W and Z weak boson production

(new results from CDF on W charge asymmetry and Z rapidity distributions)

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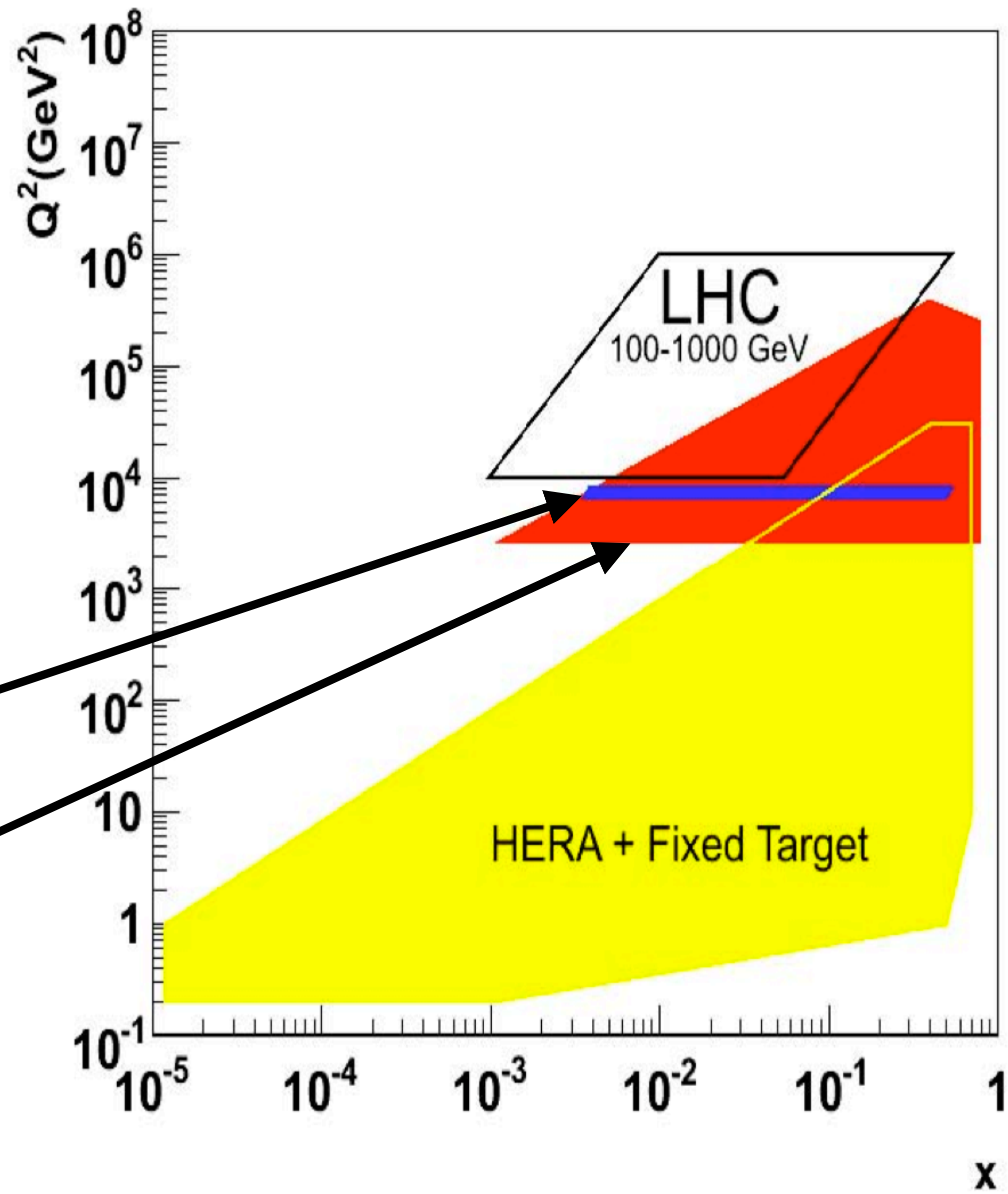
W and Z boson production - why??

W charge asymmetry, Z forward-backward asymmetry and rapidity distributions measured at Tevatron constrain the proton parton distribution functions (PDF) at large-x, essential input to all calculations of processes at present and future hadron colliders (LHC).

W mass systematic error limited by PDF (currently ~11 MeV CDF;
~ 20 MeV LHC)!

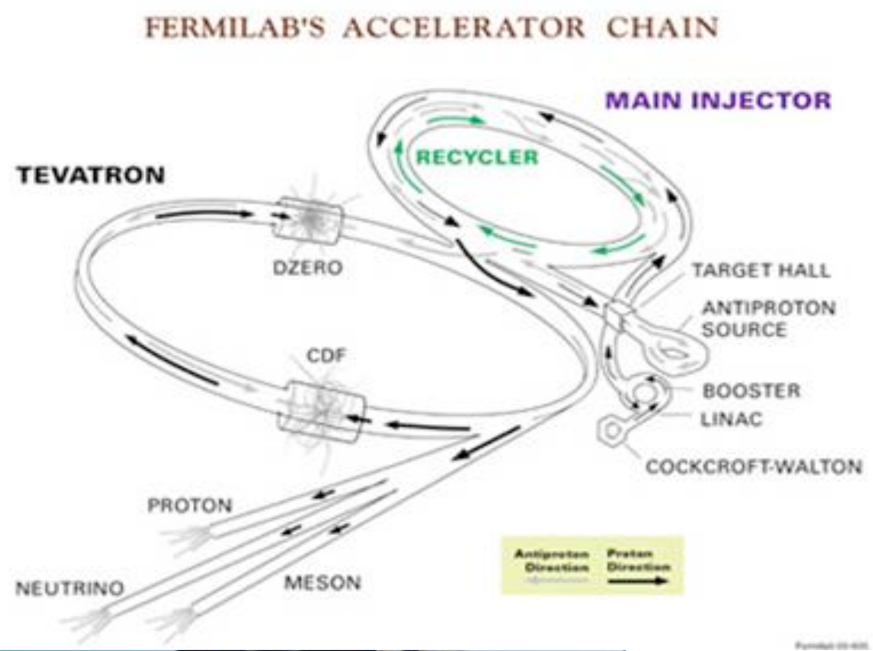
Complement measurements from HERA and neutrino experiments



W/Z asymmetries
at Tevatron

inclusive jets
at Tevatron

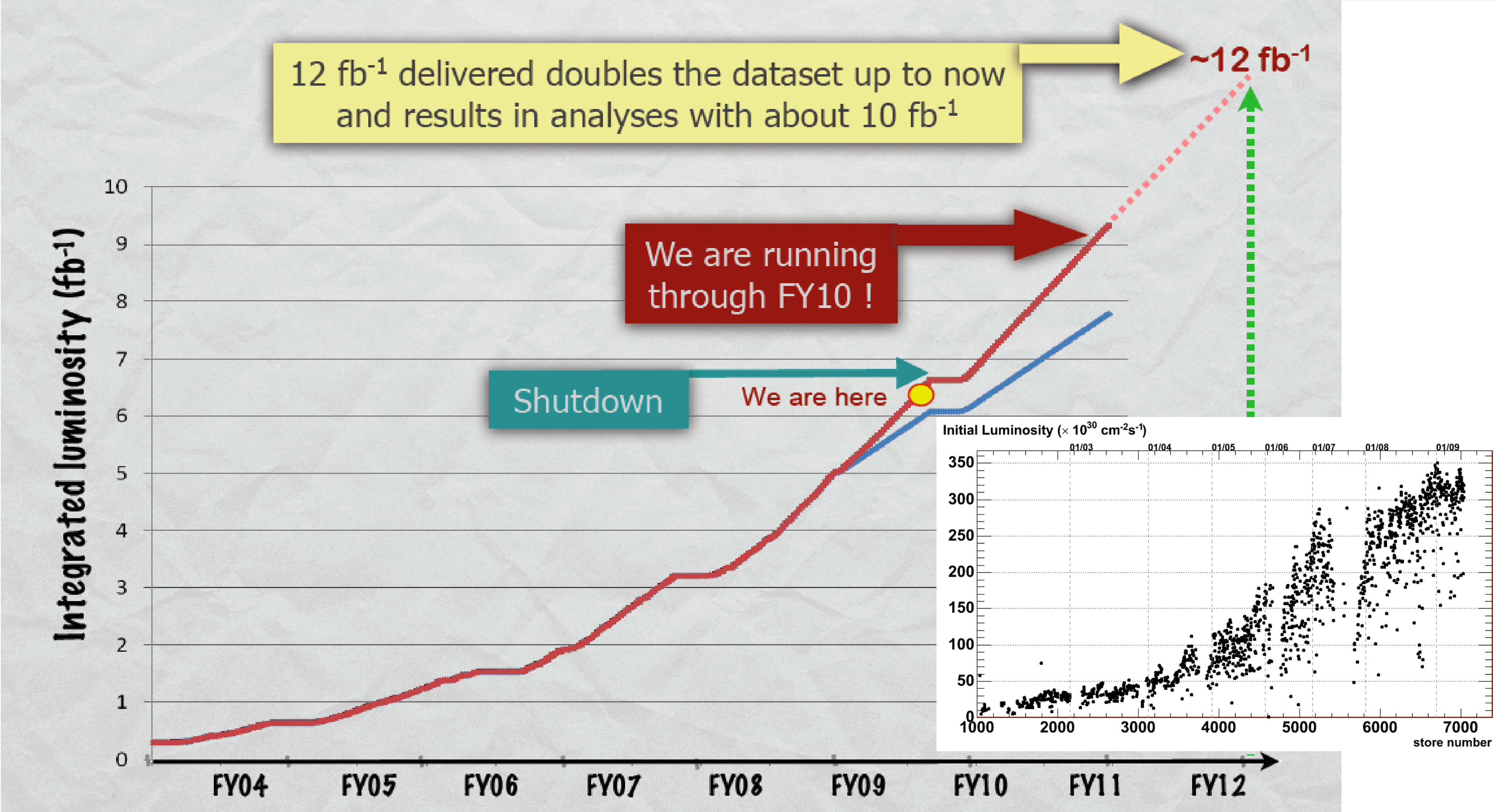
RUN-II AT TEVATRON 2001-???
Fermi National Accelerator Laboratory



New Main Injector ⇒ CM energy ($\sqrt{s}$) increased from 1800 GeV to 1960 GeV (${t\bar{t}}$ cross section increases by ~35%)

Different beam crossing time (396 ns and 132 ns later (?), instead of 3.5 μs in Run-I) - fewer multiple interactions

TEVATRON STATUS JULY 2009



- Luminosity delivered up to now: ~6.6 fb^{-1} (>5 fb^{-1} recorded)

