Carnegie Mellon University

B-Jet Trigger:
Status and Future Plans

John Alison

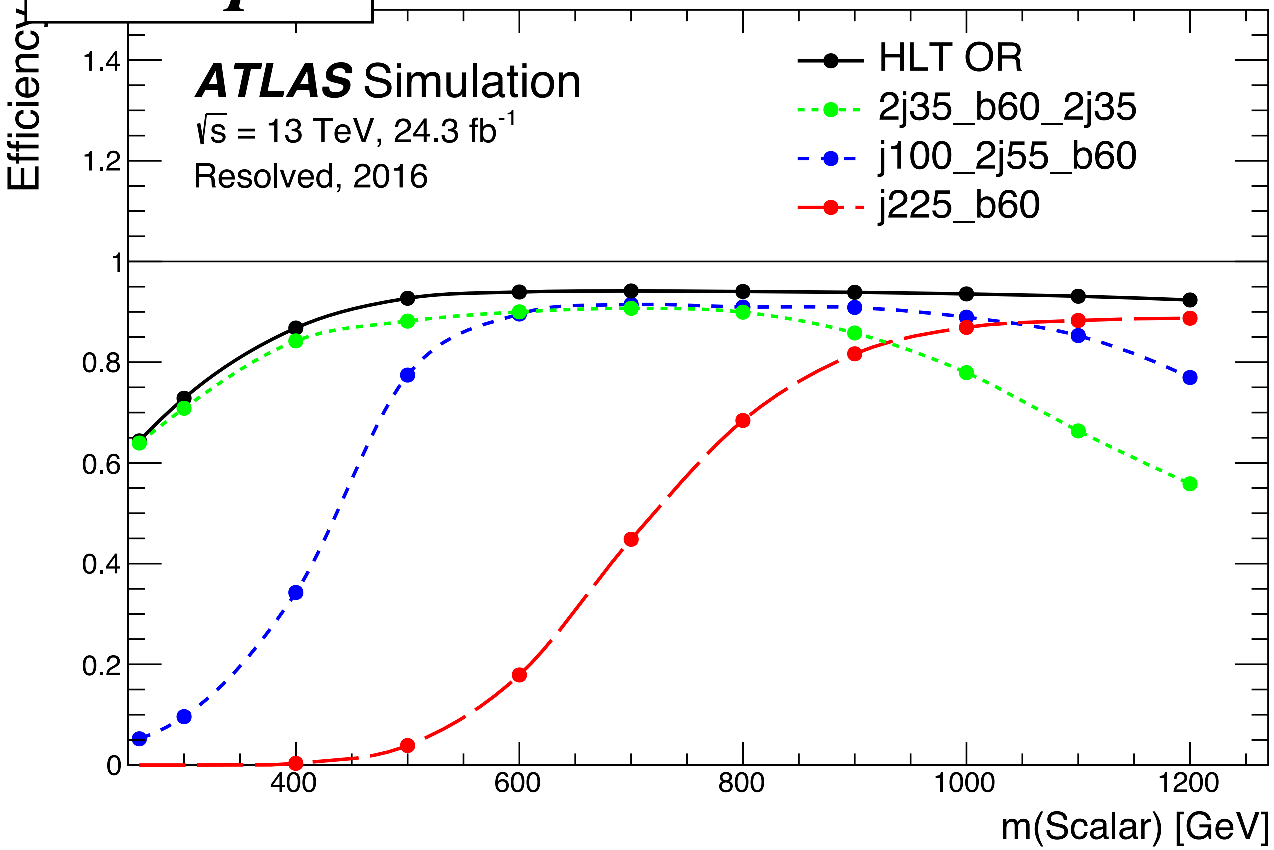
Carnegie Mellon University

on behalf of the ATLAS and CMS Collaborations

Introduction

B-jet triggers critical for hh→4b. *(Probably also in future for hh→bbττ)*

Example:



2j35_b60_2j35:
- 4 × 35 GeV jets
- 2 of b-tagged (60% WP)

j100_2j55_b60:
- 1 × 100 GeV
- 2 × 55 GeV (btagged)

j225_b60:
- 1 btag 225 GeV

Outline

B-jet triggers most complicated trigger paths at LHC.

Depend on many lower-level inputs
- L1 seed
- Primary Vertex finding
- HLT tracking
- Jet reconstruction/calibration
- b-tagging

Constraints:

L1 rate / CPU limitation in HLT / output rate

Consistency with offline algorithms

(optimized w/o these above constraints)

Outline

B-jet triggers most complicated trigger paths at LHC.

Depend on many lower-level inputs
- L1 seed
- Primary Vertex finding
- HLT tracking
- Jet reconstruction/calibration
- b-tagging

- Go through these in turn.
  Emphasize differences between ATLAS/CMS
- Discussion of Upgrades

Constraints:
L1 rate / CPU limitation in HLT / output rate
Consistency with offline algorithms
(optimized w/o these above constraints)

L1 Trigger

ATLAS

Trigger	L1 Seed	L1 Rate	HLT Rate
4j35 (2-btags)	4×J15	~3 kHz	~40 Hz
j100+2j55 (2 b-tags)	J75 + 2J20	~ 2 kHz	~10 Hz
j225 (1-btag)	J100	~3 kHz	~20 Hz

CMS

Trigger	L1 Seed	L1 Rate	HLT Rate
4j45 (3-btags)	HT ≥280 + …	~3 kHz*	~10 Hz*
2j30+2j90 (3-btags)	HT ≥280 + …	~3 kHz*	~5-10 Hz*

*Guesses based on 2018 rates

Online Primary Vertex finding

Online Primary Vertex finding

Transverse position determined from beamspot position

Reconstruct longitudinal (z) PV position event-by-event
- Mainly a CPU saver from Δz wrt PV cut
- Also used track selection / longitudinal impact parameter

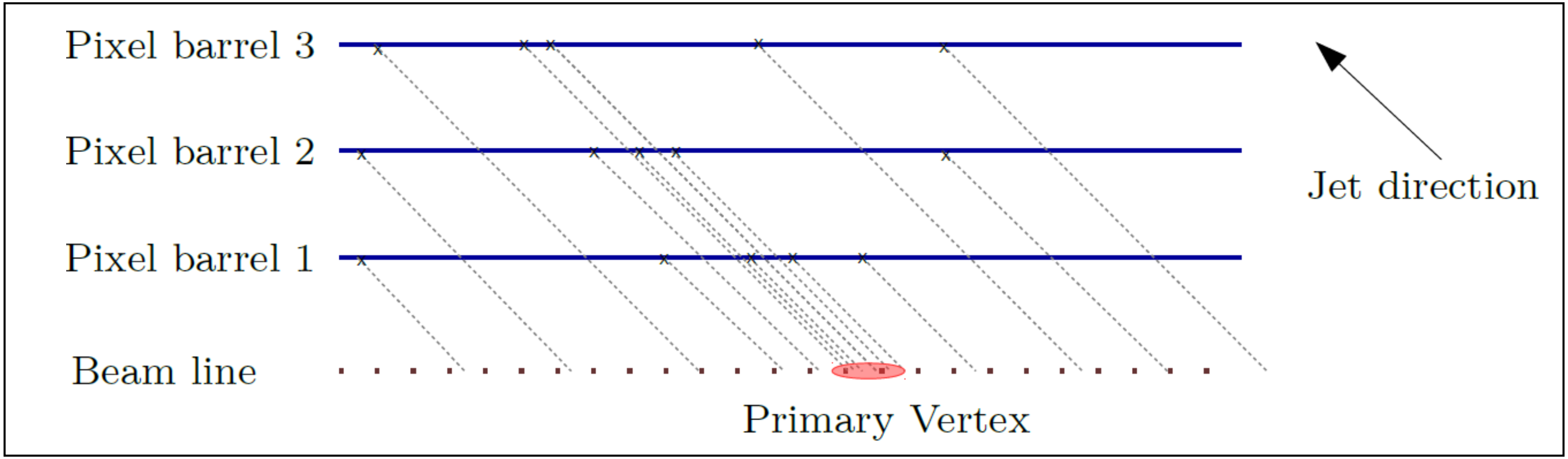
ATLAS and CMS quite different approaches.

CMS Primary Vertex finding

Iterative approach
Start with ***track-less*** vertex finding using jets + pixel clusters

CMS Primary Vertex finding

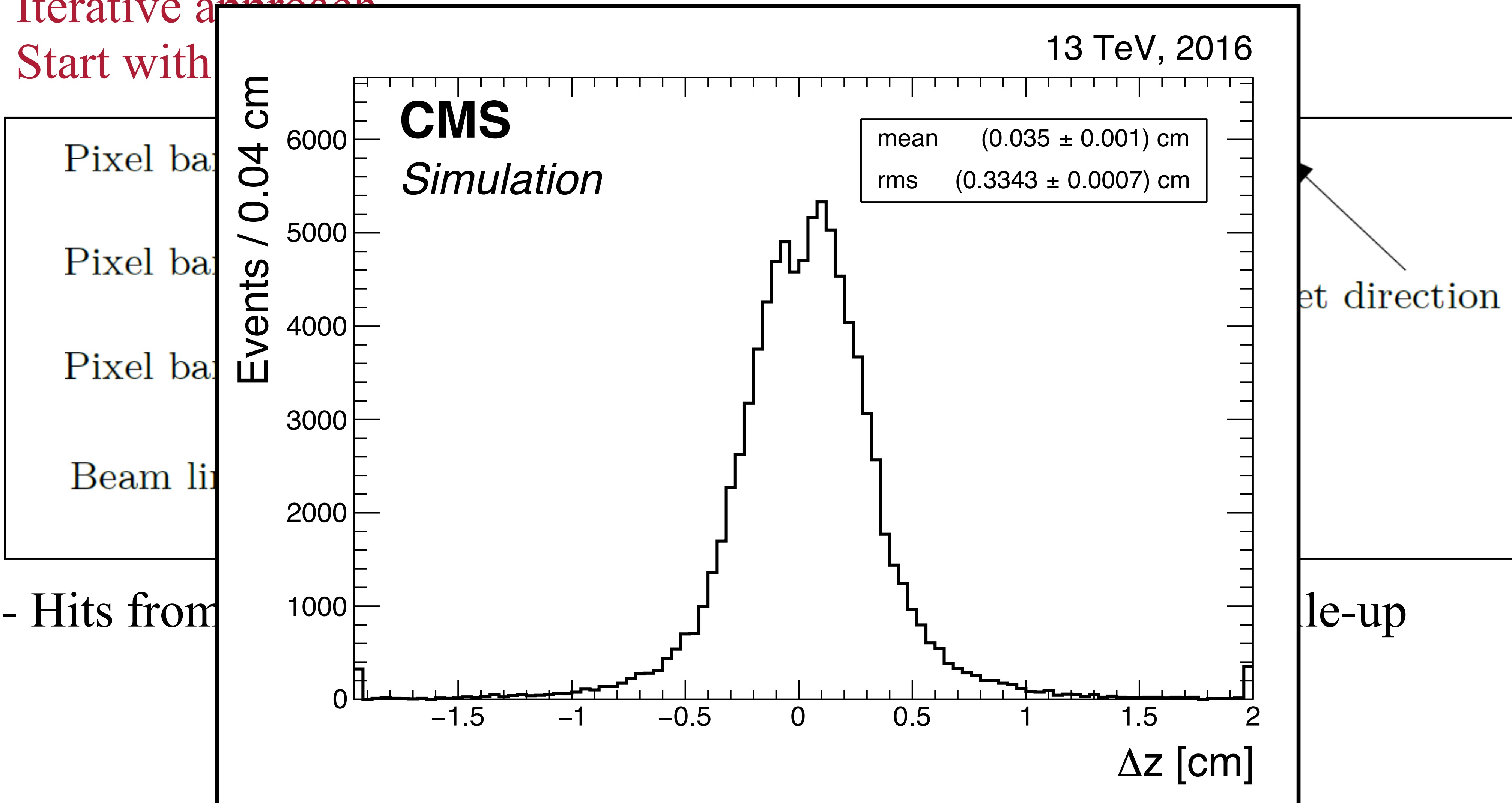
Iterative approach
Start with ***track-less*** vertex finding using jets + pixel clusters



- Hits from 4 leading jets / weighting by cluster shape mitigate pile-up

CMS Primary Vertex finding

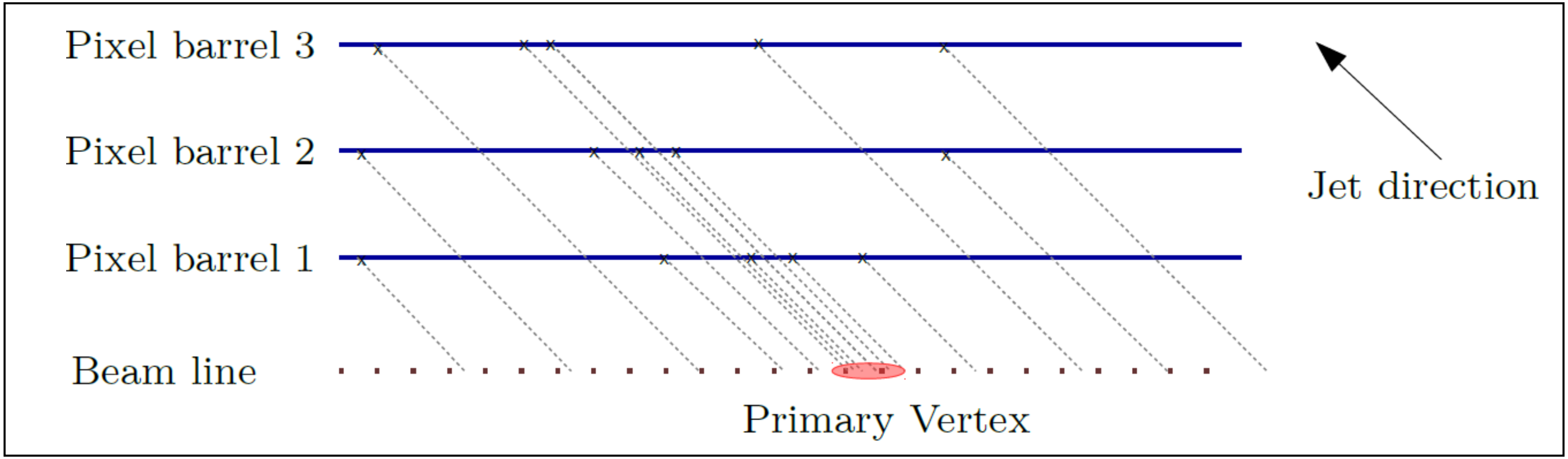
Iterative a
Start with



- Hits from ... le-up

CMS Primary Vertex finding

Iterative approach
Start with ***track-less*** vertex finding using jets + pixel clusters

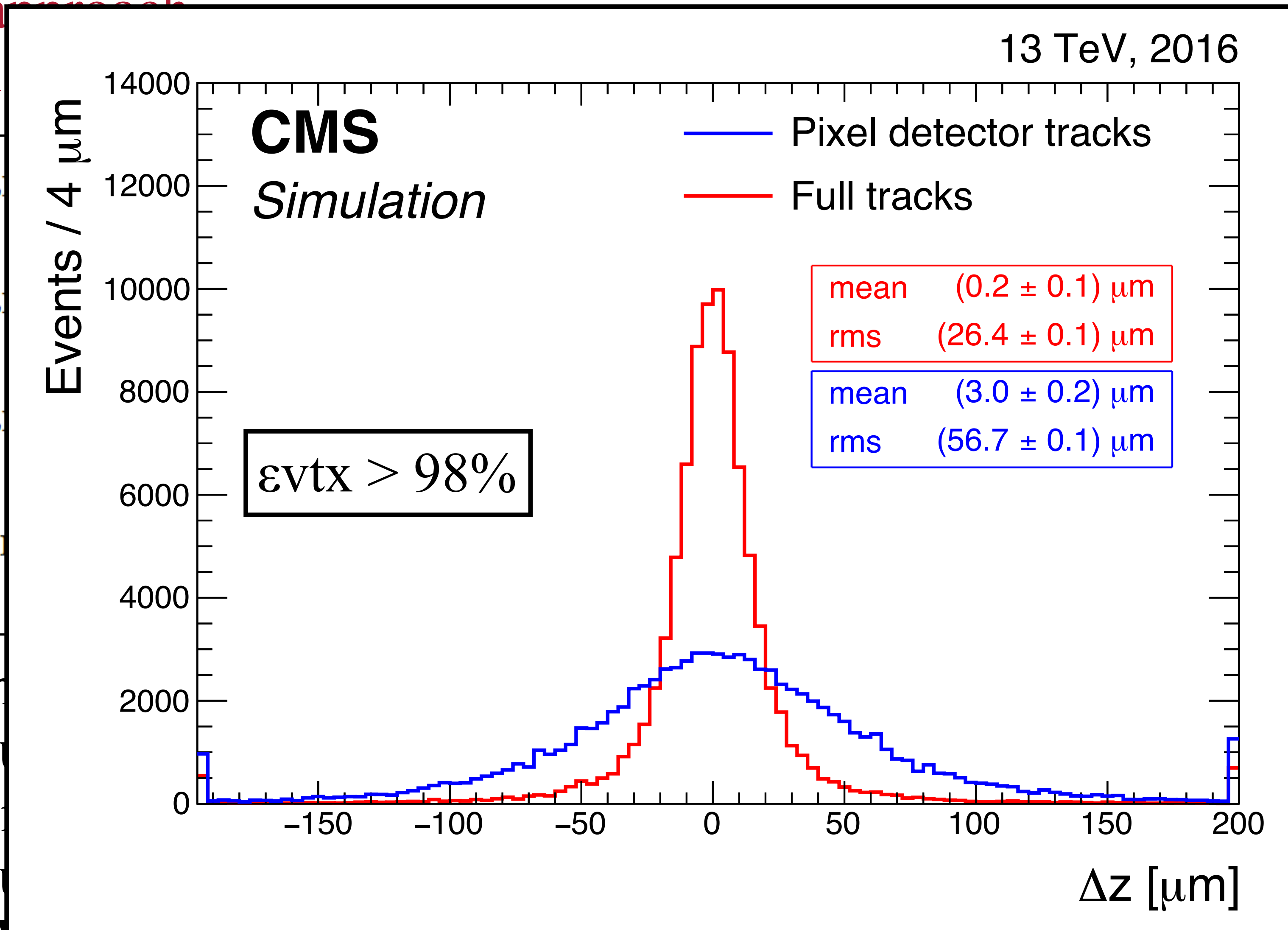


- Hits from 4 leading jets / weighting by cluster shape mitigate pile-up
- Reconstruction pixel tracks with $\Delta Z < 15$ mm
- Re-do Primary Vertex finding w/ Pixel tracks
- Reconstruction Full Pixel + Strip tracks updated PV
- Refine PV with full tracks

