PDF Constraints and Extraction of the Strong Coupling Constant from Jet Measurements at CMS

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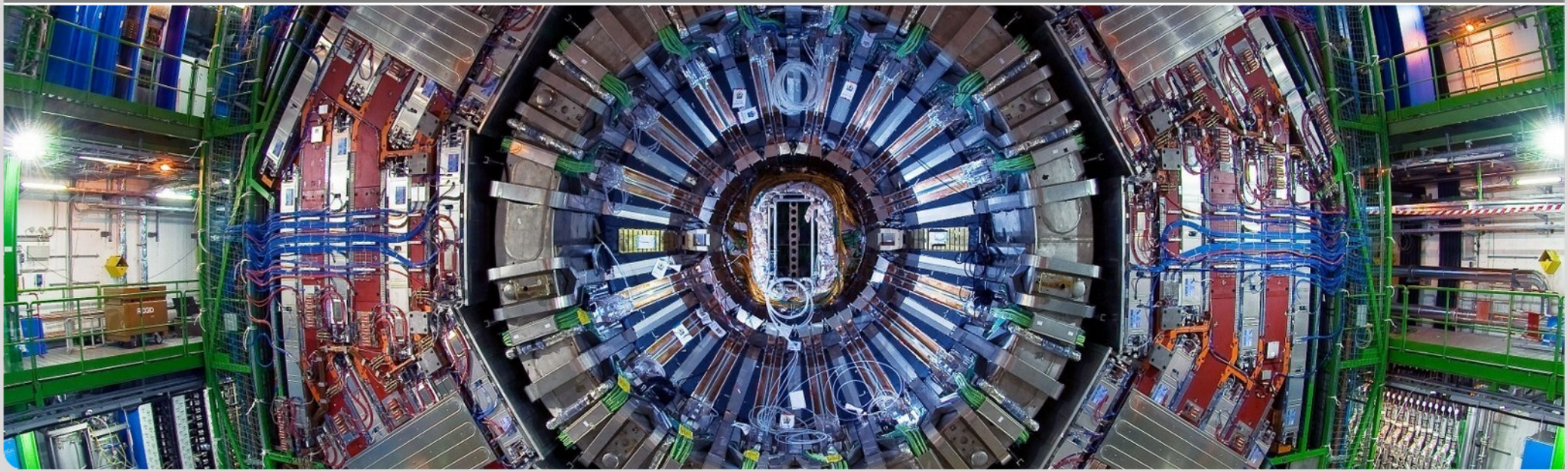
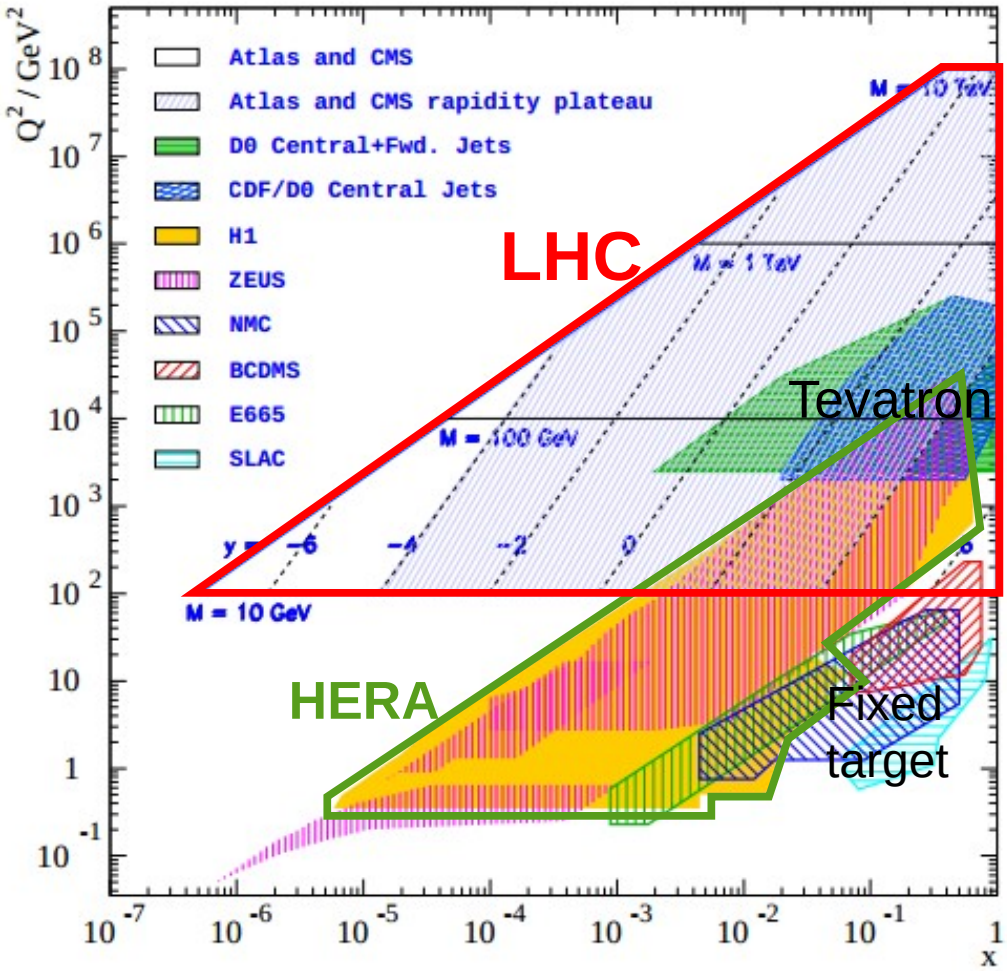


KIT – University of the State of Baden-Wuerttemberg and
National Research Center of the Helmholtz Association

Introduction

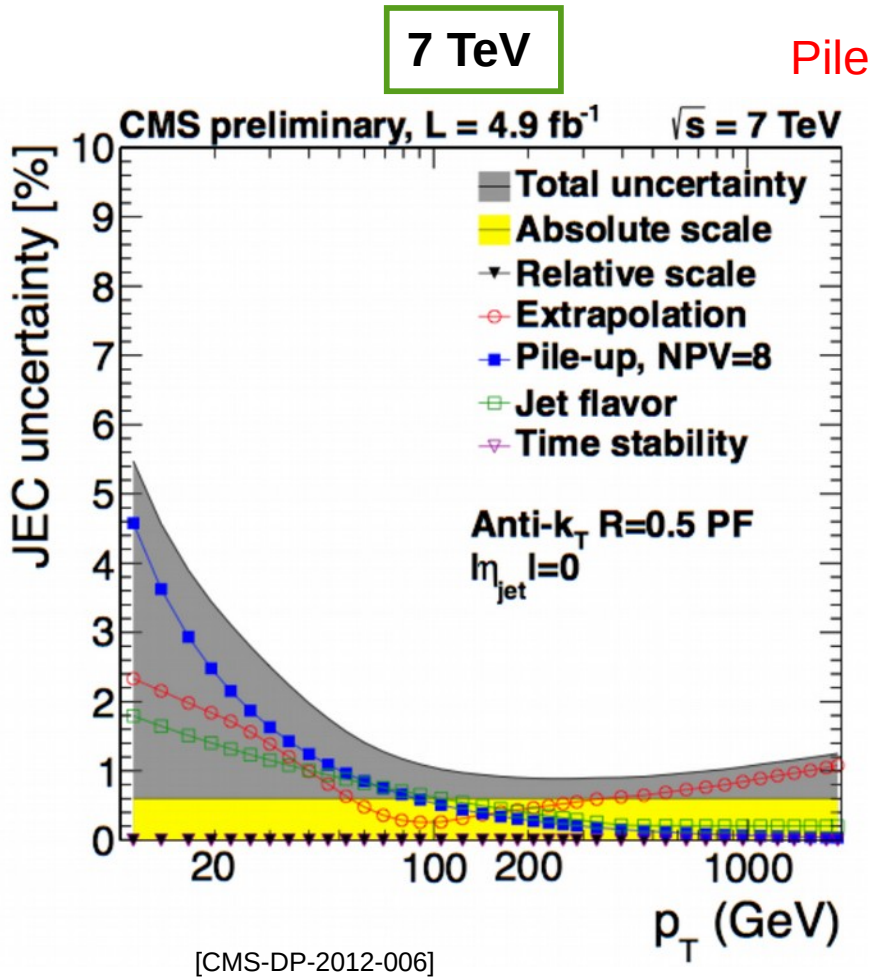
- PDFs and strong coupling are a key ingredient for precision measurements
- PDFs up to now mainly constrained by DIS and fixed-target measurements
- LHC measurements provide additional information for PDFs in unexplored phase space regions
- Determination of the Strong Coupling at the TeV scale



[Braz.J.Phys. 37 (2007) 793-797]

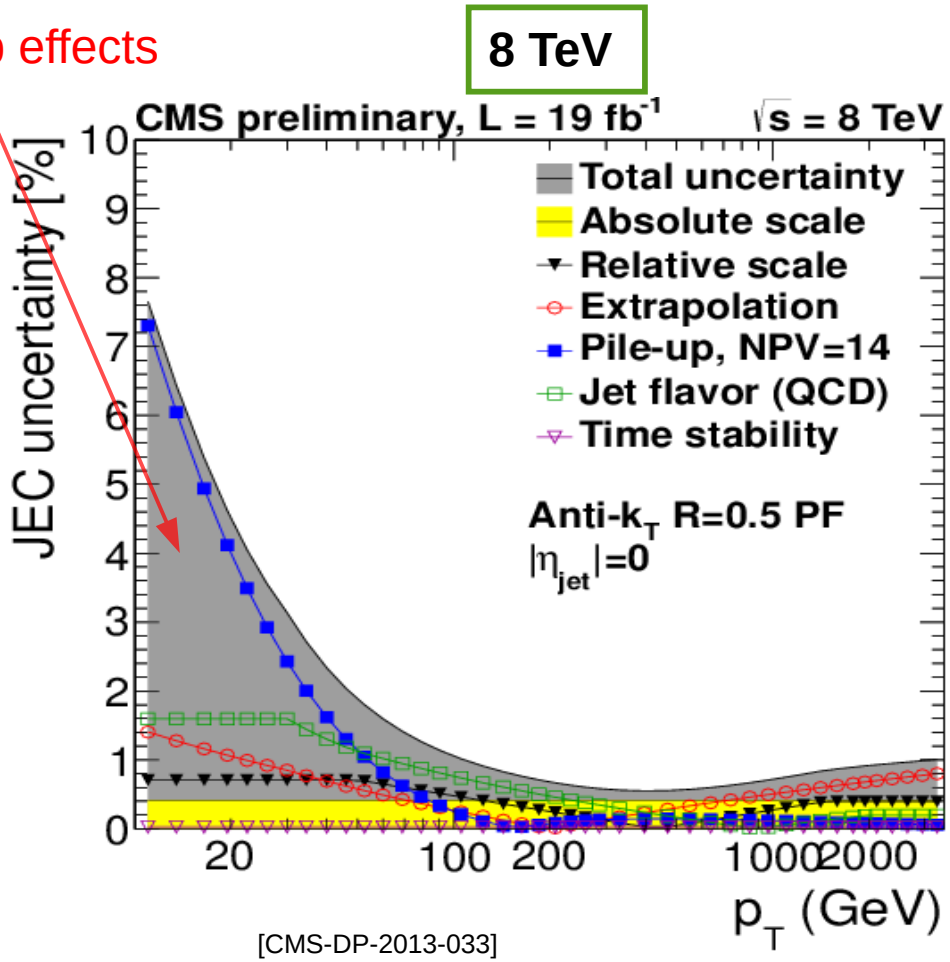
Jet Energy Scale

- Dominant experimental uncertainty for jets
- CMS achieved excellent jet energy scale uncertainties within short time



