W Asymmetry and PDF's - CDF and LHC Analyses

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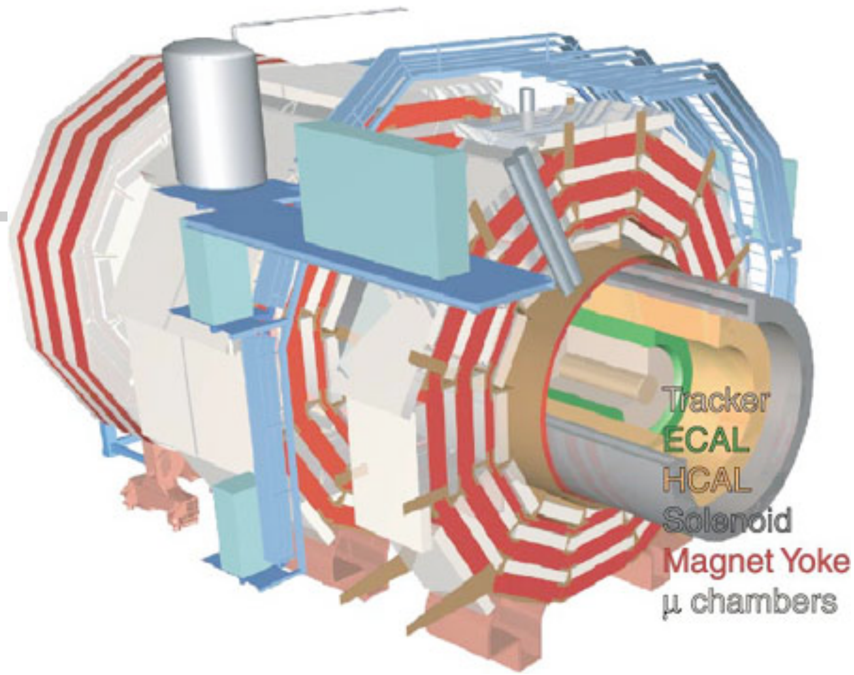


Sept. 4, 2008 Meeting of PDF4LHC 9:30 am EST

Outline

- W Asymmetry and relations to PDFs (**Better to look at W-/W+ versus y)**
- New technique used in CDF : **Unfolding the W-lepton Charge Asymmetry to extract the true W-/W+ charge asymmetry versus y**. (also may be able to extract $d\sigma W/dy$ distributions so one can measure $\sigma Z(y)/\sigma W(y)$ versus y.
- Implications of W Asymmetry measured at CDF to the LHC , PDFs and Deep Inelastic scattering.

Why measure Wasym

d/u<1 because $d_{valence} < u_{valence}$

- At the Tevatron the **W-/W+** versus y yields the:
  ratio of d/u at large x1 to d/u at small x2.

In contrast

- At the LHC **W-/W+** versus y yields the:
  absolute value of d/u at small x.

- The two measurements are complementary

For pbar -p Tevatron

W-/W+ = ratio [d/u(x1) at larger x1 / d/u (x2) at smaller x2]

W-= Cos2 [d(x1) u(x2)+ ubar(x1) dbar(x2) +s(x1) c(x2) +cbar(x1) sbar(x2)]
W-= Sin2 [d(x1) c(x2)+ ubar(x1) sbar(x2) +s(x1) u(x2) +cbar(x1) dbar(x2)]
W+ =Cos2 [u(x1)d(x2)+ dbar(x1)ubar(x2) + c(x1)s(x2) + sbar(x1)cbar(x2)]
W+ =SIn2 [u(x1)sx2)+dbar(x1)cbar(x2) + c(x1)d(x2) +sbar(x1)ubar(x2)]

$$A(y_W) \approx \frac{u(x_1)d(x_2) - u(x_2)d(x_1)}{u(x_1)d(x_2) + u(x_2)d(x_1)}$$

$$\equiv \frac{d(x_2)/u(x_2) - d(x_1)/u(x_1)}{d(x_2)/u(x_2) + d(x_1)/u(x_1)}.$$

In terms of Cos2 and sin2 of Cabbibo angle

$$\boxed{\frac{W-}{W+} \approx \frac{d(x_1)/u(x_1)}{d(x_2)/u(x_2)}.}$$

Note **x1** range at the Tevatron overlaps **x** range of muon deep inelastic scattering data on hydrogen and deuterium

For p-p LHC

W-/W+ = absolute value of d/u(x) at small x

W- = 0.949 [**d(x1)** $\underline{u}$(x2)+ $\underline{u}$(x1) **d(x2)** + s(x1) $\underline{c}$(x2) + $\underline{c}$ (x1) s(x2)]
+ 0.051 [d(x1) $\underline{c}$(x2) + $\underline{u}$ (x1) s(x2) +s(x1) $\underline{u}$(x2) + $\underline{c}$ (x1) d(x2)]

W+ =0.949 [**u(x1)** $\underline{d}$(x2)+ $\underline{d}$ (x1)**u(x2)** + c(x1) $\underline{s}$(x2) + $\underline{s}$(x1)c(x2)]
+0.051 [u(x1) $\underline{s}$(x2) + $\underline{d}$(x1) c(x2) + +c(x1) $\underline{d}$(x2) + $\underline{s}$(x1)u(x2)]

In terms of Cos2 and sin2 of Cabbibo angle

For most of the region, $\underline{d}$ (x) = $\underline{u}$(x) = $\underline{q}$(x)

$$W-/W+ = \frac{[d(x1) + d(x2)*\underline{q}(x1)/\underline{q}(x2)]}{[u(x1) + u(x2)*\underline{q}(x1)/\underline{q}(x2)]}$$

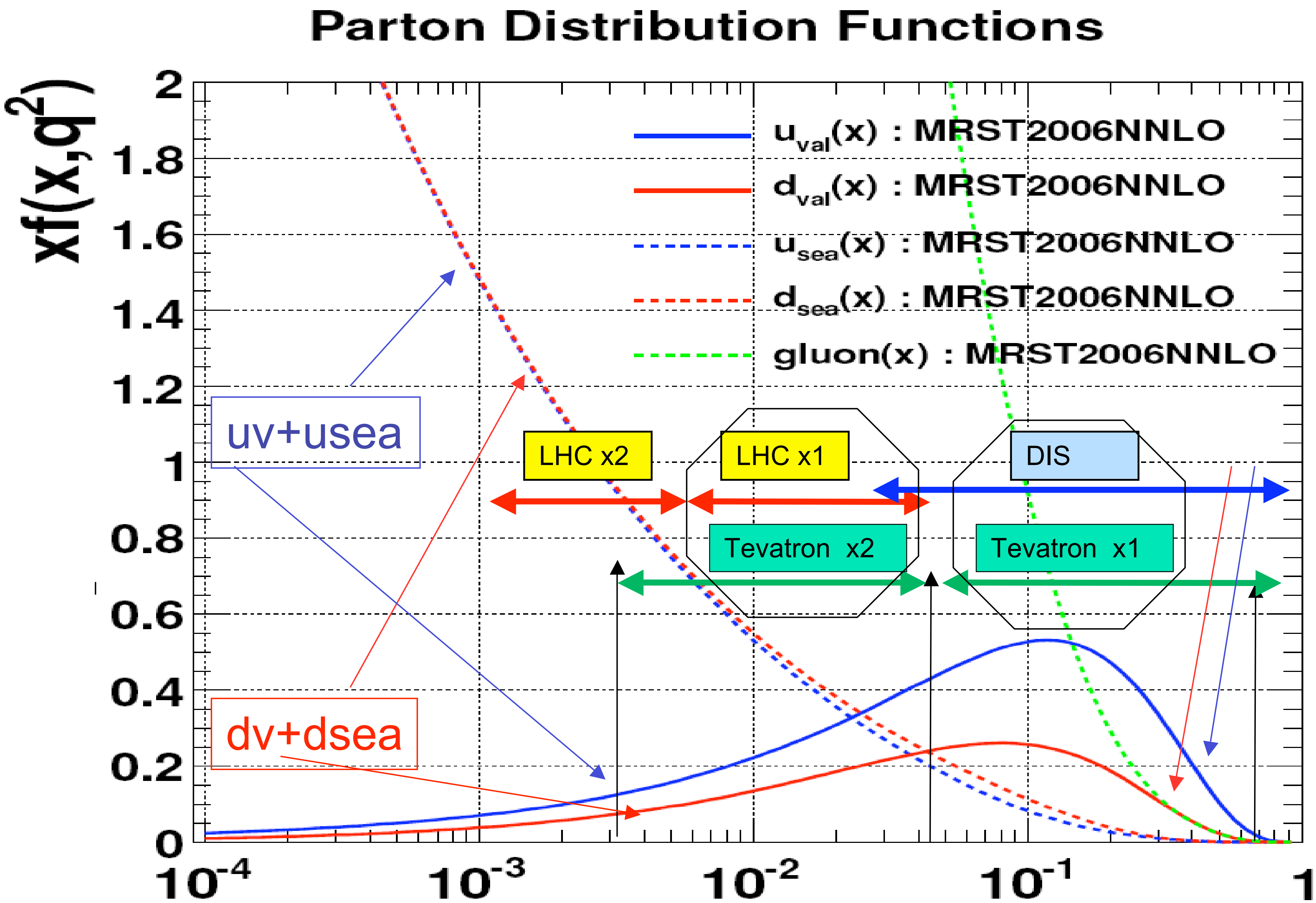
Note: **X1** at the LHC overlaps range of **X2** at the Tevatron

At small y: x1=x2 $\underline{q}$(x1)/$\underline{q}$(x2) = 1

*W-/W+ =~ [d/u (x1) + d/u (x2)]*0.5*

At **larger y:** $\underline{q}$(x1)/$\underline{q}$(x2) << 1 since x1 is large and x2 is small

W-/W+ =~ d/u (x1)



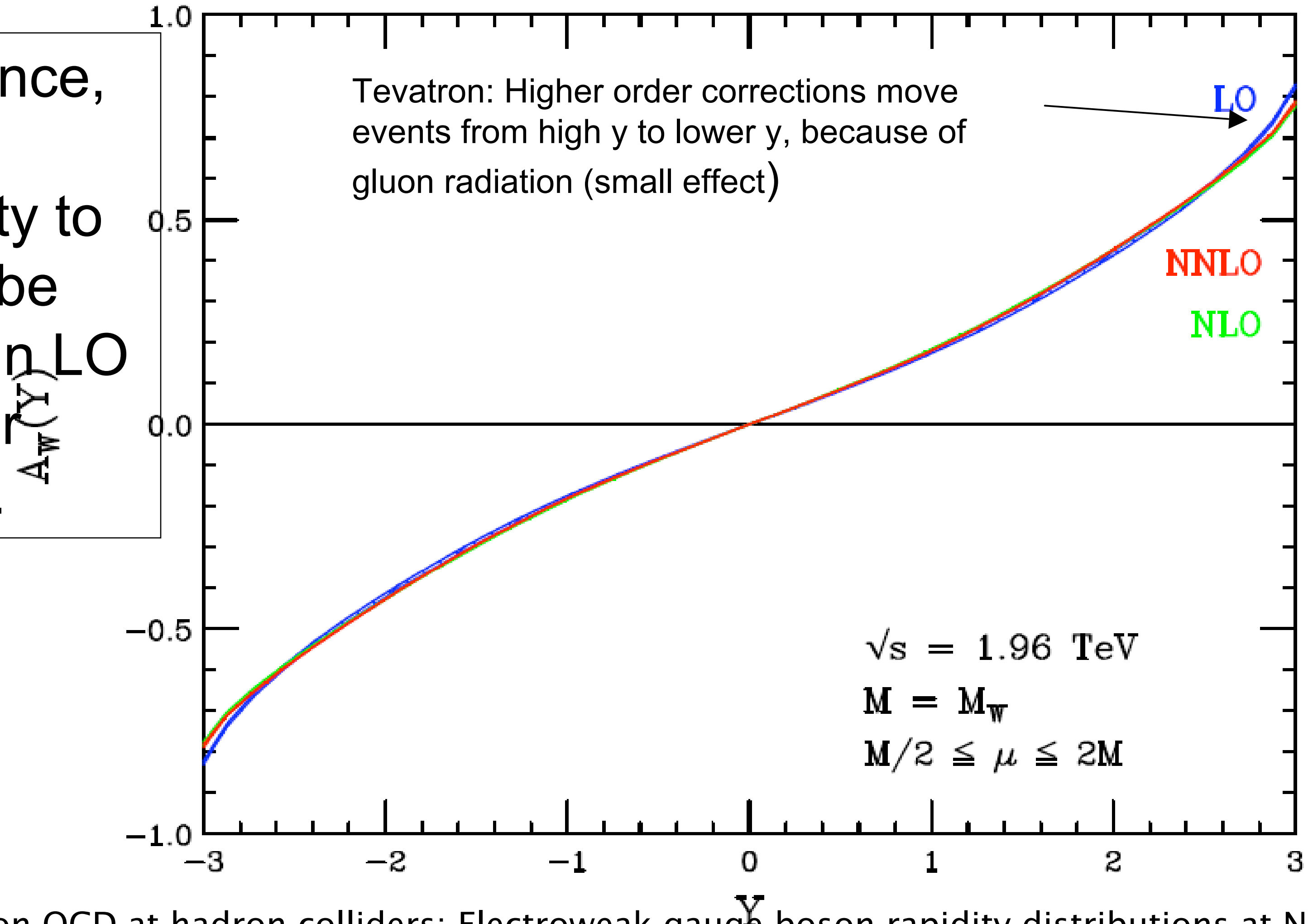
Parton Distribution Functions
xf(x,q²)
x
$u_{val}(x)$: MRST2006NNLO
$d_{val}(x)$: MRST2006NNLO
$u_{sea}(x)$: MRST2006NNLO
$d_{sea}(x)$: MRST2006NNLO
gluon(x) : MRST2006NNLO
uv+usea
dv+dsea
LHC x2
LHC x1
DIS
Tevatron x2
Tevatron x1

d/u(x=0) ~1

d/u (x=1) ~0

In General, W-/W+ and Z/W ratios are much less sensitive to QCD order. All have similar K(y) factor that convert LO distributions to NNLO (as long as NLO or NNLO PDFs are used in the LO code)

Acceptance, and sensitivity to d/u can be studied in LO + Kfactor scheme.

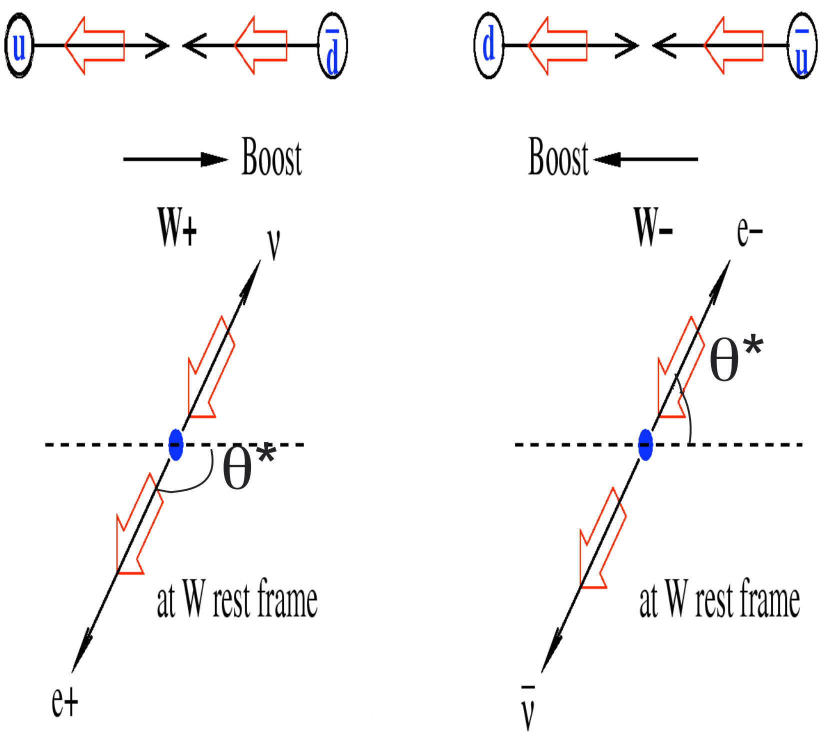


High precision QCD at hadron colliders: Electroweak gauge boson rapidity distributions at NNLO. C. Anastasiou, L. J. Dixon, K. Melnikov , . Petriello. Phys.Rev.D69:094008,2004.

