Jet performance in CMS

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QCD: Jet Physics

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Universität Hamburg

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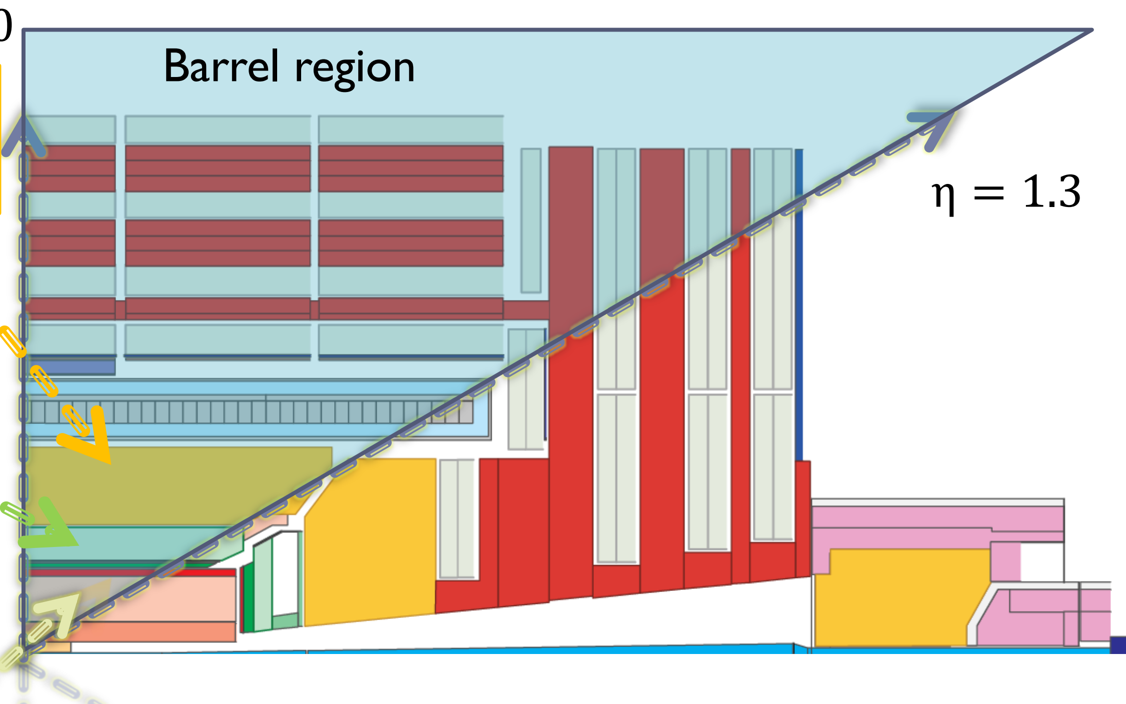
CMS detector(for jets)



HCAL: Brass/scintillator($|\eta| < 3$)

Central jets (with ECAL): $\frac{\sigma_{Calo}(E)}{E} \sim \frac{100\%}{\sqrt{E}} \oplus 5\%$

ECAL: $PbWO_4$ Crystal calorimeter

Photons (~60 GeV): 1.1-2.5% in the barrel

Tracker: Silicon Pixel and Strip detector

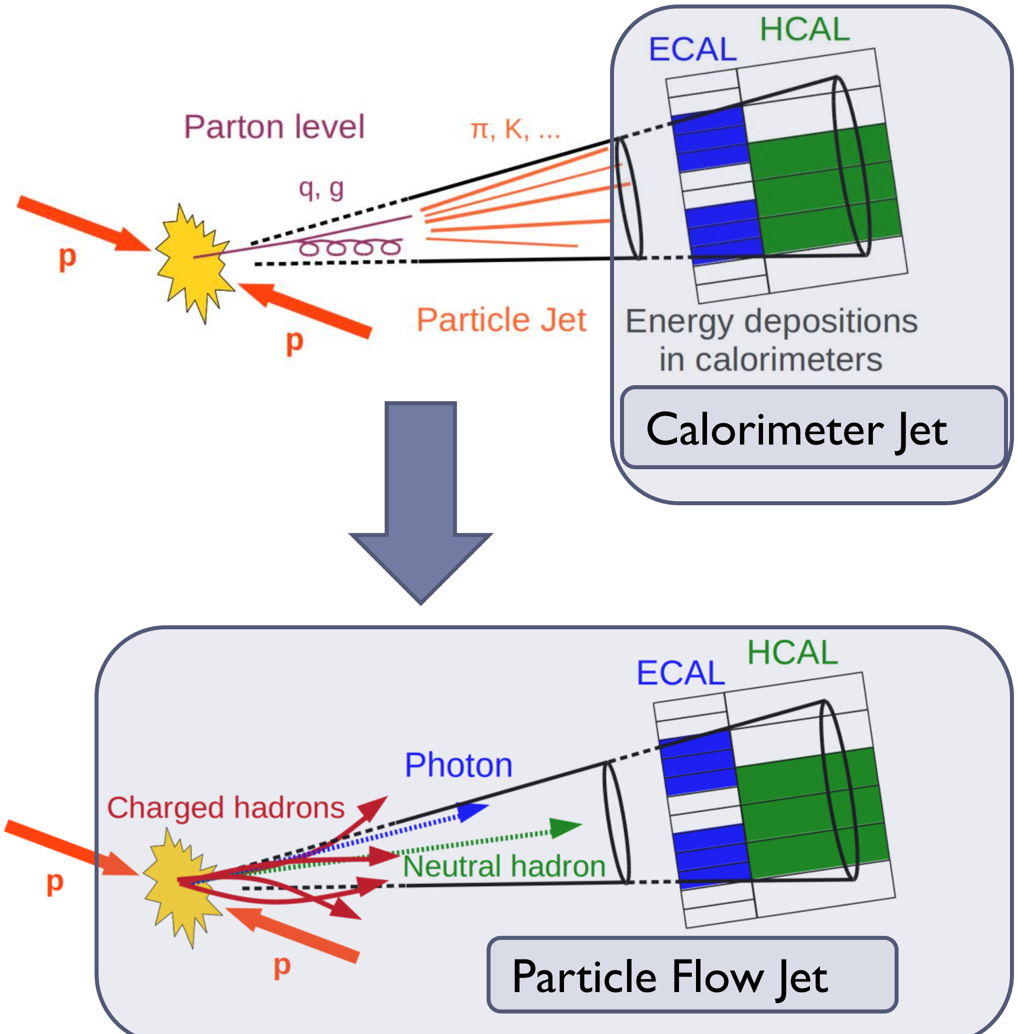
1.5% at 100 GeV

10% at 1000 GeV

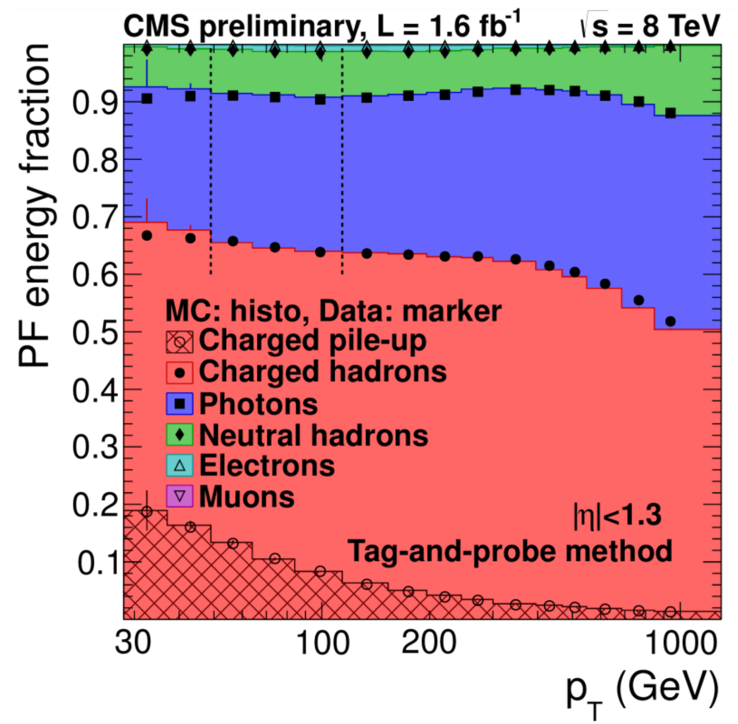
CMS specifics

- Very precise tracker and ECAL
- Highly granular ECAL
- Strong magnetic field (3.8 T)
- Tracking and calorimeters contained within superconducting magnet

