Jet Production Measurements at CMS

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Sanmay Ganguly

Tata Institute Of Fundamental Research
Mumbai, India

On behalf of CMS Collaboration

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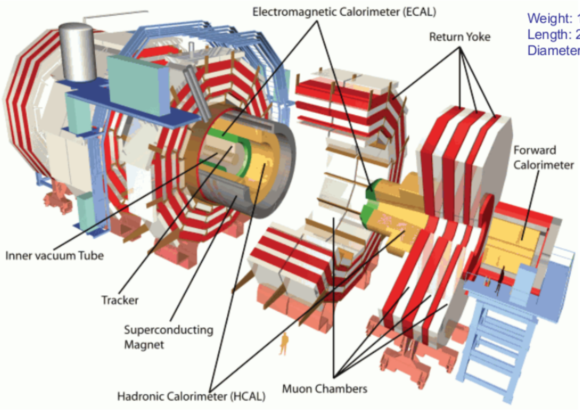


Magnetic Field: 3.8 T. Pixel resolution : $\sigma/p_T \sim 1.5 \times 10^{-4} \oplus 0.005$

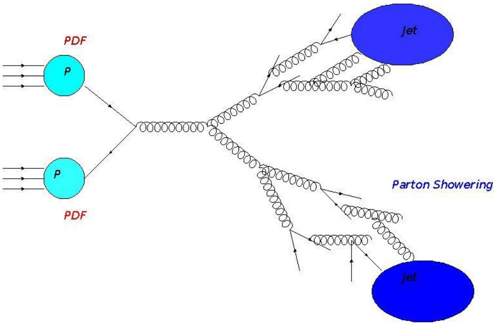
Electromagnetic Calorimeter resolution : $\sigma(\mathrm{E})/\mathrm{E} \sim 2.9\%/\sqrt{\mathrm{E}} \oplus 0.5\% \oplus 0.13\mathrm{GeV}/\mathrm{E}$.

Hadron Calorimeter resolution : $\sigma(\mathrm{E})/\mathrm{E} \sim 120\%/\sqrt{\mathrm{E}} \oplus 6.9\%$.

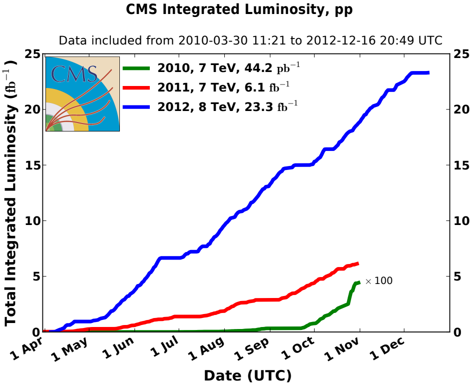
Muon Spectrometer : $\sigma(\mathrm{p_T})/\mathrm{p_T} \sim 1\%$ at low $\mathrm{p_T}$ and $\sim 5\%$ at $\mathrm{p_T}$ around 1 TeV

Motivation

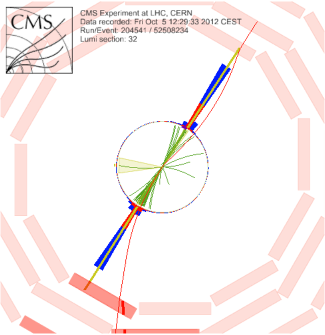
- The current jet measurements give a precise test of perturbative QCD and higher order theory predictions in a new unexplored kinematic regime.
  It also allows to test and improve different parton shower and hadronization models.
- Jet observables are used to constrain the parameters of Parton Distribution Function (PDF) and extract the value of strong coupling constant α_s.
- Jet measurements give a precise estimate of standard model background in new physics search.



CMS Data Collection



Total $\sim 30\ \mathrm{fb}^{-1}$ data collected by CMS in Run 1.



A back to back dijet event.

