Upgrade and Physics Plans for ATLAS in LHC Run 4

Offshell Virtual Conference 2021

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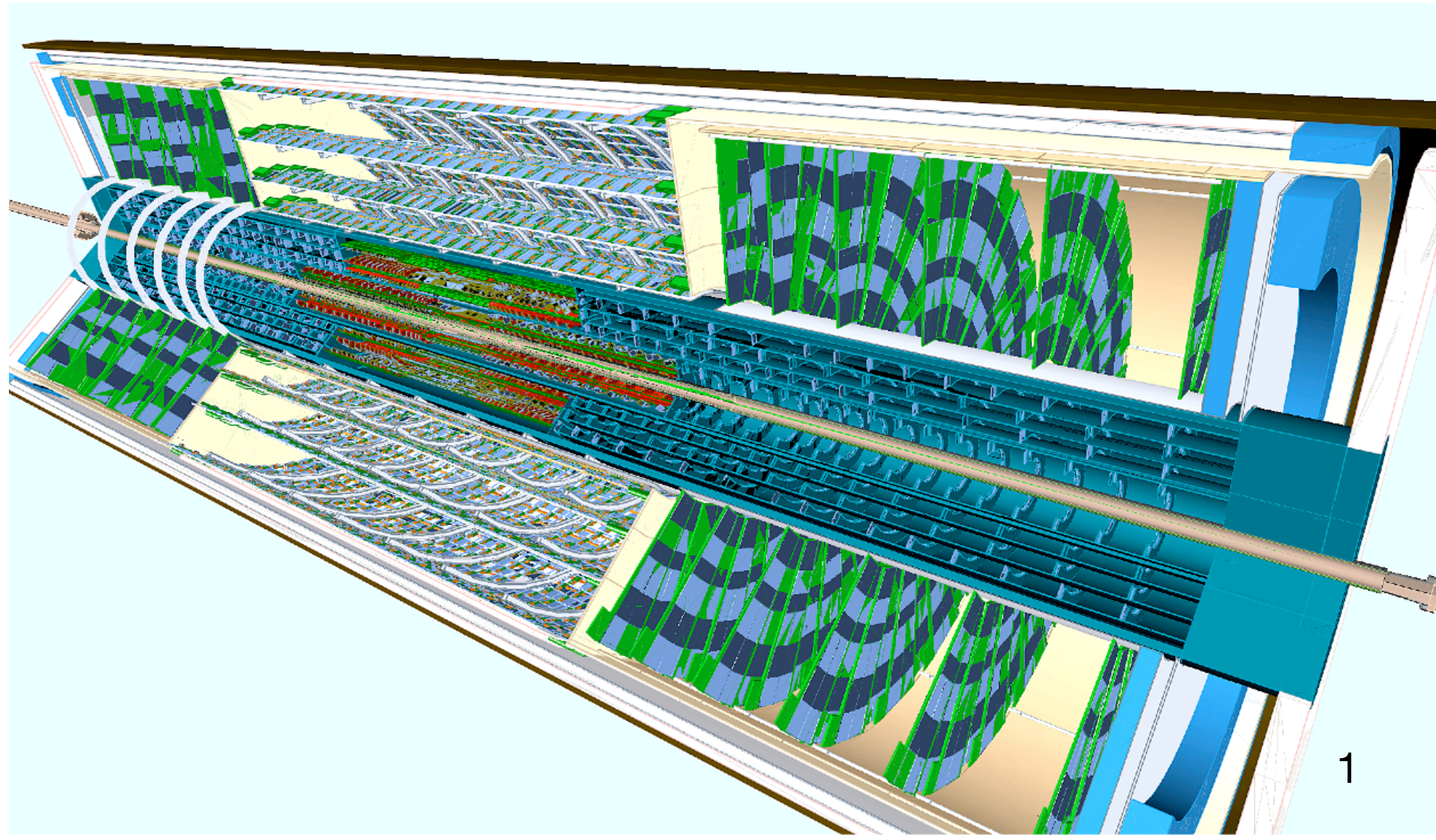
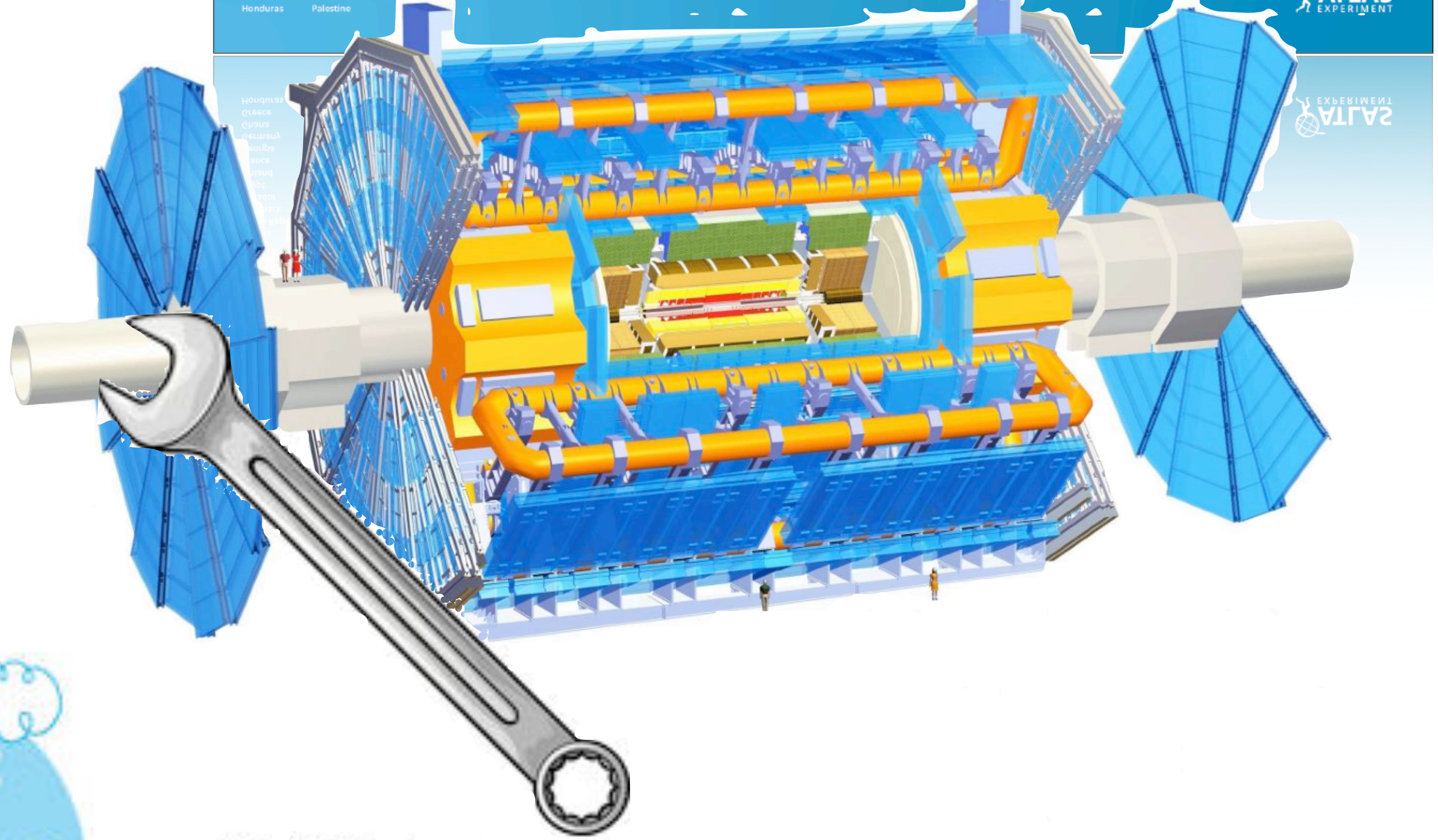
ATLAS EXPERIMENT



Overview

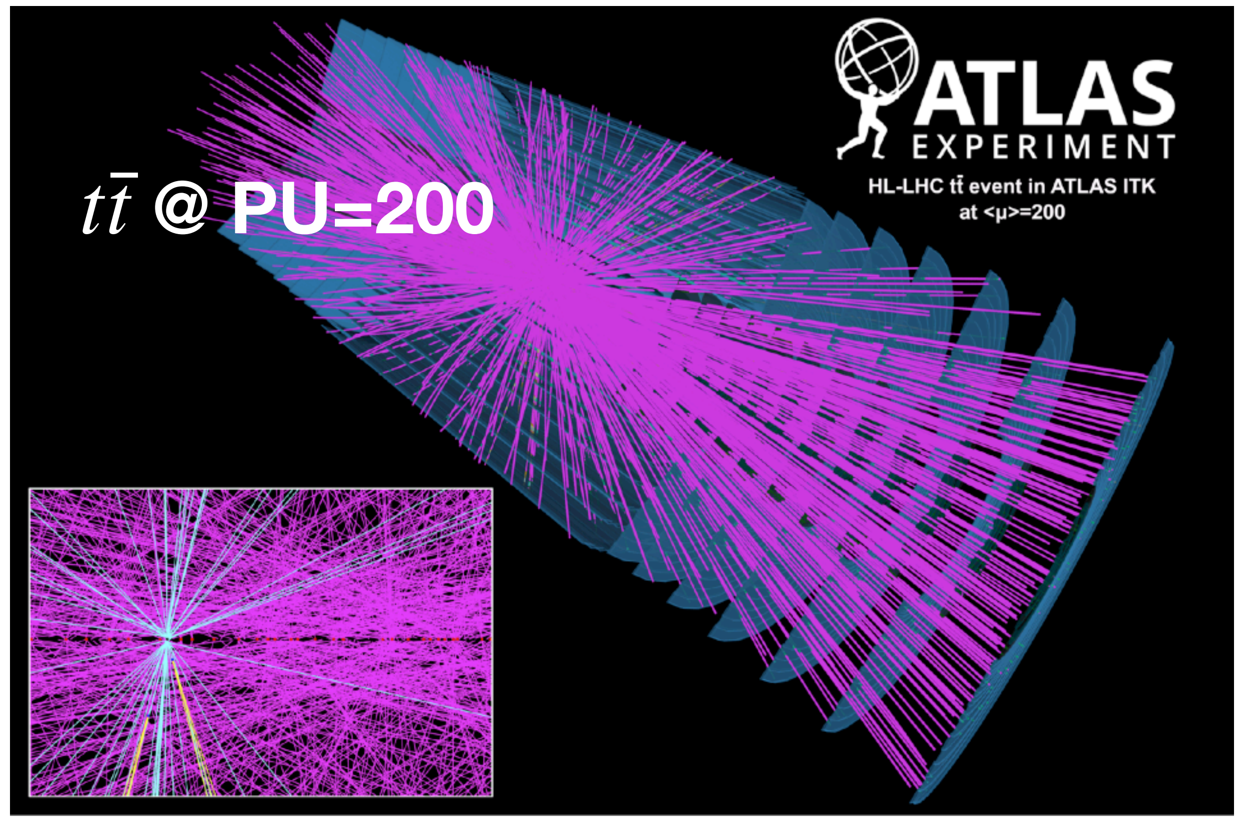
- HL-LHC Forecast
- ATLAS at HL-LHC
  - Objectives
  - Phase II Detector Improvements
    - Overview
    - Calorimeter & muon upgrades
    - New Inner Tracker (ITk),
    - High Granularity Timing Detector (HGTD)
    - Trigger and data acquisition
  - ATLAS Physics Potential at HL-LHC
    - Selected Highlights
- Conclusion

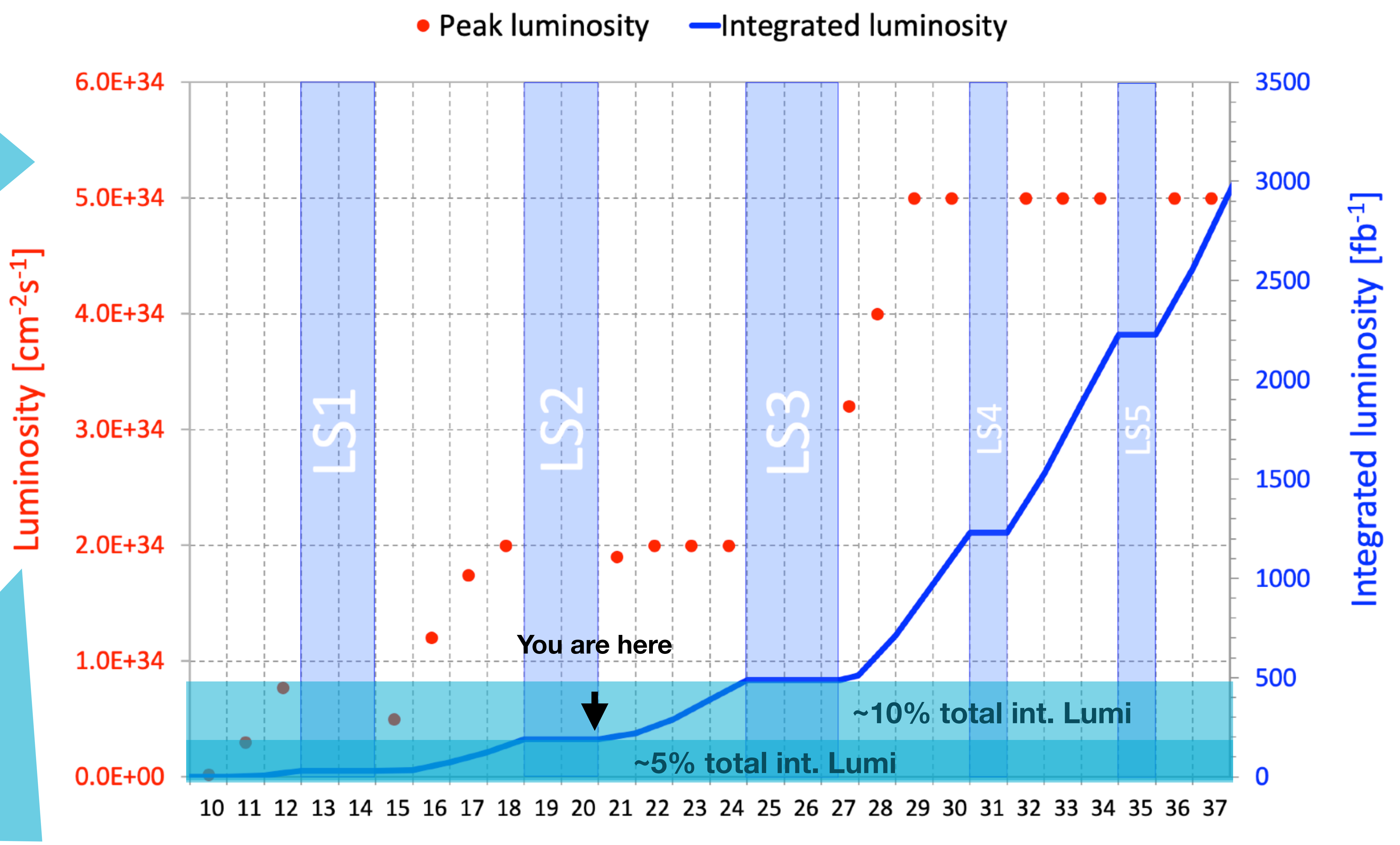


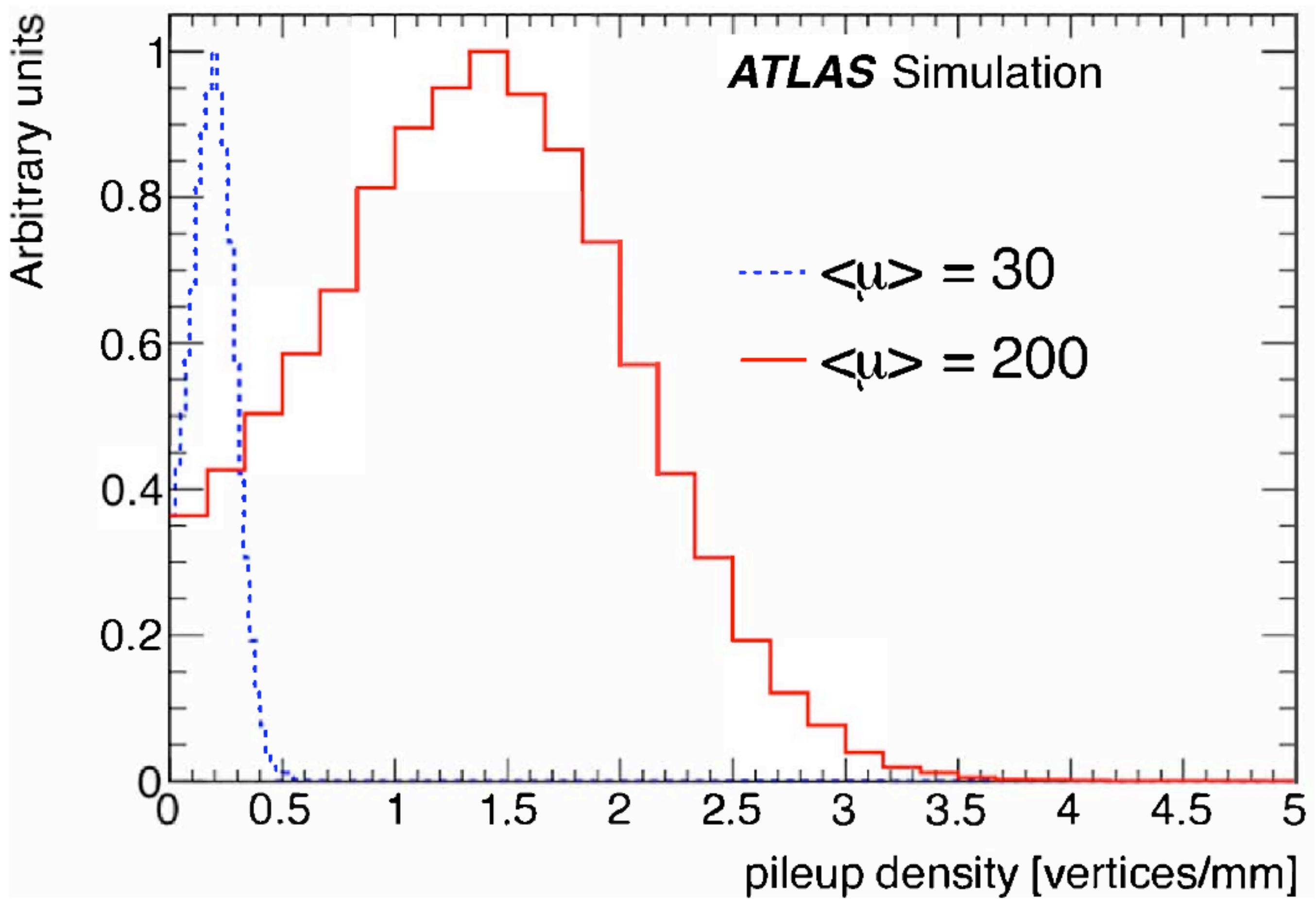
What to expect at the High-Lumi LHC

- **Start mid 2027**, 10 year period
- LHC will hit all design parameters:
  - design COM energy of $\sqrt{s}$ = **14 TeV**
  - Lumi intensity: up to ~4 x Run 3 $\mathscr{L}$ $(5 - 7.5\ x\ 10^{34}\ cm^{-2}s^{-1})$
    - Corresponding to **pile-up of 140-200** proton interactions/evt
      - 1.8 vertices/mm!
        -> and with extreme local variations
- Providing majority of our dataset:
  - Total collected data ~ **3000-4000** fb^{-1}





Assuming ion runs stopped after LS 4



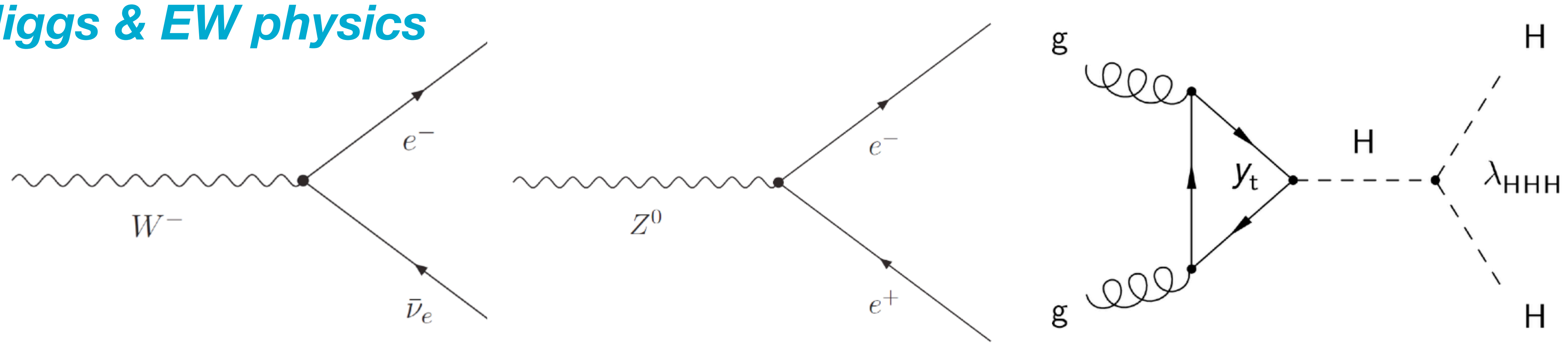
ATLAS Upgrade Objectives

ATLAS Physics Objectives

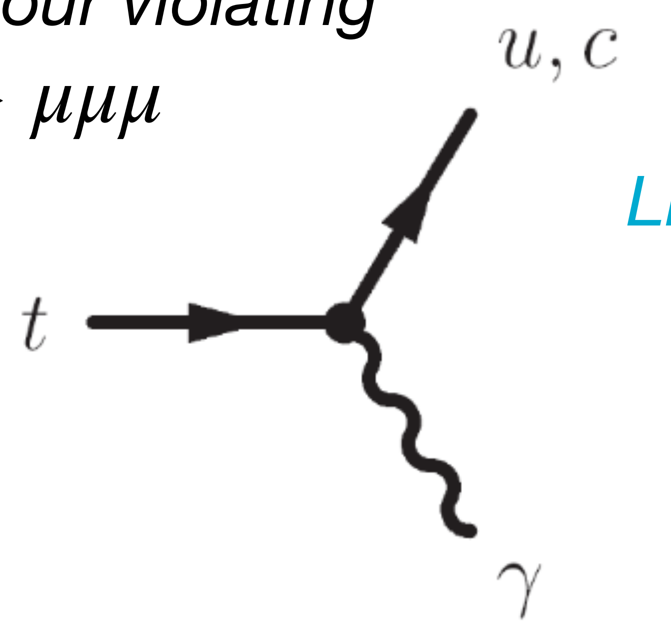
- Precise SM measurements of **Higgs properties and Electroweak processes**
  - Higgs (self) coupling measurements, m_W, m_{top}, $sin^2\theta_{eff}$
- Direct searches for **new particles**
  - SUSY, dark matter, high new energies, long-lived particles.
- Probe **flavour physics**:
  - Charged lepton flavour violation, top FCNC, rare B decays
- **Improve**
  - **forward physics** measurements
    - Measurements in vector boson fusion (VBF) & vector boson scattering (VBS) topologies
  - Knowledge of proton **parton distribution function** (PDFs)
  - Total integrated **luminosity measurements**.

SM properties (W mass, weak mixing angle, Higgs couplings…) to be probed with fine, ~1 % level, precision!

Higgs & EW physics

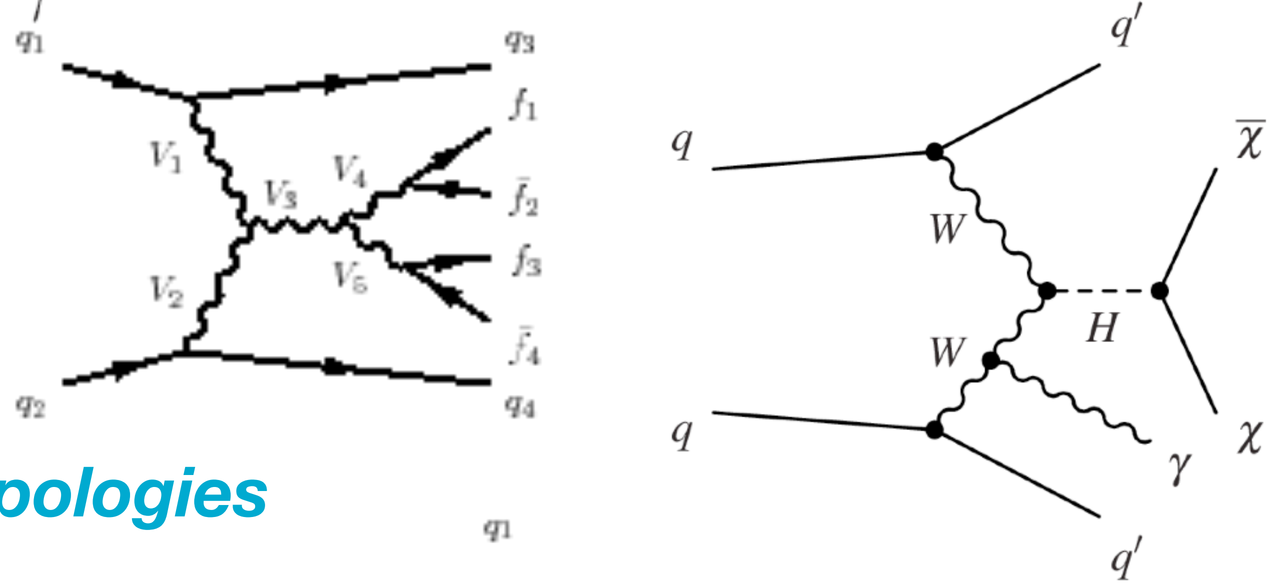


Lepton flavour violating
$\tau \to \mu\mu\mu$



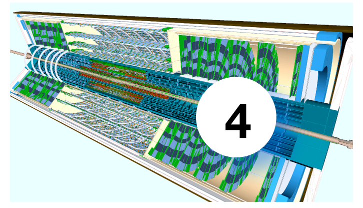
Flavour physics

LHCb, ATLAS, CMS cross-checks on flavour physics anomalies
($\mathcal{O}$ $(10^{-5})/\mathcal{O}(10^{-9})$) sensitivity on top FCNC/τ FV sensitivity on



VBS & VBF topologies

More sensitivity to physics in forward region



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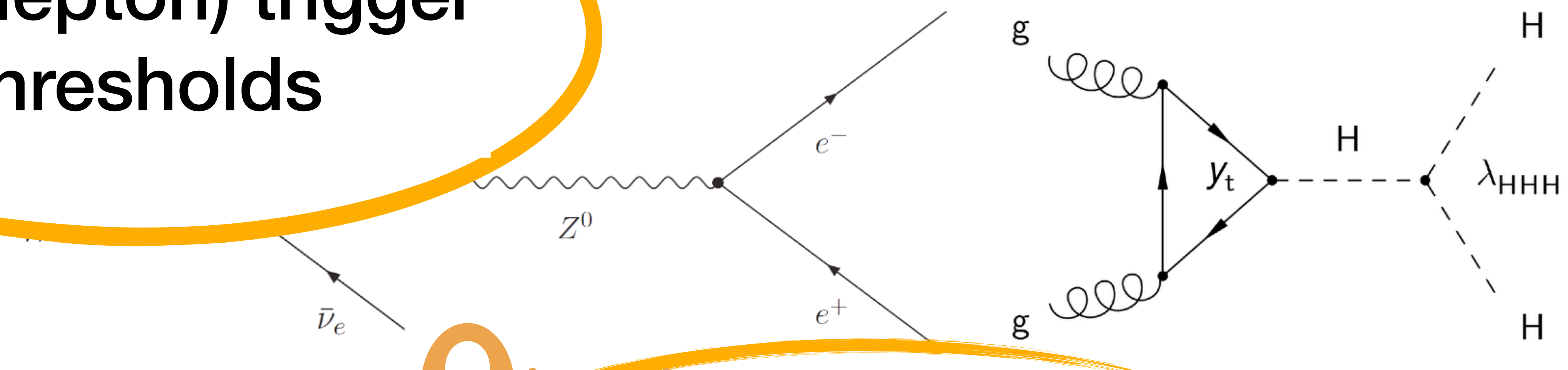
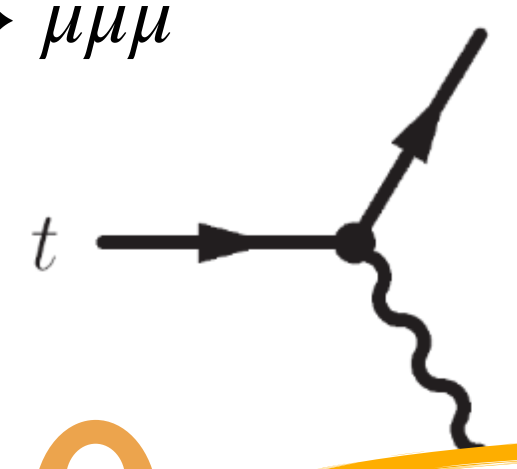
Low (lepton) trigger thresholds



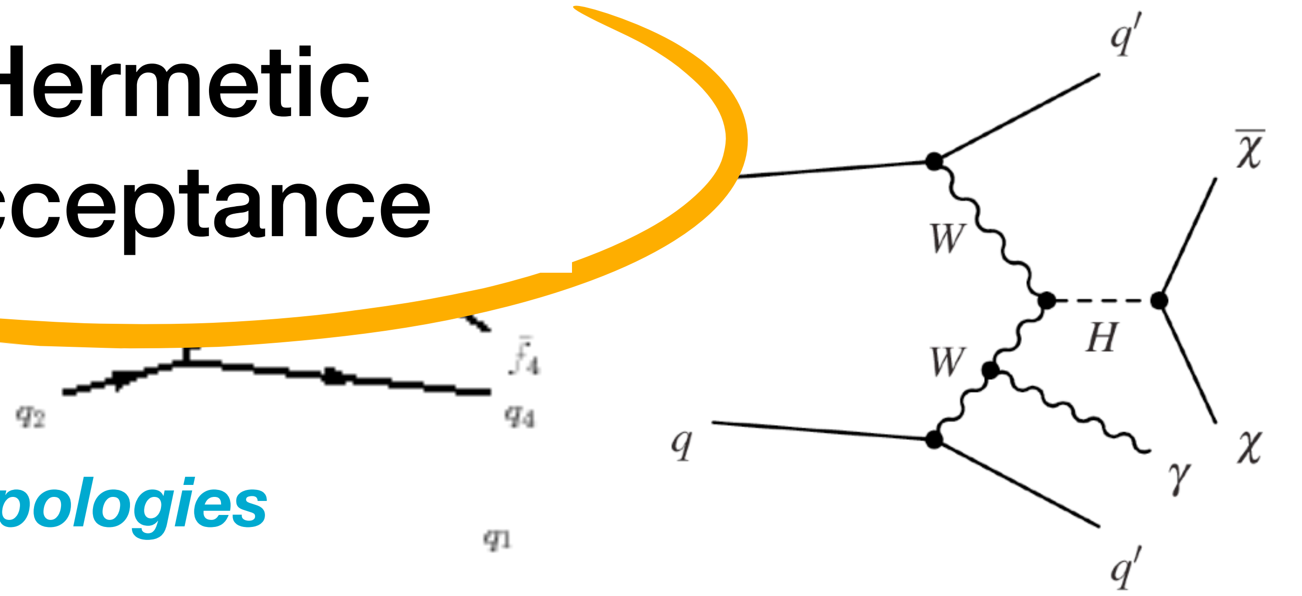
Precise tracking

Lepton flavour violating
$\tau \rightarrow \mu\mu\mu$



LHCb, ATLAS, CMS cross-checks on flavour physics anomalies
($\mathcal{O}(10^{-5})/\mathcal{O}(10^{-9})$) sensitivity on top FCNC/τ FV sensitivity on

Hermetic acceptance

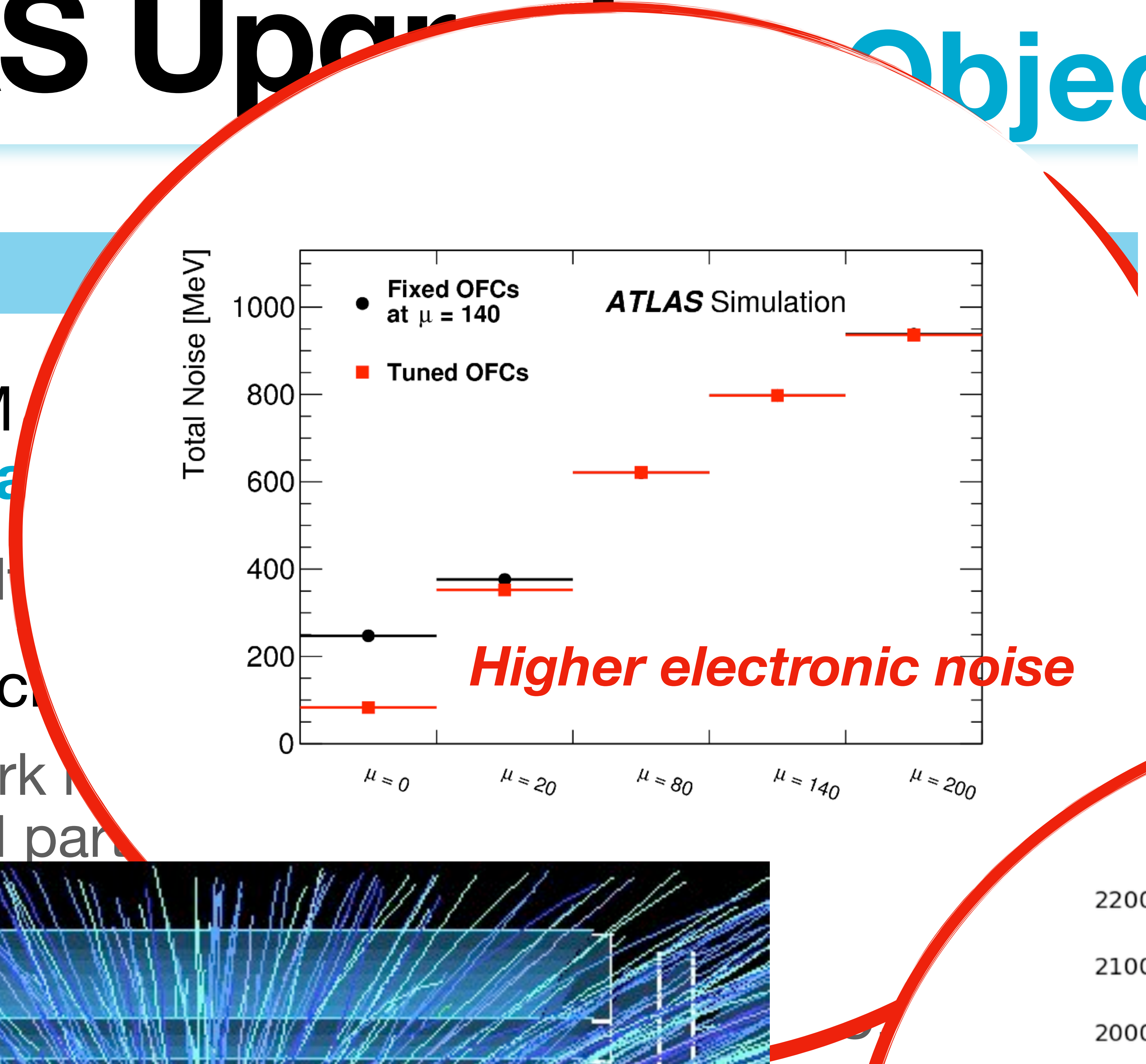


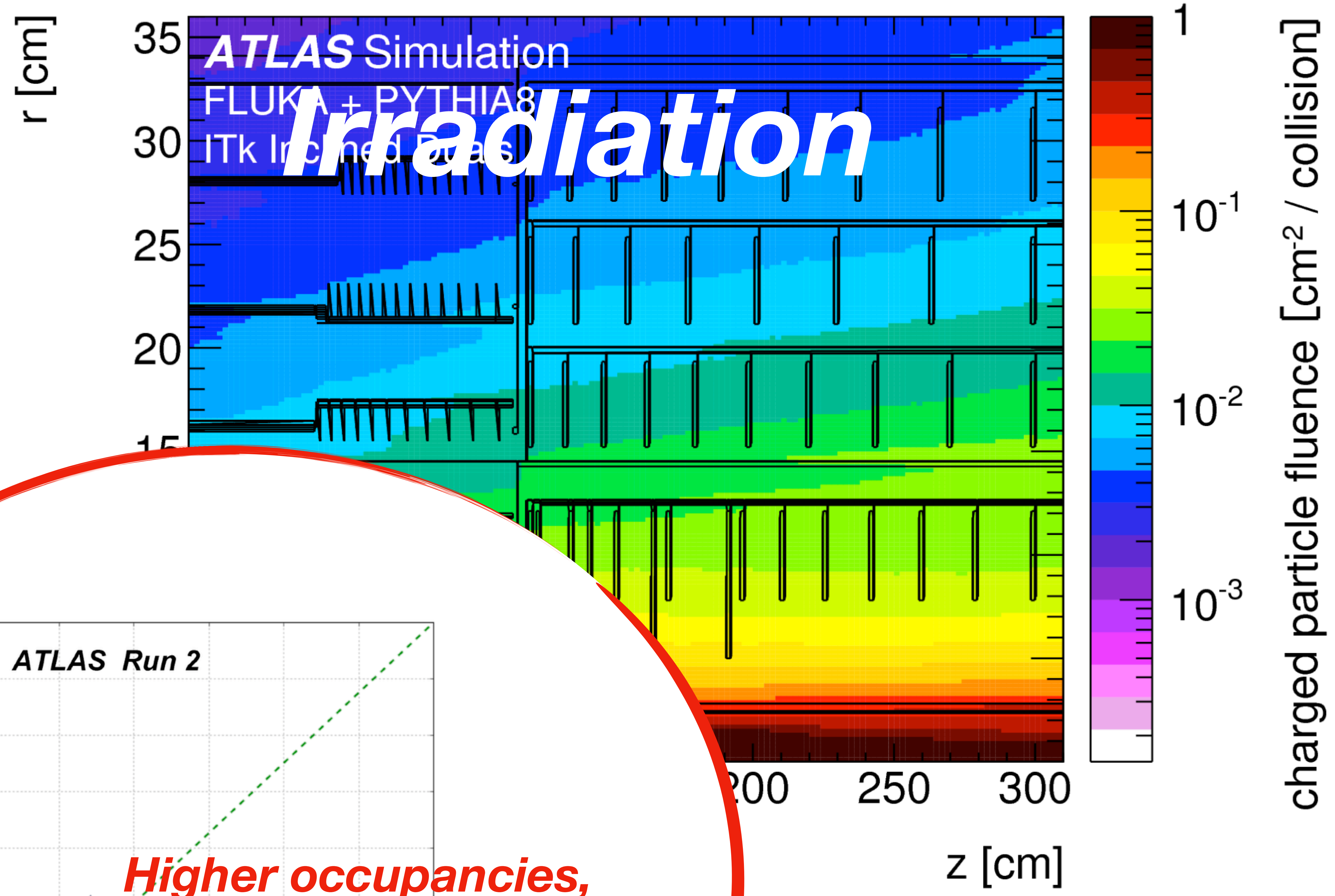
VBS & VBF topologies

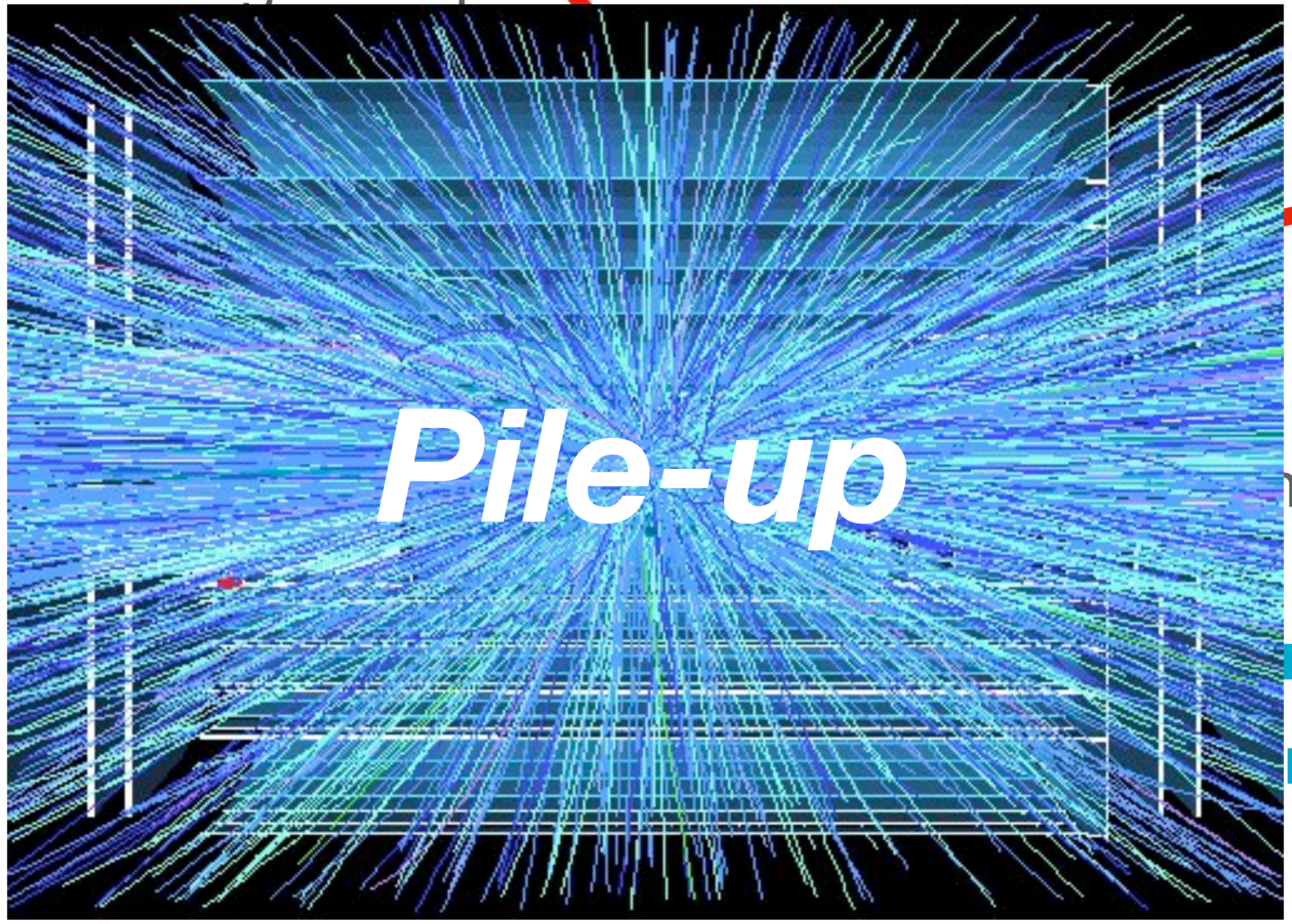
More sensitivity to physics in forward region

ATLAS Upg… Objectives

- Precise SM … Electrowea…
  - Higgs (sel…
- Direct searc…
  - SUSY, dark … long-lived par…







