Jet reconstruction and calibration in CMS during Run 2

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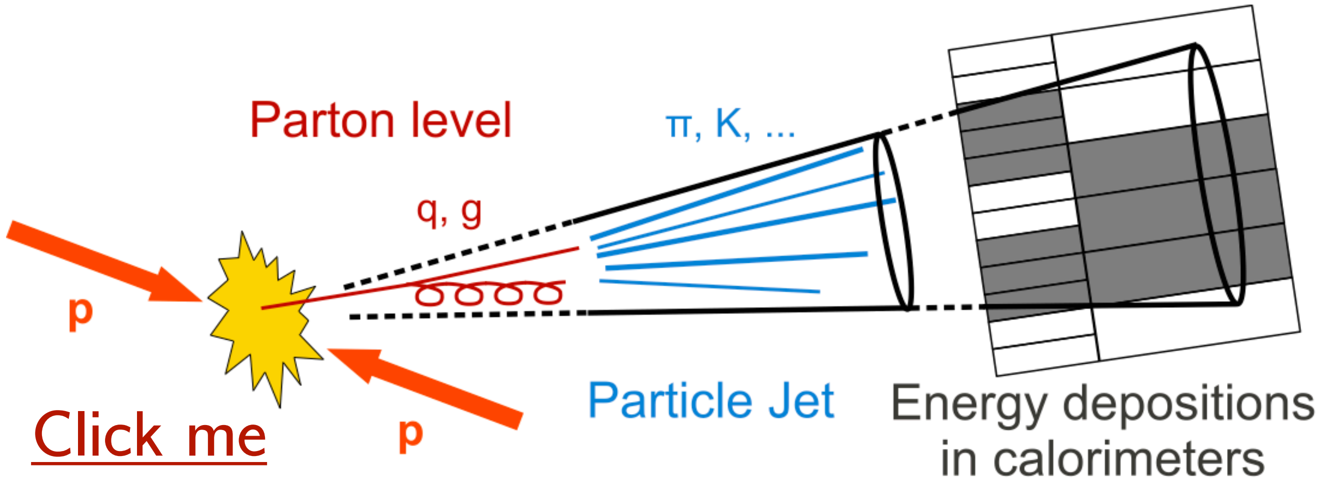
CMS
Compact Muon Solenoid

Jets

- Abundance of quarks and gluons in pp collisions
- Jets used in (almost) all SM and BSM analyses
- Need for precise reconstruction and calibration
- Challenging environment with average pileup of ~ 30 interactions



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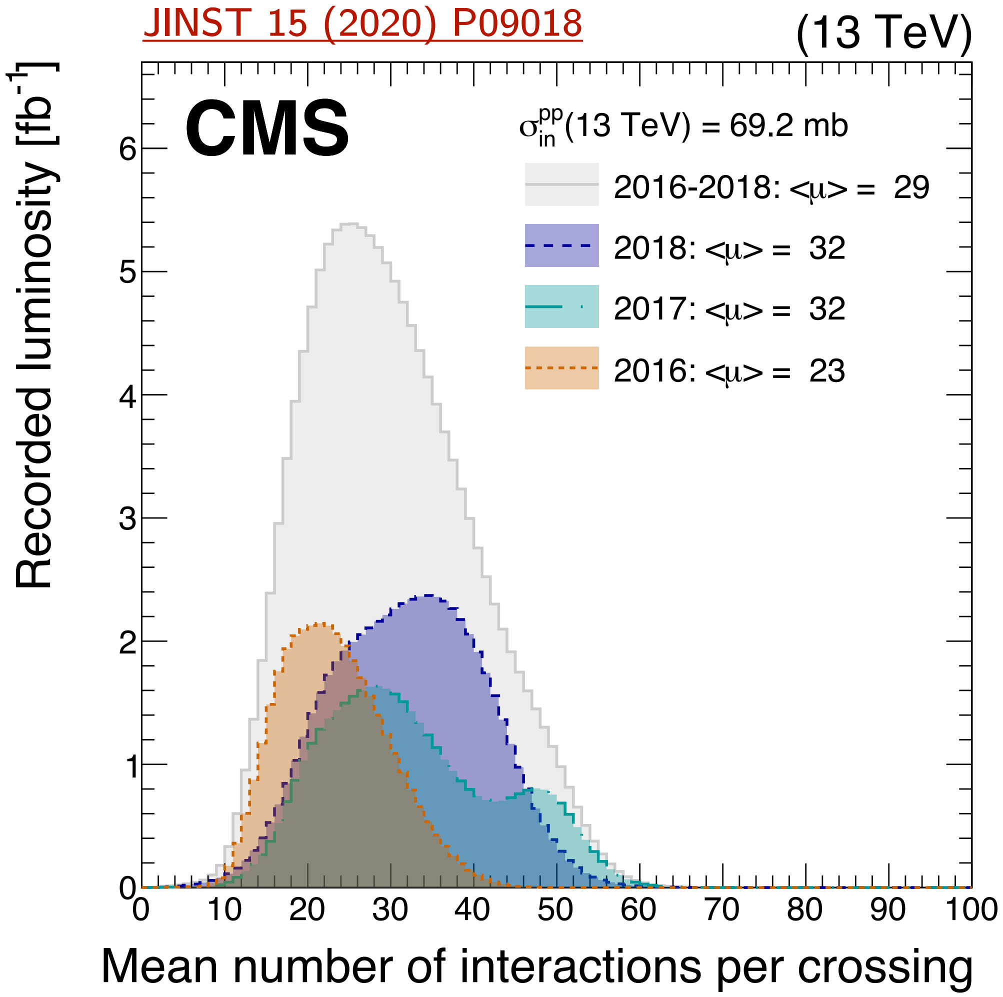

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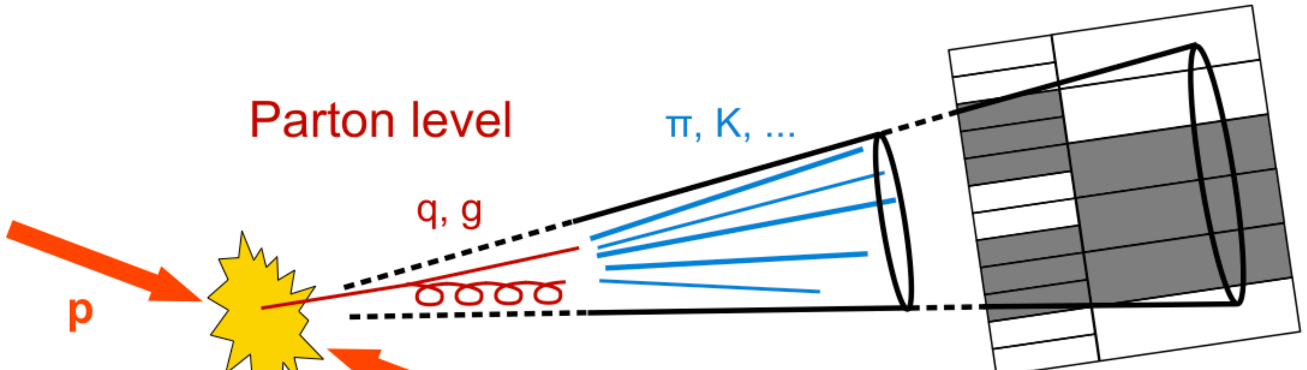
- Need for precise reconstruction and calibration
- Challenging environment with average pileup of ~ 30 interactions
- Run 3 around the corner, presenting a number of challenges



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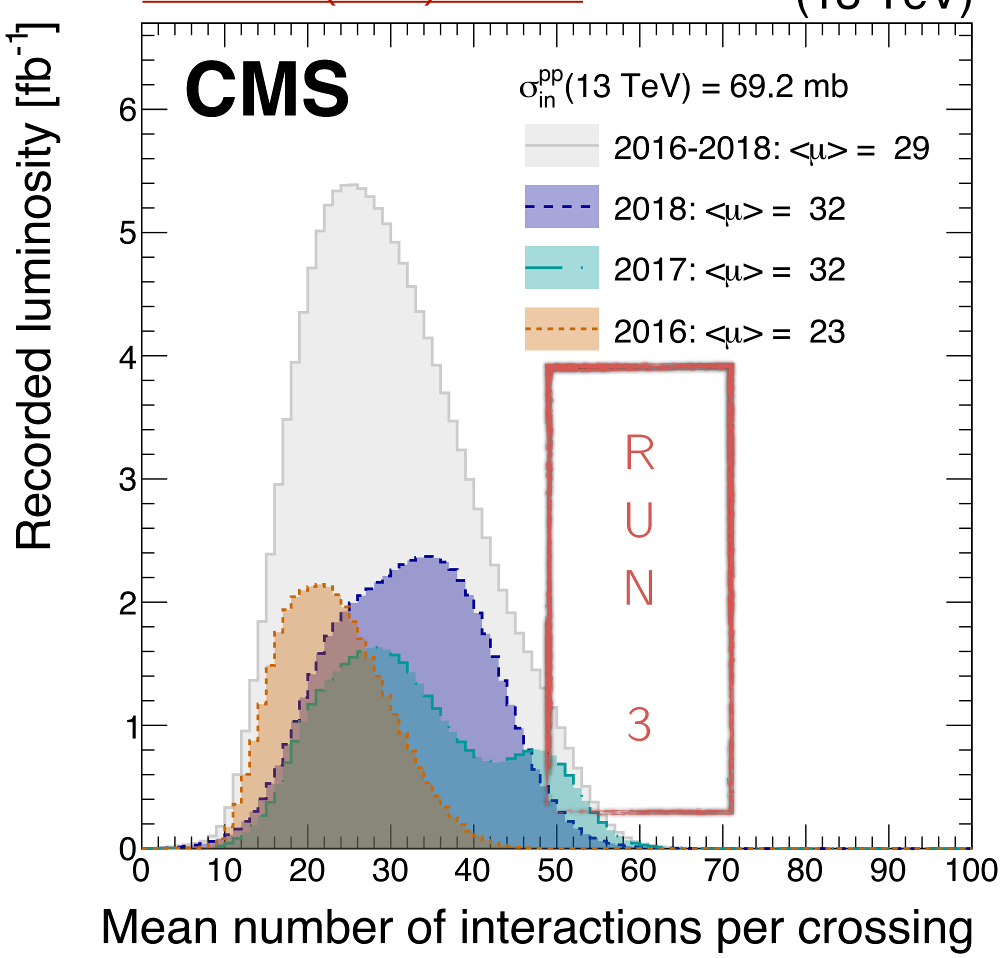

