Jet/E_T^{miss} and e/γ at the upgraded ATLAS detector

Richard Polifka*
on behalf of the ATLAS Collaboration
*CERN

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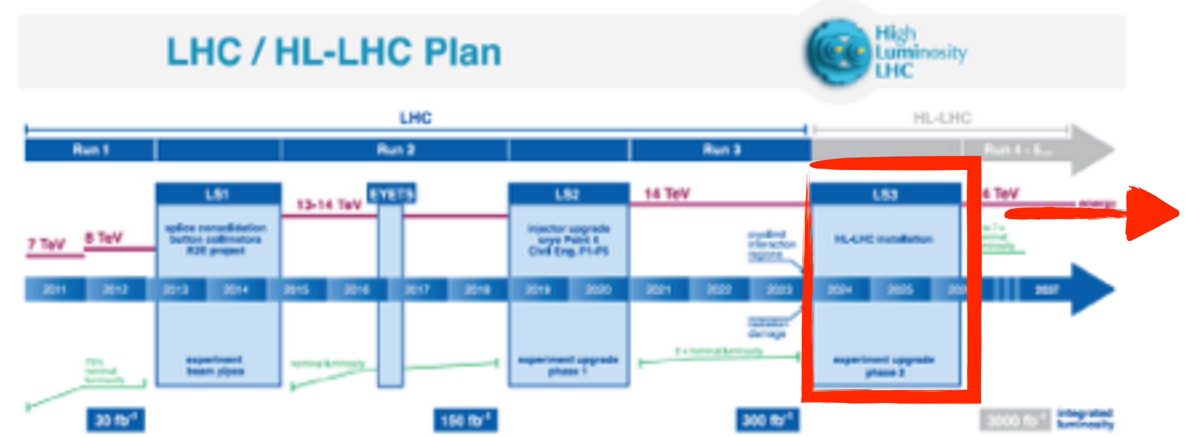
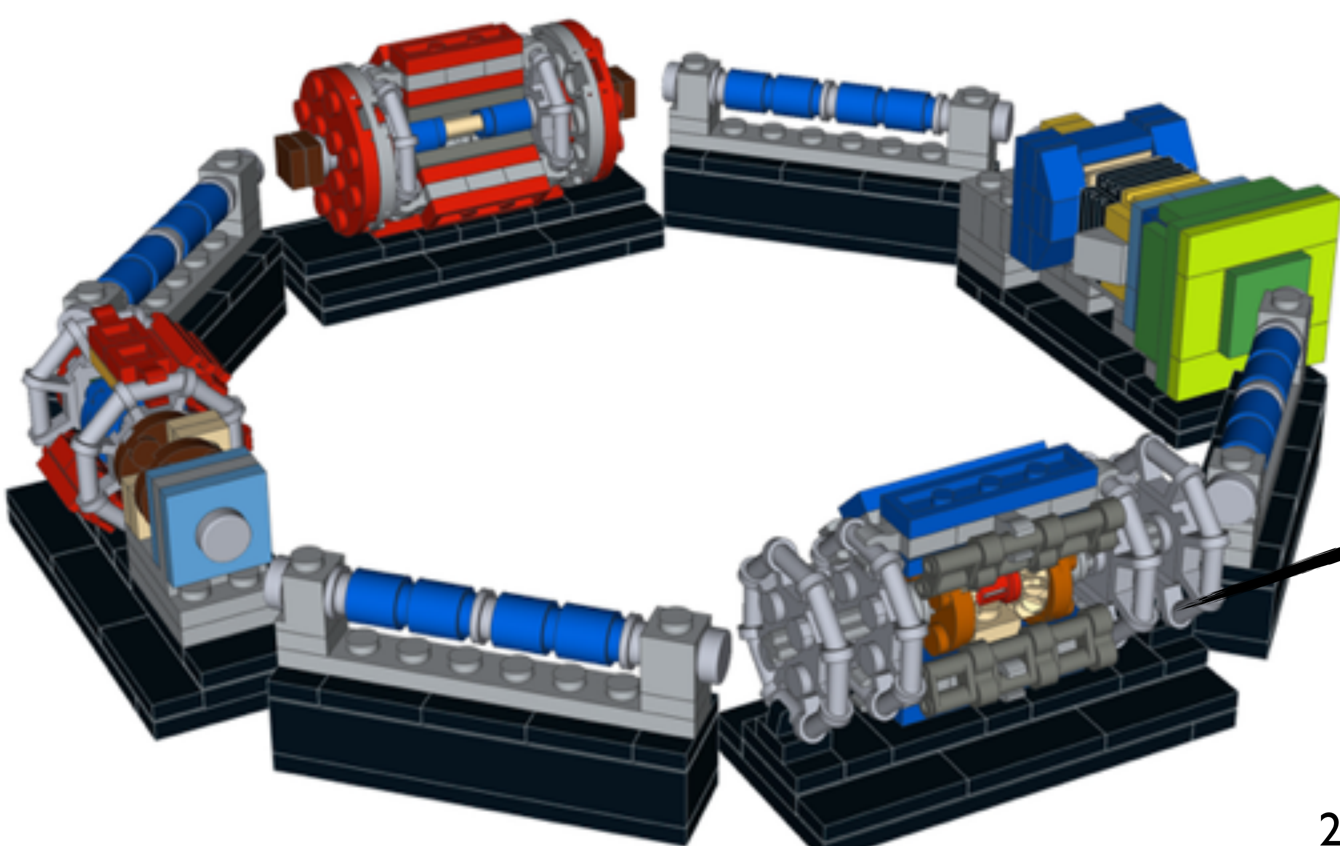
Aix-les-Bains

(HL)-Large Hadron Collider

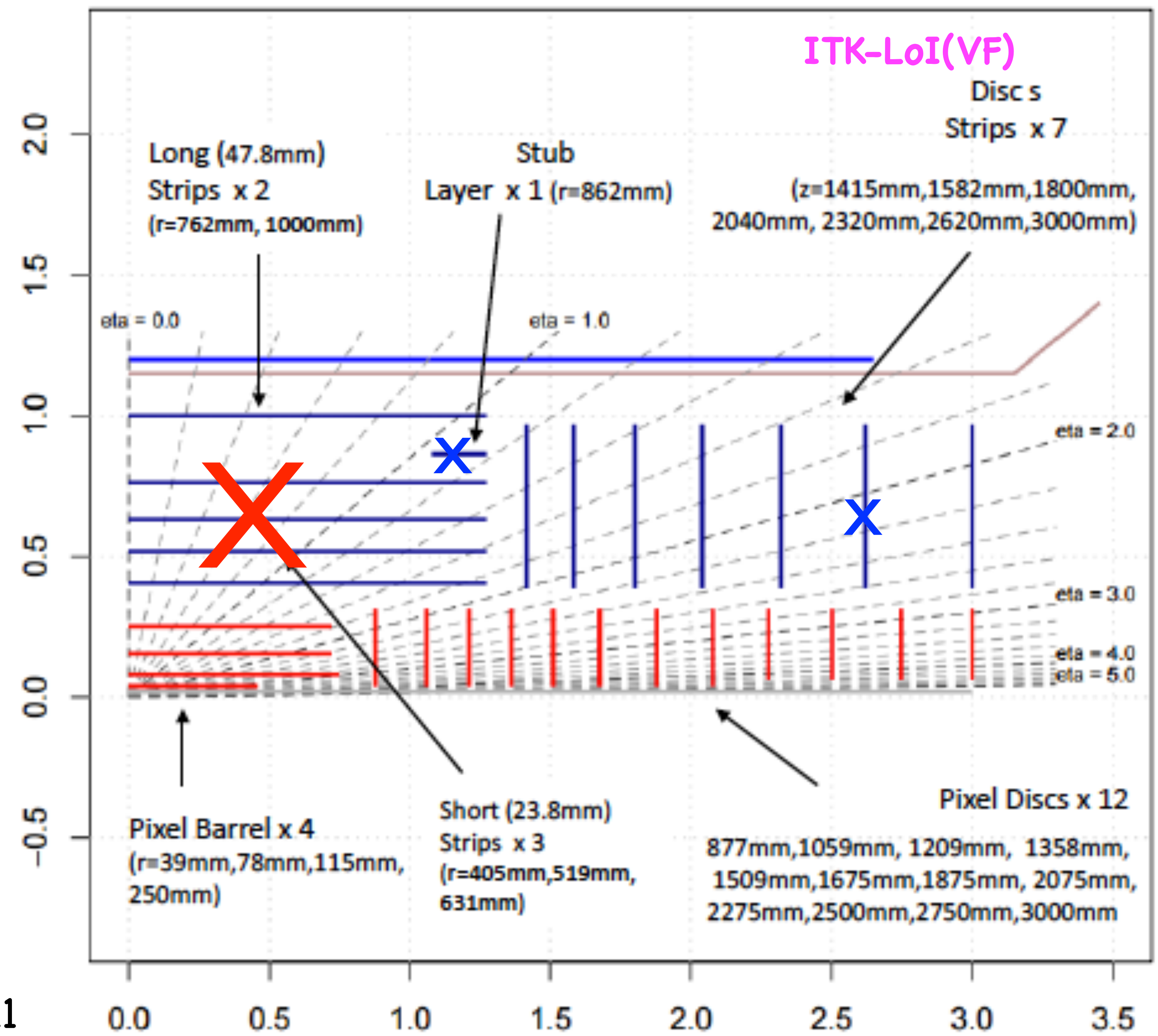
- 2023 - end of LHC with L_{Run3} = ~300 fb^{-1}
- maximum $\langle\mu\rangle$ ~80
- HL-LHC upgrade (2026-2037):
  - $L_{int} = 7.5\times10^{34}\ cm^{-2}s^{-1}$
    - L_{HLLHC} = 3000 fb^{-1}





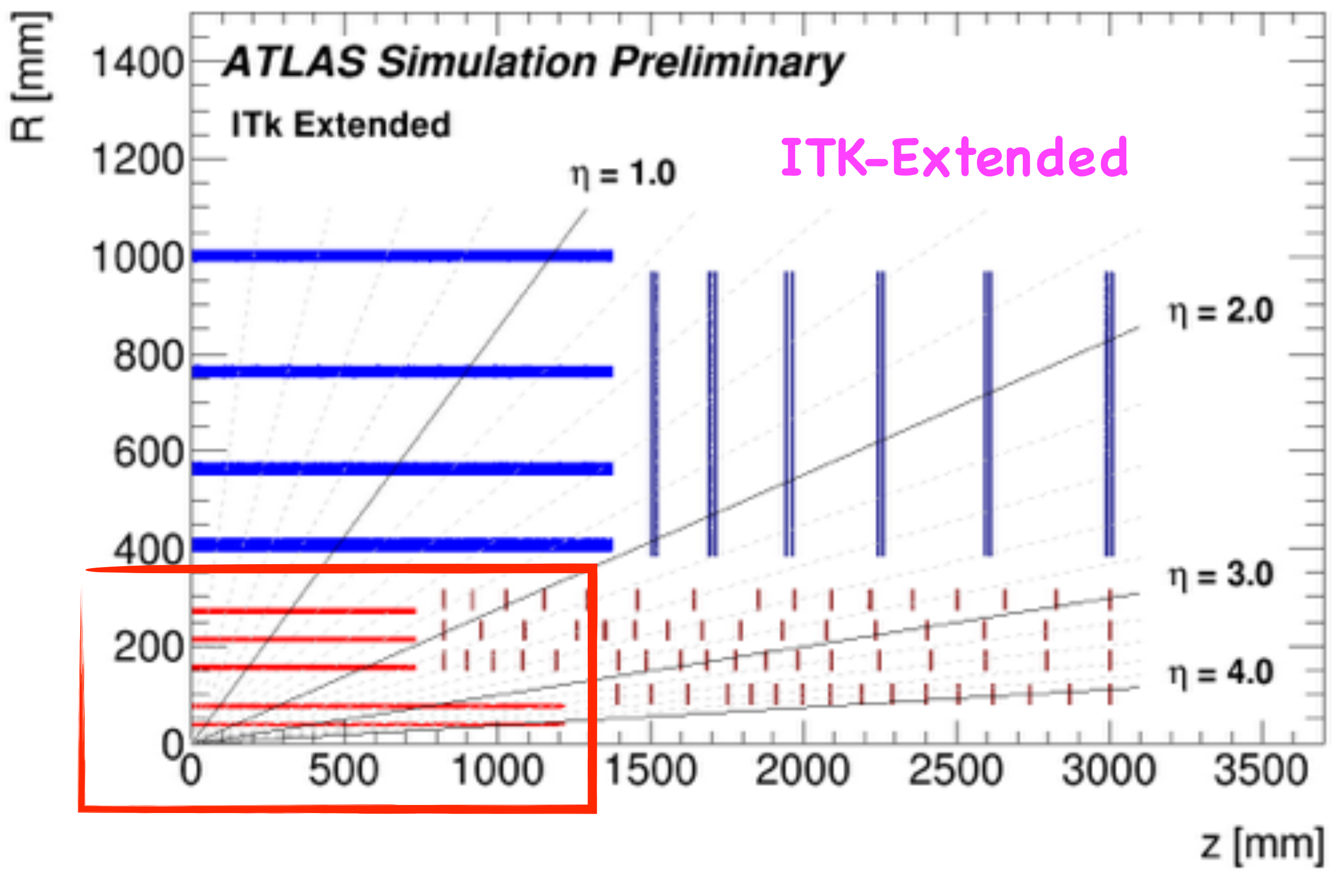
ITk-LoI & Scoping Scenarios

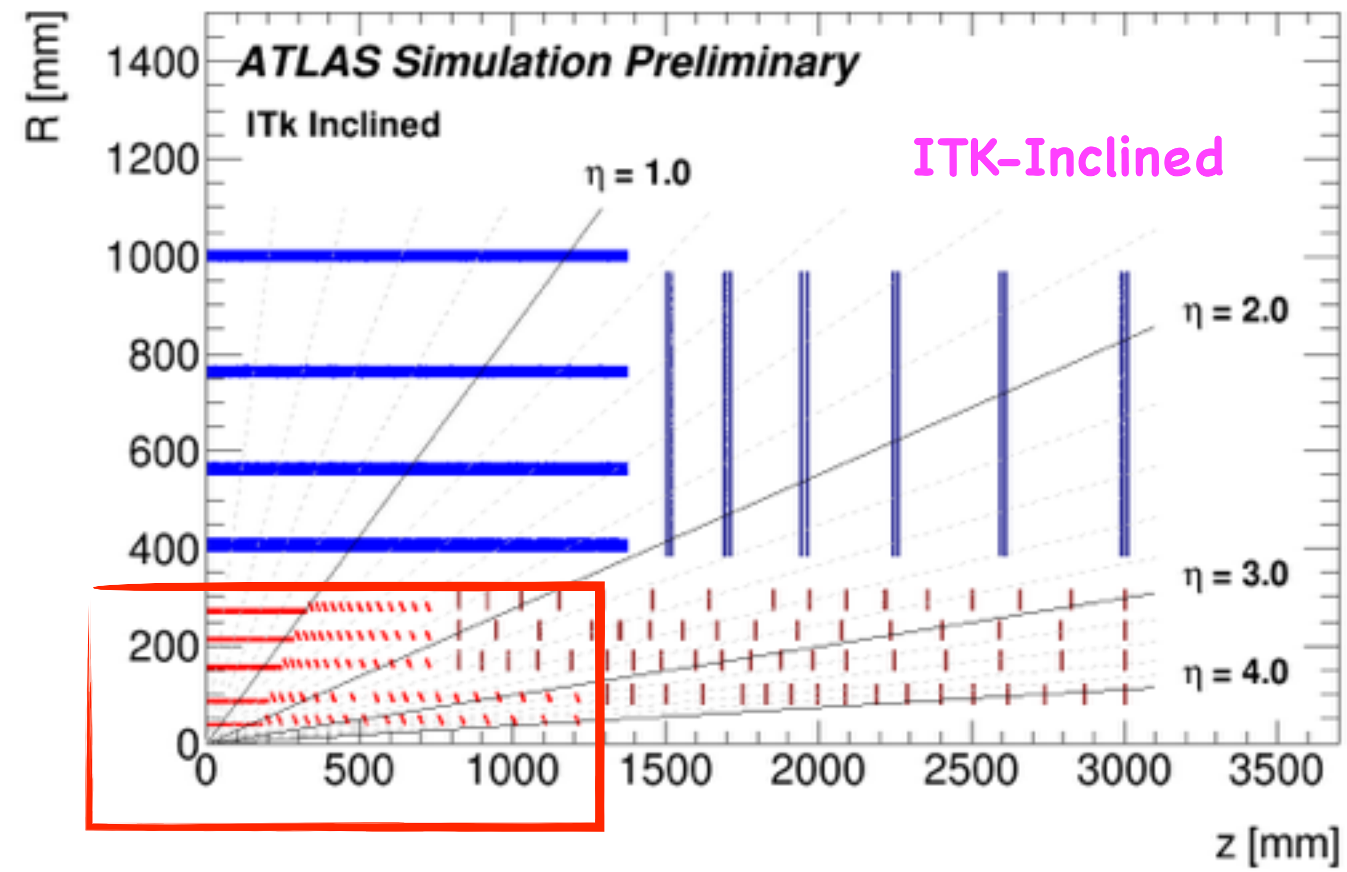
- [ATLAS Phase-II Upgrade Scoping Document] (CERN-LHCC-2015-020)
- 271MCHF – "Reference"
  - ITk up to $|\eta|$ = 4.0, HGTD...
- 229MCHF – "Middle"
  - ITk up to $|\eta|$ = 3.2, central region degradation
- 200MCHF – "Low"
  - ITk up to $|\eta|$ = 2.7, significant central region degradation
- L0 up to 40 MHz, L1 up to 400 kHz, HLT up to 10 kHz (100 kHz L1 and ~1kHz HLT in Run2)



post-Scoping layouts

ATL-PHYS-PUB-2016-025





- based on the **Reference** scenario
- |η| ≤ 4.0, #**Pix** barrel layers = 4->5
- **PixEC** provides uniform coverage through 4 concentric rings

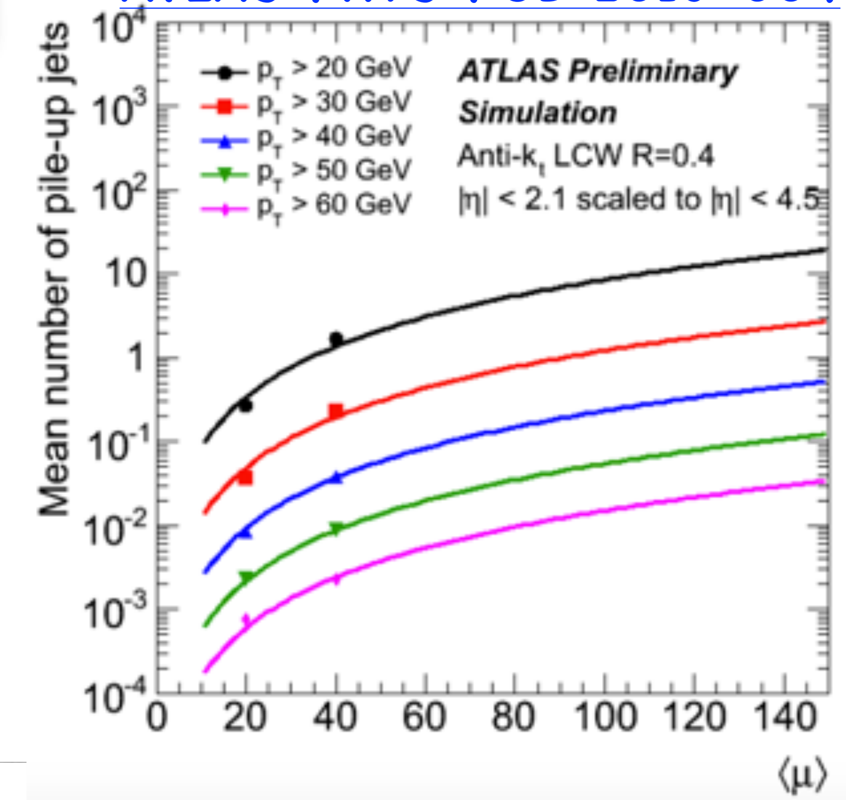
- #**Strip** double sided layers = 5->4
- **StripEC** lengthened, #EC discs = 7->6
- Strip layer in **1.0 < |η| < 1.2 removed**

pile-up, pile up, pile up!

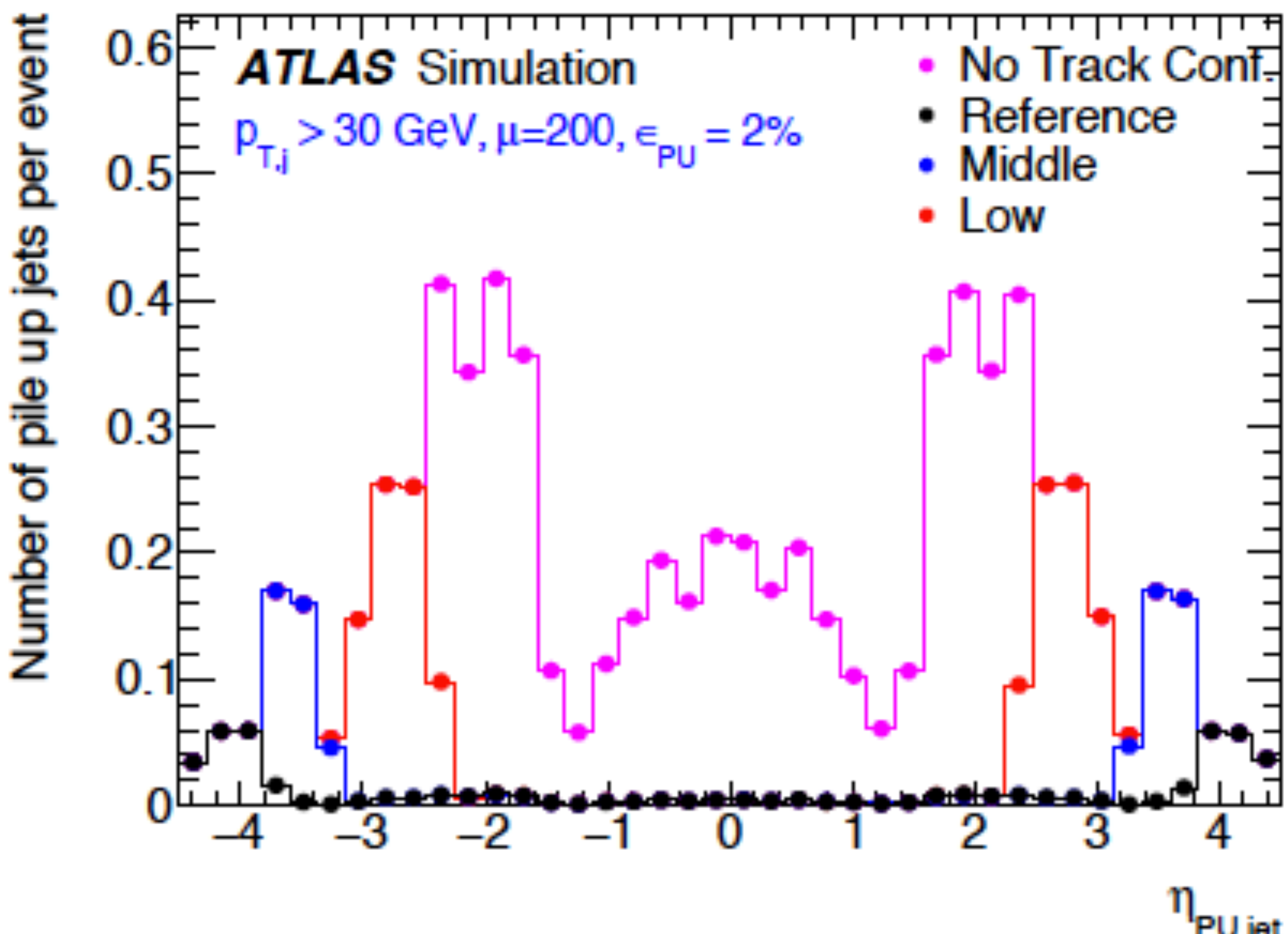
ITK-LoI(VF)

- Run1: $\langle\mu\rangle = 20$ for $p_T > 30$ GeV … $\langle n_j^{PU} \rangle$ ~0.04
- HL-LHC: $\langle\mu\rangle = 200$ for $p_T > 30$ GeV … $\langle n_j^{PU} \rangle$ 5-7
  - **pile-up mitigation most important!** (offline and online)

