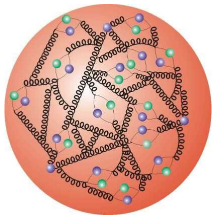
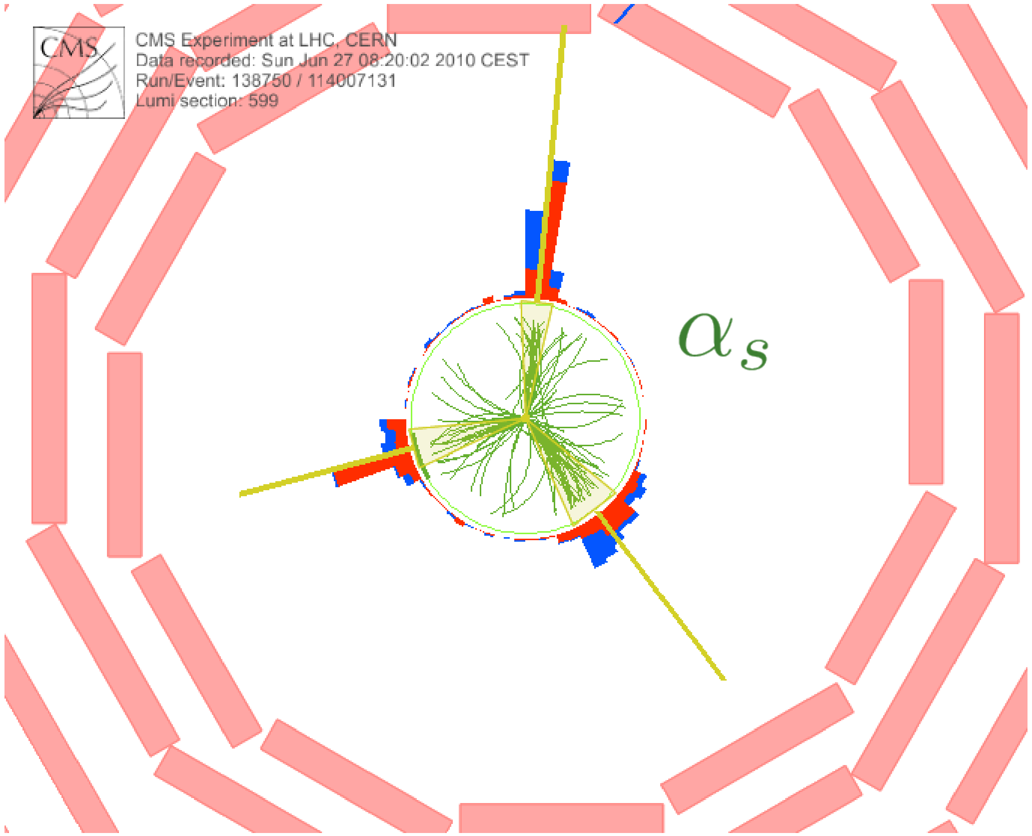
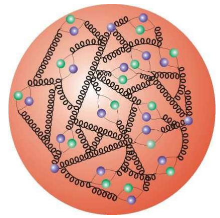
Determination of the strong Coupling from 3-Jet Rates at the Terascale



Proton Structure (PDF)





Proton Structure (PDF)

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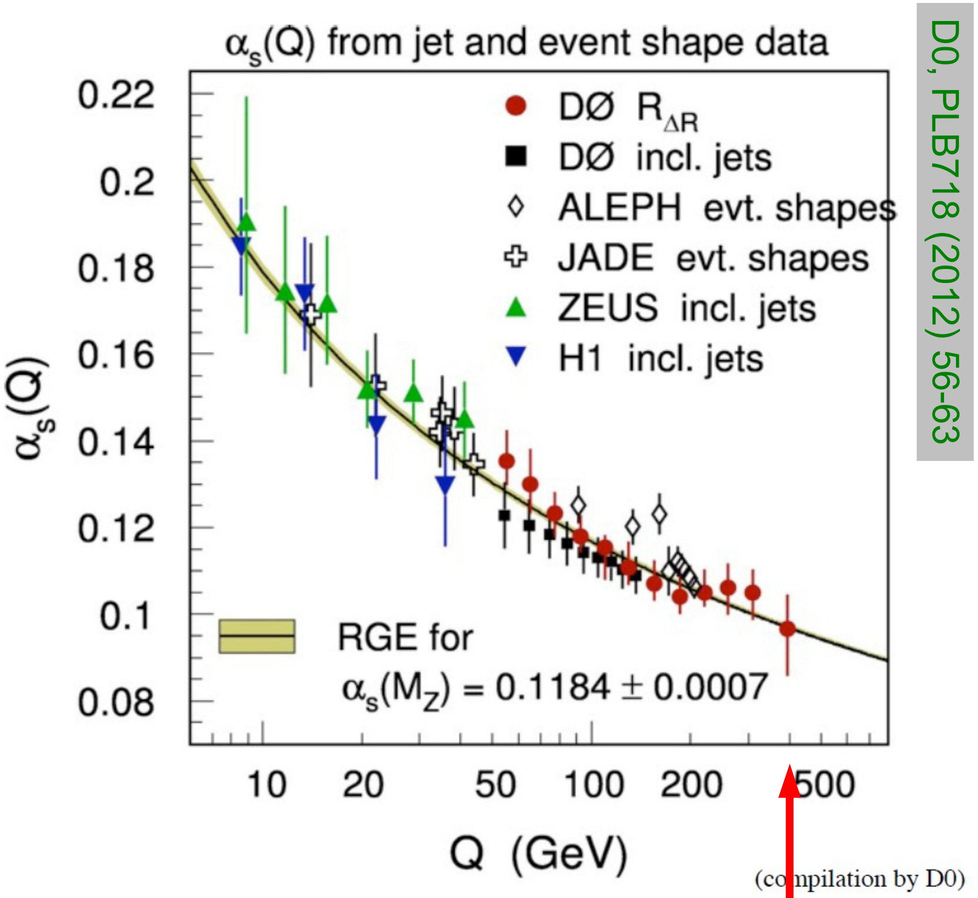
Outline

- **Motivation**
- **The Measurement**
- **Uncertainties**
- **Comparison to Theory**
- **Extraction of the strong Coupling α_s**
- **Conclusions and Outlook**



D0, PLB718 (2012) 56-63

Tevatron limit published this year

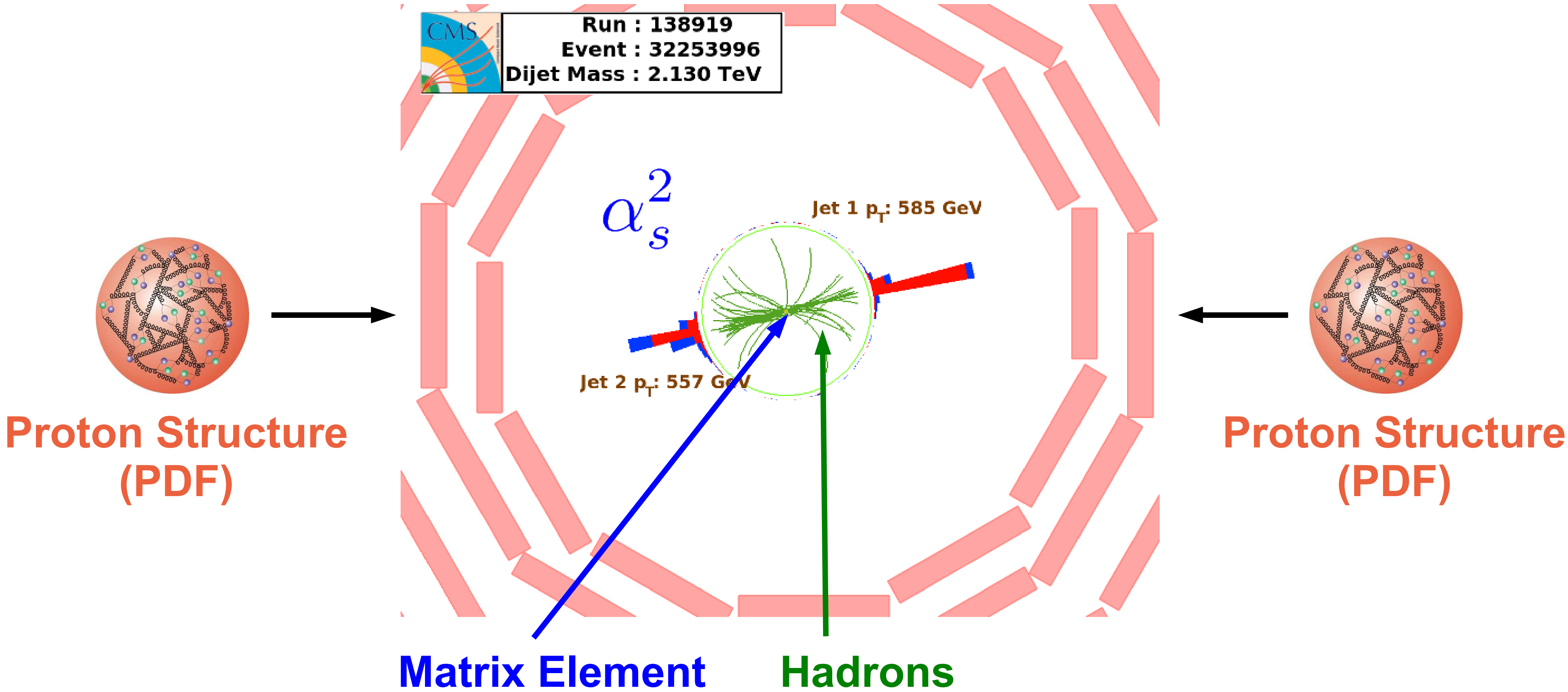
CMS-PAS-QCD-11-003 (2012).