Building jets

Local reconstruction:
Tracks, ECAL, HCAL

→

- Information from sub-detectors
- Fast in order to cope with PU

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Pileup mitigation

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- CHS
- Puppi

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Pileup mitigation →
- CHS
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Jet clustering →
- Algorithms (AK, CA)
- Cone radii (0.4, 0.8, 1.5)

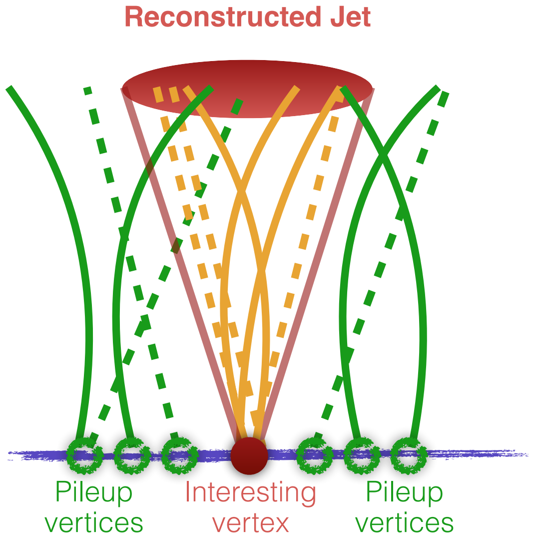
Building jets

Step	Details
Local reconstruction: Tracks, ECAL, HCAL	▶ Information from sub-detectors ▶ Fast in order to cope with PU
Particle flow (PF)	▶ Linking of sub-detectors ▶ Particle identification
Pileup mitigation	▶ CHS ▶ Puppi
Jet clustering	▶ Algorithms (AK, CA) ▶ Cone radii (0.4, 0.8, 1.5)
Jet calibration	▶ Jet energy scale & resolution ▶ Jet mass resolution

Pileup mitigation techniques

Pileup

- Multiple interactions during a bunch crossing
- Additional particles deteriorate measurements
- Major challenge in LHC physics
- Several approaches to cope with up to 200 interactions



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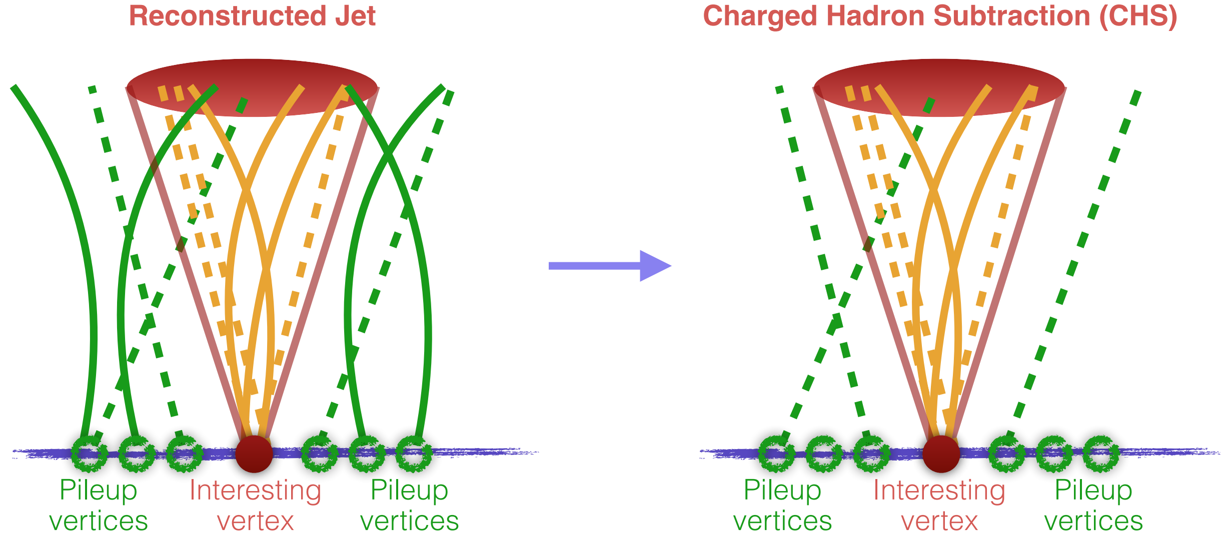
Charged Hadron Subtraction (CHS)

- Tracker information to remove charged particles associated to PU
- Applicable for $|\eta| < 2.4$



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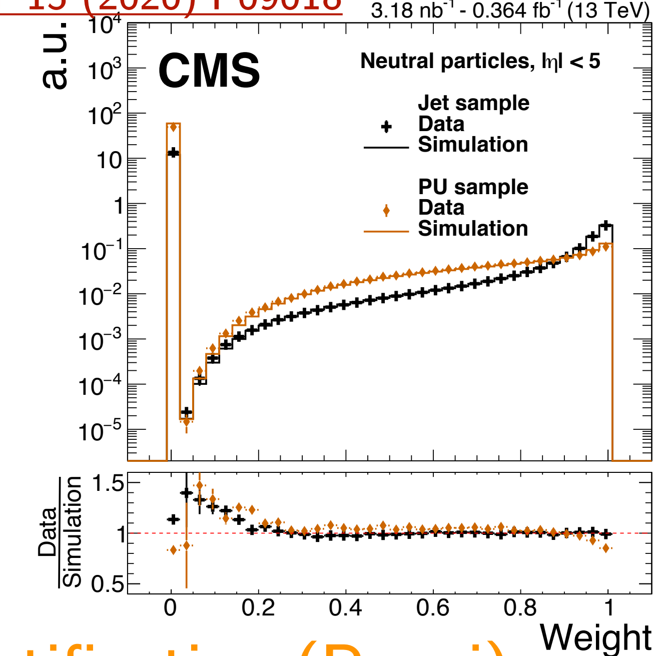

Charged Hadron Subtraction (CHS)

- Tracker information to remove charged particles associated to PU
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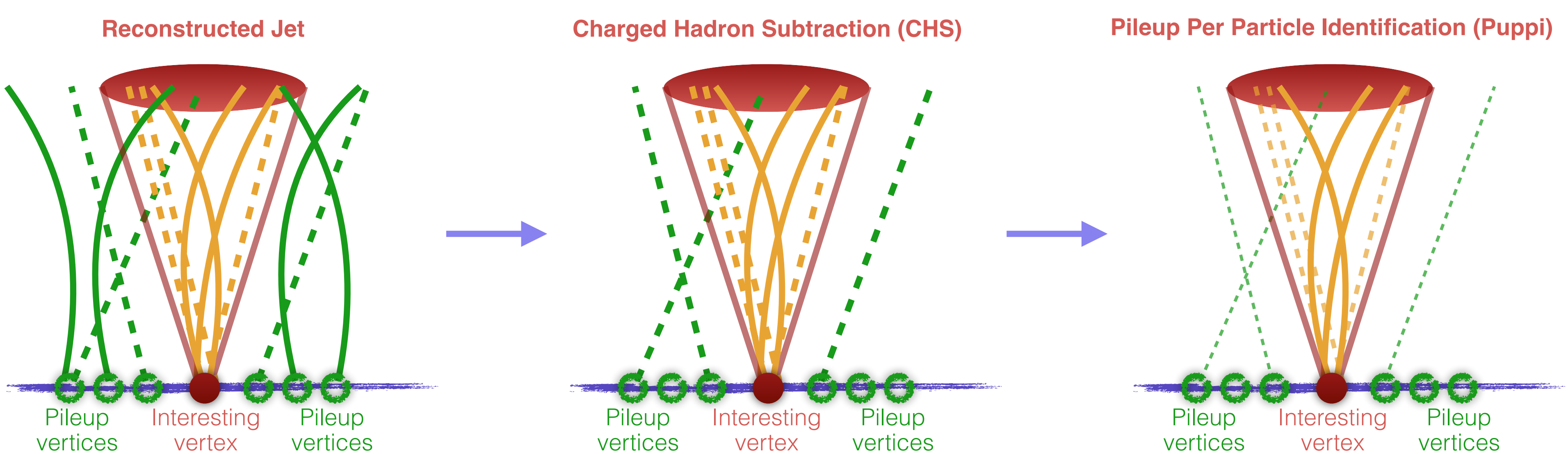
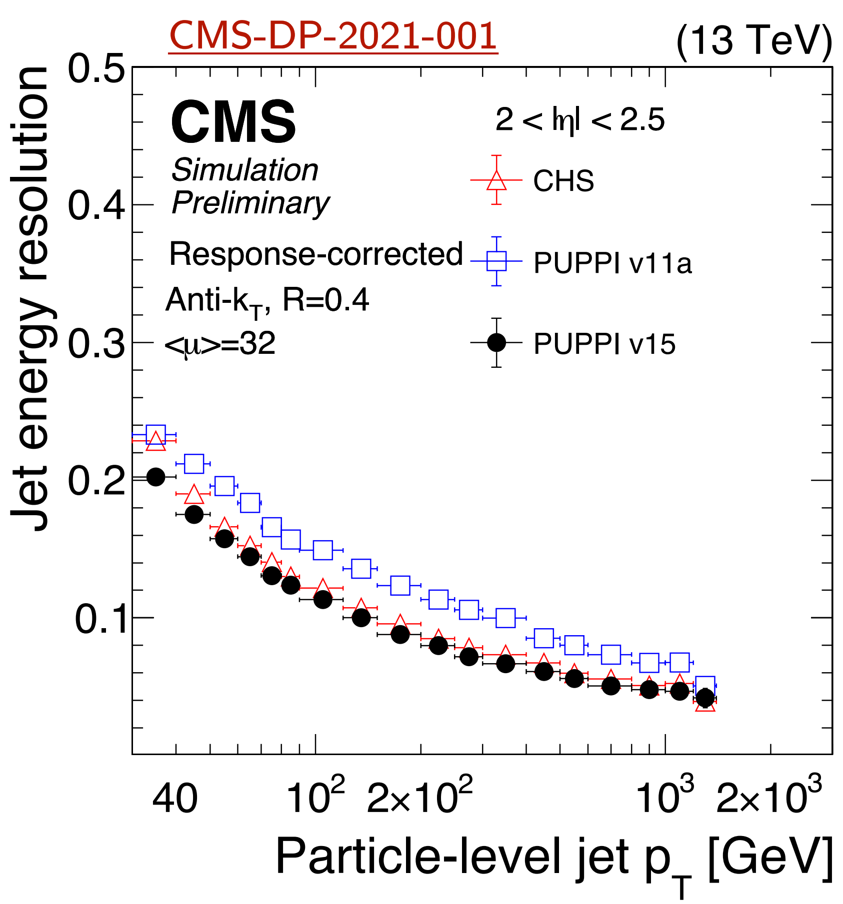
Pileup Per Particle Identification (Puppi)