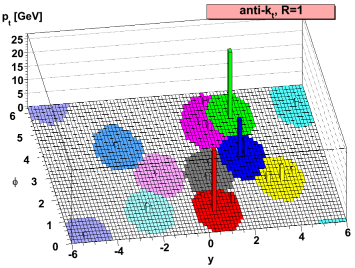
- With the collected data, precision measurements and new physics searches can be done with higher accuracy.

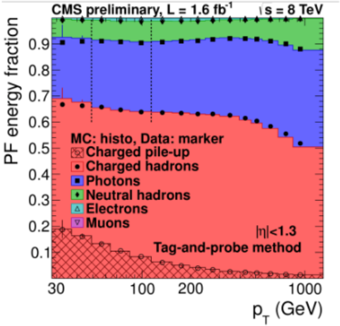
Jet Rconstruction in CMS

Particle Flow (PF) Algorithm→ An event reconstruction technique which attempts to reconstruct and identify all stable particles in an event from each sub-detector component. [CMS-PAS-PFT-09-001]

The output from PF clustering algorithm goes as the input to the Jet clustering algorithm.

- Anti-k_T jet clusterig algorithm is the most widely used jet algorithm in CMS.
- This infra-red safe algorithm produces circular jets around hard particles in y-ϕ plane. The commonly used jet radii are R = 0.5, 0.7.

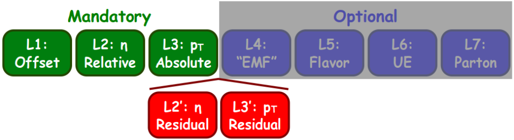


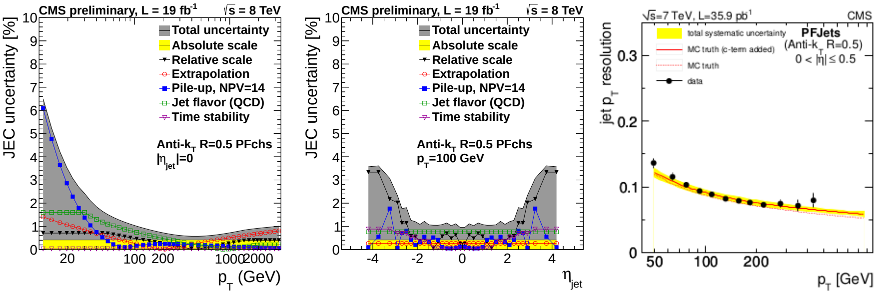


"Jet performance in CMS" talk by H. KIRSCHENMANN

Jet Energy Correction and Resolution

Factorized JEC approach in CMS:



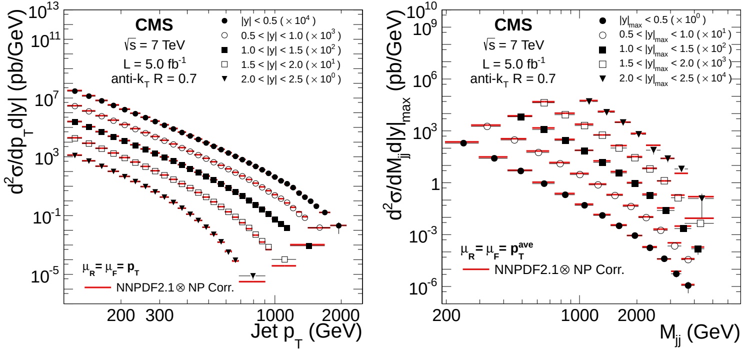


For high p_T and central jets JES uncertainty $\sim$ 1%.

