QCD Analysis of the Combined H1 and ZEUS $F_2^{c\bar{c}}$ Data and the Impact on the Z,W Cross Section Predictions at the LHC

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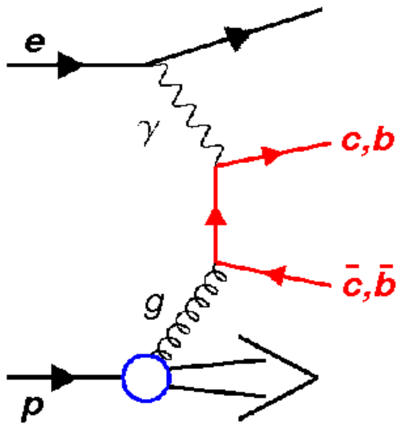
on behalf of H1 and ZEUS

HERA Charm Data: what Can we Learn?



Heavy quarks (HQs) at HERA are produced mainly in boson-gluon fusion

Test of pQCD, access to the gluon

Contribution to total DIS cross section:

Charm: up to 30% at high Q^2
Beauty: up to 3%

Heavy quark treatment in determination of Parton Distribution Functions (PDFs) is important

Different heavy quark schemes in PDF fits exist

Heavy Quark Schemes and PDF Fits

m_c=1.5, m_b=4.7 GeV - essential to treat them correctly in PDF fits

Two approaches:

Heavy Quark Schemes and PDF Fits

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Two approaches:

- **Fixed Flavour Number Scheme (FFNS)**

  light flavours in the proton,
  heavy quarks produced only in the final state, massive
  $Q^2 \gg m_{HQ}^2$: can be less precise, NLO coefficients contain terms $\sim ln(Q/m_{HQ})$

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Two approaches:

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- **Variable Flavour Number Scheme (VFNS)**

  - Zero Mass VFNS: all flavours massless. Breaks at $Q^2 \sim m_{HQ}^2$
  - Generalized Mass VFNS:
    combines massive (low scale) and massless (high scale) calculations,
    HQ mass used as a parameter at which FFNS turns into VFNS

    different implementations provided by PDF groups

Heavy Quark Treatment in PDF Fits

PDF fits assume pole mass definition for heavy quarks
pole mass defined for free quarks, large higher order corrections otherwise

Running quark mass determination → S. Alekhin's (ABM) talk

In this study: test of different implementations of GMVFNS

scheme	*used by group*	*used* m_c
RT standard	MSTW08	m_c=1.4
RT optimised	[arXiv:1006.5925]	
ACOT-full	CTEQ4,5,6HQ	m_c=1.3
S-ACOT-χ	CTEQ6.5,6.6,CT10	m_c=1.3
ZMVFNS	NNPDF2.0	m_c=1.5

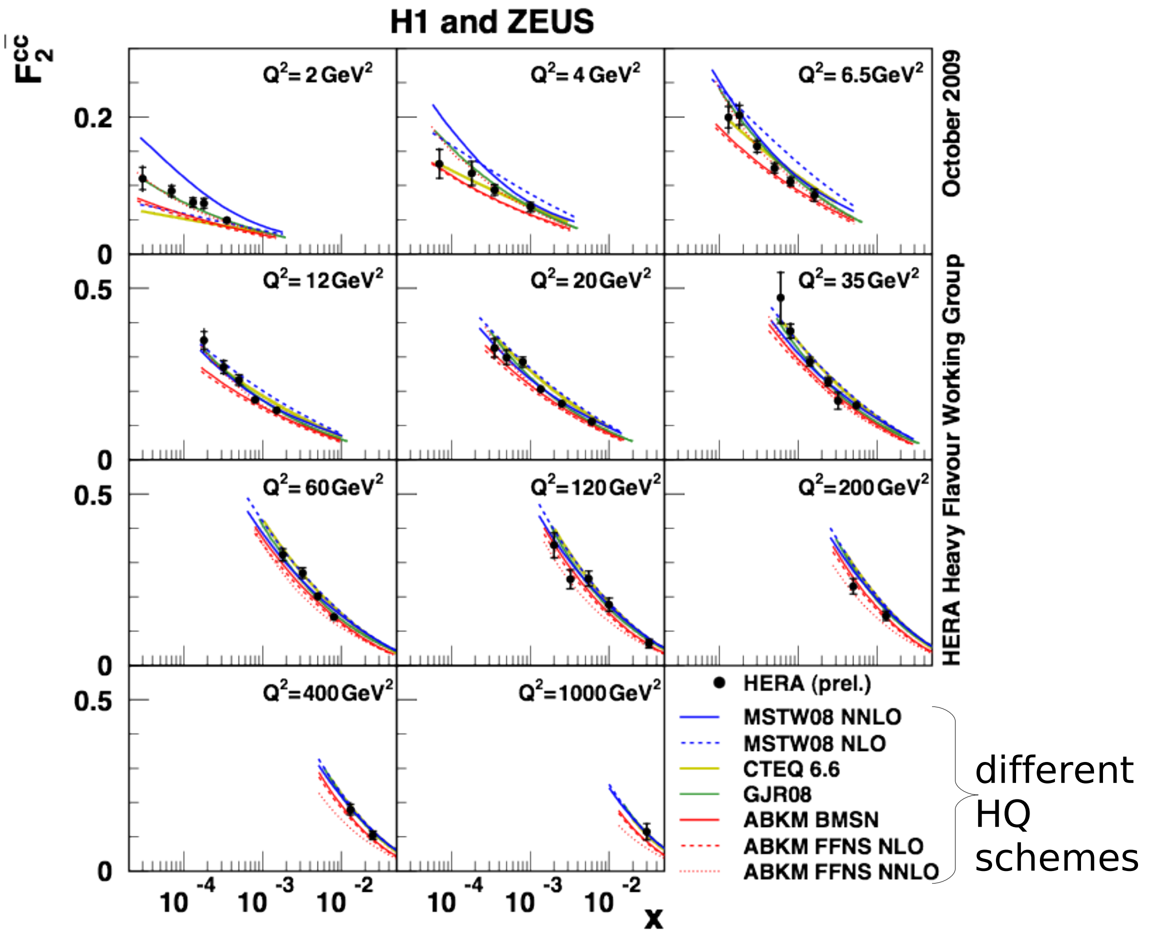
PDG: 1.66 GeV

FONLL (GMVFNS) used in NNPDF2.1, not tested here

HQ treatment in PDF fits and values of HQ masses are non trivial
Heavy quark data can help!

