Electroweak Measurements at Tevatron

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CEA-Saclay

for the CDF and DØ collaborations

Rencontres de Moriond 2005
Electroweak Interactions and Unified Theories

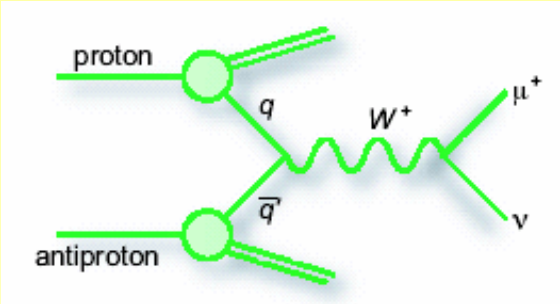
W and Z Boson Physics

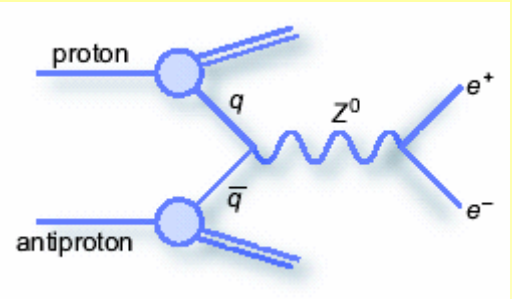
Challenge: do precision measurements in an hadronic environment (and in C++!!)

- Standard candles: single W and Z boson cross section measurements (muon or electron decays)
- W and Z into τ (τ identification)
- Forward-backward asymmetry (in dielectron events)
- W charge asymmetry
- W width and W mass

Diboson production (in Gilles' following talk)

W and Z into Electron or Muon Inclusive Cross Sections Measurements





Why?

Clean, abundant and well known signals

Test of the Standard Model (R, lepton universality)

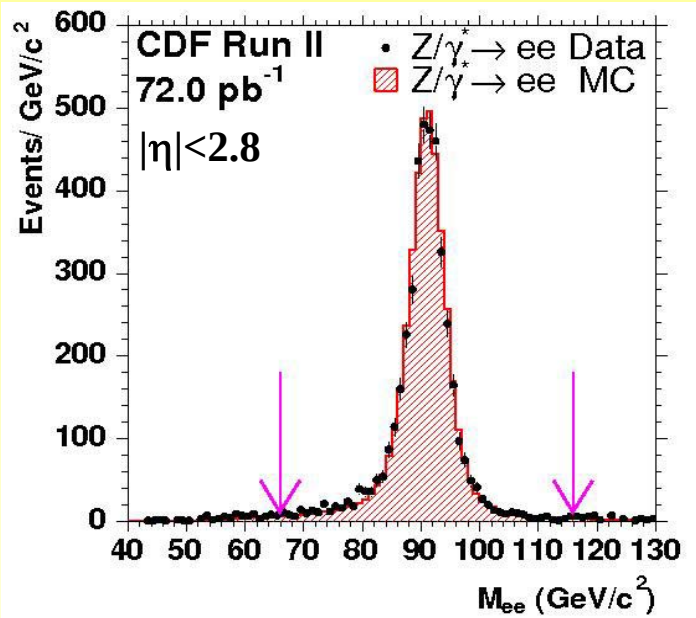
Require a high level of understanding of the detectors

Can be used to cross check the luminosity measurements

Limitations: uncertainties on

- luminosity ~ 6 %
- Parton distribution functions (PDF) ~ 1.5 %
- Others (lepton identification, Z statistics, …)

W and Z to electron(s) and muon(s)



One or two high Pt lepton (>15 to 25 GeV)

For W: $\not{E}_T$ (>15-25GeV)

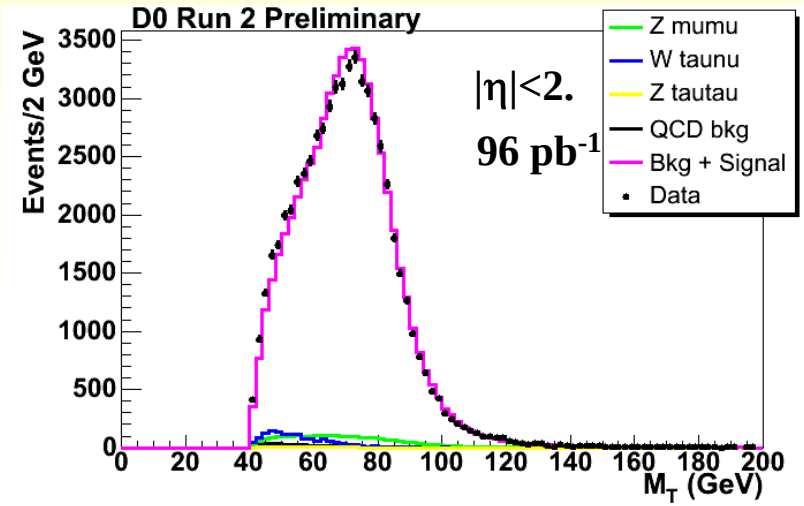
Efficiencies computed on data

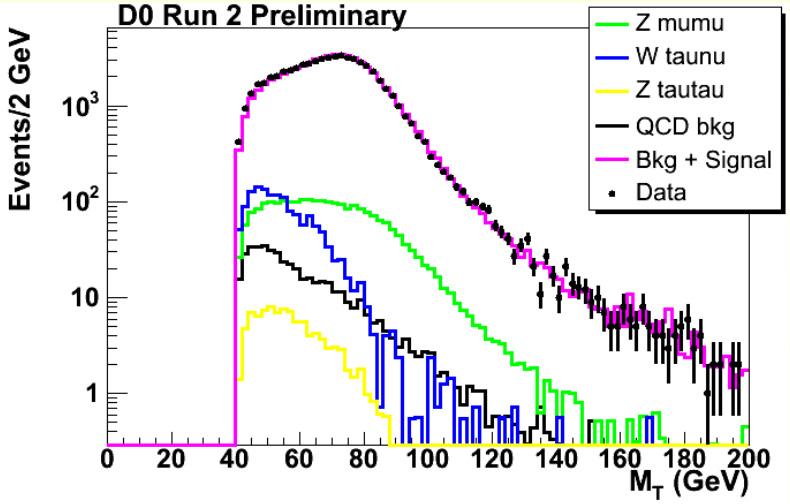
Main background:

- QCD: dijet (evaluated on data) ~1-2%
- W/Z → τ, Z → $\ell\ell$ (for W) ~ 1-6%

Main systematic uncertainty:

- PDF ~ 1.5%





W, Z Cross Sections into Muon and Electron

	CDF	DØ
$Z \to ee$	255.8 ± 3.9 (stat) ± 5.5 (sys) ± 15 (lumi) pb (72 pb^{-1})	264.9 ± 3.9 (stat) ± 9.9 (sys) ± 17.2 (lumi) pb (177 pb^{-1})
$Z \to \mu\mu$	248 ± 5.9 (stat) ± 7.6 (sys) ± 15 (lumi) pb (72 pb^{-1})	291.3 ± 3.0 (stat) ± 6.9 (sys) ± 18.9 (lumi) pb (148 pb^{-1})
$W \to e\nu$	2780 ± 14 (stat) ± 60 (sys) ± 166 (lumi) pb (central, 72 pb^{-1}) 2874 ± 34 (stat) ± 167 (sys) ± 172 (lumi) pb (plug, 64 pb^{-1})	2865 ± 8.3 (stat) ± 76 (sys) ± 186 (lumi) pb (177 pb^{-1})
$W \to \mu\nu$	2768 ± 16 (stat) ± 64 (sys) ± 166 (lumi) pb (72 pb^{-1})	2989 ± 15 (stat) ± 81 (sys) ± 194 (lumi) pb (96 pb^{-1})

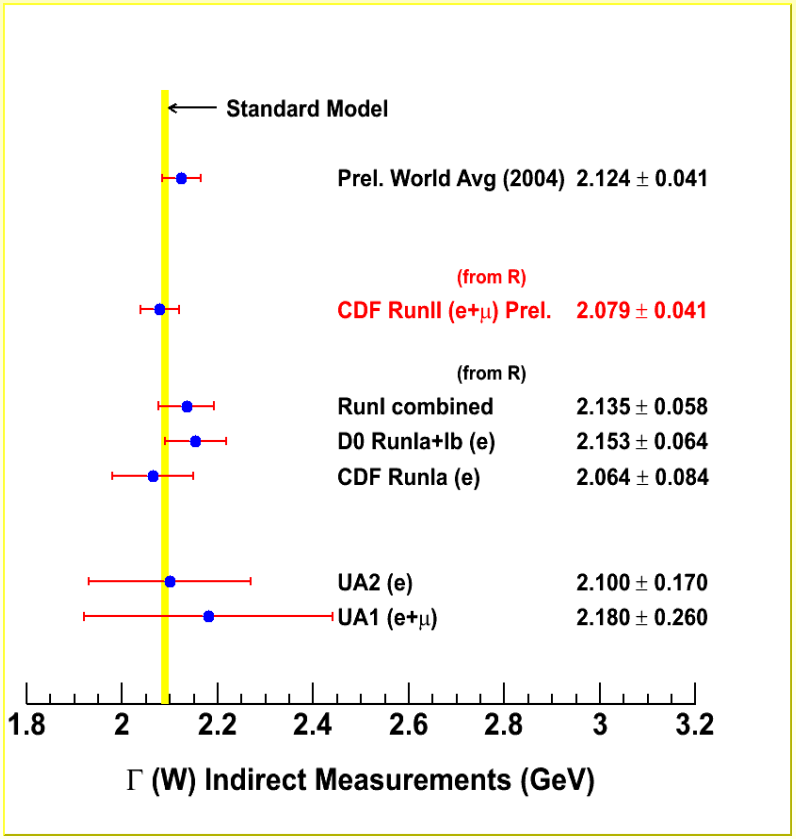
Ratio and Indirect W Width Measurement

$$R = \frac{\sigma(p\bar{p} \to W) \times Br(W \to \ell\nu)}{\sigma(p\bar{p} \to Z) \times Br(Z \to \ell\ell)} = \frac{\sigma(W)}{\sigma(Z)} \frac{1}{Br(Z \to \ell\ell)} \frac{\Gamma(W \to \ell\nu)}{\Gamma_W^{tot}}$$

