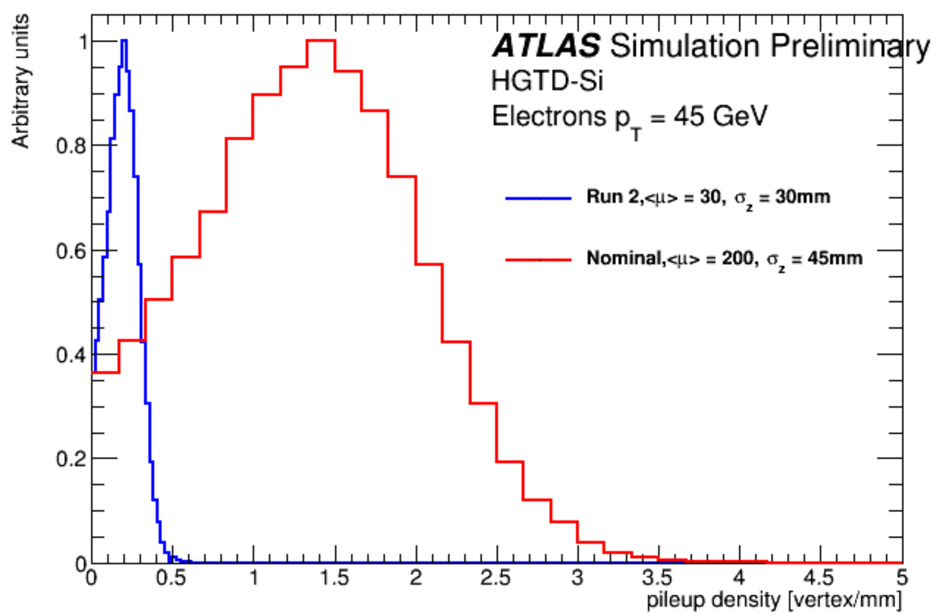
Overview of HGTD Physics and Simulation studies in TDR

Ludovica Aperio Bella

a lot of material from summary talk

10.06.19

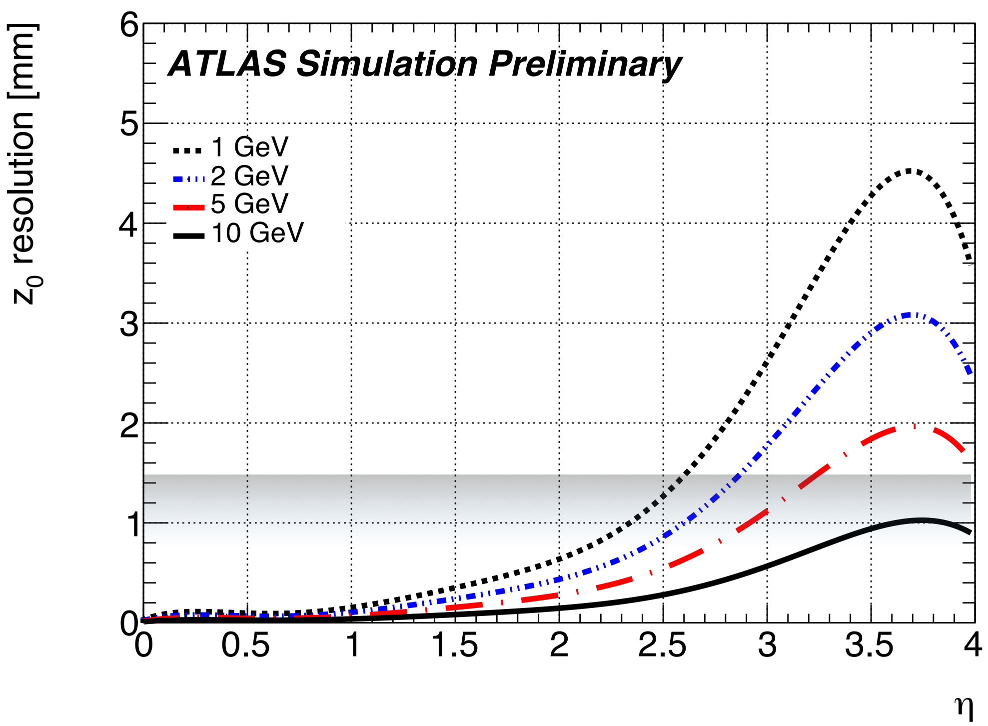
Motivation for precise time measurements

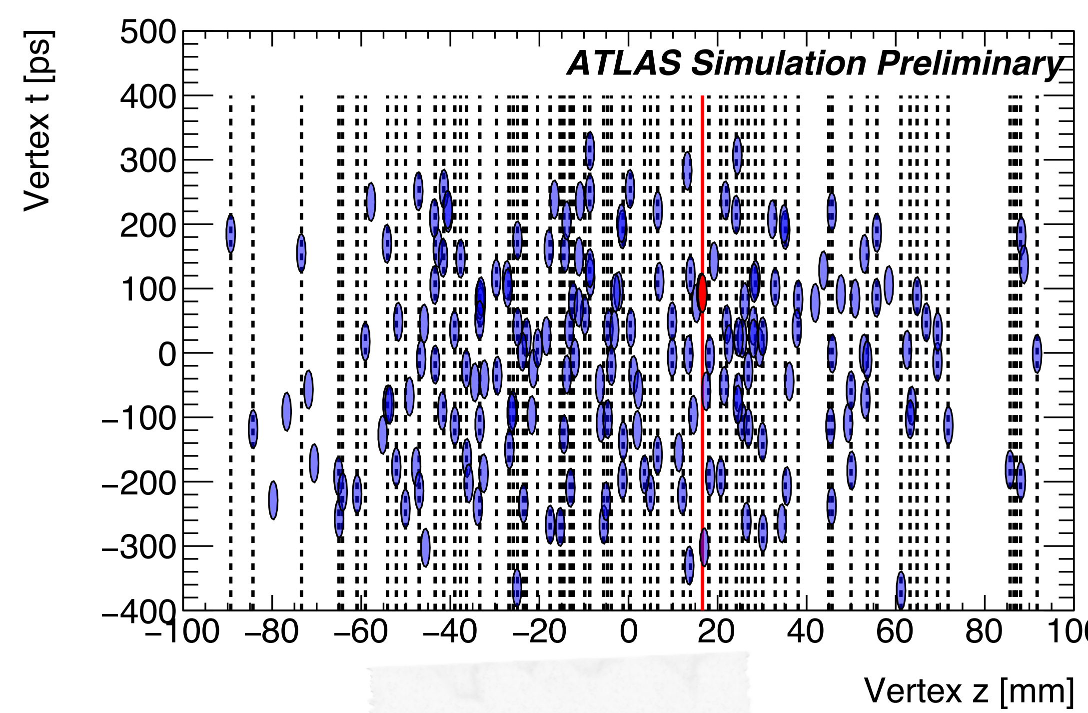


@ HL-LHC: expect <μ> = 200 and instantaneous luminosity 7.5 10^{34}

- **Pileup mitigation main focus for the physic program at HL-LHC:**
  - **Track-HS vertex association: Powerful pile-up rejection**
    - ITK provides tracking for |η| < 4
    - Average vertex density @ <μ> = 200 1.8 vtx/mm
    - z_0 resolution increases with η and several vertices can be merged

      ➡ Degradation of performance at large η
- **HGTD** goal is to extend pile-up rejection in the fwd region adding timing information





Capability to exploit time spread of additional pp interactions ~175 ps RMS
With **30ps per track resolution** PU reduction by a factor of 175/30 ~ 6

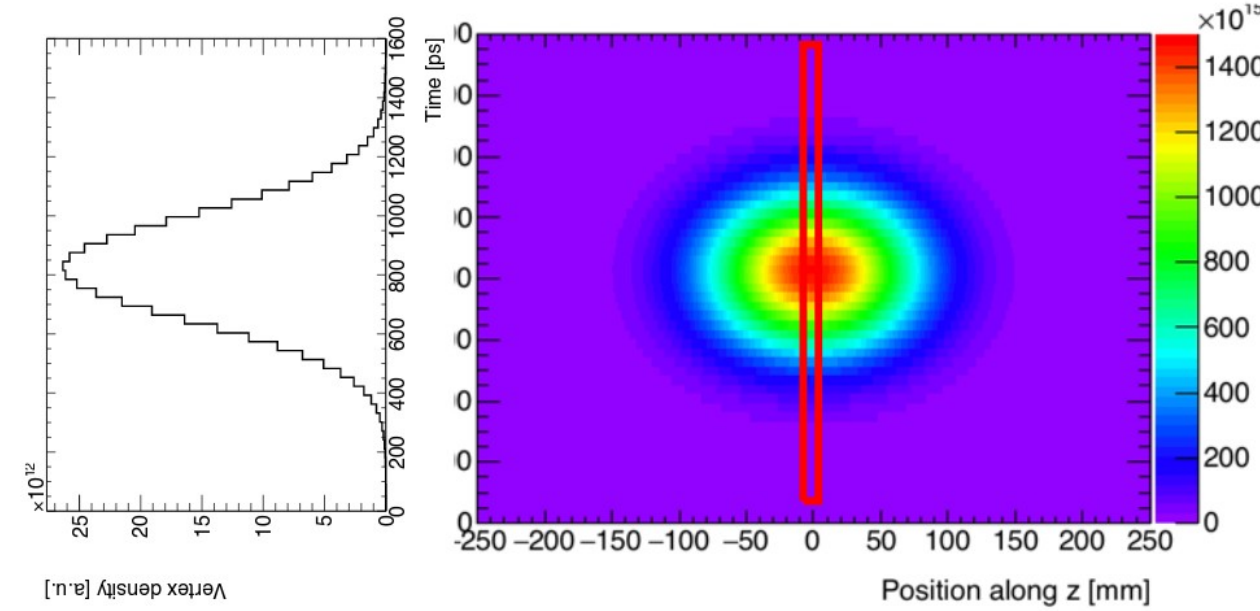
Motivation for precise time measurements

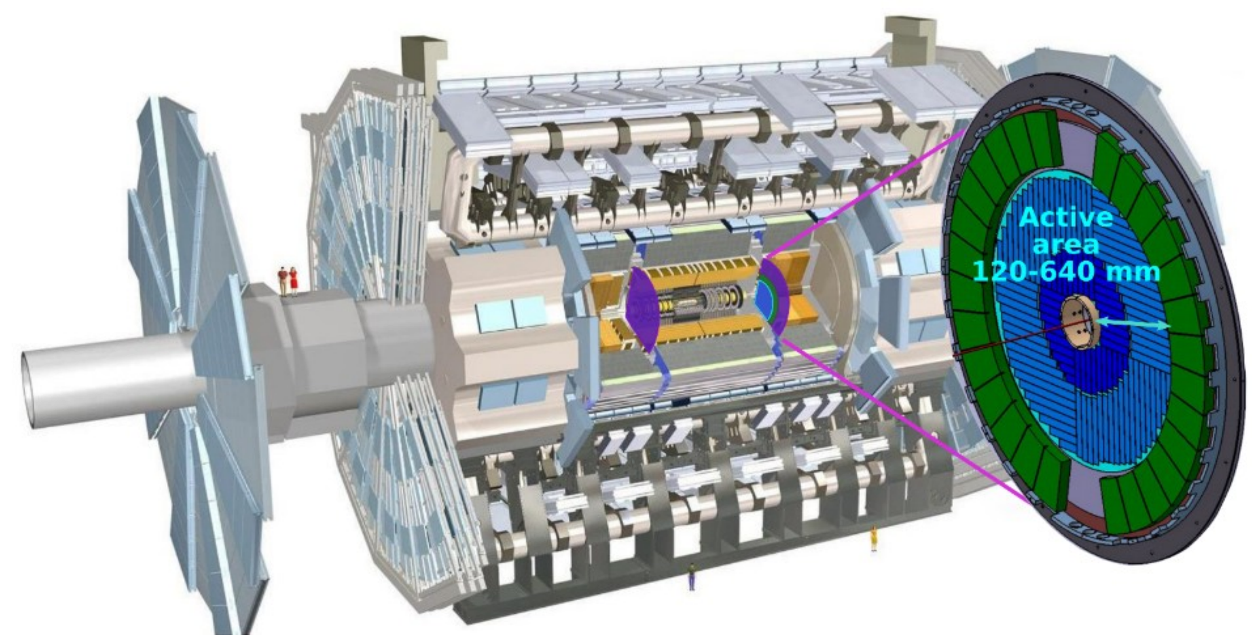
Mitigate pileup by exploiting that beam spot has time dimension, spread ~200 ps

- Two end-cap disks at z=±3.5 m
  - Si-based Low Gain Avalanche Diode technology
  - $1.3\times1.3\text{mm}^2$ pixels
- σ_t= 30 ps/track in acceptance:
  - 120 mm< R <640 mm ⇒ 2.4<|η|<4.0

Potential to *help* tracking using time in

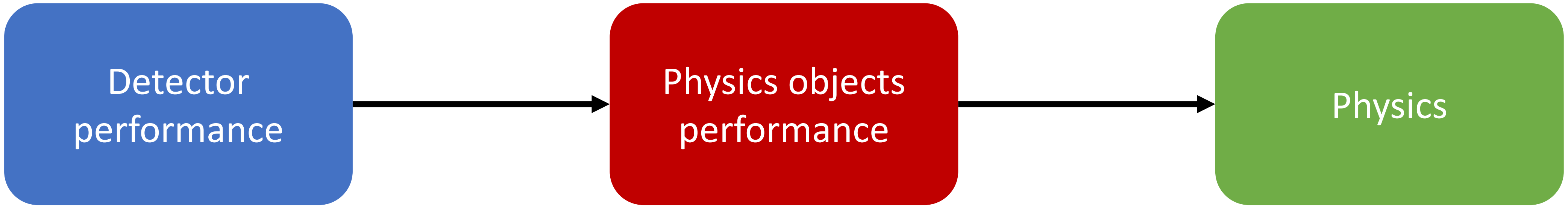
- Vertex reconstruction and jet-to-vertex association





TDR

https://cds.cern.ch/record/2665613/files/ATL-COM-UPGRADE-2019-003.pdf



Full plan designed jointly with physics upgrade and tracking groups

Discussion with physics upgrade has been critical to understand how to best use HGTD for jets and b-tagging

“Current” Strategy

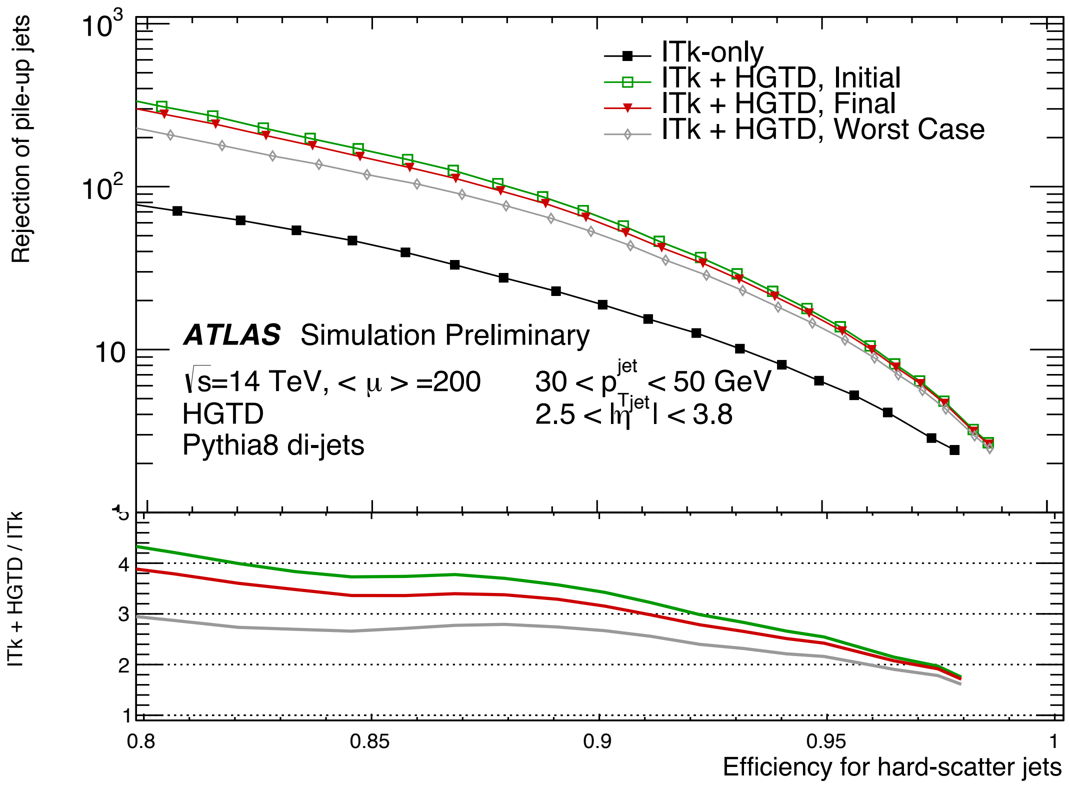
Emulation of Detector performance

PU suppression
Missing ET
b-tagging
Lepton isolation

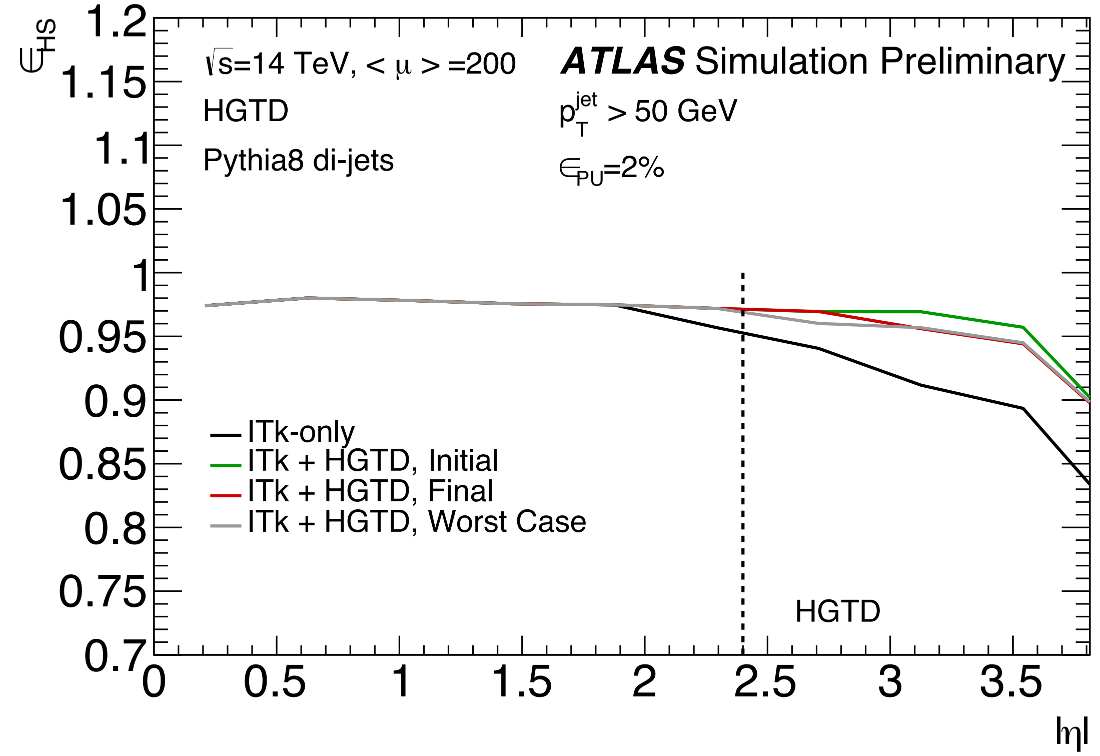
Detector performance → Physics objects performance → Physics

Current studies make use of parameterizations for track-time assignment efficiency/purity, and t_0 efficiency/misidentification

Object performances



(a) Jets with $30 < p_T < 50$ GeV.



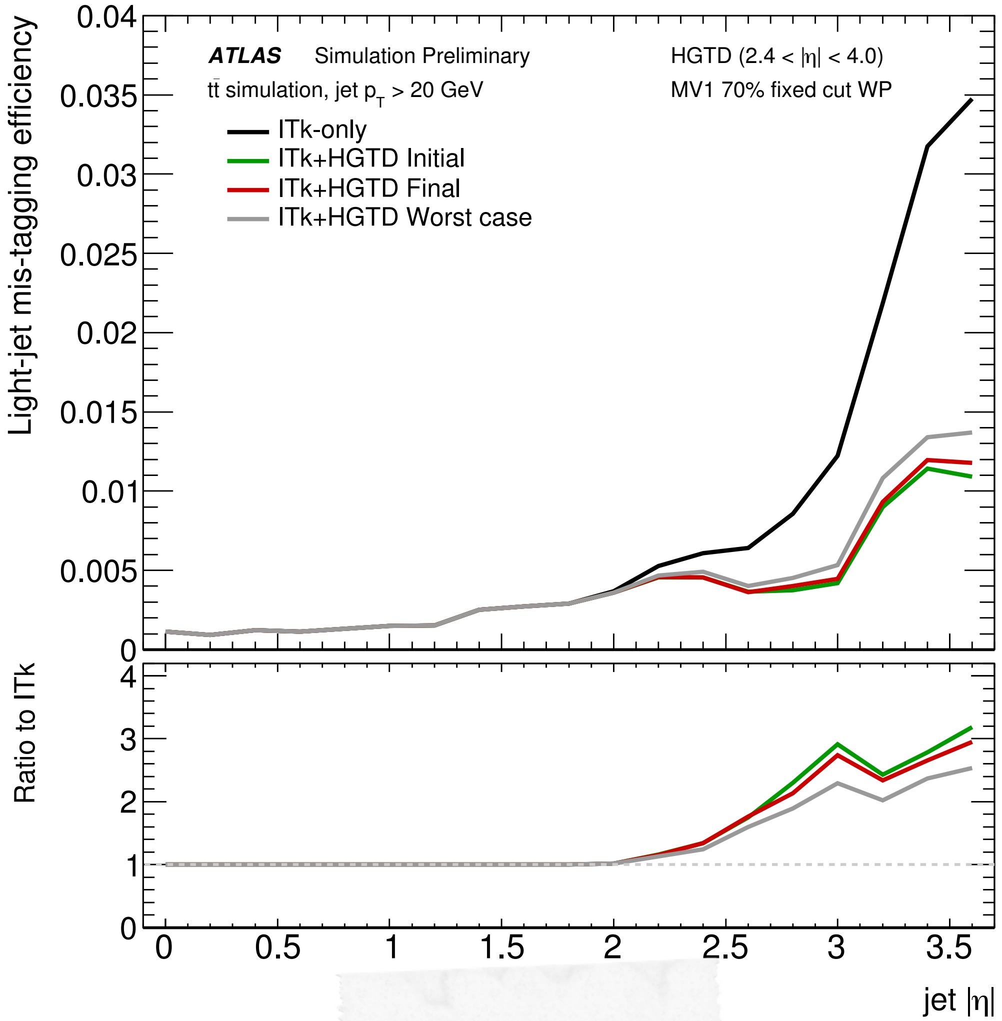
(b) Jets with $p_T > 50$ GeV.

$$R_{p_T} = \frac{\Sigma p_T^{trk}(PV_0)}{p_T^{jet}}.$$

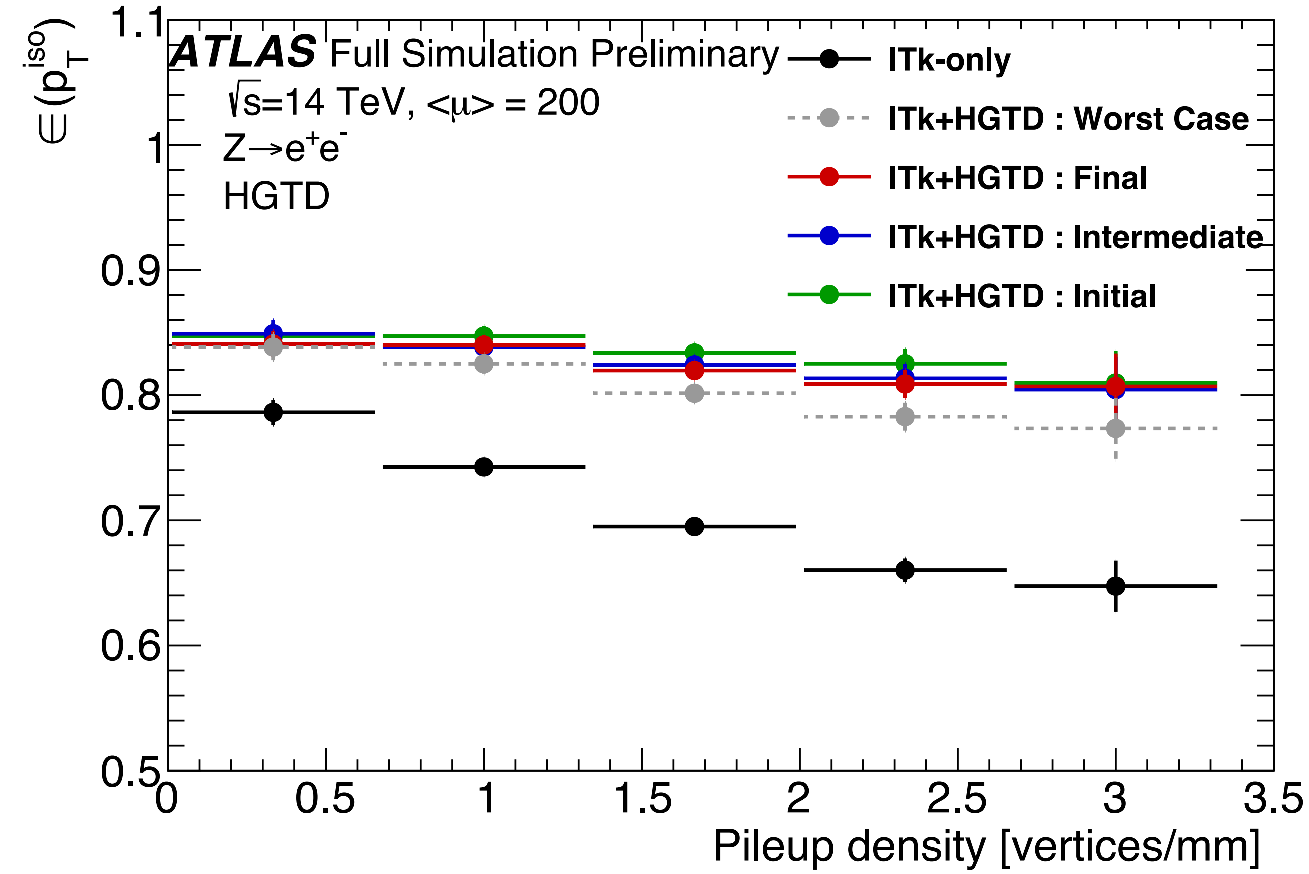
Factor of 4 higher pileup-jet rejection at constant efficiency is achieved with the use of timing information.