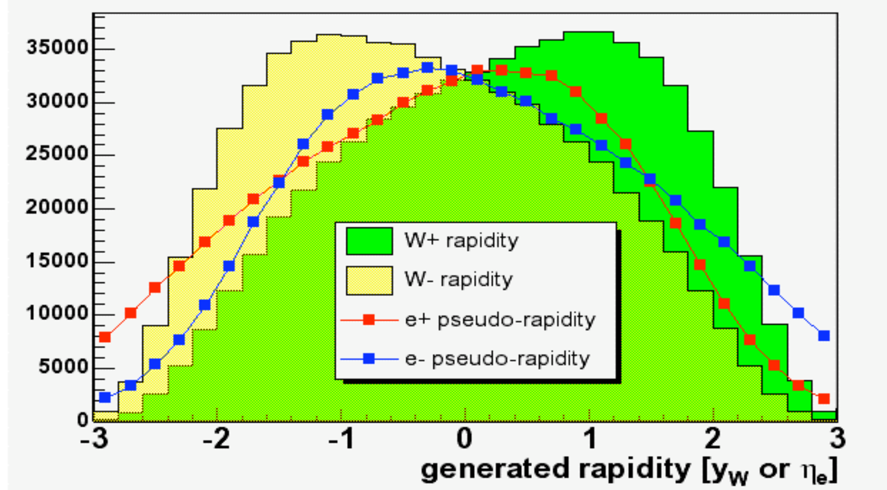
Unfolding W Charge Asymmetry at the Tevatron
u quark carries more momentum than d quark

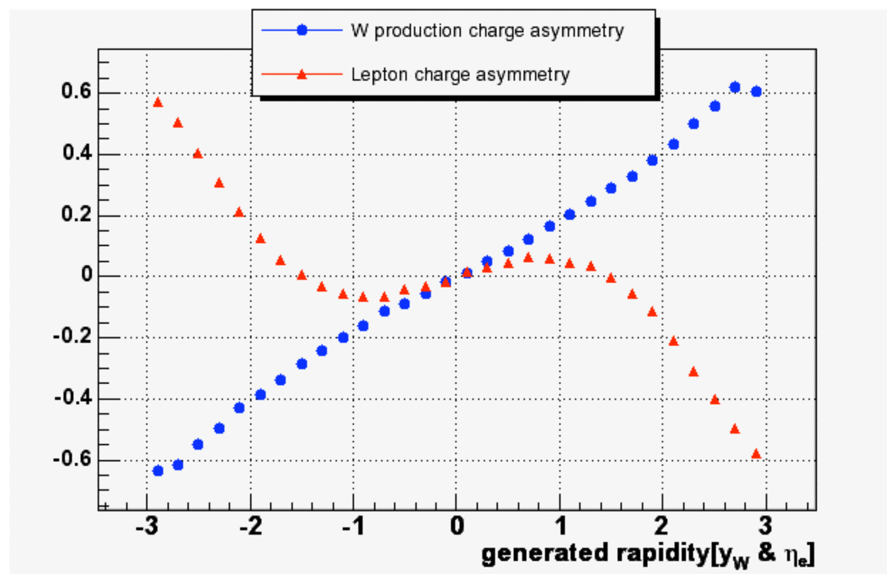
- V-A impacts
  - W production kinematics
  - W decay kinematics

$$P = (1 \pm \cos\theta^*)^2$$



←anti-proton direction proton direction→

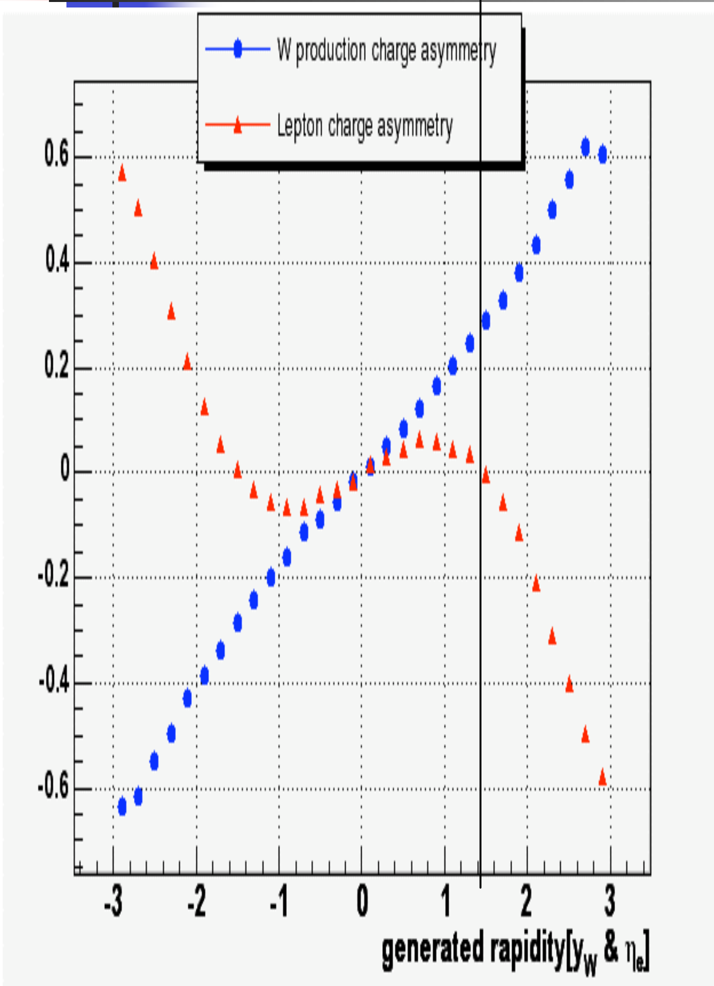


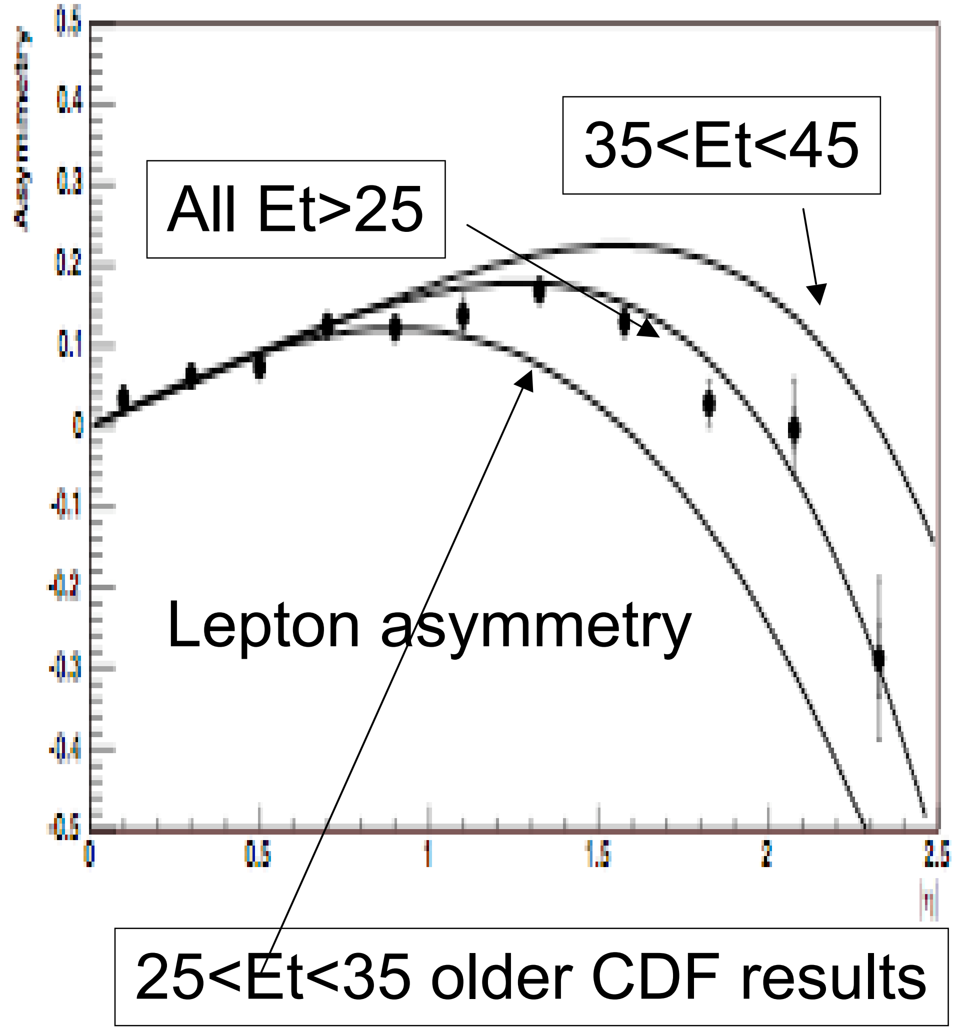


The decay lepton asymmetry averages over a range of y_w.

Information in Et, and missing ET is not used at all !

It is also sensitive to modeling of W pt distributions at low Pt.

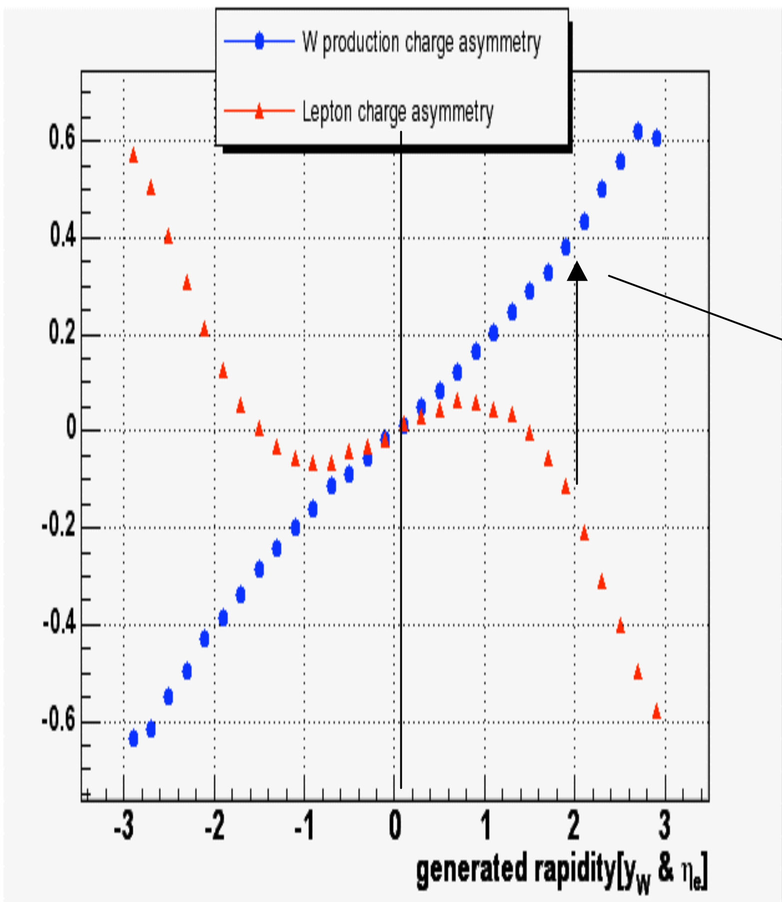


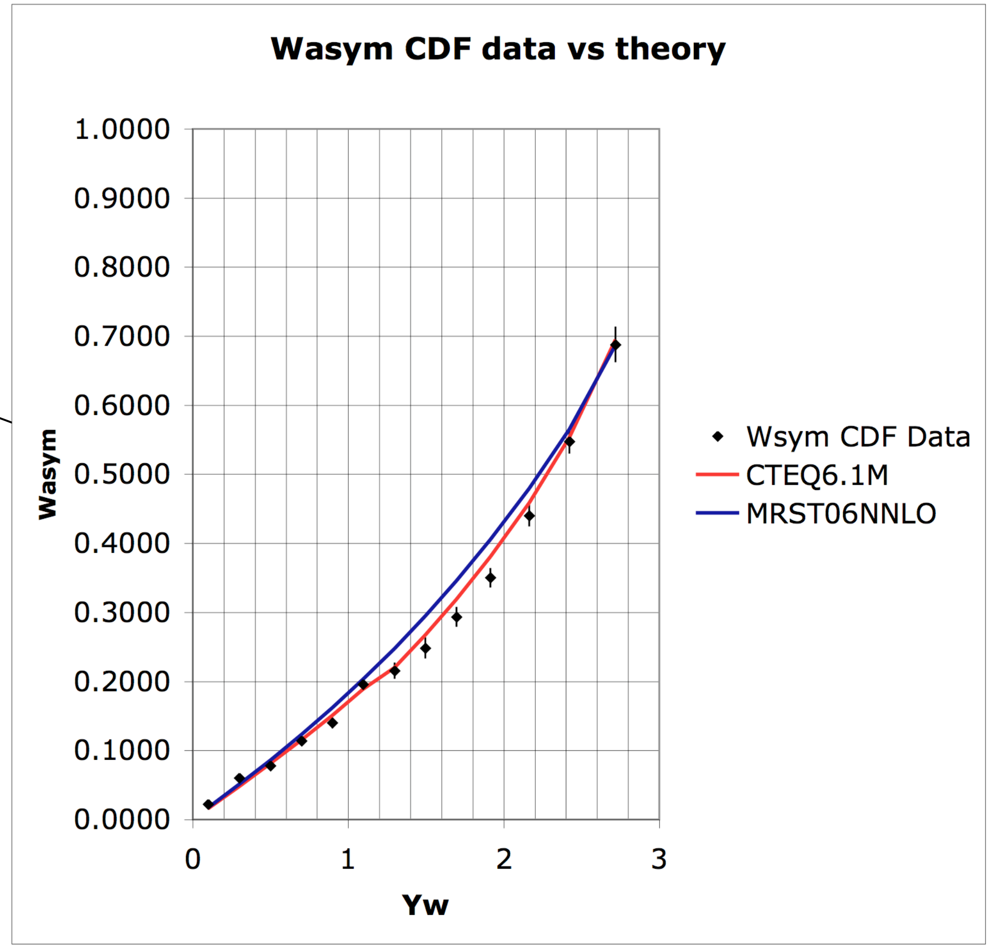


The larger the lepton Et, the closer is the lepton Asymmetry to the W asymmetry

Unfolding the W Charge Asymmetry at CDF

New analysis technique to measure the W production charge asymmetry at the Fermilab Tevatron" A. Bodek, Y-S Chung, B-Y Han, K. McFarland , E. Halkiadakis, ***Phys. Rev. D 77, 111301(R) (2008)*** ; ***B.Y. Han (Rochester- CDF PhD 2008)- update Aug. 6.08***





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Unfolding the W Charge Asymmetry -
use all the information (Et, MET, eta) in each event
There are only 2 y_w solutions for each event..

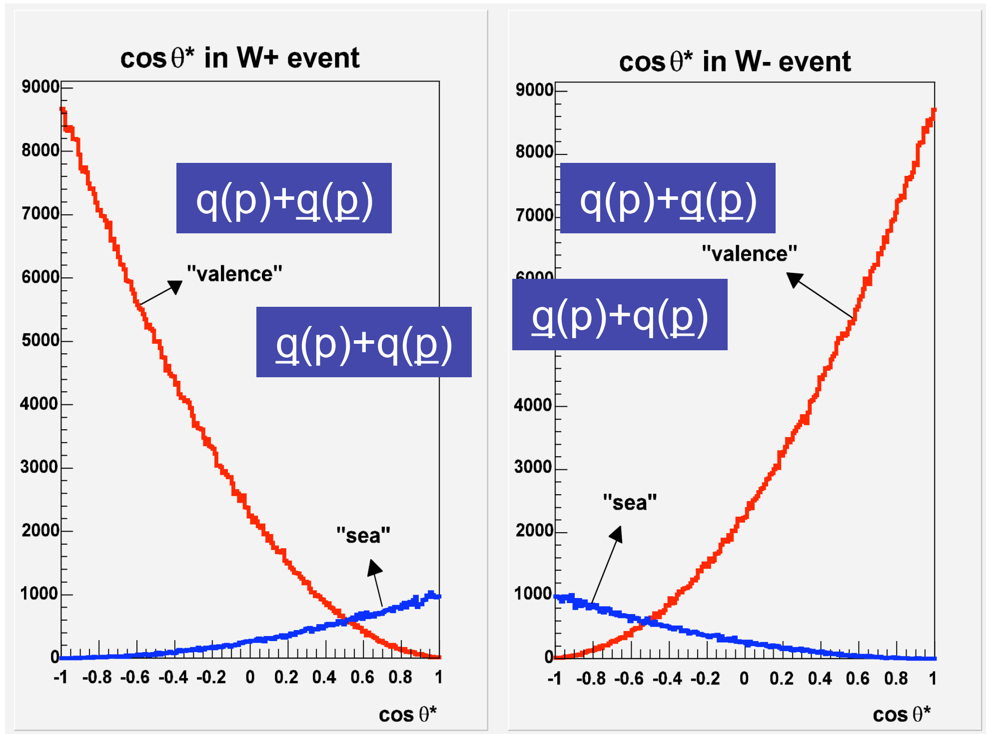
- Analysis method: Number of $W^{\pm}$ vs y_W
  - Use ME_T for P_ν: missing P_z!
  - Use M_W constraint to **get 2 possible y_W solutions**
    - Weight each of them depending on:
      - Angular distribution

$$P_\pm(\cos\theta^*, y_W, p_T{}^W) = A\{(1\mp\cos\theta^*)^2 + Q(y_W, p_T^W)(1\pm\cos\theta^*)^2\}$$

      - W cross section

$$wt^{\pm}_{1,2} = \frac{P_\pm(\cos\theta^*_{1,2}, y_{1,2}, p_T{}^W)\sigma_\pm(y_{1,2})}{P_\pm(\cos\theta^*_1, y_1, p_T{}^W)\sigma_\pm(y_1) + P_\pm(\cos\theta^*_2, y_2, p_T{}^W)\sigma_\pm(y_2)}$$