SM calculation (PDG)

NLO calculations (van Neerven)

PDG (LEP)



CDF (72 pb^{-1}):

$R(e+\mu) = 10.92 \pm 0.15\ (stat) \pm 0.14\ (sys)$

DØ (177 pb^{-1}) :

$R(e) = 10.82 \pm 0.16\ (stat) \pm 0.28\ (sys)$

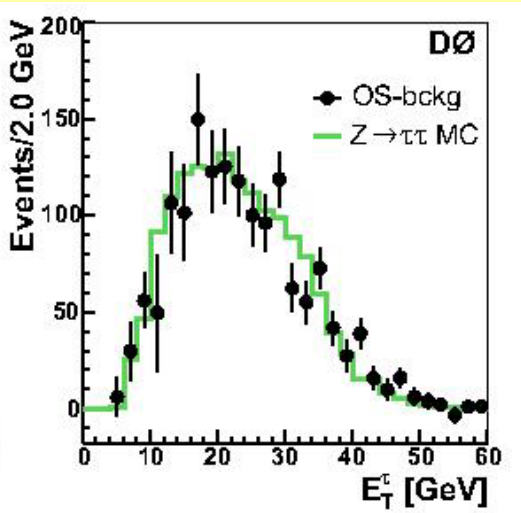
CDF: $\Gamma_W = 2.079 \pm 0.041$ GeV

Word average: $\Gamma_W = 2.124 \pm 0.041$ GeV

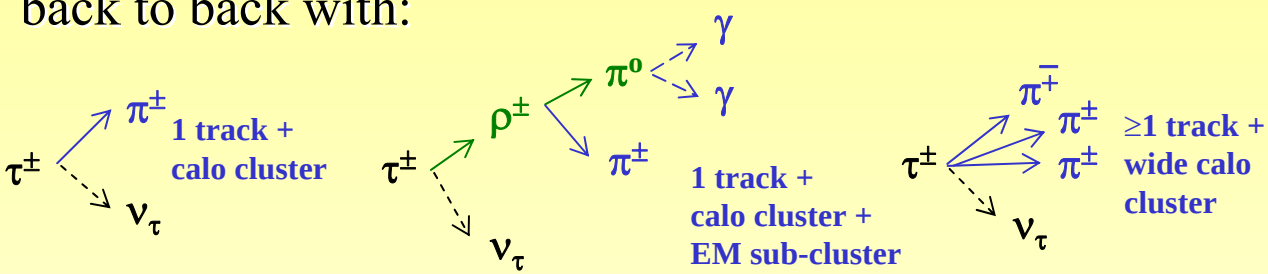
SM value: $\Gamma_W = 2.092 \pm 0.003$ GeV

Physics with τ

τ often enters non SM final states, τ identification is challenging
W/Z→τ cross-section: test the SM and ability to reconstruct τ



DØ: Z→ττ with one τ decaying into muon back to back with:



τ types identified with NNs

Main background: QCD ~ 49%, W→μν + Z→μμ ~ 6 %

Main systematic uncertainties: trigger = 3.5 %, QCD bkg = 3.5%

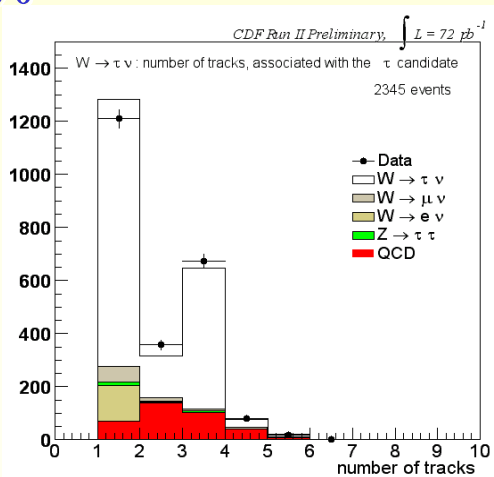
$\sigma(Z\to\tau\tau) = 237 \pm 15$ (stat) $\pm$ 18 (sys) $\pm$ 15 (lumi) pb (226 pb^{-1})

CDF: W→τν (τ→had)

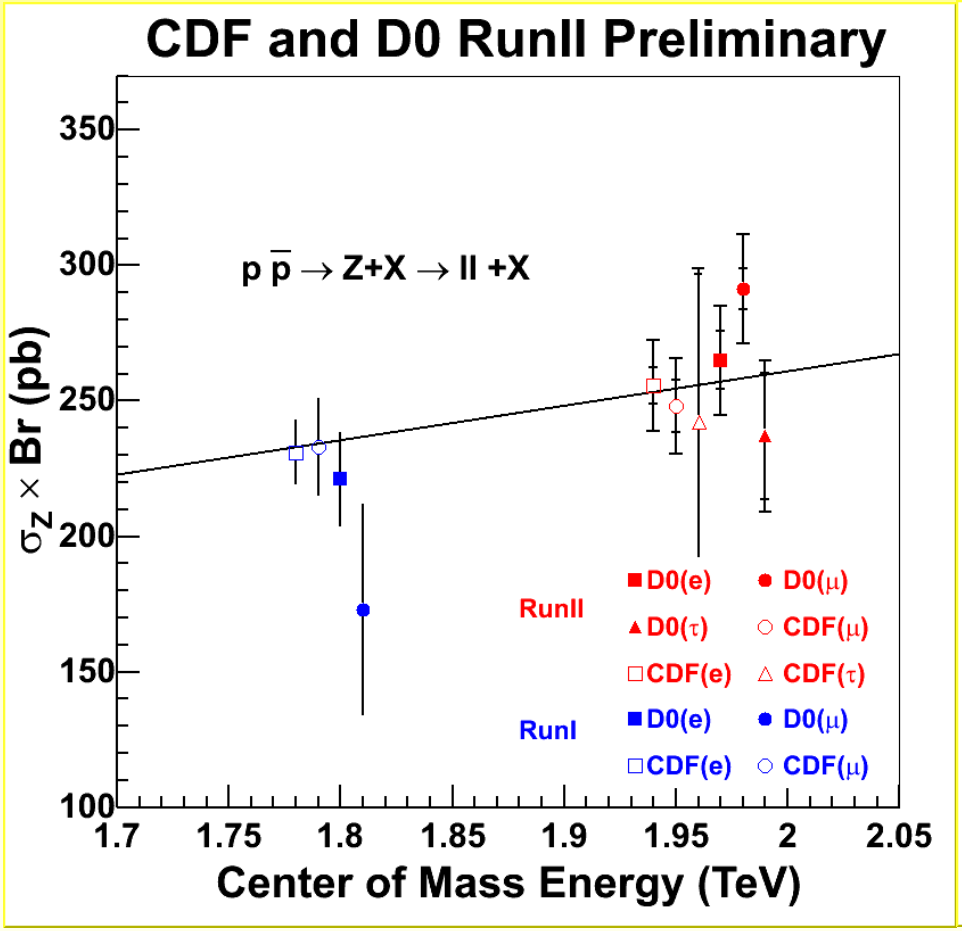
Main background: QCD: dijet ~ 15%, W →eν ~ 4%

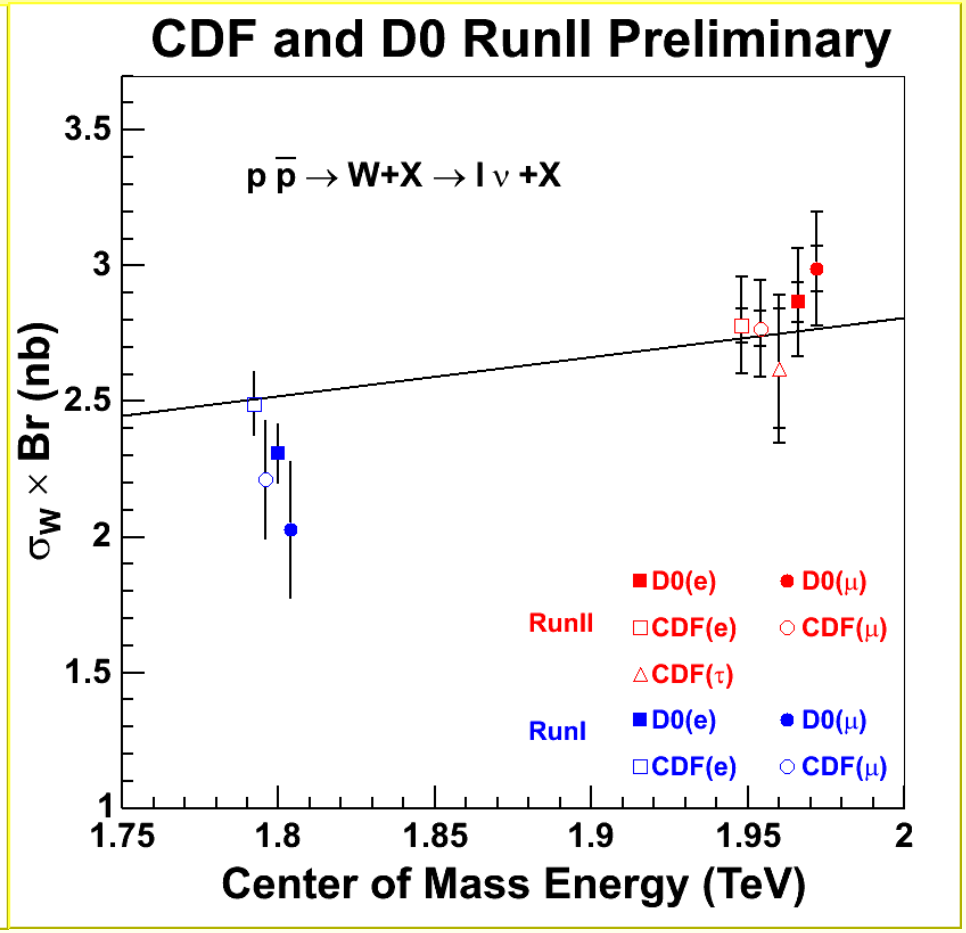
Main systematic uncertainty: τ ID ~ 5.5%

$\sigma(W\to\tau\nu) = 2620 \pm 70$ (stat) $\pm$ 21 (sys) $\pm$ 160 (lumi) pb (72 pb^{-1})