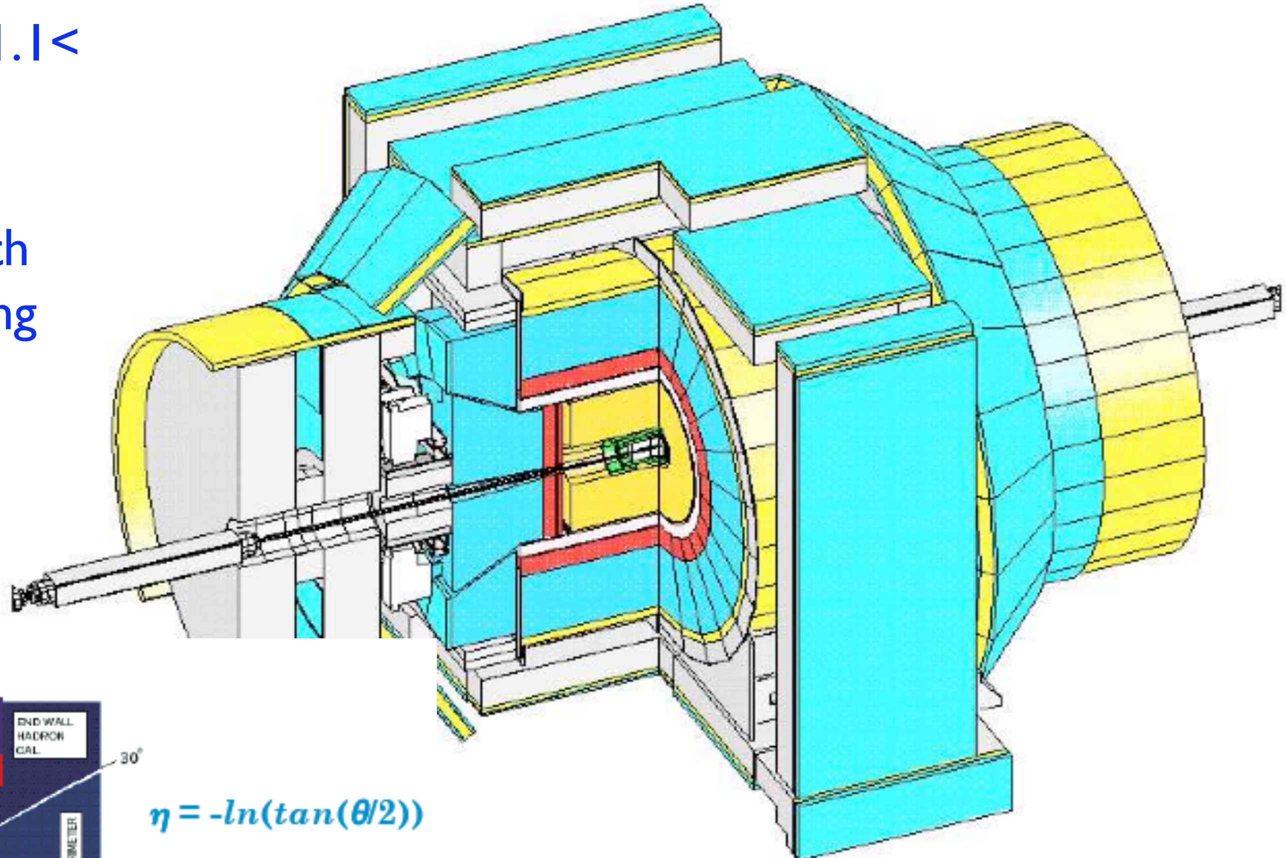
  running in 2010 approved ⇒ ~9 fb^{-1}

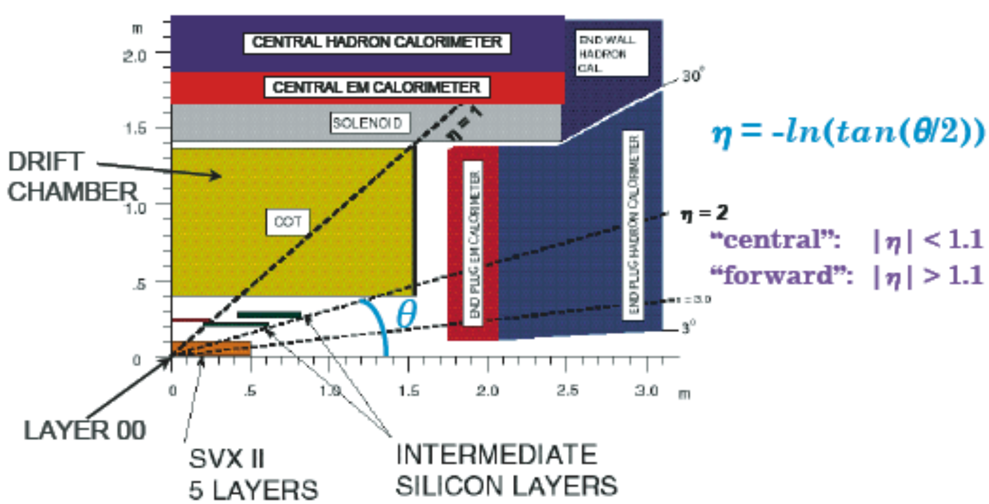
  running in 2011 considered ⇒ 12 fb^{-1}

RUN-II CDF DETECTOR

*new calorimeter for 1.1< |η|<3.5 (much better energy resolution)

*new (longer) SVX with double the Run-I tagging efficiency

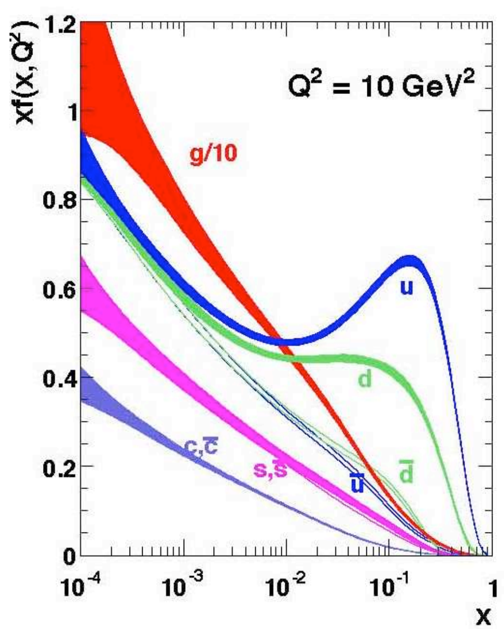


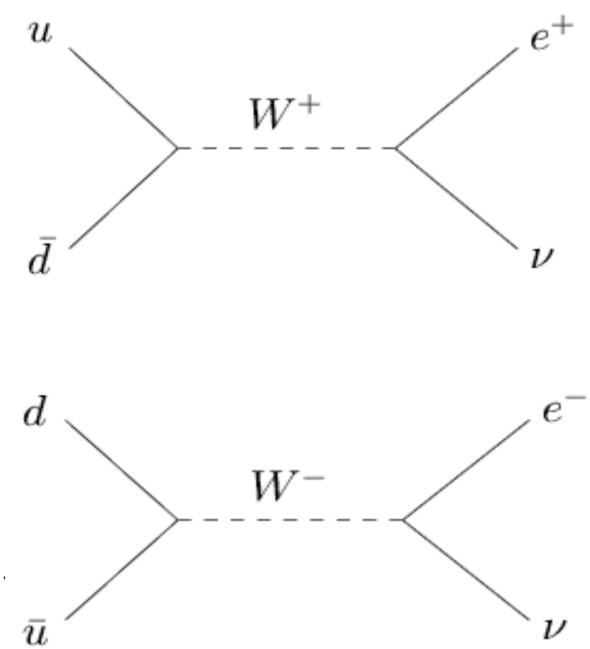


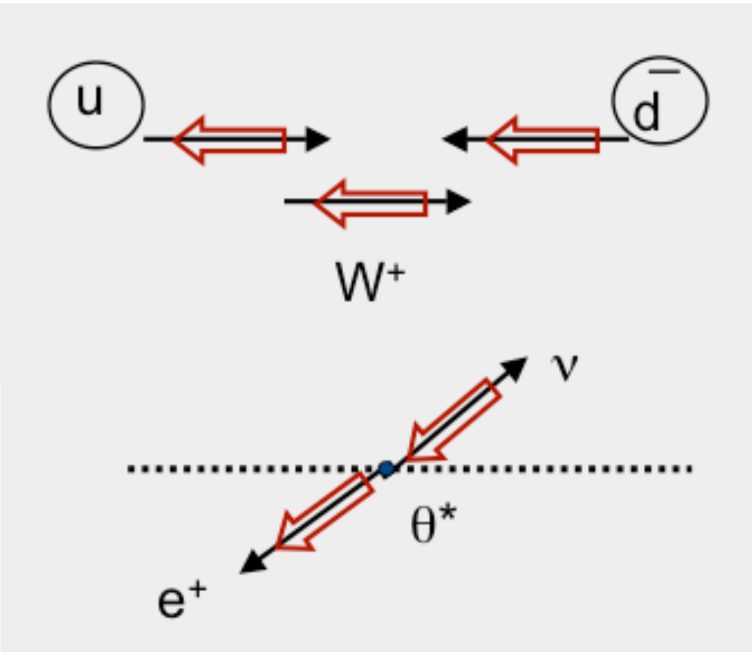
W-asymmetry in rapidity distribution

At Tevatron ($p\underline{p}$) at $\sqrt{s}$=1.96 TeV, W^+(W^-) are produced predominantly by the weak interaction of u(d) quarks and $\underline{d}$($\underline{u}$) antiquarks. Since u quarks carry (on average) larger fraction of proton's momentum than d quarks, W^+ is boosted along the proton direction (W^- is boosted in the antiproton direction). The difference in the respective rapidity distributions gives rise to a charge asymmetry:

$$A_{W^+}(\sqrt{s},y) = A_{W^-}(\sqrt{s},-y) \equiv \frac{\sigma_{W^+}(\sqrt{s},y) - \sigma_{W^+}(\sqrt{s},-y)}{\sigma_{W^+}(\sqrt{s},y) + \sigma_{W^+}(\sqrt{s},-y)}; \qquad y = \frac{1}{2}\ln\left(\frac{E+p_{\parallel}}{E-p_{\parallel}}\right).$$







W-asymmetry in rapidity distribution

- E.L. Berger, F. Halzen, C.S. Kim and S. Willenbrock; Phys. Rev. D40 (1989) 83

$$A_{W^+}(\sqrt{s}, y) = A_{W^-}(\sqrt{s}, -y) \propto \frac{u(x_1)d(x_2) - u(x_2)d(x_1)}{u(x_1)d(x_2) + u(x_2)d(x_1)}$$

where $x_1 = M_W e^y / \sqrt{s}, x_2 = M_W e^{-y} / \sqrt{s}$.

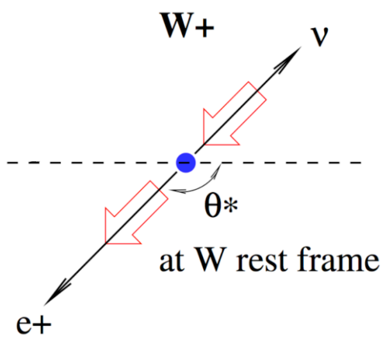
Measuring charge asymmetry constrains the proton parton distribution functions (PDF), in W case it is the ratio *u(x)/d(x)*.

In the past, Tevatron experiments measured W charge asymmetry of *leptons* from W decays as a function of *pseudorapidity* (η). Such asymmetry is a convolution of W charge asymmetry and V-A asymmetry from W decays into leptons. The two tend to cancel at large |η|~2, and the convolution complicates and weakens the constraint on proton PDF. The new CDF analysis measures *directly* $A_{W^+}(\sqrt{s}, y)$.

