Impact of CMS measurements on Proton Structure and QCD parameters

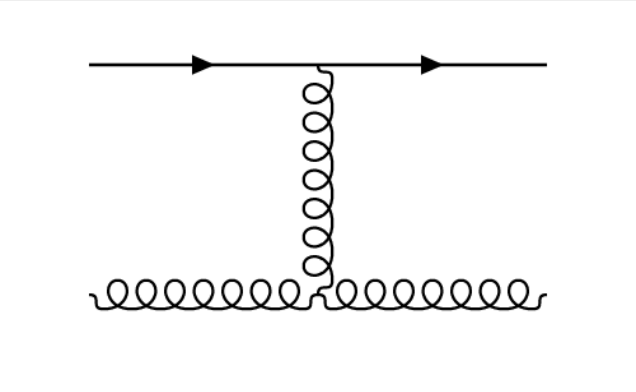
Svenja Pflitsch for the CMS Collaboration

Deep Inelasic Scattering and Related Subjects
Kobe 2018

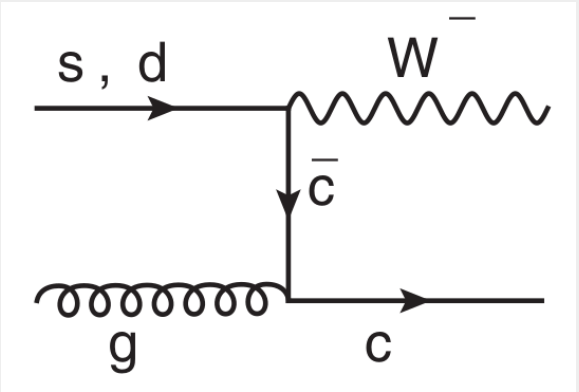
HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Measurements presented in this Talk

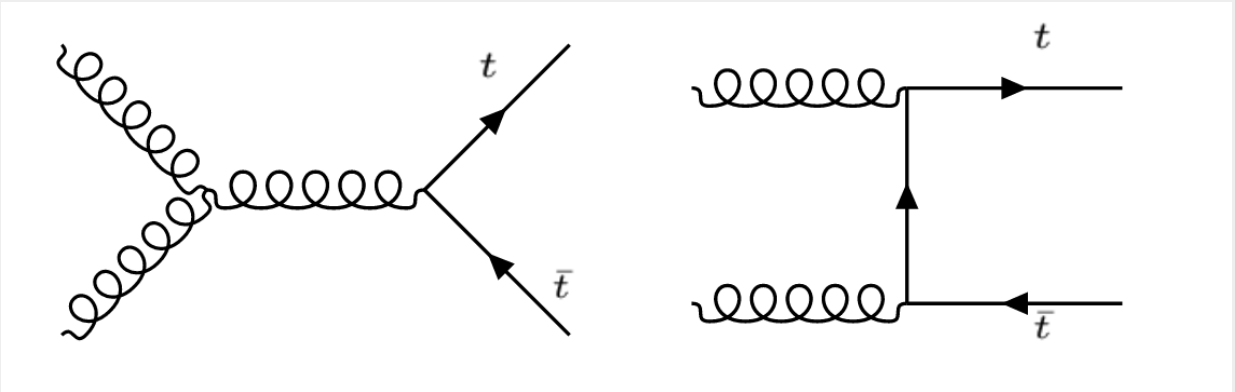
Triple Differential Dijets (8 TeV)



W+charm (13 TeV)



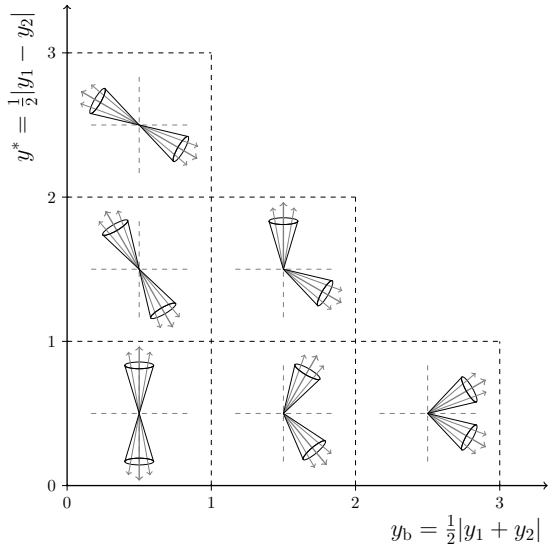
$t\bar{t}$: Double Differential (8 TeV), Inclusive (5 TeV)

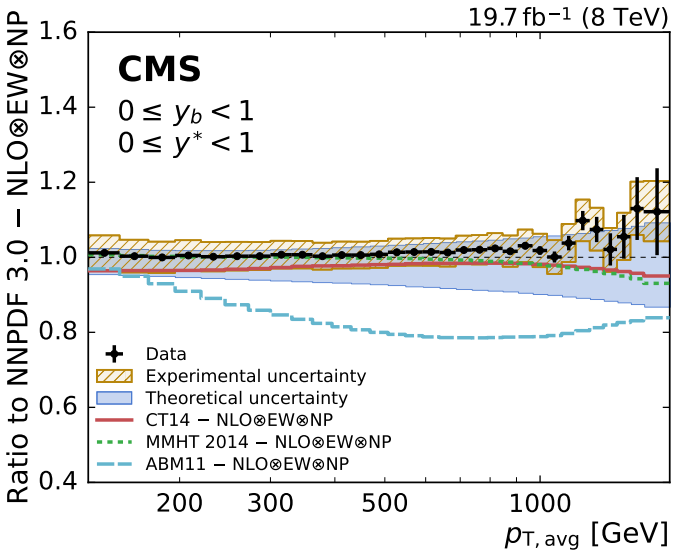


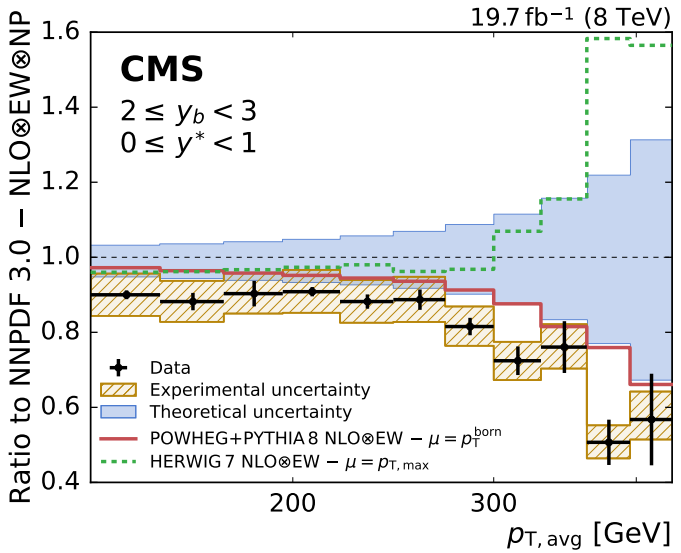
Triple Differential Dijets (8 TeV)