[CMS-DP-2012-006]

Pileup effects

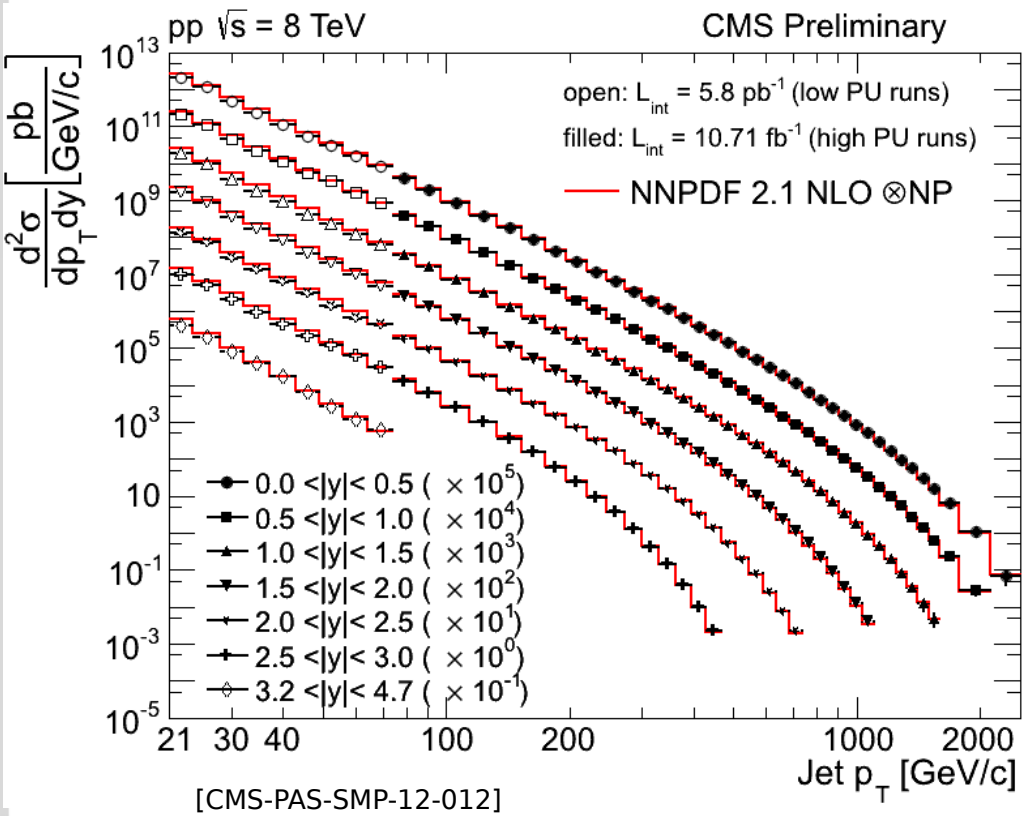


[CMS-DP-2013-033]

Inclusive Jet and Dijet Production

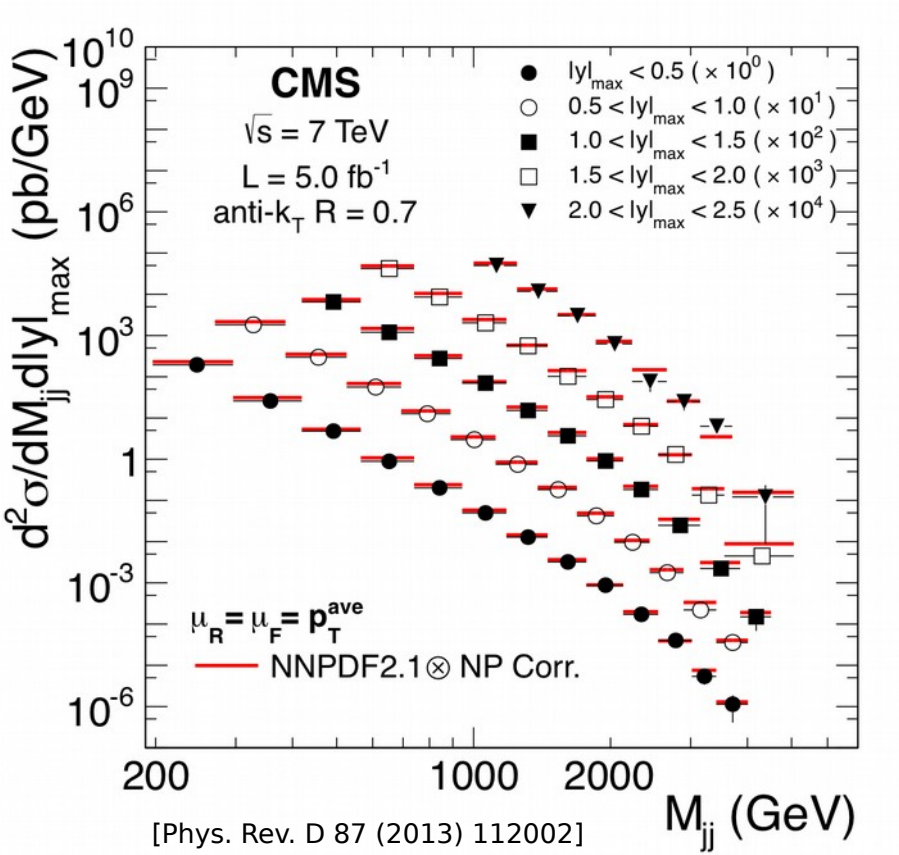
- Fundamental test of QCD
- Jet production cross sections measured by CMS at 7 and 8 TeV
- **Agreement** with NLO+NP calculations over **many orders of magnitude**

Inclusive Jets at 8 TeV



[CMS-PAS-SMP-12-012]
[CMS-PAS-FSQ-12-031]

Dijets at 7 TeV

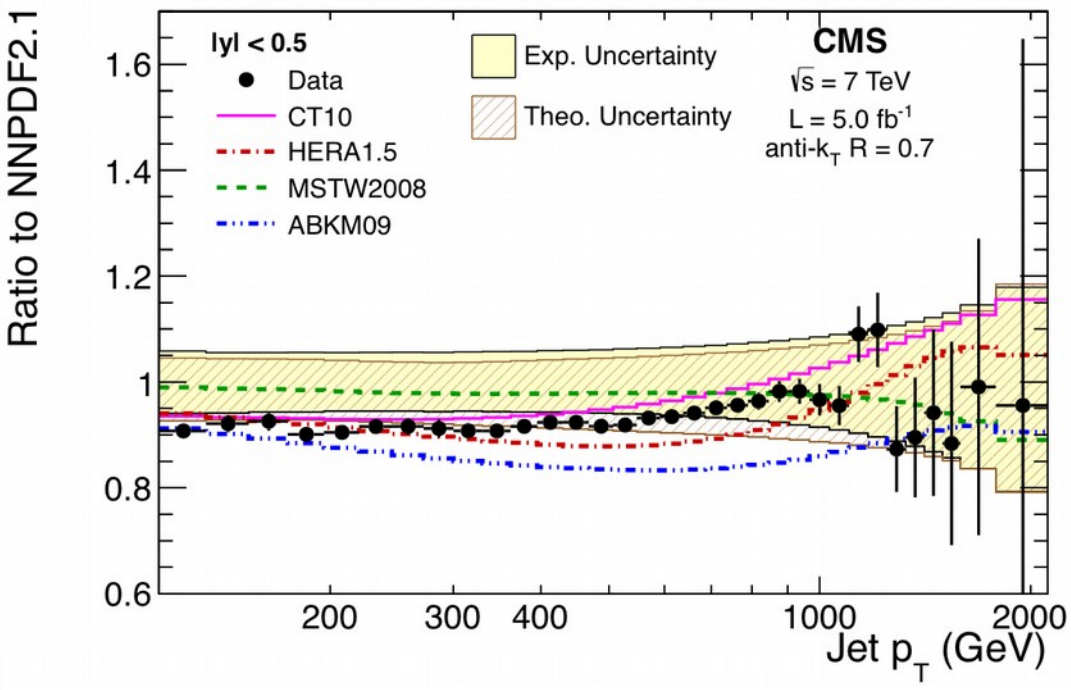


[Phys. Rev. D 87 (2013) 112002]

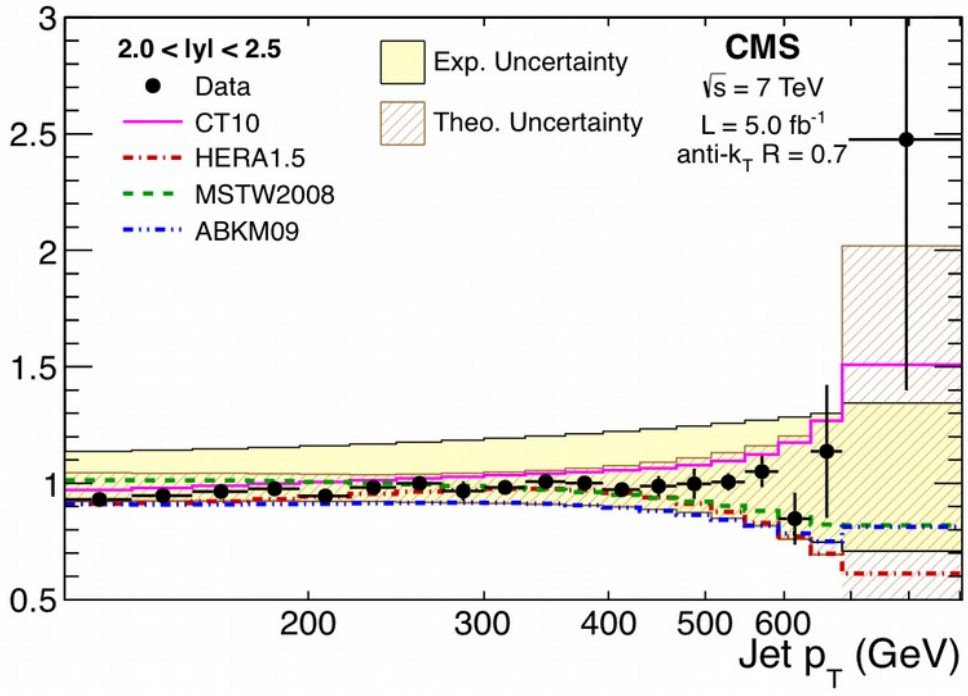
QCD Analysis of 7 TeV Inclusive Jet Data

