Differential jet cross sections at the CMS experiment

Tanmay Sarkar, on behalf of the CMS collaboration

ICHEP: July, 7-11, 2018

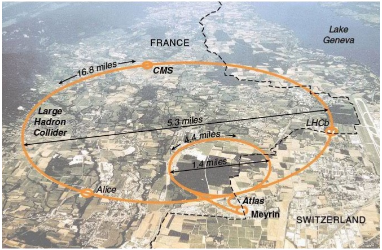
Outline

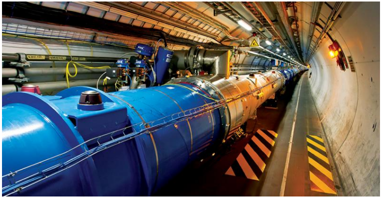
- Introduction
- LHC and CMS experiment
- Jet reconstruction
- Trigger
- Systematic uncertainty
- Results at different energies: 7, 8 and 13 TeV of CMS data
- Summary

Introduction

- Quantum chromo-dynamics, a theory of the strong (or nuclear, or color) force, fundamental theory describing strong interactions among partons, -quarks and gluons
- Inclusive jet production ($p + p \rightarrow jet + X$) is a key process to test predictions of pQCD over a wide region in phase space.
- Compared with the measurements, the parton-level calculations must be complemented with corrections for nonperturbative (NP) effects that involve the modeling of hadronisation and multiparton interactions.
- The previous measurements of 7 and 8 TeV centre-of-mass energies, good agreement with calculations at next-to-leading order (NLO) over a wide range of jet transverse momentum- p_T and rapidity- y.
- Using latest data from the LHC Run 2, performance of pQCD calculations can be tested at the new energy regime of $\sqrt{s} = 13 TeV$.

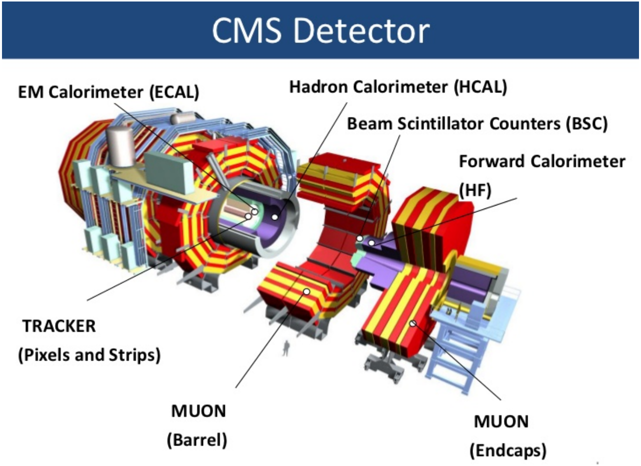
The Large Hadron Collider at CERN, Geneva





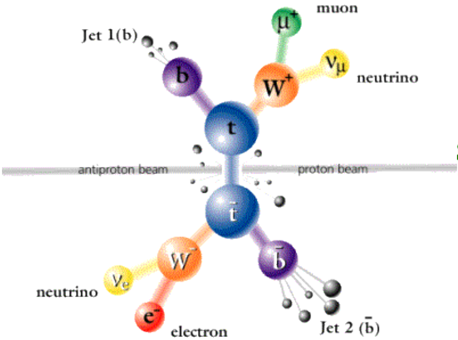
- Large Hadron collider-LHC
  - **Large** due to its size $\sim$ 27 km in circumference.
  - **Hadron**, accelerates protons or ions, which are hadrons.
  - **Collider** because these particles form two beams travelling in opposite directions and collide at four points where the two rings of the machine intersect.