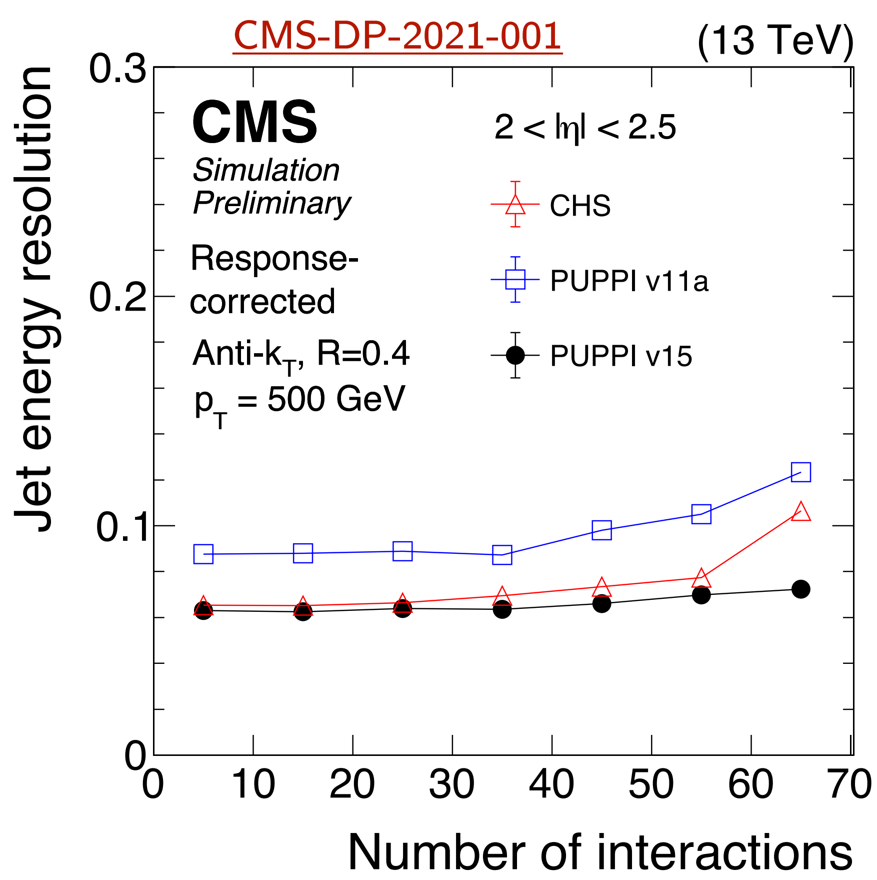
- Per-particle weight
- Scale 4-momentum before clustering
- Charged particles similar to CHS

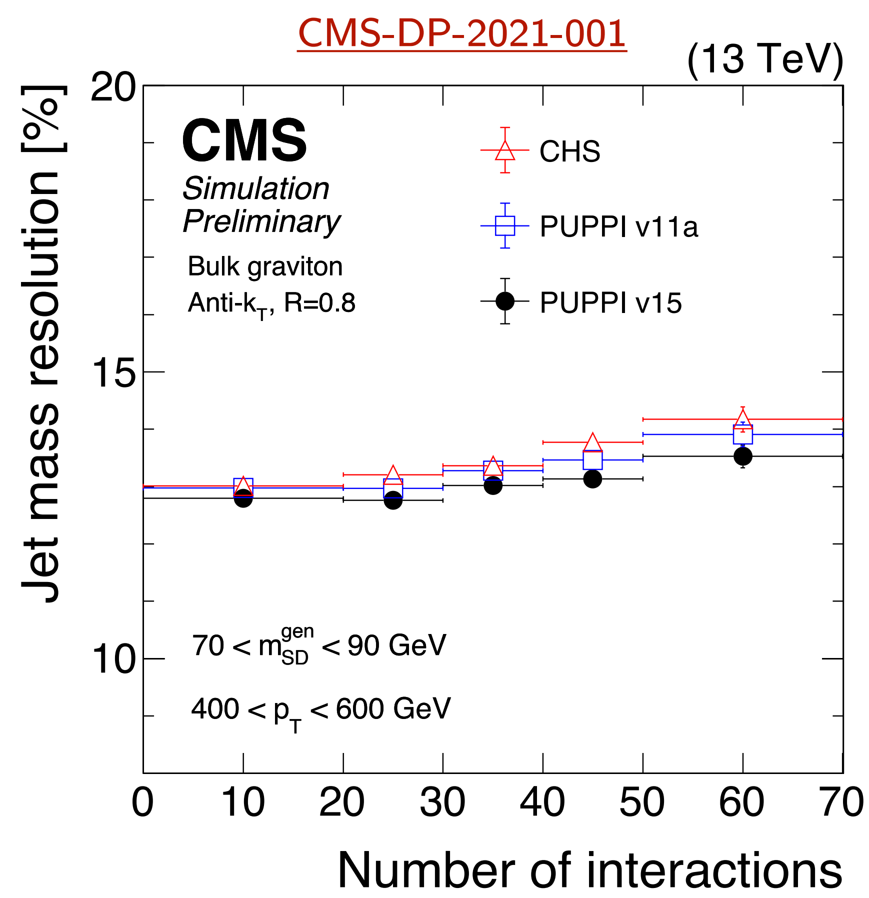


Pileup mitigation techniques – Puppi for Run 3

- Widely used in Run 2 (Puppi v11a)
- Improved all jet-related variables
- Refined requirements for charged particles (Puppi v15)
- Targeting better jet energy resolution at high-p_T
- Used for Run 2 Legacy reconstruction
- Default in Run 3

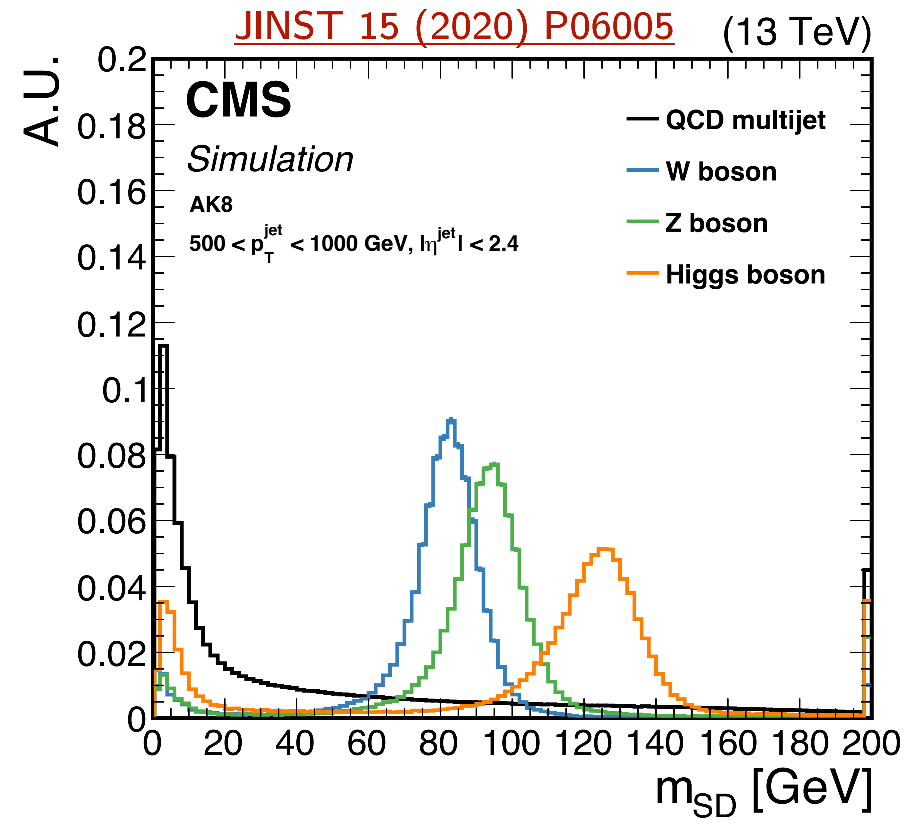


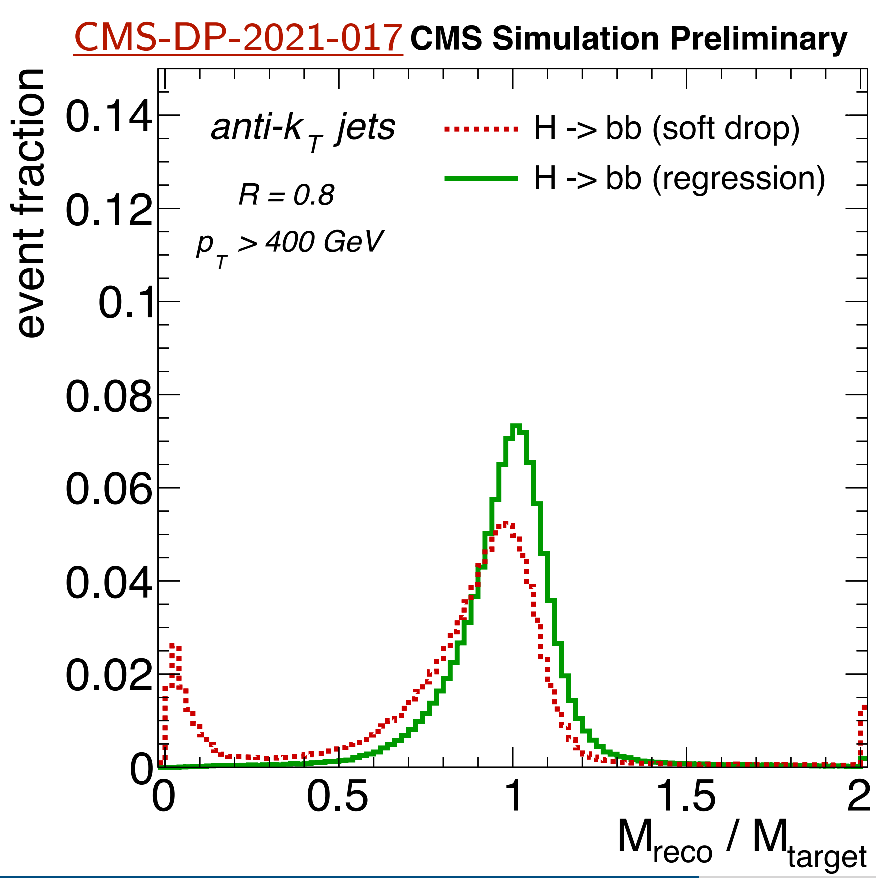




Jet reconstruction

- Clustering of PF particles
  - successfully used since Run1
  - better than calorimeter-only-based reconstruction
- Anti-k_T as default algorithm
  - small radius: R=0.4 (AK4)
  - large radius: R=0.8 (AK8)
  - alternative algorithms: HOTVR, XCone





