Determination of the Jet Energy Scale in CMS with pp Collisions at $\sqrt{s}$ = 7 TeV

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on behalf of the JEC group

CMS Approval Presentation
17 November 2010

Outline

- **Calibration Strategy**
- **Monte Carlo Truth Calibration**
- **Relative (vs η) Jet Energy Scale**
- **Absolute (vs p_T) Jet Energy Scale**
- **Uncertainties**
- **Summary**

ID of the Analysis

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CMS Draft Analysis Note

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Measurement of the Relative Jet Energy Scale in CMS with pp Collisions at $\sqrt{s} = 7$ TeV

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Abstract

The dijet transverse momentum balancing method is employed to measure the jet energy response variation in CMS as a function of pseudorapidity in the p_T range $20 - 500$ GeV. The measurement is performed using data from pp collisions at $\sqrt{s} = 7$ TeV, corresponding to an integrated luminosity of $3\,\mathrm{pb}^{-1}$. Three different jet reconstruction techniques are examined: calorimeter jets, particle flow jets and jet-plus-track jets, all energy corrected to the particle level using the Monte Carlo truth jet energy calibration. The relative response measured from the data is compared to the simulation predictions. Good agreement is observed in the region $|\eta| < 1.5$ while a deviation up to 10% is found in the Endcap and Forward regions for all jet types. A residual calibration is derived to compensate for the observed difference between data and simulation and the corresponding uncertainty is estimated.

JME-10-010

CMS PAS JME-10-010

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Determination of the Jet Energy Scale in CMS with pp Collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration

Abstract

The determination of the jet energy calibration in CMS is presented. In-situ measurements are performed using $3\,\mathrm{pb}^{-1}$ of proton-proton collisions at 7 TeV center of mass energy. The transverse momentum balancing in dijet and photon+jet events is used to measure the relative and absolute jet energy response in the CMS detector. Observations in data are compared to Monte Carlo expectations and the systematic uncertainties related to the calibration scheme are discussed. The results are presented for three different approaches to reconstruct jets in the CMS detector: calorimeter-based jet reconstruction; the "Jet-Plus-Track" algorithm, which improves the measurement of calorimeter jets by exploiting the associated tracks; the "Particle Flow" method, which attempts to reconstruct individually each particle in the event, prior to the jet clustering, based on information from all relevant sub-detectors.

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CMS Internal Note

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October 27, 2010

Absolute jet energy correction uncertainty

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Abstract

The data-based jet energy corrections use the missing-E_T projection fraction method with particle flow missing-E_T in photon+jet events to establish the absolute jet energy scale for particle flow jets in the barrel region. The measured scale is transformed to the QCD sample flavor mixture using Pythia D6T Monte Carlo generator with CMS detector simulation and then transfered to other jet reconstruction types (calorimeter, jet-plus-tracks) using direct jet matching in dijet data. The data-based corrections are provided as small residual scale factors on top of MC truth jet corrections. By default the jets are reconstructed using the anti-k_T algorithm with cone size 0.5, but correction factors for other jet types are obtained with MC simulation. We discuss the systematic uncertainties related to this calibration scheme, as well as a number of important cross-checks with alternative methods and cut variations. Future improvements and additions are also discussed.

People Involved

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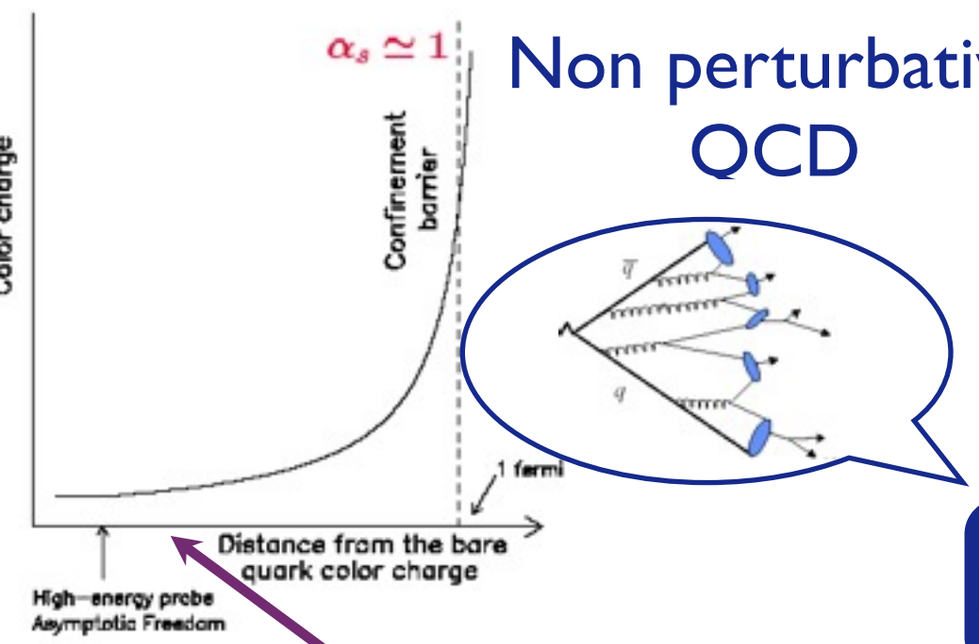
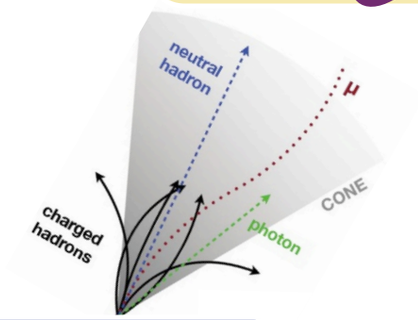
Introduction



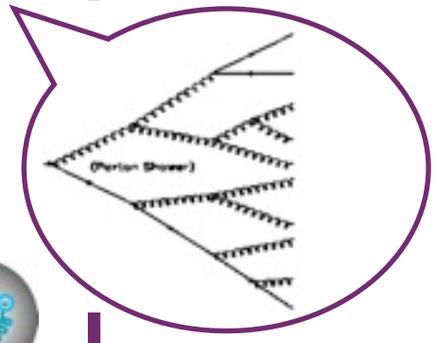
Non perturbative QCD

Detector



Hadronization

Parton showering



Perturbative QCD

$q, \bar{q}, g$

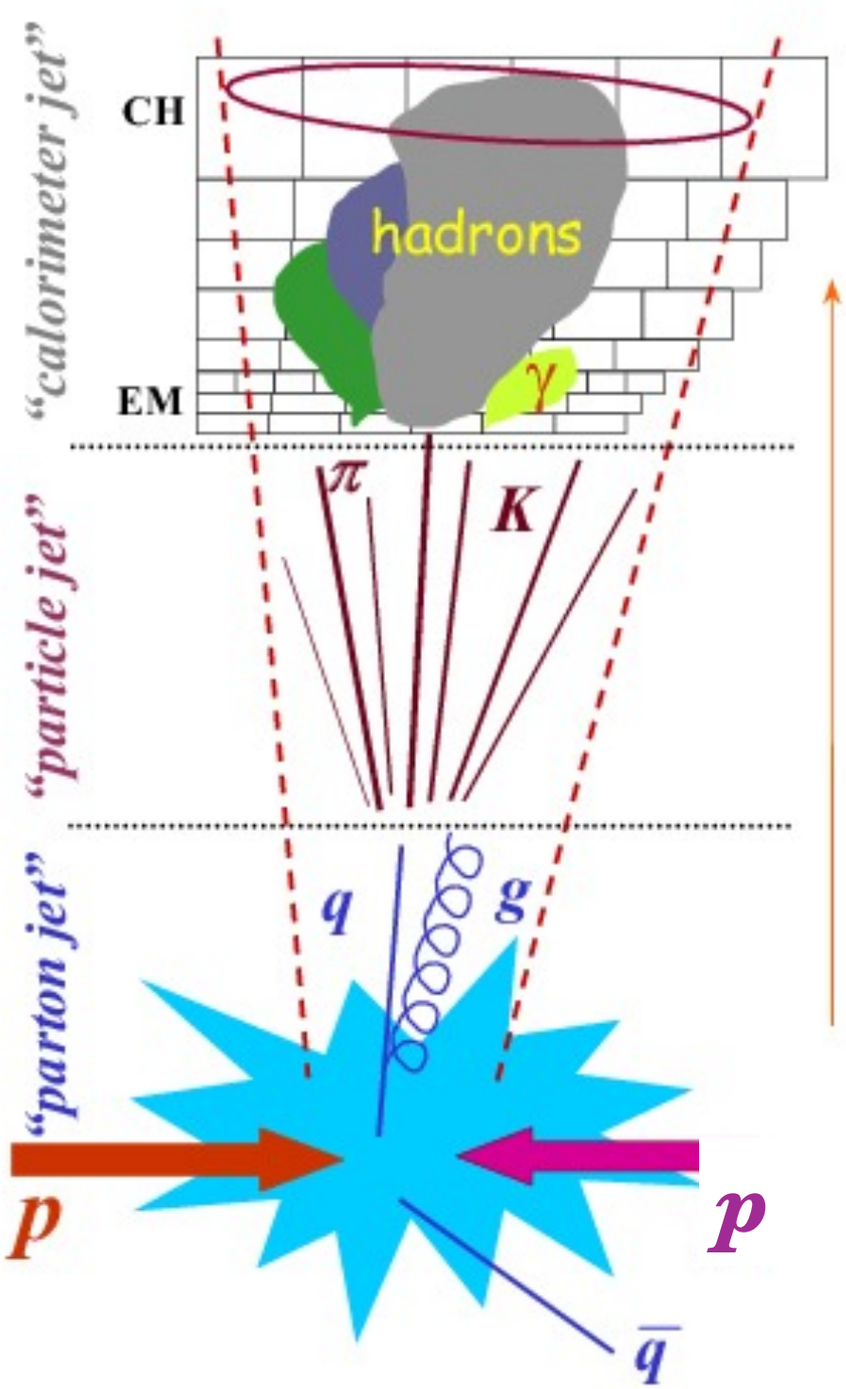
Hard parton scattering (determined by matrix QCD element and proton PDF)

✦ The energy calibration is the biggest challenge in the measurement of jets

- jets are composite objects whose composition varies
- jets are composed primarily of hadrons and these interact with matter in a complicated way

✦ The jet energy scale uncertainty is the dominant systematic in many Physics analyses

Calibration Strategy



- The jet energy calibration corrects on average the energy of a reconstructed jet to the particle level.
  - the correction factor is η and p_T dependent and multiplies all the components of the jet 4-vector
- Through the commissioning period, the CMS simulation has been proven very successful: the jet calibration starts from the MC truth JEC.
- Small residual correction is applied on top of MC truth, based on in-situ measurements
  - relative JES from dijet p_T balance
  - absolute JES from γ+jet p_T balance

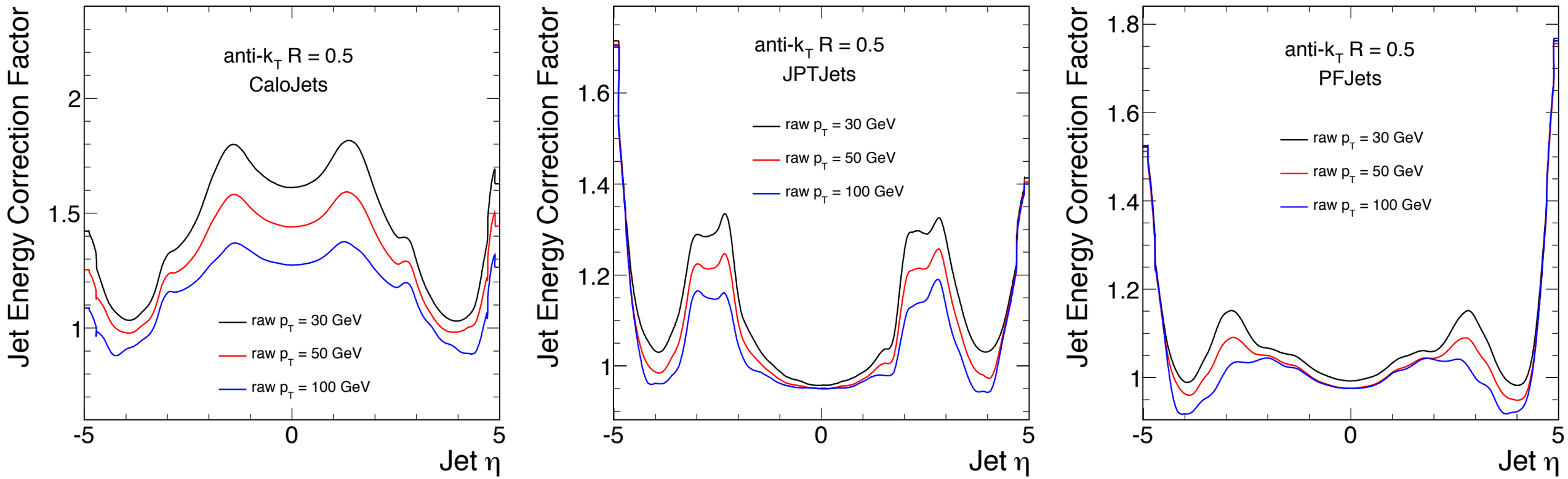
$$C(\eta, p_T) = C_{abs} \cdot C_{res}(\eta) \cdot C_{MC}(\eta, p_T)$$

Technical Details

- **Data samples:**
  - /MinimumBias/Commissioning10-Jun14thReReco_v1/RECO
  - /MinimumBias/Commissioning10-SD_JetMETTau-JunthSkim_v1/RECO
  - /JetMETTau/Run2010A-Jun14thReReco-v2/RECO
  - /JetMETTau/Run2010A-Jul16thReReco-v1/RECO
  - /JetMETTau/Run2010A-PromptReco-v4/RECO
  - /JetMET/Run2010A-PromptReco-v4/RECO
  - /EG/Run2010A-PromptReco-v4/RECO
- **MC samples:**
  - /MinBias/Spring10-START3X_V26_S09-v1/GEN-SIM-RECO
  - /PhotonJet_Pt*to*/Summer10-START36_V9_S09-v1/GEN-SIM-RECO
  - /QCD_Pt*/Spring10-START3X_V26_S09-v1/GEN-SIM-RECO
  - /QCDDiJet_Pt*to*/Spring10-START3X_V26_S09-v1/GEN-SIM-RECO
- **Integrated luminosity:**
  - ~$3pb^{-1}$
- **Jet reconstruction:**
  - anti-k_T, R=0.5 (Calo, JPT, PF)

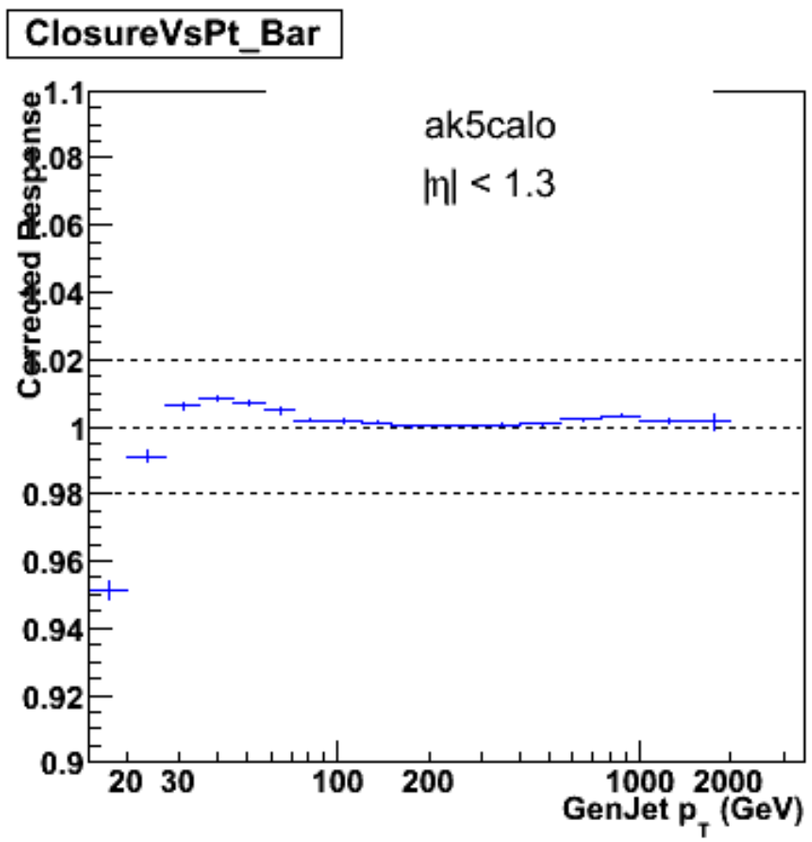
The Monte Carlo Truth Component

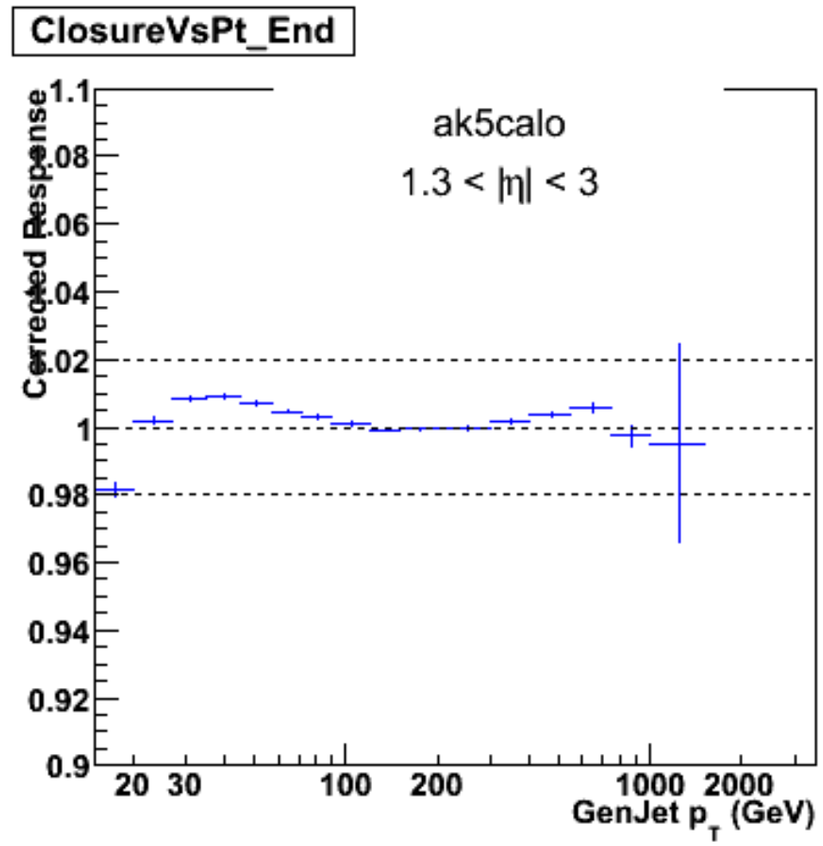
MC Truth JEC Factors

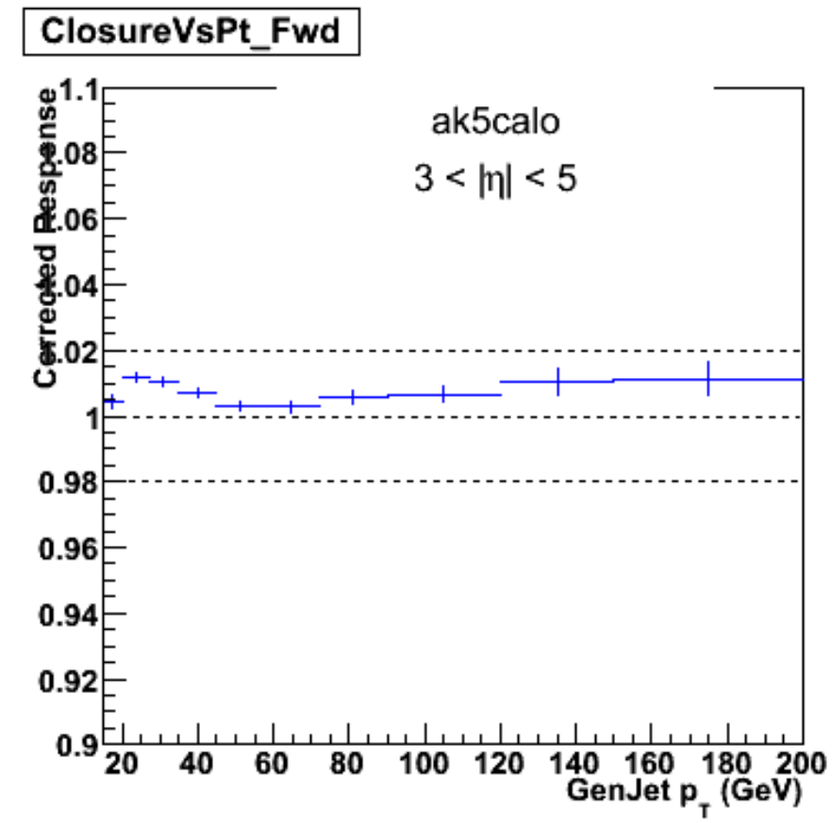


- The MC Truth JEC is derived from the Spring10 MC samples
- Spatial matching of reconstructed jets to generated jets in the η, φ plane
  - ΔR(gen,reco) < 0.25
- Measurement of the response: p_T^{reco}/p_T^{gen}
- Two step approach
  - L2Relative: makes the response uniform in η
  - L3Absolute: makes the response uniform in p_T and equal to unity
- The different jet types require vastly different calibration

MC Truth Closure (Calo)







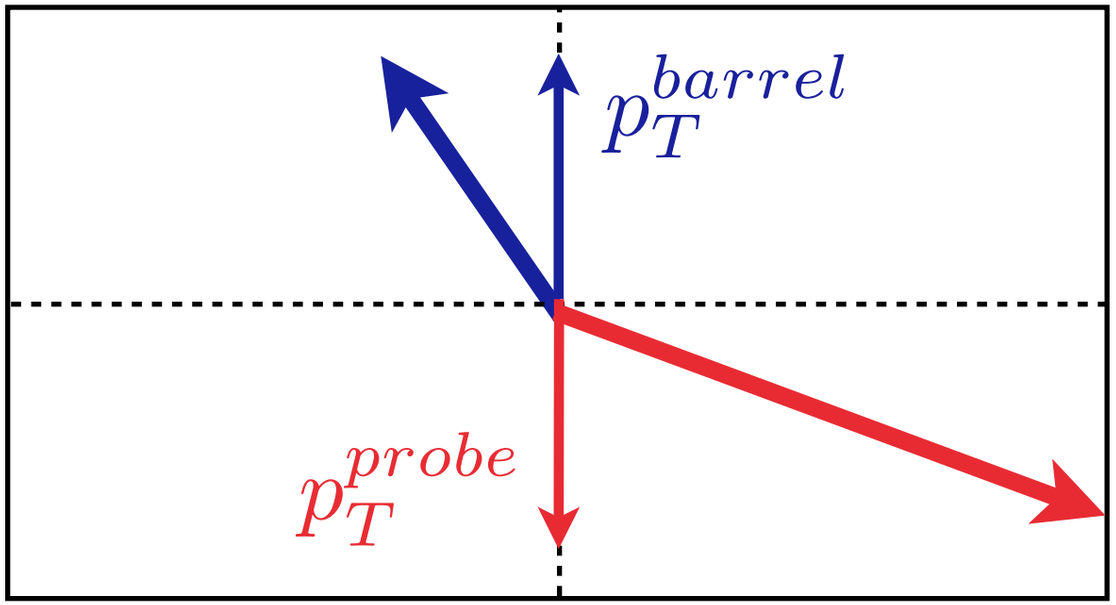
- The MC truth closure measures the consistency of the JEC by applying it to same jets used for its derivation
- Measurement of the corrected response: p_T^{cor}/p_T^{gen}
- The corrected response is consistent with unity to within 2%
  - small deviations from unity are due to the imperfections of the various fits involved in the derivation

Relative Jet Energy Scale

(response uniformity in η)

The Dijet p_T Balance Method: Overview

Barrel Jet

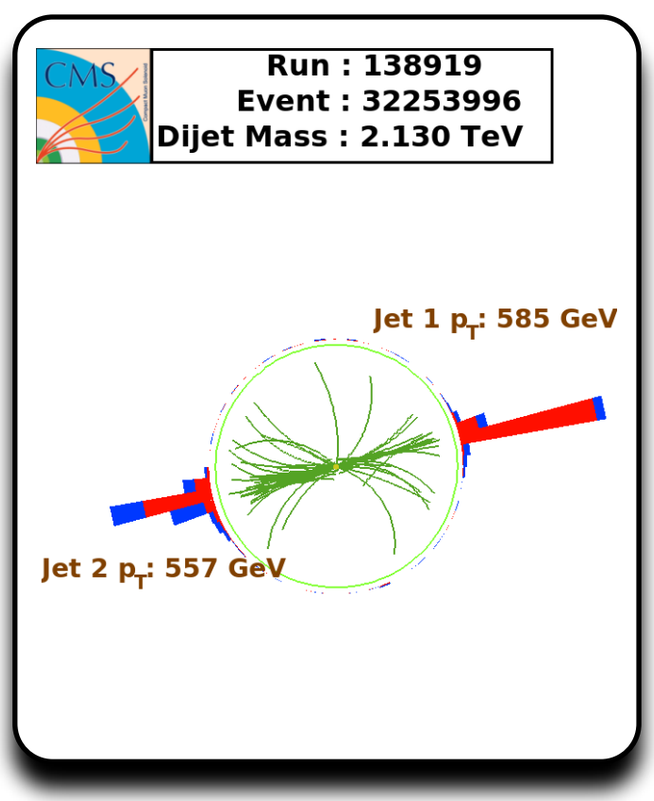


Probe Jet

$$p_T^{dijet} = \frac{p_T^{probe} + p_T^{barrel}}{2}$$

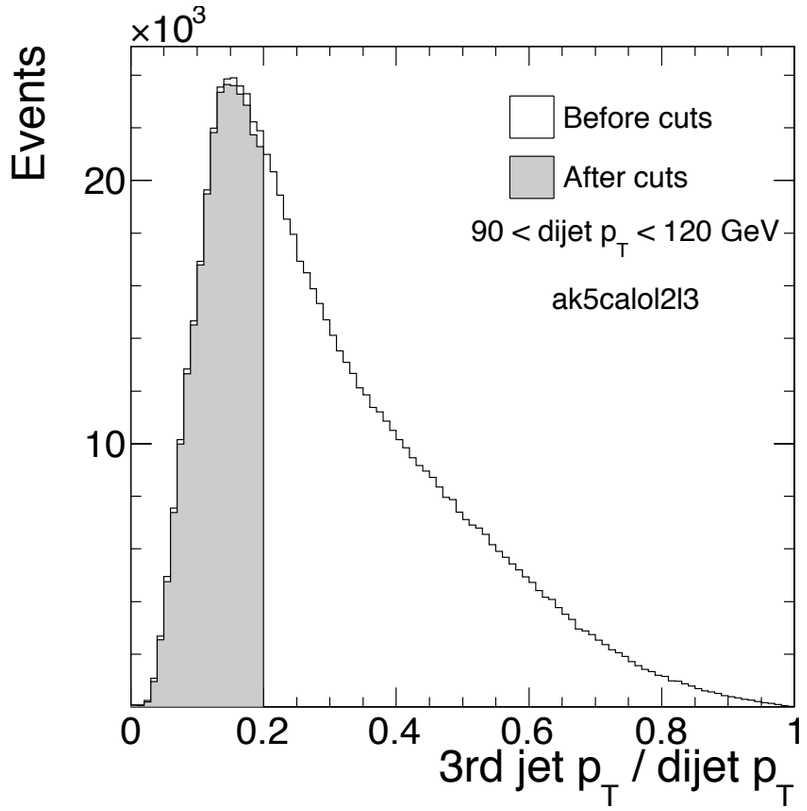
$$B = \frac{p_T^{probe} - p_T^{barrel}}{p_T^{dijet}}$$

