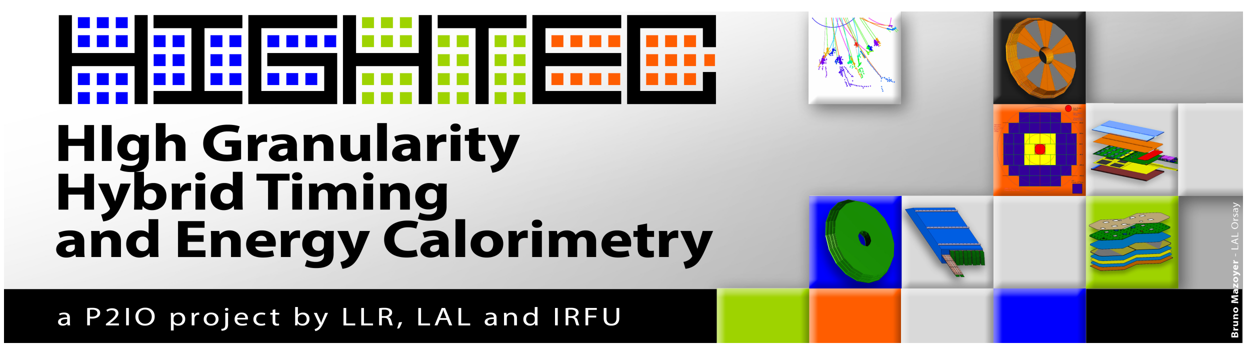
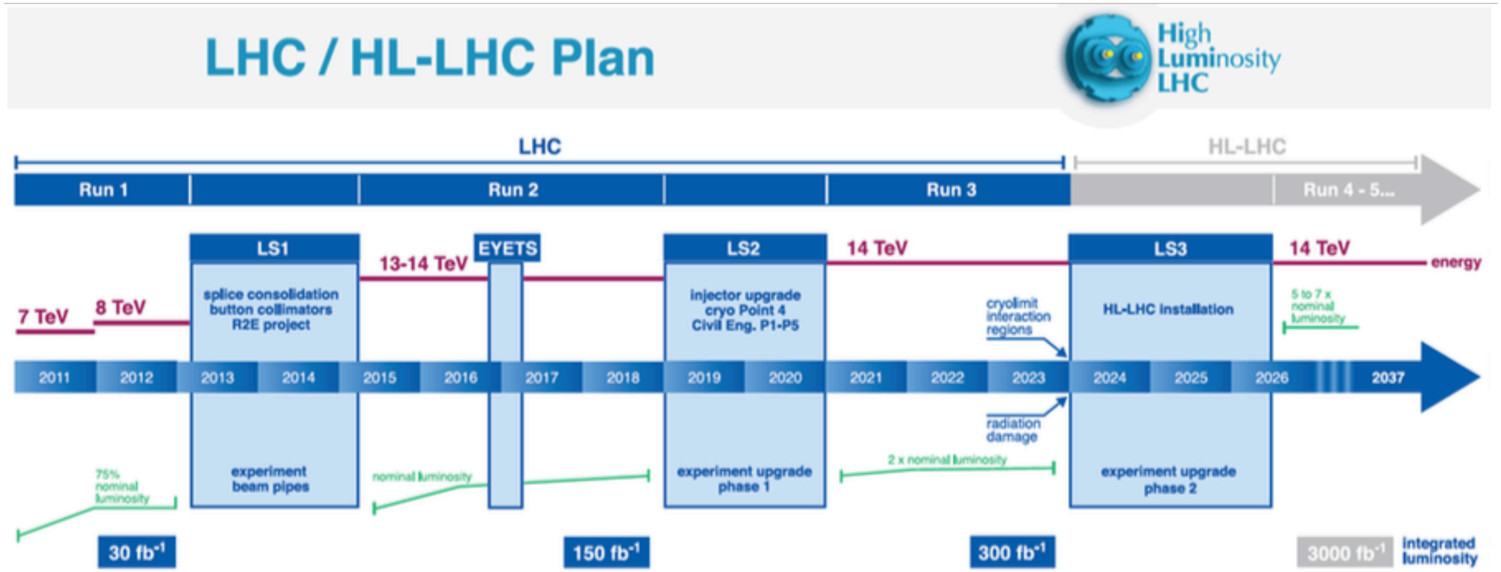
The High Granularity Timing Detector of the ATLAS Experiment

Corentin Allaire

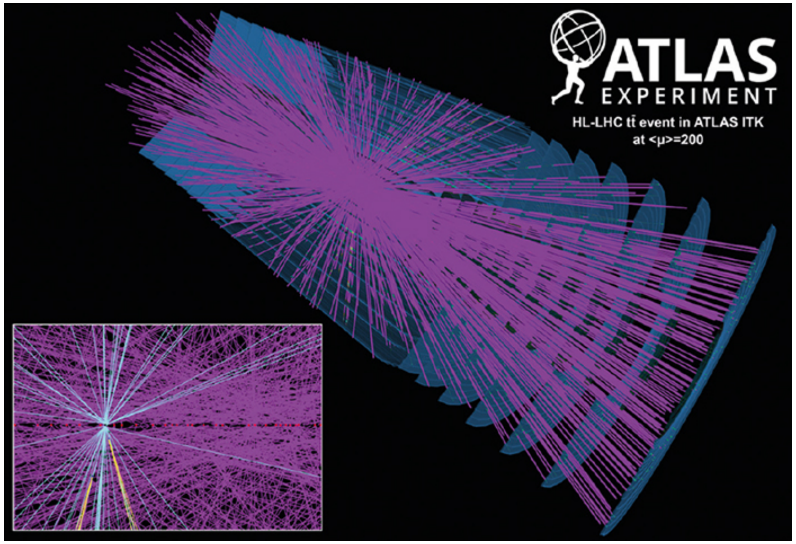


LHC and HL-LHC

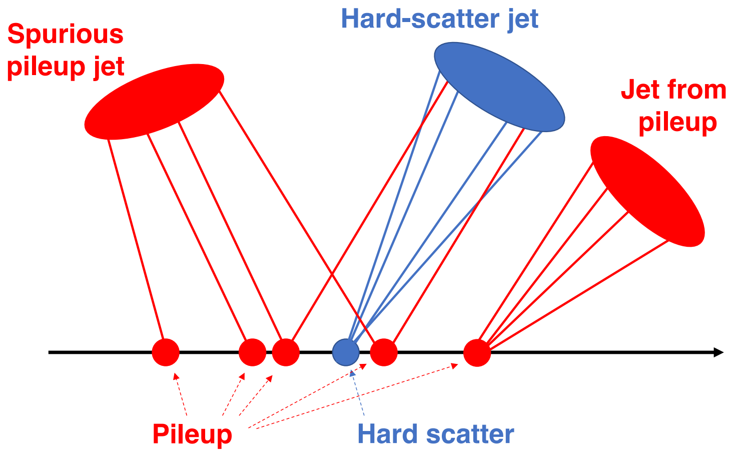


- Run2 (right now) : Energy : $\sqrt{s} = 13TeV$ Integrated luminosity : $\int L \approx 100\,fb^{-1}$ Instantaneous luminosity : $L \approx 1\times 10^{34}\,cm^{-2}s^{-1}$
- Increase of the luminosity -> Upgrade : HL-LHC (2019 and 2024)
- More luminosity -> see signal with a smaller cross section
- 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 : 40 pile up interaction in ATLAS (per bunch crossing)
- HL-LHC : 200 pile up interaction in ATLAS

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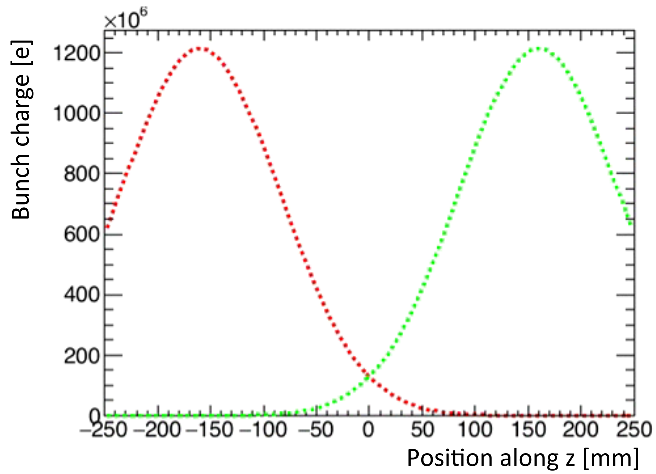

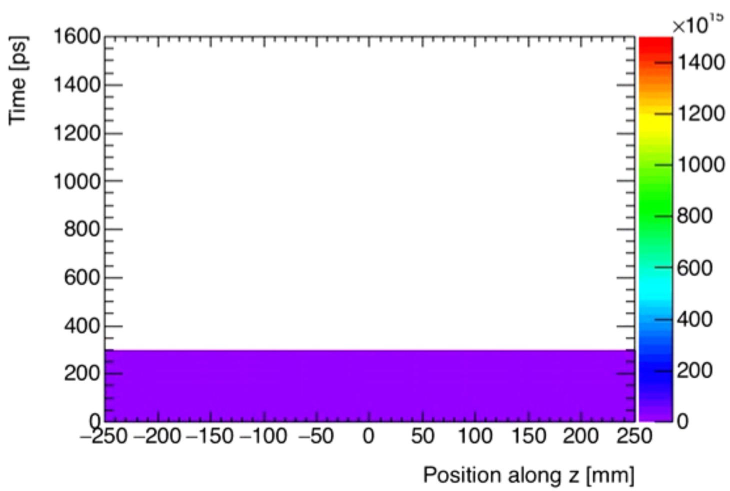

HL-LHC challenges:

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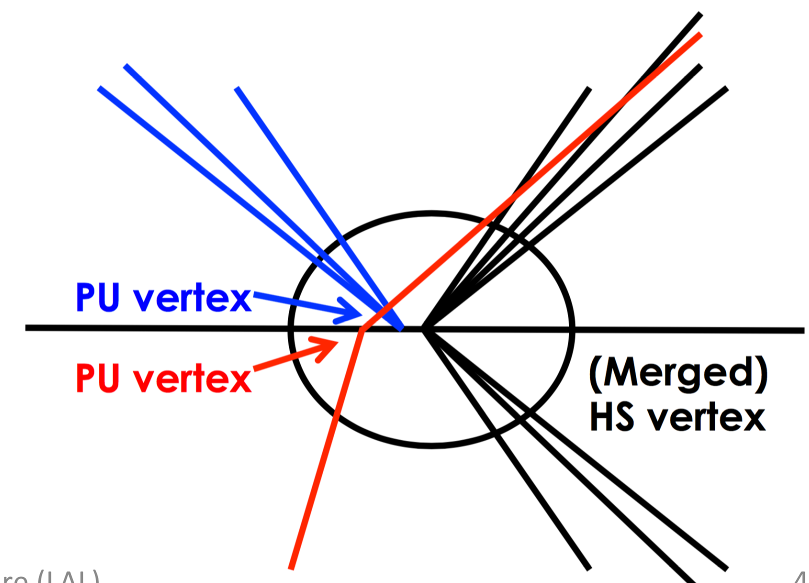

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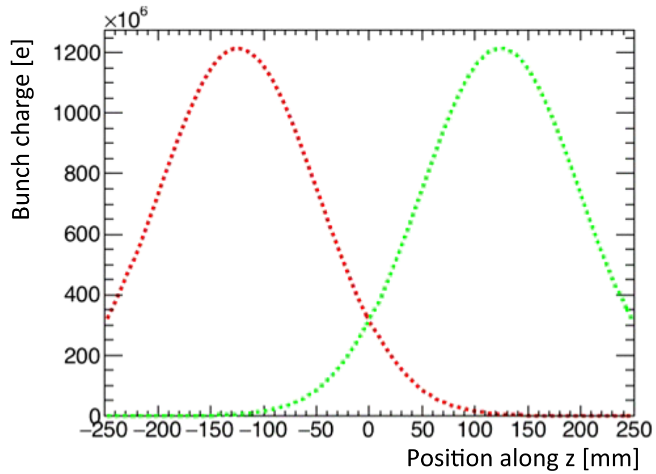

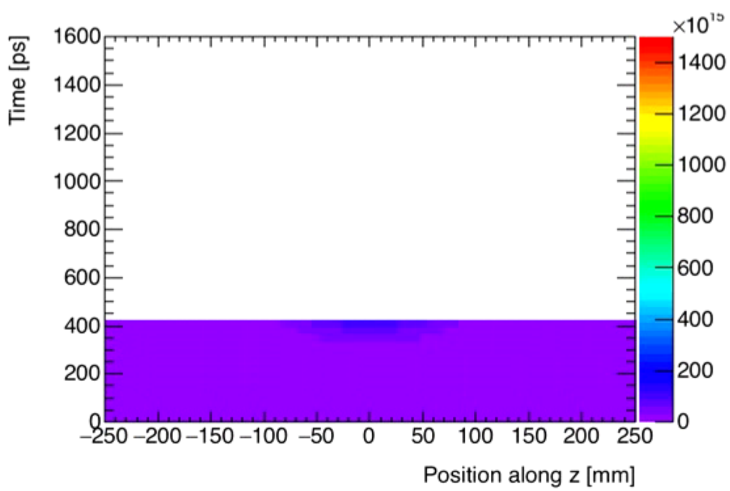

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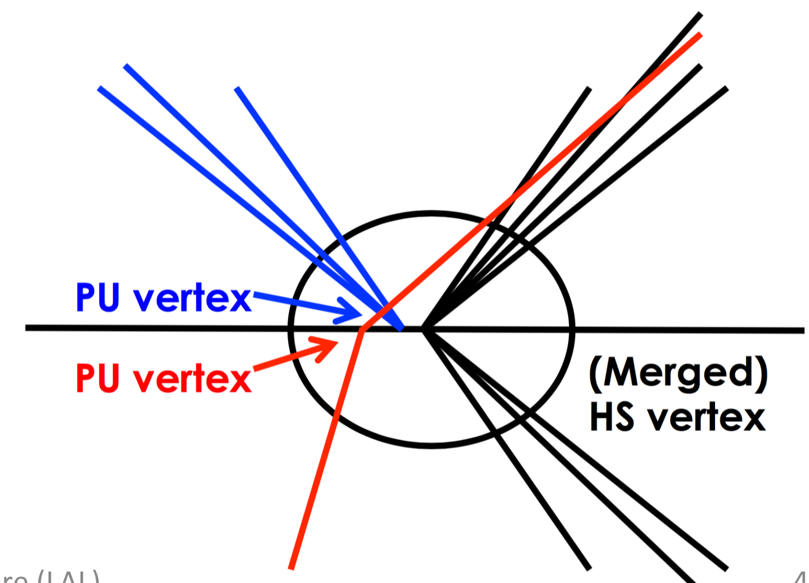

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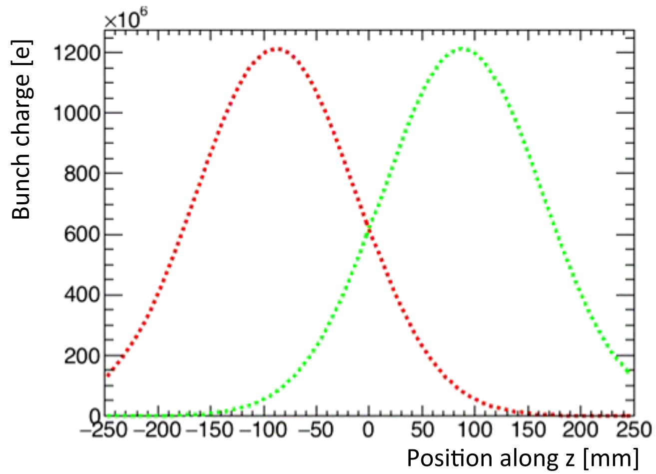

