PDF constraints and α_S from CMS

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On behalf of the CMS Collaboration

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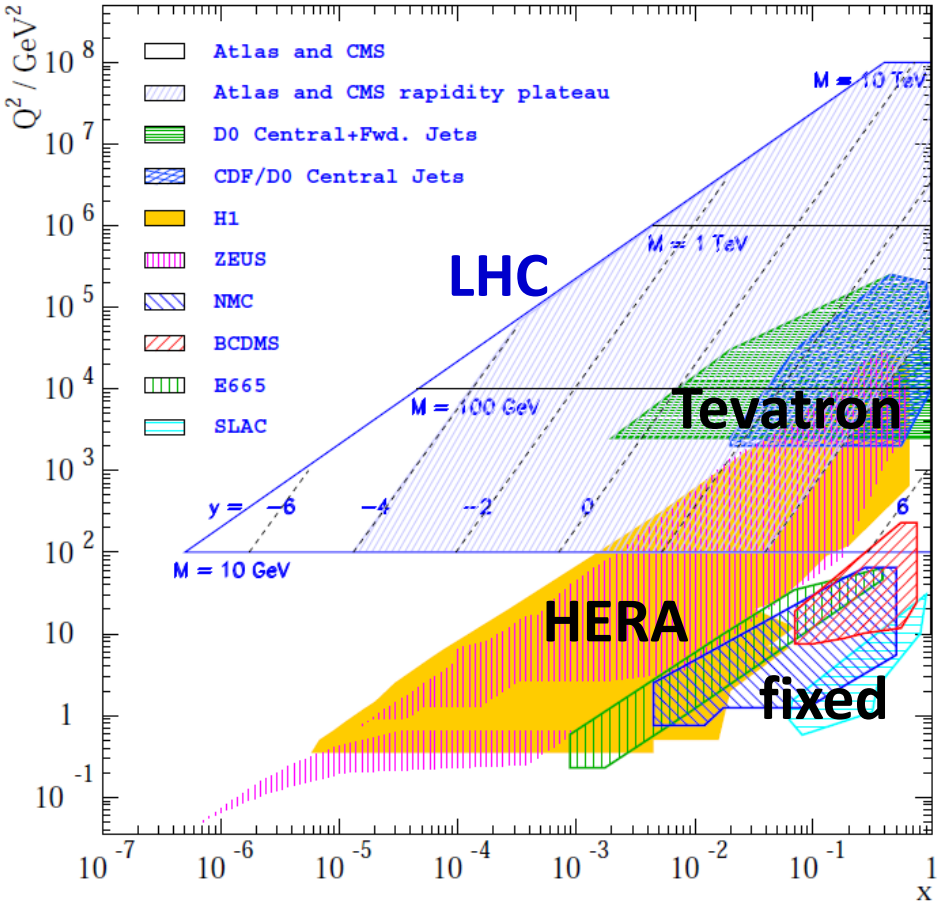
Introduction

- The Strong Coupling Constant (α_S) and the Parton Distribution Functions (PDFs) are a key ingredient for precision measurements at hadron colliders.
- With the LHC data the determination of α_S is possible at energies beyond 1 TeV.
- Up to LHC RUN I, PDFs mainly constrained by the Deep Inelastic Scattering (DIS) and Fixed Target measurements.
- The LHC measurements started already to provide additional information on PDFs in a previously unexplored energy region.

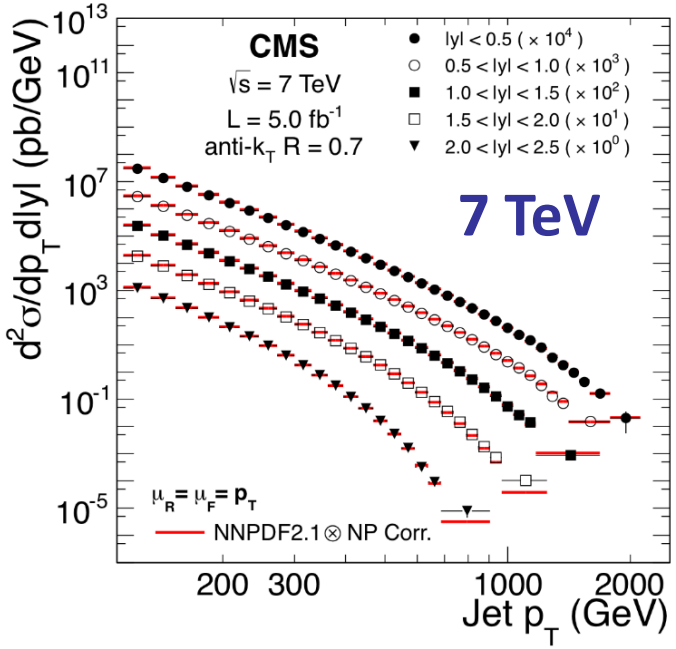
Kinematic plane of process Q^2 vs x



S.Glazov, Braz.J.Ph. 37 (2007) 793

α_S : Inclusive jet spectrum

- Measurement is based on the 2011 inclusive jet cross section at 7 TeV published by **CMS**: PRD 87,112002(2013).
- Observable : $$\frac{d^2\sigma}{dp_T\, dy} \propto \alpha_S^2$$
- Phase space : $|y| \leq 2.5$ and jet p_T: 114GeV-2TeV
- Scale choice : $\mu_r = \mu_f = p_T$



PRD 87 112002 (2013)

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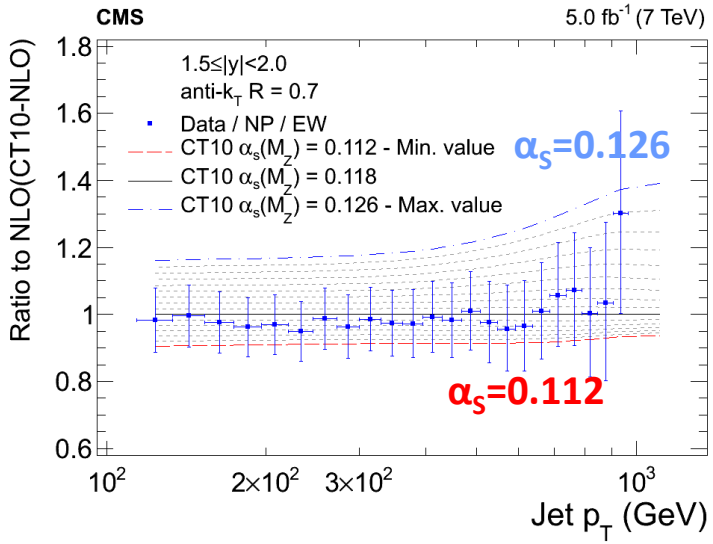
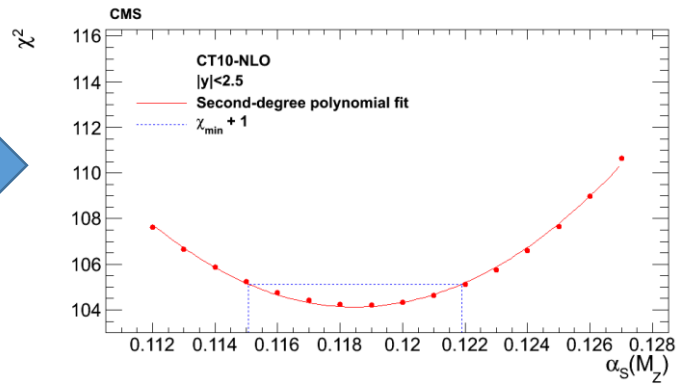


Construct χ^2

Including all correlations



α_S : Inclusive jet spectrum

- Central fit : all rapidity bins with CT10-NLO.
- Determination at **NLO**

$$\alpha_S(M_Z) = 0.1185 \pm 0.0019(\exp) \pm 0.0028(PDF) \pm 0.0004(NP) \pm {}^{0.0055}_{0.0022}(scale)$$
$$= 0.1185 \pm {}^{0.0060}_{0.0037}$$

- Results using MSTW2018 and NNPDF2.1 are in agreement with central CT10 result
- Total uncertainty 3.5 to 5.5 %.
- Dominated by missing-order terms (μ_r, μ_f)