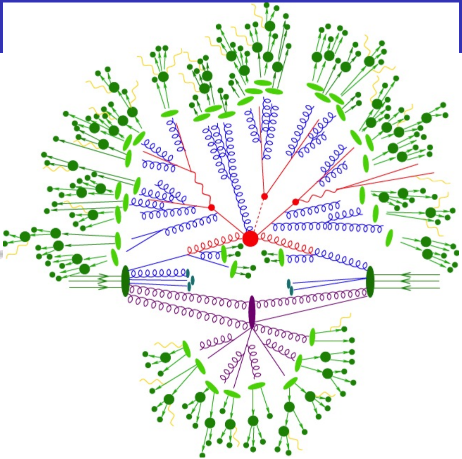
The Compact Muon Solenoid- CMS



CMS is a general-purpose detector at LHC - wide range of physics studies: Standard Model, Higgs boson, New Physics Beyond the SM, dark matter, ...

Jet reconstruction





- Collimated bunches of stable hadrons, originating from a parton is called a jet.
- Jets are the observable objects to relate experimental observations to theory predictions formulated in terms of quarks and gluons. Two kinds of mainstream algorithms

Jet reconstruction and jet cross section

- Information from the subdetectors is combined through the Particle Flow algorithm.
- Currently the LHC experiments use anti-k_T as the principal algorithm.

The double-differential inclusive jet cross section:

$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{\epsilon\mathcal{L}} \frac{N_j}{\Delta p_T \Delta y}$$

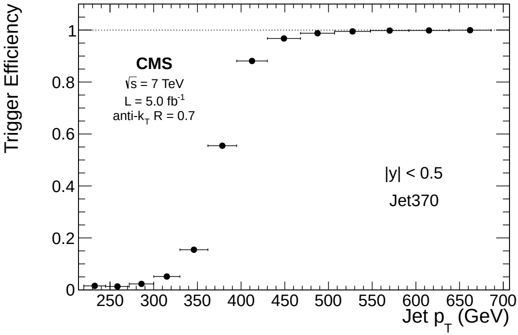
where $\mathcal{L}$ is the integrated luminosity, N_j is the number of jets in a bin of a width Δp_T in transverse momentum and Δy in rapidity, and ϵ is the product of the trigger and jet selection efficiencies, which is greater than 99%.

Trigger

- Data samples are collected with single-jet and high-level triggers (HLT).
- Exclusive division method: phase space is divided in regions according to the leading jet p_T and independent triggers are used in each region

The trigger efficiency is defined as:

$$\epsilon^{Trigger} = \frac{InclusiveRecoJet - P_T(Ref + L1Object - p_T > Z + HLTObject - p_T > Y)}{InclusiveRecoJet p_T(Ref)}$$



Fitted to an error function and turn-on point: 99% efficiency

Phys. Rev. D 87 (2013) 112002

Trigger

- Eight single-jet HLT paths are considered, seeded by Level 1 triggers based on calorimetric information.
- They require, in the full rapidity coverage of the CMS detector, at least one jet in each event with $p_T > 60, 110, 190, 240, 370$ GeV. An example of 7 TeV

Trigger p_T threshold (GeV)	$Leadingjetp_T$ (GeV)
60	114-196
110	196-300
190	300-362
240	362-507
370	> 507

Unfolding

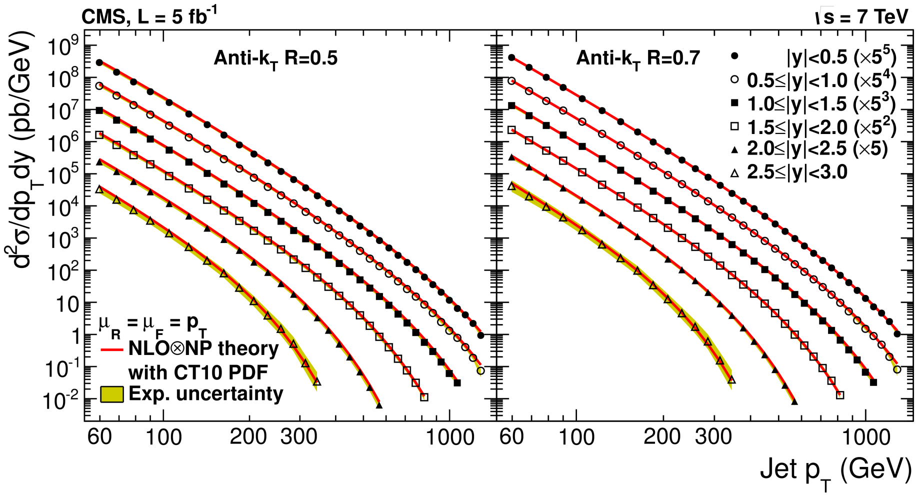
- The unfolding procedure is based on the iterative dAgostini method, as implemented in the ROOUNFOLD software package.
- Uses a response matrix that maps the predicted disribution to the measured one.
- The response matrix is obtained from a simulation, uses the theoretically predicted spectrum as input and introduces smearing effects by taking into account the jet p_T resolution.
- The iterative unfolding procedure is regularized by limiting the number of iterations to four in each rapidity bin.
- The unfolded distributions differ from the distributions at detector level by 5% to 20%.

