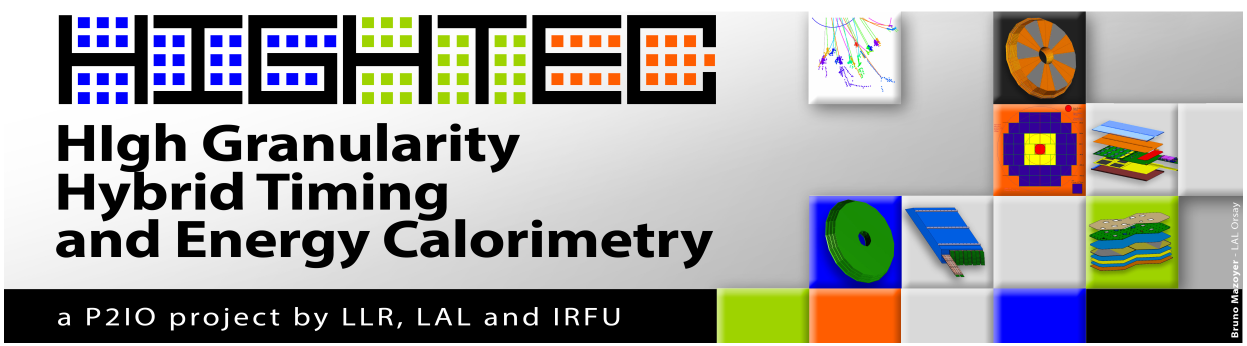
LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

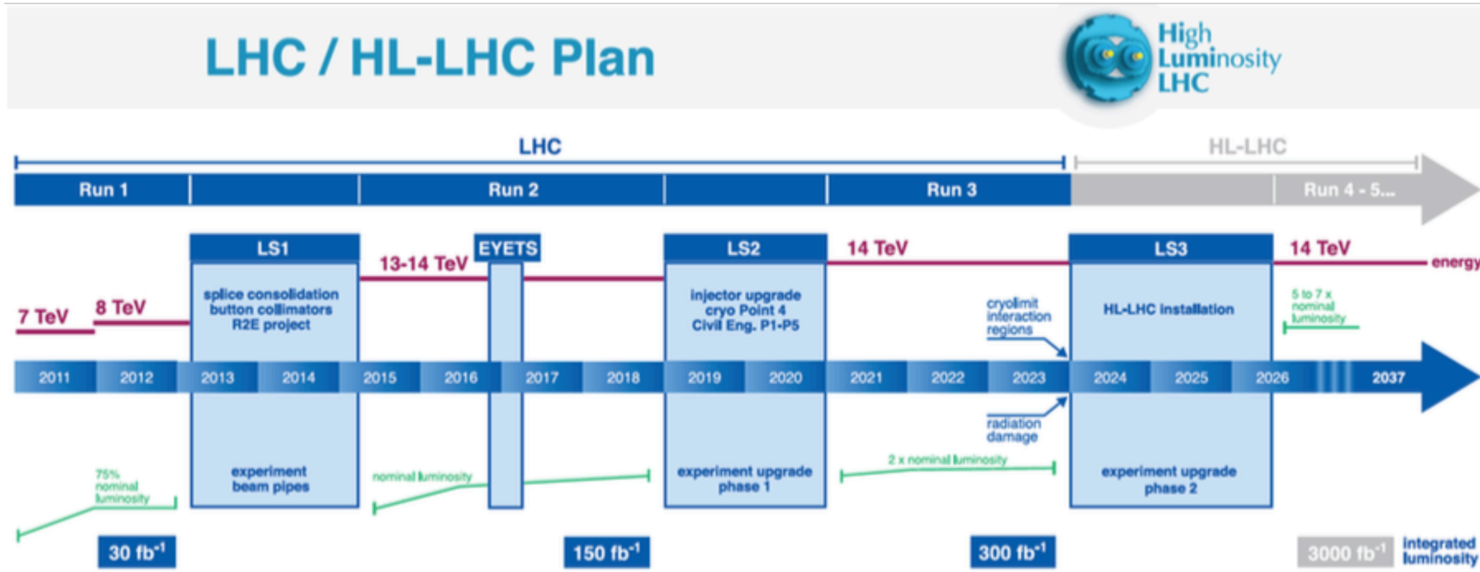
ATLAS EXPERIMENT

The High Granularity Timing Detector of the ATLAS Experiment

Corentin Allaire

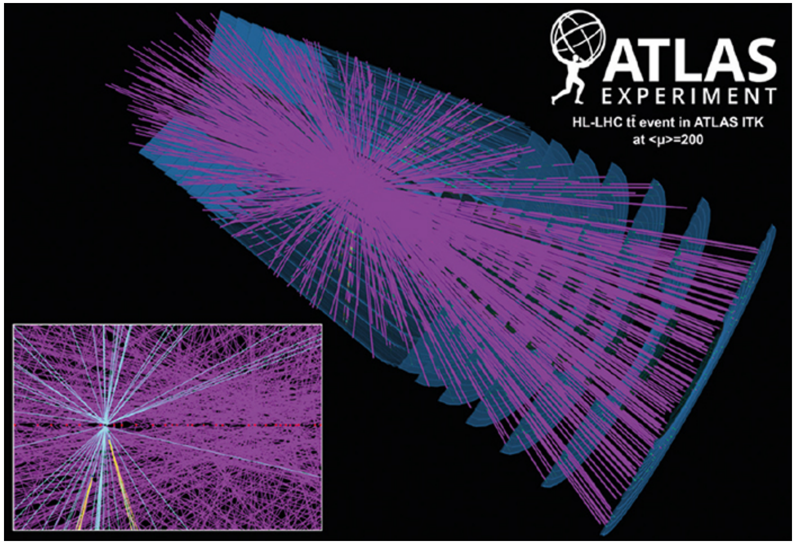


LHC and HL-LHC

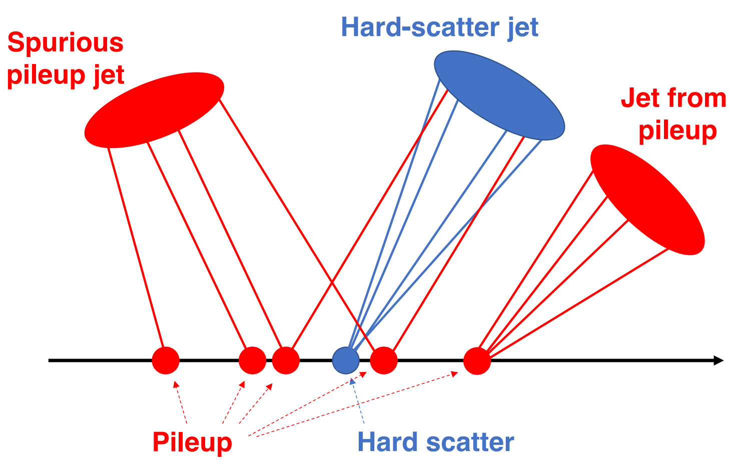


- Run2 (right now) : Energy : $\sqrt{s} = 13 TeV$ Integrated luminosity : $\int L \approx 150\, fb^{-1}$ Instantaneous luminosity : $L \approx 1 \times 10^{34} cm^{-2} s^{-1}$
- Increase of the luminosity -> Upgrade : HL-LHC (2019 and 2024)
- More luminosity -> see signal with a smaller cross section
- HL-LHC : Instantaneous luminosity : $L \approx 5 \times 10^{34} cm^{-2} s^{-1}$ Integrated luminosity (2037) : $\int L \approx 3000\, fb^{-1}$

Pile-up in ATLAS



Simulation of the pile up in Atlas for 200 events



- Pile-up : interaction happening during the same bunch crossing as the event we are interested in
- Create track and calorimeter cluster that could be associated by error to the event of interests
- Affect the signal reconstruction and can create fakes
- Increase of the instantaneous luminosity -> increase of the pile up
- Run2 : 20-60 pile up interaction in ATLAS (per bunch crossing)
- HL-LHC : 200 pile up interaction in ATLAS

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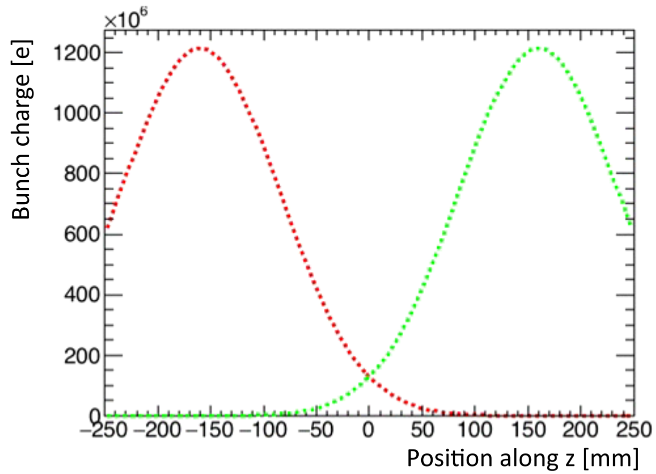

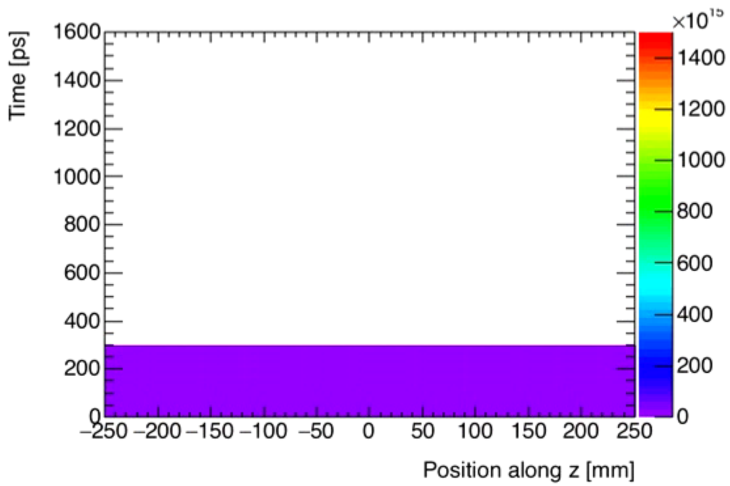

HL-LHC challenges:

- order 200 events Pileup
- z spread: 150ps (≈ 45mm nominal)
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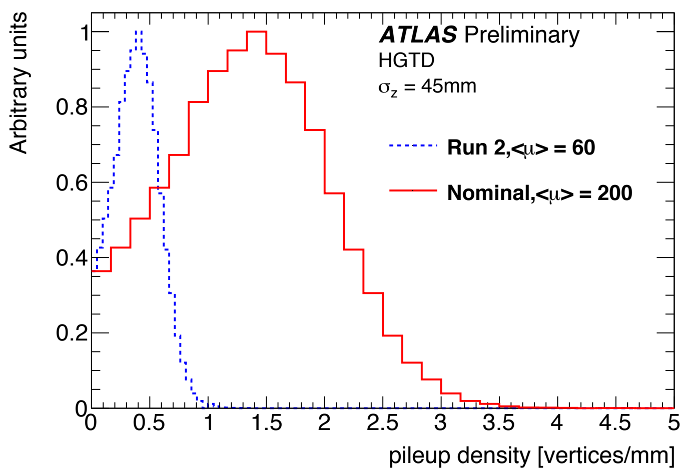

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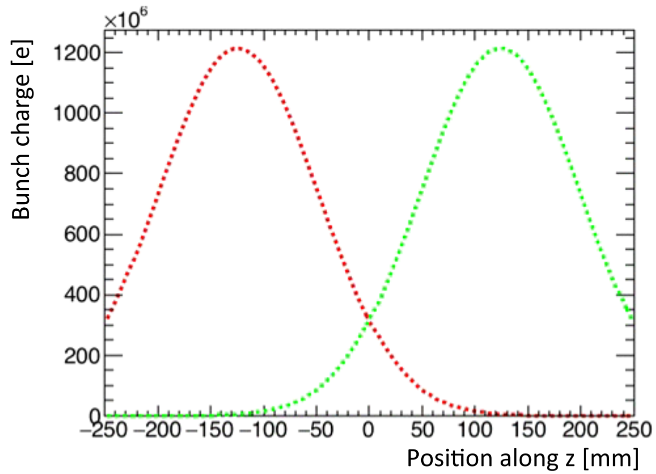

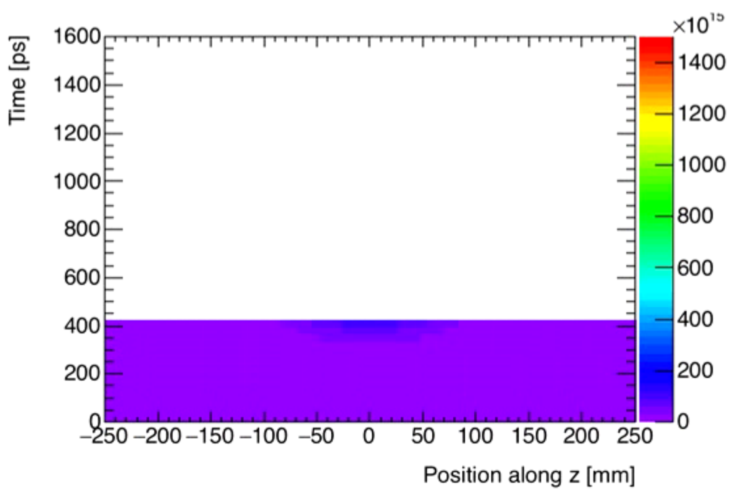

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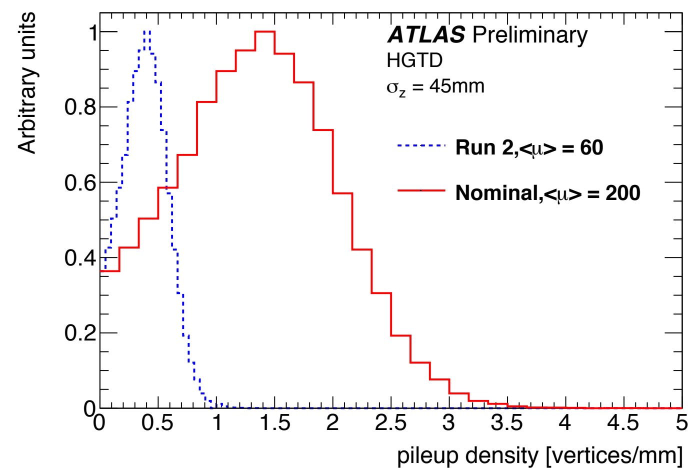

