Improved Determination of Parton Distribution Functions of the Proton through $W^{\pm}$ Production at CMS

A. Vargas, R. Plačakytė, K. Lipka, M. Guzzi

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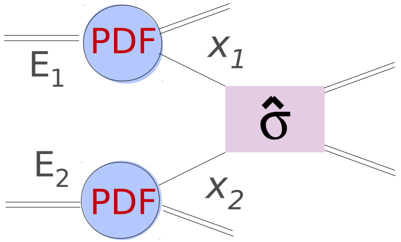
→ Introduction
→ CMS $W^{\pm}$ production data
  → W muon asymmetry and W+charm data
  → Impact of $W^{\pm}$ production data on the PDFs
→ Summary

Introduction

Precise knowledge of the PDFs are essential for predictions at the LHC
e.g. PDFs: one of main theory uncertainties in Higgs production

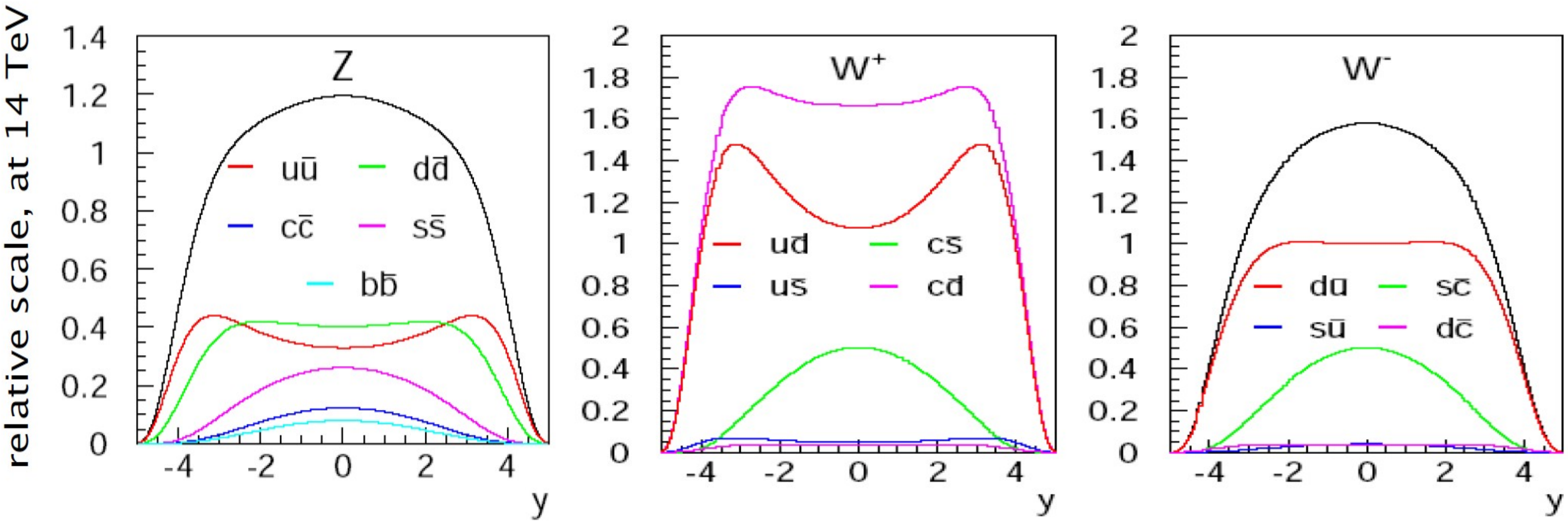
Z and W production at LHC

→ probe different flavour combinations
→ potential to improve quark PDFs



QCD factorisation:

$$\sigma \approx \hat{\sigma} \otimes \text{PDF}$$



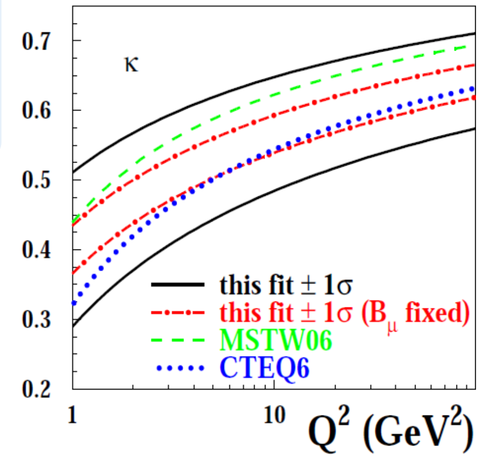
→ u and d quarks dominate for W, all flavours contribute to Z

Strange quark density determination

Strange quark density in the proton is still poorly known

→ mainly constrains come from fixed target data (NuTeV, HERMES, NOMAD)

Phys. Lett. B 675, 433 (2009)