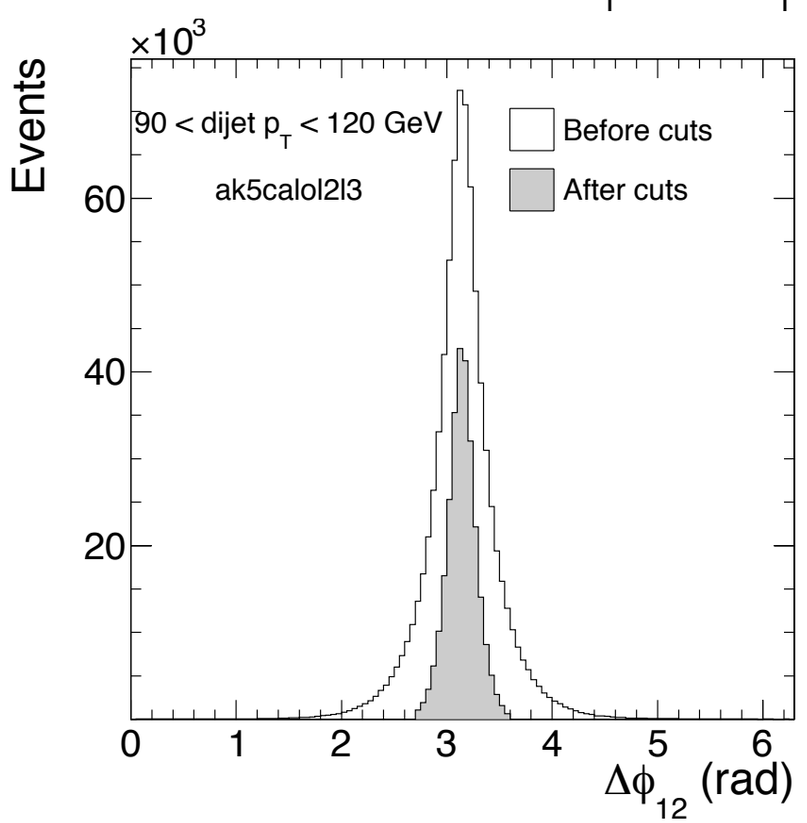
$$r = \frac{2+ < B >}{2- < B >}$$



- the dijet p_T balance measures the **relative** jet energy response of jets at arbitrary η (probe jets) with respect to the barrel region |η|<1.3 (barrel jets)
- the quantity **r** is the least biased estimator of the relative response when using bins of p_T^{dijet}

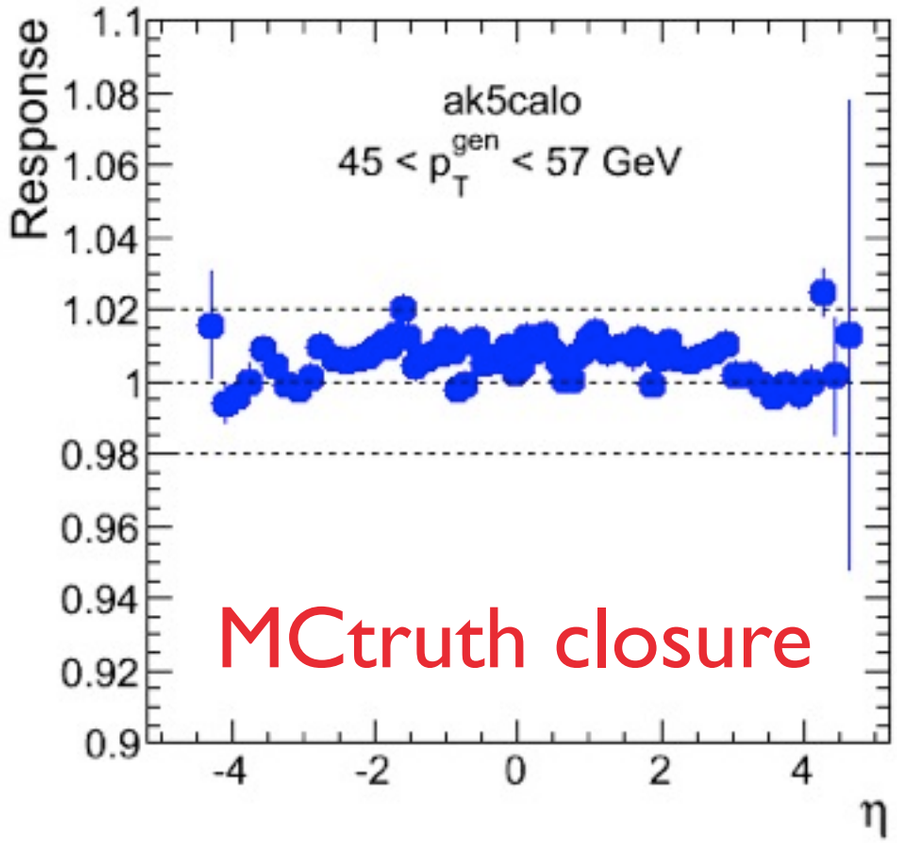
The Dijet p_T Balance Method: Selection

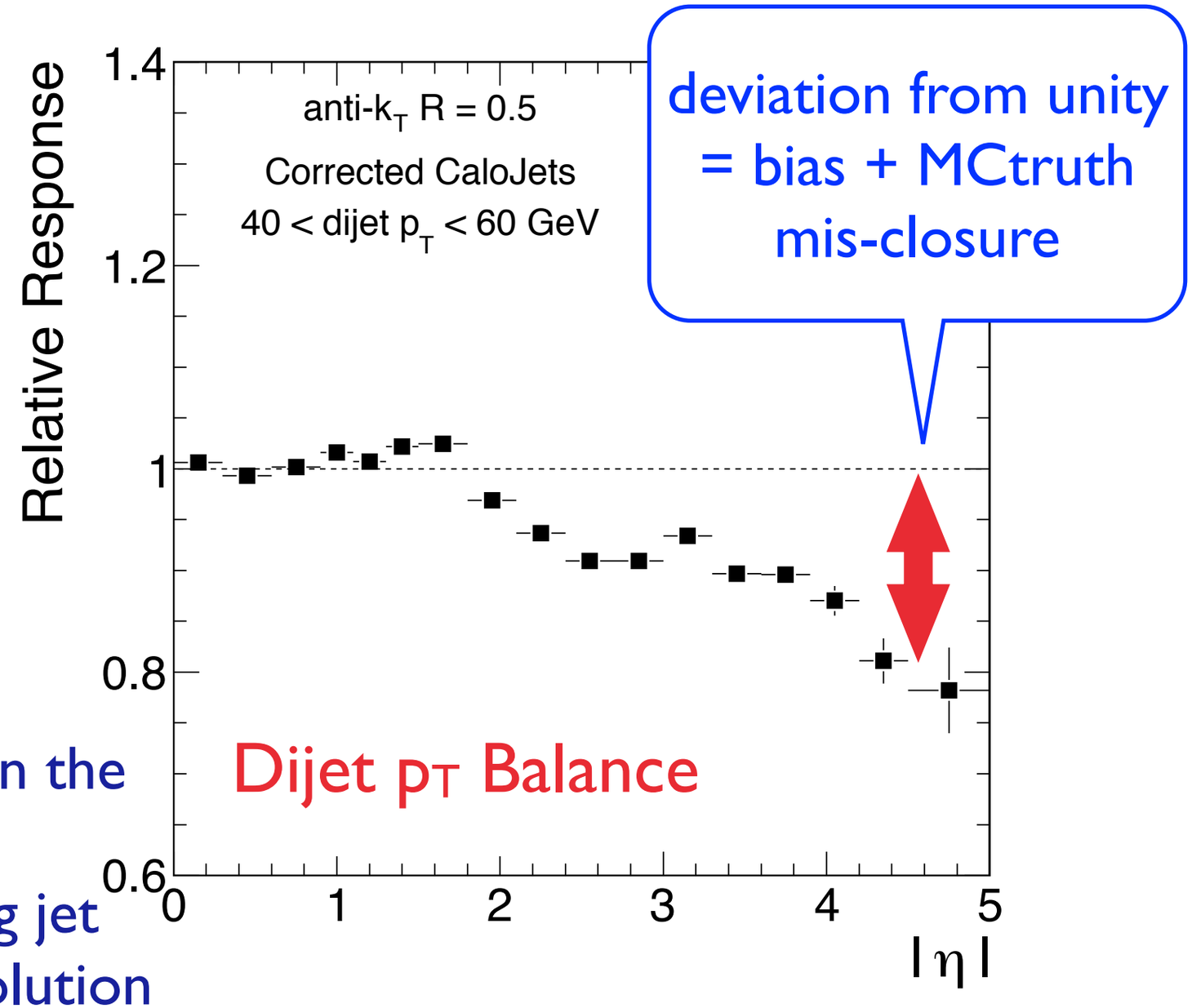




- **Event Selection**
  - DiJetAveXX triggers
  - good primary vertex
  - at least two reconstructed jets
  - at least one of the leading jets in $|\eta|<1.3$
  - jets "back-to-back" in azimuth: $\Delta\varphi > 2.7$
  - small 3rd jet activity: $p_T^{jet3}/p_T^{dijet} < 0.2$
  - reasonable balance: $|B|<1.7$
- **Jet Selection**
  - anti-k_T, R=0.5 Calo, JPT, PF
  - loose jet ID

The Resolution Bias

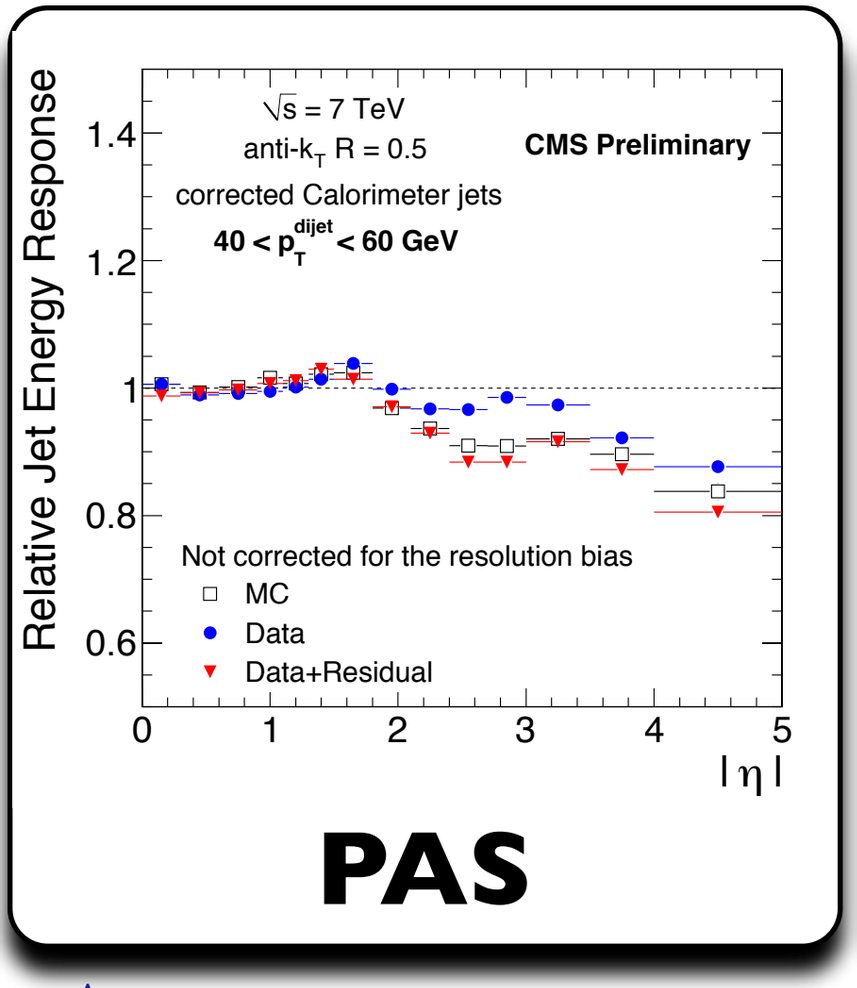


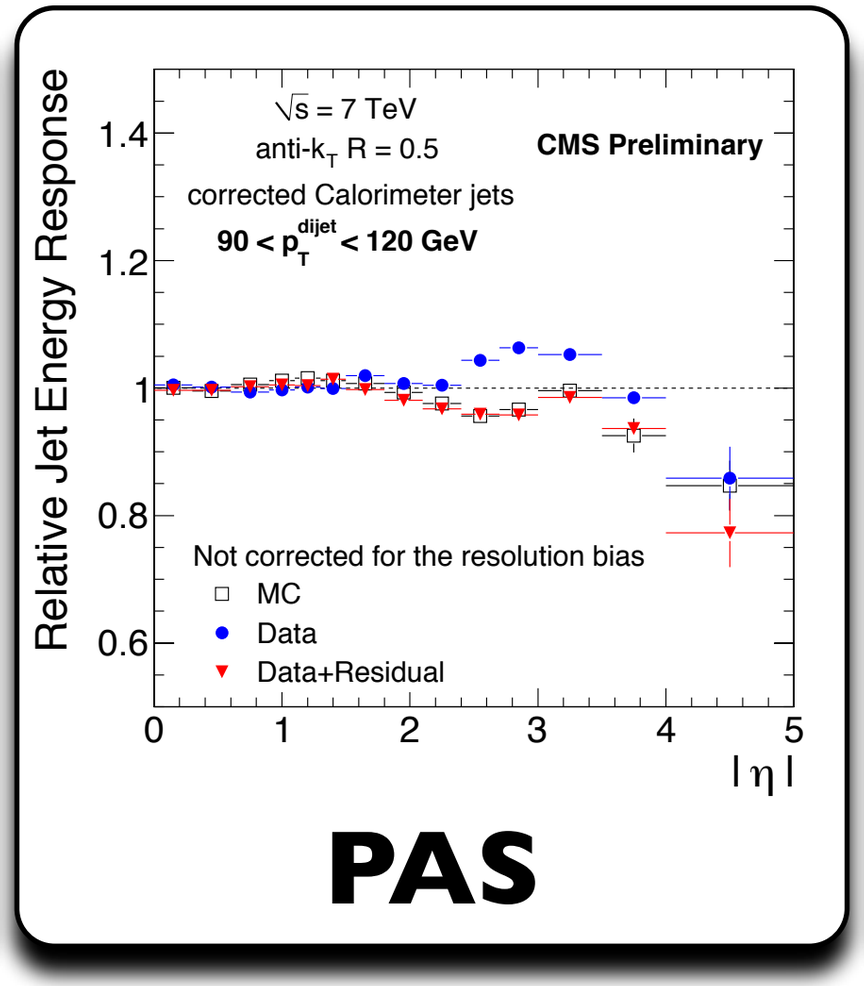


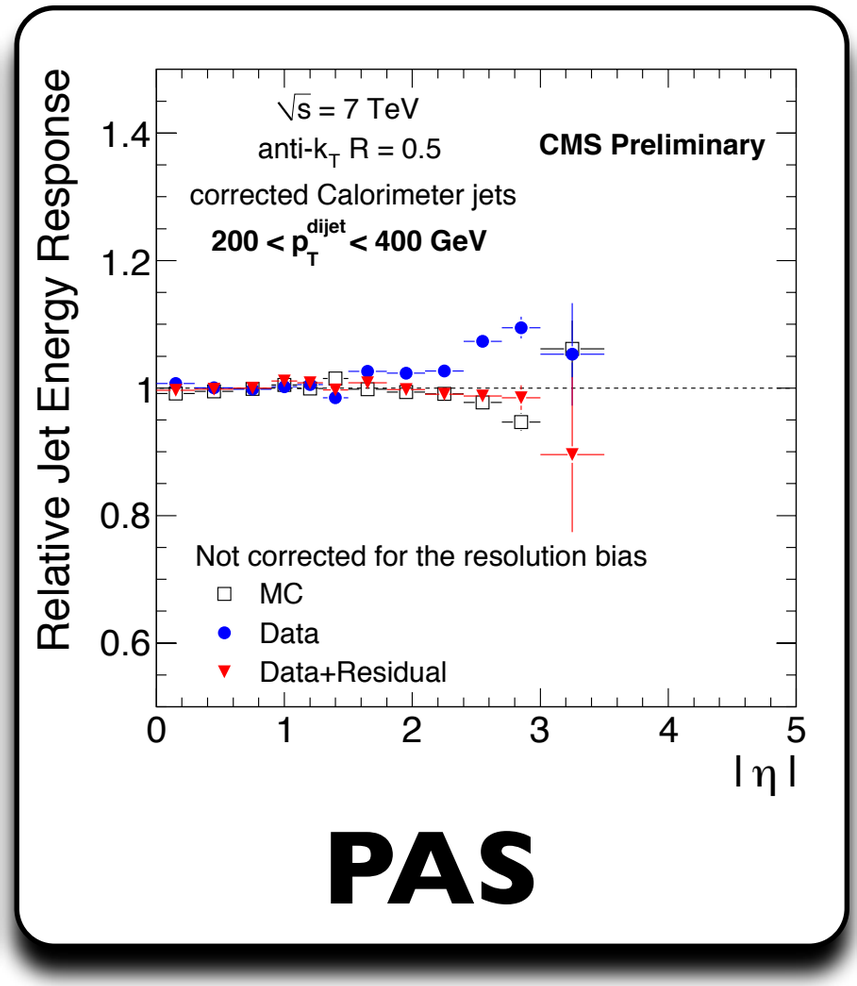
- the resolution bias is inherent in the dijet balance method
- it is caused by the steeply falling jet p_T spectrum and the different resolution of the barrel jet and probe jet
- major source of systematic uncertainty

Even with perfect calibration, the dijet p_T balance will measure higher response in the direction of the jet with the worse resolution

Relative Response (Calo)

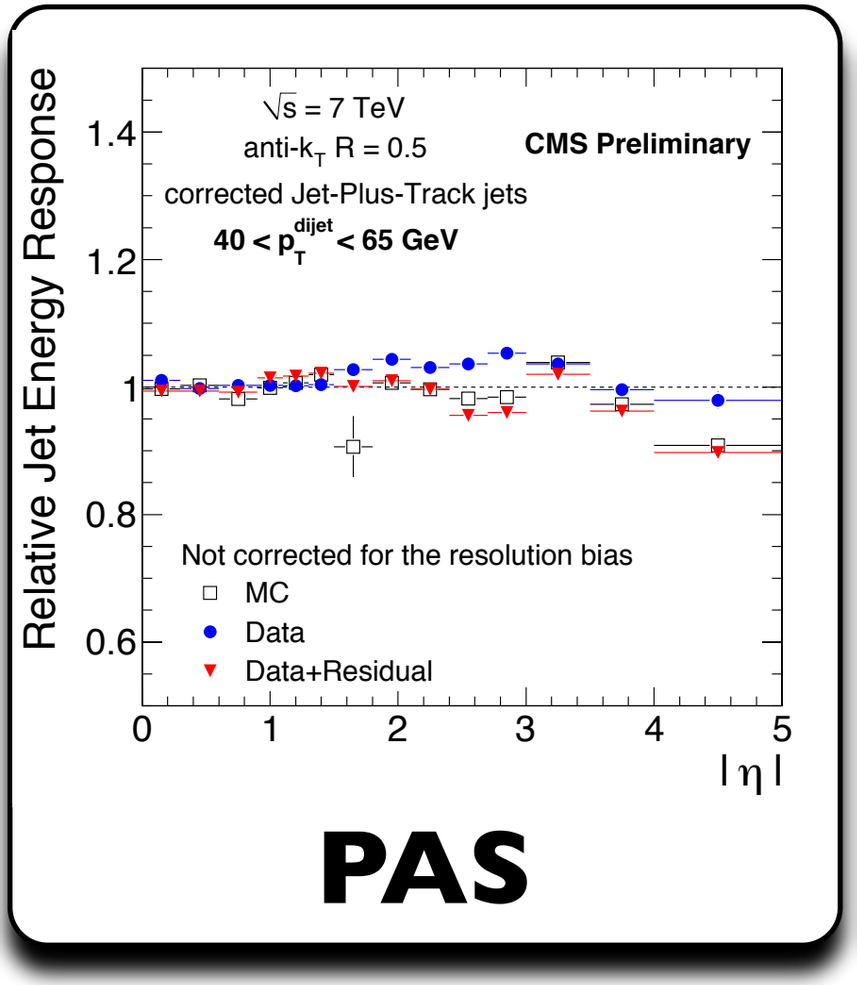


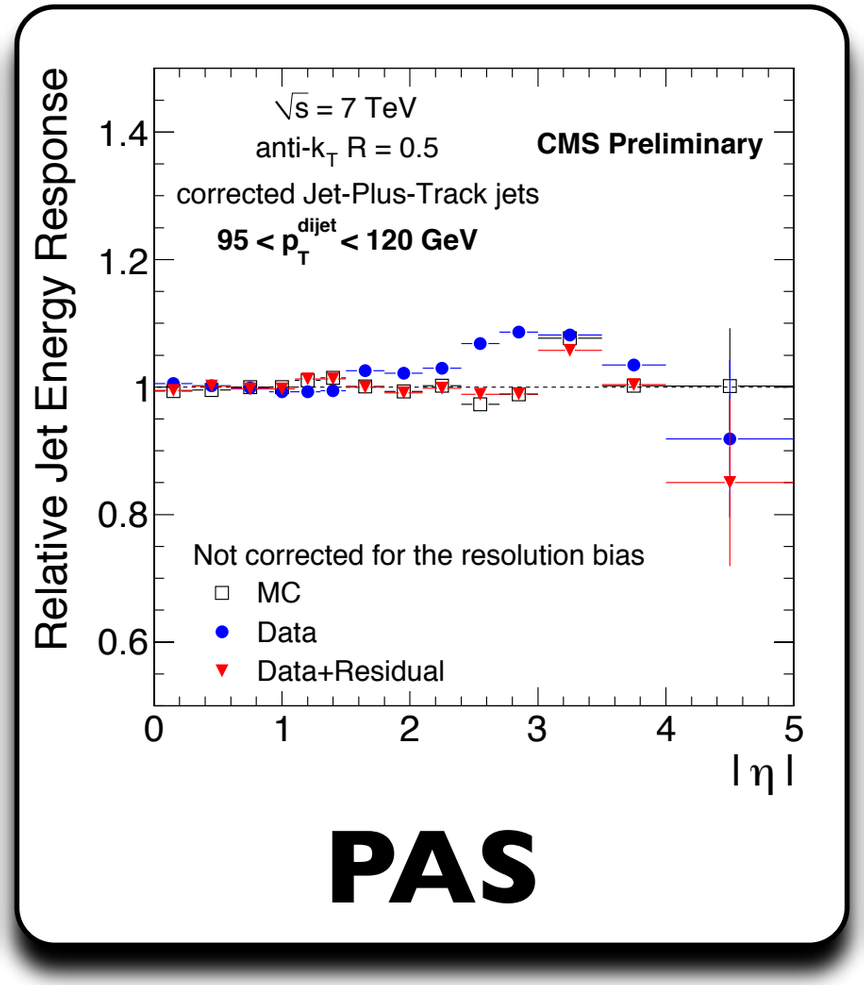


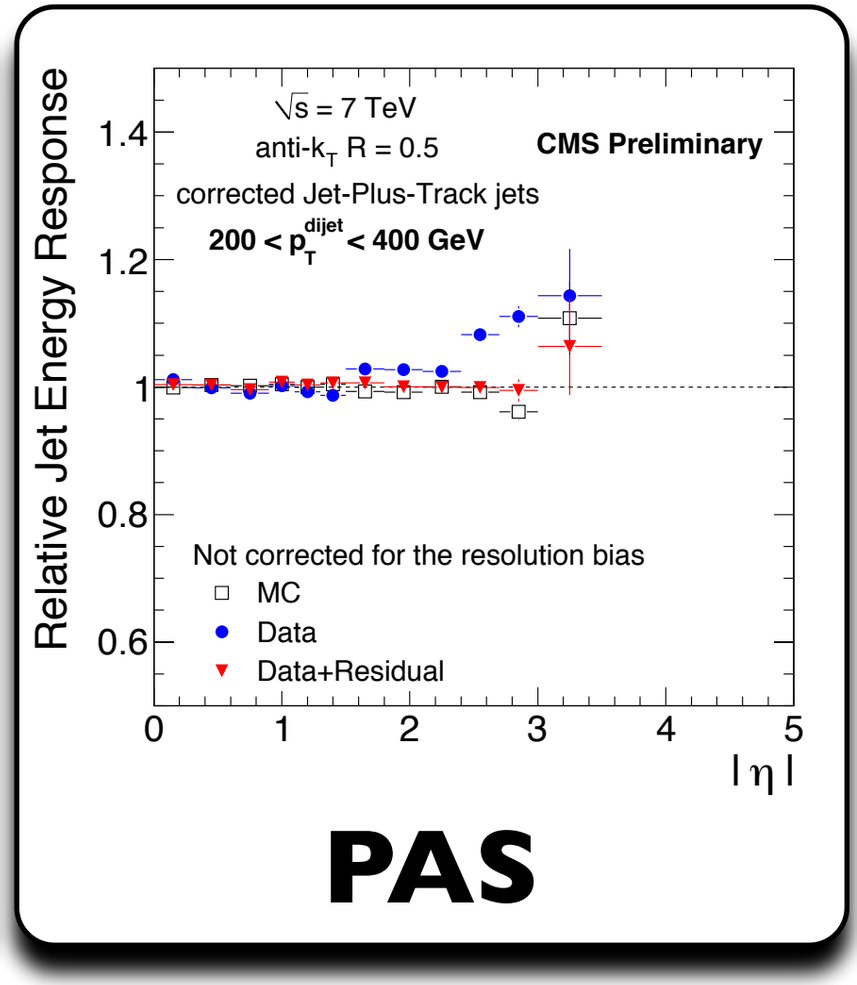


- relative response of MC truth corrected jets
  - ideally, the MC relative response should be unity
  - to first approximation, the deviation of MC from unity is the resolution bias
  - the resolution bias is more pronounced at low dijet p_T and higher η (maximal resolution difference between barrel and probe jets)
- the disagreement between data and MC is the scale difference that needs to be corrected (not greater than 10%)

Relative Response (JPT)

