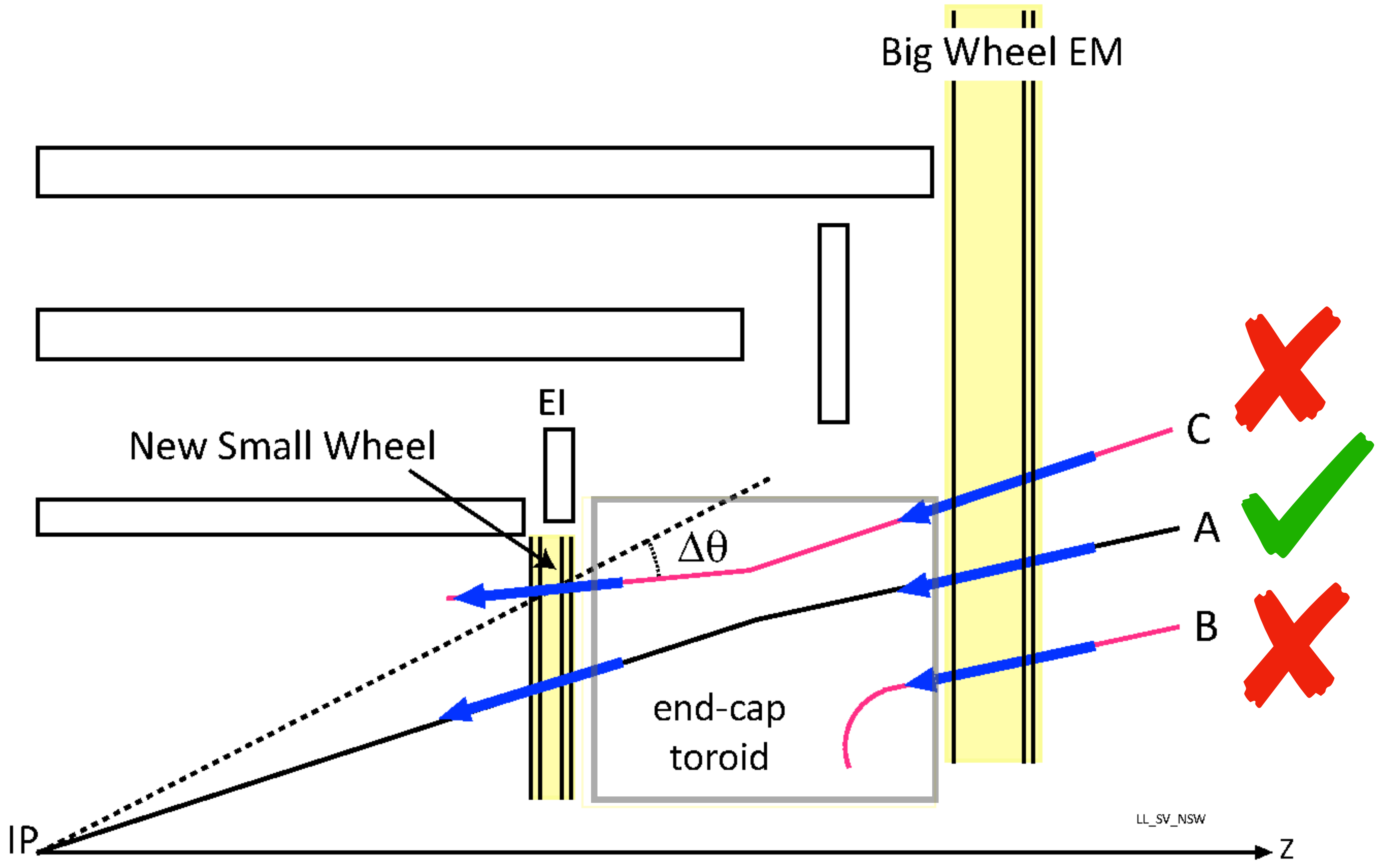
Muon System (Phase-1)



$1.3 < |\eta| < 2.7$

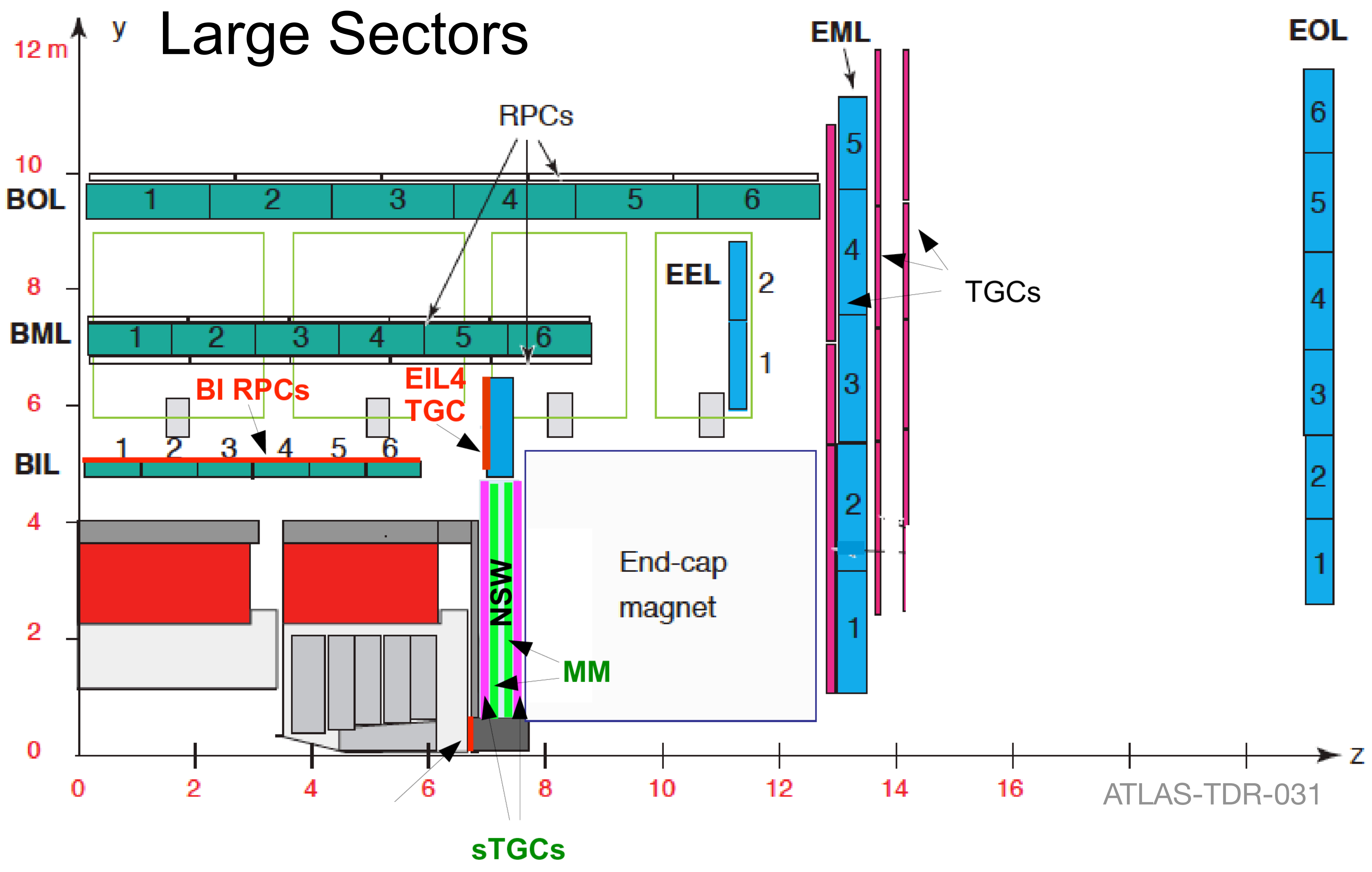
- Replacement of inner endcap wheel by the **New Small Wheels**
  - **Small-strip Thin Gap Chambers**
    - Primary trigger
    - Track segment with < 1 mrad resolution
  - **MicroMegas**
    - Primary precision tracking
    - Spatial resolution < 100 μm
  - System redundancy
    - Both technologies used for trigger and precision measurements.
    - Total of 16 space points: 8 MM + 8 sTGC
- NSW trigger and readout electronics.
- Reduce muon trigger fake rate by x7.





