Jet Measurements at CMS

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On behalf of the CMS Collaboration

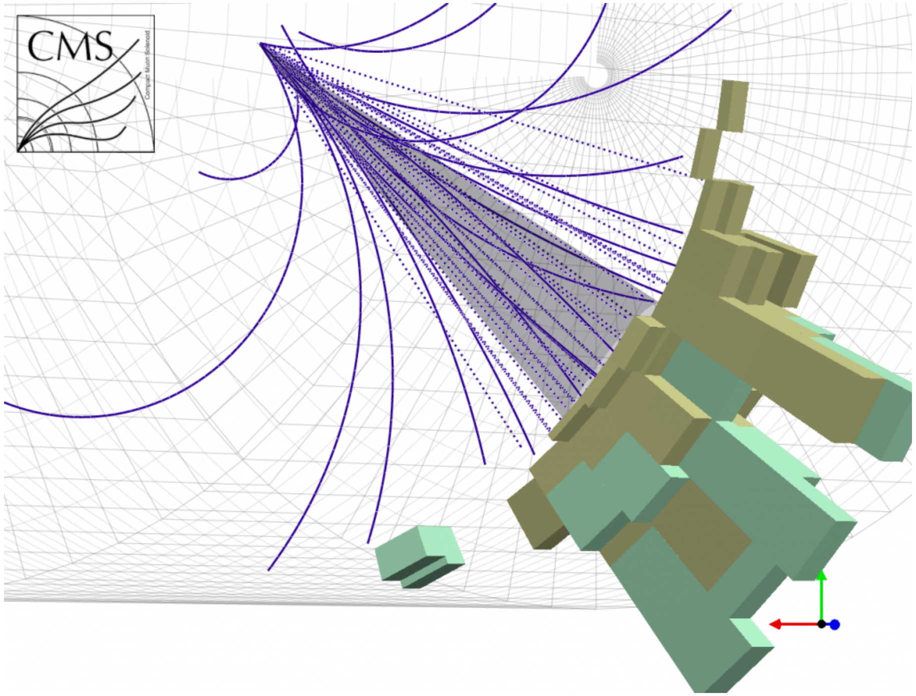
DIS 2013

Outline

- CMS detector
  - Detection techniques for jets
- CMS has produced a large amount of QCD measurements on the LHC Run 1 data sample
  - Jet inclusive spectra
  - Di-jet mass
  - 3 over 2 jet ratio
  - Event shapes

Jet reconstruction

- Jets are reconstructed with the anti-kt algorithm
- The input of jet reconstruction is Particle Flow candidates
  - Particle flow reconstruction:
    - global event reconstruction
    - Identifies muons, electrons, taus, photons, charged hadron, neutral hadrons
    - Combines the information from all detectors



Jet energy scale

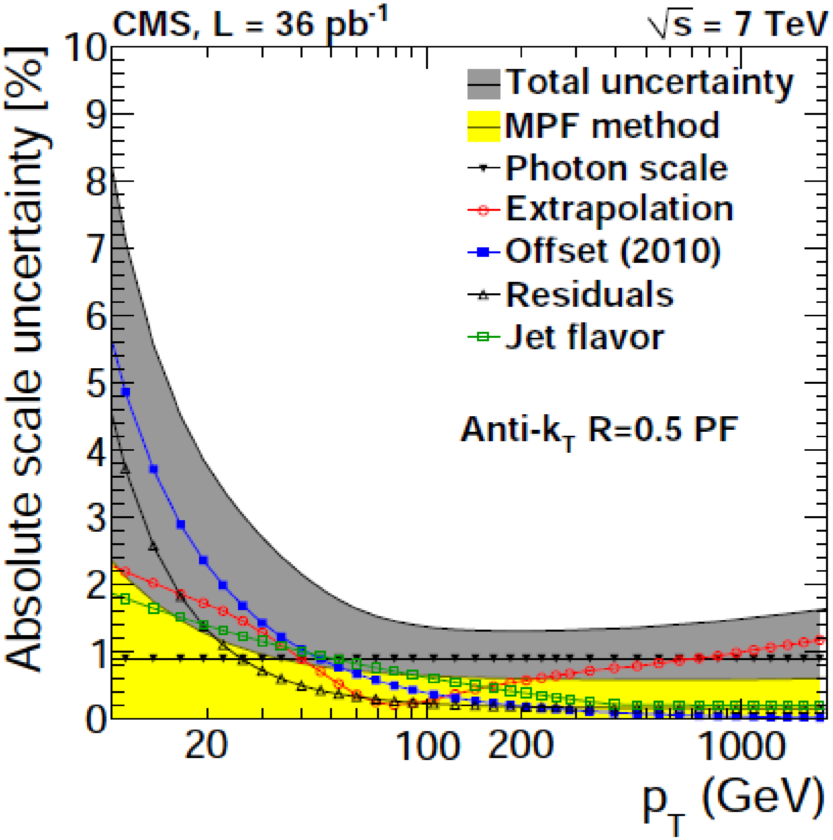
- We use a multi-step procedure to correct the energy of our jets

$$p_{\mu}^{cor} = \mathcal{C} \cdot p_{\mu}^{raw}. \qquad \mathcal{C} = C_{\text{offset}}(p_T^{raw}) \cdot C_{\text{MC}}(p_T', \eta) \cdot C_{\text{rel}}(\eta) \cdot C_{\text{abs}}(p_T'')$$

  - C_{offset} accounts for detector noise and pile-up
  - The method uses correction factors extracted from the full simulation of CMS, C_{MC}
  - Residual differences with respect to data are accounted for as further scaling factors
    - C_{rel} accounts for non-uniformity in eta. It is obtained applying on data and MC the di-jet balance method
    - C_{abs} accounts for residual absolute scale differences between data and MC. It is obtained applying on data and MC the γ+jet and Z +jet pT balancing
  - In this MC + residual method effects like the presence of additional radiation spoiling dijet or γ+jet and Z +jet balancing enter only at second order

