Recent Electroweak Results from the Tevatron

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Outline

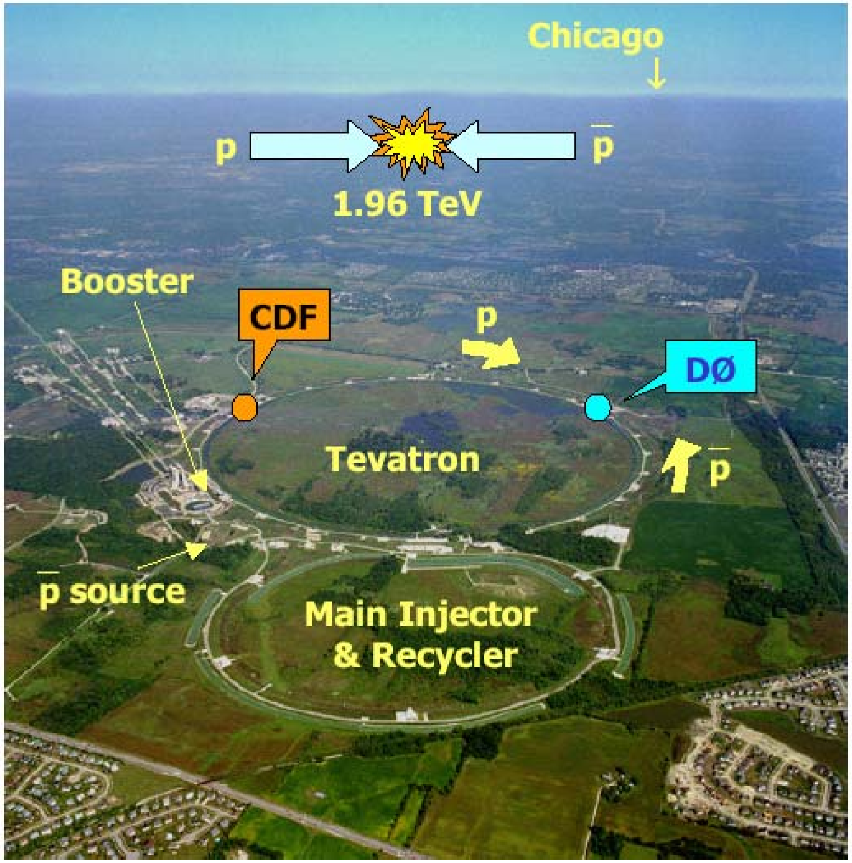
- The Tevatron and the collider experiments at Fermilab: DØ & CDF
- W and Z production cross sections in $p\bar{p}$ collisions, asymmetries, lepton universality, …
- Measurements of W mass and width
- Diboson production
- Summary

For further details and updates, see

http://fcdfwww.fnal.gov/physics/ewk/ (CDF)

http://www-d0.fnal.gov/Run2Physics/WWW/results/ew.htm (DØ)

Run 2 at the Tevatron

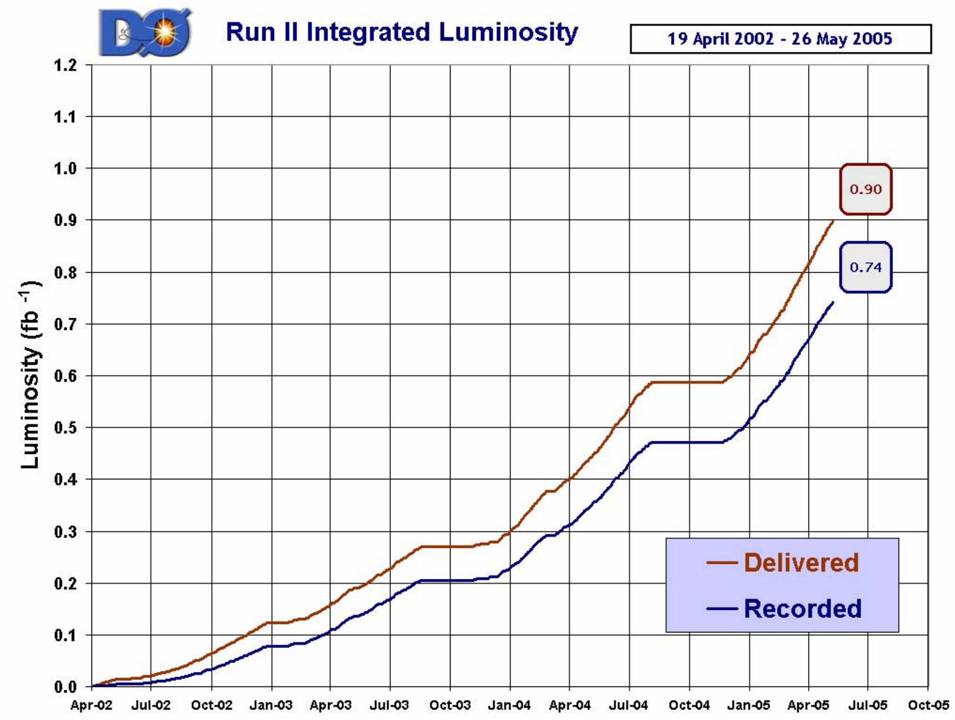


$p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV,

$\int Ldt = 0.8$ fb^{-1} recorded,

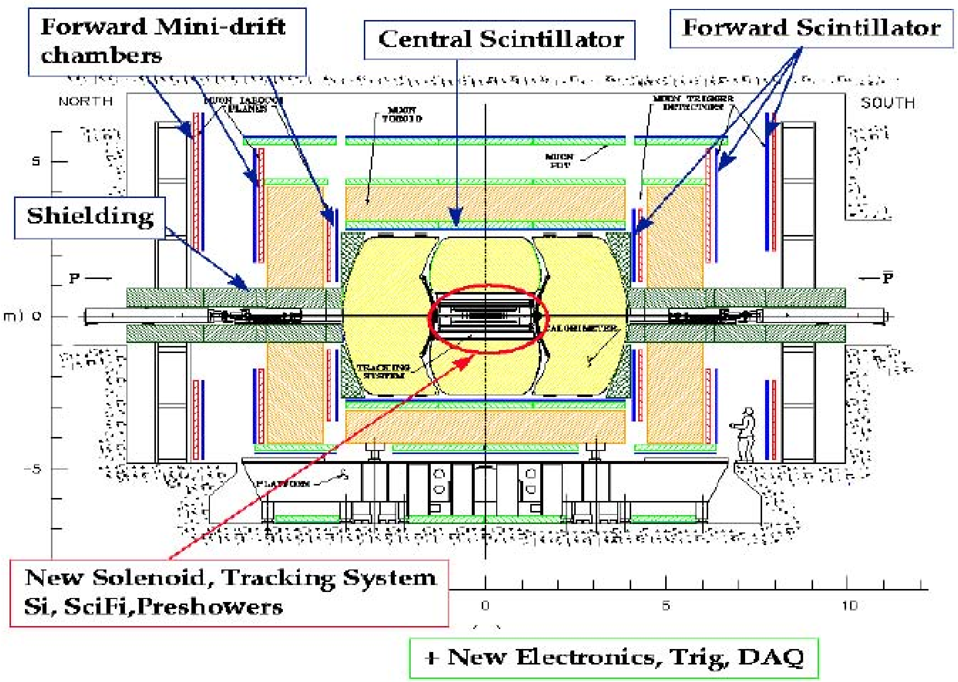
$\int Ldt \approx 0.4$ fb^{-1} analyzed so far,

