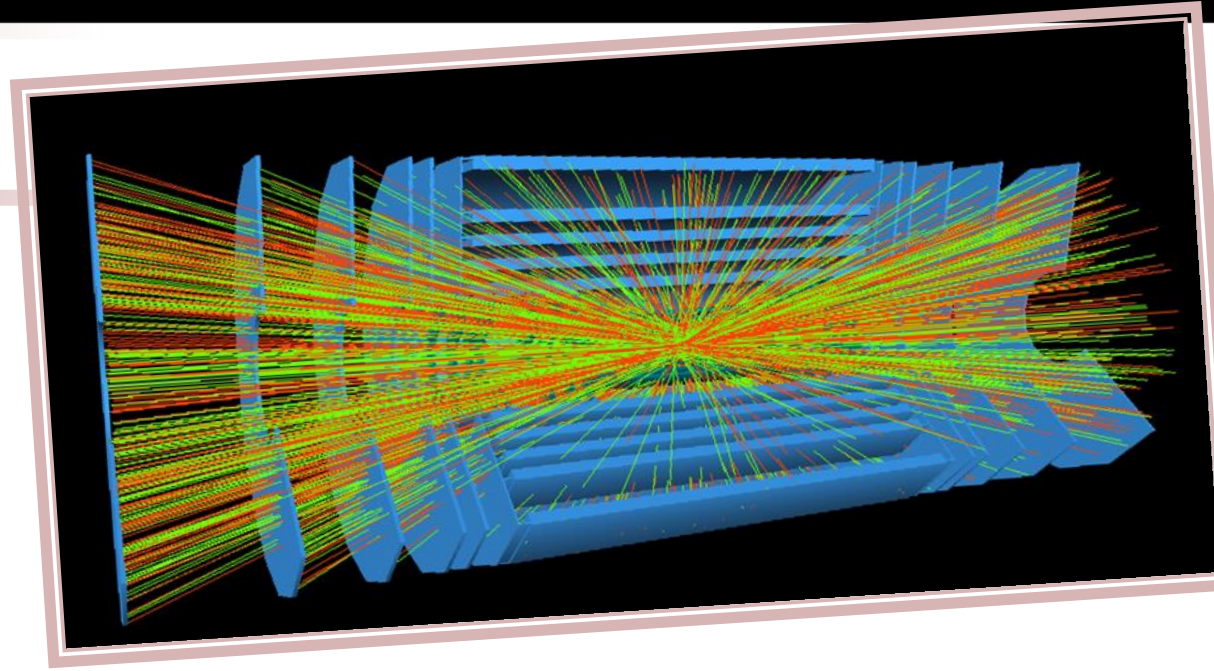
Expected Performance of the ATLAS Inner Tracker at the High-Luminosity LHC

Nora Pettersson on behalf of ATLAS

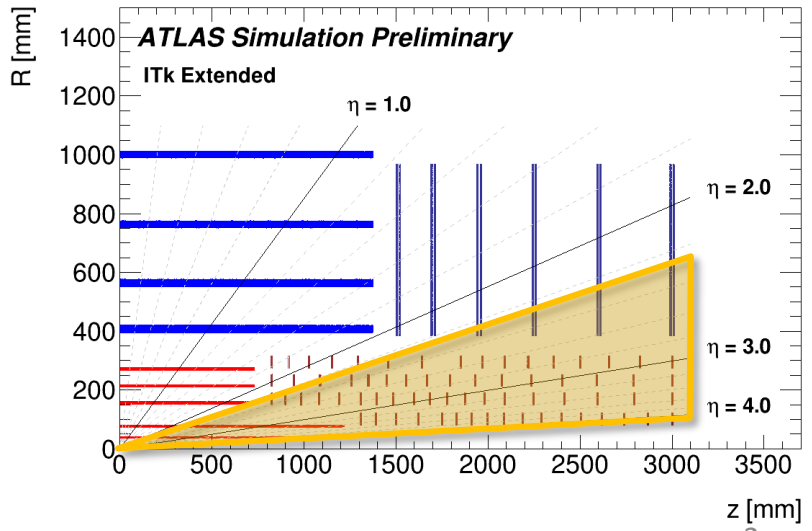
Introduction



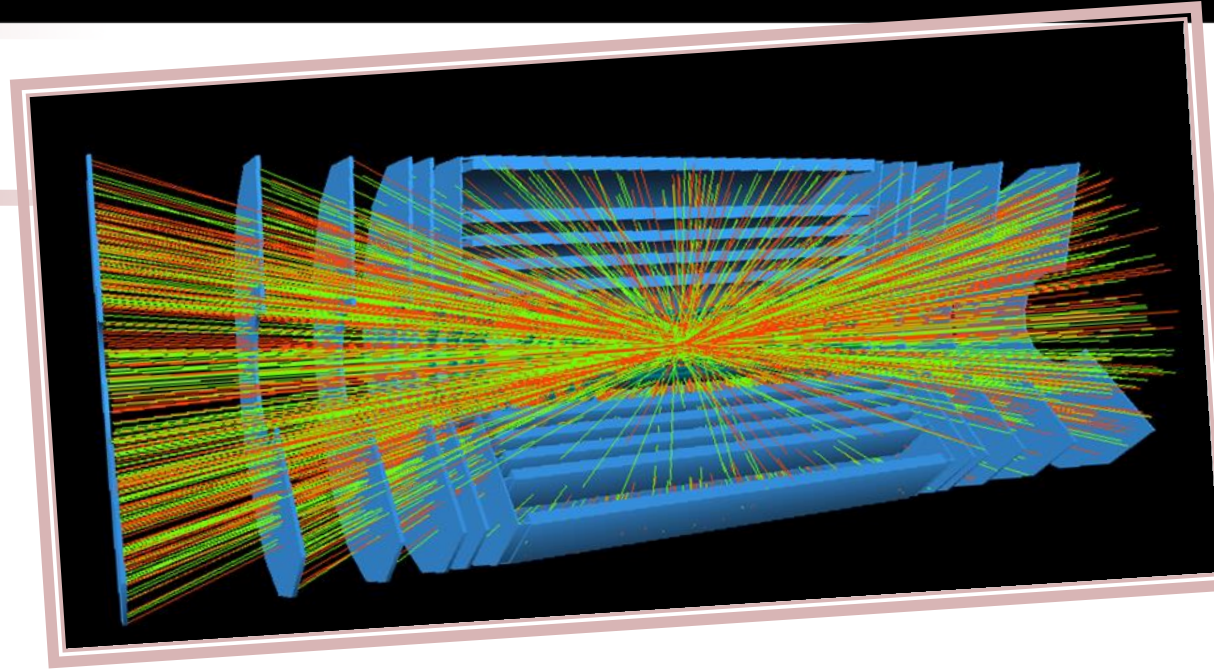
- HL-LHC will to deliver up to 4000 fb^{-1}
- Phase-II upgrade of ATLAS will replace the whole inner detector
  - ◀ A new all silicon tracker

- The new Inner Tracker (ITk) provides coverage up to $|\eta| < 4.0$
- Extended coverage benefits for example:
  - ◀ Pile-up jet suppression
  - ◀ Better identification of the hard scatter vertex
  - ◀ Identification or suppression of b-jets
  - ◀ Increased range for lepton reconstruction
- Important milestones: Strip and Pixel TDRs
  - ◀ Strip layout already final – Strip TDR in finalising process
  - ◀ Now need to decide on the pixel layout
    - ◀ Pixel TDR deadlines approaching!
    - ◀ This presentation will focus on performance of the two candidate pixel layouts!

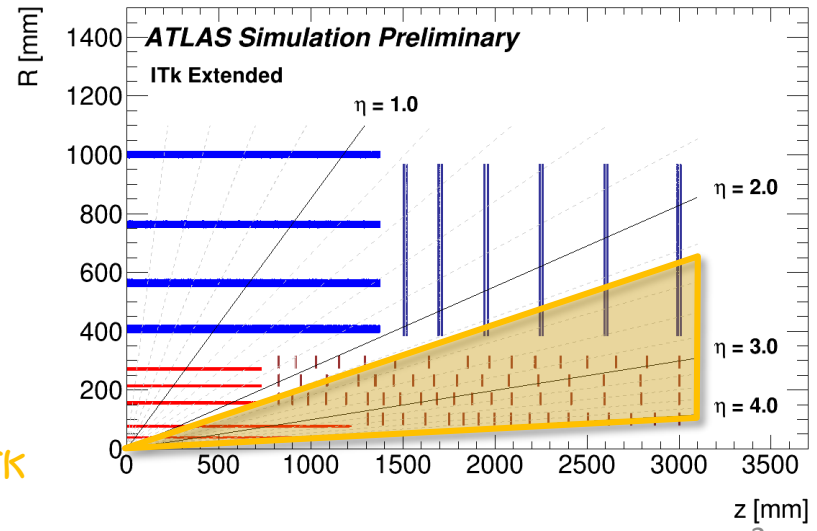
New reach of ITk



Introduction



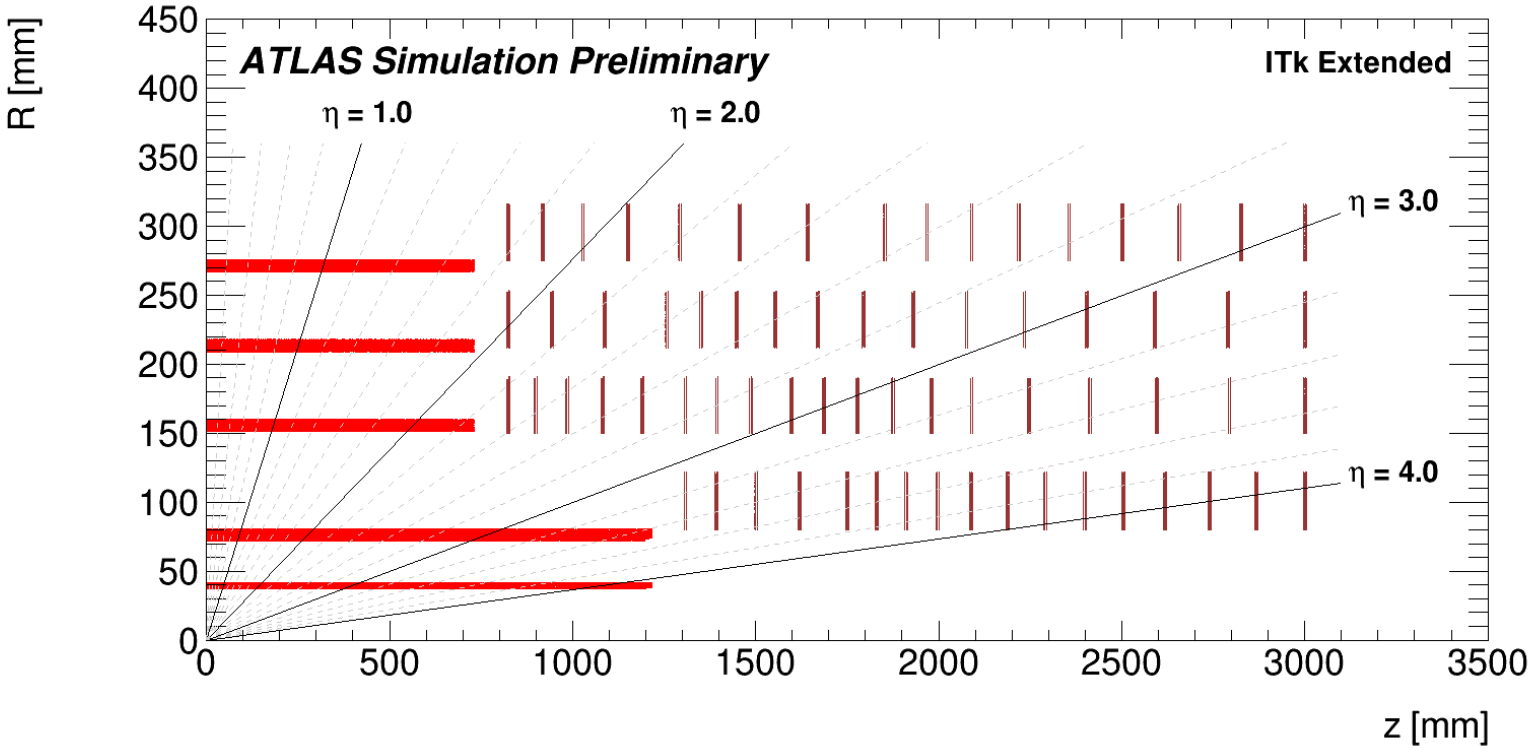
- HL-LHC will to deliver up to 4000 fb^{-1}
- Phase-II upgrade of ATLAS will replace the whole inner detector
  - ◀A new all silicon tracker
- The new Inner Tracker (ITk)
  - ◀Five pixel barrel layers and a ring end-cap system
  - ◀Four strip barrel layers and six end-cap discs
- Two proposed pixel system designs
  - ◀Extended Barrel
  - ◀Inclined Barrel