Analysis Strategy

- Published in EPJC 77 (2017) 11
- Probing x_1 and x_2
- Dijet production as a function of:
  - Jet average p_T
  - Rapidity separation
  - Boost







Triple Differential Dijets (8 TeV)

QCD Analysis

- xFitter1.1.2 - 16 parameter fit
- Baseline data: HERA inclusive DIS [EPJ C 75 (2015) 580]
- Theory via NLOJet++ via fastNLO
- Scale $\mu_r = \mu_f = p_{T,max} \cdot e^{0.3y^*}$

		HERA data		HERA & CMS data	
Data set	n_{data}	χ^2_{p}	$\chi^2_{\text{p}}/n_{\text{data}}$	χ^2_{p}	$\chi^2_{\text{p}}/n_{\text{data}}$
NC HERA-I+II e^+p $E_p = 920\,\text{GeV}$	332	382.44	1.15	406.45	1.22
NC HERA-I+II e^+p $E_p = 820\,\text{GeV}$	63	60.62	0.96	61.01	0.97
NC HERA-I+II e^+p $E_p = 575\,\text{GeV}$	234	196.40	0.84	197.56	0.84
NC HERA-I+II e^+p $E_p = 460\,\text{GeV}$	187	204.42	1.09	205.50	1.10
NC HERA-I+II e^-p	159	217.27	1.37	219.17	1.38
CC HERA-I+II e^+p	39	43.26	1.11	42.29	1.08
CC HERA-I+II e^-p	42	49.11	1.17	55.35	1.32
CMS triple-differential dijet	122	—	—	111.13	0.91

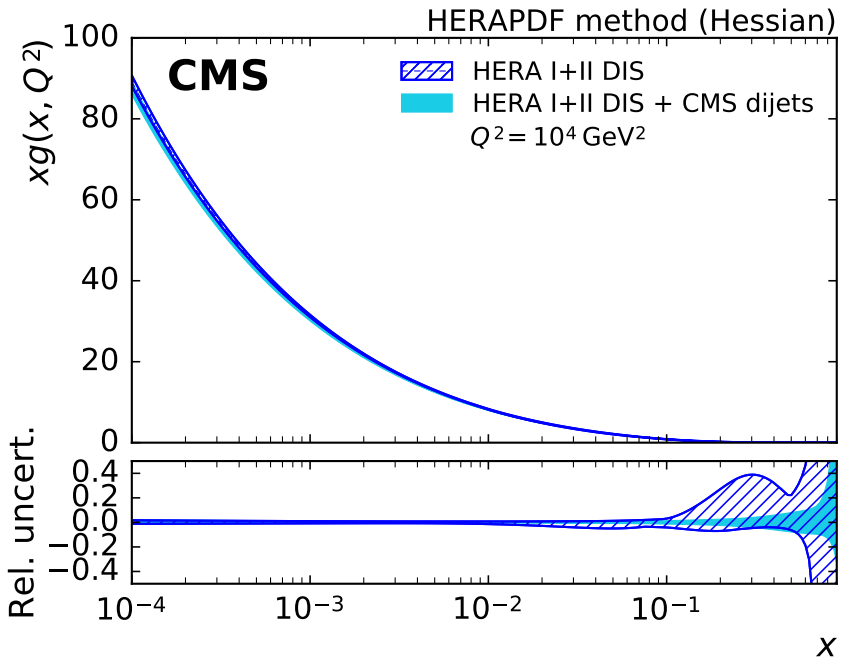
Data set(s)	n_{dof}	χ^2	χ^2/n_{dof}	χ^2	χ^2/n_{dof}
HERA data	1040	1211.00	1.16	—	—
HERA & CMS data	1162	—	—	1372.52	1.18

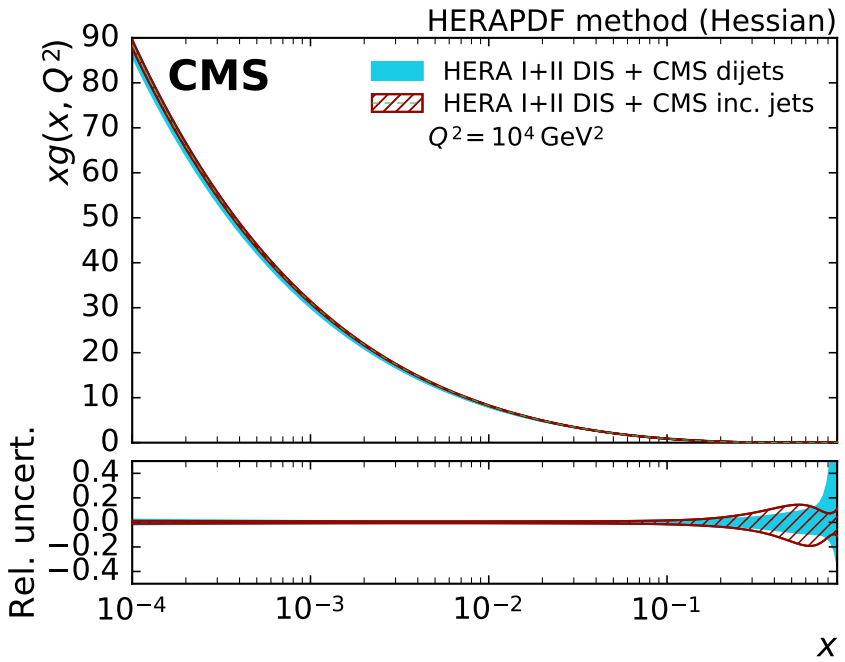
Triple Differential Dijets (8 TeV)

