

# Impact of CMS measurements on Proton Structure and QCD parameters

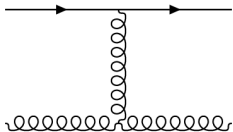
Svenja Pflitsch for the CMS Collaboration

Deep Inelastic Scattering and Related Subjects  
Kobe 2018

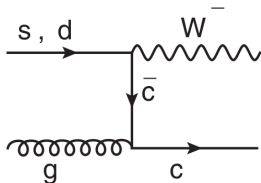


**HELMHOLTZ**  
RESEARCH FOR GRAND CHALLENGES

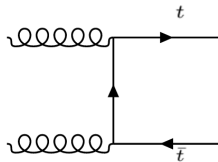
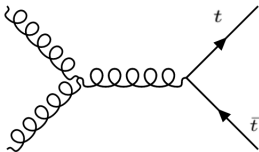
## Triple Differential Dijets (8 TeV)



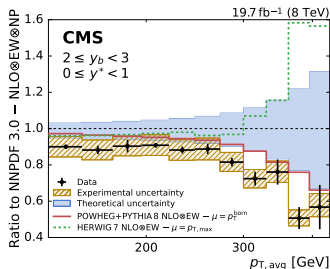
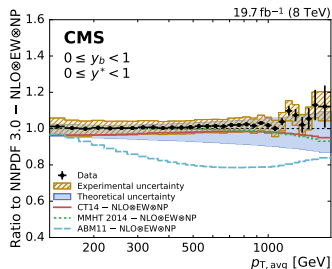
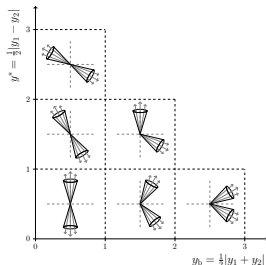
## W+charm (13 TeV)



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



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





# Triple Differential Dijets (8 TeV)

## QCD Analysis

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

Data set	$n_{\text{data}}$	HERA data		HERA & CMS data	
		$\chi_p^2$	$\chi_p^2/n_{\text{data}}$	$\chi_p^2$	$\chi_p^2/n_{\text{data}}$
NC HERA-I+II $e^+p$ $E_p = 920$ GeV	332	382.44	1.15	406.45	1.22
NC HERA-I+II $e^+p$ $E_p = 820$ GeV	63	60.62	0.96	61.01	0.97
NC HERA-I+II $e^+p$ $E_p = 575$ GeV	234	196.40	0.84	197.56	0.84
NC HERA-I+II $e^+p$ $E_p = 460$ 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)	$n_{\text{dof}}$	$\chi^2$	$\chi^2/n_{\text{dof}}$	$\chi^2$	$\chi^2/n_{\text{dof}}$
HERA data	1040	1211.00	1.16	—	—
HERA & CMS data	1162	—	—	1372.52	1.18

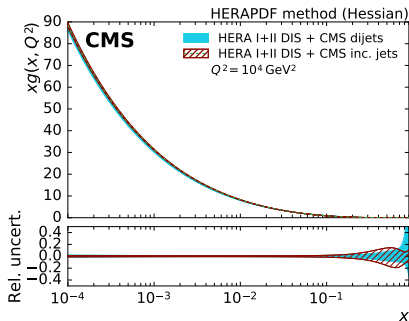
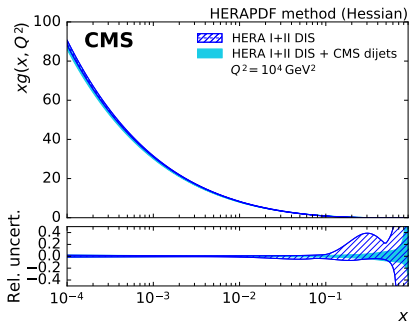


# Triple Differential Dijets (8 TeV)

QCD Analysis: Results

- Change similar to inclusive jet data [JHEP 03 (2017) 156]
- Significant reduction of uncertainty in  $g(x)$  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