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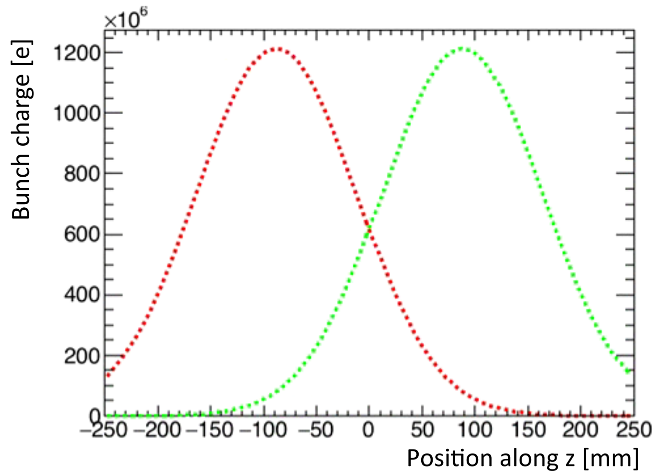

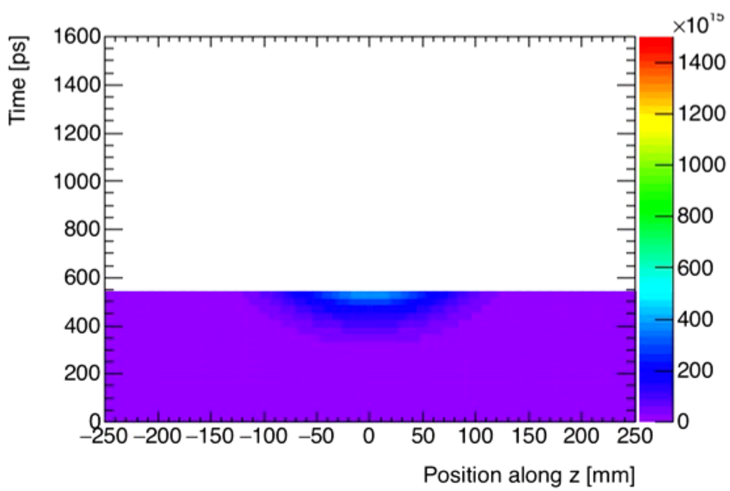

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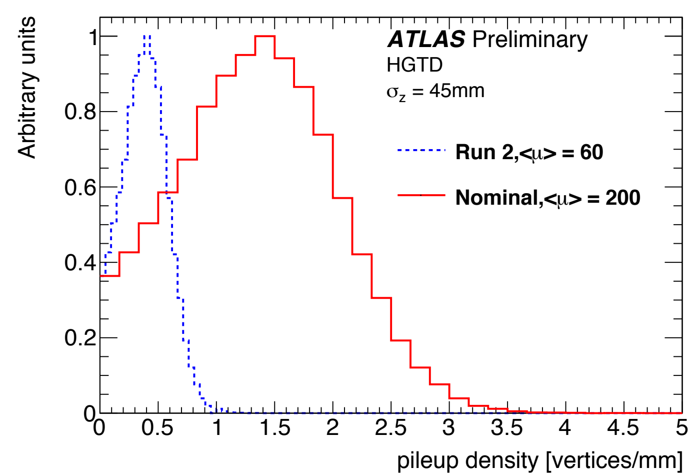

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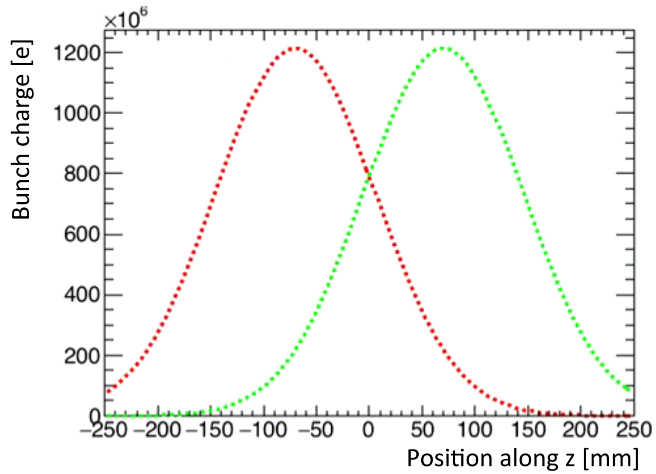

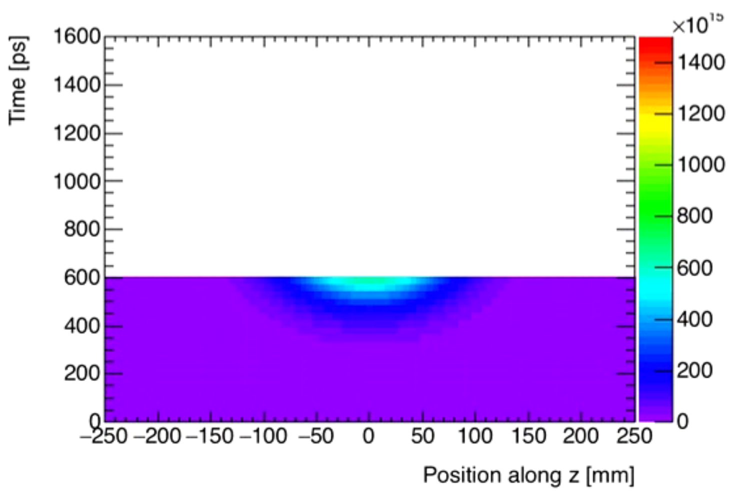

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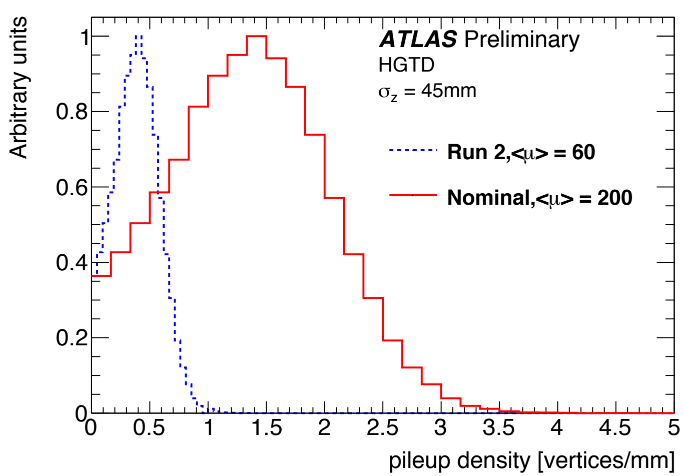

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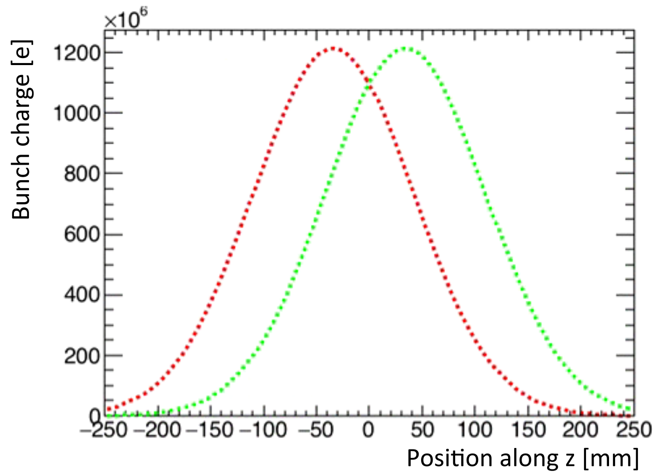

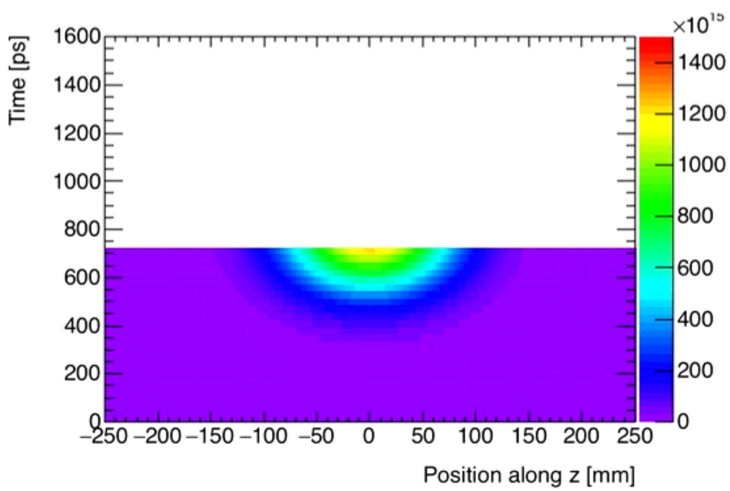

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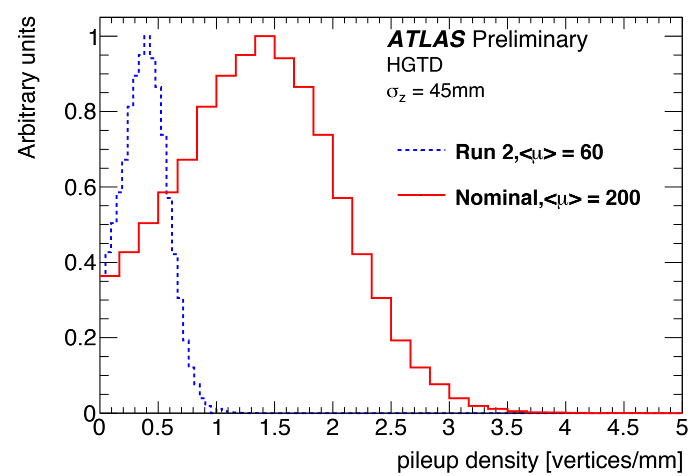

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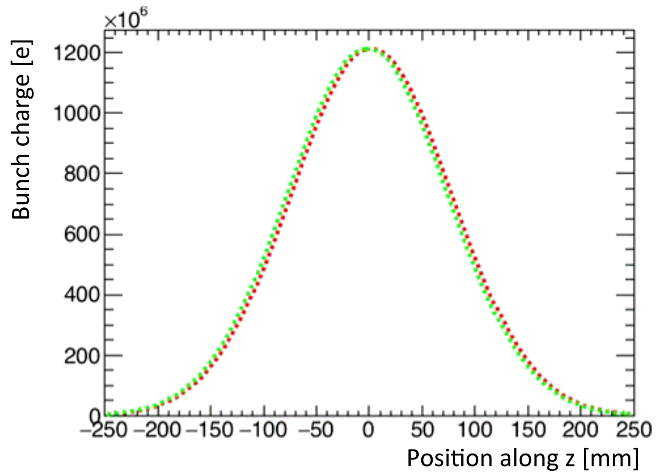

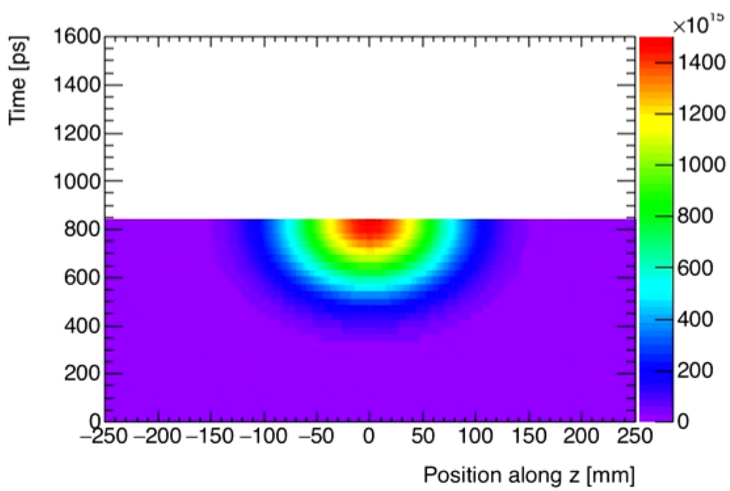

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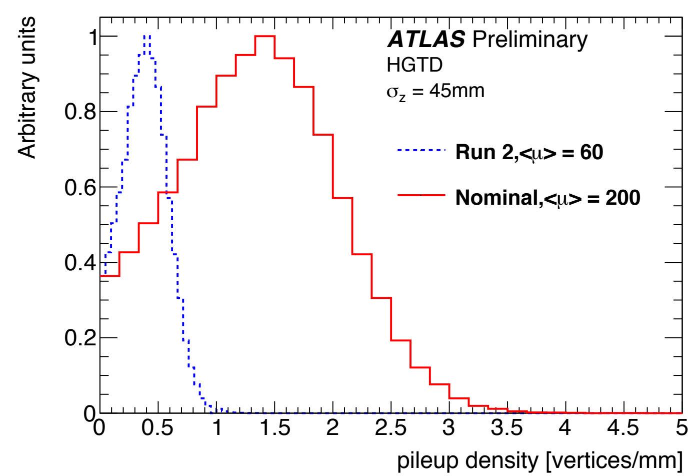

