Jet measurements from CMS

Debarati Roy

Saha Institute of Nuclear Physics

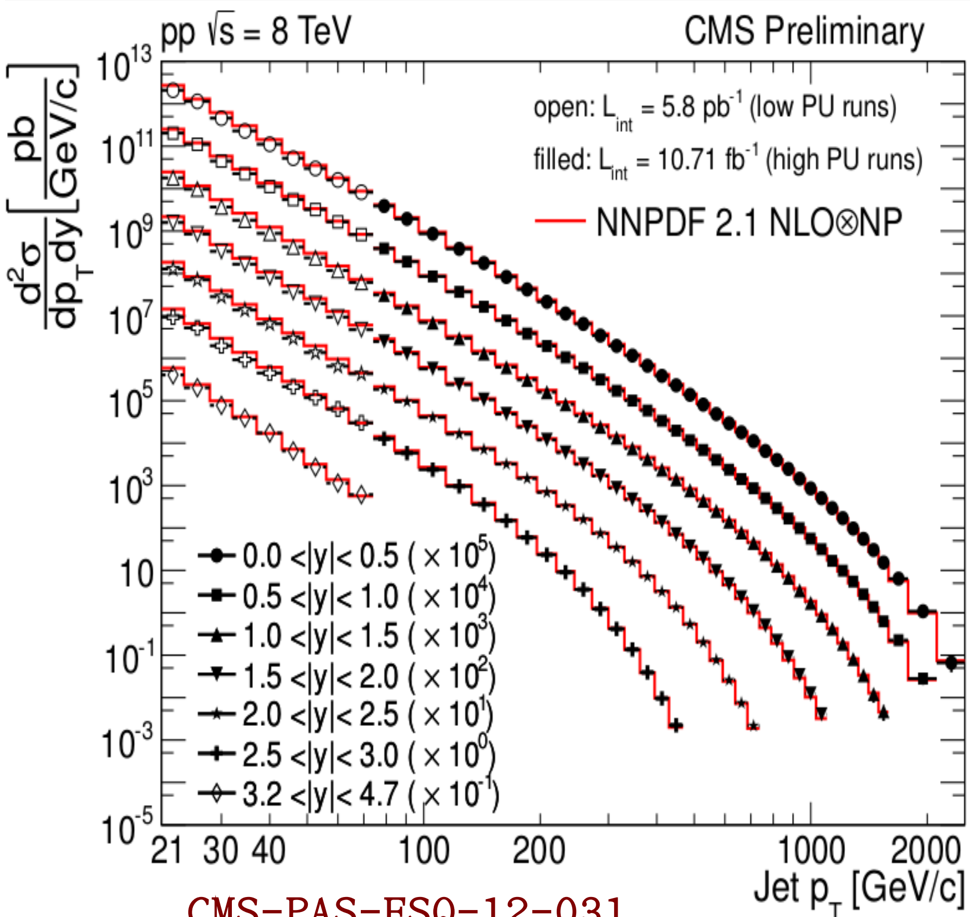
On behalf of the CMS collaboration

European Physical Society Conference on High Energy Physics 2015

Introduction

LHC is a Jet Factory

Inclusive Jet Production at 8 TeV



CMS-PAS-FSQ-12-031

Plenty of reasons to study jets !

- pQCD calculations
- α_s determination
- Constraining PDF
- Understanding non-pQCD
- MC tuning
- New particle searches with jets in final states

All results showing here are corrected for detector effect and PF AK7 jets are used.

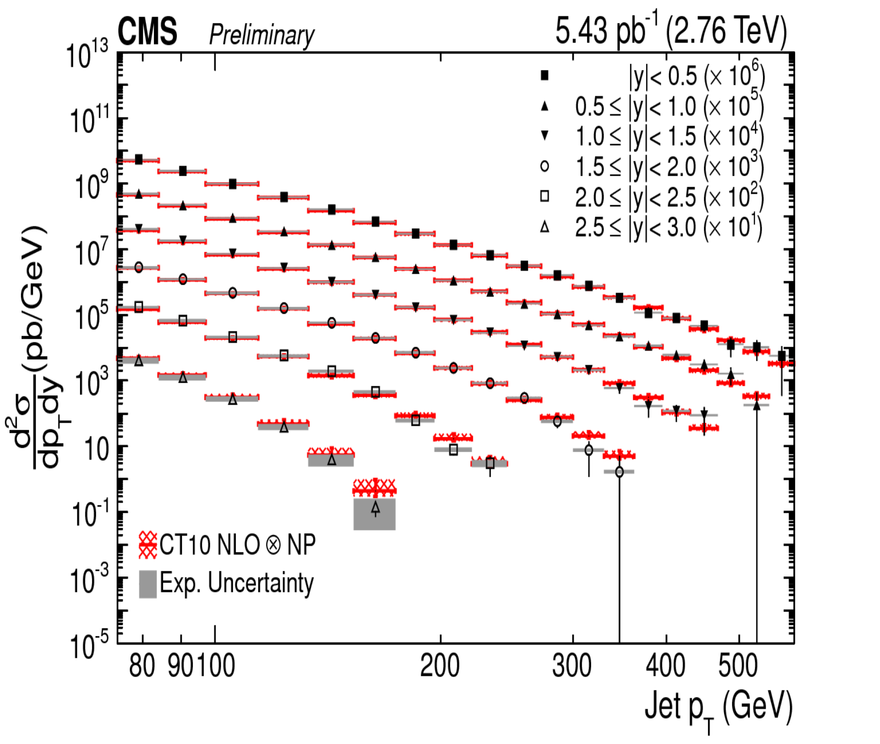
NEW !

Inclusive Jet Production at 2.76 TeV

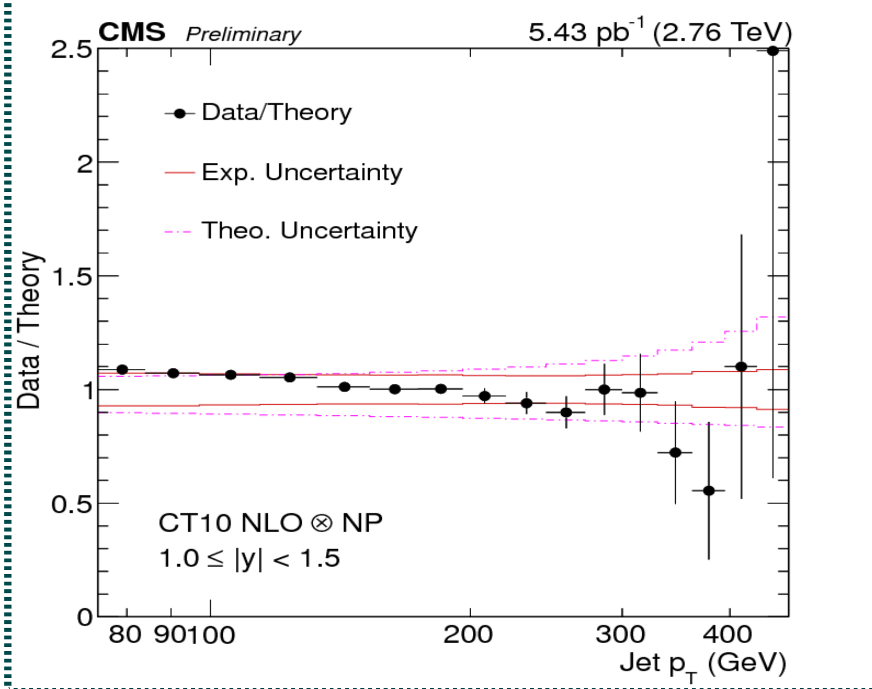
Measurement of double differential cross section with 2013 data ($5.43\ pb^{-1}$) and compared to NLO theory (CT10 PDFset)

p_T covers 74 to 592 GeV.