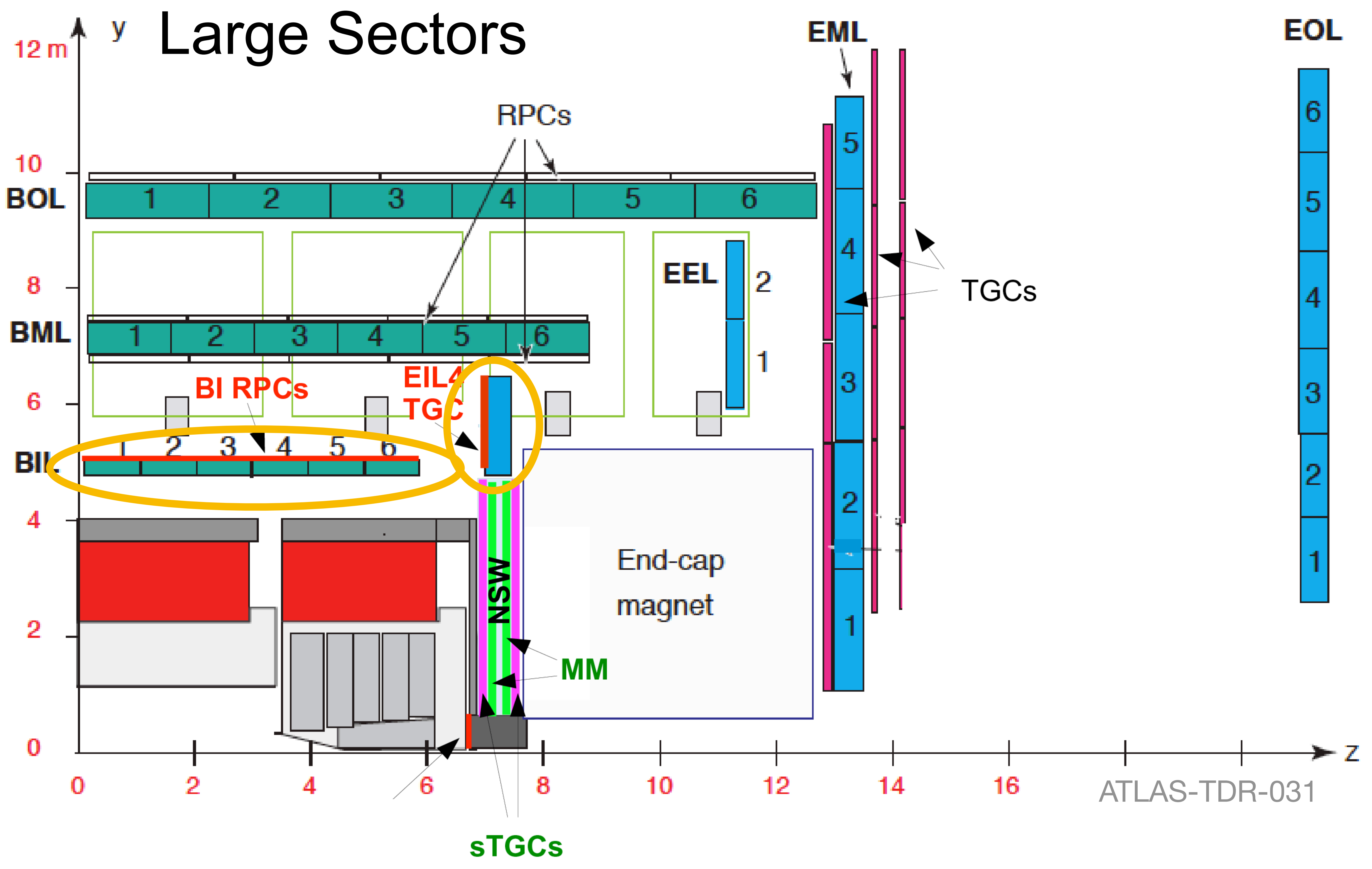
Muon System (Phase-2)

- New readout and trigger electronics
  - Current trigger and readout electronics incompatible with planned update of T/DAQ system and required to provide additional capabilities.