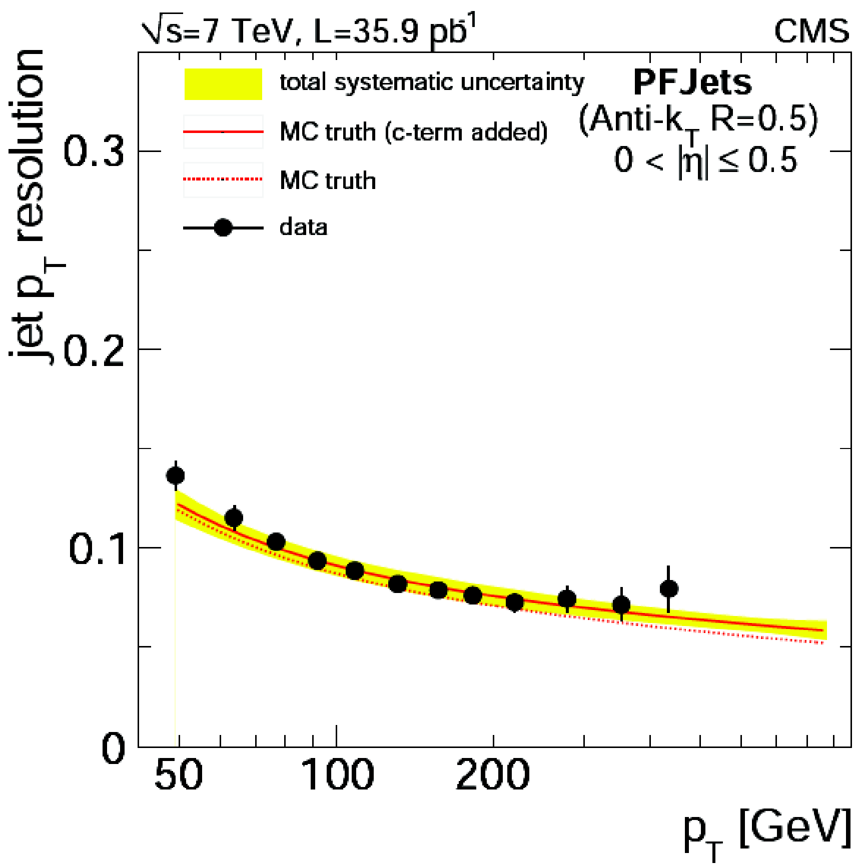
Jet energy scale

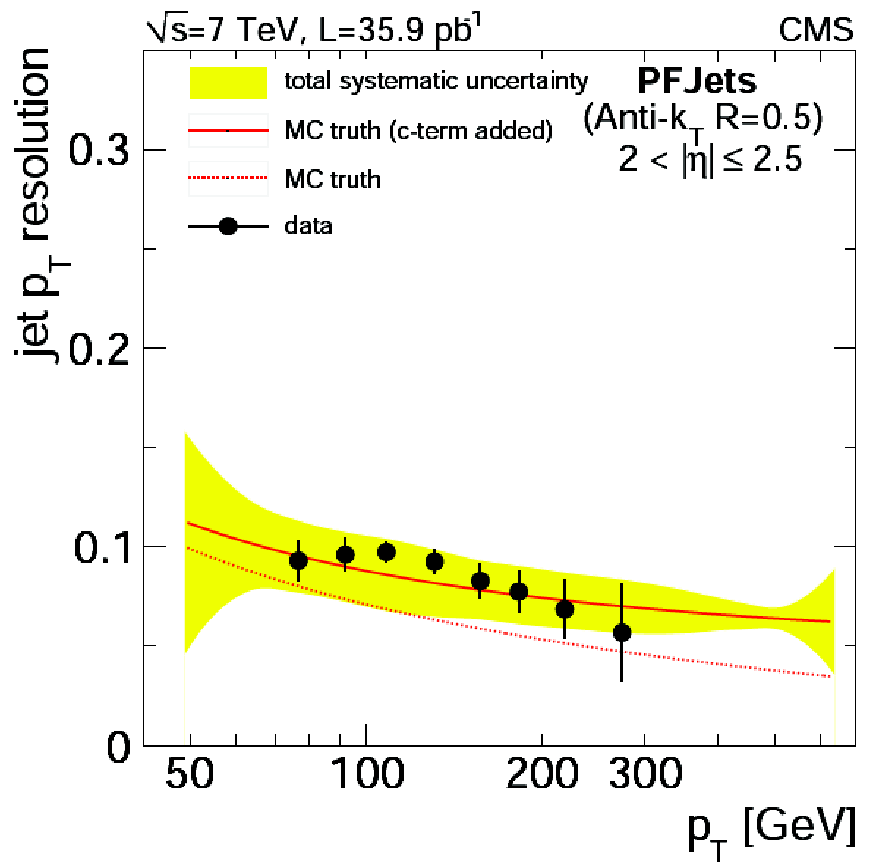
- Total systematic uncertainty on the energy scale for particle-flow jets
- The main sources of uncertainty are:
  - The photon energy scale, known at 1%
  - The relative response across detector regions
  - Pile-up effects
  - Extrapolations down to 0 for the additional activity in the balance methods
  - Dependency on jet flavor in the MC used



Jet energy resolution

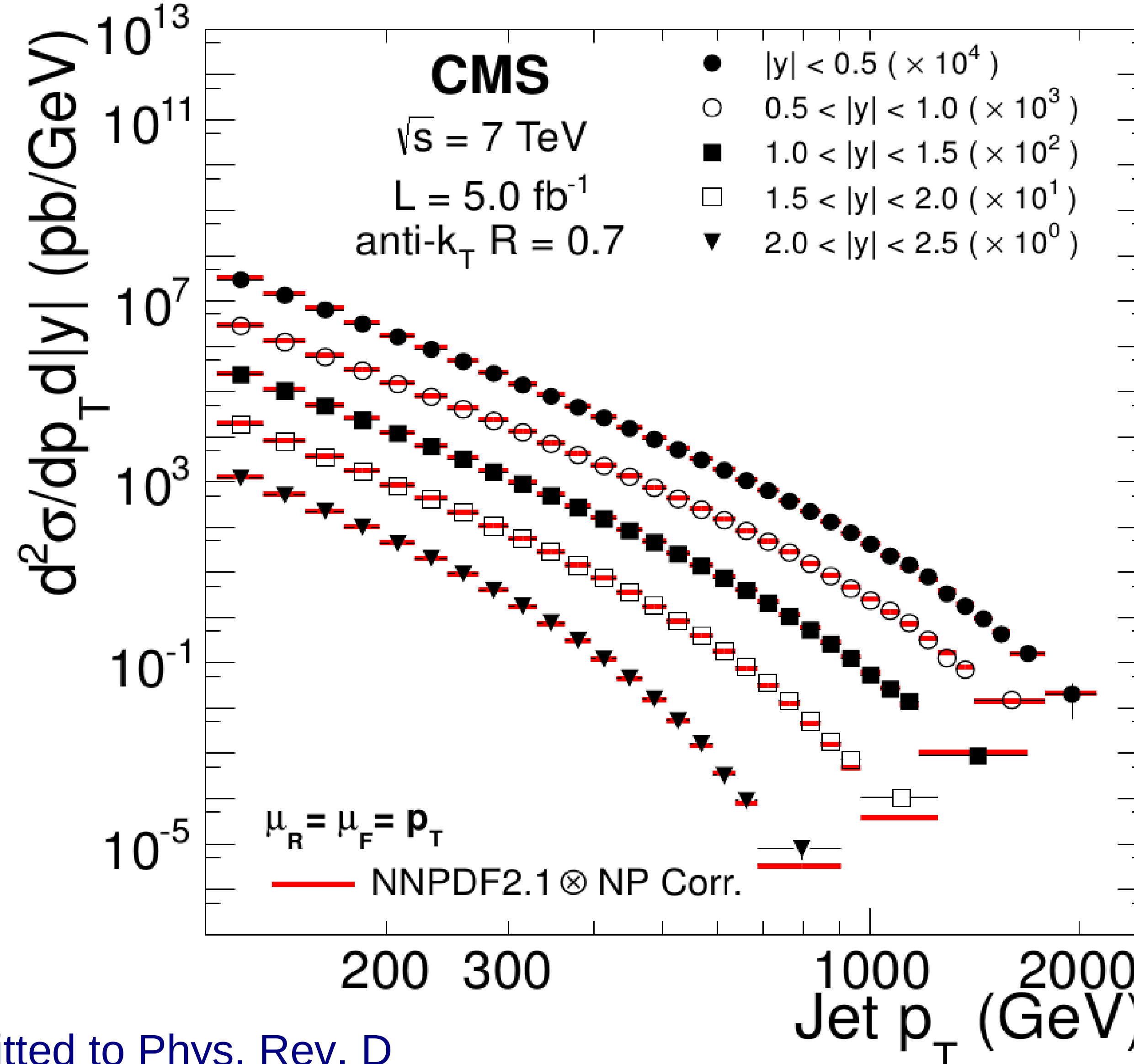
- Determined with di-jet and γ+jet pT balance
  - Plots show two example regions in η
  - Resolution is of the order of 10% around 100 GeV





Inclusive jets

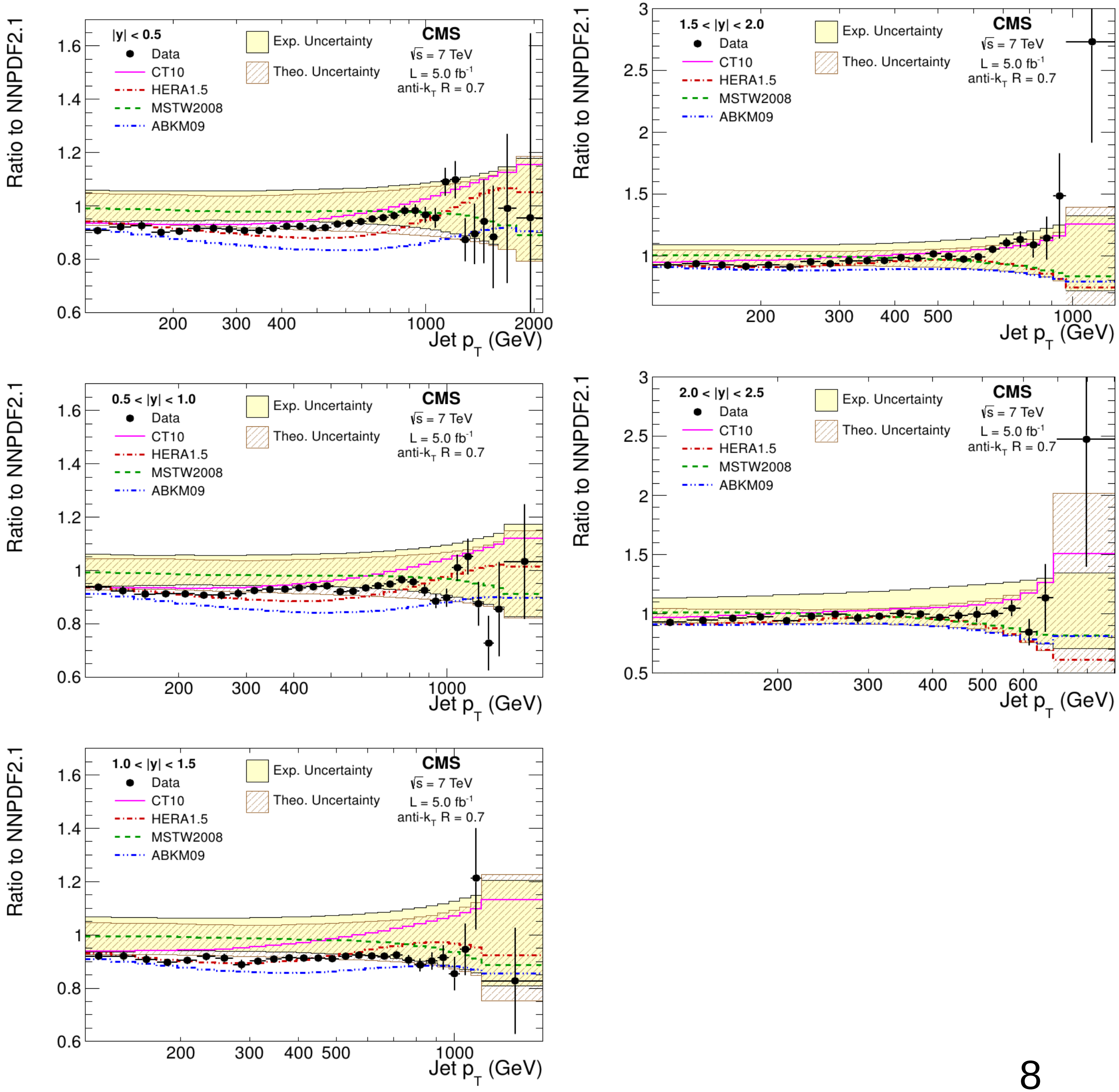
- Resolution effect are unfolded
- Main systematic: jet energy scale
- Data are compared with the predictions at NLO, including non-perturbative (NP) corrections obtained with a shower MC