      - Depends on A_w !
      - **Iterate!**



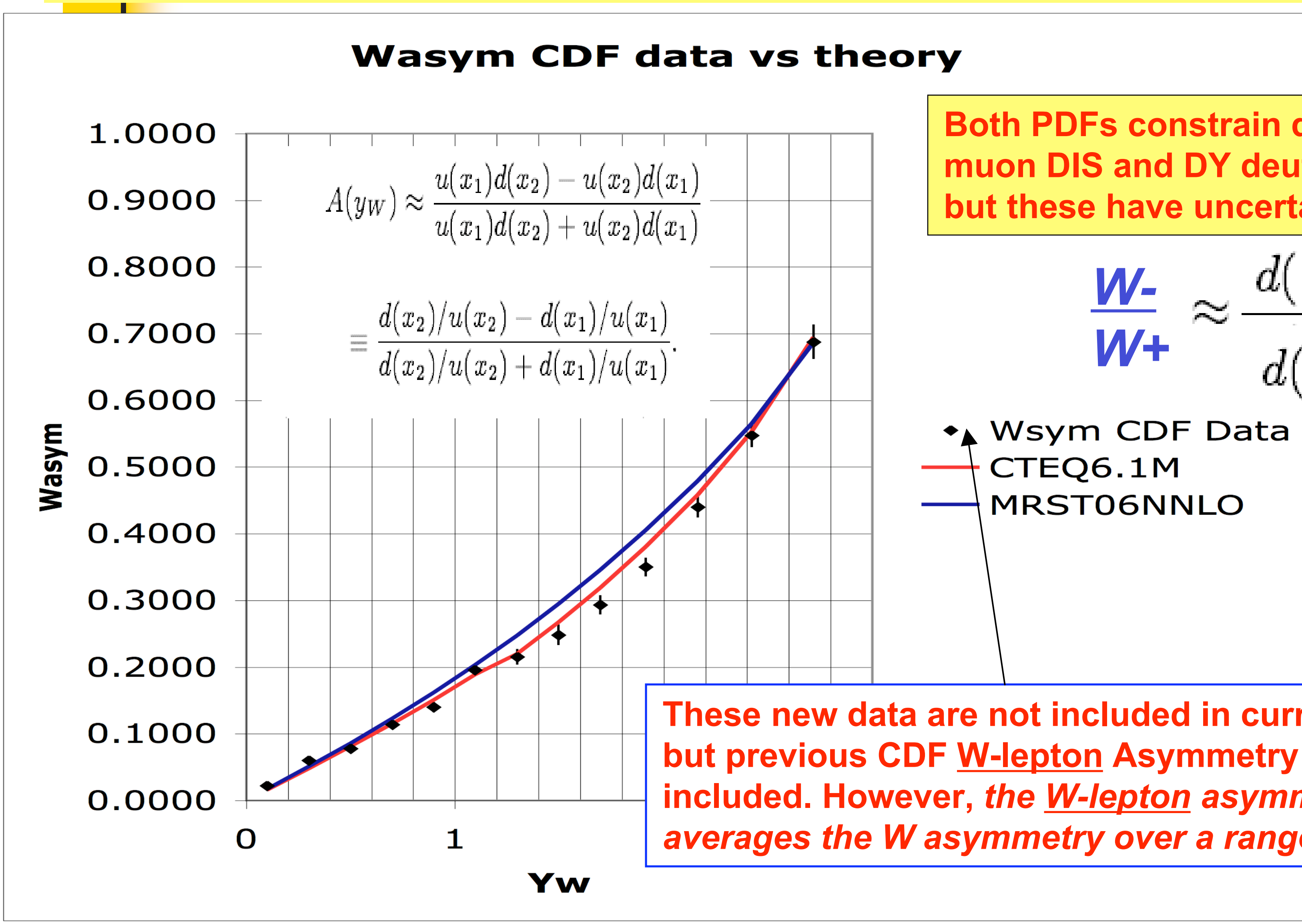
  - $A_{raw} \rightarrow A_{true}$: Corrections:

ME_T

Acceptance and smearing -

We show in Monte Carlo that the process converges

CDF 1 fm-1- W charge Asymmetry extracted from W decay lepton asymmetry (BY Han PhD Rochester-CDF 2008) updated



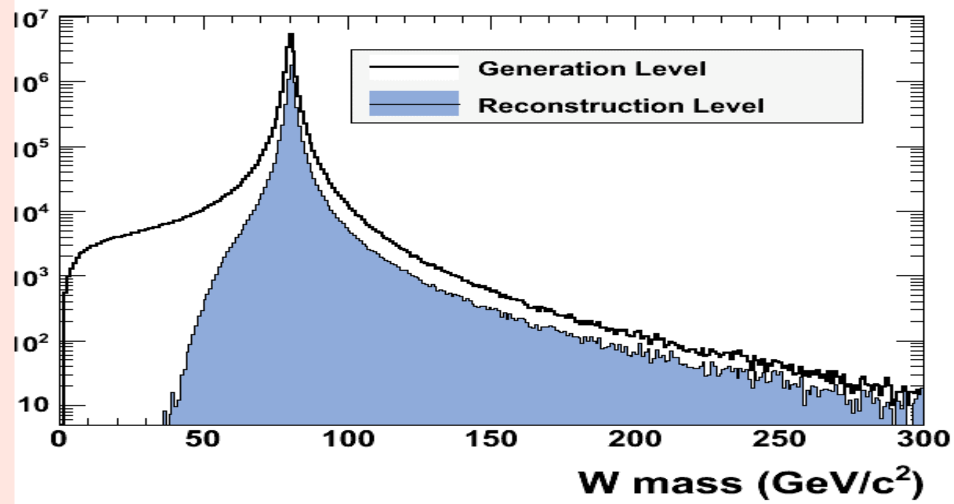
Both PDFs constrain d/u with muon DIS and DY deuterium data but these have uncertainties

$$\frac{W-}{W+} \approx \frac{d(x_1)/u(x_1)}{d(x_2)/u(x_2)}$$

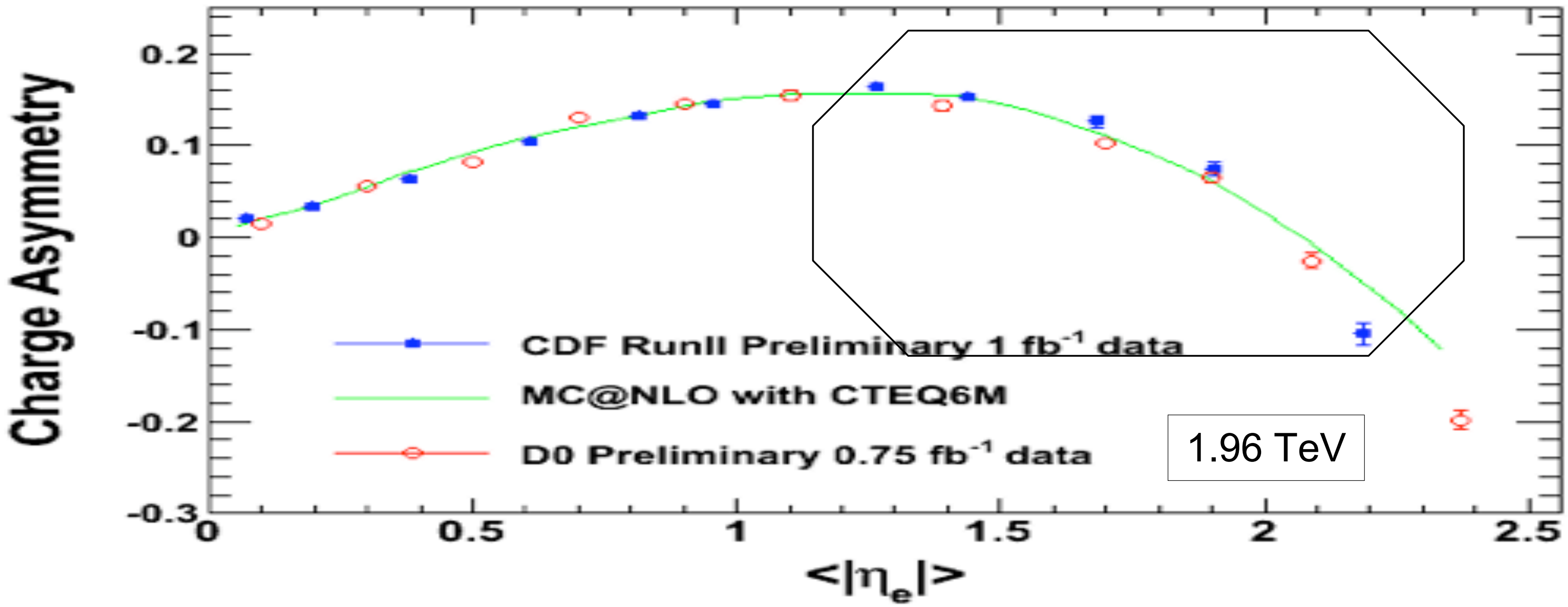
These new data are not included in current PDF fits, but previous CDF W-lepton Asymmetry data are included. However, *the W-lepton asymmetry averages the W asymmetry over a range of yw.*

Note, I have corrected the CDF data to W=80.4 GeV

Note, I have corrected the CDF data to W=80.4 GeV for <Yw> each bin. *So <u>this is my own analysis</u>*. The official CDF data shown below is given for a different <Mw> for each y bin (because of the Et and MET cuts and detector acceptance.) One alternatively can calculate the theory prediction for <yw> and <Mw> in each bin and leave the CDF data as below.



$\lvert y_W \rvert$	CDF data		CTEQ6.1M (CTEQ5L)			
	$<\lvert y_W \rvert>$	$A(y_W)\ \pm\ \sigma$	$<\lvert y_W \rvert>$	$<M_W>$	$A(y_W)$	$\frac{A_{data}}{A_{mc}}$
0.0 - 0.2	0.10	0.020 ±0.003	0.10 (0.10)	81.04 (81.04)	0.014 (0.016)	1.42 (1.22)
0.2 - 0.4	0.30	0.057 ±0.004	0.30 (0.30)	81.27 (81.27)	0.046 (0.050)	1.25 (1.15)
0.4 - 0.6	0.50	0.081 ±0.005	0.50 (0.50)	81.37 (81.37)	0.084 (0.085)	0.96 (0.96)
0.6 - 0.8	0.70	0.117 ±0.006	0.70 (0.70)	81.33 (81.33)	0.118 (0.120)	0.99 (0.97)
0.8 - 1.0	0.90	0.146 ±0.008	0.90 (0.90)	81.13 (81.14)	0.157 (0.158)	0.93 (0.92)
1.0 - 1.2	1.10	0.204 ±0.009	1.10 (1.10)	80.63 (80.63)	0.196 (0.196)	1.04 (1.04)
1.2 - 1.4	1.30	0.235 ±0.012	1.30 (1.30)	80.92 (80.92)	0.240 (0.238)	0.98 (0.99)
1.4 - 1.6	1.50	0.261 ±0.015	1.49 (1.50)	80.91 (80.92)	0.282 (0.283)	0.93 (0.92)
1.6 - 1.8	1.70	0.303 ±0.014	1.70 (1.70)	80.79 (80.79)	0.330 (0.335)	0.92 (0.90)
1.8 - 2.05	1.92	0.355 ±0.014	1.91 (1.92)	80.54 (80.55)	0.387 (0.389)	0.92 (0.91)
2.05 - 2.3	2.16	0.436 ±0.016	2.16 (2.16)	80.09 (80.10)	0.456 (0.456)	0.96 (0.96)
2.3 - 2.6	2.42	0.537 ±0.018	2.42 (2.42)	79.49 (79.49)	0.545 (0.536)	0.99 (1.00)
2.6 - 3.0	2.72	0.642 ±0.026	2.71 (2.71)	78.70 (78.65)	0.650 (0.623)	0.99 (1.03)

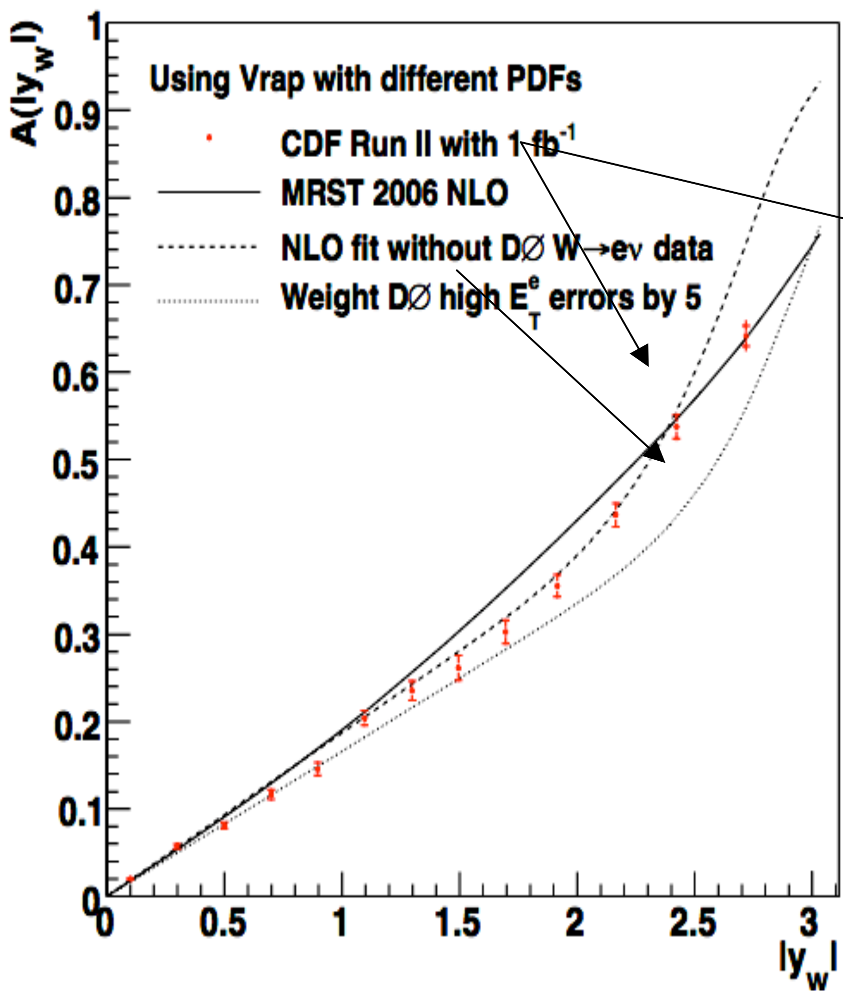


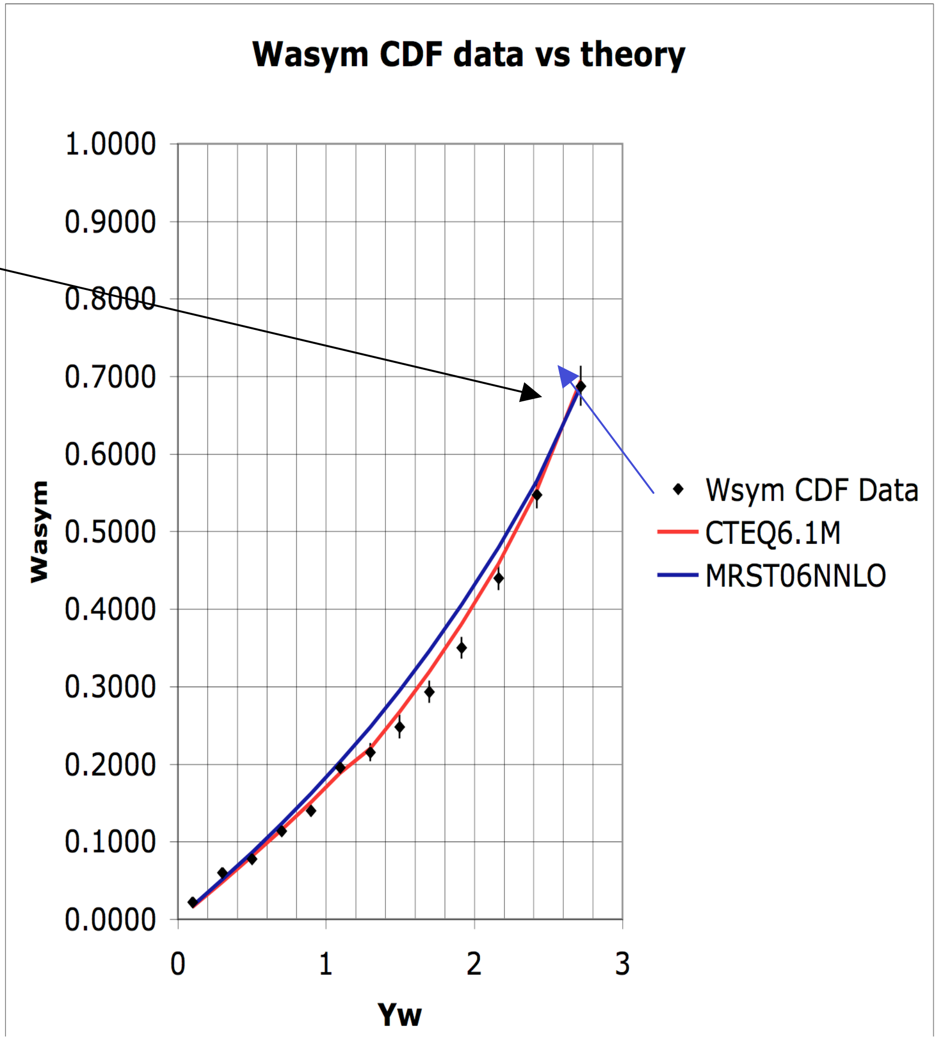
Dzero and CDF are in reasonable agreement in the charged lepton asymmetry, but a little higher for eta between 1.2 ad 1.9

Note that comparison of theory to charged lepton asymmetry is sensitive to modeling of the Pt distributions of the W's.