Cross Section Summary





SM curve: C.R. Hamberg, W.L van Neerven and T. Matsuura, Nucl. Phys.B359, 343 (1991)

Lepton Universality

e-μ universality:

tested by CDF with the ratio of the W cross-sections:

$$g_\mu/g_e = 0.998 \pm 0.004\ (\text{stat}) \pm 0.011\ (\text{sys})$$

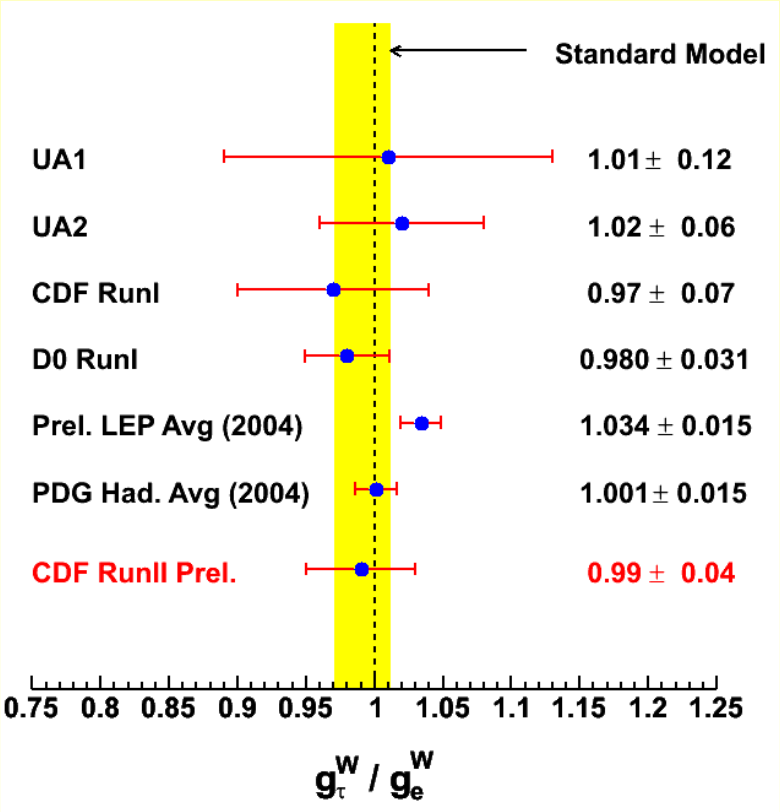
$$\sigma(W) \times Br(W \to \ell\nu) = 2775 \pm 10\ (\text{stat}) \pm 53\ (\text{sys}) \pm 167\ (\text{lumi})\ \text{pb}$$

$$\sigma(Z) \times Br(Z \to \ell\ell) = 254.9 \pm 3.3\ (\text{stat}) \pm 4.6\ (\text{sys}) \pm 15.2\ (\text{lumi})\ \text{pb}$$

e-τ universality:

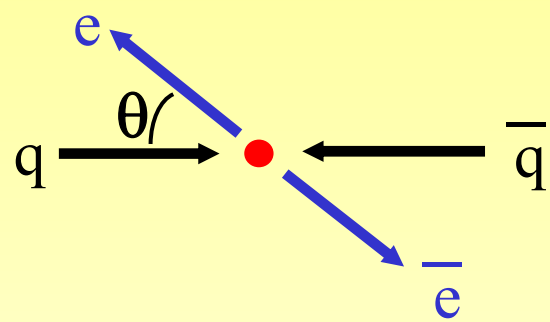
tested by CDF with the ratio of the W cross-sections:

$$g_\tau/g_e = 0.99 \pm 0.02\ (\text{stat}) \pm 0.04\ (\text{sys})$$



Forward Backward Asymmetry in $Z/\gamma^* \rightarrow ee$

The vector and axial-vector nature of the fermion couplings to Z leads to an asymmetry in the lepton production angle.



$$d\sigma(qq' \rightarrow ll)/d\cos\theta = \alpha(\beta(1+\cos^2\theta) + A_{FB}\cos\theta)$$

$$A_{FB} = \frac{d\sigma(\cos\theta > 0)/d\cos\theta - d\sigma(\cos\theta < 0)/d\cos\theta}{d\sigma(\cos\theta > 0)/d\cos\theta + d\sigma(\cos\theta < 0)/d\cos\theta}$$

A_{FB} probes the relative strengths of coupling between Z and quarks.

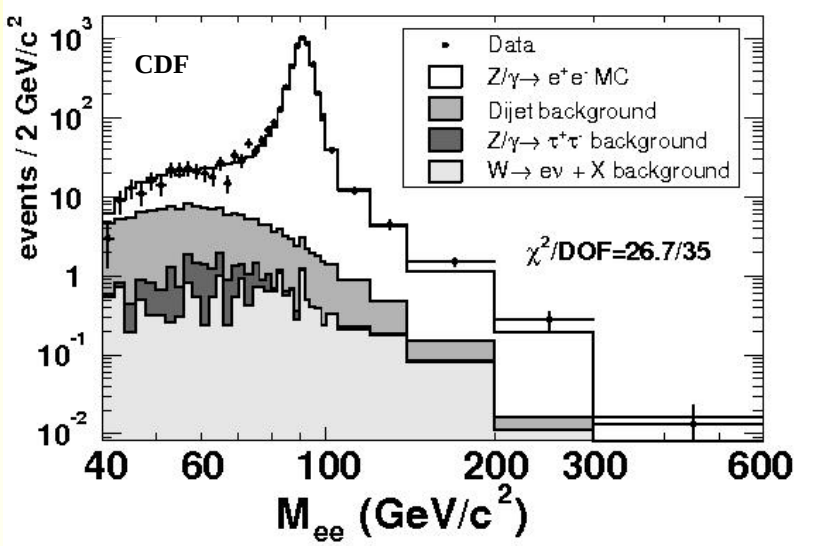
New interaction models (Z', extradimension) predict deviations from SM at high M_{ee}.

CDF measured A_{FB}:

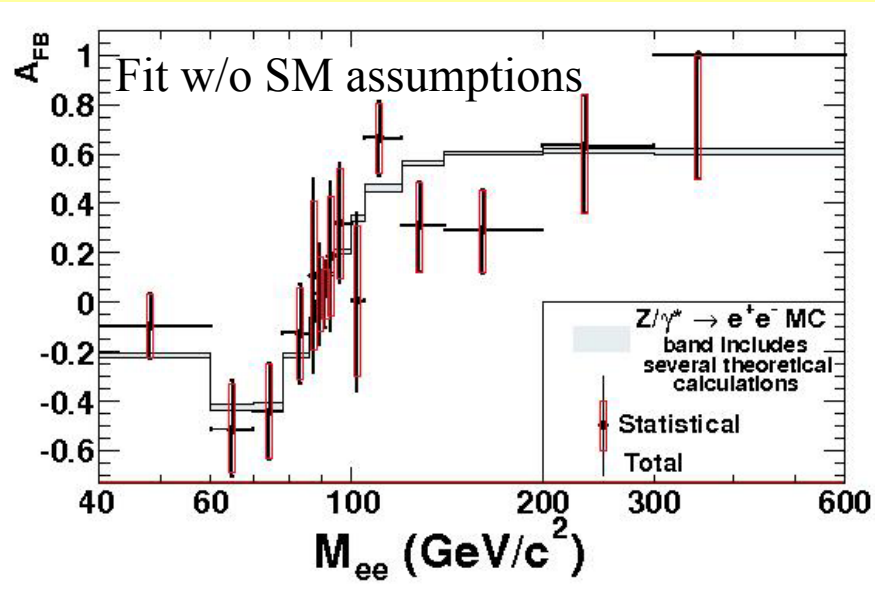
5200 $Z/\gamma^* \rightarrow ee$, 2 isolated e E_T>20GeV

Main background:
QCD (dijet) ~ 1 % (5% forward)

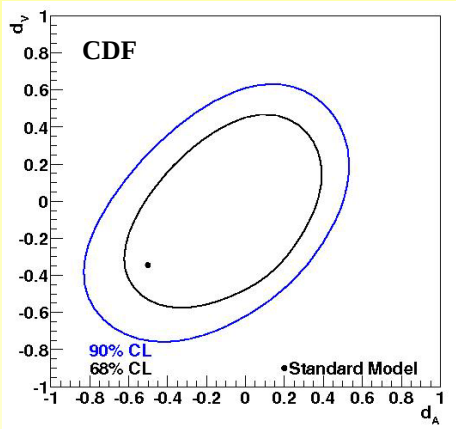
Unfolding method for acceptance and bin migration effects

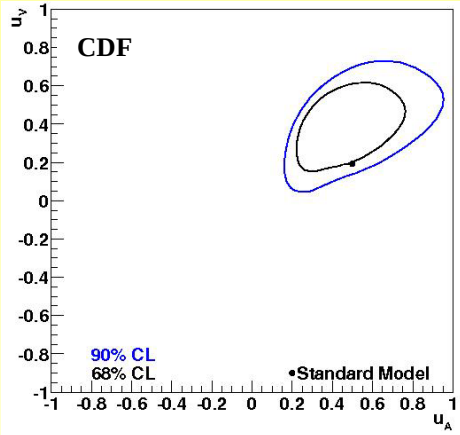


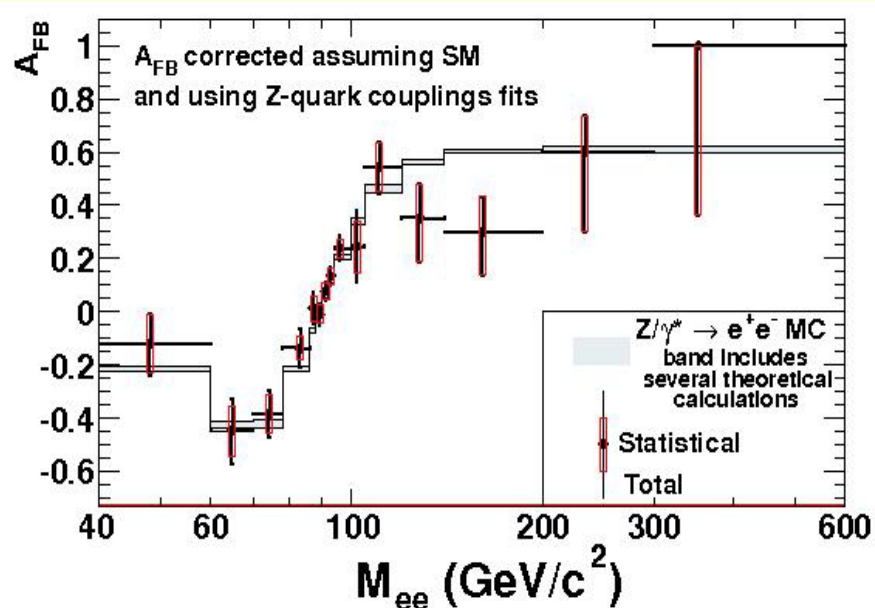
CDF A_{FB} Results



A_{FB} (u_V,u_A,d_V,d_A):
quark coupling extractions to Z







$\sin^2\theta^{eff}_W = 0.2238 \pm 0.0040$ (stat) ± 0.0030 (sys)

$\chi^2/\text{dof} = 12.5/14$

Statistically limited
Consistent with SM

W Charge Asymmetry

Many measurements at a hadron collider are limited by PDF uncertainties.

