Design layout and expected performance of Inner Tracker for ATLAS Phase 2 Upgrade

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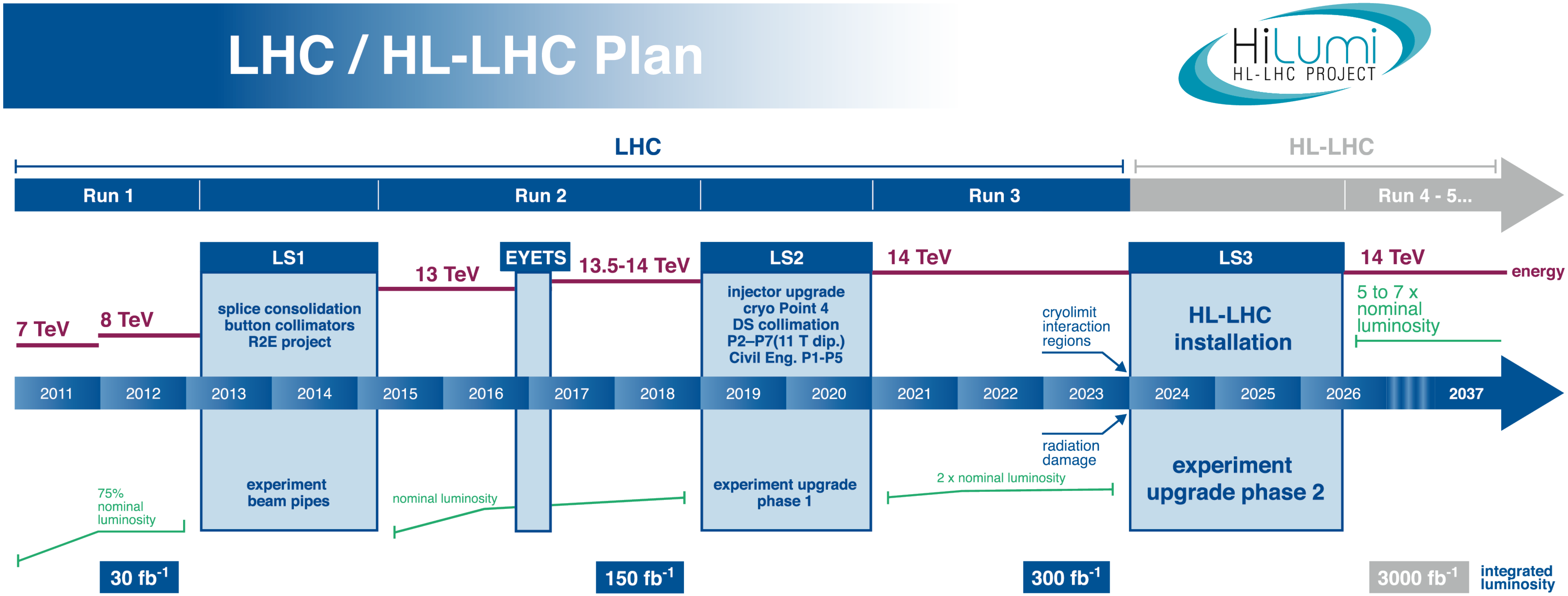
Fermilab

High Luminosity LHC (HL-LHC) upgrade



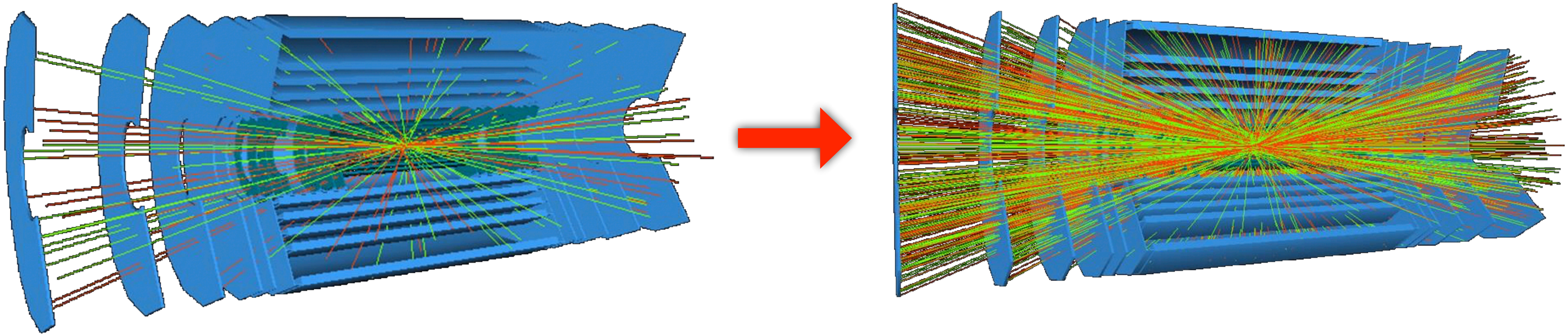
Phase 2 Upgrade

Installation: 2024 onwards, Preparation: now

10 times integrated luminosity: 3000 fb^{-1} [radiation damage]

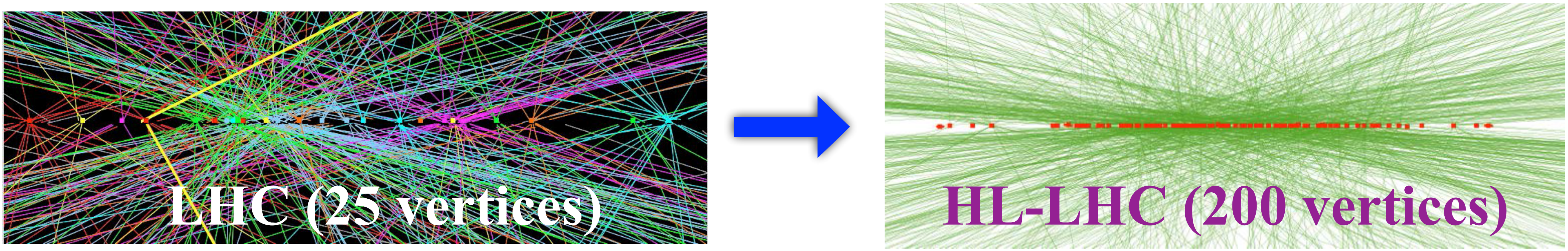
5-7 times instantaneous luminosity: 7.5x10^{34} $cm^{-2}sec^{-1}$ [particle density]

HL-LHC challenge



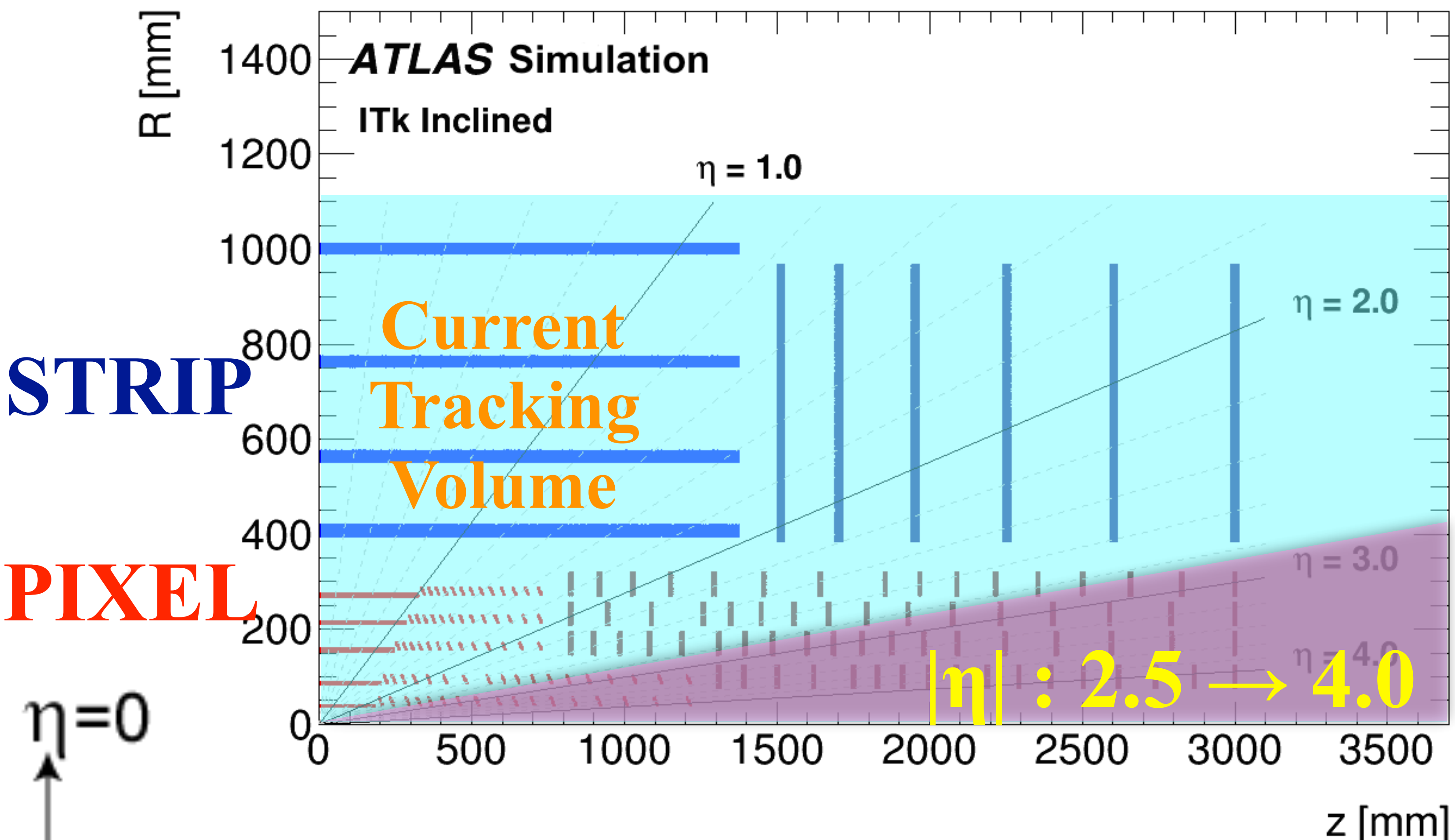
Factor of 10 increase in Pile-Up

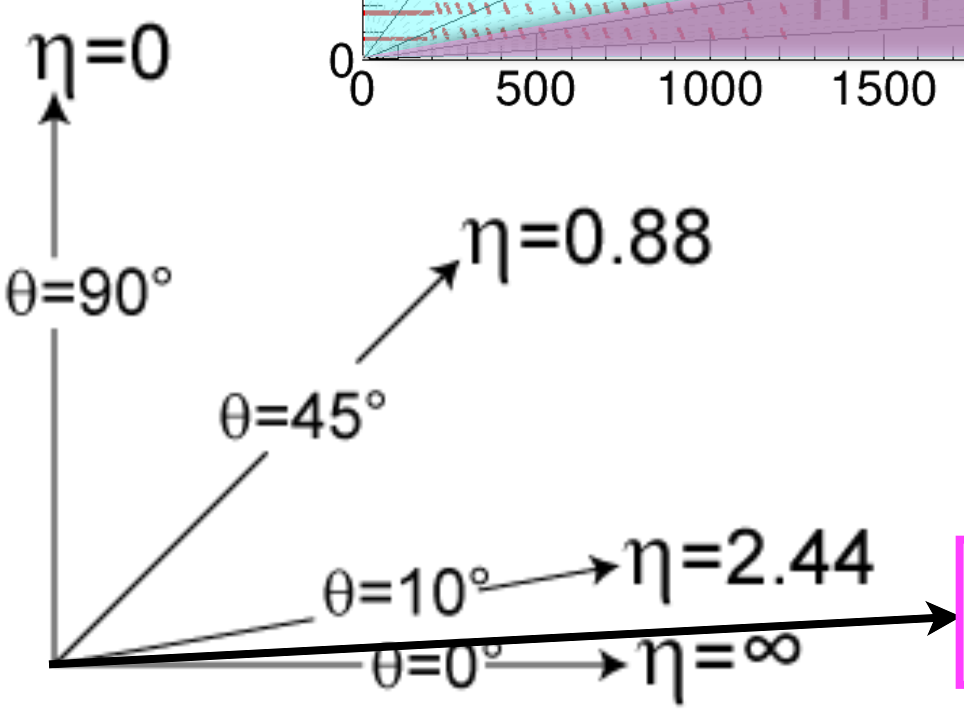
(# of interactions per bunch crossing)



