Associated Production of W+charm with CMS and Determination of the Strange-quark Content of the Proton

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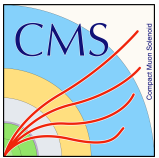
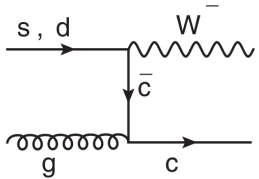
DESY

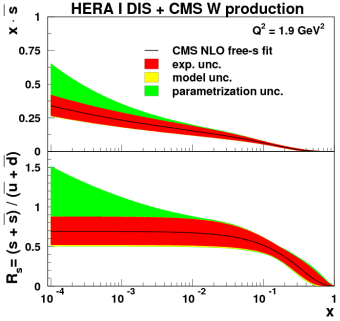
19.03.2018

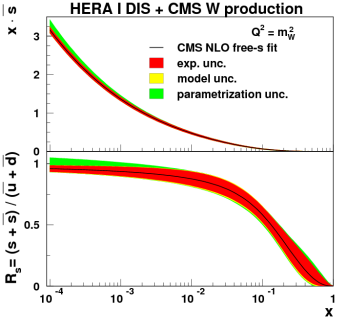


Motivation

- W+c is a direct probe of strange-quark content in the proton at EW-scale
  - $\bar{\mathbf{s}}\mathbf{g} \rightarrow \mathbf{W}^+ + \bar{\mathbf{c}}$, $\mathbf{s}\mathbf{g} \rightarrow \mathbf{W}^- + \mathbf{c}$ dominate at leading order
  - $\bar{\mathbf{d}}\mathbf{g} \rightarrow \mathbf{W}^+ + \bar{\mathbf{c}}$, $\mathbf{d}\mathbf{g} \rightarrow \mathbf{W}^- + \mathbf{c}$ are Cabibbo suppressed





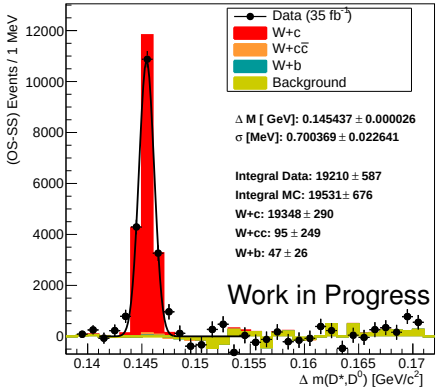


[Phys.Rev. D90 (2014) no.3]

Investigated Process: $pp \rightarrow W + c + X$

- $W \rightarrow \mu + \nu$
  - Identified by single, isolated high-p_T muon
  - + Missing transverse energy
- $c \xrightarrow{0.24} D^{*\pm} \xrightarrow{0.68} D^0 + \pi^{\mp}_{slow}$

  $D^0 \xrightarrow{0.04} K^{\pm} + \pi^{\mp}$
  - No jet required $\rightarrow$ low-p_T D^* accessible
  - Low tracking uncertainty
  - Small branching ratios

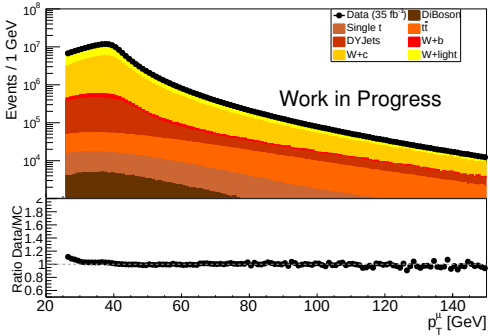


Event Selection

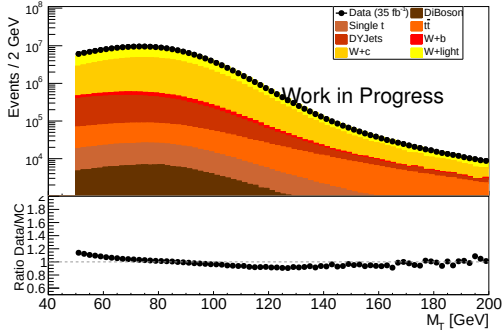
- $p_T(\mu) > 26$ GeV
- $|\eta| < 2.4$
- μ is isolated

