Jet energy scale and resolution measurements in CMS

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on behalf of the CMS Collaboration

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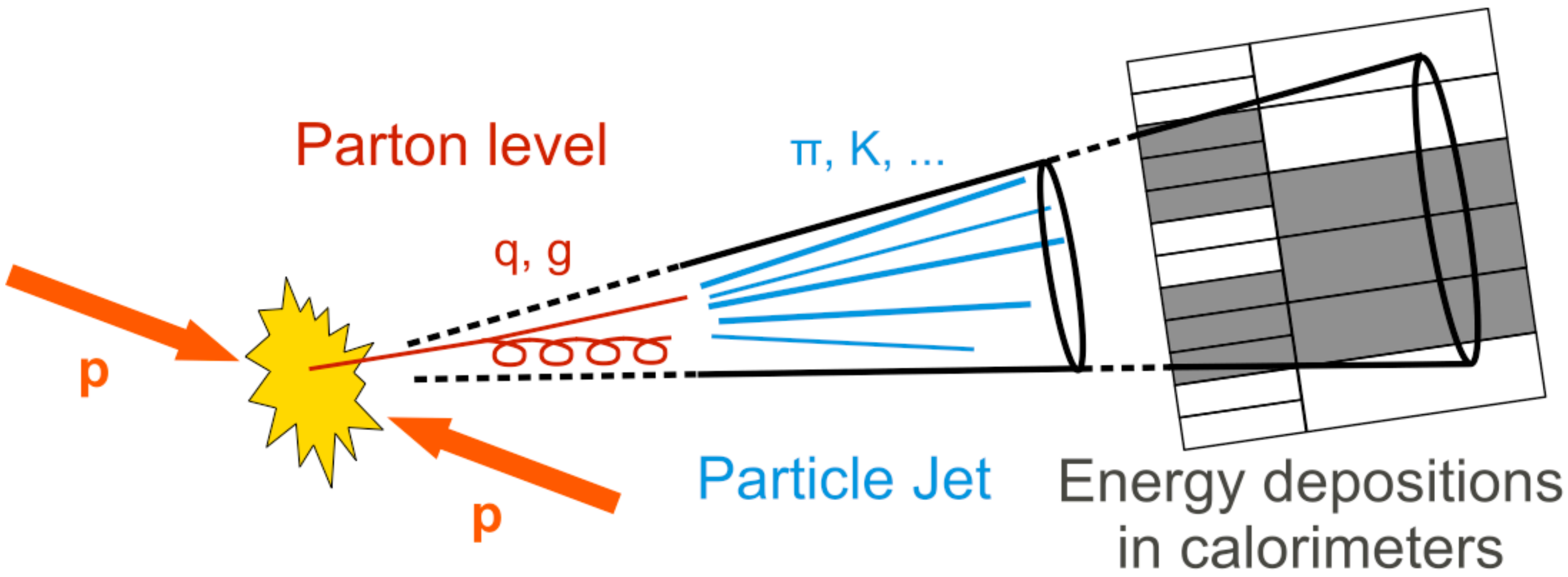
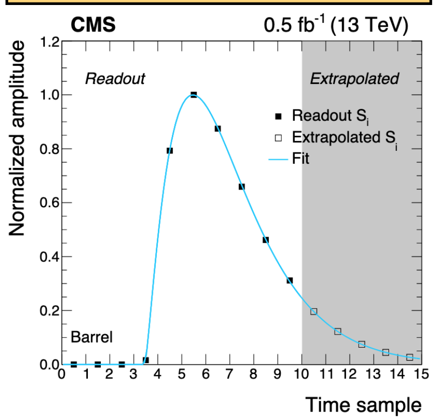
Motivation



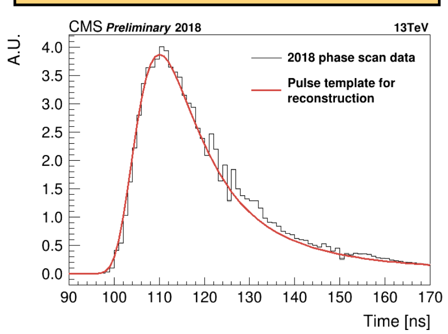
- Jets are the experimental signatures of quarks and gluons produced in pp collisions
- Jet production cross-section is several orders of magnitude higher than that of other processes
- Proper jet calibration is crucial for the majority of SM and BSM analyses and their associated systematic uncertainties e.g. top-mass measurements
- High event pileup (PU) presents a challenge for jet calibration and measurement. PU: Multiple pp collisions in the same (IT-PU) and neighbouring (OOT-PU) bunch crossing. Average of 30 pp interactions per bunch crossing in Run2

Jet reconstruction

ECAL pulse reconstruction

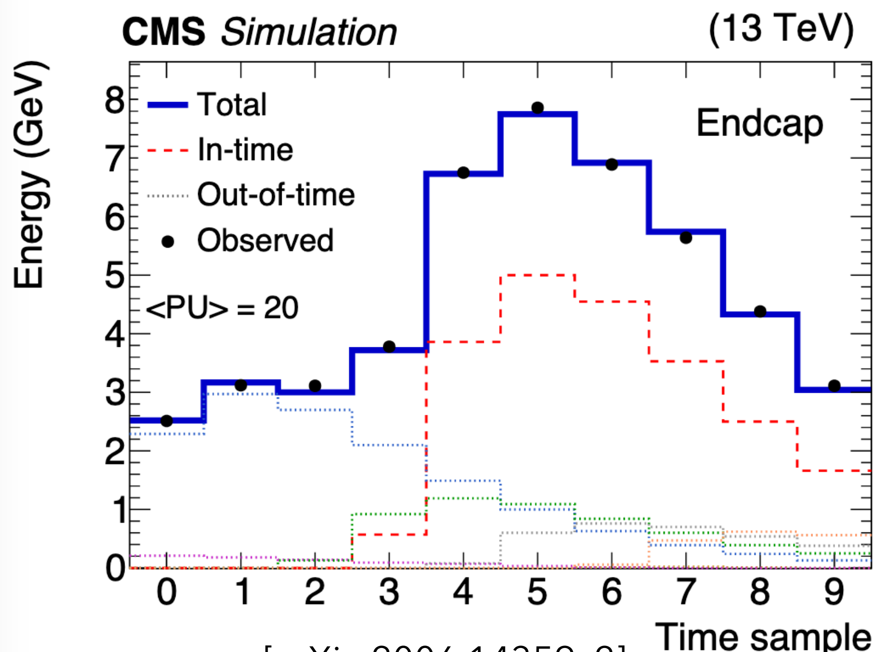


HCAL pulse reconstruction



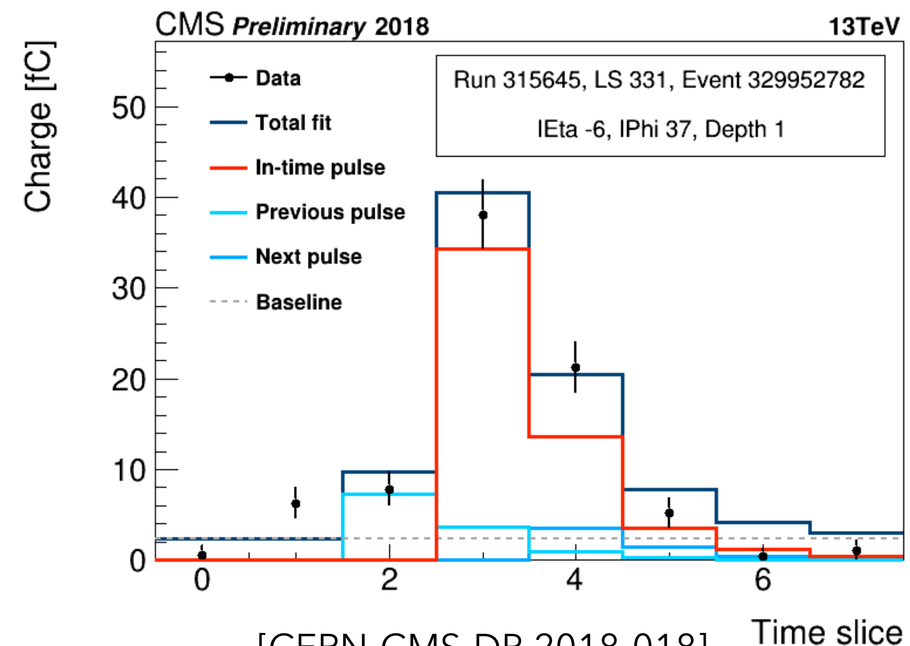
Track reconstruction

ECAL



[arXiv:2006.14359v2]

HCAL

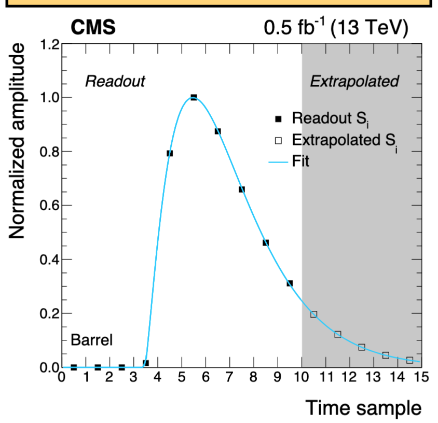


[CERN-CMS-DP-2018-018]

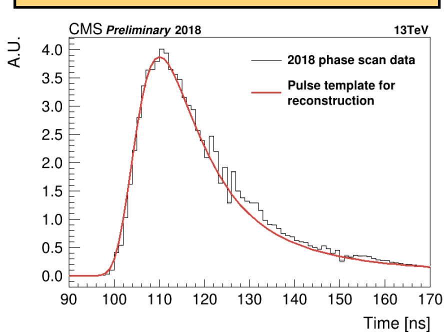
Multiple pulse shapes are fitted simultaneously to subtract OOT-PU.

