Jet cross section measurements and extraction of QCD parameters

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Internal Seminar
27 February 2017

Outline

- LHC Accelerator
- CMS Detector
- QCD and Jets
- Jet Reconstruction and Jet Energy Corrections
- CMS Measurements
  - Inclusive jet cross section and strong coupling at 7 TeV
  - 3-jet to 2-jet cross section ratio and strong coupling at 7 TeV
  - Dijet azimuthal decorrelations at 8 TeV
  - Inclusive jet cross section at 13 TeV
- Conclusions

LHC Accelerator

LINAC 2

50 MeV

PSB (Proton Synchrotron Booster)

1.4 GeV

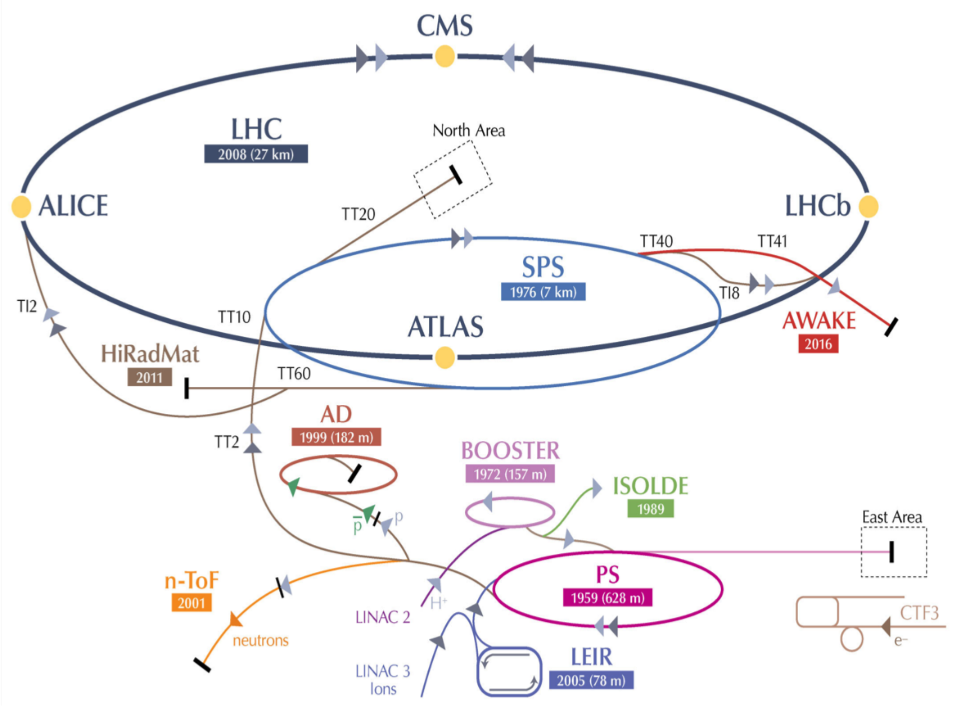
PS (Proton Synchrotron)

25 GeV

SPS (Super Proton Synchrotron)

450 GeV

LHC (Large Hadron Collider)
3.5, 4, 6.5 TeV

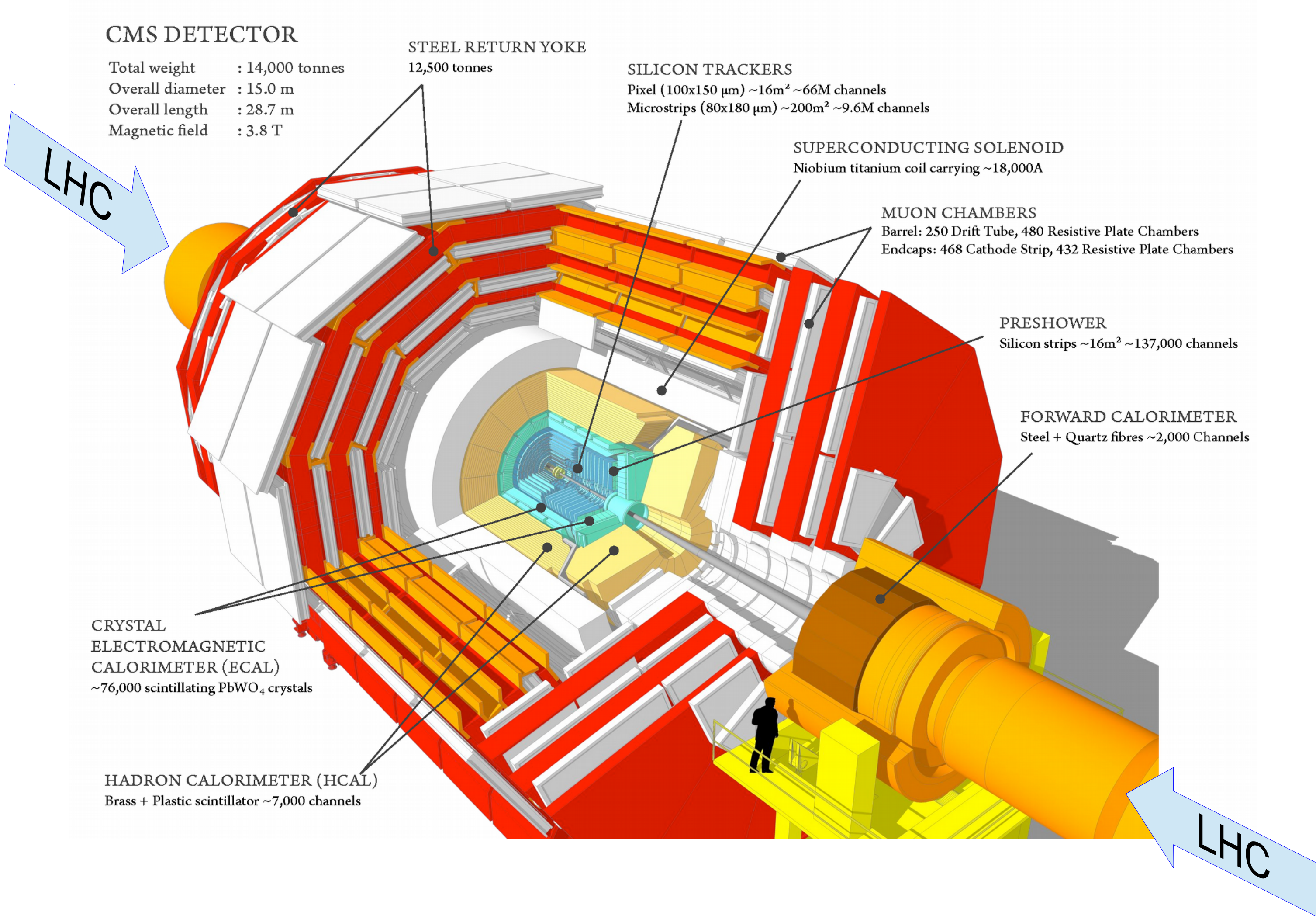


CERN’s accelerator complex.

CMS Detector

Magnetic filed: 3.8T
Tracking: |η|<2.5
Central calorimeter: |η|<3
Forward calorimeter: 3<|η|<5

$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



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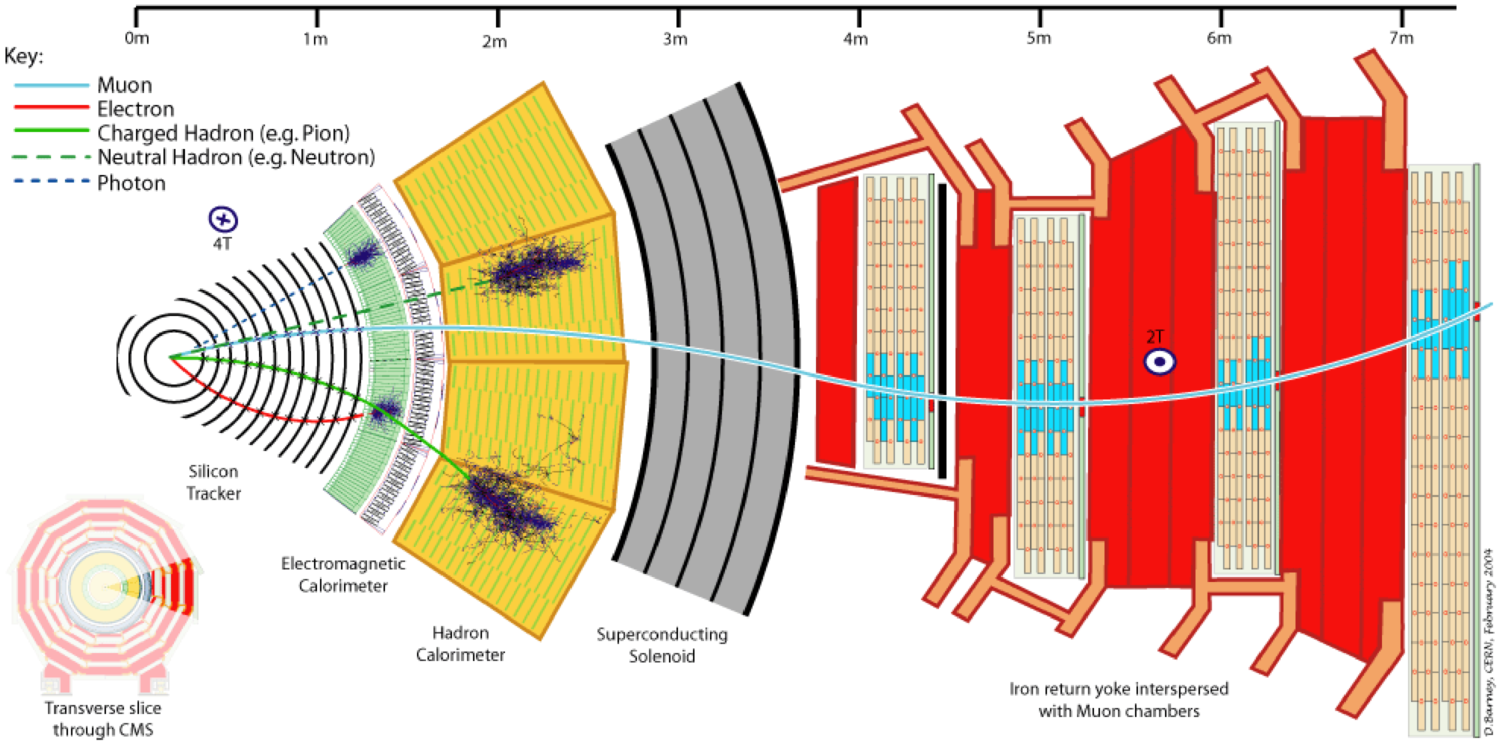
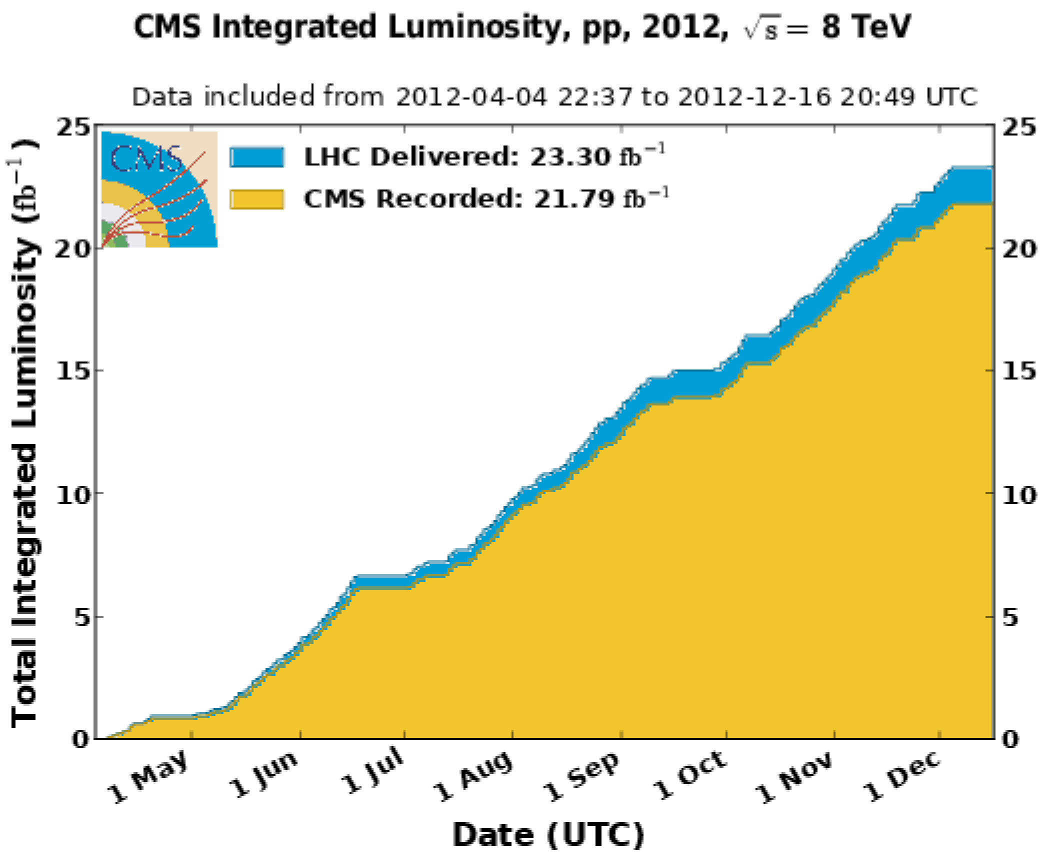