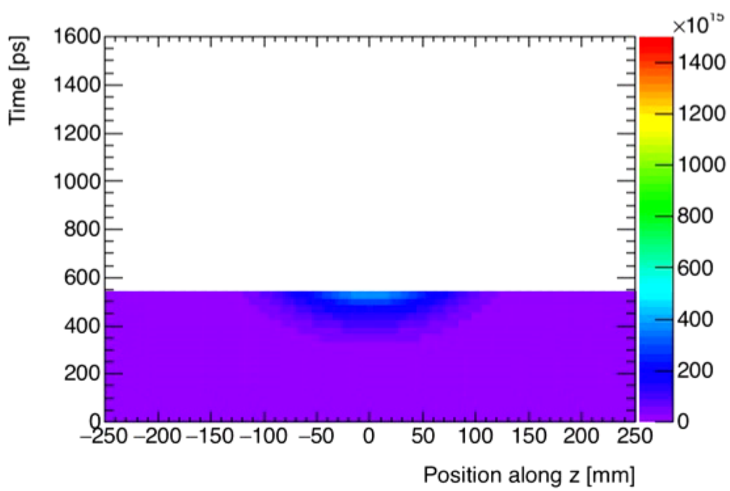

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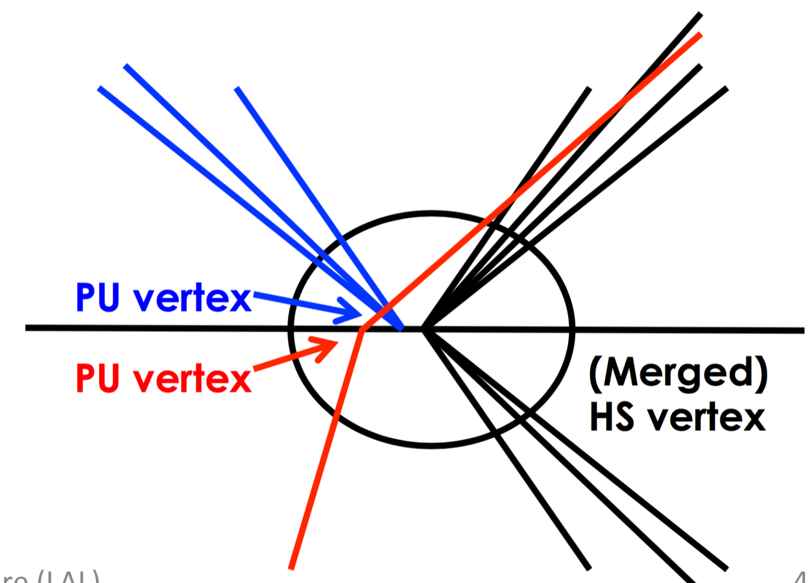

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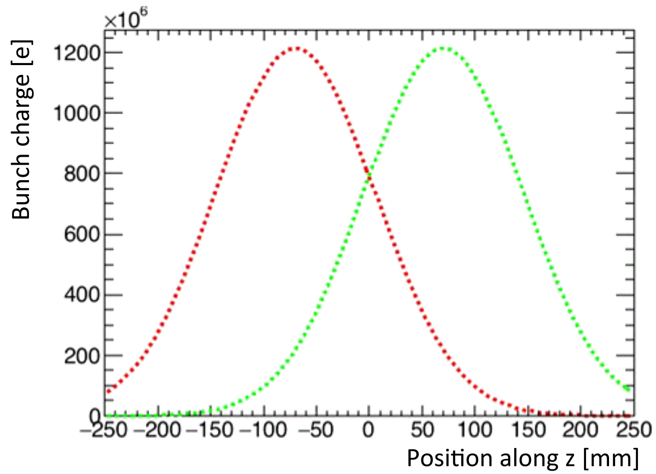

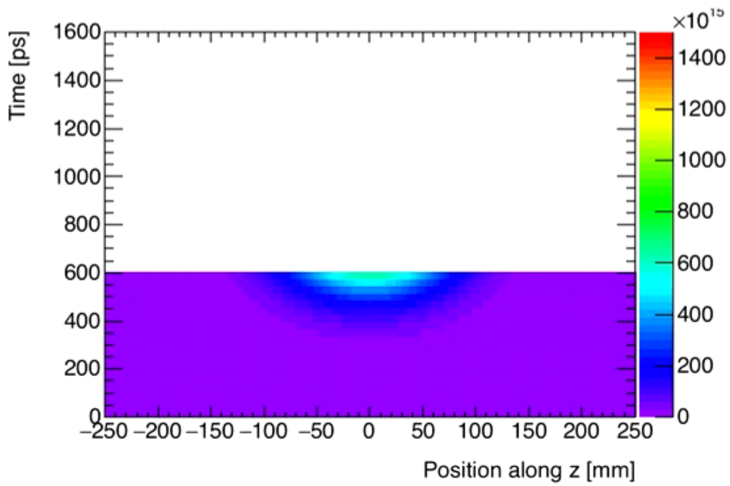

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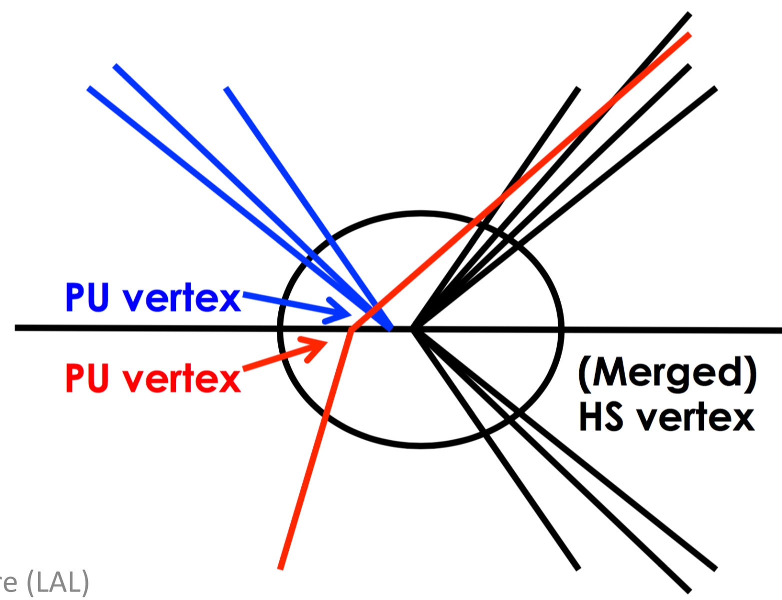

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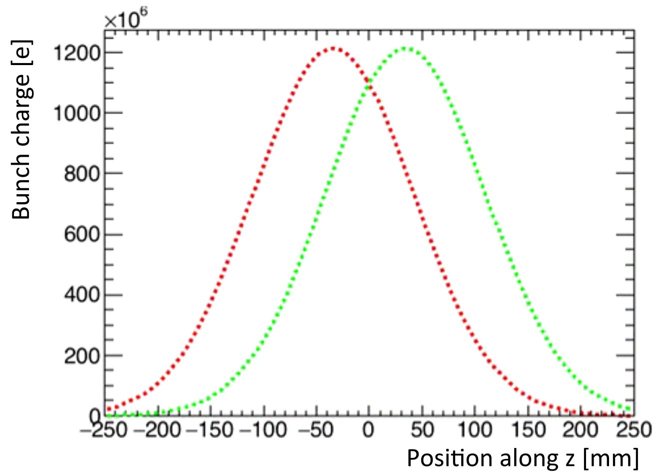

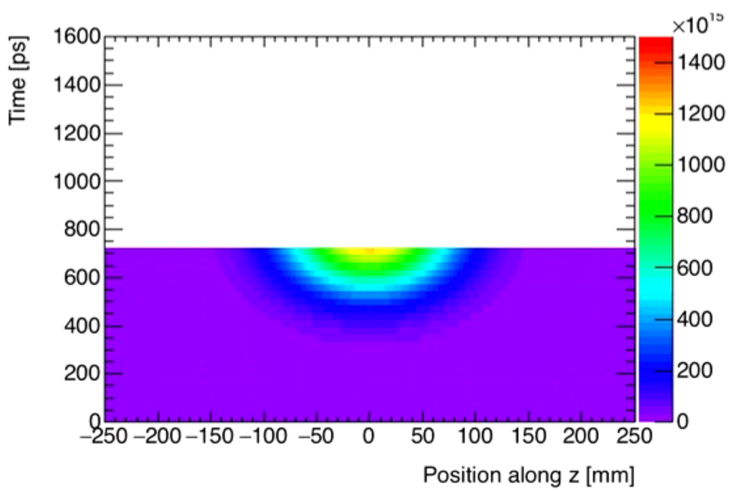

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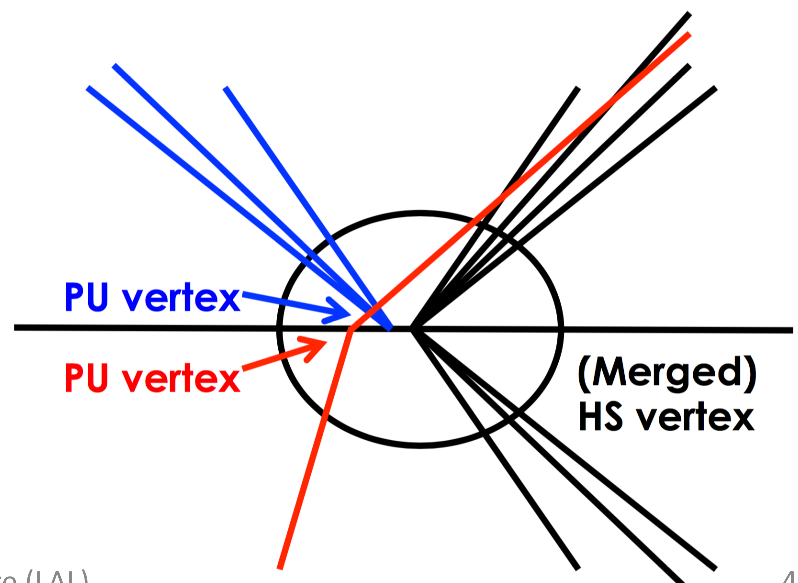

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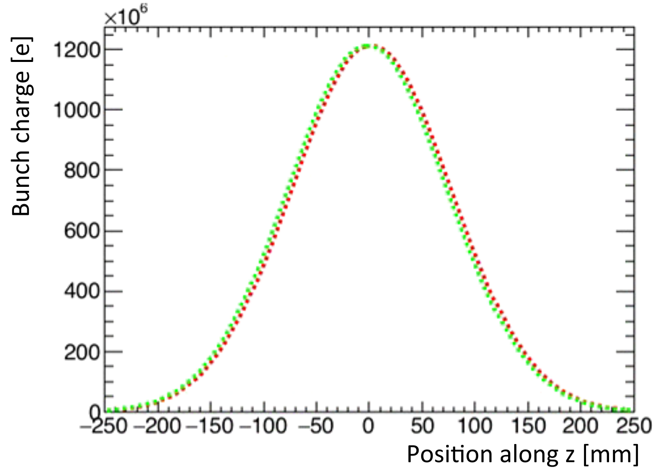

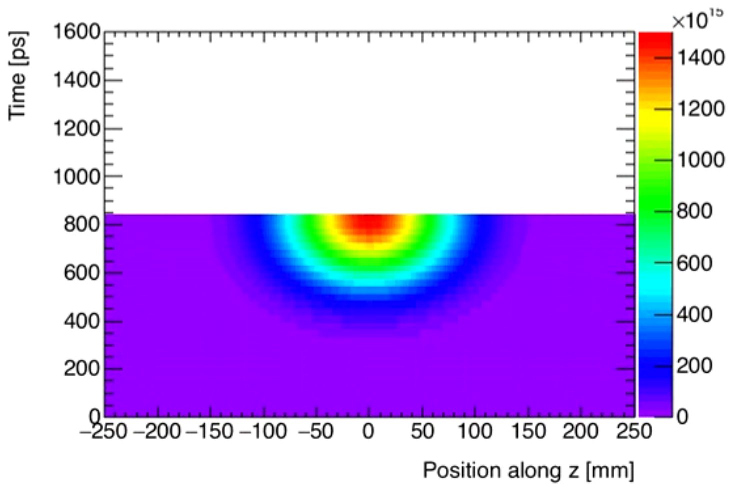

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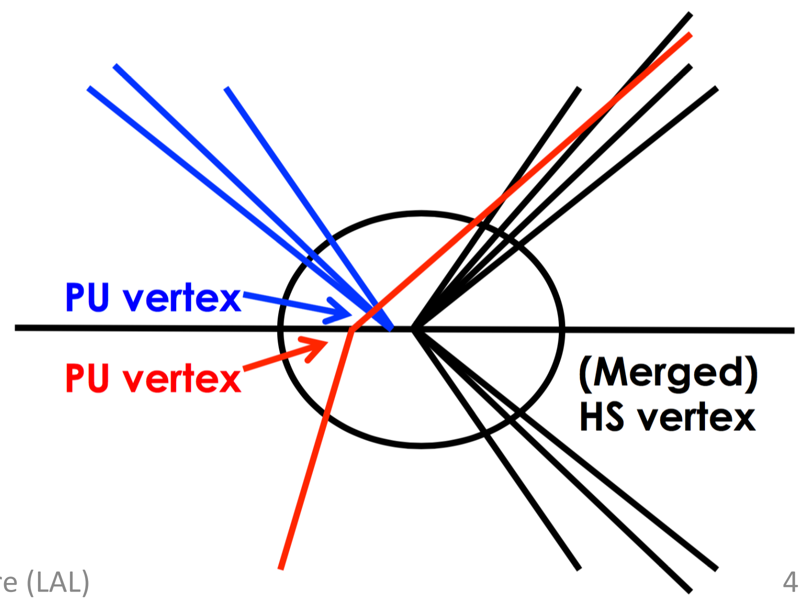

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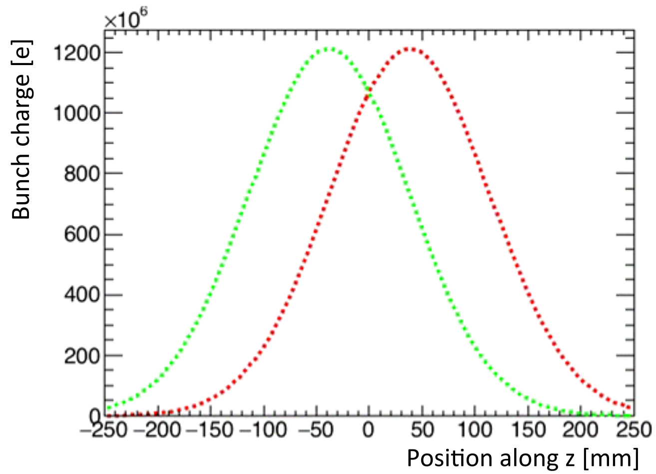