$|y|$ ranges from 0.0 to 3.0



CMS-PAS-SMP-14-017

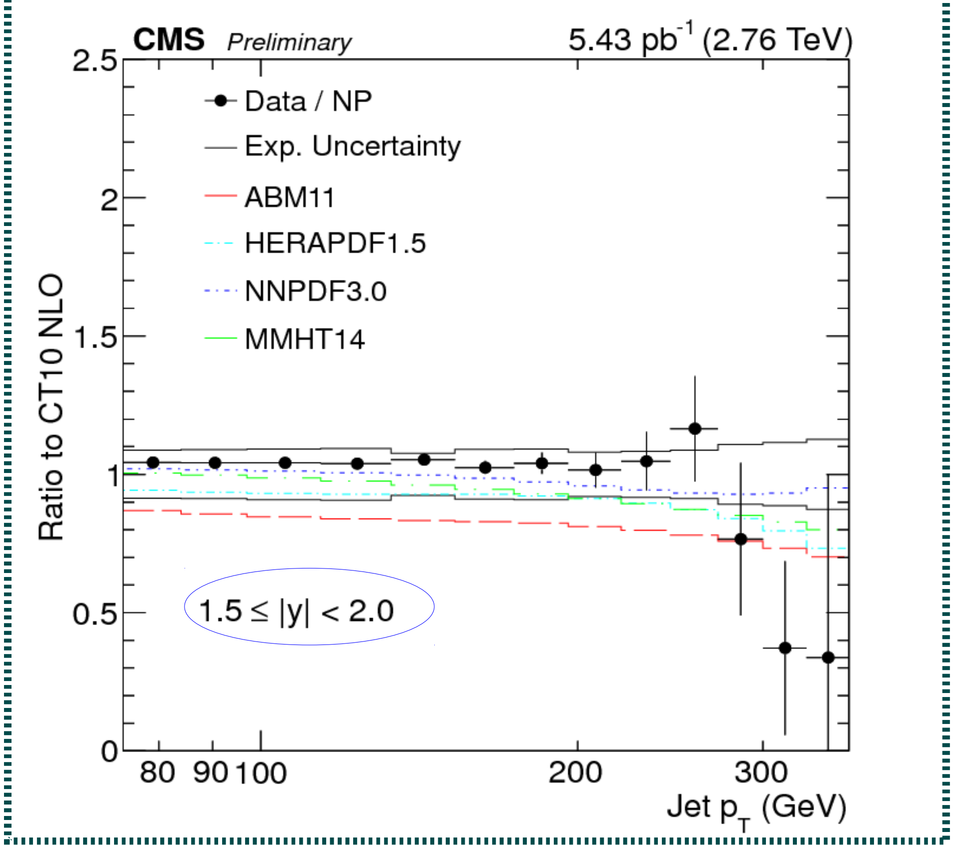


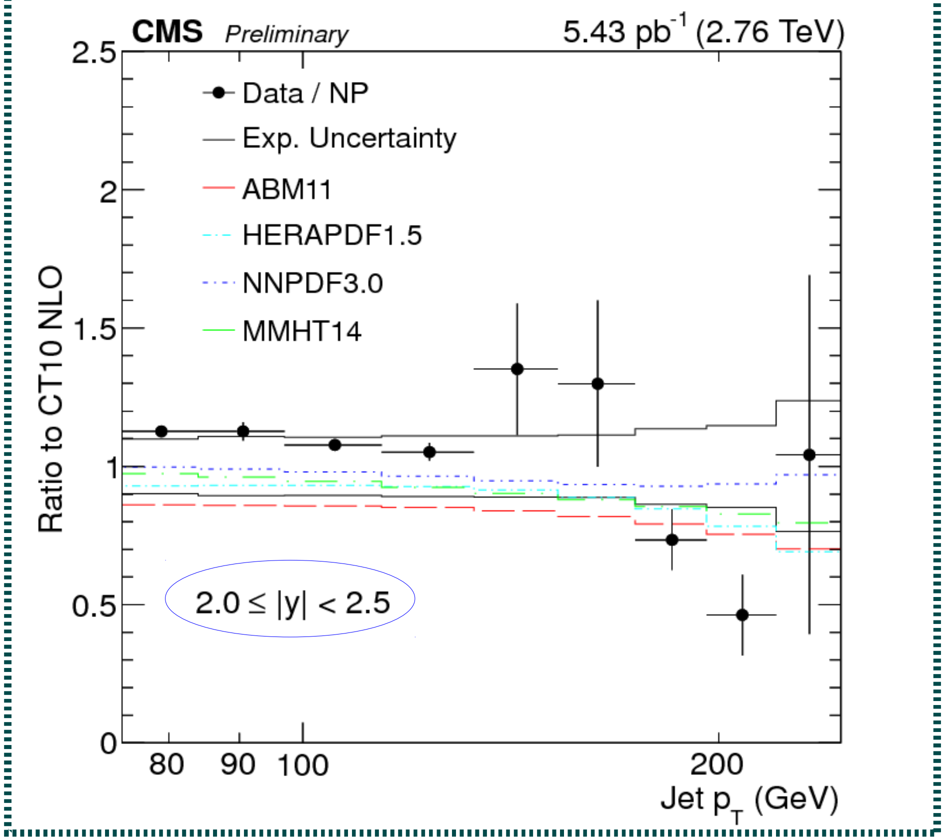
 CMS-PAS-SMP-14-017

Close agreement with NNPDF3.0

MMHT14 PDF describes the data well at low rapidities but disagrees in the higher rapidity region.

Poor agreement with the HERAPDF1.5 and ABM11 PDFs.



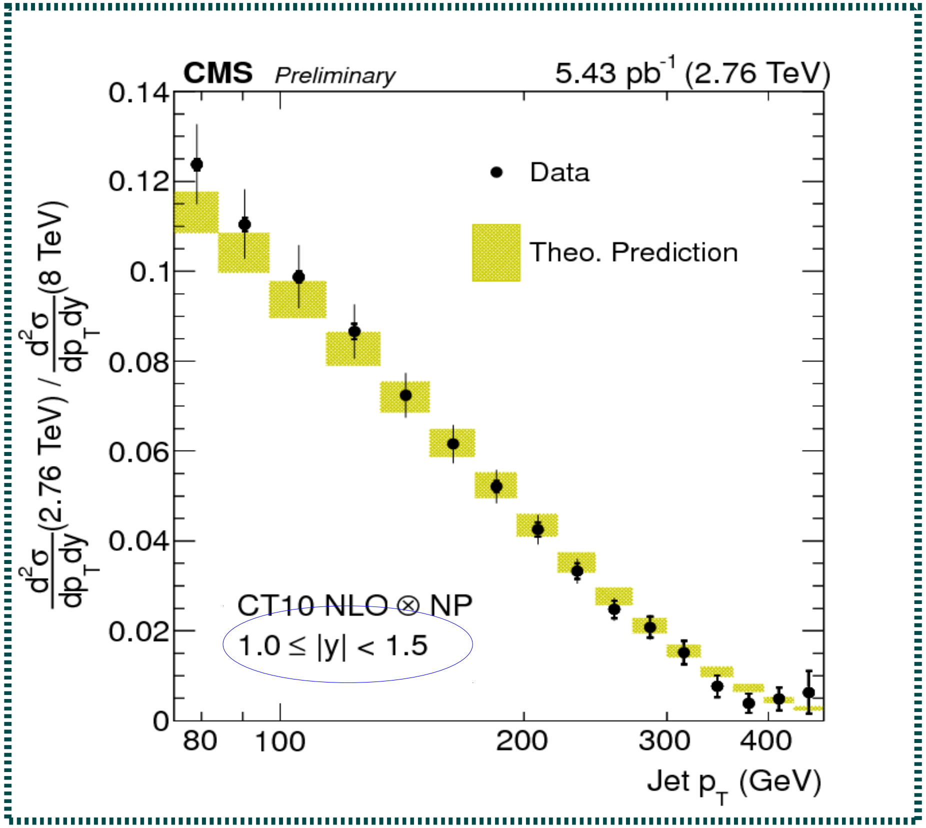


CMS-PAS-SMP-14-017

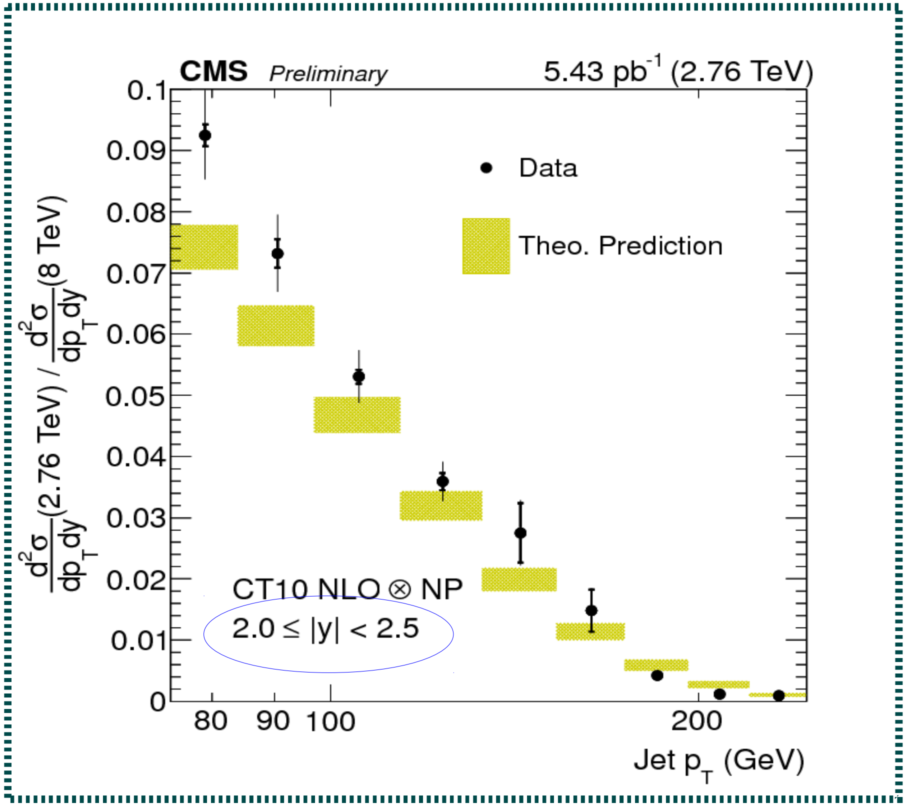
CMS-PAS-SMP-14-017

Expt.Unc. => JES (5-10%), JER(2-3%)   Theory.Unc (10-20%).=> Scale and PDF

Study of the jet cross section ratio between 2.76 TeV to 8 TeV is particularly interesting as a potential PDF constraint



