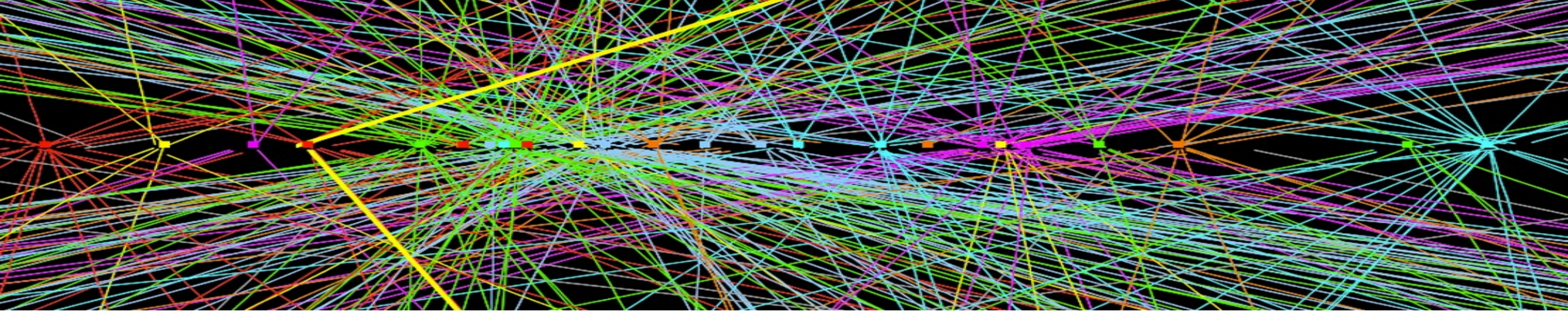

ATLAS Timing opportunities beyond Run 4

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SLAC
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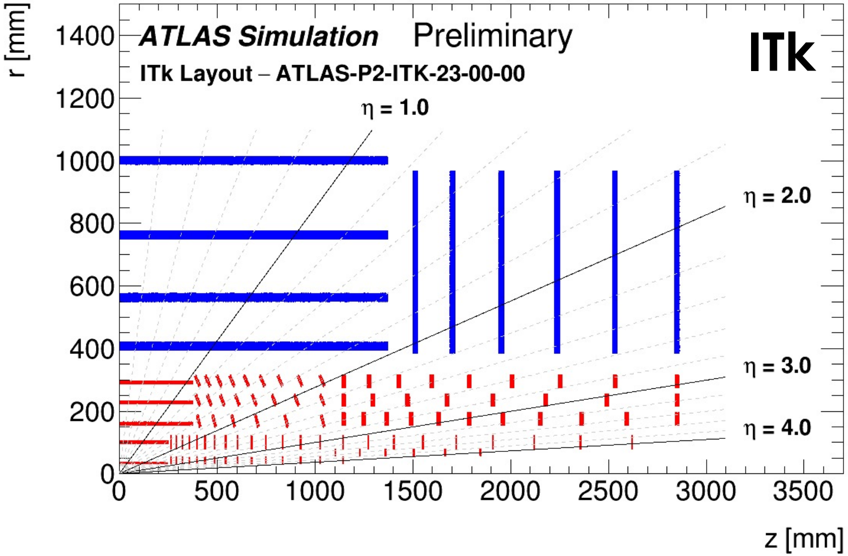
CERN

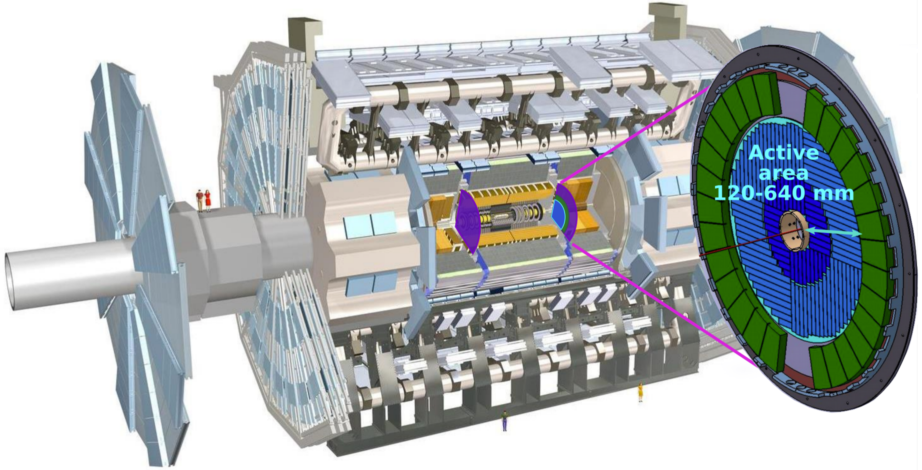
HSF Meeting: 4D Reconstruction with timing
30-June-2021