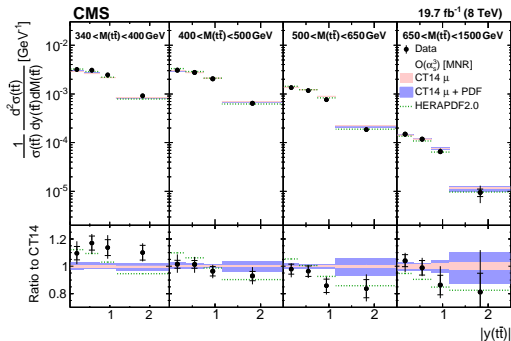
- Published in EPJC 77 (2017) 7
- $t\bar{t}$  cross section as a function of

- $p_T(t)$
- $y(t)$
- $y(t\bar{t})$
- $y(t)$
- $M(t\bar{t})$
- $M(t\bar{t})$

- NLO calculations in fixed-flavour number scheme

- LO Sensitive to PDFs

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





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

## QCD Analysis

- xFitter1.1.0 18 parameter fit
- HERA inclusive DIS [EPJ C 75 (2015) 580]
- CMS  $W^\pm$  [Eur.Phys.J. C76 (2016) 469]
- Theory for  $t\bar{t}$  MCFM via ApplGrid
- $\mu_r = \mu_f = \sqrt{m_t^2 + [p_T^2(t) + p_T^2(\bar{t})]} / 2$

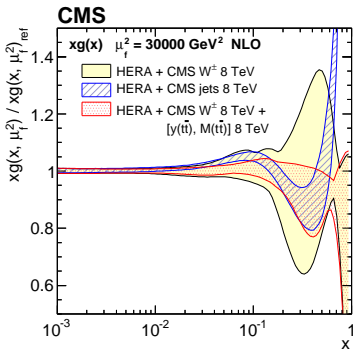
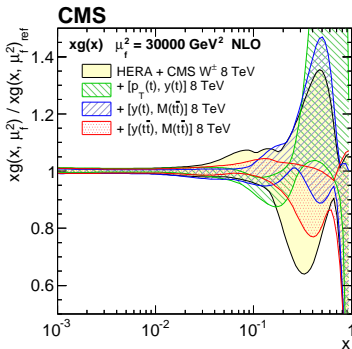
Data sets	$\chi^2/\text{dof}$			
	Nominal fit	+ $[p_T(t), y(t)]$	+ $[y(t), M(t\bar{t})]$	+ $[y(t\bar{t}), M(t\bar{t})]$
CMS double-differential $t\bar{t}$		10/15	7.4/15	7.6/15
HERA CC $e^-p$ , $E_p = 920$ GeV	57/42	56/42	56/42	57/42
HERA CC $e^+p$ , $E_p = 920$ GeV	44/39	44/39	44/39	43/39
HERA NC $e^-p$ , $E_p = 920$ 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 $\chi^2$	82	87	91	89
Log-penalty $\chi^2$	-2.5	+2.6	-2.2	-3.3
Total $\chi^2/\text{dof}$	1352/1138	1368/1153	1368/1153	1366/1153



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

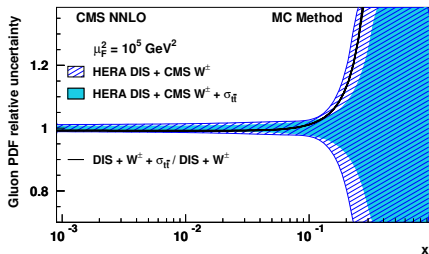
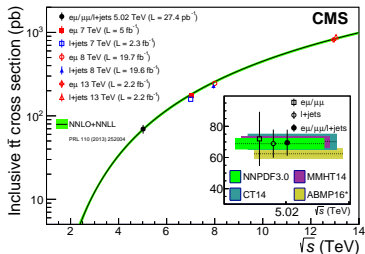
QCD Analysis: Results