Slice of CMS
(Compact Muon Solenoid)

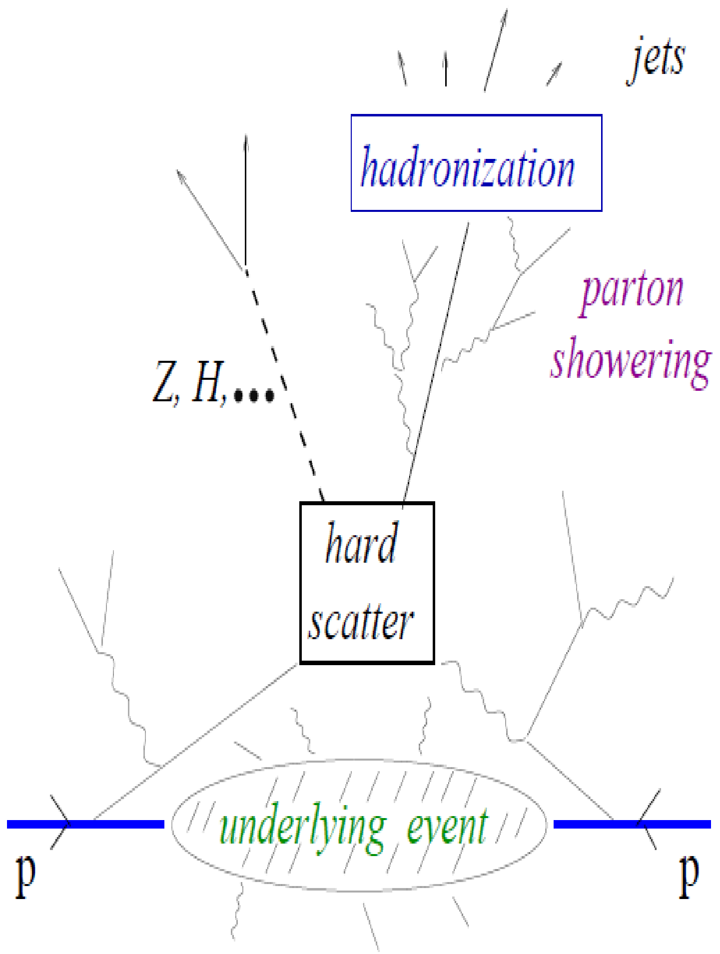
CMS Detector

High data taking efficiency.

Year	√s	$\mathcal{L}_{LHC}(fb^{-1})$	$\mathcal{L}_{CMS}(fb^{-1})$
2010	7	0.442	0.408
2011	7	6.13	5.55
2012	8	23.30	21.79
2015	13	4.22	3.81
2016	13	41.07	37.82



Quantum Chromodynamics



Jets (streams of particles)

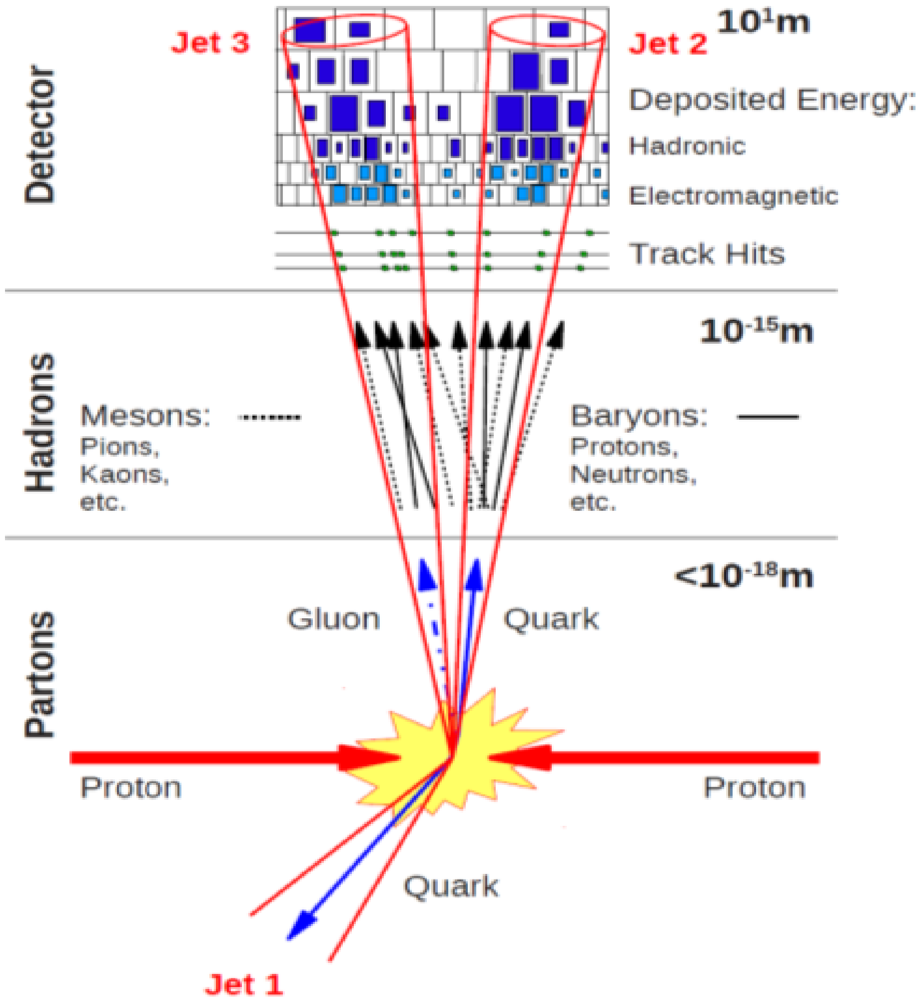
- Hard scattering is described by perturbative Quantum Chromodynamics (pQCD).
  - Quarks are assumed to behave as free particles.
  - Assymptotic behaviour of the strong coupling constant (α_s).
- Factorization theorem:

PDF x pQCD

$$\sigma^{hh} \sim \sum_{ij} dx_1 dx_2 f_i(x_1, \mu_f^2) f_i(x_2, \mu_f^2) \hat{\sigma}(x_1, x_2, Q^2/\mu_f^2)$$

μ_f: factorization scale. Arbitrary cut-off parameter.

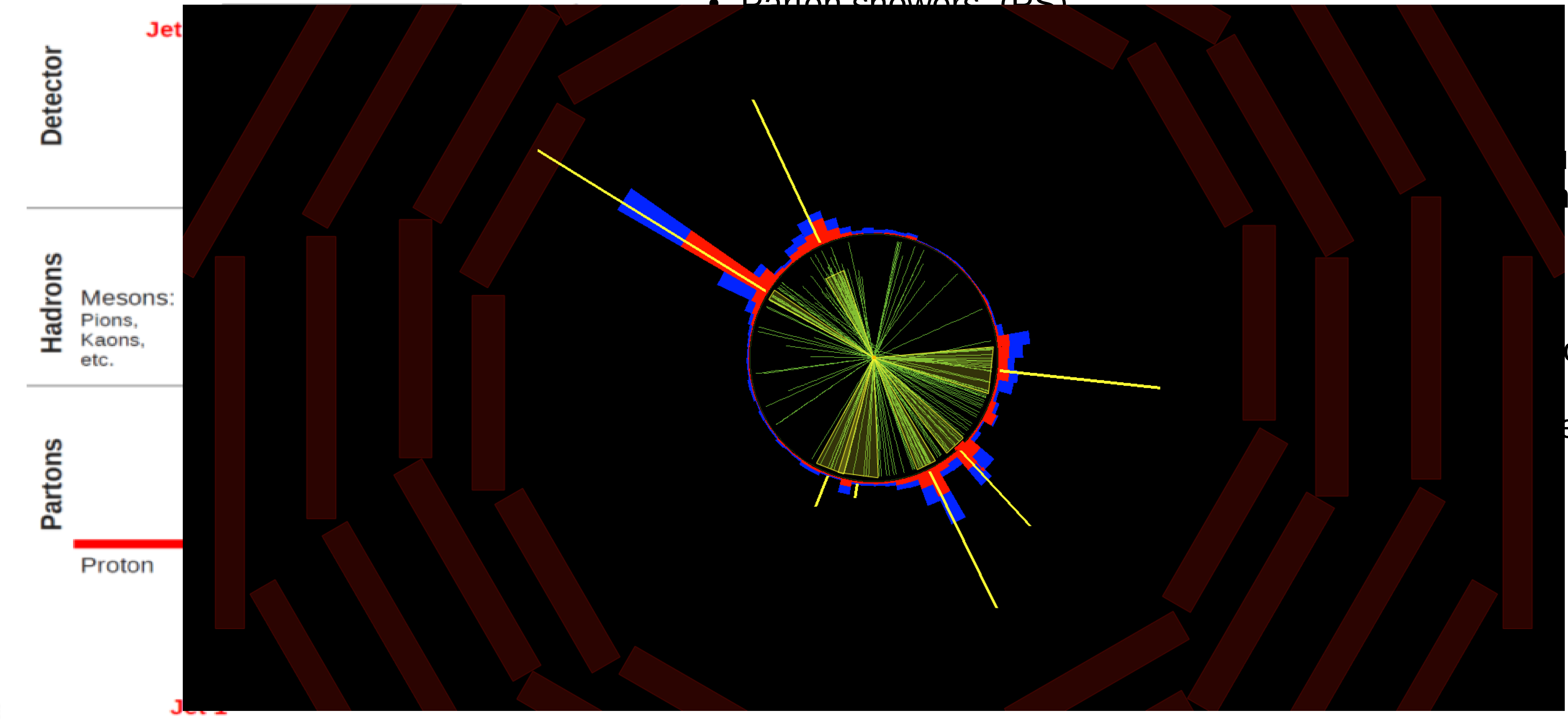
Quantum Chromodynamics



- Parton showers. (PS)
  - Quarks emit gluons, gluons split into quarks...
  - This procedure continues until partons loose enough energy and the strong coupling becomes large enough to form hadrons.
- Hadronization: (HAD)
  - Quarks form hadron that interact with matter (detector).
- PS and HAD are simulated with models that are described in HERWIG and PYTHIA.
- Jet are the signatures of quarks and gluons.

