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Performance study in the High-Granularity Timing Detector in ATLAS : Application on the lepton isolation

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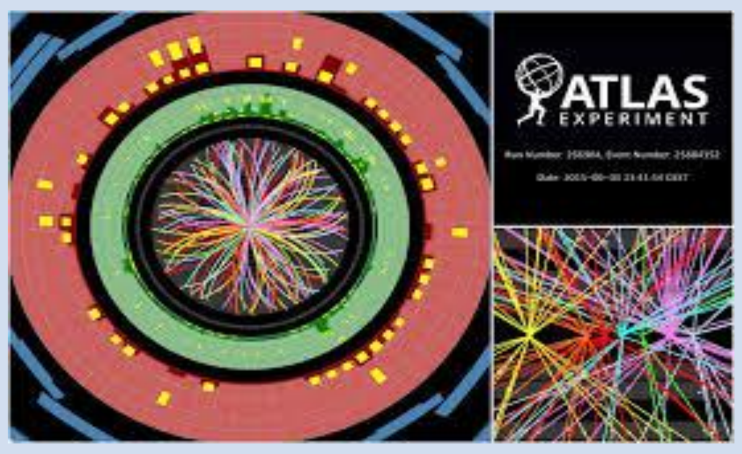
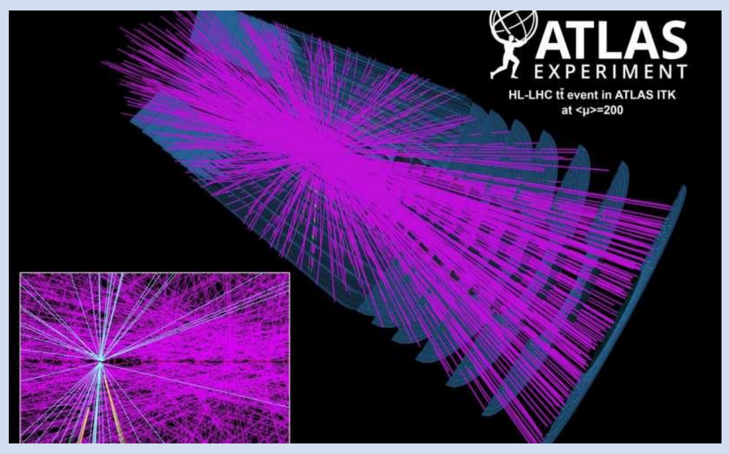
The problem

The HL-LHC is an upgrade of the LHC project, which will deliver an integrated luminosity of up to 4000 fb−1 over the subsequent decade, to achieve an instantaneous luminosity of $L = 7.5.10^{34} cm^{-2}s^{-1}$, compared to the current value of $L = 2.5.10^{34} cm^{-2}s^{-1}$. This will increase the pile-up interactions to an average of 200 simultaneous p-p interactions within the same bunch crossing interval (<μ>= 200), the space resolution to $\sigma_z = 50\ mm$, and the timing resolution to $\sigma_t = 180\ ps$.