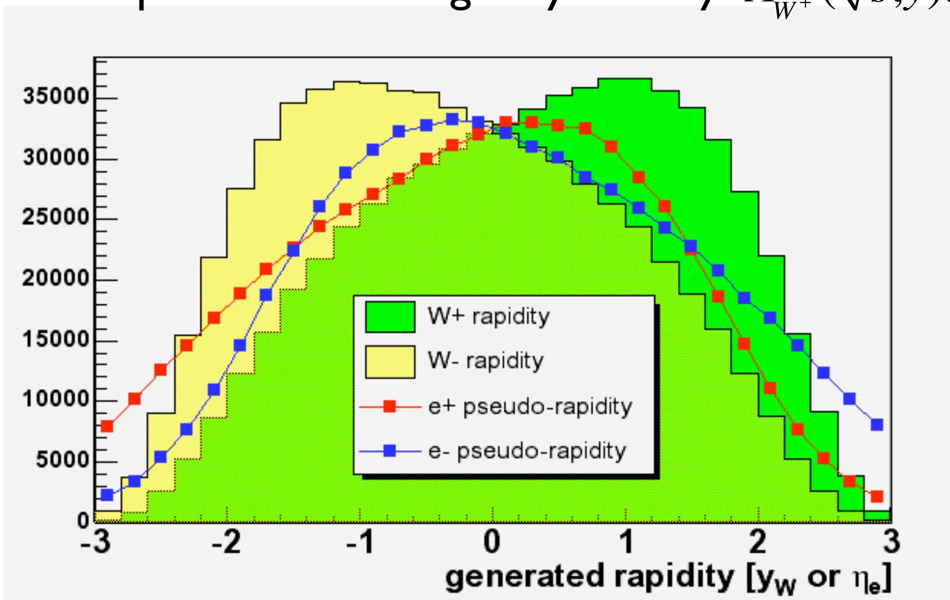
W-asymmetry in rapidity distribution

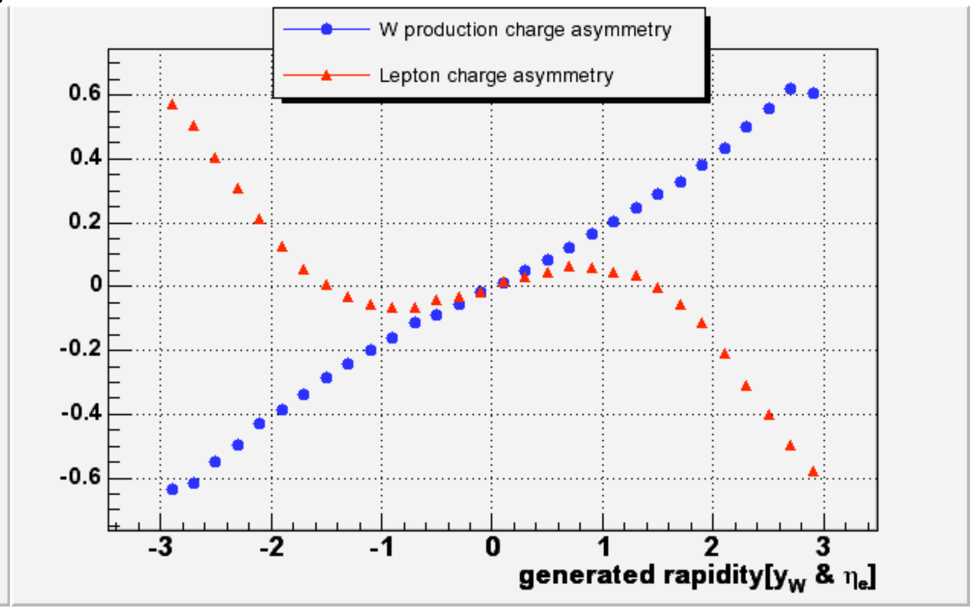
Leptons from W decay (V-A) prefer the direction opposite to that of the boost.

$$\frac{d\Gamma(W^{\pm} \to e^{\pm}\nu)}{d\Theta^{*}} \propto (1 \mp \cos\Theta^{*})^{2}$$



As a result of a convolution of production and decay asymmetries, lepton asymmetry A(η) has a turn-over at large |η|, and has *much smaller magnitude* than the production charge asymmetry $A_{W^+}(\sqrt{s}, y)$.





W-asymmetry in rapidity: new technique

How to measure W rapidity ?

$$y = \frac{1}{2}\ln(\frac{E + p_{\parallel}}{E - p_{\parallel}}).$$

$$p^{W}{}_{\parallel} = p^{lepton}{}_{\parallel} + p^{\nu}{}_{\parallel}$$

Neutrino escapes undetected, we cannot measure its momentum. However, the missing energy provides information about its transverse component, one can use the (W) mass constraint to find $p^{\nu}{}_{\parallel}$.

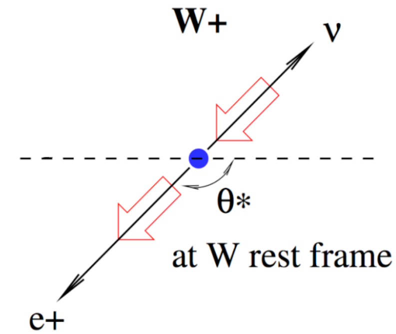
$$M_W{}^2 = (E^{lepton} + E^{\nu})^2 - (\vec{p}^{\,lepton} + \vec{p}^{\,\nu})^2$$

A quadratic equation for $p^{\nu}{}_{\parallel} \Rightarrow$ two solutions: $p^{\nu}{}_{\parallel,1}, p^{\nu}{}_{\parallel,2}$.

W-asymmetry in rapidity: new technique

This ambiguity can be resolved on a *statistical* basis, using a weighting factor:

$$w_{1,2}^{\pm} = \frac{P_{\pm}(\cos\Theta_{1,2}^{*}, y_{1,2}, p_T^W)\sigma(y_{1,2})}{P_{\pm}(\cos\Theta_{1}^{*}, y_{1}, p_T^W)\sigma(y_{1}) + P_{\pm}(\cos\Theta_{2}^{*}, y_{2}, p_T^W)\sigma(y_{2})}$$



where $\pm$ is W charge, and indices 1,2 indicate the two W rapidity solutions.

$$P_{\pm}(\cos\Theta_{1,2}^{*}, y_{1,2}, p_T^W)\sigma(y_{1,2}) = (1 \mp \cos\Theta^{*})^2 + Q(y_W, p_T^W)(1 \pm \cos\Theta^{*})^2$$

The differential cross sections, $d\sigma / dy_W$, are taken from NNLO QCD calculation*, the ratio of the two terms, Q, depends on quark/antiquark composition of the proton and was determined using MC@NLO. Factors in expression for $w_{1,2}^{\pm}$ have (very) weak dependence on the assumed W charge asymmetry $\Rightarrow$ ***ITERATE***

*C. Anastasiou, L. Dixon, K. Melnikov, F. Petriello, Phys. Rev. D69 (2004)

W-asymmetry in rapidity: new technique

input:

$(\underline{u}+\underline{d})/(u+d)$

$$d\sigma(p\underline{p} \to W^{+}X)/dy_{W} + d\sigma(p\underline{p} \to W^{-}X)/dy_{W}$$

measured (output from iteration):

$$A(y_W) = \frac{d\sigma/dy_{W^+} - d\sigma/dy_{W^-}}{d\sigma/dy_{W^+} + d\sigma/dy_{W^-}}$$

Method documented in:

A. Bodek, Y. Chung, B.-Y. Han, K. McFarland, E. Halkiadakis, Phys. Rev. D 77, 111301(R) (2008)

W event selection

Electron selection:

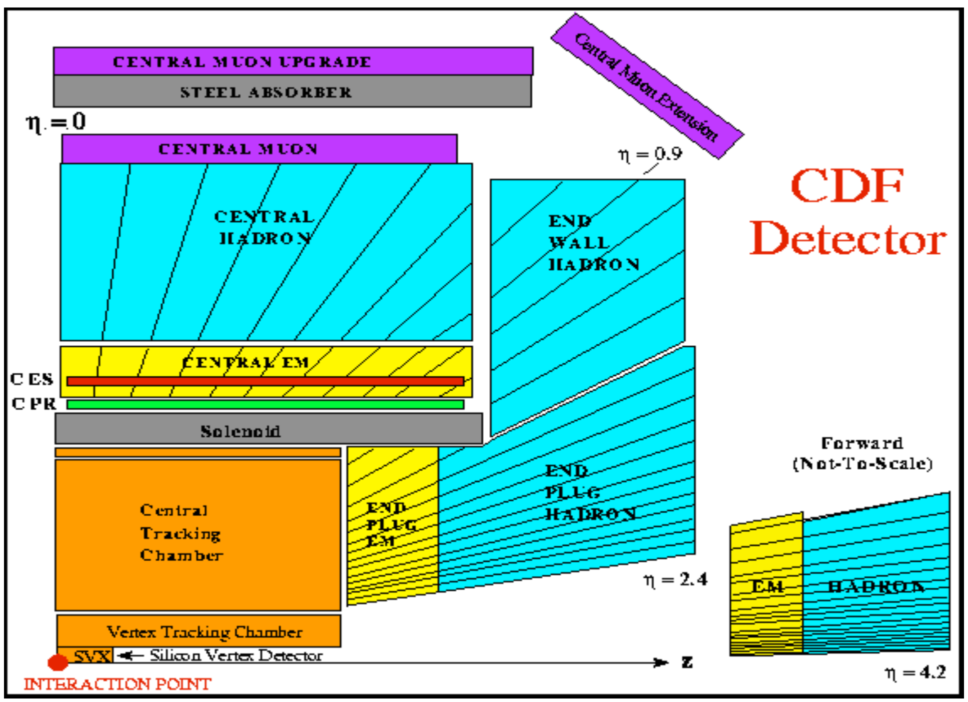
- single isolated cluster in EM calorimeter ISO(0.4)< 4 GeV
- E_T>25(20) GeV in central (forward) calorimeter

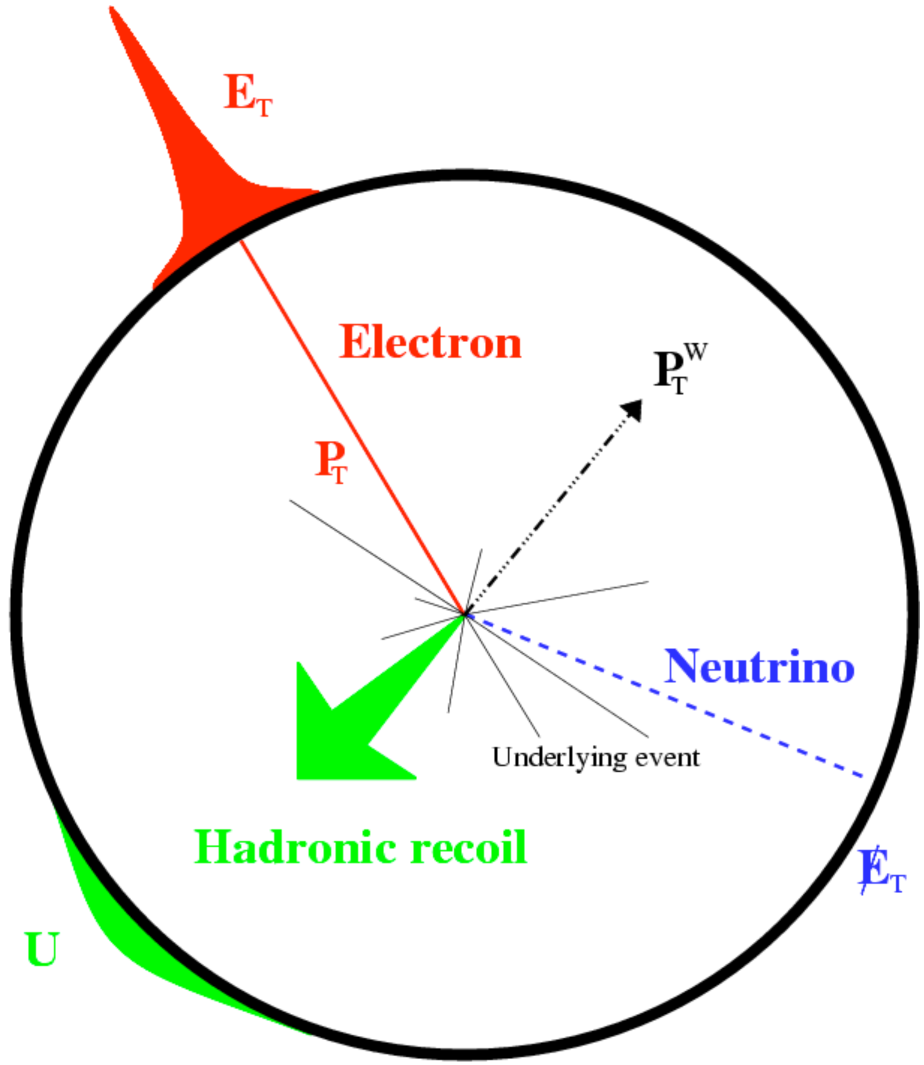
Missing E_T (neutrino) selection:

- missing E_T>25 GeV

~538 k events in central calorimeter

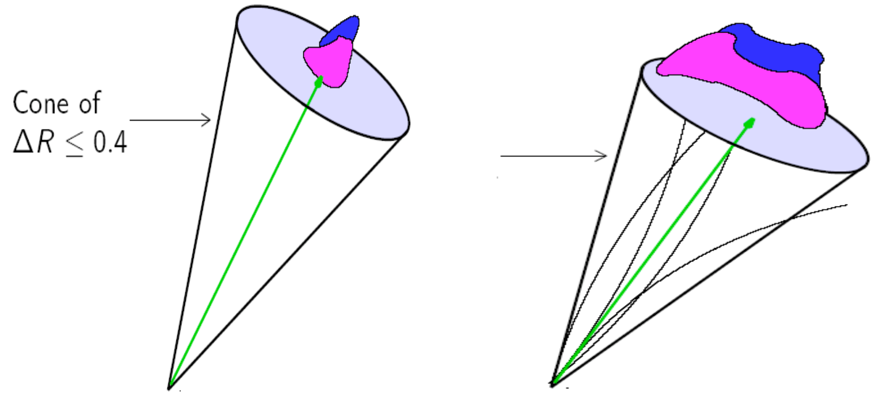
~177 k events in forward calorimeter





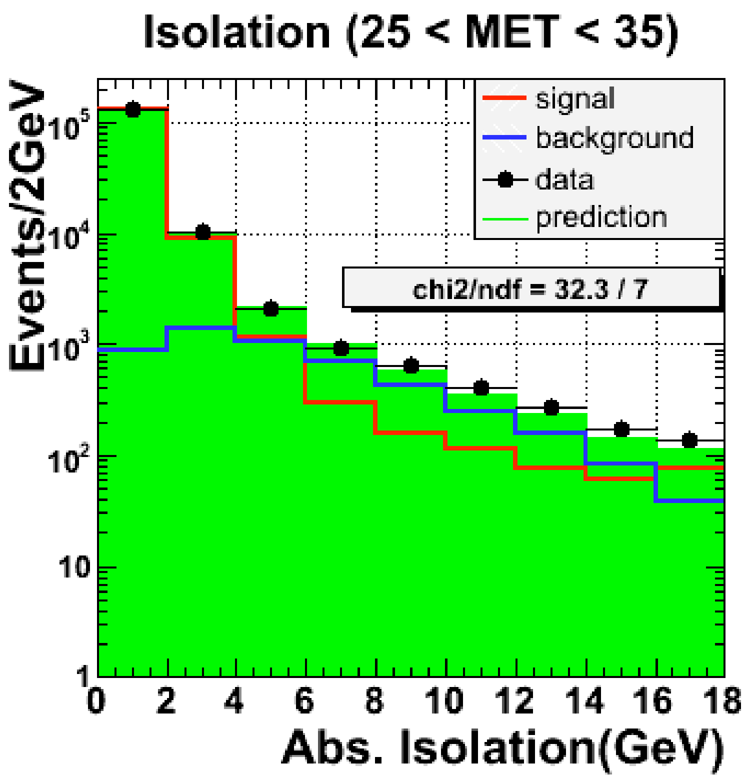
W asymmetry: backgrounds

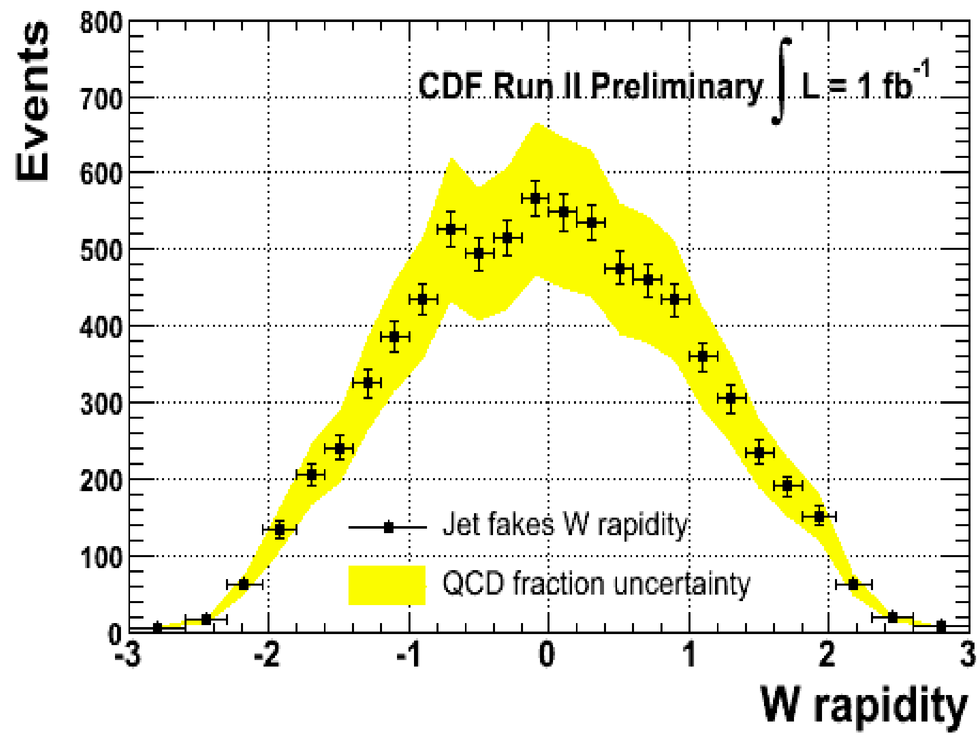
- fakes or non-isolated electrons: from the data, use energy isolation around electron, fit shape to background fraction, uncertainty is ~0.15% of the total sample



W electrons

fakes, or e in jets





W asymmetry: backgrounds
$Z \rightarrow e^+e^-$, $Z \rightarrow \tau^+\tau^-$, QCD, $W \rightarrow \tau\nu$

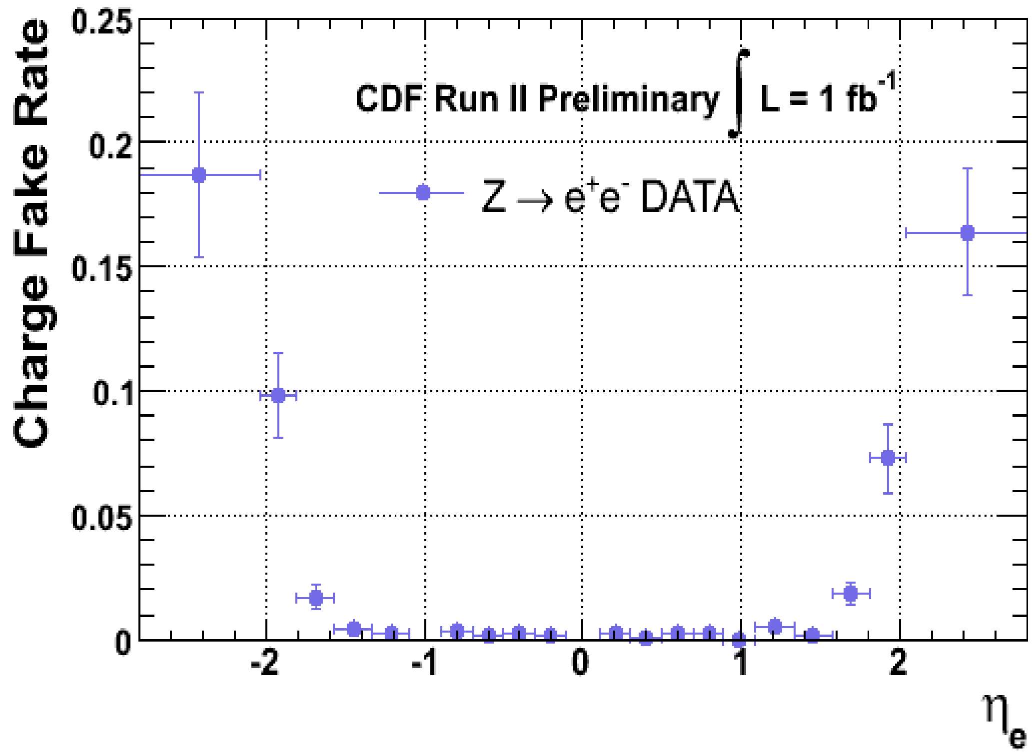
samples	central		plug	
	events	fraction (%)	events	fraction (%)
DATA	537858		176941	
$Z \rightarrow e^+e^-$	3173.36	0.59 ± 0.02 (stat.)	955.48	0.54 ± 0.03 (stat.)
$Z \rightarrow \tau^+\tau^-$	487.21	0.09 ± 0.00 (stat.)	179.81	0.10 ± 0.01 (stat.)
QCD	6508.08	1.21 ± 0.14 (stat.) ± 0.15 (syst.)	1185.50	0.67 ± 0.12 (stat.) ± 0.14 (syst.)
$W \rightarrow \tau\nu$	12370.73	2.30 ± 0.04 (stat.)	3609.60	2.04 ± 0.05 (stat.)

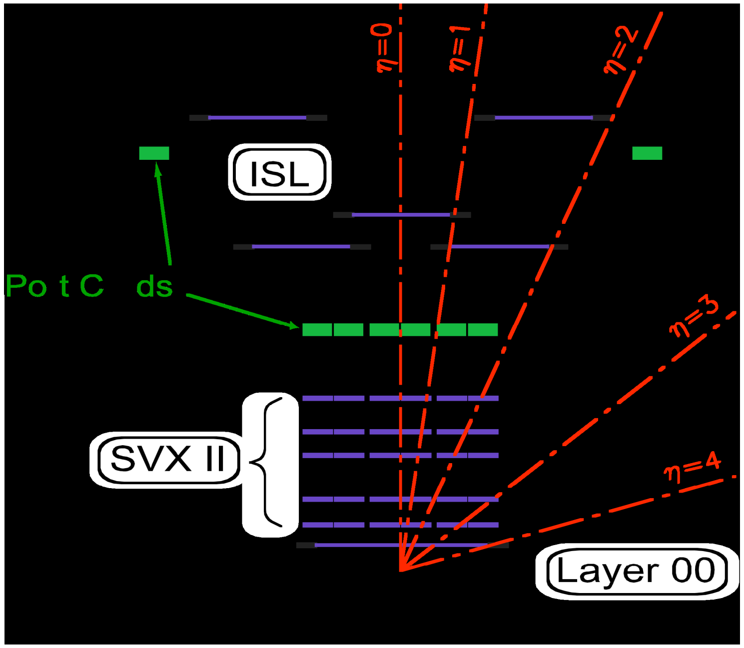
TABLE I: The predicted background contribution in $W \rightarrow e\nu$ candidates. The error represents the statistical uncertainty and the systematic uncertainty caused by our isolation fit method (QCD). Note that $W \rightarrow \tau\nu \rightarrow e\nu$ is not considered to be a background but is included in the signal acceptance for the W charge asymmetry analysis, and its contributio is shown in the last row.

