2° AI-INFN Advanced Hackathon

24 – 27 November 2025

Collegio Borromeo, Pavia

Deep Learning-Based identification of soft taus in the L1 Scouting stream for Phase-2

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1 CERN | NexTGen Next Generation Triggers

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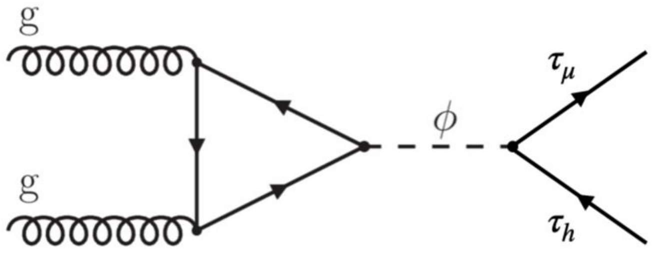
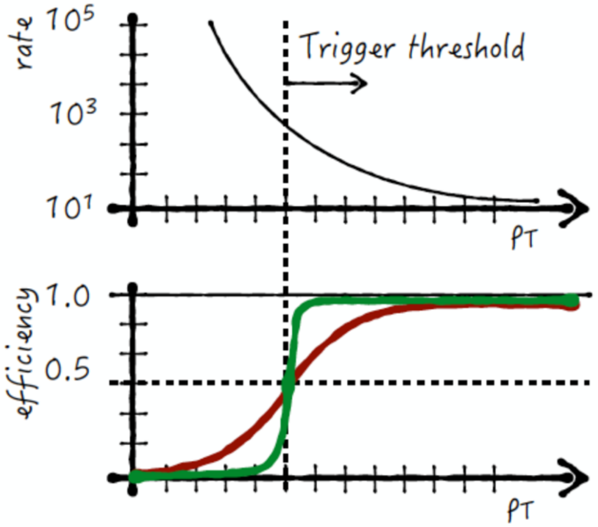
CMS

Towards Soft Tau Tagging



Goal:

- Reconstruct low-p_T taus ($5 - 60$ GeV)
- Enable searches for low-mass di-tau resonances (< 60 GeV)
  - ➢ These signals are currently out of reach at the LHC



Why are low-p_t taus invisible today?

- The **Level-1 Trigger** is the first and most restrictive stage of data acquisition, with strict rate and latency constraints
- To limit the trigger rate, L1 tau triggers require high p_T thresholds, which suppress soft taus already at the first selection step
- Current L1 tau-ID algorithms (e.g. **NNPuppiTau**) are designed and optimized for high-p_T taus, with efficiency plateauing only above ~ 50 GeV

Phase-2 L1DS Baseline

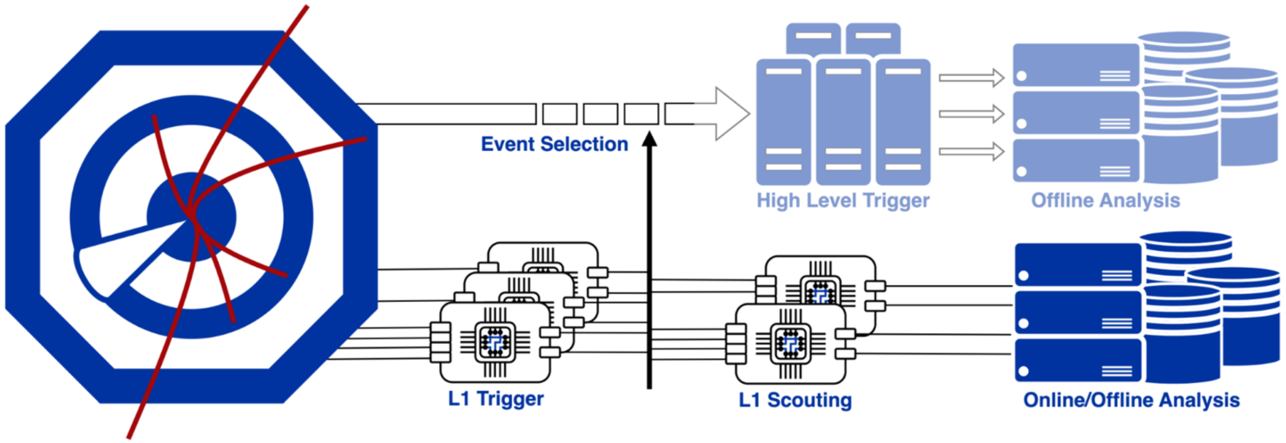
L1 Data Scouting (L1DS)
Collects and analyzes L1 trigger objects at the full 40 MHz bunch-crossing (BX) rate

Unlocks:

- Access to physics otherwise limited by L1T latency and accept rate
- Discovery of exotic signatures beyond standard triggers

Baseline Capabilities:

- Standalone muon and calorimetric objects
- Tracker objects from the GTT
- PUPPI candidates from CL2
- Global Trigger (GT) final decisions

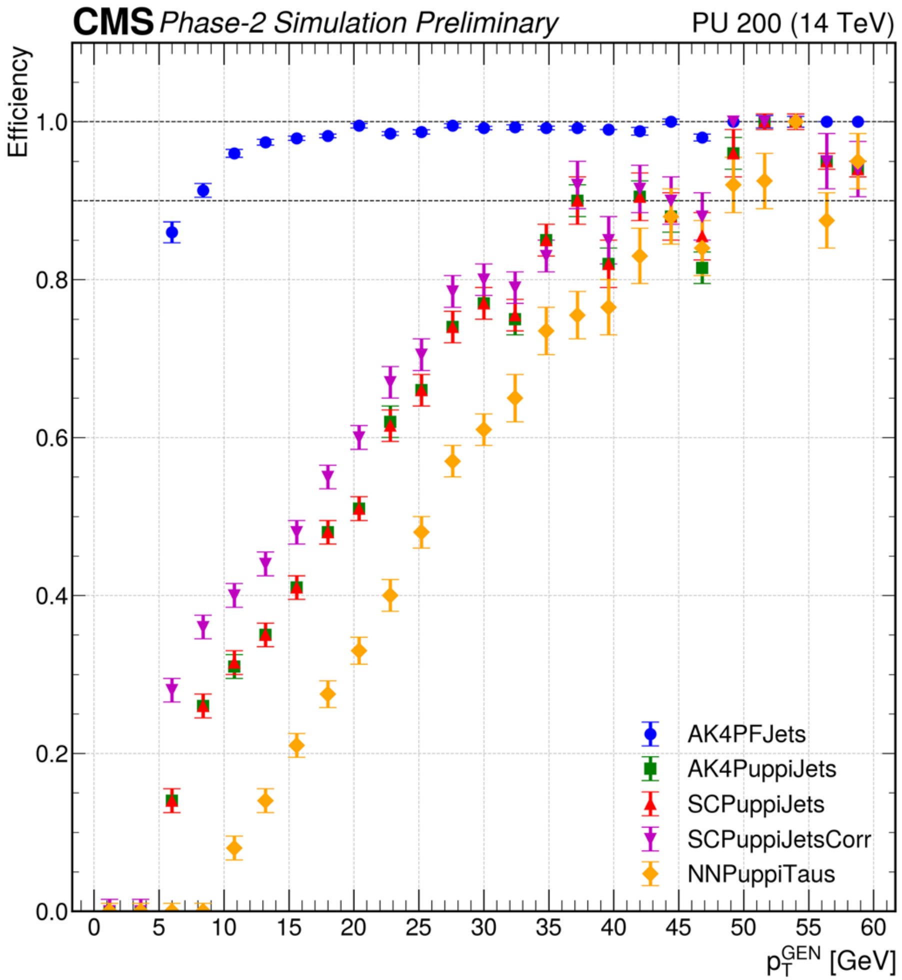


Source	Links (baseline)	Links (upstream ZS)
GT	12	12
GTT	24	24 + 48 (Tracks ZS)
GCT	6	6
GMT	18	18
CL2	30	30 + 24 (PUPPI ZS)
CL1	216 (PUPPI)	84[*] (PF |η|≤3 ZS)
Total	306	246