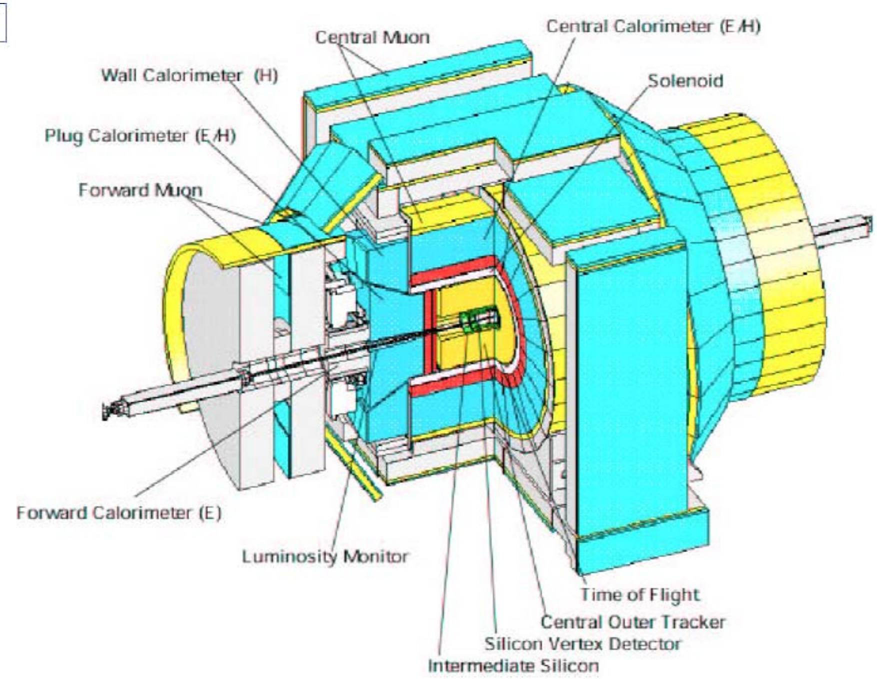
$\int Ldt \approx 4\text{–}8$ fb^{-1} expected by 2009.



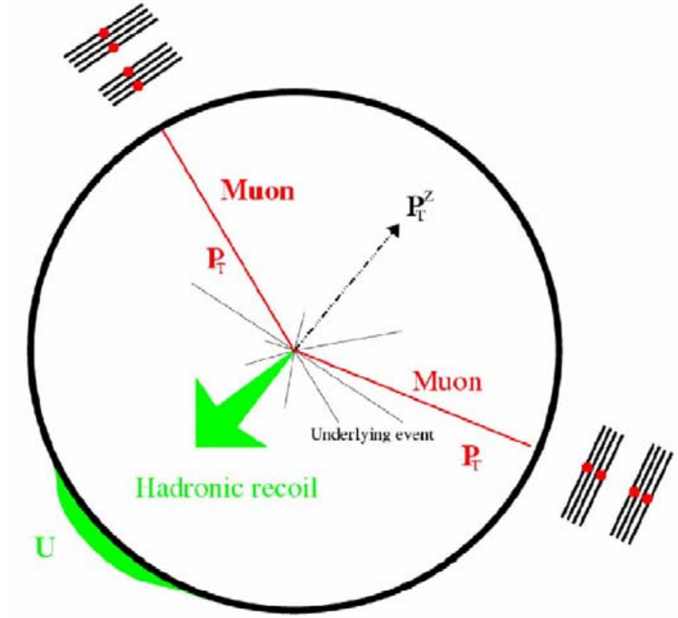
$L > 10^{32}$ cm^{-2}s^{-1} achieved

The DØ and CDF Experiments



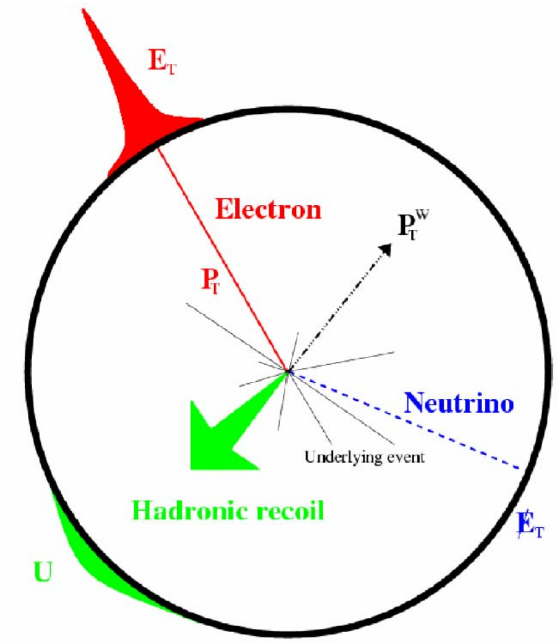


W, Z Production Cross Sections



Motivation:

- Important tests of the SM
- Leptonic (e, μ) decays $\Rightarrow$ clean signal
- Important for detector and luminosity calibrations



Limiting factors:

- Luminosity: $\Delta L/L \approx 6\%$
- PDF's: $\approx 1.5\%$
- Lepton identification efficiencies, statistics, …

Many of these cancel out in $\sigma(W)/\sigma(Z)$ ratios!

General Analysis Method

- Look for high-pT e, μ, ν from decays of W, Z in $p\bar{p} \rightarrow W/Z + X$
- Model signal and physics backgrounds using Monte Carlo,
- Model instrumental backgrounds using data,
- Design selection criteria to maximize expected signal significance,
- Estimate efficiencies using data, acceptance using Monte Carlo and detector simulation,
- $$\sigma \cdot B = \frac{N_{\text{obs}} - \langle N_{\text{bkg}} \rangle}{\varepsilon \cdot A \cdot \int L dt}$$

Some σ(W), σ(Z) results at √s=1.96 TeV

DØ:

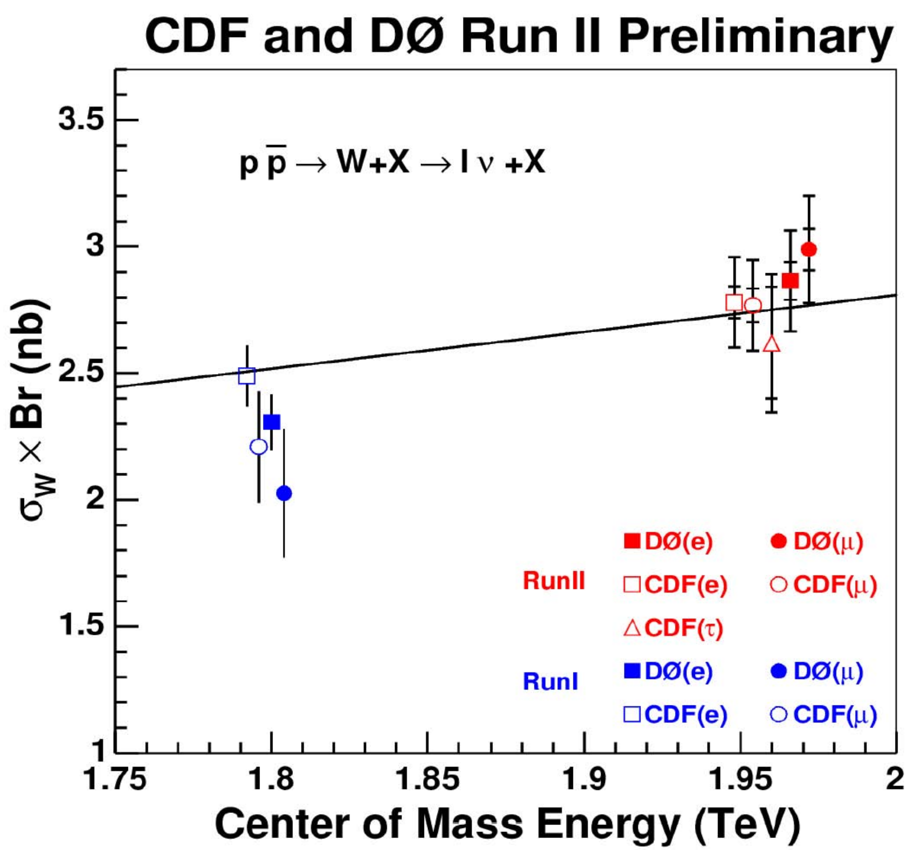
- $\sigma(p\bar{p} \to W) \cdot B(W \to e\nu) =$ 2865 ± 8 (stat) ± 76 (syst) ±186 (lum) pb
- $\sigma(p\bar{p} \to W) \cdot B(W \to \mu\nu) =$ 2989± 15 (stat) ± 81 (syst) ±194 (lum) pb

