Physics Object Performance in CMS

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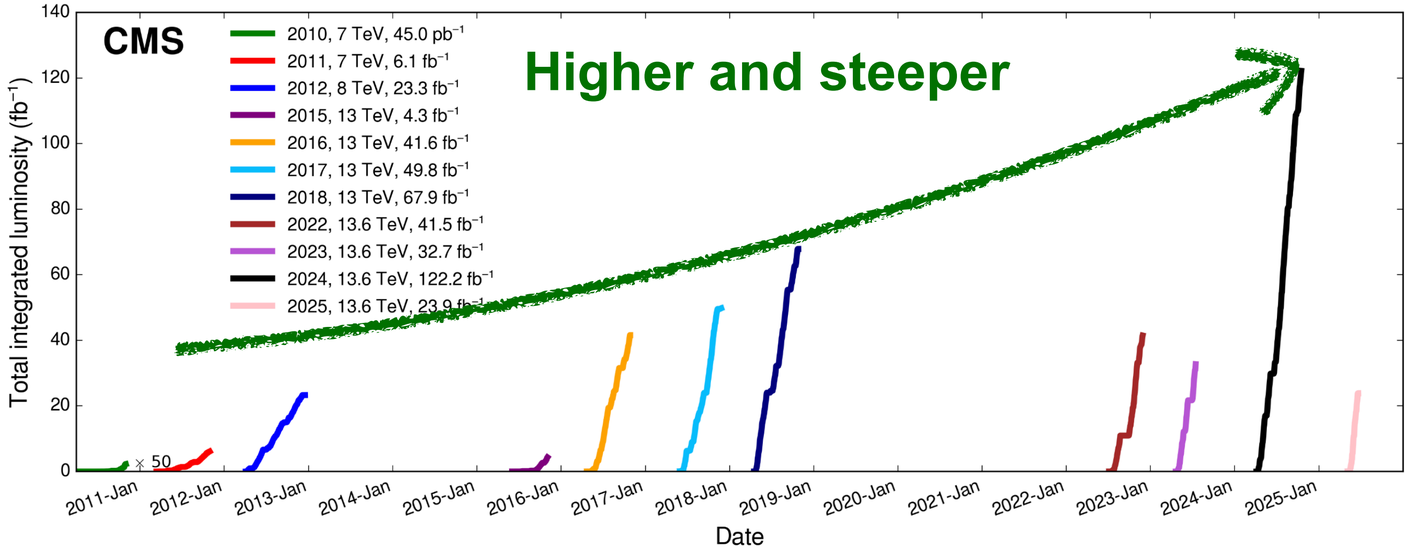
on behalf of the CMS Collaboration
EPS 2025 - Marseille
10-07-2025

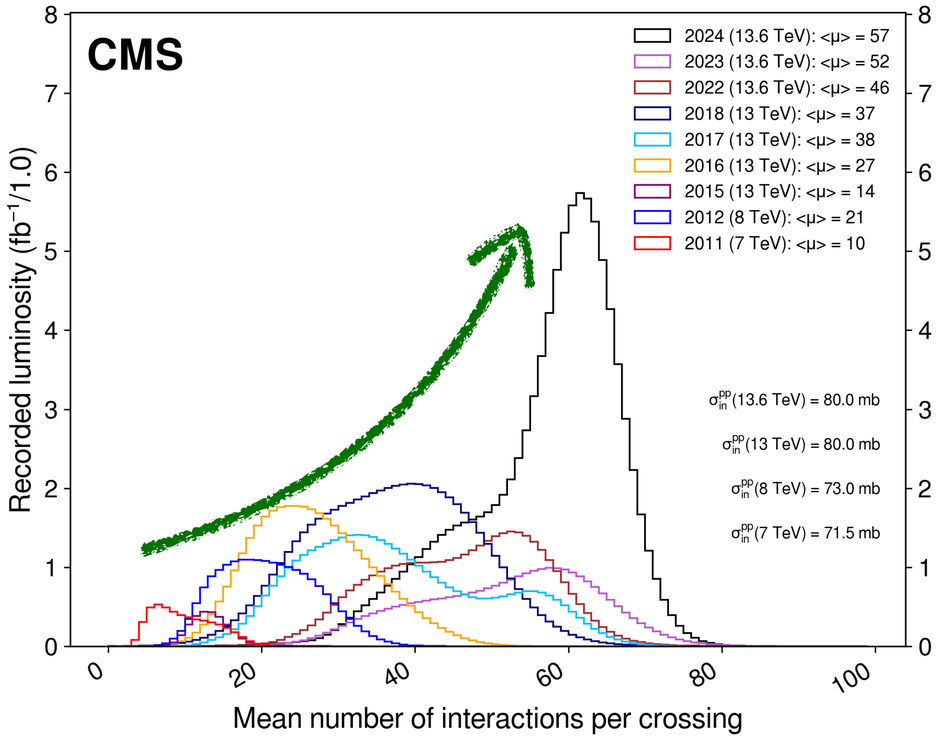
LHC Run3: records and challenges

CMS Lumi Public Results



More collisions, for longer!

How do CMS adapts to face the challenge?



- **higher instantaneous luminosities**
  - Increase number of interactions per bunch crossing - pile up

- **Lumi leveling throughout fill:**
  - Larger datasets in same recording time

Objects recipes

Reconstruction calibrations

- Radiation damage
- Macroscopic detector issues
- (Dead/noisy/masked channels)

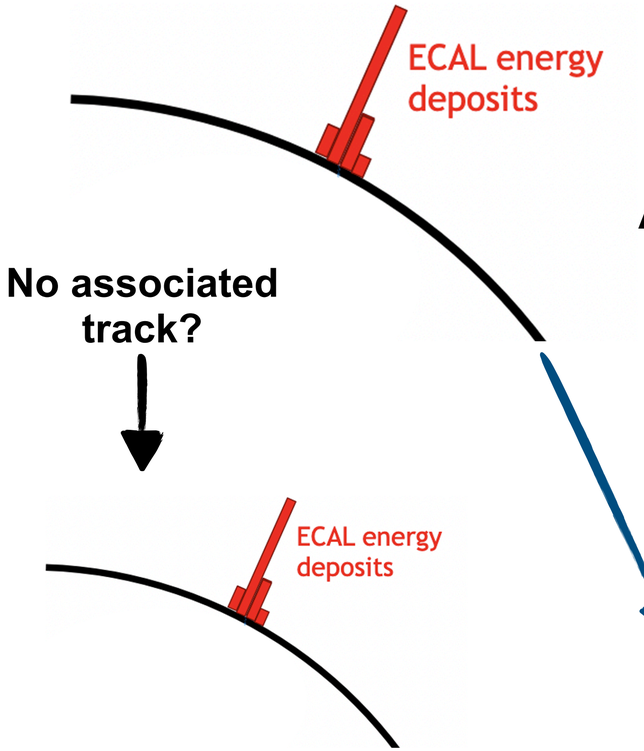
Identification

Non-standard phase spaces
High end ML techniques
in depth object characterization

Simulation Corrections

Material, radiation damage evolution
Known mismodeled variables
PU scenario dinamically changing

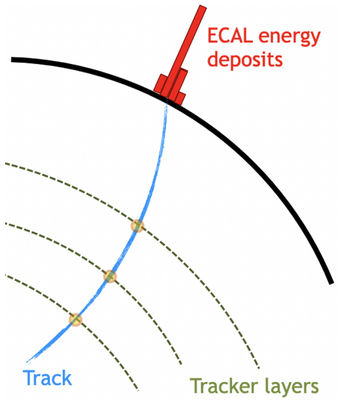
Electrons and photons



No associated track?

A photon!

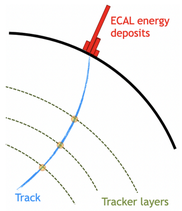
Associated track?



An electron!

Does the electron Brehm?

What if the photon converts?



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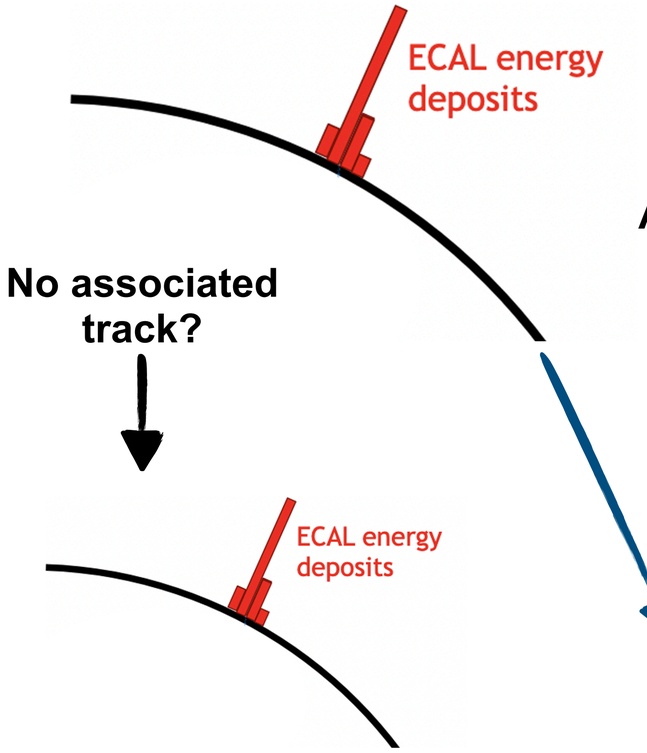
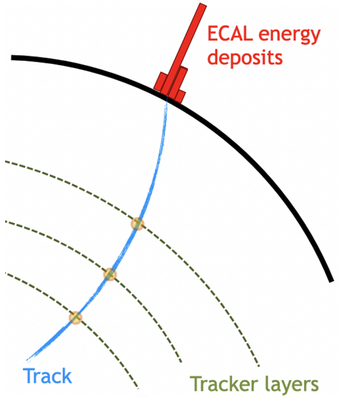


Associated track?