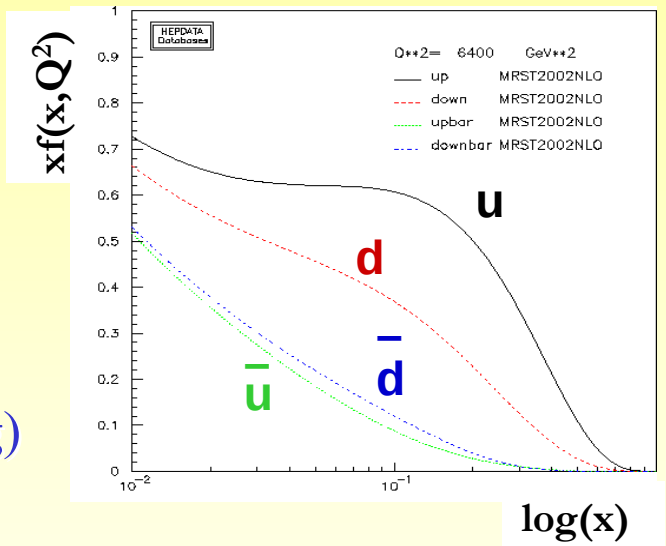
Forward-backward W charge asymmetry gives important input on u and d PDF.

u quarks carry higher fraction of the proton momentum:

$u\bar{d} \rightarrow W^+$ boosted in the proton direction

$$x_{1(2)} = \frac{M_W}{\sqrt{s}} e^{+(-)y_W}$$

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



Measure y_e instead of y_W (assume SM $W \rightarrow e\nu$ coupling)

CDF measured $A(y_W)$:

77930 $W \rightarrow e\nu$, $E_T(e)>25$GeV, $\not{E}_T>25$GeV

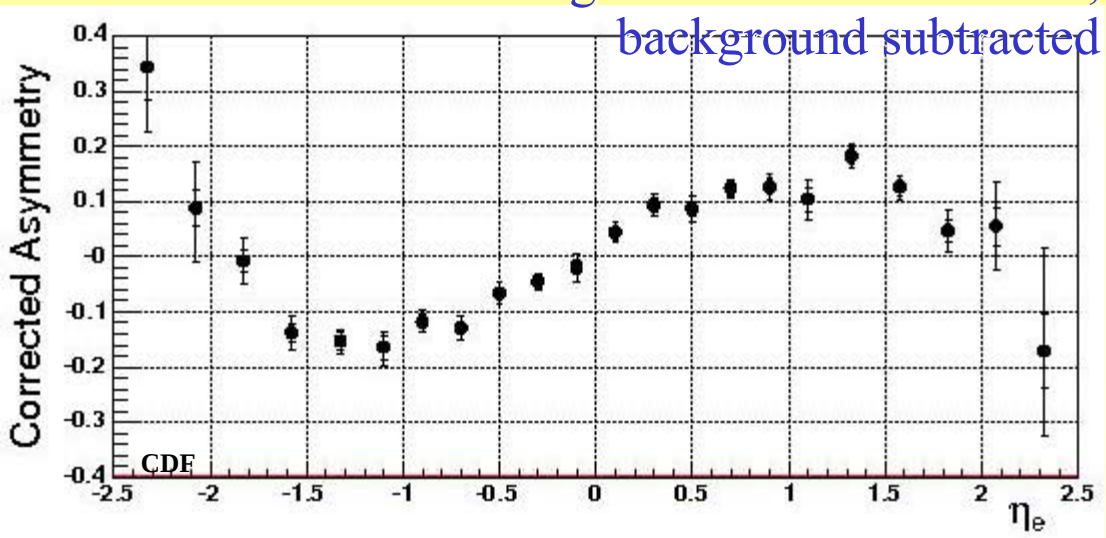
Main background:

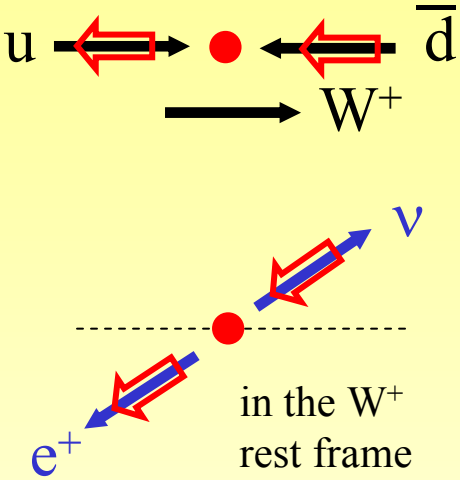
QCD (dijet) < 2 % (<15% forward)

Main systematic uncertainty: charge misidentification

CDF $A(y_W)$ Results

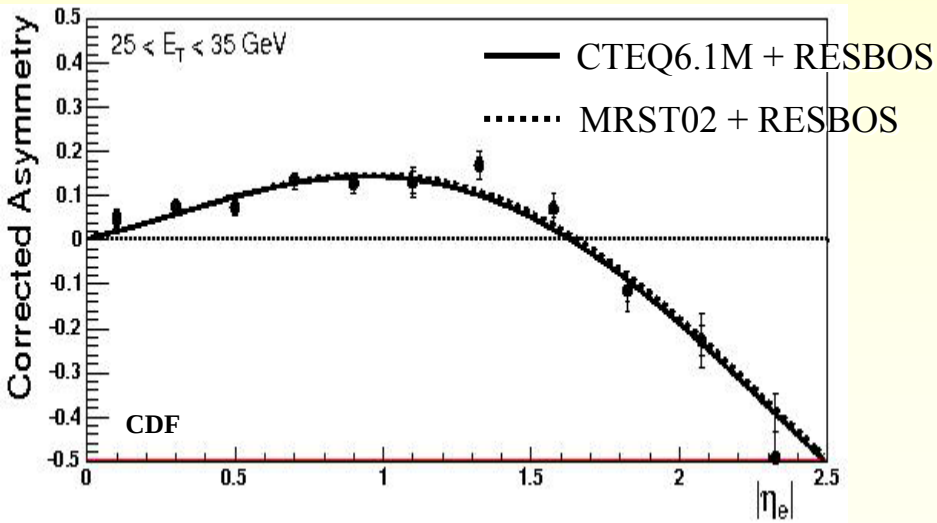
Corrected for charge misidentification rate, background subtracted