Jet reconstruction

ECAL pulse reconstruction



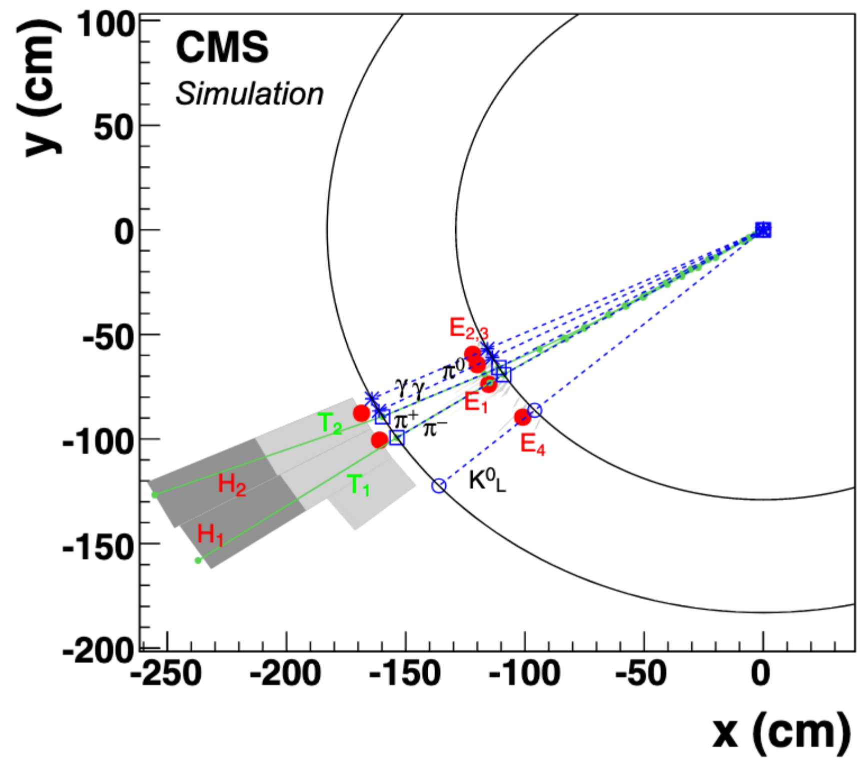
HCAL pulse reconstruction



Track reconstruction

PF cluster reconstruction and calibration

PF linking and global event reconstruction



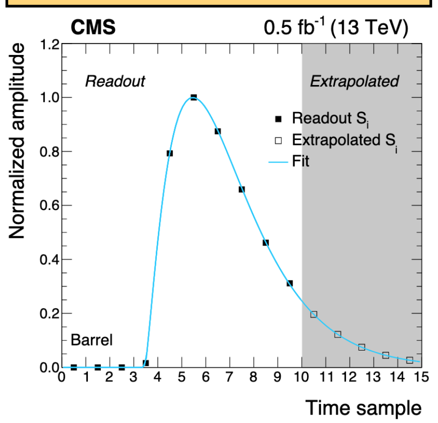
Particle Flow (PF) algorithm provides a global event description by combining information from various sub-detectors.

Identify stable final state particles as: **photons, electrons, neutral hadrons, charged hadrons, muons.**

[arXiv:1706.04965v2]

Jet reconstruction

ECAL pulse reconstruction



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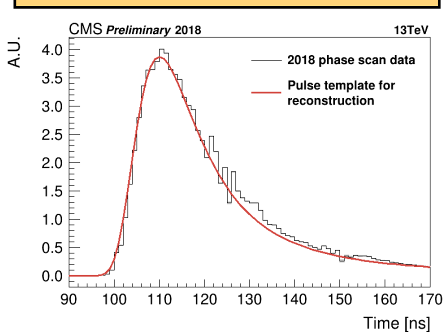

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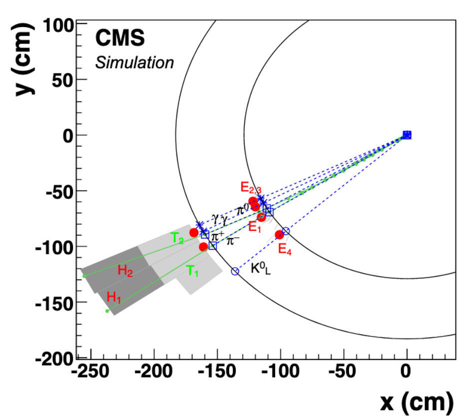


Pileup mitigation

Pileup: Multiple pp collisions in the same and neighbouring bunch crossing. Produces additional unwanted tracks and calorimeter deposits.

Charge Hadron Subtraction (CHS): removes charged particles originating from PU vertices. Drawbacks:

- Only works within tracker coverage i.e. |η| <2.5
- Only removes charged contribution

Pileup Per Particle Identification (PUPPI): uses local shape information to reduce pileup on jet variables by deriving per-particle weights. Weights used to scale 4-momenta before clustering. [arXiv:2003.00503]

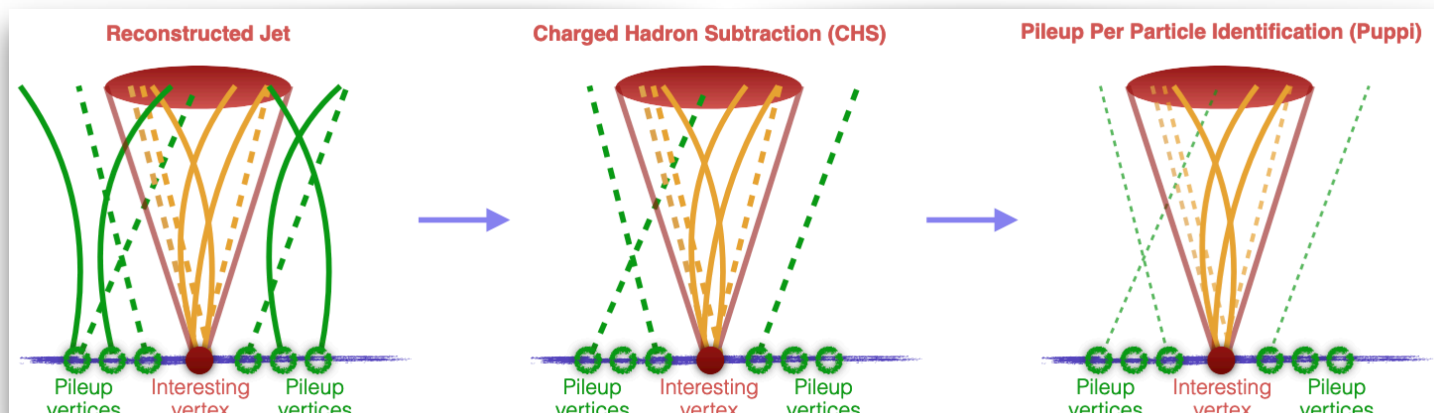
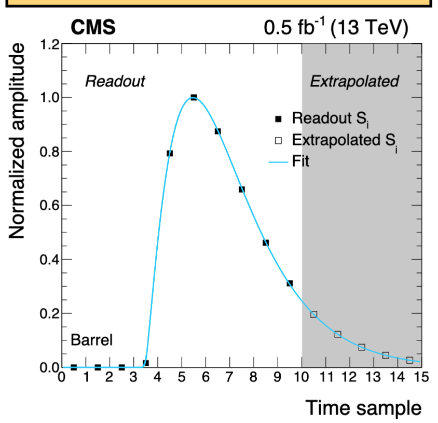


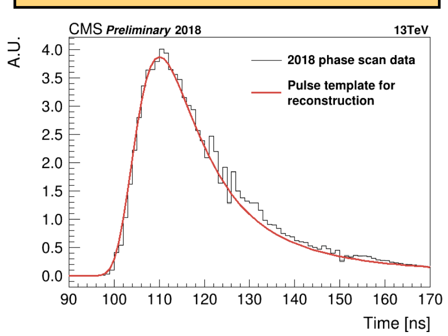
Illustration by A. Malara

Jet reconstruction

ECAL pulse reconstruction



HCAL pulse reconstruction



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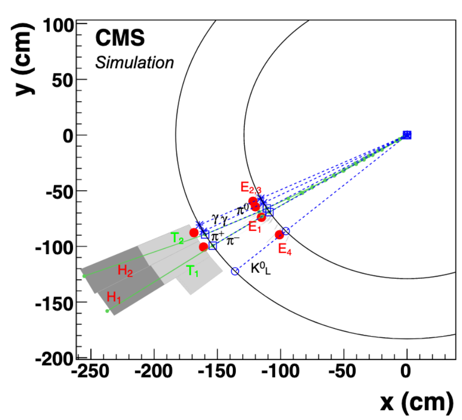