JER is determined from tag and probe dijet asymmetry method. For jet p_T = 100 GeV, JER is $\sim$ 9%.

http://cds.cern.ch/record/1545350/files/DP2013_011.pdf

Inclusive And Dijet Cross-Section at 7 TeV [PRD 87,112002 (2013)]

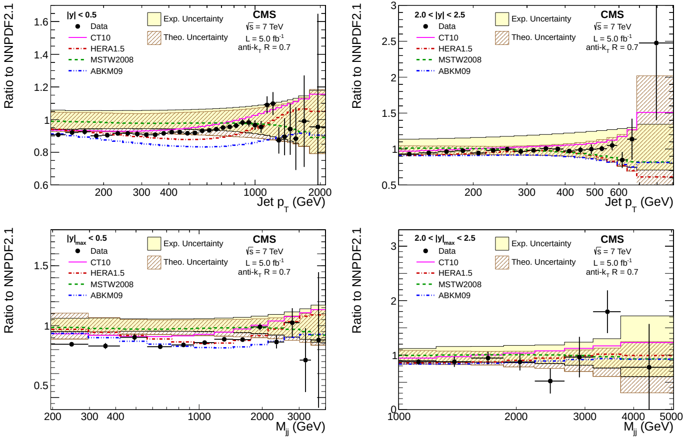


Double differential inclusive and dijet cross-section measured as a function of jet-p_T and M_{jj}.

Measured up to rapidity bin $|y| = 2.5$, with interval $\Delta|y| = 0.5$.

The measured p_T goes up to 2 TeV and M_{jj} goes up to 5 TeV at $\sqrt{s} = 7$ TeV.

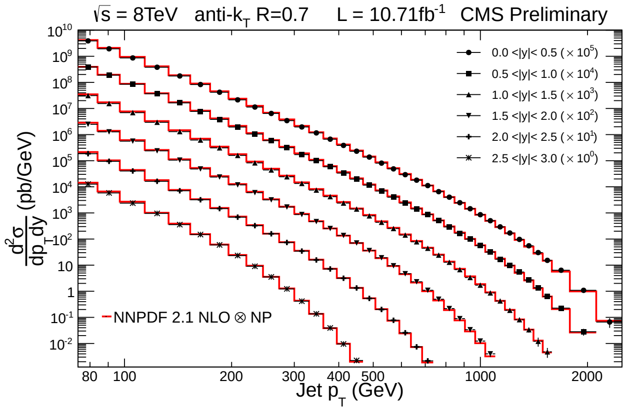
Theory Comparisons [PRD 87,112002 (2013)]



0.0 < |y| < 0.5 **2.0 < |y| < 2.5**

Data over theory compared to ratio within several PDF sets for inclusive and dijet cross-section for two rapidity bins

The central value of the cross-section and the experimental covariance matrix is available from HEP data.



Unfolded double differential inclusive jet cross-section as a function of jet p_T.

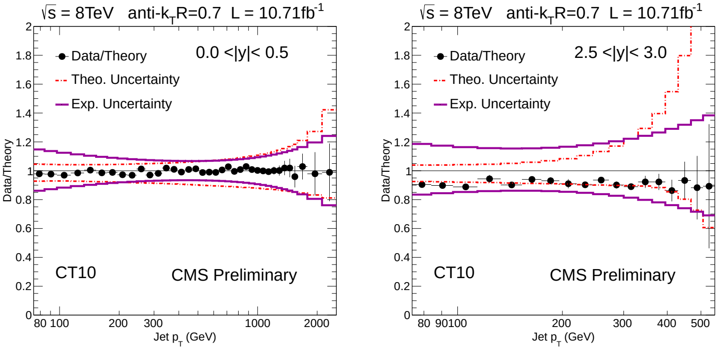
$NLO \otimes NP$ theory prediction (with **NNPDF2.1** PDF set) is compared with the measured spectrum. In this calculation $\mu_F = \mu_R = \text{jet}p_T$

Measured up to rapidity bin $|y| = 3.0$, with interval $\Delta|y| = 0.5$.

The probed p_T ranges from 74 GeV to 2.5 TeV at $\sqrt{s} = 8$ TeV.

Good agreement between data and theory are observed in general.

