# HL-LHC Performance ATLAS

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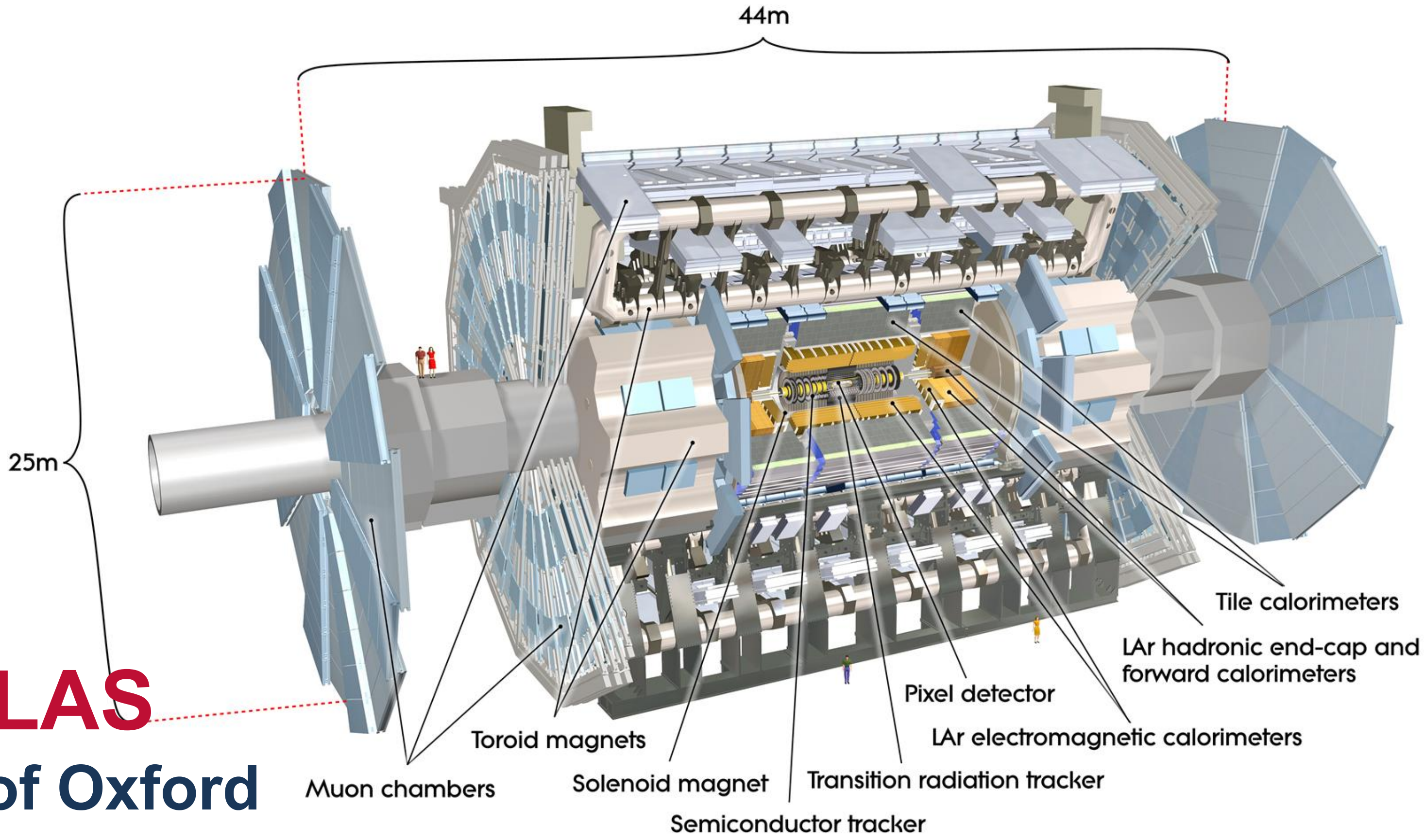
On behalf of the ATLAS Collaboration