- **Only one** muon fulfills criteria
- **No cut** on missing energy
- Transverse Mass $(M_T) > 50$ GeV

$p_T(\mu)$



M_T

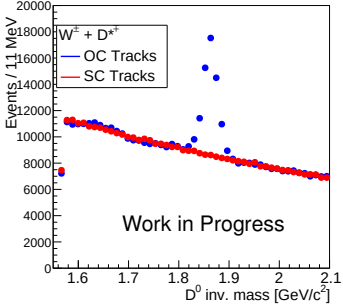


D^0 Reconstruction

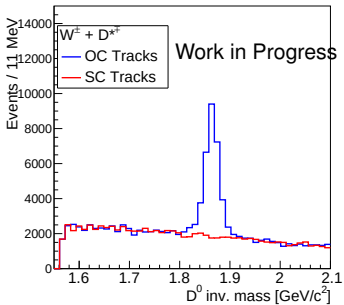
- $p_T^K, p_T^\pi > 1.0\,\text{GeV}$
- Valid secondary vertex
- $|\Delta m^{reco}(D^*, D^0) - \Delta m^{pdg}(D^*, D^0)| < 1\,\text{MeV}$

- Opposite Charge (OC): $K^\pm$, $\pi^\mp$
- Same Charge (SC): $K^\pm$, $\pi^\pm$

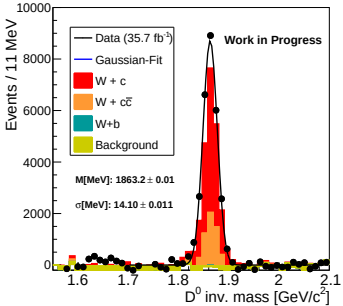
Data



MC



OC - SC

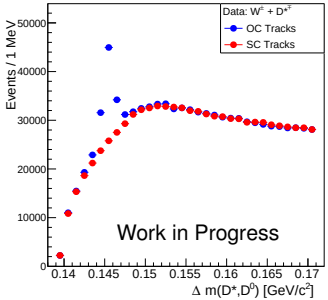


D^* Reconstruction

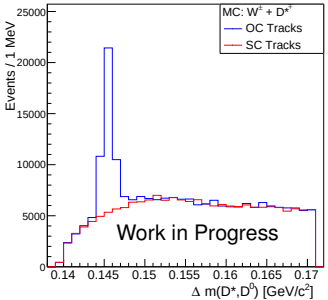
- $p_T^{\pi_{slow}} > 0.35\,\text{GeV}$
- $\Delta xy(D^0, \pi_s) < 0.1\,\text{cm}$
  $\Delta z(D^0, \pi_s) < 0.1\,\text{cm}$

- $\Delta R(D^0, \pi_{slow}) < 0.15$
- $|D^0_{rec} - D^0_{pdg}| < 40\,\text{MeV}$
- $p_T^{D^*} > 5\,\text{GeV}$

Data



MC



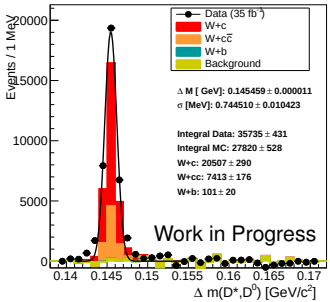
Extracting resonant W+c

- Large background from $g \to c\bar{c}$

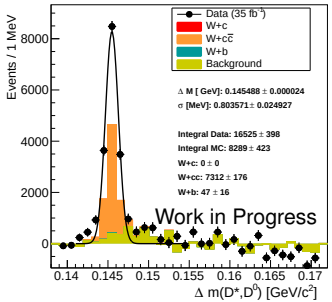
$\to$ same No. candidates with OS and SS:

- Opposite Sign (OS): $W^{\pm}$, $D^{*\mp}$
- Same Sign (SS): $W^{\pm}$, $D^{*\pm}$