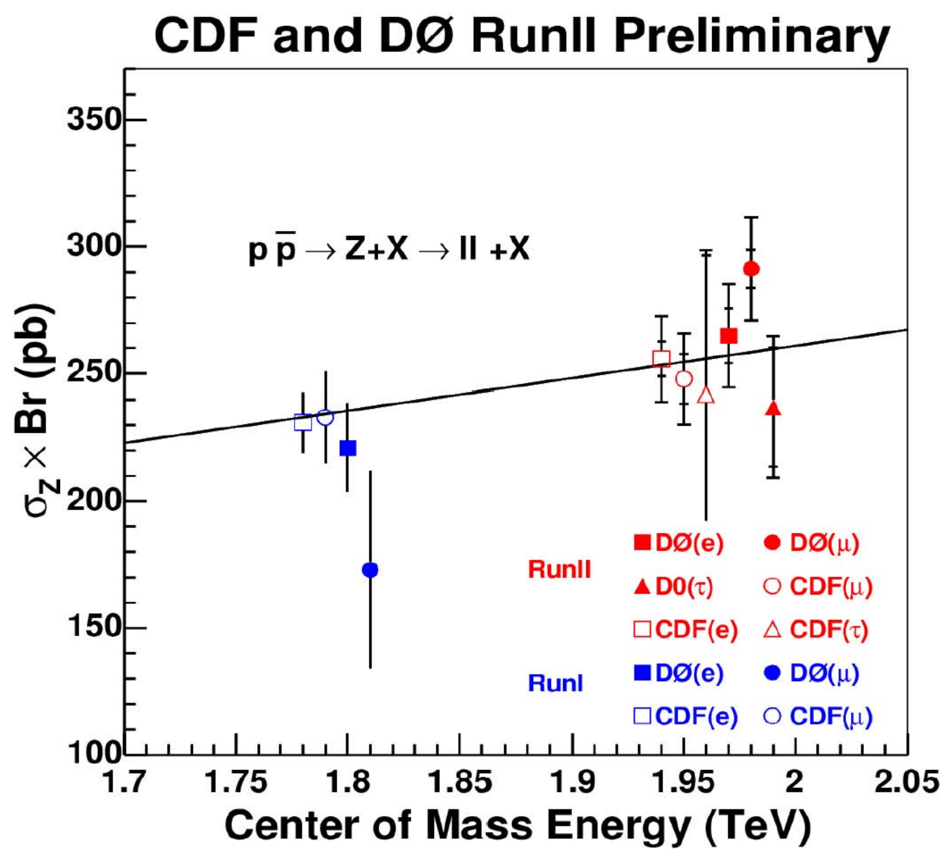
CDF:

- $\sigma(p\bar{p} \to W) \cdot B(W \to \mu\nu) =$ 2786 ±12 (stat) $^{+60}_{-54}$ (syst) ± 166 (lum) pb
- $\sigma(p\bar{p} \to Z) \cdot B(Z \to \mu\mu) =$ 253.1±6.8 (stat) $^{+8.9}_{-8.1}$ (syst) ±15.1(lum) pb
- $R \equiv \dfrac{\sigma(p\bar{p} \to W) \cdot B(W \to \mu\nu)}{\sigma(p\bar{p} \to Z) \cdot B(Z \to \mu\mu)} =$ 11.02 ± 0.18 (stat) ± 0.14 (syst)

Theory: R = 10.69±0.013

W, Z Cross Section Summary





- Theory: NNLO calculations by Hamberg, van Neerven, Matsuura (1991).

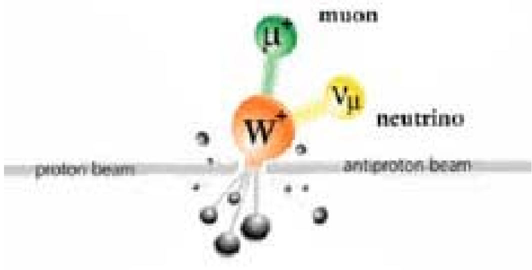
W mass in the Standard Model

- M_W expressed in terms of M_Z, m_t, and electroweak coupling:

$$m_W^2 = \frac{\pi\alpha_{EM}}{\sqrt{2}G_F(1-m_W^2/m_Z^2)(1-\Delta r)}$$

- Total uncertainty is dominated by the radiative correction term Δr ($\approx$0.067) which, in turn, is dominated by m_t and M_H. All others have been measured with precisions of ~10^{-4} or better.
- Thus, measurements of m_t and M_W together constrain M_H.
- Need a precision of 30 MeV on M_W to match the current precision of 4.3 GeV on m_t.

W mass at the Tevatron



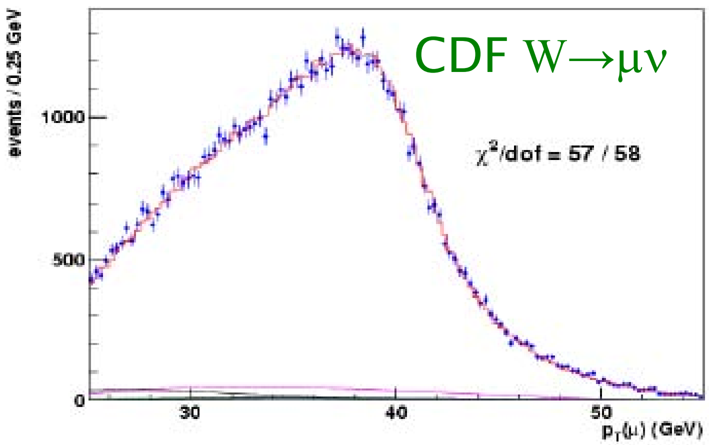
- Charged lepton momenta are the most precisely measured.
- Only the transverse component of neutrino momenta can be inferred after measuring the recoil system.
- Combine $l^{\pm}$ and ν transverse momenta to form W transverse mass:

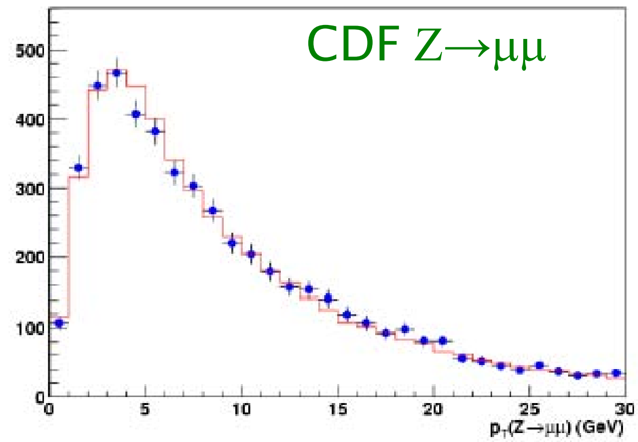
$$M_T^2 = 2 p_T^l p_T^\nu (1 - \cos \Delta\theta)$$