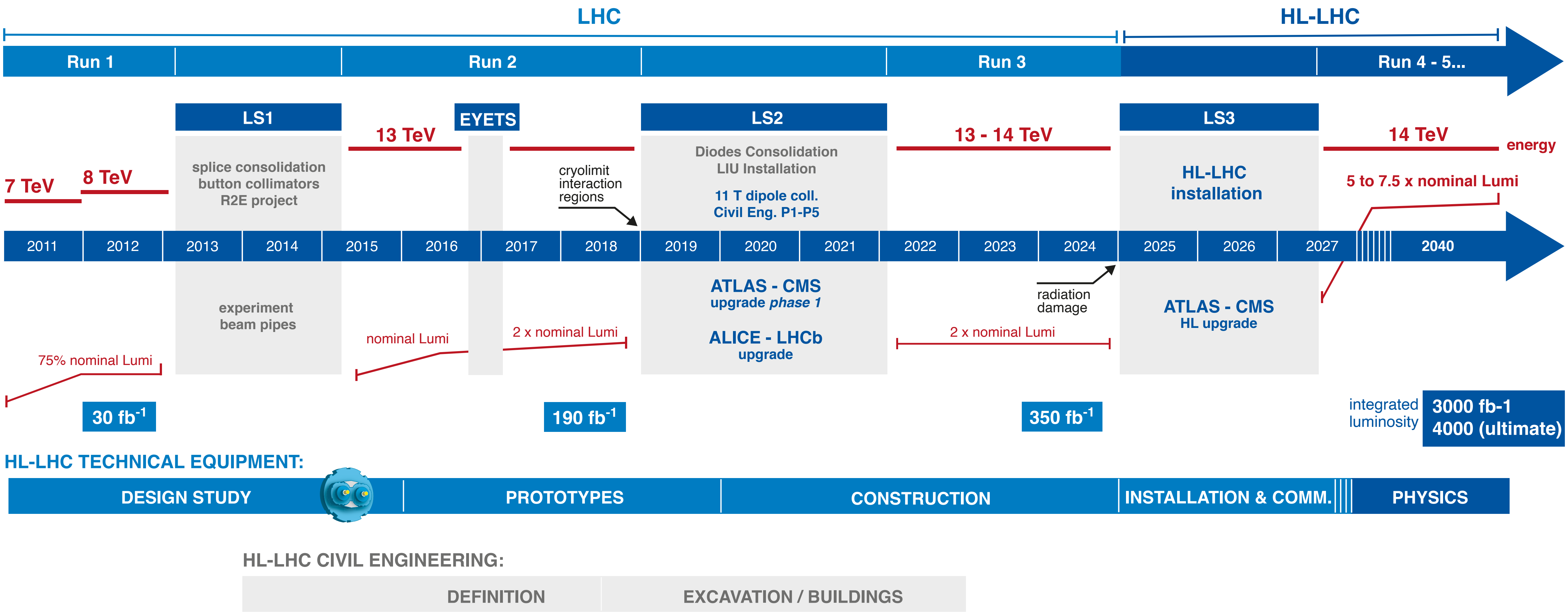



**Winter 2021 topical meeting on VBS: VBS at Snowmass**
**January 26, 2021**

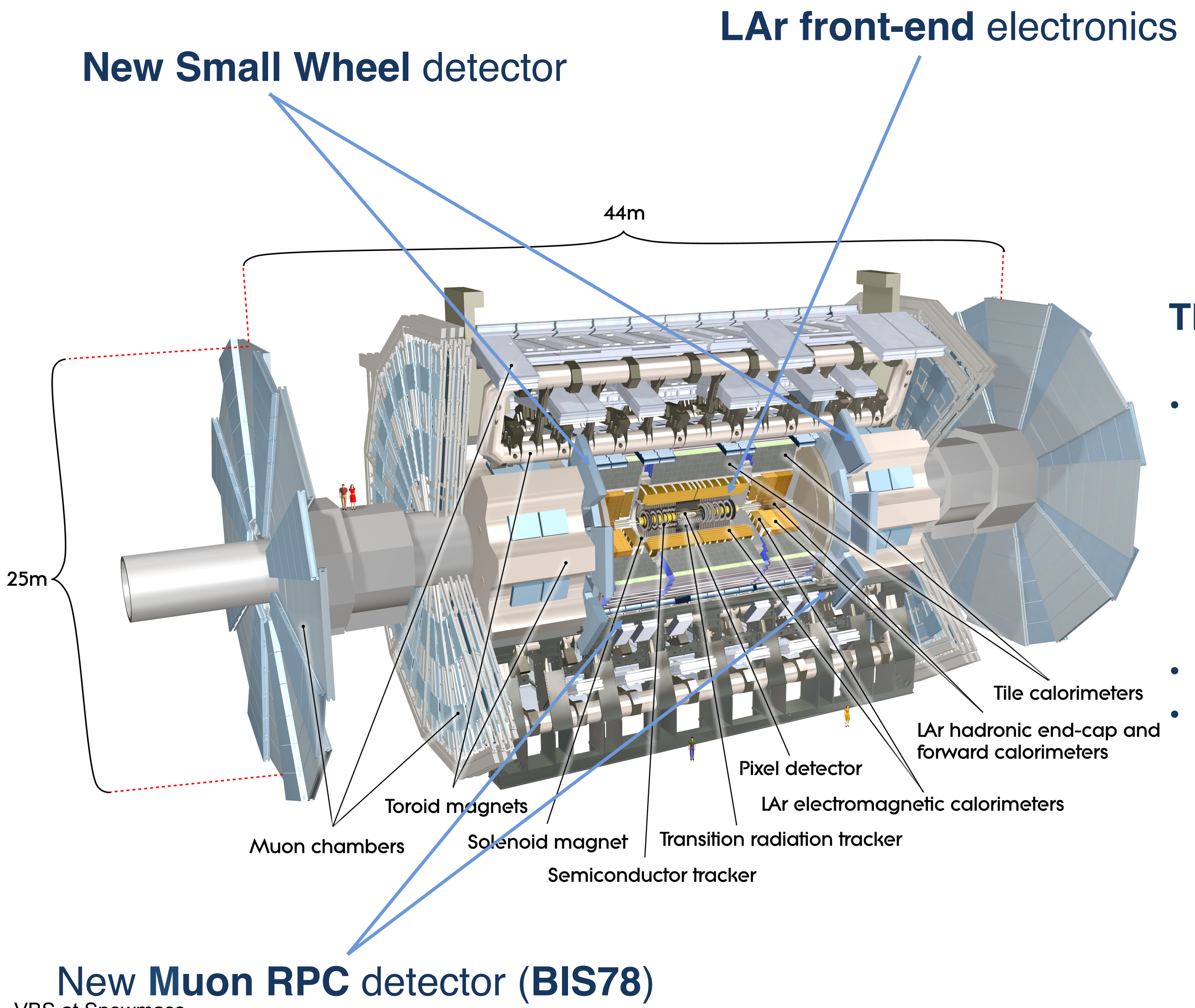
UNIVERSITY OF OXFORD

ATLAS EXPERIMENT

# LHC / HL-LHC Plan



# ATLAS Phase-I Upgrades

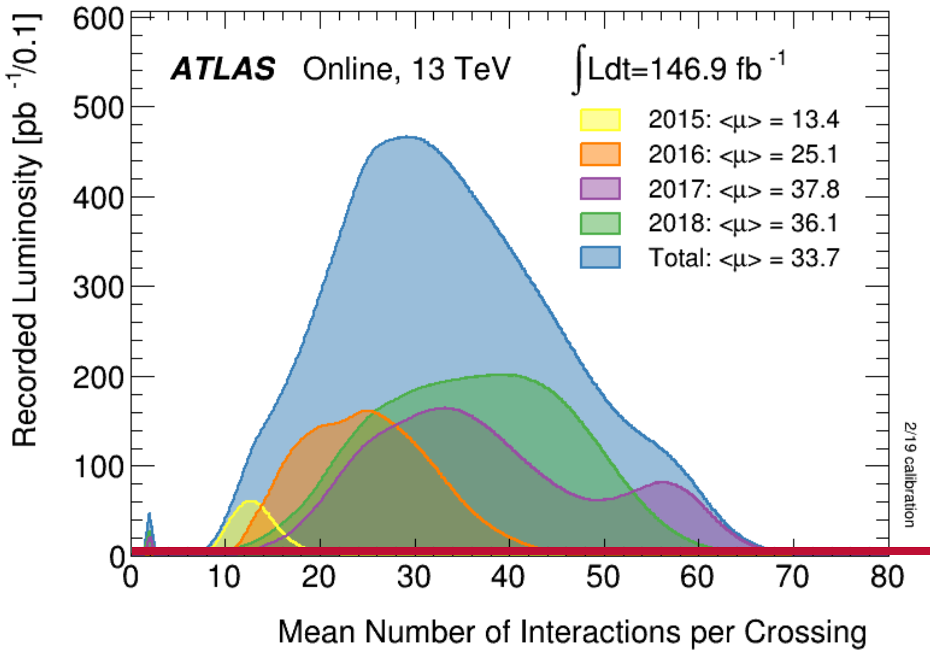


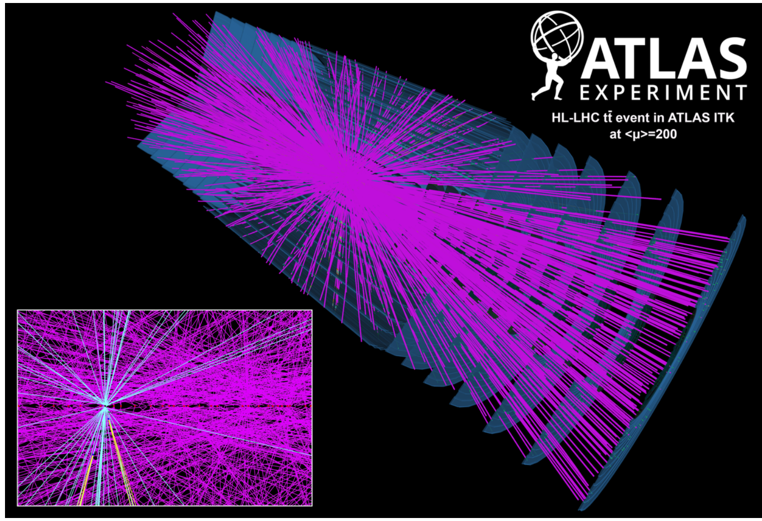

**TDAQ** off-detector electronics:

- **L1 hardware trigger**:
  - L1 calorimeter
  - L1 topological
  - L1 NSW trigger
  - L1 endcap trigger
  - L1 MuCTPi
- **Readout system**
- **HLT**

# High-Luminosity LHC (HL-LHC)

- Upgrade of the Large Hadron Collider (LHC)
  - Centre-of-mass energy: 14 TeV
  - Max. instantaneous luminosity: 7.5 x $10^{34}$ $cm^{-2}s^{-1}$
  - Integrated luminosity: up to 4 $ab^{-1}$ (over a decade)
  - Average pile-up of μ ~ 200 (p-p interactions per bunch crossing)
- Detectors need to be **upgraded** to maintain high performance in the HL-LHC environment **(high radiation)**