CMS-QCD-11-004, submitted to Phys. Rev. D

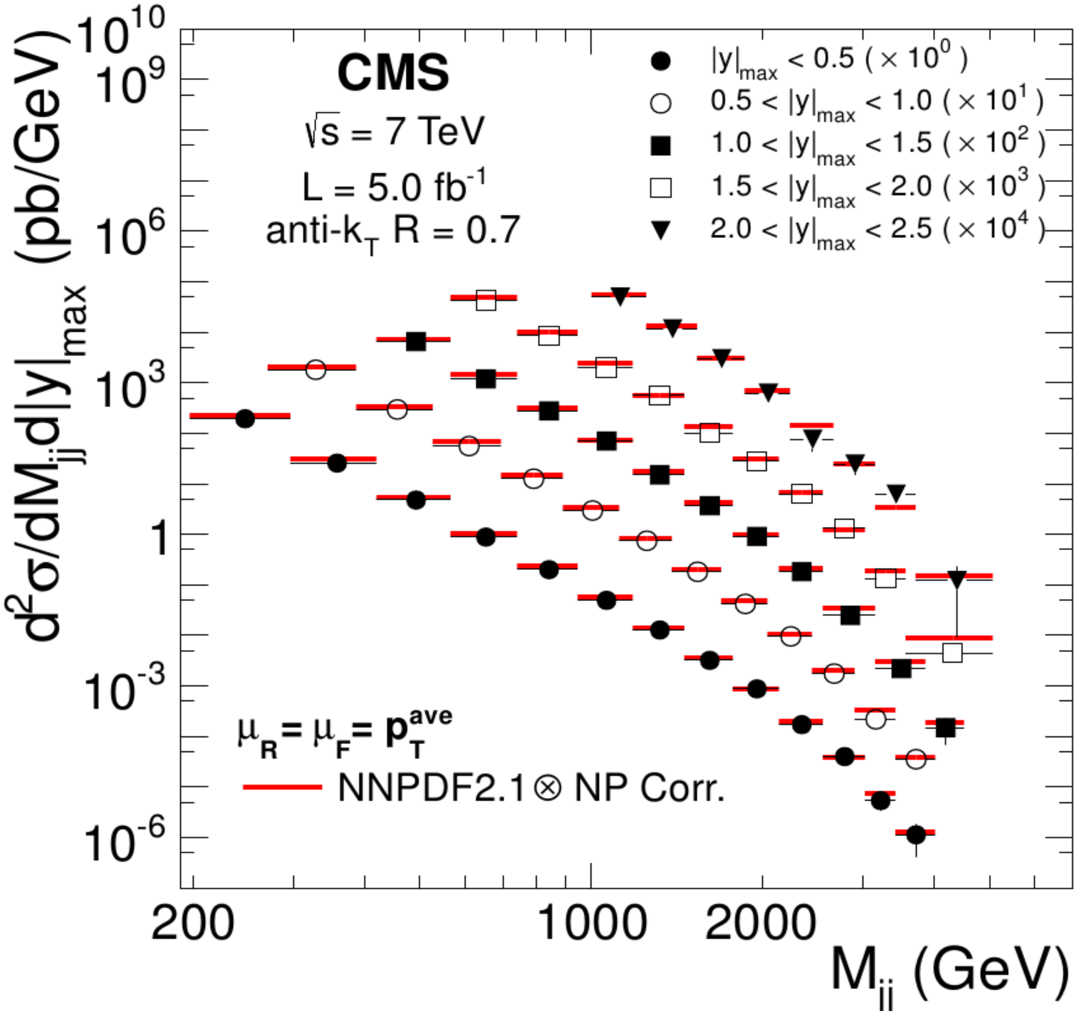
Inclusive jets

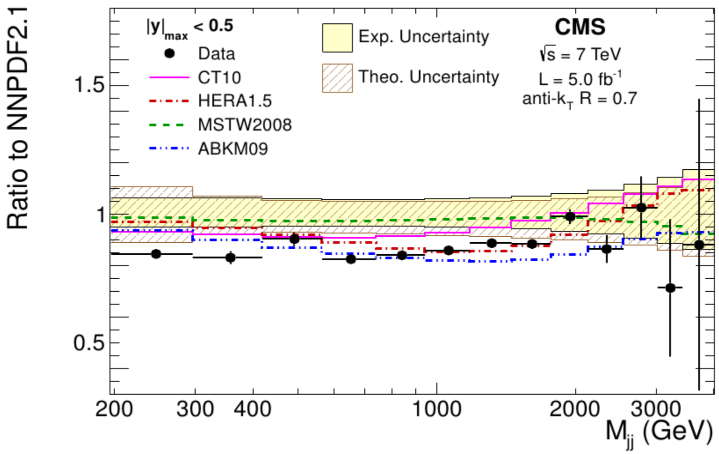
- Comparison to recent PDF sets
- Nice agreement, especially at forward rapidities
- At central rapidities, slight overestimation of the cross section
- Will be useful to improve Parton densities

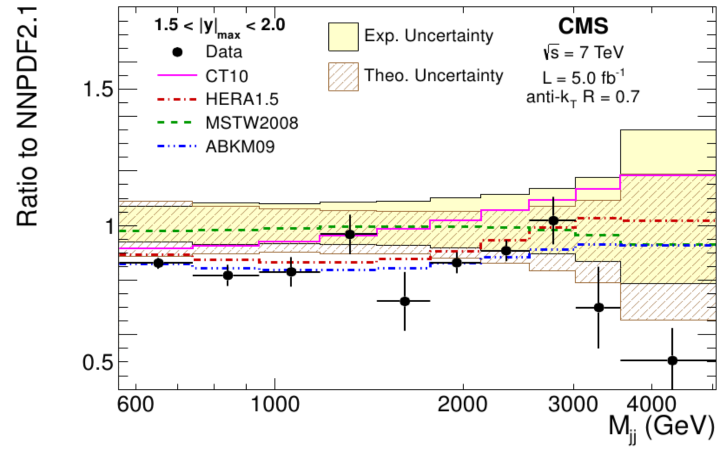


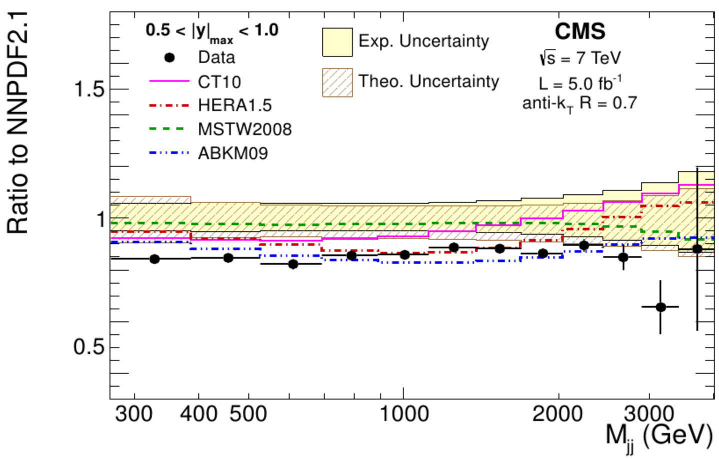
Di-jet mass

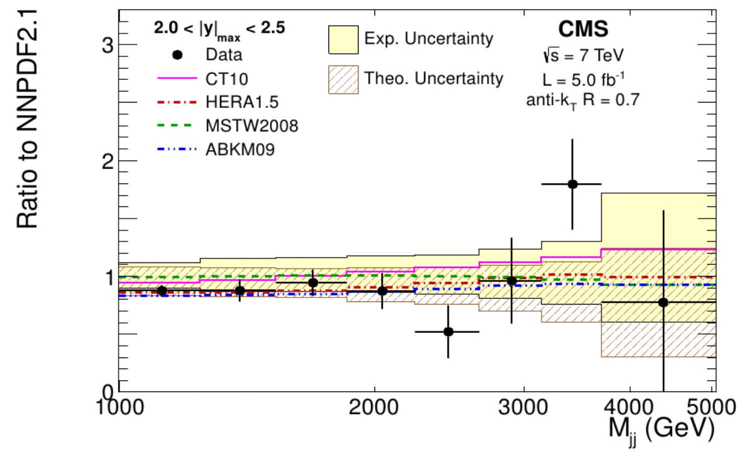
- Measured in up to 5 TeV in bins of rapidity
- Jet pT > 60 GeV, |η|<2.5
- Nice agreement with the predictions of NLO QCD