Very forward extension of Inner Tracker

Proposal: all silicon high granularity Inner Tracker (ITk) with $\eta < 4$





$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

$\theta = 2° \Rightarrow \eta = 4.0$

Higher acceptance for tracks: e, μ, τ, jets

Critical improvements in
- pile-up/fake-jet rejection
- very forward jet tagging from hard scatter process

Very forward coverage only with Pixel detector

Extending the physics reach

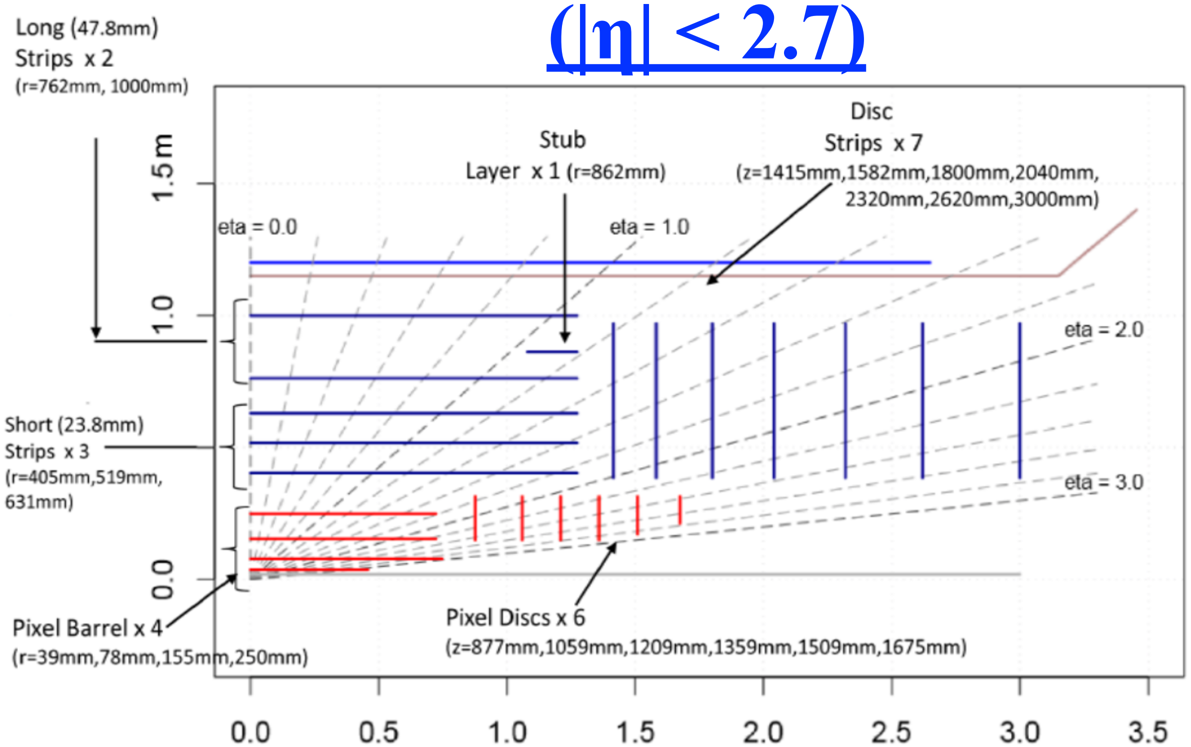
Very forward ITk has large physics gains, eg. rare and exotic Higgs decays, Vector-Boson scattering, SUSY, etc. via improvements in e/μ/b-tag acceptance & resolution, E_T^{miss} resolution, pileup rejection.

Detector system / Object Performance / Physics Process	Trigger–DAQ: Efficiency/ Thresholds $\mu^{\pm}$	Trigger–DAQ: Efficiency/ Thresholds $e^{\pm}$	Inner Tracker: b-tagging	Inner Tracker + Muon Spectrometer: $\mu^{\pm}$ Identification/ Resolution	Inner Tracker + Calorimeter: Pile-up rejection	Inner Tracker + Calorimeter: Jets	Inner Tracker + Calorimeter: E_T^{miss}
$H \longrightarrow 4\mu$	✓			✓			
VBF $H \rightarrow ZZ^{(*)} \rightarrow \ell\ell\ell\ell$	✓	✓		✓	✓	✓	
VBF $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$	✓	✓	✓	✓	✓	✓	✓
SM VBS ssWW	✓	✓		✓	✓	✓	✓
SUSY, $\chi_1^{\pm}\chi_2^{o} \rightarrow \ell b\bar{b} + X$	✓	✓	✓	✓	✓	✓	✓
BSM $HH \rightarrow b\bar{b}b\bar{b}$			✓			✓	

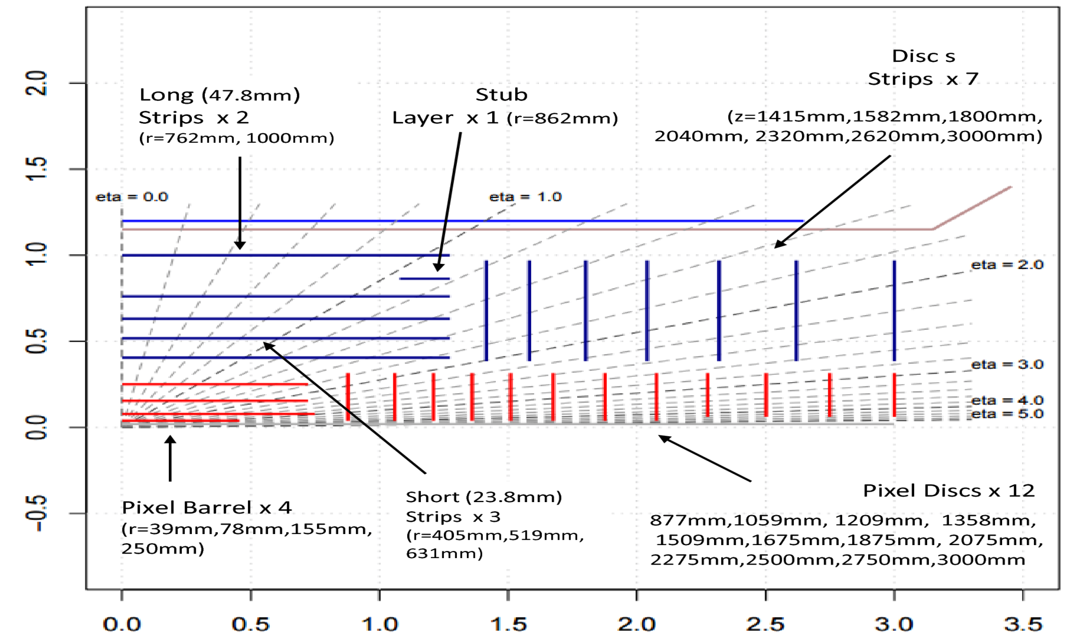
ATLAS Phase-II Upgrade Scoping Document, CERN-LHCC-2015-020. LHCC-G-166 (2015)

Evolution of ITk layouts (2012-2014)

Letter-of-Intent ($|\eta| < 2.7$)

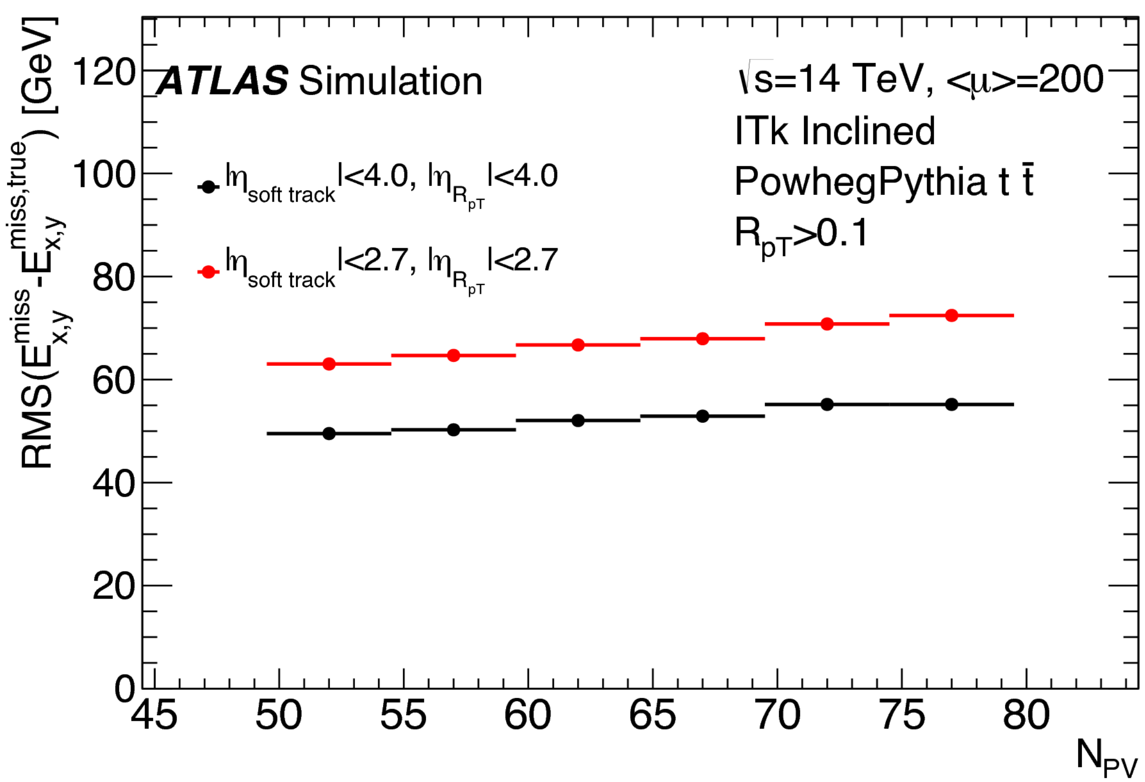


Letter-of-Intent Very-forward ($|\eta| < 4.0$)



Strip TDR

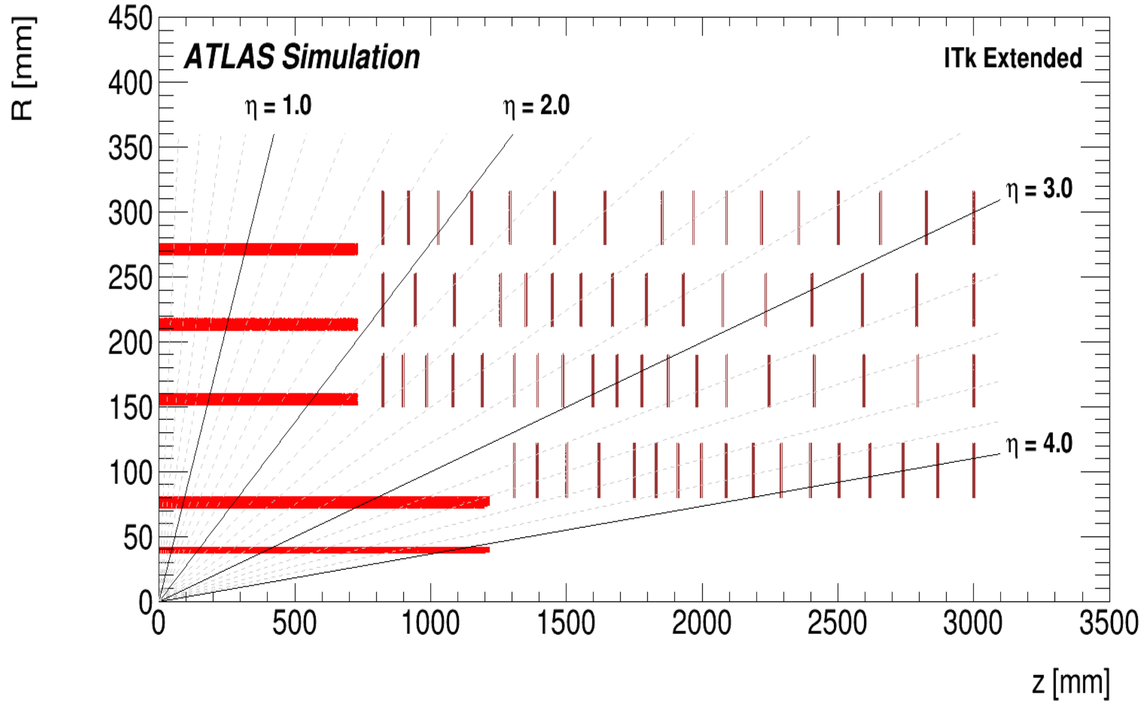
(ATL-TDR-025)



