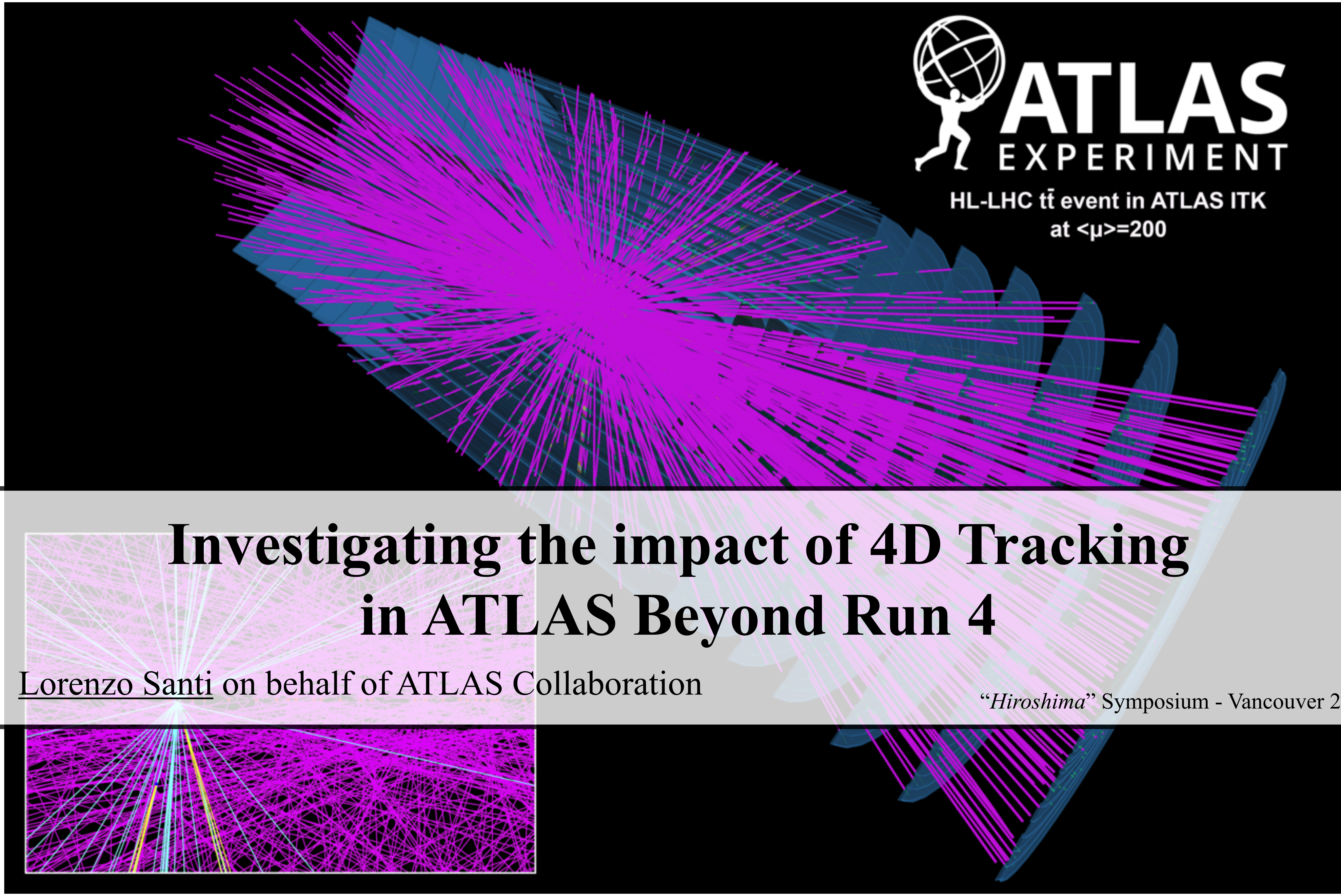


Investigating the impact of 4D Tracking in ATLAS Beyond Run 4

Lorenzo Santi on behalf of ATLAS Collaboration

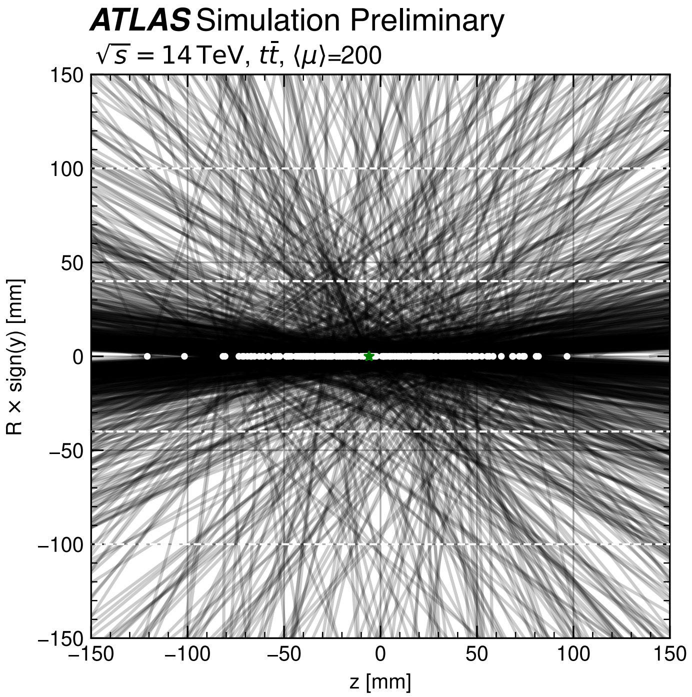
"Hiroshima" Symposium - Vancouver 2023

SAPIENZA UNIVERSITÀ DI ROMA

CERN

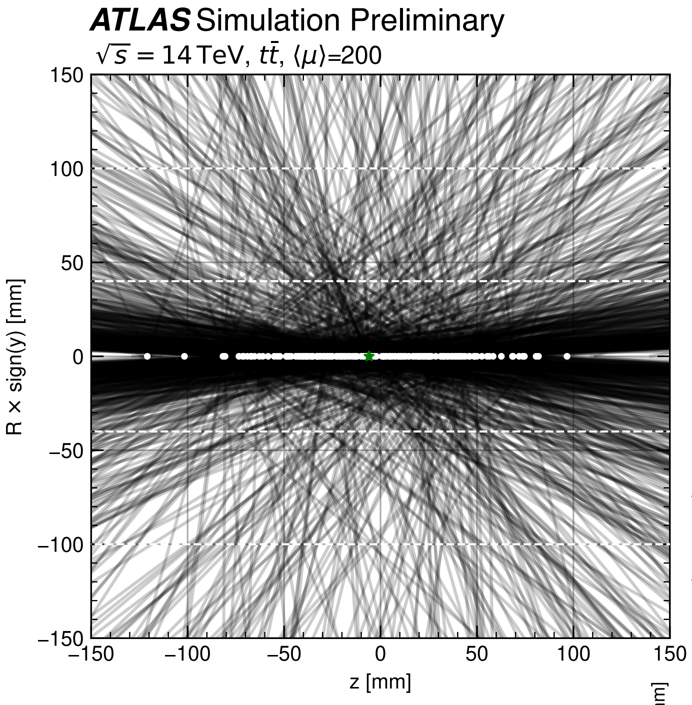
ATLAS EXPERIMENT

The Pile-Up Challenge

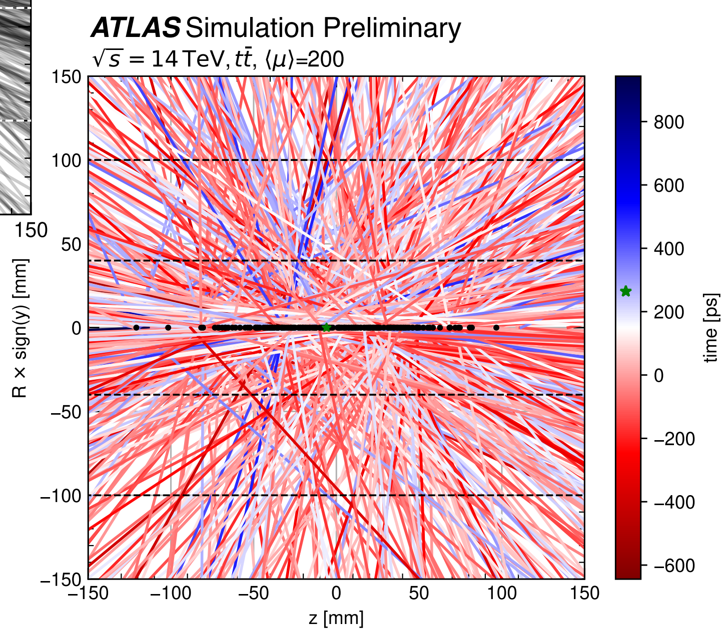


without time

The Pile-Up Challenge

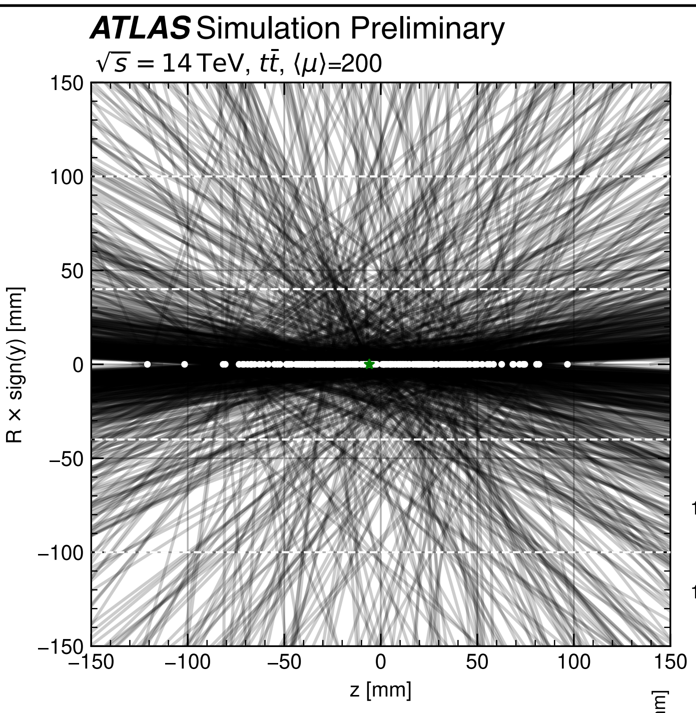


without time

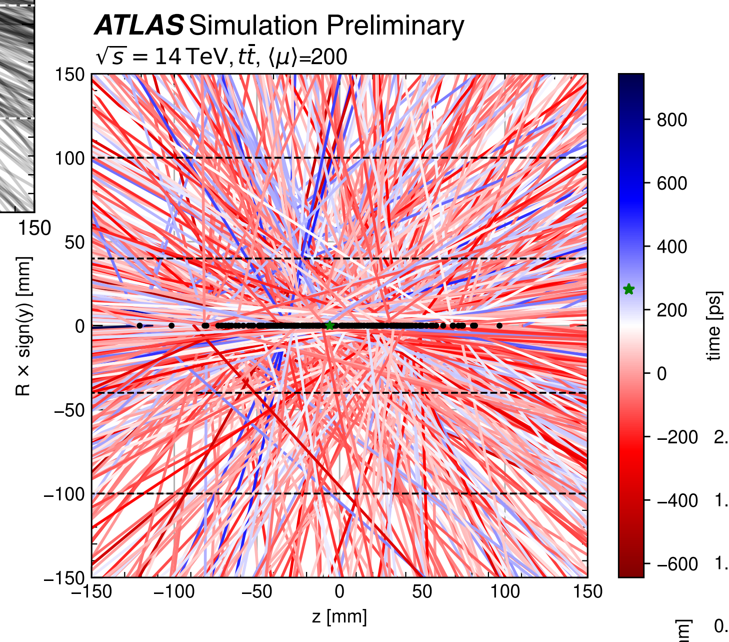


with time

The Pile-Up Challenge

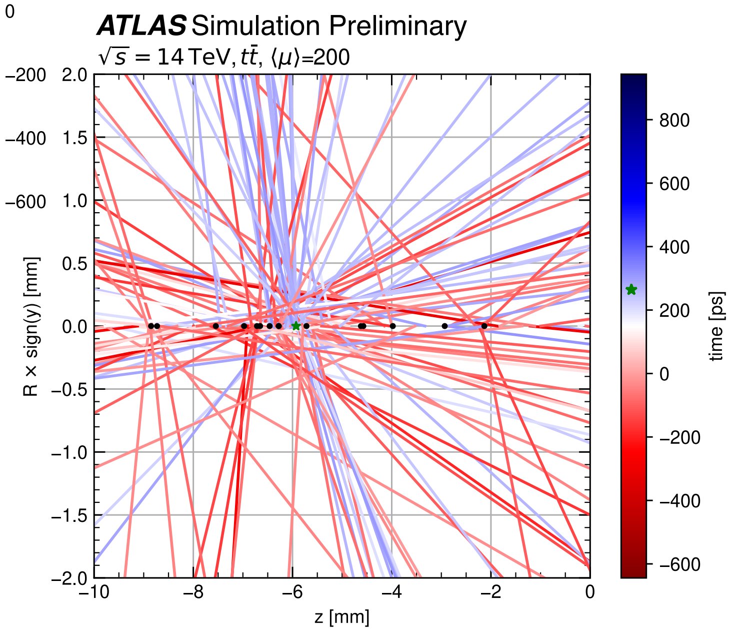


without time

