W,Z, pdf's and the strange quark distribution

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QCD Fit assumptions and pdf's
Measurement Quantities
Effects from a strange strange
Effects from ū/đ asymmetries

A case study (using numerical and MC calculations) to investigate the sensitivity of W,Z to pdf's in discussions with DESY, HH, Mainz, Oxford → note on W,Z studies in preparation.

WZ Meeting, CERN 23.10.2009

QCD Fit Assumptions on pdf's

Require **$\bar{u}=\bar{d}$** at low x (only constraint is HERA $F_2^p = 2x[4\bar{u}+\bar{d}+..]$) At larger x ~ 0.1 they differ (Exxx)
Testing the low x symmetry assumption would have required deuteron scattering at HERA.

Charm is generated dynamically. Usually $Q_0^2 > m_c^2$. Some 5-10% constraints from F_2^{cc} at H1/ZEUS

Beauty is generated dynamically above threshold and ~20% constraints from F_2^{bb} at H1/ZEUS

The high x region is not too well constrained (low HERA luminosity, nuclear corrections),
which results in larger pdf uncertainties at high x (large |rapidity|).

A stranger is the **strange quark distribution**. Some hints for s ≠ sbar. Some constraints from K, Φ.

Usual assumption

$$s + \bar{s} = (\frac{1}{2} + \epsilon) \cdot (\bar{u} + \bar{d})$$

[3]The evolution of $s+\bar{s}$ in DGLAP QCD is found to yield a linear dependence of ϵ on $\ln Q^2$ which is used to extrapolate the NuTeV result [84], obtained at 16 GeV^2, to $Q^2 = Q_0^2$.

C. Adloff *et al.* [H1], Eur. Phys. J. **C19**, 269 (2001), [hep-ex/0012052].

Recent H1pdf2009 and HERApdf1.0 [D=d+s]

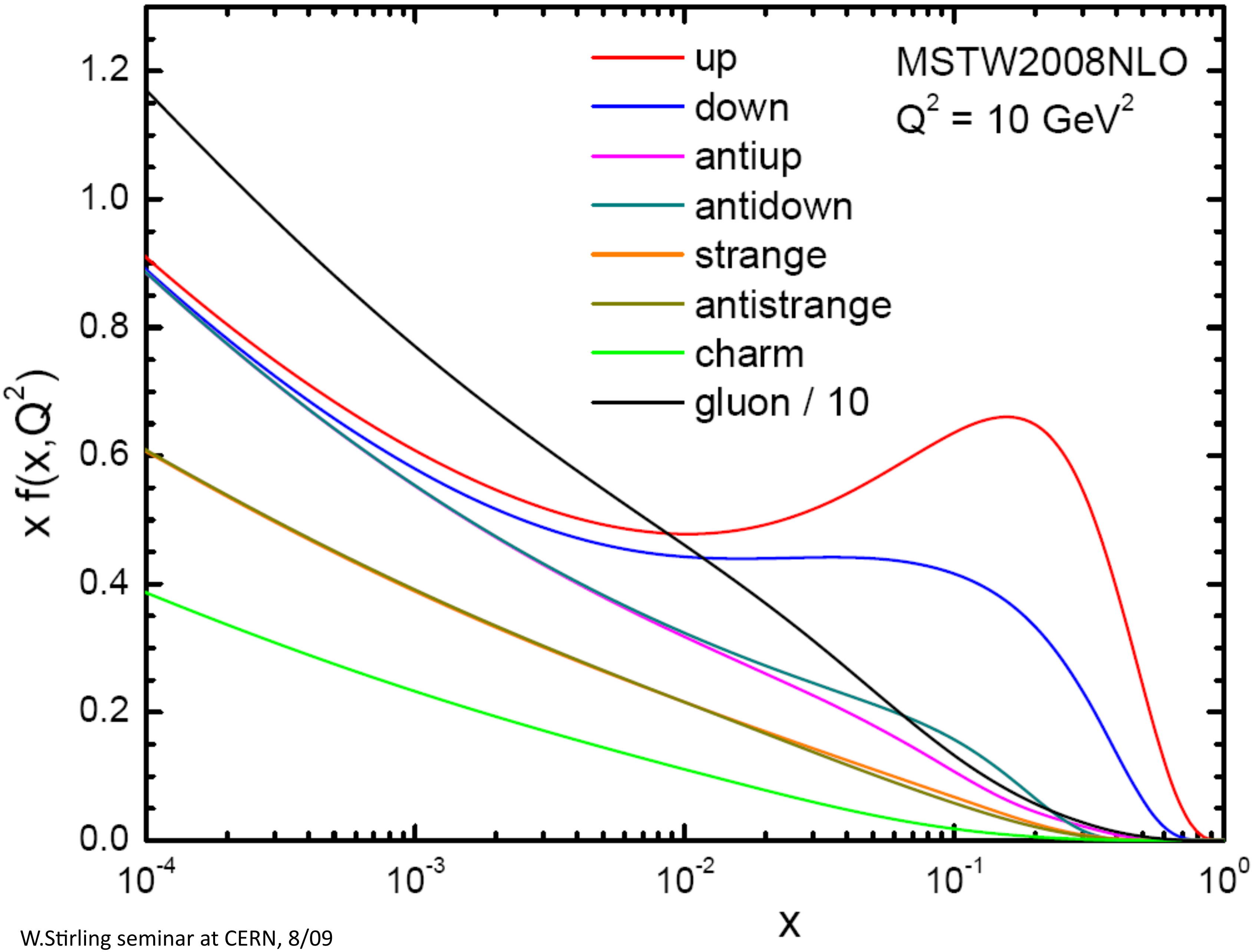
F. Aaron *et al.* [H1 Collaboration] (2009), [hep-ex/0904.3513]

$$x\bar{s} = f_s x\bar{D} \text{ at } Q_0^2.$$

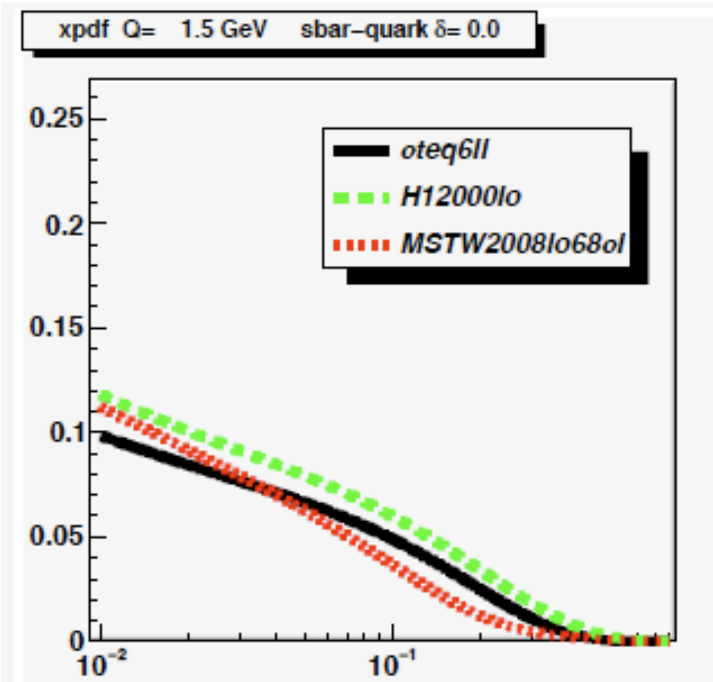
$$\varepsilon = -0.08$$

$$f_s = \frac{1+2\varepsilon}{3+2\varepsilon} = 0.296$$

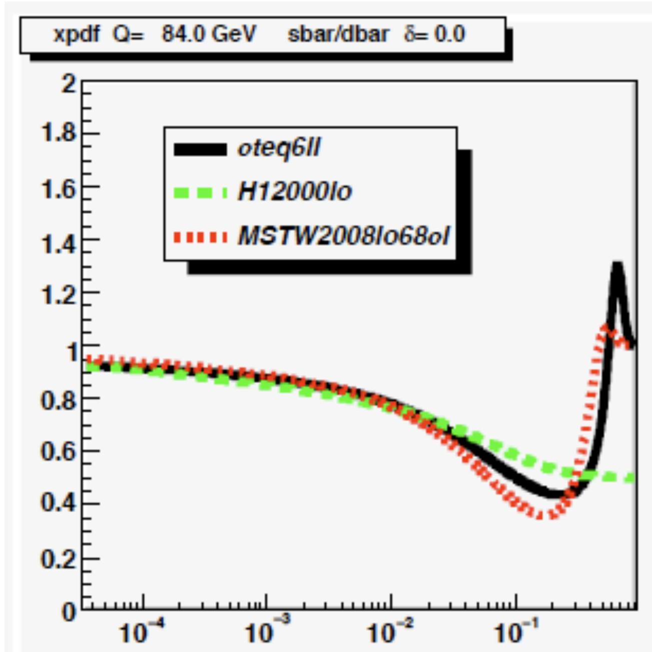
HERAPDF1.0 release imminent



W.Stirling seminar at CERN, 8/09



xpdf Q= 1.5 GeV sbar–quark δ= 0.0
oteq6ll
H12000lo
MSTW2008lo68ol
0.25
0.2
0.15
0.1
0.05
0
10^{-2}
10^{-1}