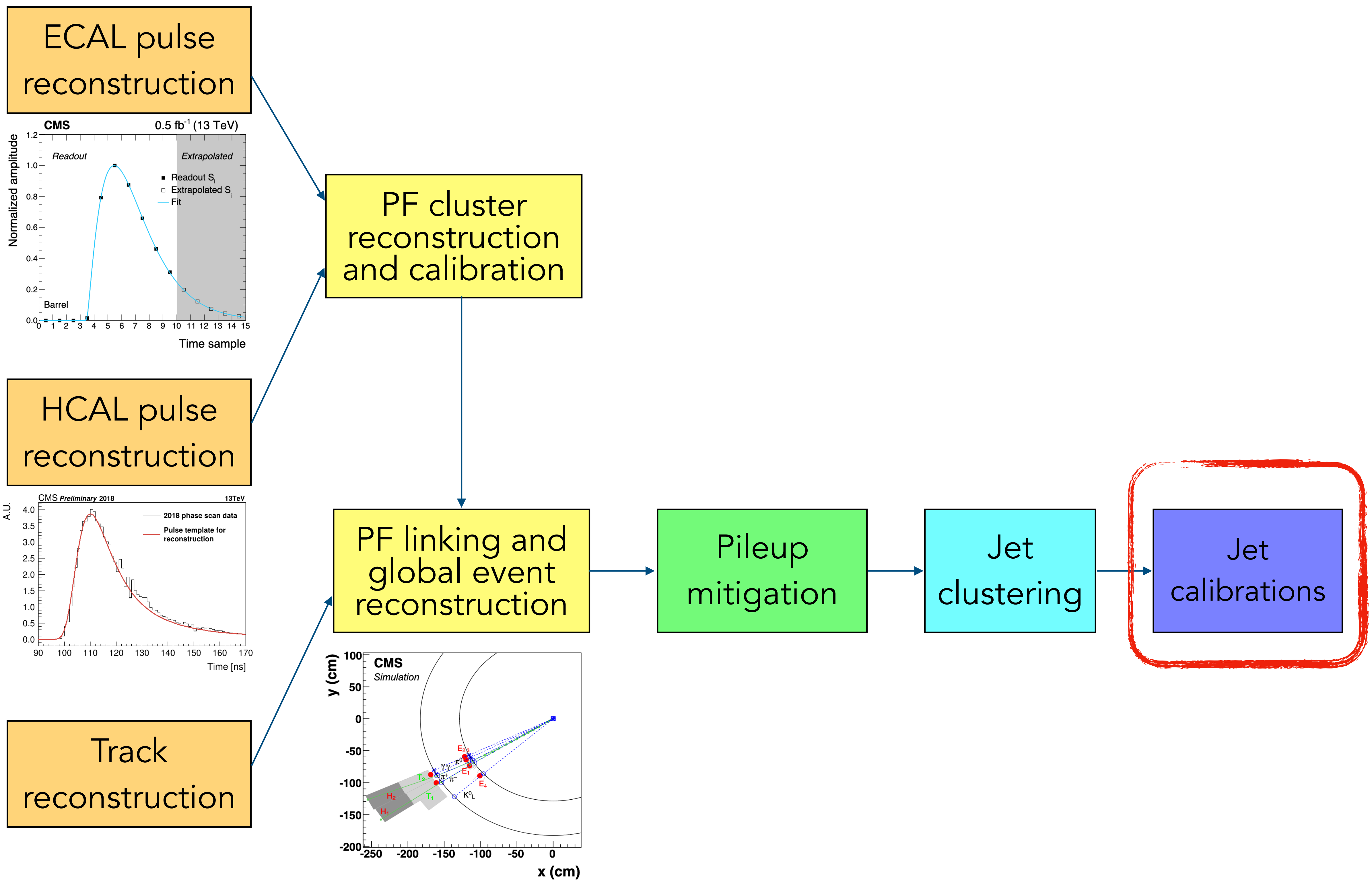
Pileup mitigation

Jet clustering

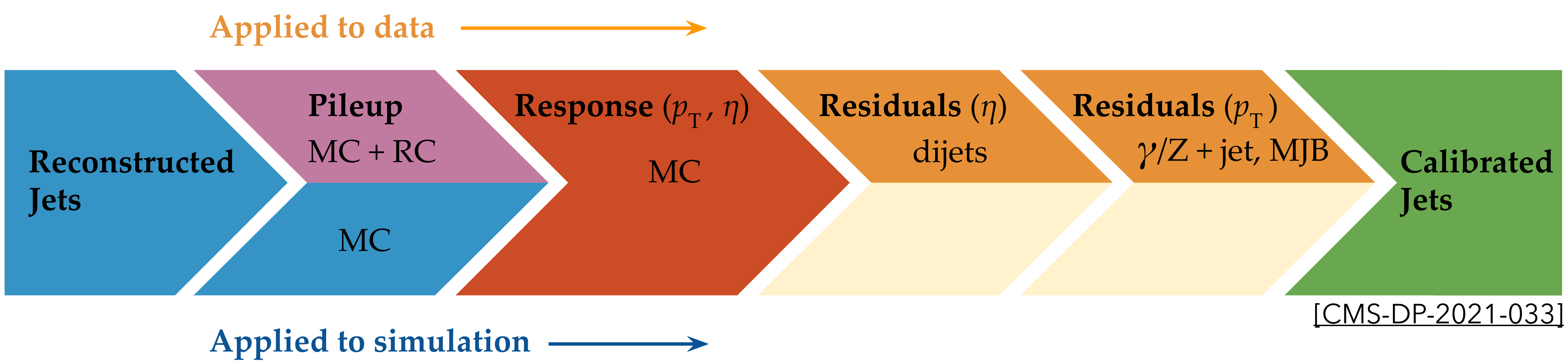
In combination with PU mitigation techniques, we cluster jets using algorithms such as kT, Anti-kT, CA, with distance parameter: 0.4, 0.8, 1.5.

CMS standard for Run2: Anti-kT jets with CHS using distance parameter 0.4 or 0.8

Jet reconstruction



Jet calibration at CMS

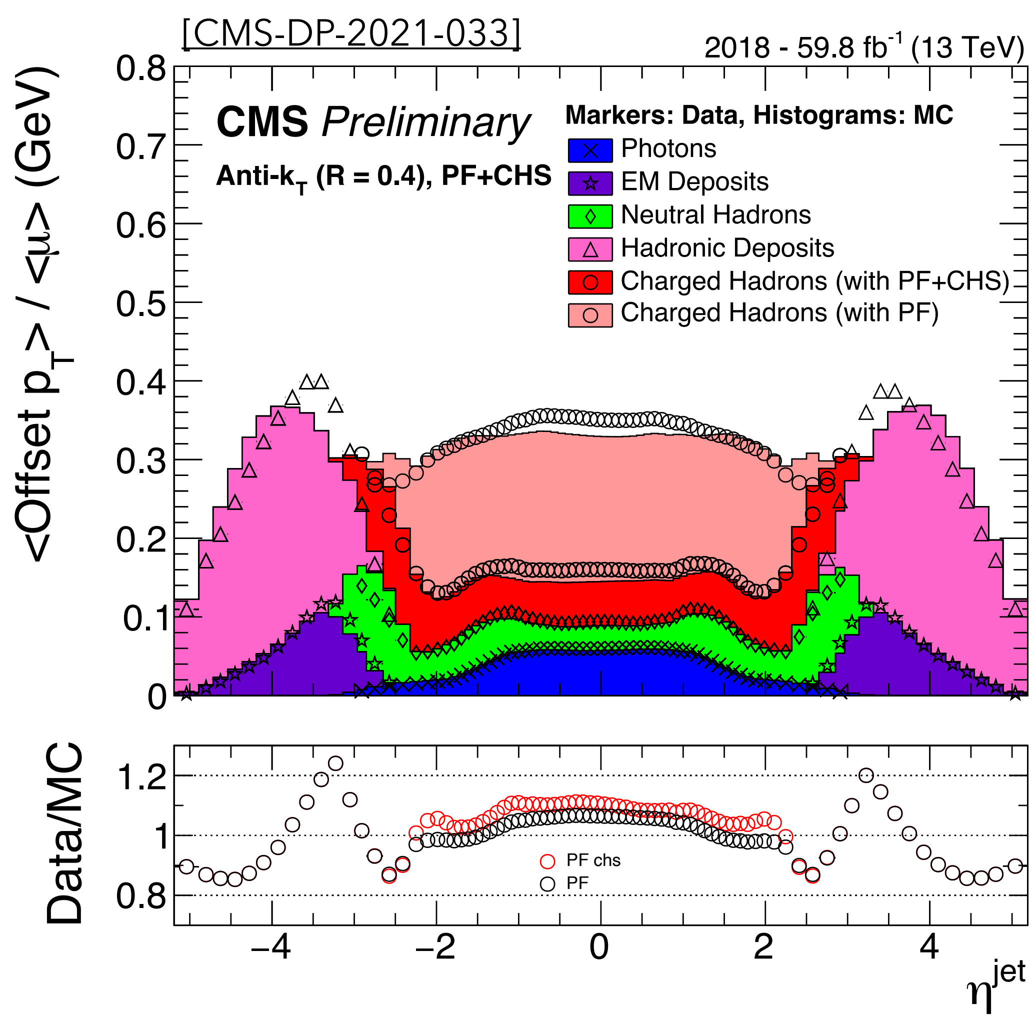


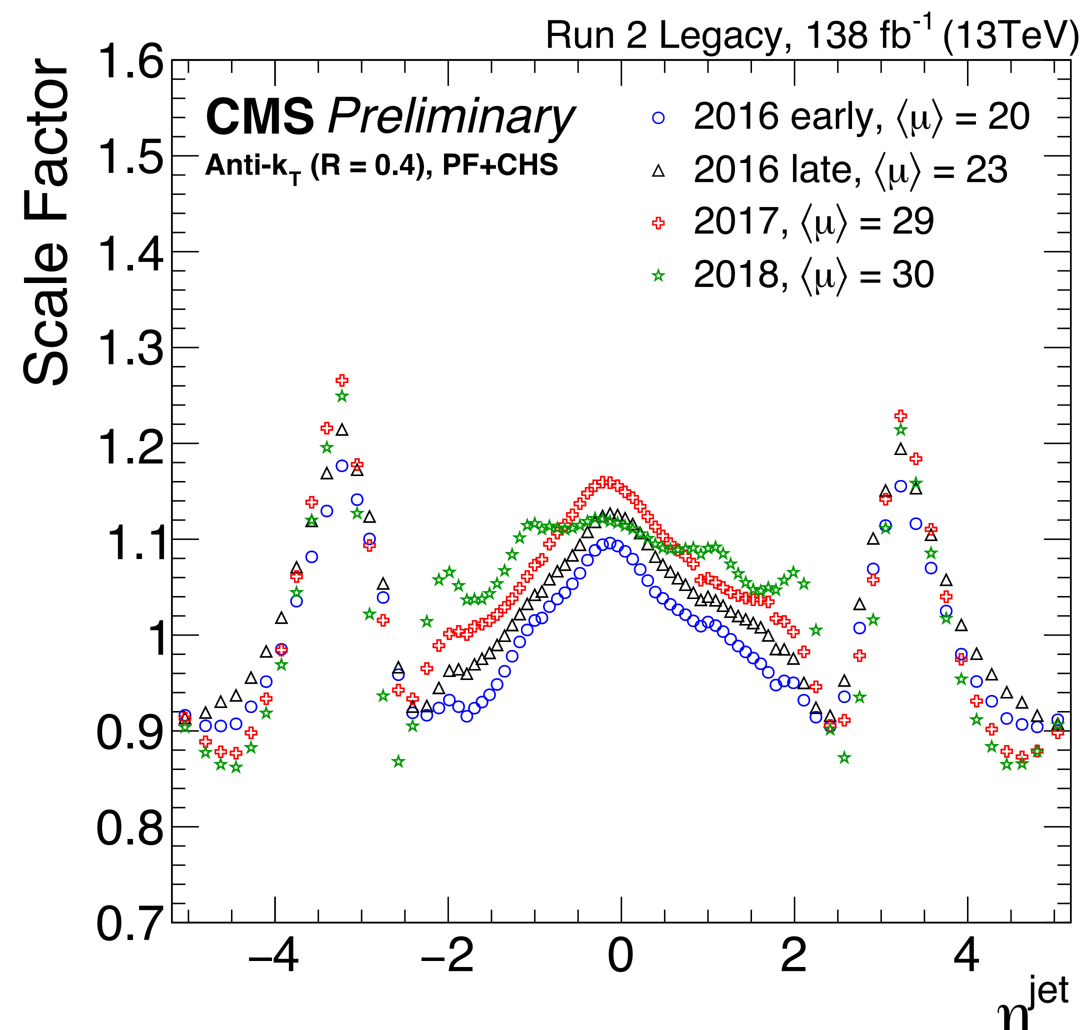
[CMS-DP-2021-033]

- CMS follows a factorised approach to correct the energy of reconstructed jets to match that of the particle-level jet
- Pileup correction in order to account for the energy coming from PU (offset energy)
- MC-truth-based correction to address non-uniformity of detector response in p_T and η
- Small residual corrections to data for pileup, relative (vs. η) and absolute (vs. p_T) scale
- Jet Energy Resolution (JER) measured in MC events vs. jet p_T , jet η and pileup. Data-to-MC scale factors are derived from dijet events