QCD Analysis: Results

- Change in gluon shape similar to inclusive jet data
- Significant reduction of uncertainty in $\mathbf{g(x)}$ at high x
- strong coupling determined simultaneously with PDFs:

$$\alpha_s(M_Z) = 0.1199^{+0.0015}_{-0.0016}(PDF)^{+0.0026}_{-0.0016}$$



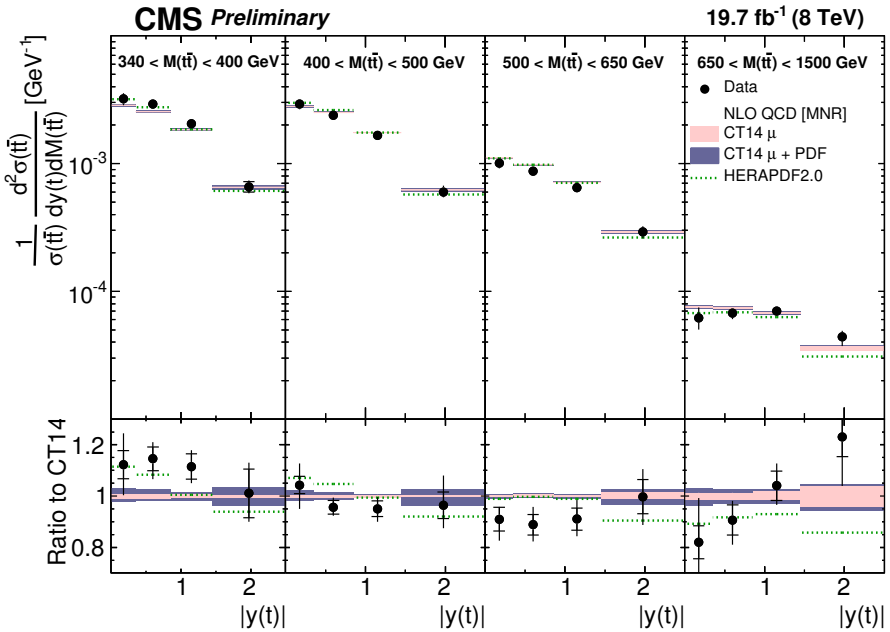


Double Differential $t\bar{t}$ (8 TeV)

Analysis Strategy

- Published in EPJC 77 (2017) 7
- $t\bar{t}$ cross section as a function of
  - $M(t\bar{t})$
  - $y(t\bar{t})$
- Predictions available at NNLO
- Sensitive to PDFs at LO

$$x_{1,2} = \frac{M_{t\bar{t}}}{\sqrt{s}} \cdot e^{\pm y(t\bar{t})}$$



Double Differential $t\bar{t}$ (8 TeV)

QCD Analysis

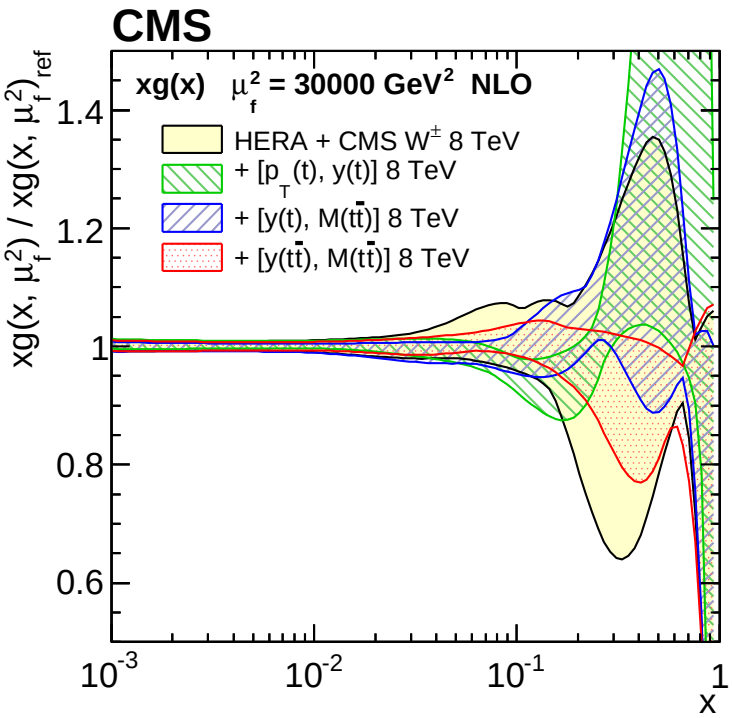
- xFitter1.1.2 18 parameter fit
- HERA inclusive DIS [EPJ C 75 (2015) 580]
- CMS $W^{\pm}$ [EPJ C76 (2016) 469]
- Theory for $t\bar{t}$ MCFM via ApplGrid
- $\mu_r = \mu_f = \sqrt{m_t^2 + \left[p_T^2(t) + p_T^2(\bar{t})\right]/2}$

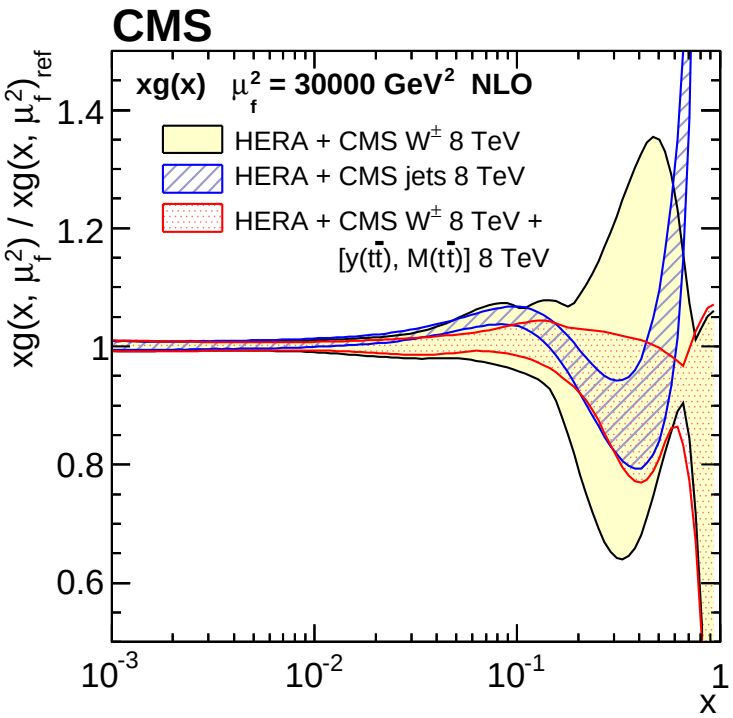
Data sets	χ^2/dof			
	Nominal fit	$+[p_T(t), y(t)]$	$+[y(t), M(t\bar{t})]$	$+[y(t\bar{t}), M(t\bar{t})]$
CMS double-differential $t\bar{t}$		10/15	7.4/15	7.6/15
HERA CC e^-p, $E_p = 920$ GeV	57/42	56/42	56/42	57/42
HERA CC e^+p, $E_p = 920$ GeV	44/39	44/39	44/39	43/39
HERA NC e^-p, $E_p = 920$ GeV	219/159	219/159	219/159	218/159
HERA NC e^+p, $E_p = 920$ GeV	440/377	437/377	439/377	441/377
HERA NC e^+p, $E_p = 820$ GeV	69/70	68/70	68/70	69/70
HERA NC e^+p, $E_p = 575$ GeV	221/254	220/254	221/254	221/254
HERA NC e^+p, $E_p = 460$ GeV	219/204	219/204	219/204	219/204
CMS $W^{\pm}$ asymmetry	4.7/11	4.6/11	4.8/11	4.9/11
Correlated χ^2	82	87	91	89
Log-penalty χ^2	−2.5	+2.6	−2.2	−3.3
Total χ^2/dof	1352/1138	1368/1153	1368/1153	1366/1153