Nucl.Phys. B876(2013) 339

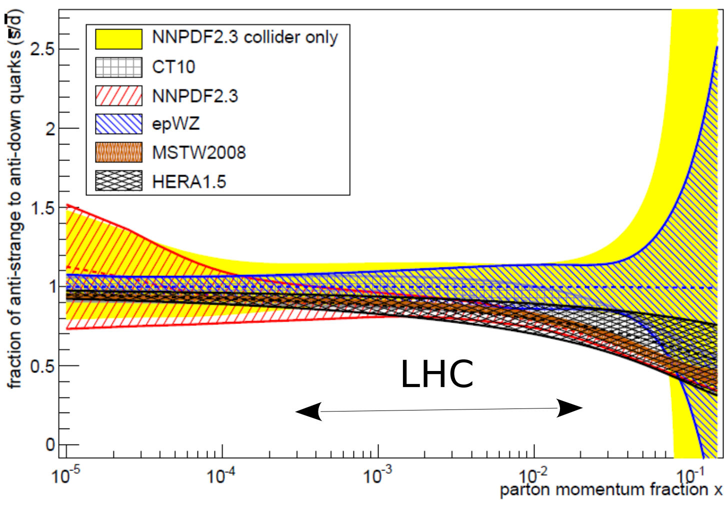
NOMAD measurement

K_s (20 GeV^2)= 0.59 ± 0.019

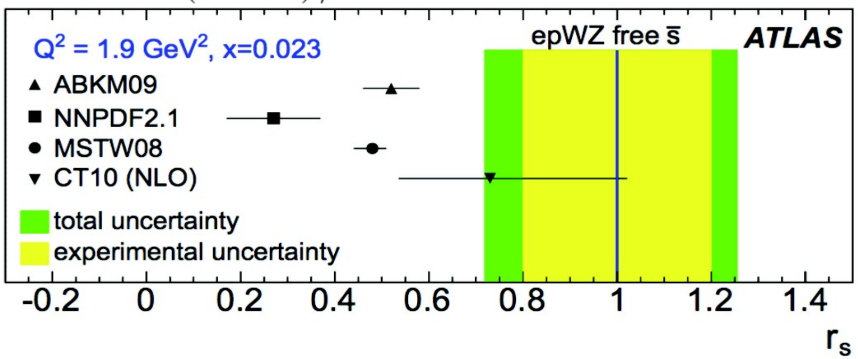
$$\kappa_s(Q^2) = \frac{\int_0^1 x\left[\bar{s}(x,Q^2)+s(x,Q^2)\right]dx}{\int_0^1 x\left[\bar{u}(x,Q^2)+\bar{d}(x,Q^2)\right]dx}$$

→ LHC Z,W and W+charm data sensitive to strange quark density

The differential ATLAS $W^{\pm}$, Z data used to measure strange quark density



$r_s = 0.5(s+\bar{s})/\bar{d}$ Phys.Rev.Lett.109(2012)012001



Atlas data suggests light quark sea at low x favor symmetric

W lepton asymmetry

$$A_W = \frac{W^+ - W^-}{W^+ + W^-} \approx \frac{u_v - d_v}{u_v + d_v + 2u_{sea}}$$

→ overall excess of W^+ over W^- due to presents of two valence *u* quarks in the proton

→ probe valence quarks and PDFs rations (u_v, d_v, d/u, d_v/u_v, dbar/ubar):

CMS W muon asymmetry measurement

→ better resolution for MET using Hadronic Recoil: $u = -MET - \Sigma p_\eta^T$

→ DY sample for normalisation correction

→ binned maximum likelihood fits of MET are used to extract signal

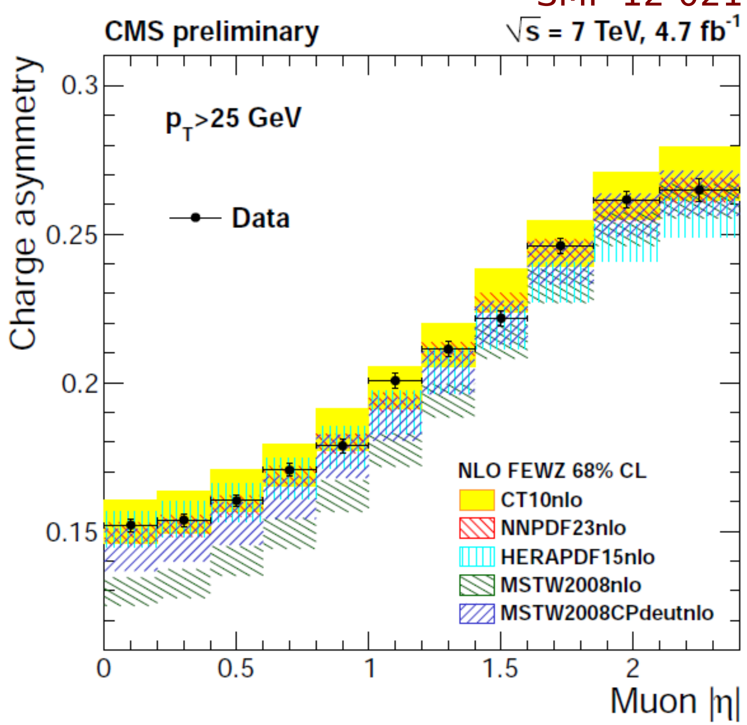
Muon charge asymmetry:

→ P^T_l>25 and 35 GeV

→ 2-4% total uncertainty

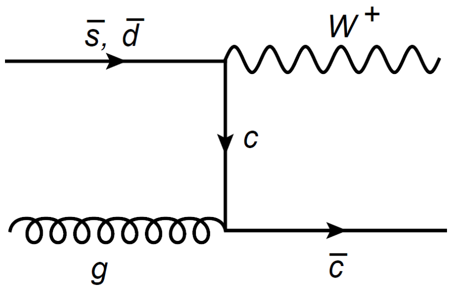
→ in the process of publication

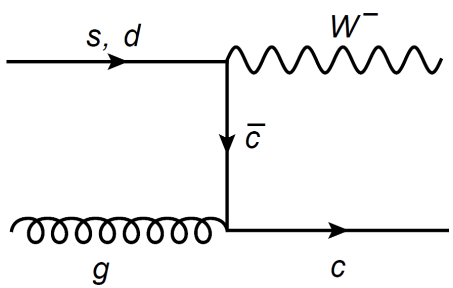
SMP-12-021



W+charm measurement at CMS

W+charm data → direct sensitivity to the strange quark





Identification:

→ W decays to charged leptons (e or μ) and neutrino

arXiv:1310:1138

→ c: charm-quark jets with p^T_{jet}>25GeV, $|\eta_{jet}|$<2.5

jets identified: secondary vertex

$$D^+ \to K^-\pi^+\pi^+ \; (D^- \to K^+\pi^-\pi^-)$$
$$D^{*+}(2010) \to D^0\pi^+ \; (D^{*-}(2010) \to \bar{D}^0\pi^-)$$
$$D^0 \to K^-\pi^+ \; (\bar{D}^0 \to K^+\pi^-)$$

semileptonic decay with well identified muon

Background subtraction: perform by subtracting the Same Sign (SS) from the Opposite Sign (OS) distributions

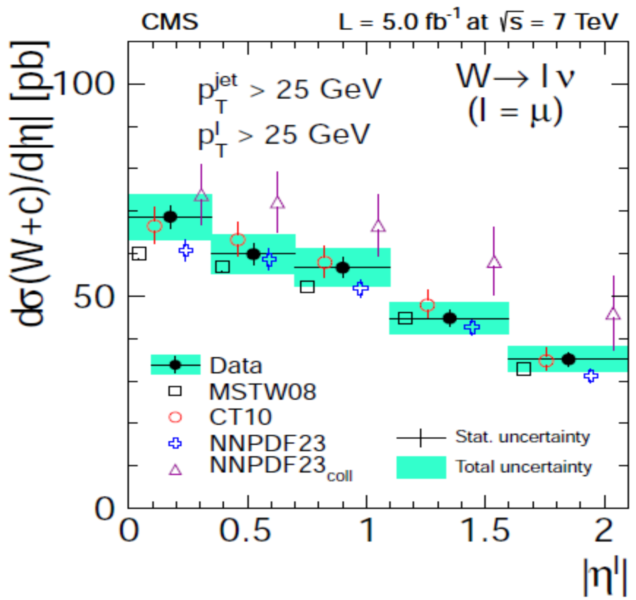
→ does not affect the signal

→ most of background processes (W→ccbar,...) has same SS and OS → significant reduction

W+charm measurements at LHC

W+charm data → direct sensitivity to the strange quark

Total and differential cross sections
$p_l^T > 25$ GeV ($W \to \mu\nu$)
$p_l^T > 35$ GeV ($W \to \mu\nu$, $W \to e\nu$)
Ratios $(W^+ + \bar{c})/(W^- + c)$



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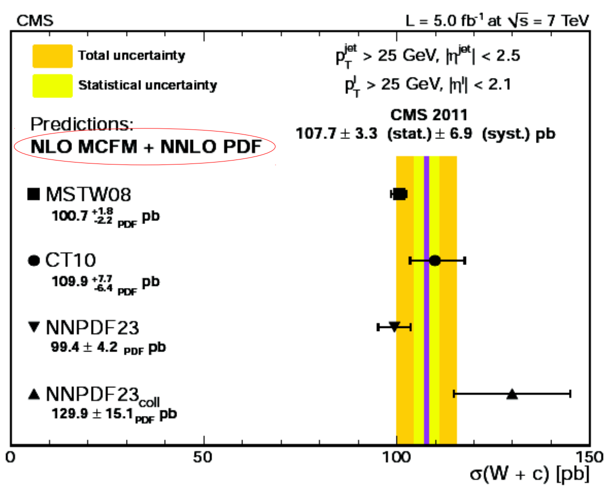
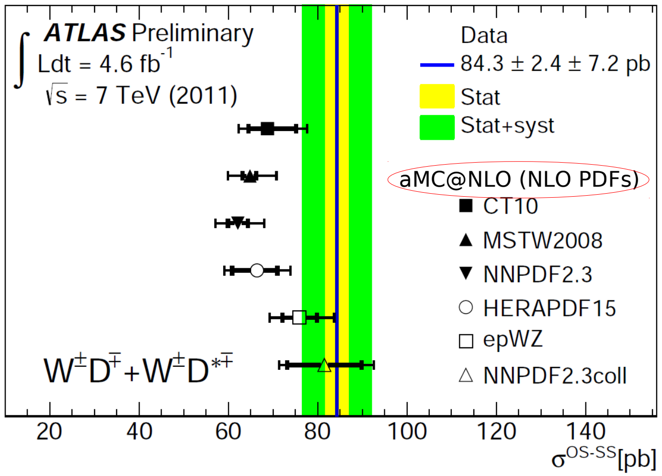