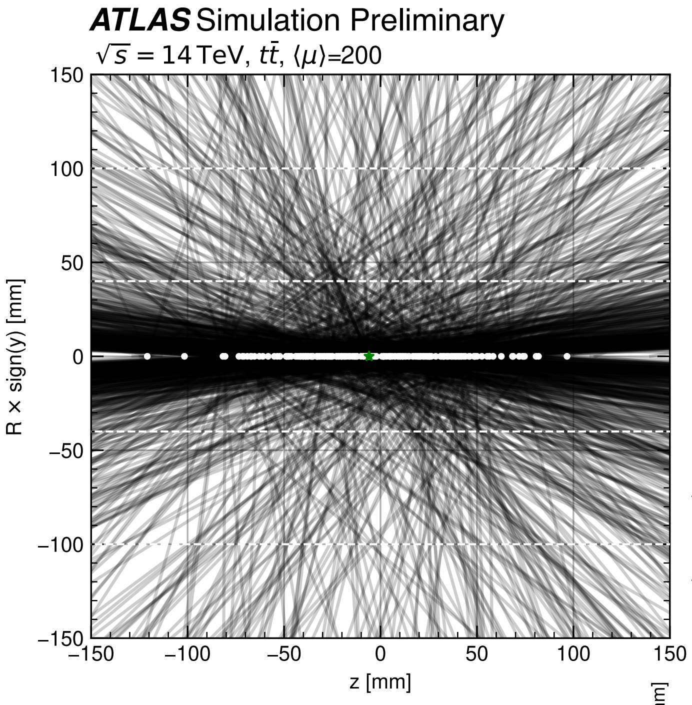


with time

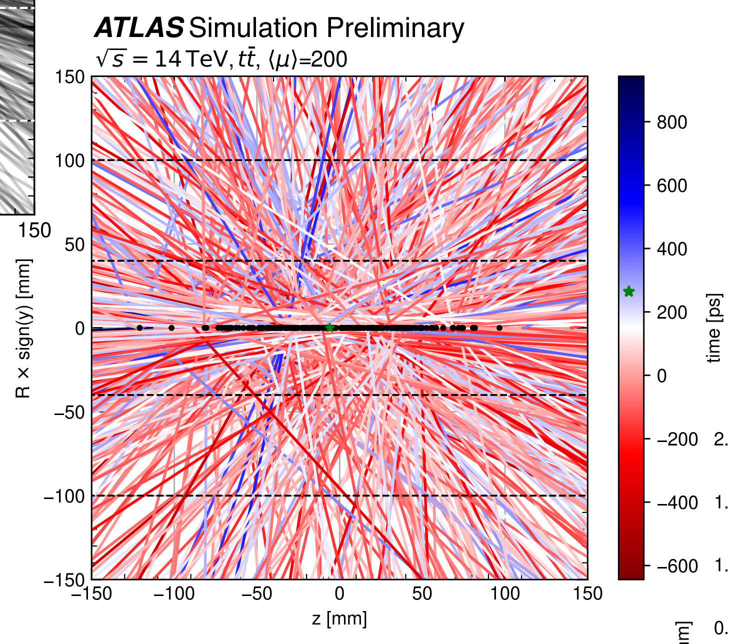
zoom in space



The Pile-Up Challenge

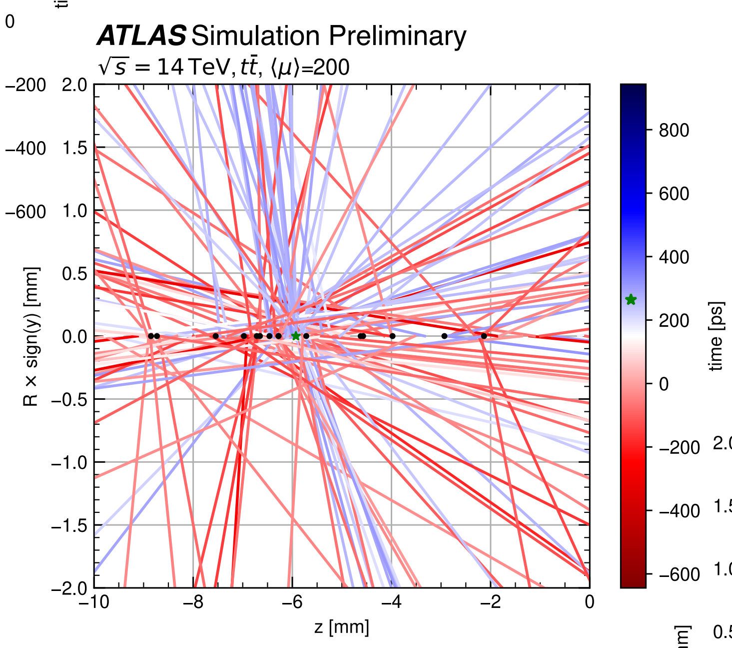


without time

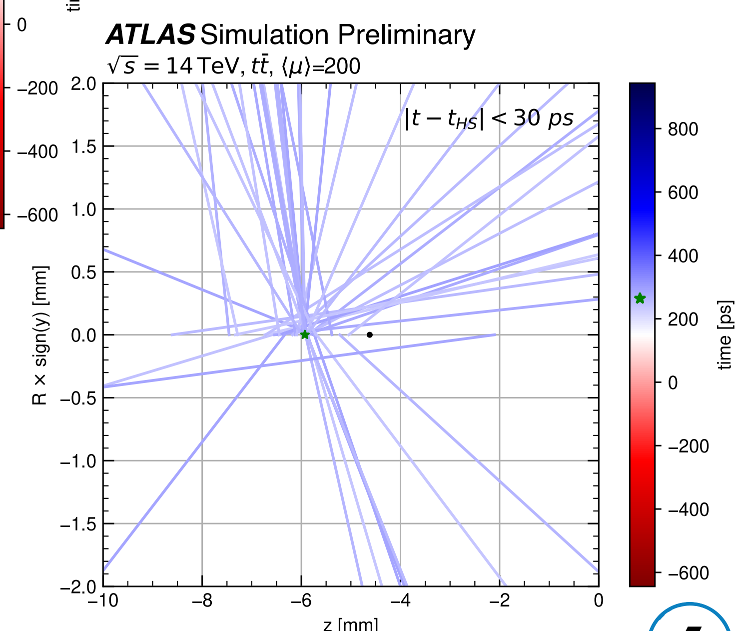


with time

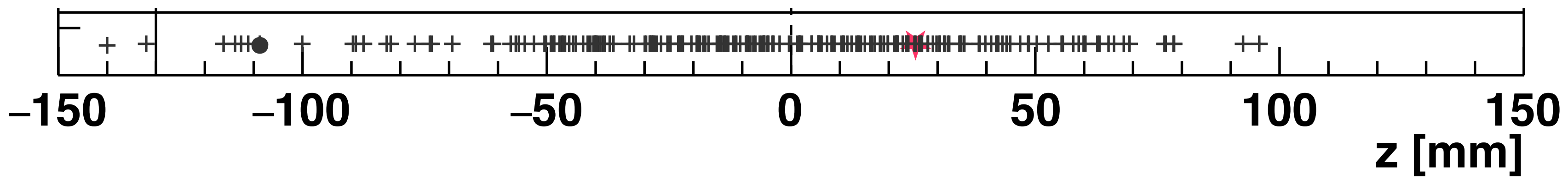
zoom in space



zoom in time



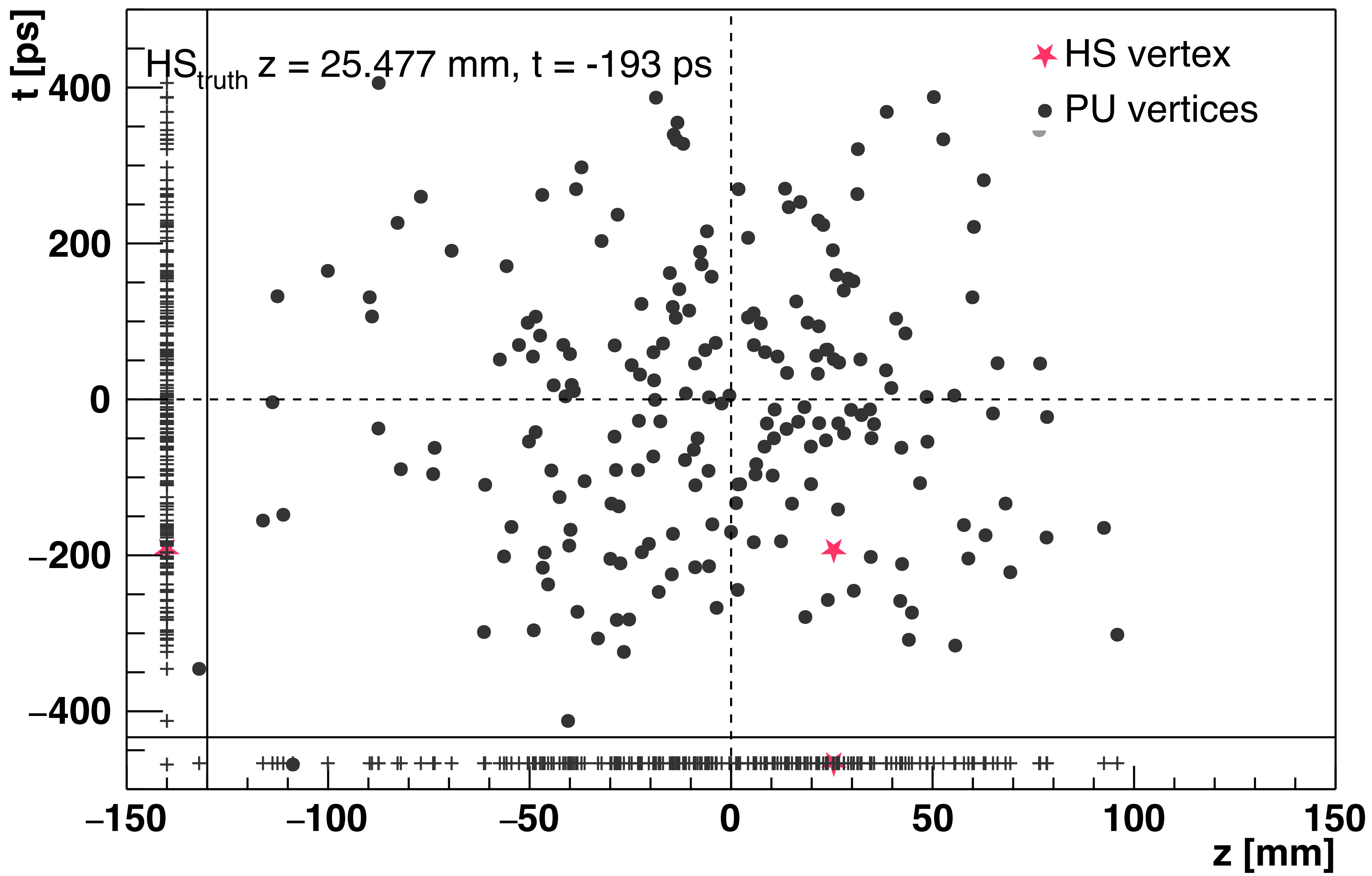
Motivations



Event display from **truth** MC $t\bar{t}$

PU: $\langle\mu\rangle = 200$

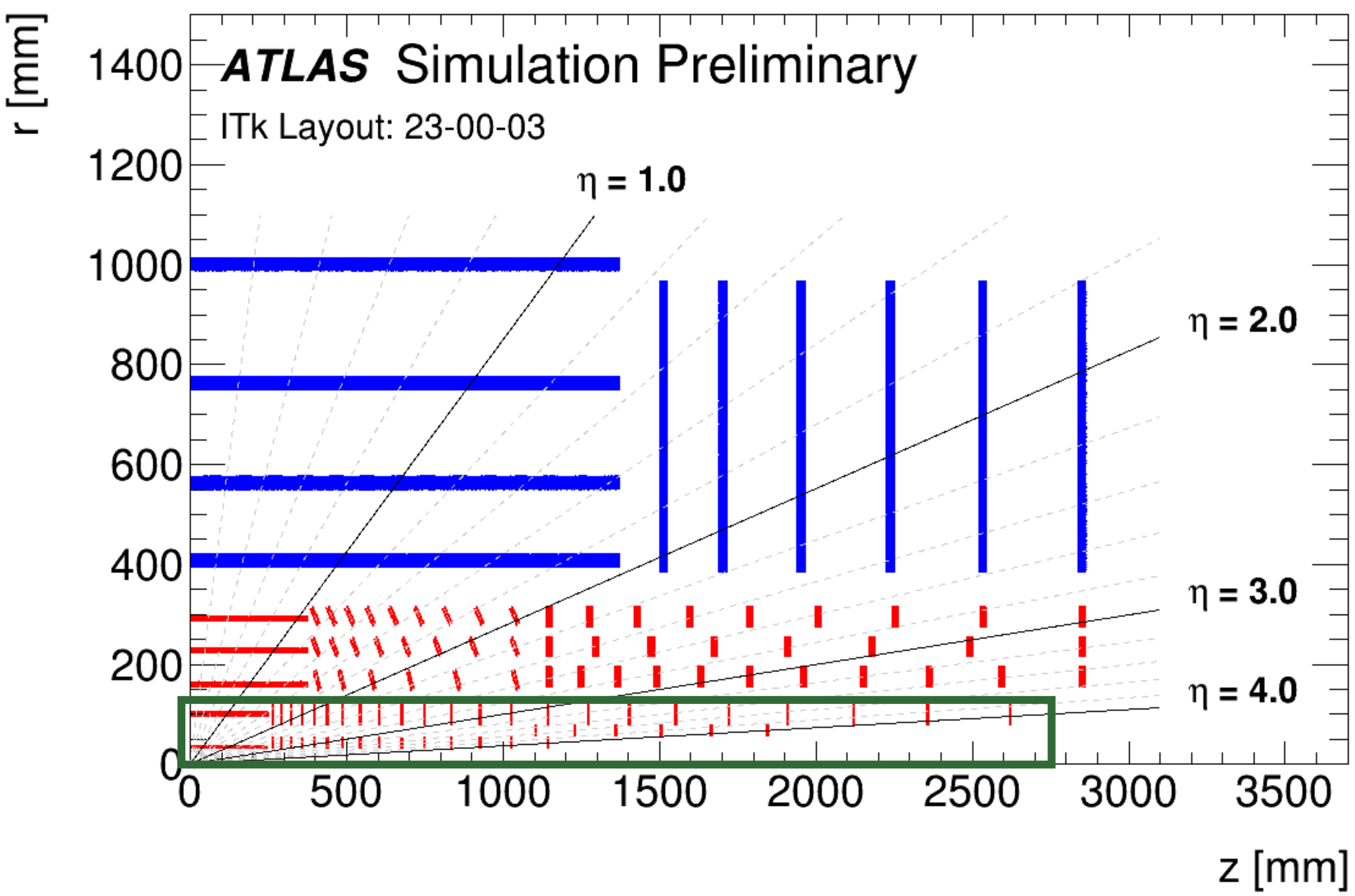
Motivations

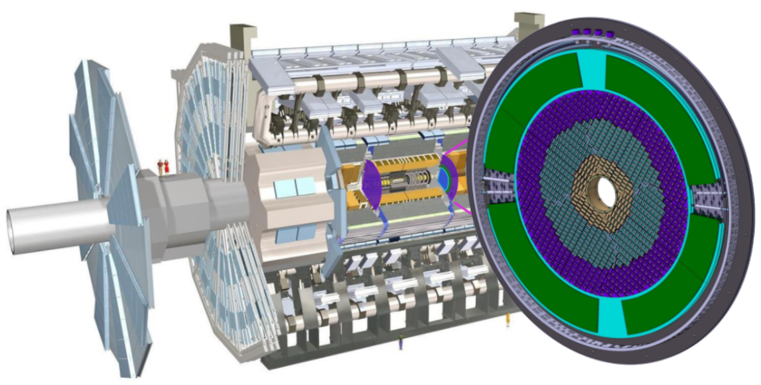


Event display from **truth** MC $t\bar{t}$

PU: $\langle \mu \rangle = 200$