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oteq6ll
H12000lo
MSTW2008lo68ol
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1.8
1.6
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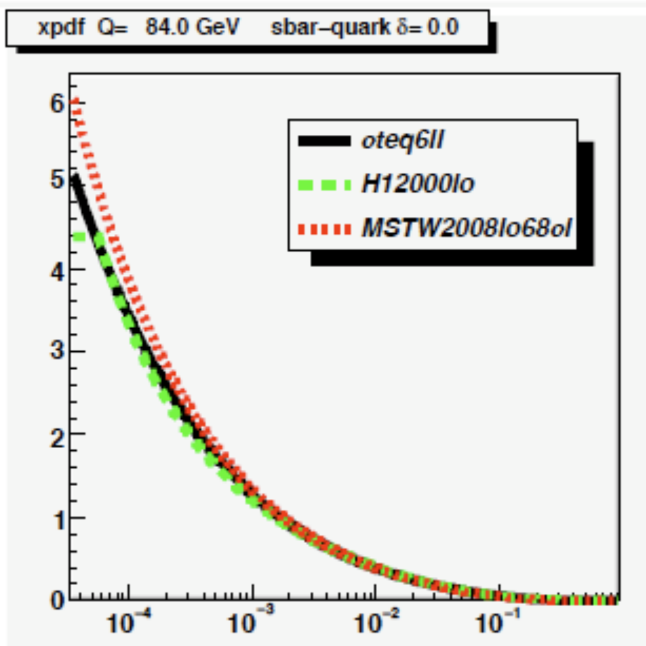
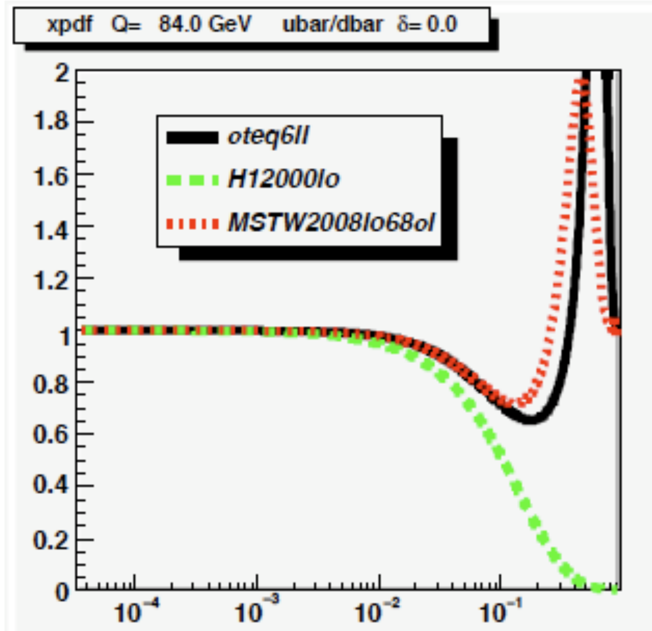
1.2
1
0.8
0.6
0.4
0.2
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}



xpdf Q= 84.0 GeV sbar–quark δ= 0.0
oteq6ll
H12000lo
MSTW2008lo68ol
6
5
4
3
2
1
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}

pdf's



xpdf Q= 84.0 GeV ubar/dbar δ= 0.0
oteq6ll
H12000lo
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2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}

Cross Sections – Drell-Yan (photon exchange)

ALL cross sections are for the lepton decays Z → ee or W→eν

$$\frac{d^2\sigma}{dMdy} = \frac{4\pi\alpha^2(M)}{9} \cdot 2M \cdot P(M) \cdot \Phi(x_1, x_2, M^2) \quad [\text{nb GeV}^{-1}]$$

$$x_1 = \sqrt{\tau}e^{y} \quad x_2 = \sqrt{\tau}e^{-y} \quad \tau = \frac{M^2}{s} \quad s = 4E_p^2$$

$$P_\gamma(M) = \frac{1}{M^4} \qquad \Phi_\gamma = \sum_q e_q^2 F_{qq}$$

$$F_{qq} = x_1 x_2 \cdot [q(x_1, M^2)\overline{q}(x_2, M^2) + \overline{q}(x_1, M^2)q(x_2, M^2)]$$

Note that $\tau = x_1 x_2$ and often one gets confused as the quark distribution term is often written without $x_1 x_2$ but the LHAPDF delivers xq which we term pdf .

With NLO corrections the cross section depends on the gluon distribution too.

Cross Sections – γ and Z exchange and interference

$$\frac{d^2\sigma}{dMdy} = \frac{4\pi\alpha^2(M)}{9} \cdot 2M \cdot P(M) \cdot \Phi(x_1, x_2, M^2) \quad [\text{nb GeV}^{-1}]$$

$$x_1 = \sqrt{\tau}e^{y} \quad x_2 = \sqrt{\tau}e^{-y} \quad \tau = \frac{M^2}{s} \quad s = 4E_p^2$$

$$P_\gamma(M) = \frac{1}{M^4} \qquad \Phi_\gamma = \sum_q e_q^2 F_{qq}$$

$$F_{qq} = x_1 x_2 \cdot [q(x_1, M^2)\overline{q}(x_2, M^2) + \overline{q}(x_1, M^2)q(x_2, M^2)]$$

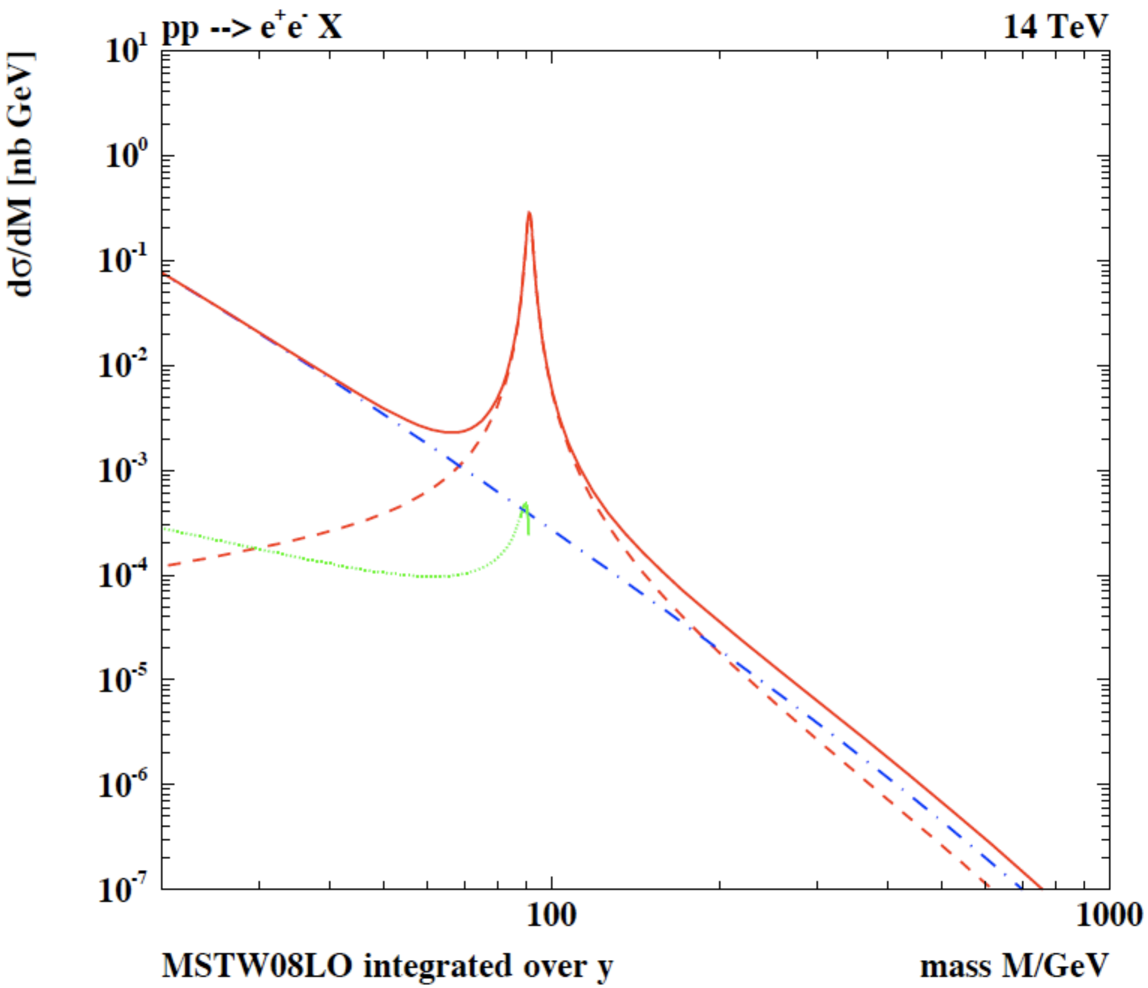
$$P_{\gamma Z} = \frac{\kappa_Z v_e(M^2 - M_Z^2)}{M^2[(M^2 - M_Z^2)^2 + (\Gamma_Z M_Z)^2]} \qquad \Phi_{\gamma Z} = \sum_q 2e_q v_q F_{qq}$$

$$v_f = I_3^f - e_f \sin^2\Theta, \quad a_f = I_3^f \quad [f = e, q] \qquad \kappa_z = \frac{1}{4\sin^2\Theta\cos^2\Theta} \quad \cos\Theta = \frac{M_W}{M_Z}$$

$$P_Z = \frac{\kappa_Z^2(v_e^2 + a_e^2)}{(M^2 - M_Z^2)^2 + (\Gamma_Z M_Z)^2} \qquad \Phi_Z = \sum_q (v_q^2 + a_q^2)F_{qq}$$

Interference must change sign at M_Z and is in itself small as $v_e = -1/2 + 2\sin^2\Theta \approx 0$

Z Mass Distribution



LO - integrated
Cross section [nb]:

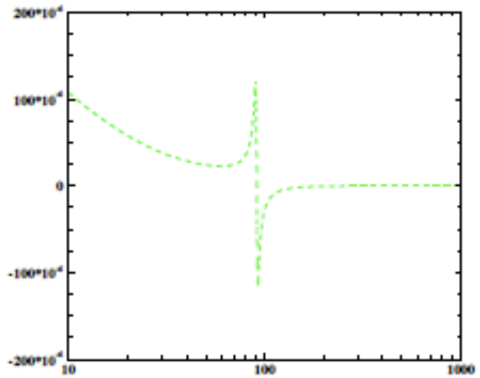
M=60-120 GeV

	all y	(|y|<2.5)
Z	1.75	(1.14)
γZ	0.003	(0.002)
γ	0.057	(0.033)