ATLAS-CONF-2013-045



reference (CT10) shows that CMS and ATLAS results are compatible

QCD analysis of CMS W production data

Motivation:

→ study the impact of the W production data on valence-quark distributions

→ test of joined sensitivity of lepton charge asymmetry and W+c data to the strange content of the proton

→ use minimal data input in the PDF fit (HERA I), use most precise CMS data

→ theory calculation for W+c production available to NLO QCD : PDF fit performed at NLO

→ HERAFItter framework is used for the PDF fit www.herafitter.org

→ NNPDF Bayesian reweighting used for qualitative studies of the data impact on the PDFs

QCD analysis settings

QCD analysis at NLO performed using HERAFitter www.herafitter.org

→ parton evolution in Q^2 via DGLAP equations as implemented in QCDNUM

Comp.Phys.Com.182:490,2011

Data: HERA I combined inclusive DIS data JHEP 1001:109 (2010)

→ uncertainty treatment follows HERAPDF1.0 prescription

CMS μ asymmetry data (P^T_l>25 GeV)

→ systematic correlations as covariance matrix

CMS W+charm data (P^T_l>35 GeV)

→ systematic and statistical correlations as full covariance matrix

Theory: predictions from APPLGRID files obtained with MCFM (NLO)

Starting scale $Q^2_0 = 1.9\ \mathrm{GeV}^2$

$m_C = 1.4$ GeV, $m_b = 4.75$ GeV

heavy flavour scheme: general mass variable flavour scheme RT

scale $\mu_R^2 = \mu_F^2 = Q^2$

strong coupling $\alpha_S = 0.1176$

→ *variation of parameters later considered in the PDF uncertainties*

Parametrisation

PDF parametrisation at the starting scale (Q^2_0=1.9 GeV^2):

"13p":

$$
\begin{aligned}
xg(x) &= A_g x^{B_g} \cdot (1-x)^{C_g} - A'_g x^{B'_g} \cdot (1-x)^{C'_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}} \cdot (1-x)^{C_{u_v}} \cdot (1 + E_{u_v} x^2), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}} \cdot (1-x)^{C_{d_v}}, \\
x\overline{U}(x) &= A_{\overline{U}} x^{B_{\overline{U}}} \cdot (1-x)^{C_{\overline{U}}}, \\
x\overline{D}(x) &= A_{\overline{D}} x^{B_{\overline{D}}} \cdot (1-x)^{C_{\overline{D}}}.
\end{aligned}
$$

A: normalisation
B: small x behavior
C: x→ 1 shape

$x\overline{U}=x\overline{u}(+x\overline{c})$

$x\overline{D}=x\overline{d}+x\overline{s}(+x\overline{b})$

$x\overline{s}=f_s x\overline{D}$ with

$f_s=x\overline{s}/(x\overline{d}+x\overline{s})=0.31$

→ *variation of parametrisation (addition of parameters) later considered in the PDF uncertainties*

Parametrisation

PDF parametrisation at the starting scale (Q^2_0=1.9 GeV^2):

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A: normalisation
B: small x behavior
C: x→ 1 shape

$x\bar{U} = x\bar{u}(+x\bar{c})$
$x\bar{D} = x\bar{d} + x\bar{s}(+x\bar{b})$
$x\bar{s} = f_s x\bar{D}$ with
$f_s = x\bar{s}/(x\bar{d}+x\bar{s}) = 0.31$

"15p" or "free-s":

$$
\begin{aligned}
xg(x) &= A_g x^{B_g} \cdot (1-x)^{C_g} - A'_g x^{B'_g} \cdot (1-x)^{C'_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}} \cdot (1-x)^{C_{u_v}} \cdot (1 + E_{u_v} x^2), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}} \cdot (1-x)^{C_{d_v}}, \\
x\overline{U}(x) &= A_{\overline{U}} x^{B_{\overline{U}}} \cdot (1-x)^{C_{\overline{U}}},
\end{aligned}
$$

~~$x\overline{D}(x) = A_{\overline{D}} x^{B_{\overline{D}}} \cdot (1-x)^{C_{\overline{D}}}.$~~ →

$$
\begin{aligned}
x\,\bar{d}(x) &= A_{\bar{d}}\, x^{B_{\bar{d}}}\, (1-x)^{C_{\bar{d}}} \\
x\,\bar{s}(x) &= A_{\bar{s}}\, x^{B_{\bar{s}}}\, (1-x)^{C_{\bar{s}}}
\end{aligned}
$$

$A_{\bar{u}} = A_{\bar{d}}\,;\, B_{\bar{u}} = B_{\bar{d}}$

$B_{\bar{s}} = B_{\bar{d}}$ for the central fit, A_s and C_s are free parameter of the fit, assumed s = sbar