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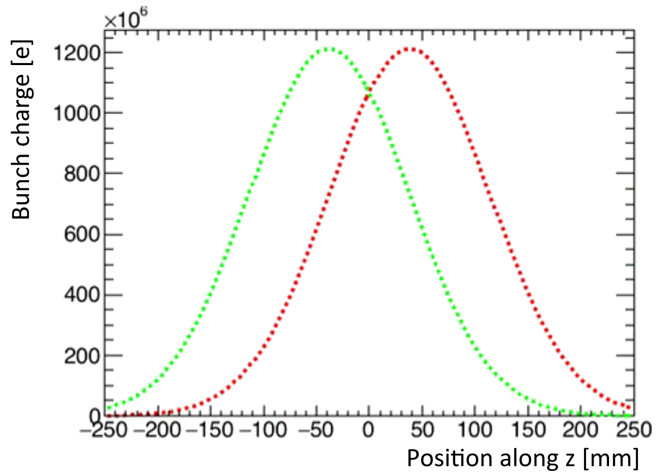

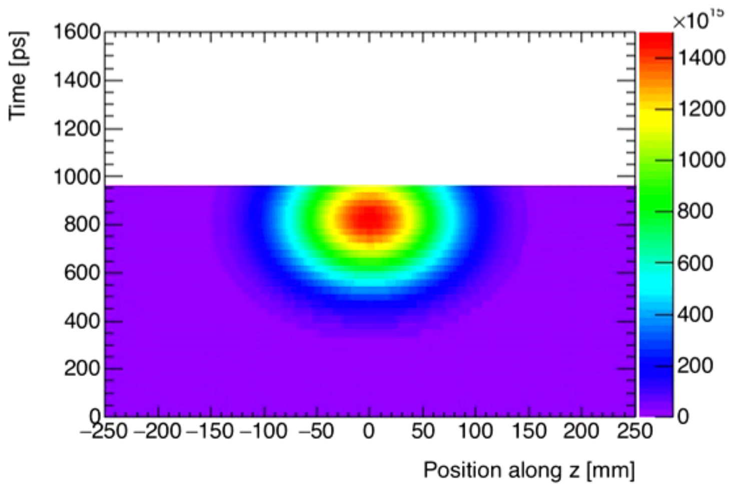

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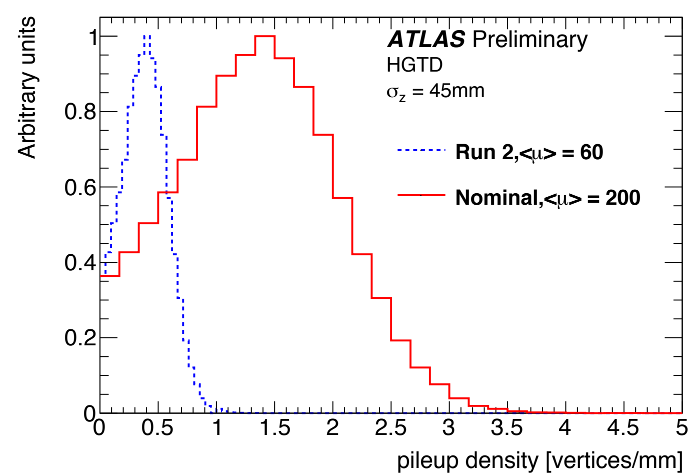

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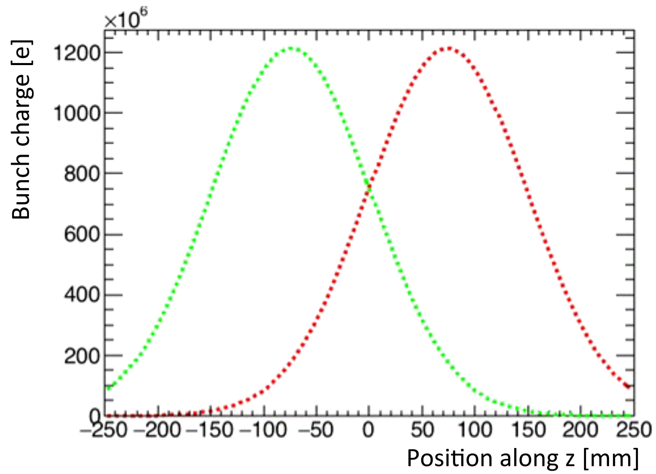

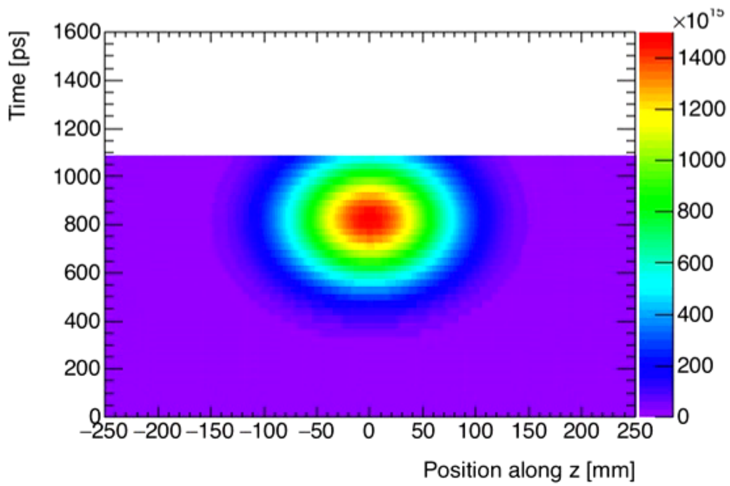

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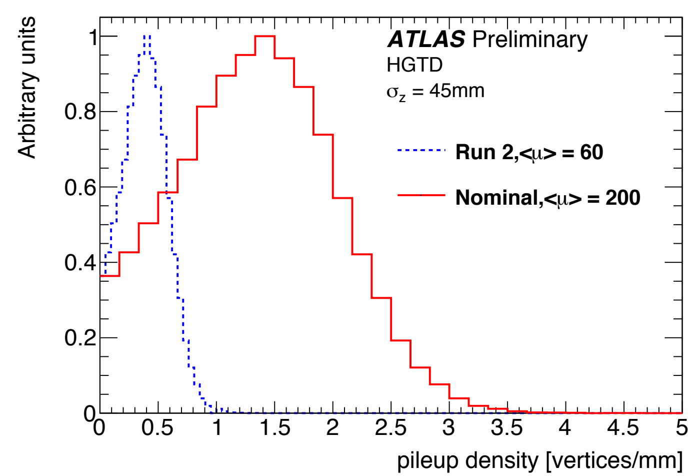

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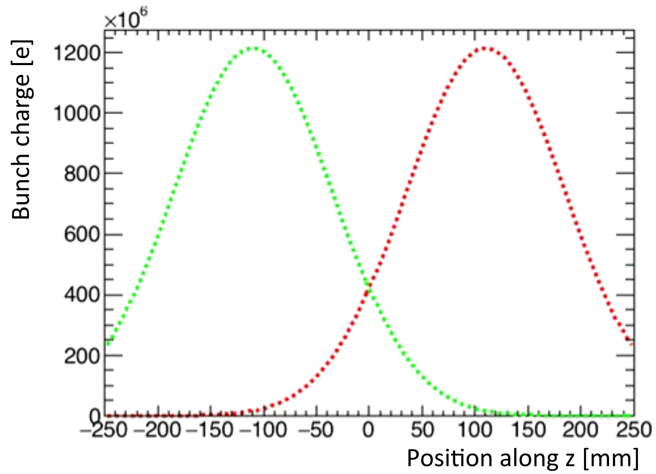

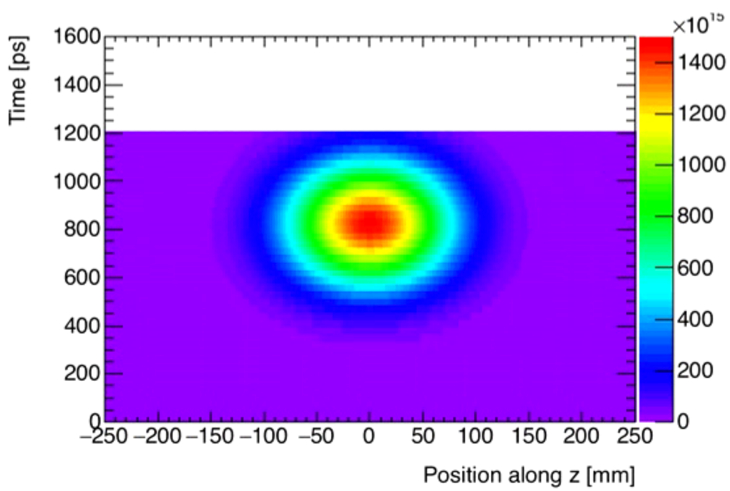

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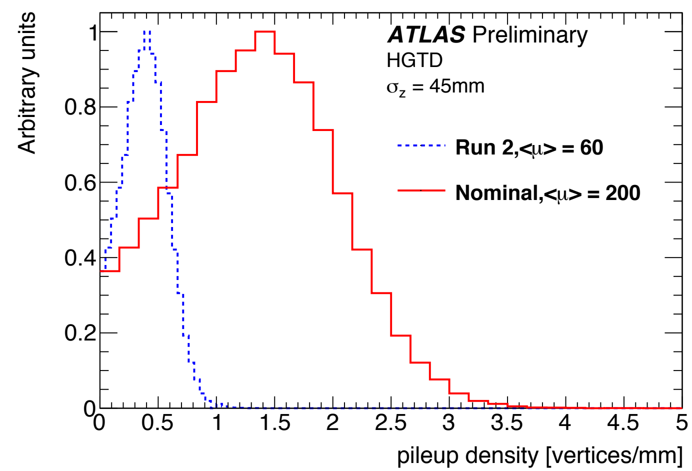

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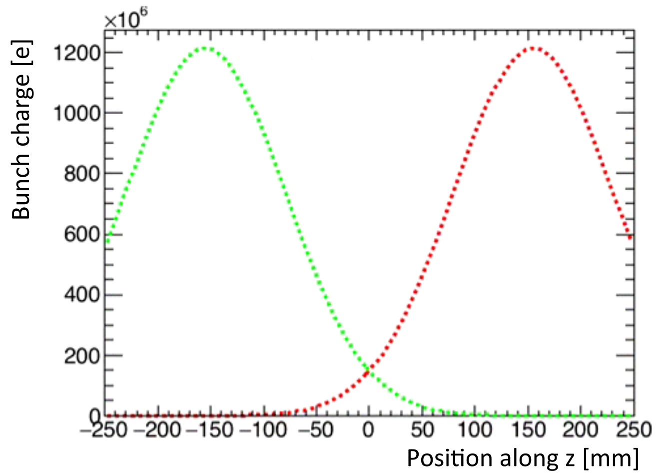

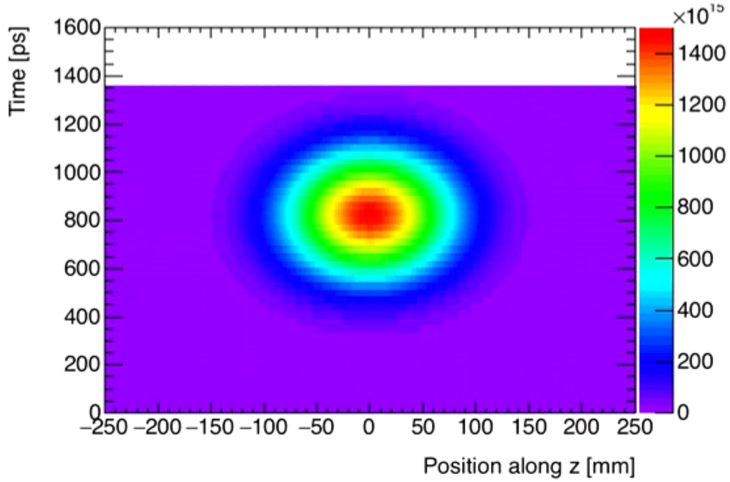

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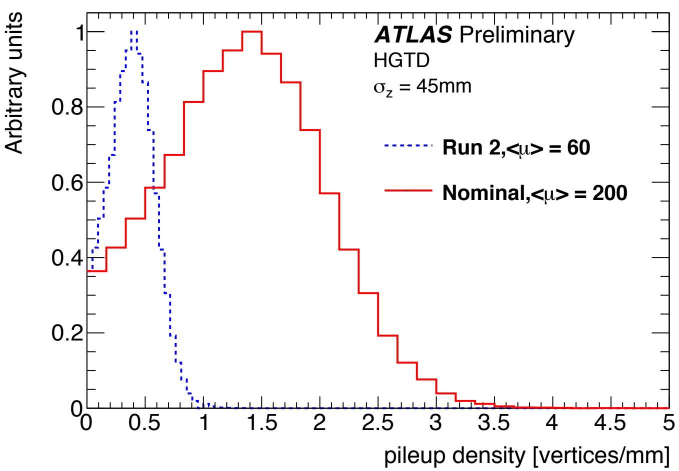

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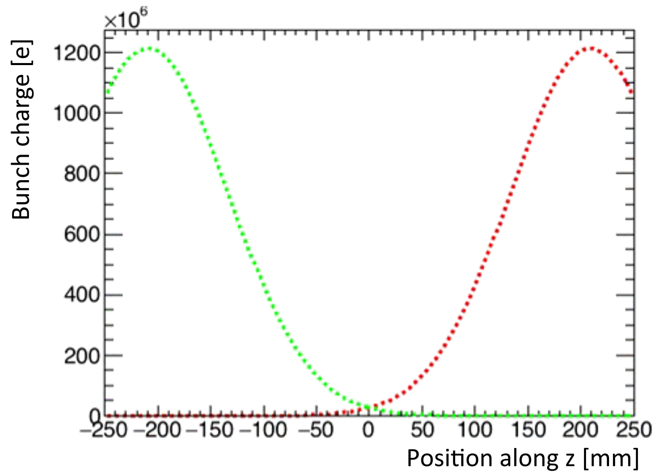