ATLAS-PHYS-PUB-2013-004



CERN-LHCC-2015-020



ε_{sig} X ε_{bkg} rejection

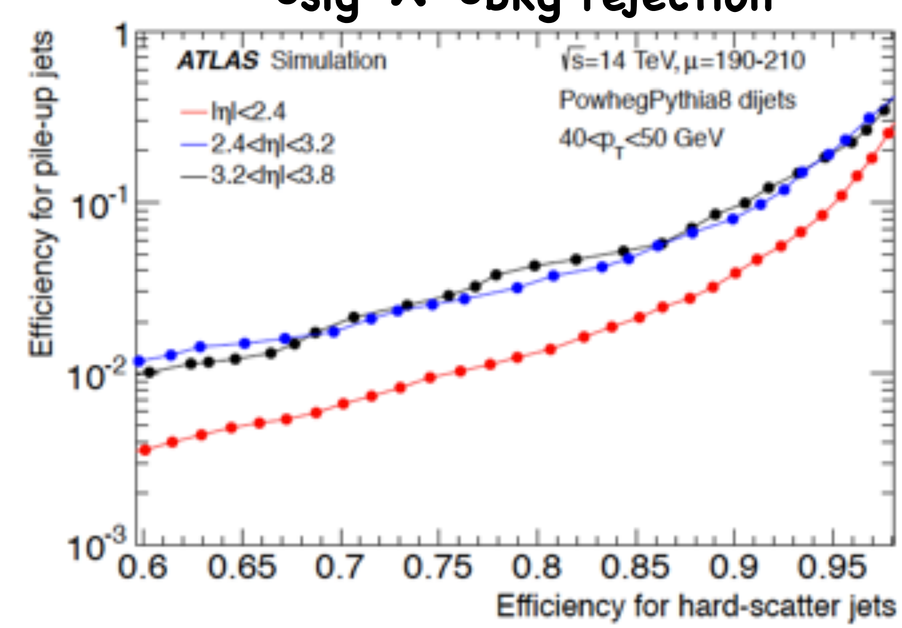


Illustration of the effect of ITk on pile up mitigation (Scoping Document)

jet energy scale calibration

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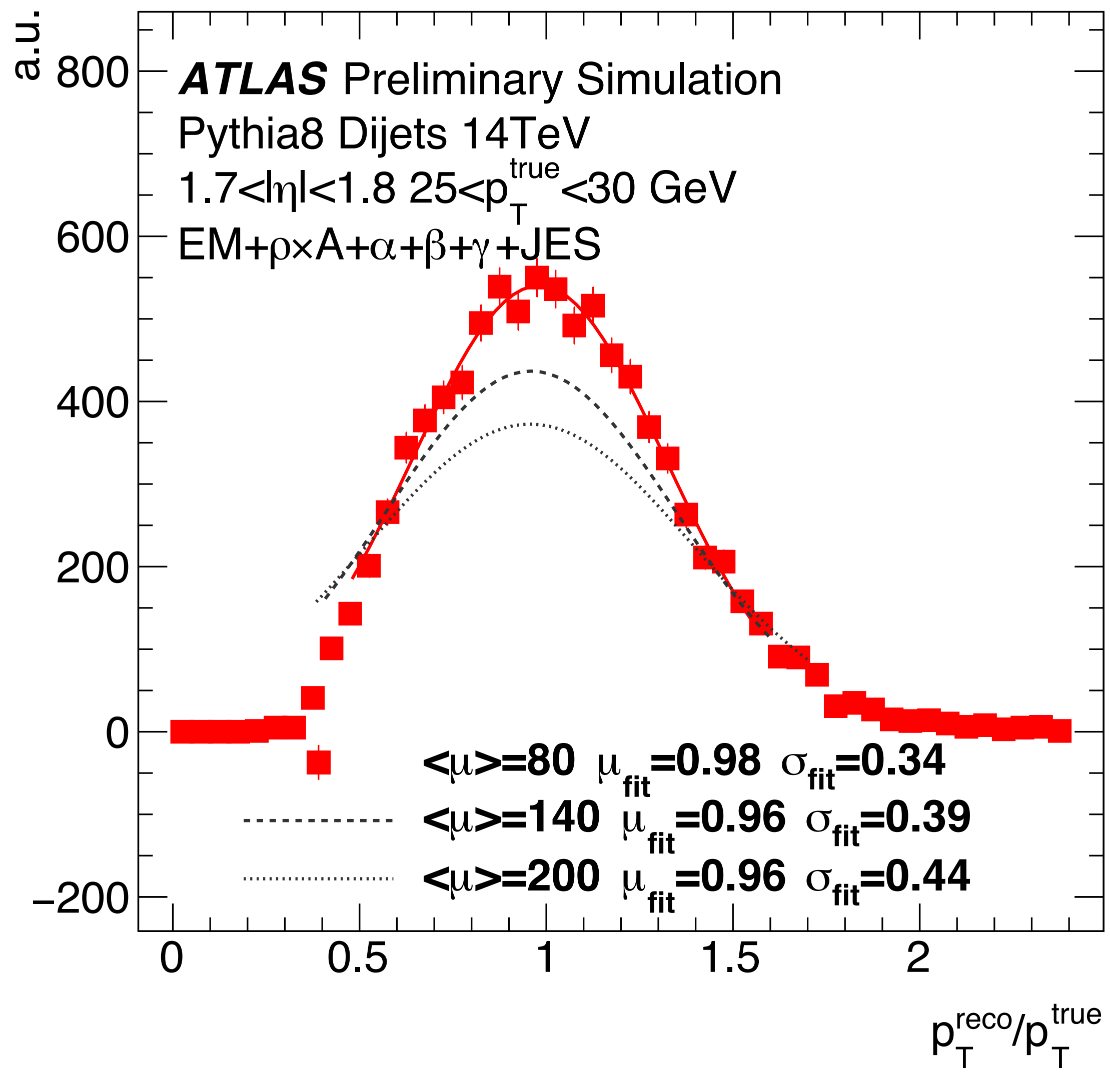
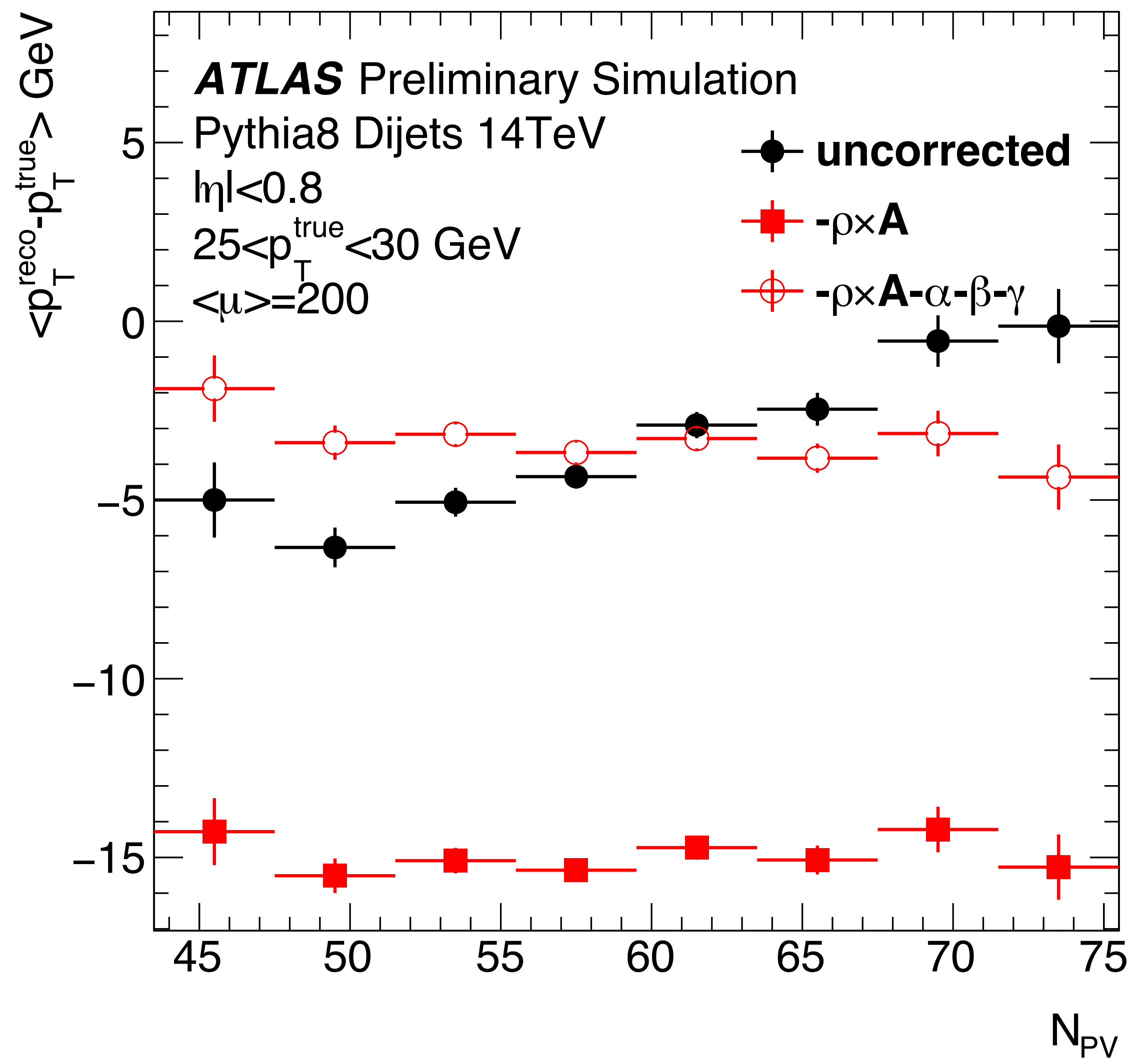
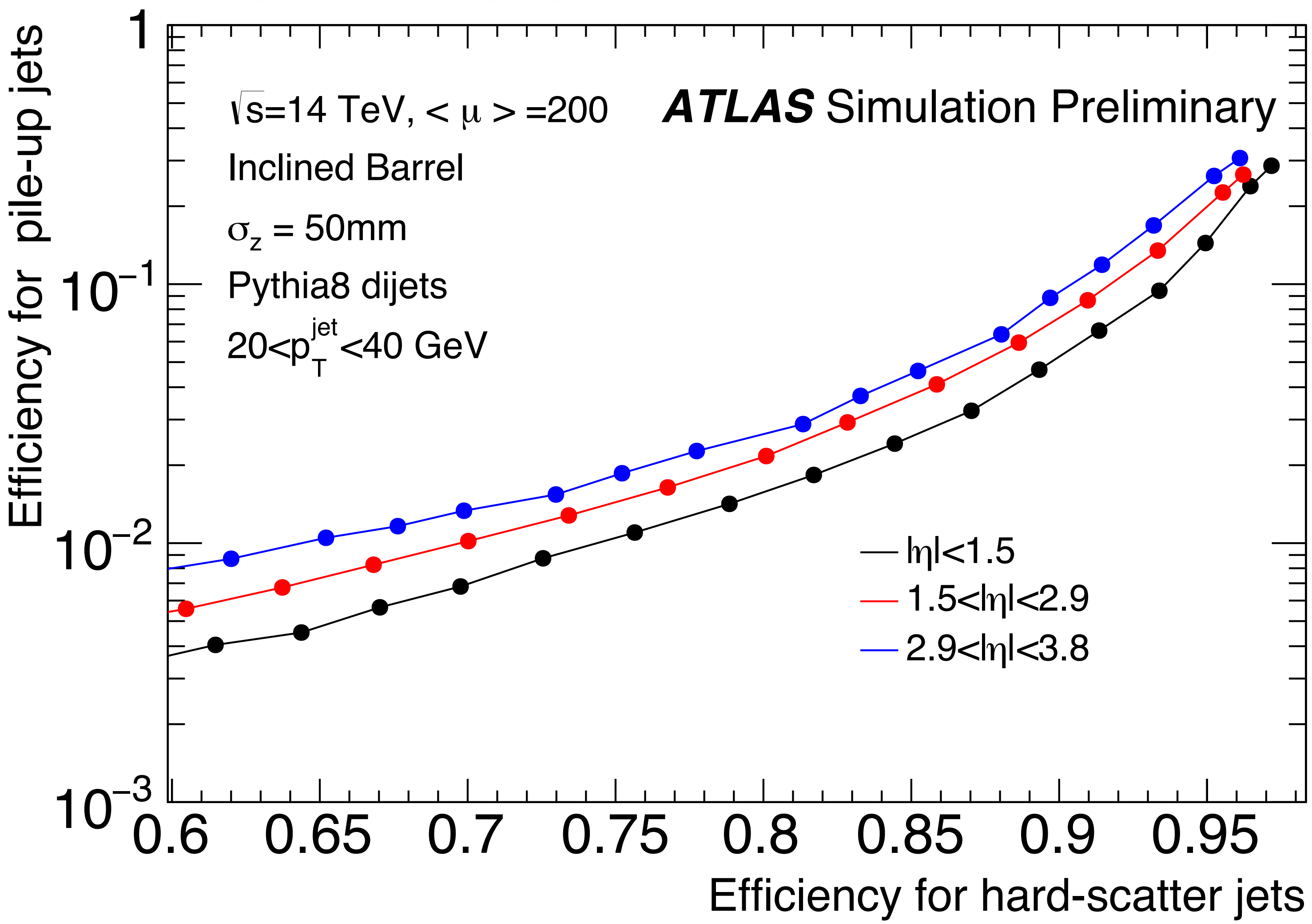




- great truth-reco correlation even at low p_T (20-30 GeV) for the full correction: ρArea + residual (μ,N_{PV}) + constant
  - non-closure within 4% with ~40% resolution
  - stable vs N_{PV} without large overcorrection

pile up suppression in small-R jets



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ITK-Inclined

$$R_{pT} = \frac{\sum_{i \in PV0} p_T^{track,i}}{p_T^{jet}}$$

- efficiency for signal selection vs background rejection through R_{pT} (charged fraction) for R = 0.4 jets
- extends up to the forward region using the "Inclined Barrel" simulation
- for 2% pile up survival probability we have ~75%, 80% and 85% depending on the η

advanced pile up mitigation - Run2

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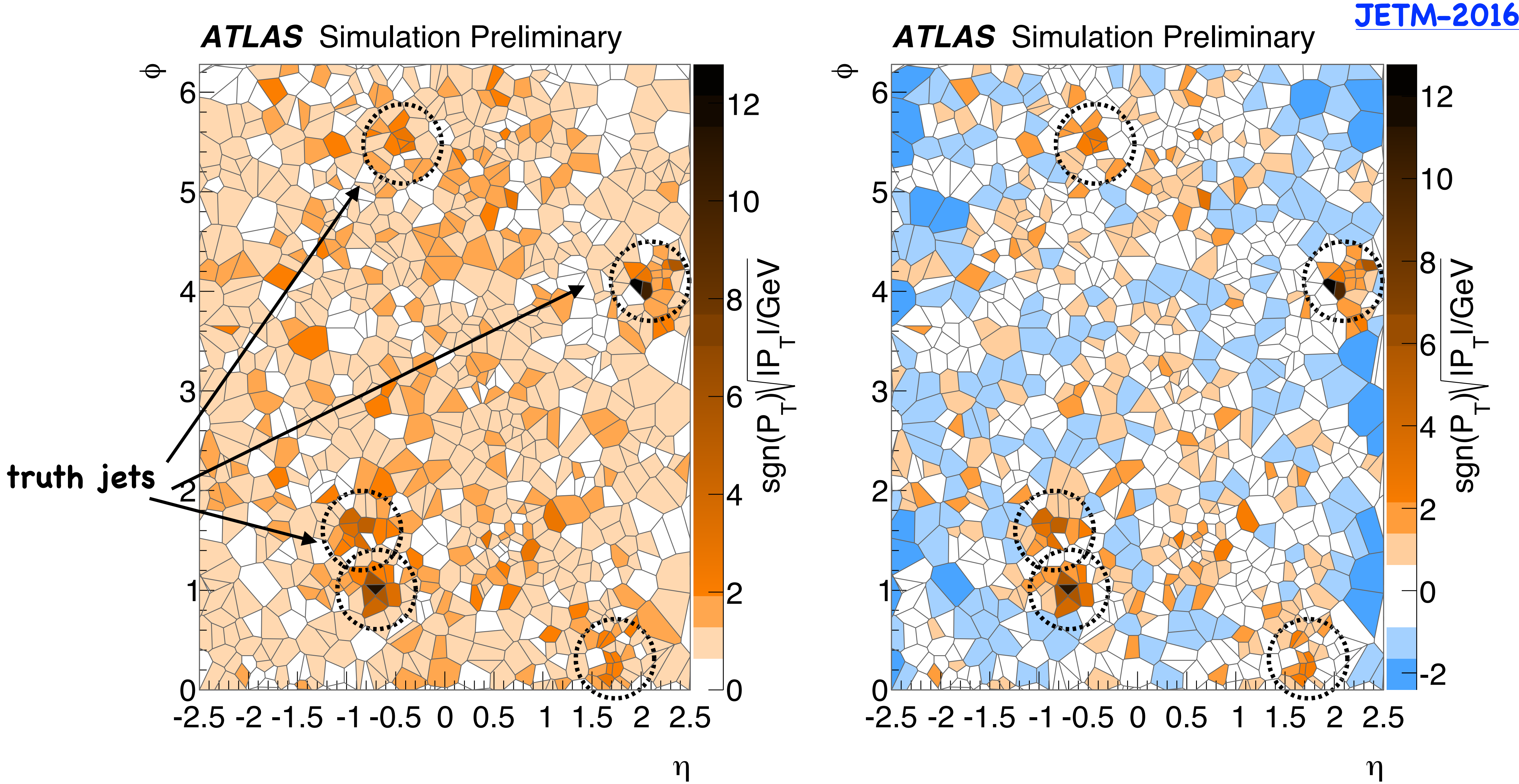

- Voronoi area for clusters (one area per cluster); Run2 conditions (<μ> = 20)
- correction p_T (before-left) —> $p_T^{corr} = p_T - \rho A$ (after - right)

advanced pile up mitigation - Run2

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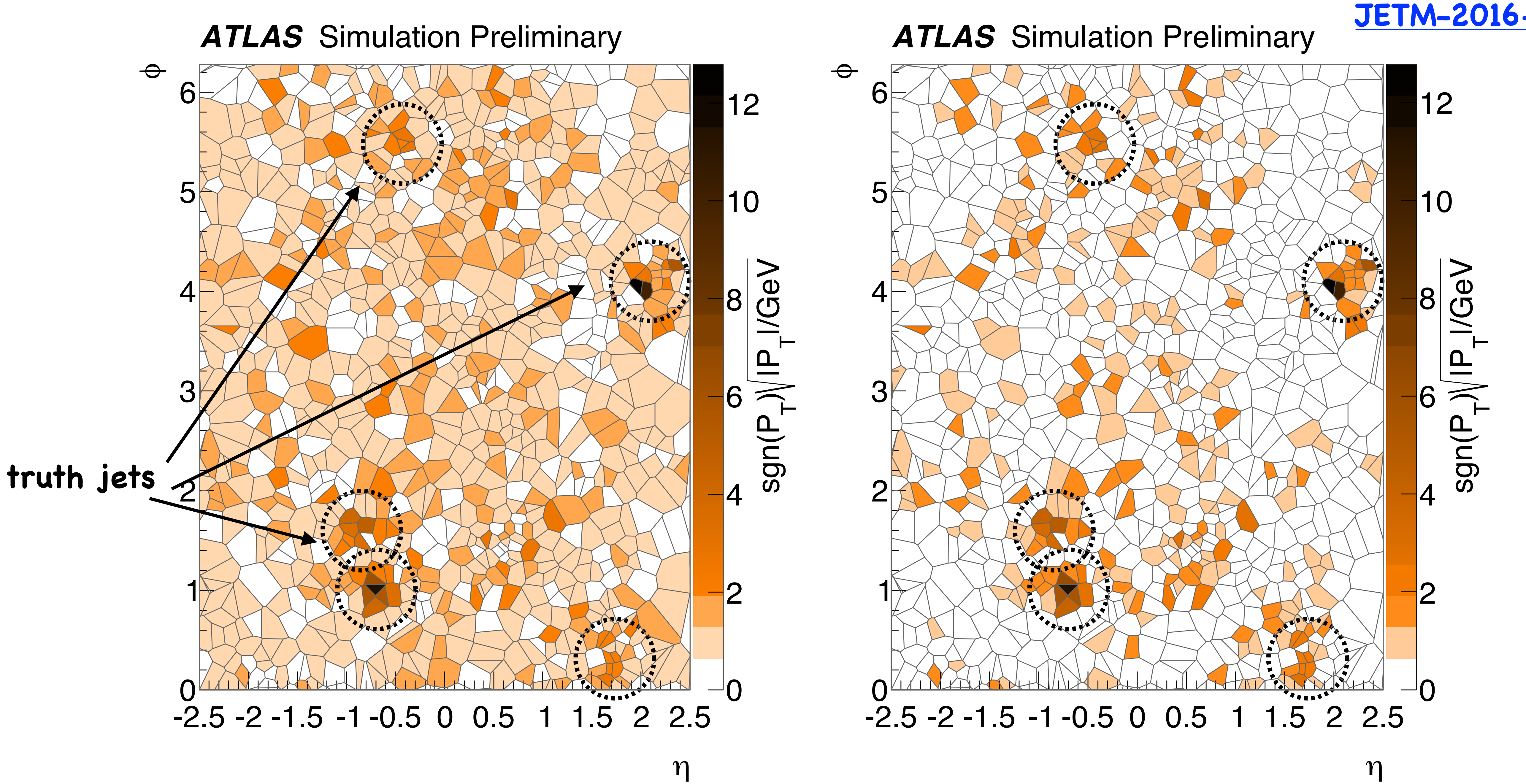