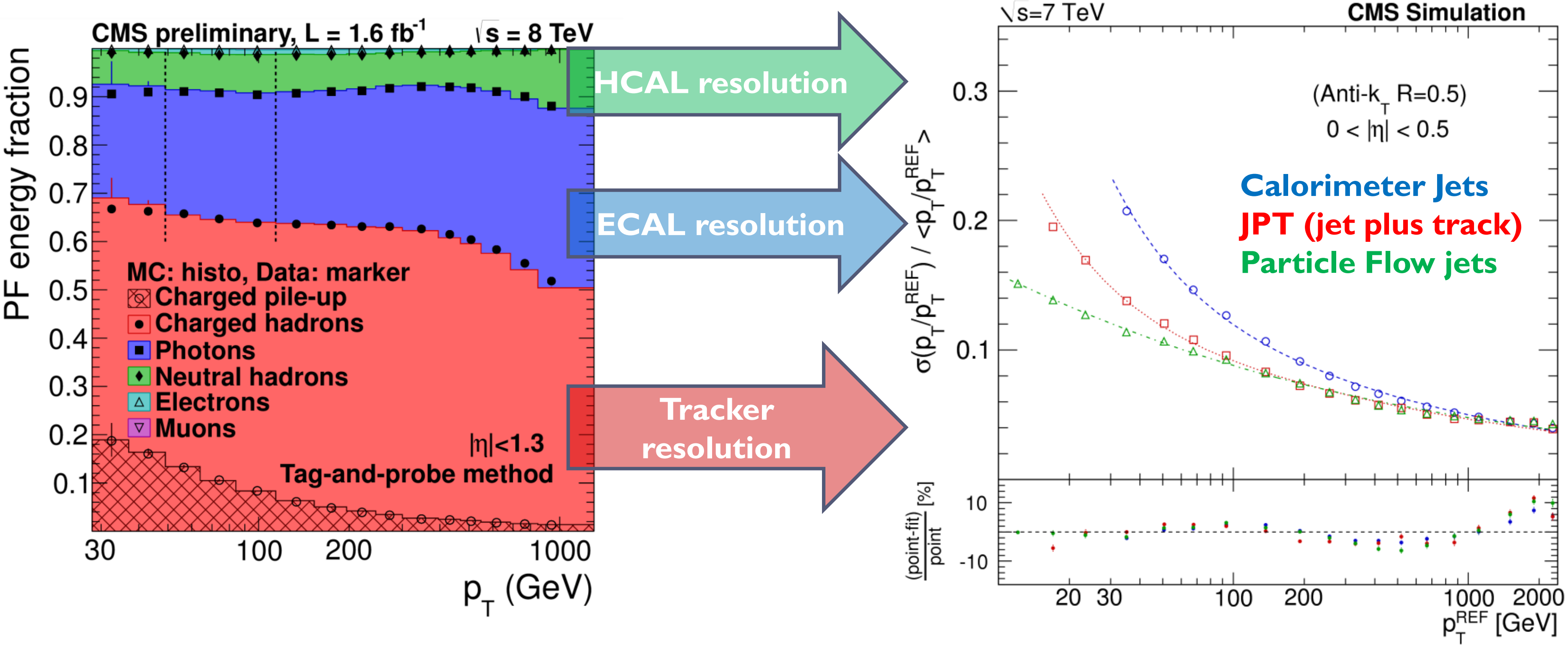
Particle Flow (PF) approach



- Tries to reconstruct individual particles to form jets using all subdetector information
- Commissioned successfully on data
- Used in most CMS analyses

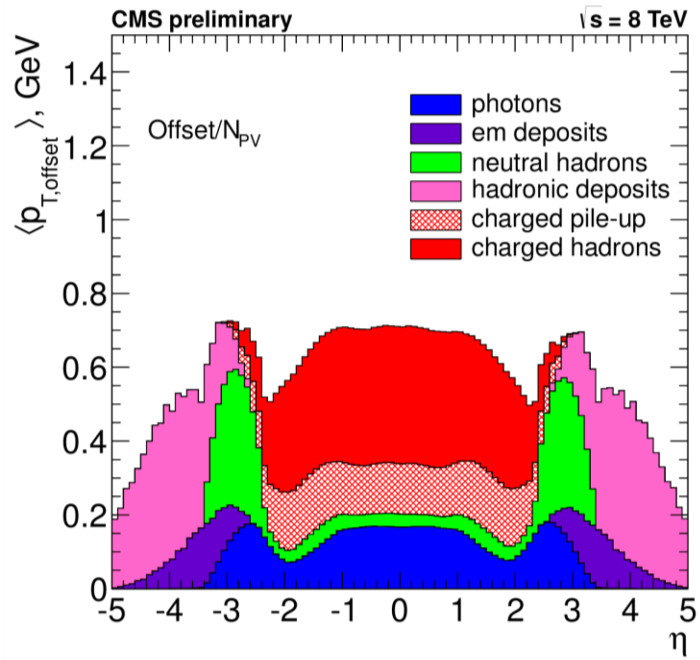


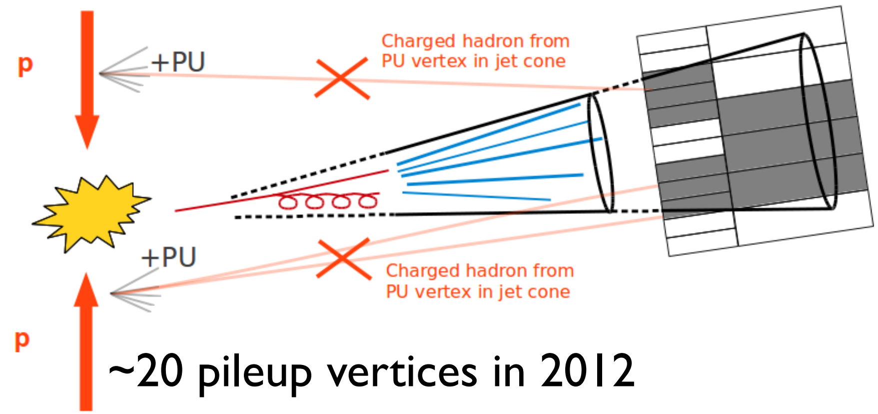
Particle Flow improves jet energy resolution



- Large fraction of PF jet components well measured by ECAL/tracker
- Jet energy resolution improved, especially at low p_T, same resolution at very high p_T for different jet types

Challenging pileup conditions in 2012





~20 pileup vertices in 2012

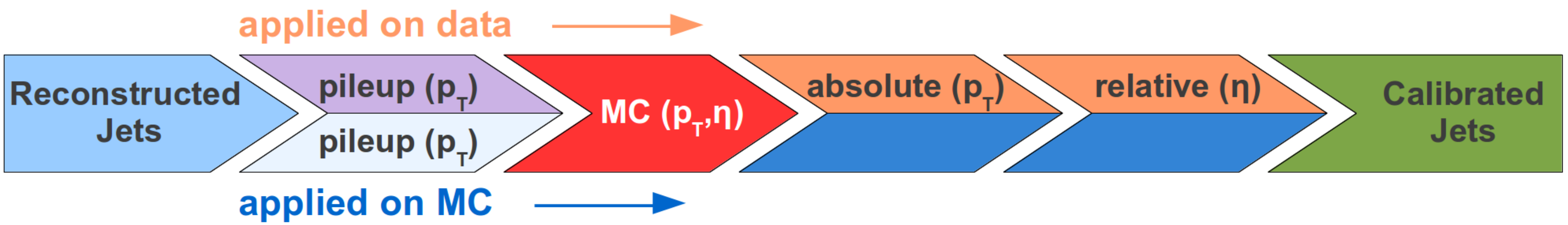
Methods for pileup mitigation:

Particle Flow Charged Hadron Subtraction (CHS)

- Majority of pileup is from charged particles
- CHS removes charged hadrons from pileup vertices

Additional pileup corrections for remaining pileup components

Jet energy corrections



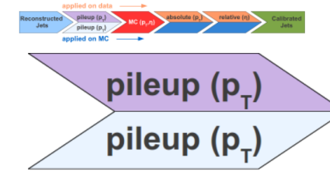
JEC corrects reconstructed jets – on average – back to particle level.