Recover forward efficiency for fixed PU jet rejection (50)

Object performances

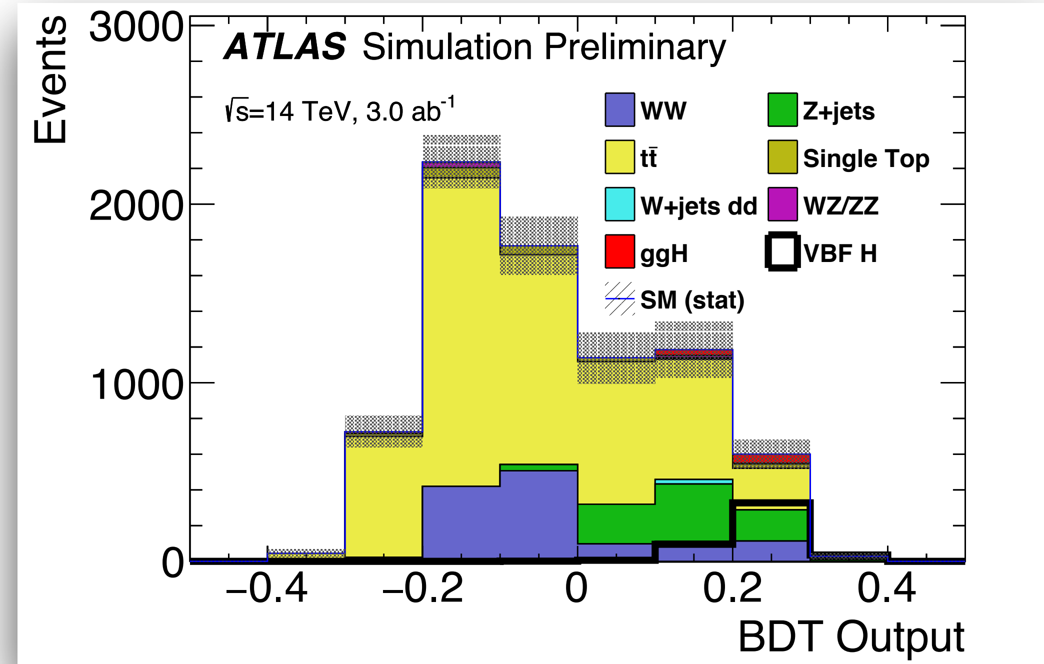


Also the performance of the b-tagger is significantly improved. For a b-tagging efficiency of 70% and 85%, the corresponding light-jet rejection for MV1 is increased by approximate factors of 1.5 and 1.2, respectively.



pileup density of the order of 1.8 vertices/mm the electron isolation efficiency is improved by about 14%

Impact on physics analysis



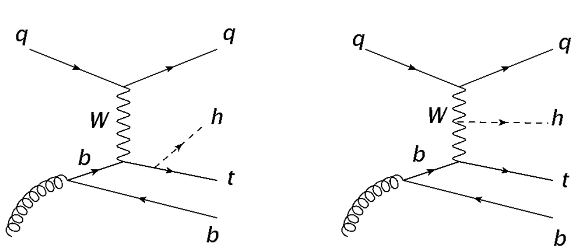
VBF H→WW

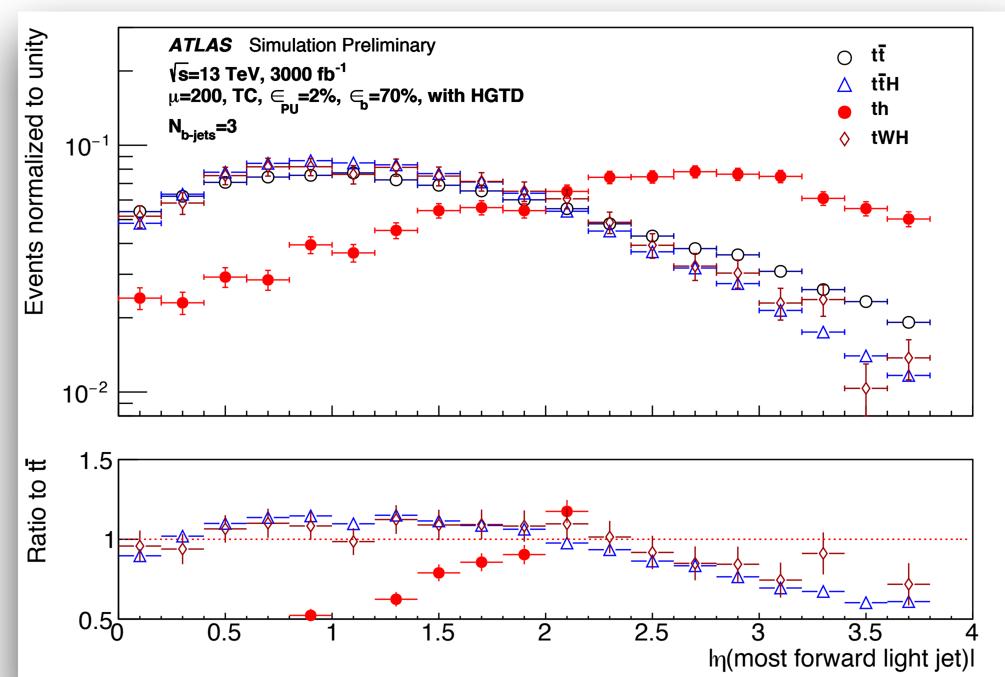
Single-object performance gains will benefit physics across ATLAS

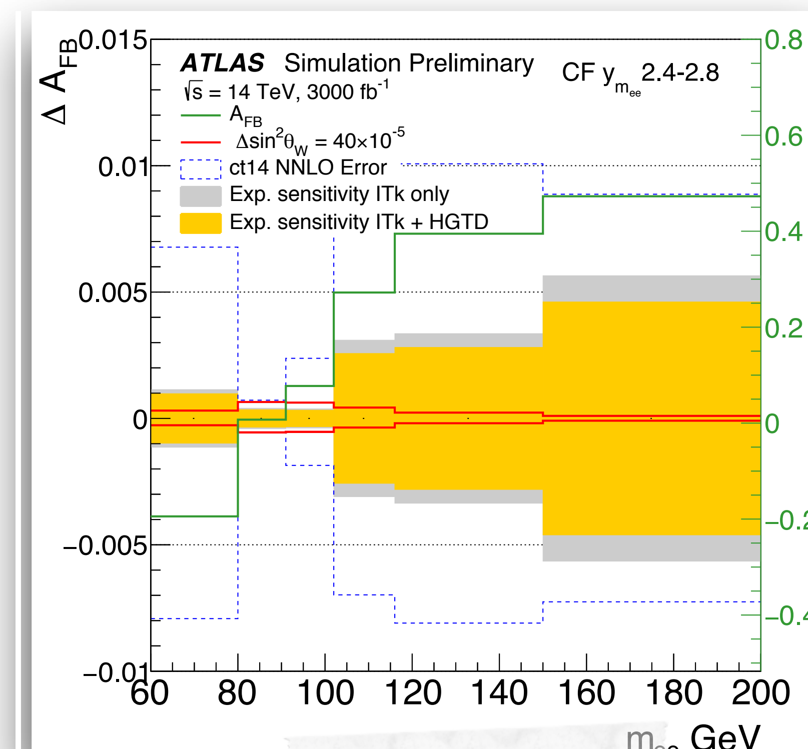
Typically see order **10%** improvement - HL-LHC

A 10% improvement corresponds to stat improvement from about one more year of HL-LHC running

tH→bb







AFB and $\sin^2\theta_W$ extraction

How to improve the Strategy?

PU suppression
Missing ET
b-tagging
Lepton isolation

Detector performance → Physics objects performance → Physics

Current studies make use of parameterizations for track-time assignment efficiency/purity, and t_0 efficiency/misidentification

↓ Detector performance

Use AOD with time assigned to vertices and tracks
(already done for leptons)

Detector simulation & performance

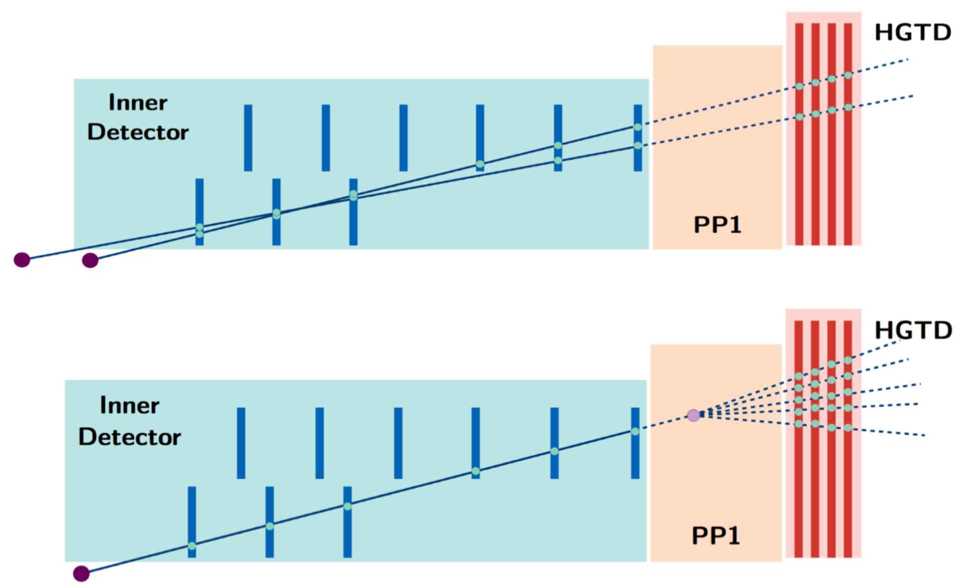
Detector performance → Physics objects performance → Physics

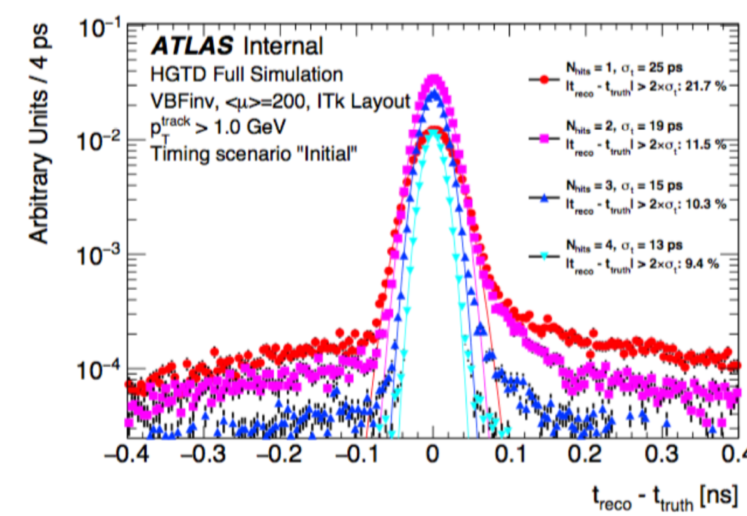
Track-time assignment:
Improve efficiency, purity

Fully integrate tracking and LAr simulation chains, in release 20.20.X

Fix scenarios for time resolution: impact of material and radiation

Add time to tracks in xAOD

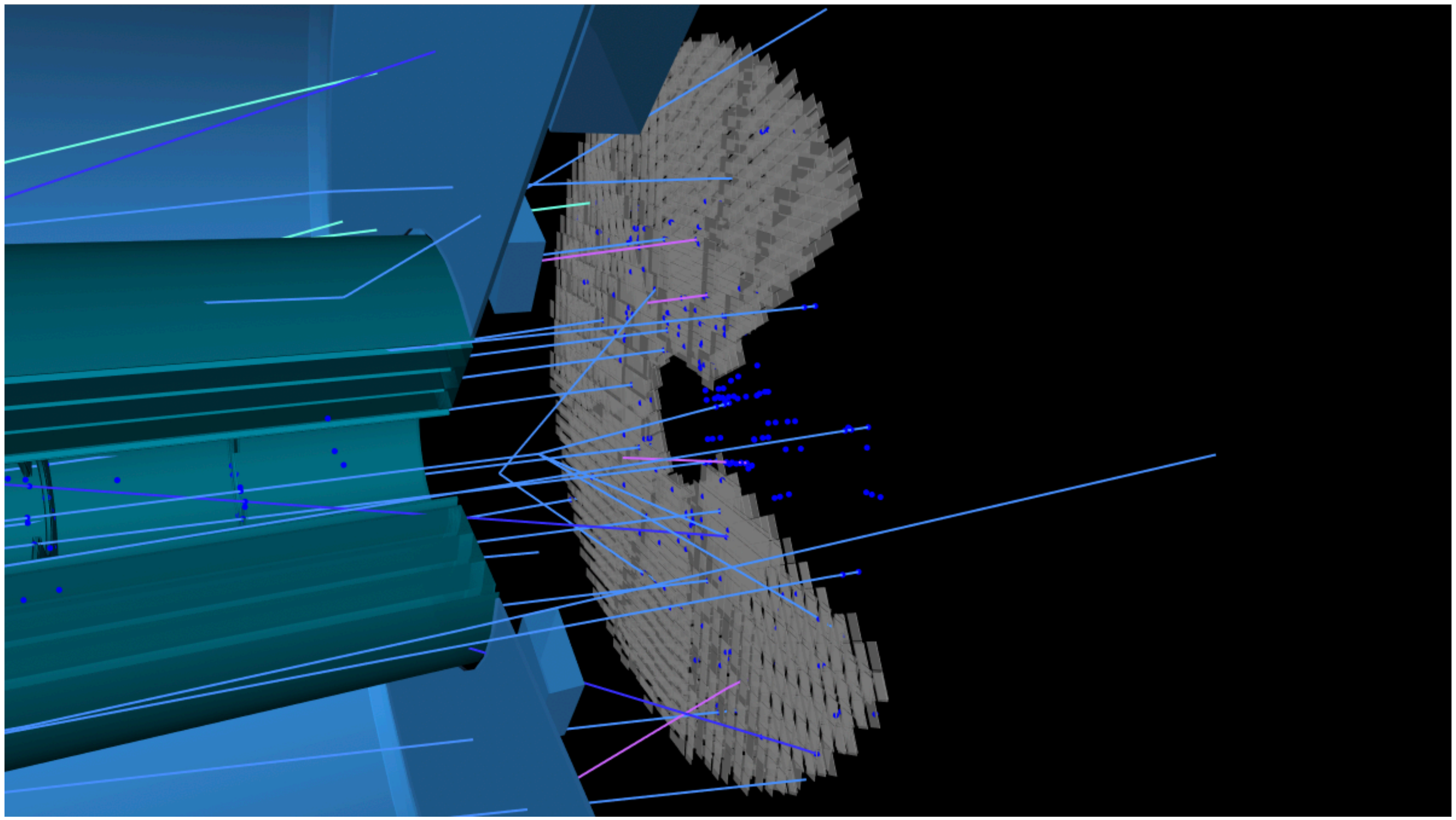




Corentin Allaire, Alex Leopold, Noemi Calace, Nora Pettersson

Simulation

The baseline of 1.3 mm × 1.3 mm is used for the padsize.



The simulation studies for the digitization and clustering step of the HGTD have been studies using **two independent methods:**

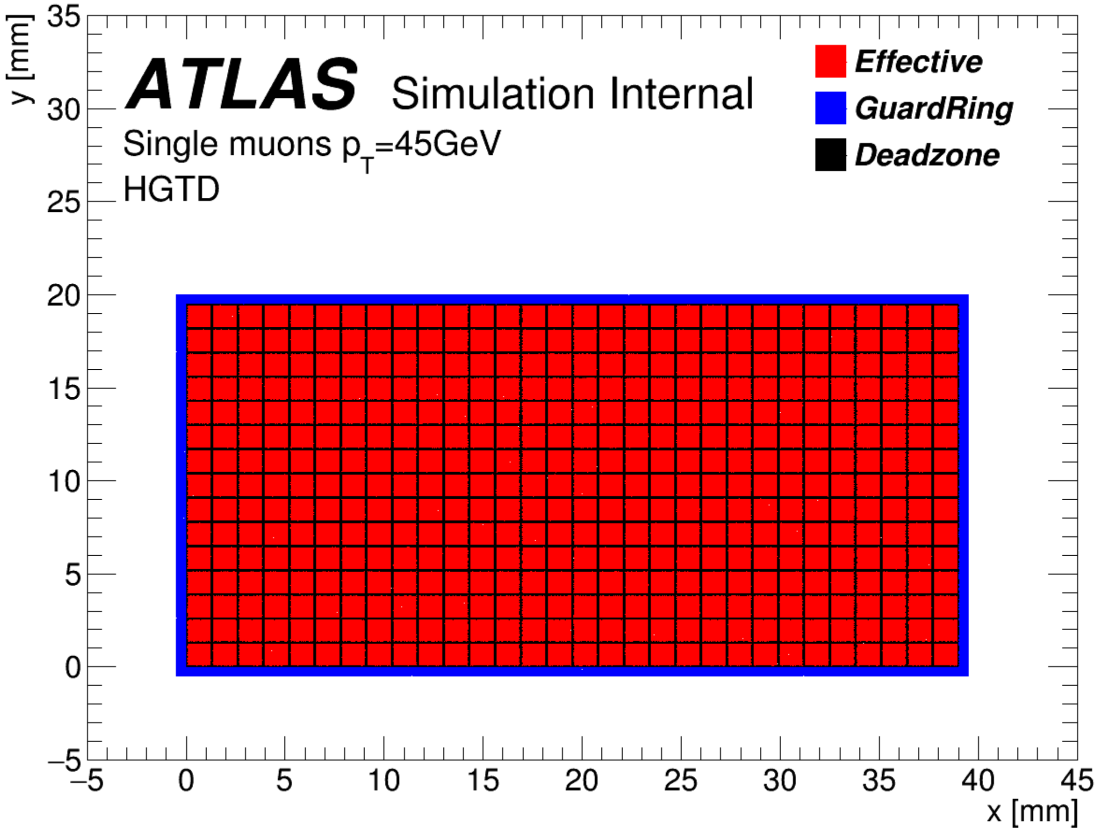
A. Using calorimeter hits which model the pulse shape in the sensor including noise effects and have an accurate timing performance for the sensors.

B. Using silicon pixel hits which contain a pixel digitization and clustering model as well as the truth association for hit information.

- Simulation emulator based on LArHits:
  - https://gitlab.cern.ch/atlas-hgtd/hgtd-simulation
- Simulation in ATHENA SIHits done and available since December in 20.20.14.1
  - https://svnweb.cern.ch/trac/atlasoff/browser/LArCalorimeter/LArG4/HGTDG4SD
  - https://svnweb.cern.ch/trac/atlasoff/browser/LArCalorimeter/LArG4/HGTDG4SD/tags/HGTDG4SD-00-01-02?order=name

LArHits Simulation

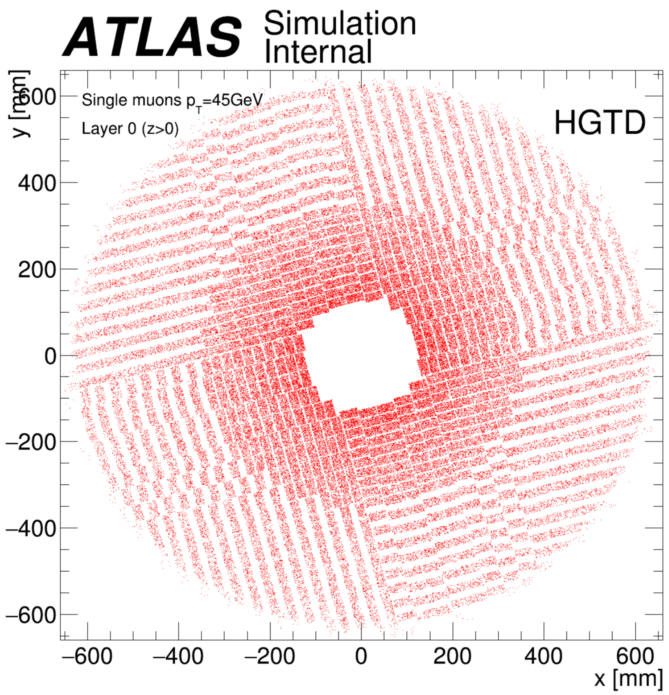
LArHits simulation

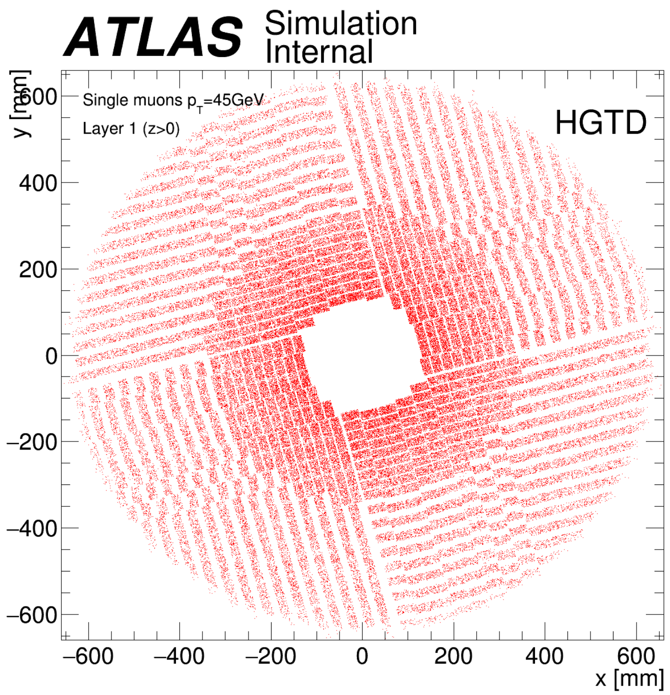


The active area of each pad is associated with a unique identifier. In the digitization step for $\langle\mu\rangle$ = 200, the hits from the different interactions are summed in energy if they are in the same 5 ps time bin. To allow for maximum flexibility at the analysis stage, the hits are then copied down to the format used for the analysis. The timing information is stored after subtracting a global offset of 11.6 ns, corresponding to the time of flight from the nominal interaction point to the center of the HGTD.

The hits are decoded at analysis level. Their position is calculated and corrected based on a lookup table containing the nominal position of each sensor.

The hits in the HGTD are shown in the transverse plane
The position of the modules can be identified.