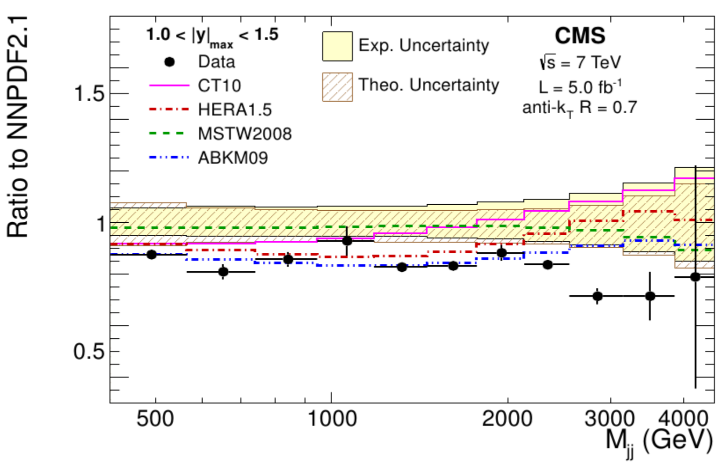








- Great sensitivity to PDFs
- Difference between different PDFs of the same order as the experimental uncertainty



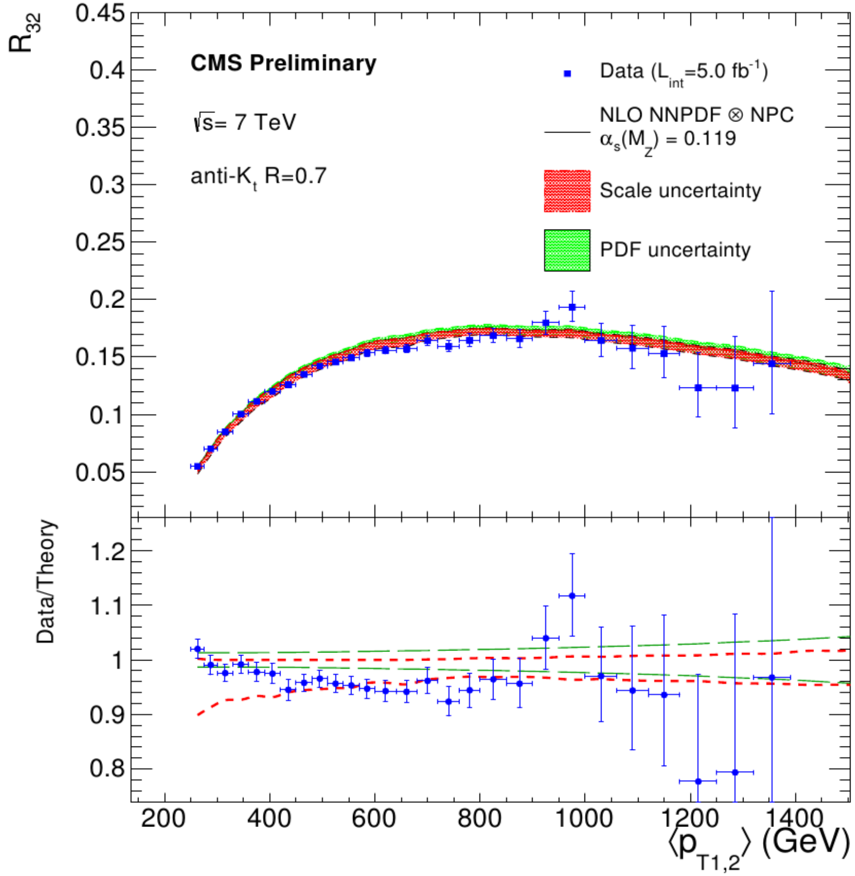
3-jets over 2-jets ratio

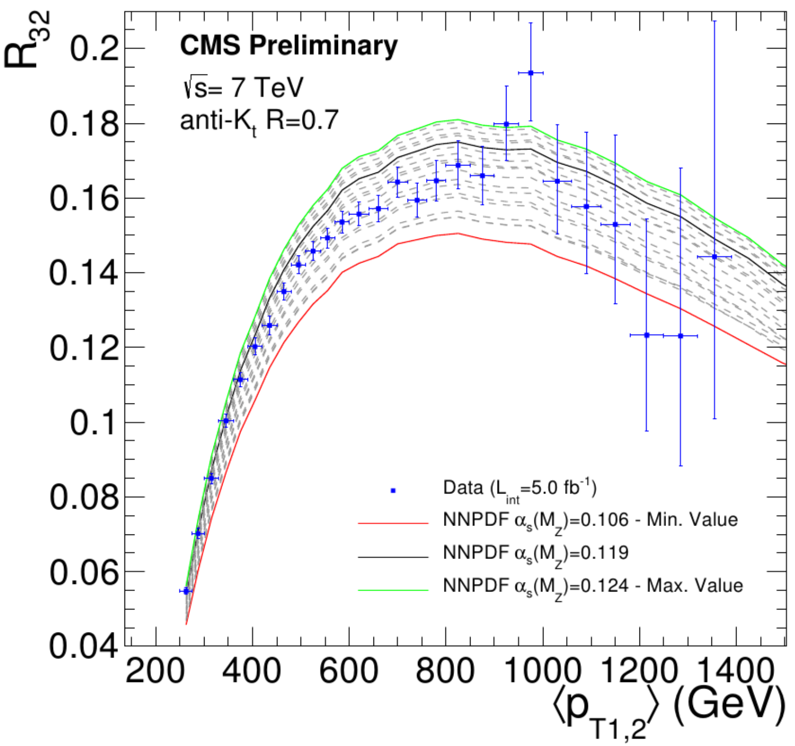
- Measurement of the ratio of events with 3 or more jets over events with 2 or more jets, as a function of average pt of the di-jet system
  - Jets: pT > 150 GeV, |y|<2.5

CMS-QCD-11-003

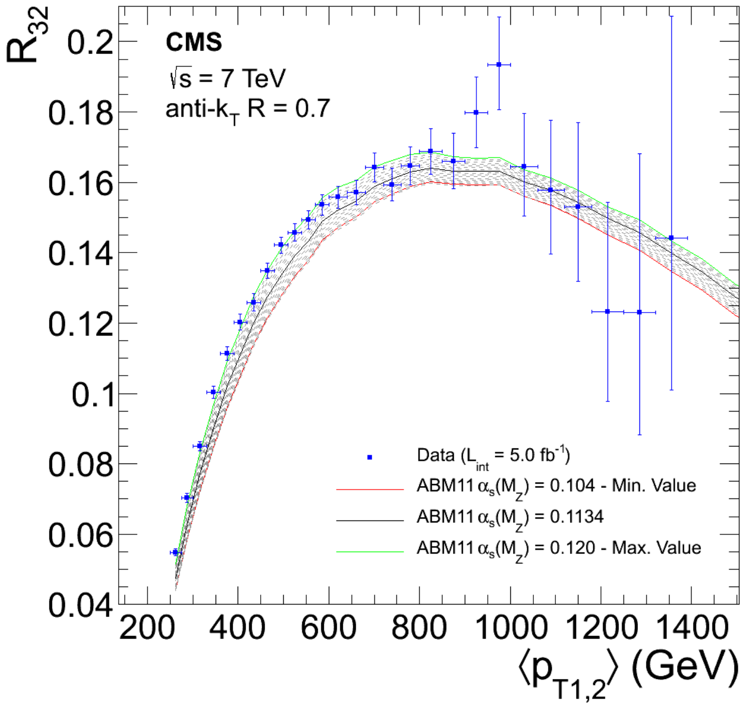
NEW!

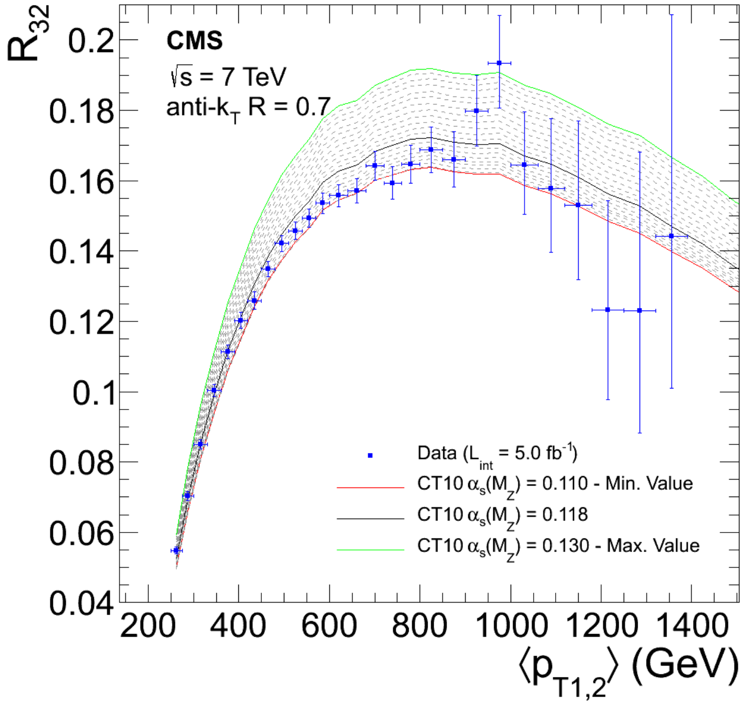
- Provides a stringent test of hard gluon radiation and higher order effects
- It is used to evaluate α_s