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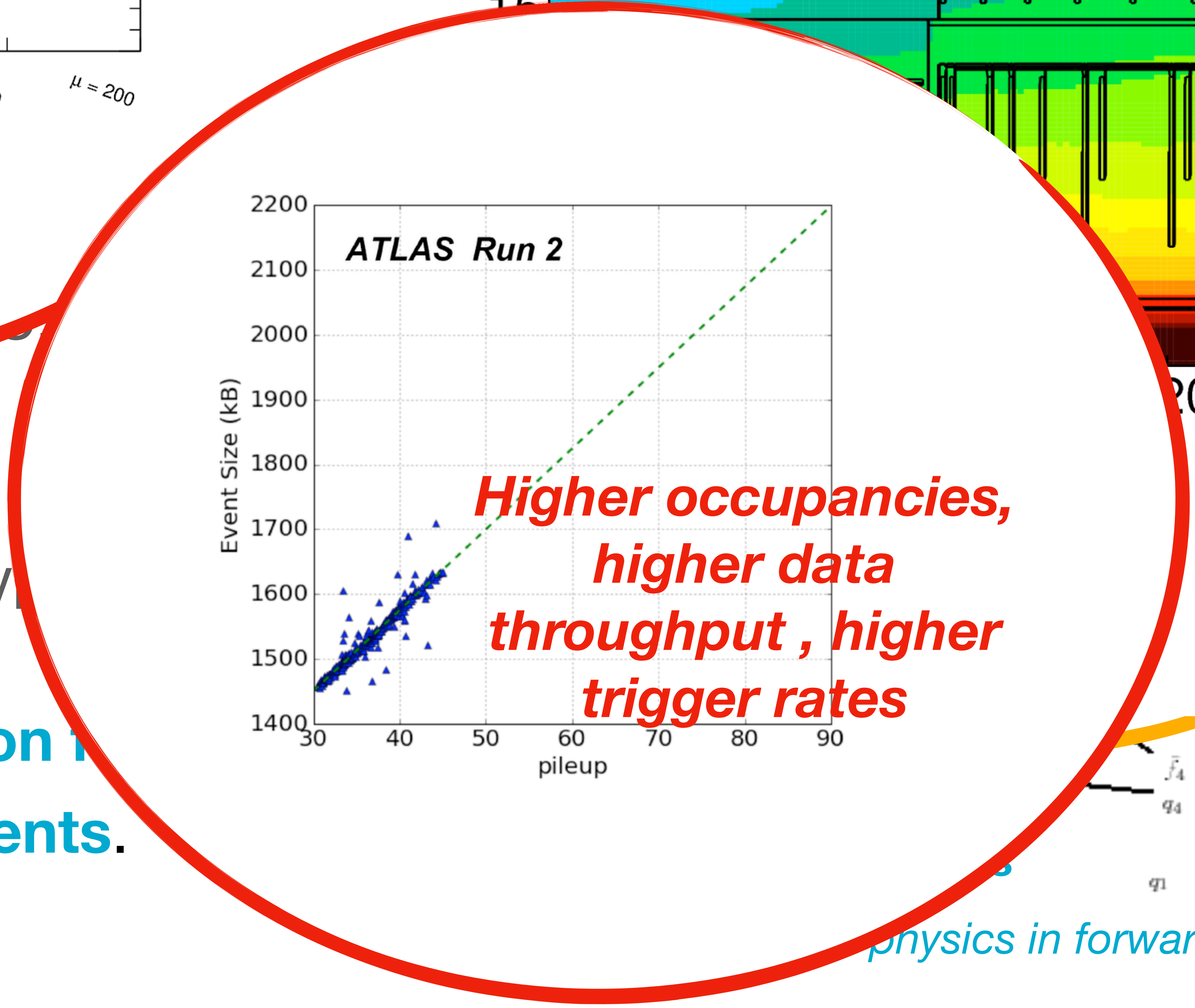
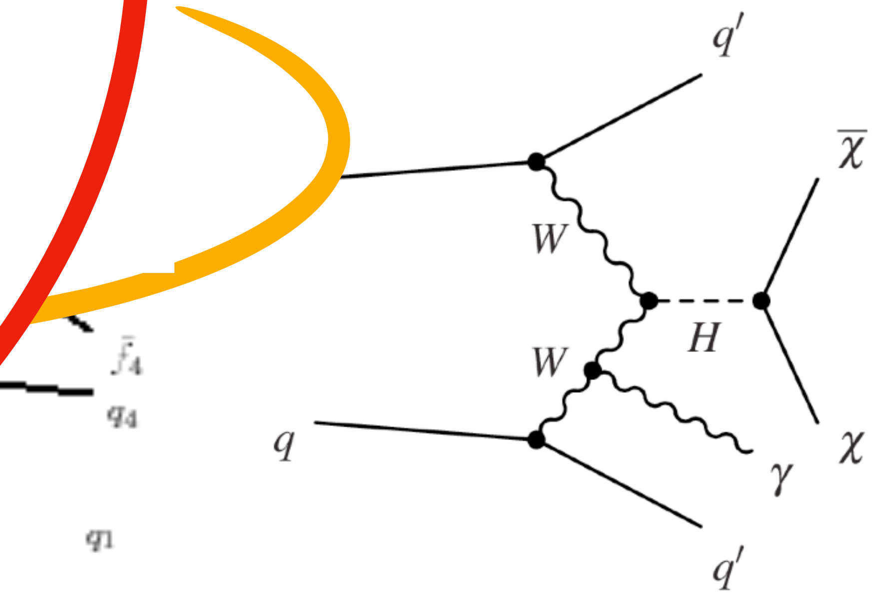
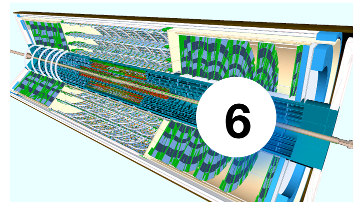




…physics in forward region



ATLAS Upgrade Objectives

To achieve

ATLAS Physics Objectives

upgrade essential

ATLAS Detector and Data Processing Objectives

- Be **robust against increased radiation** for over 10 years.
  - 10x greater w.r.t. LHC.
- **Improved readout capabilities** suitable for increased rate *and* occupancy
  - Read-out rate: 100 kHz (Run 3) -> 1 MHz (Run 4+)
- New components using new technology for
  - **Larger detector acceptance**
  - **Maintain object reconstruction performance** under increased pile-up.
    - And be even better.
- **Improved algorithms** for best possible performance, faster processing online & offline.
- Maintain **trigger thresholds**

ATLAS Detector Upgrade Overview

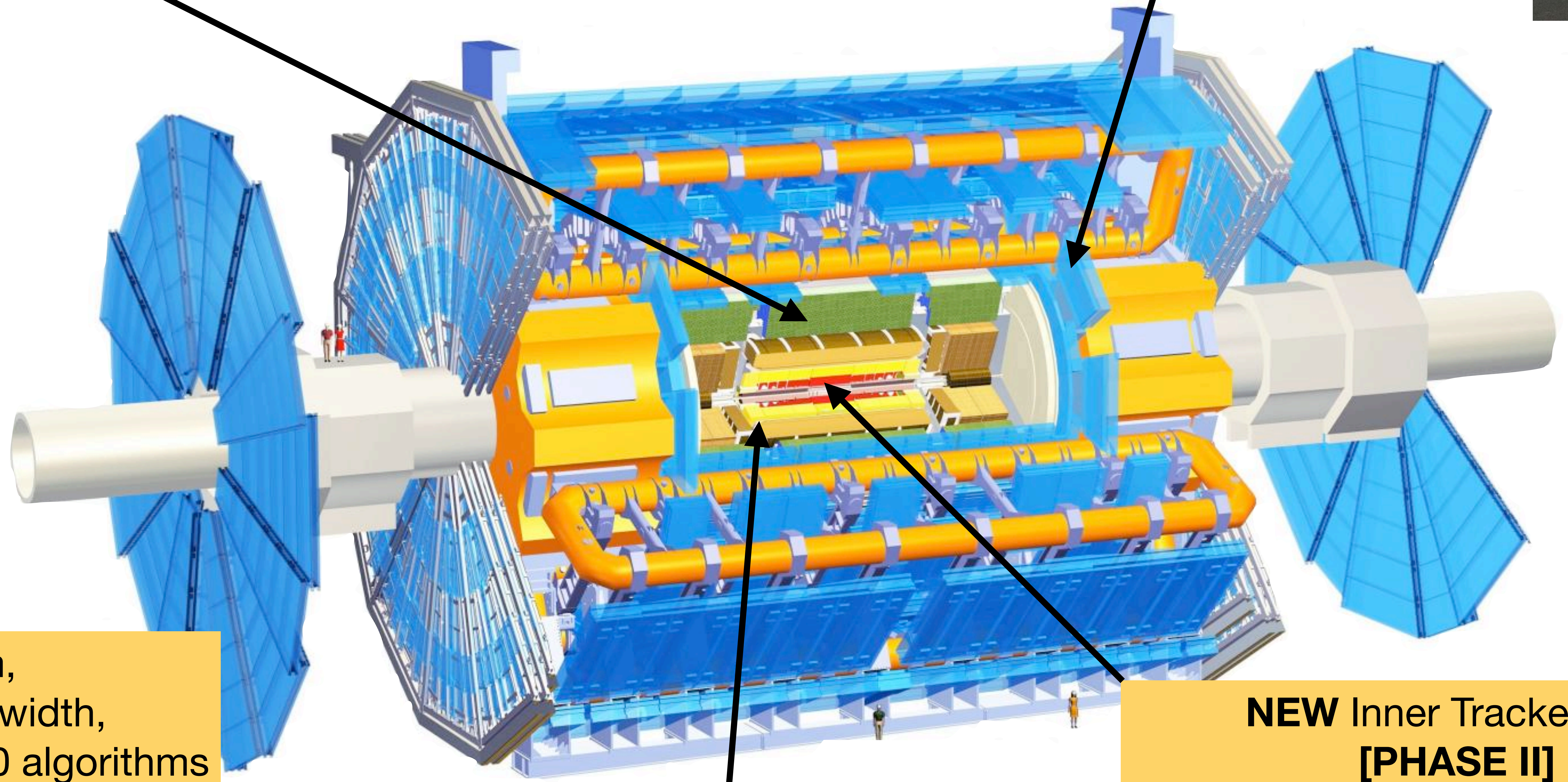
New electromagnetic calorimeter trigger processors with increased granularity **[PHASE I]**
Calorimeter front-end electronics upgrade **[PHASE II]**

Phase I Liquid Argon Upgrade TDR
Phase II Upgrade LAr TDR
Phase II Upgrade Tile TDR

New Small Wheel (endcap) **[PHASE I]**
More muon chambers **[PHASE II]**

Phase I Muon New Small Wheel TDR
Phase II Upgrade Muon TDR

Replacement most front-end electronics for suitable readout and radiation tolerance
[PHASE II]



Improved TDAQ system, with increased readout bandwidth, higher granularity, sophisticated L0 algorithms
[PHASE II]

Phase II Upgrade TDAQ TDR

NEW High Granularity Timing Detector (HGTD)
[PHASE II]

Phase II Upgrade HGTD TDR

NEW Inner Tracker (ITk)
[PHASE II]

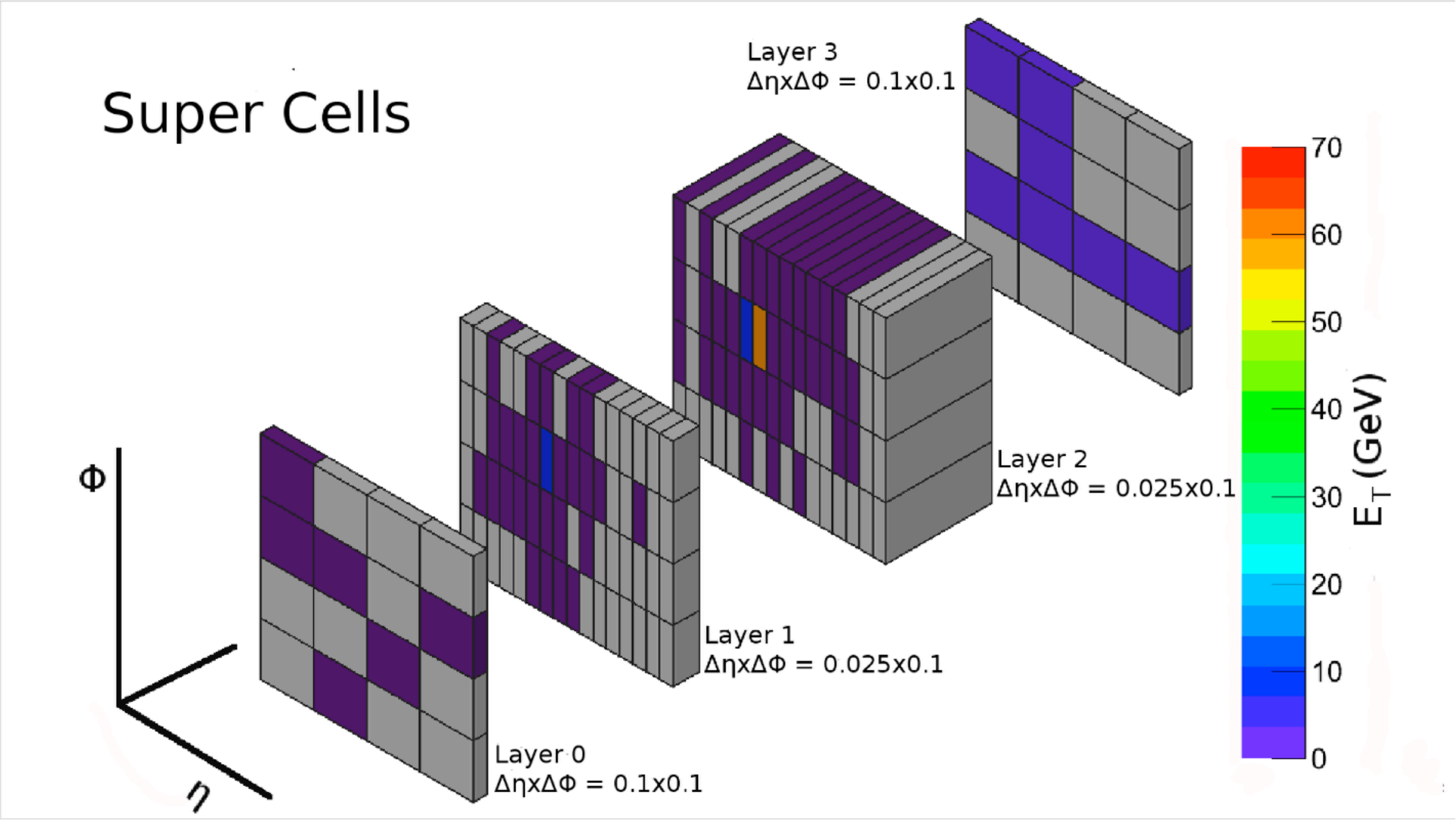
Phase II Upgrade ITk Pixel TDR
Phase II Upgrade ITk SCT TDR
ITk Expected Tracking Performance

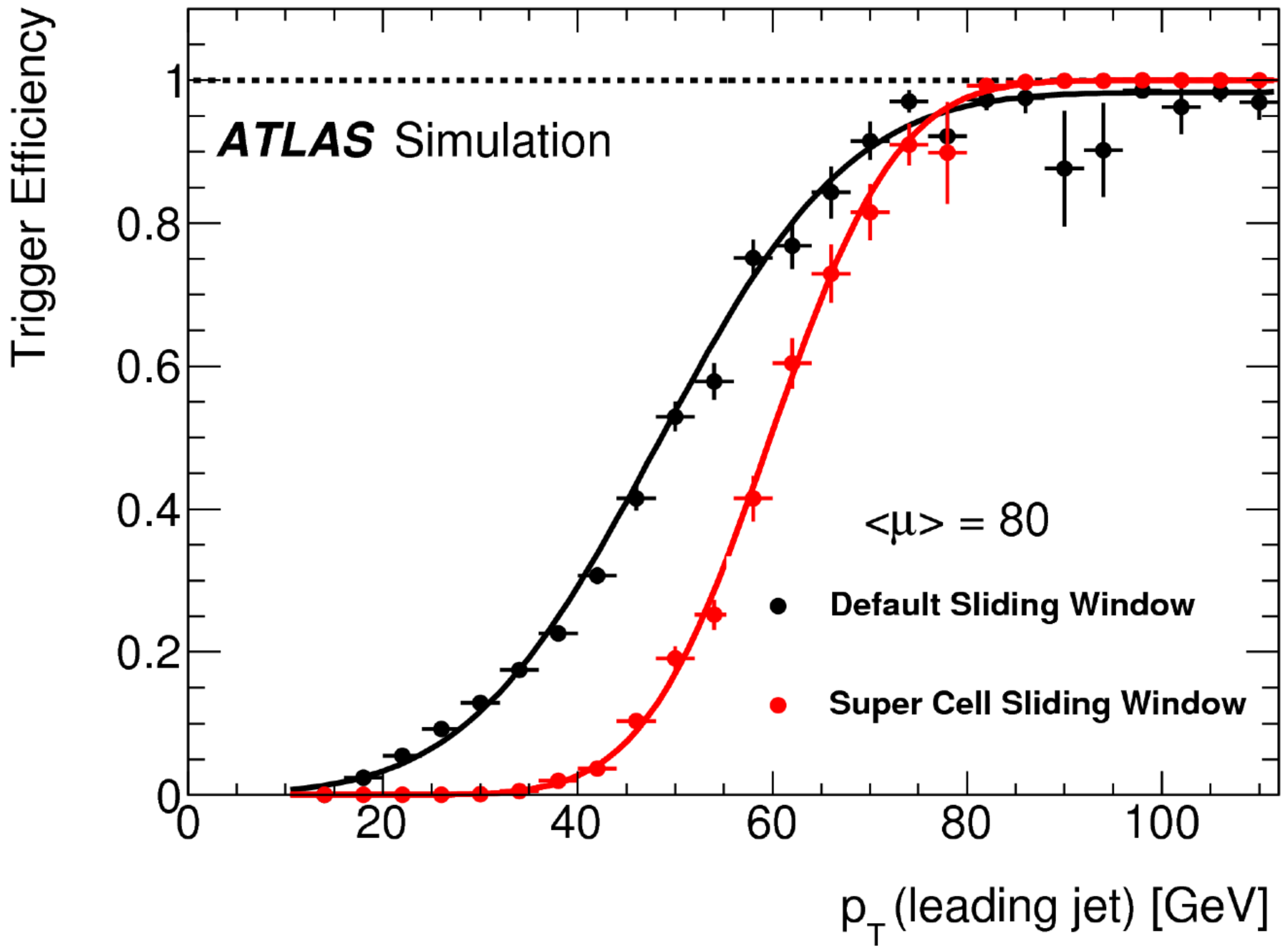
Calorimeter Upgrades Overview

PHASE I LAr trigger "FEX"s

- Level-1 trigger processing of higher granularity "super cells", with depth information
  - eFEX: Electron/photon reconstruction in EM; jFEX: jet reconstruction in EM+HAD; gFEX: global event reconstruction.

For improved energy resolution in first level hardware trigger.





Expected improved trigger turn-on curve for a single jet trigger with/without using super-cells.

PHASE II calorimeter readout upgrade

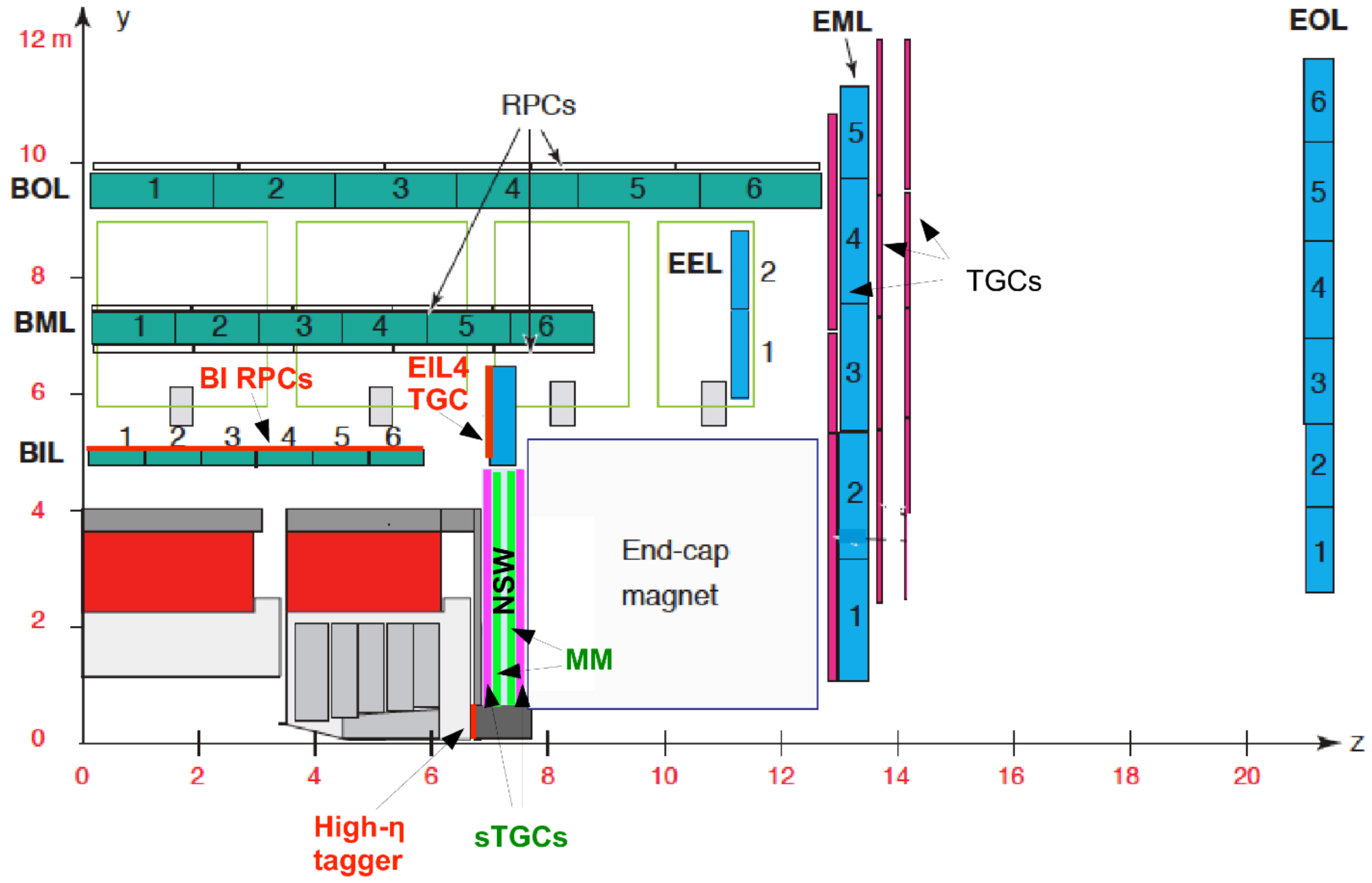
- 40 MHz free-running data readout for trigger processing.
  - Provide Level-0 trigger full granularity cell energies above threshold.
- Improved digital filtering, dynamic range.
- Suitable buffering, suitable radiation hardness.

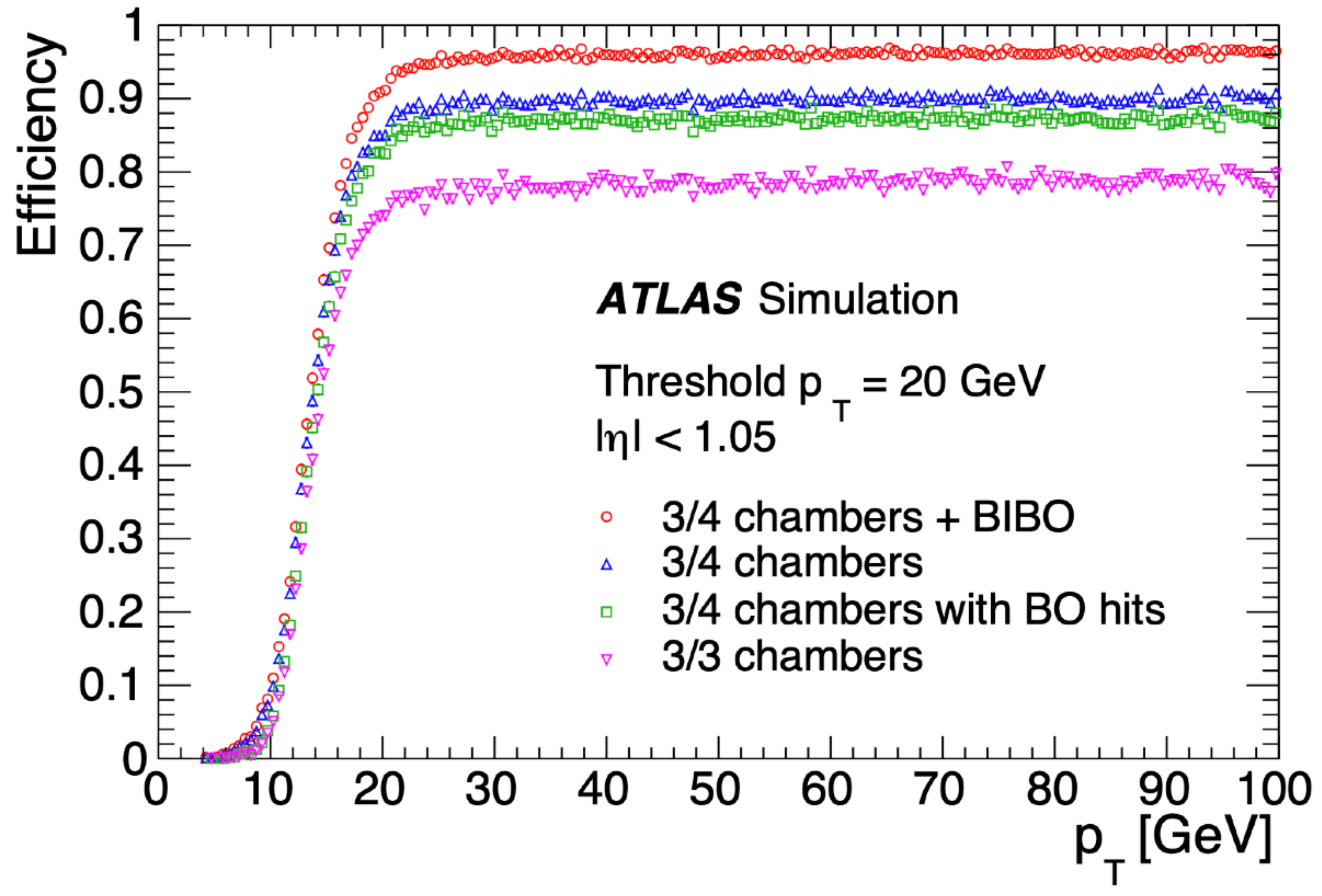
To mitigate degradation in calo resolution noise term due to pile-up.

Muon Upgrades Overview

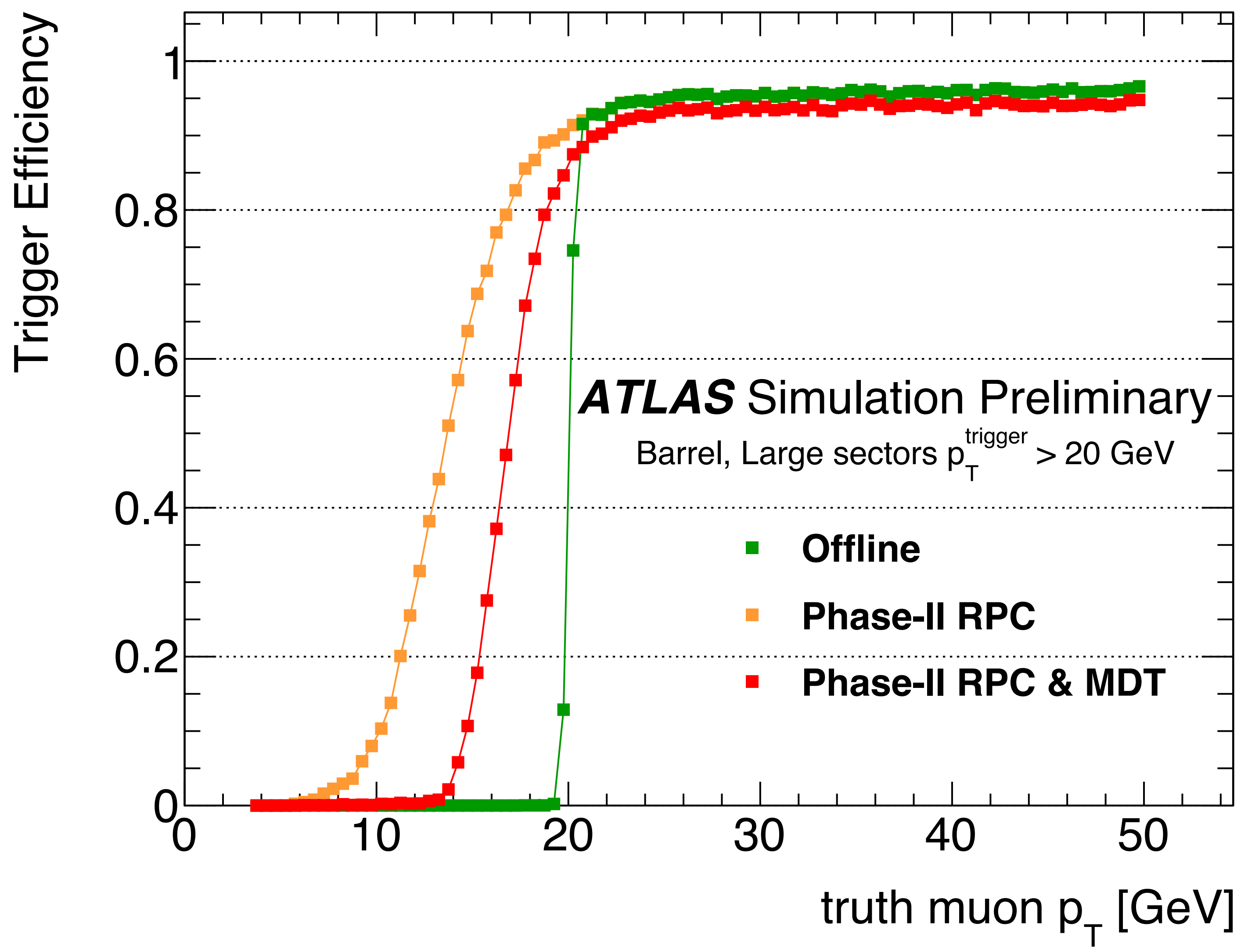
PHASE I Upgrades: New Small Wheel (NSW)

- NSW replacement of muon end-cap system
  - small-strip Thin Gap Chambers (TGCs) as primary trigger, with < 1 mrad resolution
  - MicroMegas for primary tracking, with < 100 μm resolution





Additional RPC chambers increase efficiency from relaxing number of coincidences



Expected Level-0 muon trigger efficiency at HL-LHC with and without MDT

PHASE II Upgrades: More chambers

- New Resistive Plate Chambers (RPC) in barrel will increase trigger efficiency.
- Monitored Drift Tube (MDT) chambers (higher precision) integrated at L0 trigger for seeding.
- Endcap TGC doublet chambers replaced with TGC triplets for more reliable triggering.
  - Together with NSW, reduction of fake rates in end caps for trigger.

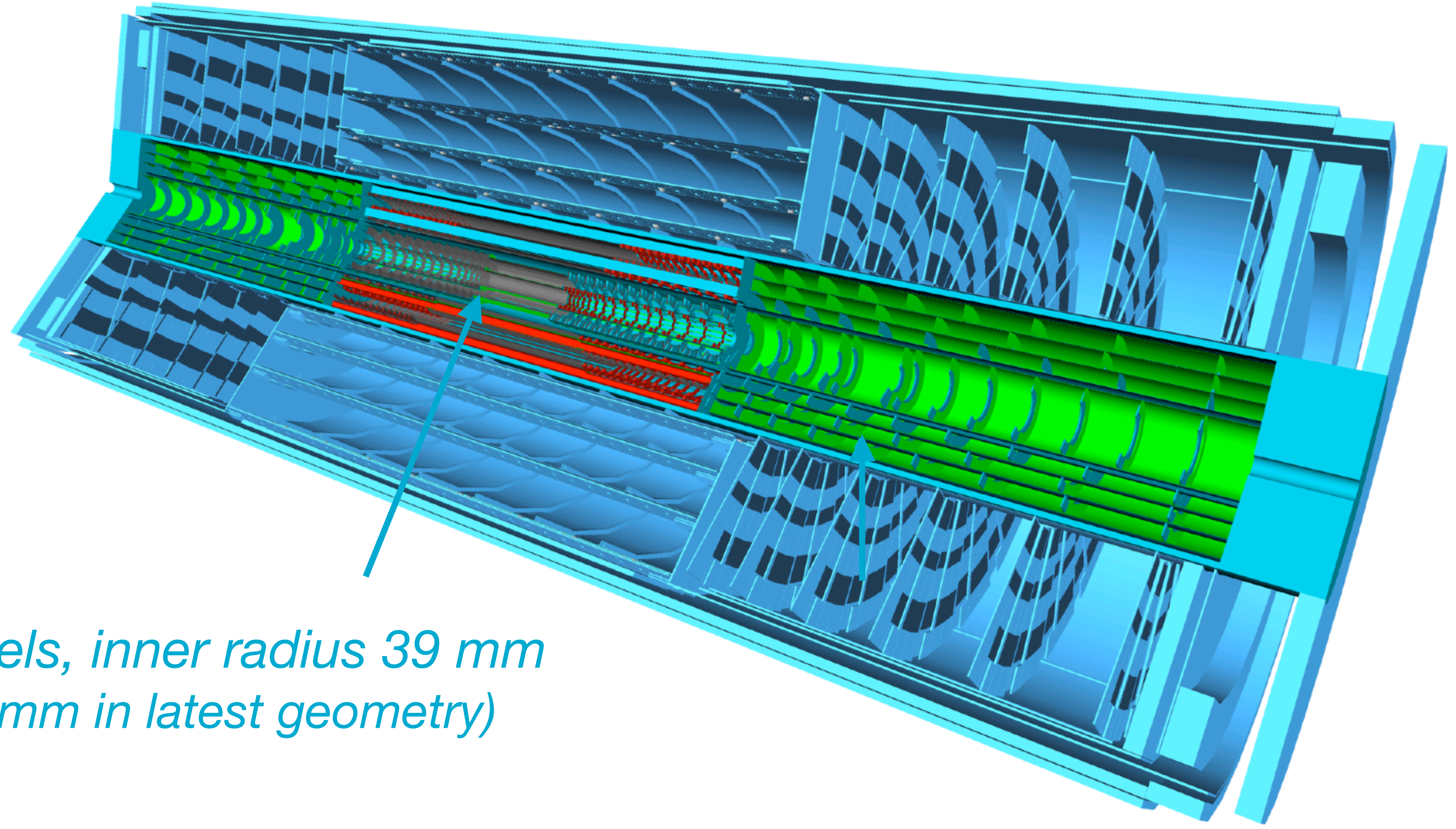
New Inner Tracker (ITk) - Phase II Description

- A full silicon tracking detector replacing entire current 10 year old tracker at end of its lifetime.

Upgraded Inner Tracker

R = 1000 mm

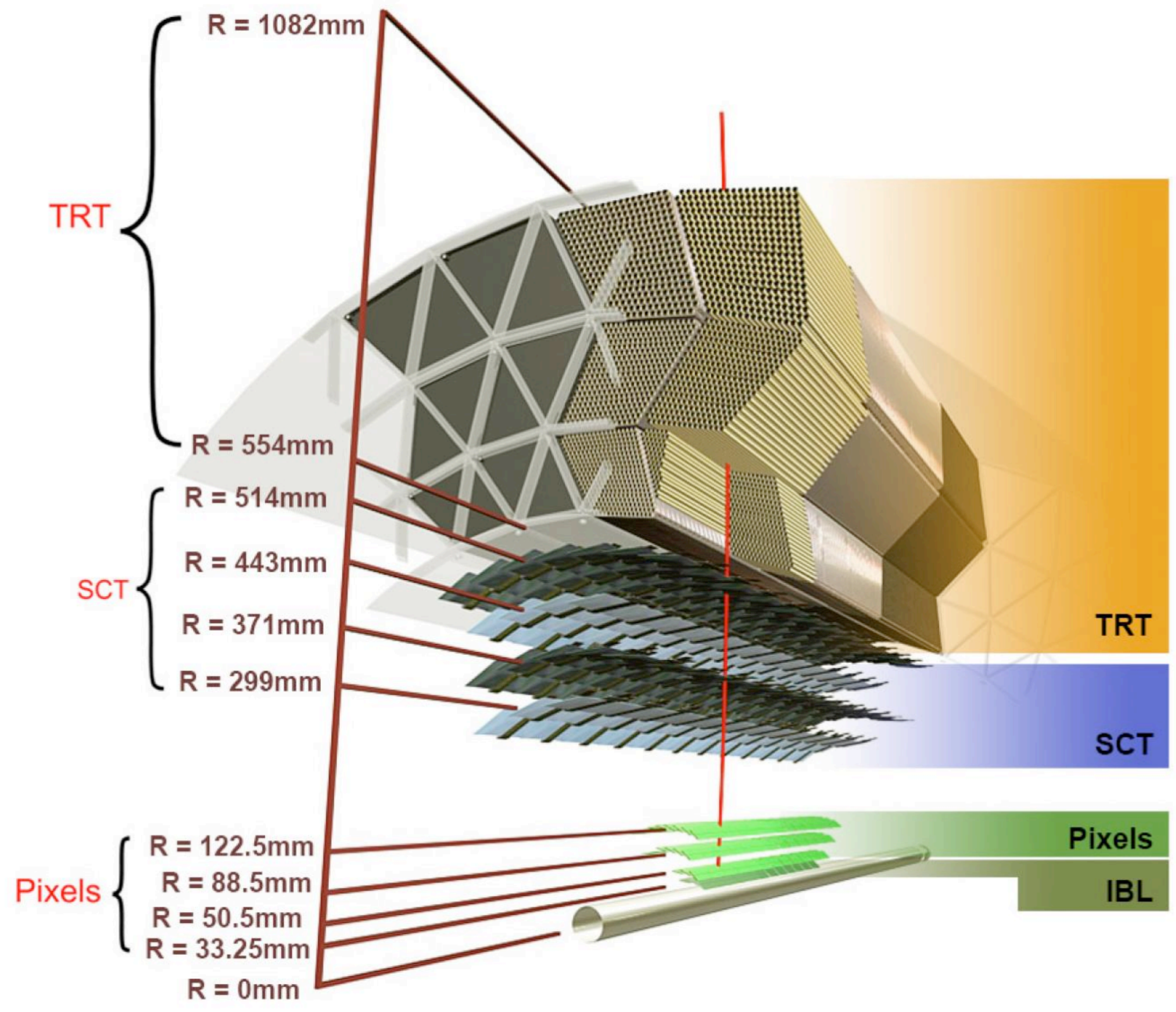
All silicon out to 1000 mm



Si pixels, inner radius 39 mm (34 mm in latest geometry)

Si strips (with stereo angle)

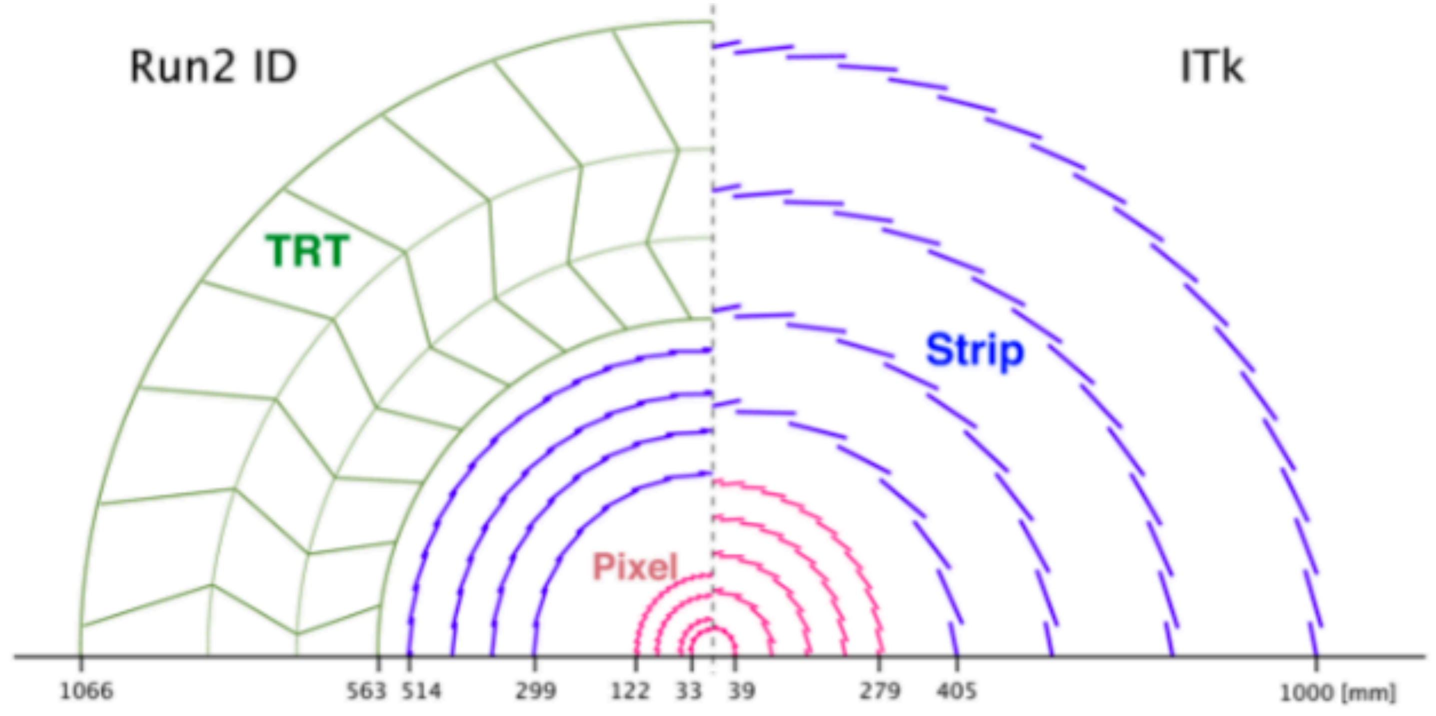
Run 2 Inner Detector



Transition Radiation Tracker: Lower precision gaseous “straw tubes”

Si strips (with stereo angle)

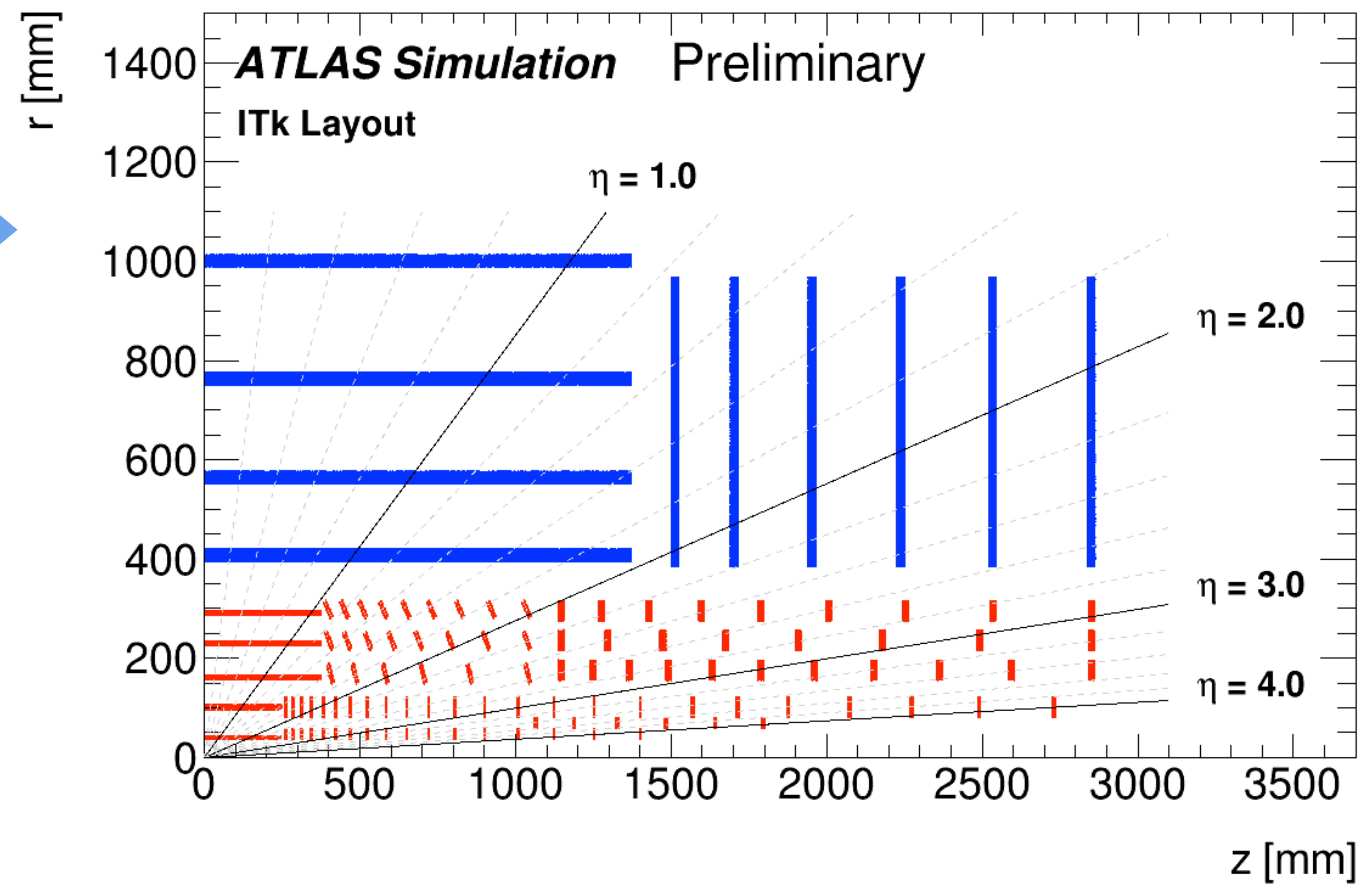
Si pixels, inner radius 33.25mm



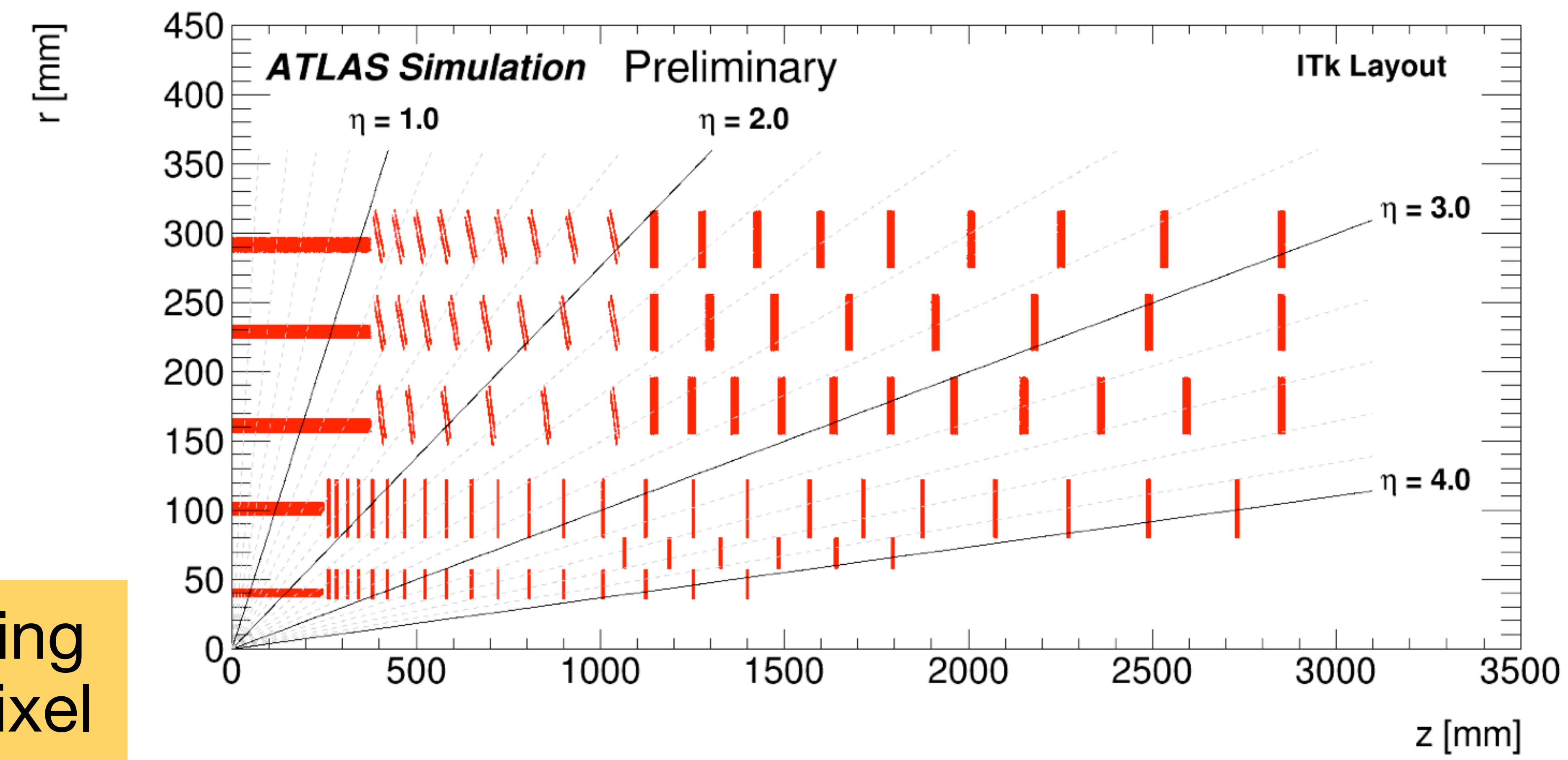
New Inner Tracker (ITk) - Phase II

Description

- **Strip subsystem:**
  - 4 barrel strip modules, 6 end-cap disks, replacing also entire Run 2 TRT detector.
- **Pixel subsystem:**
  - 5 (Run2: 4) barrel pixel layers with innermost radius of 39 mm (Run2: 33.25mm)
  - 5 inclined or vertical rings:
    - Acceptance out to |η| = 4 (Run 2: |η| = 2.5)
    - Inclined modules maximising sensitivity to hits & reduce amount of silicon needed.
  - Pixel pitch $50x50\ \mu m^2$ (Run2: $50x400\ \mu m^2$, Layer 0: $50x250\ \mu m^2$).