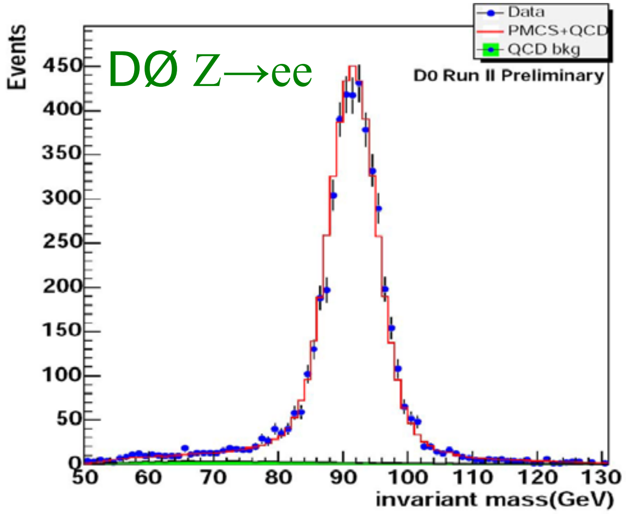
- Use leptonic Z decay events to model soft hadronic recoil system.

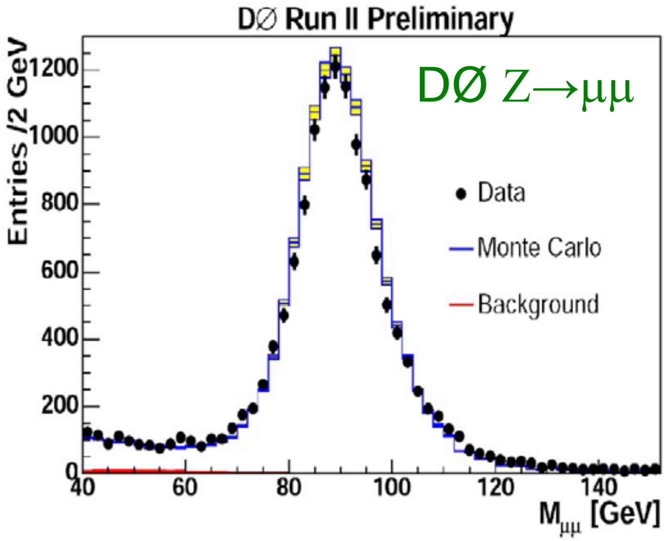
p_T's in W/Z Production & Decay

- Run 2 goal: calibrate charged lepton p_T to 0.01% (now at 0.03%).

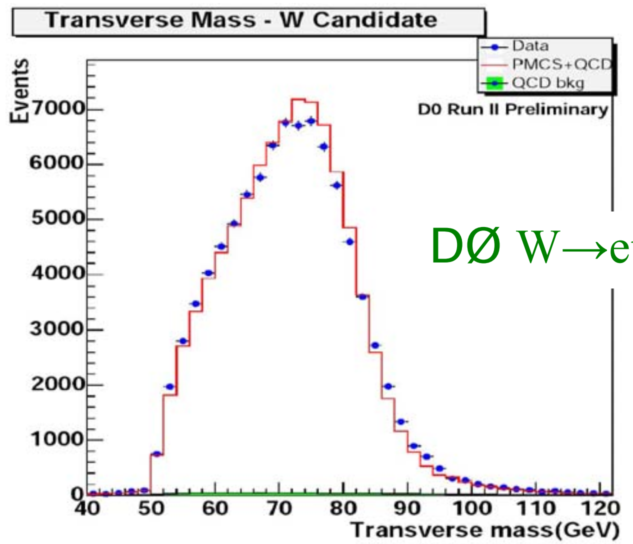


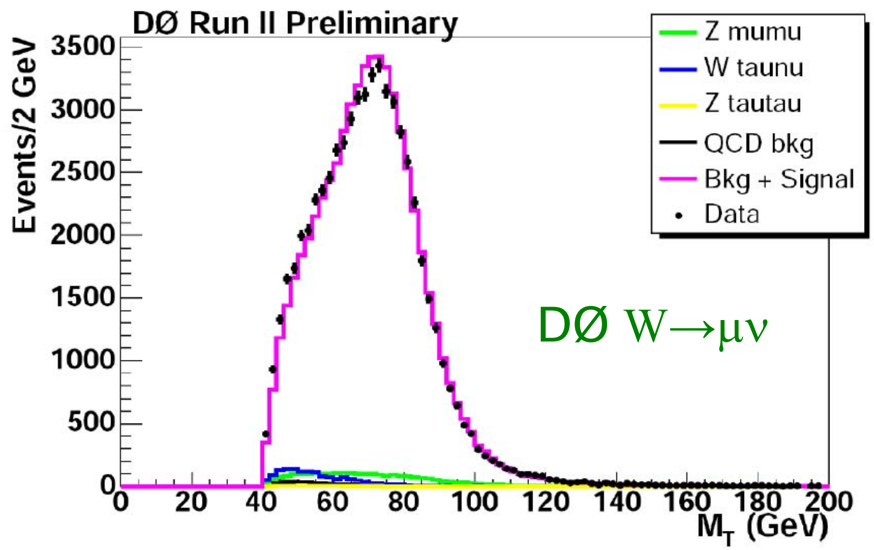


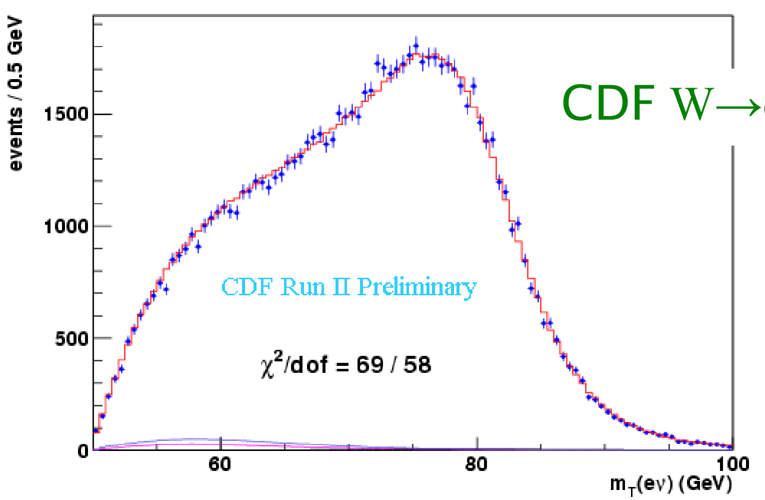


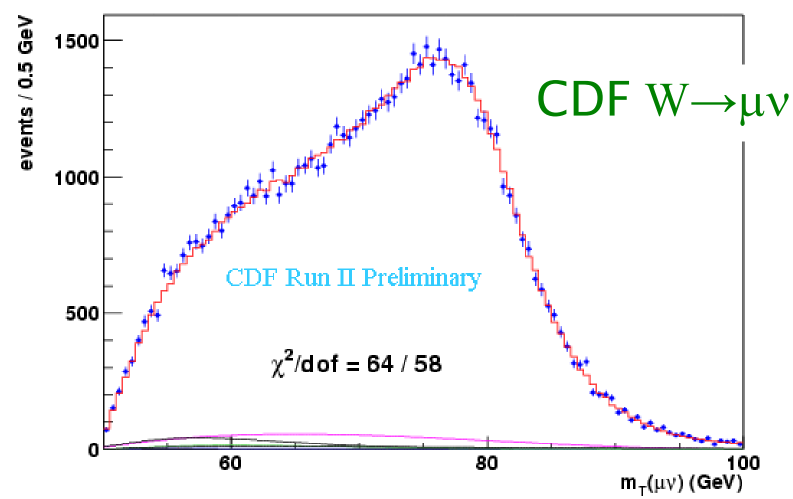


W transverse mass









CDF W Mass Summary

Source of uncertainty (MeV)	$W\to e\nu$ (Run 1b)	$W\to\mu\nu$ (Run 1b)
Lepton E scale, p resolution	70 (80)	30 (87)
Recoil E scale and resolution	50 (37)	50 (35)
Background	20 (5)	20 (25)
Production & decay model	30 (30)	30 (30)
Statistics	45 (65)	50 (100)
Total	**105 (110)**	**85 (140)**