Systematic Uncertainty

Systematic Unc	7 TeV	8 TeV	13 TeV
JES	8-35%	6-45%	8-65%
JER-Unfolding	5%	1-5%	1-2%
Luminosity	2.2%	2.6%	4.8%
Trigger Efficiency	1%	1%	1%
Pile-up	negl%	negl%	negl%
Unfolding	negl%	negl%	negl%
PDF	1-30%	5-30%	1-10%
Scale	5-40%	5-30%	1-12%
NP Correction	1-5%	0.06-1.4%	2%

The main systematic uncertainties for the jet cross section measurements arise from the JES calibration and uncertainty in the integrated luminosity.

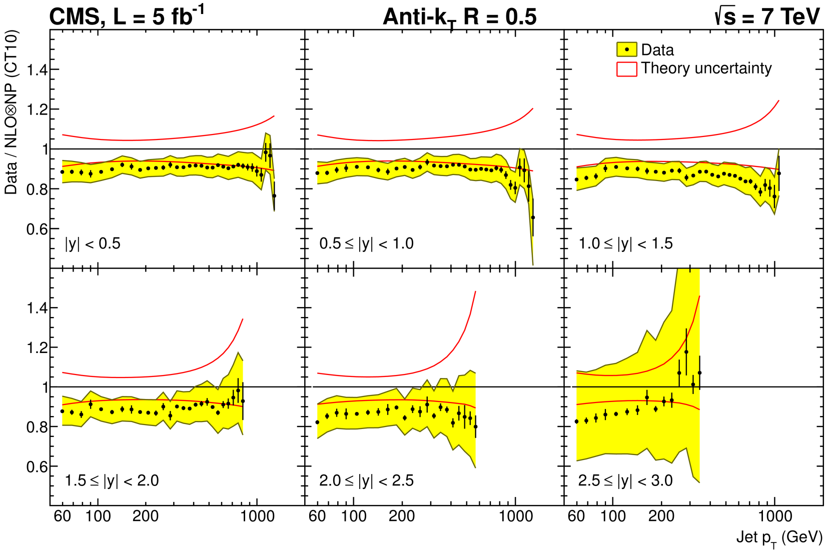
Inclusive jet cross section at 7 TeV

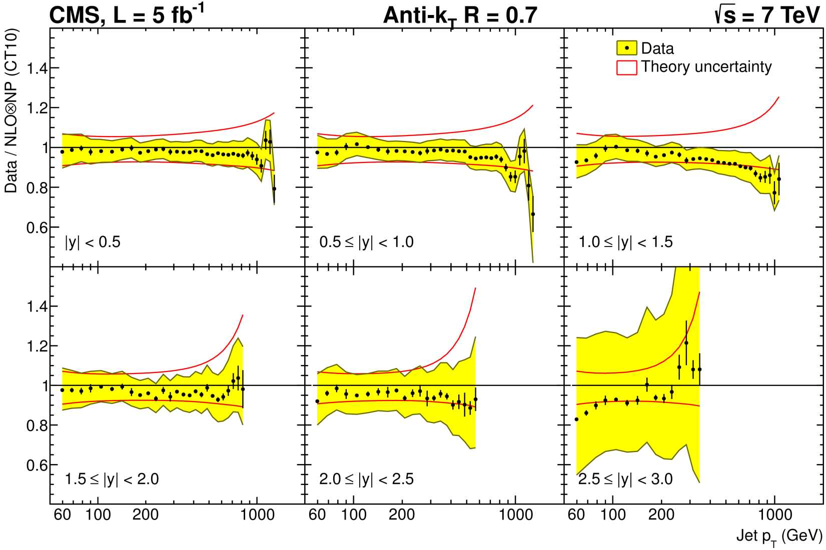


Jets with two different distance parameters help to understand in a deeper way the details of the parton evolution.