CMS Primary Vertex finding

Iterative a

Start with



- Hits from ... up
- Reconstr
- Re-do Pr
- Reconstr
- Refine PV with full tracks

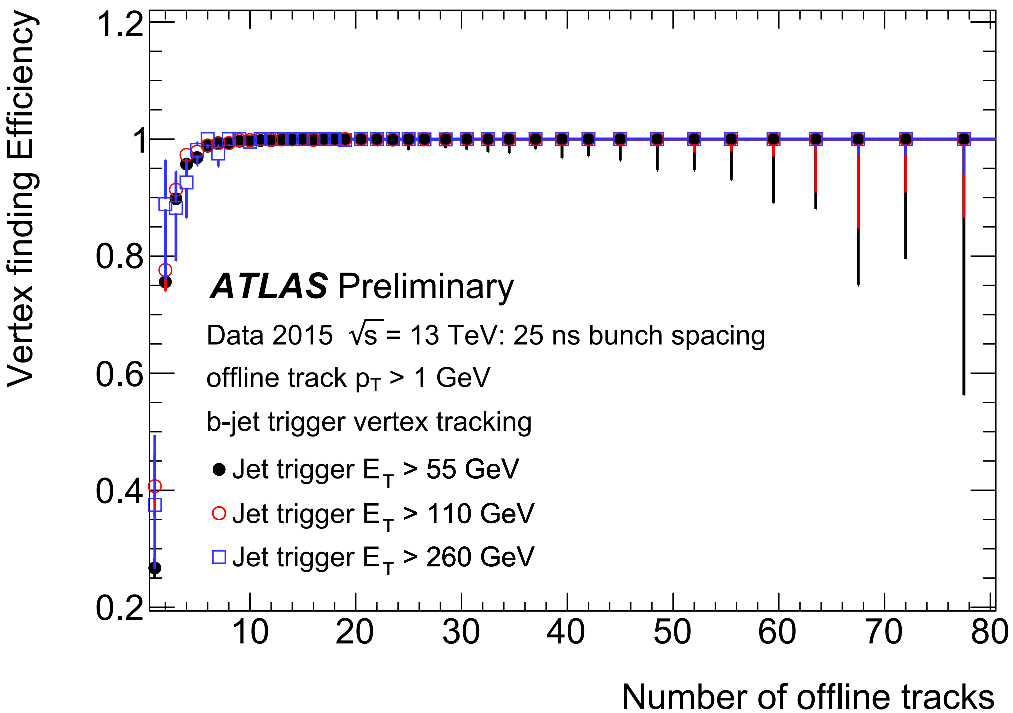
ATLAS Primary Vertex finding

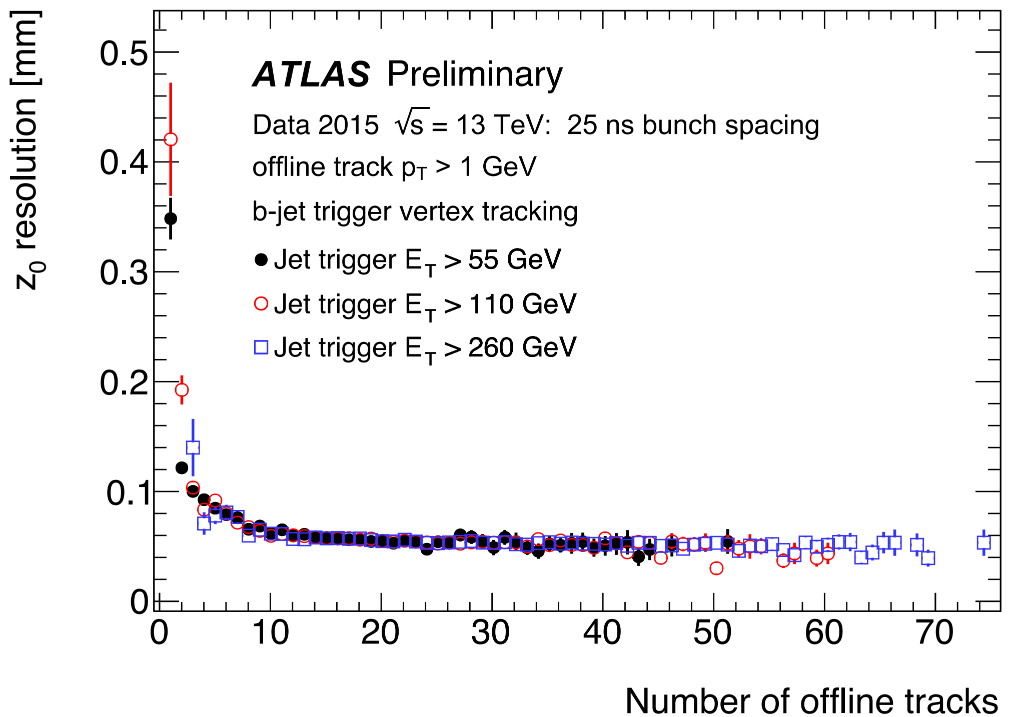
Two-step track reconstruction:

- "Super ROIs" - OR of jet ROIs 0.2×0.2 ($P_T > 30$ GeV)
- "Fast tracking" within Super-ROI. $P_T > 1$ GeV
- Primary Vertex reconstruction
- "Precision tracking" in 0.4×0.4 jet ROIs with ΔZ cut

ATLAS Primary Vertex finding

Two-step track reconstruction:
- "Super ROIs" - OR of jet ROIs 0.2×0.2 (P_T > 30 GeV)
- "Fast tracking" within Super-ROI. P_T > 1 GeV
- Primary Vertex reconstruction
- "Precision tracking" in 0.4×0.4 jet ROIs with ΔZ cut

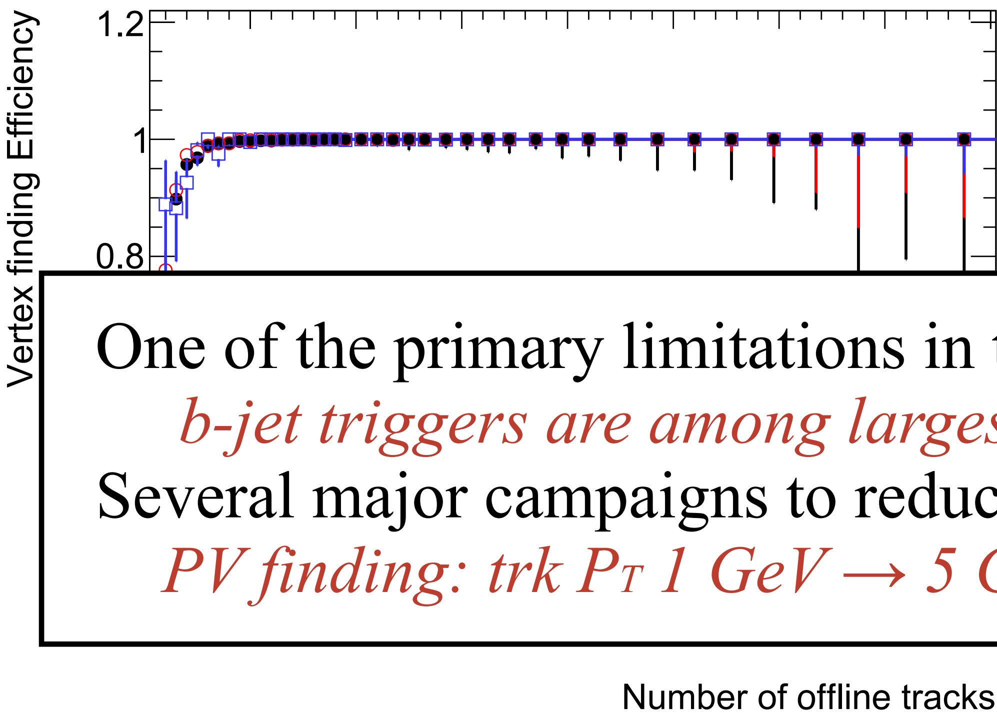


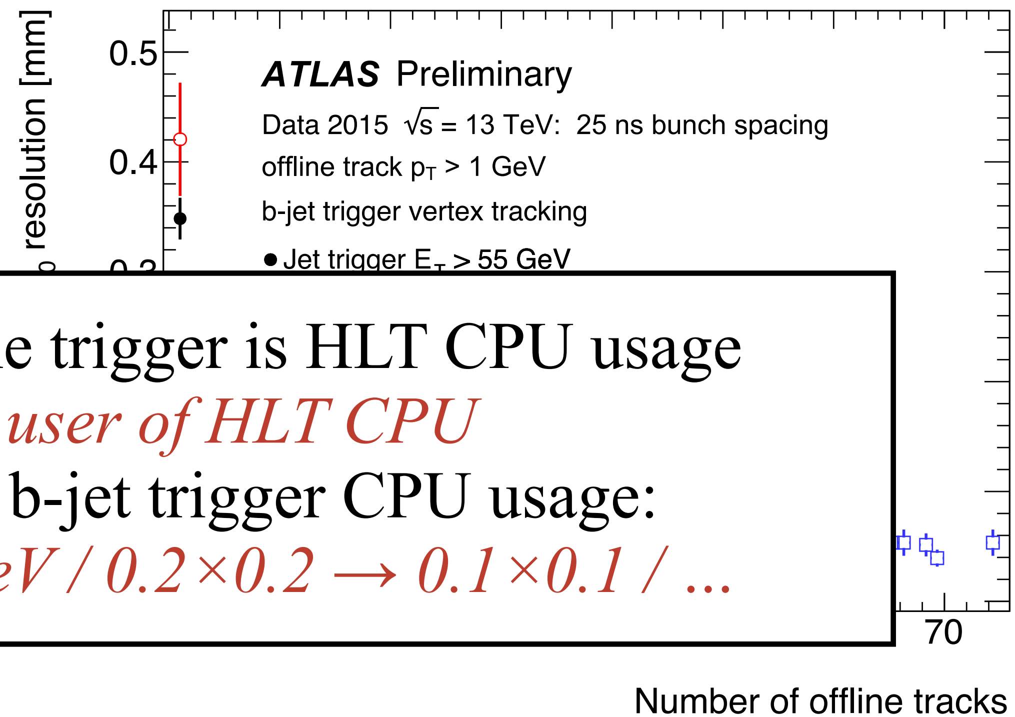


ATLAS Primary Vertex finding

Two-step track reconstruction:

- "Super ROIs" - OR of jet ROIs 0.2×0.2 (P_T > 30 GeV)
- "Fast tracking" within Super-ROI. P_T > 1 GeV
- Primary Vertex reconstruction
- "Precision tracking" in 0.4×0.4 jet ROIs with ΔZ cut





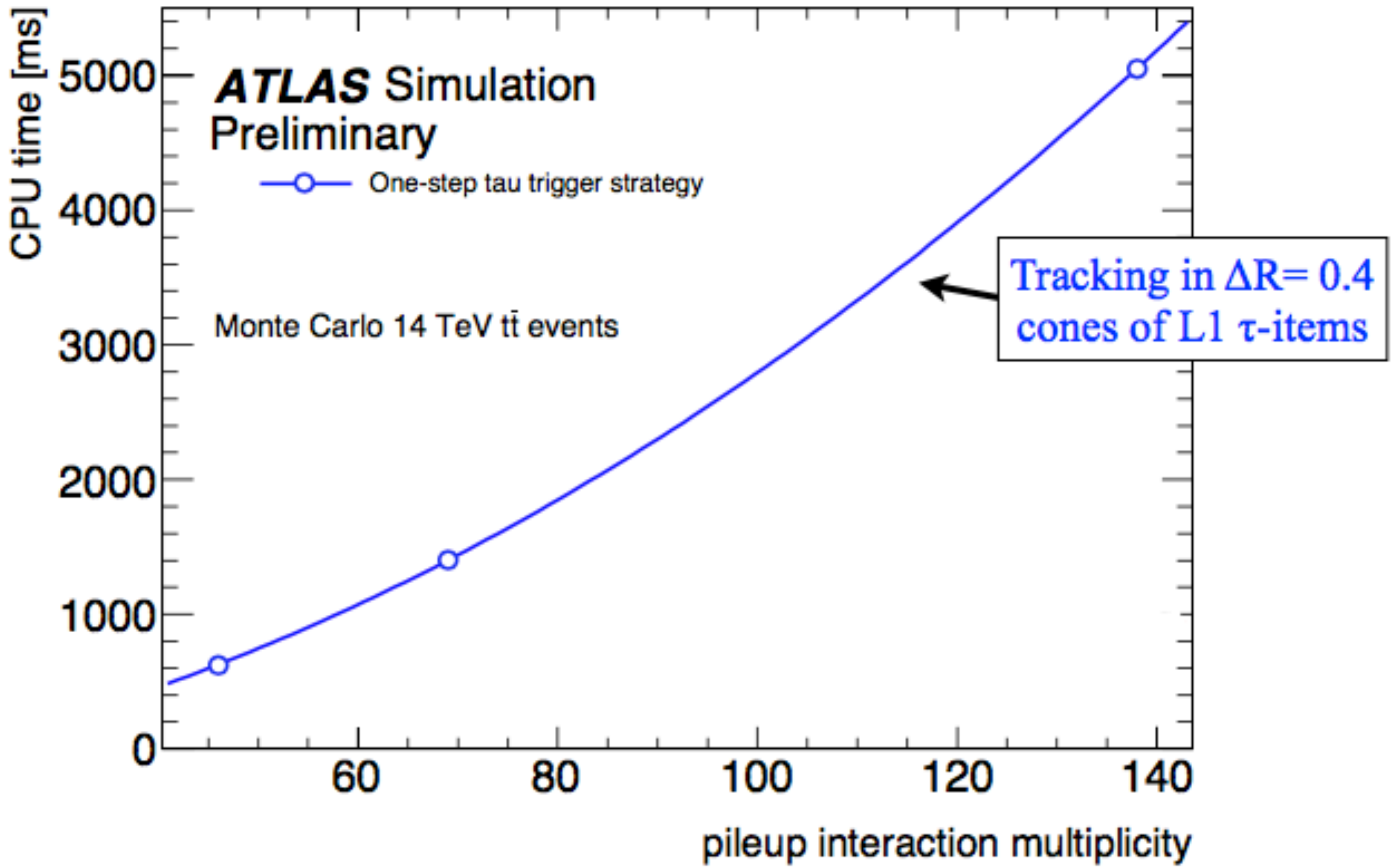
One of the primary limitations in the trigger is HLT CPU usage

b-jet triggers are among largest user of HLT CPU

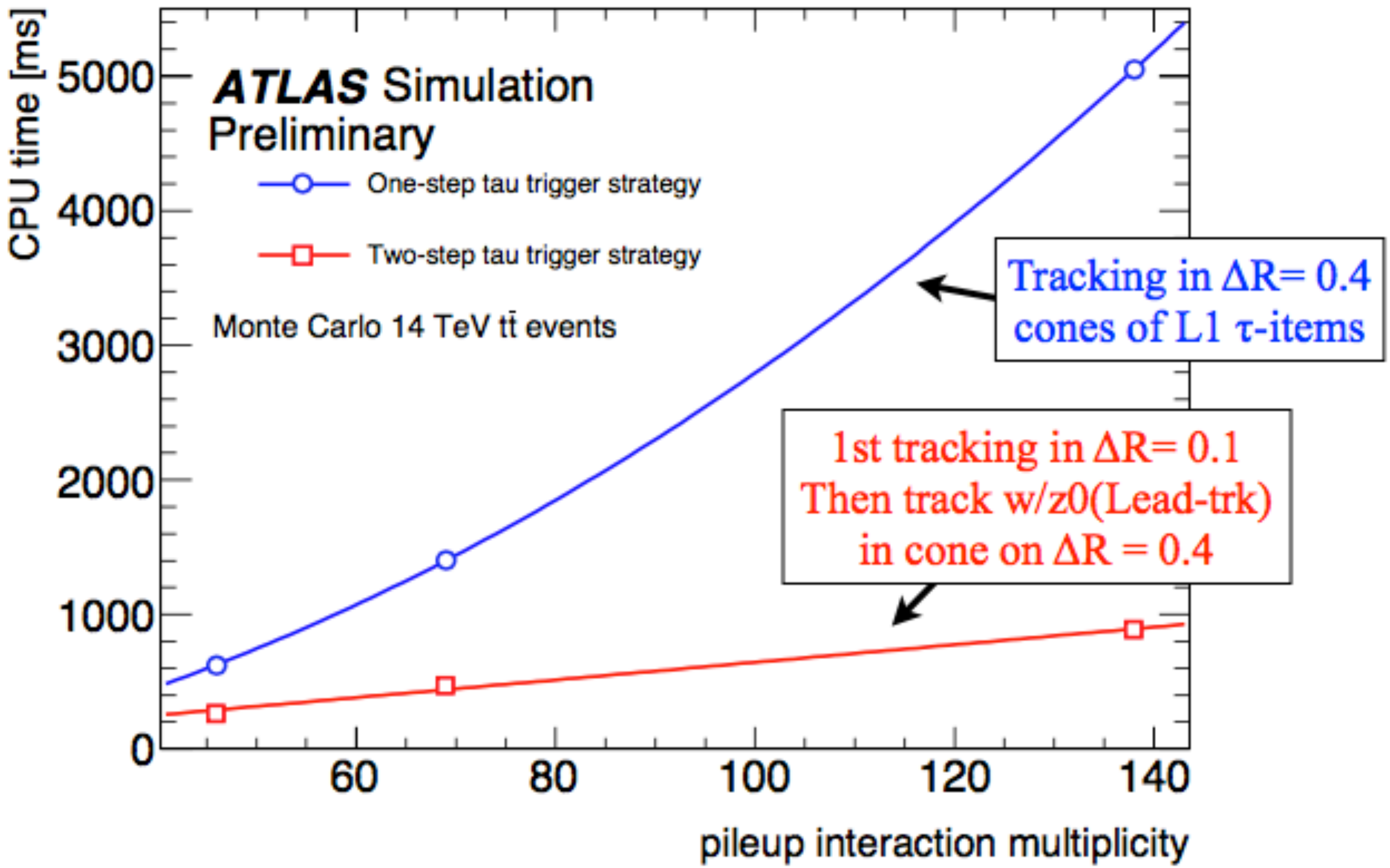
Several major campaigns to reduce b-jet trigger CPU usage:

PV finding: trk P_T 1 GeV → 5 GeV / 0.2×0.2 → 0.1×0.1 / …

Impact on HLT CPU



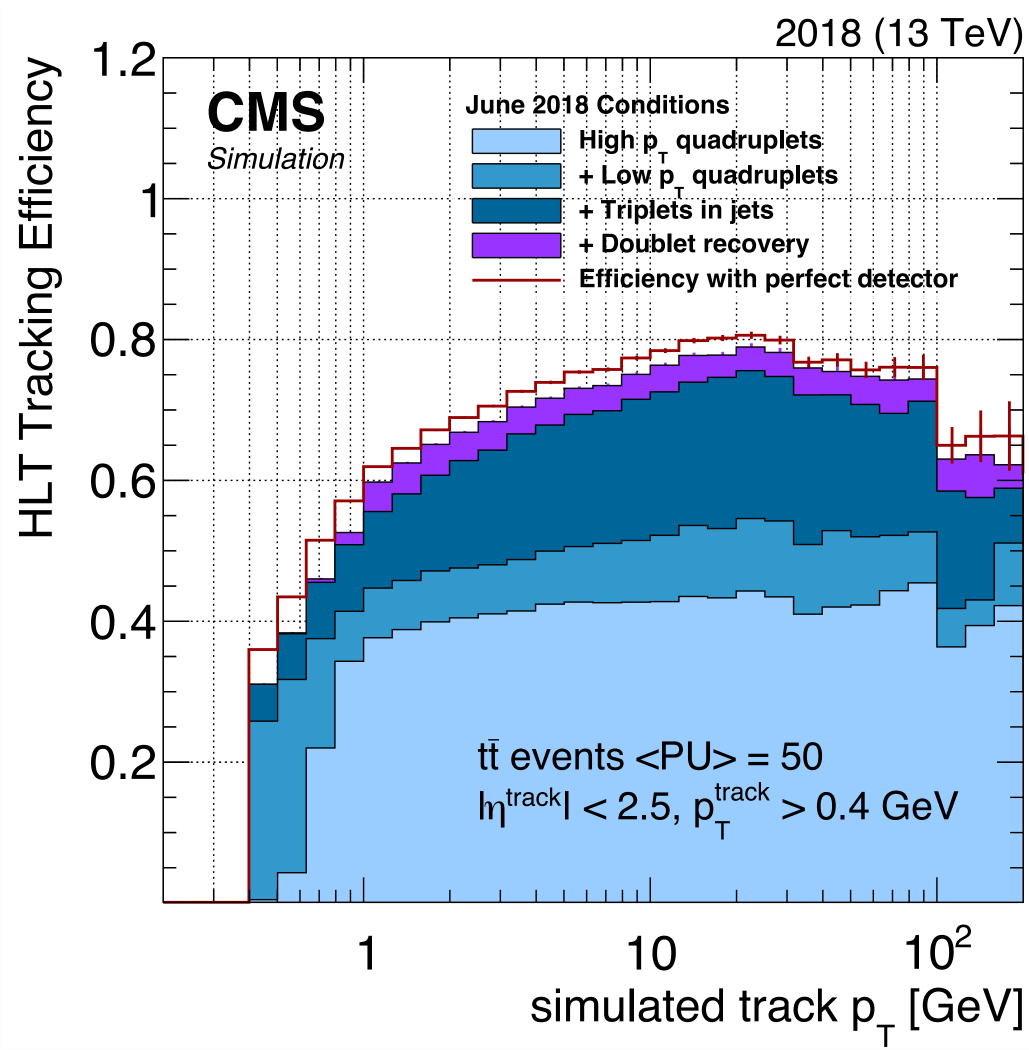
Impact on HLT CPU



Online Track Reconstruction

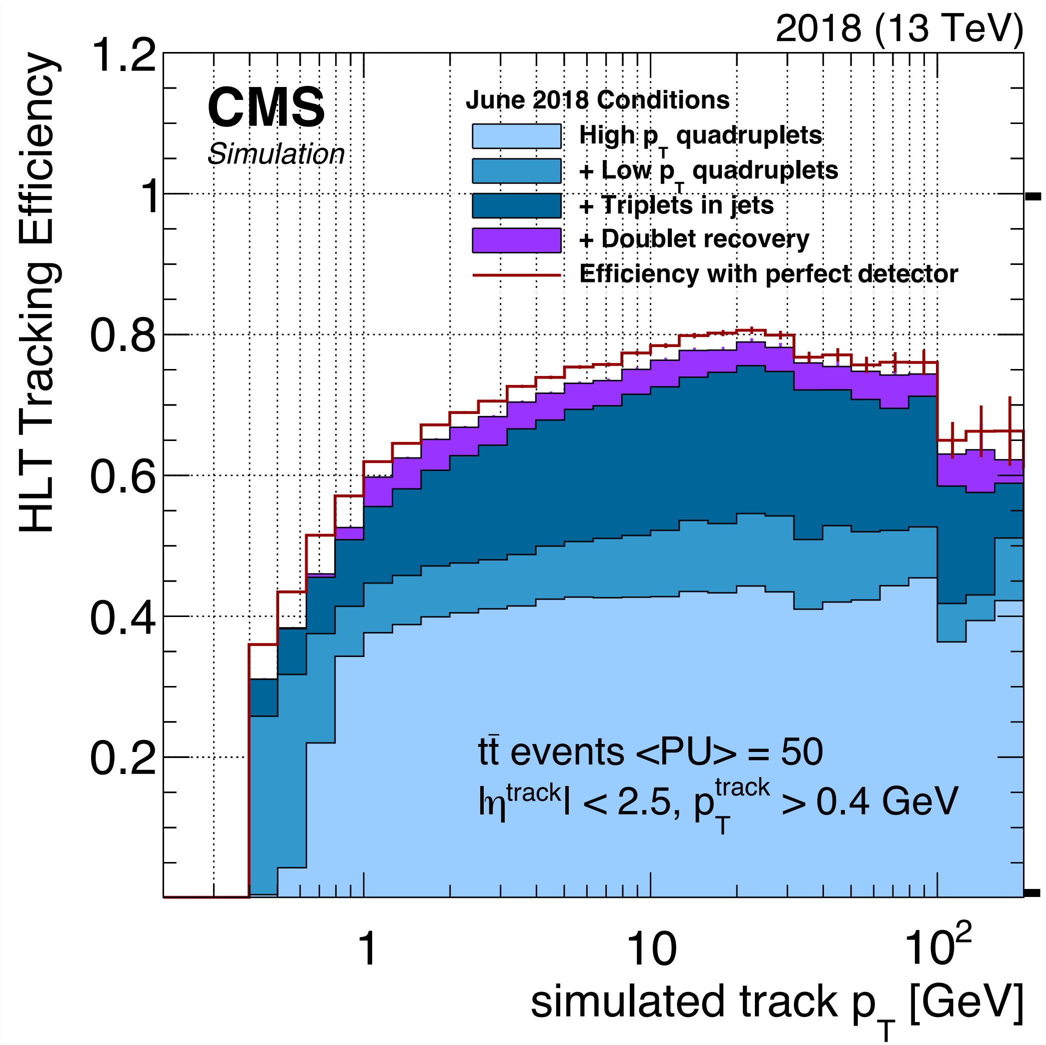
Track Efficiency

Efficiency Online

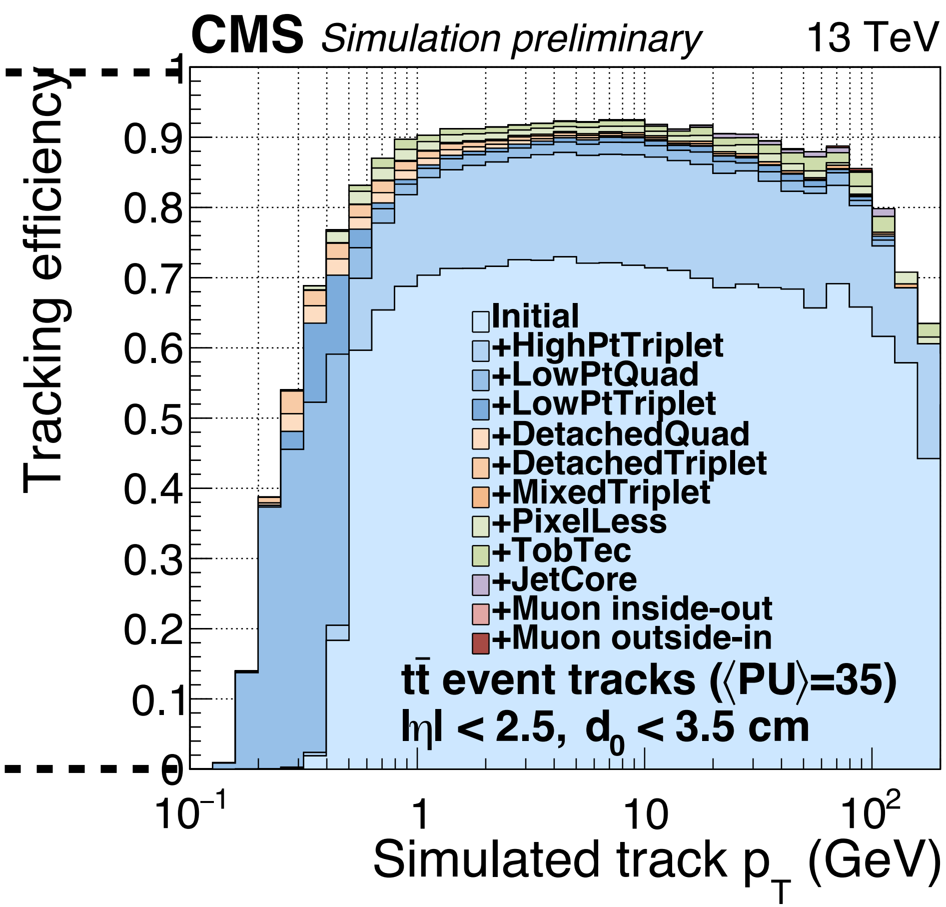


Track Efficiency

Efficiency Online

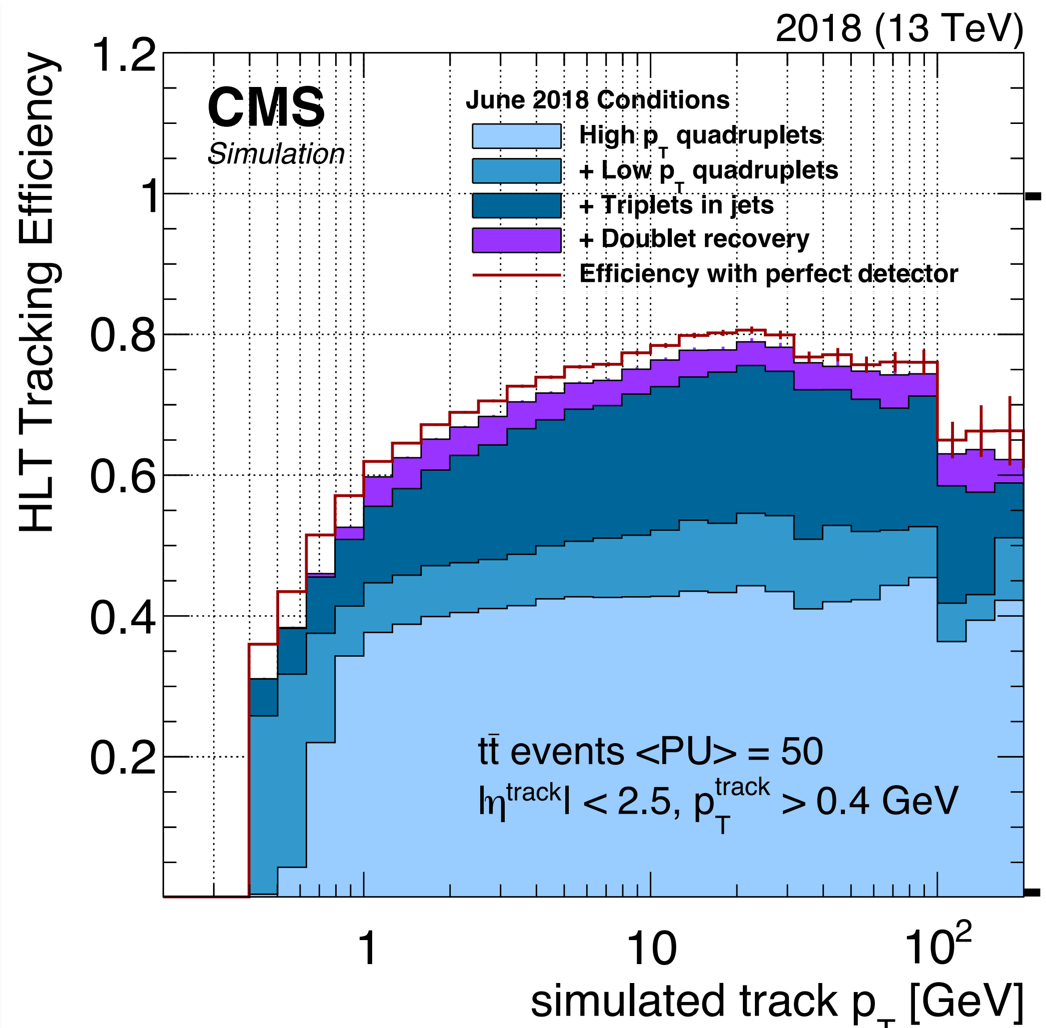


Efficiency Offline

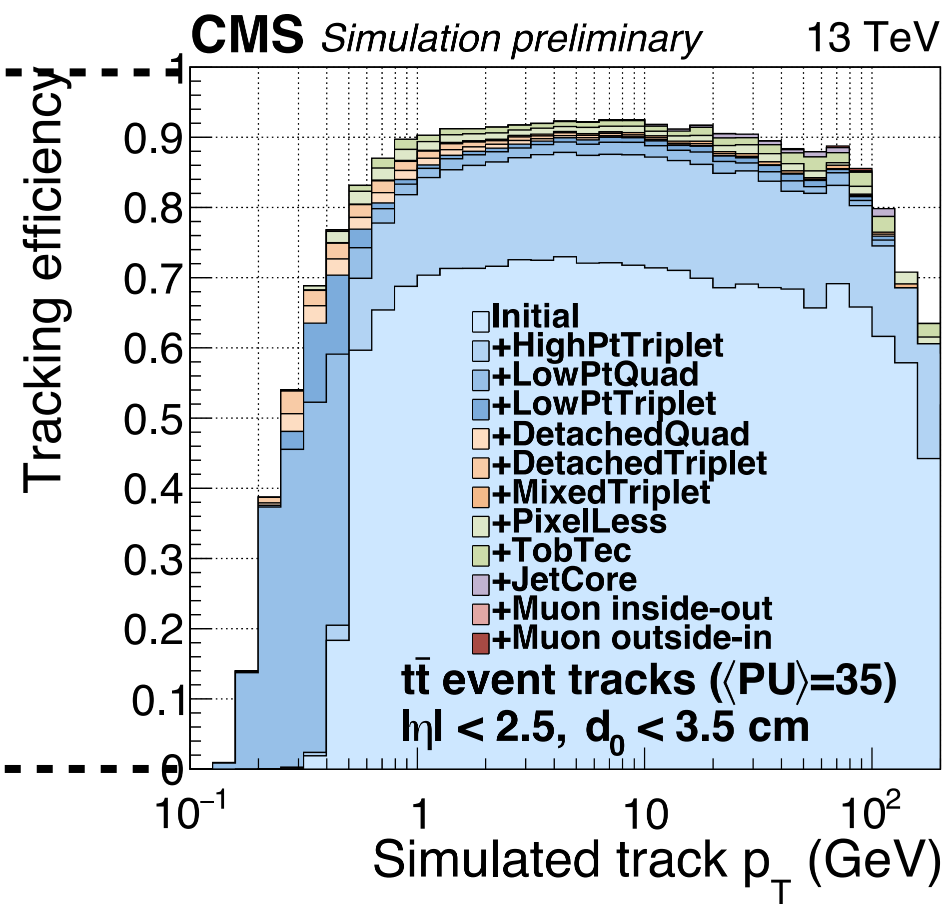


Track Efficiency

Efficiency Online

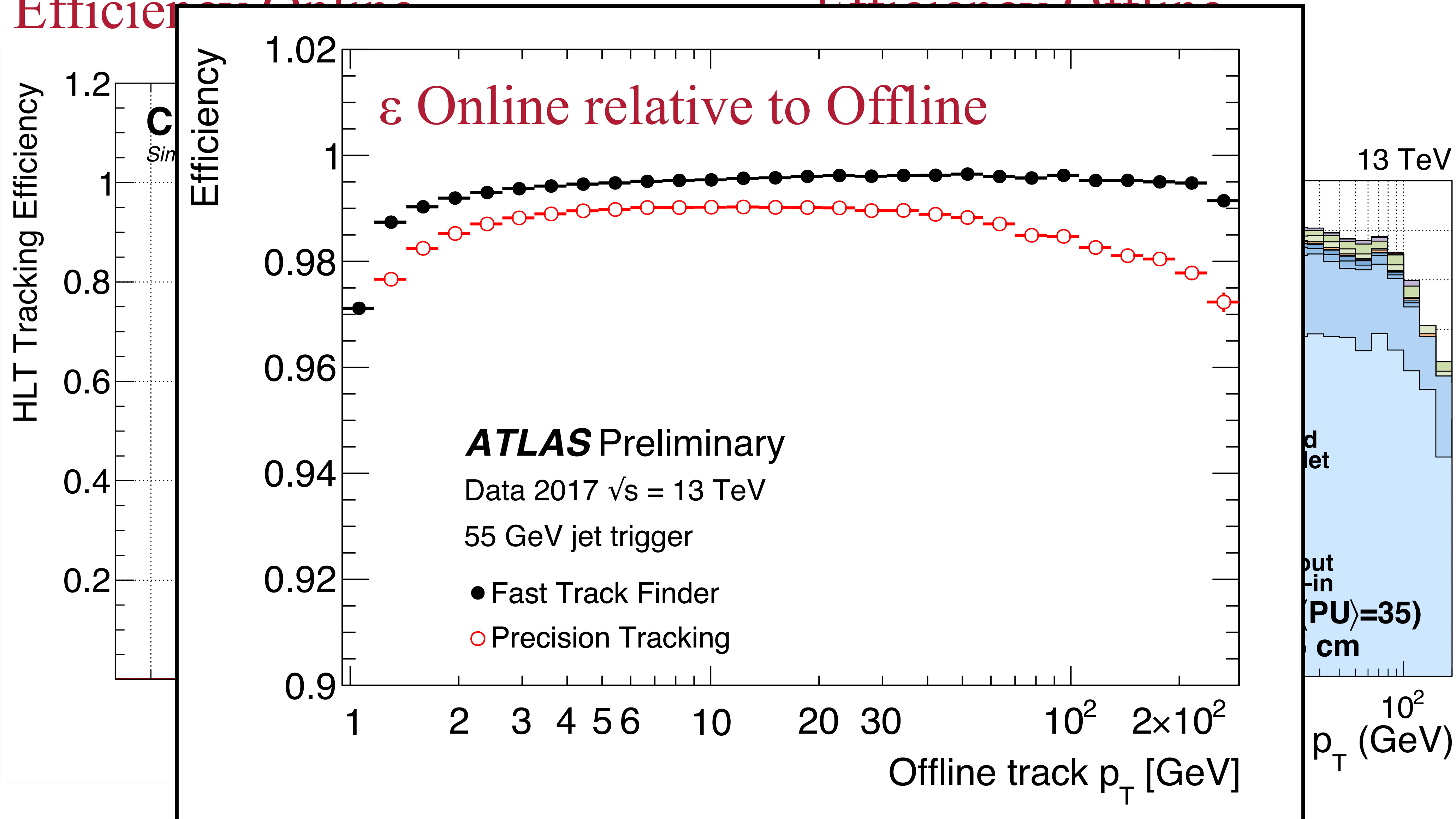


Efficiency Offline

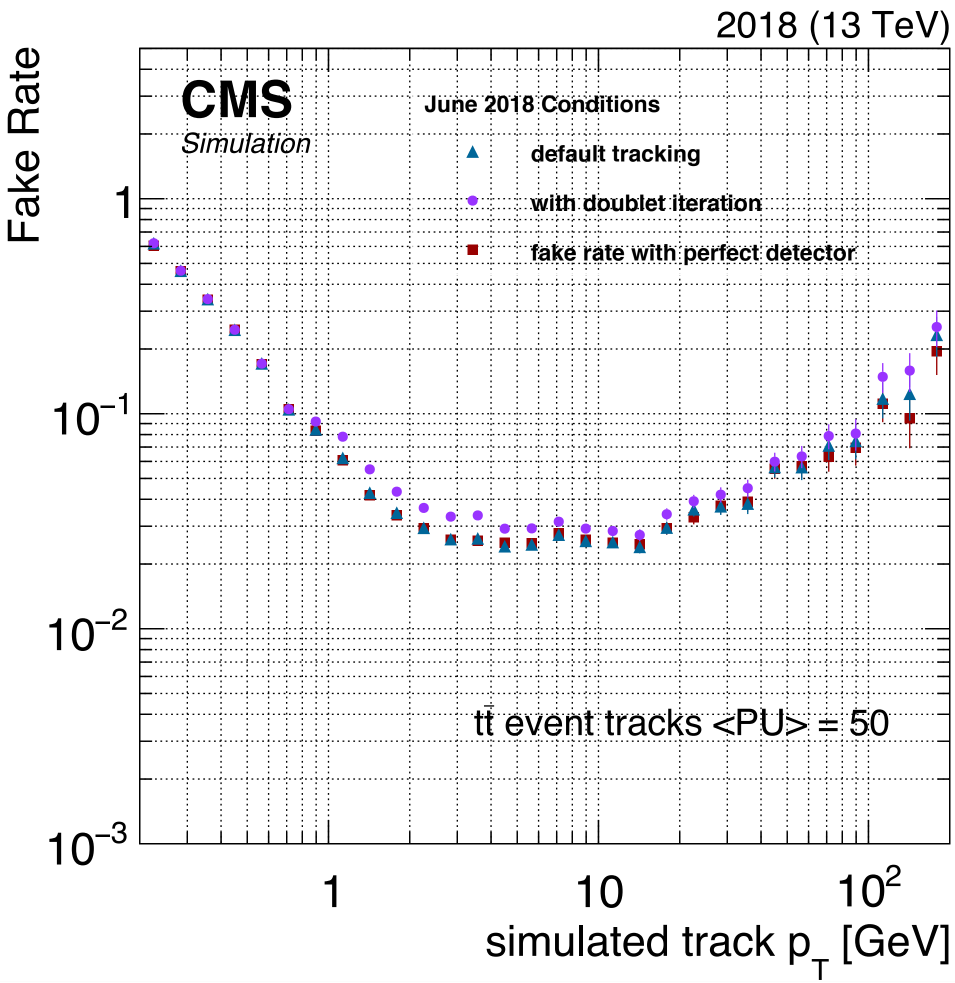


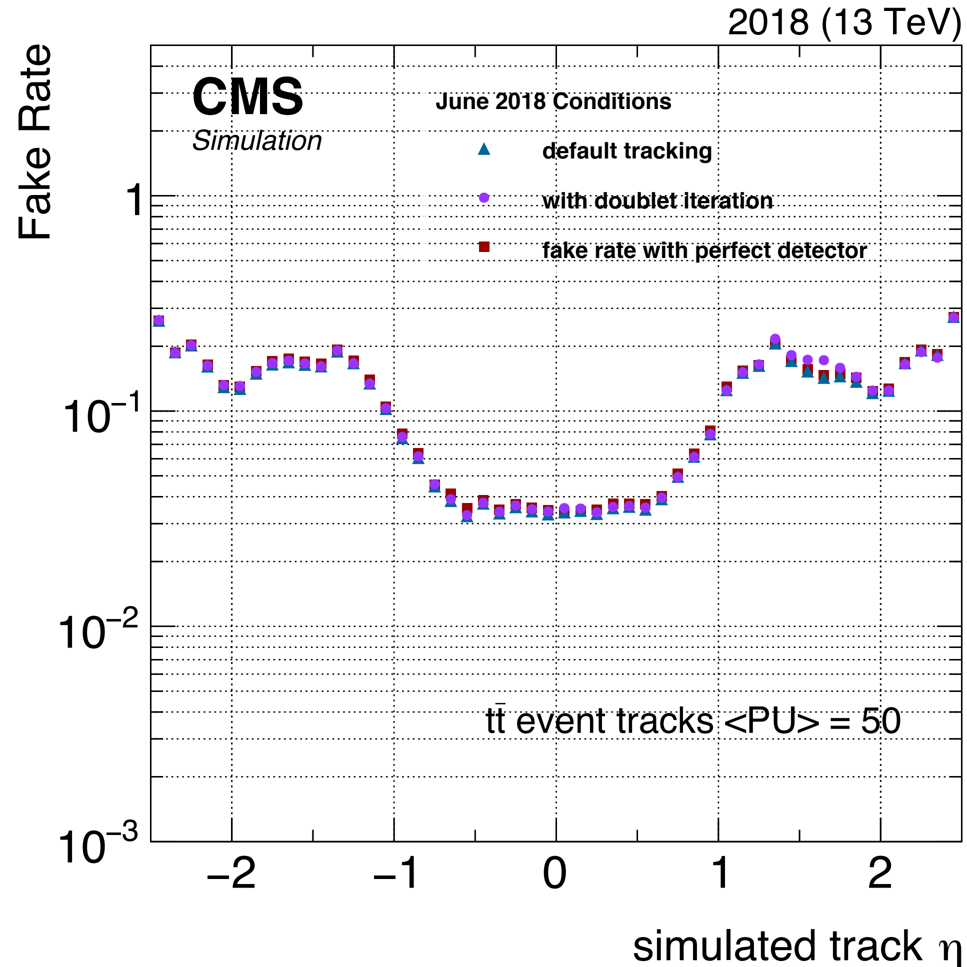
Relative 10-20% inefficiency online relative offline