New reach of ITk

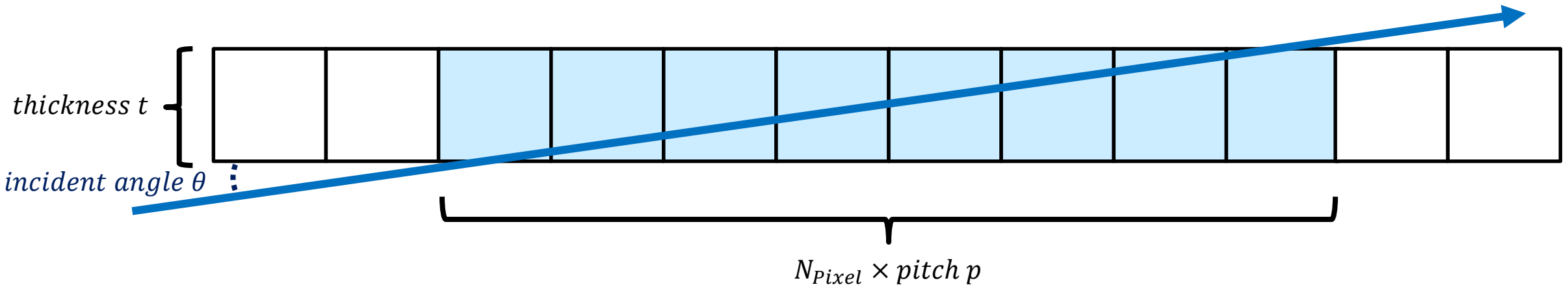
Extended Barrel

- Traditional pixel detector concept
  - ◀Staves with modules mounted parallel to the beam line
- Inner most two layers extended along the beam axis
  - ◀Barrel provides coverage for the very forward region η > 3.0



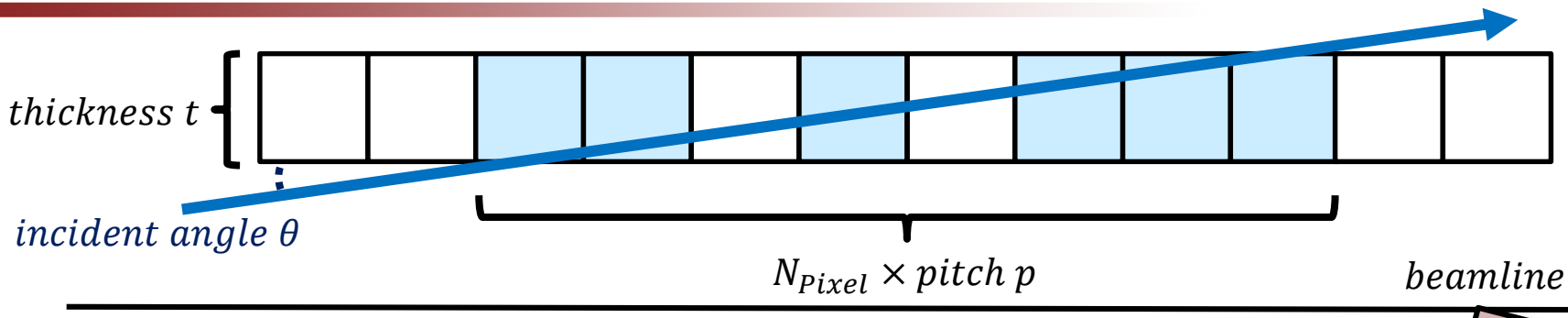
Extended Barrel

- Large incident angle particles will cross many pixels
  - ◀Produces long clusters
  - ◀Cluster length N defined as: $N = t/(p \times \tan(\vartheta)) + 1$



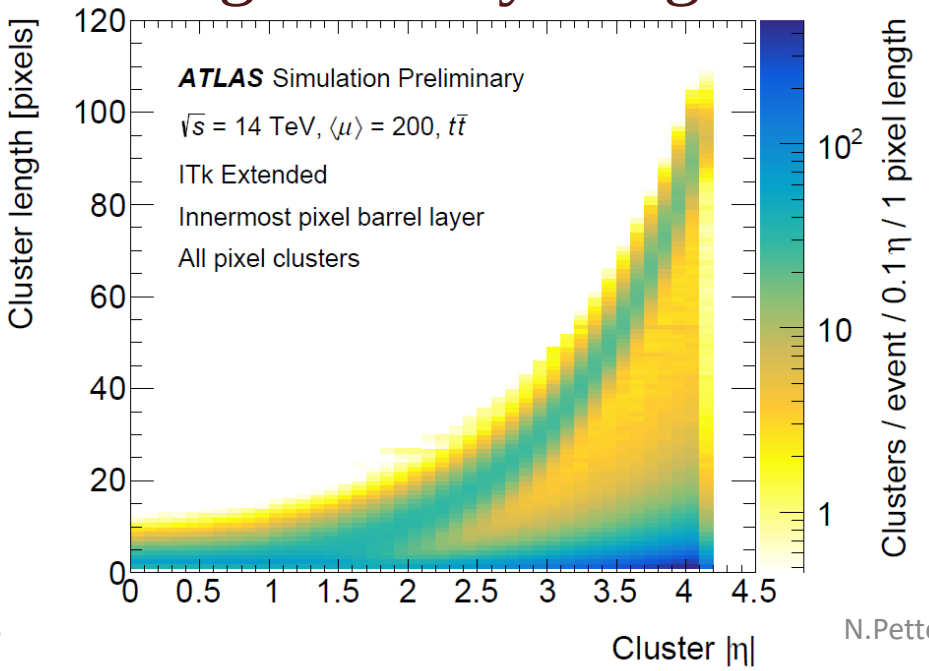
  - ◀Potential to provide more accurate position measurements
  - ◀Long clusters can be used as tracklet – Incident angle information

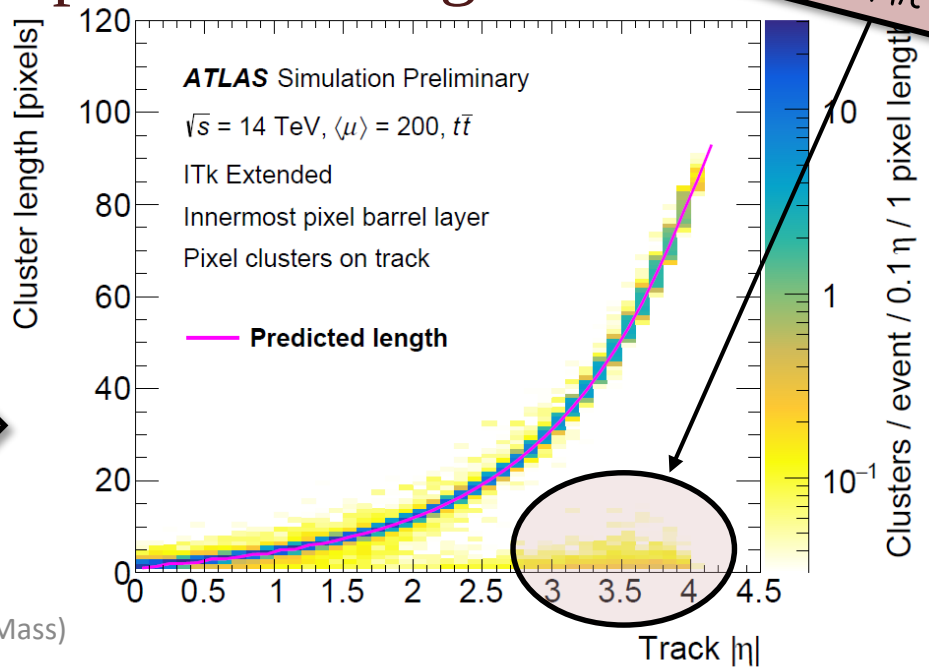
Extended Barrel



- Employ simple algorithm to merge split clusters
  - ◀Cluster length mostly in agreement with predicted lengths

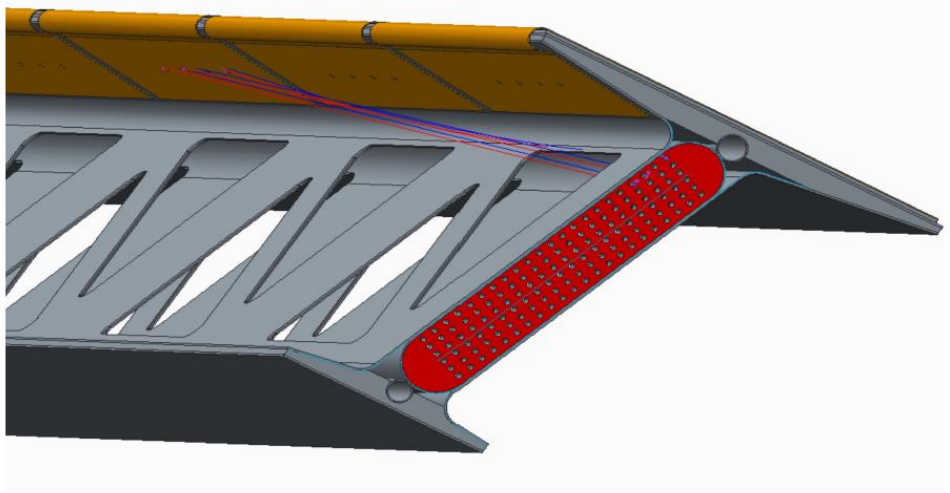
Fraction of small clusters in the forward region – secondary particles and remaining split clusters



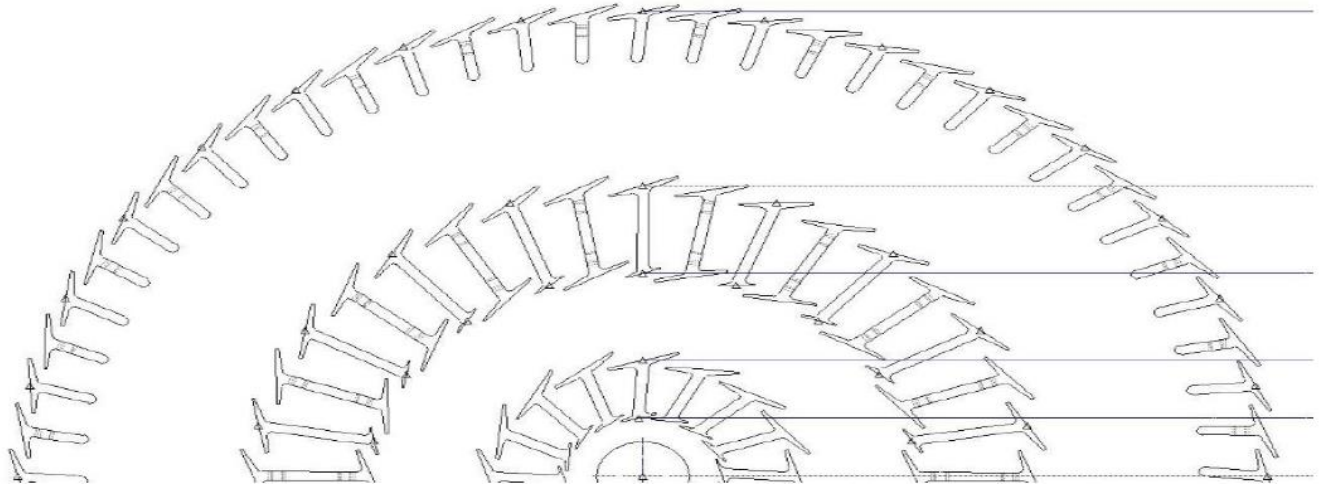


Extended Design

- Stave prototype for the Extended
  - ◀Supports dependent on the layout

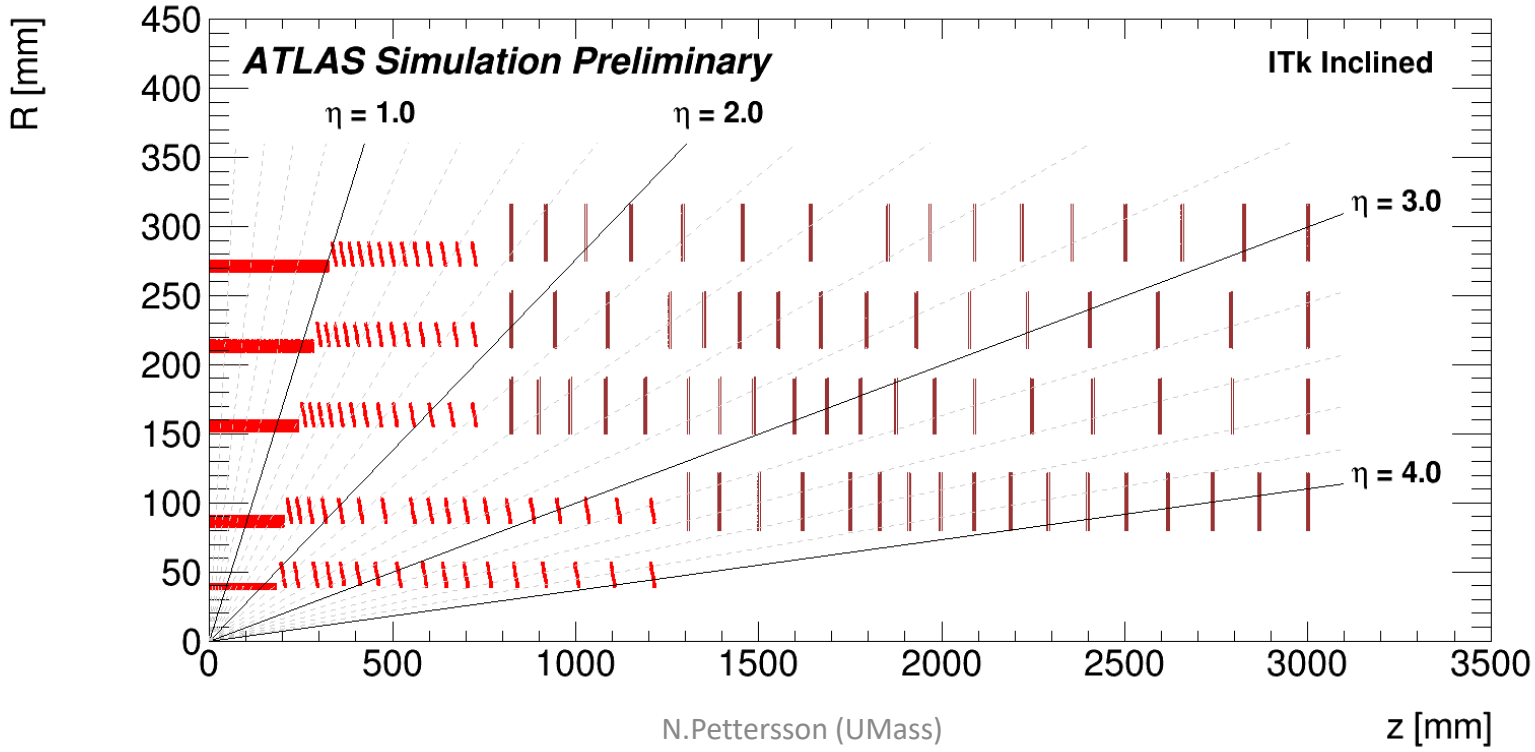


- I-Beam suggested concept
  - ◀Modules facing outwards
  - ◀Services and cooling
    - ◀Routed inside the structure