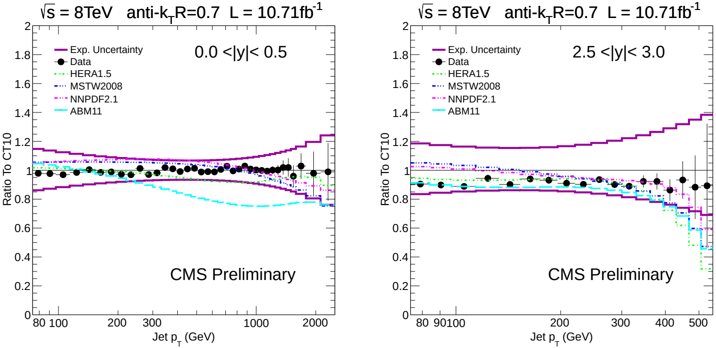
Theory Comparison [SMP-12-012]



Data over theory in the central($0.0 \leq |y| \leq 0.5$) and outer($2.5 \leq |y| \leq 3.0$) rapidity bin for CT10 PDF set.

The total experimental uncertainty gets contribution from JES(12% - 30%), Luminosity(4.4%) and Unfolding(1% - 10%) resulting into 15% - 40% total relative experimental uncertainty, across varying p_T bins, on the measured cross-section.

Comparison among Different PDF [SMP-12-012]

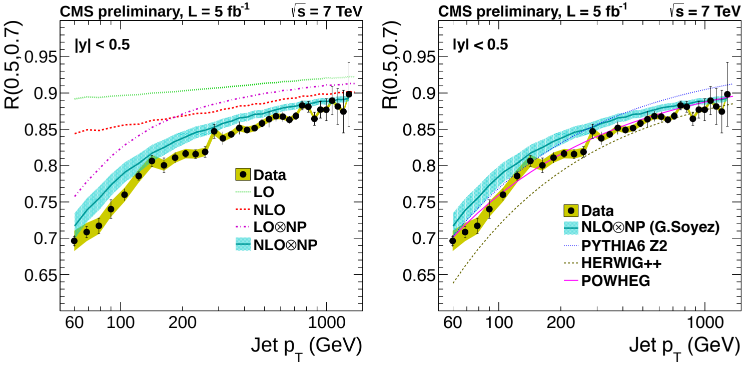


Data over theory compared to ratio with other PDF sets for CT10 PDF.

The theory predictions are computed for five different PDF sets, viz. HERA1.5, MSTW2008, NNPDF2.1, ABM11 and CT10.

The total theory uncertainty gets contribution from PDF(5% - 30%) and Scale(5% - 40%) uncertainties.

The deviations from unity are covered by total theoretical and experimental uncertainty bands.



Ak5/Ak7 inclusive jet cross section ratio compared with different order pQCD prediction and with different MC predictions.

The ratio gradually increases towards unity with increasing jet-p_T.

NLO matrix element calculation matched with parton shower has better agreement with data compared to fixed order calculation corrected for the NP factor.

Color Coherence [SMP-12-010]

- In a 3 jet event($p_{T1} > p_{T2} > p_{T3}$): If 3rd-jet is very close to 2nd jet → 3rd jet most likely originated from a gluon radiation from 2nd-jet and hence color connected with the 2nd-jet.
- Color coherence prediction : 3rd jet lies in the event plane(spanned by 2nd jet and beam axis).
- The variable $\beta = \tan^{-1}[(\phi_3 - \phi_2), \mathrm{sgn}(\eta_2).(\eta_3 - \eta_2)]$ is designed to study this property.
- Another observable is $\Delta R_{23} = \sqrt{(\eta_3 - \eta_2)^2 + (\phi_3 - \phi_2)^2}$