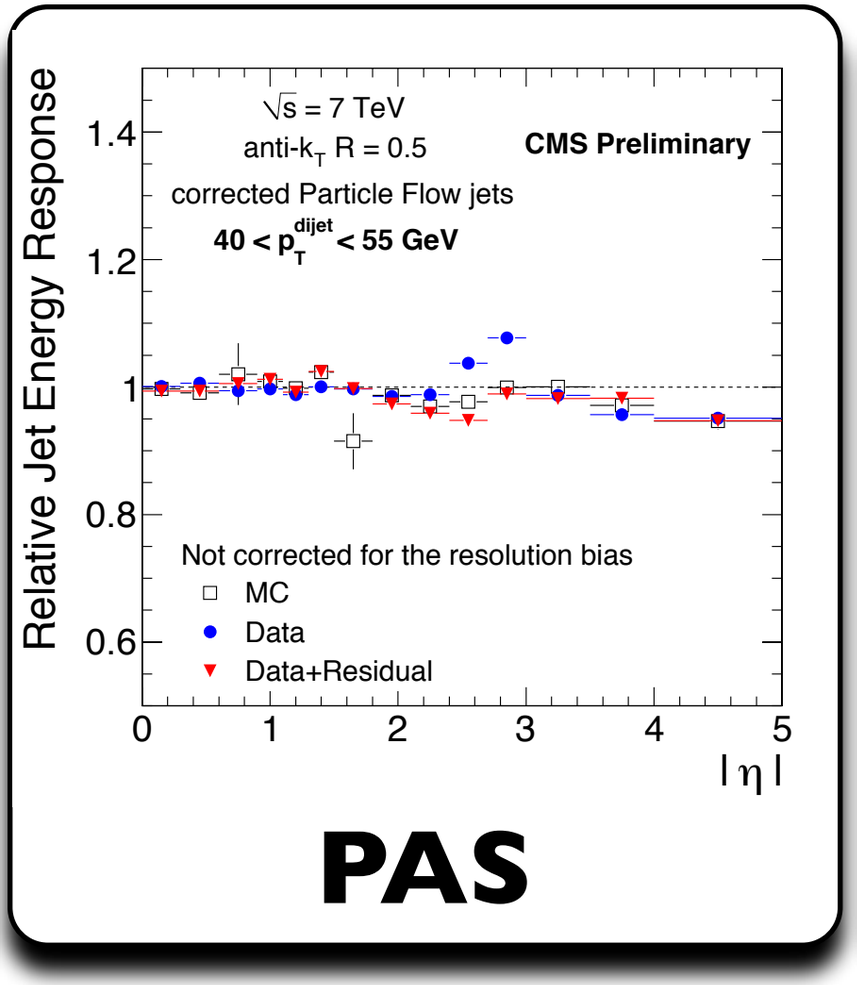


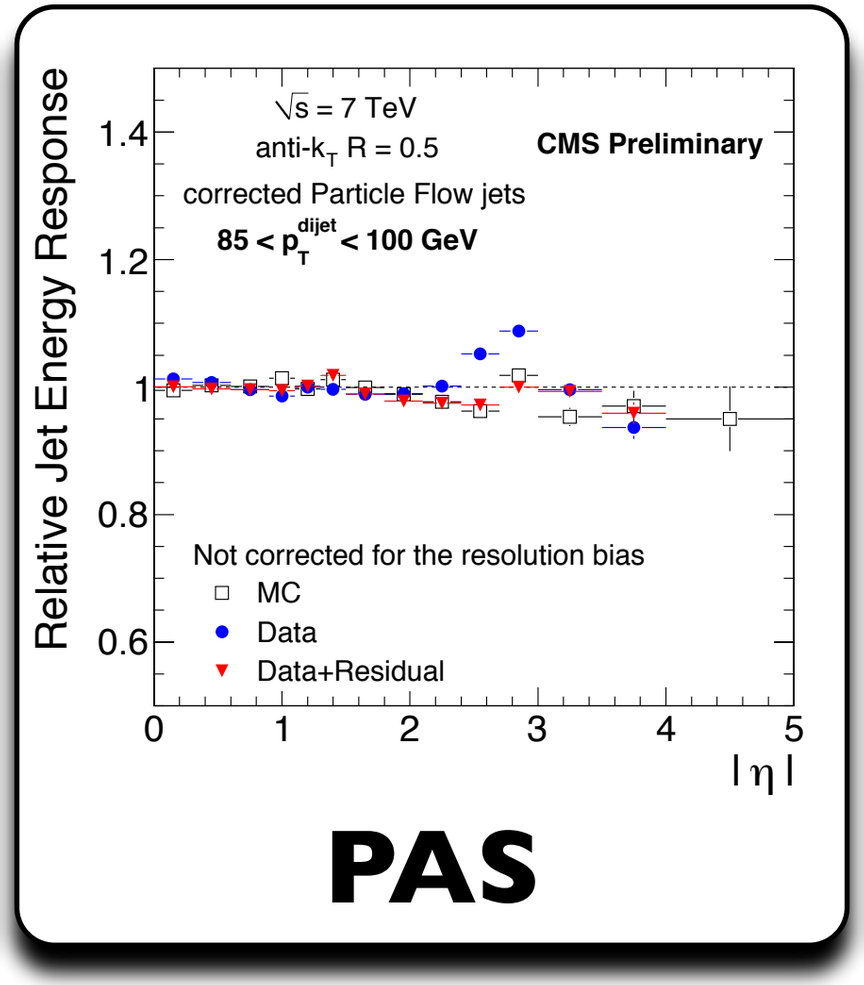


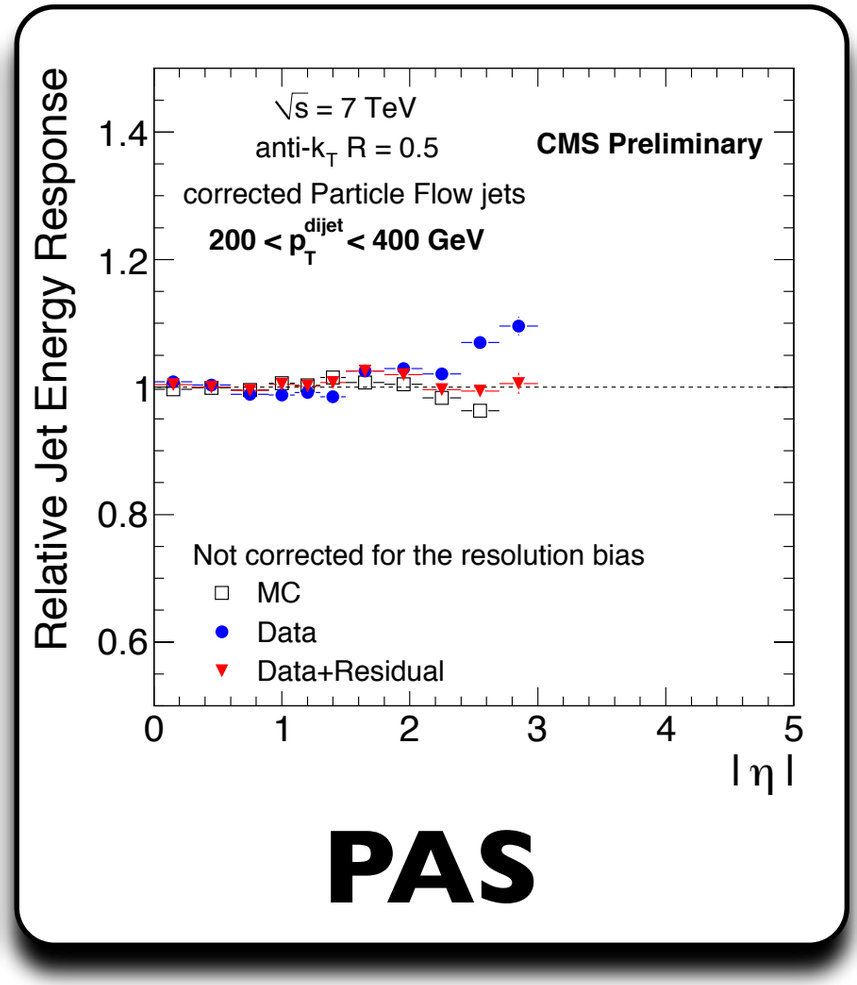


- the resolution bias effect is much weaker for JPT jets than CaloJets
  - the JPT barrel jets have much better resolution ⇒ similar to the resolution of the probe jets
- the disagreement between data and MC is similar to CaloJets

Relative Response (PF)

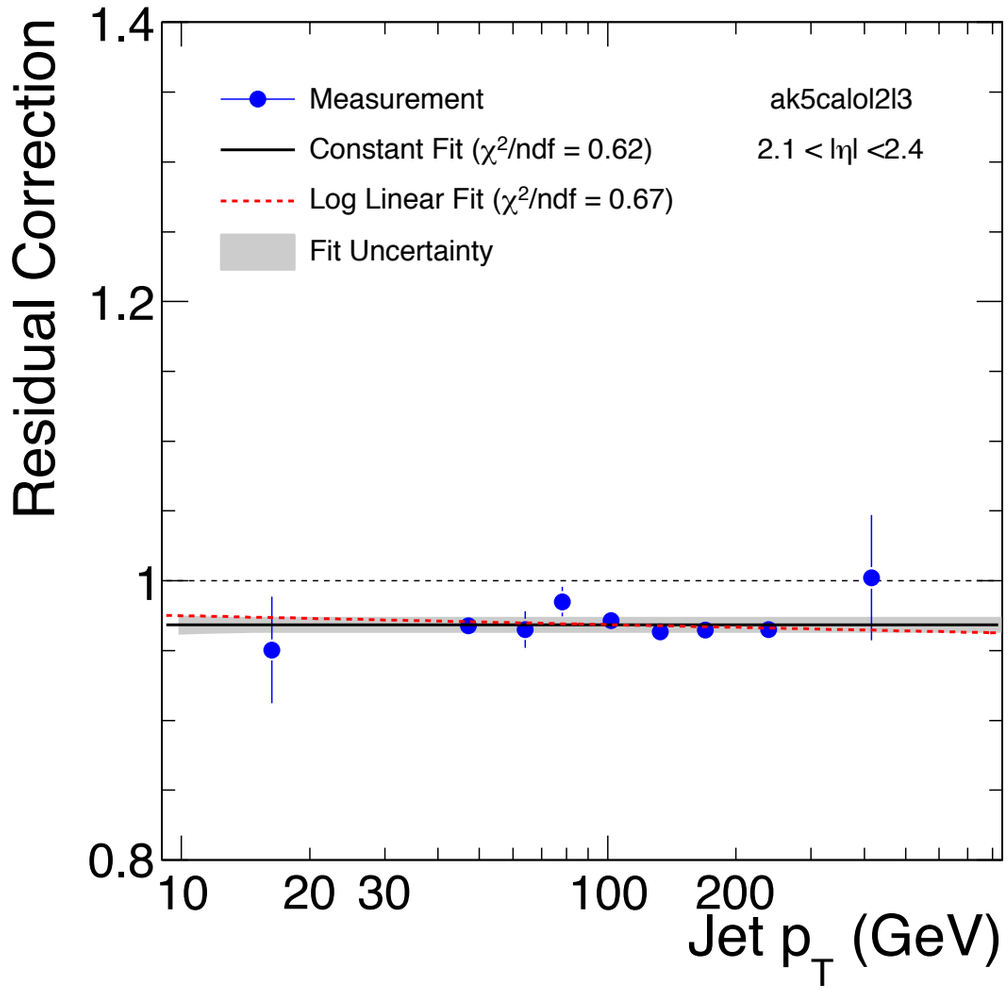


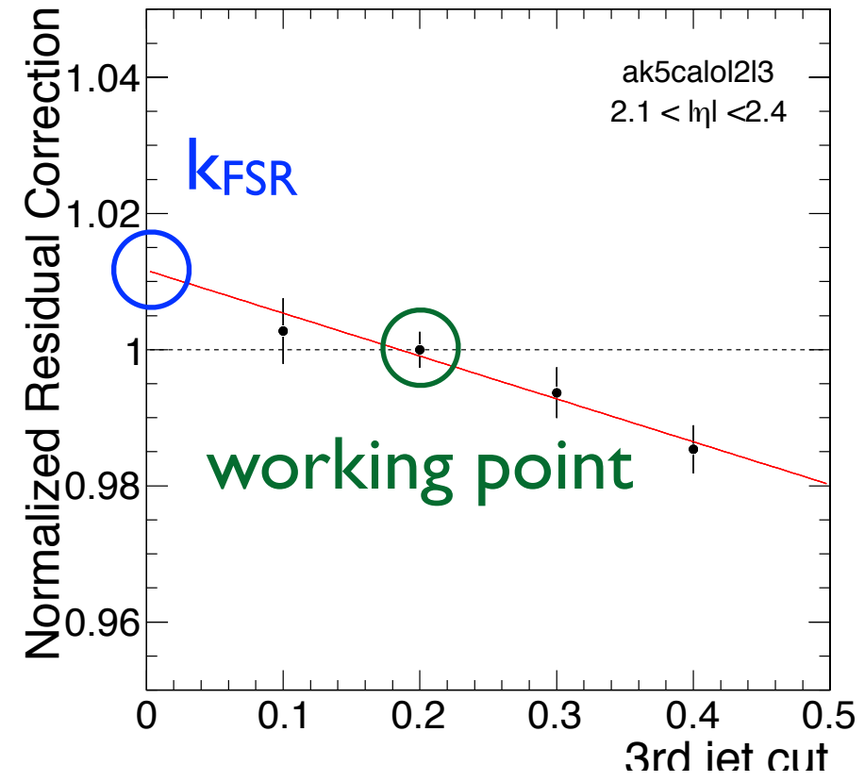




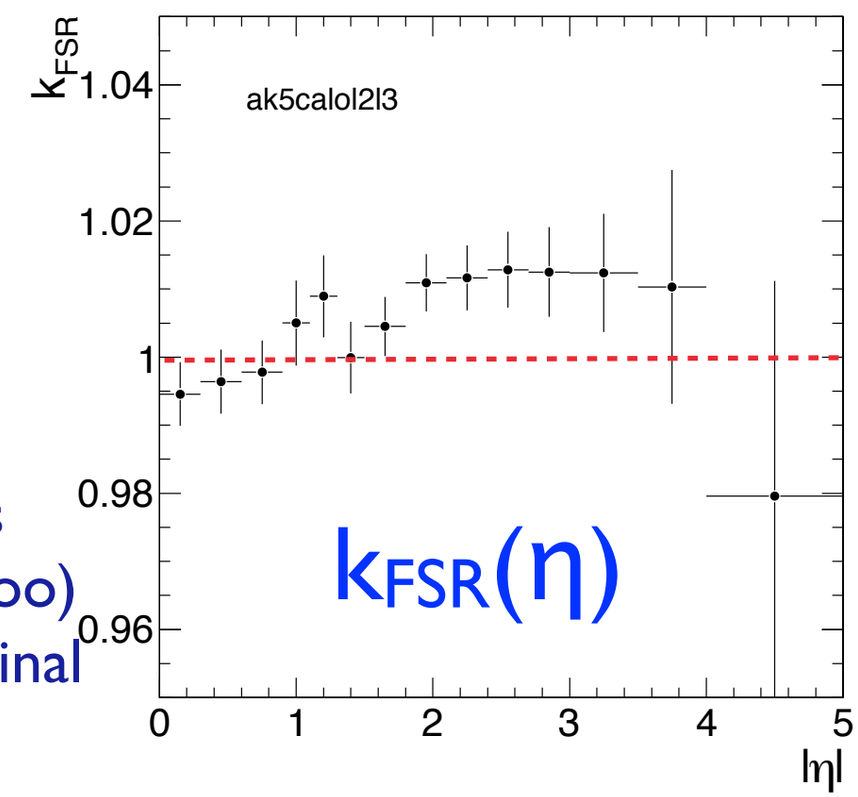
- the resolution bias effect is much weaker for PF jets than CaloJets
  - the PF barrel jets have much better resolution ⇒ similar to the resolution of the probe jets
- the disagreement between data and MC is similar to CaloJets

Residual Relative Correction: Derivation



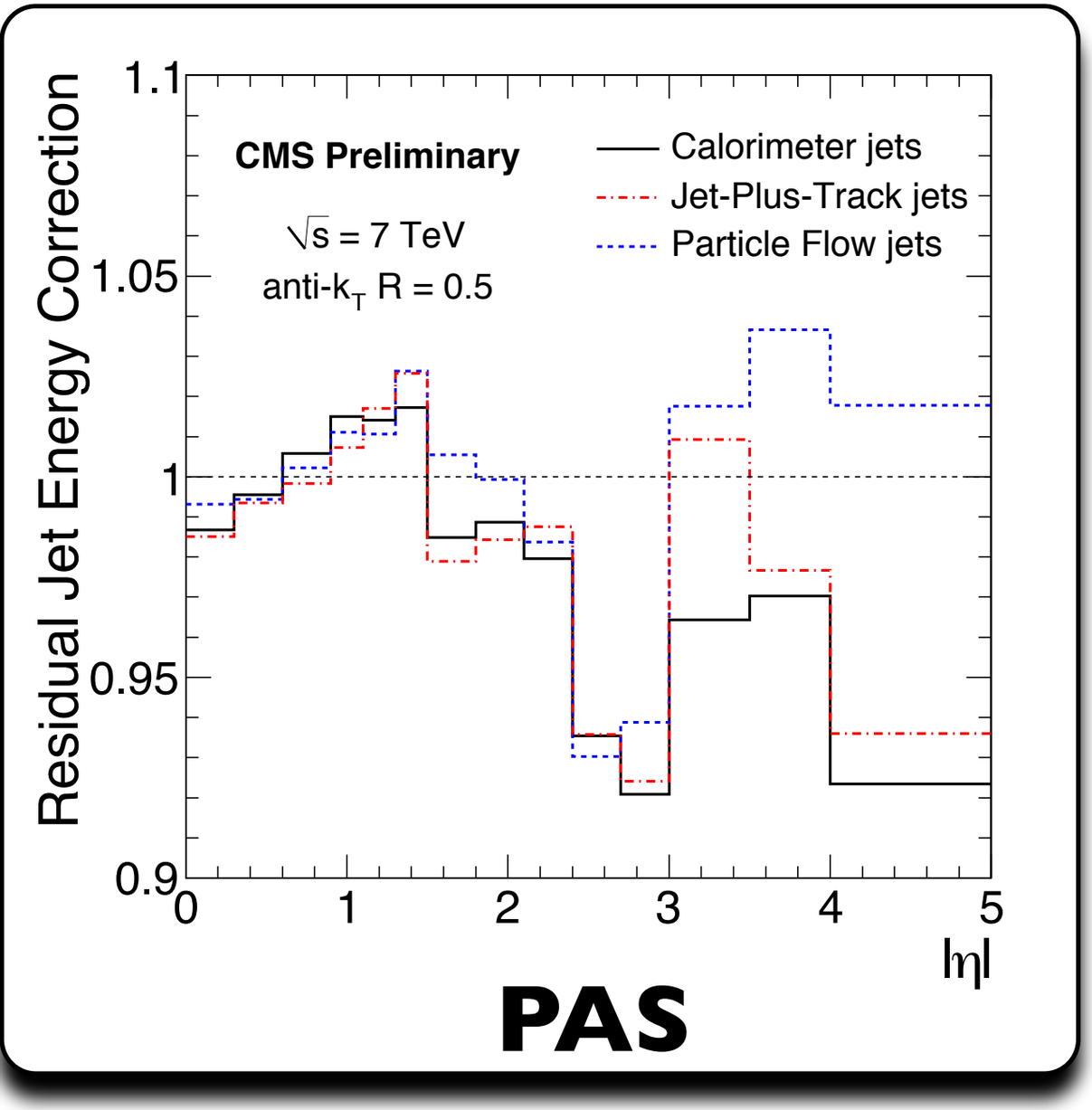


$$C_{res}(\eta) = k_{FSR}(\eta) \cdot \left\langle \frac{R^{20\%}_{MC}(\eta, p_T)}{R^{20\%}_{Data}(\eta, p_T)} \right\rangle_{p_T}$$



- residual correction: makes the data look like the MC (assumes that the resolution bias predicted by the MC holds for the data too)
- in each |η| bin the correction is averaged over p_T for the nominal working point and then extrapolated to the zero third jet p_T

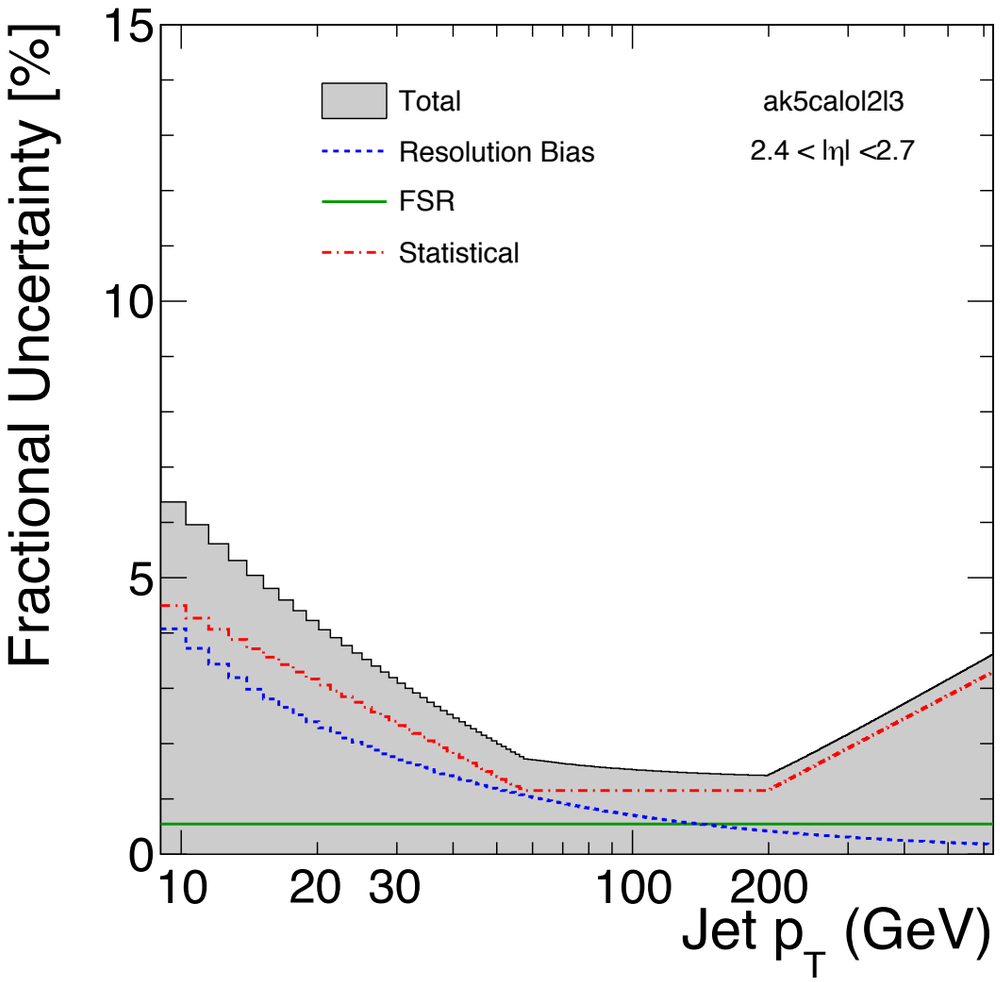
Residual Relative Correction

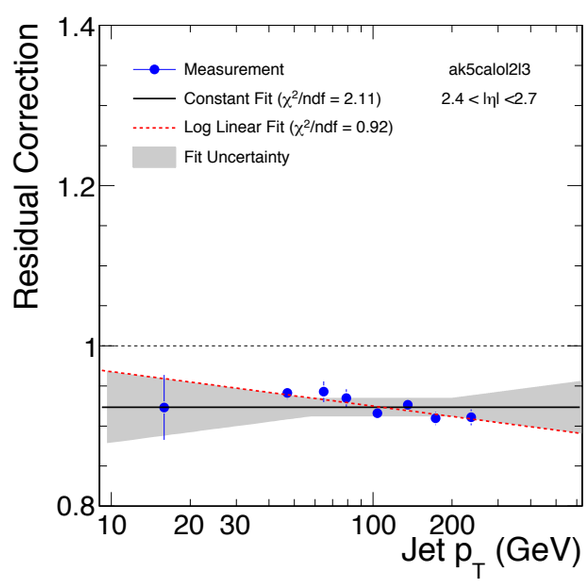


$$C_{rel}(\eta)$$

- ✦ in most |η| bins the data/MC difference is constant vs p_T
  - in those cases where there is a p_T slope, it is treated as a systematic uncertainty
- ✦ the residual correction varies between 0.92 and 1.03
- ✦ the largest correction is observed in the Endcap (similar between the jet types)
  - consistent with the single particle response measurements
- ✦ differences observed between jet types in the Forward (naive statement: all jets in HF should look alike)
  - calibration of PF candidates in HF
  - MC truth closure for JPT in HF is ~2% off
  - here we measure the RELATIVE response with respect to the Barrel (CaloJets in HF are corrected DOWN while PF and JPT are corrected UP)

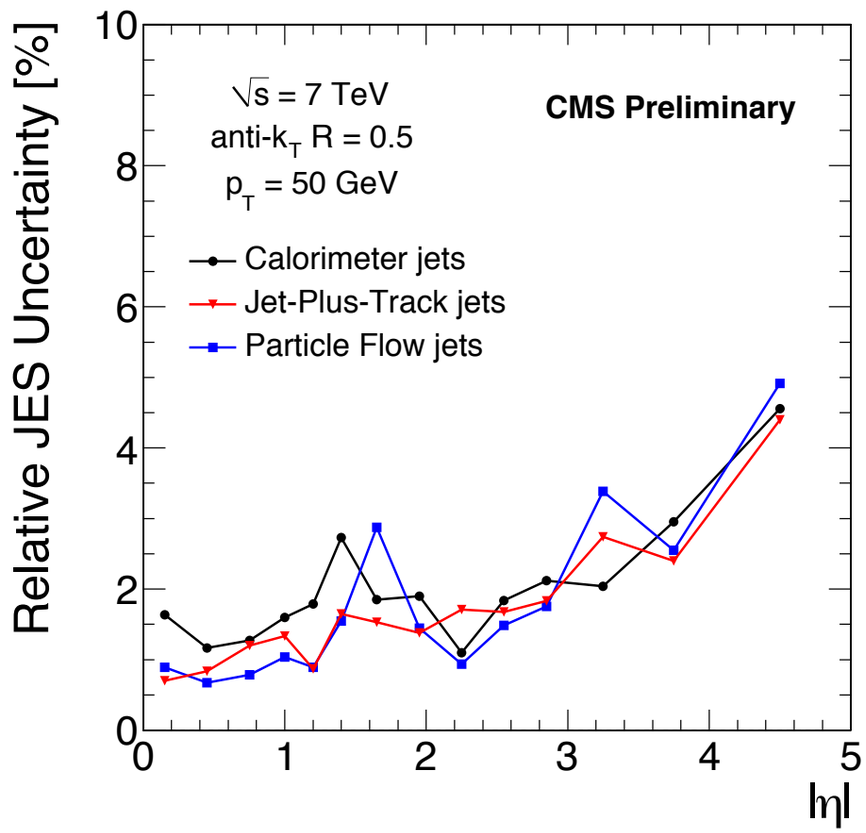
Residual Relative Correction: Uncertainties