NEW

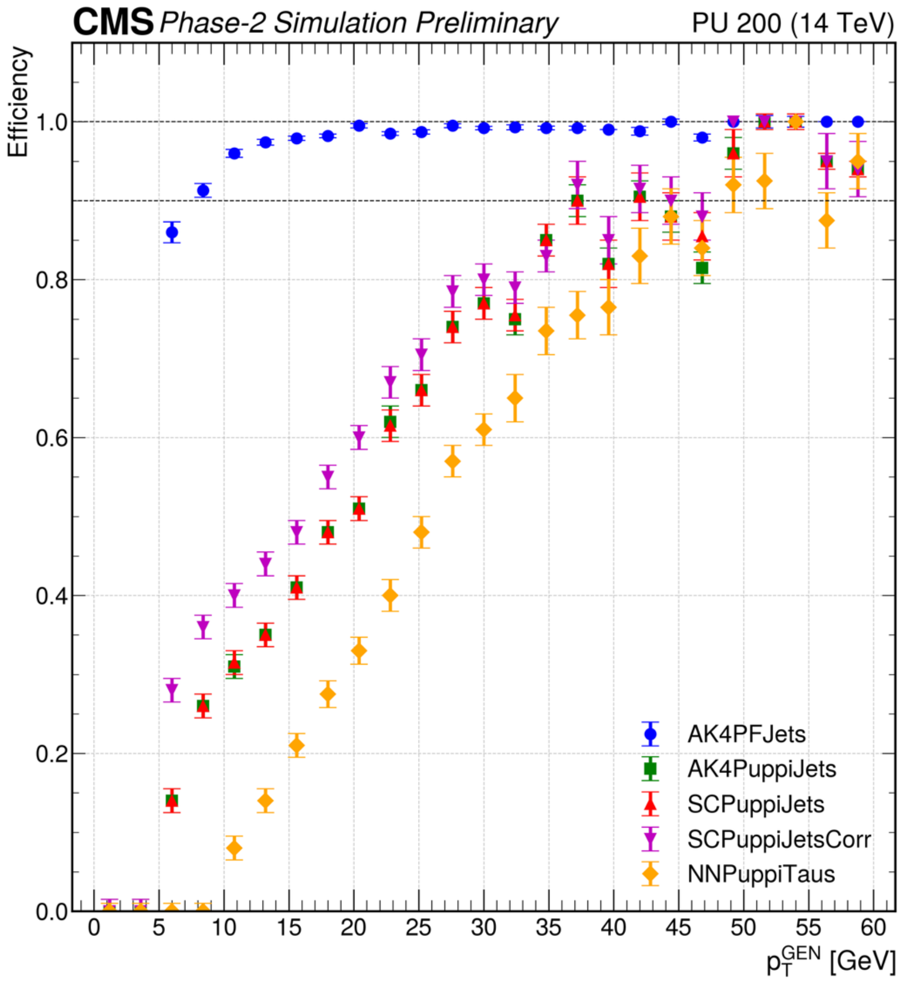
More optical links now provide access to the full PF collection

Efficiencies of τ_h and their constituents

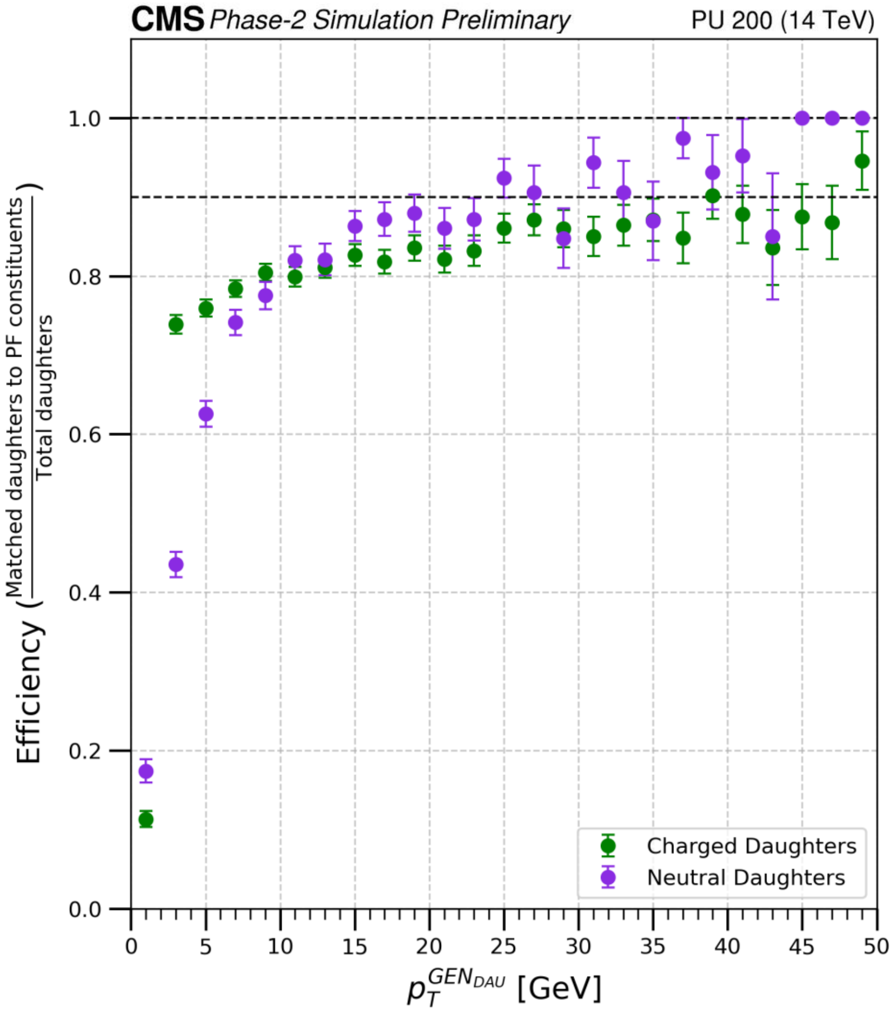


AK4PFJets outperform in efficiency

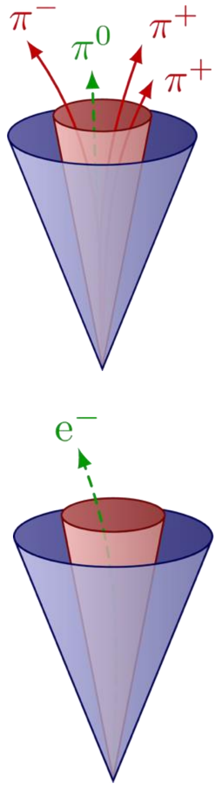
Efficiencies of τ_h and their constituents



AK4PFJets outperform in efficiency



AK4PFJets include real τ decay products

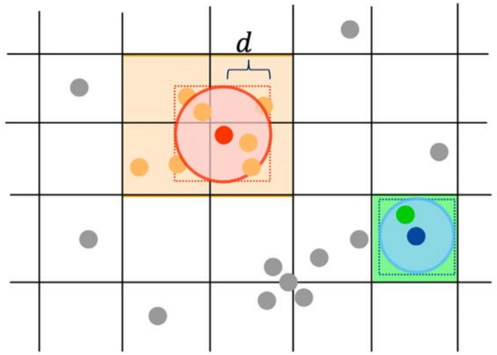


CLUE algorithm on PFs for parallel τ clustering

- CLUE as a replacement for the $anti - k_T$ algorithm, which lacks optimization for parallel execution