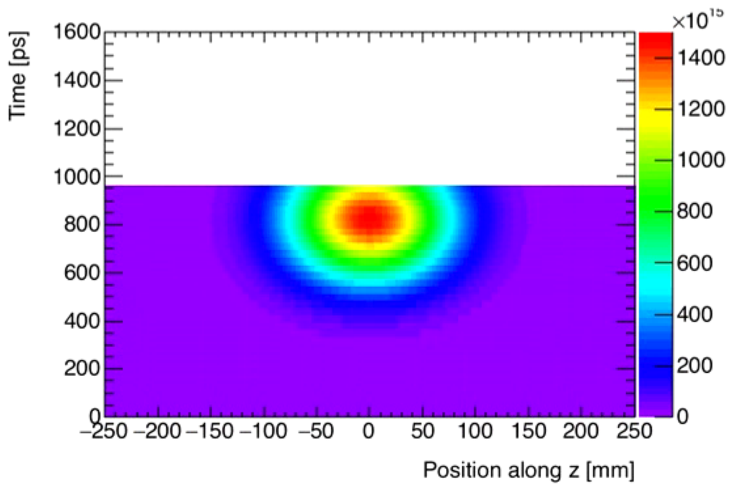

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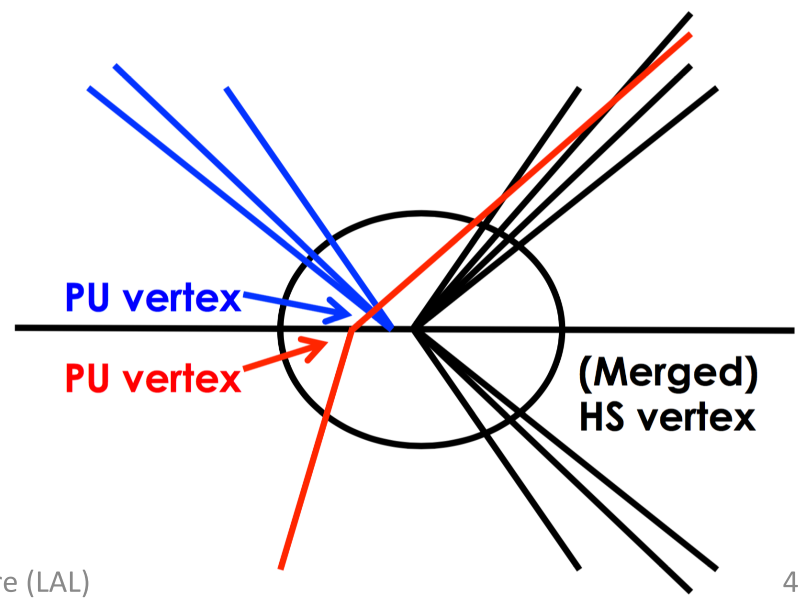

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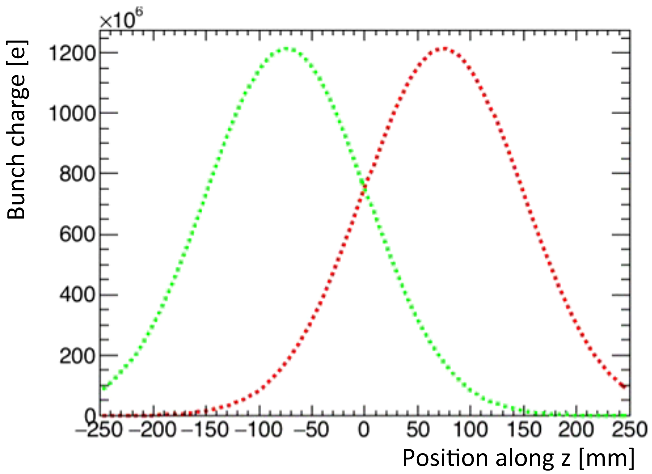

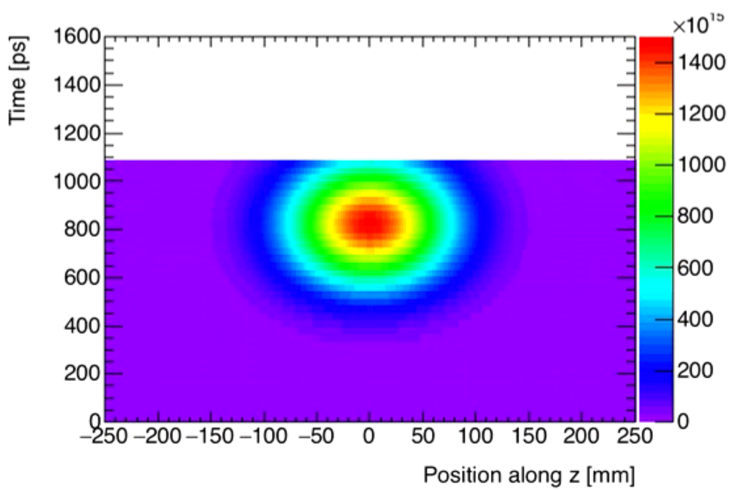

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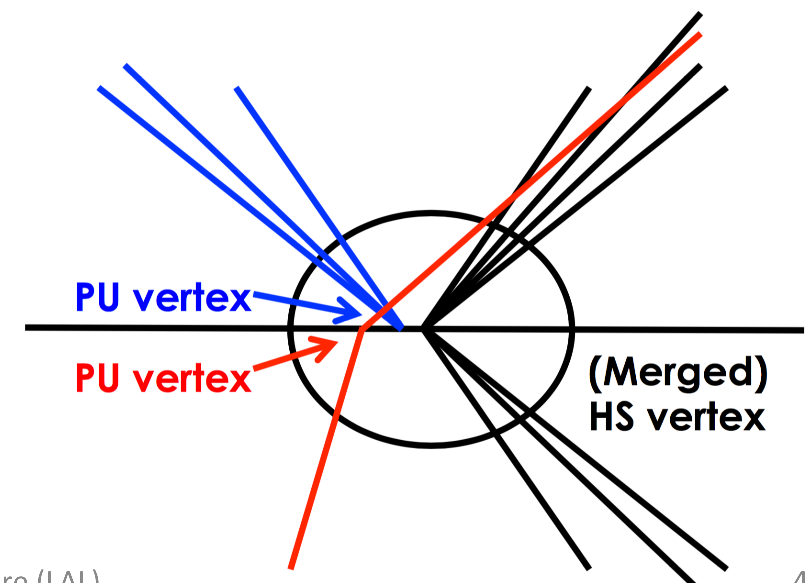

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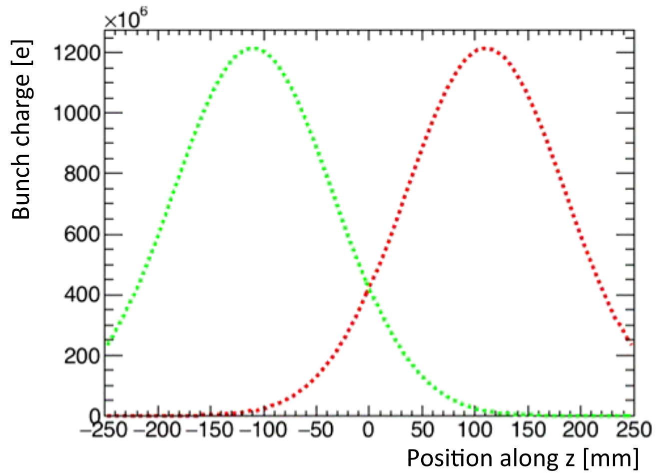

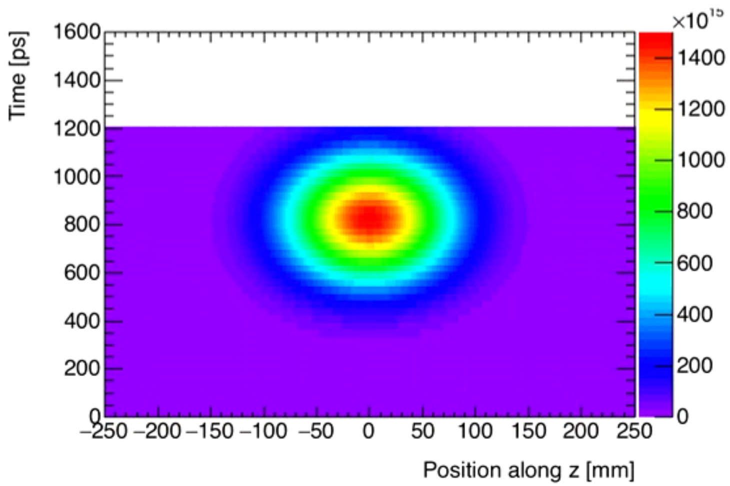

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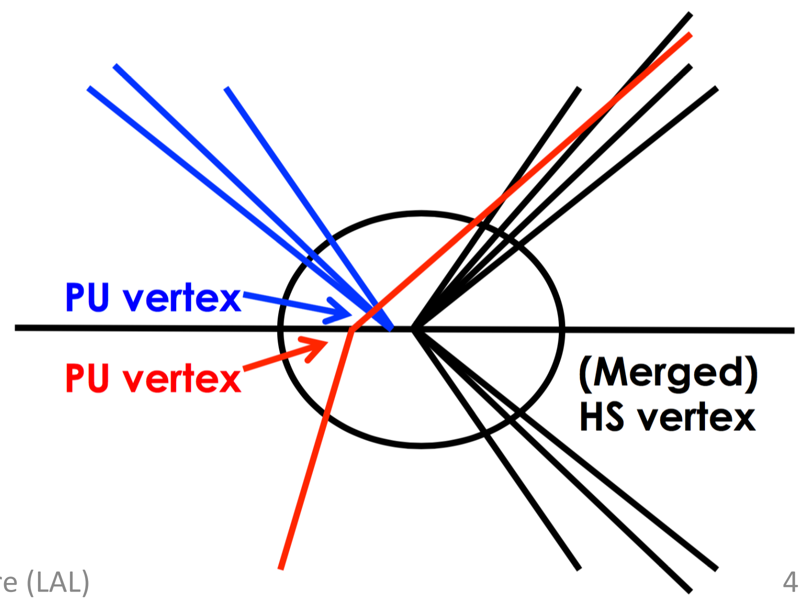

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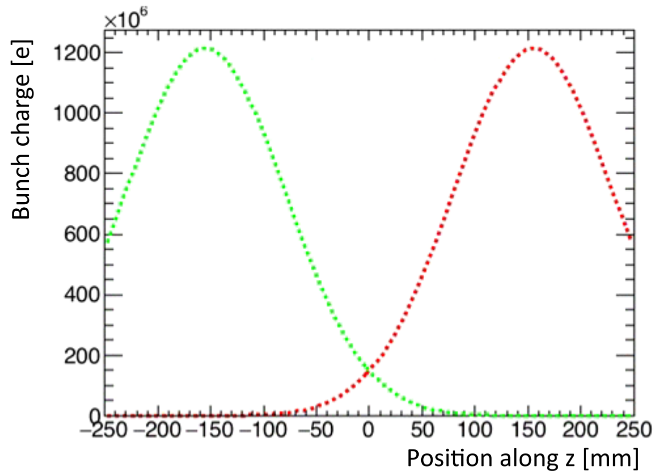

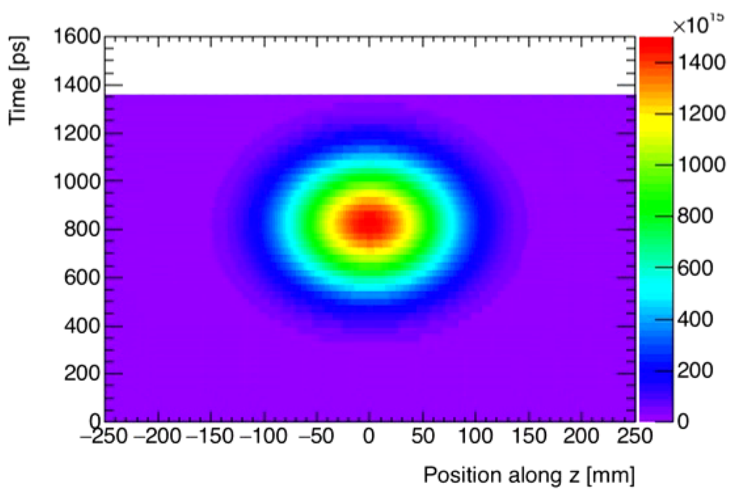

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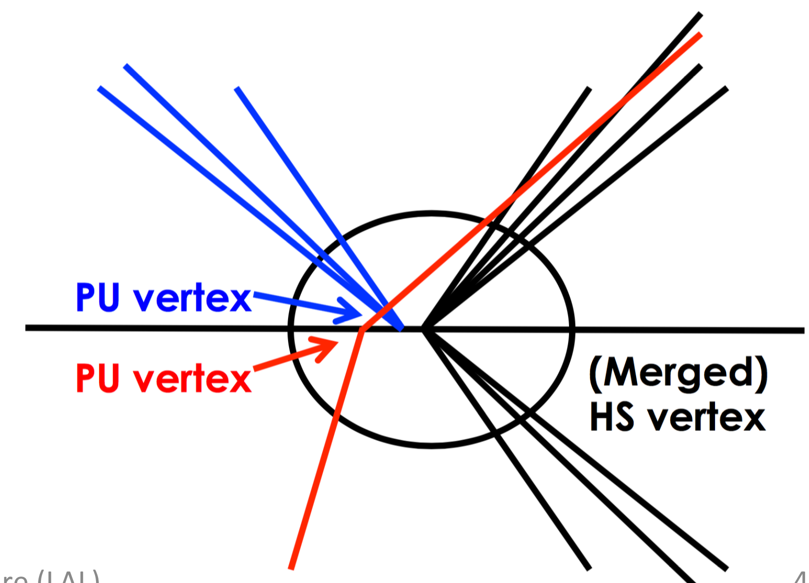

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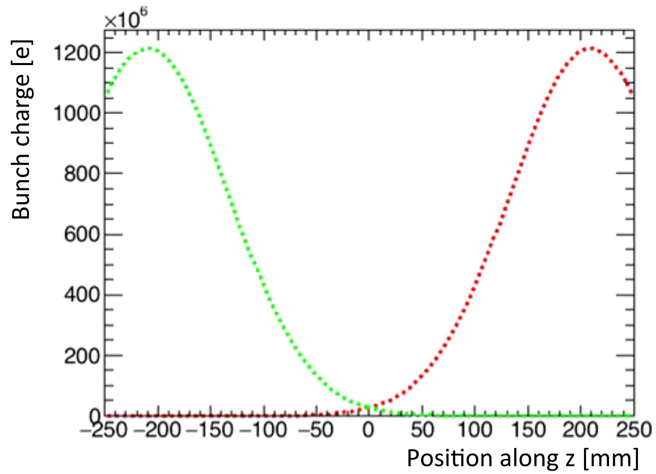