Double Differential $t\bar{t}$ (8 TeV)

QCD Analysis: Results

- Strongest constraints from 2d distributions in $M_{t\bar{t}}$ and $y_{t\bar{t}}$
- Results compared to 8 TeV inclusive jets [JHEP 03 (2017) 156]
- Recommended use of both data sets for improvement of $g(x)$ at high x

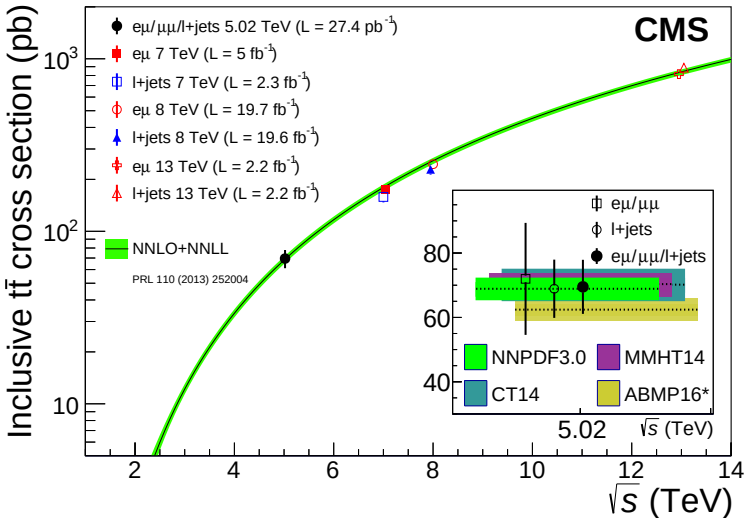


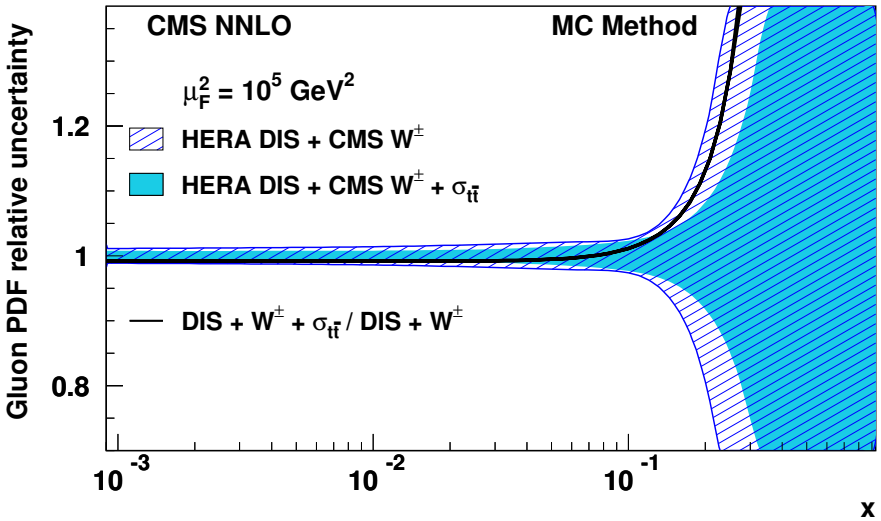


Inclusive $t\bar{t}$ (5 TeV)

QCD Analysis

- Published in JHEP 03 (2018) 115
- New kinematic range probed
- Theory: HATHOR, m_t = 172.5 GeV
- Moderate effect on $g(x)$ at high x





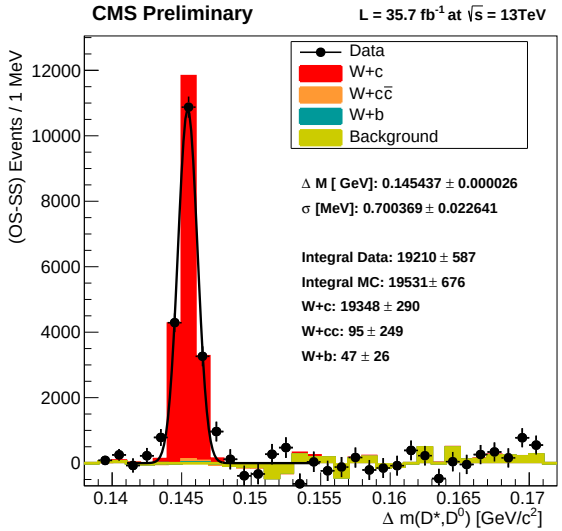
W+charm (13 TeV)
Analysis Strategy

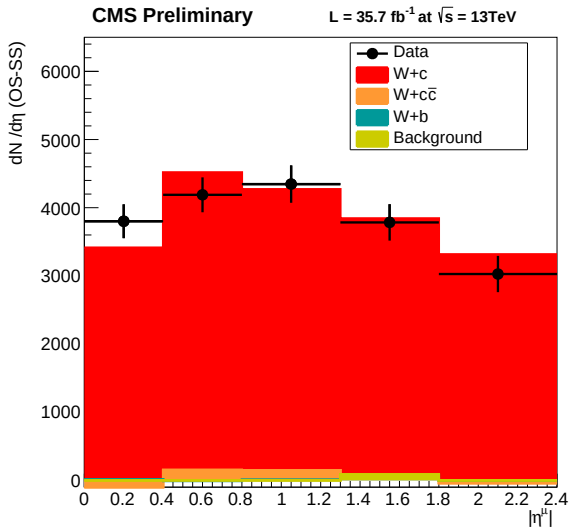
- CMS-PAS-SMP-17-014

- $W \to \mu\nu$
  - $p_T^{\mu} > 26\,\text{GeV}, |\eta^{\mu}| < 2.4$
  - $M_T > 50\,\text{GeV}$