Strip + Pixel

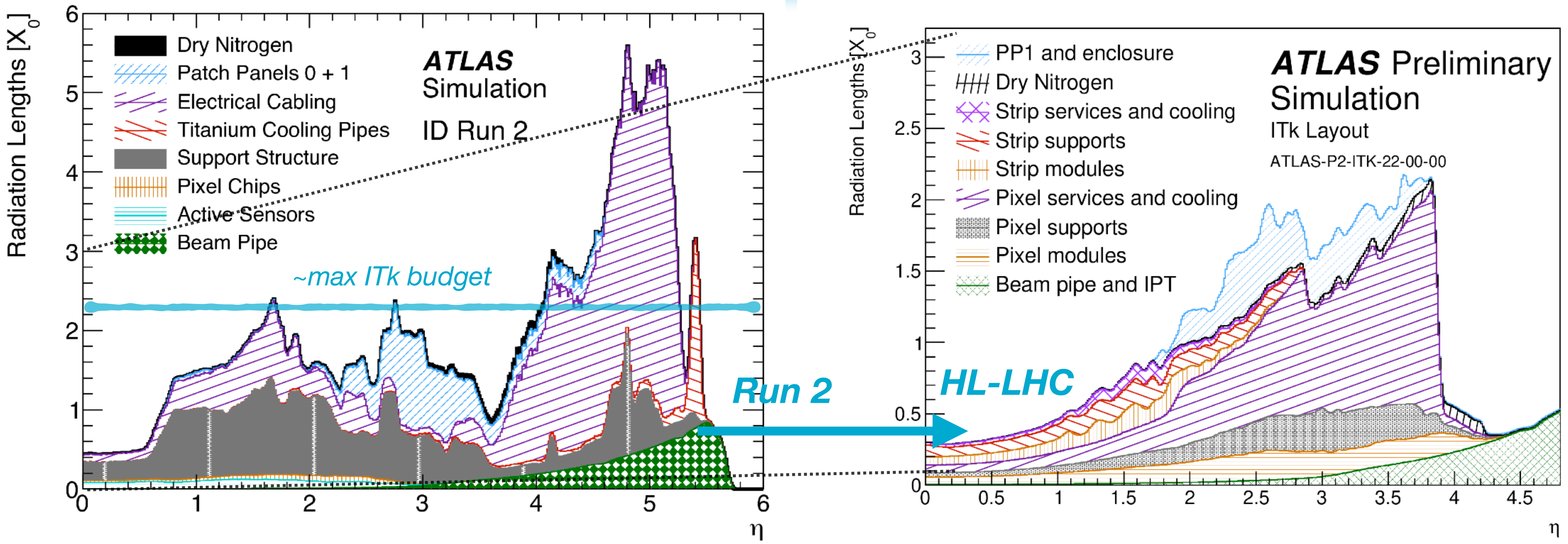


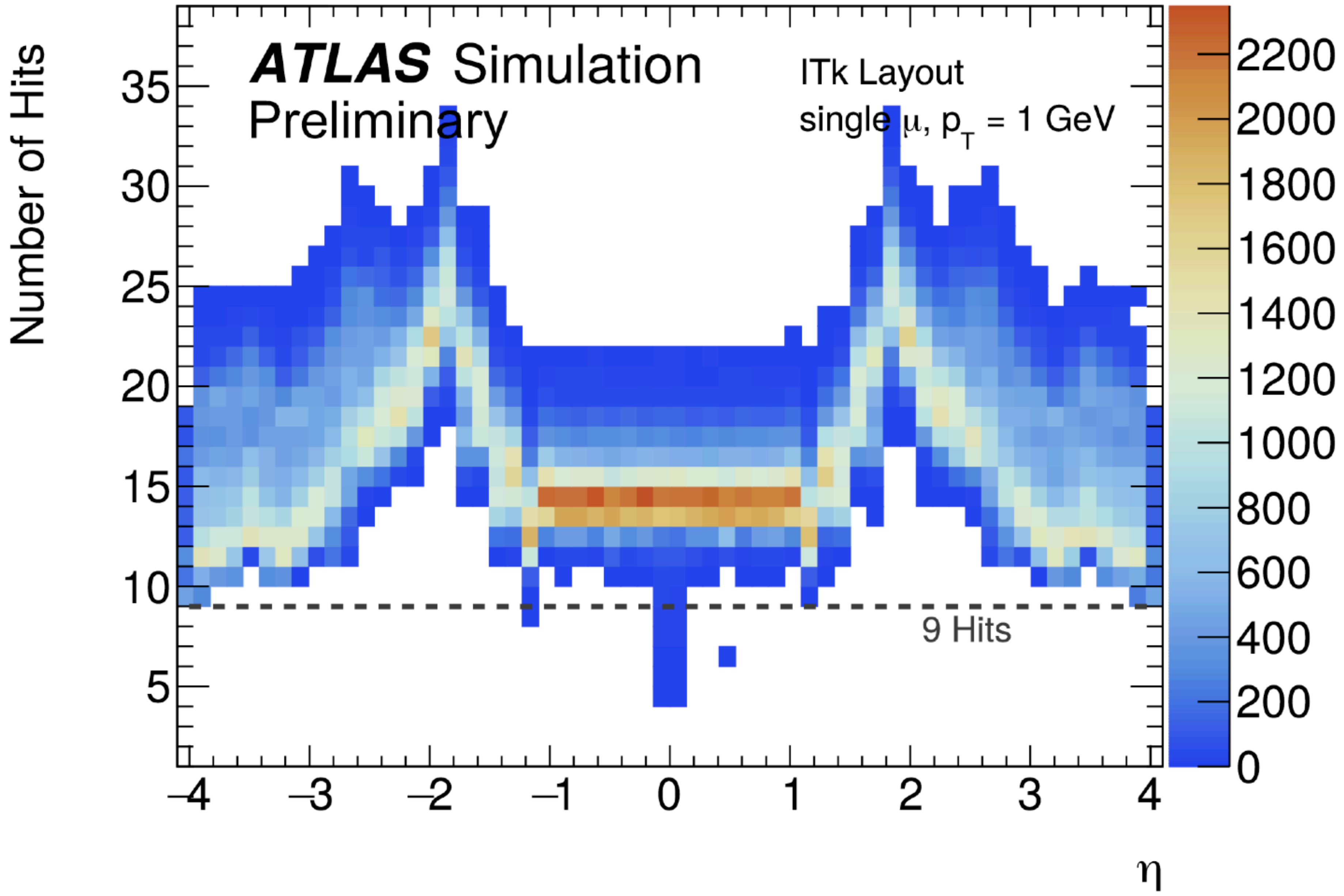
Pixel only

NOTE: **Latest public results shown.** New performance plots coming out soon with updated ITk simulation with main changes: Tighter Pixel layer-0 inner radius of 39 mm -> 34 mm; accurate material budgeting, inner-most barrel layer pIxel pitch 50x50 -> 25x100 μm^2.

New Inner Tracker (ITk) Improvements

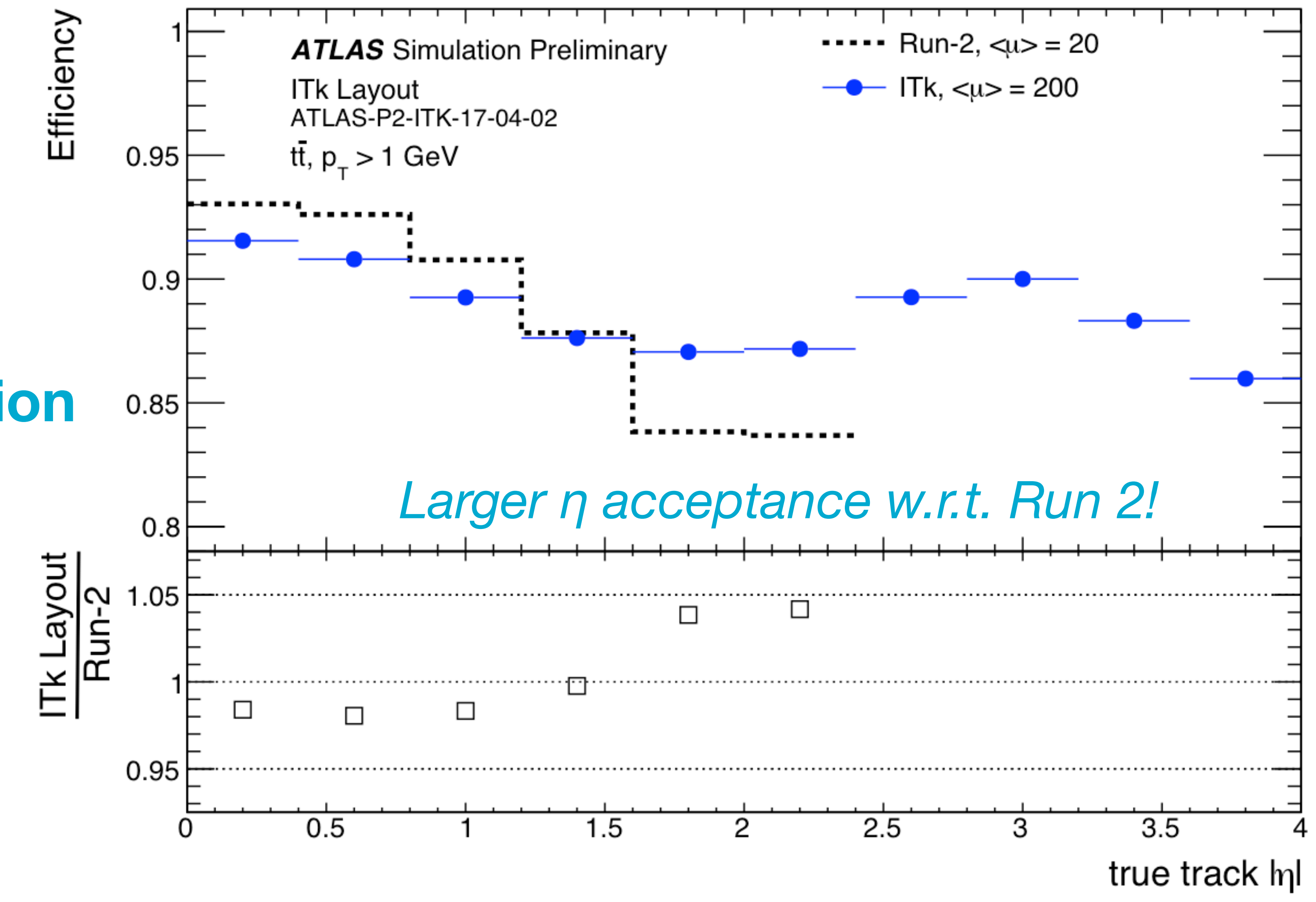
- Sufficiently **radiation tolerant** (up to 9.9 MGy) with replacement of 2 inner layers after 2000 fb^{-1}.
- **New front-end chip design**:
  - Design by CERN RD53 collaboration for both ATLAS & CMS, using 65nm CMOS technology.
  - Sufficient radiation tolerance, greater readout rate (> 5 GB/s).
- **Reduced material budget** -> less hit loss/ scattering.
  - Serial powering -> less cabling.
  - Lower read-out chip power consumptions -> lighter cables, reduced cooling requirements.
- Geometry and material improvements means **better hit efficiency:**
  - Minimum number of hits/track for ITk: 9 hits (Run2: 7 min. hits) -> refined track measurement.



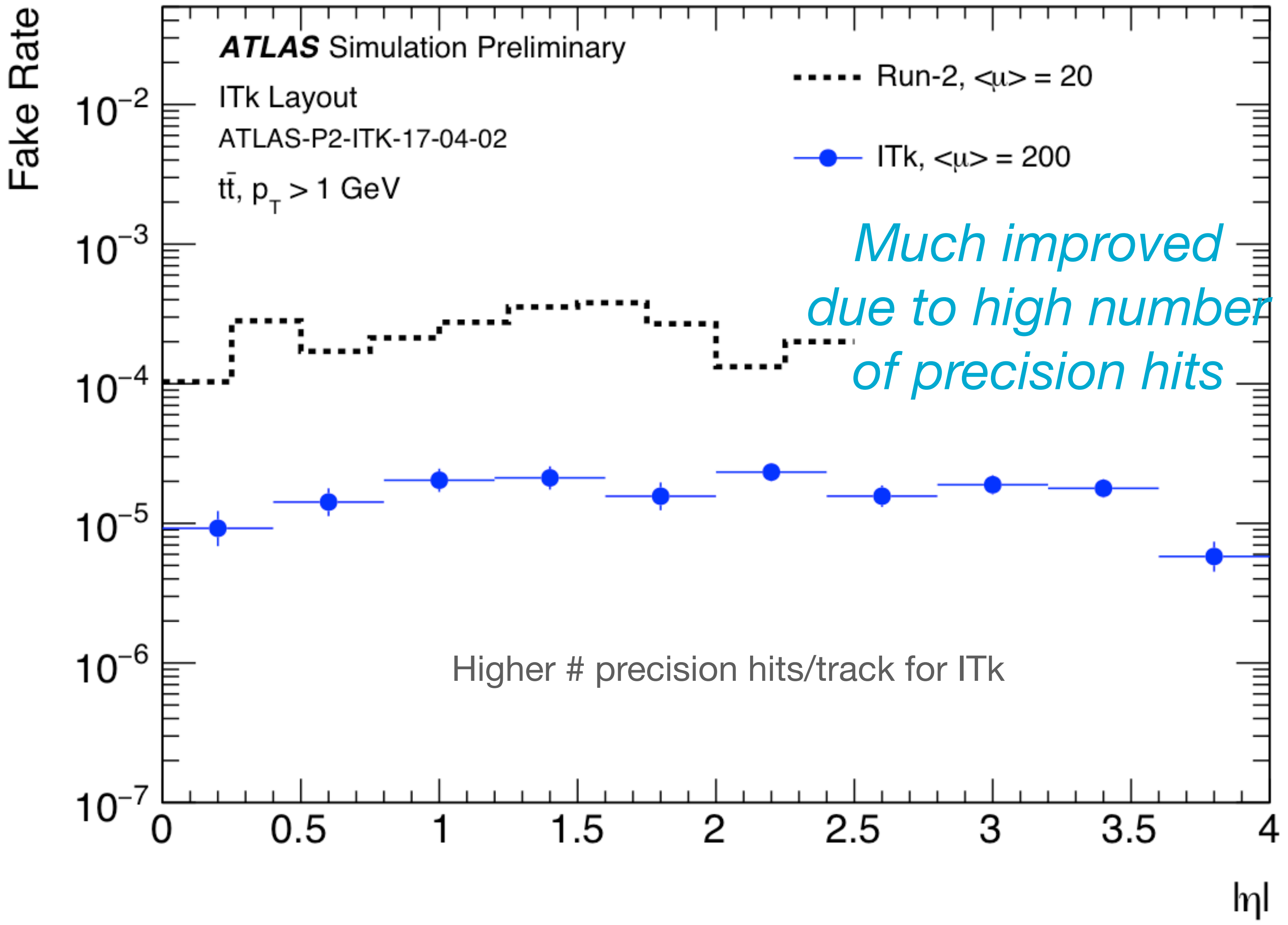


New Inner Tracker (ITk) Performance

Track reconstruction efficiency vs η

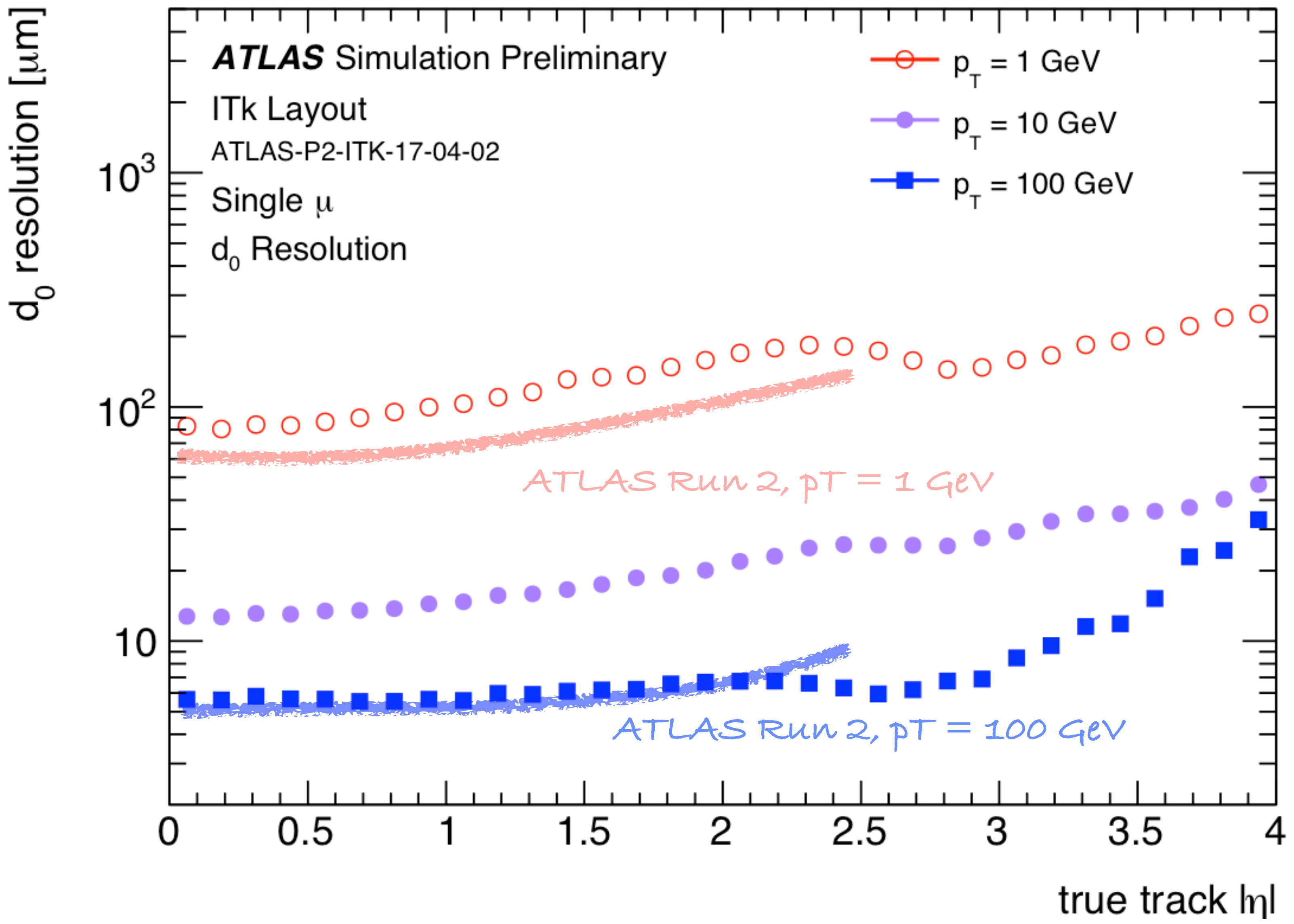


Fake rate vs η



d0 resolution

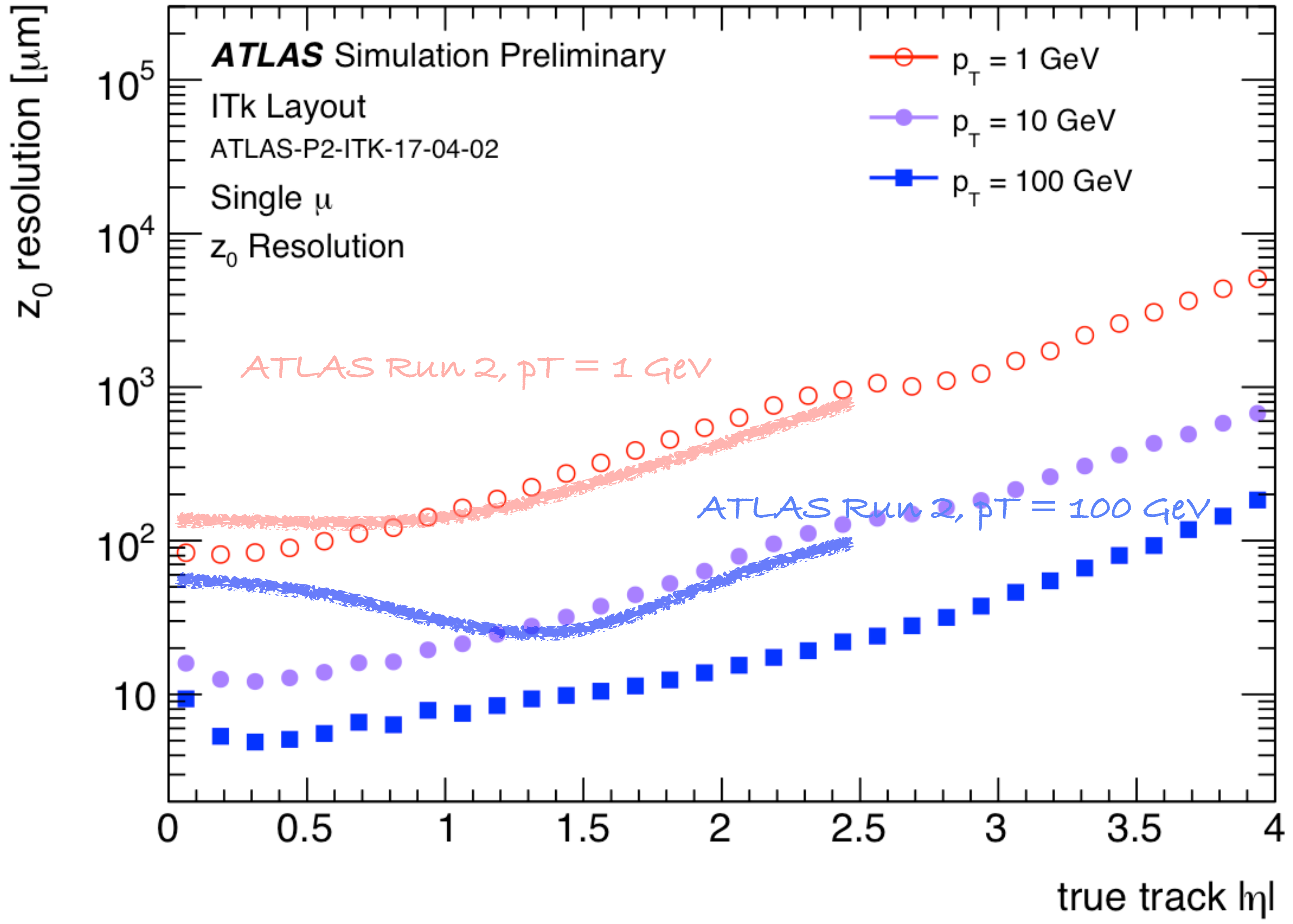
Comparable to Run 2



Improved tracking -> improved vertexing, flavour tagging

z0 resolution

Better than Run 2, as smaller longitudinal pixel pitch.



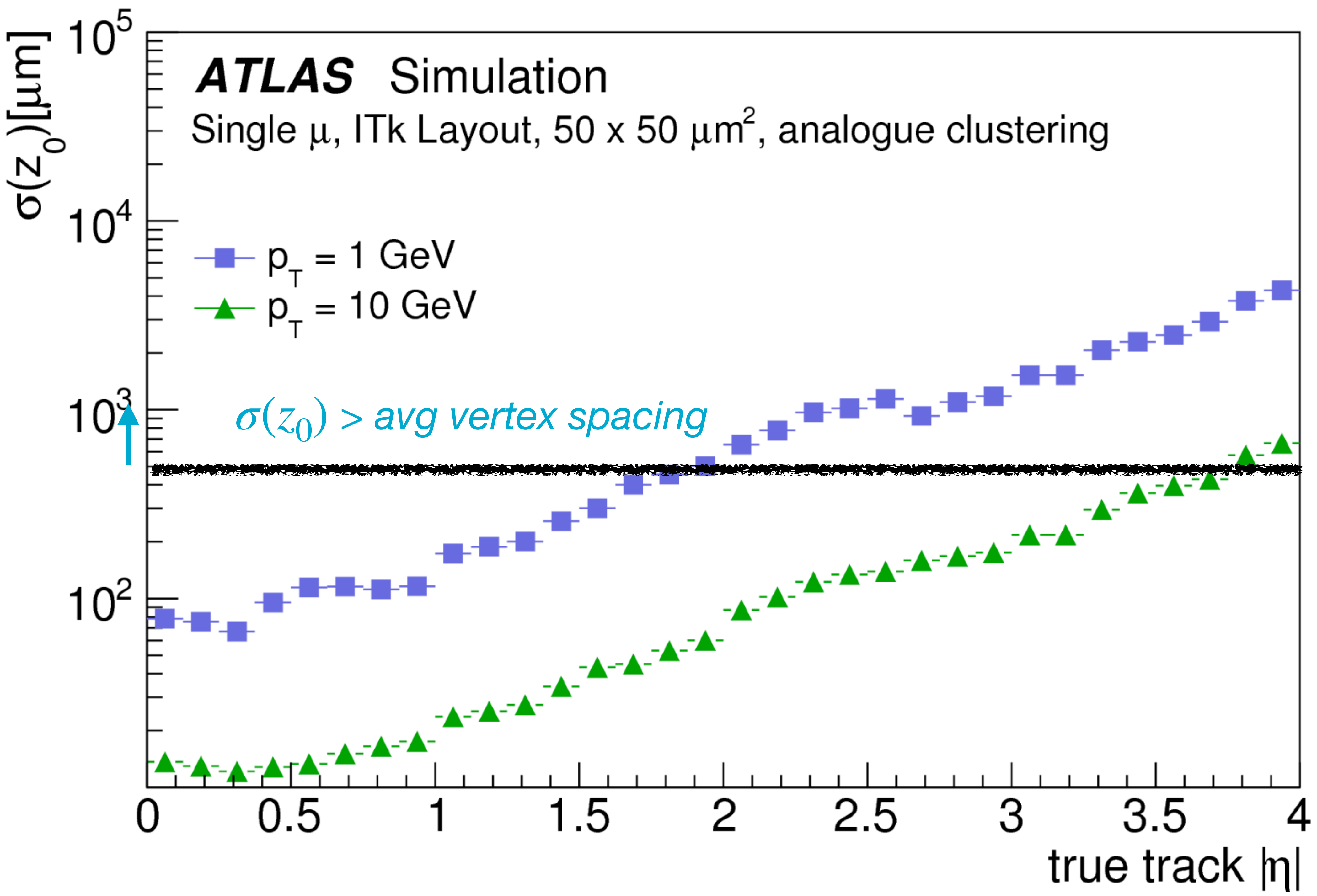
New High Granularity Timing Detector (HGTD) Objectives

HGDT will provide hit timing information in the forward region.

Why do we want hit timing information in the forward region?

Forward pile-up

- At higher track |η|, trk z0 resolution > pile-up density
  - A low pT track would be associated to <avg> ~9 interaction vertices!
  - Need additional information to distinguish tracks from different vertices and **regain performance in forward region.**



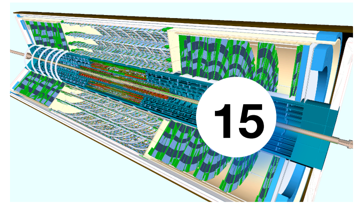
Luminosity

- **Provide bunch-by-bunch luminosity measurement**
  - Luminosity uncertainties expected to be dominating uncertainty for key Higgs analyses.
  - Uncertainty is systematic dominated:
    - Independent sources of lumi measurements needed.

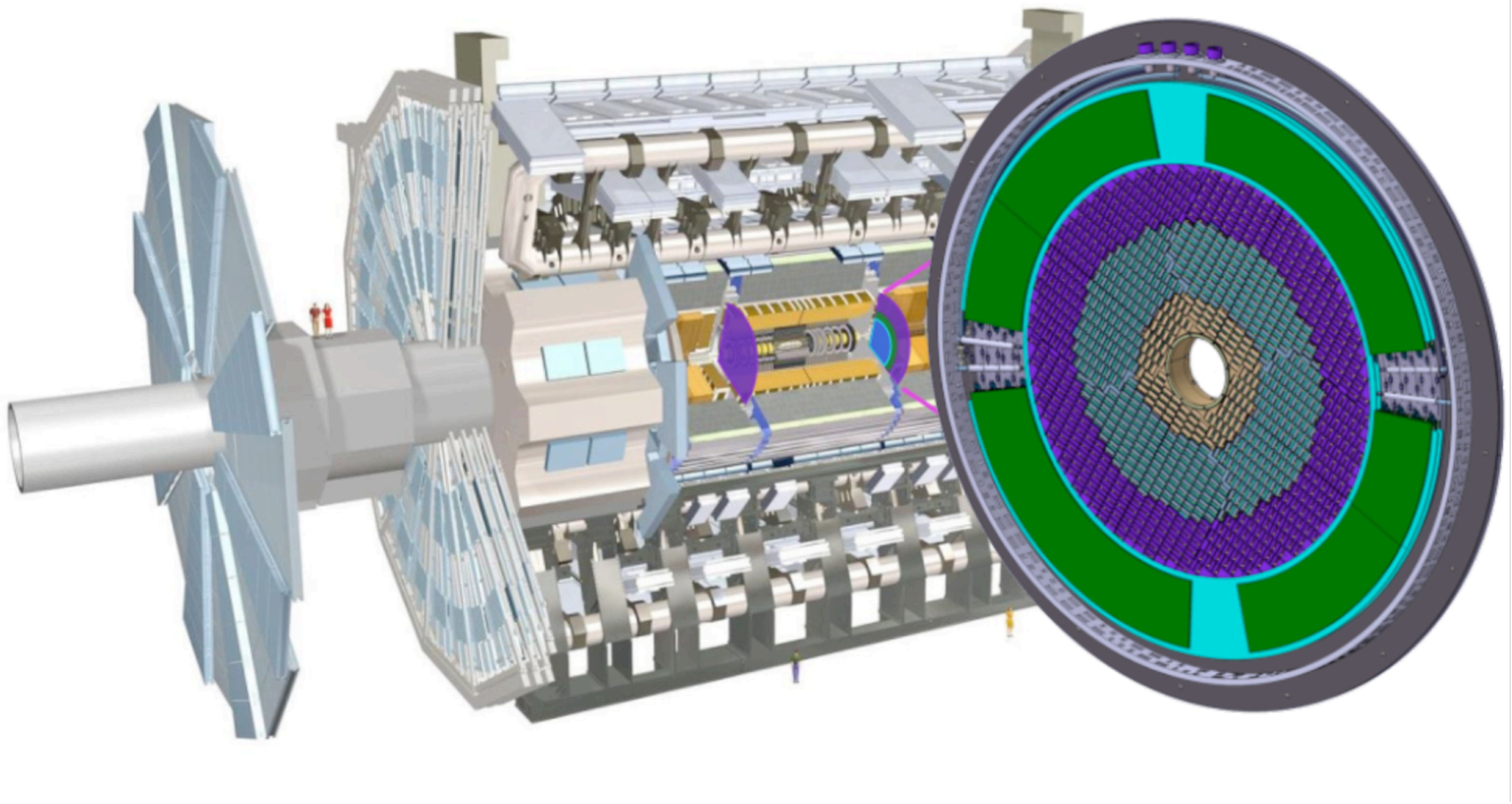
$\sigma_{\mathscr{L}} \sim 2\,\%$

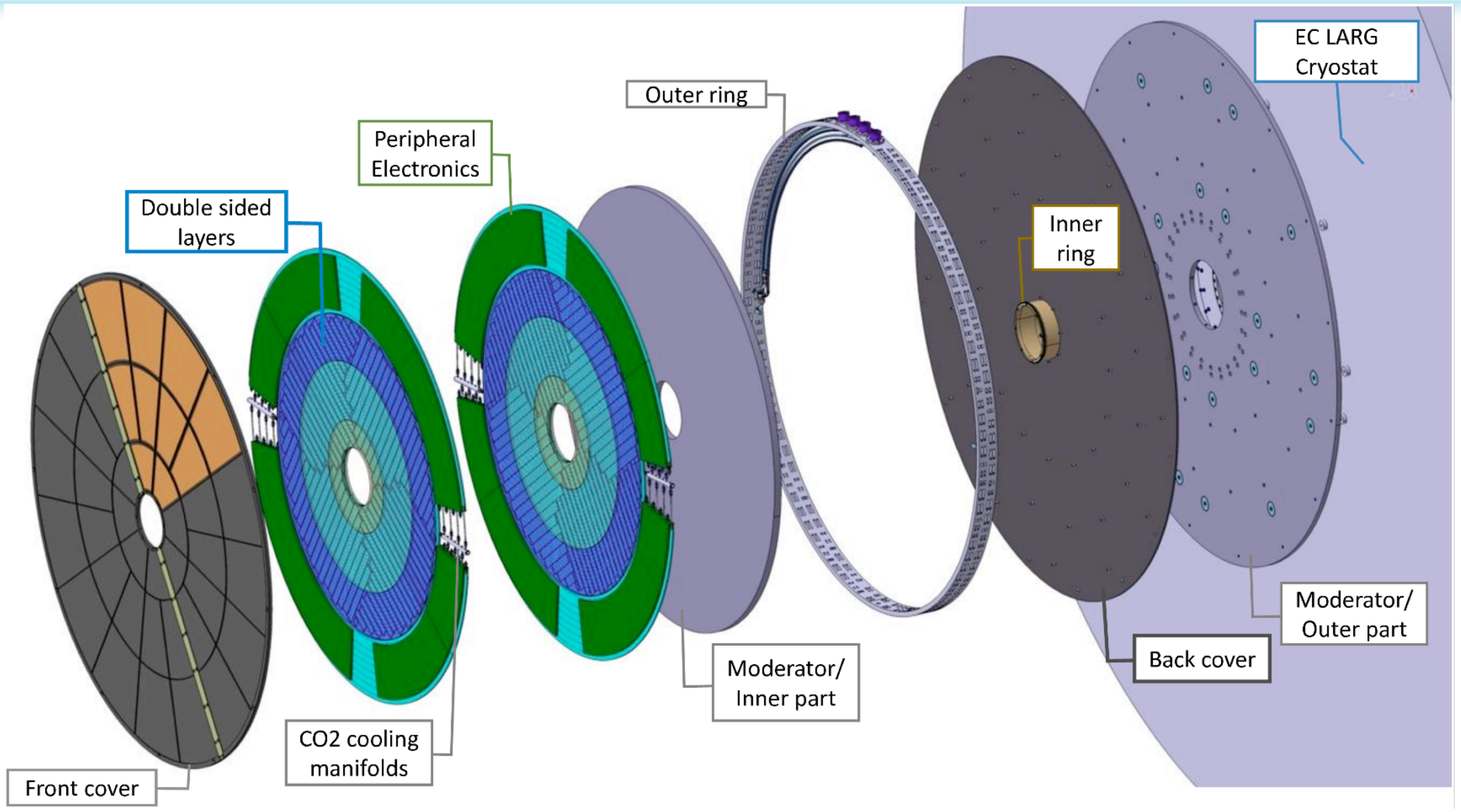
Analysis channel	Largest uncertainty	$\Delta\sigma/\sigma_{SM}$
Cross section for $ggH(\rightarrow\gamma\gamma)$	Photon isolation efficiency	1.9%
Cross section for $ggH(\rightarrow ZZ^*)$	Electron eff. reco. total	1.5%
Cross section for $ggH+$VBF, $H\rightarrow\tau\tau$	QCD scale ggH, $p_T^H \geq 120\,$GeV	1.7%

List of dominant uncertainties (excluding the uncertainty on the integrated luminosity) affecting various expected Higgs boson cross section results at the HL-LHC using 3000 fb^{-1} of data. An uncertainty on the luminosity measurement of 2% would be the dominant source of uncertainty for all these measurements.

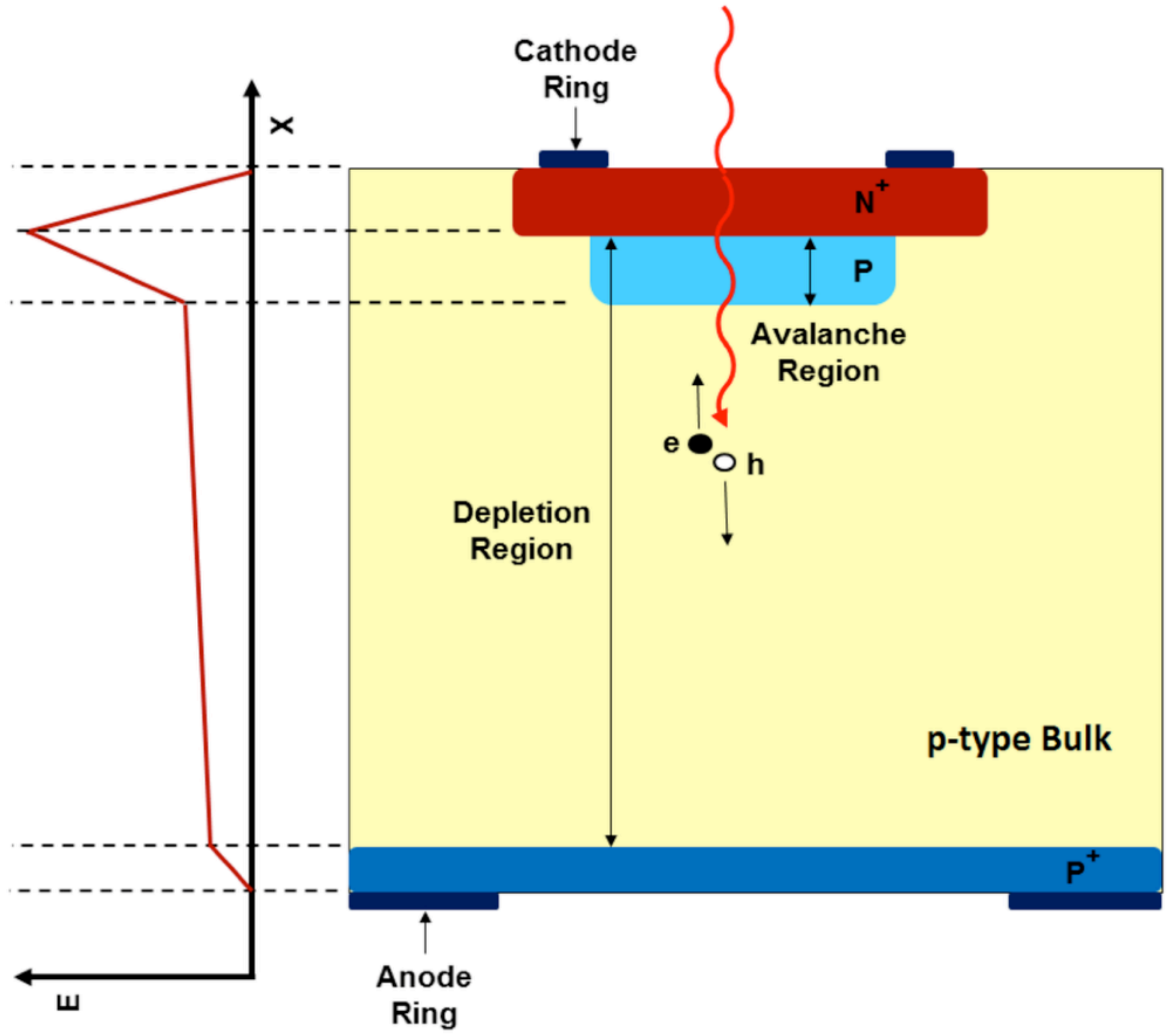


HGTD Description

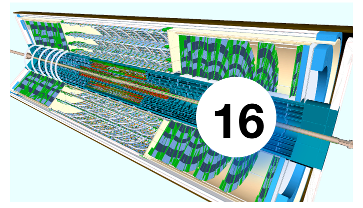




- **2 disks either side in gap between ATLAS barrel and end cap.**
  - Each instrumented double-sided layer supported by cryostat/support structure, moderator pieces for protection against back splash.
  - Acceptance at $2.4 < |\eta| < 4$
  - Low-Gain Avalanche Silicon Detectors (LGAD) sensors
    - Enable precision timing, retain signal efficiency after heavy irradiation

