Karlsruhe Institute of Technology

Bundesministerium für Bildung und Forschung

CMS

# Performance of Jets and Missing Transverse Energy in CMS

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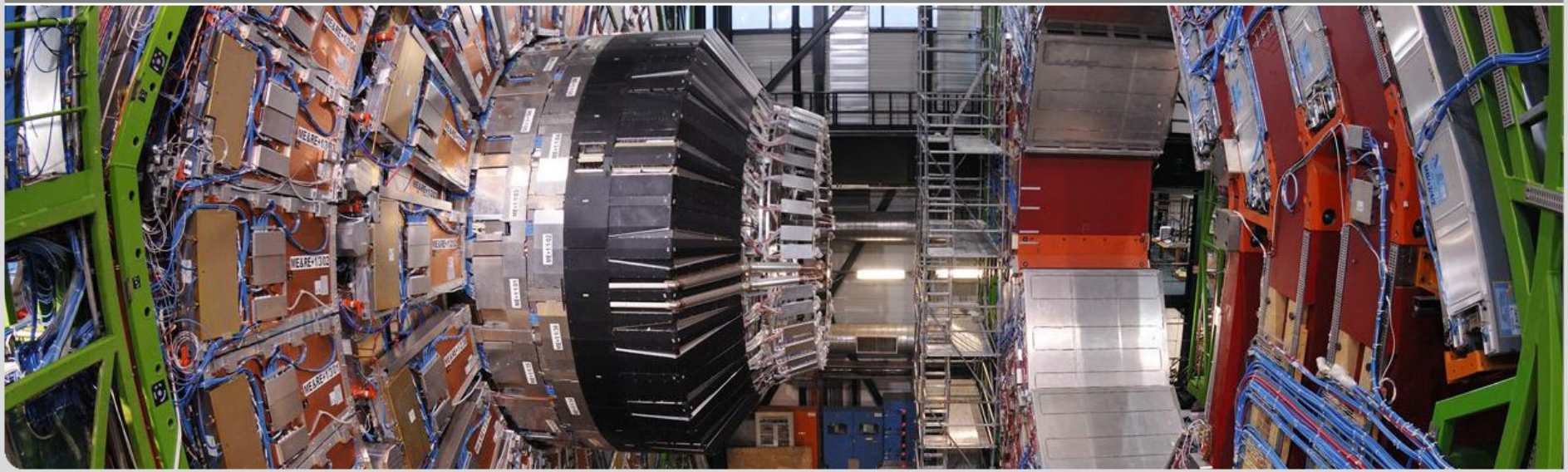
## Joram Berger for the CMS Collaboration

INSTITUT FÜR EXPERIMENTELLE KERNPHYSIK (EKP) · DEPARTMENT OF PHYSICS

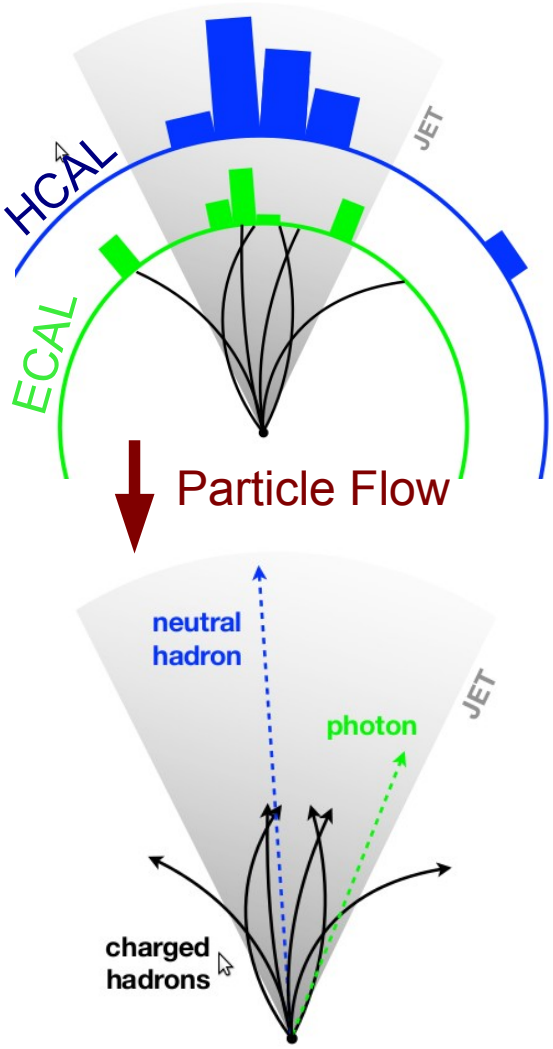



# Jet Reconstruction – Particle Flow Approach

- jets are ubiquitous at the LHC
- well calibrated jets are important for any analysis
- well understood missing transverse energy (MET) is the key for many new physics searches

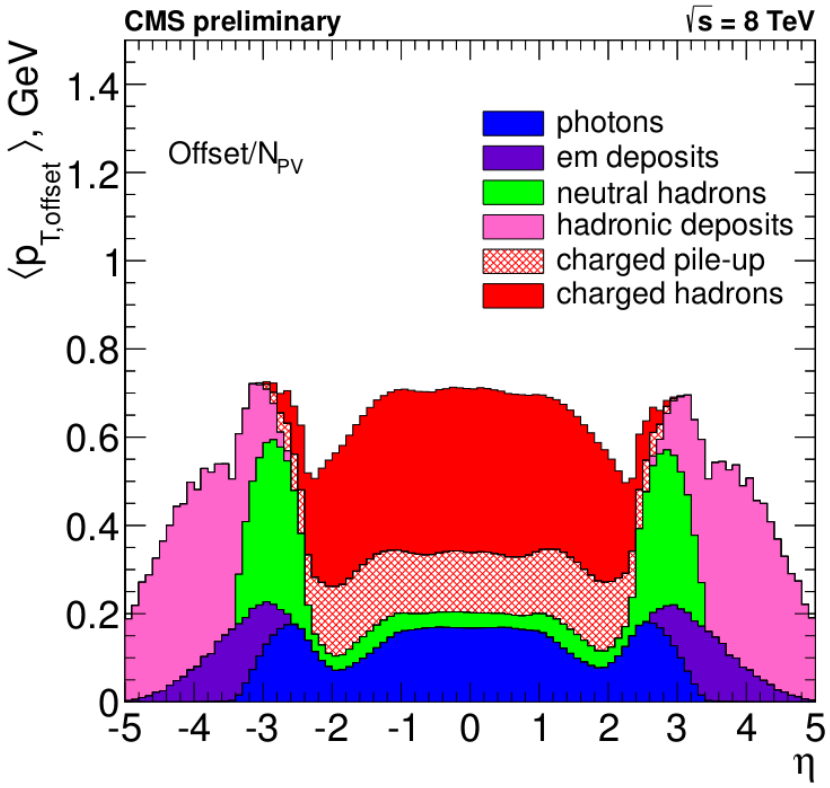
CMS “Particle Flow” approach:

- combining the information of all detector components prior to jet clustering, MET calculation etc.
- improved resolution
- contribution from different detector components accessible
- used in most CMS analyses



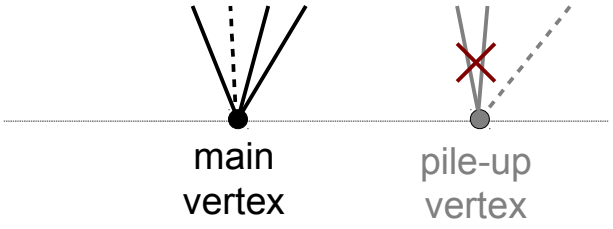

http://moriond.in2p3.fr/QCD/2011/ThursdayMorning/Pandolfi.pdf

# Major Challenge in 2012: Increase of Pile-Up



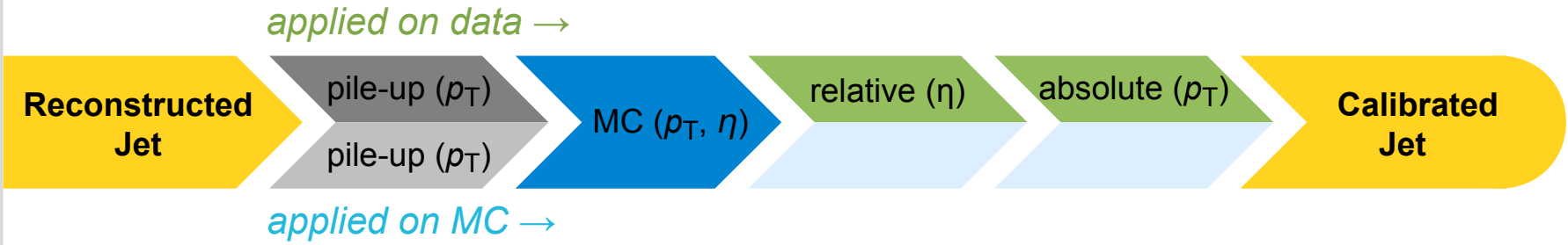

- dramatic increase of pile-up due to higher luminosity in 2012
- 12 primary vertices per event

- methods for **pile-up mitigation**:
  - Charged Hadron Subtraction *removes charged hadrons from pile-up vertices*




  - pile-up corrections for jets and missing energy

# Jet Energy Corrections in CMS



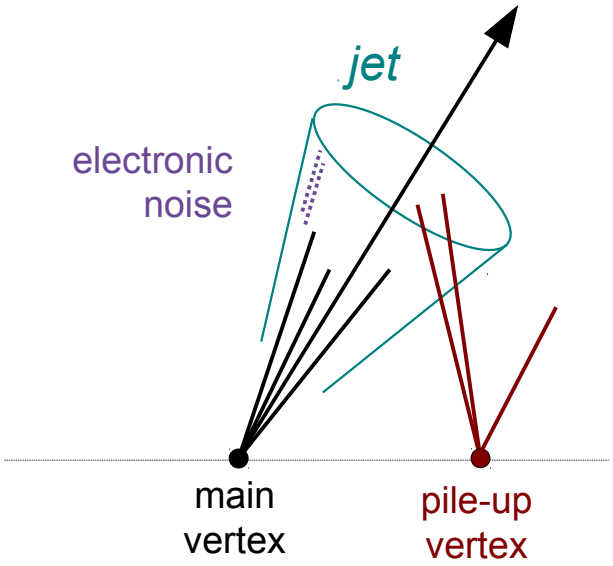

## Factorized approach for jet calibration in CMS

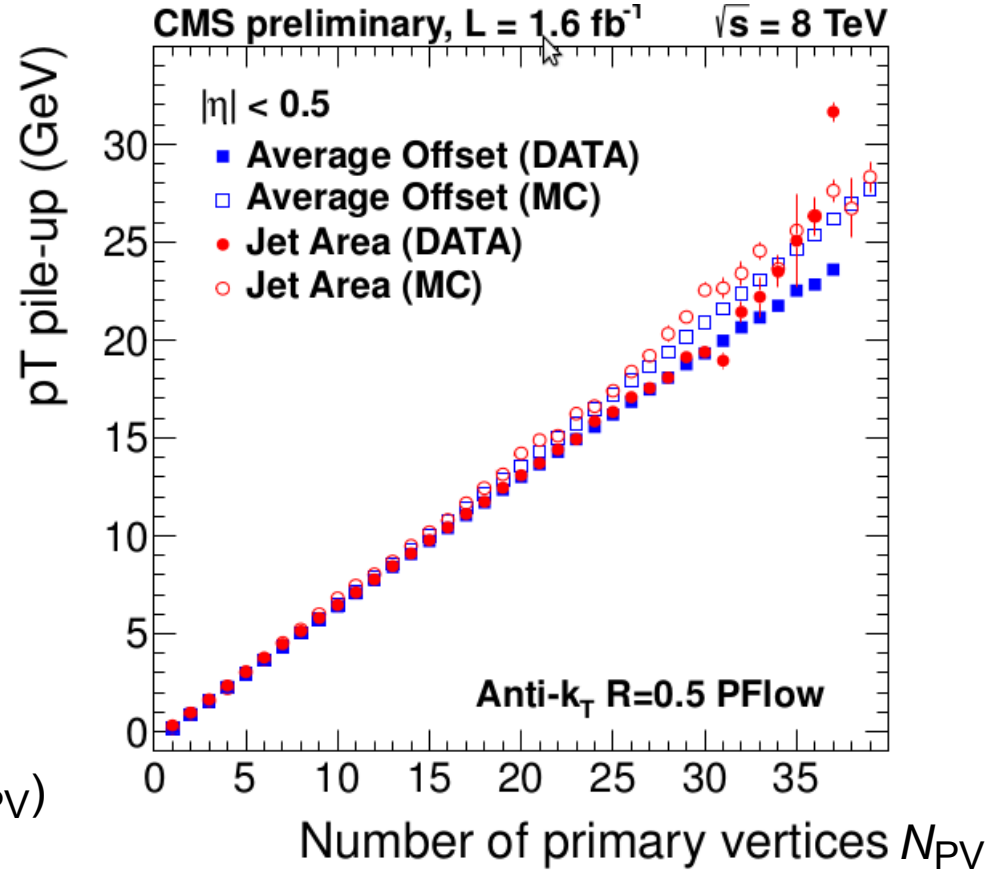
1) offset corrections for ***pile-up*** and ***electronic noise***
2) corrections for **detector** calibration and **reconstruction** efficiencies from MC — MC based
3) relative residual corrections for $\eta$ dependence — data driven
4) residual corrections to absolute $p_T$ — data driven