We'll start here ...

All results without explicit reference are taken from this CMS analysis!

Jets at LHC

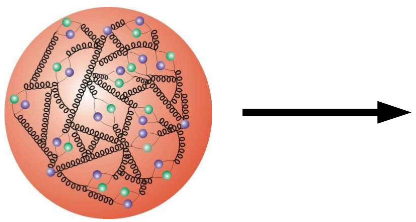
Abundant production of jets → hadron colliders are "jet laboratories"
Learn about hard QCD, the proton structure, non-perturbative effects ...



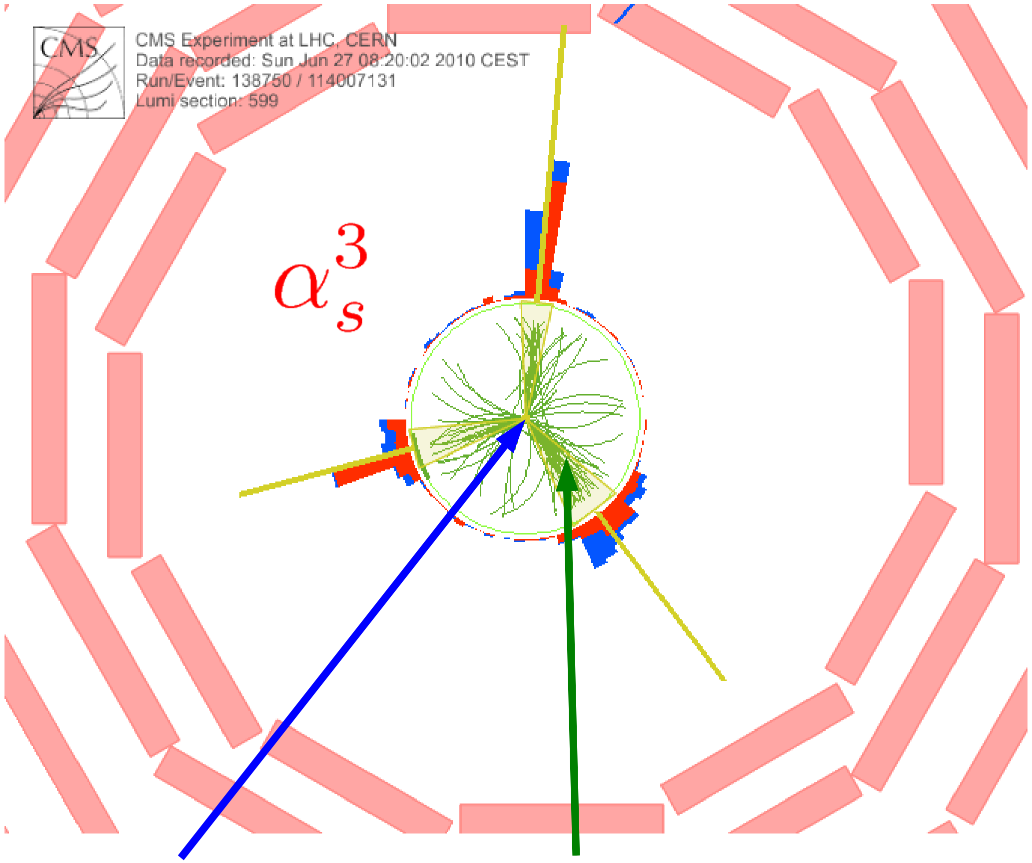
Jets at LHC

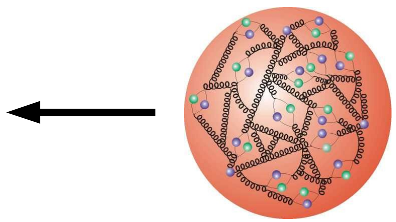
Abundant production of jets → hadron colliders are "jet laboratories"

… and the strong coupling alpha_s !



Proton Structure (PDF)





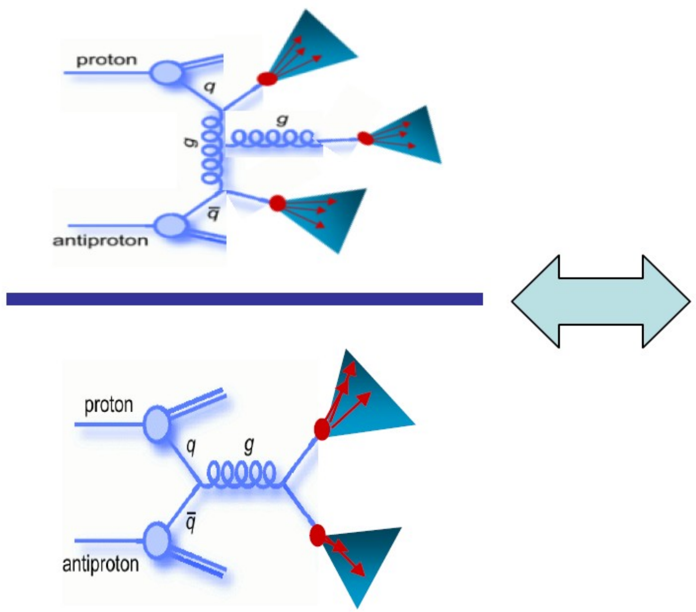
Proton Structure (PDF)

Matrix Element **Hadrons**

3-Jets and α_s

M. Wobisch

- **Avoids direct dependence on PDFs and the RGE of QCD**
- **Use cross-section ratios!**
- **→ reduces other theor. and exp. uncertainties along the way**
- **→ eliminates luminosity dependence (normalization)**
- **Choices of CMS:**
  - **Ratio of inclusive 3-jet to 2-jet production**
  - **Average dijet p_T as scale**
  - **Scalar p_T sum (H_T) disfavoured**
- **Other 3-jet observables possible, see e.g. propositions by D0**



α_s

$$R_{32} = \frac{d\sigma_{3+}/dp_{\mathrm{T}}}{d\sigma_{2+}/dp_{\mathrm{T}}} \propto \alpha_s(Q)$$

$$Q = \langle p_{\mathrm{T}1,2} \rangle = \frac{p_{\mathrm{T}1} + p_{\mathrm{T}2}}{2}$$

D0, PLB718 (2012) 56-63

Analysis Setup

- CMS data of 2011 $\mathcal{L}_{\text{int}} = 5.0\,\text{fb}^{-1}$
- Anti-kT jet algorithm with R = 0.7
  - Compatible results with R = 0.5 as alternative
- Selection in rapidity y (1 bin): $|y| < 2.5$
  - Ensure tracker coverage
  - Two jets leading in p_T must be selected
  - Ensure hard dijet event
- Minimal transverse momentum p_T: $p_{\text{T}} > 150\,\text{GeV}$
  - Alternative thresholds 50 and 100 GeV checked
  - Alternative relative cut on hardness of 3rd jet tested
- Minimal average 2-jet $\langle p_{T1,2} \rangle$ (27 bins): $\langle p_{\text{T}1,2} \rangle > 250\,\text{GeV}$
- O(2000) 2-jet ev. incl. O(300) 3-jet events above 1 TeV

Data Treatment

- Three single-jet triggers (highest p_T threshold 370 GeV) $\epsilon = 100\%$
  - Efficiency checked separately for incl. 2- and 3-jet events
- Particle-flow technique to reconstruct input objects to jet clustering $\epsilon > 99\%$
- Standard CMS event and jet selection criteria apply
- (η,p_T)-dependent jet energy correction factors, typically: $c_{\mathrm{JEC}} \approx 1.2 \ldots 1.0$
- Correction of detector effects using Bayesian iterative unfolding (RooUnfold) $c_{\mathrm{DET}} < 5\%$
  - Propagation of stat. uncertainties & correlations with MC toy method
  - Cross-checked with SVD unfolding
  - Comparison of directly unfolded ratio R_{32} versus separate unfolding of inclusive 2- and 3-jet spectra