- Substructure for AK8:
  - mass regression
  - key role in jet tagging
  - softdrop algorithm as baseline
  - Additional improvement with DNN

- Event signature defines clustering
- Return exactly N jets
- Examples from top-mass measurement
- Large improvement for the jet mass resolution

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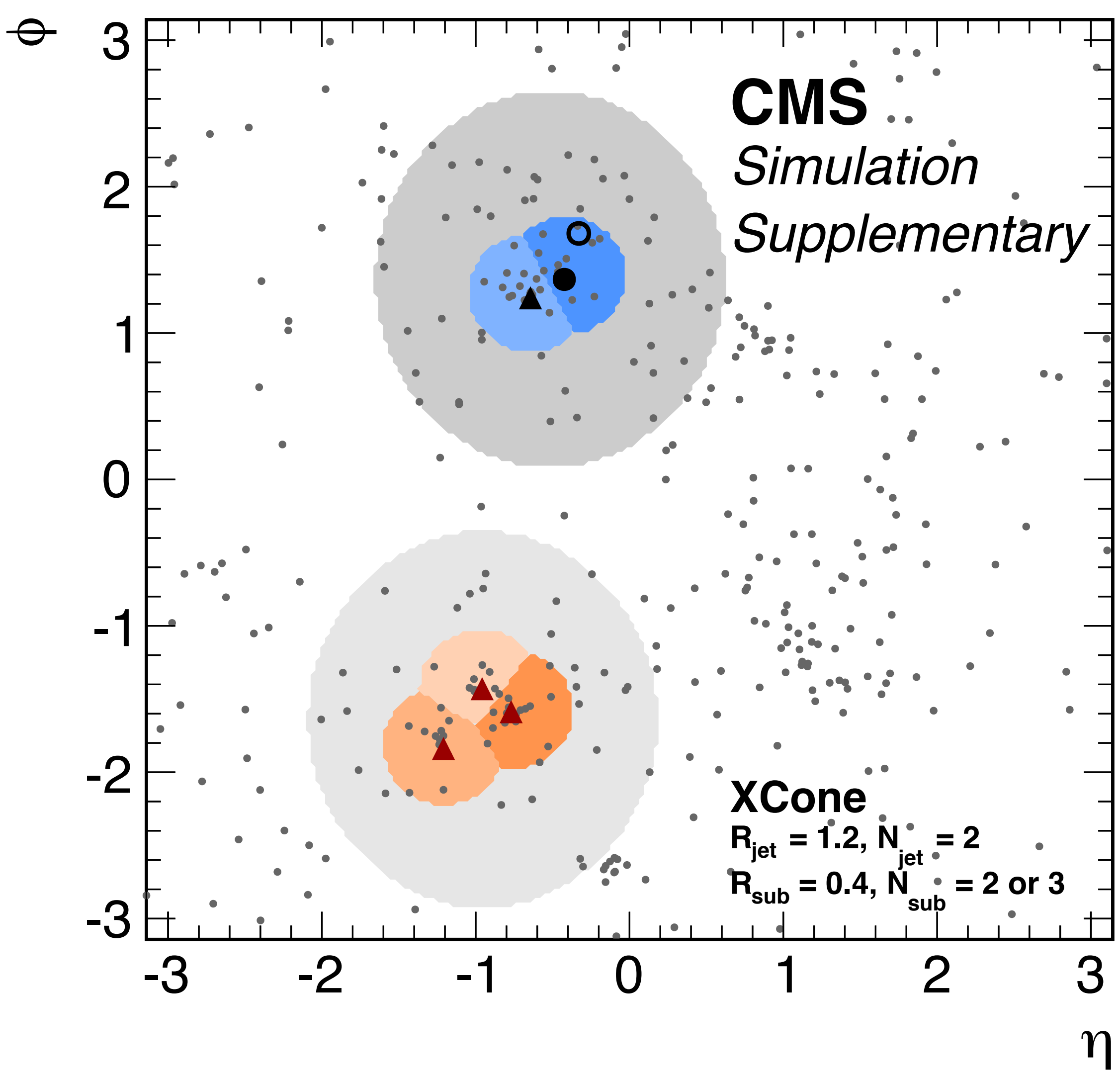

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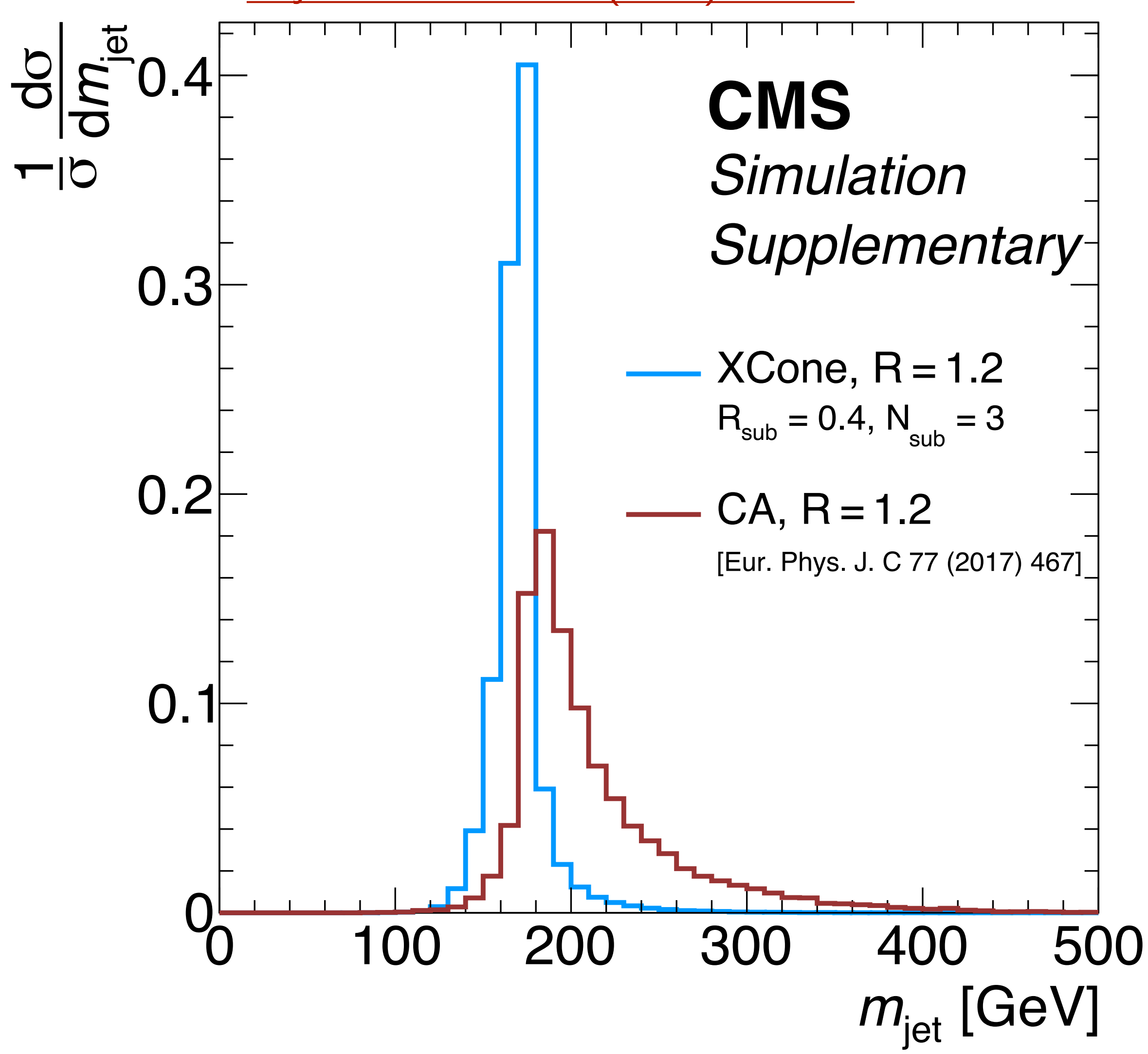
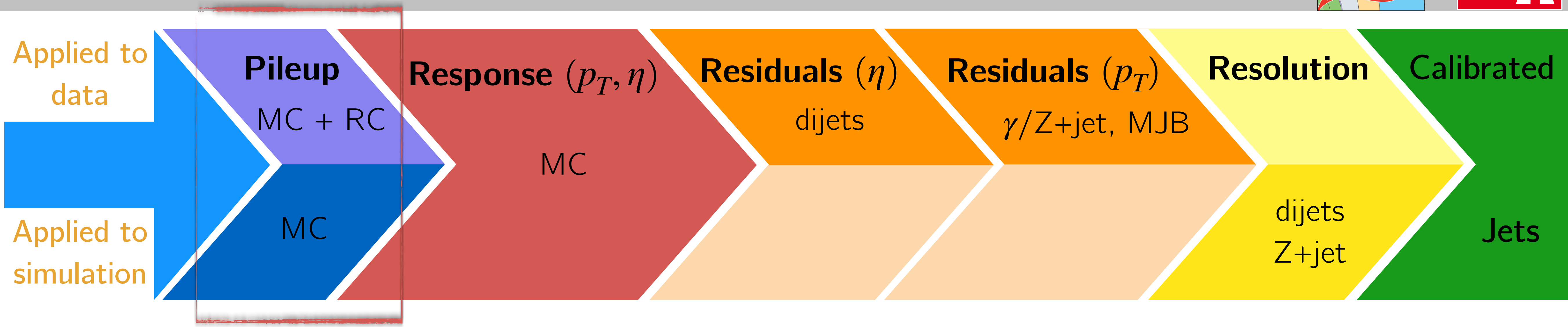