CMS jet energy corrections combine

- ✔ the advantages of MC based studies with
- ✔ the robustness and accuracy of data-driven methods

# Pile-Up Corrections




2 combined methods to measure and correct for pile-up and noise

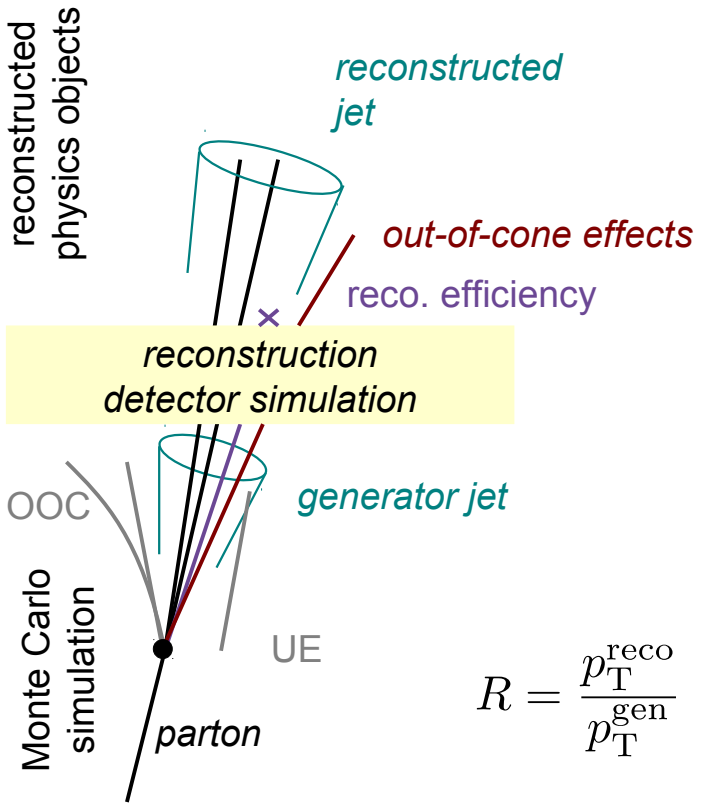
- Average Offset Correction ($N_{PV}$)
- Jet Area Correction ($A_j$, $\rho$)

  $A_j$: jet area

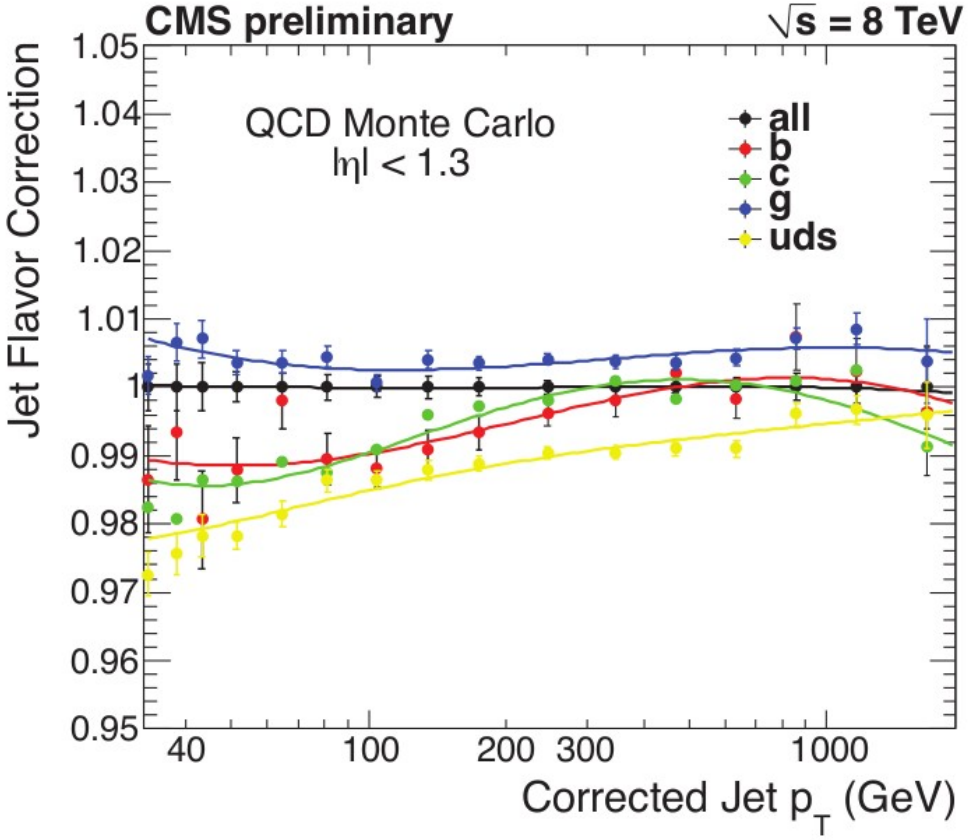
  $\rho$: energy density from pile-up in the event

  [arXiv:0707.1378v2] Salam. et al.