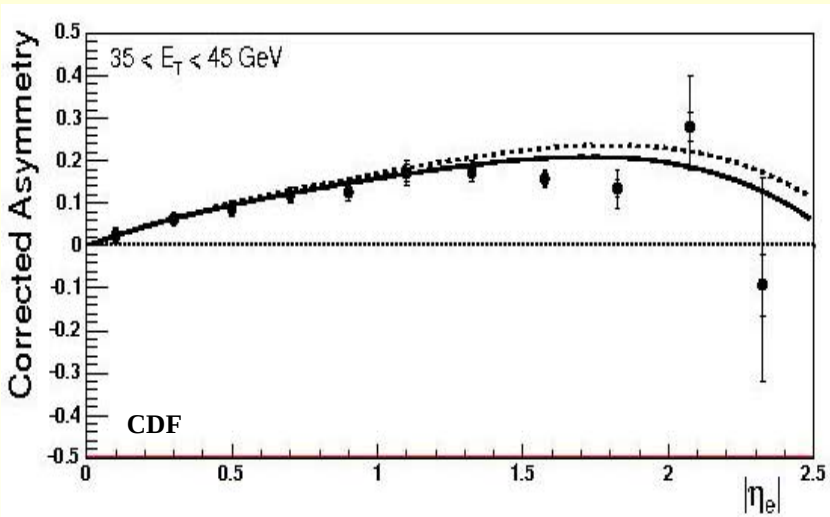




No indication of CP asymmetry

Gain sensitivity with separated E_T bins



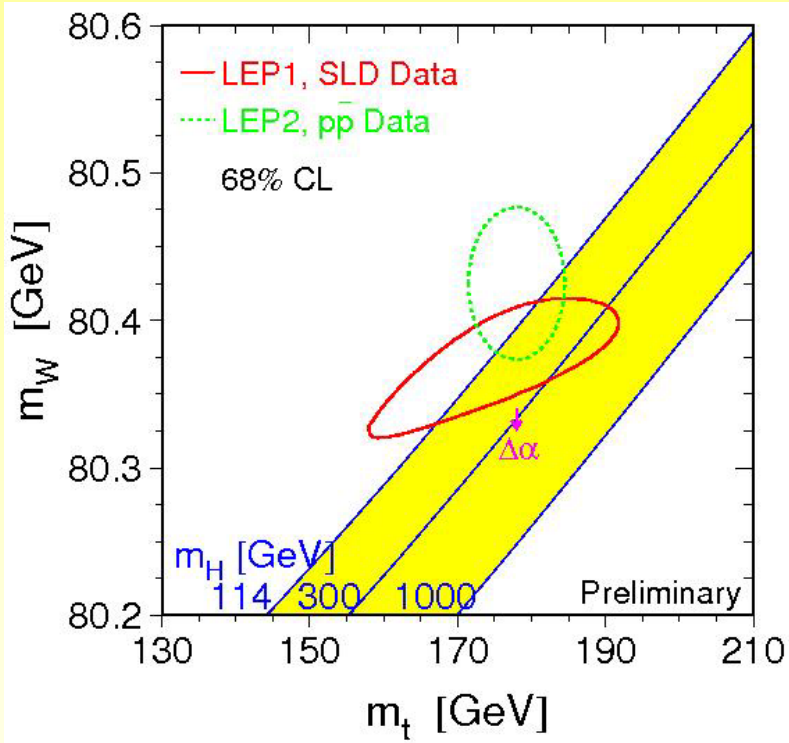


W Mass and Direct Width Measurements

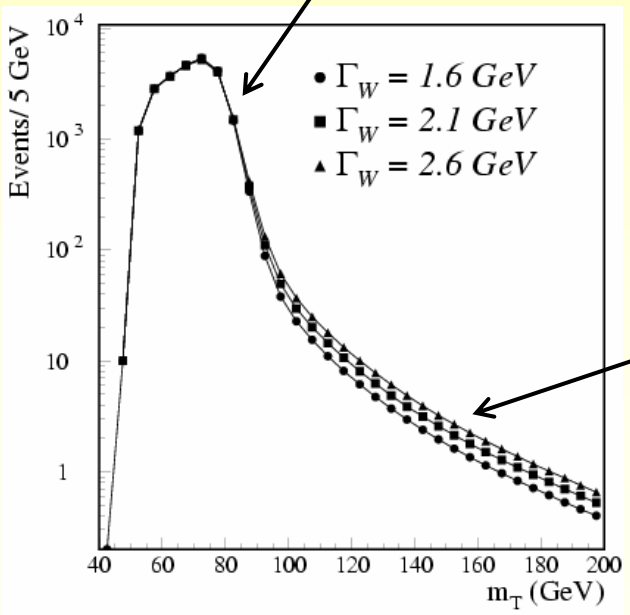
W mass and couplings test the nature of the electroweak symmetry breaking.

$$M_W^2 = \frac{\pi\alpha(M_Z^2)}{\sqrt{2}G_F}\frac{1}{(1-(M_W^2/M_Z^2))}\frac{1}{(1-\Delta r)}$$

$\Delta r \sim Mt^2$, $\Delta r \sim \ln(M_H)$



mass



width

Require the best knowledge of the detectors

Run I Combined W Mass and Width Results

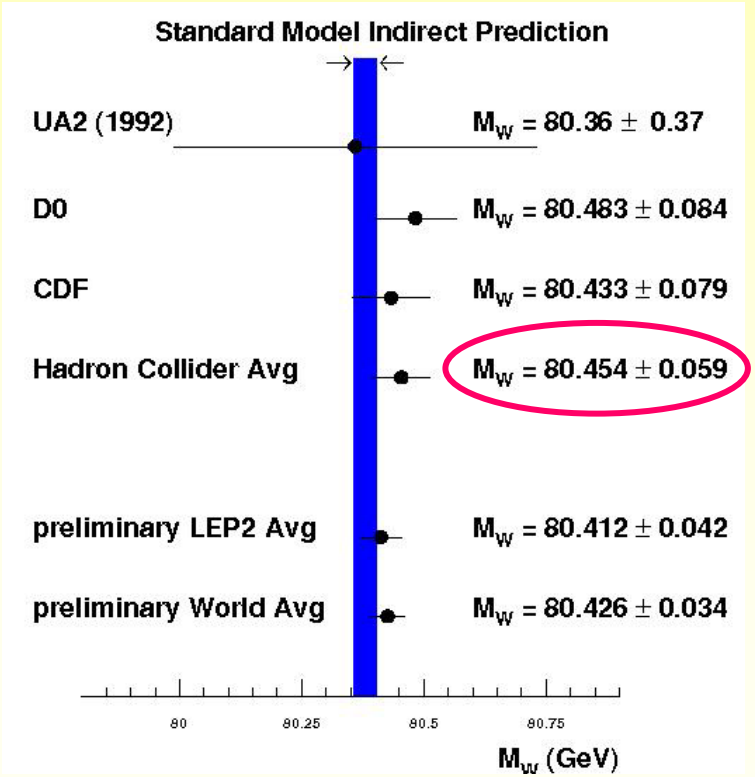
Published: Phys. Rev. D70: 092008, 2004

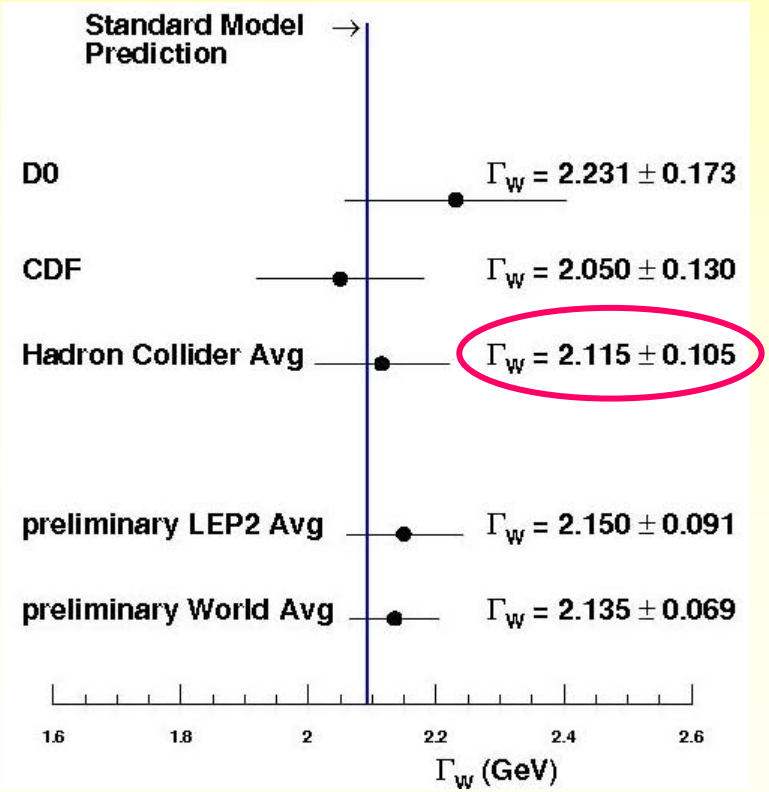
Correlated uncertainties on W mass

	CDF	DØ
PDF	15	8
Radiative corr	11	12
W width	10	10
Total	19 MeV	

Uncorrelated uncertainties

- statistics
- lepton scale and resolution
- $p_T(W)$ and recoil
- background





DØ Run II W Width Direct Measurement

Method: fit the transverse mass distribution in the region $100 < M_T(W) < 200$ GeV

Selection: $W \rightarrow e\nu$, 177 pb^{-1}

625 candidates with $100 < M_T(W) < 200$ GeV

Main systematic uncertainties:

Hadronic response and resolution ~ 64 MeV

Underlying event ~ 47 MeV

EM resolution ~ 30 MeV

Simulation:

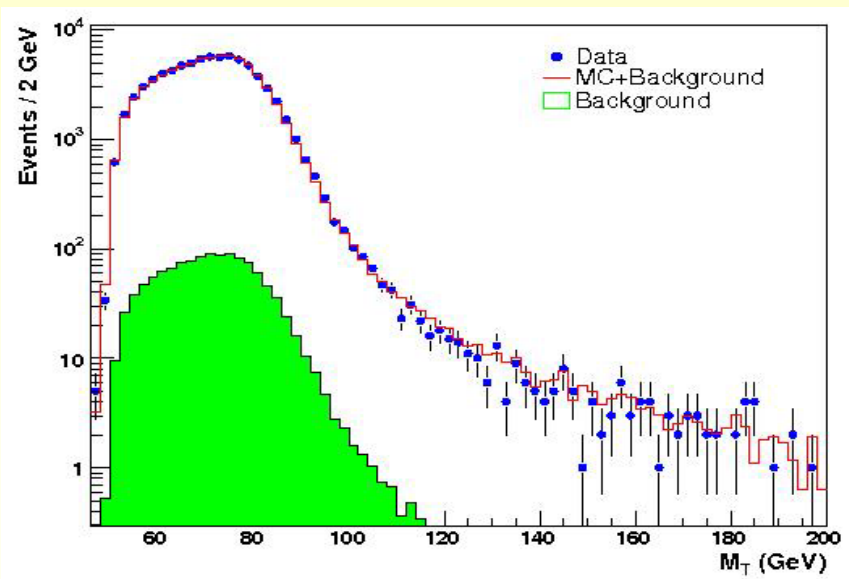
EM calorimeter response:

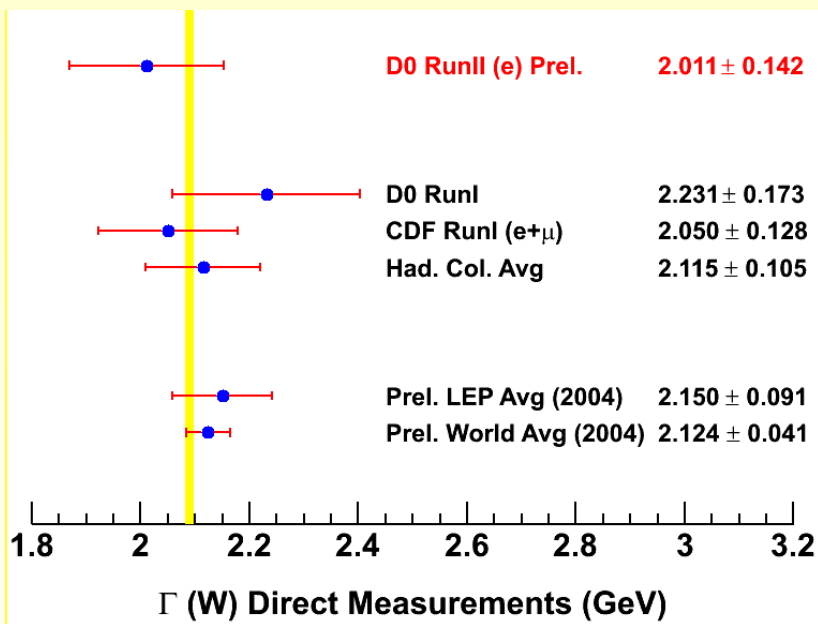
$E = \alpha E + \beta$ ($\alpha = 1.0054 \pm 0.001$)