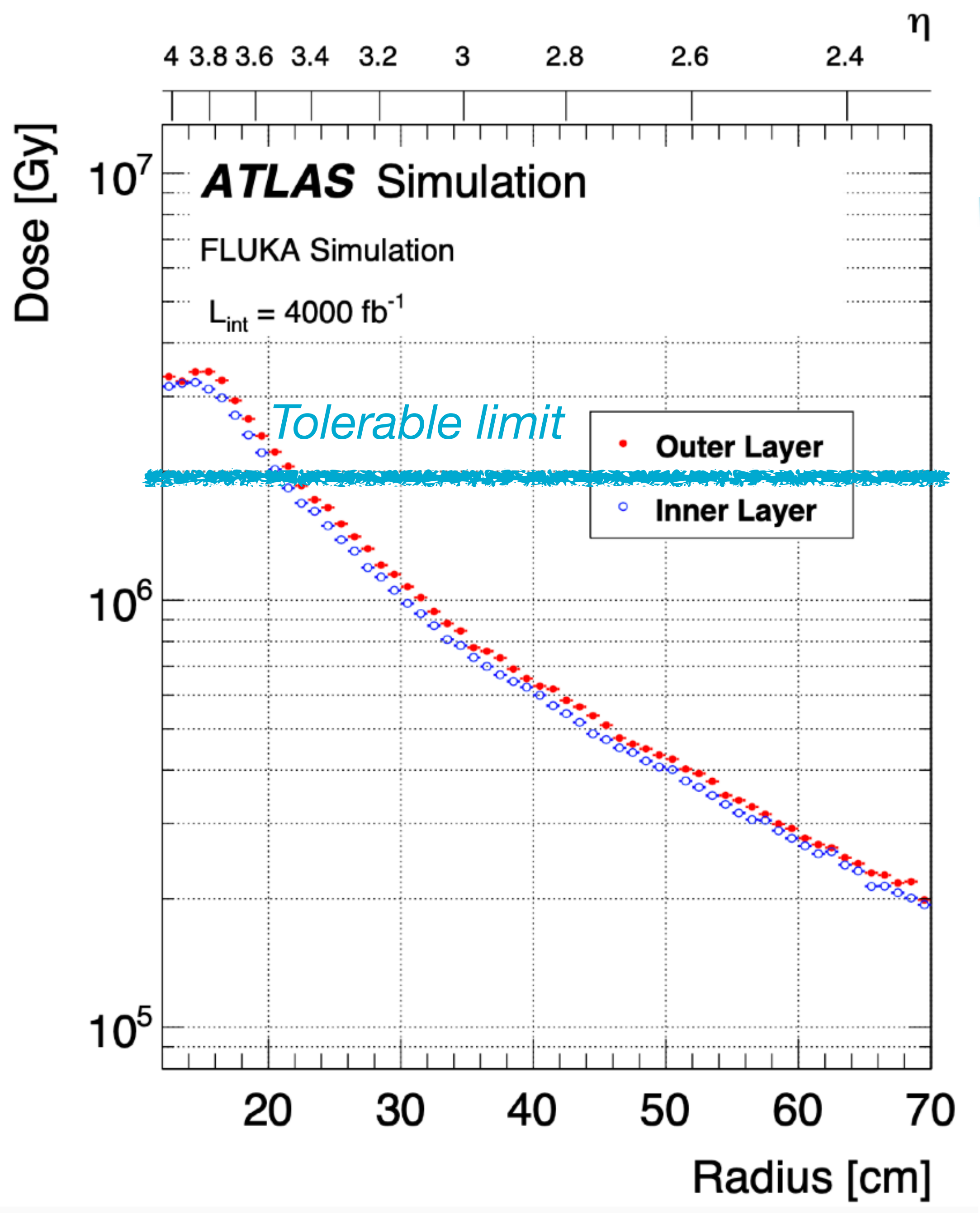


LGAD sensor:
Silicon detector with internal low gain

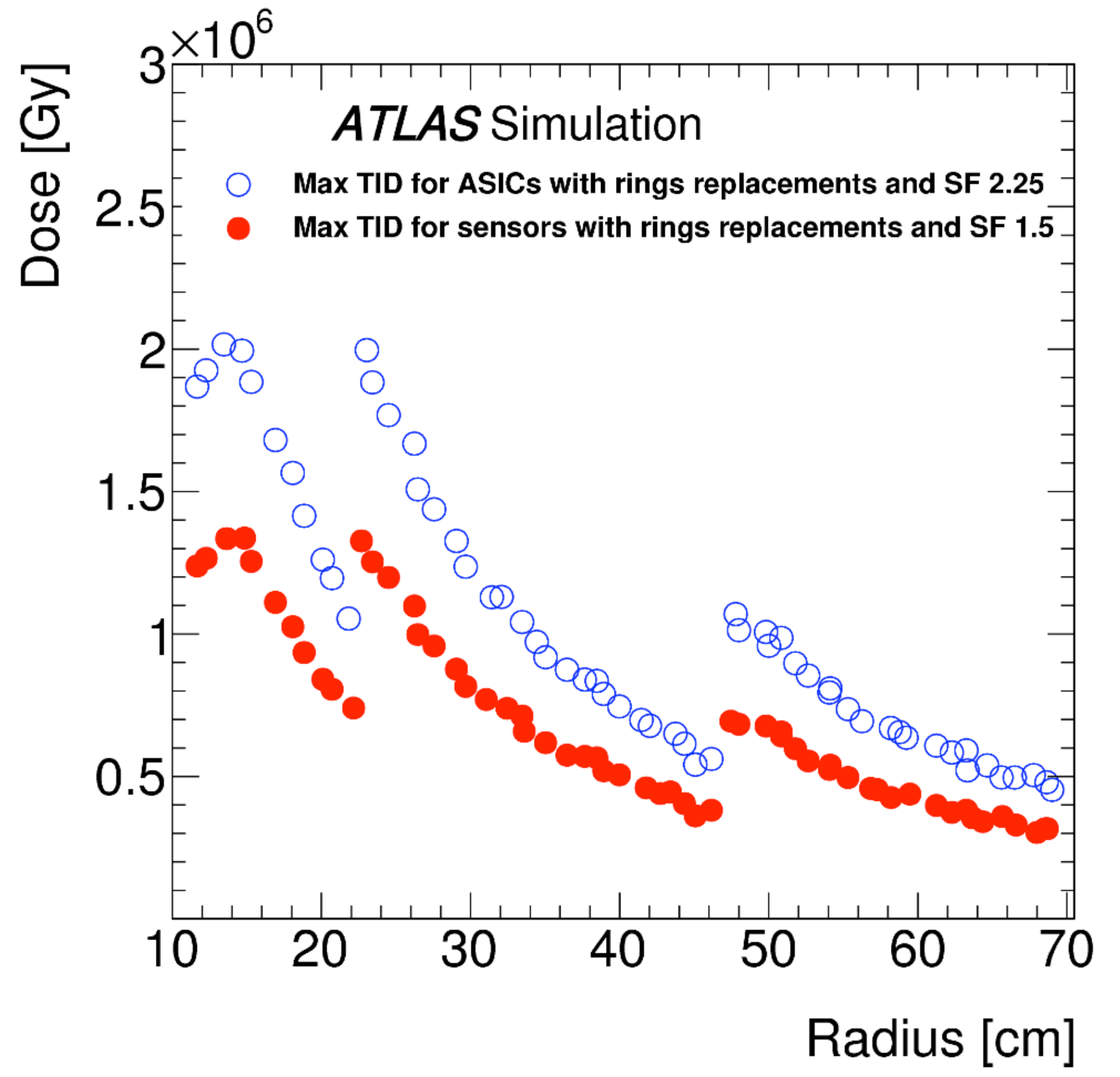


HGTD Description

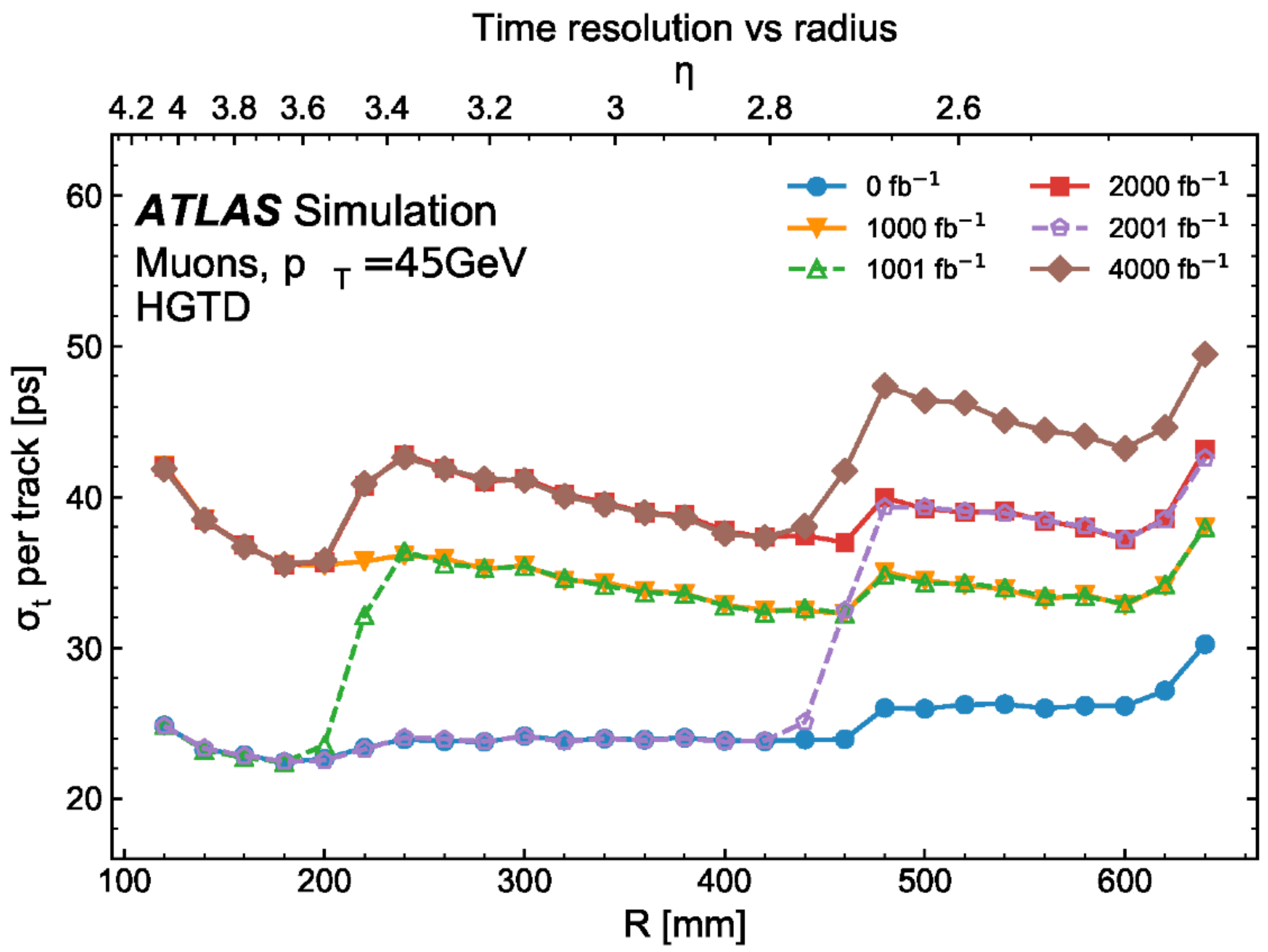
- **Custom electronics for processing and readout**
  - Custom ASICs with requirement on radiation hardness and timing precision + 40 MHz readout for luminosity measurements.
    - Tolerable radiation level for maintaining high signal eff. (min threshold of 4 fC charge)
      - < 2.0 MGy dose, achievable if exchange inner rings after 1000 ifb (very inner) and 2000 ifb (inner).
    - Target track timing resolution: 30 ps - 50 ps (degrades over time)



Expected total radiation dose versus radius



Expected radiation dose versus radius with replacement of inner layers



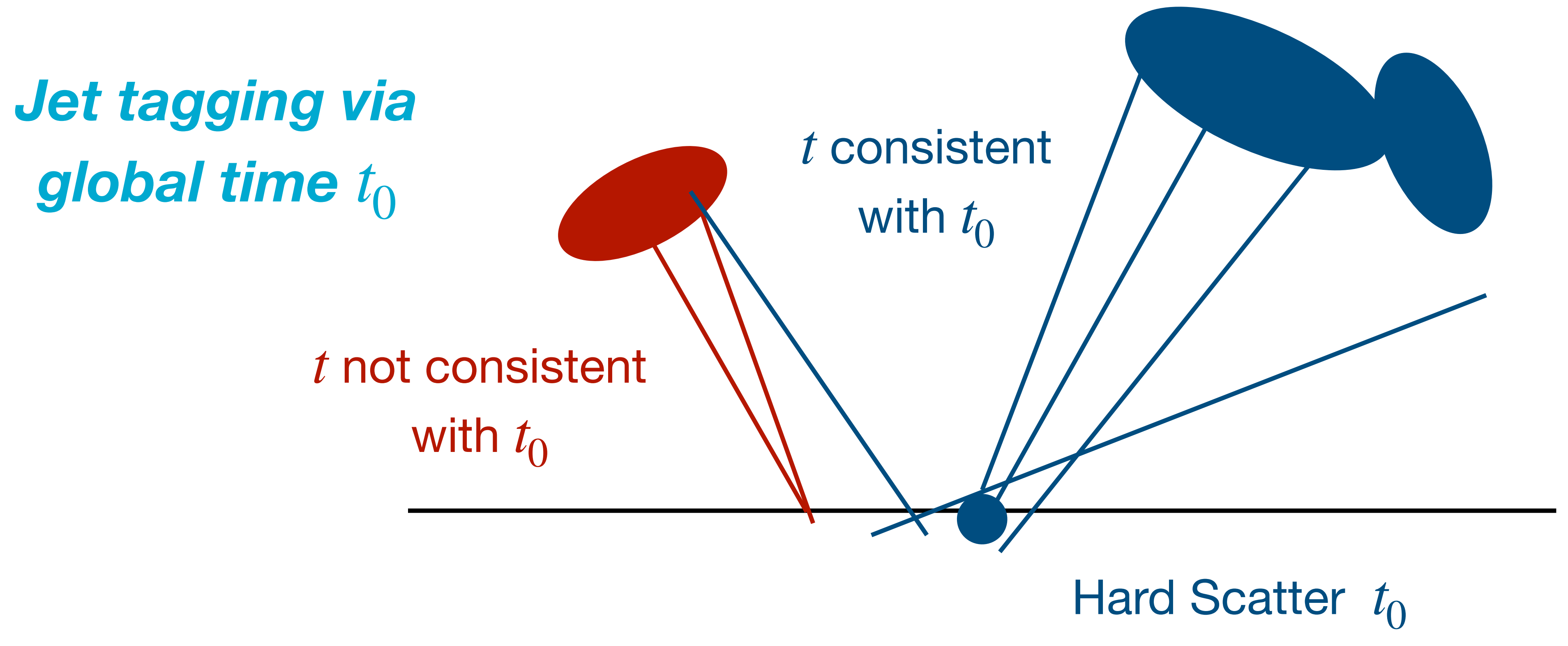
Track timing resolution with inner ring replacements

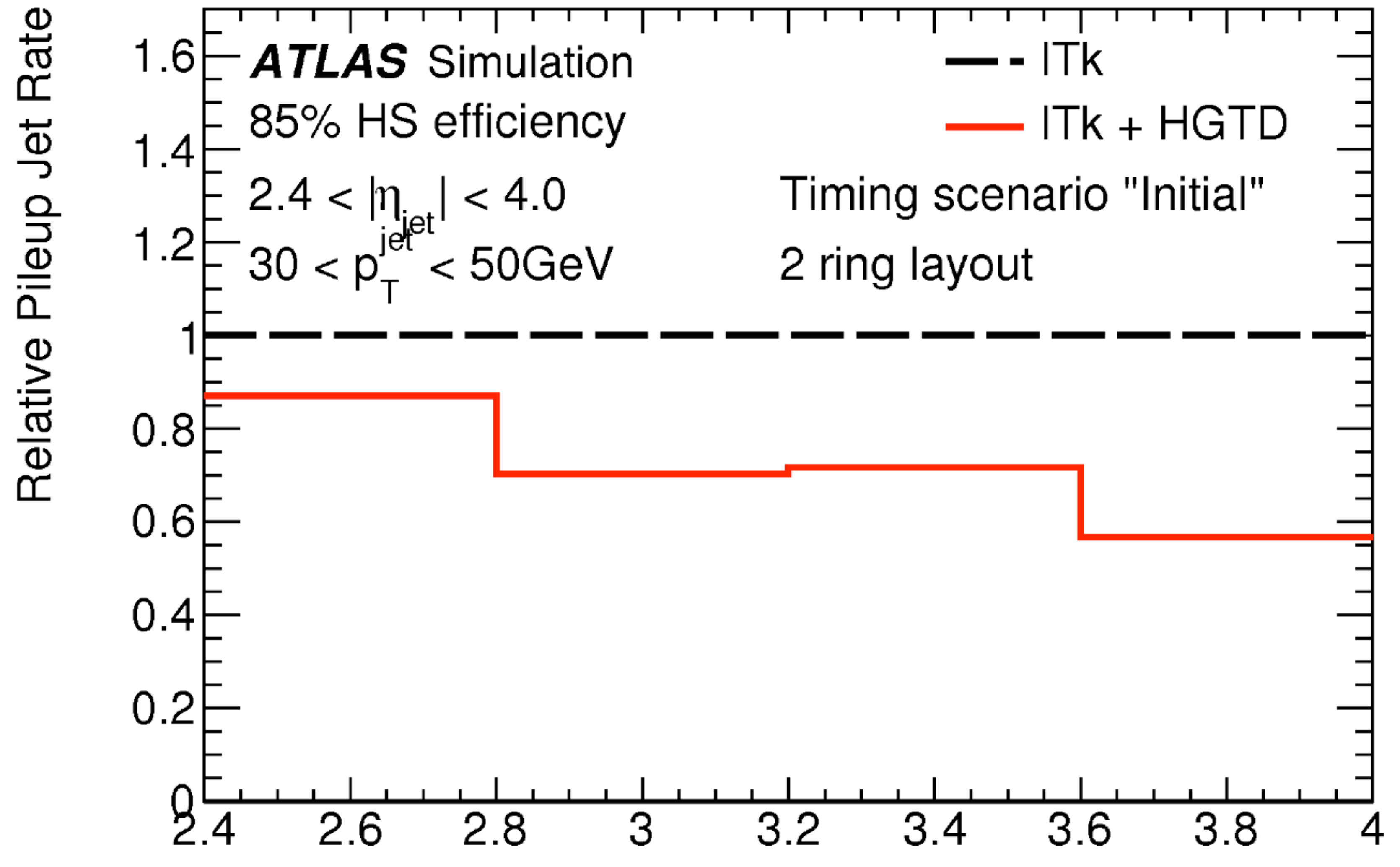
HGTD Expected performance

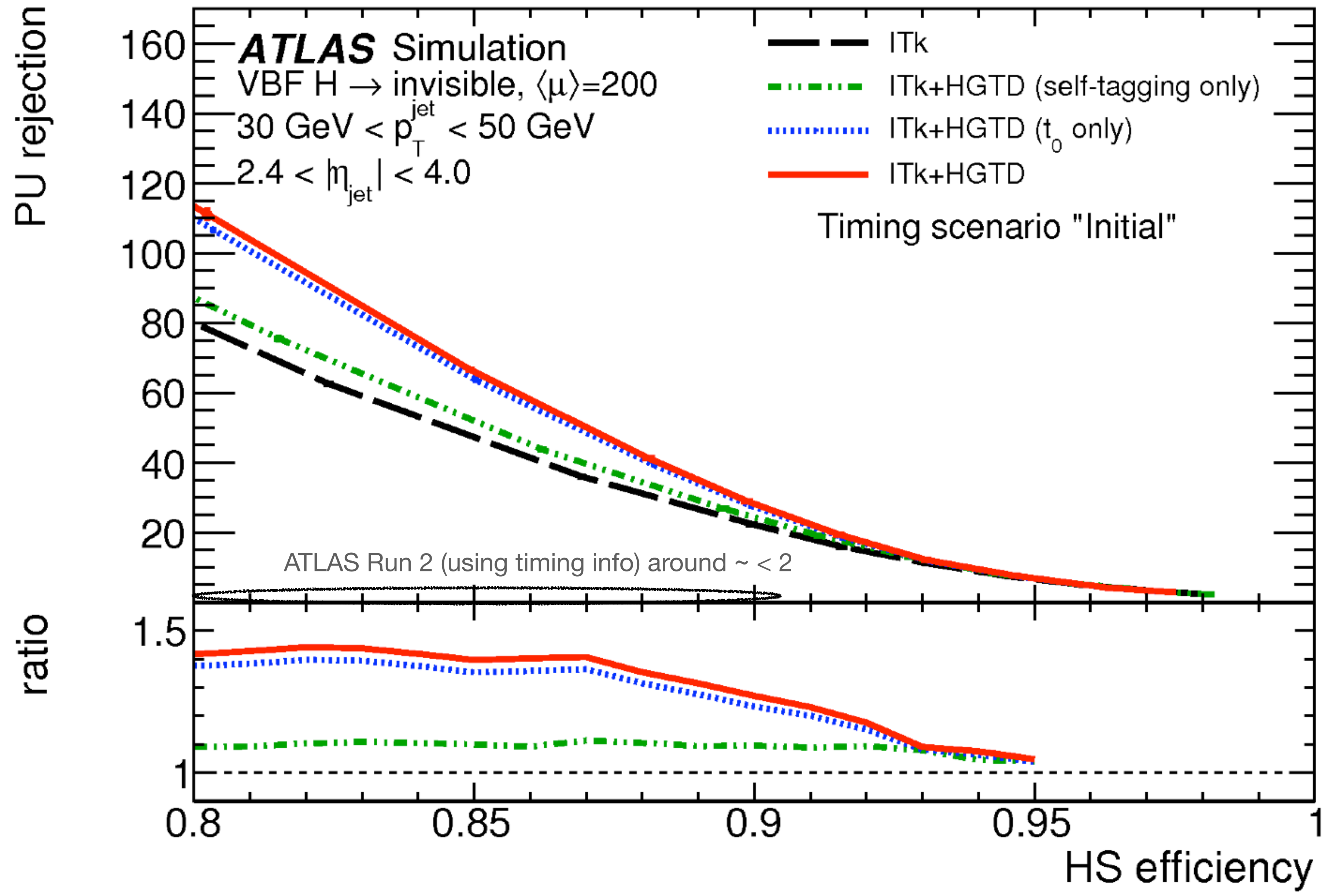
In rejecting pile-up

- Using simple algorithms, expect substantial pile-up rejection power:
  - Up to factor ~1.4 greater forward jet pile-up rejection over ITk only for 30 GeV < jet pT < 50 GeV
    - Note: Also factor > 50 better compared to Run 2 (of very limited means for rejecting pile-up at |η| > 2.5)

Expect further improvements on performance as algorithms grow more sophisticated and benefit from new ideas!



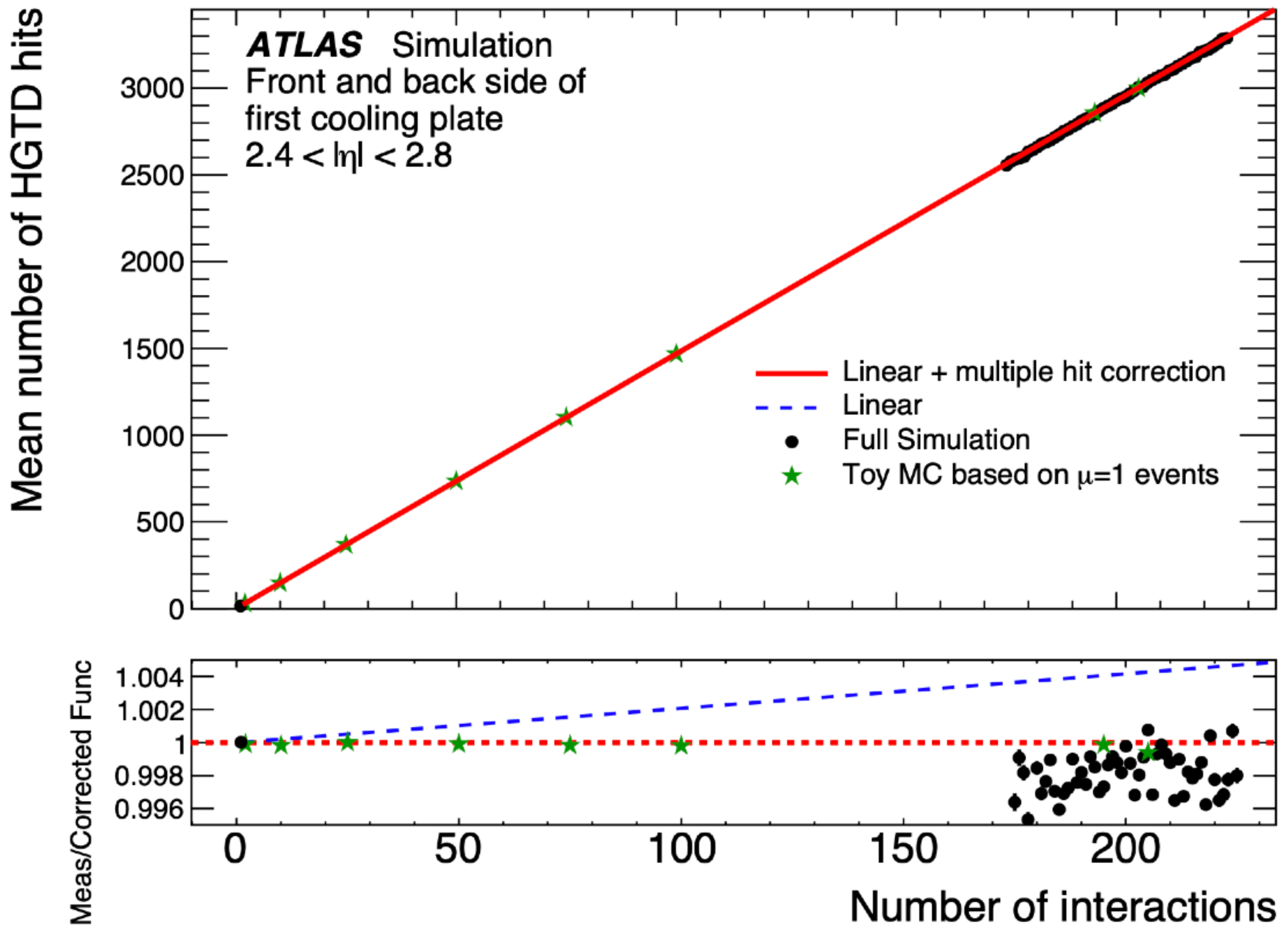




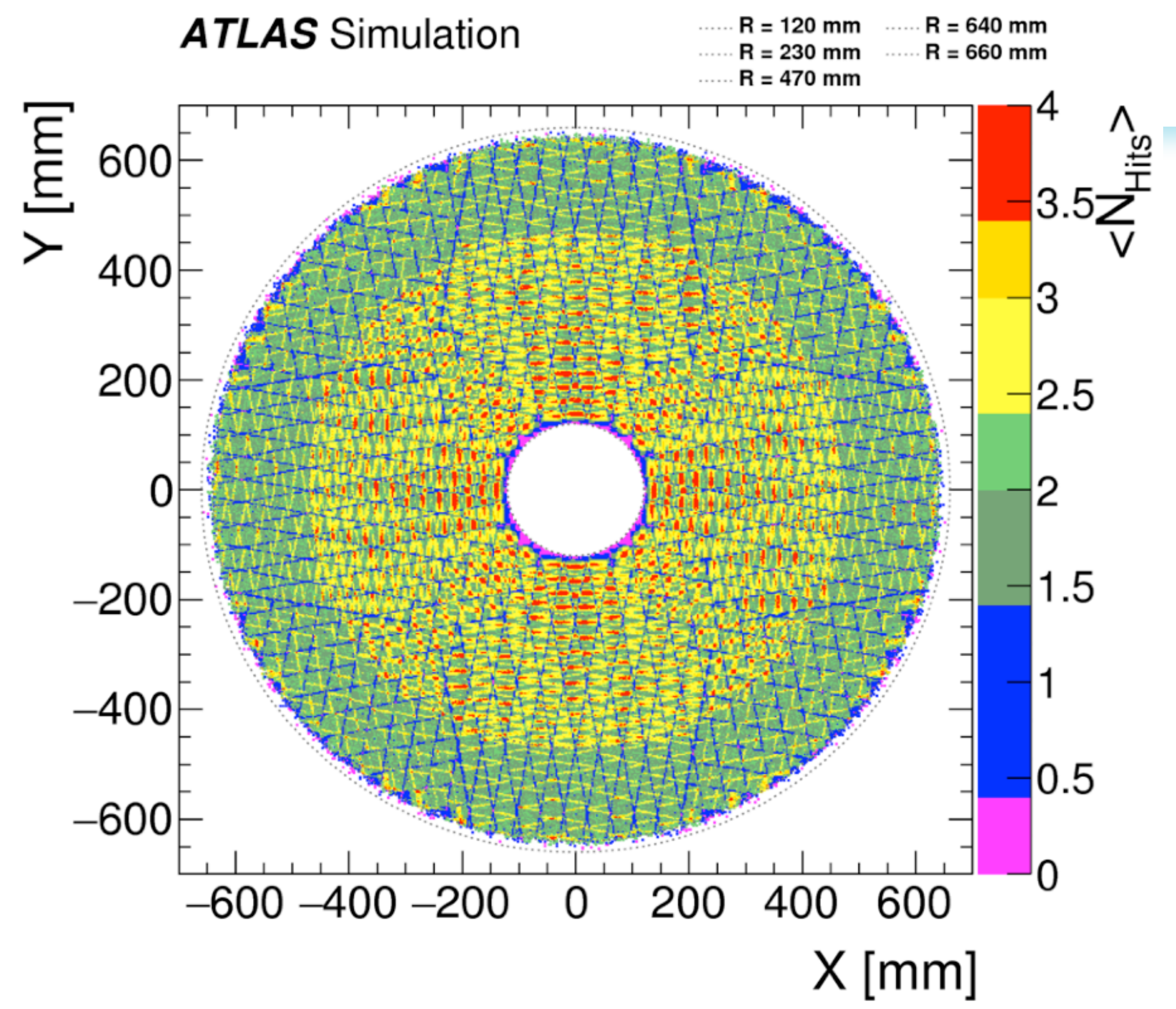
HGTD Expected performance

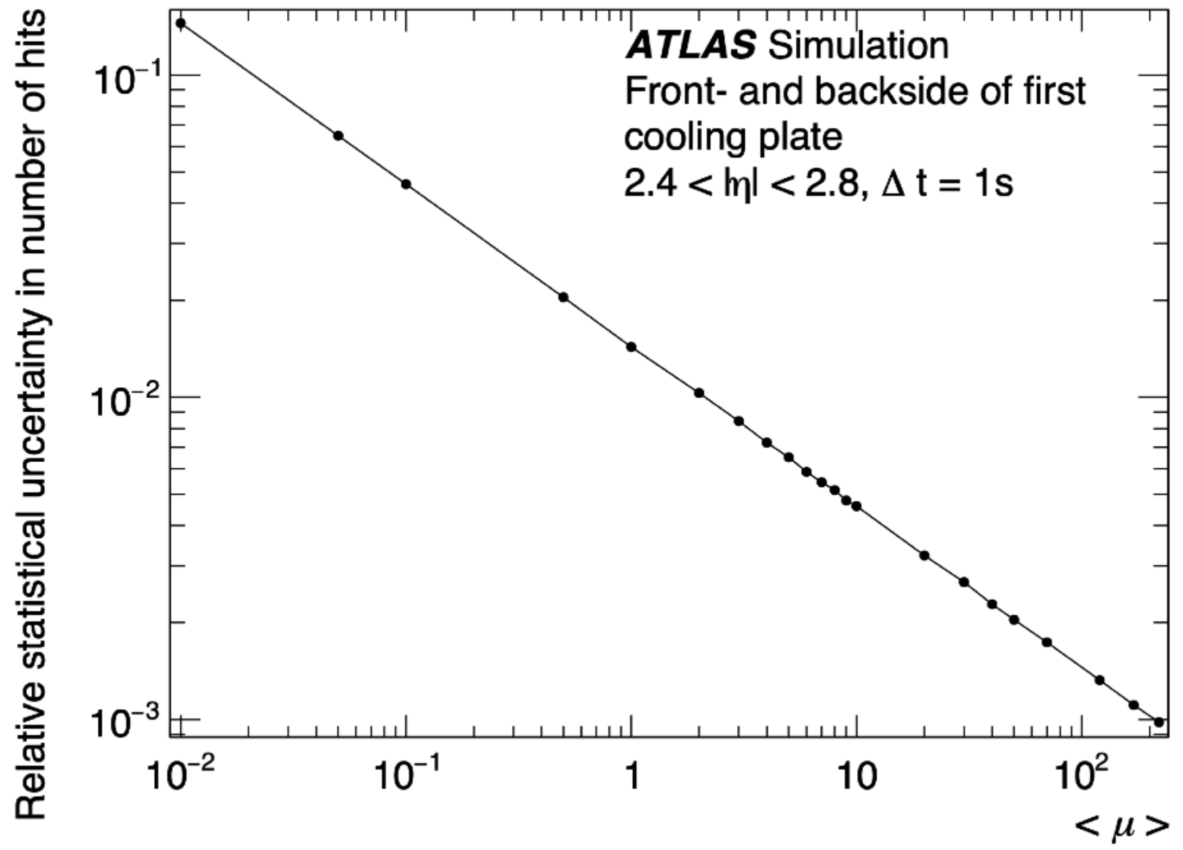
As a luminometer

- HGTD can provide another **independent measurement of bunch-by-bunch $\mathscr{L}$** via hit count, **with several key advantages**
  - Excellent <avg> hit count vs $\mathscr{L}$ linearity, (high granularity)
  - Good statistical precision (40 MHz readout, large # tracks).
  - Good background handle: Signal sampling within bunch-crossing possible for *central* and *side-band* windows of Δt ~ 3.125 ns —> mitigation of *afterglow* and instrumental noise effects.
  - Read out at 40 MHz independent of trigger - unbiased online measurement for each BCID.



Linearity of $< n_{hits} >$ vs μ for toy MC and full simulation.



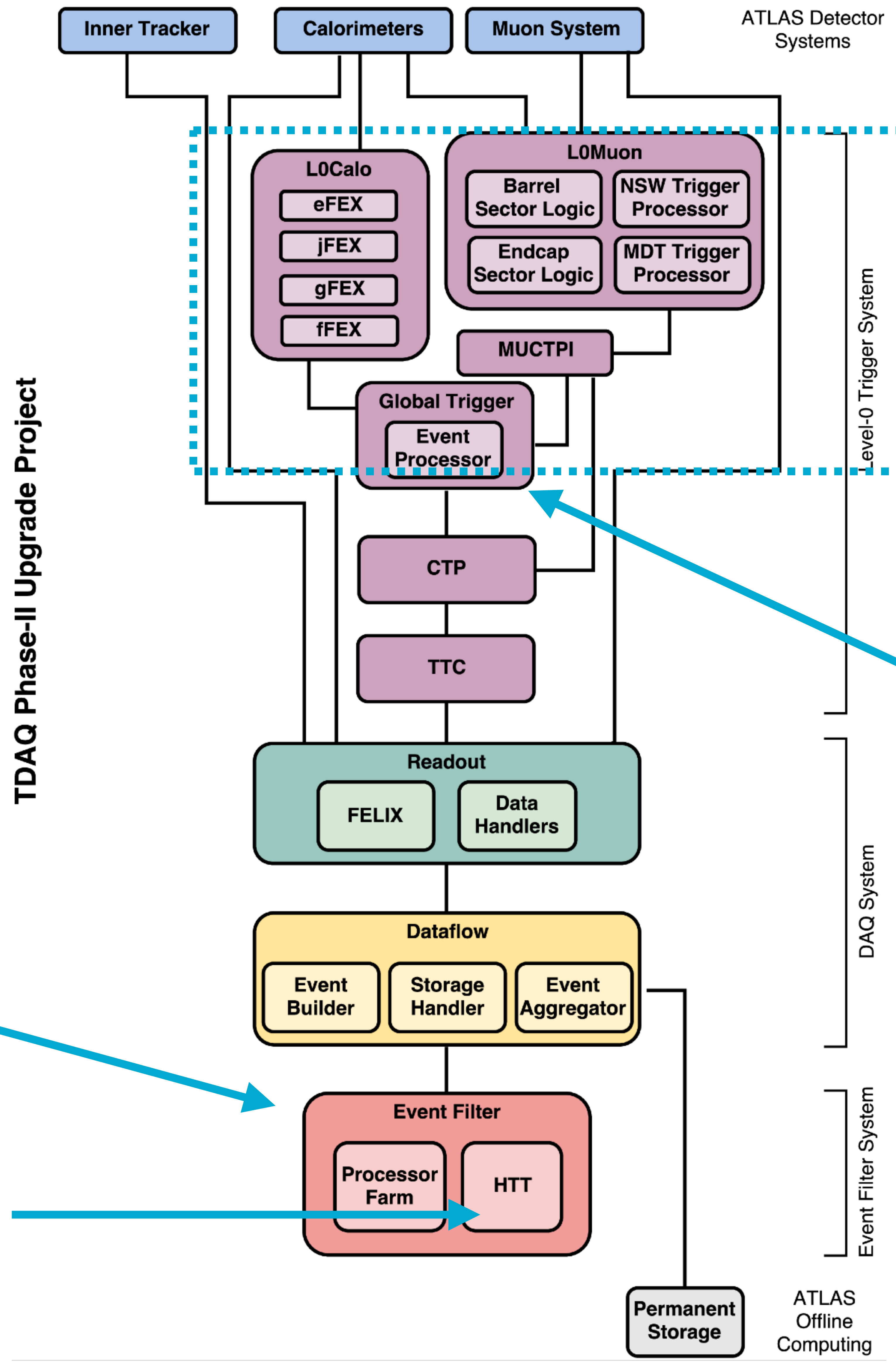


Statistical precision vs μ assuming measurement time of 1s, for online Lumi measurement

Require < ~1% overall luminosity uncertainty for key analyses at HL-LHC and HGTD might be crucial to achieve this!

Trigger and Data Acquisition Description

- Phase-II TDAQ 2-tiered trigger system:
  - 1) **Hardware based Level-0**
    - **New Global Trigger** for full-granularity calorimeter processing, topological selections.
  - 2) **Software based Event Filter** with possibly hardware-based accelerators.
    - Accelerator strategies for **online tracking**.
- Trigger design to handle
  - 1 MHz L0 output rate
  - 10 kHz final Event Filter output rate to storage.
  - Max latency of 10 μs at L0 -> > 5x larger latency to make room for more complicated algorithms.



L0 largely PHASE I upgrades
L0Calo FEXes with higher granularity super-cell reconstruction
L0Muon with New Small Wheel trigger processor,
***PHASE II** MDT trigger processor for refined timing*

L0 Global Trigger:
To process full granularity calorimeter information, run offline-like algorithms (e.g. Anti-kT)
Apply topological selections

Event Filer:
CPU-based processing

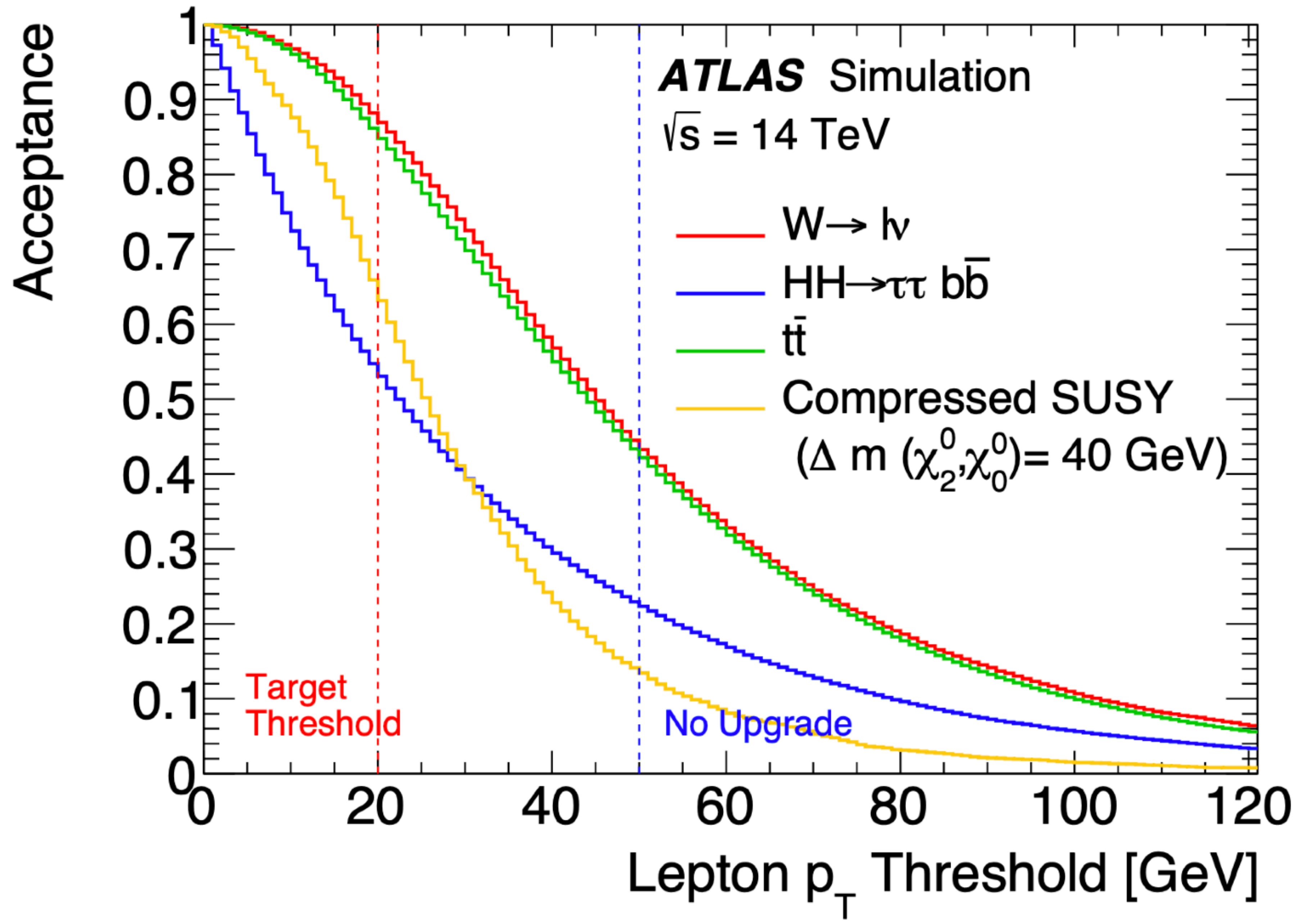
Hardware Track Trigger
component currently under review, while considering commodity based heterogeneous computing solutions or pure SW solution

TDAQ

Goals for trigger menu

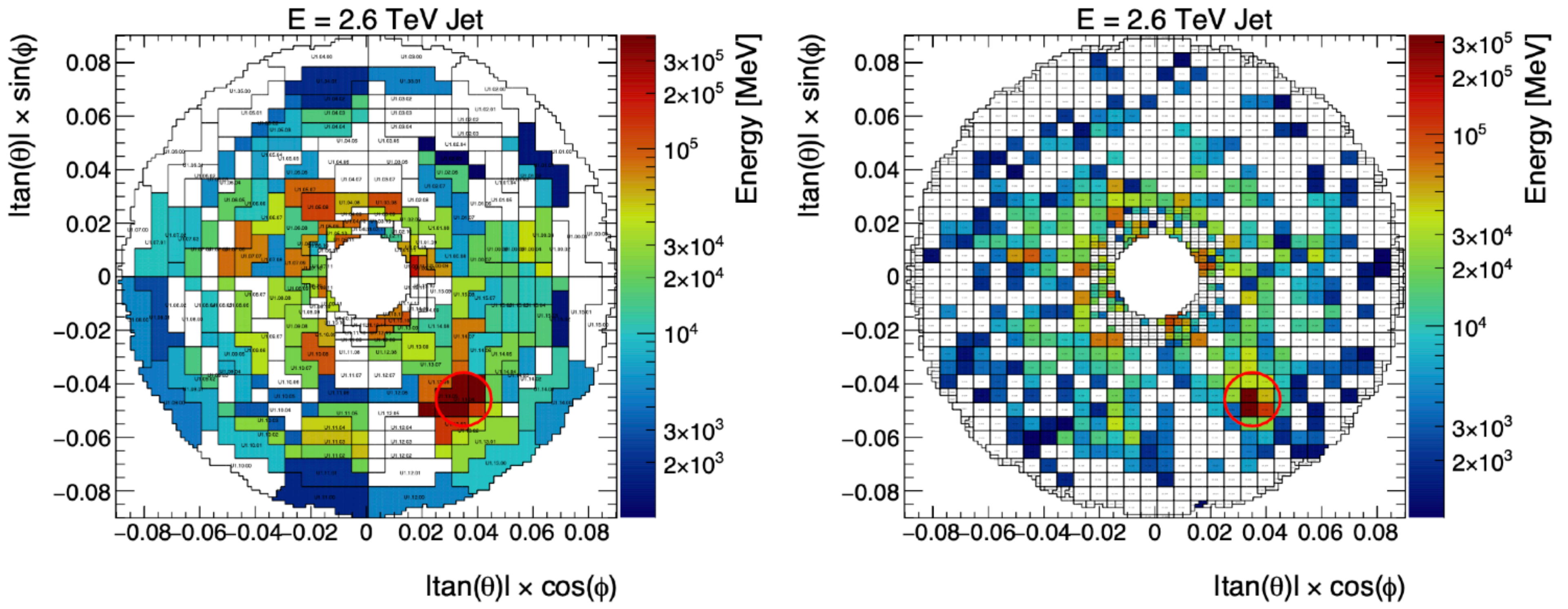
- **Primary aim: Maintain low lepton trigger thresholds, while mitigating the large rate of QCD jet events.**
  - 20 GeV Lepton trigger threshold target maintains > ~50% signal acceptance for key signals:
    - W/Z decays (e.g. $W \to l\nu$), $HH \to \tau\tau b\bar{b}$, new physics with couplings to leptons (e.g. Compressed SUSY)
- **Remain inclusive** by ensuring performance also for difficult regions e.g.
  - Forward signatures, displaced or out-of-time signatures, signals suffering under pile-up (multijet resonances, $HH \to b\bar{b}b\bar{b}$)

Trigger Selection offline threshold (GeV)	Run1	Run2	HL-LHC
isolated single e	25	27	**22**
Isolated single μ	25	27	**20**
di-γ	25,25	25,25	**25,25**
di-τ	40,30	40,30	**40,30**
four-jet w/ b-jets	45	45	**65**
MET	150	200	**200**



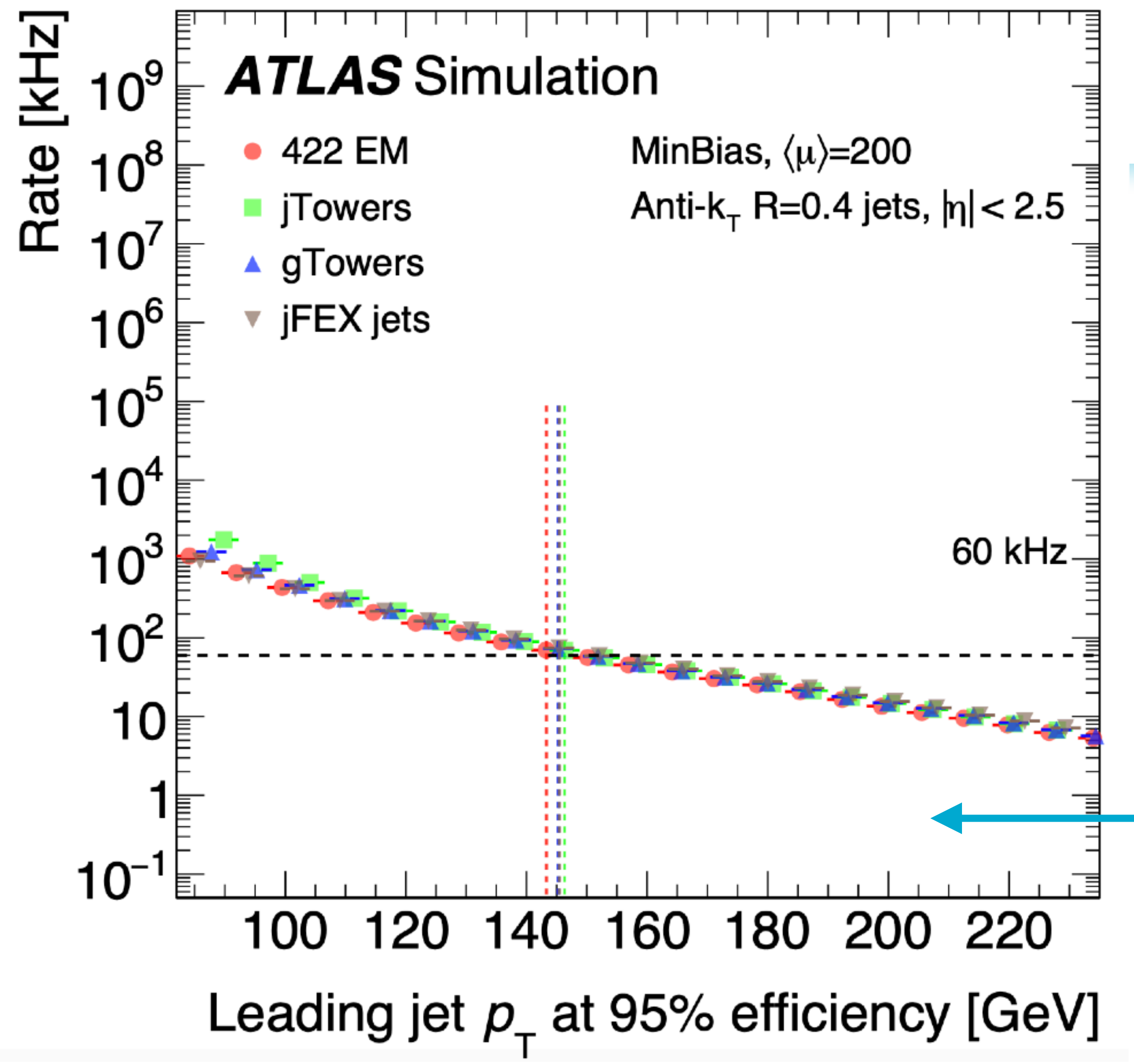
Increased granularity to Global Trigger will improve reconstruction in forward region