# Corrections Based on MC Simulation



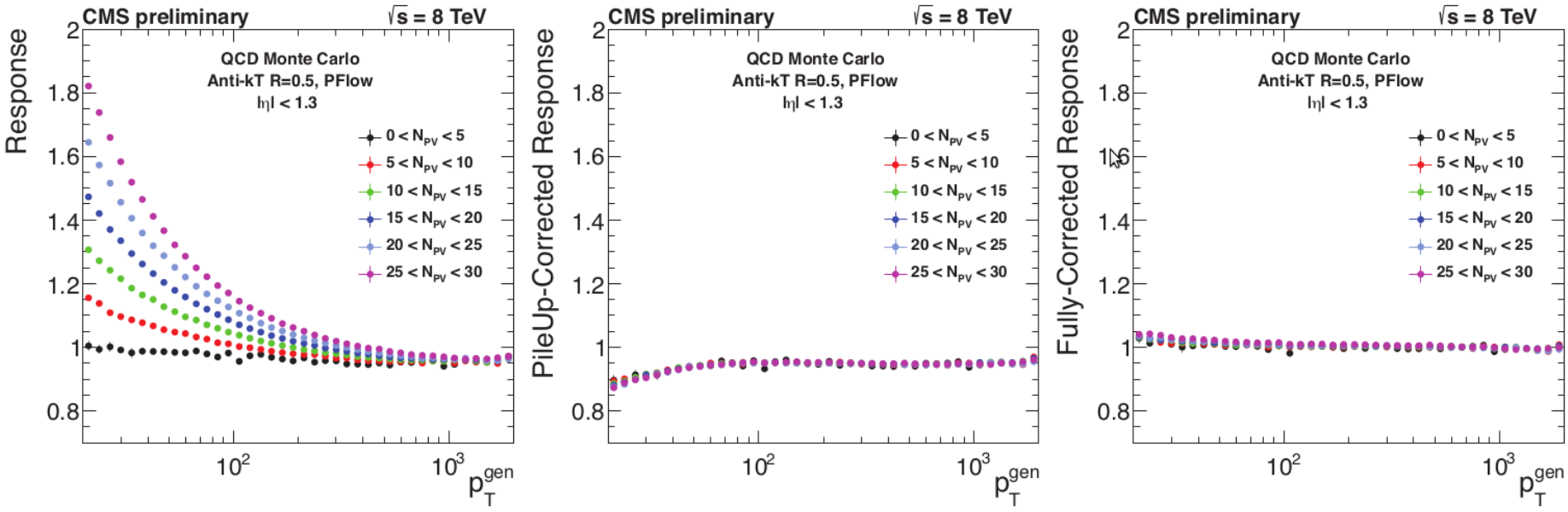

$$R = \frac{p_{\mathrm{T}}^{\mathrm{reco}}}{p_{\mathrm{T}}^{\mathrm{gen}}}$$




- correction for $p_{\mathrm{T}}$ and $\eta$ dependence
- reconstructed jet $p_{\mathrm{T}}$ is corrected to the generator jet (based on QCD MC)

- Particle Flow minimizes flavor dependence (< 3% in barrel)
- no flavor corrections by default

# Closure Test of MC Corrections




**Before corrections**

- high contribution of PU especially at low $p_T$
- additional $p_T \sim N_{PV}$

**After pile-up corrections**

- pile-up dependence removed
- consistent for any number of PU interactions $N_{PV}$

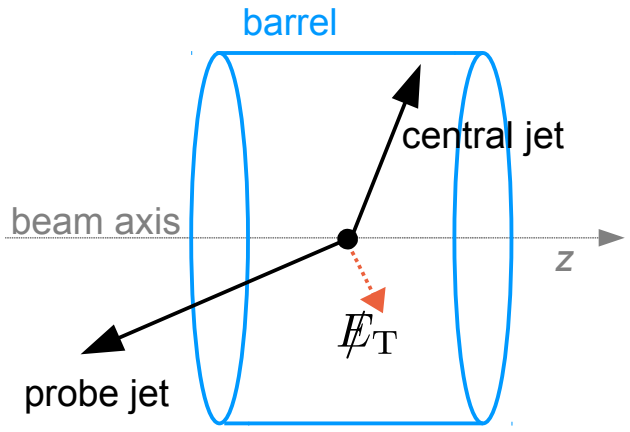
**After MC truth corrections**

- closure at unity over the whole $p_T$ and $\eta$ range

*final correction for simulation, additional corrections for data needed*

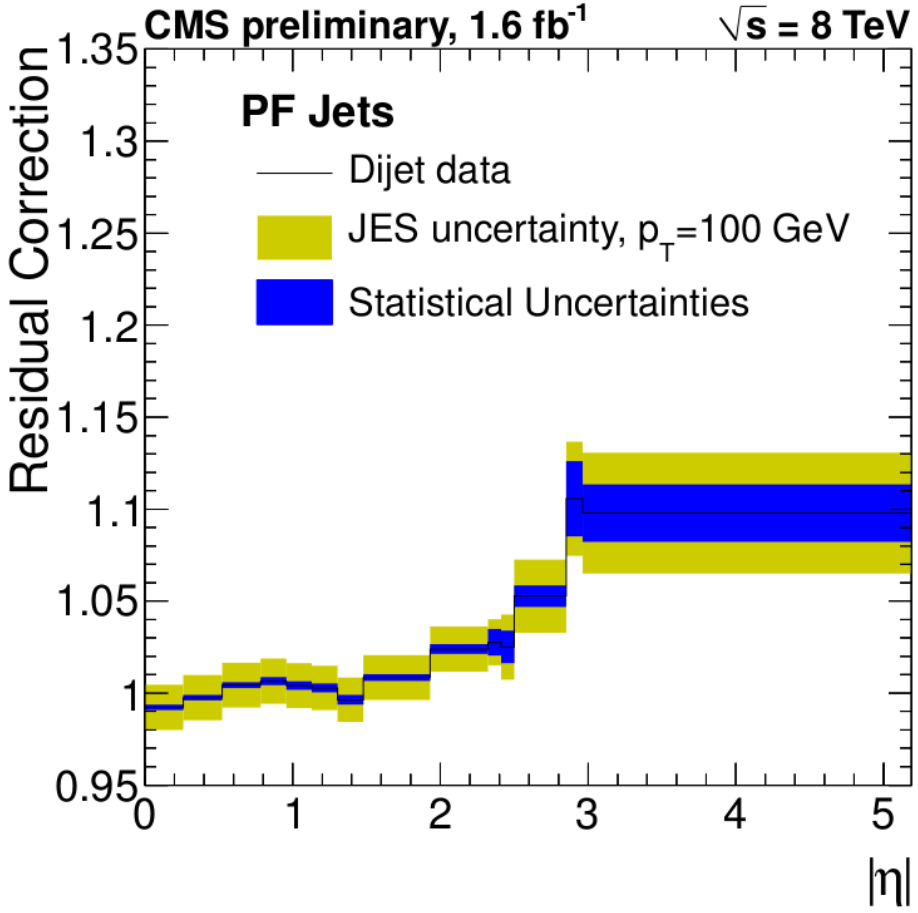
# Data-Driven Corrections for $\eta$ Dependence

- correct for residual difference in $\eta$ between data and MC
- derived from dijet balance