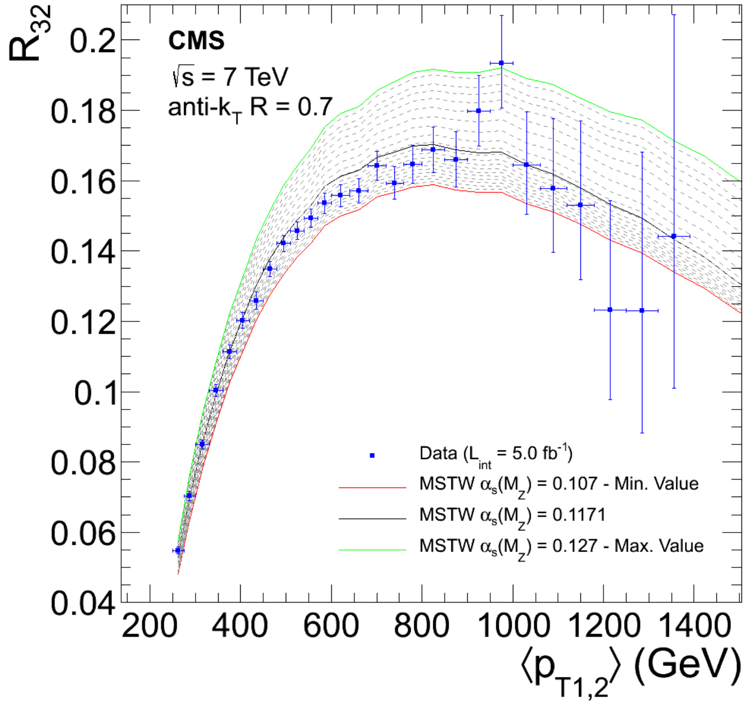




- The comparison with other PDF sets is slightly different
  - The variation of the predicted value of R32 is different over the different PDF sets for the same step in alpha value
  - This will translate in a difference in the experimental error in the fitted value of alpha when different sets are used

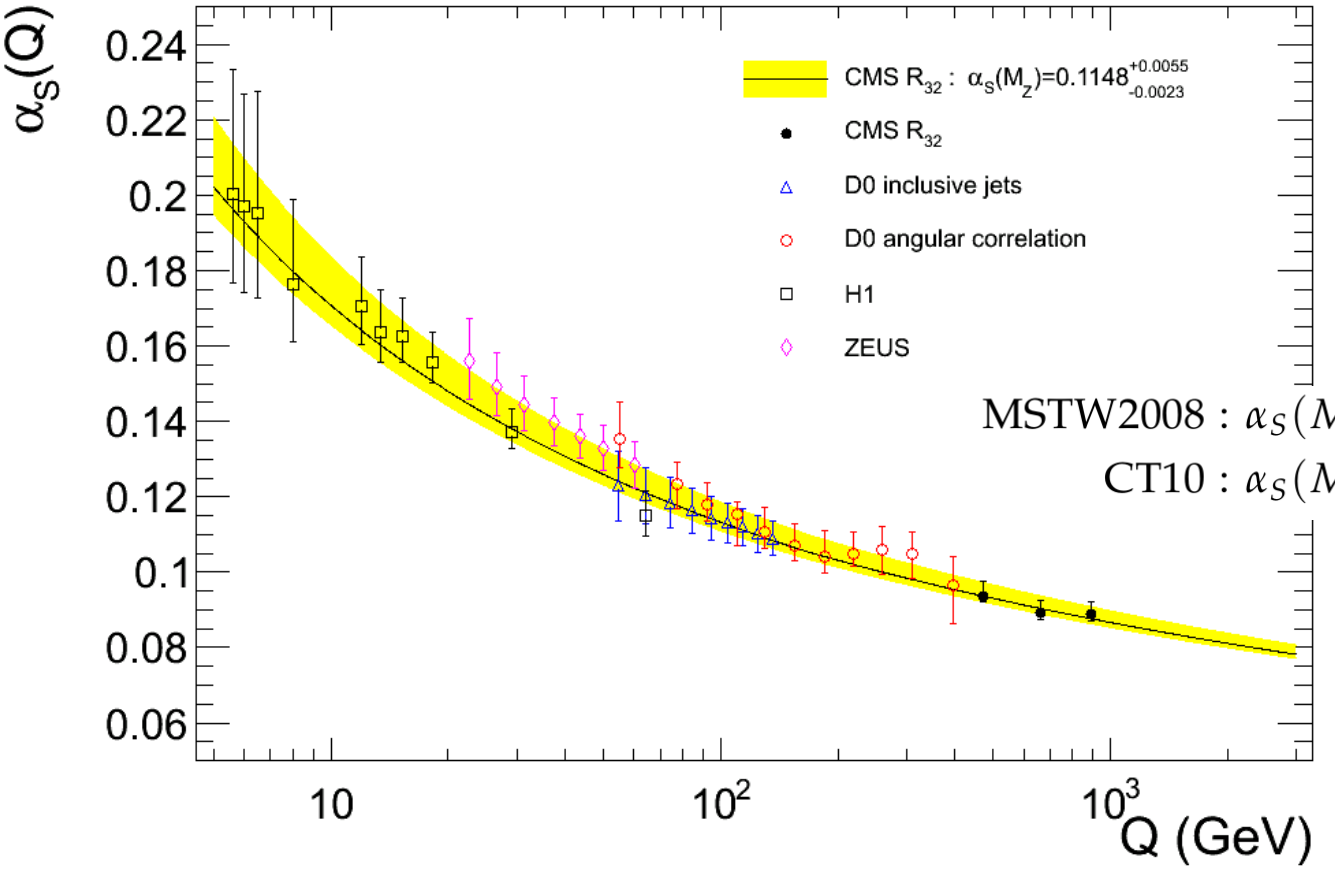






3-jets over 2-jets ratio

- α_s is determined via a chi^2 fit that minimizes the difference between the data points and the predictions in 3 bins of average pT.
- Predictions are from NLOJET++ with consistent value of α_s in the NLO calculation and in the PDFs (NNLO set from NNPDF2.1)



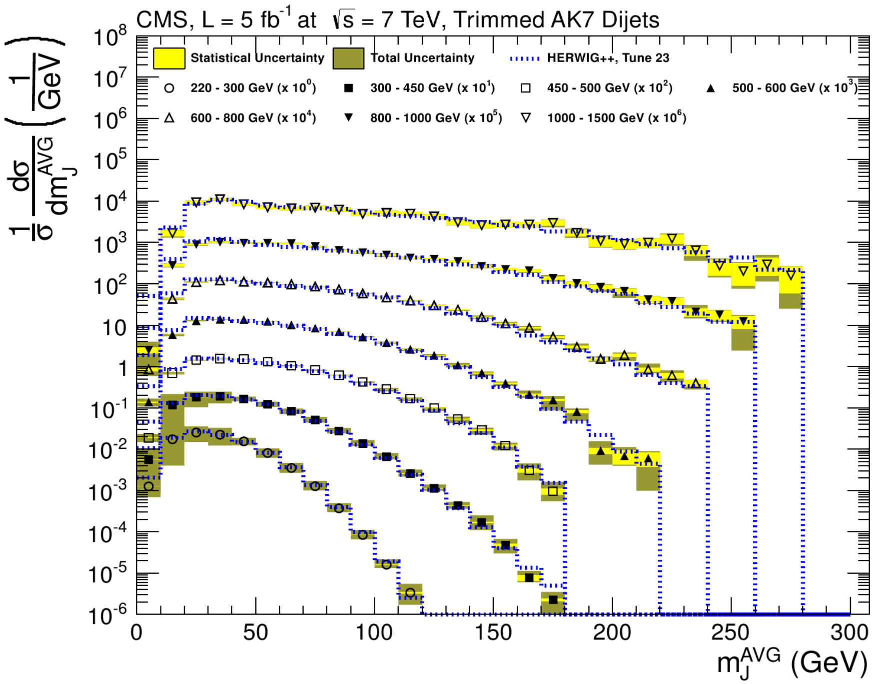
MSTW2008 : $\alpha_S(M_Z) = 0.1135 \pm 0.0096(exp.)$