LArHits simulation

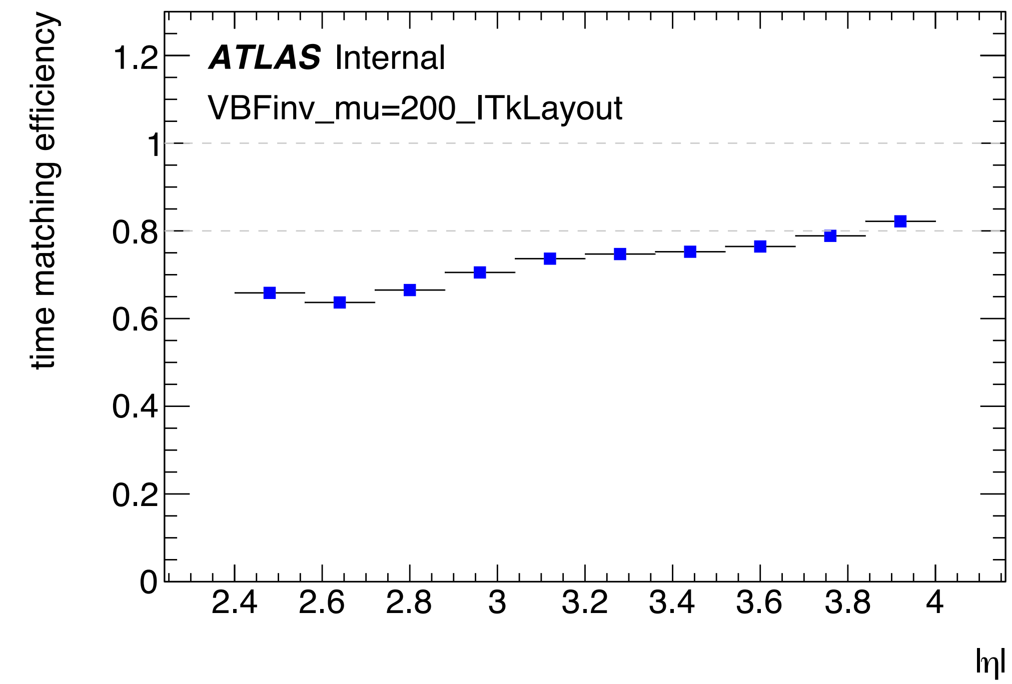
Hit-track matching

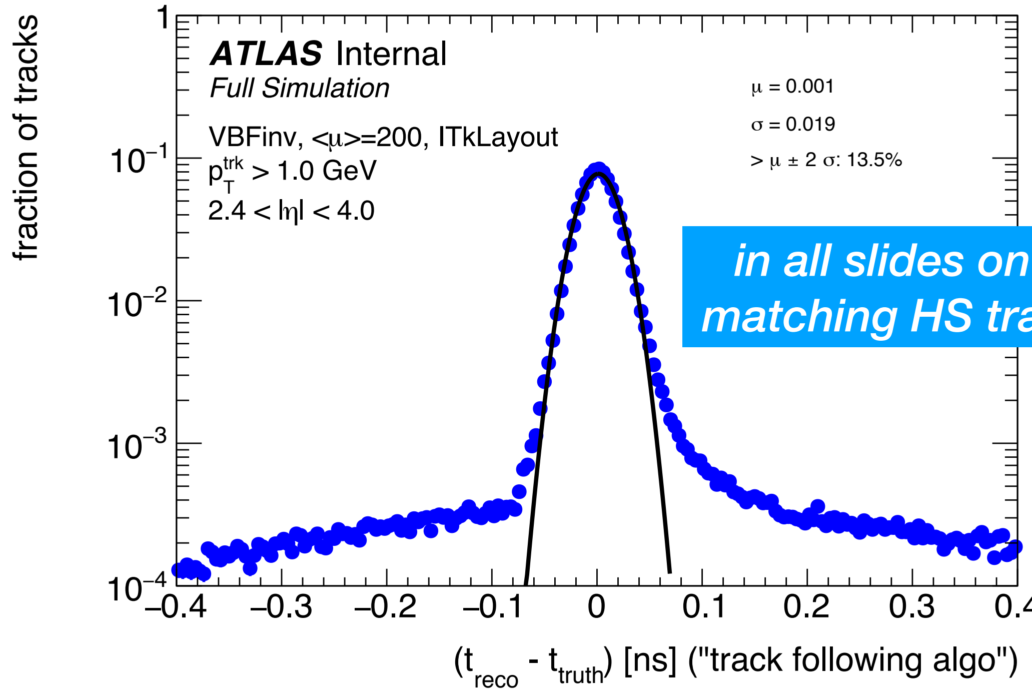
simplified approach

- collect all hits within **1.4 mm** radius in each layer
- find hit combination, with times within a **±2.5 σ_t** window (σ_t =25ps), taking the hit closest to the IP as the reference
- take combination with most hits and smallest sum squared[1] as the track's time

↣ due to spatial cut of 1.4mm, removed check to see if hits line up

↣ for higher efficiency, ***also accept cases where only 1 hit in all layers is found!***





in all slides on track-hit matching HS tracks[2] only!

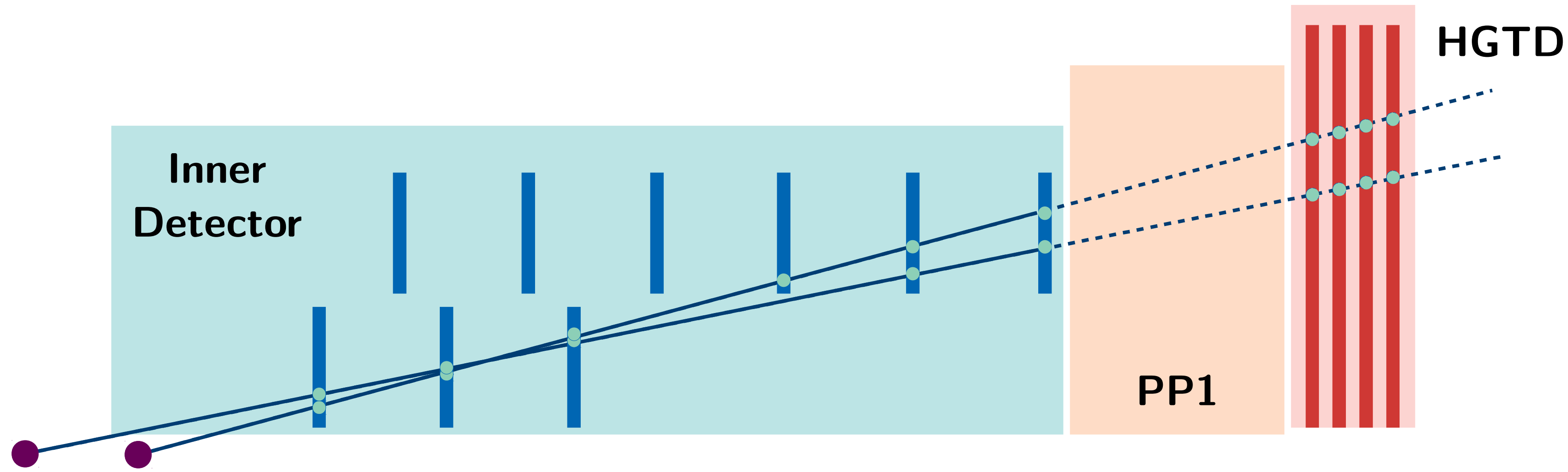
[1] $S = \sum_i (\vec{x}_{i,\mathrm{hit}} - \vec{x}_{i,\mathrm{extrap}})^2$

[2] HS track: tracks linking to truth particles of the HS vertex, barcode < 200k, status=1, charged

SIHits Simulation

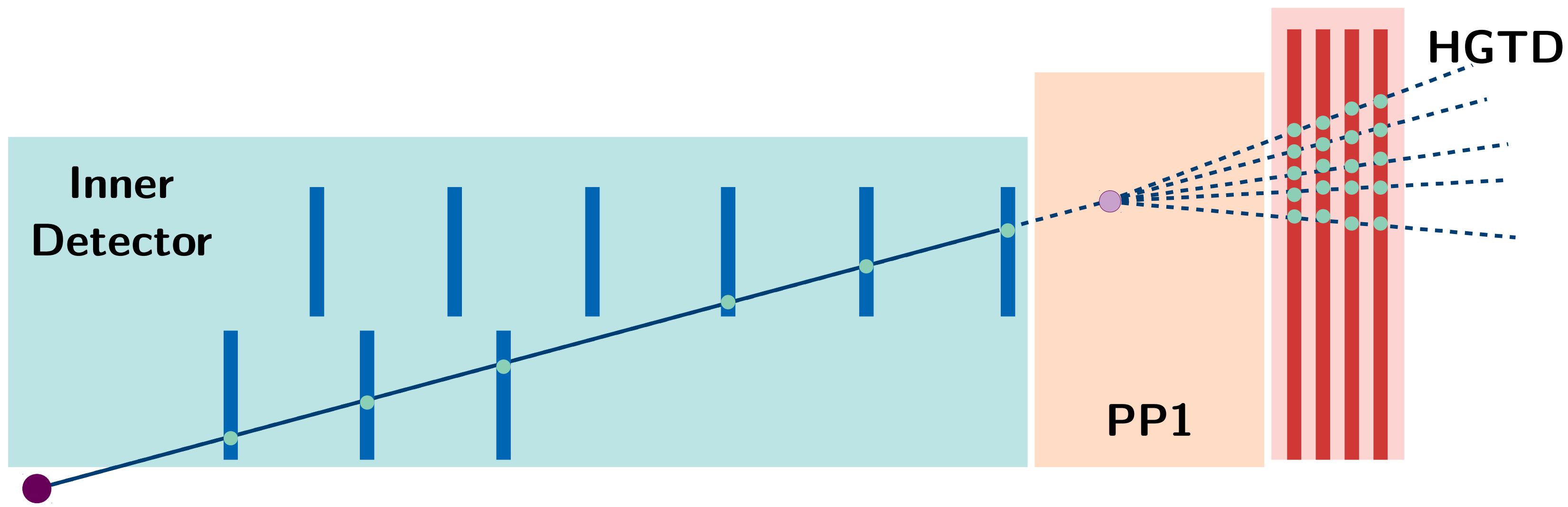
- Attaching HGTD hits to a track
  - Resolve multiple vertices → Exploiting timing information

A)



- Attaching HGTD hits to a track after EM and/or hadronic interactions
  - Associate the children to the right time bin after the interaction

B)

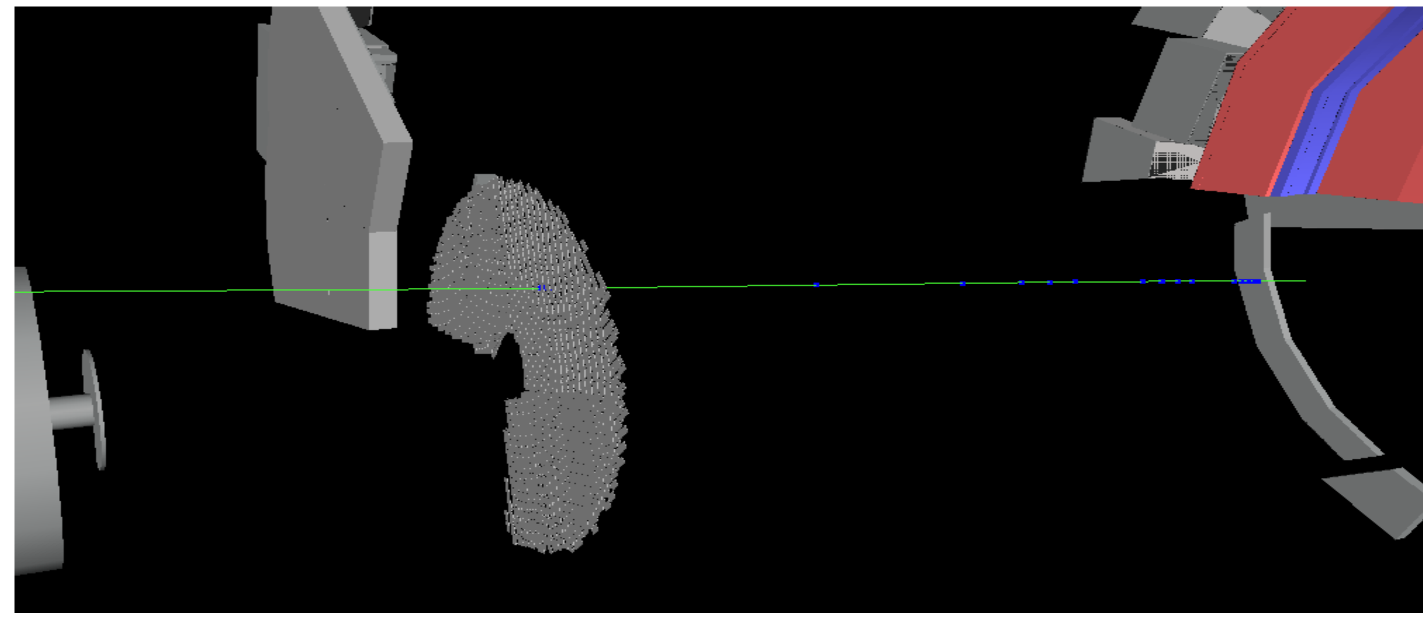


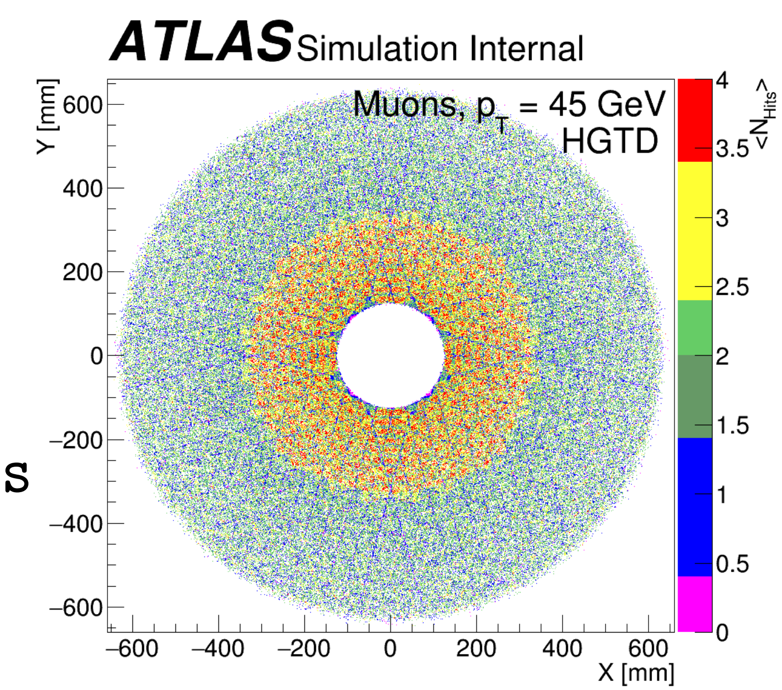
SIHits Simulation

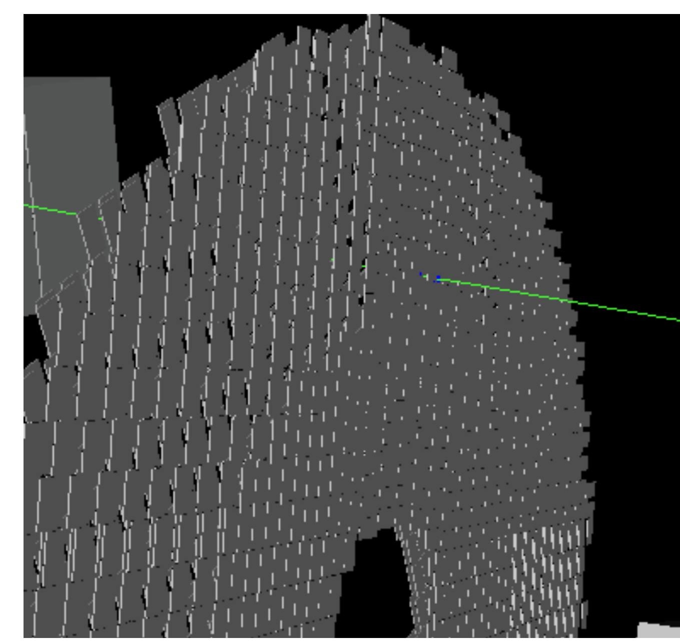
Hits information available

Track reconstruction using HGTD requires few important and unavoidable steps:

- **Simulation → Implemented in 20.20.14.1 (Dec 2018)**
  - When the HGTD geometry is built, we need to associate to each silicon element its own `SiDetectorElement` object
    - Treated as a pixel module we need to propagate pixel basics: pixel Id helper, pixel manager, Lorentz angle svc, etc.
    - Define the diode map that will be used later on in digitization
  - Allow the HGTDG4SD to fill a new `SiHitCollection` with HGTD `SiHits`
    - G4 truth stored



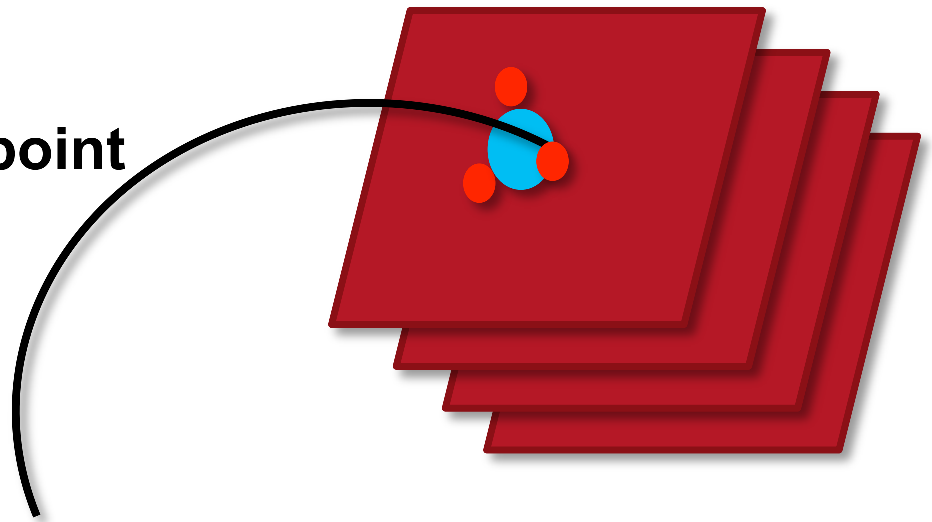




SIHits Simulation

Tracks extrapolation

Starting point: Extrapolate from **last hit on track** to **HGTD layer 0**



Then, for each layer:

1. Look for **surfaces** near the **extrapolated crossing point**
   - Pick up all surfaces in a ~5x5cm region around the crossing
   - Currently optimised for efficiency rather than speed

2. Look for the **cluster best matching the track**
   - Candidates: All clusters on surfaces selected in 1.)
   - For each cluster: Use KalmanUpdator to attempt to add measurement to track
   - Keep the one cluster with the best incremental chi^2

3. Keep cluster if **satisfactory fit outcome**
   - Cutting at chi^2/n.d.f < 5

4. In case of **successful** extension: Use **updated** track parameters from Kalman forward filter for extrapolation to next layer

Result: Set of 4 outcomes (either one cluster or failure) for the 4 layers.

SIHits Simulation

Information available for the analysis

Result of this procedure:

Decorated to xAOD::TrackParticles for analysis in **InDetPhysValMonitoring**

track association code

vertex code

Stored information:

Track quality based on presence/absence of hits on last Pixel/Strip layer

True production time from truth particle's production vertex

Reco track time based on chi² weighted average of cluster times on track

- Also available: Version with arithmetic mean
- Also storing RMS of times of associated clusters – sensitive to PU contamination!
- See below for def of cluster time!

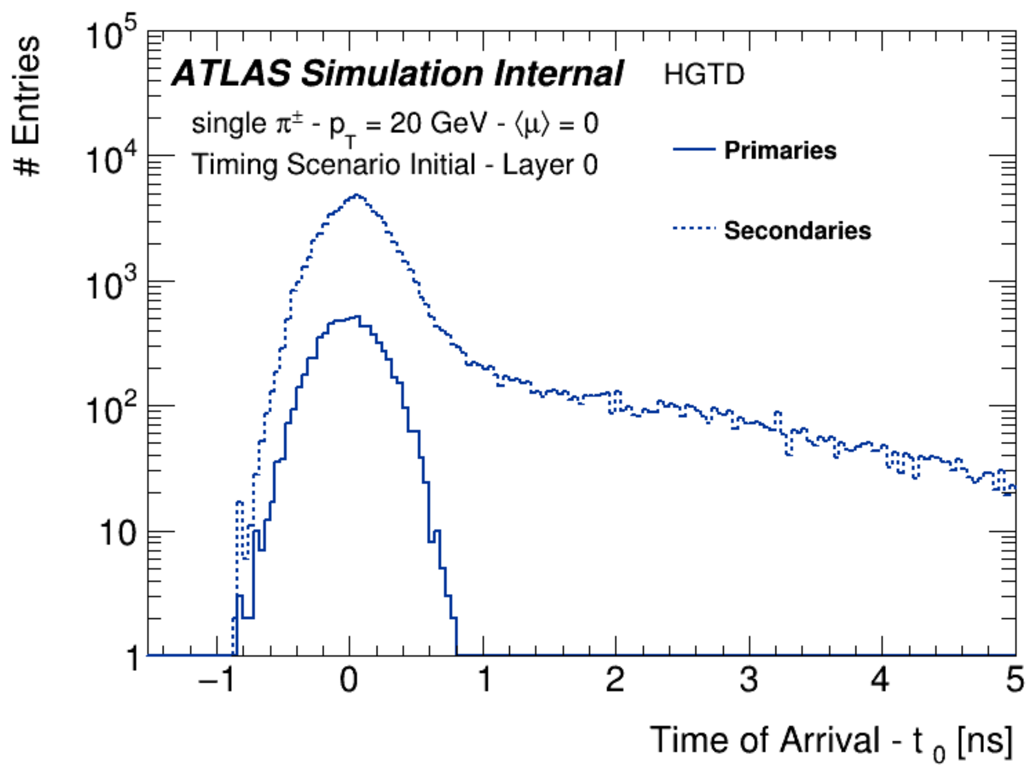
Information **per layer:**

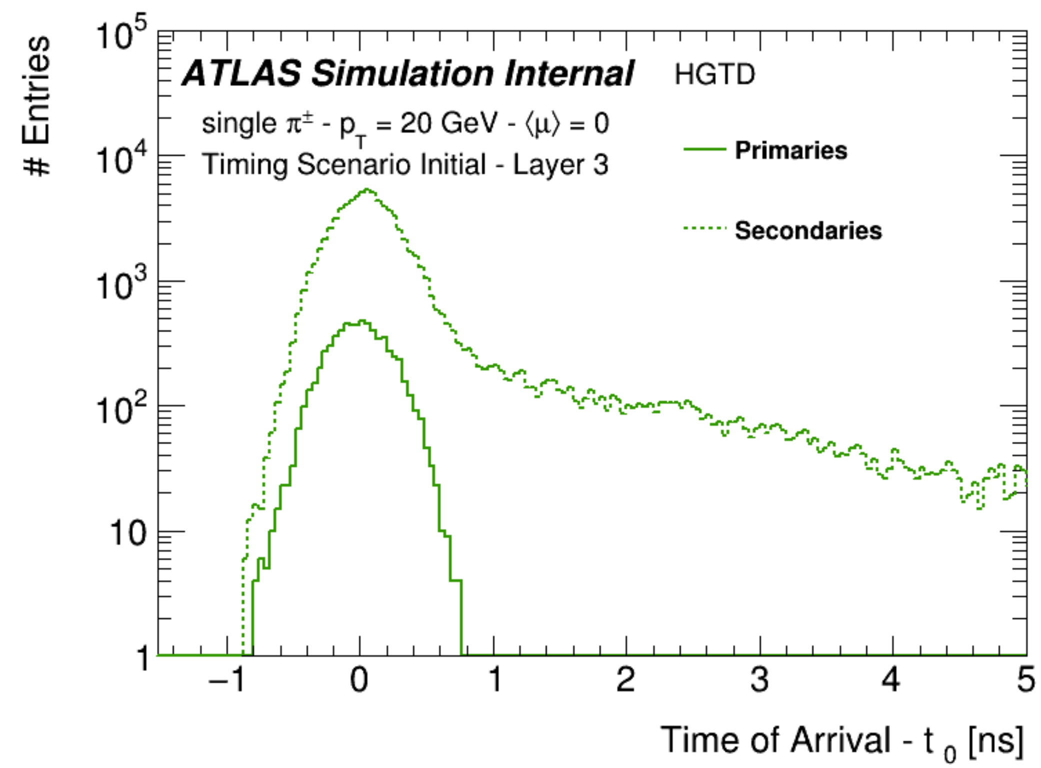
- **Presence/absence** of associated cluster
- **Cluster time –** Defined as time measured in HGTD corrected for time of flight from track origin (0,0,z_0)
- **Incremental chi²**
- **Location** in x,y,z,R
- **Truth classification of cluster –** see extra slides
- Information on **existence** of a cluster on the layer from the track regardless of association outcome
  - Using truth – see extra slides

SIHits Simulation

Detector performances

Time distribution: Primaries vs Secondaries



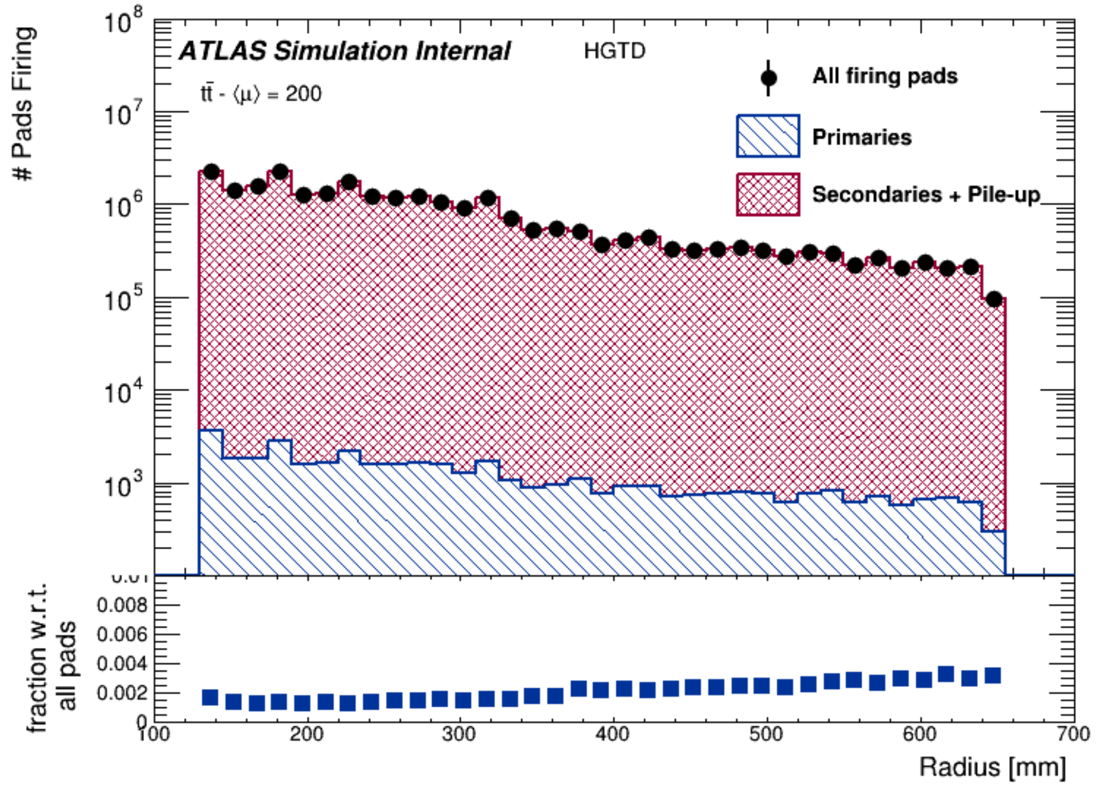


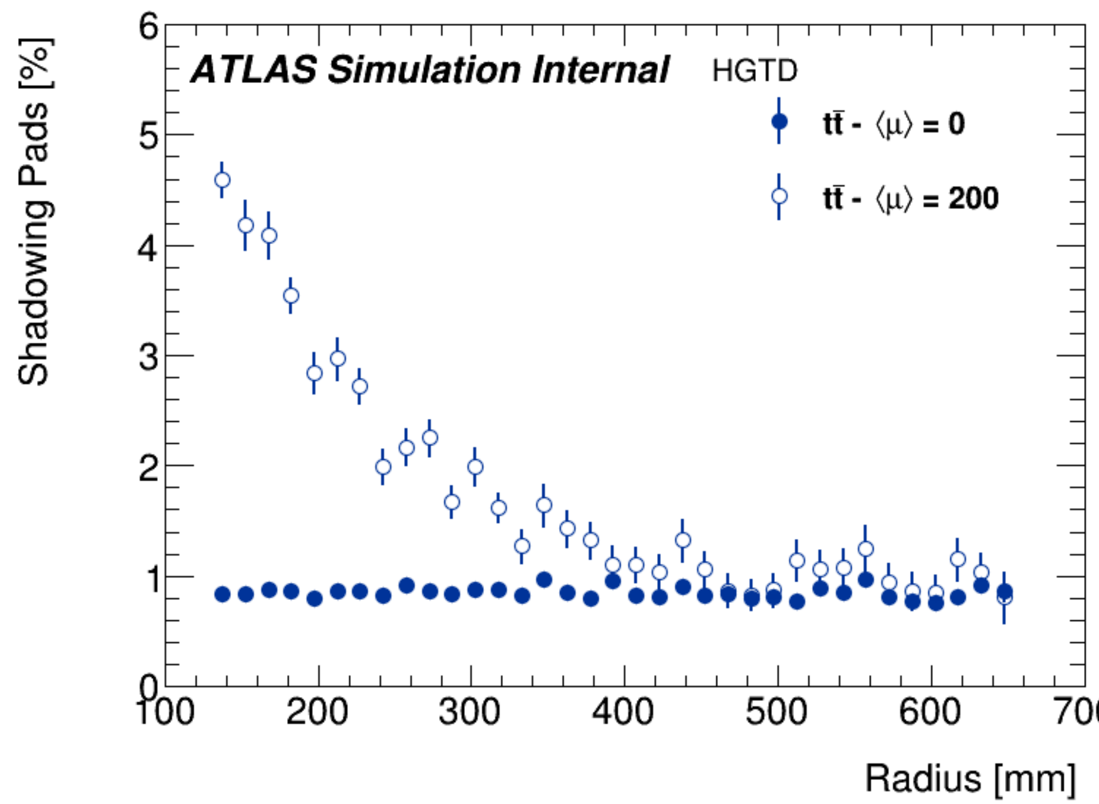
- Distribution of the (ToA - t_0) on the first and last HGTD layer for primary and secondary particles produced in single pion events with p_T=20 GeV. While primaries stay within [- 1, 1] ns, a very pronounced tail is shown for secondaries. The latter indeed can arrive late with respect to the primary particles.
  - [ToA: Time of Arrival; t_0: expected ToA for particles propagating on a straight line from the centre of the detector]

SIHits Simulation

Detector performances II

Contributions to fired pads w/ pileup





Distribution of the number of fired pads as a function of the radius of the sensor in ttbar events with 200 overlaid pile-up events. The breakdown shows the contributions of pads fired by primaries or secondaries and pile-up particles. Pads fired by primary particles correspond to 0.2 % of the of the fired pads.