Experimental Uncertainties

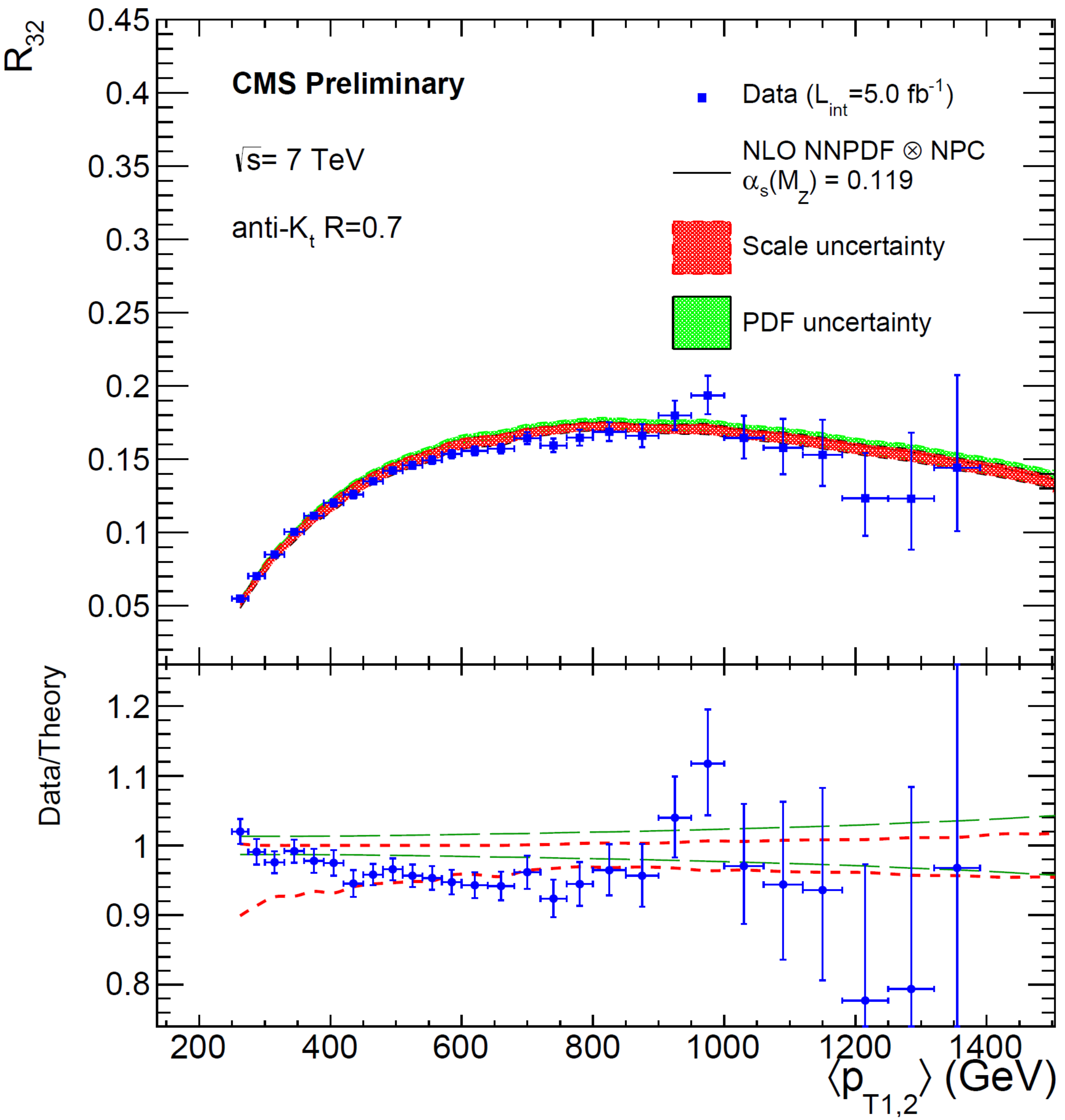
- **Jet energy correction, known to 2.0 - 2.5%:** $\Delta R/R \approx 1.2\%$
  - **Provided as 16 mutually uncorrelated sources; fully correlated within source; Gaussian behaviour assumed**
  - **Dominated by absolute scale, followed by high pT extrapolation**
- **Unfolding uncertainty accounting for:** $\Delta R/R < 1.0\%$
  - **Variation of jet p_T spectral slopes following differences from Pythia6 Z2 (agrees with MadGraph) and Herwig++ 2.3**
  - **Variation of jet energy resolution (JER)**
  - **Addition of non-Gaussian tails to JER**
- **Luminosity (normalization) uncertainty cancels**
- **No assumptions on bin-to-bin correlations with respect to y necessary, only 1 bin considered**
- **Statistical uncertainties propagated via unfolding**

Theory Predictions

- Using NLOJet++ within fastNLO framework
  - Fast recalculable NLO incl. 2- and 3-jet cross sections
  - Same binning as the data
- Using global PDF sets at NNLO with fits for series of alpha_s values
  - NNPDF21, MSTW2008, CT10 and ABM11
  - Difference between use of NLO vs. NNLO PDF found negligible for R_{32}
- Scale uncertainties evaluated via 6-point scheme
  - Max. deviations using scale factors (1/2,1/2), (1/2,1), (1,1/2), (1,2), (2,1), (2,1/2) for renormalization and factorization scales
- Non-perturbative corrections account for effects of multiple parton interactions and hadronization
  - Correction below 2%, uncertainty negligible

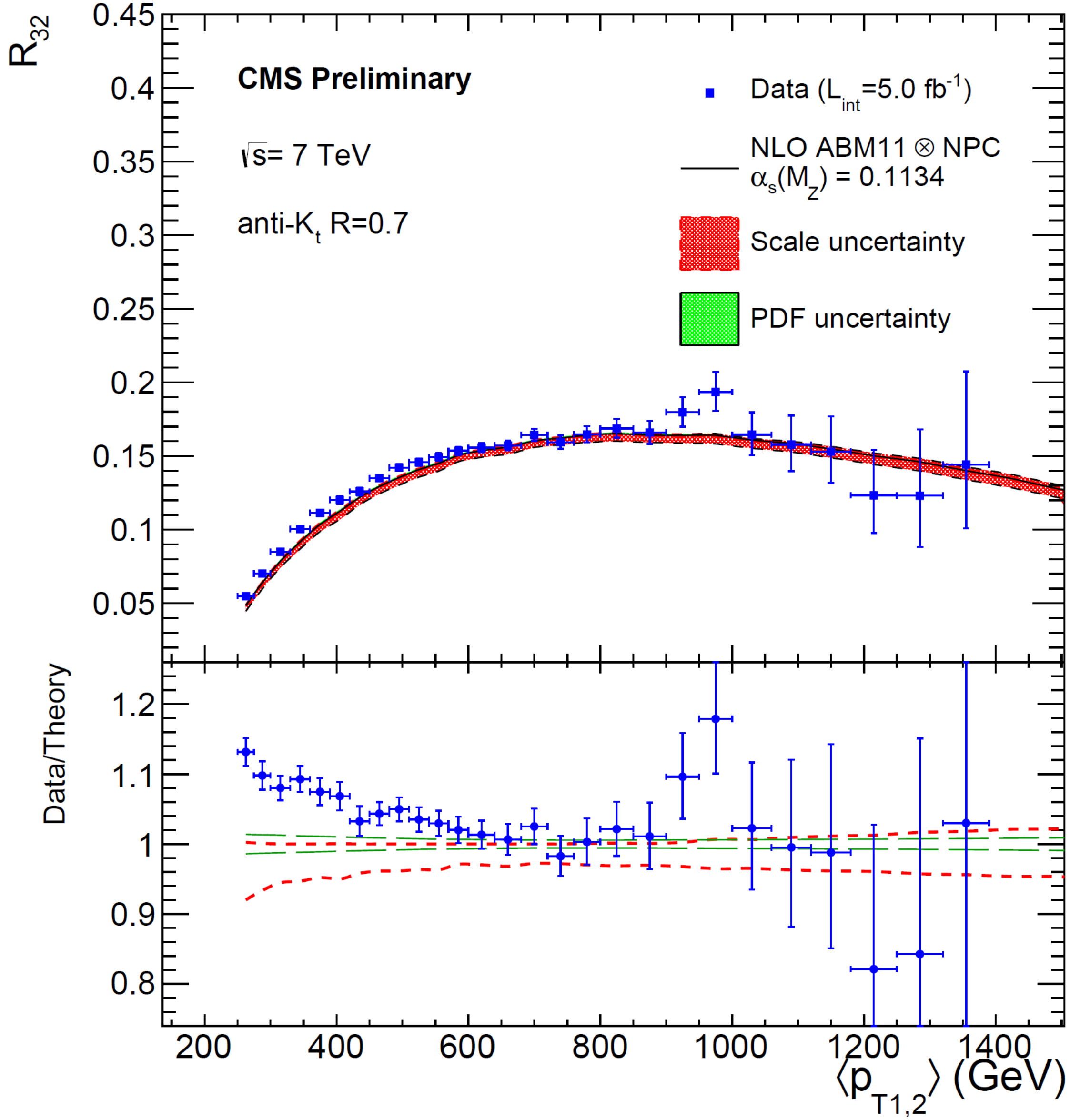
Data comparison to NNPDF21

- **Agreement within uncertainties**
  - **Scale uncertainty:** $^{+2}_{-5}\%$
  - **PDF uncertainty:** $1.5 - 2.3\%$
- **Fits only above 400 GeV to avoid threshold effects**
- **Similarly described by CT10 and even better by MSTW2008**
- **Discrepancies observed with ABM11**