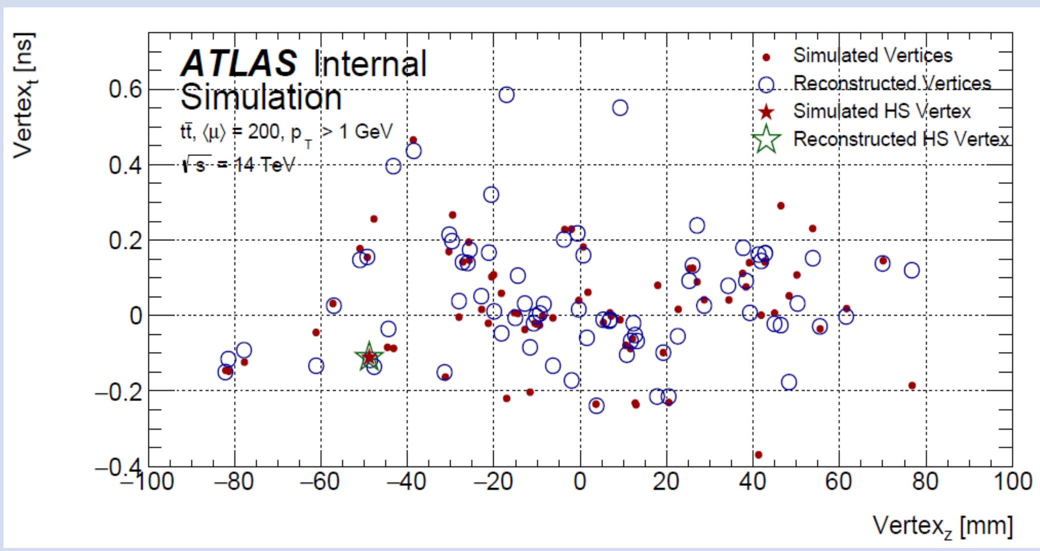
Run-2



Run-4

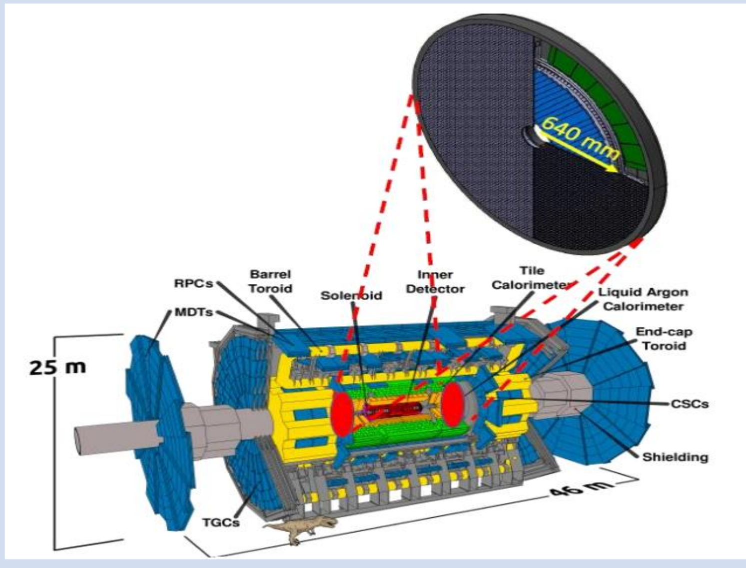
A solution

Main handle against pileup is the **tracker** that will be extended up to **|η| = 4.0** instead of |η| < 2.5 up to now, but the timing information can help to further reduce pile-up effect. The figure bellow shows a single $t\bar{t}$ event with 200 interactions in the z–t plane. The event contains the simulated Hard Scatter (HS) vertex and pile-up vertices. The tracker sees the event as a one dimensional projection on the z axis, where a large number of tracks close in space lead to ambiguities in the track-to-vertex association. The timing information of the HGTD reduces the density of vertices for a given track, and allows the effective separation of the HS vertex from pile-up vertices surrounding it in the z direction.

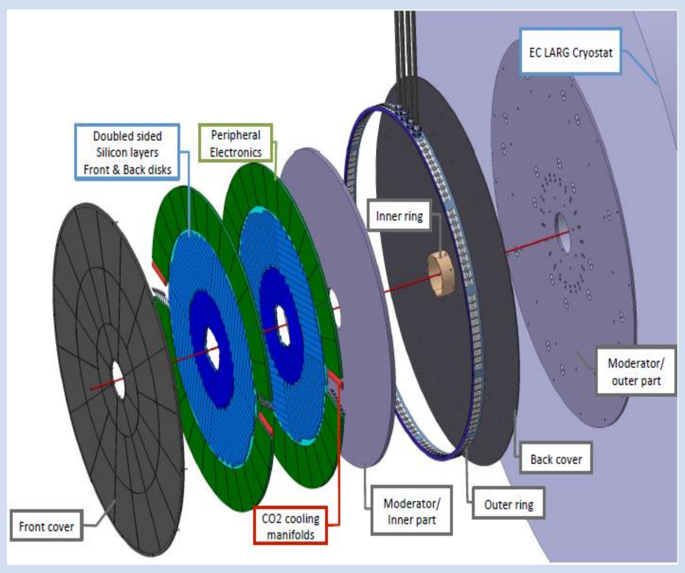


Visualisation of the primary vertices in an event in the z–t plane

Hight Granularity Timing Detector(HGTD)



Position of the HGTD within the ATLAS Detector



Global view of the HGTD to be installed on each of two calorimeter extended barrels.

Pseudo-rapidity coverage	$2.4 < \|\eta\| < 4.0$
Thickness in z	75 mm (+50 mm moderator)
Position of active layers in z	$z = \pm 3.5$ mm
Radial extension:	
Total	110 mm $< r <$ 1000 mm
Active area	120 mm $< r <$ 640 mm
Pad size	1.3 mm × 1.3 mm
Active sensor thickness	50 μm
Number of channels	3.59 M
Active area	6.4 m^2
Average number of hits per track	
$2.4 < \|\eta\| < 3.1$	≈2
$3.1 < \|\eta\| < 4.0$	≈3
Collected charge	> 2.5 fC
Average time resolution per hit	
$2.4 < \|\eta\| < 3.1$	≈ 40 ps (start) ≈ 70 ps (end)
$3.1 < \|\eta\| < 4.0$	≈ 40 ps (start) ≈ 85 ps (end)
Average time resolution per track	≈ 30 ps (start) ≈ 50 ps (end)