CMS-PAS-SMP-14-017

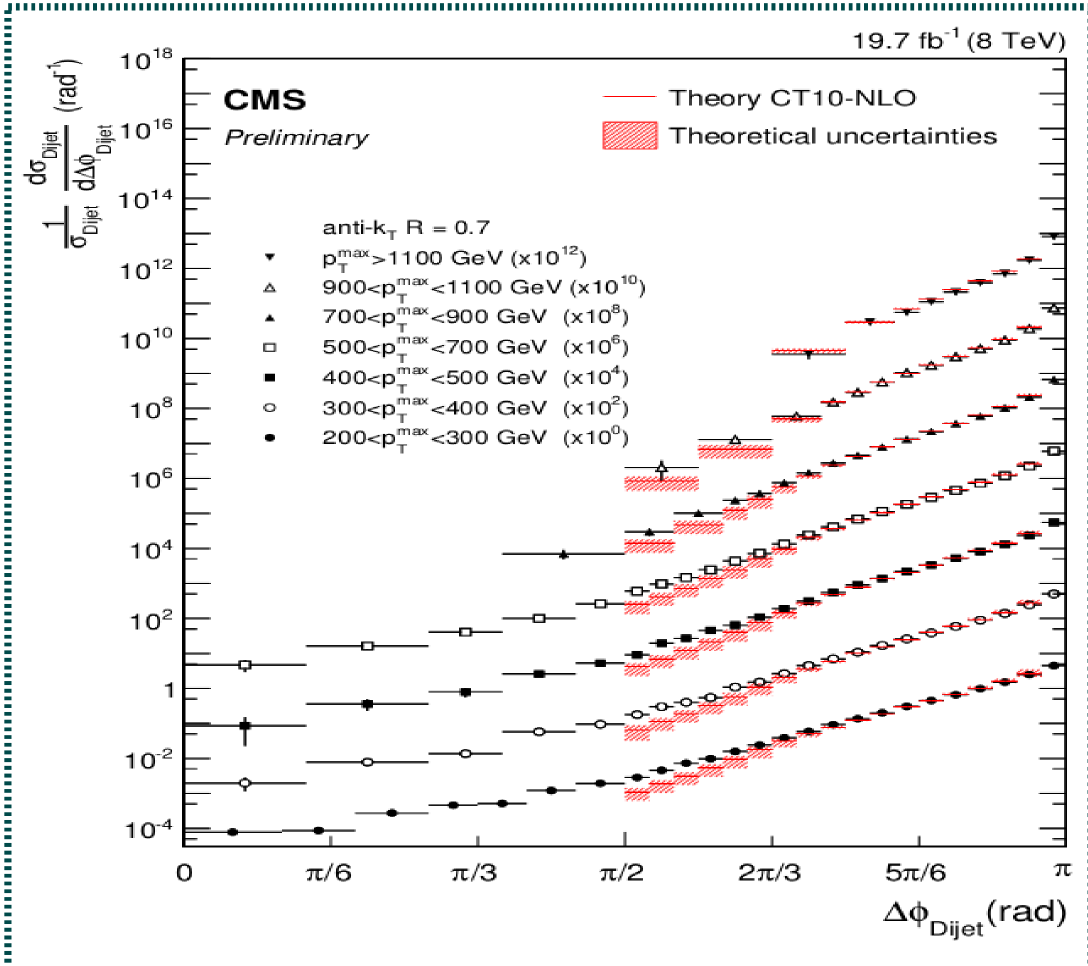


CMS-PAS-SMP-14-017

Precision improves due to a partial cancellation of uncertainties.
Cross-section ratios are in the range 0.1-14%
Good agreement is observed in low rapidity region.

NEW !

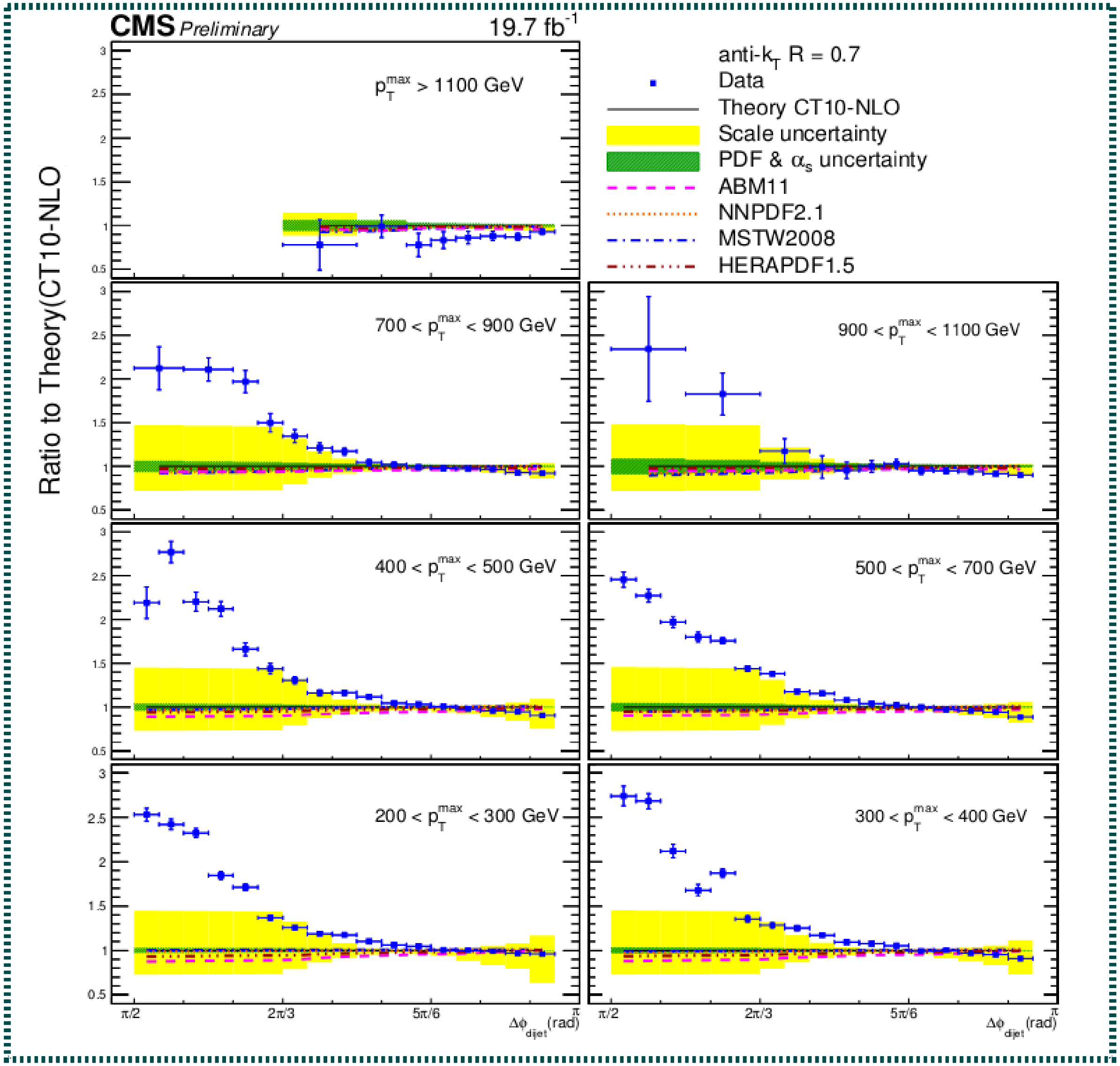
Dijet azimuthal decorrelations at 8 TeV



- $\Delta\phi_{Dijet} = |\phi_{jet1} - \phi_{jet2}|$ can distinguish dijet from multijet events.
- Dijet cross section as a function of $\Delta\phi_{Dijet}$, in jet p_T slices, normalized to (σ_{Dijet}).
- Jet p_T > 100 GeV, |y| < 5 selected. In which the two leading jets have |y| < 2.5 and the leading jet p_T > 200 GeV, are chosen.
- Available theory calculations $\pi/2 < \Delta\phi_{Dijet} < \pi$

CMS-PAS-SMP-14-015

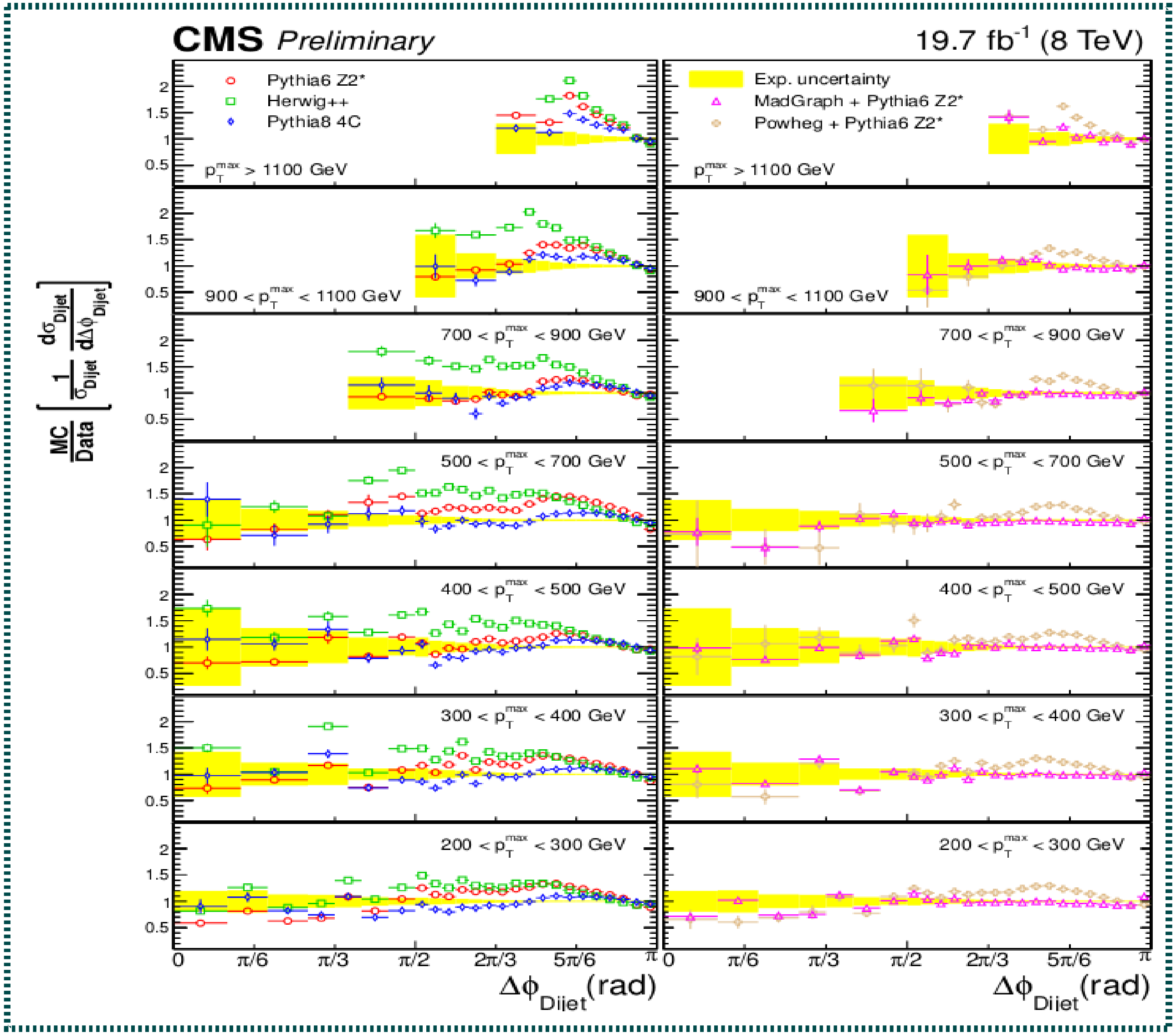
Expt.Unc. => JES(1-7%),JER(1-5%)