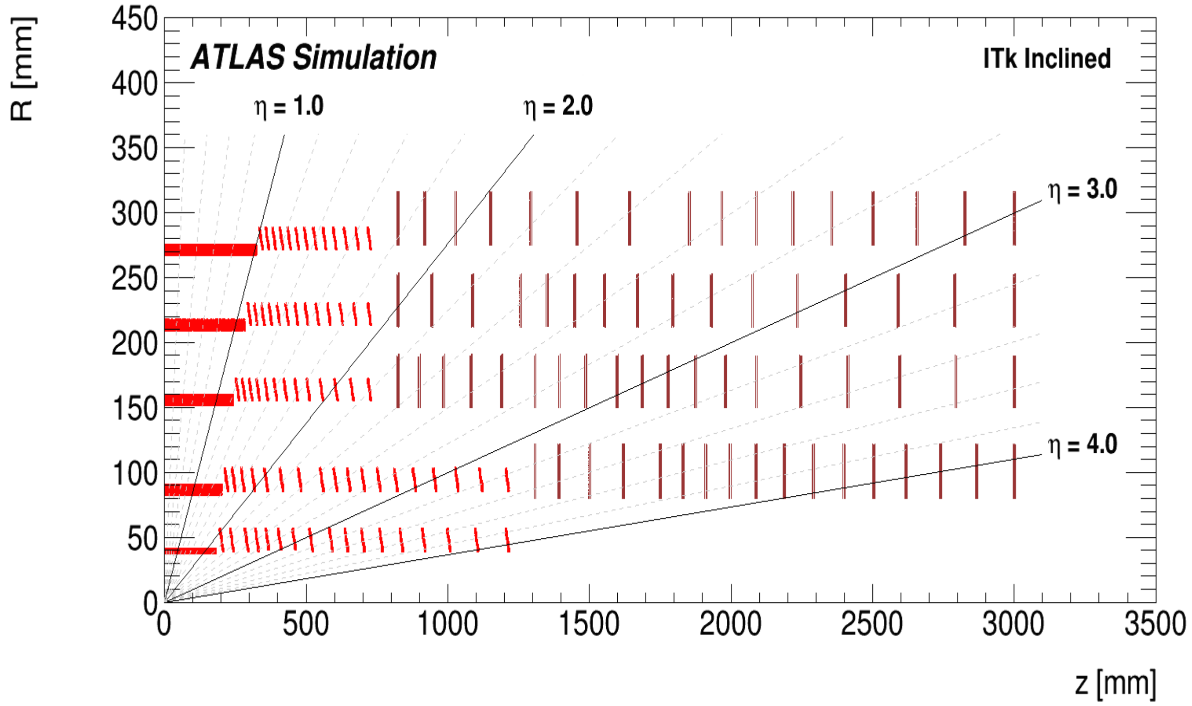
Improvement due to addition of more pixel detectors in the very forward region visible specially at high pile-up

Evolution of ITk layouts (2015-2016)

