Jet Reconstruction and Measurements of Jet Performance at CMS

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Workshop on "Jet Reconstruction and Spectroscopy at Hadron Colliders"
Pisa, April 18th 2011

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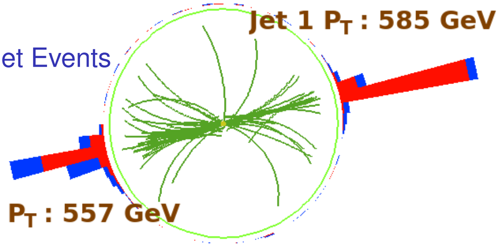
- Introduction
  - Jet Reconstruction
  - Jet Energy Corrections

- Measurements using Dijet Events
  - Dijet Asymmetry Method
  - Residual Correction
  - Jet Resolution
  - Jet Resolution Tails
- Measurements using Photon-Jet Events
  - Methods
  - Jet Resolution
  - Absolute Jet Energy Scale



- Summary
  - Jet Energy Scale
  - Jet Resolution
  - Conclusion

Jets at CMS

Jet algorithms using FastJet 2.4.x:

- anti-k_T $R = 0.5$, $R = 0.7$
- k_T $D = 0.4$, $D = 0.6$
- (Iterative Cone $R = 0.5$)

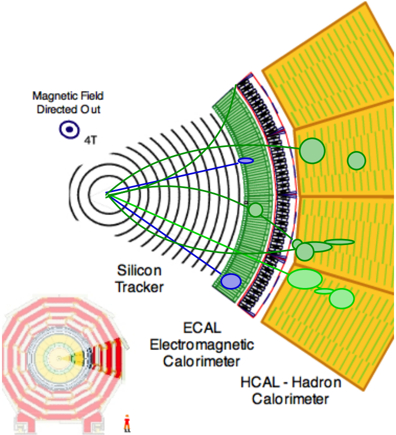
Recombination scheme

E-scheme (sum of momentum Lorentz vectors)

Jets at CMS

Jet types:

- Generator jets
  input: stable generated particles



Jets at CMS

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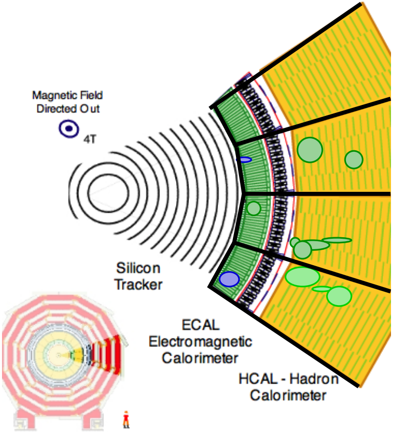
- Calorimeter jets

  input: calorimeter towers (HCAL cells + ECAL crystals) after threshold cuts against noise



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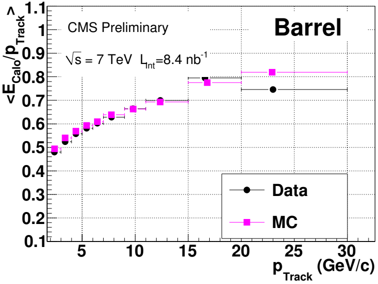

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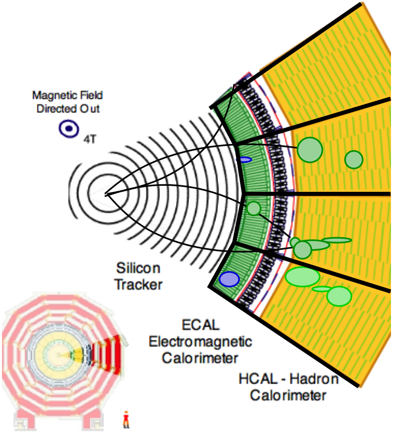
  correct reconstructed calorimeter jets with tracks



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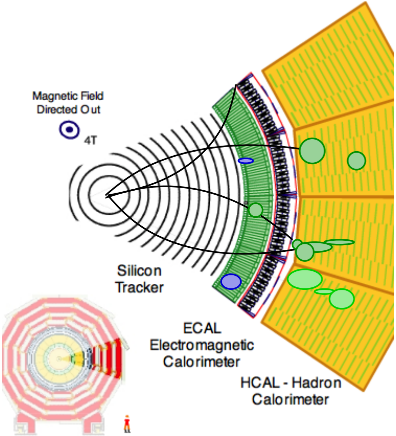
- Particle Flow
  combines information from all CMS sub-detectors and reconstructs muons, electrons, photons, charged hadrons and neutral hadrons