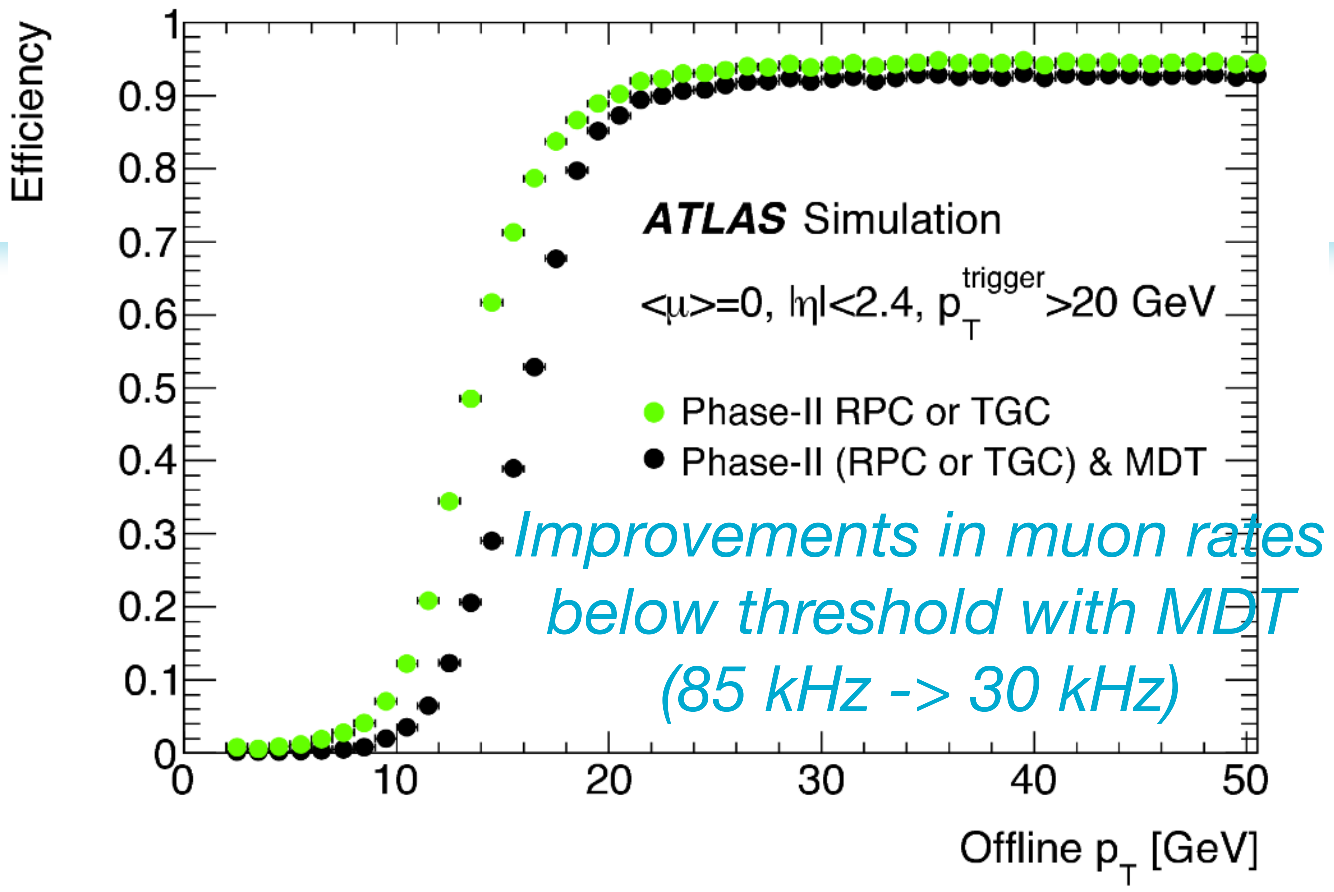
—->



TDAQ Rate control

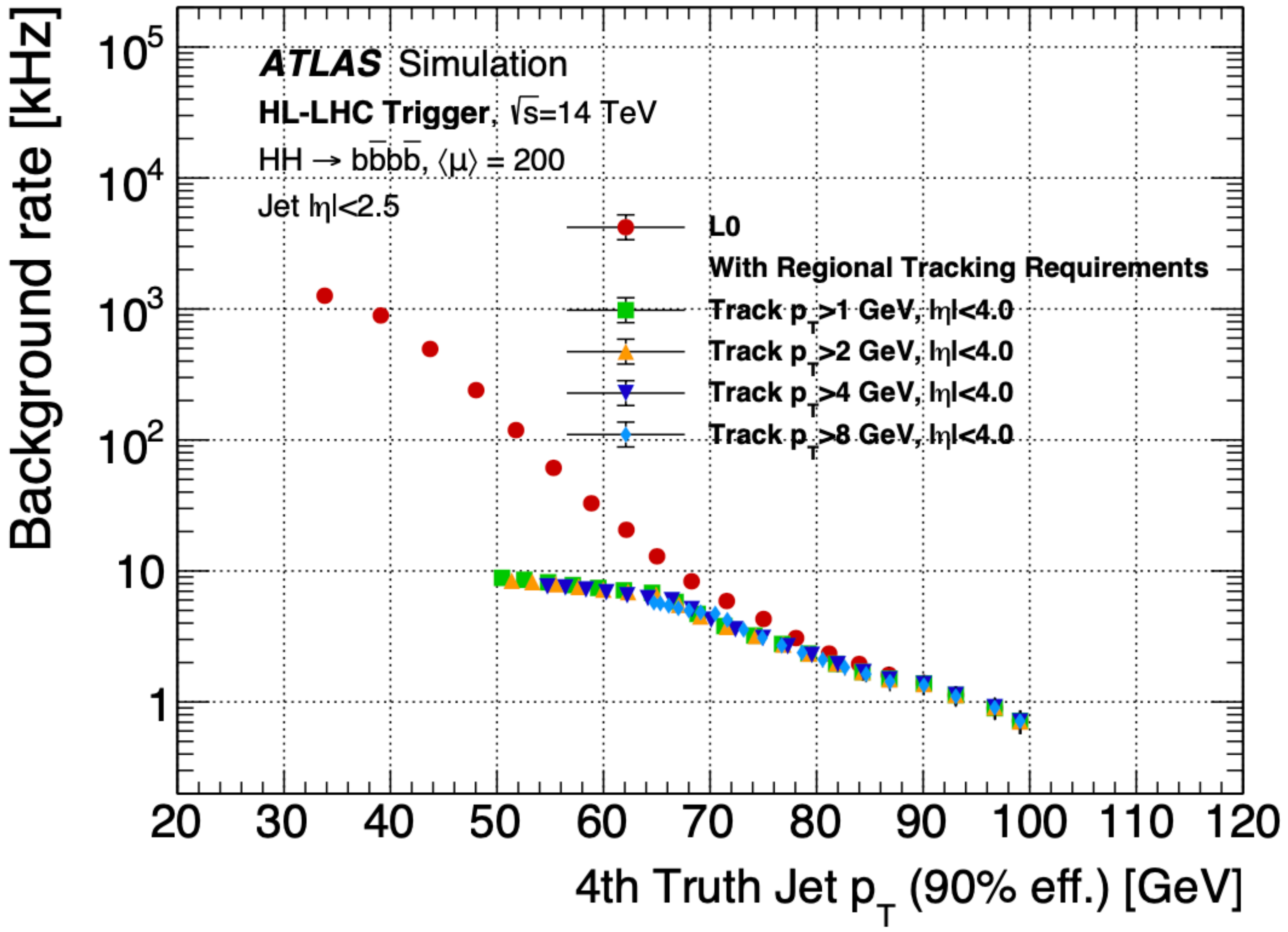
- **Online reco improvements important at all levels to control high HL-LHC rates:**
  - Better online energy resolution, better fake rejection, smarter algorithms at L0, will purify trigger selection and reduce rate
  - Use online tracking early on to mitigate pile-up jets, to improve measurement of E_T^{Miss} and to enable lepton and photon identification



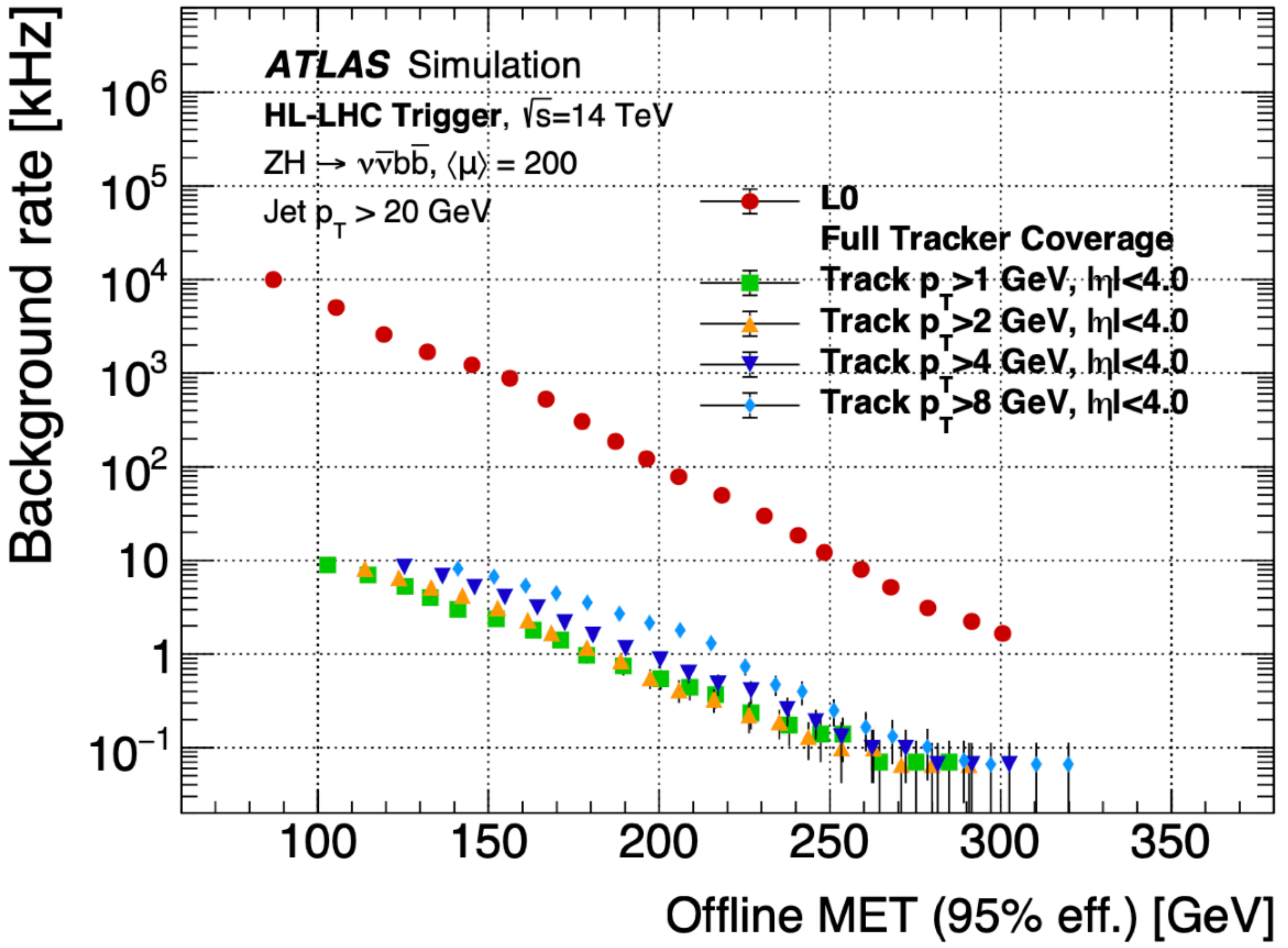


Improvements in muon rates below threshold with MDT (85 kHz -> 30 kHz)

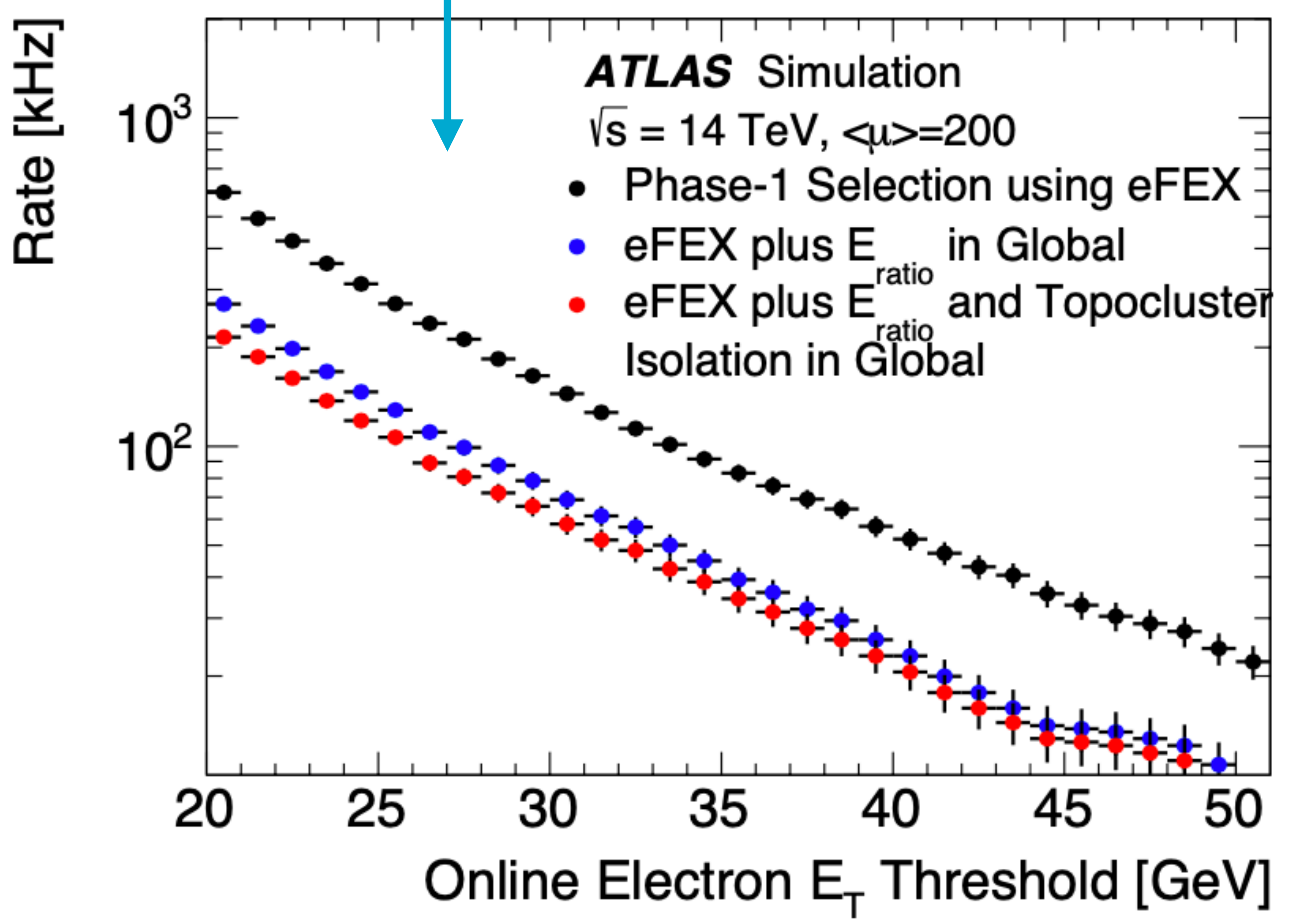
Use of Global Trigger will allow lower thresholds while controlling rate from improved energy resolutions (e.g. Anti-kT jet clustering) & tighter cuts (e.g. energy ratio & isolation requirements on leptons)



Estimated rate control from using tracking to identify pile-up jets in multijet events

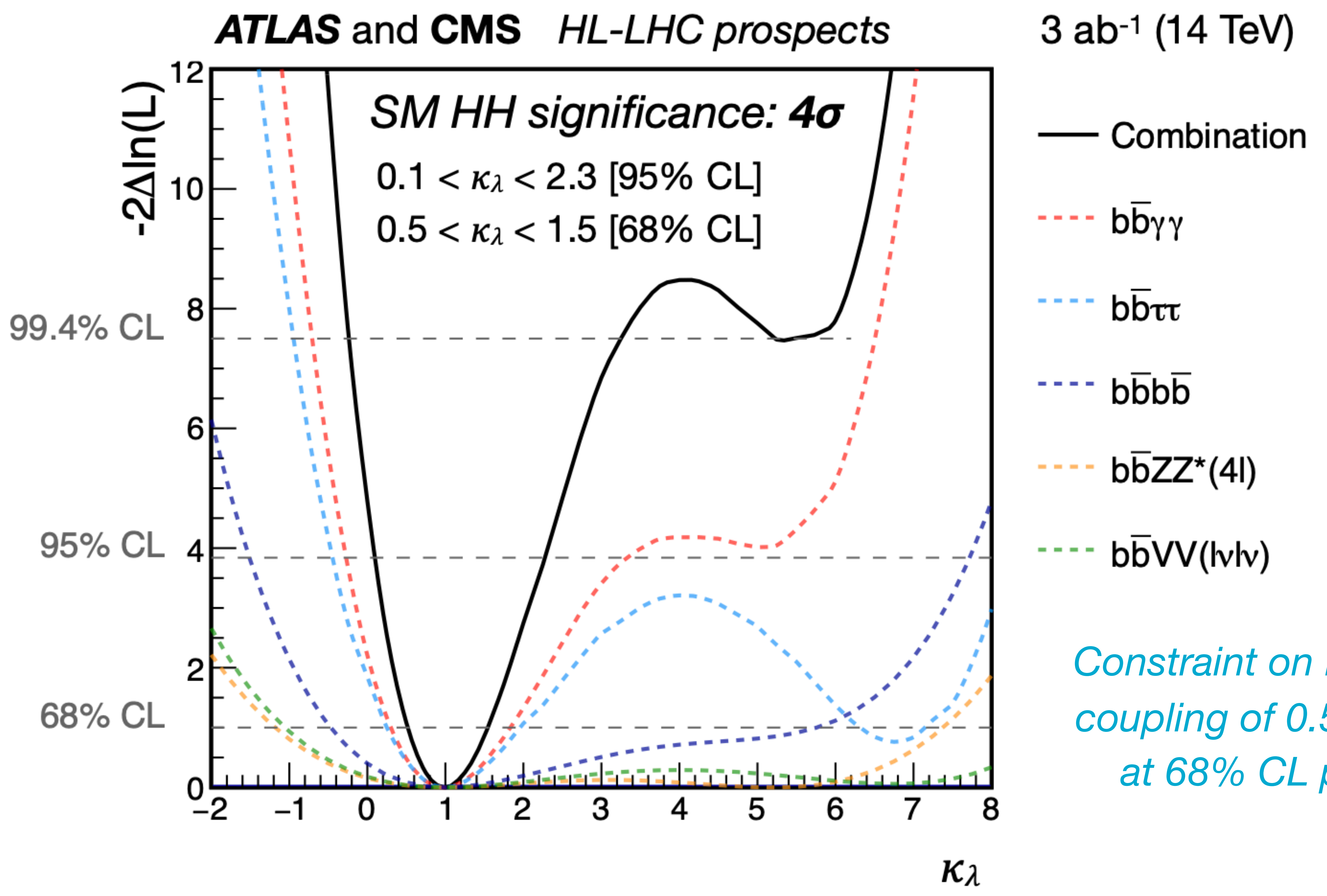


Estimated rate control from using tracking to compute track-based soft term for E_T^{Miss}



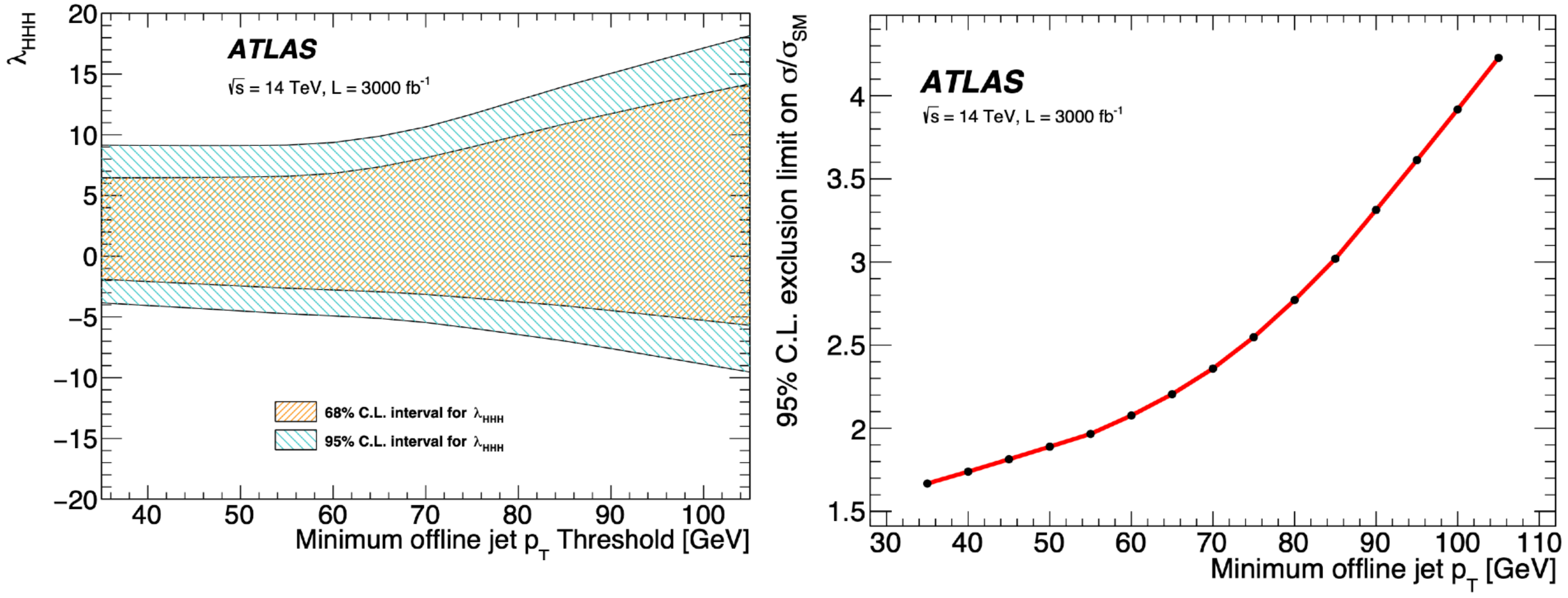
ATLAS Physics Potential Higgs self-coupling

- **Higgs self-coupling** possible constraints with 6000 ifb (ATLAS+CMS combined)
  - **Trigger will be key** to maximising statistical precision

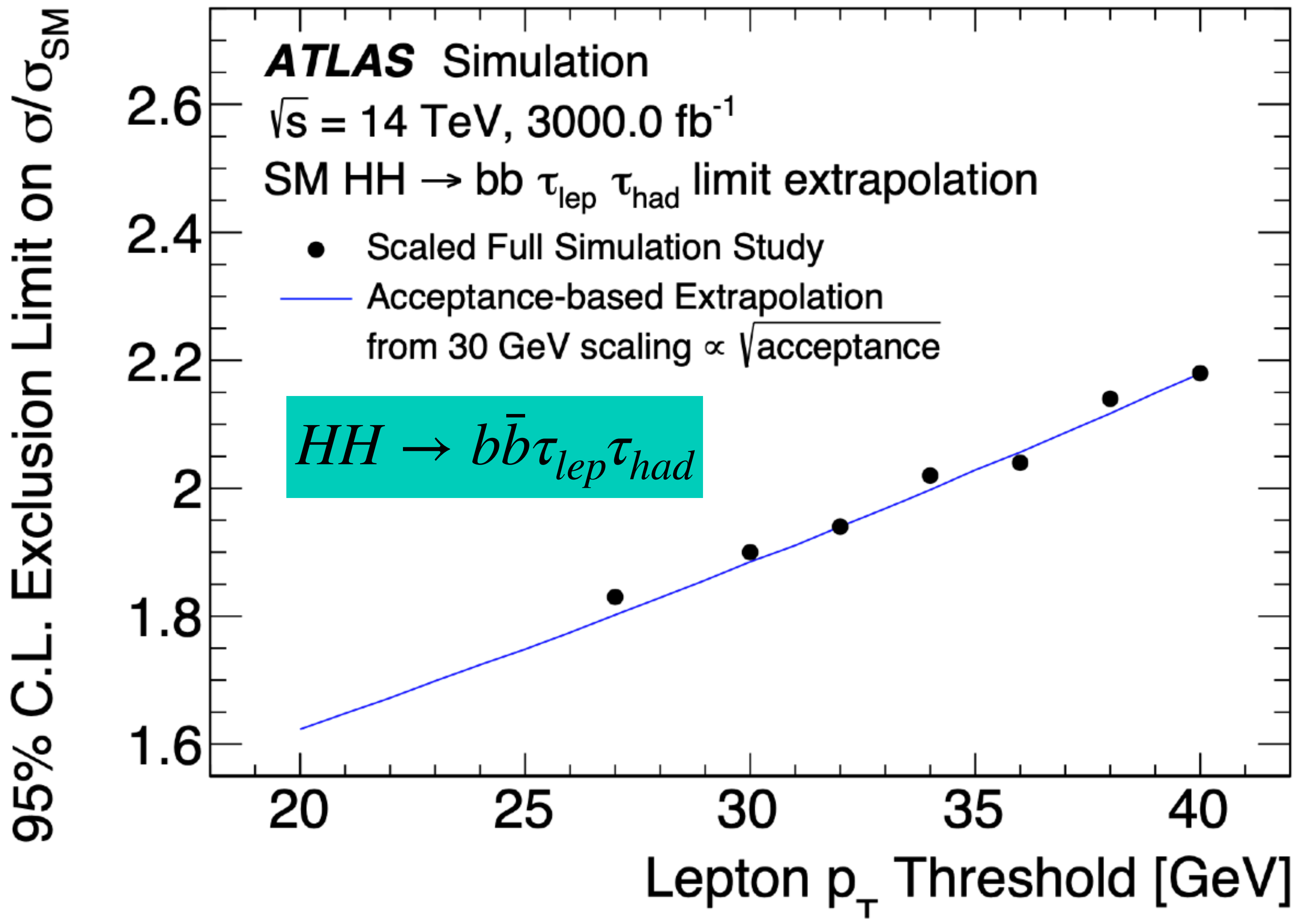


Constraint on Higgs self-coupling of $0.5 < \kappa_\lambda < 1.5$ at 68% CL possible

$HH \rightarrow b\bar{b}b\bar{b}$

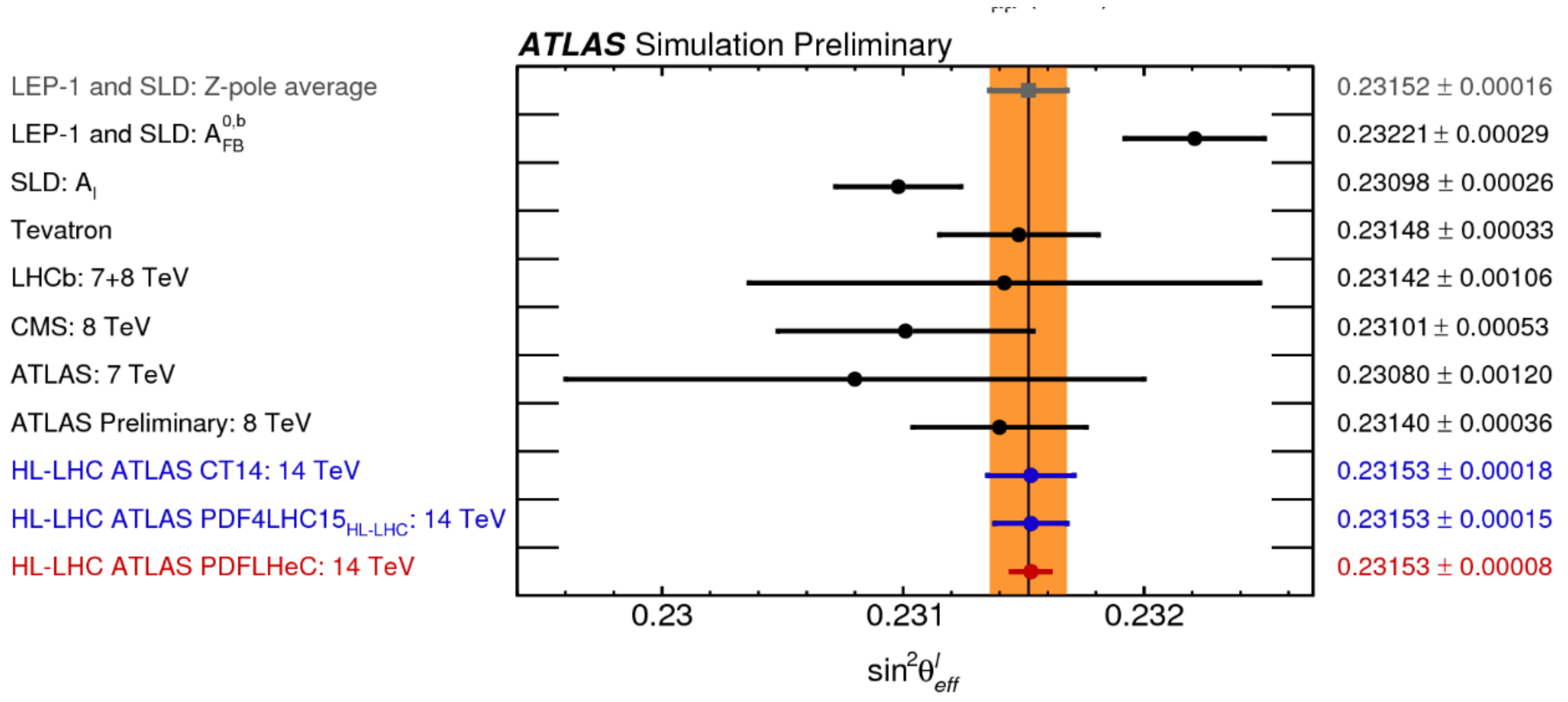


While sensitivity to New Physics enhanced.

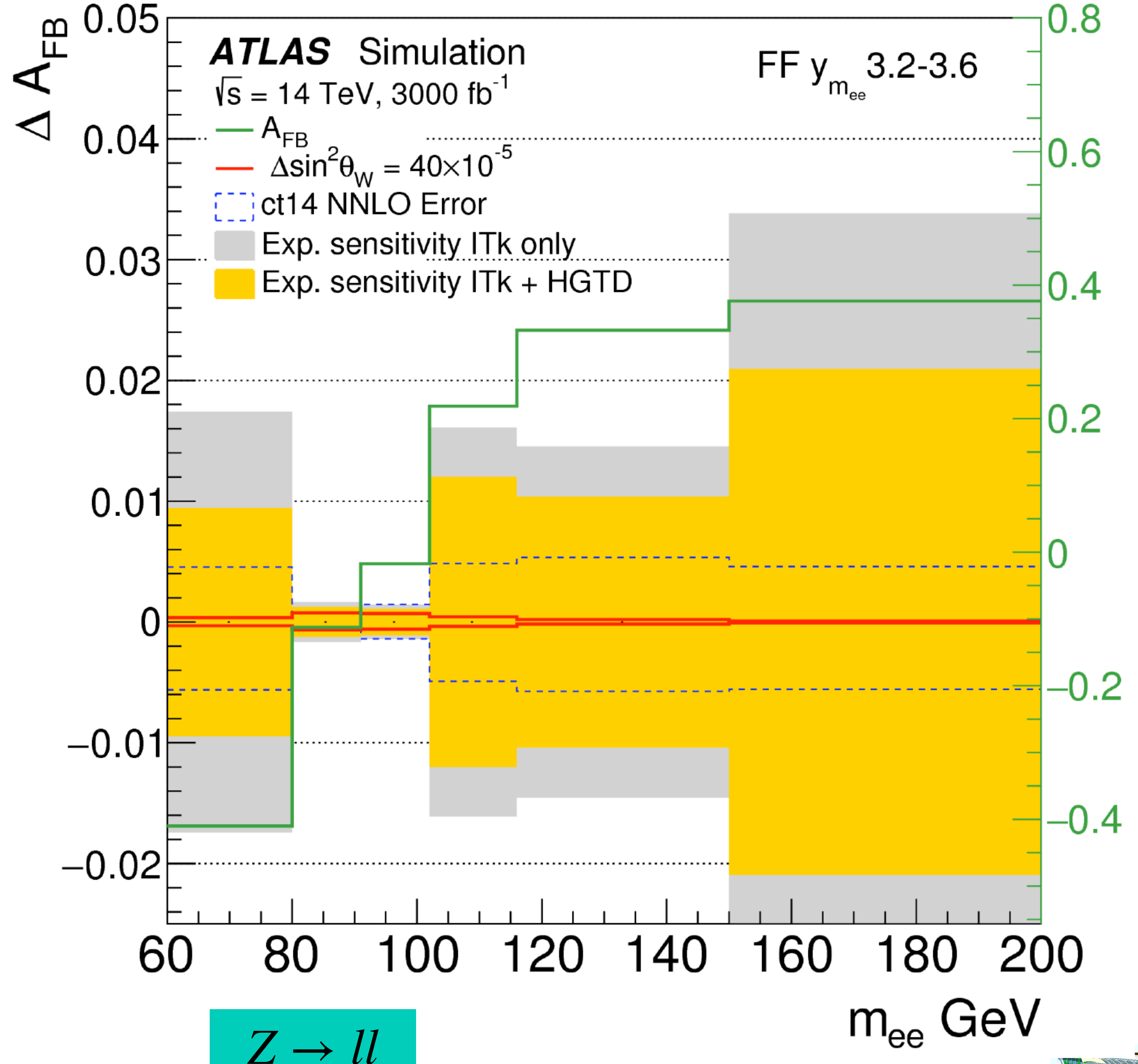


Trigger thresholds crucial to constraining exclusion limits

ATLAS Physics Potential Weak mixing angle



Expected sensitivity on forward backward asymmetry in $Z \to ll$ with both leptons in forward region, using ITk + HGTD



$Z \to ll$

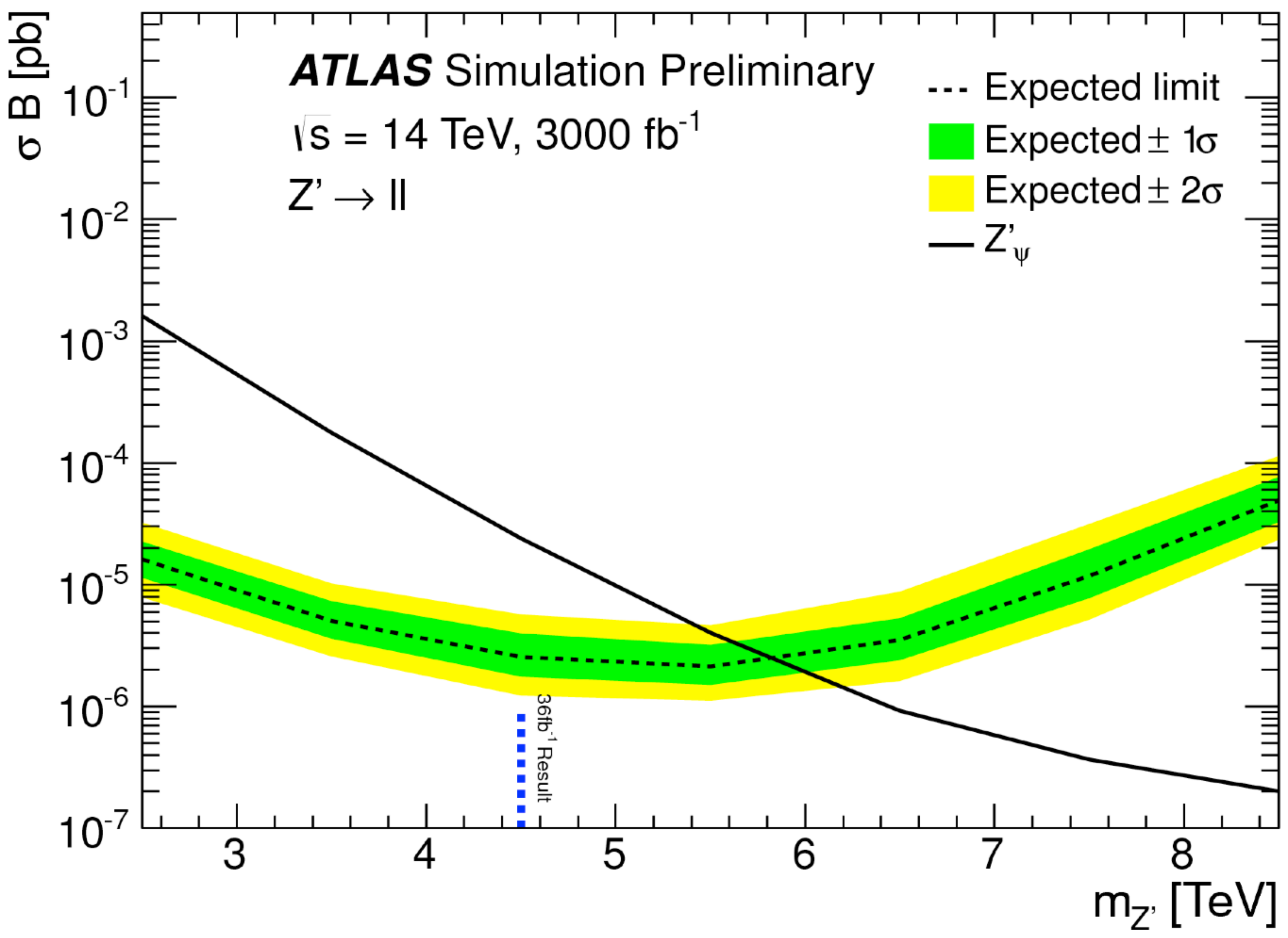
- Projected ATLAS limits on $sin^2\theta_{eff}$ shows precision of minimum +/- $\sim 18 \times 10^{-5}$, resolving current discrepancy between LEP and SLD.
- Via **forward region access** with ITk + HGTD, expect +/- 16×10^{-5} (pdf) +/- 9×10^{-5} (exp)
  - PDF uncertainties dominate -> **further improvement with new PDF measurements!**

ATLAS Physics Potential

$f\bar{f}$ resonances

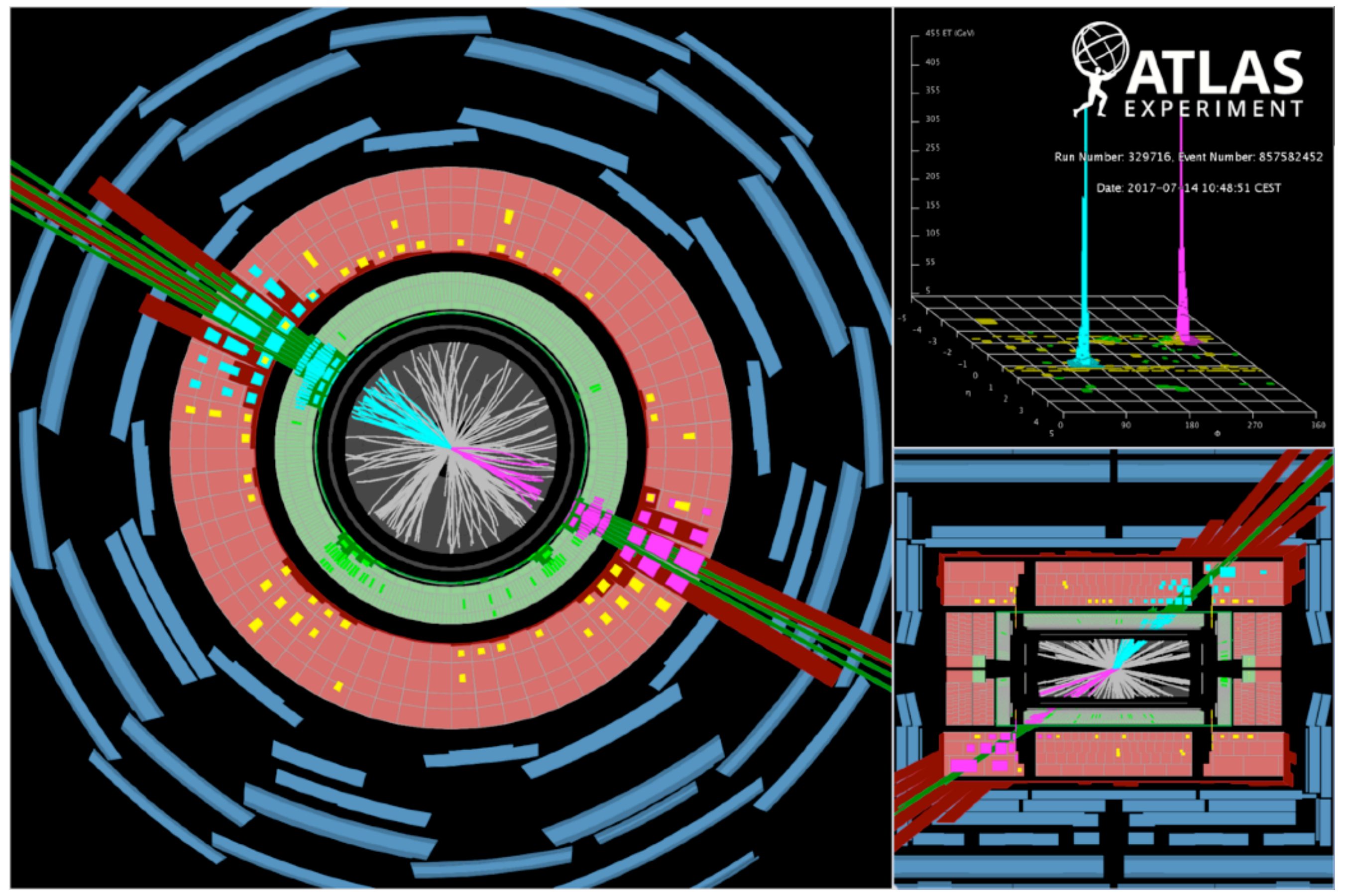
- Meanwhile, very central region remains interesting:
  - **Di-lepton/di-jet resonance bumphunts** will access higher masses with greater statistics and with higher collision energies.