Preliminary HERA Charm Data

HERA F_2^{cc} measurement



Most precise determination of F_2^{cc} from HERA

- combination of 9 H1 and ZEUS measurements (HERA I + part of HERA II)
- different charm tagging methods
- covers $2 < Q^2 < 1000$ GeV^2 and $10^{-5} < x < 10^{-1}$
- 5-10% uncertainty

Data help understand differences in HQ schemes

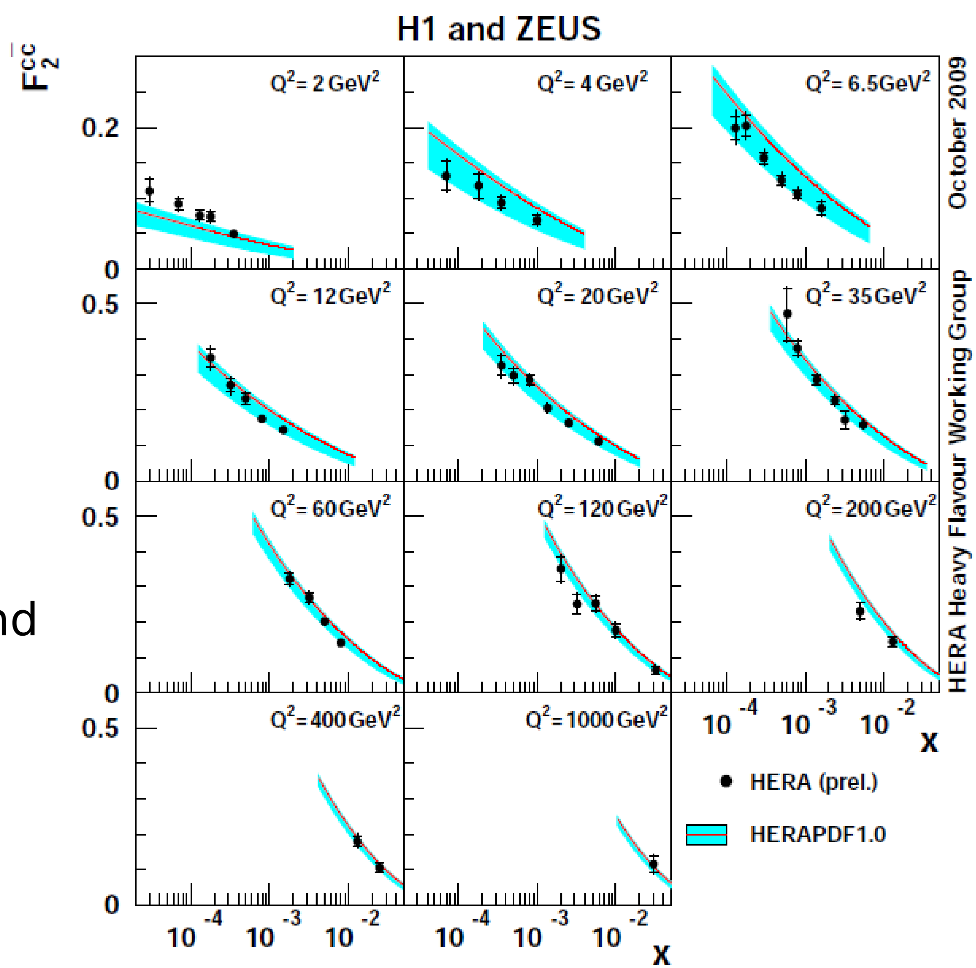
HERA Charm Data

Good agreement of HERAPDF1.0 predictions with F_2^{cc} data

- Band represents HERAPDF1.0 uncertainty from m_c^{model} parameter variation (1.35 – 1.65 GeV)

- Data are within the uncertainty band

→ can provide significant constraint on m_c^{model}



QCD Analysis Settings

NLO QCD analysis of the preliminary HERA F_2^{cc} data
together with the published inclusive HERA data (HERAPDF1.0,arXiv:0911.0884)

standard **HERAPDF1.0** settings used (**qcdnum17.0**, arXiv:1005.1481)
(α_S =0.1176, scale μ_R=μ_F=Q^2, Q^2_{min}= 3.5 GeV^2)

with two parametrisation assumptions:

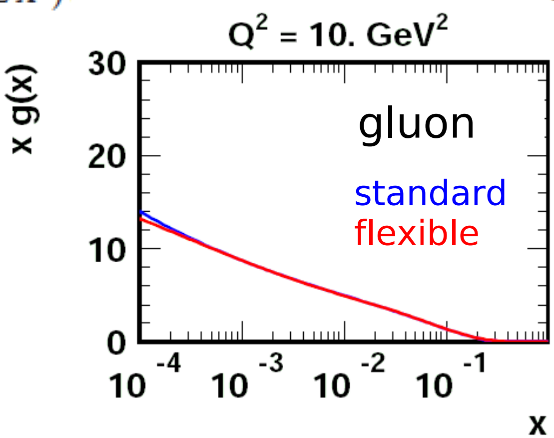
standard:

$$xf(x) = Ax^B(1-x)^C(1+Ex^2)$$

flexible:

$$xg(x) = A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{25}$$

(allows for a negative gluon contribution at low x)