Quantum Chromodynamics

- Parton showers (PS)



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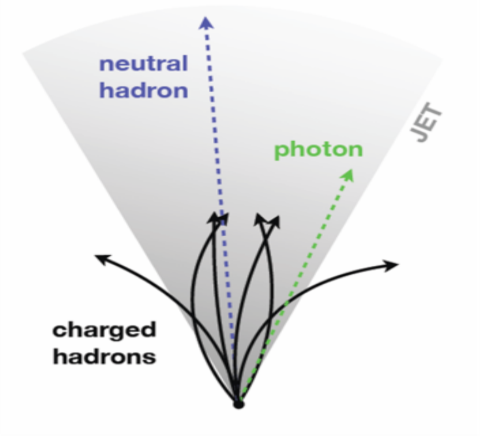
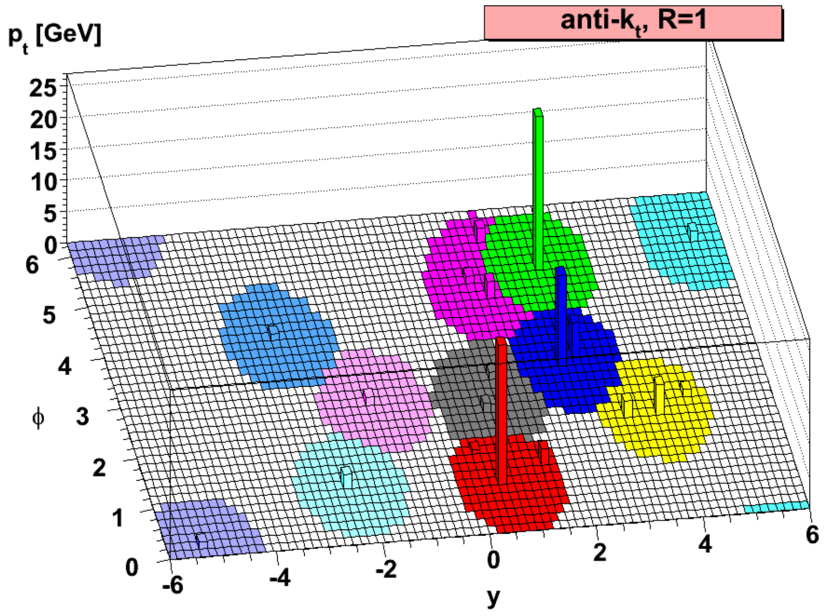
Jet Reconstruction and Calibration

Particle Flow Jets (PF Jets): Combines information from all sub-detectors to reconstruct and identify all stable particles used in jets.

Anti-k_T clustering algorithm: Infrared and collinear safe. Used with various values of R.





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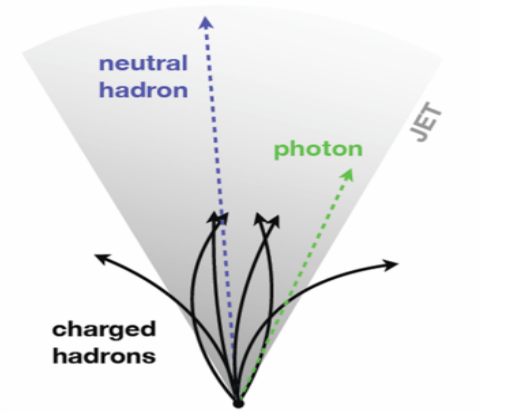
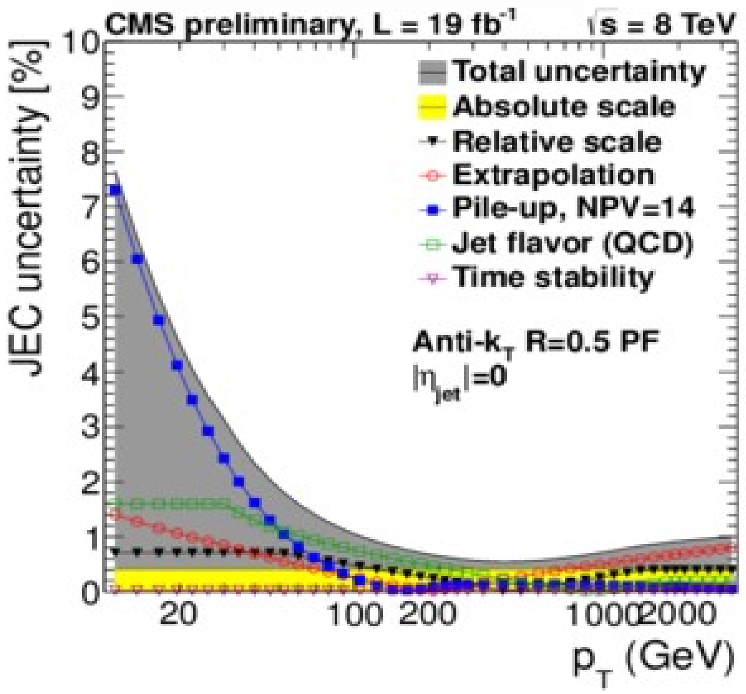


Anti-k_T clustering algorithm: Infrared and collinear safe. Used with various values of R.

Factorized JEC approach in CMS

Calibrated Jet = Raw Jet × Offset Correction (pile-up) × Relative Correction (vs η) × Absolute Correction (vs pT)

JINST 6 (2011) 11002
CMS DP2012-006
CMS DP2013-033

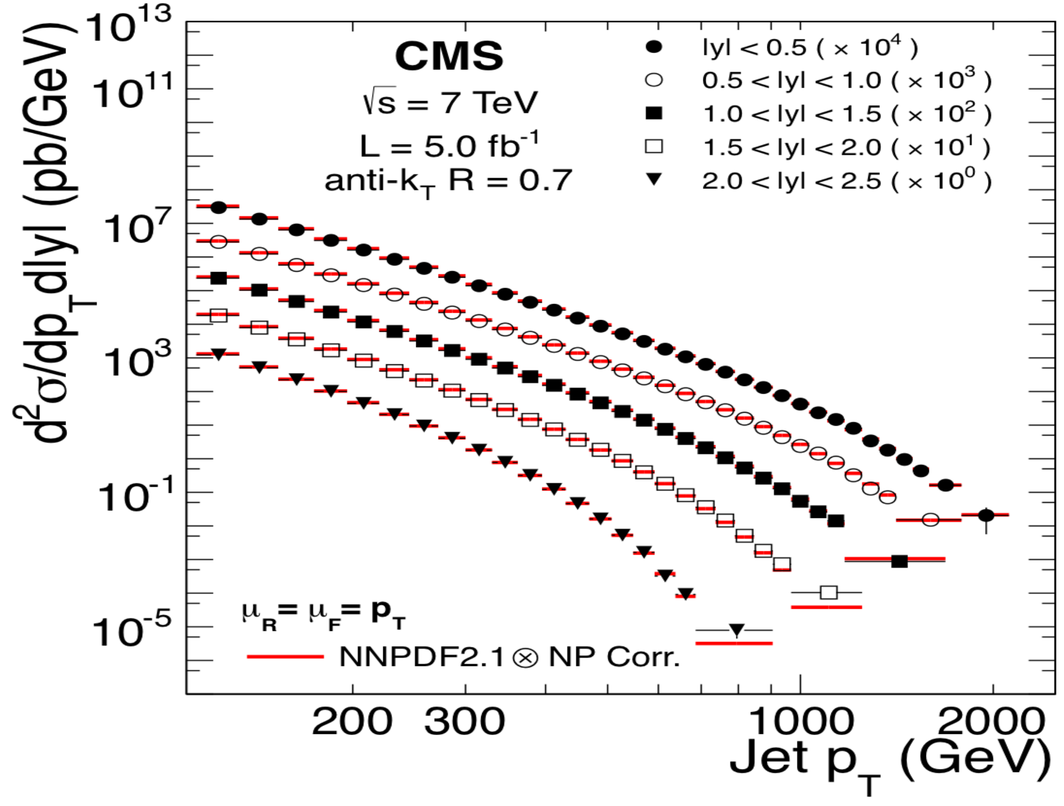


Inclusive jet cross section and strong coupling 7 TeV

- Measurement of double differential cross section on p_T and y as a function of p_T.
- Comparison with theoretical calculations using NNPDF2.1.
- Jets up to |y|=2.5, p_T=2TeV. Five rapidity bins of Δ|y|=0.5.
- p_T range 114 GeV – 2TeV

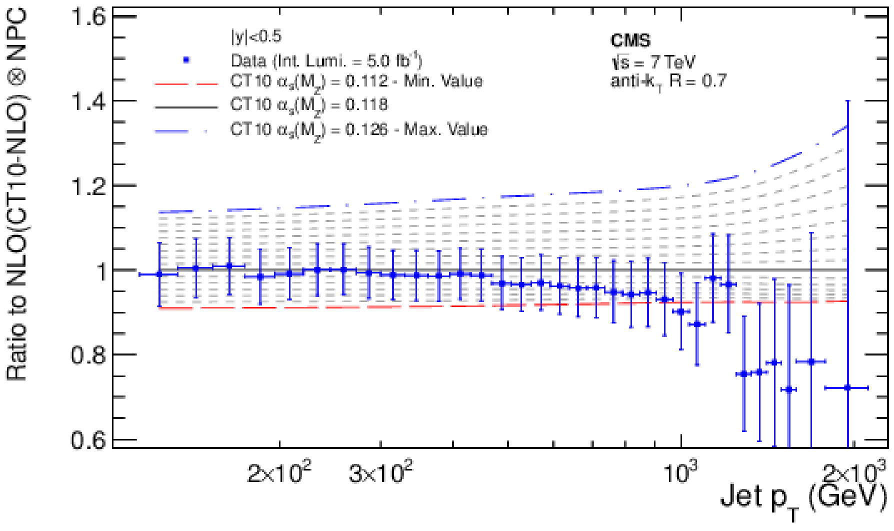
  Main systematic uncertainties:
  - JES 10-20%
  - Unfolding 3-4%
  - Luminosity 2.2%
  - Residuals 1%

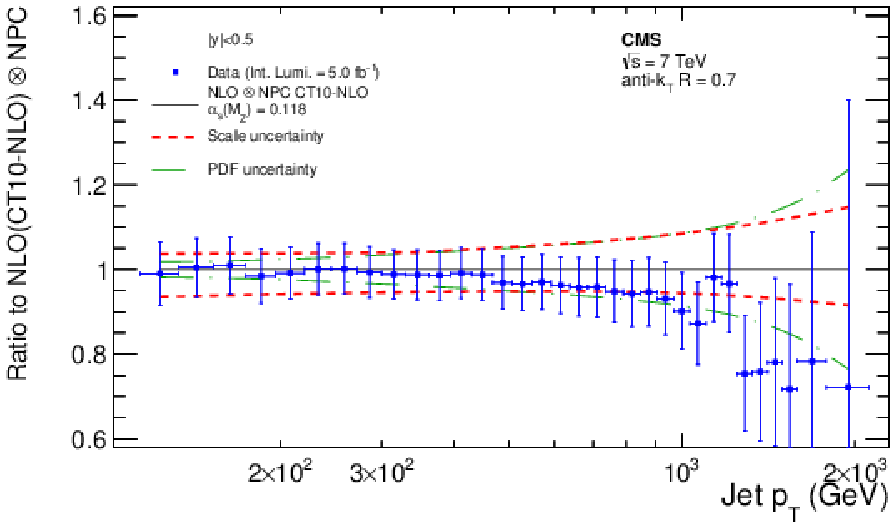
$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{\epsilon \cdot \mathcal{L}_{\text{eff}}} \frac{N_{\text{jets}}}{\Delta p_T (2 \cdot \Delta|y|)}$$



PRD 87,112002 (2013)

- Bottom left: Ratio of data (and theory with various α_s values) to theoretical calculation with $\alpha_s(M_Z)$=0.1180.
- CT10-NLO PDF is used with range of α_s **0.112-0.126.**
- As expected the cross section is sensitive to the variations of α_s.
- Theory describes well the data in the whole range of p_T.