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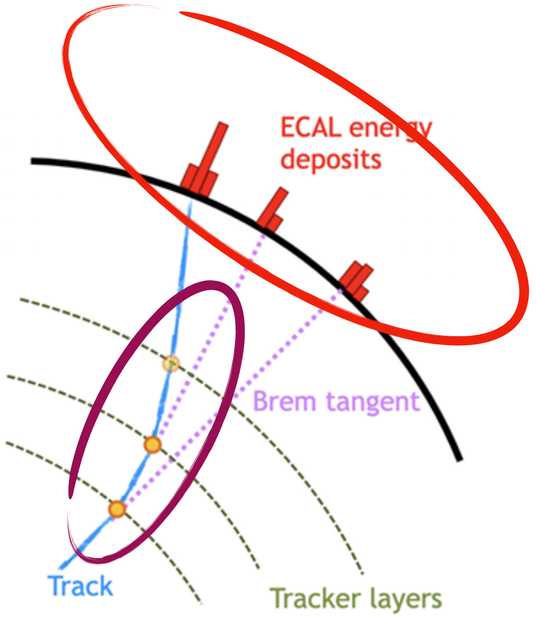
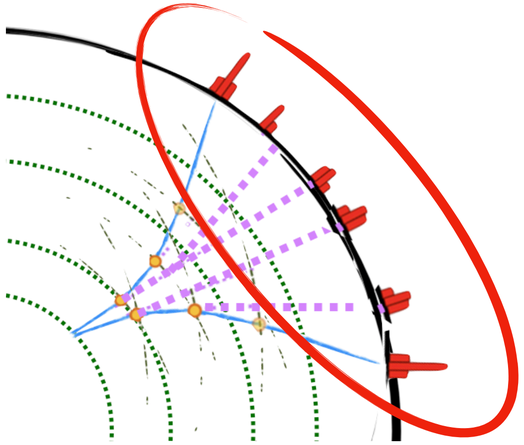


Dedicated tracking algorithm (GSF)
Recover from
Brehm kinks

What if the photon converts?

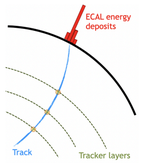


Dedicated clustering algorithms
patch all the energy deposits
together

Energy deposit regression + E-p combination
pT and E best estimates

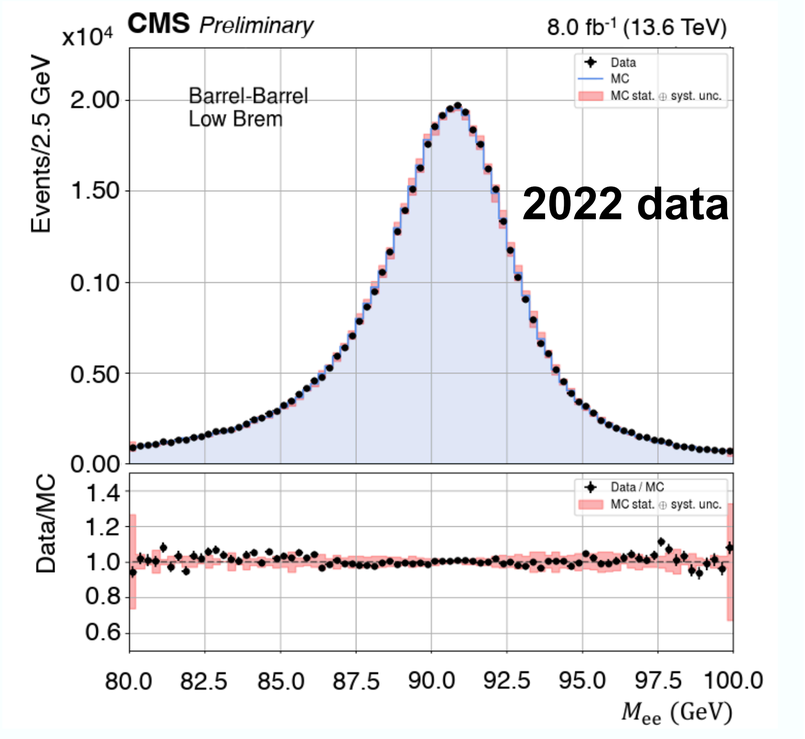
Simulation corrections

DP-2024-052



Scale and smearing corrections

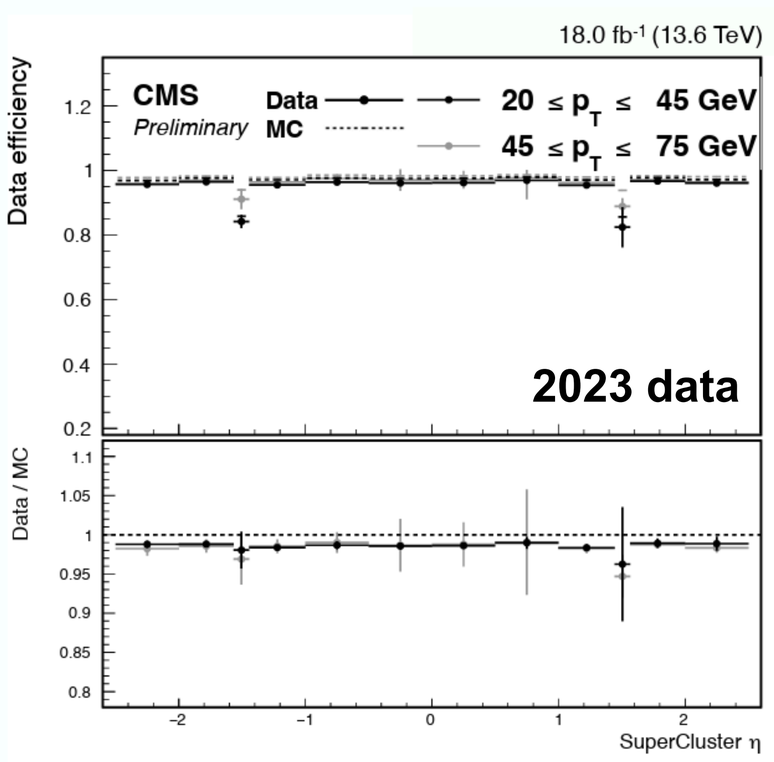
Residual energy corrections computed Z -> e+ e- standard candle



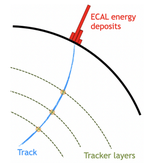
ECAL energy measurement:
shifted in DATA to match the SIM peak position
smeared in SIM to match DATA resolution

Reconstruction efficiency Scale Factors (electrons)

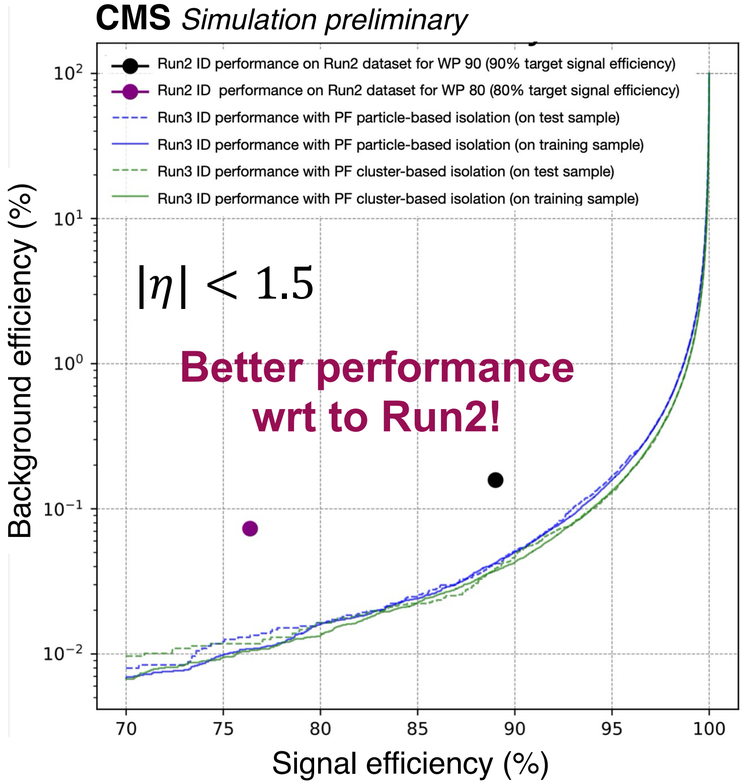
How many times does a Z->e+ e- energy deposit in ECAL has a corresponding associated track?