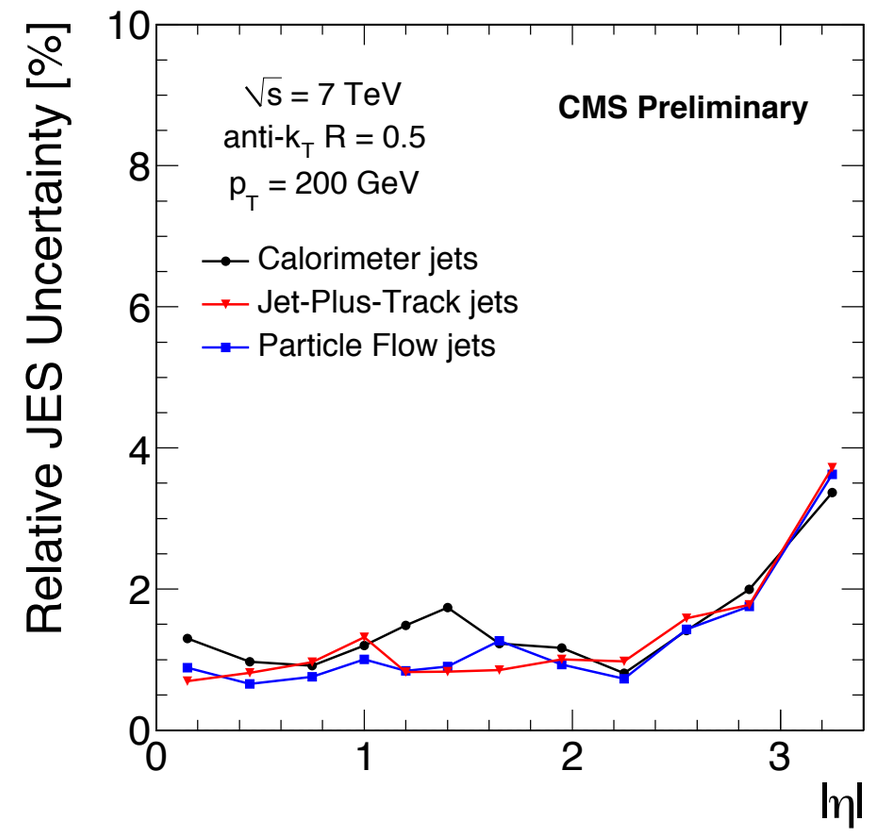




- **Simulation**
  - resolution modeling
    - studied the sensitivity to 10% (20%,25%) worse resolution in Barrel (Endcap, Forward)
  - jet p_T spectrum
    - studied the sensitivity to ±10% slope change
- **Data**
  - statistics
    - standard deviation of data points around the constant fit (larger than the fit error)
  - p_T dependence
    - difference between log-linear and constant fits taken as systematic
  - trigger
    - 100% efficiency in the selected bins
  - pile-up
    - no effect observed
  - extrapolation to zero 3rd jet
    - error of the extrapolation line

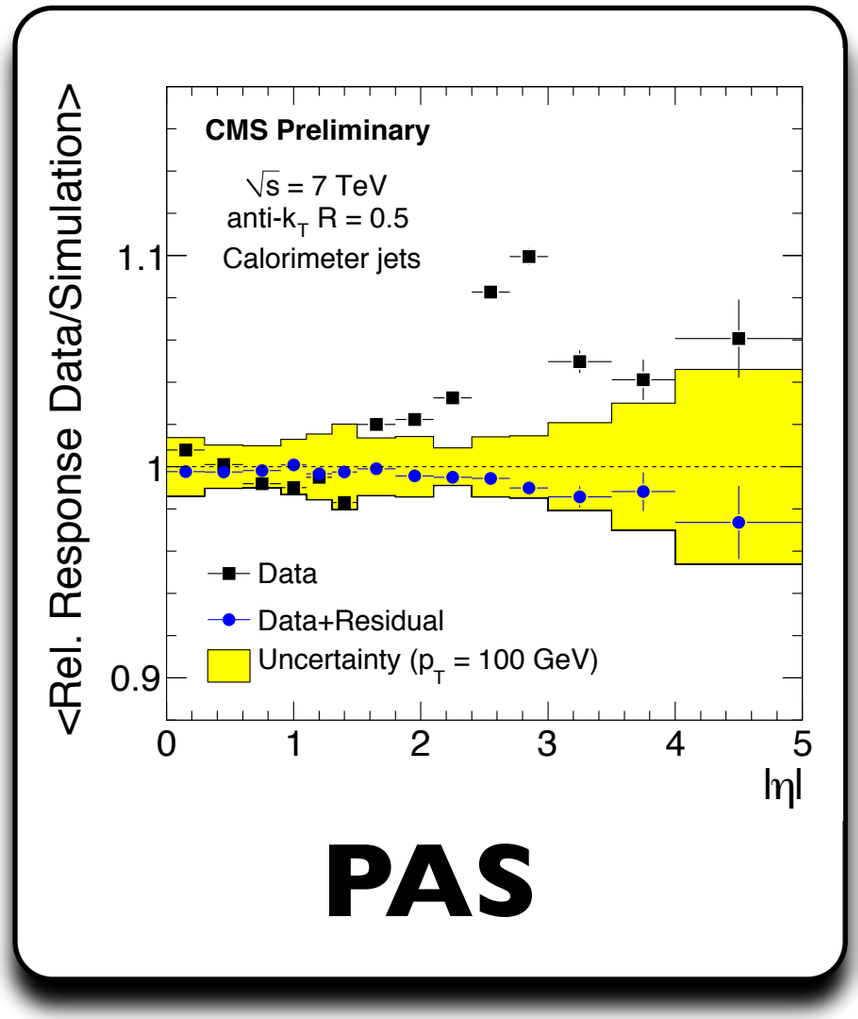
Residual Relative Correction Uncertainty

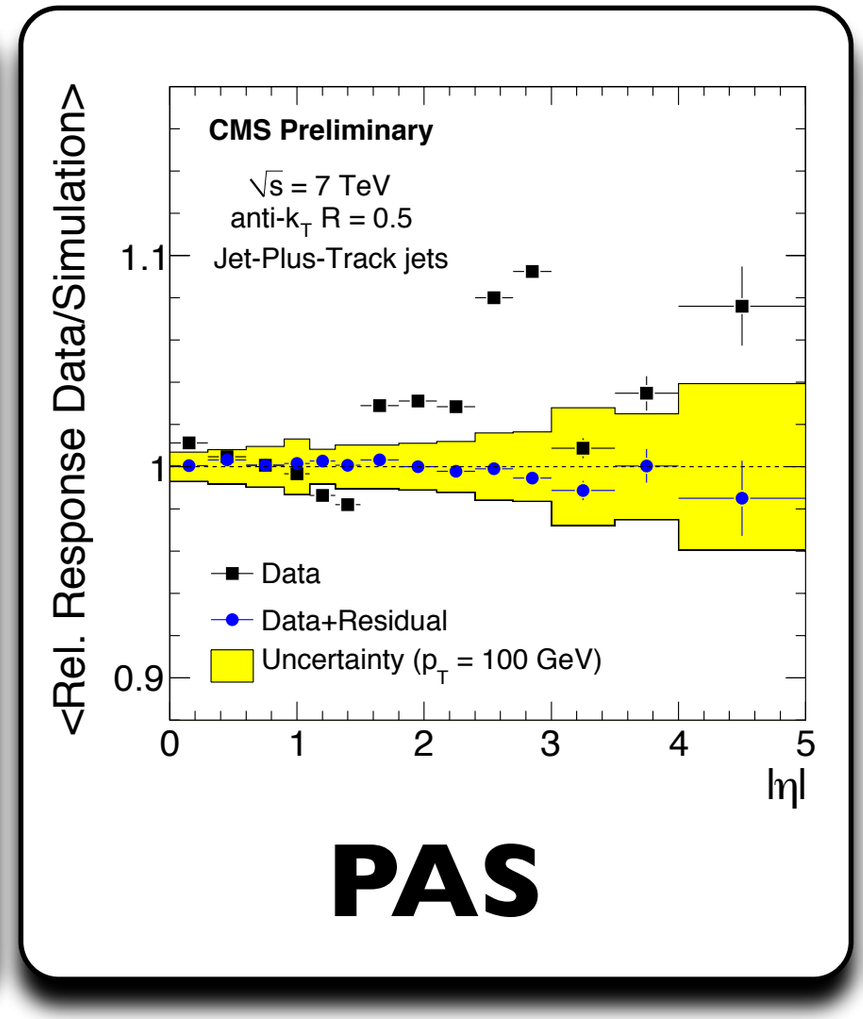


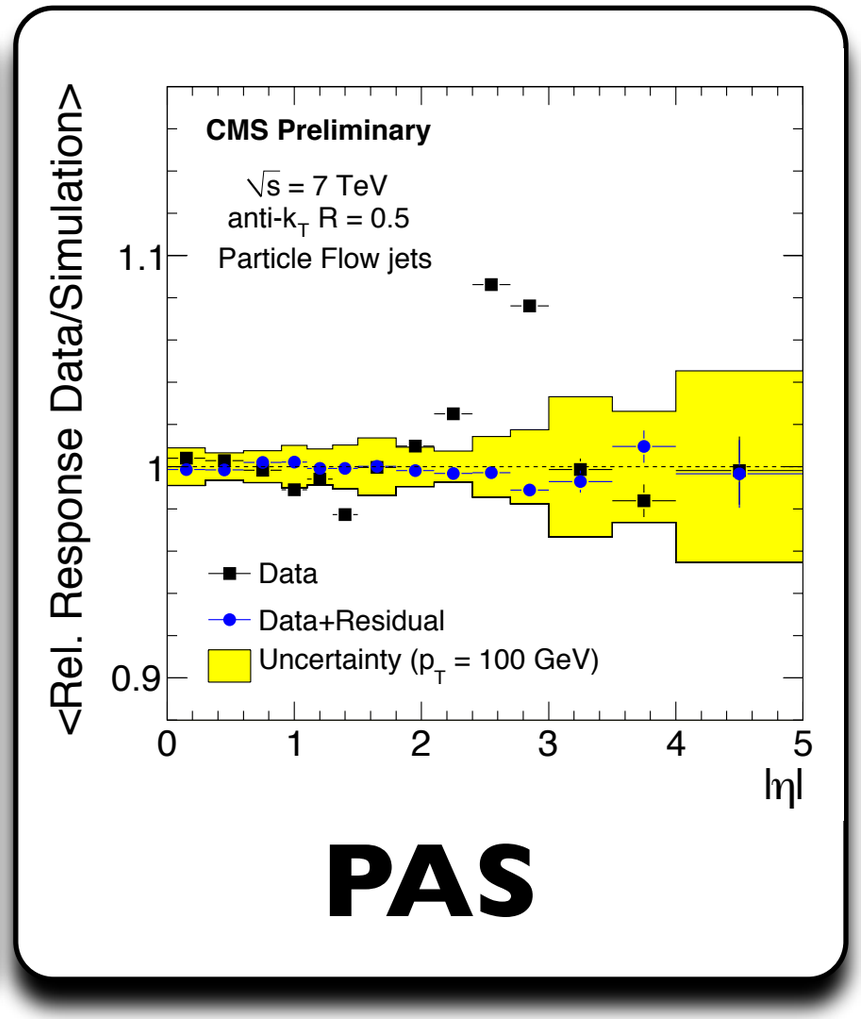


- uncertainty typically rises in outer $|\eta|$
  - larger resolution bias and worse statistics
- measurement mostly statistically limited
- differences between jet types due to statistics and p_T slope

Applying the Residual Correction







- up to 10% higher response in data is observed (mainly in the Endcap)
- the residual correction restores the data/MC agreement to unity within uncertainties

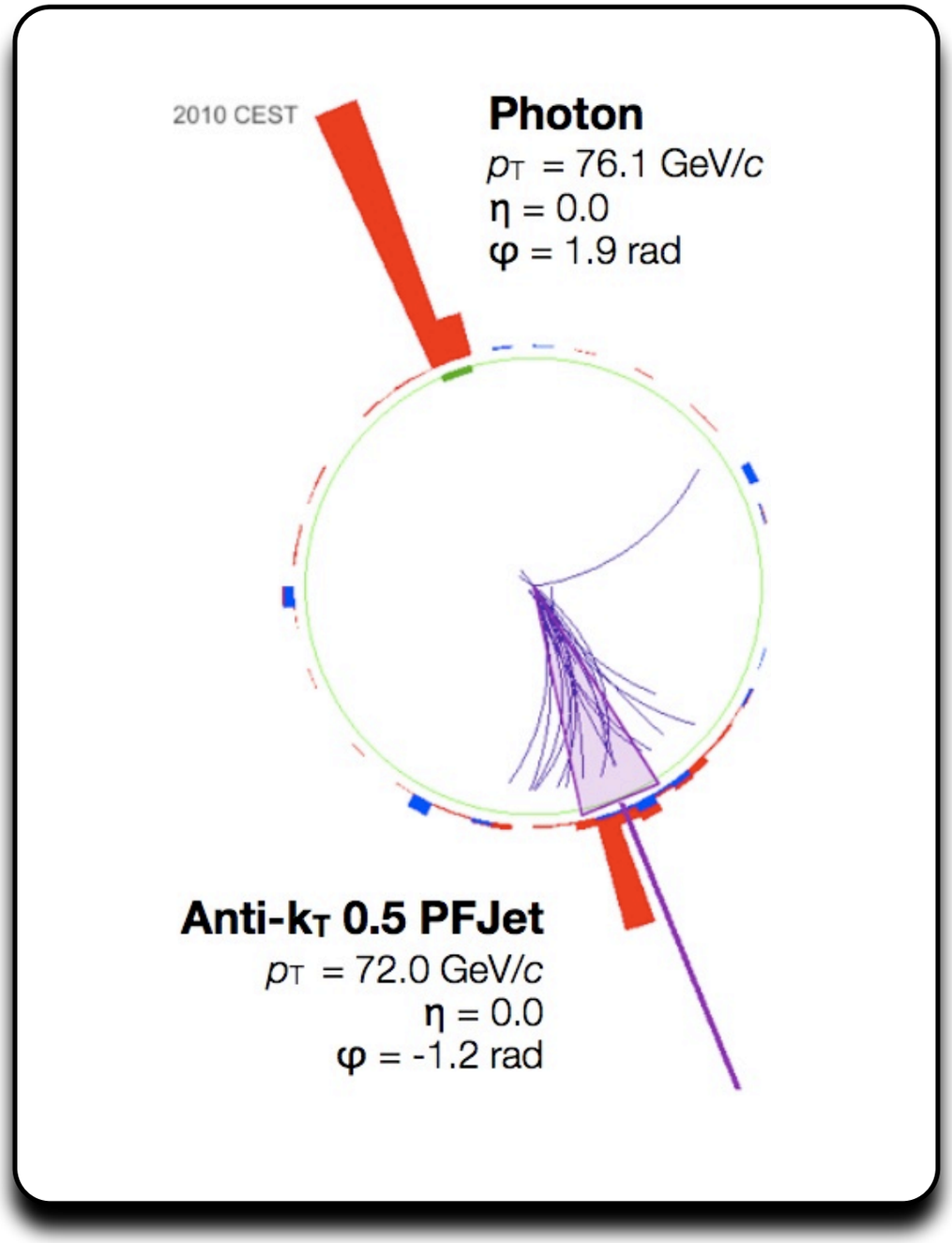
Absolute Jet Energy Scale

(restoration of the p_T scale in $|\eta|<1.3$)

Absolute Energy Scale: Overview

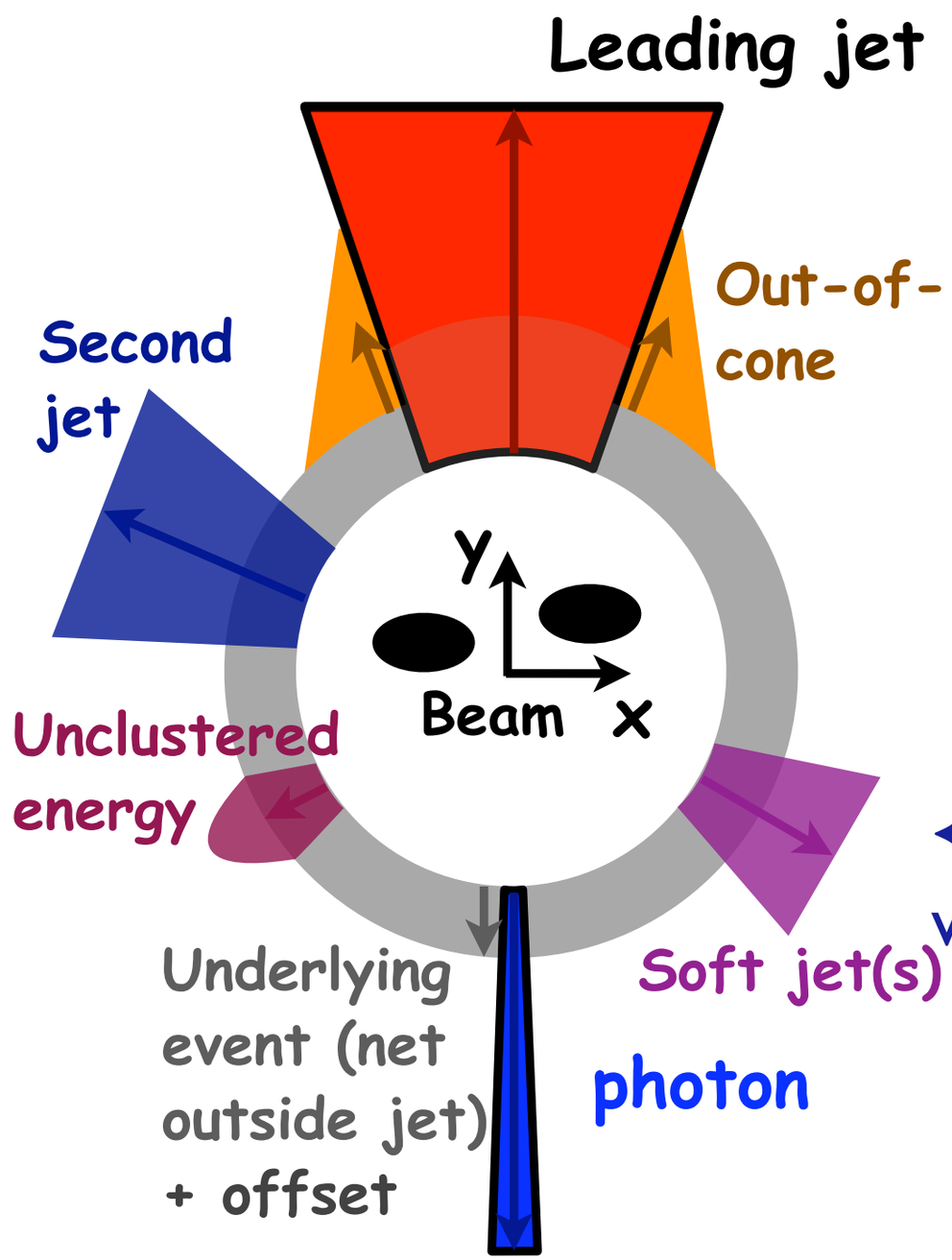
- **The absolute jet energy scale is measured in the Barrel ($|\eta|<1.3$) using photon+jet events**
  - the relative energy correction that has preceded ensures that the response in uniform vs η: it suffices to measure the absolute response in the Barrel
- **The goal of the measurement is to verify that the simulated absolute scale agrees with the data**
- **Two methods employed**
  - missing E_T projection fraction (MPF): main method
  - photon+jet p_T balance: auxiliary method, used for cross-checks
- **The MPF method is ideal for PFJets**
  - the measurement is performed primarily with PFJets and then "transferred" to the other jet types by direct jet-by-jet matching

Photon+Jet p_T Balance: Selection



- **Event Selection**
  - Single photon triggers
  - good primary vertex
  - photon with p_T > 15 GeV and $|\eta|<1.3$
  - standard photon isolation and ID
  - recoiling jet in $|\eta|<1.3$
  - photon-jet "back-to-back" in azimuth: $\Delta\varphi > 2.7$
  - small 2nd jet activity: $p_T^{jet2}/p_T^{\gamma} < 0.2$
  - second jet outside the $\Delta R > 0.25$ cone around the photon
- **Jet Selection**
  - anti-k_T, R=0.5 Calo, JPT, PF
  - loose jet ID

The MPF Method



$$\vec{p}_{T,\gamma} + \vec{p}_{T,recoil} = \vec{0}$$

$$R_\gamma \vec{p}_{T,\gamma} + R_{recoil}\vec{p}_{T,recoil} = -\vec{E}_T^{miss}$$

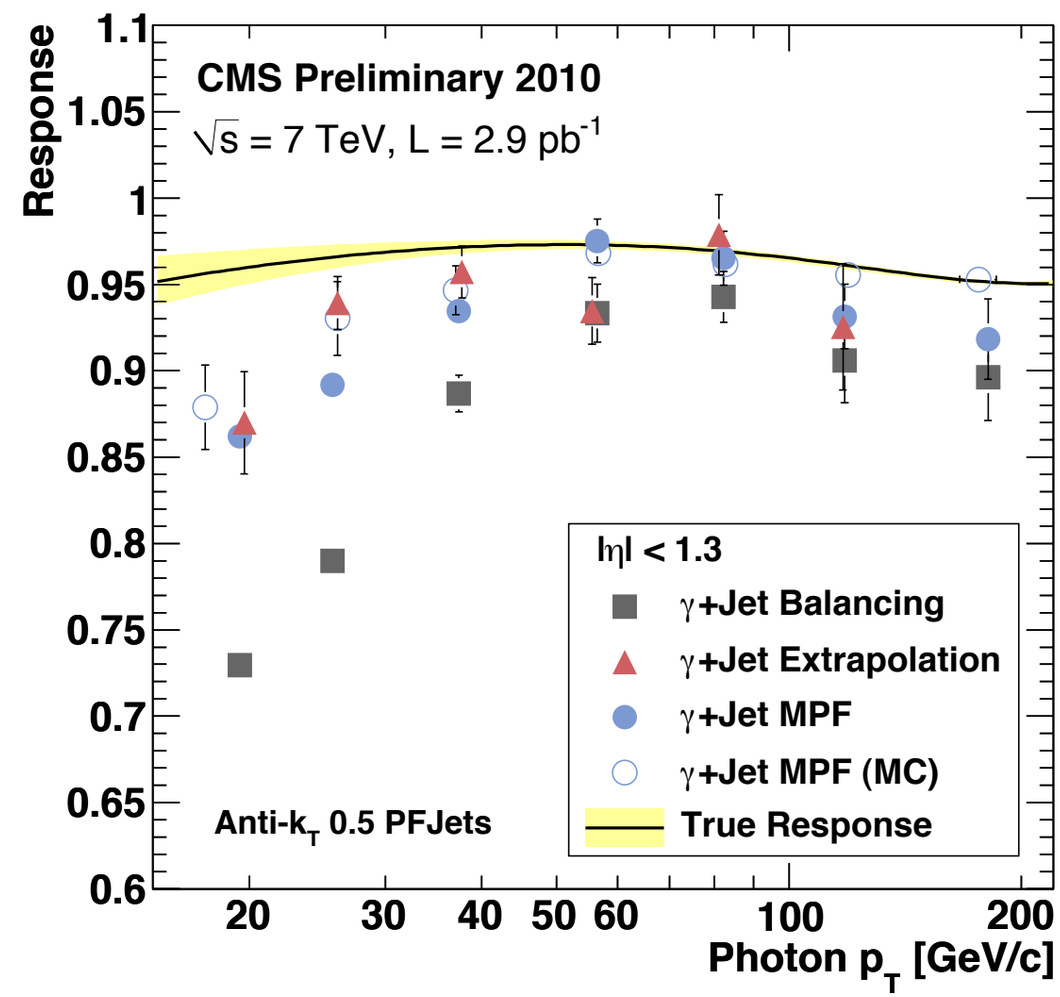
$$R_{MPF} \equiv \frac{R_{recoil}}{R_\gamma} = 1 + \frac{\vec{E}_T^{miss} \cdot \vec{p}_{T,\gamma}}{(p_{T,\gamma})^2}$$

$$R_{recoil} = R_{lead\,jet}\left(1 + \Delta R_{recoil} \cdot \hat{p}_{T,recoil}\right)$$

- no real missing E_T: balances the photon with the full recoil
  - the MPF response is interpreted as the leading jet response if the different parts of the topology have similar response (ideally suited to PFJets)
- generally less sensitive to systematics than the classical p_T balance for PFJets

Absolute Response

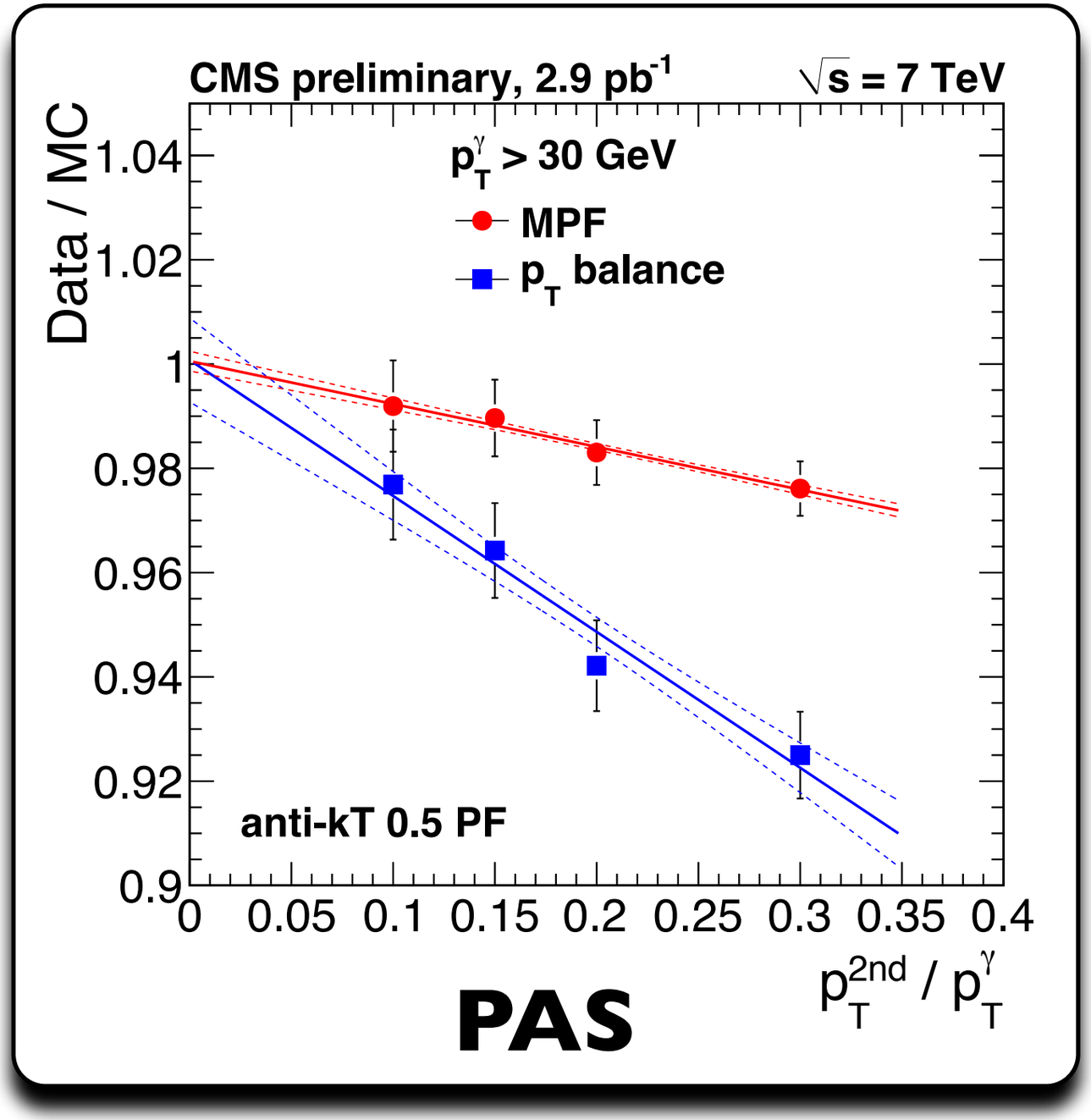
- different methods compared to the true response in pure photon+jet sample
  - large bias in the p_T balance method due to the presence of additional jet (corrected by extrapolation to $p_T^{2nd} \rightarrow 0$)
- remaining bias at p_T < 30 GeV between MPF and Truth
  - probably due to jets and particles out of detector acceptance
  - expect reasonable modeling by MC