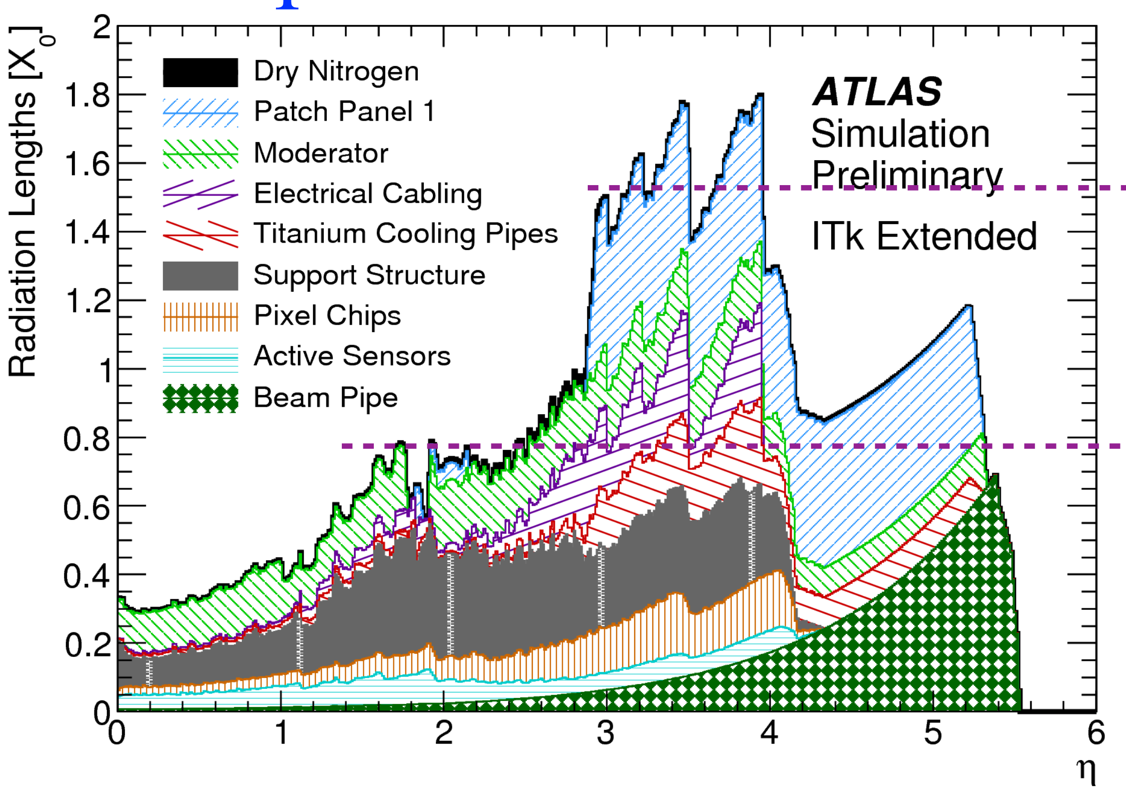
Extended Layout



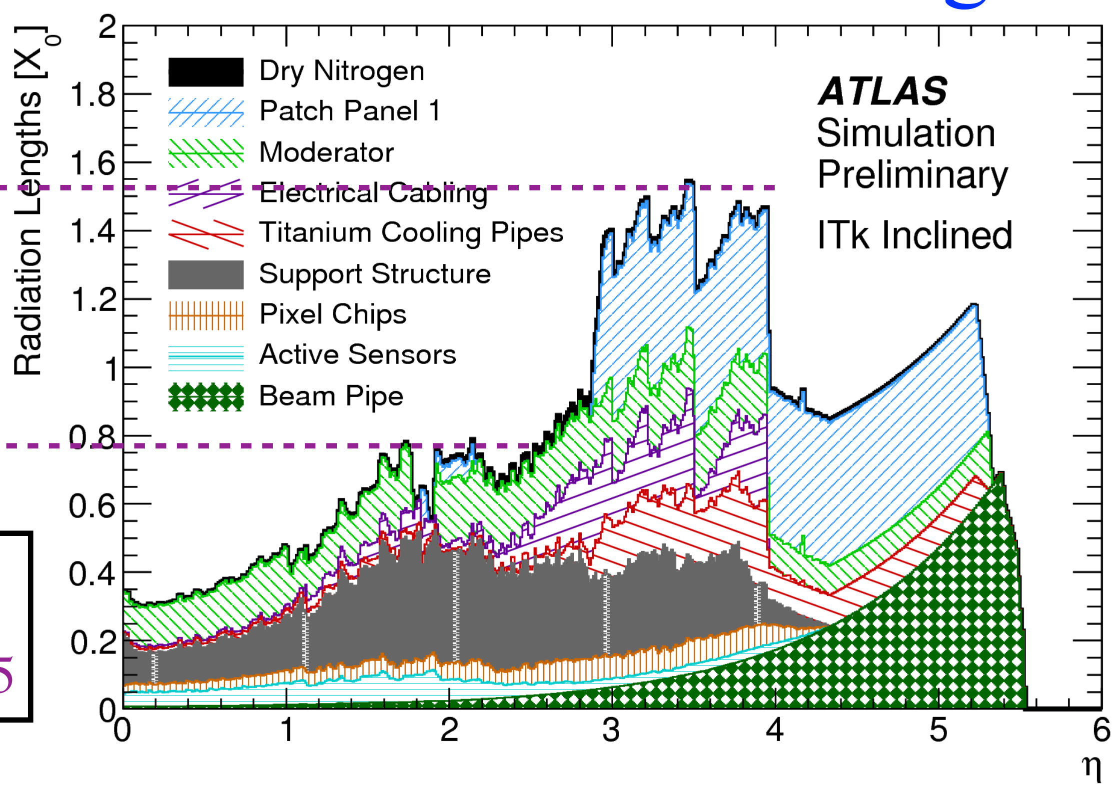
Inclined Layout



Composition of simulated materials in terms of radiation length



ATL-PHYS-PUB-2016-025

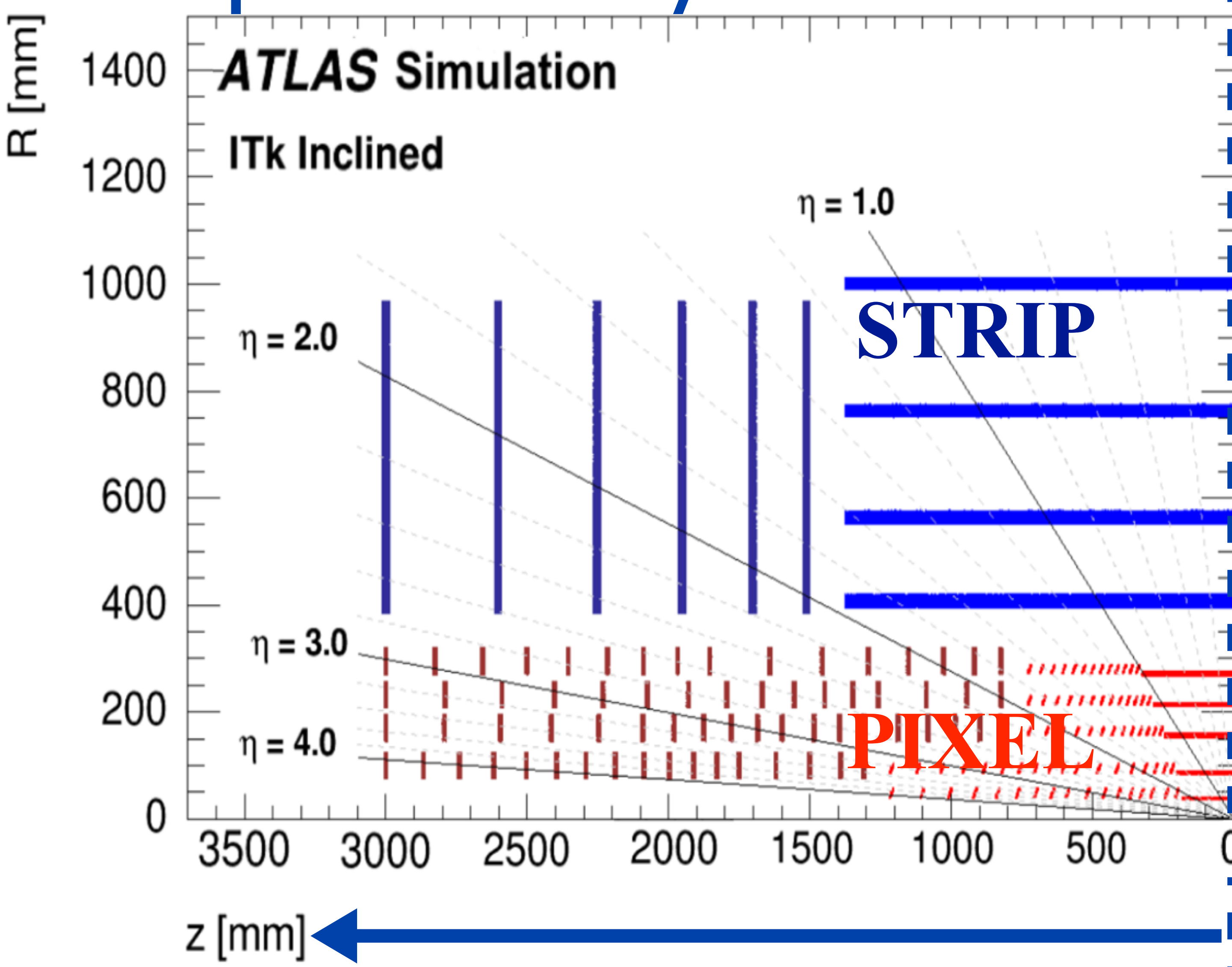


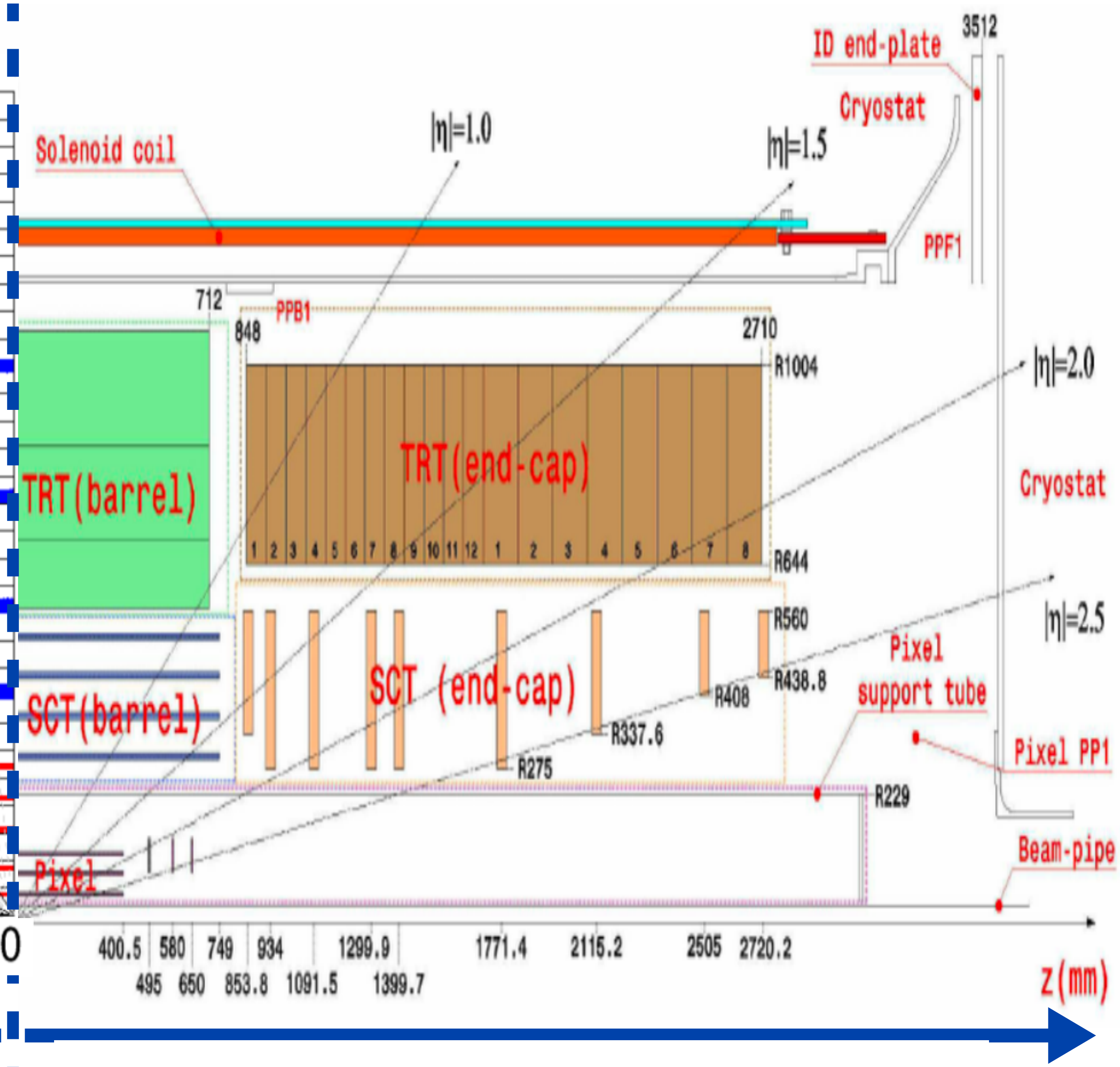
ITk layout for Strip TDR (April 2017)

Phase II Upgrade all-silicon ITk

Current silicon and straw tracker

One quarter of the layout in r-z shown





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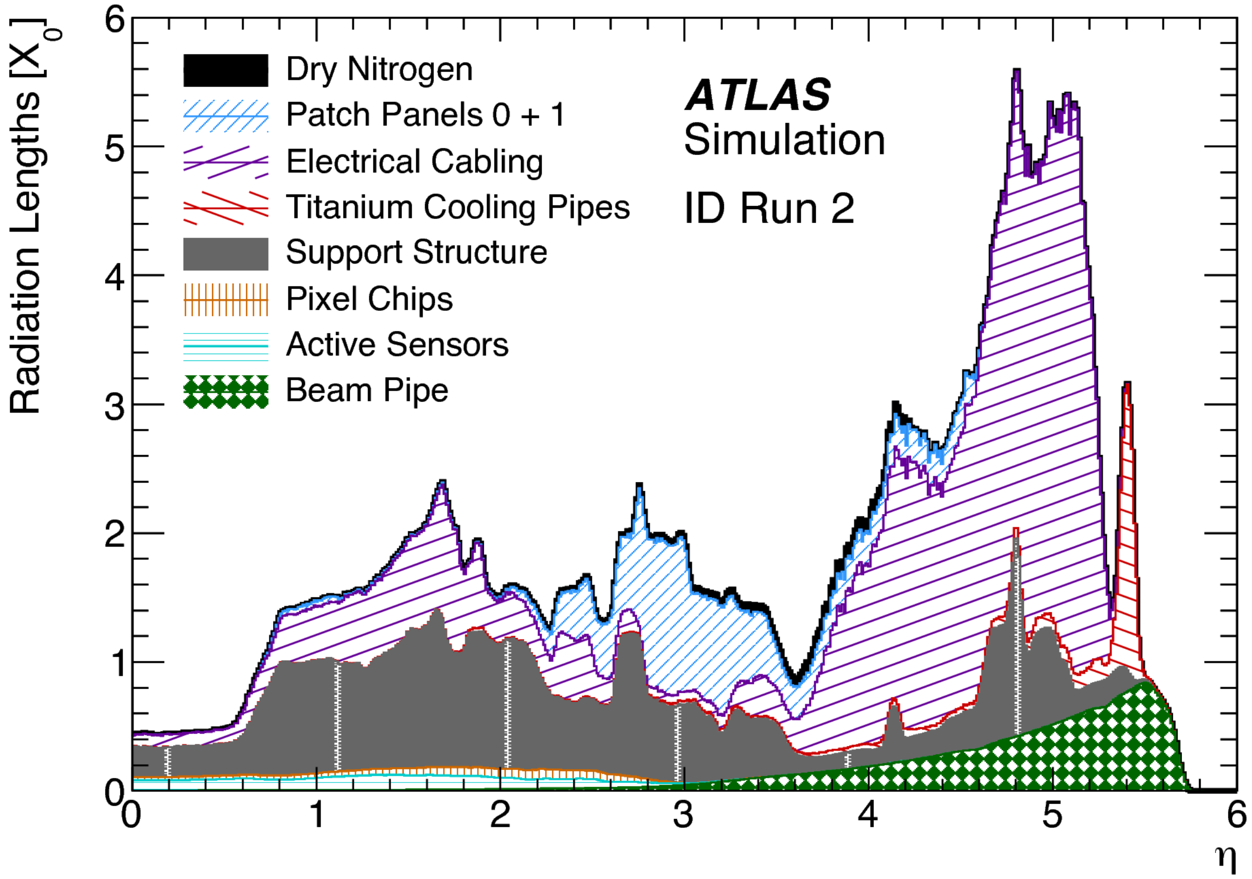
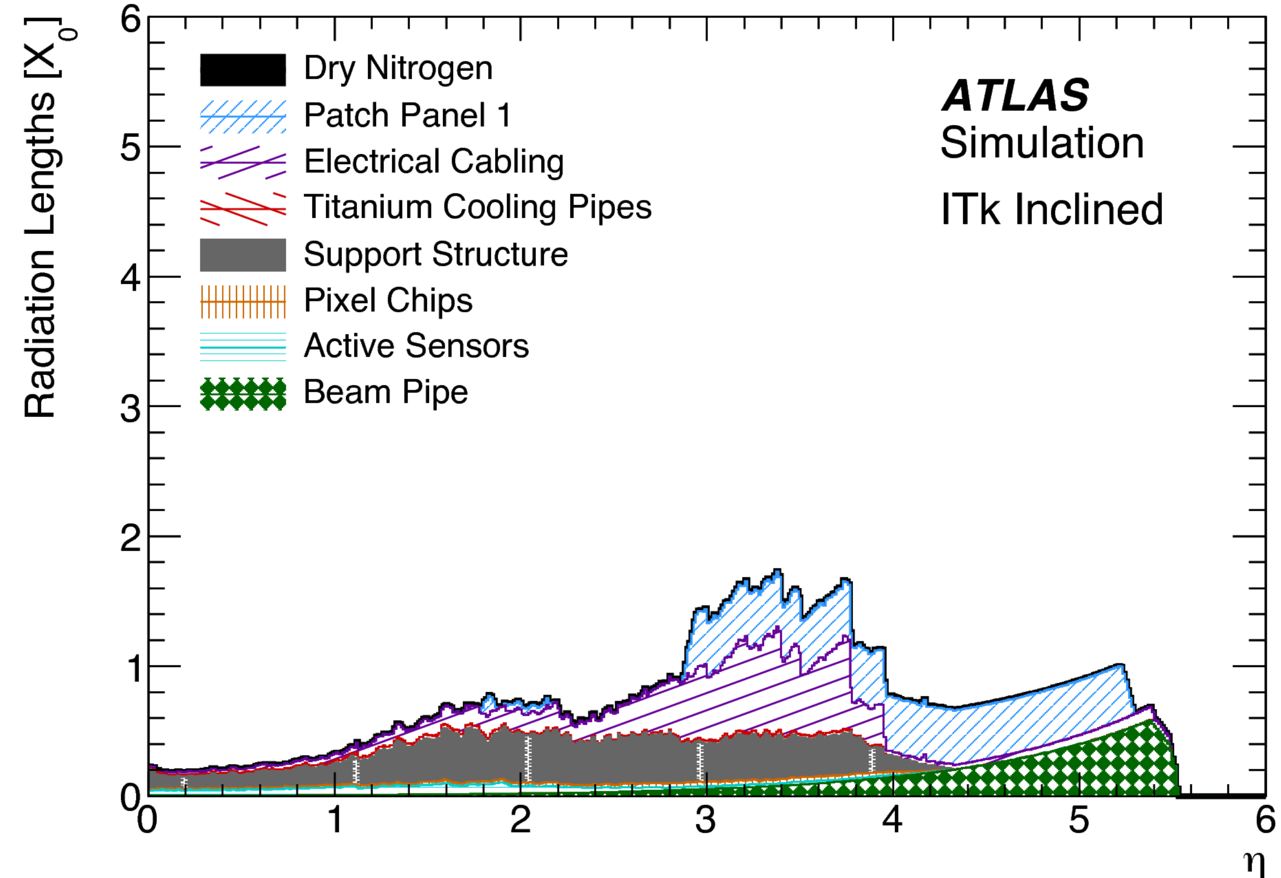
ATLAS Collaboration, JINST 3 (2008) S08003

Material description





Tracks travel transverse to inclined modules and thus require less materials to provide coverage up to |η| < 4.0 in the new ITk layout.