Motivations





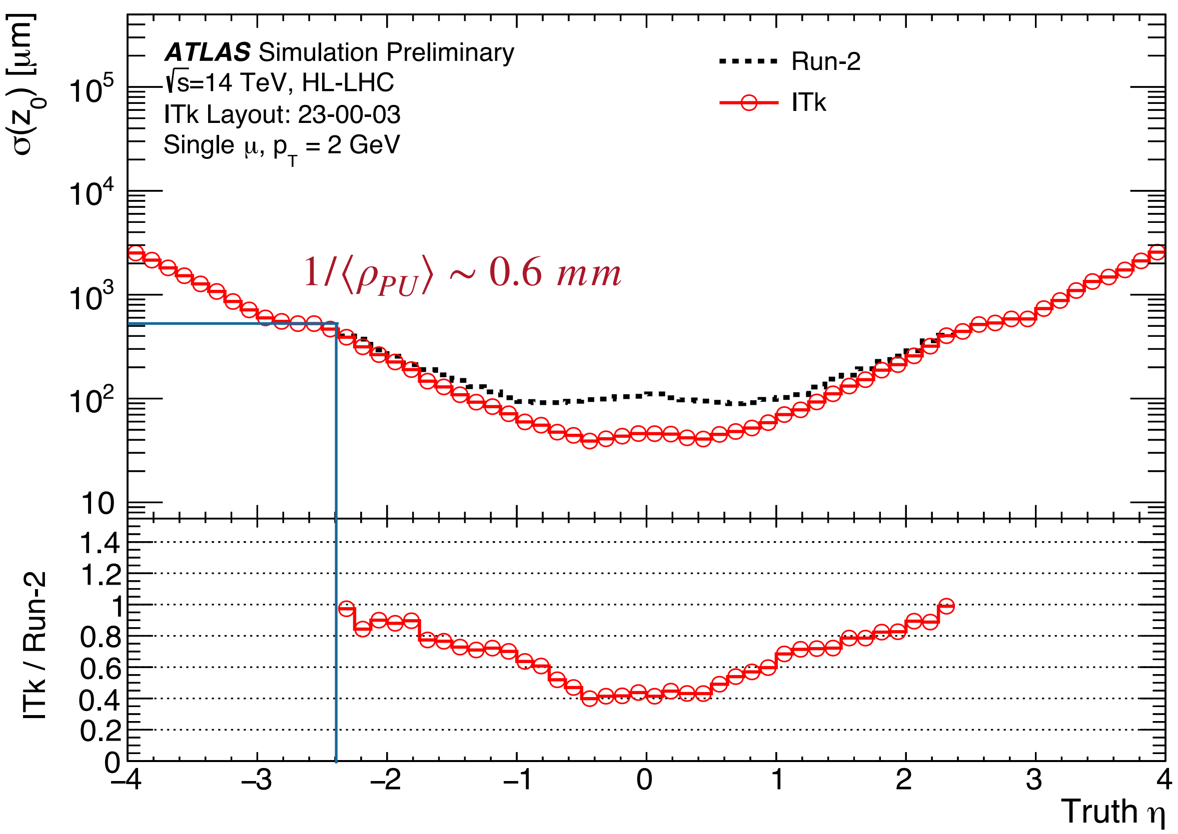
HGTD coverage: $2.4 < \eta < 4$
resolution up to: $t_{trk} \sim 30ps$

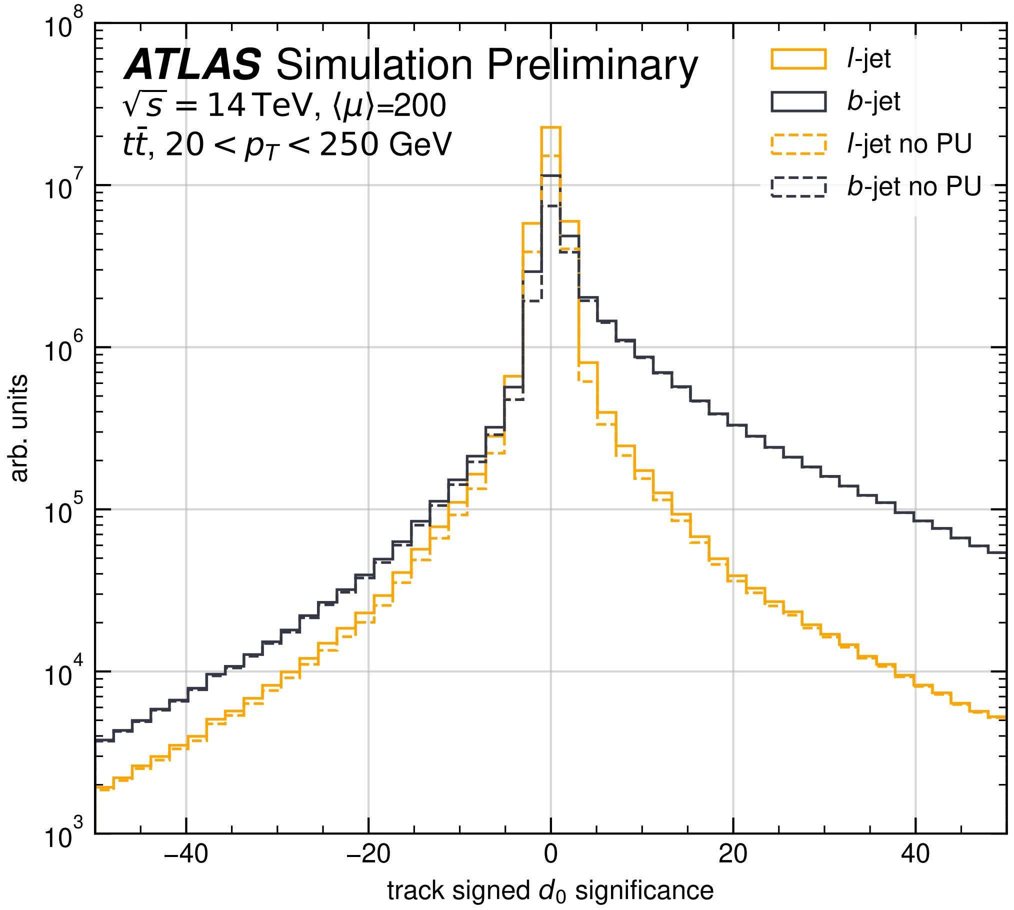
Two innermost pixel layers [link] need to be replaced due to hard radiation after 2000 $fb^{-1}$of data

Can we extend timing coverage to the **barrel**?

Can we determine *precisely* vertex t_{vtx} on **all** events?

Motivations





HGTD:

PU removal in forward region

Timing in the barrel:

performance / physics improvements…

Determination of t_{HS}

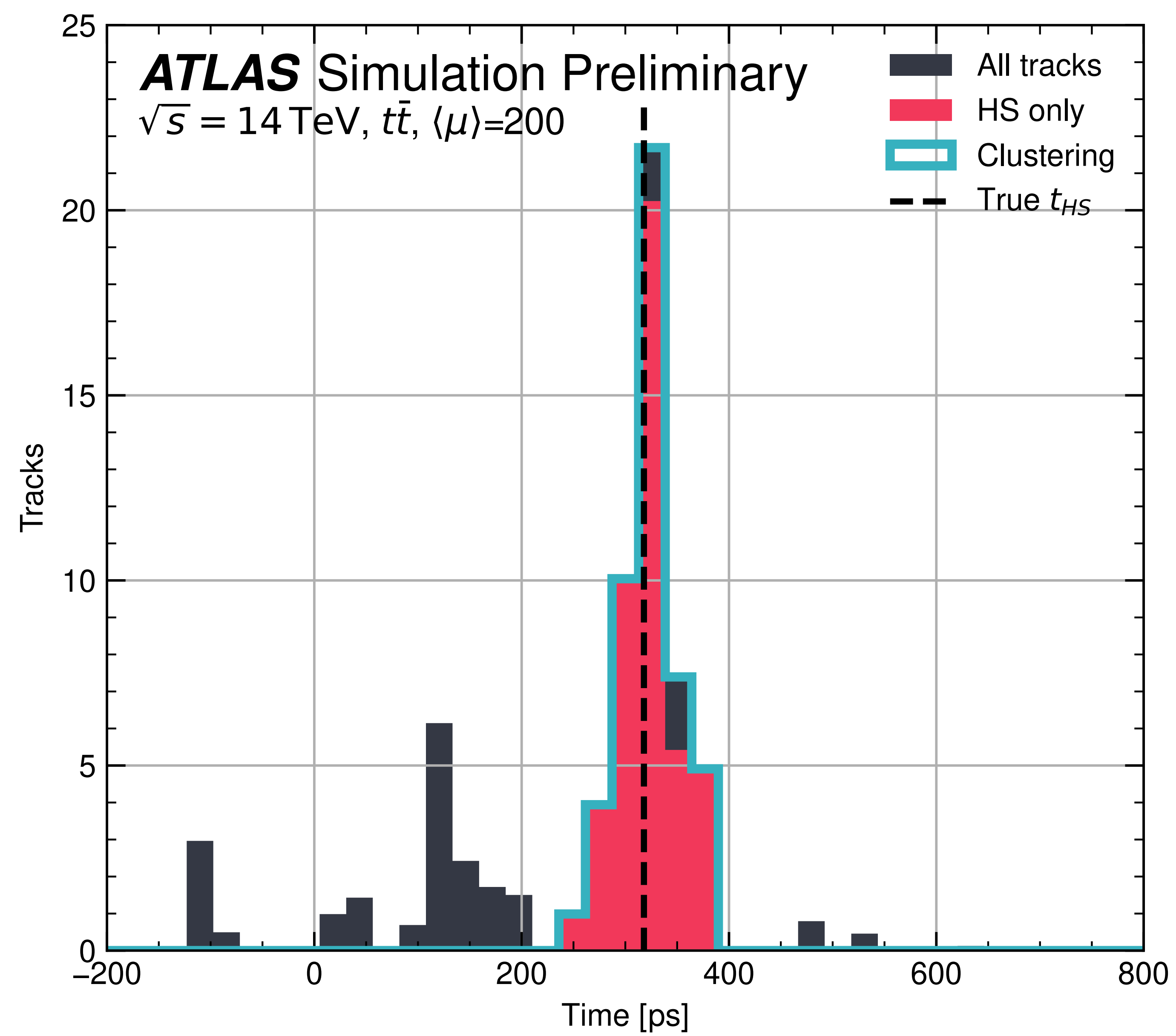
reco vertex time is computed as:

$$t_{all}^{reco} = \sum_{trk} t_{trk} w_{trk}$$

$$t_{HS}^{reco} = \sum_{trk \in HS} t_{trk} w_{trk}$$

$$t_{clus}^{reco} = \sum_{trk \in clus} t_{trk} w_{trk}$$

Clustring is implemented with DBSCAN



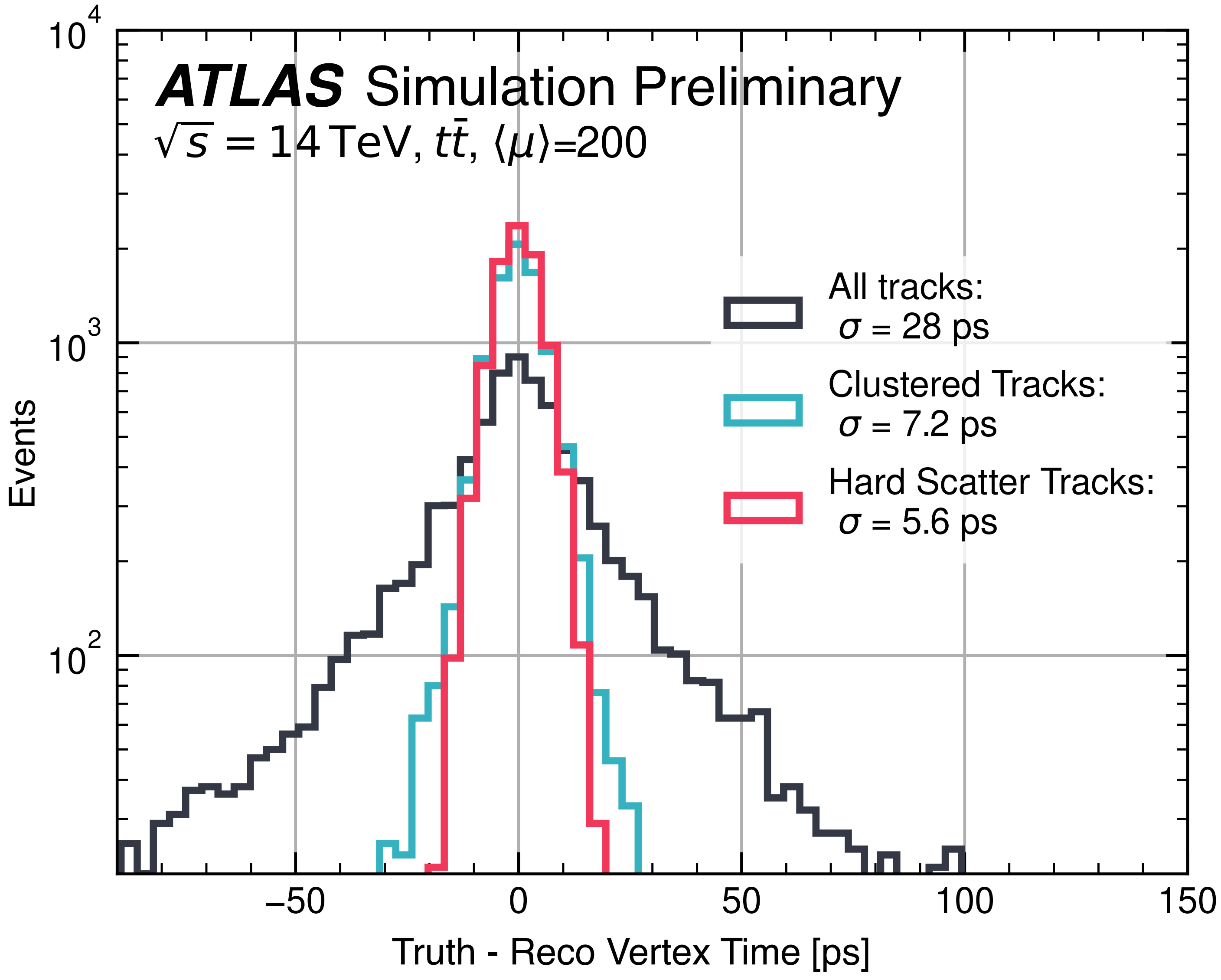
Vertex time resolution

Inclusive resolution for 30ps smearing and three cases

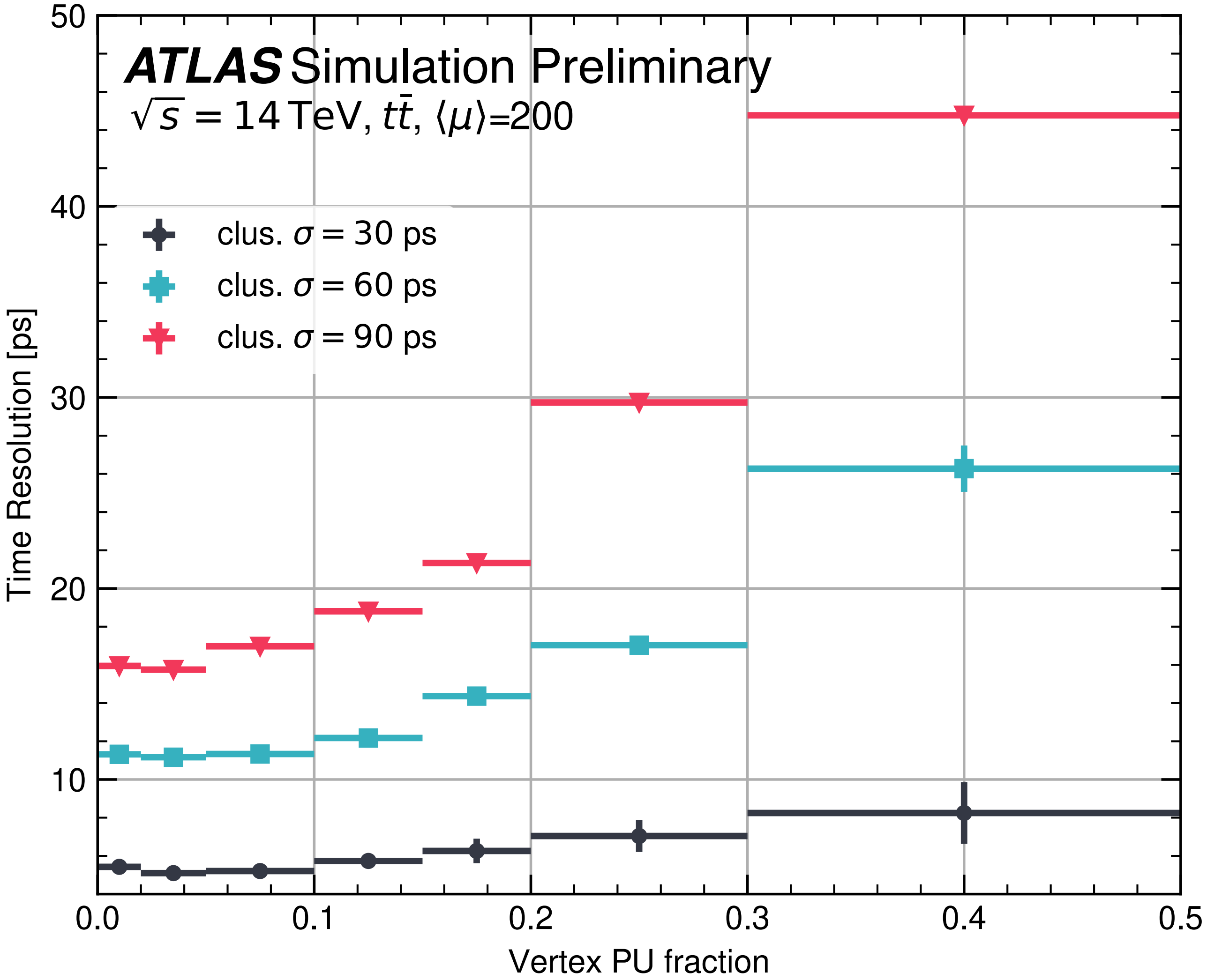
The t_{HS} resolution (std. dev.) can be improved up to the ideal one where only the HS tracks are considered

28ps → 7.2ps (~x4)

5.6ps ideal case where no PU is considered



Vertex PU contamination



New PU discriminating variable (per vtx):

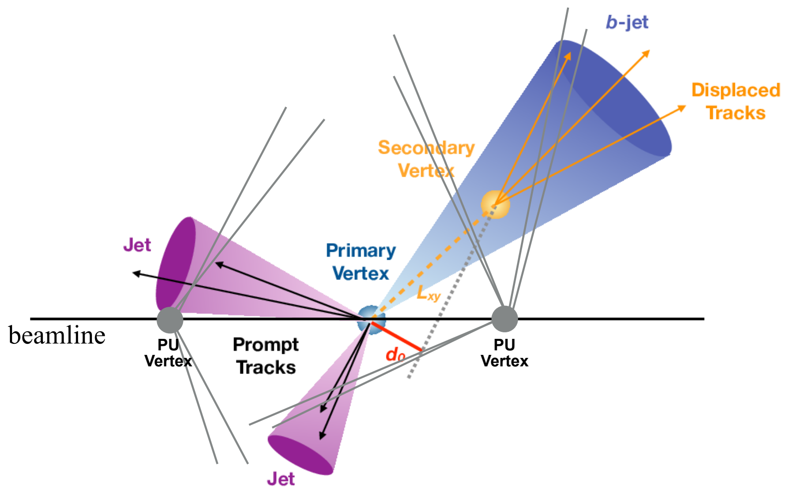
$$\text{PU fraction} = \frac{\#trk_{PU}}{\#trk}$$

Different track time resolutions are considered

Degrading the resolution the improvement on the t_{HS} resolution decreases

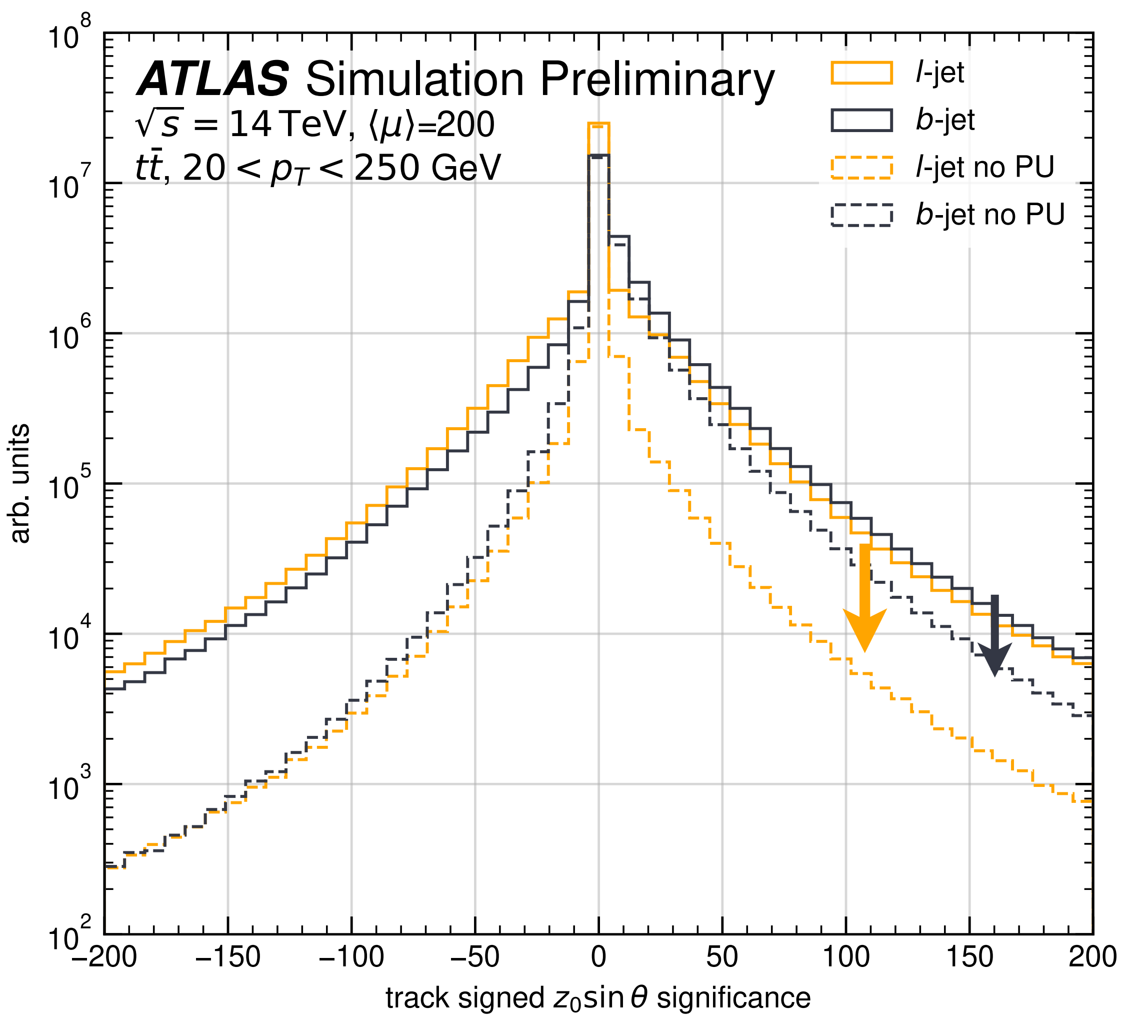
The improvement comes at larger PU fraction

Flavour Tagging



flavour-tagging in a nutshell

jet + tracks → **Algo** → jet flavour



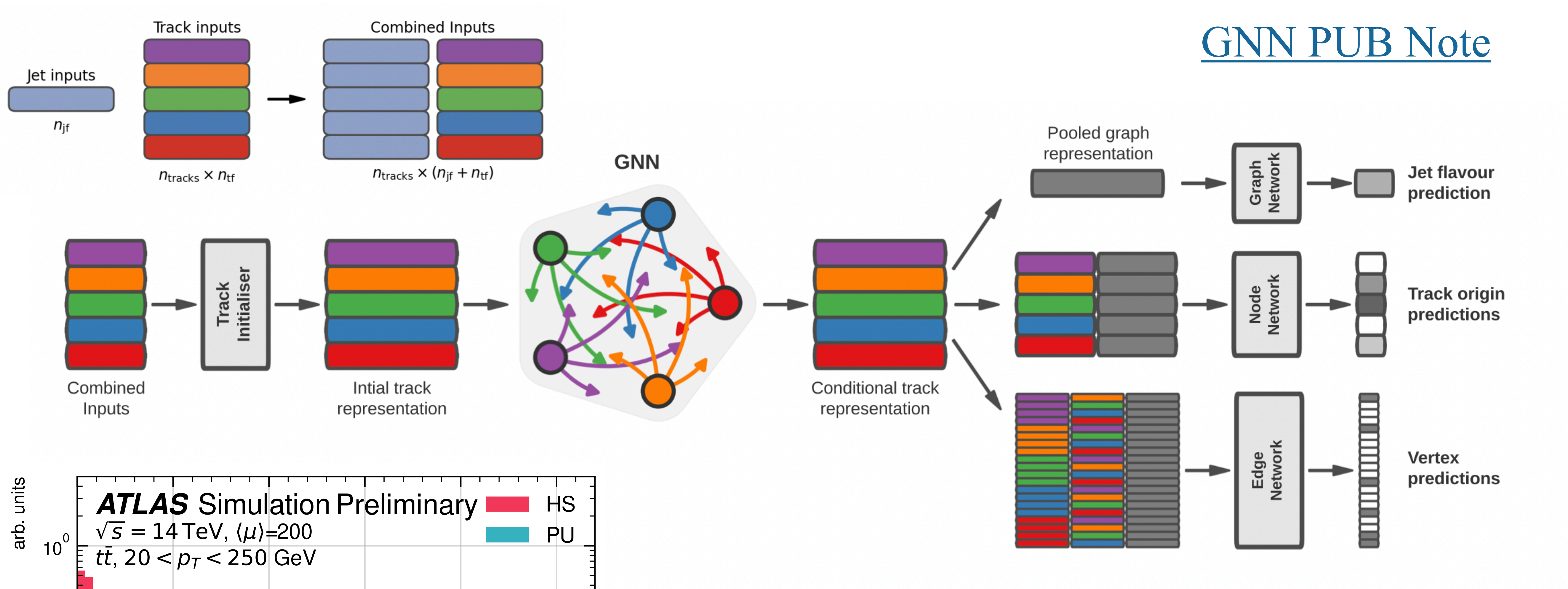
Flavour Tagging: identification of the flavour of the parton originating the jet