Pileup offset correction

- Pileup offset in simulation - calculated by taking the average difference in p_T between matched jets in simulated samples with and without pileup overlay
- Residual offset correction using data are derived using Random Cone (RC) method
- The data-to-simulation scale factor is estimated from random-triggered events and simulation samples



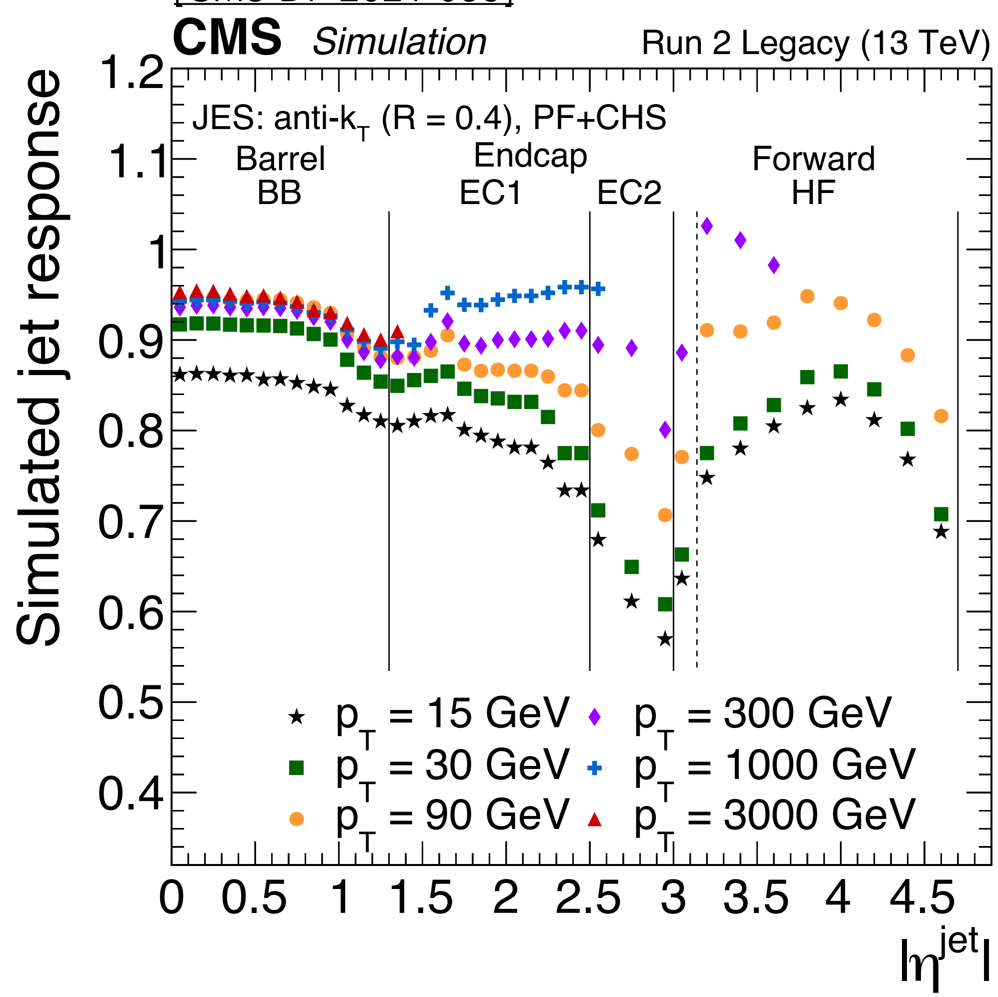


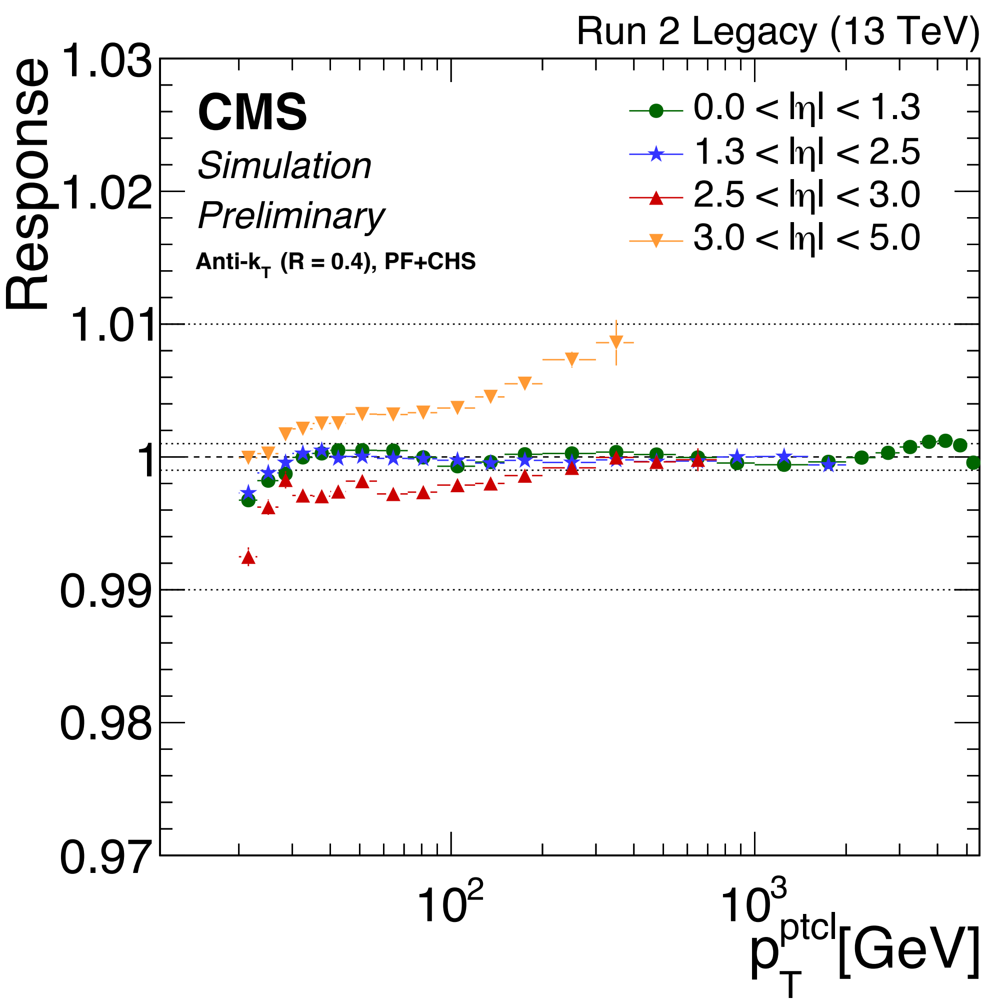
Random cone offset measured in data (markers) and simulation (histograms) (left), data-to-simulation pileup offset scale factors vs. η (right)

Simulated response correction

- Derived from jets that are already corrected for pileup offset, to address the non-uniformity of the detector response as a function of p_T and η of the jet.

[CMS-DP-2021-033]