CMS-PAS-SMP-14-015

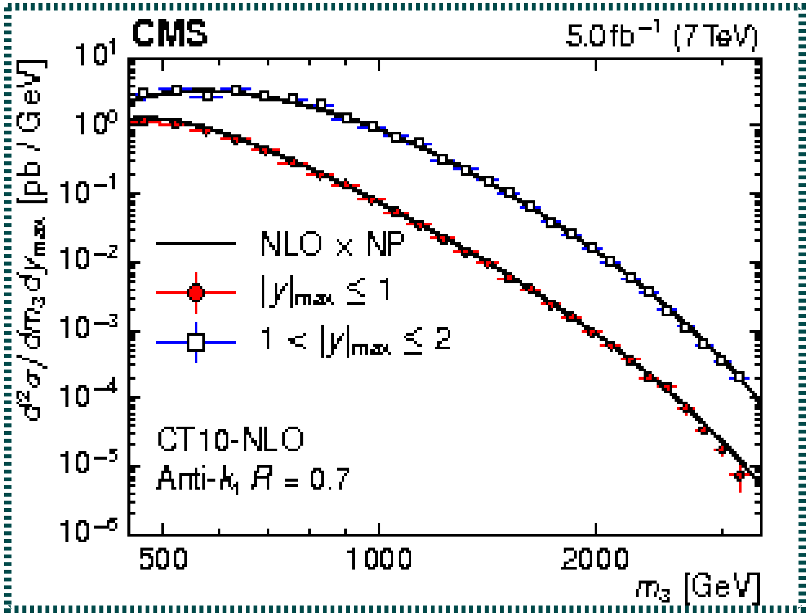
- 3-jet at NLO ($2\pi/3 < \Delta\phi_{Dijet} < \pi$), LO ($\pi/2 < \Delta\phi_{Dijet} < 2\pi/3$) generated using NLOJET ++.
- Theory shows deviations up to 10% beyond uncertainties from data in 3-jet NLO region of $2\pi/3 < \Delta\phi_{dijet} < \pi$.
- In the range $\pi/2 < \Delta\phi_{dijet} < 2\pi/3$, calculation is LO only, large discrepancies visible.

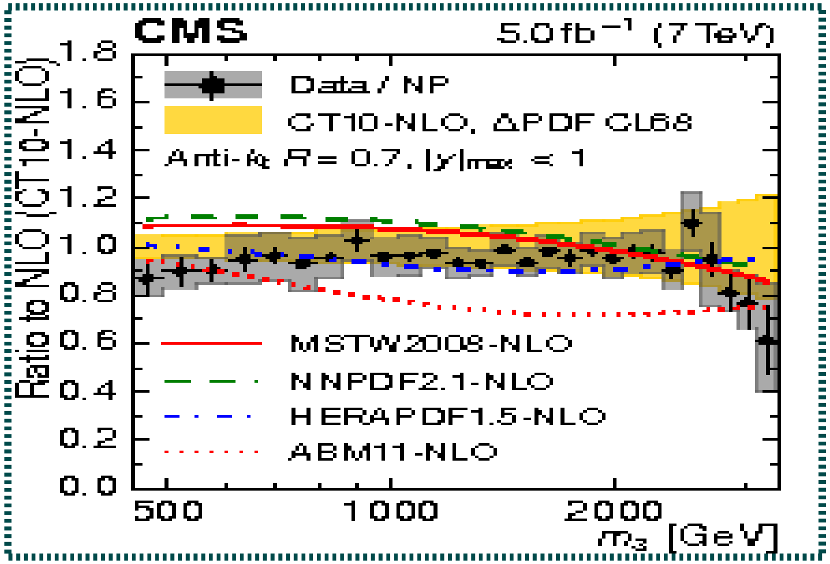
- Among parton shower generators PYTHIA8 (4C tune) predicts closest to data.
- PYTHIA6 and HERWIG++ systematically overshoot the data in particular around $\Delta\phi_{Dijet} = 5\pi/6$.
- Among all generators both at LO and NLO, MADGRAPH, showered with PYTHIA6 (Z2* tune) performs the best even better than POWHEG.



CMS-PAS-SMP-14-015

3-jet mass differential cross section at 7 TeV





- Cross section measured as a function of the invariant mass of the three jets in a range of 445—3270 GeV.
- Events studied in which at least three jets are found upto a rapidity of |y|=3, with p_T > 100 GeV.
- A comparison between the measurement and the prediction from perturbative QCD at NLO performed.
- Data and theory calculations with different PDF sets are in agreement except significant deviations with ABM11 PDFset.

Largest Expt.Unc. => JES

Eur. Phys. J. C (2015) 75:186

Inclusive Multijet production at 7 TeV

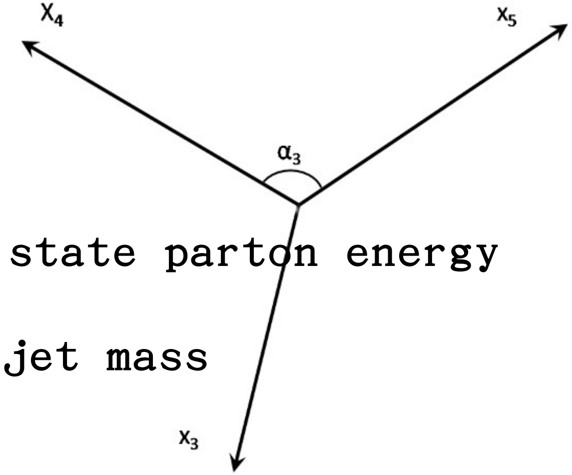
- Three jet variables (3 parton finalstate)

$X_i = 2E_i/M_{345}$

$i = 3,4,5$

E_i = final state parton energy

M_{345} = three jet mass

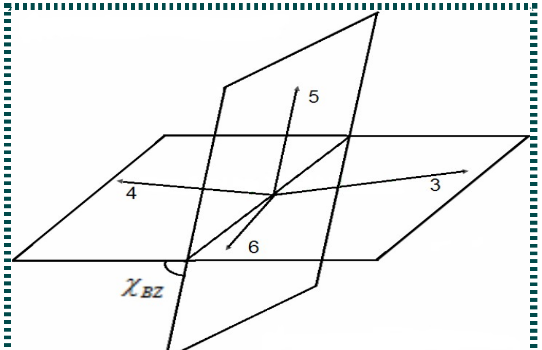


Measured variables : $X_{3,}$ $X_{4,}$ M_{345}

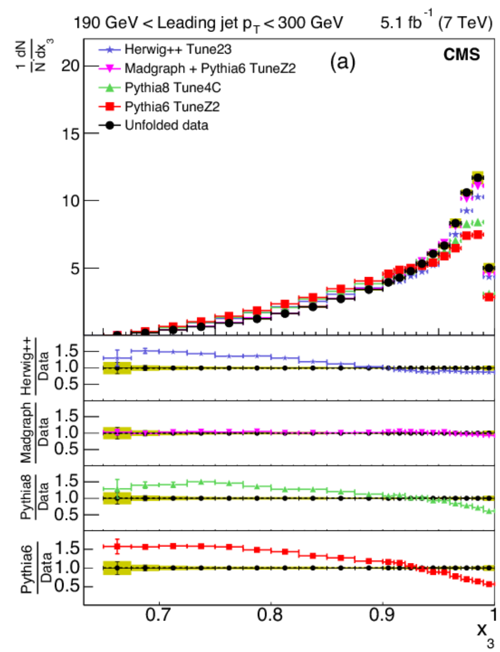
- Four jet variables (4 parton finalstate)

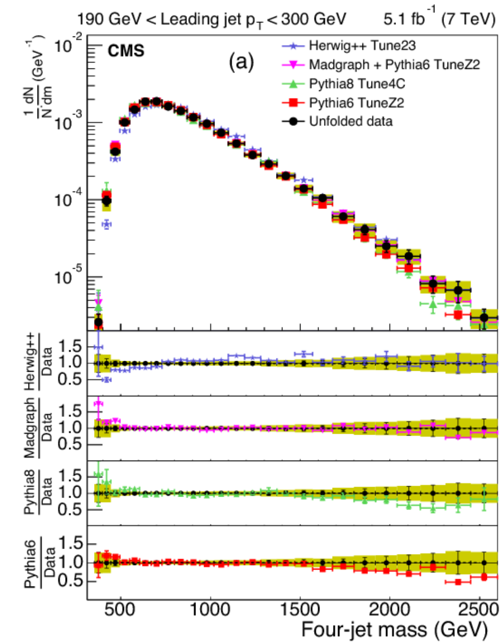
$$\cos\theta_{NR} = \frac{(\vec{p}_3 - \vec{p}_4)\cdot(\vec{p}_5 - \vec{p}_6)}{|\vec{p}_3 - \vec{p}_4||\vec{p}_5 - \vec{p}_6|}$$

$$\cos\chi_{BZ} = \frac{(\vec{p}_3 \wedge \vec{p}_4)\cdot(\vec{p}_5 \wedge \vec{p}_6)}{|\vec{p}_3 \wedge \vec{p}_4||\vec{p}_5 \wedge \vec{p}_6|}$$



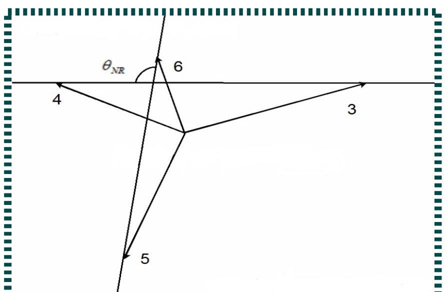
Measured variables : $\cos\theta_{NR,}$ $\chi_{BZ,}$ M_{3456}





Eur. Phys. J. C (2015) 75:302

MADGRAPH performs steadily better than rest.