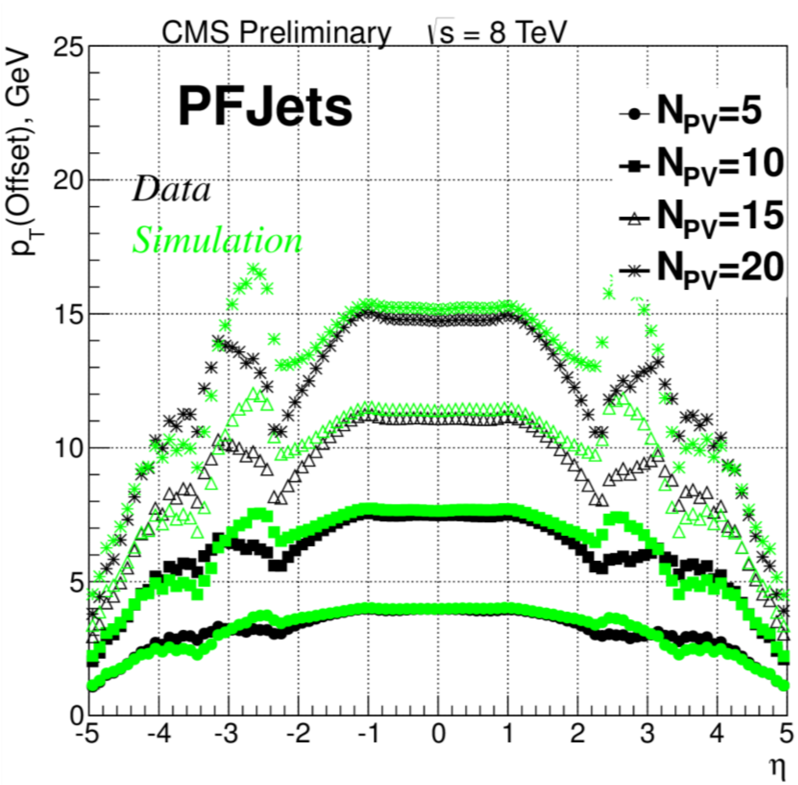
Factorized approach:

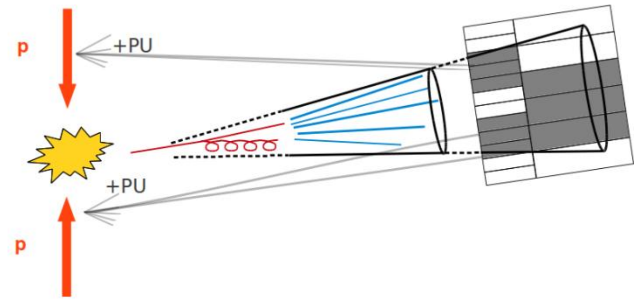
- Pileup corrections to correct for offset energy
- Correction to particle level jet vs. p_T and η from simulation

- Only for data: Small residual corrections (relative and absolute) to correct for differences between data and simulation

Pileup corrections

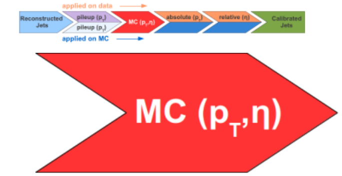


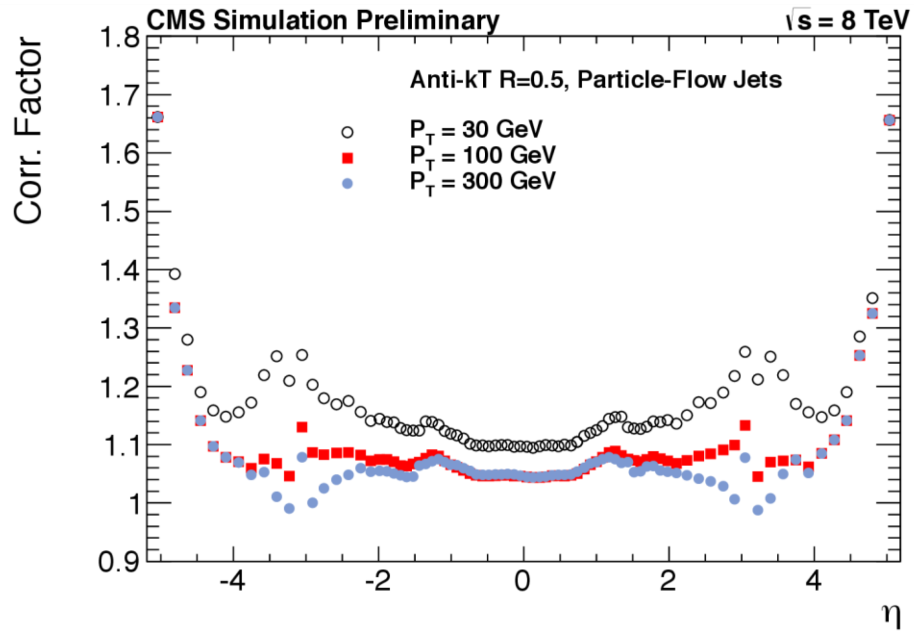




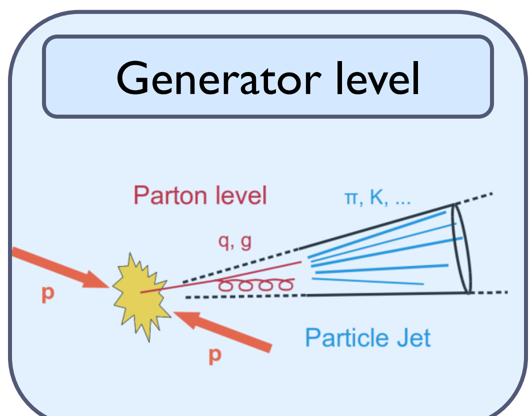
- Average per-event UE/pileup density ρ and jet-area A used to subtract offset energy from additional minimum bias events (pileup).
- Parameterized for data and simulation as a function of ρ, A, p_T and η

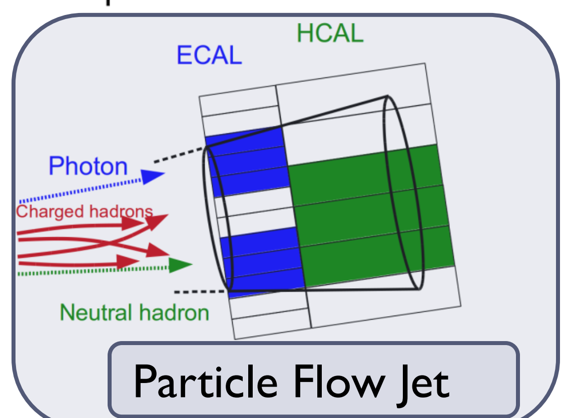
Corrections from simulation



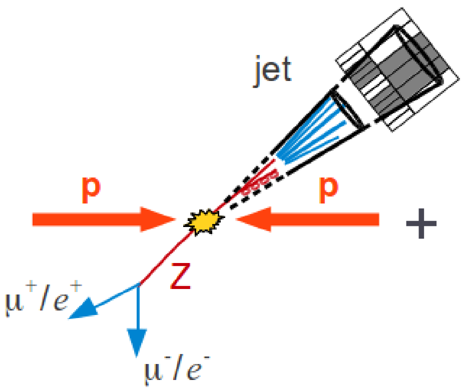


- Correction for p_T and η dependence
- Reference scale is that of the particle/generator jet
- Final correction step for simulated data