$B_{\bar{s}} \neq B_{\bar{d}}$ fit included into parametrisation uncertainty

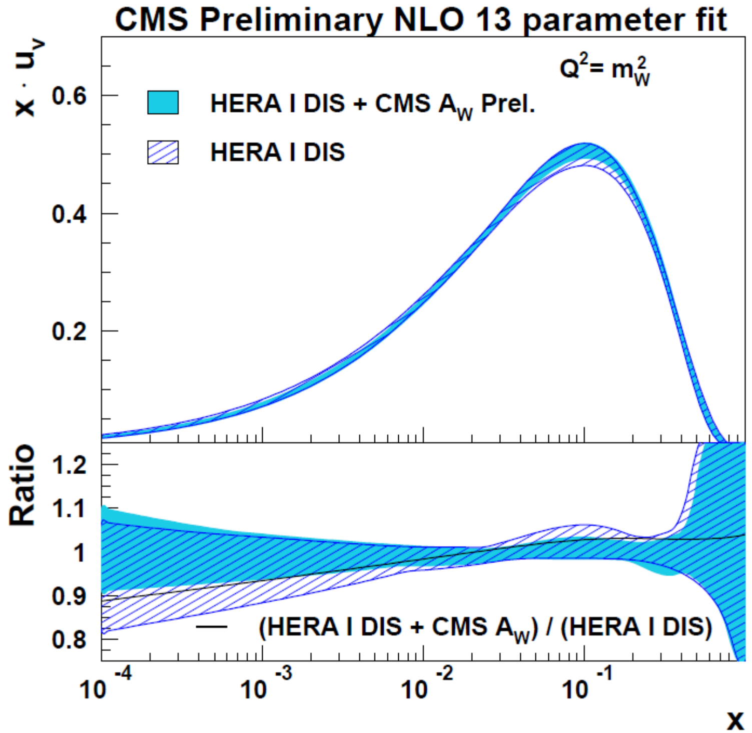
HERA data alone cannot be fitted with this parametrisation because has no sensitivity to s

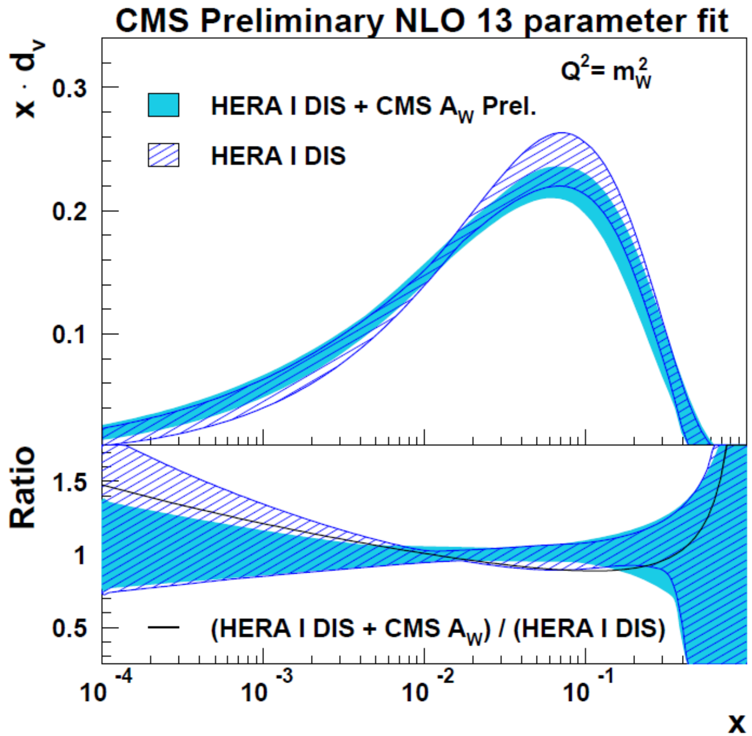
→ *variation of parametrisation (addition of parameters) later considered in the PDF uncertainties*

Results: CMS W asymmetry data

QCD analysis at NLO, 13 parameter (fixed-s fit)

- HERA I combined DIS data JHEP 1001:109 (2010)
- Muon charge asymmetry in W production at 7 TeV SMP-12-021