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p_T range (GeV)	Q (GeV)	$\alpha_S(M_Z)$	$\alpha_S(Q)$	No. of data points	χ^2/n_{dof}
114–196	136	$0.1172^{+0.0058}_{-0.0043}$	$0.1106^{+0.0052}_{-0.0038}$	20	6.2/19
196–300	226	$0.1180^{+0.0063}_{-0.0046}$	$0.1038^{+0.0048}_{-0.0035}$	20	7.6/19
300–468	345	$0.1194^{+0.0064}_{-0.0049}$	$0.0993^{+0.0044}_{-0.0034}$	25	8.1/24
468–638	521	$0.1187^{+0.0067}_{-0.0051}$	$0.0940^{+0.0041}_{-0.0032}$	20	10.6/19
638–905	711	$0.1192^{+0.0074}_{-0.0056}$	$0.0909^{+0.0042}_{-0.0033}$	22	11.2/21
905–2116	1007	$0.1176^{+0.0111}_{-0.0065}$	$0.0866^{+0.0057}_{-0.0036}$	26	33.6/25

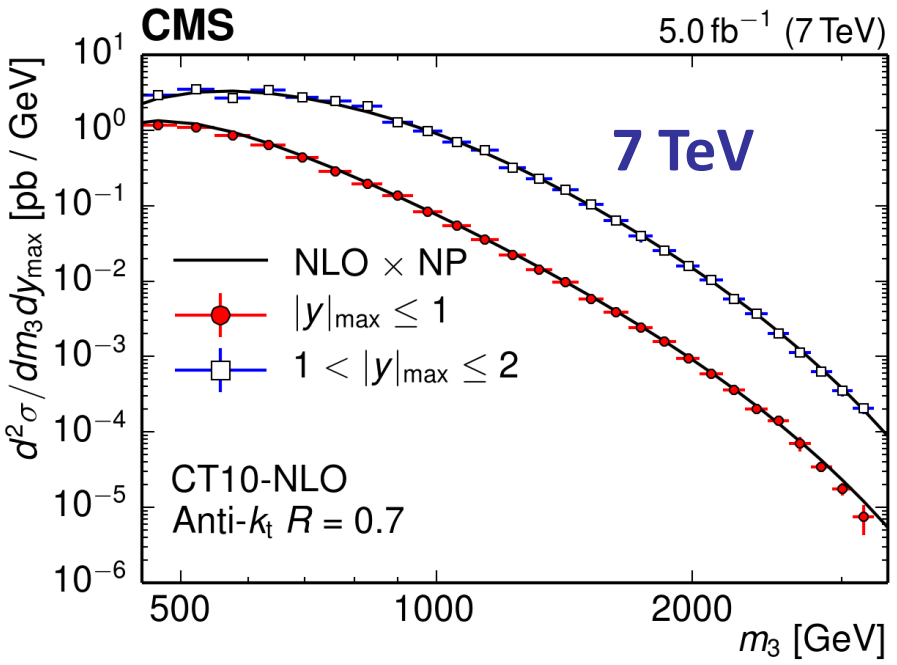
- α_S running : Perform fit for separate p_T ranges
- Test consistency with the α_S running

α_S : Three-jet mass cross section at 7 TeV

- Measurement by **CMS** of the double differential 3-jet cross section in m_3 and y_{max}

$$\frac{d^2\sigma}{dm_3\, dy_{max}} \propto \alpha_S^3$$

$$m_3^2 = (p_1 + p_2 + p_3)^2$$
$$|y|_{max} = \max(|y_1|, |y_2|, |y_3|)$$



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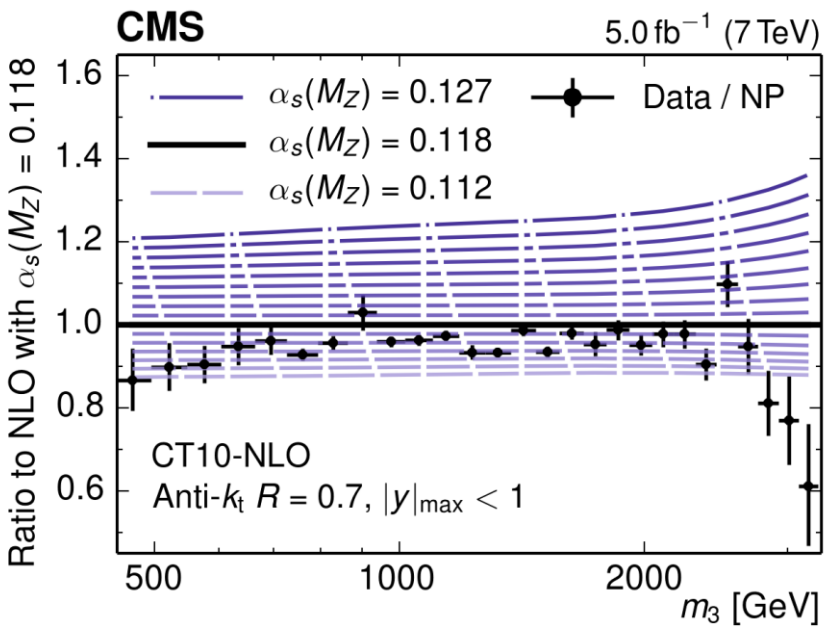

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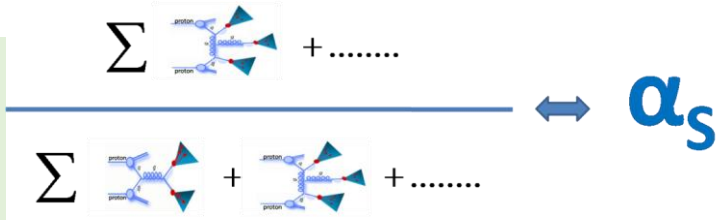
- Central fit : Two rapidity bins with CT10-NLO
- Determination at **NLO**
- Total uncertainty 4 to 6 %

$$\alpha_S(M_Z) = 0.1171 \pm 0.0013(\exp) \pm 0.0024(PDF) \pm 0.0008(NP) \pm {}^{0.0069}_{0.0040}\,(scale)$$

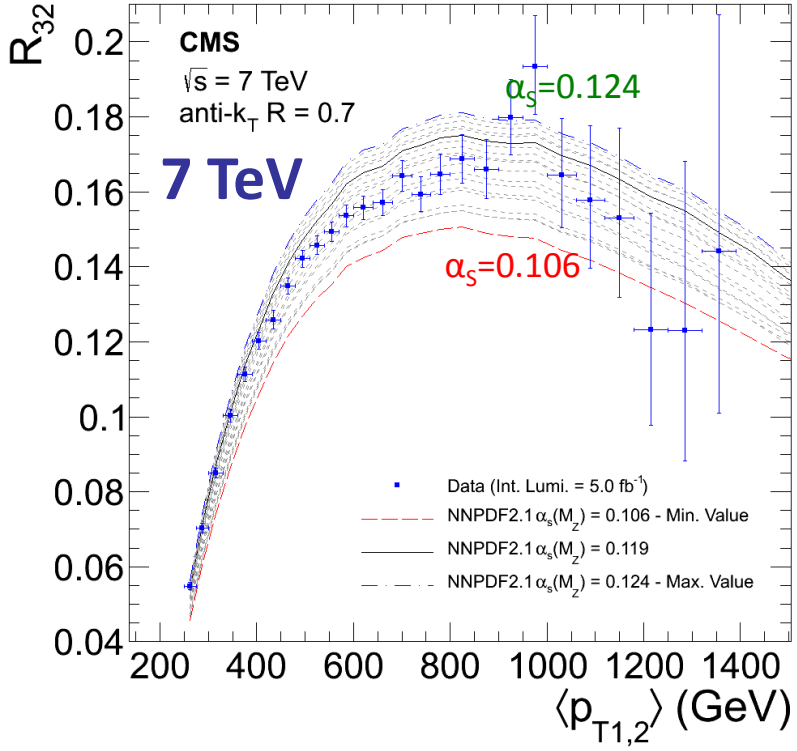
α_S : 3/2 inclusive jet cross sections ratio (R_{32}) at 7 TeV

$$R_{32} = \frac{\sigma_3}{\sigma_2} = \frac{\sigma(pp \to n \text{ jets} + X;\ n \geq 3)}{\sigma(pp \to n \text{ jets} + X;\ n \geq 2)} =$$

$$\text{vs} \quad \langle p_{T1,2} \rangle = \frac{p_{T1} + p_{T2}}{2}$$



$\Leftrightarrow$ α_S



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- Phase space: Jet p_T>150 GeV, |y|<2.5.
- Scale choice: $\mu_r=\mu_f=\langle p_{T1,2}\rangle$
- Advantages : Reduces experimental and other theoretical uncertainties.