Expt. Unc => JES(0.1-10%),JER(0.1-15%), Unfolding(0.1-8.0%).Theory Unc. => PDF (1-2%), Hadronization (<5%).

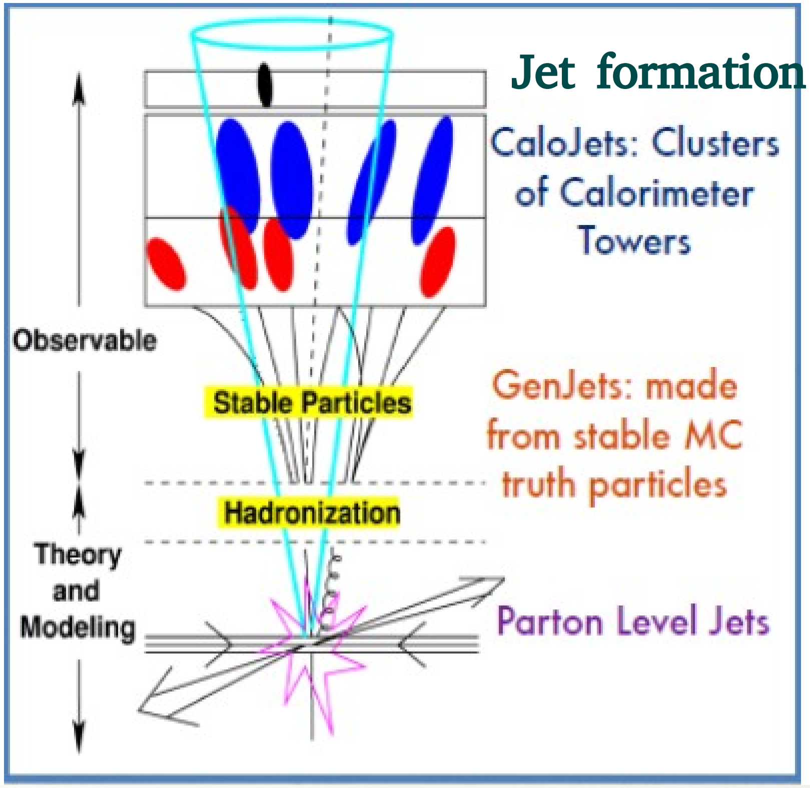
Summary

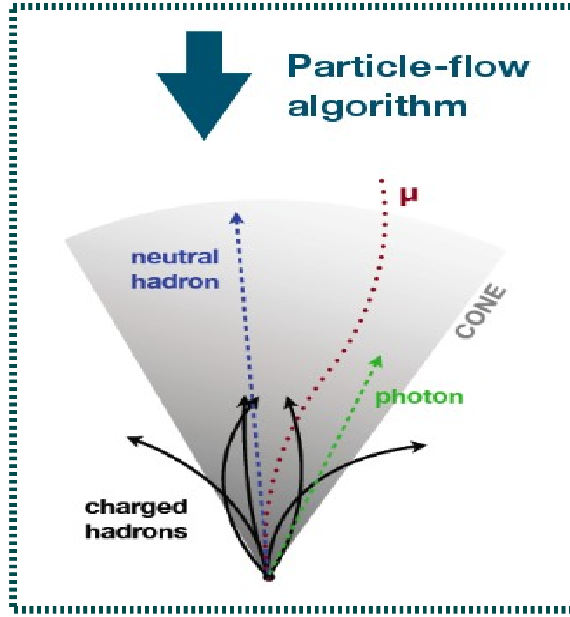
- All these exceptionally detailed studies provide a deep insight to understand pQCD and non-pQCD physics in LHC as we approach higher energy.

- Results can be further utilized in improving MC models, constraining PDFs.

- Corrected data for detector effect can be used to compare data from other experiments/theory.

Supporting material

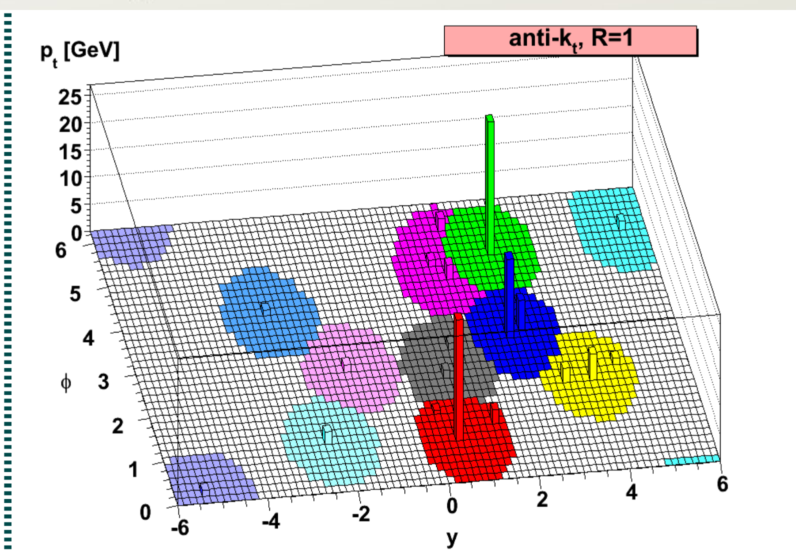




PF jet : from identified particles using all detector components

$$d_{ij} = \min\left(\frac{1}{p_{T,i}^2}, \frac{1}{p_{T,j}^2}\right) [(\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2]/R^2$$

$$d_i = \frac{1}{p_{T,i}^2}$$

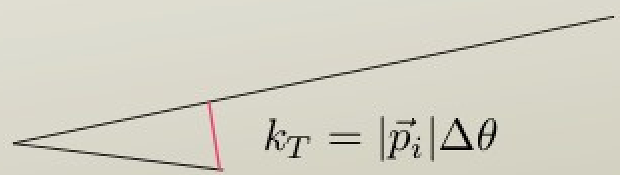


Why the name?

$$d_{ij} = \min(p_{T,i}^2, p_{T,j}^2)\,[(\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2]/R^2$$

is essentially

$$d_{ij} = k_T^2/R^2$$



$$k_T = |\vec{p}_i|\Delta\theta$$

CMS-PAS-FSQ-12-031

- With low pile up runs (5.8 pb^{-1}) corresponding jet p_T 21 – 74 GeV.

- 2012 data sample with low pile-up runs with an average of 4 interactions per bunch crossing at 8 TeV are used.

Event Selection

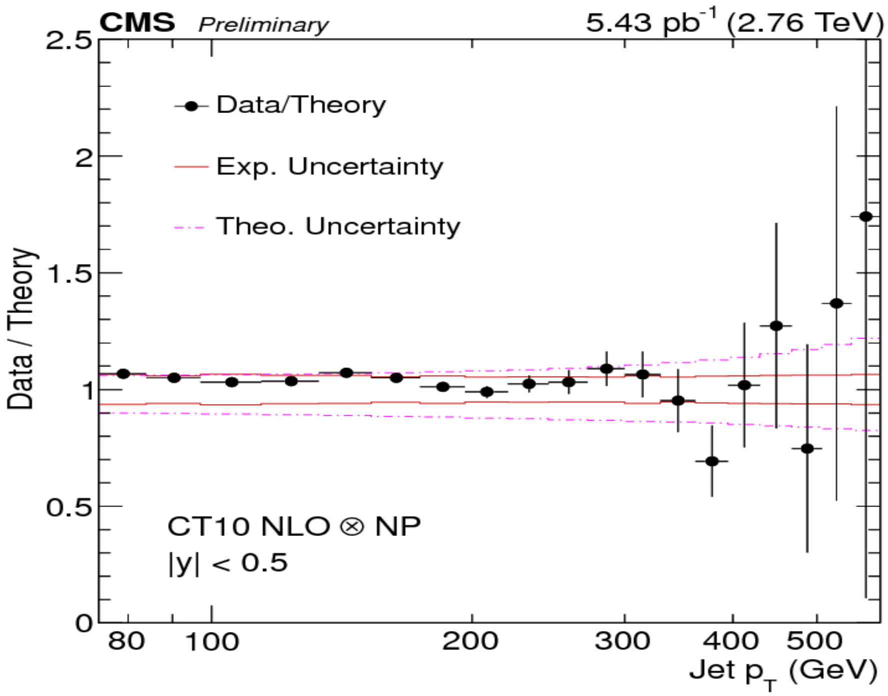
$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{\mathcal{L}_{\text{eff}}} \cdot \frac{N}{\Delta p_T \cdot \Delta y} \quad [\text{pb}/(\text{GeV}/\text{c})]$$