Data comparison to ABM11

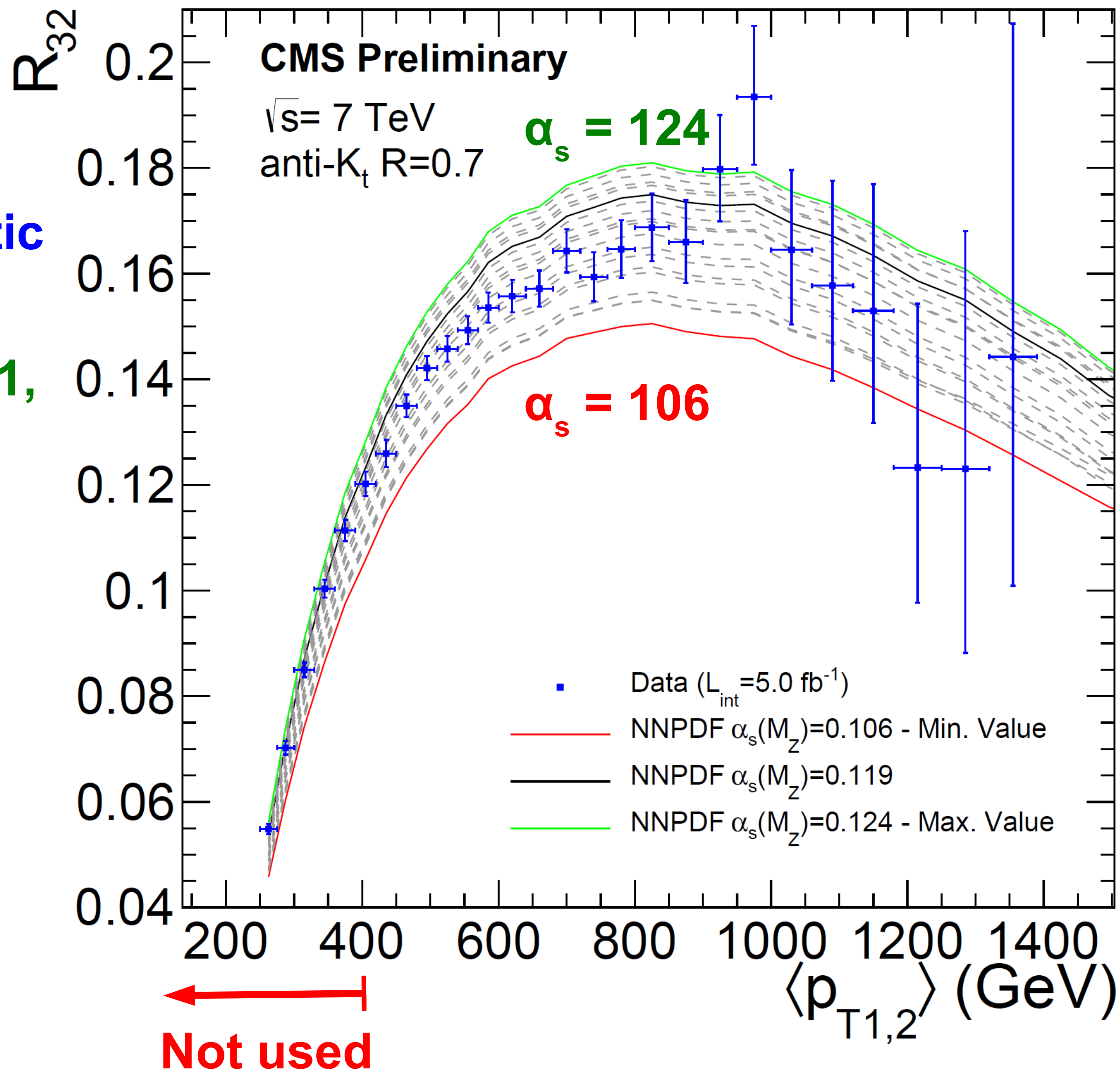
- **Discrepancies with ABM11 especially below 600 GeV**
- **Fits of the strong coupling tend versus the upper edge of the available series in alpha_s**
  - **No result from ABM11 to report**
- **Much smaller gluon down to 50% at high x at the same time as preference for smaller couplings**
- **Decorrelation of gluon and alpha_s via higher twist not present in other global PDFs ?**
- **Provide ABM11 PDFs with different settings for higher twist ?**
- **To be further discussed ...**



Sensitivity to alpha_s

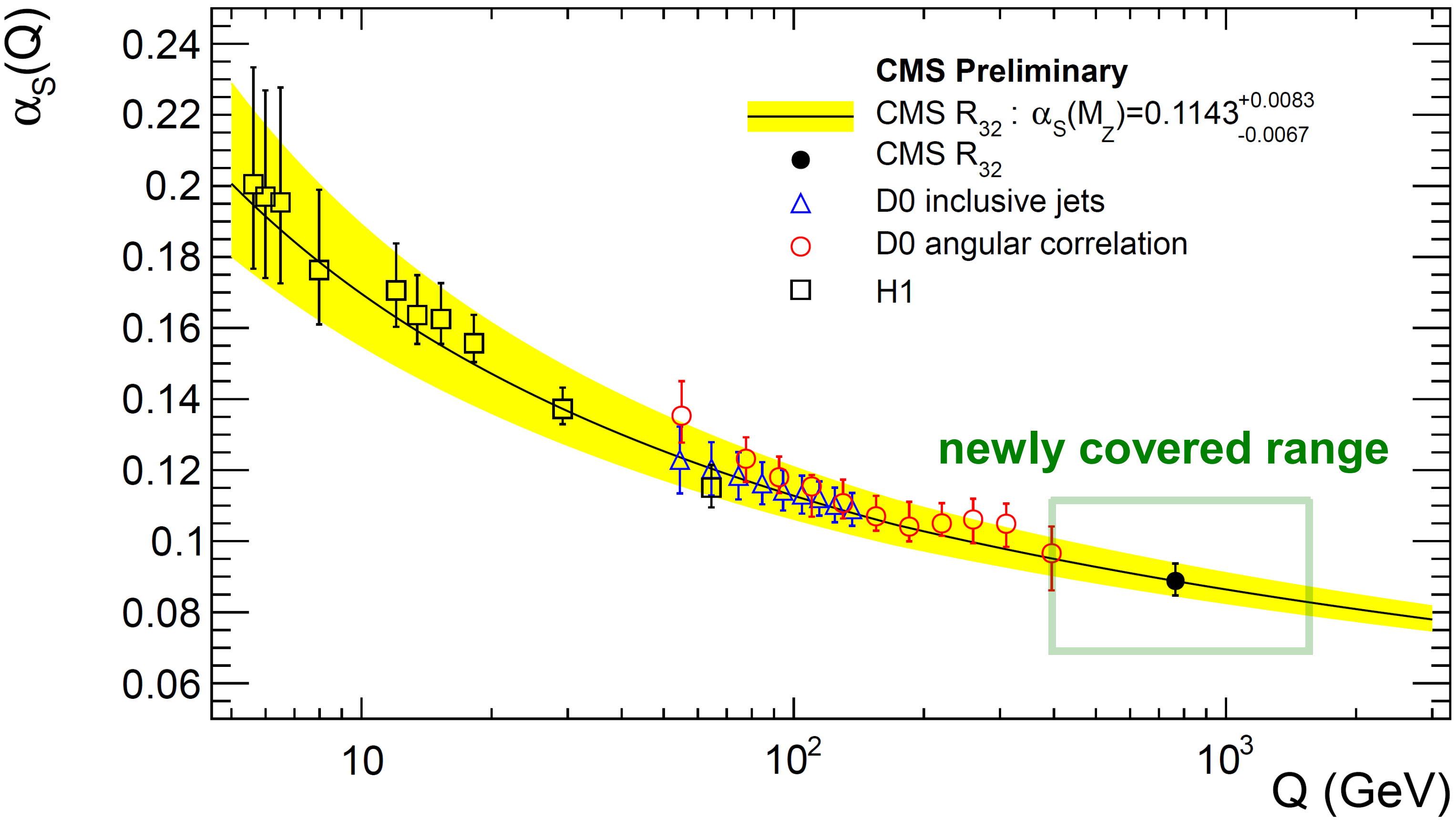
- Fits only above 400 GeV to avoid threshold effects
- Error bars show full uncertainty including the correlated systematic ones
- Compatible results from NNPDF21, CT10 and MSTW2008 with χ^2 fit using correlated experimental uncertainties:

NNPDF21: $\alpha_s(M_Z) = 0.1143 \pm 0.0064$
CT10: $\alpha_s(M_Z) = 0.1130 \pm 0.0080$
MSTW2008: $\alpha_s(M_Z) = 0.1135 \pm 0.0096$



Determination of alpha_s

- **Comparison to extractions from other hadron collider experiments**
- **Although only one point shown here extraction works equally well in e.g. four subranges**



PDF uncertainty: **Repeat fit for each replica → get estimators for μ and σ**
Scale uncertainty: **Repeat fit for all six variations → get maximal deviation**

$$\alpha_s(M_Z) = 0.1143 \pm 0.0064\,(\mathrm{exp}) \pm 0.0019\,(\mathrm{PDF}) \pm^{0.0050}_{0.0000}\,(\mathrm{scale})$$