PAS

Secondary Jets

- Data seem to have more secondary jets close to the leading jet (final state radiation) than MC
  - appears as slope in the extrapolation: the harder the cut the better the data/MC agreement
  - corrected by extrapolation to $p_T^{2nd} \rightarrow 0$
  - no p_T^{γ} dependence
- Both the MPF and the p_T balance methods agree very well between data/MC after the extrapolation

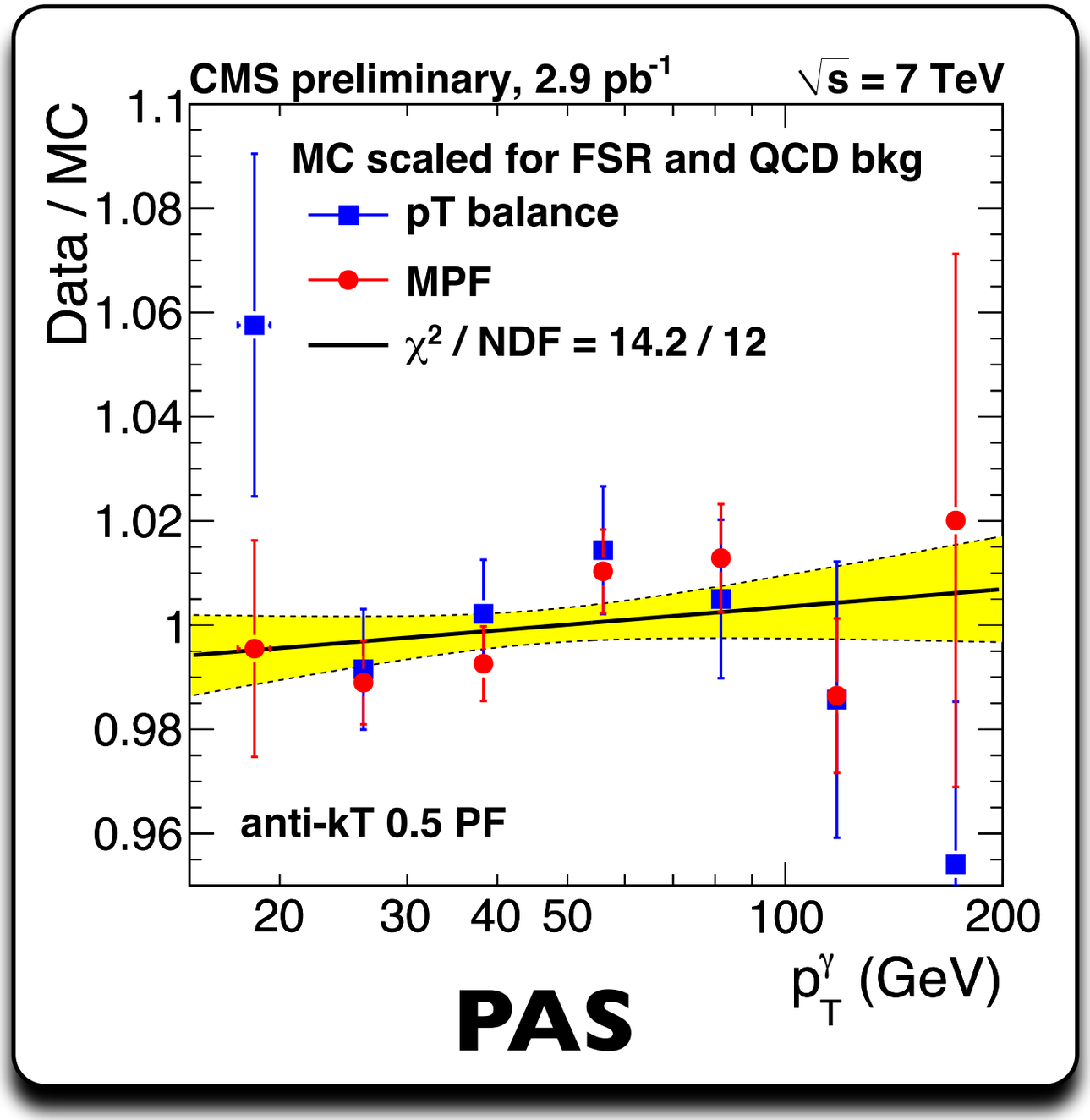


Absolute Response: Final Comparison

✦ After correcting to $p_T^{2nd} \rightarrow 0$, the MPF and p_T balance measurements are consistent, with no statistically significant slope vs p_T

✦ After a combined fit of the two set of points (largely un-correlated) we get **Data/MC = 0.993±0.004(stat) ±0.026(syst)** at **p_T = 50 GeV**

✦ A small absolute residual of **0.7%** needs to be applied to the data



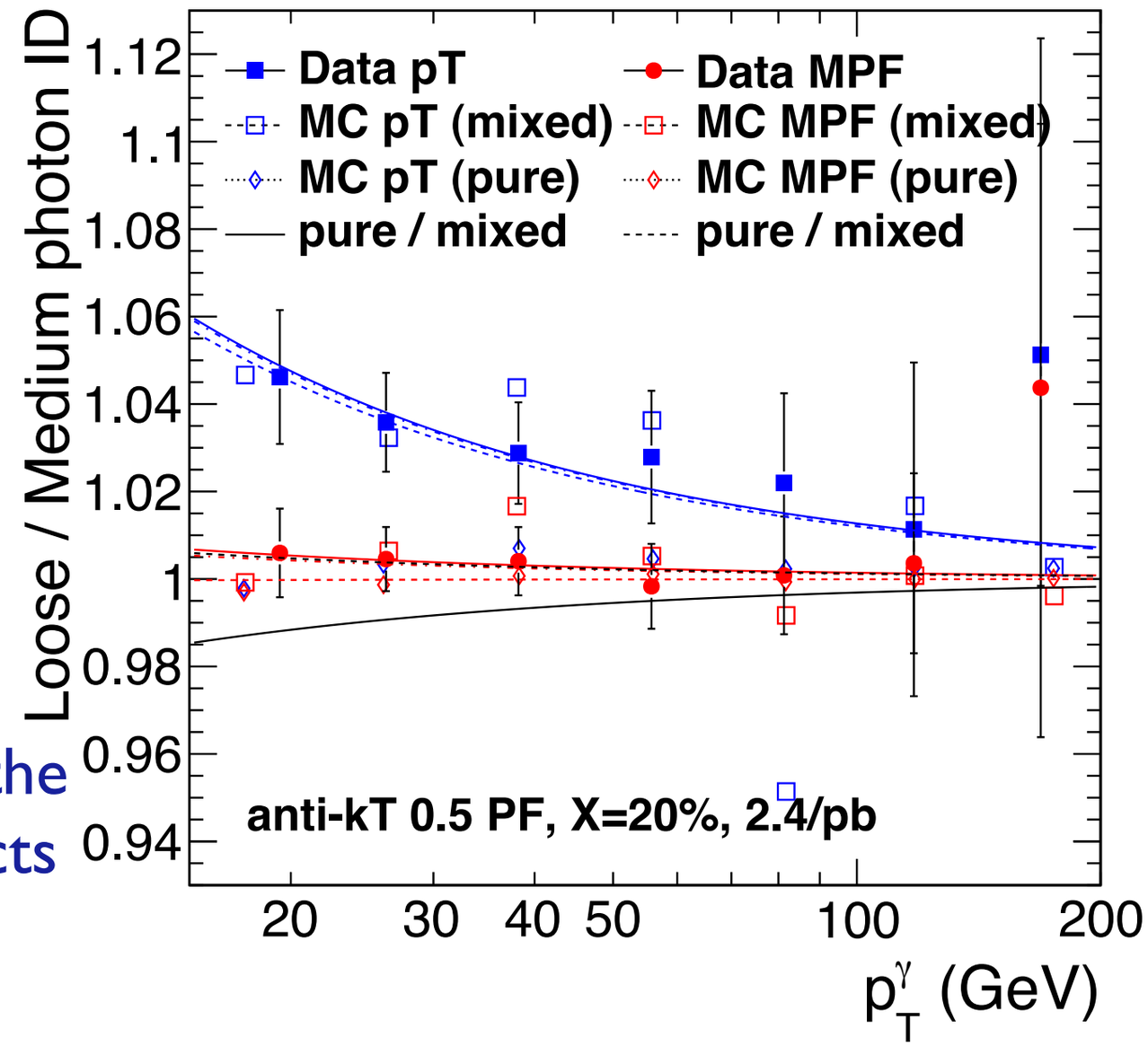
$$C_{abs} = 1.007$$

Absolute Scale: Uncertainty Sources

- **MPF method**
  - secondary jets
  - flavor mapping
  - parton correction
  - QCD background
  - proton fragments
- **photon energy scale**
- **extrapolation to high-p_T**
  - single particle response
  - fragmentation modeling
- **offset due to noise and pile-up**
- **residuals**
  - MCtruth closure
  - jet-by-jet-matching

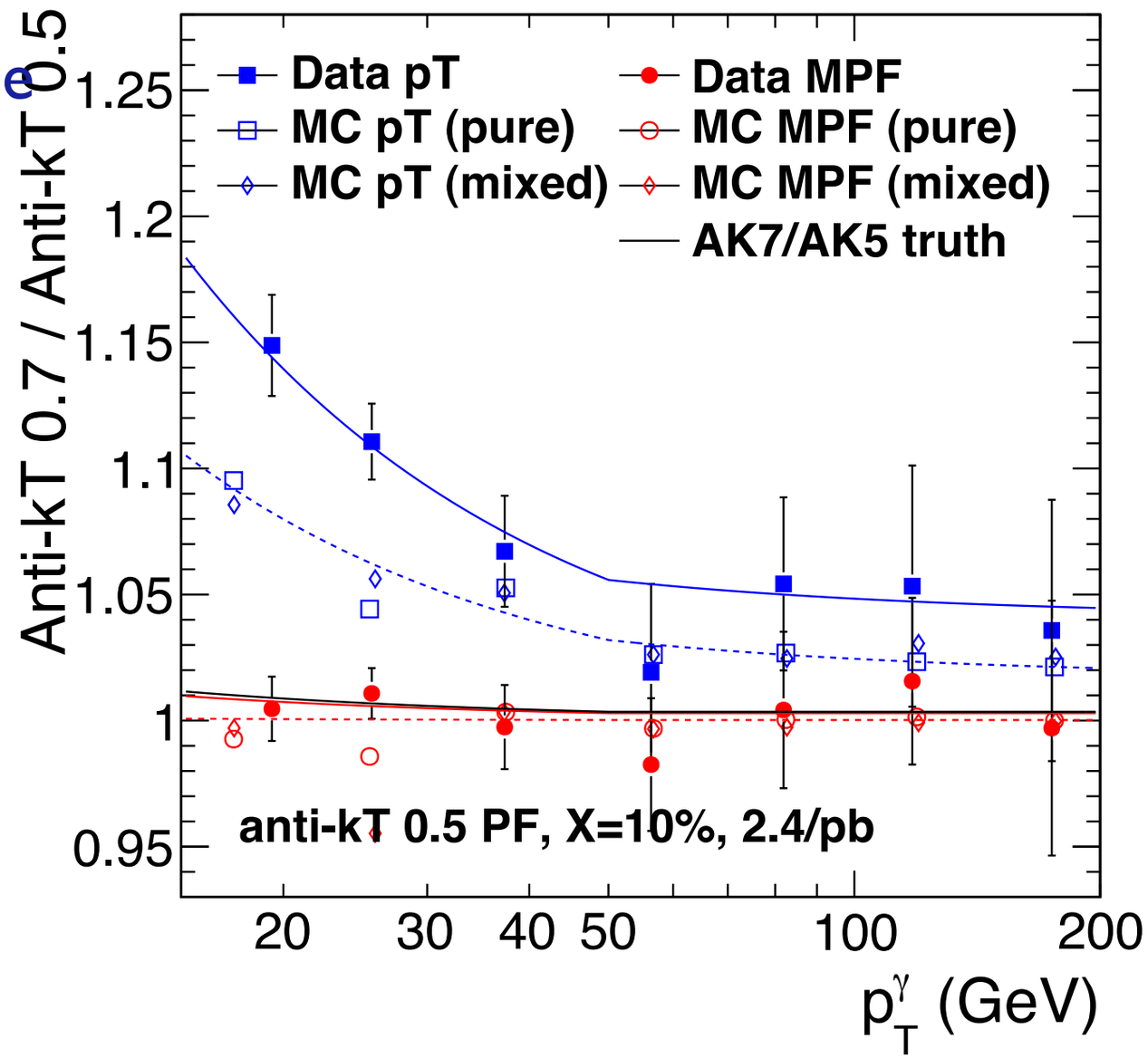
MPF Uncertainties: QCD Background

- QCD background: $\pi^0 \rightarrow \gamma\gamma$
  - a leading jet fragments into a hard isolated π^0 which carries a fraction of the initial parton energy
- sensitivity checked by loosening the photon ID cuts
  - increase QCD background
- MPF insensitive to the QCD background
  - in the MPF method all is needed is the recoil balancing a well measured objects
- p_T balance sensitive to the QCD background
  - the balance is directly spoiled
- both methods modeled well in the MC



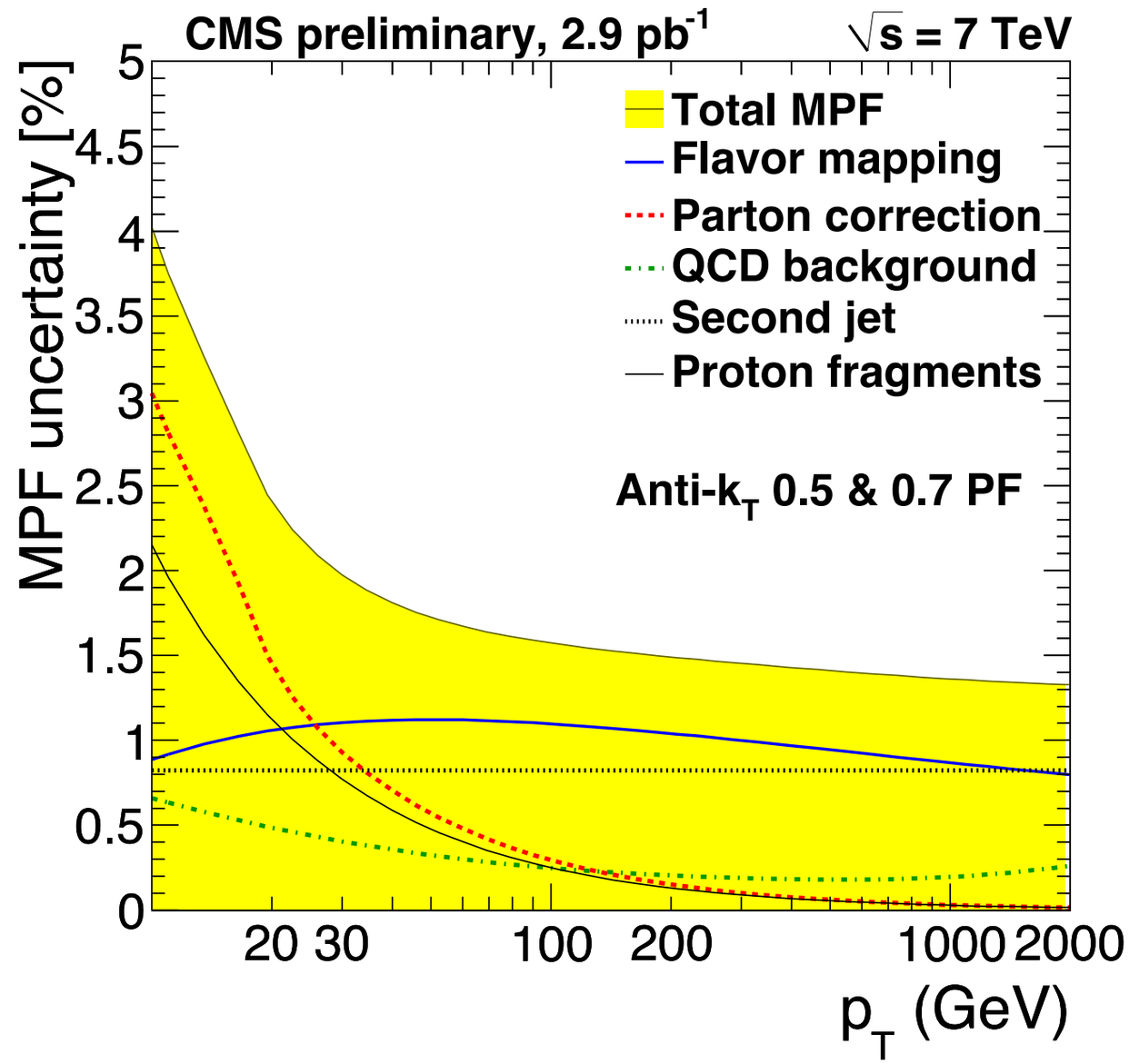
MPF Uncertainties: Parton Correction

- the MPF measures the response to the parton level
- MC correction to the particle level
- MC uncertainty
  - underlying event (UE)
  - out-of-cone (OOC)
- check the sensitivity of the MPF measurement with wider jets (R=0.7)
  - the assumed parton correction uncertainty is conservative, when compared to the MPF sensitivity

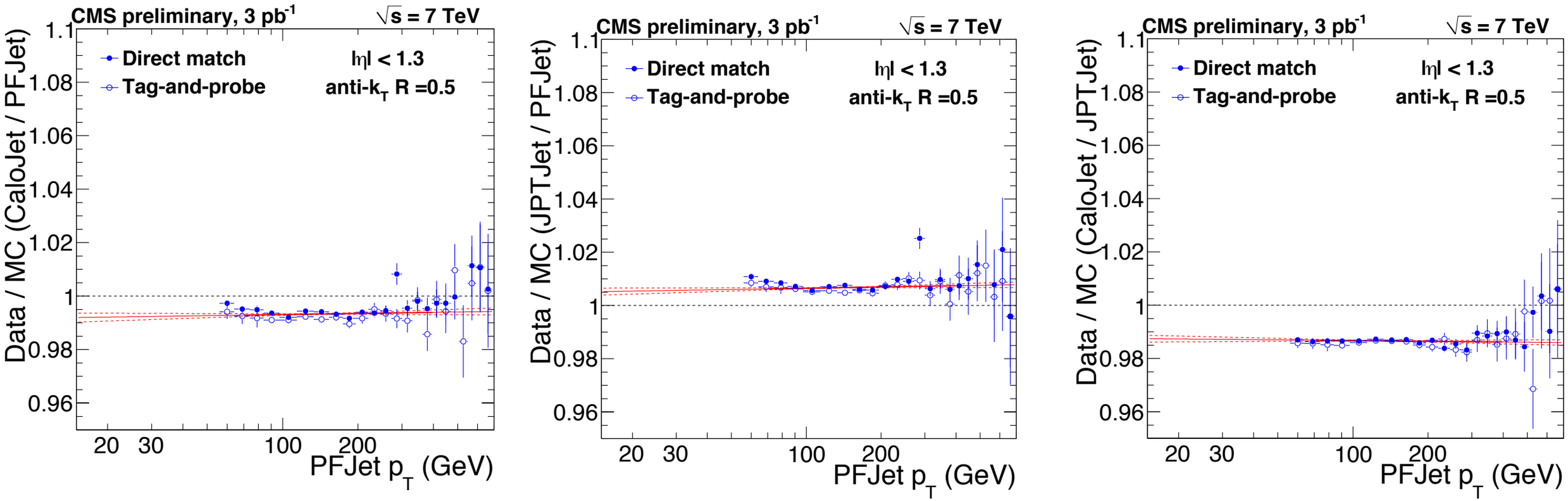


MPF Uncertainties: Summary

- flavor response mapping from the quark-rich photon+jet sample to the gluon-rich QCD dijet sample
  - no constrain from data
  - uncertainty = 50% of the mapping
- parton correction
- QCD backround
- secondary jets
  - 50% of the extrapolation



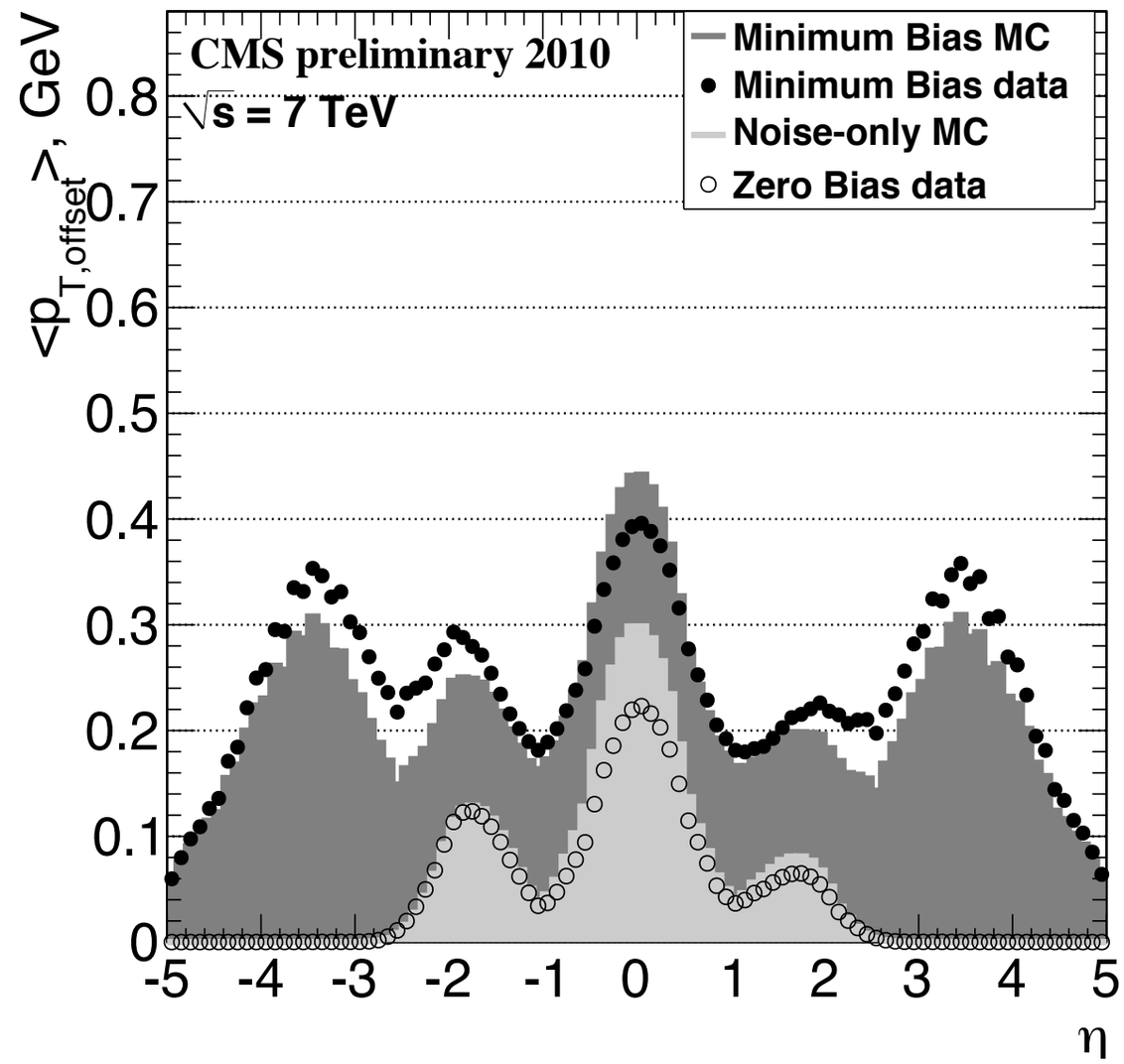
Jet-by-Jet Matching



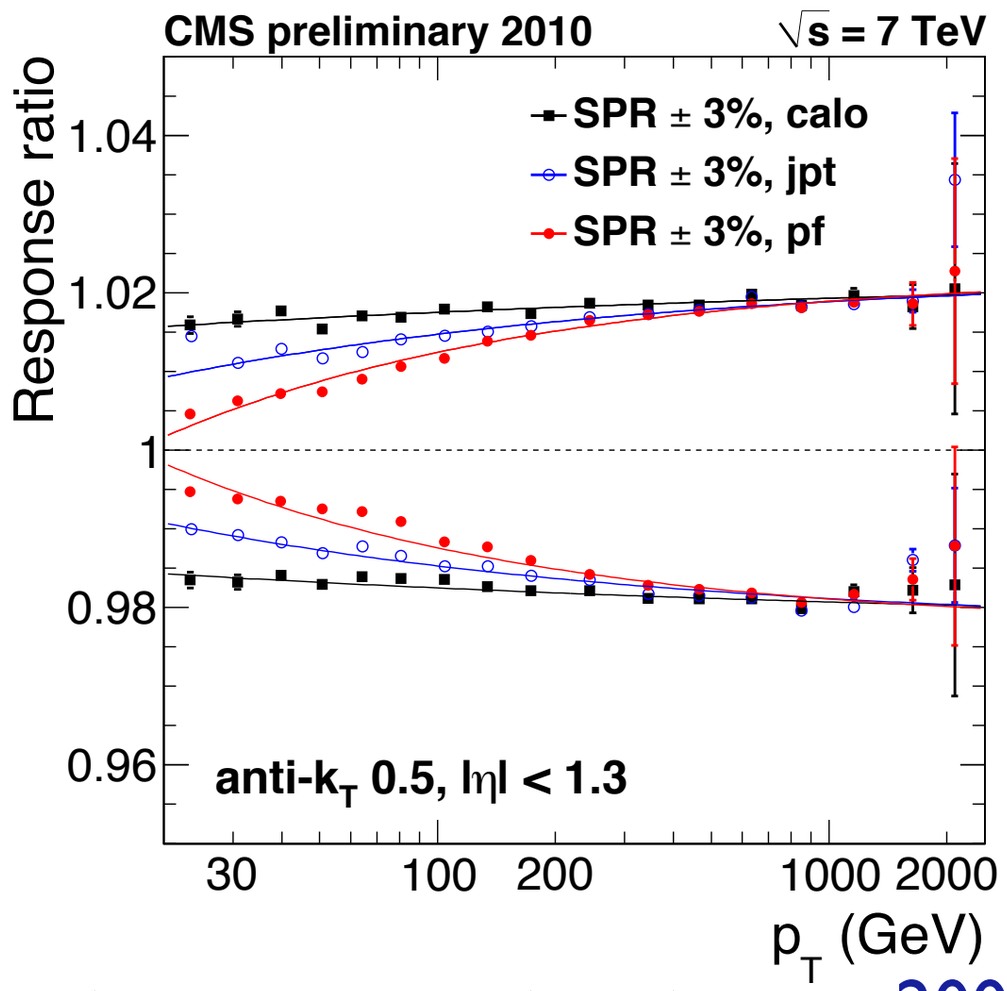
- ✦ the MPF method is used to estimate the PFJet energy scale uncertainty
- ✦ transfer to the other jet types by direct matching and tag & probe method
  - triple spatial jet-by-jet matching between PF-Calo-JPT jets
  - measure the response with respect to the jet with the best resolution (Calo/PF, Calo/JPT, JPT/PF) as a function of PFJet p_T
- ✦ reasonable agreement between data/MC
  - Calo/PF: ~-1%
  - JPT/PF: ~+1%