- 200 pb^{-1} of data analyzed by CDF.
- Combined uncertainty on M_W (76 MeV) smaller than Run 1(79 MeV).
- DØ finalizing calorimeter calibration.
- Expect to achieve δM_W<40 MeV per experiment by the end of Run 2.

Lepton Universality in W Decays

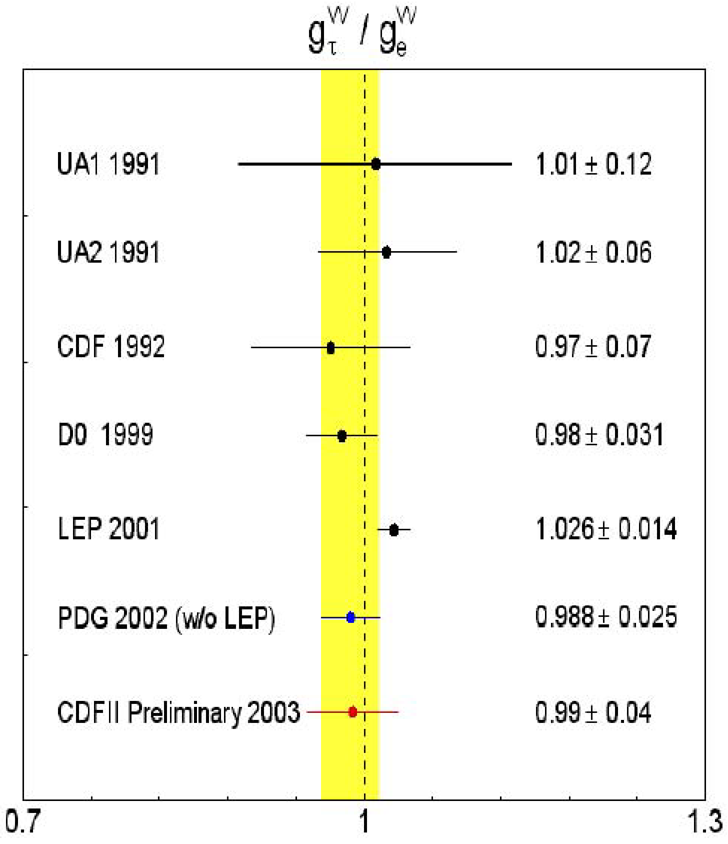
$$U \equiv \frac{\sigma(p\bar{p} \to W) \cdot B(W \to \mu\nu)}{\sigma(p\bar{p} \to W) \cdot B(W \to e\nu)} = \frac{\Gamma(W \to \mu\nu)}{\Gamma(W \to e\nu)} = \frac{g_\mu^2}{g_e^2}$$

Many systematic uncertainties cancel out.

$$\frac{g_\mu}{g_e} = 0.998 \pm 0.012$$

Similarly,

$$\frac{g_\tau}{g_e} = 0.99 \pm 0.02_{\text{stat}} \pm 0.04_{\text{syst}}$$



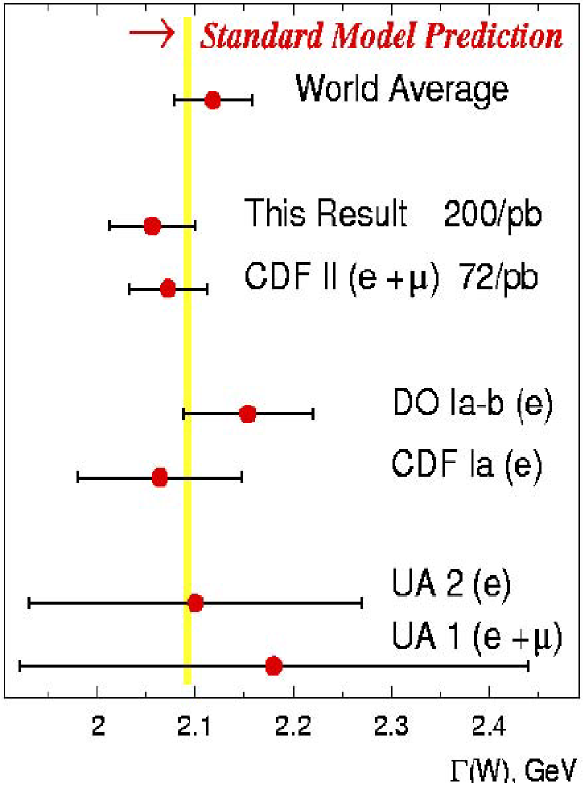
W width: Indirect Measurement

Using direct measurements of leptonic partial widths & Z lineshape, one can extract the total width of the W boson from

$$R \equiv \frac{\sigma(p\bar{p} \to W) \cdot B(W \to l\nu)}{\sigma(p\bar{p} \to Z) \cdot B(Z \to ll)} = \frac{\sigma(p\bar{p} \to W) \cdot \Gamma(W \to l\nu) \cdot \Gamma(Z)}{\sigma(p\bar{p} \to Z) \cdot \Gamma(Z \to ll) \cdot \Gamma(W)}$$

CDF measurements from Run 2:

Channel	Γ(W) [MeV]	$\int Ldt$ (pb^{-1})
e+μ	2079±41	72
e	2056±44	194
World avg.	2124±41	



W width: Direct Measurement

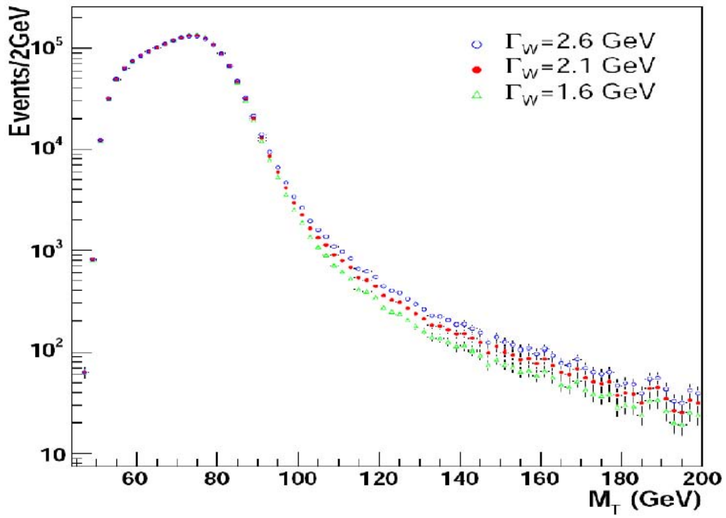
DØ: 177 pb^{-1} $W \rightarrow e\nu$ sample