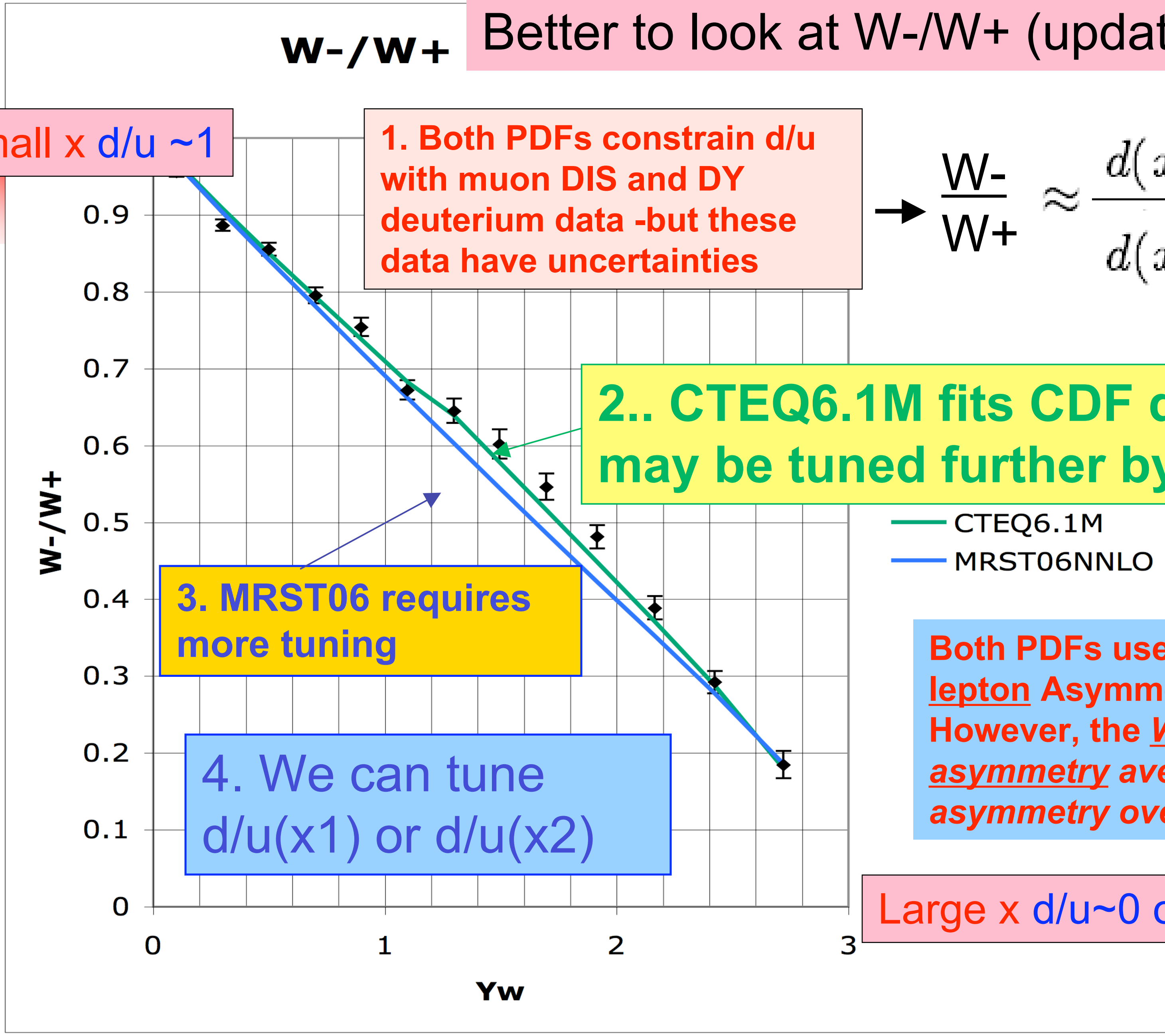
In contrast, the unfolding of the W asymmetry is less sensitive to the modeling of W Pt.

The recent Dzero "lepton" asymmetry implies an lower W Asymmetry and a larger difference from MRST2006nnlo than implied by the CDF data (plot from Thorne for one specific W Aymmetry for Dzero that will fit the Dzero Data). Note: weighting Dzero data by a factor of 5 is not a good way to check consistency. I will also compare to this "Dzero curve" "assuming" that the errors are the same as CDFs, even though it was obtained by "greatly reducing the Dzero errors).





Better to look at W-/W+ (updated)



Small x d/u ~1

1. Both PDFs constrain d/u with muon DIS and DY deuterium data -but these data have uncertainties

$$\rightarrow \frac{W-}{W+} \approx \frac{d(x_1)/u(x_1)}{d(x_2)/u(x_2)}.$$

2.. CTEQ6.1M fits CDF data, but may be tuned further by CDF data

3. MRST06 requires more tuning

4. We can tune d/u(x1) or d/u(x2)

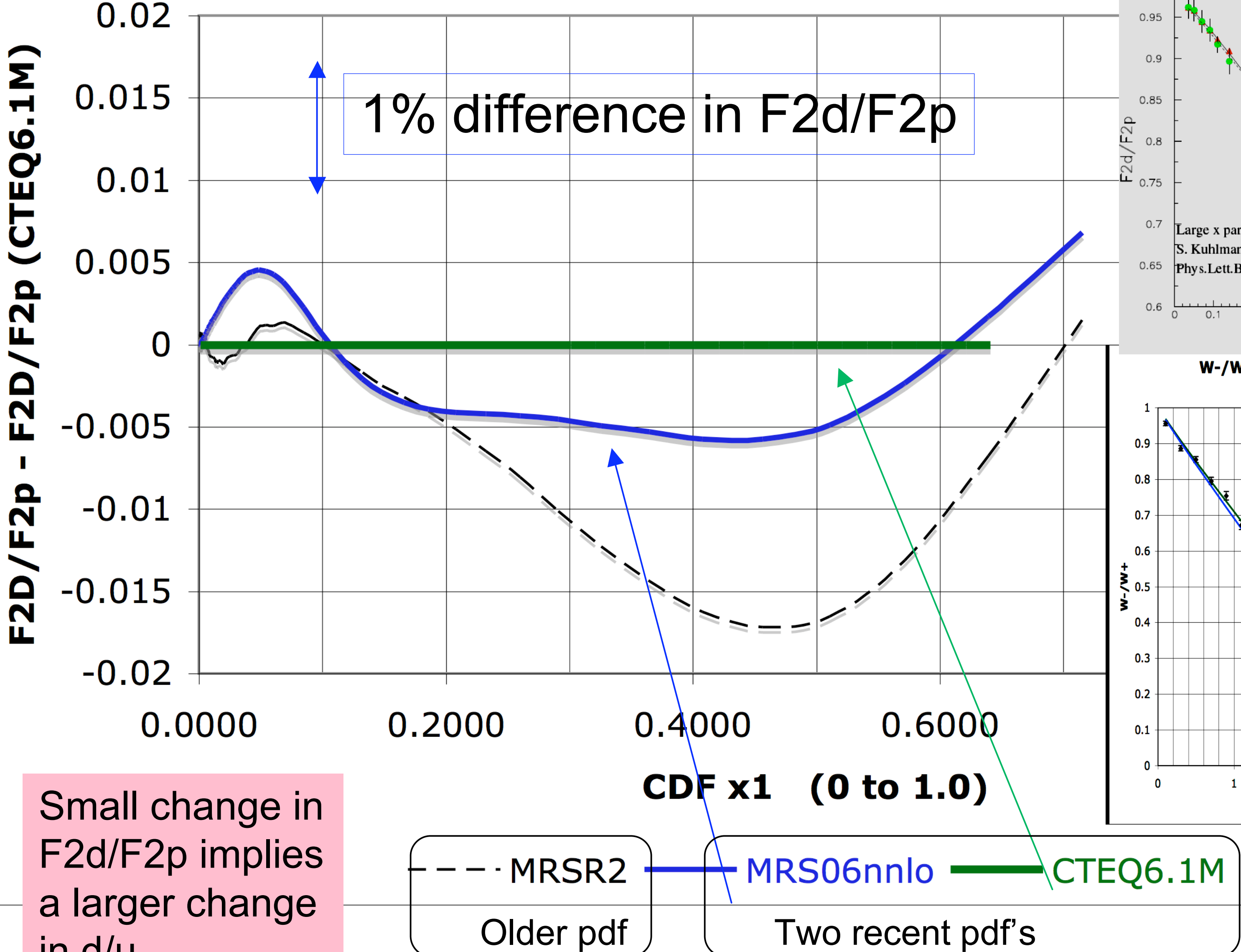
Both PDFs use revious CDF W-lepton Asymmetry data. However, the *W-lepton asymmetry averages the W asymmetry over a range of yw.*

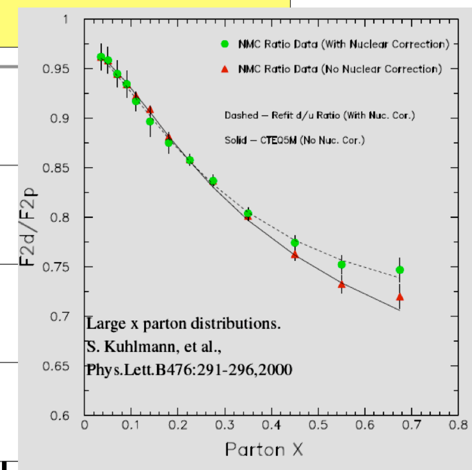
Large x d/u~0 or 0.2

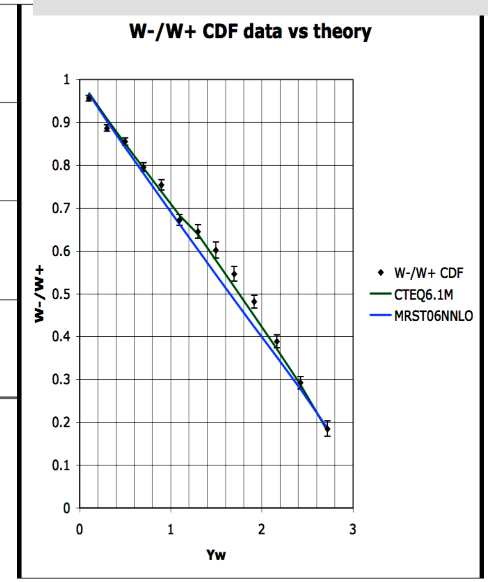
5. If we tune to Dzero “lepton” asymmetry data, we need much more tuning

LO F2D/F2p (PDF) - F2D/F2p (CTEQ6.1M) Q2=6400

If we could measure F2D/F2p at Q2=6400 how different are the MRST06nnlo predictions from CTEQ6.1M ???

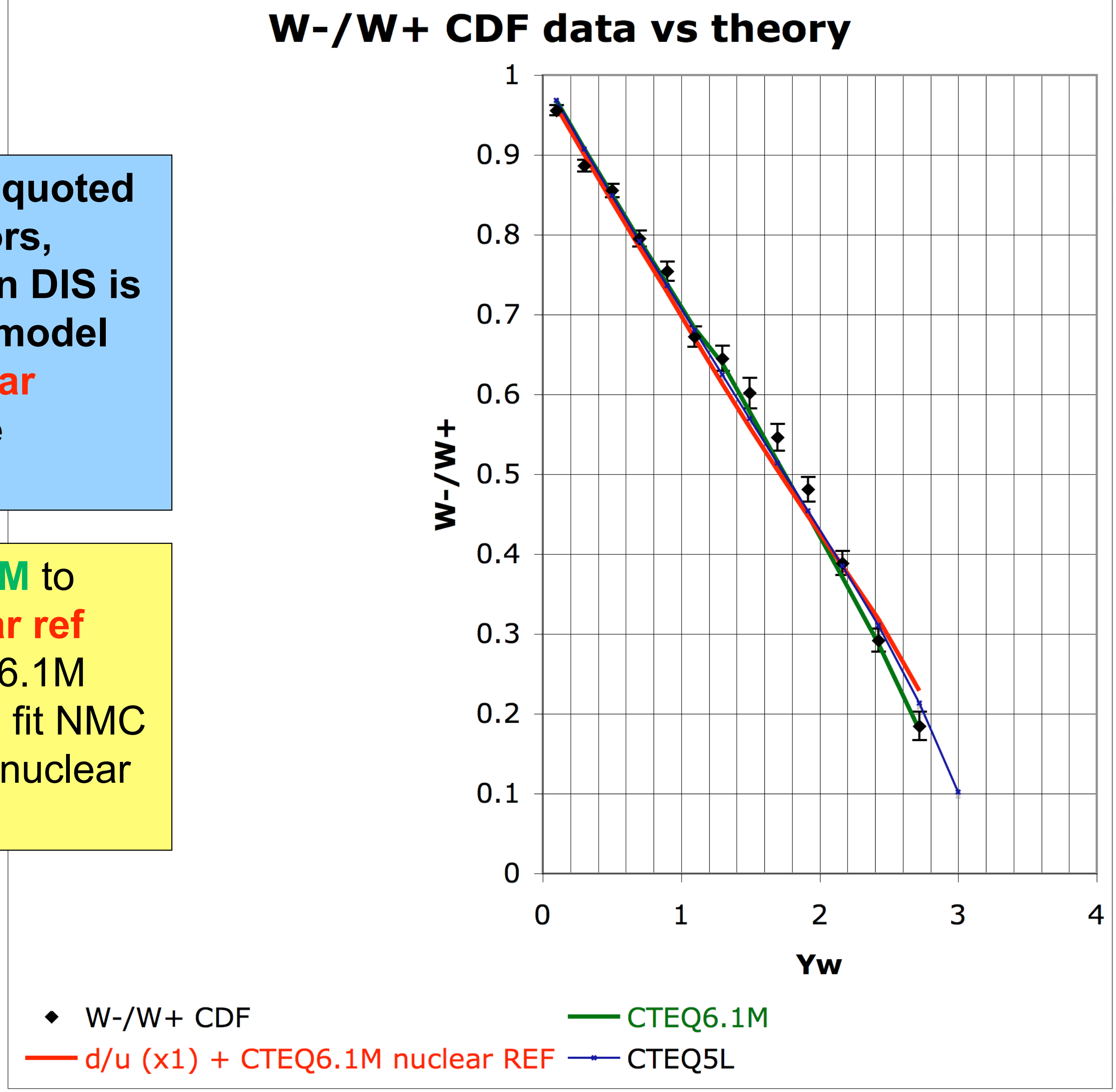






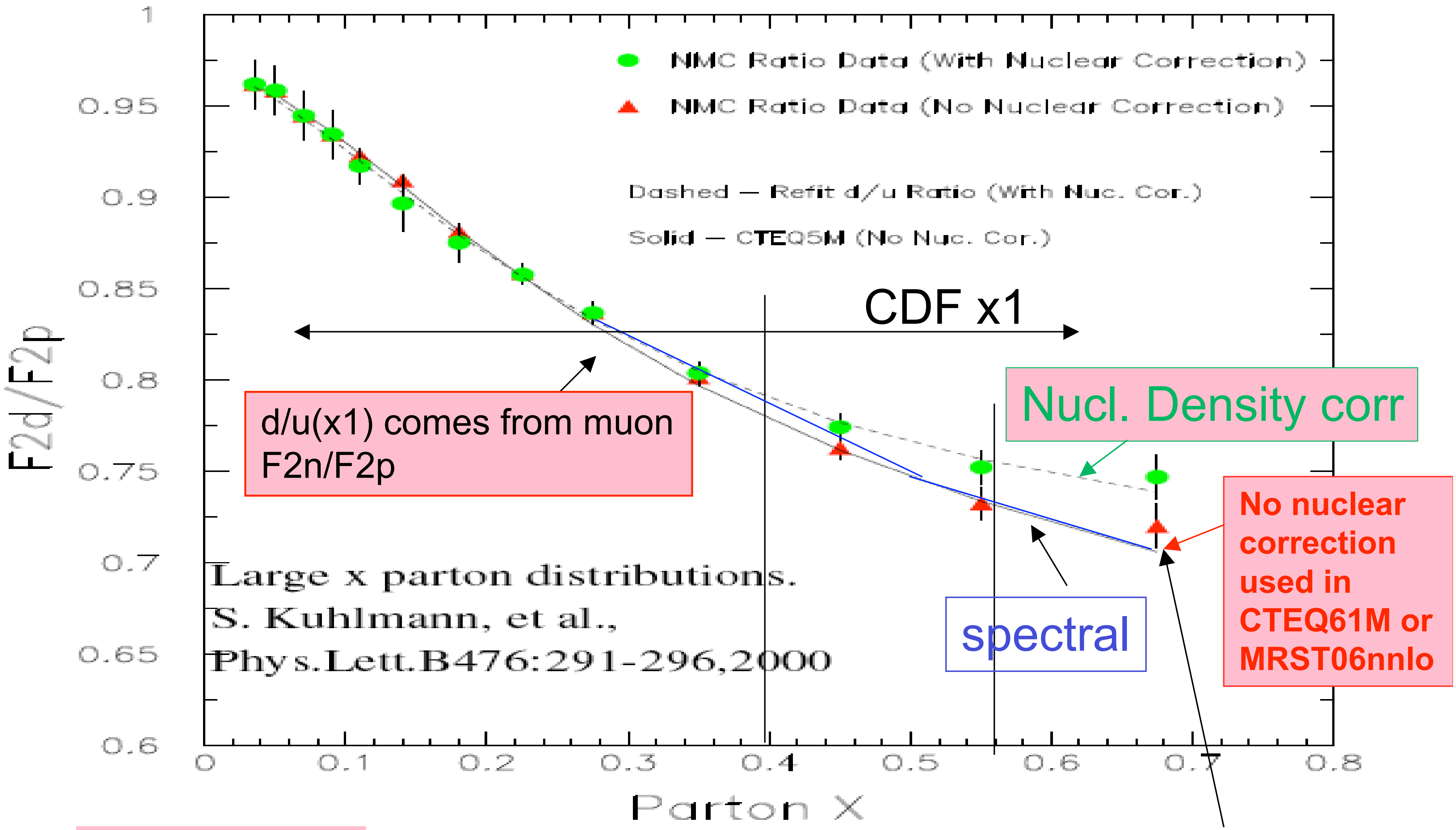
Small change in F2d/F2p implies a larger change in d/u.