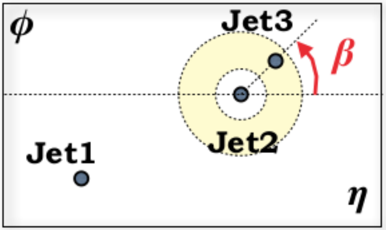
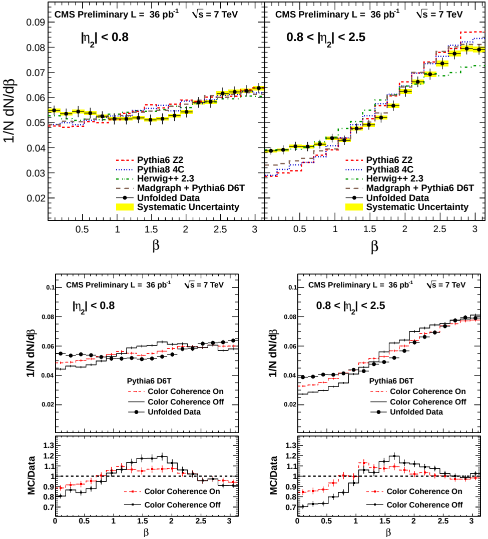


fig. by K. Kousouris

- $\beta = 0$: 3rd-jet is between 2nd-jet and closest proton remenant.
- $\beta = \pi$: 3rd-jet is between 2nd-jet and farthest proton remenant.

β Distribution [SMP-12-010]



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Discussion

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THANK YOU !!

Back UP

Cross Section Measurements

• The double differential Inclusive Jet cross section is measured using the formula:

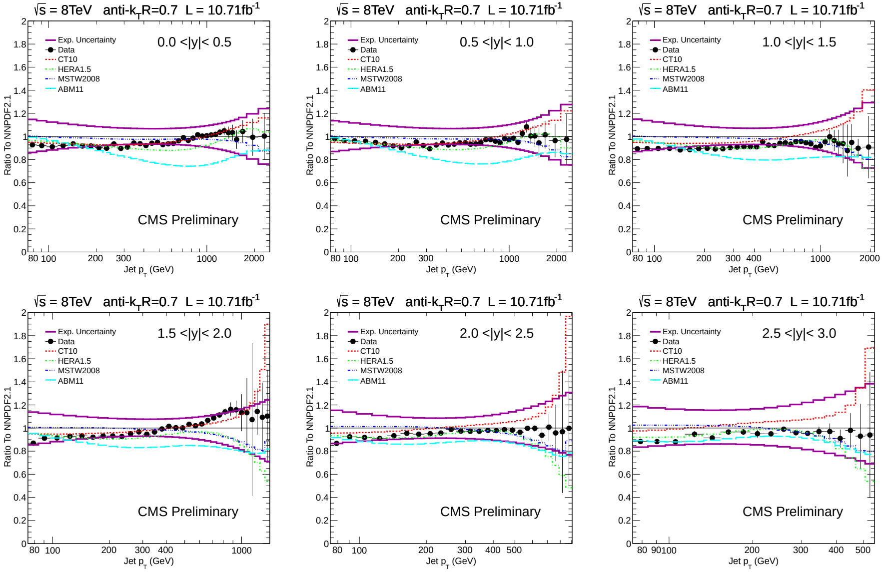
$$\frac{d^2\sigma}{dp_T d|y|} = \frac{1}{\epsilon L} \frac{N}{\Delta p_T \Delta |y|} \times C_{unsmearing}$$

• The double differential DiJet invariant cross section is measured using the formula:

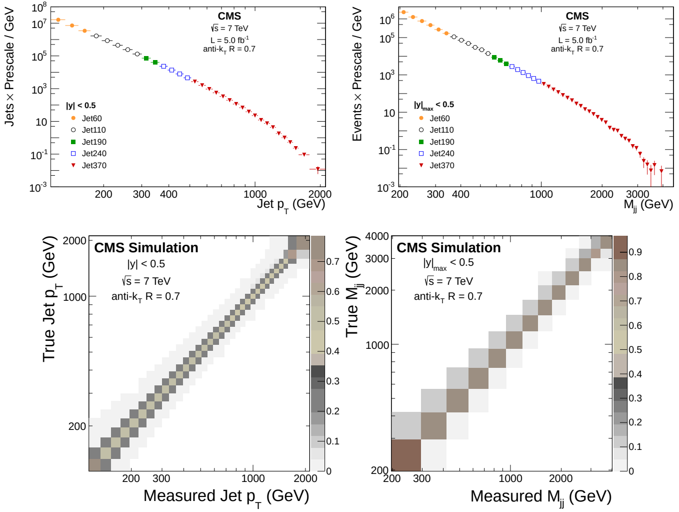
$$\frac{d^2\sigma}{dM_{jj} d|y|} = \frac{1}{\epsilon L} \frac{N}{\Delta M_{jj} \Delta |y|} \times C_{unsmearing}$$