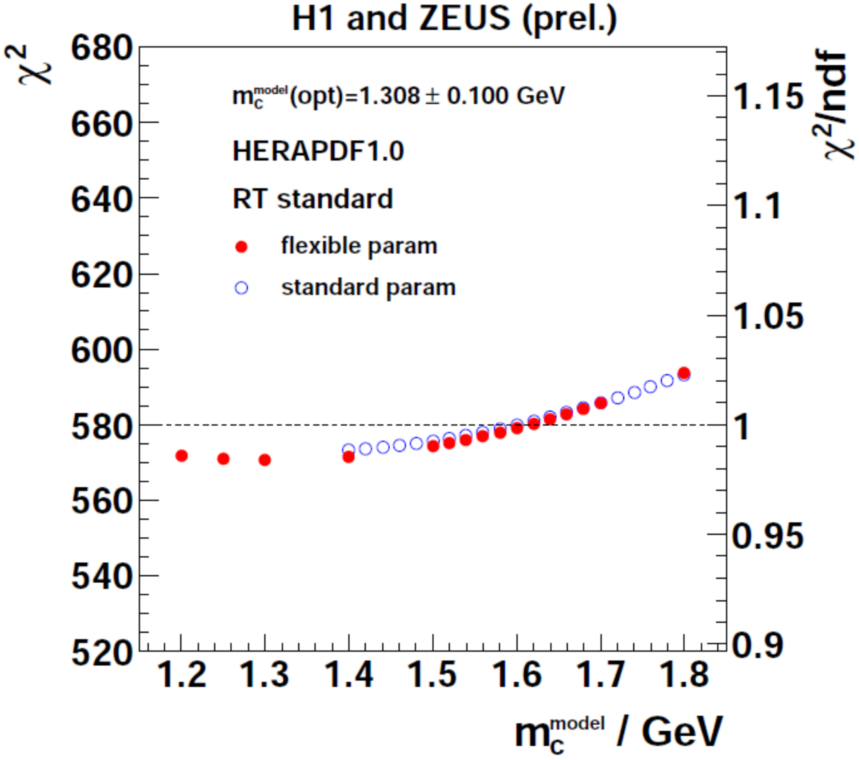


standard: Q^2_0=1.9 GeV^2, m_c^{model} scan: 1.4 – 1.8 GeV

flexible: Q^2_0=1.4 GeV^2, m_c^{model} scan: 1.2 – 1.8 GeV

Constraints on PDFs from HERA Charm Data

Inclusive ep data



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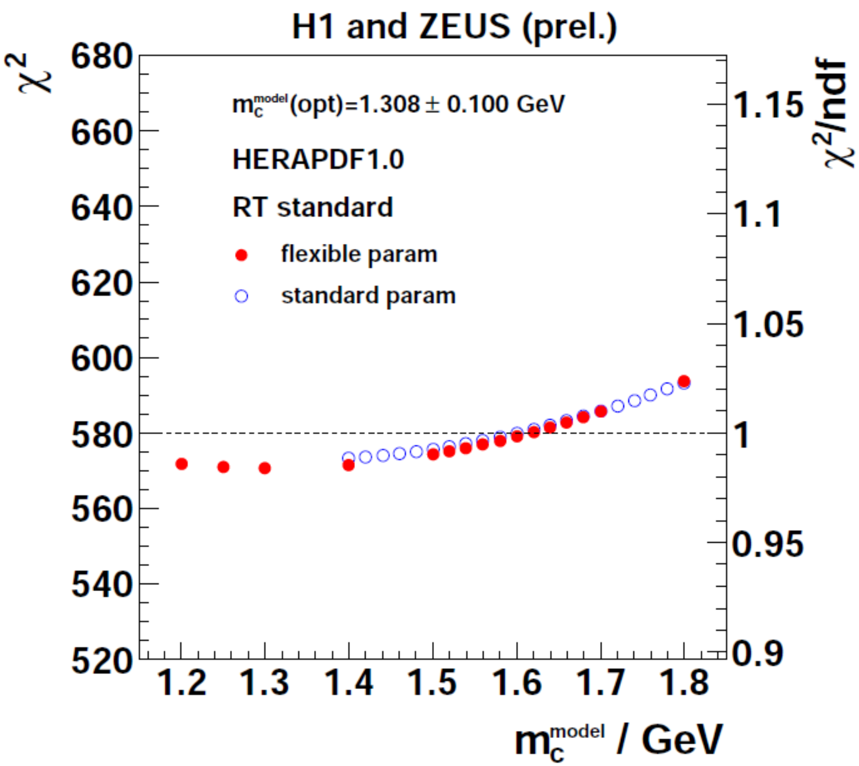
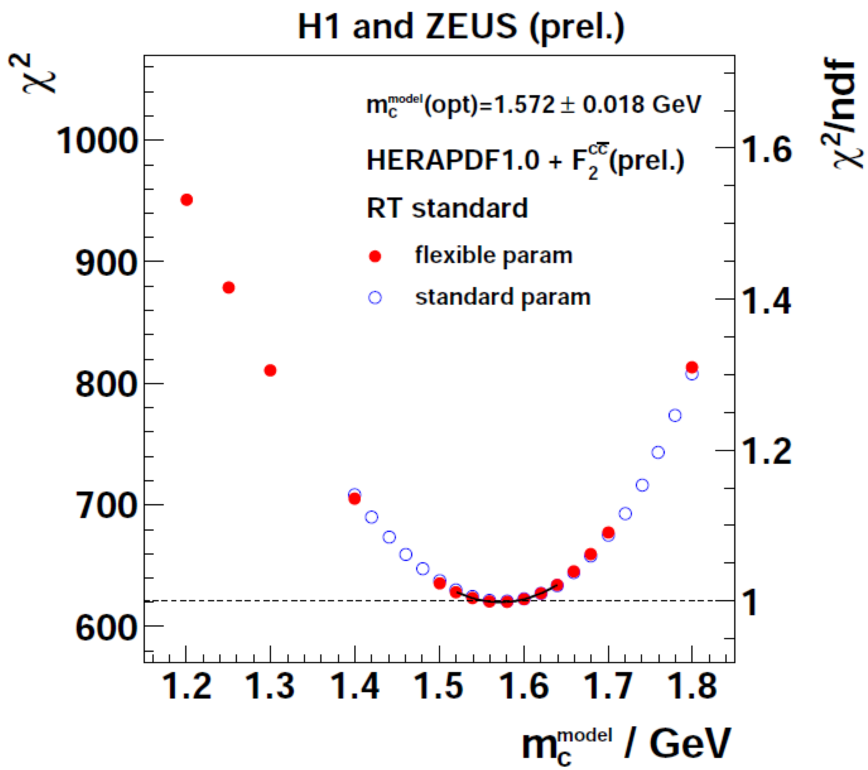