Drell Yan 20-60 GeV:
1.3 (0.60) nb →
O(1000) events/pb^{-1}

Low/hi mass DY is sizeable

Interference is negligible



Cross Sections - W$^{+/-}$

$$\frac{d^2\sigma}{dMdy} = \frac{4\pi\alpha^2(M)}{9} \cdot 2M \cdot P(M) \cdot \Phi(x_1, x_2, M^2) \quad [\text{nb GeV}^{-1}]$$

$$P_W = \frac{\kappa_W^2}{(M^2 - M_W^2)^2 + (\Gamma_W M_W)^2}$$

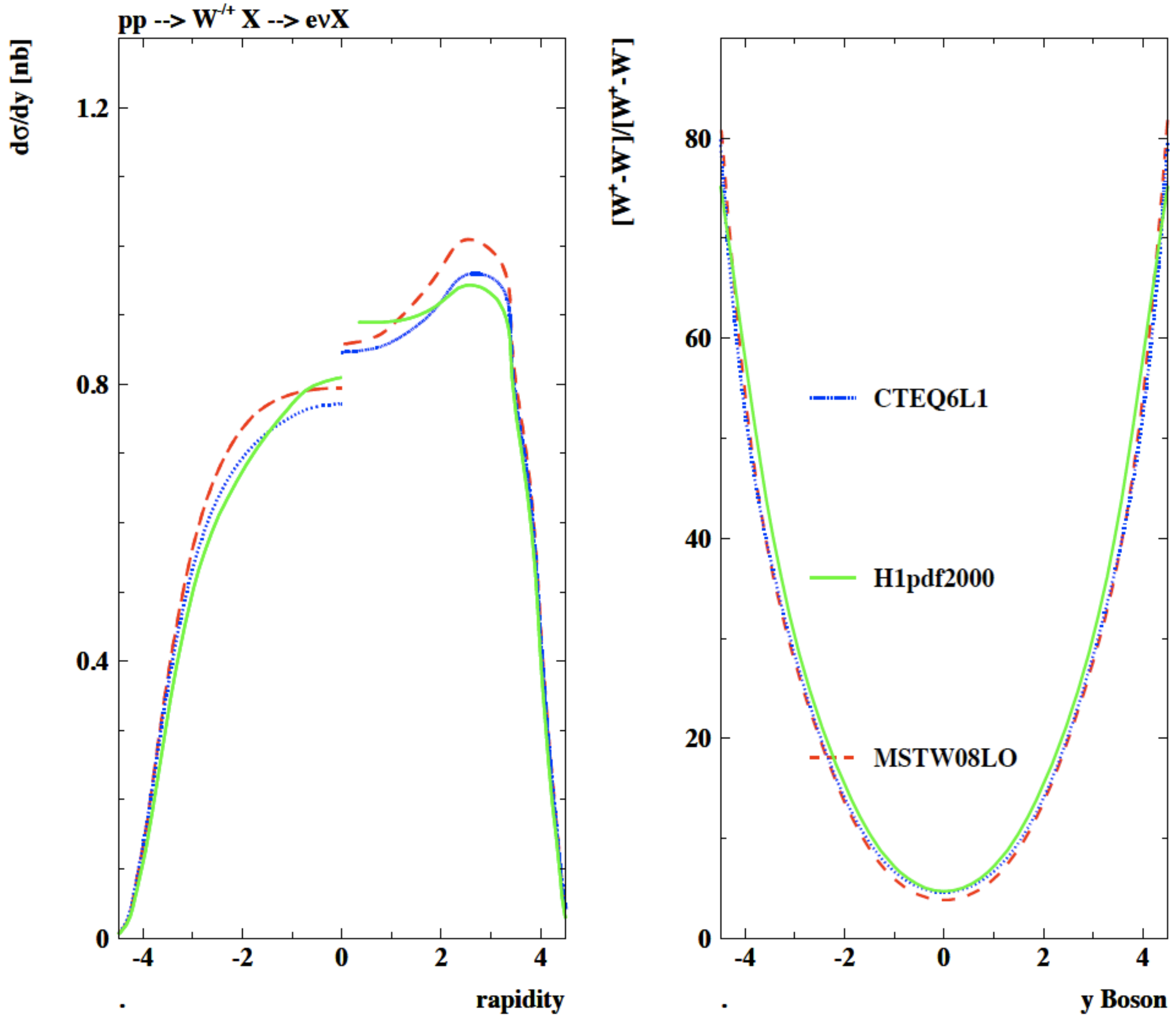
$$\Phi_{W^+} = x_1 x_2 [U_{ud}^2(u_1\overline{d}_2 + u_2\overline{d}_1) + U_{cs}^2(c_1\overline{s}_2 + c_2\overline{s}_1) + U_{us}^2(u_1\overline{s}_2 + u_2\overline{s}_1) + U_{cd}^2(c_1\overline{d}_2 + c_2\overline{d}_1)]$$

$$\Phi_{W^-} = x_1 x_2 [U_{ud}^2(\overline{u}_1 d_2 + \overline{u}_2 d_1) + U_{cs}^2(\overline{c}_1 s_2 + \overline{c}_2 s_1) + U_{us}^2(\overline{u}_1 s_2 + \overline{u}_2 s_1) + U_{cd}^2(\overline{c}_1 d_2 + \overline{c}_2 d_1)]$$

for 4 flavours and $\kappa_W = \frac{1}{4\sin^2\Theta}$ $\quad q_i = q(x_i, M^2)$

$U_{ud}^2 = U_{cs}^2 = 0.94$, $U_{us}^2 = U_{cd}^2 = 0.05$

y Distributions and Asymmetries $W^{+/-}$



10 TeV

LO

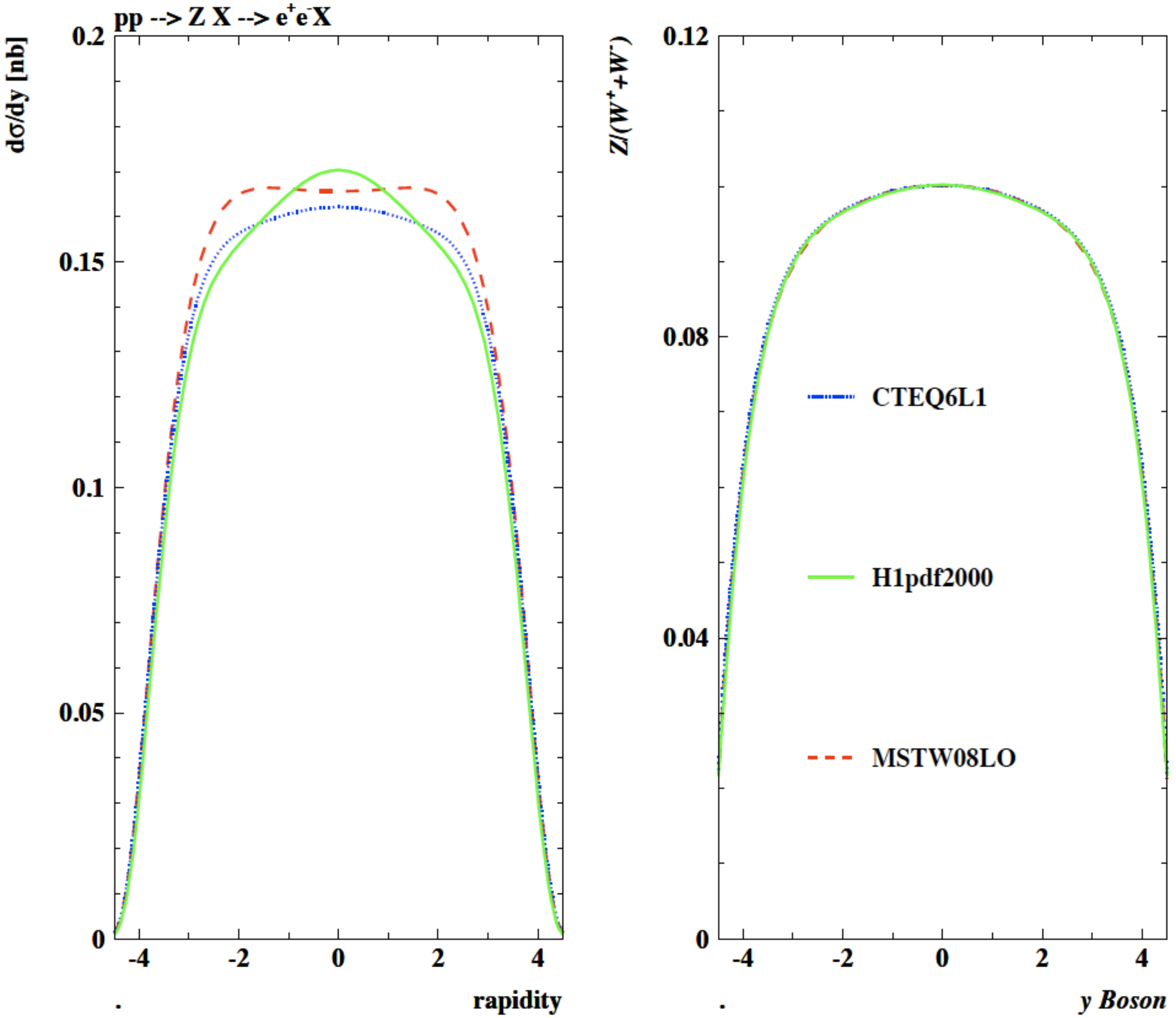
MSTW08
CTEQ6
H1pdf2000

broad agreement

Differences in plateau of O(5-10)%

y Distribution of Z and Universal $Z/(W^+ + W^-)$

Large cancellation in $\frac{Z}{W^+ + W^-} \propto \frac{u\bar{u} + d\bar{d}}{u\bar{d} + d\bar{u}} = 1$ if u=ubar=d=dbar



10 TeV

LO

MSTW08
CTEQ6
H1pdf2000

broad agreement

Differences in plateau of O(5)%

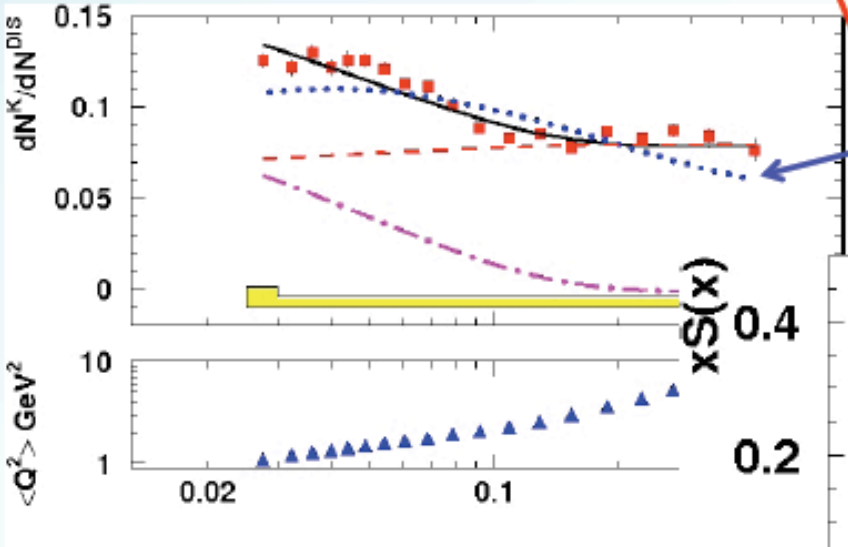
S(x) from Kaon Multiplicities

hermes

$$\frac{dN^{K\pm}}{dN^{DIS}} = \frac{Q(x)\int D_Q^K(z)dz + S(x)\int D_S^K(z)dz}{5\,Q(x) + 2\,S(x)} \xrightarrow{x>0.3} \frac{\int D_Q^K(z)dz}{5}$$