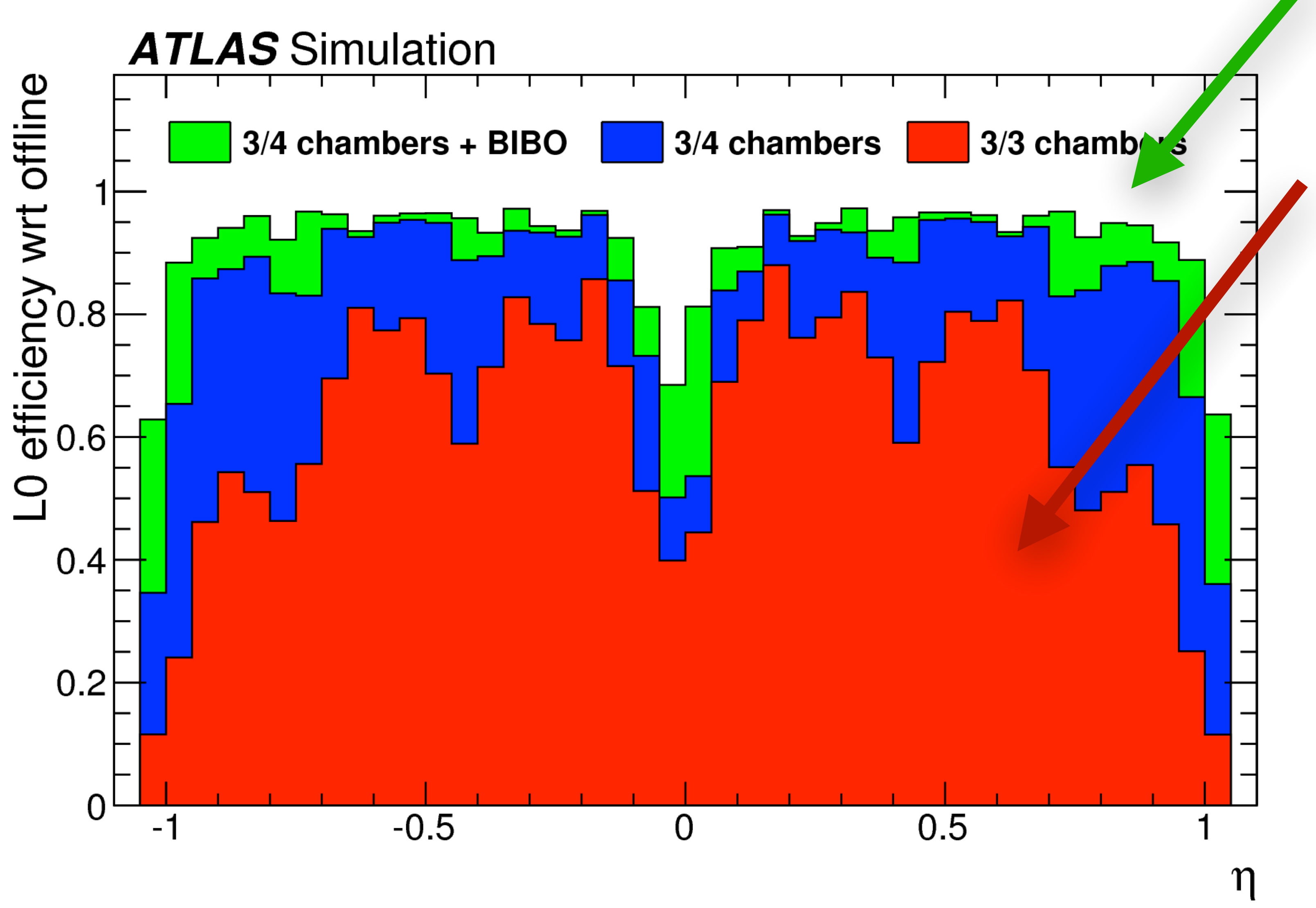


Muon System (Phase-2)

- New readout and trigger electronics
  - Current trigger and readout electronics incompatible with planned update of T/DAQ system and required to provide additional capabilities.
- New Barrel Inner RPC layer.
- New EIL4 TGC triplet module.