Track Efficiency

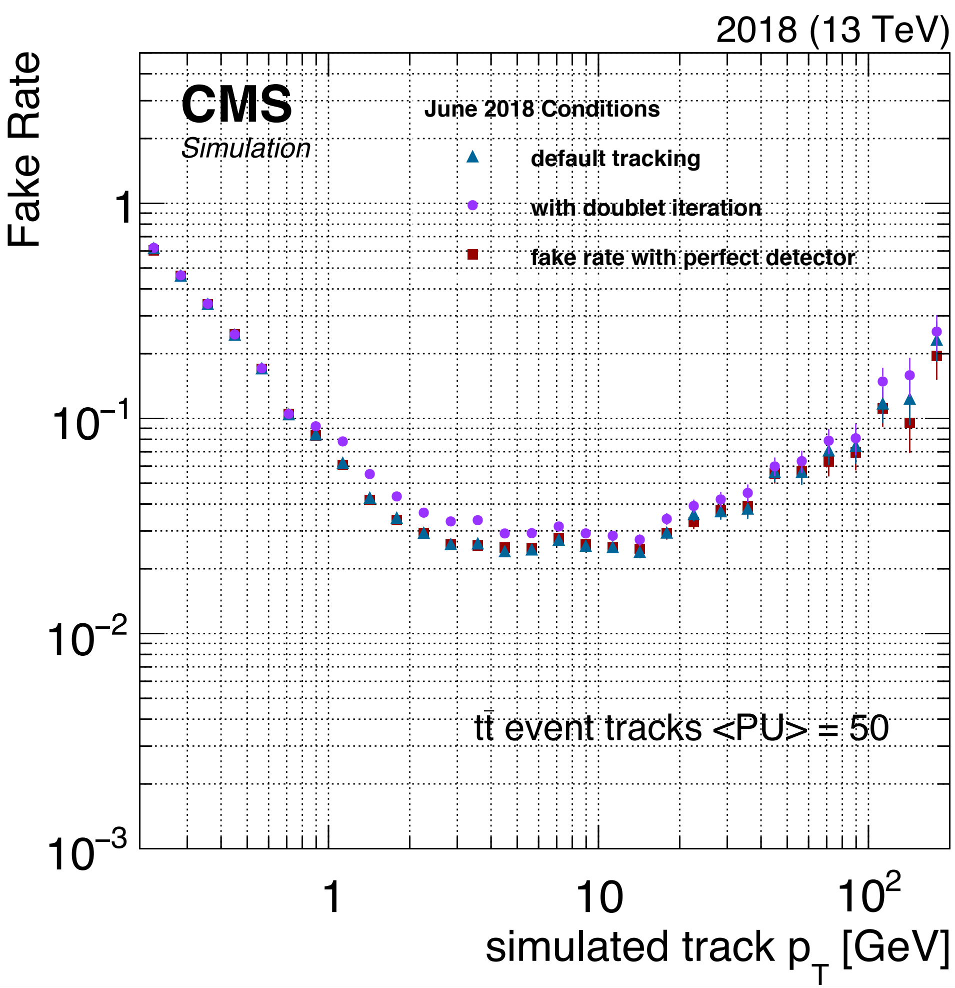


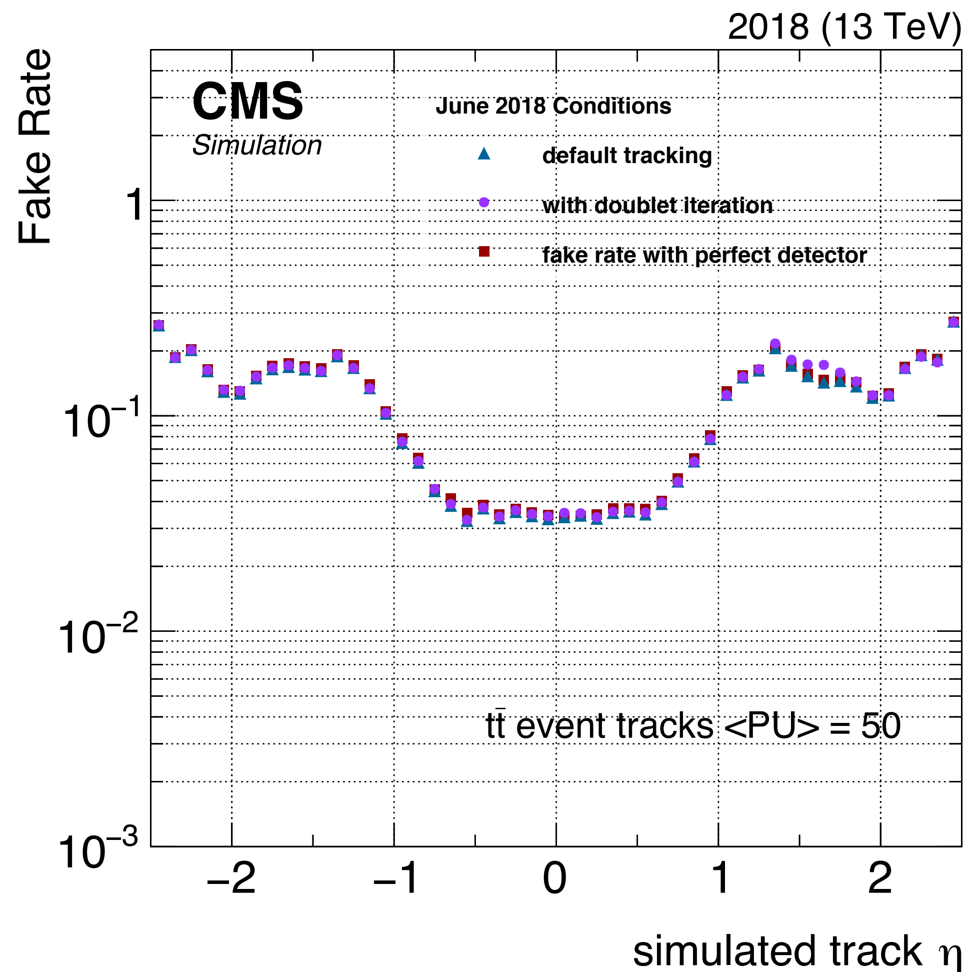
Track Fake Rates





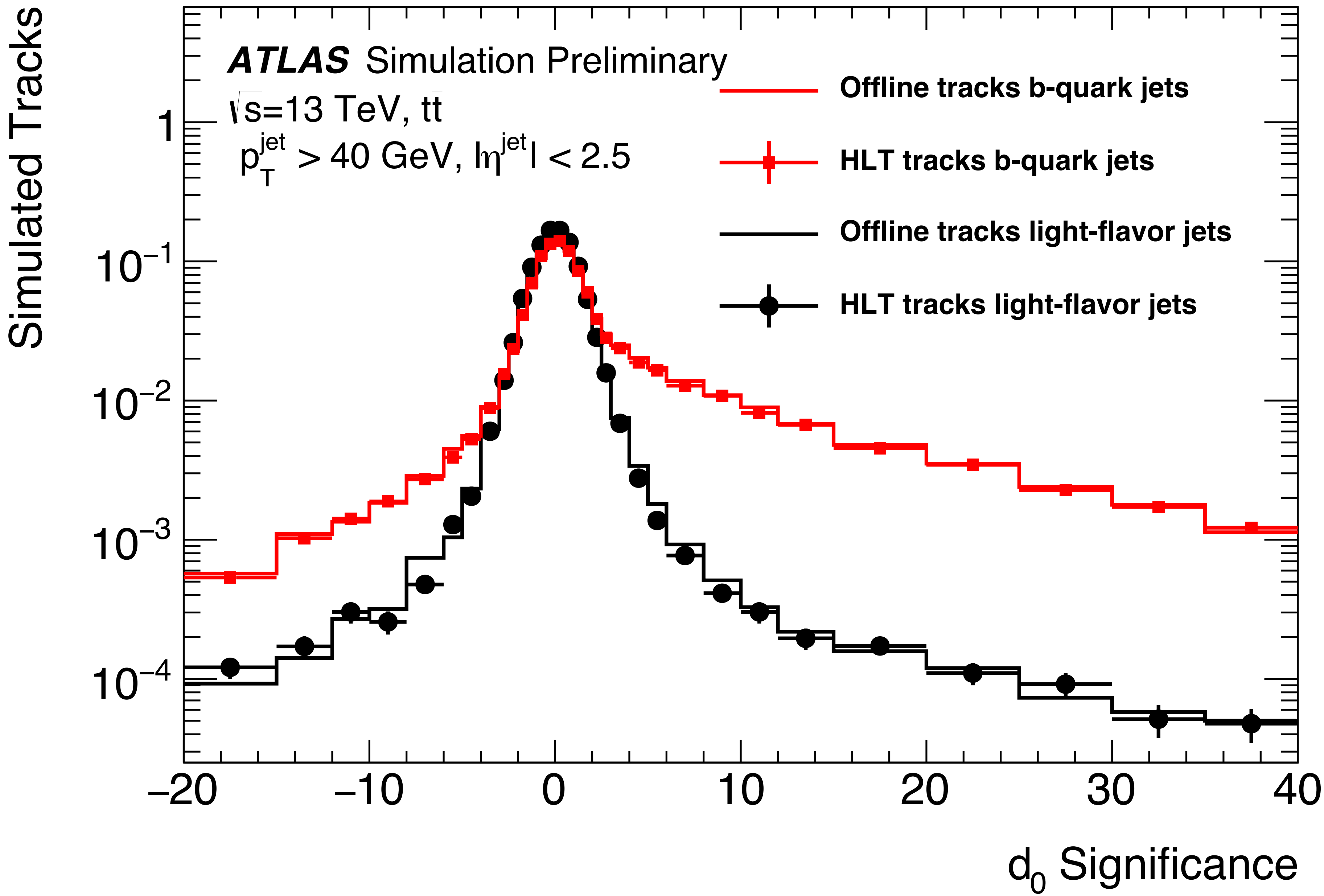
Track Fake Rates



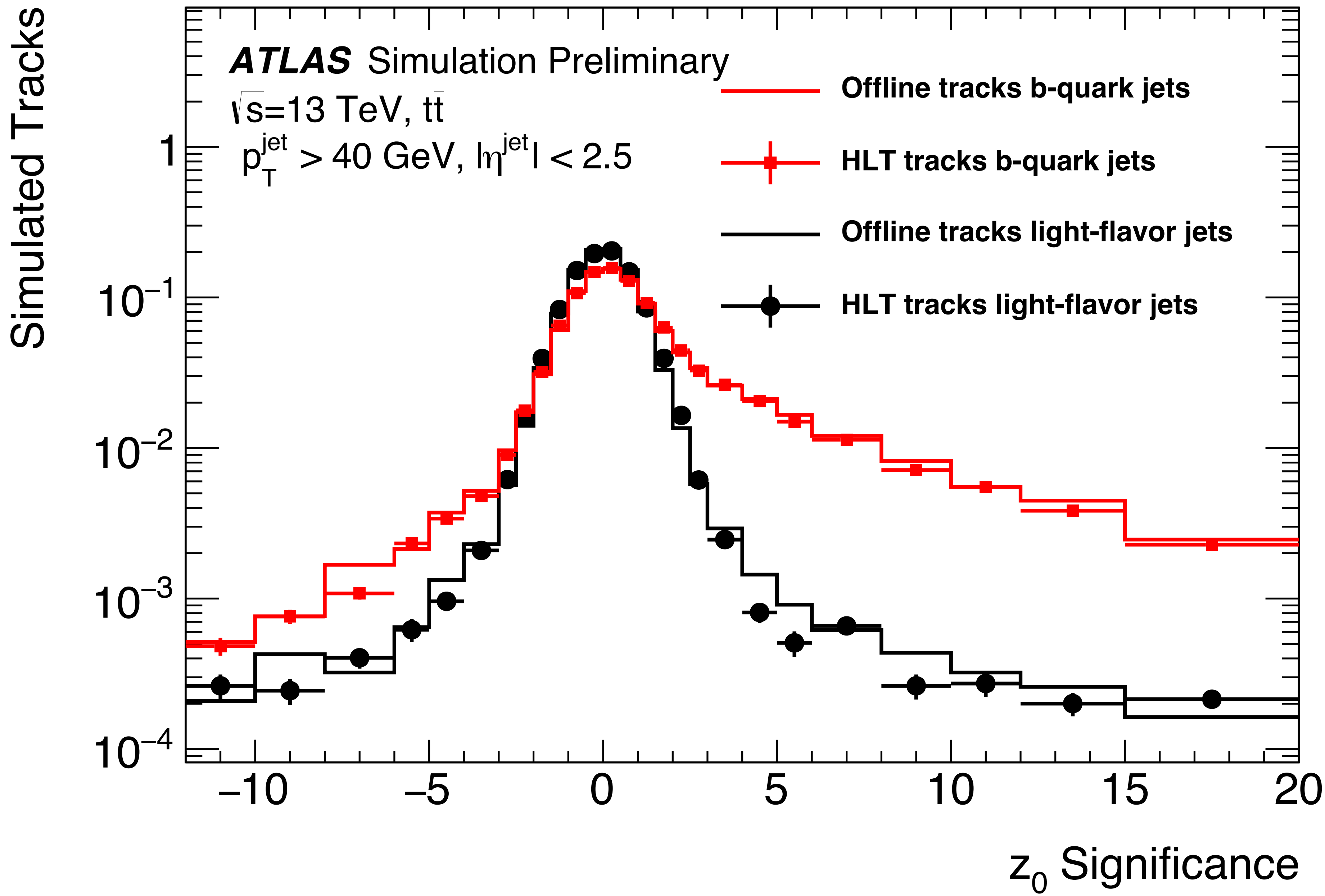


Unfortunately corresponding ATLAS results not public…

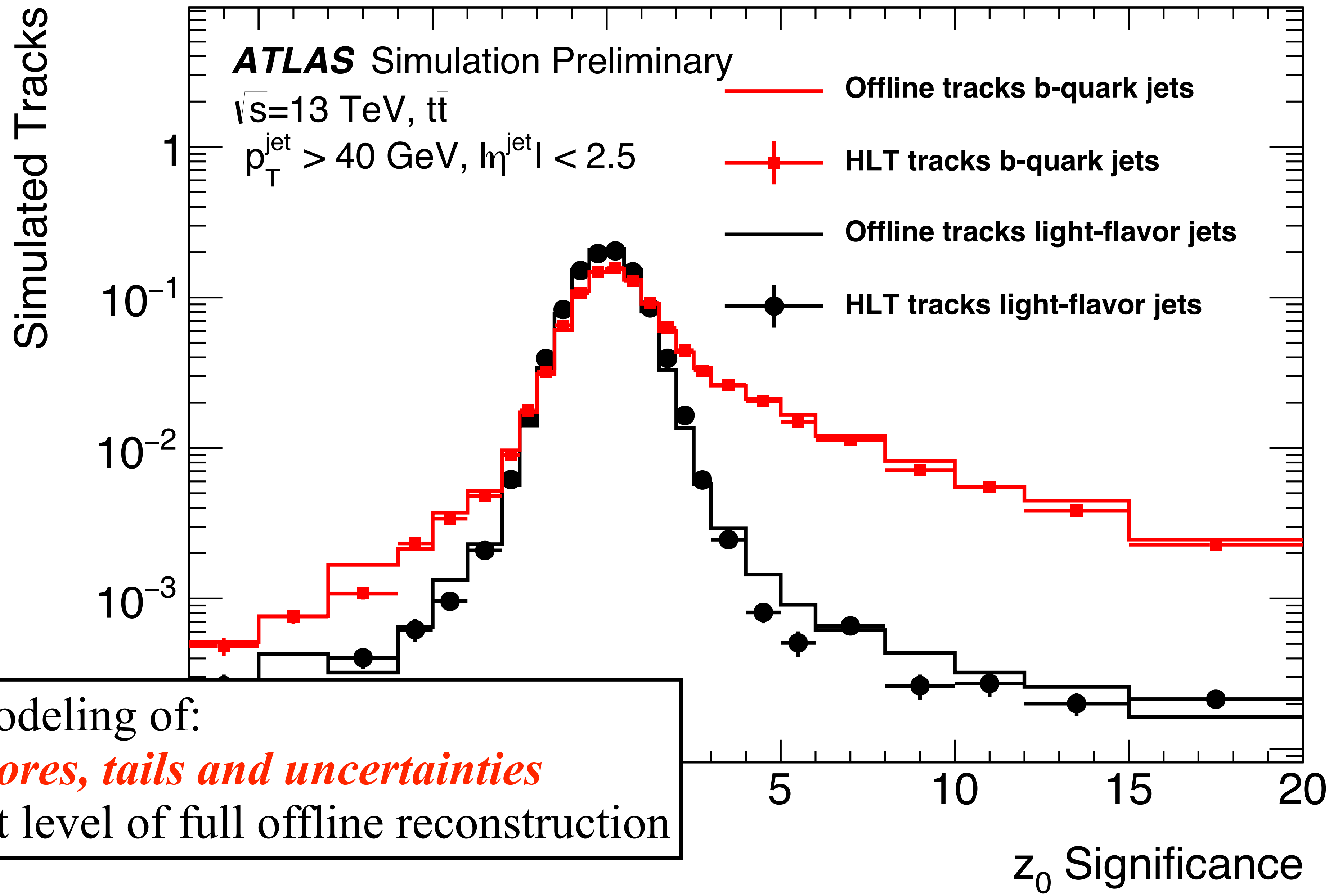
Track Parameters



Track Parameters



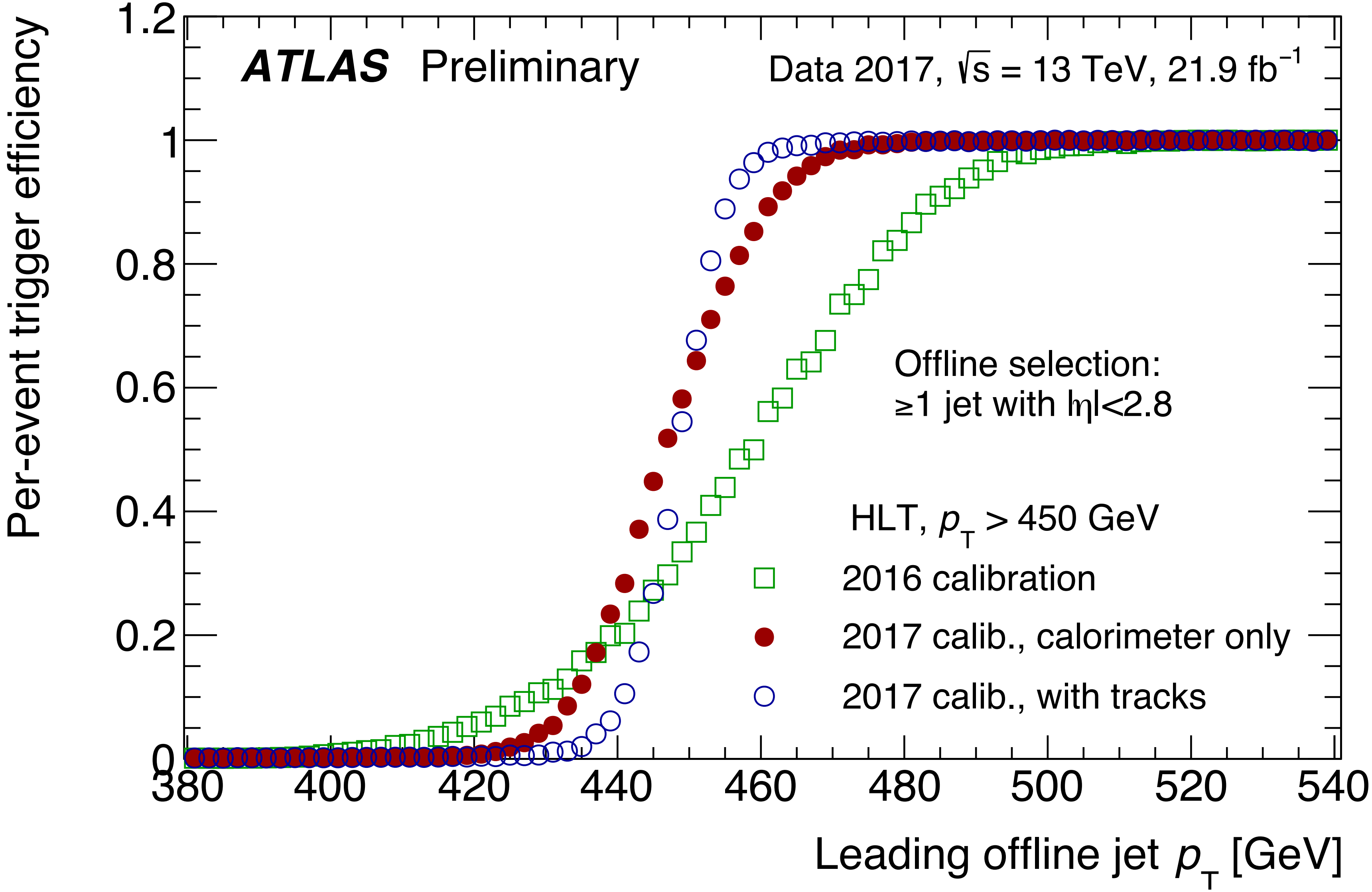
Track Parameters



Modeling of:
cores, tails and uncertainties
at level of full offline reconstruction