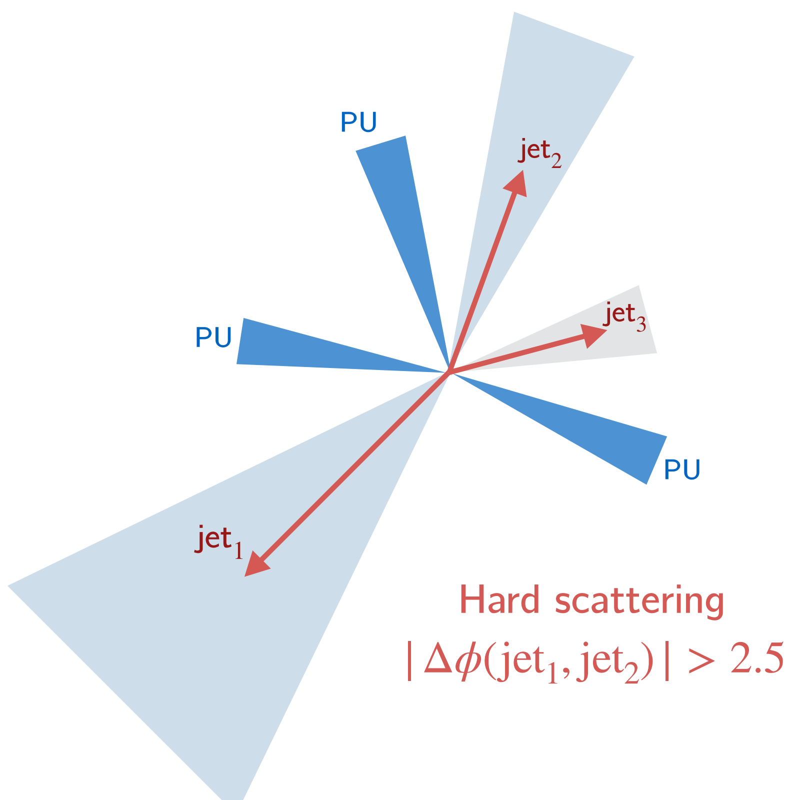


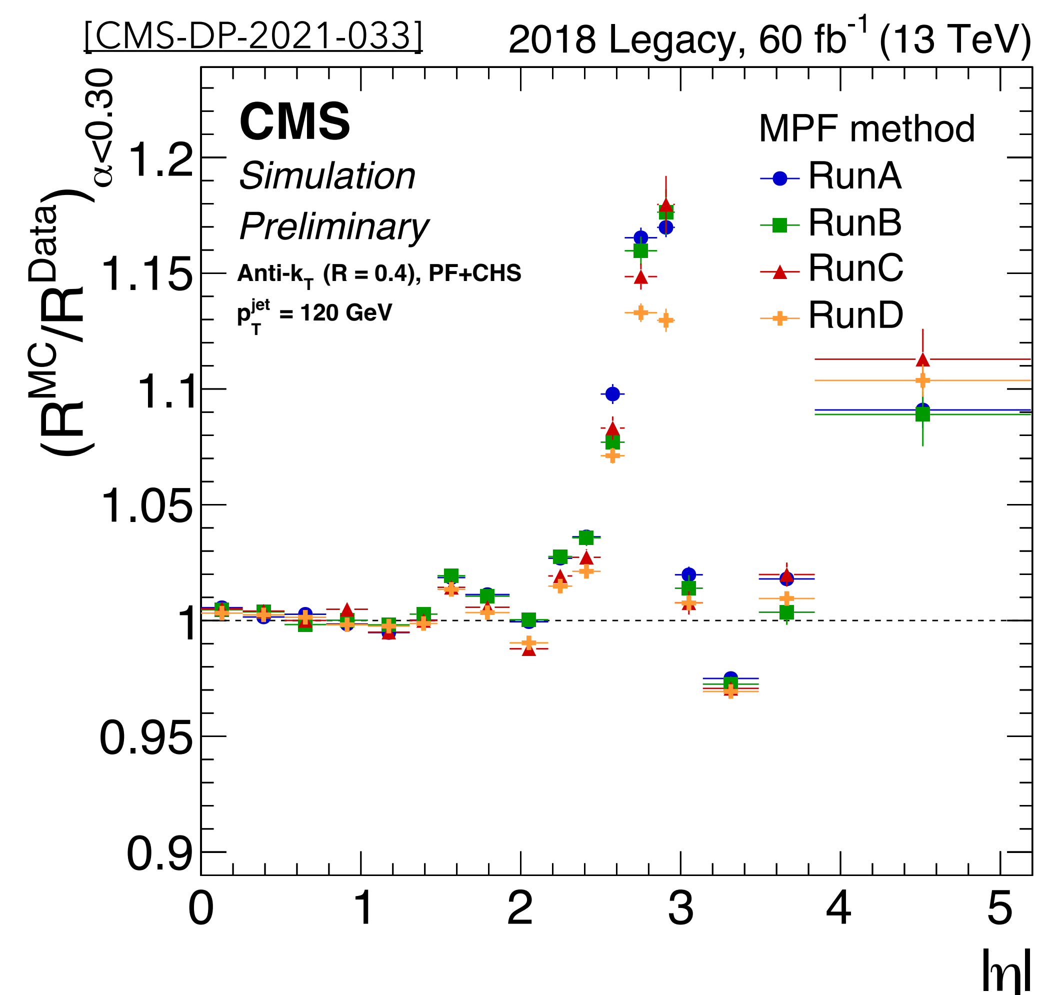
Simulated jet response vs. reconstructed jet |η| (left) and corrected simulated jet response vs. $p_{T,\,ptcl}$ (right), both for PF+CHS jets.

Residual corrections for data

Relative η-dependent corrections

- Residual corrections for data as a function of jet η are determined with dijet events, where the response of jets of any η for a wide range of p_T is corrected relative to one of the jets in the barrel region. The response is derived using the Missing transverse momentum Projection Fraction (MPF) method.





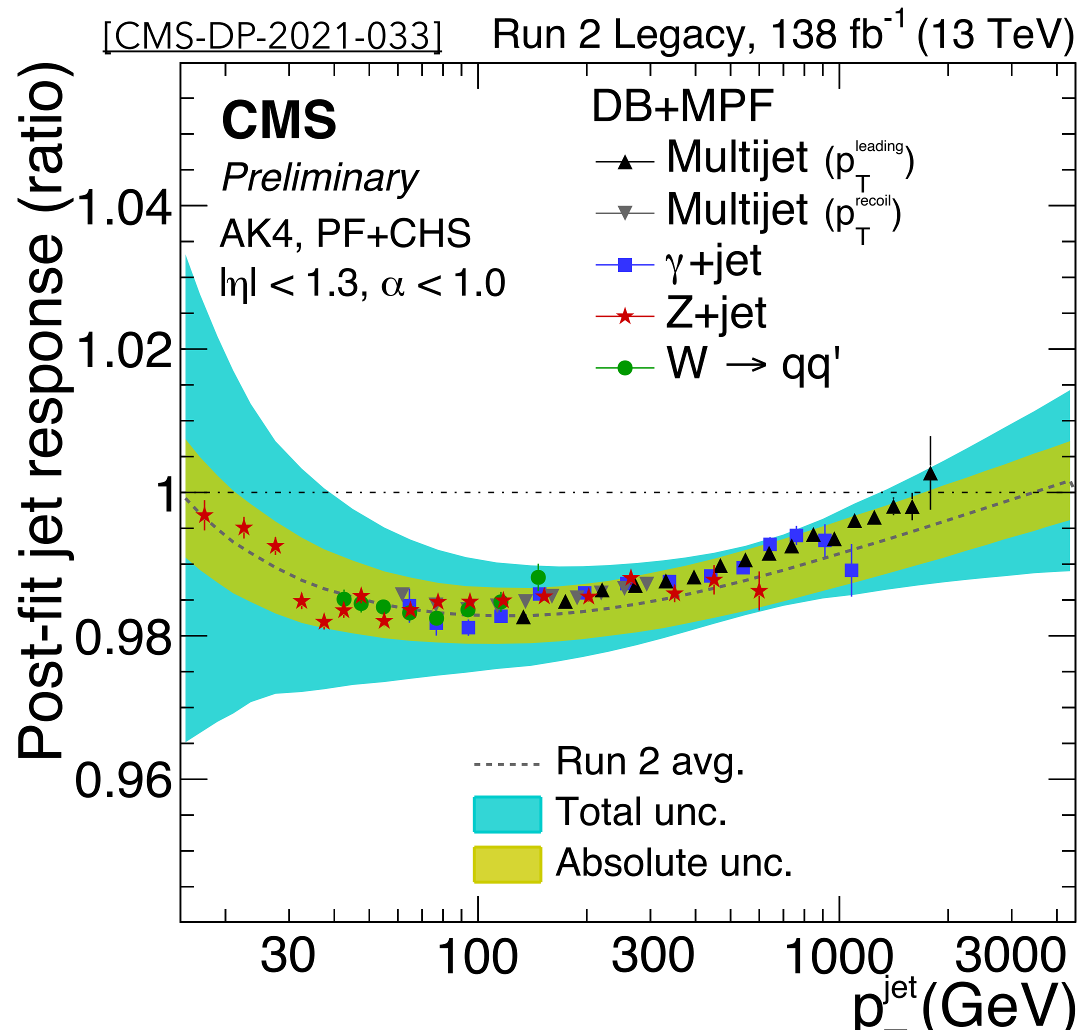
Schematic for p_T balance method (left), k_{FSR} factor as a function of |η| (right)

Residual corrections for data

Absolute p_T-dependent corrections

- Residual corrections for data as a function of jet p_T are determined with Z+jet, γ+jet, W(qq)+jet and multijet events by exploiting the transverse momentum balance between the jet to be calibrated and a reference object that is calibrated precisely.

- The absolute p_T scale is then fitted simultaneously to Z+jet, γ+jet and multijet channels and combining the results from p_T balance and MPF methods.