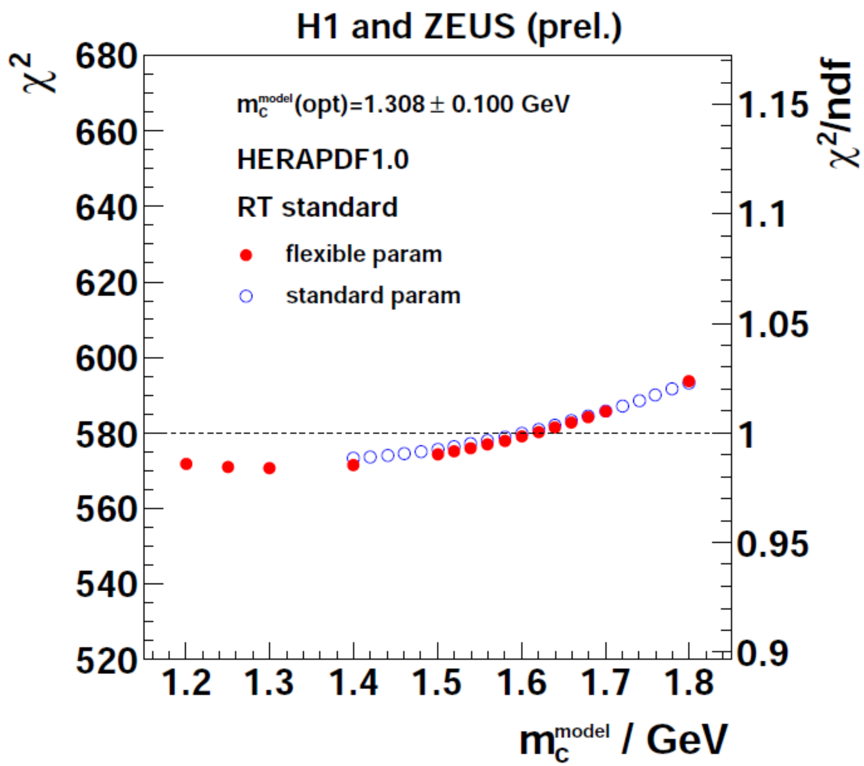
Inclusive ep data + F_2^{cc}



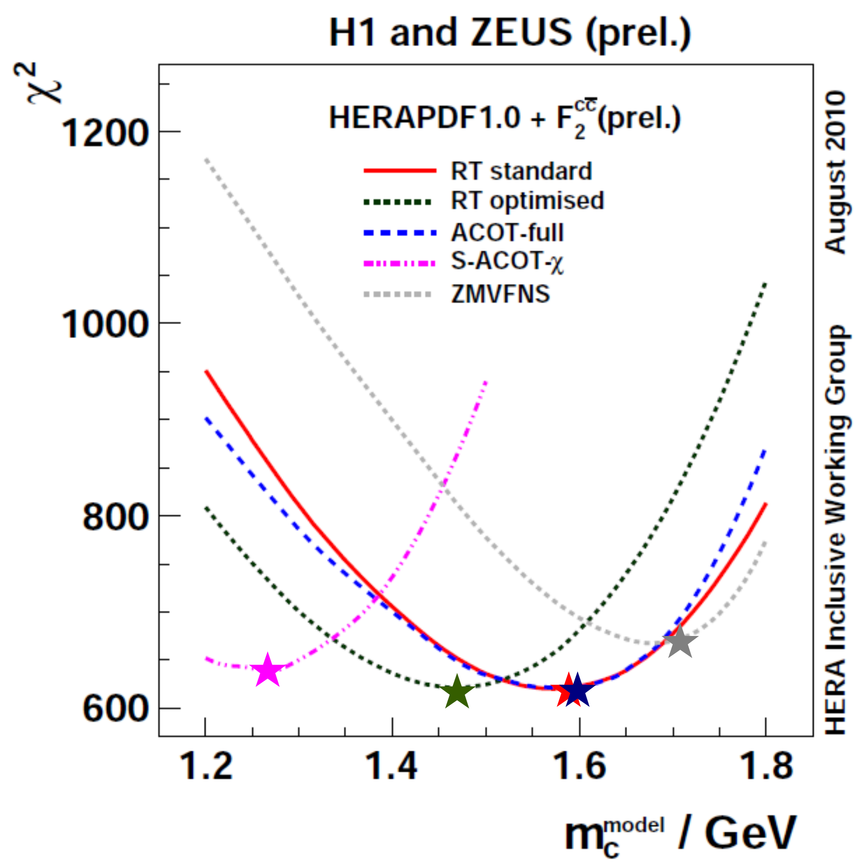
Charm data allow to constrain m_c^{model}

Constraints on PDFs from HERA Charm Data

Inclusive ep data

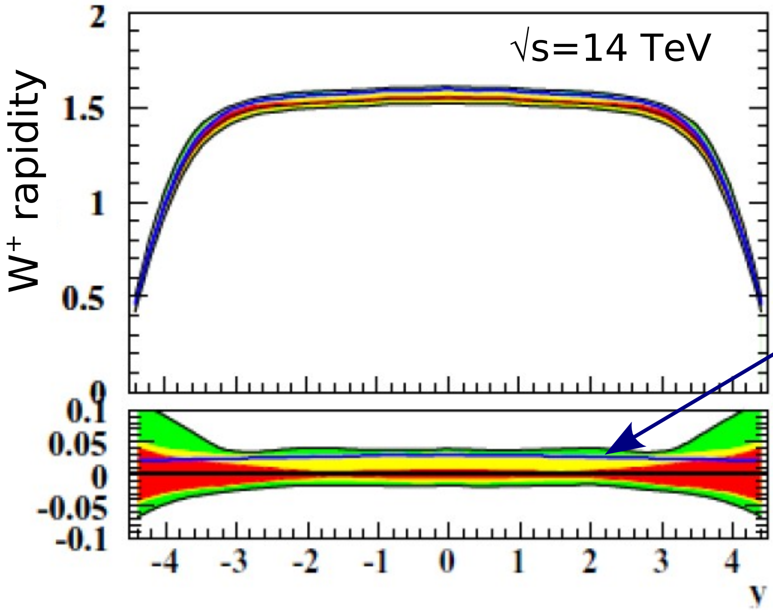


Inclusive ep data + F_2^{cc}
for different HQ schemes



Different HQ schemes have different optimal m_c^{model}

Proton-Proton Collisions: W,Z production

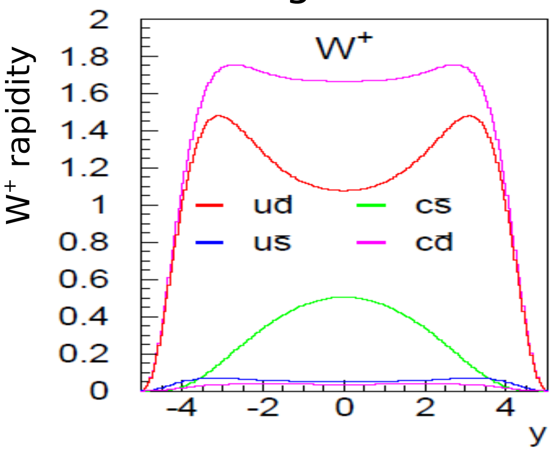


W+ cross section prediction with HERAPDF1.0

central value: m_c^{model} = 1.4 GeV

m_c^{model} variation (m_c^{model}= 1.65 GeV)