Jet energy scale determination in data



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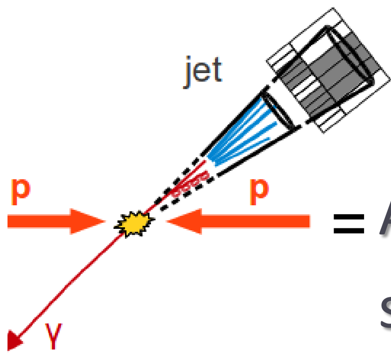
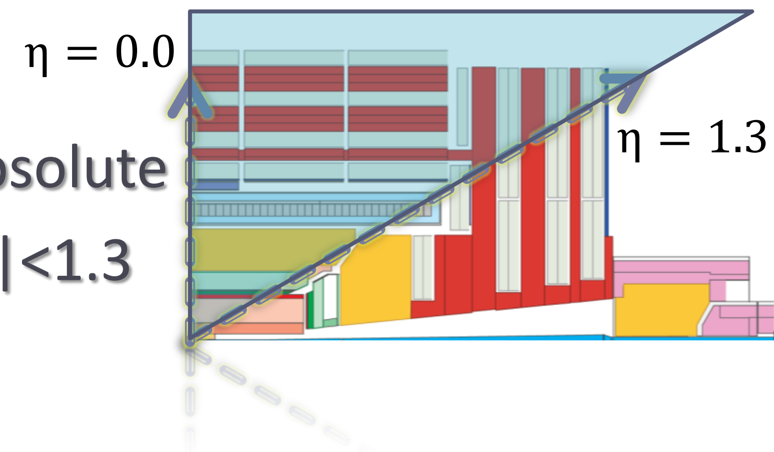
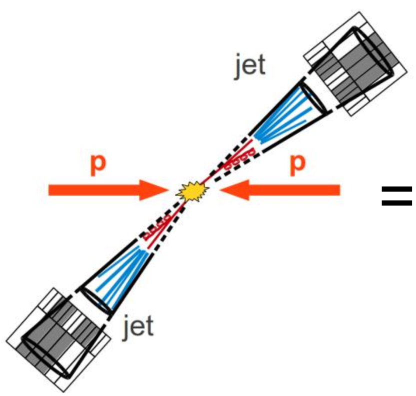
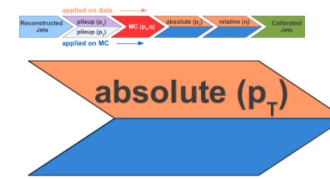


= Average absolute scale in |η|<1.3

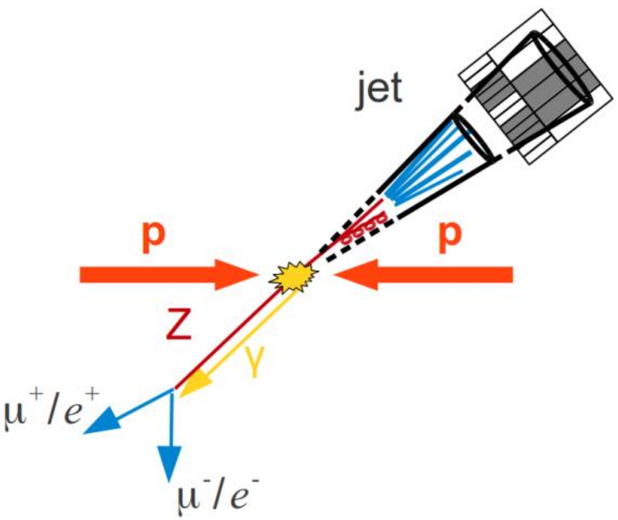


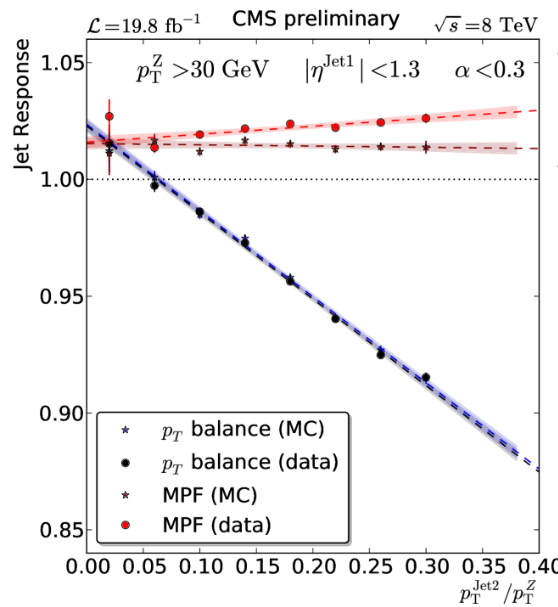


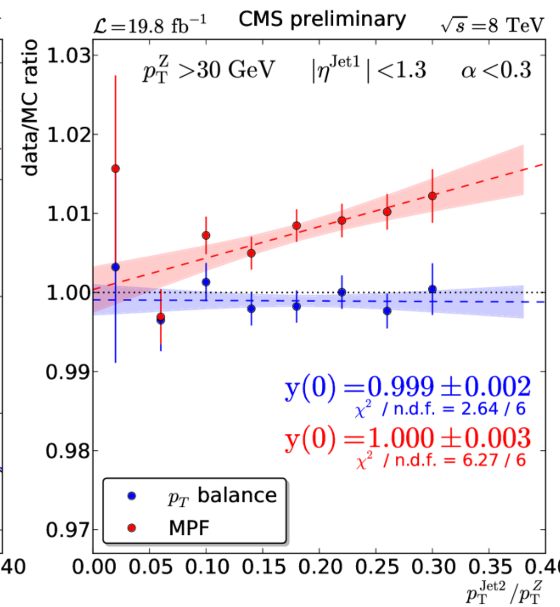
= Scale relative to |η|<1.3 (as function of η)



Absolute residuals (γ/Z+jet)







$R_{balance} = \frac{p_T^{jet}}{p_T^{\gamma/Z}}$ and $R_{MPF} = 1 + \frac{\vec{E}_T^{miss} \cdot \vec{p}_T^{\gamma/Z}}{\left(p_T^{\gamma/Z}\right)^2}$

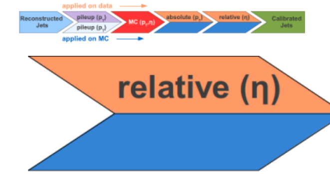
MPF (Missing $\vec{E}_T$ Projection Fraction)

- Idea: No intrinsic $\vec{E}_T^{miss}$ in such events (only induced by mismeasurement): projection of $\vec{E}_T^{miss}$ along reference object axis gives response

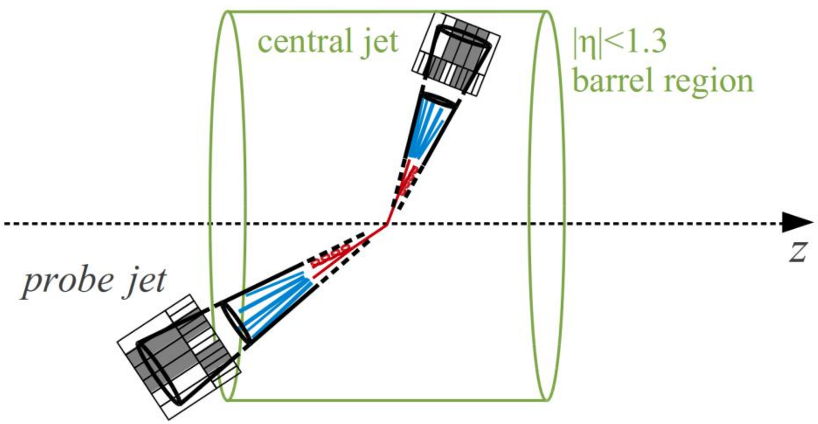
Complementary analyses/topologies used for calibration of central detector (|η|<1.3)