CLUE is a density-based clustering algorithm specifically intended for CMS HGCAL

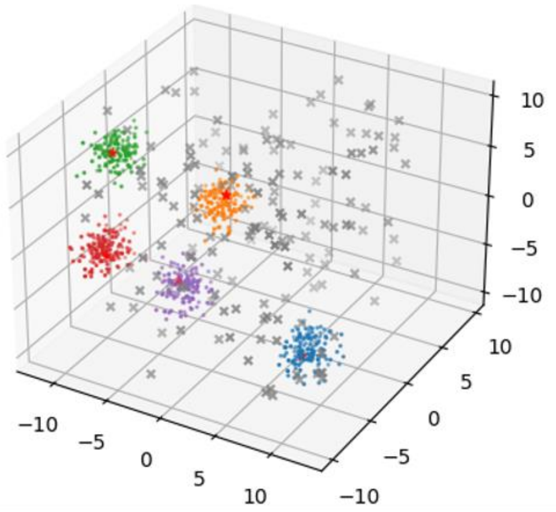
CLUE is specifically designed for parallelism and being GPU-friendly, which can be used to take advantage of the heterogeneous computing of the Phase-2 L1T Scouting online processing step



✓ CLUE hyper-parameters tuned on τ physics achieve efficiency and fake-rate comparable to $anti - k_T$

ScoutPFTaus NEW

TauID ***starting from costituents***



Model Architecture & Training

PyTorch

Adam Optimizer
Early Stopping
RLonPlateau

CrossEntropy loss + MAE loss

batch_size	:	20
learning rate	:	10^{-4}
num_heads	:	8
enc_layers	:	1
emb_dim	:	$[128, 512, 128]$

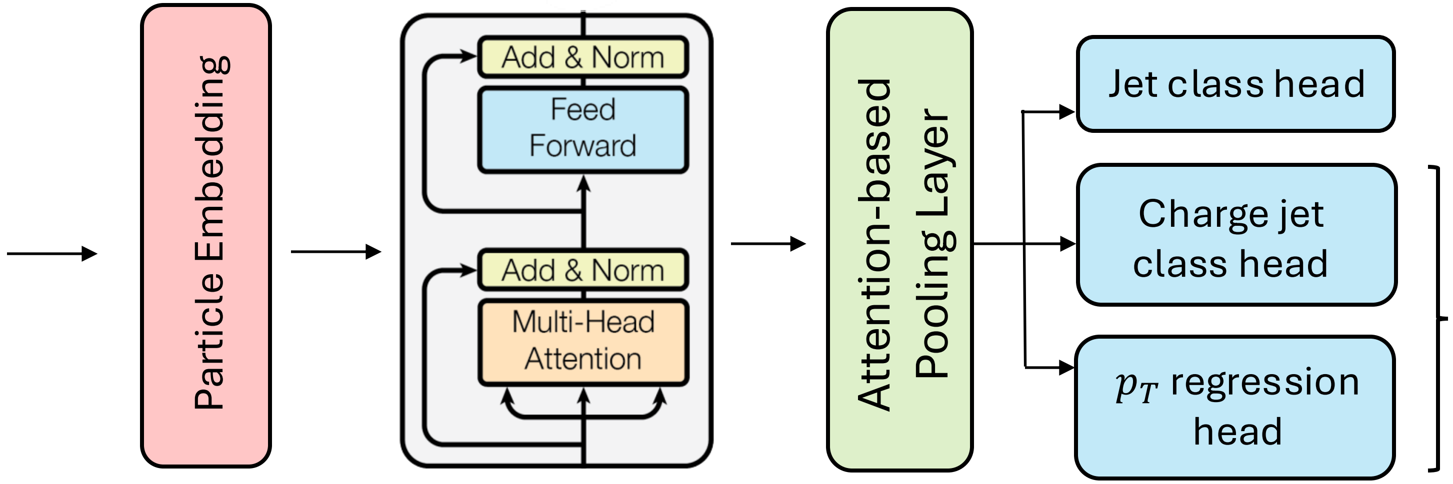
Hyperparameters

 # Parameters : $\sim 400k$
% GPU usage : 60%
$\sim 20s$ *per epoch*

Features up to 16 ScoutPFTau costituents

- p_T
- $\Delta\eta$
- $\Delta\Phi$
- vz
- charge
- *is_charged_hadron*
- *is_neutral_hadron*
- *is_electron*
- *is_muon*
- *is_photon*

Embedding — ***Transformer Encoder block*** — ***Projection*** — ***Output***

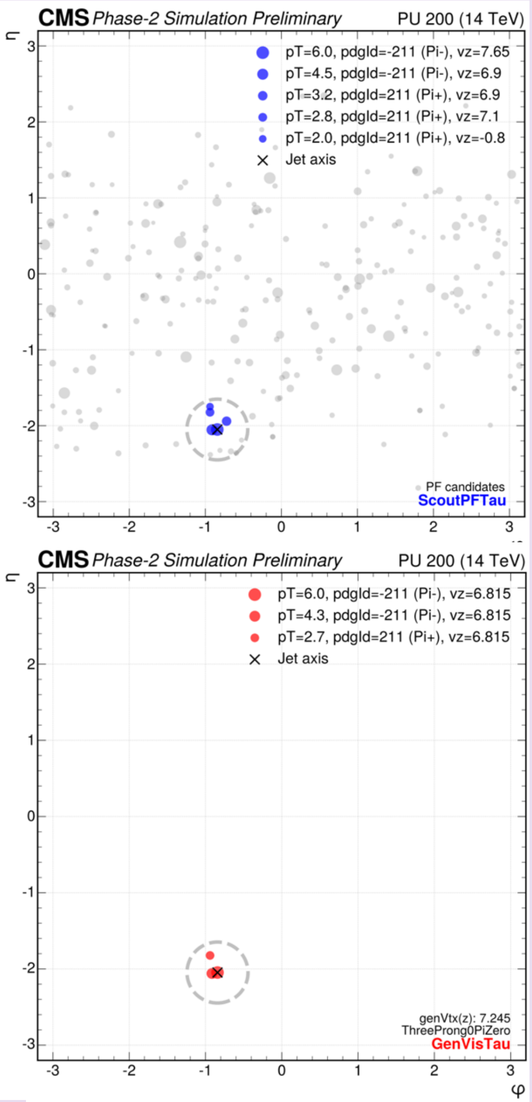


tau score (genuine vs. fake)

p_T corrected and charge (genuine τ)

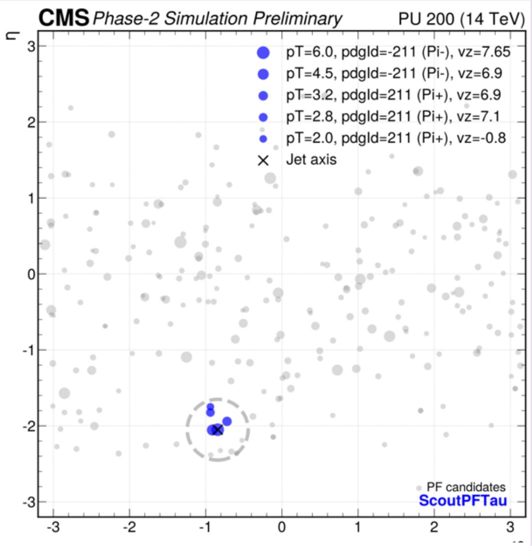
TASK

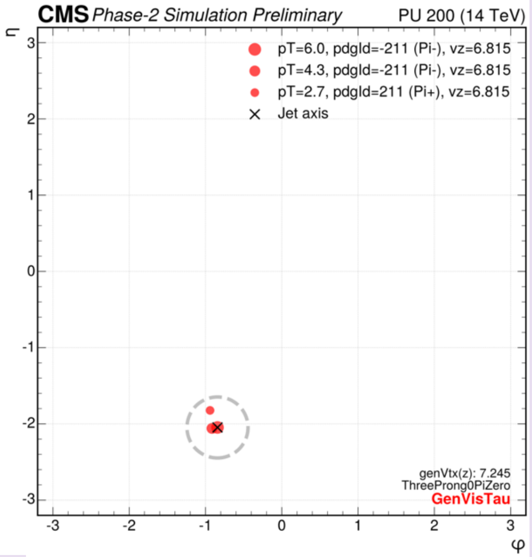
Detect pileup particles & recover $p_T, charge$