Increase in **trigger efficiency**

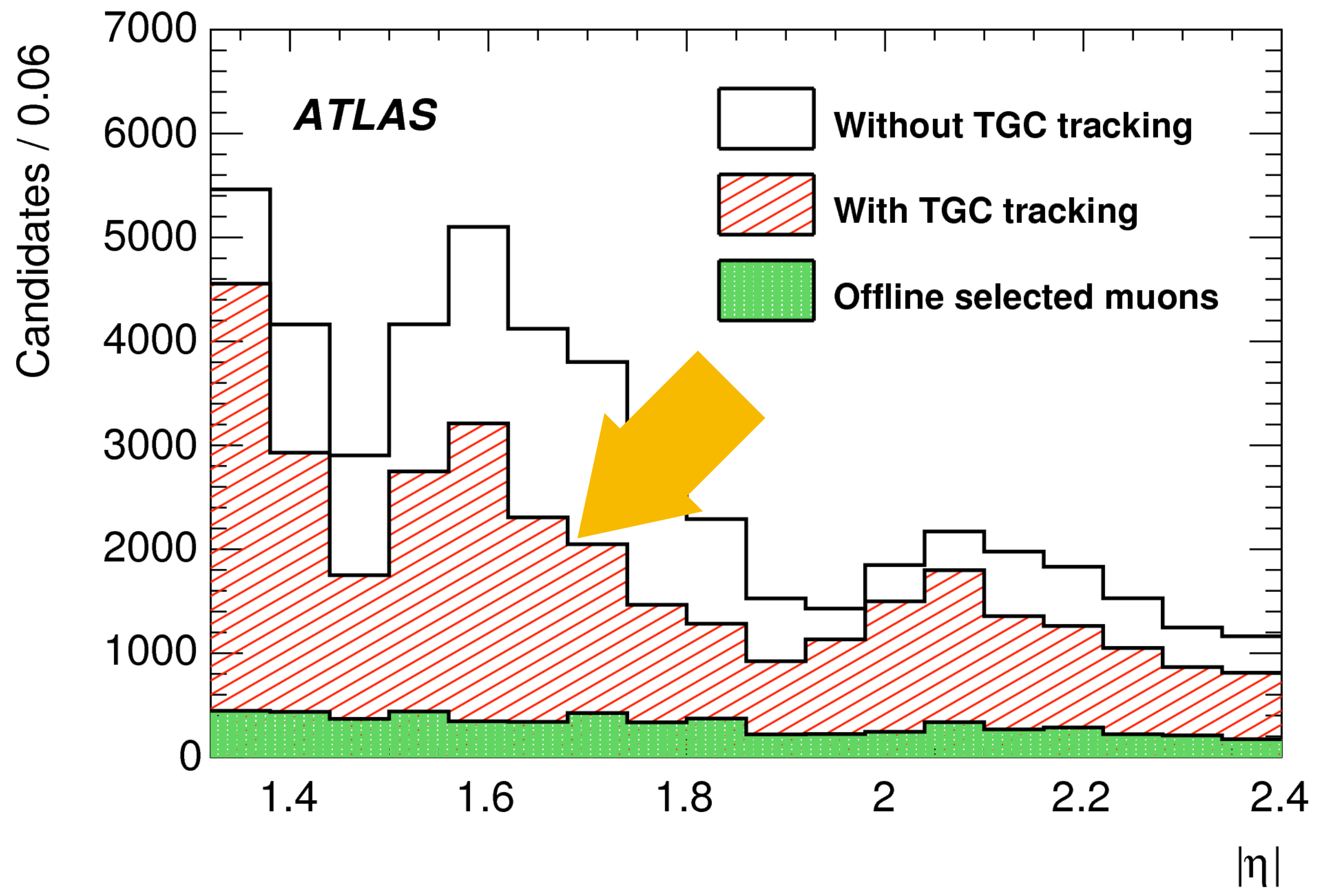


Expected HL-LHC

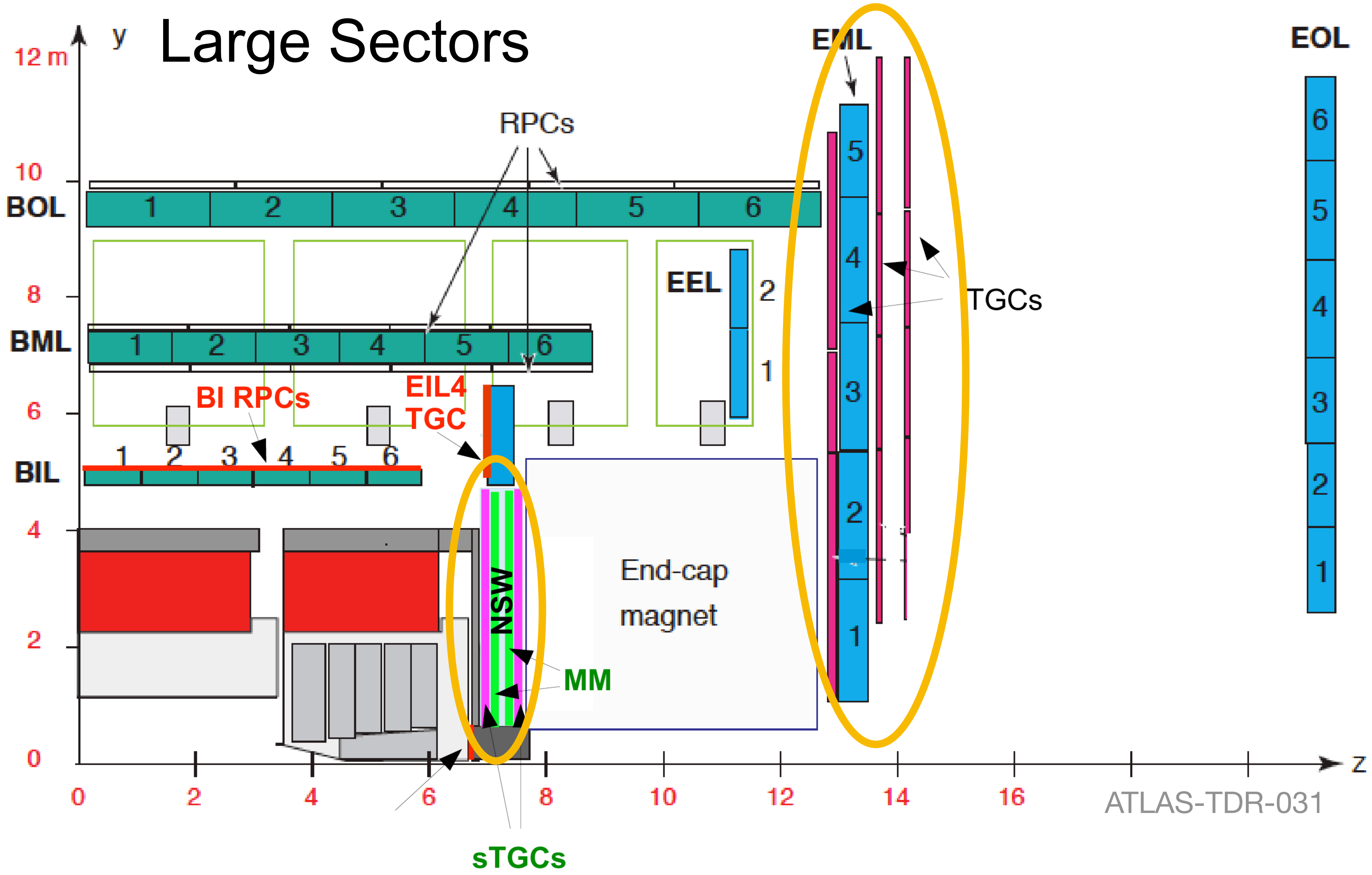
Run-2

Muon System (Phase-2)

- New readout and trigger electronics
  - Current trigger and readout electronics incompatible with planned update of T/DAQ system and required to provide additional capabilities.
- New Barrel Inner RPC layer.
- New EIL4 TGC triplet module.
- Combine NSW-TGC trigger information.