- 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  $x$





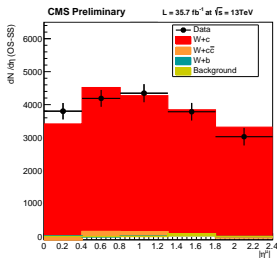
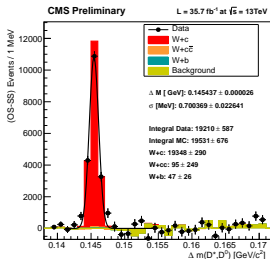
- Published in JHEP 03 (2018) 115
- New kinematic range probed
- Theory: HATHOR,  $m_t = 172.5$  GeV
- Moderate effect on  $g(x)$  at high  $x$





# W+charm (13 TeV) Analysis Strategy

- CMS-PAS-SMP-17-014
- $W \rightarrow \mu\nu$ 
  - $p_T^\mu > 26 \text{ GeV}, |\eta^\mu| < 2.4$
  - $M_T > 50 \text{ GeV}$
- $c \rightarrow D^{*\pm} \rightarrow D^0 + \pi_{slow}^\mp$ 
  - $p_{T,reco}^{D^*} > 5 \text{ GeV}$
  - $p_{T,gen}^c > 5 \text{ GeV}$
- Differential measurement  $|\eta^\mu|$

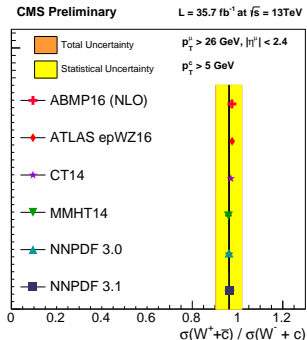
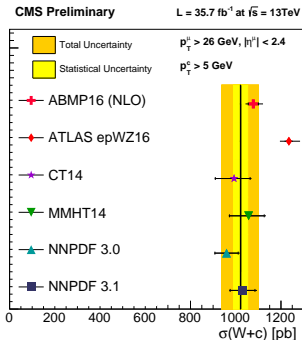




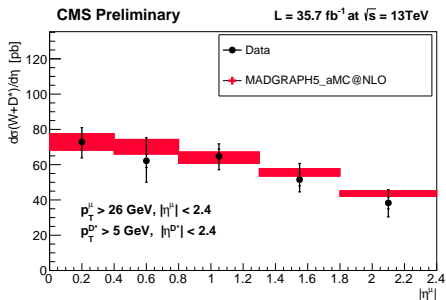
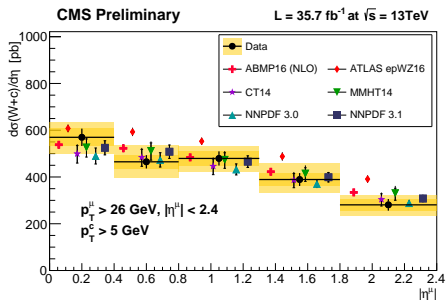
# W+charm (13 TeV)

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%



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





# W+charm (13 TeV)

## QCD Analysis

- xFitter 2.0.0 - Fit performed at NLO
- 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 ( $Q_0^2 = 1.9 \text{ GeV}^2$ ):

$$xu_v(x) = A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2)$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}$$

$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}} (1 + E_{\bar{U}} x^2)$$

$$x\bar{d}(x) = A_{\bar{d}} x^{B_{\bar{d}}} (1-x)^{C_{\bar{d}}}$$

$$x\bar{s}(x) = A_{\bar{s}} x^{B_{\bar{s}}} (1-x)^{C_{\bar{s}}}$$

$$xg(x) = A_g x^{B_g} (1-x)^{C_g} (1 + D_g x)$$

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

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

$$xs = x\bar{s}$$

released

released

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

[arXiv:1708.01067]