Phys. Rev. D 90 (2014) 072006

Inclusive jet cross section at 7 TeV: Ratio-1

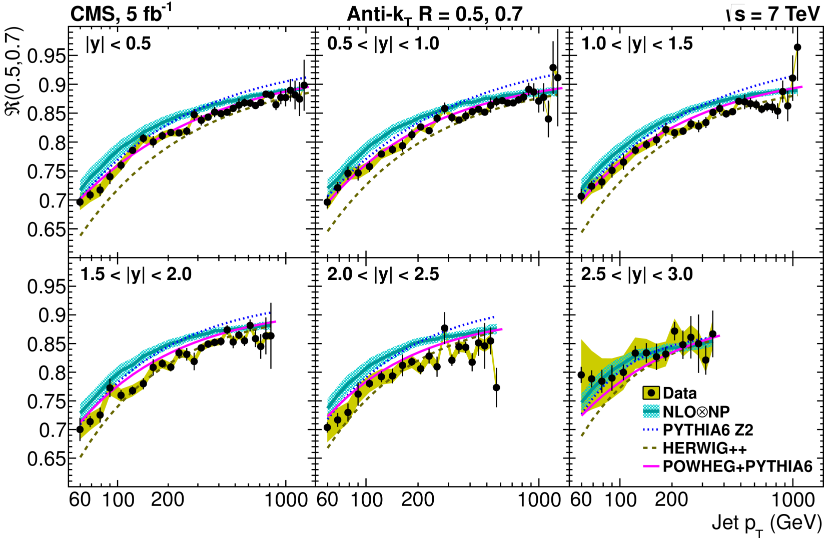




Very good data agreement for jets with larger cone size

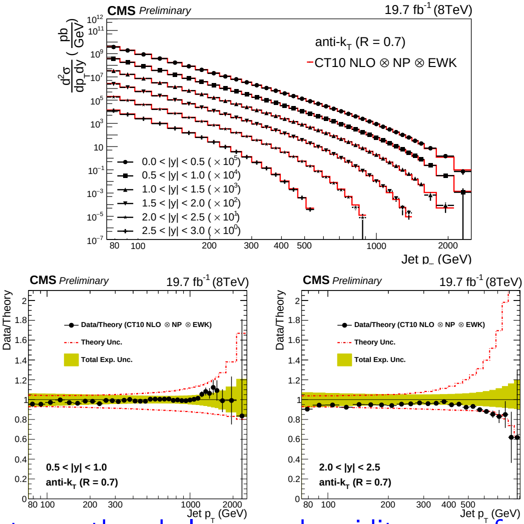
Phys. Rev. D 90 (2014) 072006

Inclusive jet cross section at 7 TeV: Ratio-3



Cross section ratio between the two cone sizes well reproduced by NLO matrix elements interfaced to PS and MPI simulation(POWHEG + PYTHIA6).