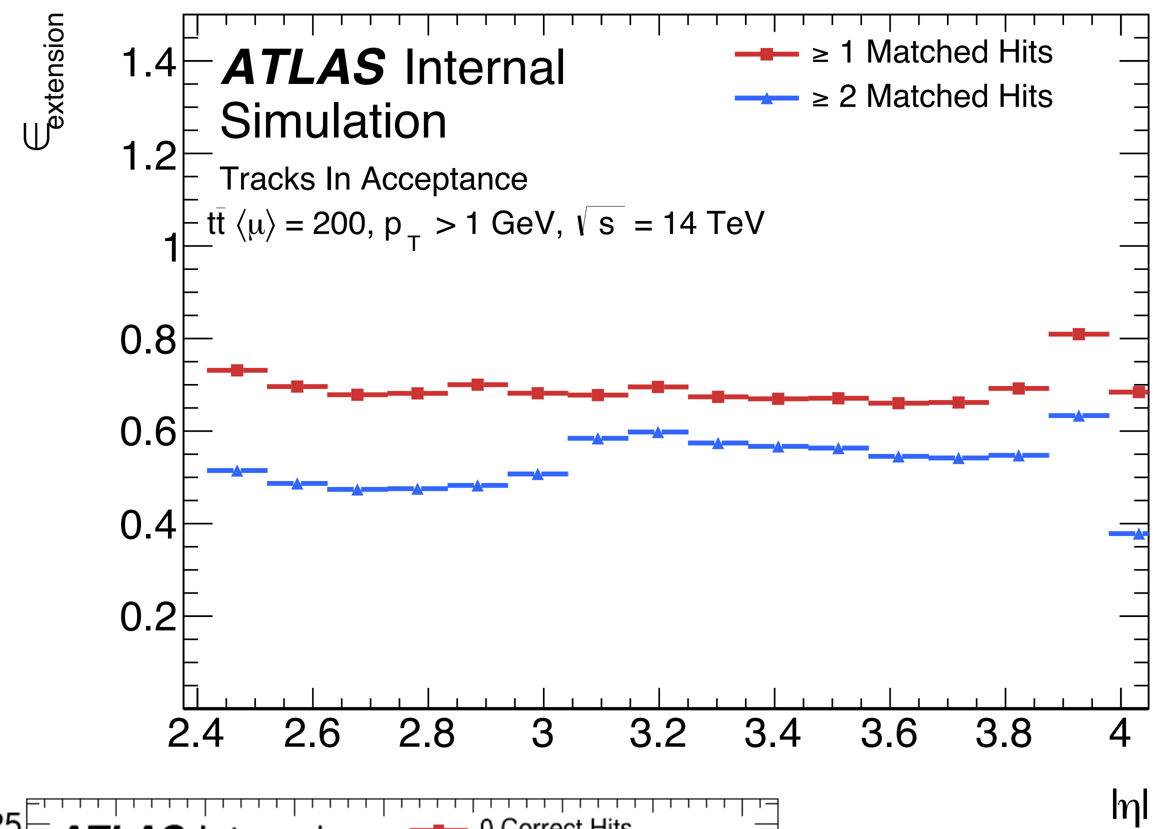
- Percentage of pads fired by secondaries and pile-up particles shadowing a primary particle with respect to the number of pads receiving contribution from primary particles as a function of the radius of the sensor.

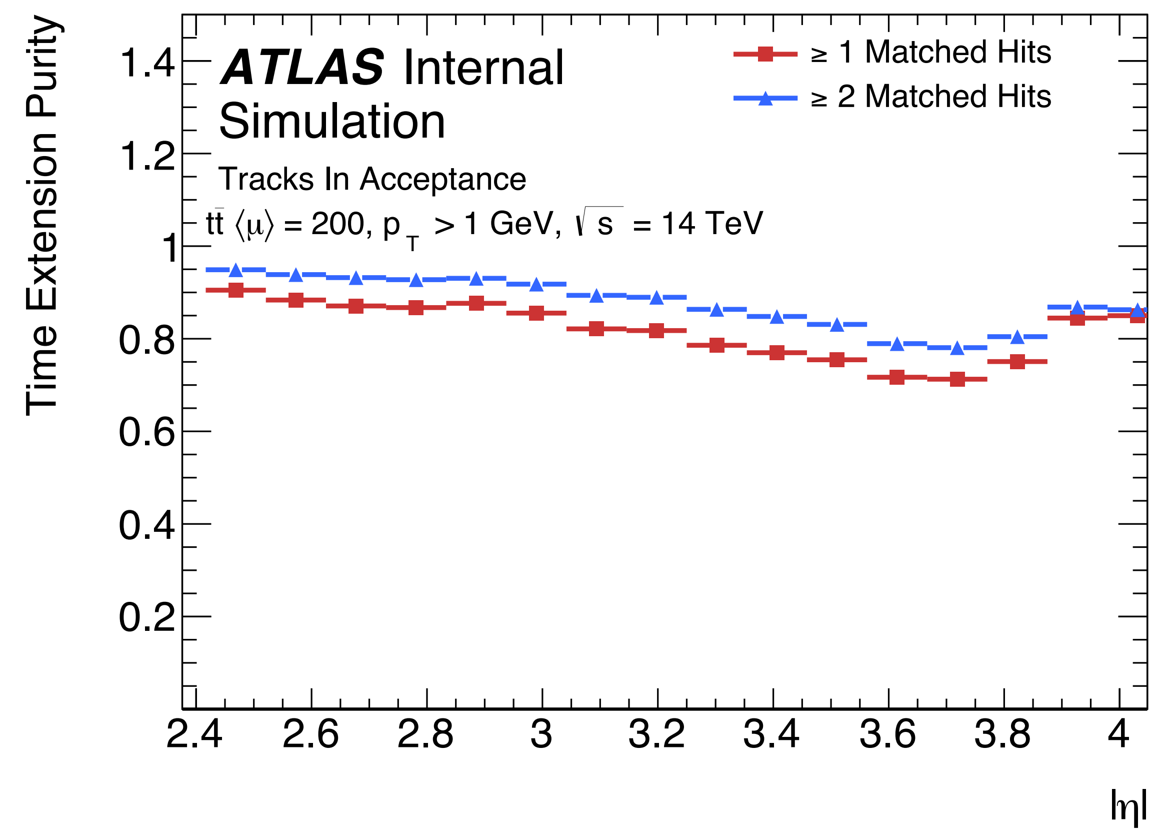
interesting talk

SIHits Simulation

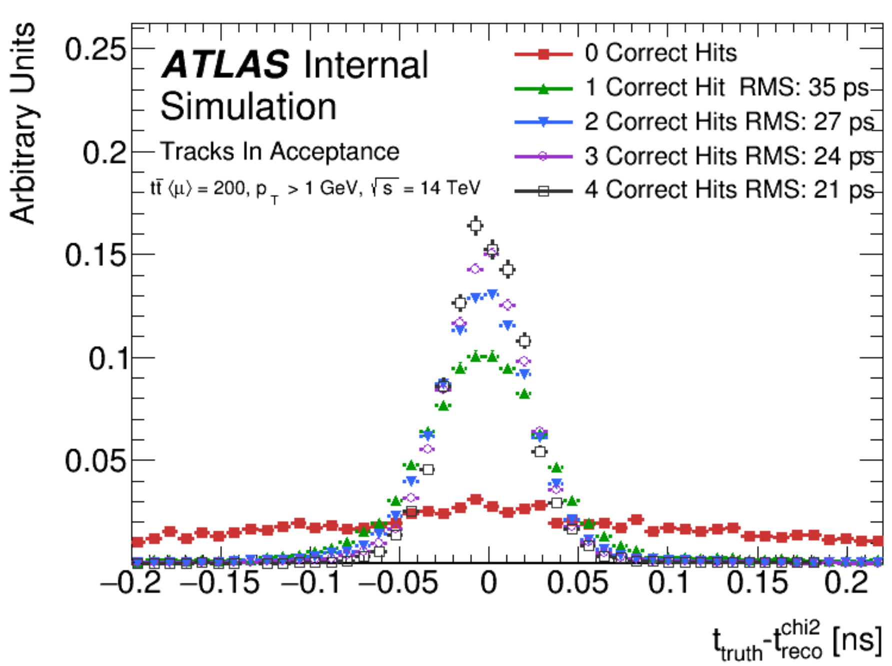
Detector performances III

Fraction of tracks within the HGTD acceptance that have at least 1 or 2 matched timing hits



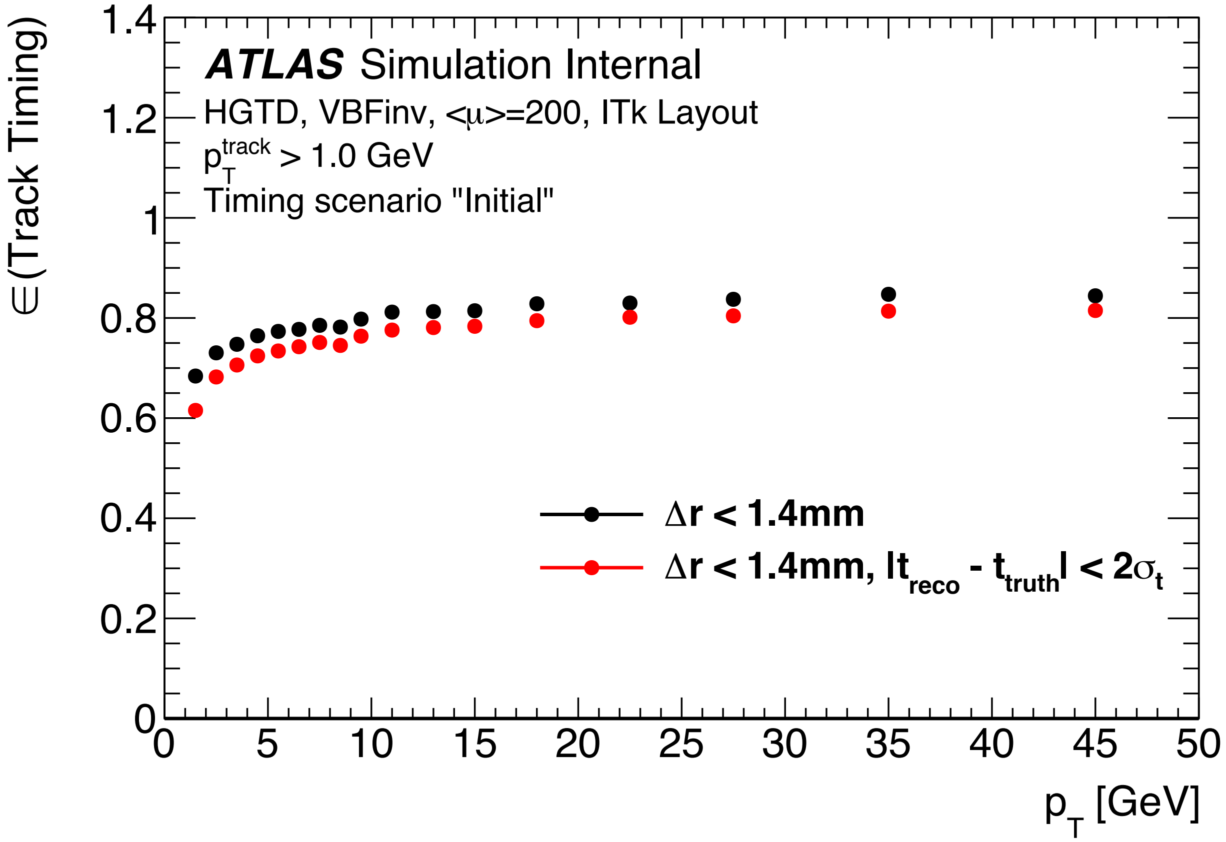


(b) Purity



Reconstructed times weighted by the χ^2 of the hits
Time resolution shows a dependence on the number of correctly or wrongly assigned hits

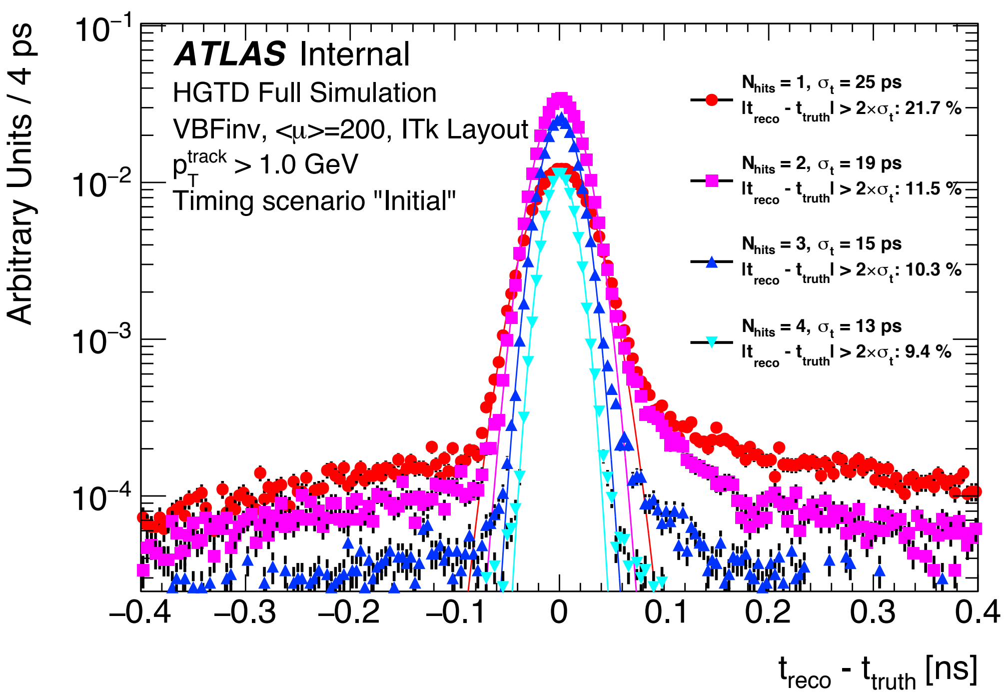
Time Association



Efficiency of having at least one time associated with a track

Efficiency of having at least one time associated with a track with the reconstructed time of the track within 2σ of the truth time

The efficiency increase with Pt



We are now using the last point of the track to do the extrapolation

Decrease the DeltaR between the track and the hits for low Pt

For Pions and Muons we now associate the closest hit in a window of 1.4 mm

Decrease the mismatching

This study is a first step in the development of the association of the track information with timing information in the HGTD. The main inefficiency, of not finding a hit within the window, has been identified as interactions in the material in front of the HGTD. More sophisticated pattern recognition algorithms are being studied to improve this efficiency.

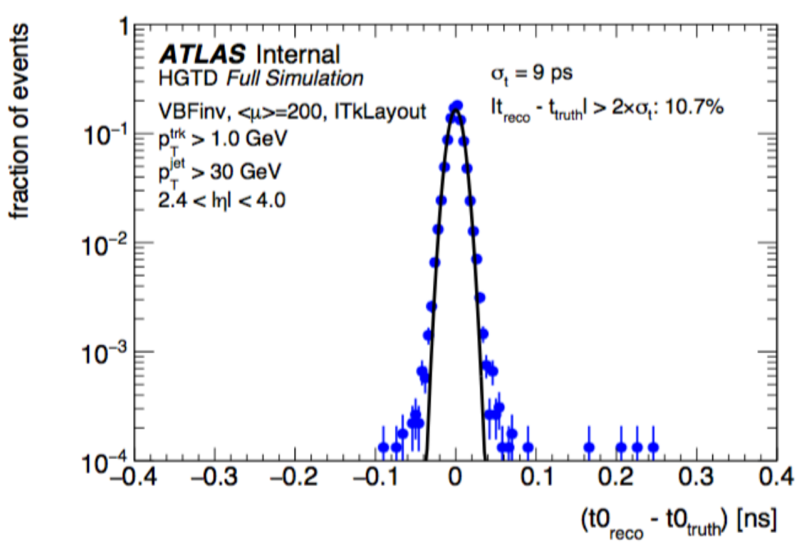
Plan towards the TDR

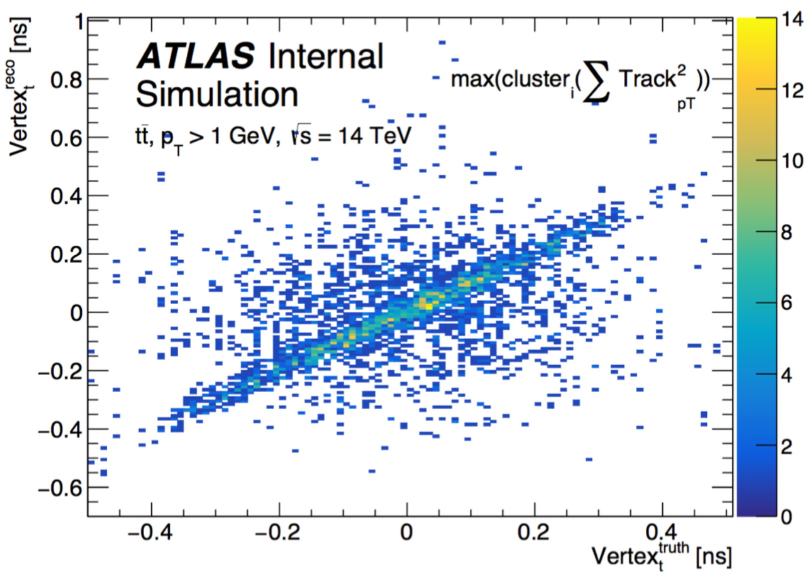
Investigate new methods for global t_0 reconstruction

- based on jets
- based on the underlying event
- based on vertexing

Detector performance → Physics objects performance → Physics

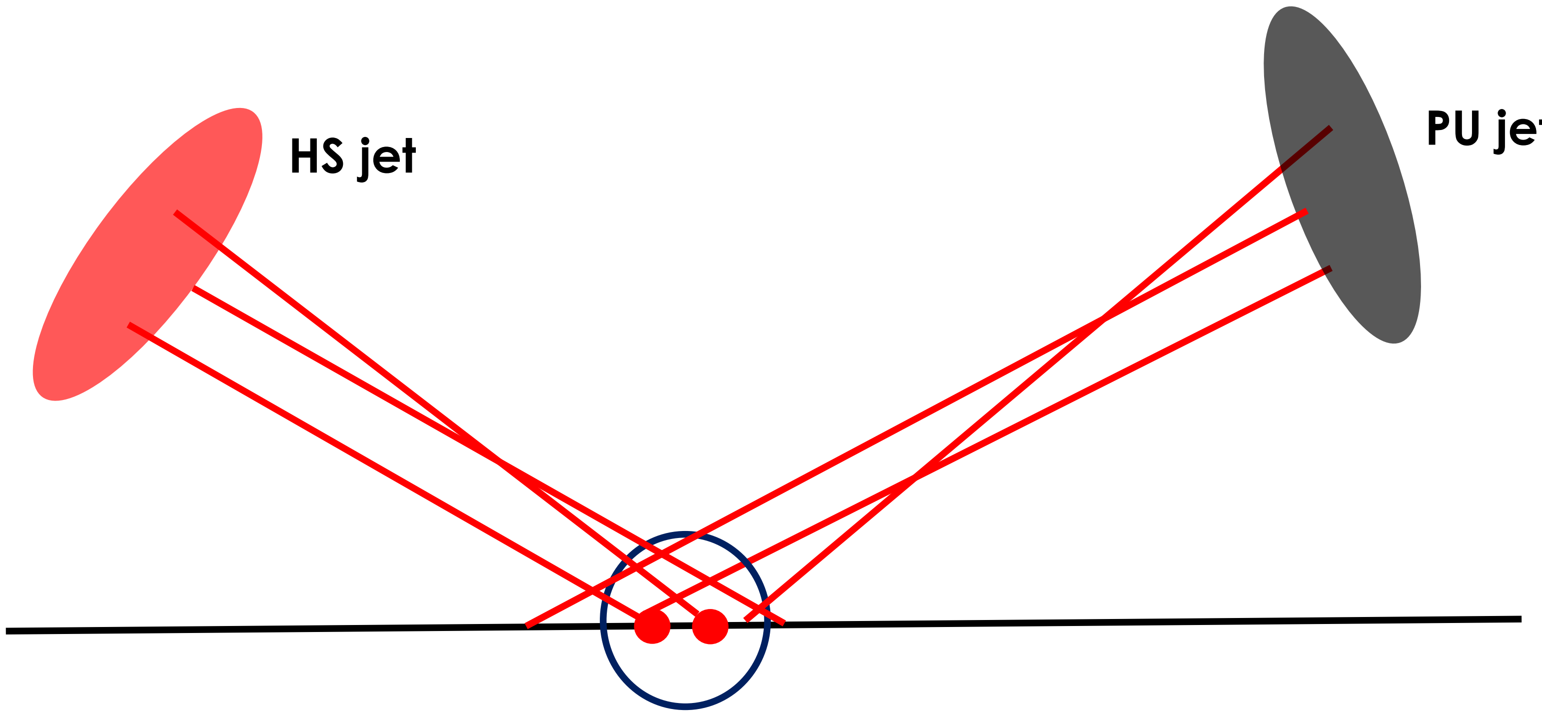
t_0 reconstruction, vertexing, track-to-vertex association