larger m_c → less c in sea
→ more u, larger cross section

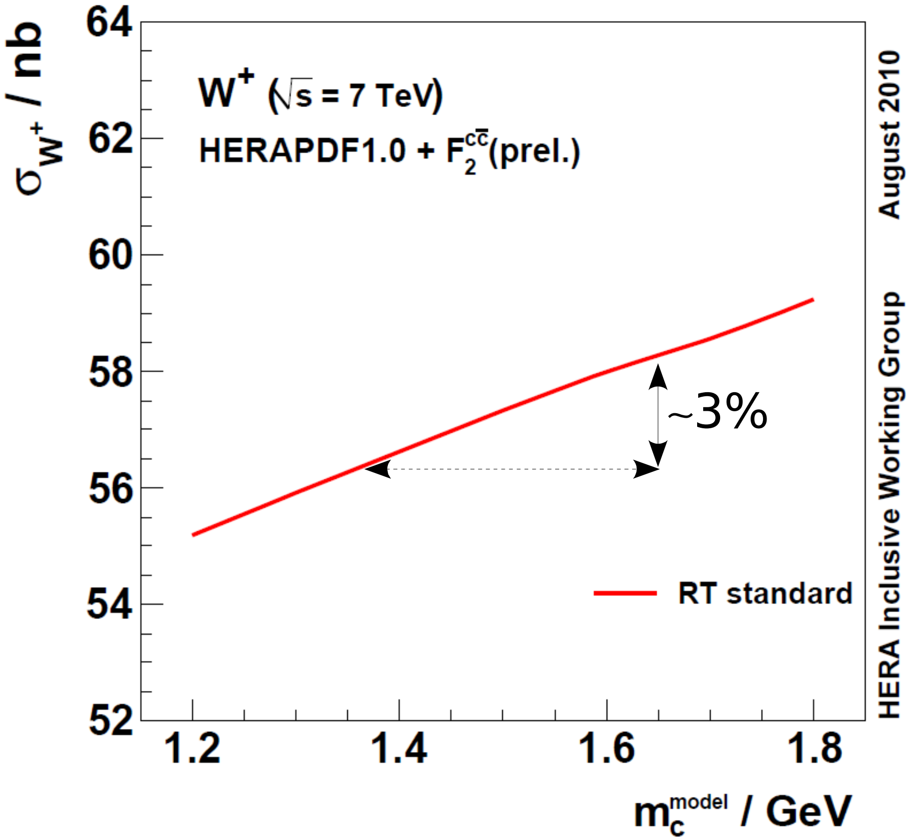


Variation of m_c^{model} changes cross section prediction by ~3%

Use optimal m_c^{model} determined with HERA charm data to calculate Z, W cross section predictions at LHC

HERA Charm data and W,Z Cross Sections at LHC

Use PDFs with m_c^{model}(opt) to predict Z,W cross sections at LHC



m_c variation in PDF:

$1.35 < m_c < 1.65$ GeV

3% uncertainty on W cross section

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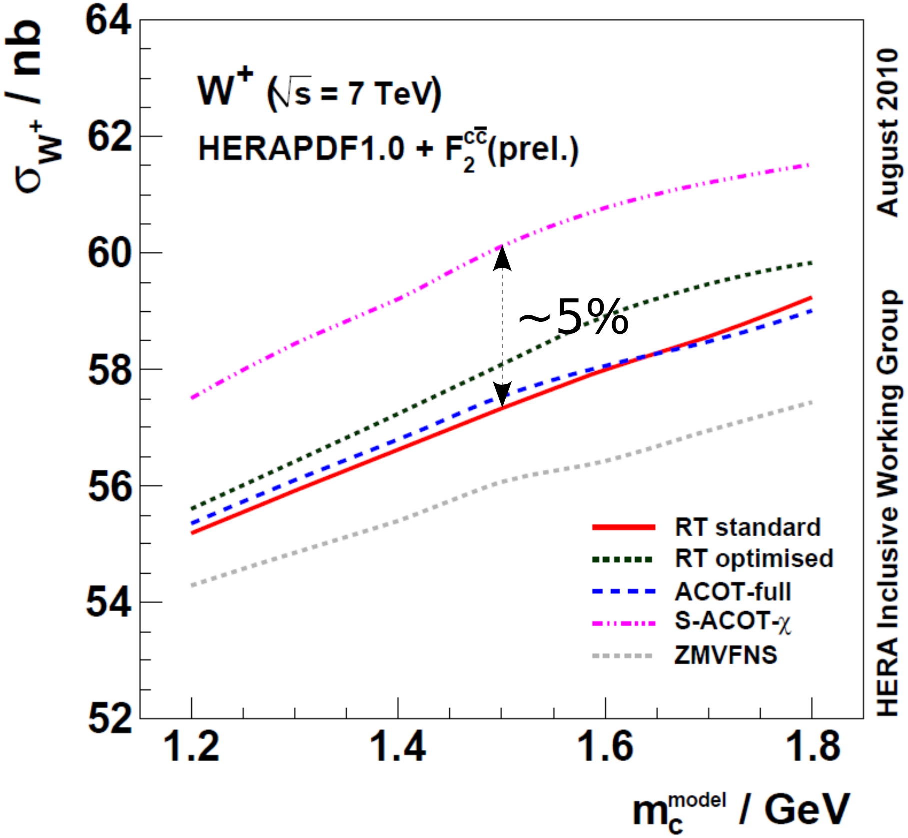

m_c variation in PDF:

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3% uncertainty on W cross section

Using different HQ schemes:
~5% for given m_c

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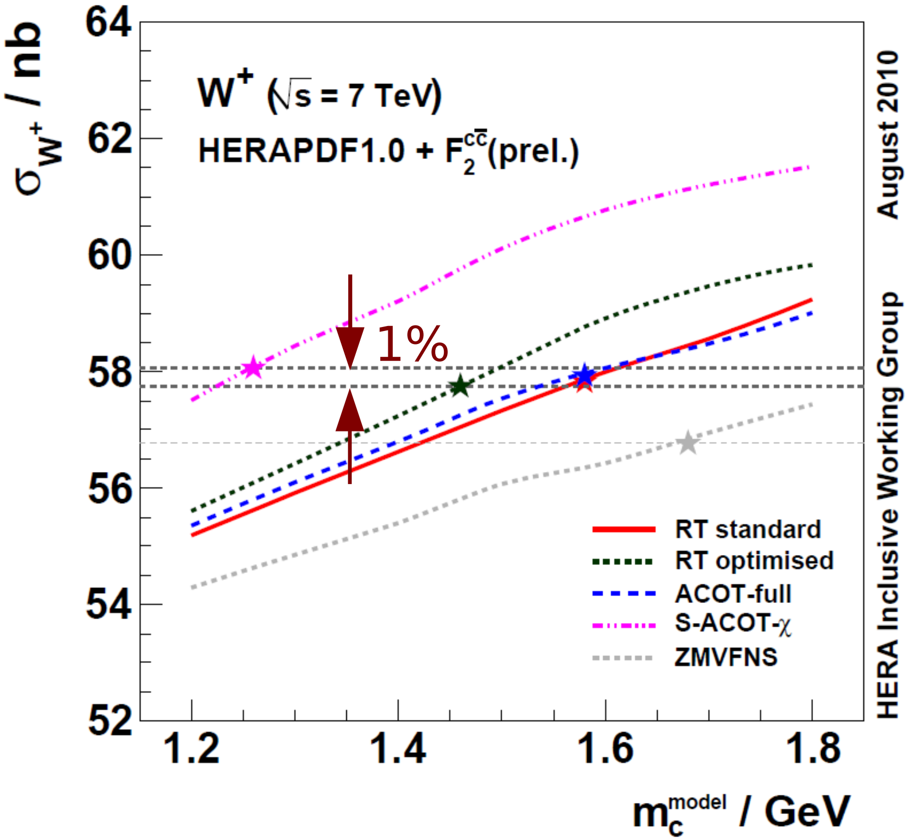