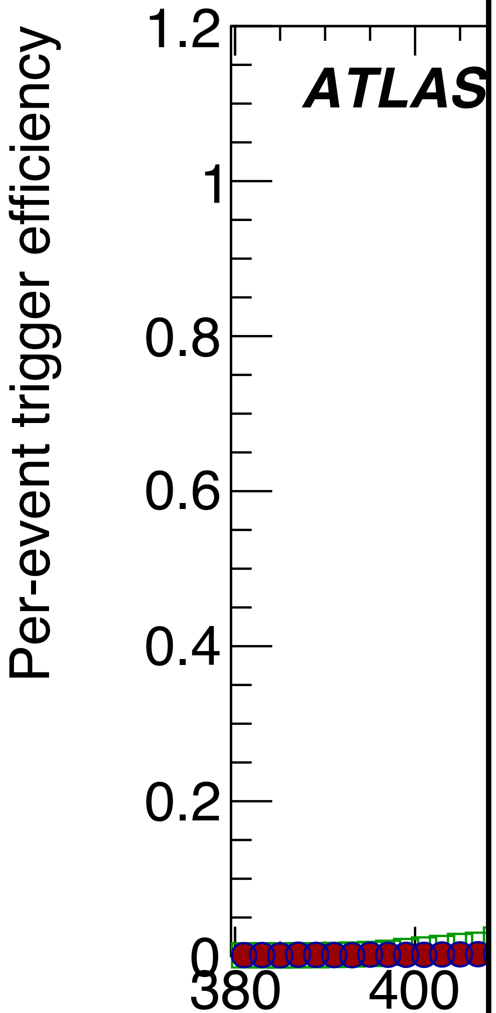
Online Jet Reconstruction

Push toward making online calibration closer to offline

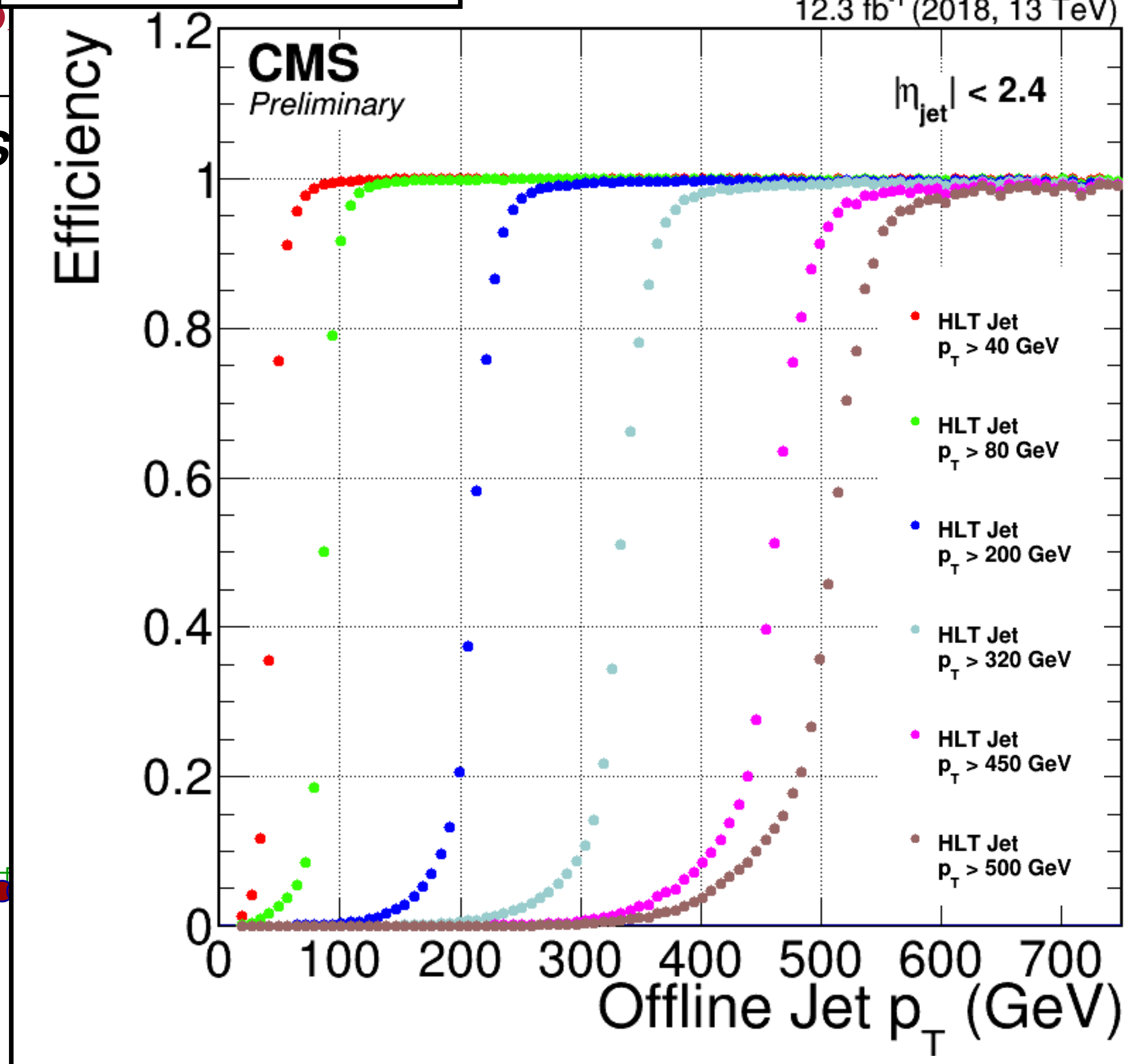


Online Jet Reconstruction

Push toward making o

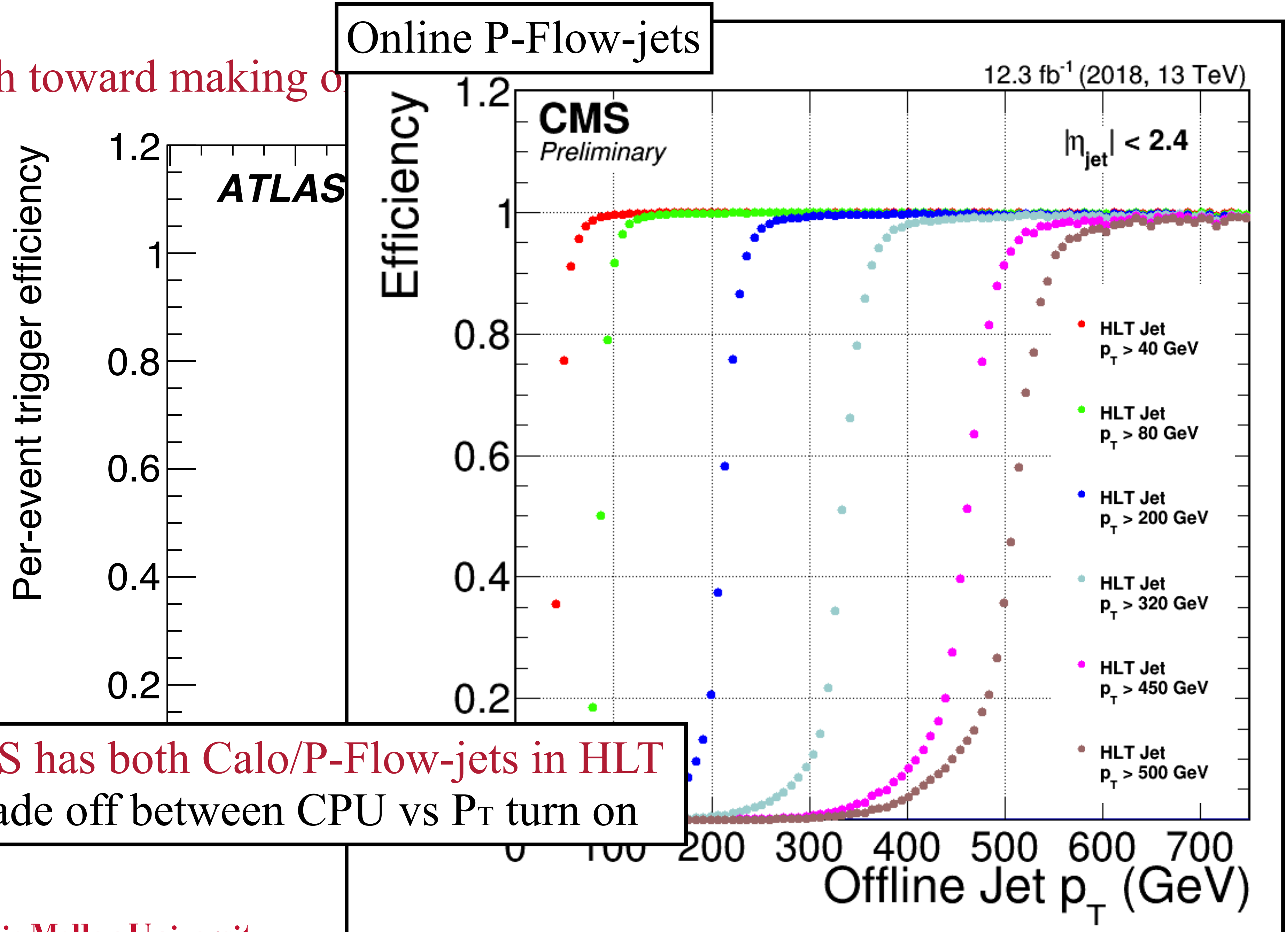


Online P-Flow-jets



Online Jet Reconstruction

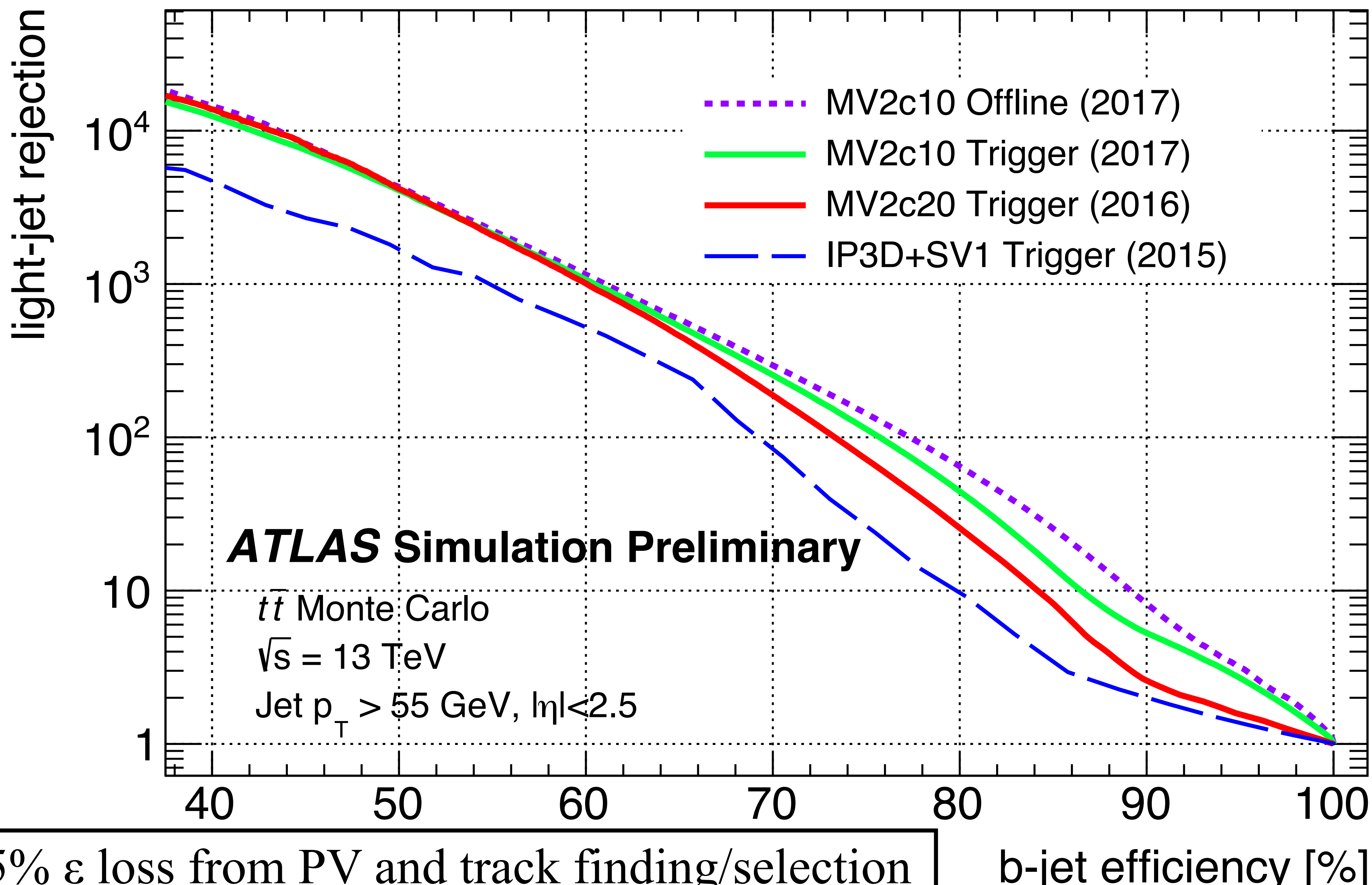
Push toward making o



CMS has both Calo/P-Flow-jets in HLT

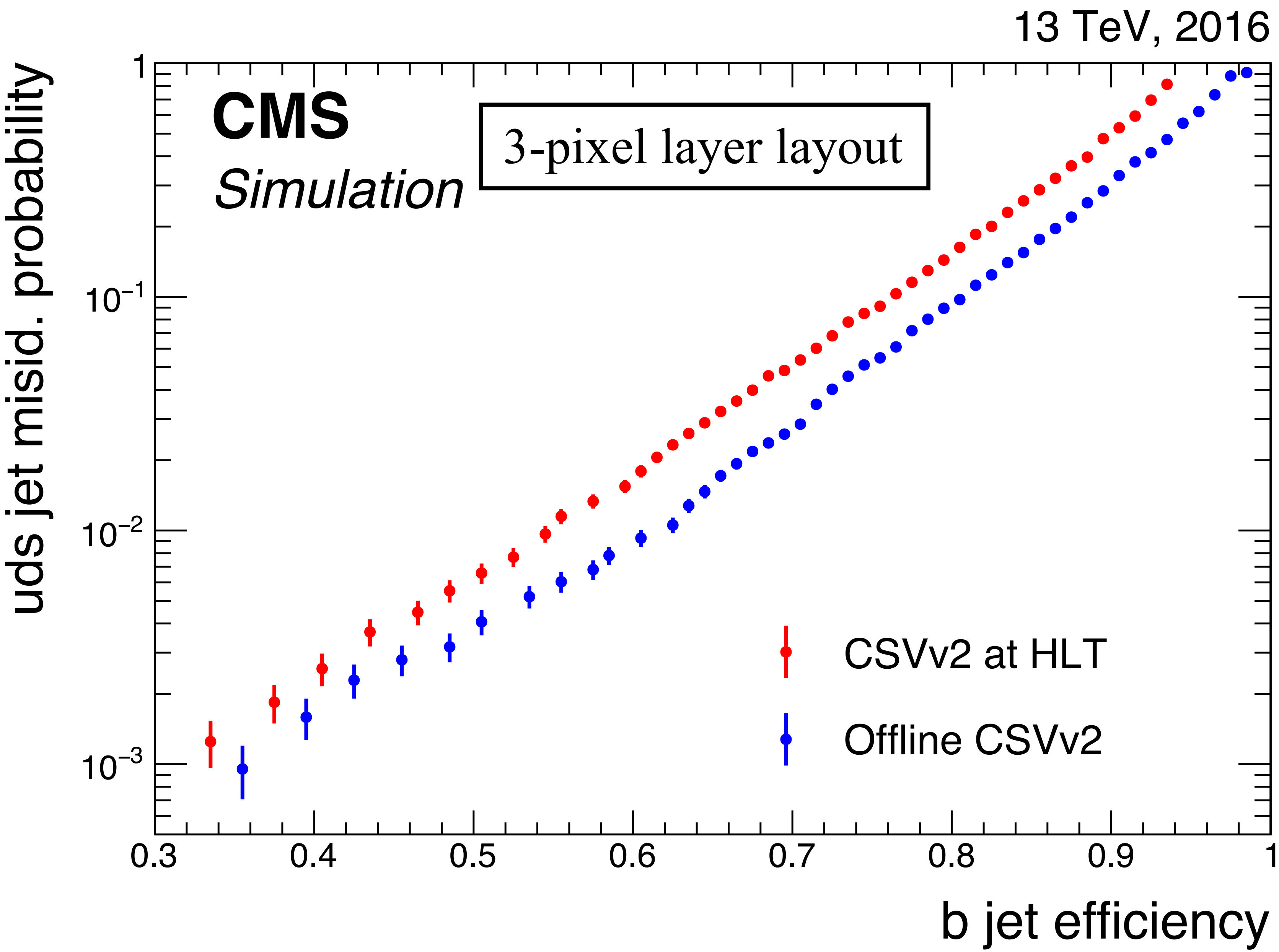
Trade off between CPU vs P_T turn on

Online b-tagging

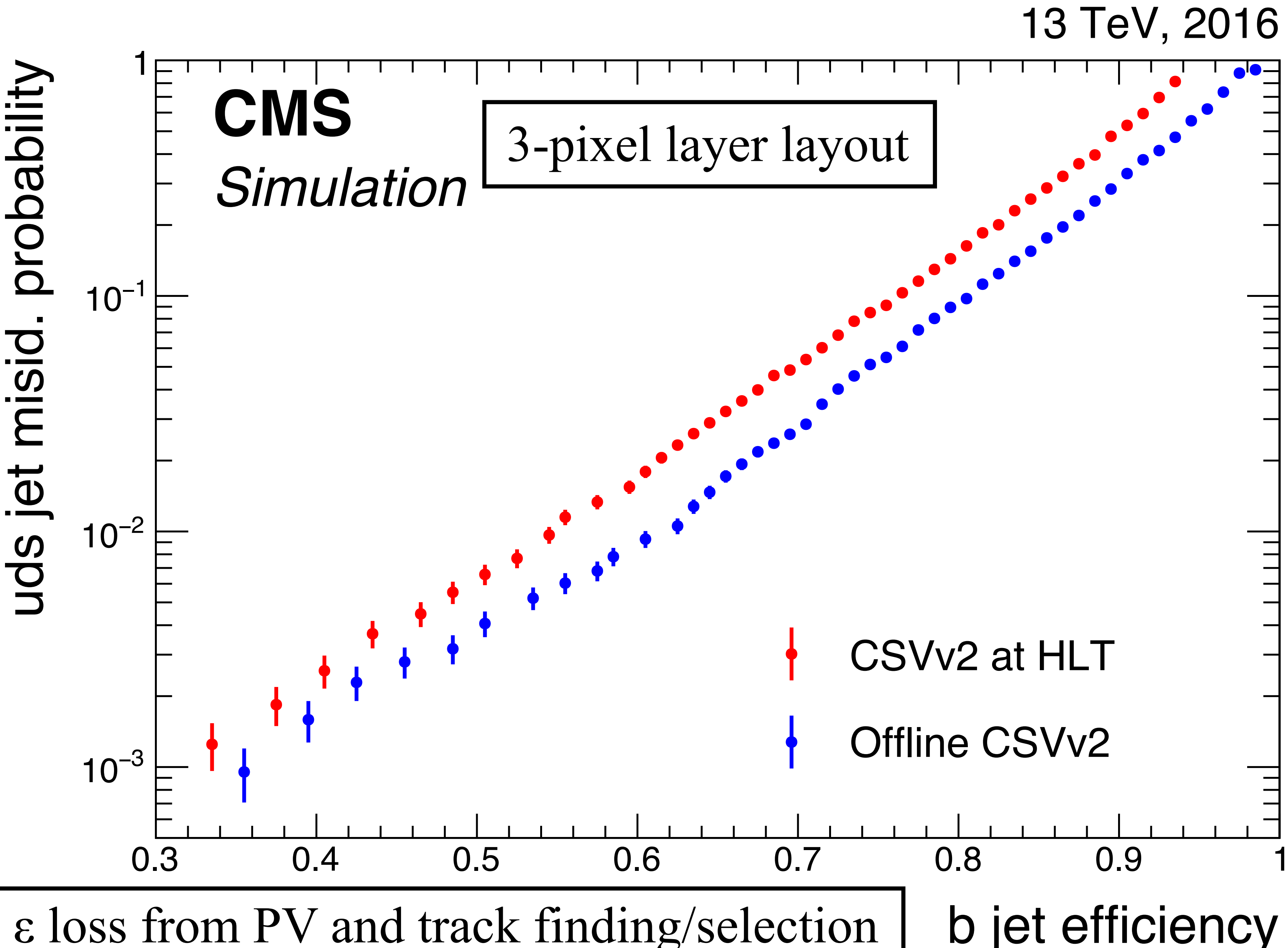


~5% ε loss from PV and track finding/selection

Online b-tagging

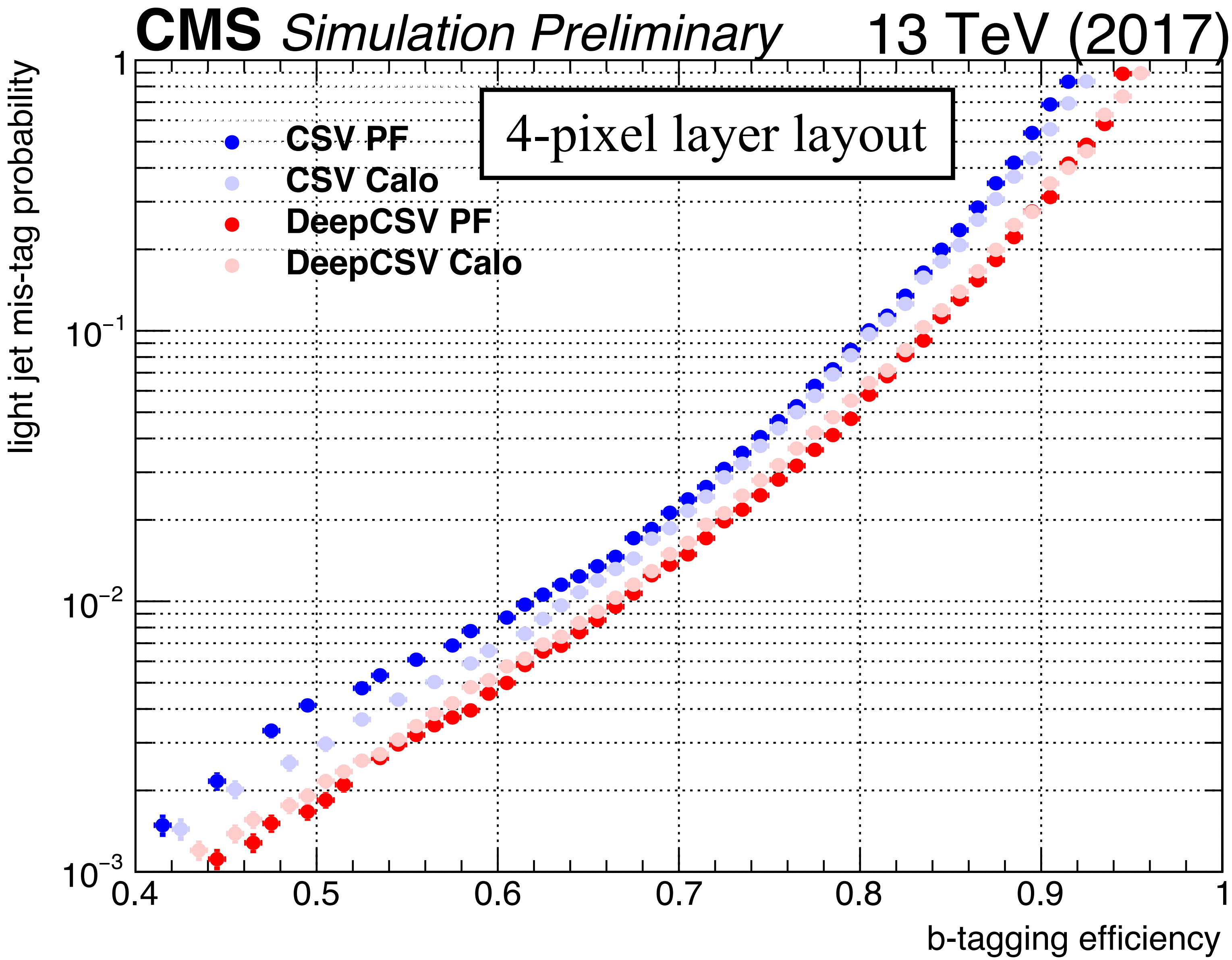


Online b-tagging



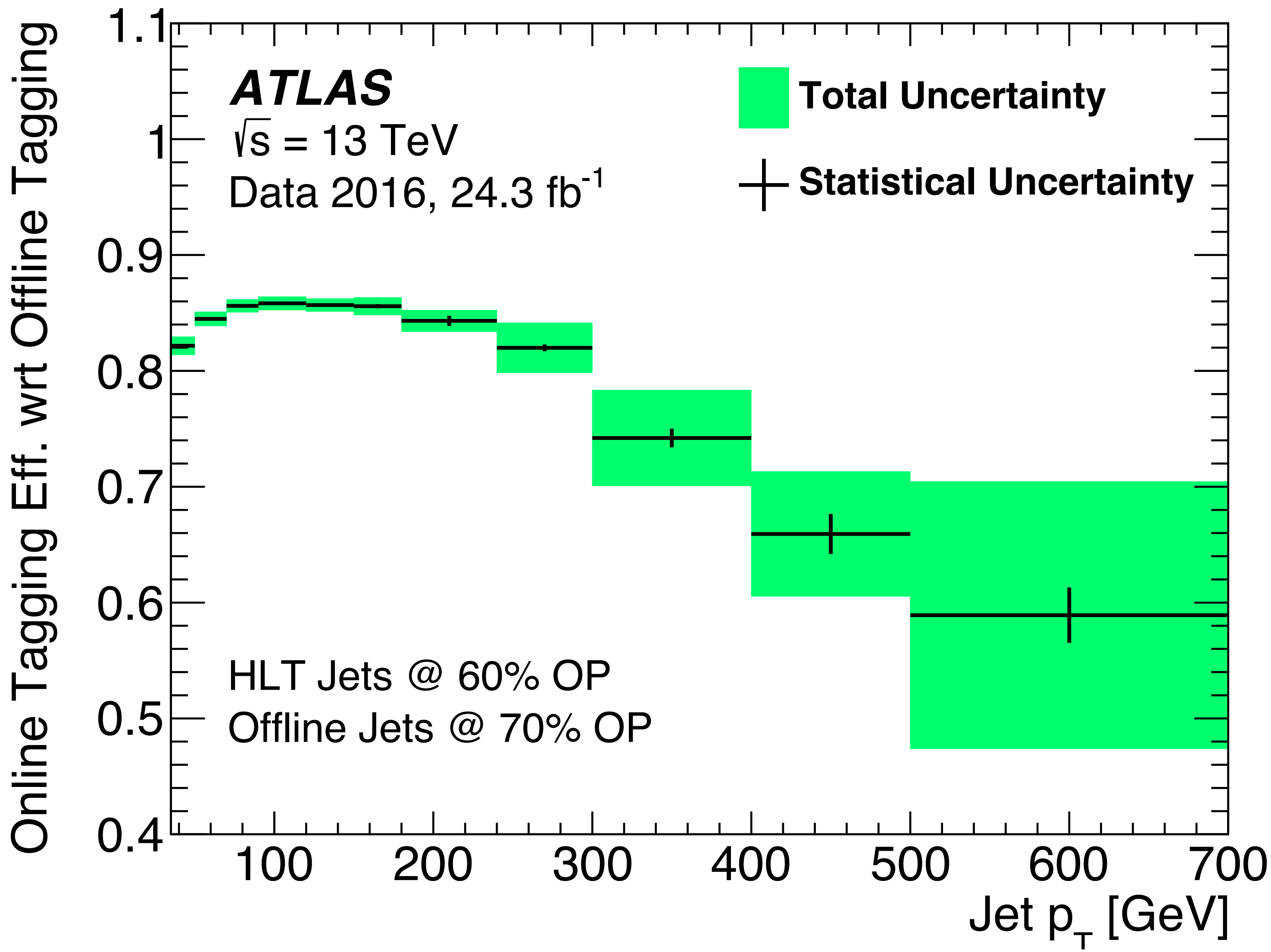
~5% ε loss from PV and track finding/selection

Online b-tagging



b-jet Trigger Calibration

Measure jet-level efficiency in fully-leptonic ttbar events