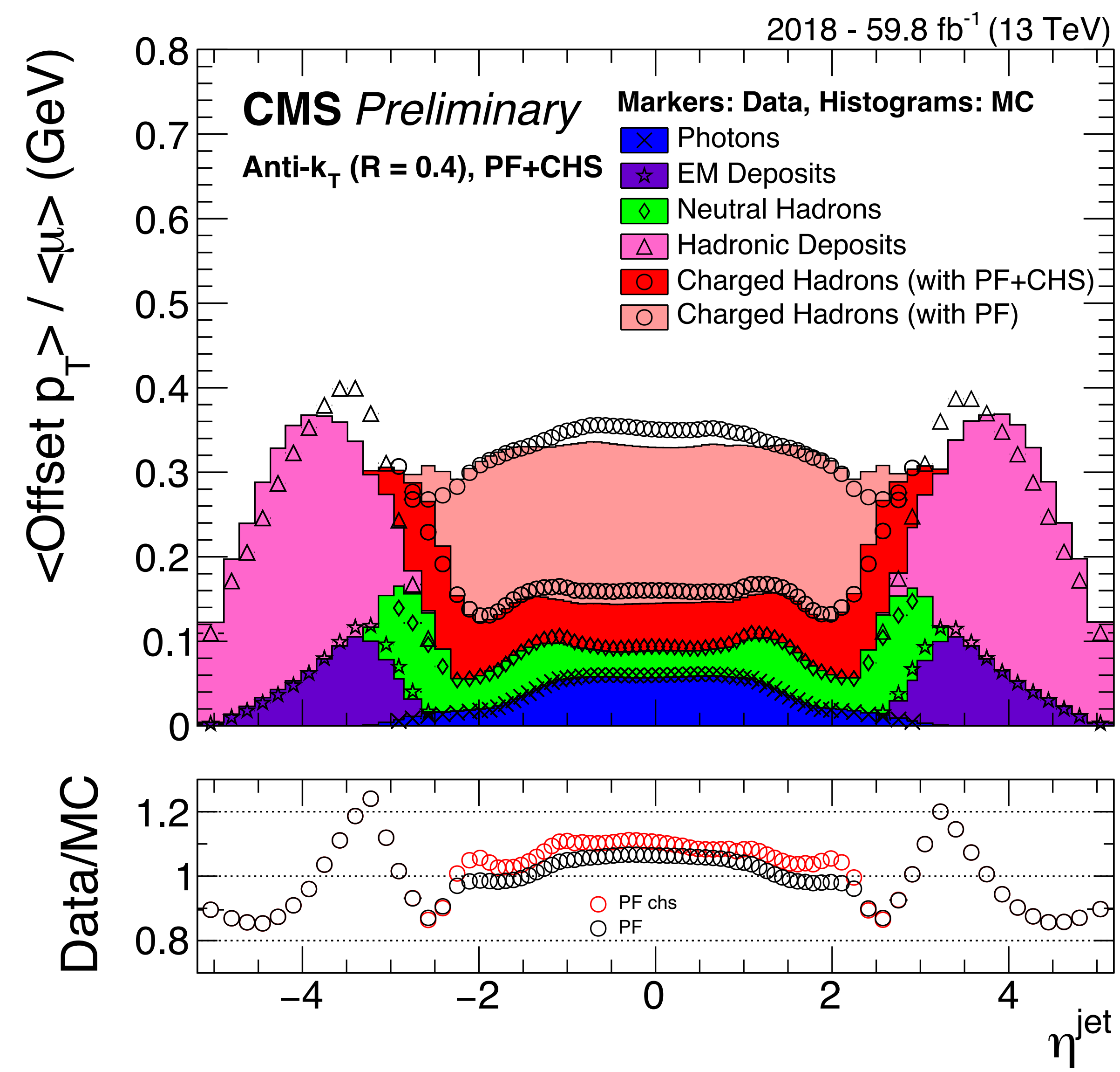
Jet calibration



MC truth correction:

PU subtraction

- Simulation-based correction
- Average offset due to PU
- Residual corrections derived with Random Cone algorithm applied to data
- Monitored for each type of PF candidate



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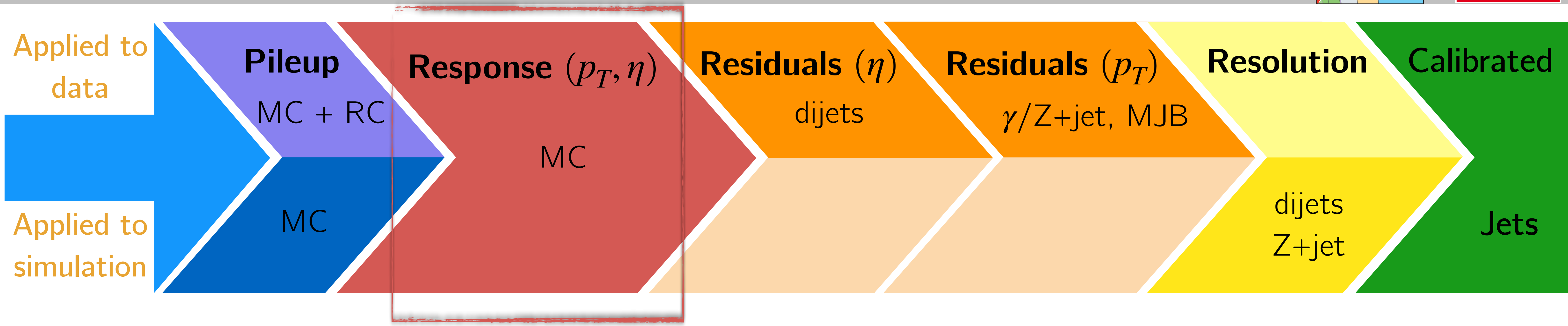
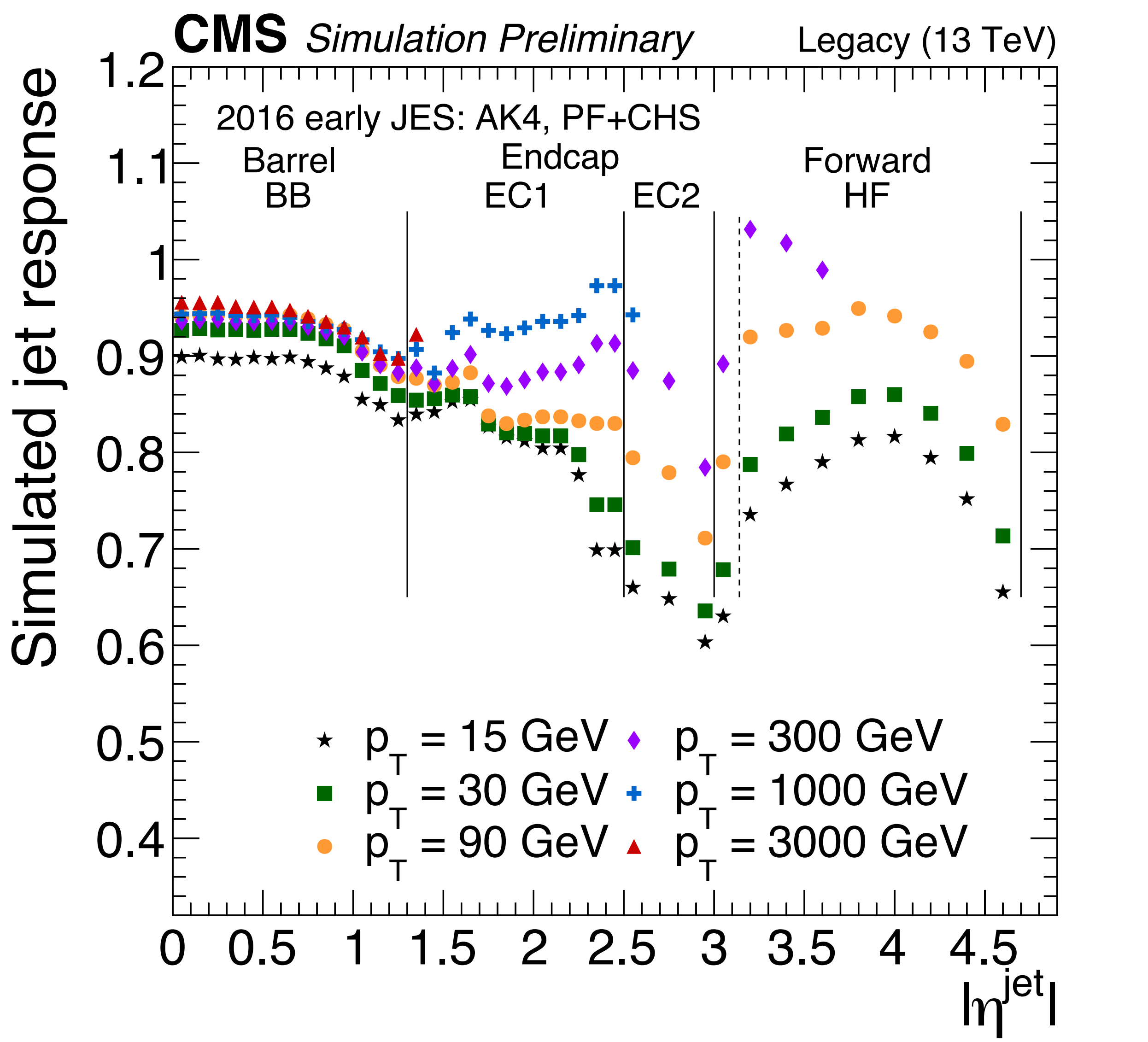


MC truth correction:

PU subtraction

Jet response calibration

- Core of the JEC
- Simulation-based
- Accounts for detector effects
- Change in performance due to detector acceptance