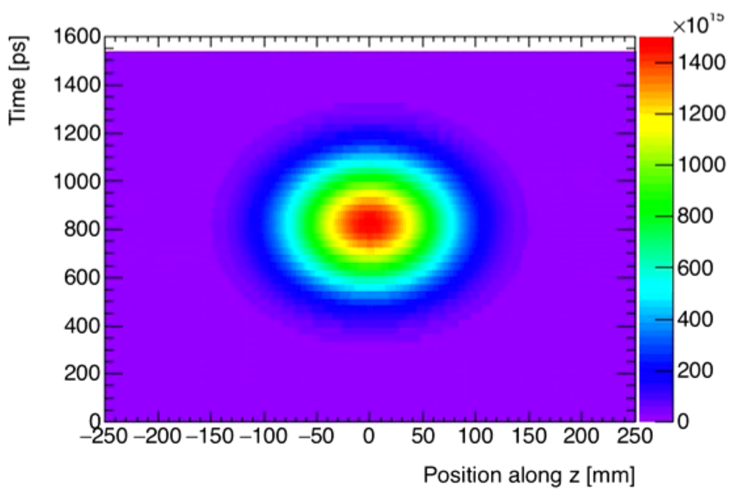

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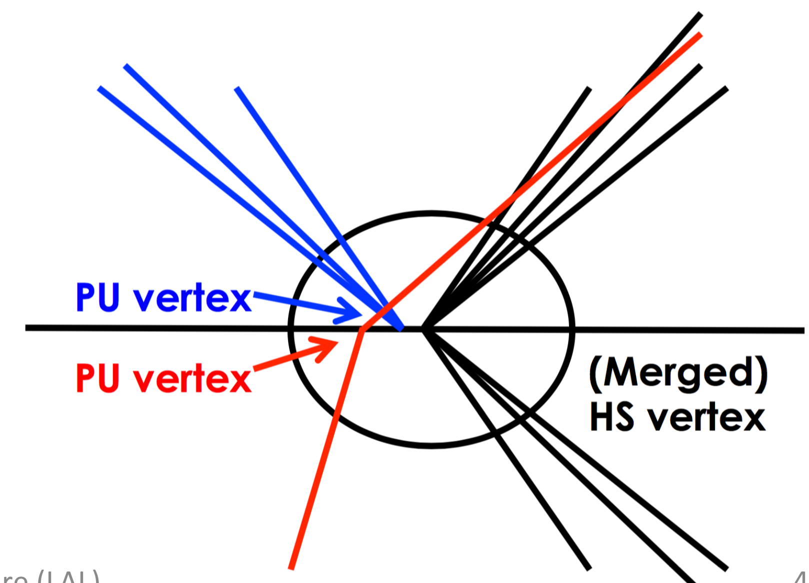

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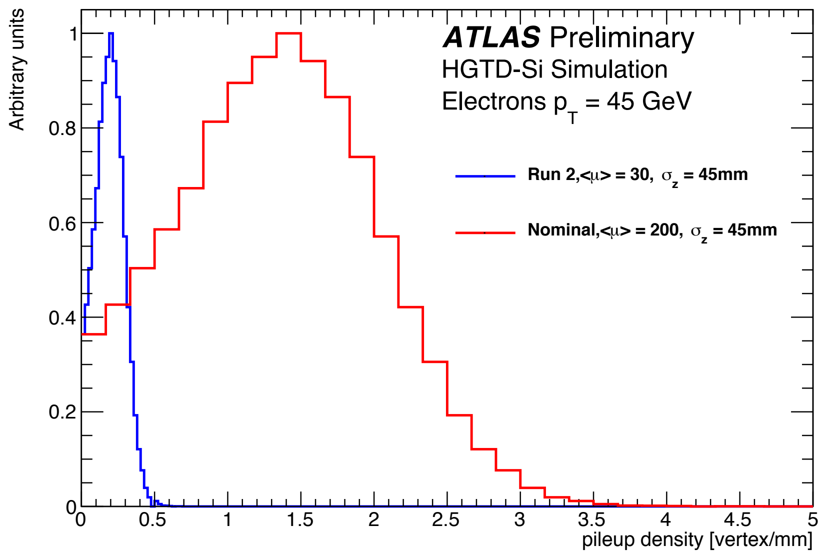
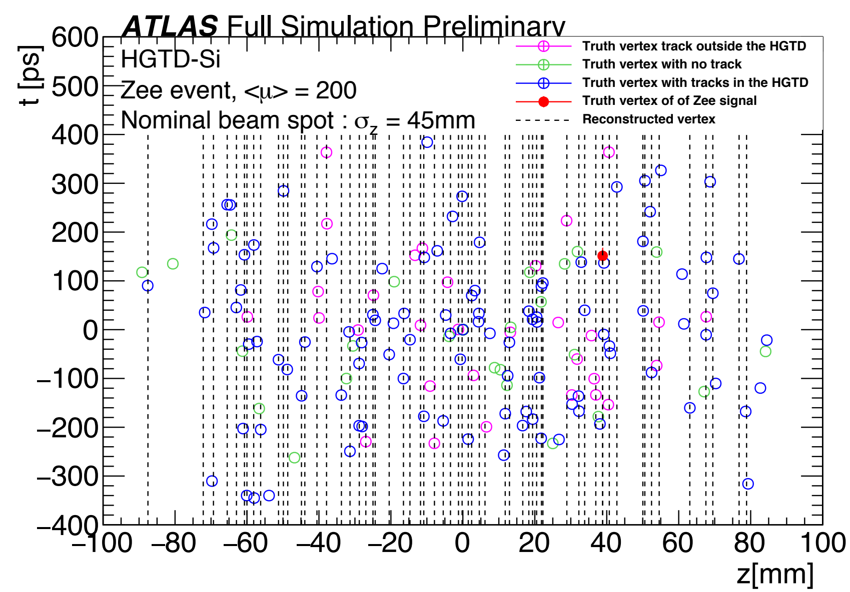


Merged vertices :

- HL-LHC : same interaction region, more interaction -> increase of the density of interaction
- Larger probability of having merged vertex

HGTD:

- Forward region
- Use timing to resolve the vertices at same z, but distributed in time
- Allows us to determine if a track is coming from pile-up or from the event



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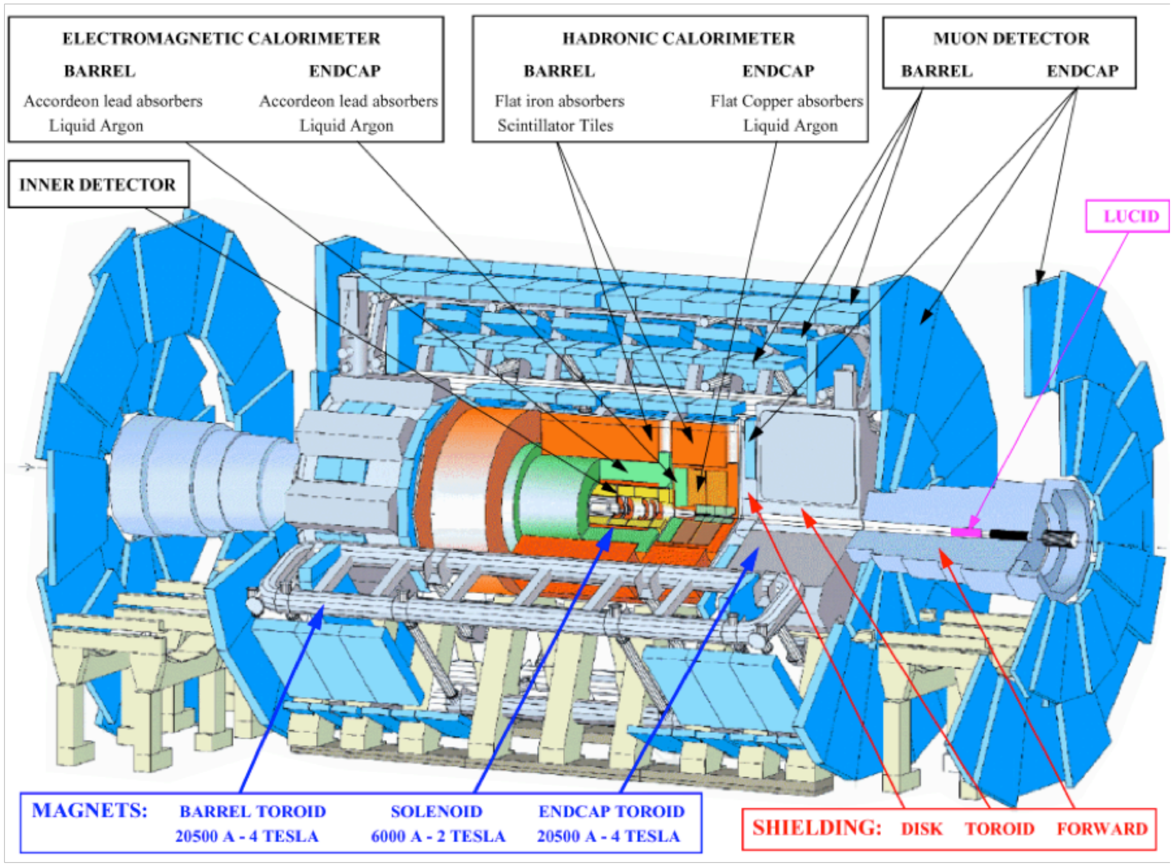

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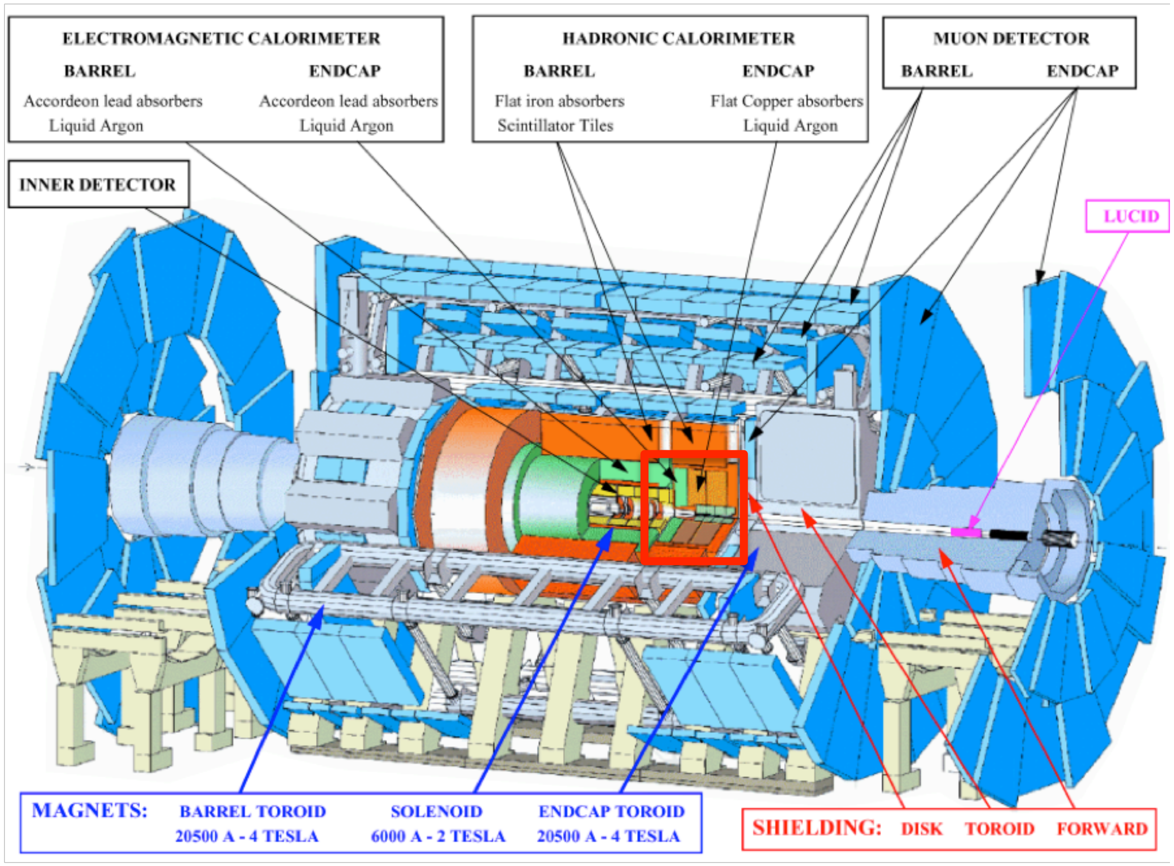

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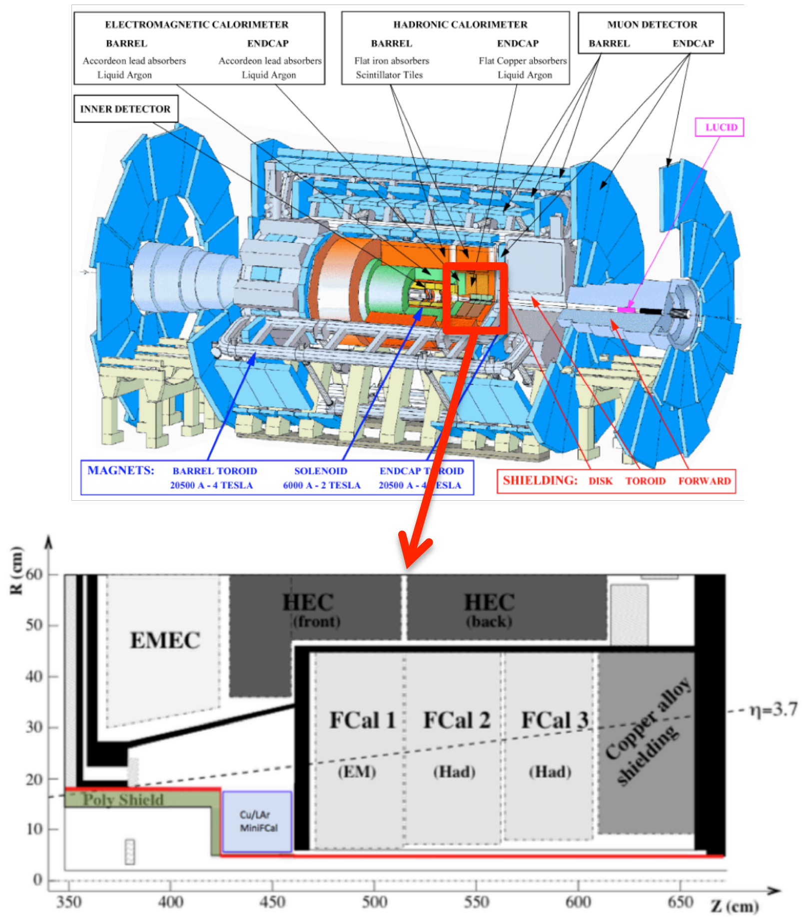

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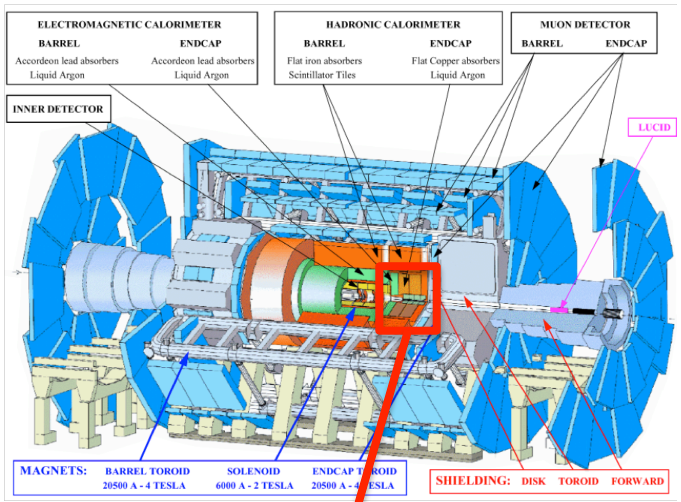