Nuclear Corrections



In addition to the quoted experimental errors, d/u(x1) from muon DIS is also sensitive to model dependent nuclear corrections in the deuteron

Compare **CTEQ6.1M** to **CTEQ6.1 M-nuclear ref** (This PDF is CTEQ6.1M with d/u changed to fit NMC muon D2 data with nuclear density corrections)

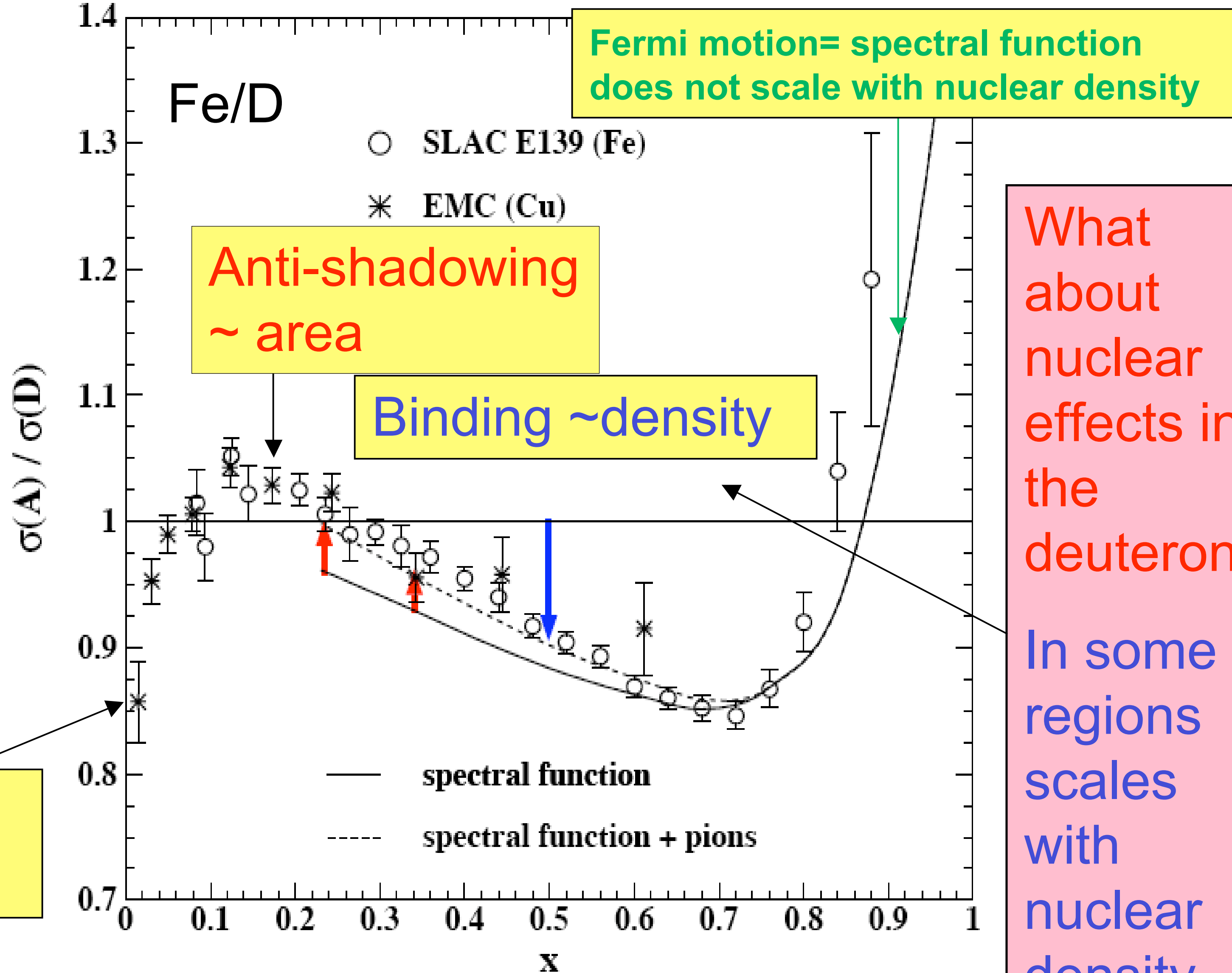


Small change in F2d/F2p implies a larger change in d/u.

F_2^d/F_2^p is directly related to d/u.
$2F_2^d/F_2^p - 1 \simeq (1+4d/u)/(4+d/u)$ at high

F2n/F2p = 2F2d/F2p - 1

Ratio of electron scattering for iron and deuterium used to correct for nuclear effects in iron for neutrino experiments



Shadowing ~ area

What about nuclear effects in the deuteron?

In some regions it scales with nuclear density.

Figure 1. Existing data for the EMC effect for nuclei near Fe [1, 2], along with two calculations by Benhar, Pandharipande and Sick [3]. The solid line is their binding-only calculation, while the dotted line includes their calculation of the contribution from nuclear pions.

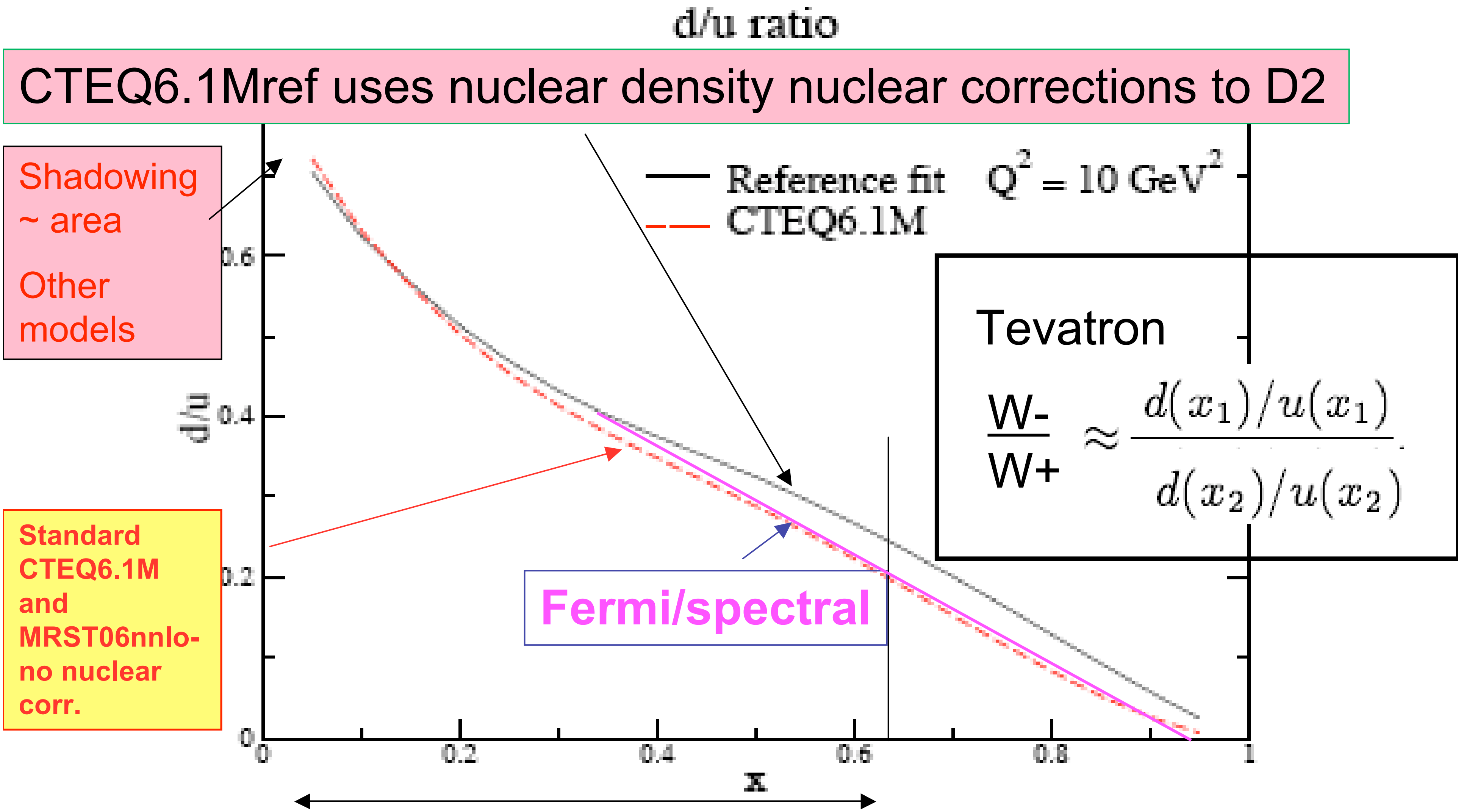
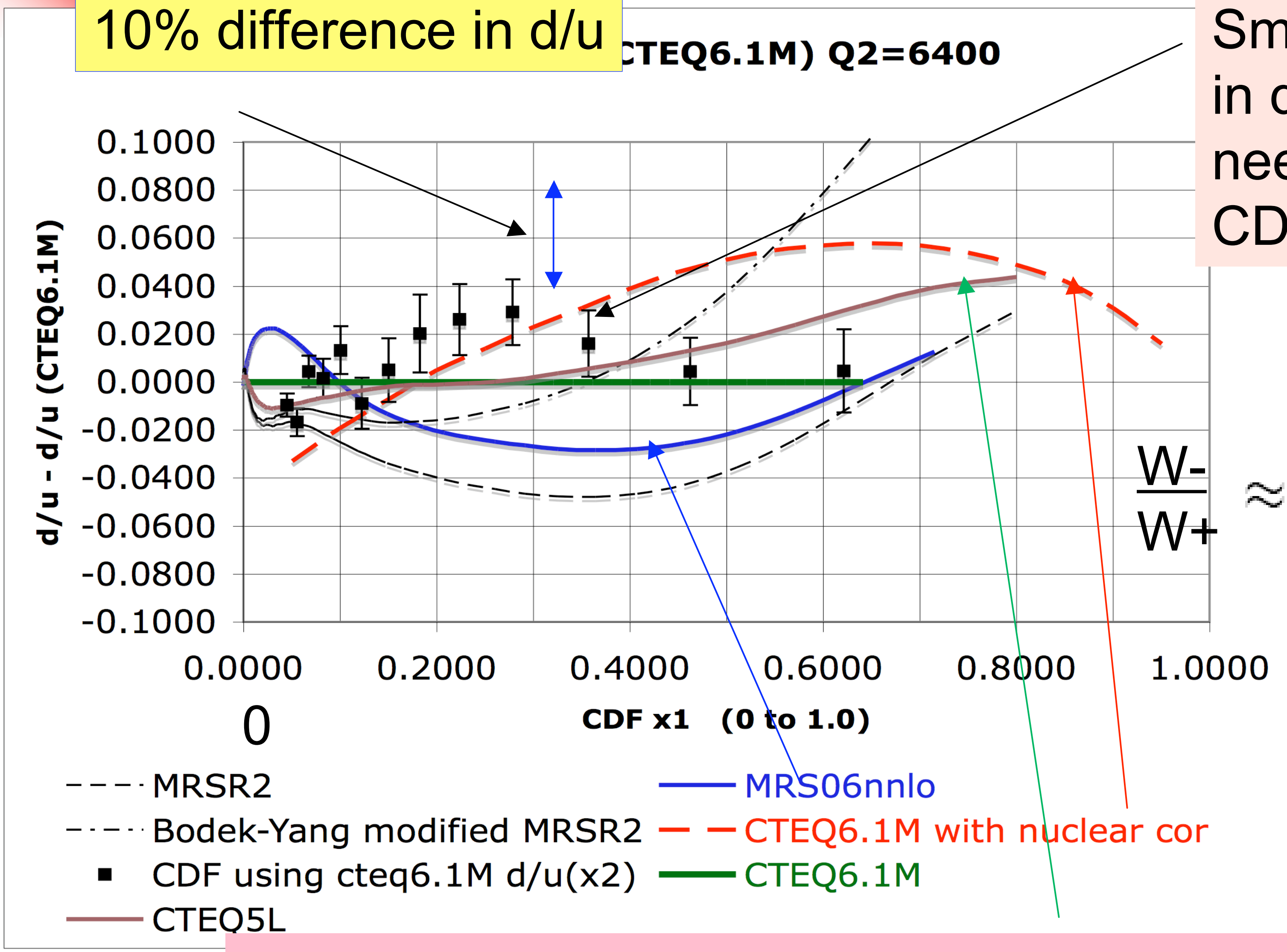


FIG. 3: Comparison of the d/u ratios from the reference fit and the CTEQ6.1M PDFs at $Q^2 =$ 10 GeV^2.

X1 at Tevatron

How different is d/u in **CTEQ6.1M nuclear** from **CTEQ6.1M, from MRST06 - And what change in d/u(x1) is needed to fit CDF data.**

10% difference in d/u

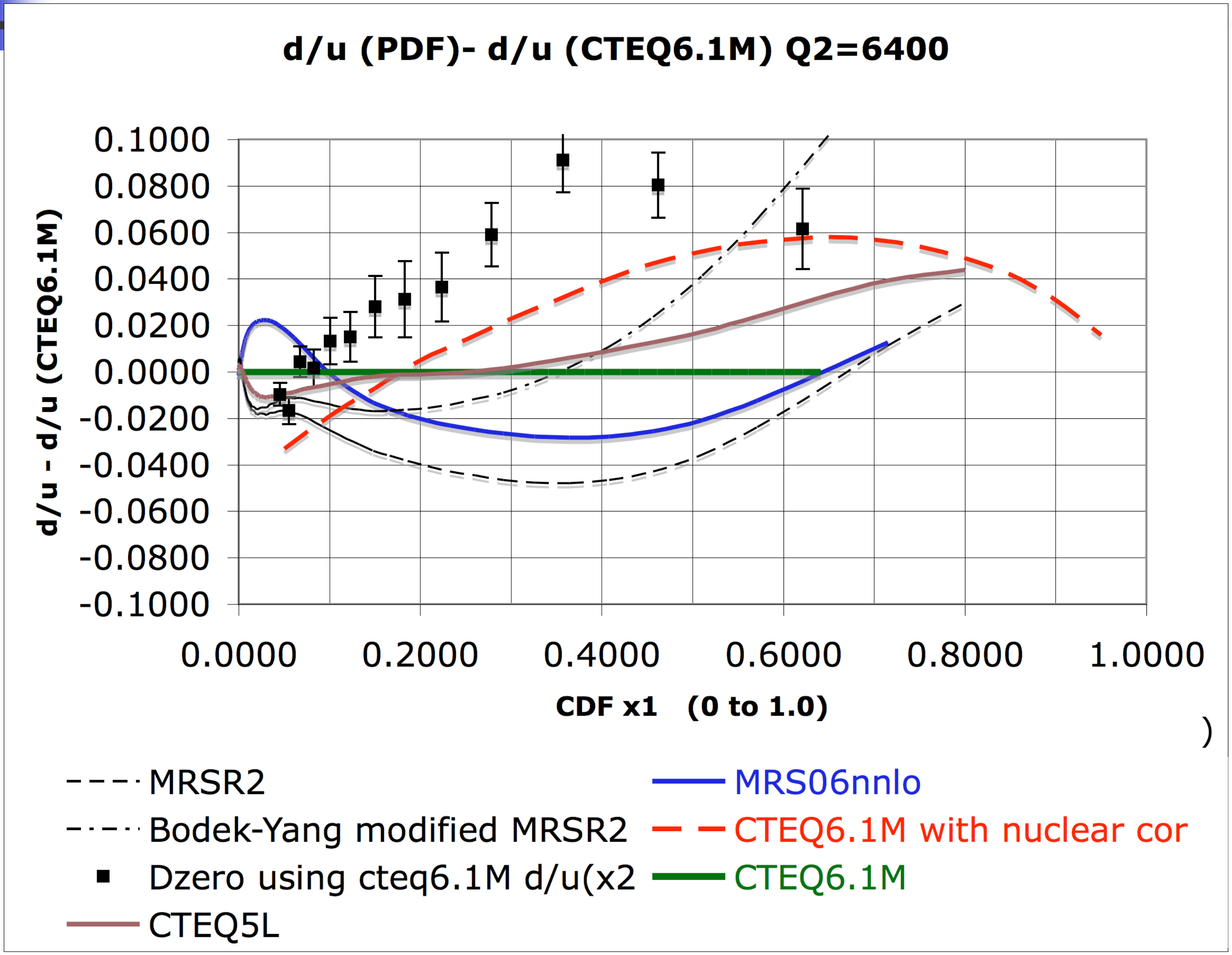


Small change in d/u(x1) needed to fit CDF data

$$\frac{W-}{W+} \approx \frac{d(x_1)/u(x_1)}{d(x_2)/u(x_2)}.$$

Small change in F2d/F2p implies a larger change in d/u.