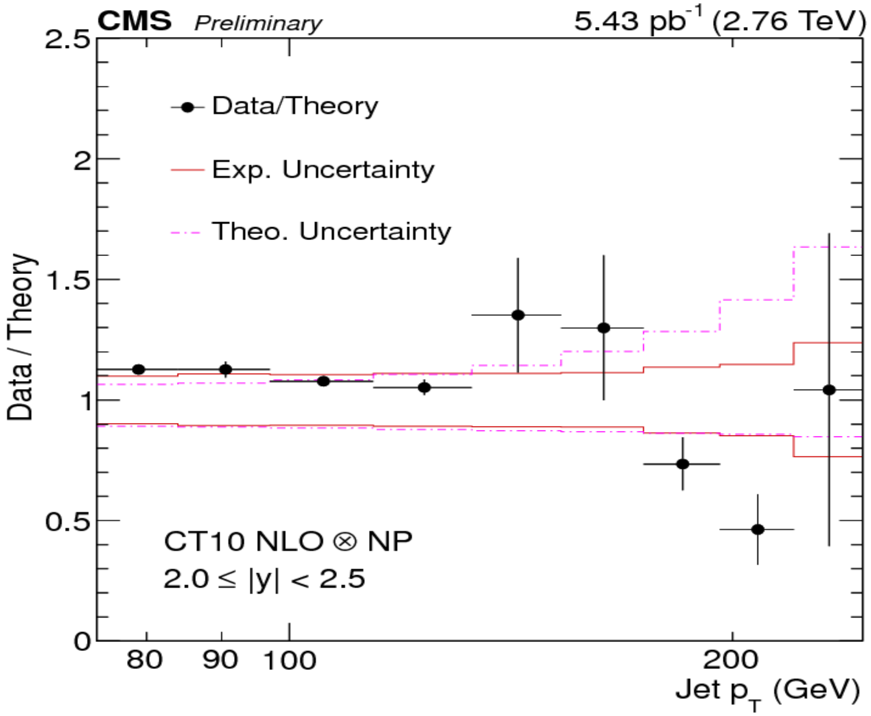
Events fired by a Zero Bias trigger which requires at least two charged tracks reconstructed in the pixel detector. selected events were required to have a good primary vertex (PV): PV required to be reconstructed from at least 5 tracks and to lie within ±24 cm in z direction.
Dominant uncertainties : JES (**5-45%**) (on p_T and η dependence, **2 – 6%** at |y| < 4.7)
unfolding uncertainty : 3-25%
NP correction factor : POWHEG (NLO) with SMC (Sequential Monte Carlo) method.
JER : 3% – 17%. Integrated luminosity uncertainty 4.4%

CMS-PAS-SMP-14-017

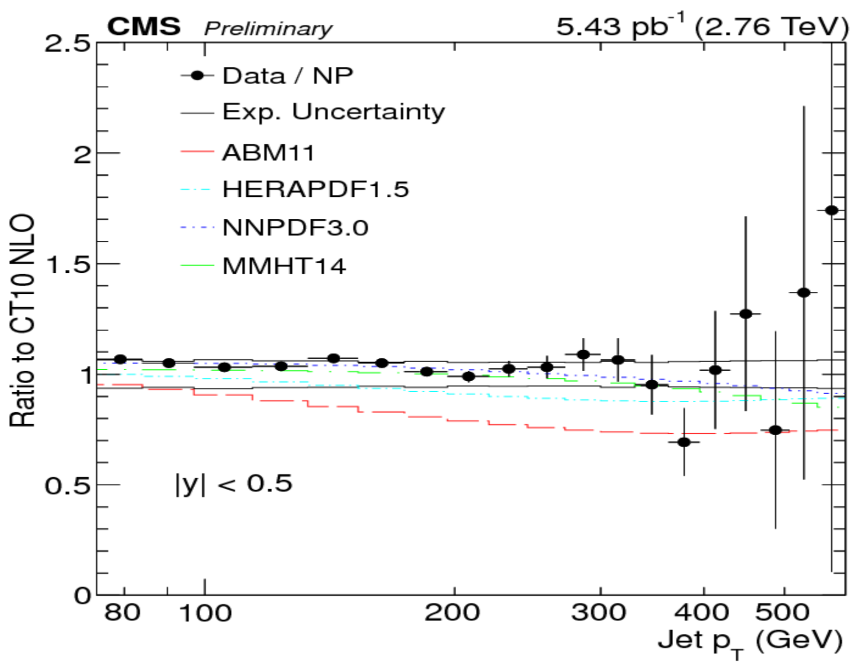
$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{\epsilon \mathcal{L}_{int,eff}} \frac{N}{\Delta p_T \, (2 \cdot \Delta|y|)}$$

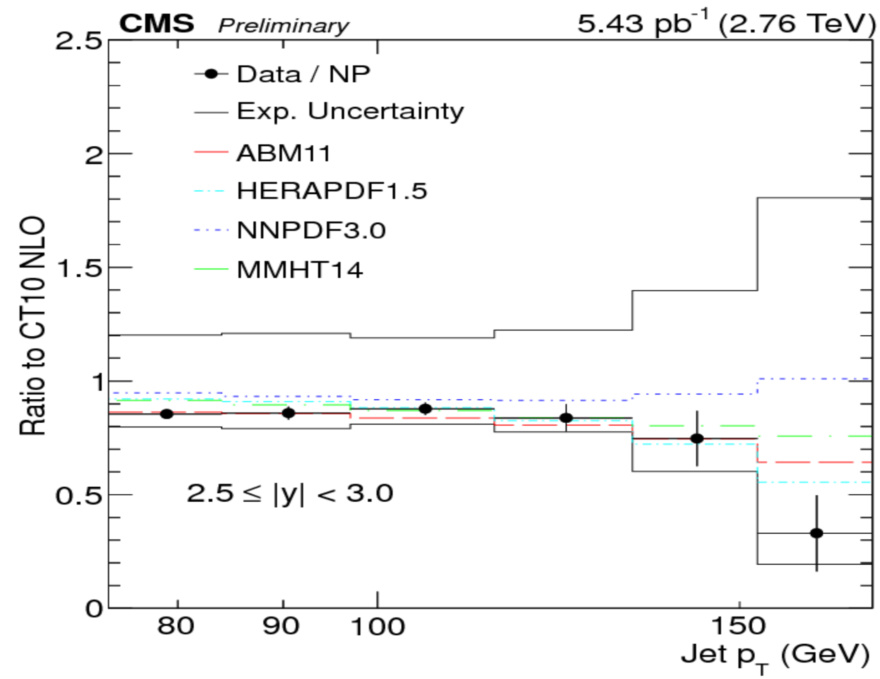
$L_{int,eff}$ the effective integrated luminosity corrected for trigger pre-scales, ε is the overall reconstruction efficiency which includes the trigger and jet selection efficiencies, ΔpT and Δ|y| are the sizes of a particular jet pT and rapidity bin, and N is the number of jets falling in that bin. Six |y| bins between 0.0 to 3.0 are used, with Δ|y| = 0.5. The jet pT values range from 74 to 592 GeV, with variable bin sizes.