New identification algorithms



Run3 standard electron ID

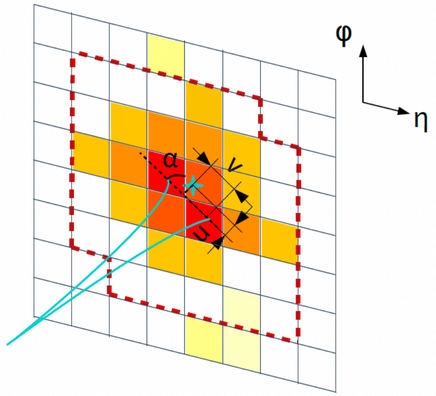


DP-2024-052

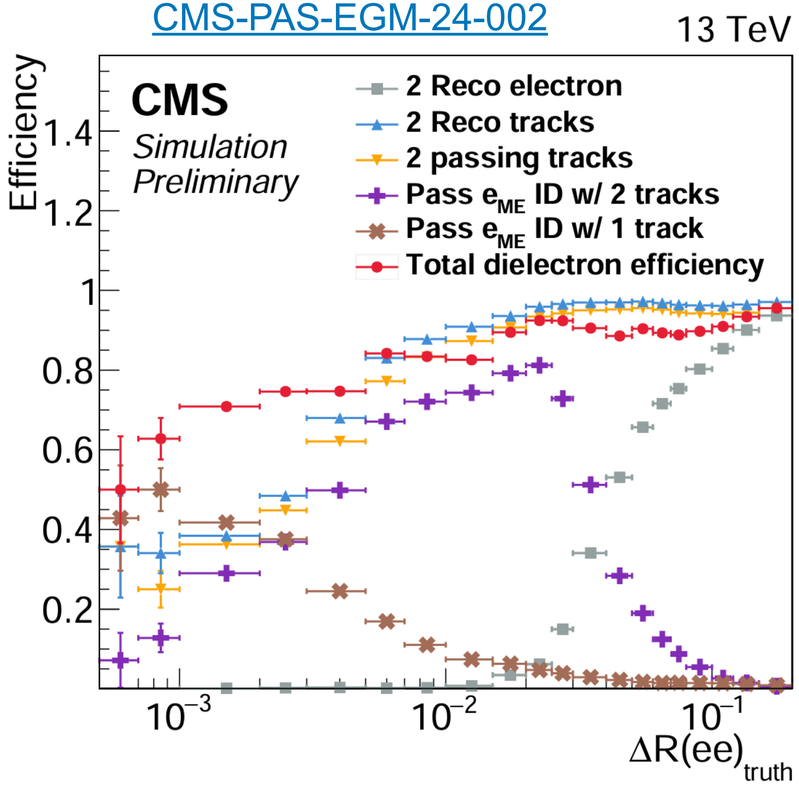
Highly boosted di-electron pairs identification

NEW!

1-2 tracks + single merged ECAL cluster



CMS-PAS-EGM-24-002



Di-track

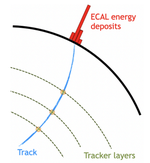
Standard di-electron

2 trk merged ID

1 trk merged ID

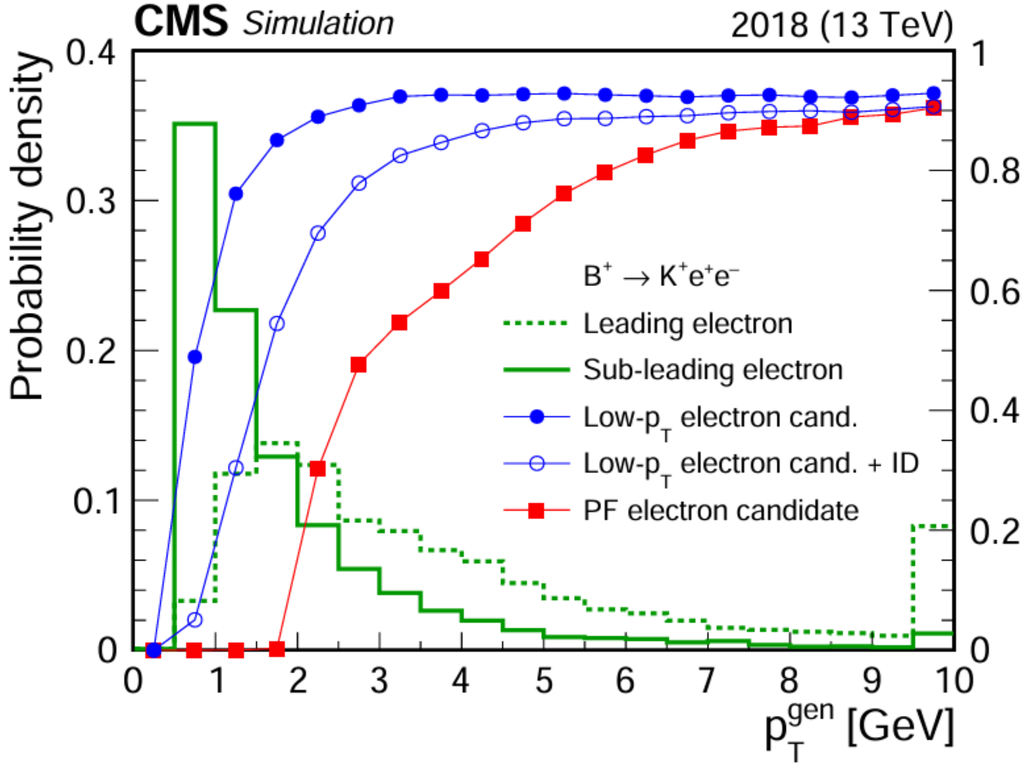
EGM novelties:

arXiv:2403.16134



Novel phase spaces:
Low Pt electron collection

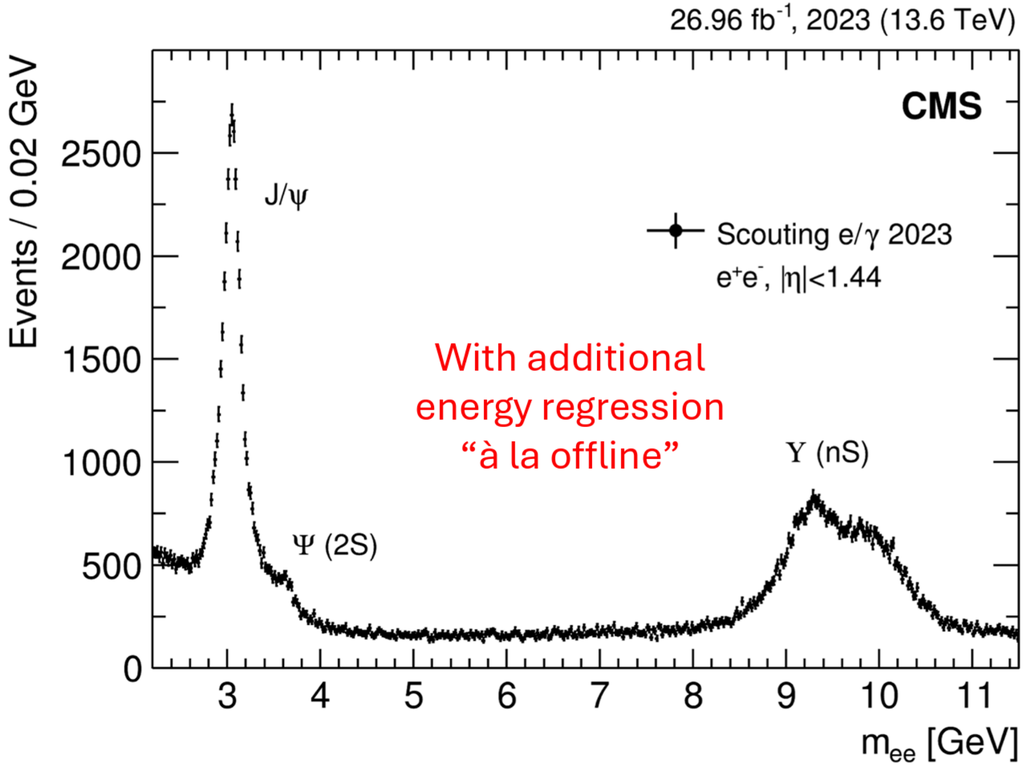
GSF track with looser track seed
Enhanced reconstruction efficiency in [1-10] GeV pT range
Fight rising background via dedicated ID



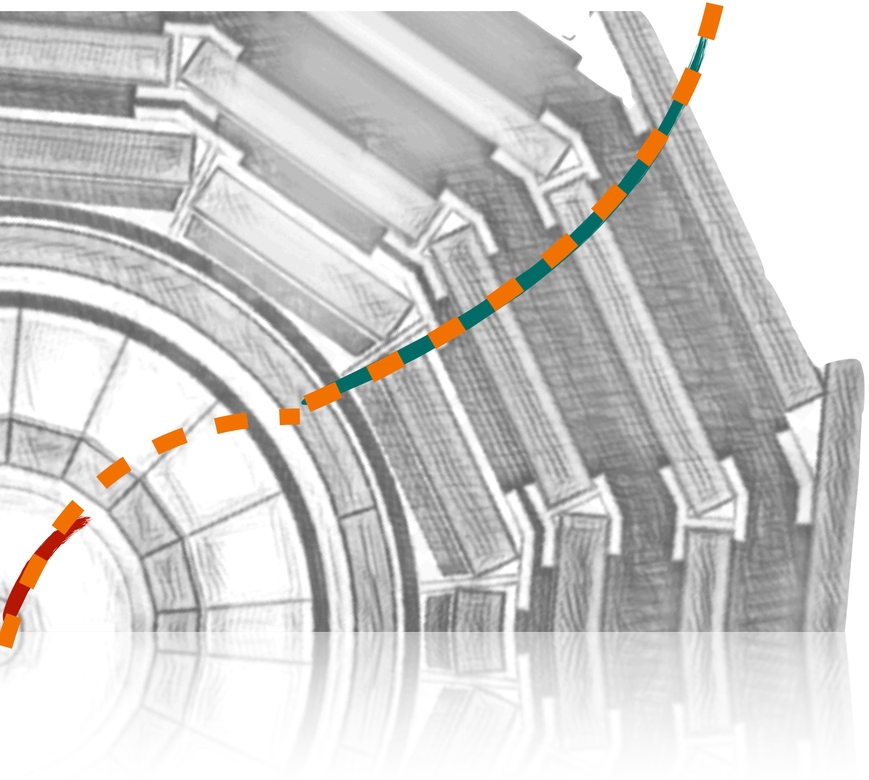
From Run3 available centrally in all CMS datasets!