m_c variation in PDF:

$1.35 < m_c < 1.65$ GeV

3% uncertainty on W cross section

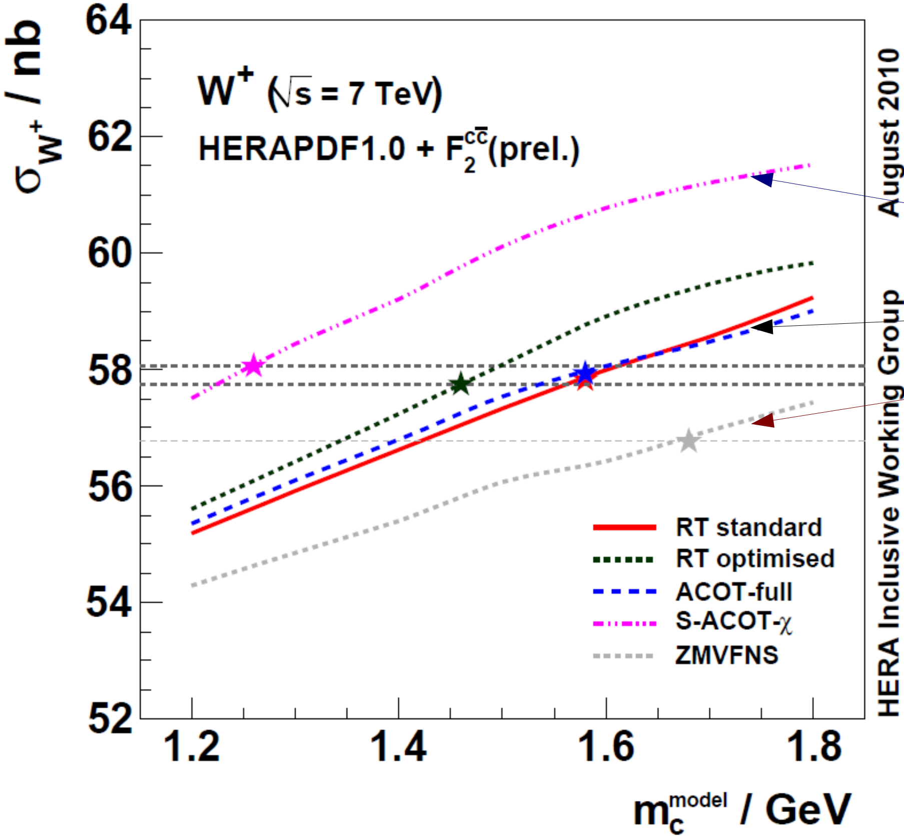
Using different HQ schemes: ~5% for given m_c

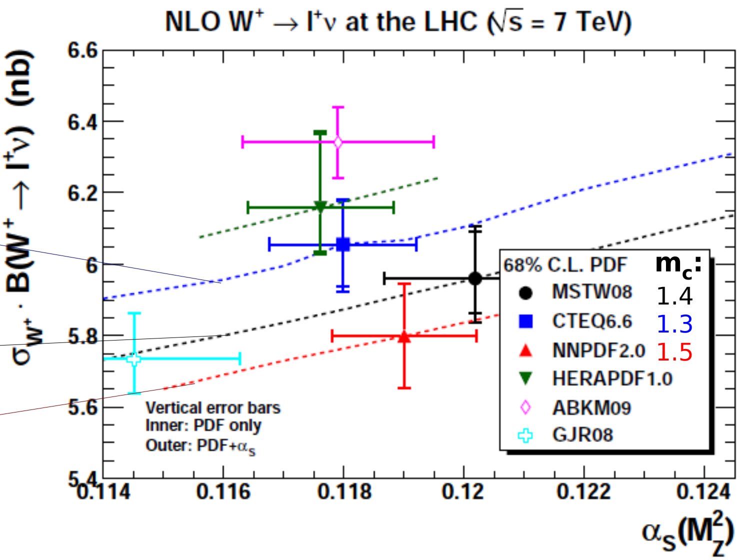
predictions with m_c^{model} (opt) have much smaller spread: <1%

☆ in the plot indicate value of m_c^{model}(opt)

Optimal m_c^{model} determined with HERA charm data reduce the uncertainty of cross section predictions

HERA Charm data and W,Z Cross Sections at LHC





Comparison of W^+ cross sections as a function of $\alpha_S(M_Z^{\ 2})$

G.Watt, PDF4LHC 26.03.2011

$m_C^{\ model}$ can explain part of differences between cross section predictions obtained with different PDFs

Summary

A NLO QCD analysis of HERA charm data:

- data help understanding differences in HQ schemes
- HQ schemes have different value of optimal m_c

HERA charm data reduce the uncertainties of W,Z cross section predictions at LHC

Back-up slides

PDF determination in HERAPDF 1.0

DGLAP at NLO → QCD predictions

PDFs parametrised (at starting scale Q^2_0) using standard parametrisation form:

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1+E_{u_v}x^2\right), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}, \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.
\end{aligned}
$$