- Central fit : Using the NNPDF2.1 PDF set
- Determination at **NLO**
- Total uncertainty 4.7 %

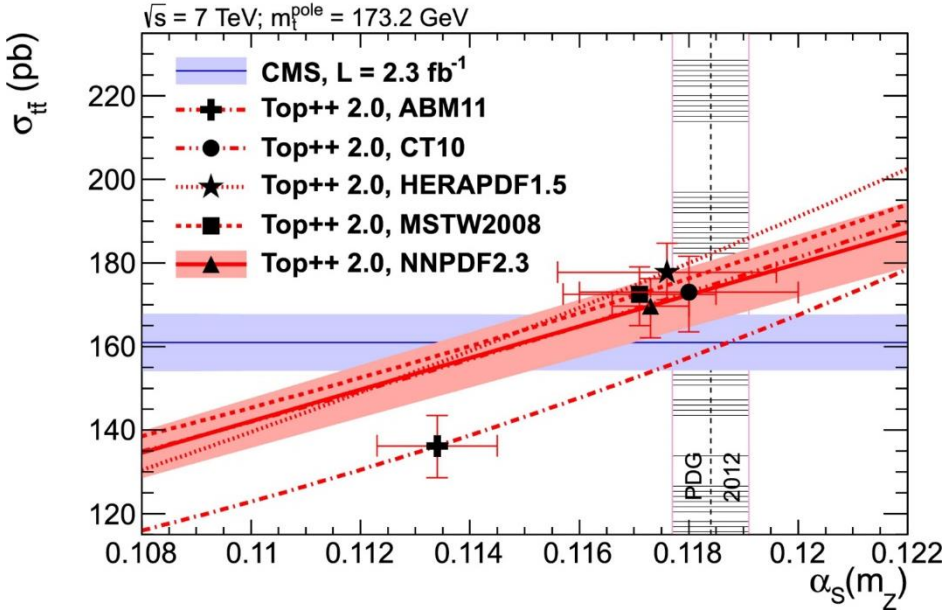
$$\alpha_S(M_Z) = 0.1148 \pm 0.0014(\exp) \pm 0.0018(PDF) \pm 0.0050(Theory)$$

α_S from top-pair production cross section

- α_S determination from the top-pair production cross section in the dilepton channel. (7 TeV CMS **PRD 85(2012) 112007**)
- The top-pair production is sensitive to m_t^{pole} and α_S.

Fix m_t^{pole} =173.2±1.4 GeV
→ constrain α_S

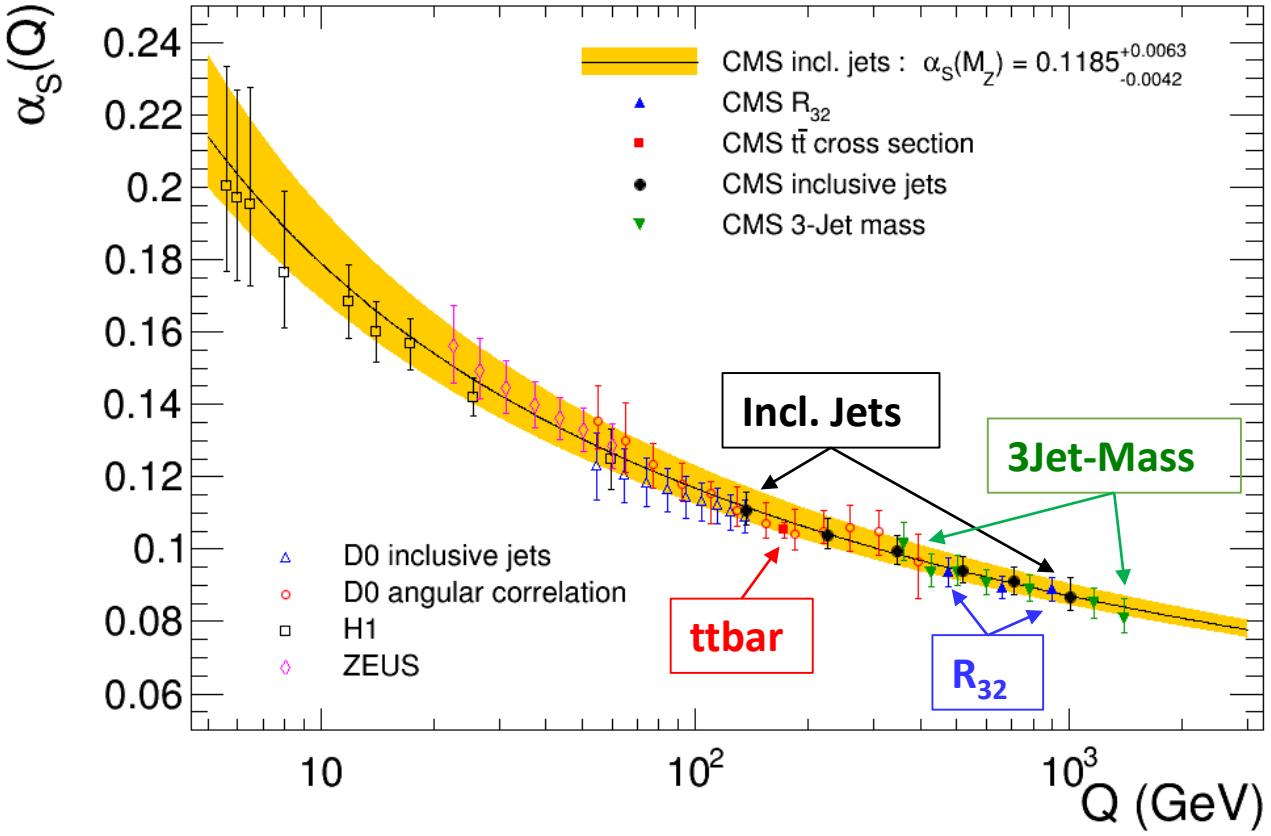
PLB 728 (2014) 496

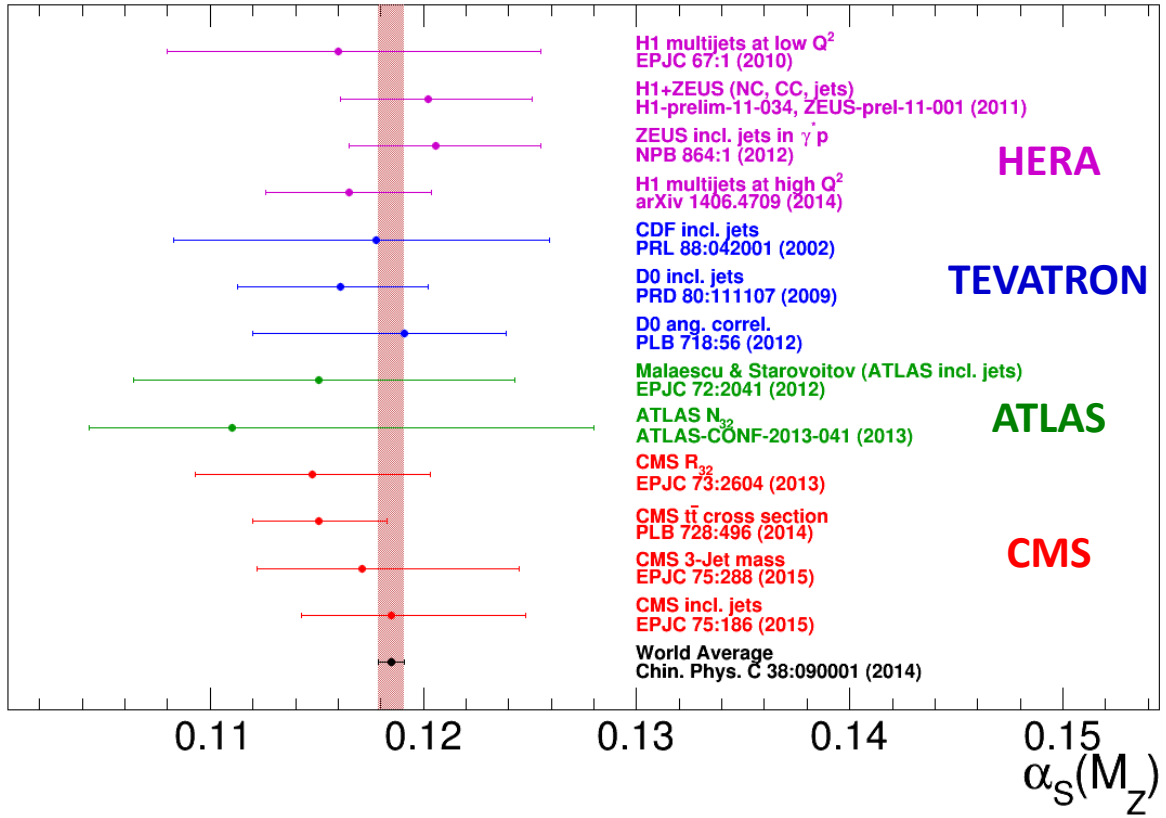


- Central fit : NNPDF2.3-NNLO (Theory at **NNLO+NNLL**)
- Most precise measurement at Hadron collider : total uncertainty 2.4 %.