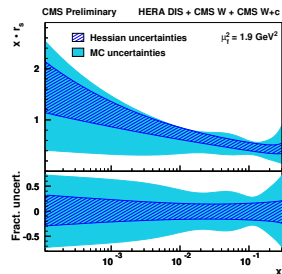
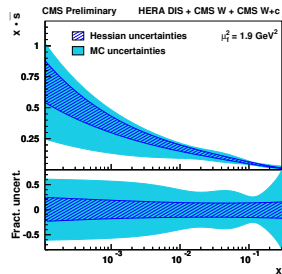


# W+charm (13 TeV)

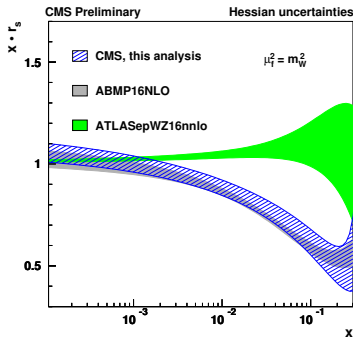
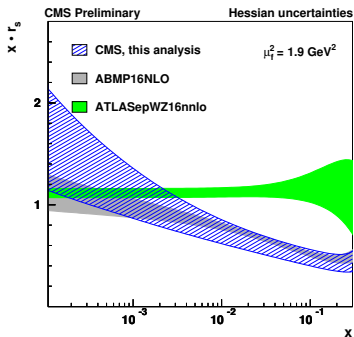
## QCD Analysis: Results

- Good agreement among the CMS measurements

Dataset	$\chi^2/n_{dp}$
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 $\chi^2$	87
Total $\chi^2 / \text{dof}$	1385 / 1160



- Results compatible with ABMP16 NLO
- No observation of enhanced strangeness



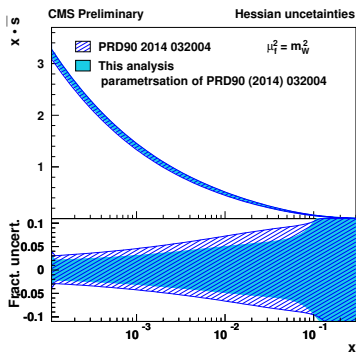
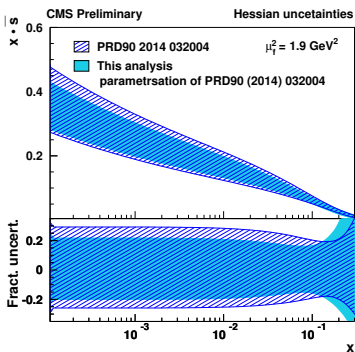




# W+charm (13 TeV)

QCD Analysis: Comparison with 7 TeV

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



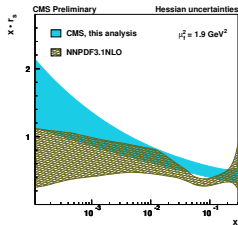
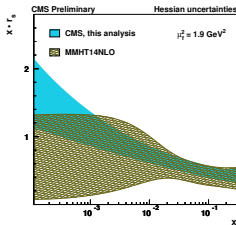
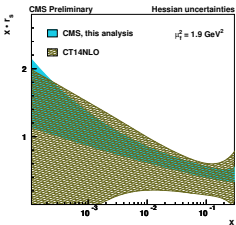


- CMS data used for improvement of PDF accuracy
  - Run I
    - Jet data:  $g(x)$  at medium & high  $x$ ,  $\alpha_s$
    - 2-d  $t\bar{t}$ :  $g(x)$  at high  $x$
  - Run II
    - $t\bar{t}$  at 5 TeV:  $g(x)$  at high  $x$
    - $W + c$ :  $s(x)$  at medium  $x$
- New measurements will arrive soon
- Even better understanding of the proton structure

# Backup: $W+\text{charm}$ (13 TeV)

## Comparison with other PDFs

$Q_0^2$



$m_W^2$