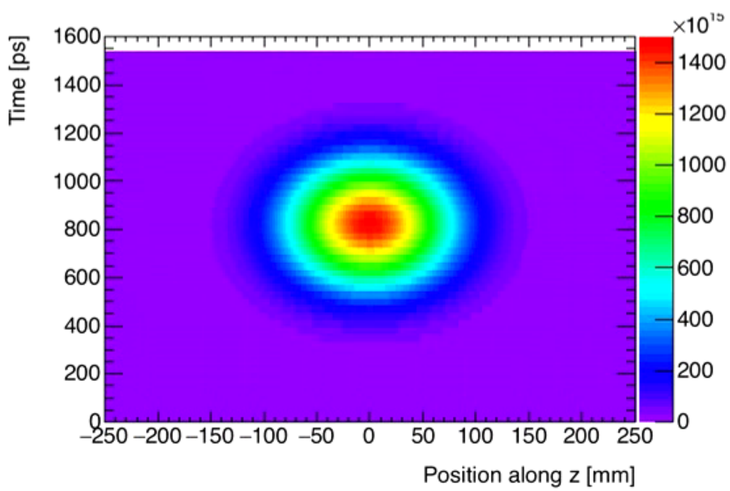

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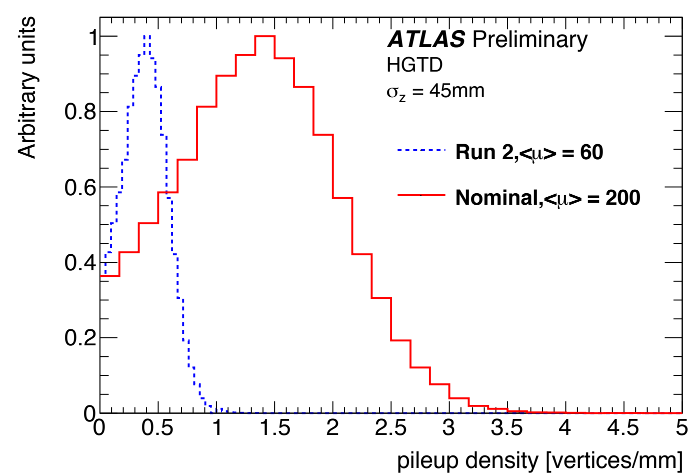
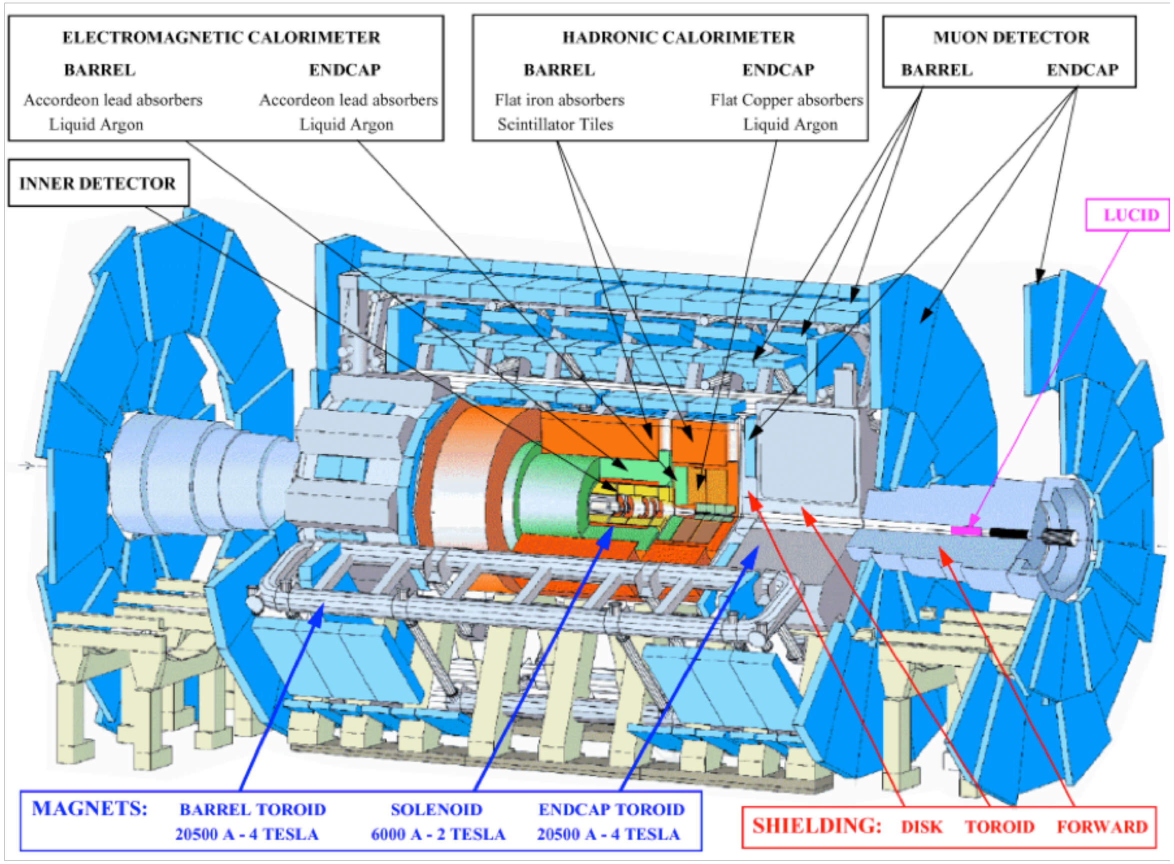


HGTD in ATLAS



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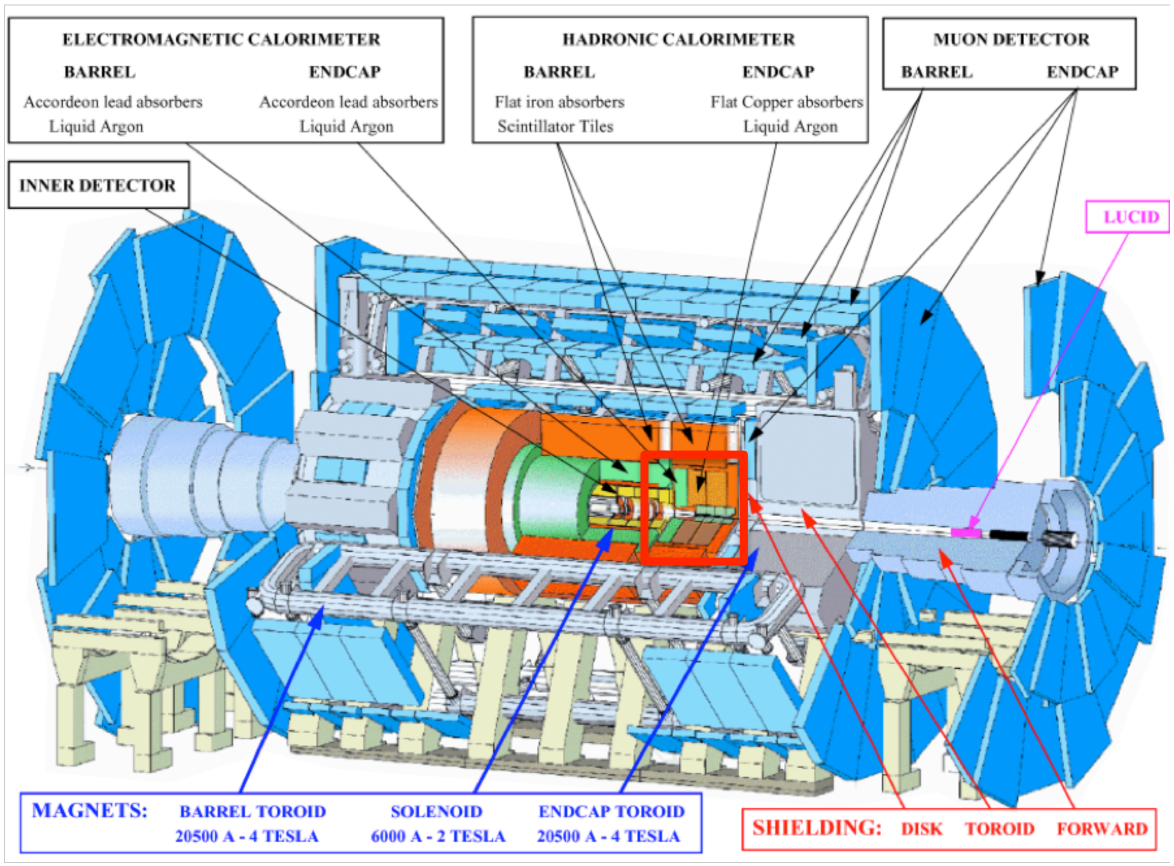

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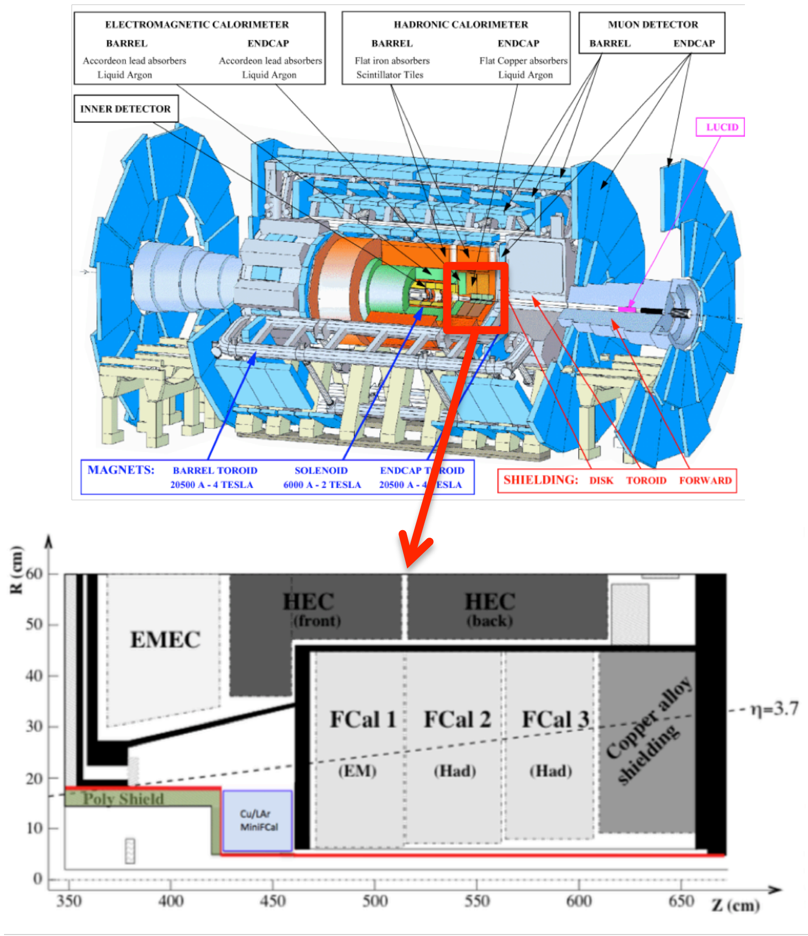

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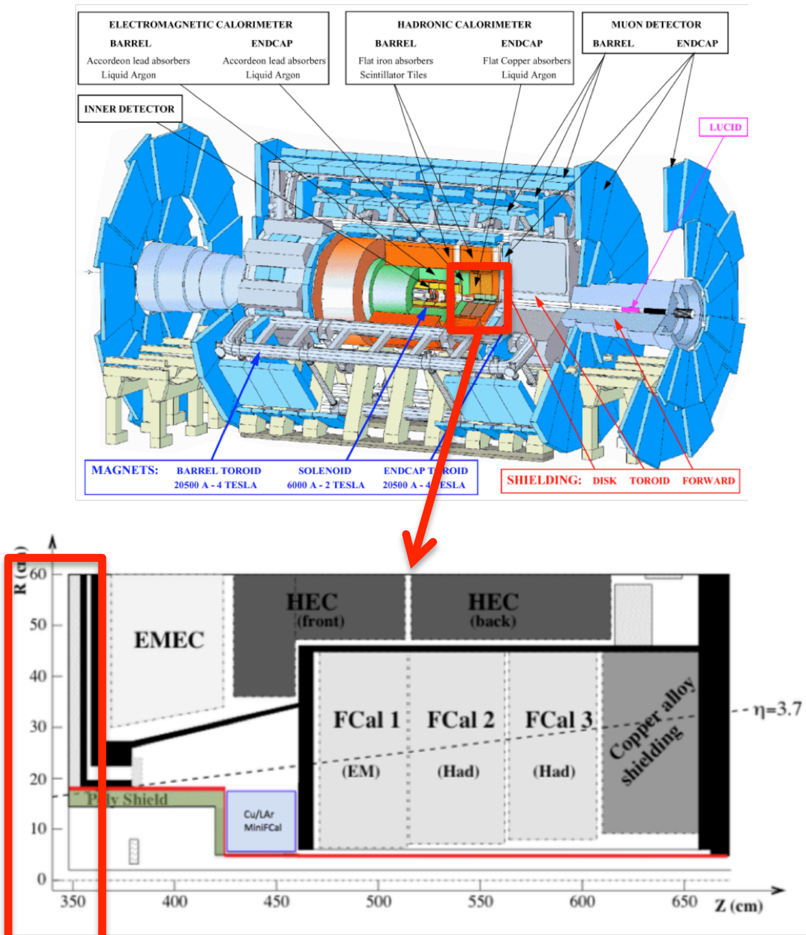