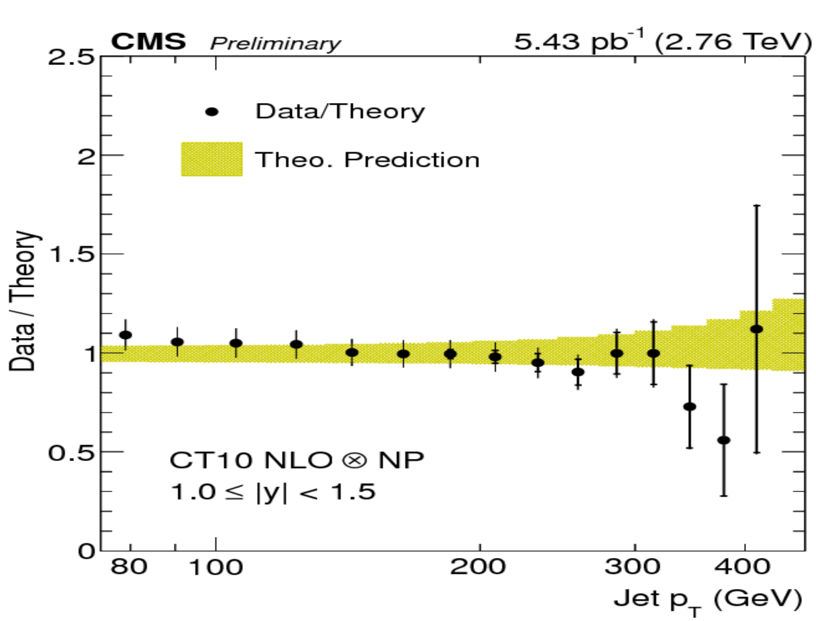


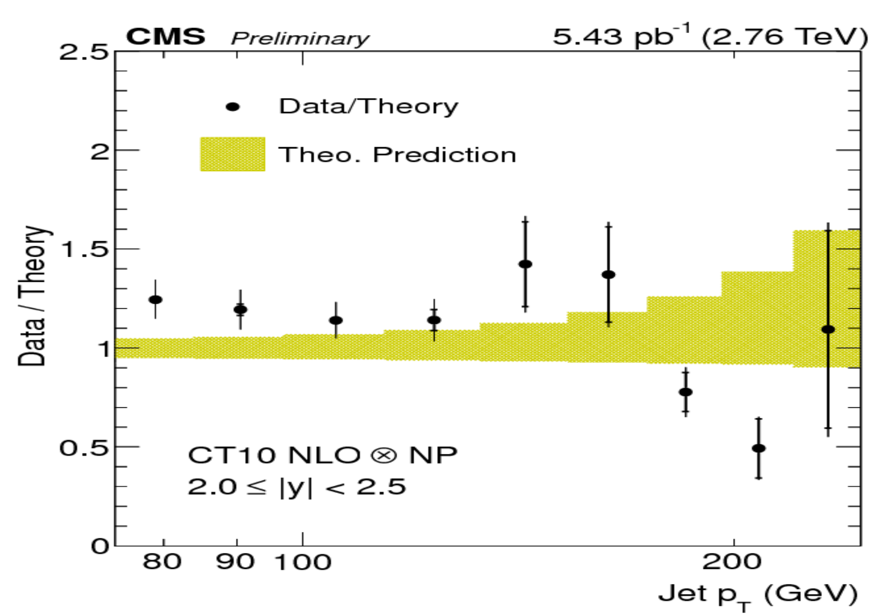


CMS-PAS-SMP-14-017





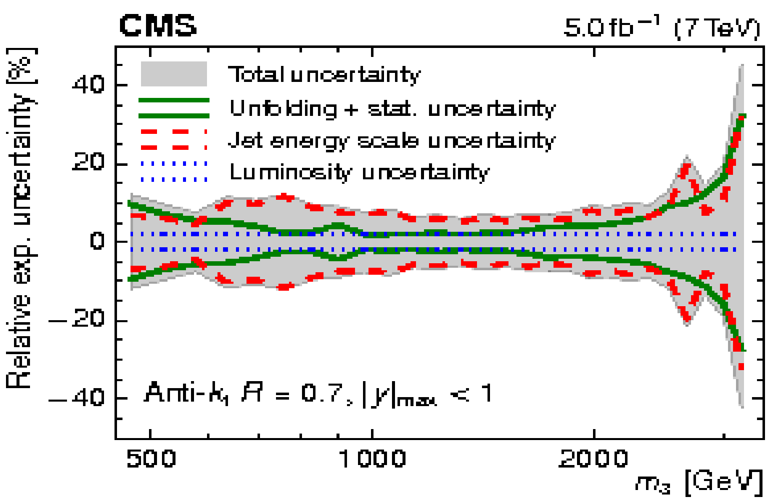


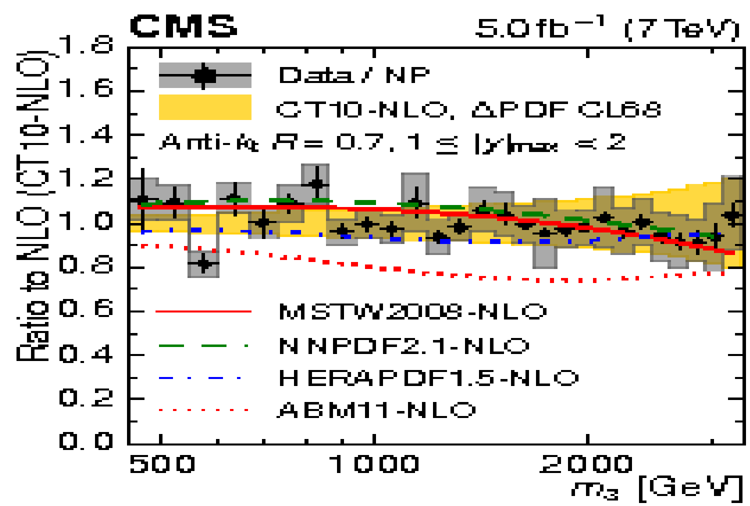


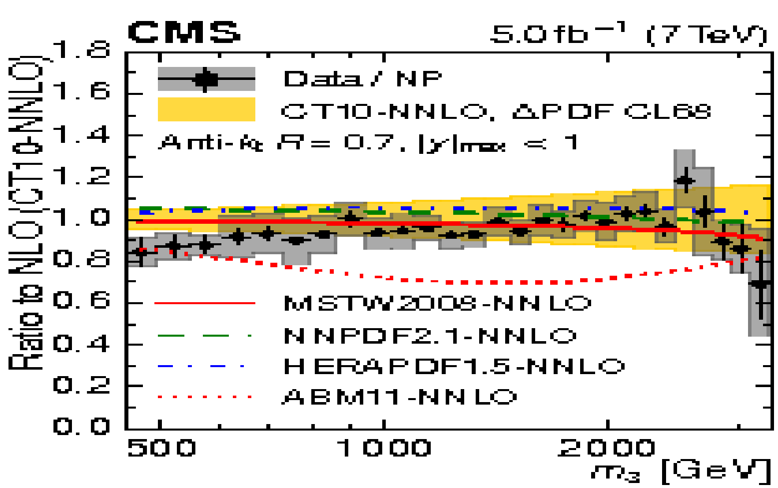
CMS-PAS-SMP-12-027

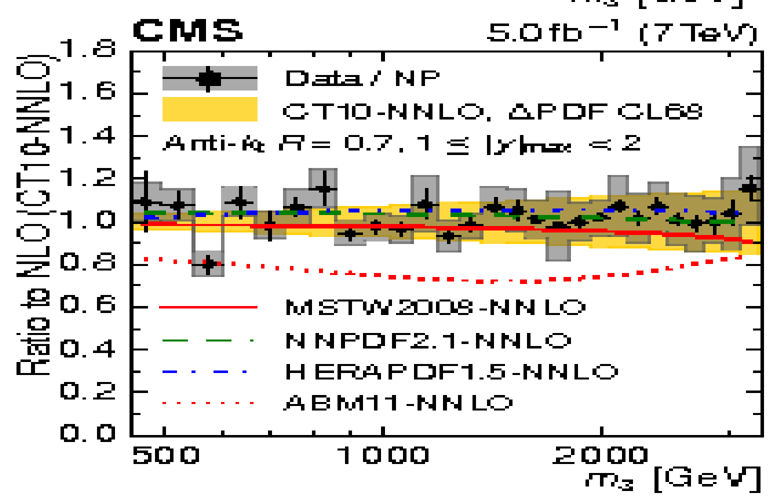
$$\frac{d^2\sigma}{dm_3 dy_{max}} = \frac{1}{\epsilon \mathcal{L}_{eff}} \frac{N}{\Delta m_3 (2 \cdot \Delta |y|_{max})}$$

ε is the product of the selection efficiencies, L_{eff} is the integrated luminosity and N is the number of events in the bin. The width of the 3-jet mass bins is based on the 3-jet mass resolution, which is derived from a full detector simulation and which progressively increases with m3 . The phase space is split into an inner |y| max < 1 and an outer 1 ⩽ |y|max < 2 rapidity region. The bin widths in ymax are then equal to two.