Jets at CMS

Jet types:

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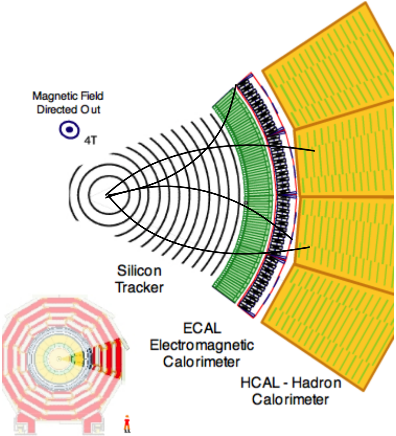
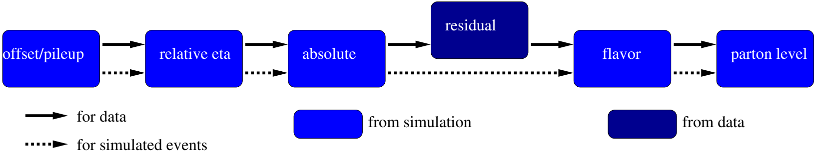
- Jet-Plus-Track jets
  correct reconstructed calorimeter jets with tracks
- Particle Flow
  combines information from all CMS sub-detectors and reconstructs muons, electrons, photons, charged hadrons and neutral hadrons
- Track jets
  input: well measured tracks



Jet Energy Corrections



Factorized Approach:

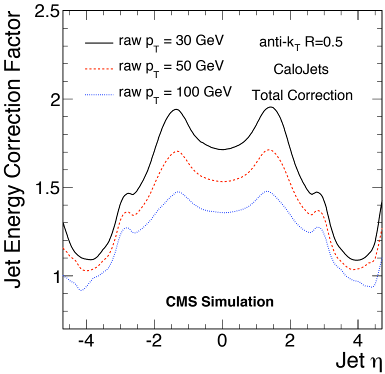
- offset: removal of pile-up and electronic noise
- relative η: variations of jet responses with η
- absolute: correction to particle level jet response
- (only for data) residual: correct for differences between data and simulation
- flavor: correct to particle level assuming different flavors
- parton: correct to parton level

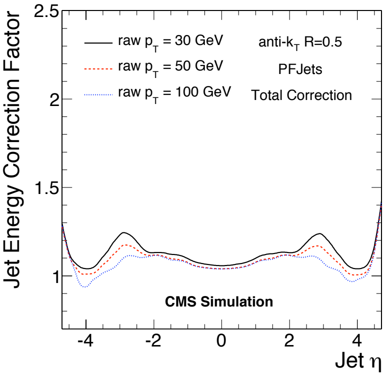
Monte Carlo Truth Jet Energy Corrections

Absolute and relative correction: $C(p_T, \eta)$

input: **PYTHIA** QCD events and **GEANT4** simulation

goal: bring response $R = \frac{p_T^{jet}}{p_T^{GenJet}}$ to one



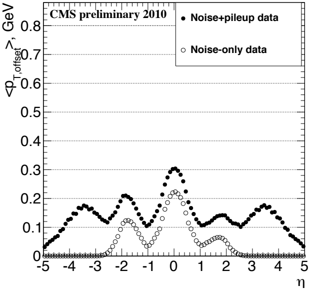


Pileup Correction

Algorithms:

- estimate amount of Pileup using
  - number of primary vertices (PVs)
  - compute UE/pileup density ρ using **FastJet**

  ... correct jets for number of PVs or jet area
- explicitly remove particles from other PVs before clustering jets



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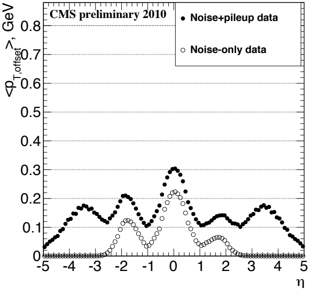


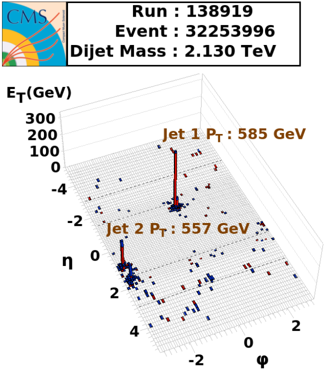
In the following:

validate jet reconstruction and correction on data!