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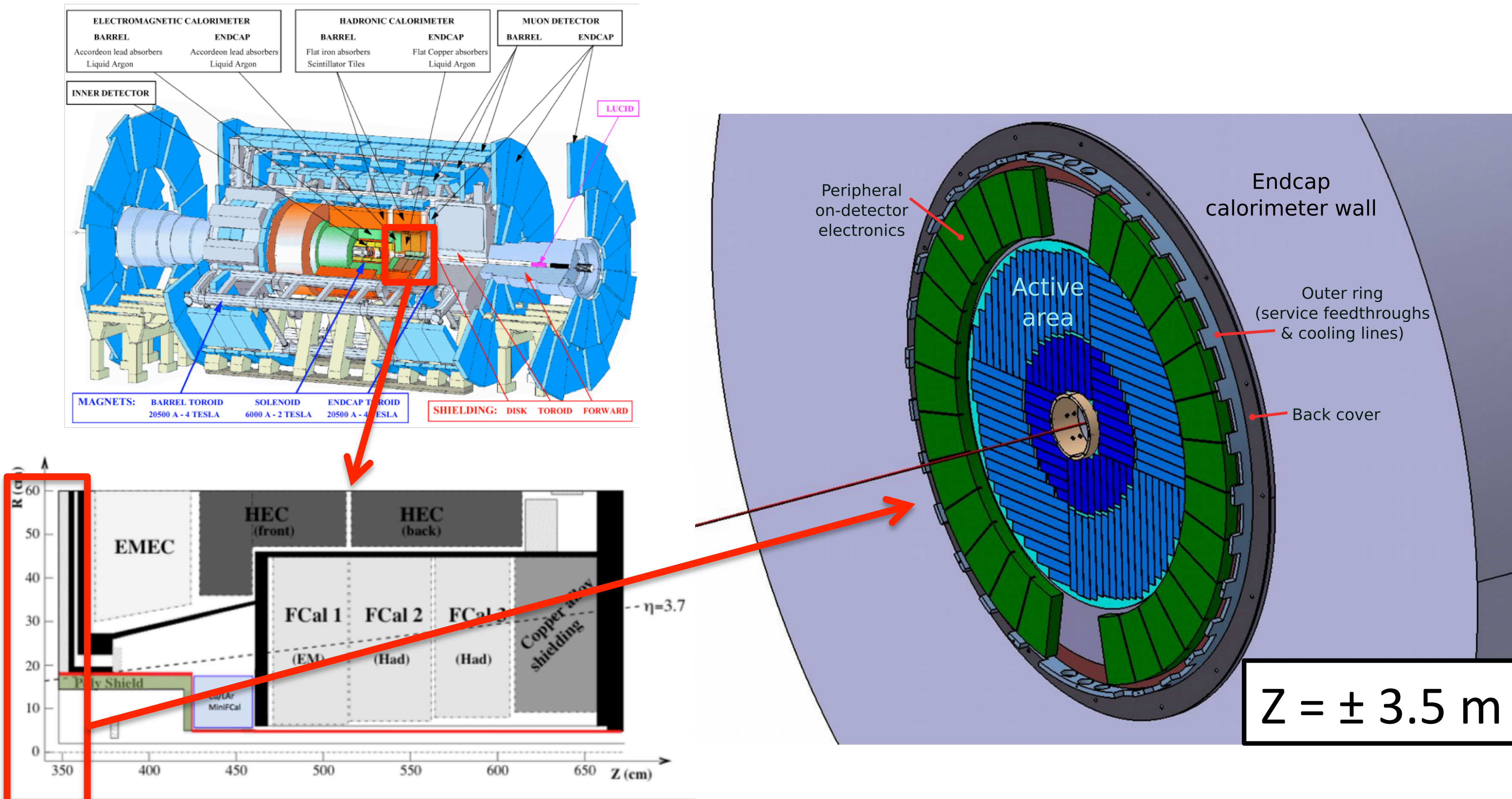
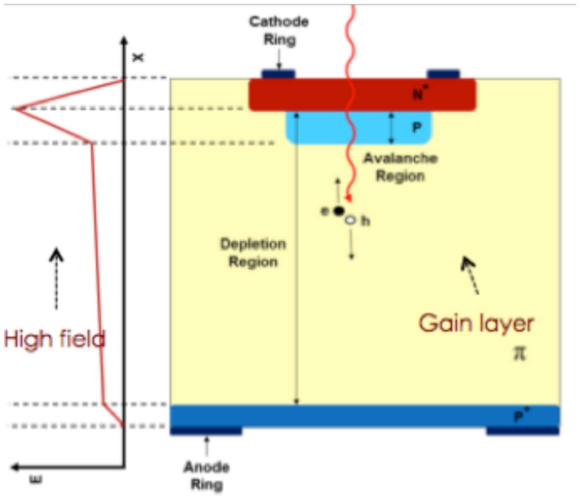
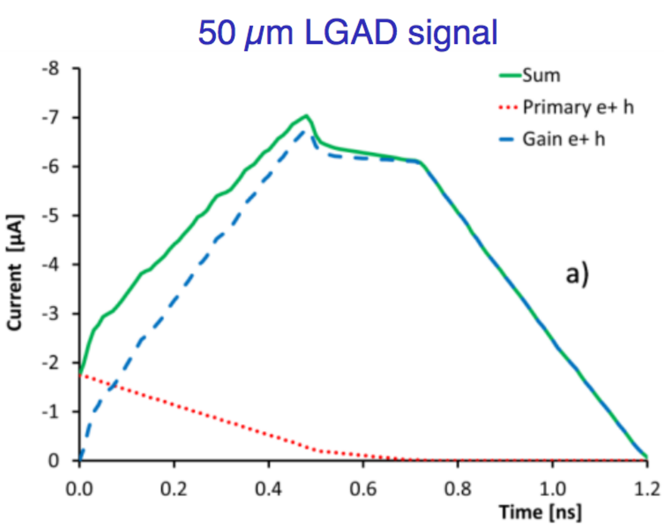


Precise timing measurement ?



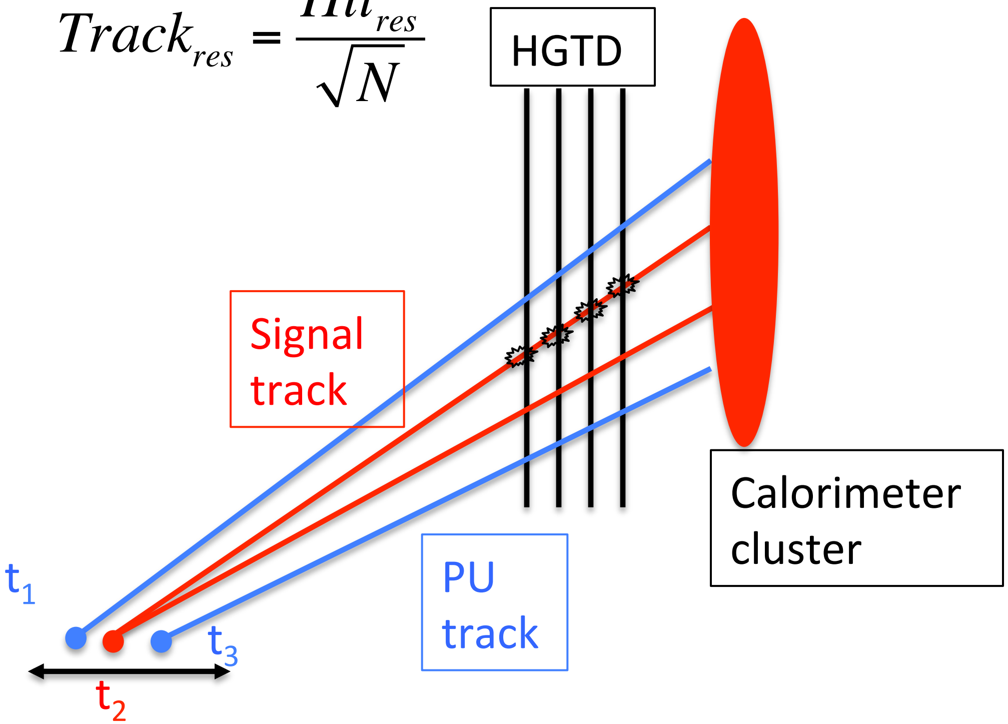


- Silicon based detector (PN junction)
- Particle go through the detector -> creation of electrons-holes pairs
- The drifting of those pairs create the signal
- Timing resolution inversely proportional to (Signal/background)
- LGAD sensors : Silicon detector with a gain : extra PN junction in the detector -> high electric field -> showering -> Gain
- Expected time resolution : 30 ps (60 ps after irradiation)

Principe of the timing measurement

N layers hits :

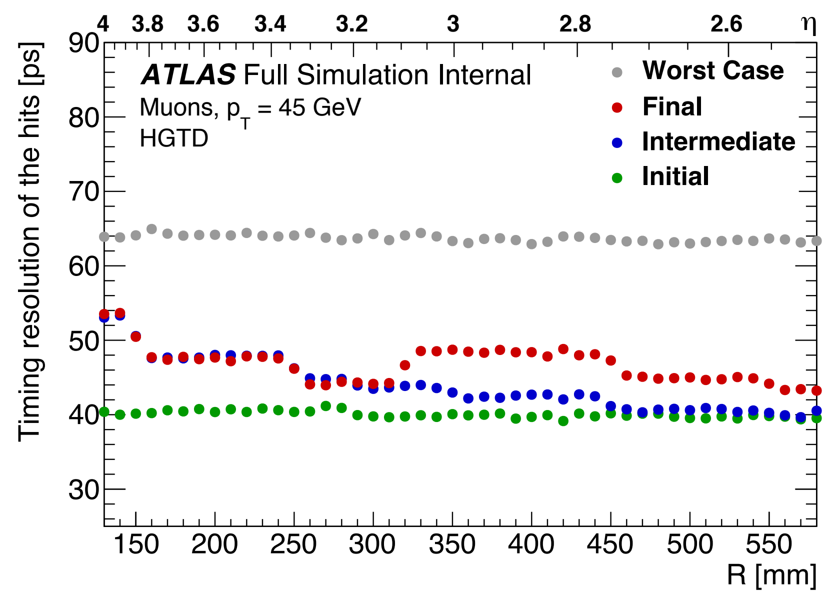
$$Track_{res} = \frac{Hit_{res}}{\sqrt{N}}$$

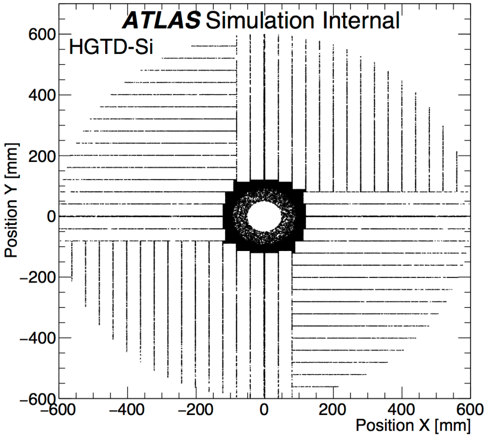


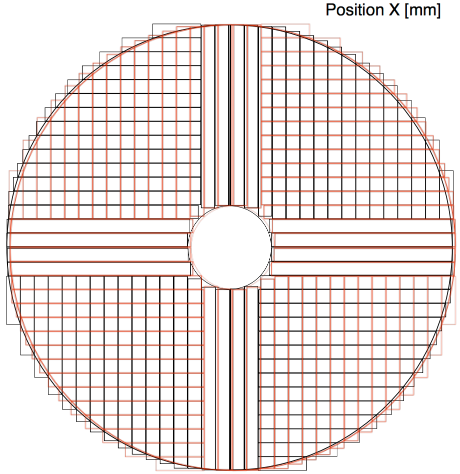
If $|t_1 - t_2| > 2 \times \sqrt{Track_{res1}^2 + Track_{res2}^2}$
Then track can be separated using timing

- Sensor timing resolution is of 30 ps before irradiation
- 25 ps added quadratically to take into account the effect of the electronic

- 3 different timing scenarios :
  - Initial : 30 ps per pad and 25 ps for the electronic
  - Intermediate : timing resolution after 2000 fb^{-1}
  - Final : timing resolution after 4000 fb^{-1}







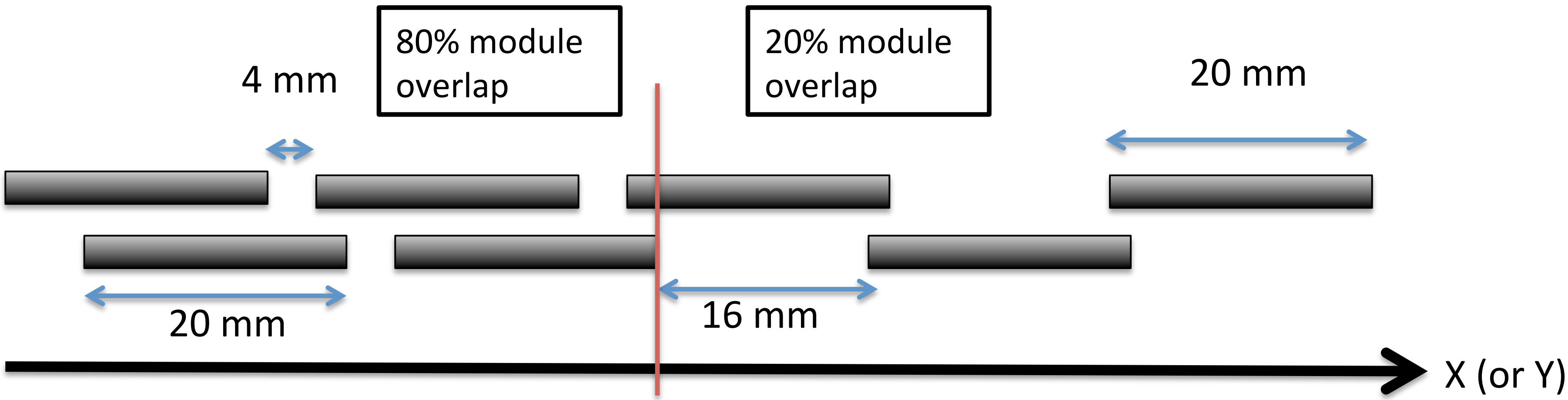
HGTD Geometry

Constraint for the development of the geometry :