- negative suppression -> blue regions are set to zero

advanced pile up mitigation - Run2

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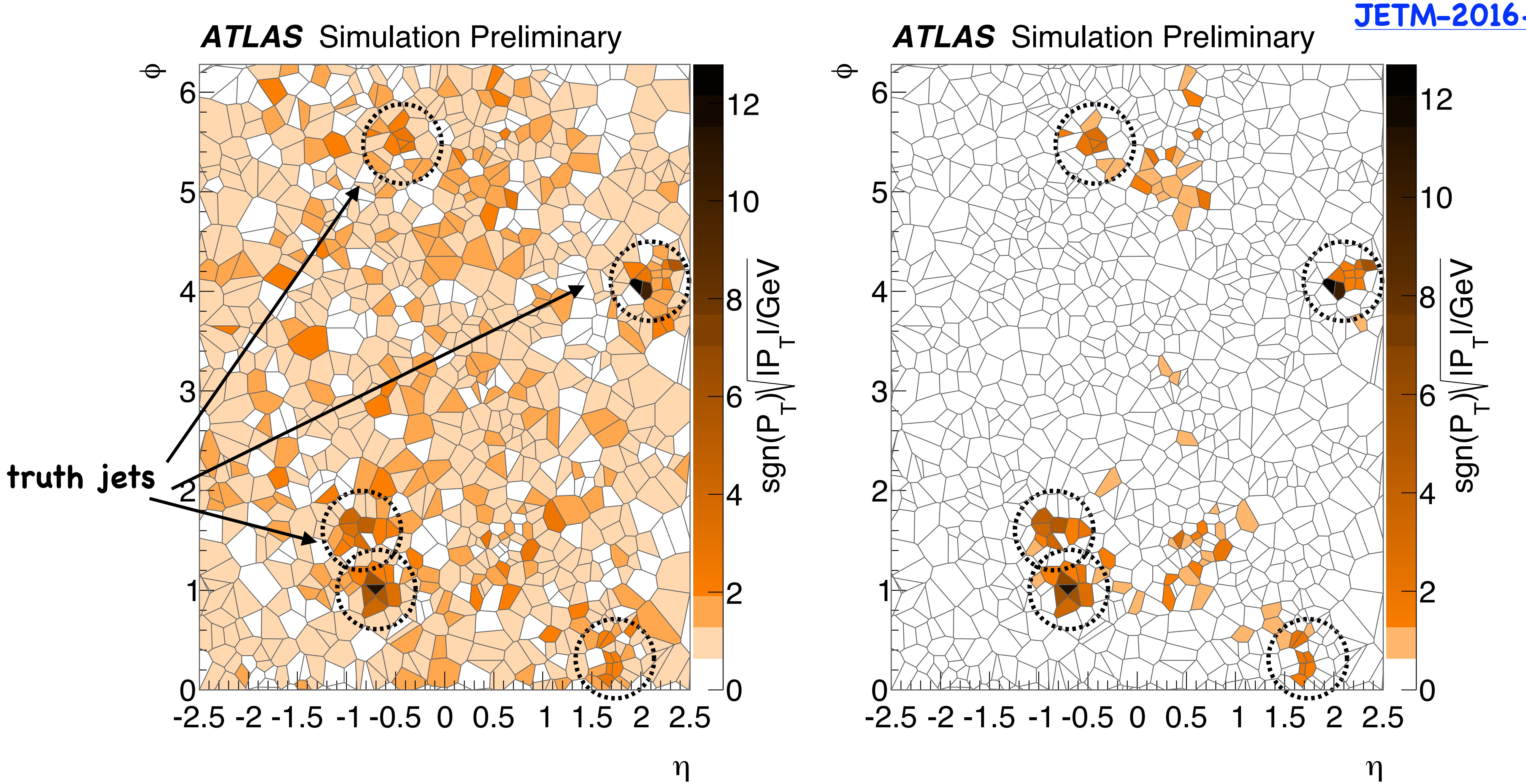
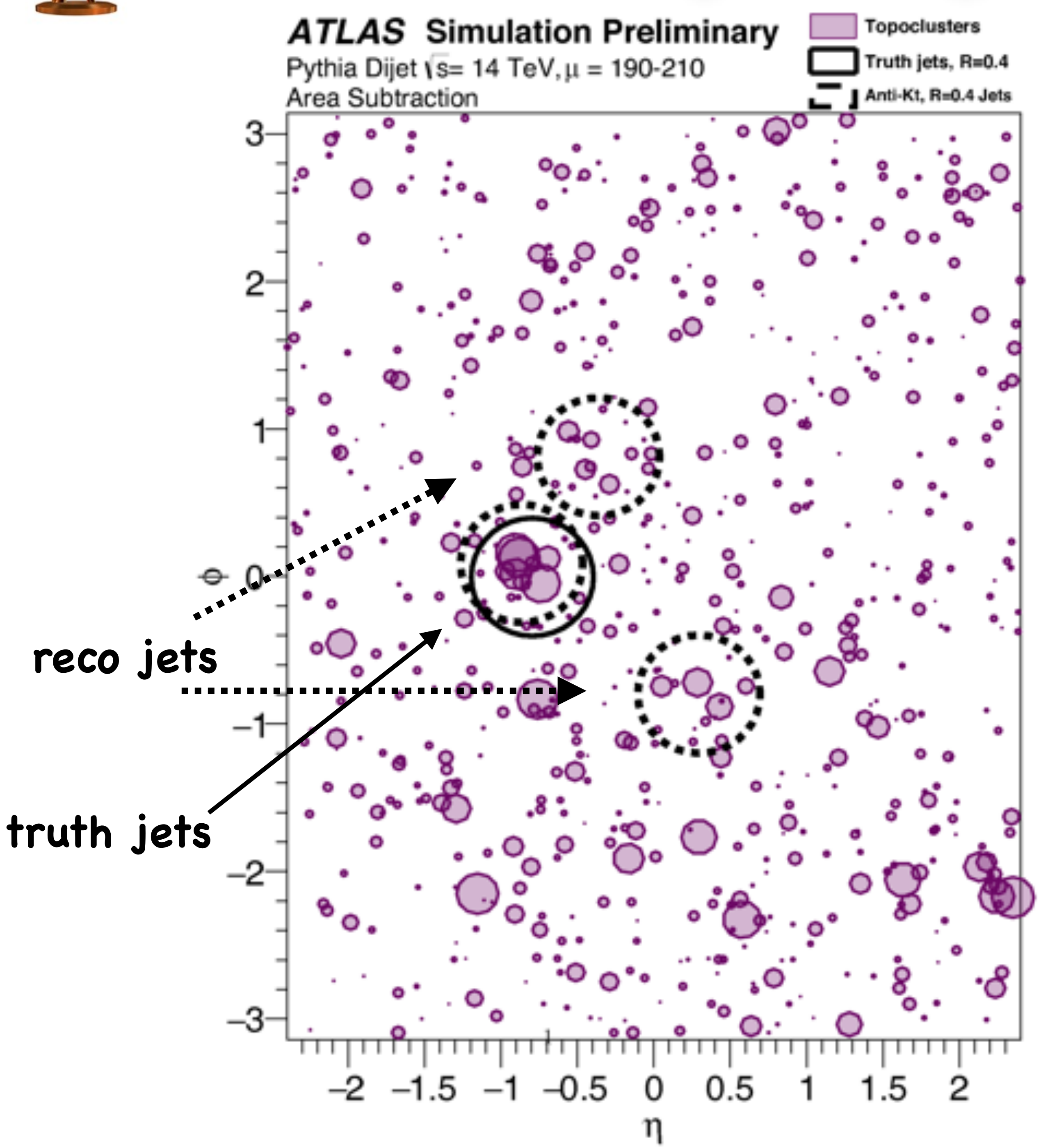
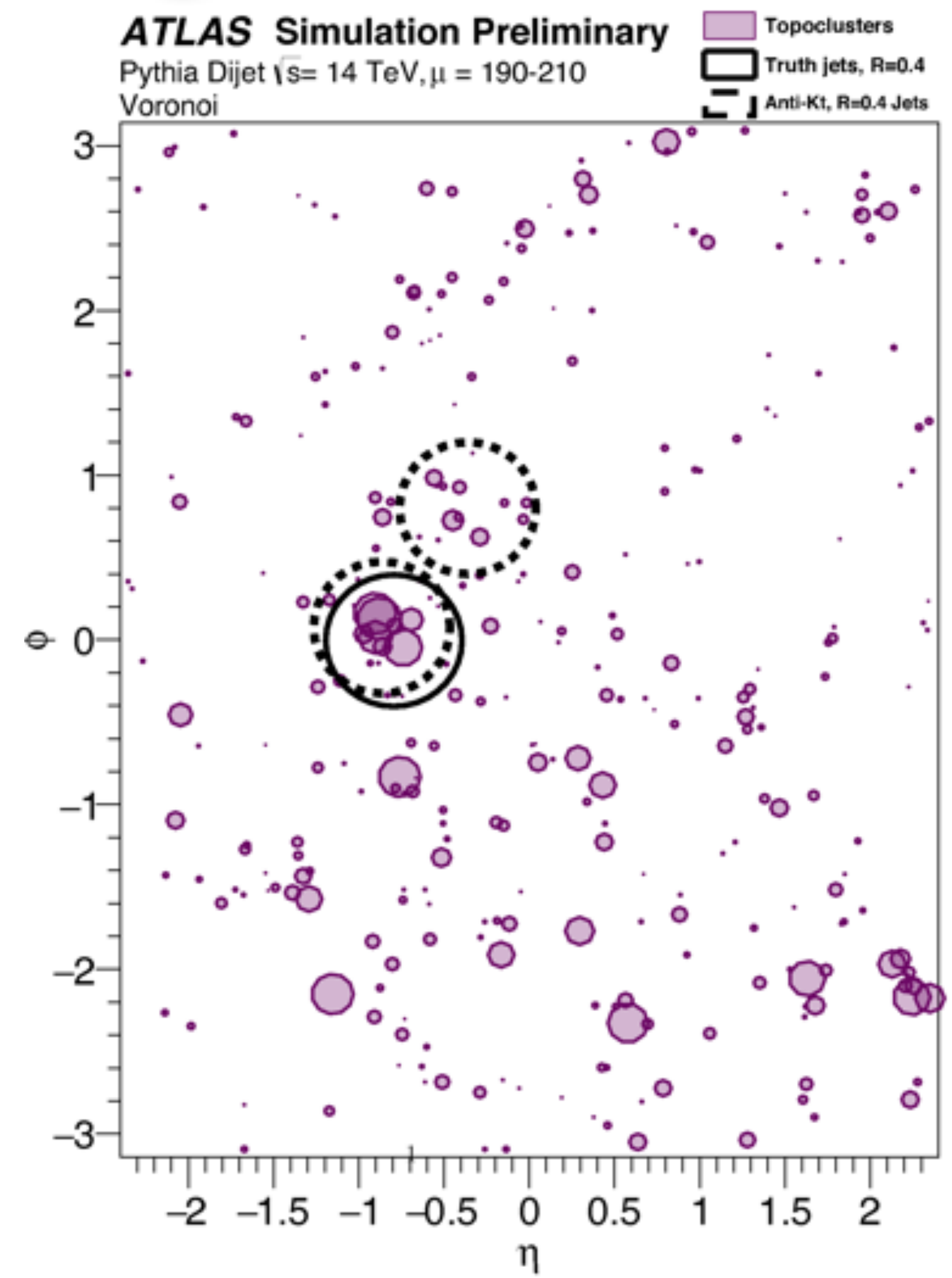


- spreading - spread negative energy to neighbouring clusters
- based on idea that pile up fluctuations on average cancel

advanced pile up mitigation - HL-LHC





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- ρA area subtraction (on jets)
- Voronoi subtraction (on Voronoi areas), zero suppression

advanced pile up mitigation - HL-LHC

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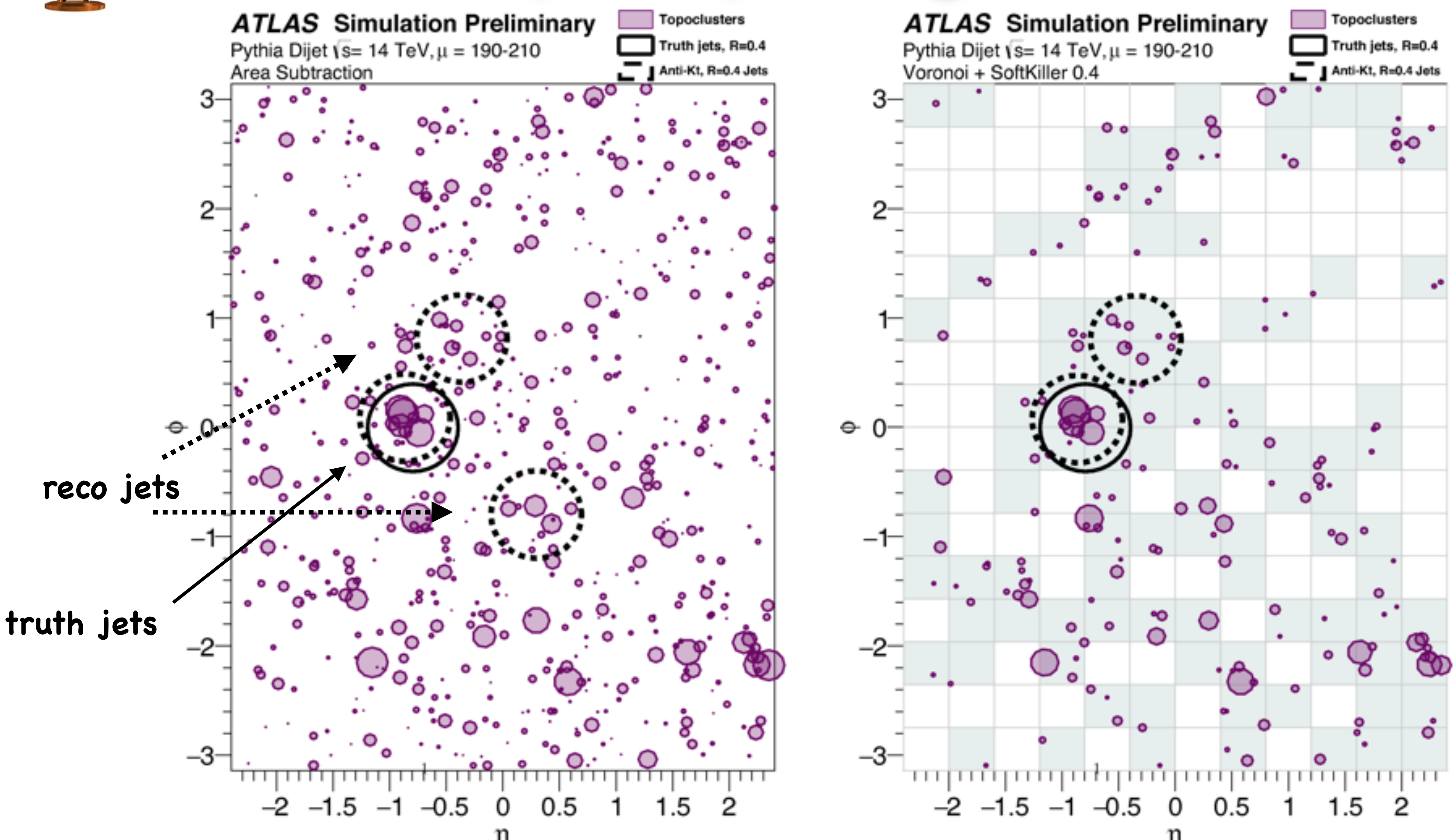
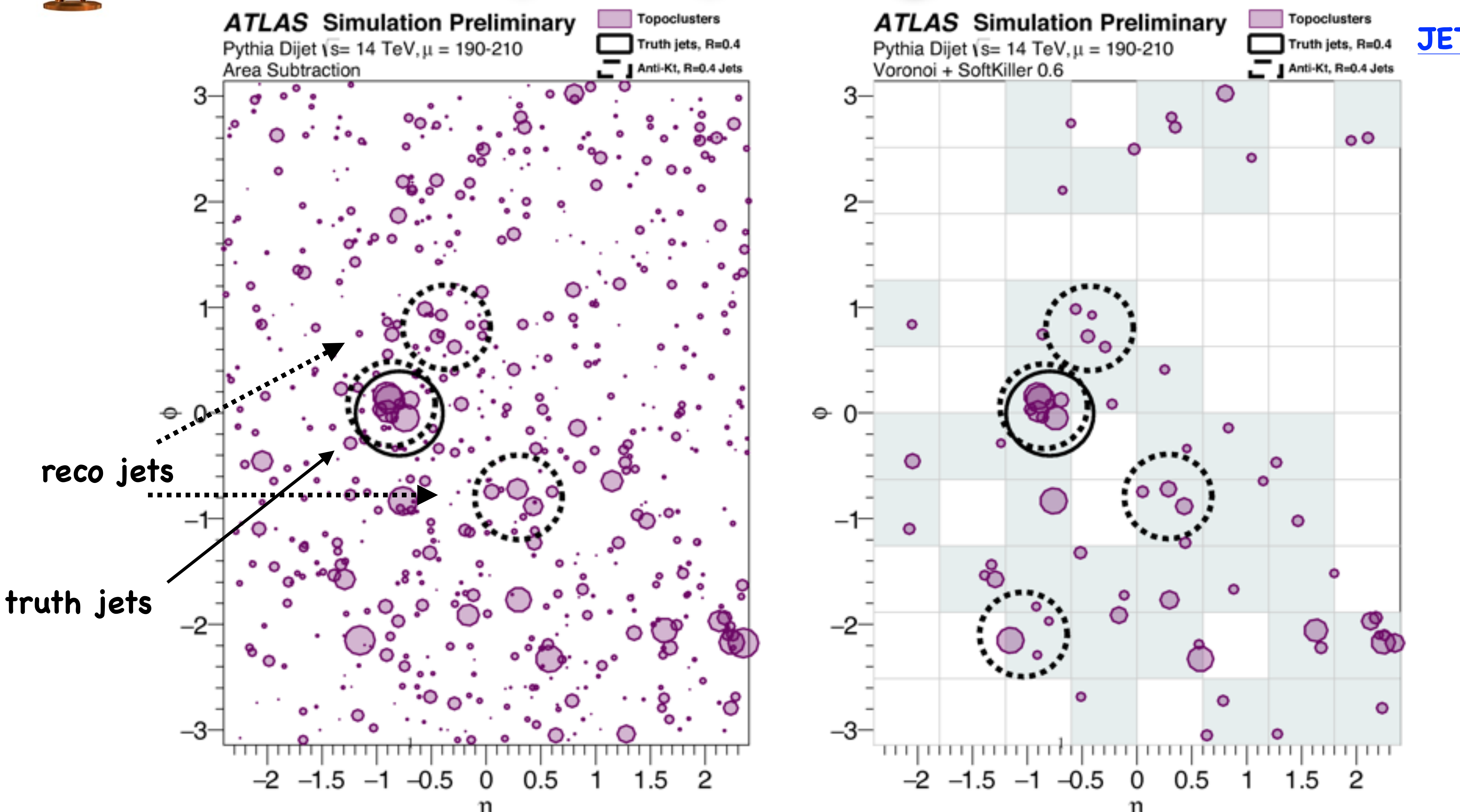


- Soft Killer - divides the detector in grid (**0.4x0.4** here) and defines a (soft) p_T cut to leave the grid half empty
- provides additional cleaning of pile up activity

advanced pile up mitigation - HL-LHC

JETM-2016-012



- Soft Killer - divides the detector in grid (0.6x0.6 here) and defines a (soft) p_T cut to leave the grid half empty
- provides additional cleaning of pile up activity

advanced pile up mitigation - HL-LHC

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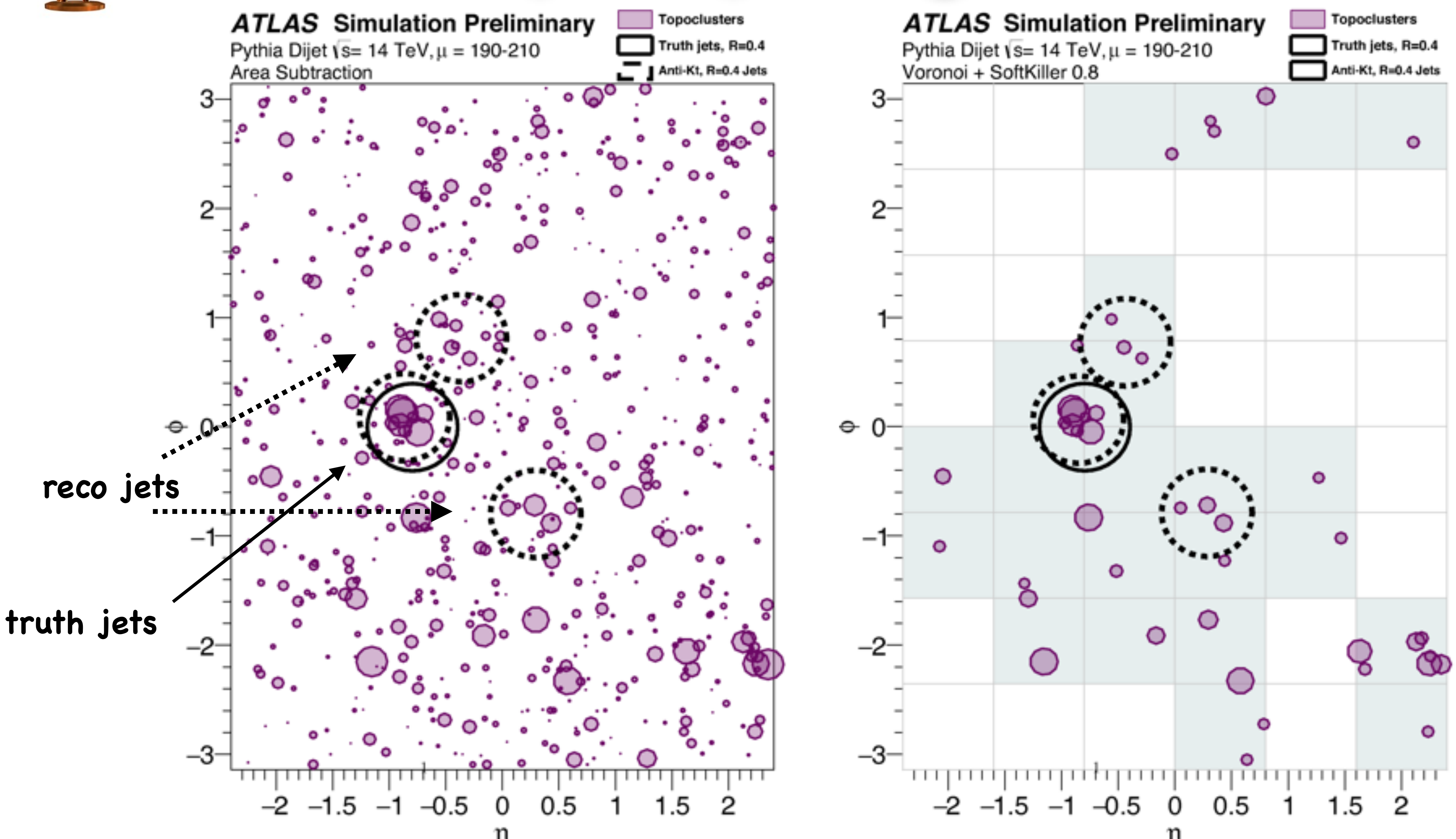

- Soft Killer - divides the detector in grid (0.8x0.8 here) and defines a (soft) p_T cut to leave the grid half empty
- provides additional cleaning of pile up activity

Fat jets @ HL-LHC

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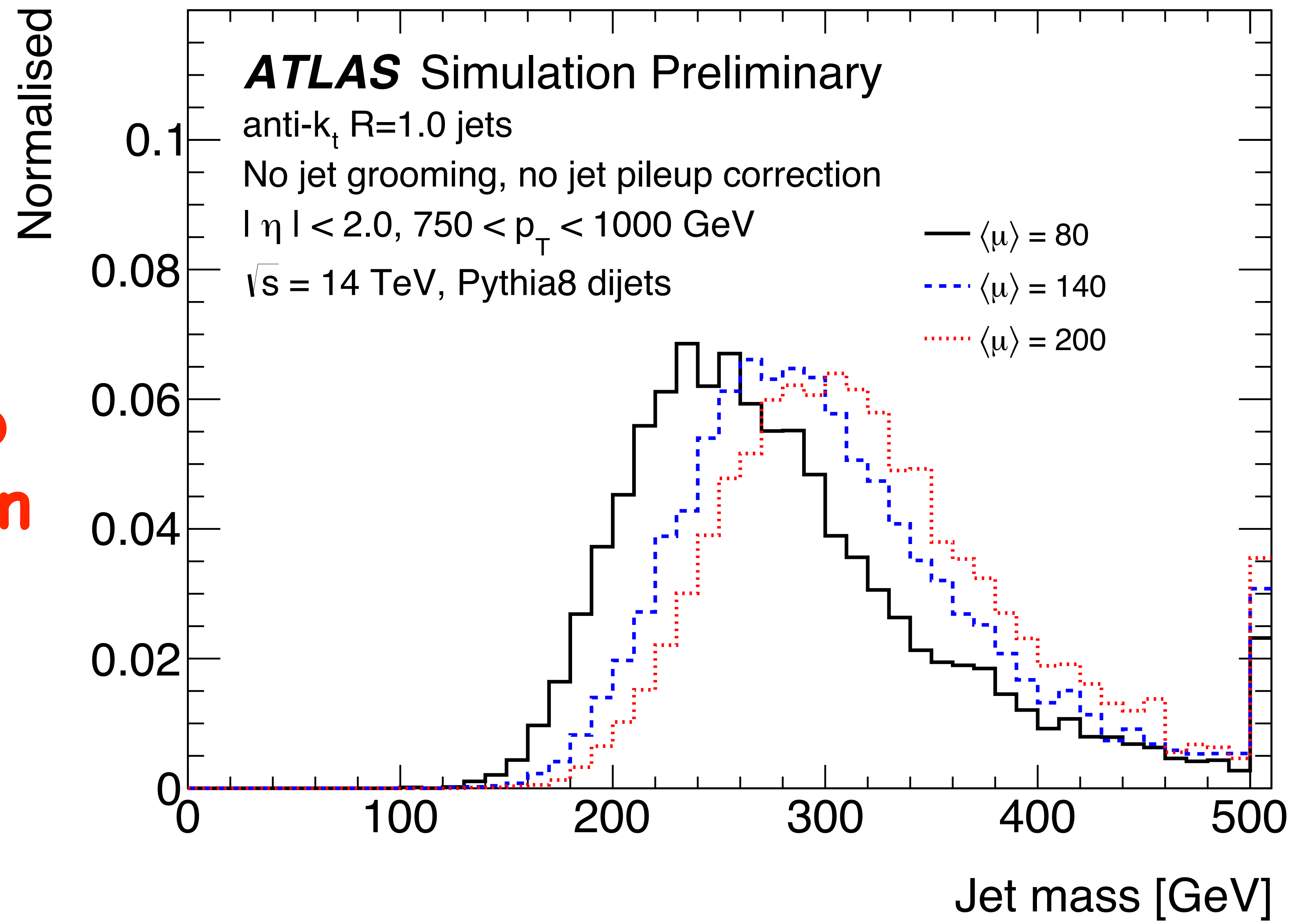

no pile up suppression

QCD Dijets

$|\eta| < 2.0$

$750 < p_T < 1000$ GeV

- used in boosted topologies (typically contains ≥ 1 small jets)
- typically large radius (1.0, 1.2)
- used to reconstruct jet mass -> strong need to mitigate PU

Fat jets @ HL-LHC

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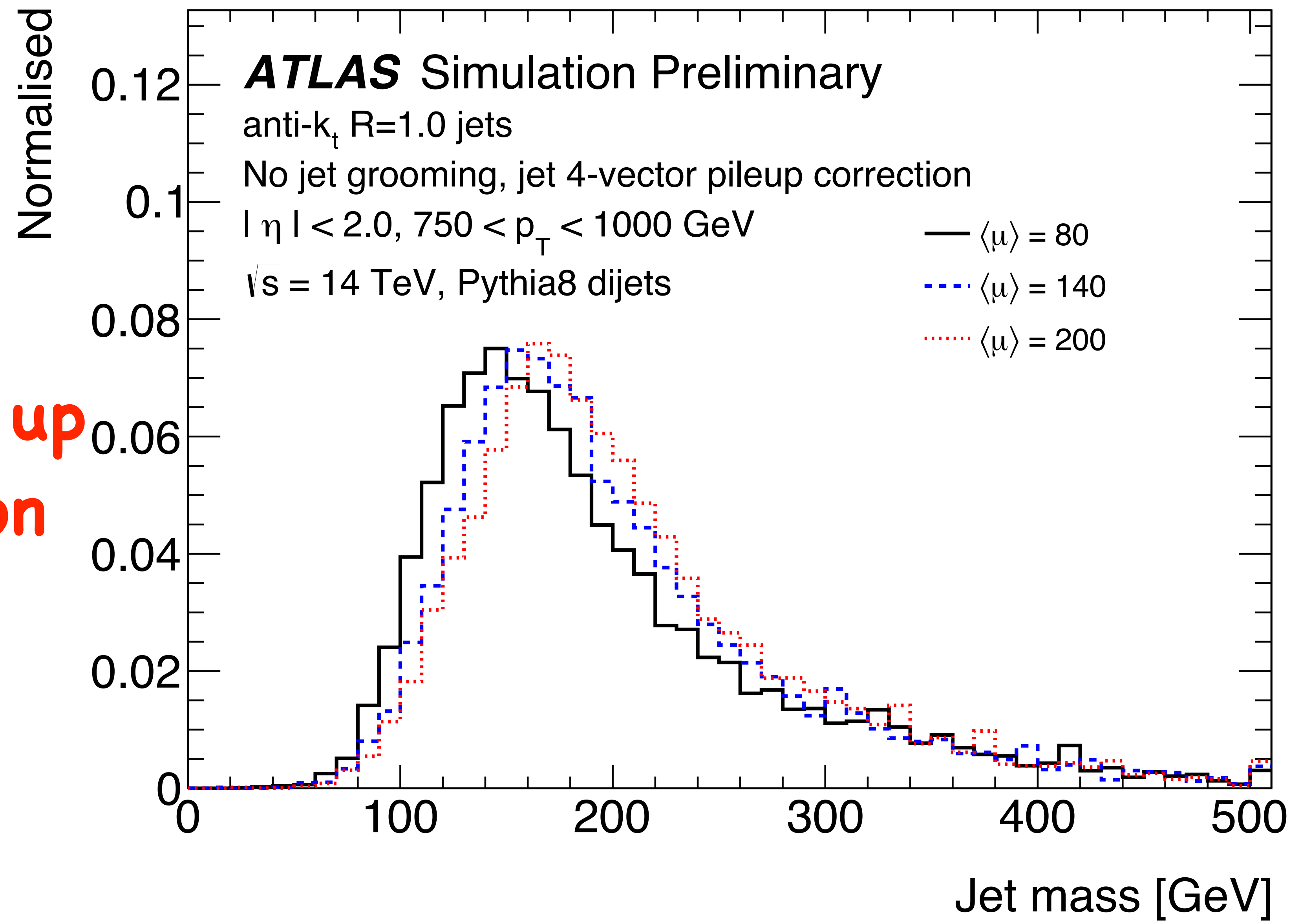
ρA jet pile up suppression