- Discrimates between PDFs
- In particular the gluon PDF at high-x can be constrained
- The strong coupling can be extracted at high jet-p_T

|y| < 0.5



2.0 < |y| < 2.5

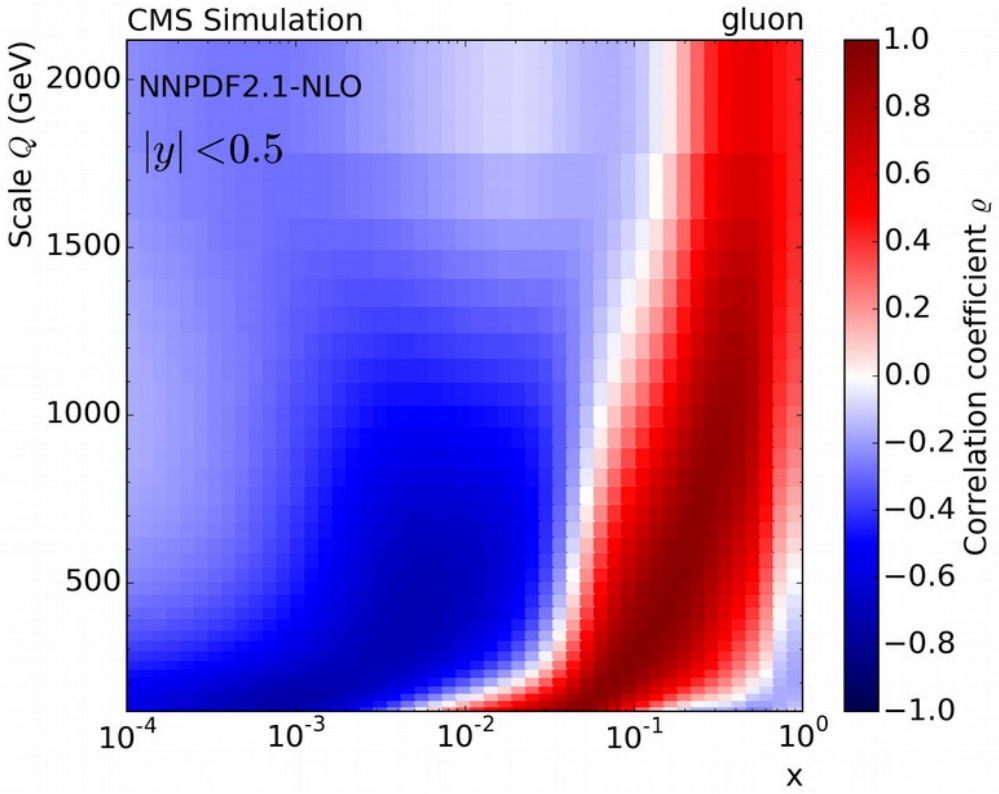


[Phys. Rev. D 87 (2013) 112002]

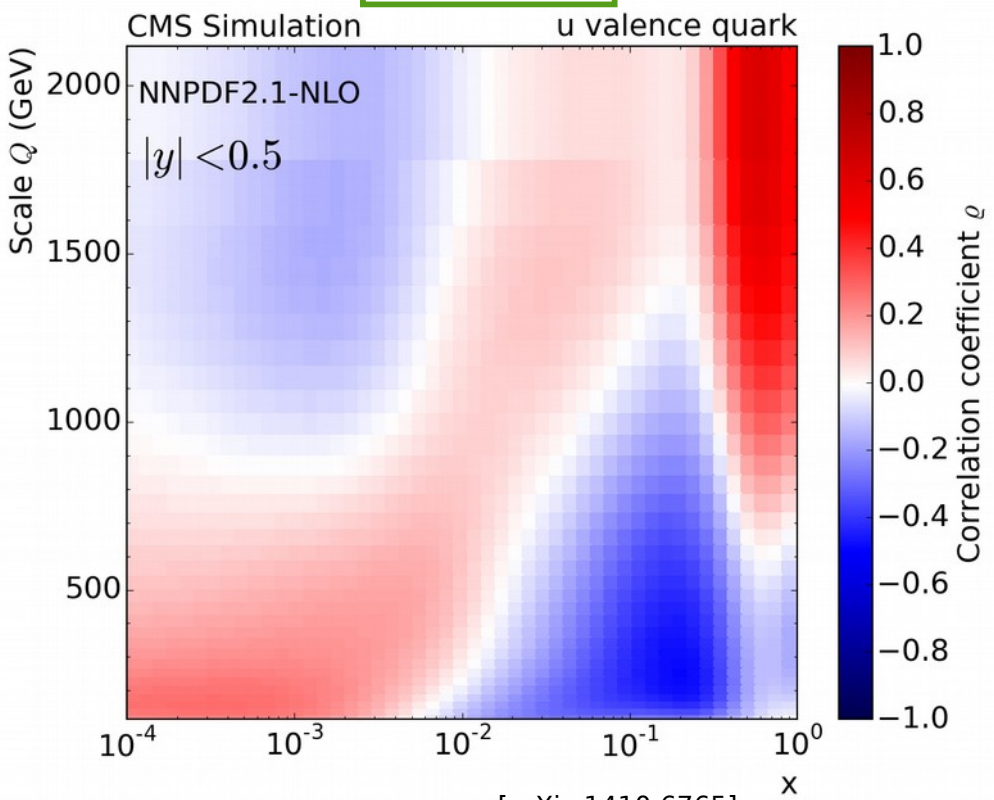
Correlation of Gluon PDF and σ_{jet}

- Gluon PDF: High correlation at 0.05 < x < 0.7 and Q < 1500 GeV
- Quark PDF: High correlation at 0.4 < x < 0.7 and Q > 1000 GeV
- **Constraints on PDFs expected at high-*x***

gluon



u_{val} quark

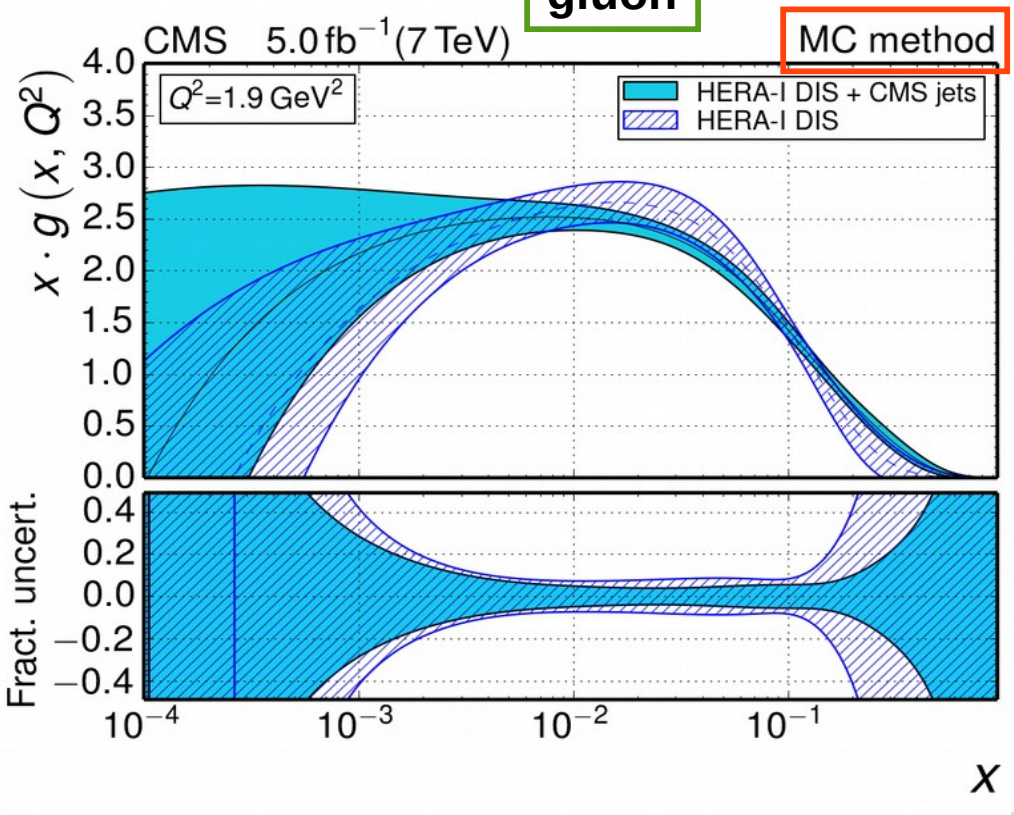


[arXiv:1410.6765]

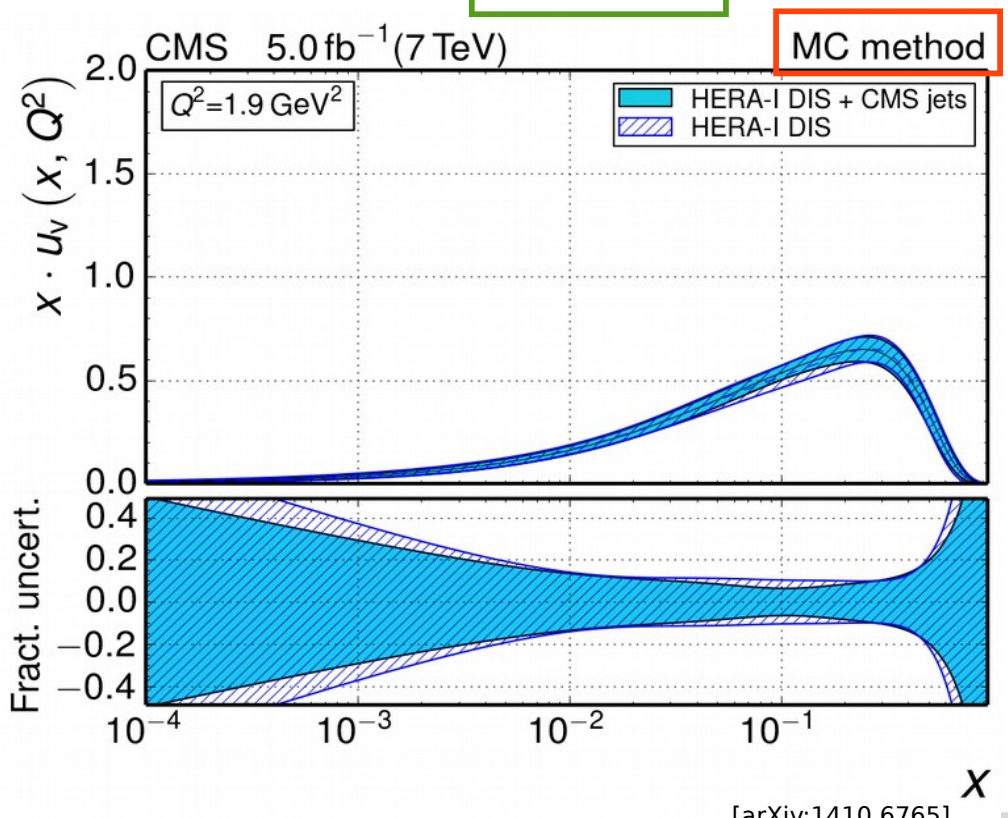
Inclusive Jet Production: PDF Constraints