$Q(x) = u(x)+\bar{u}(x)+d(x)+\bar{d}(x)$; $S(x) = s(x) + \bar{s}(x)$

N/q	U	L	T
U	f_1		h_1
L		g_1	h_{1L}
T	f_{1T}	g_{1T}	h_1 h_{1T}



- S(x) from CTEQ6L with $\int D_Q^K(z)dz$ & $\int D_S^K(z)dz$ as free parameters (dotted) does not fit the data

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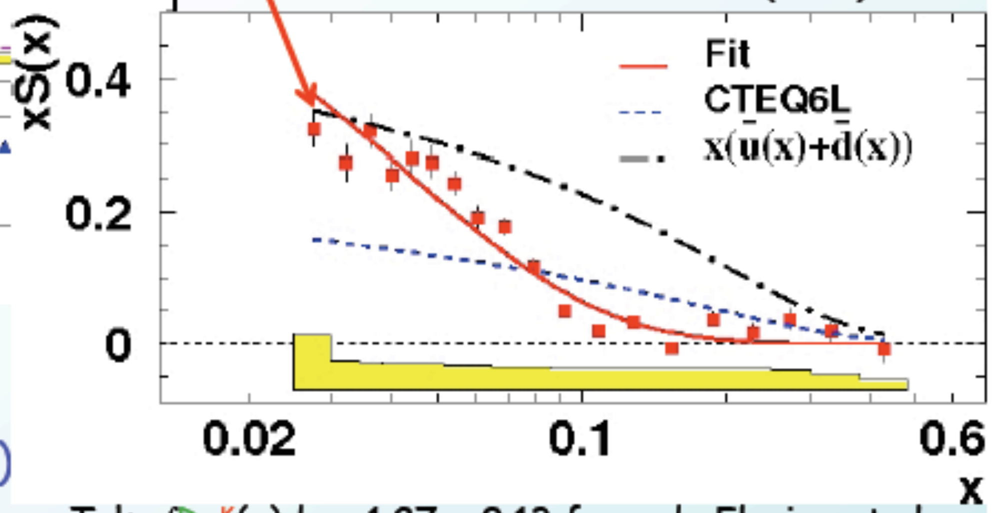


- S(x) much softer than assumed by current PDFs (mainly based on $\overset{(-)}{\nu}N \rightarrow \mu^+\mu^- X$)

Take $\int D_S^K(z)dz = 1.27 \pm 0.13$ from de Florian et al.

10

Different x dependence than ubar+dbar and possibly 2 times higher than assumed so far at low x.

What constrains F_2?

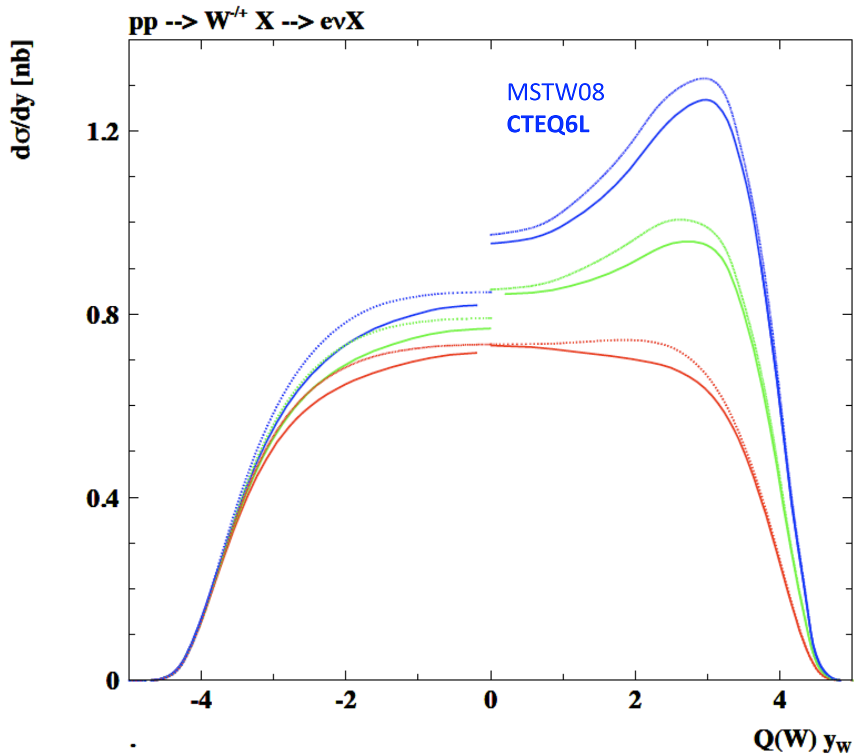
$$F_2(x,Q^2) = x(e_u^2[U+\overline{U}] + e_d^2[D+\overline{D}])$$
$$U = u_v + u_s + c$$
$$\overline{U} = \overline{u} + \overline{c}$$
$$D = d_v + d_s + s$$
$$\overline{D} = \overline{d} + \overline{s}$$
$$u_s = \overline{u}, d_s = \overline{d}, s = \overline{s}, c = \overline{c}$$
$$\overline{s} = f_s \cdot (\overline{u} + \overline{d}), \overline{u} = \overline{d}$$

IF s was very different at lowish x, yet F_2 is to be kept constant (just now measured to 1% accuracy in relevant x range). Thus then d or u .. have to compensate this

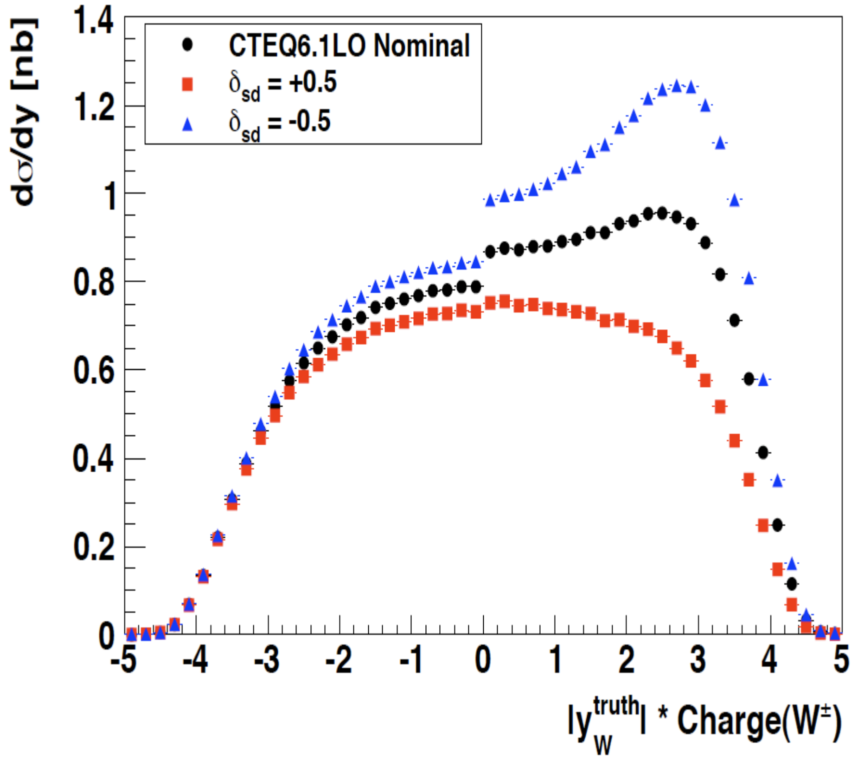
Deuteron data, as from BCDMS, provide some information on u-d
Further constraints exist from DY and dimuon data, Gottfried
sum rule… The HERMES result will have to be confronted
with world data on pdf's. Here study only W,Z and keep F_2 fixed
as we are interested in lower x.

$W^{\pm}$ Rapidity Cross Section

$$s \rightarrow s \cdot (1 + \delta_{sd})$$
$$d \rightarrow d - s \cdot \delta_{sd}$$

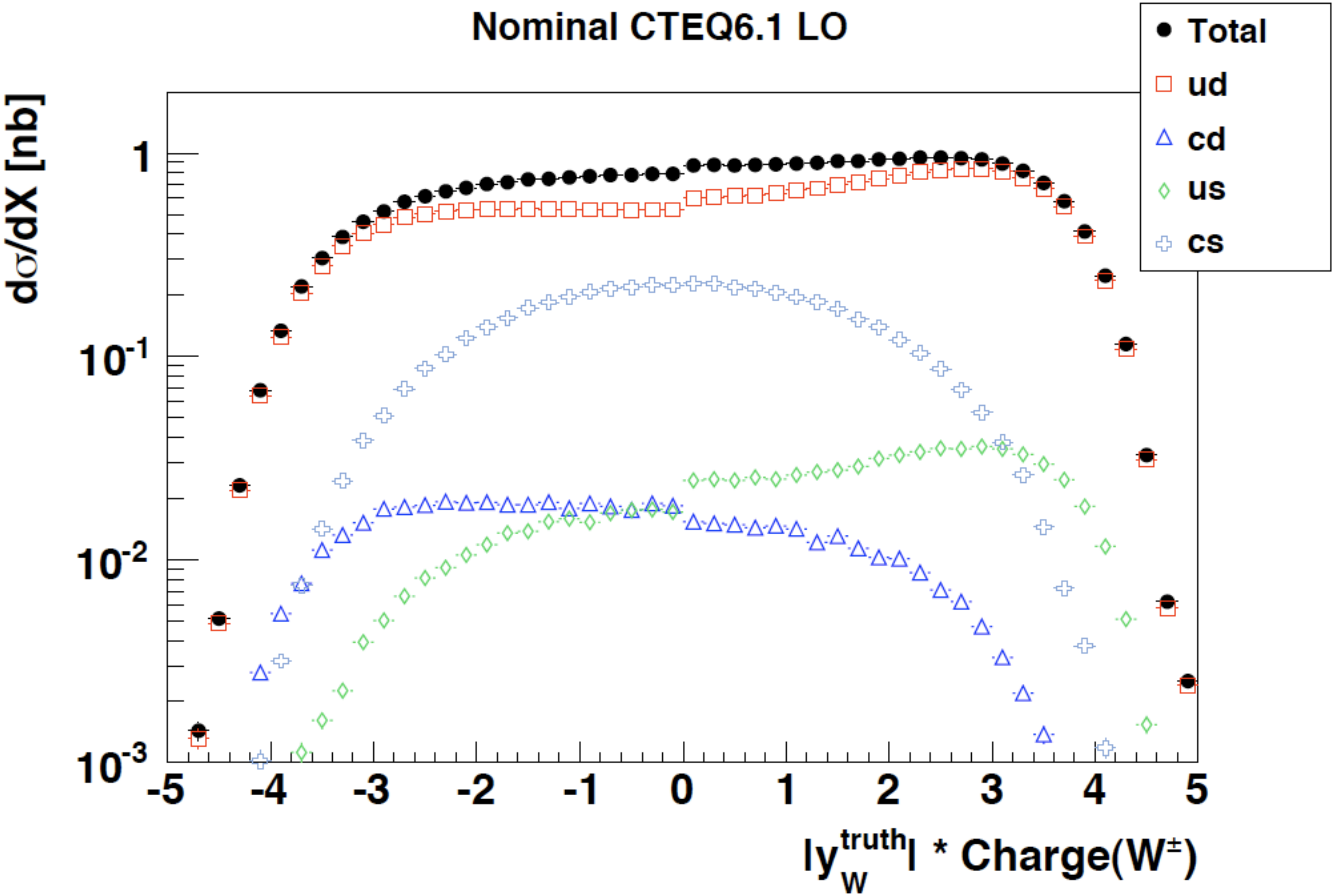


Numeric. (MSTW08LO and CTEQ6L)