W asymmetry: charge misidentification

- crucial for the measurement, forward tracks have fewer hits and shorter lever arm
- measure charge using Z→ee sample

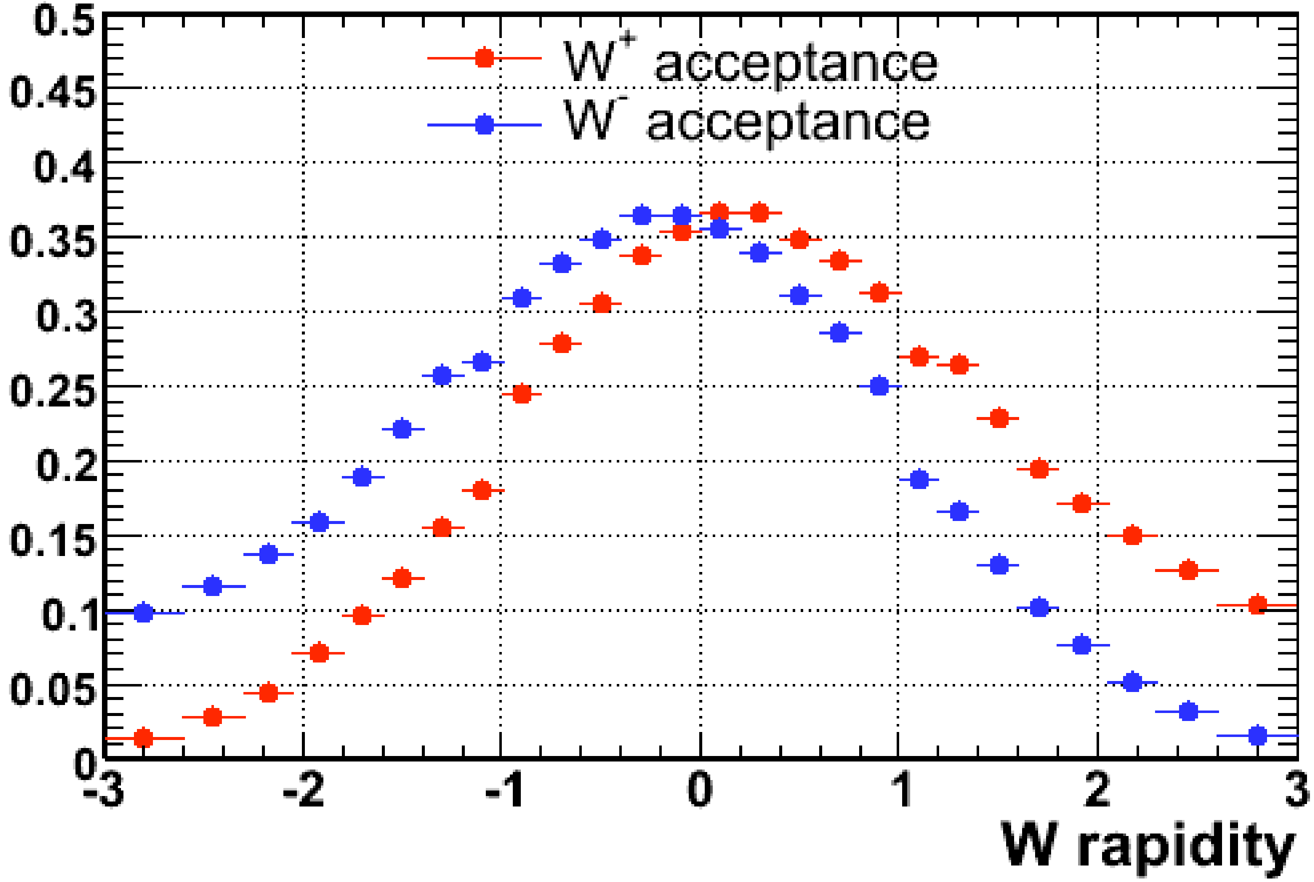
$$f = \frac{N_{samesign}}{N_{samesign} + N_{oppositesign}}$$





W asymmetry: acceptance

$$Acc^{\pm}(y_W) = \frac{\sum w^{\pm}(y_W)}{d\sigma / dy_W^{generated}}$$



W asymmetry: uncertainties

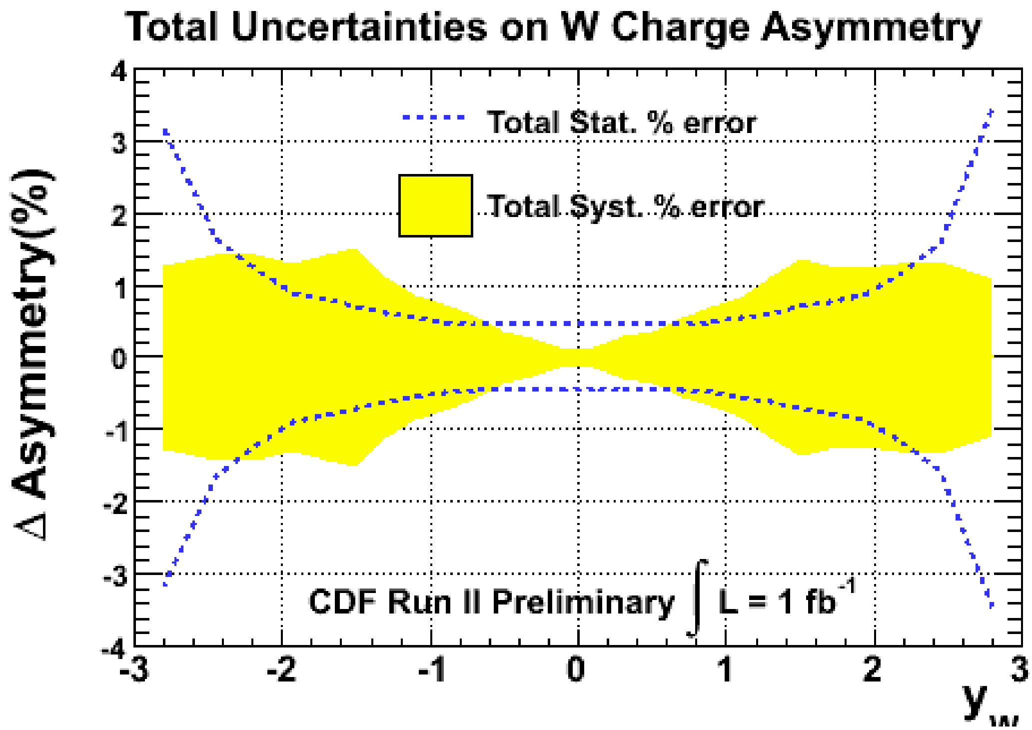
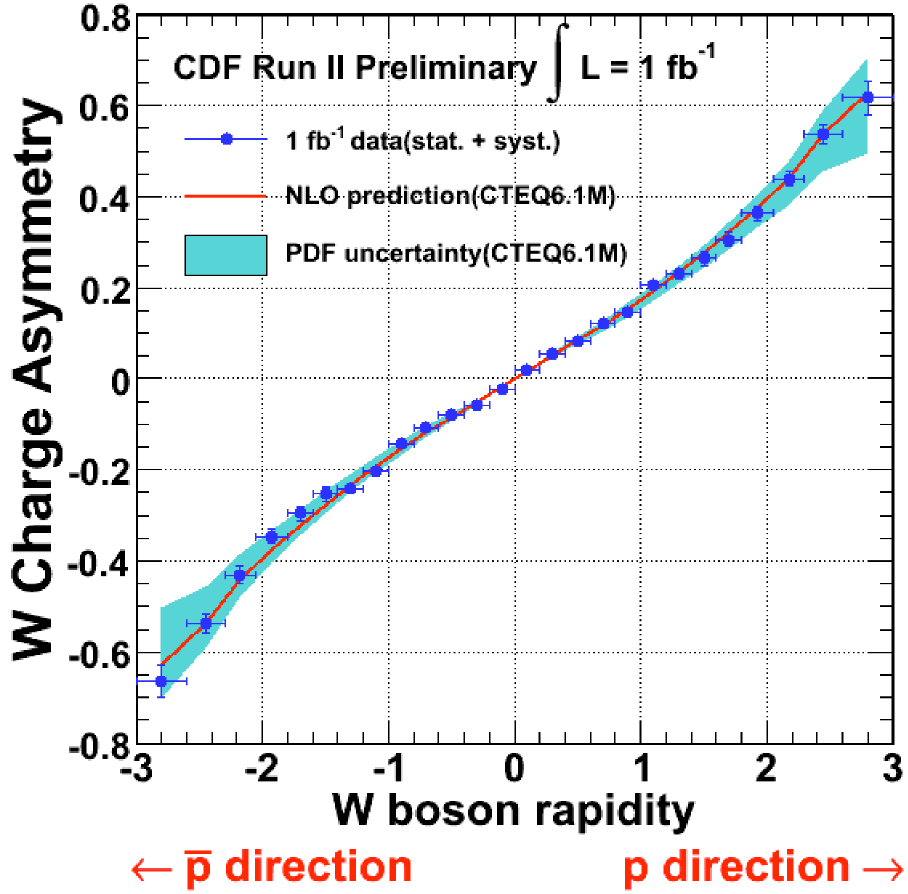


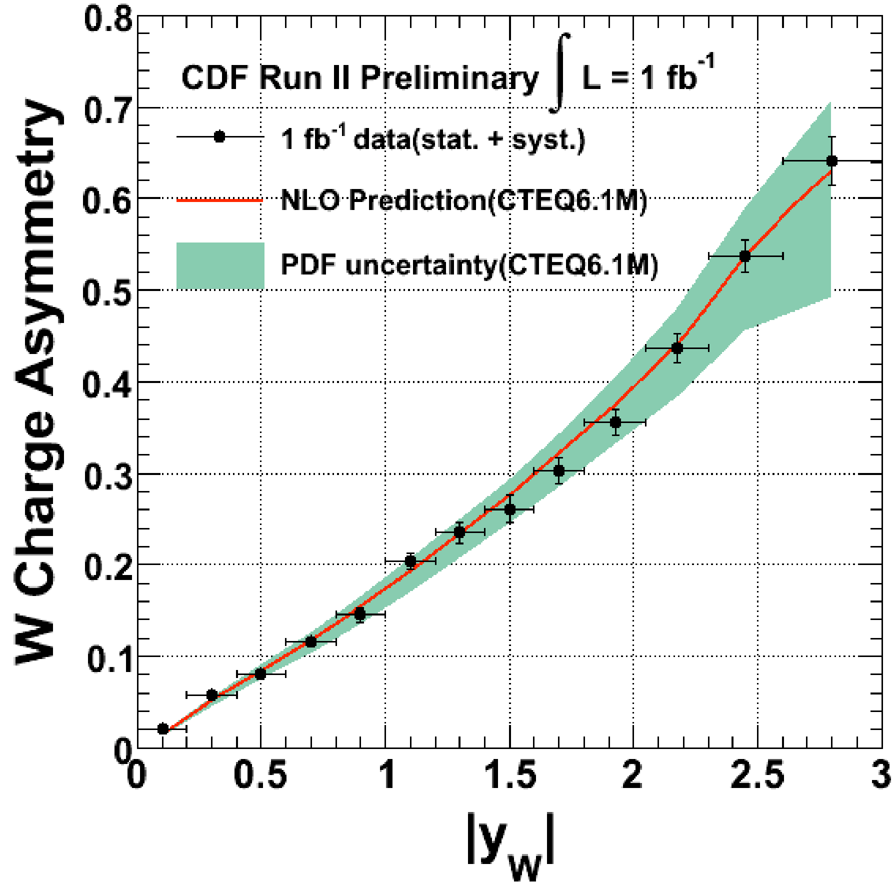
TABLE I: Statistical and systematic uncertainties for the W production charge asymmetry. All values are $(\times 10^{-2})$ and show the correlated uncertainties for both positive and negative rapidities.