Expected limits on m'_Z for $Z' \rightarrow ll$ + theoretical Z` x-section of a E6 gauge group model [Yellow Report VII]



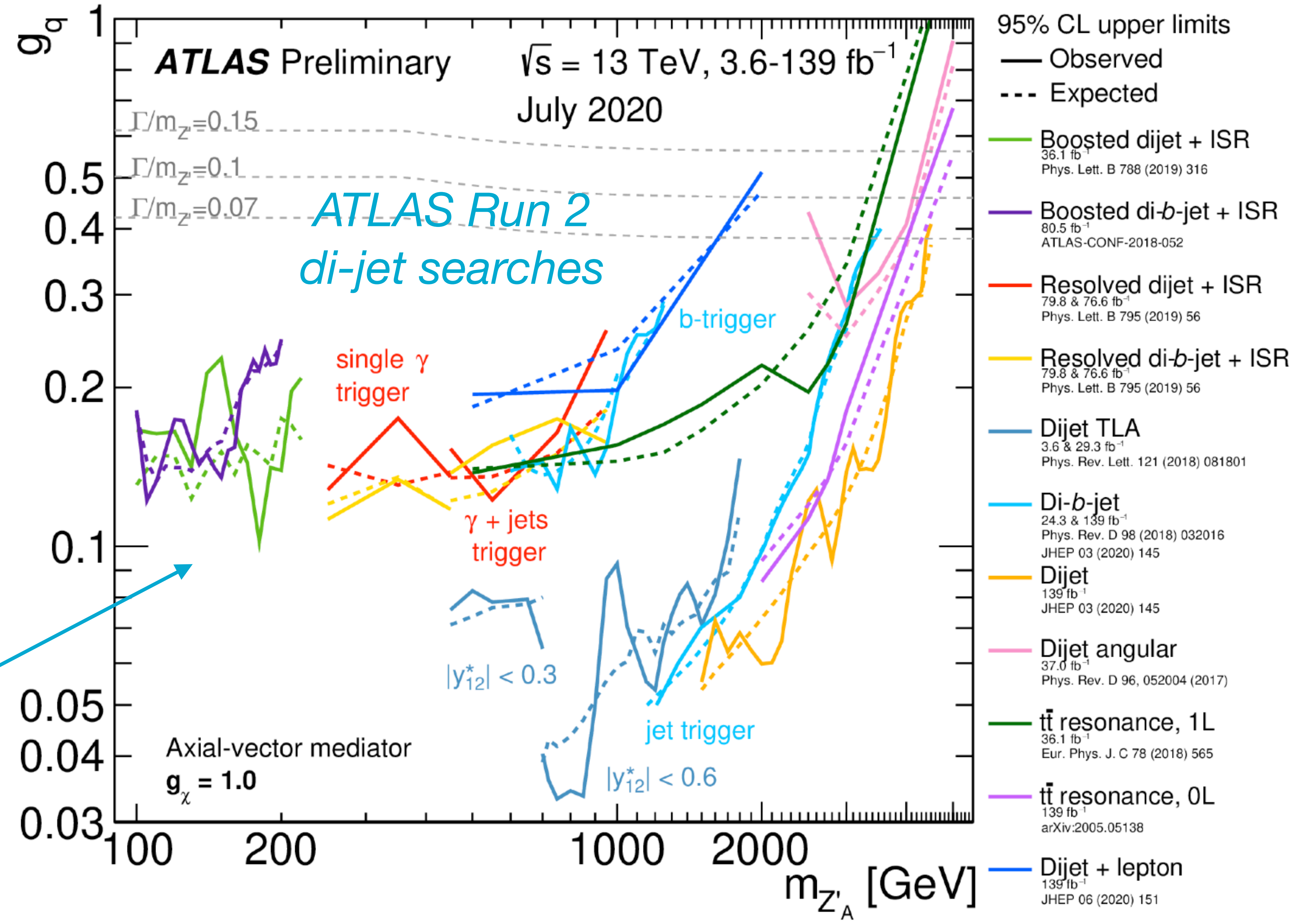
ATLAS Run 2 di-jet event, $m_{jj} = 9.3TeV$

Calorimeter upgrade crucial for remaining unsaturated at high energies at HL-LHC



Also low mass searches remain important for rare new physics uncoverable with more stats.

Rely on tricks to overcome trigger thresholds (dijet+γ ISR, data scouting…)



Upgrade Status

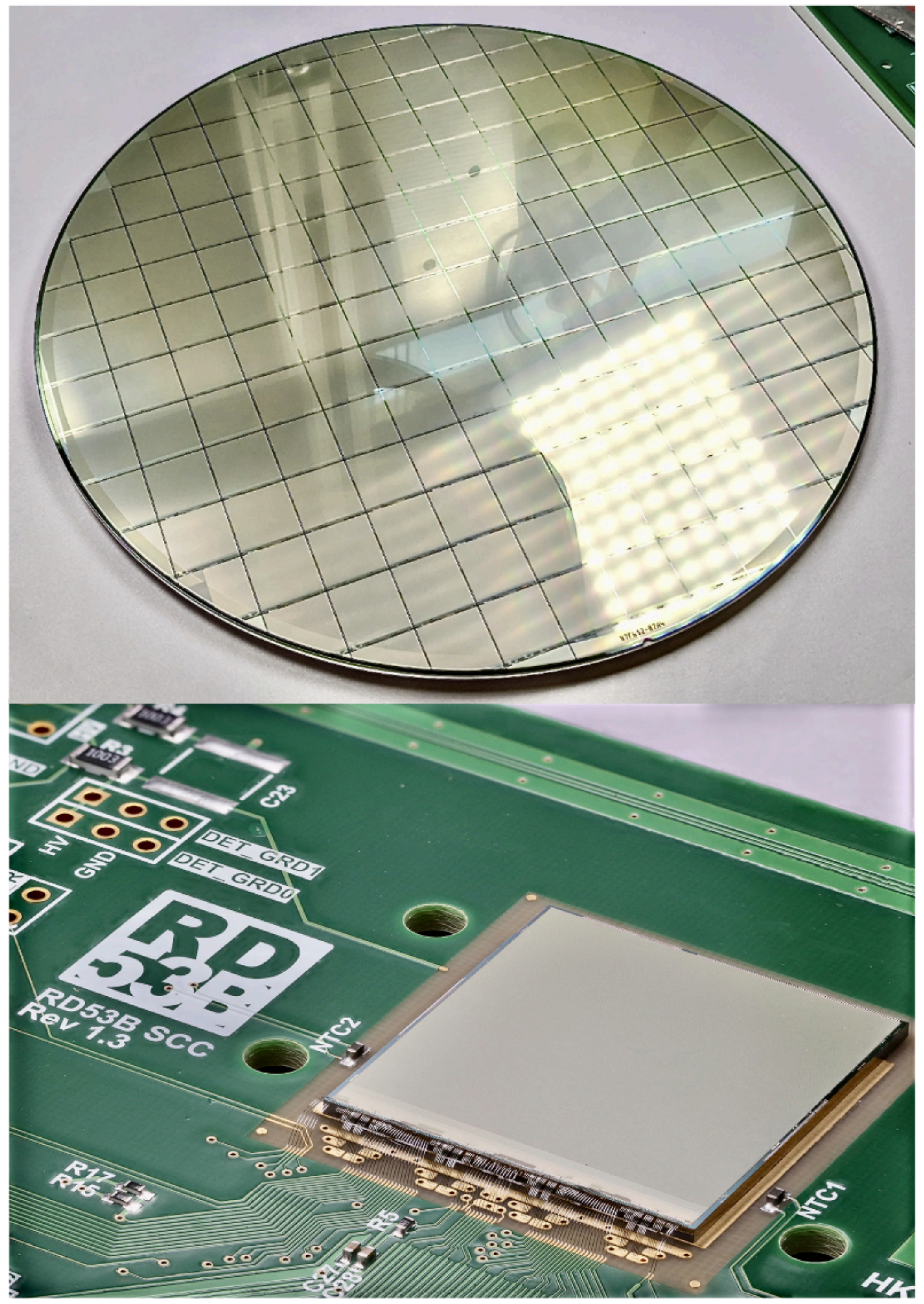
PHASE I

- **Muon New Small Wheel:**
  - After some initial delays installation of both Wheels underway.
  - New Small Wheel Endcap A to be completely installed mid July.
  - New Small Wheel Endcap C commissioning started, to be installed in Autumn.
- **EM calorimeter upgrades:**
  - Delays for eFEX due to global chip shortages
  - Production and commissioning underway on all FEXs.

Installation of final sector on New Small Wheel A (left)

PHASE II

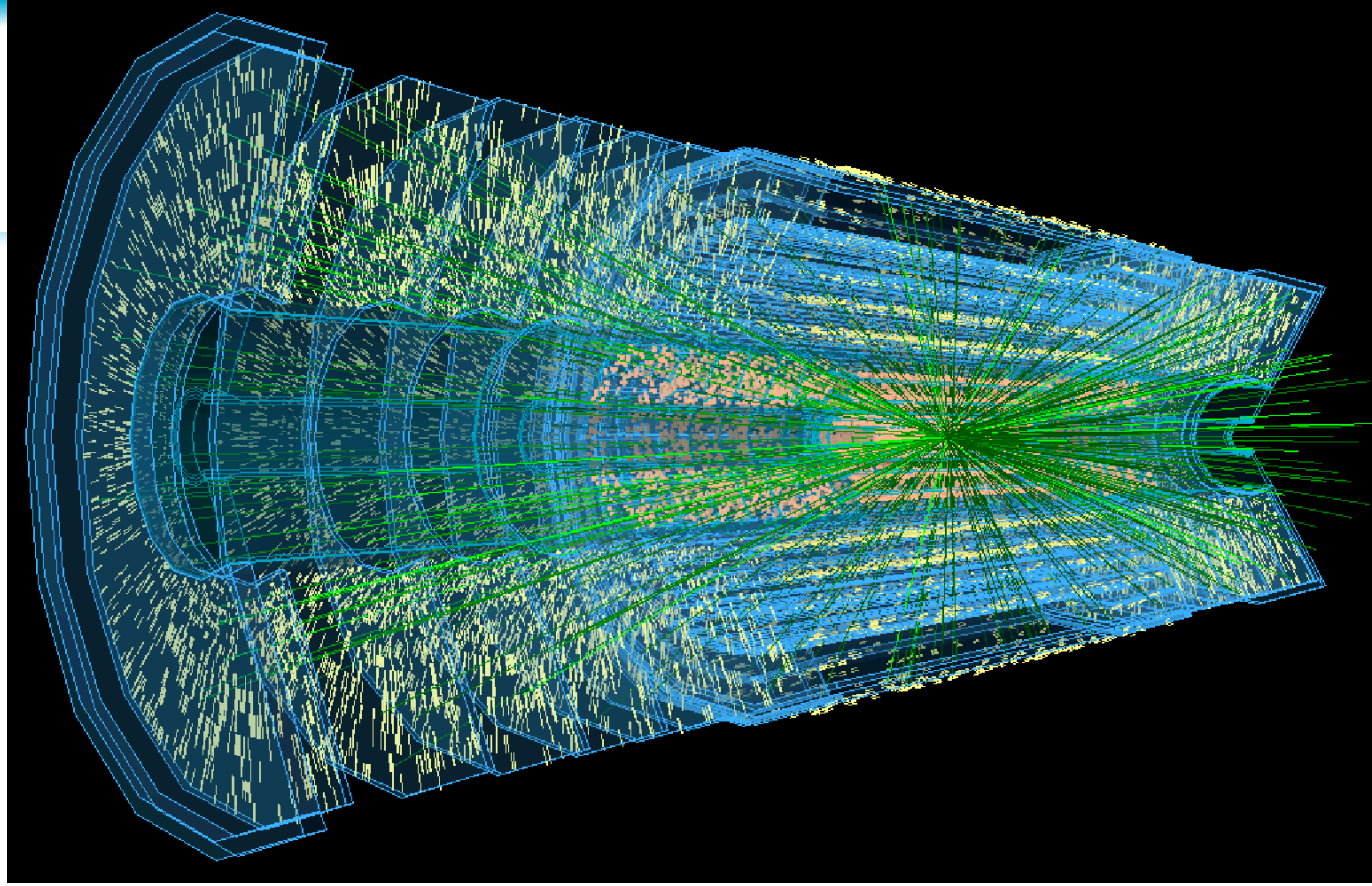
- **ITk:**
  - Project entering pre-production stage.
  - Delays of ~half year, mainly due to COVID.
- **HGTD:**
  - TDR approved ~1 year ago. Lots of various activities such as test beams for sensor testing underway.
- **TDAQ:**
  - Accelerator solutions for tracking at Event Filter under review:
    - Custom based, commodity based “heterogeneous” or pure SW based solutions being studied.



ITkPixv1 wafer and chip (RD53 collaboration)

Summary

- **HL-LHC will provide tough running conditions:**
  - High radiation, high occupancy, high rates
- **However will also present opportunity to improve measurements from statistics precision AND beyond:**
  - New detector components will give ATLAS access to new phase space
    - New Inner Tracker to extend tracking to $|\eta| = 4$.
    - New High Granularity Timing Detector to afford precise timing measurements for the first time in ATLAS
      - **Room for novel ideas!**
- **ATLAS has broad physics program ahead which relies on exploiting as much as possible new upgrades**
  - Will be able to probe new physics by testing Standard Model properties or searching for new signals directly. Many possibilities for **new physics** exist…



Anomalous electroweak coupling?

New particles out-of-time or out-of-place?

New particles in light-by-light scattering?

New physics in SM Higgs physics?

New physics at extremely high masses?

UNIVERSITÉ DE GENÈVE

FACULTÉ DES SCIENCES
Département de physique nucléaire et corpusculaire

Thank you for listening!

ATLAS EXPERIMENT

BACK UP

NSW Upgrade

- Efficiency of WH associated production with $W \to \mu\nu$ & $H \to b\bar{b}$ or $H \to W^+W^- \to \mu\nu qq'$

L1MU threshold (GeV)	$H \to b\bar{b}$ (%)	$H \to W^+W^-$ (%)
$p_T > 20$	93	94
$p_T > 40$	61	75
$p_T > 20$ barrel only	43	72
$p_T > 20$ with NSW	90	92

ATLAS New Small Wheel TDR

- Expected L1 rate for different pT thresholds & with/without NSW

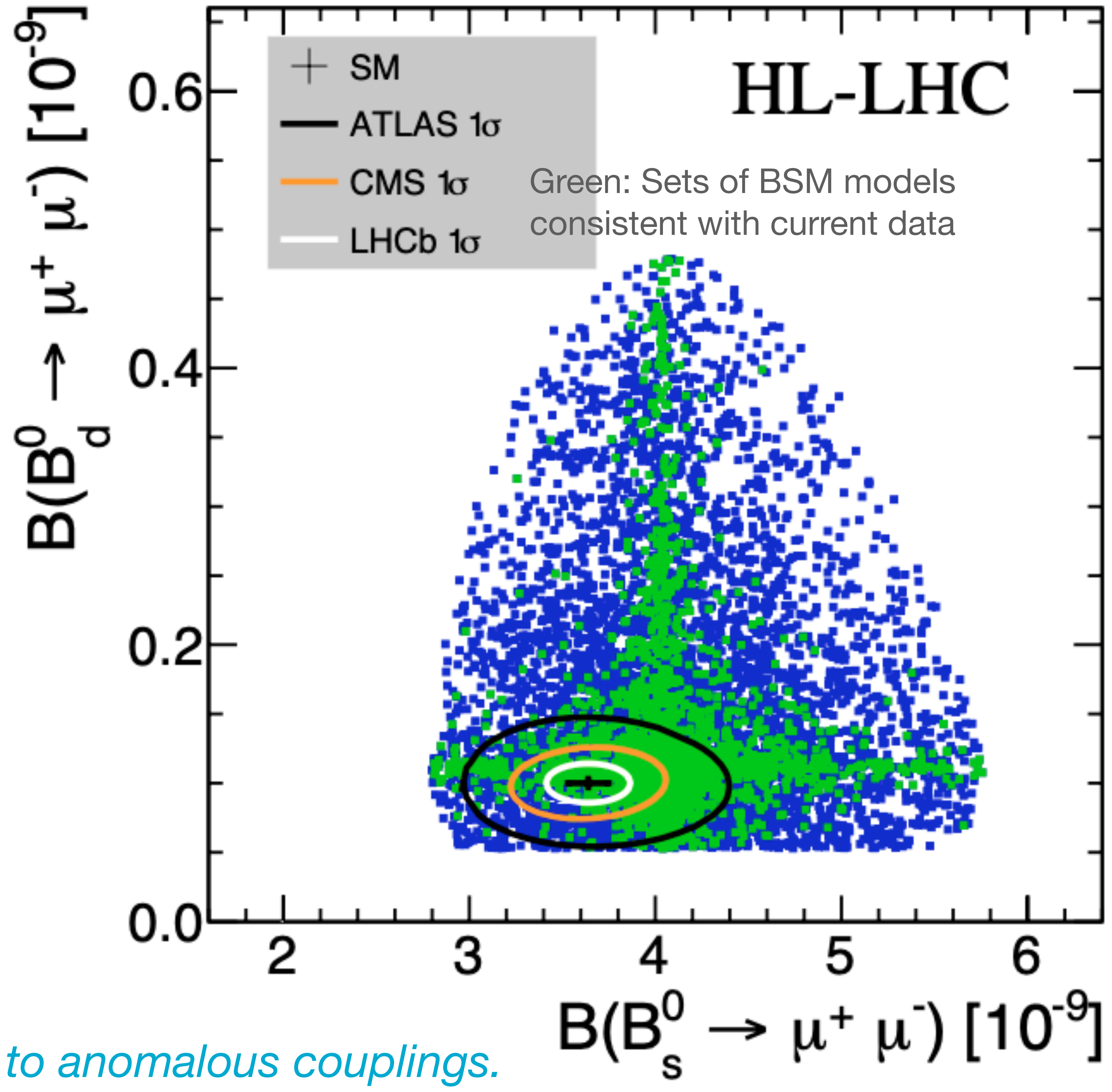
L1MU threshold (GeV)	Level-1 rate (kHz)
$p_T > 20$	60 ± 11
$p_T > 40$	29 ± 5
$p_T > 20$ barrel only	7 ± 1
$p_T > 20$ with NSW	22 ± 3
$p_T > 20$ with NSW and EIL4	17 ± 2

Flavour Physics Potential at HL-LHC

- Signs for New Physics, particularly in
  - τ vs μ/e in $c \to sl\nu$ (charged currents)
  - μ vs e in $b \to sl^+l^-$ (neutral currents)
    - High potential: Current data still allows 20% contribution from New Physics for most FCNC process

Tracker upgrade for precise muon reconstruction, low lepton trigger thresholds and good angular separation of muons.

Opportunities in Flavour Physics at the HL-LHC and HE-LHC



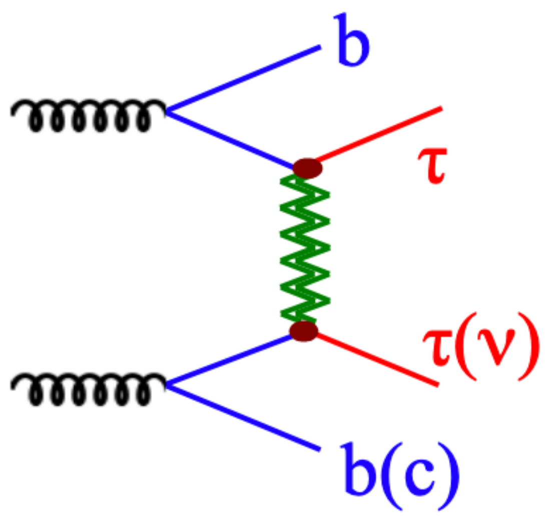
- Benchmark channels for ATLAS, CMS:
  - $B_{s,d} \to \mu\mu, B^0 \to K^{*0}\mu\mu, B_{s,d} \to J/\psi\phi,$
  - $\tau \to \mu\mu\mu$ (lepton flavour violation): HL-LHC competitive with Belle II.
  - Top FCNC: $t \to c(u)\gamma, c(u)Z, c(u)g$ (stats limited)

Projected reach for 95% C.L. on branching ratio to anomalous couplings.

$t \to gu$	$t \to gc$	$t \to qZ$	$t \to \gamma u$	$t \to \gamma c$	$t \to Hq$
3.8×10^{-6}	3.2×10^{-5}	$2.4 - 5.8 \times 10^{-5}$	8.6×10^{-6}	7.4×10^{-5}	10^{-4}

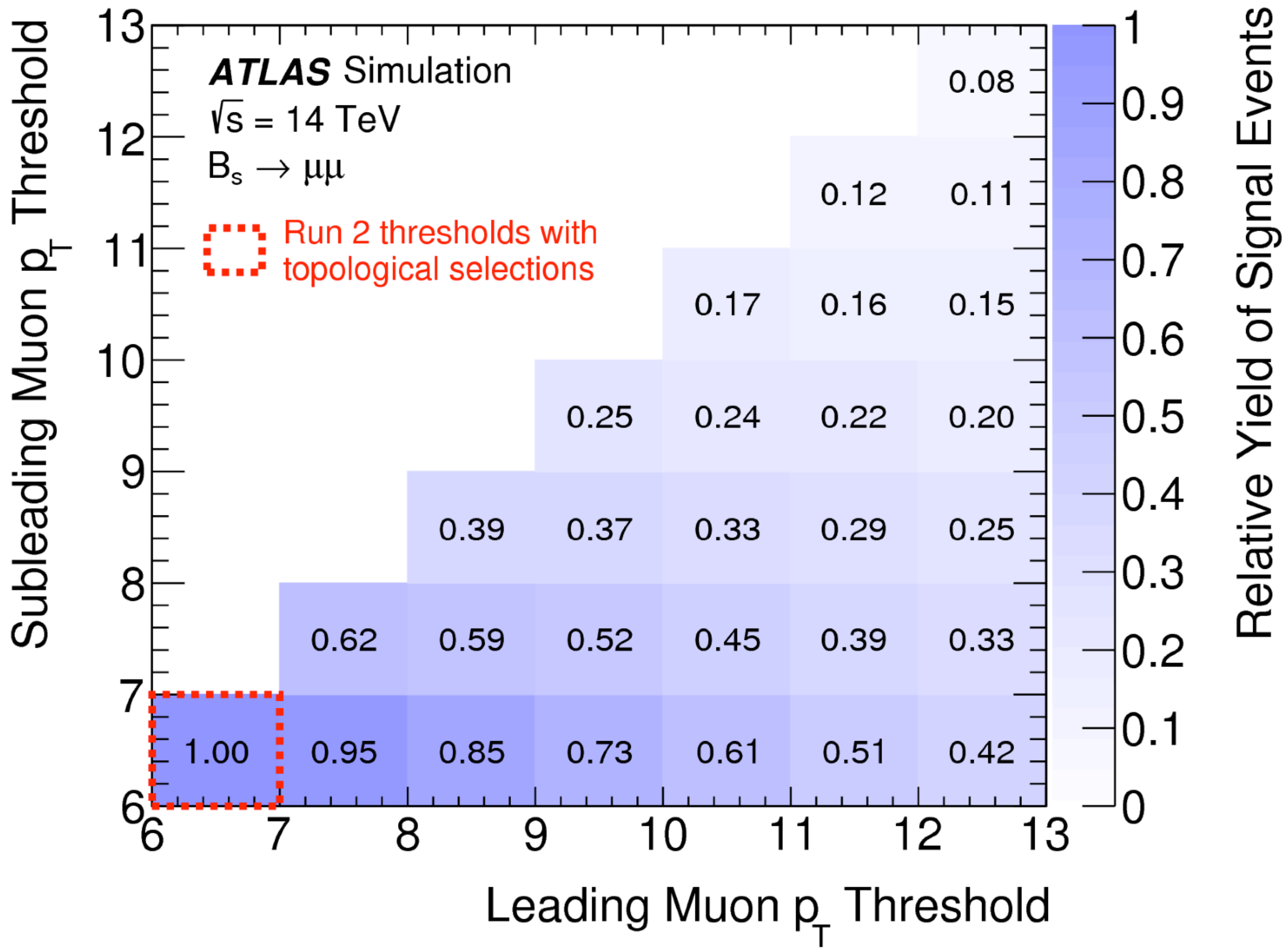
- Lepto-quarks: Contribute to semi-leptonic transitions at tree-level (exhibiting anomalies) vs loop-level for 4-quark/ 4-lepton contact interactions (no anomalies)

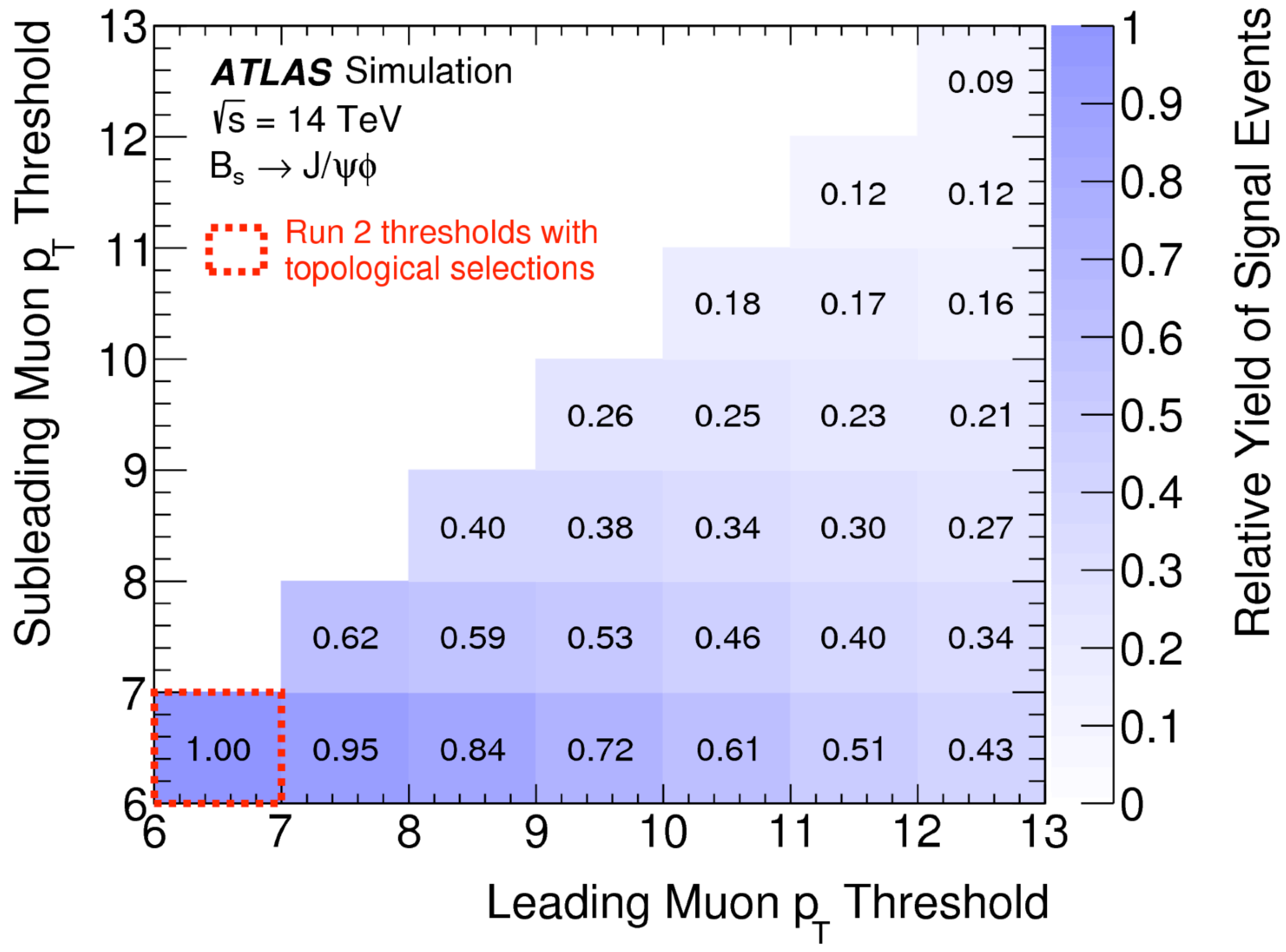
Lepto-quark signature



Reading the footprints of the B-meson flavor anomalies

Flavour Physics Potential at HL-LHC





- Flagship signatures, $B_{s,d} \rightarrow \mu\mu$, $B_{s,d} \rightarrow J/\psi(\mu^+\mu^-)\phi(K^+K^-)$, require low muon thresholds and good separation to optimise sensitivity.

Phase II Upgrade TDAQ TDR

trigger muon threshold		inefficiency	
$p_{T,1}$	$p_{T,2}$	$B_s \rightarrow \mu^+\mu^-$	$B_s \rightarrow J/\psi\phi$
6 GeV	4 GeV	0.5%	5.7%
6 GeV	6 GeV	1.2%	13.7%
10 GeV	6 GeV	2.3%	23.1%
10 GeV	10 GeV	8.2%	58.8%

ITk: Latest changes

Geometry

ITK-2020-002: Following the ATLAS decision to reduce the radius of the Pixel innermost layer in January 2020, there has been an optimization of the layout of the Pixel Inner System including: reducing the L0 barrel sensor radius to 34 mm, reducing the inner radius for the R0 rings sensors to 33.2 mm, reducing the number of staves in the L0 barrel from 16 to 12, reducing the necessary number of rings in the end-cap (-1 R1, -2R0), increasing the gap between barrel and endcap , adapting the z-position of some rings, changing the number of single 3D modules in R0 (from 20 to 18) and R0.5 (from 28 to 30). In addition, a change in the design of the Outer End-cap has been implemented to increase the clearance between the two split half-rings from 10 mm to 11 mm. The nominal ring positions have been left unchanged, except for the lower-z ring, moving its nominal position 0.5 mm up in z.

Material budget

ITK-2019-001: In October 2019, a new iteration of the ATLAS ITk Geant4 simulation geometry was produced, updating various aspects with respect to the version presented in ATL-PHYS-PUB-2019-014. While the position of sensitive detector elements remains largely unchanged (L0 barrel radius = 39 mm, L0 end-cap radius = 36 mm, Pixel pitch = 50x50μm2}, significant updates were made to the passive materials. In particular, the Patch Panel 1 region of the detector, located beyond the last tracking hit but in front of the High Granularity Timing Detector (HGTD) vessel, was implemented with a much greater level of detail.These updates, along with various other improvements to e.g. data cable and cooling pipe compositions and positions, provide a much more realistic description of the ITk material budget, closely matching recent engineering estimates. A set of plots are presented demonstrating the material distributions as implemented in this latest iteration of the simulation geometry (labelled as “ATLAS-P2-ITK-22-00-00”, as matching the geometry tag from the Detector Description Database).

ITk latest geometry

Pixel Barrel region

Barrel Layer	Radius [mm]	Rows of Sensors	Flat sensors per Row	Inclined sensors per Row	Type	Hits
0	34	12	12	-	singles	1
1	99	20	6	-	quads	1
2	160	32	9	6	quads	1
3	228	44	9	8	quads	1
4	291	56	9	9	quads	1

Pixel end-cap region

Ring Layer		Radius [mm]	Rings	Sensors per Ring	Type	Hits
barrel	R0	33.20	15	18	singles	2-4
endcap	R0.5	58.70	6	30	singles	3-4
endcap	R1	80.00	23	20	quads	2-4
endcap	R2	154.50	11	32	quads	1-2
endcap	R3	214.55	8	44	quads	1
endcap	R4	274.60	9	52	quads	1

Detector Part	Surface [m^2]
Inner Barrel Flat	0.48
Endcap Inner Rings	1.77
Inner Total	2.26
Outer Barrel Flat	3.69
Outer Barrel Inclined	3.25
Outer Barrel Total	6.94
Endcap Outer Rings	3.64
Barrel Total	7.42
Endcap Total	5.41
Total	12.83

Pixel Barrel region

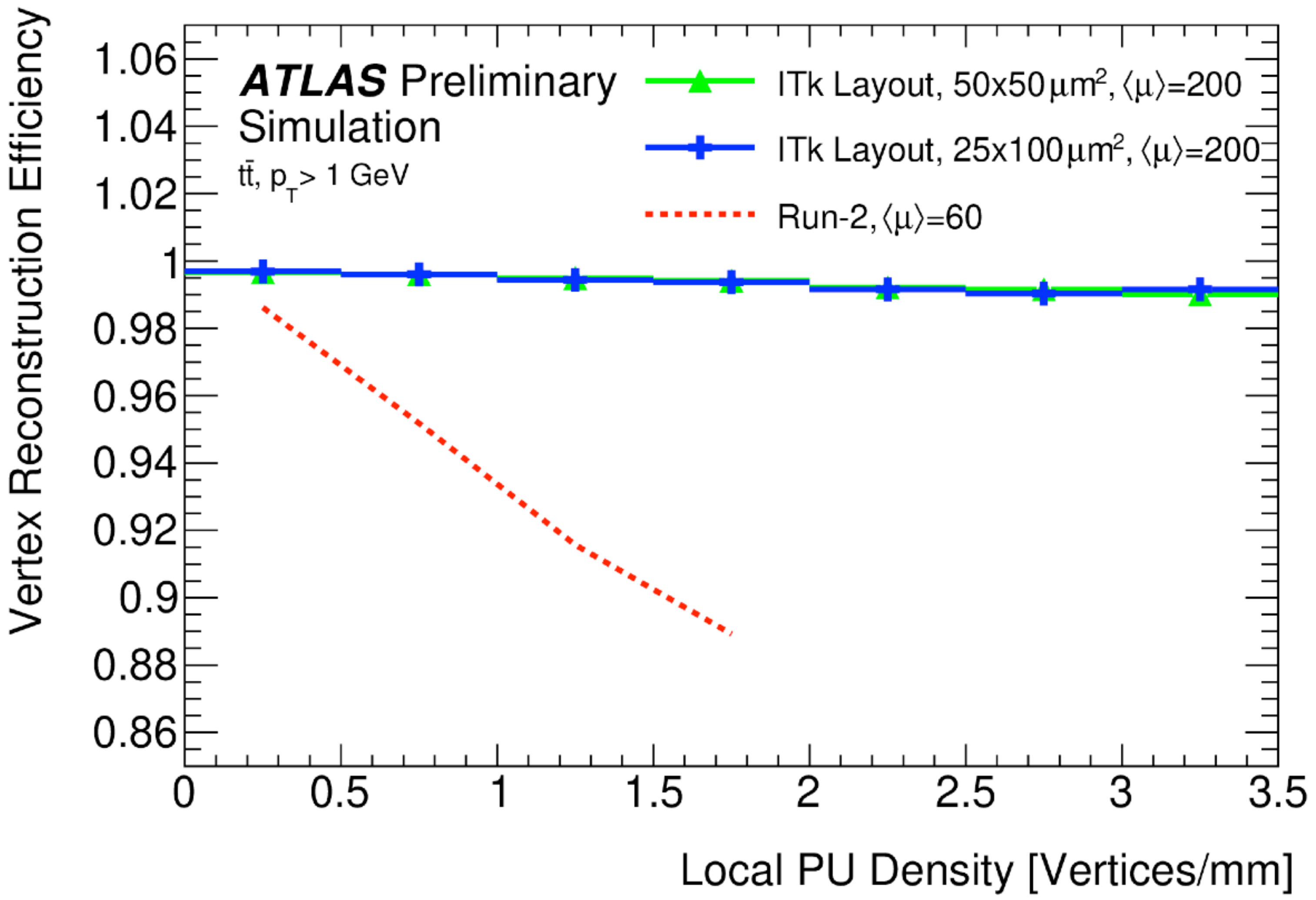
Ring Types	Positions in z [mm]
Coupled Rings	263, 291, 322, 357, 396, 437, 486, 543, 604, 675, 749, 835, 925, 1026, 1142
R0.5 Rings	1103, 1229, 1359, 1503, 1665, 1846
R1 Rings	1272, 1403, 1553, 1721, 1909, 2120, 2357, 2621

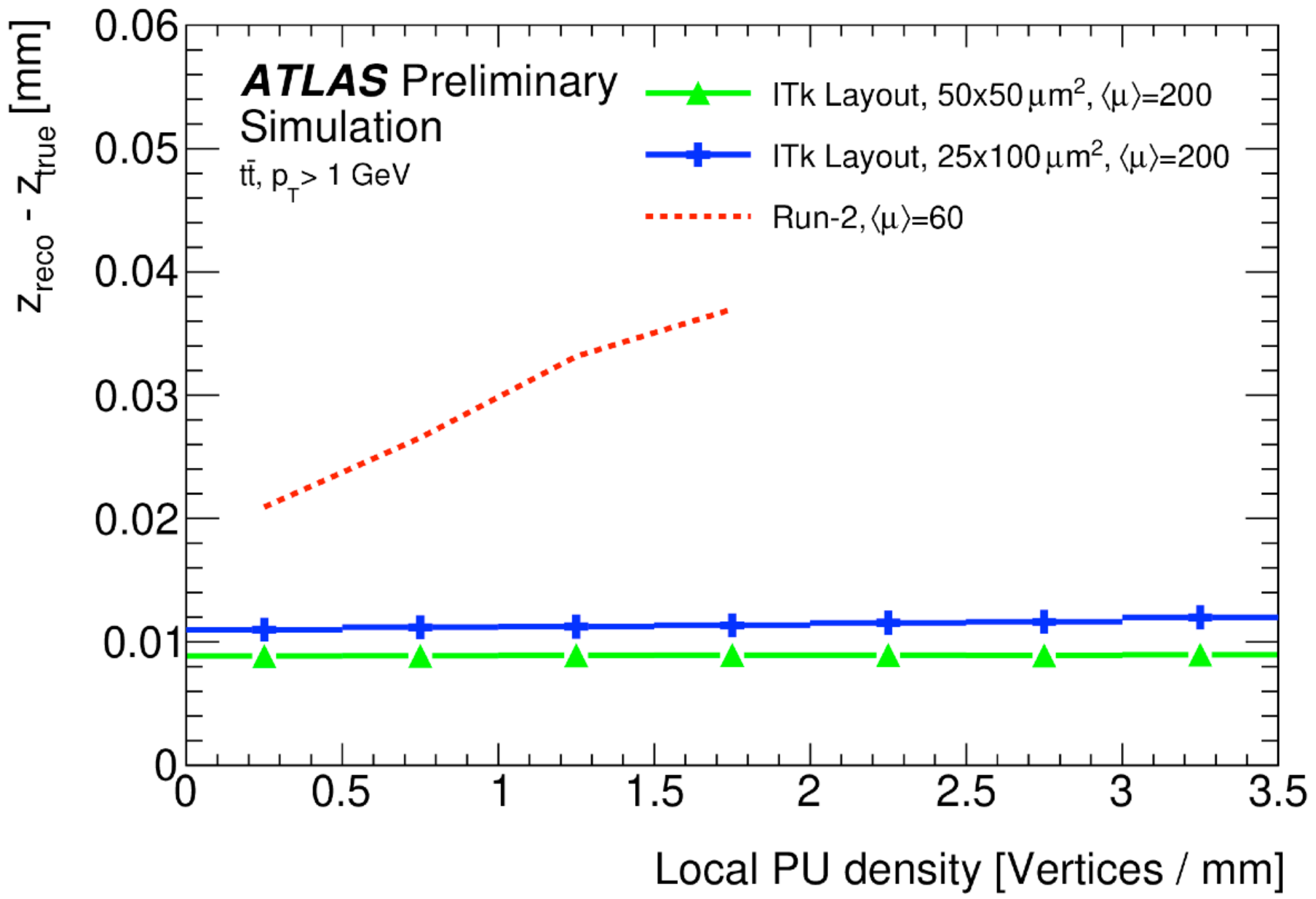
Link to plots

Pixel end-cap region

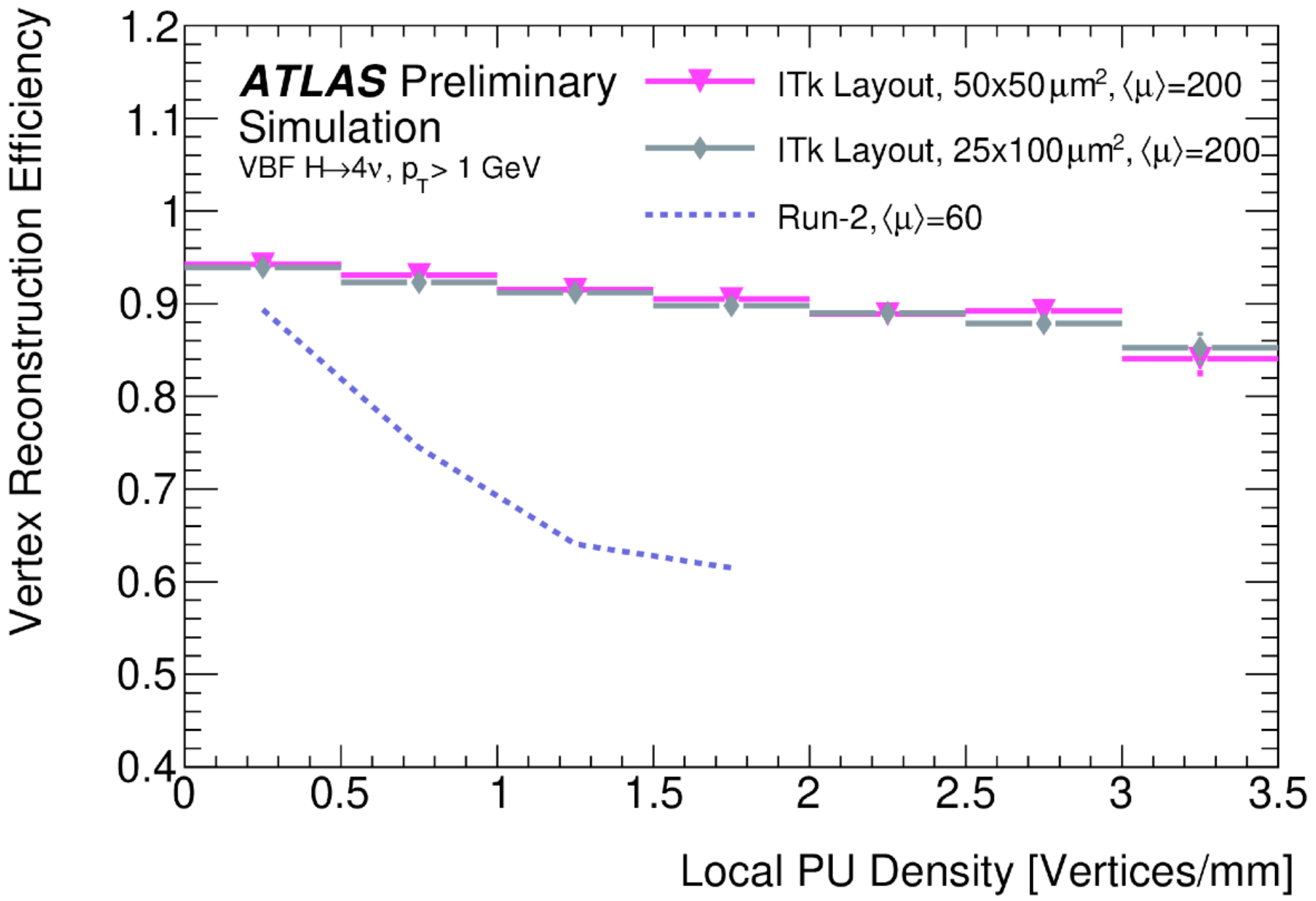
Ring Endcap	Positions in z [mm]	Split between half rings [mm]
R2	1145.5, 1249, 1365, 1492, 1633, 1789, 1961, 2151, 2361, 2593, 2850	11
R3	1145.5, 1297, 1473, 1676, 1910, 2180, 2491, 2850	11
R4	1145.5, 1277, 1427, 1597, 1789, 2007, 2253, 2533, 2850	11