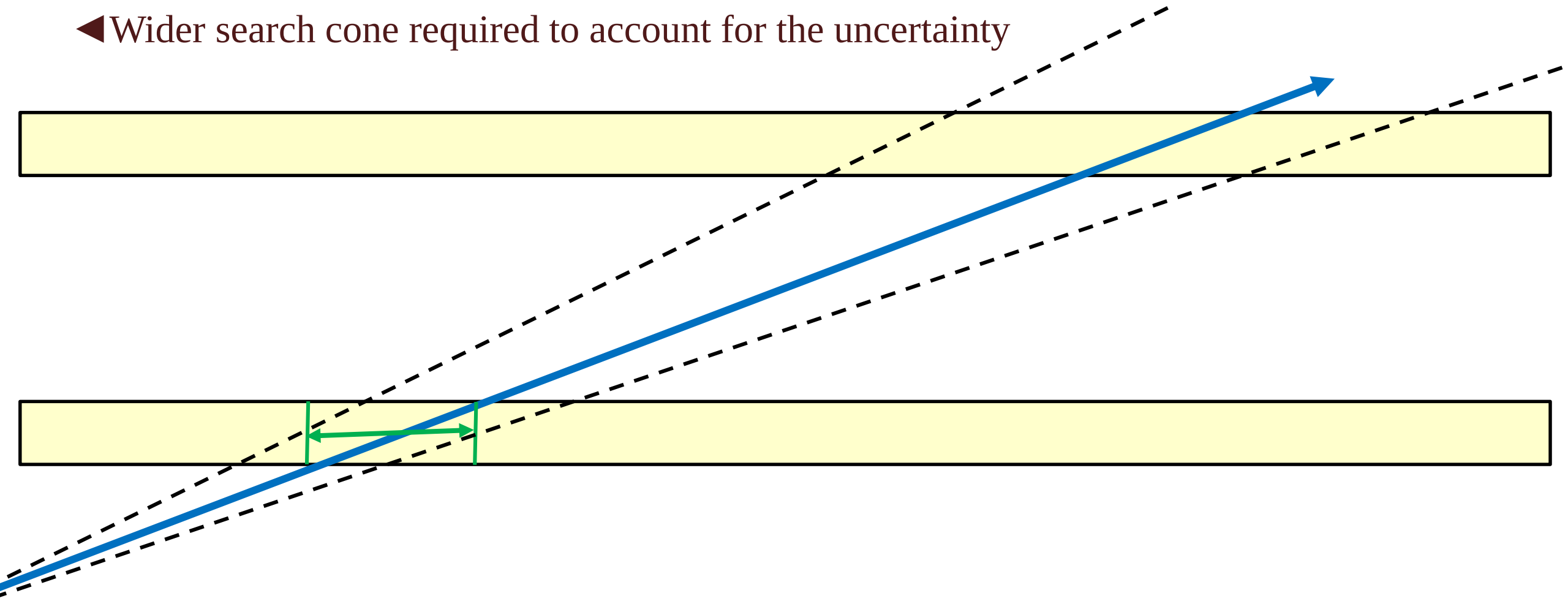
Inclined Barrel

- Shorter traditional barrel $\eta < 1.0$
- Modules are placed at an inclination in all five layers
  - ◀ The barrel provide coverage up to η: 4.0
- For this version of the layout, the Inclined uses the same End-Cap ring system as the Extended
  - ◀ To provides better comparison of the two different barrel pixel candidate layouts
  - ◀ The Inclined gets an ”excess” of hits in the forward region due to this
  - ◀ Will be optimised!



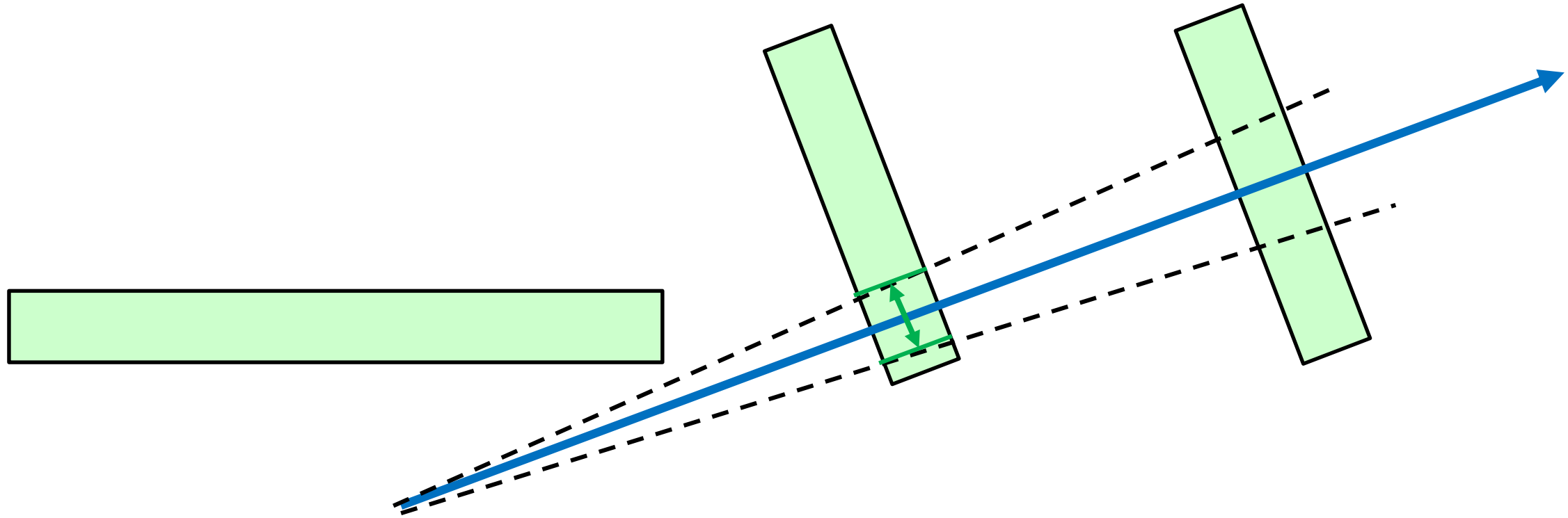
Extended Traditional Barrel versus Inclined Barrel

- In traditional barrel the amount of material crossed increase with incident angles
  - ◀Wider search cone required to account for the uncertainty



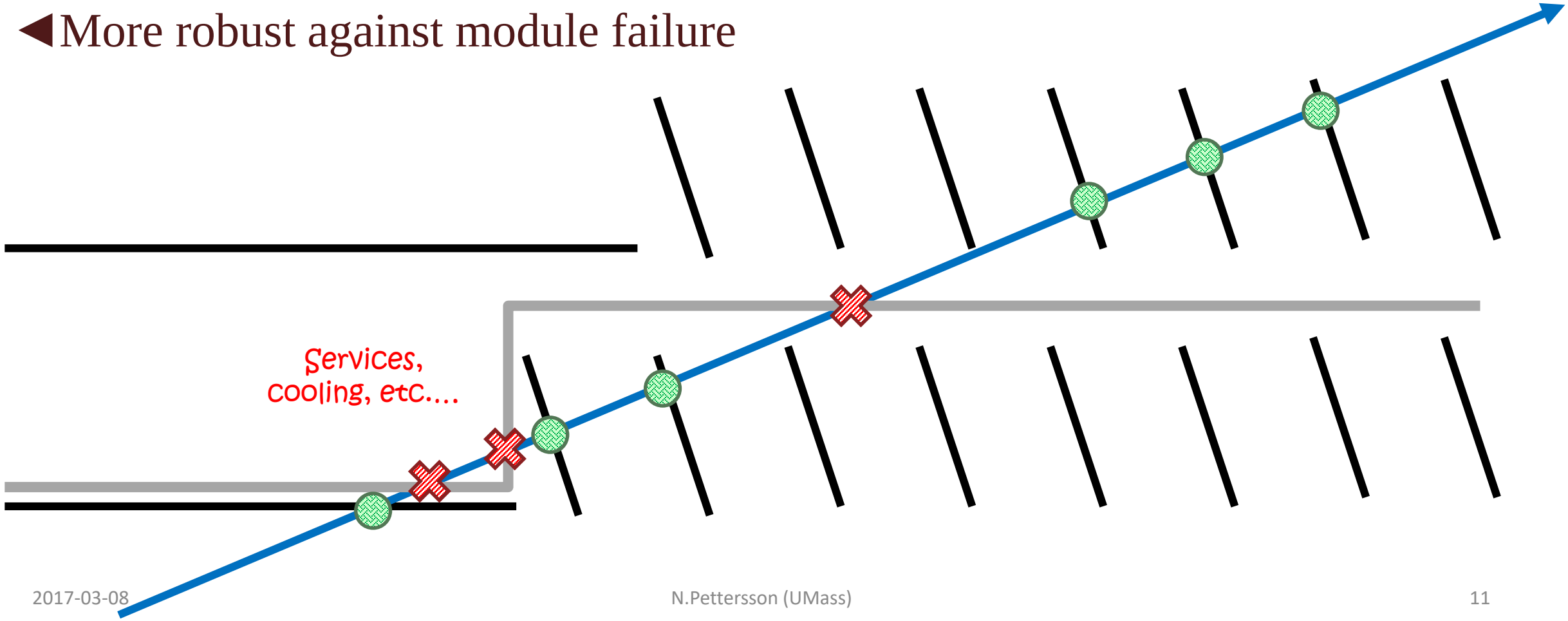
Inclined Barrel

- Smaller incident angles on tilted surfaces
  - ◀Less material traversed → smaller uncertainties before the next measurement



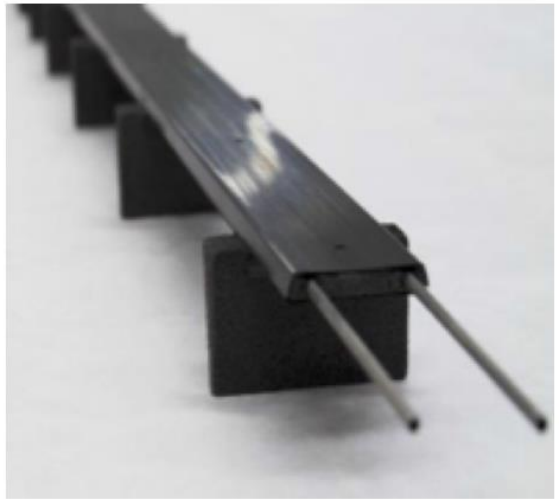
Inclined Barrel

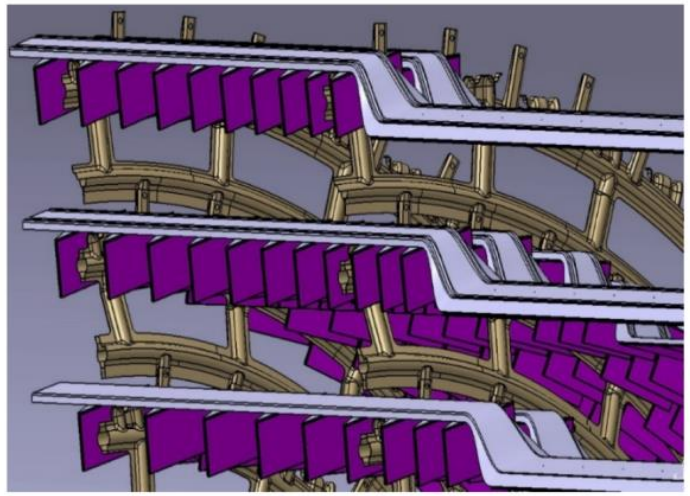
- Multiple hits aids the pattern recognition
  - ◀By minimising extrapolation distance between hits and material crossed
  - ◀More robust against module failure