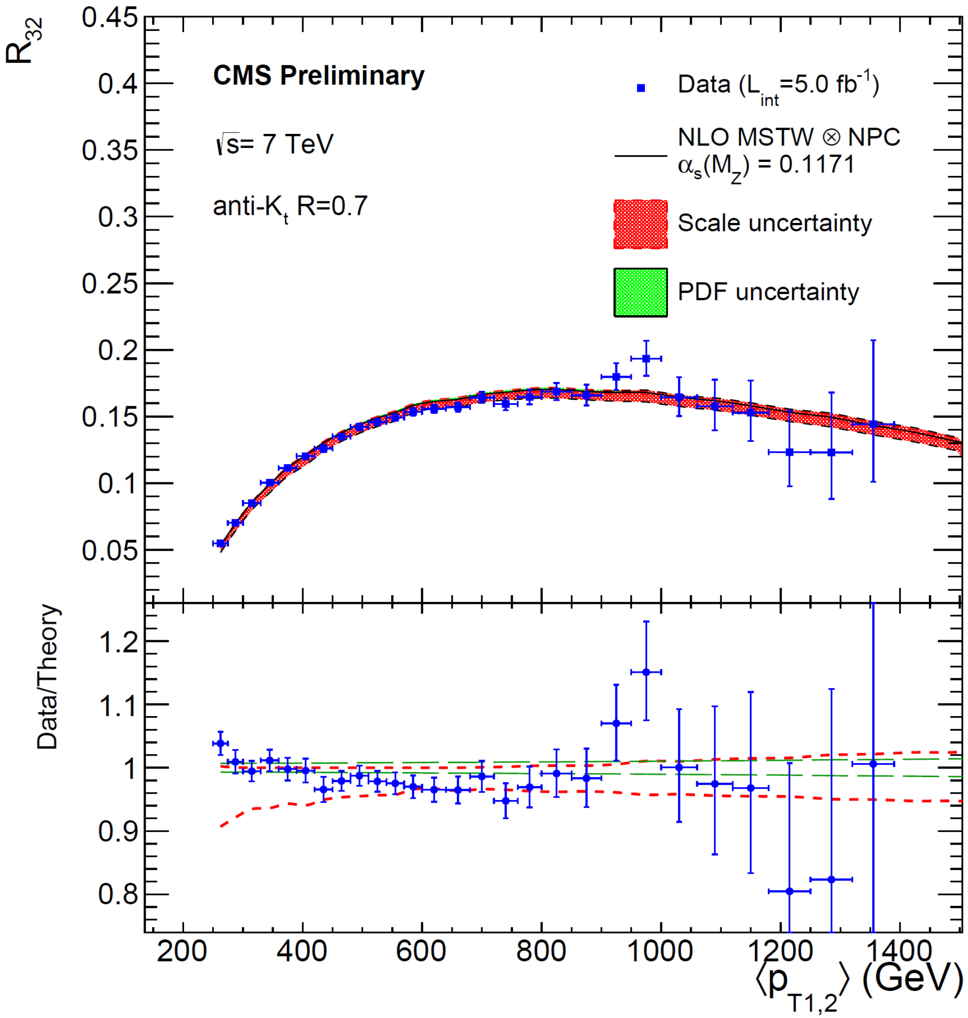
Conclusions & Outlook

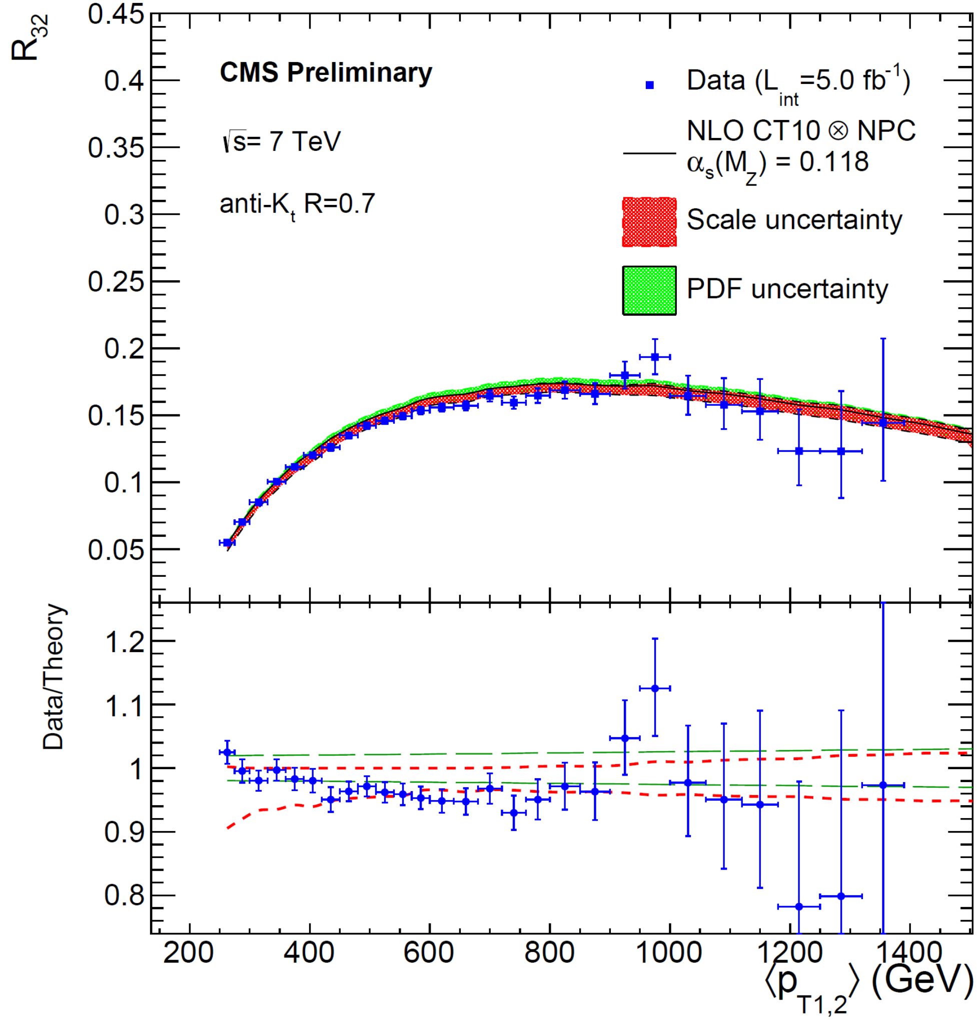
- First determination of the strong coupling at the Terascale (TeV)
- Running of α_s tested with mostly PDF independent ratio observable R_{32}
- No deviation from expected running, i.e. almost flat at high p_T, observed as could be expected from new coloured particles e.g. gluinos
- More data at high pT and test of other observables may still improve achievable statistical and experimental accuracy
- More precise theory (jets at NNLO …) desperately wanted!

Thank you for your attention!