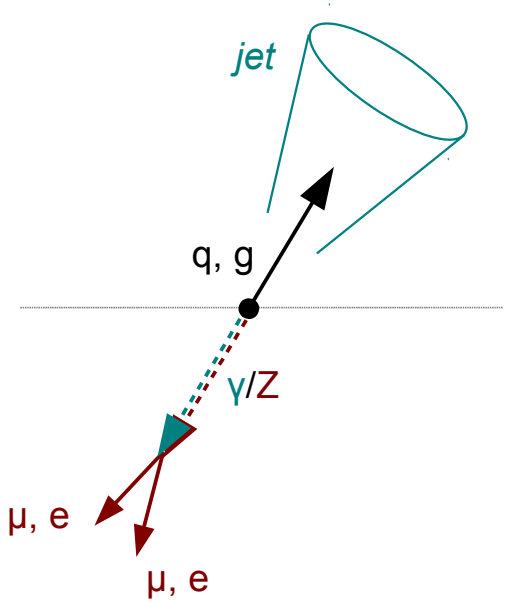

- calibration factor is derived such that reconstructed MET vanishes

  (MPF method, → backup)
- extrapolation to perfect topology with no additional jet activity

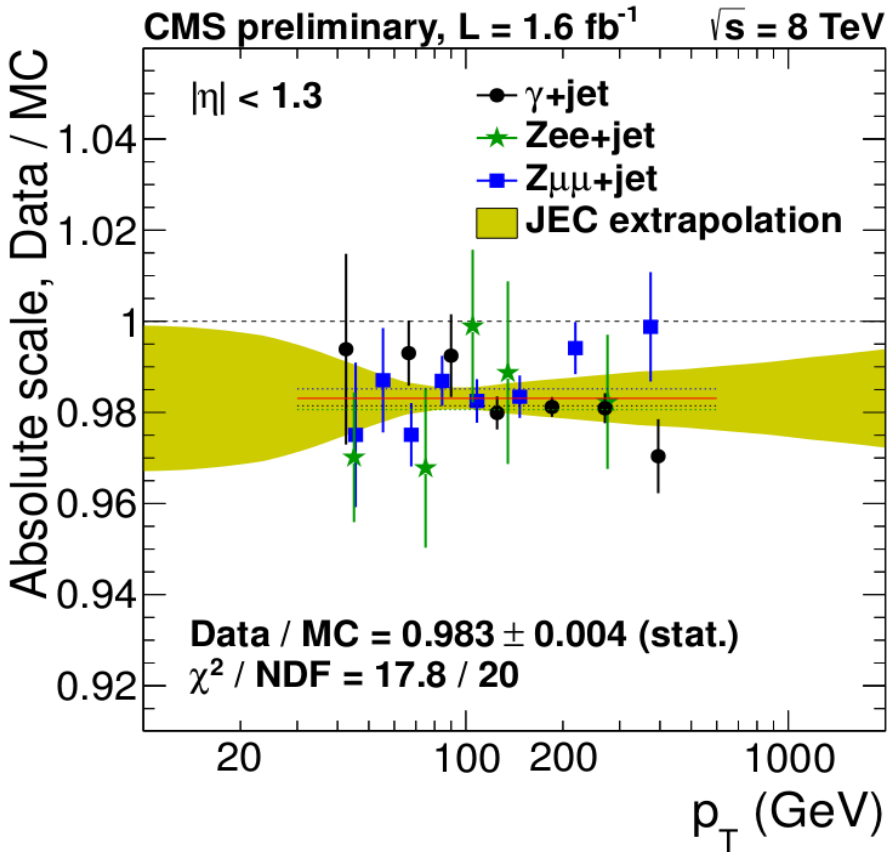


# Data-Driven Corrections of the Absolute Scale

- correction for residual differences in $p_T$ between data and MC
- 3 complementary topologies:
  - γ + jet
  - Z(→ee) + jet
  - Z(→μμ) + jet