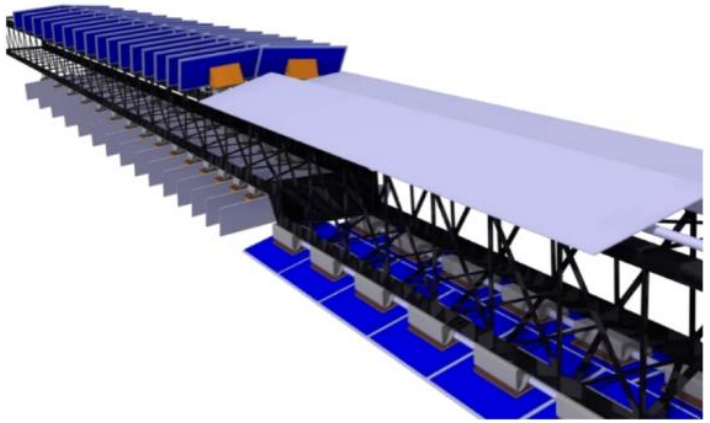
Inclined Design

- Two stave prototypes are proposed for the Inclined
  - ◀Alpine and SLIM – Must hold two types of modules

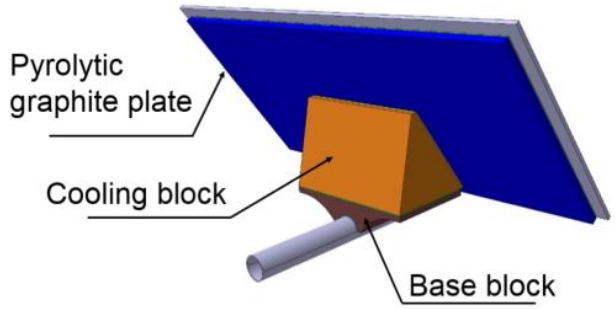




SLIM:
Supports two layers of modules
Individual modules "easy" to replace due to the module cells

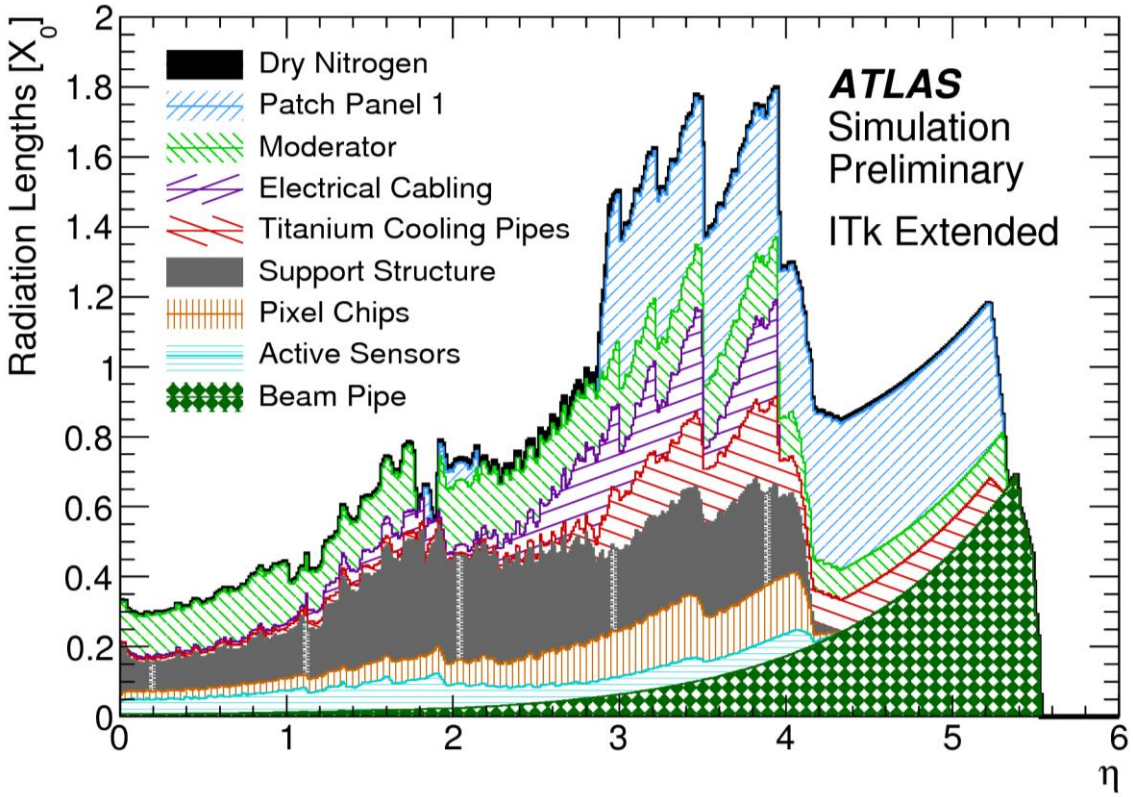


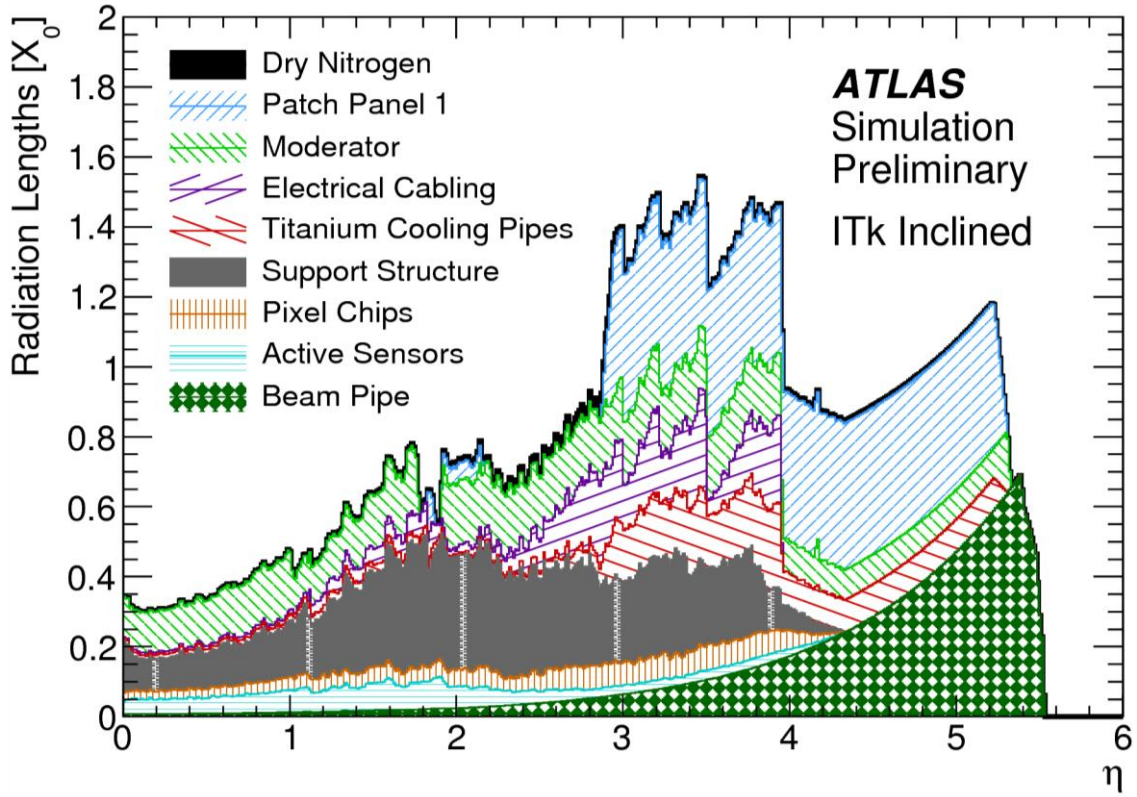
Alpine:
Carbon foam mountains and carbon fibre stave design



Material Budget of the ITk

- Early estimate of the material budget for the two layouts
  - ◀Preliminary modelling
    - ◀Includes uncertainty with respect to the current engineering solutions
  - ◀Inclined has less material – as it is designed to be

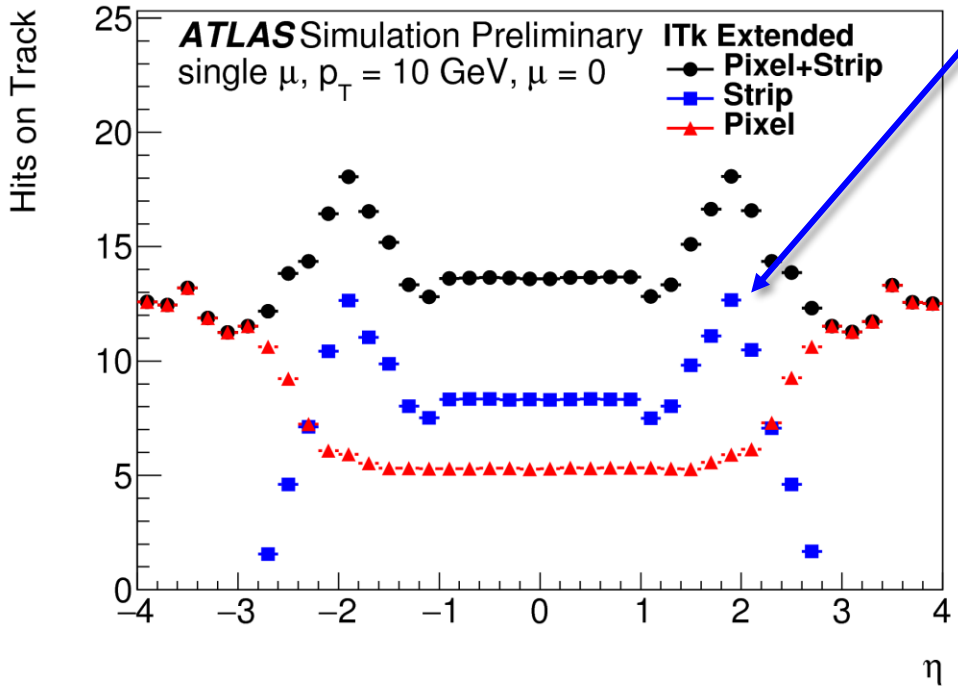


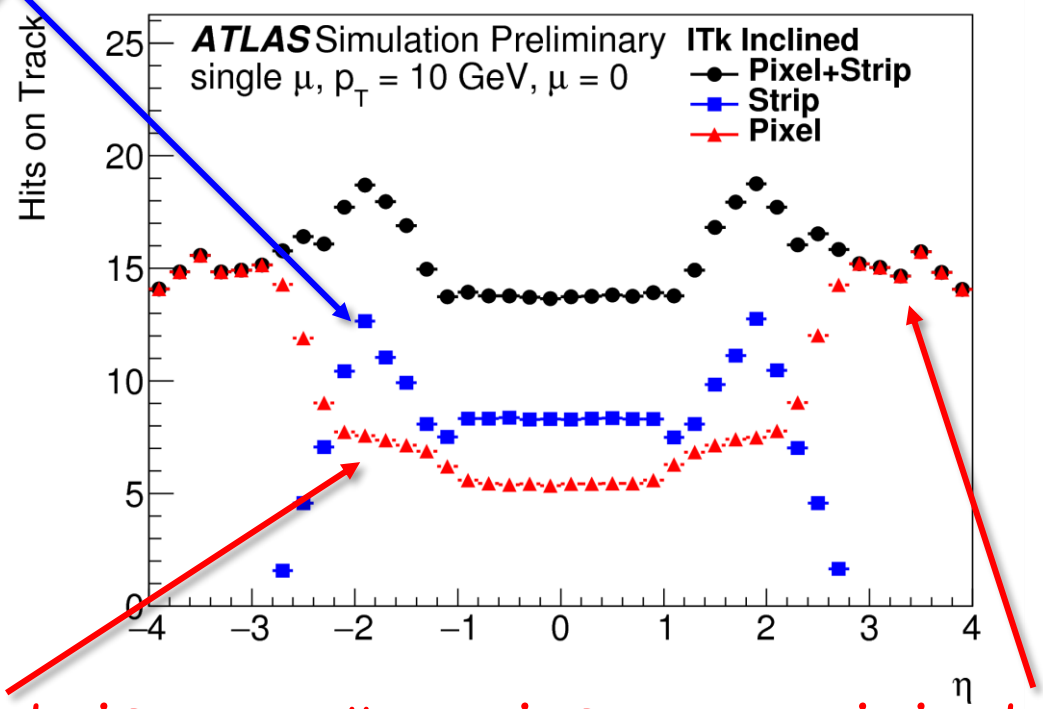


Average Number of Hits

- Both layouts to provide hermetic coverage with an average of >=9 hits
  - ◀Going from z-vertex position: -15.0 to +15.0 cm
  - ◀In the very forward the extended produces 6 hits rather than 9

Both Layouts have the same Strip system and therefore the same number of Strip Hits





The Inclined provides more pixel hits due to its design, as well as using a non-optimised ring system