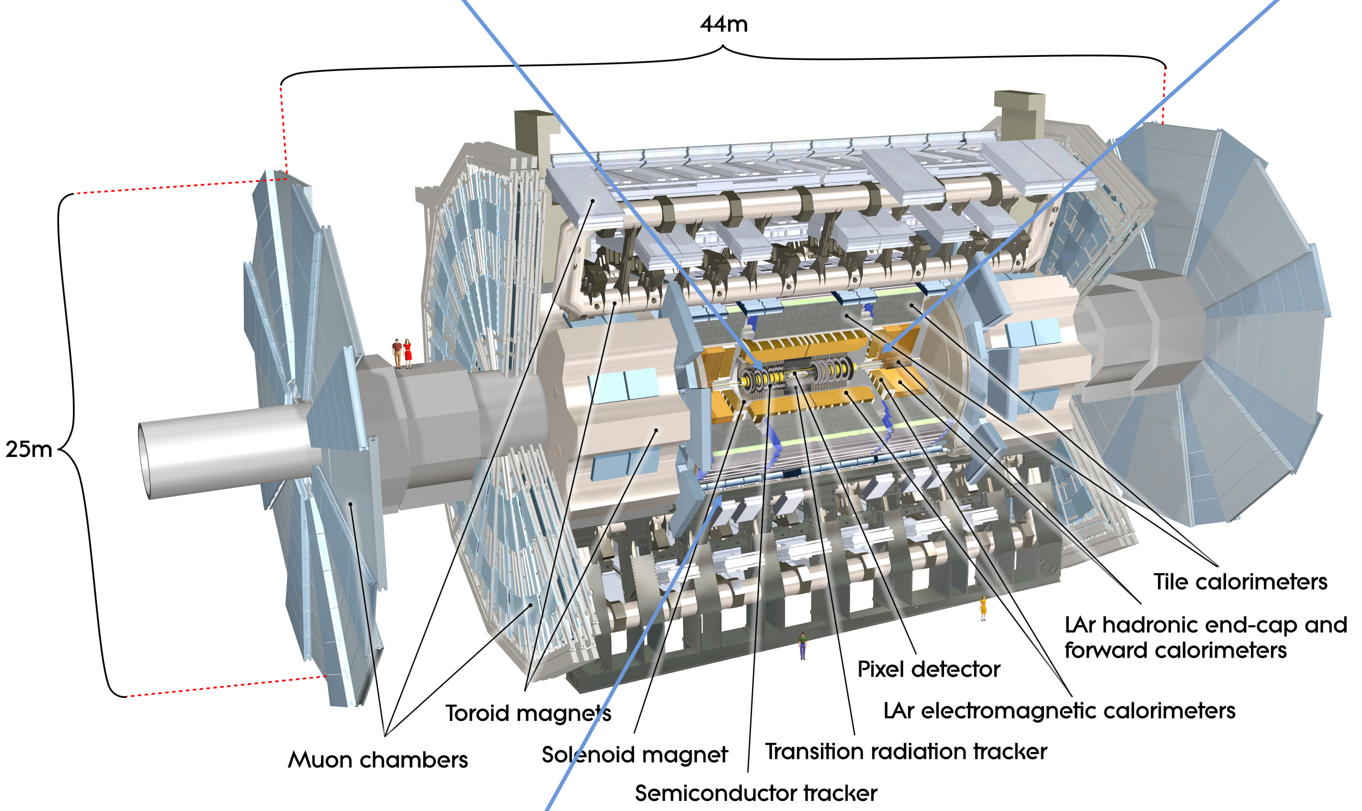




μ = 200

# ATLAS Phase-II Upgrades

New **all-silicon inner tracker** (**ITK**) with eta coverage up to 4

**Calorimeters and High Granularity Timing Detector** (**HGTD**) in forward region

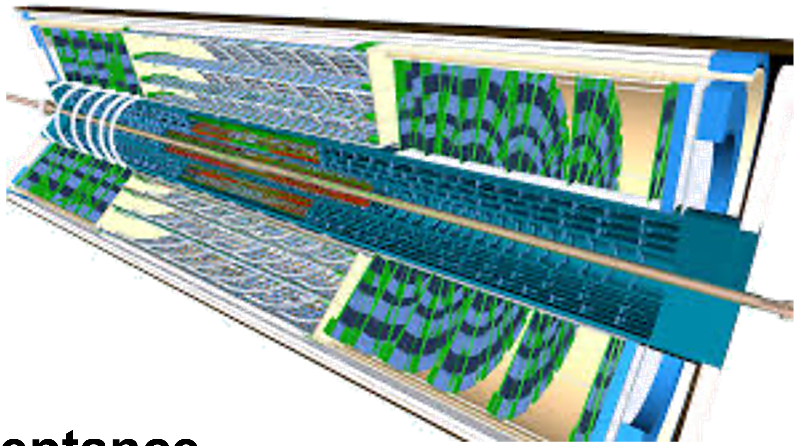



**TDAQ** off-detector electronics:

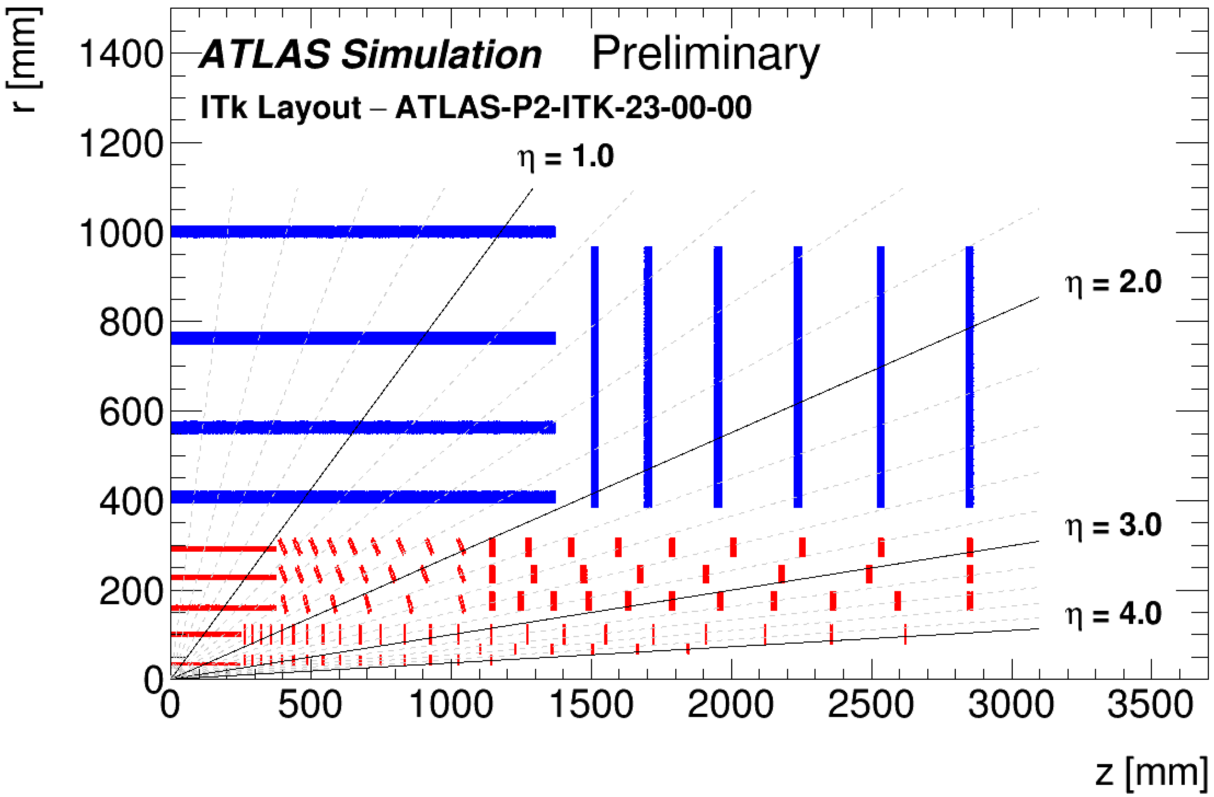
- **L0 hardware trigger**:
  - L0 calorimeter
  - L0 topological
  - L0 muon
  - L0 global
- **Readout system**
- **HLT**

New **muon chambers** in the barrel inner region (BI)

# ATLAS Inner Tracker (ITk)



- **New all-silicon** tracker (replaces the current inner detector)
  - Finer granularity and improved radiation hardness
  - Extended forward coverage (up to η = 4), **increased tracking acceptance**

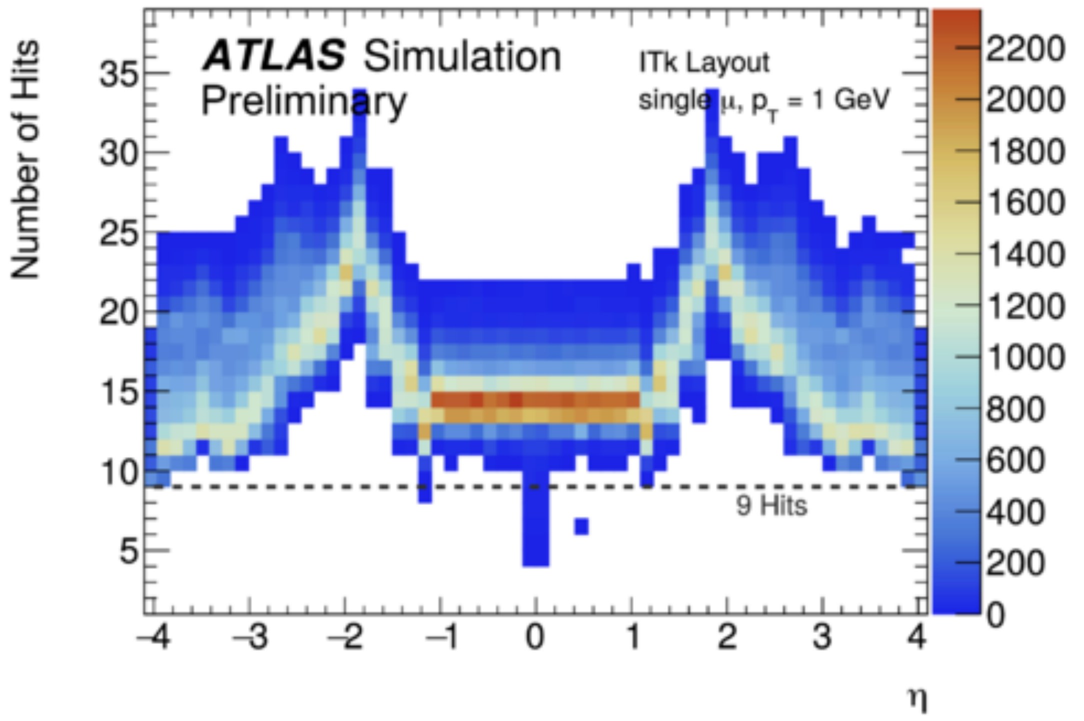


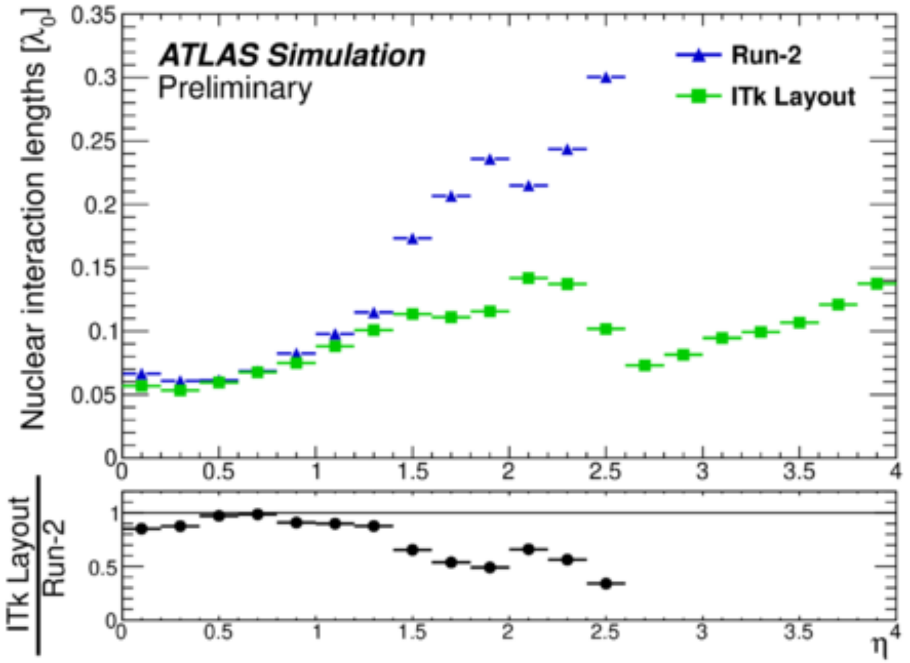

- Strip sub-system up to |η| < 2.7:
  - 4 barrel layers
  - 6 end-cap disks
- Pixel sub-system up to |η| < 4:
  - 5 barrel layers + **inclined** modules
  - barrel + end-cap rings

- Nominal pixel pitch of 50 x 50 μm$^2$
- Innermost pixel layer at 3.9 cm

# ATLAS Inner Tracker (ITk)

- **Hermetic coverage within |η| < 4**
  - **Providing ≥ 9 hits for particles with $p_T$ > 1 GeV and $|z_{vtx}|$ < 150 mm**
  - Allows for **tighter track selections** without compromising reconstruction efficiency
  - Maintains **high efficiencies and low fake rate in dense environments**