N : Number of jets in Δp_T or M_{jj} bin.
$\Delta p_T, \Delta M_{jj}$: p_T, M_{jj} bin width
$\Delta |y|$: Rapidity bin width.
ϵ : Product of Trigger and Event selection efficiencies.
L : Total Integrated Luminosity.
$C_{unsmearing}$: Unsmearing correction factor

Comparison Among Different PDF [SMP-12-012]

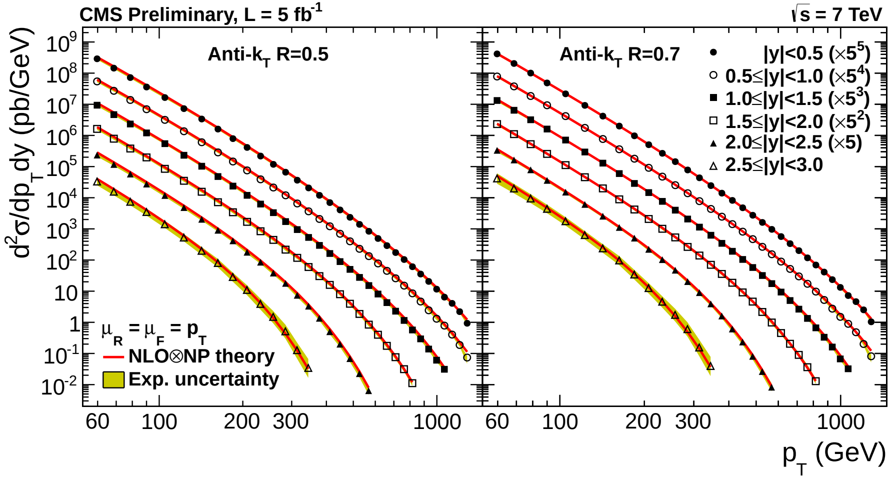


Jet Yield and Unfolding Matrix [QCD-11-004]



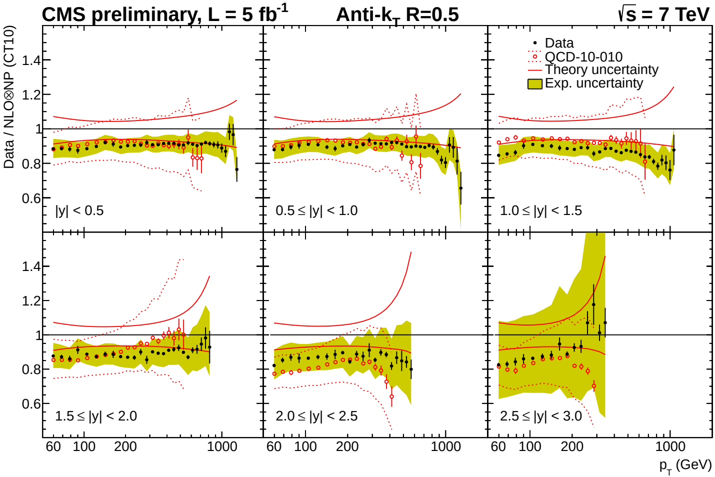
Raw jet yield and Unfolding matrix for the Inclusive and Dijet spectrum for $\sqrt{s} = 7$ TeV.