$$\alpha_S(M_Z) = 0.1151 \pm^{0.0017}_{0.0018} (\exp) \pm^{0.0013}_{0.0011} (PDF) \pm 0.0013(m_t^{pole})$$
$$\pm 0.0008(E_{LHC}) \pm^{0.0009}_{0.0008} (scale)$$
$$= 0.1151 \pm^{0.0028}_{0.0027}$$

α_S measurements



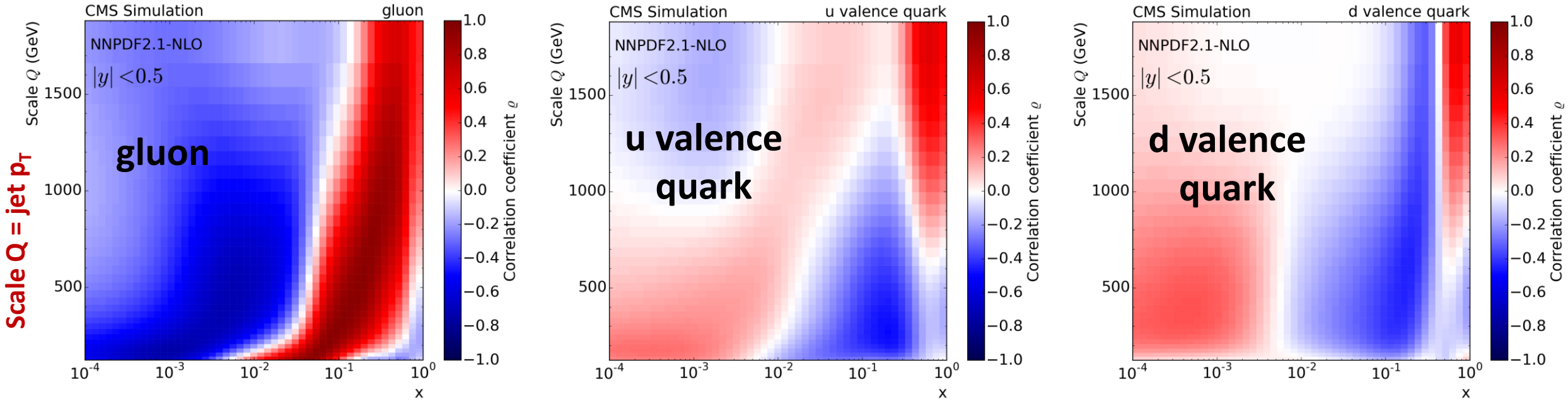


No deviation from the predicted running of α_S is observed.

CMS measurements in good agreement with those of other experiments and the word average value.

PDF constraints : Inclusive spectrum

- Gluon PDF : High correlation for most jet p_T
- Quark PDF : Higher correlations at high jet p_T and high x
- Significant reduction of PDF uncertainties is expected by including CMS data.



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PDF constraints : Inclusive spectrum

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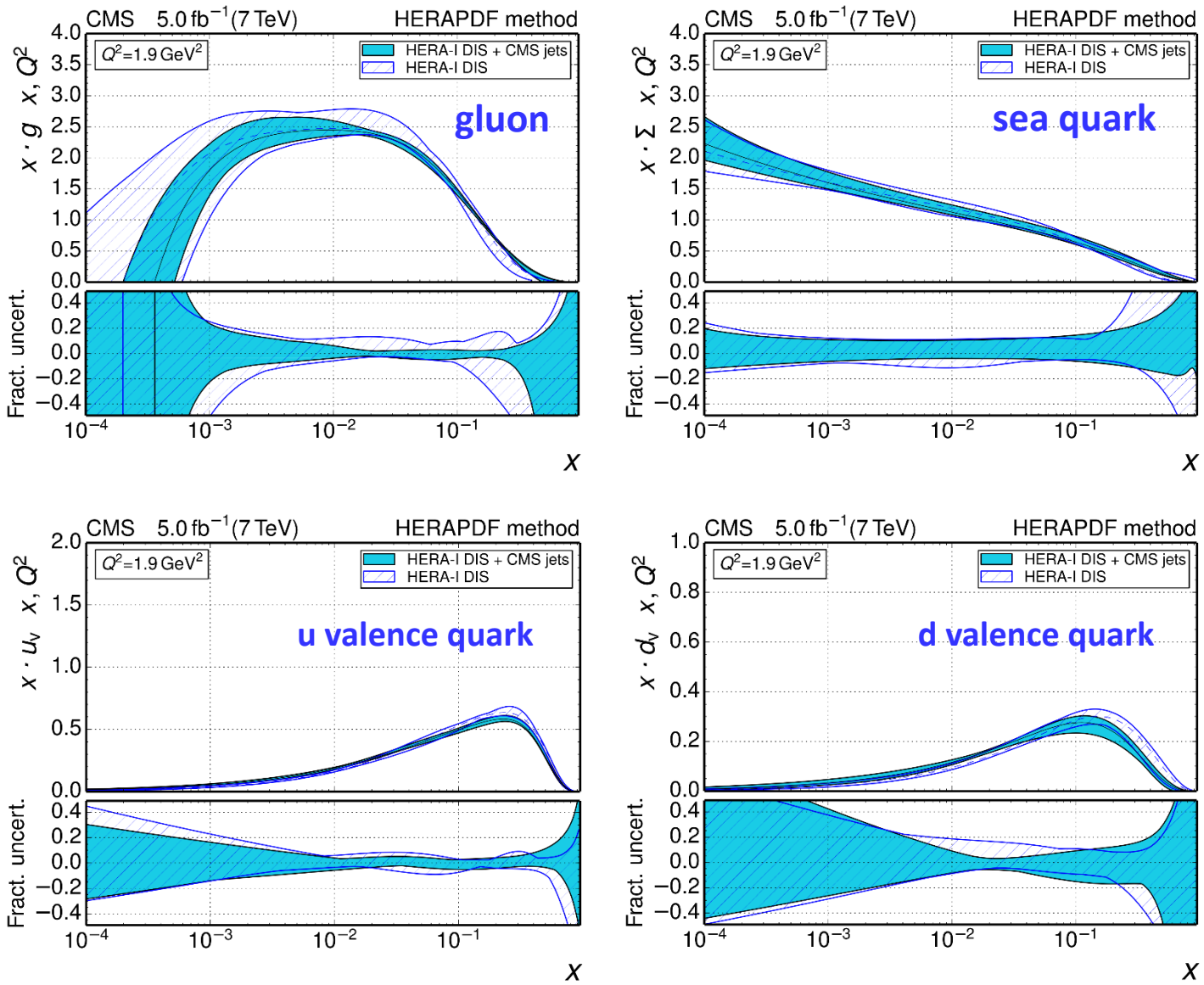