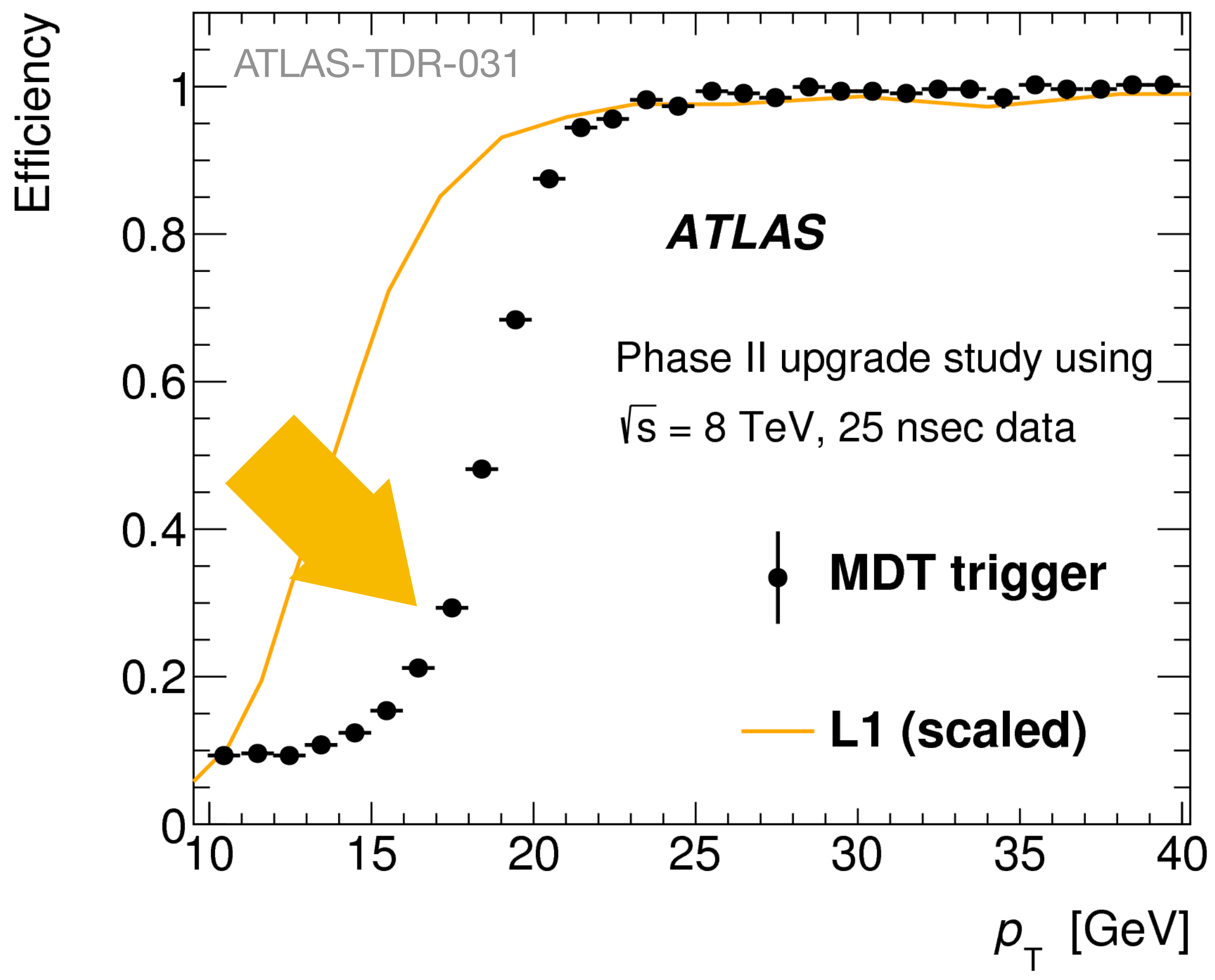


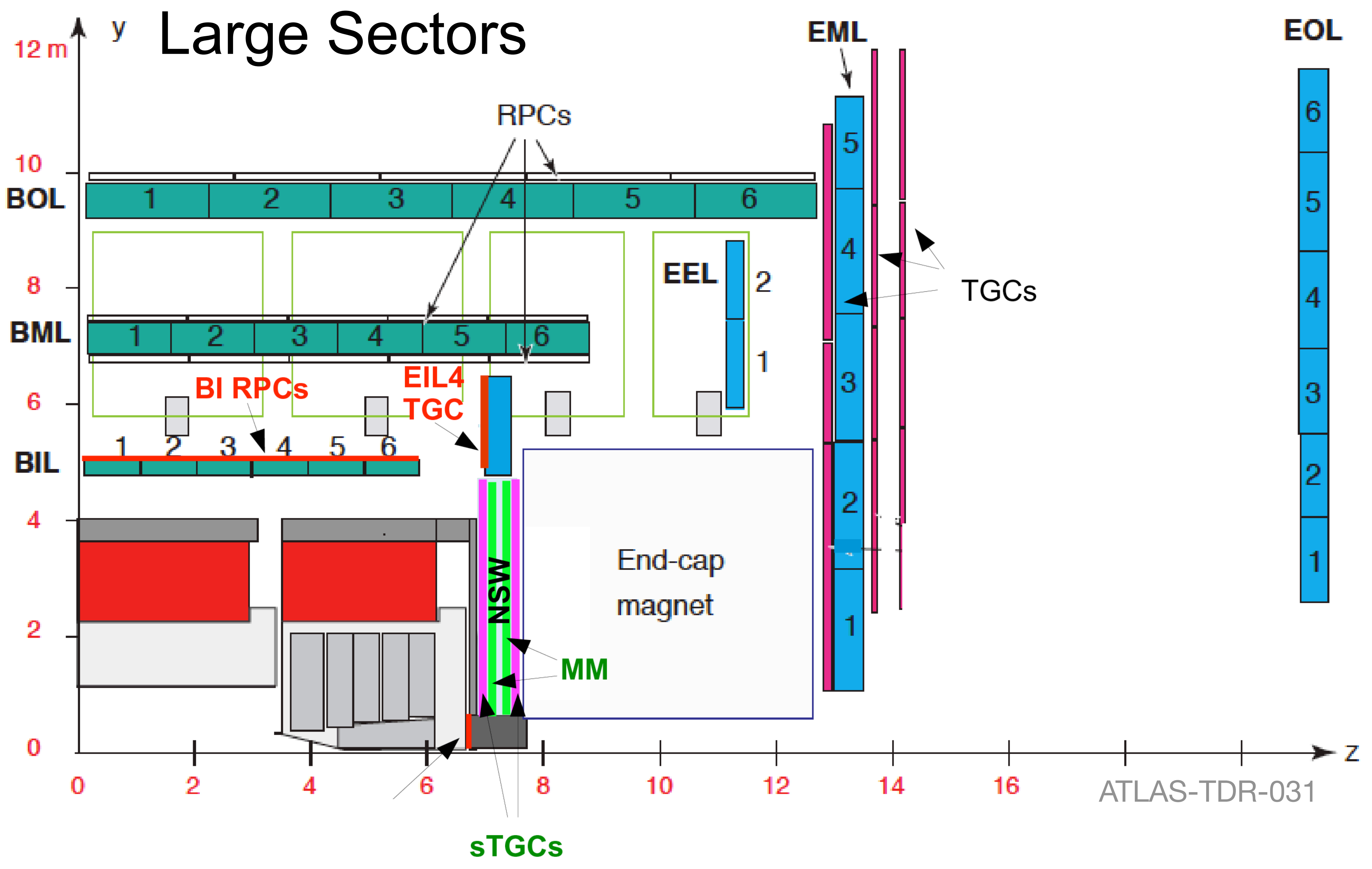
Decrease in **fake trigger rate**



Muon System (Phase-2)

- New readout and trigger electronics
  - Current trigger and readout electronics incompatible with planned update of T/DAQ system and required to provide additional capabilities.
- New Barrel Inner RPC layer.
- New EIL4 TGC triplet module.
- Combine NSW-TGC trigger information.
- Use MDT data at the first trigger level.