Main parameters of the HGTD

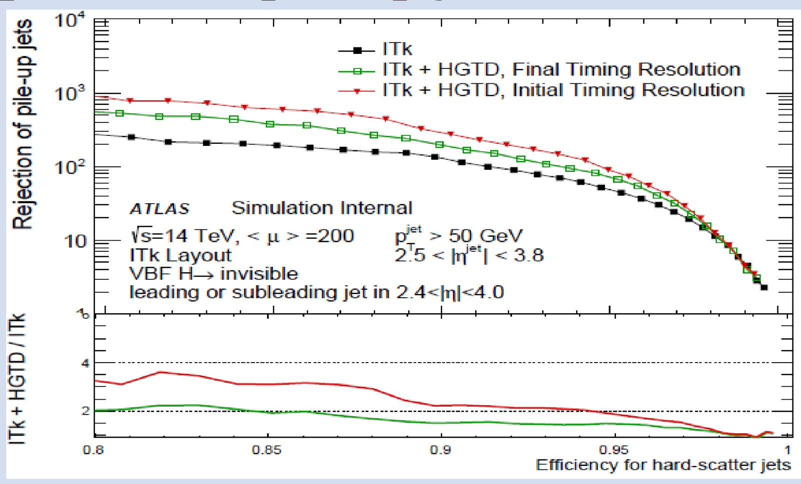
The HGTD detector will be located in the region lies outside the ITk volume and in front of the end-cap and forward calorimeters in the volume currently occupied by the Minimum-Bias Trigger Scintillators (MBTS), which will be removed. Each end-cap is the integration of one hermetic vessel, two instrumented double sided layers and two moderator pieces placed inside and outside the hermetic vessel. Each cooling/support disk is physically separated in two half circular disks.

A silicon-based timing detector technology is preferred due to the space limitations. The sensors must be thin and configurable in arrays. The Low Gain Avalanche Detector (LGAD) pads of 1.3mm x1.3mm with an active thickness of 50 μm fulfil these requirements. This pad size ensures occupancies below 10% at the highest expected levels of pile-up, small dead areas between pads, and low sensor capacitance which is important for the time resolution(30 ps per track).

A custom ASIC (ALTIROC), which will be bump-bonded to the sensors, is being developed to meet the requirements on time resolution and radiation hardness. The ASIC will also provide functionality to count the number of hits registered in the sensor and transmit this at 40MHz to allow unbiased, bunch-by-bunch measurements of the luminosity and the implementation of a minimum-bias trigger.

HGTD performances

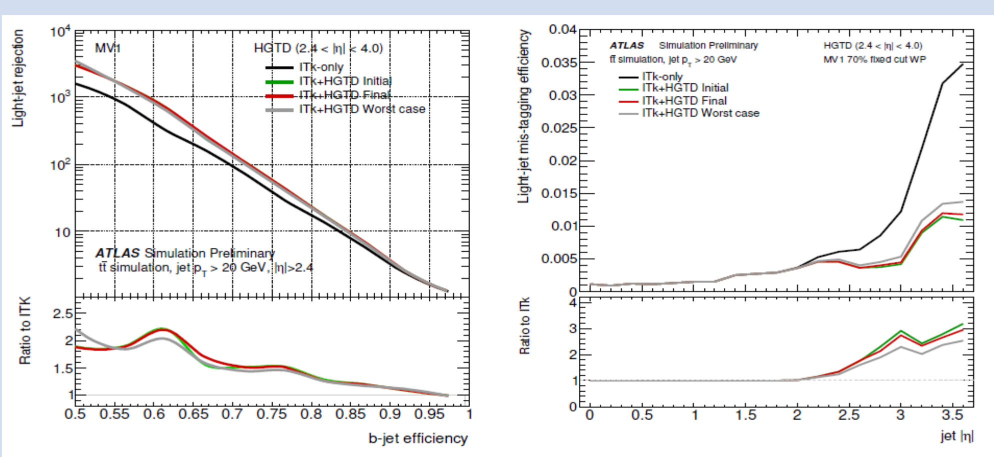
Suppression of pile-up jets



Pile-up jet rejection as a function of hard-scatter jet efficiency

The main impact of the HGTD in this study is to remove stochastic pileup jets.