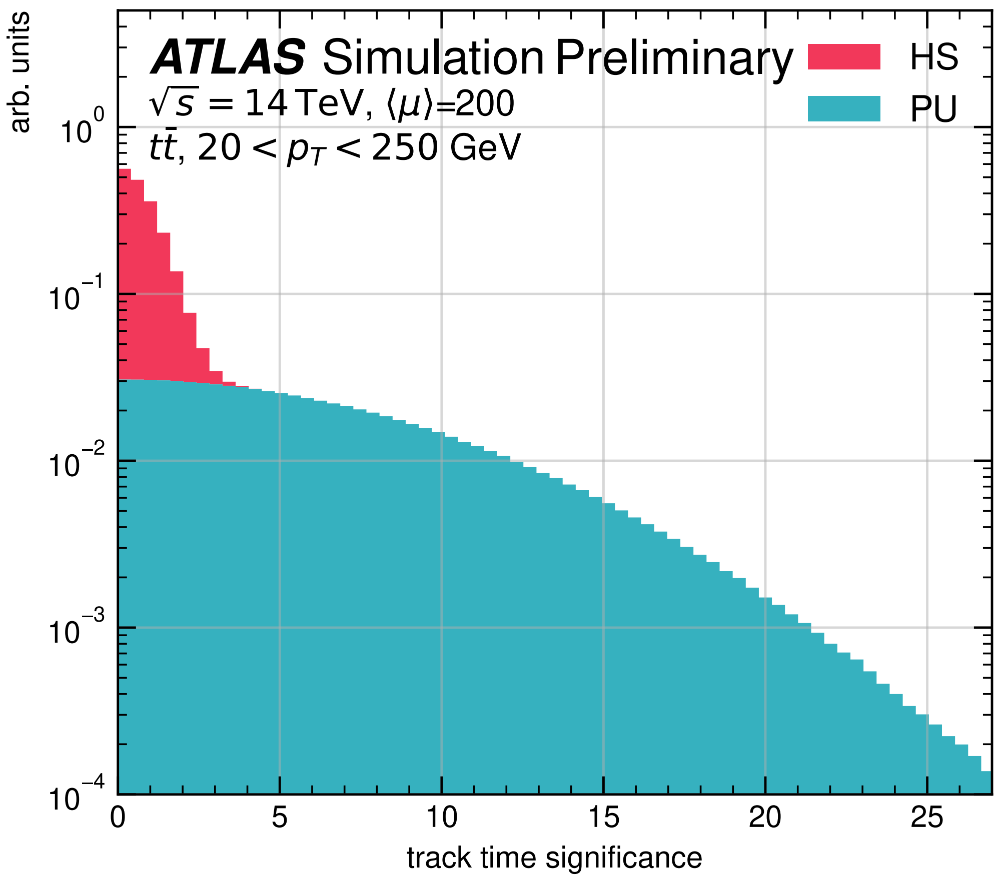
Impact parameters are the most discriminant variables in FTAG

PU, primarily prompt with a low transverse impact parameter (d_0), significantly impacts the longitudinal dimension (z_0)

Graph Neural Networks for FTAG

GNN PUB Note



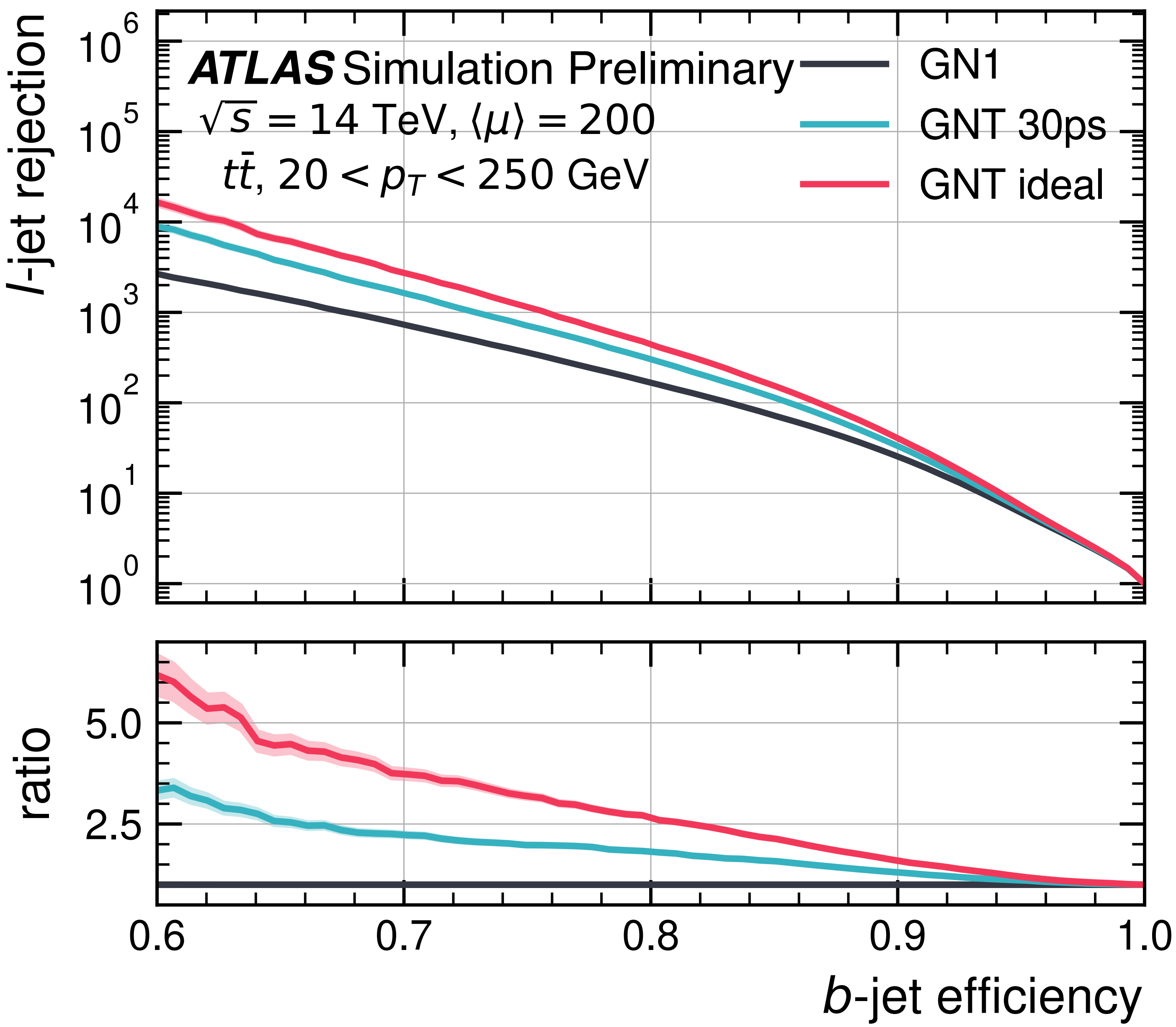


GNT = GN1 + time significance

Time significance to discriminate between PU and HS:

$$s(t) = \frac{|t_{trk} - t_{HS}|}{\sigma_t}$$

Performances: ROC



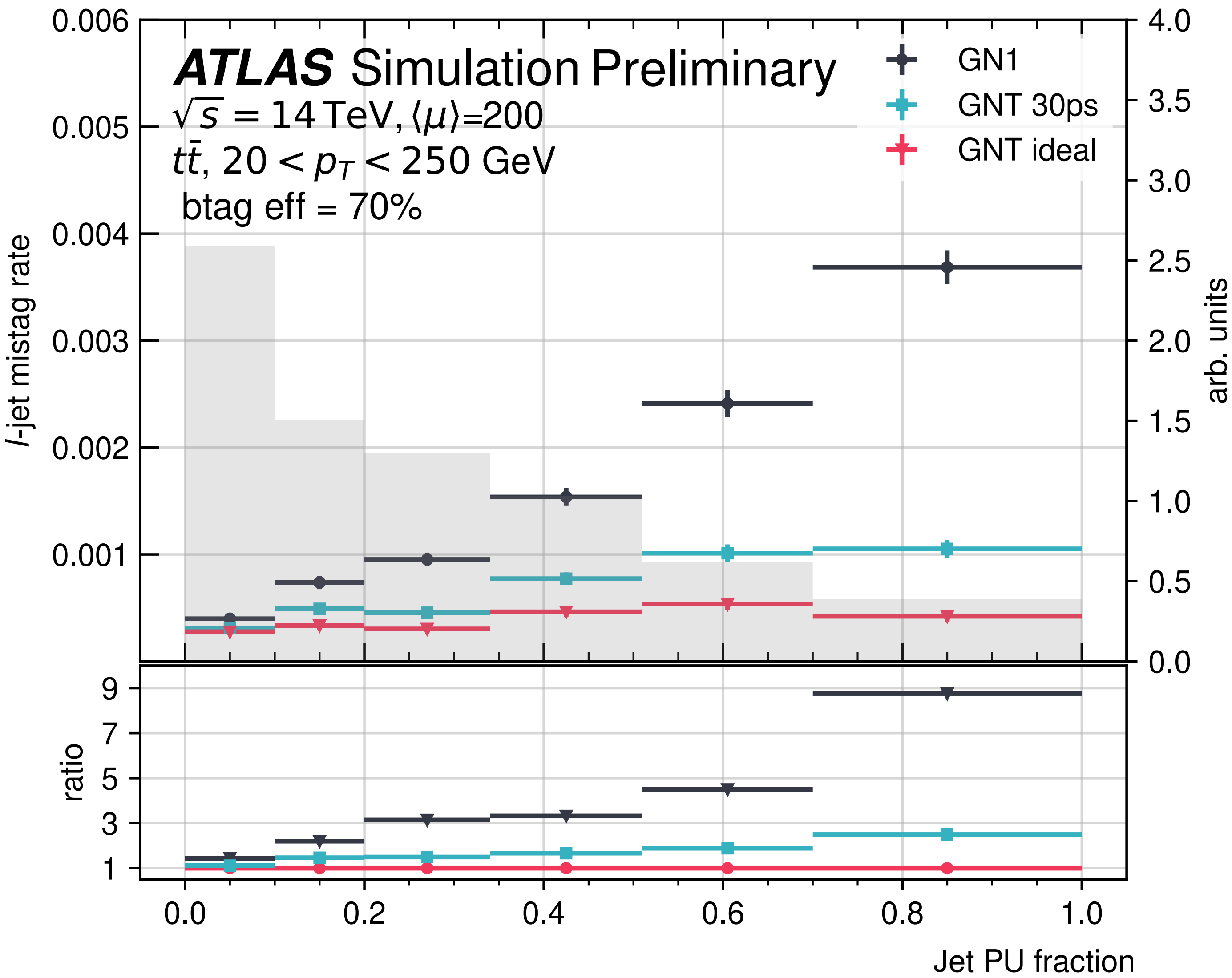
GN1 is the standard FTAG network

GNT 30ps is GN1+timing and 30ps smearing

GNT ideal is GN1+timing and no smearing

Up to a factor of 3 improvement in l-jet rejection with 30ps smearing on already great performances of GN1

Performances: l-jet mistag rate



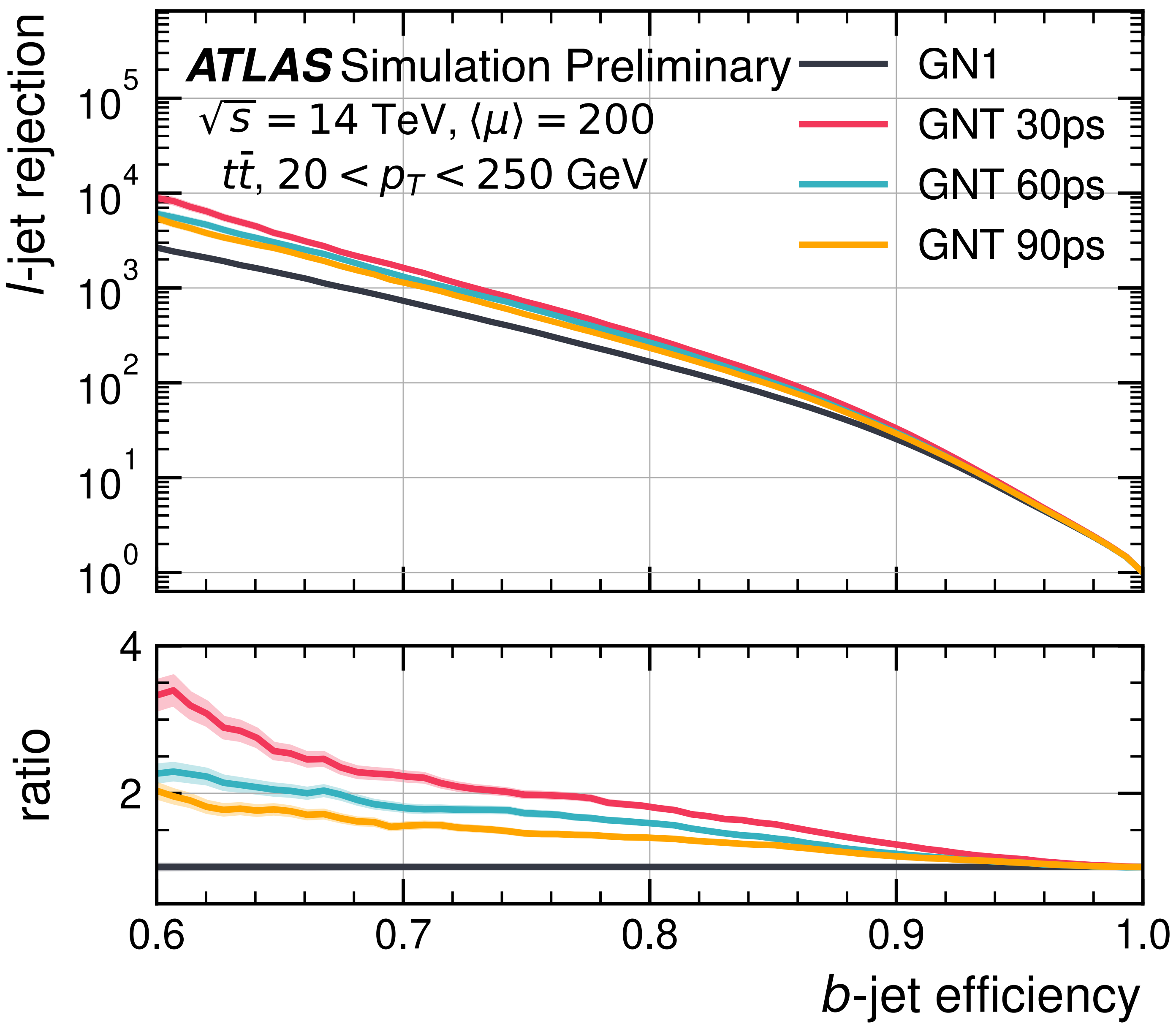
New PU discriminating variable (per jet):