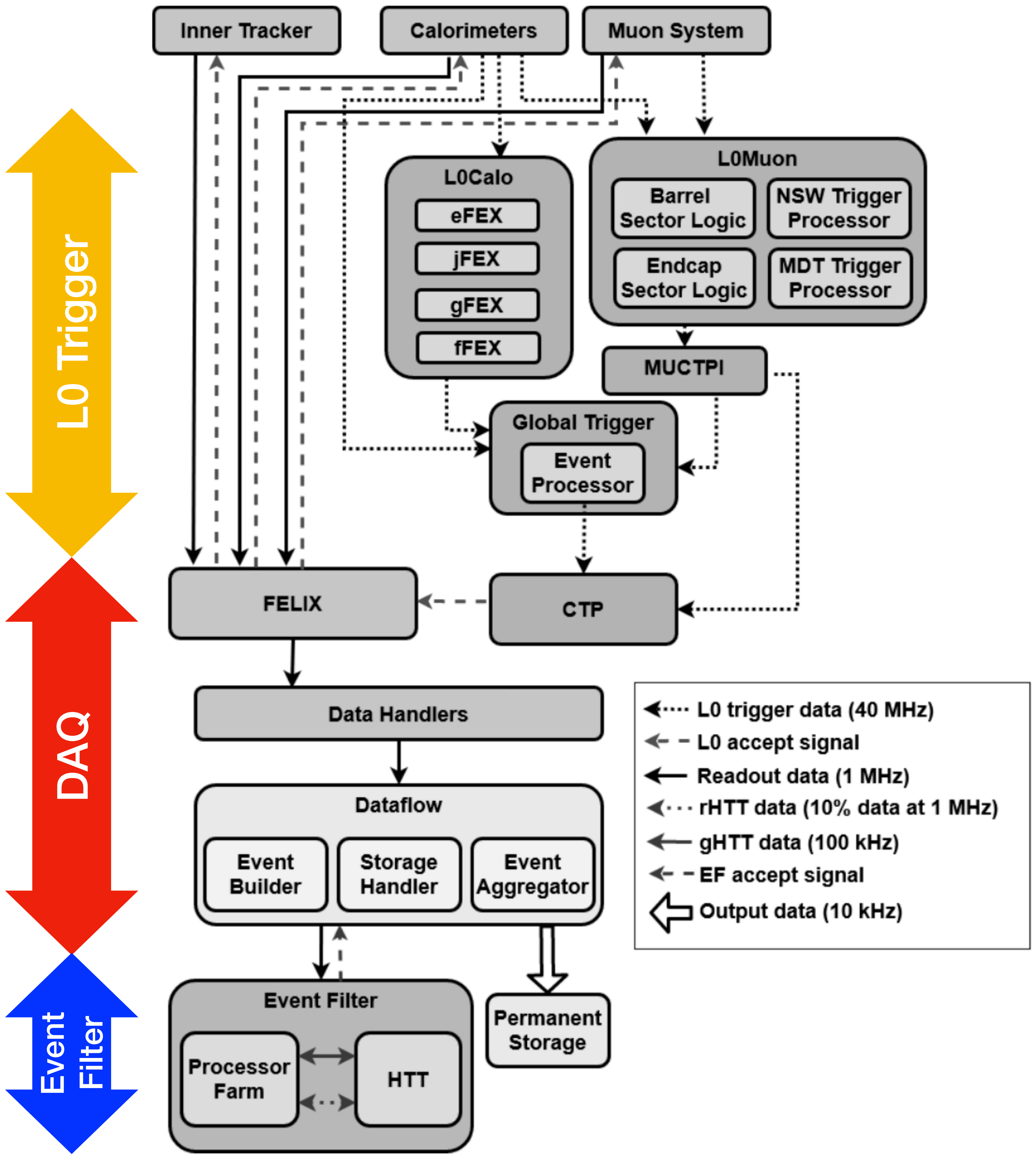




Improvement in trigger momentum resolution

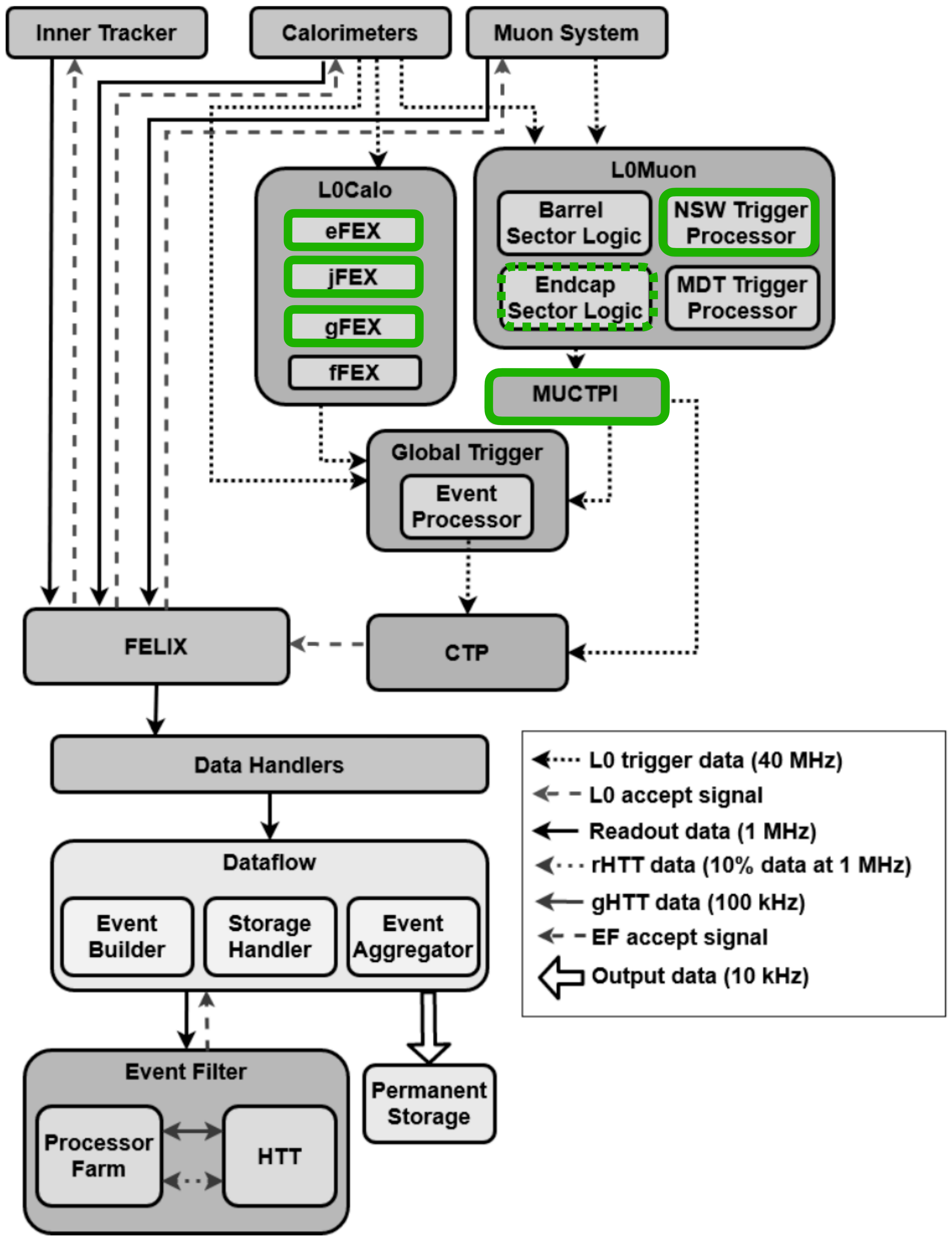
Trigger / DAQ Upgrade

- Two-level trigger architecture.
- Phase-1/2: Evolution of many interfaces, firmware, algorithms, etc.