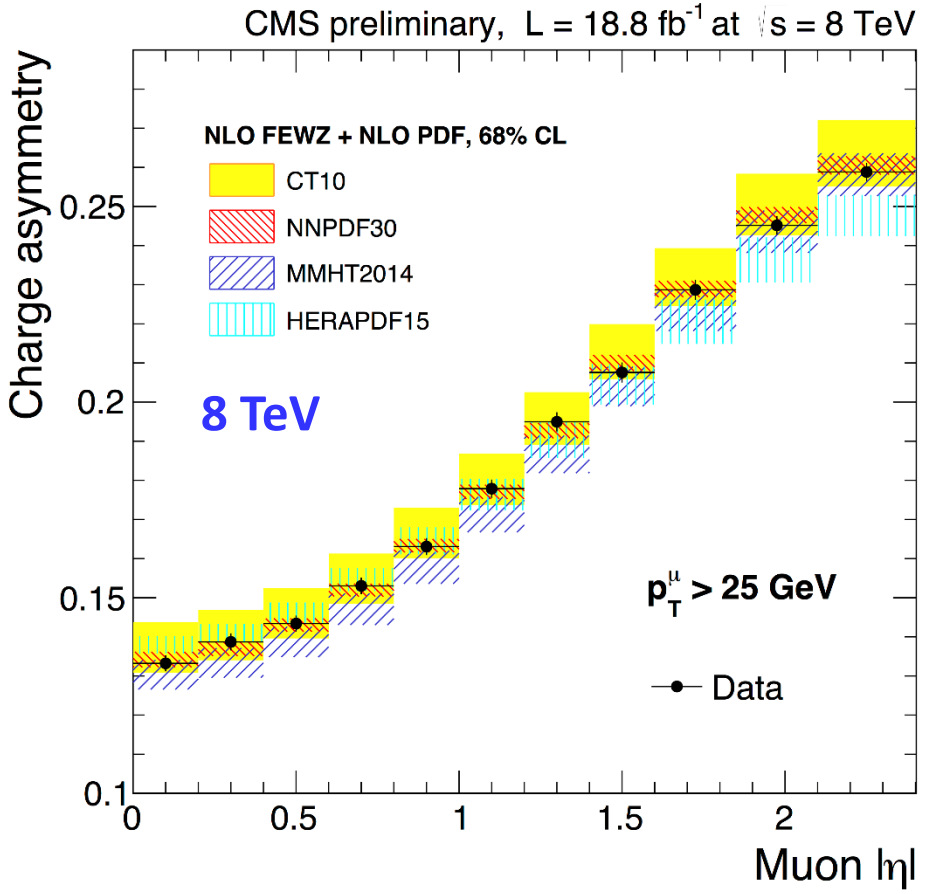
- The impact of the CMS inclusive jet data is demonstrated by adding data to PDF fit using HERA-I DIS data.
- For **gluon** distribution, the parametrization and model uncertainties are reduced significantly for almost all x range.
- For **u valence**, **d valence**, and **sea quark** distributions some reduction in their uncertainty is visible at high x

PDF constraints : Muon charge asymmetry in $pp \to W + X$

- W boson production : $u\bar{d} \to W^+ \quad d\bar{u} \to W^-$
- Muon Charge Asymmetry

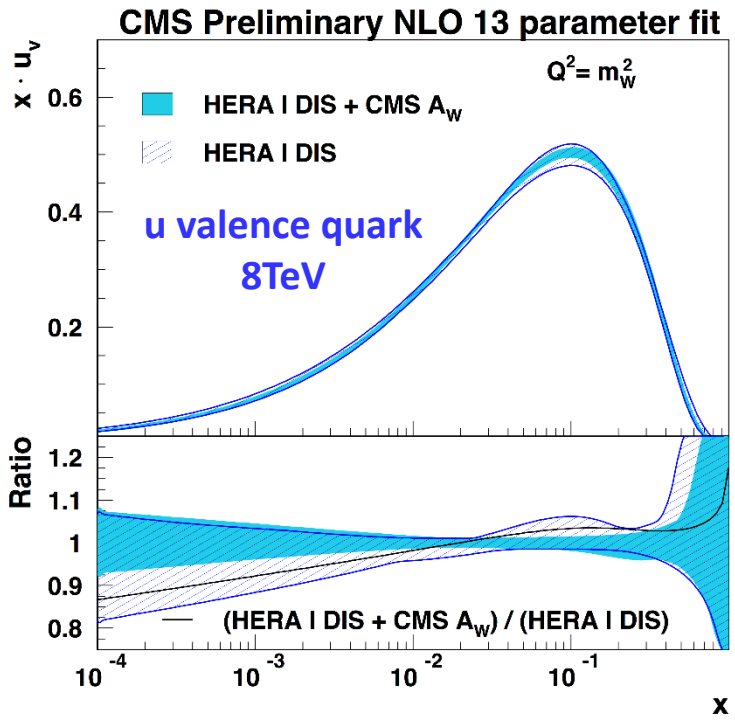
$$\mathcal{A}(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\nu) - \frac{d\sigma}{d\eta}(W^- \to \mu^-\bar{\nu})}{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\nu) + \frac{d\sigma}{d\eta}(W^- \to \mu^-\bar{\nu})}$$

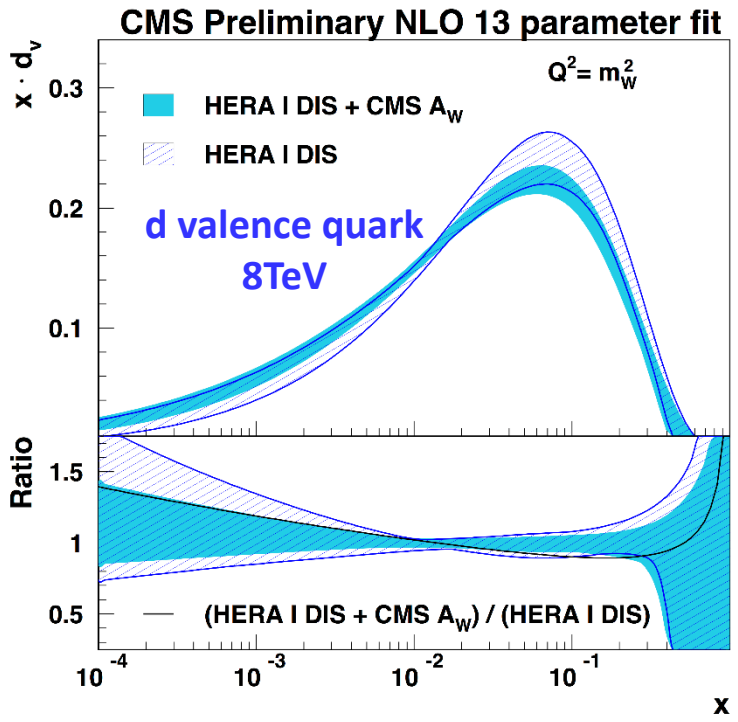
- Phase space: muon p_T>25 GeV, |y|<2.4
- The measured charge asymmetry is well described by all considered PDF models within their uncertainties.
- $\mathcal{A}(\eta)$ probes the valence-quark distribution (see also 7 TeV analysis **PRD 90 (2014) 032004**)



CMS PAS SMP-14-022

PDF constraints : Muon charge asymmetry in $pp \to W + X$





CMS PAS SMP-14-022

- Extraction of valence u and d quark PDF: reduction of uncertainties and a change in the shapes within the total uncertainties is observed.

Summary

- CMS has provide already the measurement of the **Strong Coupling Constant** with four different observables.
  - All measurements are in good agreement with those of other experiments and the word average value
  - The running of α_S is confirmed at the **1 TeV** region
  - For the moment the measurement of α_S is dominated by the theoretical scale uncertainties
  - **NNLO** calculations are needed to improve the precision in α_S

- CMS measurements provide constraints to **PDFs**
  - The inclusive jet spectrum improves significantly the **gluon PDF**
  - The muon charge asymmetry impose stronger constraints on **valence quarks**

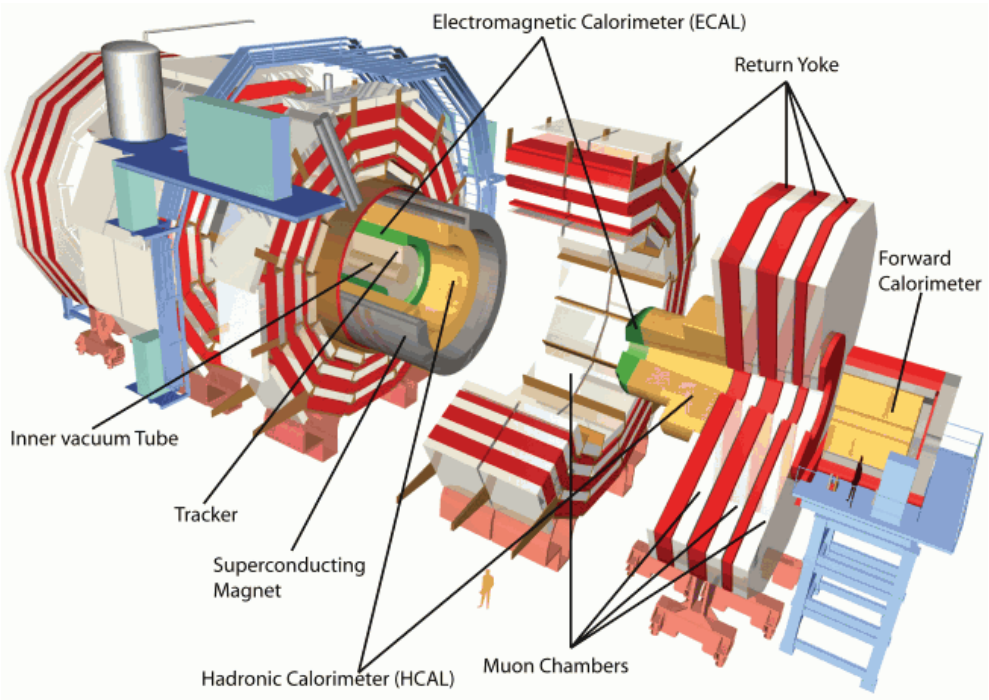
More interesting results by CMS:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP

Spare

Outline

- Introduction
- Measurements of the Strong Coupling Constant
  - From the Inclusive jet cross section
  - From the 3-jet mass cross section
  - From the ratio 3/2 of incl. jet cross sections
  - From top-pair production cross section
- PDF constraints
  - From the Inclusive jet cross section
  - From muon charge asymmetry in inclusive $pp \rightarrow W + X$ production
- Summary

CMS detector and Integrated Luminosity

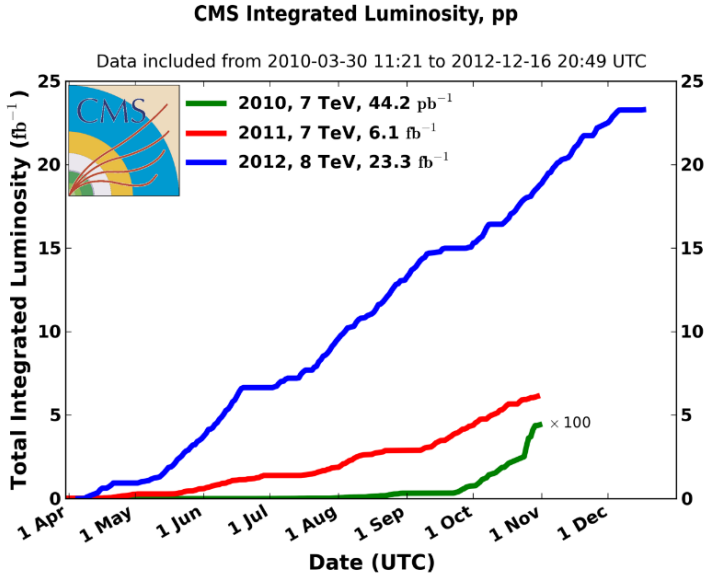


CMS detector pseudorapidity coverage:

- Tracking: $|\eta|<2.5$
- Central Calorimetry: $|\eta|<3$
- Forward Calorimetry: $3<|\eta|<5$

Very successful LHC operation and CMS data recording during Run 1 :

- 7 TeV (2010 & 2011)
- 8 TeV (2012)



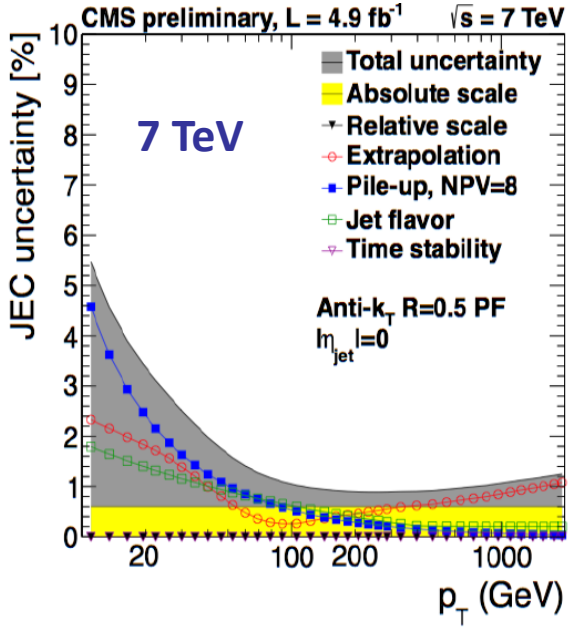
Jet Energy Scale Calibration

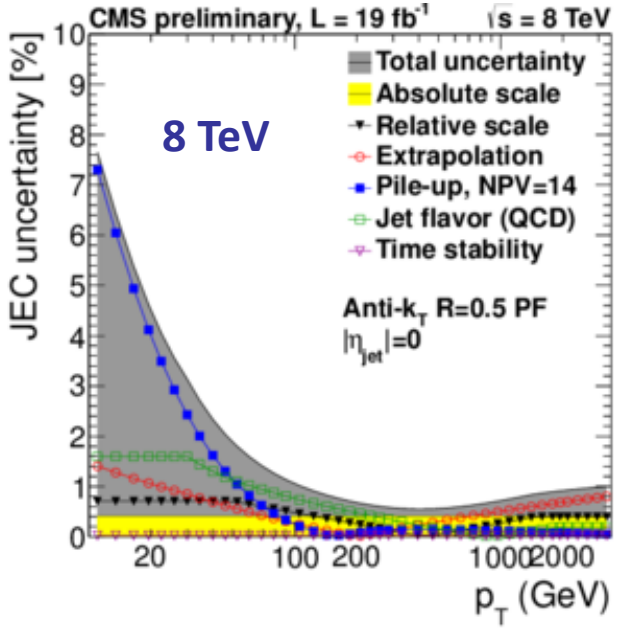
- For the jet energy scale calibration CMS adopted a Factorized approach.

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

- **Offset** → substruction $\rho \times A_{jet}$ (ρ : the global energy density, A_{jet}: the jet area)
- **Relative** → derived from Di-jet Balance
- **Absolute** → derived from $\gamma + jet$ and $Z + jet$ (p_T balance and MPF)

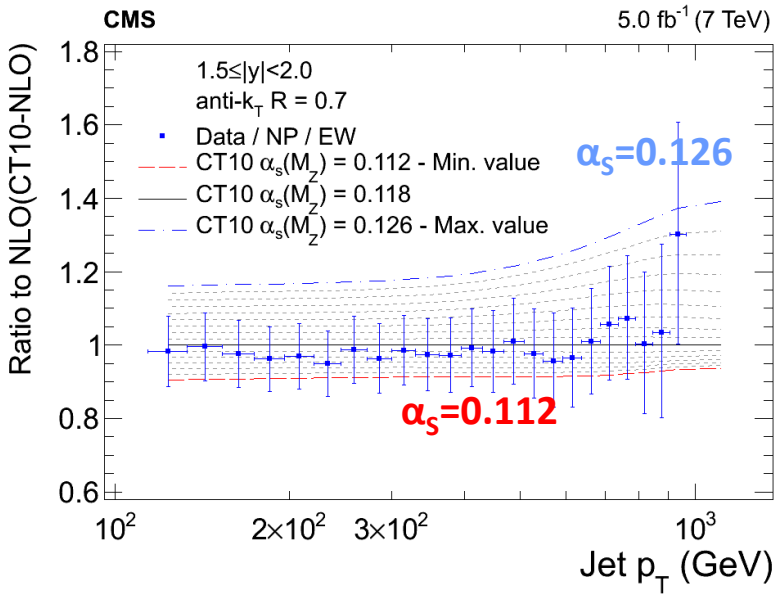
CMS DP-2012-006





CMS DP-2013-033

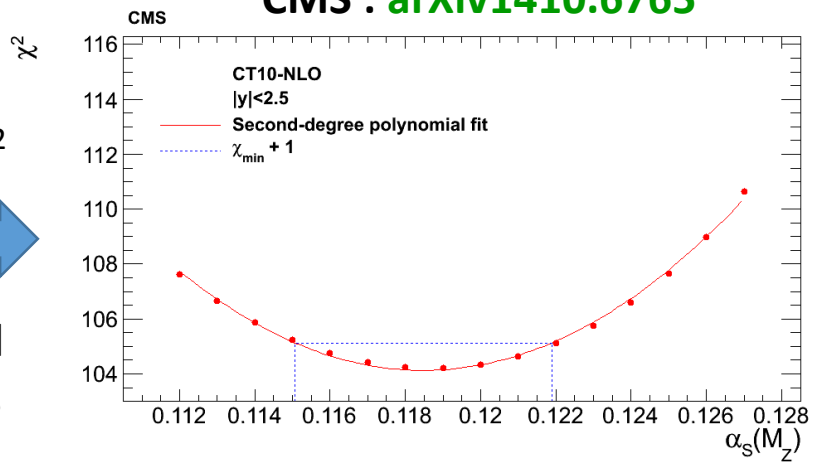
α_S from the inclusive jet cross section at 7 TeV