What if we use Thorne's "D0 weighted by 5, fitted W asymmetry PDFs? There is a larger difference from standard PDFs. - this is sensitive to W Pt modeling



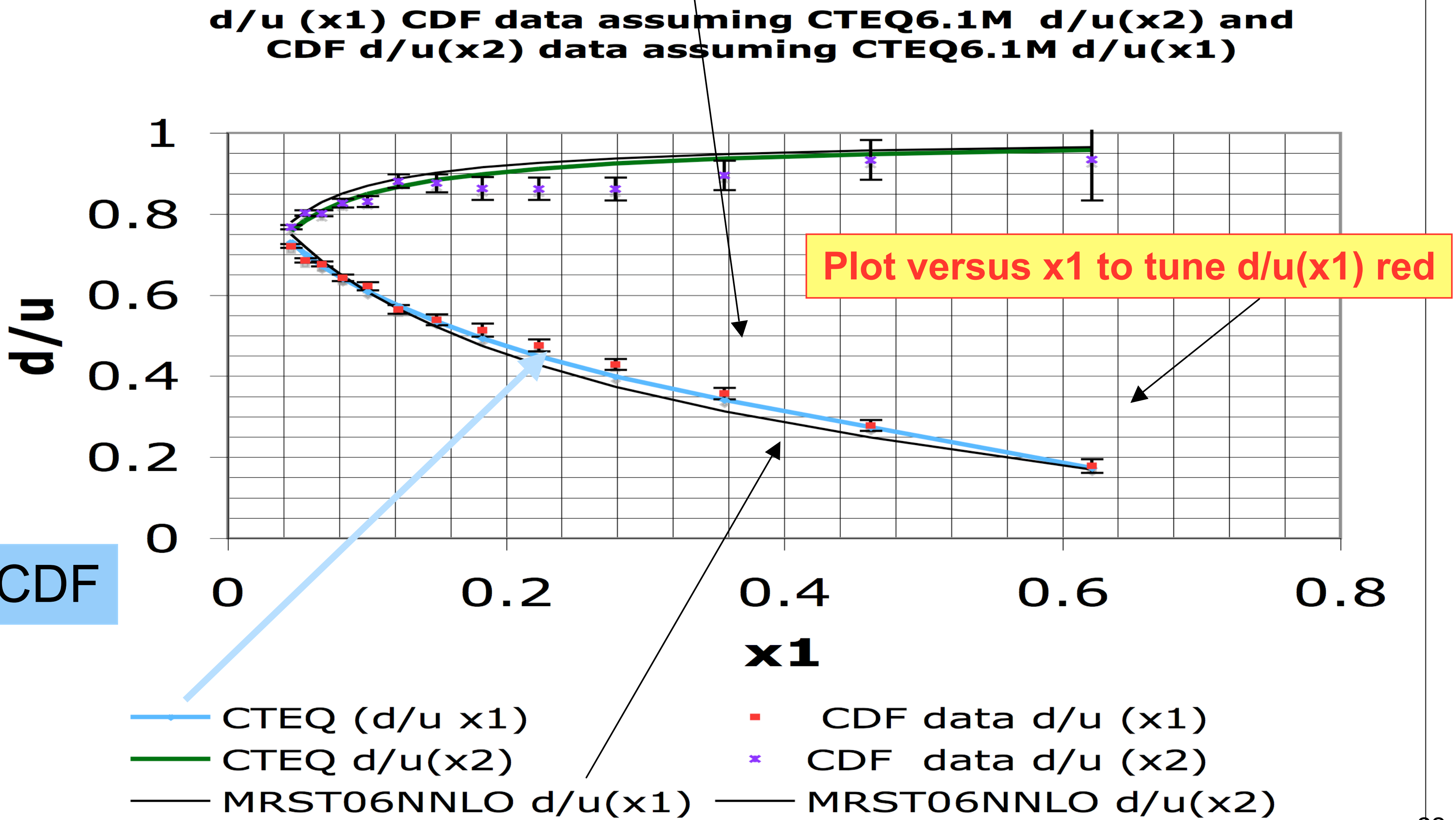
Tuning PDFs to fit W-/W+ data at the Tevatron

- The W-asym data are very precise **-more sensitive to d/u than F2d/F2p**
- We can change the PDFs to fit the CDF data, **but have a choice between changing d/u(x1) within the uncertainties of the DIS data, or changing d/u(x2)** (keeping all other PDFs the same). Dzero data require a larger change.
- There are no precise measurements of d/u(x2) at small x. DIS and Drell-Yan data on Deuterium vs are used (but what about shadowing corrections?)
- PDFs assume a functional form constrained by (Regge x->0, d/u->1), (quark counting d/u->0 as x->1), number sum rules (~1 $d_{valence}$ and ~ $2_{uvalence}$ with QCD) corrections to determine $d_{valence}$.
- ***LHC W-/W+ directly measure d/u at small x***
- ***Combined LHC and CDF data constrain d/u & are not sensitive to nuclear&shadowing corr.***

CTEQ6.1M fits CDF data, but may be tuned further by CDF data eg **d/u(x1)**

$$\frac{W-}{W+} \approx \frac{d(x_1)/u(x_1)}{d(x_2)/u(x_2)}.$$

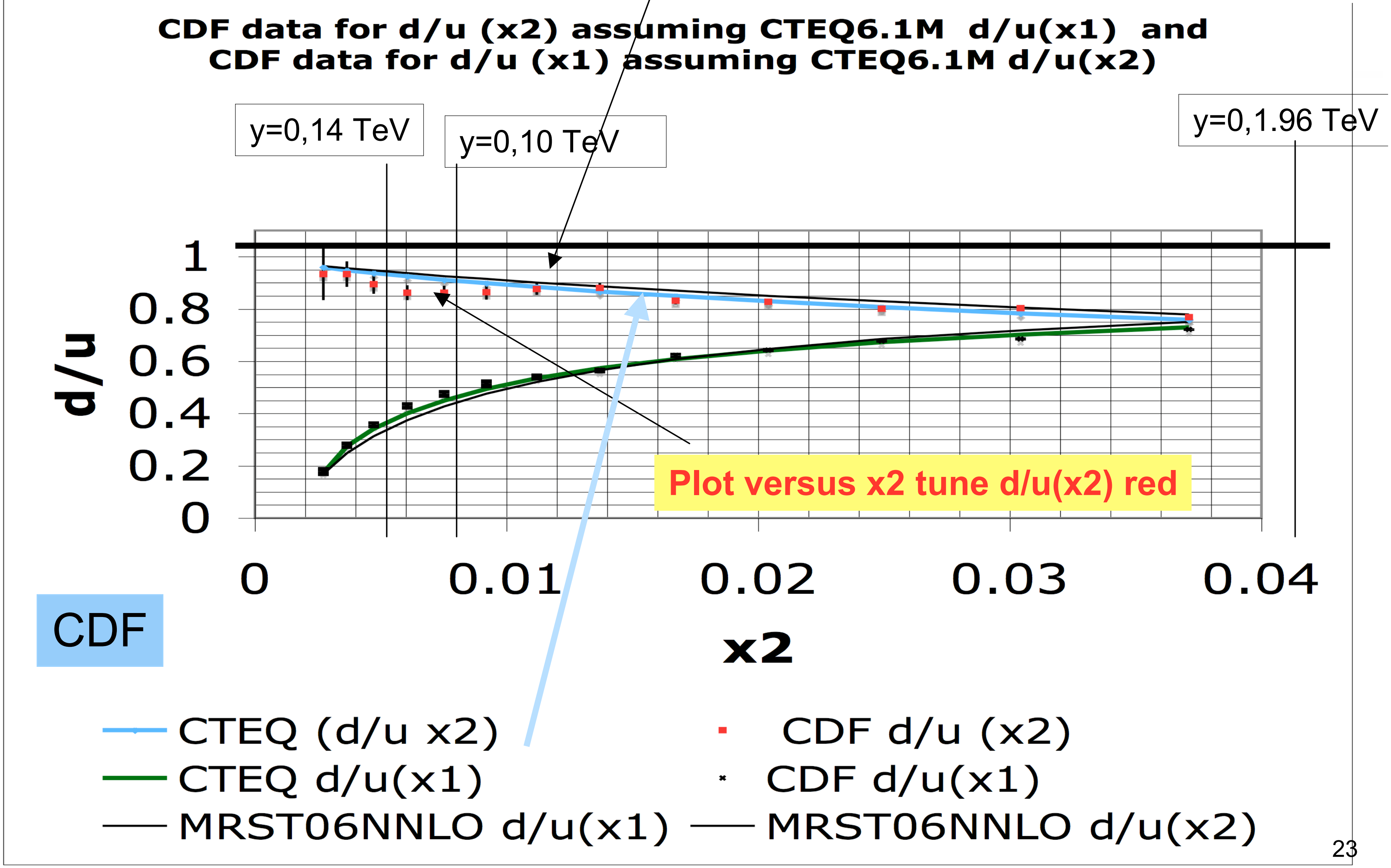
updated



CDF

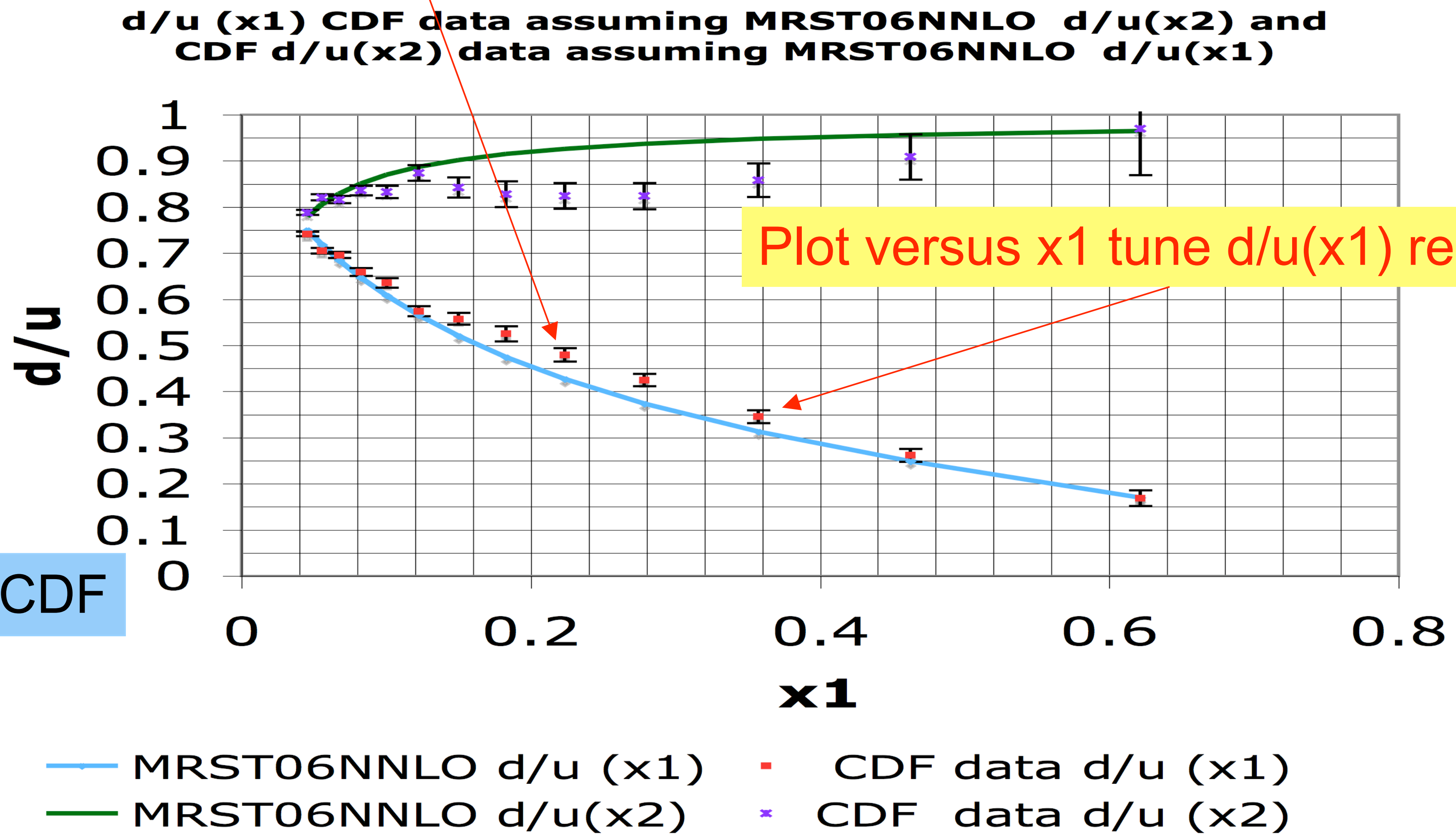
CTEQ6.1M fits CDF data, but may be tuned further by tuning **d/u(x2) - updated**