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Fat jets @ HL-LHC

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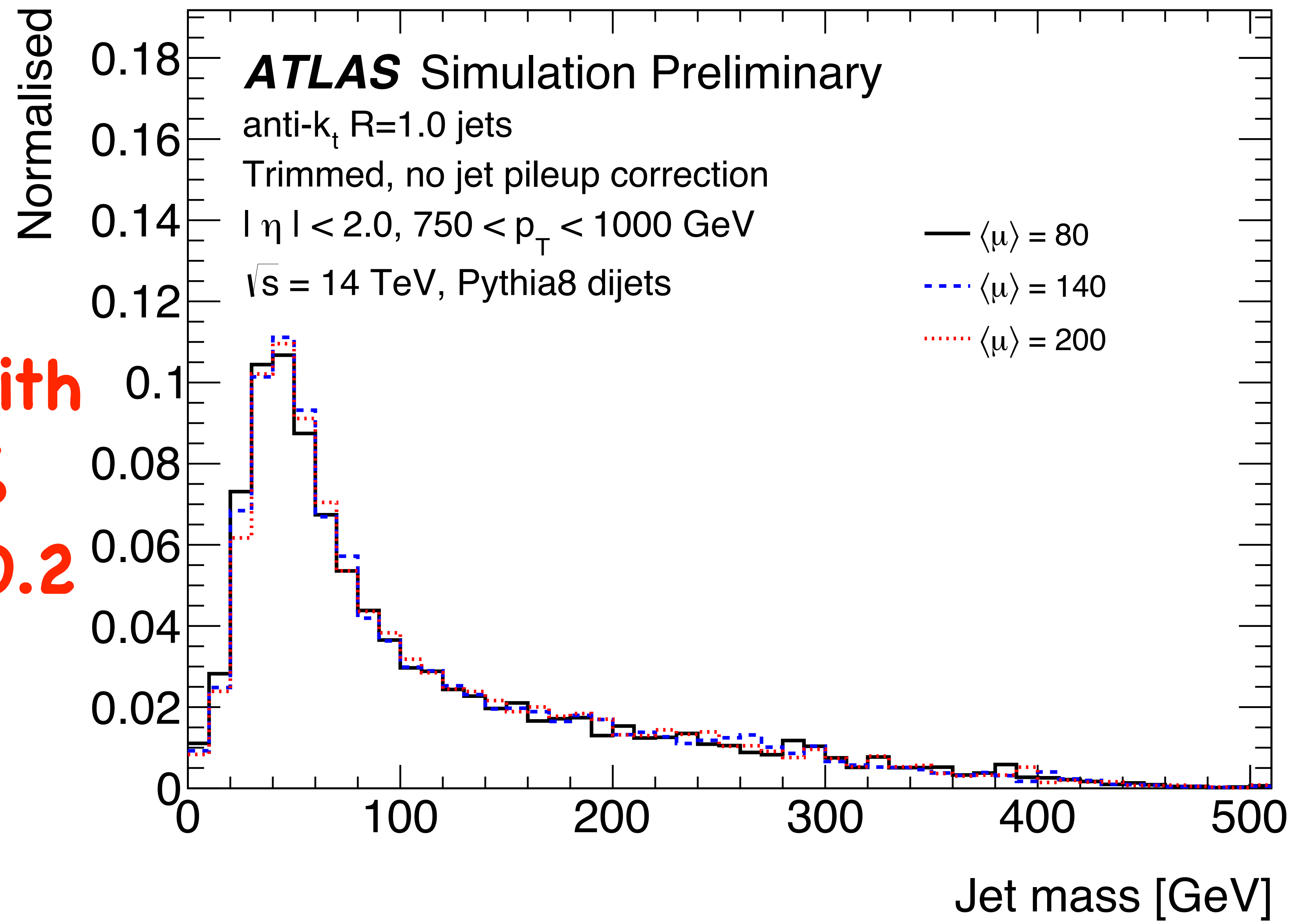
trimmed with f_{cut} = 5% and R_{sub} =0.2



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Fat jets @ HL-LHC

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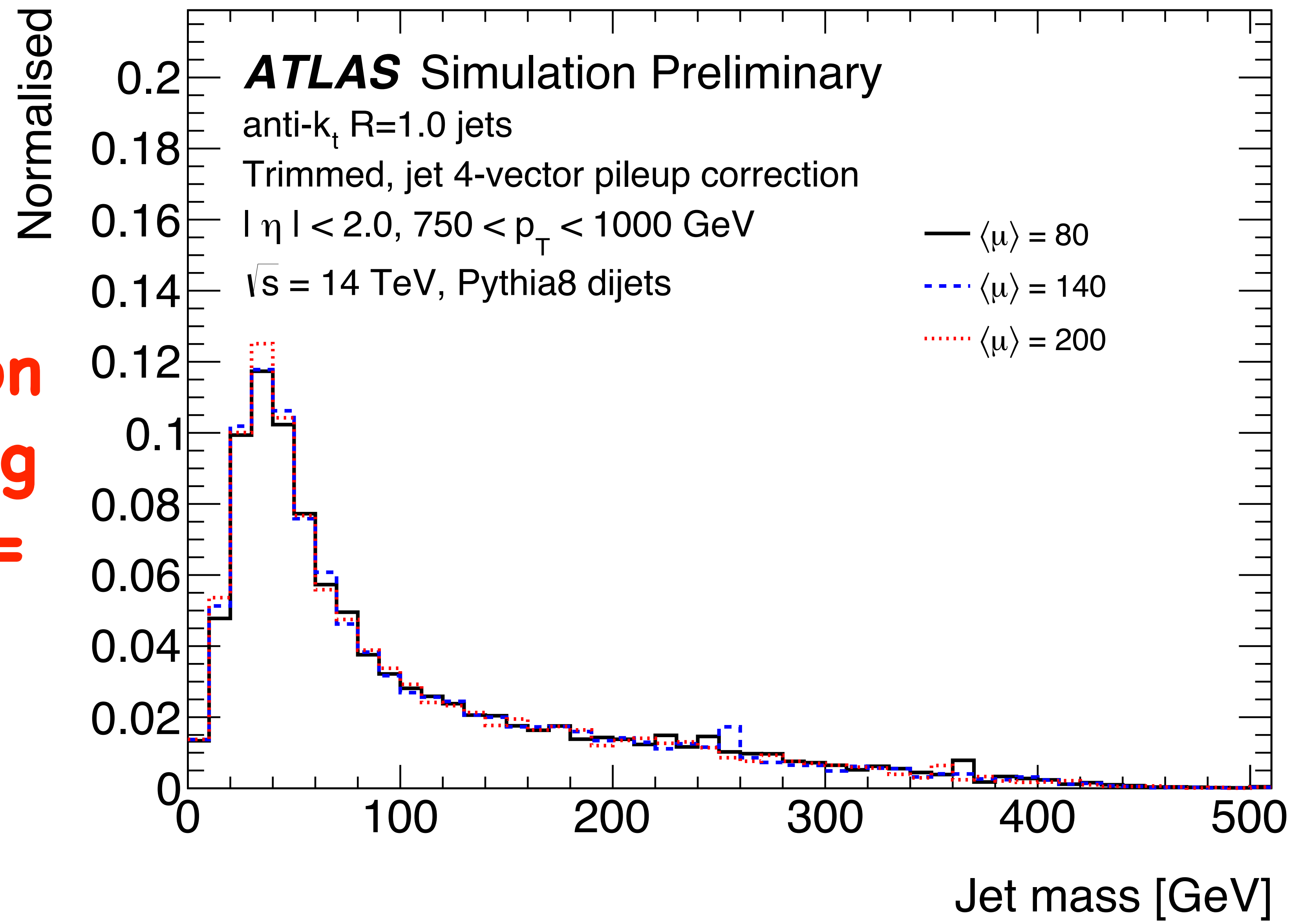
ρA jet pile up suppression + trimming with f_{cut} = 5% and R_{sub} =0.2



QCD Dijets

|η| < 2.0

750 < p_T < 1000 GeV

- overlap of peaks for all three pile up scenarios shows that correction managed to remove most of pile up effects

Z'->tt

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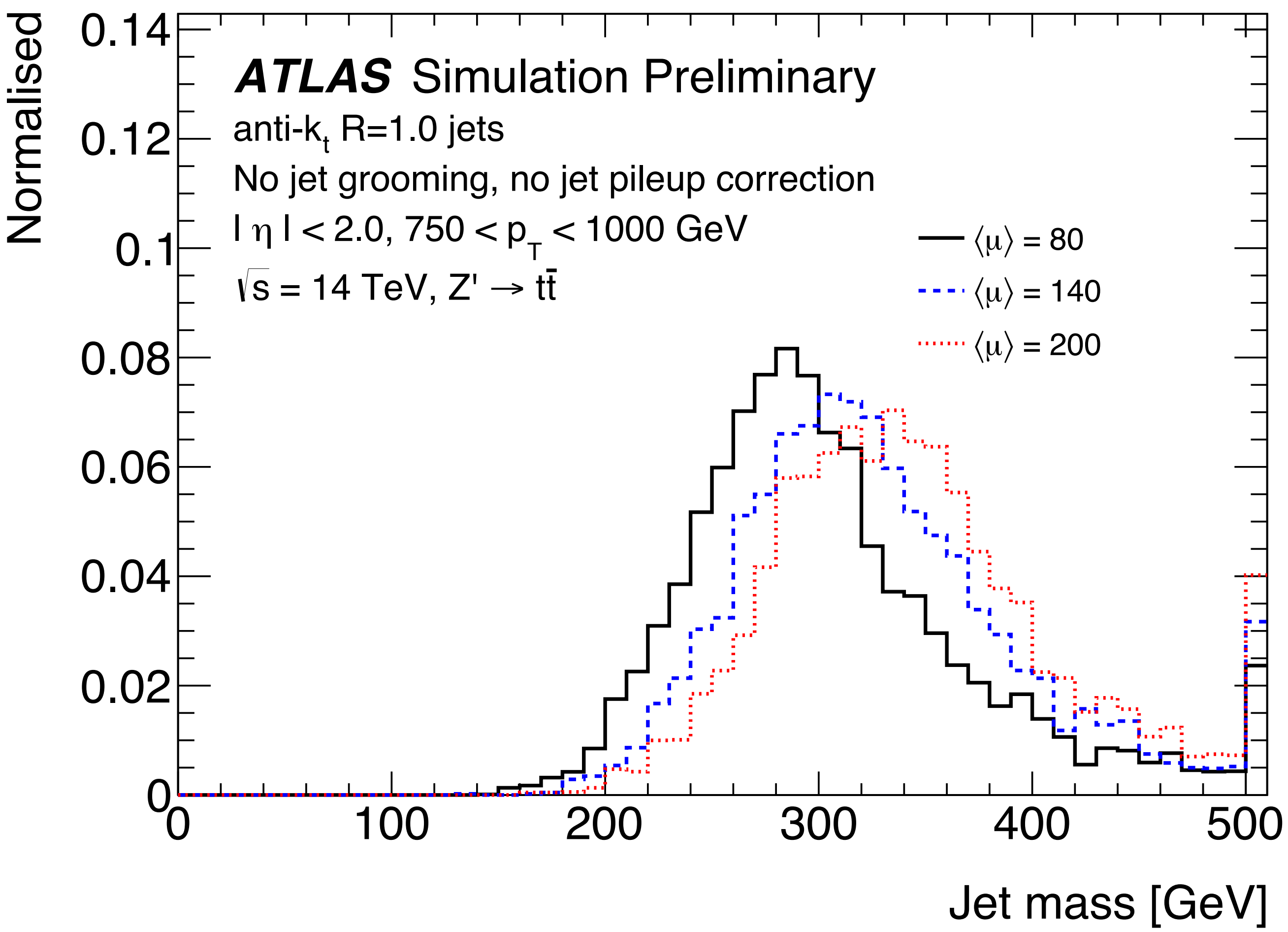
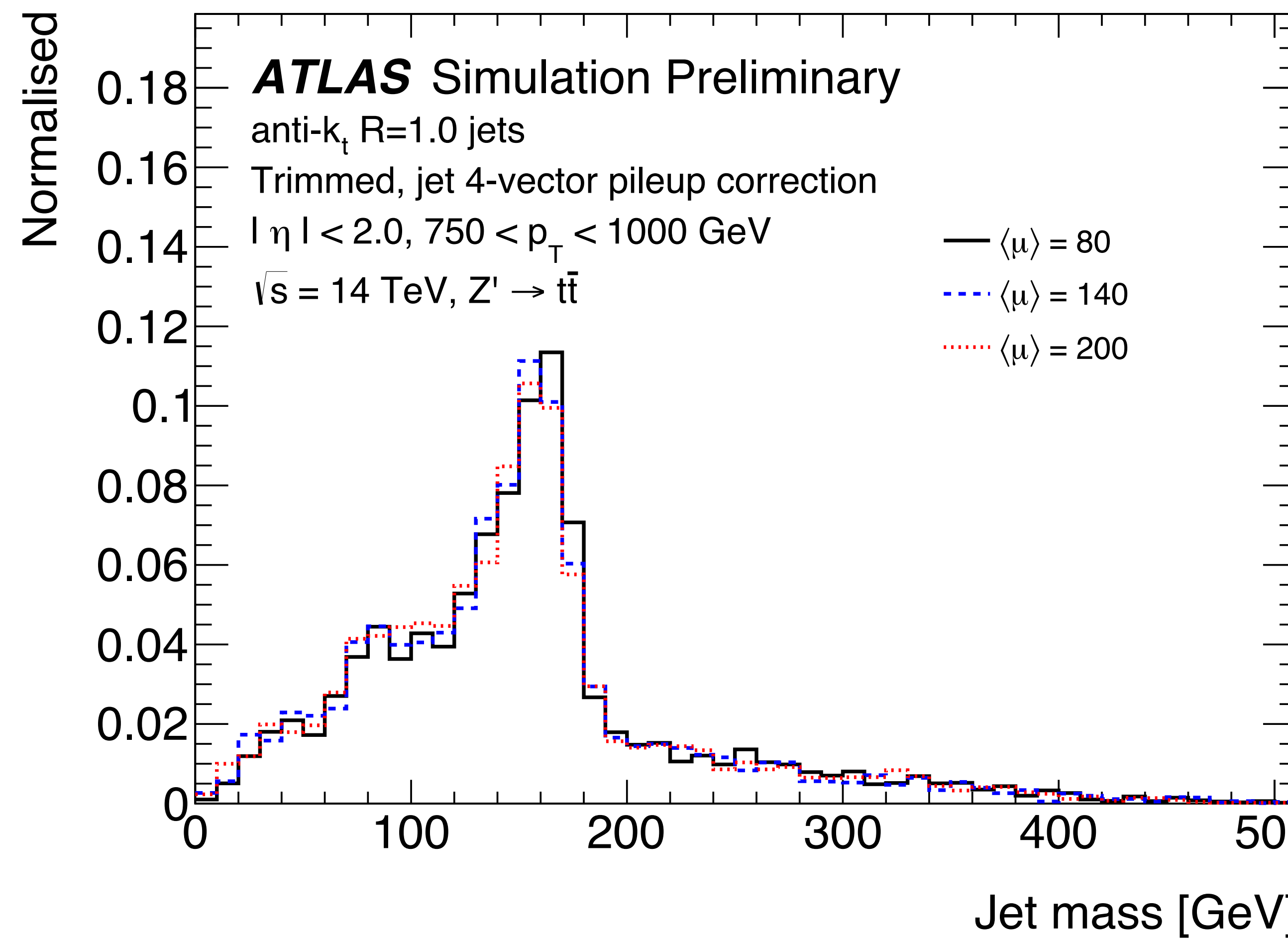
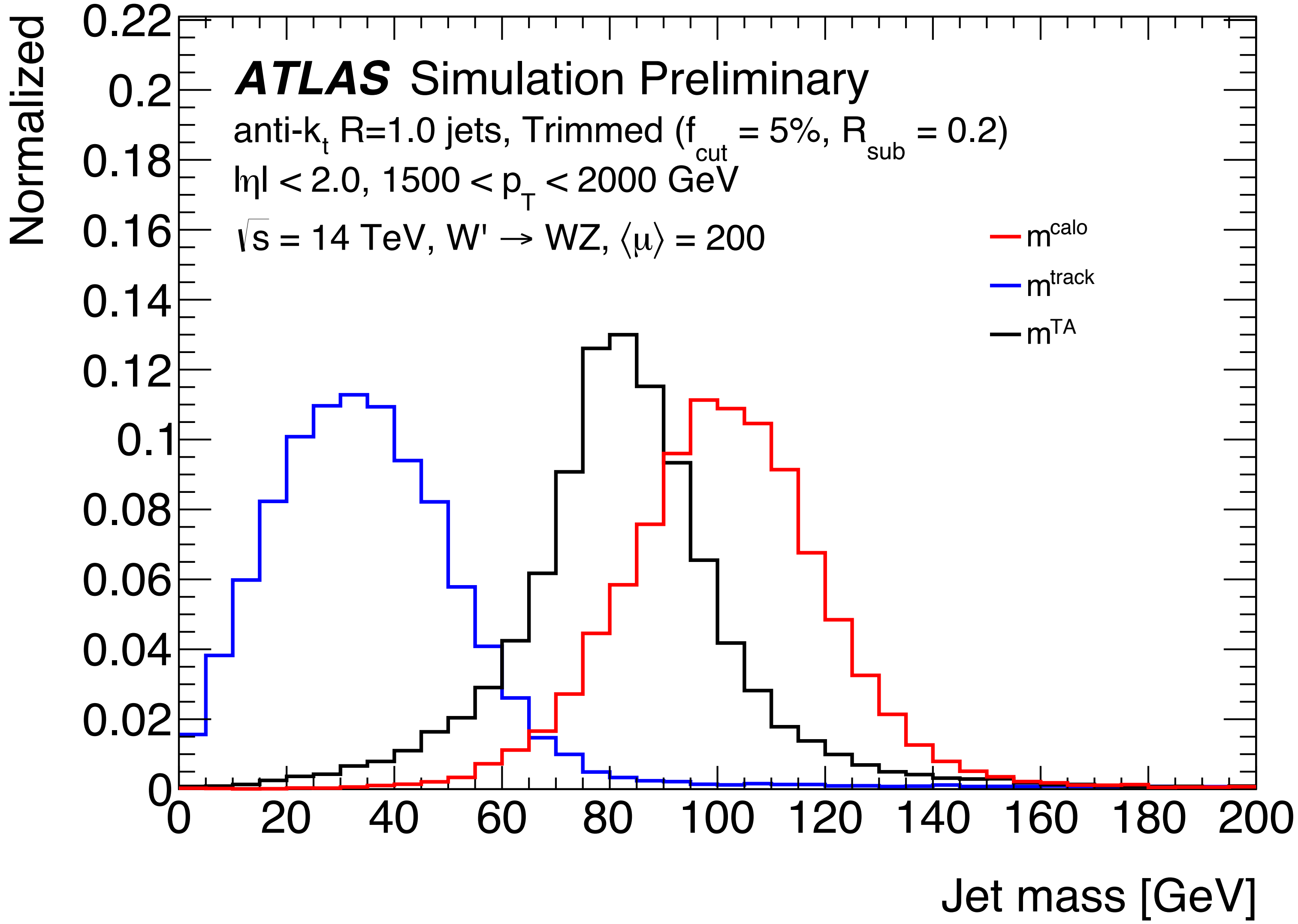




- leading top-jet mass
- combined trimming and ρA subtraction restore the mass information

jet mass(es)



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ITK-Inclined

$|\eta| < 2.0$

$1500 < p_T < 2000$ GeV

- W-jet masses reconstructed with different techniques: **calorimeter-based mass**, **track-based jet mass** (mass from associated tracks) and **track-assisted jet mass** (correction for neutral contribution from p_T^{calo}/p_T^{track})
- R=1.0, trimmed (f_{cut} = 5%, R_{sub}=0.2)
- **track-assisted jet mass is closest to the real mass of the W**

substructure techniques

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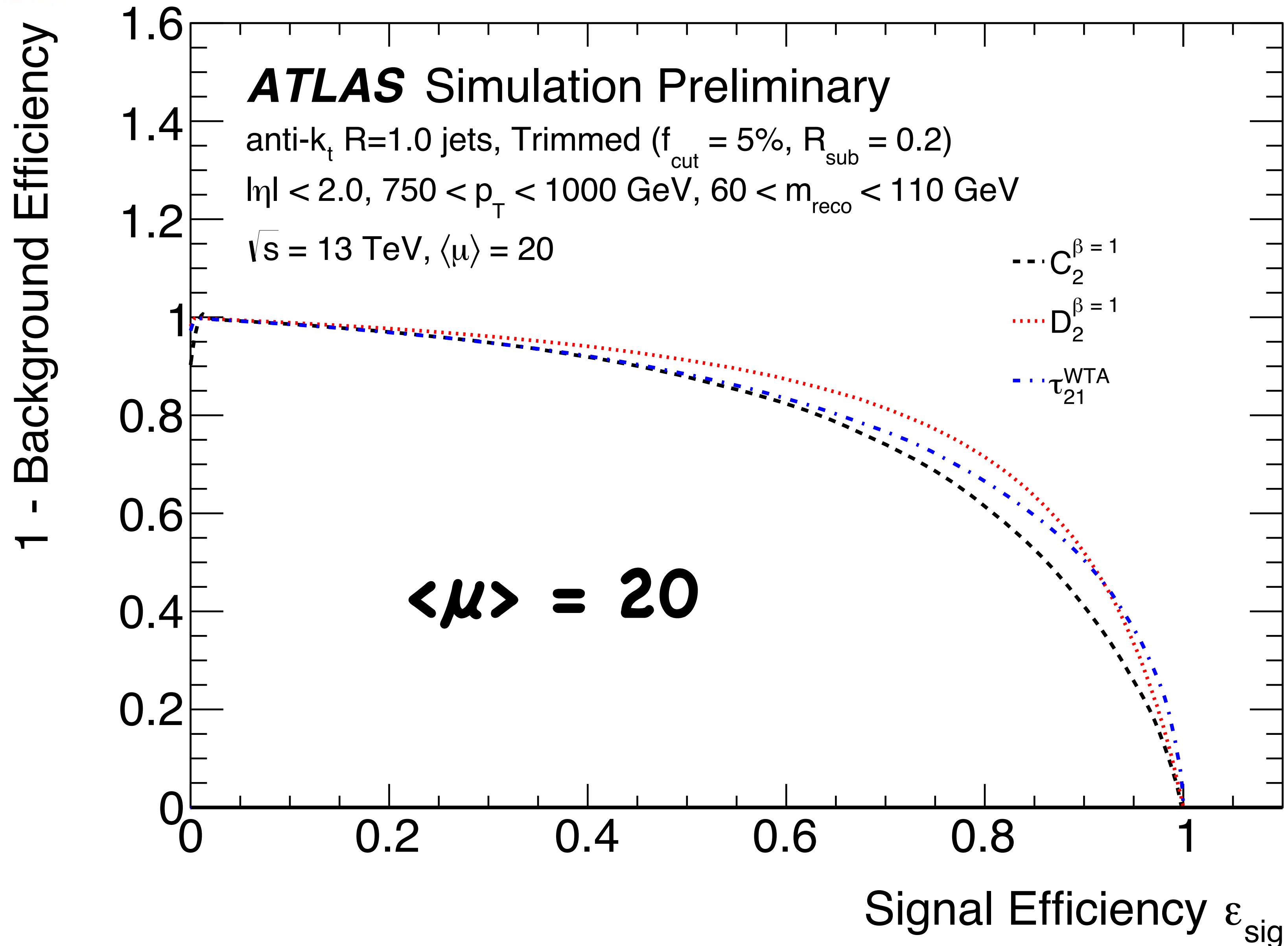
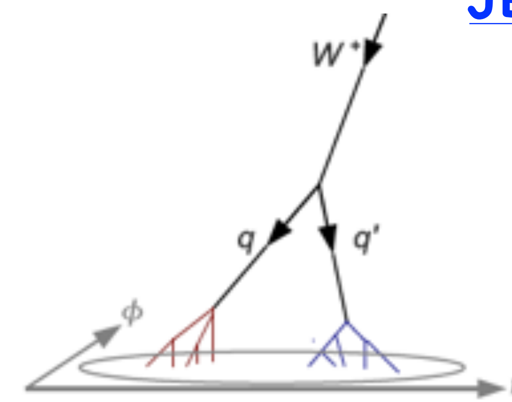
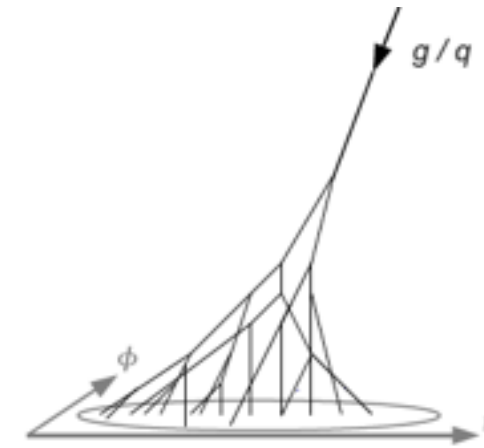