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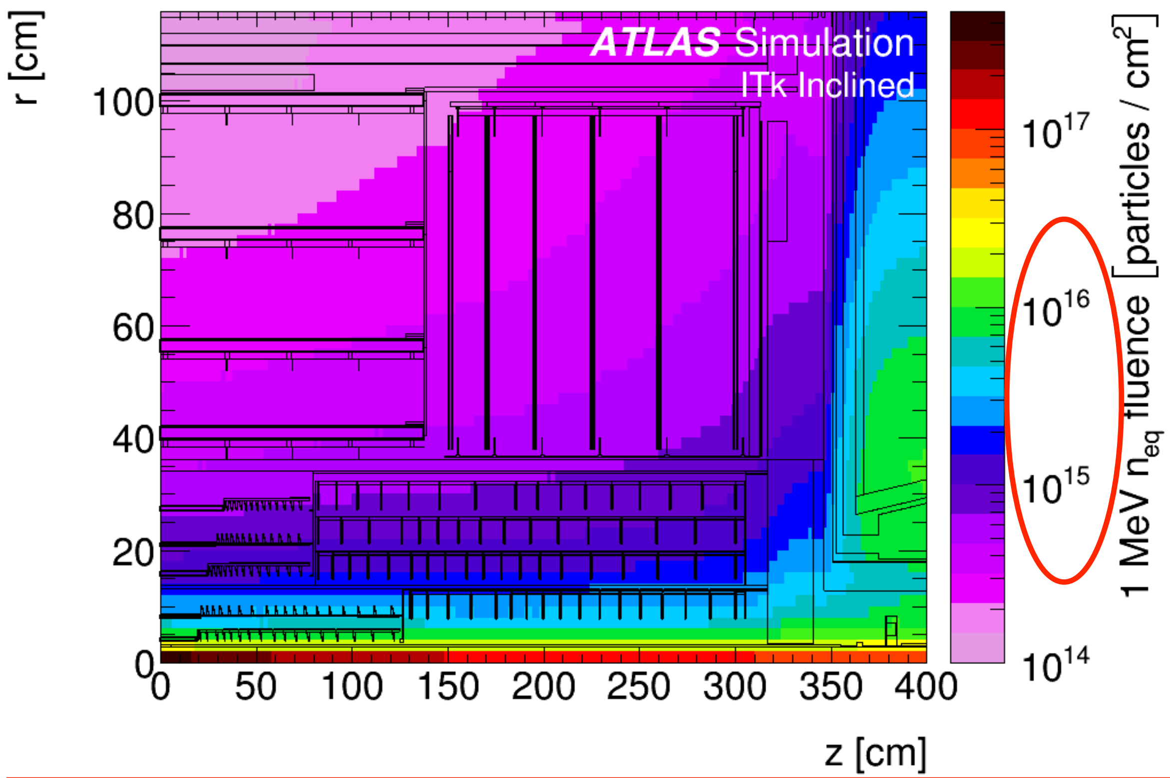
Radiation damage

FLUKA simulation normalized to 3000 fb^{-1} of pp collisions at 14 TeV:



- Possibility to extract & replace inner pixel layers if needed
- Newer technology for radiation hard sensors [hybrid / CMOS]
- Thinner silicon sensors
- Robust readout system

1 MeV neutron equivalent fluence

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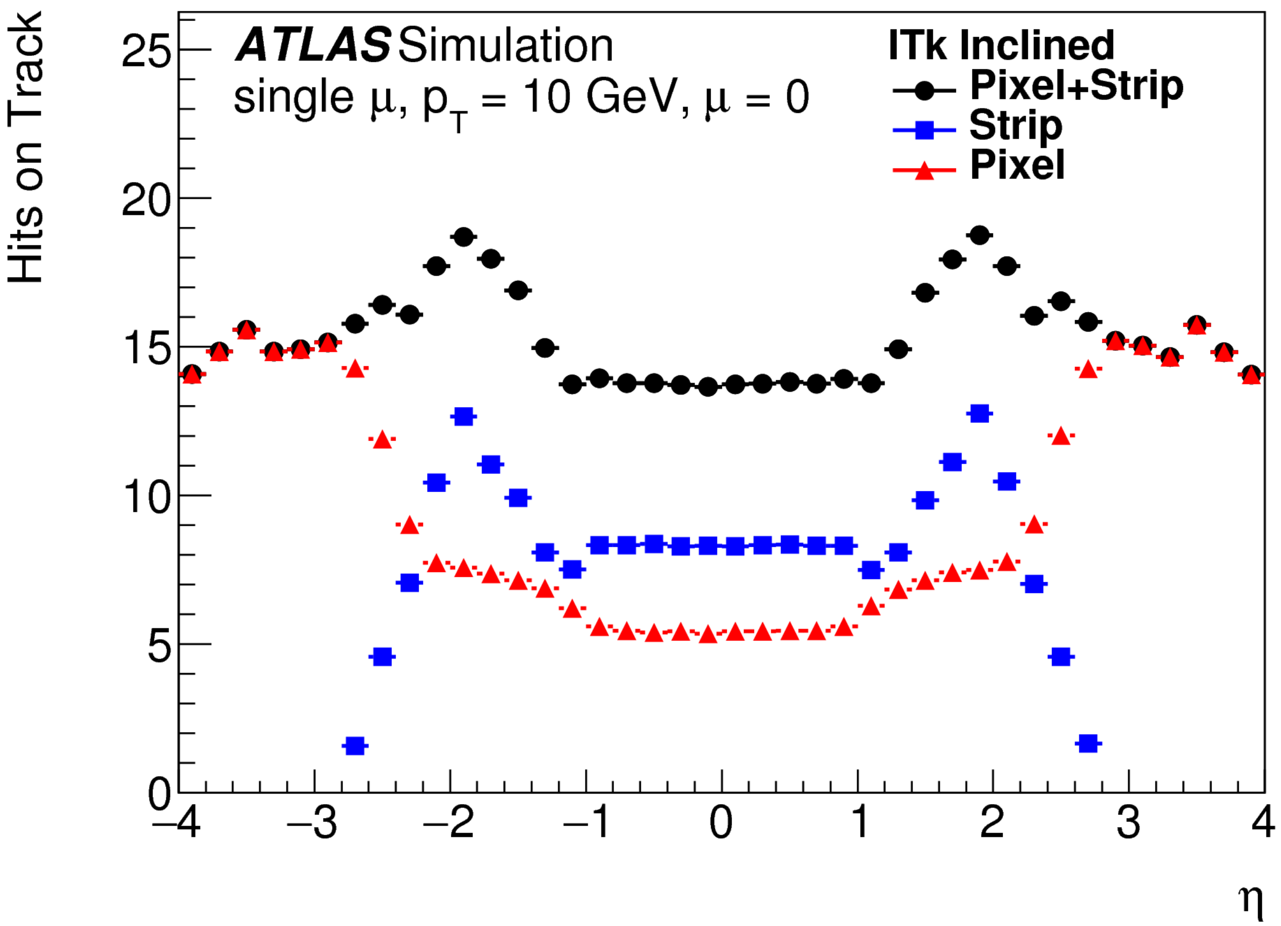
Layer	Radius [mm]	Maximal Fluence [n_{eq}/cm^2]	Maximal Dose [MRad]
Strips			
Long Strips	762	3.8×10^{14}	9.8
Short Strips	405	7.2×10^{14}	32.5
End-cap	385	1.2×10^{15}	50.4
Pixels			
Layer 0	39	1.87×10^{16}	1268
Layer 1	75	0.59×10^{16}	549
Layer 2	155	0.22×10^{16}	129
Layer 3	213	0.15×10^{16}	87
Layer 4	271	0.11×10^{16}	53
End-cap	80	0.62×10^{16}	477

Track reconstruction

Non-homogeneous detector and reduced magnetic field in forward regions:



Requirement	Pseudorapidity interval	
	$\lvert\eta\rvert < 2.7$	$2.7 < \lvert\eta\rvert < 4.0$
Pixel+Strip clusters	≥ 9	≥ 9
Pixel clusters	≥ 1	≥ 1
Holes	< 3	< 3
Pixel holes	< 2	< 2
Strip holes	< 3	< 3
Double Strip holes	< 1	
p_T [MeV]	> 900	> 400
$\lvert d_0\rvert$	≤ 2 mm	≤ 10 mm
$\lvert z_0\rvert$	≤ 25 cm	≤ 25 cm