A: overall normalisation

B: small x behavior

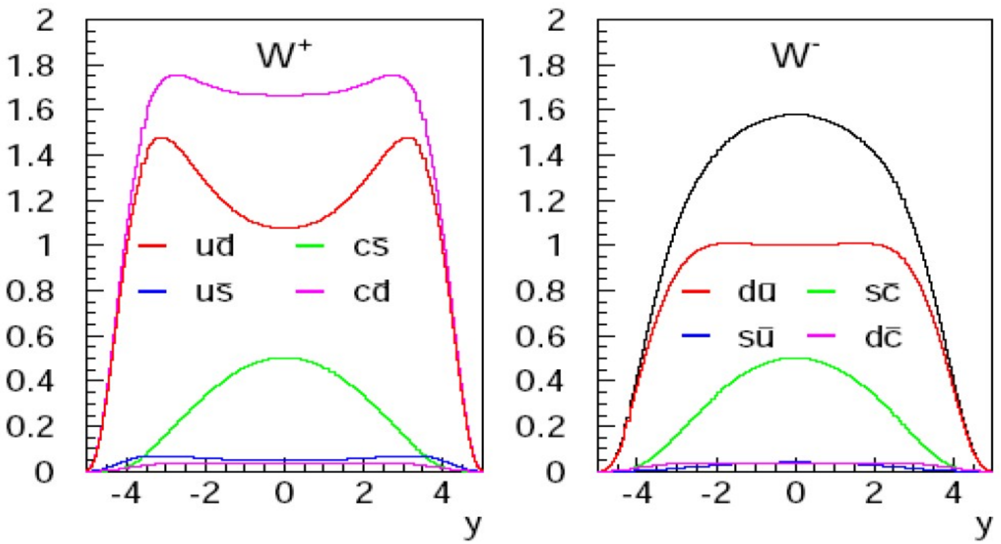
C: x→1 shape

xg, xu_v, xd_v, xU, xD
where $xU=xu$ and $xD=xd+xs$ at the starting scale ($xs=f_s xD$ with $f_s=0.31$)

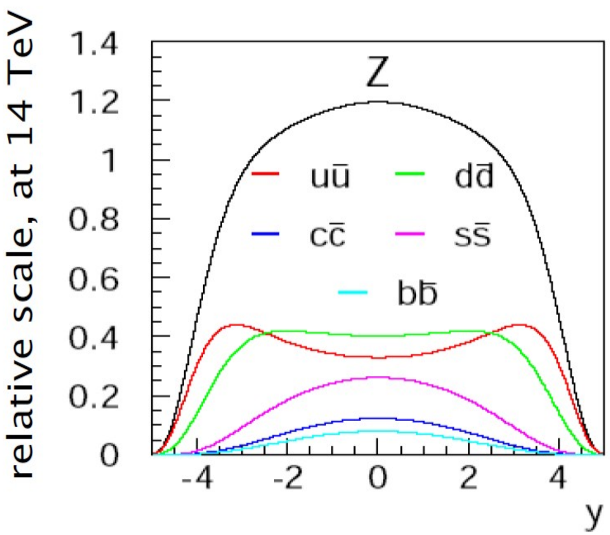
A_g, A_{uv}, A_{dv} are fixed by sum rules

extra constrains for small x behavior of d- and u-type quarks:
$B_{uv}=B_{dv}$, $B_U=B_D$, $A_U=A_D(1-f_s)$

Proton-Proton Collisions: W,Z production



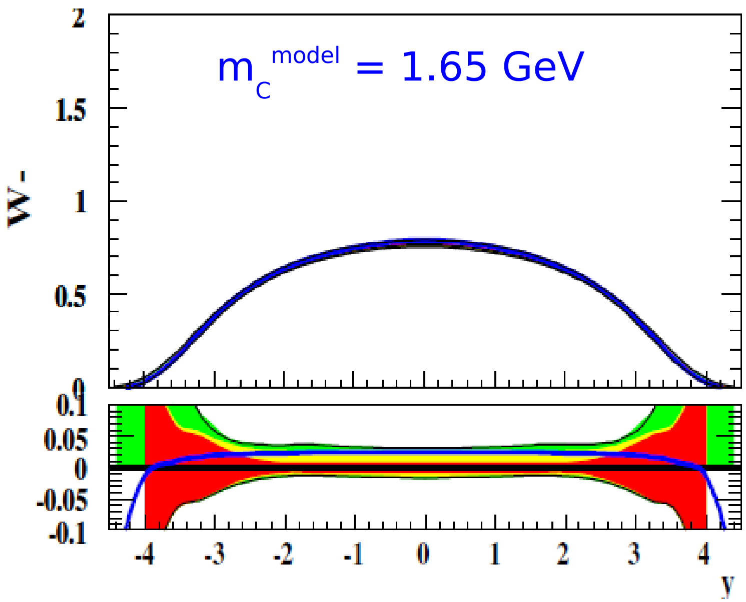
- for W **u** and **d** quarks dominate



- all flavours contribute to Z

Precise parton distributions are needed for LHC analyses

Impact on the LHC predictions



- variation of m_c^{model} changes predictions of Z/W cross sections at LHC by ~3%

A.M.Cooper-Sarkar, PDF4LHC, March 2010

- sensitivity to charm of the LHC cross section predictions comes from flavour sensitivity of the inclusive DIS data

$$xU = xu + xc \quad x\bar{U} = x\bar{u} + x\bar{c} \quad xD = xd + xs \quad x\bar{D} = x\bar{d} + x\bar{s}$$

- where *U* is fixed by F_2 data
  larger m_c^{model} → less *c* in sea → more *u (= d)*

- important at low Q^2 and low x

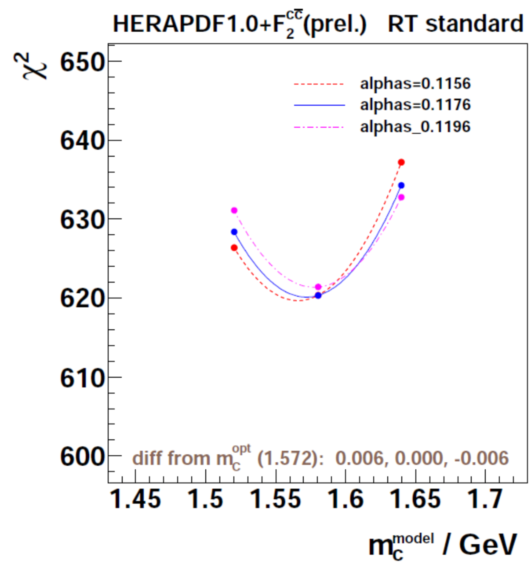
Systematic Uncertainty on m_c^{model}

- to determine systematic uncertainty on m_c^{model} HERAPDF1.0 prescription was used:

  - α_s variation ($\pm$0.002)
  - vary parametrisation (e.g. $Bu_v \neq Bd_v$)
  - vary model parameters (f_s,m_B,Q^2_{min},Q^2_0)