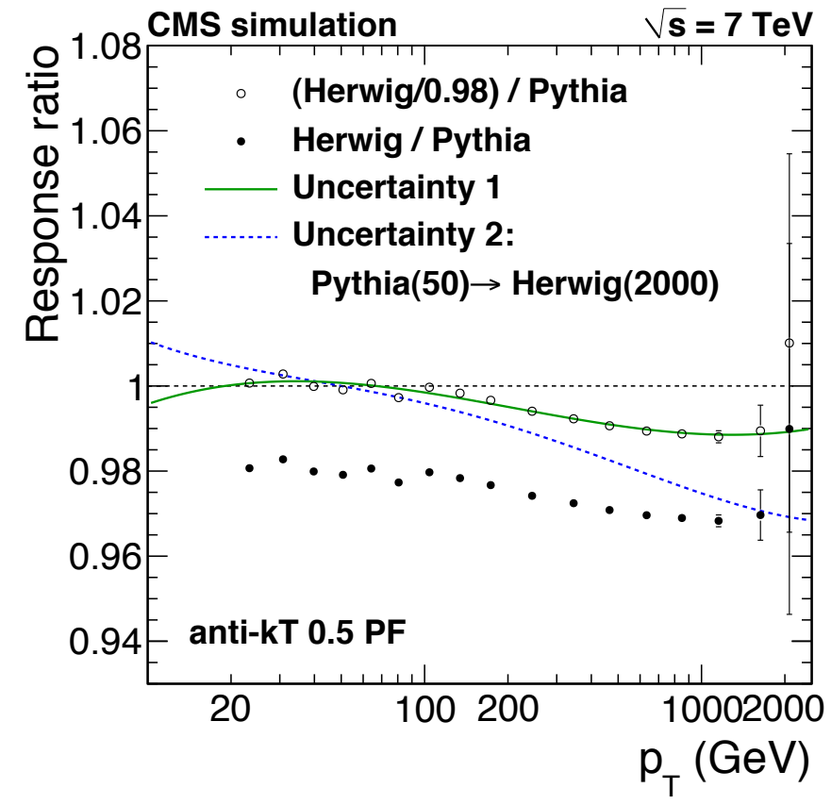
Offset

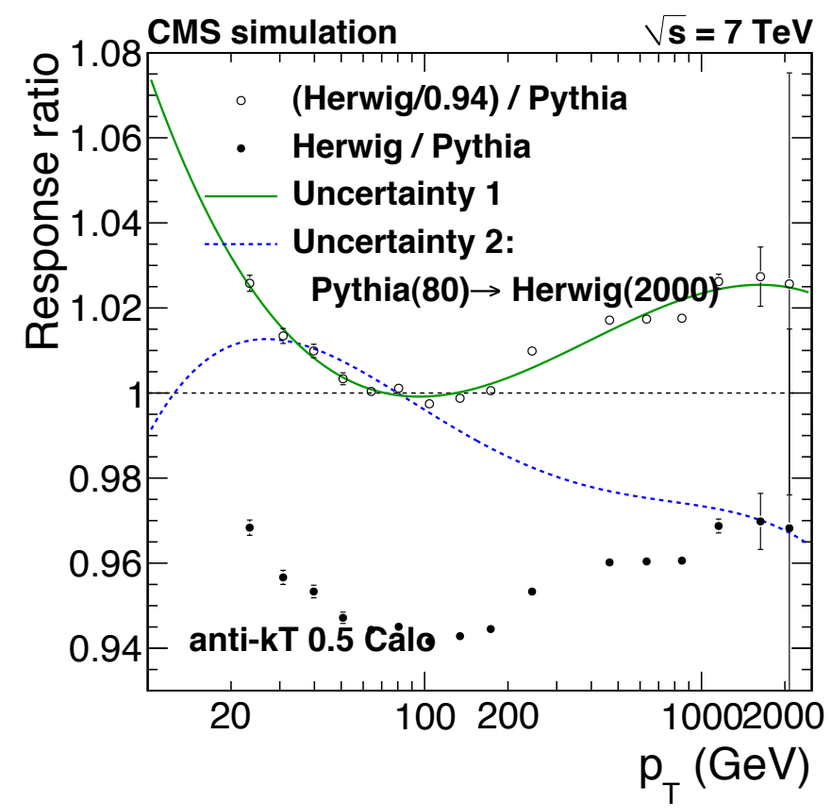
- Detector noise < 0.2 GeV in p_T
  - mostly in Barrel
  - folded into the MC truth JEC
- Pile-up contribution roughly 0.2-0.3 GeV in p_T per additional vertex
  - average 1 pile-up event
  - not corrected yet
  - taken as a systematic



High-p_T Extrapolation

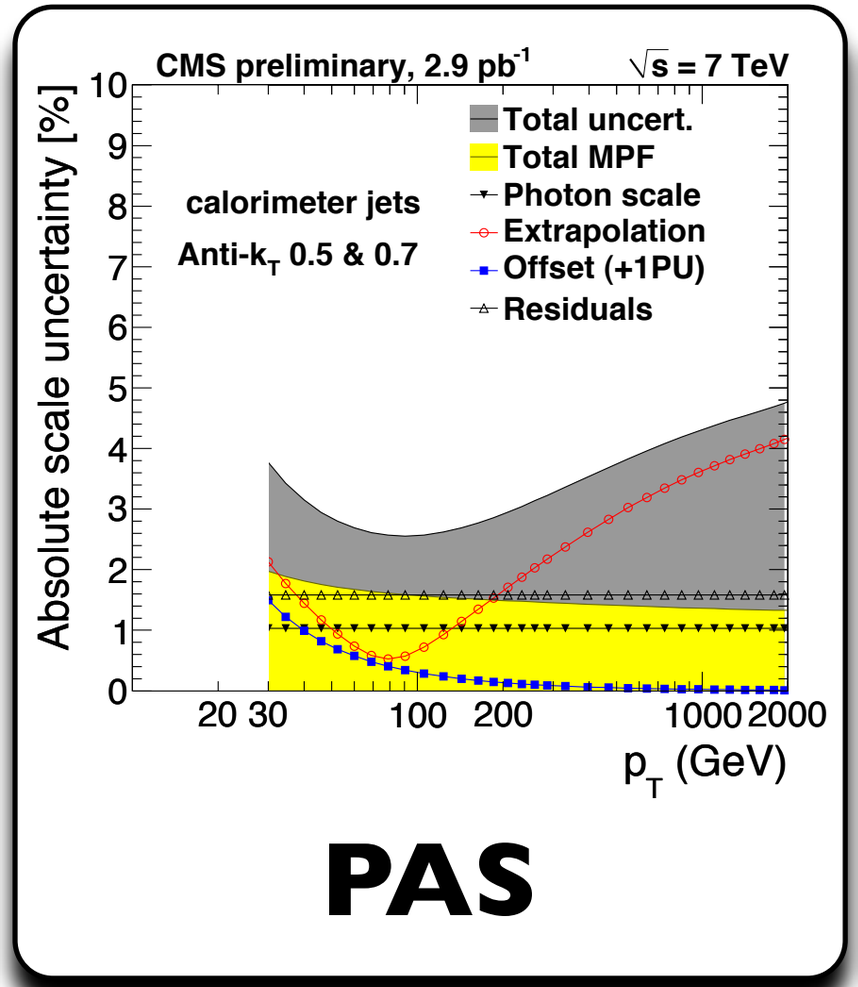


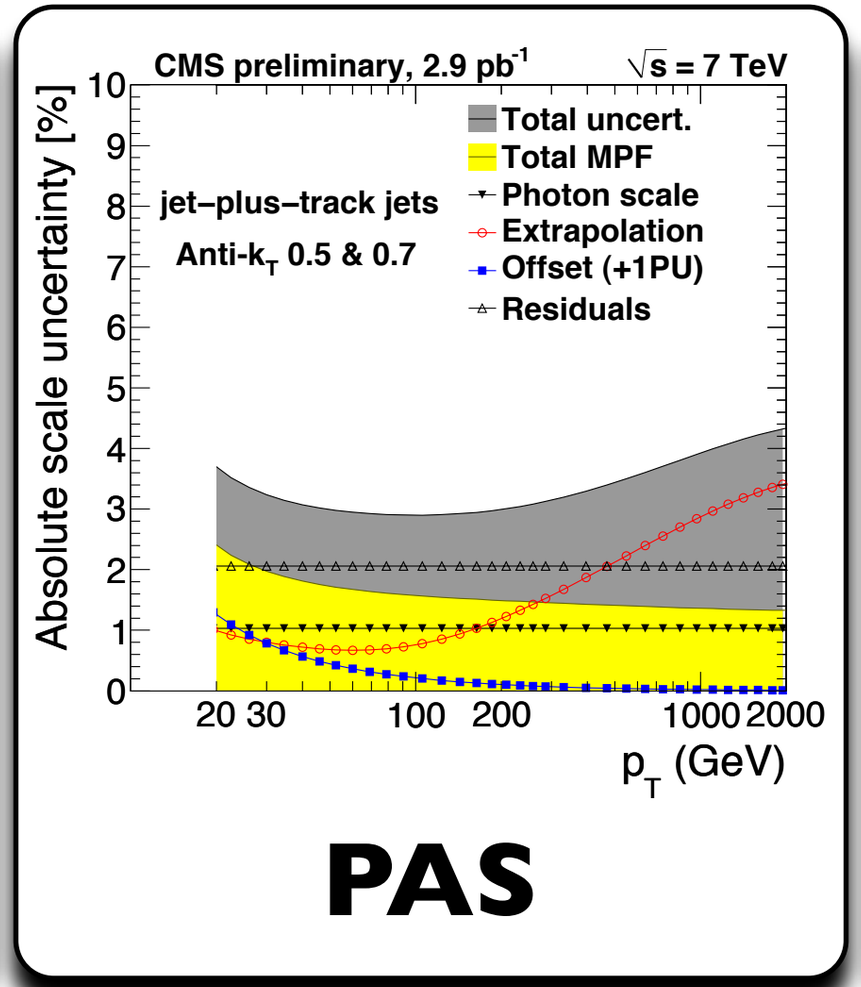


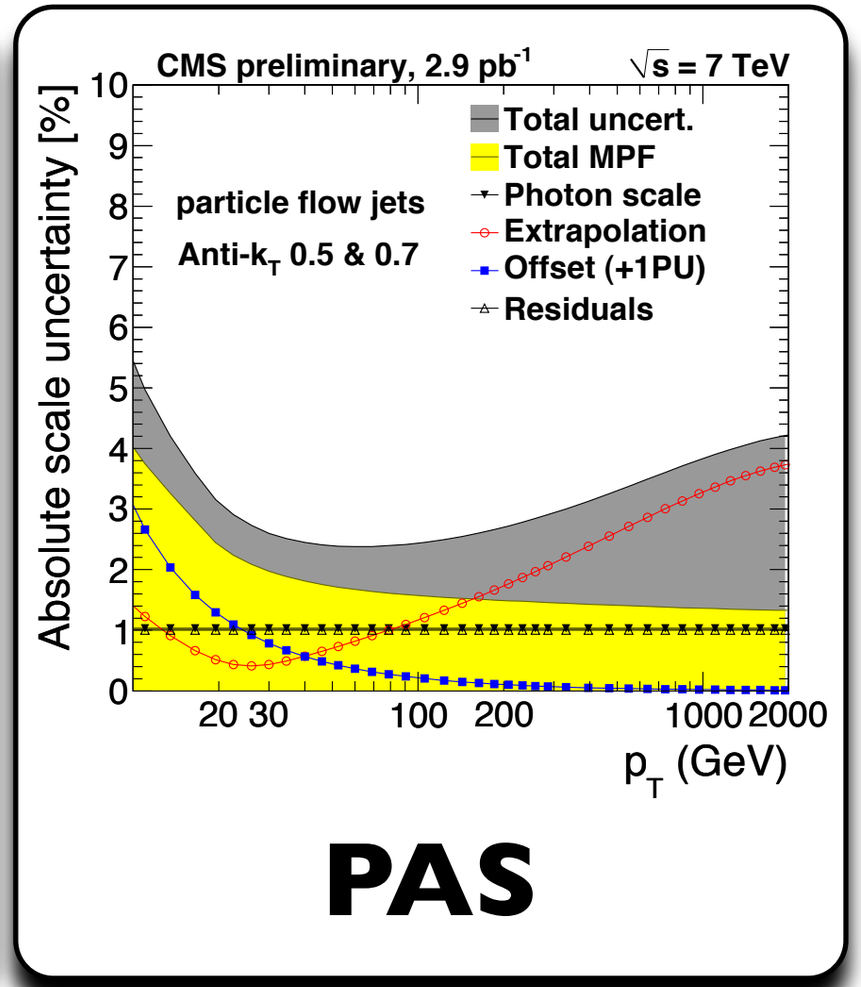


- direct measurement up to $p_T \sim 200$GeV
- extrapolation to higher p_T using the MC truth
  - single particle response (SPR)
    - varied the SPR by ±3% with FastSim
  - fragmentation
    - jet energy response variation between Pythia6 and Herwig++

Absolute Scale Uncertainty



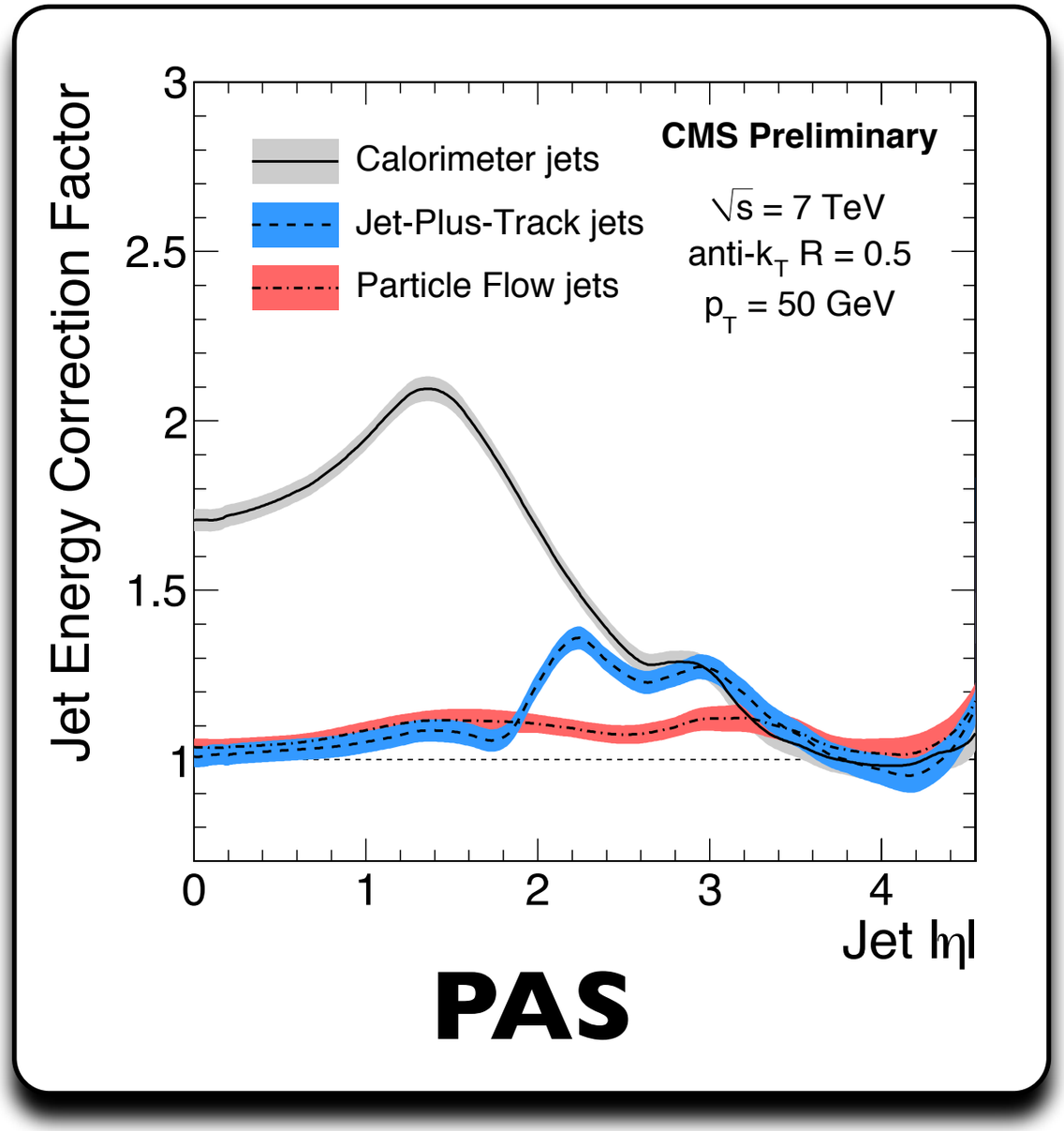


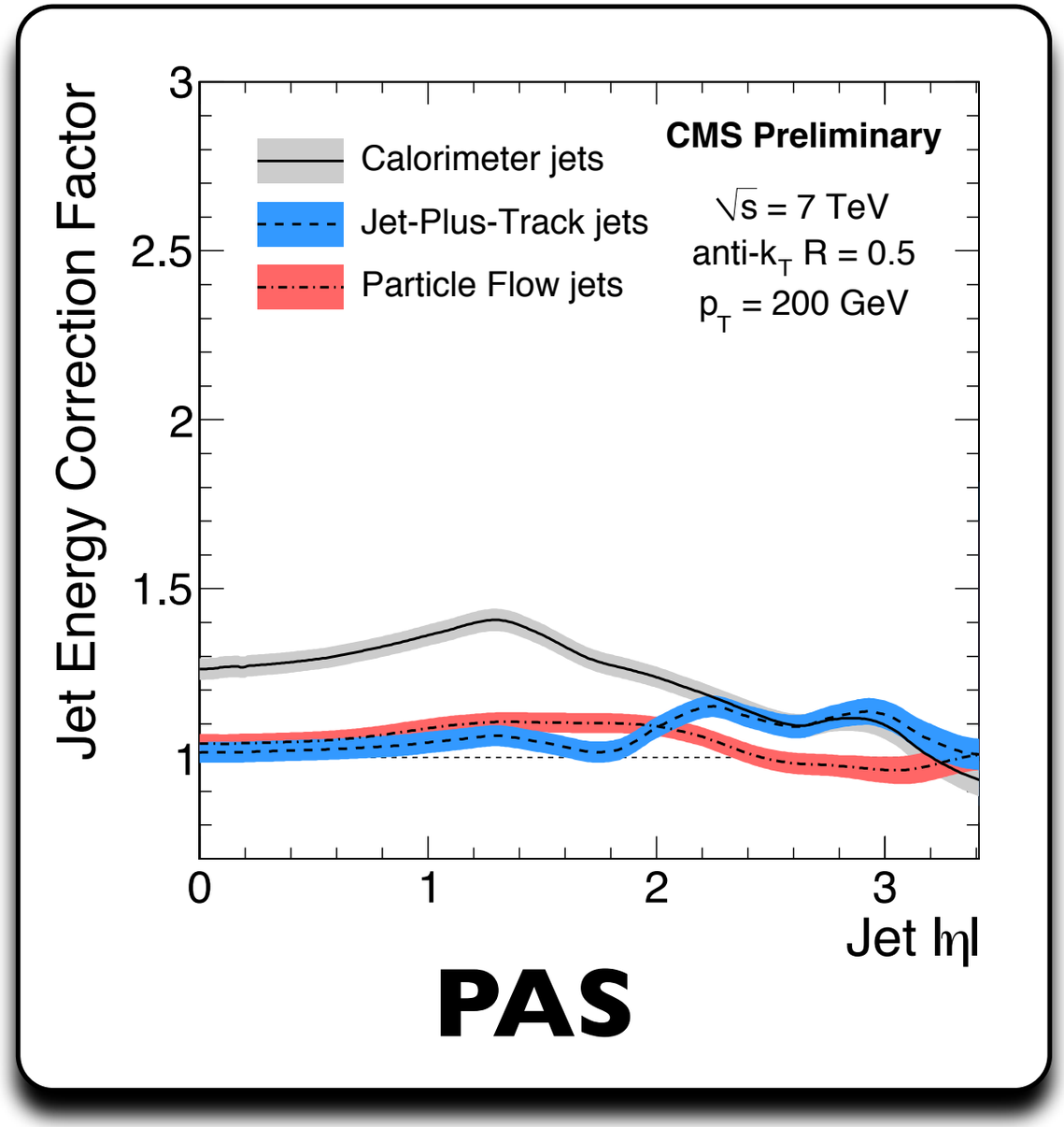


- Absolute scale uncertainty 3-5% in the entire p_T range
- Minimum recommended p_T values
  - Calo: 30 GeV
  - JPT: 20 GeV
  - PF: 15 GeV

Final Calibration

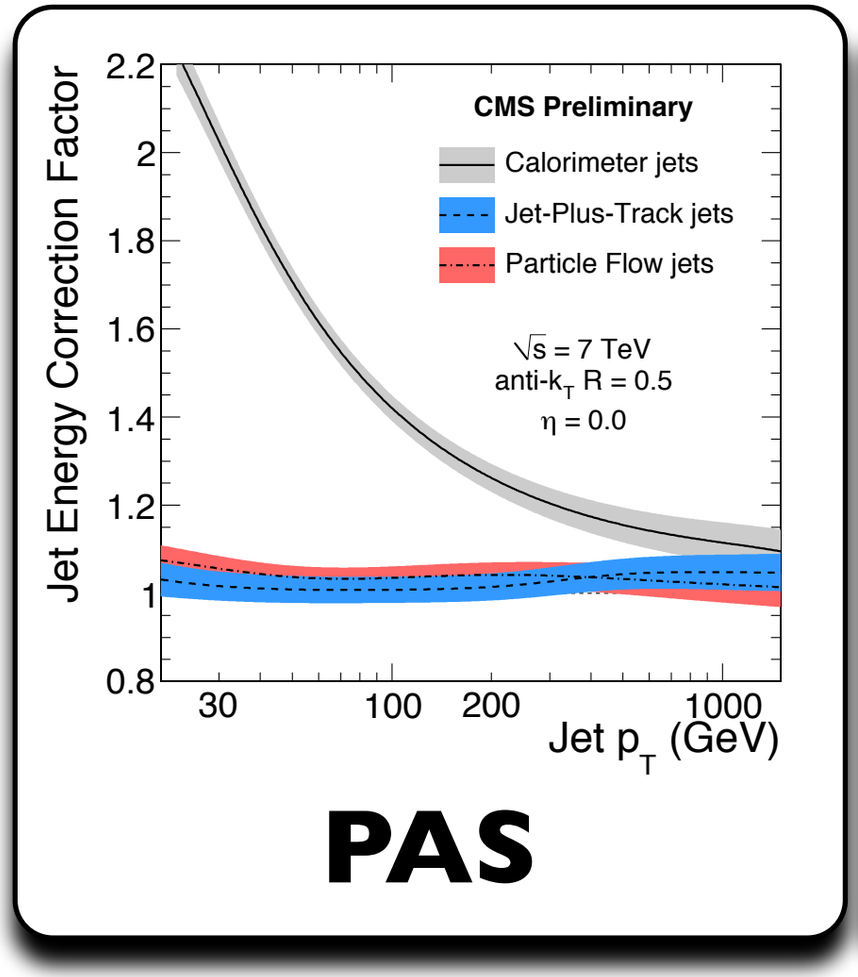
Combined JEC vs η

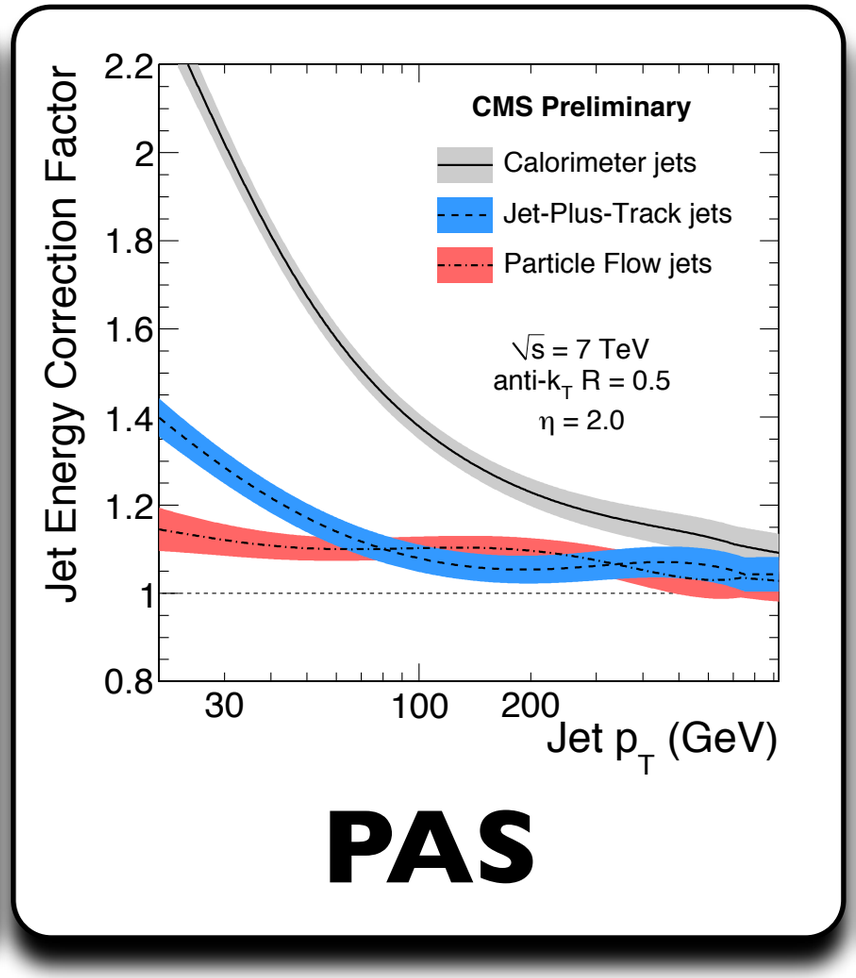


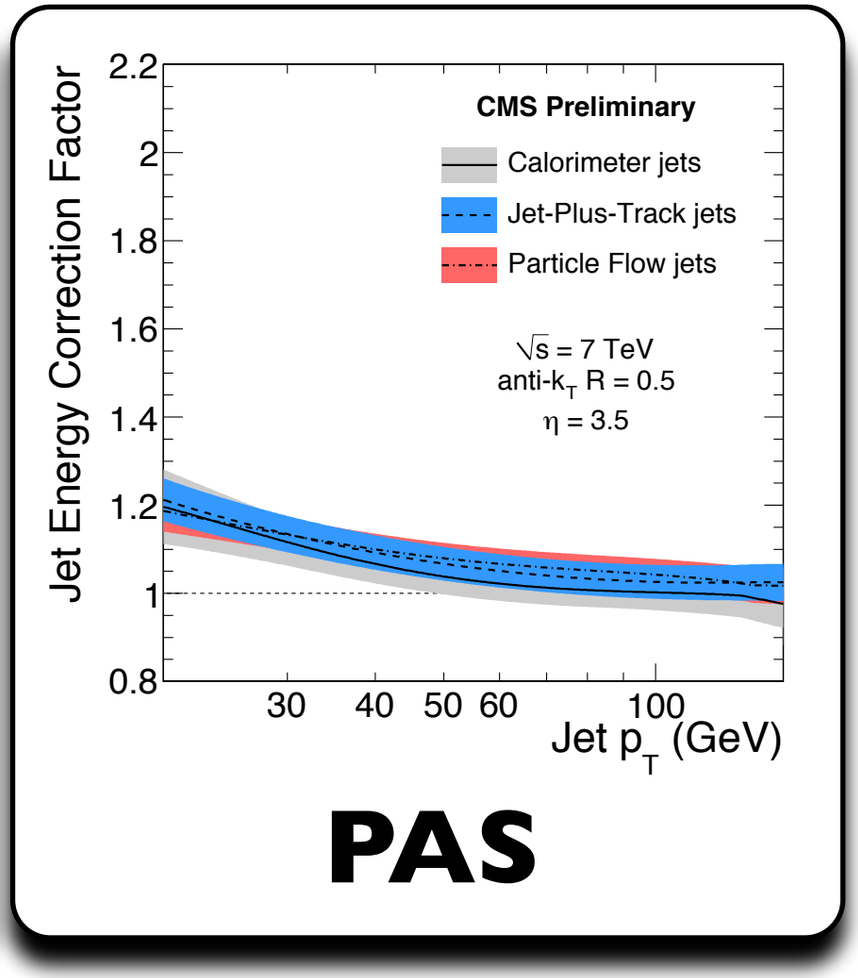


- Combined JEC factors and uncertainties vs |η|
  - MCTruth + Relative Residual + Absolute Residual