Jet Spectrum for Jet Radii Ratio [SMP-13-002]



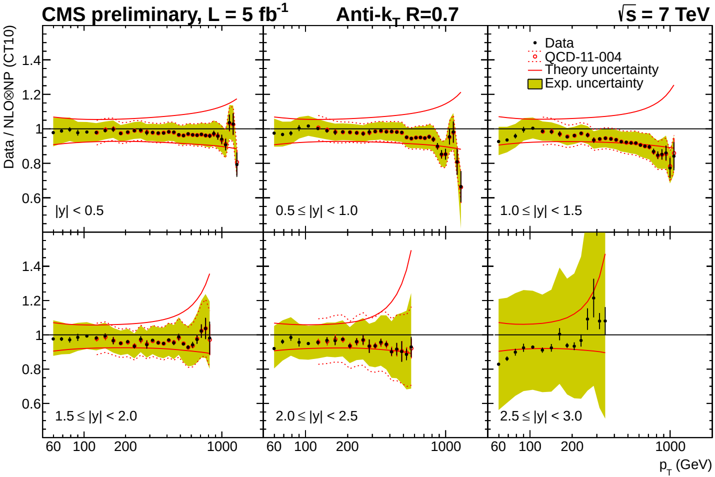
Inclusive Jet spectrum for Ak5 and Ak7 jets. The Ak7 jet spectrum matches well with the previous measurement.

Theory Comparison Ak5 Jet. [SMP-13-002]

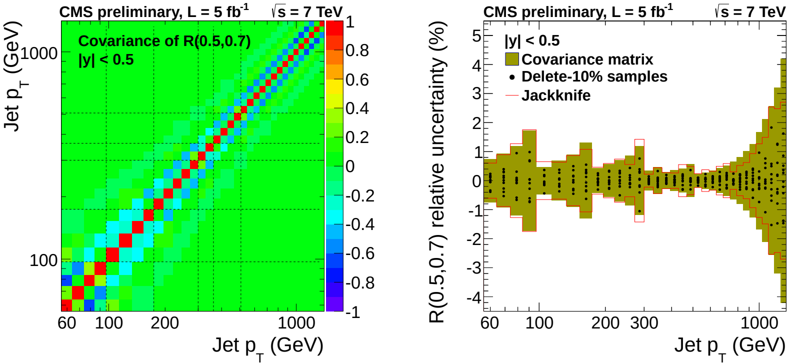


Ak5 jet spectrum compared to NLO theory and earlier measurement [QCD-10-010].

Theory Comparison Ak7 Jet. [SMP-13-002]



Ak7 jet spectrum compared to NLO theory and earlier measurement [QCD-11-004].

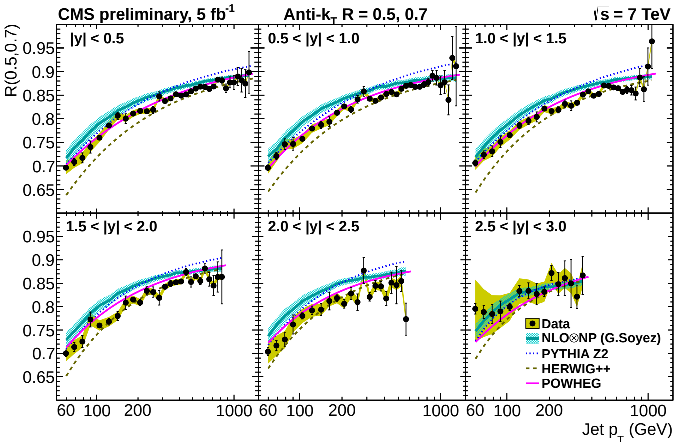


Correlation matrix and relative uncertainty in the jet radius ratio measurement for $0.0 \leq |y| \leq 0.5$.

The main source of experimental uncertainty is Pileup.

The total systematic uncertainty varies from about 0.4% to 4% for $|y| \leq 0.5$ and for $2.5 \leq |y| \leq 3.0$ it varies between 3% to 8%.