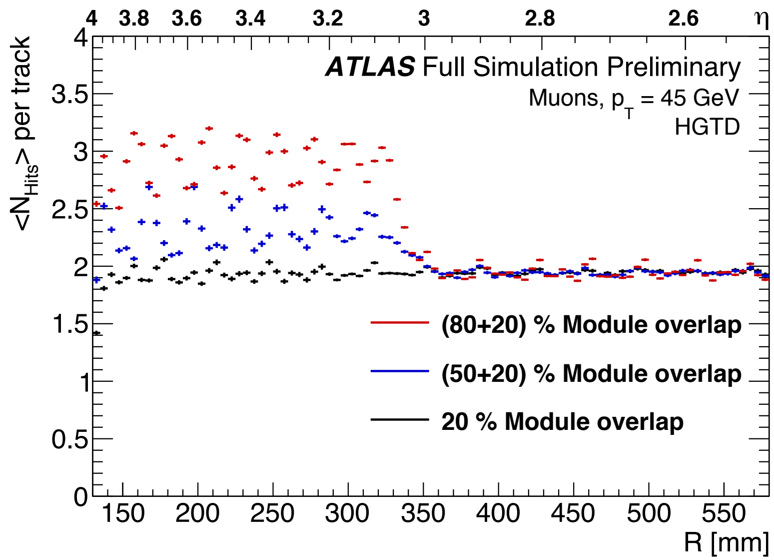
- Maximise the coverage at low radius
- Avoid too long staves
- Minimise dead area

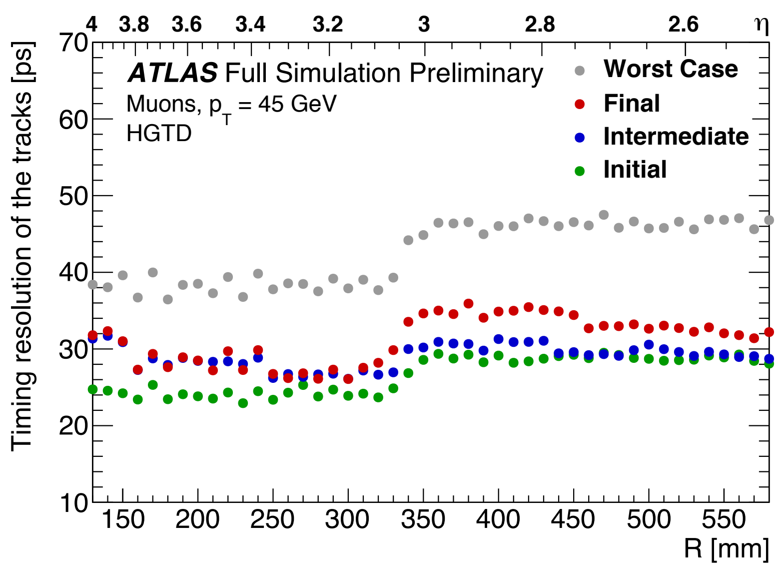
Helix_2 :

- 1.3x1.3 mm^2 pads (1x1 mm^2 in simulation) -> occupancy bellow 10%
- 2 Layers, the second one is the mirror image of the first one
- For each stave, modules on both side of the coolling plate (20% overlap for R>320mm and 80% for R<320mm)



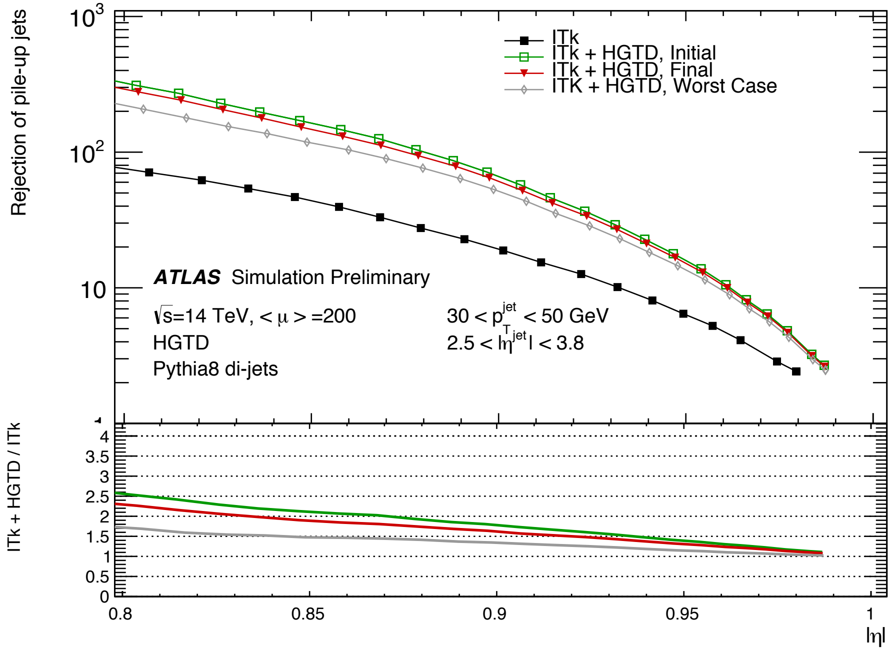
Hits multiplicity





- Single muons with a flat distribution in R have been used to study the hit multiplicity in the detector
- More hits need at low radius to balance the timing resolution -> Study of the hit multiplicity
- Result consistent with the one obtain previously :
  - ~2 hits at large radius (R>320 mm)
  - ~3 hits at low radius (R<320 mm)
- Oscillation at low radius : period ≈ module size
- For different radius the **timing resolution** is computed : it is the sigma of the distribution of $t_{reco} - t_{truth}$

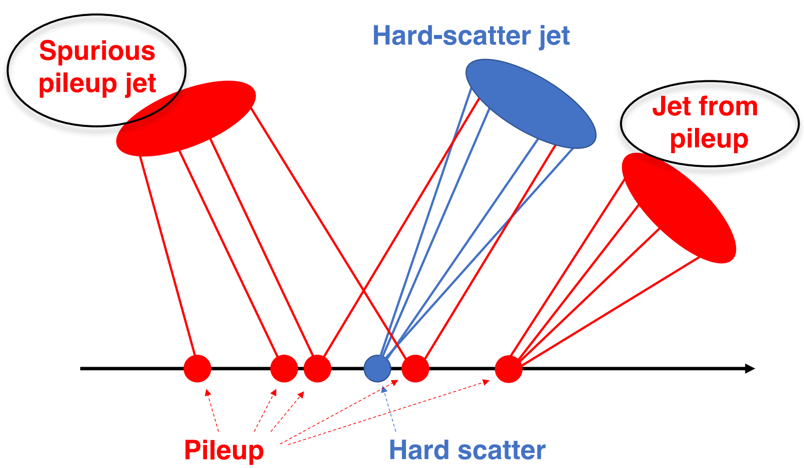
Pileup-jet rejection

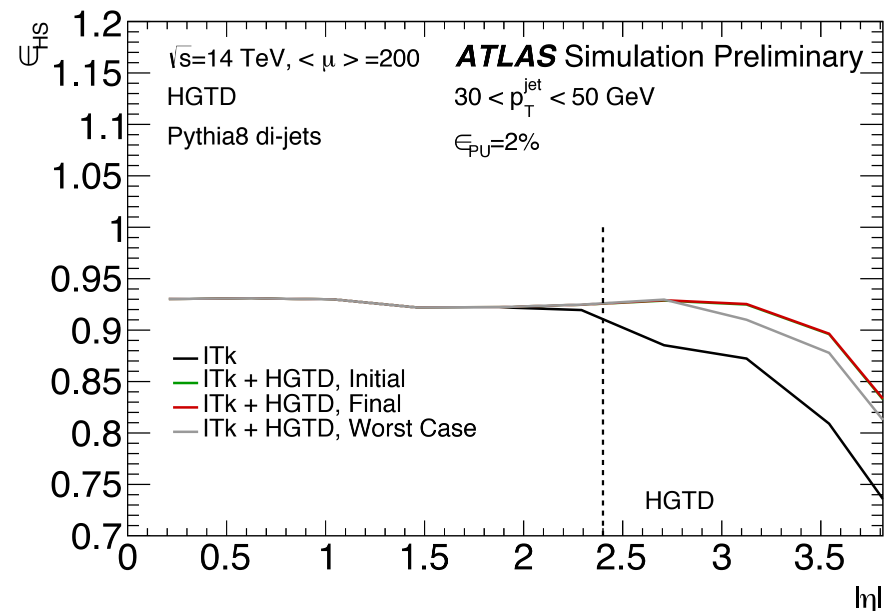


- Rejection of pile-up jets done using R_{pt} (PU -> low R_{pt})

$$R_{PT} = \frac{\sum P_T^{track}}{P_T^{Jet}}$$

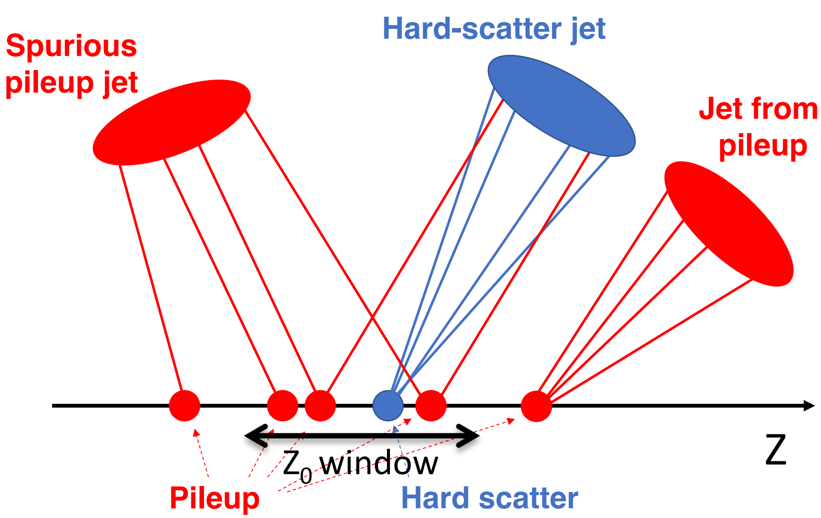
- Effect of the R_{pt} reduce for high PU
- Use the HGTD to remove the track not in time with the primary vertex
- Recover the barrel performance of R_{pt} in the endcaps

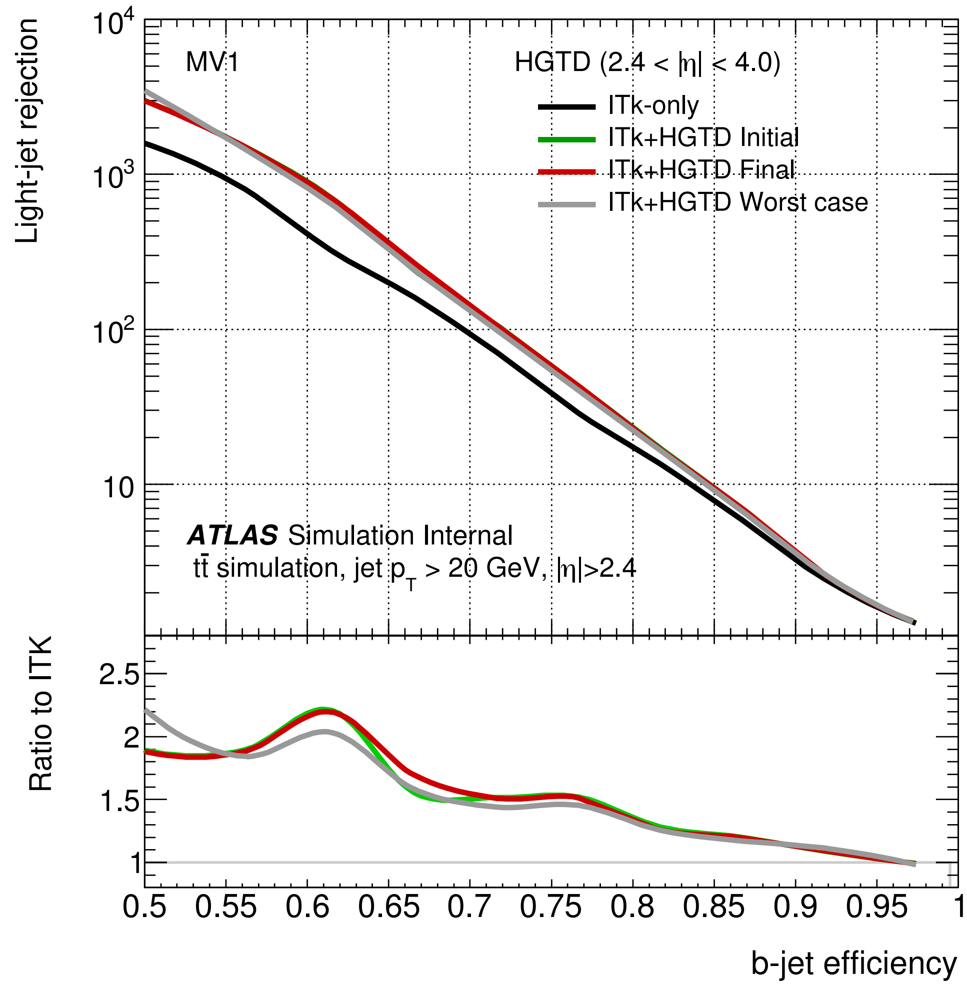




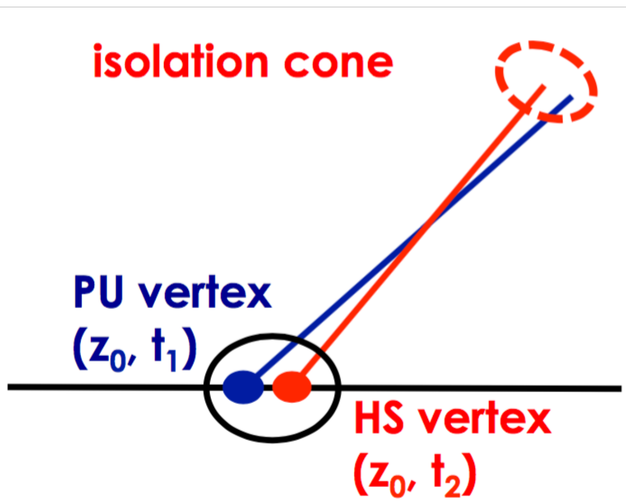
b-tagging

- Studies of H->bb need a way to identify jets coming from b -> *b*-tagging
- *b*-jets -> displaced vertex -> large z_0 window -> very sensitive to pileup-track contamination
- HGTD -> reduction of the PU contamination -> Improvement of the *b*-tagging efficiency