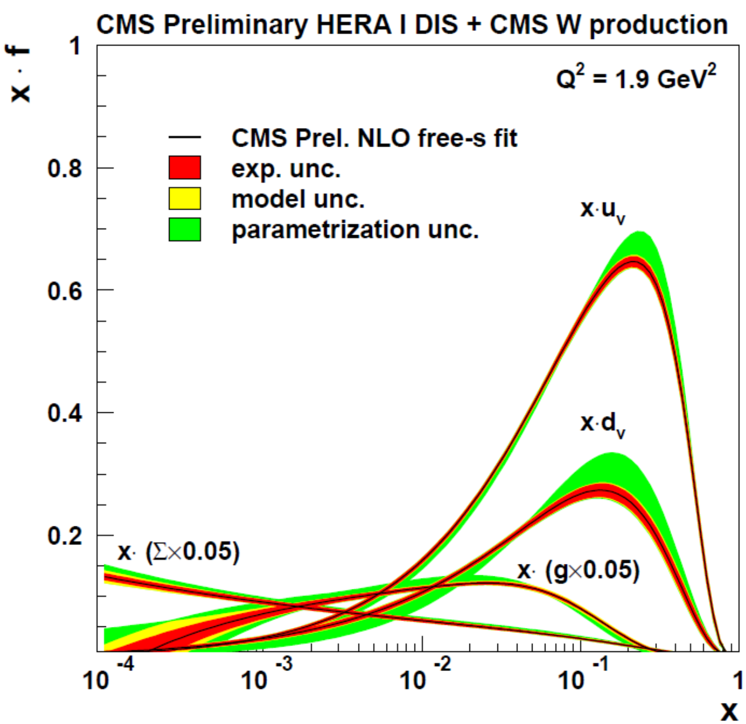


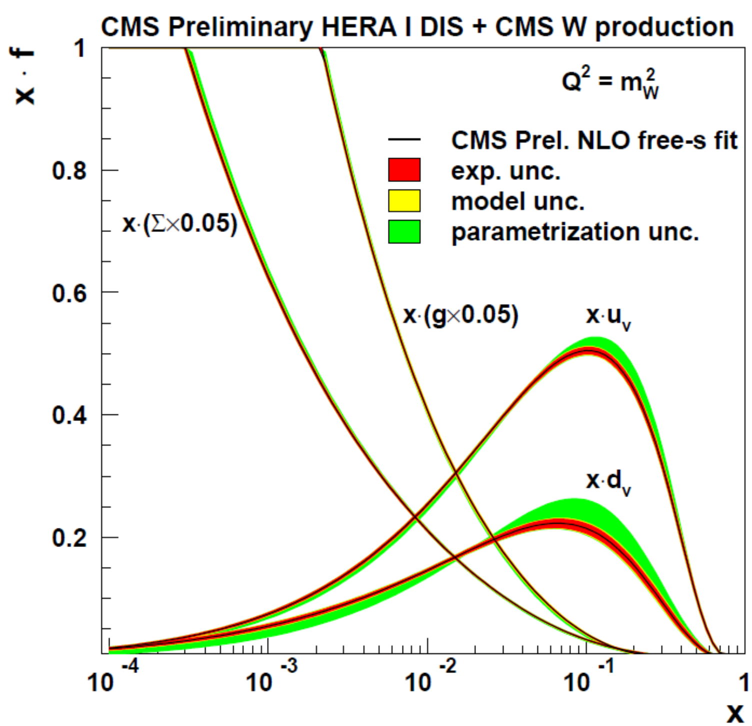
error bands represent total uncertainties, (experimental, model and parametrisation uncertainties)

Change of PDF shape, improved constraints on the valence distributions

QCD analysis at NLO, 15 parameter (free-s fit)

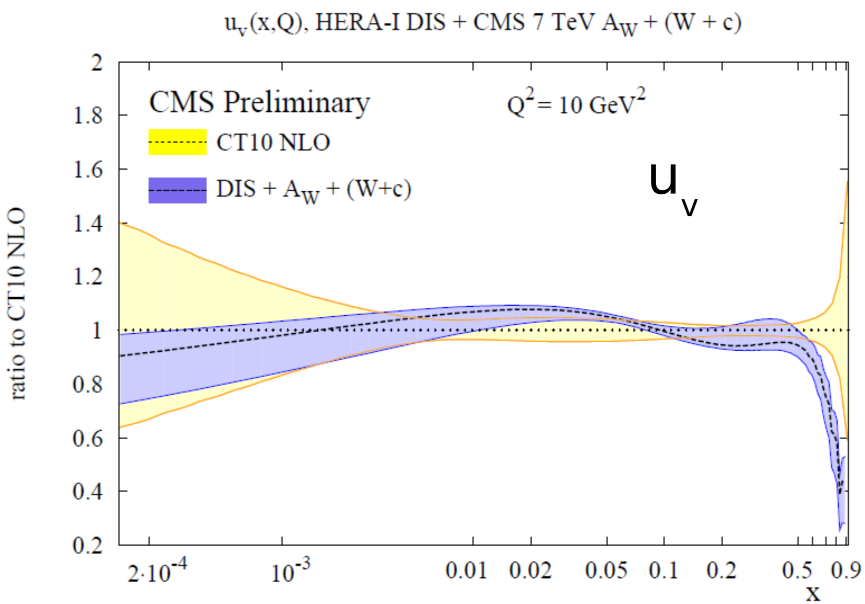
- HERA I combined DIS data JHEP 1001:109 (2010)
- Muon charge asymmetry in W production at 7 TeV SMP-12-021
- Differential cross sections of associated W+c production at 7 TeV arXiv:1310:1138