Disclaimer

This talk discusses potential applications of fast-timing in ATLAS beyond Run 4. These are only “personal” ideas and do not reflect any ATLAS official effort

ATLAS Run 4

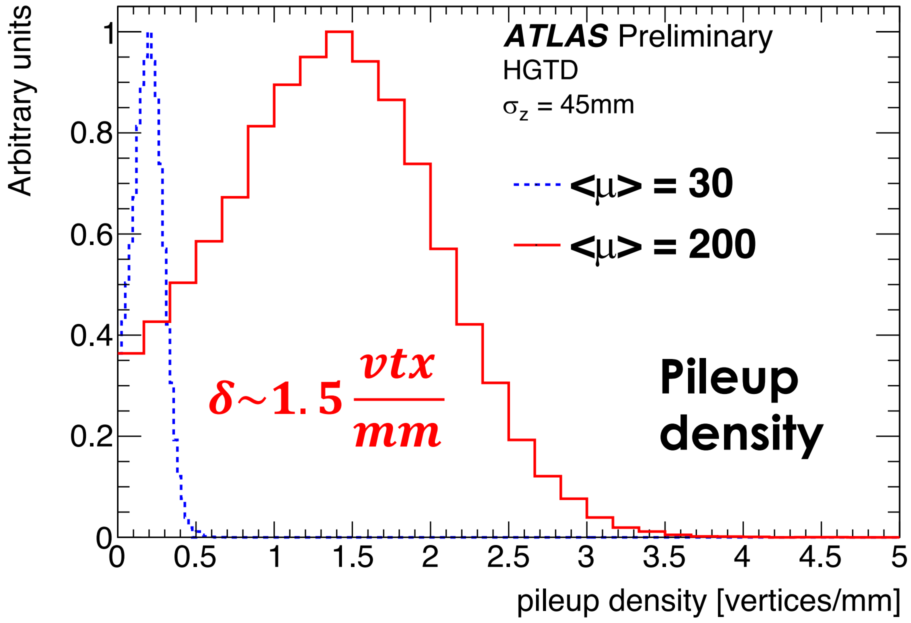


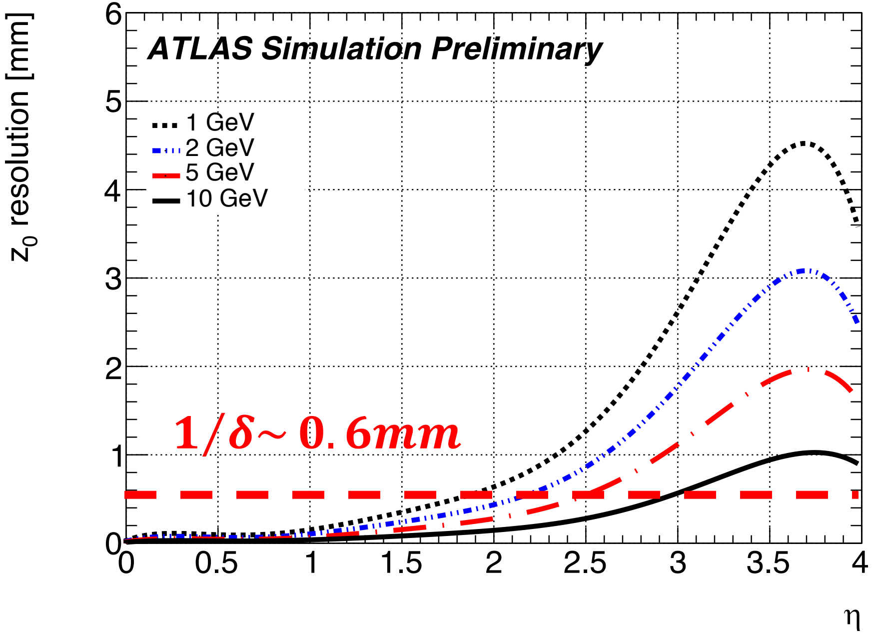


HGTD

- HL-LHC upgrade requires new detectors to cope with increased radiation level, data rates, and pileup
- New Silicon Tracker (**ITk**) and High Granularity Timing Detector (**HGTD**)