Construct χ^2

Including all correlations

CMS : arXiv1410.6765



$$\chi^2 = \sum_{ij}^{N} (D_i - T_i) C_{ij}^{-1} (D_i - T_i)$$

$$C = \mathrm{cov}_{\mathrm{stat}} + \mathrm{cov}_{\mathrm{uncor}} + \left(\sum_{\mathrm{sources}} \mathrm{cov}_{\mathrm{JES}} \right) + \mathrm{cov}_{\mathrm{unfolding}} + \mathrm{cov}_{\mathrm{lumi}} + \mathrm{cov}_{\mathrm{PDF}}$$

- **Systematics** :
  - **PDF uncertainty** : repeat fit for PDF sets errors following prescriptions of each set eigenvectors (CT10, MSTW2008) or replicas (NNPDF2.1)
  - **NP uncertainty** : vary the non-pertubative correction factor considering the half of the spread of the three MC calculations as uncertainty.
  - **Scale uncertainty** : repeat fit for different scale settings by varying independently μ_r/Q and μ_f/Q from ½ to 2, and get maximal deviation.

α_S Running

3-Jet mass

m_3[GeV]	$\langle Q \rangle$ [GeV]	$\chi^2/n_{\rm dof}$	$\alpha_S(Q)$	$\pm$(exp)	$\pm$(PDF)	$\pm$(NP)	$\pm$(scale)
664–794	361	4.5/3	0.1013	$\pm^{0.0027}_{0.0028}$	$\pm^{0.0013}_{0.0011}$	± 0.0005	$\pm^{0.0052}_{0.0030}$
794–938	429	7.8/3	0.0933	± 0.0022	$\pm^{0.0012}_{0.0011}$	± 0.0005	$\pm^{0.0048}_{0.0028}$
938–1098	504	0.6/3	0.0934	± 0.0021	± 0.0014	± 0.0005	$\pm^{0.0043}_{0.0025}$
1098–1369	602	2.6/5	0.0902	± 0.0016	± 0.0016	$\pm^{0.0005}_{0.0004}$	$\pm^{0.0036}_{0.0017}$
1369–2172	785	8.8/13	0.0885	$\pm^{0.0010}_{0.0011}$	$\pm^{0.0017}_{0.0018}$	$\pm^{0.0004}_{0.0003}$	$\pm^{0.0038}_{0.0020}$
2172–2602	1164	3.6/5	0.0848	$\pm^{0.0019}_{0.0023}$	$\pm^{0.0020}_{0.0023}$	± 0.0004	$\pm^{0.0034}_{0.0021}$
2602–3270	1402	5.5/7	0.0807	$\pm^{0.0022}_{0.0021}$	$\pm^{0.0028}_{0.0021}$	± 0.0001	$\pm^{0.0044}_{0.0026}$

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R_{32}

$\langle p_{T1,2} \rangle$ range (GeV)	Q (GeV)	$\alpha_S(M_Z)$	$\alpha_S(Q)$	No. of data points	$\chi^2/N_{\rm dof}$
420–600	474	0.1147 ± 0.0061	0.0936 ± 0.0041	6	4.4/5
600–800	664	0.1132 ± 0.0050	0.0894 ± 0.0031	5	5.9/4
800–1390	896	0.1170 ± 0.0058	0.0889 ± 0.0034	10	5.7/9

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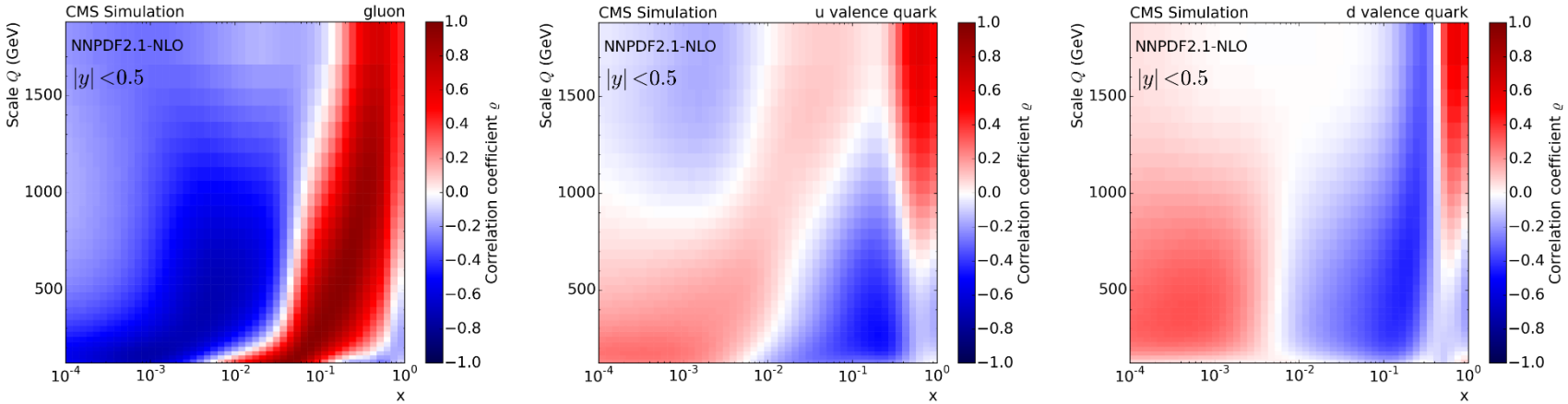
Correlation Coefficients

- Using the replicas of the NNPDF2.1 PDF set the correlation coefficient $\rho_i(x,Q^2)$ between the inclusive jet cross section $\sigma_{jet}(Q)$ and x times the parton distribution function $f_i(x,Q^2)$ is derived.



$$\rho_f\left(x,Q^2\right)=\frac{N_{rep}}{\left(N_{rep}-1\right)}\cdot\frac{\left\langle\sigma_{jet}(Q)_i\cdot xf\left(x,Q^2\right)_i\right\rangle-\left\langle\sigma_{jet}(Q)_i\right\rangle\cdot\left\langle xf\left(x,Q^2\right)_i\right\rangle}{\Delta_{\sigma_{jet}(Q)}\Delta_{xf\left(x,Q^2\right)_i}}$$