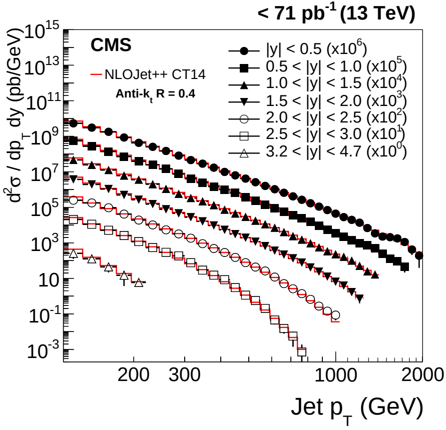
Inclusive jet cross section at 8 TeV

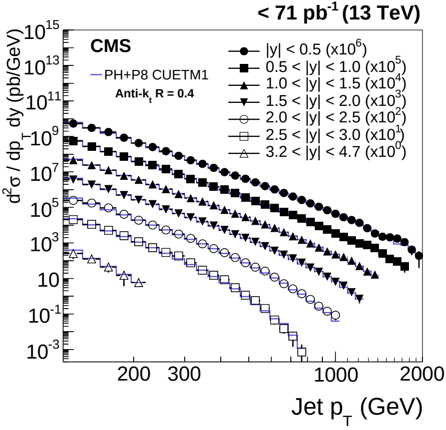


Good agreement over the whole p_T and rapidity range for fixed-order calculations corrected for NP and EW effects.

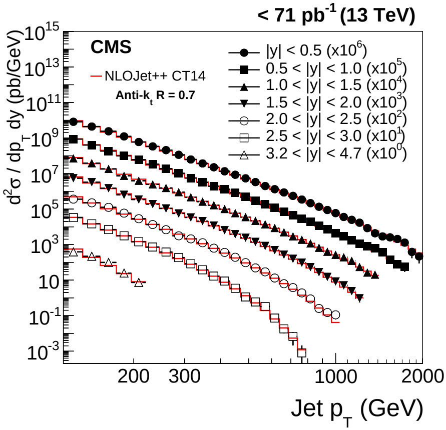
J. High Energ. Phys. (2017) 156

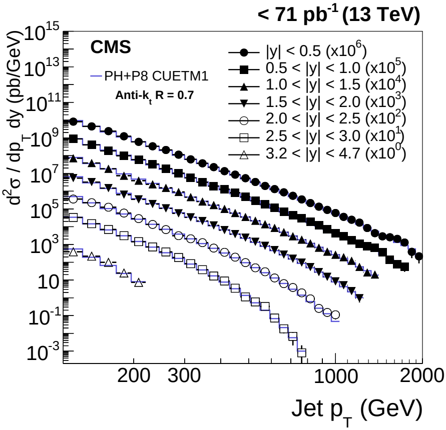
Inclusive jet cross section at 13 TeV





Inclusive jet cross section at 13 TeV

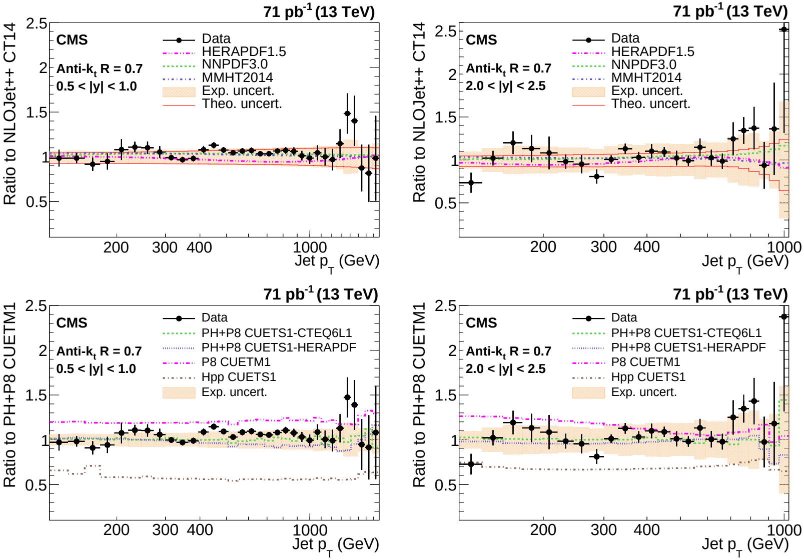




- Double-differential inclusive jet cross section as function of jet p_T.
- Predictions from NLOJet++, based on the CT14 PDF, corrected for the NP non-perturbative effect.
- Predictions from POWHEG + PYTHIA8 with tune CUETM1.