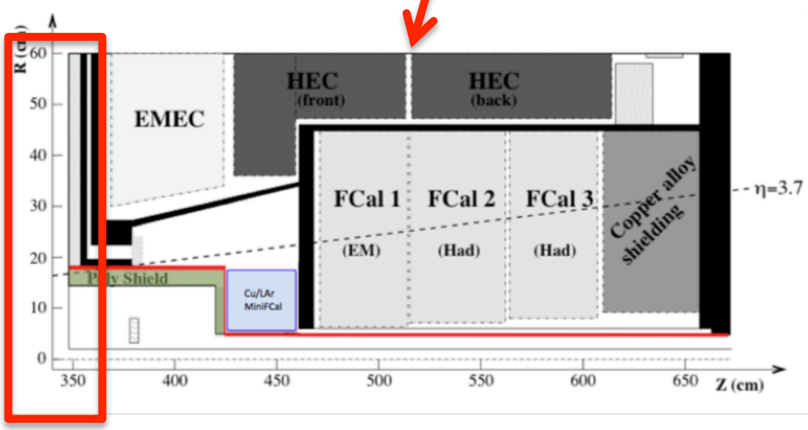

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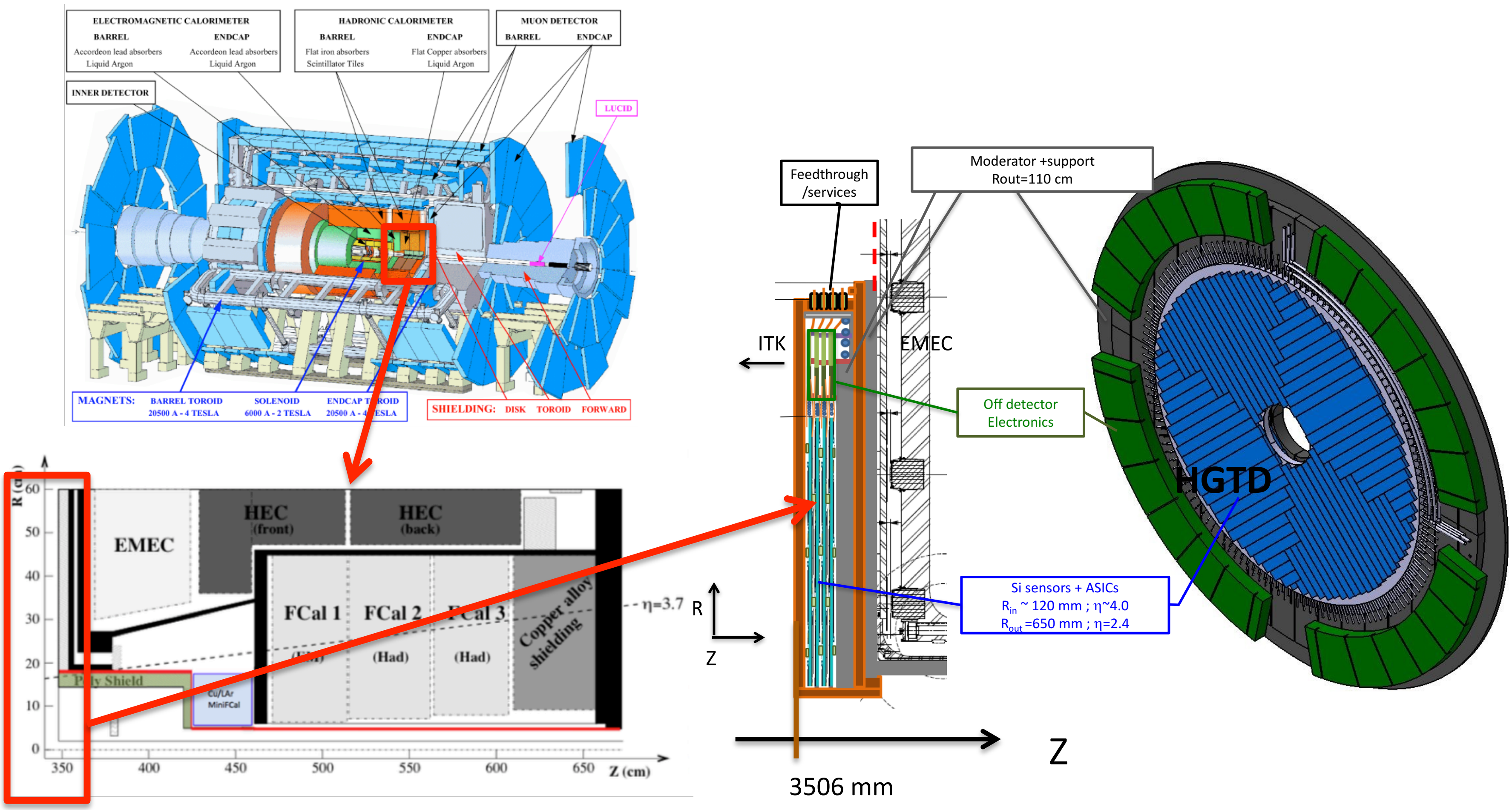
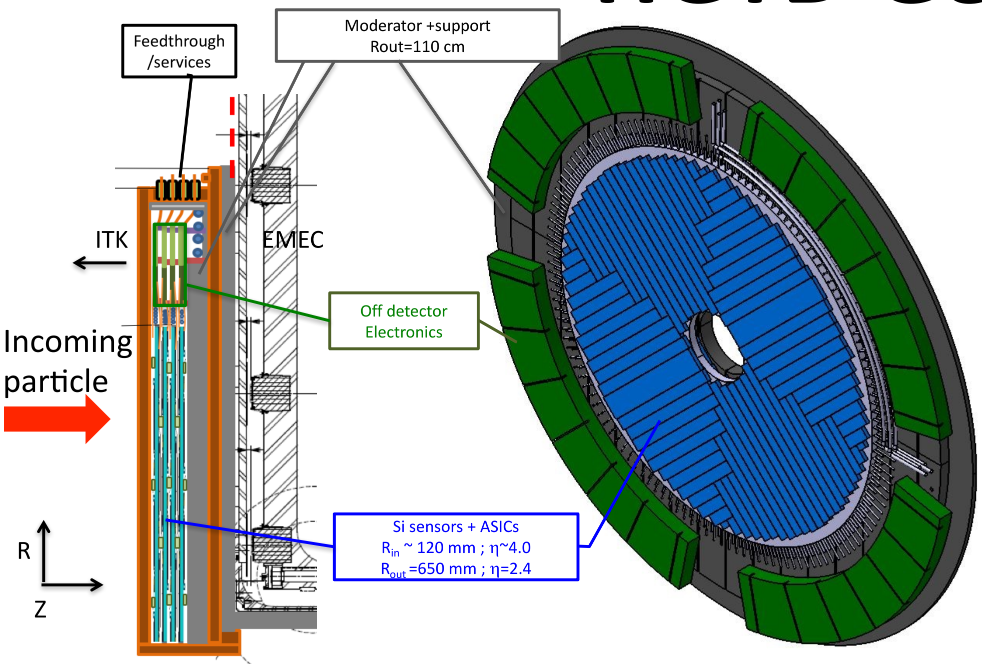
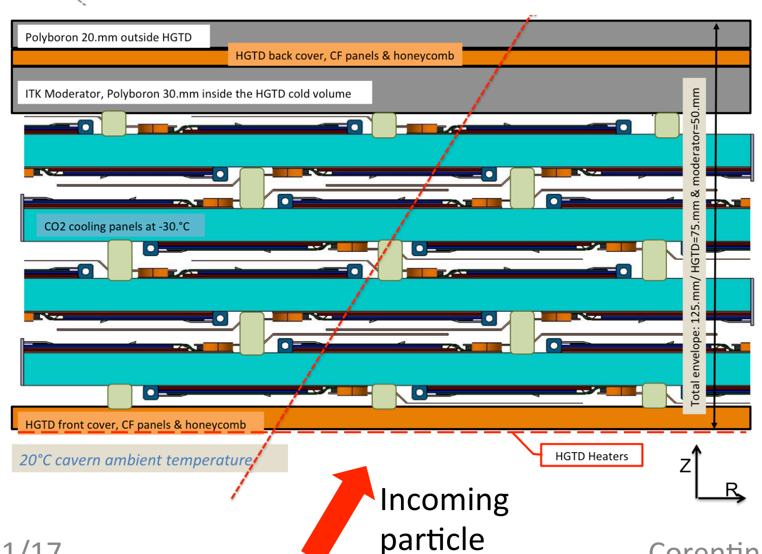
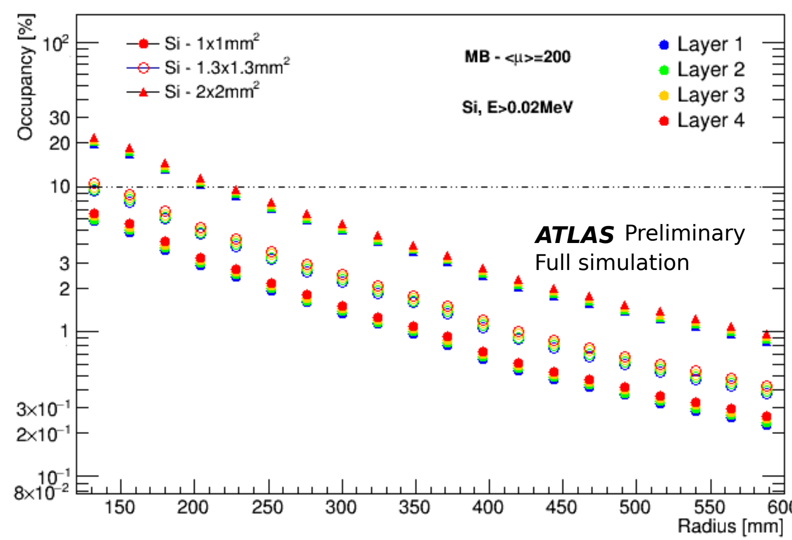


HGTD Geometry

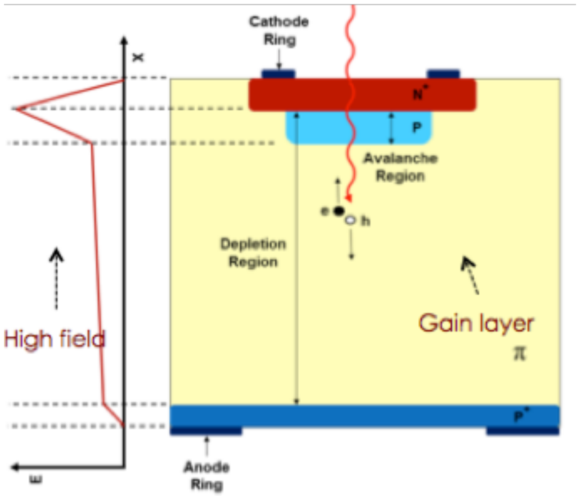


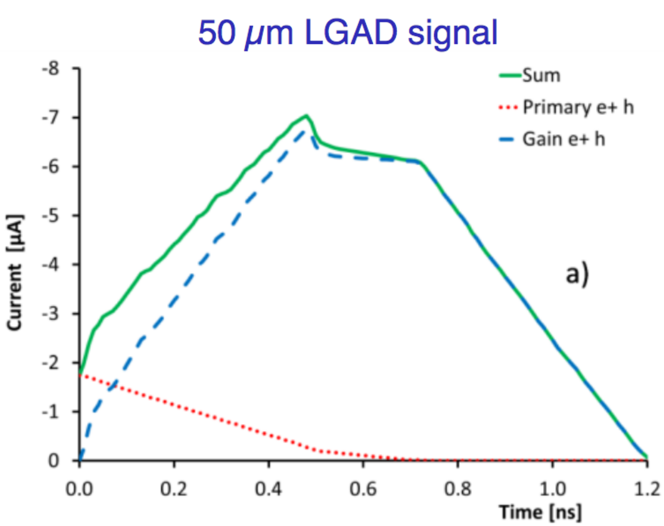
- Detector in the end-caps (3.5 meter from the interaction point)
- Pseudorapidity coverage : 2.4 < |η| < 4 (120 < R < 640 mm)
- 2-4 layers of active material (to be decided)
- Granularity : 1.3x1.3 mm^2 sensors -> stay bellow 10% occupancy





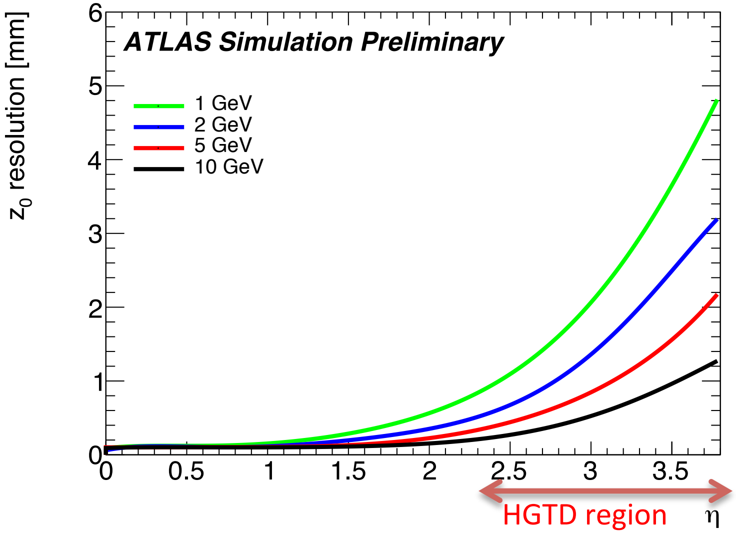
Precise timing measurement ?