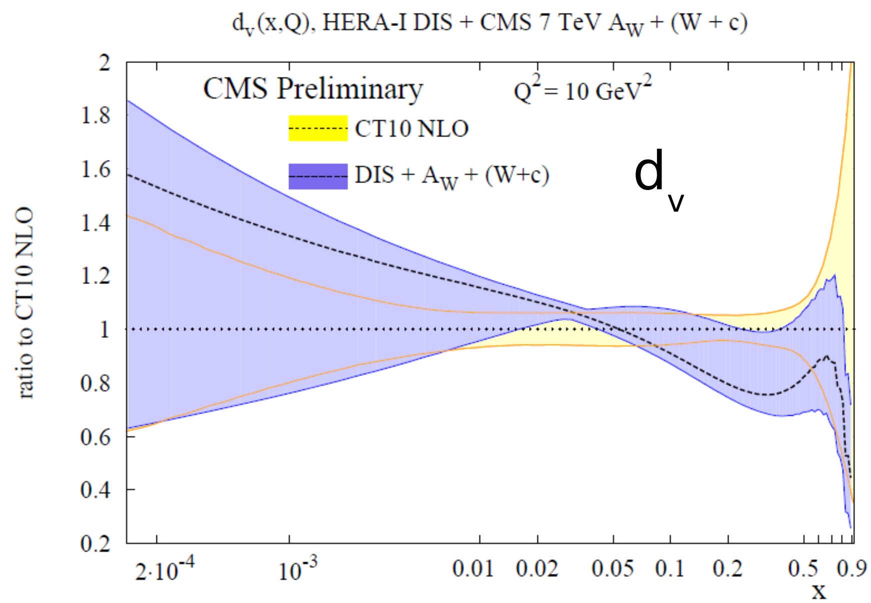


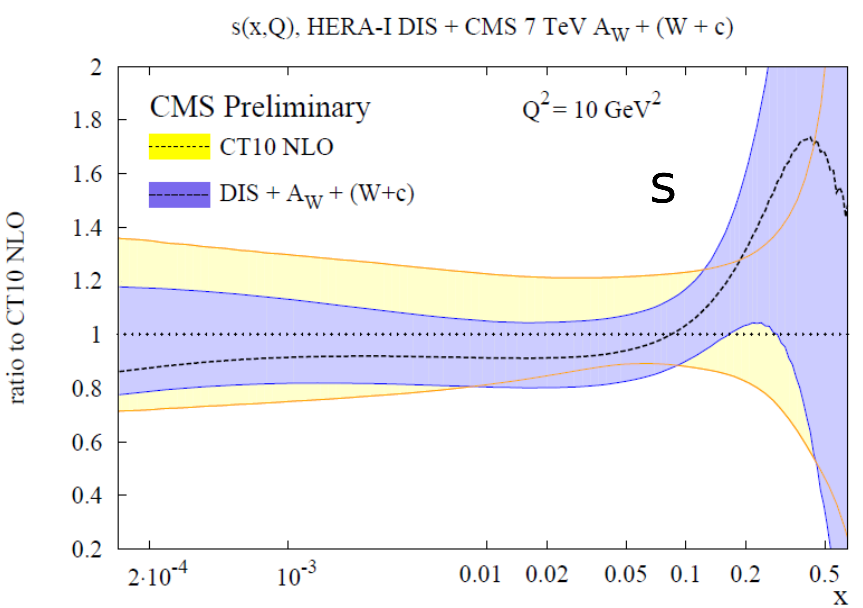


PDFs can be directly compared to NLO results by different PDF groups

Comparison to CT10 PDFs



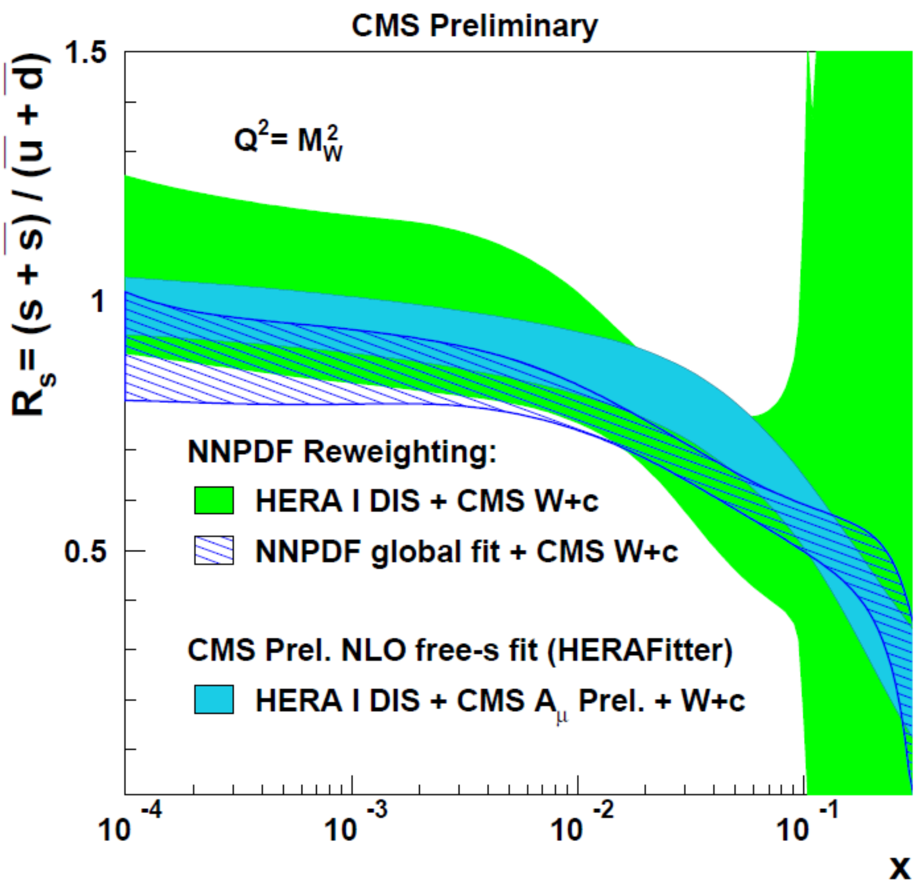




all uncertainties 68% CL

good agreement with CT10NLO
(does not include any LHC data)