Future: Phase I

FTK: ATLAS Phase I Track Trigger Upgrade

- Full scan Inner Detector tracking at 100kHz (L1 output)
- $P_T > 1$ GeV / $d0 < 2$mm / $\varepsilon \sim 90\%$ wrt offline
- Latency $O(100\mu s) \Rightarrow$ tracks available as input to HLT

Future: Phase I

FTK: ATLAS Phase I Track Trigger Upgrade

- Full scan Inner Detector tracking at 100kHz (L1 output)
- P_T > 1 GeV / d0 < 2mm / ε ~ 90% wrt offline
- Latency O(100μs) ⇒ tracks available as input to HLT

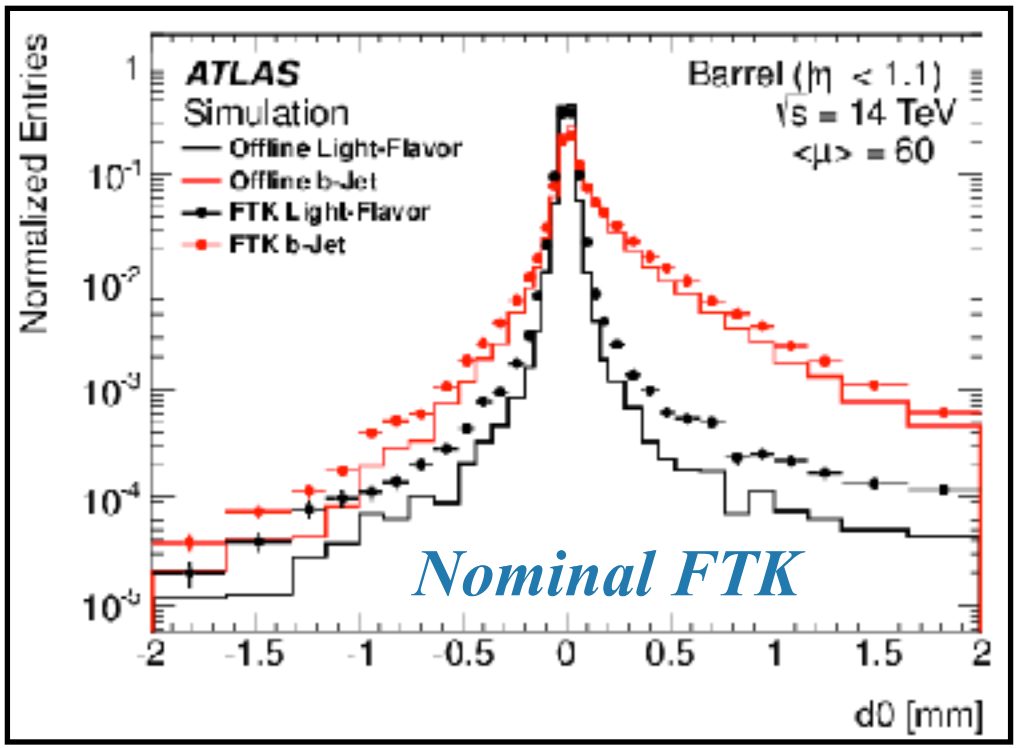
Major impact on CPU usage:

- Monitor Beam-spot
- PV Finding
- Track-based Jet calibration
- CPU based tracks / re-fitted FTK tracks for b-tagging
- … + other improvements not as relevant for *hh*

Future: Phase I

FTK: ATLAS Phase I Track Trigger Upgrade

- Full scan Inner Detector tracking at 100kHz (L1 output)
- P_T > 1 GeV / d0 < 2mm / ε ~ 90% wrt offline