EM calorimeter resolution:

$\sigma/E = \sqrt{C^2 + S^2/E}$ ($C = 4.20 \pm 0.23$ %)

$\Gamma_W = 2.011 \pm 0.093$ (stat) ± 0.099 (sys)



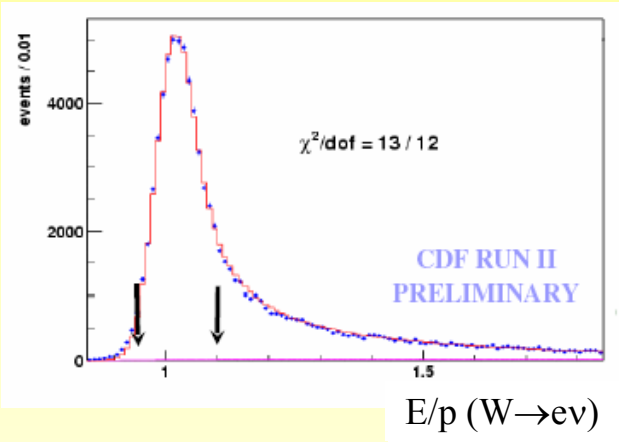


CDF Run II W Mass Analysis

$W \rightarrow e/\mu\nu$, ~ 200 pb^{-1}, first part of analysis complete, uncertainties determined

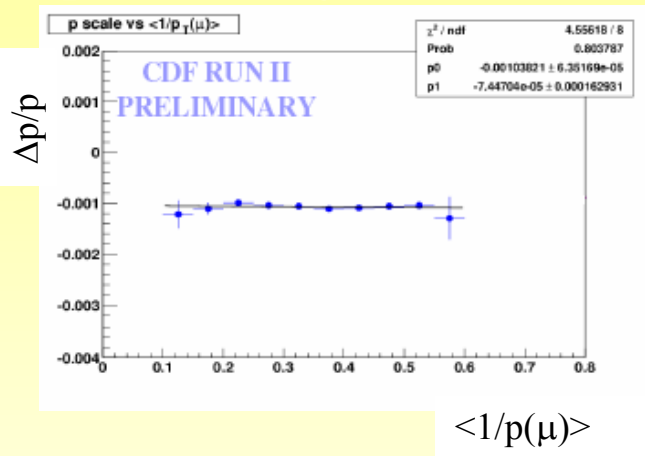
Electron channel

Energy scale using E/p



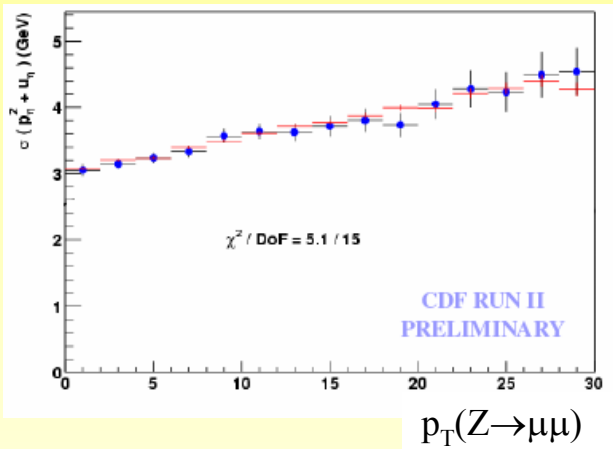
Muon channel

p scale using J/Ψ and Υ



Recoil model

Tune using $Z \rightarrow \mu\mu$



Systematic uncertainties in MeV	e	μ
Lepton energy scale and resolution	70	30
Recoil scale and resolution	50	50
Statistics	45	50
Production and decay model	30	30
Background	20	20

Total: 76 MeV (RunI: 79 MeV)

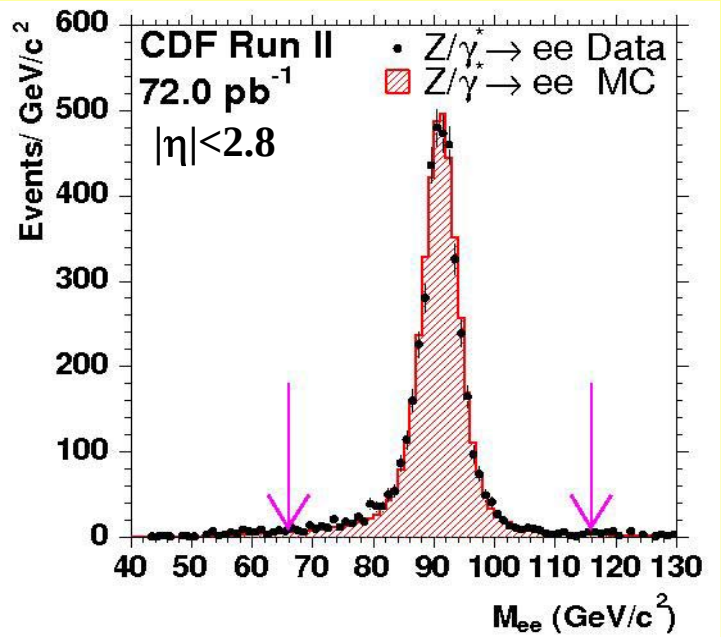
Conclusion

- Extensive electroweak program at Tevatron well underway
  - ✓ cross section measurements
  - ✓ Proof of physics with τ
  - ✓ Asymmetry measurements
  - ✓ W mass underway
- All results consistent with SM expectations
- Expect CDF and DØ to provide higher precision measurements in the incoming years

See results on diboson production in the next talk

Backup Slides

Z to electrons



One or two high Pt lepton (>15 to 25 GeV)

For W: $\not{E}_T$ (>15-25GeV)

Efficiencies computed on data

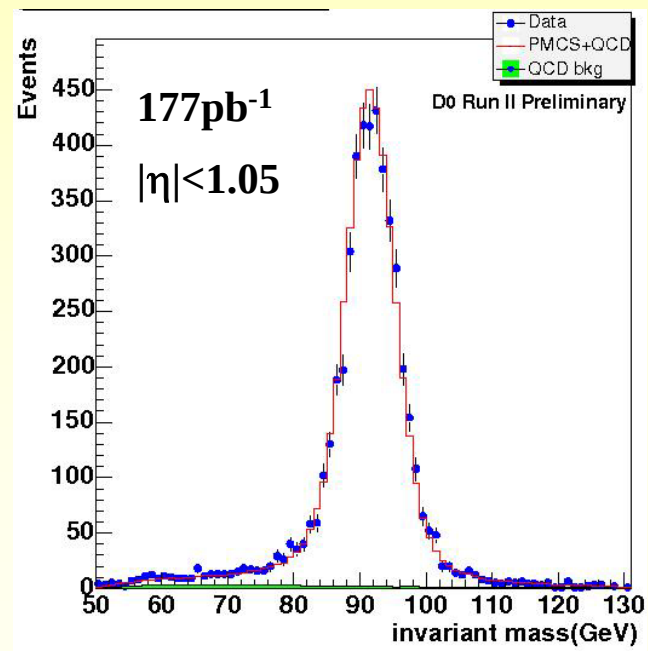
Main background:

QCD: dijet (evaluated on data) ~1-2%

W/Z → τ, Z → μ(for W) ~ 1-6%

Main systematic uncertainty:

PDF ~ 1.5%



CDF: 4242 candidates (72 pb^{-1})

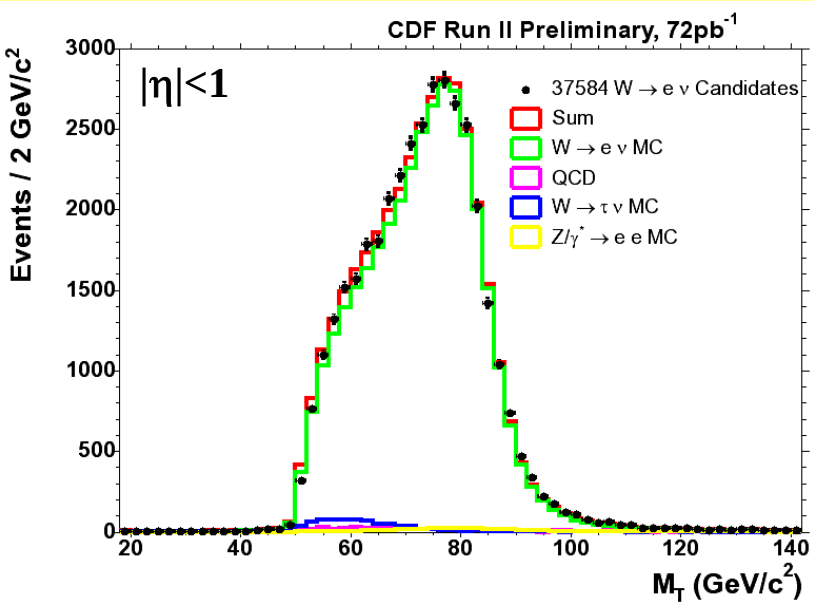
$\sigma = 255.8 \pm 3.9(\text{stat}) \pm 5.5(\text{sys}) \pm 15\ (\text{lumi})$ pb

DØ: 4625 candidates (177 pb^{-1})

$\sigma = 264.9 \pm 3.9(\text{stat}) \pm 9.9(\text{sys}) \pm 17.2\ (\text{lumi})$ pb

Z →ee candle to measure e efficiencies, calibrate the calorimeters

W to electron



$E_T(e) > 25$ GeV (central), 20 GeV (forward)

$\not{E}_T > 25$GeV

Main background:

- QCD: dijet (evaluated on data) ~2%
- $W \to \tau\nu + Z \to ee \sim 2\%$

Main systematic uncertainties:

- PDF ~ 1.5%
- electron identification ~ 1.5%

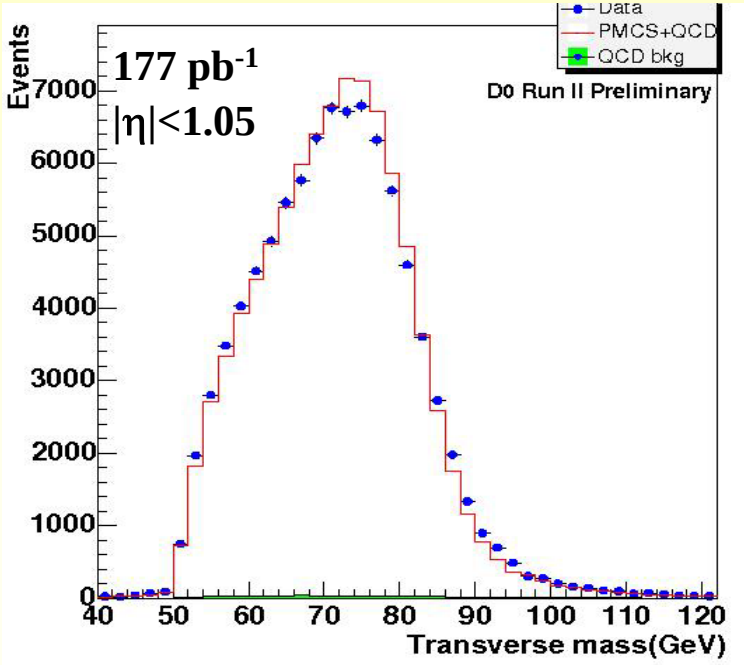
CDF: 37584 candidates (in central, 72 pb^{-1})

$\sigma = 2780 \pm 14(\text{stat}) \pm 60(\text{sys}) \pm 166$ (lumi) pb (central)

$\sigma = 2874 \pm 34(\text{stat}) \pm 167(\text{sys}) \pm 172$ (lumi) pb (plug)

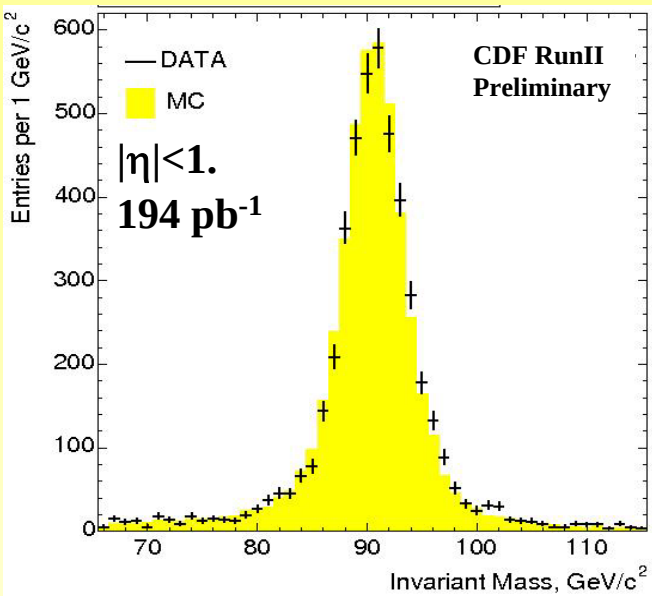
DØ: 116569 candidates (177 pb^{-1})

$\sigma = 2865 \pm 8.3(\text{stat}) \pm 76(\text{sys}) \pm 186$ (lumi) pb



F. Deliot, Moriond EW'05

Z to muons



2 muons with P_T> 20 GeV (CDF), 15 GeV (DØ)

Efficiencies computed on data

very small background ~ 1 % (QCD, $Z \rightarrow \tau\tau$, …)

Main systematic uncertainties:

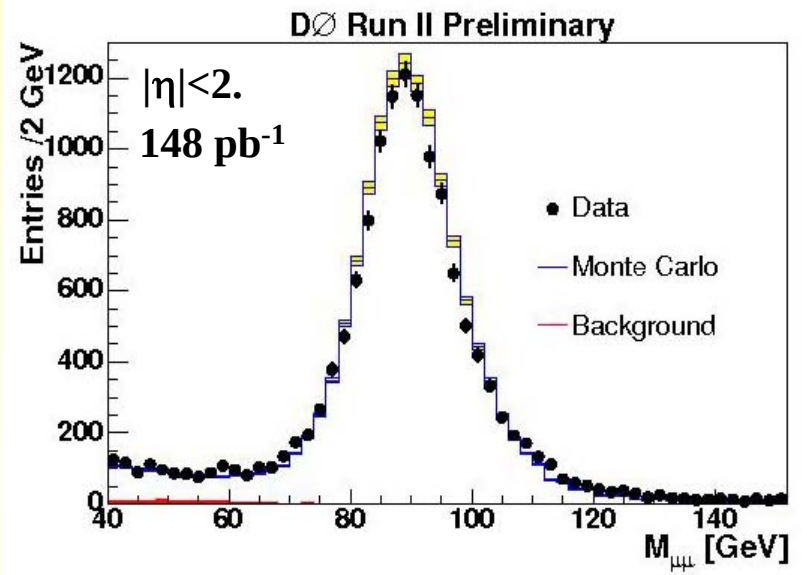
- efficiencies ~ 1%,
- Drell Yan correction ~ 1.5%
- PDF ~ 1.5 %

CDF: 3568 candidates (194 pb^{-1})

$\sigma = 251 \pm 4.2(stat) \pm 7.3(sys) \pm 15.2(lumi)$ pb

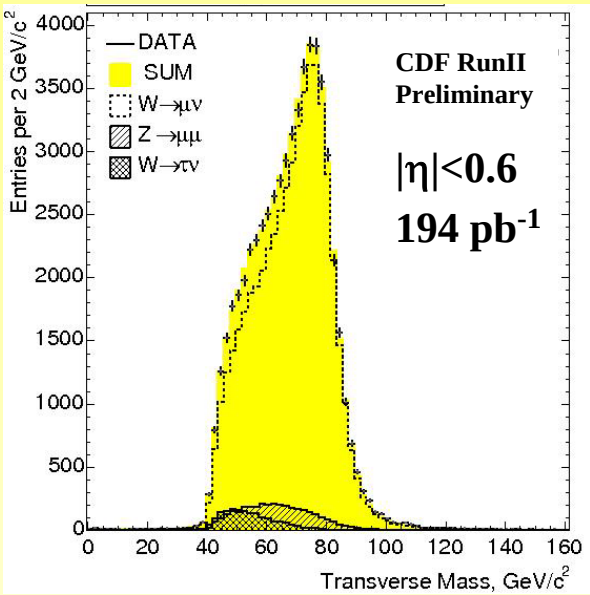
DØ: 14352 candidates (148 pb^{-1})

$\sigma = 291.3 \pm 3.0(stat) \pm 6.9(sys) \pm 18.9$ (lumi) pb



$Z \rightarrow \mu\mu$ candle to measure μ efficiencies on data

W to muon



$P_T(\mu) > 20$ GeV, $\not{E}_T > 20$GeV

Main background:

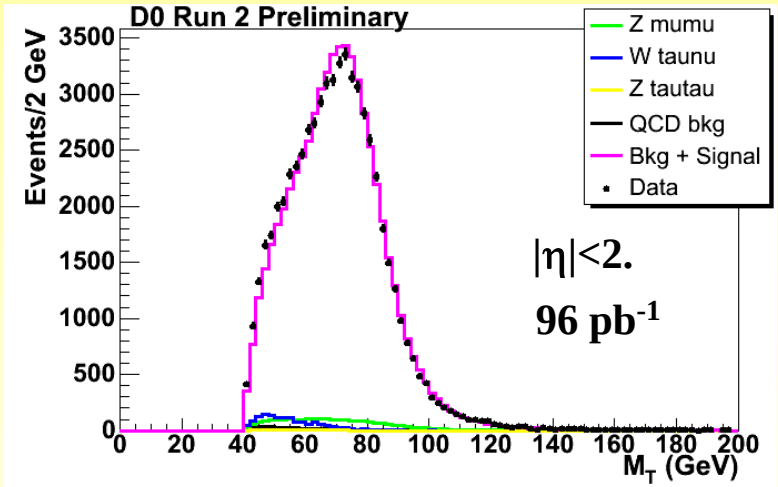
QCD: $b\bar{b}$ (evaluated on data) ~1%

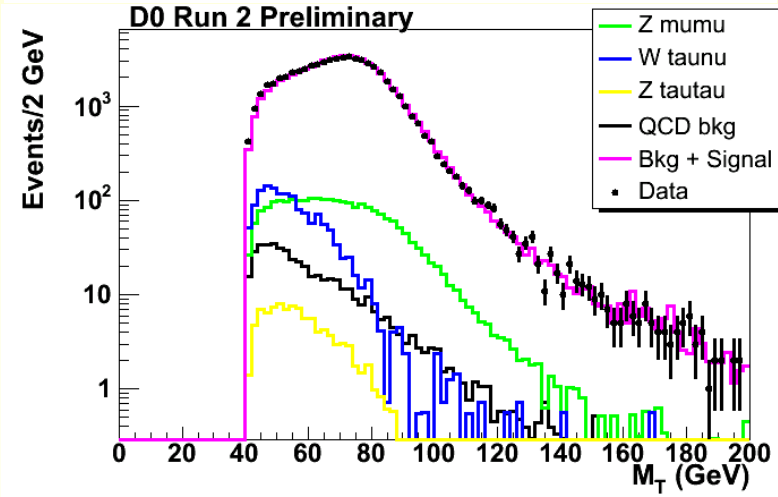
$W \to \tau\nu + Z \to \mu\mu$ ~ 6%

Main systematic uncertainties:

PDF ~ 1.%

efficiencies ~ 1.5%





CDF: 57109 candidates (194 pb^{-1})

$\sigma = 2786 \pm 12(stat) \pm 60(sys) \pm 166$ pb

DØ: 62285 candidates (96 pb^{-1})