- $c \to D^{*\pm} \to D^0 + \pi^{\mp}_{slow}$
  - $p_{T,reco}^{D^*} > 5\,\text{GeV}$
  - $p_{T,gen}^{c} > 5\,\text{GeV}$

- Differential measurement $|\eta^{\mu}|$

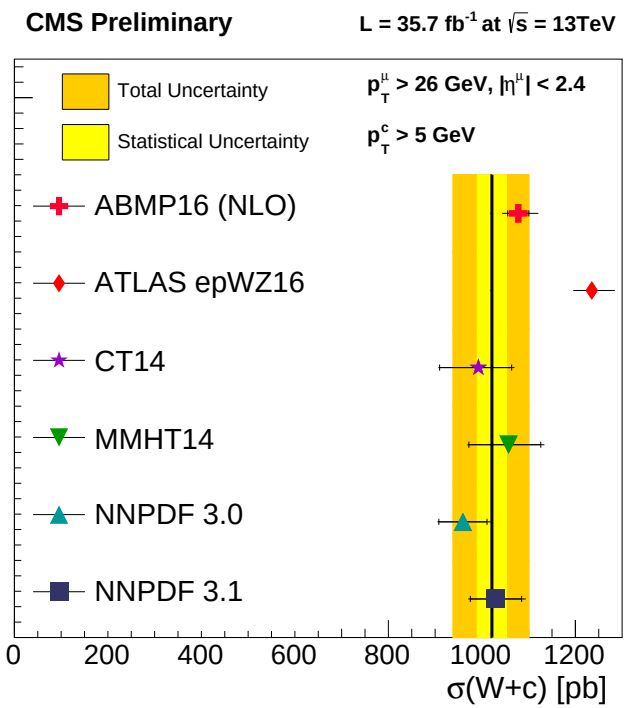


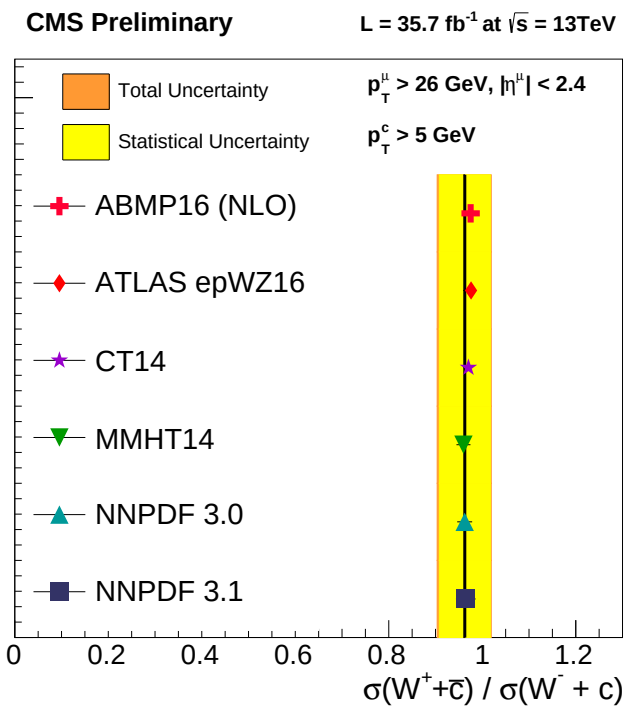


W+charm (13 TeV)

Theoretical Predictions: Inclusive

- Calculations done with MCFM, $W + c$ available at NLO
- Scale: $\mu_r = \mu_f = M_W$
- $\frac{1}{2}\mu < \mu_r = \mu_f < 2\mu$ amount to an uncertainty of 3%