…ks available as input to HLT

…n

…d FTK tracks for b-tagging

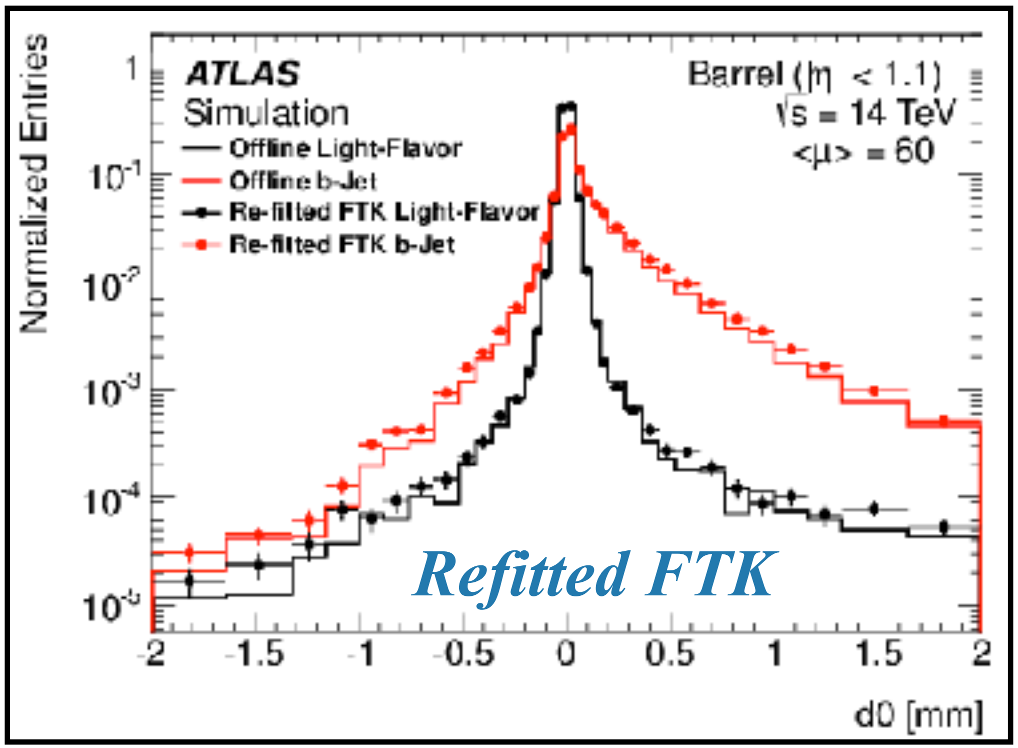
not as relevant for *hh*

Future: Phase I

FTK: ATLAS Phase I Track Trigger Upgrade

- Full scan Inner Detector tracking at 100kHz (L1 output)
- P_T > 1 GeV / d0 < 2mm / ε ~ 90% wrt offline

ks available as input to HLT



n

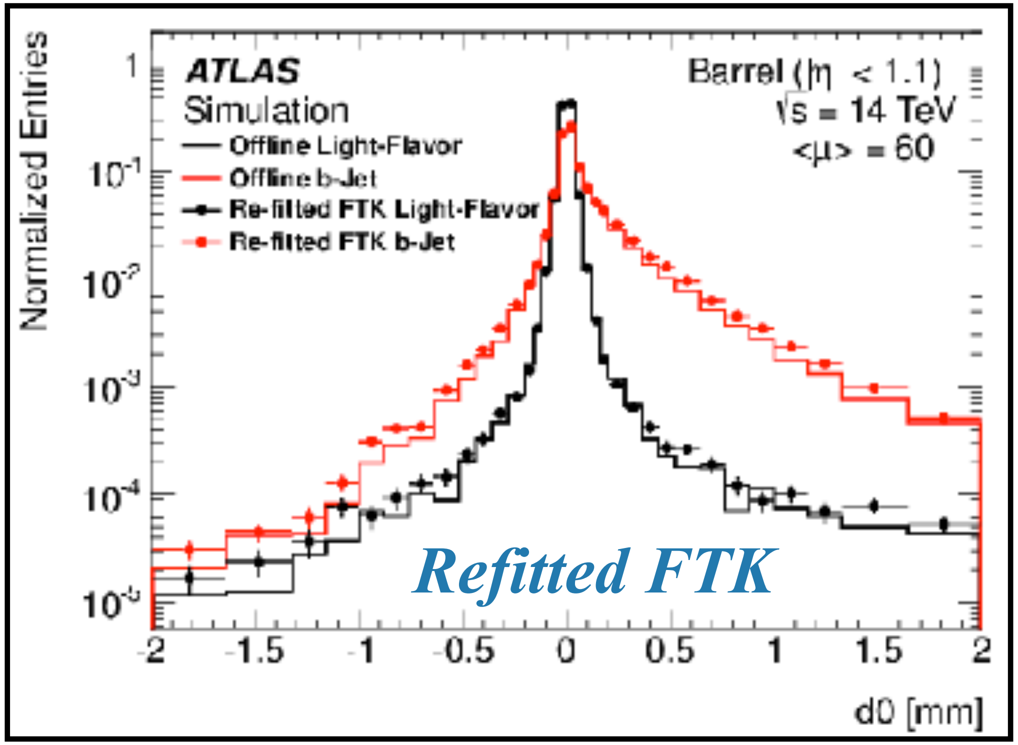
d FTK tracks for b-tagging

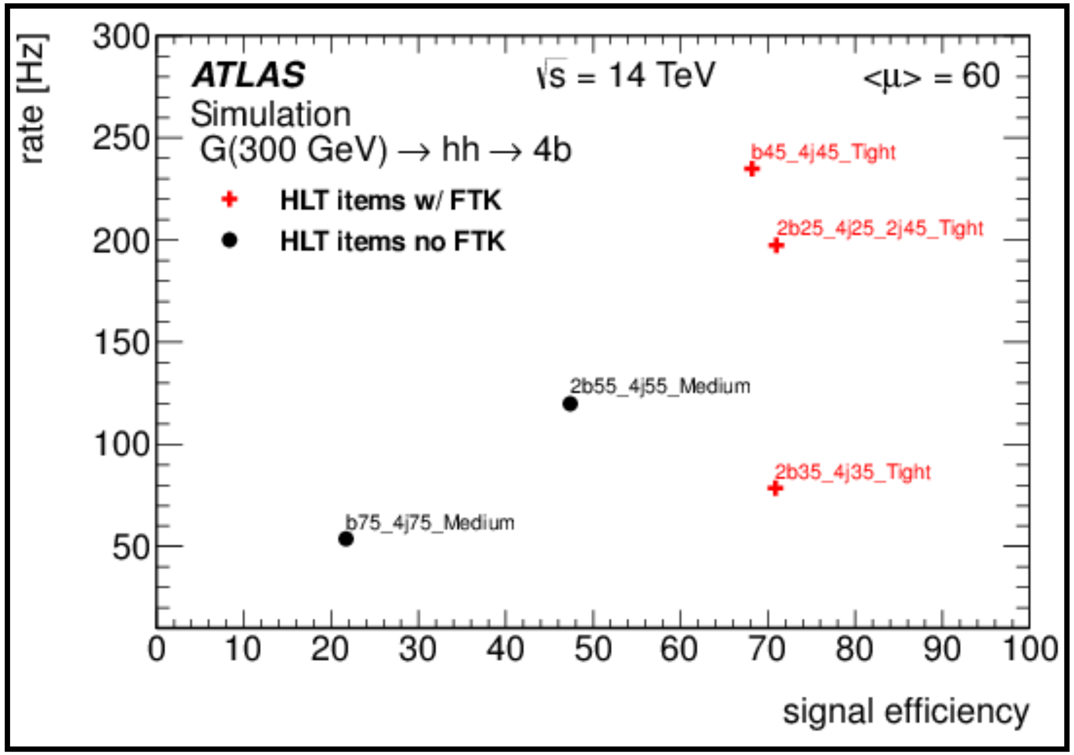
not as relevant for *hh*

Future: Phase I

FTK: ATLAS Phase I Track Trigger Upgrade

- Full scan Inner Detector tracking at 100kHz (L1 output)
- P_T > 1 GeV / d0 < 2mm / ε ~ 90% wrt offline





Future: Phase-II

ATLAS: 1MHz Strips + outer pixel layer *(baseline)*
~100 kHz tracks w/all pixel layers
$P_T > 1$ GeV / d0 < 2 mm / |eta| < 4

CMS: 40 MHz Strips + outer pixel layers
$P_T > 2$ GeV / d0 < 2 mm / |eta| < 2.5
500-750 kHz pixel readout

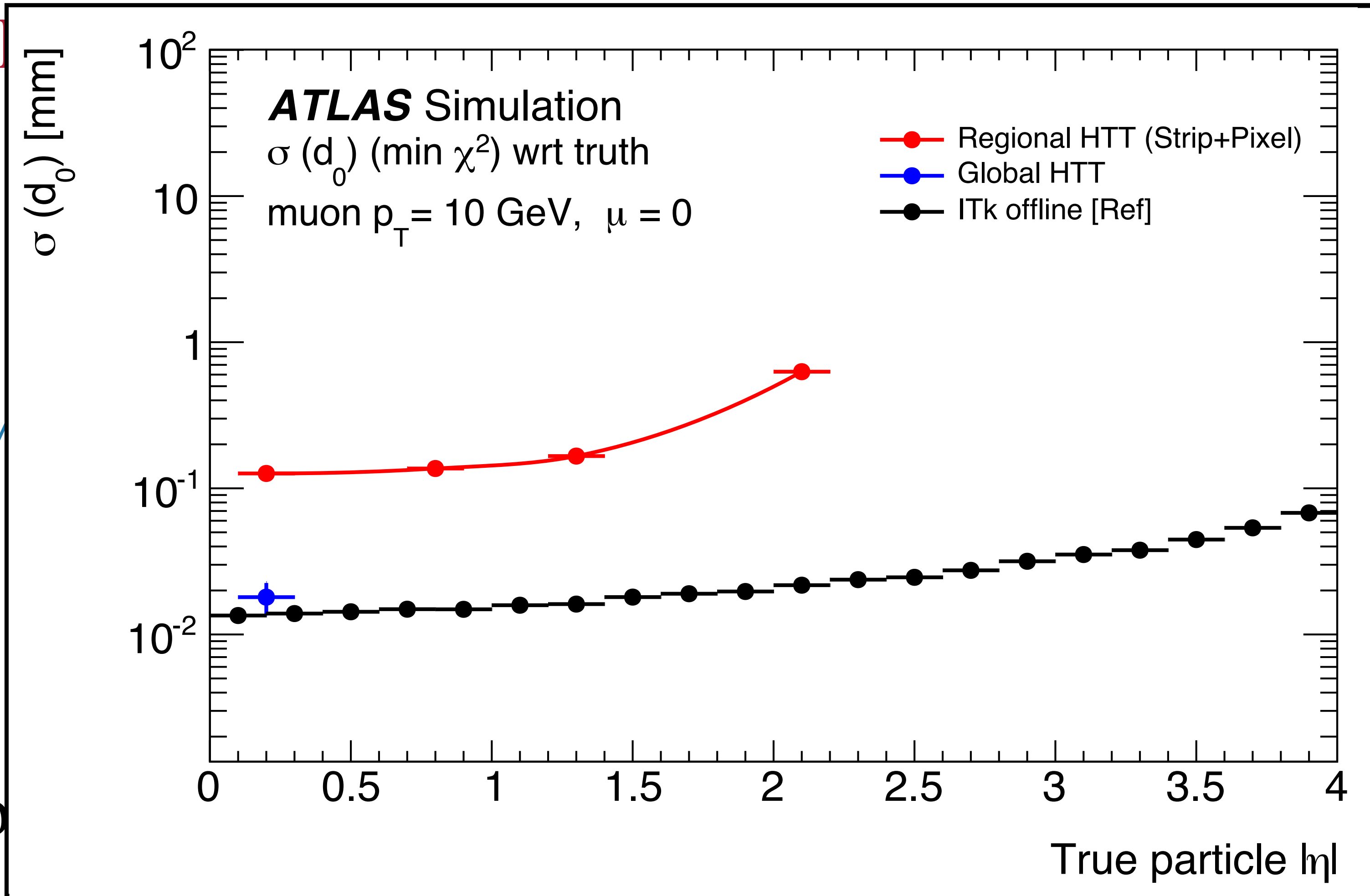
Not much yet specific to b-jet trigger performance…

Future: Phase-II

ATl

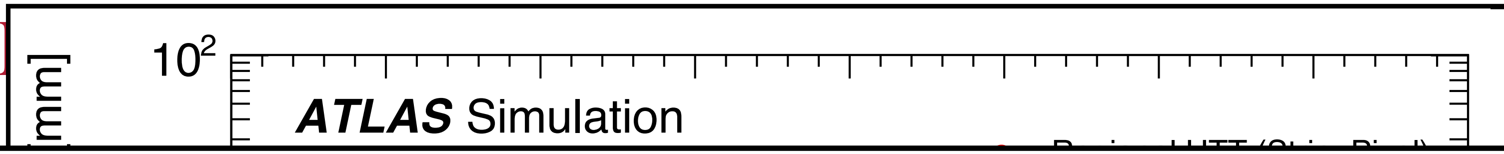
CM

No …

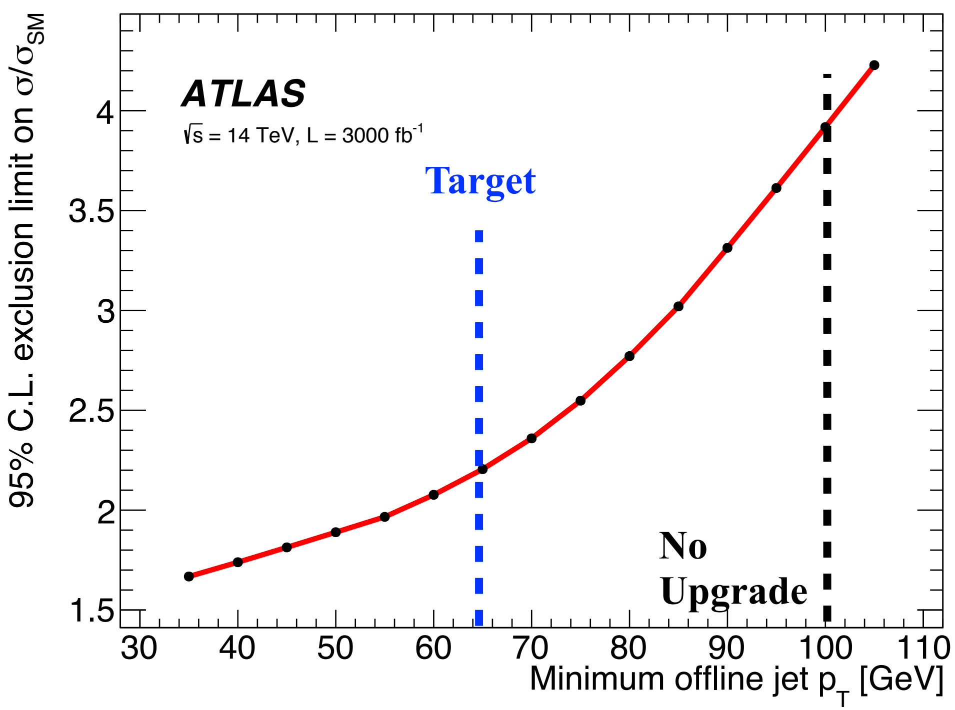


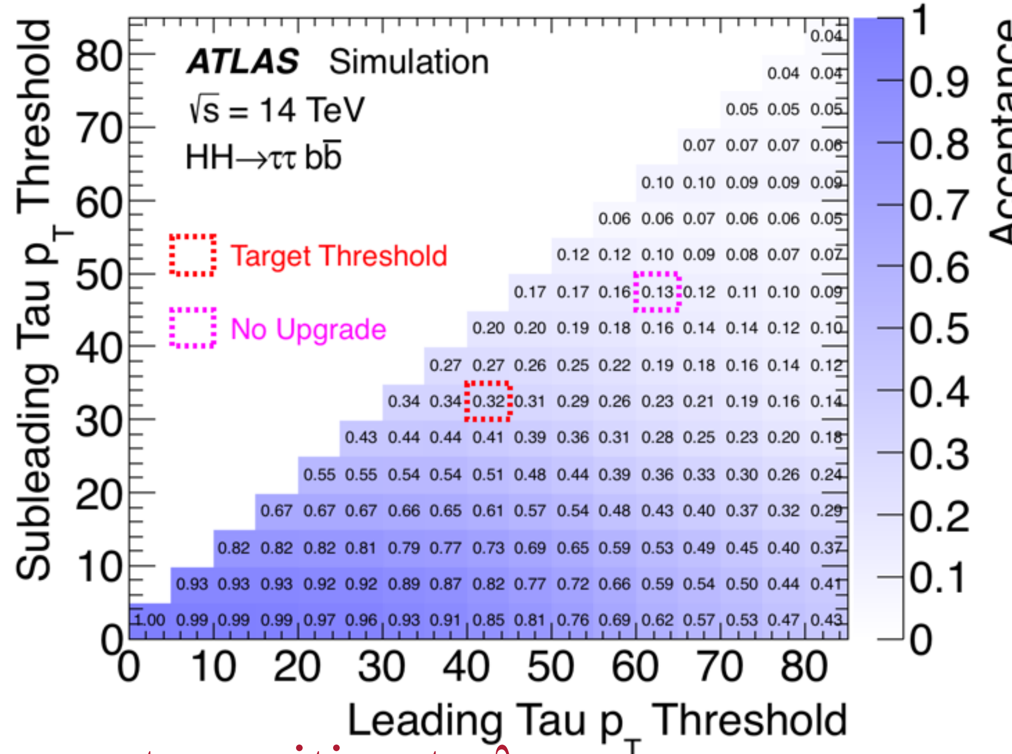
Future: Phase-II

AT



Di-Higgs sensitivity is a main driver for upgrade design





Trigger losses hurt the most in region most sensitive to λ

Conclusions

b-jet trigger is a major experimental challenge

Will continue to get harder with increasing luminosity

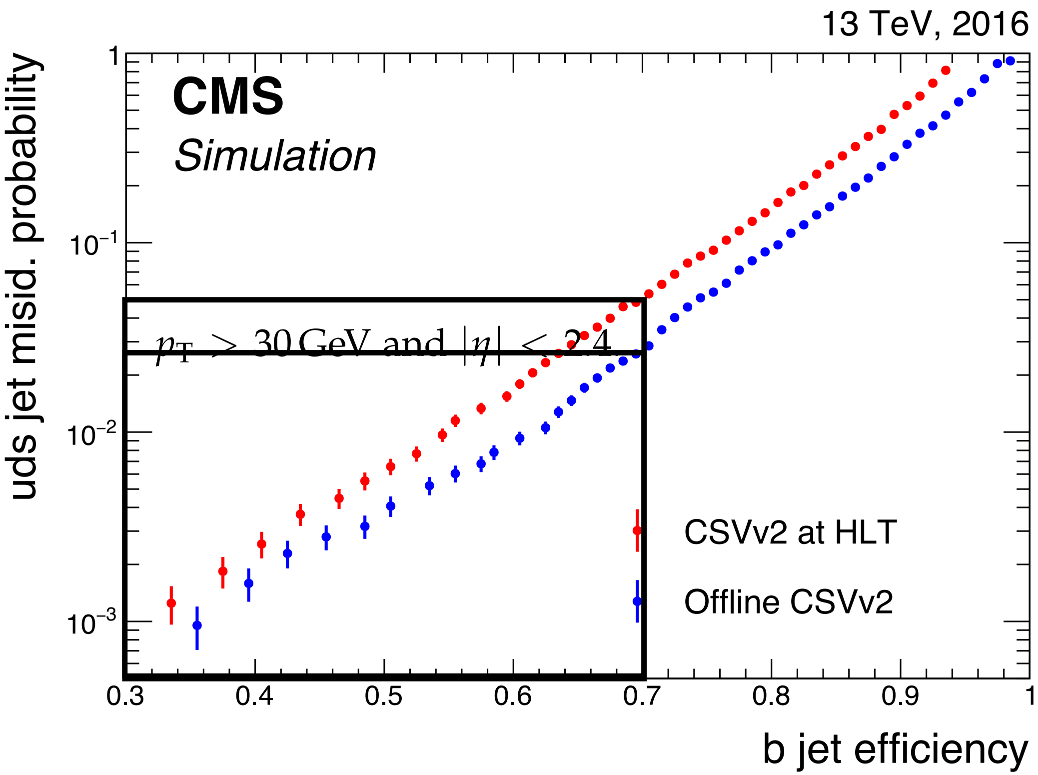
Critical to di-Higgs program: $hh \rightarrow 4b$ ($hh \rightarrow bb\tau\tau$)

Experiments quite different approaches:
Common theme: making online more like offline