Alexander Leopold, Valentina Cairo, Nora Pettersson, Sabrina Sacerdoti

Tracks, vertices, and time

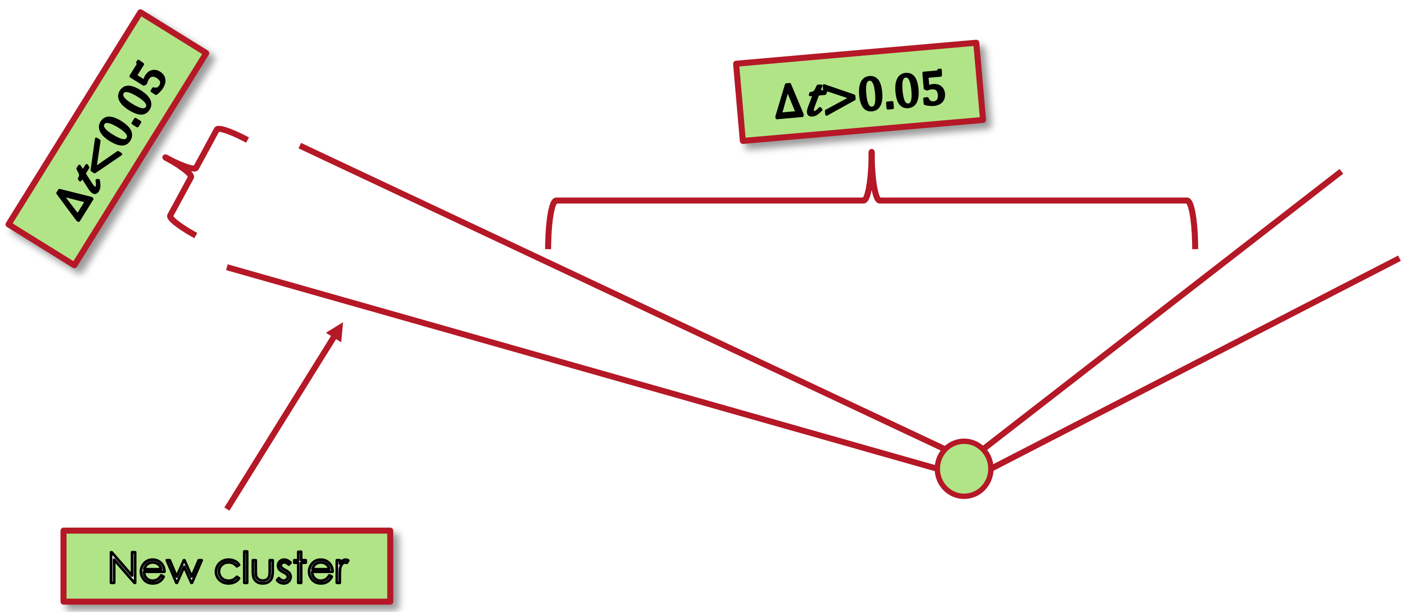


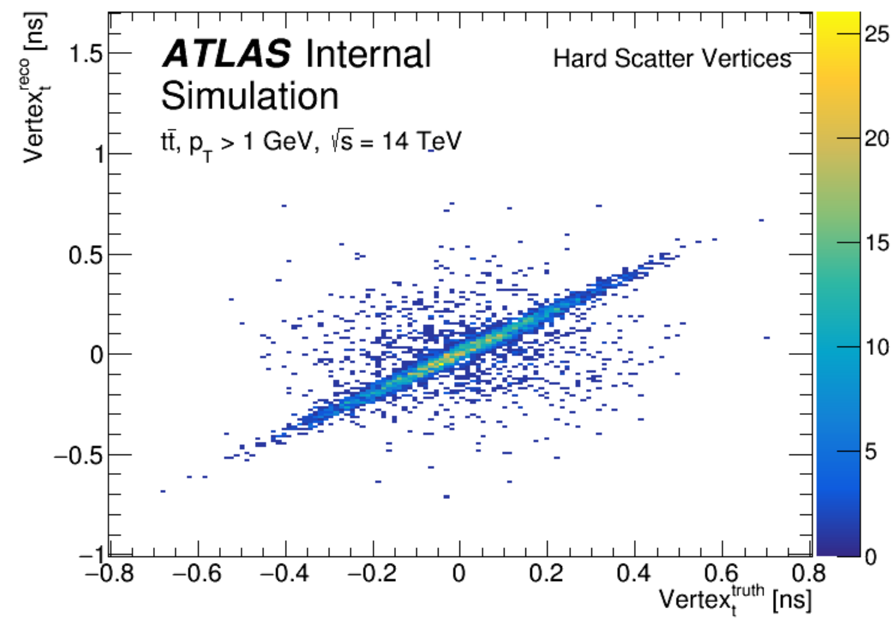
- **In the forward region, where the z0 resolution is larger than the typical separation between vertices, the association of tracks to primary vertices becomes ambiguous**
  - Use time information to resolve ambiguities
  - Improve PU jet suppression, jet reconstruction, b-tagging, missing ET, lepton isolation

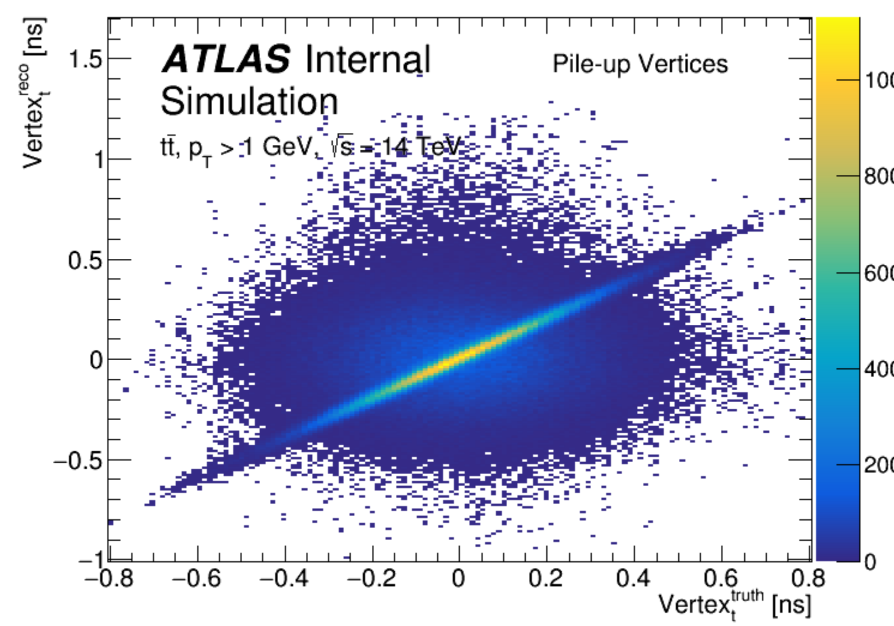
SIHits Simulation

Cluster - vertex matching

- Cluster time in each vertex depending on their own time:
  - Group tracks together if Δt < 0.05 ns
    - About 2 sigma of the time resolution of the tracks
    - Choose the best time-cluster based on the highest Σp_T^2
      - Of course other strategies can/should be investigated

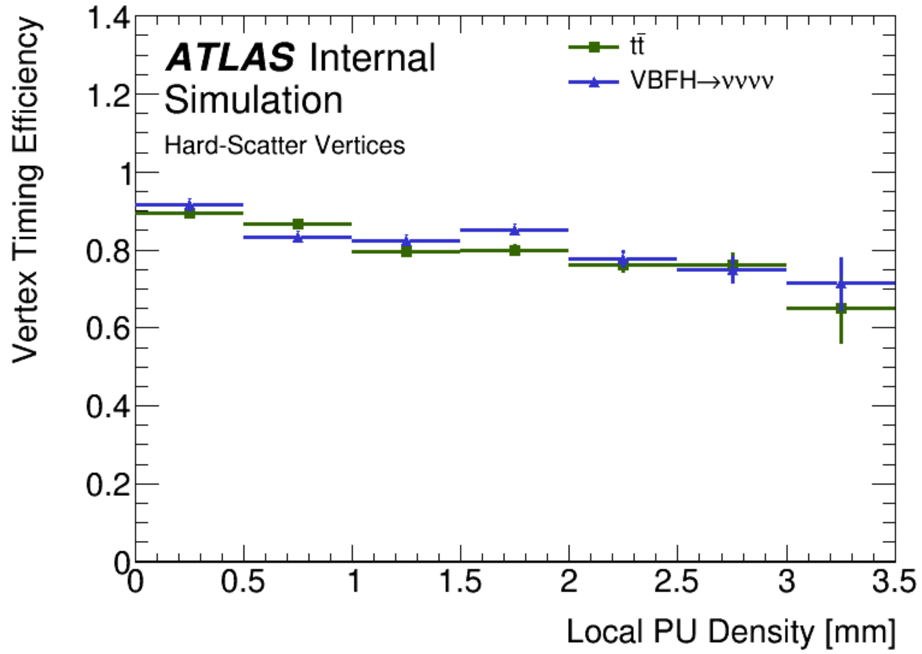


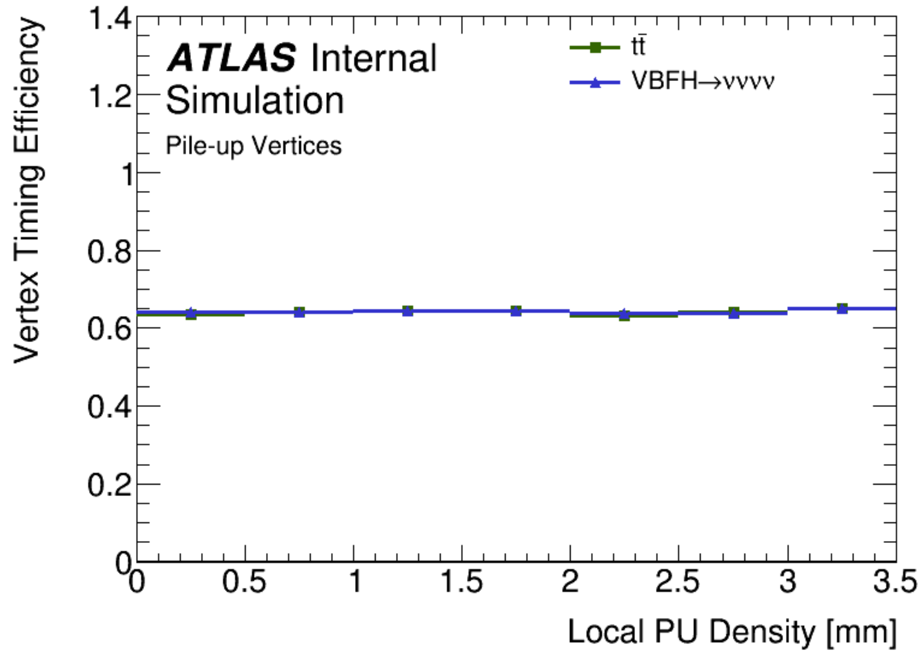




SlHits Simulation

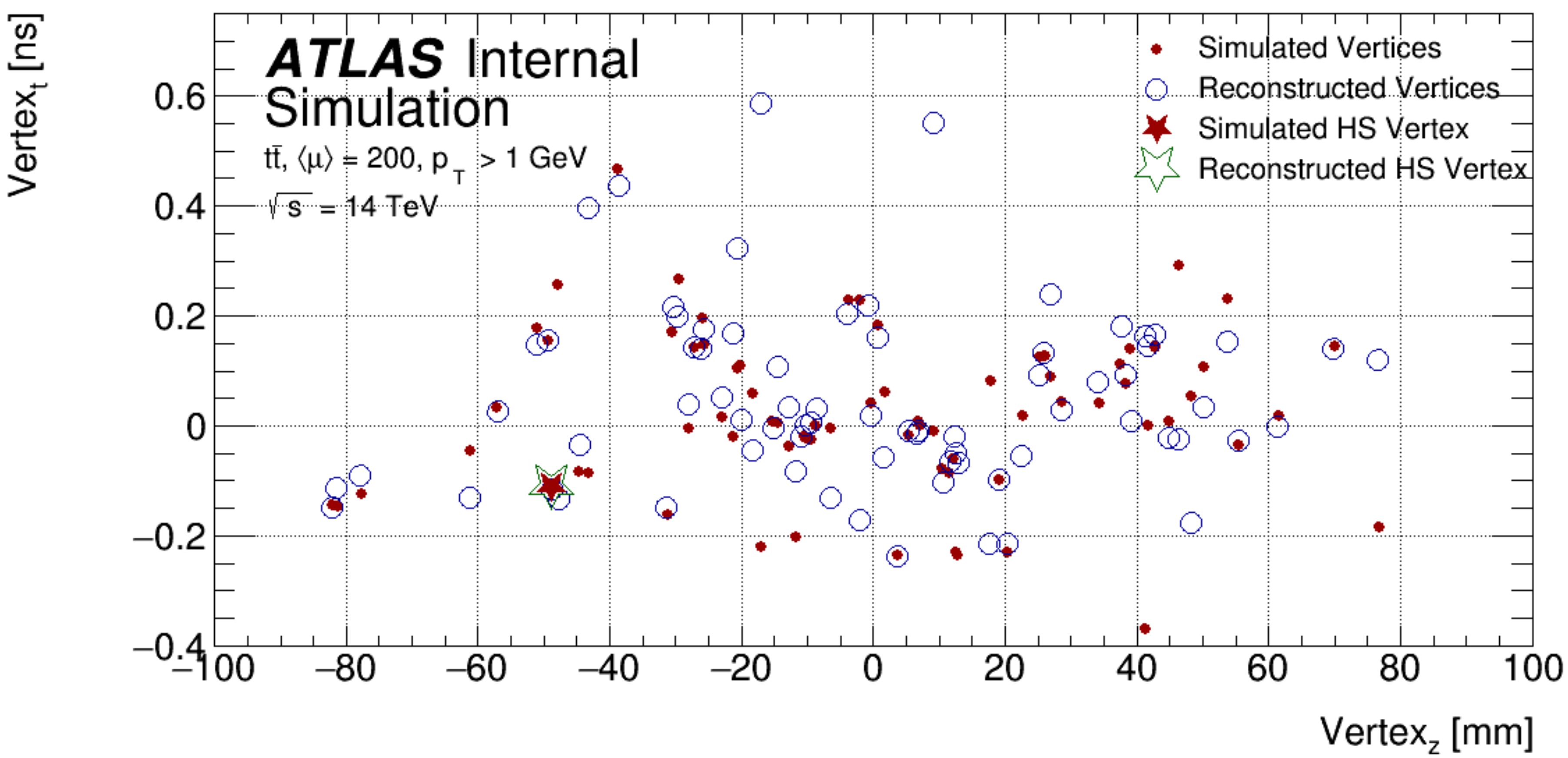
Vertex timing performances





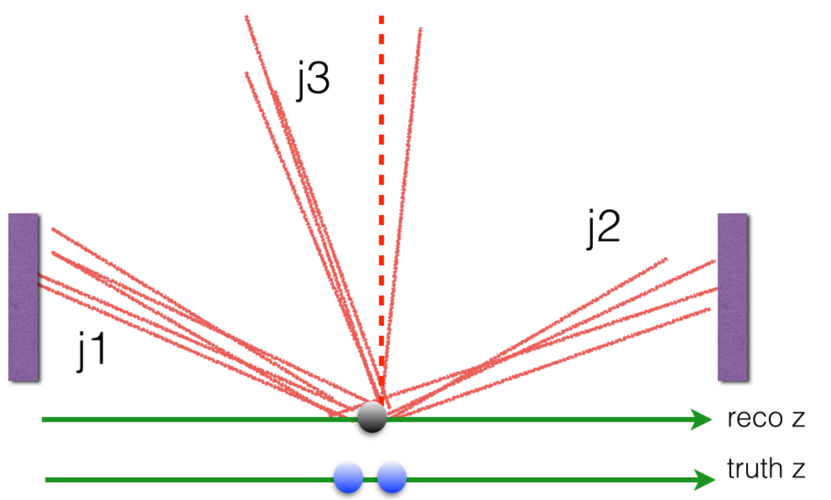
Fraction of vertices within a time window of 0.1ns of the true interaction time as a function of the local pile-up density(*)

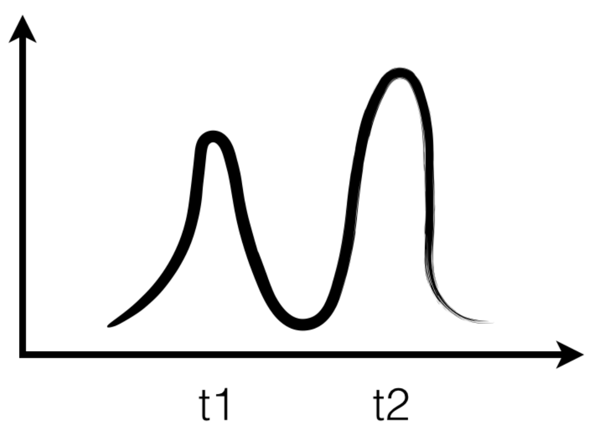
(*) number of generated vertices per unit length within a symmetrical ±2 mm longitudinal window.



Vertex timing

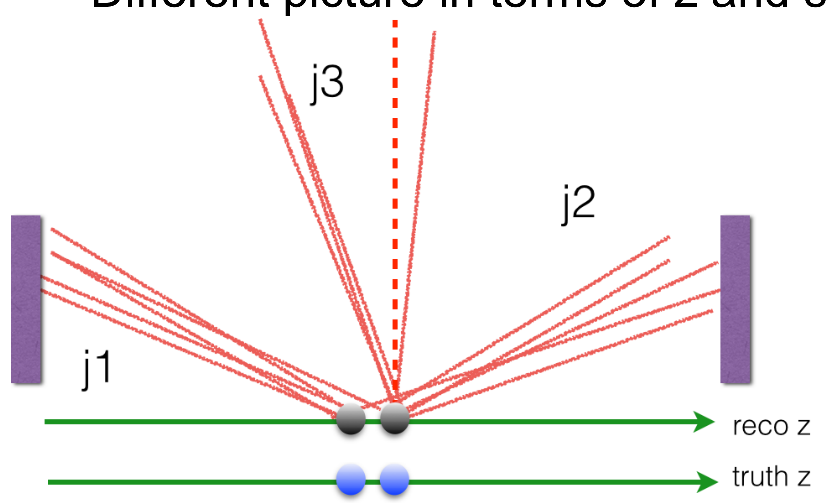
One of the goals would be to use this information to discriminate the HS vertex from pile-up → Non-trivial problem

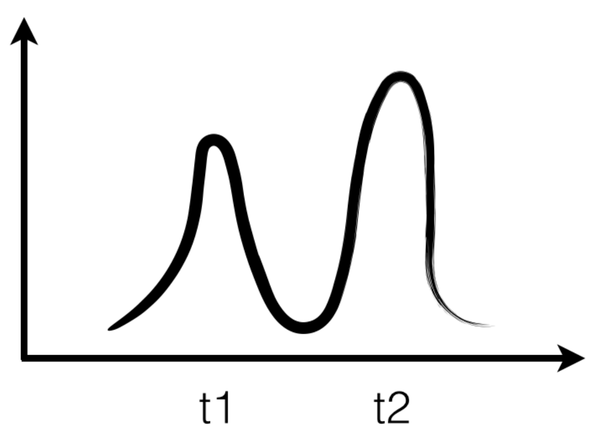




How do we know which jet is associated to a certain time? Which of the two is a HS jet? Track-only info may not be enough

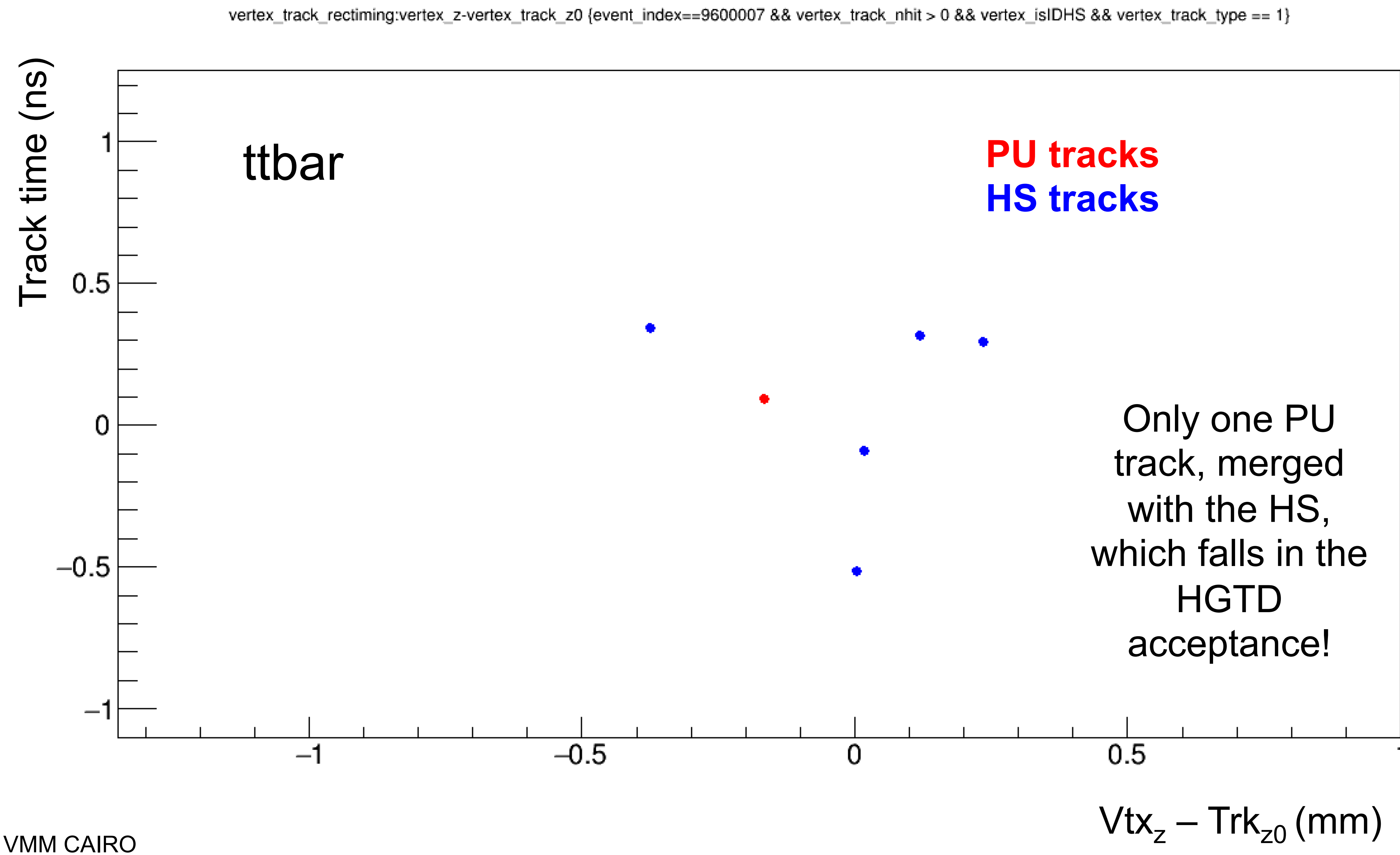
Different picture in terms of z and similar picture in terms of time





If the resolution is good enough to reconstruct two separate vertices, the info on vertex$_z$ helps

HGTD acceptances



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VMM CAIRO

Observation

- Tracks have been decorated with a timing information and, at the analysis level, they can be clustered to get a time associated to the vertex
  - Track selection, clustering, etc can still be optimised
- How to actually use the vertex time is the real challenge!
  - Many different scenarios
    - Time to step back before moving on
    - Need to understand how relevant the various cases are, i.e. how frequent is a certain signature in a certain physics process? Thus, which aspect of the problem gets high priority/attention?
  - Will tackle this in the next months!

New challenge ?