$$\text{PU fraction} = \frac{\#trk_{PU}}{\#trk}$$

Large improvement in highly PU contaminated jets

l-jets mistag rate gets flattened with time information

Impact of smearings



The improvement decreases with increasing the track time smearing

But an improvement remains also with lower resolution

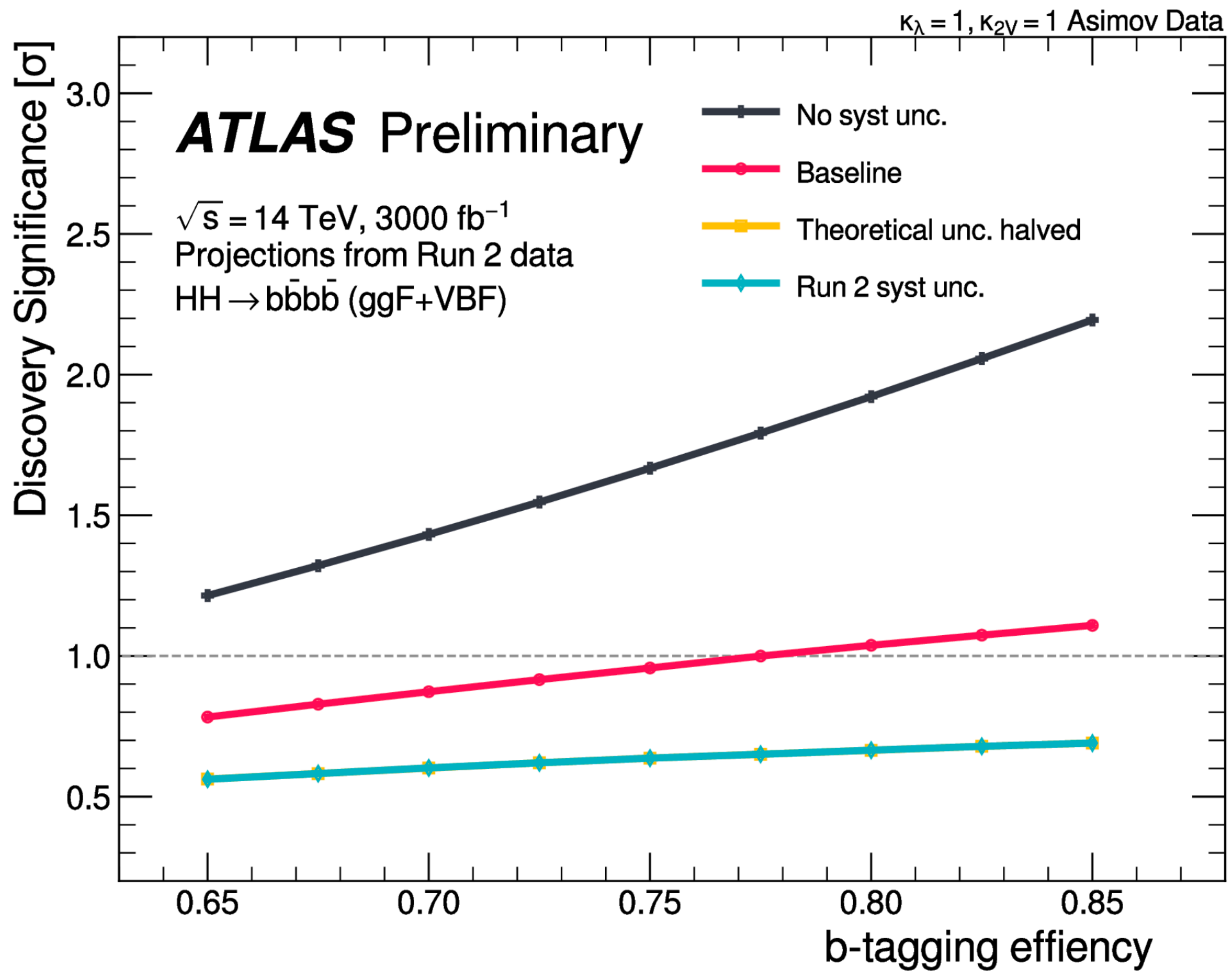
Impact on HH

b-tagging has a huge impact on di-higgs since one of the two H is required to decay to a couple of b quarks (BR~60%)

$HH \rightarrow bbbb$ in the plot

Improving the b-tagging efficiency at fixed l-jet rejection will impact the significance of the analysis and the possibility to see the triliniar coupling during HL-LHC

This is potentially applyable to partial HL-LHC statistics



Impact on LLP

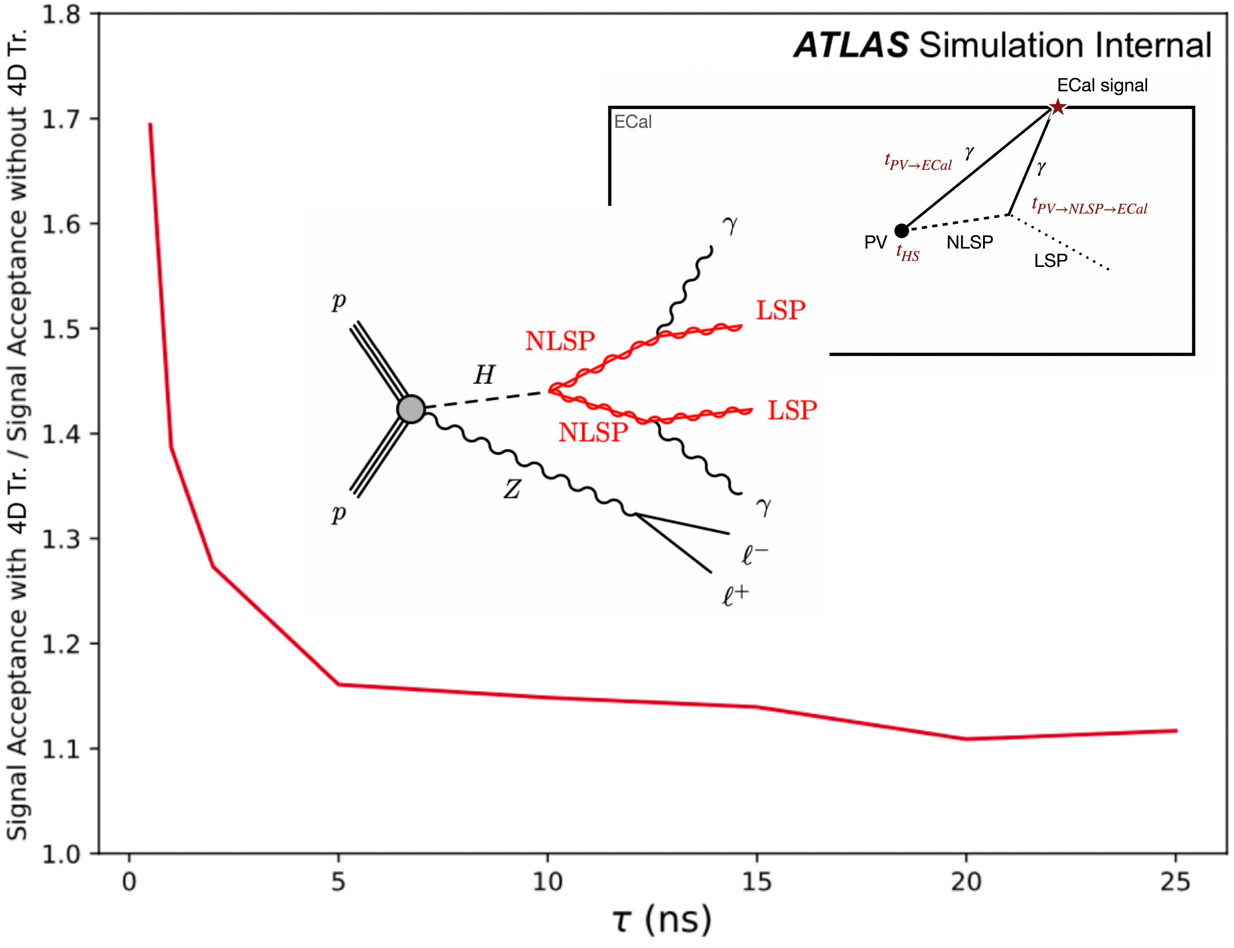
4D tracking can also improve the sensitivity to LLP:

- LLP with small $c\tau$
- displayed photons (in this note)

time resolution of delayed photons is 190ps due to the lack of knowledge about t_{HS}

$$\Delta t = t_0 + t^{\text{Reconstructed}}_{\text{IP}\rightarrow\text{ECal}} - t_{\text{IP}\rightarrow\text{ECal}} - t^{\text{Reconstructed}}_0$$

180ps 100ps 4D improves!



Conclusion

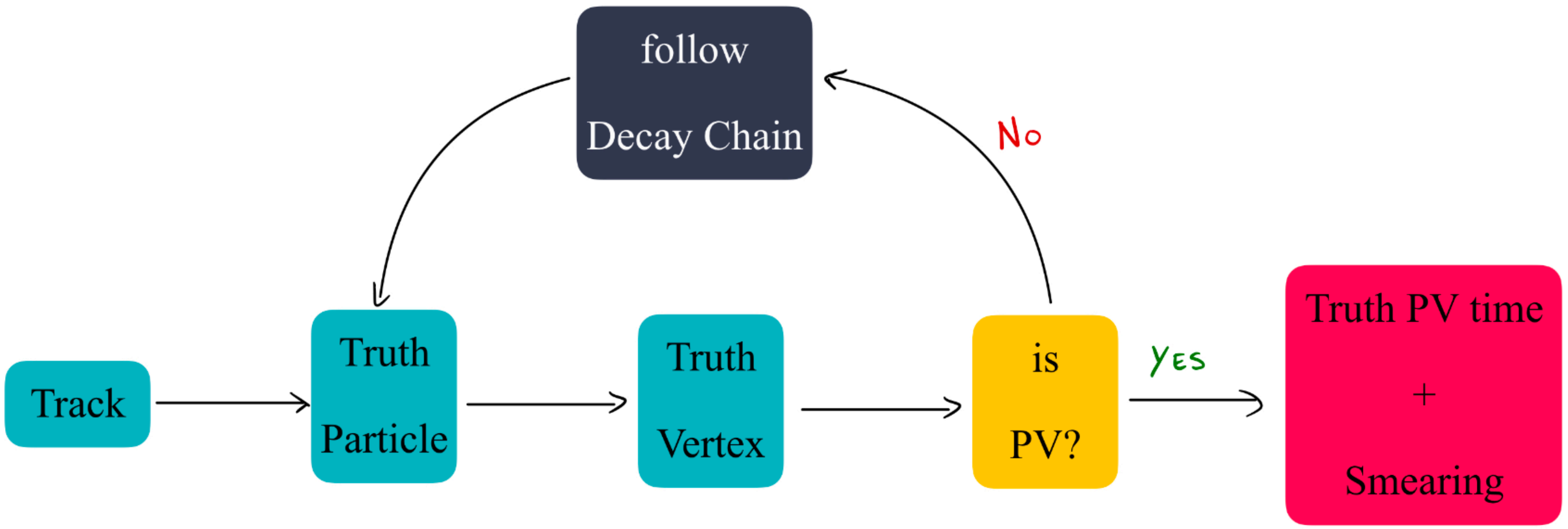
This study is the first study of potential impact of hermetic timing coverage in the tracker of ATLAS

The work suggest that 4D tracking can potentially improve performances and physics cases

These results motivate in-depth studies with more realistic detector assumptions and more sophisticated algorithms

Backup

Track time assignment

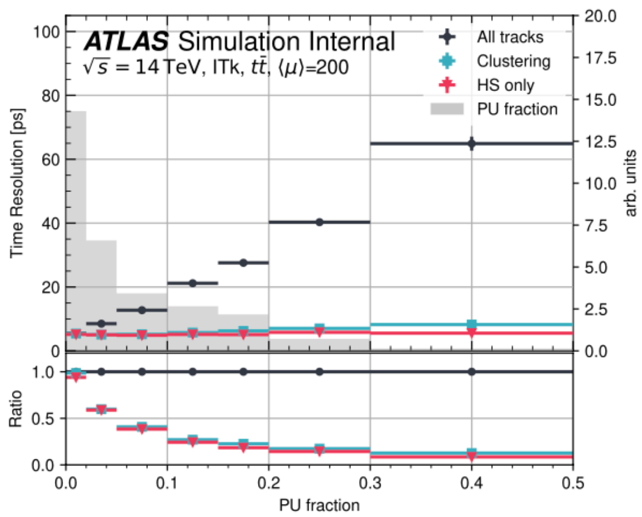


Track **time** is retrieved from **truth level** information

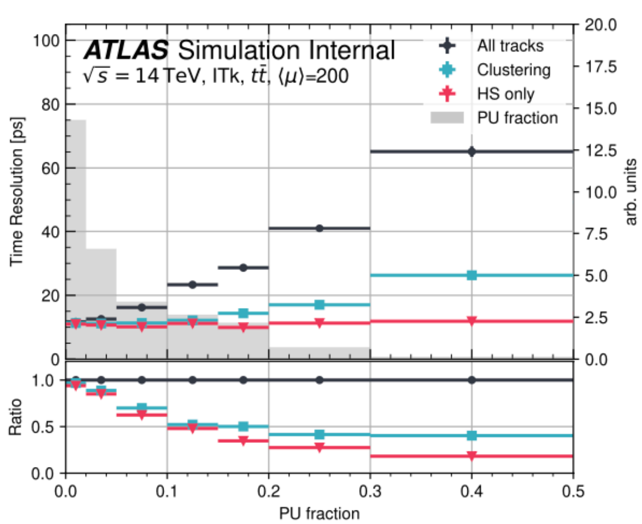
Different **smearings** (gaussian) are considered: 30, 60, 90ps

A relevant quantity is the **relative time** to the HS

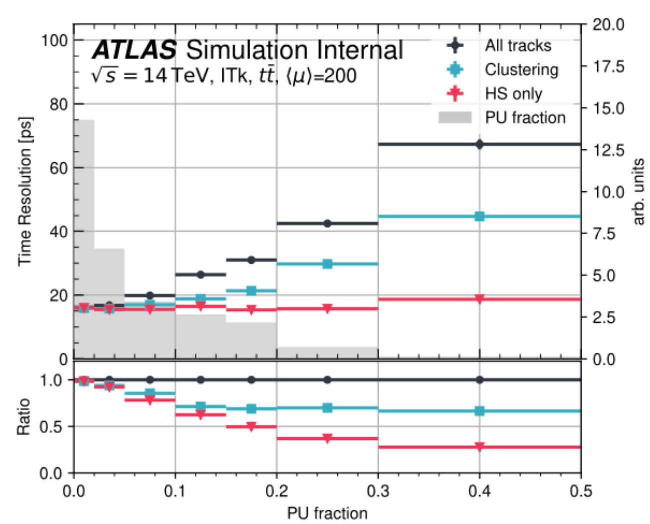
Vertex PU contamination



(a) 30 ps resolution



(b) 60 ps resolution



(c) 90 ps resolution

New PU discriminating variable (per vtx):