Novel data rates:
Scouting electrons

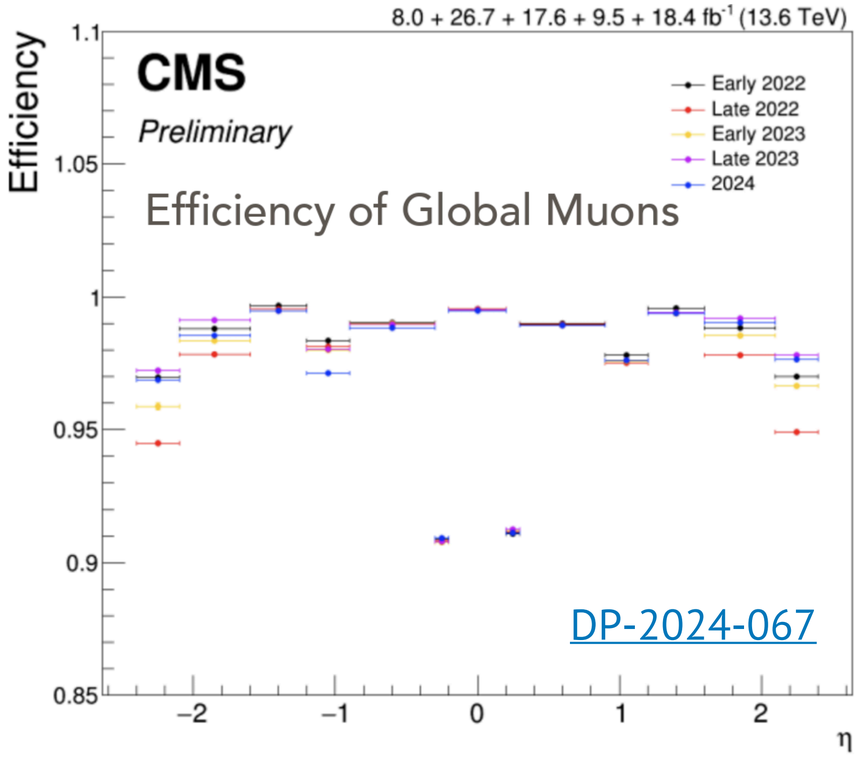
Limited event content information
Prompt HLT recostruction
Smaller event size = lower HLT thresholds!



Muon reconstruction



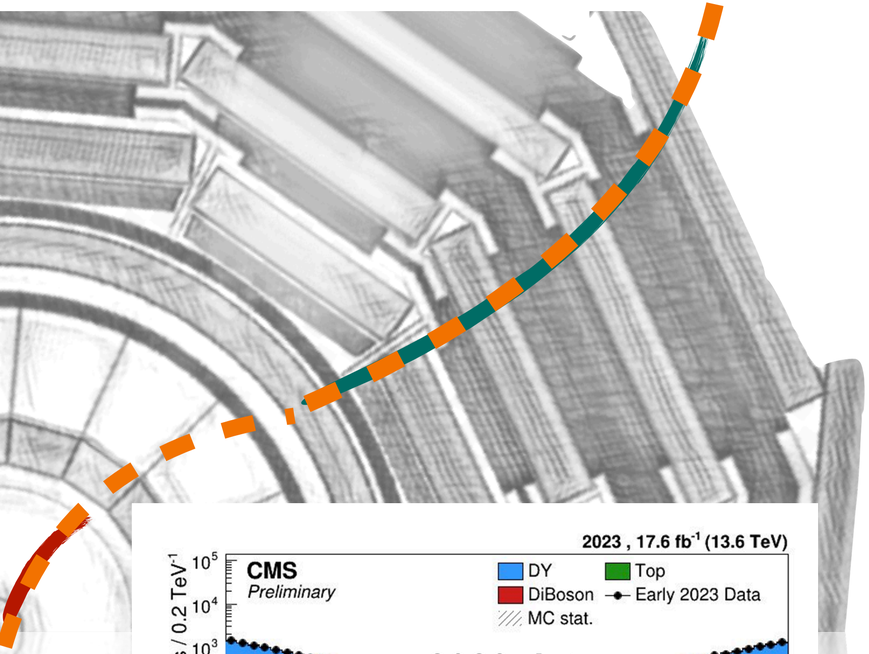
Global muon reconstruction efficiency > 95%!

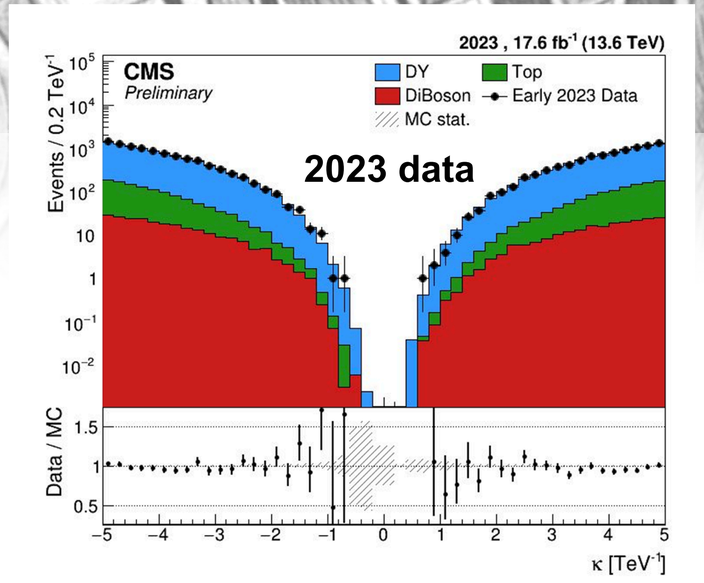


- **Tracker Muon:** Track + loose match to Muon system detectors
- **Standalone Muon:** Kalman Filter in the muon system only
  - LLP proxy
- **Global Muon:** outside in standalone-to-tracker match

Muon scale and smearing corrections

DP-2024-065





High pT: q/Pt method only

Medium pT: two steps procedure

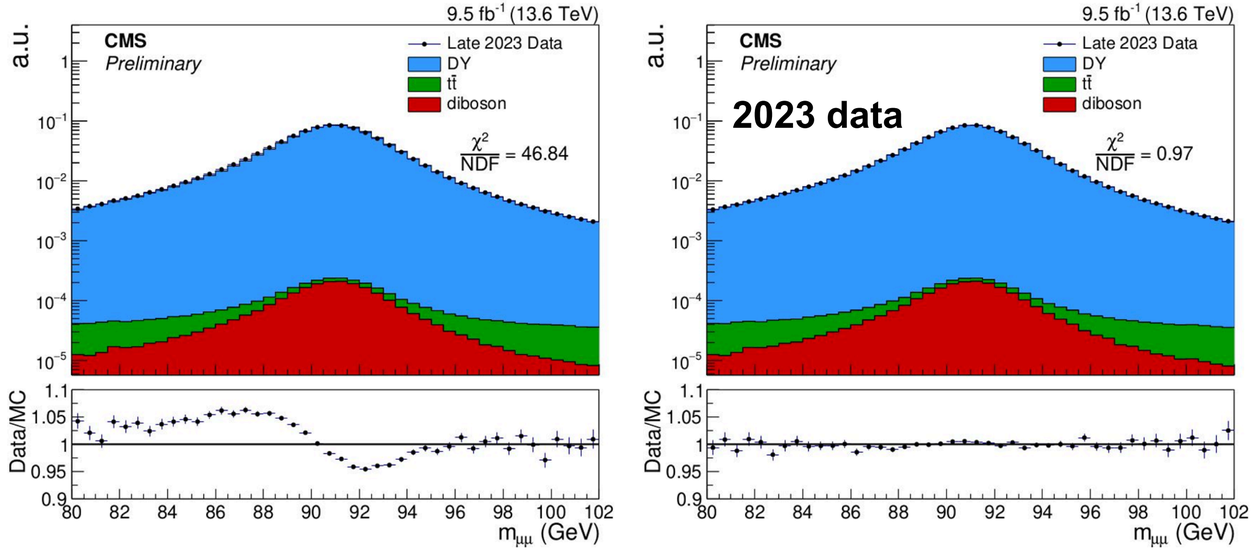
1. 1/pT correction per muon

- Assumes same behavior for μ^+ μ^- in
  - Kinematics
  - Sim vs data

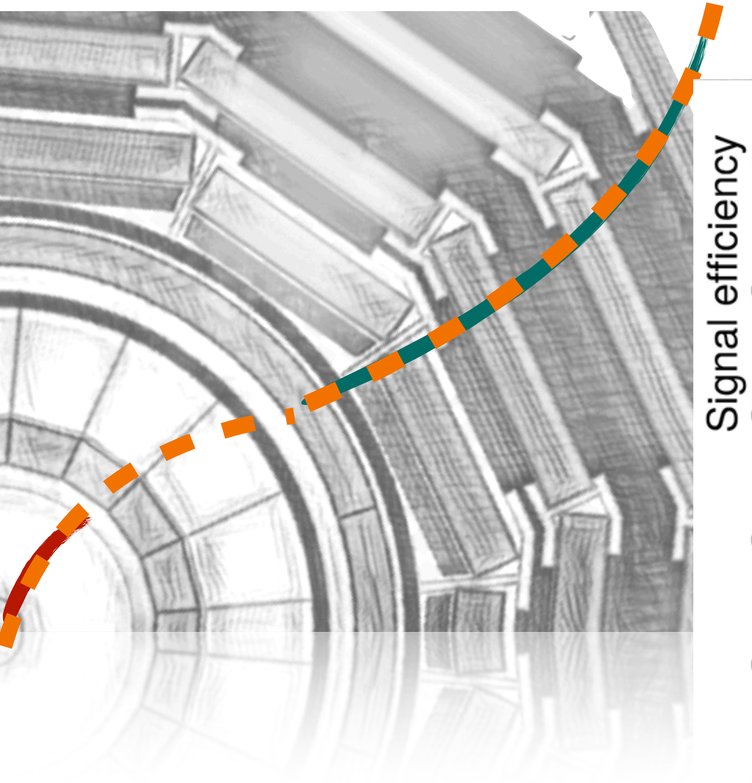
a. $\langle 1/p_T \rangle_{gen,\,neg} = M \langle 1/p_T \rangle_{reco,\,neg} - A$

b. $\langle 1/p_T \rangle_{gen,\,pos} = M \langle 1/p_T \rangle_{reco,\,pos} + A$