Tagging of heavy flavour jets



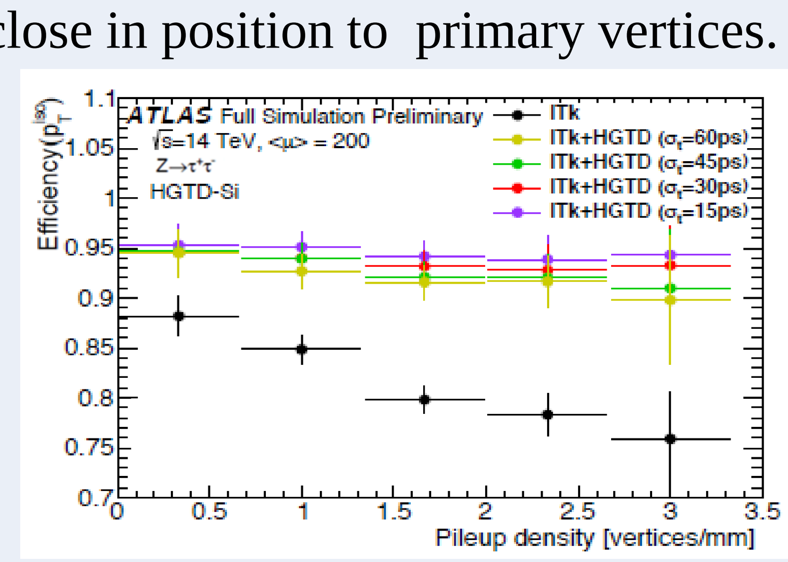
(a) Light-jet rejection. (b) Light-jet mis-tag efficiency.

The addition of the HGTD removes the majority of pile-up tracks from the track selection. As a result, the performance of the b-tagger is significantly improved.

Lepton Isolation

- Isolated Lepton ➔ No track with pT > 1 GeV surrounding the lepton in a cone of ΔR < 0.2.

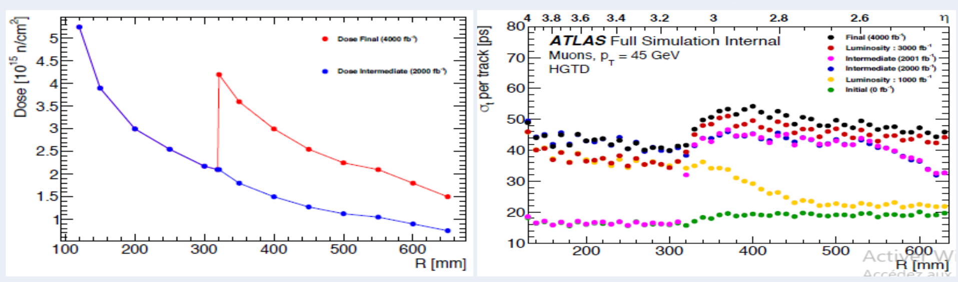
- The HGTD improves identification of leptons in the forward region, by the rejection of tracks with transverse momentum close to the energy of reconstructed electrons in the calorimeter, and/or tracks close in position to primary vertices.



•**Efficiency = f(Pileup density)** for ITK and ITK+HGTD:

- Pileup density: number of vertices per mm
- 4 scenarios used : sigma(t) = 15, 30, 45 et 60 ps
- The highest value of efficiency is matched to the best scenario (15ps)
- The efficiency drops fastly for the ITK
- For HGTD : Efficiency ≈ Cst

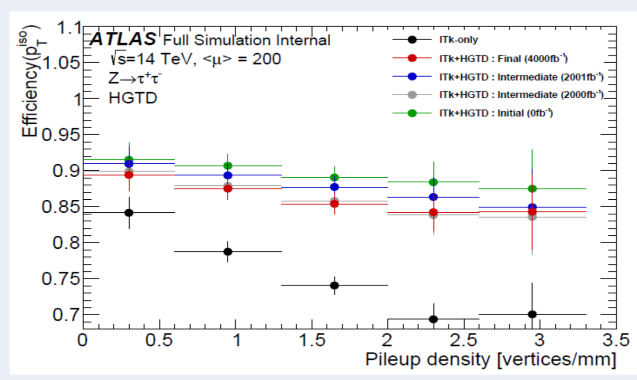
Radiation effect on the Si sensors:



→ Increase timing resolution of the HGTD .

→ Remplacement of the HGTD inner disk when integrated luminosity will achieve 2000 fb $^{-1}$

→ Study lepton isolation efficiency for integrated luminosity scenarios instead of timing resolution ones:



Initial (beginning: 0 fb $^{-1}$) , Intermediate (before disk replacement: 2000 fb $^{-1}$), Intermediate(after disk replacement: 2001 fb $^{-1}$), Finale (after 10 years: 4000 fb $^{-1}$).

Radiation →loose of efficiency

Conclusion

The HGTD will provide a timing resolution of 30 ps per track, and cover the forward region of the ATLAS detector in η between 2.4 and 4.0. This will decrease the pileup effect, and improve performances such lepton isolation .