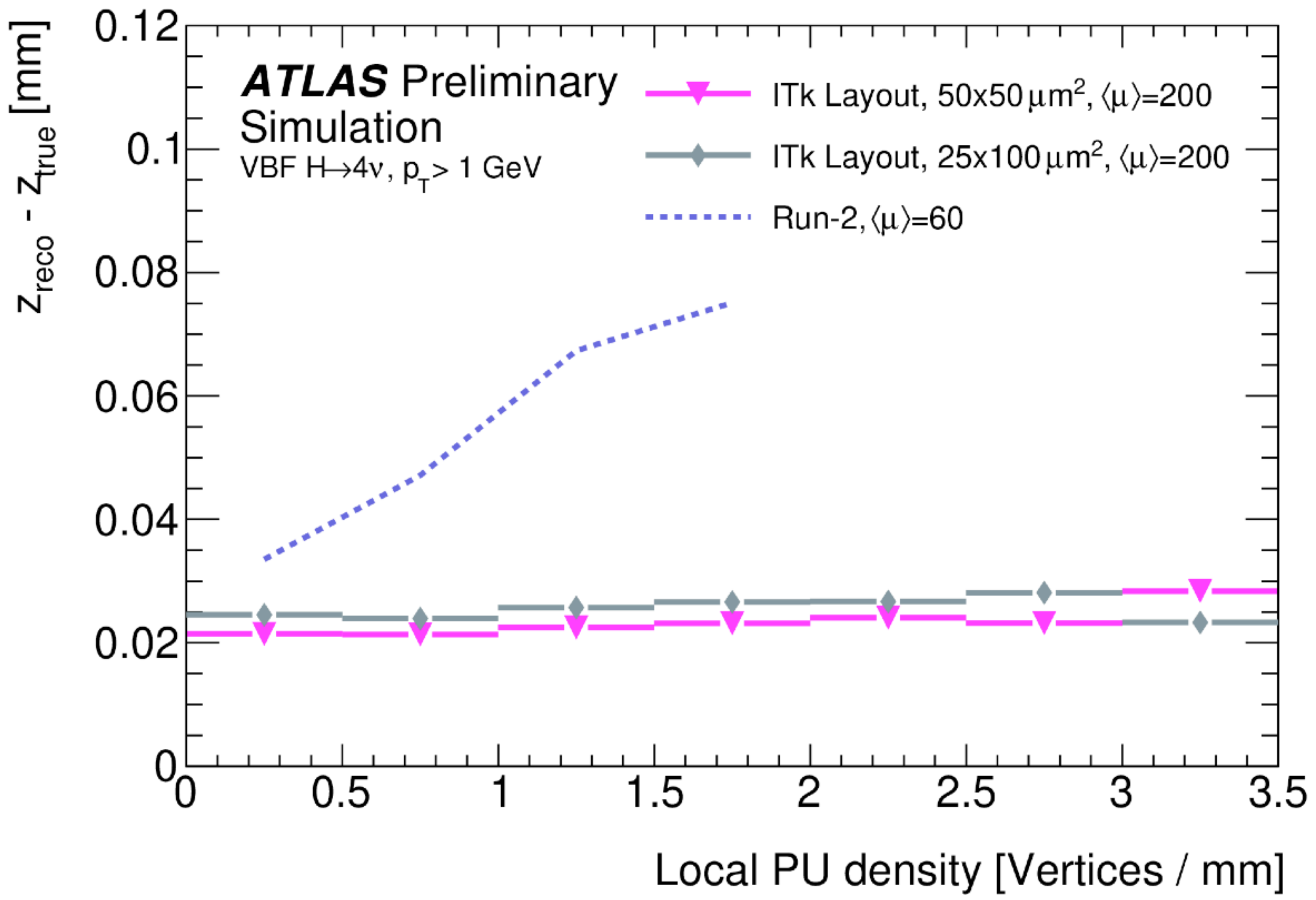
ITk expected performance





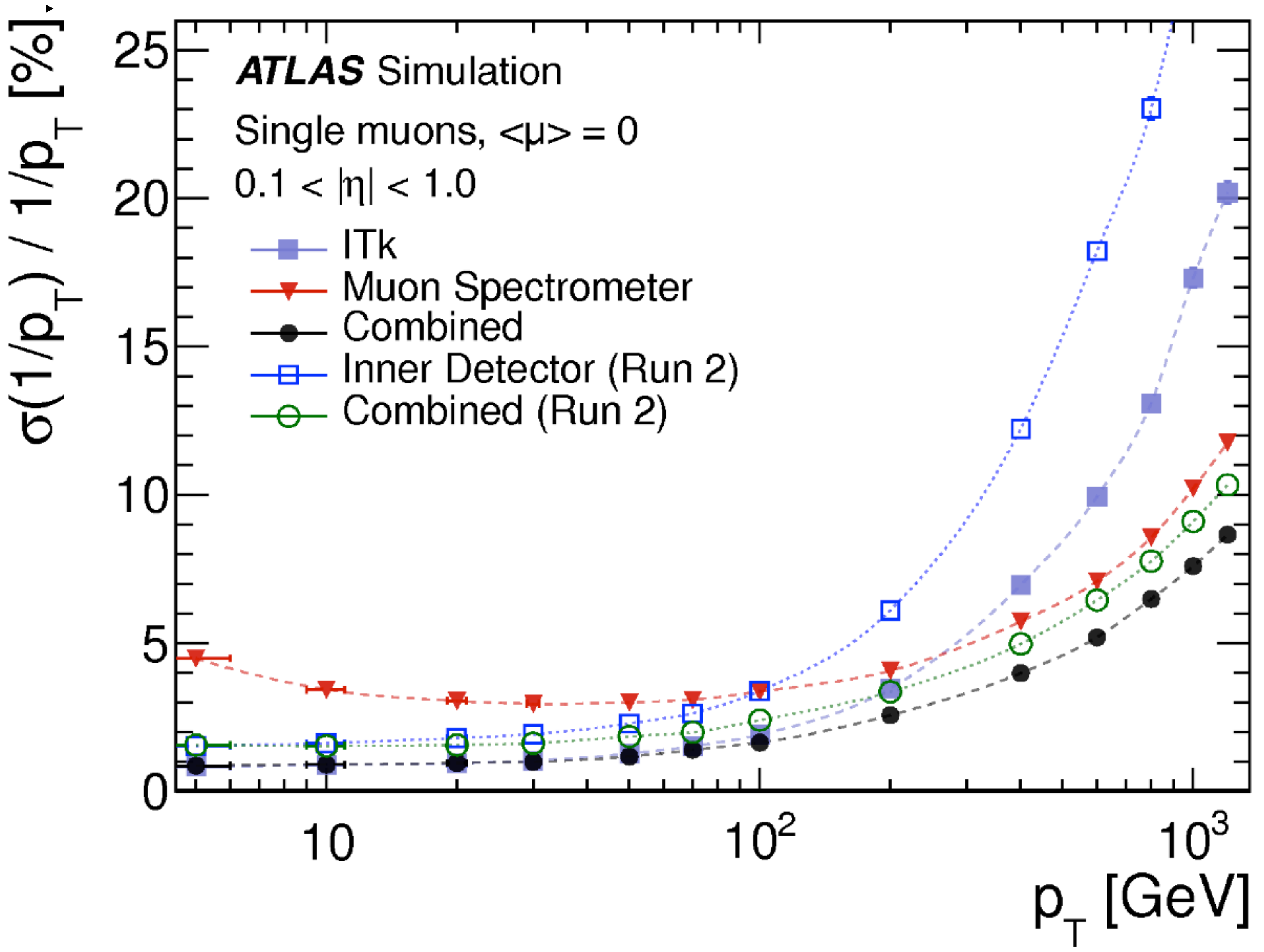
- [“Expected Tracking Performance of the ATLAS Inner Tracker at the HL-LHC” ATL-PHYS-PUB-2019-014]

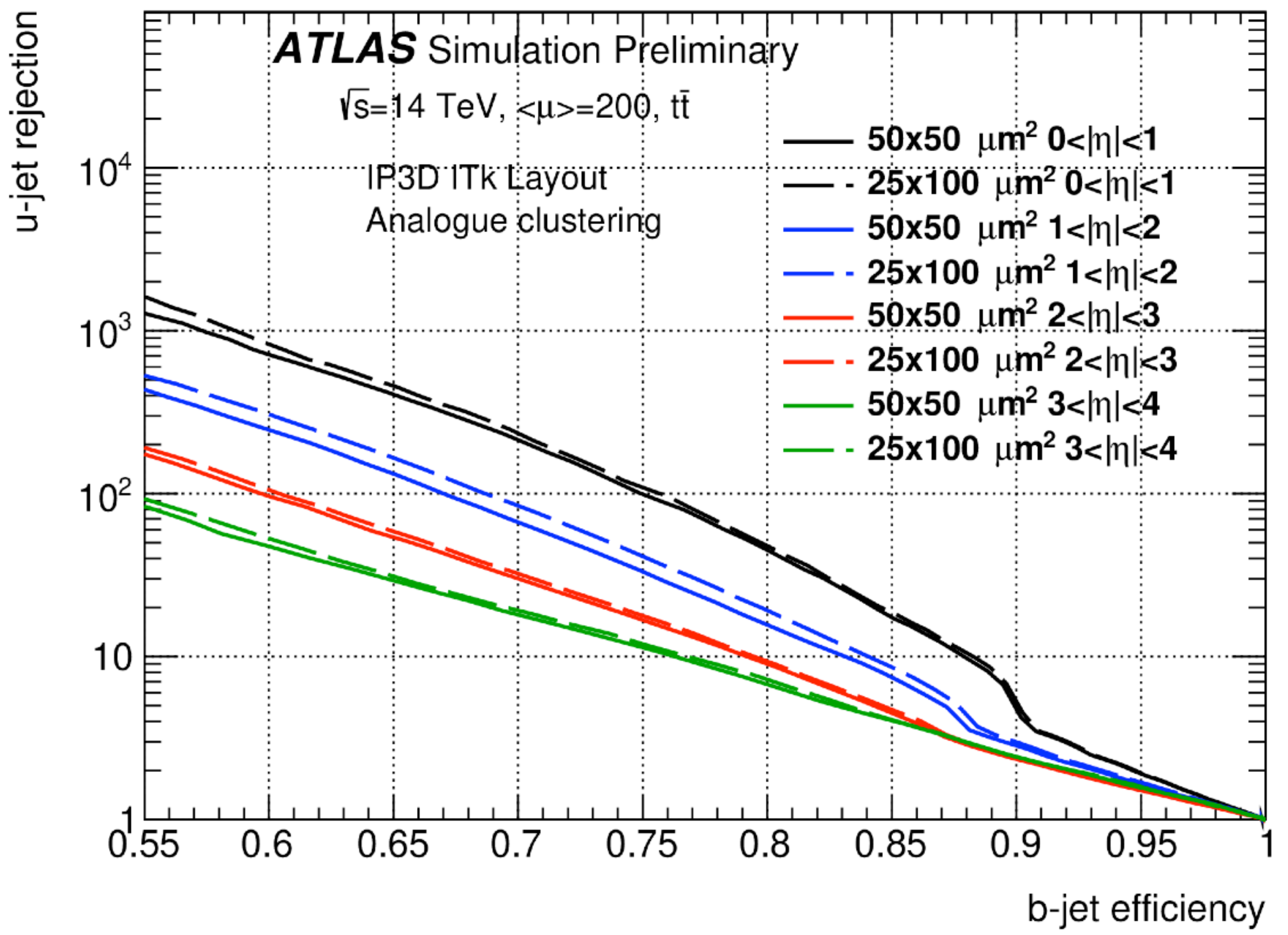


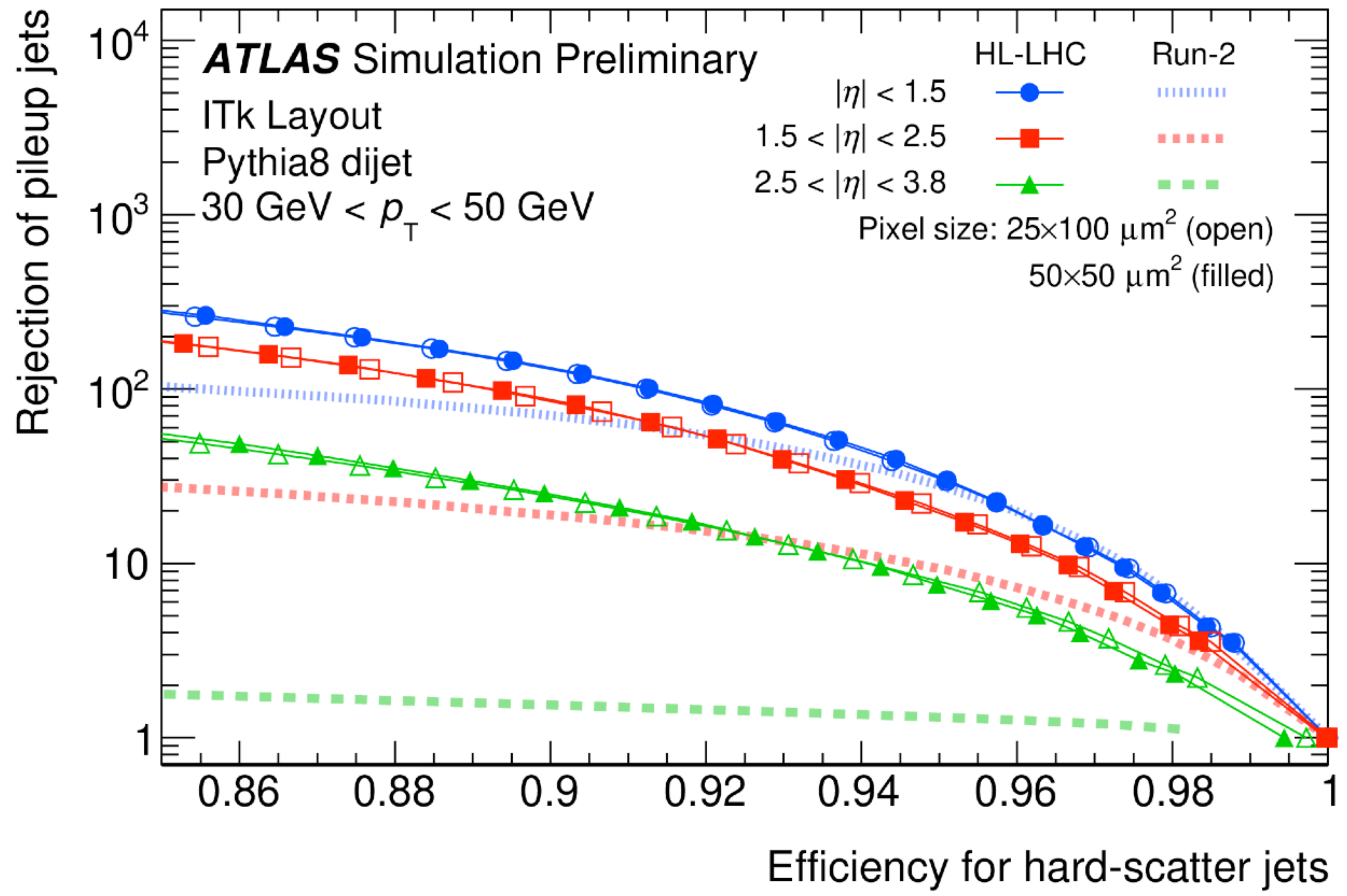


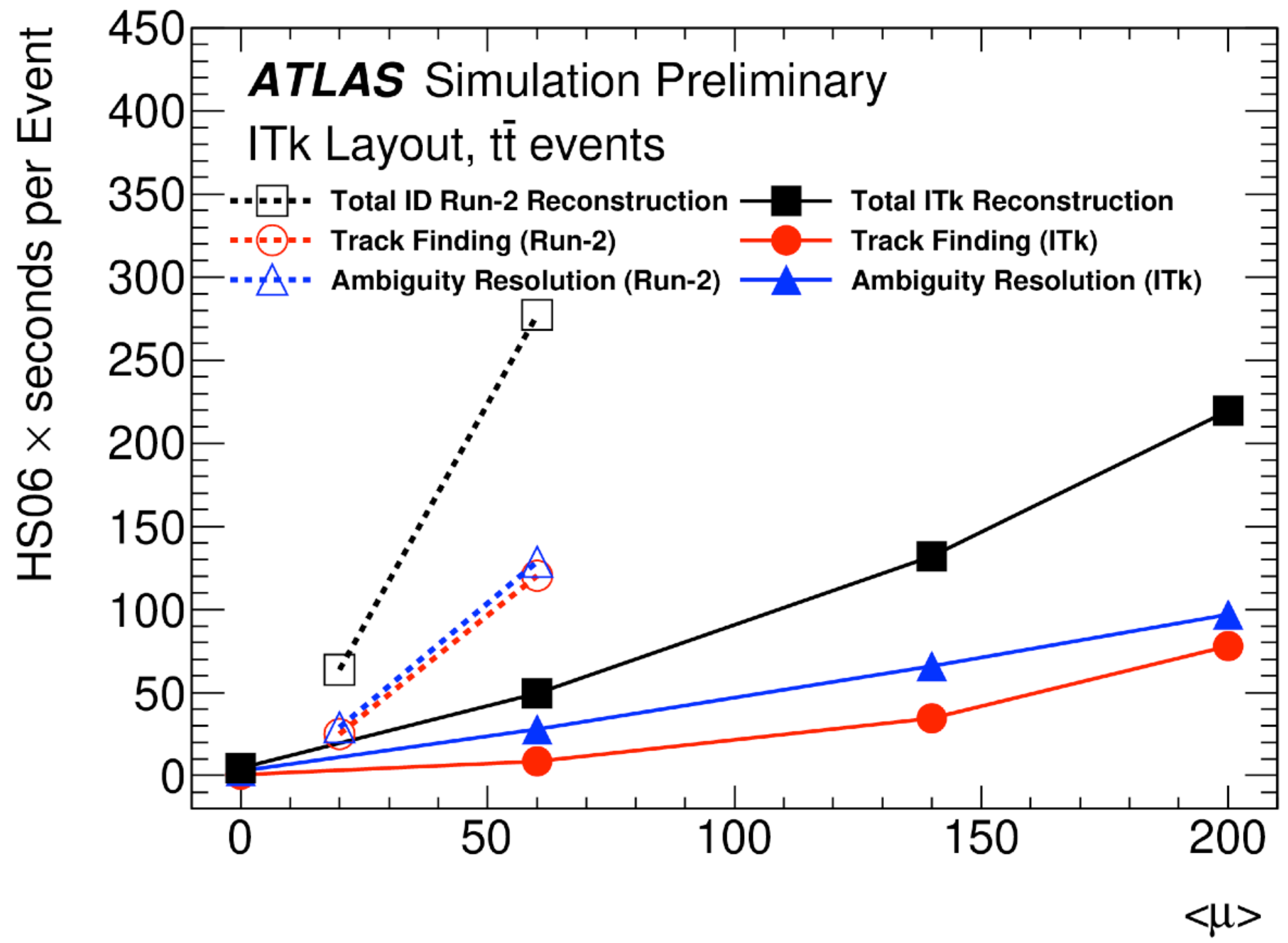
ITk expected performance

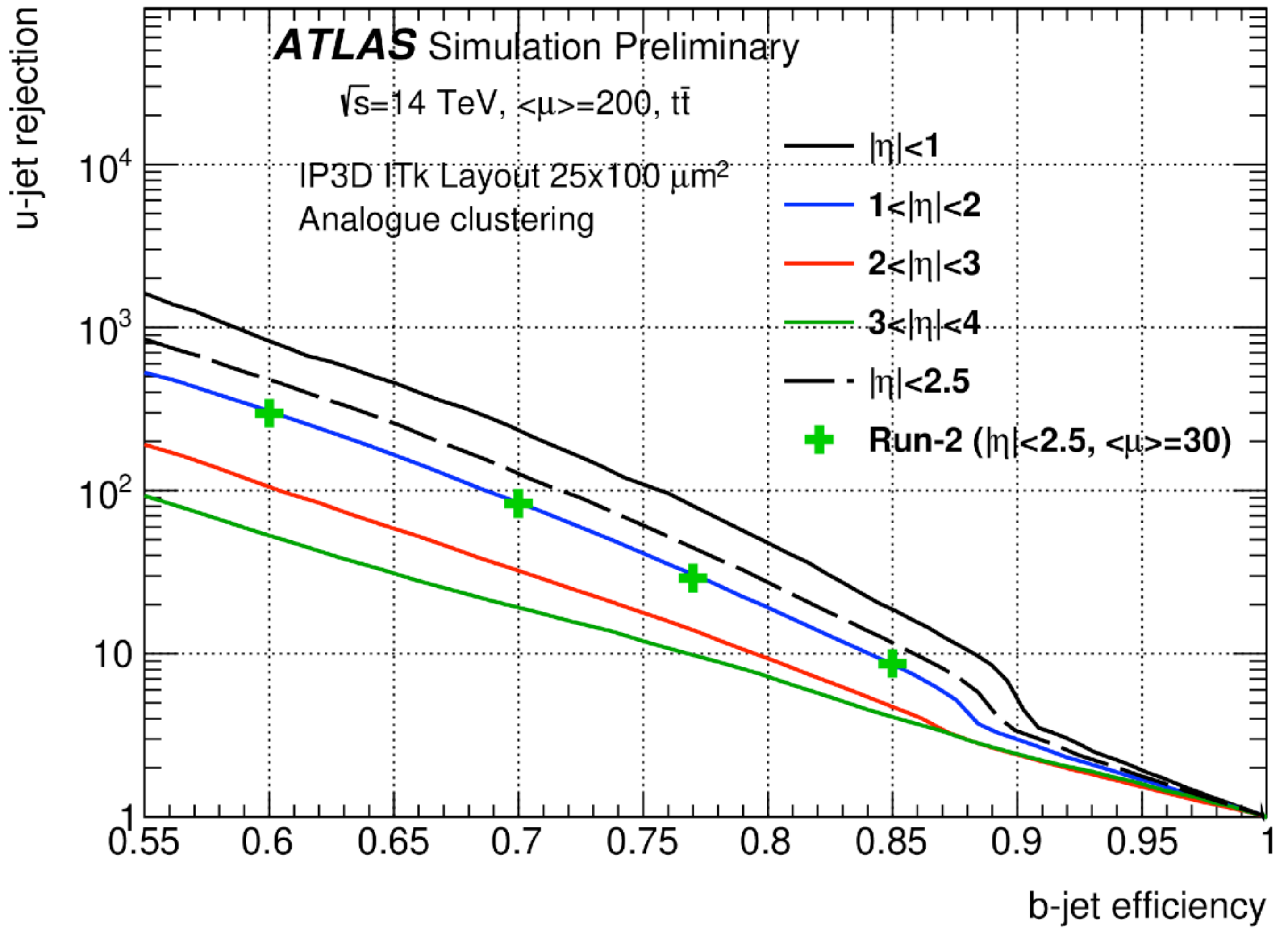
- "Expected Tracking Performance of the ATLAS Inner Tracker at the HL-LHC" ATL-PHYS-PUB-2019-014





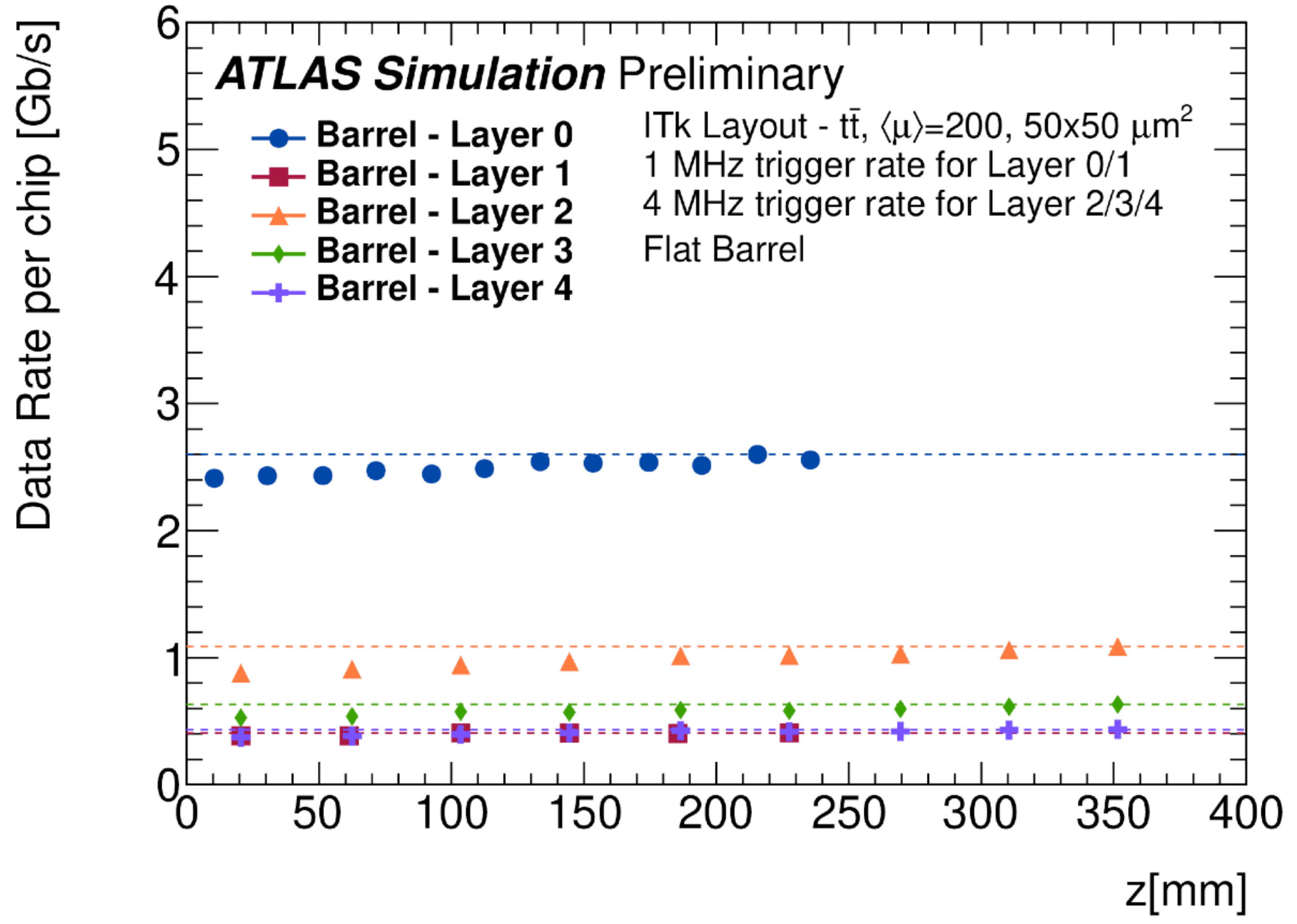


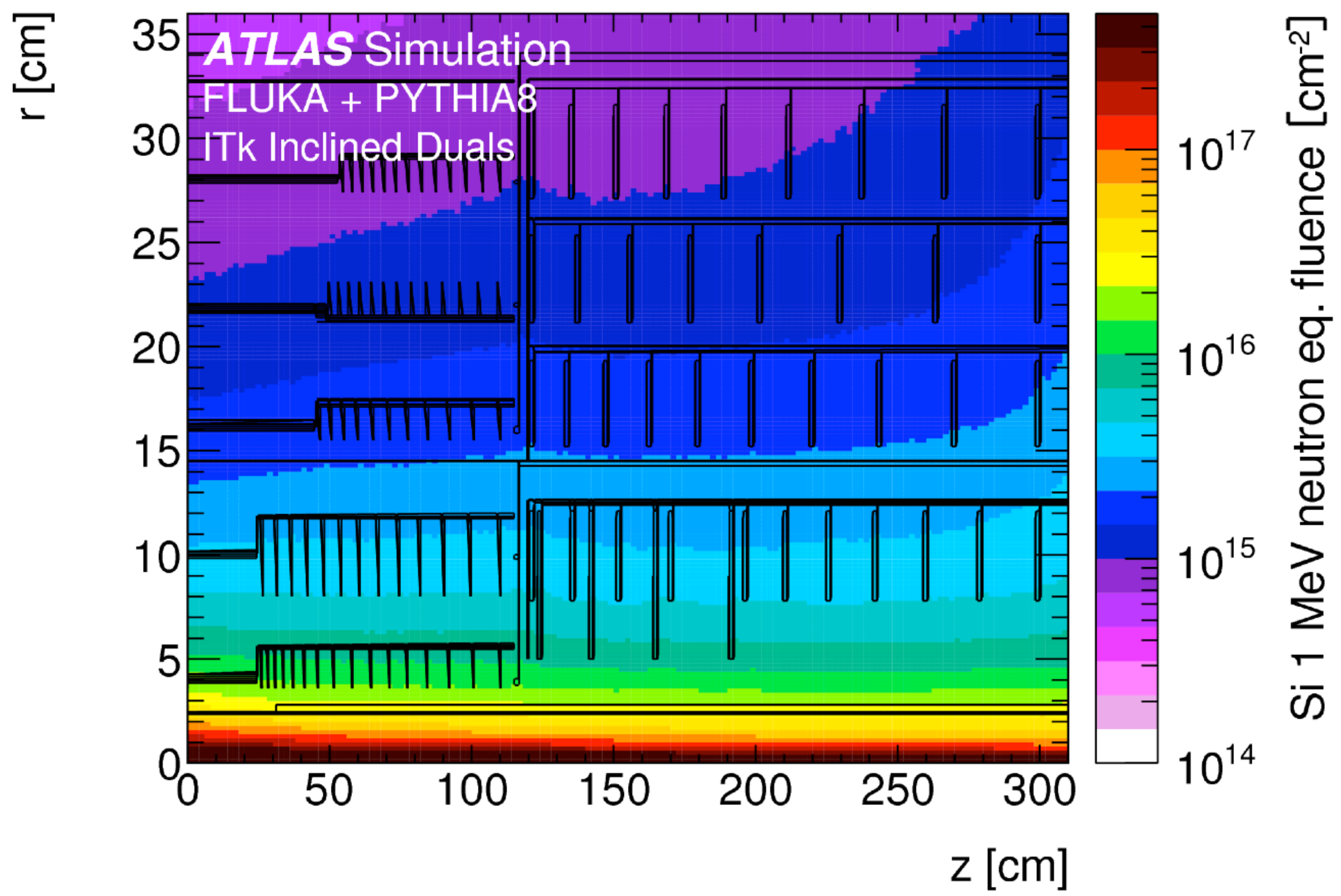


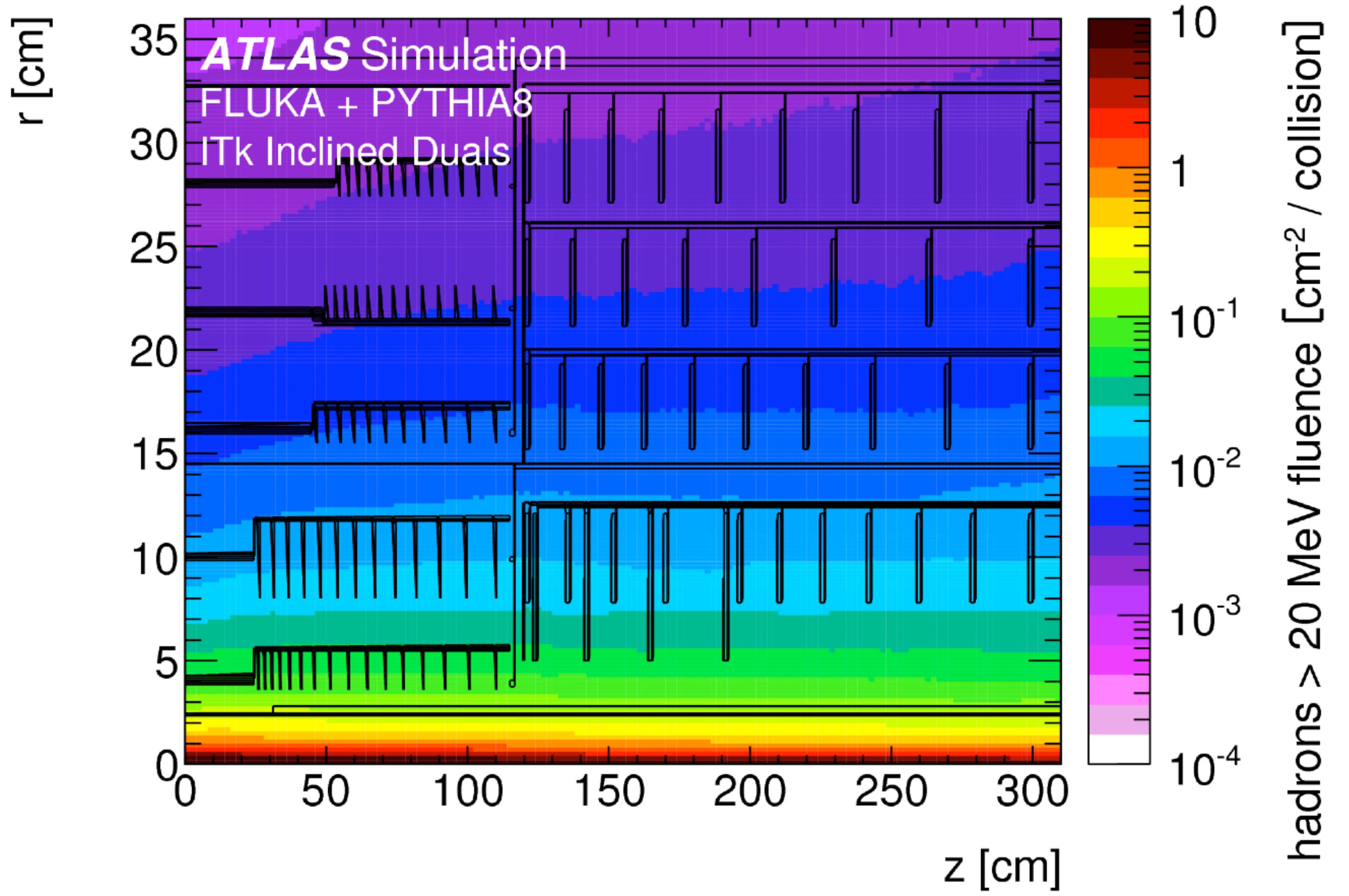


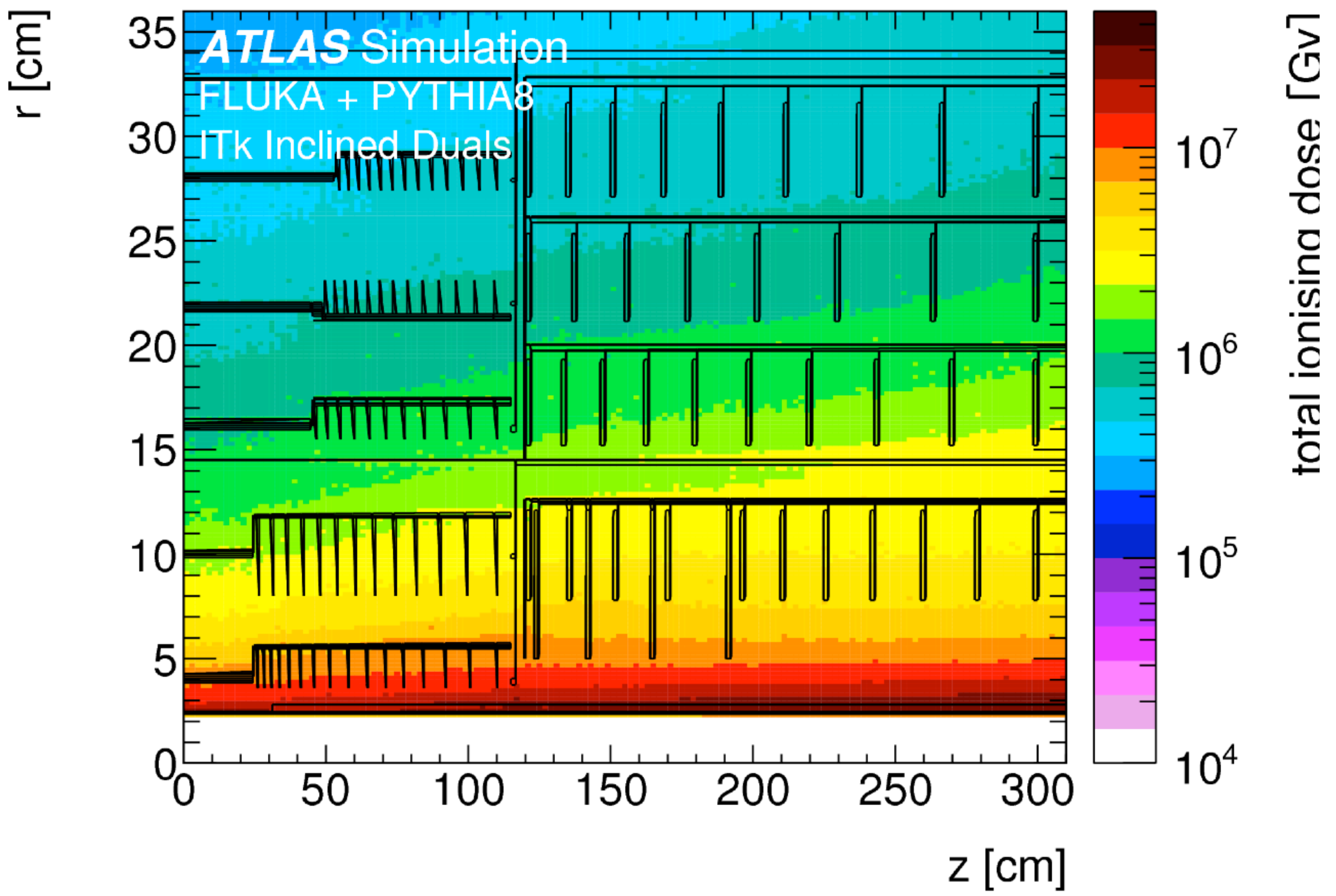
Radiation Levels in Pixel detector

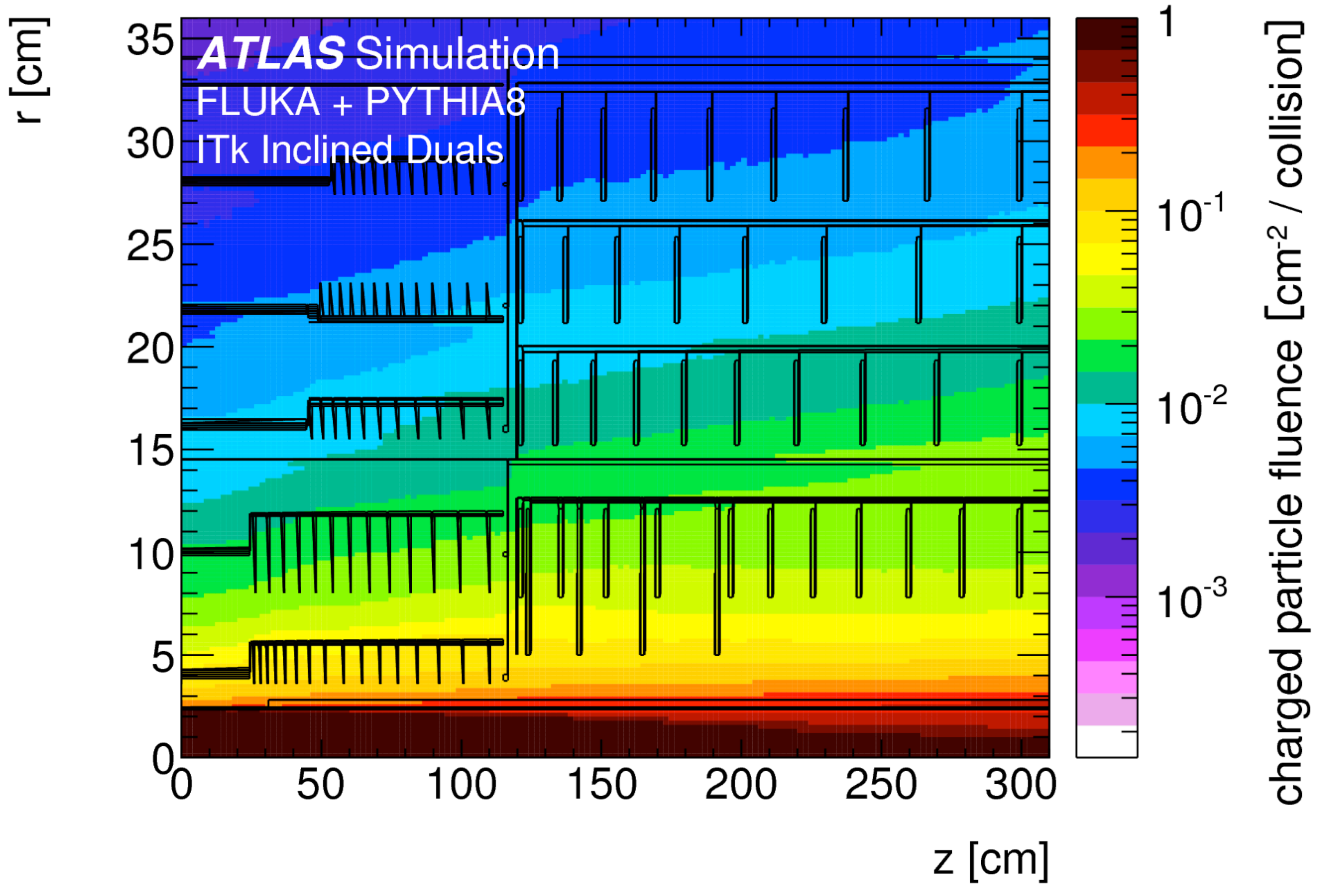
- ITk Pixel TDR







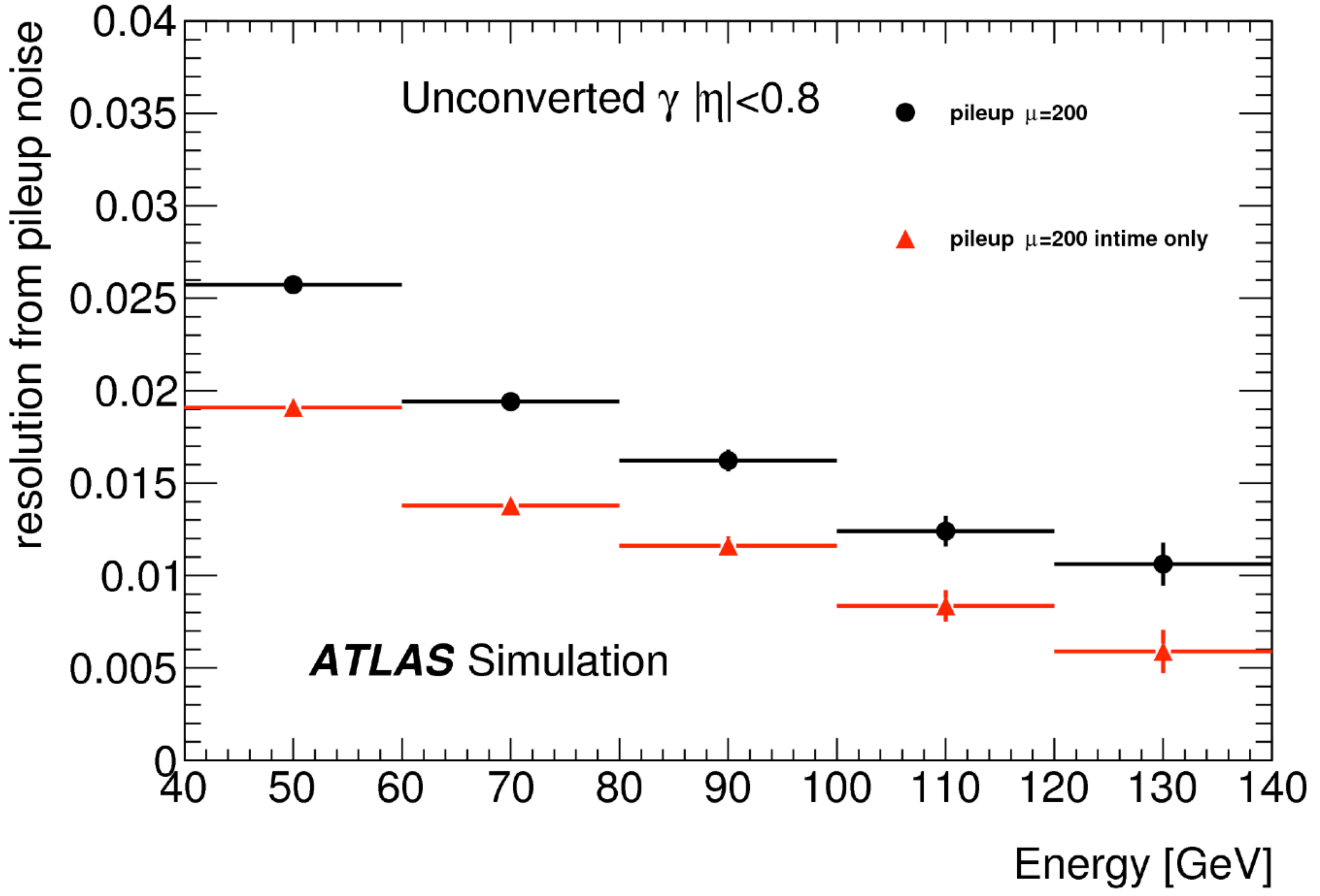


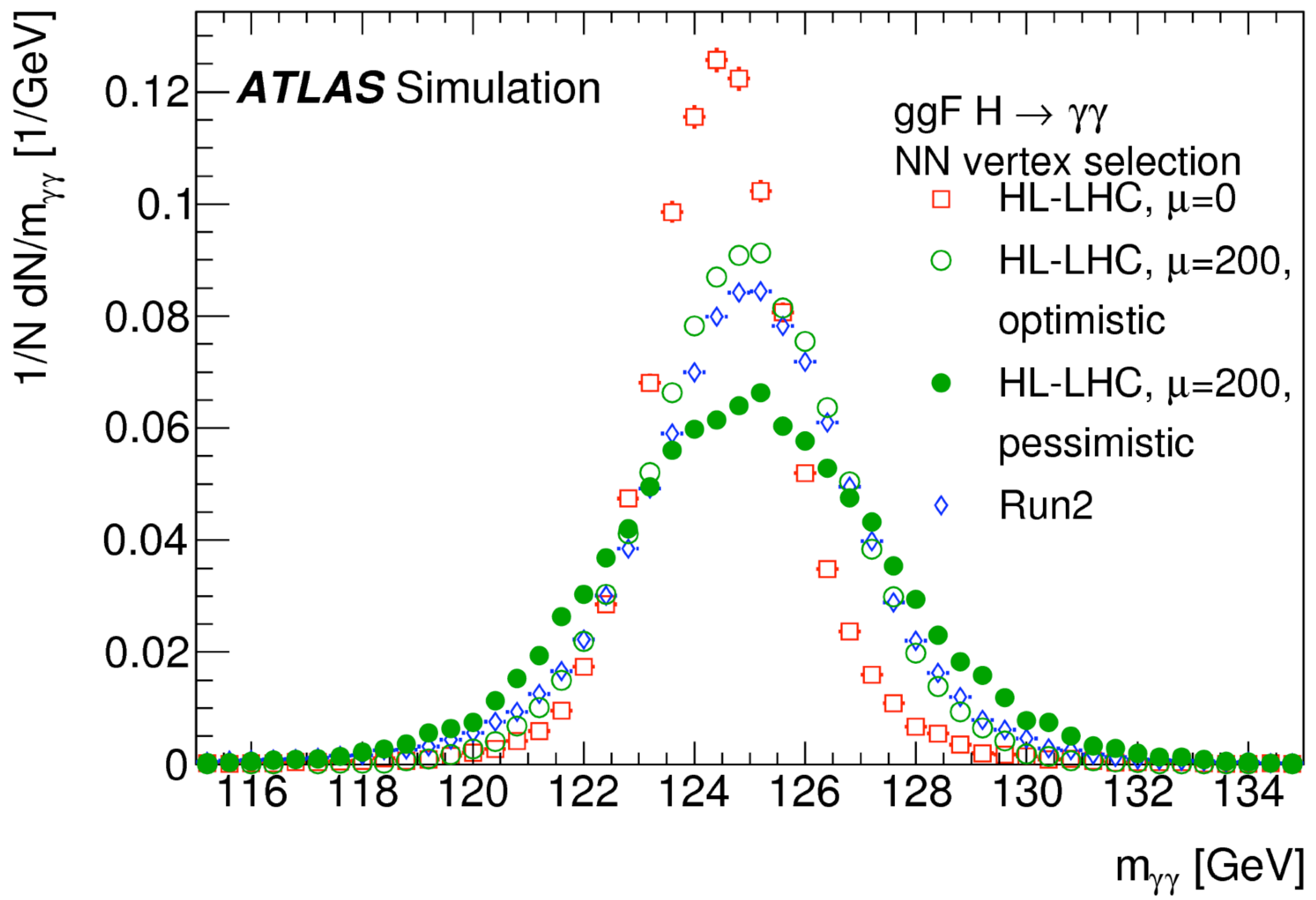


LAr Upgrade $m_{\gamma\gamma}$ resolution

- Expected photon mass resolution:
  - Due to higher pile-up noise, calorimeter energy noise term may degrade photon energy resolution.
  - Resolution degradation can be offset with:
    - Reduced energy global constant term with more precise (high stats) calibrations down to 0.7% design value (pessimistic scenario assumes same global constant term as in Run 2)
    - Smaller material budget in inner detector (true for ITk)
    - Use of improved ITk tracking resolution in converted photons