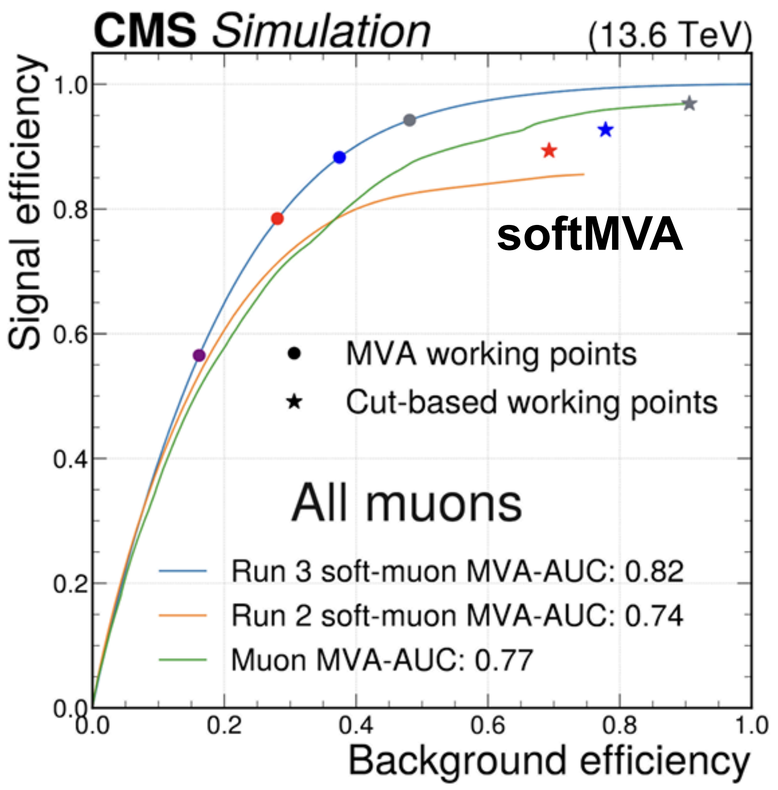
2. $Z \rightarrow \mu\mu$ peak position and resolution

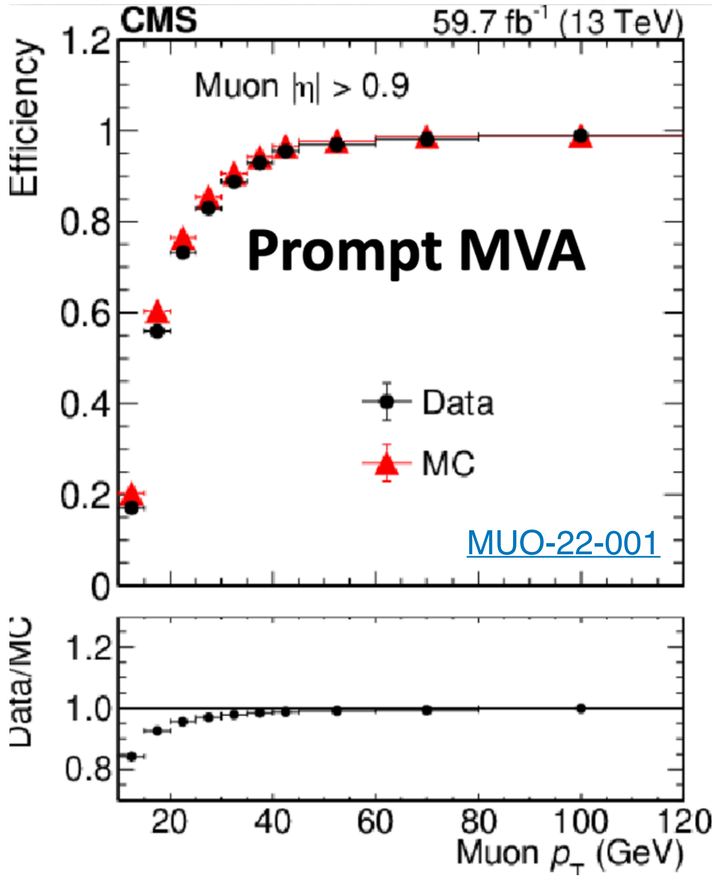


Same muons, different phase spaces:



arXiv:2412.17590





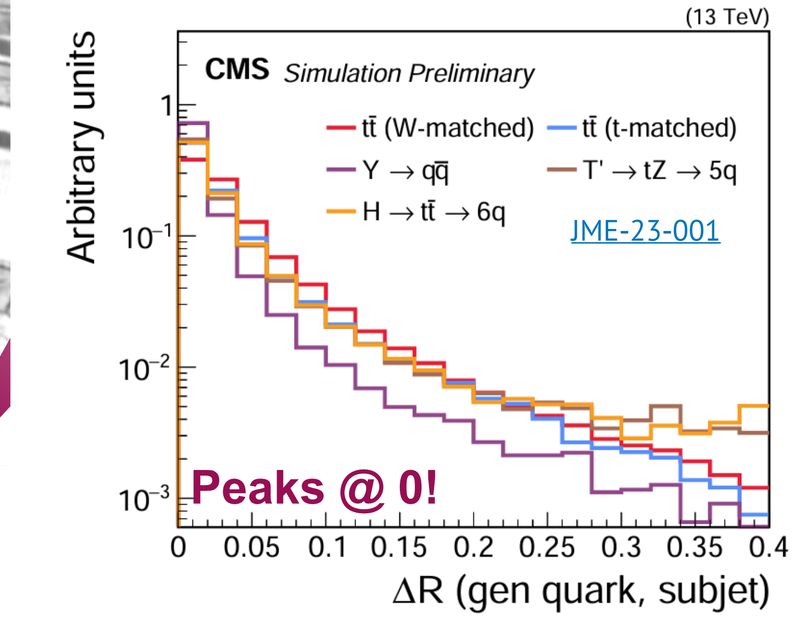
Less strict on prompt requirements
Optimized for B-meson/low-energy physics
Retrained for Run3 with better performance!

Specific for prompt SM processes:
W,Z H, τ decays,

Jets - Run3 standards

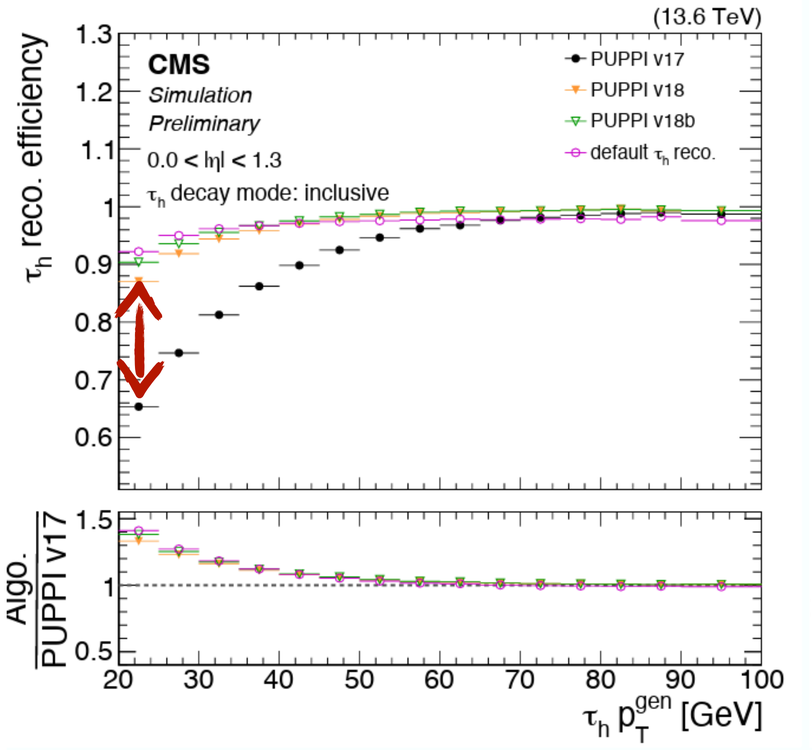
DP2024_043

Jet substructure information



- Via declustering: exclusive-kT algorithm
  - Build **quark-subjet pairs** in merged jets
- Jet is decomposed in subjets
  - Corrected **independently**

baseline algorithm: PUPPI



Hadronic taus often yield tracks not used in vtx fit
V17 not tuned to protect this tracks