Combined JEC vs p_T

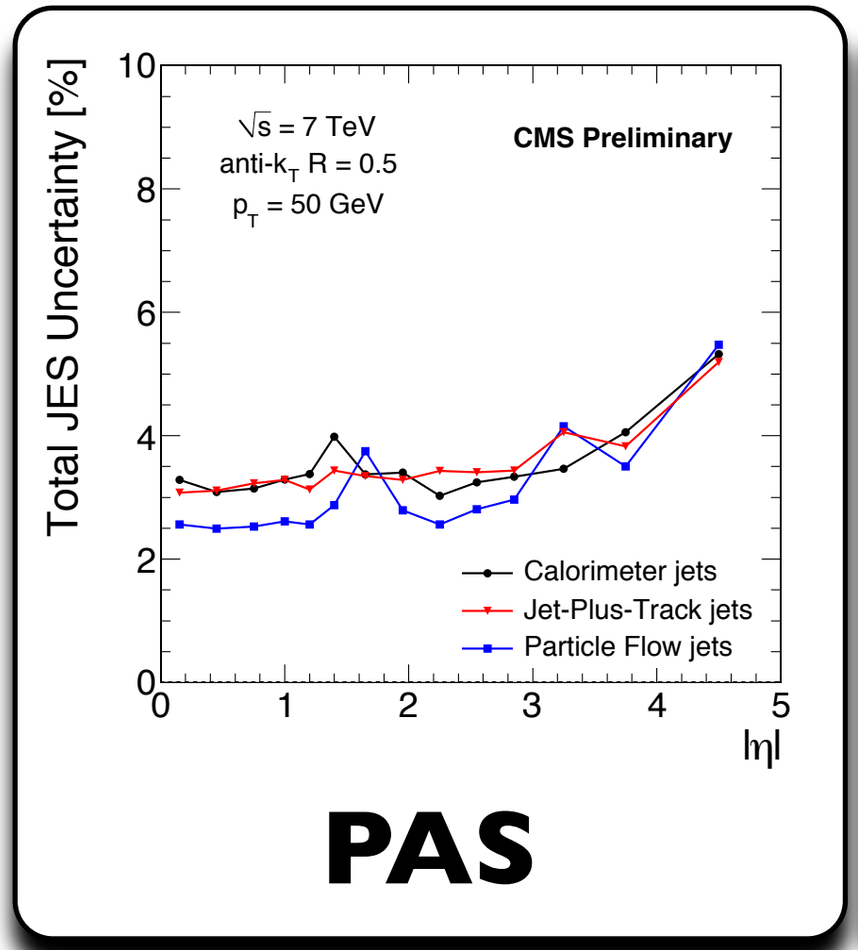


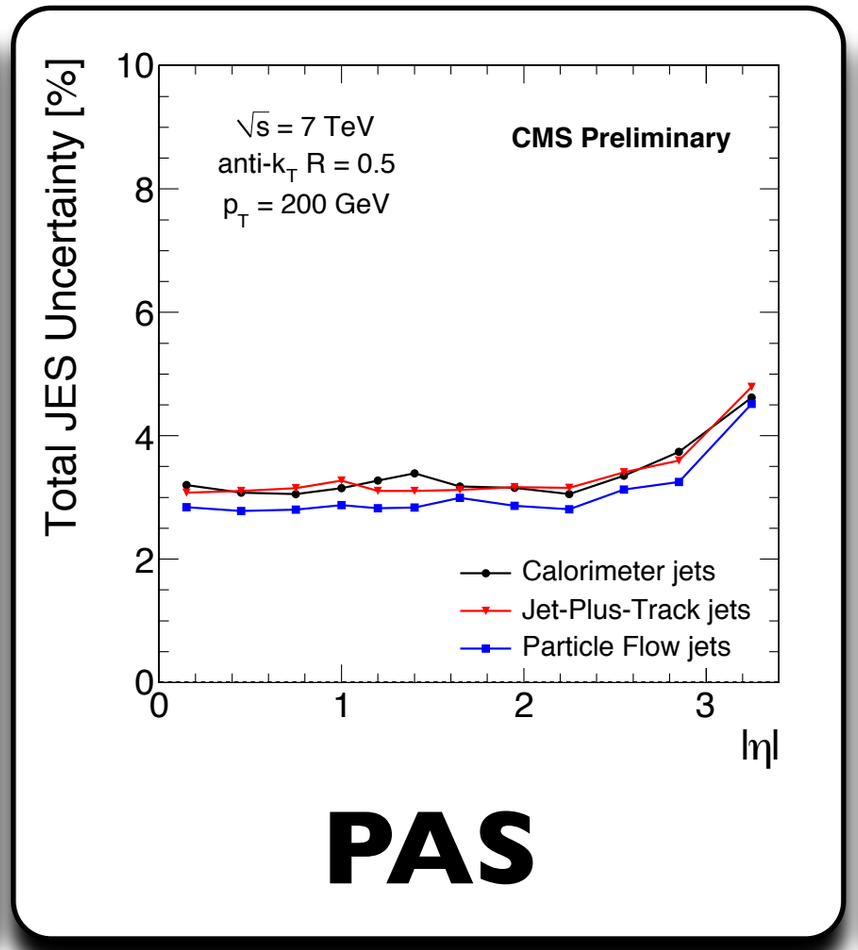


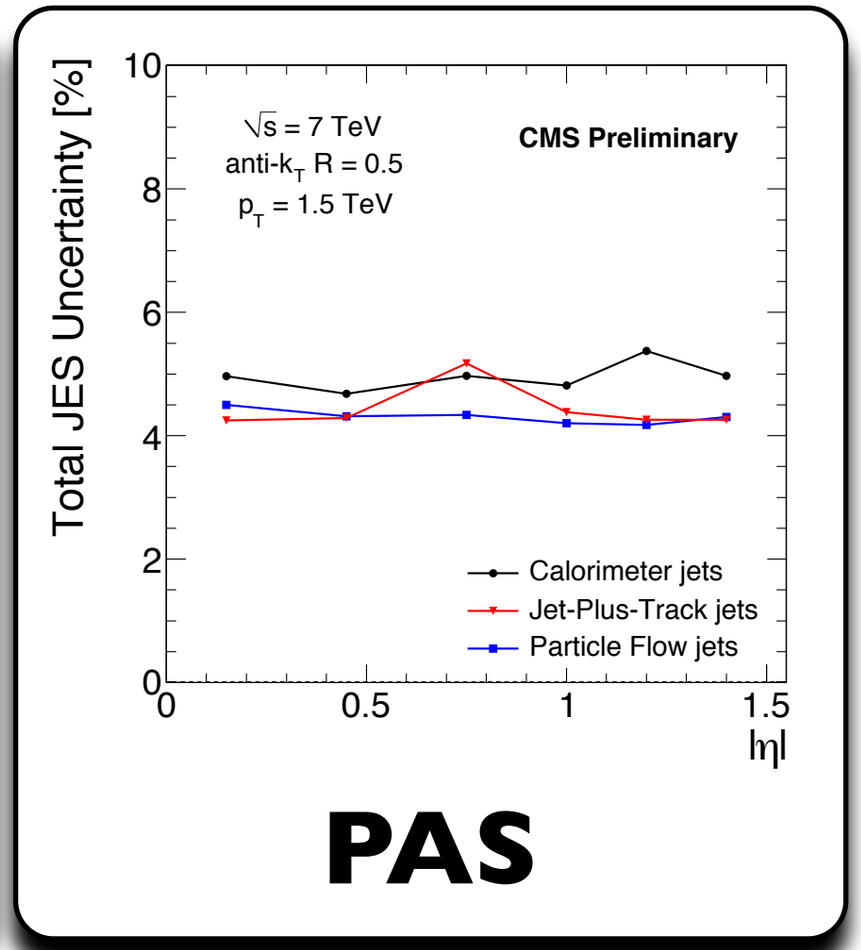


- Combined JEC factors and uncertainties vs p_T
  - MCTruth + Relative Residual + Absolute Residual

Combined JEC Uncertainty vs η

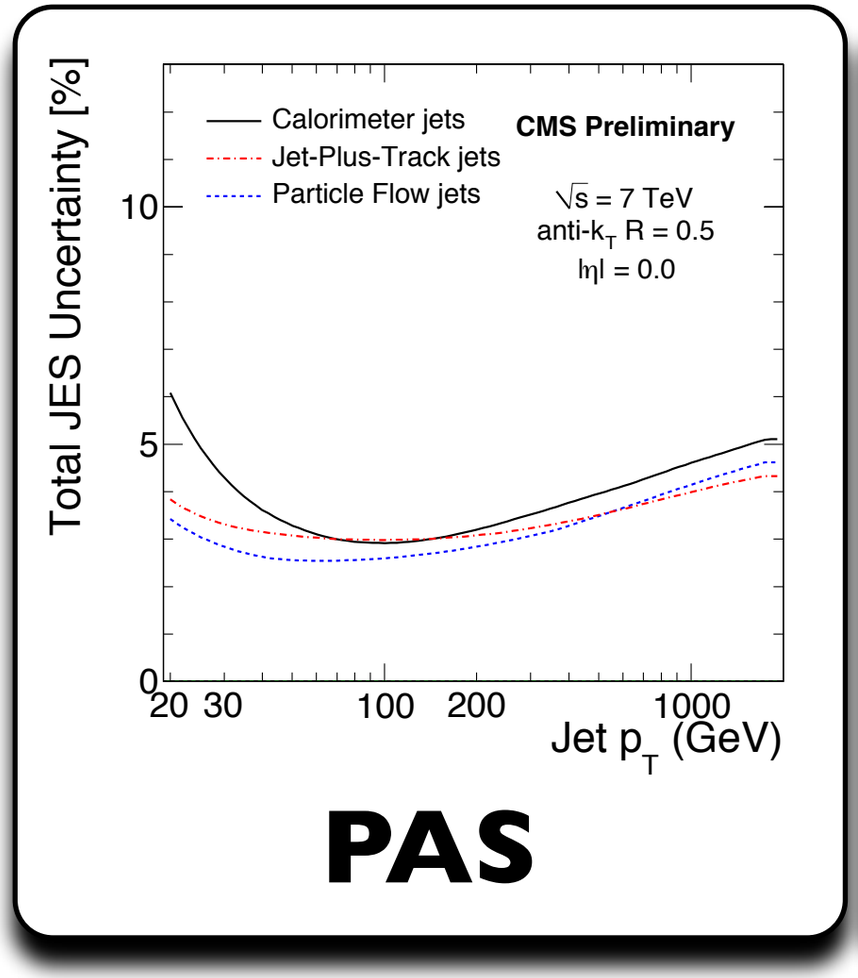


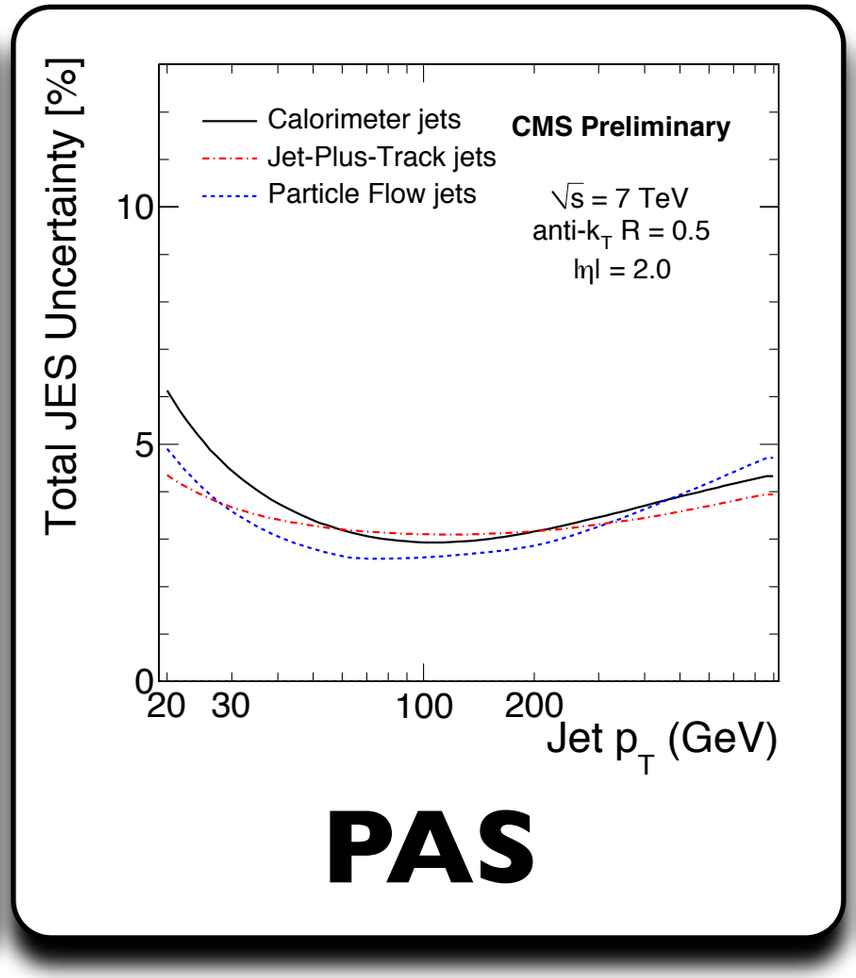


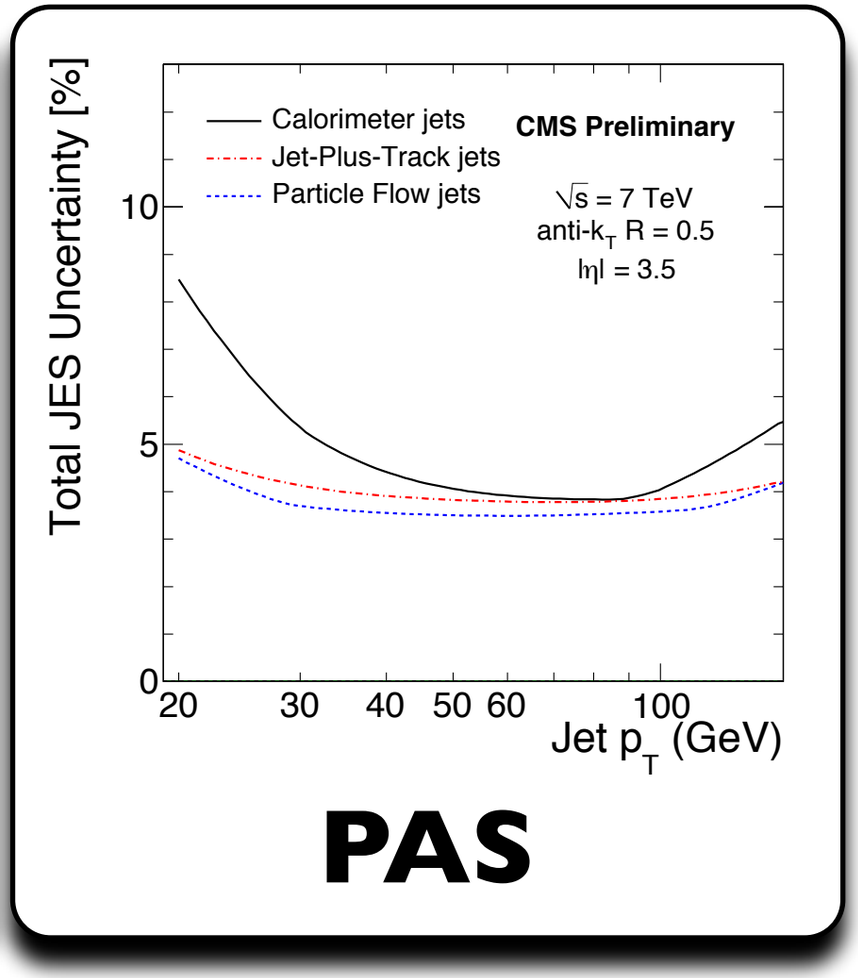


- Combined JEC uncertainty vs |η|
  - Relative Scale + Absolute Scale

Combined JEC Uncertainty vs p_T







- Combined JEC uncertainty vs p_T
  - Relative Scale + Absolute Scale

Summary

- We have estimated the jet energy corrections and their uncertainties using 3 pb^{-1} of collision data at $\sqrt{7}$ = TeV

- In general the MC truth JES is in reasonable agreement with the data and can be used as a starting point for the jet calibration

- Small residual corrections need to be applied on top of MCtruth
  - relative scale: η dependent, constant in p_T residual between 0.92 and 1.03
  - absolute scale: constant factor 1.007

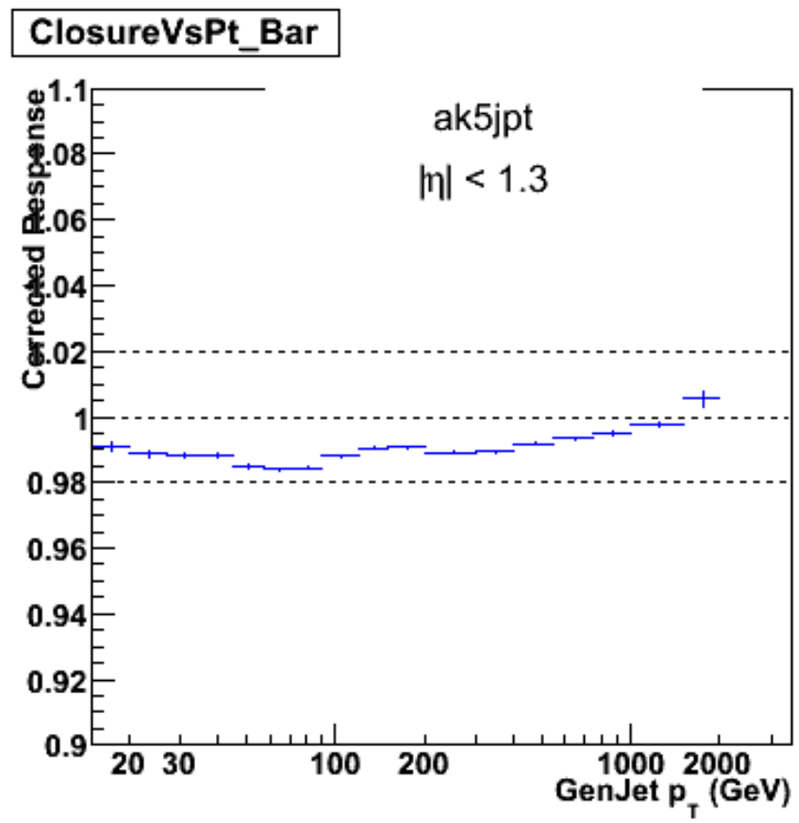
- Relative scale uncertainty 1- 4%, dominated by statistics and the resolution modeling in the MC

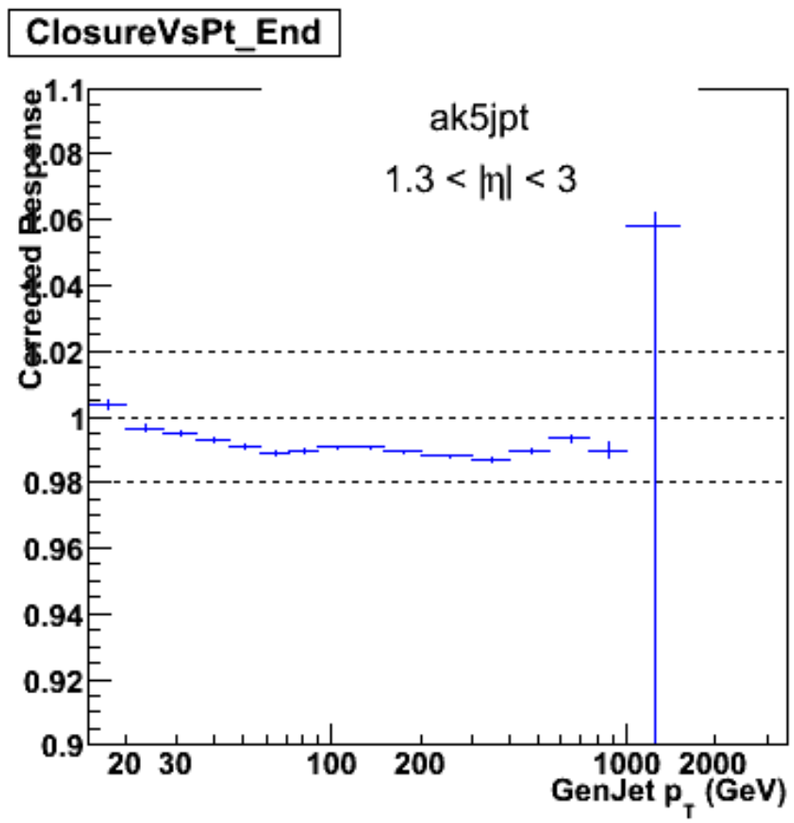
- Absolute scale uncertainty 3-5%, systematics dominated

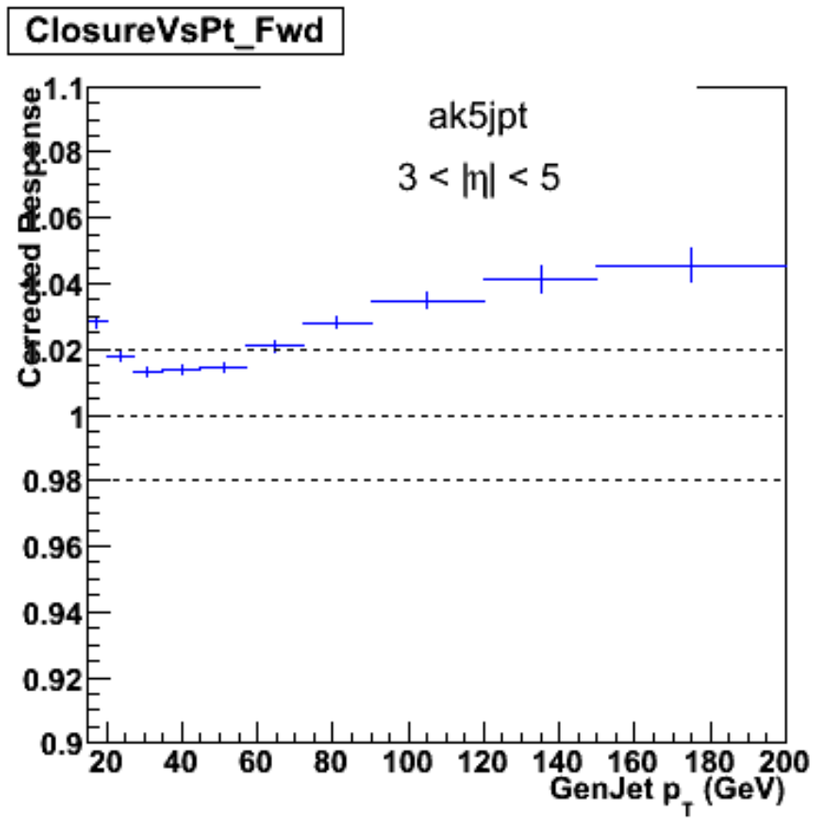
- Roughly same uncertainty for all jet types