Variation	Standard	Lower	Upper
fs	0.31	0.23	0.38
m_B	4.75	4.3	5
Q^2_{min}	3.5	2.5	5
Q^2_0	1.4	-	1.9

(uncertainty from Q^2_0 assumed to be symmetric and treated as procedural)



Systematic uncertainties on m_c^{model} obtained for each heavy flavour scheme →

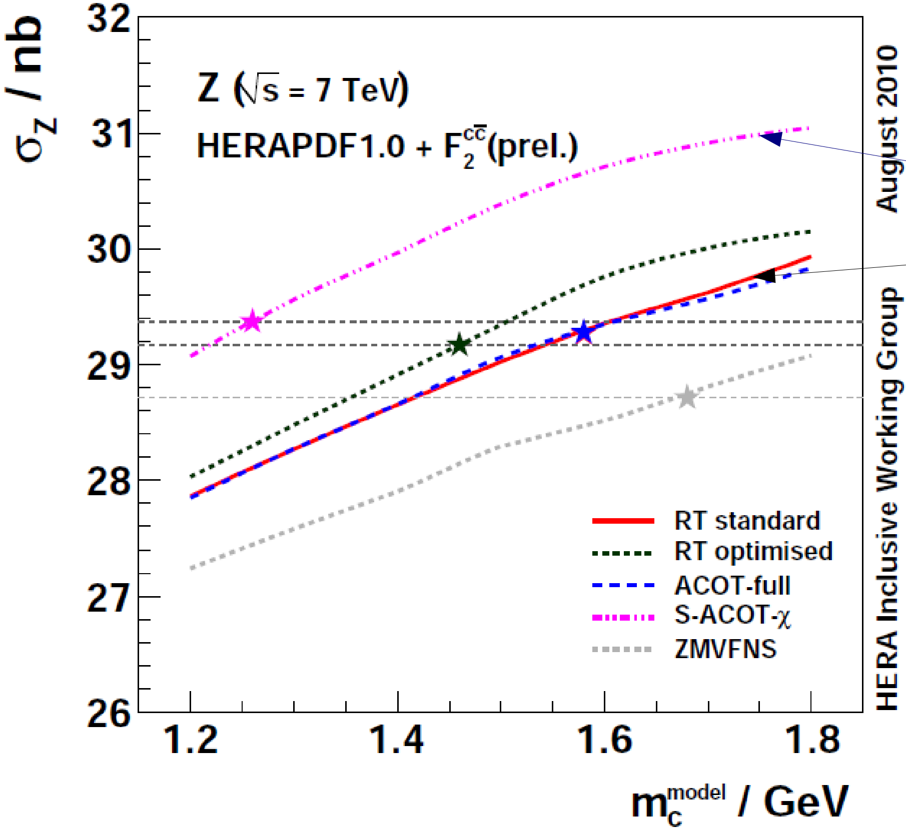
scheme	*m_c^{model}(opt)*
RT standard	$1.58^{+0.02}_{-0.03}$
RT optimised	$1.46^{+0.02}_{-0.04}$
ACOT-full	$1.58^{+0.03}_{-0.04}$
S-ACOT-χ	$1.26^{+0.02}_{-0.04}$
ZMVFNS	$1.68^{+0.06}_{-0.07}$

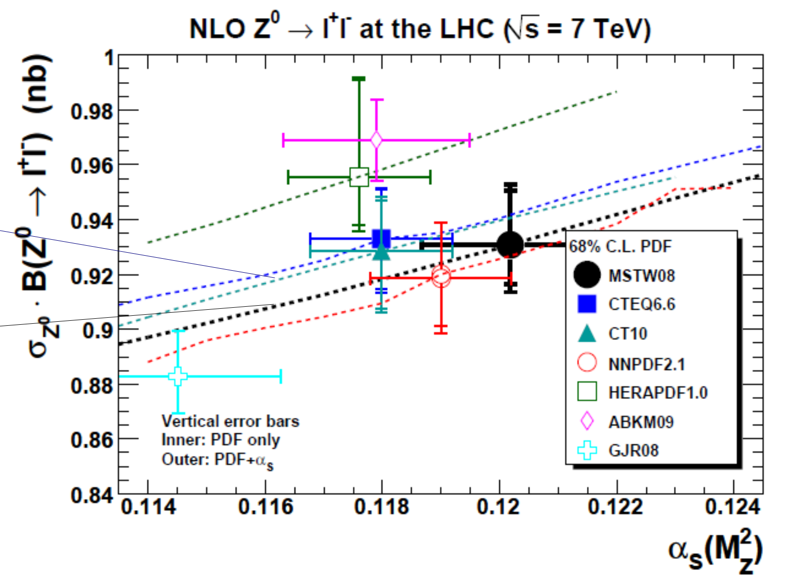
W,Z Cross Sections at LHC: summary

scheme	m_c^{model}(opt)	χ^2/dof	χ^2/ndp (F_2^{cc})	σ_Z(nb)	σ_{W^+}(nb)	σ_{W^-}(nb)
RT standard	$1.58^{+0.02}_{-0.03}$	620.3/621	42.0/41	$29.27^{+0.07}_{-0.11}$	$57.82^{+0.14}_{-0.22}$	$40.22^{+0.10}_{-0.15}$
RT optimised	$1.46^{+0.02}_{-0.04}$	621.6/621	46.5/41	$29.17^{+0.07}_{-0.13}$	$57.75^{+0.14}_{-0.26}$	$40.15^{+0.10}_{-0.18}$
ACOT-full	$1.58^{+0.03}_{-0.04}$	621.2/621	59.9/41	$29.28^{+0.10}_{-0.13}$	$57.93^{+0.18}_{-0.24}$	$40.16^{+0.12}_{-0.16}$
S-ACOT-χ	$1.26^{+0.02}_{-0.04}$	639.7/621	68.5/41	$29.37^{+0.08}_{-0.15}$	$58.06^{+0.16}_{-0.30}$	$40.23^{+0.11}_{-0.21}$
ZMVFNS	$1.68^{+0.06}_{-0.07}$	667.4/621	88.1/41	$28.71^{+0.19}_{-0.20}$	$56.77^{+0.33}_{-0.34}$	$39.46^{+0.24}_{-0.25}$
			max diff:	0.7%	0.5%	0.2%
			(with ZMVFNS)	2.3%	2.3%	2.0%

- same conclusions with HERAPDF1.5
  (preliminary combined inclusive HERA I+II data)

Z/W cross sections at LHC





- comparison of Z cross sections as a function of $\alpha_S(M_Z^2)$

G.Watt, PDF4LHC 07.03.2011

☆ in the plot indicate value of m_c^{model}(opt)