Track Reconstruction Requirements

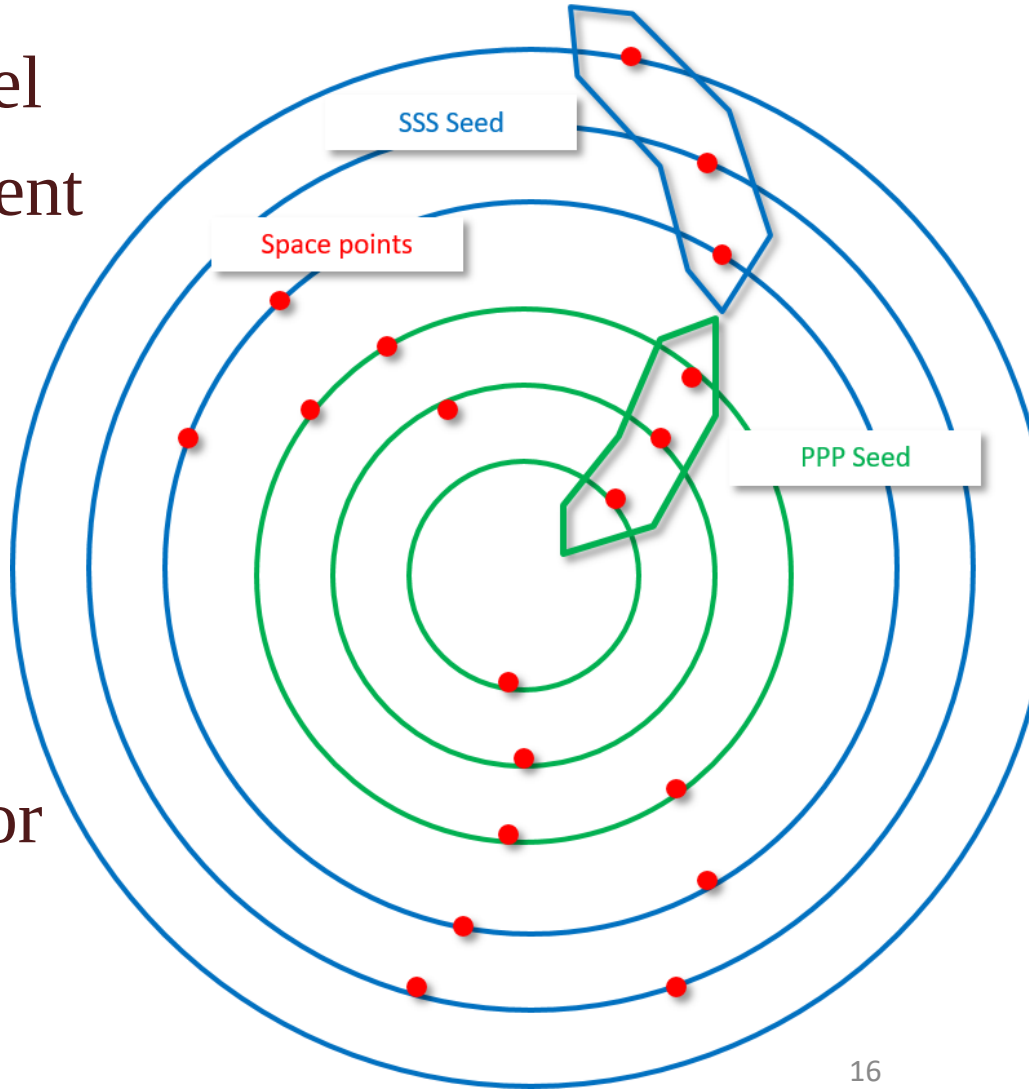
- Designed with 1 GeV particles in mind
- Split the requirements up in intervals of η
  - ◀The magnetic field declines η > ~2.5
    - ◀Worse the p_T resolution in the forward regions
  - ◀Number hits available reduced for the Extended layout

Extended (Inclined) layout

Requirement	Pseudorapidity interval		
	$\lvert\eta\rvert < 2.7$	$2.7 < \lvert\eta\rvert < 3.4$	$3.4 < \lvert\eta\rvert < 4.0$
Pixel+Strip clusters	≥ 9	$\geq 7(9)$	$\geq 6(9)$
Pixel clusters	≥ 1	≥ 1	≥ 1
Holes	< 3	< 3	< 3
Pixel holes	< 2	< 2	< 2
Strip holes	< 3	< 3	< 3
p_T [MeV]	> 900	> 400	> 400
$\lvert d_0\rvert$	≤ 2 mm	≤ 10 mm	≤ 10 mm
$\lvert z_0\rvert$	≤ 25 cm	≤ 25 cm	≤ 25 cm

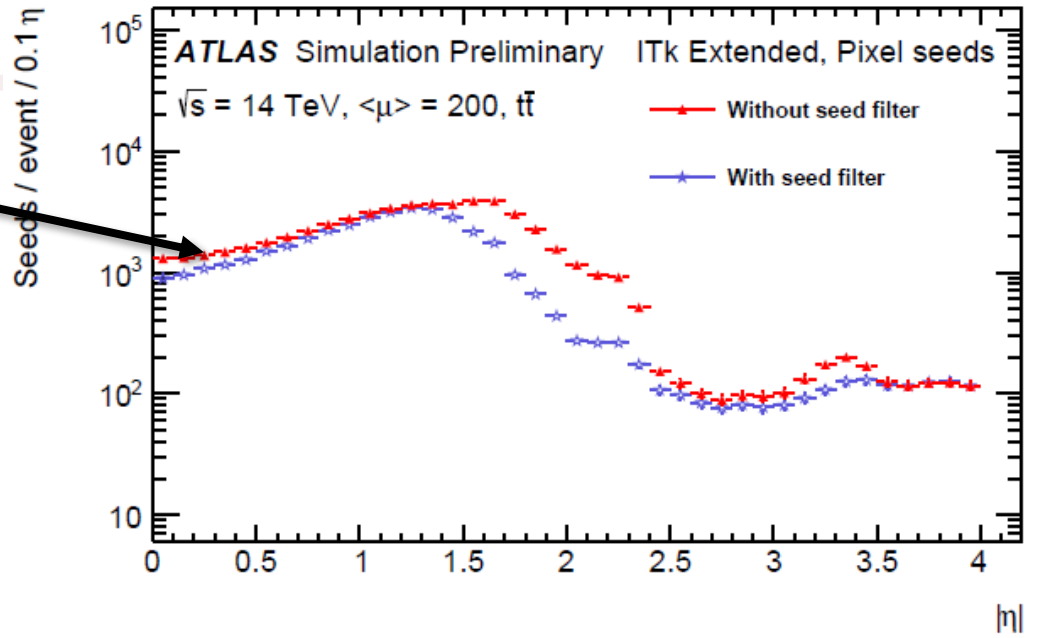
Track Seeding

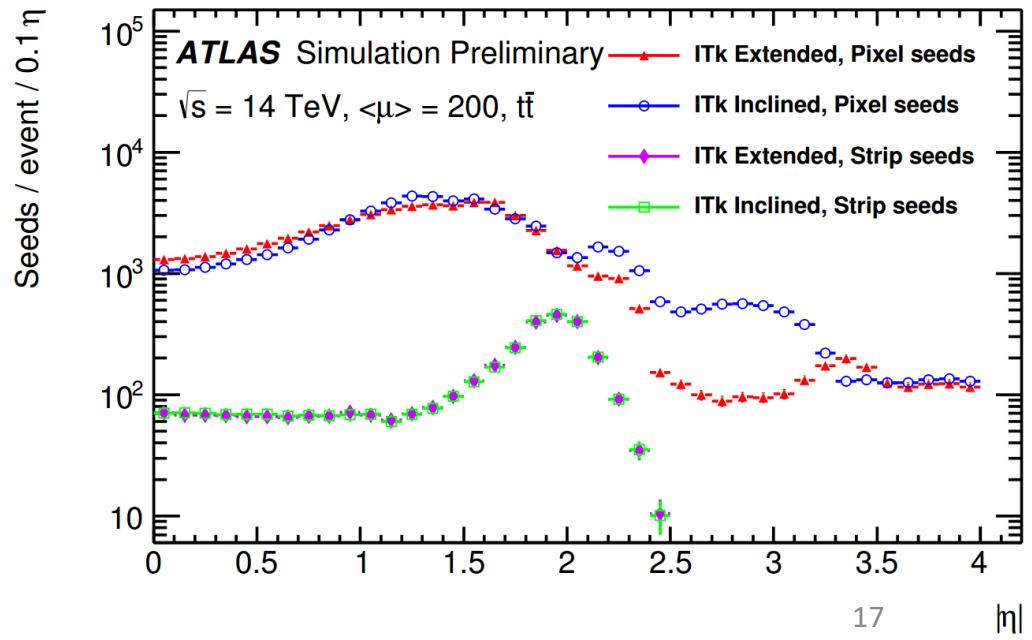
- Seed are formed by 3 x space points (SP)
  - Must be compatible with a helical track model
  - PPP (Pixel) and SSS (Strips) will have different purity as the hit density and SP resolution
- Fourth layer confirmation
  - The 3 x SP extended inwards or outwards
  - Adding an extra hit in the layer
    - Must be compatible with the seed helix
  - Reduce the number of candidates to search for



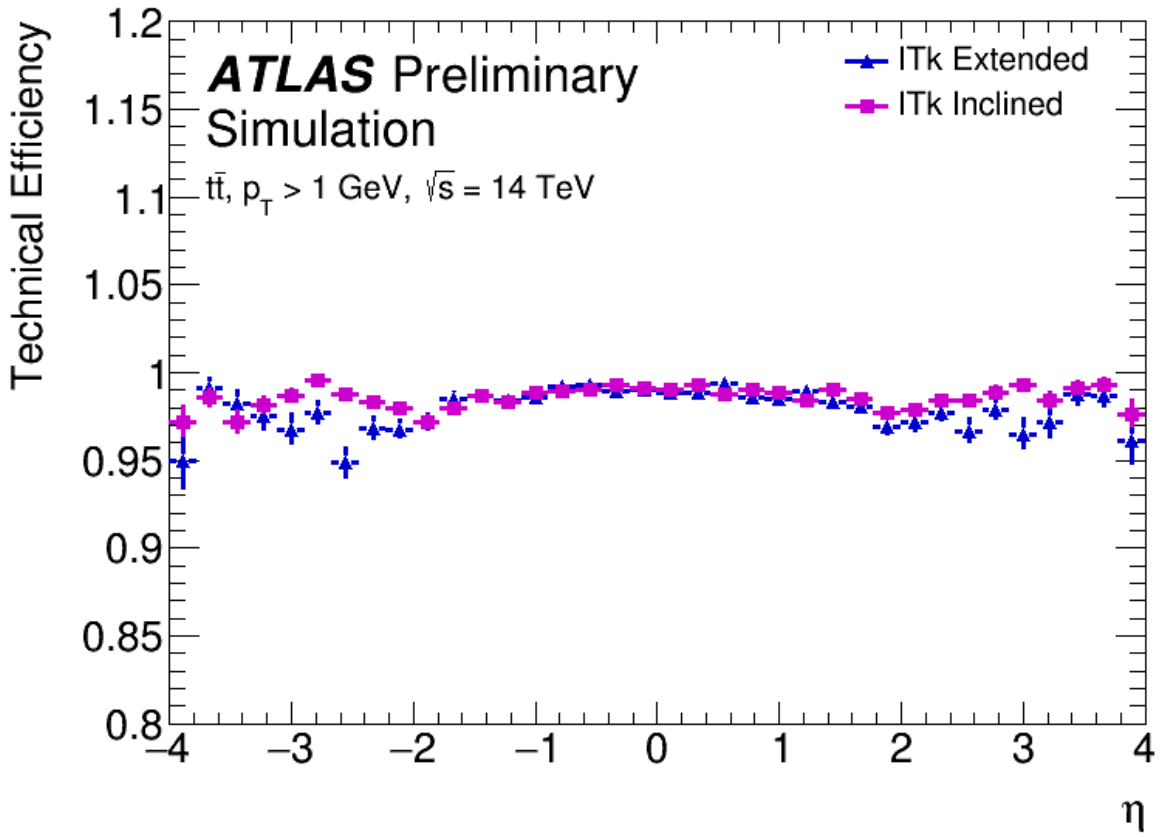
Track Seeding

- Seed filter developed for the Extended
  - Reject seeds with a barrel pixel cluster inconsistent with the seed angle
  - Intended to reduce the number of initial seeds to save computing resources
- Similar number of seeds for both layouts $|\eta| < 2.0$
  - Central pixel barrel much the same
  - Identical Strips designs
- The forward region $2.0 < |\eta| < 3.5$
  - Inclined has more seeds as it has more available hits
- Nearly the same results $|\eta| > 3.5$