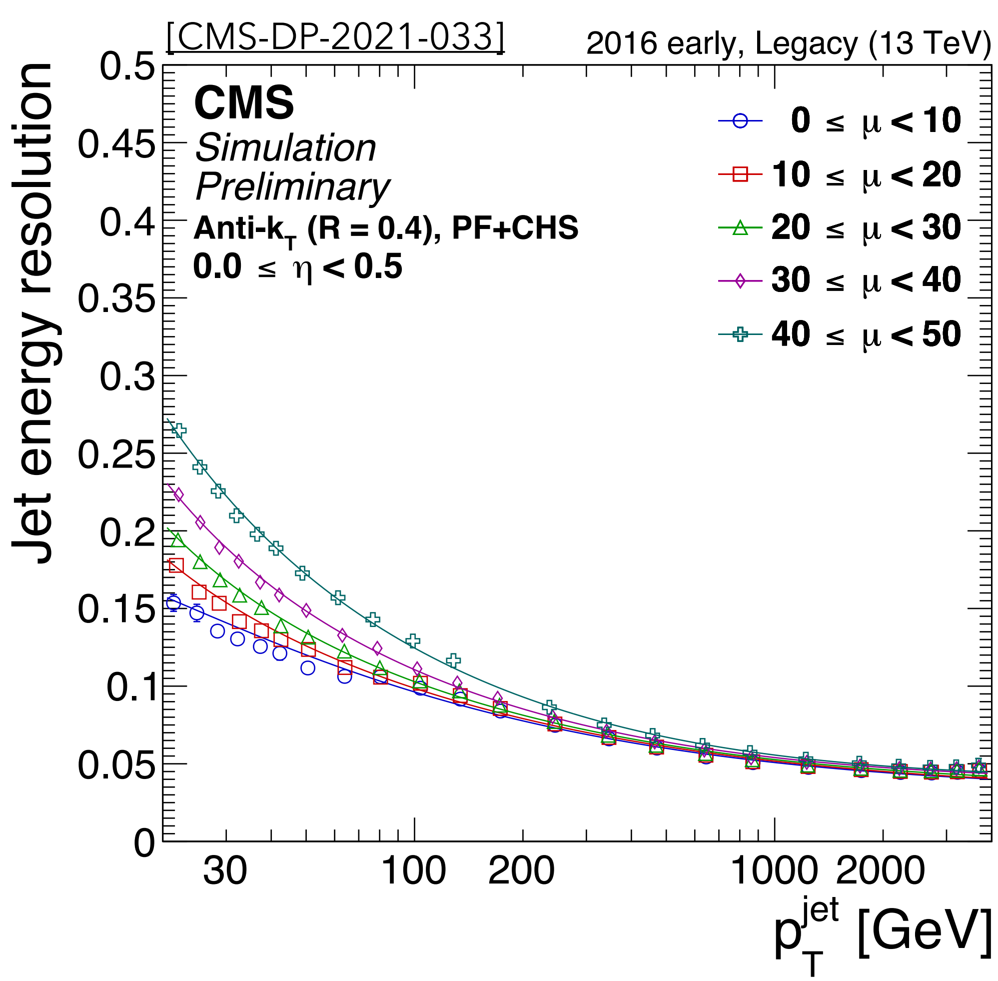


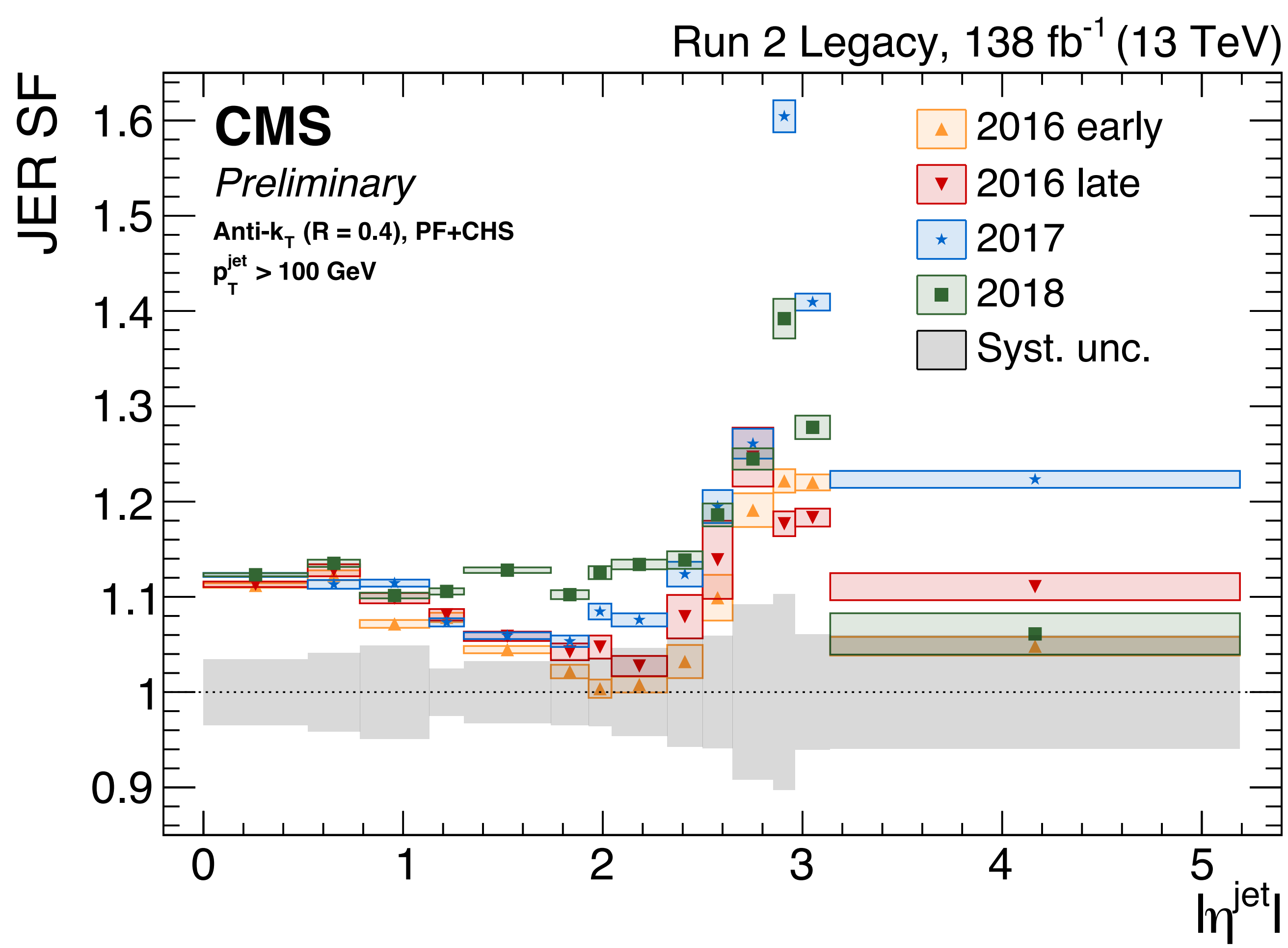
Fit of Absolute scale vs. p_T

Jet momentum resolution

- Particle level momentum resolution is determined using simulation and data-to-simulation scale factors are extracted using data-based methods.

- Jet energy resolution (JER) in simulation is the width of the gaussian fit to the particle-level response ($p_T/p_{T,ptcl}$).

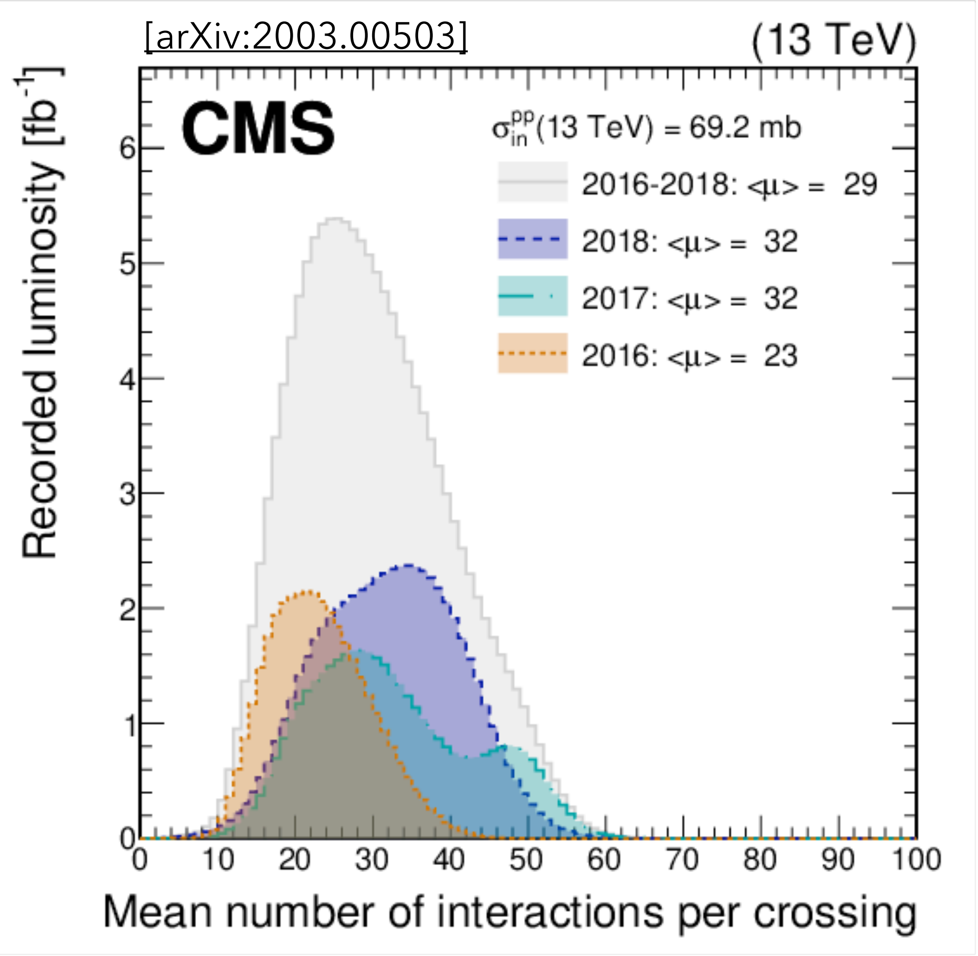


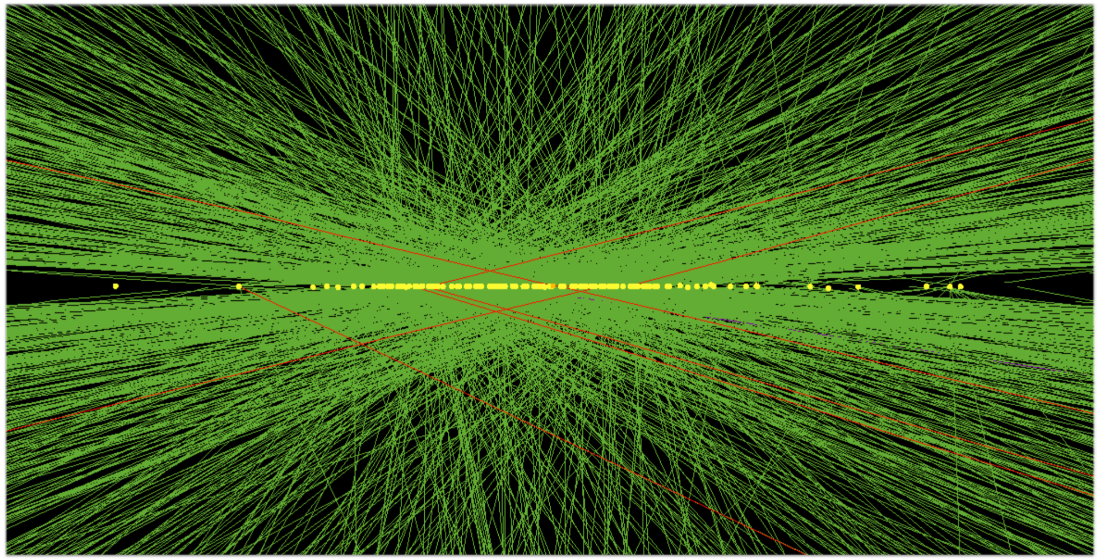


JER vs. p_T in barrel for varying levels of pileup (left), JER scale factors as a function of $|\eta|$ (right)

Outlook

- Using PUPPI as the default PU removal algorithm for Run3 [PUPPI DP Note]
- Higher JES precision by employing new techniques
- Automation of JEC sequence for faster derivation (using columnar analysis tools such as COFFEA)
- PUPPI the only option for Phase2 with PU~200 interactions