W' jet



QCD jet

- C_2, D_2 … concept of particle energy-correlations within a jet, does not need subjet re-clustering
- τ_N … N-jet sub-jettiness - how much a jet looks like to be composed of N sub-jets
- optimised for boosted Z (2-prong) vs QCD jet identification

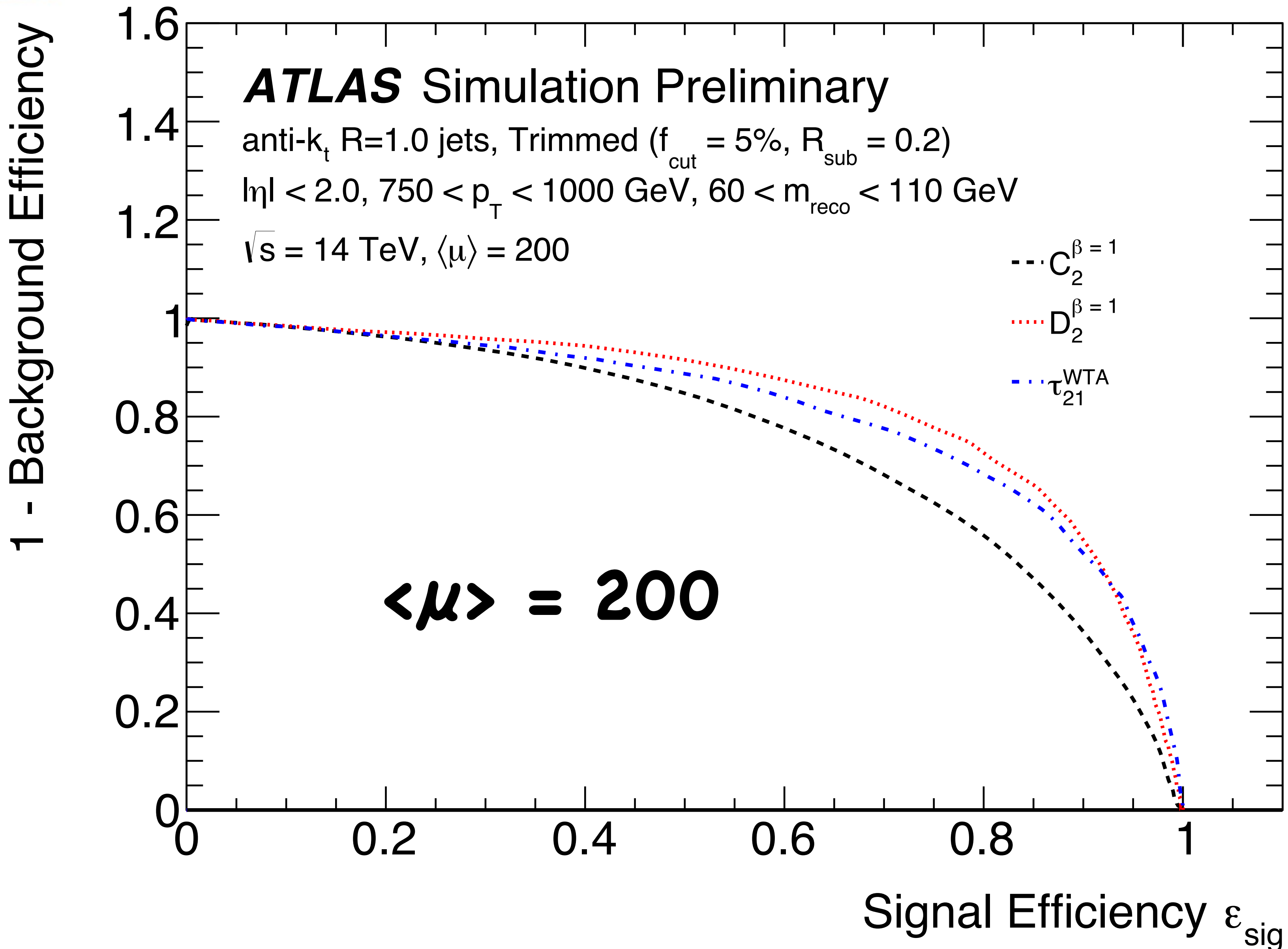
$C_2^{\beta=1}$ … built from 3-point correlations

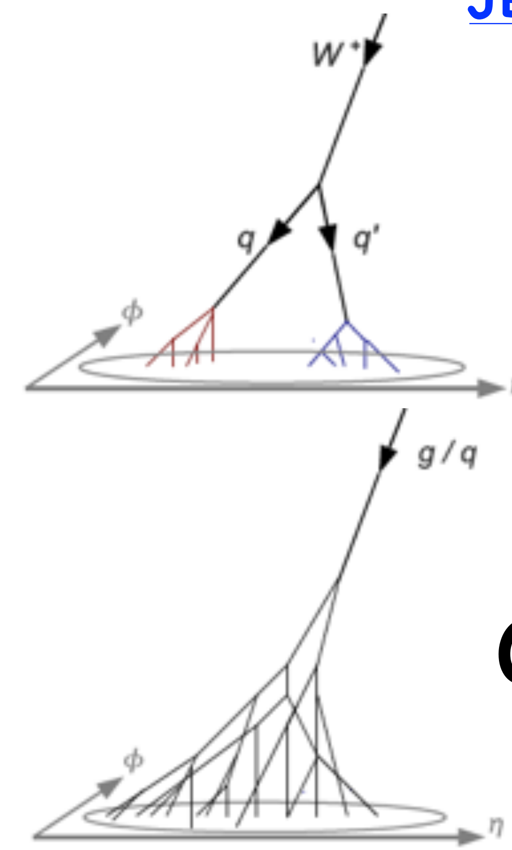
$D_2^{\beta=1}$ … built from 2- and 3-point correlations

τ_{21}^{WTA}… τ_2/τ_1, minimises distance to sub-jets

substructure techniques

[JETM-2016-012]





W' jet

QCD jet

while D_2 and τ_N stay ~unaffected, the C_2 (3-point only correlation) algorithm degrades with high pile up by ~10%

$C_2^{\beta=1}$ ... built from 3-point correlations

$D_2^{\beta=1}$ ... built from 2- and 3-point correlations

τ_{21}^{WTA}... τ_2/τ_1, minimises distance to sub-jets

E_T^{miss} resolution

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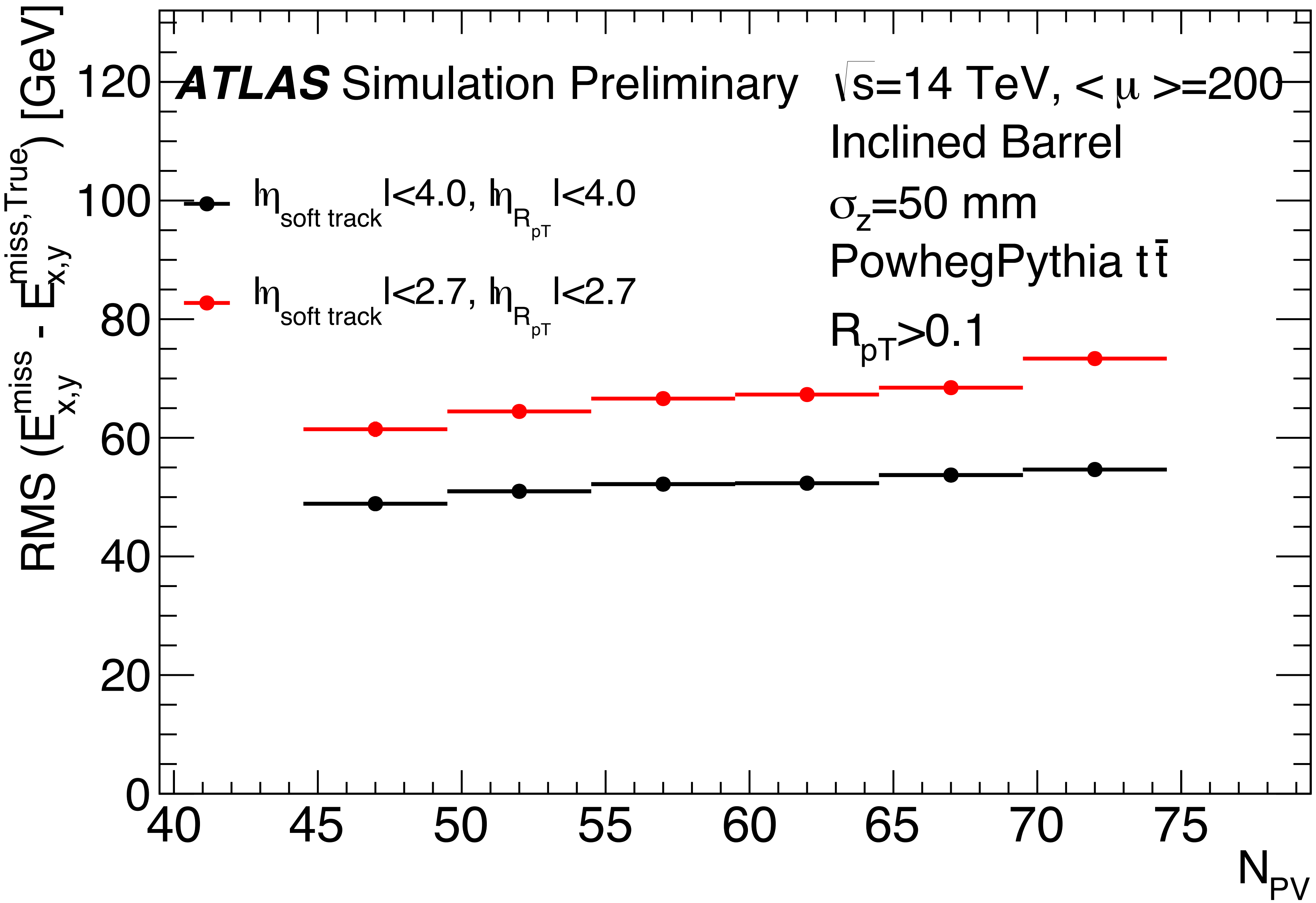
ITK-Inclined



- improvement in the E_T^{miss} resolution due to the tracking extension
- largest improvement through pile up mitigation of forward jets (R_{pT} > 0.1)

electron identification

- electron identification re-optimised in the context of high pile up and new inner detector - no TRT (full Si), new Pixel and Strip
- using calo based as well as track based ID variables:
  - f_1, w_{stot}, E_{ratio}, $w\eta_2$, R_η, R_Φ, f_3, R_{had}, R_{had1}
  - n_{Blayer}, n_{2nd}, n_{Pix}, n_{Si}, $z_0 \sin\theta$, $d_0/\sigma(d_0)$, $|\Delta\eta|-|\Delta\eta|$
- Tight, Medium and Loose working points derived
- main backgrounds: photon conversions and jet-fakes
- charge mis-identification (0.026±0.013)% from Z->ee

Tight ID Run2 (<μ>=14):

ε_{sig} = 85%

fake rate 1-2x10^{-3} @ 45GeV

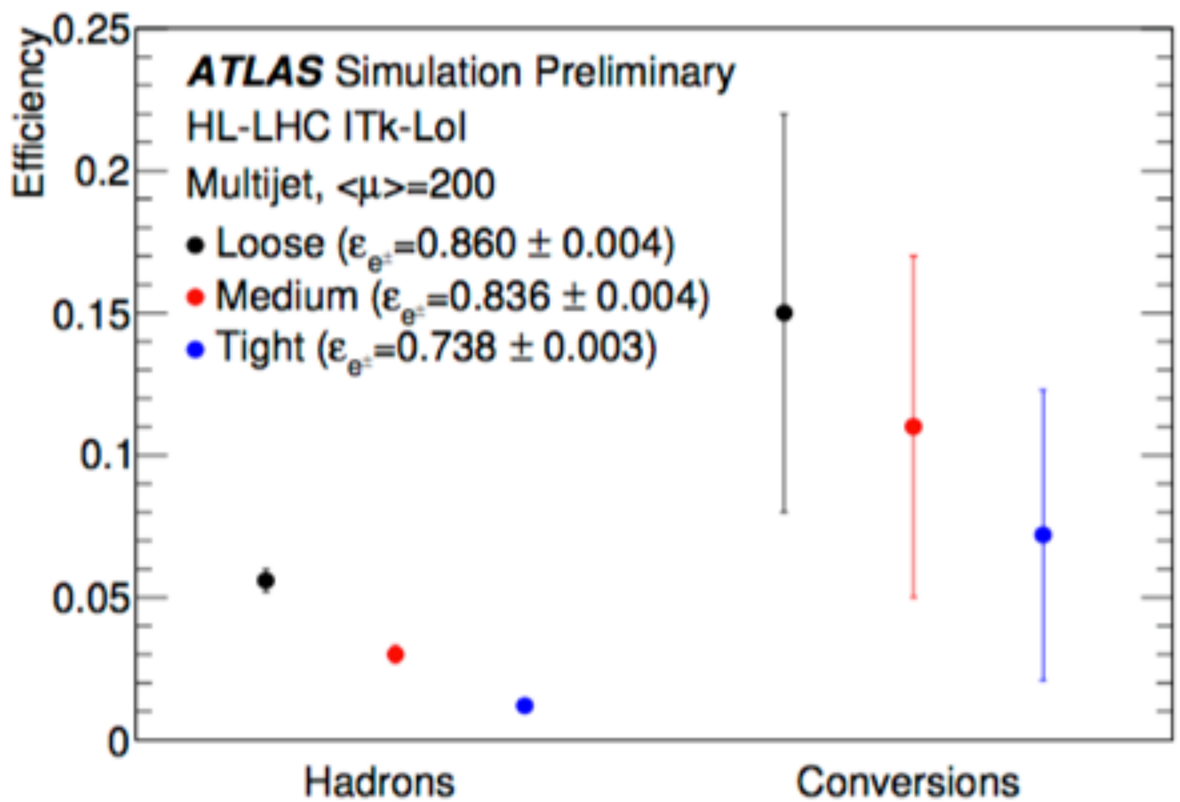
Tight ID HLLHC (<μ>=200):

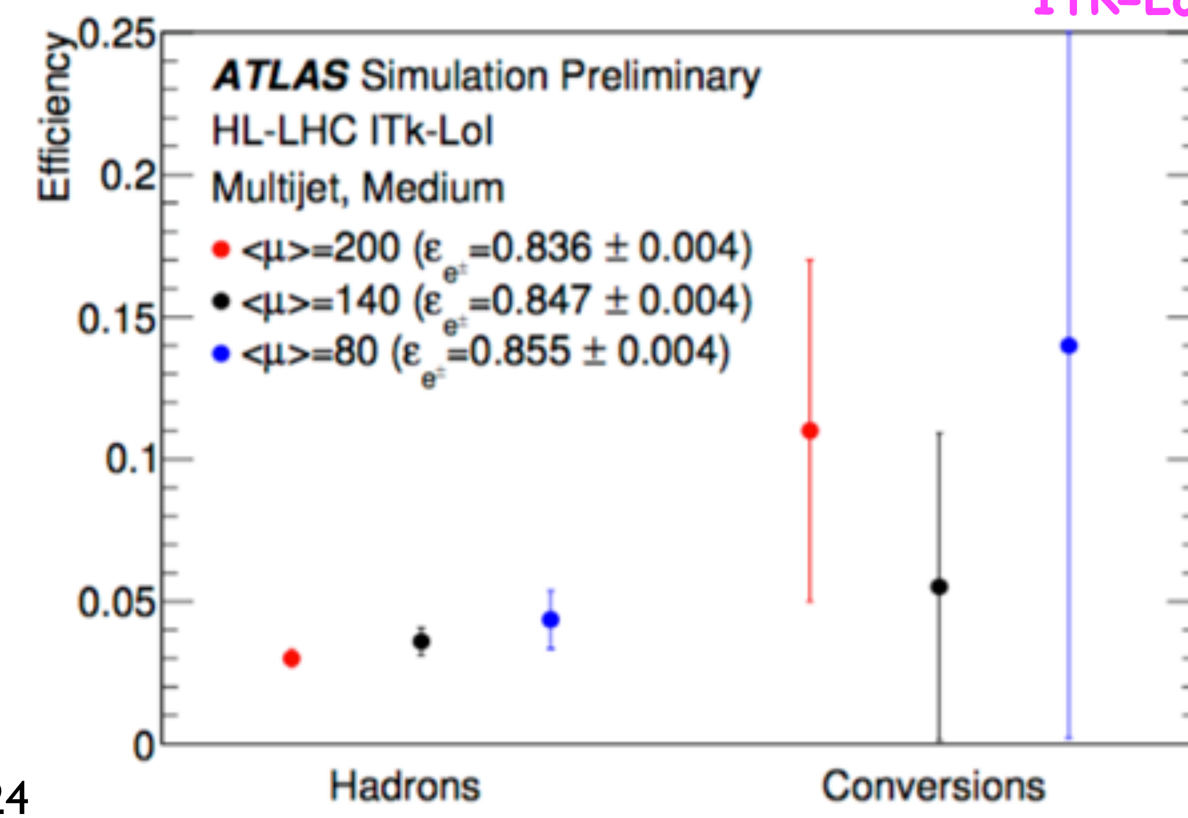
ε_{sig} = 70%

conversion rate ~0.2(±0.2)

fake rate ~7x10^{-3} @ 45GeV

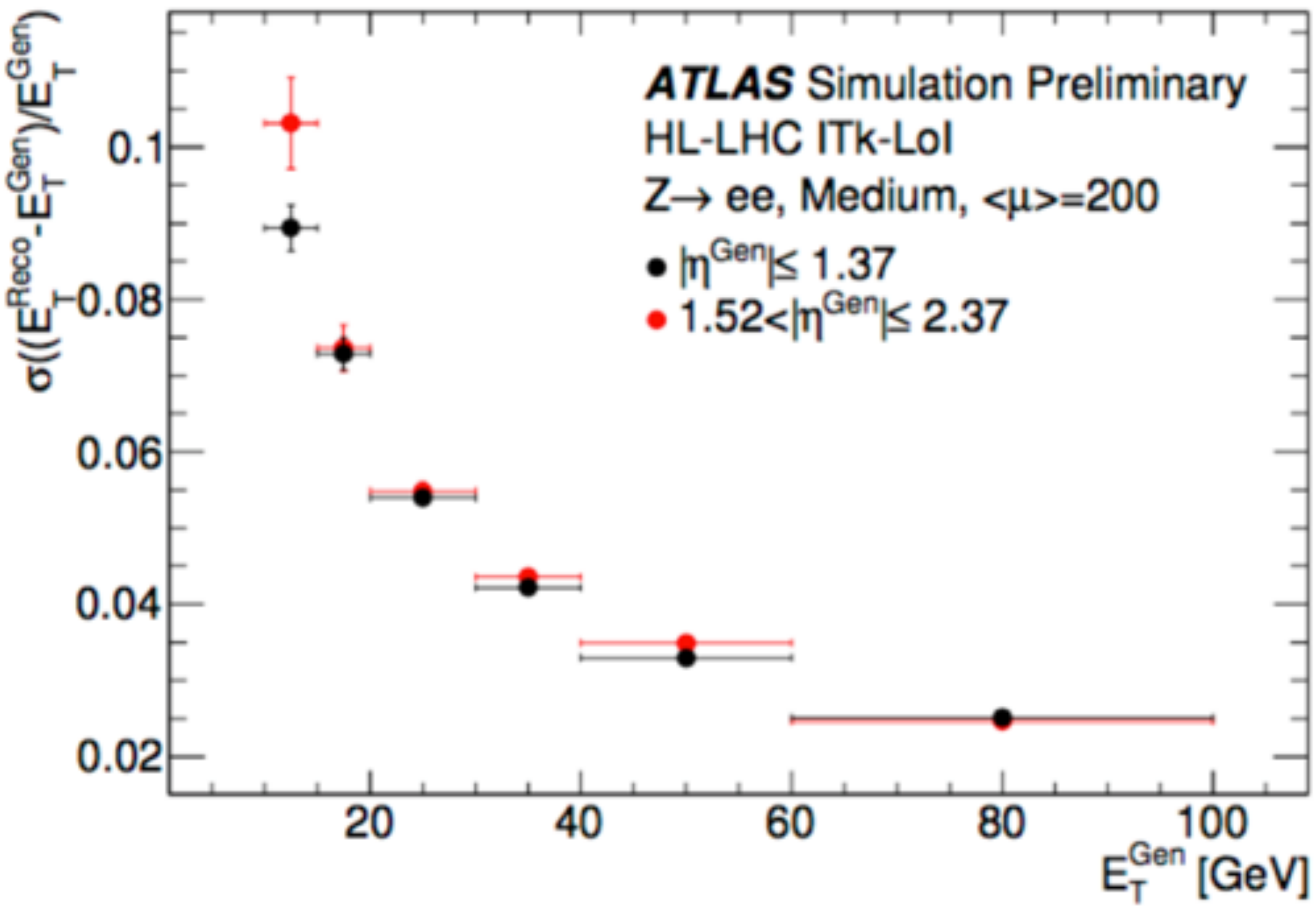
ITK-LoI(VF)