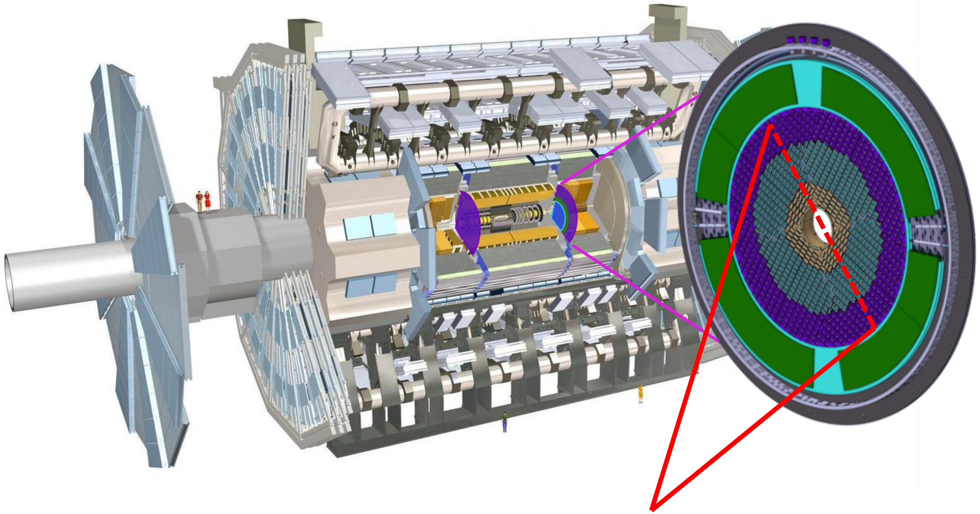
Forward Tracking Challenge





- HL-LHC pile-up density is comparable or larger than the longitudinal impact parameter resolution of ITk, particularly above |η|>2.5
  - **The association of tracks to vertices becomes ambiguous**

ATLAS HGTD



Pseudorapidity coverage: *2.4<|η|<4.0*

Radial extension: *12* cm < R < *64* cm

z position: *3.5* m

Thickness in z: 7.5cm

2 double, 3-ring, planar layers per endcap

Pixel detector with coarse spatial resolution but precision timing

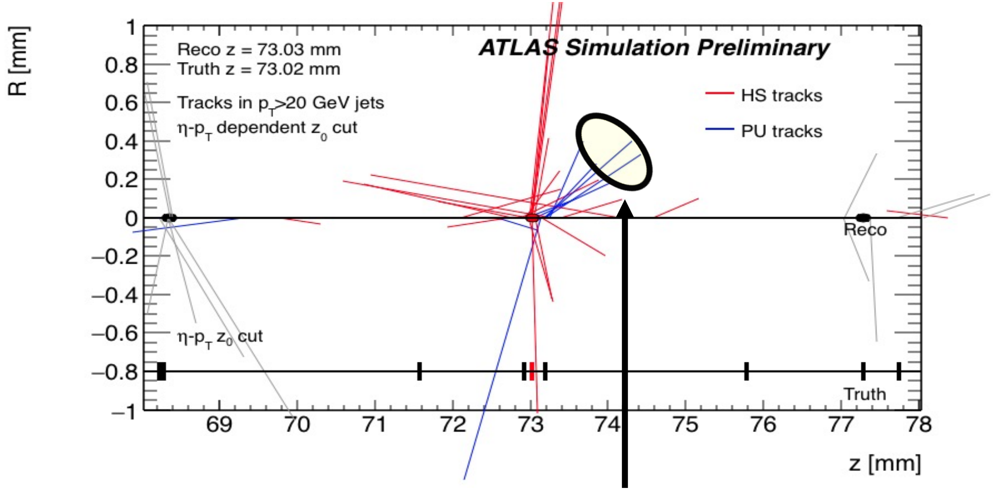
LGAD Si sensors:

- pad size: 1.3 x 1.3 mm^2
- 3.6M channels
- 6.4 m^2

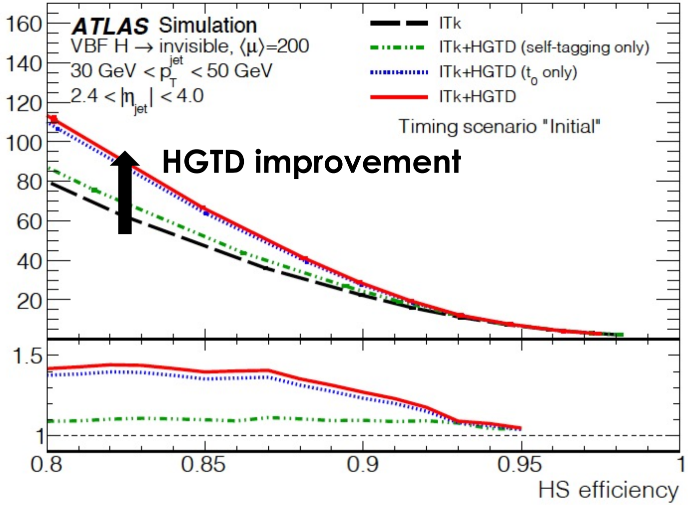
Target time resolution:

- 35-70 ps/hit up to 4000 fb-1
- 30-50 ps/track

ATLAS HGTD



Pile-up jet misidentified as hard-scatter jet when using only using 3D tracking



Time of primary vertex (**t_0**)

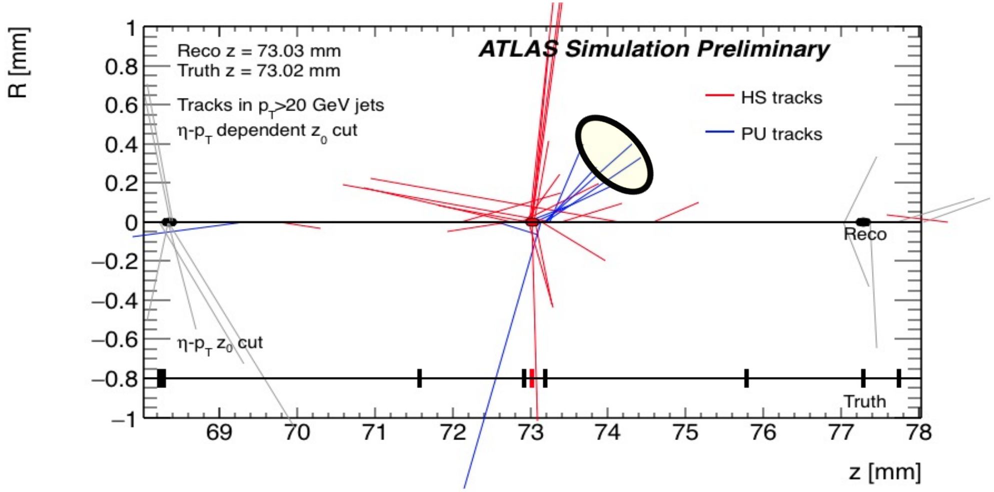
$$\frac{z_0 - z_{vtx}}{\sigma_z} < S$$

HGTD

$$\frac{t_{trk} - t_0}{\sigma_t} < S$$

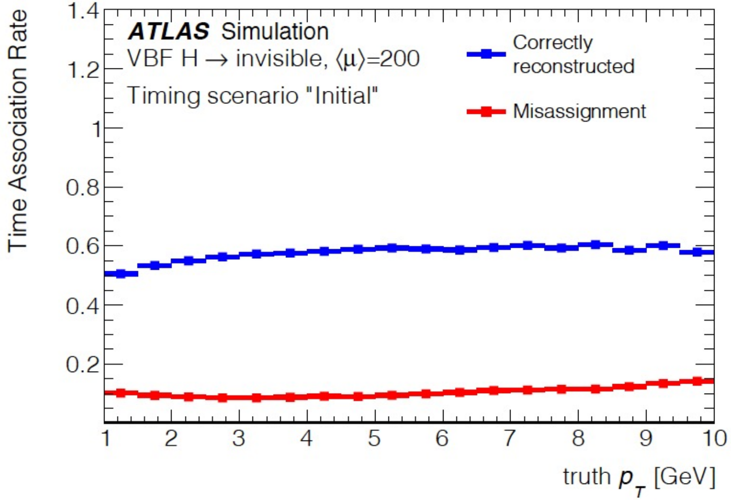
Vertex t_0

2 key challenges:



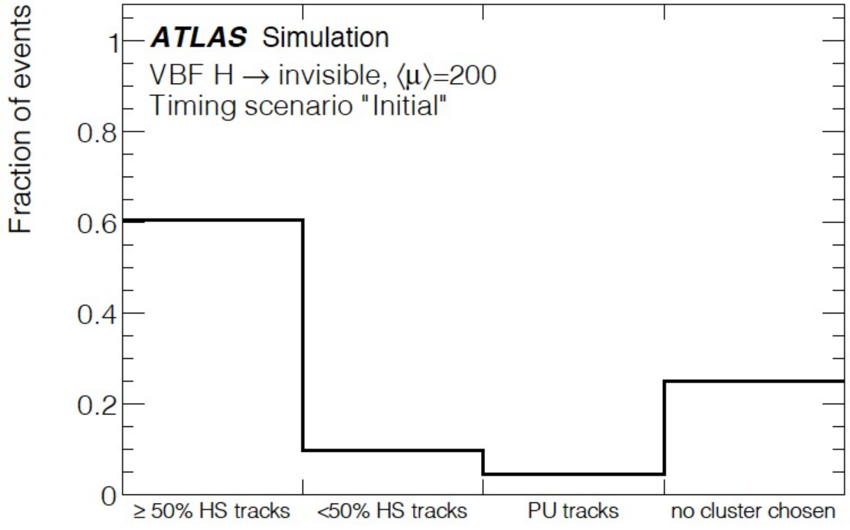
Limited eta acceptance of HGTD: primary vertex needs to have enough number of high p_T tracks with $|\eta| > 2.4$