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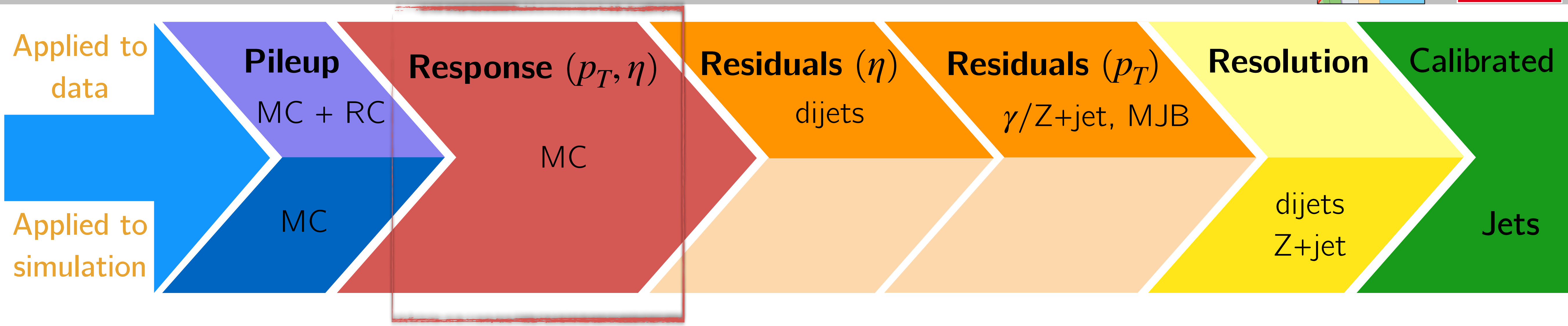
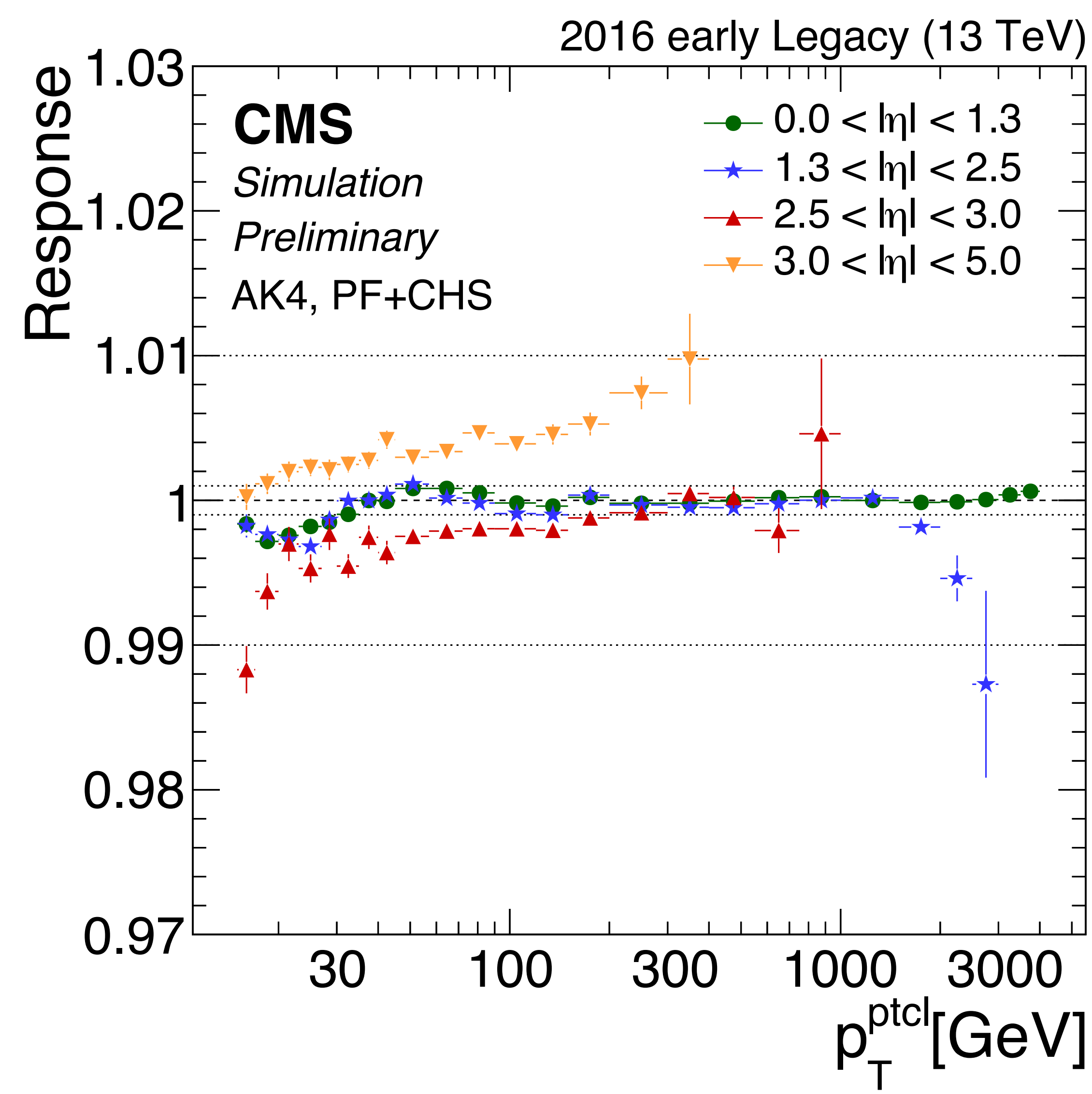


MC truth correction:

PU subtraction

Jet response calibration

- Core of the JEC
- Simulation-based
- Accounts for detector effects
- Change in performance due to detector acceptance
- Closure better that 1% everywhere (0.1% in central region)



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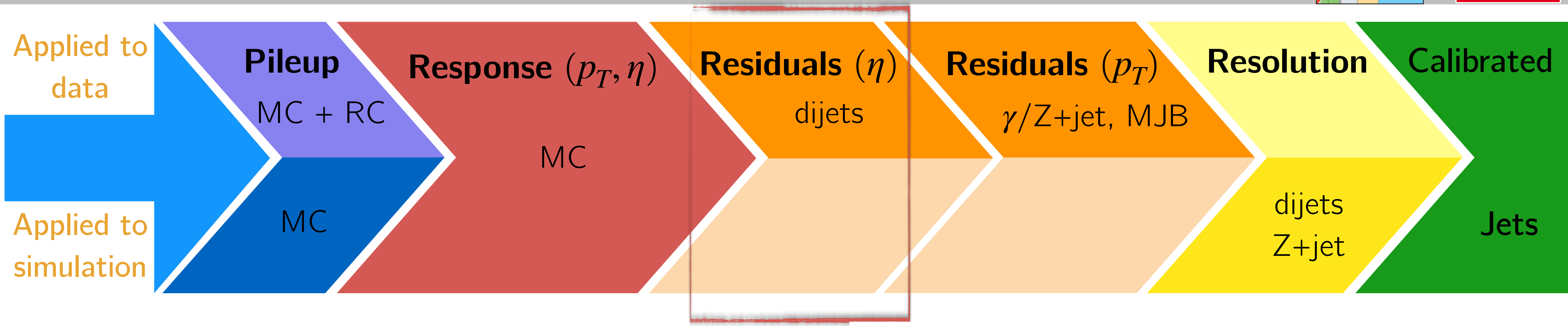

MC truth correction:

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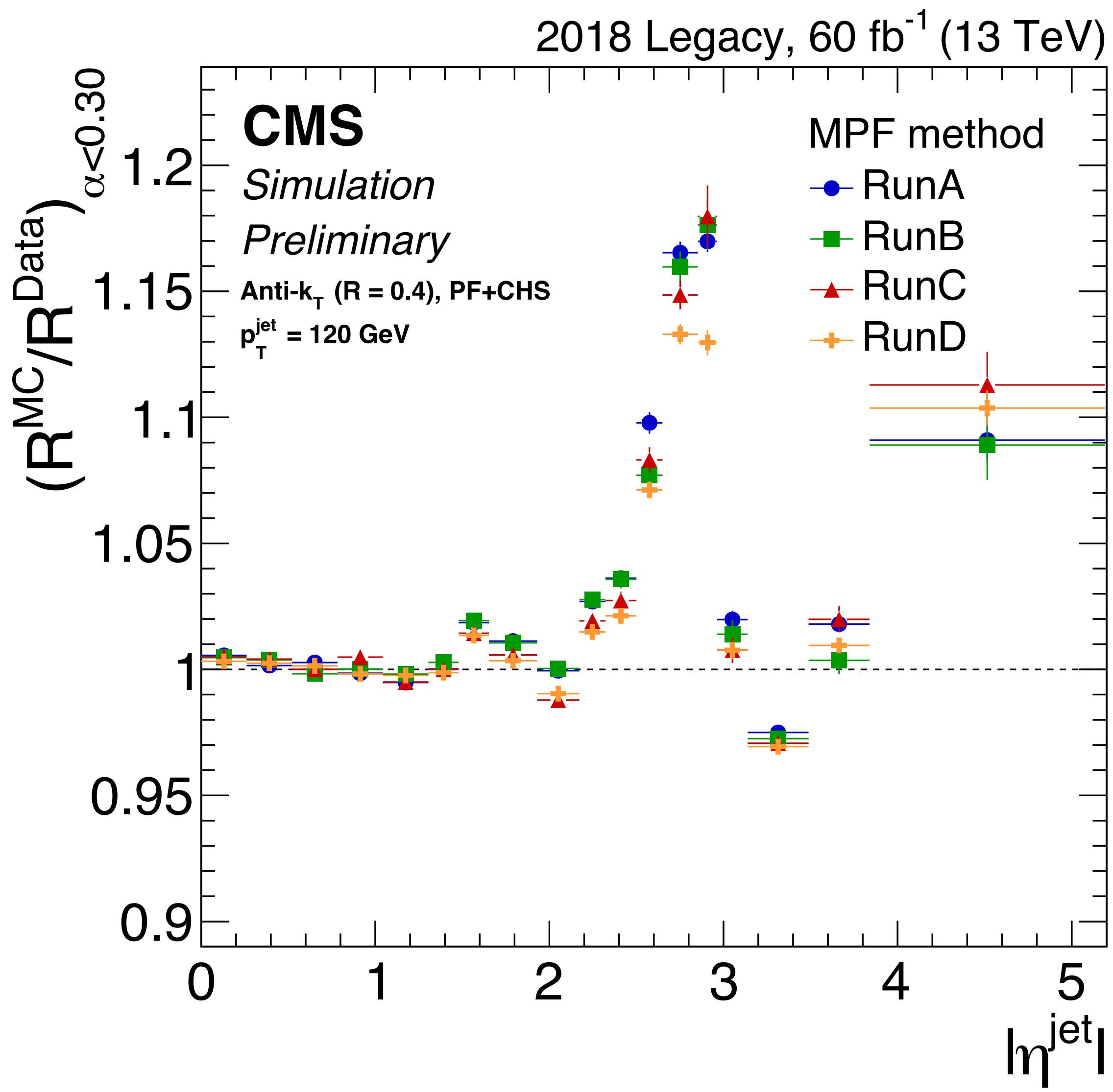
Jet response calibration

Residual corrections

- Small residual correction of jet response applied to data
- Address different response in each sub-detector (η dep.)
- Sizeable corrections only in detector transition regions



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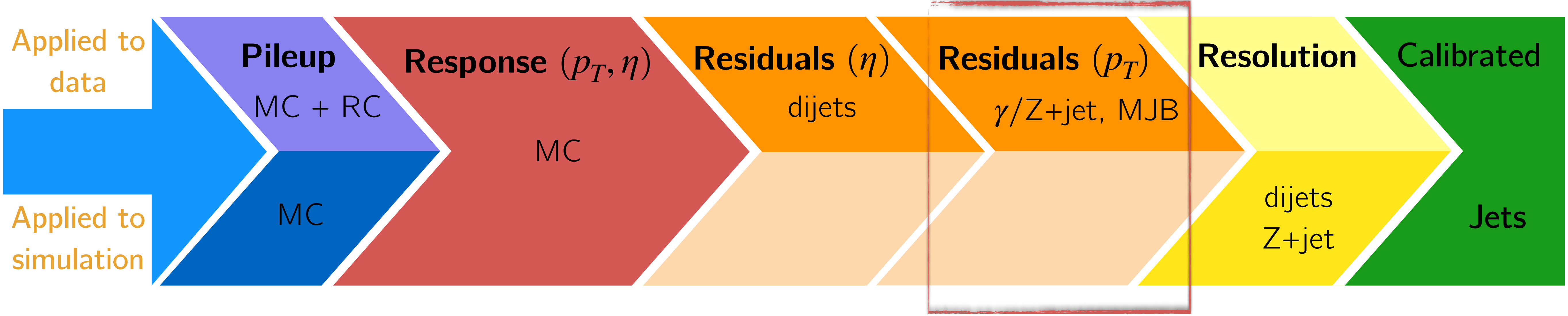