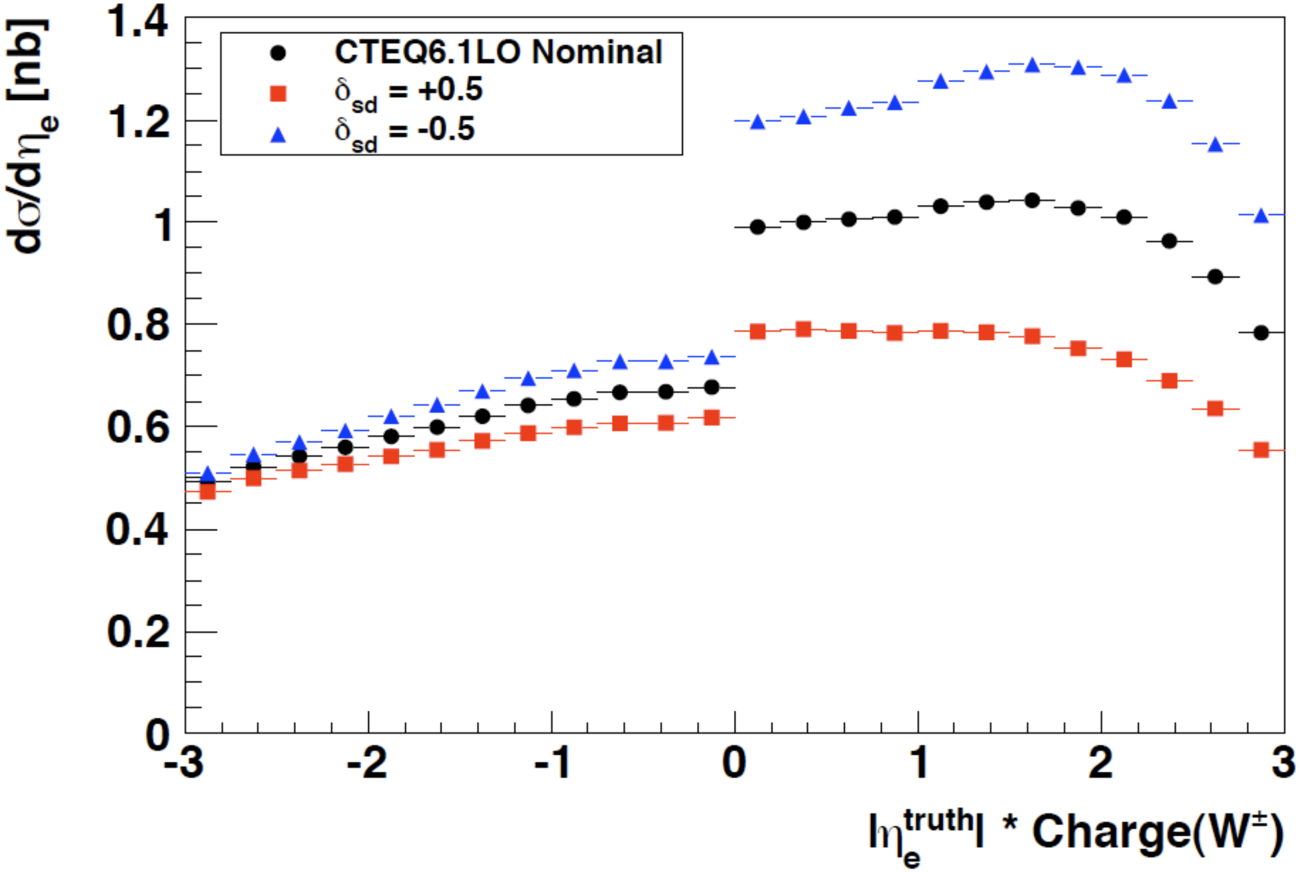
MC reweighted (CTEQ)

Possibly significant strange-down effects in W^+ some in W^-



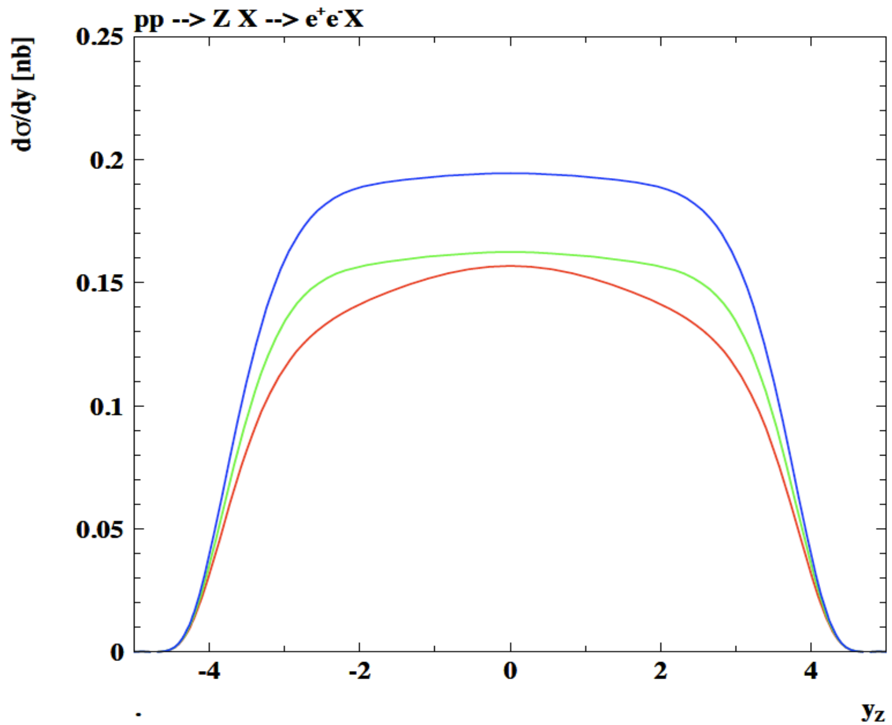
Different sensitivity of W^+ vs W^- can be traced back to flavour contributions

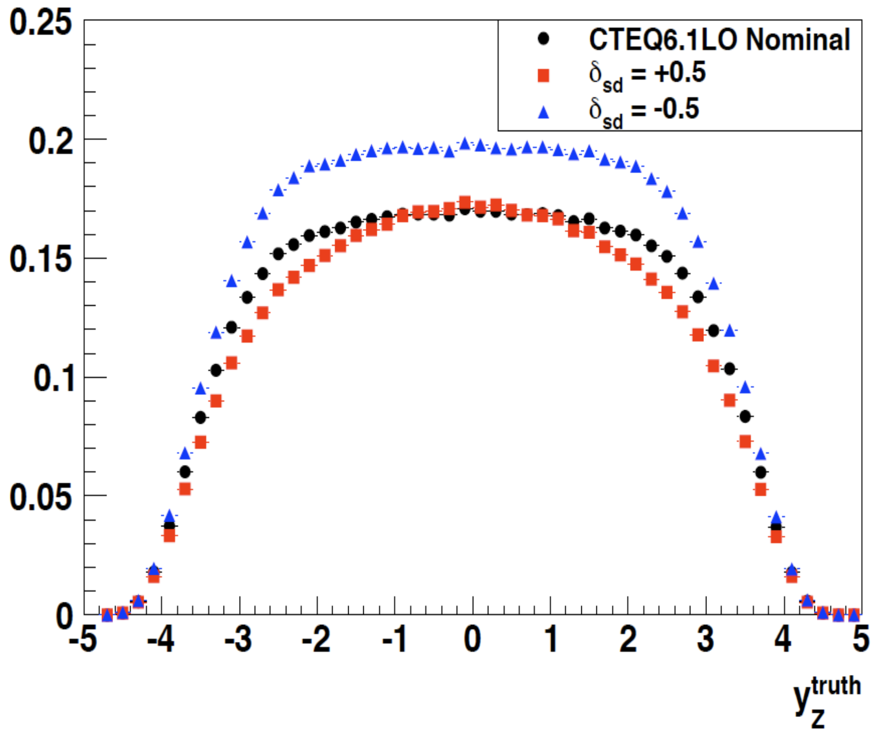
$W^{\pm}$ Cross Section in η_e



Similar observation would be made in pseudo-rapidity distribution

Z Rapidity Cross Section





A reduced strange density and enlarged down sea would enhance the Z cross section