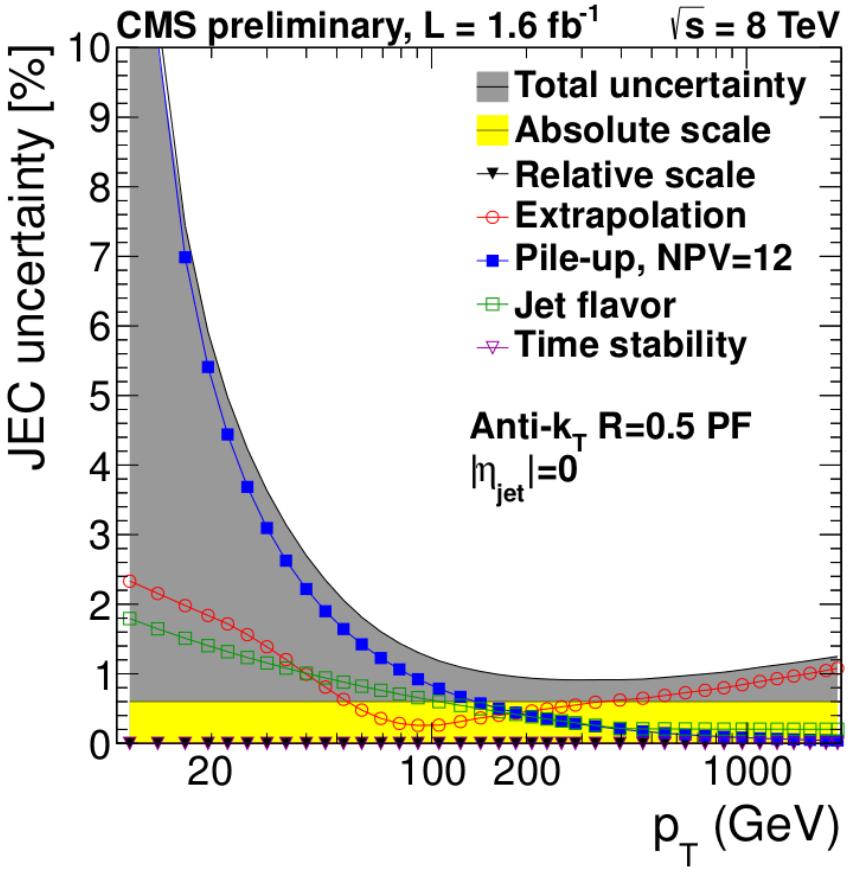


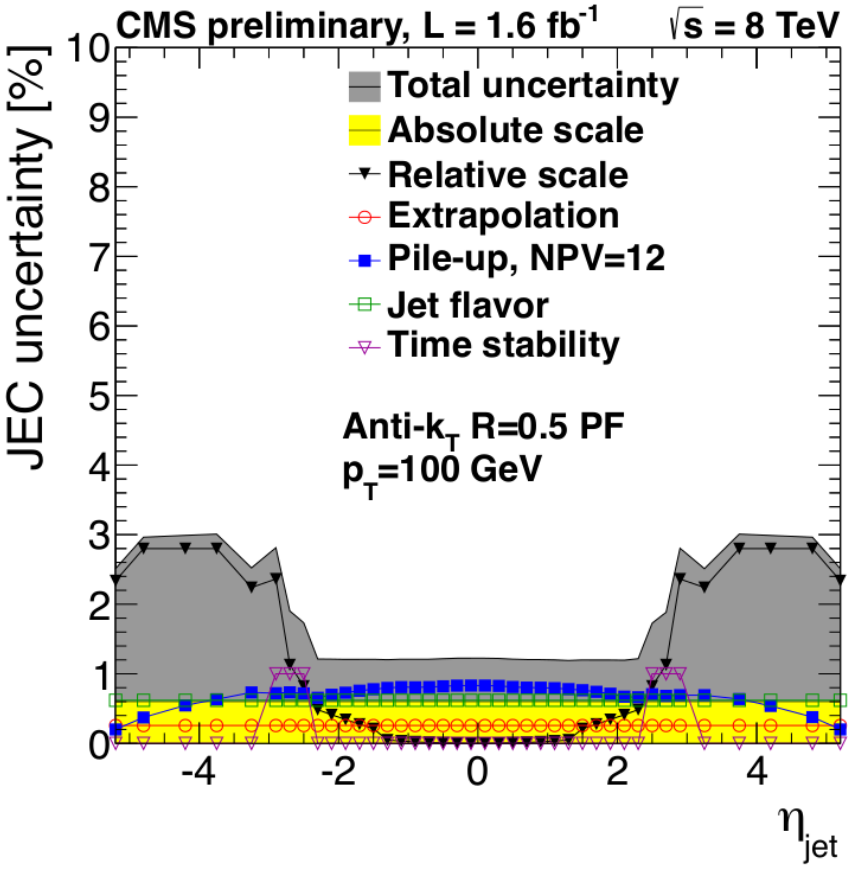

⇒ *final correction of jet $p_T$*




- γ/Z measurement with high precision
- absolute scale with MPF method
- extrapolation to perfect topology

# Jet Energy Correction Uncertainties



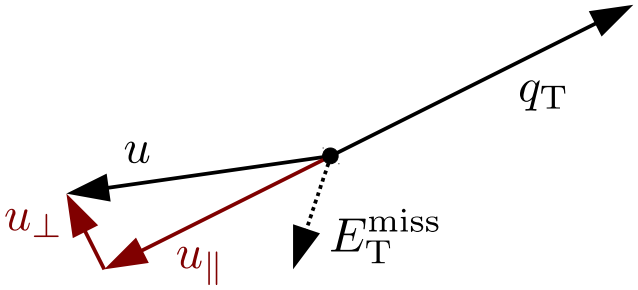




- the contribution of different uncertainty sources depends on $p_T$ and $\eta$
- total uncertainty of the jet energy scale is close to 1% for $|\eta| < 2.4$

# Missing Energy Performance

- measured in Z(→μμ) events
  - clean final state
  - no intrinsic MET

$$\vec{u}^{\,\mathrm{recoil}} + \vec{q}_{\mathrm{T}}^{\,\mathrm{Z}} + \vec{E}_{\mathrm{T}}^{\,\mathrm{miss}} = 0$$