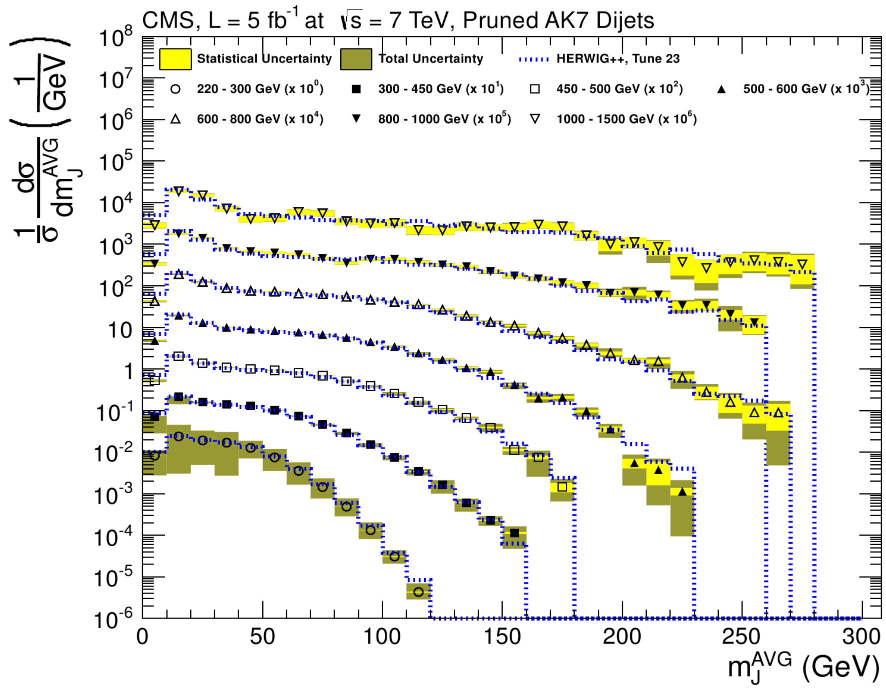
CT10 : $\alpha_S(M_Z) = 0.1130 \pm 0.0080(exp.)$

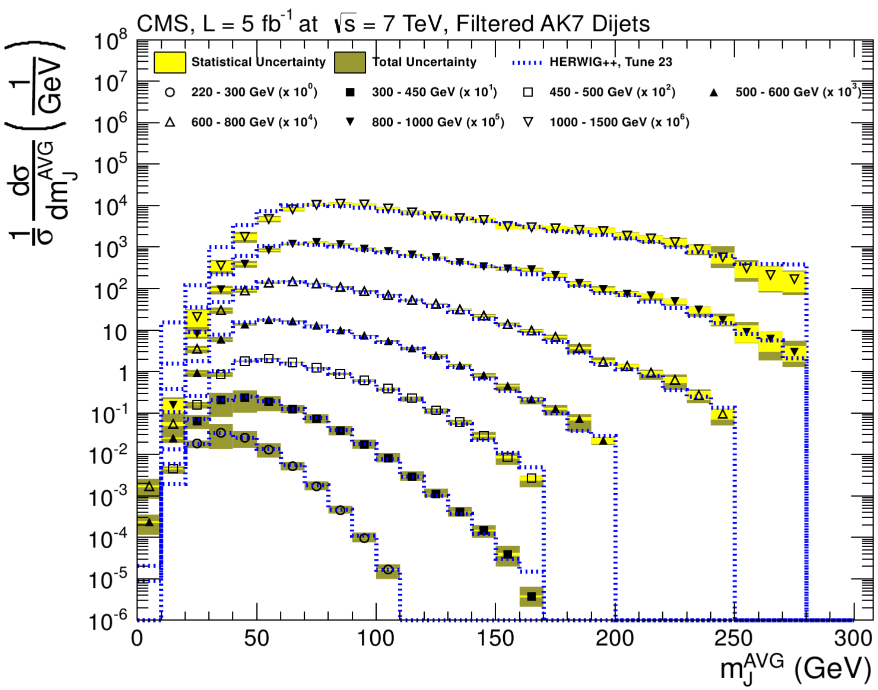
$\alpha_S^{NNPDF}(MZ) = 0.1148 \pm 0.0014\ (exp.) \pm 0.0018\ (PDF)\ ^{+0.0050}_{-0.0000}\ (scale)$

Jet substructure

- Study of jet mass via jet-substructure resolution techniques
- In dijets and V+jets
- Three techniques are studied
  - Jet Filtering:
    - For each jet the constituents are re-clustered via the Cambridge-Aachen (CA) algorithm (R=0.3)
    - The jet momentum is re-defined as the sum of the three hardest sub-jets
  - Jet Trimming:
    - Recluster jet components with kT algorithm with smalled radius, accepting only sub-jets above a given pT threshold
  - Jet Pruning:
    - Recluster jet components with CA
    - When clustering two particles the softer is removed if it below a certain fraction of the other particle pT
  - The net effect is that jets are made smaller, and the contribution of UE is reduced

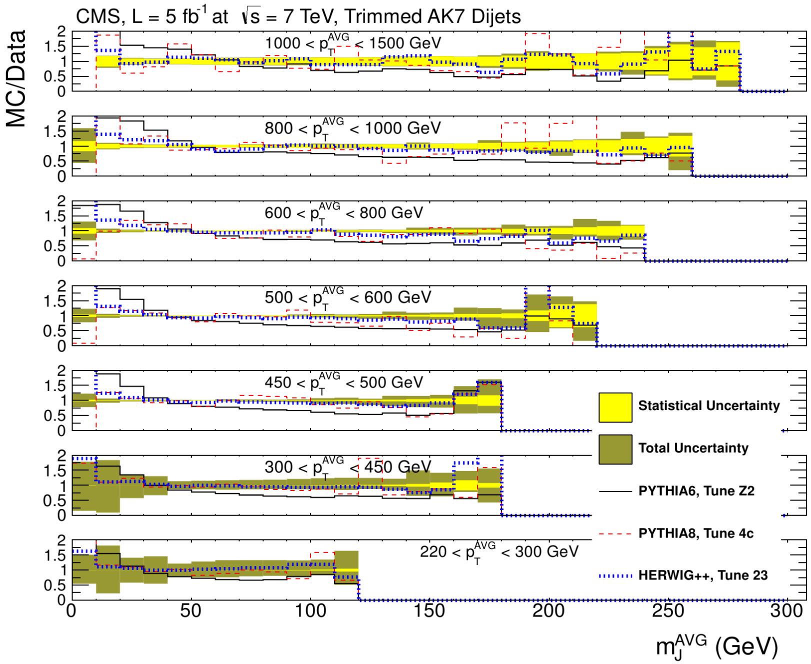


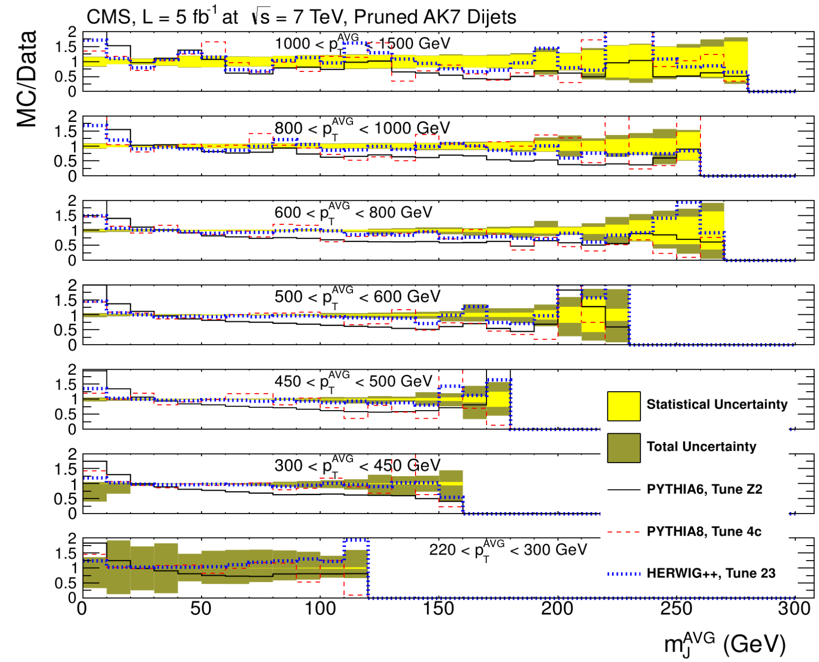


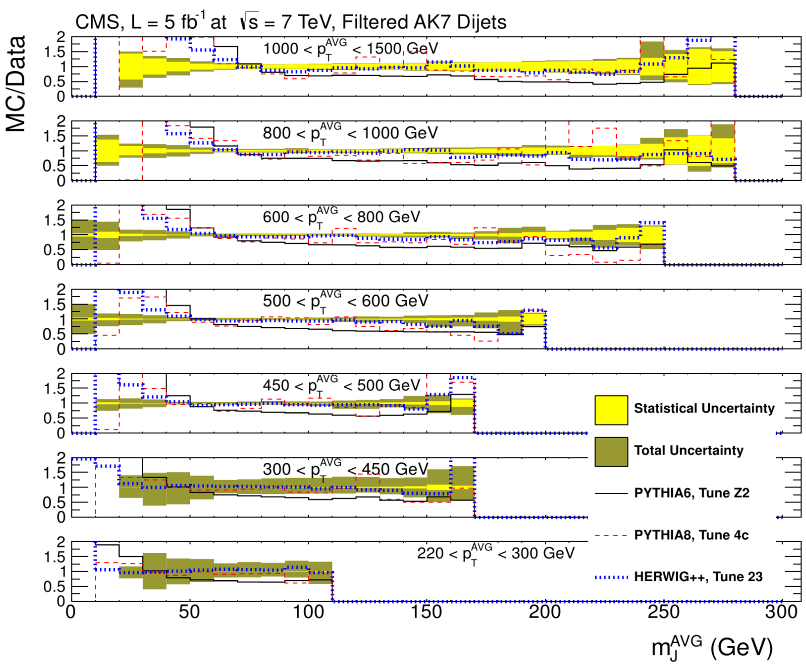


- This is a measurement of jet shapes in di-jet events
- Herwig++ shows nice agreement with the data, especially for jet pT above 300 GeV
- The agreement is worse for softer jets