Dijet Asymmetry Method

Event Selection:

- use special triggers on average p_T of dijet system
- two highest p_T jets:
  - pass jet quality cuts
  - $\Delta\varphi(\text{jet1}, \text{jet2}) > 2.7$
  - $p_T^{\text{ave}} = (p_T^{\text{jet1}} + p_T^{\text{jet2}})/2$
- cut on $p_{T,\text{rel}}^{\text{jet3}} = \frac{p_T^{\text{jet3}}}{p_T^{\text{ave}}}$

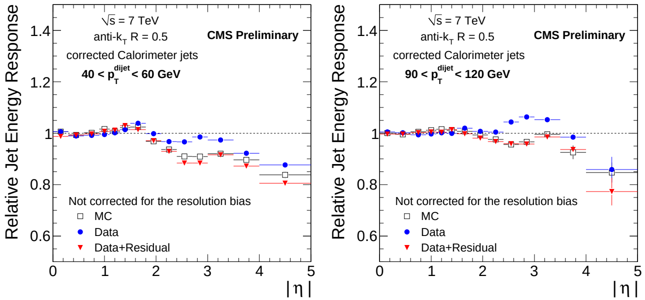


Study:

- Asymmetry: $A = \frac{p_T^{\text{jet1}} - p_T^{\text{jet2}}}{p_T^{\text{jet1}} + p_T^{\text{jet2}}}$
- relative Response: $R(\eta^{\text{jet2}}, p_T^{\text{ave}}) = \frac{1+<A>}{1-<A>} \rightarrow \frac{p_T^{\text{jet1}}}{p_T^{\text{jet2}}}$ for one event

Relative Response

require one (tag) jet in barrel ($|\eta| < 1.3$) and $R(\eta^{\text{probe}}, p_T^{\text{ave}}) = \frac{1+<A>}{1-<A>}$

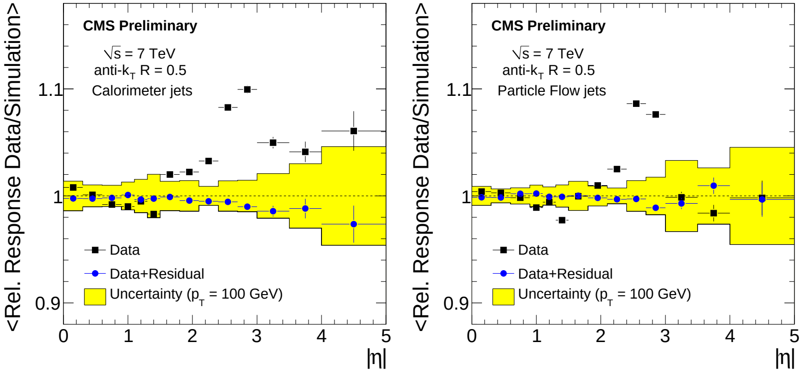


- *resolution bias* due to steeply falling spectrum and varying resolution in *eta*
- effect due to soft radiation (FSR) (different modelling in MC compared to data)

-> look at ratio $\frac{R^{\text{data}}}{R^{\text{simulation}}}$ and extrapolate it to $p_{T,\text{rel}}^{\text{jet3}} = 0$

Dijet Balance on $L = 2.9\ pb^{-1}$

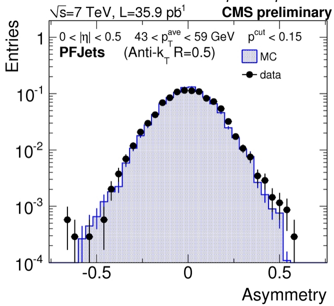
Ratio of relative responses: $\frac{R^{data}}{R^{simulation}}$:

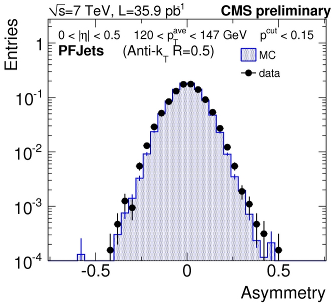


- residual correction clearly needed
- already good precision with first data
- update for full 2010 data set done, but not yet published

Jet Resolution from Dijet Asymmetry

Asymmetry: $A = \frac{p_T^{jet1} - p_T^{jet2}}{p_T^{jet1} + p_T^{jet2}}$





In the limit $p_T = < p_T^{jet1} > = < p_T^{jet2} >$ and $\sigma(p_T) = \sigma(p_T^{jet1}) = \sigma(p_T^{jet1})$:
$\frac{\sigma(p_T)}{p_T} = \sqrt{2}\sigma_A$.

- extra activity from soft radiation
- particle-level imbalance (out-of-cone showering) -> ???

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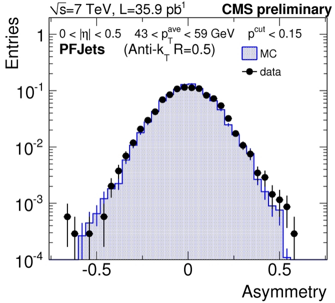

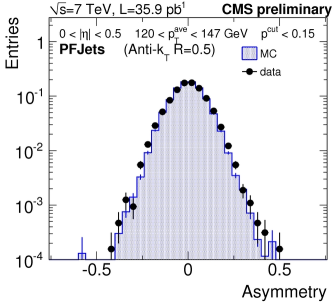

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- extra activity from soft radiation -> extrapolate to $p_{T,rel}^{jet3} = 0$
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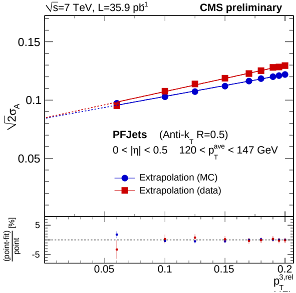

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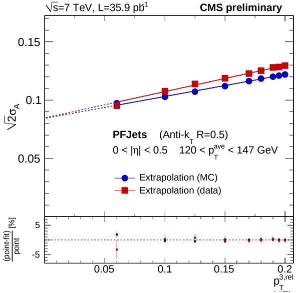

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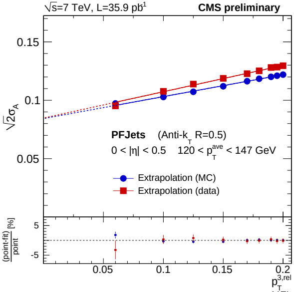
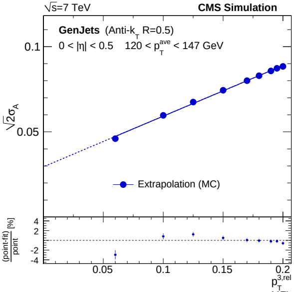
  -> correct measurement using simulation

Jet Resolution from Dijet Asymmetry

Asymmetry: $A = \frac{p_T^{\text{jet1}} - p_T^{\text{jet2}}}{p_T^{\text{jet1}} + p_T^{\text{jet2}}}$





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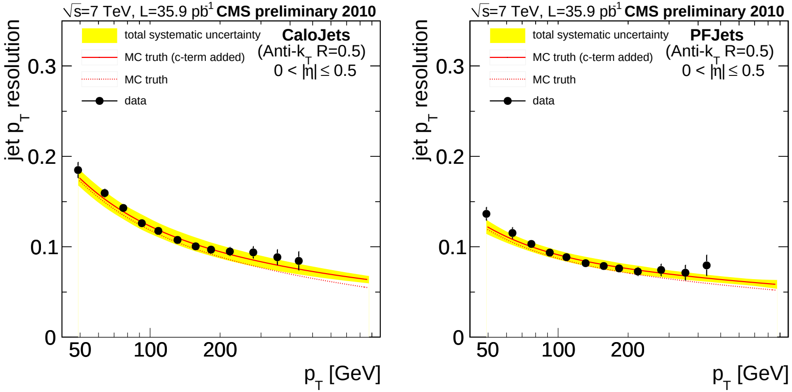
- extra activity from soft radiation -> extrapolate to $p_{T,\text{rel}}^{\text{jet3}} = 0$
- particle-level imbalance (out-of-cone showering) -> correct measurement using simulation