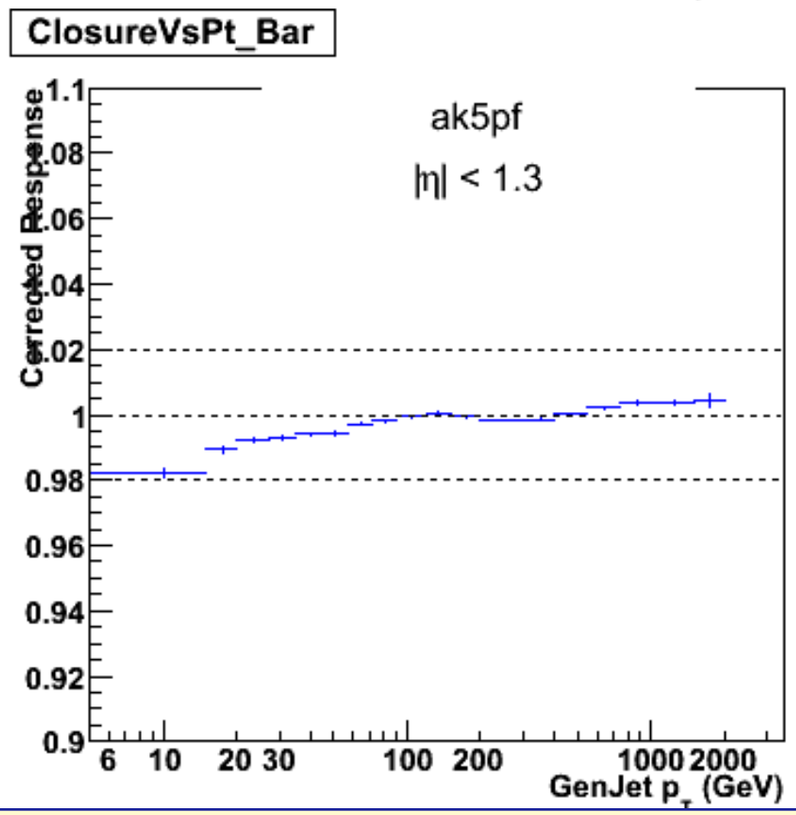
Backup

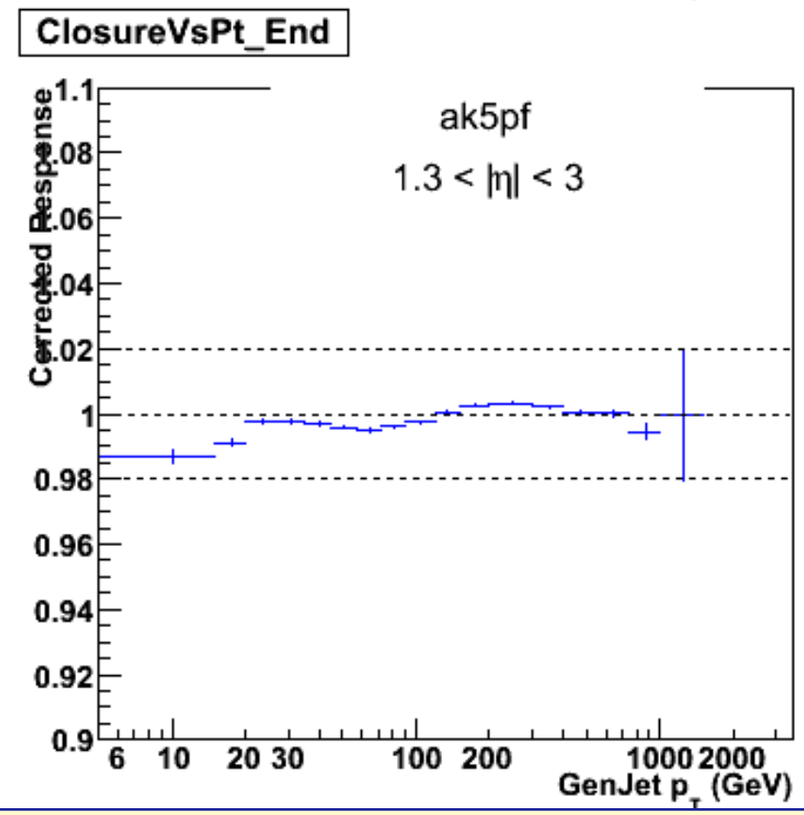
MC Truth Closure (JPT, PF)

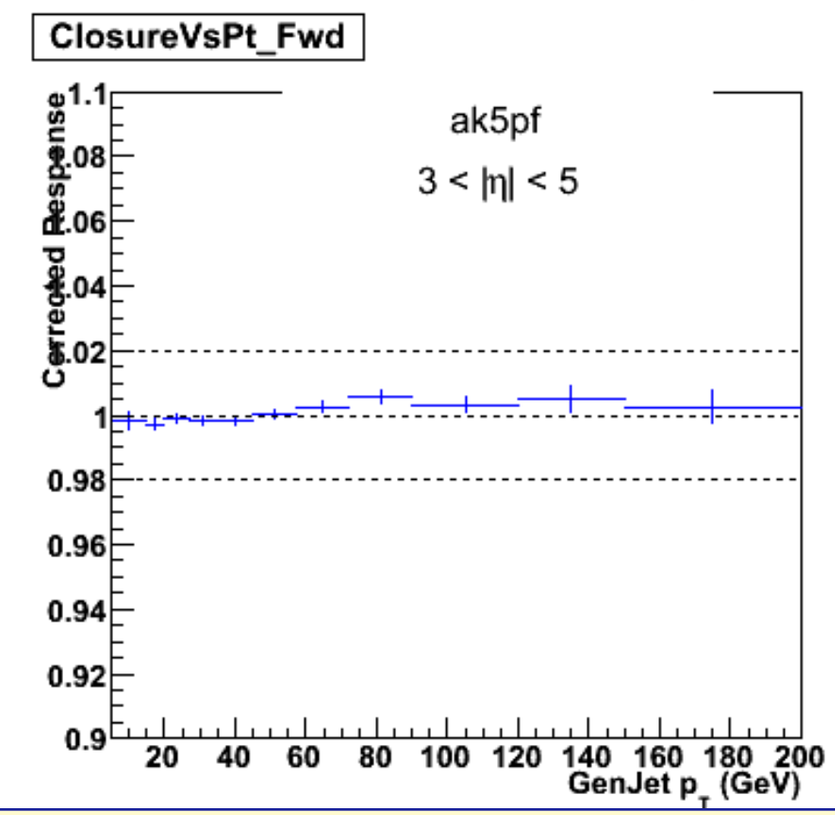




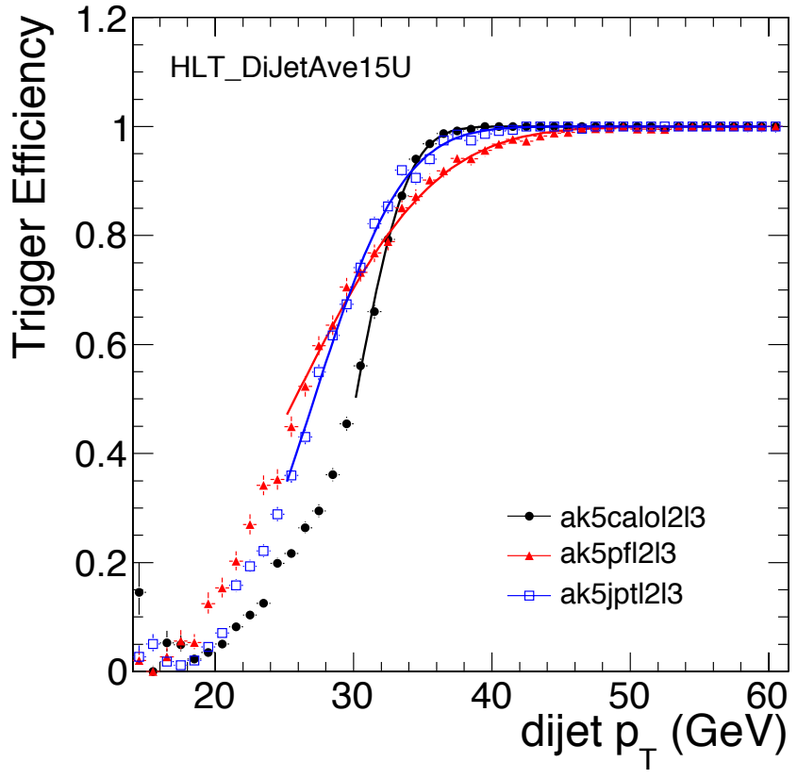


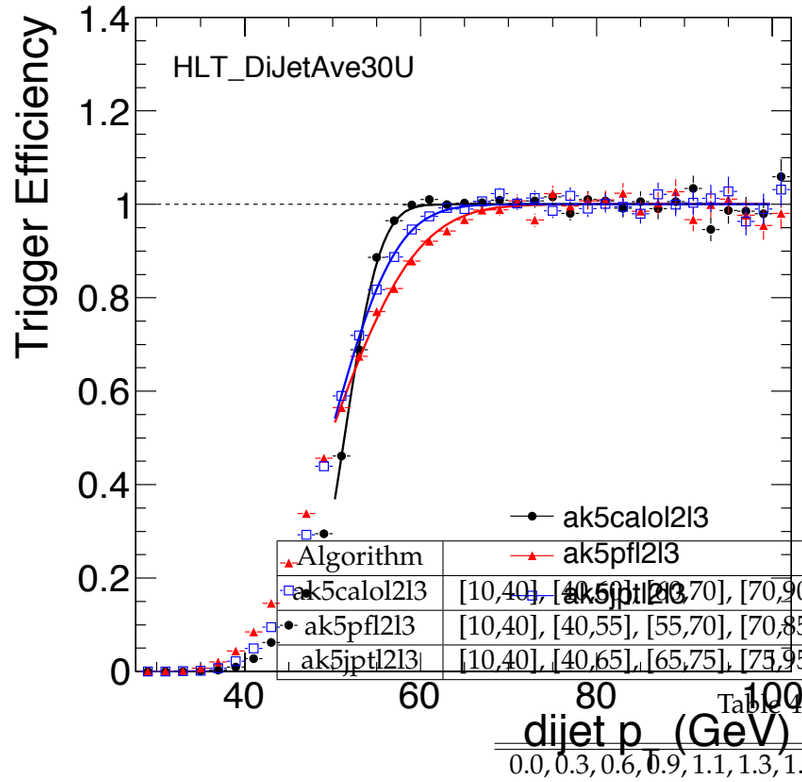


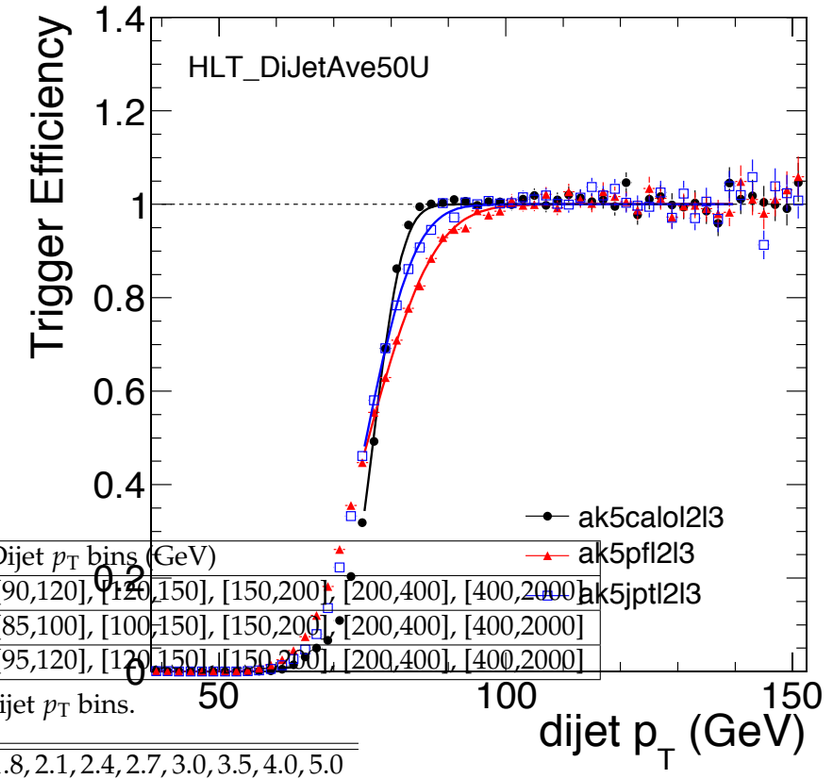




Trigger Efficiency







Algorithm	Dijet p_T bins (GeV)
ak5calol2l3	[10,40], [40,50], [50,70], [70,90], [90,120], [120,150], [150,200], [200,400], [400,2000]
ak5pfl2l3	[10,40], [40,55], [55,70], [70,85], [85,100], [100,150], [150,200], [200,400], [400,2000]
ak5jptl2l3	[10,40], [40,65], [65,75], [75,95], [95,120], [120,150], [150,200], [200,400], [400,2000]

Table 4: Dijet p_T bins.

0.0, 0.3, 0.6, 0.9, 1.1, 1.3, 1.5, 1.8, 2.1, 2.4, 2.7, 3.0, 3.5, 4.0, 5.0

Table 5: $|\eta|$ bin boundaries.

Trigger/Turn-on (GeV)	ak5calol2l3	ak5pfl2l3	ak5jptl2l3
HLT_DiJetAve15U	37	40	39
HLT_DiJetAve30U	59	68	64
HLT_DiJetAve50U	87	97	92

Binning

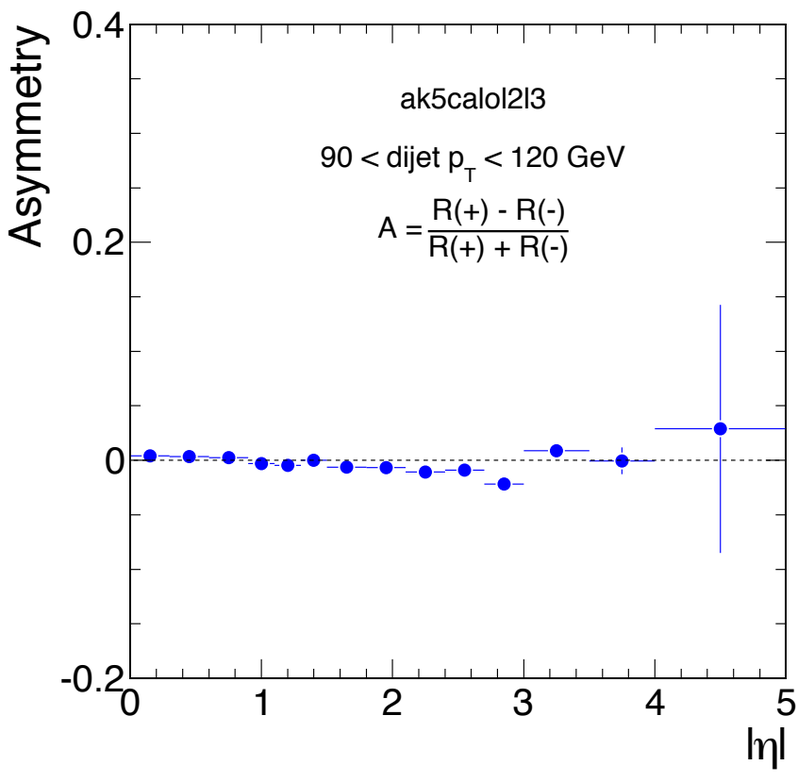
Algorithm	Dijet p_T bins (GeV)
ak5calol2l3	[10,40], [40,60], [60,70], [70,90], [90,120], [120,150], [150,200], [200,400], [400,2000]
ak5pfl2l3	[10,40], [40,55], [55,70], [70,85], [85,100], [100,150], [150,200], [200,400], [400,2000]
ak5jptl2l3	[10,40], [40,65], [65,75], [75,95], [95,120], [120,150], [150,200], [200,400], [400,2000]

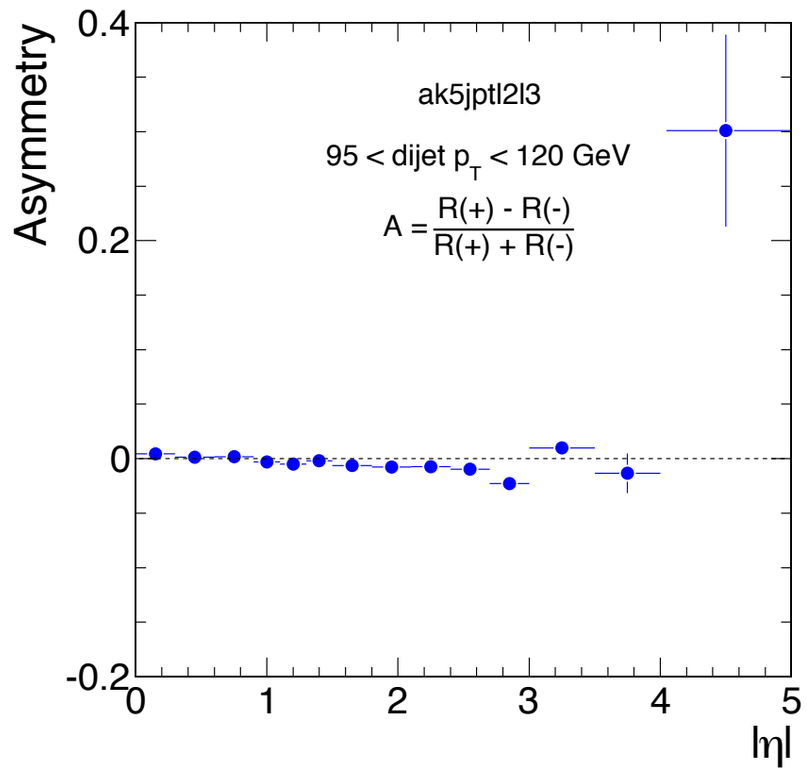
Table 4: Dijet p_T bins.

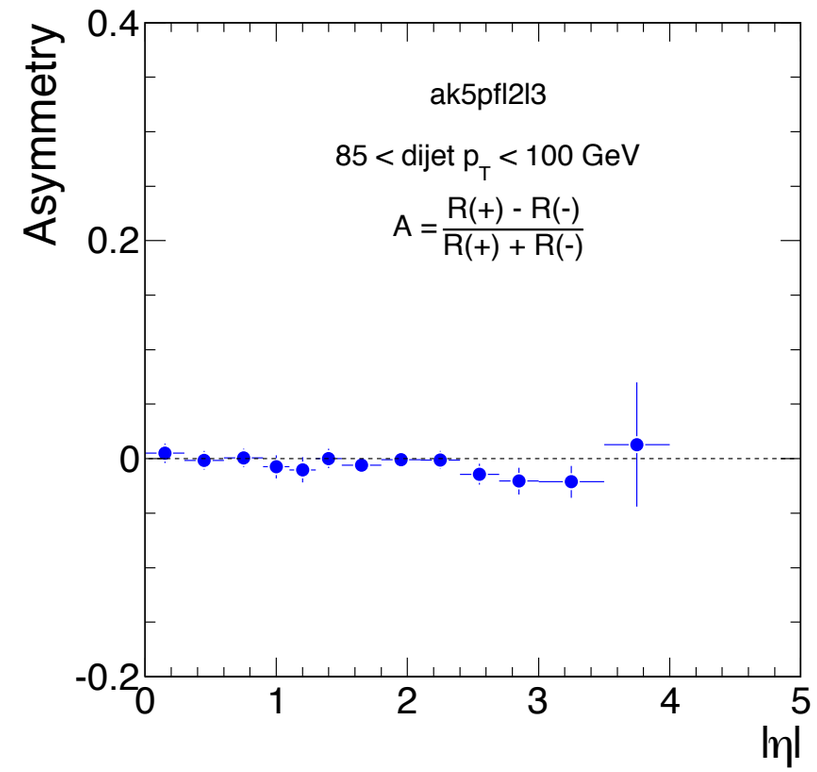
$0.0, 0.3, 0.6, 0.9, 1.1, 1.3, 1.5, 1.8, 2.1, 2.4, 2.7, 3.0, 3.5, 4.0, 5.0$

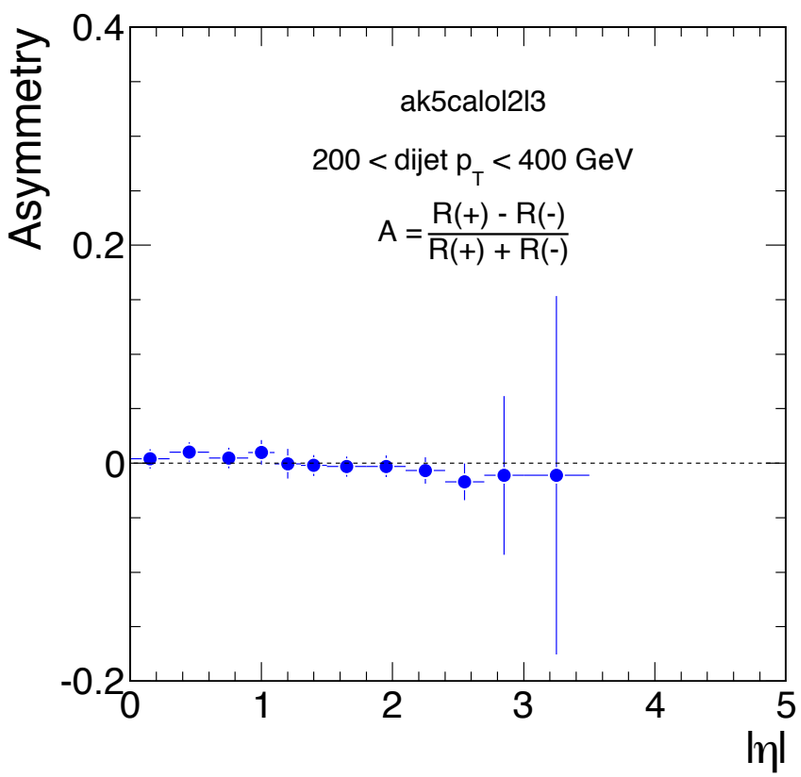
Table 5: $|\eta|$ bin boundaries.

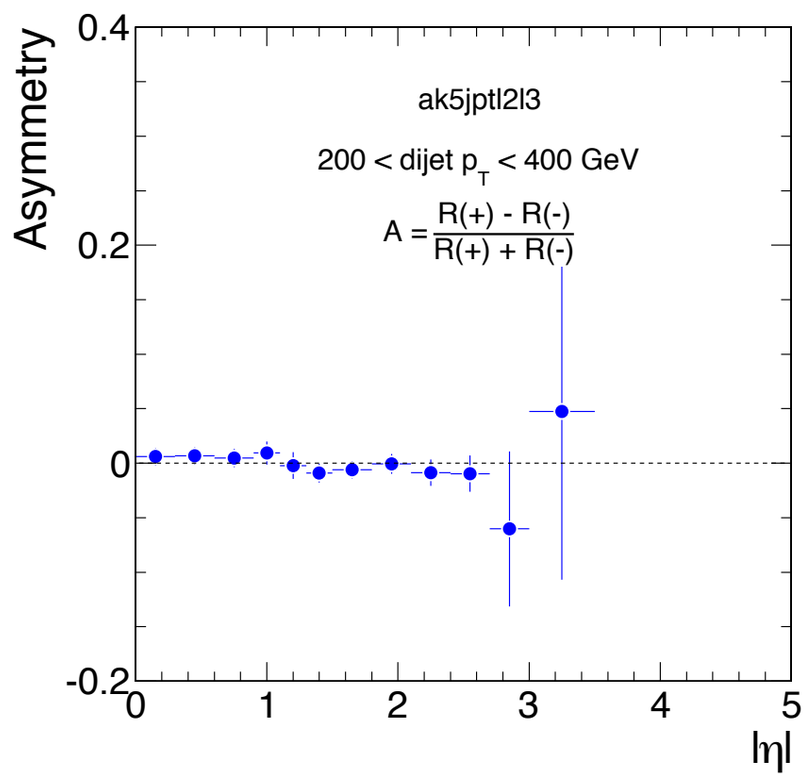
Asymmetry in η

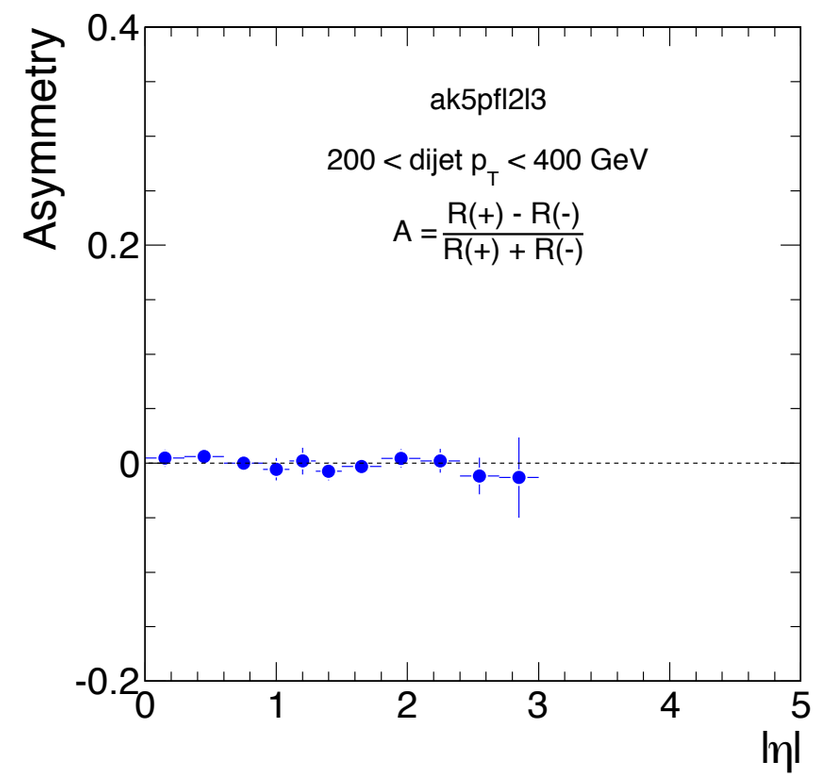




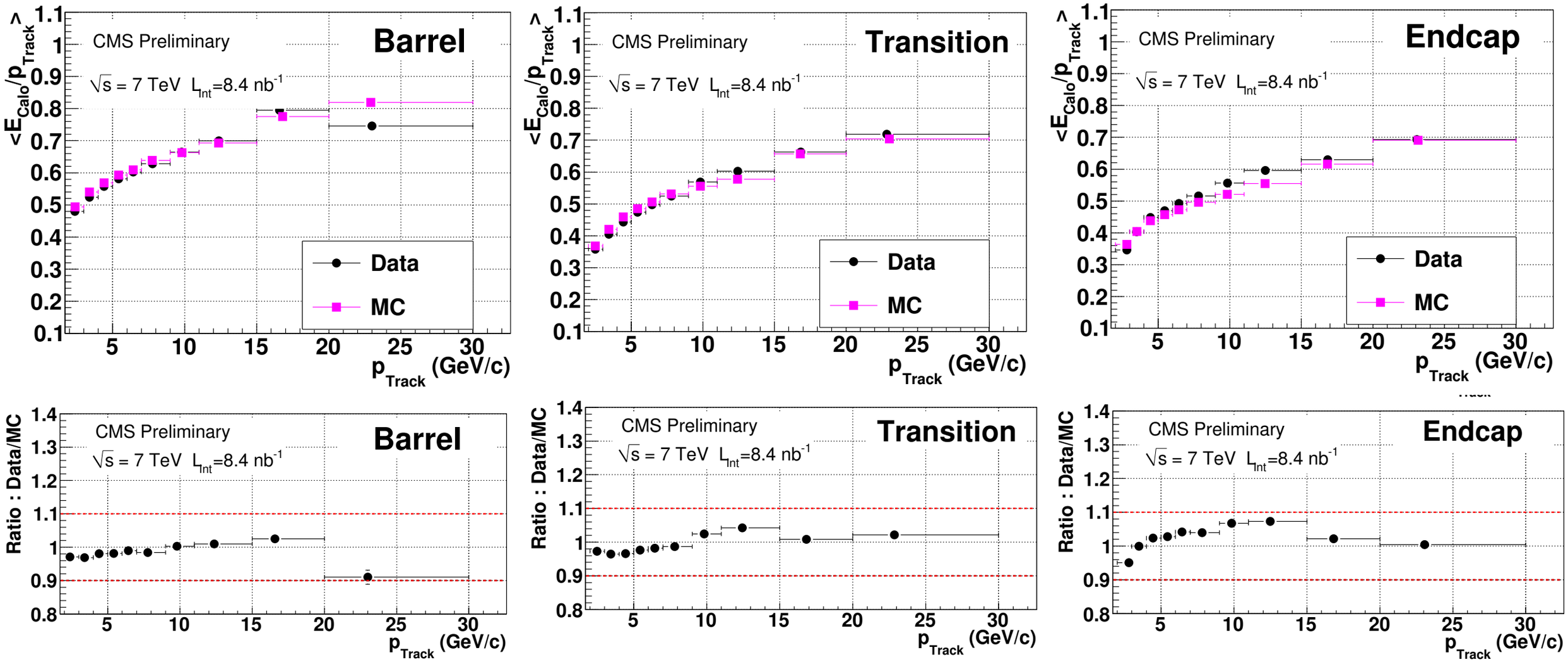








Single Particle Response



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