Trigger / DAQ Upgrade

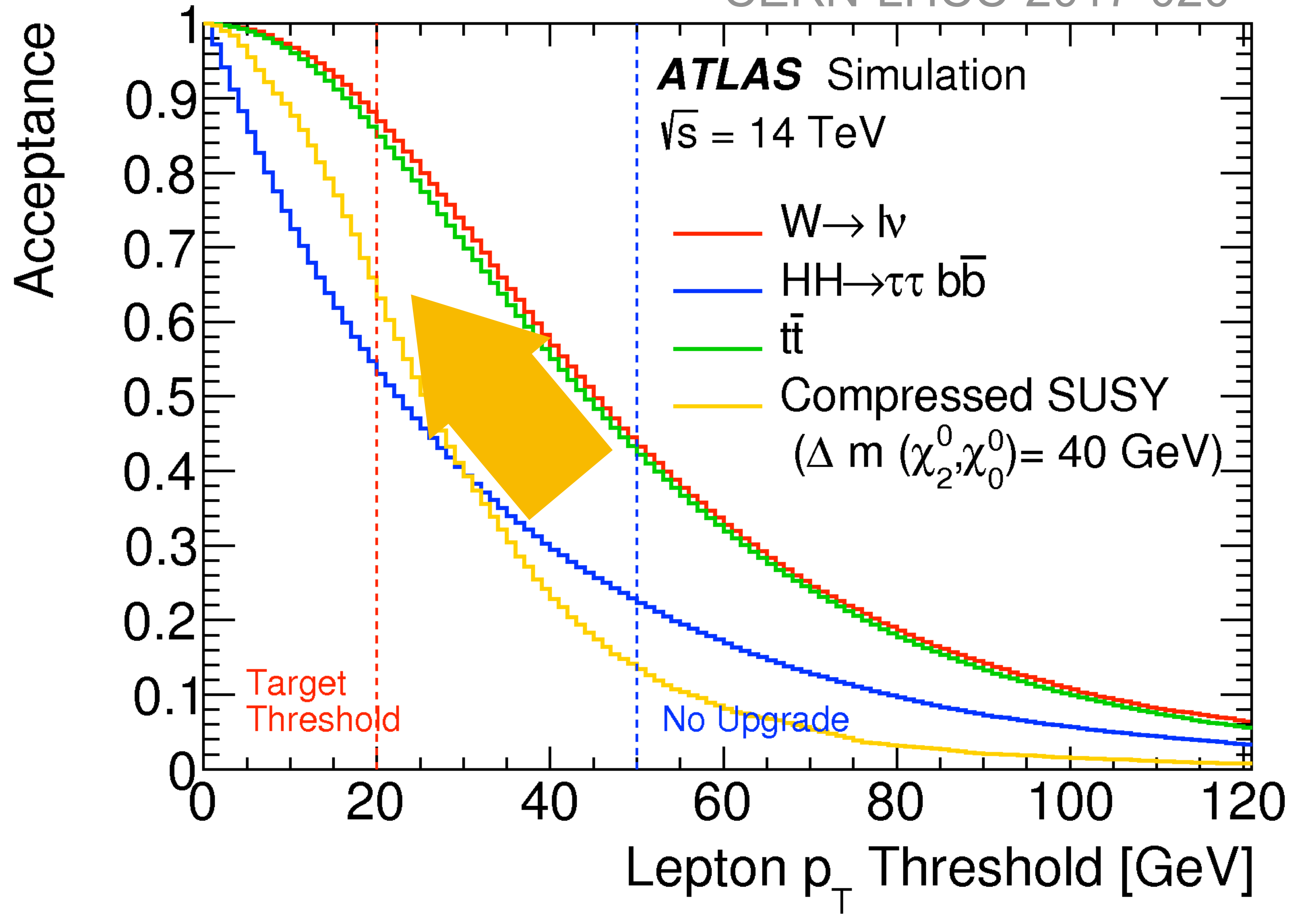
- Two-level trigger architecture.
- Phase-1/2: Evolution of many interfaces, firmware, algorithms, etc.
- Phase-1:
  - Increase background rejection of e/γ triggers (→ New LAr trigger electronics)
  - Improve muon trigger reconstruction and fake rate in endcap (→ NSW)