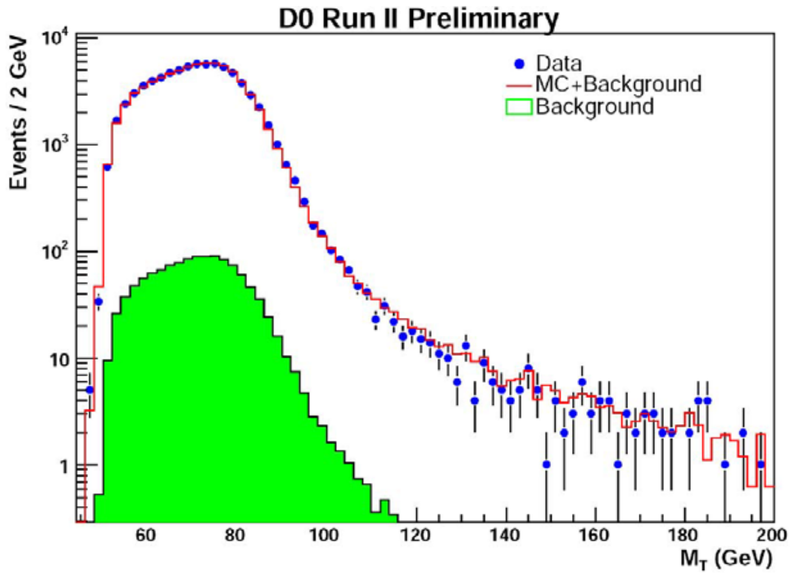
Method

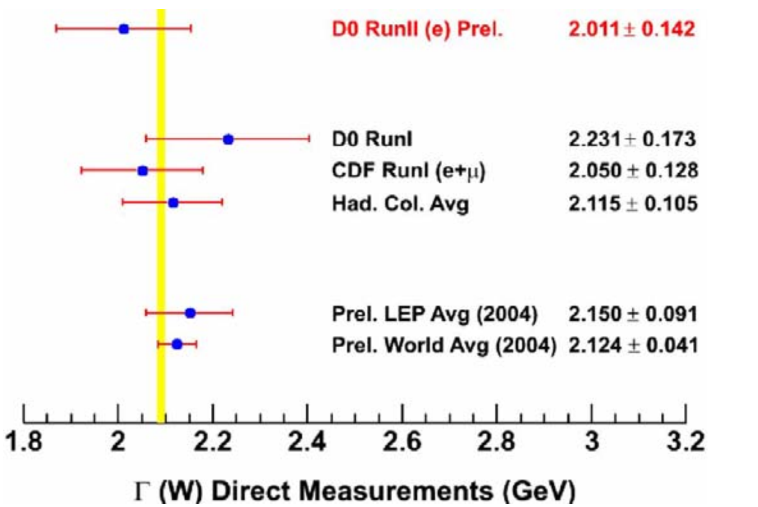
- Generate MC templates with different W widths
- Compare to the tail of M_T^W distribution

Main systematic uncertainties

- Hadronic response and resolution: ~64 MeV
- Underlying event: ~47 MeV
- EM resolution: ~30 MeV

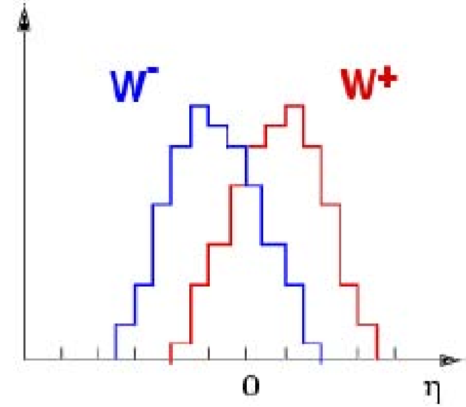




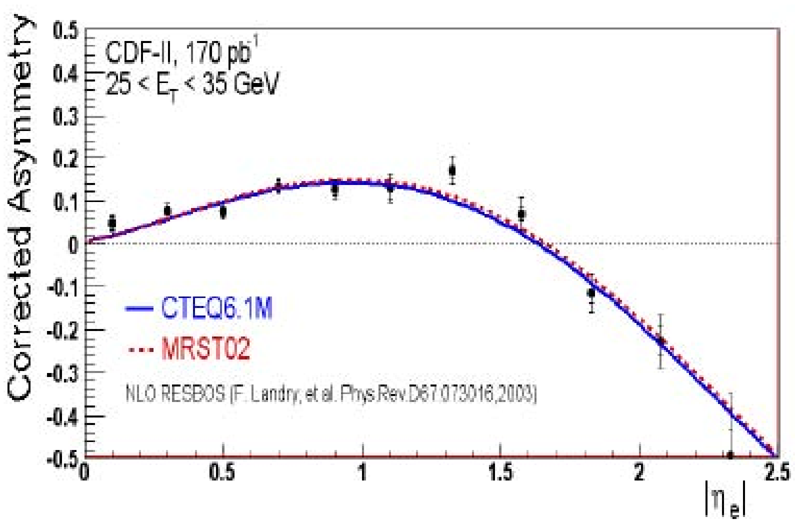


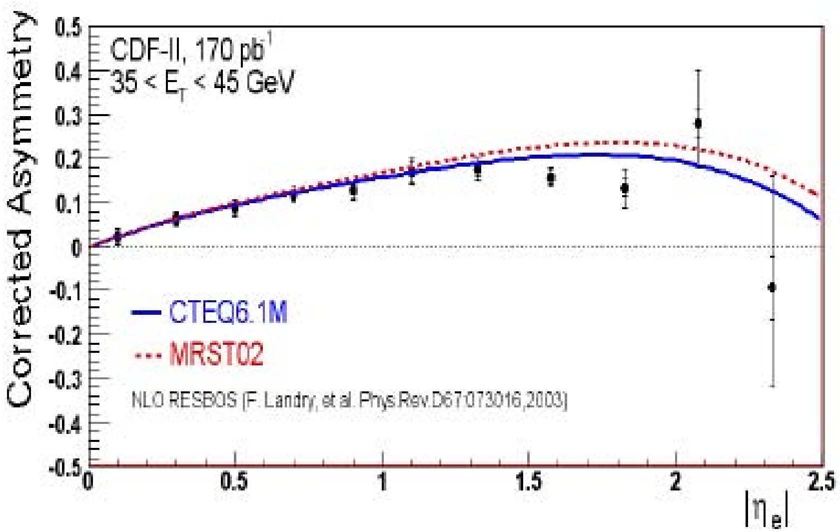
W Charge Asymmetry

- Probes the proton structure:
- Relies on lepton charge identification
- Convolution of W production asymmetry and V–A decay:



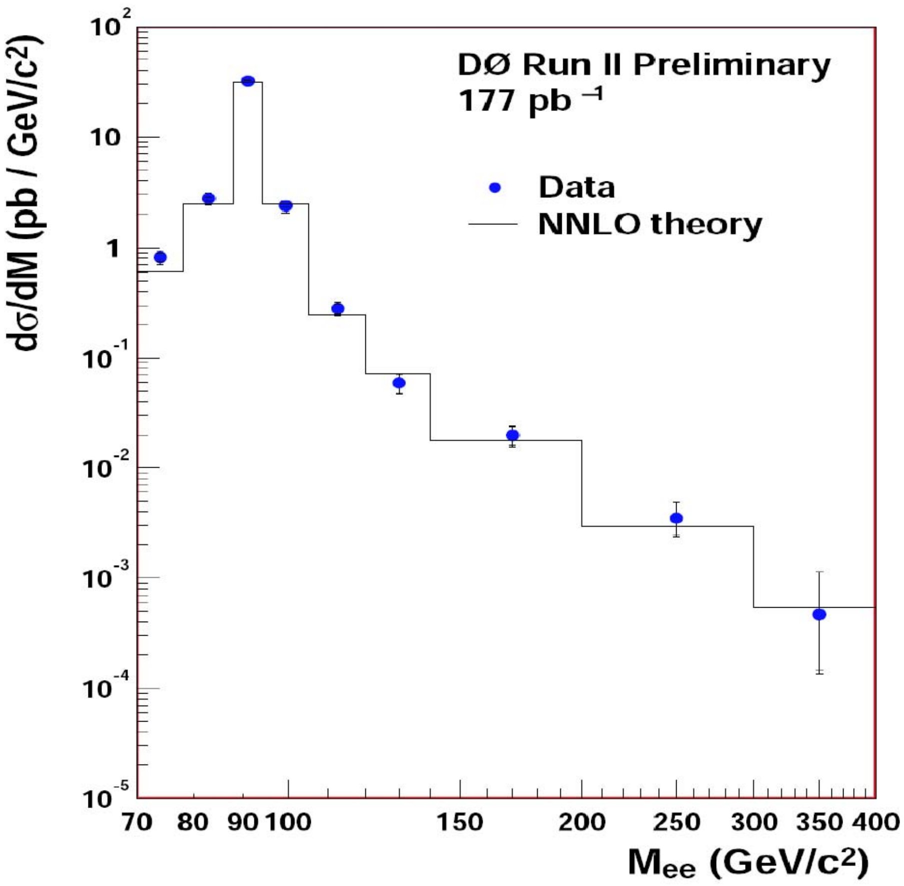
$$A(\eta_l) = \frac{d\sigma(l^+)/d\eta - d\sigma(l^-)/d\eta}{d\sigma(l^+)/d\eta + d\sigma(l^-)/d\eta}$$





$$\frac{d\sigma(Z/\gamma^* \to ee)}{dM_{ee}}$$

- Sensitive to new physics
- QED radiative corrections
- Main background: jets misidentified as electrons
- Systematic uncertainties:
  - Background estimation
  - PDFs
  - Detector modeling
  - Z/γ p_T in Monte Carlo

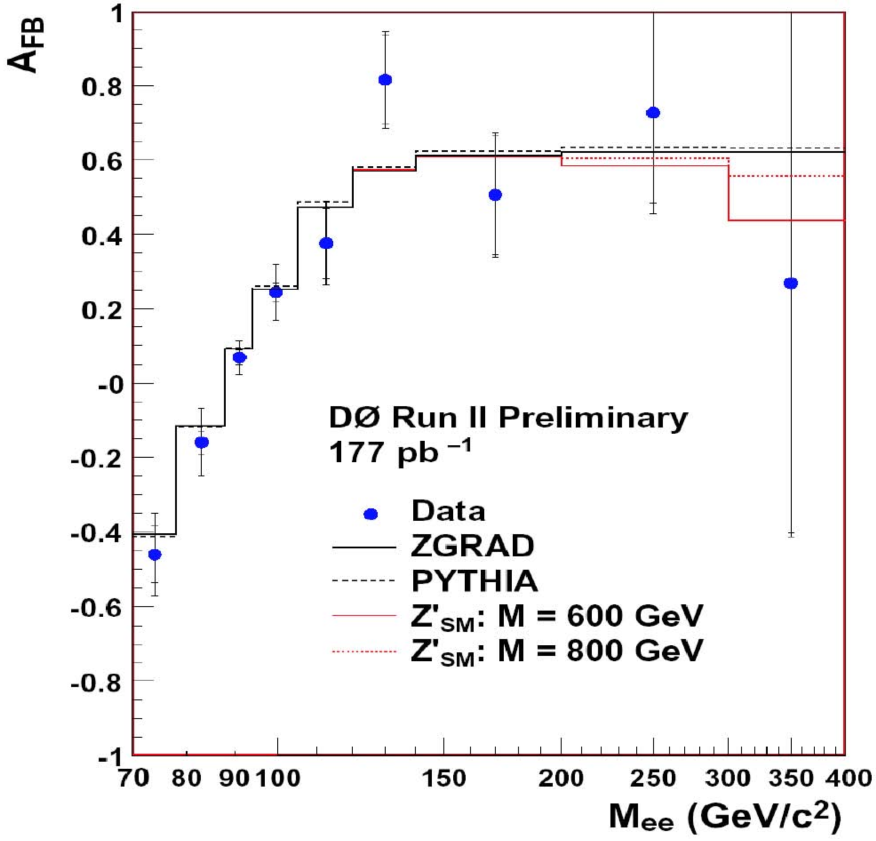


$Z/\gamma^* \rightarrow ee$ Forward-Backward Asymmetry

- An extension of the $\frac{d\sigma}{dM}$ analysis
- V-A nature of fermion-Z coupling leads to asymmetry in lepton production angle w.r.t beam axis:

$$A_{FB} \equiv \frac{\int_0^1 \frac{d\sigma}{d(\cos\theta)} d(\cos\theta) - \int_{-1}^0 \frac{d\sigma}{d(\cos\theta)} d(\cos\theta)}{\int_0^1 \frac{d\sigma}{d(\cos\theta)} d(\cos\theta) + \int_{-1}^0 \frac{d\sigma}{d(\cos\theta)} d(\cos\theta)}$$

- AFB vs. mass has different sensitivity to u, d quarks in proton
- Mix of V and A couplings change with mass.



Diboson Production: Wγ, WW, WZ, Zγ

- Measure cross sections, look for physics beyond the SM.
- Background for top pair production, Higgs, NP searches.
- Only leptonic final states used to keep backgrounds manageable.
- Similar to LEP and Run1 measurements.

Test for Anomalous Couplings via L_{eff}:

$$L_{WWV}/g_{WWV} = g_V^1(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + \kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda_V}{M_W^2} W^\dagger_{\lambda\mu} W_\nu^{\ \mu} V^{\nu\lambda}$$

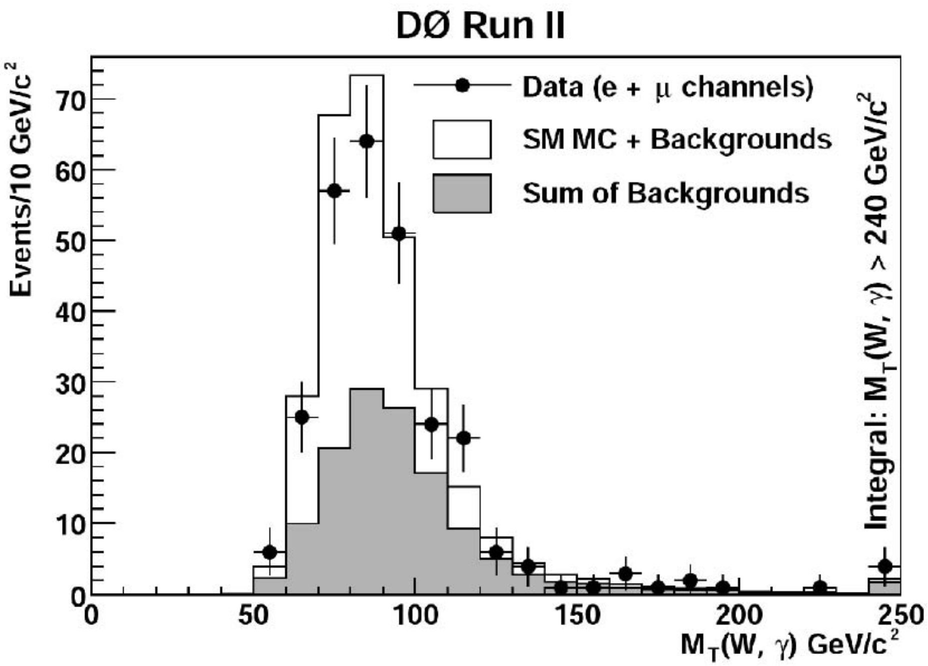
Where V = Z, γ.