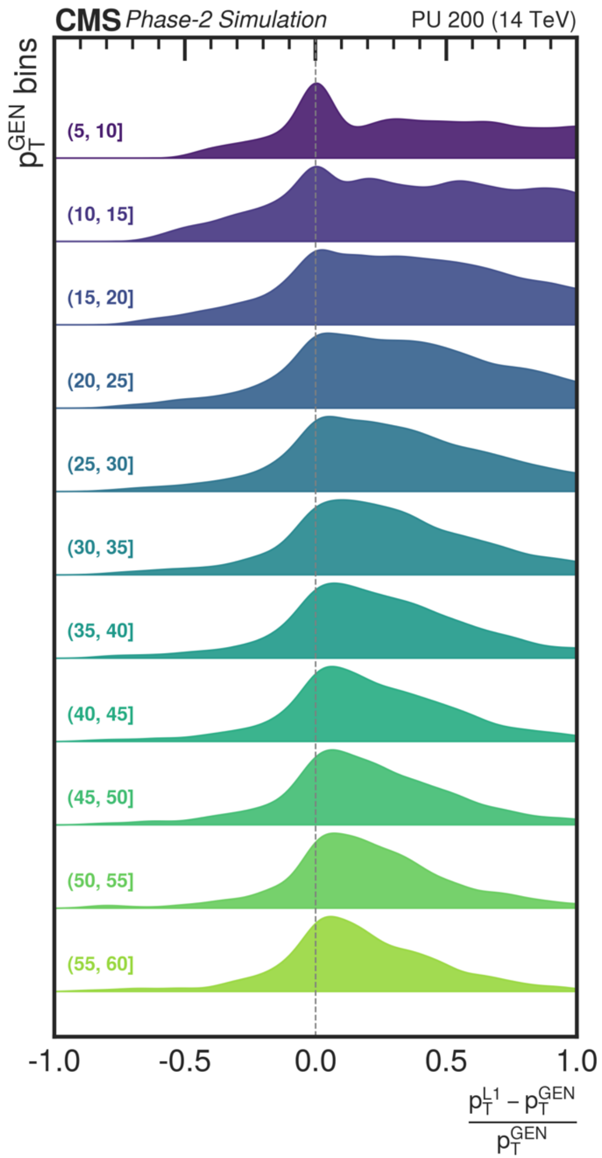
TASK

Detect pileup particles & recover $p_T, charge$





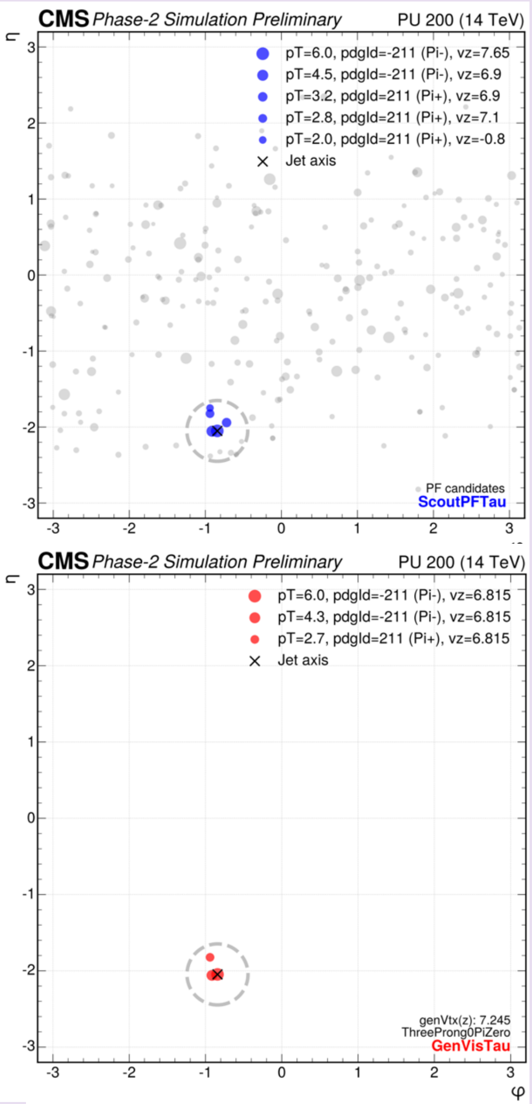
p_T regression



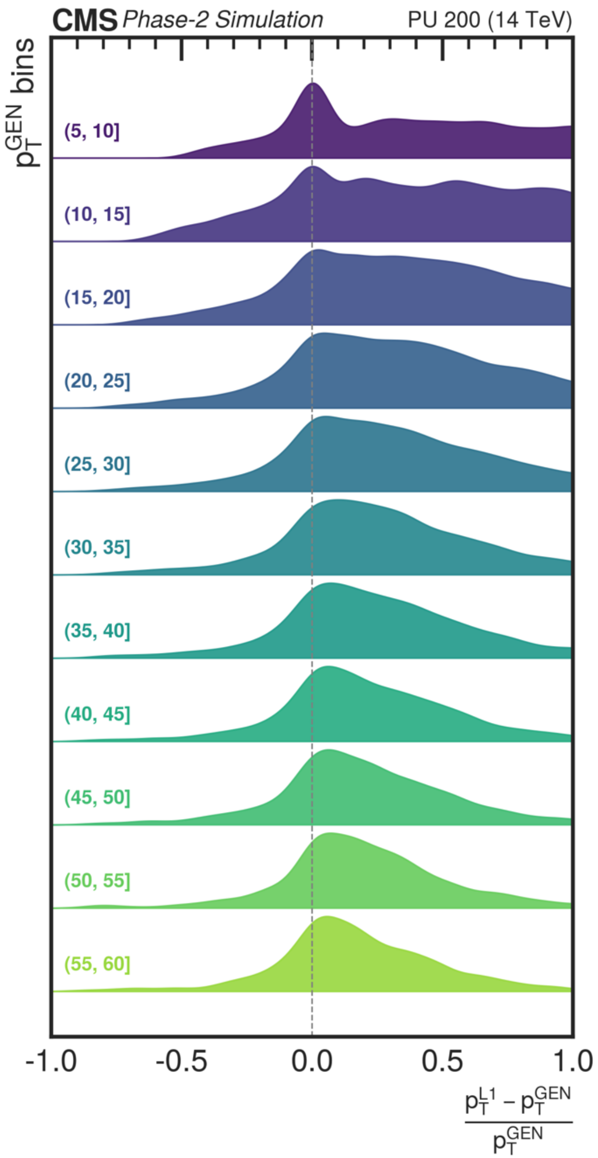
before

TASK

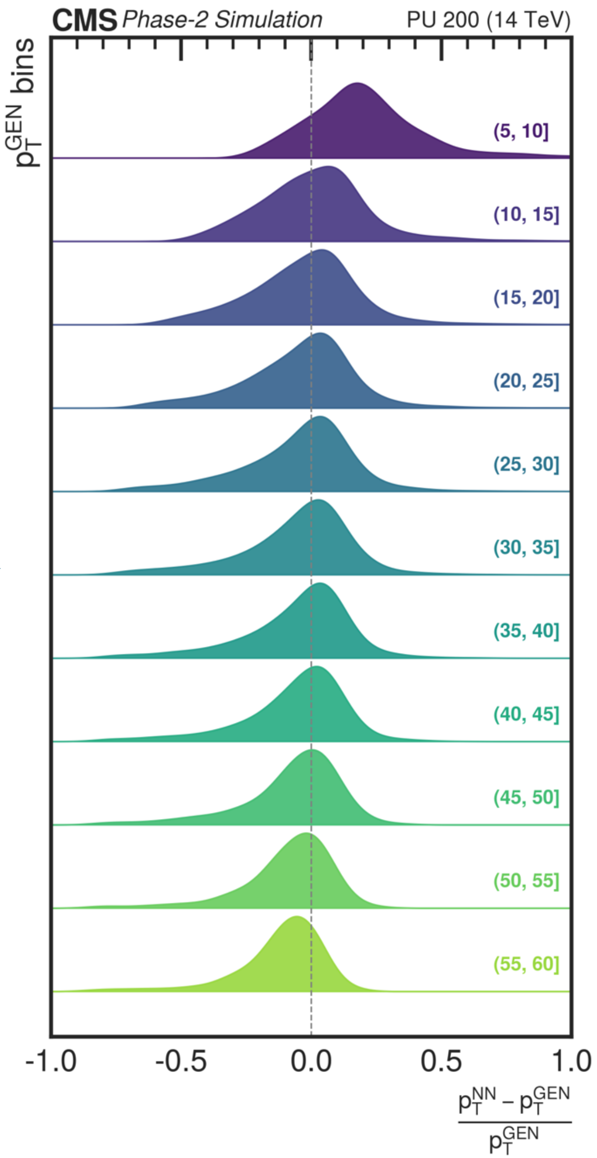
Detect pileup particles & recover $p_T, charge$