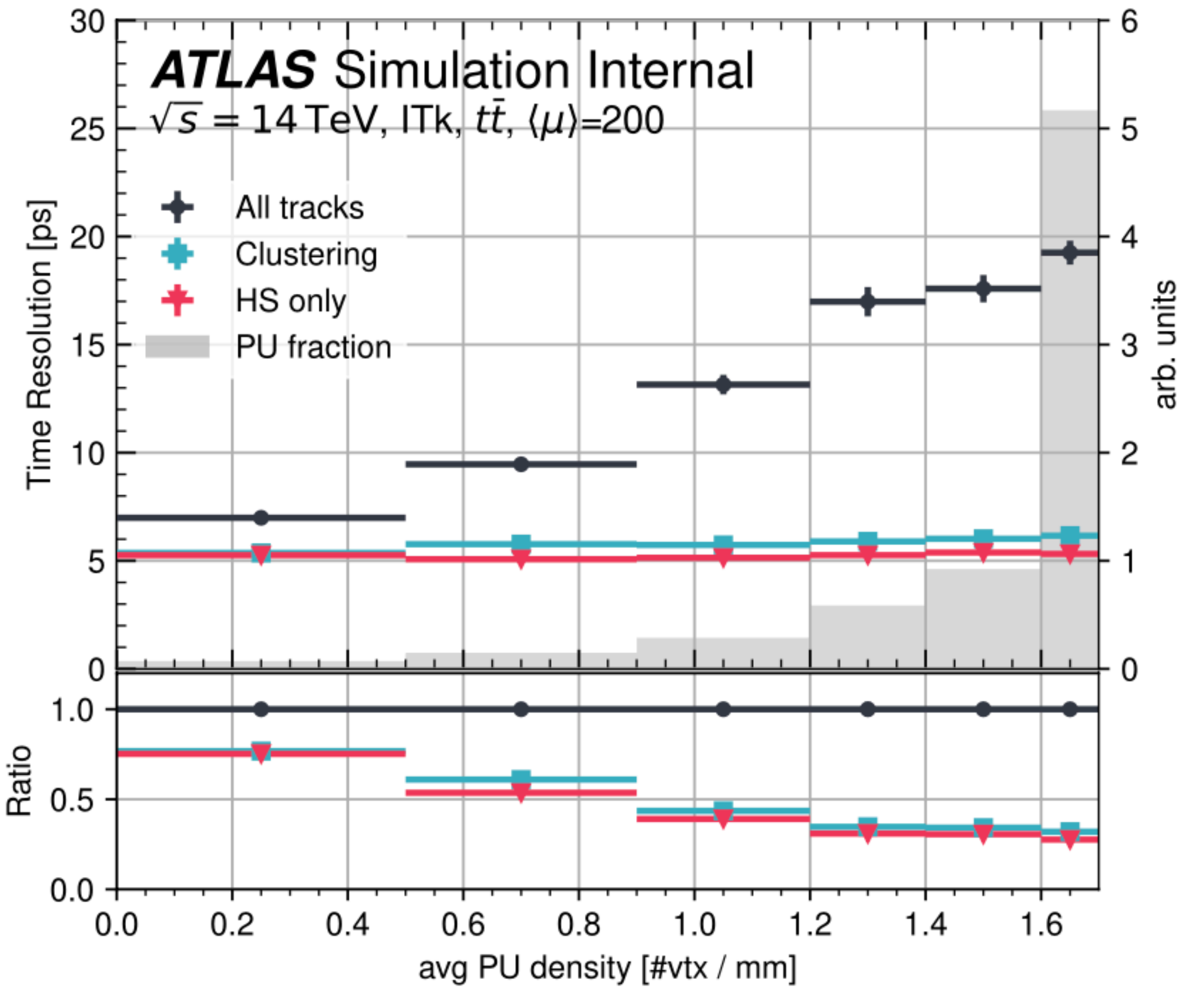
$$\text{PU fraction} = \; = \frac{\#trk_{PU}}{\#trk}$$

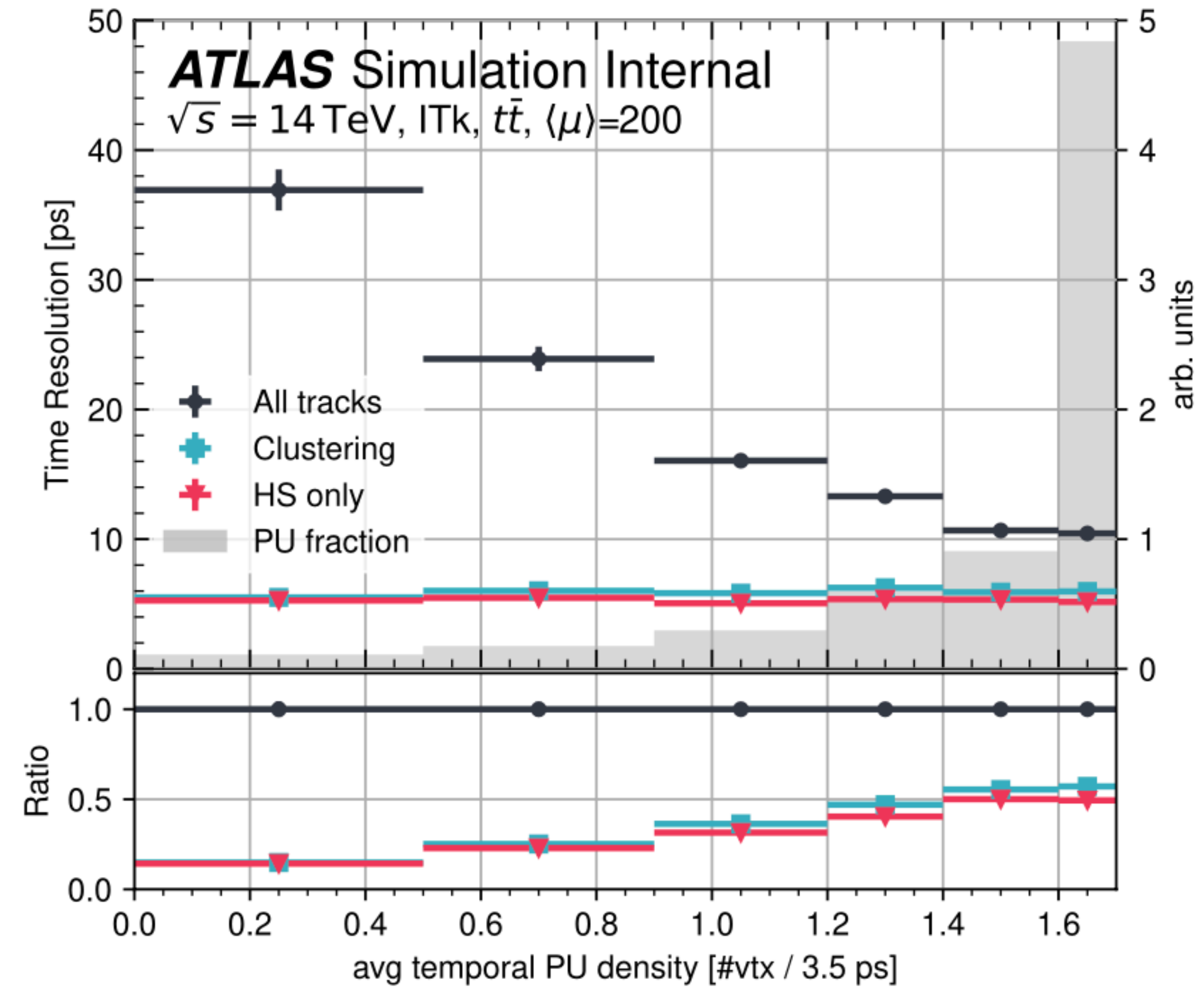
Different track time resolutions are considered

Degrading the resolution the improvement on the t_{HS} resolution decreases

The improvement comes at larger PU fraction

Average spatial and temporal PU density

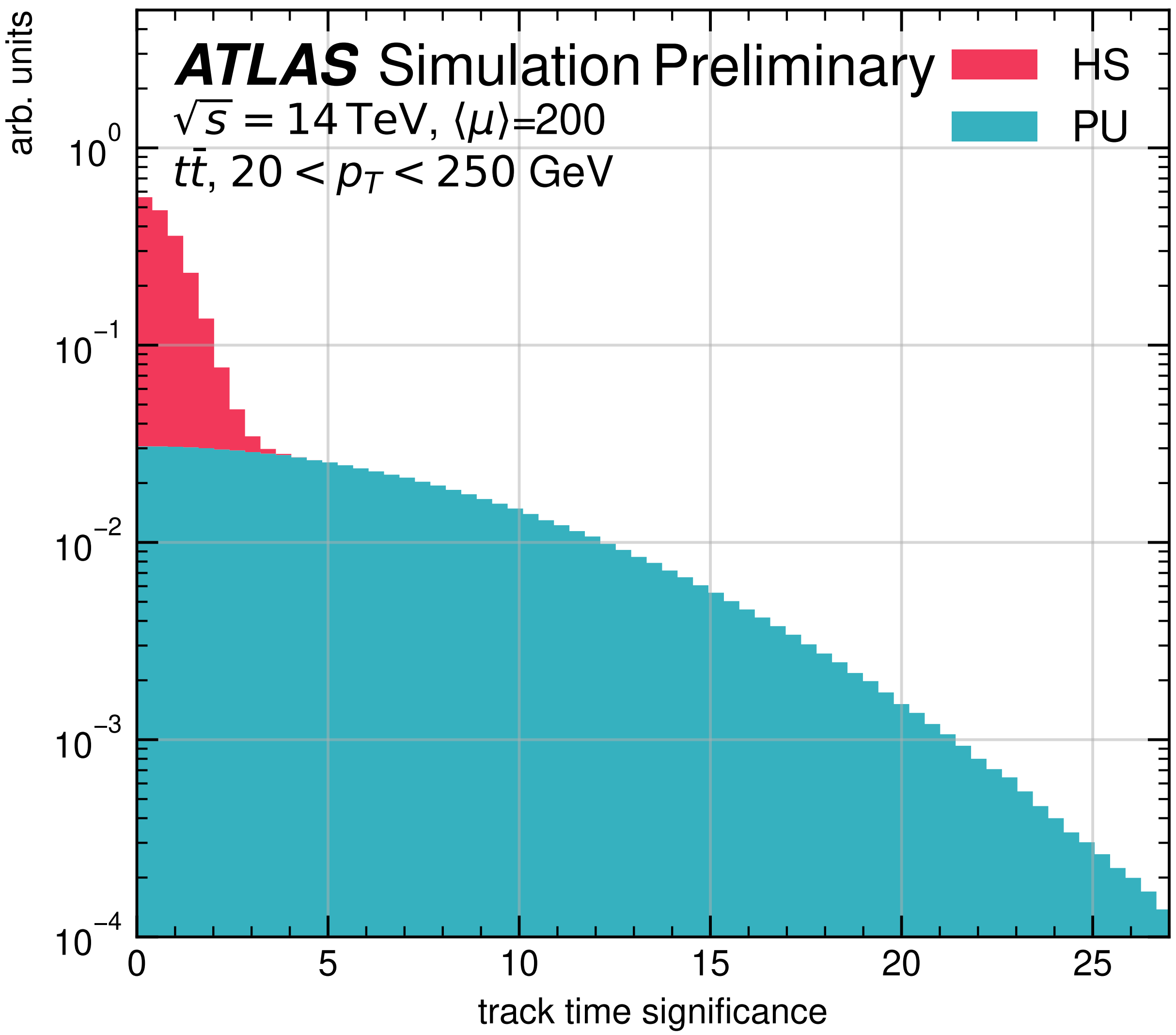




In both cases the distribution gets flattened

FTAG studies: GNN

Track	GN1 ITk	GNT
d0	x	x
z0SinTheta	x	x
σ(Theta)	x	x
qOverP	x	x
σ(qOverP)	x	x
φ	x	x
σ(φ)	x	x
signed d0	x	x
signed z0	x	x
Δη(trk, jet)	x	x
Δφ(trk, jet)	x	x
n pix hits	x	x
n pix hits (11	x	x
$(t-t_{HS})/\sigma(t)$		x



