PHYSICS AND PERFORMANCE OF THE HIGH GRANULARITY TIMING DETECTOR

-LHCP POSTER SESSION-

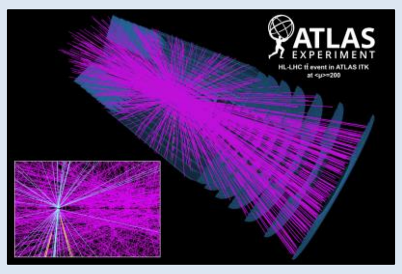
The 10th Edition of the Large Hadron Collider Physics Conference, May 16–20, 2022

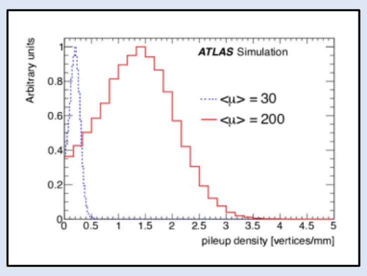
Pileup challenge at High-Luminosity LHC

- Instantaneous luminosity up to L ≈ 7.5 × 10^{34}cm^{-2}s^{-1}
- Main challenge for High-Luminosity LHC :

  pile-up contamination!

  - Pile-up density reaching an average number of 200 p-p interactions per bunch crossing (< μ >= 200)
  - Generating an average of 1.6 collisions/mm





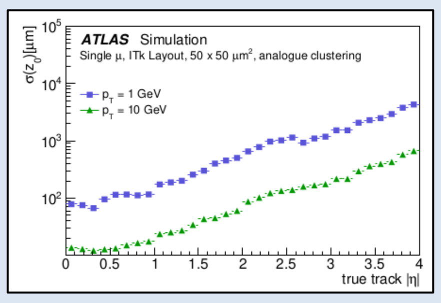
- Delivering an integrated luminosity of 4000 fb^{-1}
- ATLAS detector will need more upgrades, including:
  - The inner detector will be replaced (by ITK)
  - New detector: **High Granularity Timing Detector**

HGTD Motivation

- **Issue :** at < μ >= 200, the impact parameter resolution degrades dramatically in the end-cap region

  => Several vertices being merged

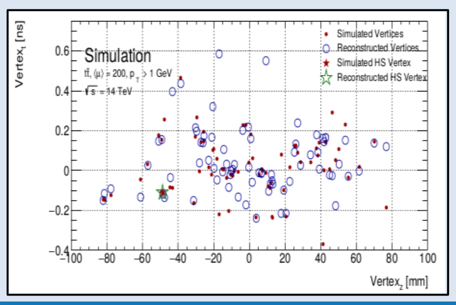
  => The longitudinal impact parameter resolution ($\sigma(z_0)$) becomes poorer for track association when η gets higher



- **Solution :** adding additional timing information will improve the track vertex association

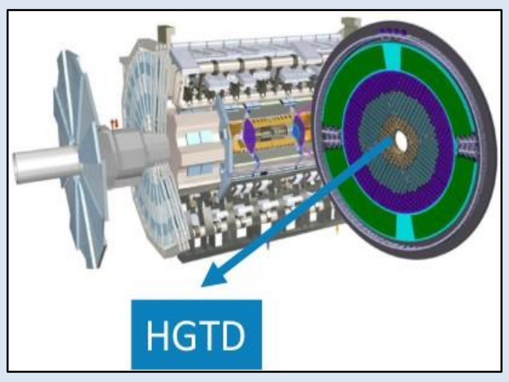
=> New detector is proposed : **High Granularity Timing Detector (HGTD)**

=> Timing information helps to distinguish vertices that are close in space and separated in time



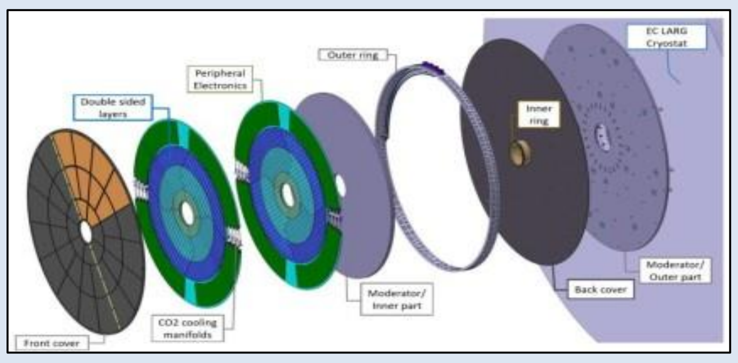
HGTD System

- High Granularity Timing Detector (HGTD) with a high precision in time resolution(30 ps per track) will be installed in the forward region between tracker and end-cap calorimeter (z = ±3.5 m)