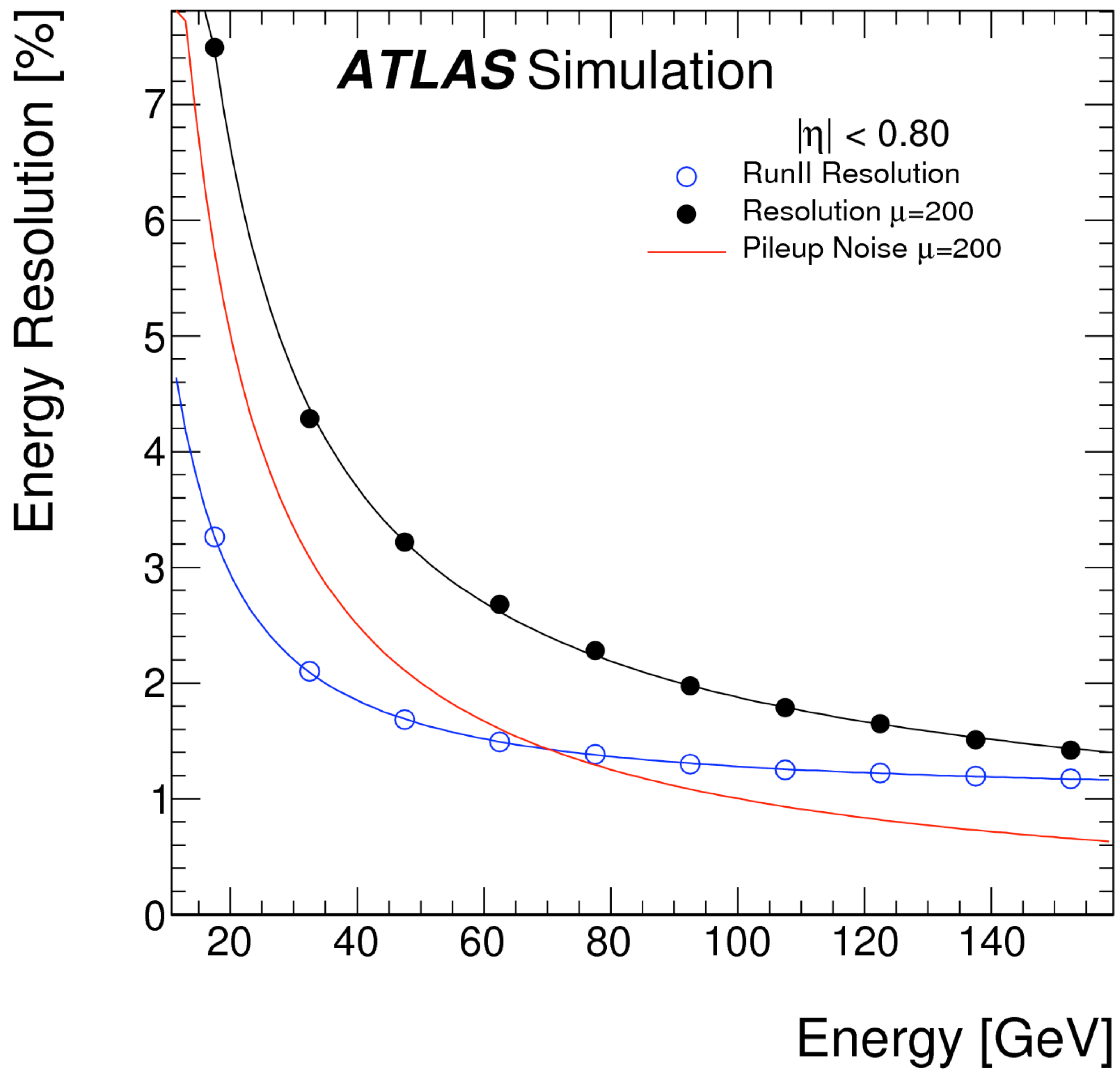
Phase II Upgrade LAr TDR





LAr Upgrade $m_{\gamma\gamma}$ resolution

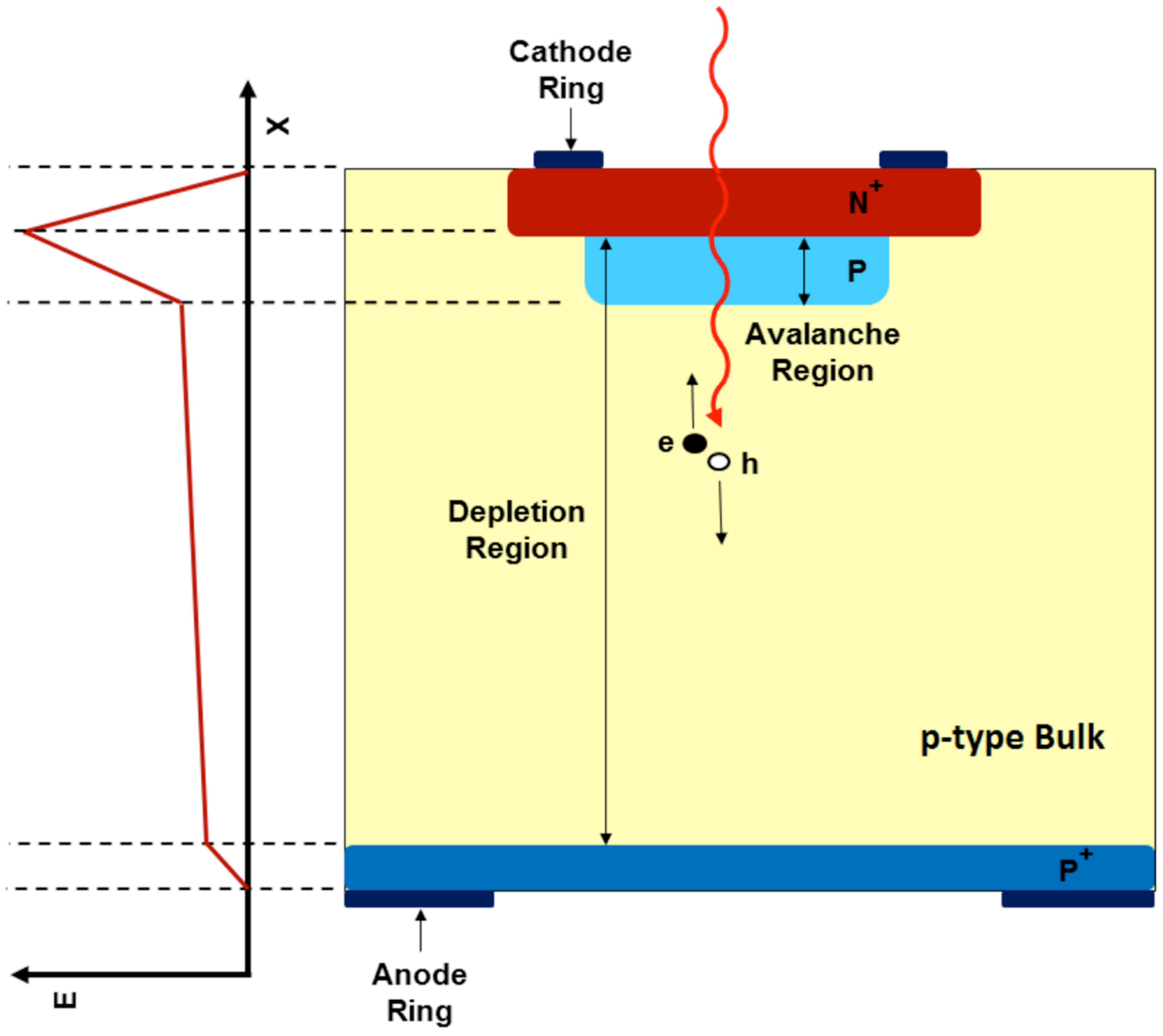
Phase II Upgrade LAr TDR

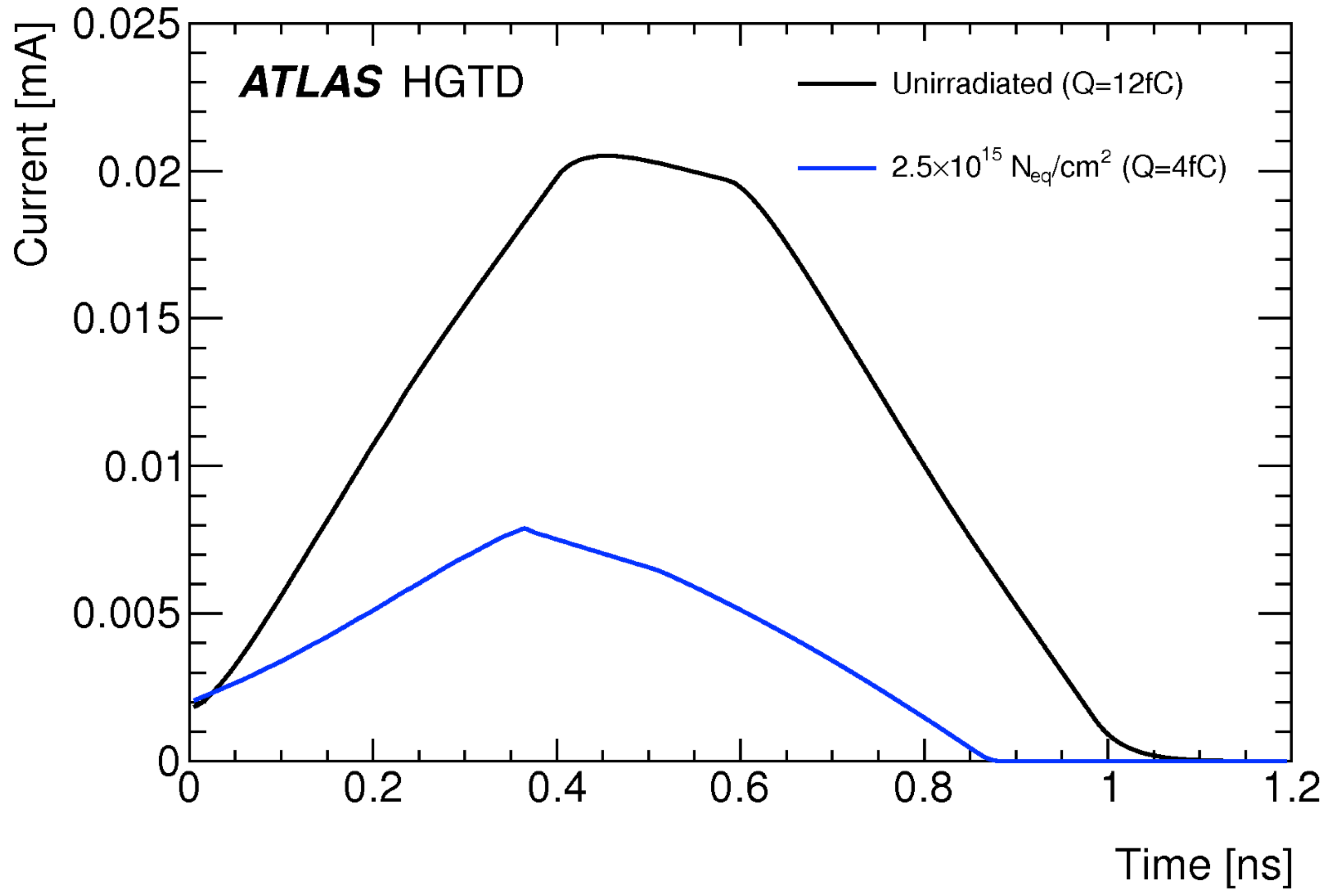


- Expected electron total energy resolution + pile-up contribution only.

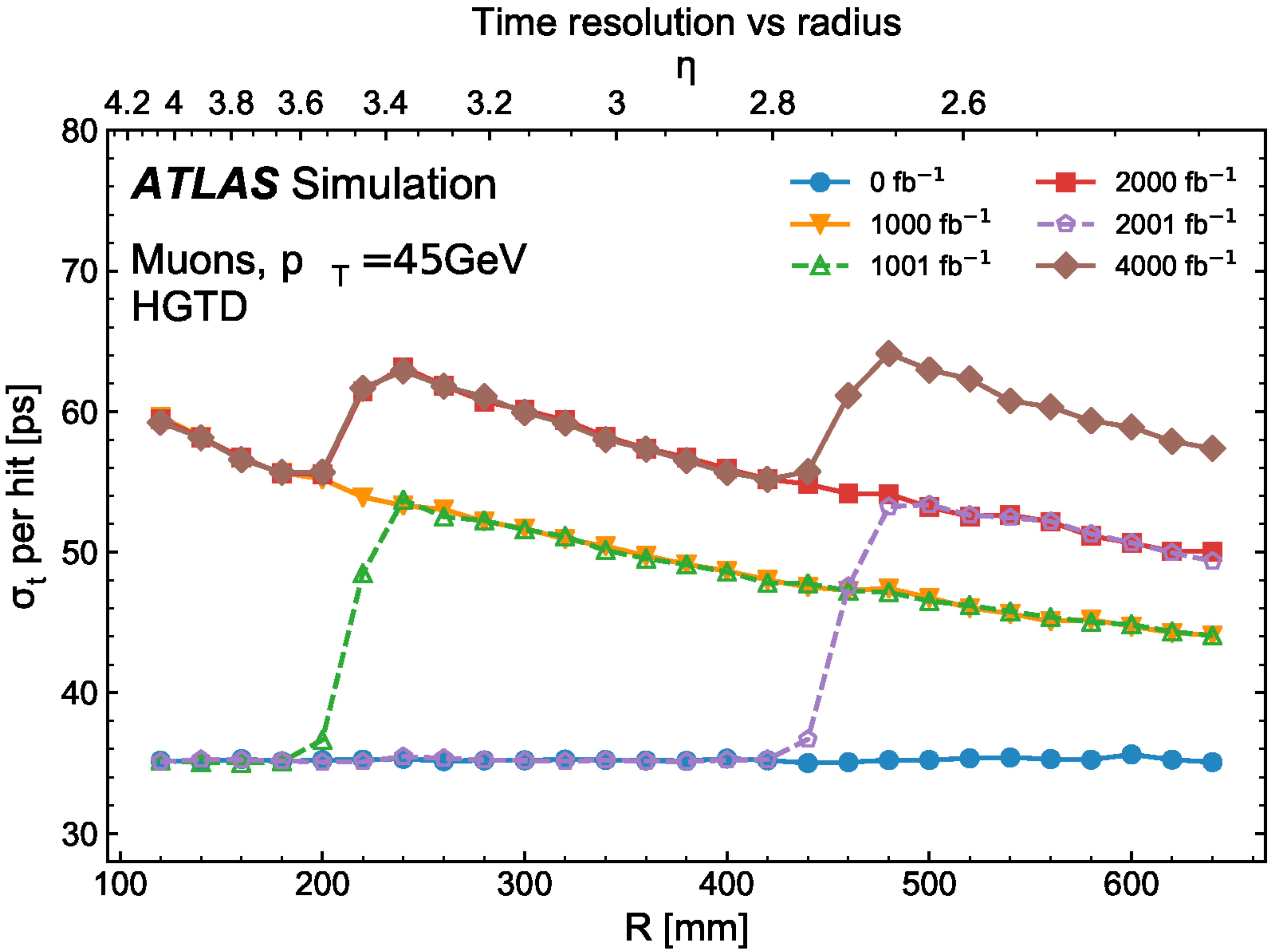
HGTD sensors

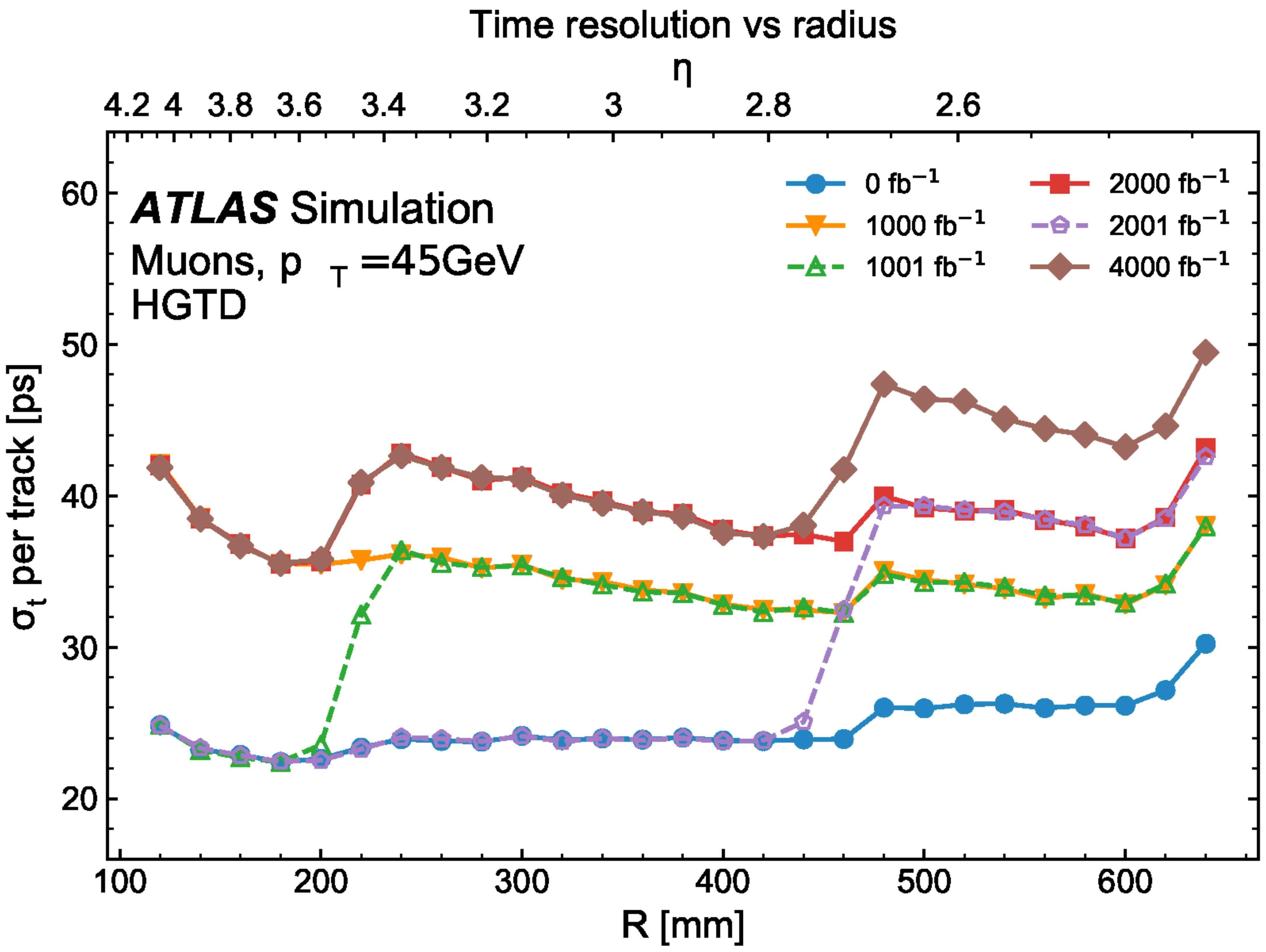
- Cross section of an LGAD + simulated signal current in LGADs at start and after full integrated neutron fluence.



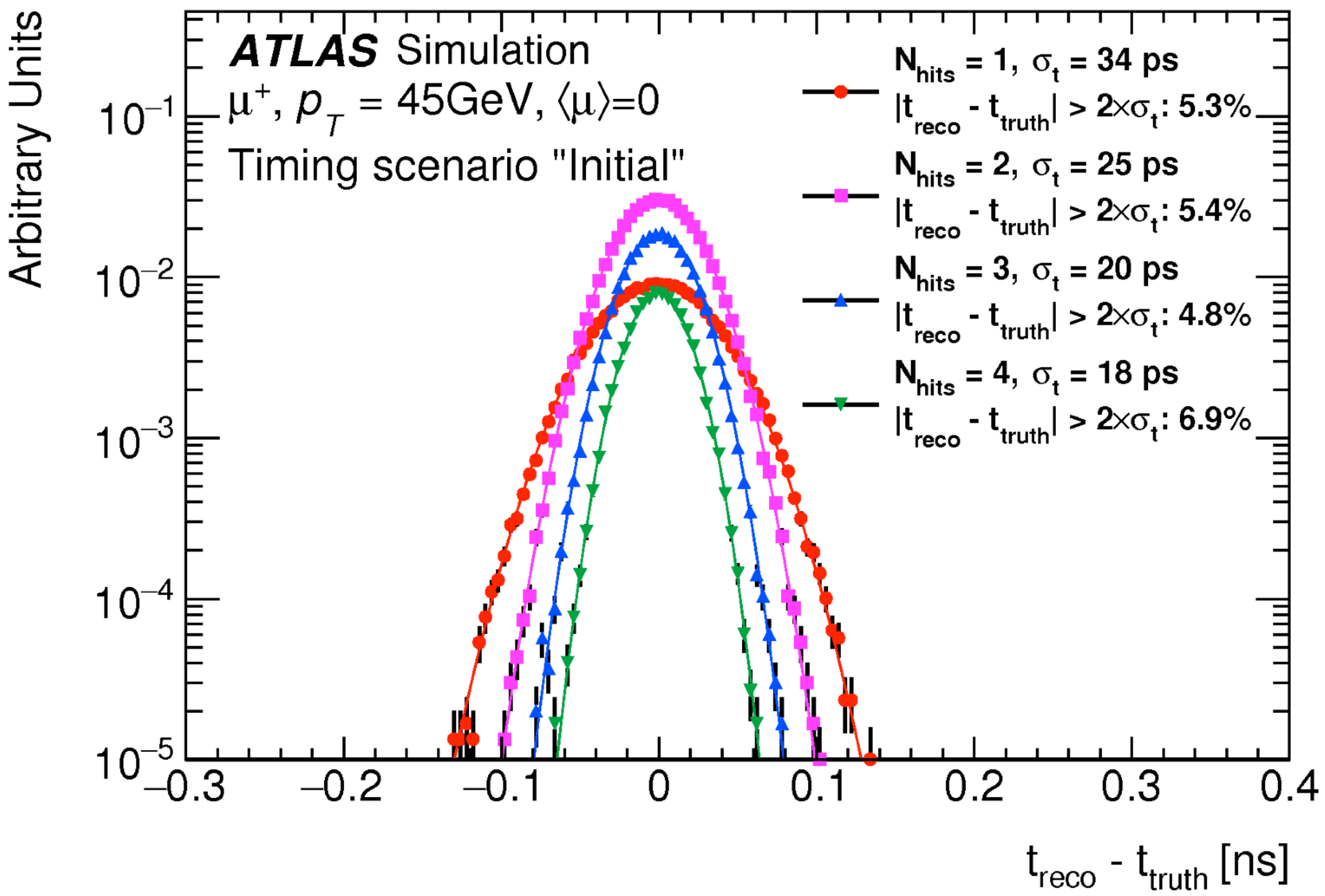


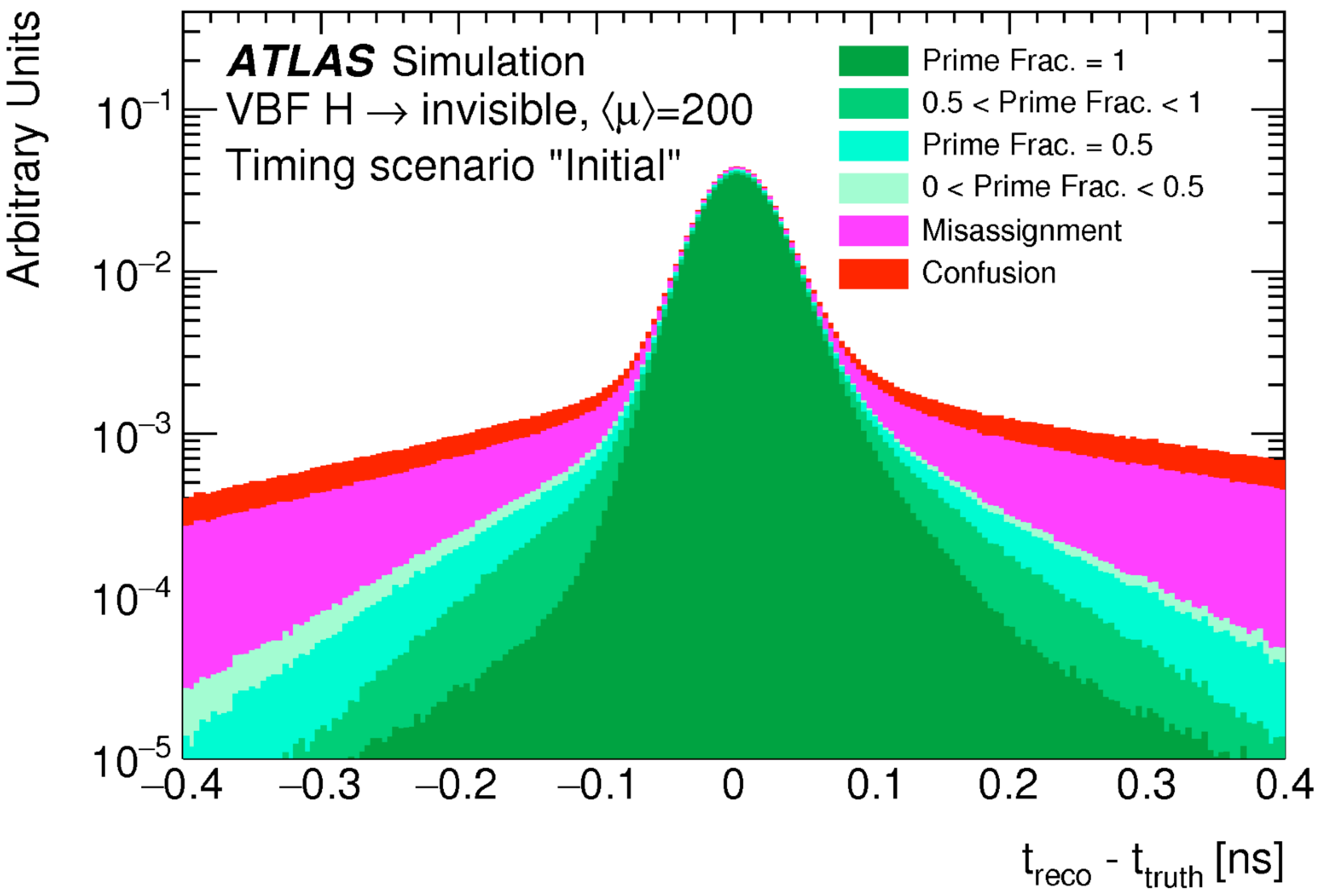
HGTD performance



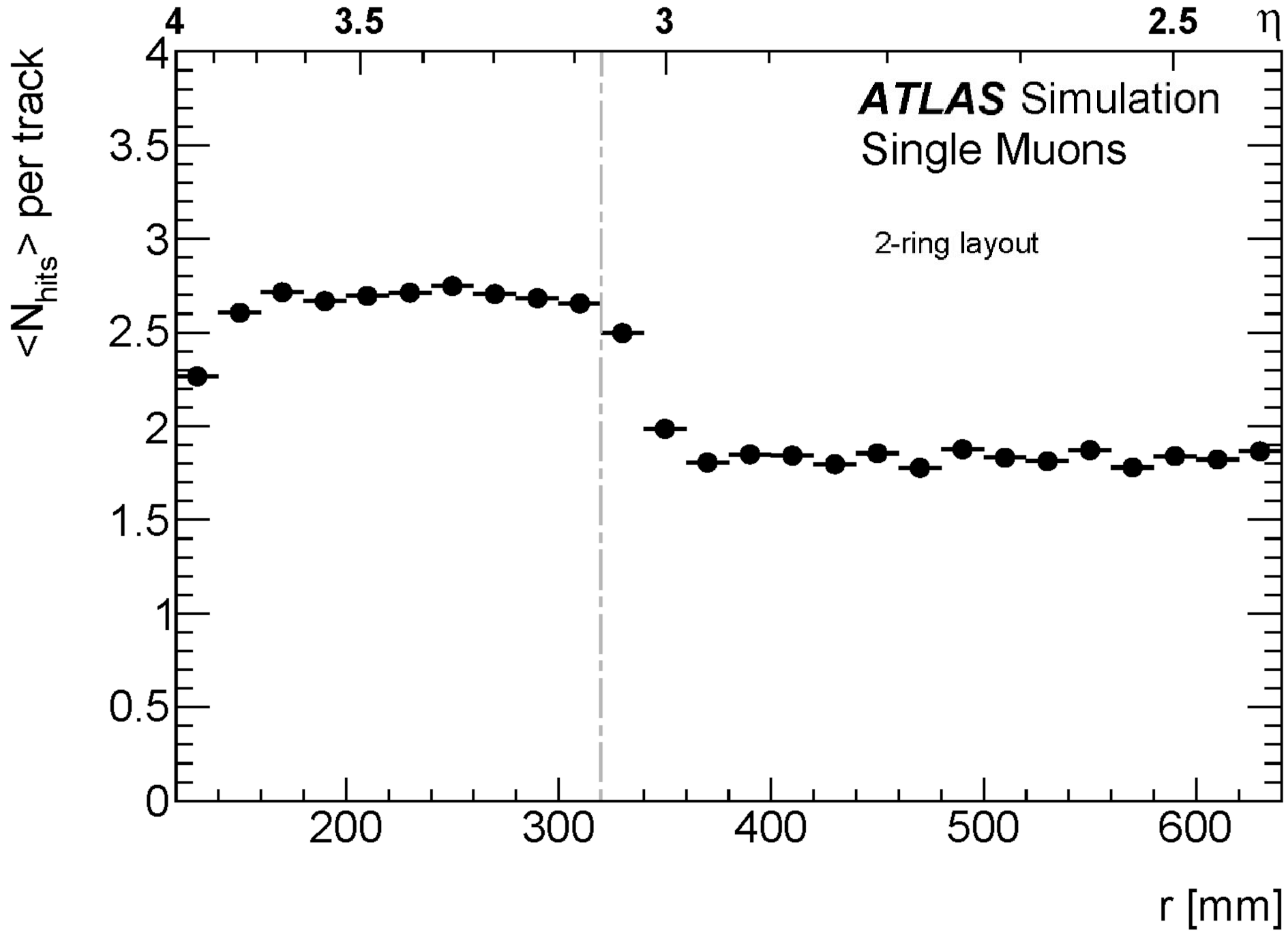


HGTD performance

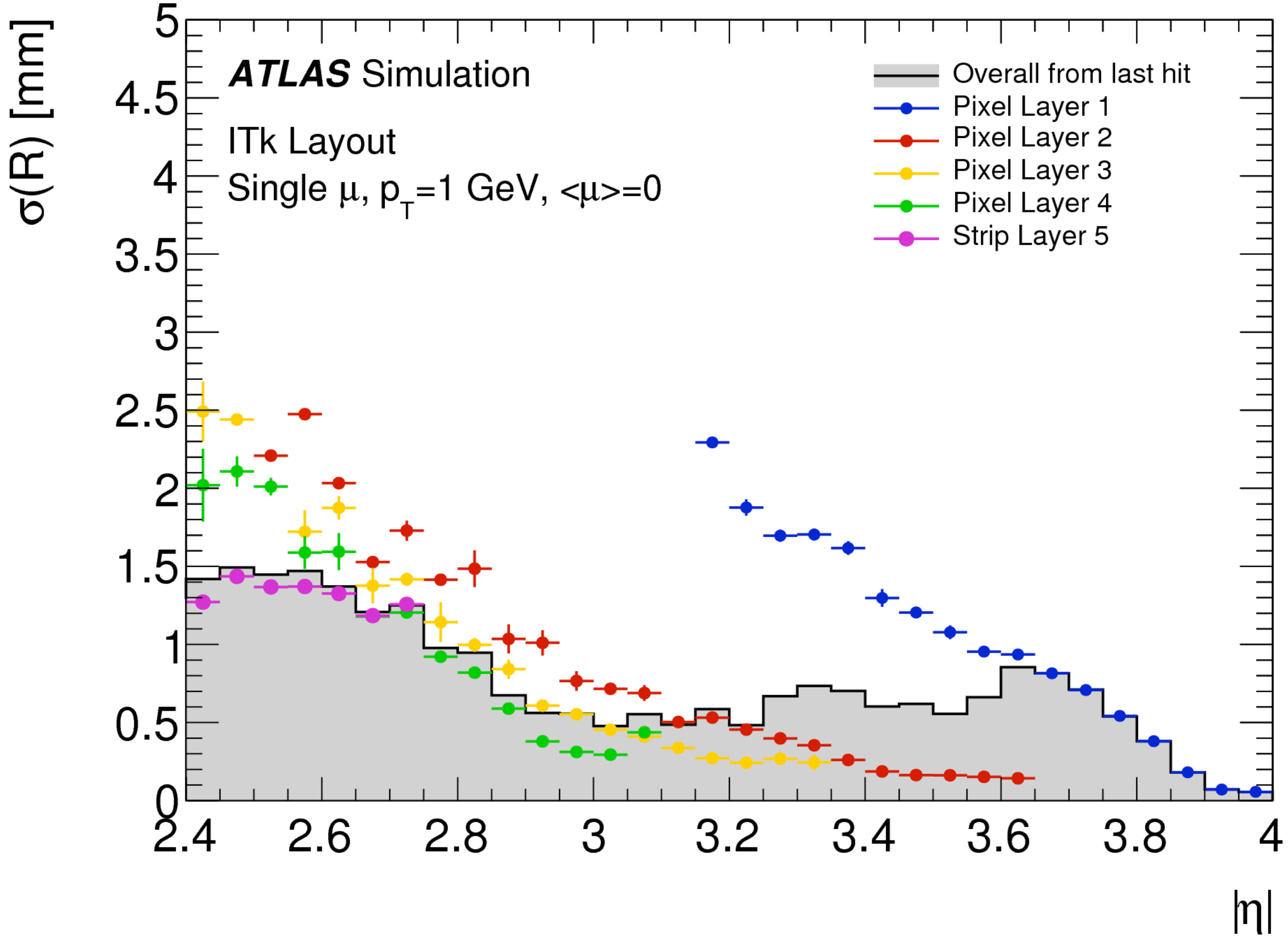


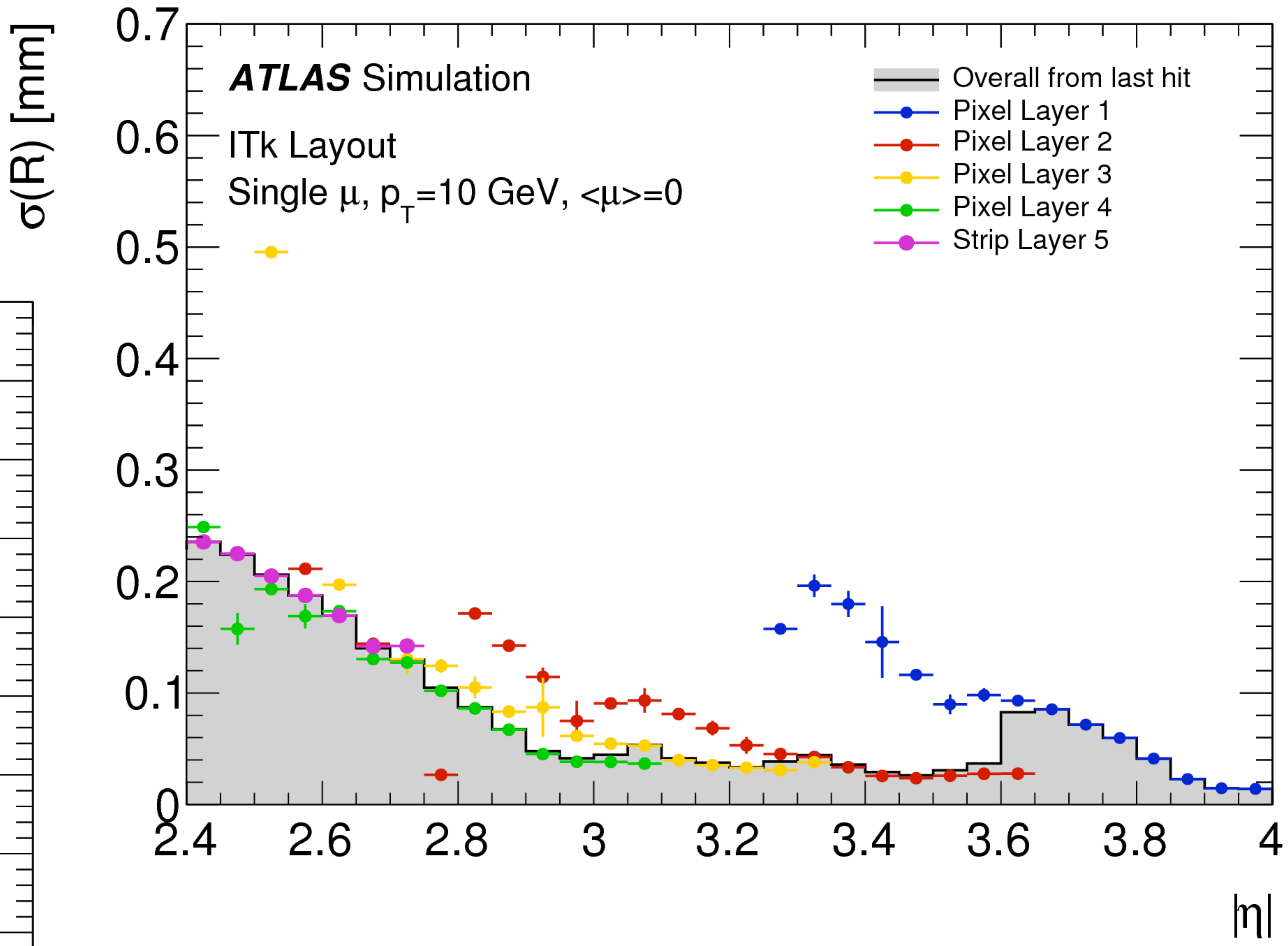


HGTD performance



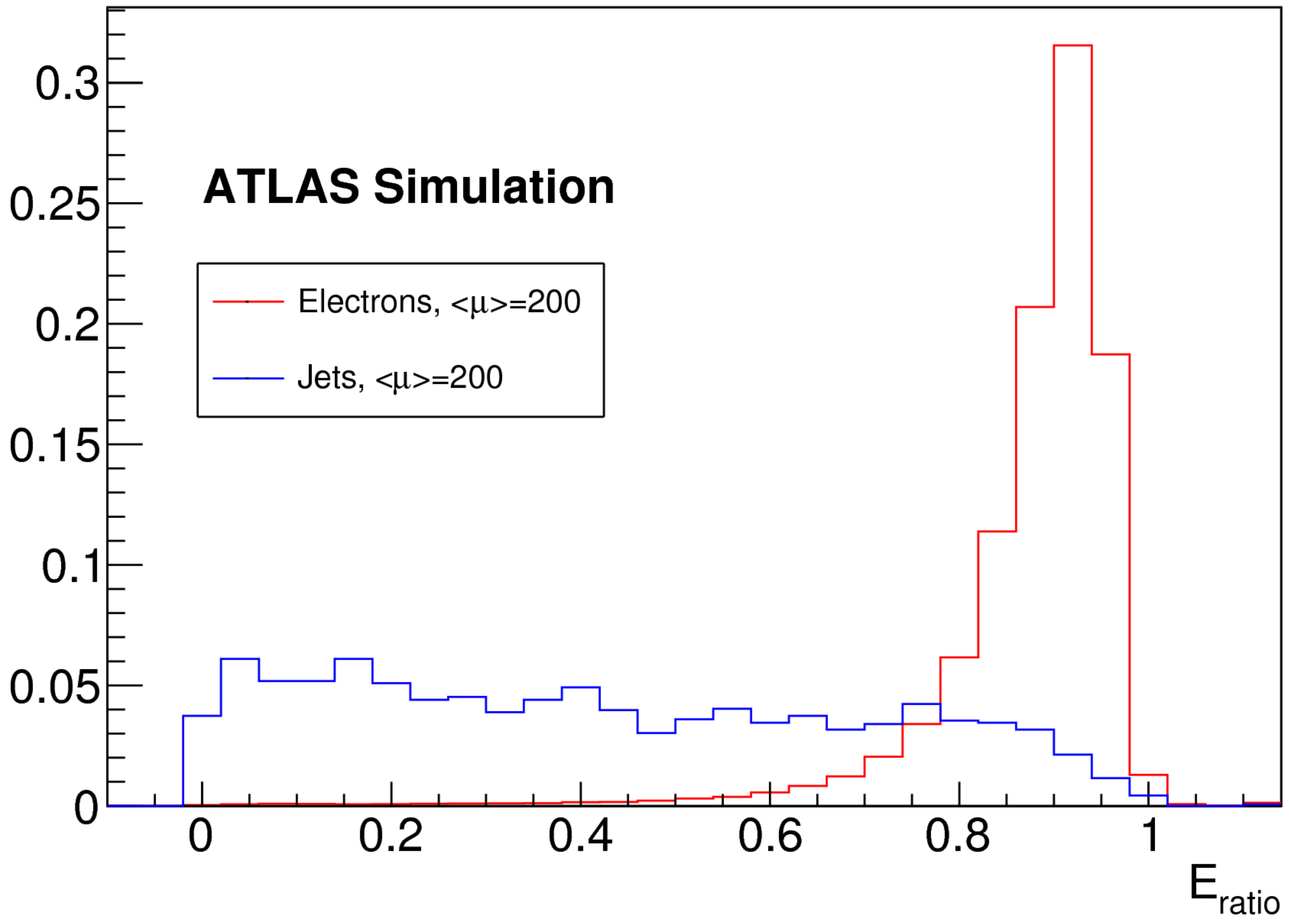
HGTD performance

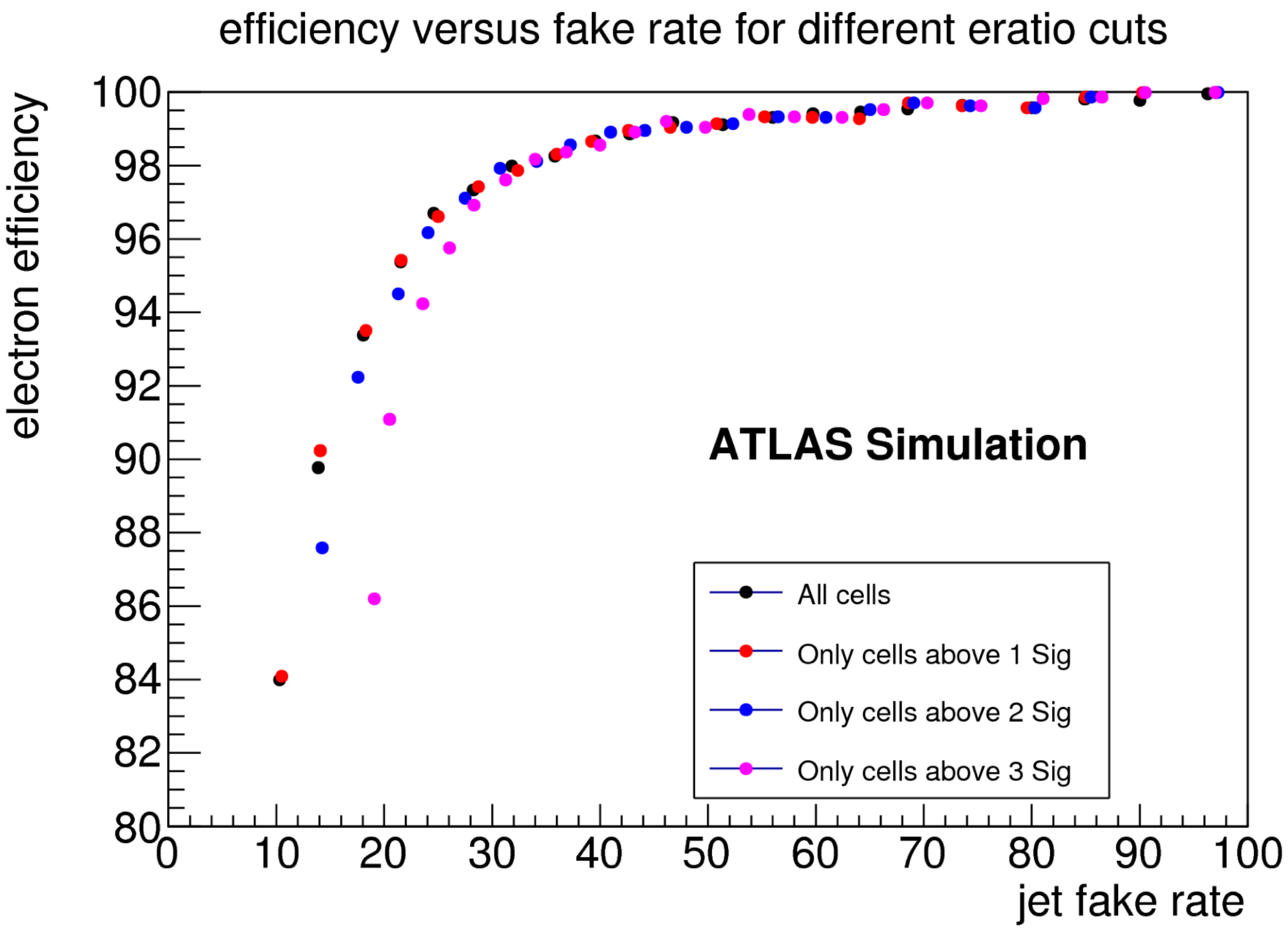




TDAQ online EM selections

- Using E_{ratio} helps reject hadronic jets in L0 EM





Higgs coupling expected sensitivity

- 1% level precision expected