Deeper understanding of how (forward) PU impacts physics final states and how to use HGTD (global vs local t_0)

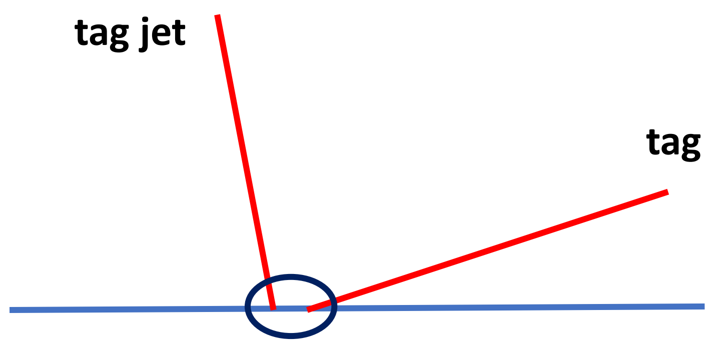
Detector performance → Physics objects performance → Physics

Re-evaluate smearing functions with the new reconstructed chain and detector performance algorithms

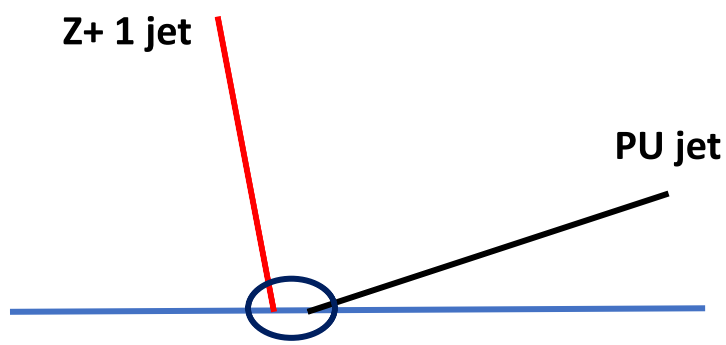
VBF/VBS (pileup suppression)
tH (b-tagging)
Weak mixing angle (lepton isolation)

VBF (H> $\tau\tau$) event topology

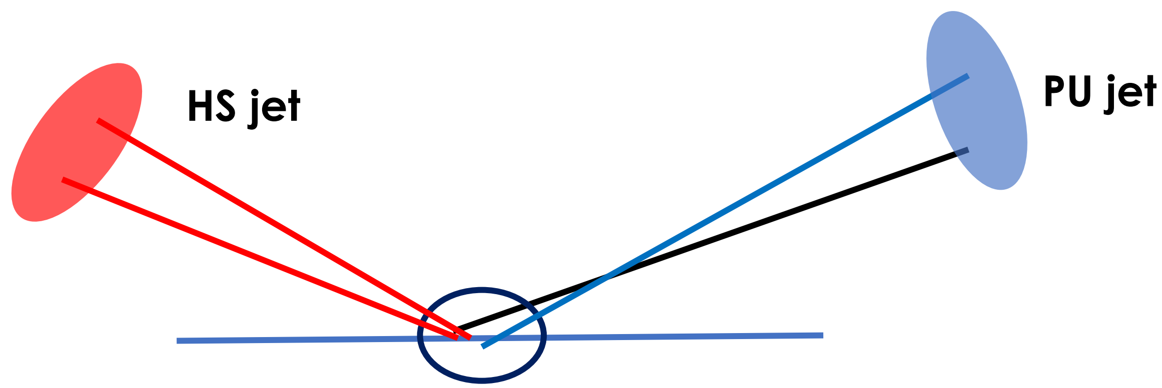
- **Signal**:
  - 2 tag jets with large invariant mass



- **Background:**
  - Z+2 jets with large invariant mass:
    - very low rate
    - Z+1jet + forward PU becomes an important background



Example 1



- HGTD can require time coincidence between jets:
  - Independent determination of jet times
  - No need for global t_0

Small fraction of background events with 2 forward jets

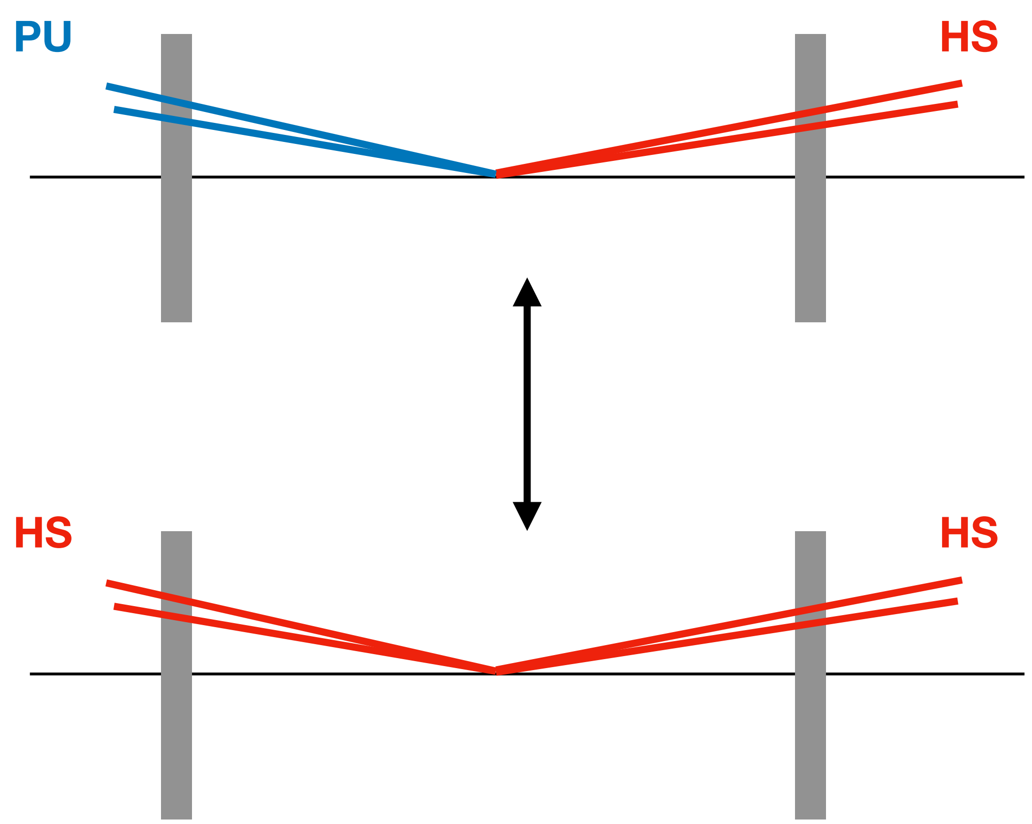
2 forward jets within HGTD acceptance
VBF background event

Event level pile-up suppression studies

simple approach to separate HS/HS events from HS/PU events

based on ***leading*** ghost associated tracks of jets that pass a $\Delta z(p_T, \eta)$ cut relative to the primary vertex

look for time difference between those tracks



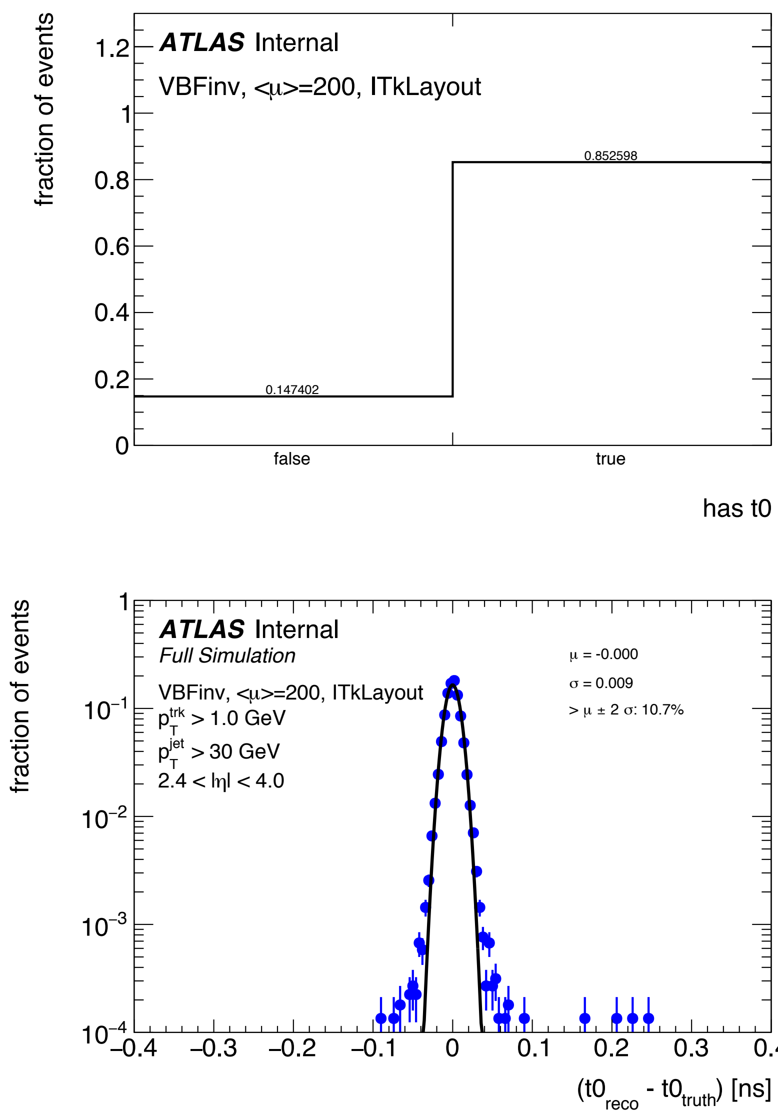
LArHits Simulation

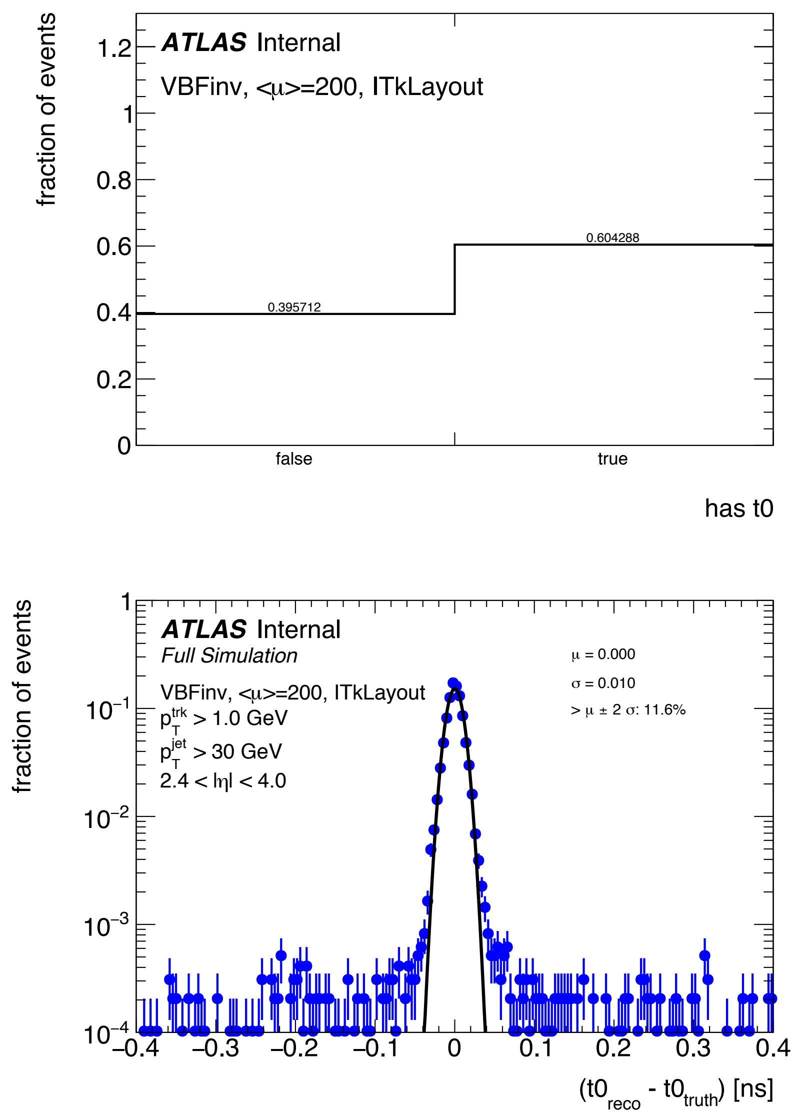
t0 (from jet) including 1 hit case

leading jet

subleading jet

accepting 1-hit track times improves the efficiency of the jet-time algorithm, while having only a small impact on the impurities





plot on top left:
fraction of leading jets in HGTD that give a t0

plot on top right:
fraction of subleading jets in HGTD that give a t0, if leading is not in HGTD

LArHits Simulation

why PU jets don’t contribute to t0

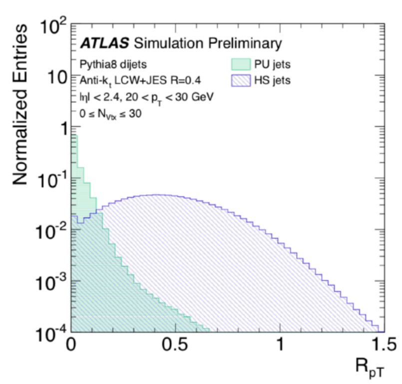
<u>only a very small fraction of the PU jets *has* a time associated</u> (~5%)

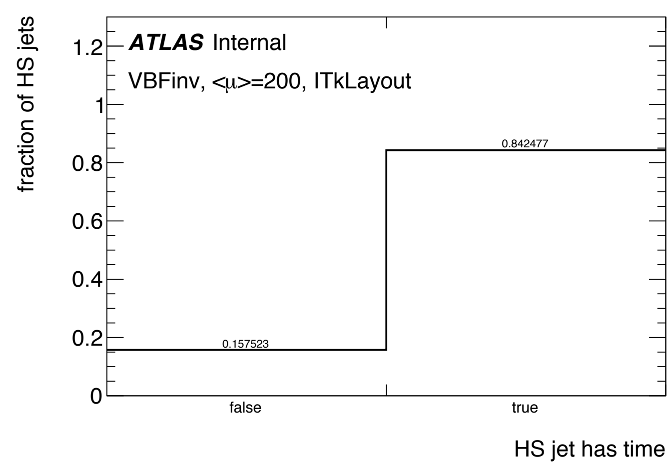
reason: the number of ghost associated tracks that **survive the Δz(pT, η) cut** is very low in PU jets

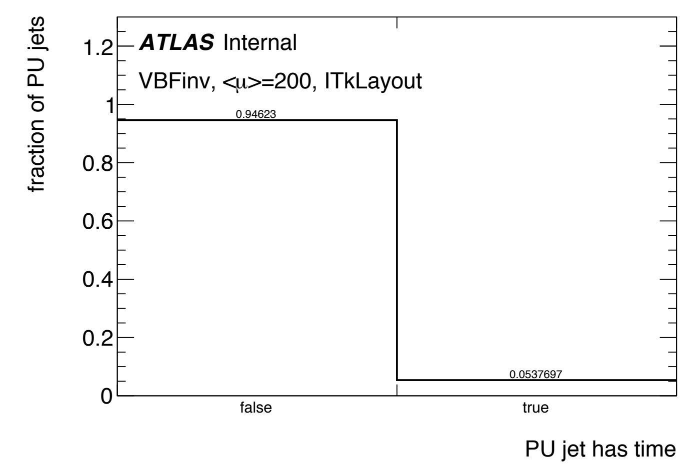
jet time reconstructed by clustering the accepted ghost associated tracks (=their times) and using the biggest cluster

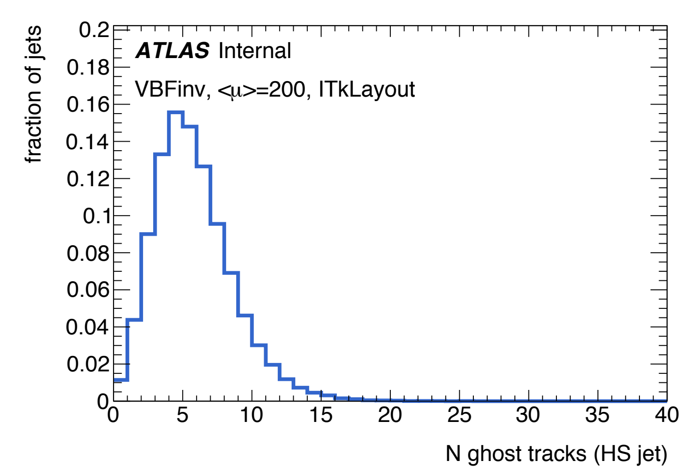
↠ comparing with RpT distribution, this makes sense!

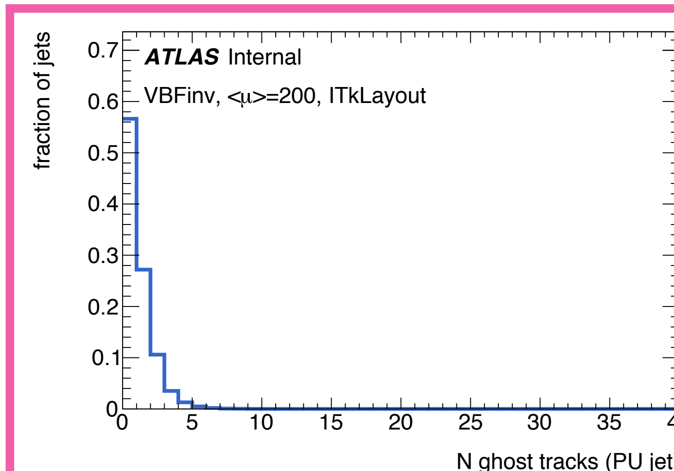
$$R_{pT} = \frac{\sum_k p_{T,k}^{track}(PV_0)}{p_T^{jet}}$$











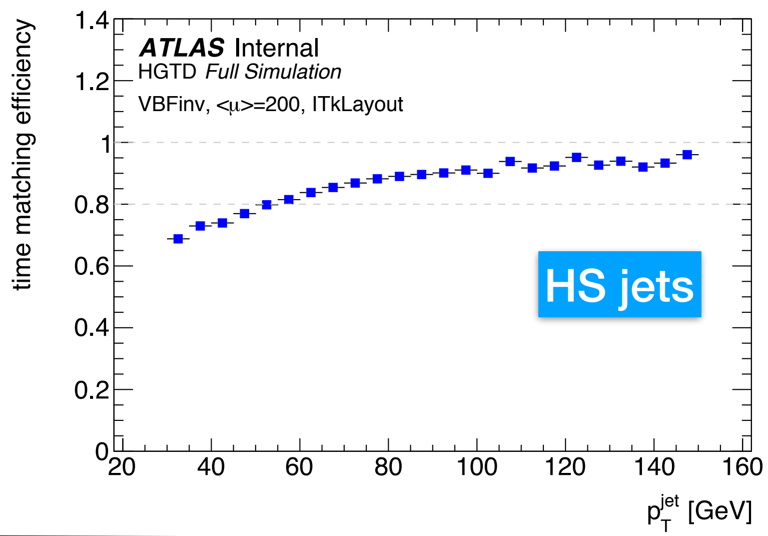
LArHits Simulation

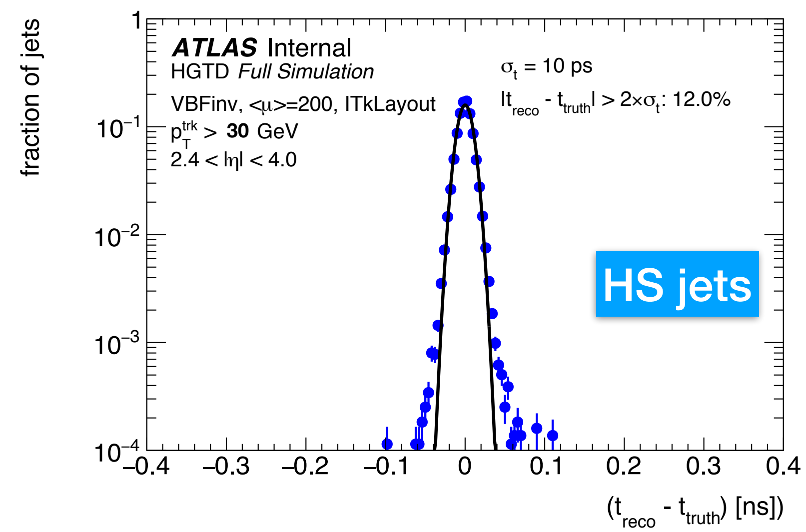
Jet-time reco. performance

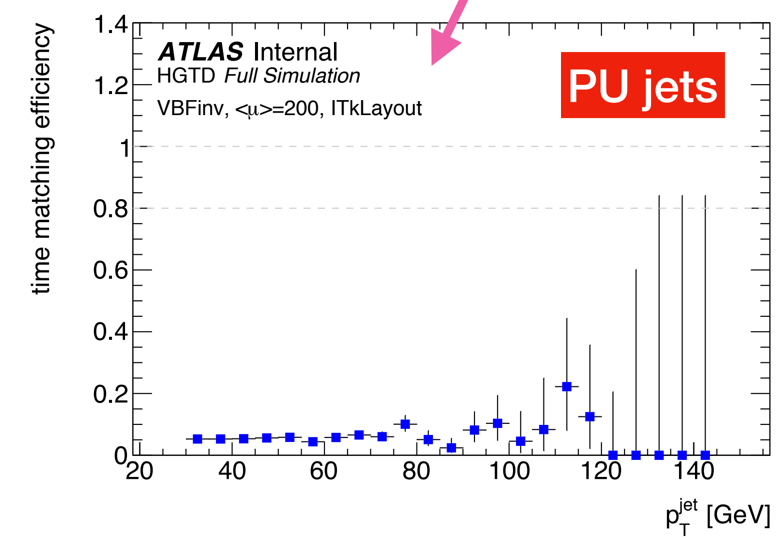
Which of the jet-associated tracks should one use?
- removing ghost tracks that can't be associated to the PV, only ~5% of PU jets get a time assigned
- using all ghost tracks, higher impurities on the jet time is seen