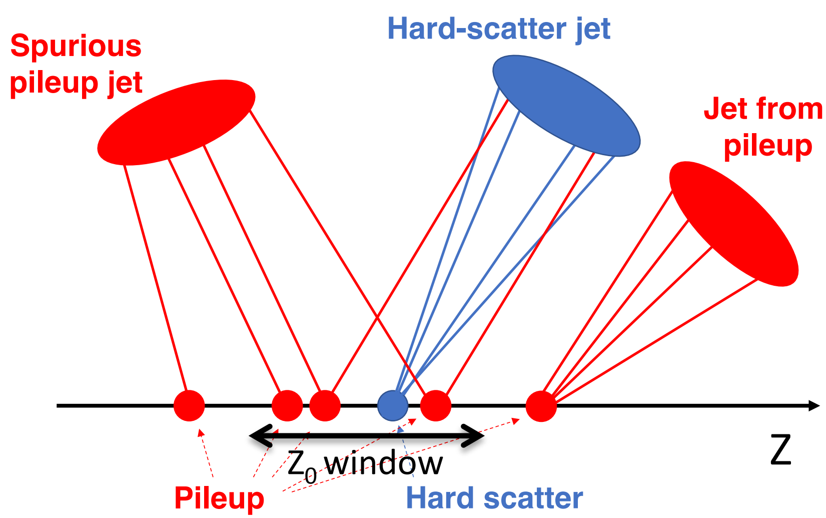




- Silicon based detector (PN junction)
- Particle go through the detector -> creation of electrons-holes pairs
- The drifting of those pairs create the signal
- Timing resolution inversely proportional to (Signal/background)
- LGAD sensors : Silicon detector with a gain : extra PN junction in the detector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

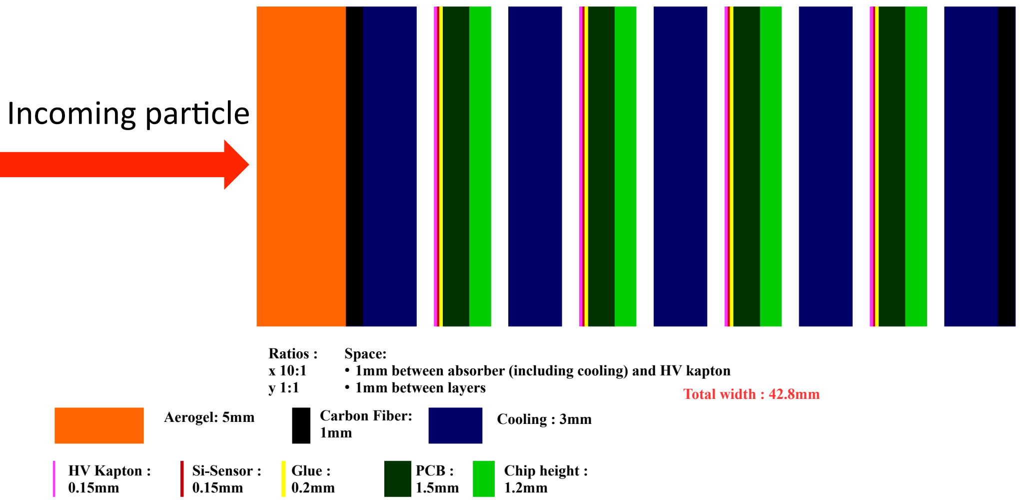
Forward detector





- Forward detector : 2.4 < |η| < 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

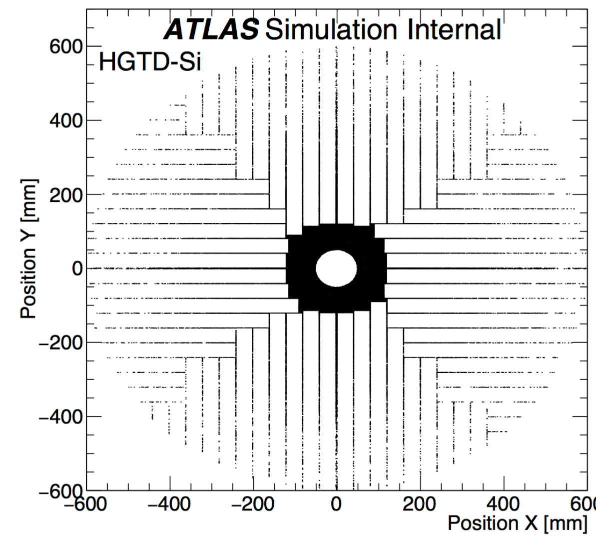
HGTD full simulation



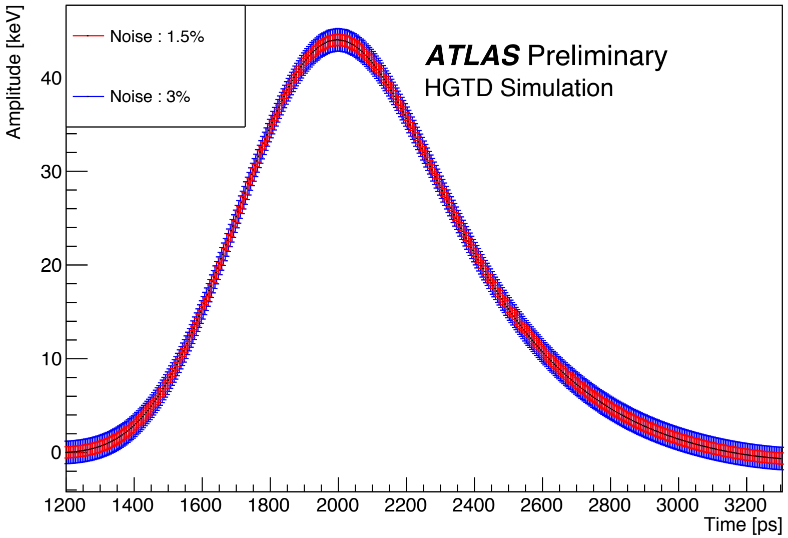
- Geometry simulated in a “simplistic” way in Geant4
- More advanced implementation of the geometry done at the analysis level

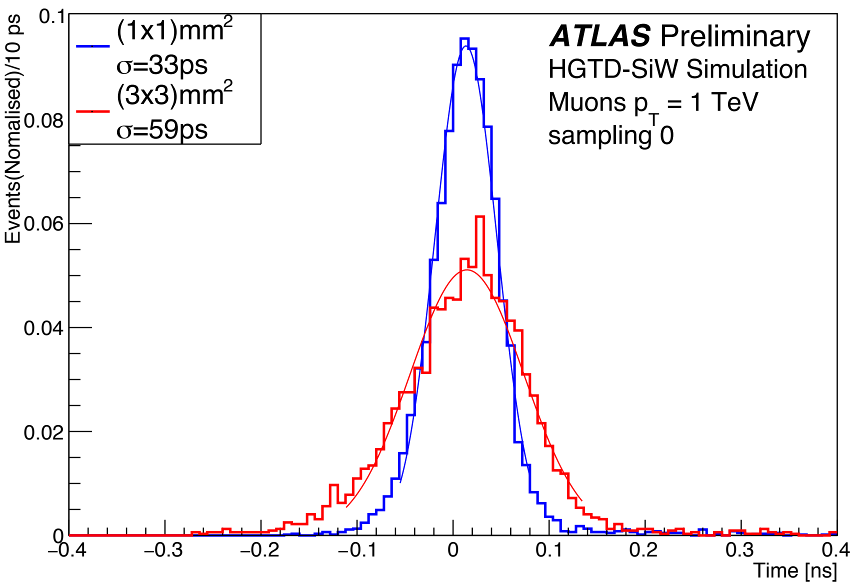
Detector composed of :

- 1.3mm x 1.3mm pads in a 4x2cm^2 modules
- Modules put together into “staves” of various length
- Dead area between the staves and between the quarter of detector



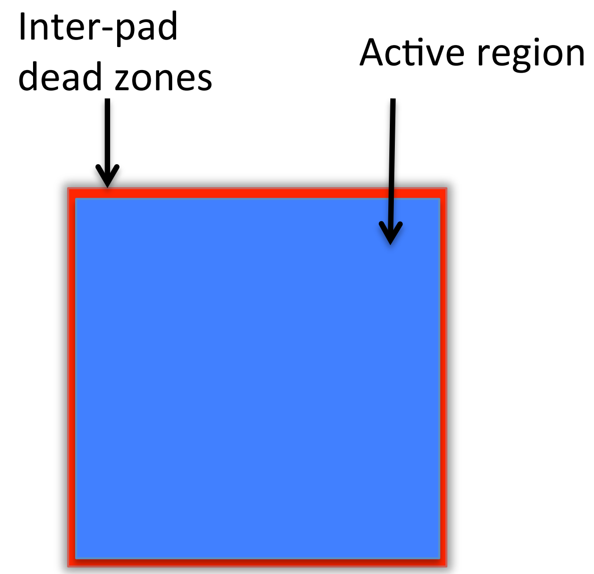
Time Simulation in the HGTD





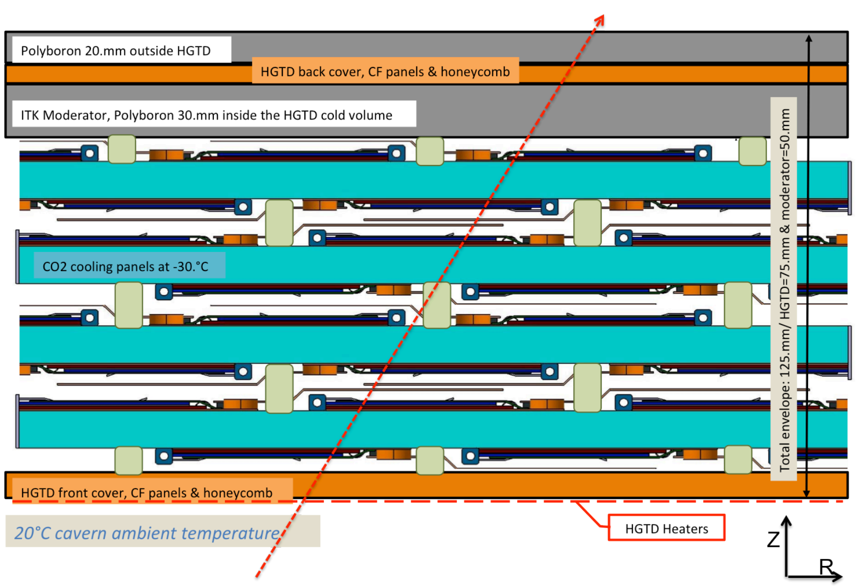
- Applied knowledge from test beam to the simulation
- Pulse shape obtain using august 2016 test beam
- Cell resolution simulated by adding a gaussian noise on the pulses and by making the width vary to simulate the Landau fluctuation.
- Time resolution dominated by Landau fluctuation and not the noise on the amplitude
- Each hit in the HGTD -> 1 pulse :
  - Energy defined as E_{max}
  - Time defined at $E = E_{max}/2$ (pseudo CFD)
- Time resolution (Amplitude + form + electronic resolution) : 32 ps

Design studies



Fill factor : 90%
Pad : 1 x 1 mm^2
Inter-pad : 50µm

- HGTD : Detector not yet approved -> design still need to be studied
- Important variable : number of hit associated to a track -> directly proportional to the time resolution
- Fill Factor : fraction of active area wrt the size of the pad (link to the inter-pad space)

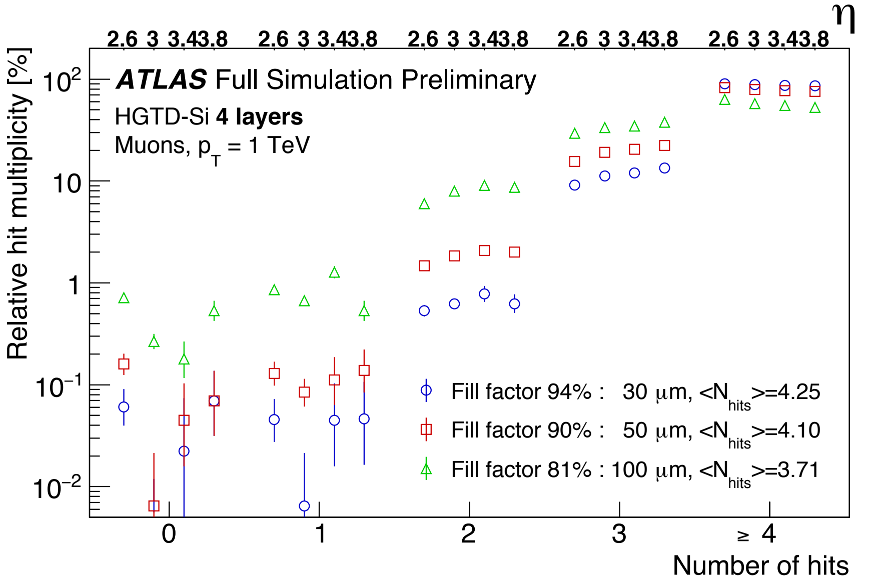


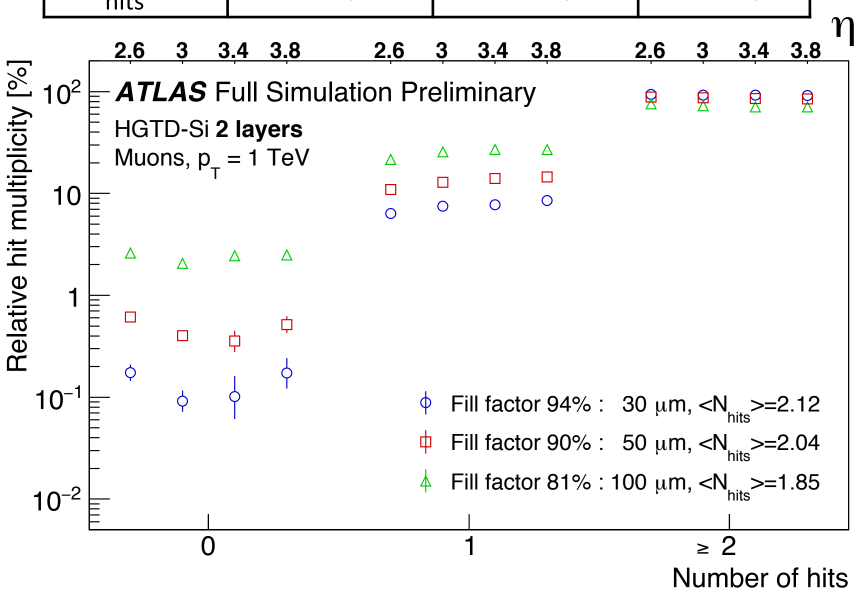
- In the design the pads are put together in 2x4 cm modules
- The modules are on both side of each layer
- 20% overlap
- Those two effects where studied in the simulation using 1 TeV Muons

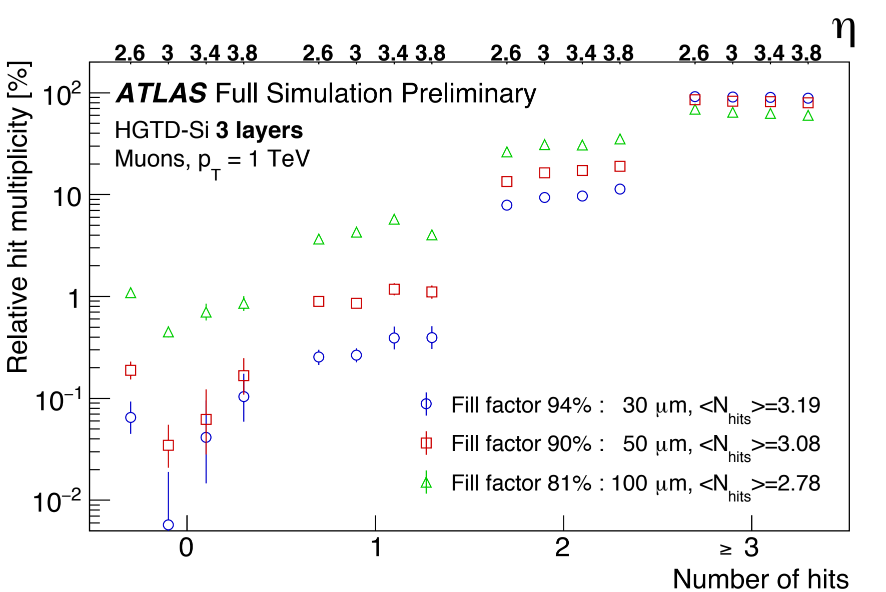
Hit Multiplicity

- Number of hit in the HGTD taking into account the fill factor and the overlap
- Normalize to 1 hit per layer matched to the extrapolated track
- Studies of the performance of the detector as function of the number of layer needed to optimise the cost