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Inclusive jet cross section and strong coupling 7 TeV

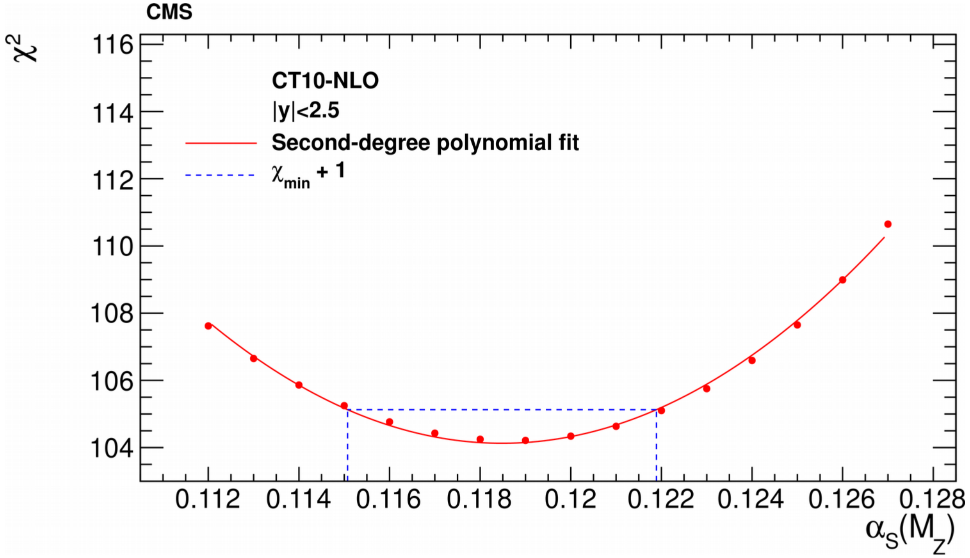
- Fitted regions: **114 – 2116 GeV**

  133 data points.

- The main result was extracted using CT10-NLO PDF. Data used in fit combined by all the rapidity regions (0<|y|<2.5).

- Scale and PDF uncertainties are the dominant in the measurement.

- The result is compatible with the world average:
  $\alpha_s(M_Z) = 0.1184 \pm 0.0007$



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$$\boldsymbol{\alpha_s(M_Z) = 0.1185 \pm 0.0019\,(\mathrm{exp.}) \pm 0.0028\,(PDF) \pm 0.0004\,(NP)\,^{+0.0053}_{-0.0024}\,(scale)}$$
$$\boldsymbol{= 0.1185\,^{+0.0065}_{-0.0041}}$$

$$\boldsymbol{\chi^2/ndof = 0.8}$$

3-jet to 2-jet cross section ratio and α_s 7 TeV

$$R_{32}(<p_{T1,2}>) = \frac{\sigma_3}{\sigma_2} = \frac{\sigma(pp \rightarrow njets + X; n \geq 3)}{\sigma(pp \rightarrow njets + X; n \geq 2)},$$

$$<p_{T1,2}> = Q = \frac{p_{T1} + p_{T2}}{2}$$

Average dijet p_T as scale

Data Selection:

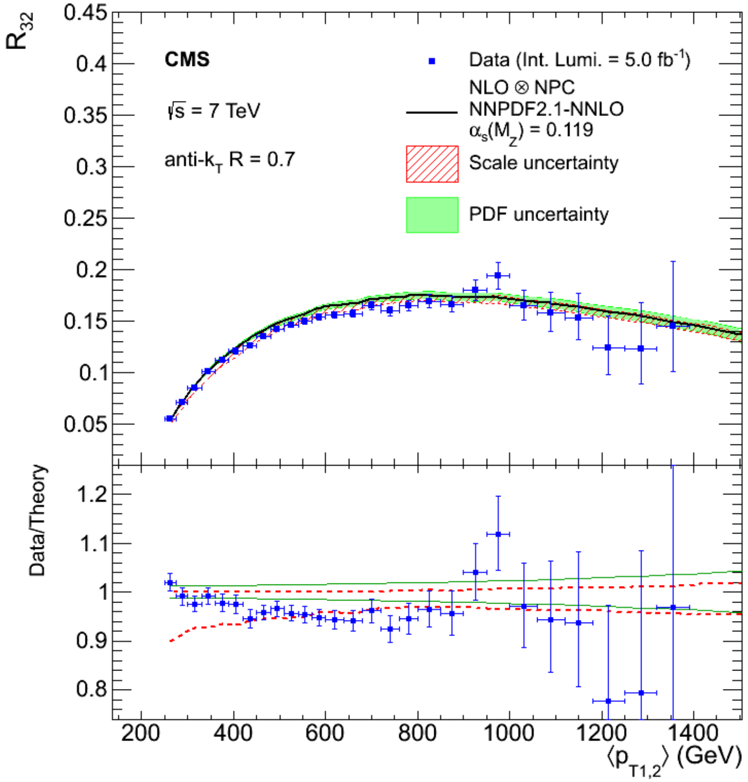
Jet p_T>150 GeV

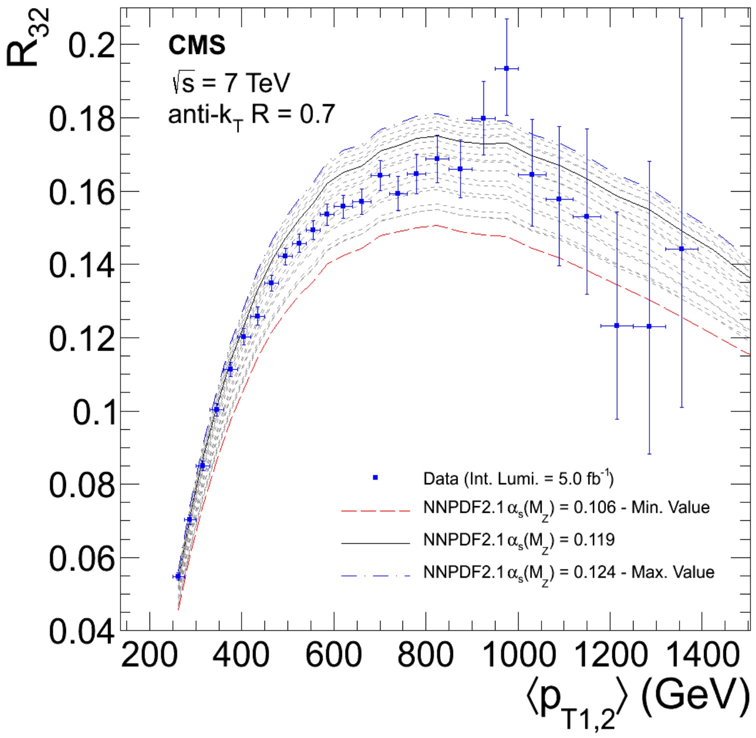
Rapidity |y|<2.5

Advantages of ratio:

Ratio reduces both experimental and theoretical uncertainties.

EPJC (2013)73:2604



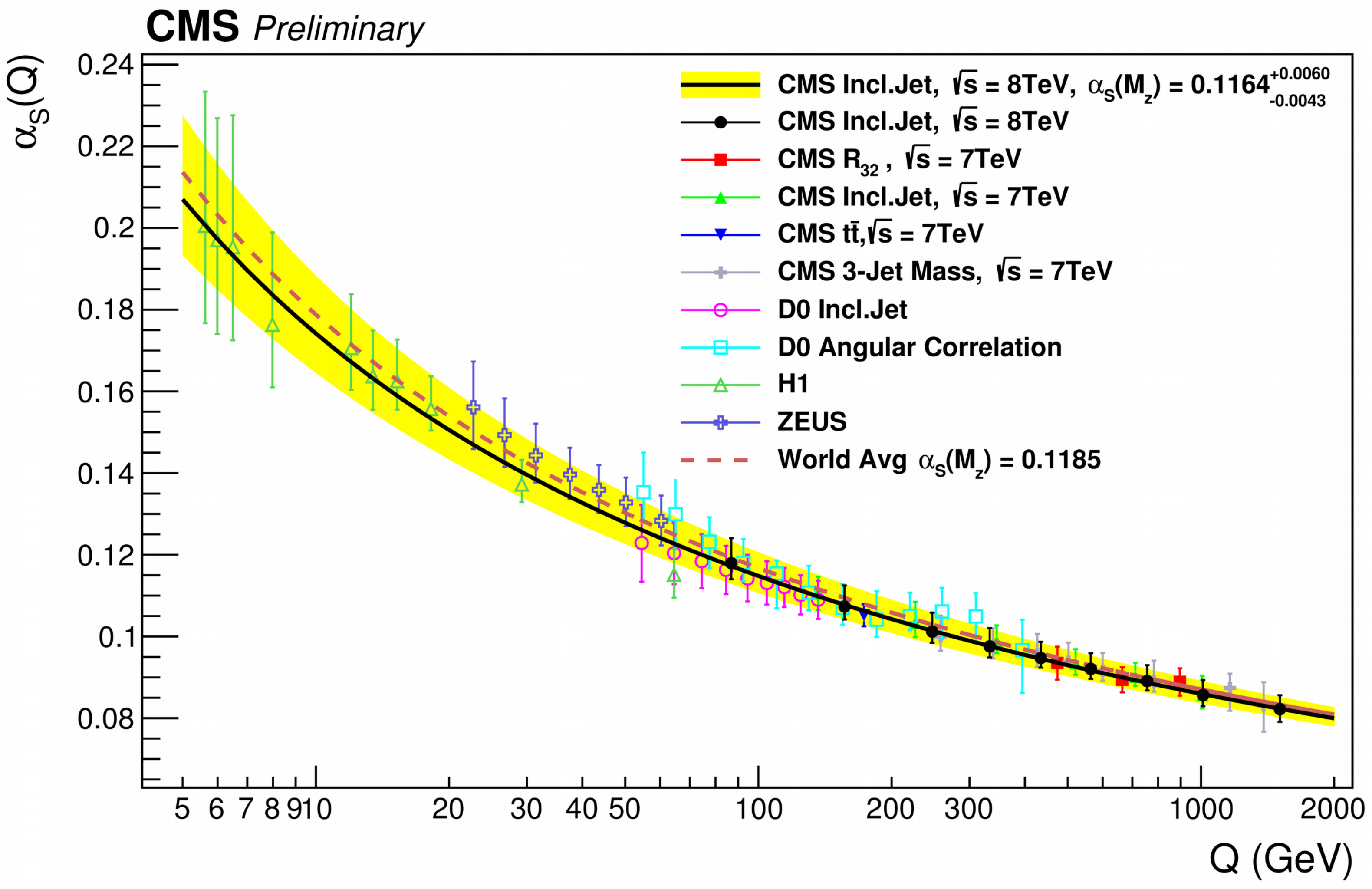


Using NNPDF2.1NNLO PDF set we get the following result:

$$\alpha_s = 0.1148 \pm 0.0014(\exp) \pm 0.0018(PDF) \pm 0.0050(theory)$$

$$\chi^2 / ndof = 1.1$$

The running of the α_s



No deviation from the QCD predictions is observed.