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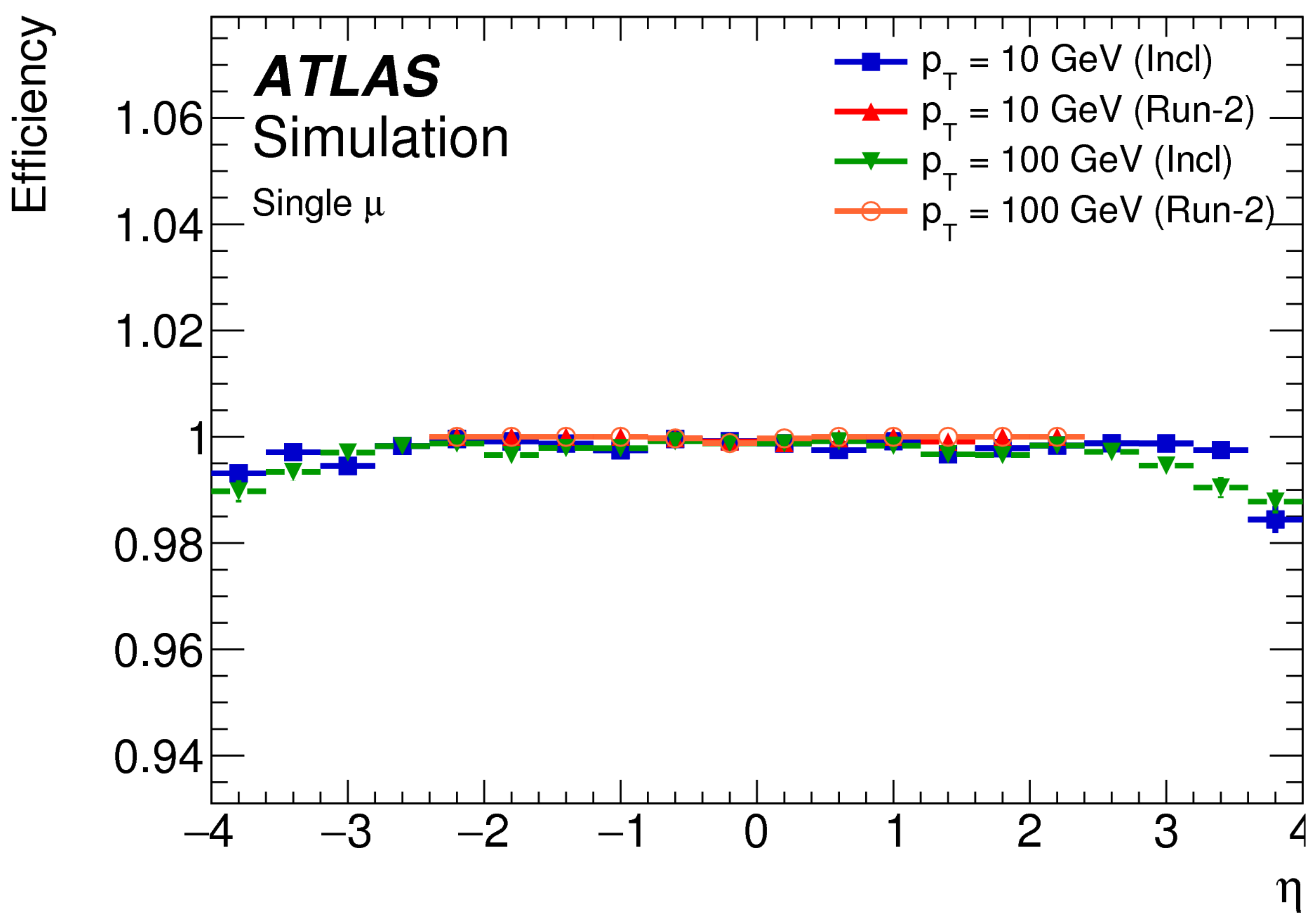
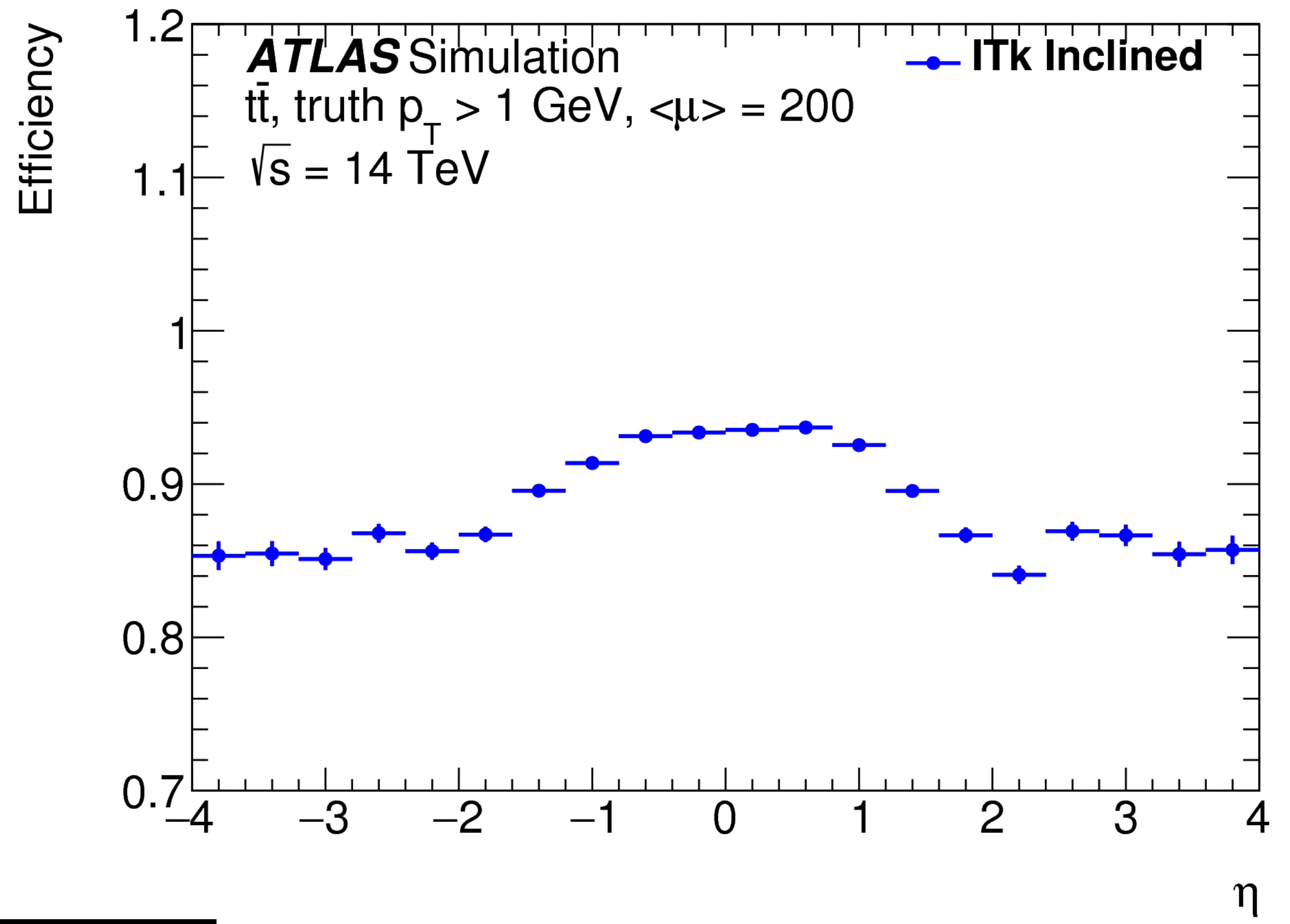
Tracking efficiency

- Good efficiency defined as fraction of stable, charged, primary particles (p_T > 1 GeV, |η| < 4.0) for a given reconstructed track
- Uniform efficiency of single-muon tracks versus η
- Efficiency ~ 85% (95%) in forward (central) region in $t\bar{t}$ samples due to high particle density





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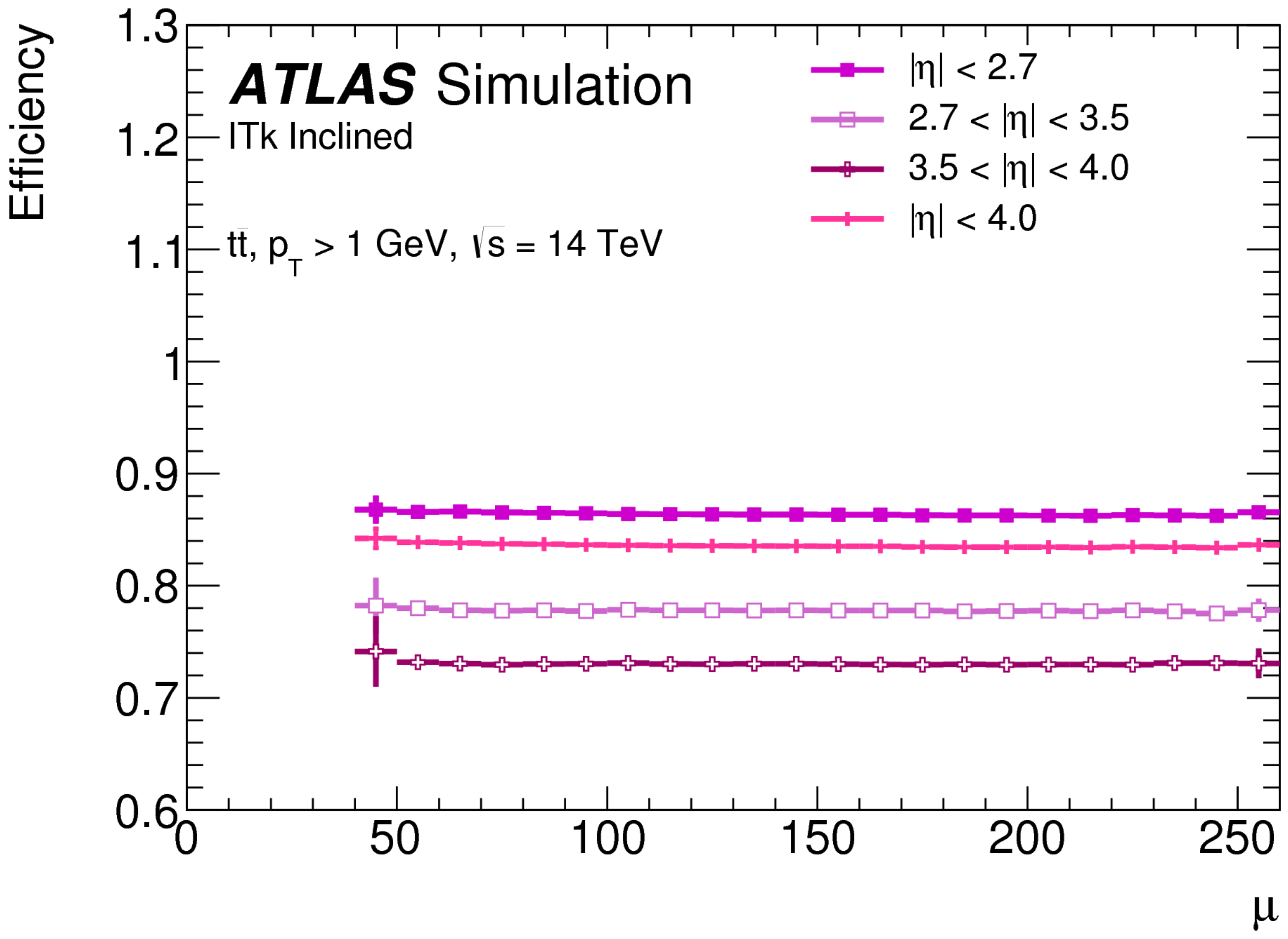
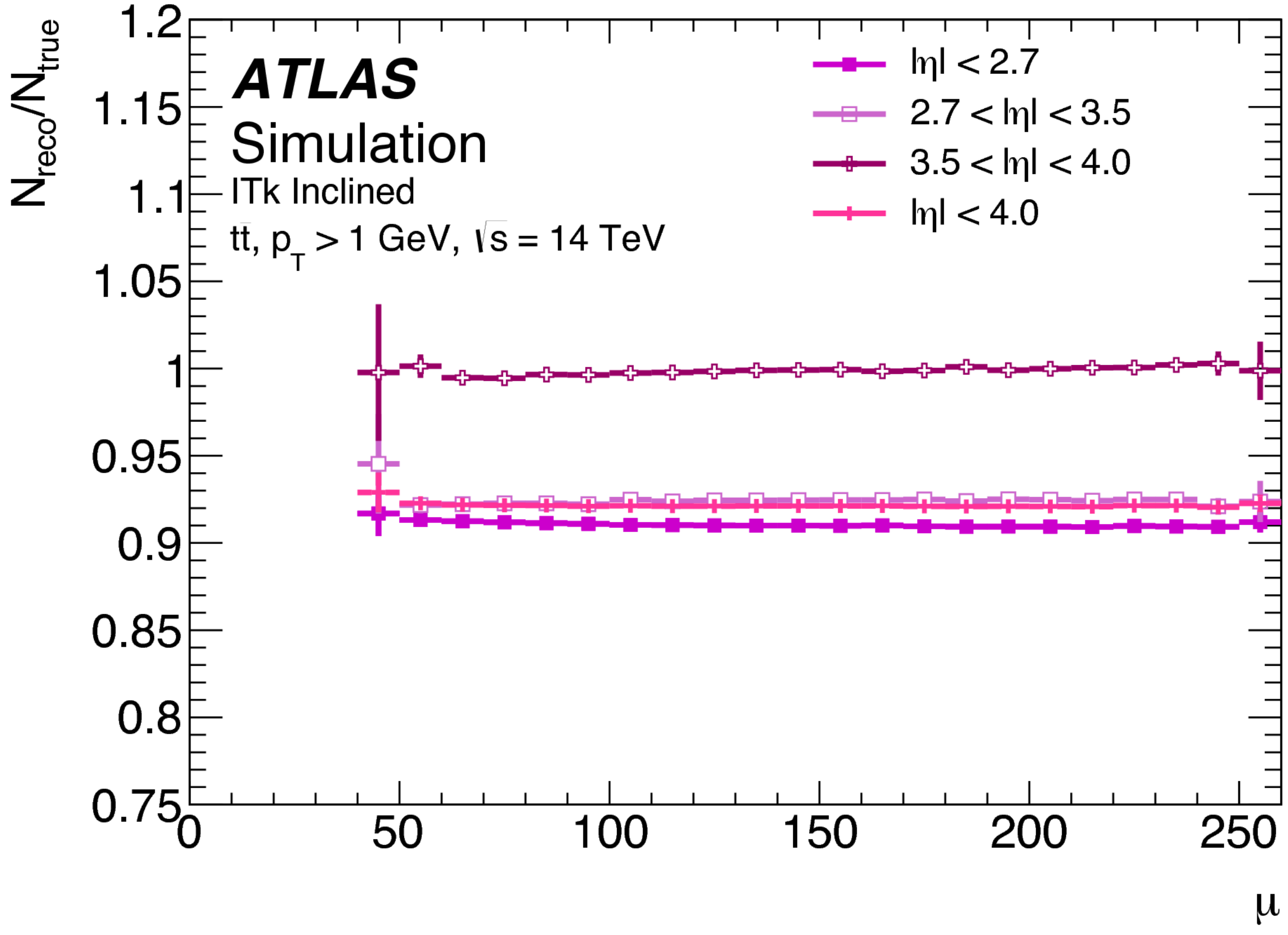
Pile-up robustness