The HF region included. Eur. Phys. J. C 76 (2016) 451

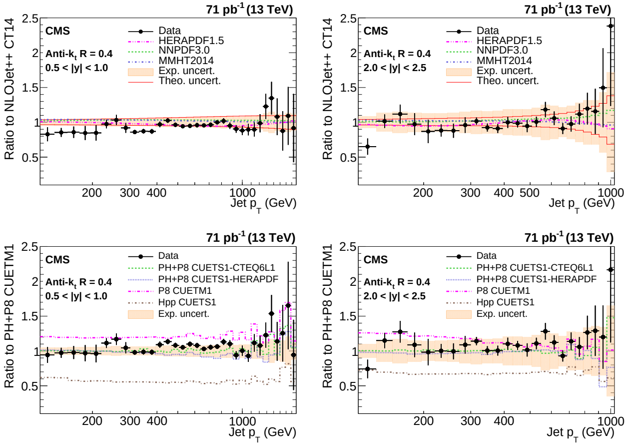
Inclusive jet cross section at 13 TeV: Ratio



Predicted cross sections follow the data well in each rapidity bin

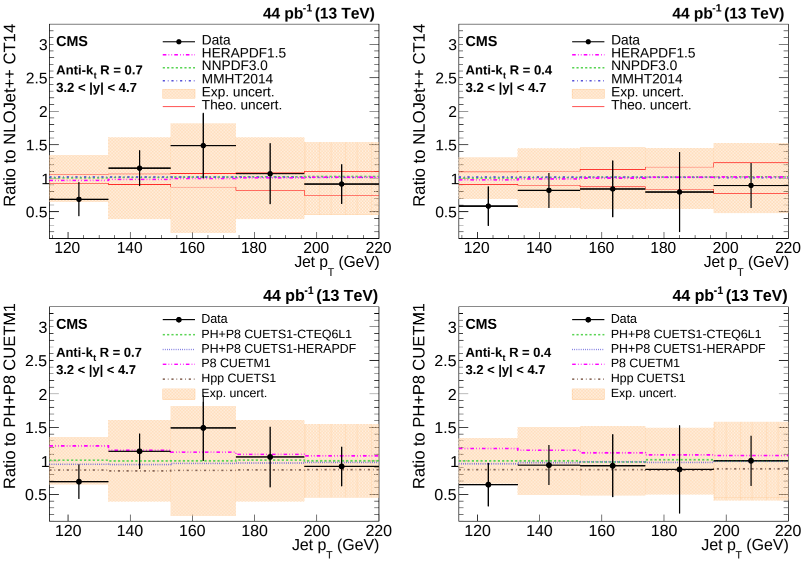
Eur. Phys. J. C 76 (2016) 451

Inclusive jet cross section at 13 TeV: Ratio



- Relatively poor agreement for R = 0.4
- Due to PS and soft-gluon resummation contributions, which are missing in fixed- order calculations.
- This is relevant for smaller jet cone sizes because of out-of-cone effects.

Inclusive jet cross section at 13 TeV: forward region



Predicted cross sections follow the data well in the outermost rapidity region Eur. Phys. J. C 76 (2016) 451

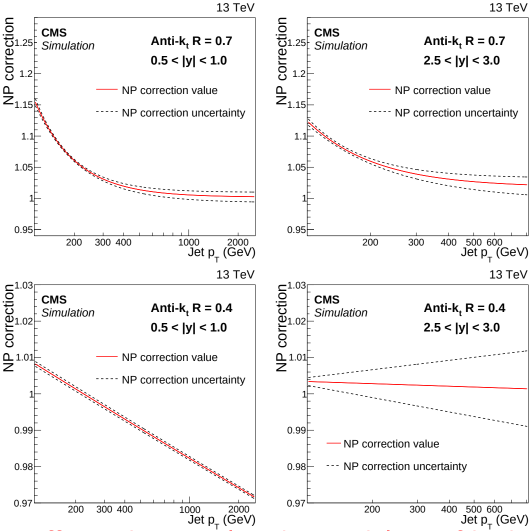
Summary

- The CMS experiment performed a wide range of jet measurements at various collision energies and up to $\sqrt{s} = 13$ TeV
- Double-differential cross section distributions are measured for inclusive jets in p_T (30-2500) GeV, with forward region -$|y| < 4.7$
- Systematic effects are evaluated and main contributions come from JES uncertainties at each energy
- Fixed-order NLO calculations reproduce well jet cross sections in various rapidity bins but are better for large R for the clustering algorithm
- MC event generators with NLO matrix element follow slightly better the data for jets clustered with small R
- Jet measurements are becoming precision physics and exploring new phase space territory and are challenging the precision of theoretical predictions