New version v18 keeps non vertexed tracks from pT>4 GeV

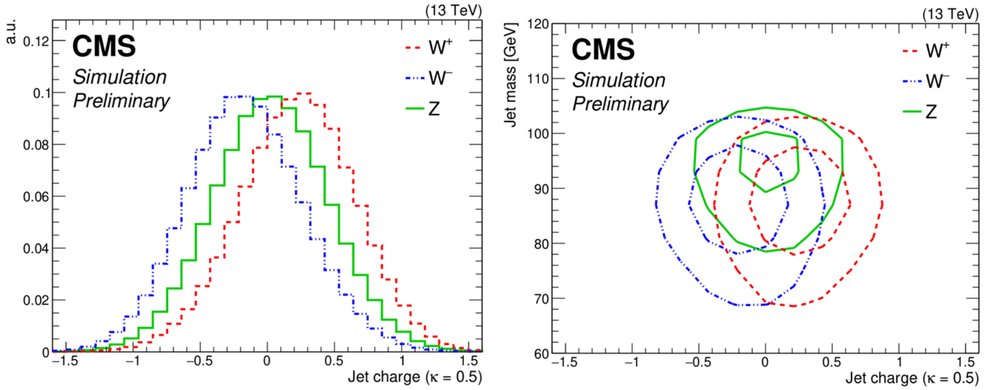
Hadronically decaying vector bosons ID

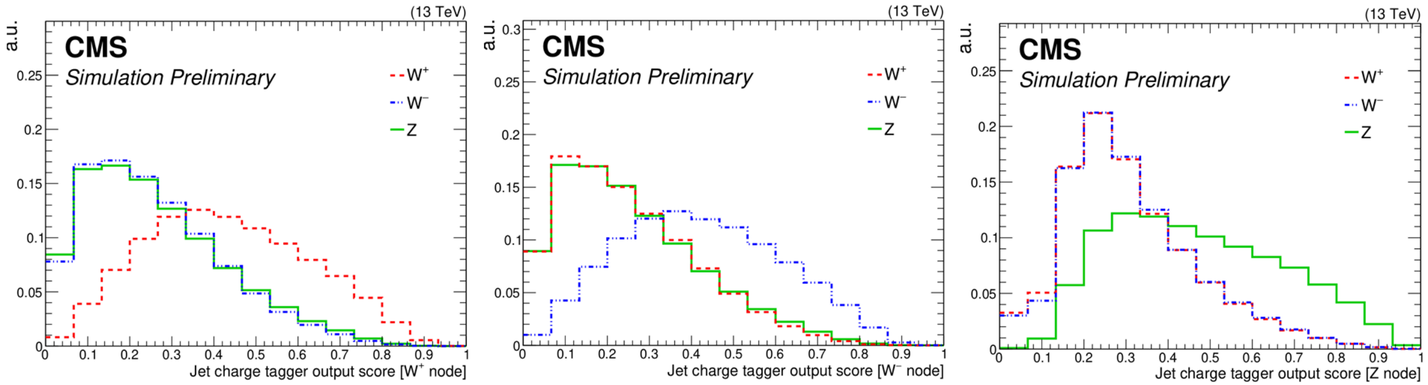
DP 2024-24

Jet charge taggers:

- Dynamic Graph Convolutional Neural Network (DGCNN) based on pNet
- On AK8 jets
- Binary (W+ vs W-) or ternary (W+,W-,Z) classification

Classification via jet variables



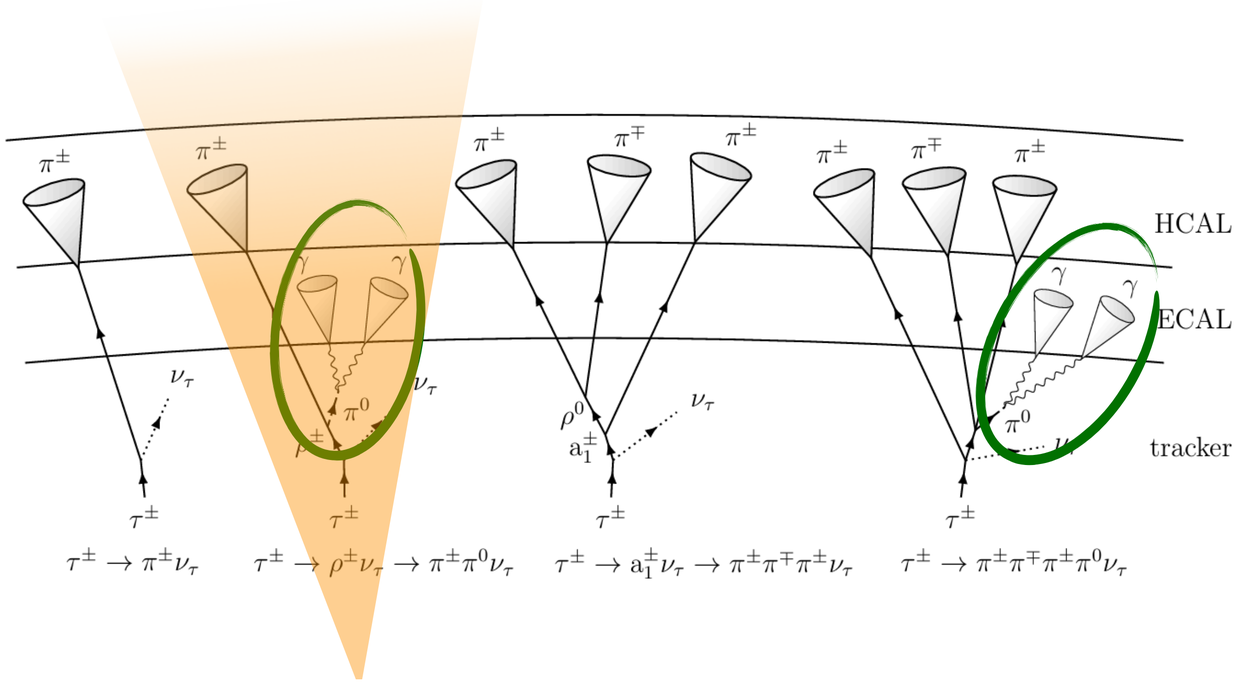


Classification via jet charge tagger

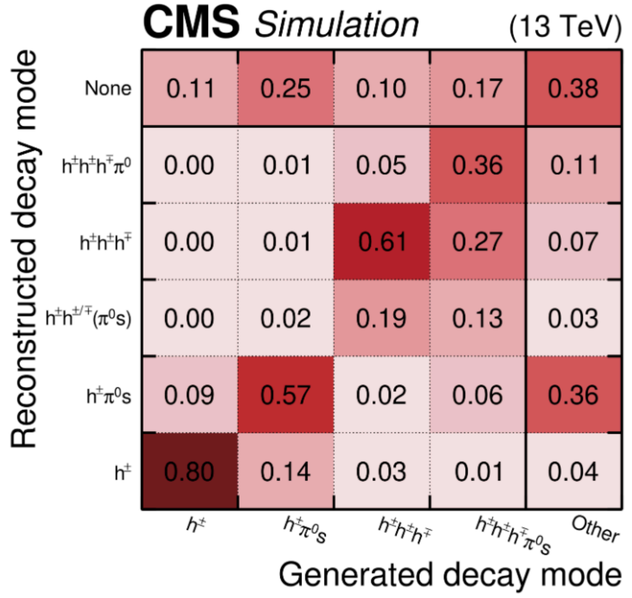
Tau reconstruction

JINST 13 (2018) 10, P10005

- Tau seeding region defined by **jets**
- Charged hadrons (HCAL + tracks)
- **HPS** (Hadron + strips) reconstructs $\pi^0 \rightarrow \gamma\gamma$
As ECAL energy strips



- Several combinations of charged and neutral pi0
- To build tau candidate
  - Selections in charge, mass compatibility **per decay channel**
- Leading pT canditate after selections: **Tau candidate**

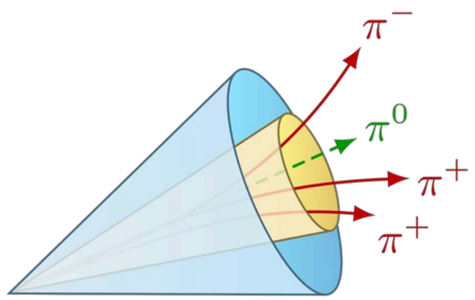


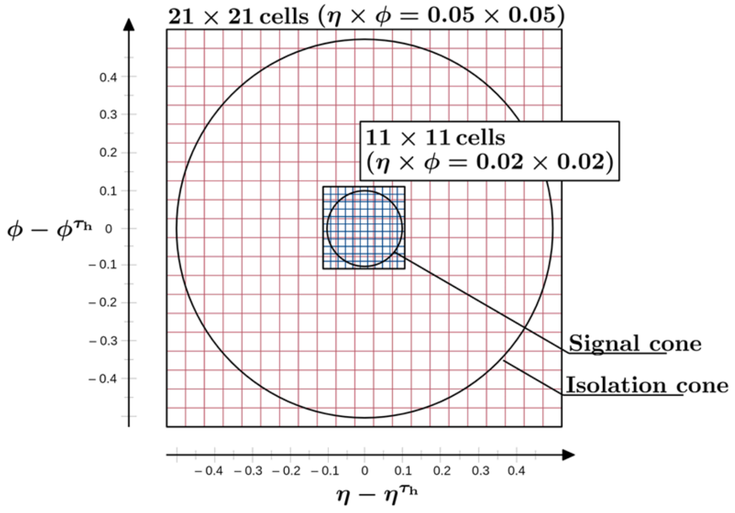
More on developments in tau's reco and ID in Paola's poster

Deep Tau with domain adaptation

CMS-PAS-TAU-24-001

More in Stepan's poster





CNN with:

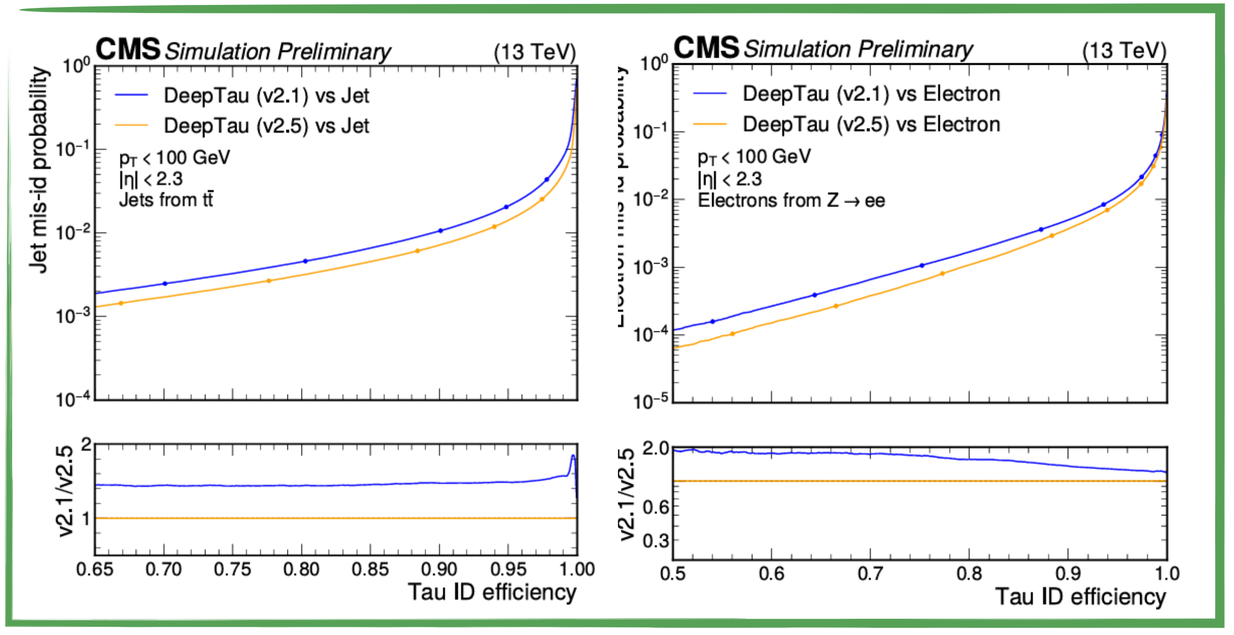
- Particle level input split in **two $\eta - \phi$ separate grids**
- High level tau candidate features

- **Mixed SM processes** for training

Train 1 epoch on mix of SIM + Data in control regions

Domain adaptation: **Run3 NEW!**

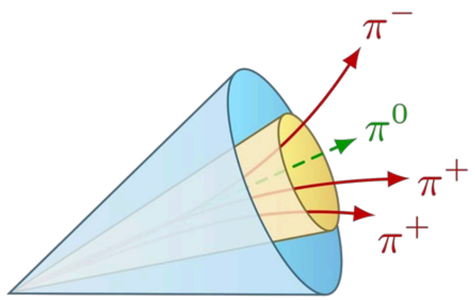
- **Target:** cure unwanted sim to data discrimination
  - Yielded by mismodelled variables + DNN train on SIM only
  - **Maximise** classification performance
  - **Minimize** discrimination between data and SIM

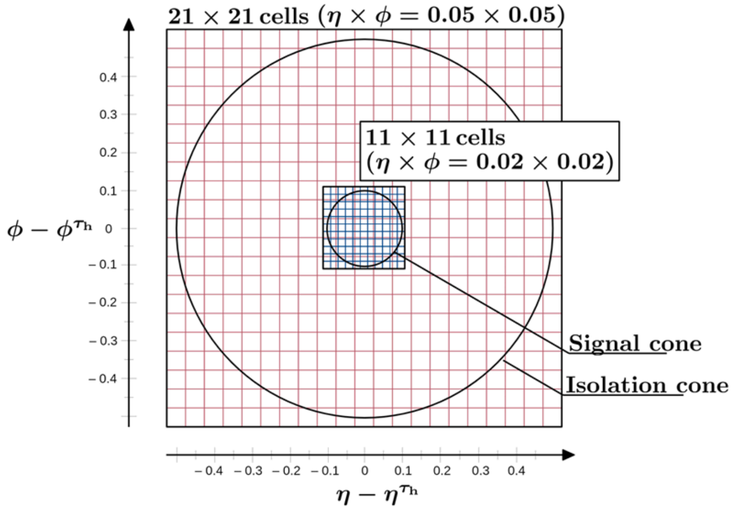


Deep Tau with domain adaptation

CMS-PAS-TAU-24-001

More in Stepan's talk





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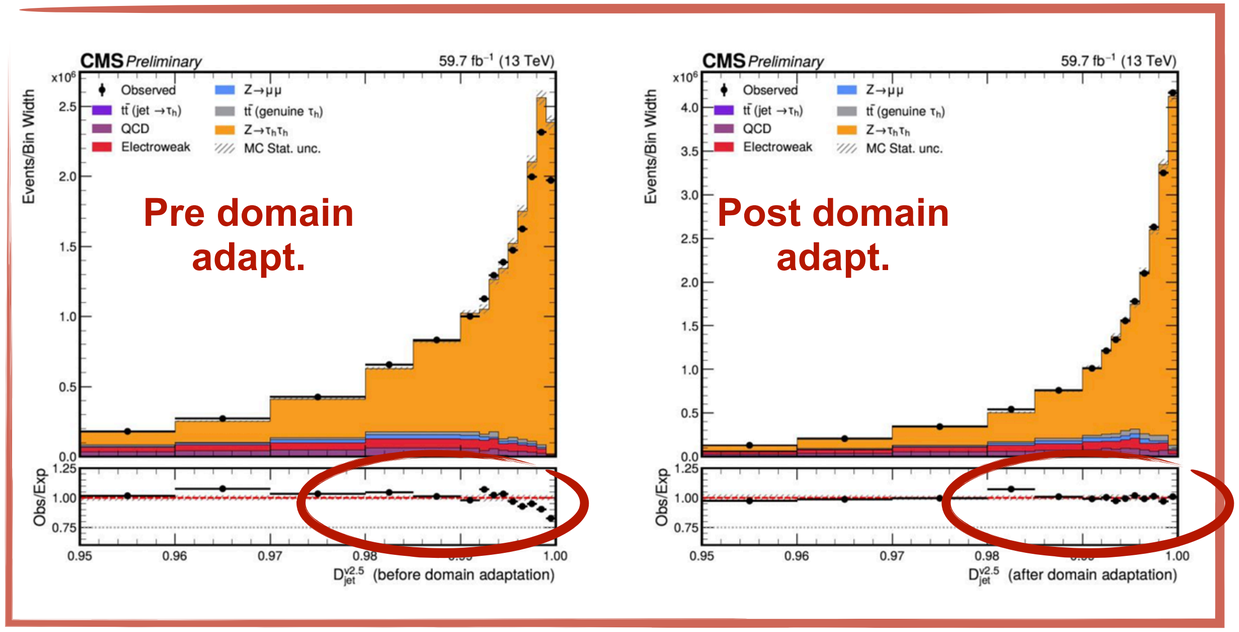
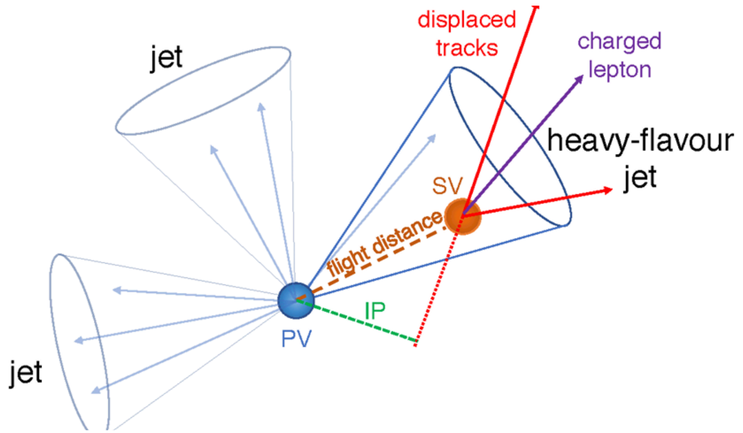