Resolution Measurement with L $= 36\ \mathrm{pb}^{-1}$

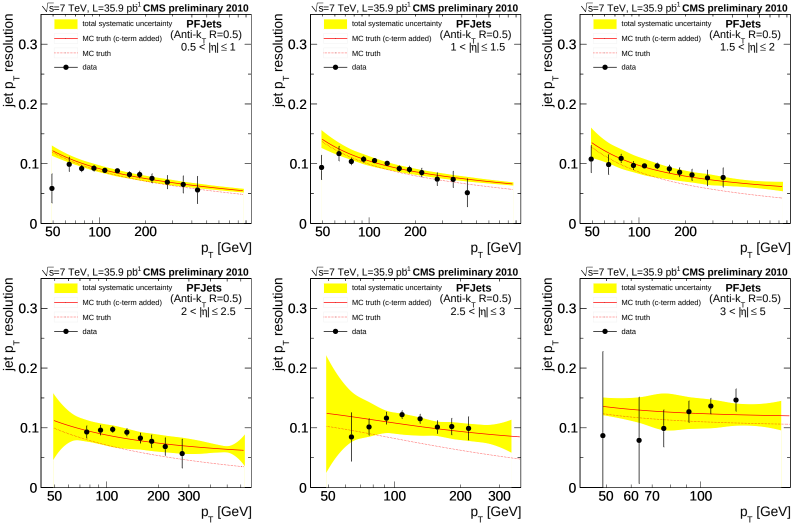
fit: $\frac{\sigma(p_T)}{p_T} = \sqrt{\mathrm{sgn}(N)(\frac{N}{p_T})^2 + S^2 \cdot p_T^{(M-1)} + C^2}$



- PF jets have better resolution than Calorimeter jets
- $\approx$ 10% worse resolution in data than simulation (compatible with larger constant term in resolution formula)

Resolution of PF jets with L= 36 pb^{-1}

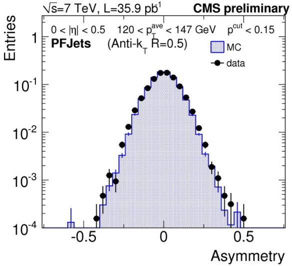
fit: $$\frac{\sigma(p_T)}{p_T} = \sqrt{\mathrm{sgn}(N)\left(\frac{N}{p_T}\right)^2 + S^2 \cdot p_T^{(M-1)} + C^2}$$

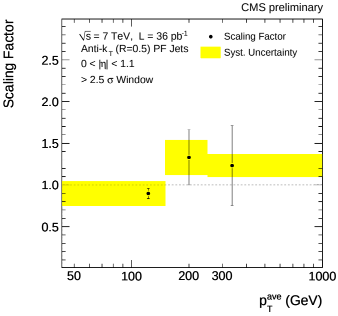


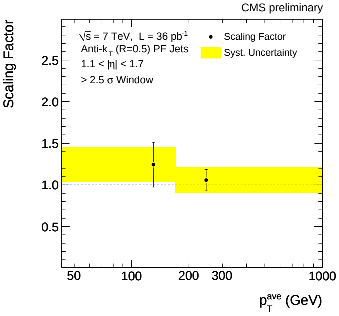
Response Tails from Dijet Balance on $L = 36\ \text{pb}^{-1}$

Idea:

- count events in tail of asymmetry
- extrapolate $p_{T,\text{rel}}^{\text{jet3}} = 0$
- compare with simulation



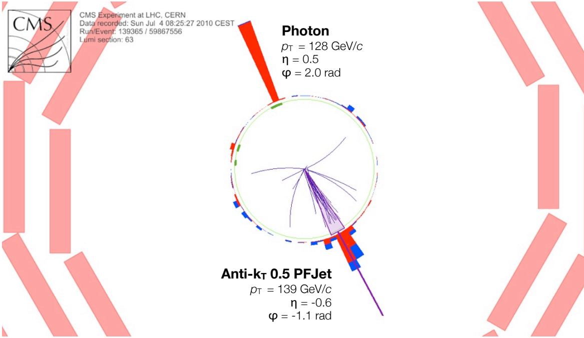




Photon-Jet Events

Event Selection:

- use photon trigger
- one photon and highest p_T jet:
- cut on $p_{T,\mathrm{rel}}^{\mathrm{jet2}} = \frac{p_T^{\mathrm{jet2}}}{p_T^{\gamma}}$

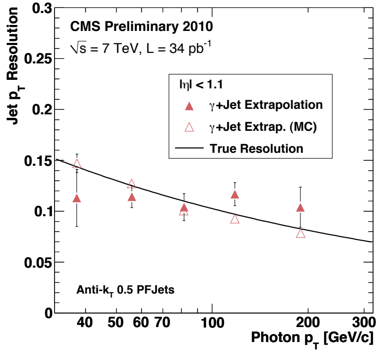


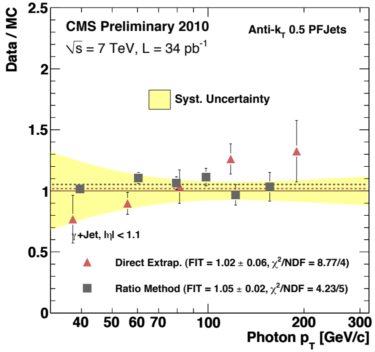
Study:

- jet balancing: $R_{\mathrm{jet}} = \frac{p_T^{jet}}{p_T^{\gamma}}$
- MPF (missing E_T projection method) $R_{\mathrm{jet}} \approx R_{MPF} = R_{\gamma} + \frac{\vec{E}_T^{\mathrm{miss}} \cdot \vec{p}_T^{\gamma}}{(p_T^{\gamma})^2}$

Photon-jet Balance on $L = 36\ \mathrm{pb}^{-1}$

estimate resolution from $\sigma(\frac{p_T^{jet}}{p_T^{\gamma}})$, extrapolate to $p_{T,\mathrm{rel}}^{\mathrm{jet2}} = 0$

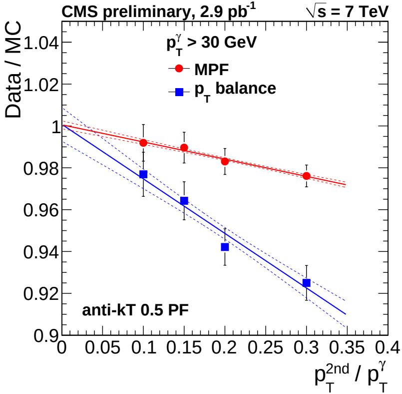


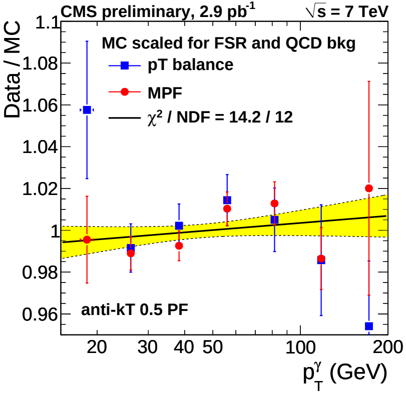


- agreement between data and MC
- cross check to dijet asymmetry result

Absolute Jet Energy Scale L$= 2.9\ \text{pb}^{-1}$

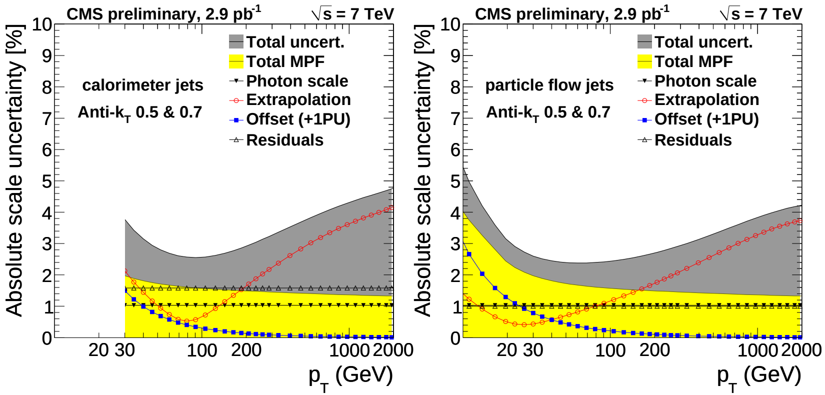
response ratio: $\frac{R_{\text{jet}}^{\text{data}}}{R_{\text{jet}}^{\text{simulation}}}$:





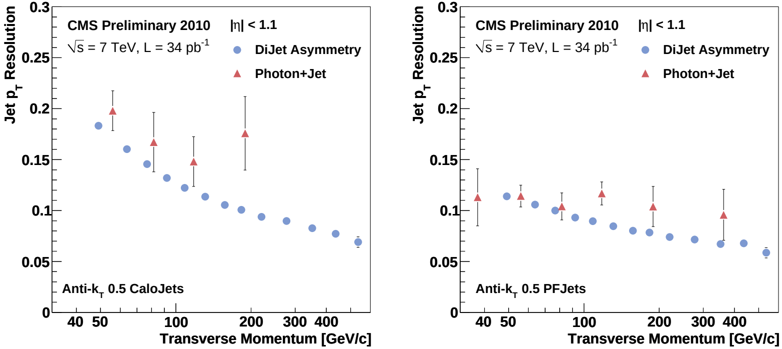
- extrapolate to $p_{T,\text{rel}}^{\text{jet2}} = 0$
- derive scale relative to ECAL for $p_T = 50$ GeV from fit: ratio: $0.993 \pm 0.004(\text{stat.}) \pm 0.026(\text{syst.})$

Summary: Uncertainty of Jet Energy Scale



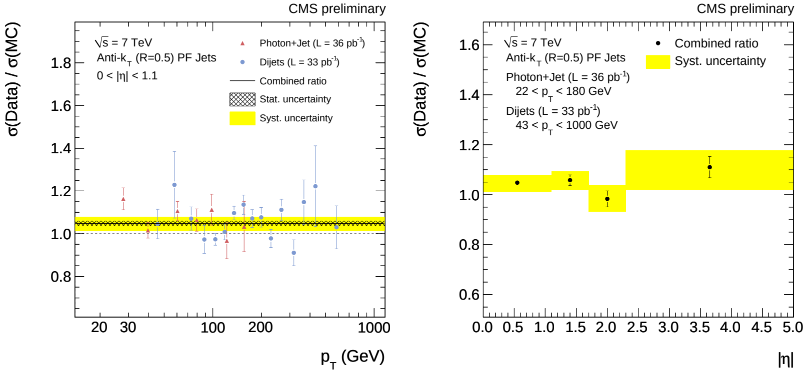
- uncertainty on absolute jet energy scale: $3-6\%$ with $L = 2.9\ \text{pb}^{-1}$
- improved version for full 2010 data set soon

Summary: Jet Resolution



- PF jets have better resolution than Calorimeter jets
- agreement between Dijet and photon-jet results
- with more data: improve precision and reach, add Z-jet

Summary: Resolution Comparison for PF jets



≈ 10% worse resolution in data than simulation

Summary

Summary:

- three well established jet types:
  Calorimeter jets, JetPlusTrack jets and Particle Flow jets
- established methods to measure relative and absolute jet energy scale corrections and jet resolution in data
- derived (small) residual jet energy corrections using first data uncertainty on absolute scale from 3 pb^{-1}: 3 - 6 %.
- measured the jet resolution in Dijet and Photon-jet events

Outlook:

with more data:

- improve methods
- add additional channels (Z-jet)
- reduce jet energy scale uncertainty
- improve understanding of jet response (resolution)

Physics Analysis Summaries

- “Single-Particle Response in the CMS Calorimeters”, CMS-PAS-JME-10-008, 2010
- “Jet Performance in pp Collisions at 7 TeV”, CMS-PAS-JME-10-003, 2010
- “Jet Energy Corrections determination at 7 TeV”, CMS-PAS-JME-10-010, 2011
- “Jet Energy Resolution in CMS at $\sqrt{(}s) = 7$ TeV”, CMS-PAS-JME-10-014, 2011
- “Jet Substructure Algorithms”, CMS-PAS-JME-10-013, 2011
- “Commissioning of the Particle-Flow reconstruction in Minimum-Bias and Jet Events from pp Collisions at 7 TeV”, CMS-PAS-PFT-10-002, 2010