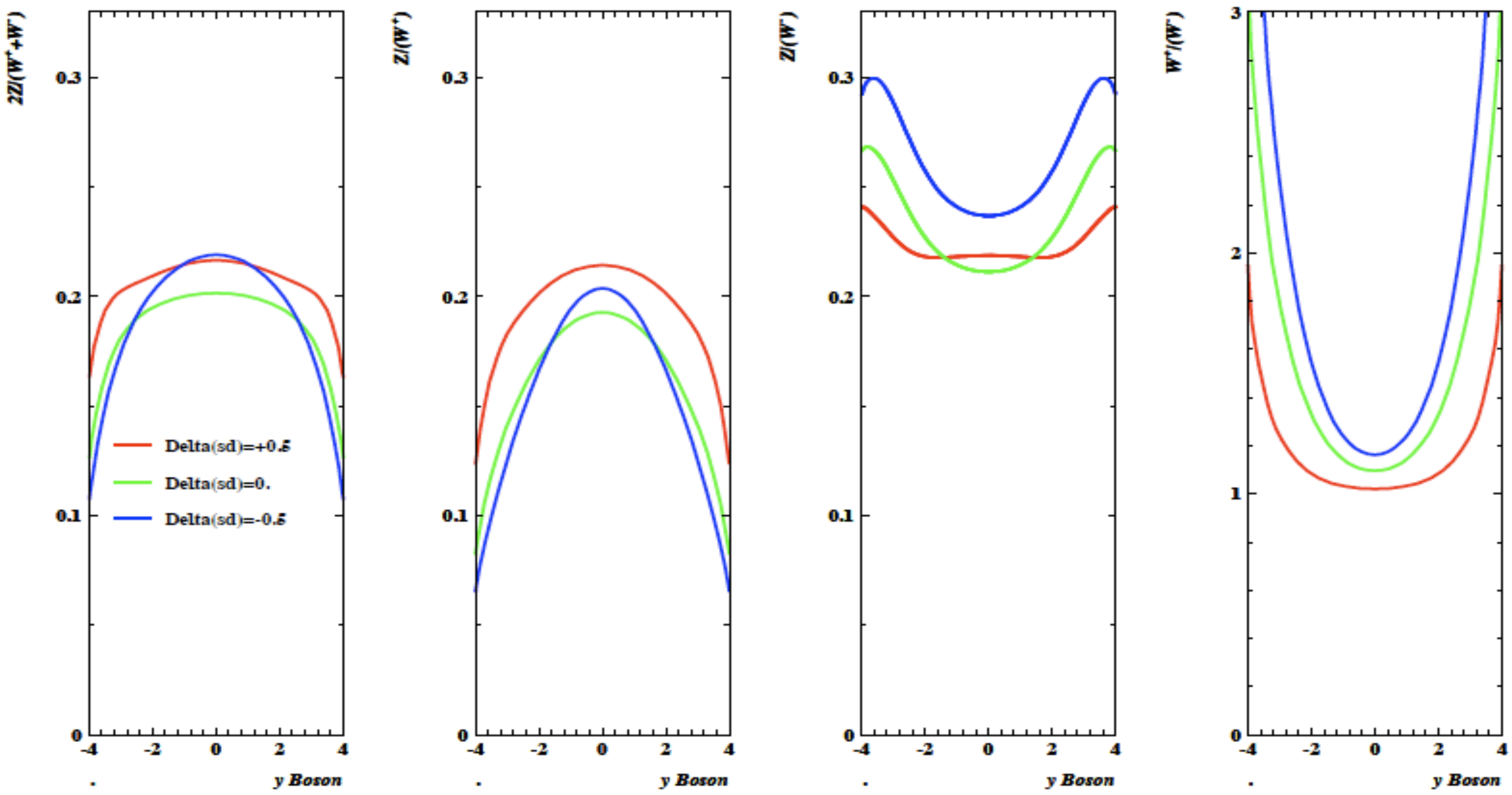
[50% reduced s would enlarge cross section by 20%, enlarged s would be rather hidden]

[Z cross sections and ratios still being checked with MC calculation]

$$s \to s \cdot (1 + \delta_{sd})$$
$$d \to d - s \cdot \delta_{sd}$$

Cross Section Ratios [sd]

CTEQ6L



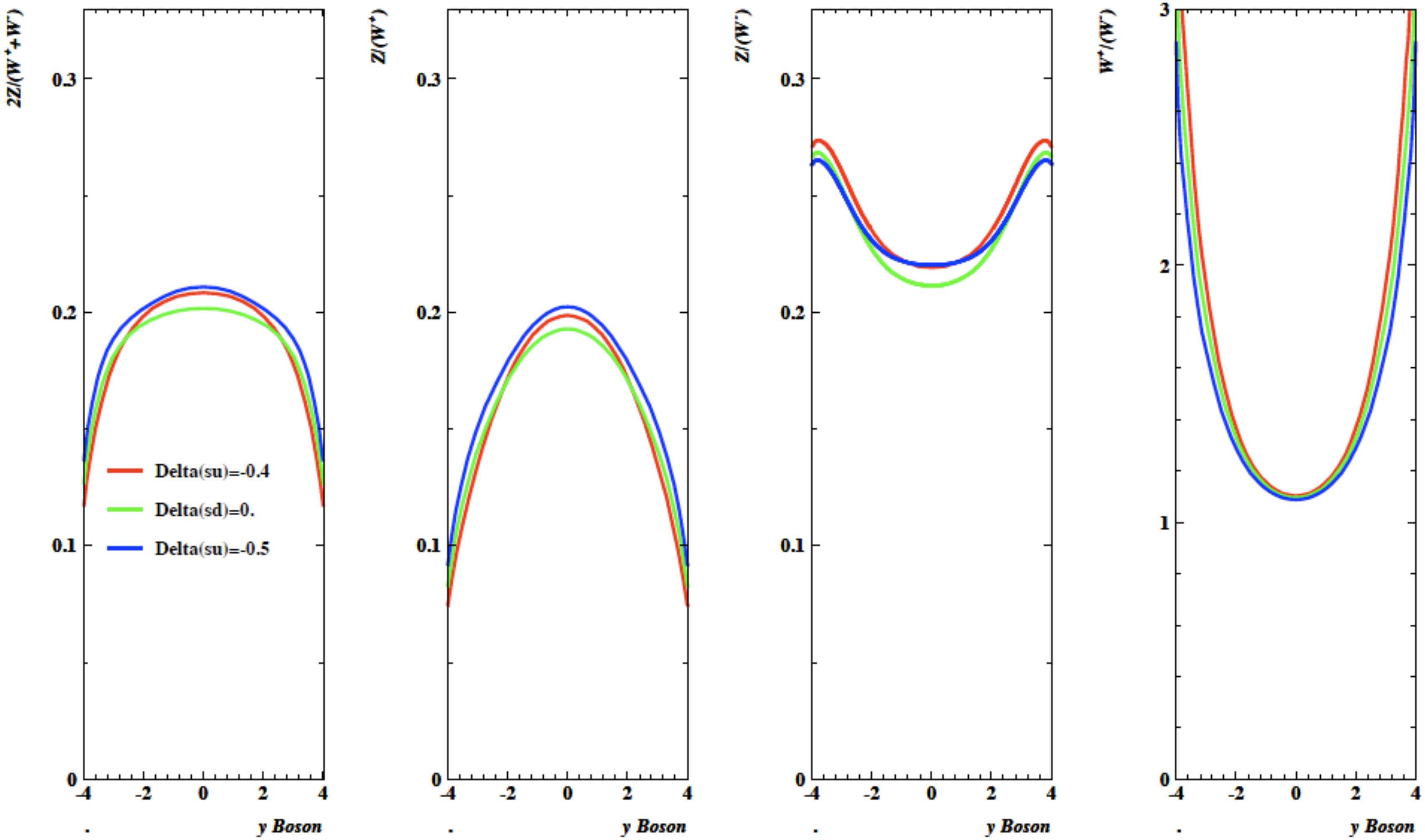
The cross section ratios may come out different than predicted, due to pdf variations.

A change of s would increase the $2Z/(W^+ + W^-)$ ratio, but the sign may be deduced from W^+/W^-.

$$s \rightarrow s \cdot (1 + \delta_{su})$$

Cross Section Ratios [su]

$$u \rightarrow u - s \cdot \delta_{su} \cdot [\frac{e_d}{e_u}]^2$$

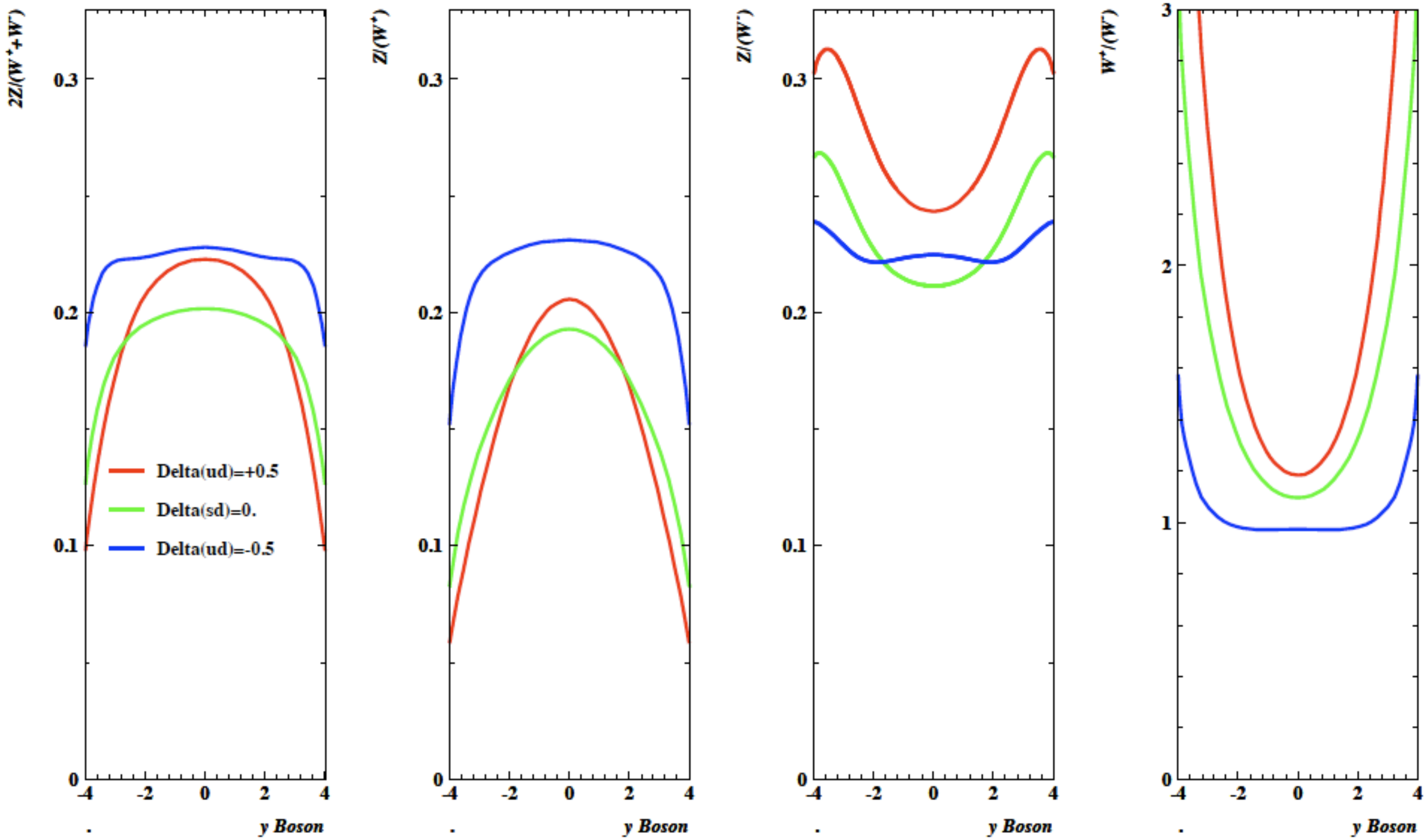


A change in s which would modify ū would be difficult to monitor. A conventional result on W/Z would thus not imply necessarily that the strange was conventional too..