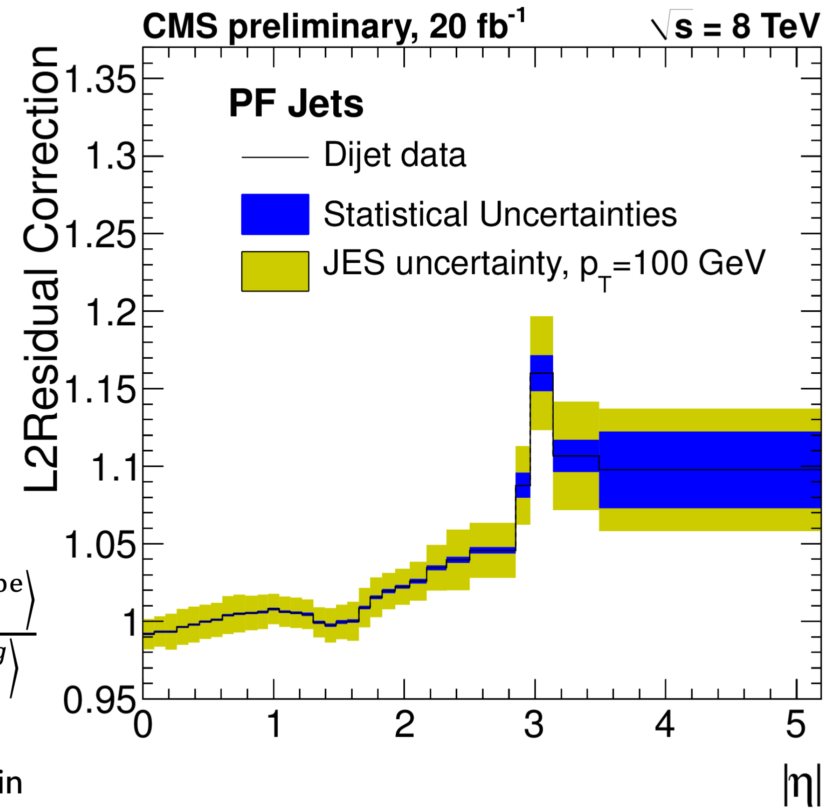
- $Z \rightarrow \mu^+\mu^-$ as central method, $Z \rightarrow e^+e^-, \gamma$ as cross checks
- Extrapolation to perfect topology

Residual difference of response from MPF method used as residual correction



Relative residuals (dijet)





Relative response from dijet balance

$$B = \frac{p_T^{\mathrm{probe}} - p_T^{tag}}{p_T^{\mathrm{ave}}} \rightarrow \langle R_{\mathrm{balance}} \rangle = \frac{2+\langle B \rangle}{2-\langle B \rangle} = \frac{\langle p_T^{\mathrm{probe}} \rangle}{\langle p_T^{tag} \rangle}$$

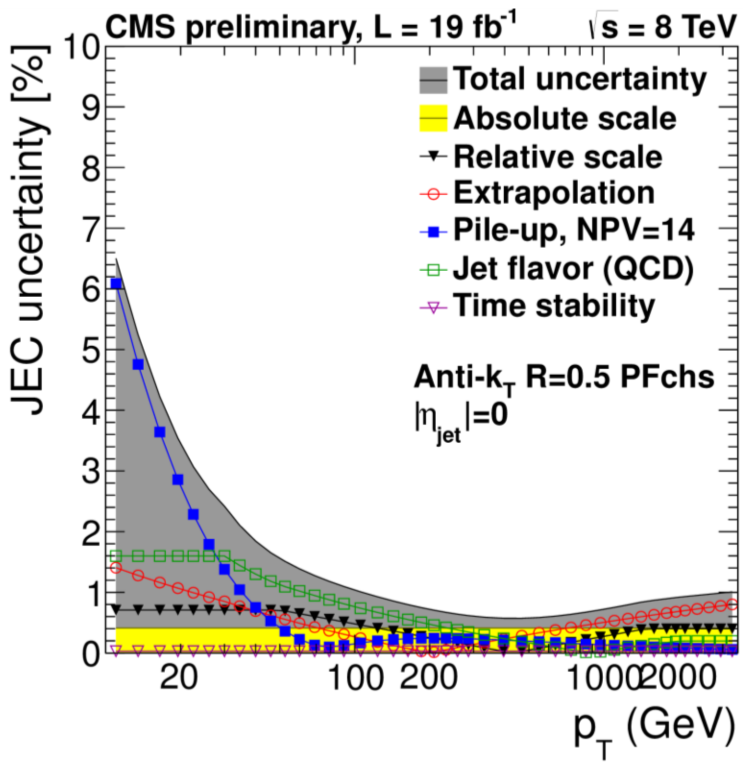
$$R_{\mathrm{MPF}} = 1 + \frac{\vec{E}_T^{\mathrm{miss}} \cdot \vec{p}_T^{tag}}{\left(p_T^{tag}\right)^2}$$

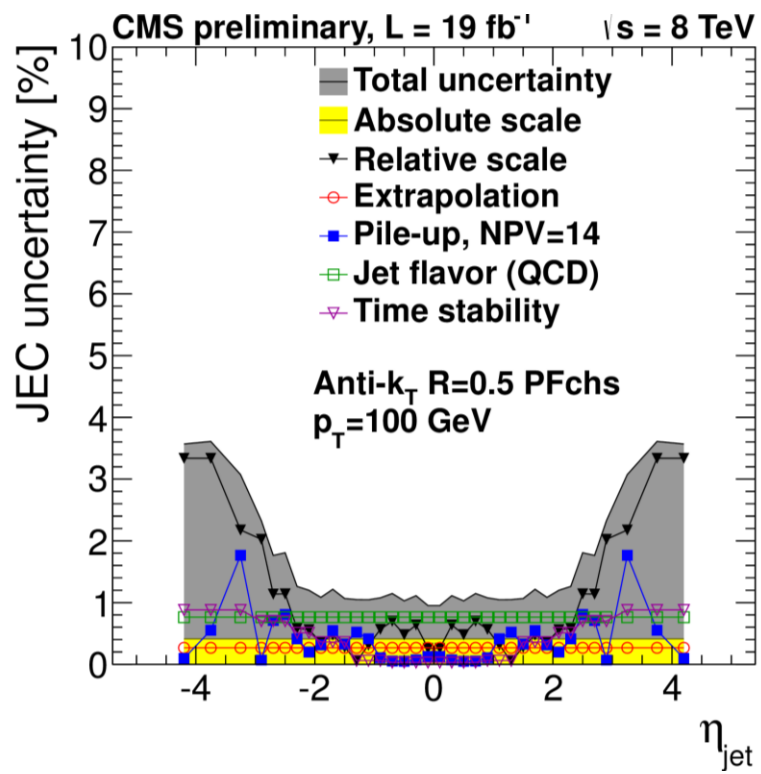
narrow p_T^{ave} bin

Dijet events used to relate response in central barrel region to any η

- Suppression of additional event activity (third jet)
- MPF method, traditional dijet balance as cross-check
- Below 5% within tracker coverage