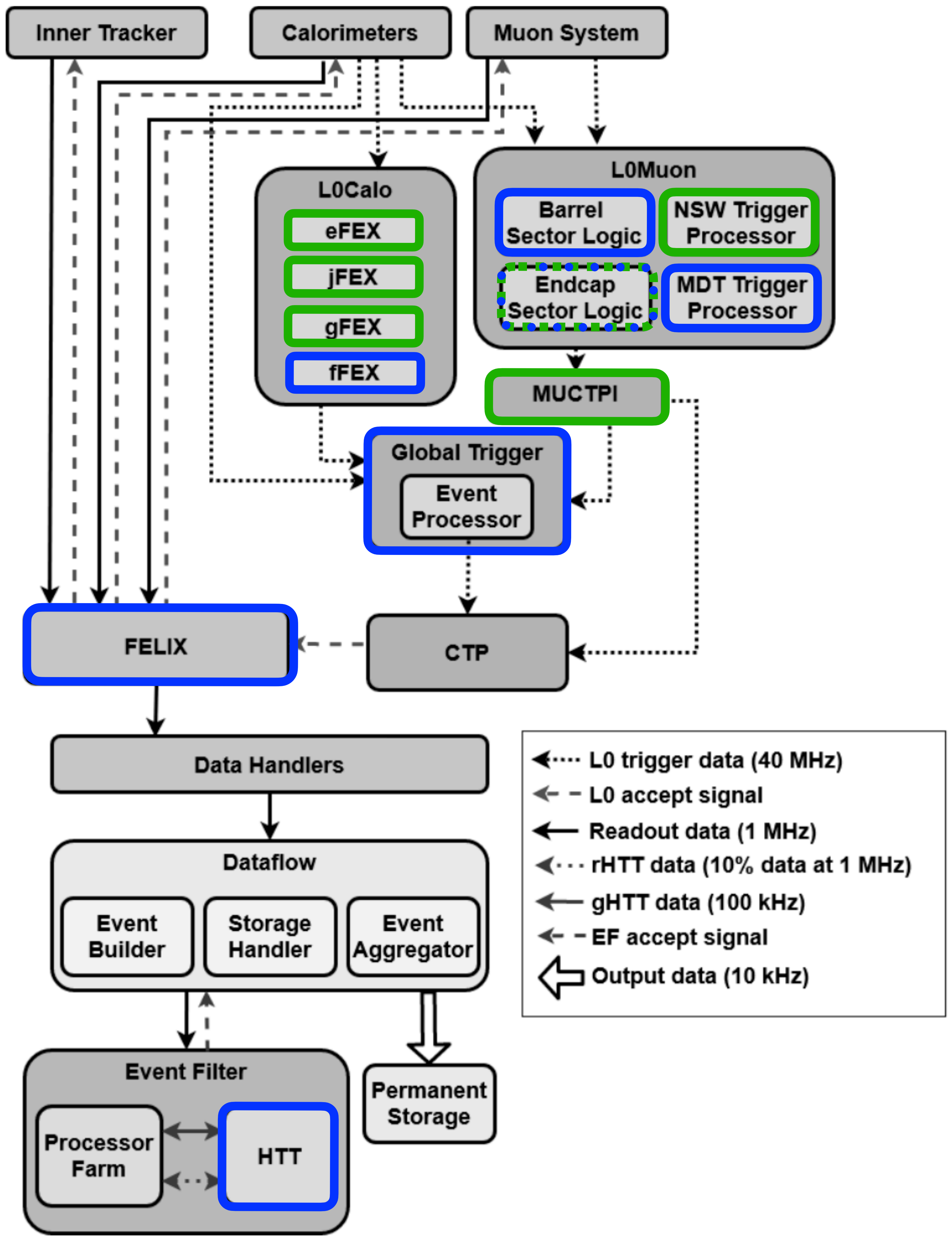


Trigger / DAQ Upgrade

- Two-level trigger architecture.
- Phase-1/2: Evolution of many interfaces, firmware, algorithms, etc.
- Phase-2:
  - Provide the required **bandwidth** and **processing capacity** to efficiently select events at HL-LHC.
    - Exploit full detector granularity in first trigger level
    - Improve efficiency for muon-based triggers
    - Perform hardware-based tracking profiting from extended coverage of the ITk.
  - Characteristics:
    - First level hardware trigger based on muon and calorimeter data with maximum rate of 1 MHz and 10 μs latency.
    - Average final trigger output rate to 10 kHz
    - Tracking data used at Event Filter using "Hardware Track Trigger"

CERN-LHCC-2017-020





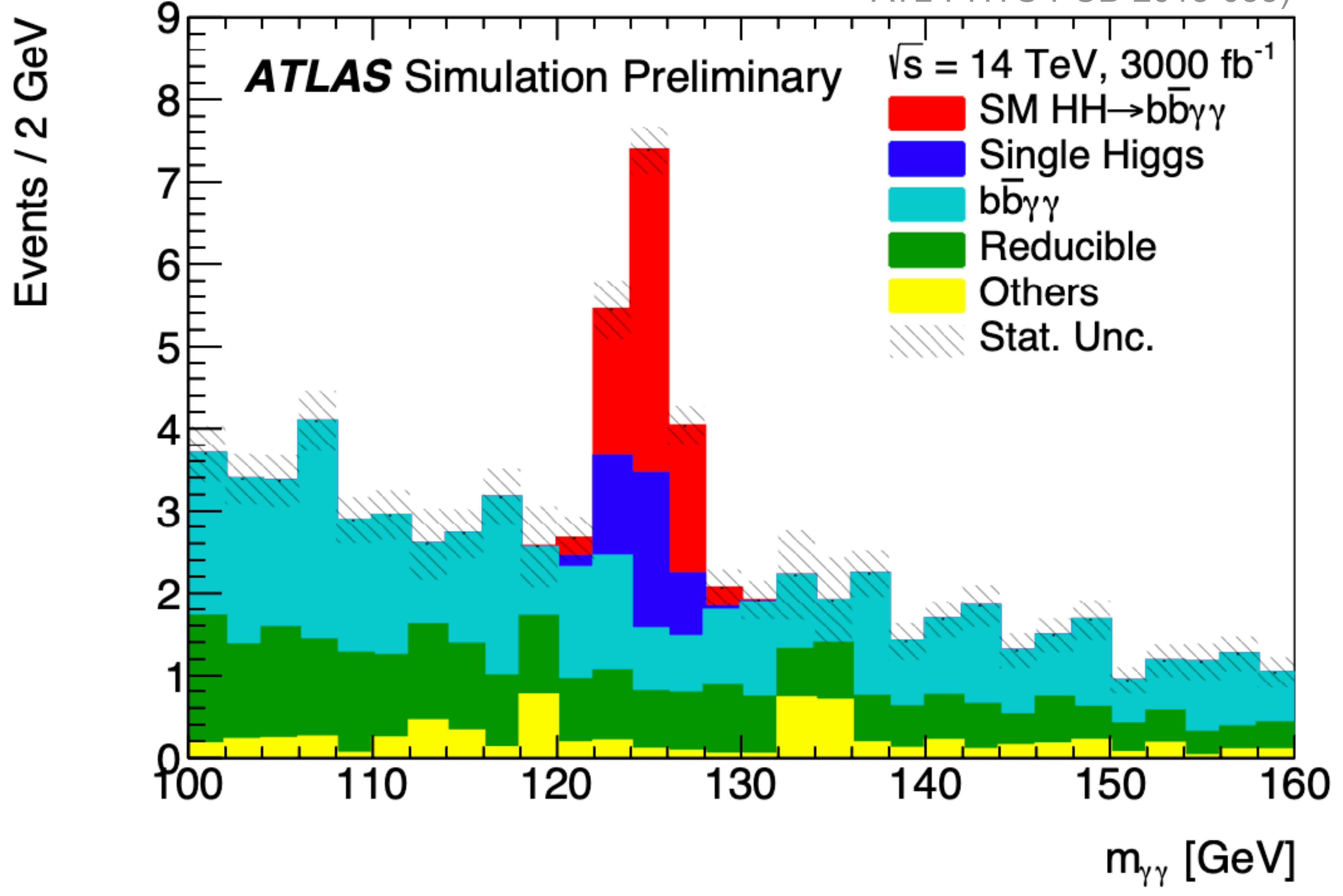
Summary

- Experimental conditions at HL-LHC will exceed current ATLAS detector capabilities.
  - Major upgrade to the ATLAS detector required
    - take advantage of new technologies and ideas
    - Design for flexibility and capacity

- ATLAS upgrades staged into two phases.
  - Phase-1 Upgrades
    - NSW, LAr trigger electronics, TDAQ
    - Commissioning in full swing at CERN.
  - Phase-2 Upgrades:
    - ITk, HGTD, Calorimeters electronics, Muon system, TDAQ
    - Most components in prototyping cycle or in some cases, starting pre-production soon.

- Impact of COVID-19 pandemic
  - Lock down of labs, reduced lab operation efficiency, delays in component delivery schedule.

ATL-PHYS-PUB-2018-053)



Projected ATLAS significance for Higgs self-coupling in SM: ~ $3\sigma @ 3000\ \mathrm{fb}^{-1}$ from di-Higgs production $bb\tau\tau / bb\gamma\gamma / bbbb$

Evolution of ATLAS detector will enable full physics potential of HL-LHC