Dijet azimuthal decorrelations 8TeV

• Measurement of the normalized differential cross section

$$\frac{1}{\sigma_{Dijet}}\frac{d\sigma}{d\Delta\phi_{Dijet}}$$

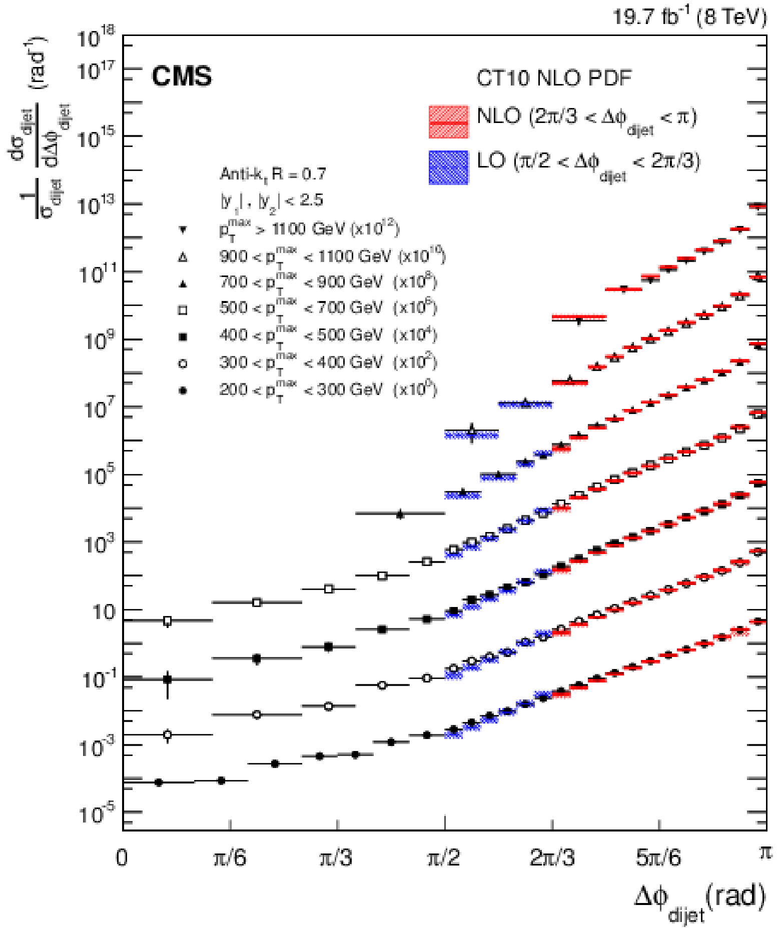
as a function of $\Delta\phi_{Dijet} = |\phi_{jet1} - \phi_{jet2}|$

• Jets with p_T>100GeV and |y| < 2.5

• Comparison with NLOJet++ (fastNLO) calculations with various PDF sets. (3-jet NLO)

• Comparison with various Monte Carlo generators matched to PS.

• Probe multijet events by measuring the angular separation of the two leading jets.



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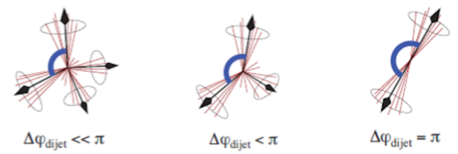
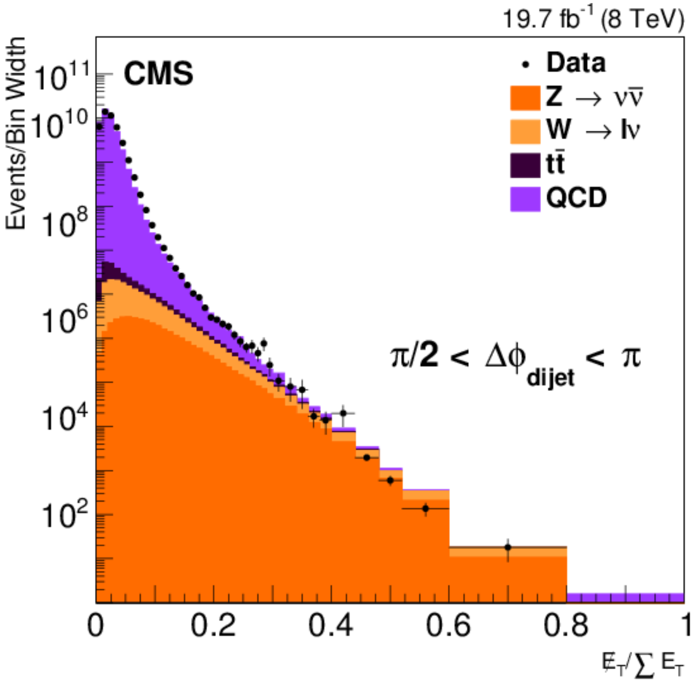
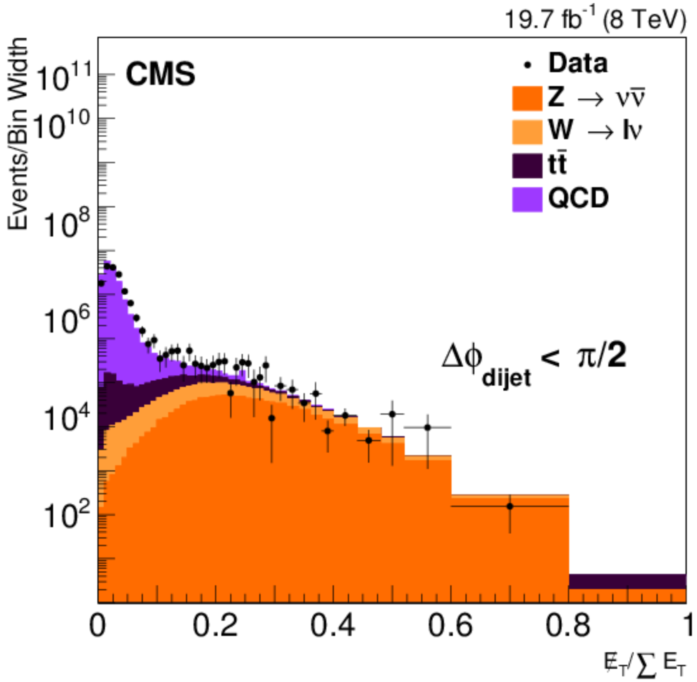


Dijet azimuthal decorrelations 8TeV

- Background of the measurement: Z(vv)+Jets, W(lv)+Jets and tt.

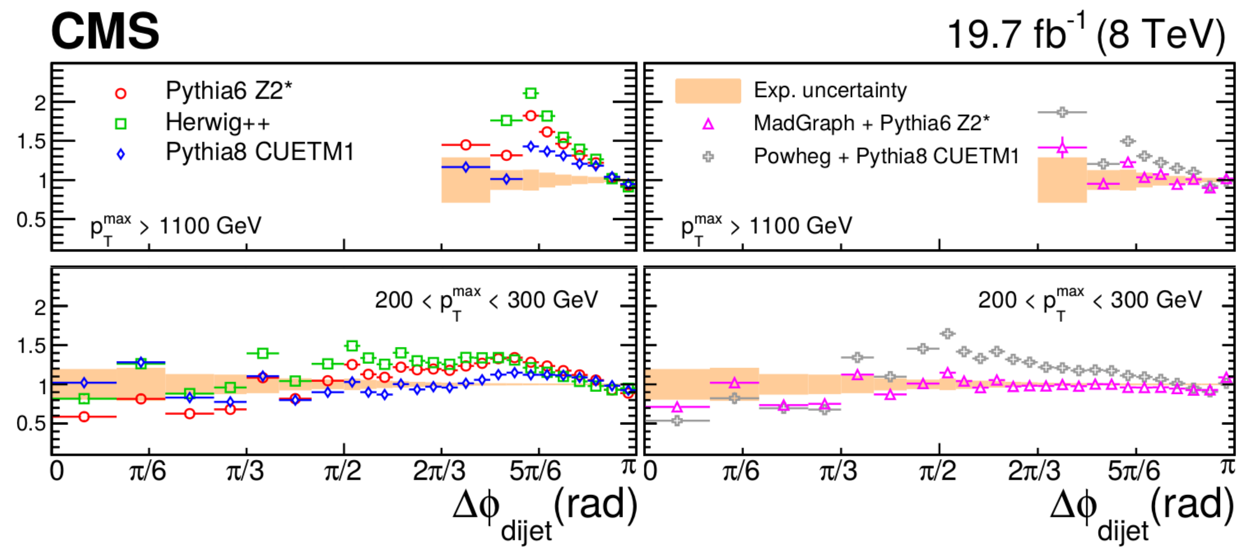


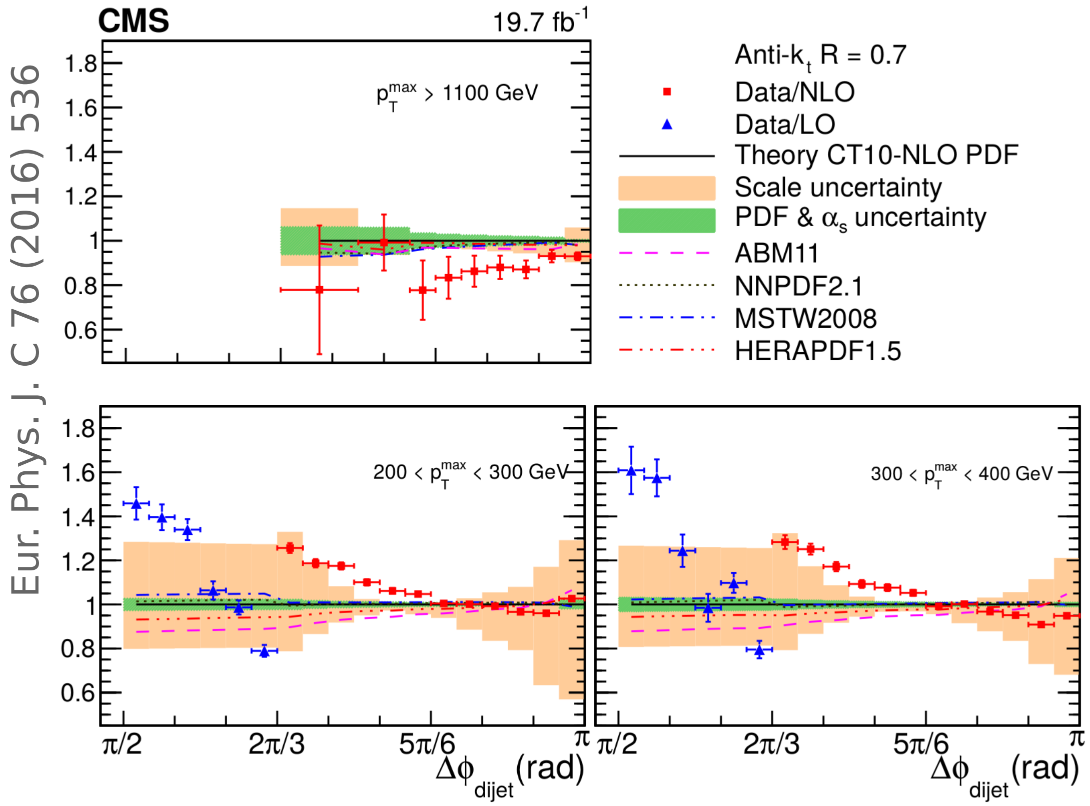


- Rejection of background using missing energy over the sum of transverse energy.
- Event selection: $\not{E}_{\mathrm{T}}/\sum E_{\mathrm{T}} < 0.1$
- Rejects **~0.7%** of the data sample.

Dijet azimuthal decorrelations 8TeV

- Various PDF sets tested, all agree with each other.
- 3-jet calculations good agreement in region $\Delta\phi_{Dijet} > 5\pi/6$
- Deviations at small $\Delta\phi_{Dijet}$ of NLO and LO region.





- Comparison with various MC generators matched to PS.
- Madgraph gives the best description

Inclusive jet differential cross sections 13TeV

- Measurement of double differential cross section on p_T and y as a function of p_T.
- Comparison with fixed order pQCD and MC generators matched to PS. Using various tunes and PDF sets.
- Jets up to $|y|=4.7$, $p_T=2$TeV. Six rapidity bins of $\Delta|y|=0.5$ + one $\Delta|y|=1.5$
- Theory describes data within uncertainty.