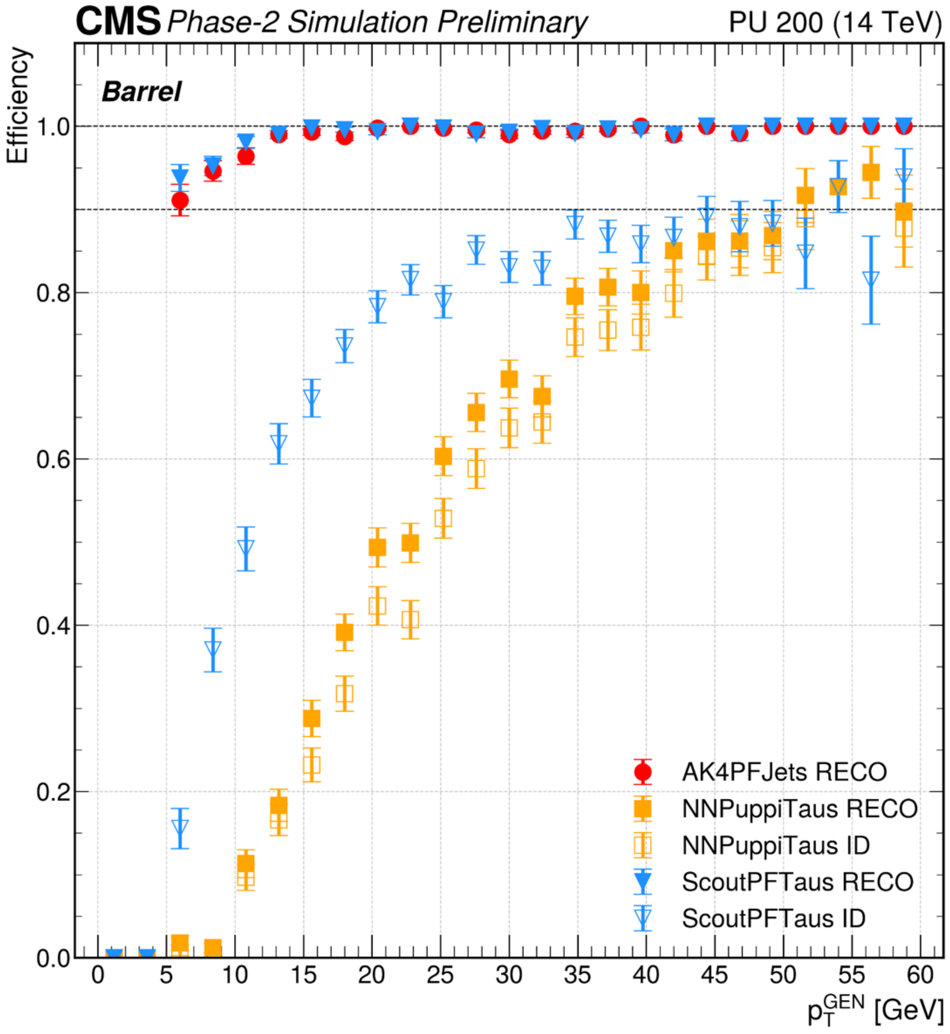
p_T regression

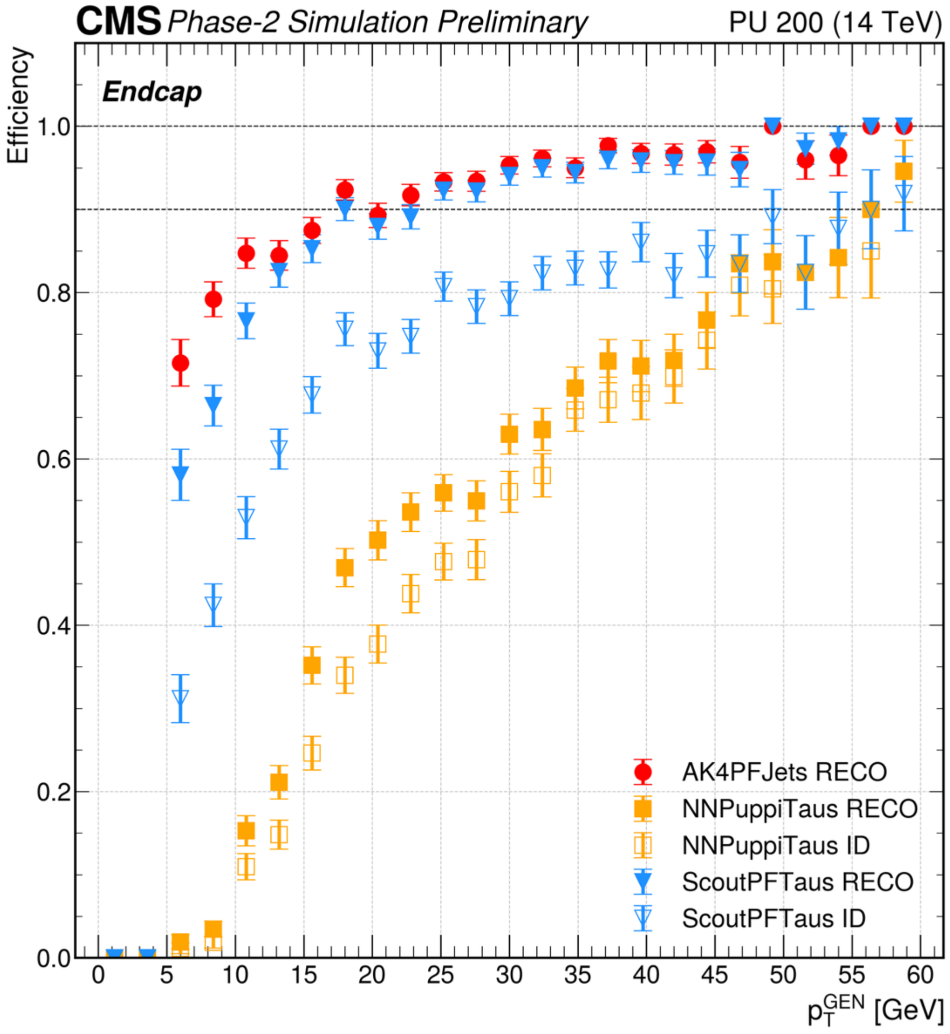


TauID correction



Overall efficiency





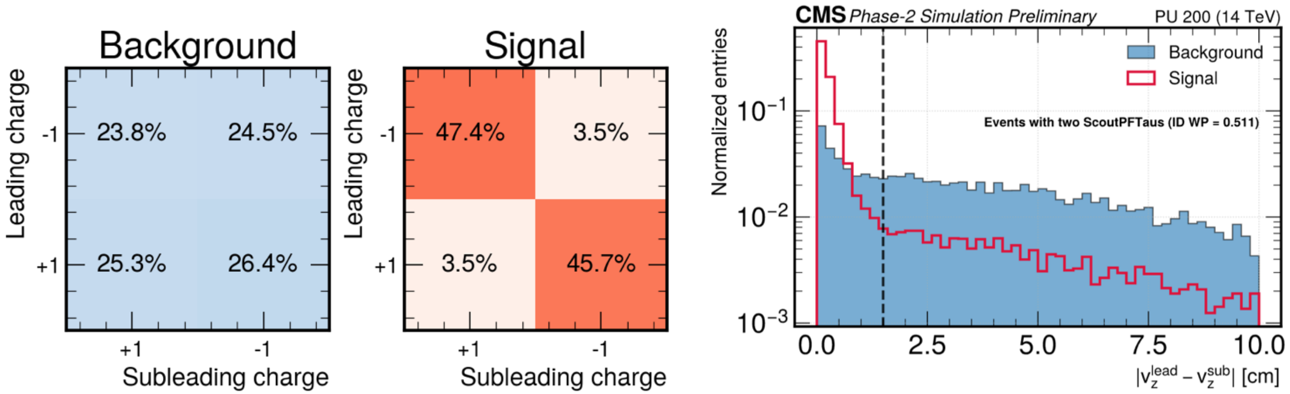
RECO
Eff./fake rate for all τ candidates from clustering (anti-k_T / CLUE), no ID applied

ID
Eff./fake rate for τ candidates passing ID (NNPuppiTau or Transformer NN)

… from single τ to di-τ

4 WPs:
- *class score*
- *charge score (+1, -1)*
- *Δvz cut*

a **grid search** selects the combination maximizing total efficiency



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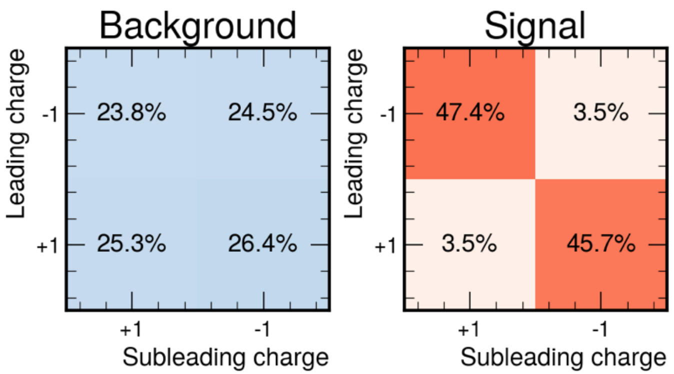