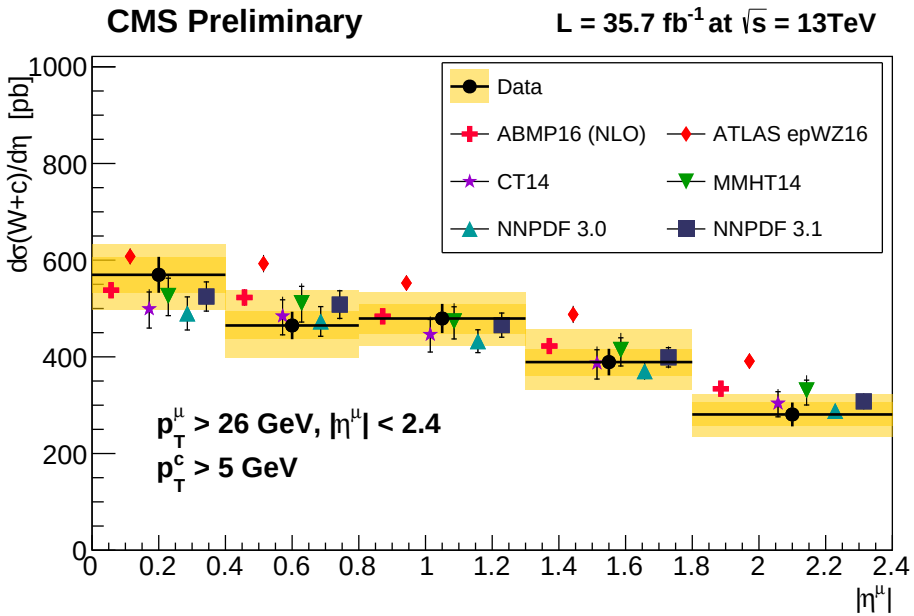


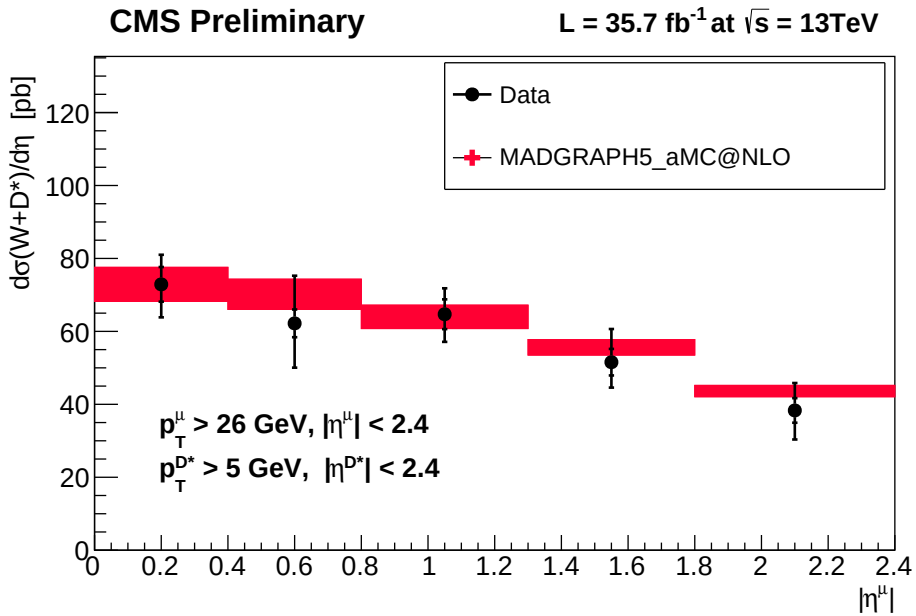
W+charm (13 TeV)

Theoretical Predictions: Differential

- Good agreement with predictions
- Particle level measurement as cross check
  - Additional cut $|\eta^{D^*}| < 2.4$

$\rightarrow$ Fiducial range of detector





W+charm (13 TeV)

QCD Analysis

- xFitter 2.0.0 - 15 parameter fit
- HERA I+II combined inclusive DIS data
  [Eur.Phys.J. C75 (2015) 12]
- CMS lepton charge asymmetry
  - 7 TeV [Phys. Rev. D 90, 032004]
  - 8 TeV [Eur.Phys.J. C76 (2016) 469]
- CMS W+charm
  - 7 TeV [JHEP 02 (2014) 013]
  - 13 TeV [CMS-PAS-SMP-17-014]
  - systematic errors as nuisance parameters
    (100% bin-to-bin correlation)

At the starting scale (Q_0^2 = 1.9 GeV^2):

$$
\begin{aligned}
x u_{\mathrm{v}}(x) &= A_{u_{\mathrm{v}}}\, x^{B_{u_{\mathrm{v}}}}\, (1-x)^{C_{u_{\mathrm{v}}}}\, (1+E_{u_{\mathrm{v}}} x^2) \\
x d_{\mathrm{v}}(x) &= A_{d_{\mathrm{v}}}\, x^{B_{d_{\mathrm{v}}}}\, (1-x)^{C_{d_{\mathrm{v}}}} \\
x \overline{\mathrm{U}}(x) &= A_{\overline{\mathrm{U}}}\, x^{B_{\overline{\mathrm{U}}}}\, (1-x)^{C_{\overline{\mathrm{U}}}}\, (1+E_{\overline{\mathrm{U}}} x^2) \\
x \bar{d}(x) &= A_{\bar{d}}\, x^{B_{\bar{d}}}\, (1-x)^{C_{\bar{d}}} \\
x \bar{s}(x) &= A_{\bar{s}}\, x^{B_{\bar{s}}}\, (1-x)^{C_{\bar{s}}} \\
x g(x) &= A_g\, x^{B_g}\, (1-x)^{C_g}\, (1+D_g x)
\end{aligned}
$$

$f_s = \bar{s}/(\bar{d}+\bar{s})$ released

$B_{\bar{u}} = B_{\bar{d}} = B_{\bar{s}}$ released

$xs = x\bar{s}$

$A_{\overline{U}} = A_{\overline{D}}(1-f_s)$

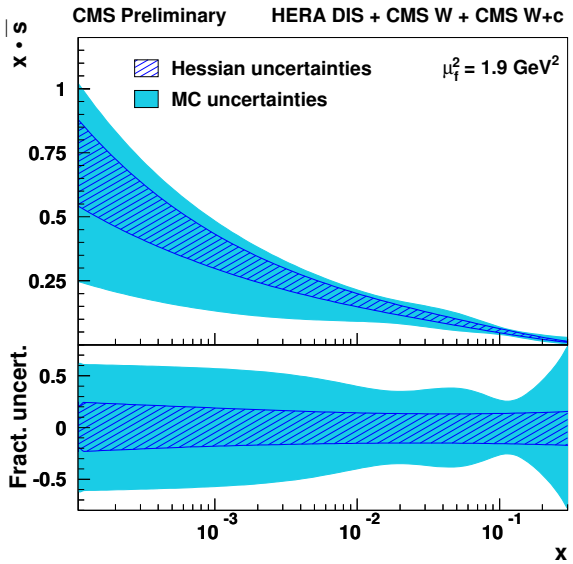
[arXiv:1708.01067]

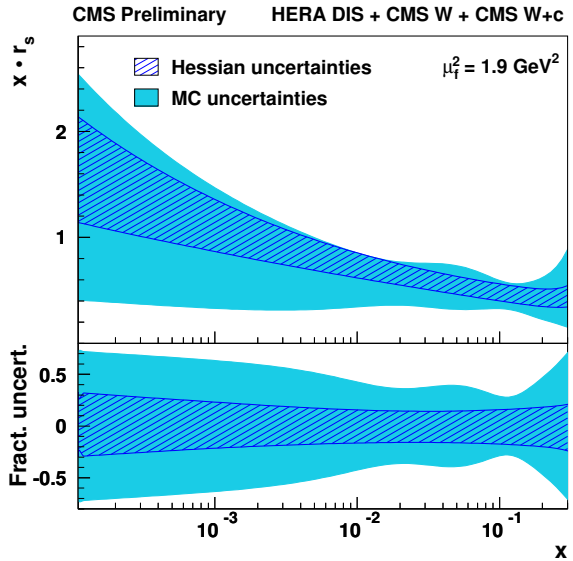
W+charm (13 TeV)