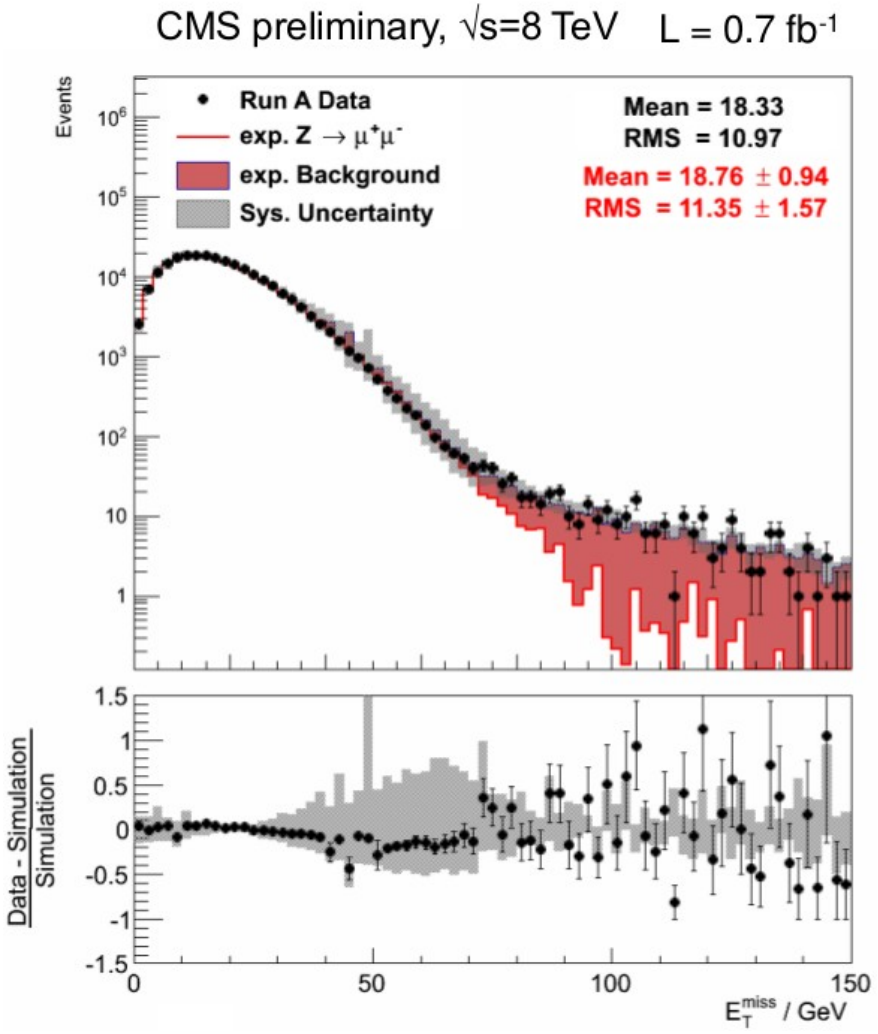



- measure for MET scale

$$\left\langle -\frac{u_{\parallel}}{q_{\mathrm{T}}} \right\rangle$$

- measure for MET resolution

$$\sigma(-u_{\parallel} - q_{\mathrm{T}}), \sigma(u_{\perp})$$

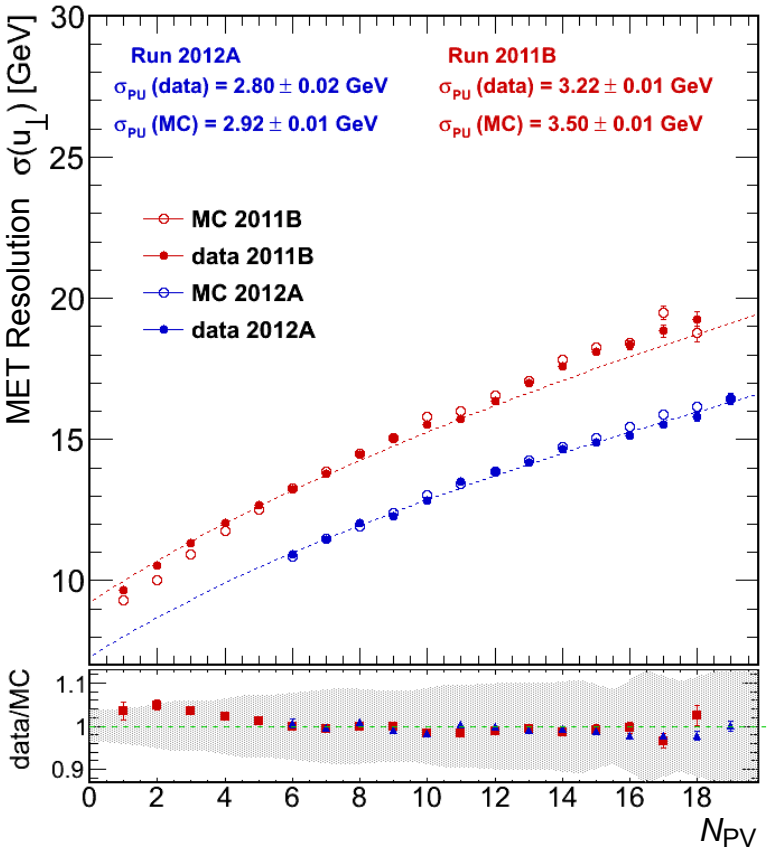


# Missing Energy Resolution and Pile-Up

- MET resolution for different $N_{PV}$ is fitted with:

$$\sigma_{\text{tot}} = \sqrt{c^2 + \frac{N_{\text{PV}}}{0.7} \cdot \sigma_{\text{PU}}}$$

- the fit yields:
  - $c$ : average resolution without PU
  - $\sigma_{PU}$ : degradation in resolution caused by PU
- improved resolution in 2012 for fixed $N_{PV}$
  - improved ECAL/HCAL energy reconstruction
    ⇒ reduces out-of-time pileup effects
  - MET pile-up corrections applied
- pile-up introduces an additional smearing of ~ 3 GeV on MET resolution $\sigma_{PU}$ (in quadrature)



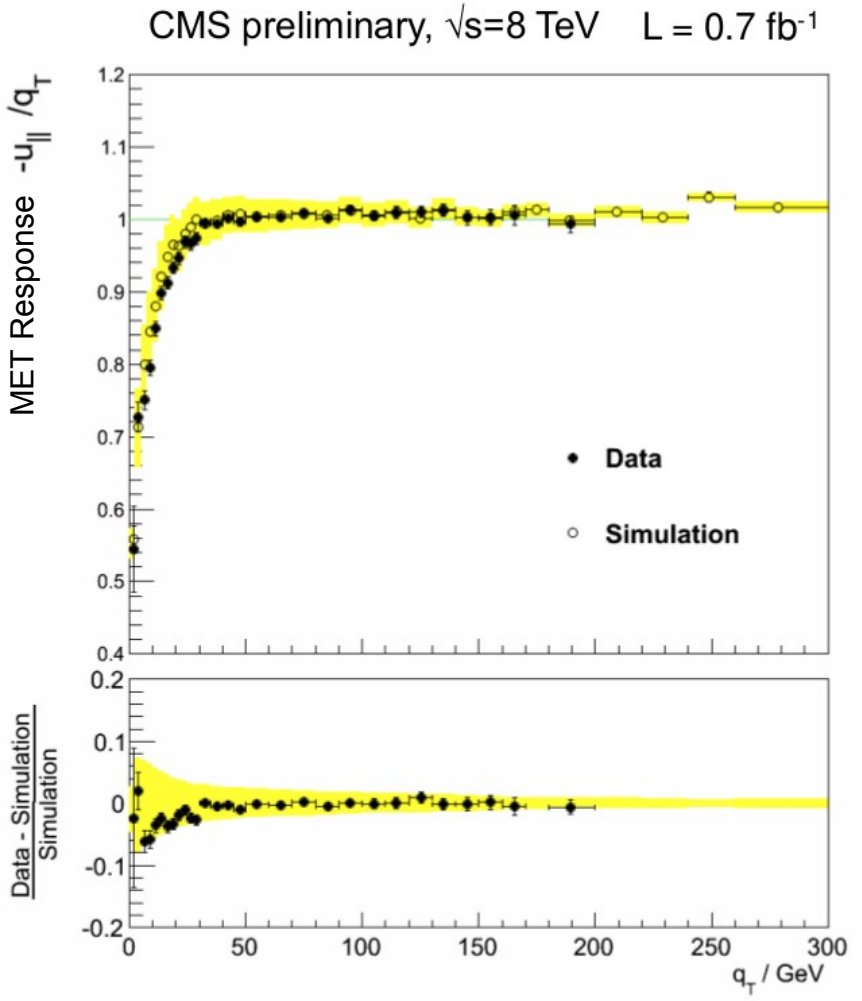

⇒ working on improved algorithms to reduce the effect of PU

⇒ we can keep up with increasing luminosity

# Missing Energy Corrections

- corrected MET:
  - (1) jet corrections are applied
  - (2) MET is recalculated

- MET response is close to unity after corrections in data and MC



# Conclusion

- CMS **successfully** uses a **factorized approach** to **jet energy corrections**
  - Jets are measured with a **precision** of **up to 1%** in CMS
- **MET** is **well understood** and calibrated
- Robust **data-driven techniques** reduce systematical uncertainties

- Methods described in
  - JINST 6 (2011) P11002 http://iopscience.iop.org/1748-0221/6/11/P11002
  - JINST 6 (2011) P09001 http://iopscience.iop.org/1748-0221/6/09/P09001
- Recent results are available in
  - DP 2012/003 http://cdsweb.cern.ch/record/1454656
  - DP 2012/006 http://cdsweb.cern.ch/record/1454659

# Back-up

# Jet Energy Uncertainty Sources

**Absolute scale**

- reference scale (combined photon (EM) and Z→μμ (tracking) uncertainties)
- statistical uncertainty
- FSR + ISR correction

**Relative scale** ($\eta$-dependence)

- jet $p_T$ resolution
- statistical uncertainty (averaged out over wider detector regions, only important outside tracking)
- FSR correction