$$s \rightarrow s \cdot (1+\delta_{ud})$$

$$u \rightarrow u - s \cdot \delta_{ud} \cdot [\frac{e_d}{e_u}]^2$$

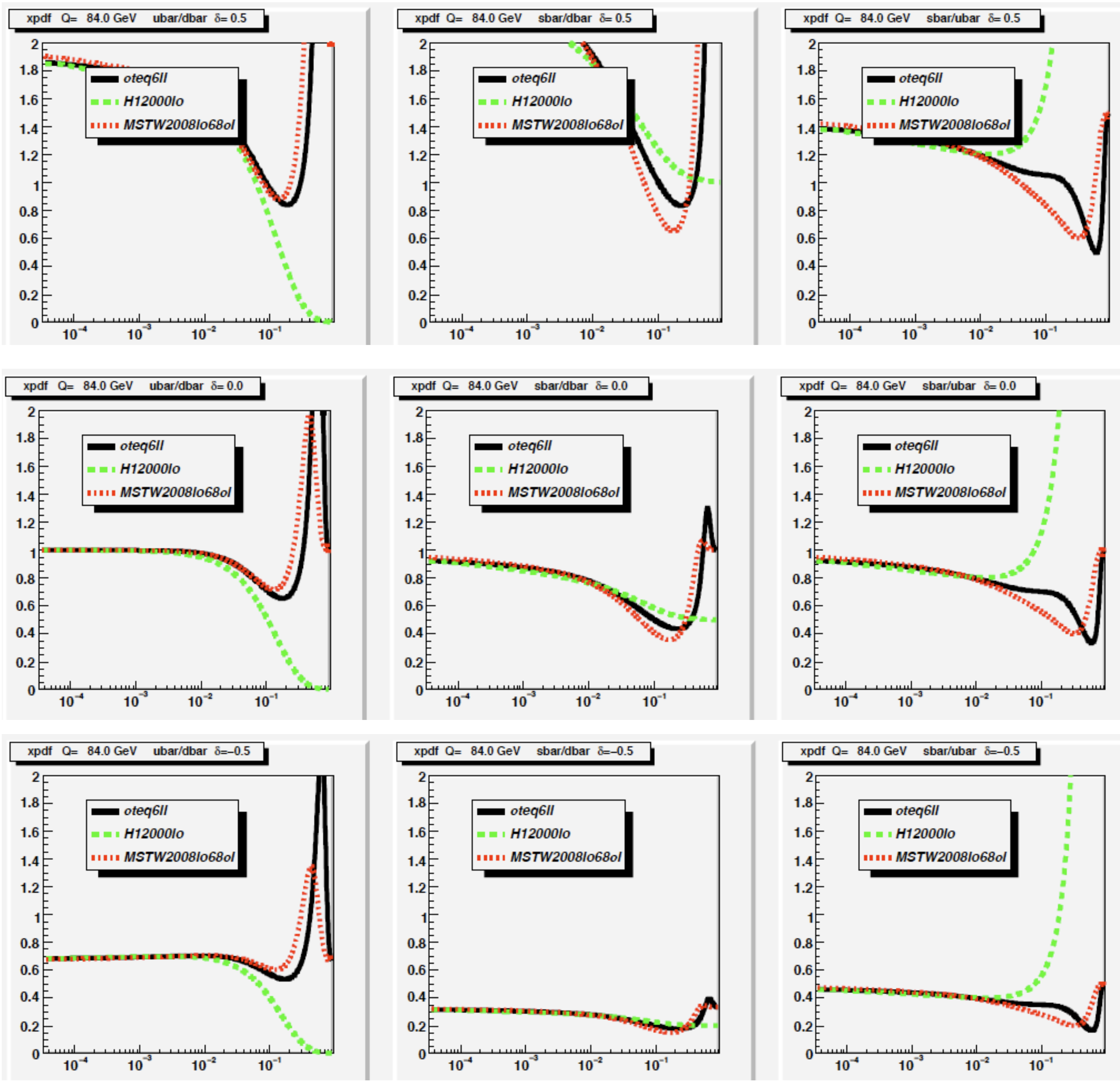
Cross Section Ratios [ud]



Significant effects would occur if đ ≠ ū to a large extent [50% gives 10% in W^+/W^-]

$$s \to s \cdot (1 + \delta_{sd})$$
$$d \to d - s \cdot \delta_{sd}$$

Direct Effects on pdfs



+0.5

Nominal

-0.5

Summary

The current pdf measurements have some freedom, which leads to simplifying QCD fit assumptions.

The W and Z cross sections and their ratios may provide further constraints on this.

If indeed the strange quark distribution was much larger than hitherto assumed, and if that was balanced by an reduced down sea, for example, then the $Z/(W^+ + W^-)$ and the W^+/W^- ratios would allow tagging such an effect (50% change of s roughly corresponding to 5-10% asymmetry effects).

The rapidity (x) dependence is of interest, and the η_e dependence leads to similar effects as y.

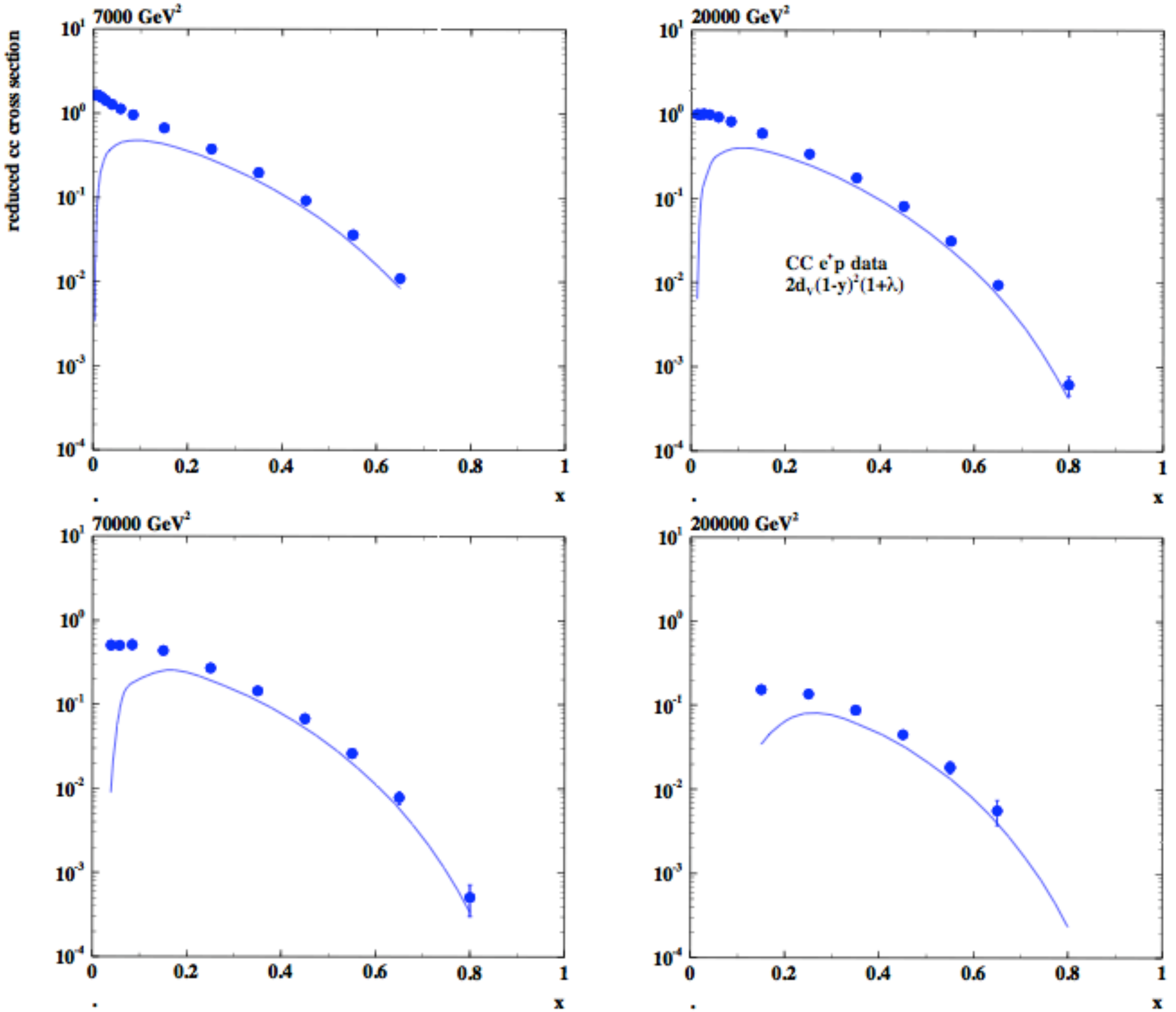
The variations as studied are to set a scale, not to indicate that so large variations are to be considered. Some checks are still being done and an NLO study may be of interest.

It is possible, that the W, Z cross sections and their ratios as functions of the rapidity may deviate from the canonical predictions as most of these use common assumptions in the Bjorken x range of interest.