low efficiency, because # ghost assoc tracks that pass the Δz cut is very small

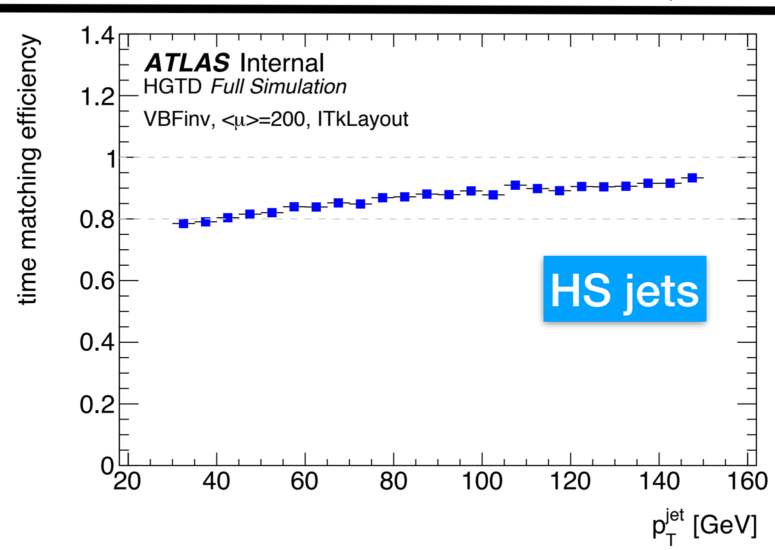
pass $z<\Delta(\eta,p_T)$

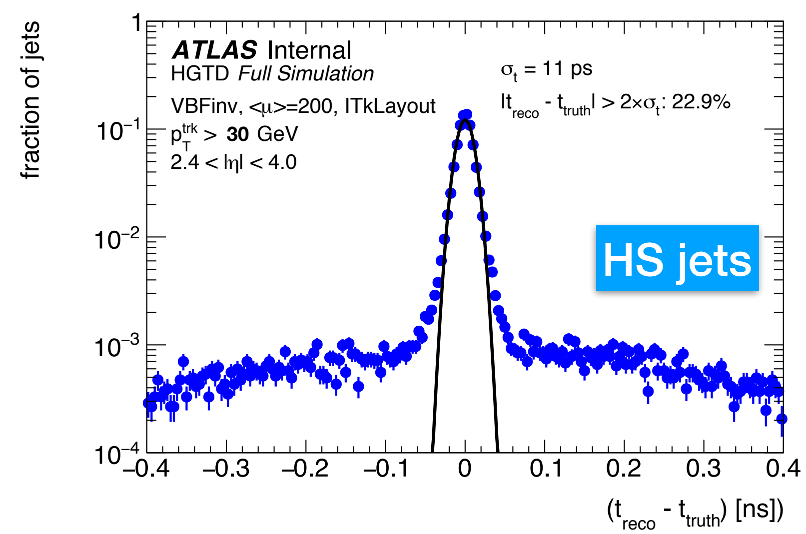


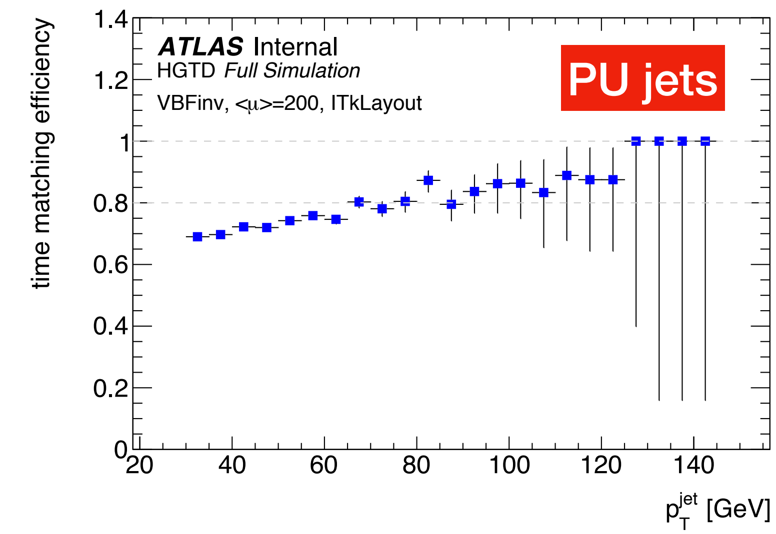




all ghost tracks



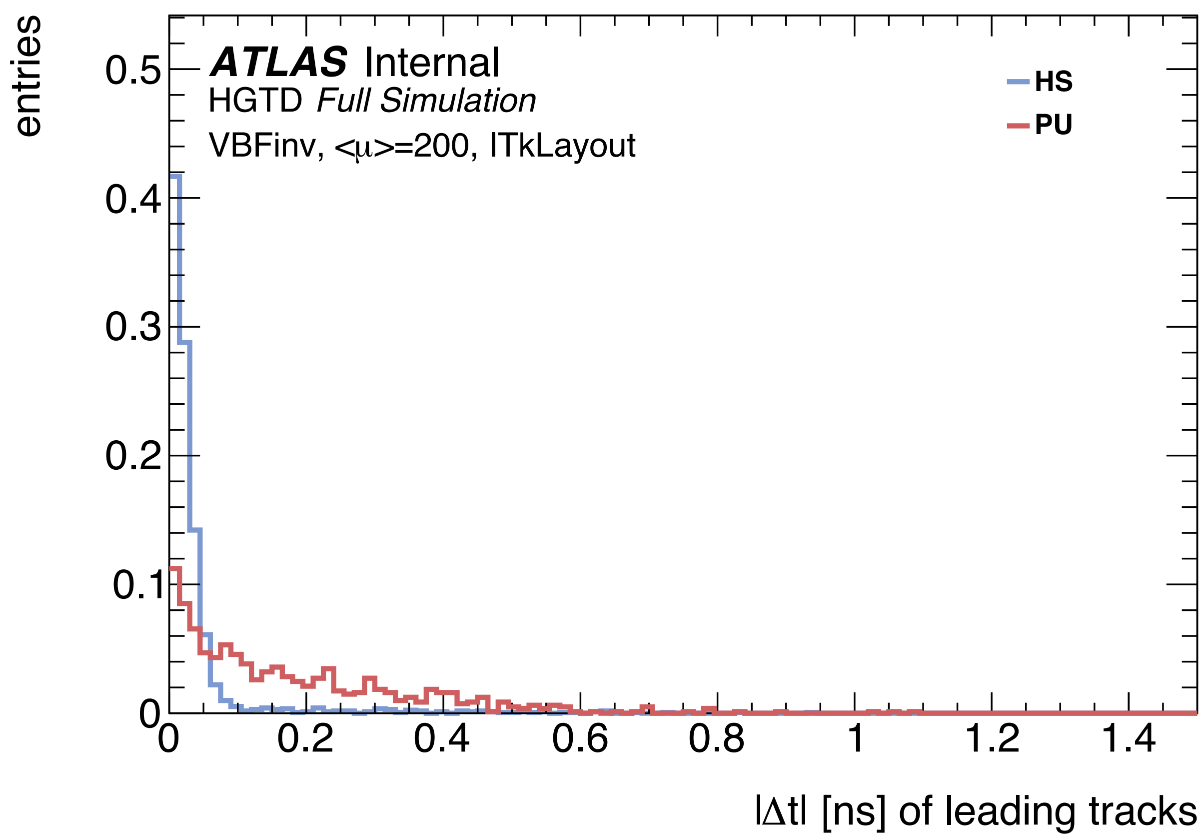


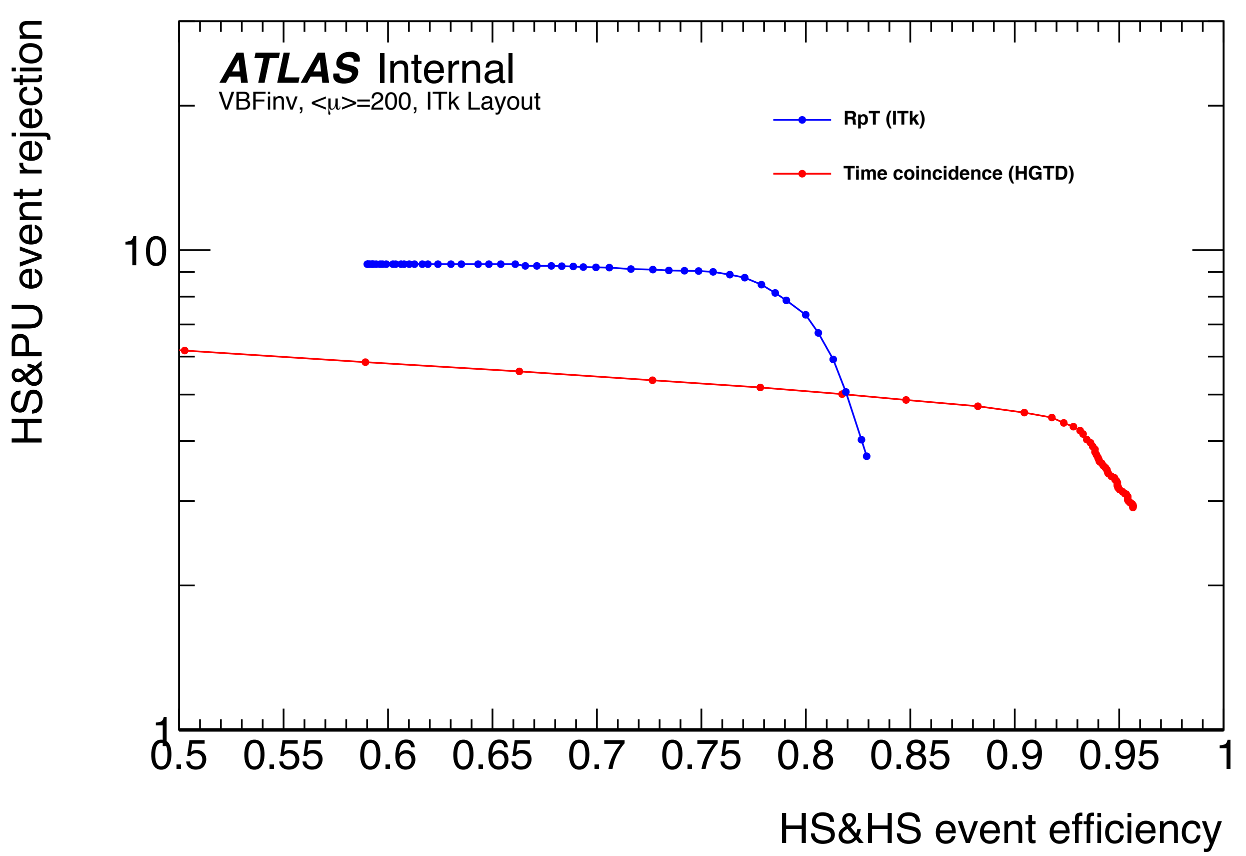


Performance

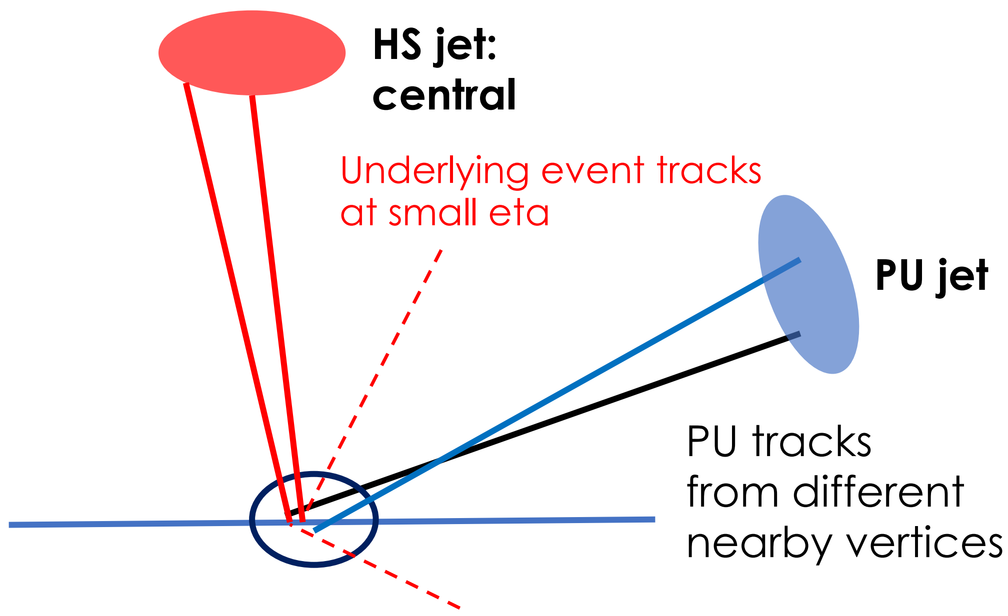
- select events (VBF mu200 sample) with 2 back-to-back jets, both in HGTD acceptance
- get time of leading track in each jet
- if Δt<cut, accept event as HS/HS, else reject as HS/PU
- *if either of the two leading tracks has no time assigned, event is accepted*

➡ compared performance (ROC curve) to RPT approach





Example 2a



1 forward jets within HGTD acceptance
VBF background event

- Global t_0 required to associate forward jet tracks to HS vertex time
  - challenging if HS activity is mostly central
- **Self-tagging approach**: HGTD can require time coincidence between tracks within the forward jet:
  - No need for global t_0
  - Reduced applicability: stochastic PU jets only

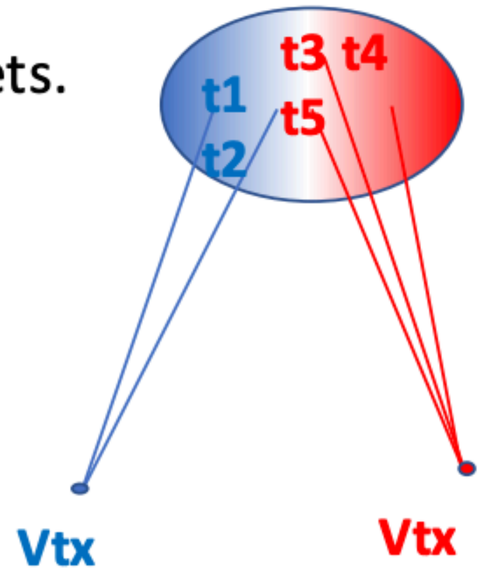
Self-tagging idea

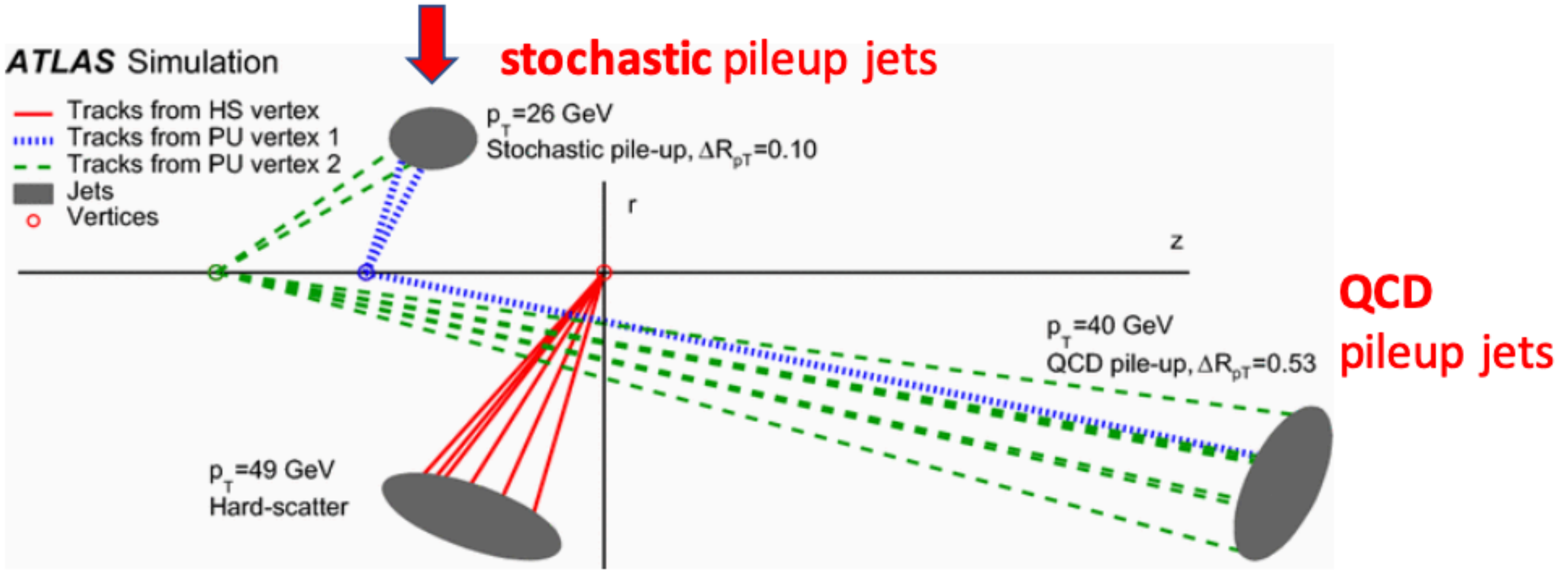
Self-tagging of pileup jets

- Idea borrowed by the b-tagging.
- Split tracks in jets based on reconstructed time into 2 (or more) subjets.

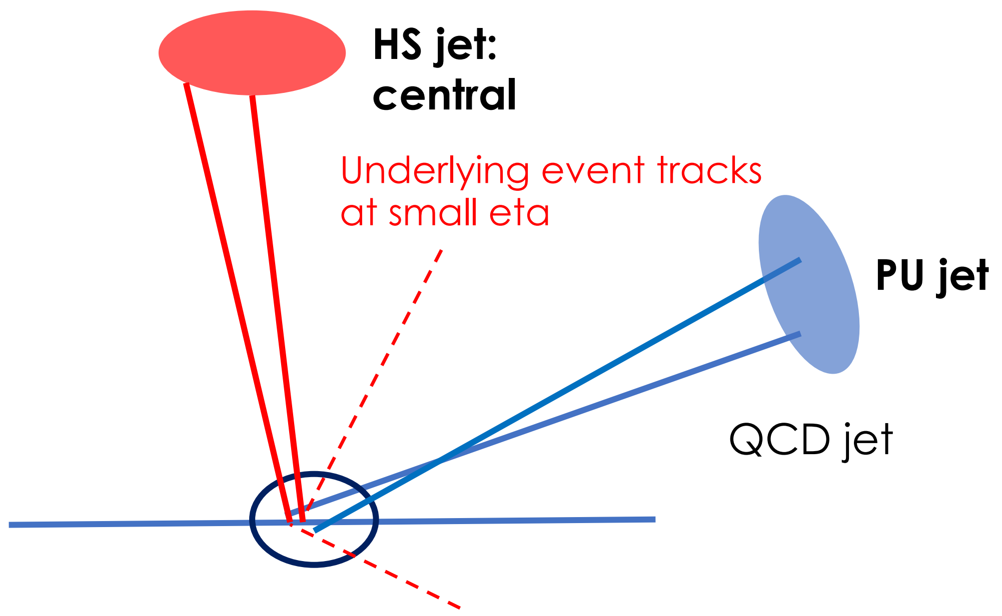
- If the computed times of the subjets are not consistent the jet is a **stochastic** pileup jets and can be rejected

- The method don't need the t0 determination
- It can reject only stochastic pileup jets not QCD pileup jets
  - QCD jets have tracks with consistent times
  - Other methods needed for them (fJVT?)





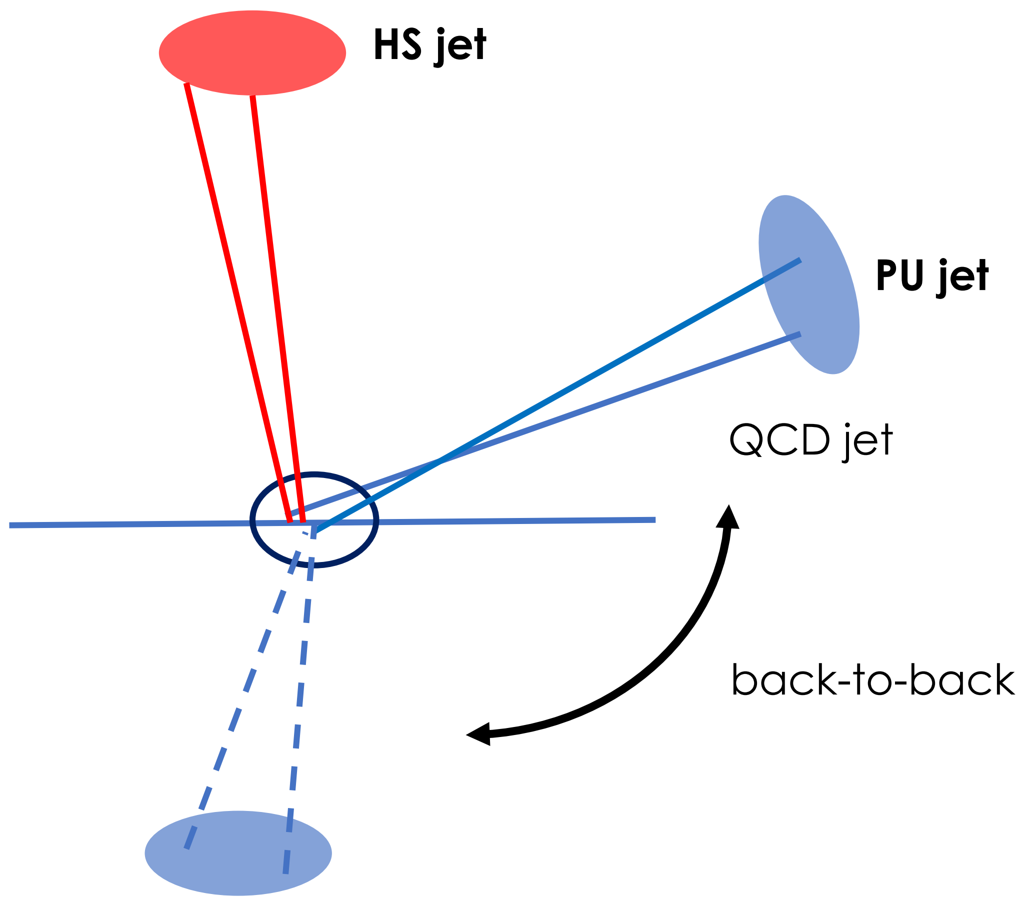
Example 2b



1 forward jets within HGTD acceptance
VBF background event

- <u>Global t_0 required</u> to associate forward jet tracks to HS vertex time
  - challenging if HS activity is mostly central
- Self-tagging approach not applicable

Example 2b (fJVT)



- Global t_0 required to associate forward jet tracks to HS vertex time
  - challenging if HS activity is mostly central
- Self-tagging approach not applicable
- Note that fJVT may work well in this case! → Needs to be studied!

Physics analysis under discussion

Physics (I)

HGTD can reduce the impact of (forward) pileup on physics analyses at various levels depending on the physics objects and the reliance on global t_0:

- **Physics analysis with forward leptons are well understood**
  - Weak mixing angle
- **Physics analysis with forward b-jets (tH)**
  - Need to establish the performance of the "self-tagging" approach, and continue to develop global t_0 reconstruction algorithms (Chiara, Alex, Valentina, Nora, Sabrina)
  - Need to understand the impact of b-tagging performance (light-jet rejection) and how it is impacted with pileup (truth-level study) (Spyros)

Physics analysis under discussion II

Physics (II)

- HGTD can reduce the impact of (forward) pileup on physics analyses at various levels depending on the physics objects and the reliance on global t_0:

- **VBF/VBS**:
  - Better understanding of contribution of stochastic/QCD PU jets, and establish self-tagging PU suppression (Marianna)
  - Need improved, truth-level, understanding of the impact of forward pileup in analysis sensitivity (physics upgrade group, Simone, Corinne, Ben, Pilar, …)
- **Luminosity**
  - Key in Higgs precision measurements. HGTD can provide high precision, independent, offline luminosity, as well as bunch-by-bunch online luminosity. Address extremely useful comments from luminosity experts
- **Long lived particles:**
  - Need to study impact of acceptance, use of timing information, and complementarity with ITk.

Road map

Summary/Plan

- **Physics and performance plan towards the TDR consists of three main components, which will be pursued in parallel**

1. **Detector performance**
   - Integration of HGTD simulation with ITk in R20.20.X: **track-assignment algorithm**
   - Fix scenarios: material, radiation, time resolution.
   - t_0 reconstruction algorithms
   - vertexing + underlying event t_0 reconstruction
   - Deliverable: assign times to tracks and vertices in AOD
     - Completely based on full simulation and using the more performance algorithms
   - Jointly with tracking and physics upgrade group

Road map

Summary/Plan

- **Physics and performance plan towards the TDR consists of three main components, which will be pursued in parallel**

2. **Performance**
    - Use AOD time information as input
        - No parameterizations
    - Study impact of t_0 reconstruction on PU jet suppression and b-tagging
    - Establish self-tagging approach for b-tagging and pileup jet suppression
    - Develop new smearing functions
    - Jointly with physics upgrade group

Road map

Summary/Plan

- **Physics and performance plan towards the TDR consists of three main components, which will be pursued in parallel**

3. **Physics studies**
    - Deeper understanding of impact of PU in VBF/VBS analysis, and b-tagging in tH
    - What final states require global t_0, what self-tagging? Develop optimized strategy to apply HGTD in physics and feedback into performance algorithms (smearing functions)
    - Application of smearing functions as a next step
    - Jointly with physics upgrade group

The challenges towards TDR

HGTD Performance/Physics: TDR Timing Issue

Ariel Schwartzman, Dirk Zerwas
SLAC, LAL
April 10, 2019

Common Issues:
- Svn stopped
- afs stopped
- 20.20. has OS dependence

Every delay is problematic

End 2019:
- Tighter schedule
- Closer to svn stop (in case new analysis is requested by LHCC)

April 2020:
- Less tight schedule
- Longer after svn stop (in case new analysis is requested by LHCC)

Total balance: April 2020 preferred slightly
- A bit more time in April 2020
- LHCC review N months, so 3 months more post svn stop compared to total is negligeable

Backup

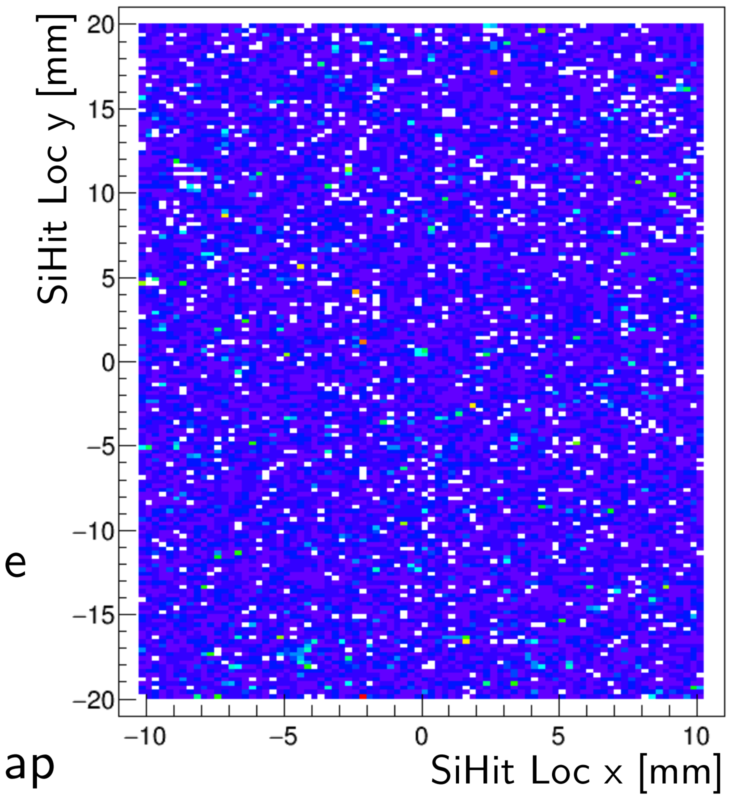
Digitization → From SiHits to RDOs

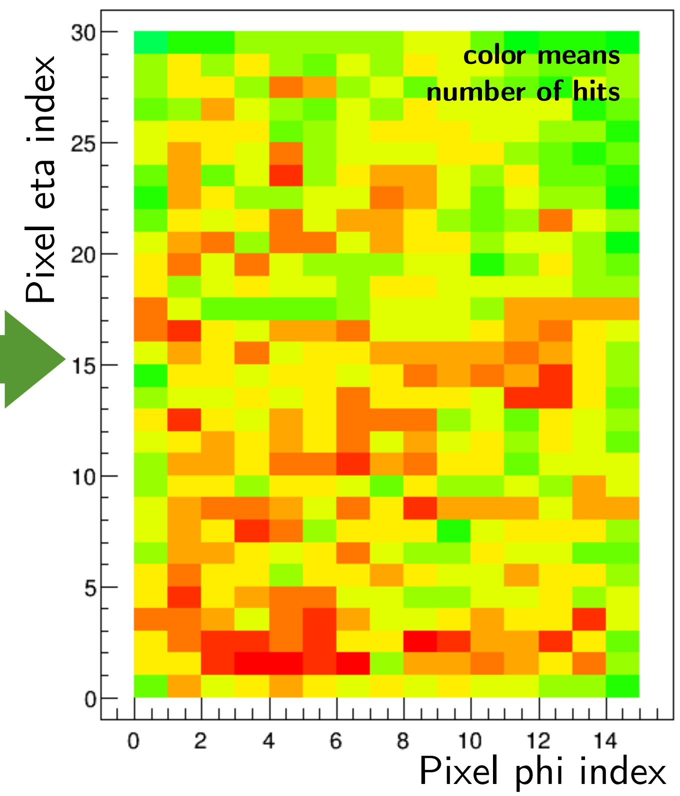
- A diode map is associated to the detector element and is used to translate the charge deposited in the active area to fired pixel
  - Using the same PixelDigitizationTool as defined for the pixel endcap modules
  - Lorentz angle is set to 0.

- LGAD sensor (20.5×40 mm^2)
  - 1.3×1.3mm^2 pixels → 15x30 pixels
  - Active: 50 µm

- During digitization, the time information is carried on only for the first hit on each diode → shadowing effect :(

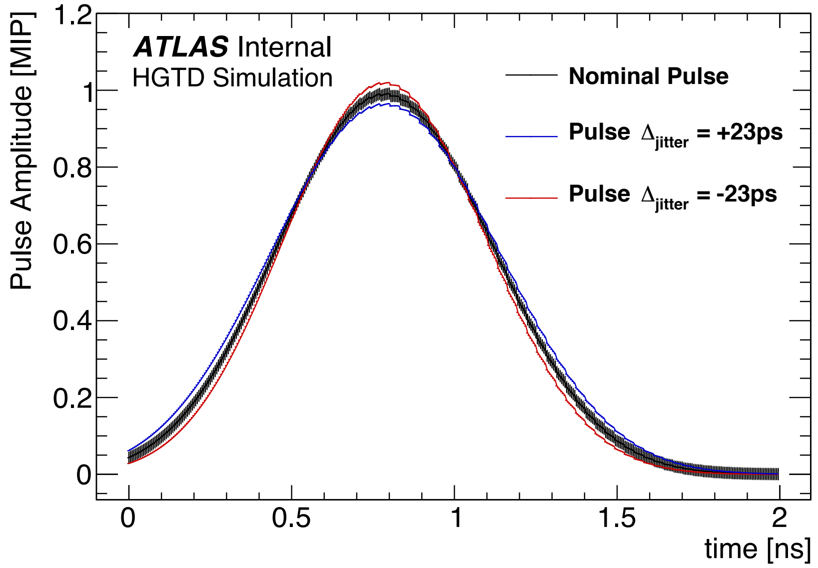
Technically, time is stored instead of the charge in the charge deposits in the SDO map

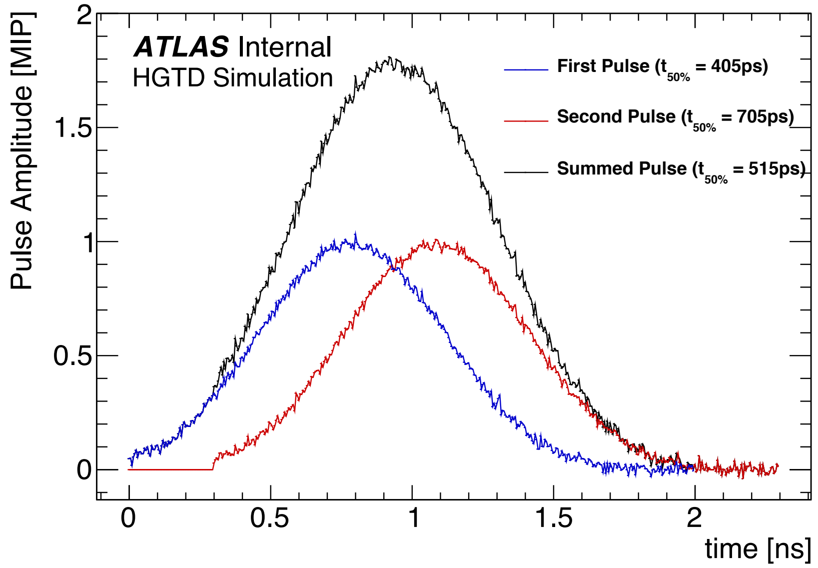




LArHit simulation emulator

The simulation provides the energy deposit in the sensitive layer of the HGTD as single energy deposit for each particle traversing it. The simulation of the non-uniform distribution of the charges in the sensitive volume as well as the effect of the electronics chain (time walk, jitter) are taken into accçount at analysis level. For each hit a pulse is simulated to compute the time and energy in each pad. Data derived from the 2016 HGTD test beam were used to derive the pulse shape. A convolution of a Gaussian with a Landau distribution was found to give the best description of the pulse shape. The non-uniform energy deposit is modeled via the width of the Gaussian. The signal time is defined on its leading edge, therefore the variation models adequately the induced timing uncertainty. Fig. 3.5 shows the nominal shape and the effect of two hits in the same pad, separated by 300 ps.