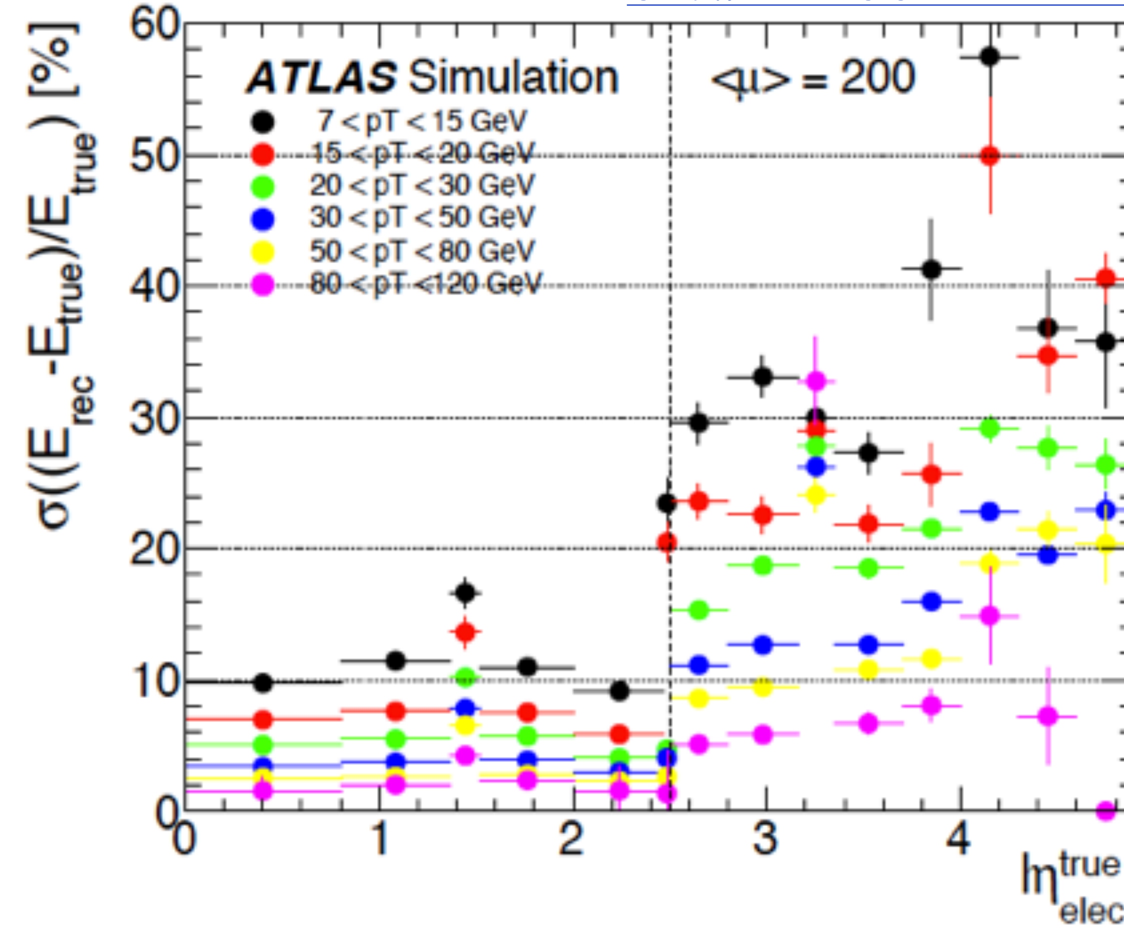


electron resolution

ITK-LoI(VF) current analysis



CERN-LHCC-2015-020

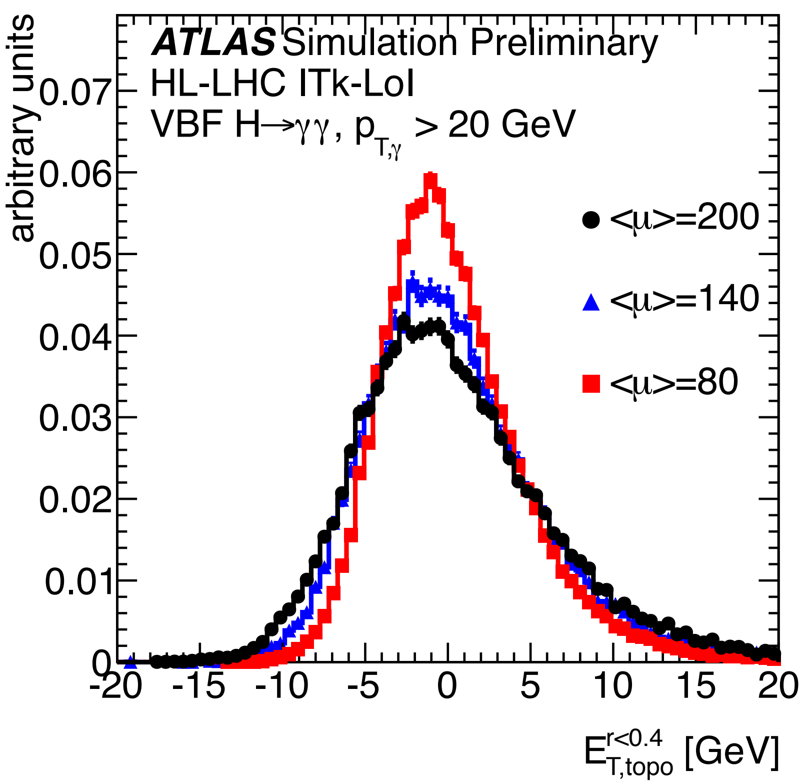


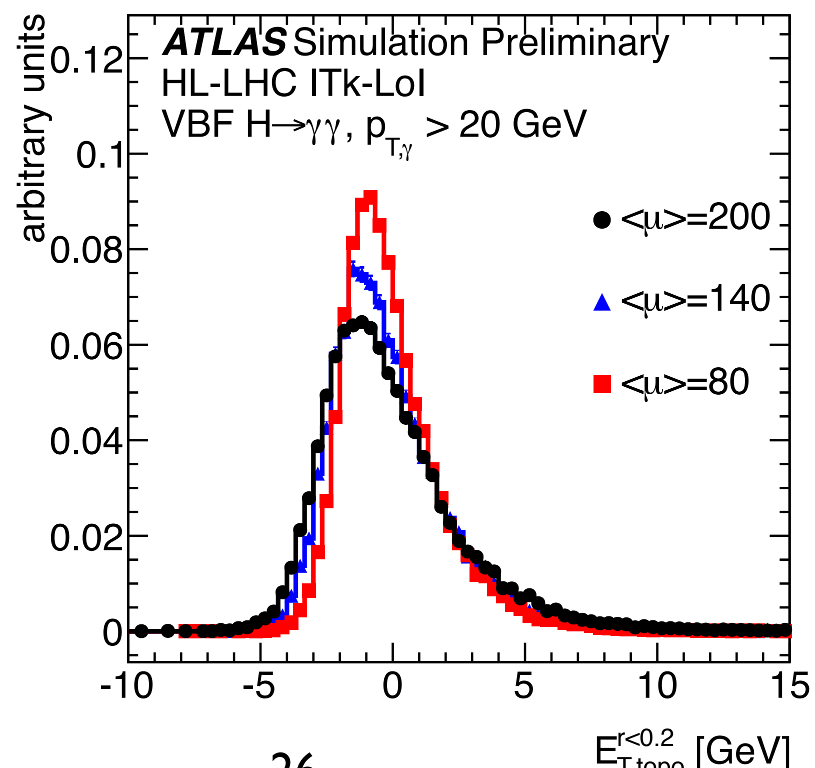
- large pile up affects only lowest p_T electrons
- sampling and constant term are ~same as measured in Run1
- calibration as extracted in Run2 was used
- both analyses are consistent, showing bad performance in the forward region (without the HGTD upgrade)

photon reconstruction

- photon identification was revised for the LoI ITk layout and μ=200 samples
- using calo based variables only:
  - w_{stot}, E_{ratio}, $w\eta_2$, R_η, R_Φ, R_{had1}, ΔE
  - MVA used to derive box cuts, p_T^γ > 20 GeV, 2 bins in η (Barrel and EndCap)
- Tight ID derived from VBF H->$\gamma\gamma$ samples (<p_T^γ> ~60 GeV),
- ε_{sig} = 70% for truth jet fakes at most 10^{-3} and pile up 10^{-4}
- to avoid fakes from photons in jets, isolation was applied (after optimisation for μ=200)

ITK-LoI



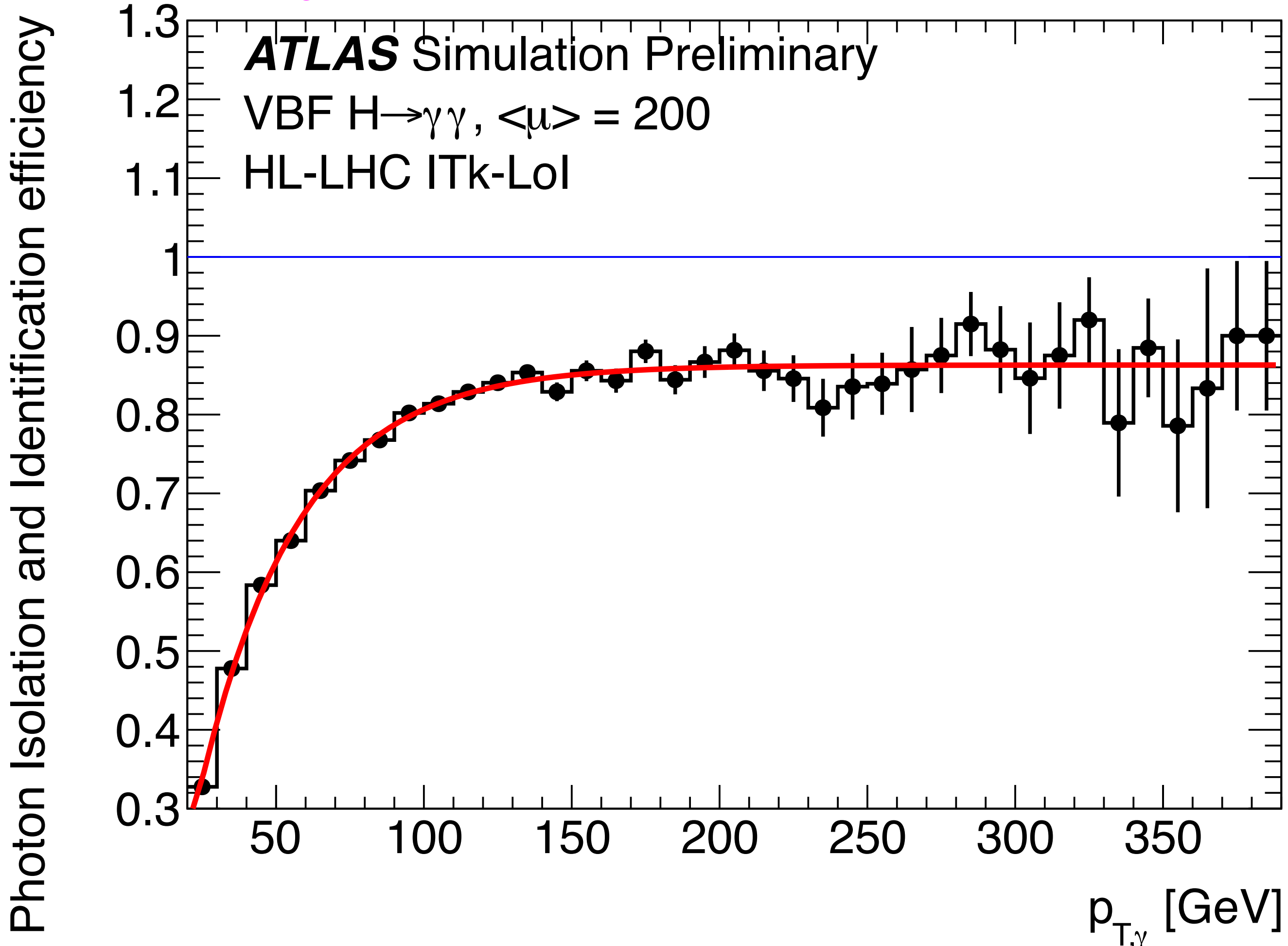


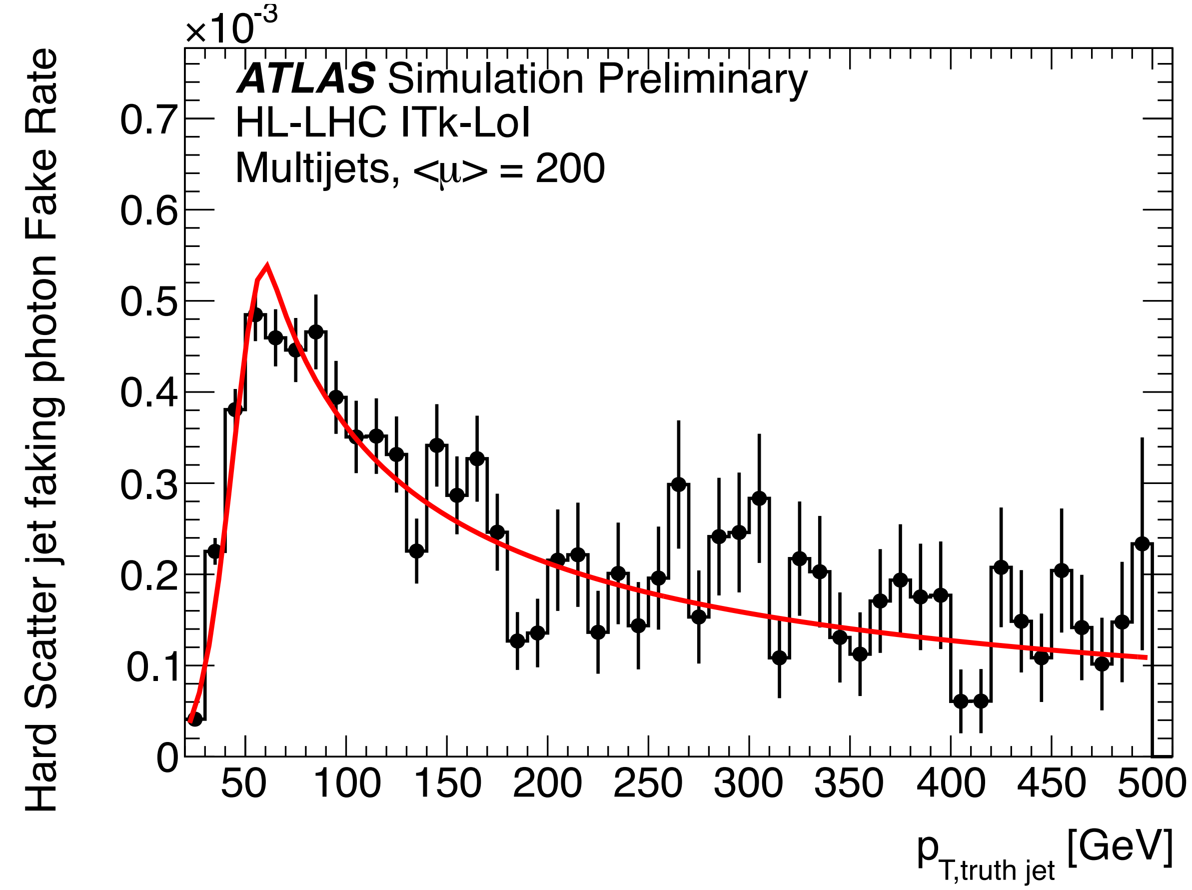
energy around the γ in the radius of 0.4 and 0.2

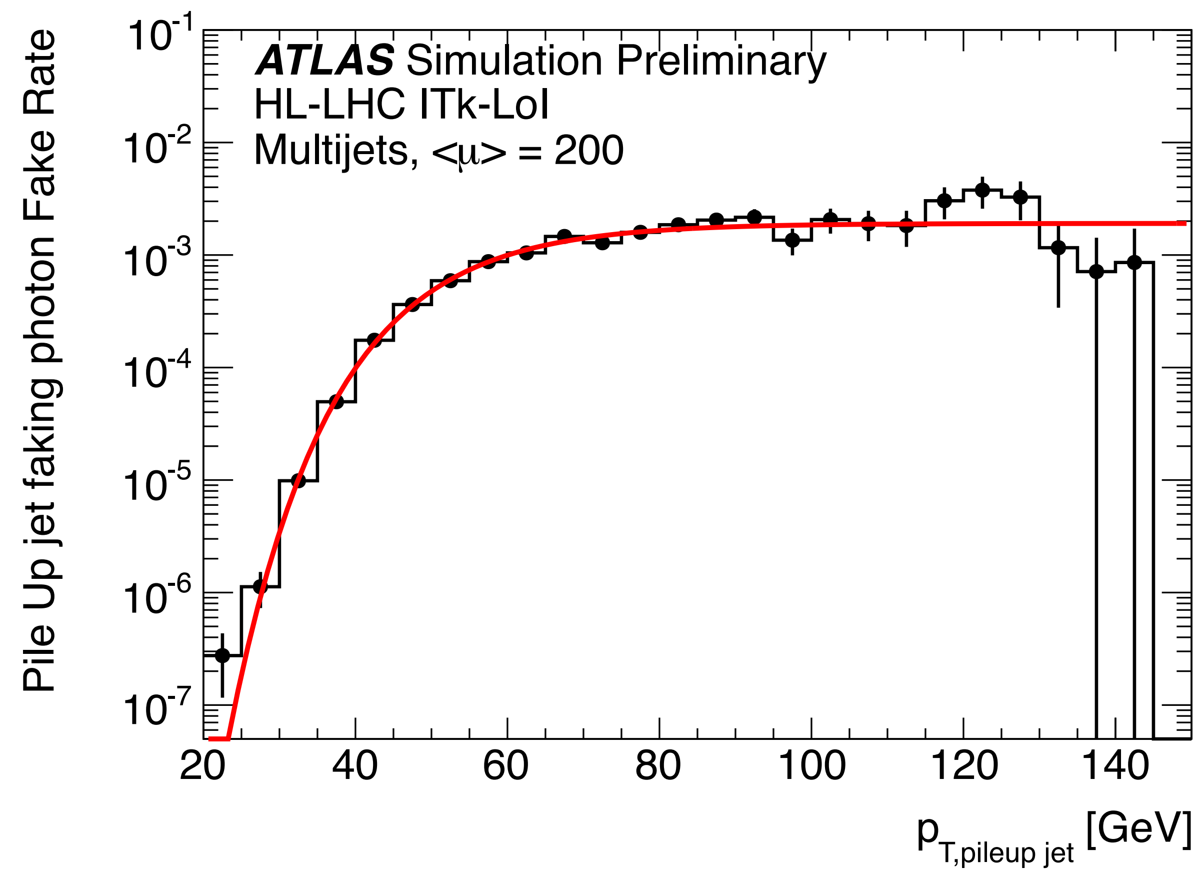
- 0.2 more pile up robust than 0.4
- cut **$E_T^{r<0.2}$ < 6 GeV** found to provide > 95% efficiency and good isolation

photon isolation and identification

ITK-LoI



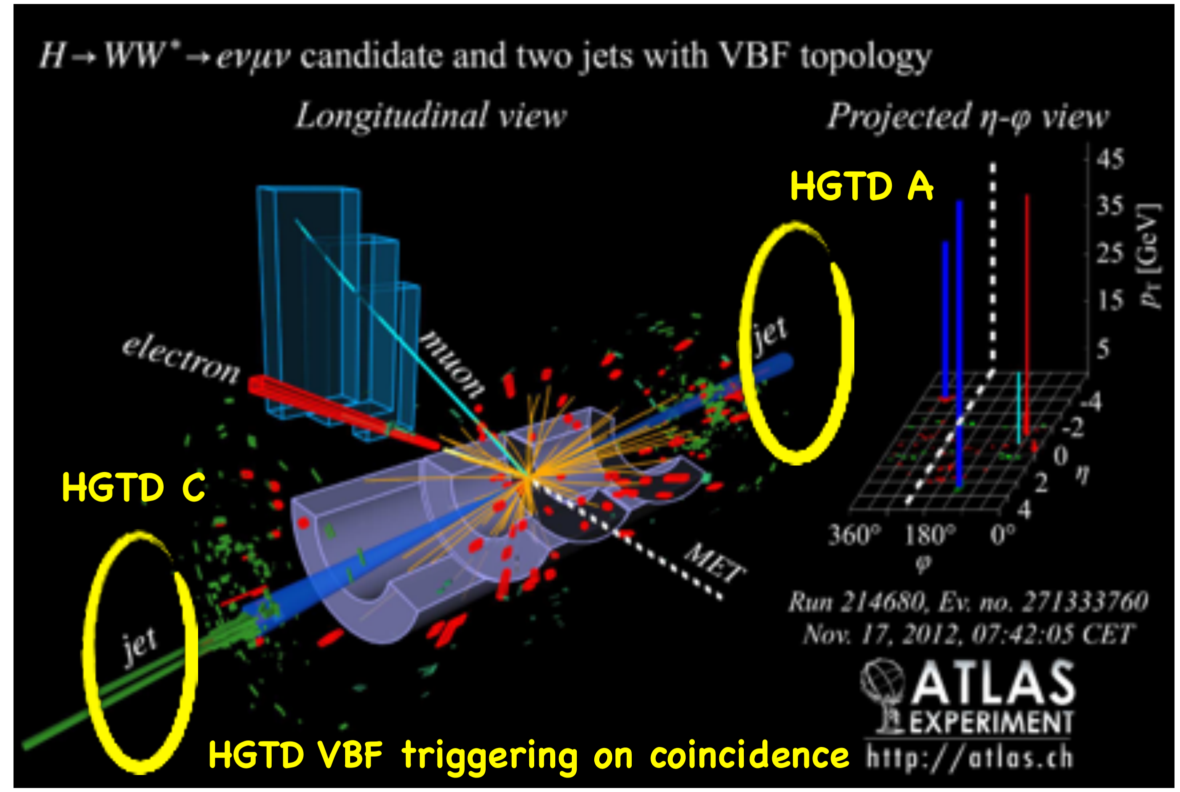




- mean combined signal efficiency still **~70%**
- averaged combined fake rates of **2.5×10^{-4}** for the jets emerging from HS interaction, **7×10^{-5}** for identified photons emerging from pile up

High Granularity Timing Detector

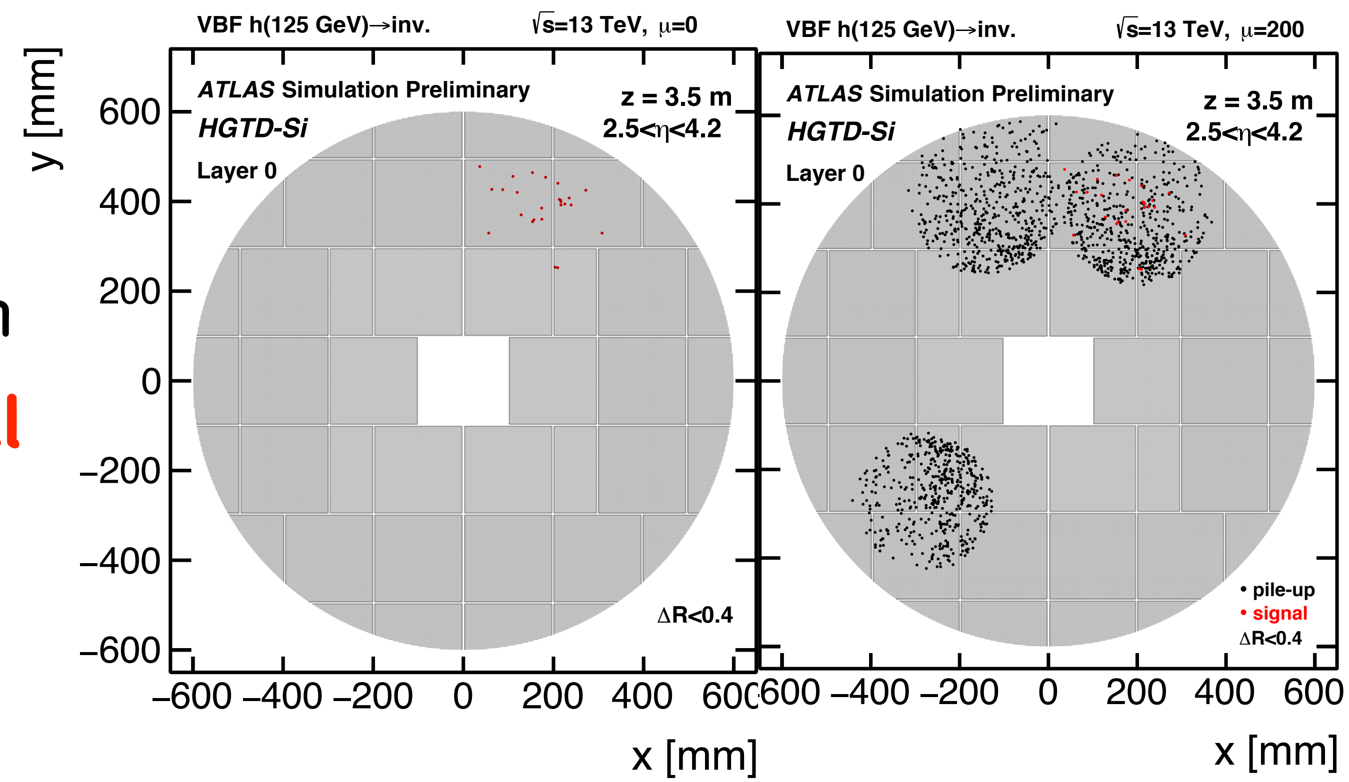
- thin (~5cm) forward detector (2.4 < |η| < 4.3) with 4 layers of LGAD sensors with excellent timing resolution (~30ps) allowing to measure time-of-flight of collision products
- motivation:
  - **pile up mitigation** in the forward region covering the acceptance of the jets produced (mostly) by vector-boson fusion
  - optionally with three tungsten layers to improve also the **forward electron/ photon reconstruction**
  - fast **trigger at 40MHz designed for selecting VBF topologies**
- **for more details, see D.Zerwas' talk tomorrow at 13:00**