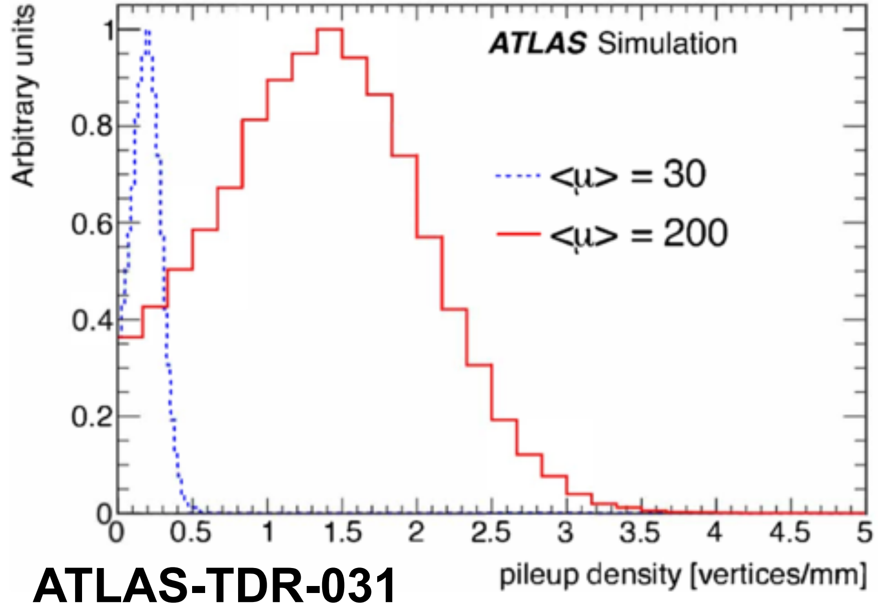



- Greatly reduced forward material budget of Itk
  - Up to 50 % reduction versus Run-2 inner detector

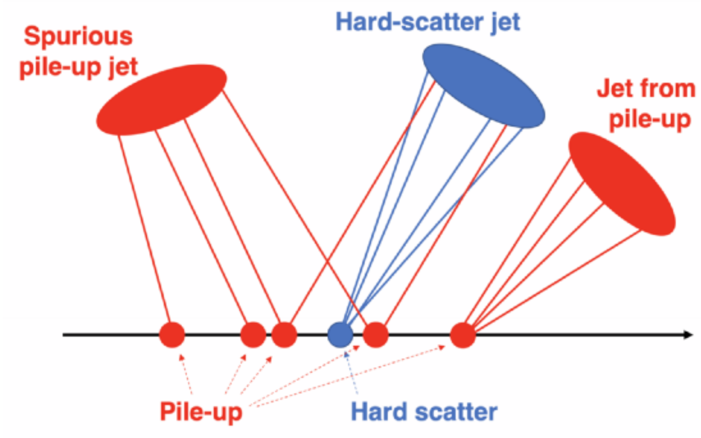
- **Minimises effects of multiple-scattering and energy losses** before outer detectors

# High Granulatiry Timing Detector (HGTD)



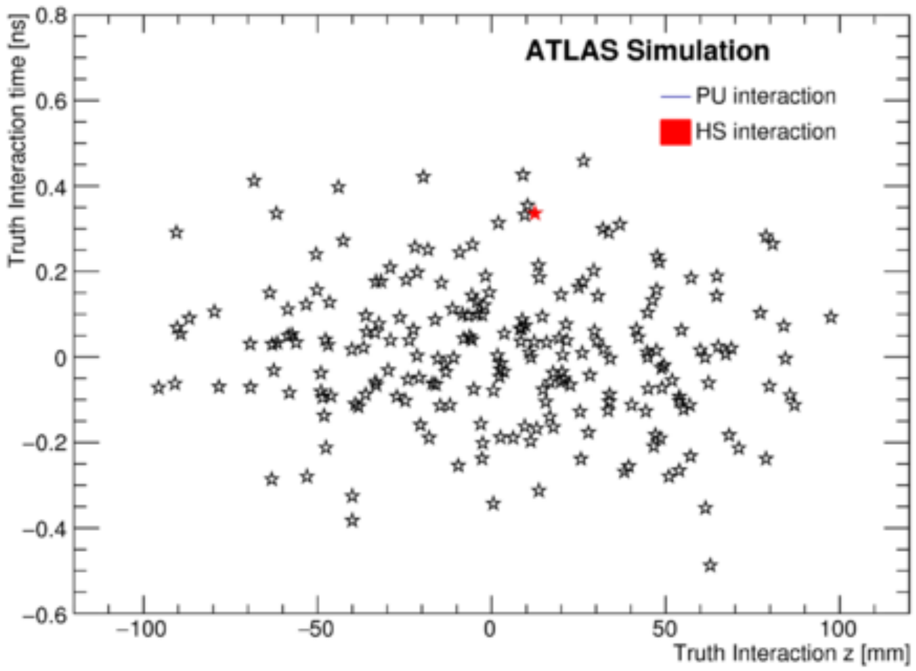

**ATLAS-TDR-031**

- **Goal: improve ATLAS performance in high-pileup environment**
- At μ = 200, expecting ~1.6 vertices / mm



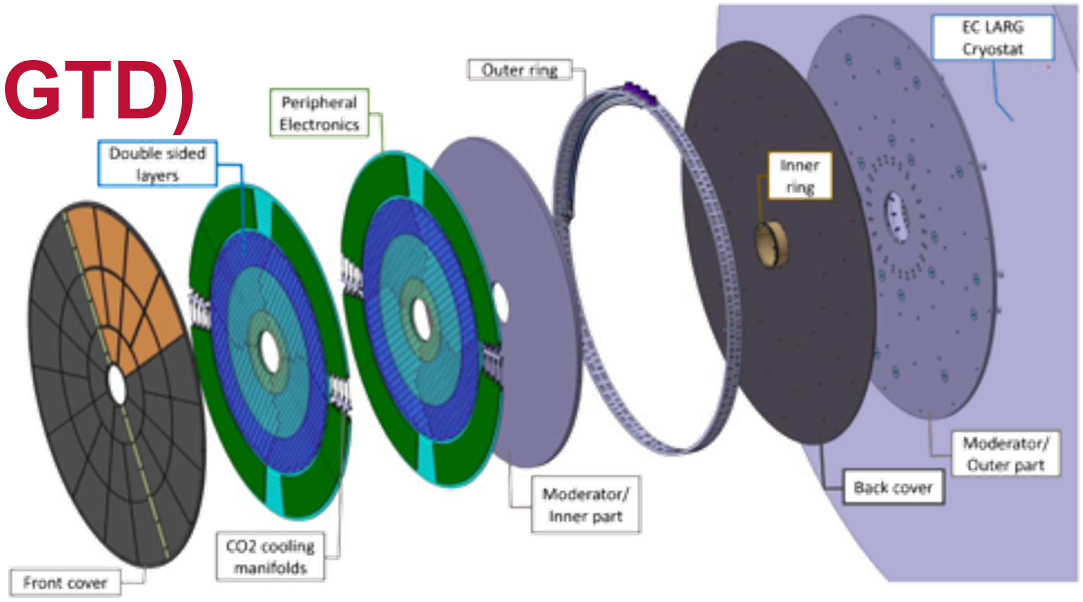

- Pile-up (PU) contributions include
  - PU contributions to hard-scatter (HS)
  - PU jets
  - Spurious PU jets

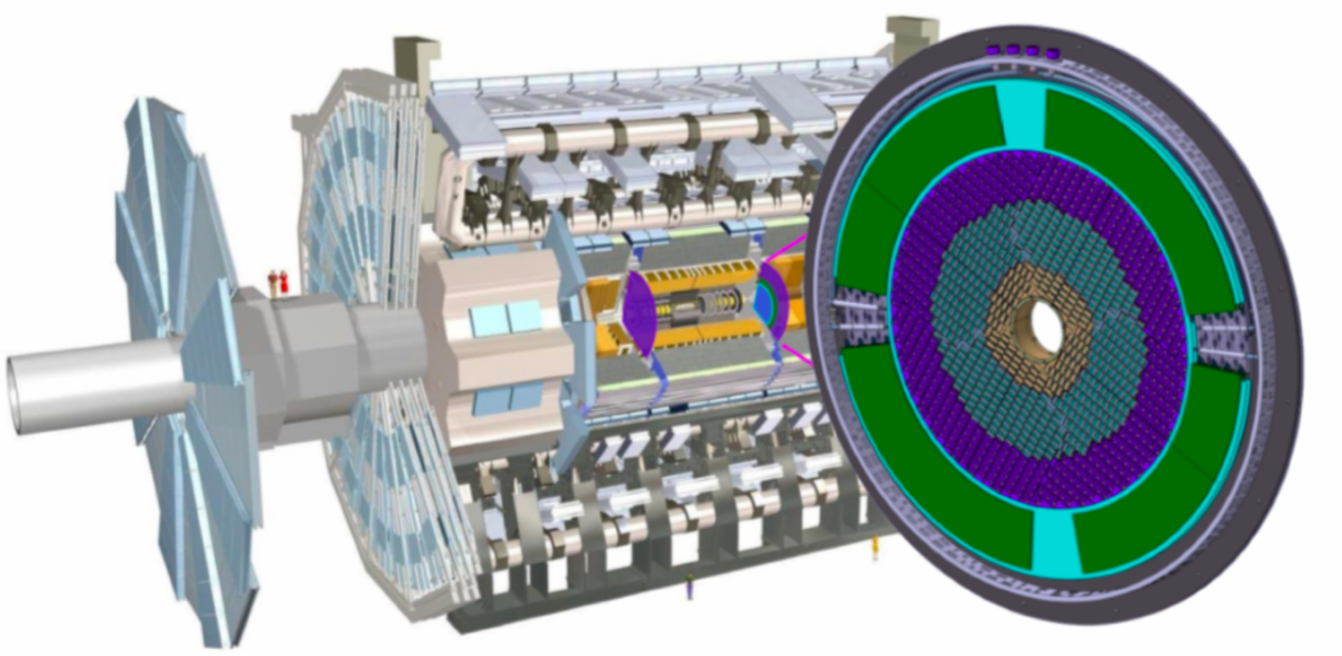
- HGTD provides **timing information**
  - In the forwar region ($2.4 < |\eta| < 4$)
  - **Offers extra handle to fight pile-up**