Pseudorapidity coverage	$2.4 < \lvert\eta\rvert < 4.0$
Thickness in z	75 mm (+50 mm moderator)
Position of active layers in z	3435 mm < z < 3485 mm
Radial extension:	
Total	110 mm < R < 1000 mm
Active area	120 mm < R < 640 mm
Time resolution per track	30 ps
Number of hits per track:	
$2.4 < \lvert\eta\rvert < 3.1$	2
$3.1 < \lvert\eta\rvert < 4.0$	3
Pixel size	1.3 × 1.3 mm^2
Number of channels	3.54M
Active area	6.3 m^2

- An overview of the different components of the HGTD detector



- Two double-instrumented disks per end-cap
- Rotated in opposite direction by 15° to avoid gaps
- **Target time resolution: 30 ps/track (50 ps after irradiation)**

HGTD Low Avalanche Gain Detector : Timing Measurement

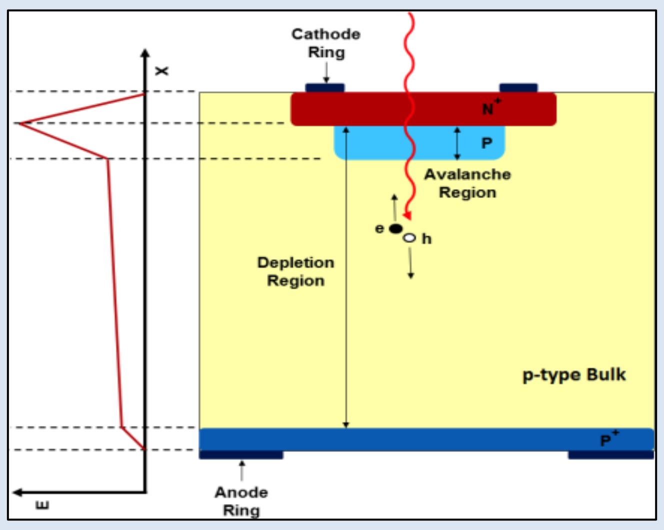
- The Low Gain Avalanche Detector (LGAD) is a new thin radiation-resistant sensor used in HGTD to optimize a high time resolution
- Principle of LGAD technology **:**
  - **n-on-p silicon detectors with an additional p-type doped layer**
  - **high electric field : internal gain >20 before irradiation and >8 at the end of lifetime**
  - **achieving an excellent timing resolution (35–70 ps/hit)**

- Measurement of time resolution is based on three major effects:

$$\sigma^2_{total} = \sigma^2_{Landau} + \sigma^2_{elec} + \sigma^2_{clock}$$

  - $\sigma^2_{\mathrm{Landau}}$ **: Landau fluctuation from non-uniform energy deposits**
  - σ^2_{elec} **: time walk from amplitude variations and Jitter caused by the electronic noise**
  - σ^2_{clock} **: clock distribution 15 ps**

- **The thickness, gain and readout electronics are optimized to achieve the designed resolution**



HGTD Performance

- Correctly associating tracks to vertices is the key element to reducing the pile-up contamination
- The association of tracks to vertices is based on the assignment of tracks that are geometrically compatible in z with the vertex position :

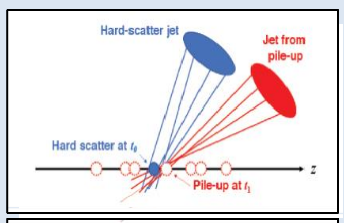
$$\frac{|z_0 - z_{vertex}|}{\sigma_{z_0}} < 2.5$$

At high η, several pile-up events overlap with the hard-scattering event if only the position is used !