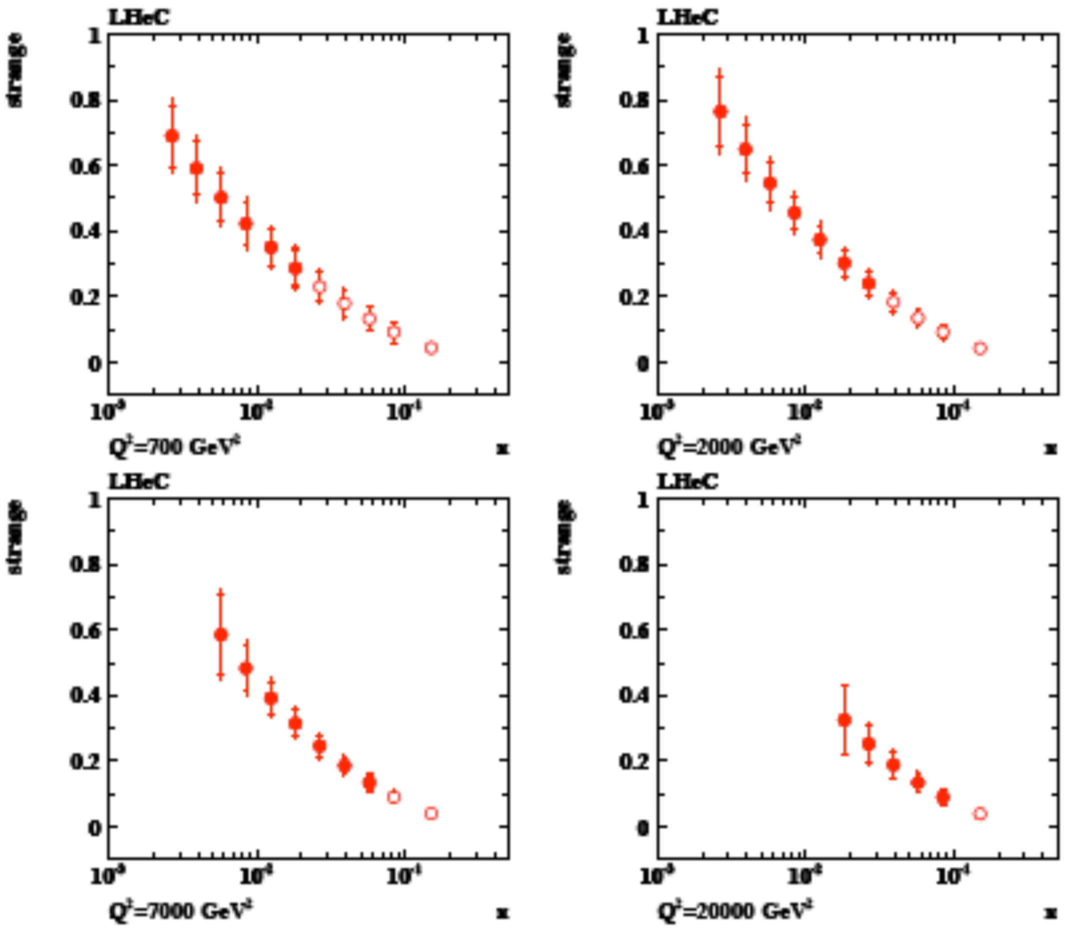
In particular, the famous W/Z ratio may turn out to look different and this may not hint to an ATLAS problem.. A differential, accurate measurement of W^+, W^- and Z cross sections and their ratios is important.

backup

Charged currents (e^+)



Strange quark distribution



$W^+ s \rightarrow c$

$1\, fb^{-1}$

$\varepsilon_c = 0.1$

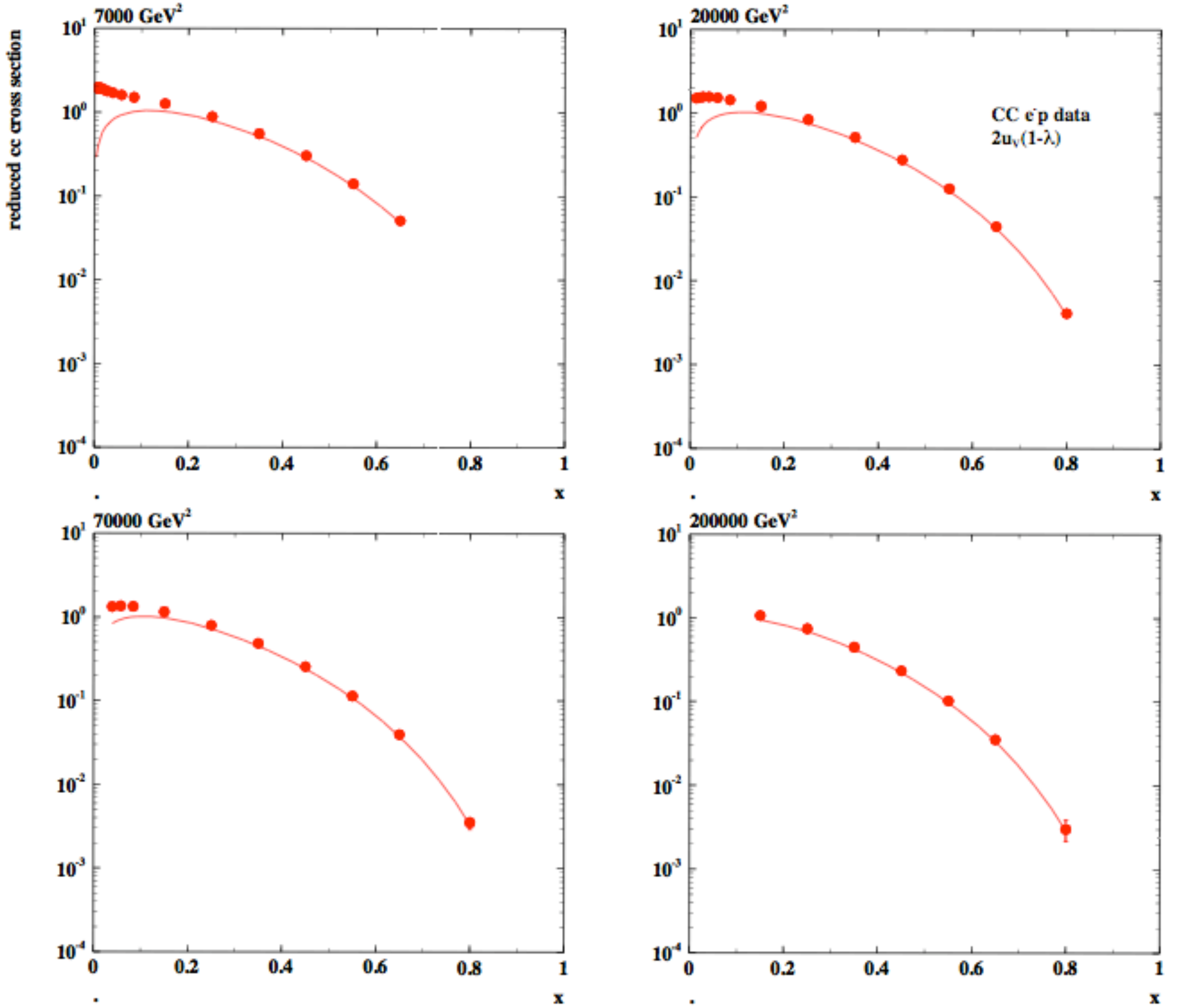
$\varepsilon_q = 0.01$

$\delta_{syst} = 0.1$

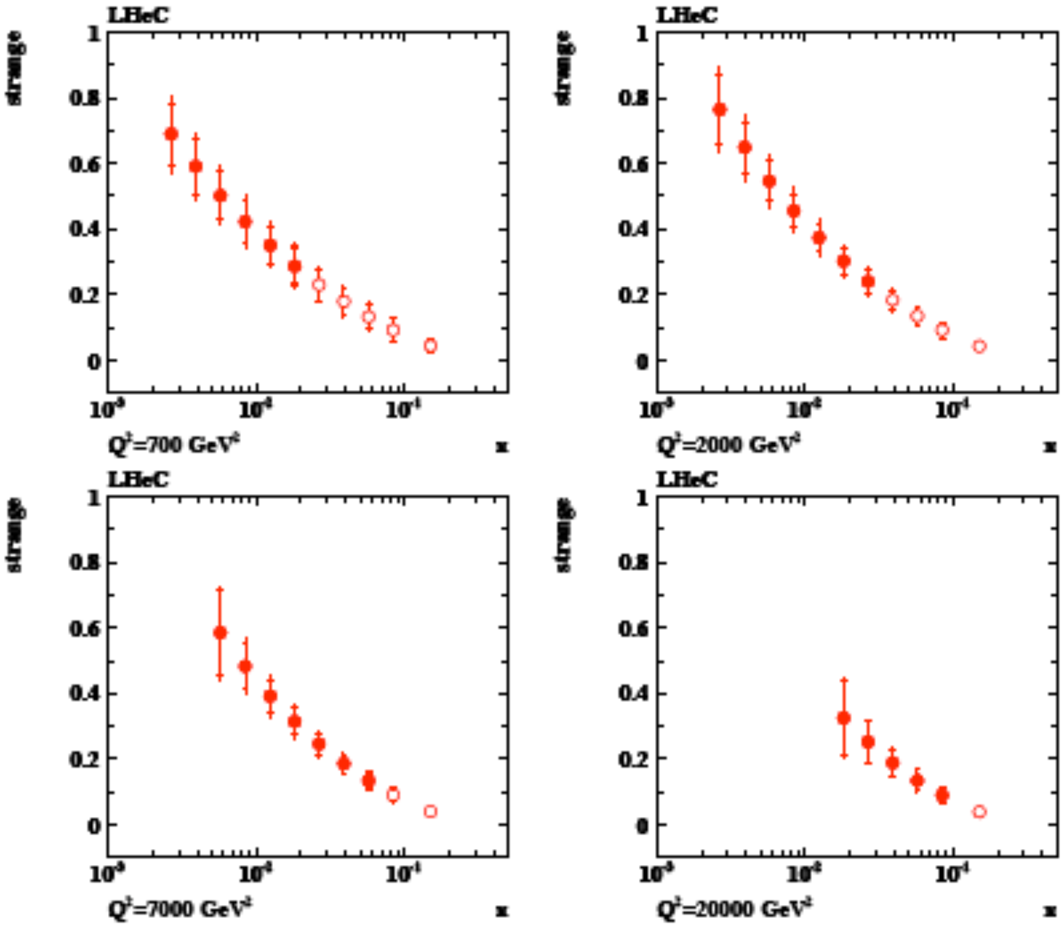
$\circ - \vartheta_h \geq 1^o$

$\bullet - \vartheta_h \geq 10^o$

Charged currents (e^-)



Anti-Strange quark distribution



$W^- sbar \rightarrow cbar$

$1\,fb^{-1}$

$\varepsilon_c = 0.1$

$\varepsilon_q = 0.01$

$\delta_{syst} = 0.1$

$\circ - \vartheta_h \geq 1^o$

$\bullet - \vartheta_h \geq 10^o$