$\sigma = 2989 \pm 15(stat) \pm 81(sys) \pm 194$ pb

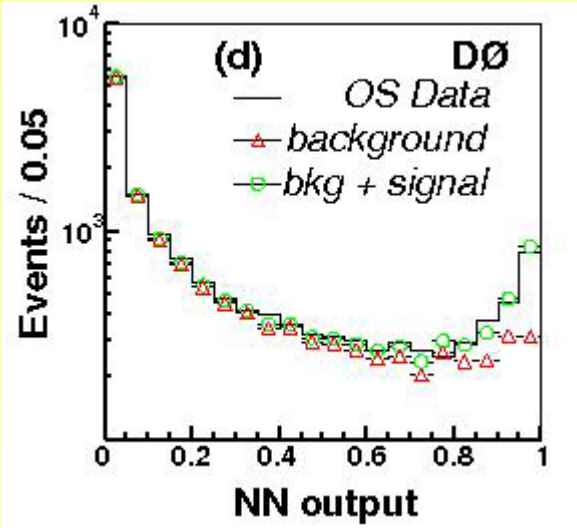
τ at DØ

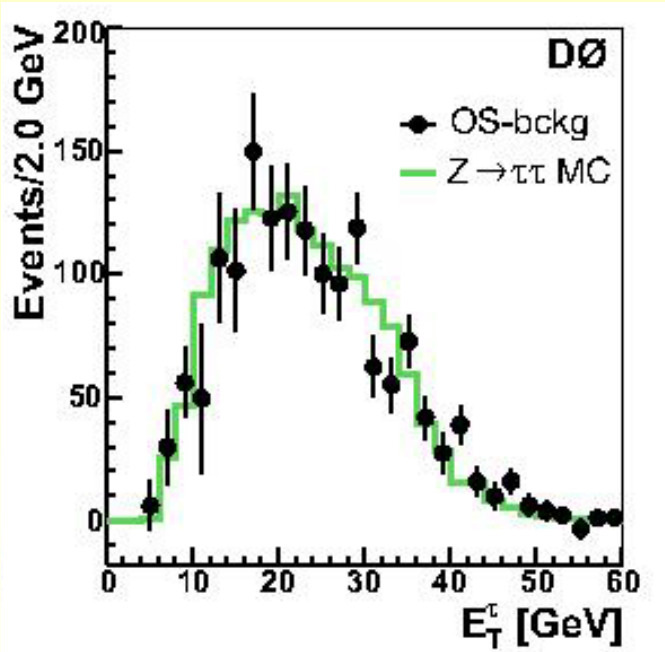
$Z \rightarrow \tau\tau$ with one τ decaying into muon

back to back with:

1. τ "π like": one track + calo cluster (no EM subclusters)
2. τ "ρ like": one track + calo cluster + EM subclusters
3. 1 ≥ tracks and a calo cluster

τ types identified with NNs





Main background:

QCD ~ 49%, $W \rightarrow \mu\nu + Z \rightarrow \mu\mu$ ~ 6 %

Main systematic uncertainties:

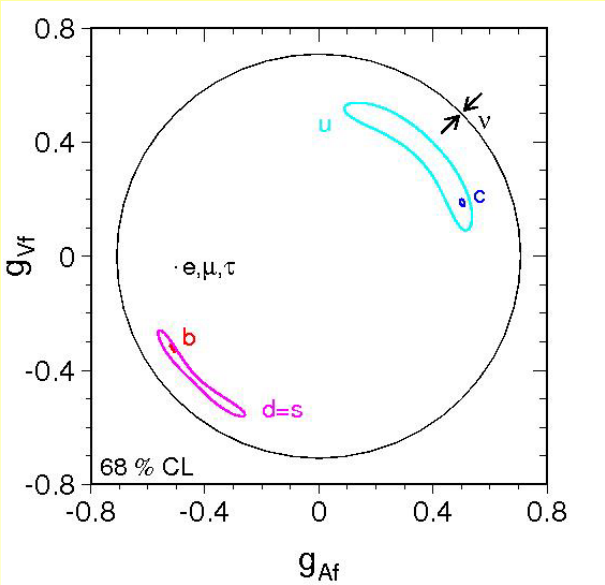
trigger = 3.5 %

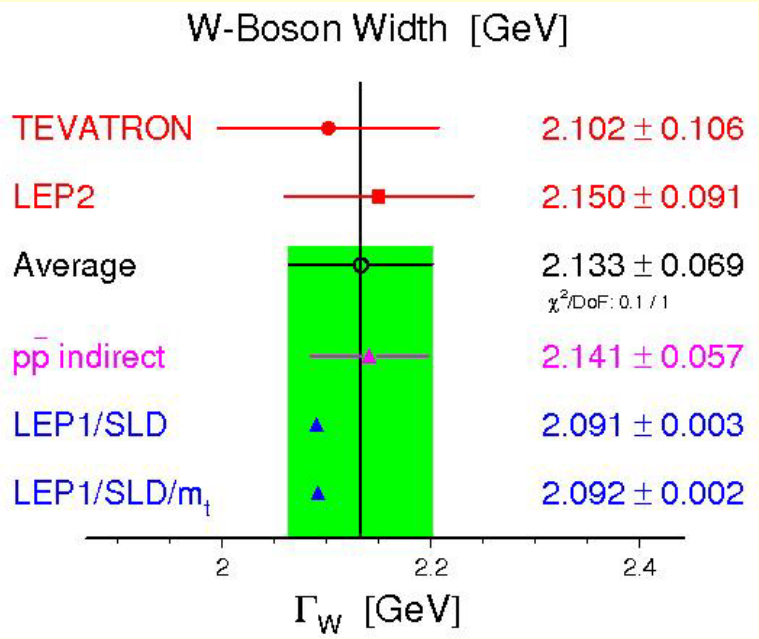
QCD background = 3.5%

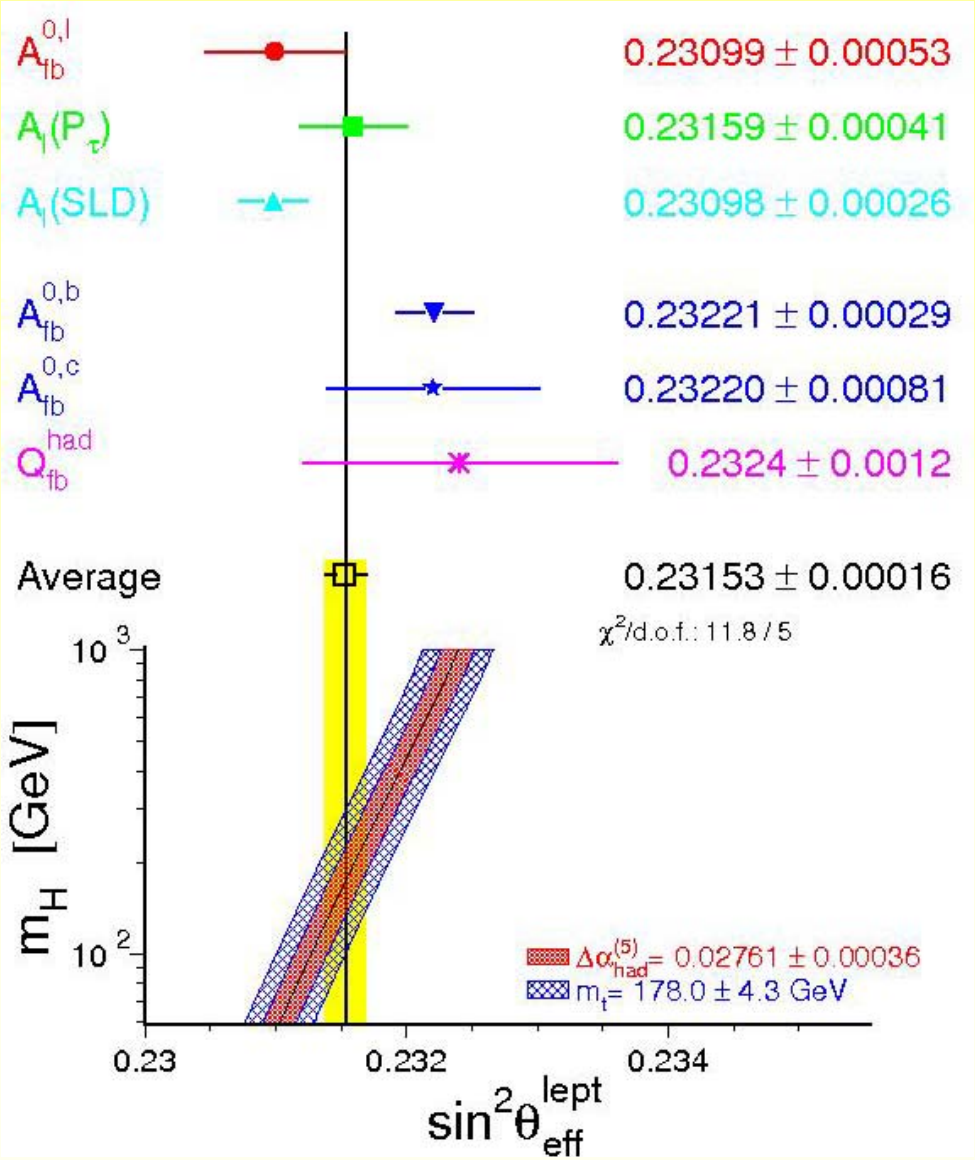
DØ: 1104 candidates (226 pb^{-1})

$\sigma = 237 \pm 15(stat) \pm 18(sys) \pm 15\ (lumi)$ pb

LEP Results


0.8
0.4
0
-0.4
-0.8
-0.8
-0.4
0
0.4
0.8
g_{Vf}
g_{Af}
u
ν
c
e,μ,τ
b
d=s
68 % CL


W-Boson Width [GeV]
TEVATRON
2.102 ± 0.106
LEP2
2.150 ± 0.091
Average
2.133 ± 0.069
χ^2/DoF: 0.1 / 1
$p\bar{p}$ indirect
2.141 ± 0.057
LEP1/SLD
2.091 ± 0.003
LEP1/SLD/m_t
2.092 ± 0.002
2
2.2
2.4
Γ_W [GeV]


$A_{fb}^{0,l}$
0.23099 ± 0.00053
$A_l(P_\tau)$
0.23159 ± 0.00041
A_l(SLD)
0.23098 ± 0.00026
$A_{fb}^{0,b}$
0.23221 ± 0.00029
$A_{fb}^{0,c}$
0.23220 ± 0.00081
Q_{fb}^{had}
0.2324 ± 0.0012
Average
0.23153 ± 0.00016
χ^2/d.o.f.: 11.8 / 5
10^3
10^2
m_H [GeV]
$\Delta\alpha_{had}^{(5)}$ = 0.02761 ± 0.00036
m_t = 178.0 ± 4.3 GeV
0.23
0.232
0.234
$\sin^2\theta_{eff}^{lept}$