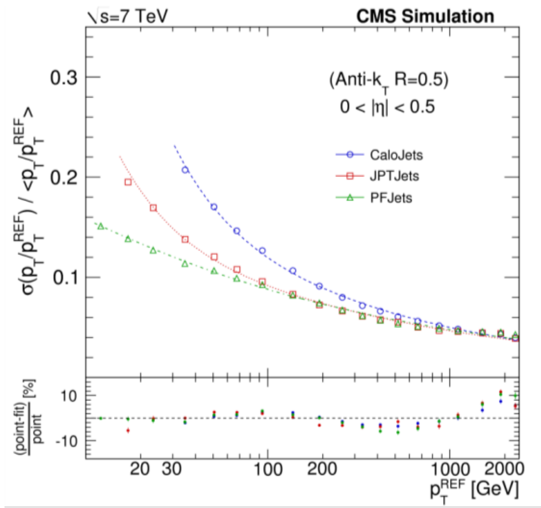
JEC uncertainties

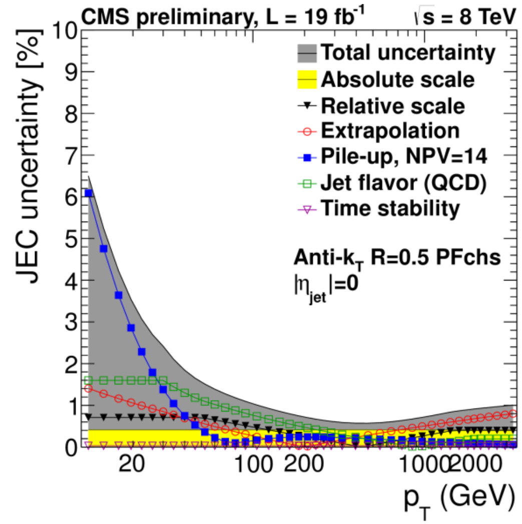


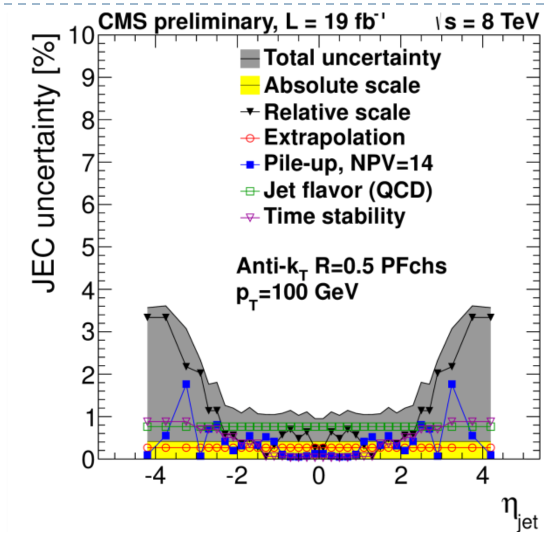


- Pileup, extrapolation, and jet flavor dominating uncertainties in |η|<1.3, relative scale at high |η|
- Uncertainties below 1% for jets with p_T>100 GeV

Conclusion







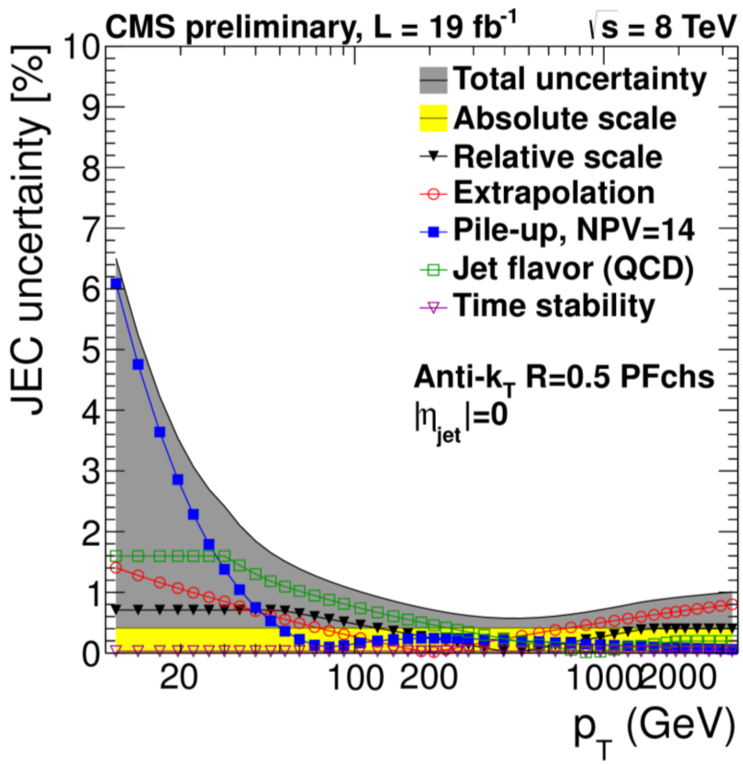
- Partice Flow algorithm used for most analyses in CMS(energy resolution better than 12 % at $p_T > 30$ GeV)
  - Challenging pileup conditions tackled by advanced techniques like charged hadron subtraction
- CMS factorizes Jet Energy corrections:
  - Make best use of simulation that accurately describes data
  - Correct for small remaining differences using data-driven residual corrections
- Small additional correction on data: ~2% absolute scale (Z+jet), relative inter-η (dijets)
- JES uncertainty <1% for $p_T > 100$ GeV in central region

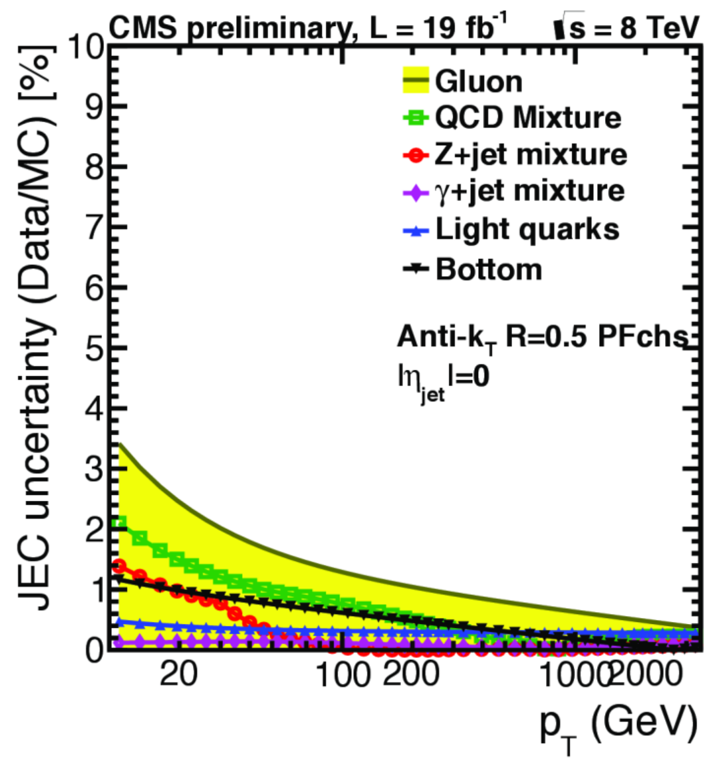
Backup

References

- **Determination of jet energy calibration and transverse momentum resolution in CMS**
  - *JINST* **6** P11002
  - Most recent paper on Jet Energy Correction and Uncertainties
- **Detector performance summaries**
  - Status of the 8 TeV Jet Energy Corrections and Uncertainties based on 11fb^{-1} of data in CMS (CMS DP-2013/011)
  - Jet Energy Corrections and Uncertainties. Detector Performance Plots for 2012 (CMS DP 2012/012)
  - Jet Energy Scale performance in 2011 (CMS DP-2012/006)
- **CMS Physics Analysis Summaries**
  - Jet Performance in pp Collisions at $\sqrt{s} = 7TeV$ (JME-10-003)
  - Jet Energy Corrections determination at $\sqrt{s} = 7TeV$ (JME-10-010)
  - Commissioning of the Particle-flow Event Reconstruction with the first LHC collisions recorded in the CMS detector (CMS-PAS-PFT-10-001)

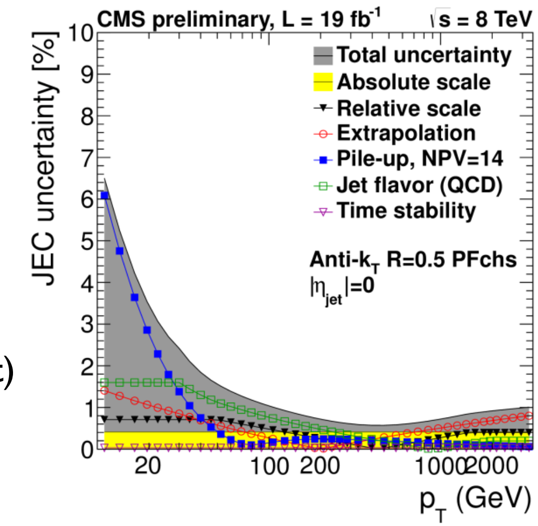
JEC uncertainty sources





- Flavor uncertainties now relative to reference Z+jet flavor composition, default assumed composition for uncertainties is QCD mixture.
- Part of uncertainty source framework: Provide ~20 individual sources that are mutually uncorrelated. Propagating individual sources to potentially reduce total uncertainty on measured quantities.