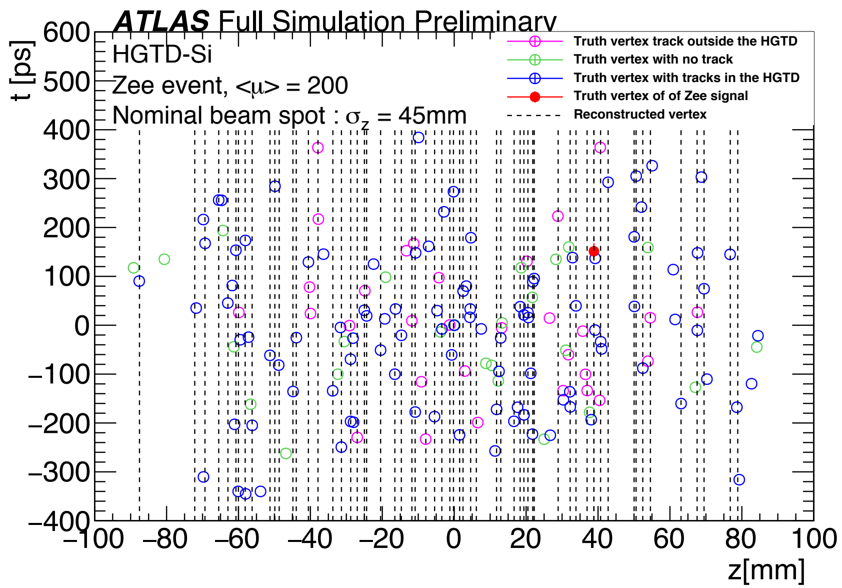
Fill factor : 90%	2 Layers	3 Layers	4 Layers
$<\sigma_t>$	43 ps	37 ps	32 ps
$N_{hits}=0$	0.5 %	0.11 %	0.07 %

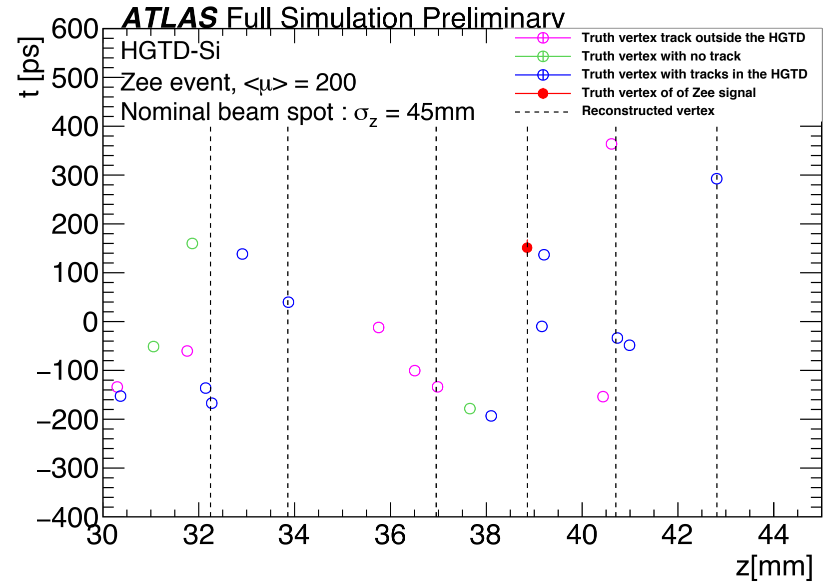






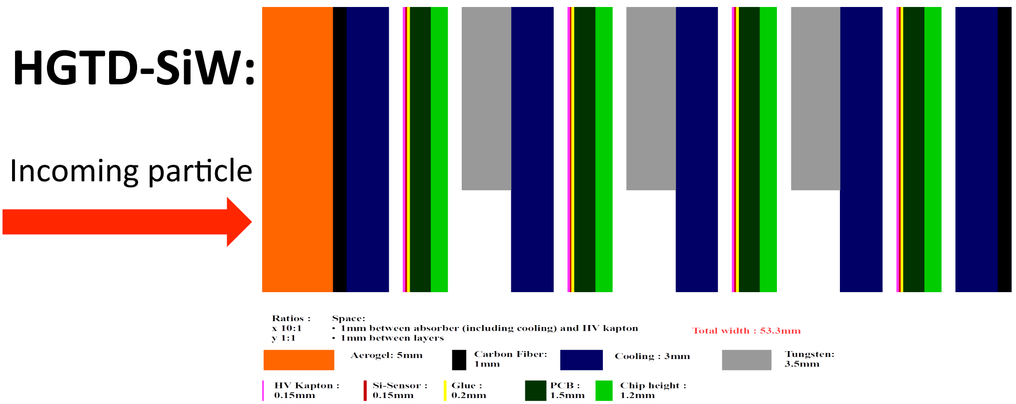
Tracking studies





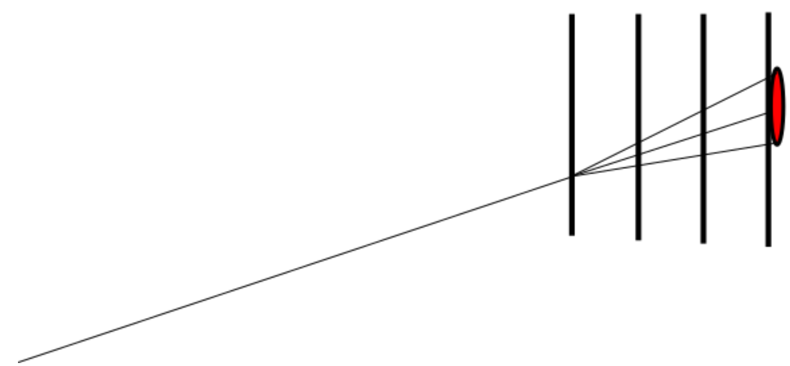
- Position in z and t of the Truth Vertex, <μ>=200 and nominal beam spot
- All tracks are extrapolated up to the HGTD (z= ±3500 mm) and match to a truth vertex
- For the track within the acceptance of the HGTD the number of hit match to the track (at most one per layer) is used to compute the timing resolution on that vertex
- More than 50% of the vertices have at least a track in the HGTD

5D electron reconstruction

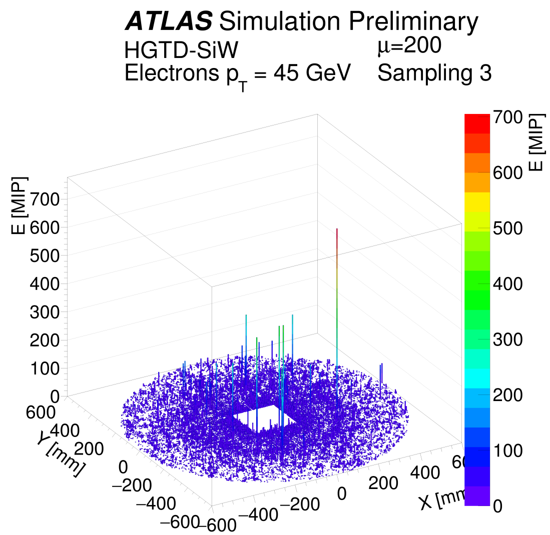


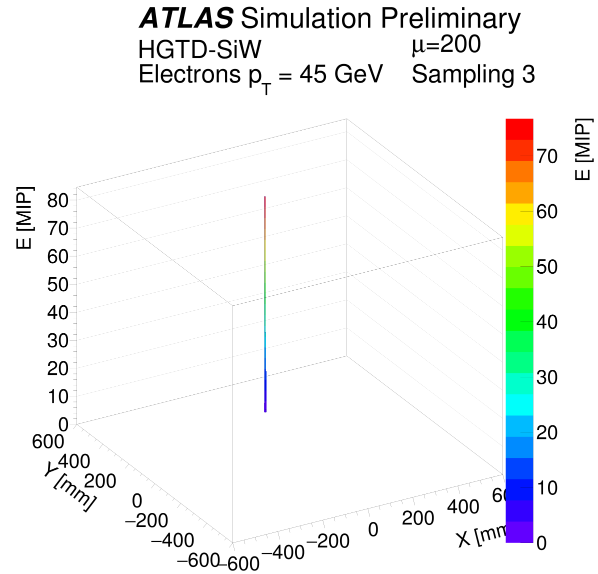
- Studied the possibility of HGTD with tungsten absorber
- 5D algorithm to reconstruct electron (x,y,z,t,E)
- Electron : EM shower -> Conical
- Pile-up : Hadronic shower -> Cylindrical

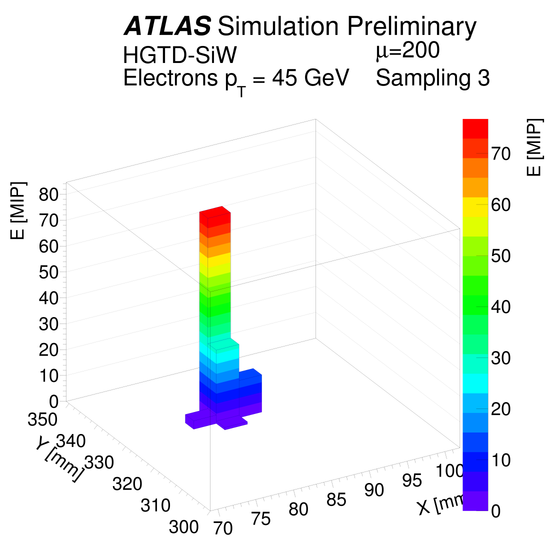
- First layer = beginning of the Cluster
- Compute “tracks” inside the HGTD
- Reject the one not in time and use the remaining one to determine if the cluster is or not an electron



5D electron reconstruction

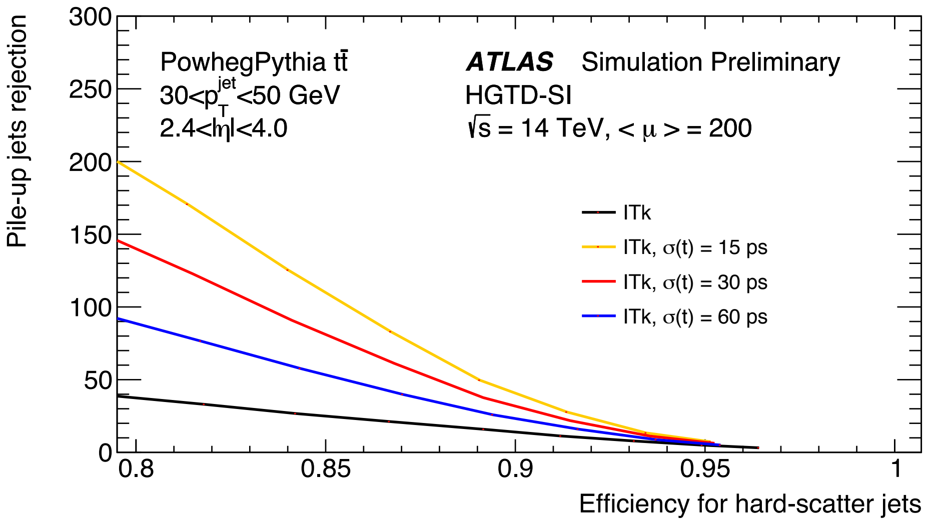




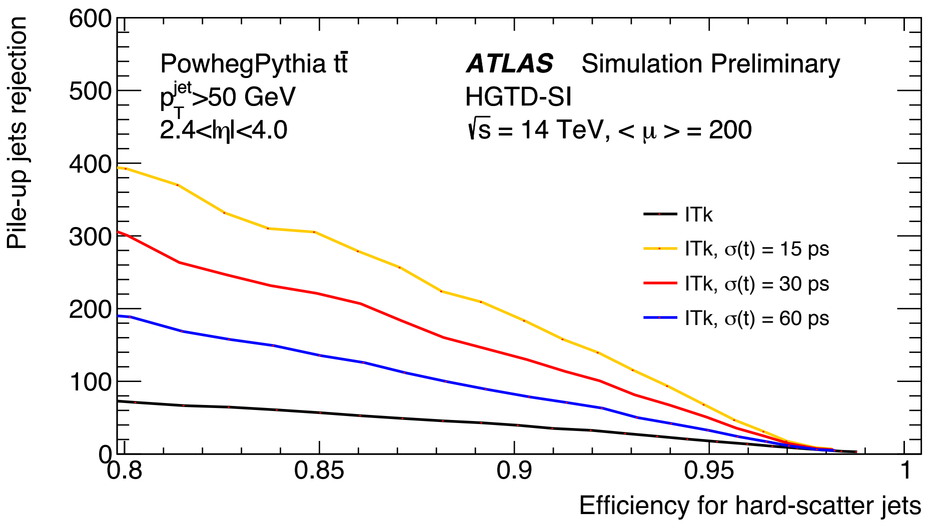


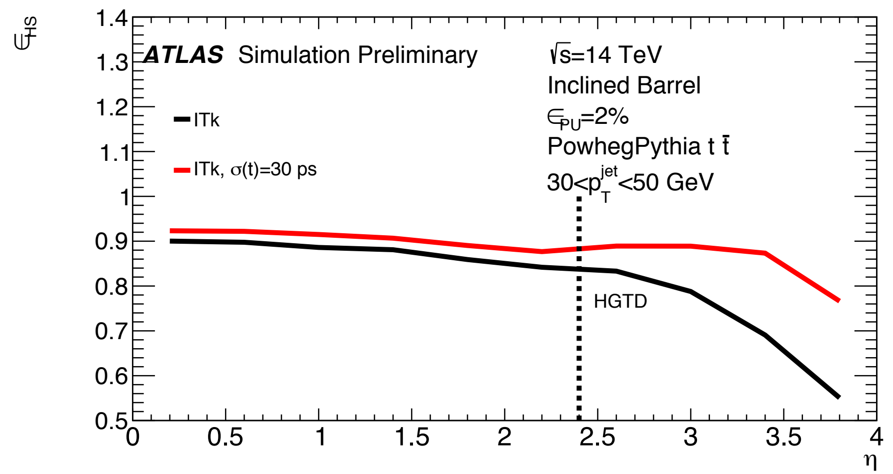
- Example of the discrimination of pileup
- Work using only HGTD information
- The resolution on the time of the electron cluster is of the order of 10ps
- The use of tungsten in the HGTD was later abandoned because of additional radiation induced in the ITk and the dynamic range of the electronics

Pileup-jet rejection



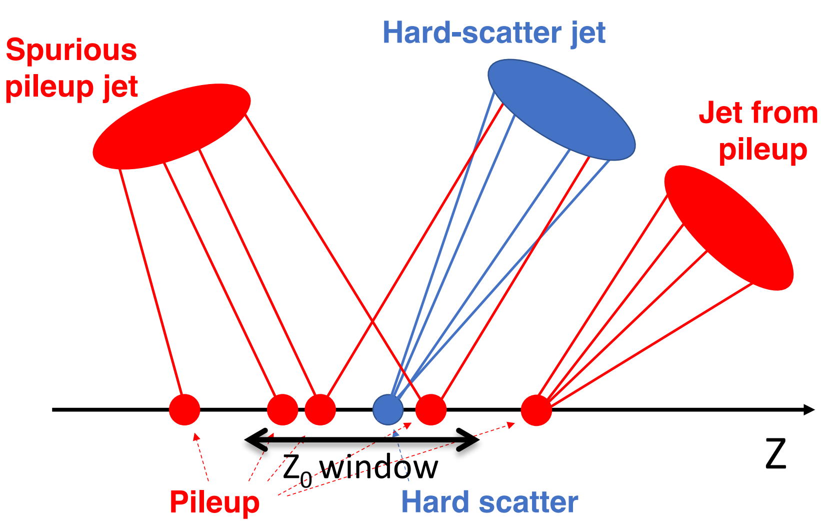
- Pileup-jet rejection in forward region as a function of hard-scatter jet efficiency
- ITk-only (black) and ITk + HGTD with different σ(t)
- With σ(t) = 30 ps, rejection improved by factor of 4
- HGTD gives performance similar to that in barrel out to η = 4