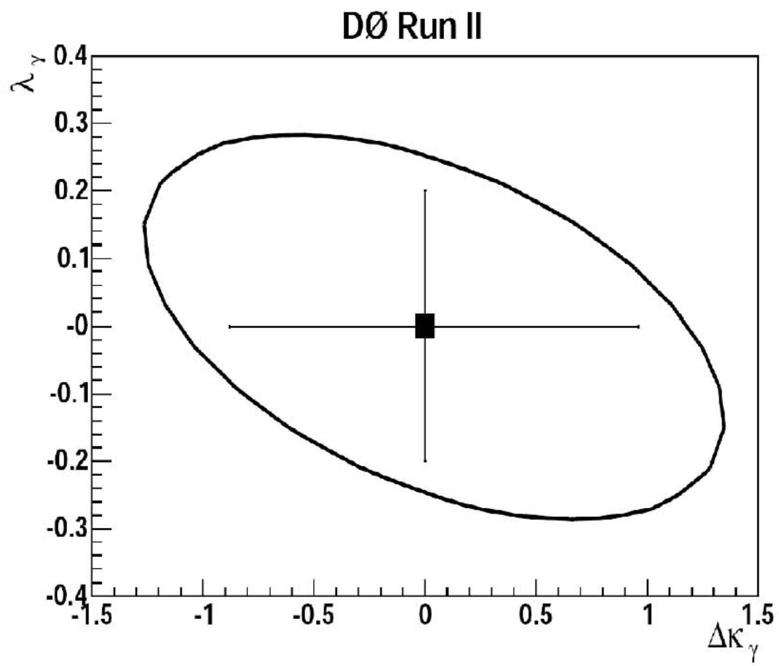
In the SM, $g^1_V = \kappa_V = 1$; $\lambda_V = 0$.

Determine from data: $\Delta g^1_V = g^1_V - 1$; λ_V; $\Delta\kappa_V = \kappa_V - 1$

Example: Wγ anomalous coupling

Binned likelihood fits to $E_T(\gamma)$ gives 1d, 2d results on λ_γ, $\Delta\kappa_\gamma$





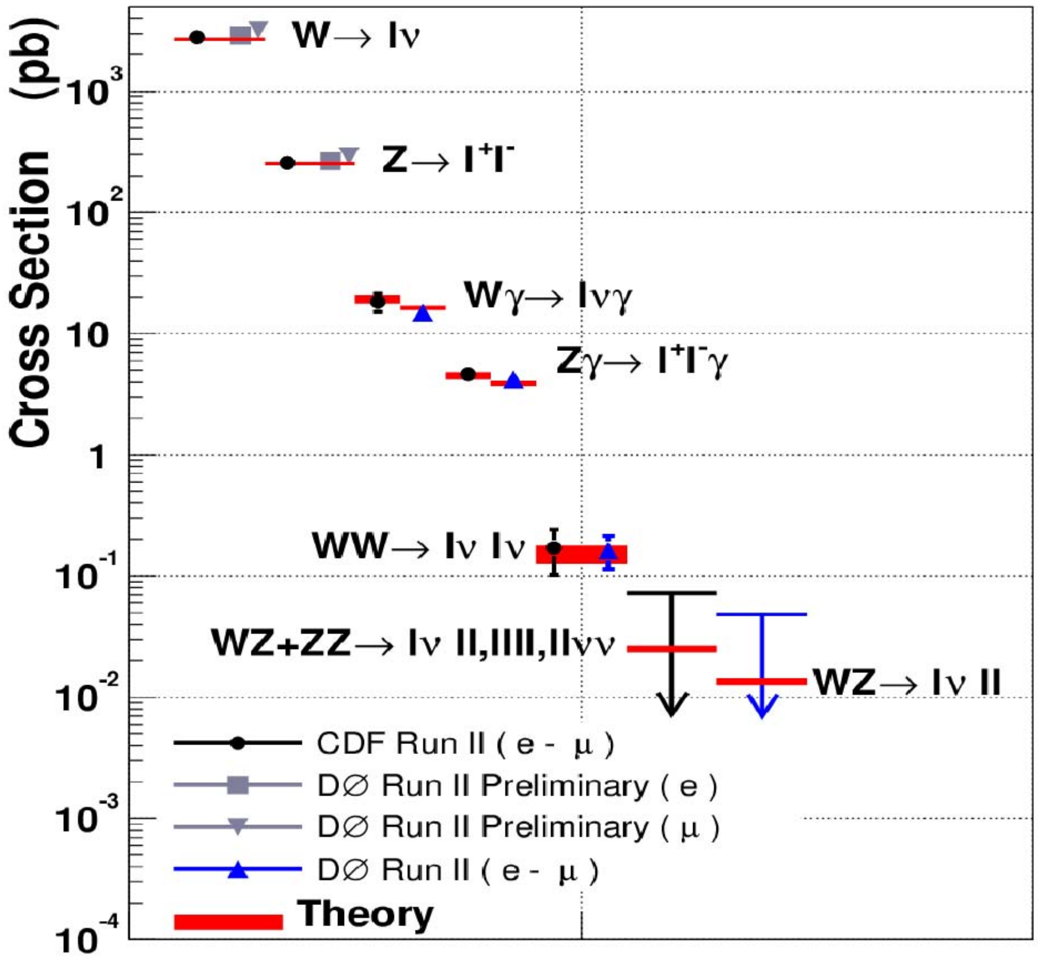
1d limits at 95% CL ($\Lambda = 2$ TeV):

$-0.88 < \Delta\kappa_\gamma < 0.96$,

$-0.20 < \lambda_\gamma < 0.20$

2d limit at 95% CL ($\Lambda = 2$ TeV)

Diboson Summary



No significant departure observed from SM predictions in any channel.

Summary

A successful electroweak physics program is shaping up with the ongoing Run 2 of the Tevatron

- W mass measurement is on course to an unprecedented ∽30 MeV precision (CDF ⊕ DØ, all channels combined).
- Most systematic uncertainties scale with $(\int Ldt)^{-1/2}$. [⇐Run 1]
- Inclusive cross section measurements have reached high precision and are in good agreement with SM expectations.
- Competitive results on W width and lepton universality. $\delta\Gamma_W < 50$ MeV should be possible with $\int Ldt \approx 2\text{fb}^{-1}$.
- W charge asymmetry measurements pressing PDFs.
- No significant departure from SM found so far, but we'll stay alert …

Backup Slides

CDF W mass measurement

- Precision of $O(10^{-4})$ requires detailed modeling of measured line shapes.
- QCD corrections to W/Z production (RESBOS for $p_T(W/Z)$): $\delta M_W = \pm 13$ MeV.
- QED corrections to W/Z decays (FS γ's w/ WGRAD): $\delta M_W = 15-20$ MeV.
- Muon momentum calibration using J/ψ & Υ decays: $\delta M_W = \pm 25$ MeV.
- Electron energy calibration using E/p: $\delta M_W = \pm 55$ MeV.
- Hadronic recoil energy estimated by vectorially summing energies in all calorimeter towers except those associated with the charged lepton.

  Hadronic response parametrized using $Z \rightarrow \mu\mu$ events. $\delta M_W = \pm 37$ MeV.
- Background from cosmic rays, QCD jets faking isolated $l^{\pm}$: $\delta M_W = \pm 20$ MeV.