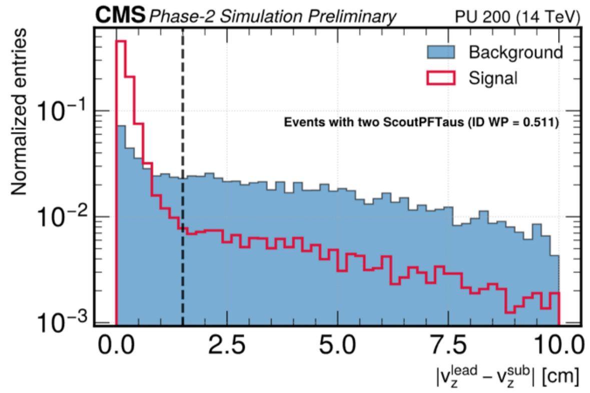
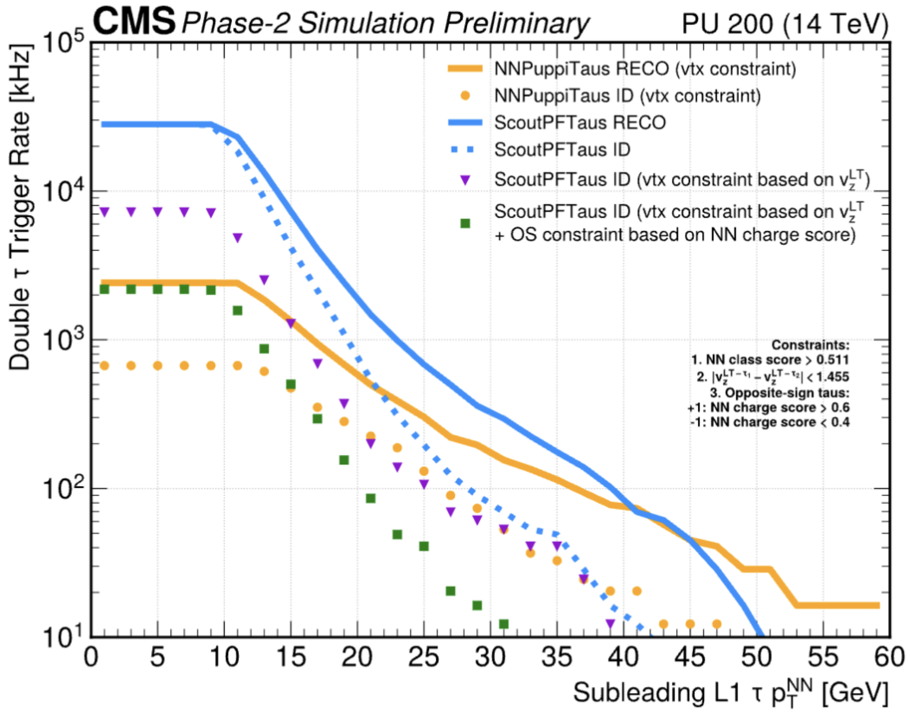
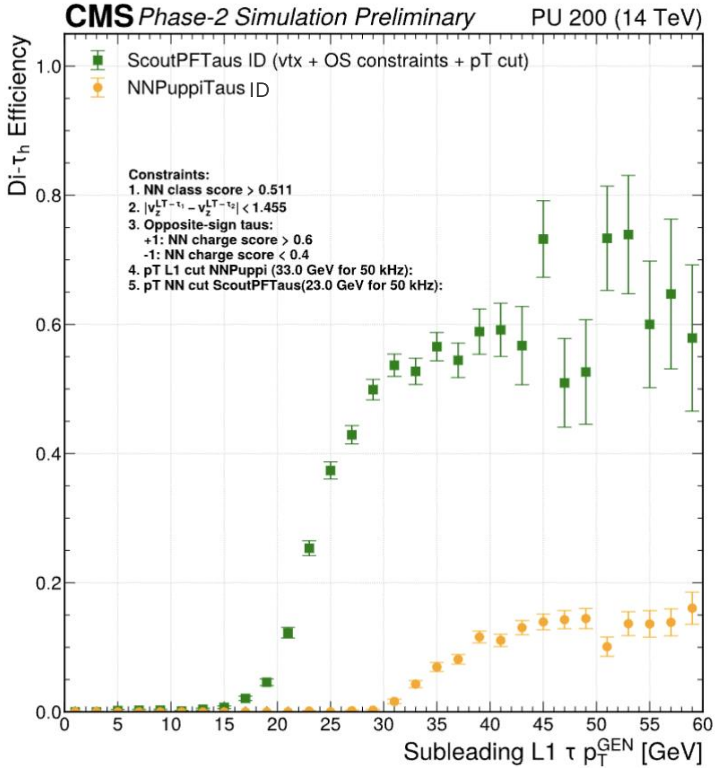






Fix fake rate to 50 kHz



! Significant gain compared to NNPuppiTaus

Conclusions

- ✓ Developed framework that improves low-p_T tau efficiency at sustainable fake rate within L1T Scouting
- ✓ Alternative clustering algorithm tested & tuned: performance similar to anti-k_T, with parallelization advantage
- ~ Ongoing: integrate CLUE in CMSSW & Scouting framework

unpacking ➡ ***CLUEstering*** ➡ ***TauID inference***

Thank you for the attention!