Technical Tracking Efficiency



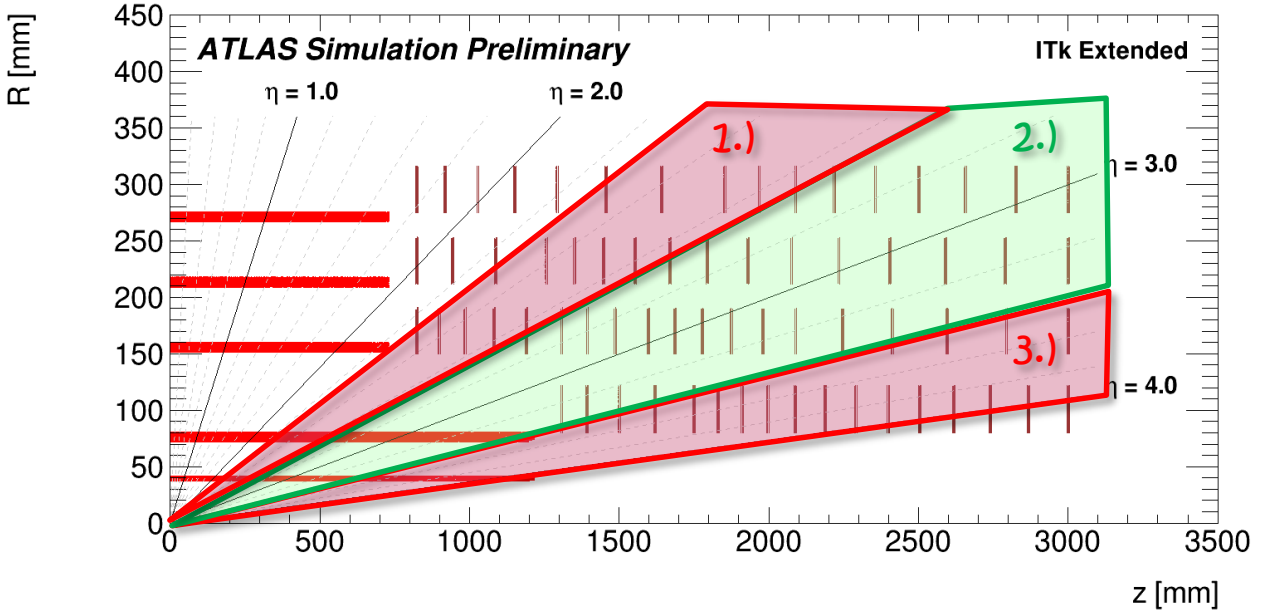
- Any non-acceptable weakness in the tracking shows up as inefficiency in the technical efficiency
  - ◀Take into account only particles leaving enough measurements to be reconstructed
  - ◀Losses due to material interactions are neglected

Close to 1 in the central region! But few problematic regions in the forward…
Mostly caused by remaining pattern recognition problems for the Extended layout $|\eta|$:~2.5-4.0

Technical Tracking Efficiency

- The Extended layout has a few pattern recognition problems with the long clusters
  - ◀More likely to have seeds where the inner-most SP is not in the inner-most layer
  - ◀Deterioration of the seeds $\sigma(d_0)$
  - ◀Fails certain seeding criteria

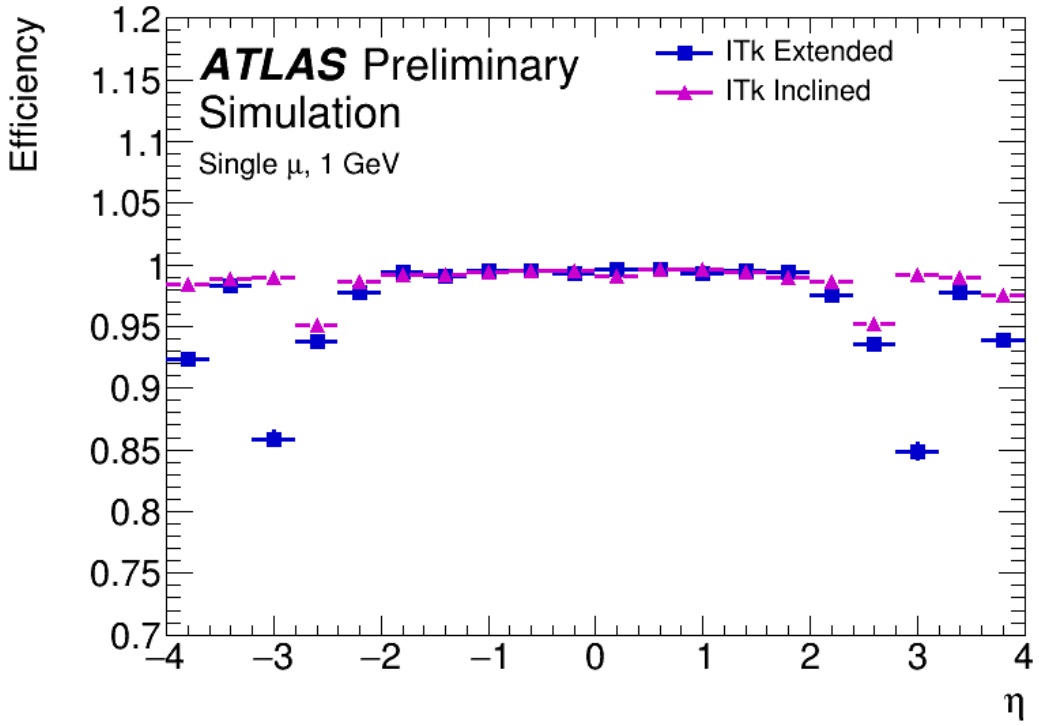
1) Start to lose efficiency at $|\eta| > 2.0$
2) Regain for $|\eta| > 2.7$ by increasing d_0 cut from 2 mm to 10 mm
3) Start losing again for $|\eta| > 3.5$ where the cut 10 mm is not enough anymore
   - ◀This region also has problems picking up all clusters...

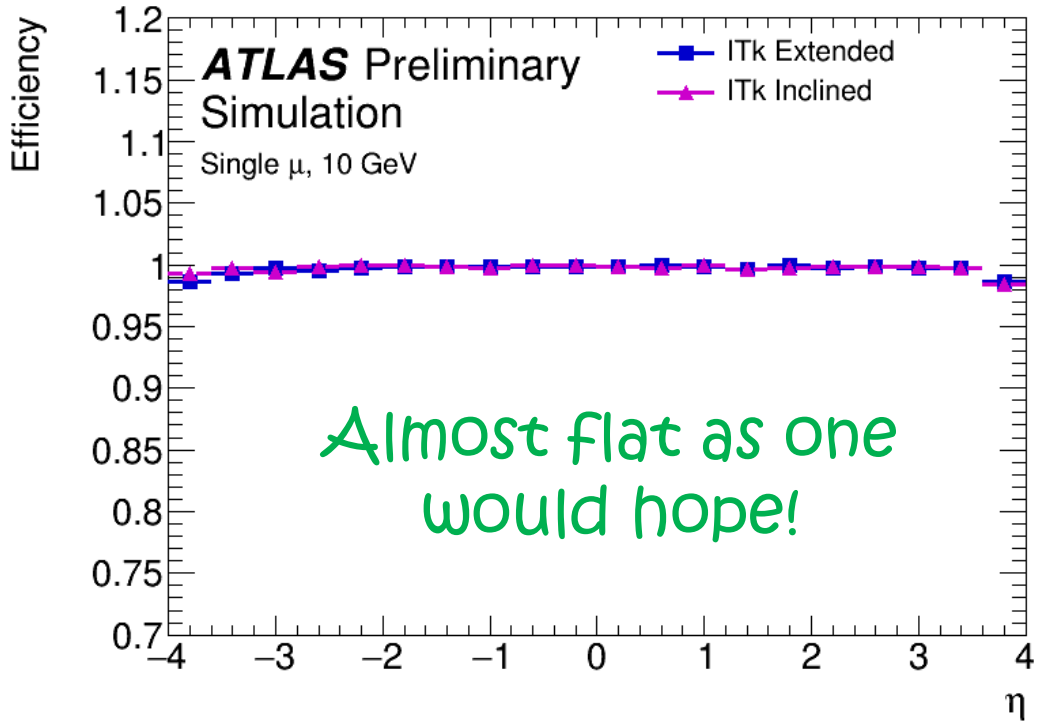


Requirement	Extended (Inclined) layout: Pseudorapidity interval		
	$\lvert\eta\rvert < 2.7$	$2.7 < \lvert\eta\rvert < 3.4$	$3.4 < \lvert\eta\rvert < 4.0$
$\lvert d_0\rvert$	≤ 2 mm	≤ 10 mm	≤ 10 mm

Physics Tracking Efficiency

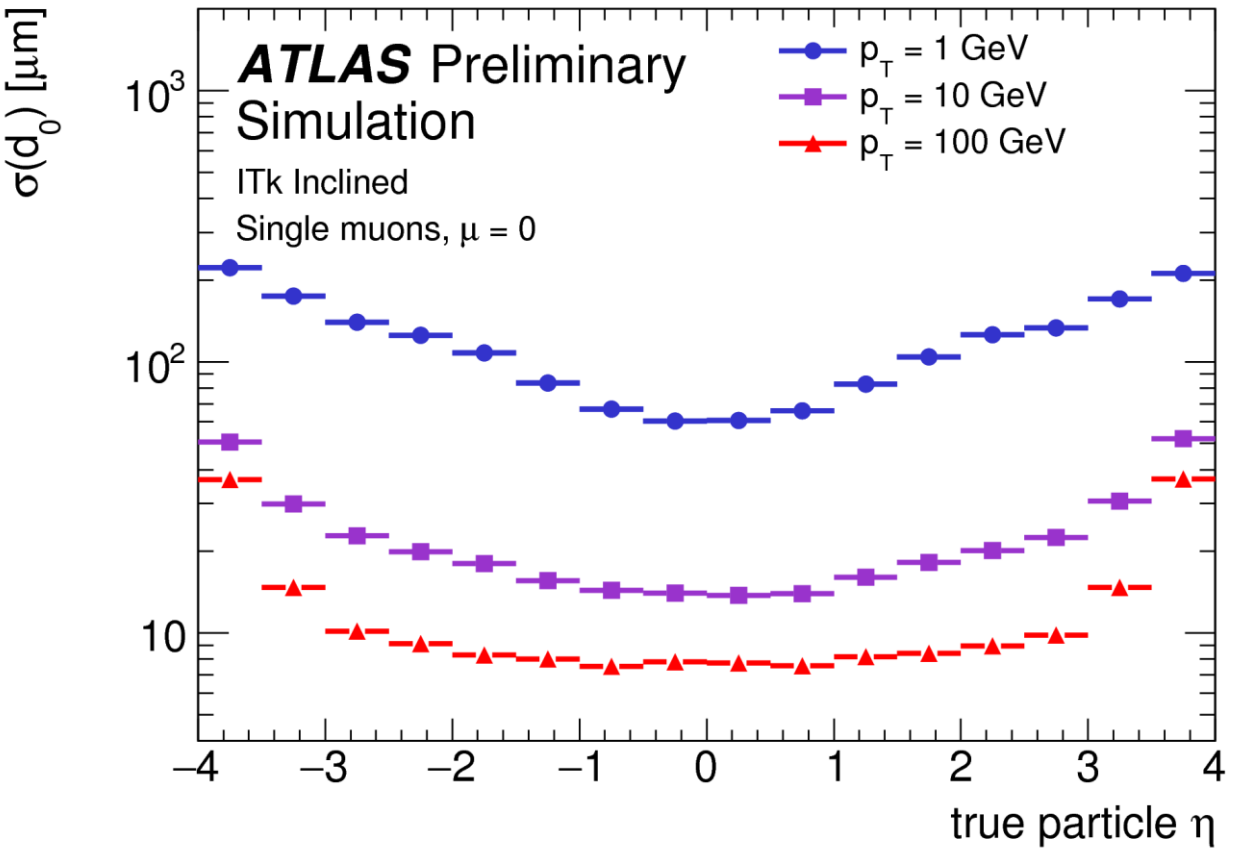
- Going back to the normal efficiency definition…
  - ◀Looking at single muon with fixed p_T of 1 GeV and 10 GeV
- At low momentum the pattern recognition problems are enhanced
  - ◀Also the inclined layout shows decreasing efficiency $|\eta| > 2.0$
    - ◀Indicating that the η-cut-off are not ideal - need to revisit cut intervals...