QCD Analysis: Results

- Good agreement among the CMS measurements

Dataset	χ^2/n_{dp}
HERA1+2 CCep	43 / 39
HERA1+2 CCem	57 / 42
HERA1+2 NCem	218 / 159
HERA1+2 NCep 820	69 / 70
HERA1+2 NCep 920	448 / 377
HERA1+2 NCep 460	216 / 204
HERA1+2 NCep 575	220 / 254
CMS W muon charge asym. 7 TeV	13 / 11
CMS W muon charge asym. 8 TeV	4.2 / 11
W+c 7 TeV	2.2 / 5
W+c 13 TeV	2.1 / 5
Correlated χ^2	87
Total χ^2 / dof	1385 / 1160

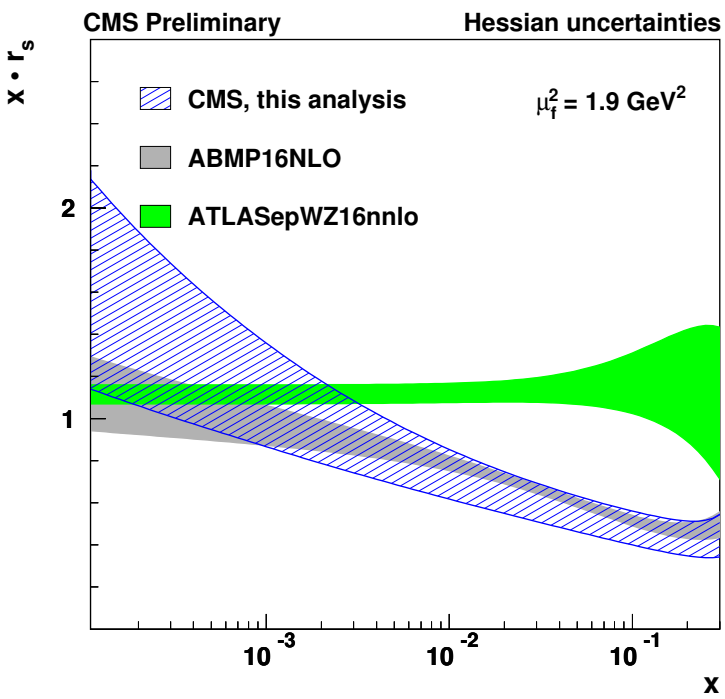


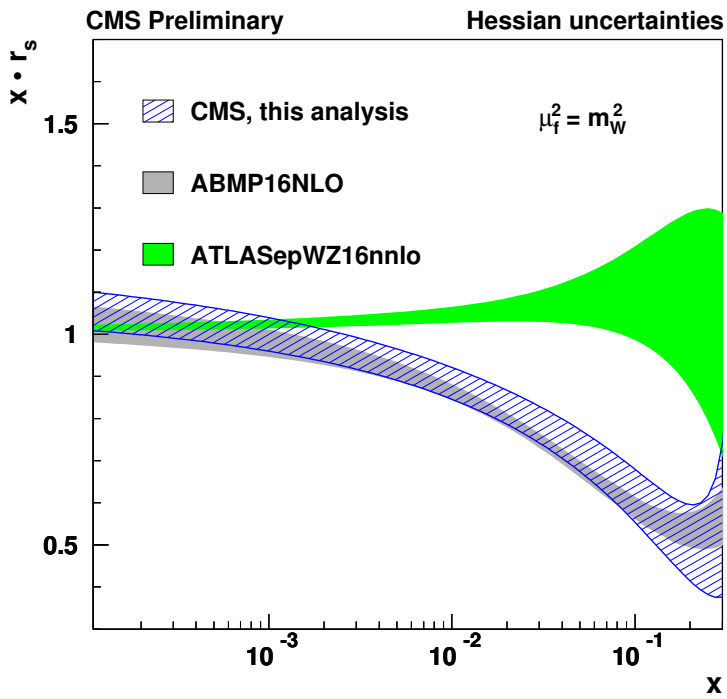


W+charm (13 TeV)