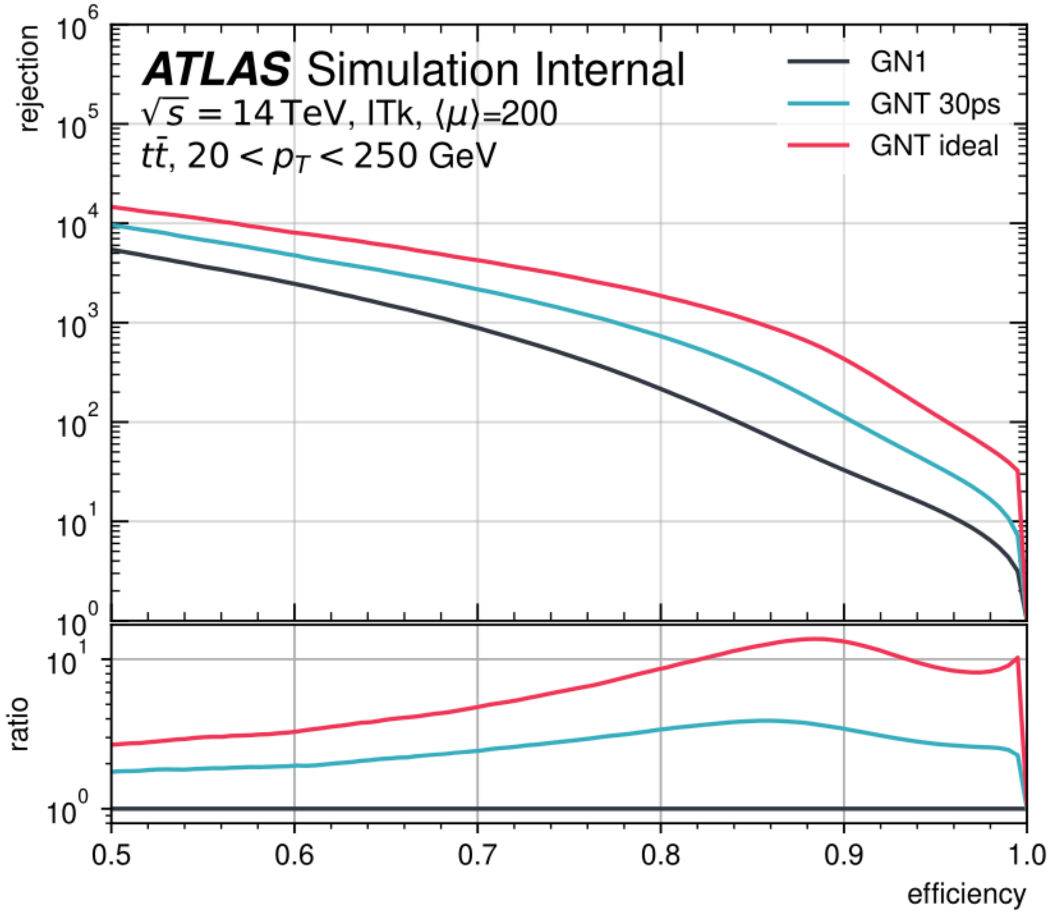
GNT = GN1 + time

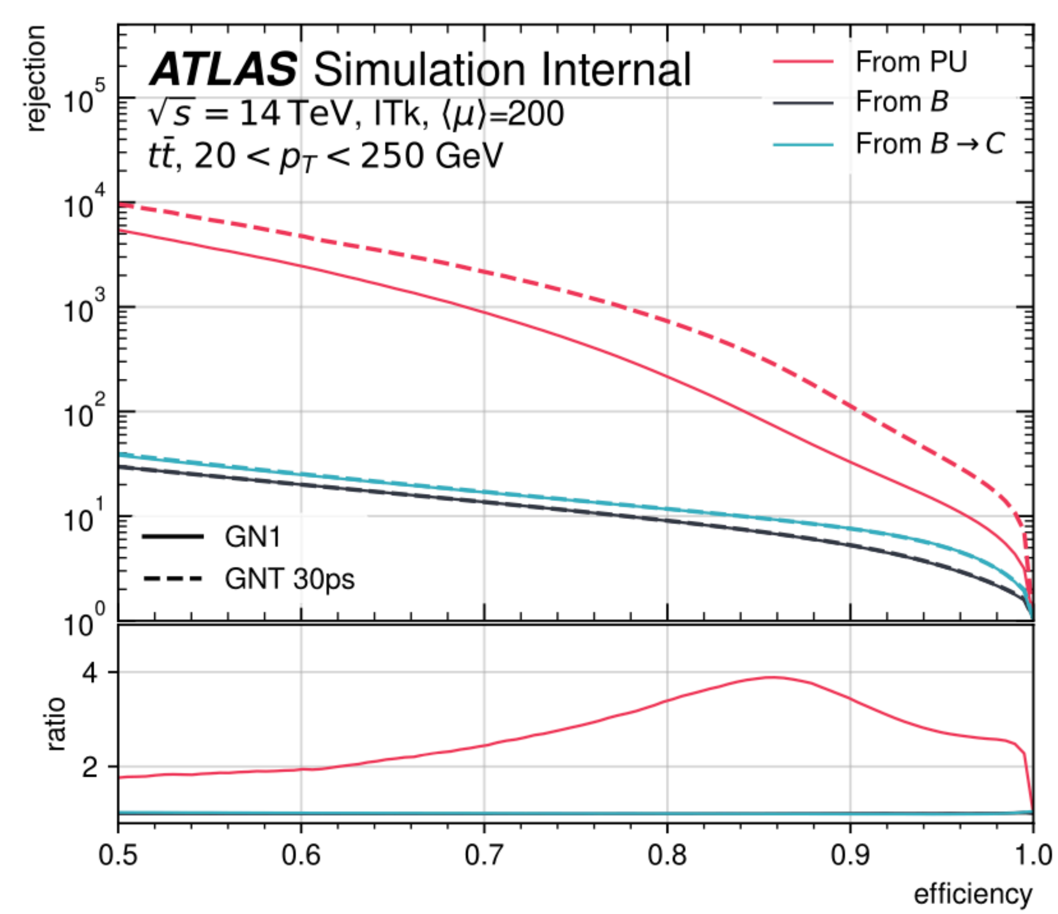
ideal → no smearing

Time significance to discriminate between PU and HS:

$$s(t) = \frac{|t_{trk} - t_{HS}|}{\sigma_t}$$

Track classification





The largest impact on the track classification happens on PU track as expected

Tracks from HF are inclusively unchanged

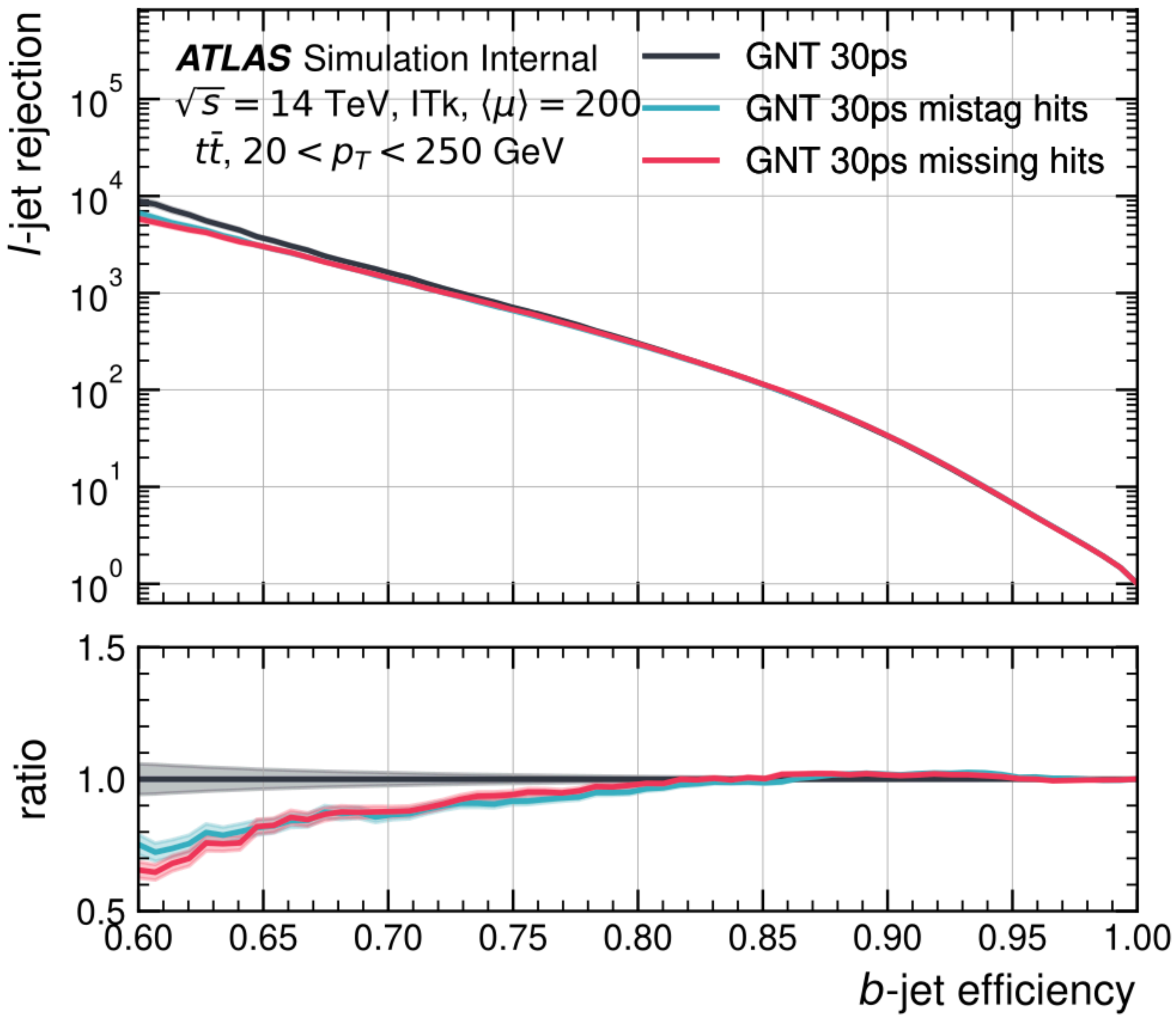
Missing and Mistag

A complete simulation is needed for an accurate study

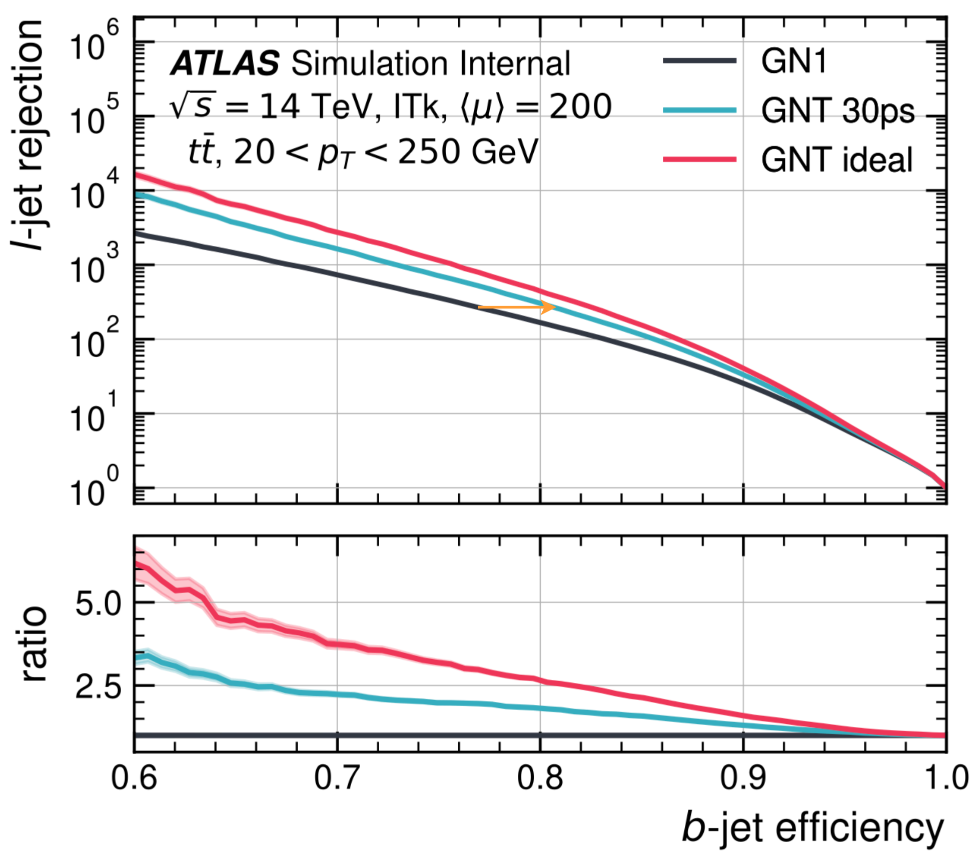
We investigated independently the impact of **missing hits** and **mistag hits** showing that the performances get degraded mostly at low b-jet efficiencies

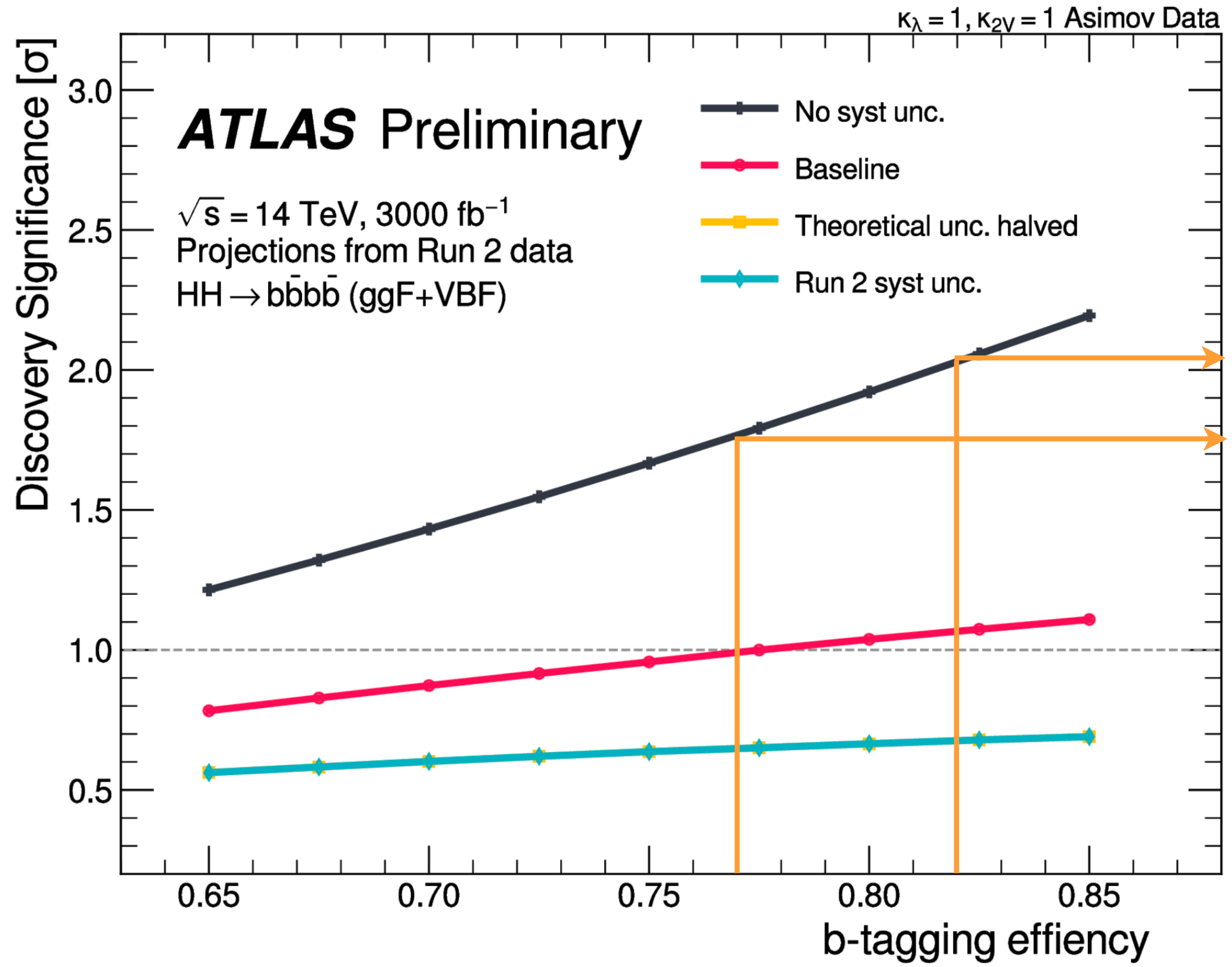
missing hit: assuming time only in 2nd layer; if a track has no hit the significance of the track is randomly emulated as HS

mistag hit: for tracks with Truth Match Probability < 80% the significance is randomly emulated as PU



Impact on HH





caveat:

- possible only on partial HL-LHC stat

5% improvement in b-tagging eff. can lead to a 0.3σ improvement