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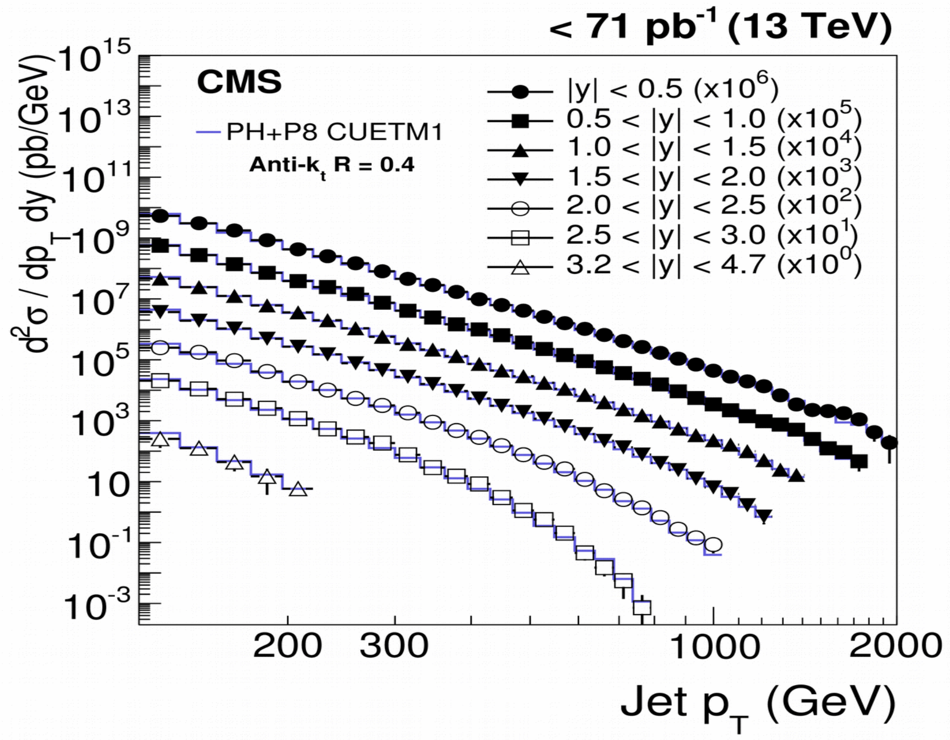

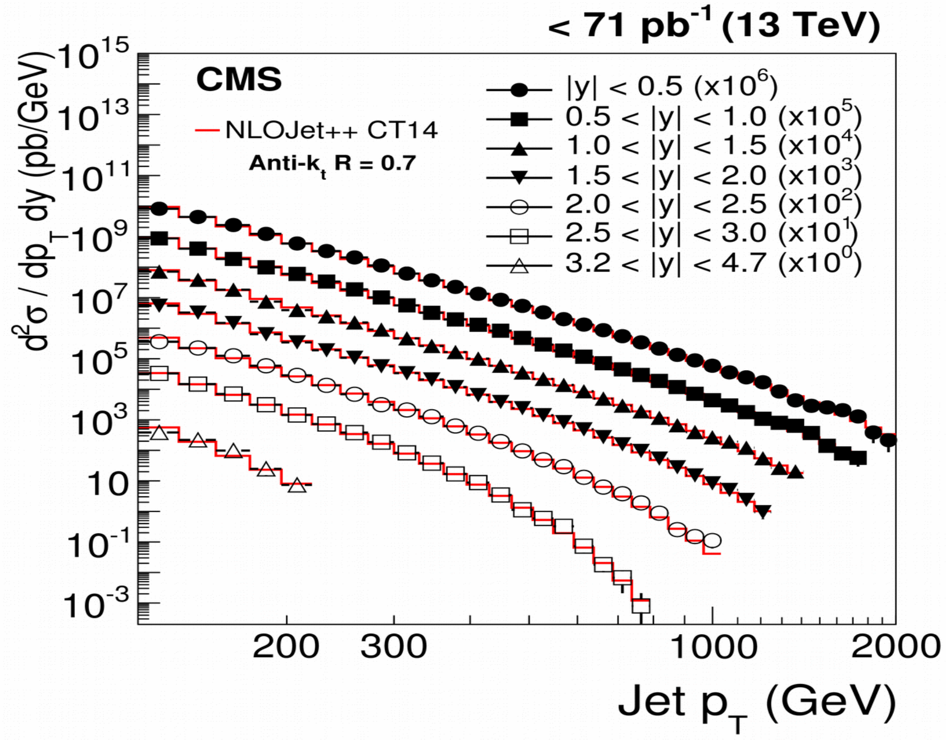

Inclusive jet differential cross sections 13TeV

- Measurement of double differential cross section on p_T and y as a function of p_T.
- NLO calculations describe data within uncertainty.
- LO generators exhibit significant discrepancies. Shape of HERWIG++ in agreement with data for all rapidity bins while PYTHIA8 differs for the outer rapidity bins.

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

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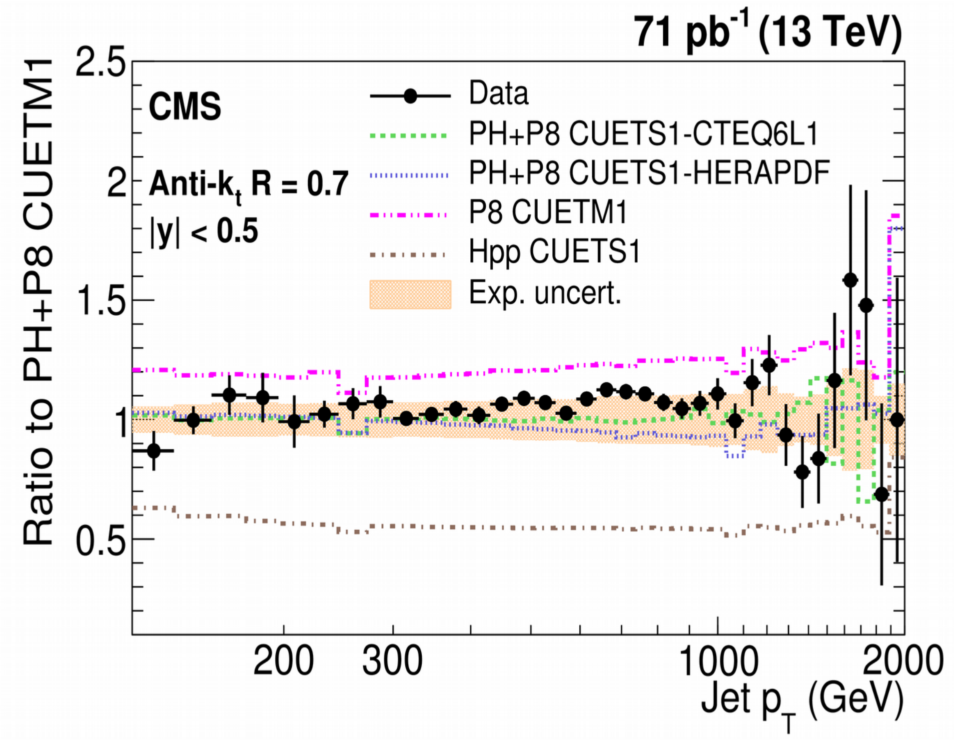

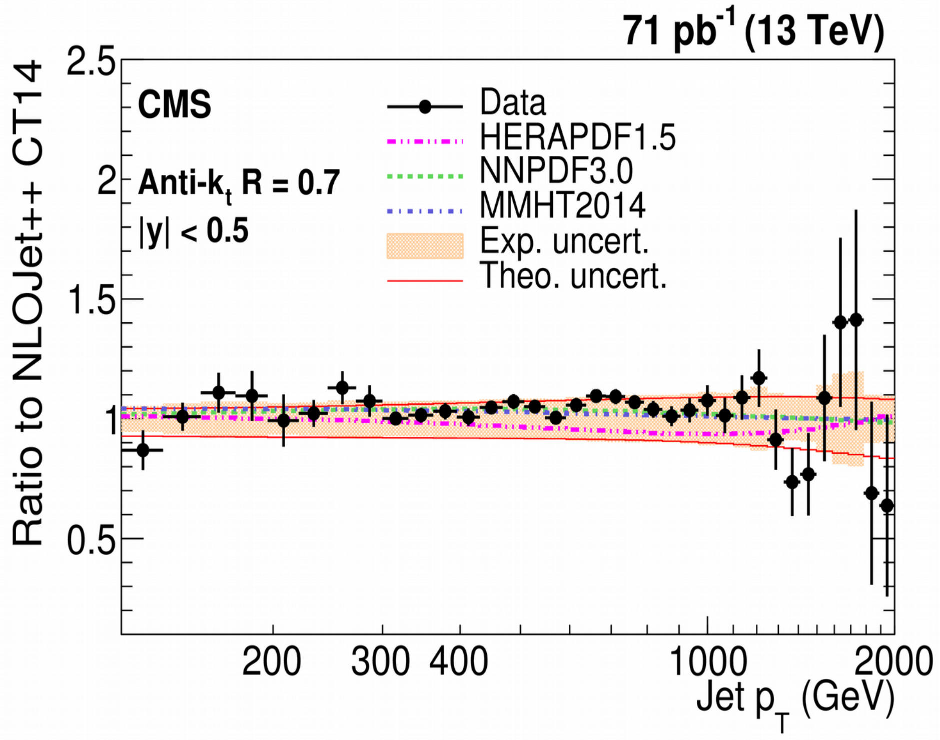

Inclusive jet differential cross sections 13TeV

- Measurement of double differential cross section on p_T and y as a function of p_T.
- Comparisons with fixed order NLOJet++ shows that cross sections for the larger jet cone size is described better.
- NLO generator POWHEG interfaced to PYTHIA8 describes cross sections for both jet cones well.