Example: VBF events with two forward jets vs forward-central topology

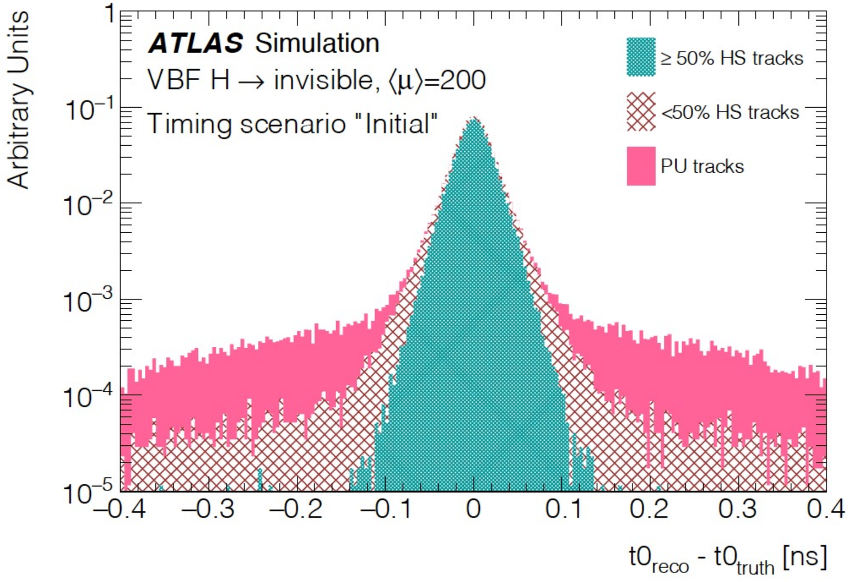


Limited track-time association efficiency due to HGTD location: Material interactions with ITk and services before HGTD, plus quality cut requirements