- Impact of CMS inclusive jet data demonstrated by adding data to PDF fit using HERA-I DIS data
- MC approach employed similar to NNPDF method
- Harder gluon and significant reduction of gluon uncertainties at high-x
- Some reduction u_{val} quark uncertainties

gluon



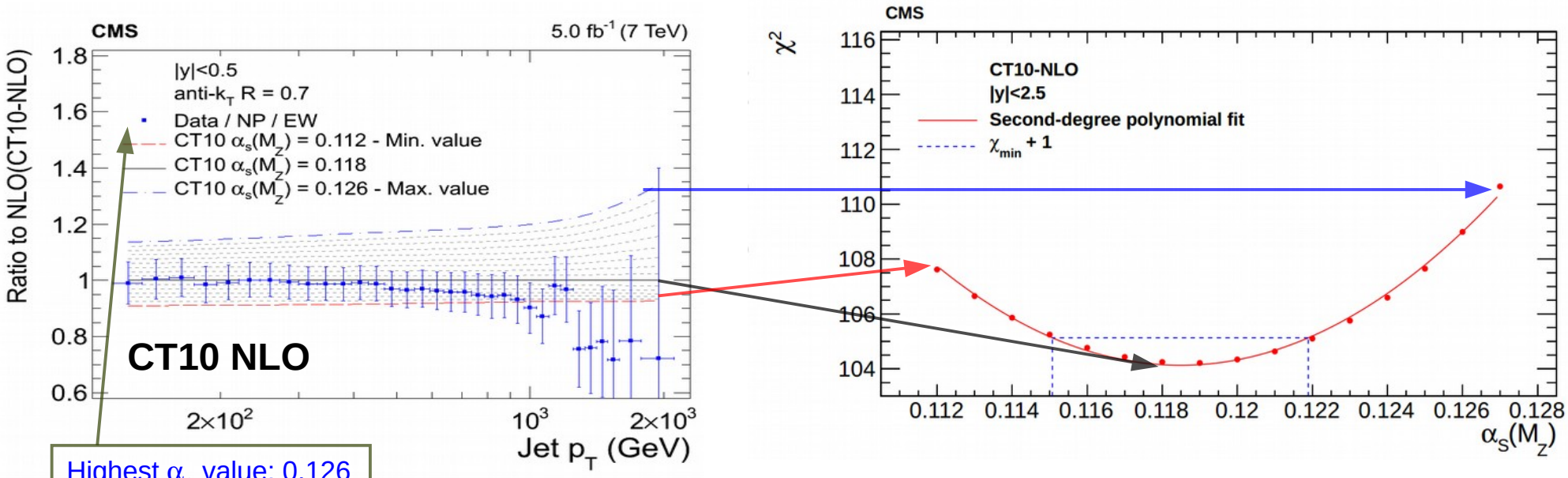
u_{val}-quark



[arXiv:1410.6765]

Sensitivity of $\alpha_s(m_z)$: CT10-NLO

- Sensitivity plots show the ratio of predictions with different values of $a_s(m_z)$ to the central PDF predictions
- NLO+NP theory prediction using the $\alpha_s(M_z)$ series of the PDF groups compared to data using χ^2-test
- Fitted value of $\alpha_s(M_z)$ close to central PDF of CT10



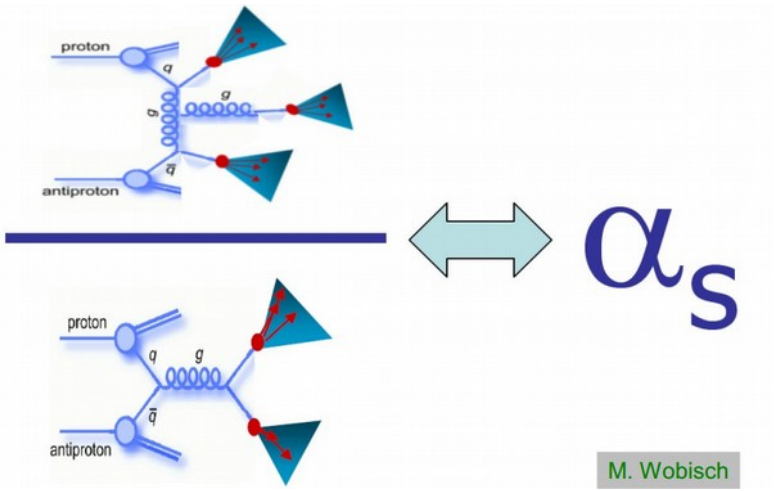
Highest α_s value: 0.126
Central α_s value: 0.118
Lowest α_s value: 0.112

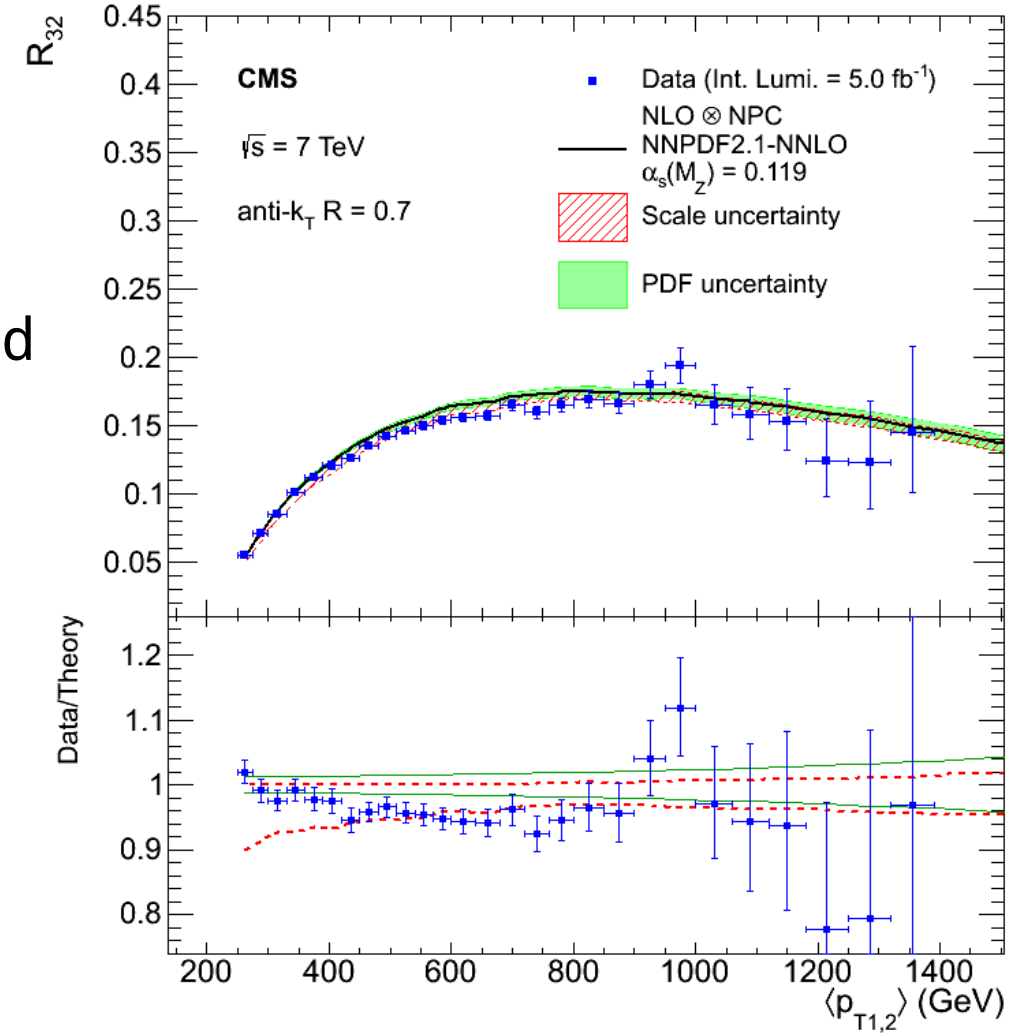
[arXiv:1410.6765]

$$\alpha_S(m_Z) = 0.1185 \pm 0.0019(\text{exp.}) \pm 0.0028(\text{PDF}) \pm 0.0004(\text{NP})^{+0.0053}_{-0.0024}(\text{scale})$$

3-jet to 2-jet cross section ratio

- Ratio of 3-jet and 2-jet production as function of the average jet p_T
- Cancellation of luminosity uncertainty and reduction of systematic uncertainties
- Reduced dependence on PDFs and RGE of QCD



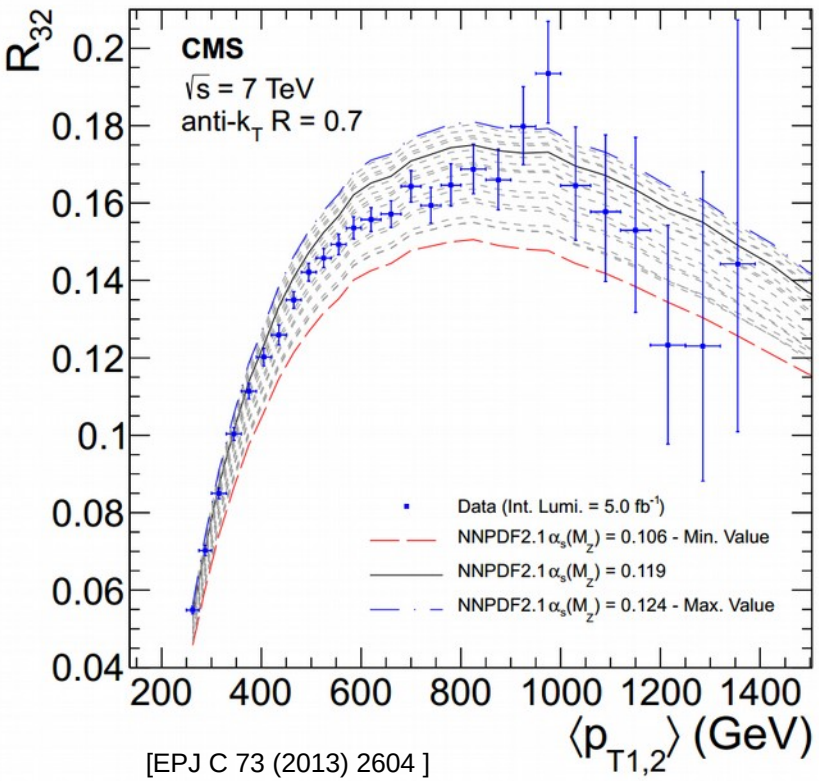


[EPJ C 73 (2013) 2604]

3-jet to 2-jet cross section ratio

- To avoid threshold effects, only region > 400 GeV fitted
- Scale choice is the average p_T of the two leading jets
- Fit result:

$$\alpha_S(m_Z) = 0.1148 \pm 0.0014(\text{exp.}) \pm 0.0018(\text{PDF}) \pm 0.0050(\text{theory})$$