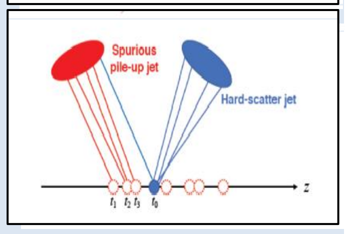
=> HGTD complements the ITK in the forward region, 2.4 < |η| < 4

- Two approaches are available to correctly associate tracks to the corresponding hard-scatter vertex :
  - the hard-scatter vertex time t_0 :

$$\frac{|t_{trk} - t_0|}{\sigma_t} < 2$$



  - the self-tagging approach: the knowledge of t_0 is not required



- Timing information provided by HGTD enhances the forward reconstruction of physics objects : **tagging jets, tagging b-jets, lepton isolation...**

=> HGTD can enhance the physics potential of ATLAS

Pile-up jet suppression

- The key element to reject the pile-up in jets is the precise association of jets with tracks and primary vertices:
  - Using the powerful discriminant $\mathbf{R}_{p_T}$: $R_{pT} = \frac{\Sigma\, p_T^{trk}(PV0)}{p_T^{jet}}$

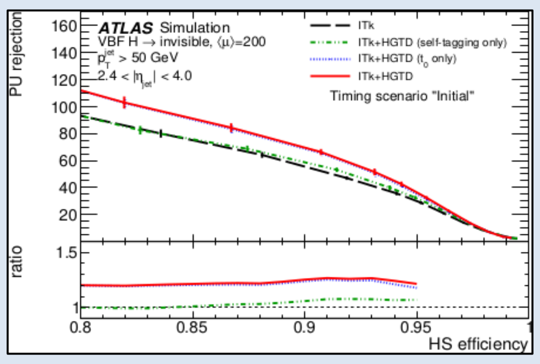
    * Large values of R_{p_T} correspond to the hard-scatter jets
    * Small values of R_{p_T} correspond to the pile-up jets

  - At high-level of pile-up (especially in the forward region): the discriminant power of this variable gets reduced

=> The use of the timing information increases the separation power between hard-scattering and pile-up jets

$$R_{p_T} = \frac{\sum p_T(PV0, t_0)}{p_T^{jet}}$$

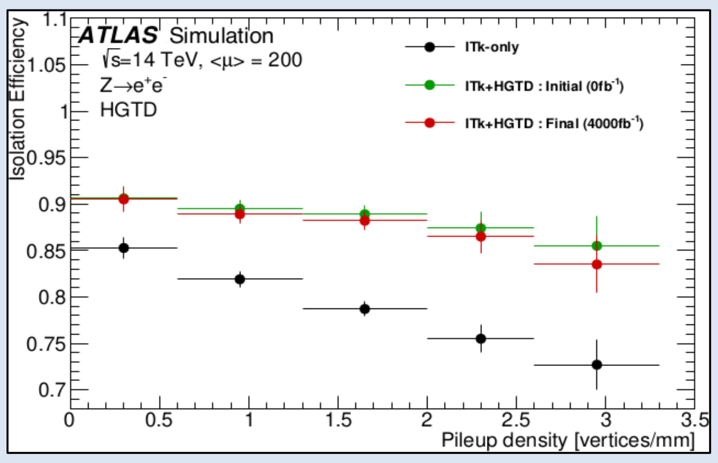
- The use of the HGTD provide a significant improvement **~ 20%** in the pile-up jets suppression



Electron Isolation Efficiency

- The efficiency is defined as the probability that no track with p_T > 1 **GeV** other than the electron track is within **ΔR = 0.2** from the electron
- The electron isolation efficiency is improved by about **10%** for a local pile-up density of the order of **1.6** vertices/mm thanks to the timing information provided by HGTD

=> This confirms that the improvement given by the HGTD shows that the pile-up density dependence is lowered



References

[1] ATLAS Collaboration. Technical Design Report for the High-Granularity Timing Detector for the ATLAS Phase-II Upgrade. Technical report, CERN, Geneva, June 2020

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Conclusion

- **The precise timing information provided by the HGTD detector will be a powerful new tool to mitigate the pile-up interactions in the forward region at HL-LHC**
- **The LGAD technology and layout for HGTD are designed to achieve a time resolution better than 50 ps/track up to the end of the detector lifetime**
- **The HGTD offers a clear improvement for physics objects performance by complementing the performance of the updated ITK in the forward region of ATLAS**

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