$\|y_W\|$	Charge MisID	Back-grounds	Energy Scale & Resolution	Recoil Model	Electron Trigger	Electron ID	PDFs	Stat.
0.0 - 0.2	0.02	0.04	0.01	0.11	0.03	0.02	0.03	0.31
0.2 - 0.4	0.01	0.09	0.04	0.22	0.08	0.07	0.08	0.32
0.4 - 0.6	0.02	0.11	0.06	0.22	0.13	0.17	0.15	0.33
0.6 - 0.8	0.03	0.15	0.07	0.34	0.14	0.30	0.22	0.32
0.8 - 1.0	0.03	0.20	0.07	0.42	0.11	0.47	0.24	0.34
1.0 - 1.2	0.04	0.18	0.08	0.33	0.09	0.69	0.27	0.38
1.2 - 1.4	0.05	0.18	0.15	0.67	0.06	0.78	0.28	0.43
1.4 - 1.6	0.04	0.14	0.14	1.10	0.04	0.85	0.28	0.50
1.6 - 1.8	0.08	0.12	0.26	0.92	0.03	0.89	0.29	0.55
1.8 - 2.05	0.22	0.13	0.31	0.82	0.06	0.80	0.34	0.62
2.05 - 2.3	0.44	0.21	0.53	0.59	0.17	0.85	0.42	0.83
2.3 - 2.6	0.45	0.19	0.62	0.40	0.27	0.86	0.50	1.10
2.6 - 3.0	0.14	0.10	0.60	0.43	0.28	0.65	0.53	2.30

W asymmetry: results 1 fb^{-1}

Positive and negative agree $\Rightarrow$ FOLD into a single plot





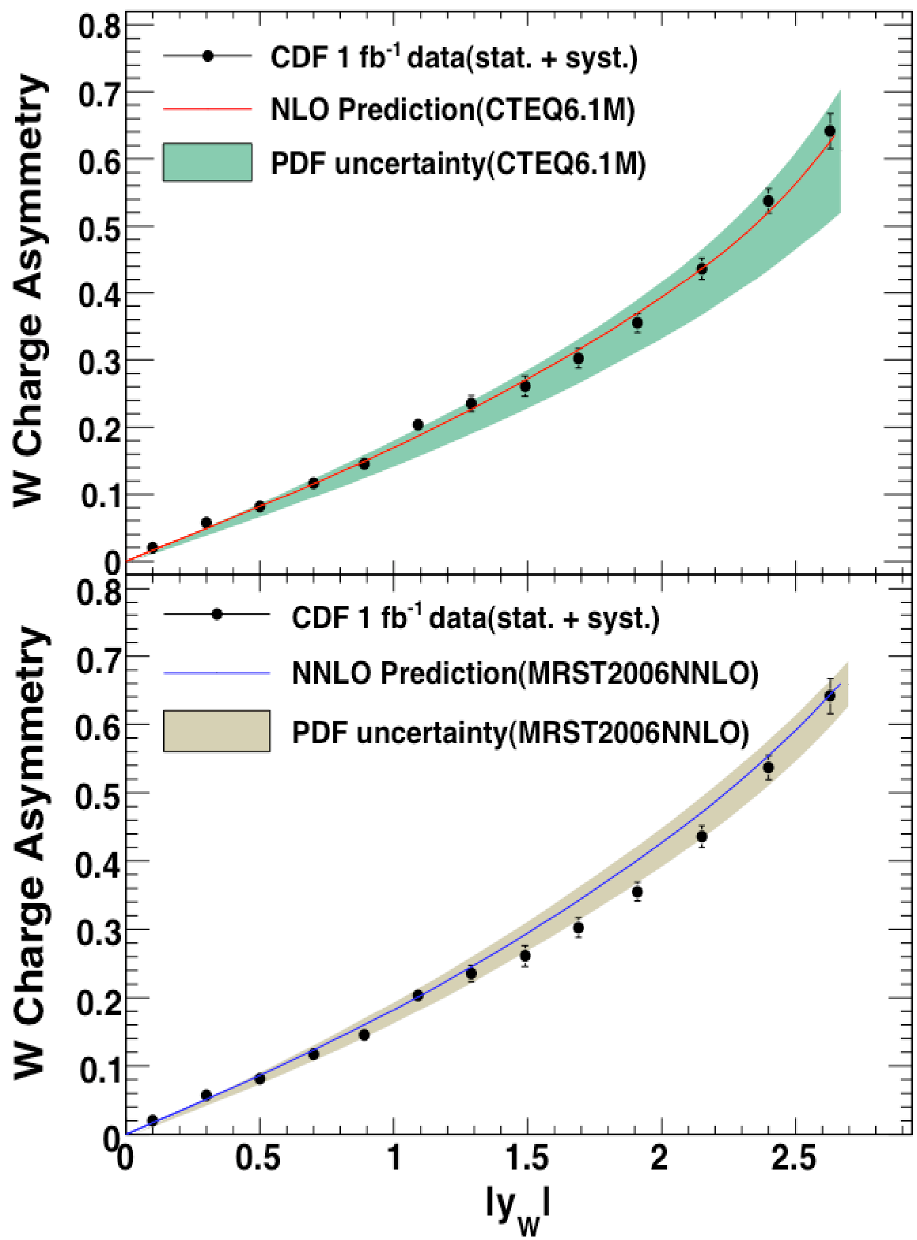
W asymmetry: results 1 fb^{-1}

Phys. Rev. Lett. 102 (2009) 181801

compare with NLO and NNLO (better)

TABLE II: The W production charge asymmetry with total systematic and statistical uncertainties.

$\|y_W\|$	$< \|y_W\| >$	$A(y_W)$	σ_{sys}	$\sigma_{sys+stat}$
0.0 - 0.2	0.10	0.020	±0.001	±0.003
0.2 - 0.4	0.30	0.057	±0.003	±0.004
0.4 - 0.6	0.50	0.081	±0.004	±0.005
0.6 - 0.8	0.70	0.117	±0.006	±0.006
0.8 - 1.0	0.89	0.146	±0.007	±0.008
1.0 - 1.2	1.09	0.204	±0.008	±0.010
1.2 - 1.4	1.29	0.235	±0.011	±0.012
1.4 - 1.6	1.49	0.261	±0.014	±0.015
1.6 - 1.8	1.69	0.303	±0.014	±0.014
1.8 - 2.05	1.91	0.355	±0.013	±0.014
2.05 - 2.3	2.15	0.436	±0.013	±0.016
2.3 - 2.6	2.40	0.537	±0.014	±0.018
2.6 - 3.0	2.63	0.642	±0.012	±0.026



Z rapidity distribution

Drell-Yan process is another very useful source of information about the proton PDF. In events in which dilepton pairs are produced at large rapidity, y, one parton carries large and the other small momentum fraction x. In LO, the momentum fractions x_1, x_2 are related to rapidity through:

$$x_1, x_2 = (M / \sqrt{s}) e^{\pm y}.$$

CDF new result is based on data sample of 2.1 fb^{-1}, with the measured rapidity range extending to |y|<2.9 (kinematical limit y=3.0). Three topologies of e^+e^- are considered:

(CC) both leptons in central calorimeter |y|<1.1

(CP) one lepton in central and the other in plug calorimeter (1.1<|y|<3.6)

(PP) both leptons in plug calorimeter

Z rapidity/ cuts

Cuts: E_T

> 25 GeV for CC and PP events

> 20 GeV for CP events

Tracking:

CC and CP: central electron must have a matched track in COT ($|y|<1.2$)

PP: at least one electron matched SVX track (85% matching efficiency)

Mass window:

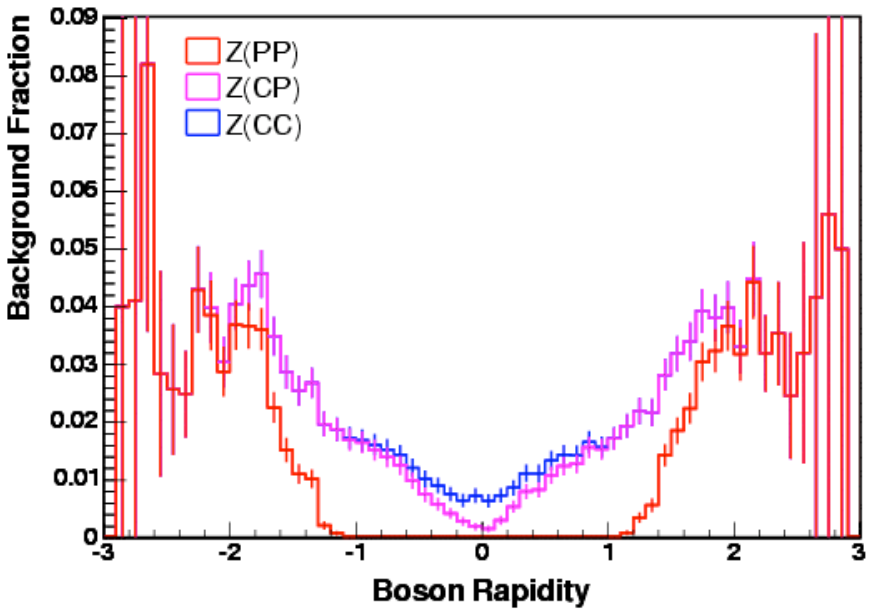
$66\ GeV/c^2 < M(e^+e^-) < 116\ GeV/c^2$

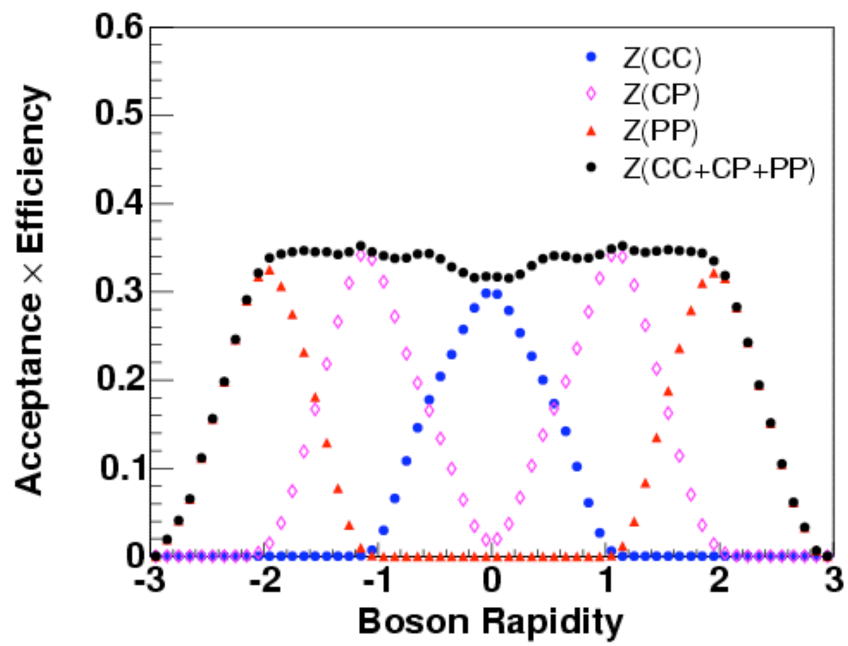
topology	# events	background fraction
CC	51 k	0.24 ± 0.03 %
CP	86 k	1.55 ± 0.44 %
PP	31 k	3.40 ± 0.75 %

Z rapidity/ background/ acceptance

Electroweak backgrounds (WW, WZ, W inclusive and $Z \rightarrow \tau\tau$) and $t\underline{t}$ inclusive processes small, estimated from simulations 0.41±0.02 %.

Acceptance from Pythia (LO) combined with CDF detector simulation.