Uncertainty sources



Absolute scale

- Scale uncertainty (combined ECAL (photon) and tracking (Z) reference scale)
- FSR +ISR correction
- Statistical uncertainty

Relative scale

- Jet energy resolution
- Residual p_T-dependence (difference between log-linear and constant fit)
- Statistical uncertainty
- Modelling/FSR correction

Extrapolation

- Underlying event and fragmentation differences from PYTHIA/Herwig++
- Single particle response variation (±3%) propagated to jets

Pileup

- 20% of Data/MC differences in data-based random cone method (separate corrections provided)
- p_T- dependence of measured offset, e.g. due to zero suppression effects
- Random cone method bias in MC

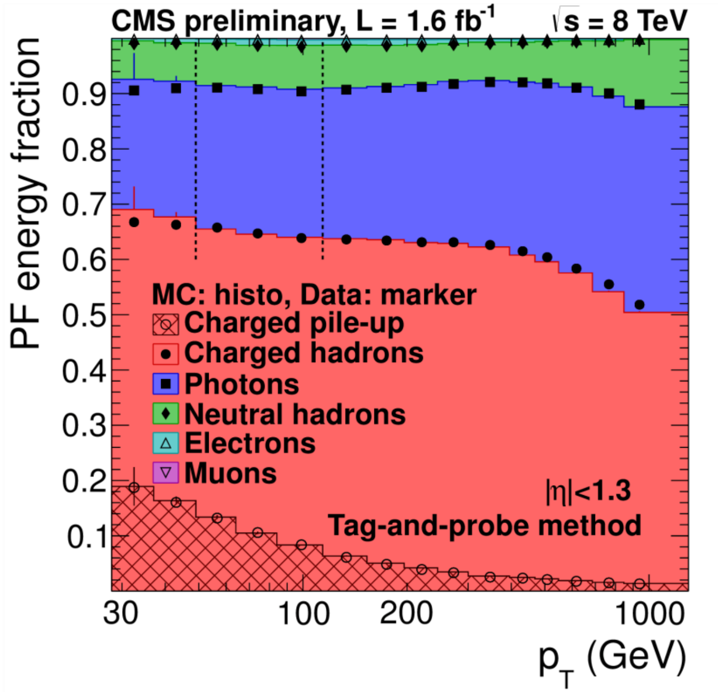
Jet flavor

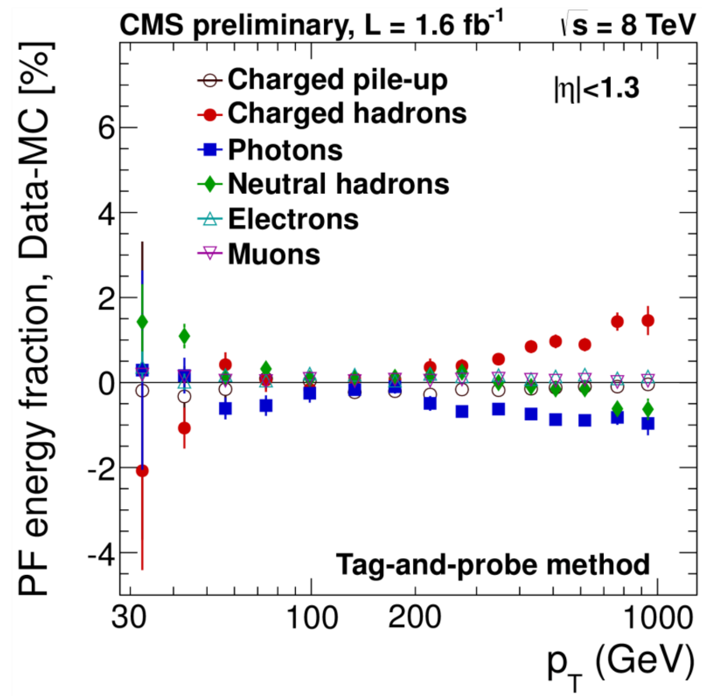
- Based on PYTHIA/Herwig++ differences in uds/c/b-quark and gluon responses, default covers extrapolating from Z+jet to dijet QCD flavor mixture, but gives access to individual sources

Time

- Observed instability in the endcap region, presumably linked to aging

Particle Flow Composition

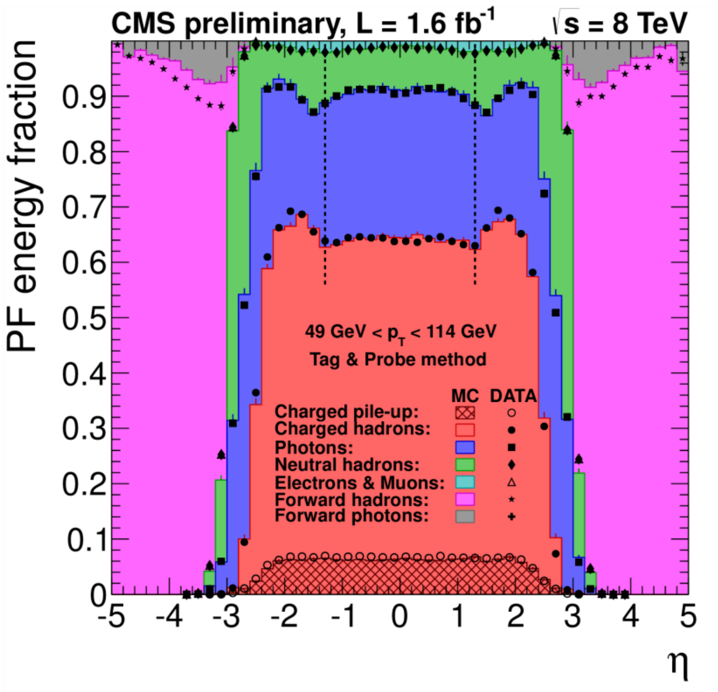


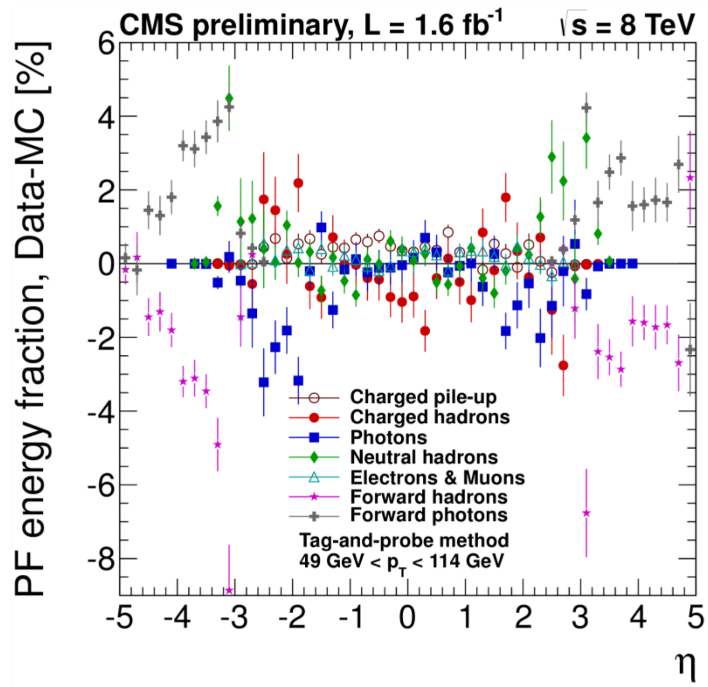


Particle Flow Composition

- Additional handle to quality of MC modelling
- agreement for track (charged hadrons), ECAL (photons), and HCAL (neutral hadrons) energies to **within 1%** in barrel