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

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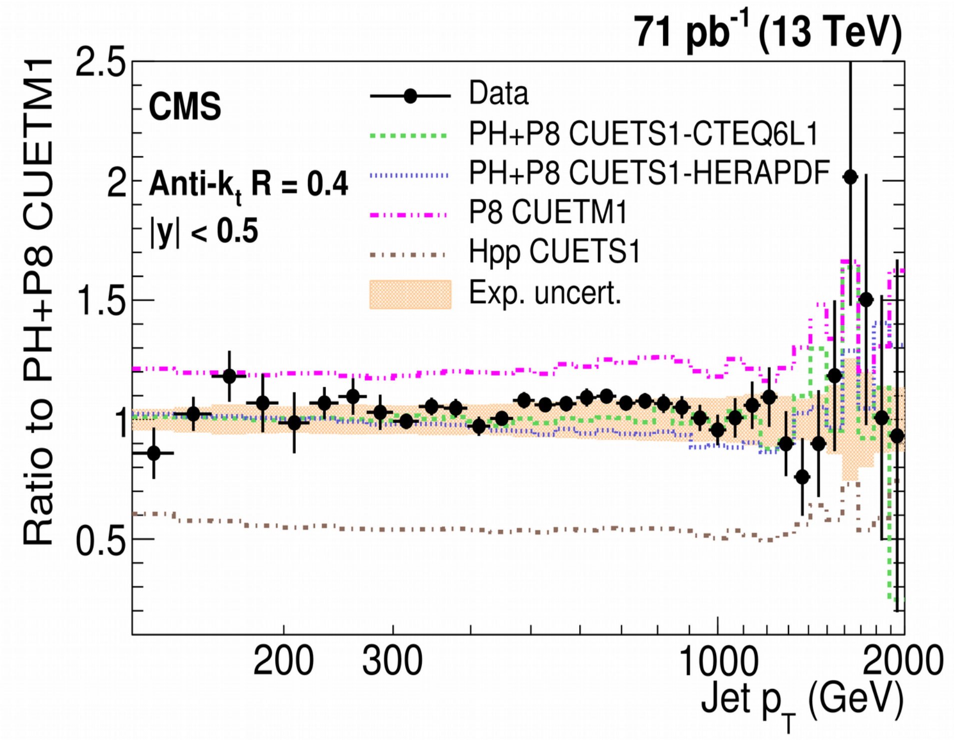
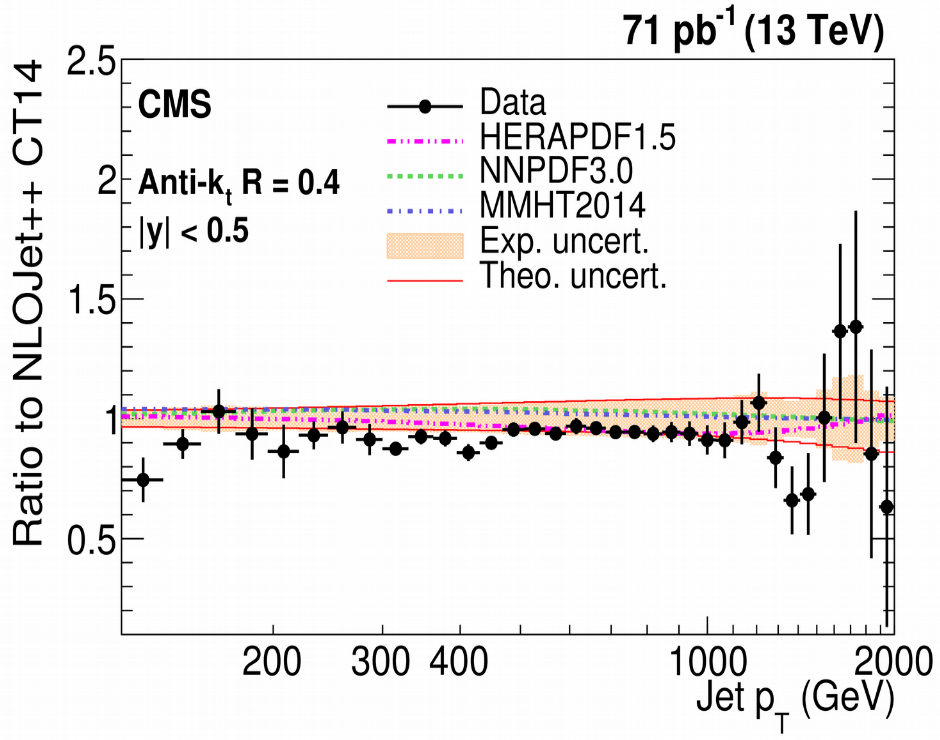
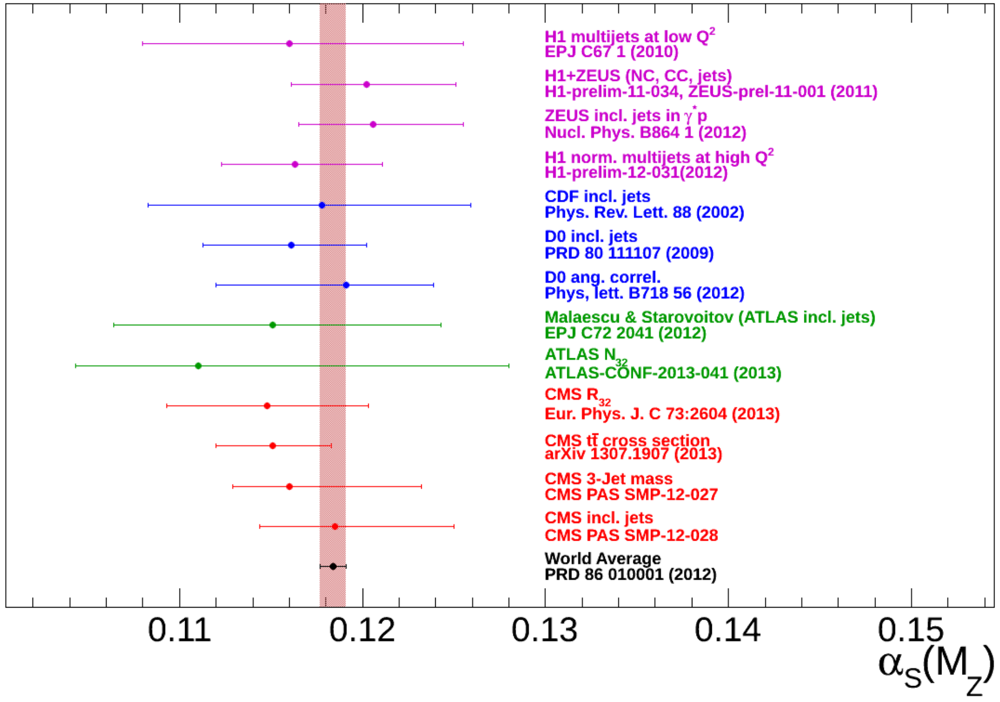




Conclusions

- Excellent understanding of jet reconstruction and calibration.
- High performance of data collecting leads to precision measurements
- Various jet measurements improve our understanding of QCD.
- Inclusive jet cross-section measurement is presented from 7 and 13 TeV data.
- Multijet cross section measurements at 7 and 8 TeV.
- Strong coupling extraction at 7 and (8 TeV).
- We performed measurements of the strong coupling constant at Q~1.5TeV region and no deviations from the QCD predictions observed.
- Currently the theoretical uncertainties being the dominant ones.



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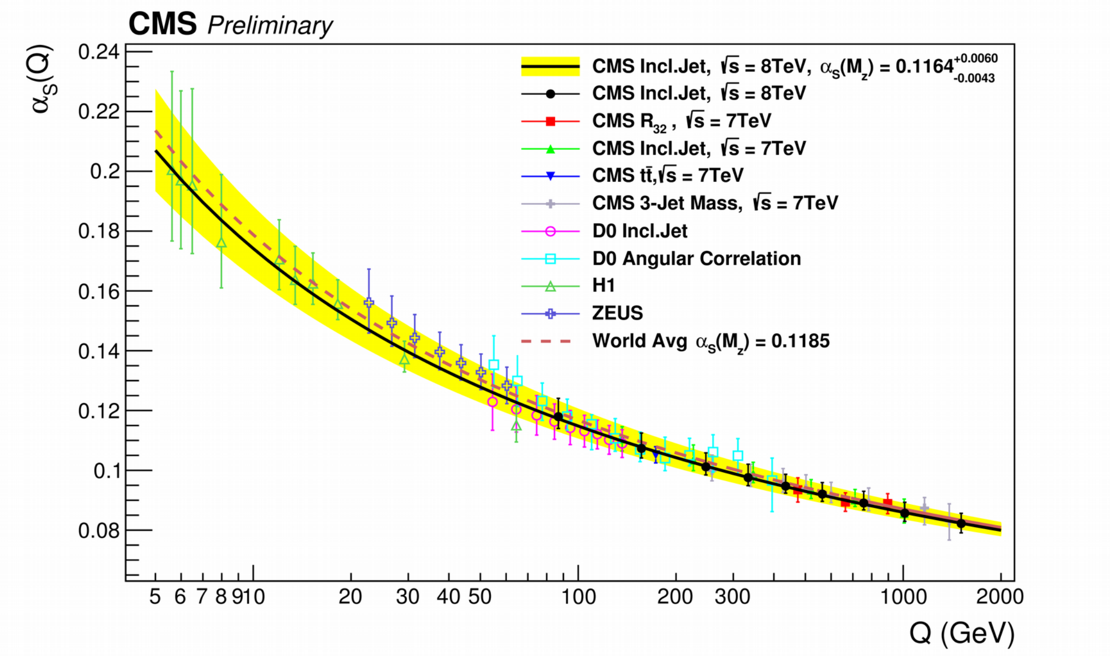
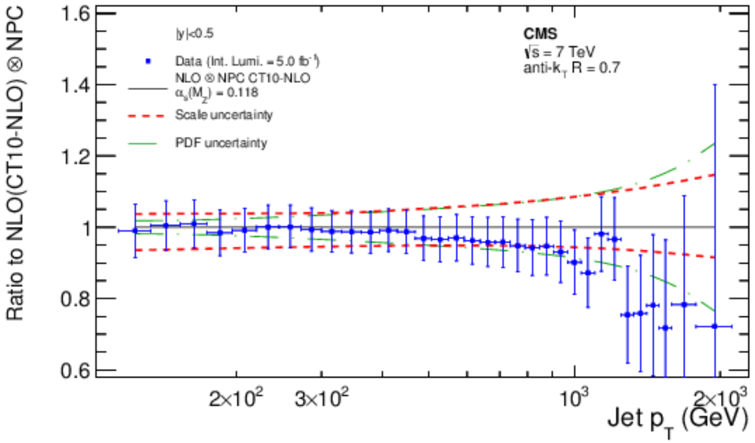
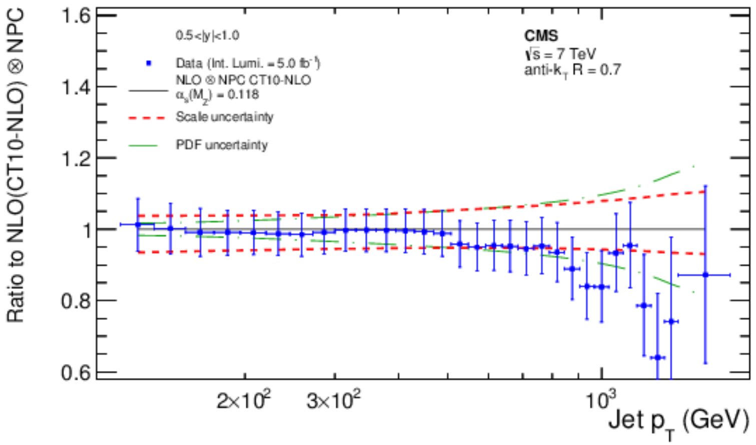
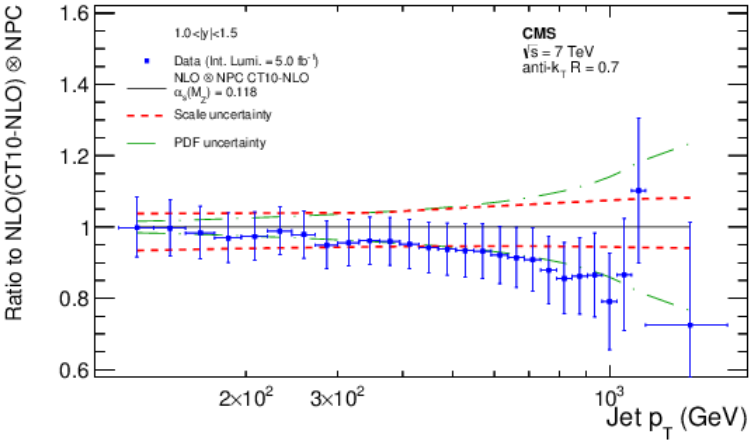


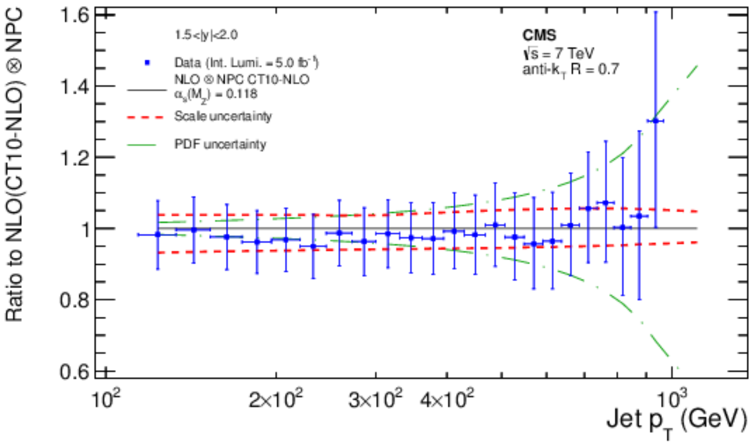
SPARE SLIDES

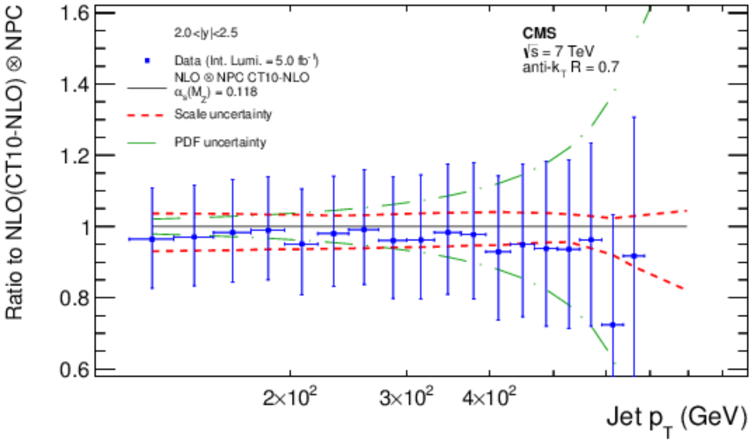
Inclusive jet cross section and strong coupling 7 TeV