$$\frac{W-}{W+} \approx \frac{d(x_1)/u(x_1)}{d(x_2)/u(x_2)}$$



Fixing **MRST2006nnlo** by changing **d/u(x1**) updated

$$\frac{W-}{W+} \approx \frac{d(x_1)/u(x_1)}{d(x_2)/u(x_2)}$$

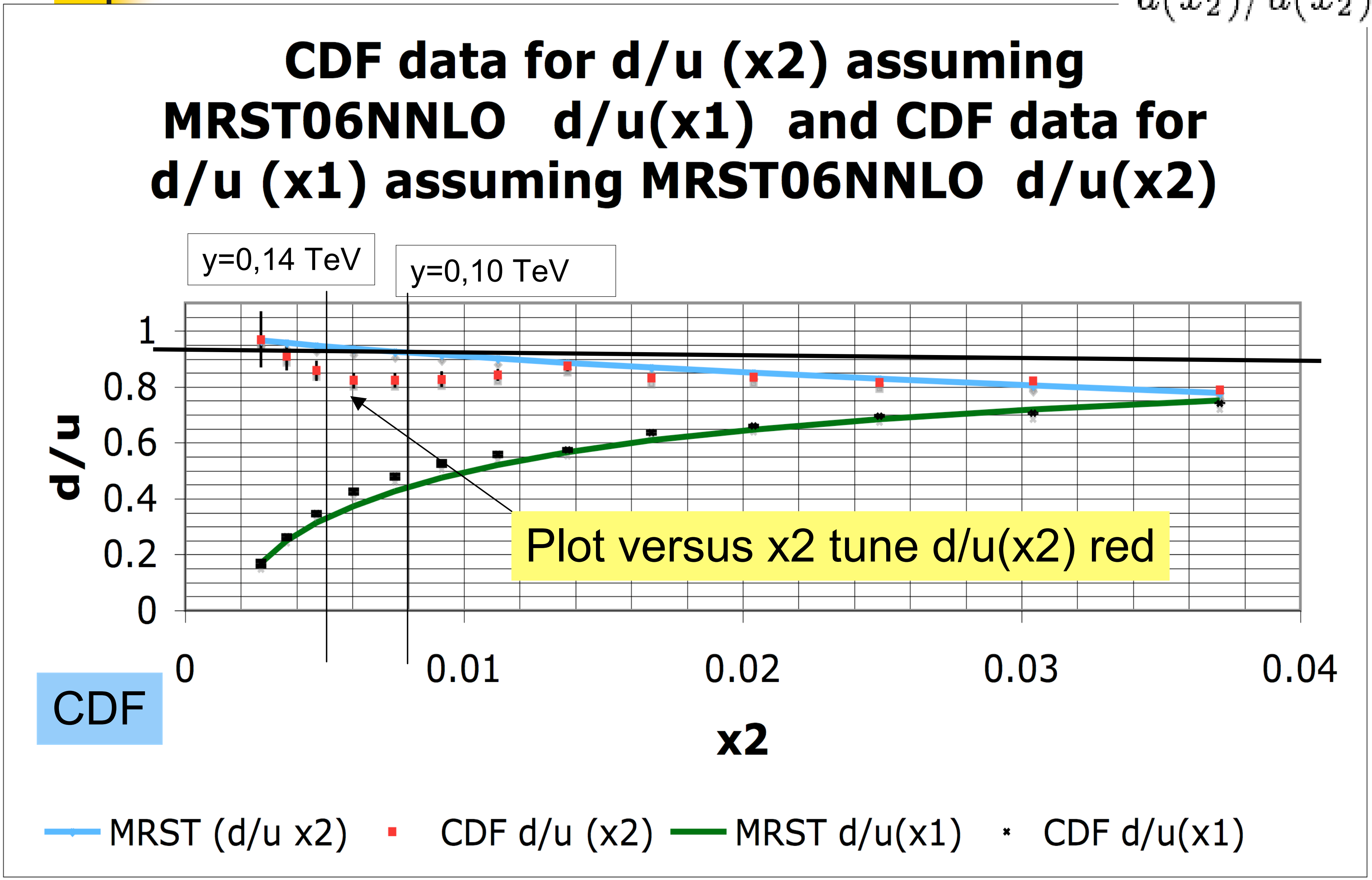


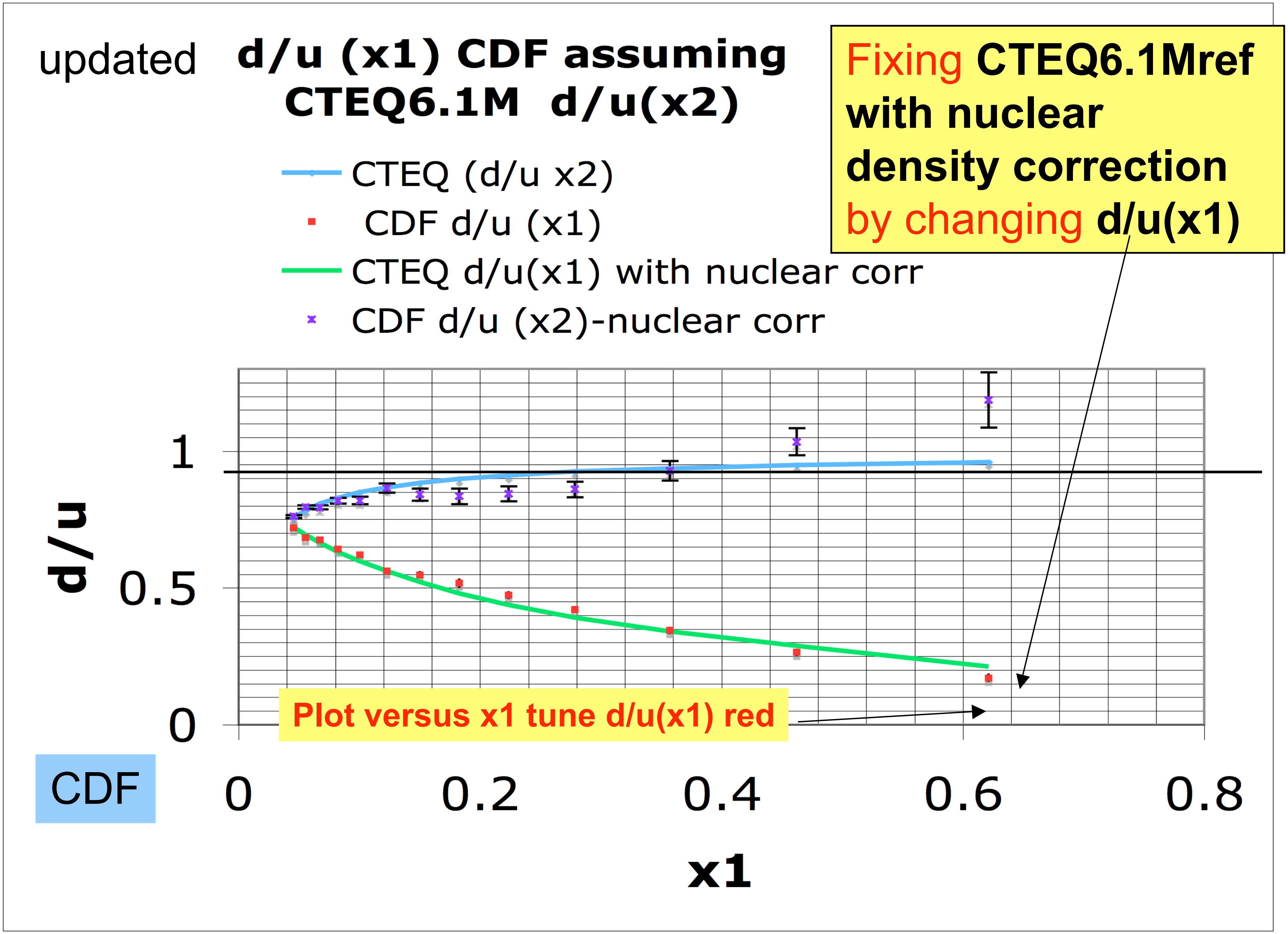
Plot versus x1 tune d/u(x1) red

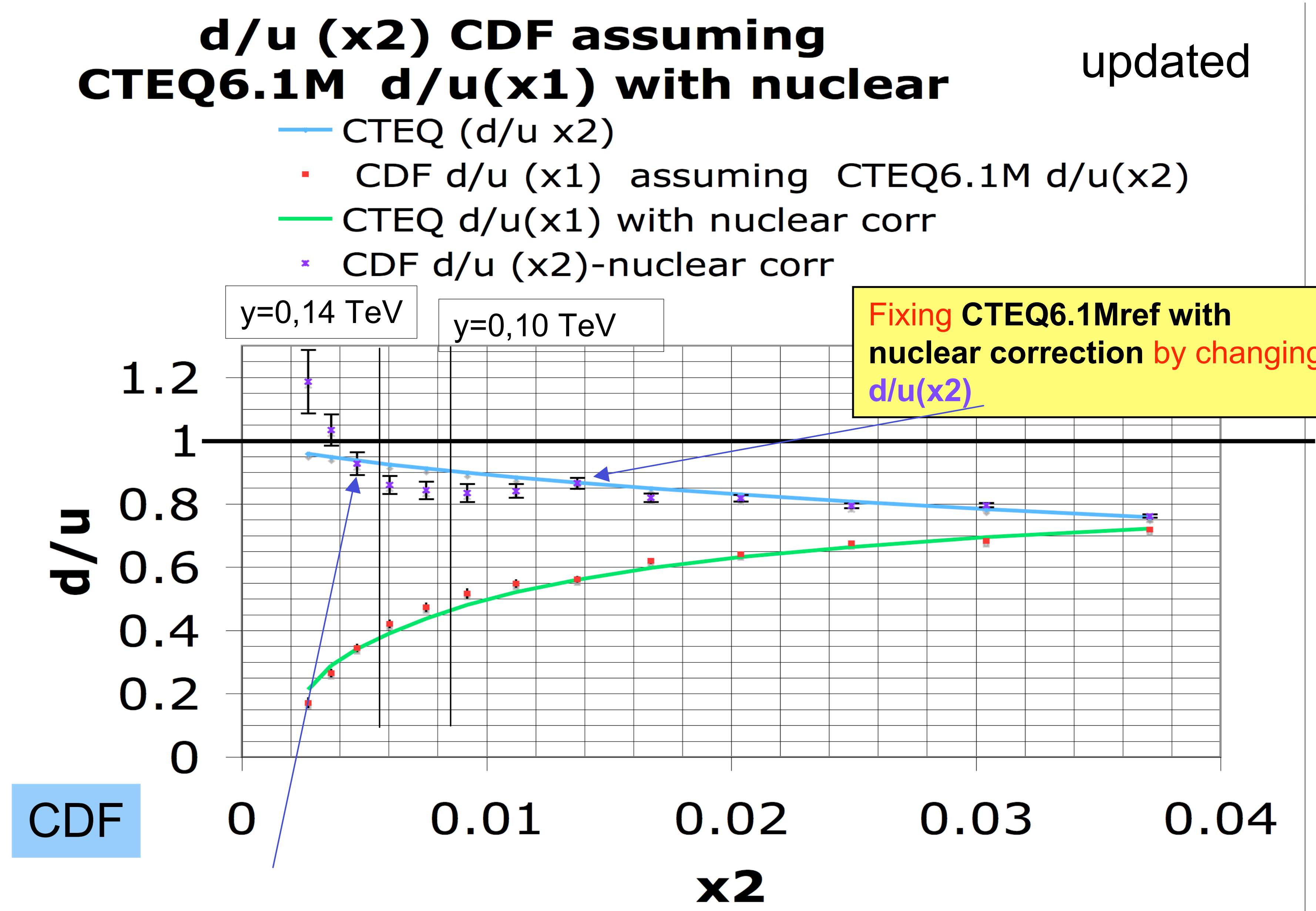
CDF

Fixing **MRST2006nnlo** by either changing **d/u(x2) - updated**

$$\frac{W-}{W+} \approx \frac{d(x_1)/u(x_1)}{d(x_2)/u(x_2)}$$




updated
d/u (x1) CDF assuming
CTEQ6.1M d/u(x2)
CTEQ (d/u x2)
CDF d/u (x1)
CTEQ d/u(x1) with nuclear corr
CDF d/u (x2)-nuclear corr
Fixing CTEQ6.1Mref
with nuclear
density correction
by changing d/u(x1)
Plot versus x1 tune d/u(x1) red
d/u
1
0.5
0
0
0.2
0.4
0.6
0.8
x1
CDF



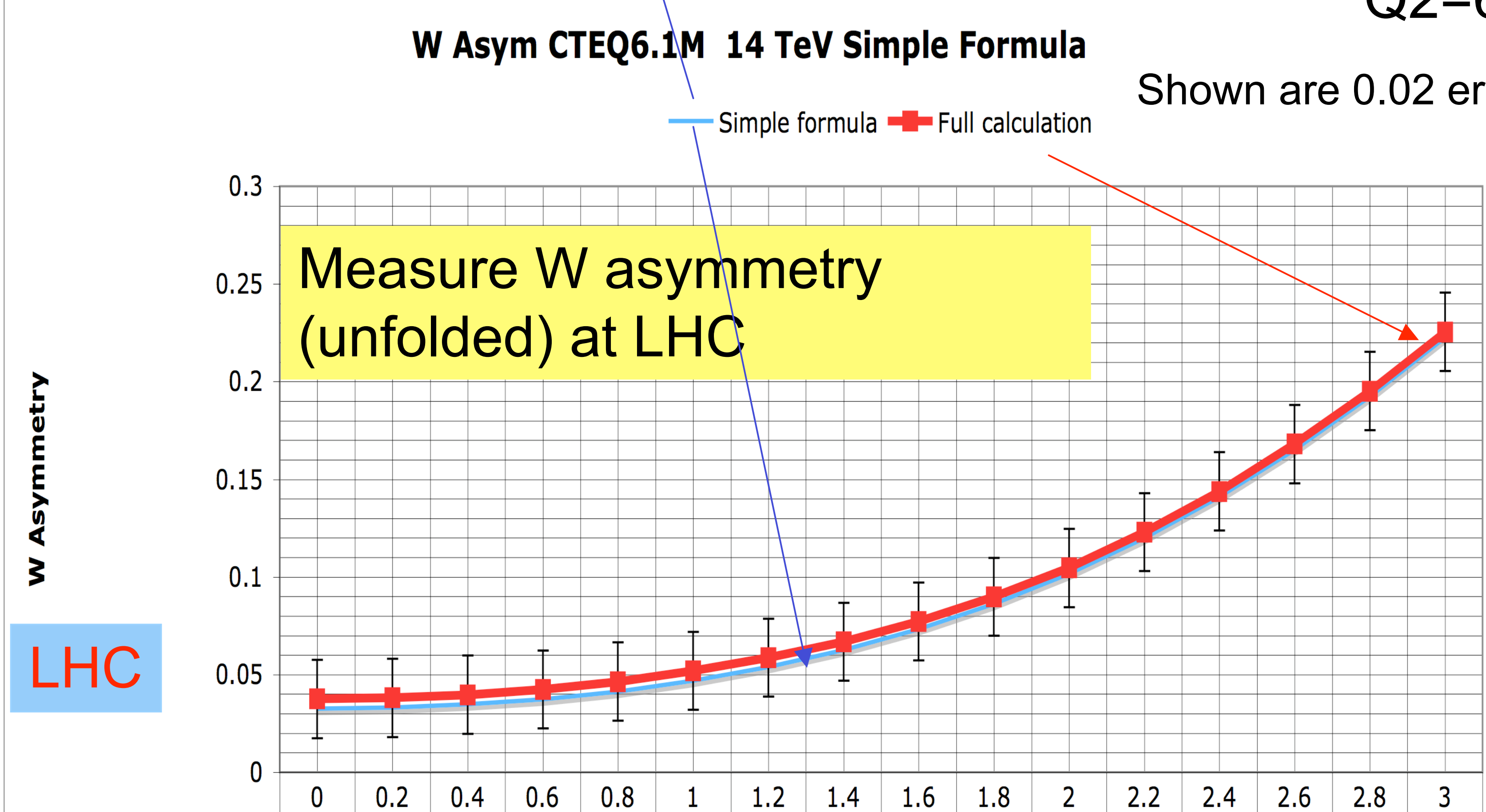
Plot versus x2 tune d/u(x2) purple

$$W^- = 0.949\,[\,\mathbf{d(x1)}\,\underline{u}(x2) + \underline{u}(x1)\,\mathbf{d(x2)} + s(x1)\,\underline{c}(x2) + \underline{c}\,(x1)\,s(x2)]$$
$$+\,0.051\,[\,d(x1)\,\underline{c}(x2) + \underline{u}\,(x1)\,s(x2) + s(x1)\,\mathbf{u}(x2) + \underline{c}\,(x1)\,d(x2)]$$
$$W^+ = 0.949\,[\,\mathbf{u(x1)}\,\underline{d}(x2) + \underline{d}\,(x1)\,\mathbf{u(x2)} + c(x1)\,\underline{s}(x2) + \underline{s}(x1)c(x2)]$$
$$+0.051\,[\,u(x1)\,\underline{s}(x2) + \underline{d}(x1)\,c(x2) + +c(x1)\,\underline{d}(x2) + \underline{s}(x1)u(x2)]$$

Q2=6400

Shown are 0.02 errors

LHC



	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3
Simple formula	0.033	0.033	0.035	0.037	0.041	0.047	0.054	0.062	0.073	0.086	0.102	0.12	0.141	0.165	0.192	0.222
Full calculation	0.038	0.038	0.04	0.042	0.046	0.052	0.059	0.067	0.077	0.09	0.105	0.123	0.144	0.168	0.195	0.225

Rapidty y

Y

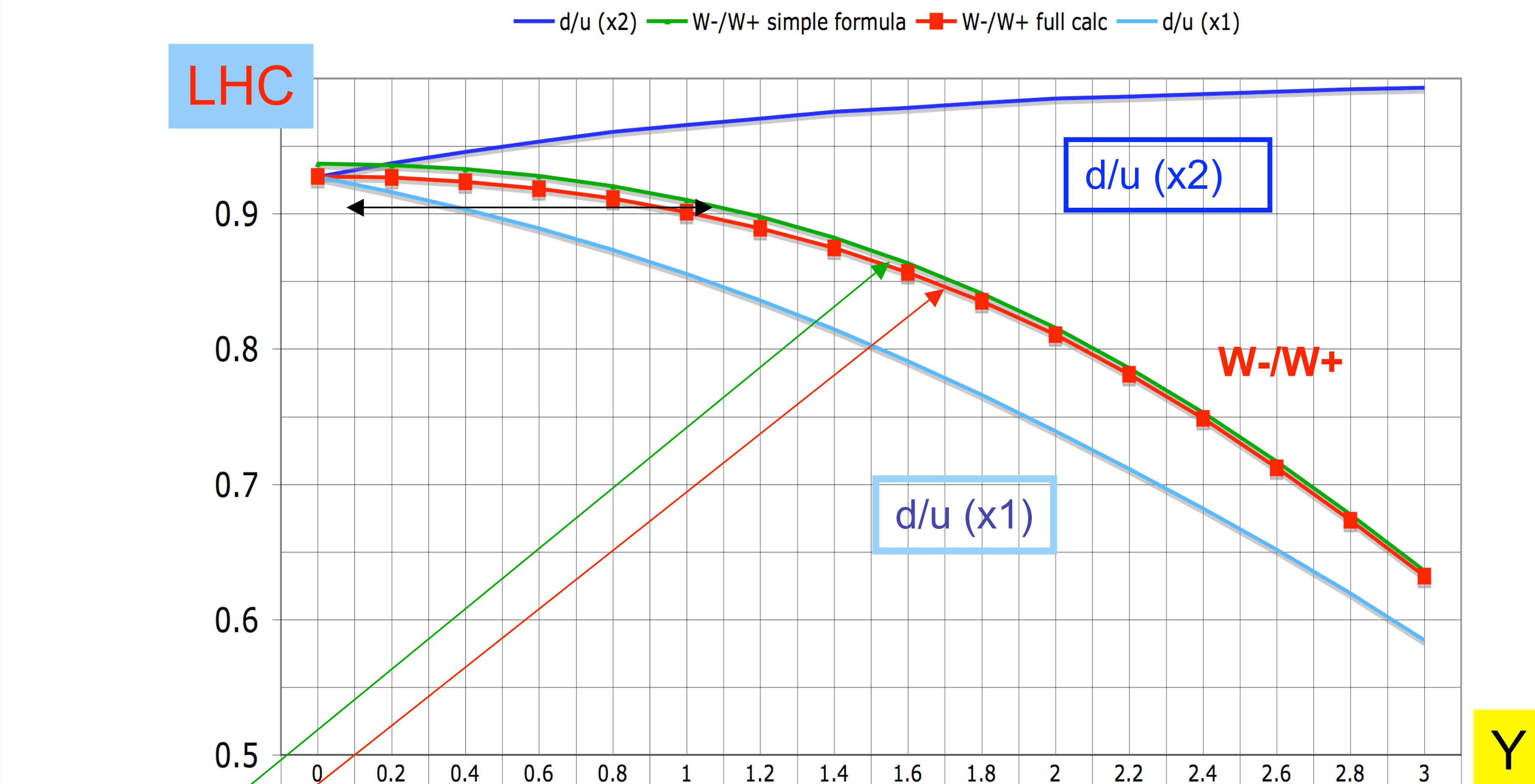
Compare d/u and 2s/(all sea) for several PDFs