[EPJ C 73 (2013) 2604]

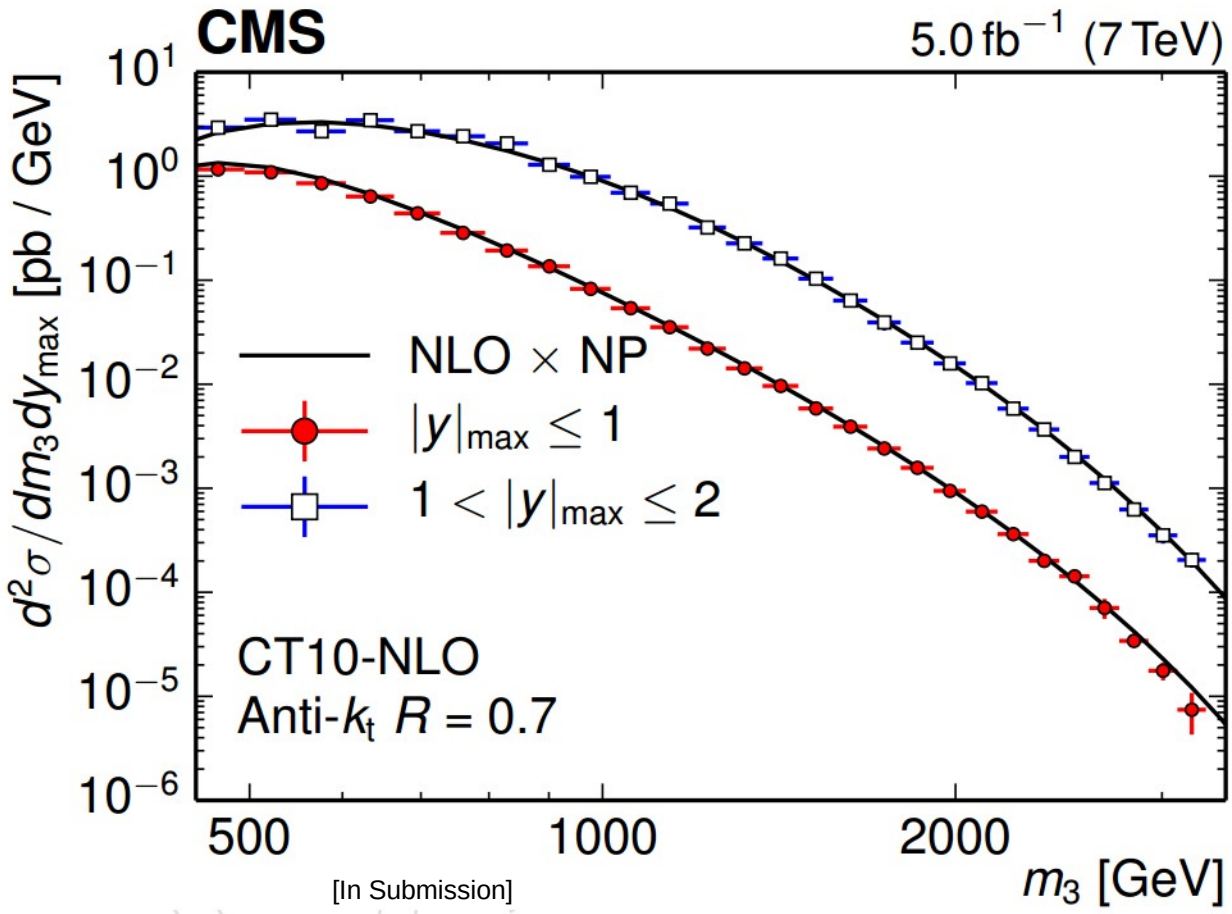
- Running can be tested by splitting measurement in Q-dependent regions

$\langle p_{T1,2} \rangle$ range (GeV)	Q (GeV)	$\alpha_S(M_Z)$	exp.	PDF	theory
420–600	474	0.1147	±0.0015	±0.0015	±0.0057
600–800	664	0.1132	±0.0018	±0.0025	±0.0039
800–1390	896	0.1170	±0.0024	±0.0021	±0.0048

3-Jet Production Cross Section

- Phase space defined by
  max. rapidity and invariant mass of the three-jet system
- Measured double differential 3-jet cross section
- Sensitive to PDFs and α_S

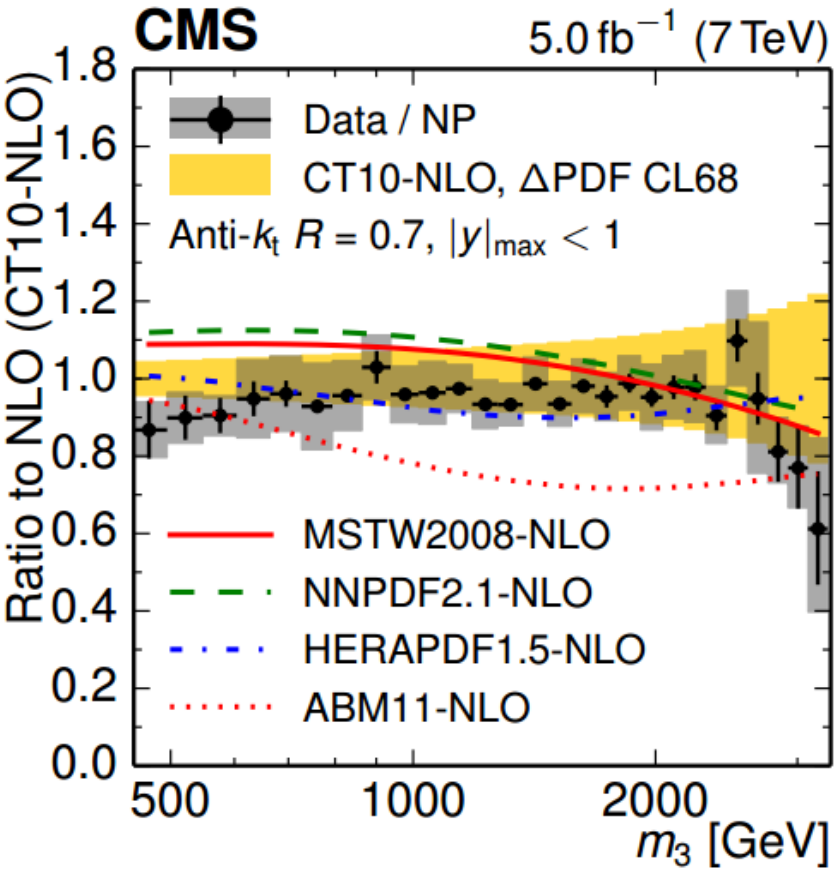
$$\frac{d^2\sigma}{dm_3 d|y|_{\max}}$$

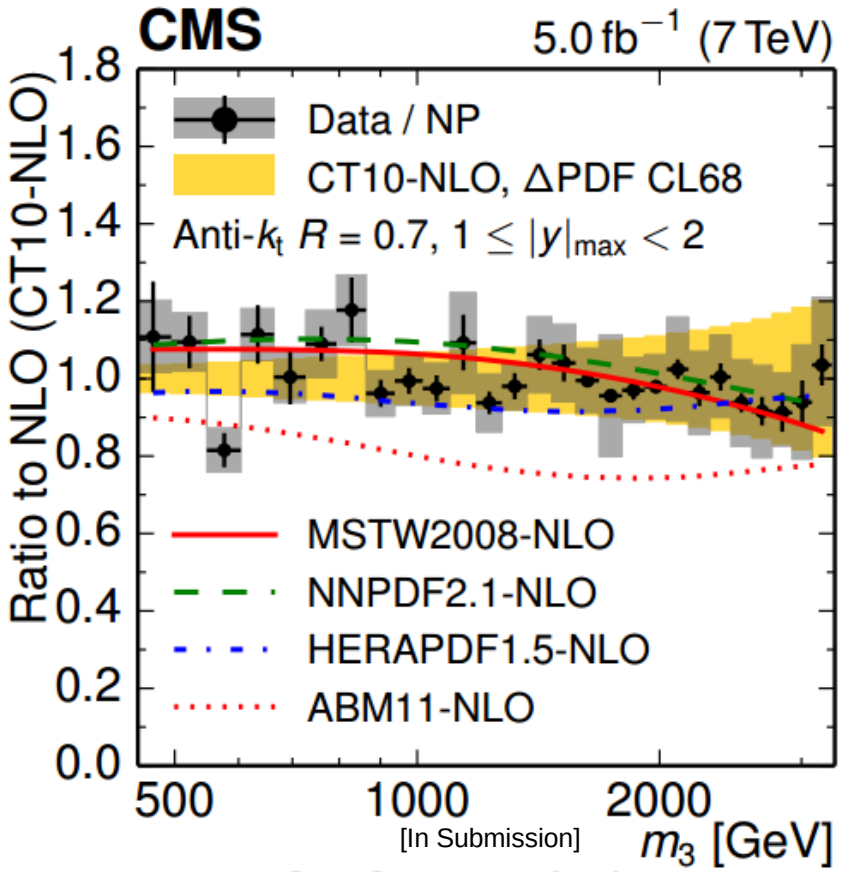


[In Submission]