Vertex t_0

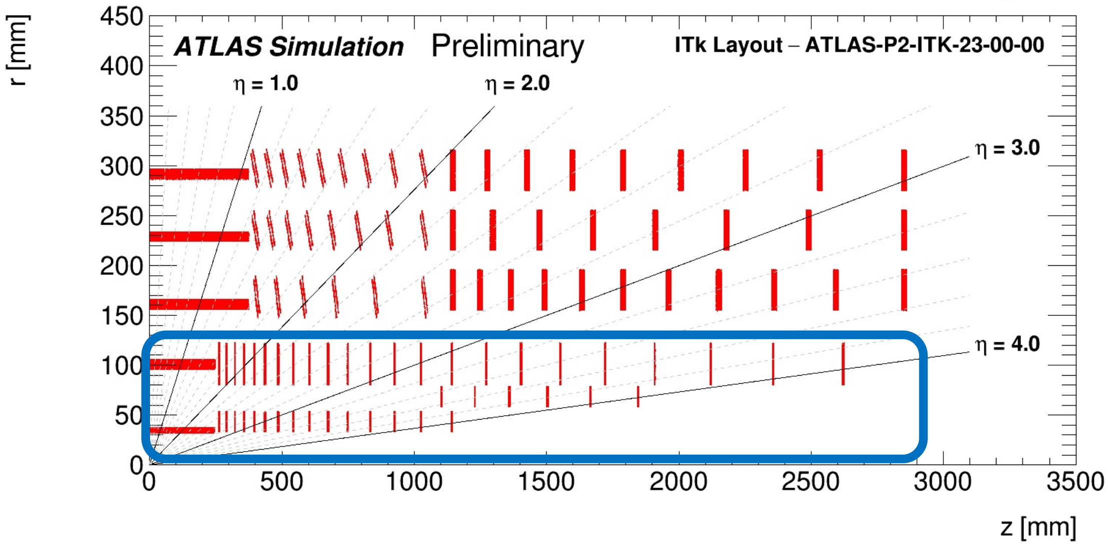


Efficiency



Resolution

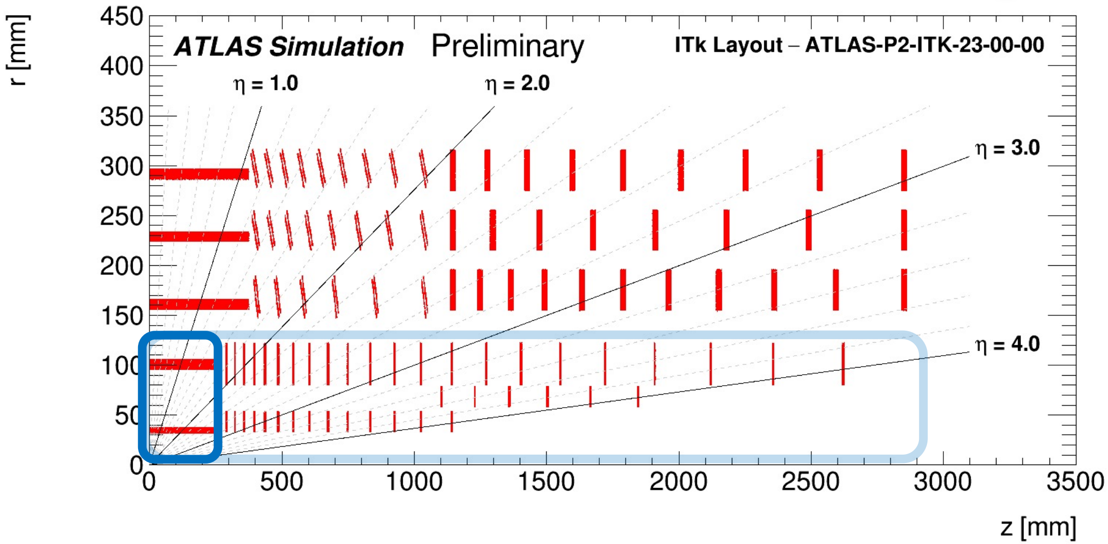
4D tracking motivations for ATLAS beyond Run 4



Inner Pixel replacement presents opportunities for new detector technologies to significantly enhance the physics potential for the 2nd half of HL-LHC.

Inner Pixel is designed to last 2000 fb^{-1}, to be replaced mid-way through HL-LHC

4D tracking motivations for ATLAS beyond Run 4



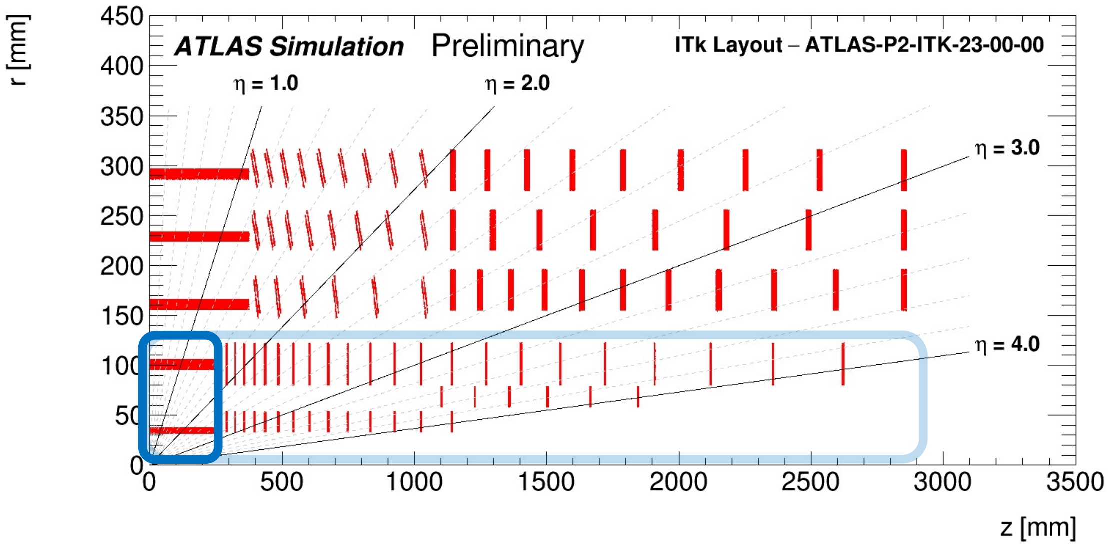
Inner Pixel is designed to last 2000 fb^{-1}, to be replaced mid-way through HL-LHC

Inner Pixel replacement presents opportunities for new detector technologies to significantly enhance the physics potential for the 2nd half of HL-LHC.