References

[1] CMS Collaboration, "Enriching the physics program of the CMS experiment via data scouting and data parking", Phys. Rept. 1115 (2025) 678

[2] CMS Collaboration, "Search for a low mass resonance decaying to $\tau\tau$ using data collected with a dedicated high-rate data stream", CMS-PAS-EXO-24-012

[3] CMS Collaboration, "NNPuppiTaus: PUPPI tau reconstruction in the Level-1 trigger with real-time machine learning.", CMS-DP-2024-018

[4] CMS Collaboration, "The Phase-2 Upgrade of the CMS Level-1 Trigger", CERN-LHCC-2020-004; CMS-TDR-021

[5] Marco Rovere et al., "CLUE: A Fast Parallel Clustering Algorithm for High Granularity Calorimeters in High Energy Physics", arXiv:2001.09761

[6] Matteo Cacciari et al,"The anti-k_t jet clustering algorithm.", JHEP 0804:063,2008

[7] Ashish Vaswani et al., "Attention is all you need.", arXiv:1706.03762

BACKUP

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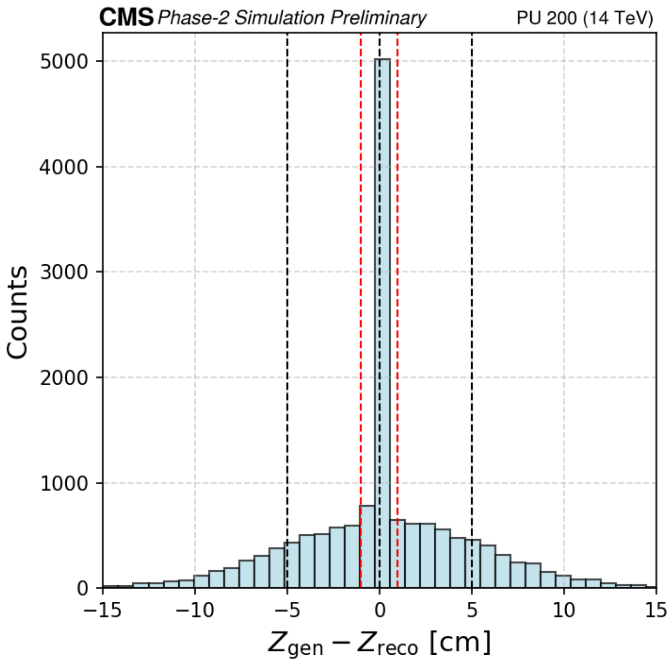
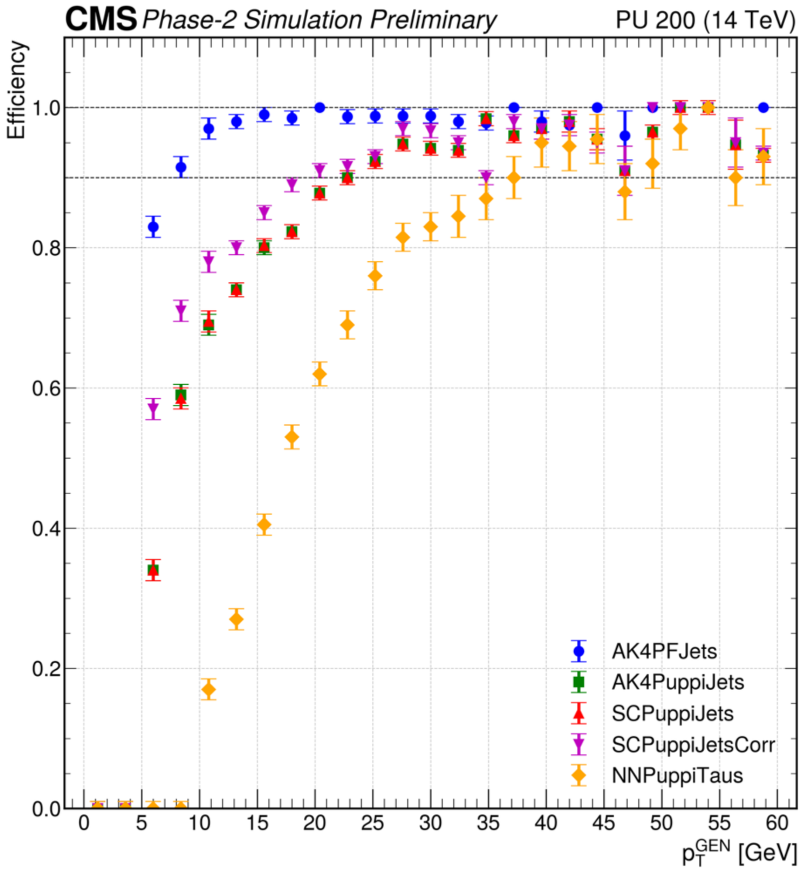
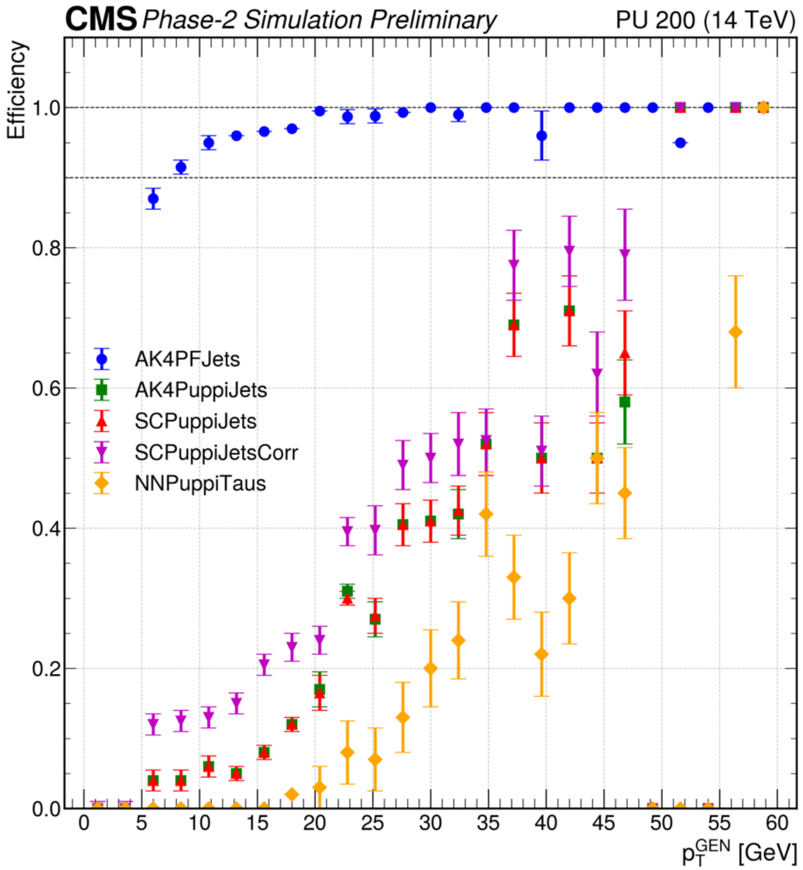
Why is PUPPI underperforming?