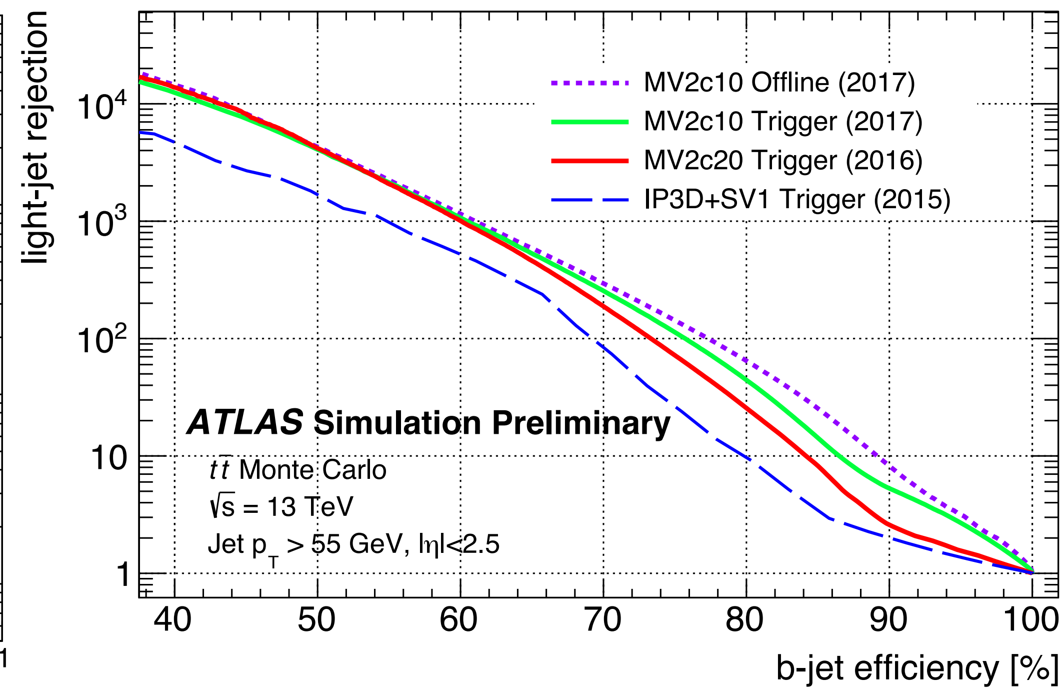
Dedicated track-trigger upgrades coming to the LHC.
Big impact on ultimate Di-Higgs/λ sensitivity

Backup

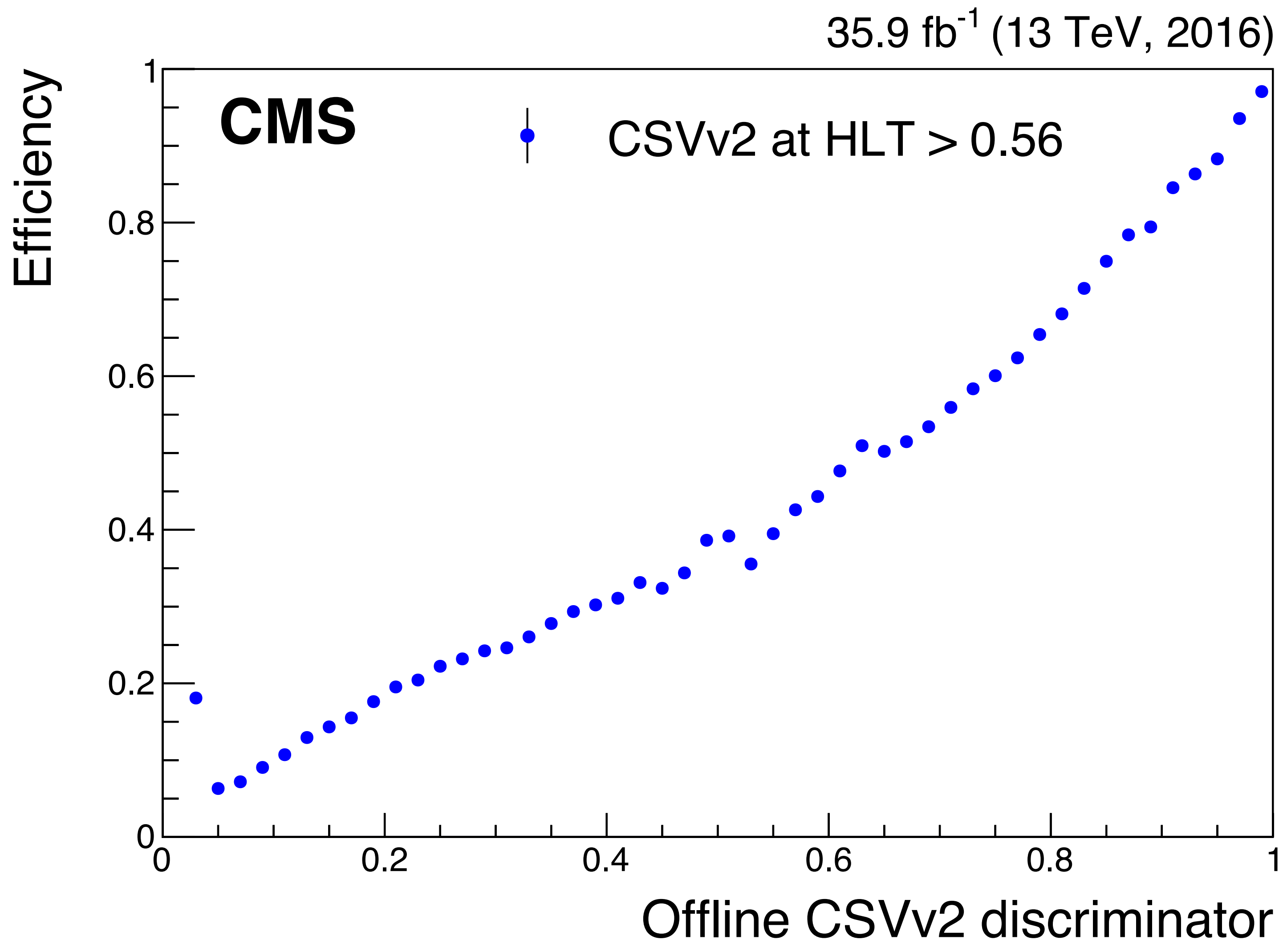
Comparison

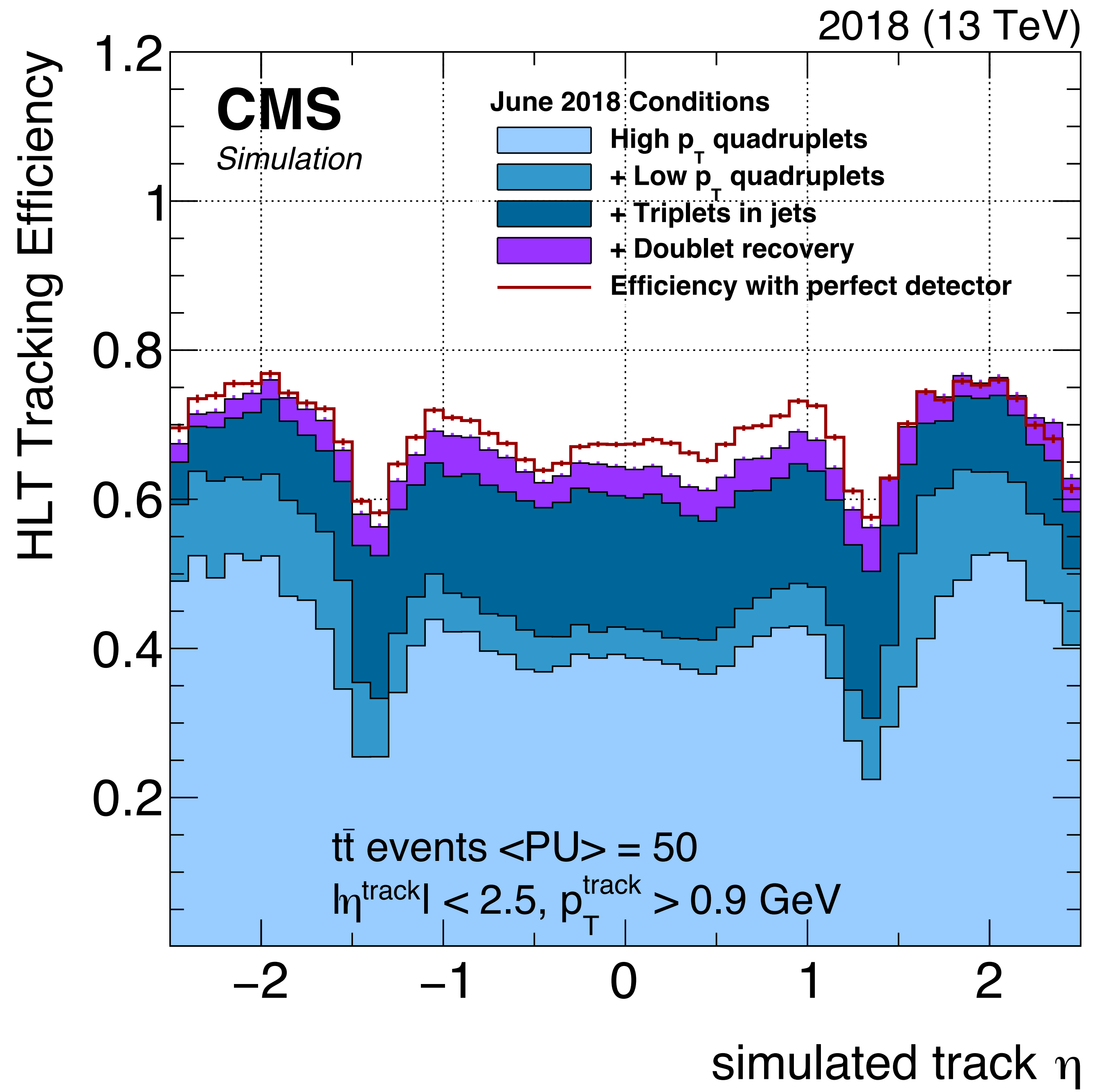


13 TeV, 2016
CMS
Simulation
uds jet misid. probability
$p_T > 30$ GeV and $|\eta| < 2.4$
CSVv2 at HLT
Offline CSVv2
b jet efficiency

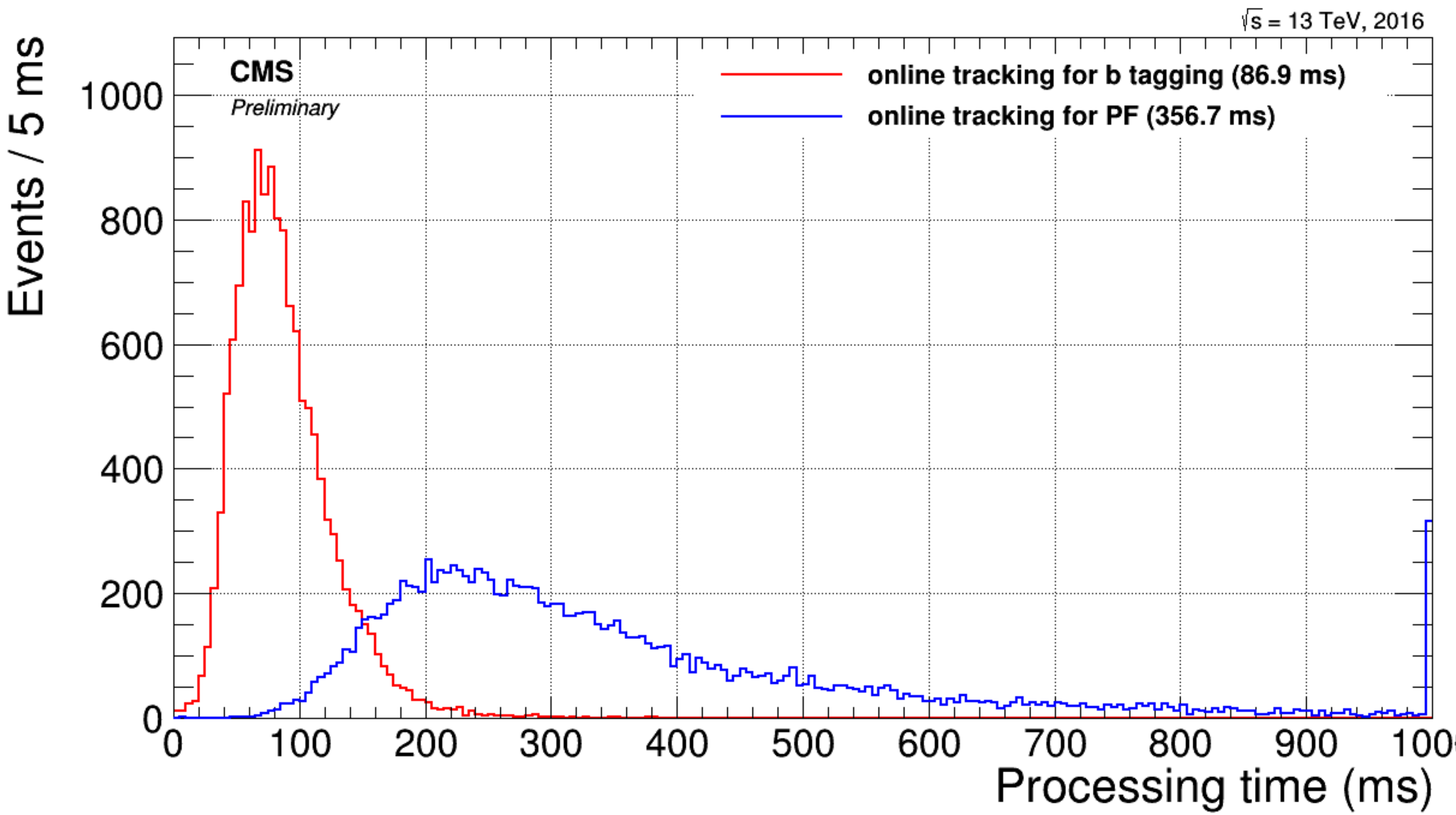


light-jet rejection
MV2c10 Offline (2017)
MV2c10 Trigger (2017)
MV2c20 Trigger (2016)
IP3D+SV1 Trigger (2015)
ATLAS Simulation Preliminary
$t\bar{t}$ Monte Carlo
$\sqrt{s}$ = 13 TeV
Jet p_T > 55 GeV, $|\eta|$<2.5
b-jet efficiency [%]


35.9 fb^{-1} (13 TeV, 2016)
CMS
CSVv2 at HLT > 0.56
Efficiency
Offline CSVv2 discriminator
0
0.2
0.4
0.6
0.8
1



2018 (13 TeV)
CMS
Simulation
June 2018 Conditions
High p_T quadruplets
+ Low p_T quadruplets
+ Triplets in jets
+ Doublet recovery
Efficiency with perfect detector
HLT Tracking Efficiency
1.2
1
0.8
0.6
0.4
0.2
tt̄ events <PU> = 50
|η^track| < 2.5, p_T^track > 0.9 GeV
−2
−1
0
1
2
simulated track η


√s = 13 TeV, 2016
CMS
Preliminary
online tracking for b tagging (86.9 ms)
online tracking for PF (356.7 ms)
Events / 5 ms
0
200
400
600
800
1000
0
100
200
300
400
500
600
700
800
900
1000
Processing time (ms)

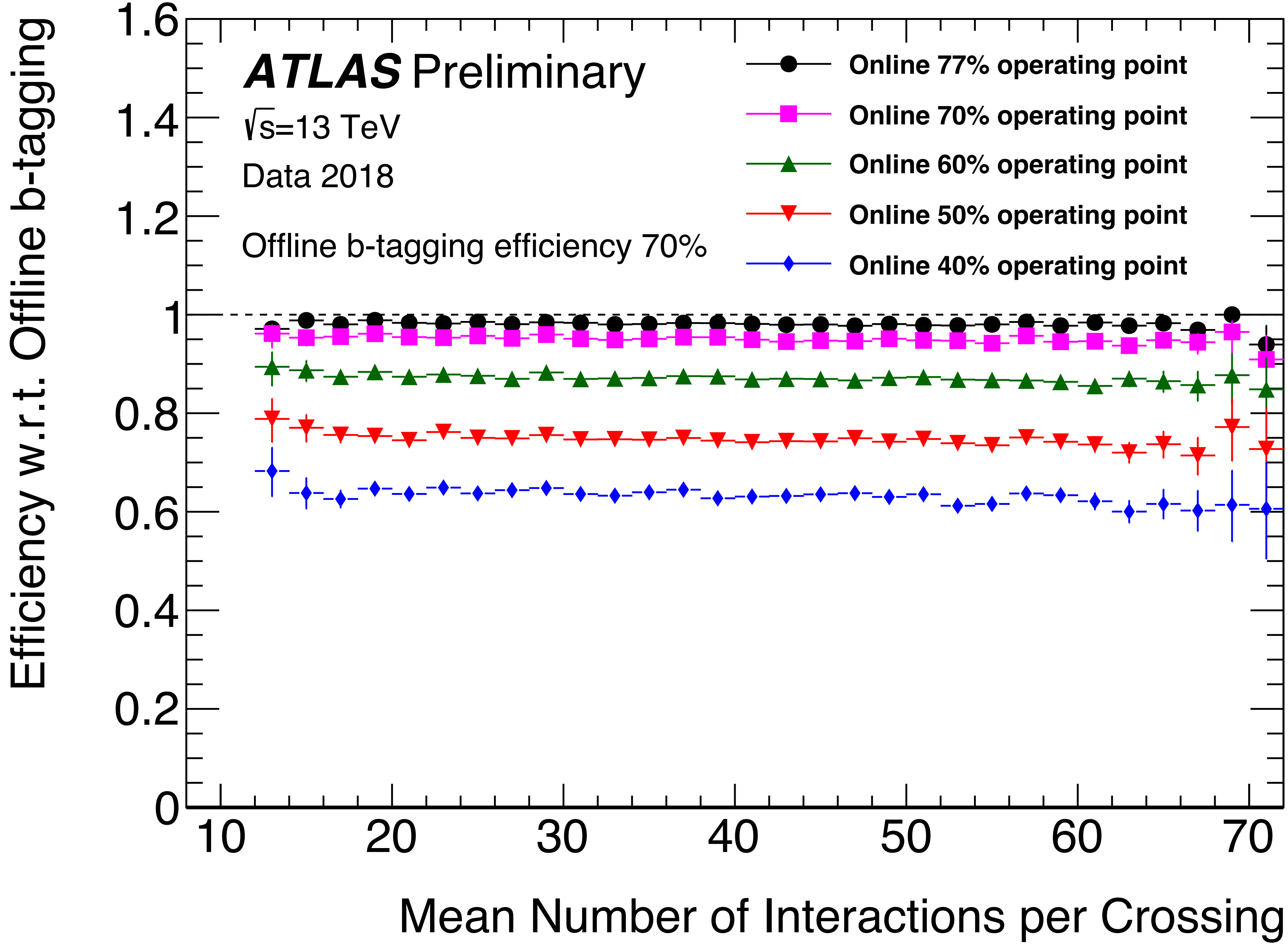
4b Trigger Scale Factors

Need to:
- Correct modeling efficiency w/performance measured in data
- Derive systematic on modeling of the trigger efficiency

Can only measure jet-level trigger efficiencies in data.

Challenge:
Derive event-level efficiencies/uncertainties from jet-level inputs using proper correlations between jets and triggers.

Done this using simple toy MC.
- Randomly assign jets pass/fail trigger (based jet-level ε_{Trig})
- Repeated N-time to measure pass fraction.
- Above is repeated M-times with varying ε_{Trig} with in $\Delta\varepsilon_{Trig}$
- Gives distribution of pass fractions: μ - SF / σ - event-level systematic



ATLAS Preliminary
√s=13 TeV
Data 2018
Offline b-tagging efficiency 70%
Online 77% operating point
Online 70% operating point
Online 60% operating point
Online 50% operating point
Online 40% operating point
Efficiency w.r.t. Offline b-tagging
Mean Number of Interactions per Crossing
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
10
20
30
40
50
60
70