N_{rep} : NNPDF2.1 PDF set replicas

σ_{jet} : incl. jet cross section

f_i : the parton distribution function for parton flavour i

x : the fractional parton momentum x

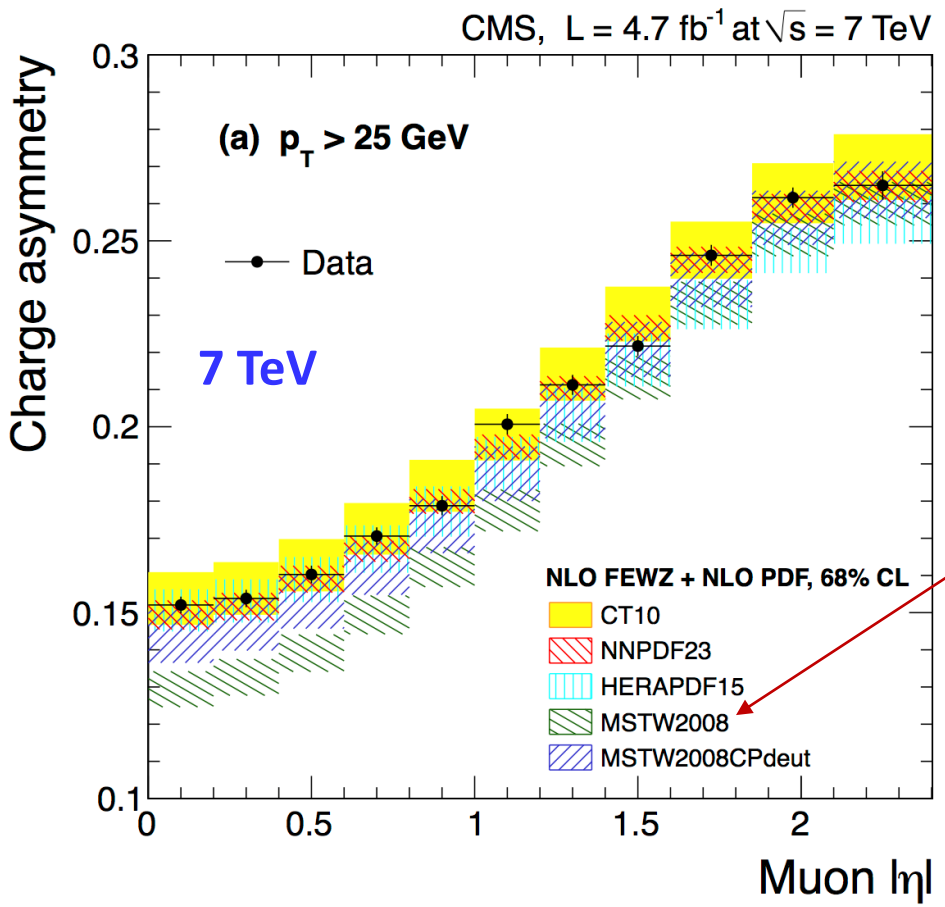
Q : the relevant momentum scale

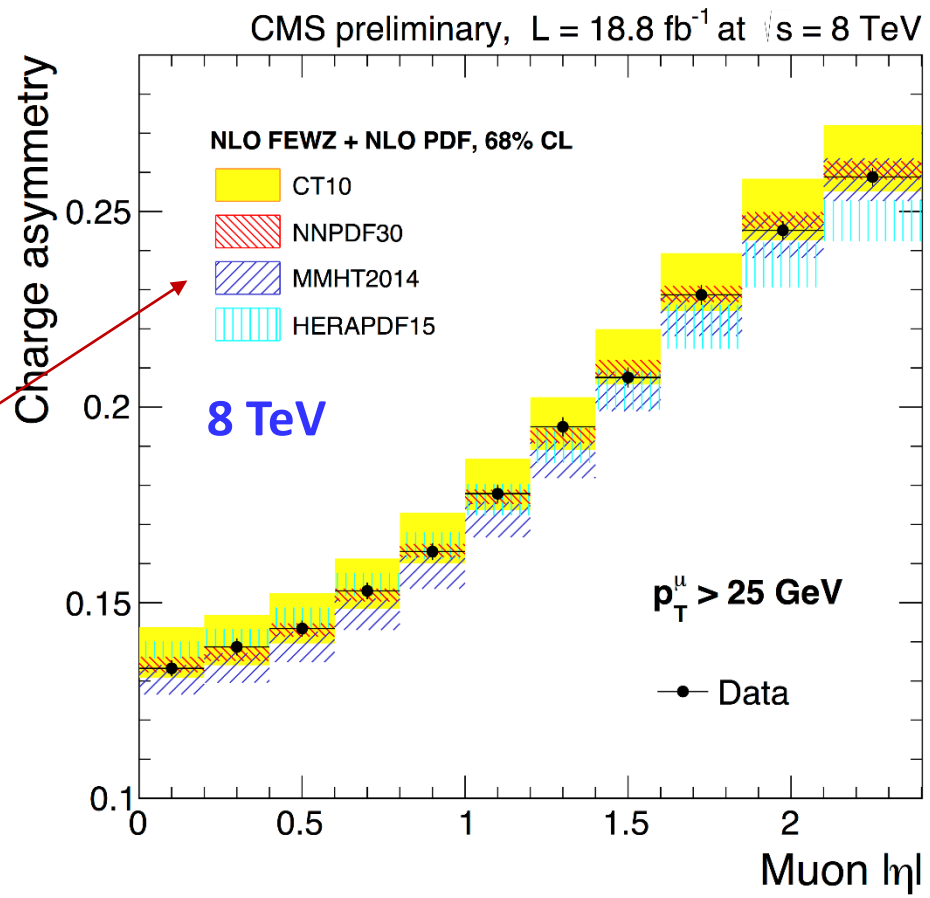
Δ : the standard variation around the ensemble mean of $\sigma_{jet}(Q)$ and $xf\left(x,Q^2\right)_i$

i : runs over all quark, anti-quark and gluon flavours.

PDF constraints : Muon charge asymmetry in $pp \to W + X$

PRD 90 (2014) 032004





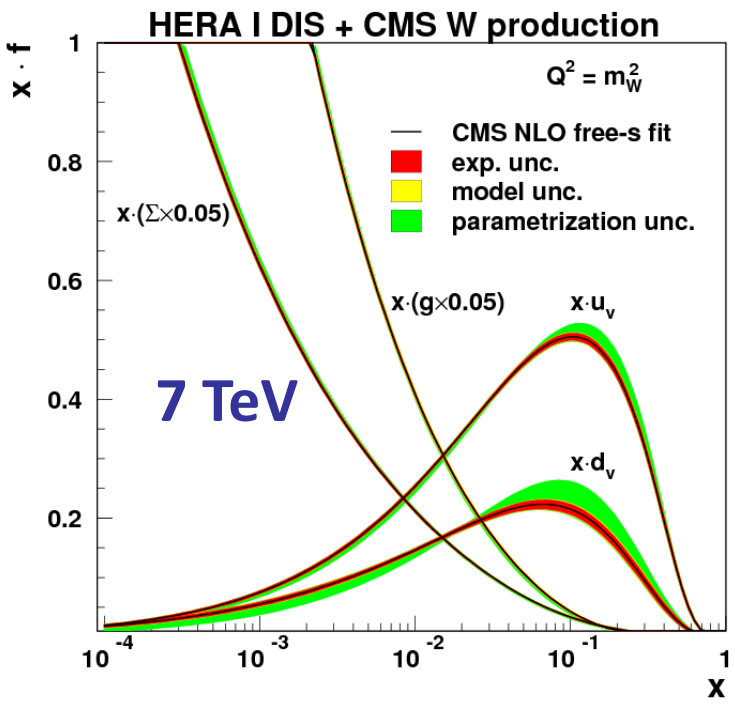
CMS PAS SMP-14-022

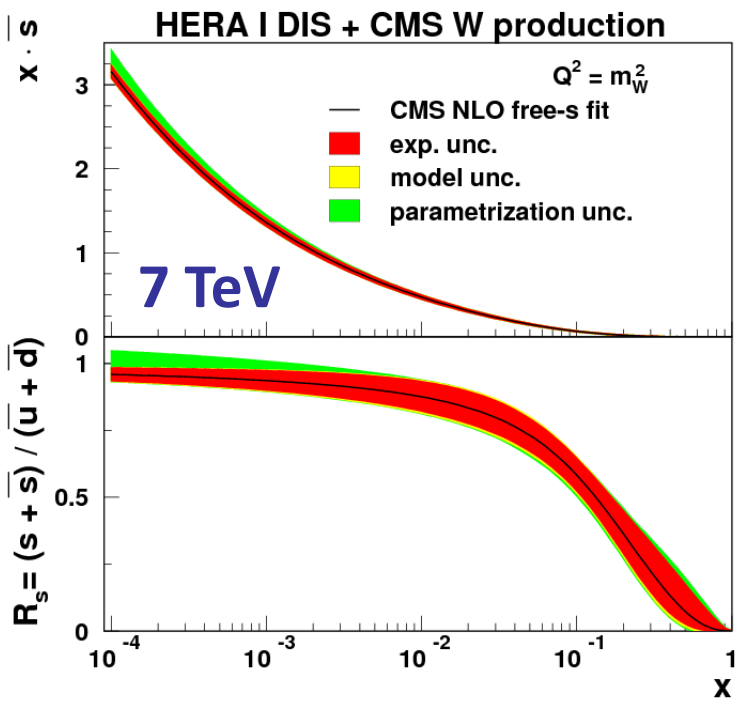
Big Improvement : MSTW2008 -> MMHT2014

PDF constraints : CMS W production at 7 TeV

- PDF constraints using the CMS muon charge asymmetry and the W+charm measurement (JHEP 02 (2013) 013)
- Study of light quark distributions in proton and determination of strange quark density.

PRD 90 (2014) 032004





- The total uncertainty (left) is dominated by the parametrization uncertainty.
- The strange-quark fraction rises with energy and reaches a value comparable to that of u and d antiquarks at intermediate to low x.