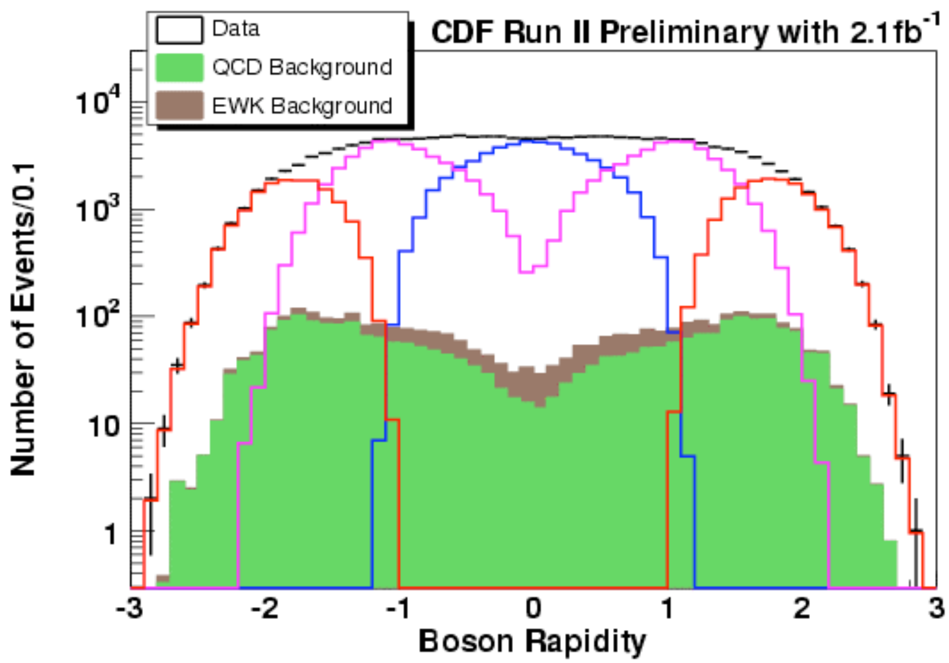
Z rapidity/ results 2.1 fb^{-1}

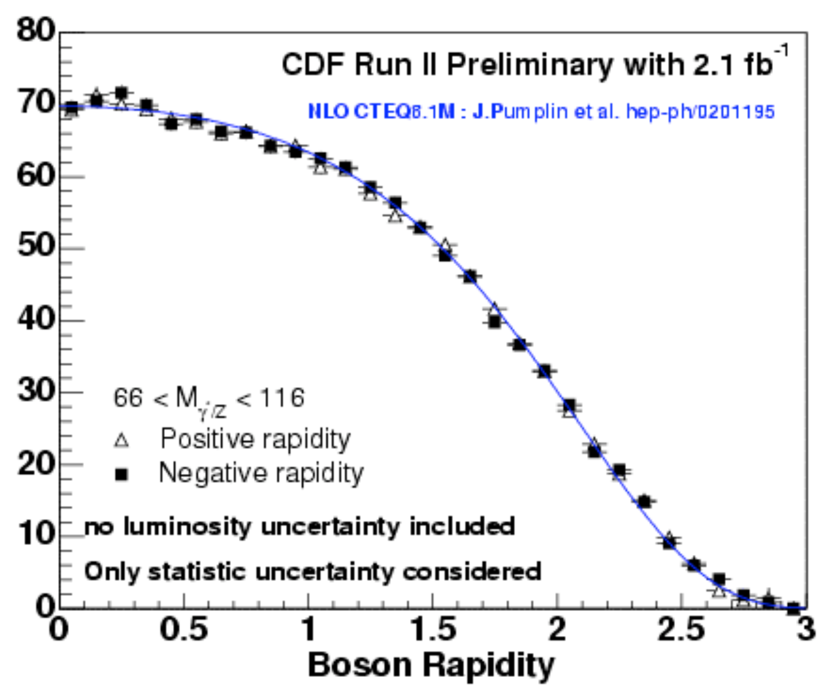
Total cross section: |y|<2.9

σ=256.0±0.7(stat)±2.0(syst) pb + 6% luminosity error (not included)

(236.1±9.3 pb NLO CTEQ6M)

(252.6±3.1 pb NNLO MRST 2006)





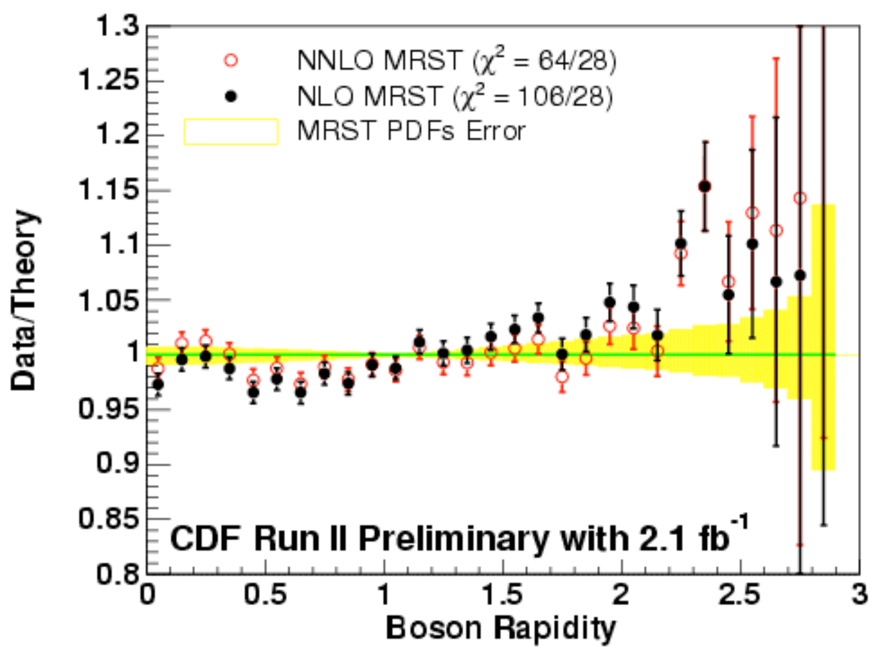
Z rapidity/ results 2.1 fb^{-1}

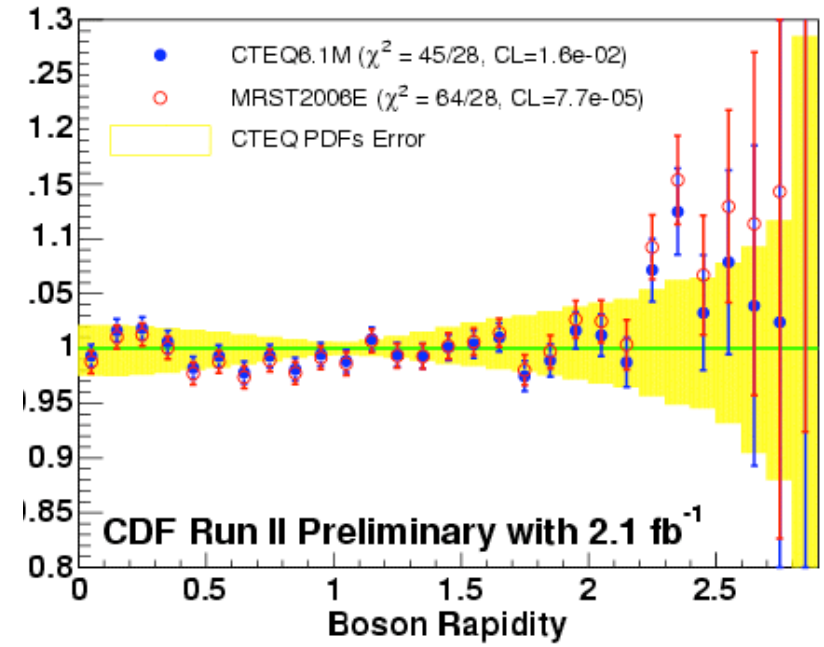
Comparison of rapidity distributions with NLO and NNLO.

NLO : χ^2=38/28 DOF, CL=0.094

NNLO: χ^2=58/28 DOF, CL=0.0064

Both need tuning

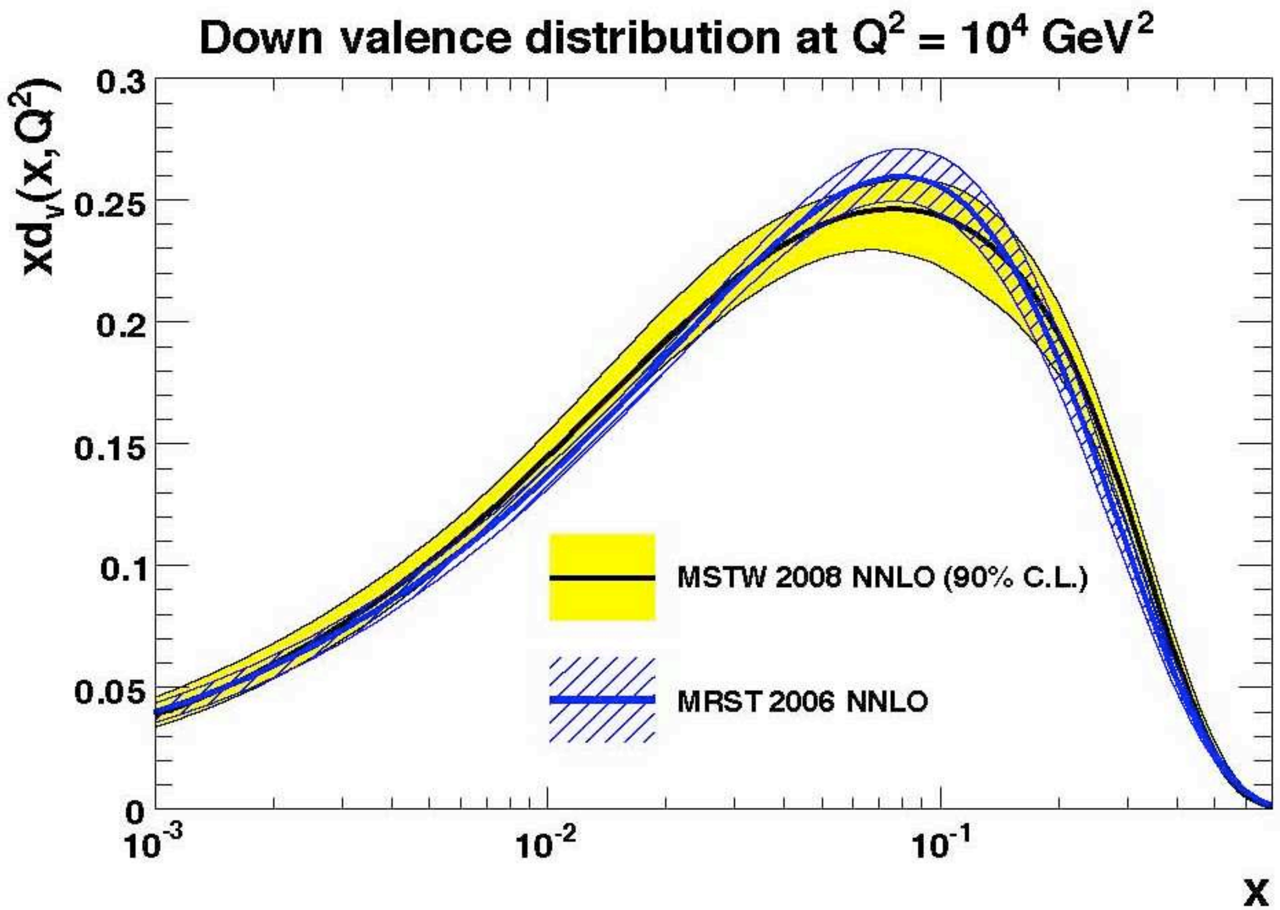




Z rapidity results 2.1 $fb^{-1} \Rightarrow xd_v(x,Q^2)$

The new CDF (and D0) results have allowed a better (more robust) parametrization of valence d-quark distribution: Martin, Stirling, Thorne, Watt, hep-ph/0901.0002 (MSTW 2008)

⇒ increase at x≈0.3. decrease at x≈0.07. wider error band. more flexible



Summary

CDF has new measurements of:

- W charge asymmetry, $A_W(y)$ as a function of W *rapidity* (1 fb^{-1})
- Z rapidity distribution in a range $|y| < 2.9$ (2.1 fb^{-1})

W, Z boson production results provide new constraints on proton valence quarks PDF's (primarily for d-quark, as u-quark is well constrained from other PDF data); comparisons with NLO and NNLO calculations indicate need of additional tuning

⇒ important for reducing W mass systematic error

CDF II preliminary $L = 200\ pb^{-1}$

m_T Uncertainty [MeV]	Electrons	Muons	Common
Lepton Scale	30	17	17
Lepton Resolution	9	3	0
Recoil Scale	9	9	9
Recoil Resolution	7	7	7
$u_{\|}$ Efficiency	3	1	0
Lepton Removal	8	5	5
Backgrounds	8	9	0
$p_T(W)$	3	3	3
PDF	11	11	11
QED	11	12	11
Total Systematic	39	27	26
Statistical	48	54	0
Total	62	60	26