α_s from the 3-Jet Production Cross Section

- Unfolded spectrum compared NLO+NP calculations
- Most PDFs describe data well



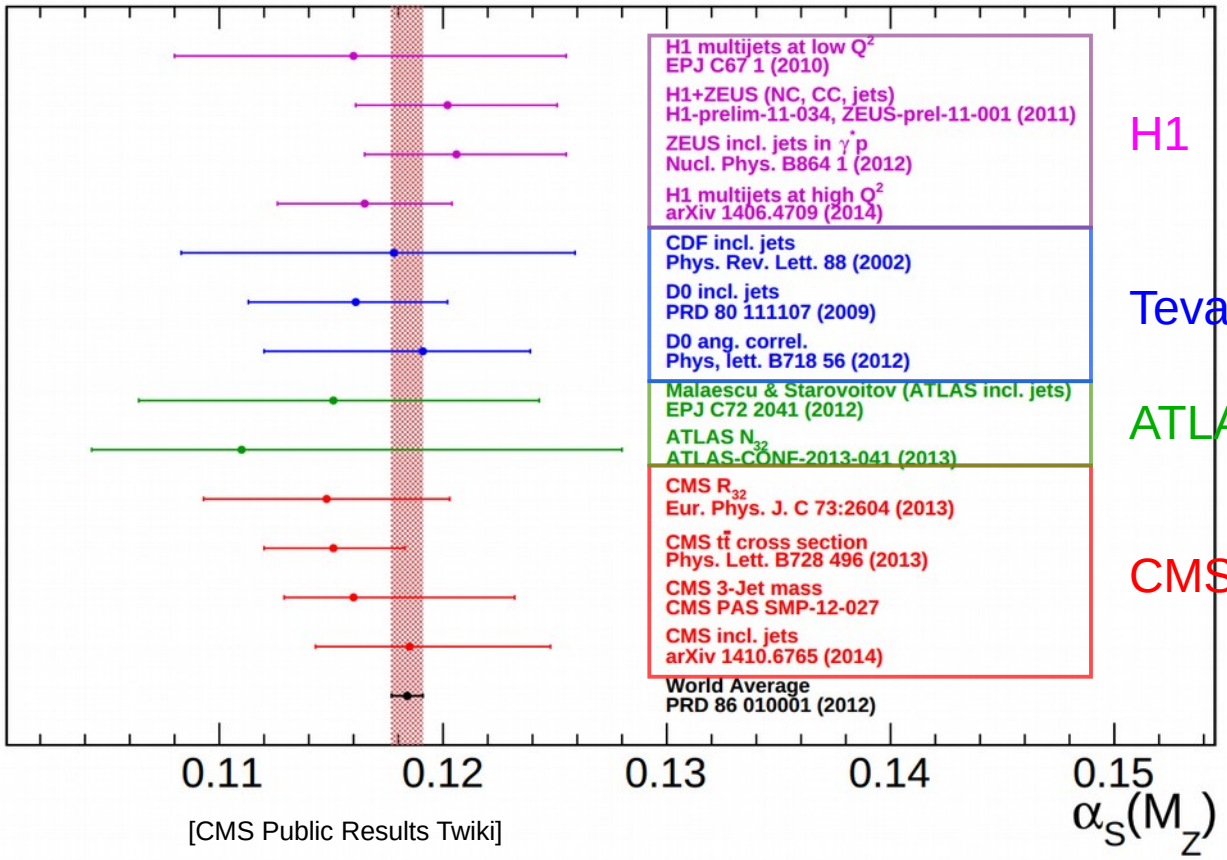


- Strong coupling extracted from both rapidity regions

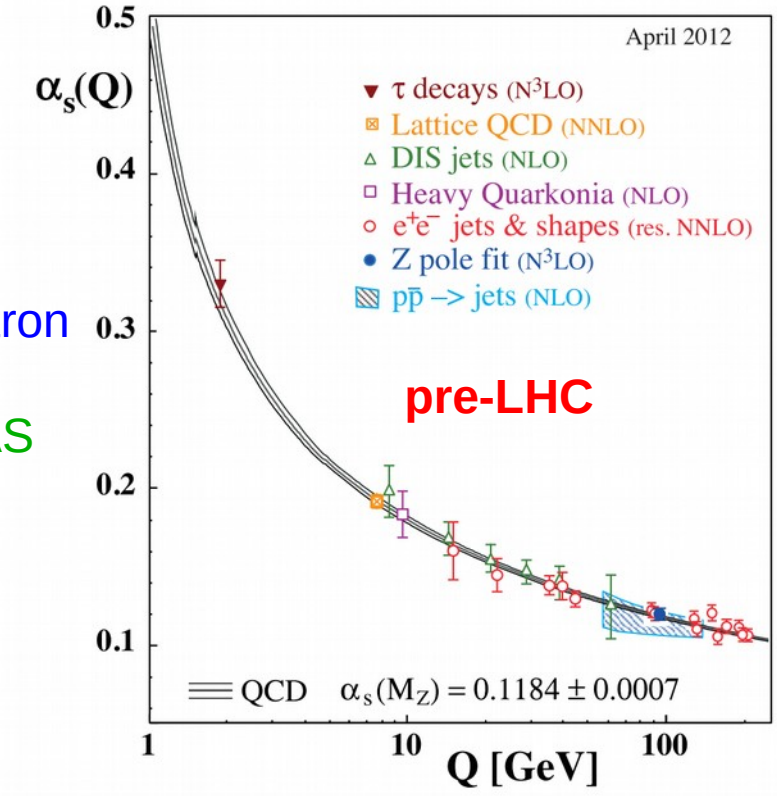
$$\alpha_S(m_Z) = 0.1171 \pm 0.0013(\text{exp.})^{+0.0073}_{-0.0047}(\text{theory})$$

Comparison of Results

- All extracted values of $\alpha_S(m_Z)$ from CMS measurements are in good agreement with each other and the world average
- Measurements can be used to test running of the Strong Coupling

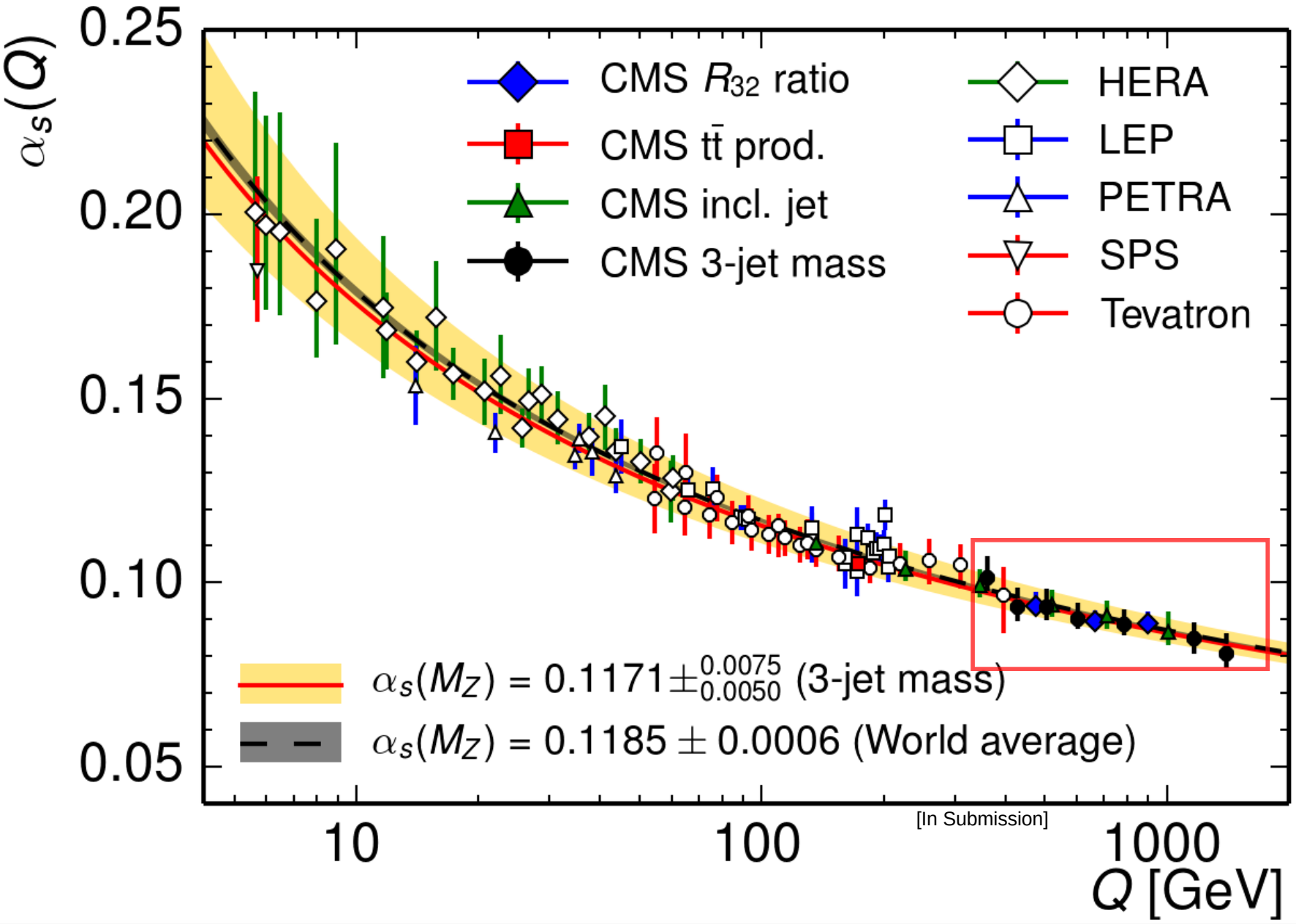


[CMS Public Results Twiki]

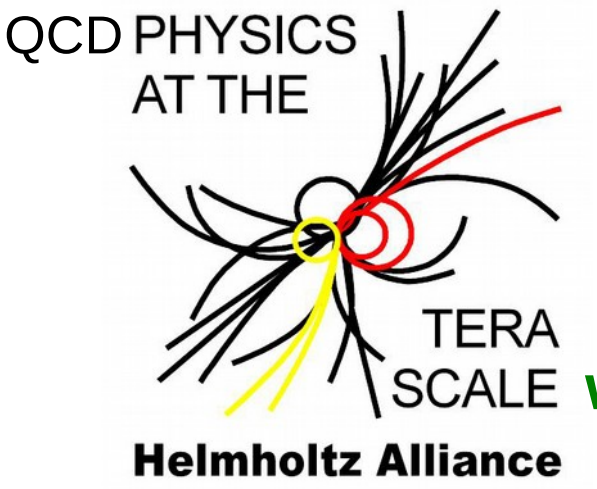


[PDG 2012]