Focus of this talk: adding timing capabilities to the **2nd inner pixel barrel layer**: **4D timing layer**

- Balance of timing precision, granularity, and material budget
- Detailed detector studies needed to assess feasibility

4D tracking motivations for ATLAS beyond Run 4



Inner Pixel is designed to last 2000 fb^{-1}, to be replaced mid-way through HL-LHC

3 key opportunities:

Improve vertex t_0 for HGTD:

forward jets and leptons

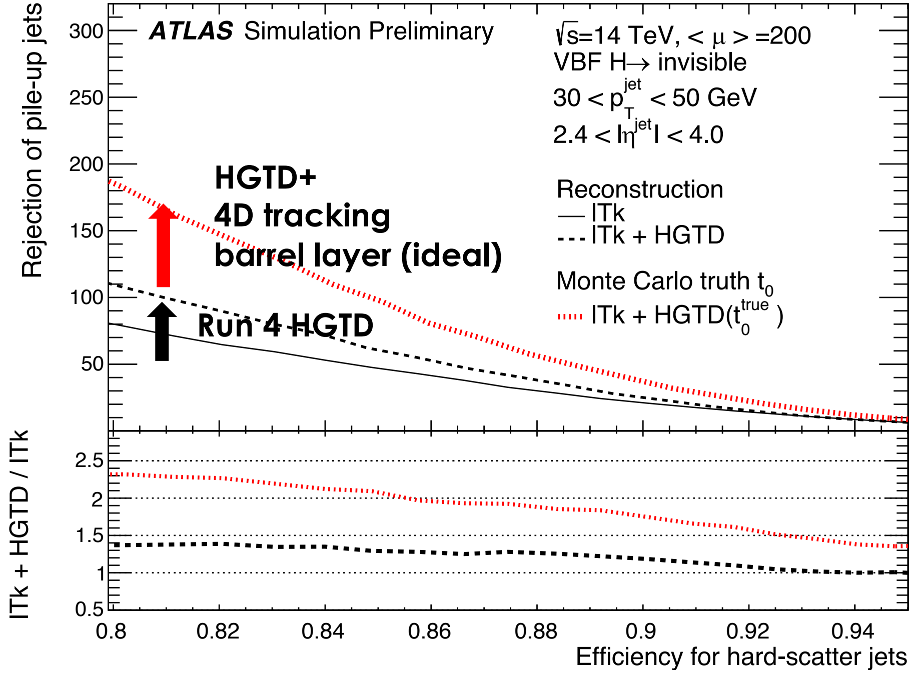
Improve physics object reconstruction in the central region:

b-tagging, particle flow. Missing ET

Improve track reconstruction:

Speed, efficiency, purity, and IP resolution

4D tracking motivations for ATLAS beyond Run 4



First opportunity

Improve vertex t_0 for HGTD:

forward jets and leptons

4D tracking layer in the 2nd inner pixel barrel would address the two key challenges of HGTD to determine the vertex t_0:

- Improved track-hit association efficiency (less material)
- Full eta-acceptance

4D tracking motivations for ATLAS beyond Run 4

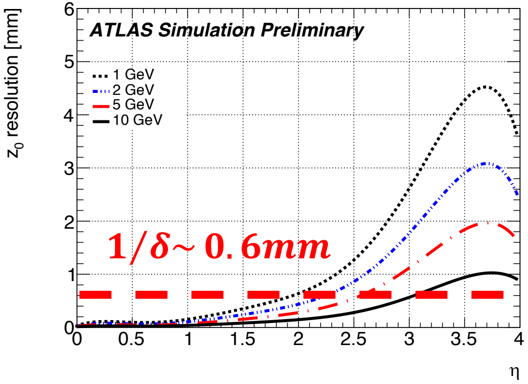
Track-vertex association is challenging with a 3D tracker when the track z_0 is comparable or larger than the typical separation between PU vertices

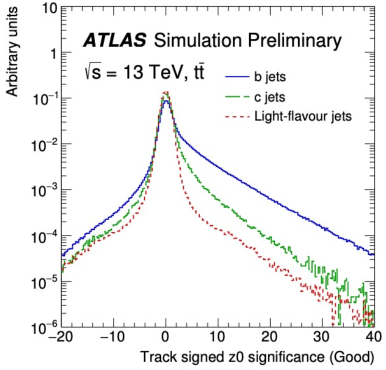
- **Low p_T (prompt) forward tracks** (HGTD)
- **Displaced central tracks from b-jets** (4D layer)

Second opportunity:

Improve physics object reconstruction in the central region:

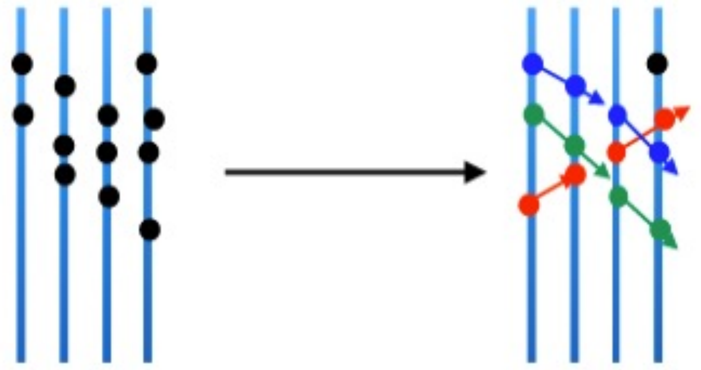
b-tagging, particle flow. Missing ET





Potentially large physics impact and broad applicability:
Di-Higgs and many final states containing b-jets

4D tracking motivations for ATLAS beyond Run 4



Third opportunity:

Improve track reconstruction:

Speed, efficiency, purity, and IP resolution

This concept requires timing hits in multiple layers (at least 2)

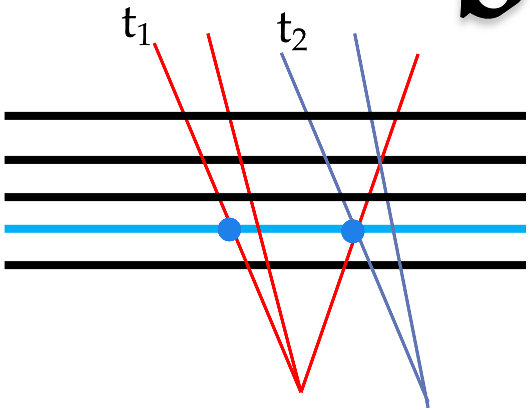
Use pixel hit time in track pattern recognition:

- Reduce combinatorics:
  - Improve efficiency and purity → IP resolution
- Speed up tracking reconstruction

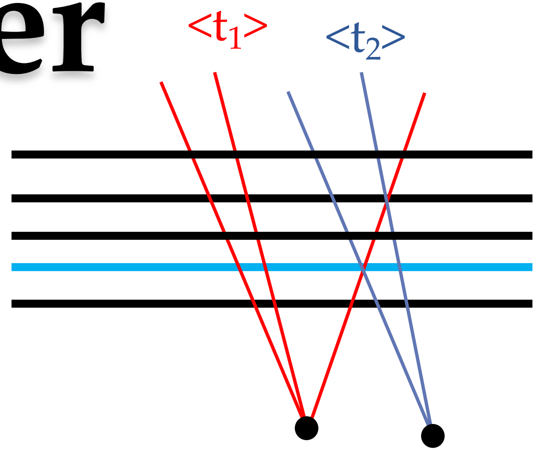
4D Vertexing

What could ATLAS do if we only instrument one pixel barrel layer with timing information?

Tracking with a 4D timing barrel layer



2 ideas



1. Find (high quality) track → assign t_1
2. Find additional tracks with time compatibility → refine average time
3. Select all hits with a 2-3 sigma window and find all tracks from a common vertex
4. Iterate

1. Find vertex clusters in z (zscan)
2. Compute the average time of each z-cluster and define time-RoI to run tracking

Tracking with a 4D timing barrel layer

- Track-to-vertex association requires to compare the track time to the (primary) vertex time (pileup jet suppression / b-tagging)
- Assuming pixel time resolution = 50ps, since primary vertices have >25 tracks → vertex t_0 resolution ~ 50ps/5 < 10ps
  - **This will enable precise vertex t_0 reconstruction to be combined with HGTD 30ps track resolution in the forward region**
- Need studies to establish the per-pixel time resolution required for significant b-tagging improvements

Next steps

- Run **ACTS** with the ITk geometry
- Study impact of pixel time resolution, pitch, layer position
- Evaluate impact/interplay of additional material/timing capabilities
- Physics studies: b-tagging, forward pileup suppression (with HGTD), …

Summary

- **ATLAS Inner pixel replacement presents an exciting new opportunity to bring technological innovations, including fast-timing**
- **A single 4D pixel barrel layer might bring physics and reconstruction improvements through a more powerful mitigation of pileup:**
  - Complement/Improve HGTD performance in the forward region (maximize investment in HGTD)
  - Add a new capabilities to improve b-tagging, particle-flow, and missing ET
  - Improve track reconstruction speed, purity, and resolution
- **Need detailed simulation studies to evaluate various detector layout concepts, understanding of material, single-layer 4D tracking algorithms, etc.**