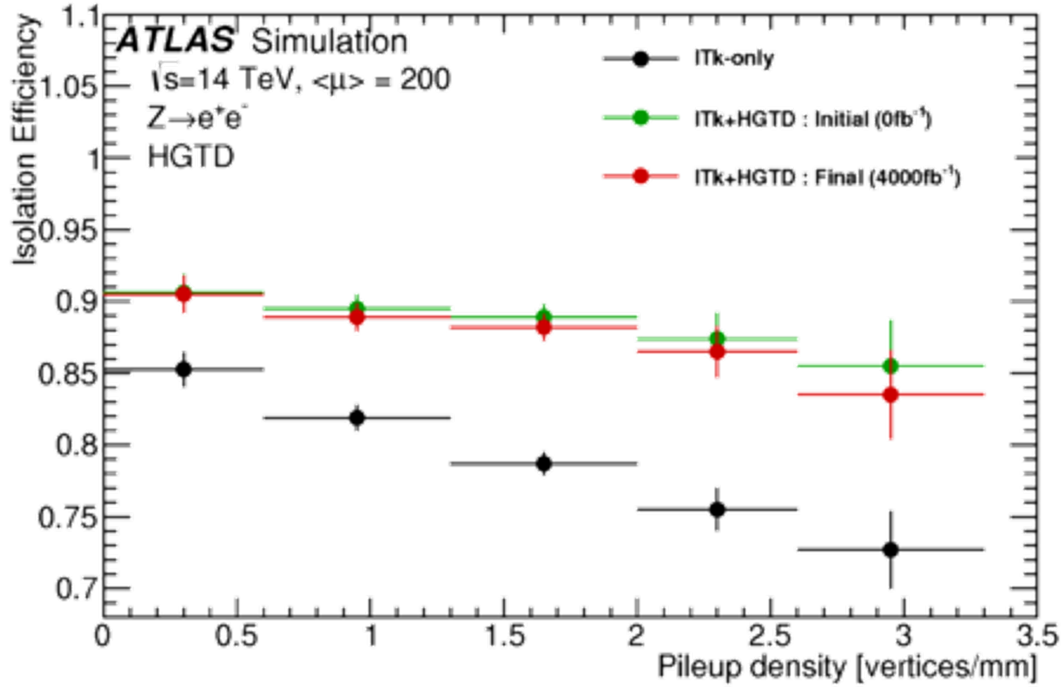


# High Granulatiry Timing Detector (HGTD)

- Improves ATLAS performance in high-pileup environment
- Two disks on each side of the ATLAS interation point
- R: 12-64 cm ; z: ±3.5 m ; 2.4 < |η| < 4
- Time resolution of 30-50 ps per track



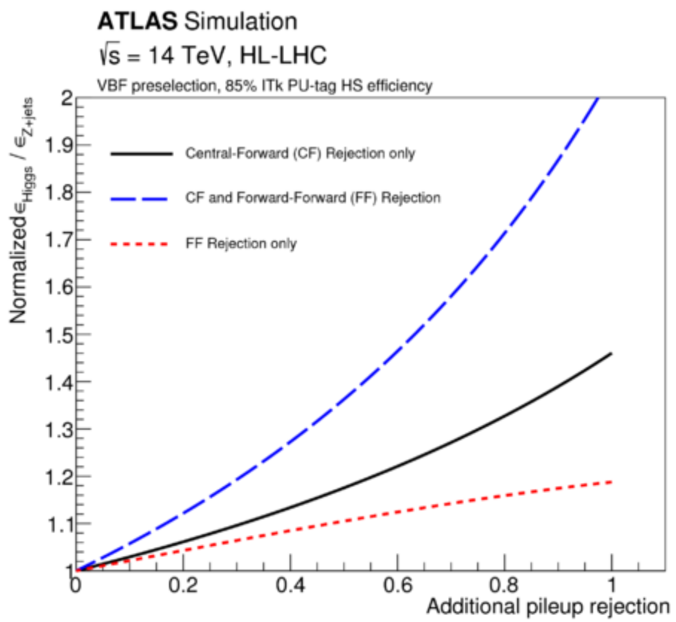



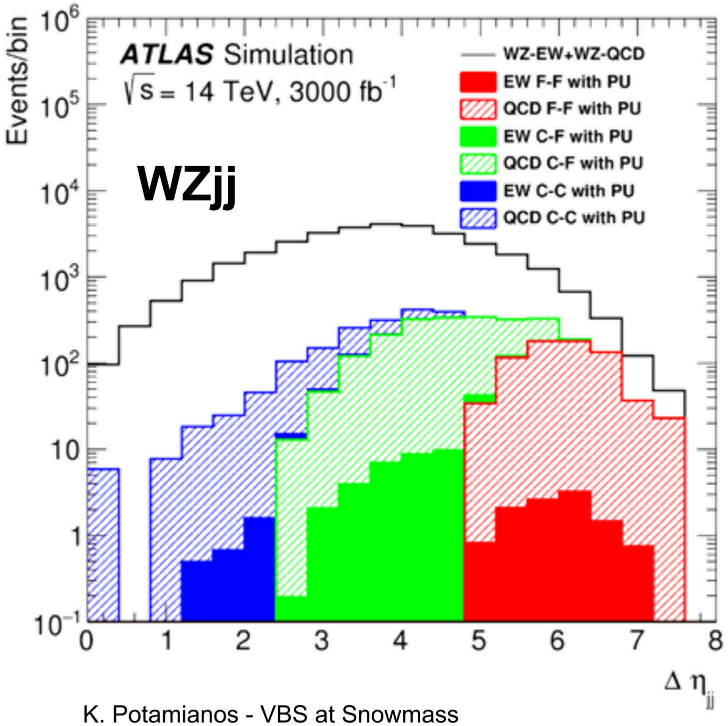


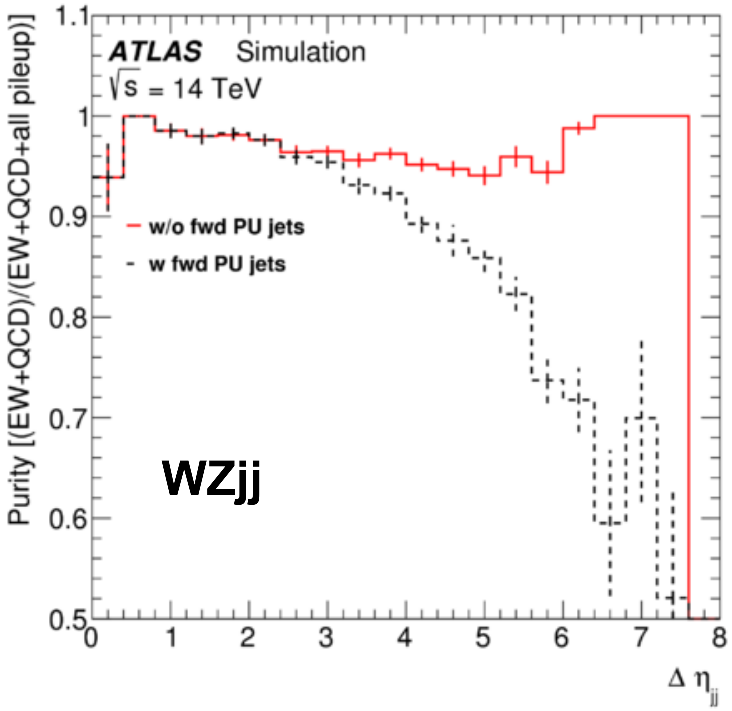

7-20 % improvement

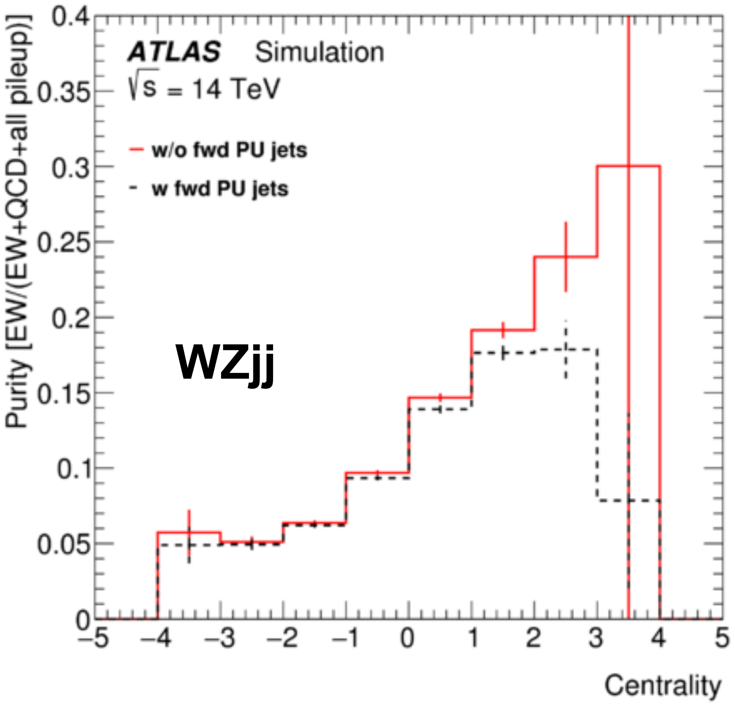
# HGTD Performance

- Significant gains relative to ITk-only pileup jet suppression
- Study performed for EW WZjj and QCD WZjj
  - Significant increase in purity with PU suppression