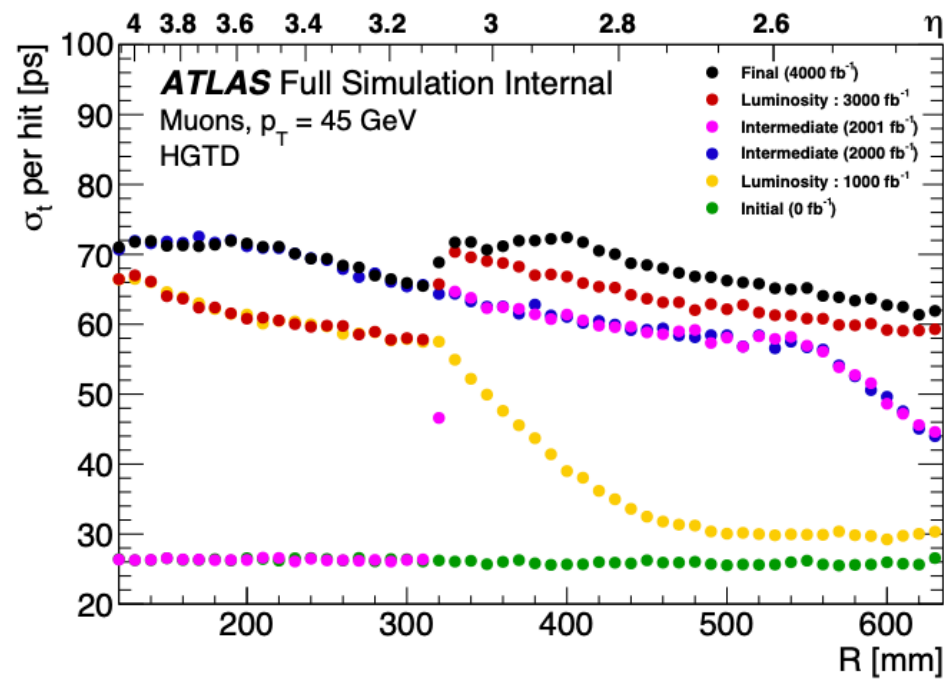


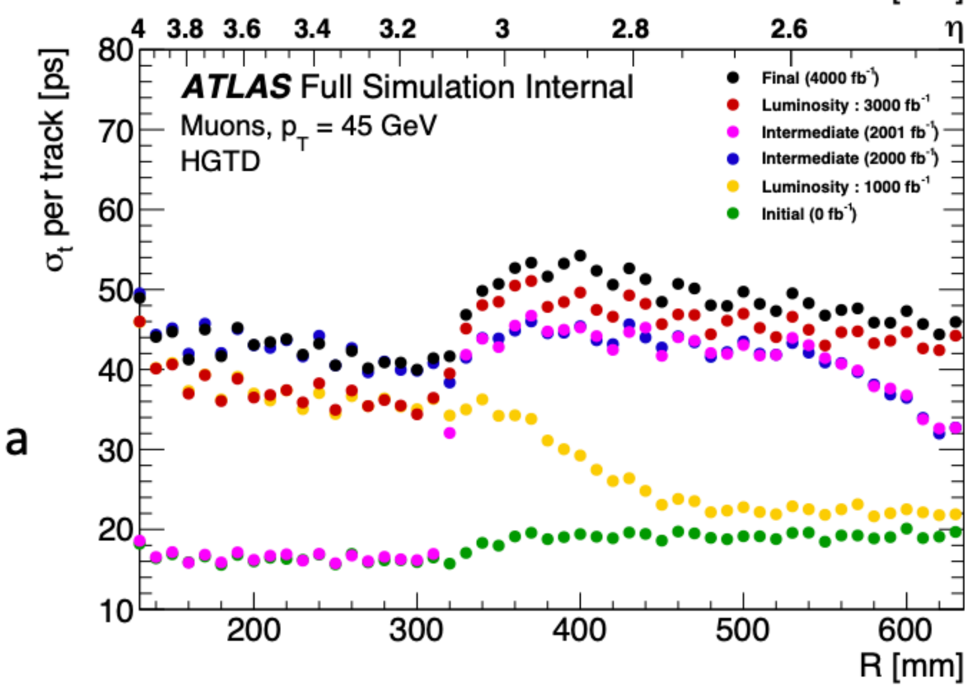
For each hit, a pulse is simulated with 200 points of a step size of 5 ps where the width of Gaussian contribution is driven by the desired timing resolution of the sensor. The maximal amplitude of the pulse is the deposited energy. The time corresponding to the first point of the pulse is chosen to be the time of the hit. Additionally a Gaussian noise with of 1.5% of the energy of a MIP (0.2 keV) is added to the amplitude in each time bin.

For each pad, the pulses are then summed together. A pseudo constant fraction discriminator (CFD) algorithm defines the time as the time of the first point with an energy above 50% of the maximum amplitude. Therefore the time of a pad is offset by 0.405 ns.

The contribution of electronic noise to the timing resolution is taken into account as a function of the position of the sensor and the accumulated integrated luminosity with a Gaussian smearing. The dose received by the sensor as a function of its radius was computed using FLUKA, then data from test bench measurements of sensors define the corresponding gain for the sensor. The gain is transformed into the timing resolution using measurements with ALTIROC0. This procedure results in a Gaussian smearing of minimum 10 ps and maximum 60 ps.

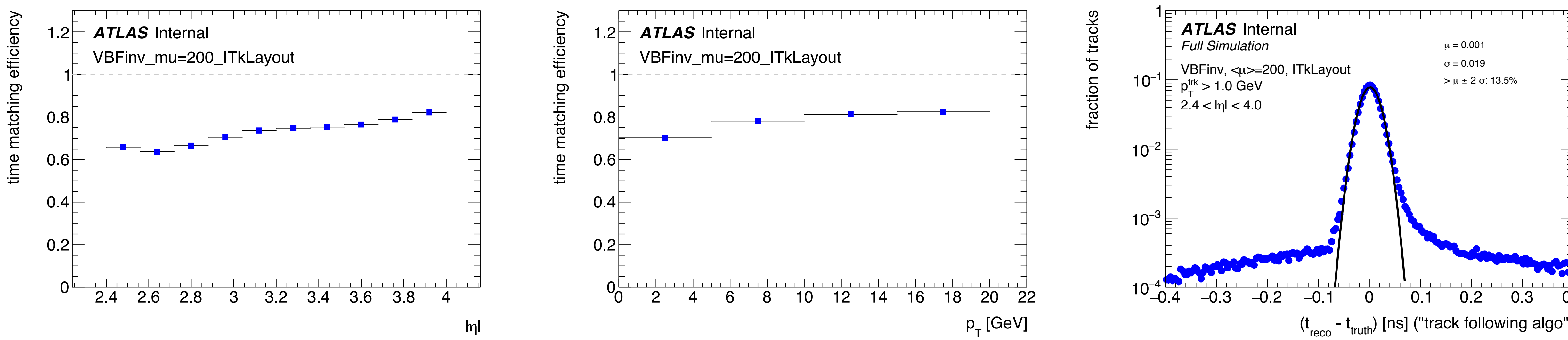
- The time resolution computed using <μ>=0 single muons samples
- Timing resolution per hit computed using the simulation (t_{hit}-t_{truth} for all hit)
- The time of a track is obtain by :
  - Taking in each layer the closest hits in a Δr<1.4mm
  - Correct the times of those hits using the TOF between (0,0,Z of the track) and the hits.
  - Averaging the times of all the associated hits
- For each point t_{reco}-t_{truth} is drawn and fitted with a gaussian
- Effect of the number of associated hits clearly visible



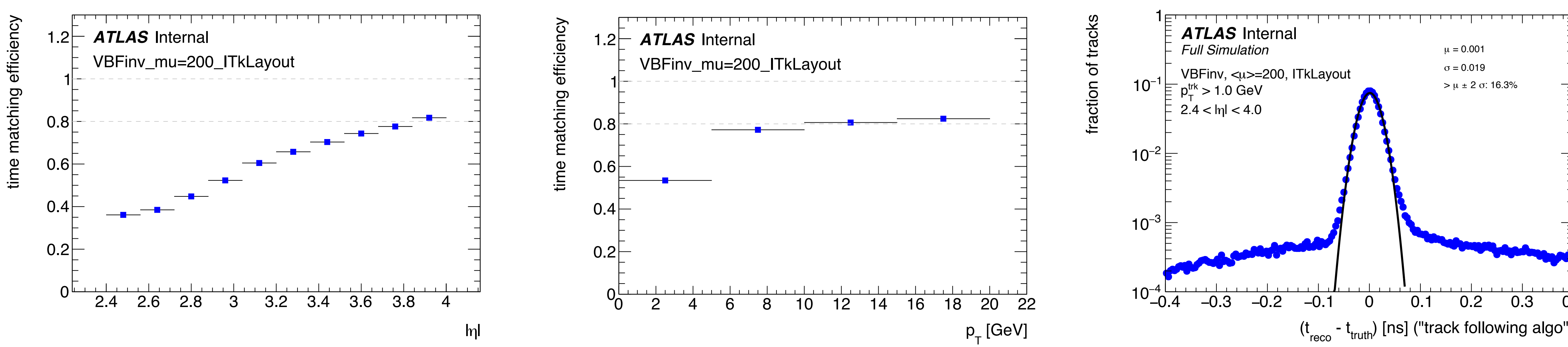


Comparison last-hit vs. perigee

extrapolation to HGTD from last hit on track

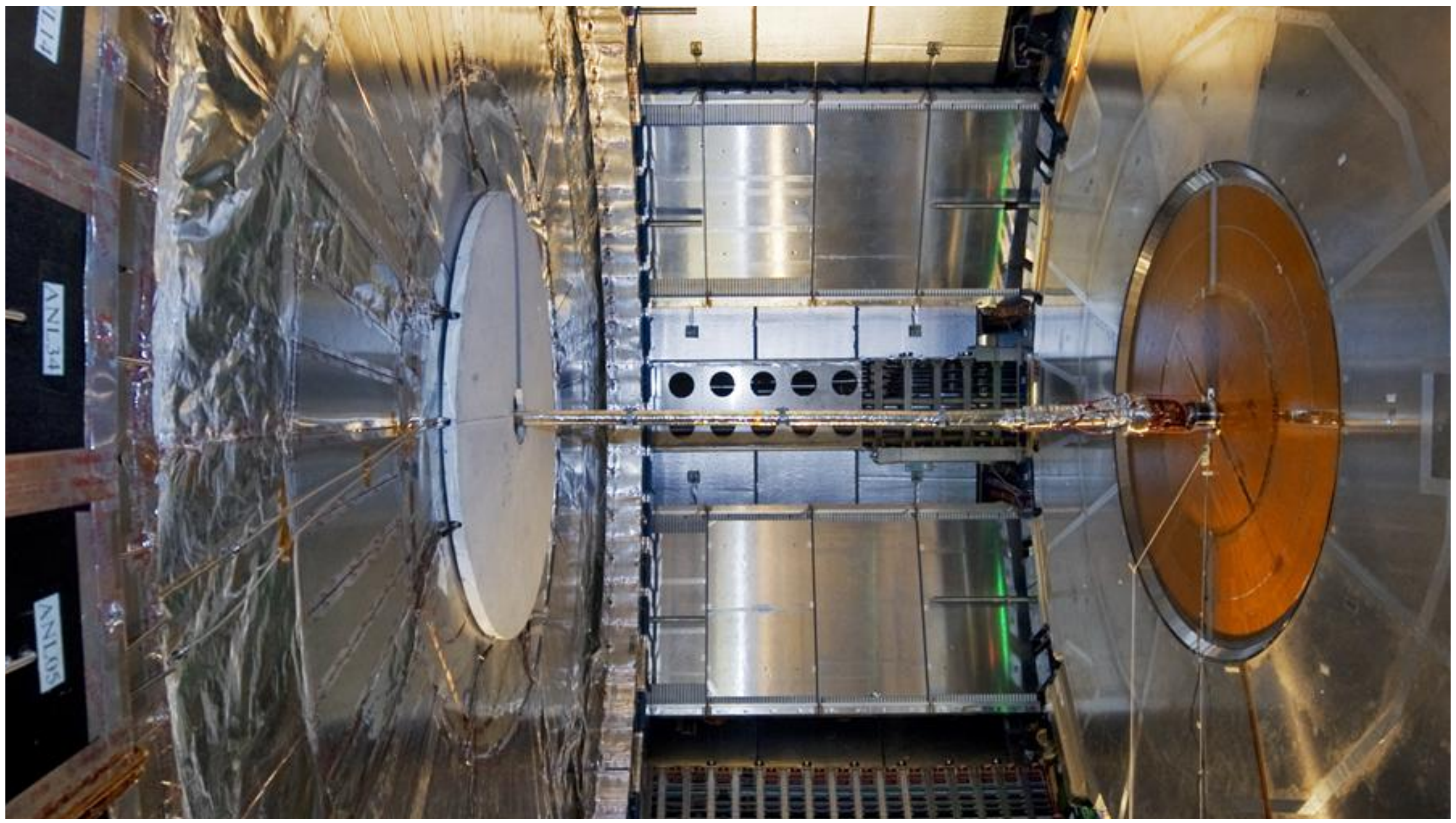


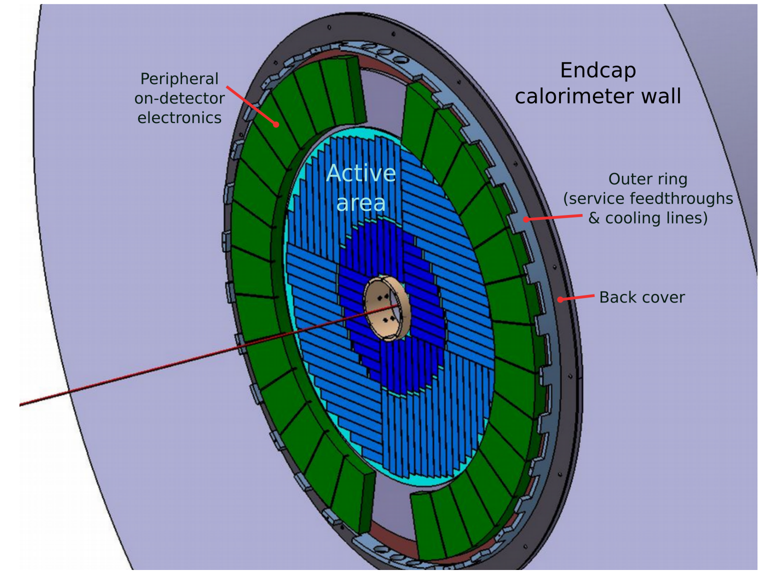
extrapolation to HGTD from perigee



HGTD layout

Design requirements: excellent time resolution, radiation-hard, low occupancy, modular shape given the quite constrained by the space available and the physics goal:





Pseudorapidity coverage	$2.4 < \|\eta\| < 4.0$
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:	
$2.4 < \|\eta\| < 3.1$	2
$3.1 < \|\eta\| < 4.0$	3
Pixel size	1.3×1.3 mm^2
Number of channels	3.54M
Active area	6.3 m^2

Technology and layout:

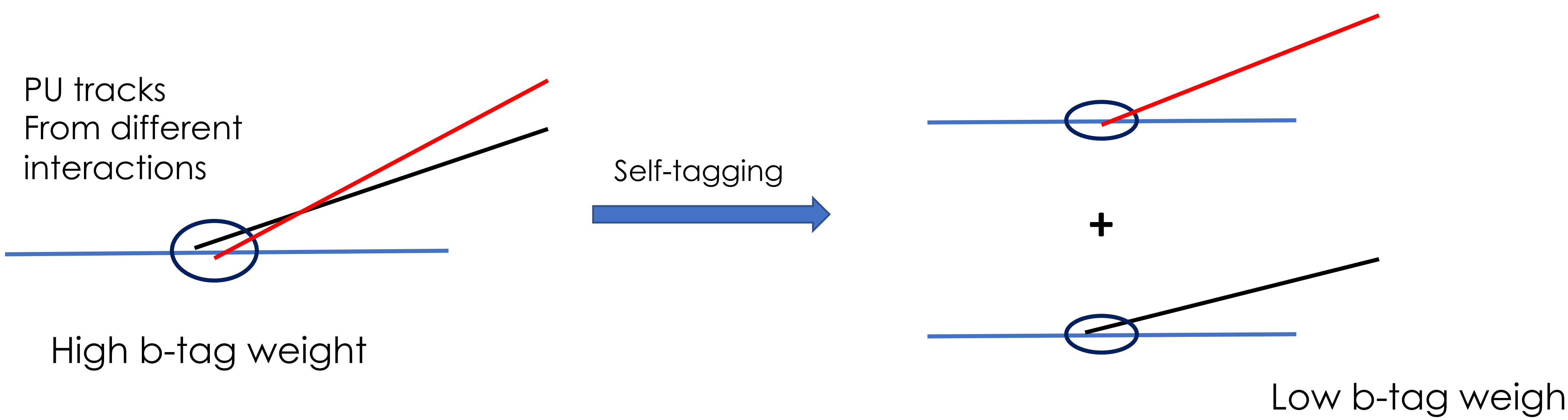
- **Low Gain Avalanche Detectors (LGADs):** pixel detector with coarse spatial resolution (→high granularity, **1.3x1.3 mm²** for occupancy < 10%) but precision timing (**30 ps**)
- 2 double-sided **planar layers** in each endcap (to optimise the number of hits per track)
- **overlapping sensors** for each layer (to deal with worsening time resolution after large irradiation to the small radius sensors overlap is much larger (80%) in the inner region.)
- specially-designed **ASIC ALTIROC** front-end (to reduce electronic noise of time resolution)

PU suppression
Missing ET
b-tagging
Lepton isolation

Consider main physics topologies and global/local t_0 information ("self-tagging")

Detector performance → Physics objects performance → Physics

Need to study and establish the self-tagging approach with full simulation



LArHits Simulation

Event displays for t0 determination

for the HS/PU case where one of the two jets is in the barrel region, an independent vertex time t0 determination is necessary

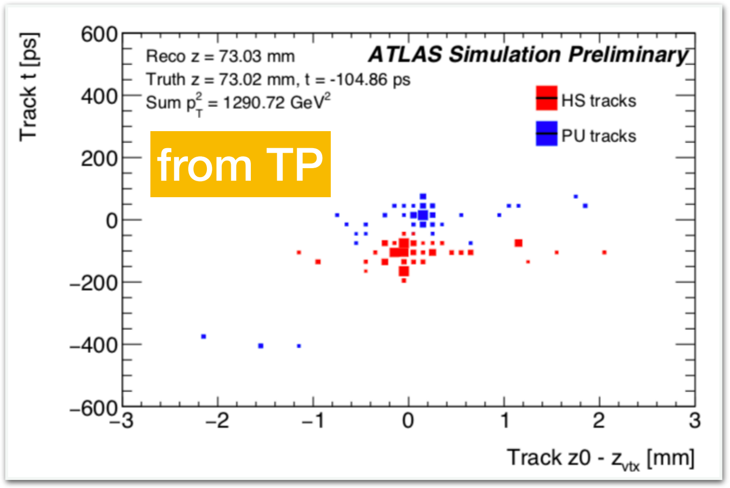
→ we don't want to compare the jet with itself

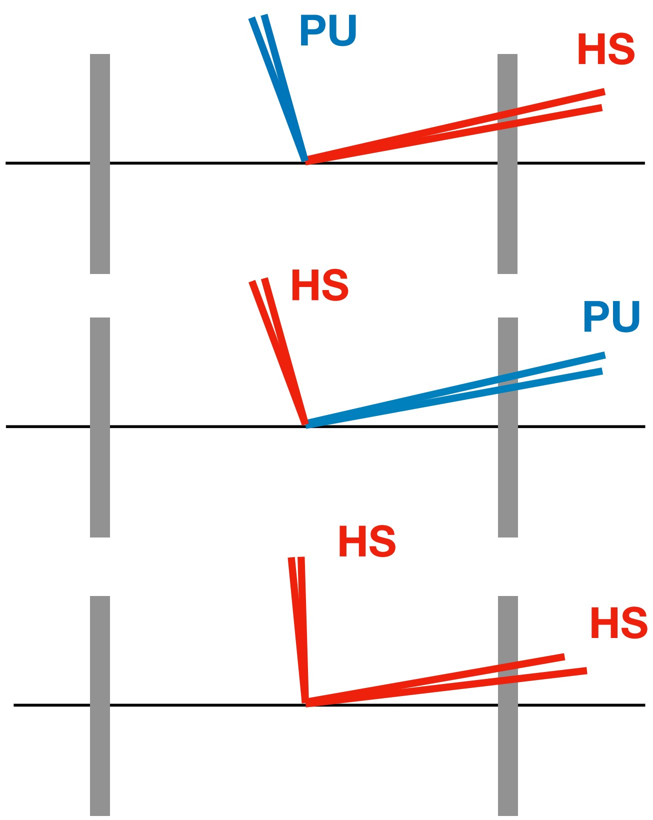
Sel. of events with 2 jets, 1barrel&1fwd

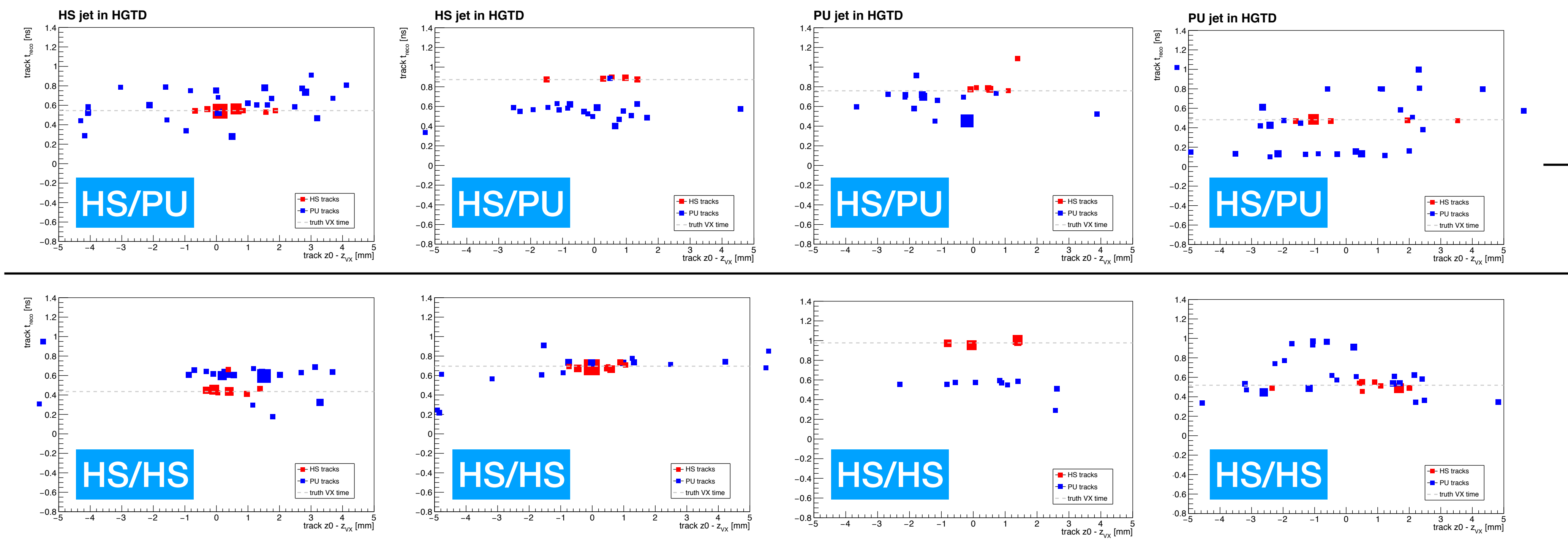
use tracks **outside of the jet**:

pT>1.0GeV, pass Δz(pT, η)

marker size ∝pT







☞ more plots here