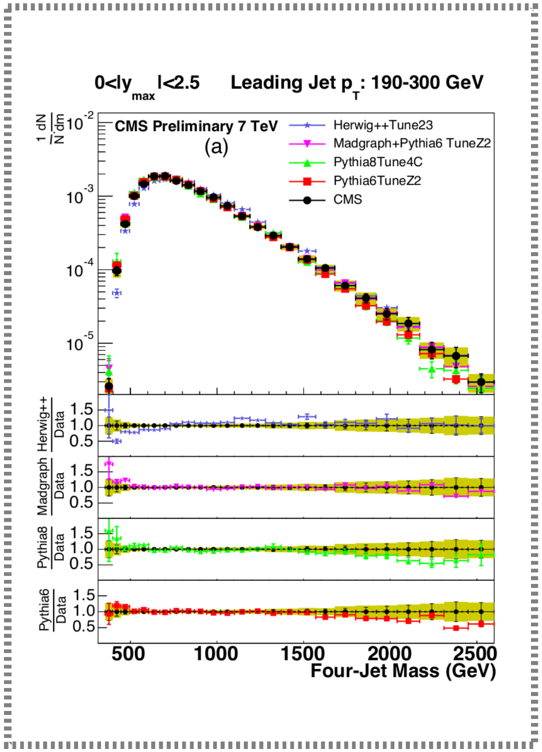




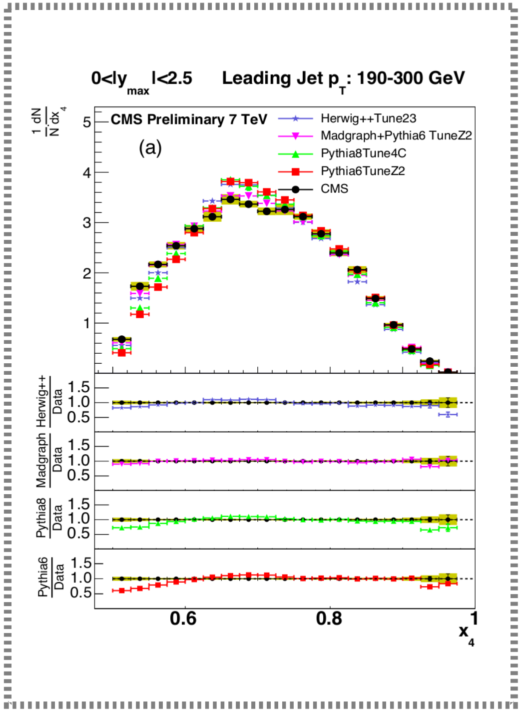


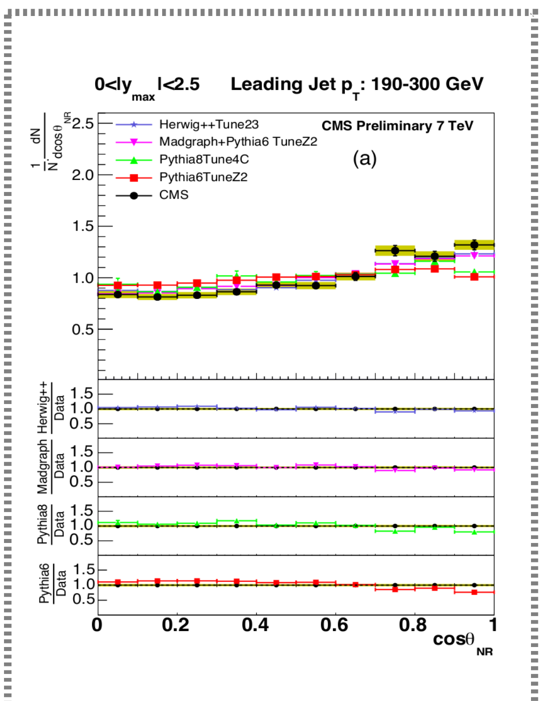


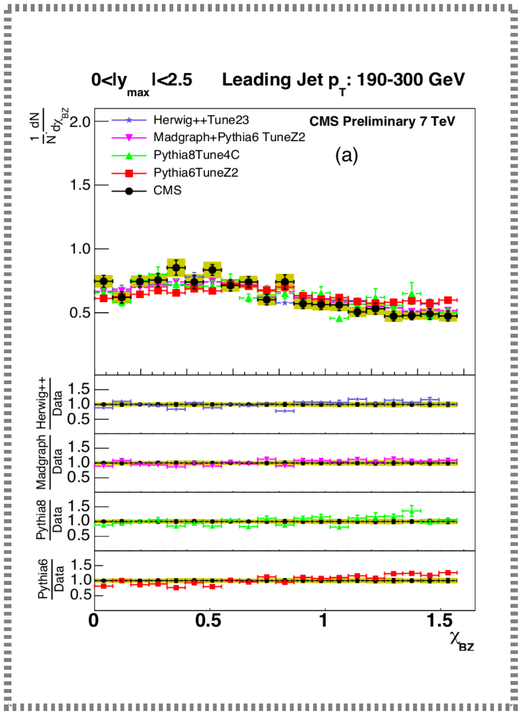
CMS-QCD-11-006



Uncertainty Source	Leading jet p_T	
	110:190 GeV	> 500 GeV
Three-jet Mass		
Jet and event selection	0.1%	0.1%
Jet energy scale	(0.3 – 5.0)%	(0.2 – 5.5)%
Jet resolution	(0.1 – 10.0)%	(0.2 – 6.0)%
Model dependence in unfolding	(0.2 – 11.0)%	(0.2 – 5.0)%
Total systematic	(0.3 – 12.7)%	(0.2 – 7.9)%
Statistical fluctuation	(1.4 – 14.5)%	(0.7 – 10.2)%
Scaled energy of the leading jet		
Jet and event selection	0.1%	0.1%
Jet energy scale	(0.1 – 1.7)%	(0.1 – 1.4)%
Jet resolution	(0.2 – 6.2)%	(0.1 – 5.4)%
Model dependence in unfolding	(0.1 – 6.0)%	(0.5 – 3.6)%
Total systematic	(0.7 – 7.2)%	(1.1 – 5.6)%
Statistical fluctuation	(1.6 – 17.2)%	(0.6 – 14.2)%
Scaled energy of the second-leading jet		
Jet and event selection	0.1%	0.1%
Jet energy scale	(0.1 – 2.0)%	(0.1 – 2.0)%
Jet resolution	(0.1 – 5.0)%	(0.1 – 4.2)%
Model dependence in unfolding	(0.4 – 9.0)%	(0.1 – 3.5)%
Total systematic	(1.0 – 8.3)%	(0.1 – 4.6)%
Statistical fluctuation	(1.3 – 16.4)%	(0.9 – 8.0)%
Four-jet Mass		
Jet and event selection	0.1%	0.1%
Jet energy scale	(0.4 – 6.9)%	(0.3 – 7.0)%
Jet resolution	(0.4 – 11.7)%	(0.2 – 4.9)%
Model dependence in unfolding	(0.3 – 7.0)%	(0.5 – 8.1)%
Total systematic	(0.4 – 13.7)%	(0.5 – 11.6)%
Statistical fluctuation	(3.1 – 30.9)%	(1.4 – 12.5)%
Nachtmann-Reiter angle		
Jet and event selection	0.1%	0.1%
Jet energy scale	(0.1 – 1.0)%	(0.1 – 1.1)%
Jet resolution	(0.1 – 4.6)%	(0.2 – 2.1)%
Model dependence in unfolding	(0.2 – 2.1)%	(0.4 – 5.0)%
Total systematic	(0.9 – 5.0)%	(0.9 – 5.2)%
Statistical fluctuation	(3.4 – 4.2)%	(1.3 – 1.6)%
Bengtsson-Zerwas angle		
Jet and event selection	0.1%	0.1%
Jet energy scale	(0.1 – 3.0)%	(0.2 – 2.4)%
Jet resolution	(0.4 – 5.4)%	(0.2 – 5.0)%
Model dependence in unfolding	(0.3 – 3.5)%	(0.1 – 6.4)%
Total systematic	(1.4 – 5.9)%	(1.0 – 8.1)%
Statistical fluctuation	(5.1 – 8.4)%	(2.8 – 4.0)%







Jet Energy Calibration

CMS-PAS-JME-10-010

Reconstructed Jet

↓

Offset Correction

- removes pile-up and noise contributions

↓

MC Correction (η & p_T)

- flattens the jet response in η and corrects the jet p_T to particle level

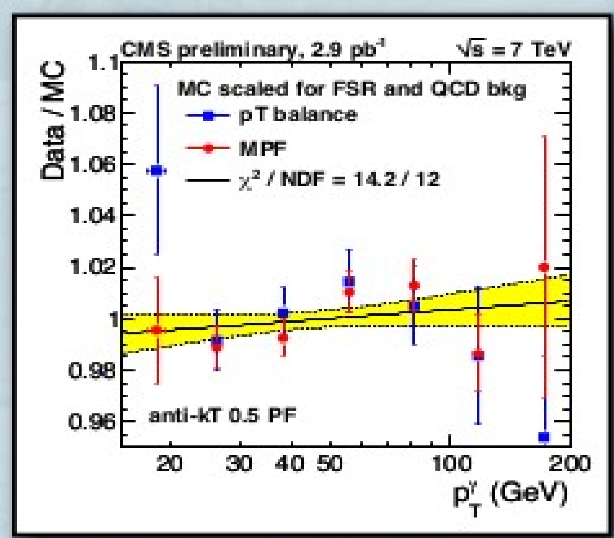
↓

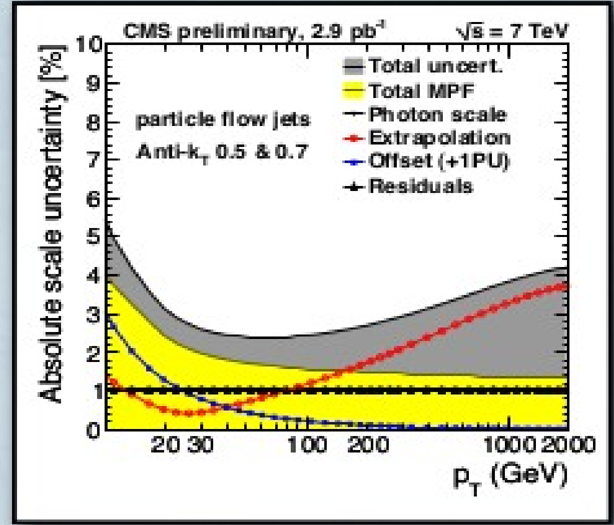
Residual Correction (η & p_T)

- accounts for the differences between data and MC (dijet p_T balance, MPF method)

↓

Calibrated Jet





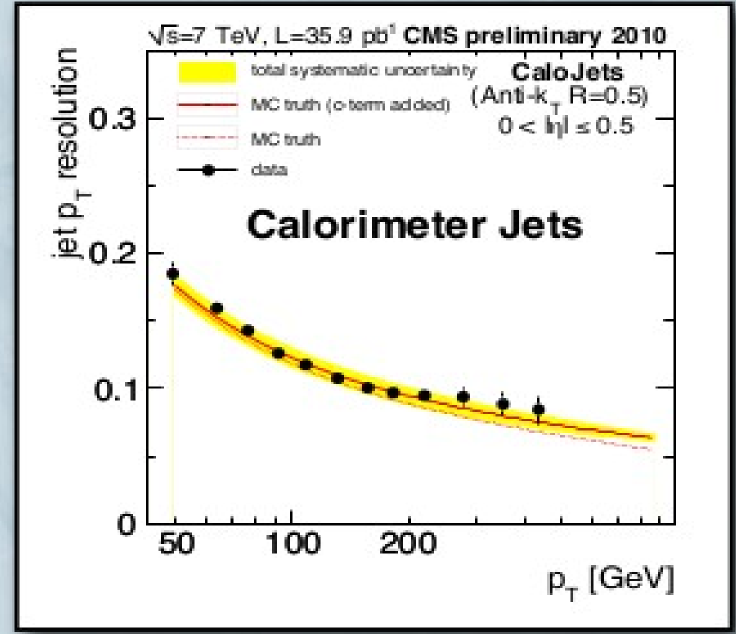
Jet Energy Resolution

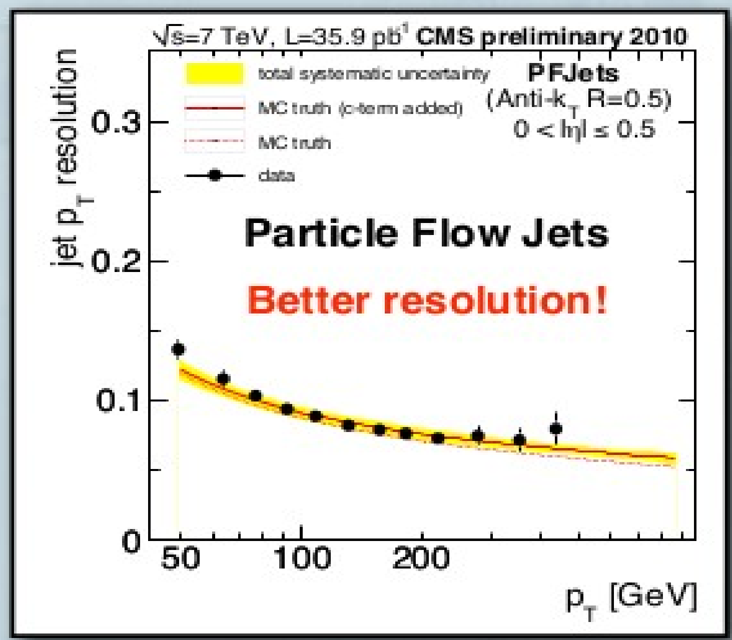
CMS-PAS-JME-10-014

- Determined using the dijet asymmetry method (dijet p_T balancing)
- **The asymmetry** is: $A = \frac{p_T^{jet1} - p_T^{jet2}}{p_T^{jet1} + p_T^{jet2}}$

  jet1, *jet2* - leading jets in the event (3rd jet $p_T \rightarrow 0$)
- The jet p_T resolution is related to the width of the asymmetry distribution

$$\frac{\sigma(p_T)}{p_T} = \sqrt{2}\sigma_A$$





Cosmin Dragoiu 7 DIS 2011