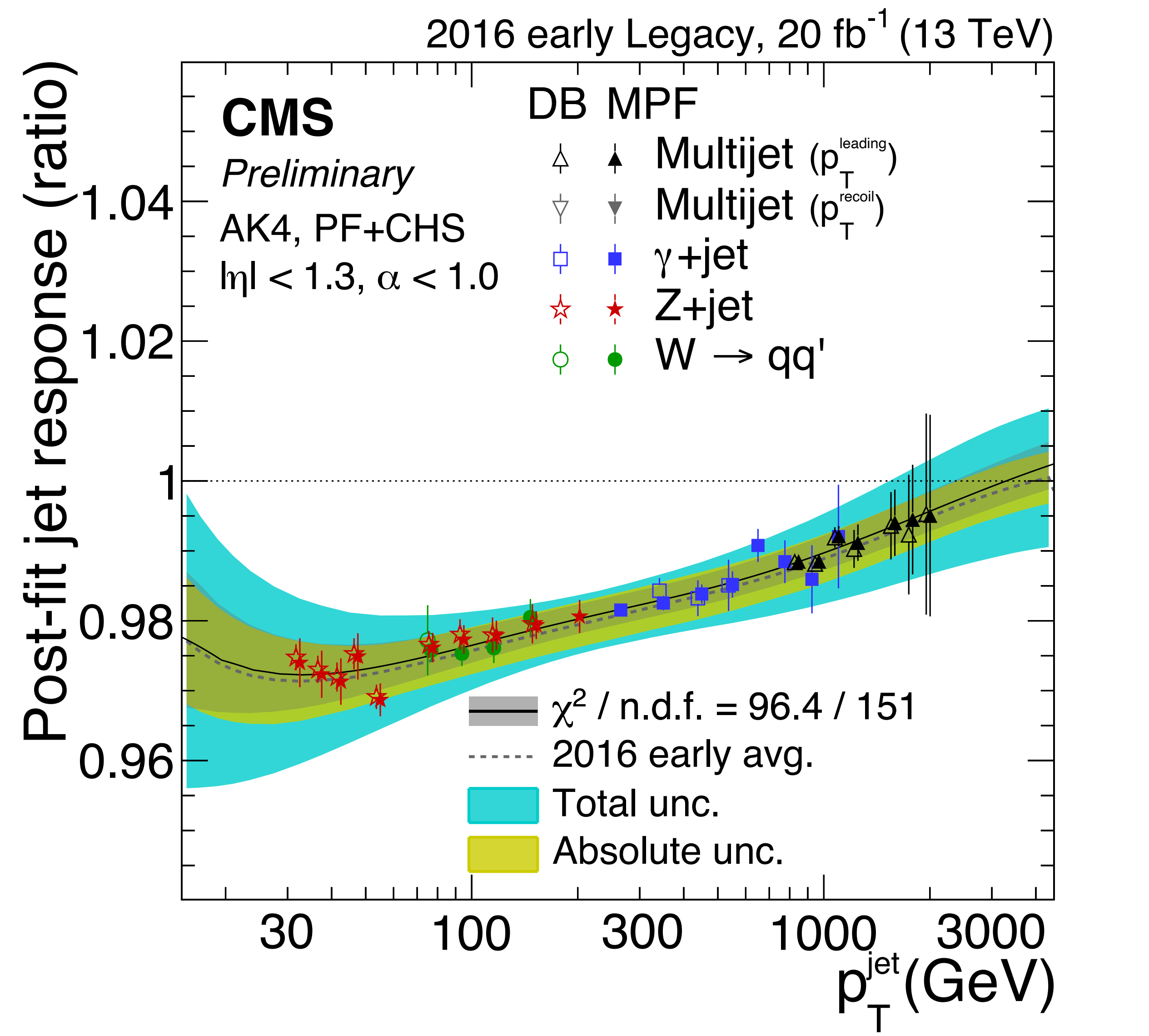
MC truth correction:

PU subtraction

Jet response calibration

Residual corrections

- Additional p_{T} dep. corrections accounting for abs. scale in barrel
- Determined relative to precisely measured reference objects (μ, e, γ, W)
- Combined in a global fit (reference object scales as nuisance parameters)



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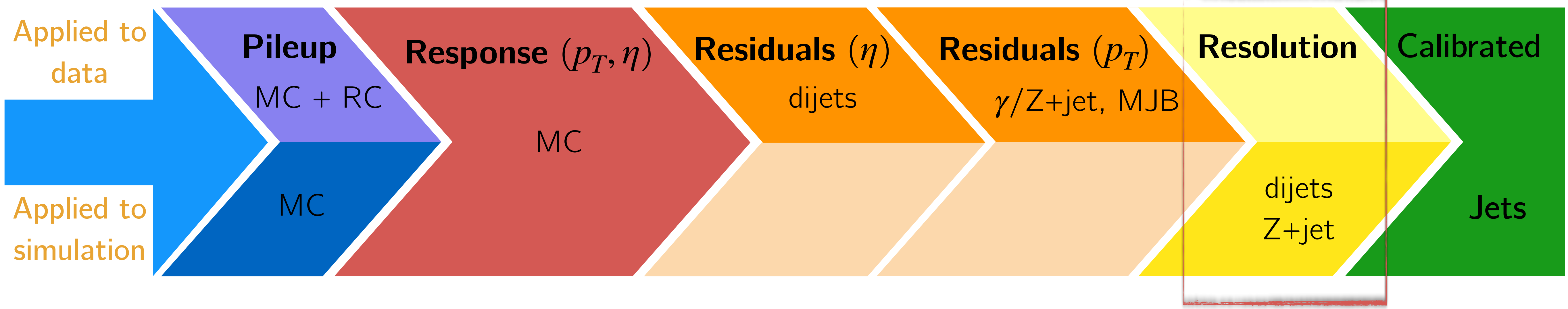


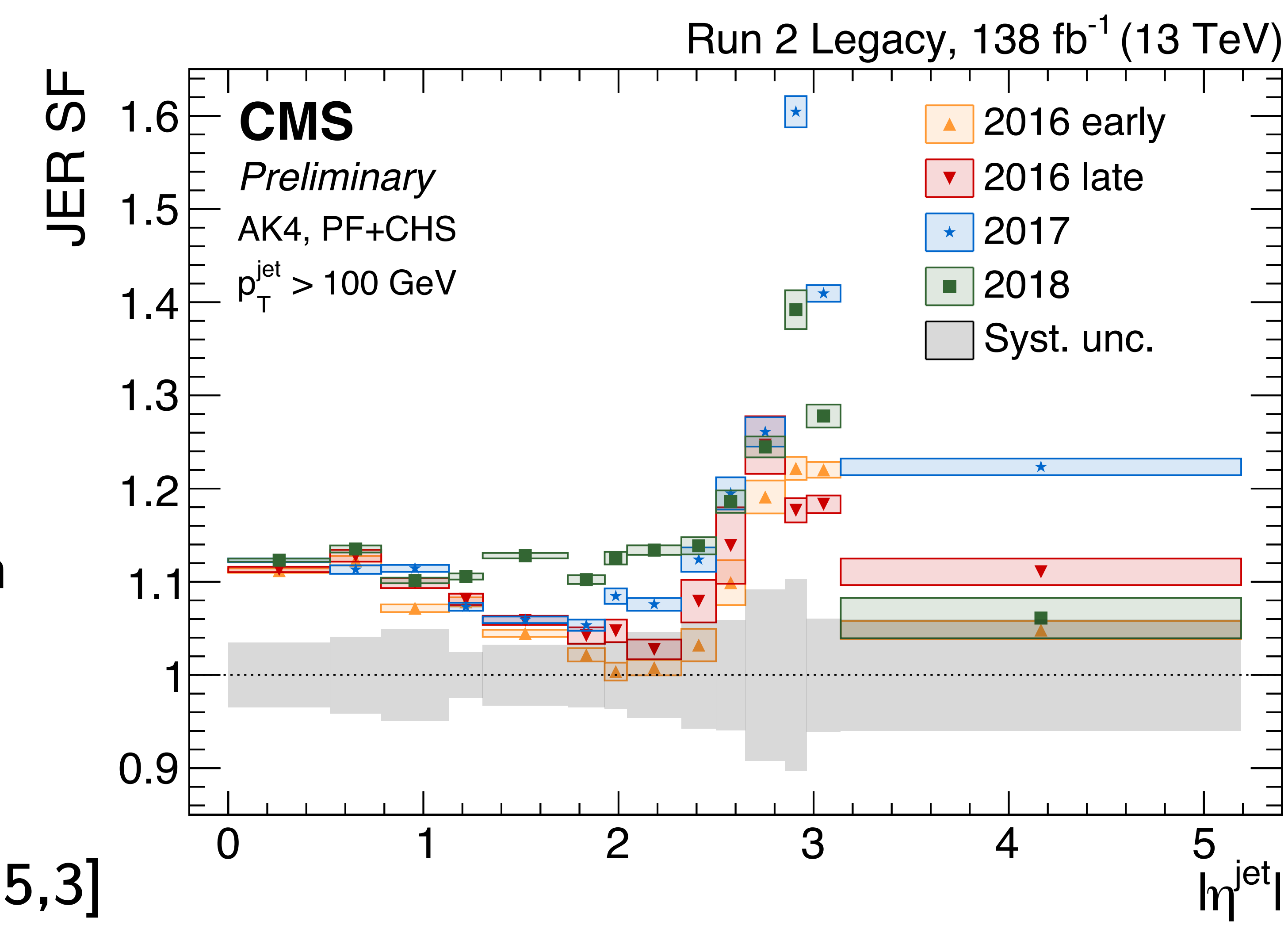
MC truth correction:

- PU subtraction
- Jet response calibration

Residual corrections

Jet energy resolution smearing

- ▶ Scale factors (SFs) applied to simulation to match resolution in data
- ▶ Direct balance in dijet events ($p_{\mathrm{T}} > 100$ GeV)
- ▶ SFs up to 20%, larger in $|\eta| \in [2.5, 3]$