Particle Flow Composition





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Relative Residuals, dijets

Need for very high statistics
- QCD dijet events have very high statistics (and high pt-reach)

Caveat
- Not as well defined reference object

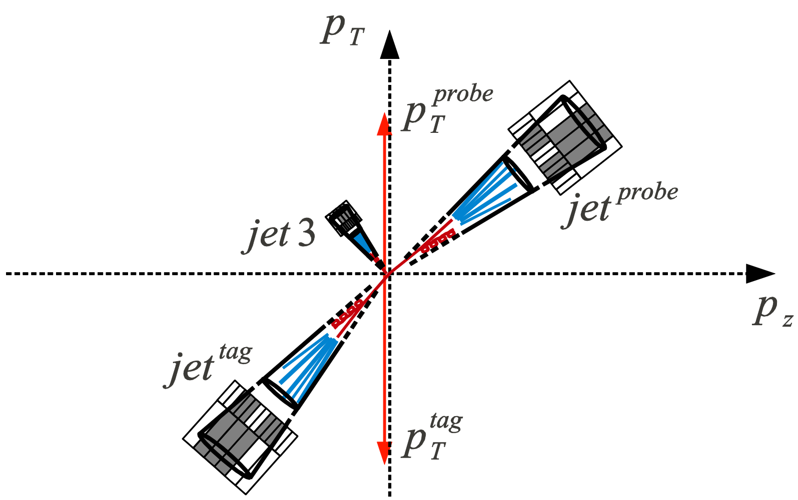
Strategy
- Calibrate jets relative to central region
- Data/MC ratios as residual correction
- Extrapolate to perfect topology

Event selection
- Two highest p_T jets
- $\Delta\varphi(j1, j2) > 2.7$
- $|\eta_{\mathrm{tag}}| < 1.3$

Relative response from dijet balance

$$B = \frac{p_T^{\mathrm{probe}} - p_T^{tag}}{p_T^{\mathrm{ave}}} \rightarrow \langle R_{\mathrm{balance}} \rangle = \frac{2+\langle B \rangle}{2-\langle B \rangle} = \frac{\langle p_T^{\mathrm{probe}} \rangle}{\langle p_T^{tag} \rangle}$$

narrow p_T^{ave} bin



MPF (Missing $\vec{E}_T$ Projection Fraction)

$$R_{\mathrm{MPF}} = 1 + \frac{\vec{E}_T^{\mathrm{miss}} \cdot \vec{p}_T^{\,tag}}{\left(p_T^{tag}\right)^2}$$

Absolute residuals, Z+jet and γ+jet

2 complementary response estimators:

p_T balance

- $R_{\text{balance}} = \frac{p_T^{\text{jet}}}{p_T^{\gamma}}$

MPF (Missing $\vec{E}_T$ Projection Fraction)

- $R_{\text{MPF}} = 1 + \frac{\vec{E}_T^{\text{miss}} \cdot \vec{p}_T^{\gamma}}{(p_T^{\gamma})^2}$
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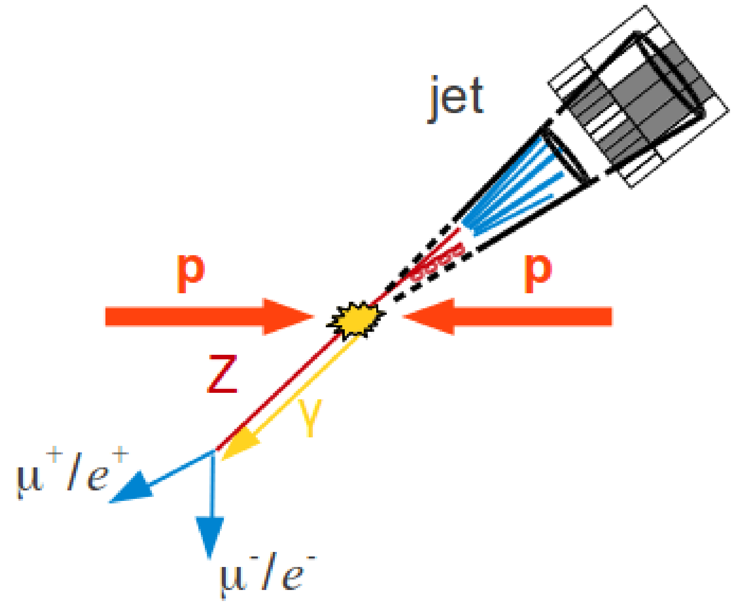
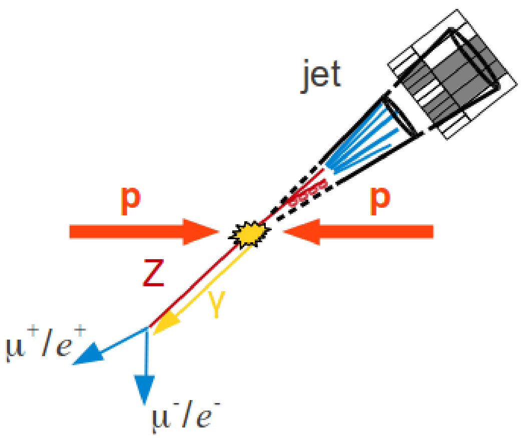
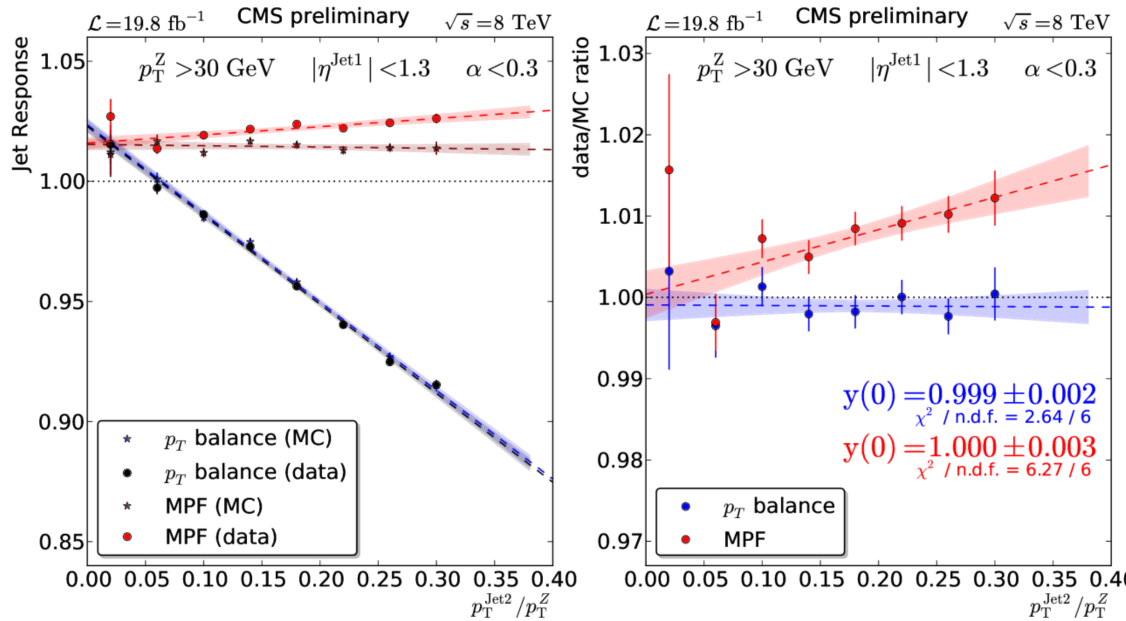


Data/MC ratio determined for different cuts on p_T^{Jet2}

- Extrapolation to zero additional event activity
- MPF largely reduces dependence (default method)

Absolute residuals, Z+jet and γ+jet





Z+jet gives central value

- Data/MC ratios of both methods agree
- Z+jet and γ+jet as cross checks