CMS-SMP-12-019



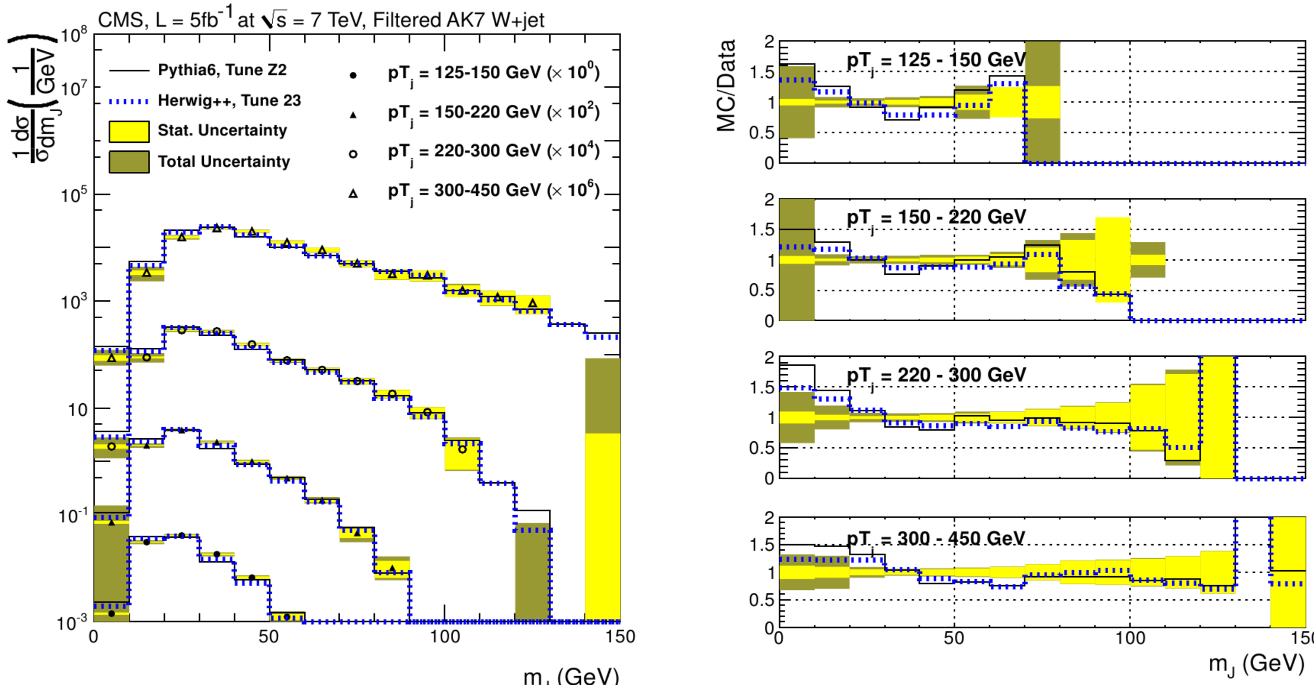


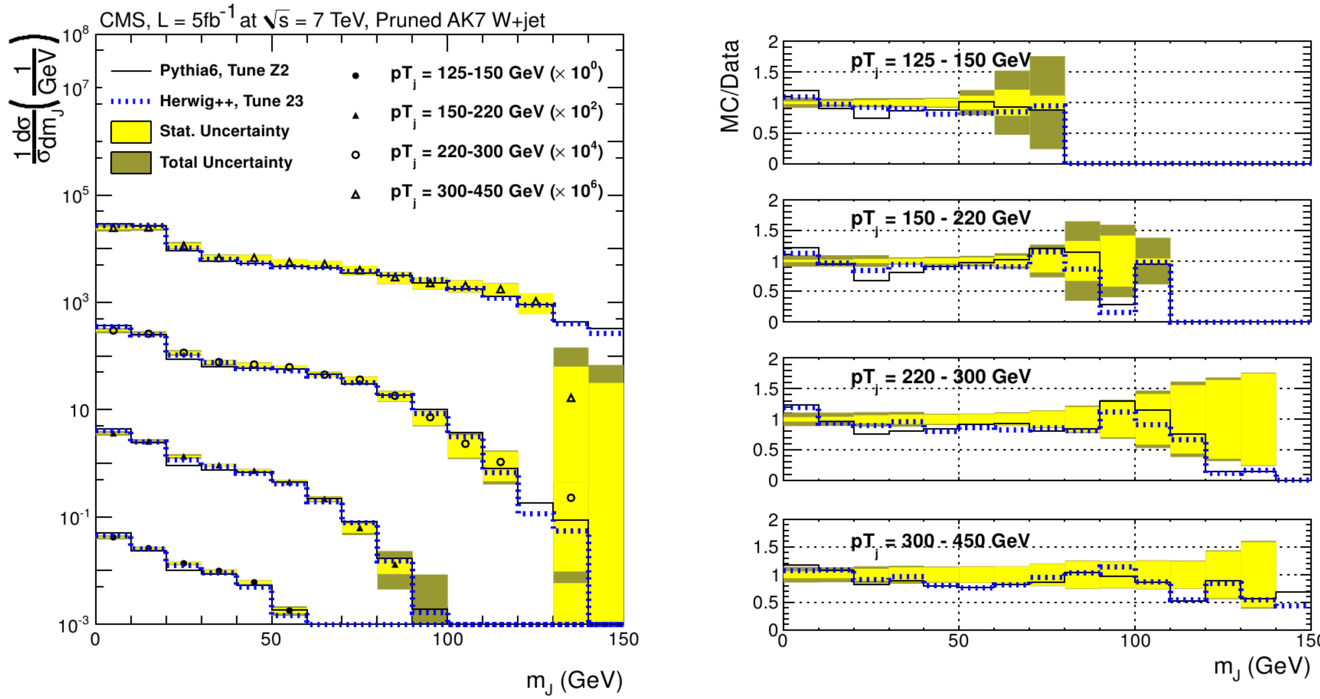


- Herwig++ is the generator that shows best agreement with the data
- Pythia6 and Pythia8 are very similar

CMS-SMP-12-019

- Jet shape of the leading jet in W/Z+jets
- The agreement with both Pythia and Herwig is good for jets above above 300 GeV of pT
- The description is worse for softer jets





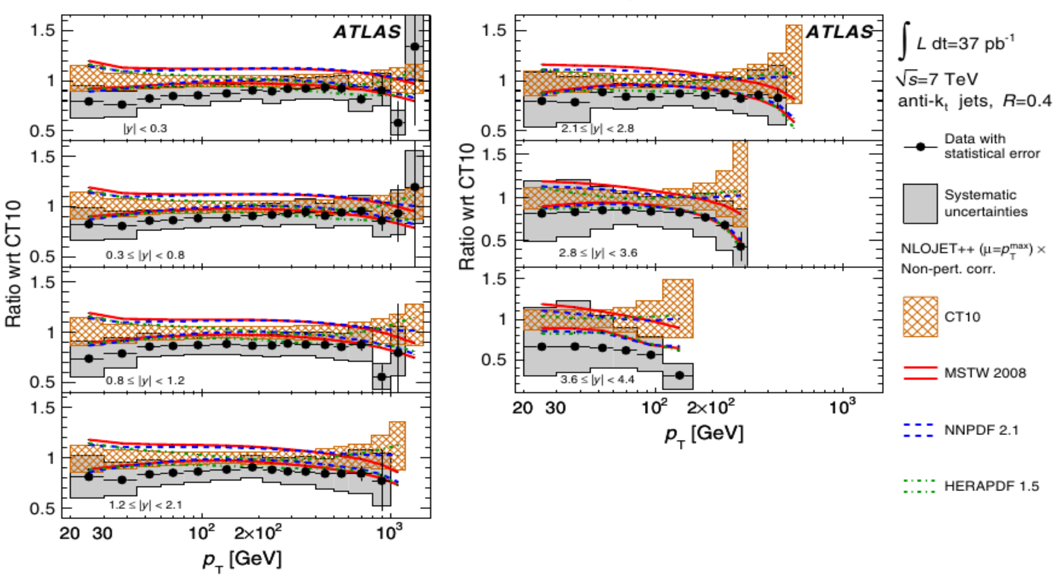
Conclusion

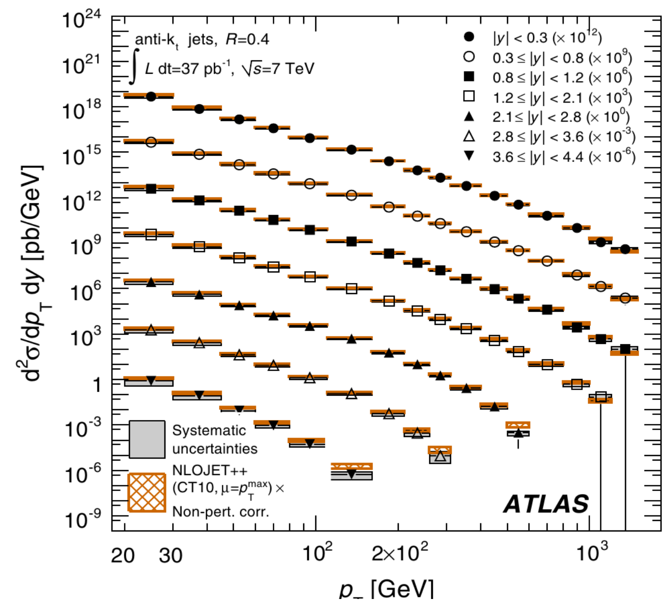
- Several recent results from CMS with full 2011 5/fb statistics
- More measurements are coming at 8 TeV
- First determination of α_s at the LHC
- Detailed study of jet substructure