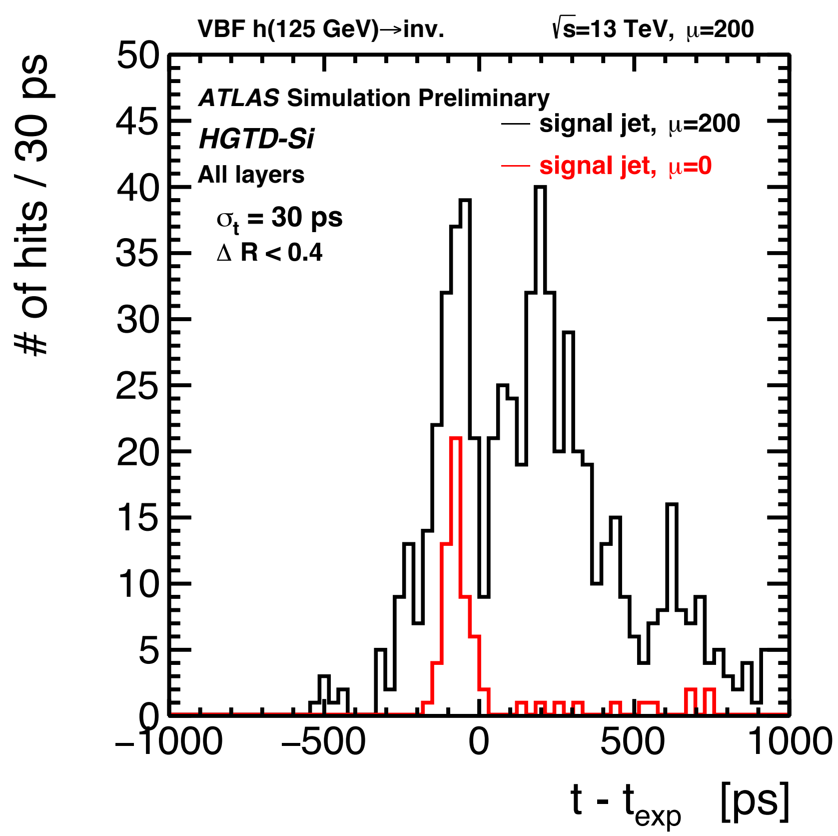


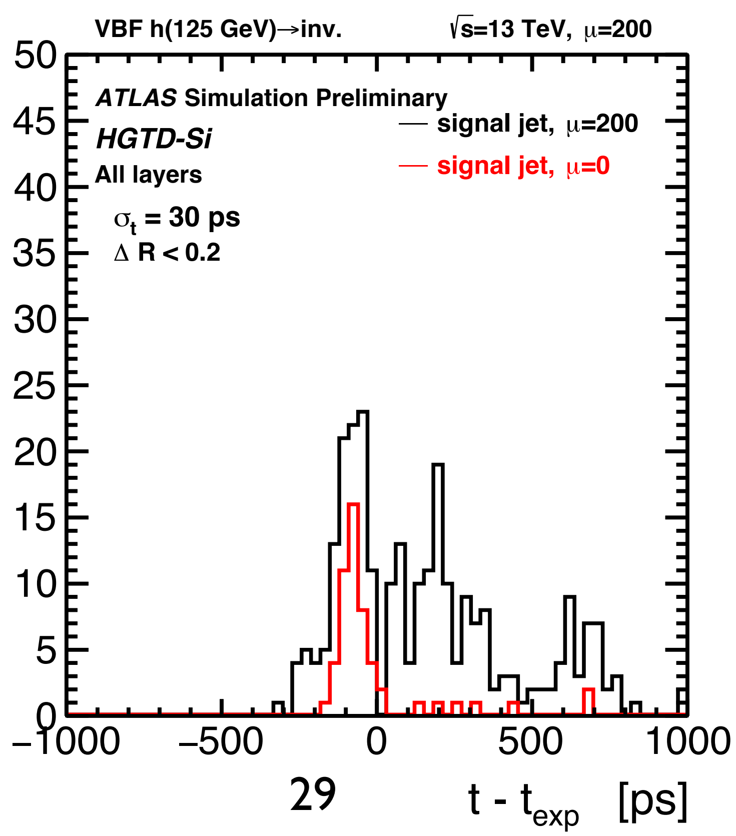
trigger	SD value	physics (SM Higgs-oriented)
di-γ	25-25 GeV	di-photon
di-τ	40-30 GeV	H->$\tau\tau$
4-jet	75 GeV	H->bb, HH->4b
E_T^{miss}	200 GeV	H->Invisible

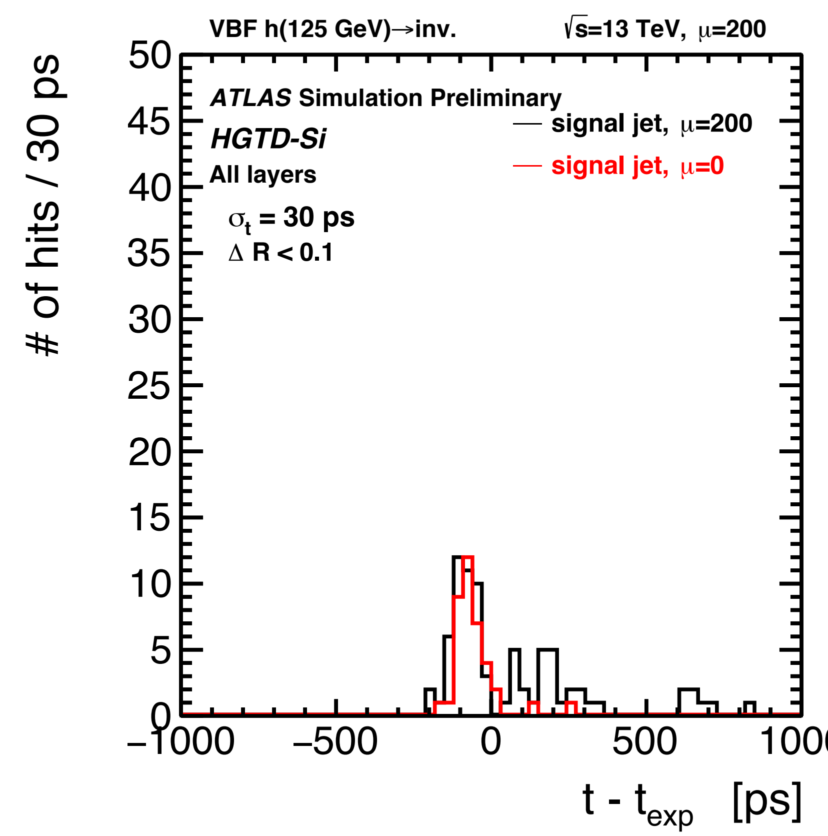
High Granularity Timing Detector

- investigation of potential of time sub-structure of jets
- VBF jets investigated, time distribution of all particles (hits) compared – **signal "μ=0"** versus **signal+pileup "μ=200"**
- **first step in development of signal jet identifying algorithms**



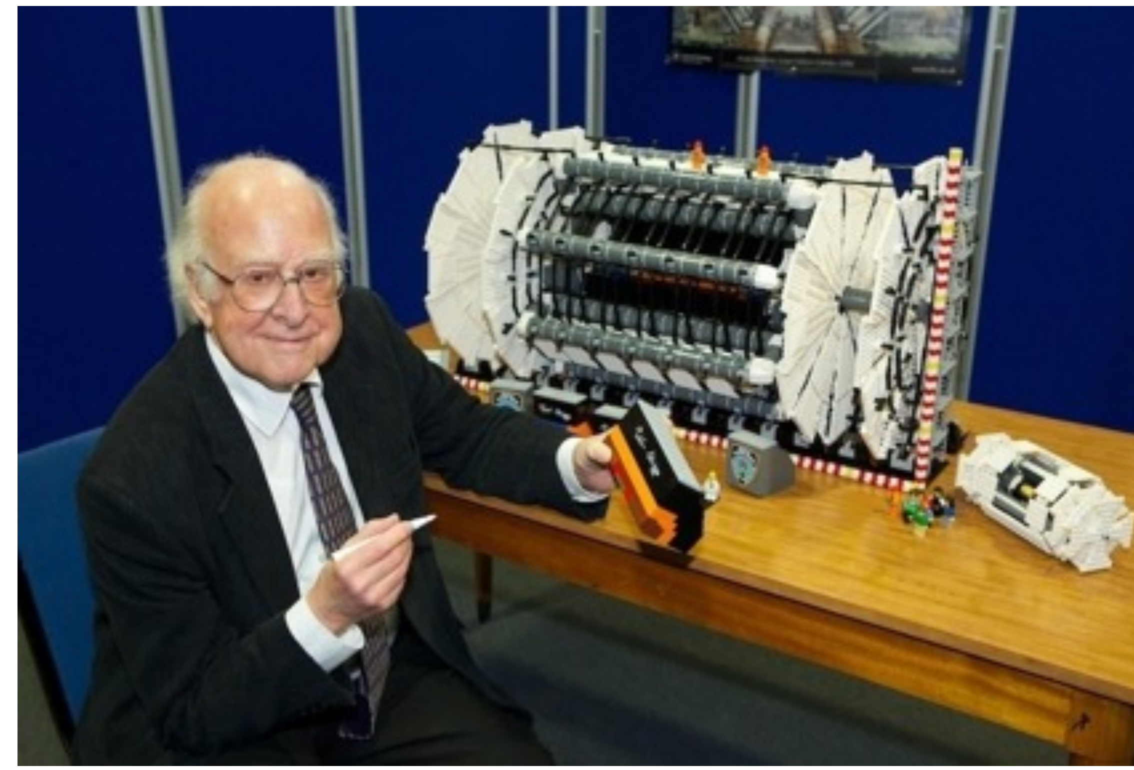


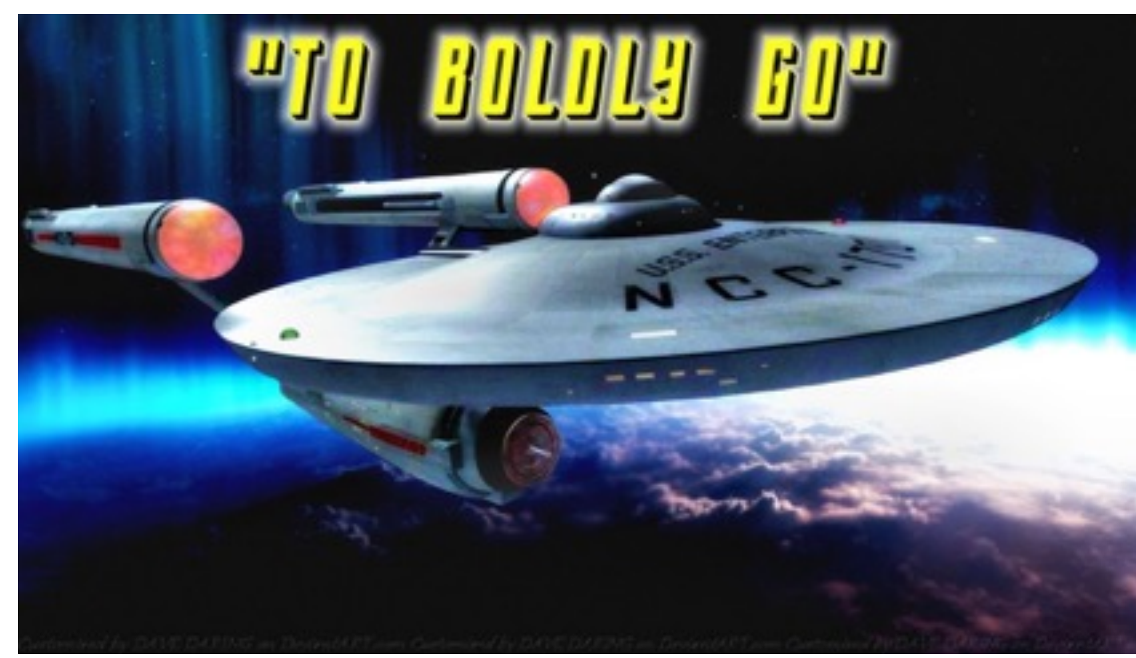




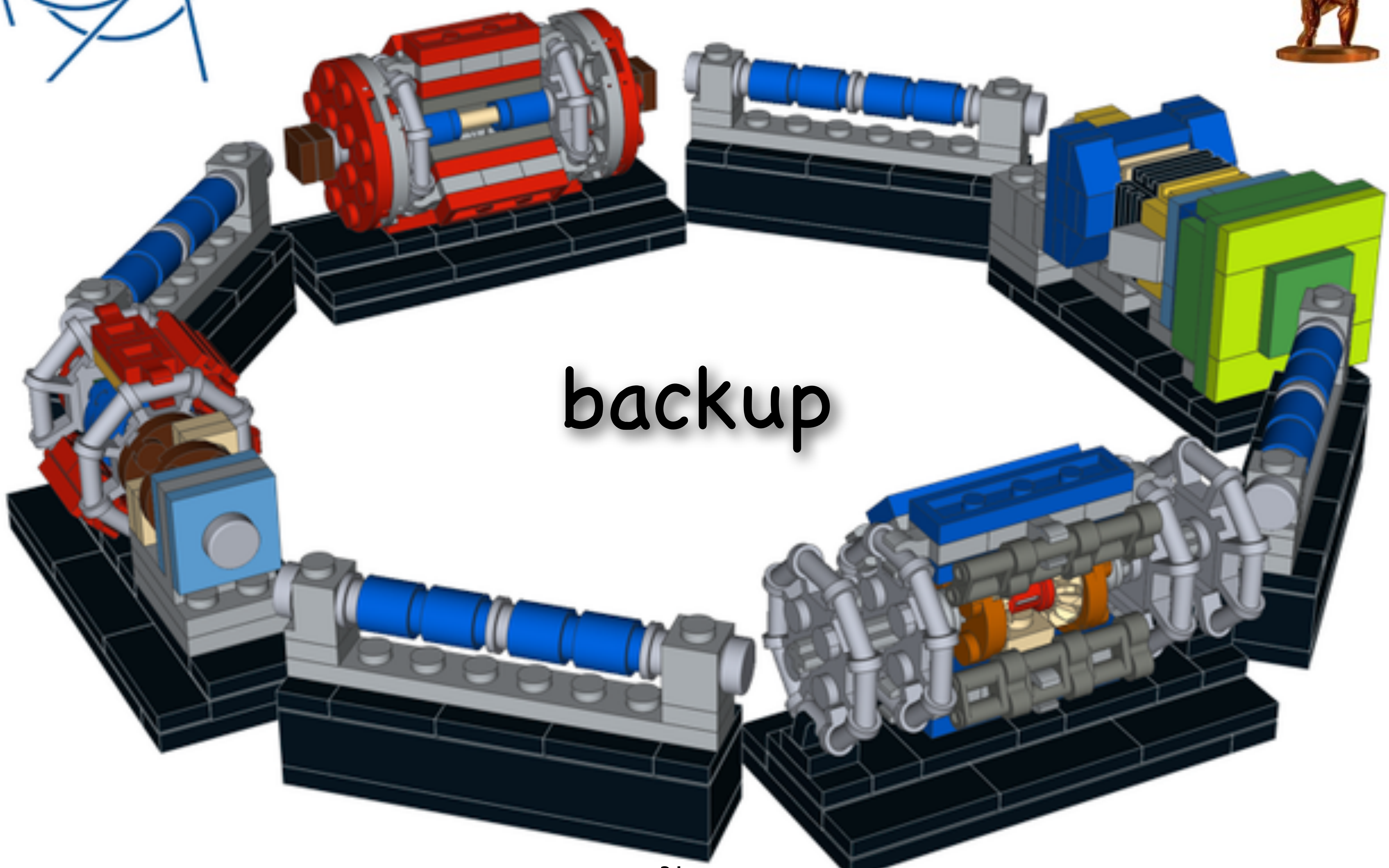
Summary

- ATLAS is preparing a **challenging detector upgrade**
- high pile up environment requires maximum focus on **pile up mitigation with all possible techniques**
  - active field of development
  - Voronoi subtraction, trimming, HGTD,..
- electron and photon identification performance show **no major degradation** even at highest <μ>
- more to come in the coming Technical Design Reports (**2017-2018**)





backup



Trigger and Data Acquisition	Scoping Scenarios Reference (275 MCHF)	Middle (235 MCHF)	Low (200 MCHF)
Level-0 Trigger System			
Central Trigger	✓	✓	✓
Calorimeter Trigger (e/γ)	$\|\eta\| < 4.0$	$\|\eta\| < 3.2$	$\|\eta\| < 2.5$
Muon Barrel Trigger	MDT everywhere RPC-BI Tile-μ	MDT (BM & BO only) Partial η coverage RPC-BI Tile-μ	MDT (BM & BO only) No RPC-BI Tile-μ
Muon End-cap Trigger	MDT everywhere	MDT (EE&EM only)	MDT (EE&EM only)
Level-1 Trigger System			
Output Rate [kHz]	400	200	200
Central Trigger	✓	✓	✓
Global Trigger	✓	✓	✓
Level-1 Track Trigger (*RoI based tracking*)	$p_T > 4$ GeV $\|\eta\| \leq 4.0$	$p_T > 4$ GeV $\|\eta\| \leq 3.2$	$p_T > 8$ GeV $\|\eta\| \leq 2.7$
High-Level Trigger			
FTK++ (*Full tracking*)	$p_T > 1$ GeV 100 kHz	$p_T > 1$ GeV 50 kHz	$p_T > 2$ GeV 50 kHz
Event Filter	10 kHz output	5 kHz	5 kHz
DAQ			
Detector Readout	✓ [400 kHz L1 rate]	✓ [200 kHz L1 rate]	✓ [200 kHz L1 rate]
DataFlow	✓ [400 kHz L1 rate]	✓ [200 kHz L1 rate]	✓ [200 kHz L1 rate]

track e/gamma variables

- n_{Blayer} - Number of hits in the innermost pixel layer.
- n_{2nd} - Number of hits in the second to innermost pixel layer.
- n_{Pixel} - Number of hits in the pixel detector.
- n_{Si} - Number of hits in the silicon detector.
- $z_0 \sin\theta$ - Longitudinal impact parameter of the track to the beam spot.
- d_0/σ_{d_0} - Transverse impact parameter significance of the track to the beam-spot.
- $|\Delta\eta_1|$ - $|\Delta\eta|$ between the cluster position in the strip layer and the extrapolated track.

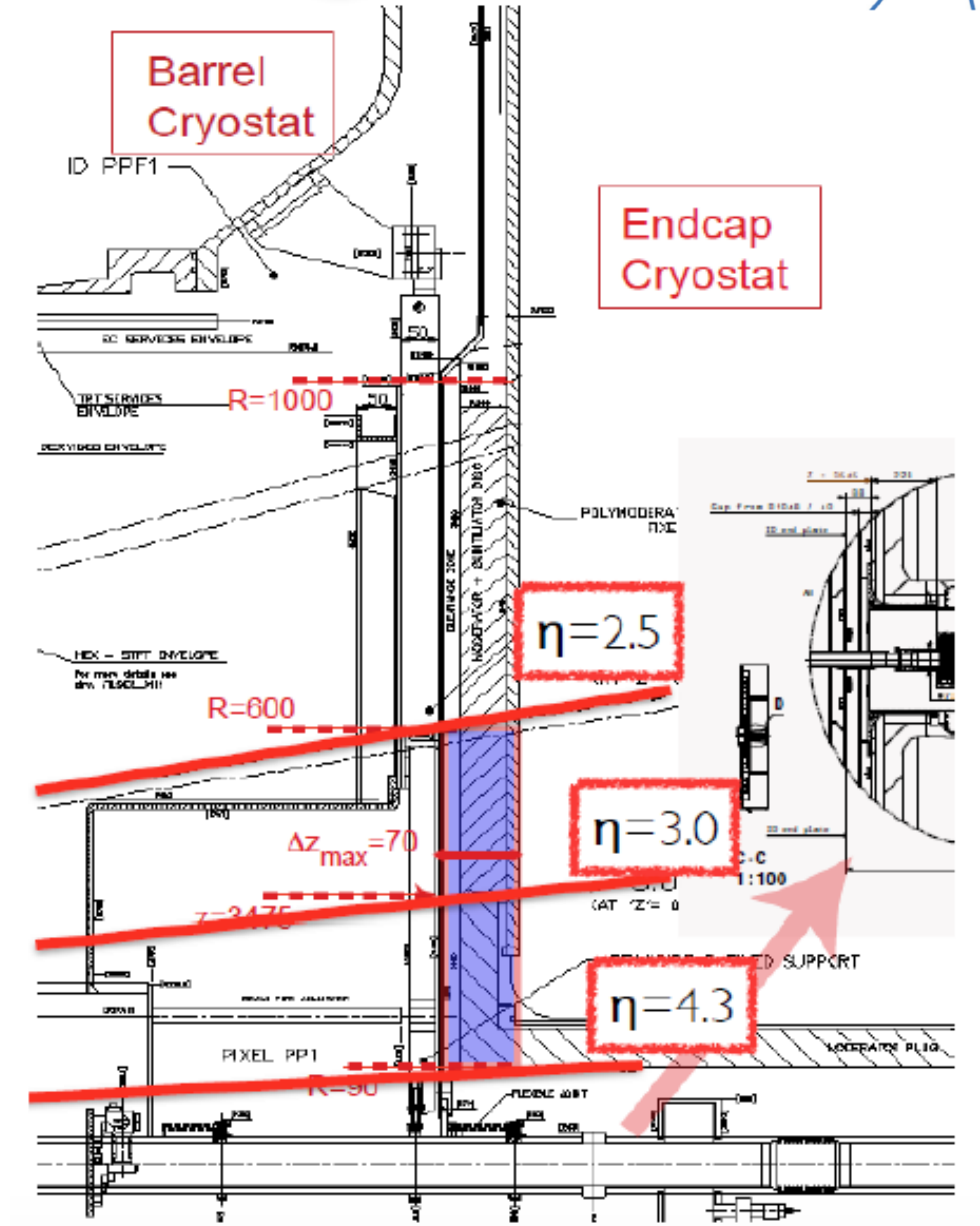
calo e/gamma variables

- f_1 - Ratio of energy in the strip layer to energy in the whole ECal.
- w_{stot} - Shower width $\sqrt{(\Sigma E_i(i - i_{\text{max}})^2)/(\Sigma E_i)}$, where i runs over all strips in a window of $\Delta\eta \times \Delta\phi \approx 0.0625 \times 0.2$ and i_{max} is the index of the highest-energy strip.
- E_{Ratio} - Ratio of the energy difference between the largest and second largest energy deposits in the first layer, divided by their sum.
- $w_{\eta 2}$ - Lateral shower width, $\sqrt{(\Sigma E_i \eta_i^2)/(\Sigma E_i) - ((\Sigma E_i \eta_i)/(\Sigma E_i))^2}$, where the sum is calculated within a window of 3×5 cells.
- R_η - Ratio of the energy in $\eta \times \phi$ of 3×7 cells and 7×7 cells, centred on the energy cluster.
- R_ϕ - Ratio of the energy in $\eta \times \phi$ of 3×3 cells and 3×7 cells, centred on the energy cluster.
- f_3 - Ratio of the energy in the back layer to the total energy in the ECal.
- R_{had} - Ratio of E_T in the hadronic calorimeter to E_T of the EM cluster (used over the range $0.8 < |\eta| < 1.37$).
- R_{had1} - Ratio of E_T in the first layer of the hadronic calorimeter to E_T of the EM cluster (used over the range $|\eta| < 0.8$ and $|\eta| > 1.37$).

In addition the variable ΔE, defined as the difference between the energy associated with the second maximum in the strip layer and the energy reconstructed in the strip with the minimal value found between the first and second maxima, is used as well in this case since it is potentially useful to separate clusters generated by single photons from those generated by multiple photons from meson decays.