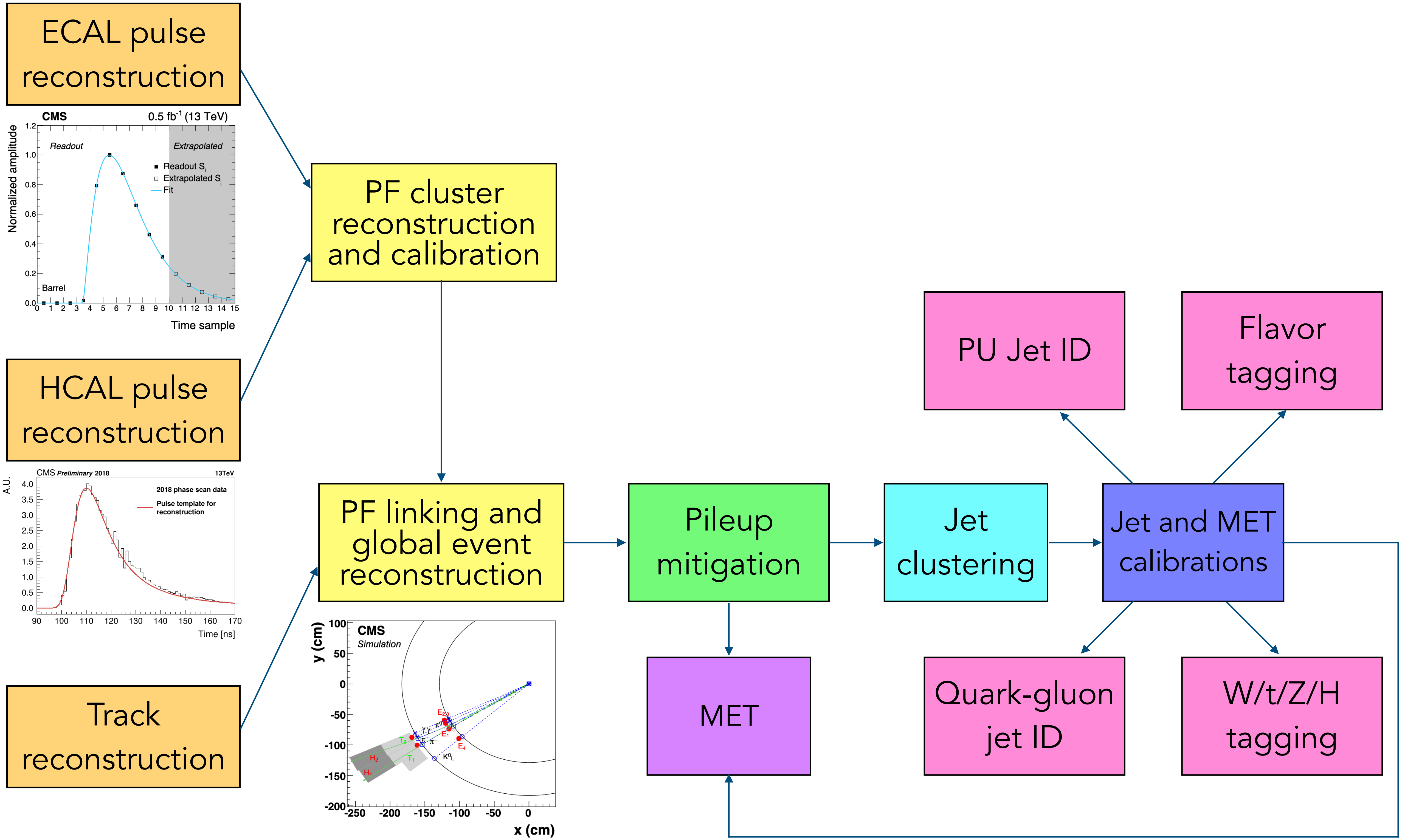




Exiting times ahead!

BACKUP

Jet and MET reconstruction

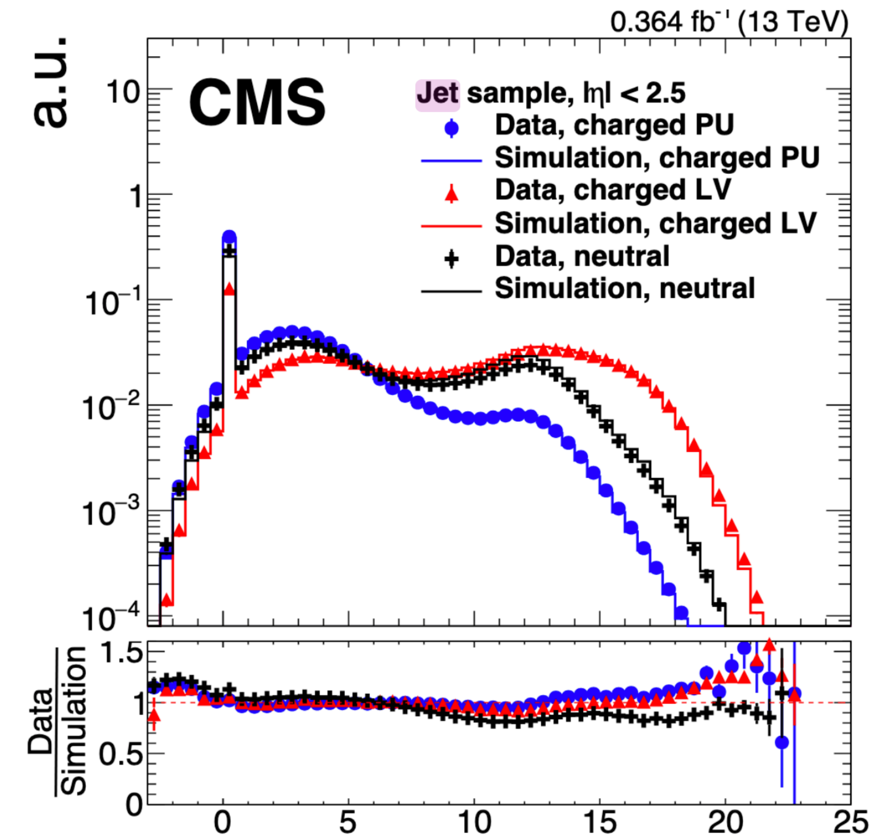


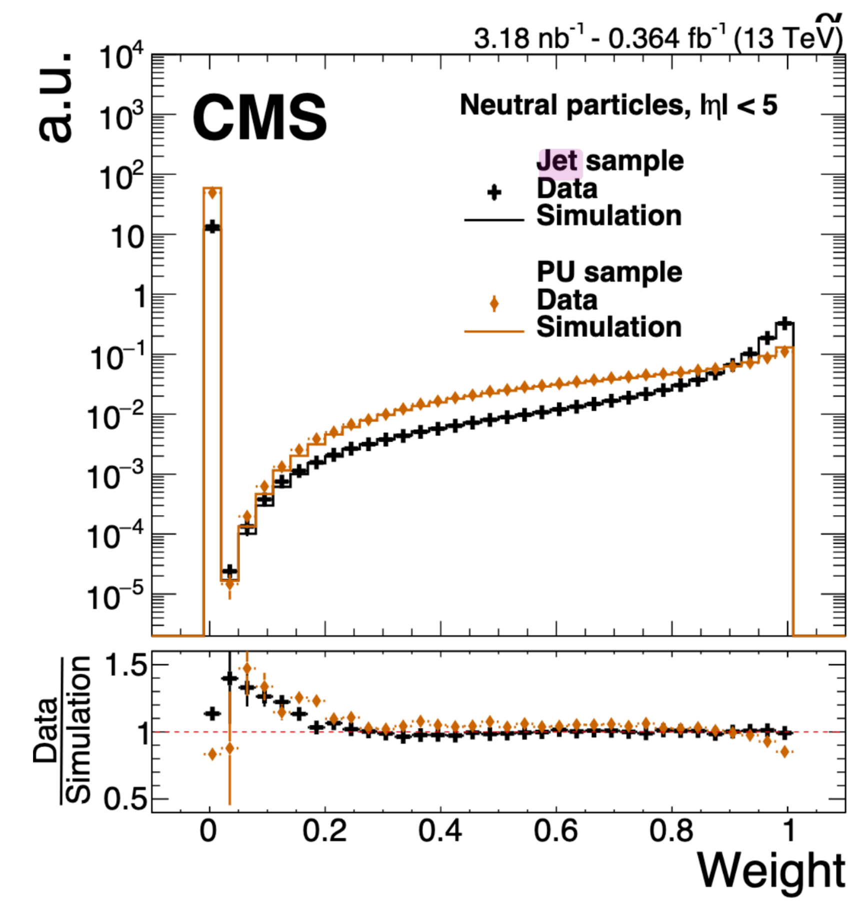
PUPPI

- Uses the information of vertices reconstructed from charged-particle tracks
- For charged particles, the PUPPI weight is assigned based on tracking information
    - Weight for Charged particles associated to LV = 1
    - Weight for Charged particles associated to PU vertex = 0
- Neutral particles assigned weights based on α

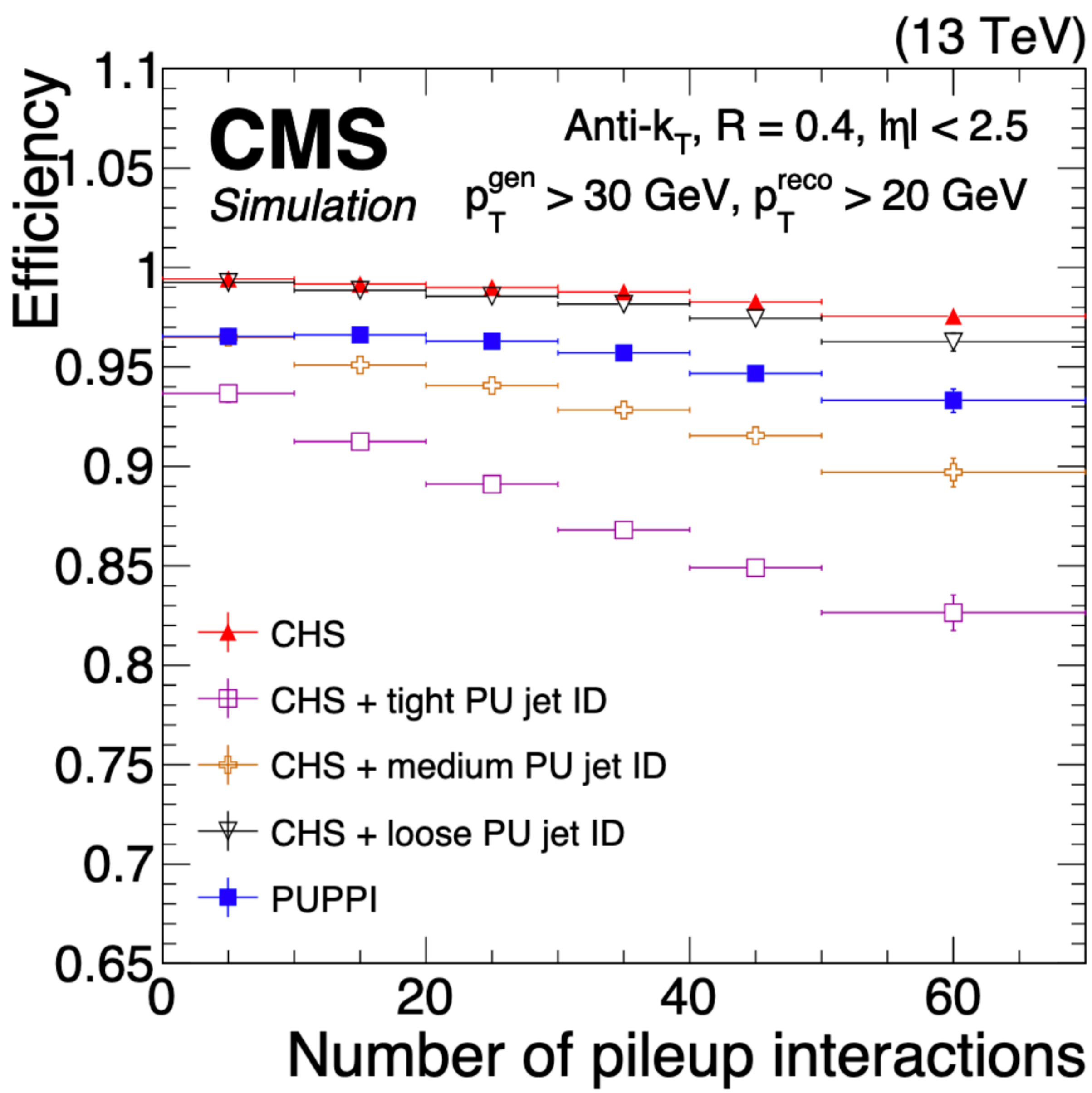
$$\alpha_i = log \sum_{j \neq i, \Delta R_{ij} < R_0} \left(\frac{p_{T,j}}{\Delta R_{ij}} \right)^2$$