QCD Analysis: Comparison with other PDFs

- Results compatible wit ABPM16 NLO
- No observation of enhanced strangeness

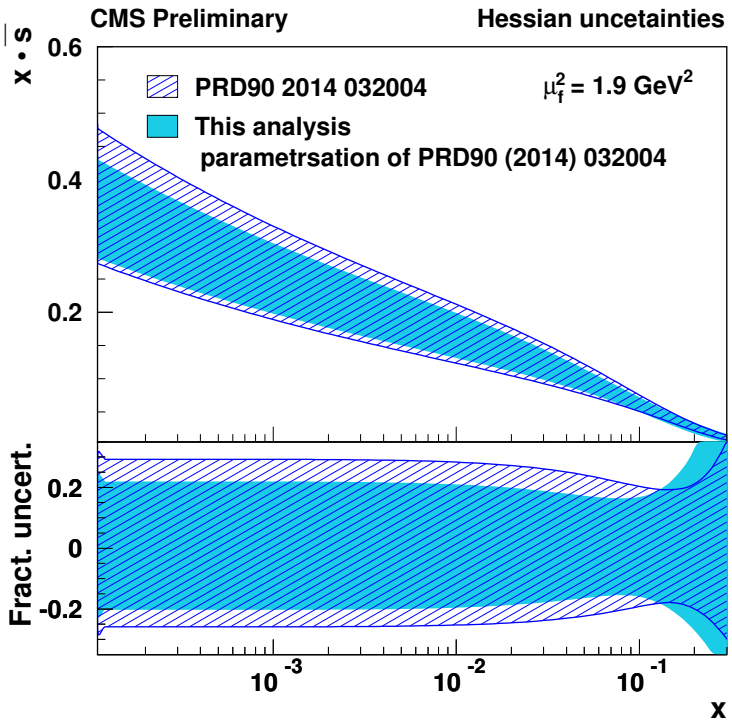


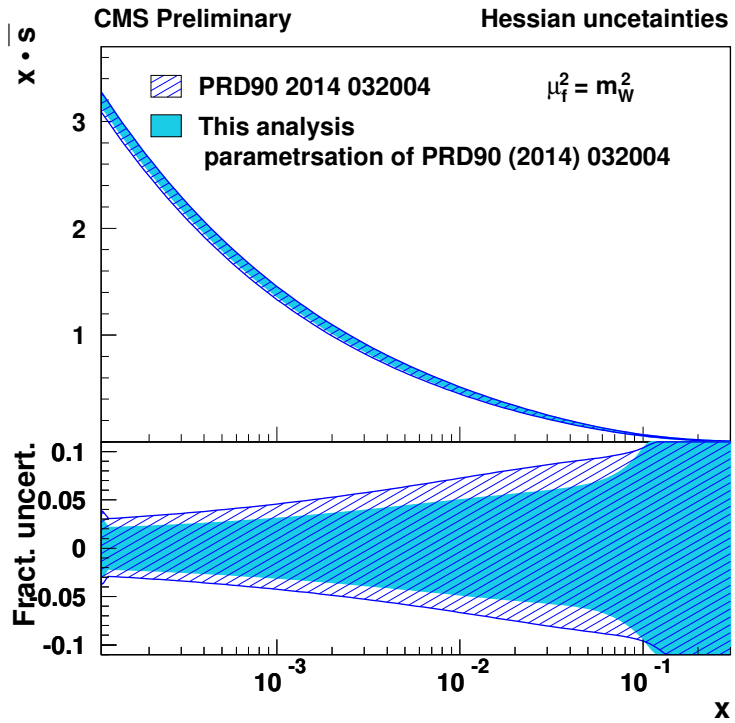


W+charm (13 TeV)

QCD Analysis: Comparison with 7 TeV

- In agreement with 7 TeV PDF fits with same parametrization
- Reduced PDF uncertainties





Summary

- CMS data used for improvement of PDF accuracy
- Run I
  - Jet data: $g(x)$ at medium & high x, α_s
  - 2-d $t\bar{t}$: $g(x)$ at high x
- Run II
  - $t\bar{t}$ at 5 TeV: $g(x)$ at high x
  - $W + c$: $s(x)$ at medium x

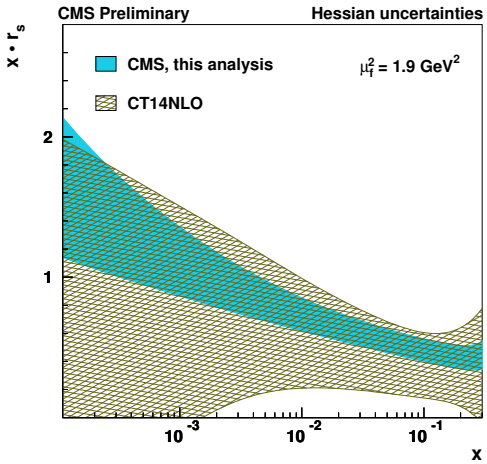
$\rightarrow$ New measurements will arrive soon

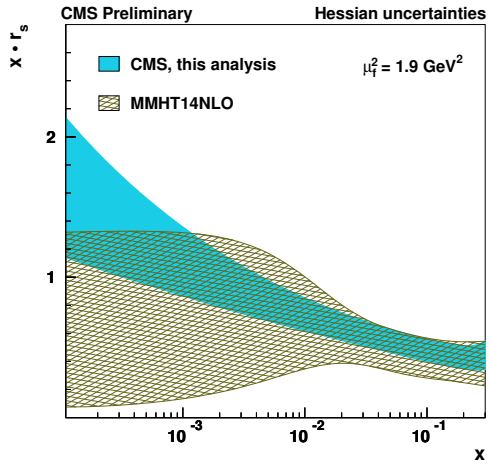
$\rightarrow$ Even better understanding of the proton structure

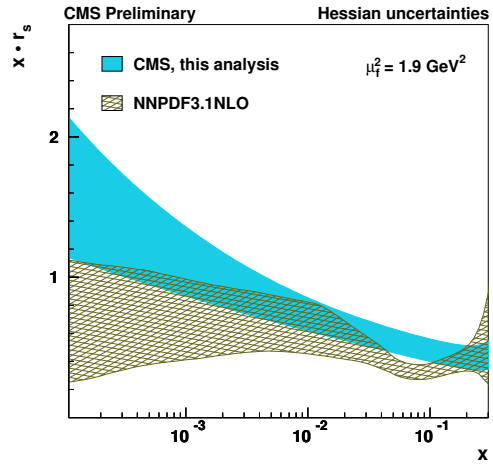
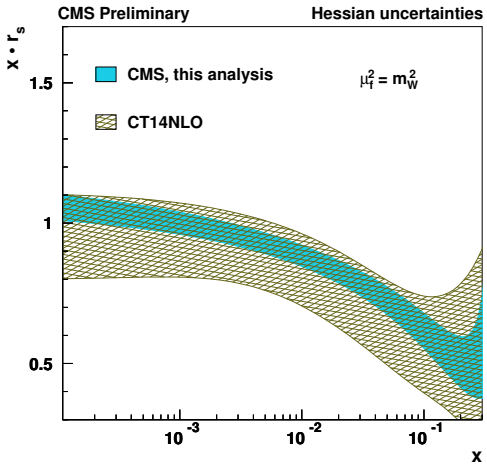
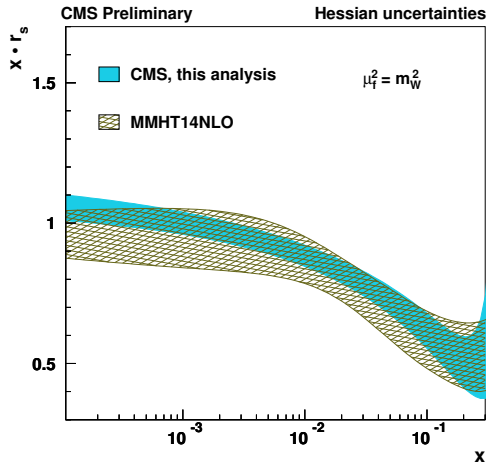
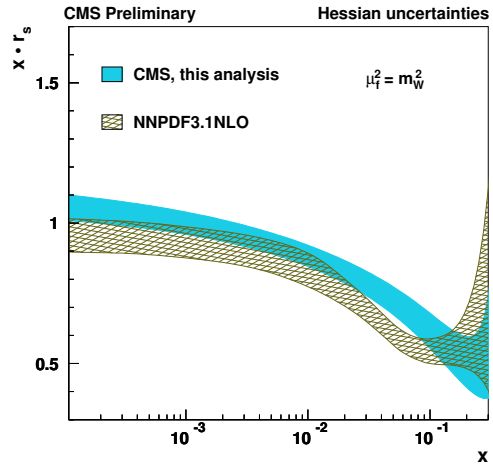
Backup: W+charm (13 TeV)

Comparison with other PDFs

Q_0^2







m_W^2