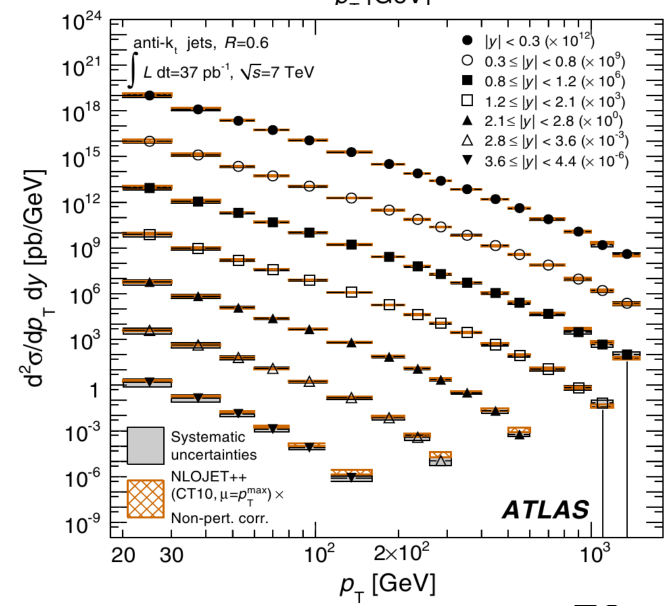
Backup

Inclusive jets

- From 20 GeV to 1.5 TeV
- It is interesting to compare different jets sizes
  - Difference contribution of hadronization and UE corrections
- Main systematic: jet energy scale
- Data are compared with the predictions at NLO, including non-perturbative (NP) corrections obtained with a shower MC
- Good agreements NNPDF and CT10
- MSTW better at large rapidities

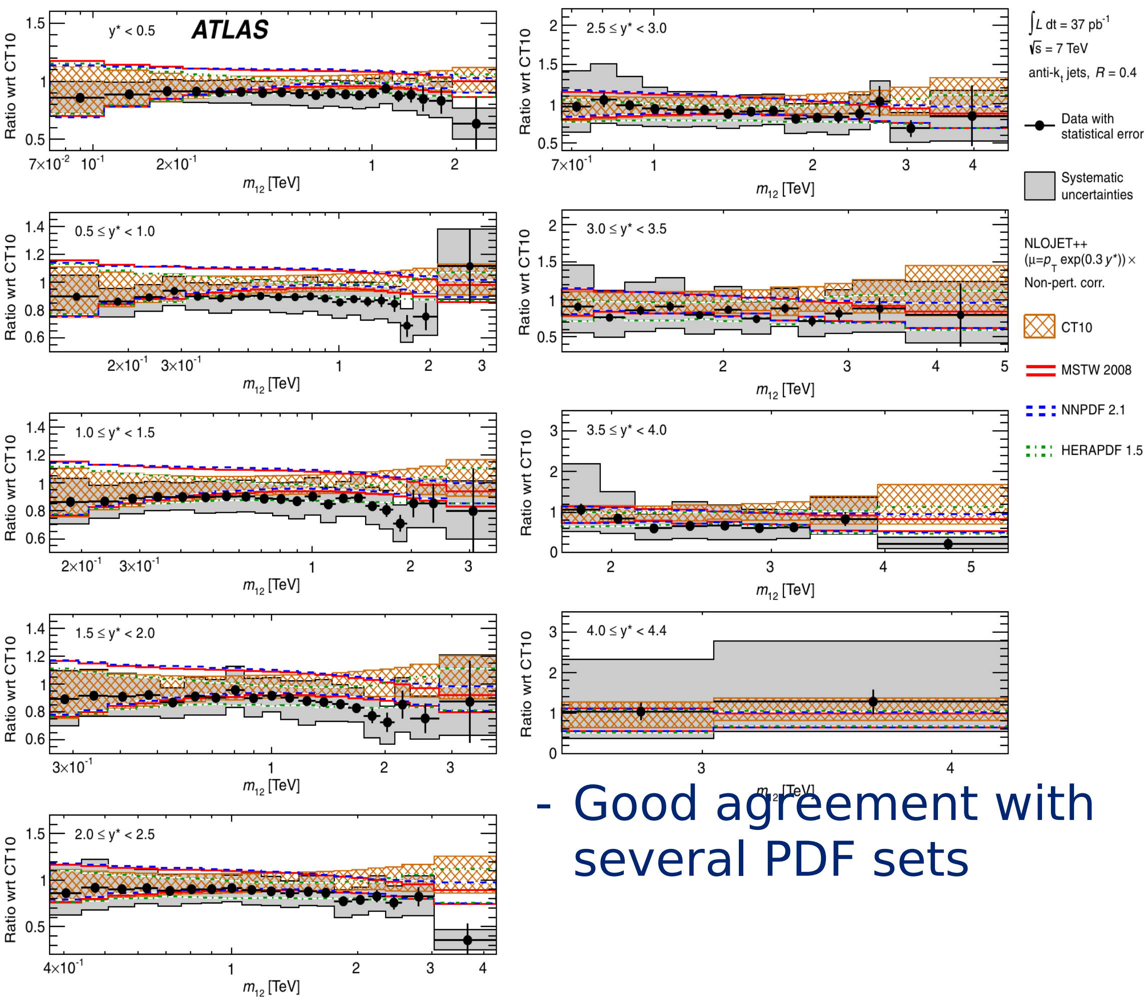




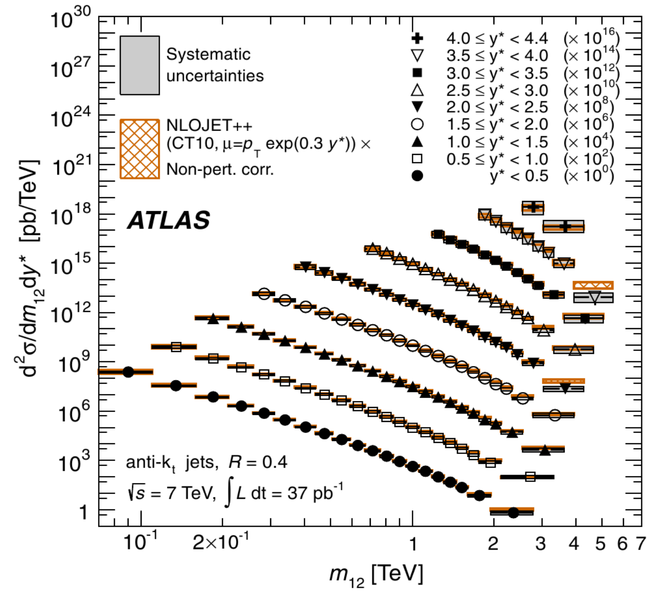


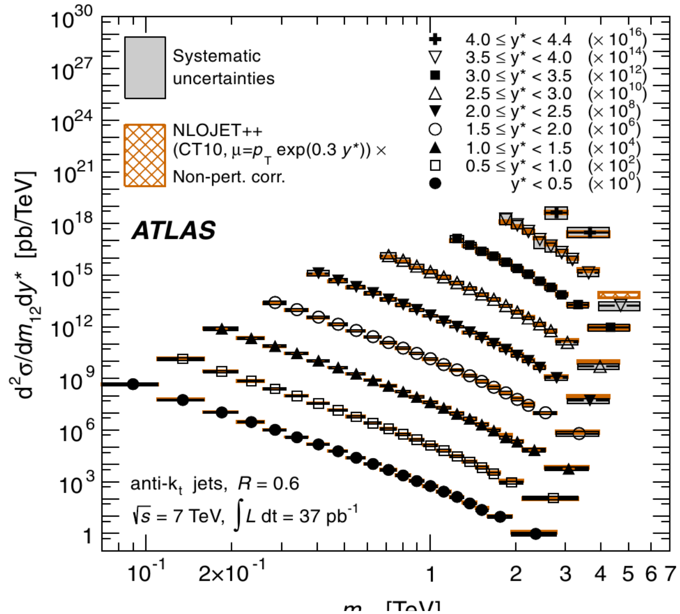
Di-jet mass

- Measured in up to 5 TeV in bins of rapidity
- Jet pT > 20 GeV, |η|<4.4



- Good agreement with several PDF sets





Constraints of strange quark content

- ATLAS studied the ratio of (s+sbar)/d using W and Z cross section measurements
- CMS measured W+c cross sections to constraint s and sbar density