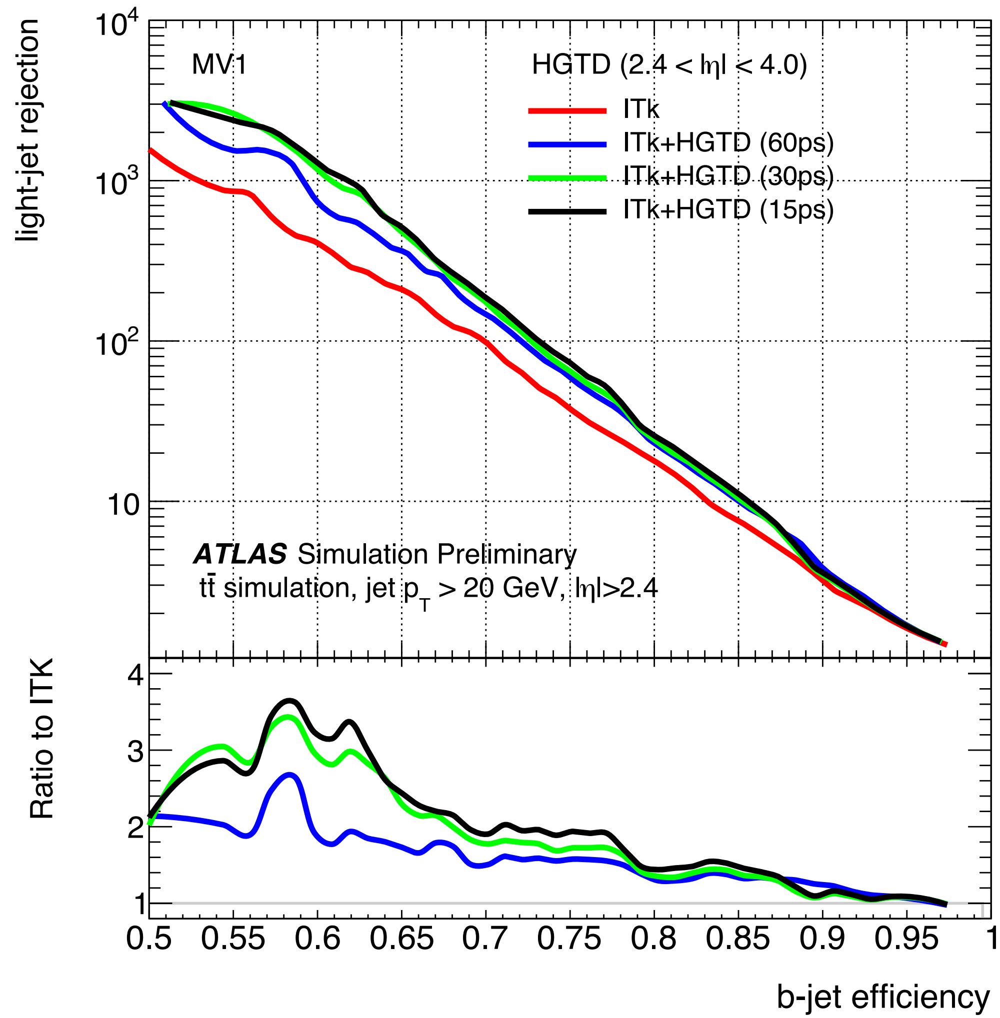




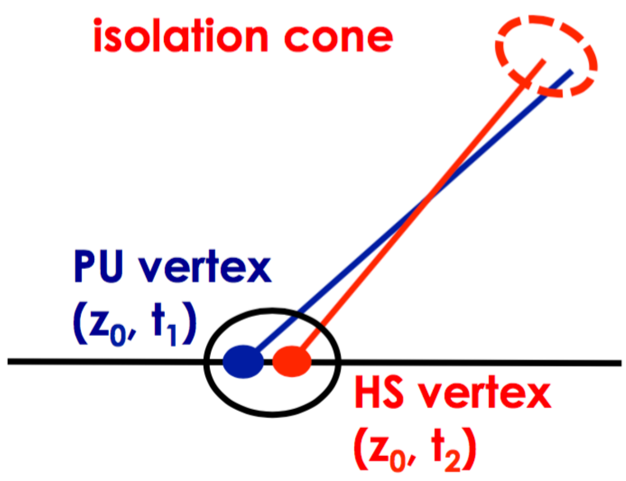
b-tagging

- 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

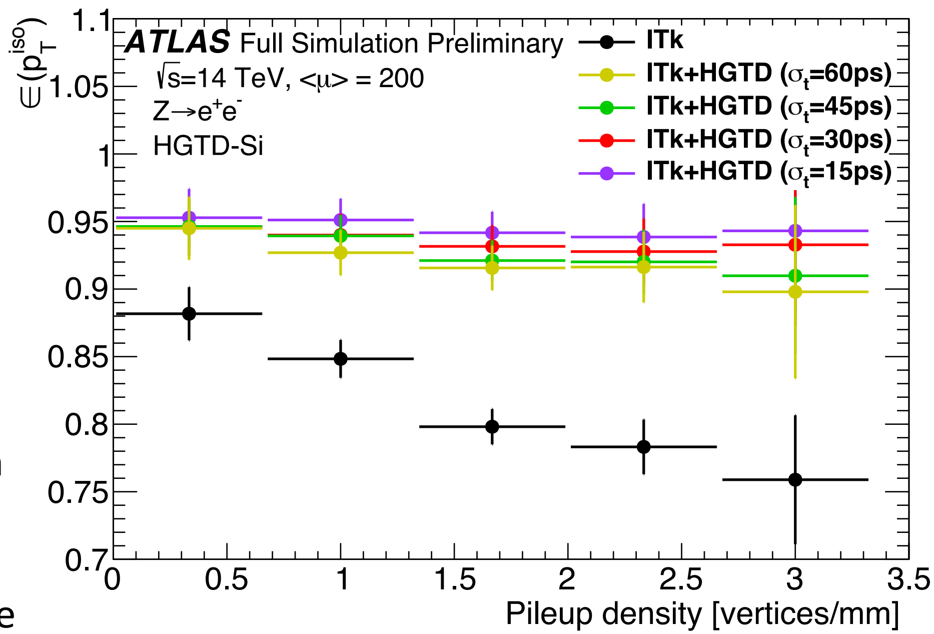




Lepton isolation



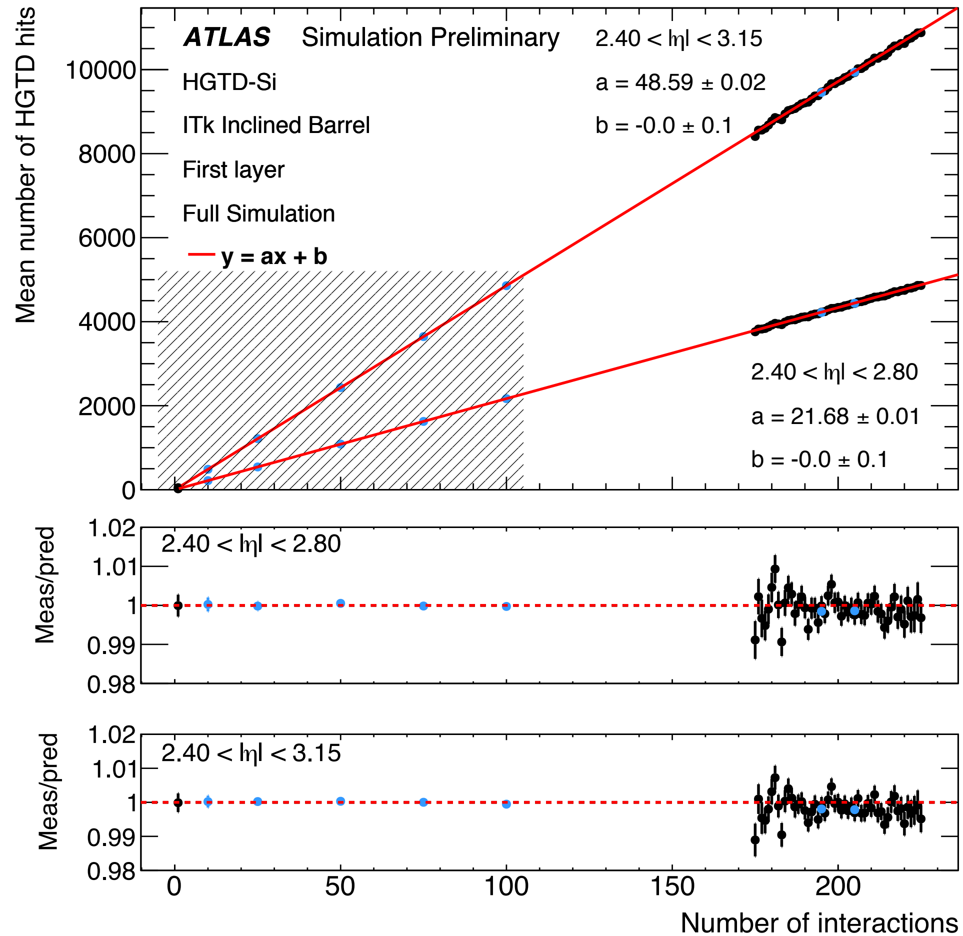
- Track isolation used in many analysis with leptons to fight QCD background
- Isolated lepton -> Lepton that come from the studied process (and not from showering)



- 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

Luminosity

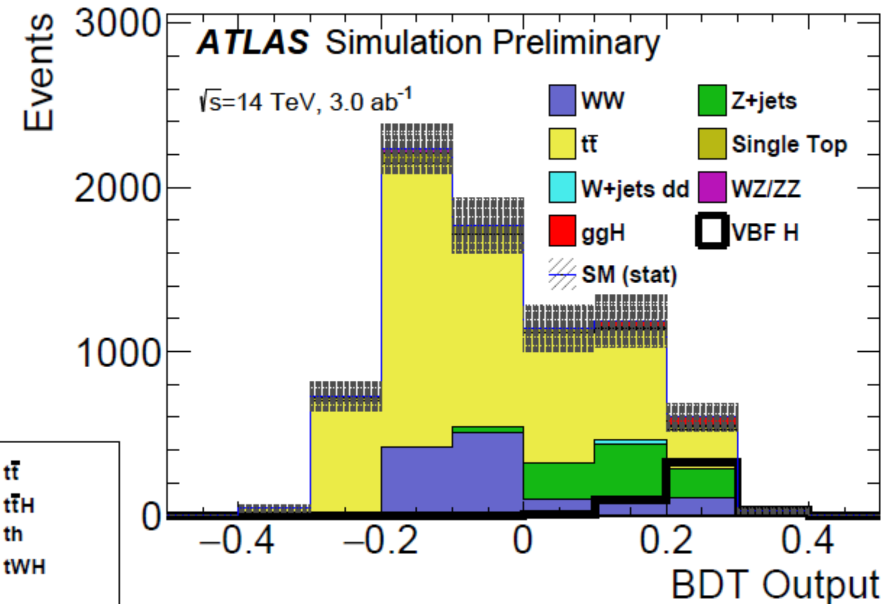
- Knowing precisely the number of interaction per crossing is important :
  - Correction of the signal in the calorimeter
  - Luminosity already the dominant uncertainty in in (some) SM measurement
- High granularity detector in the forward region -> good luminometer
- Number of hits in the HGTD scale 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

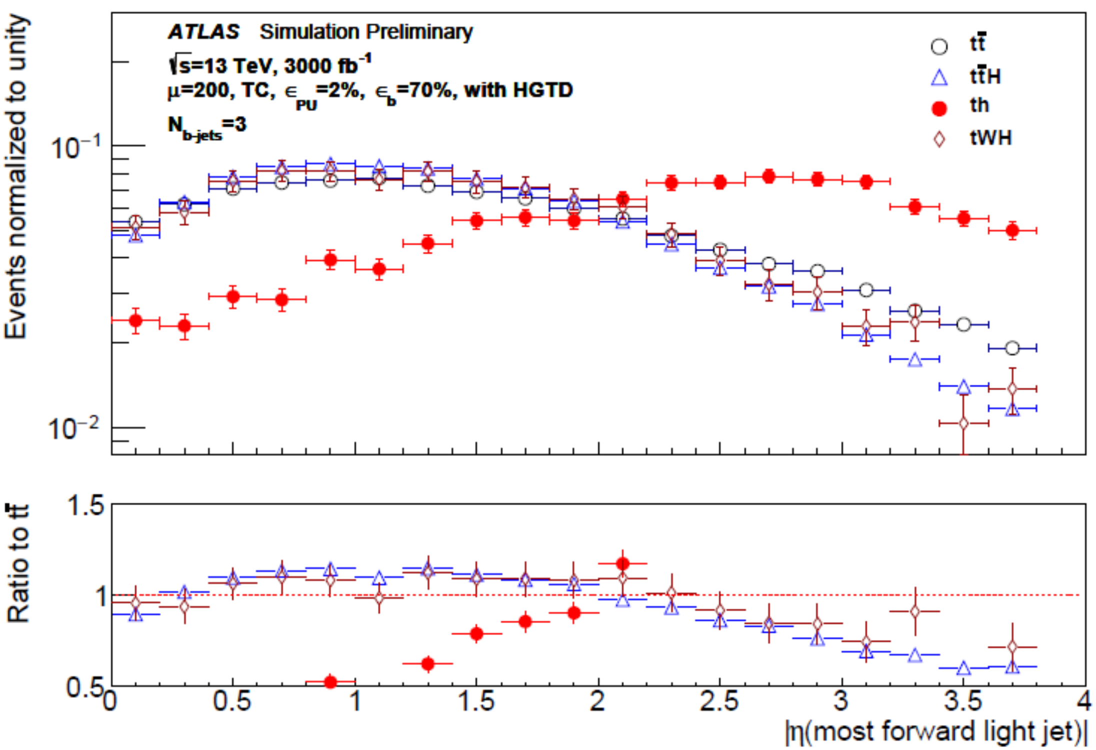


Physics channels (examples)

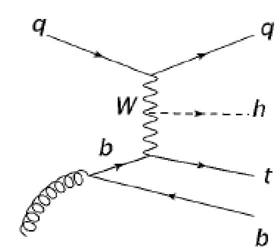
VBF: qqH→qqWW* → qq eνμν:

- BDT
- 43% bg reduction
- dominated by top background rejection (fwd b-tagging)
- 3% pileup rejection
- Relative improvement : 8%





tH with H to bbar:



Relative improvement : 11%

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 …
- Can provide luminosity mesurement

The design of this detector was fully simulated allowing us to study :

- The different possible design of the Detector
- The performance of the detector with object reconstruction