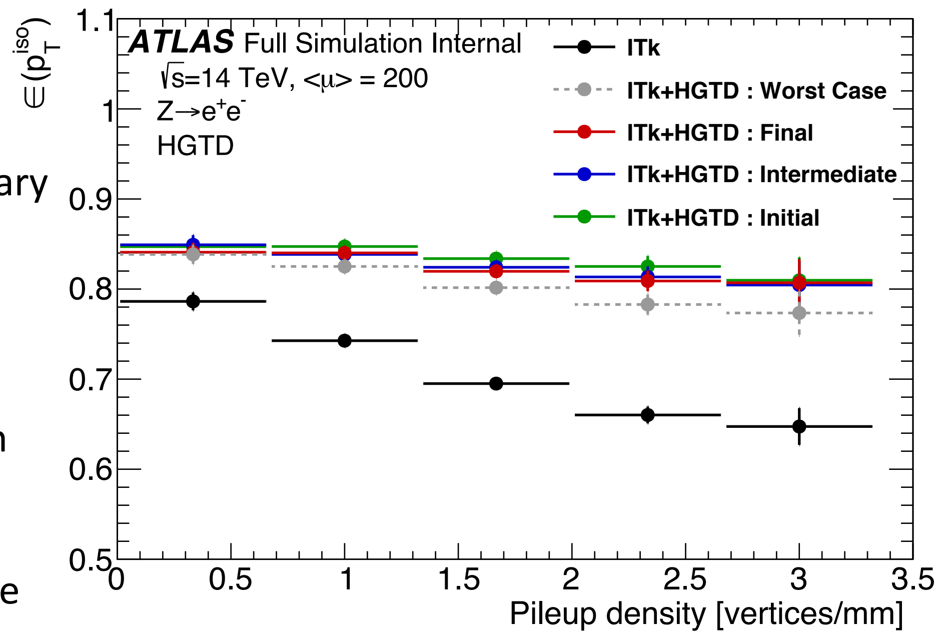




Isolation des Leptons



- Track isolation used in many analysis with leptons to fight QCD background
- Isolated lepton -> Lepton that come from the studied process (and not from showering)



- Pileup-robust when using only tracks from primary vertex
- Not robust to merged/close-by vertices
- HGTD can mitigate the merged vertices problem by associating a time to each track
- Computed with full simulation and different time resolution

Conclusion

Timing information can enhance the ATLAS detector capabilities under HL-LHC conditions :

- Assigning time to tracks can improve offline physics
  - Lepton isolation, *b*-tagging, pileup-rejection …
- Can also be used for luminosity mesurement, studies of non-collision beam background, …

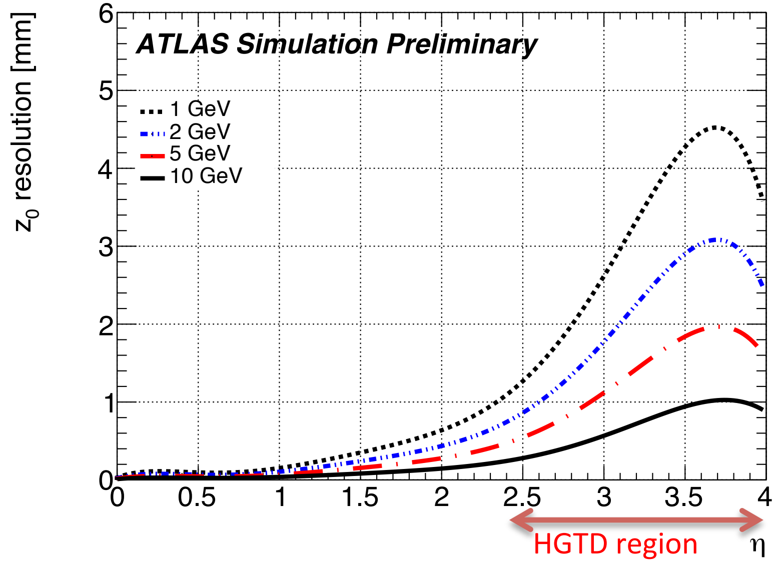
The HGTD was optimise to minimise the inefficiency and the timing resolution for each tracks

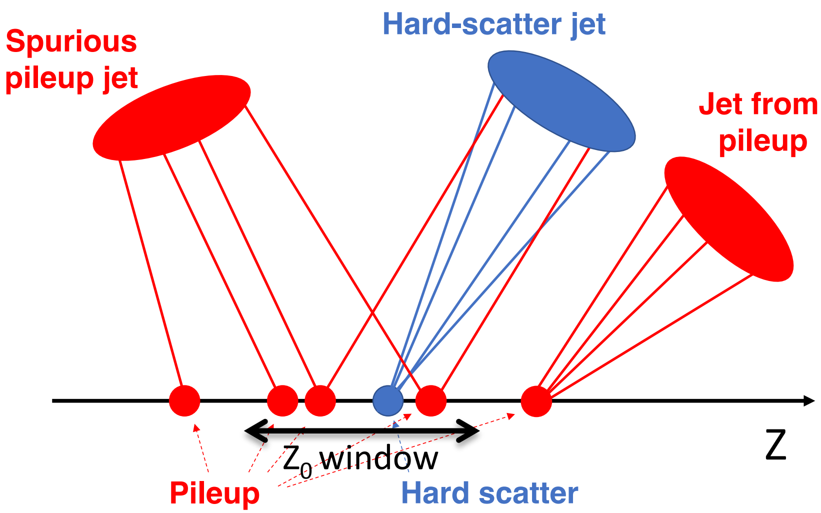
- Helix_2 geometry with two layer which are mirror image of each other
- Sensor on both side of the cooling plate with an overlap of 80% for R<320 mm and 20% for R>320 mm

This detector as been officially approved as an Atlas Phase-II upgrade Project last March.

Backup

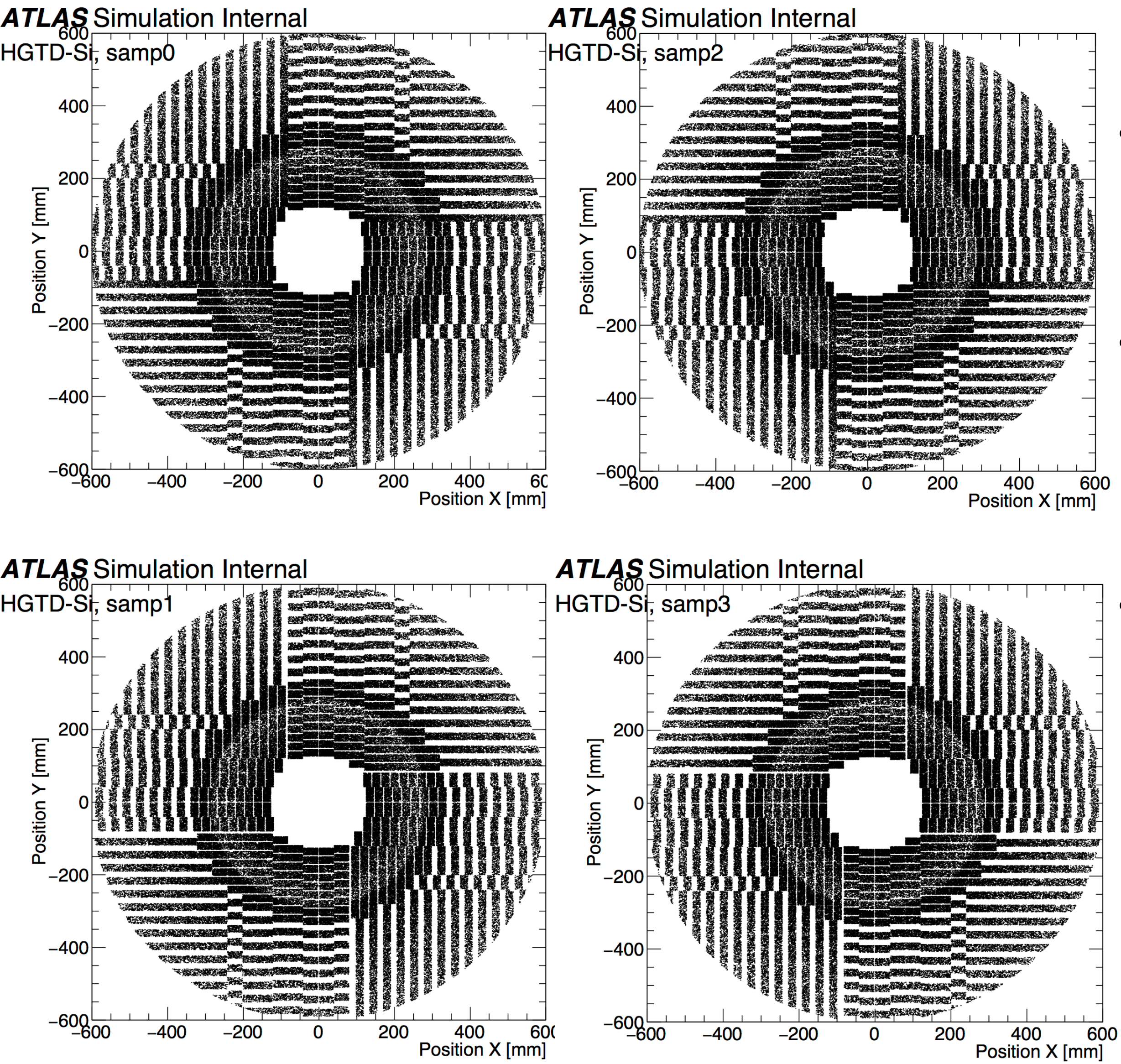
Forward detector





- Forward detector : $2.4 < |\eta| < 4$ (between 2° and 10° from the beam axis)
- In the forward region the resolution of the tracker on the position of the vertices decrease
- It is much more likely to have merged vertex in this region
- Forward detector :
  - Useful for the VBF production of the Higgs in which the Higgs is produced with 2 forward jets
  - Can be use to increase the η region in which some analysis are perform
  - Can provide luminosity measurement that can improve all the analysis

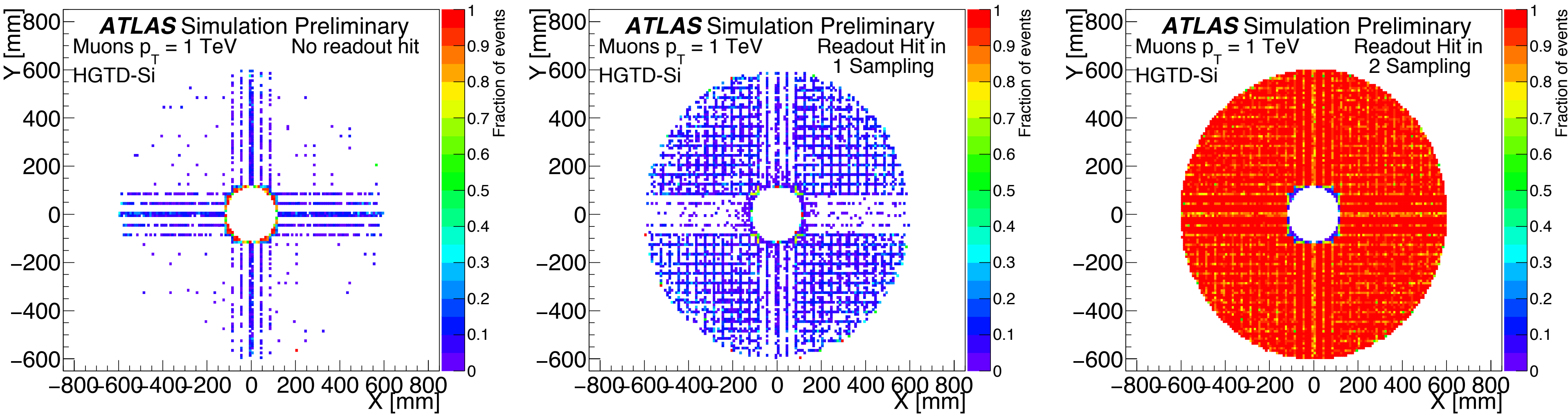
Layers Geometry



- Illustration of the implementation of the HGTD in the simulation
- Each black rectangle correspond to a modules. The with space correspond to the non-instrumented region
- Inter modules dead zones as function of the radius :
  - 4 mm for 80% overlap
  - 16 mm for 20% overlap