Thank you for your attention

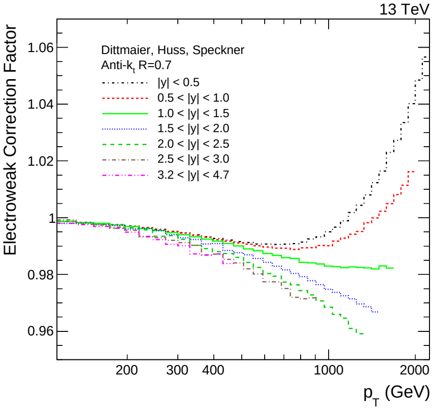
Back Up

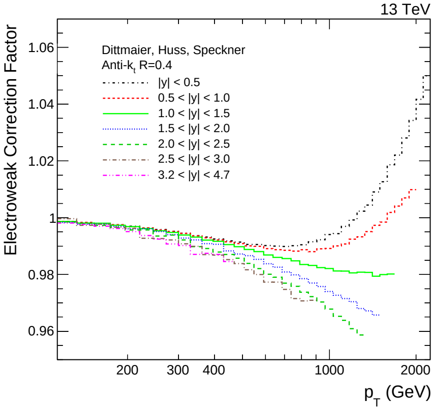
Nonperturbative corrections: 13TeV



Non-perturbative effects that involve the modeling of hadronisation and multiparton interactions. $C_{NP} = \frac{\frac{d\sigma^{nom}}{dp_T}}{\frac{d\sigma^{MPI,HADoff}}{dp_T}}$

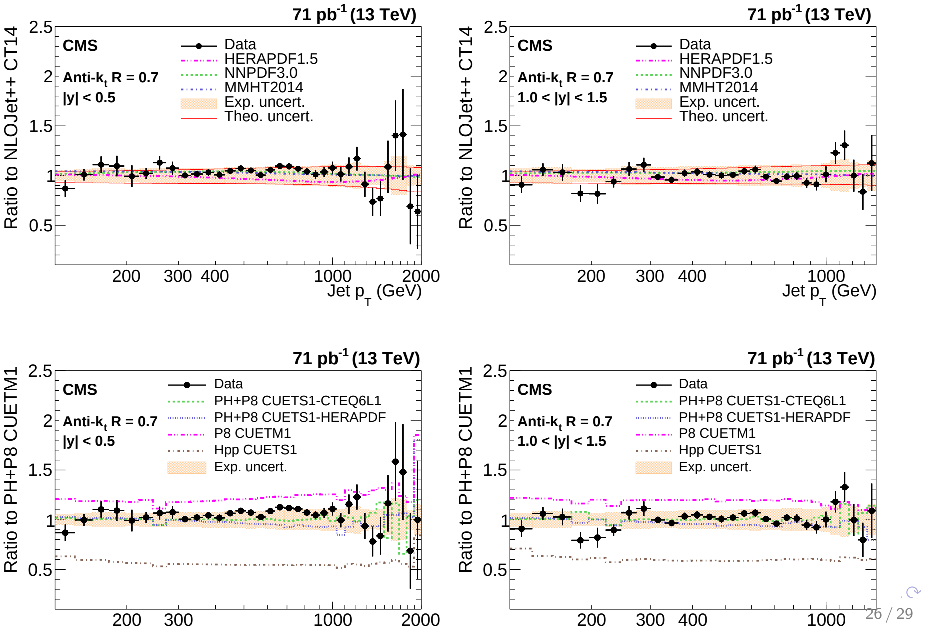
Electroweak correction factors for the seven rapidity bins: 13TeV