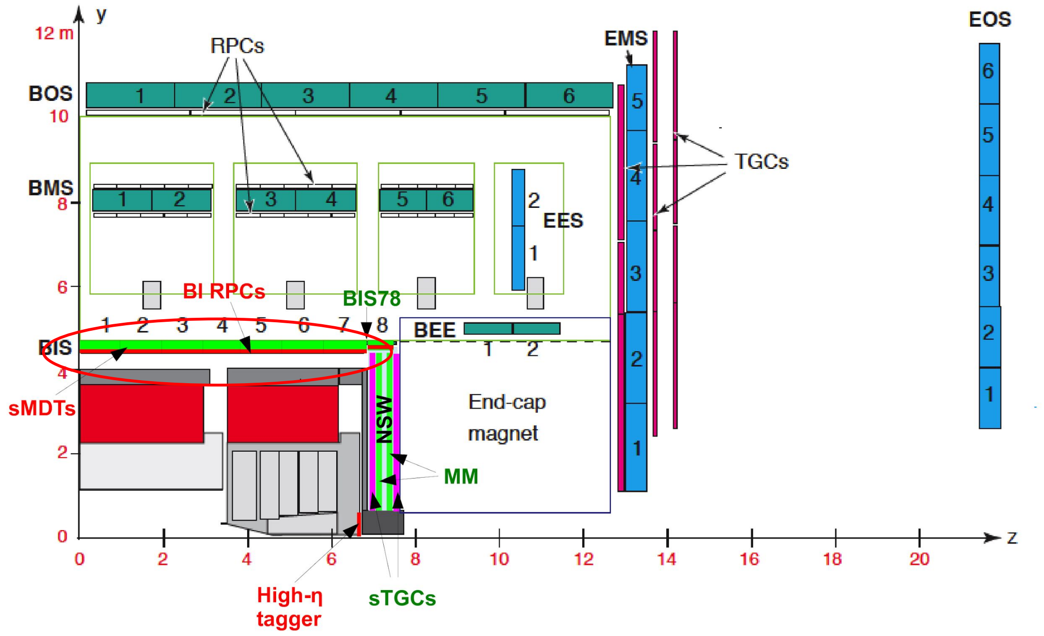



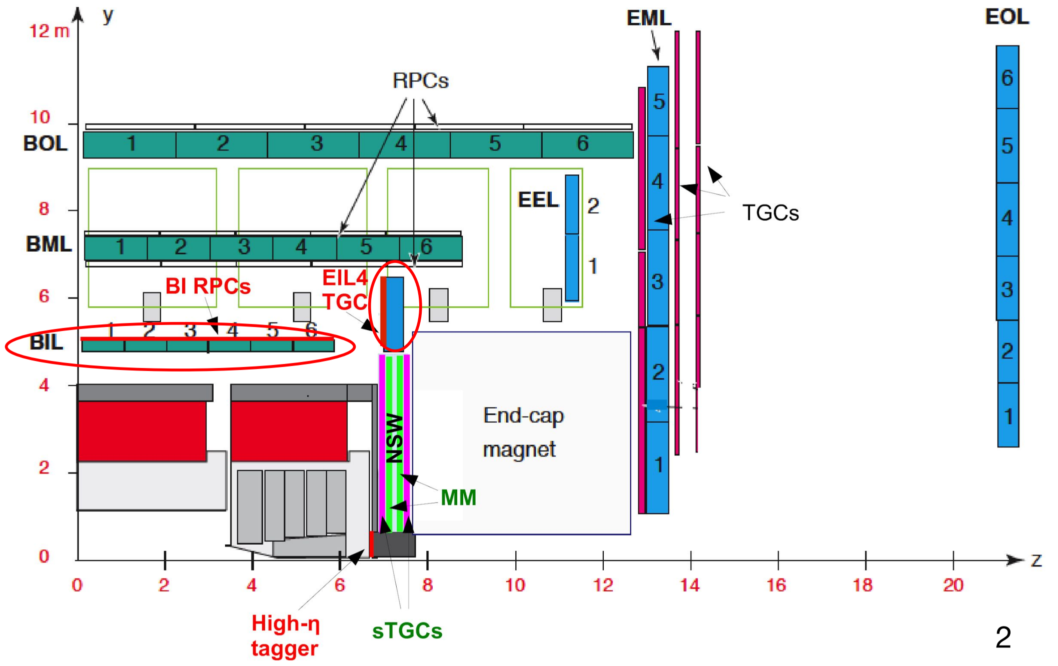



# Muon Subsystem Upgrades

- **ATLAS Muon Spectrometer before Phase-II**
  - 3 stations of Resistive Plate Chambers (RPCs) in the barrel
  - 3 stations of Thin Gap Chambers (TGCs) in the end-cap
  - RPC/TGC used for hardware based Level-1 (L1) Trigger
  - 3 stations of Monitored Drift Tubes (MDTs) in barrel/end-cap for tracking
  - **New Small Wheel (Micro-Megas + sTGC) before magnet for tracking and trigger**

- **Phase-II Upgrades**
  - New RPC chambers with increased rate capability in inner barrel sections (BIS)
  - New sMDT in the BIS stations
  - New TGC triplets in the EIL4 station
  - Hardware-based trigger now called Level-0 (L0)

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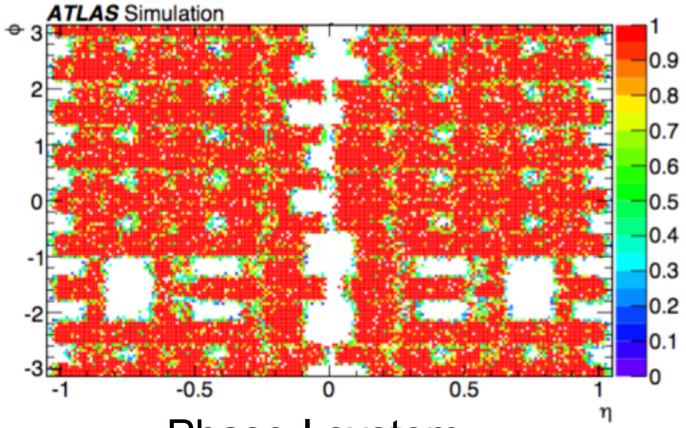
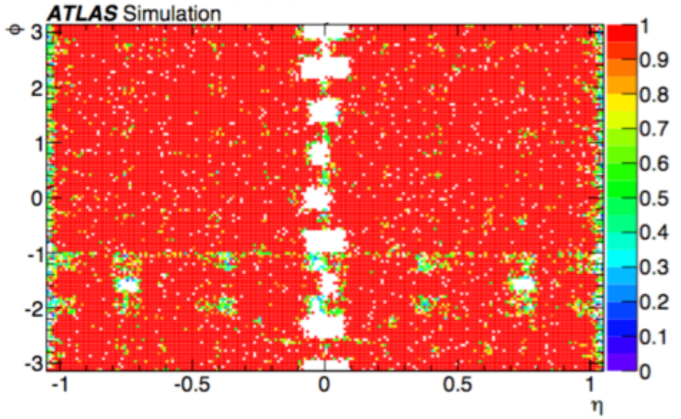
# Muon Performance

- **Increased trigger coverage** under HL-LHC conditions
- New algorithm shows a **higher efficiency** than the current system

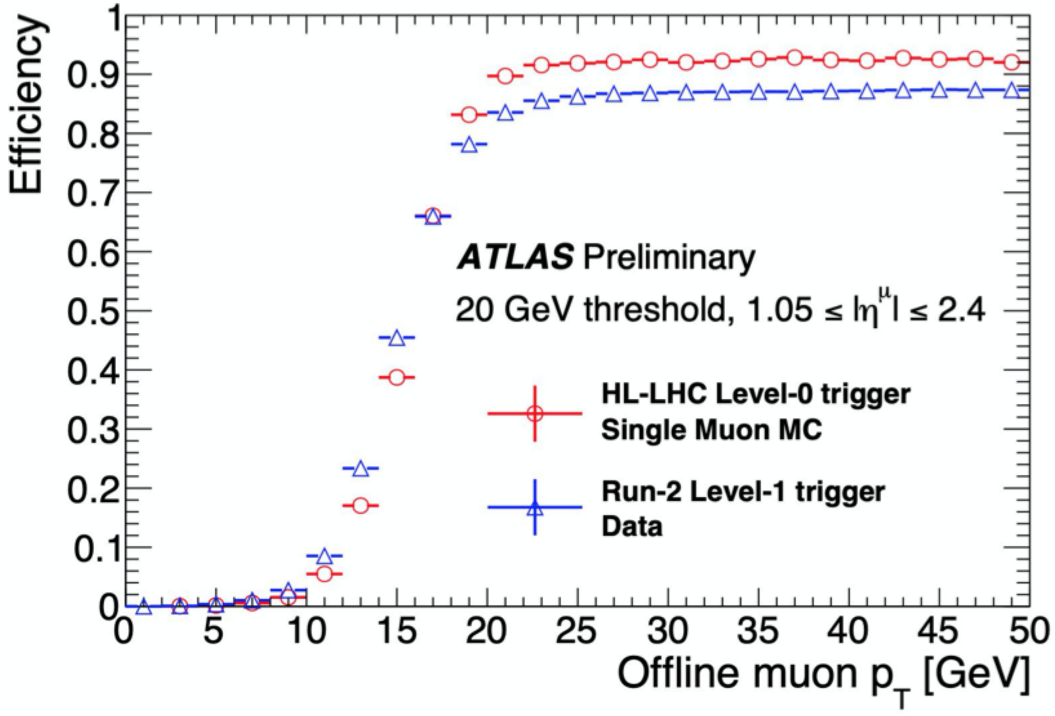
Muon trigger coverage in barrel (|η|<1) in HL-LHC conditions