For y=0 at 14 TeV (W production)

y=0	0.005743 x			only	Q2
d/u	2s/(all sea)			d/u Asym	
0.927288	0.845418	CTEQ6.1M		0.0377277	6400
0.940283	0.970942	CTEQ6.6M		0.0307776	6400
0.939349	0.858893	MRST2006NNLO		0.031274	6400
0.934616	0.857605	MRST2004NLO		0.033797	6400
0.933419	0.799886	ZEUS2005-ZJ		0.0344372	6400
0.936695	0.839626	MRST2004F4LO		0.0326873	6400
0.924448	0.683733	GRV98LO	no-c or b	0.0392593	6400
0.881951	0.778952	GRV94LO	no-c or b	0.062727	6400
0.898151	0.690727	ALEKHIN02NNLO		0.0536568	6400

W-/W+ : CTEQ6.1M simple formula vs full calculation.

cteq6.1M : d/u (y=0, x=0.0056) ~ 0.93 (other pdfs 0.92-0.94)



	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3
d/u (x2)	0.9273	0.9372	0.9459	0.9534	0.9605	0.9656	0.9703	0.9753	0.9784	0.9819	0.985	0.9866	0.9886	0.9904	0.992	0.993
W-/W+ simple formula	0.937	0.936	0.933	0.9278	0.9205	0.9103	0.8977	0.8824	0.8636	0.8411	0.8156	0.7859	0.7532	0.7168	0.6777	0.6361
W-/W+ full calc	0.9277	0.9267	0.9237	0.9186	0.9113	0.9013	0.8893	0.8748	0.8566	0.8352	0.8107	0.7812	0.7486	0.7123	0.6735	0.6321
d/u (x1)	0.9273	0.916	0.9033	0.8891	0.8731	0.8554	0.8359	0.8145	0.7911	0.7661	0.7394	0.7114	0.6822	0.6515	0.6193	0.5848

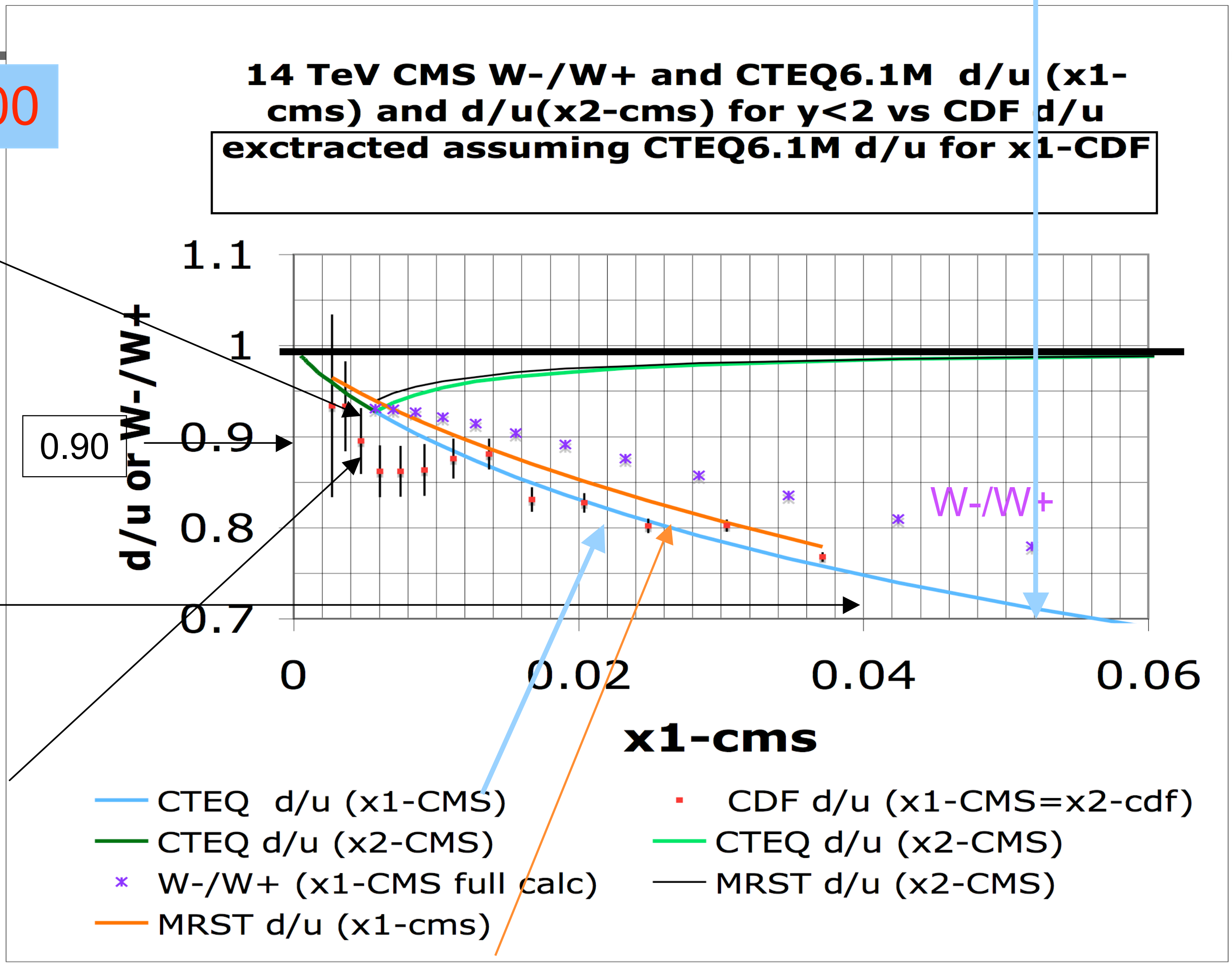
Data with errors are d/u(x1-cms) at LHC extracted from CDF data assuming d/u(x1-cdf)=CTEQ6.1M

LHC 6400

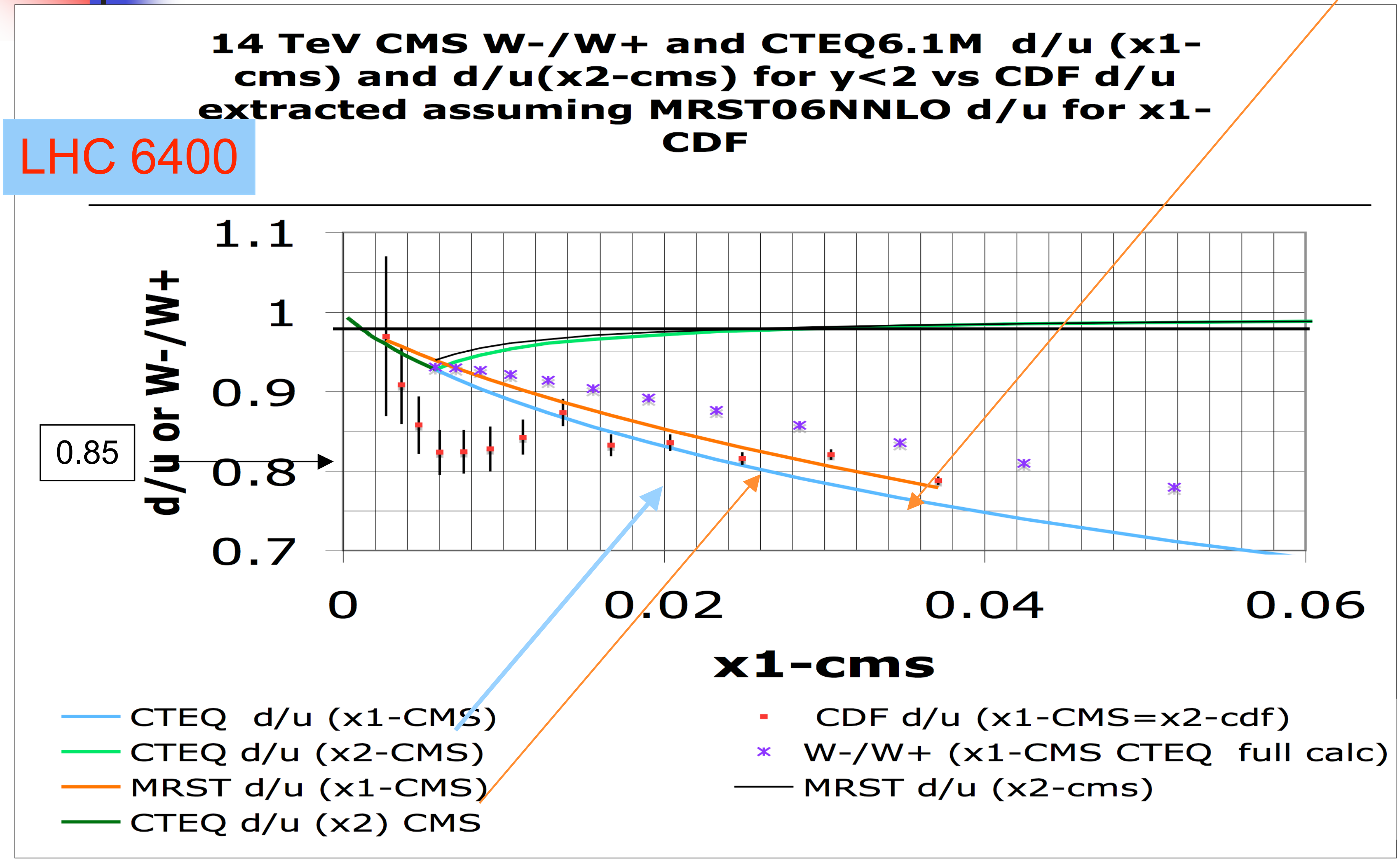
	CM E	14 TeV
y	x1	x2
0	0.0057	0.00574
0.2	0.007	0.0047
0.4	0.0086	0.00385
0.6	0.0105	0.00315
0.8	0.0128	0.00258
1	0.0156	0.00211
1.2	0.0191	0.00173
1.4	0.0233	0.00142
1.6	0.0284	0.00116
1.8	0.0347	0.00095
2	0.0424	0.00078
2.2	0.0518	0.00064
2.4	0.0633	0.00052
2.6	0.0773	0.00043
2.8	0.0944	0.00035
3	0.1153	0.00029
y	X1	x2

W/W+=0.9+-0.06
Asym=0.05+-0.03

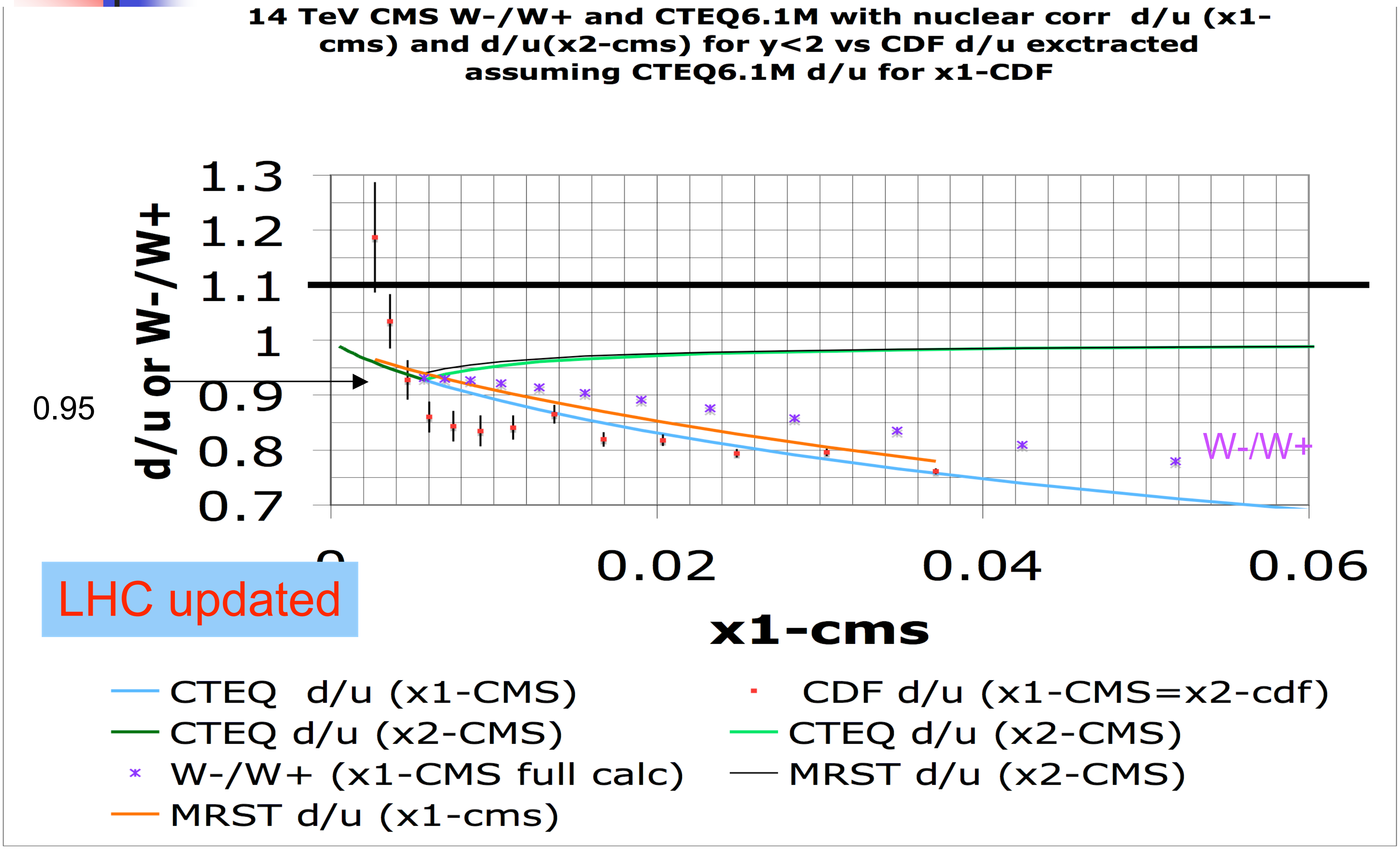
0.90



Data with errors are d/u(x1-cms) at LHC extracted from CDF data assuming d/u(x1-cdf) =MRST2006nnlo



Data with errors are d/u(x1-cms) at LHC extracted from CDF data assuming d/u(x1-cdf)=CTEQ6.1Mref with nuclear corrections



W Asym - conclusions

- New technique to unfold W-lepton eta distribution and extract the W+- rapidity distributions allows **measurements of W-/W+ (y) at the CDF and LHC**.
- It will take some work to adapt the procedure from CDF to CMS.
- d/u**(x1) at LHC may be less well known than assumed in current PDF fits.** **Current PDFs have d/y (y=0, x=0.0056) varying from 0.92 to 0.94**. However, *It is possible that* ***0.84 < d/u*** (y=0, x=0.0056) ***<0.96.***
- A combined analysis of CDF and CMS W-/W+ data versus y *yields d/u(x) over a wide range of x1,x2,* **independent of nuclear and shadowing corrections in the deuteron**.
- Consistency requirements between LHC/CDF data on d/u(x) and DIS and Drell Yan data on hydrogen and deuterium is ***useful in testing models of nuclear effects and shadowing corrections in deuterium and heavy nuclei*****.(evolve down to lower Q2).** Better understanding of nuclear corrections in D2 would make existing muon, neutrino DIS and Drell-Yan data on H, D and nuclear targets more useful in global PDF analyses (e.g. smaller errors on u+d).