Comparison to the NNPDF reweighting



NNPDF reweighting studies:
Juan Rojo

Comparison with:

- HERA I only and W+c data
- global NNPDF2.3 set (includes the neutrino DIS and the ATLAS W,Z data)

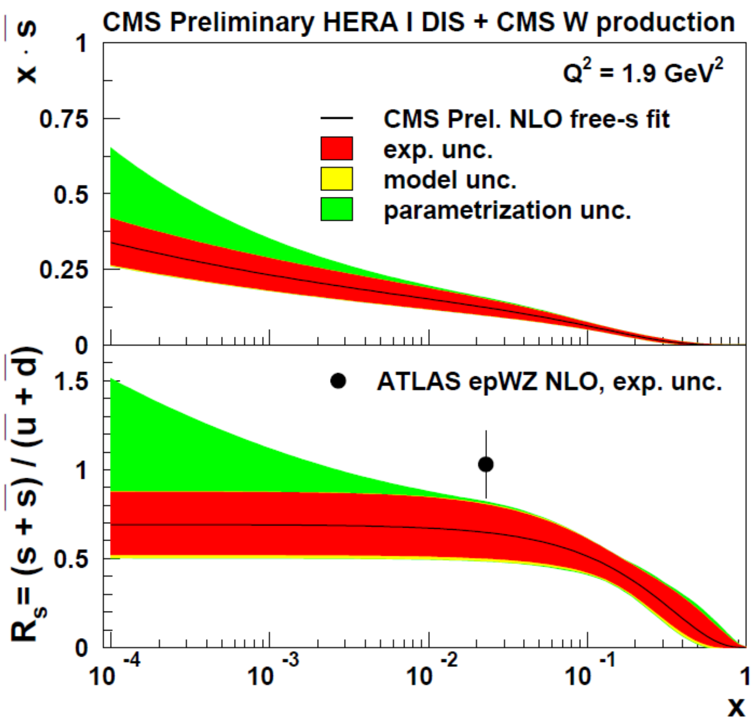
Results of full QCD analysis and NNPDF reweighting are in agreement

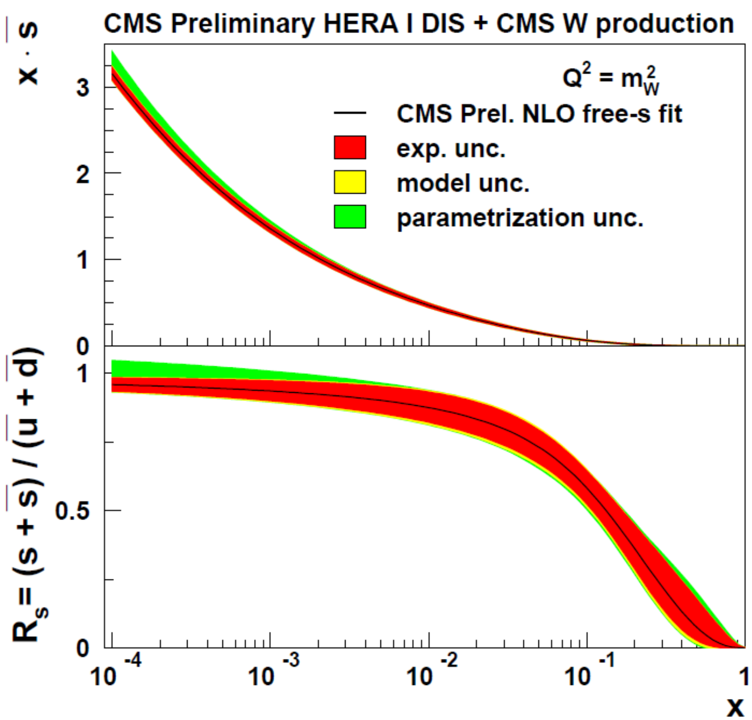
Determination of strangeness using collider only data

Results consistent to the constraints imposed by the neutrino scattering experiments

Results: s quark density

Determination of s quark density in the proton by using W production at CMS





Atlas epWZ NLO result at Q^2=1.9 GeV^2, x=0.023 is shown on the plot

Phys.Rev.Lett.109(2012)012001

Determined strange fraction is consistent with Atlas NLO result at fixed x

Summary

The QCD analysis at NLO with CMS W production data:

Precise CMS measurements of muon charge asymmetry impose stronger constraints on valence quarks

An interplay of W production measurements at CMS is exploited in a PDF fit

→ strange fraction $R_s(x)$ determined, found to be consistent with ATLAS NLO result for fixed x

→ strangeness suppression $\kappa_s(Q^2=20\ \mathrm{GeV}^2)$ is determined and is consistent with the NOMAD result (not shown in this talk)

→ obtained PDFs consistent with CT10 NLO PDF set

→ results are supported by the NNPDF reweighting studies

Back-up slides