Phase-I system



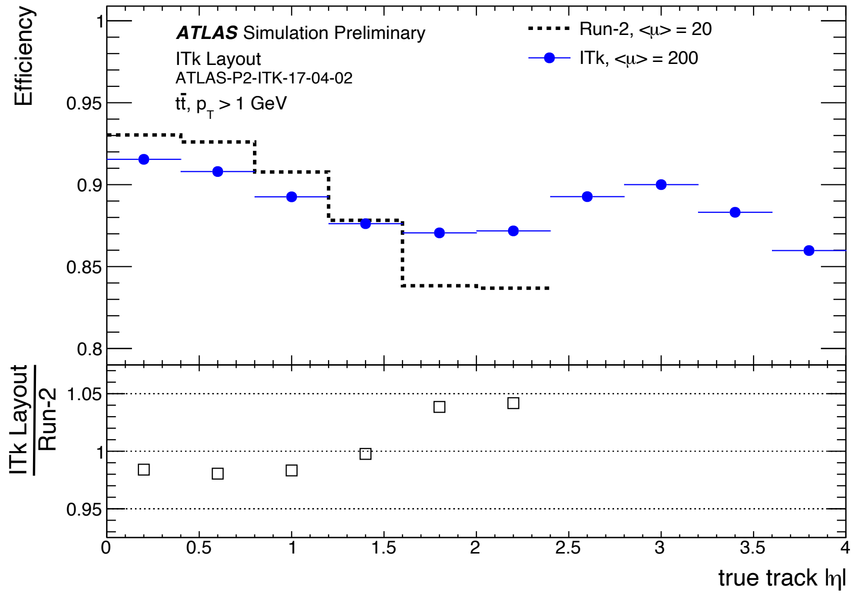

Phase-II system with RPC operated with a two-station coincidence

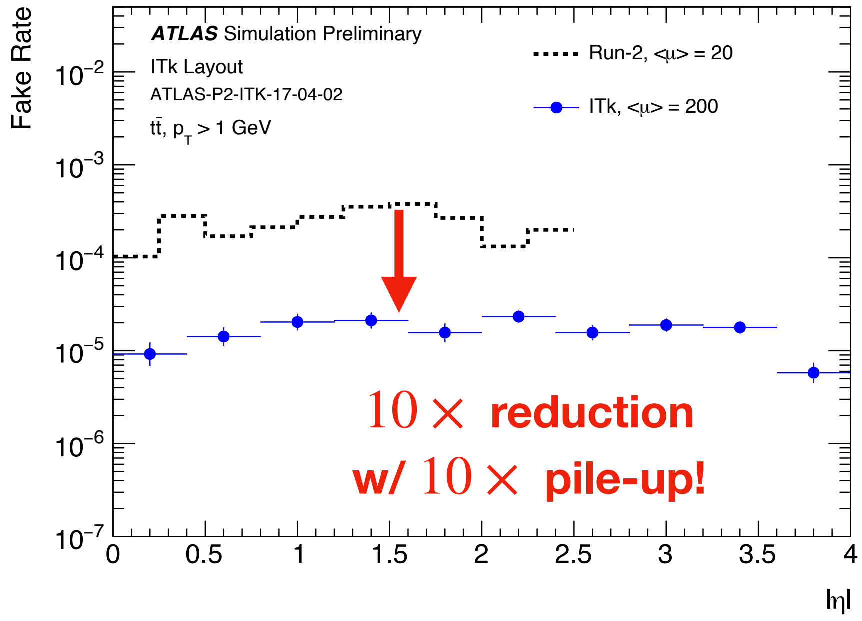


# Track Efficiency and Fake Rates

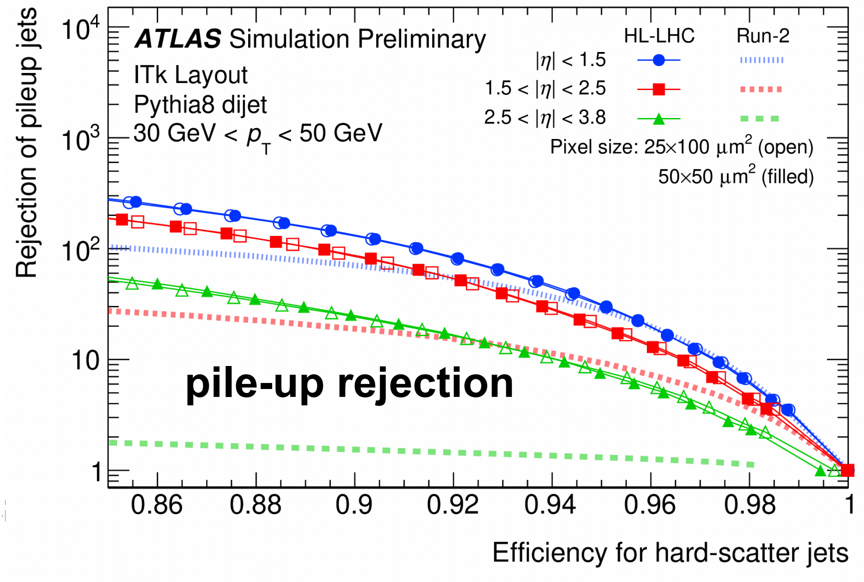
- **Efficiency** is the fraction of all **reconstructed true prompt particles**
  - Maintain **over 85%** efficiency up to $|\eta| = 4.0$
  - Comparable with Run-2 ID at $\langle\mu\rangle = 20$
- **Fake rate** is the fraction of all **reconstructed tracks unmatched** to a **true particle**
  - Excellent improvements over Run-2 ID, even with 10 × pile-up

- Overall significant improvements in forward region up to extent of Run-2 ID, plus extended coverage!
  - Reduced **material budget** → minimize material interactions
  - Increase in overall **hit counts** → tighter track selections
  - Improved **hermiticity** → more hits + fewer holes on track