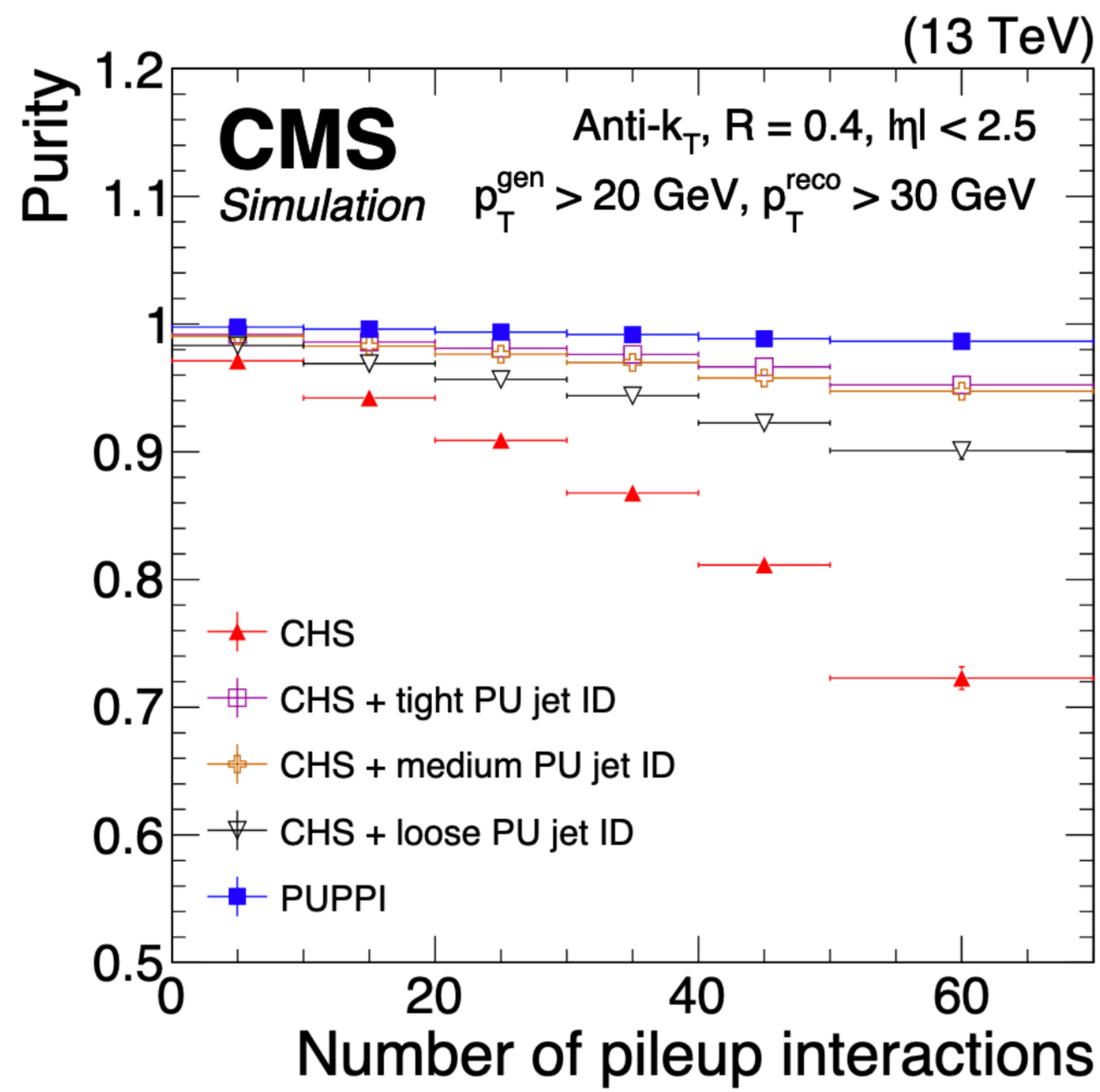
In |η| < 2.5, where tracking information is available, only charged particles associated with the LV are included as particle j, whereas all particles with |η| > 2.5 are included.





CHS vs PUPPI

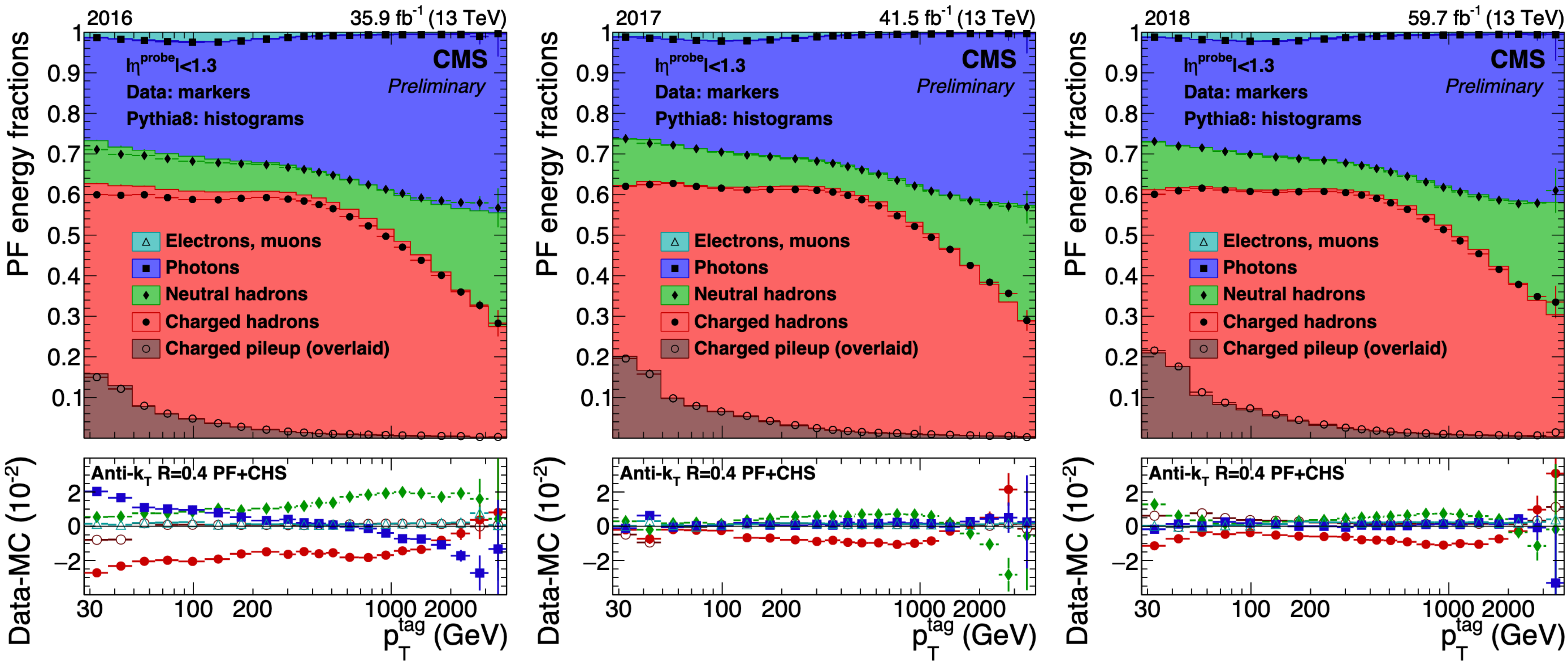




- PUPPI has a good performance in both efficiency and purity
- CHS efficiency is nearly close to 100% but purity impacted at high PU scenarios
- PUPPI performs better than CHS at high η

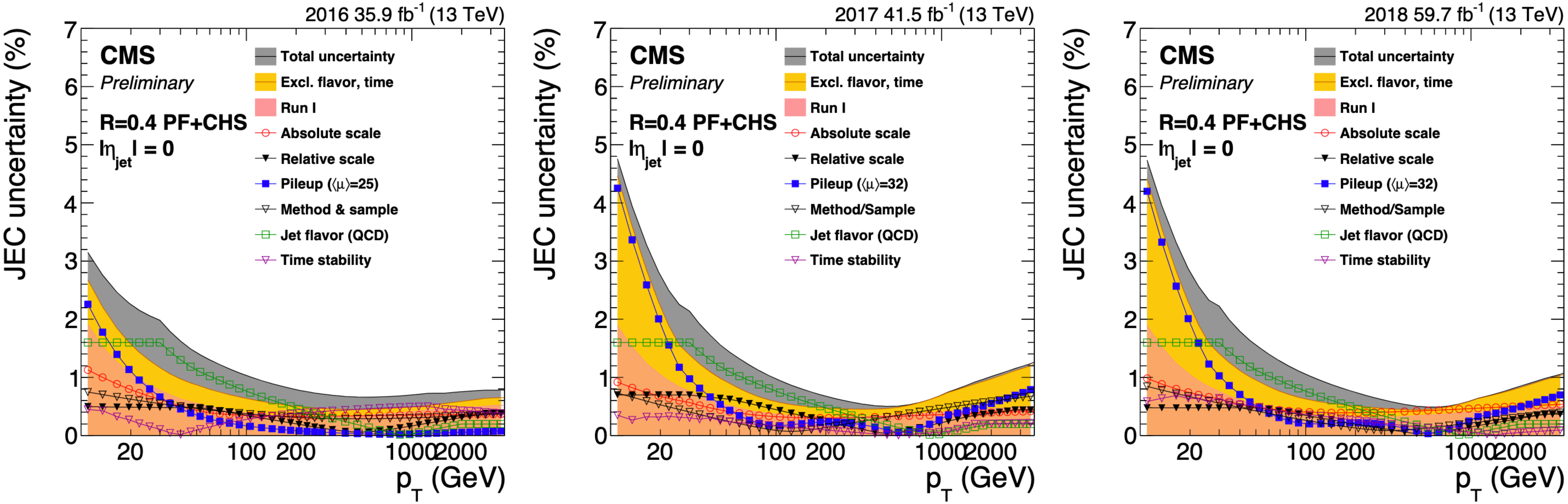
Jet PF composition

EOY plots – will be updated for Legacy Run2 in the upcoming JERC paper



JES Uncertainties

EOY plots – will be updated for Legacy Run2 in the upcoming JERC paper



- JES uncertainty sources and total uncertainty (quadratic sum of individual uncertainties)