**Extrapolation for high $p_T$**

- differences in fragmentation and underlying event (based on Pythia6 Z2/Herwig++2.3)
- single pion response to PF jets (based on propagation of ±3% variation)

**Jet flavor** (uds, c, b, g)

- differences in quark and gluon responses relative to QCD mixture (based on Pythia6 Z2/Herwig++2.3)

**Time stability**

- observed instability in the endcap region over the year, presumably due to the EM laser correction instability

**Pile-up corrections**

- data/MC differences vs. $\eta$ in Zero-Bias data
- residual out-of-time pile-up for prescaled triggers, if reweighing MC to unprescaled data
- offset dependence on jet $p_T$, e.g. due to zero suppression effects
- differences in measured offset from a neutrino gun MC and from MC truth in the QCD sample
- observed jet rate variation versus $N_{PV}$ in 2011 single jet triggers, after applying L1 corrections

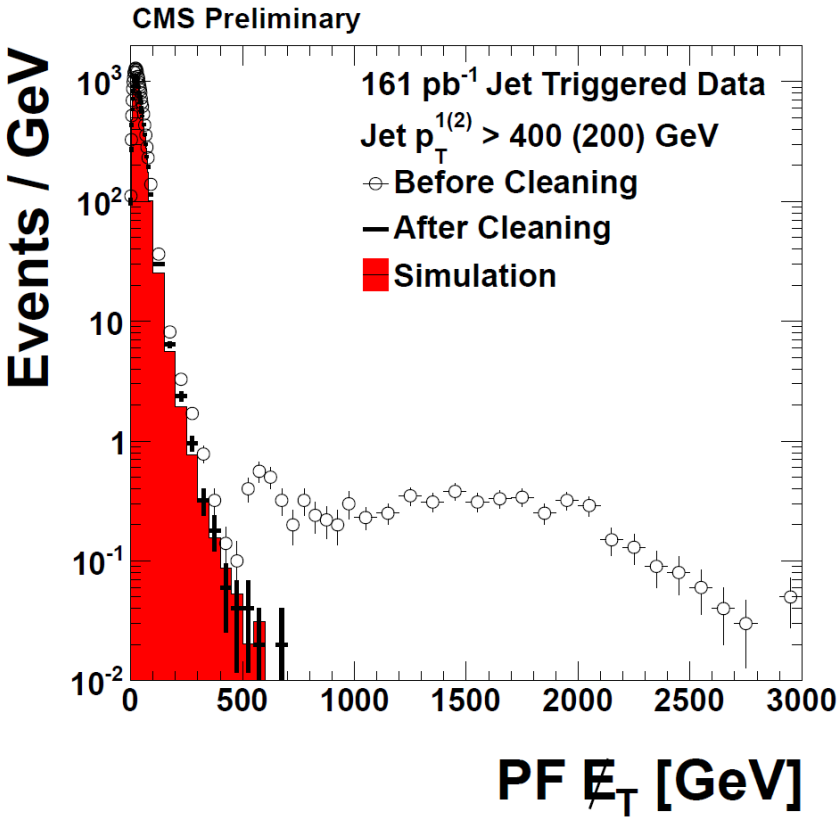
# False MET and Event Cleaning/Filtering

**Sources of false MET includes:**

- particle momentum mismeasurements
- particle misidentification
- detector malfunctions
- particles impinging on poorly instrumented regions of the detector
- cosmic-ray particles
- beam-halo particles

**Event Cleaning and Filtering**

- uses timing, pulse shape, topology of signal
- improve the agreement between data and simulation




CMS-DP-2011-010

# The MPF Method and Extrapolation to Zero Additional Jets

- in events without intrinsic MET the system of equations is solved:

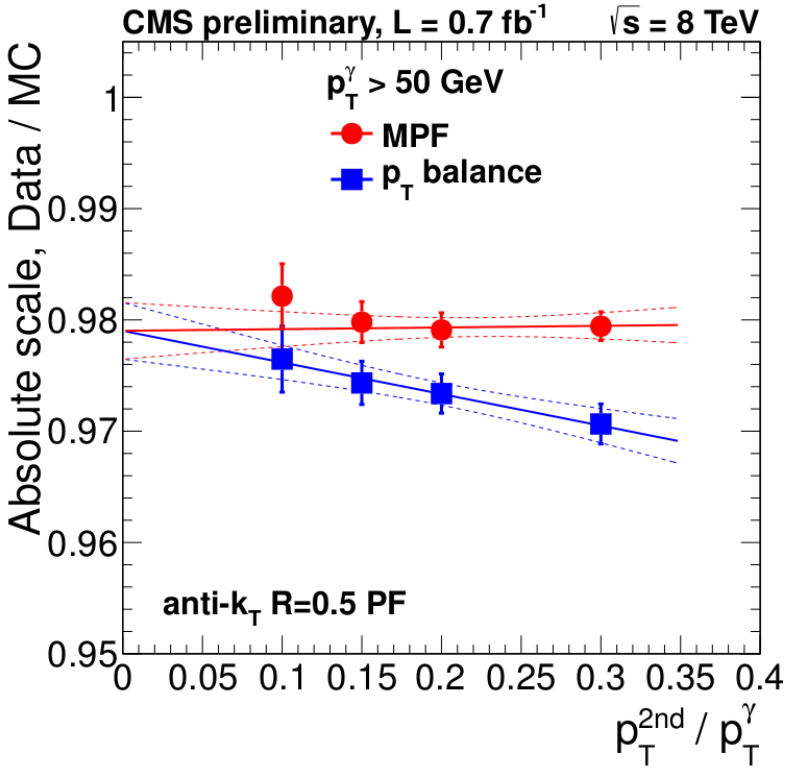
$$\vec{p}_{\mathrm{T}}^{\,\mathrm{jet}} + \vec{p}_{\mathrm{T}}^{\,\mathrm{ref}} = 0$$

$$R_{\mathrm{MPF}} \cdot \vec{p}_{\mathrm{T}}^{\,\mathrm{jet}} + \vec{p}_{\mathrm{T}}^{\,\mathrm{ref}} = \vec{E}_{\mathrm{T}}^{\mathrm{miss}}$$

$$\Rightarrow \quad R_{\mathrm{MPF}} = 1 - \frac{\vec{E}_{\mathrm{T}}^{\mathrm{miss}} \cdot \vec{p}_{\mathrm{T}}^{\,\mathrm{ref}}}{|\vec{p}_{\mathrm{T}}^{\,\mathrm{ref}}|^2}$$

*example for 2 balancing objects*

- this method is compared to the direct $p_{\mathrm{T}}$ balancing




- the cut on the additional jet activity is varied
- extrapolation to 0 additional activity
- MPF does not need extrapolation