- Track reconstruction efficiency is stable as fraction of pile-up
- Inclusive rate of number of reconstructed over number of generated as measure of non-fake tracks also stable vs pile-up





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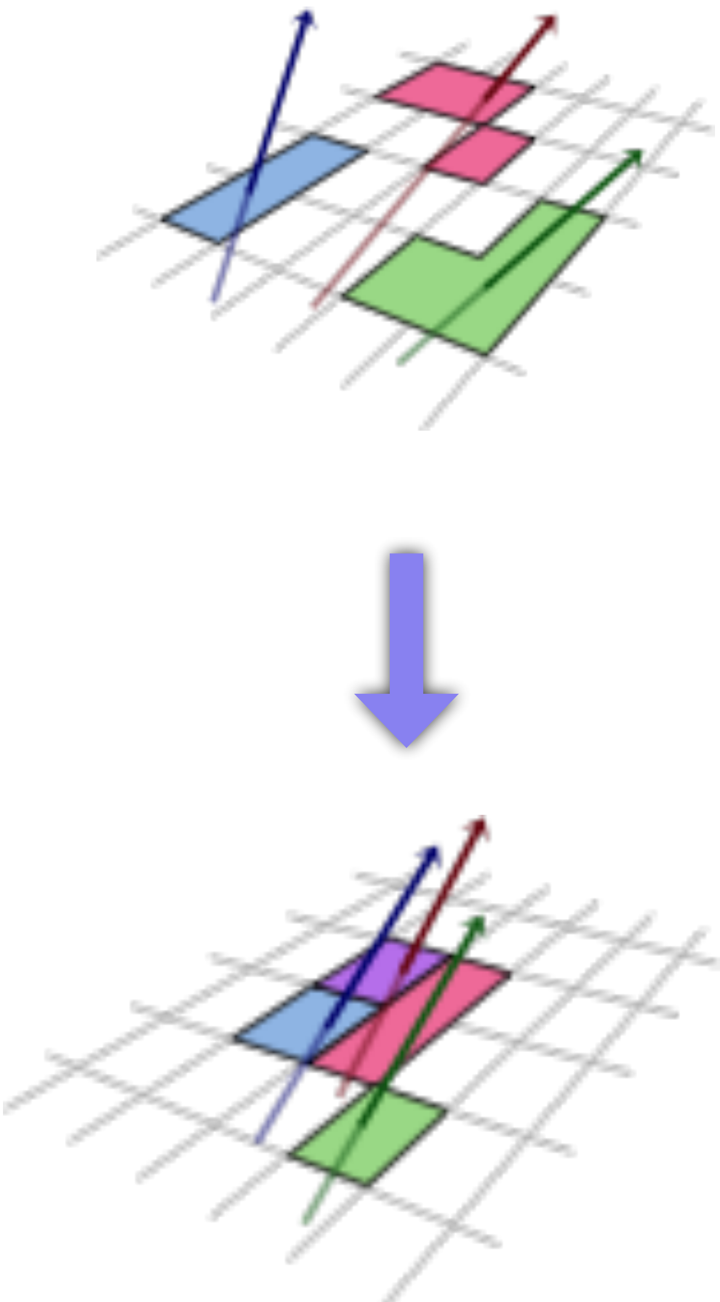
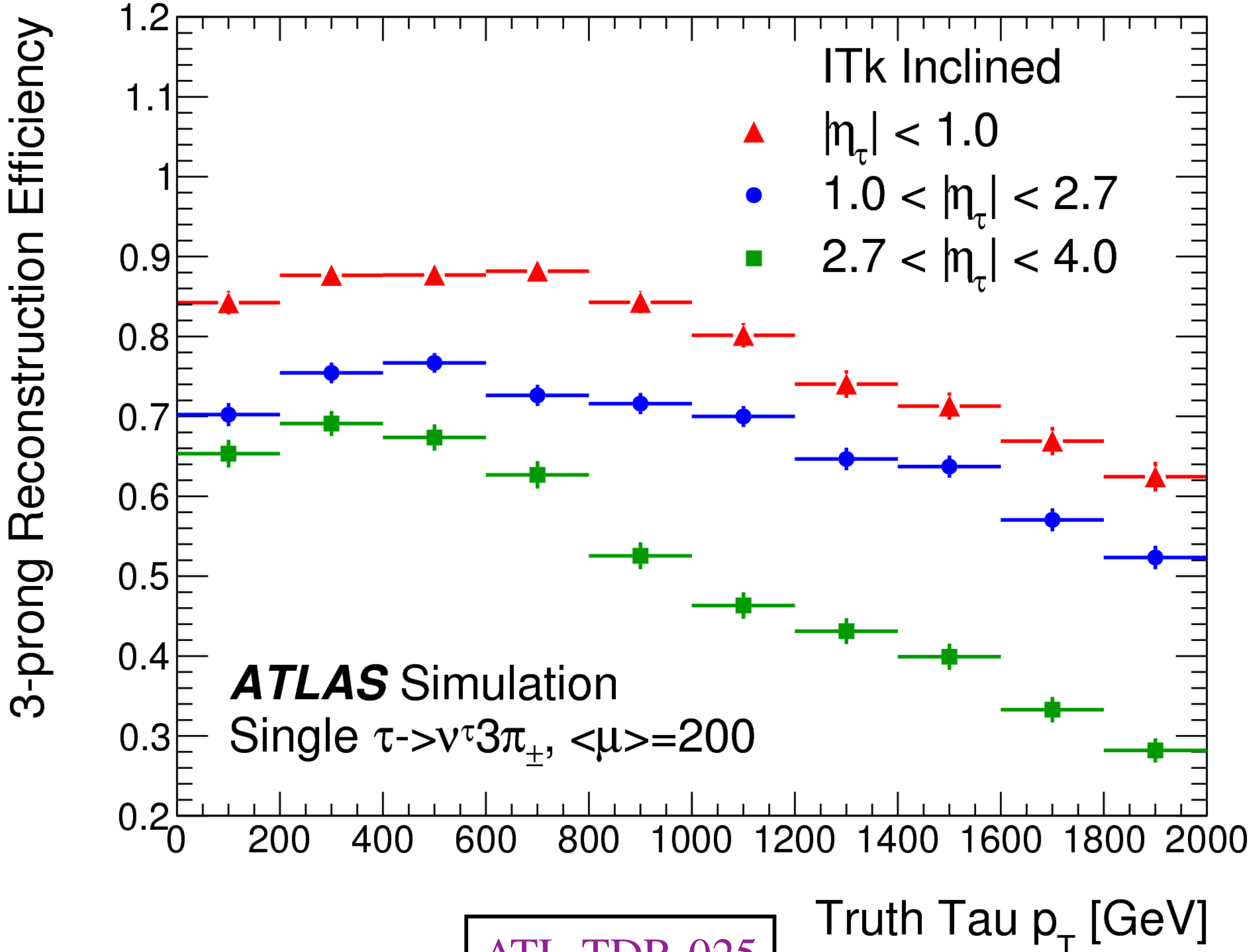
Tracking in dense environment

- Good efficiency to resolve all tracks in highly collimated boosted 3-prong τ decays in dense environment





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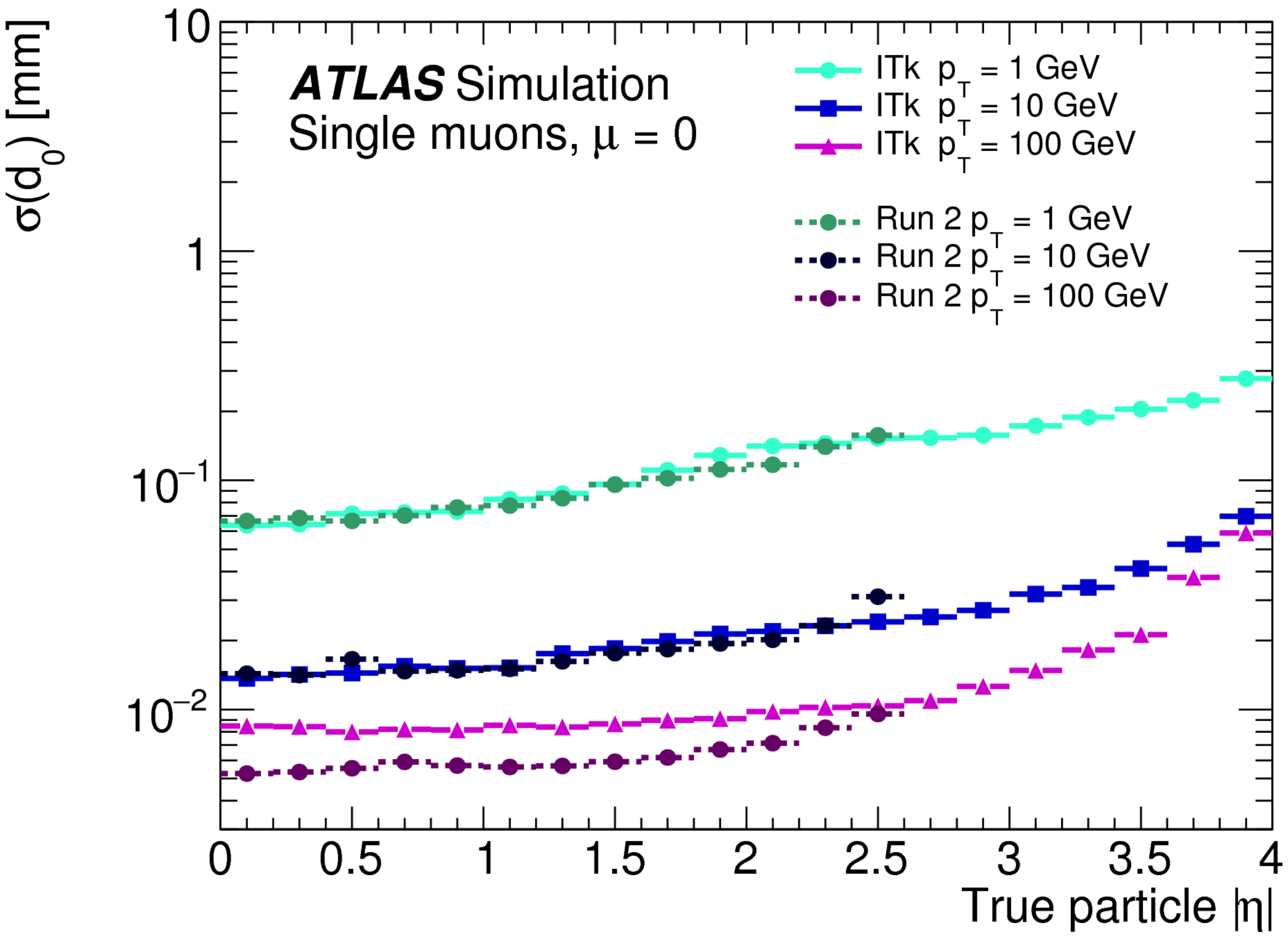