HGTD technology

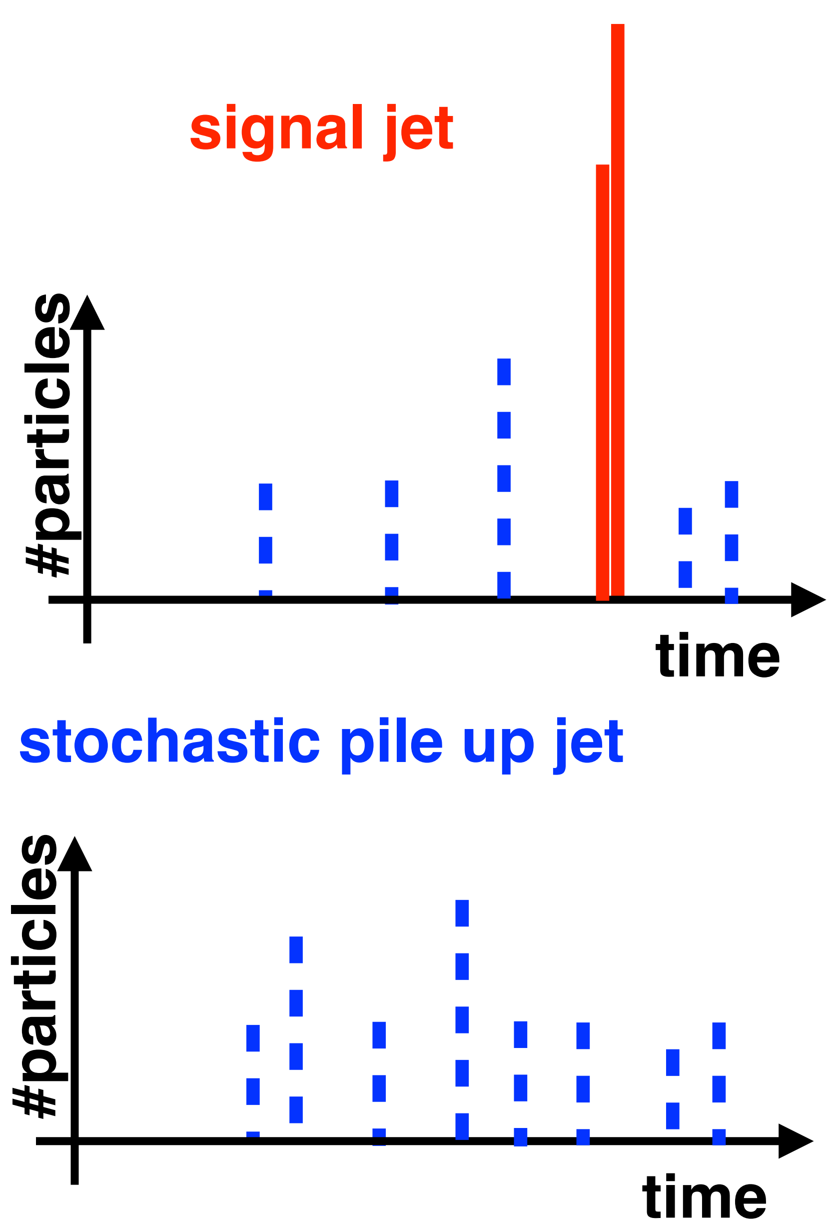
- challenging spatial requirements: Δz = 70mm, R: 90-600mm
  - R=50mm (η=5.0) possible
- surface ~9m^2, ~10^5 cells 1x1 - 3x3 mm^2 (radius dependent)
- 4 sensitive layers with possible 3 W-absorbers (only up to $|\eta|$ < 3.2)
- sensor technology:
  - main option: Low-Gain Avalanche Detectors
    - Active R&D ongoing with thinner sensors (300μm-->50μm) and new dopants (Ga) to insure time and radiation hard requirements of HGTD
  - back up: silicon-based (standard pin diode)

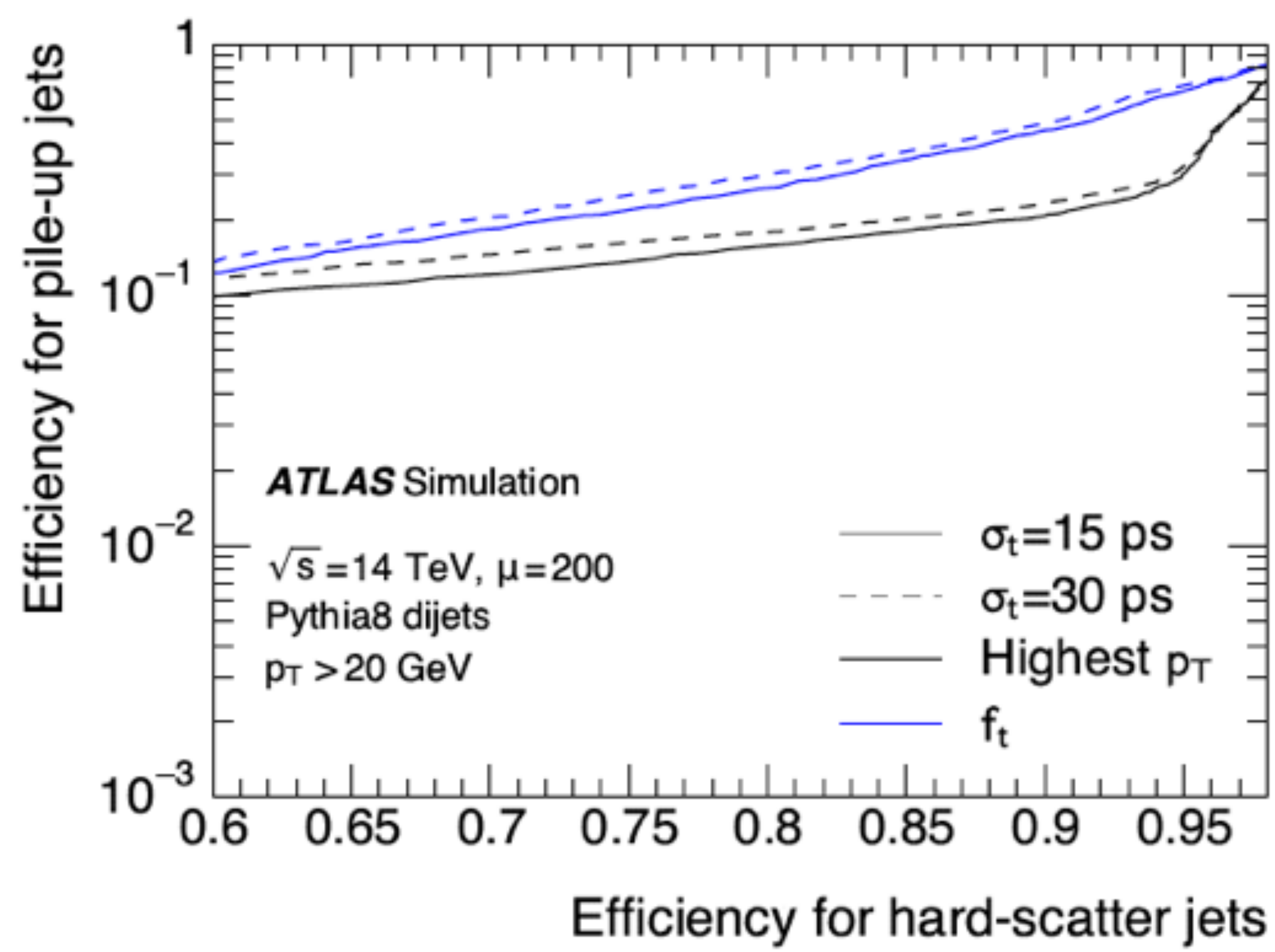


technology and concept of the detector to be decided in ~a year

offline pile up mitigation

- pile up mitigation through detailed timing information in the jet sub-structure
- 30ps HGTD: ~89% pile up rejection at 80% signal efficiency

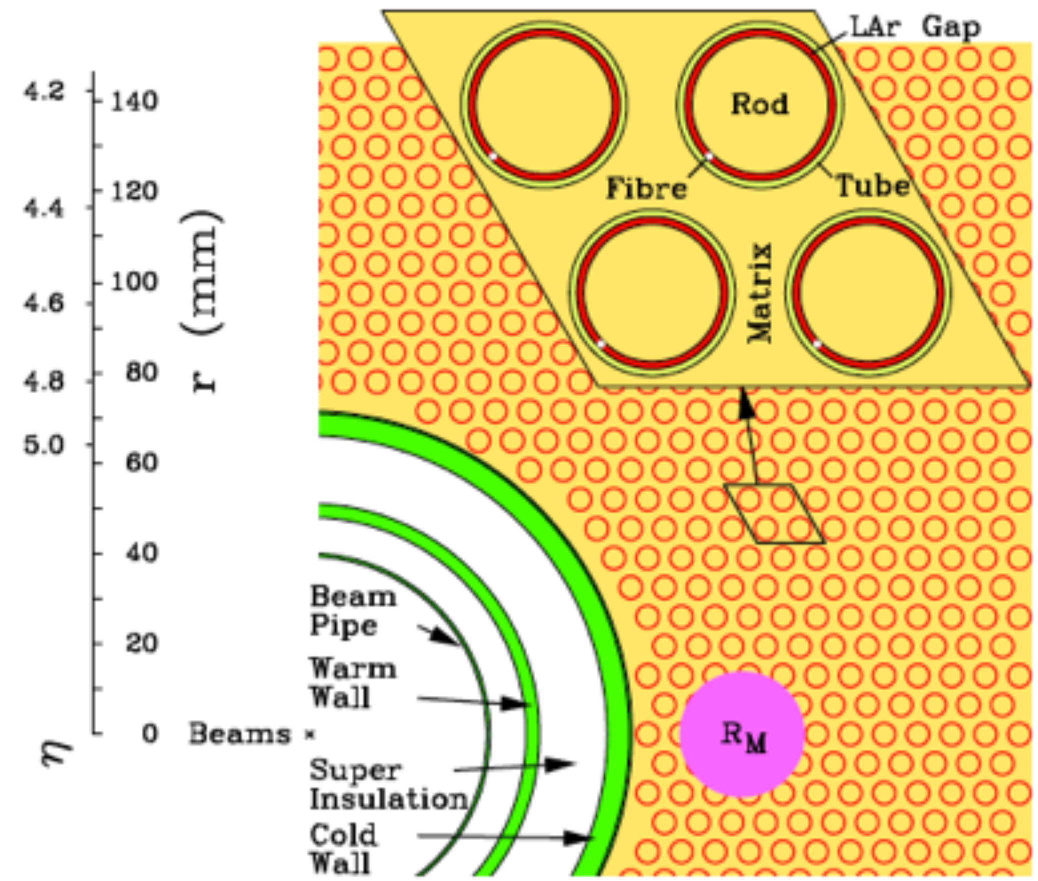


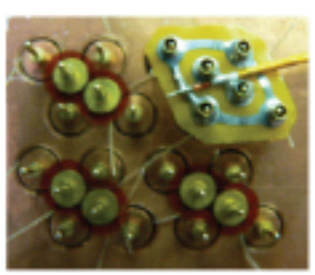


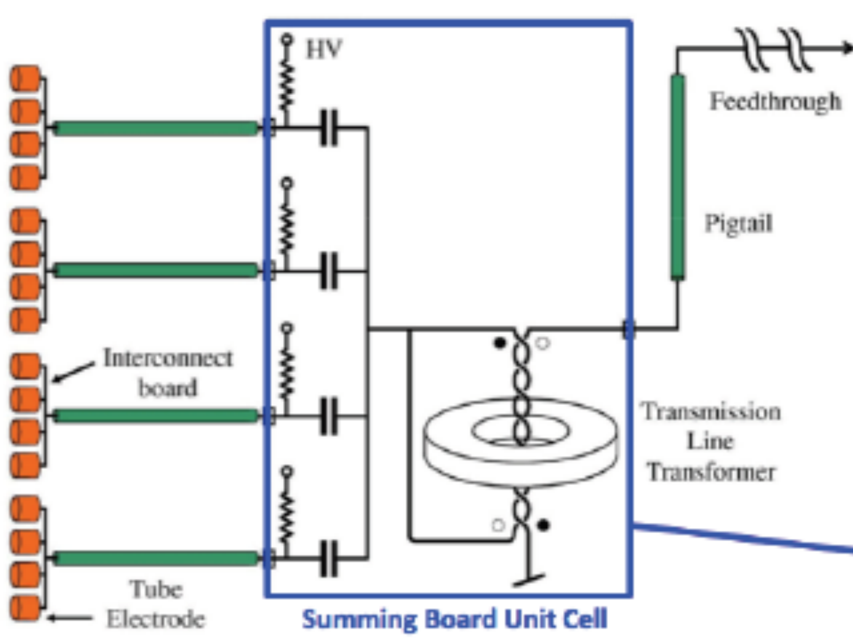
timing substructure helps stochastic PU mitigation

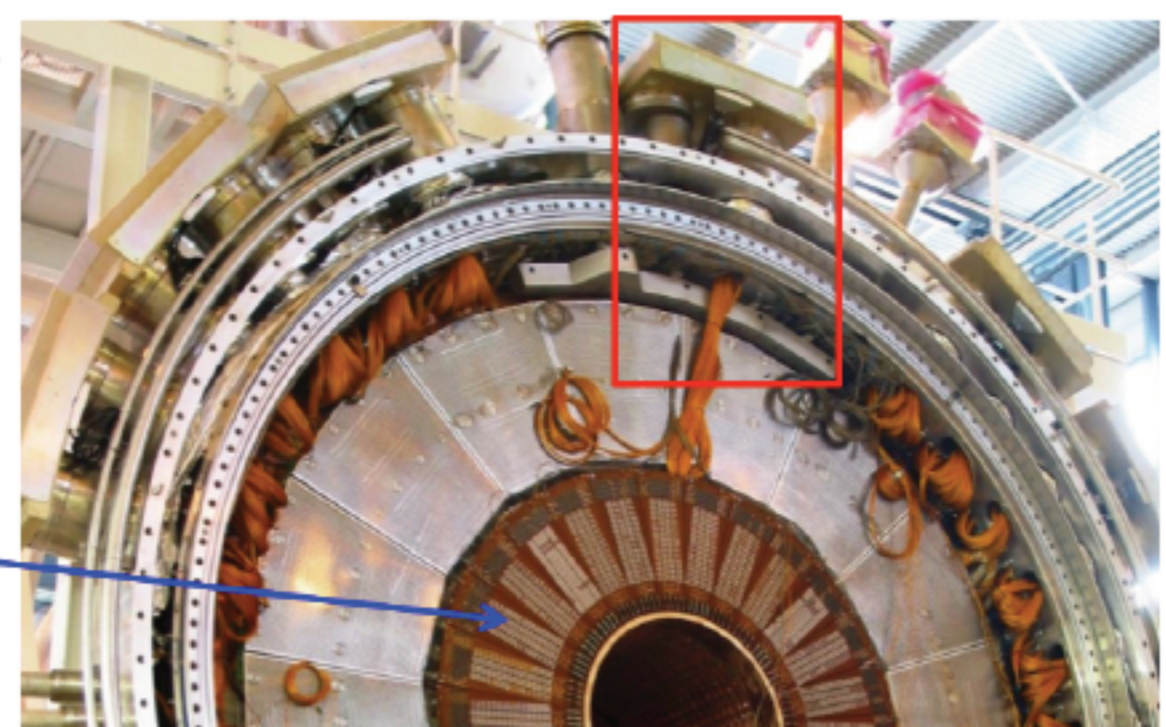
sFCal

- 100μm gaps with LAr for FCal ($3.2 < |\eta| < 4.9$)
- remove summing of FCal channels to increase granularity
- risk analysis of EndCap opening needs to be evaluated





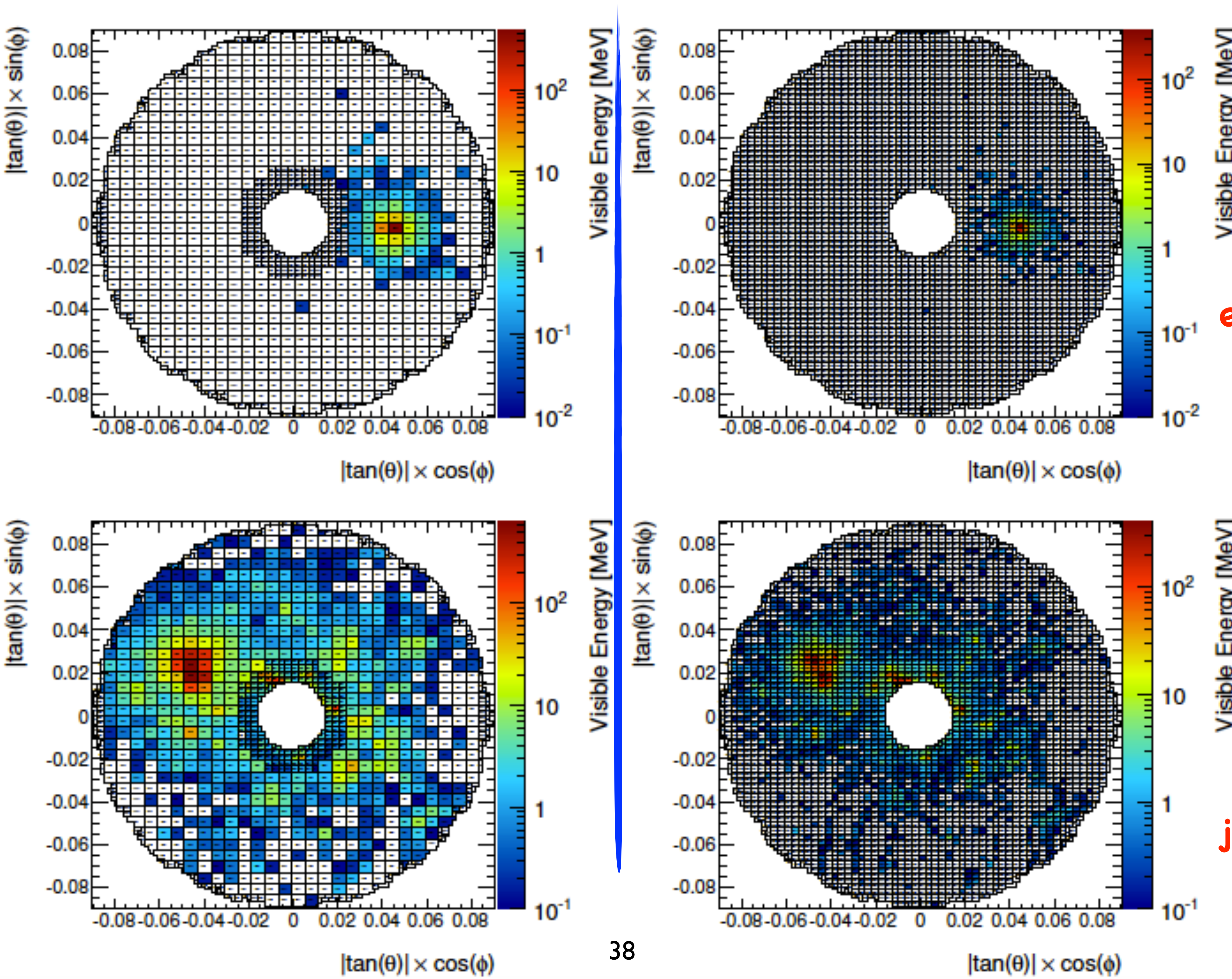




4->1 summing

review: 2016

Same objects in FCal and sFCal

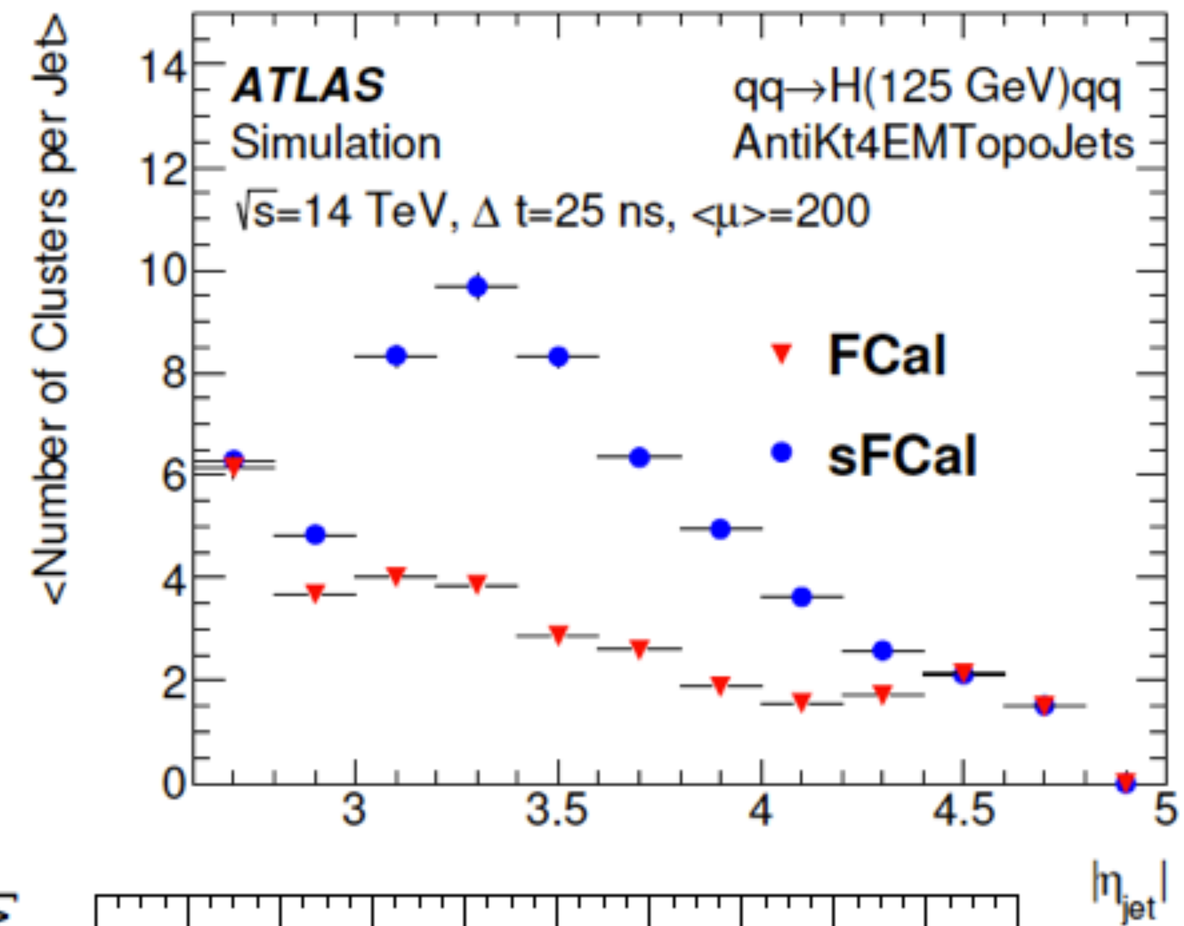


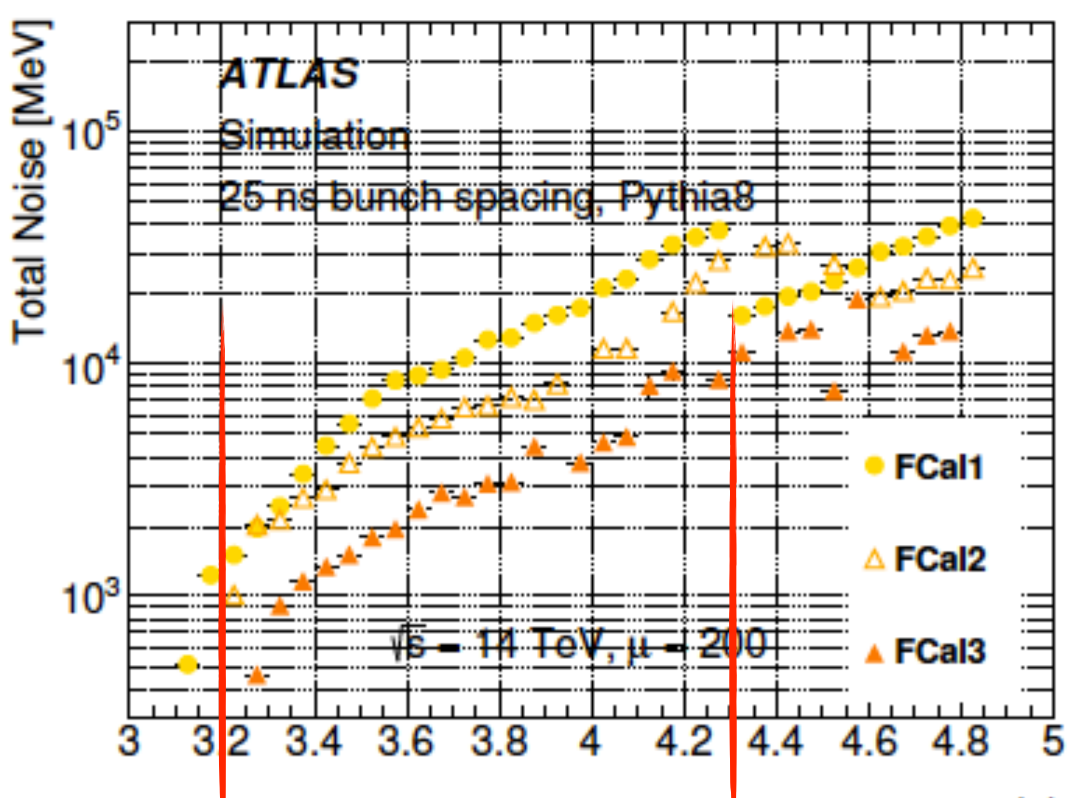
electron

jet

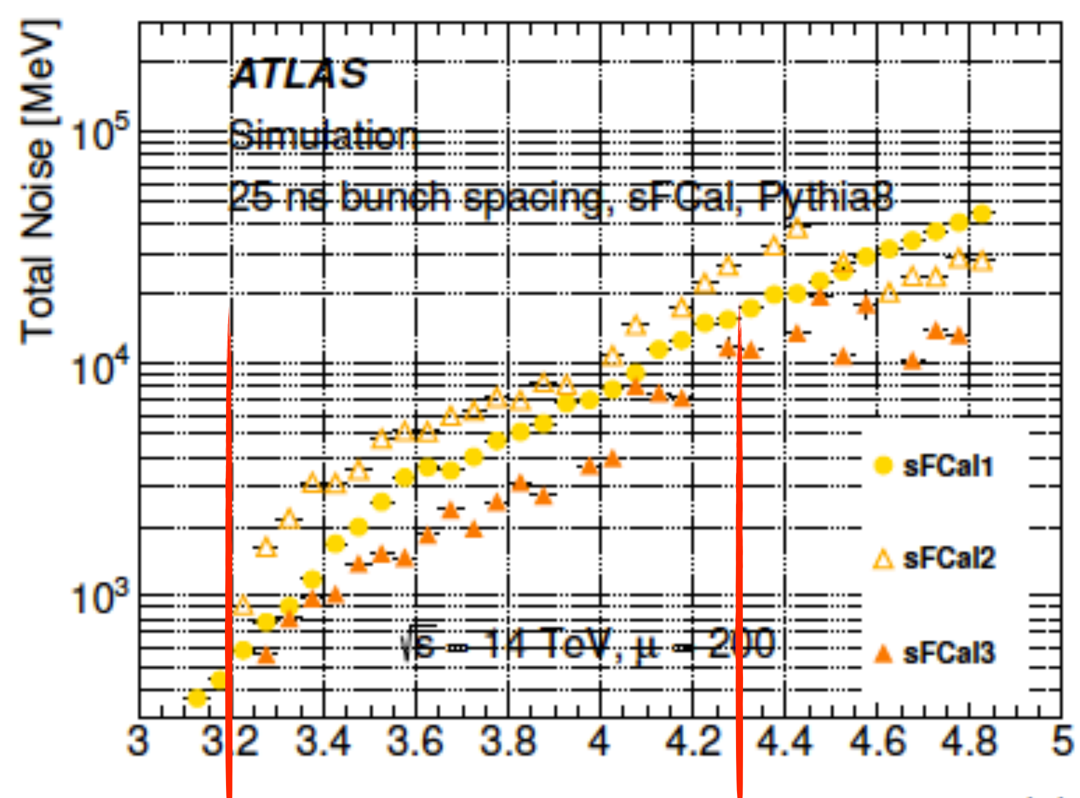
expected performance

- due higher granularity:
  - significant noise reduction
  - increased jet substructure information





current granularity



increased granularity