D0 1 fb^{-1}

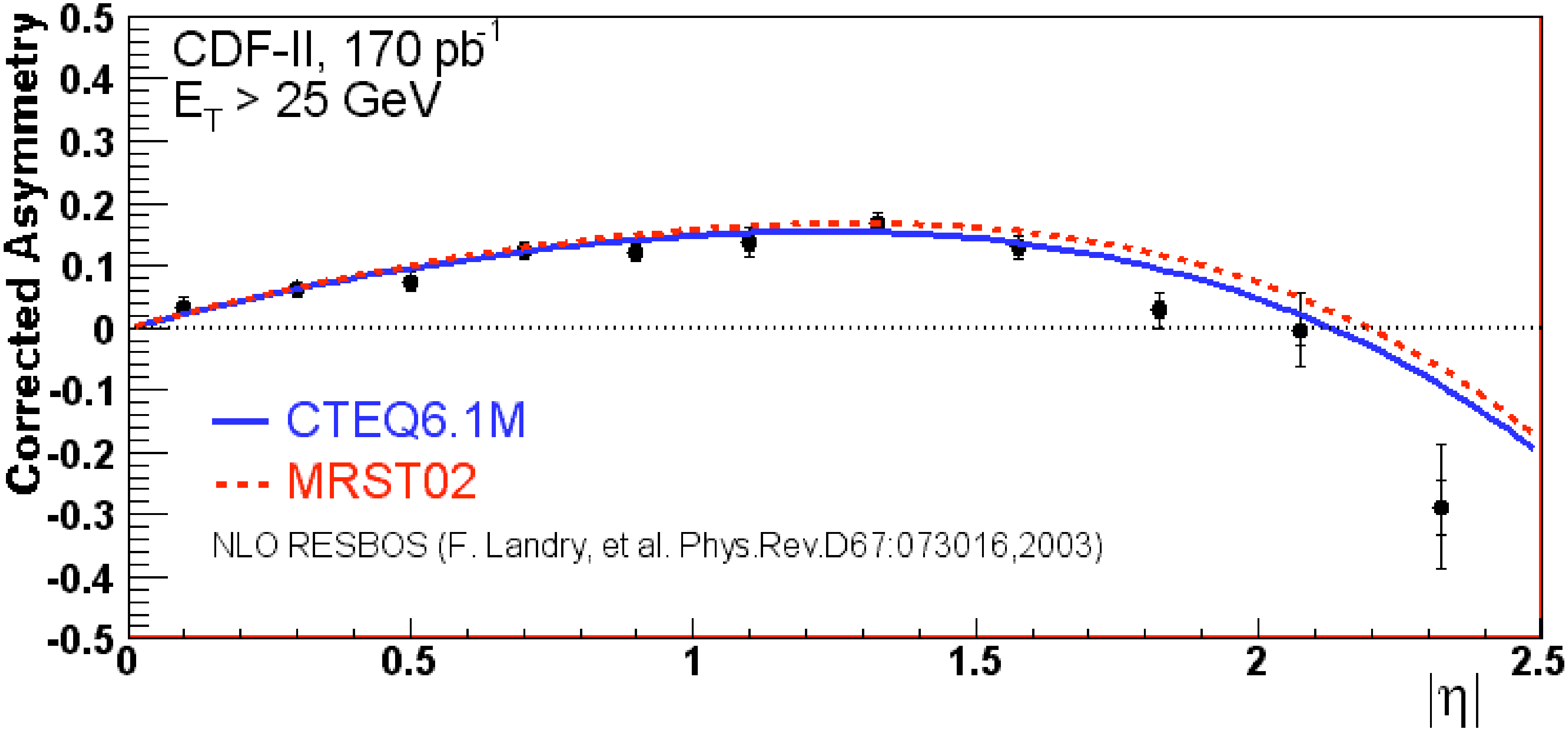
Source	$\sigma(m_W)$ MeV m_T	$\sigma(m_W)$ MeV p_T^e	$\sigma(m_W)$ MeV $\not{E}_T$
Experimental			
Electron Energy Scale	34	34	34
Electron Energy Resolution Model	2	2	3
Electron Energy Nonlinearity	4	6	7
W and Z Electron energy loss differences	4	4	4
Recoil Model	6	12	20
Electron Efficiencies	5	6	5
Backgrounds	2	5	4
Experimental Total	35	37	41
W production and decay model			
PDF	9	11	14
QED	7	7	9
Boson p_T	2	5	2
W model Total	12	14	17
Total	37	40	44

Additional slides

W lepton pseudorapidity asymmetry

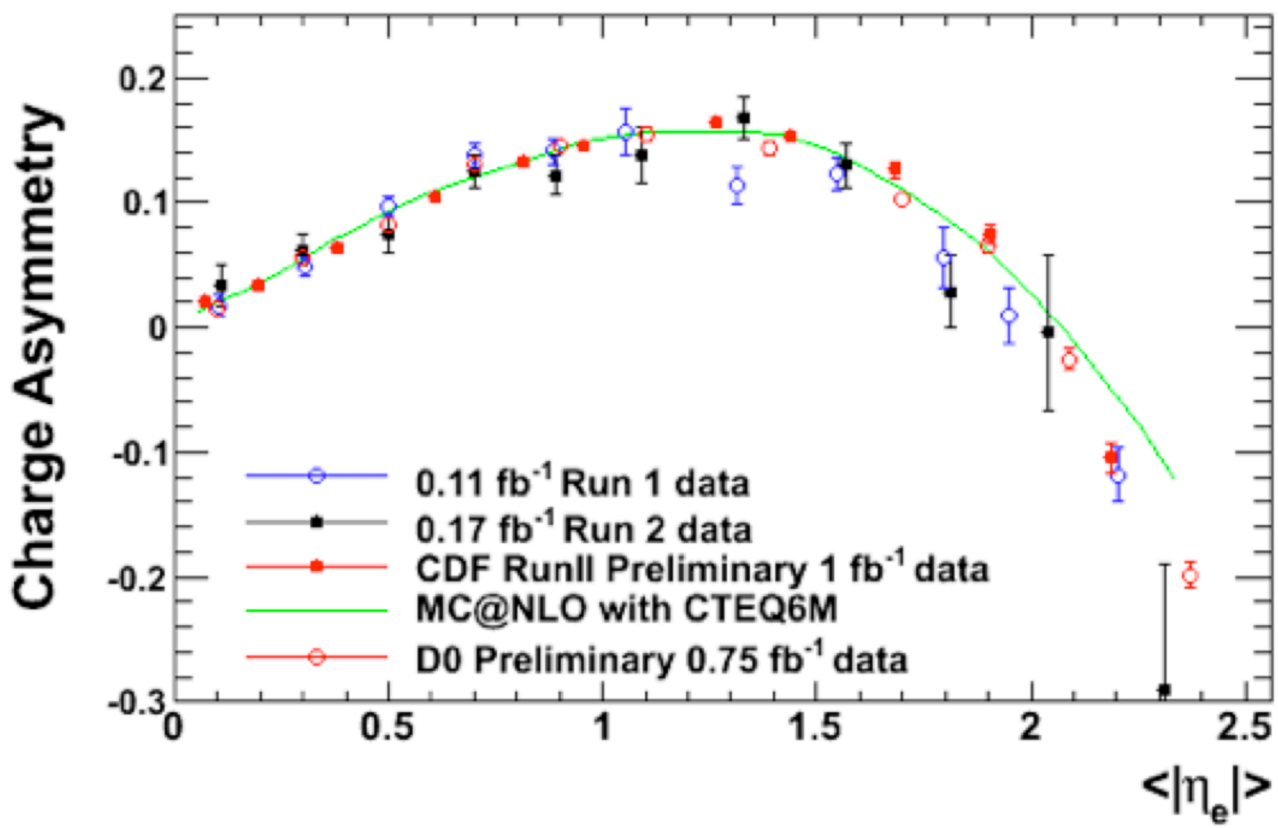
CDF Run-II

Phys. Rev. D71 (2005) 051104

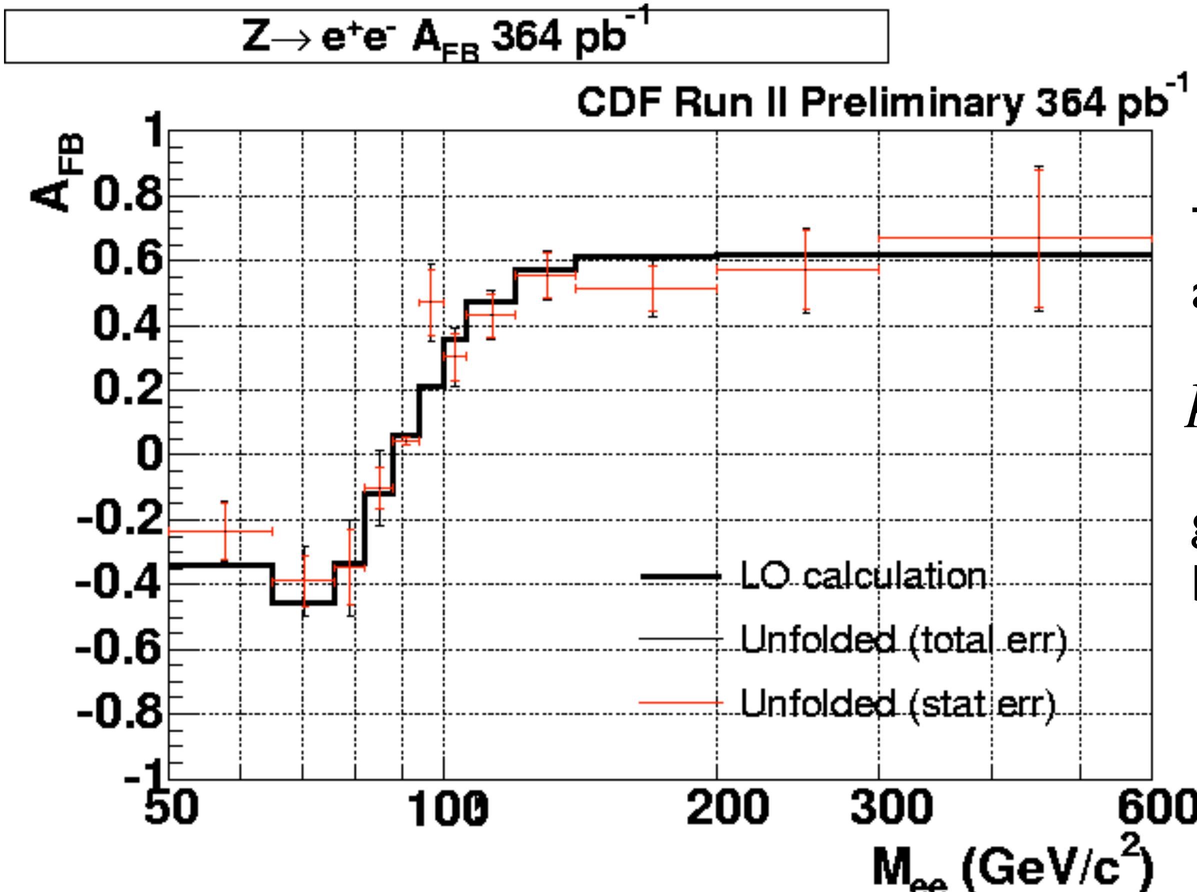


W asymmetry D0 vs CDF

- CDF provides *raw stat.* data for $A_{lepton}(\eta)$ only (1 fb^{-1})
- D0 (0.75 fb^{-1}) data a bit lower than CDF for $0.8<|\eta|<2.0$



Z asymmetry (364 pb^{-1})



The presence of both the axial and vector couplings in

$$p\bar{p} \rightarrow Z/\gamma^{*} \rightarrow e^{+}e^{-}$$

gives rise to a forward-backward charge asymmetry

Bin	Mass (GeV)	#Forward	#BG Forward	#Backward	#BG Backward	A_{FB} (bg subtracted)	Unfolded #Forward	Unfolded #Backward	Unfolded A_{FB}
1	50–65	97	9.6	120	7.6	−0.125	1875.6	3036.1	−0.236
2	65–76	207	15.8	284	12.7	−0.173	704.9	1603.2	−0.389
3	76–82	330	9.5	394	7.3	−0.094	486.5	1006.4	−0.348
4	82–88	1791	8.9	1817	7.5	−0.008	3153.1	3871.7	−0.102
5	88–94	6935	12.6	6295	10.1	0.048	39087.9	35762.7	0.044
6	94–100	1853	8.3	1348	6.8	0.158	3229.1	1160.2	0.471
7	100–106	333	8.5	169	6.0	0.331	1215.4	649.6	0.303
8	106–120	288	18.6	130	13.3	0.395	843.5	334.2	0.432
9	120–140	166	14.9	58	11.9	0.532	453.0	129.7	0.555
10	140–200	140	22.7	53	14.7	0.508	300.3	97.0	0.512
11	200–300	45	7.5	15	4.1	0.550	91.0	24.8	0.571
12	300–600	10	0.8	3	0.7	0.600	21.4	4.3	0.668