Physics Reach [SMP-13-002]



NLO matrix element calculation matched with parton shower has better agreement with data compared to fixed order calculation corrected for the NP factor.

At $|y| \geq 2.5$ large experimental uncertainties limits the discrimination between different models.

Exp Uncertainty [SMP-12-010]

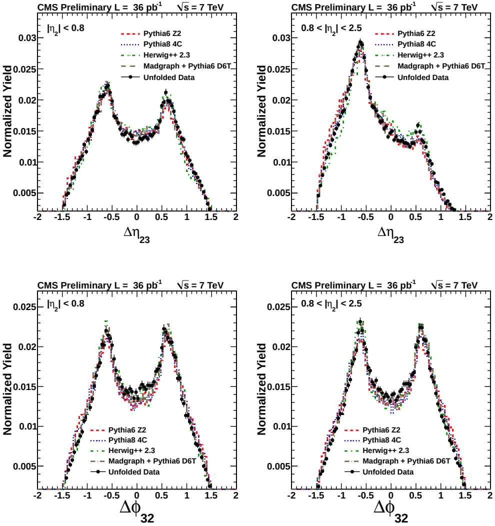
Uncertainty source	$\lvert\eta_2\rvert < 0.8$	$0.8 < \lvert\eta_2\rvert < 2.5$
Jet Energy Scale (JES)	1.0 %	1.0 %
Jet Energy Resolution (JER)	0.4 %	0.5 %
Jet Angular Resolution (JAR)	0.5 %	0.6 %
Physics Model used in unfolding (PM)	0.6 %	0.7 %
Statistical fluctuations	4.0 %	3.7 %

Individual experimental uncertainty components

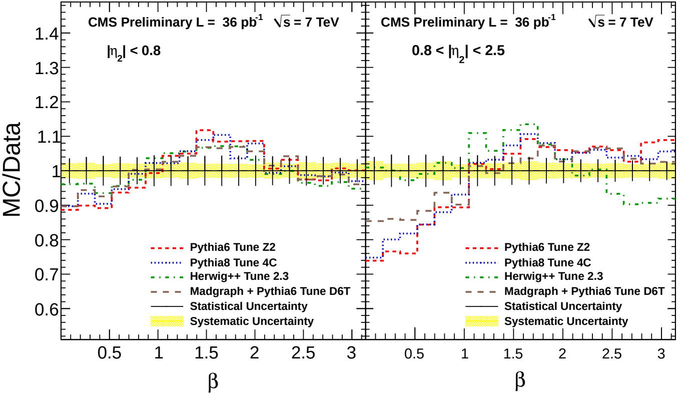
	χ^2/NDF	
MC event generator	$\lvert\eta_2\rvert < 0.8$	$0.8 < \lvert\eta_2\rvert < 2.5$
PYTHIA 6 Z2	2.5	8.1
PYTHIA 8 4C	1.7	6.4
HERWIG ++ 2.3	1.2	3.5
MADGRAPH (+PYTHIA 6 D6T)	1.6	3.3

ChiSquare/NDF for each of the MC distribution.

Angular correlation between 2nd and 3rd jet in an event is studied for 3jet events.



Effect Of Color Coherence [SMP-12-010]



MC over data for normalized β distribution.

In general HERWIG++ matches with data well except in the forward region $\beta \sim \pi$.

Madgraph predictions for exactly $2 \rightarrow 3$ process at **LO** gives beter predictions than PYTHIA6 alone.

Effect Of Color Coherence [SMP-12-010]

Selection criteria
$p_{T1} > p_{T2} > p_{T3} > 30$ GeV
$\|\eta_1\|, \|\eta_2\| < 2.5$
$M_{12} > 220$ GeV
$0.5 < \sqrt{(\Delta\eta_{23})^2 + (\Delta\phi_{23})^2} < 1.5$

Event selection criteria for color coherence measurement