Impact Parameter Resolutions

- *Transverse impact parameter d_0* for the Inclined layout

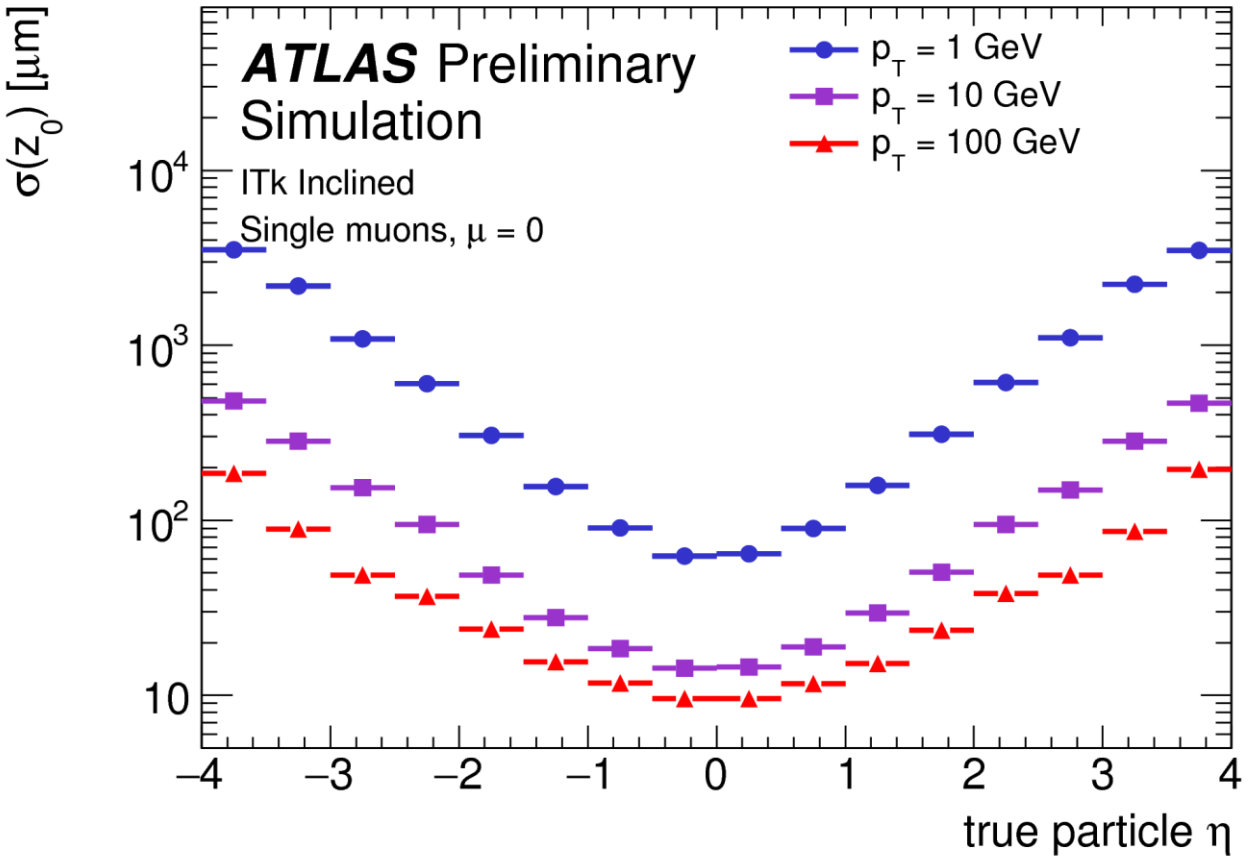


- Low p_T = 1 GeV
  - ◀Expected to perform very similar to the Run-II ATLAS ID
- Middle p_T = 10 GeV
  - ◀Again similar expect results
- High p_T = 100 GeV
  - ◀Possibility to improve the resolution in the future by applying analogue clustering

Impact Parameter Resolutions

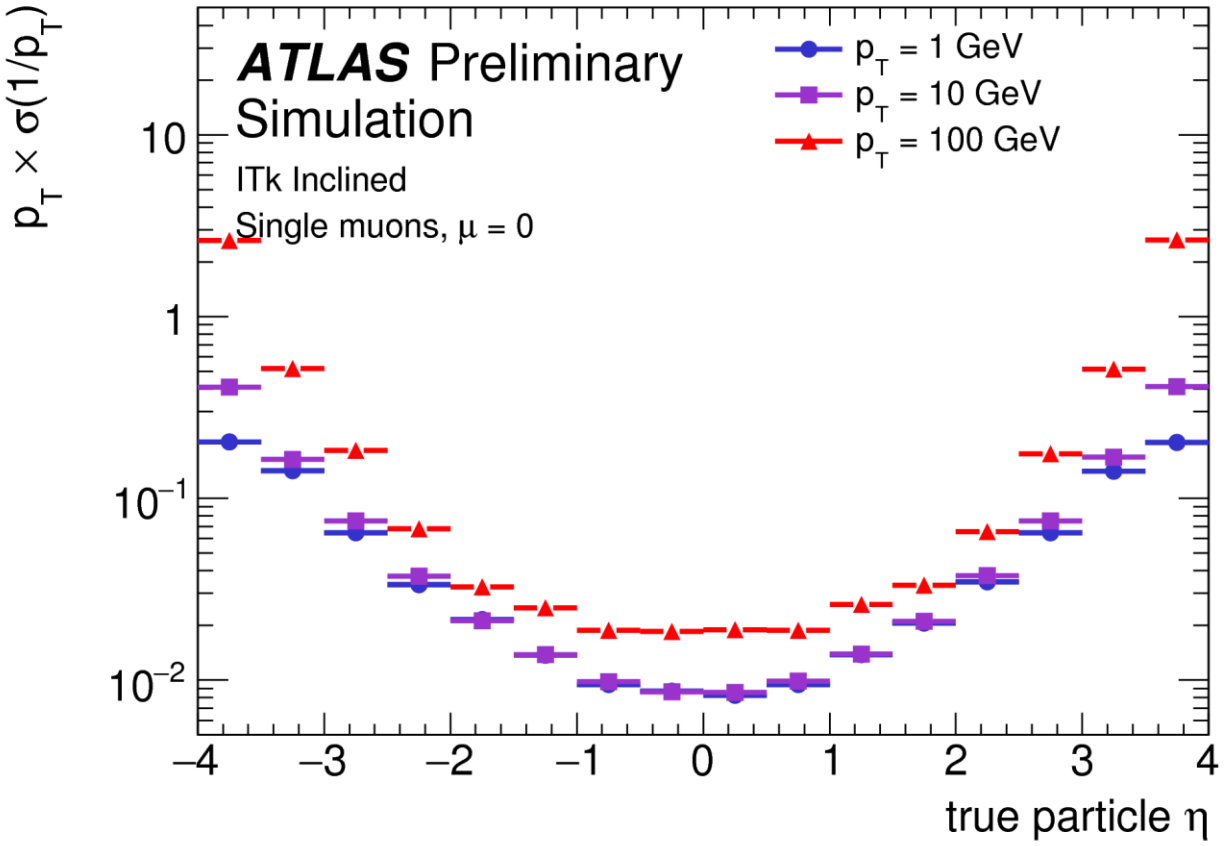
- *Longitudinal impact parameter* z_0 for the Inclined layout

- Smaller longitudinal pixel pitch in the ITk than in current ATLAS
  - ◀$50 \times 50\ \mu m^2$ ITk
  - ◀$50 \times 250(400)\ \mu m^2$ Run-II IBL (Rest)
- ITk performing is expected to perform better at all momenta
  - ◀Difference increases at higher p_T where the intrinsic resolution plays a key role



Momentum Resolutions

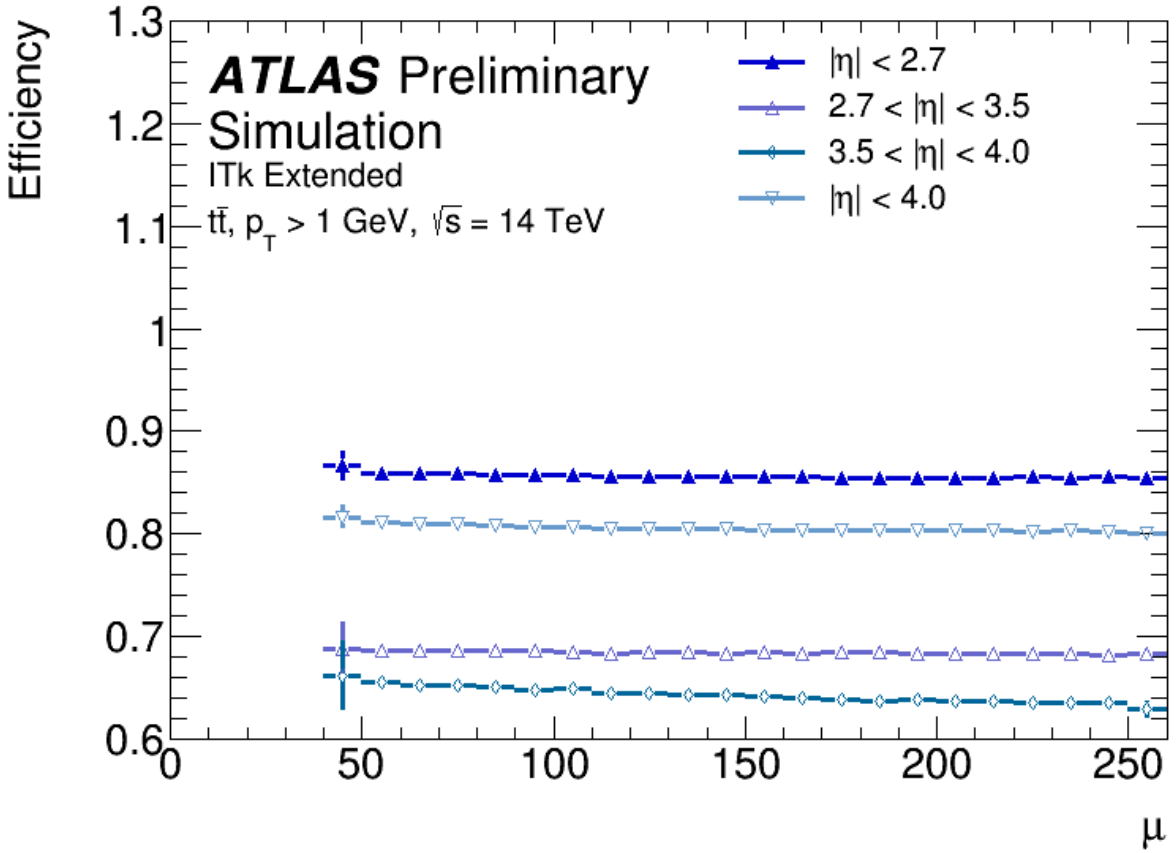
- Momentum resolution $p_T \times \sigma(^1/_{p_T})$ for the Inclined layout

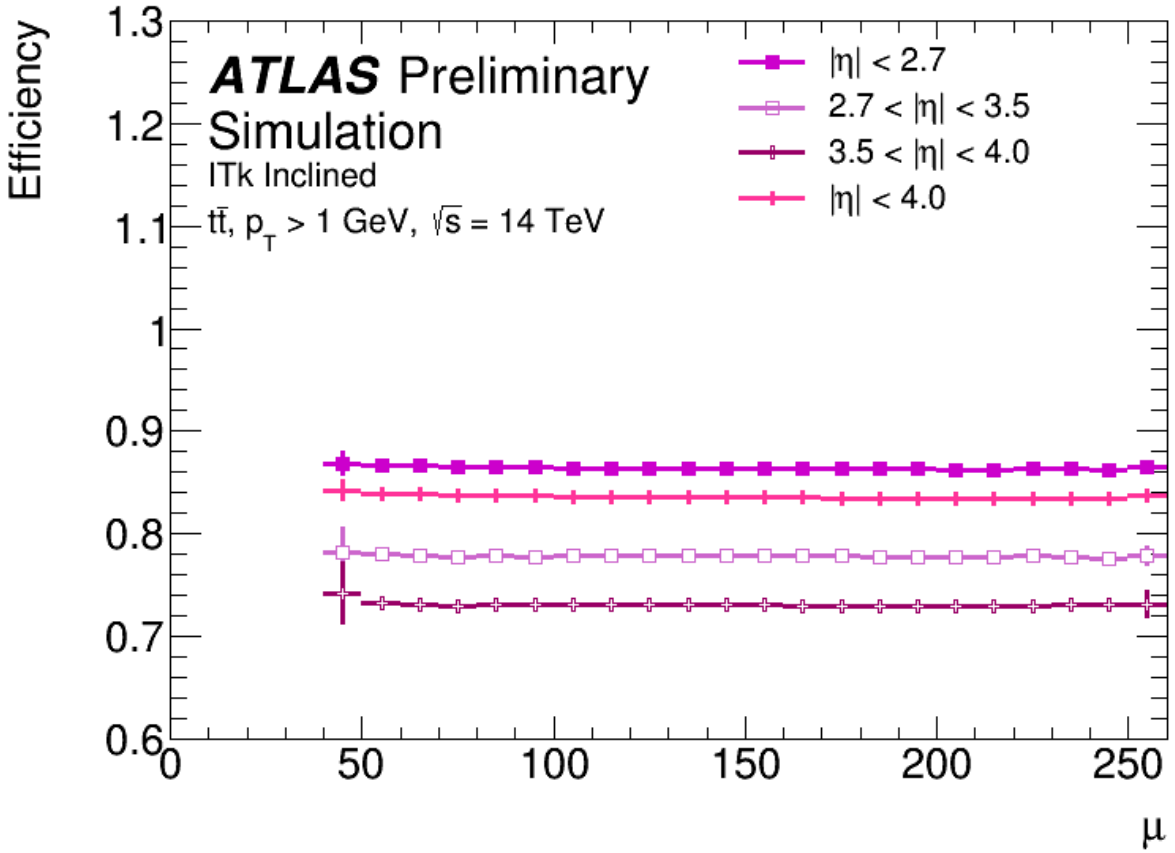


- The benefit of high precision measurements of the all-silicon tracker of the ITk should yield a better momentum resolution than the current ATLAS ID