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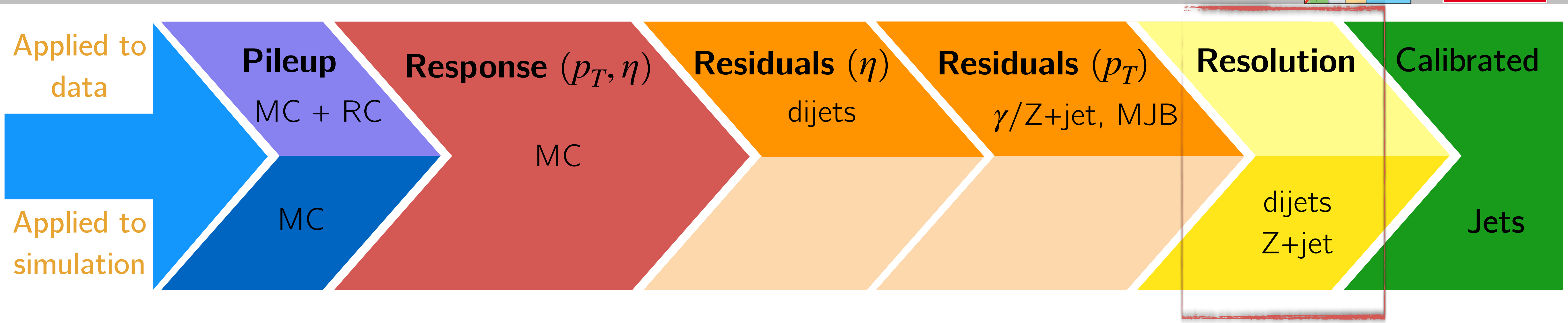


MC truth correction:

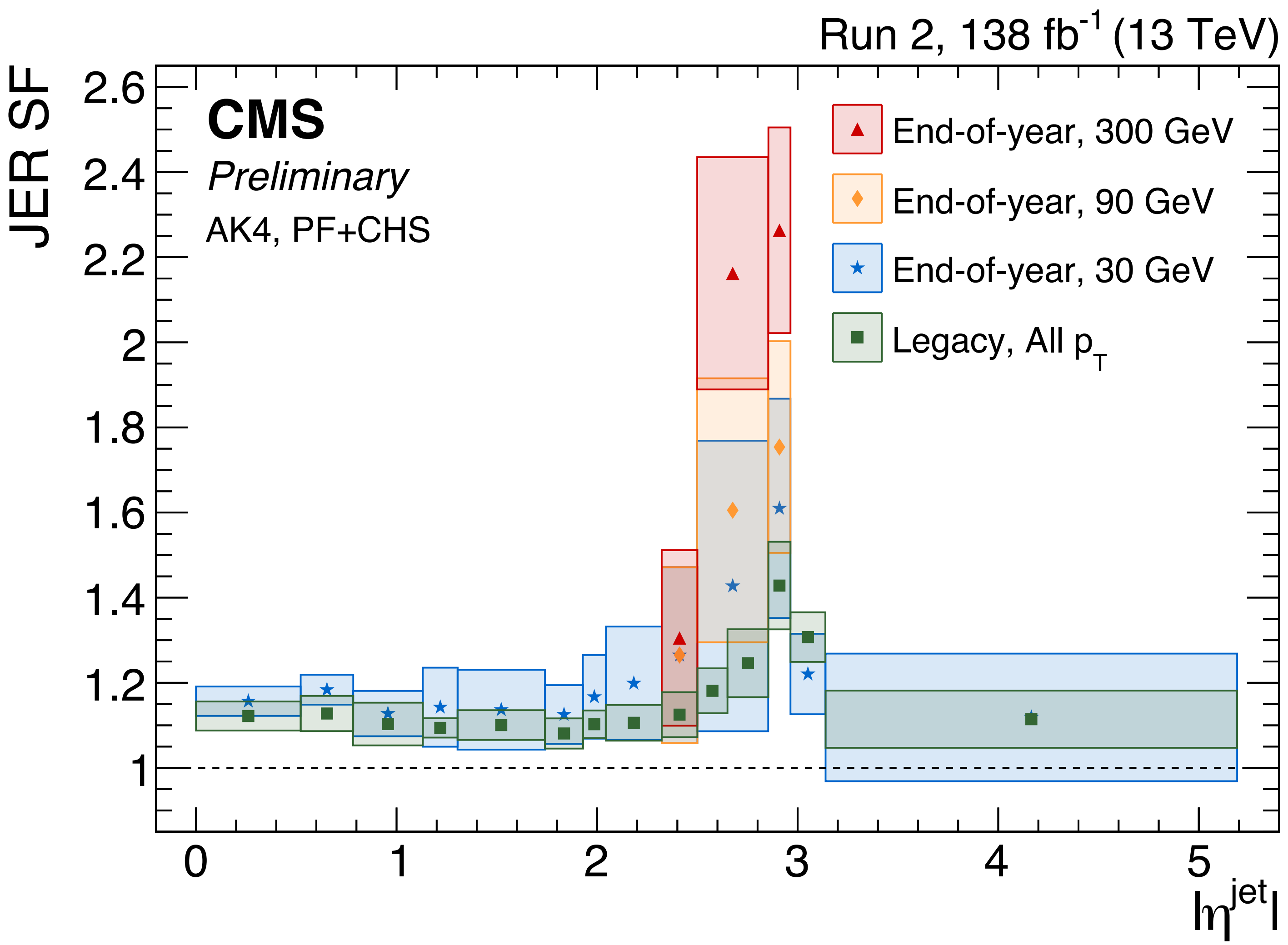
PU subtraction

Jet response calibration

Residual corrections

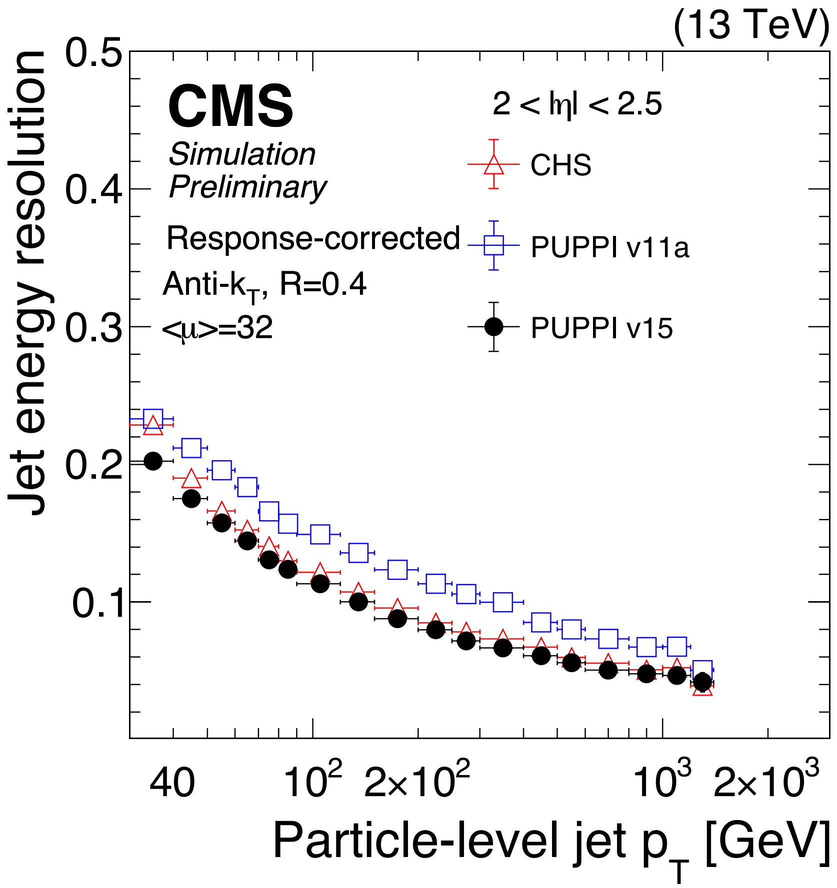
Jet energy resolution smearing

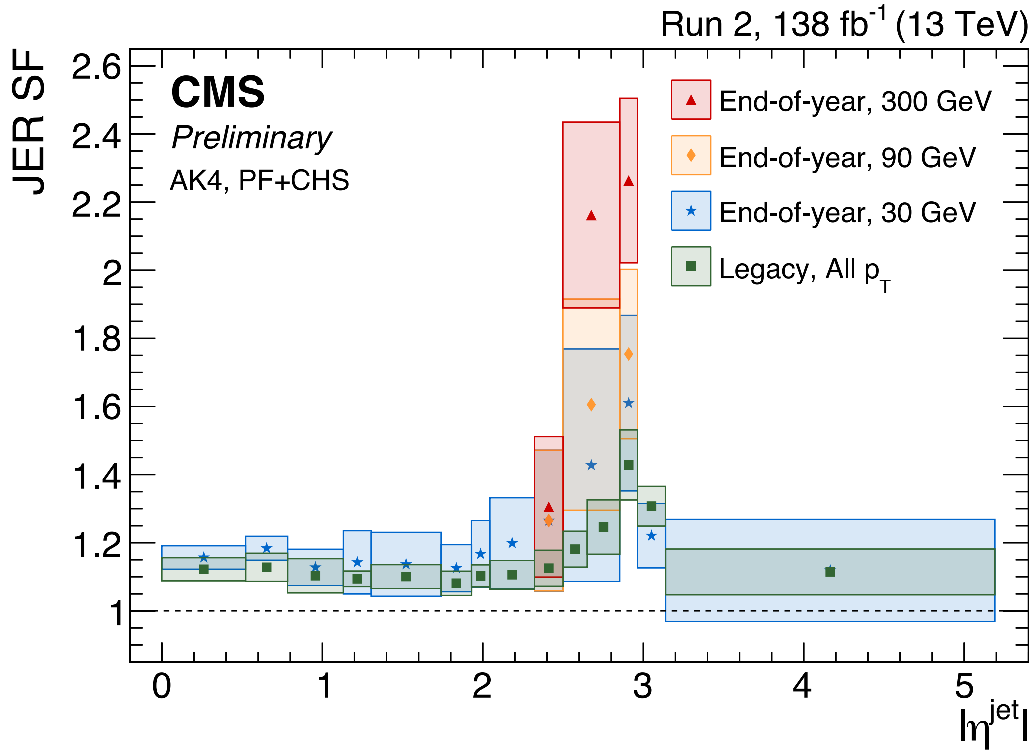
- Luminosity-weighted average of the JER SF per year with total uncertainty.
- p_T -dependent SFs for the End-of-year



Outlook

- Run 2 experience fully exploited for accurate jet performance
- Several high-performance methods presented
- Ready to cope with high PU expected for Run 3 (Puppi very promising)
- But it's not the end of the story
  - Run 2 legacy corrections to improve performances (planned <1% JEC unc.)
  - Increasing the granularity of the corrections to tackle detector ageing
  - ML-based approaches will help





More exciting results are yet to come