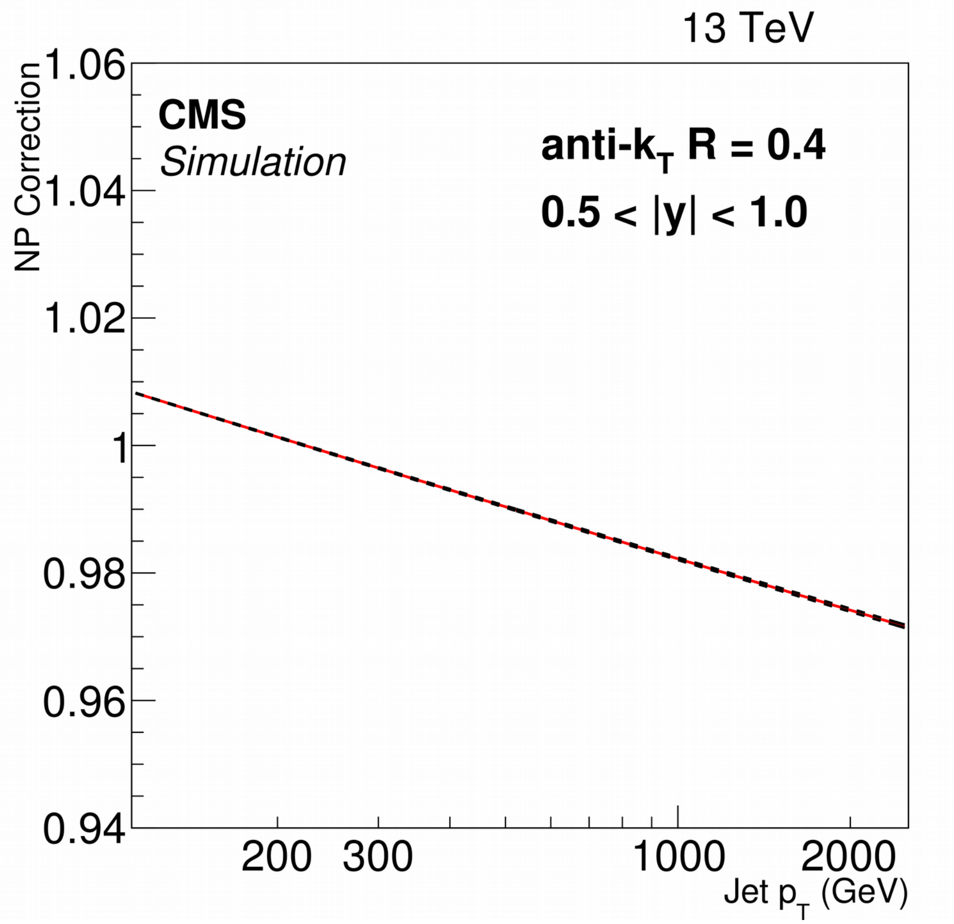


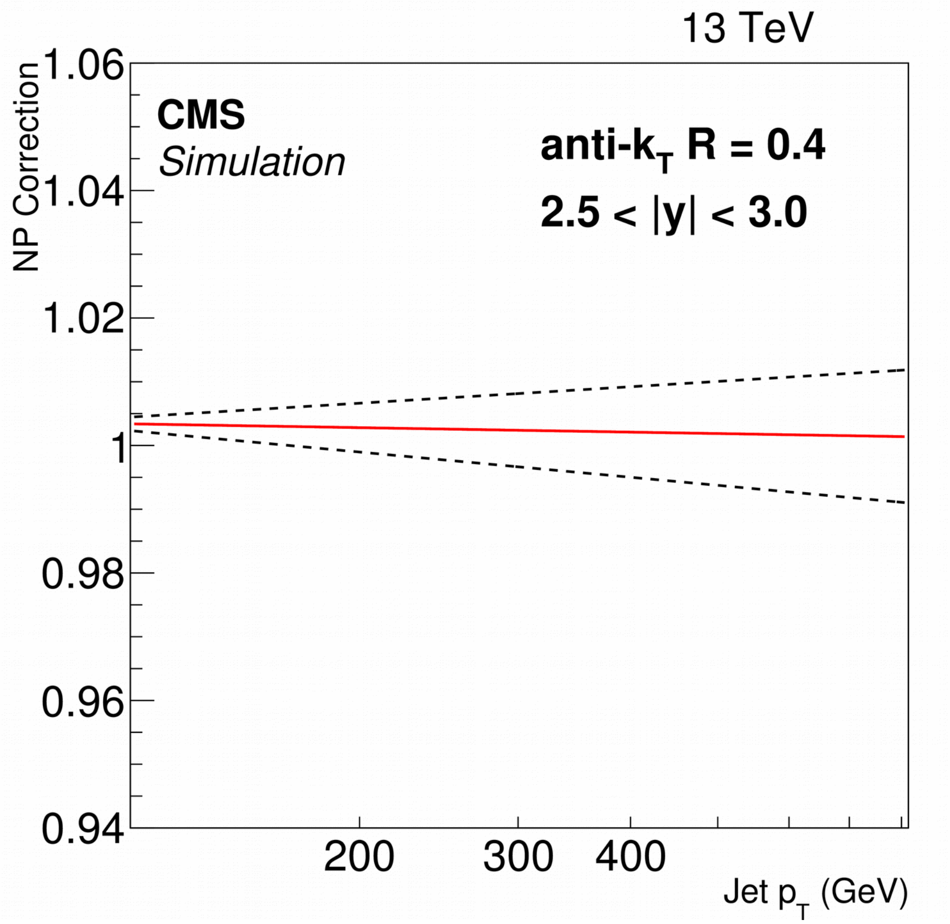






NP corrections 13TeV





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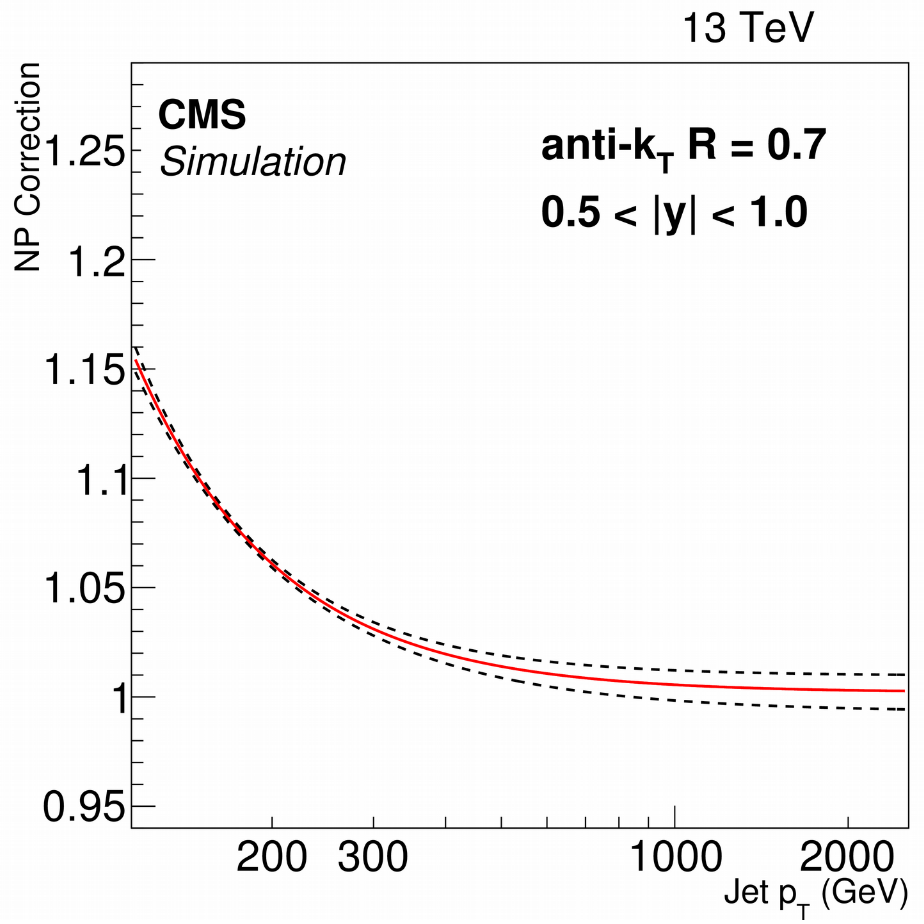

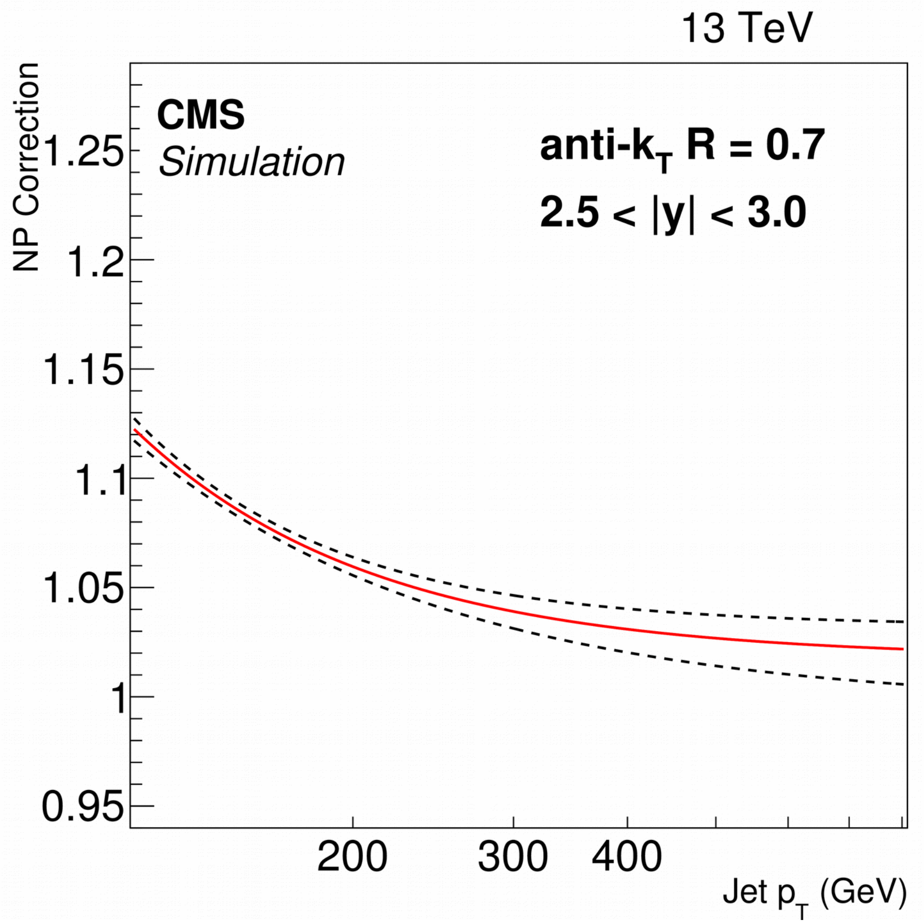

3-jet to 2-jet cross section ratio and α_s 7 TeV