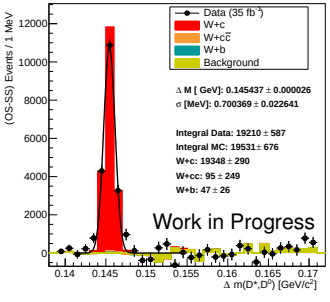
OS



SS



OS - SS



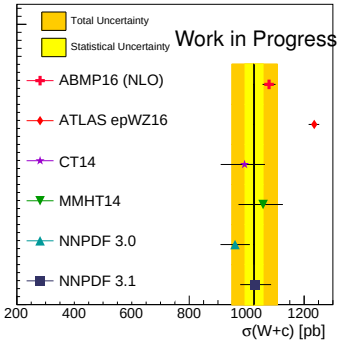
Comparison with theoretical Predictions

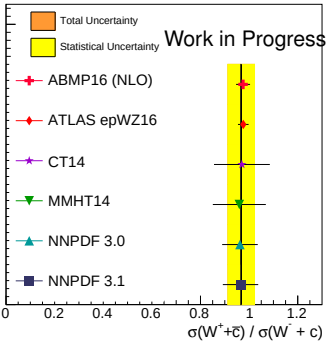
- Calculations done with MCFM 6.8. W+c is available at NLO
- EW Parameters have been updated to values of MCFM 8.0
- Scale variations amount to an uncertainty of 3%

Configuration:

- Scale: $\mu_r = \mu_f = M^W$
- charm-mass: 1.5 GeV

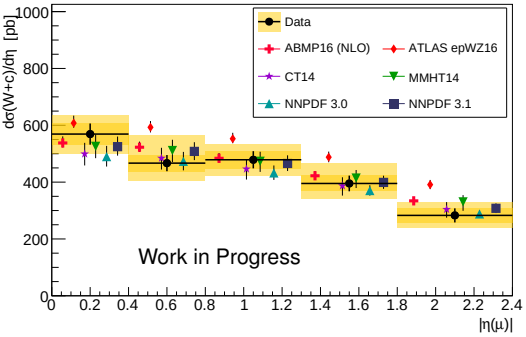
- $p_T^{\mu} > 26.$ GeV
- $|\eta^{\mu}| < 2.4$
- $p_T^{jet} > 5.0$ GeV
- $|\eta^{jet}| < 8$



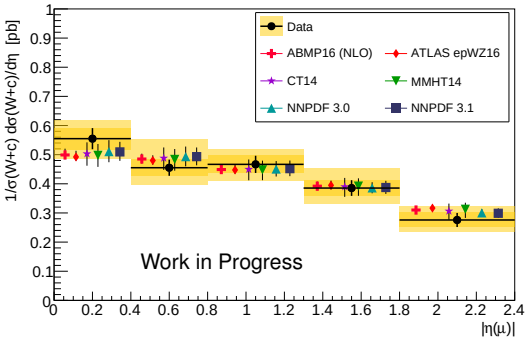


Differential Cross-Section $W + c$

$$\frac{\mathbf{d}\sigma(\mathbf{W}+\mathbf{c})}{\mathbf{d}\eta^{\mu}}$$



$$\frac{\mathbf{1}}{\sigma(\mathbf{W}+\mathbf{c})} \cdot \frac{\mathbf{d}\sigma(\mathbf{W}+\mathbf{c})}{\mathbf{d}\eta^{\mu}}$$



- Absolute cross section is input for QCD analysis

QCD Analysis: Setup

- Test of joined sensitivity to strange-quark content of the proton
  - PDF fit performed at NLO
- xFitter framework used for the full PDF fit (ver. 2.0.0, www.xfitter.org)
- Parton evolution in Q^2 via DGLAP equations, as implemented in QCDNUM

- Data Input:
  - HERA I+II combined includive DIS data, charged and neutral current Eur.Phys.J. C75 (2015)
  - Muon charge asymmetry in W production at 7/8 TeV [arXiv:1312.6283, arXiv:1603.01803
  - Associated W+charm production at 7/13 TeV [arXiv:1310.1138]

QCD Analysis: Parametrization

- Free s-Fit with 15 Parameters:

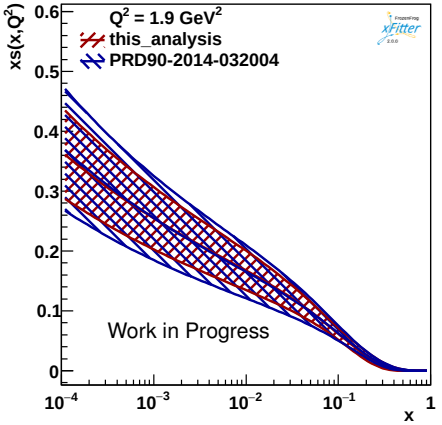
→ Sample procedure as in 7 TeV analysis: [Phys. Rev. D90 no.3, arXiv:1312.6283]

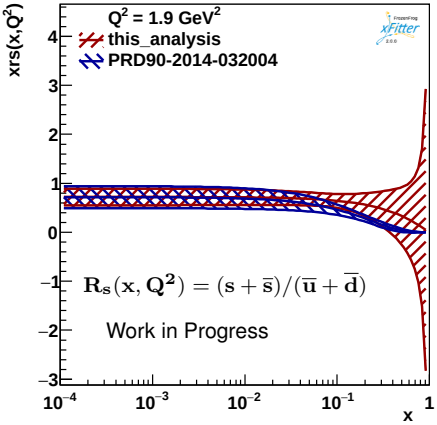
$$
\begin{aligned}
xg(x) &= A_g x^{B_g} \cdot (1-x)^{C_g} - A'_g x^{B'_g} \cdot (1-x)^{C'_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}} \cdot (1-x)^{C_{u_v}} \cdot (1+E_{u_v} x^2), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}} \cdot (1-x)^{C_{d_v}}, \\
x\overline{U}(x) &= A_{\overline{U}} x^{B_{\overline{U}}} \cdot (1-x)^{C_{\overline{U}}},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

$A_{\bar{u}} = A_{\bar{d}}$; $B_{\bar{u}} = B_{\bar{d}}$ ensures same normalization for u and d- antiquarks at $x \to 0$

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

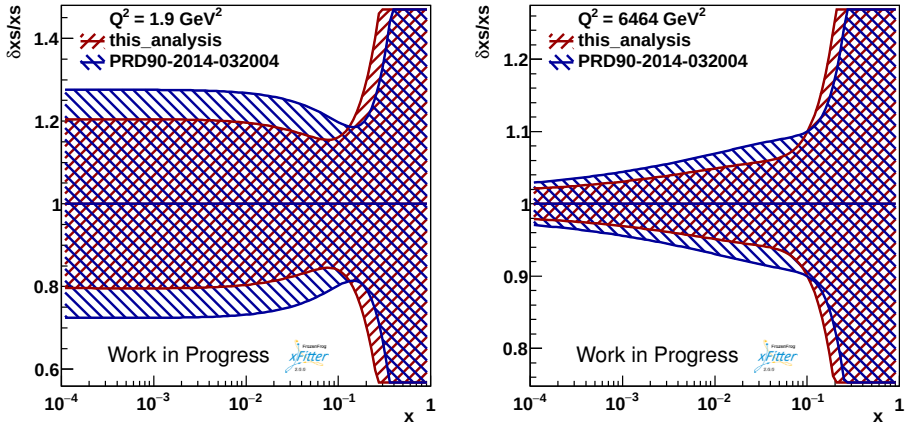
Fit Results: Strange Quark Distributions





- Compared to 7 TeV results
- Unchanged central value, but reduced PDF uncertainties

Fit Results: Strange Quark Distributions



- Normalized to 1 for better comparison

Fit Results: χ^2 of the Datasets

Dataset	χ^2/n_{dp}
HERA1+2 CCep	48 / 39
HERA1+2 CCem	61 / 42
HERA1+2 NCem	222 / 159
HERA1+2 NCep 820	70 / 70
HERA1+2 NCep 920	453 / 377
HERA1+2 NCep 460	217 / 204
HERA1+2 NCep 575	222 / 254
CMS W muon asymmetry 7 TeV	13 / 11
CMS W muon asymmetry 8 TeV	4.7 / 11
W+c 7 TeV	2.2 / 5
W+c 13 TeV	2.9 / 5
Correlated χ^2	84
Log penalty χ^2	-0.11
Total χ^2 / dof	1400 / 1162