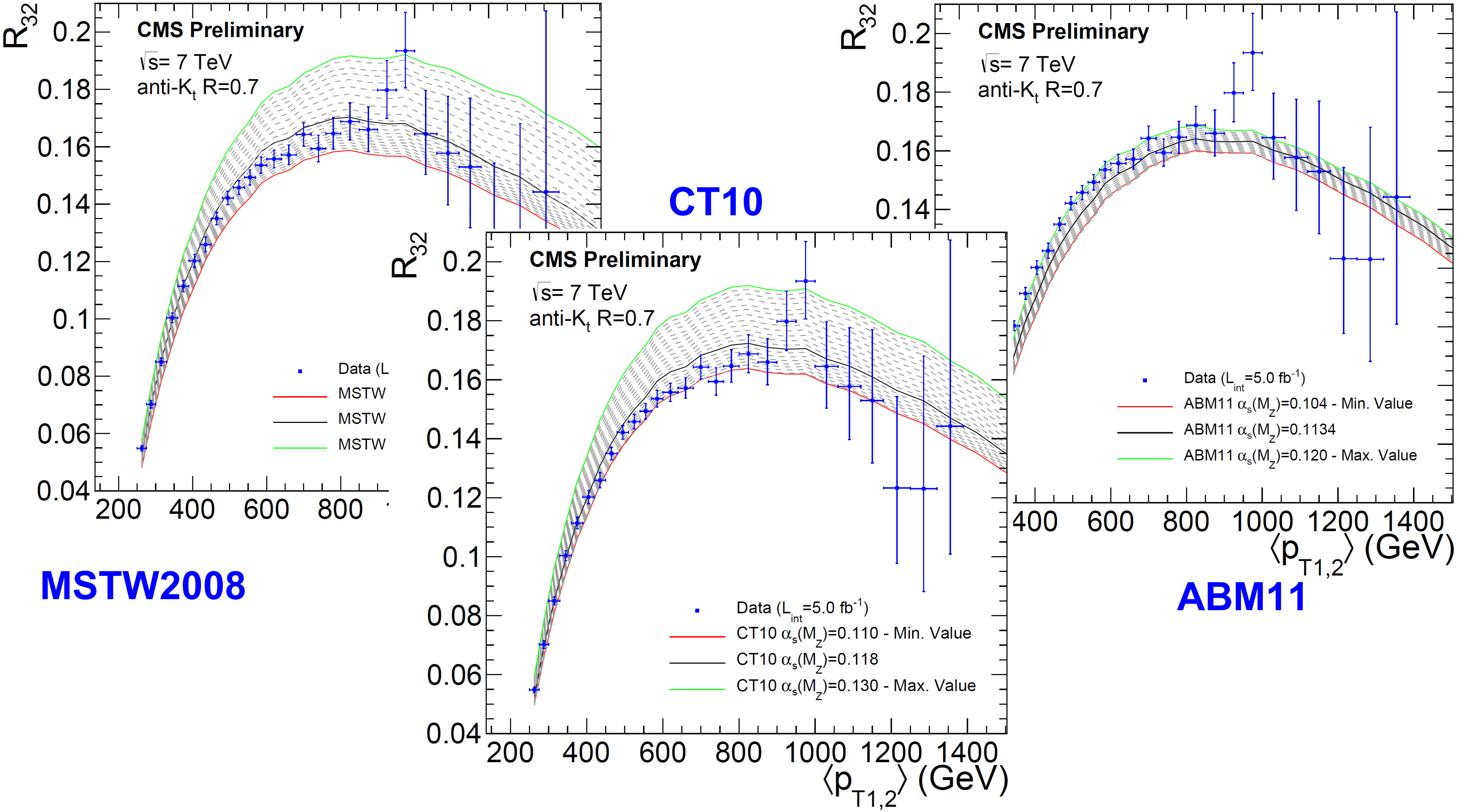
Backup Slides

Data comparison to MSTW2008 and CT10



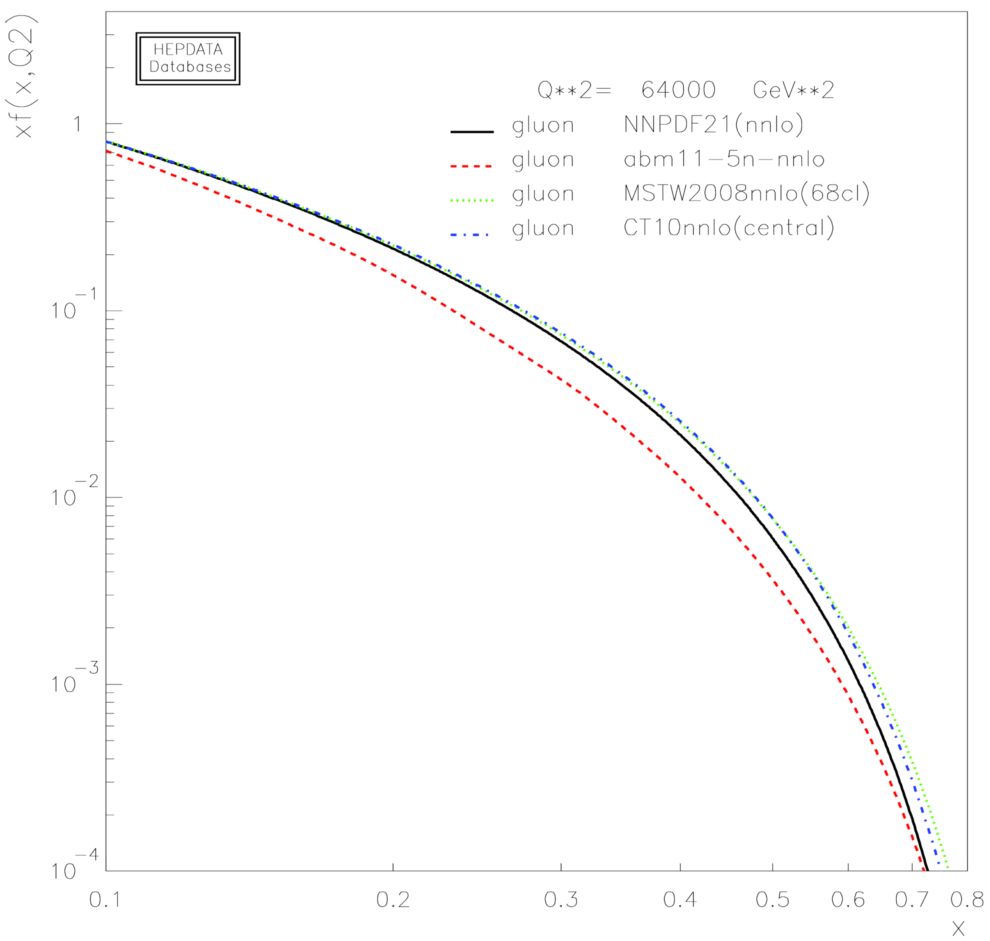


Sensitivity to alpha _s (other PDFs)

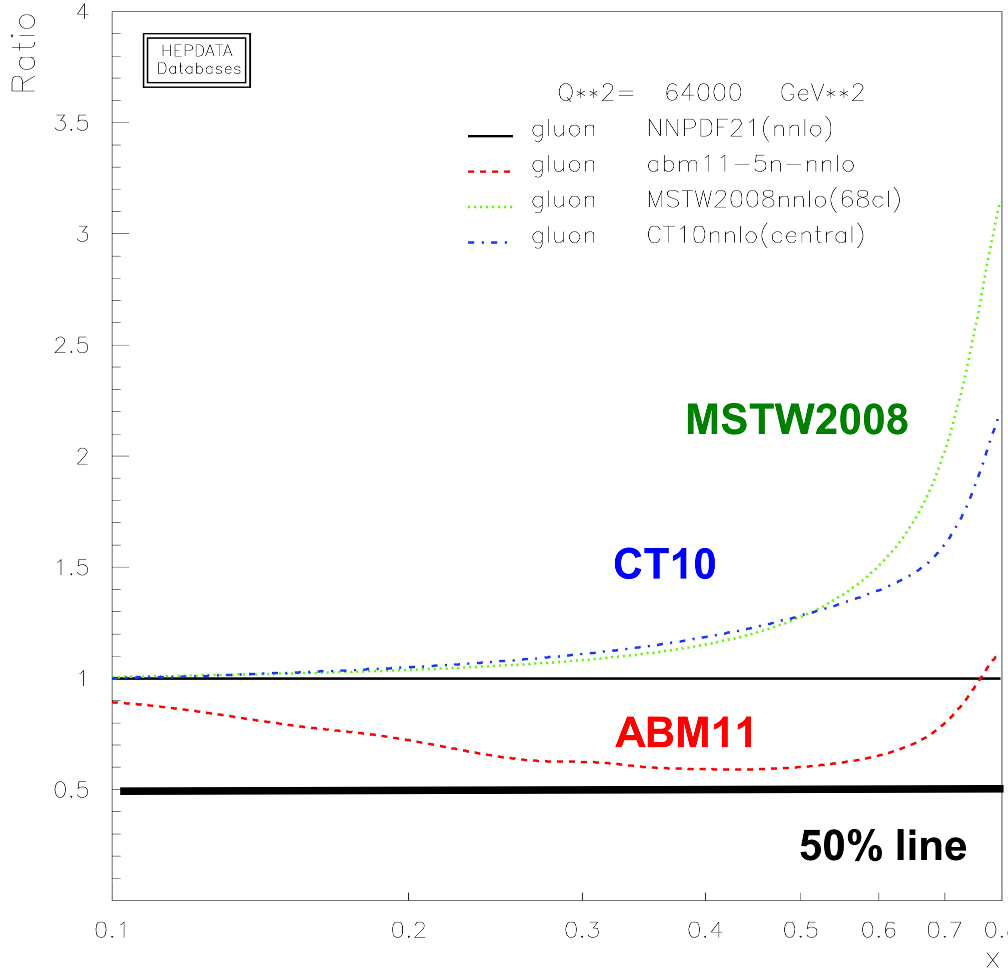


Gluon PDF at high x

xg(x,Q2)



Ratio to NNPDF21

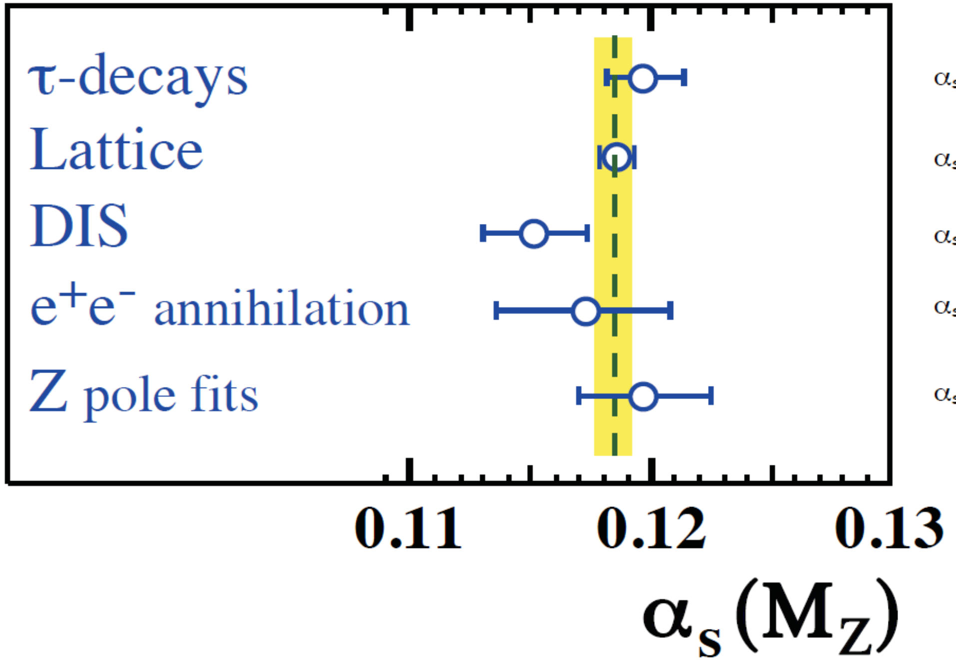


x from 0.1 to 0.8; Q^2 = 64000 GeV^2

HEPDATA PDF Plotter

Strong Coupling α_s

World Summary of alpha_s 2012, S. Bethke:



$\alpha_s(M_Z) = 0.1197 \pm 0.0016$

$\alpha_s(M_Z) = 0.1185 \pm 0.0007$

$\alpha_s(M_Z) = 0.1151 \pm 0.0022$

$\alpha_s(M_Z) = 0.1172 \pm 0.0037$

$\alpha_s(M_Z) = 0.1197 \pm 0.0028$

-> $\alpha_s(M_Z) = 0.1184 \pm 0.0007$

PDG2012

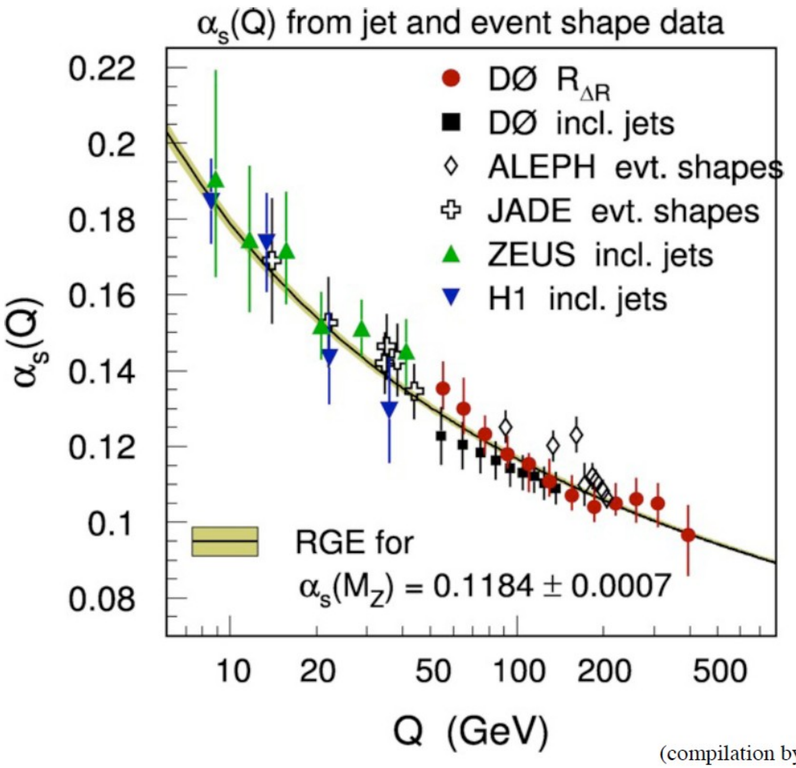
NLO alpha_s in global PDFs:

ABM11:	**0.1134 (NNLO)**
CT10:	**0.1180**
GJR08:	**0.1178**
HERAPDF1.5:	**0.1176**
MSTW2008:	**0.1200**
NNPDF2.1:	**0.1190**

But:
Jet data from hadron colliders not included!