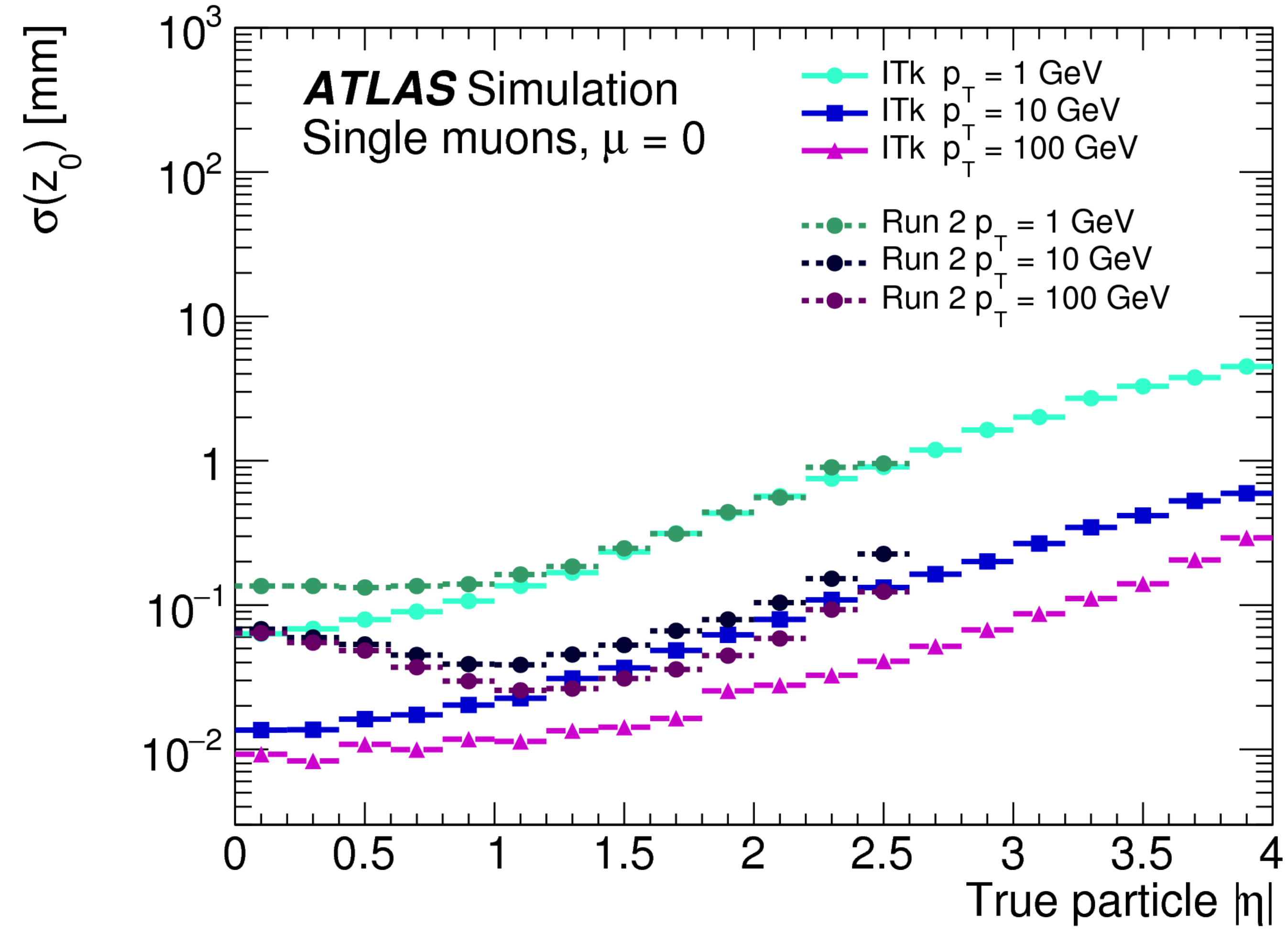

Excellent impact parameter resolution

muons with p_T = 10 GeV	$\sigma(d_0)$	$\sigma(z_0)$
$\lvert\eta\rvert < 3.5$	40 μm	300 μm

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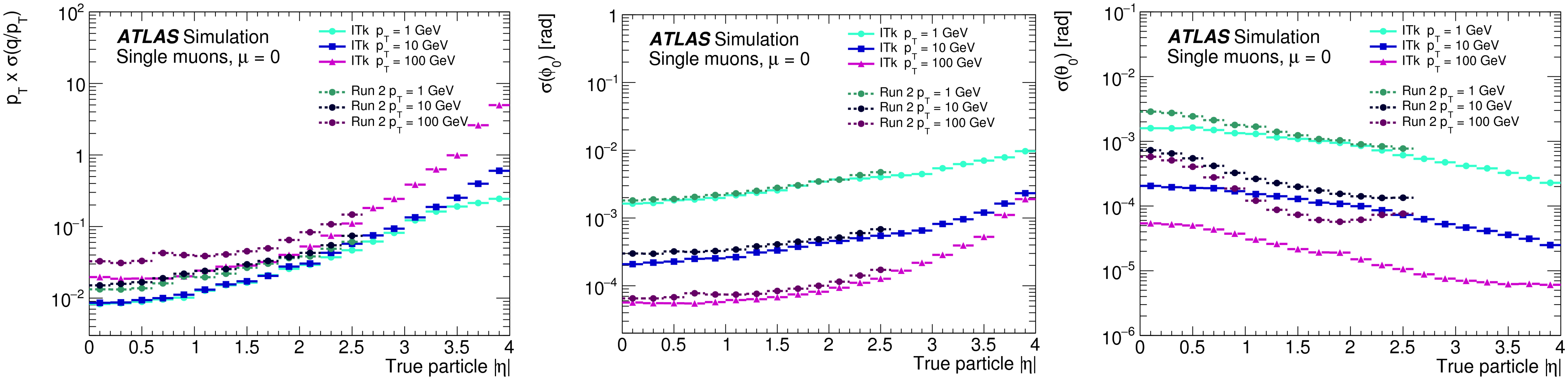
Impact parameter resolutions

Improved p_T resolution in central part w.r.t current detector, but degraded in forward due to reduced lever-arm in magnetic field



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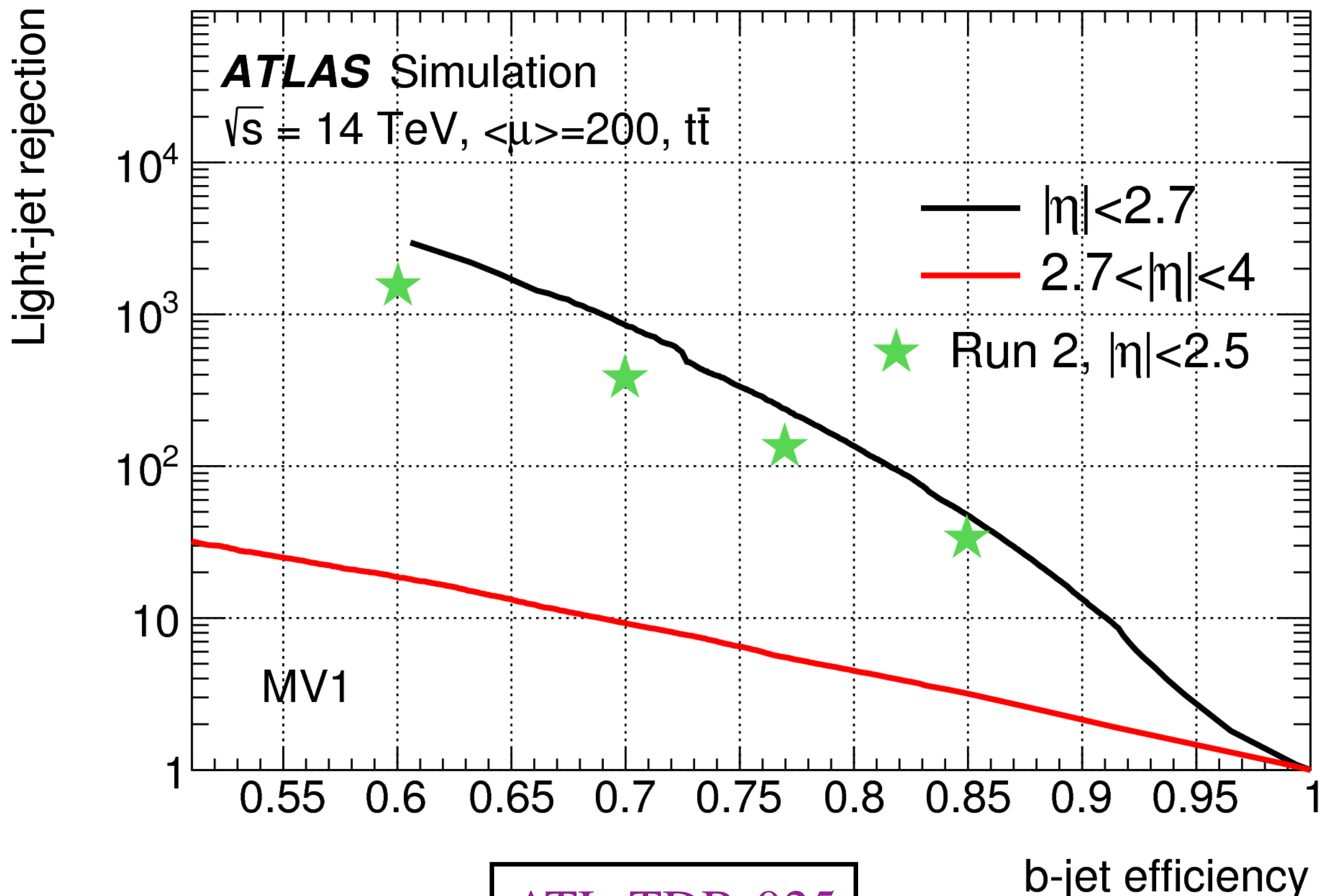
B-tagging performance

- Comparison w.r.t MV1 algorithm used in Run 2 shown
- B-tagging implemented all the way up to $|\eta| < 4.0$
- For efficiency ~ 70%:
  - rejection for ITk is ~ 1000 (10) for $|\eta| < 2.7$ (4.0)
  - factor of 2 better than Run 2



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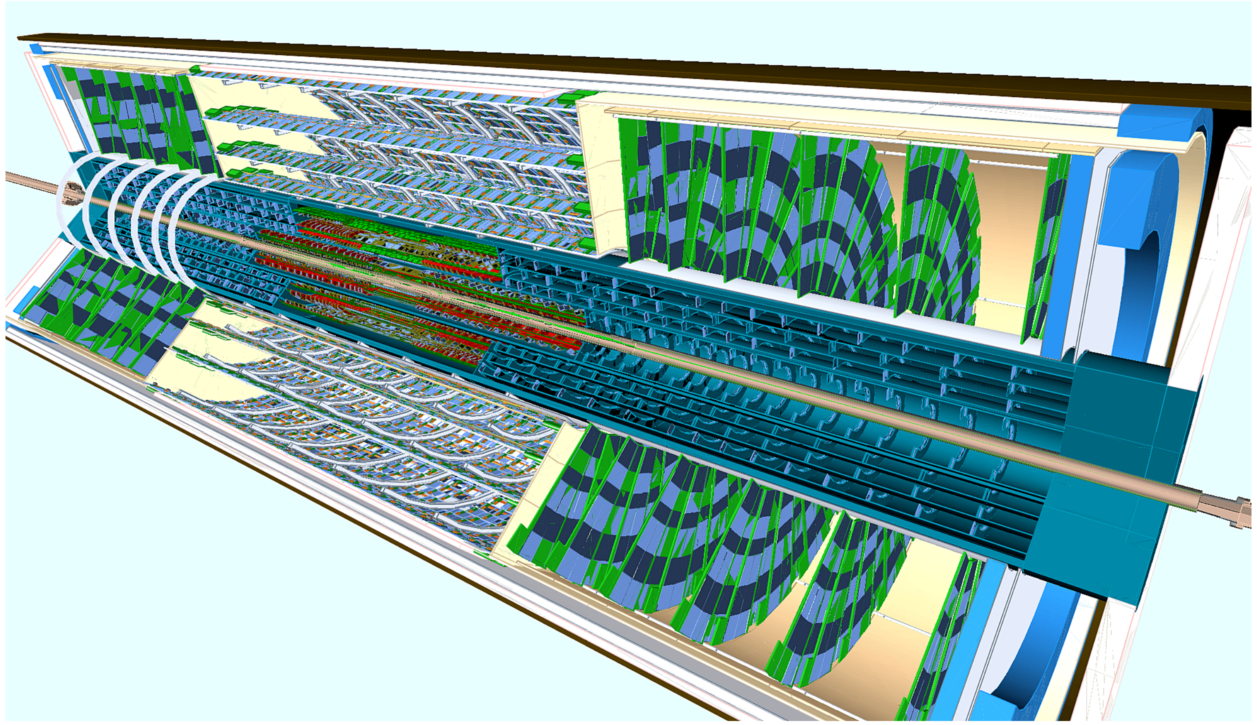
Summary

Schematic design of ITk layout



ATL-TDR-025

- ITk simulation helps to choose optimal detector layout
- New all silicon ITk planned for Phase II upgrade
- Strip TDR finalized in April 2017: 4 barrel, 2x6 disks endcap
- Pixel TDR timeline is end of 2017 : 5 layer barrel, endcap rings
- Inclined layout for Pixel
  - less material traversed
  - new developments for support structure
  - improvements w.r.t Run2 observed