Deeper and neater - jet flavor tagging

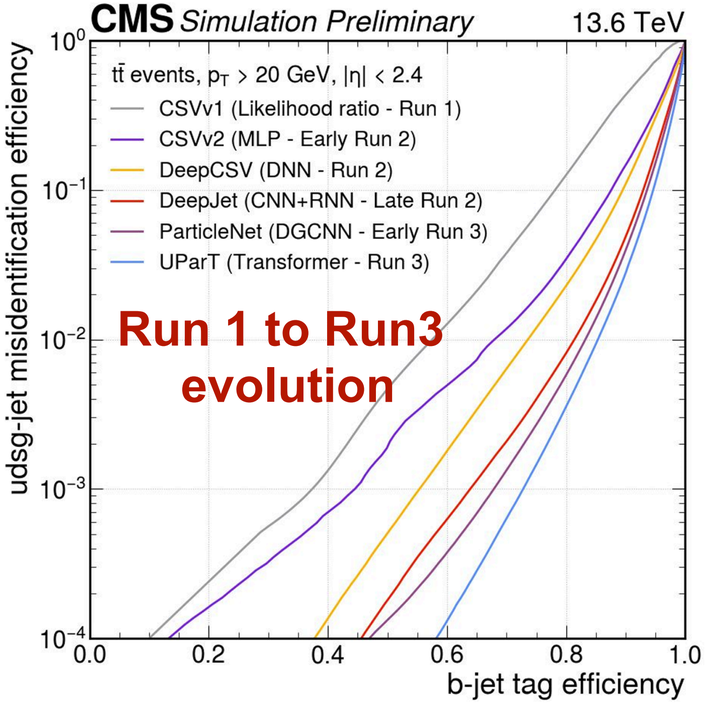
DP2024_066

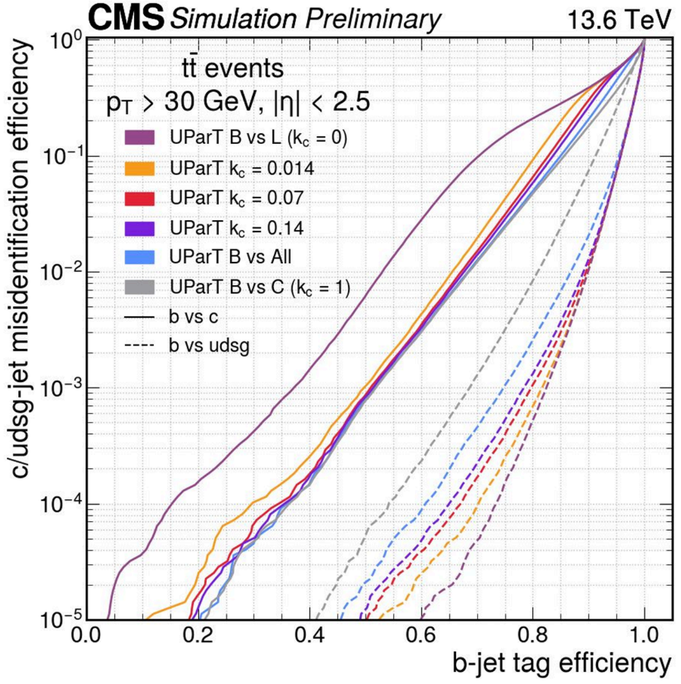


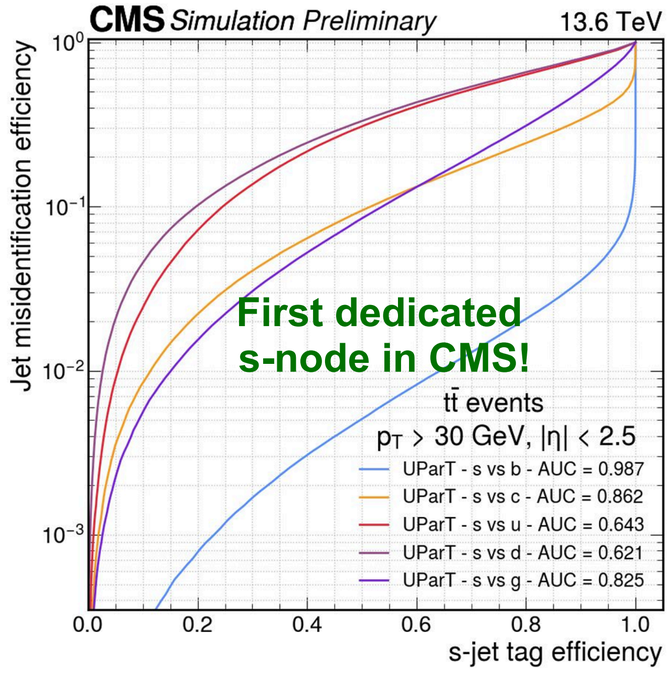
Multiple ML tasks via loss customization

$$L = \underbrace{CatEntropy(x, x_{truth})}_{\text{Classification}} + \underbrace{\gamma_{regr} \cdot log(cosh(y - y_{truth}))}_{\text{Regression}} + \underbrace{\gamma_{quantile} \cdot [p_{0.16}(z - z_{truth}) + p_{0.84}(z - z_{truth})]}_{\text{Quantile regression (resolution estimation)}}$$

UParT: the transformer paradigma





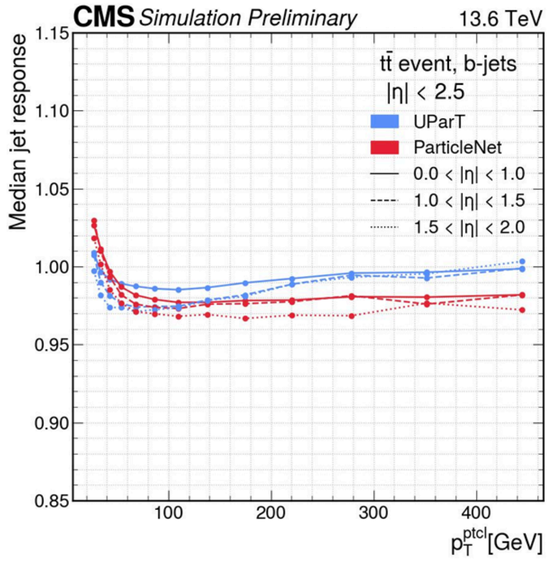


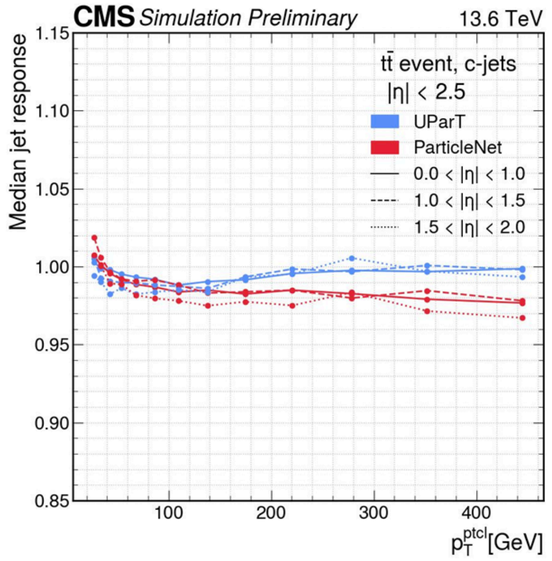
jet constituents x SV pairwise interaction novel info for discrimination

…and the other tasks

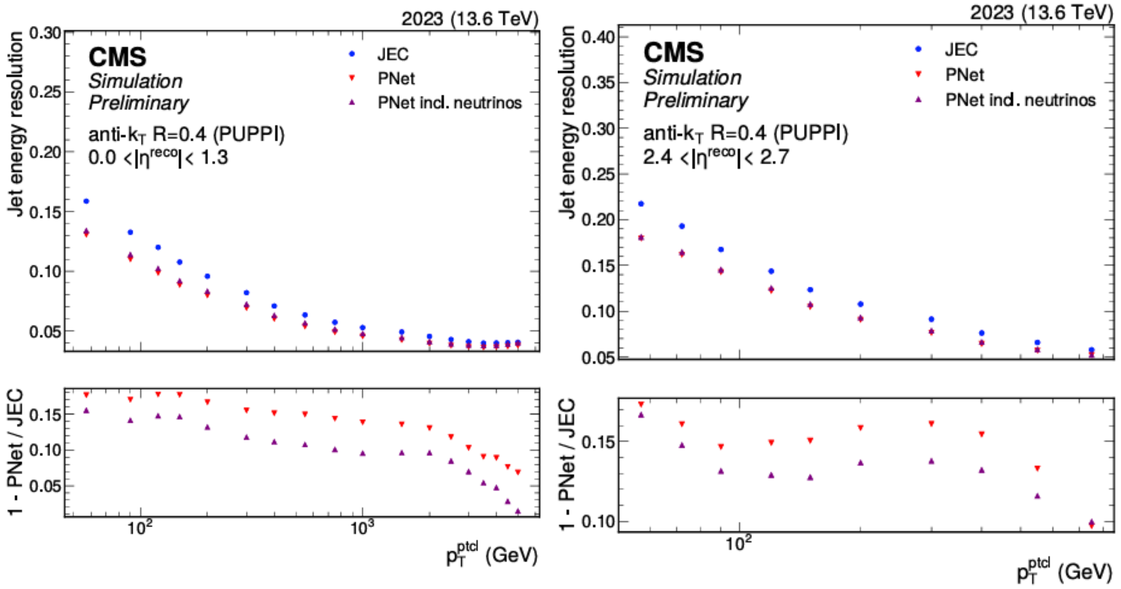
DP2024_066

Jet energy regression





Jet energy resolution



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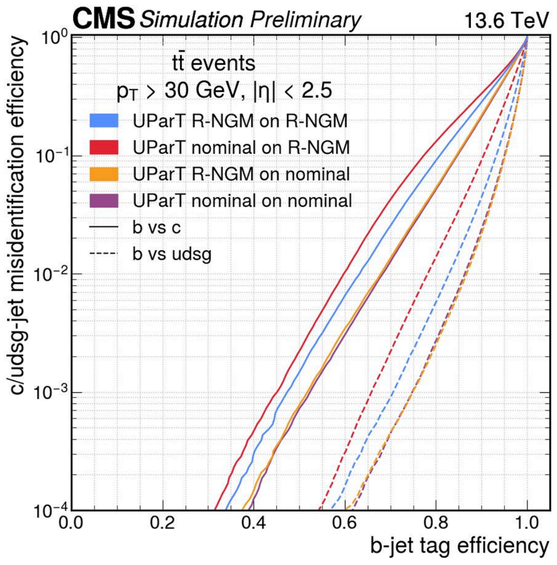
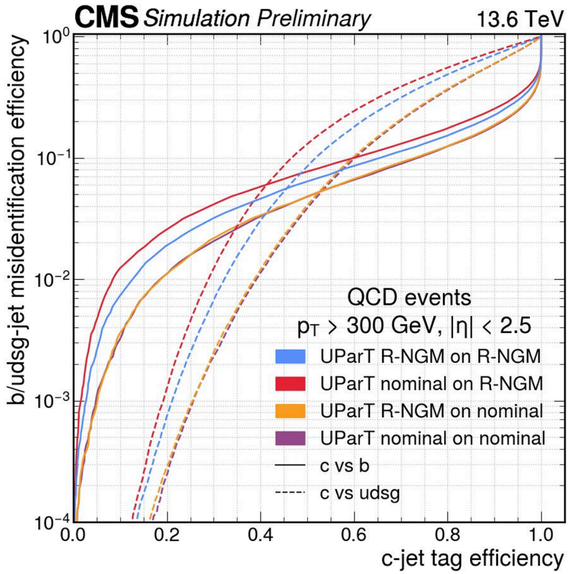
See Donato's talk for more

Enhanced robustness with Rectified Normal Gradient Method





Conclusions

- CMS objects treatment keeps evolving:
  - **Novel** detector conditions
  - **Unprecendented** radiation levels
  - **Unprecedented** data taking conditions
  - **On-edge** ML development to toggle general and topical tasks
- Presented a **not at all exhaustive review** of main techniques and developments
- Run3 problem solving: **bridge towards impressive run conditions for HL-LHC**