Dead zones in the HGTD

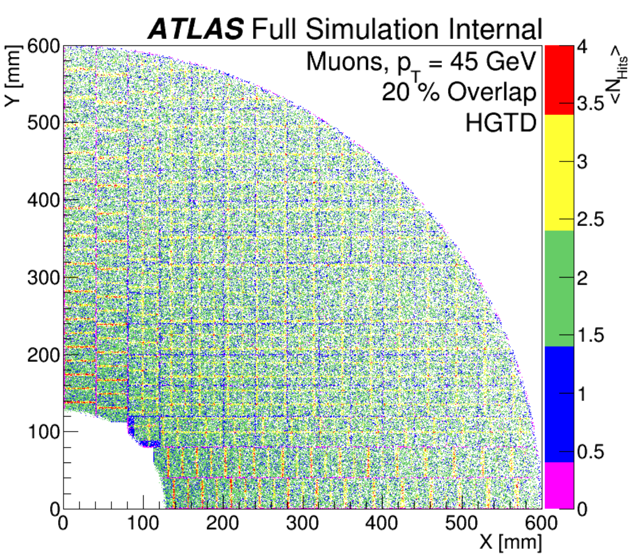
- Between each stave there is a 1 mm dead zones
- Between each half circle there is a 3 mm dead zones (in the simulation one between each quadrant)
- Dead zones align between layer 1 and 2 -> the particle can be completely lost -> mirror symmetry between the two layer
- 0,7% of the muons with a flat distribution in eta go through the detector without interacting

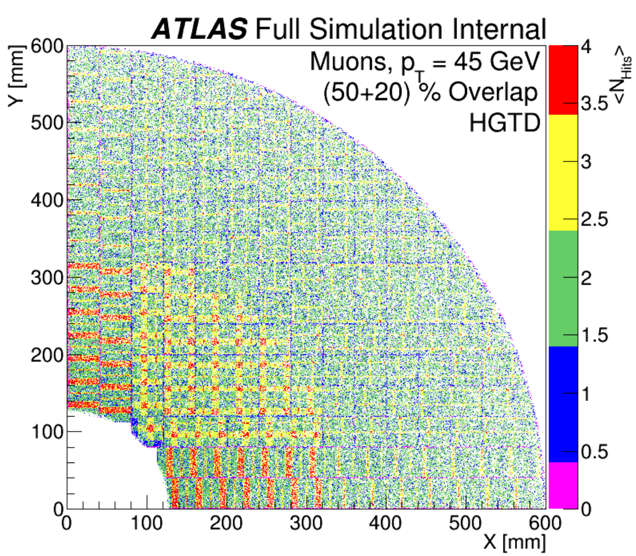


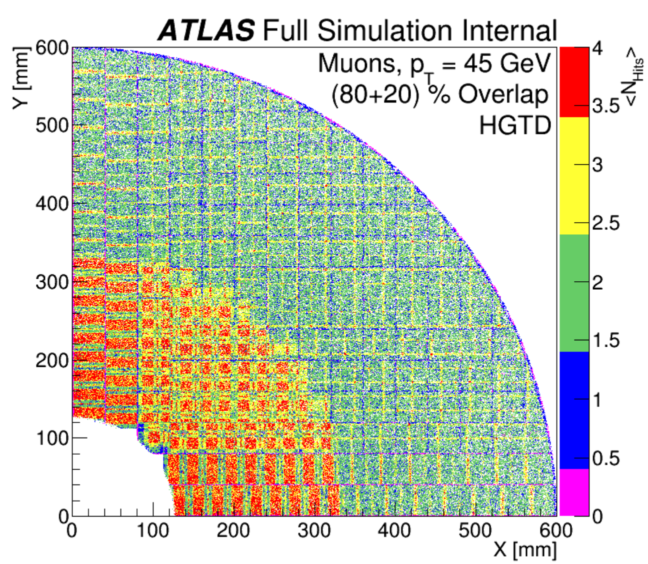
Hits multiplicity

- Single muons with a flat distribution in R have been used to study the hit multiplicity in the detector

- 3 overlap scenarios :
  - 20% overlap everywhere
  - 20% overlap for R>320 mm and 50% for R<320 mm
  - 20% overlap for R>320 mm and 80% for R<320 mm



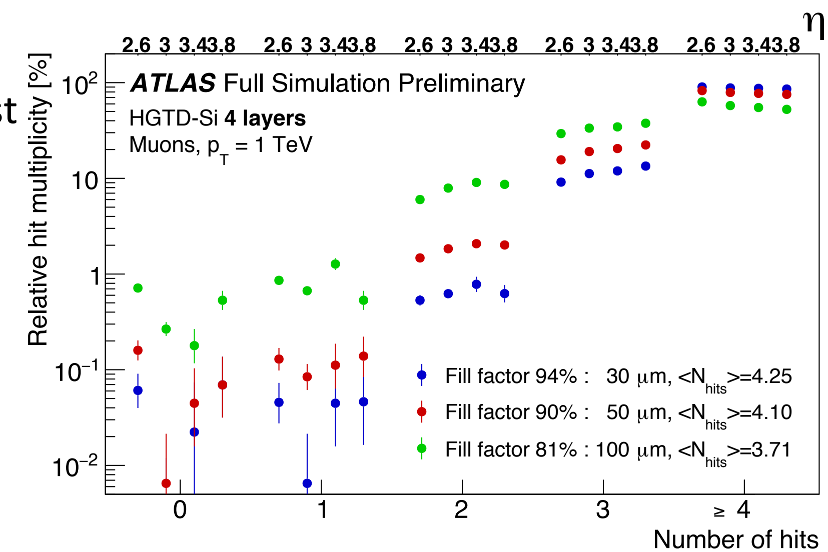


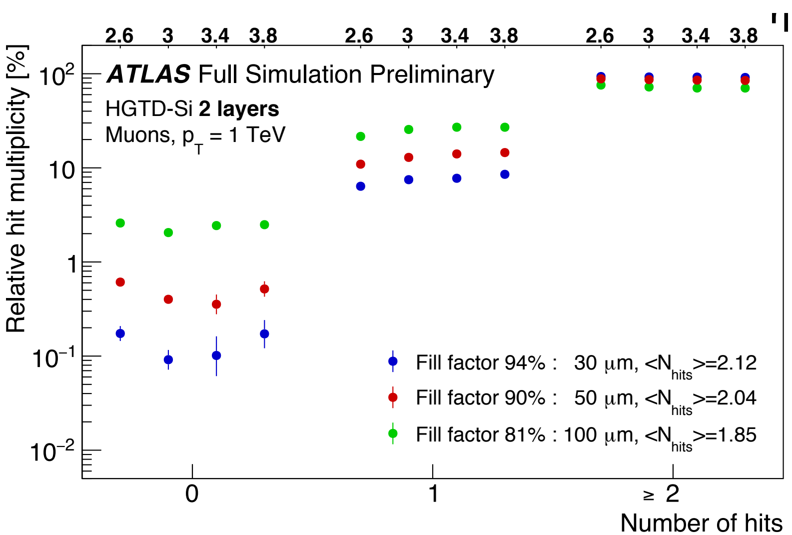


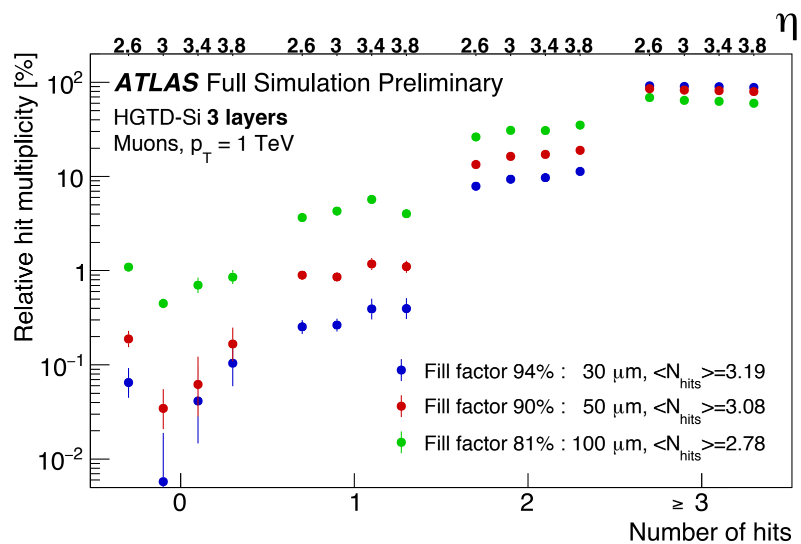
Number of layers

- Number of hits per track in the HGTD as function of the number of layer
- Studies of the performance of the detector as function of the number of layer to optimise the cost
- After irradiation the timing resolution is worst at low radius so a geometry with 2 layer with 3 effective layer at low radius have been chosen

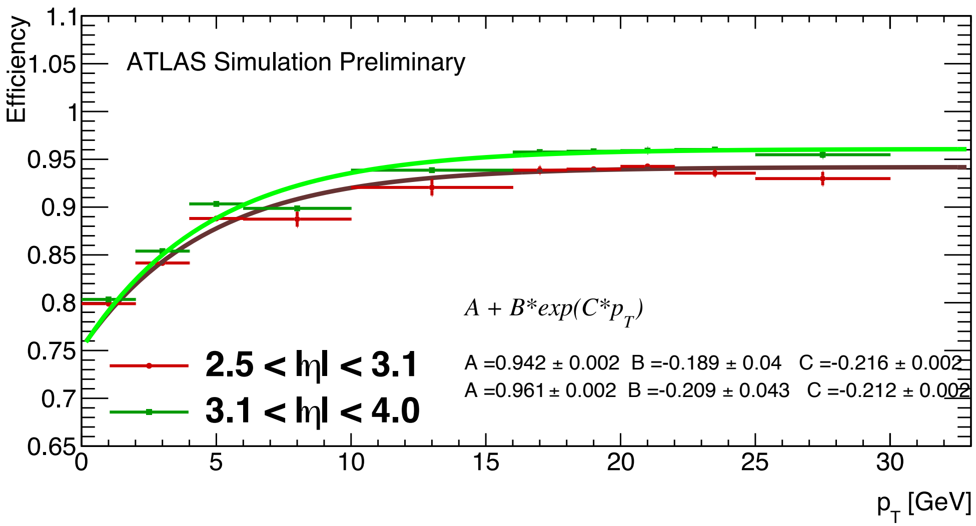
	Two layers	Three layers	Four layers
$N_{\text{hits}} \geq N_{\text{layers}}$	86%	82%	78%
$N_{\text{hits}} = 0$	0.5%	0.11%	0.07%
$< N_{\text{hits}} >$	2.04	3.08	4.1
$< \sigma_t >$	43 ps	37 ps	32 ps







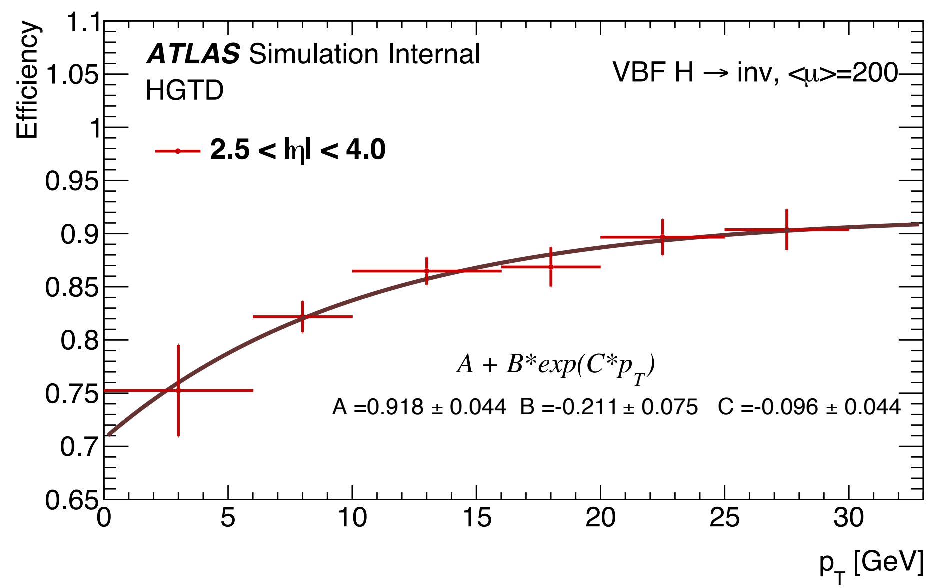
Track matching efficiency



- One of the main objective of the HGTD is to remove PU track using timing information
- A way to associate hits in the HGTD to ITk track is need
- The tracks are extrapolated up to the HGTD then the closest hit (less than 5mm away) in each layer is associated to the track

- Matching efficiency defined as the probability of having at least one hit matched with the track

- Without PU it goes up to 95% at high $P_{T,}$ with PU the result are similar but 4% lower



Luminosity

- Knowing precisely the number of interaction per crossing is important :
  - Correction of the signal in the calorimeter
  - Luminosity already the dominant uncertainty in in (some) SM measurement
- High granularity detector in the forward region -> good luminometer
- Number of hits in the HGTD scale linearly with the number of vertex
- Non linearity :
  - Multihit -> Solve by the low occupancy
  - Afterglow (background activity) -> can be determine with the time resolution by looking before and after the collision