Events with
$|z_{genvtx} - z_{recovtx}| < 1\ cm$

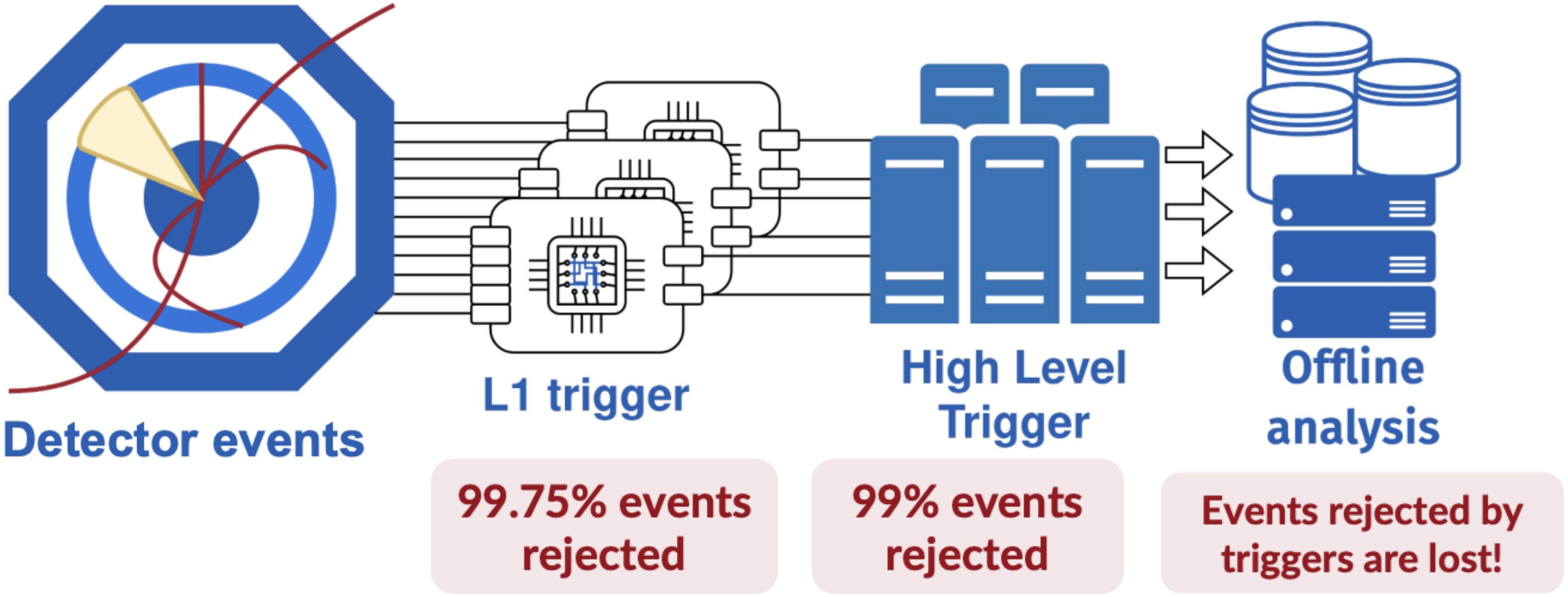


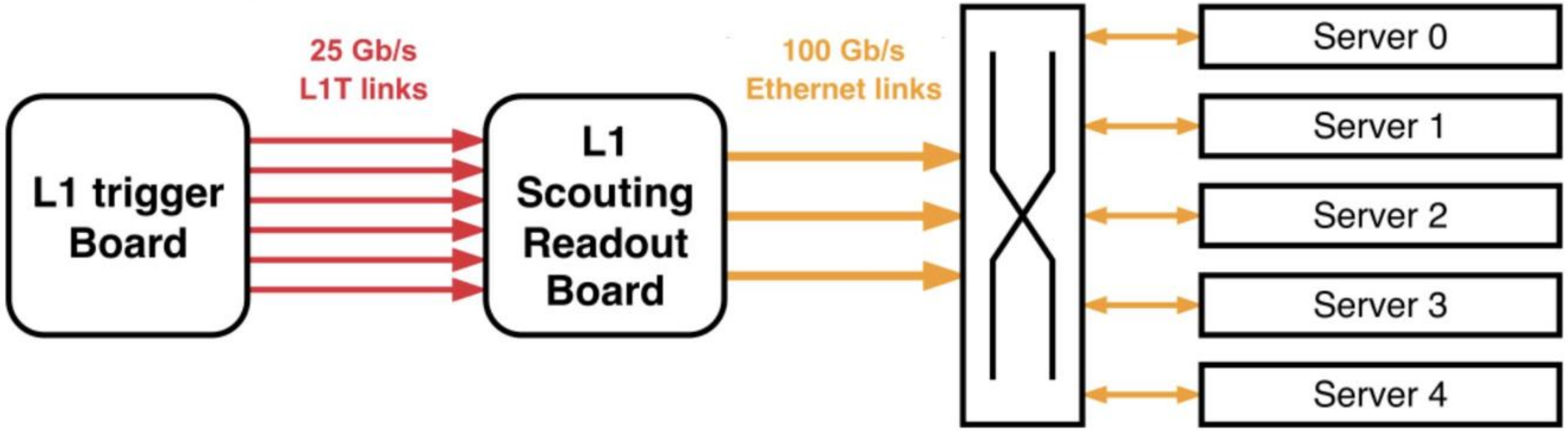
Events with
$|z_{genvtx} - z_{recovtx}| \geq 1\ cm$



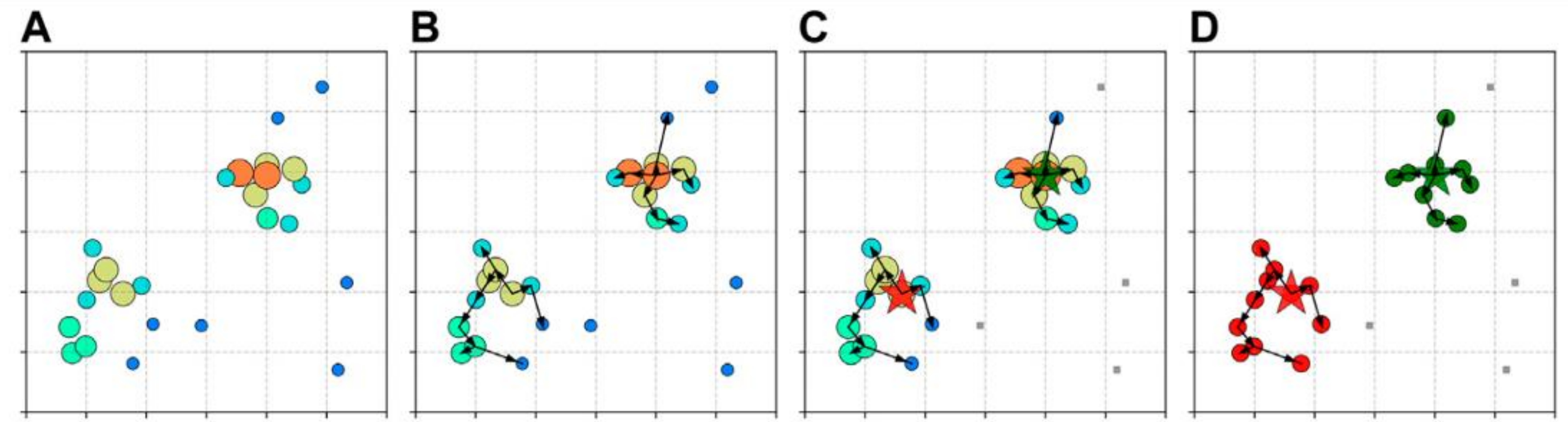
Frequent vertex misidentification reduces the performance of PUPPI-based tau jets collection

CMS DATA FLOW





How CLUE works?



Step A: Local Density calculation

Step B: Nearest-Higher and Separation calculation

Step C: Seed promotion and outlier demotion

Step D: Cluster Propagation