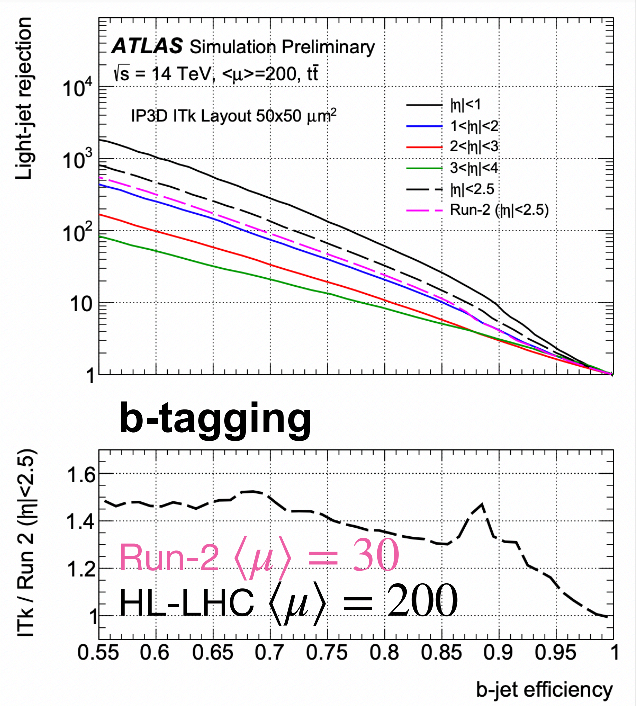


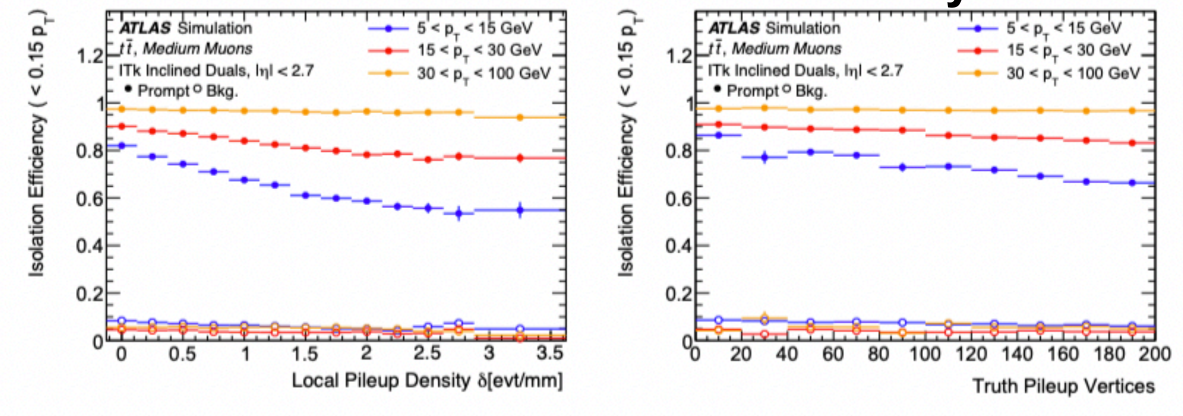
# Tracking Impact on Physics Objects



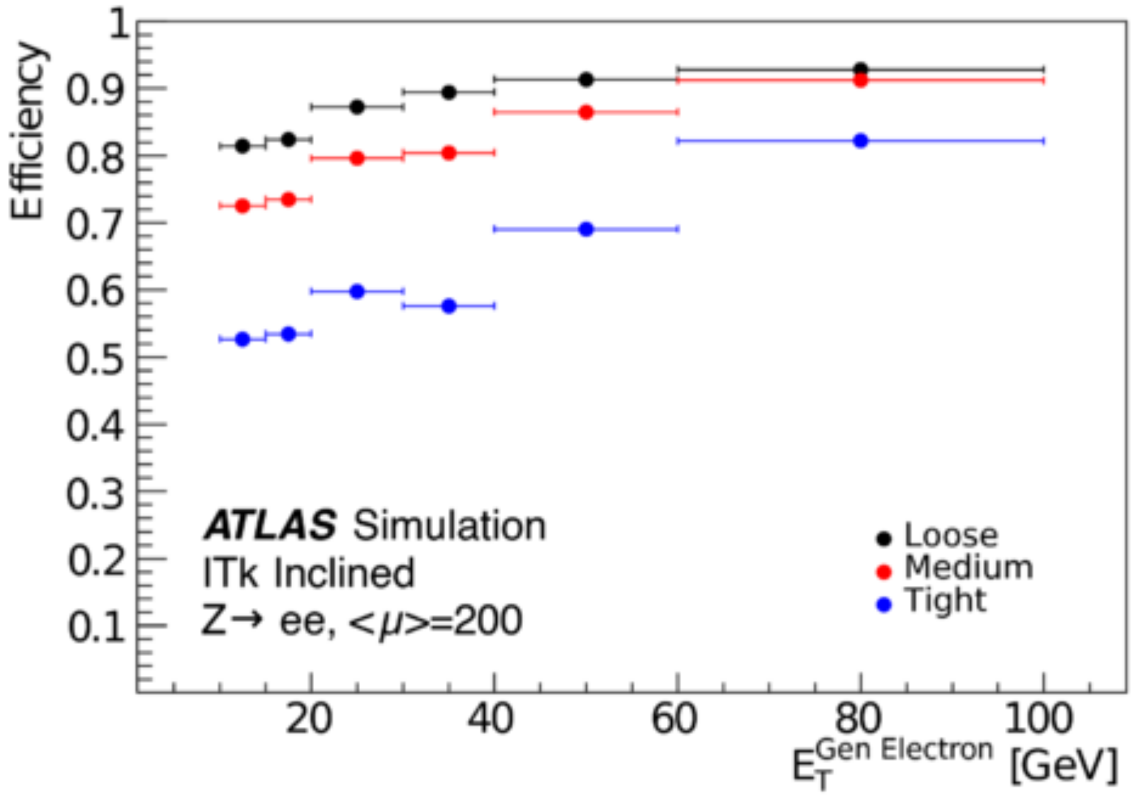

- Excellent **prospects for object reconstruction and combined performance for the HL-LHC**
- Significant improvements in **pile-up jet rejection** in the forward region (Run-2 ID limited to | η | < 2.5)
- Prompt **muon track isolation efficiency stable** against increasing local and global pile-up for pT > 30 GeV
  - Background rejection essentially flat with pile-up regardless of muon pT
- **Comparable b-tagging performance** to Run-2 ID, even at much larger pile-up
  - **Large room for improvements from ITk-specific optimisation**

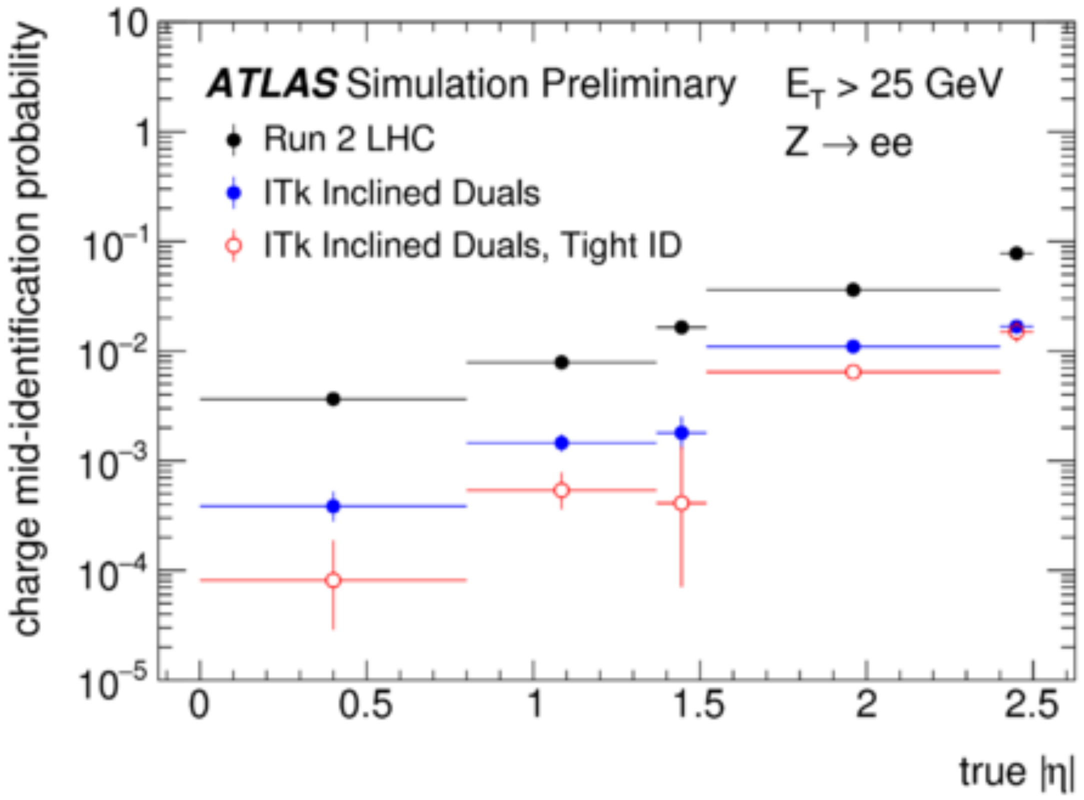



## Muon Track Isolation Efficiency



# HL-LHC Performance



# Example Trigger Menu

## @ ATLAS HL-LHC

| Trigger Selection | Run 1 Offline $p_T$ Threshold [GeV] | Run 2 (2017) Offline $p_T$ Threshold [GeV] | Planned HL-LHC Offline $p_T$ Threshold [GeV] | L0 Rate [kHz] | After regional tracking cuts [kHz] | Event Filter Rate [kHz] |
|---|---|---|---|---|---|---|
| isolated single $e$ | 25 | 27 | 22 | 200 | 40 | 1.5 |
| isolated single $\mu$ | 25 | 27 | 20 | 45 | 45 | 1.5 |
| single $\gamma$ | 120 | 145 | 120 | 5 | 5 | 0.3 |
| forward $e$ | | | 35 | 40 | 8 | 0.2 |
| di-$\gamma$ | 25 | 25 | 25,25 | | 20 | 0.2 |
| di-$e$ | 15 | 18 | 10,10 | 60 | 10 | 0.2 |
| di-$\mu$ | 15 | 15 | 10,10 | 10 | 2 | 0.2 |
| $e-\mu$ | 17,6 | 8,25 / 18,15 | 10,10 | 45 | 10 | 0.2 |
| single $\tau$ | 100 | 170 | 150 | 3 | 3 | 0.35 |
| di-$\tau$ | 40,30 | 40,30 | 40,30 | 200 | 40 | $0.5^{\dagger\dagger\dagger}$ |
| single $b$-jet | 200 | 235 | 180 | 25 | 25 | $0.35^{\dagger\dagger\dagger}$ |
| single jet | 370 | 460 | 400 | | | 0.25 |
| large-$R$ jet | 470 | 500 | 300 | 40 | 40 | 0.5 |
| four-jet (w/ $b$-tags) | | $45^{\dagger}$(1-tag) | 65(2-tags) | 100 | 20 | 0.1 |
| four-jet | 85 | 125 | 100 | | | 0.2 |
| $H_T$ | 700 | 700 | 375 | 50 | 10 | $0.2^{\dagger\dagger\dagger}$ |
| $E_T^{miss}$ | 150 | 200 | 210 | 60 | 5 | 0.4 |
| VBF inclusive | | | 2x75 w/ ($\Delta\eta > 2.5$ & $\Delta\phi < 2.5$) | 33 | 5 | $0.5^{\dagger\dagger\dagger}$ |
| $B$-physics$^{\dagger\dagger}$ | | | | 50 | 10 | 0.5 |
| Supporting Trigs | | | | 100 | 40 | 2 |
| Total | | | | 1066 | 338 | 10.4 |

† In Run 2, the 4-jet $b$-tag trigger operates below the efficiency plateau of the Level-1 trigger.
†† This is a place-holder for selections to be defined.
††† Assumes additional analysis specific requires at the Event Filter level

# Summary

- Large HL-LHC datasets will allow to perform **precision measurements** Vector Boson Scattering (VBS) sector, the exploration of extremely rare **Standard Model processes**, as well as the search for **new phenomena** beyond Standard Model
- **Phase-I upgrades:**
  - **Improved rate capabilities and background rejection to stand with L = 2-3 x $10^{34}$ $cm^{-2}s^{-1}$**
  - **Production completed for most of the systems, installation will be completed this year**
- **Phase-II upgrades:**
  - **Designed for L = 5-7.5 x $10^{34}$ $cm^{-2}s^{-1}$ and 3000 $fb^{-1}$**
  - **Up to factor 10 increase in radiation hardness**
  - **Improved pile-up handling with new tracker and timing detector**
  - **Increased Trigger and readout capabilities due to muons and TDAQ upgrades**
- **More information in the various TDRs: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/AtlasTechnicalDesignReports**