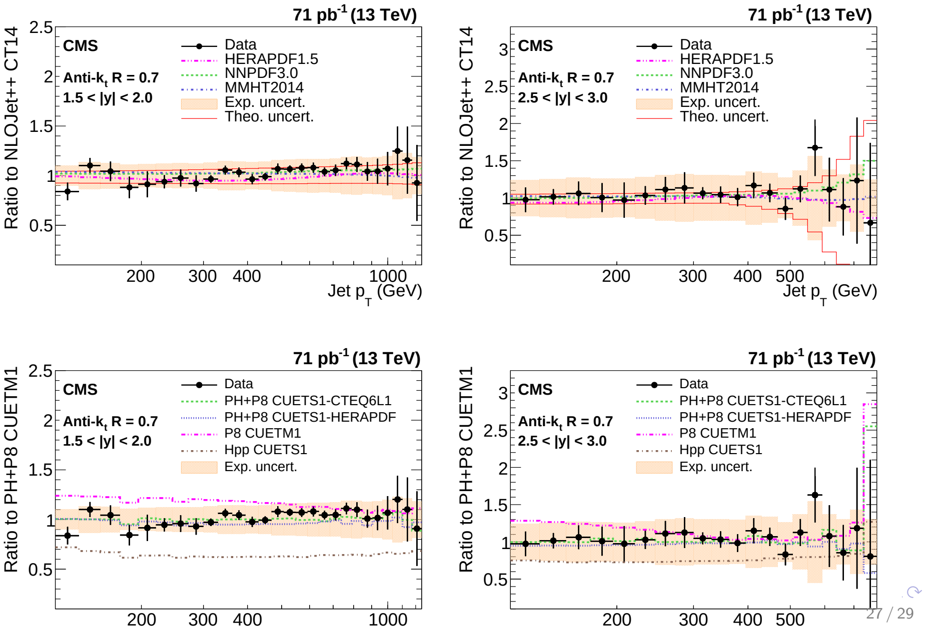


Eur. Phys. J. C 76 (2016) 451

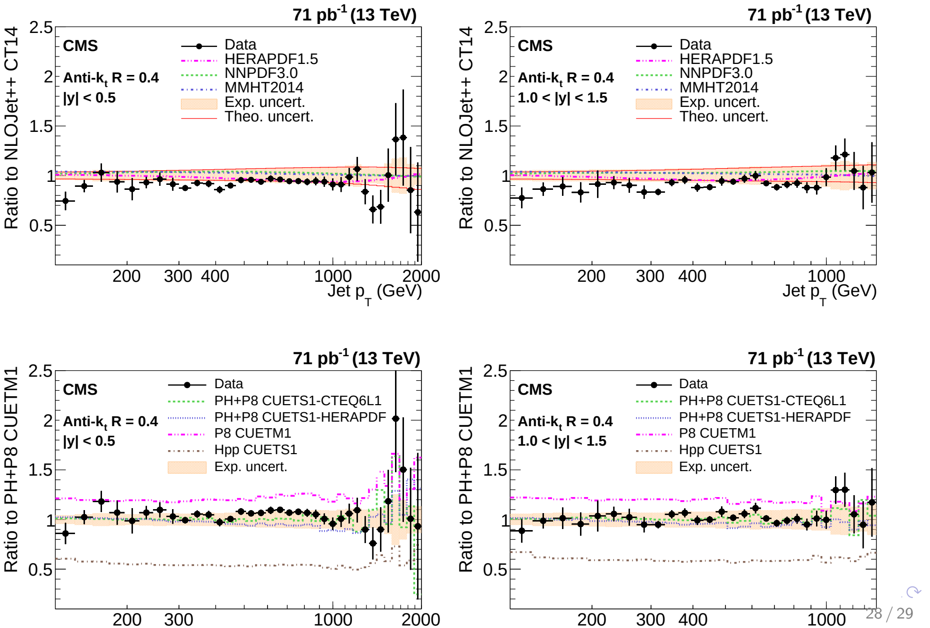
Inclusive jet cross section at 13 TeV: Ratio



Inclusive jet cross section at 13 TeV: Ratio



Inclusive jet cross section at 13 TeV: Ratio



Inclusive jet cross section at 13 TeV: Ratio