Jets at NNLO urgently needed!

Recent progress reported by Th. Gehrmann at QCD@LHC.



(compilation by D0)

alpha_s from inclusive Jets

CDF: $\alpha_s(M_Z) = 0.1178 \pm 0.0001(\text{stat})^{+0.0081}_{-0.0095}(\text{expt.syst})$

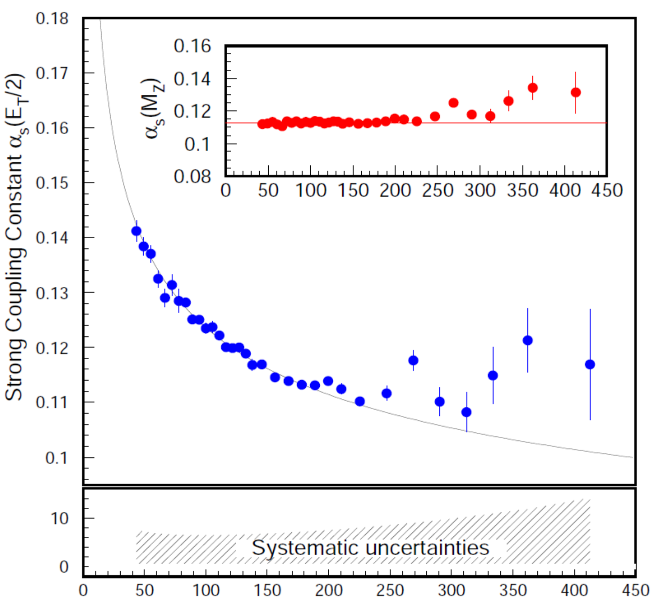
D0: $\alpha_s(M_Z) = 0.1161^{+0.0041}_{-0.0048}(\text{total})$

M/S: $\alpha_s(M_Z) = 0.1151 \pm 0.0001(\text{stat}) \pm 0.0047(\text{expt.syst})^{+0.0080}_{-0.0073}(\mathrm{p_T}, \mathrm{R}, \mu, \mathrm{PDF}, \mathrm{NP})$

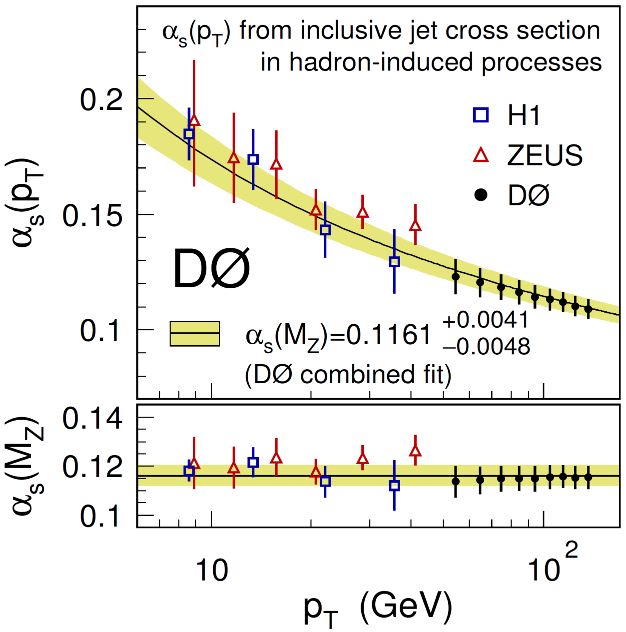
Problem:

Via the PDFs assumes the validity of the running of alpha_s according to the RGE

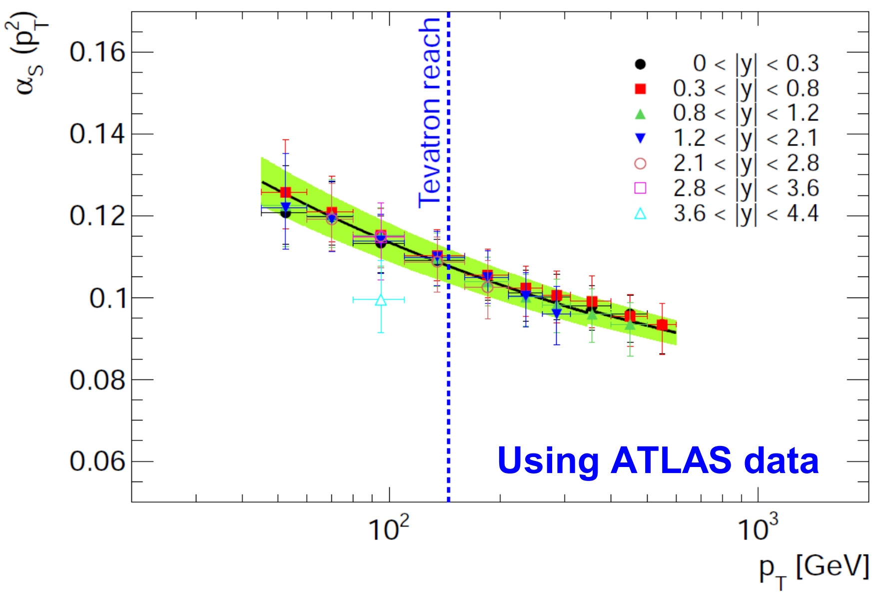
D0 explicitly restricts phase space to where the RGE is already established.