Summary

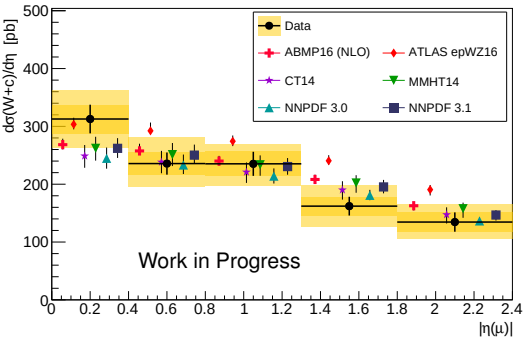
- W + charm at 13 TeV
  - Inclusive cross section of $W + c$ has been determined for the fiducial cuts of
    - $p_T^{\mu} > 26\,\text{GeV}$
    - $|\eta^{\mu}| < 2.4$
    - $p_T^{c} > 5\,\text{GeV}$
  - Differential cross section has been determined in 5 bins of $|\eta^{\mu}|$
  - The results were compared to theoretical predictions done with MCFM in combination with different PDF-sets.

  $\rightarrow$ A good agreement between the measurements and predictions is observed

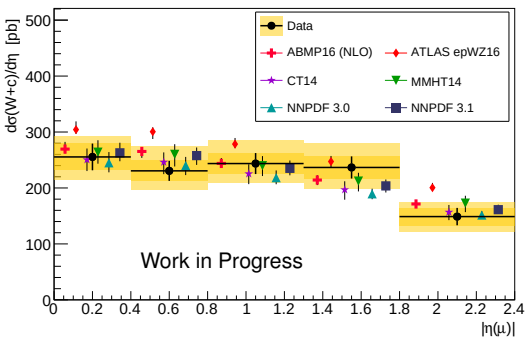
- QCD analysis
  - A 15 parameter free-strangeness fit has been performed using xfitter
  - $W + c$ at $\sqrt{s} = 7\,\text{TeV}$ and $\sqrt{s} = 13\,\text{TeV}$ are used as input
  - s-quark distribution is consistent with results of neutrino experiments.

Backup: Differential Cross-Section $W + c$

$W^+ + \bar{c}$



$W^- + c$



Backup: Theory Input

- Calculations for W and W+charm done with MCFM, interfaced with APPLGRID
- Starting scale: $Q_0^2 = 1.9\,\text{GeV}^2$
- Heavy quark treatment:
  - General mass variable flavor number (GMVFN) scheme by Thorne-Robers
  - renormalization and factorization scales set to $\mu_r^2 = \mu_f^2 = Q^2$
  - strong coupling: α_s=0.118
  - m_c=1.5 GeV
  - m_b=4.75 GeV

PDF Model uncertainties:

Originate from variations of model input parameters:
1.35 GeV $< m_c <$ 1.65 GeV, 4.3 GeV $< m_b <$ 5.0 GeV,
$f_s = 0.31 \pm 0.08$, 3.5 GeV $< Q^2_{min} <$ 5.0 GeV

QCD Analysis: Uncertainties

Experimental uncertainties:

Originate from uncertainties of the data considered, criterion $\Delta\chi^2$=1 applied

PDF Model uncertainties:

Originate from variations of model input parameters:
1.35 GeV $< m_c <$ 1.65 GeV, 4.3 GeV $< m_b <$ 5.0 GeV,
$f_s = 0.31 \pm 0.08$, 3.5 GeV $< Q^2_{min} <$ 5.0 GeV

Parametrisation Uncertainties

Variation on assumed parametrisation (to be done):
$\rightarrow$ Additional Parameters are added one-by-one in functional form
Variation of $1.5 < Q^2_0 < 2.5\,\text{GeV}^2$
Largest difference to central value is assigned as parametrisation uncertainty