Running of the Strong Coupling



Summary

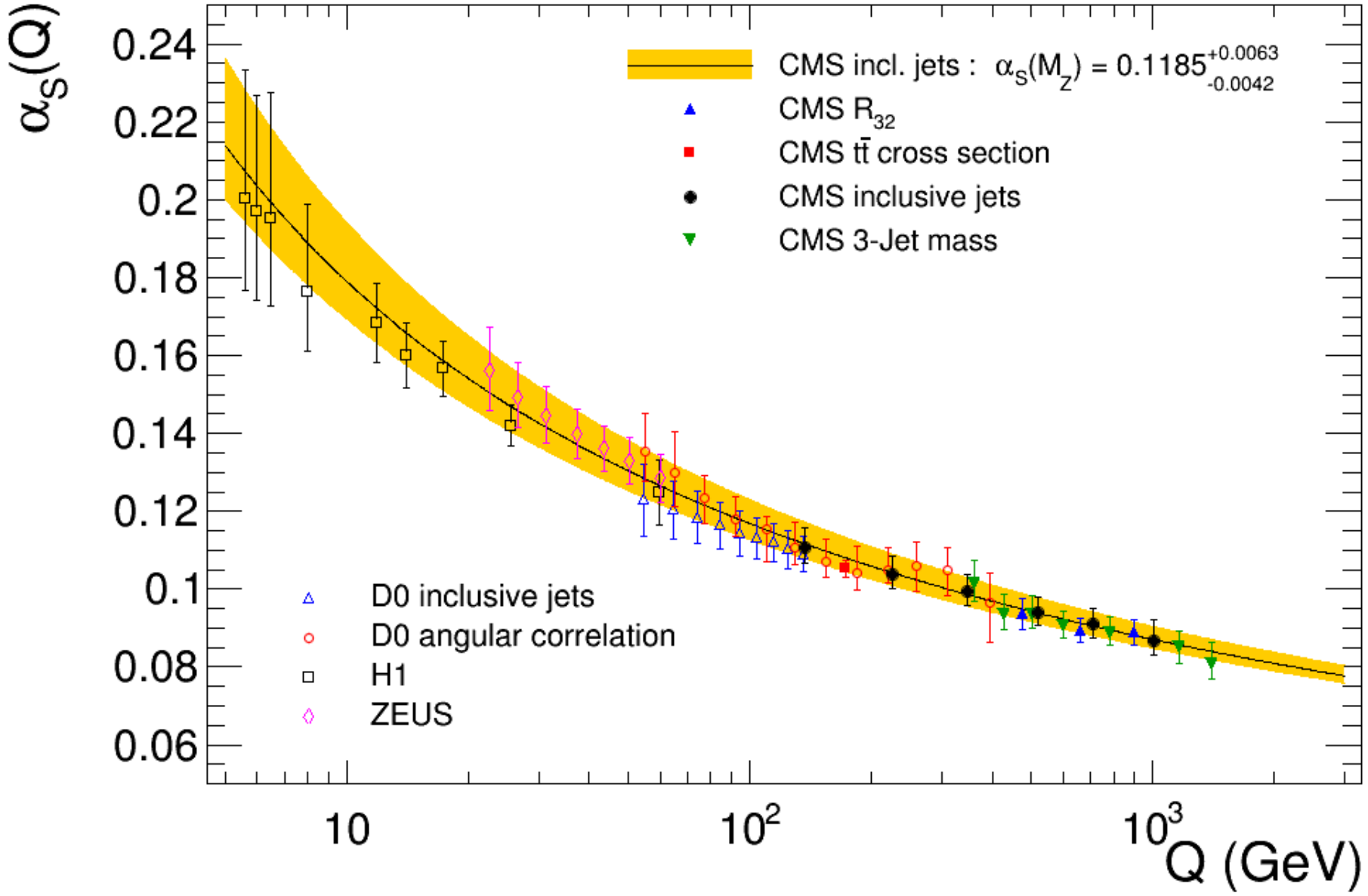


works magnificently!

- ✔ CMS measured jet production cross sections at **the TeV scale**
- ✔ Precision of **PDFs** and **Strong Coupling** improved with jet data
- ➔ **NNLO** jet calculations will further improve the precision and reduce the scale uncertainties
- ➔ Preparations for LHC Run 2 ongoing
  - ➔Probe QCD at even higher scales

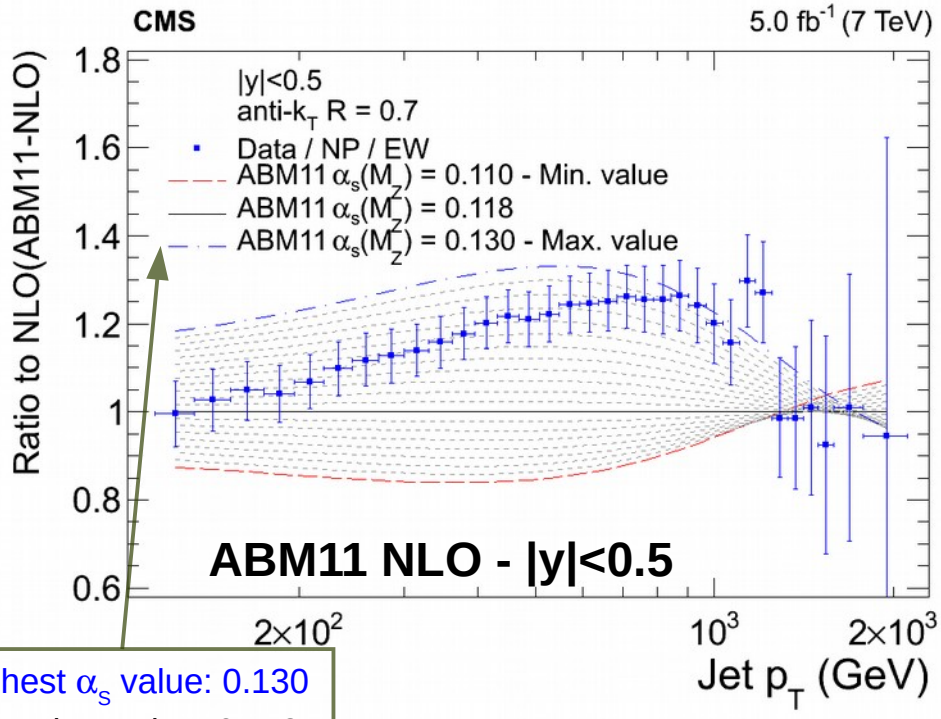
Additional material

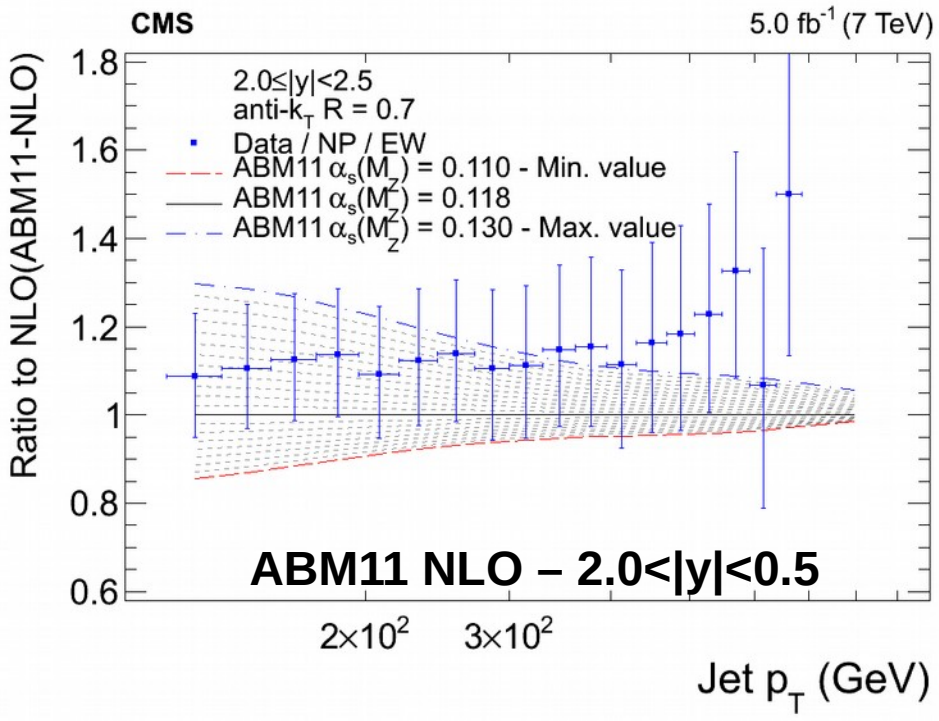
Running of the Strong Coupling



Sensitivity of $\alpha_s(m_Z)$: ABM11-NLO

- Sensitivity plots show the ratio of predictions with different values of $\alpha_S(m_Z)$ to the central PDF predictions
- Data with total uncertainty is shown
- Inclusive jet data are not well described using ABM PDFs
  - omitted from further study



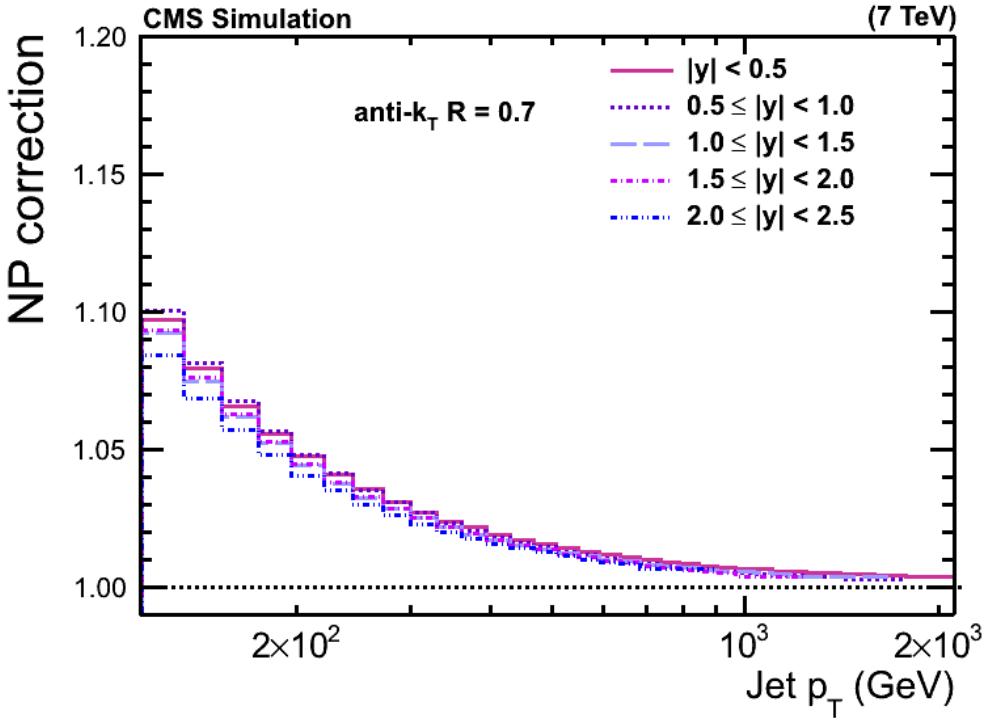


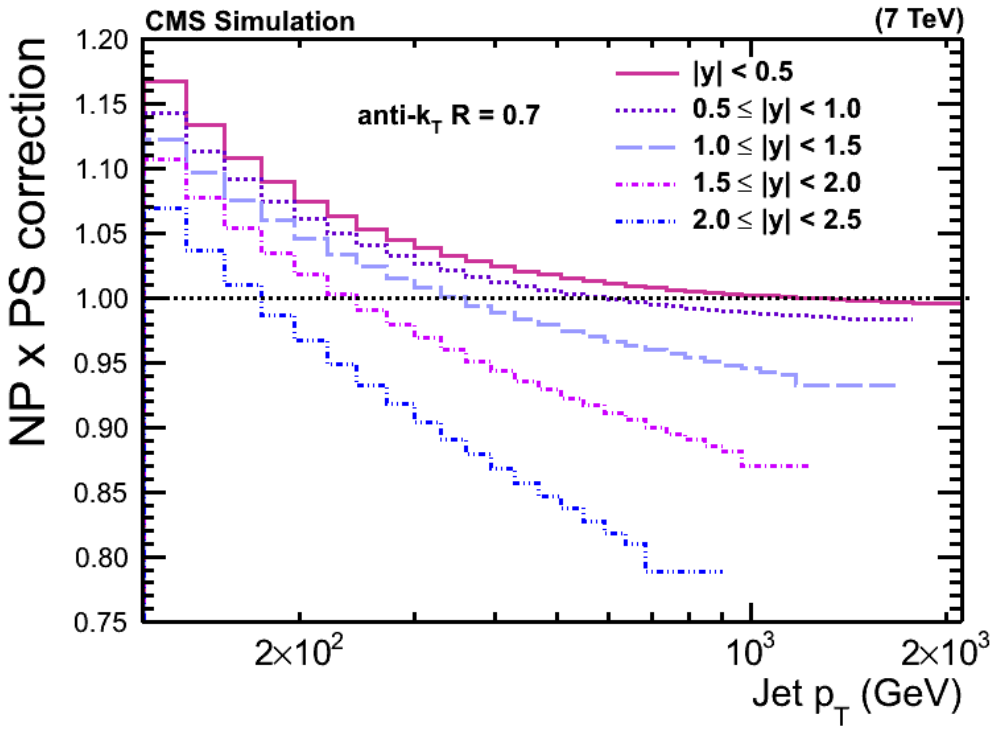
Highest α_s value: 0.130
Central α_s value: 0.118
Lowest α_s value: 0.110