CDF, PRL88, 2002

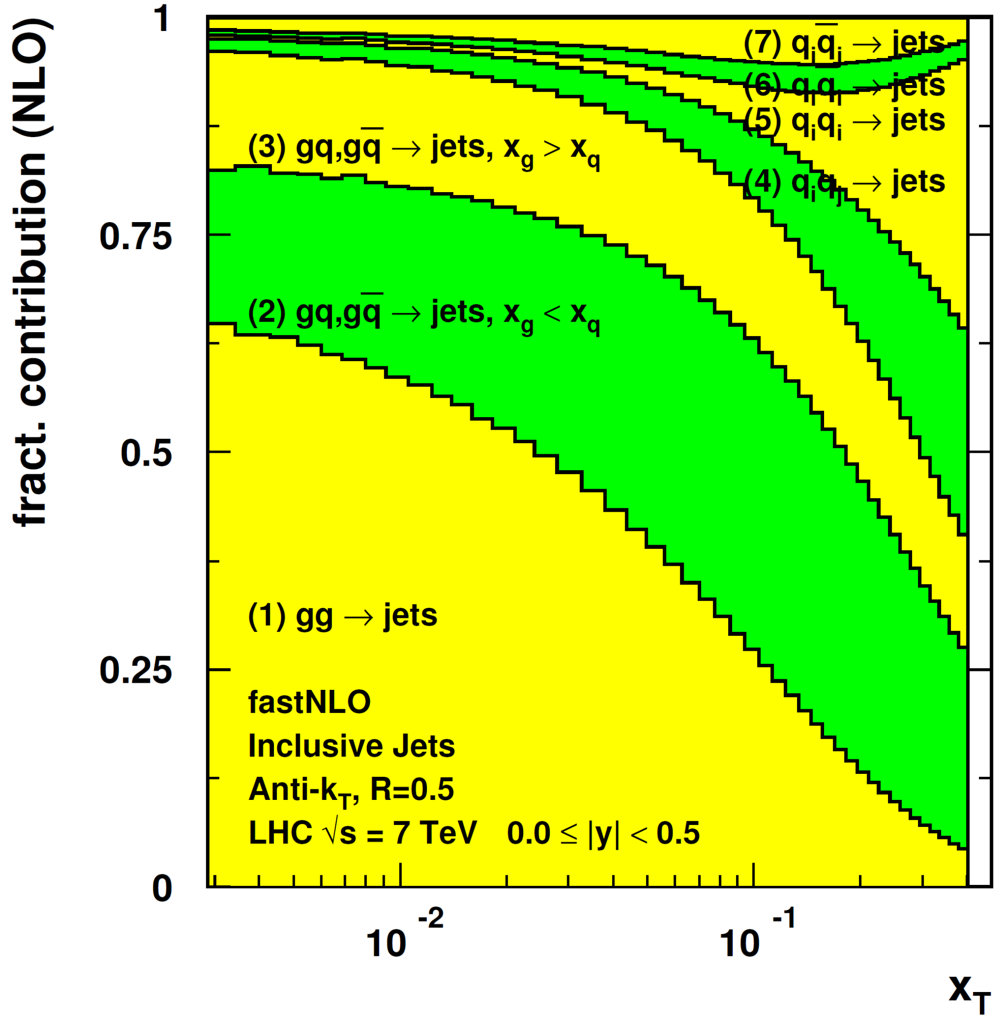


D0, PRD80, 2009

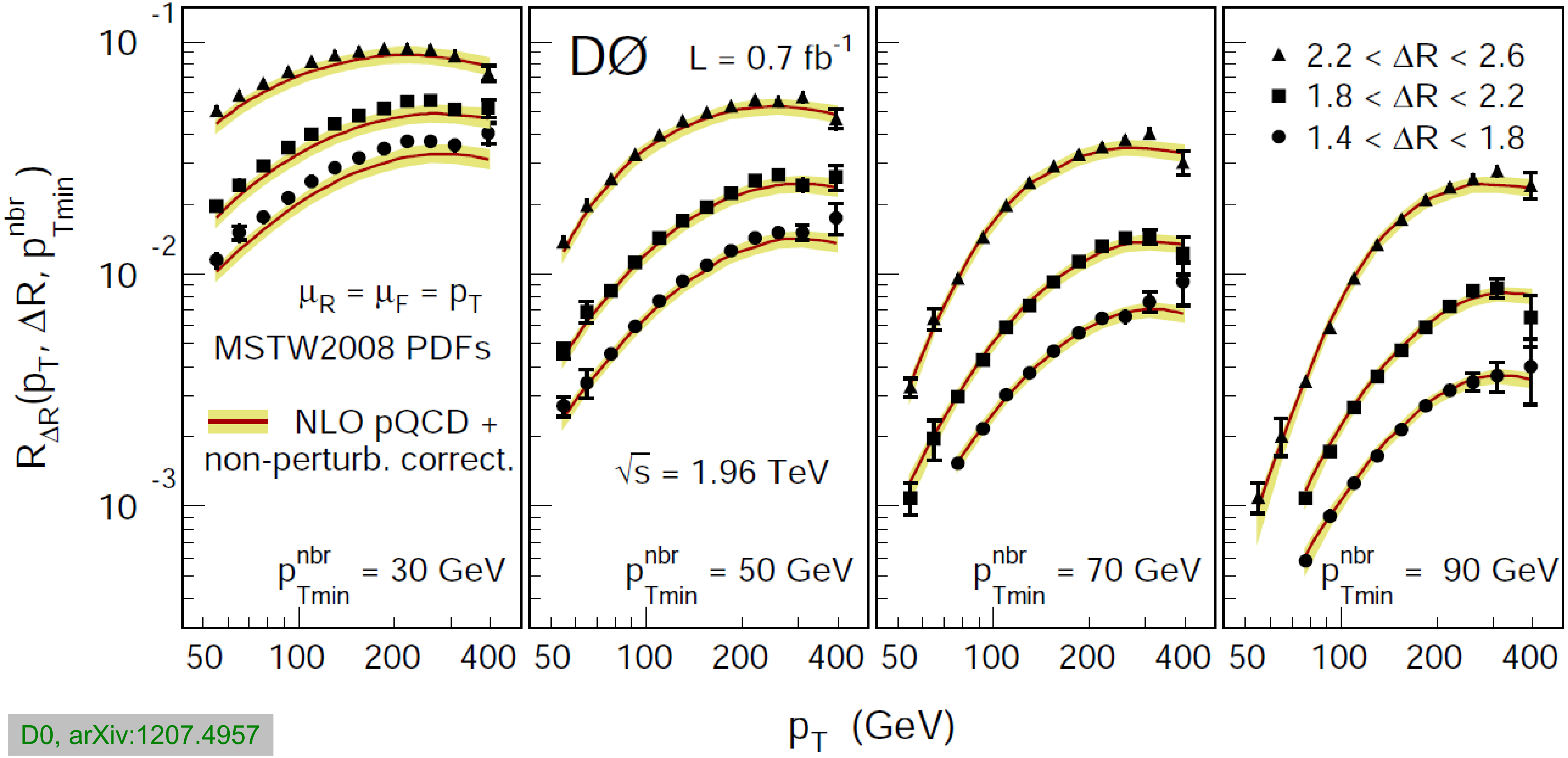


Malaescu/Starovoitov, EPJC72, 2012

Inclusive Jets



New jet angular correlation Observable from D0



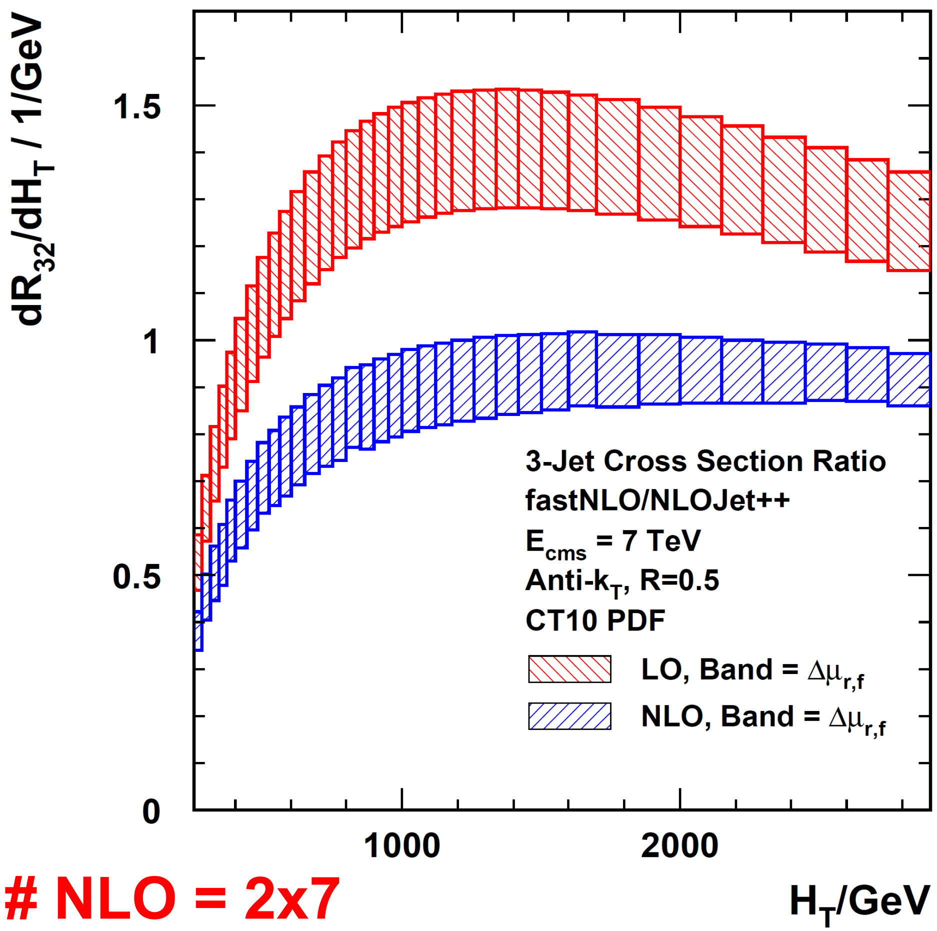
D0, arXiv:1207.4957

$$\alpha_s(M_Z) = 0.1191^{+0.0048}_{-0.0071}(\text{total})$$

$$\pm 0.0003(\text{stat}) +^{+0.0007}_{-0.0009}(\text{exp.}) +^{+0.0002}_{-0.0001}(\text{NP}) +^{+0.0010}_{-0.0005}(\text{MSTW}) +^{+0.0000}_{-0.0024}(\text{PDFset}) +^{+0.0046}_{-0.0066}(\text{scale})$$

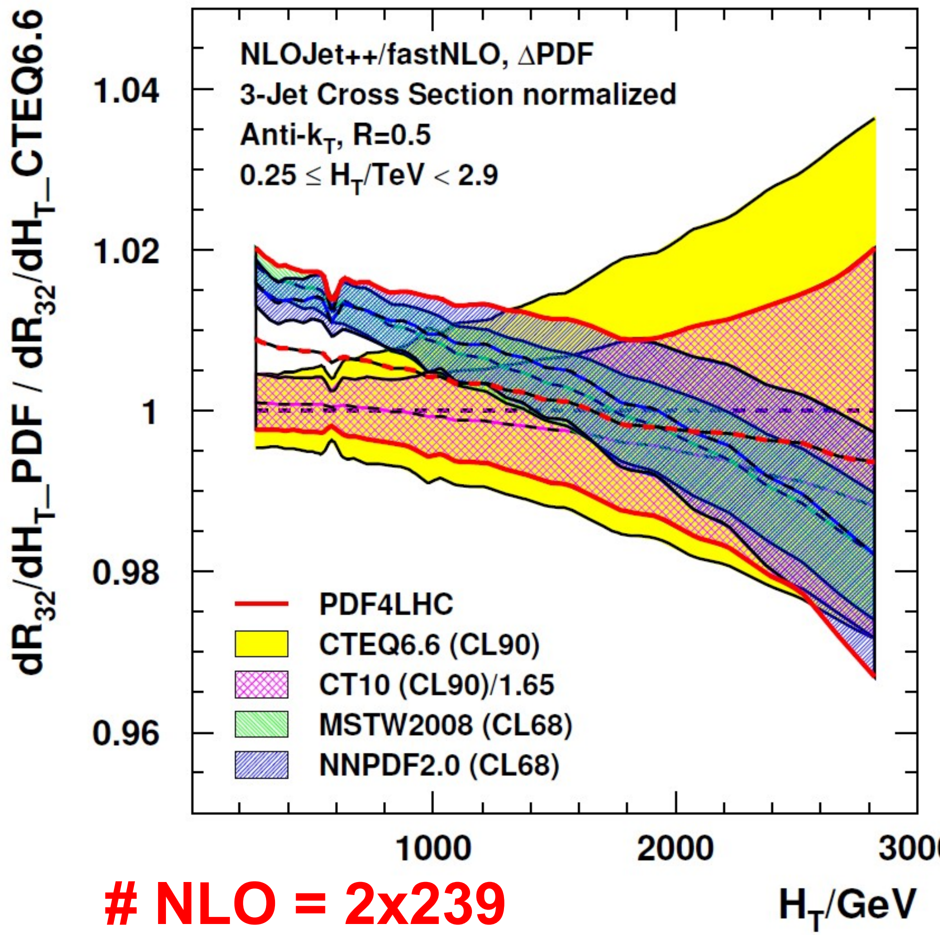
3+/2+: NLO Prediction & ΔPDF

CMS like selection
(ATLAS not very different)
LO > 1 ?!
K factors ~ 0.67



NLO = 2x7

PDF uncertainty reduced by a factor ~ 10 in ratio



NLO = 2x239