Pile-up Robustness

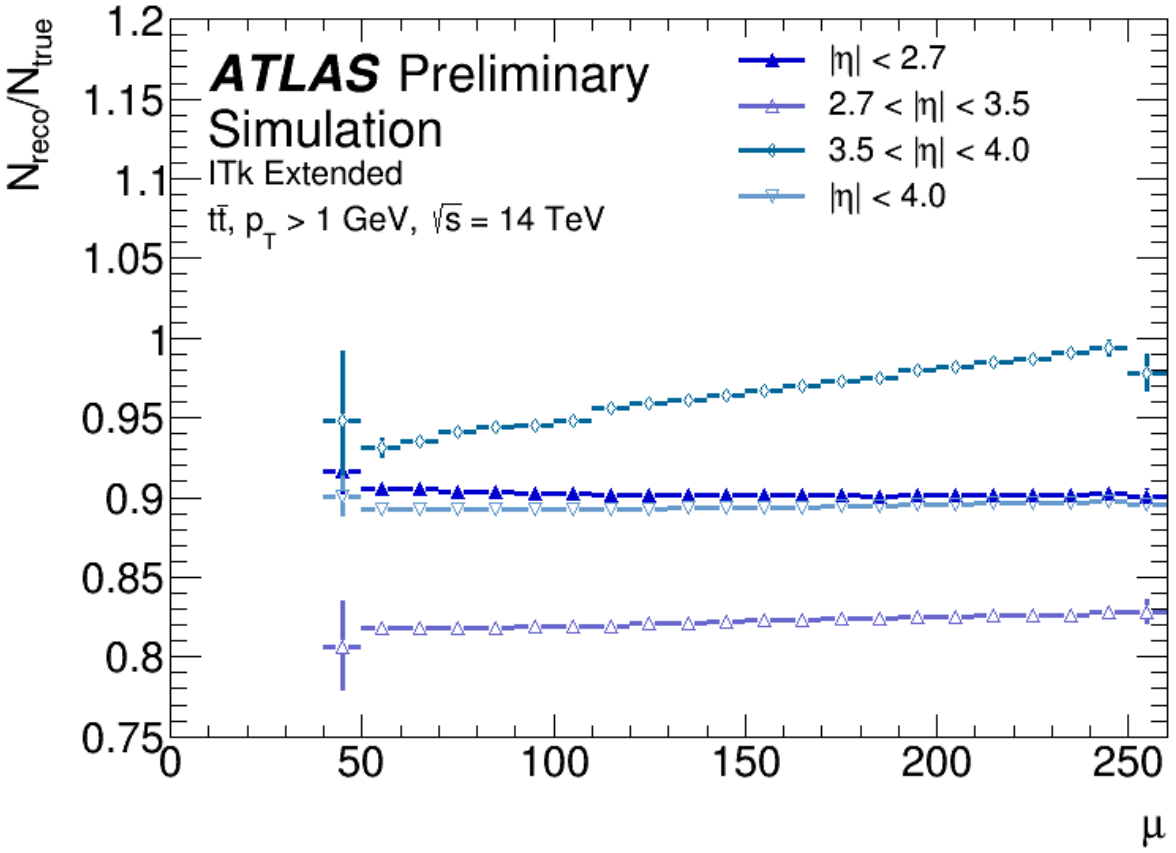
- The future tracker must be able to cope with the environments produced by the HL-LHC
  - Track reconstruction efficiency versus μ extremely stable for all intervals of η
  - Exception for the Extended layout in the very forward bin $3.5 < |\eta| < 4.0$ where the efficiency decreases with pile-up

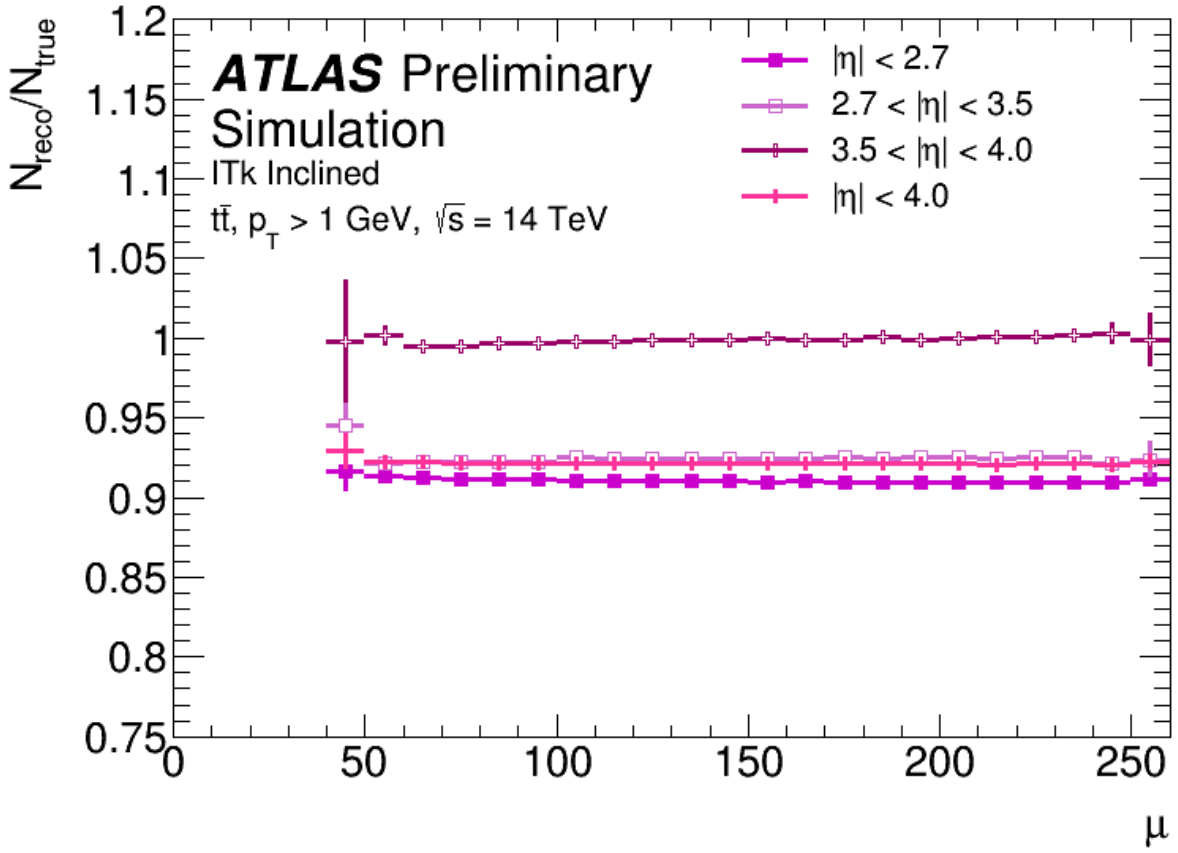




Pile-up Robustness

- An inclusive rate of number of reconstructed tracks over the number of generated particles
- Likewise the efficiency, these rates are independent of pile-up for the inclined layout
  - ◀ Which indicates these candidate layout has no problem with increased number of fakes
- The extended layout show a slight increase in the rate with μ for $|\eta| > 3.5$

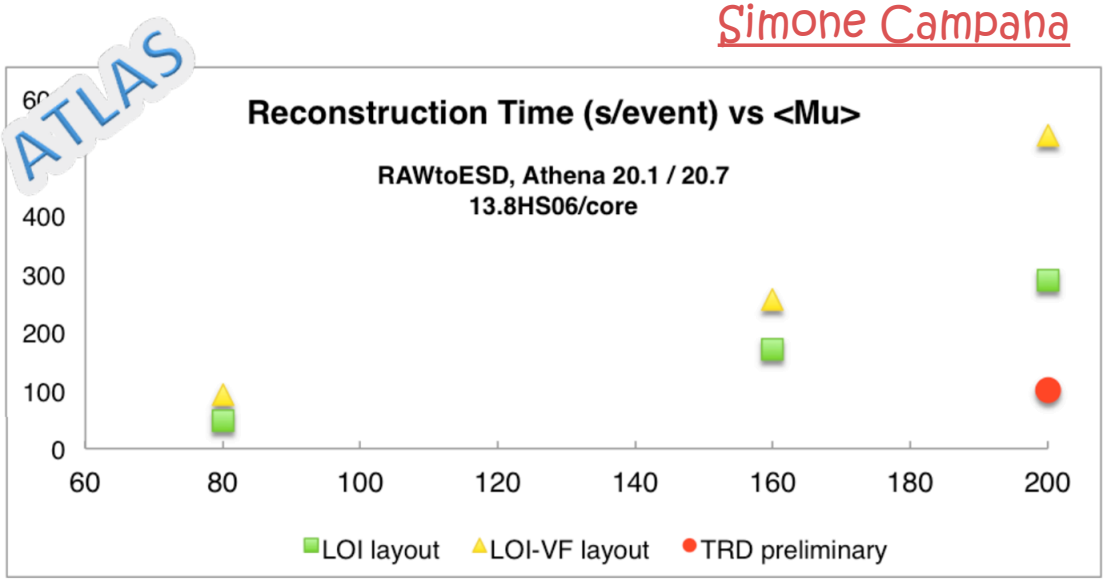




Evaluation of Computing Requirements

Simone Campana

- Reconstruction CPU for the The LoI (2012 Letter of Intent) and the ITk
- Reconstruction is faster for the ITk layout candidates than Run-II
  - ◀Full silicon tracker and less material helps speed up
- Significant improvements to reconstruction since the LoI-era has yielded a decrease nearly a factor of 2



- Break down of the major parts of reconstruction shows that both layouts are very similar
  - ◀ Extended somewhat slower in the clusterization
    - ◀Cluster merging algorithms employed
    - ◀Can be improved with optimisation

Conclusion & Discussion

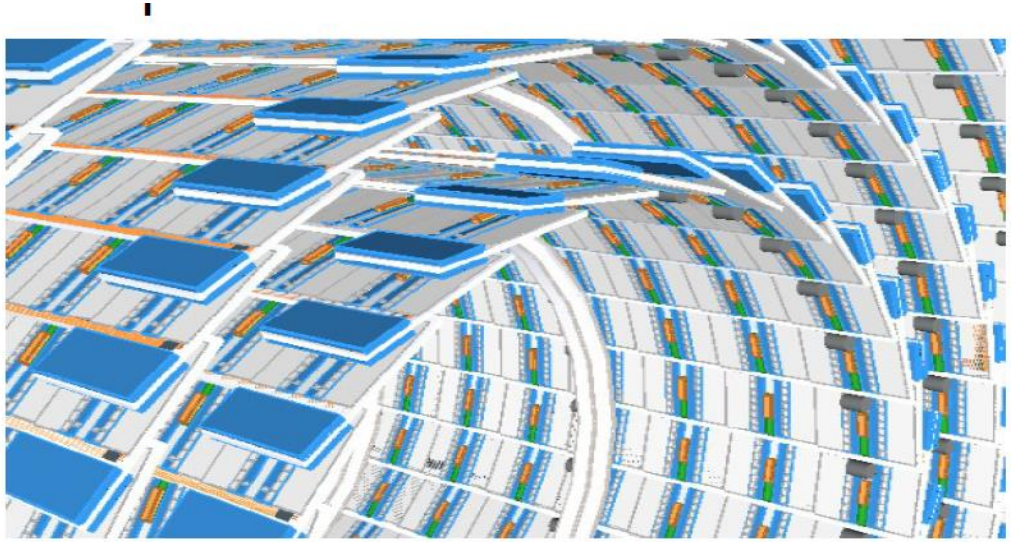
- The two candidate layouts for the future ITk show promising results
  - ◀High efficiency for all η-regions
  - ◀Similar or better resolutions
    - ◀Except for d_0 which is to be improved with analogue clusterization methods
  - ◀Extremely stable efficiency and fake rate with pile-up
- For the future as we move to a more realistic layout proposal…
  - ◀Looking into any improvements that can be made
    - ◀Suggestions are of course very welcome!
  - ◀Move towards ACTS – See talk on Thursday

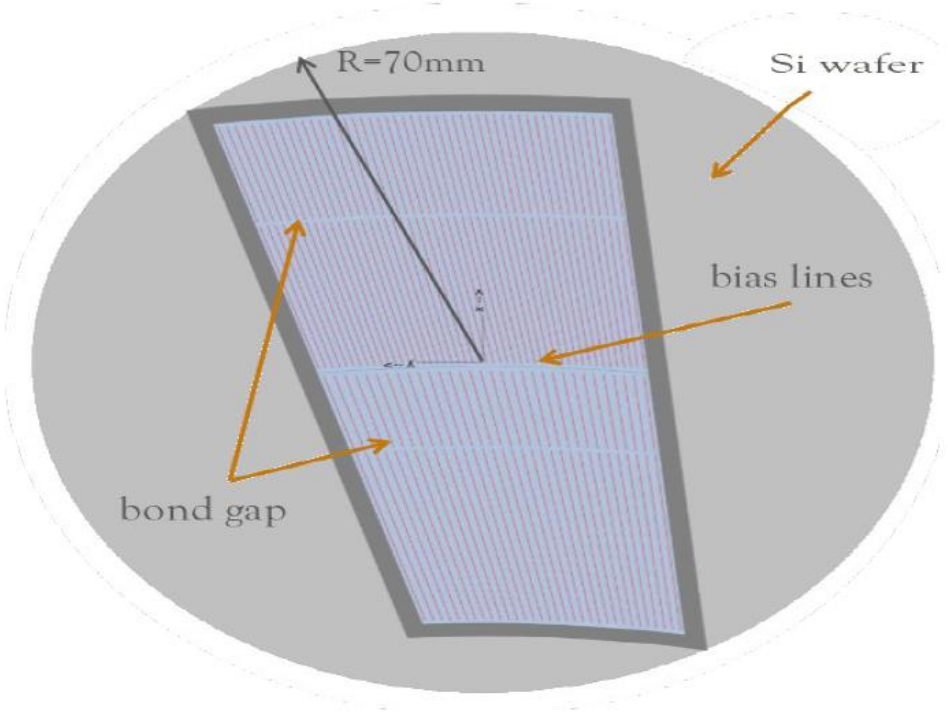
[1] ATL-PHYS-PUB-2016-025
[2] ITk Performance

BACKUP

ITk Strip Design

- Barrel consist of 4 double-sided layers
  - ◀With stereo angle of ±26 mrad





- Endcap got 6 double sided petals
  - ◀Different types of sensors
    - ◀Depending on radius