[arXiv:1410.6765]

NP & PS Correction

- NP defined as the center of the envelope given by the three predictions $C^{\mathrm{NP}} = \dfrac{\sigma_{\mathrm{(N)LO+PS+HAD+MPI}}}{\sigma_{\mathrm{(N)LO+PS}}}$
- PS correction determined as the average of the predictions from the two extreme scale limits $C^{\mathrm{PS}} = \dfrac{\sigma_{\mathrm{NLO+PS}}}{\sigma_{\mathrm{NLO}}}$
- NP * PS correction investigated in a complementary study

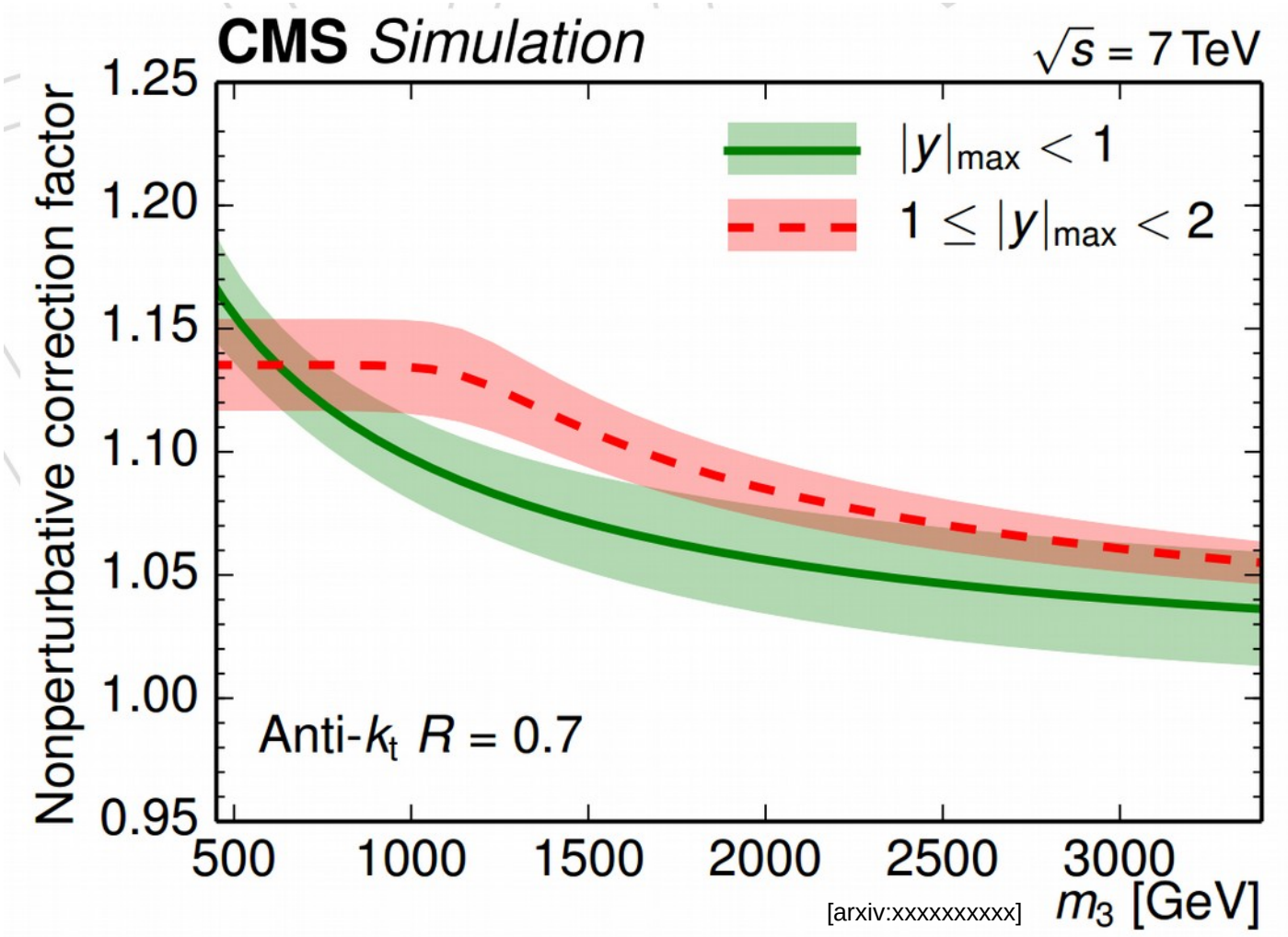




[arXiv:1410.6765]

NP Corrections 3-Jet Production Cross Section

- NP corrections derived using Sherpa and MG5+P6
- Improved multijet simulation compared to Herwig++/Pythia



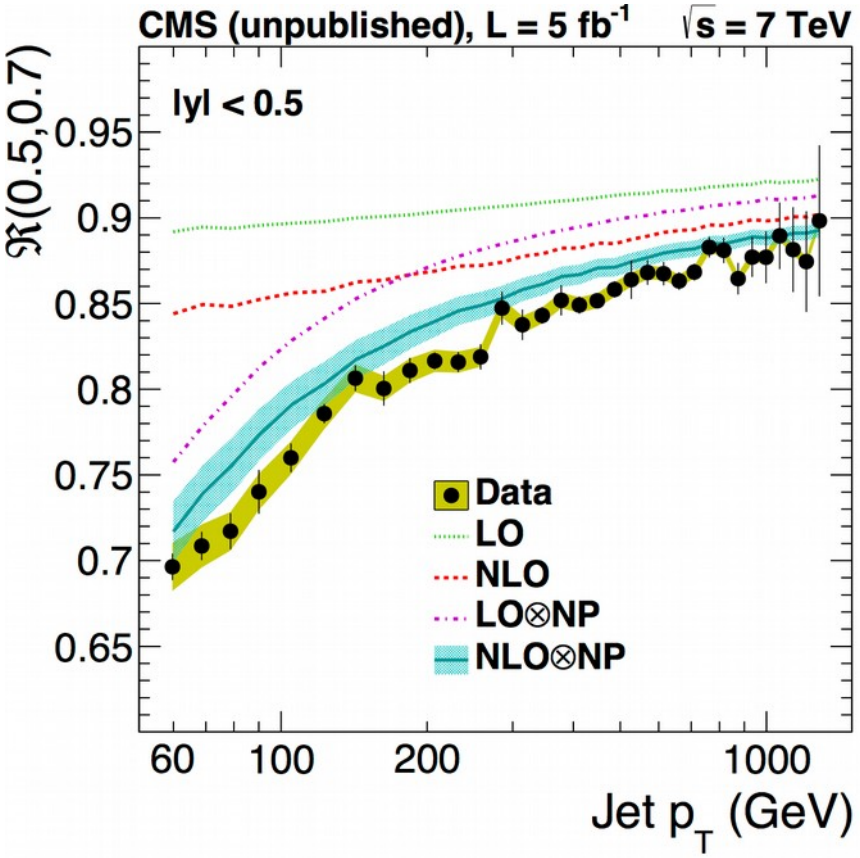
PDF determination using Data Driven Regularization

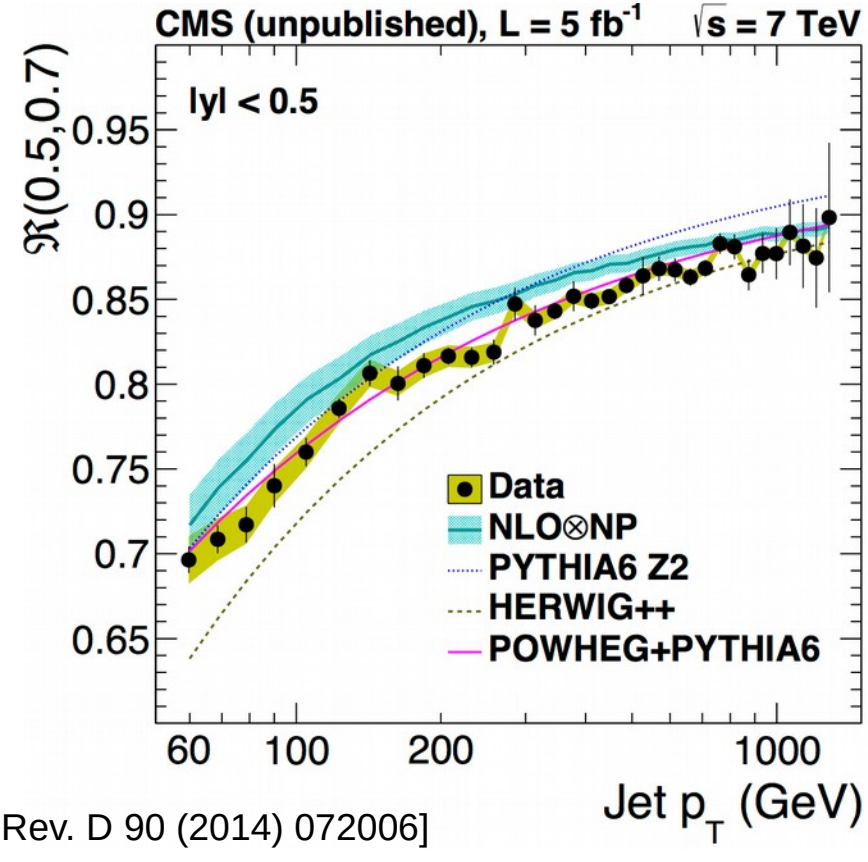
- Possibly the 13p-parametrization is to strict
  - It isn't possible to fit with more free parameters due to reduced datasets (DIS+CMS jet data) → global PDF fits use more parameters AND more data
  - multiple minima appear/ no miminization possible
- HERAFitter offers possibility to use data-driven-regularization to fit PDFs with more free parameters 22p
  - very similar to NNPDF method
- Strategy

1) Replica pseudo-datasets created as in Toy Monte Carlo study
2) Pseudo-data sample is split into a fit and control sample
3) PDF fit is performed with the fit sample and Chi2 of the fit sample is minimized
4) At the same time the chi2 of the control sample is calculated using the pdf parametrization of current iteration of the PDF fit
5) At the beginning of the fit, chi2 of fit and control sample both decrease monotonically
6) When the minimization begins to fit statistical fluctuations the Chi2 of the control sample begins to increase while the chi2 of the fit sample decreases further
7) Fit is stopped to prevent overfitting

Inclusive Jets – Ratio of R=0.5 and 0.7

- Ratio of different jet clustering sizes
- Large discrepancies when comparing to LO simulations and also to fixed order calculation at NLO+NP
- NLO calculation with matched parton showers describe data well





[Phys. Rev. D 90 (2014) 072006]