Electroweak Results from the Tevatron

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for the CDF and DØ Collaborations

Physics at LHC

Cracow, Poland

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Weak Boson Physics

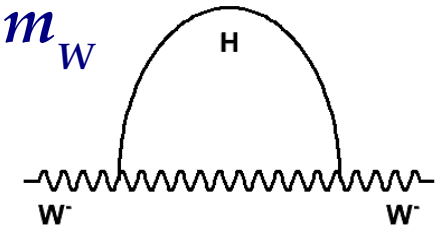
Z boson parameters measured precisely by LEP:

* **17** million measured *Z* candidates: δm_Z = **2.1** MeV, $\delta\Gamma_Z$ = **2.3** MeV

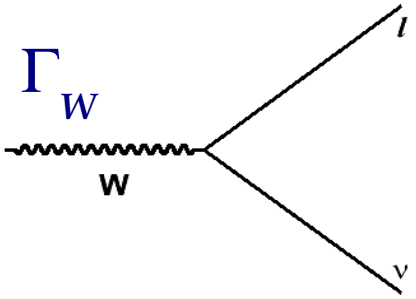
Tevatron goal:

* World's most precise *W* boson measurements
* Expect **15** million measured *W* candidates

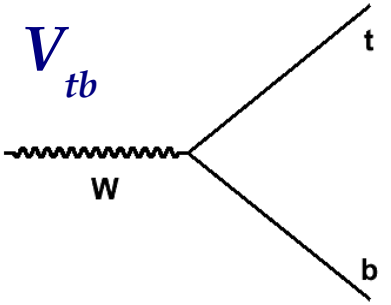
m_W



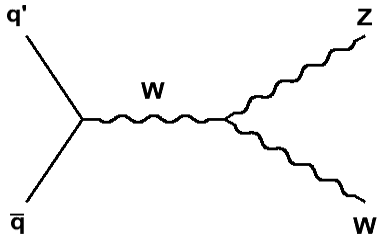
Γ_W



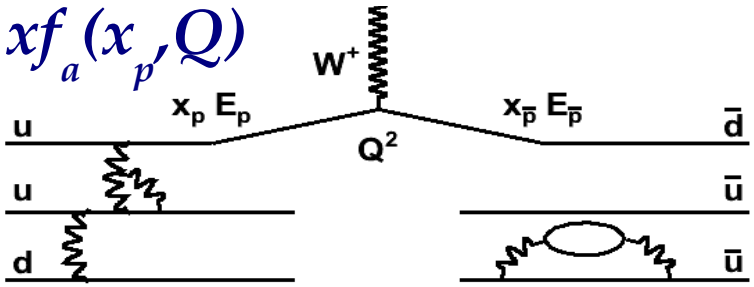
V_{tb}



WWZ coupling

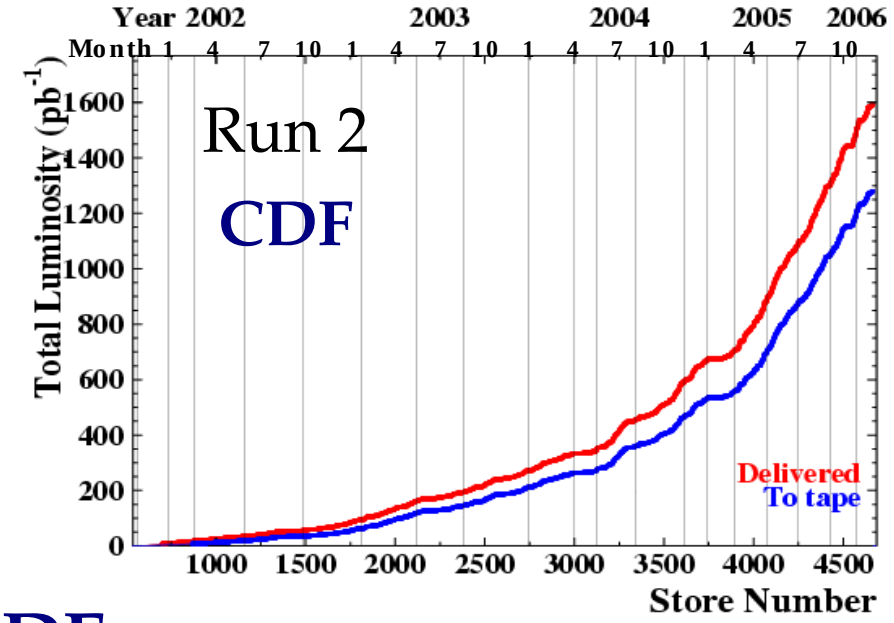


$xf_a(x_p,Q)$



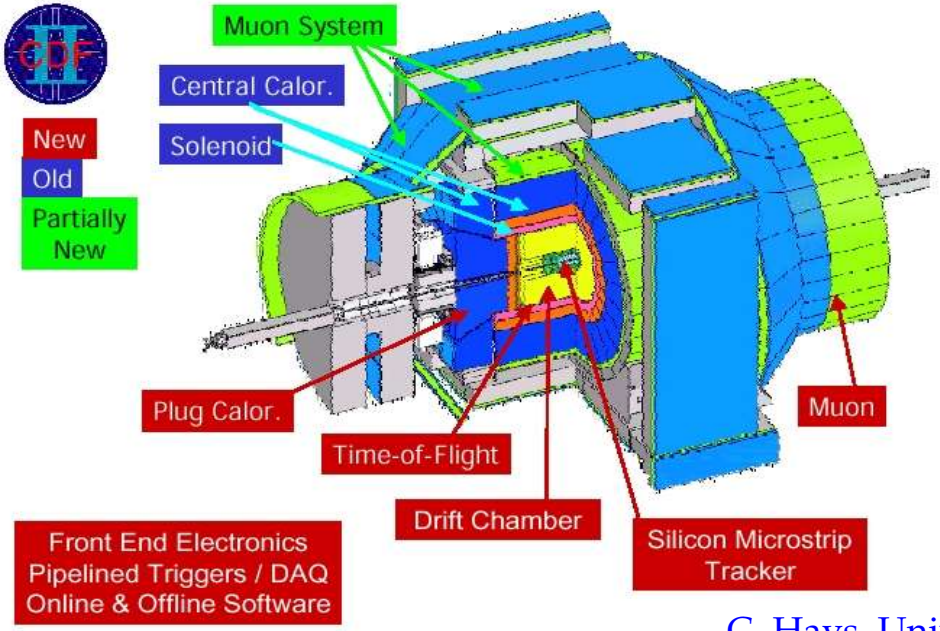
Tevatron results will indicate dominant LHC W uncertainties

Luminosity and Detectors

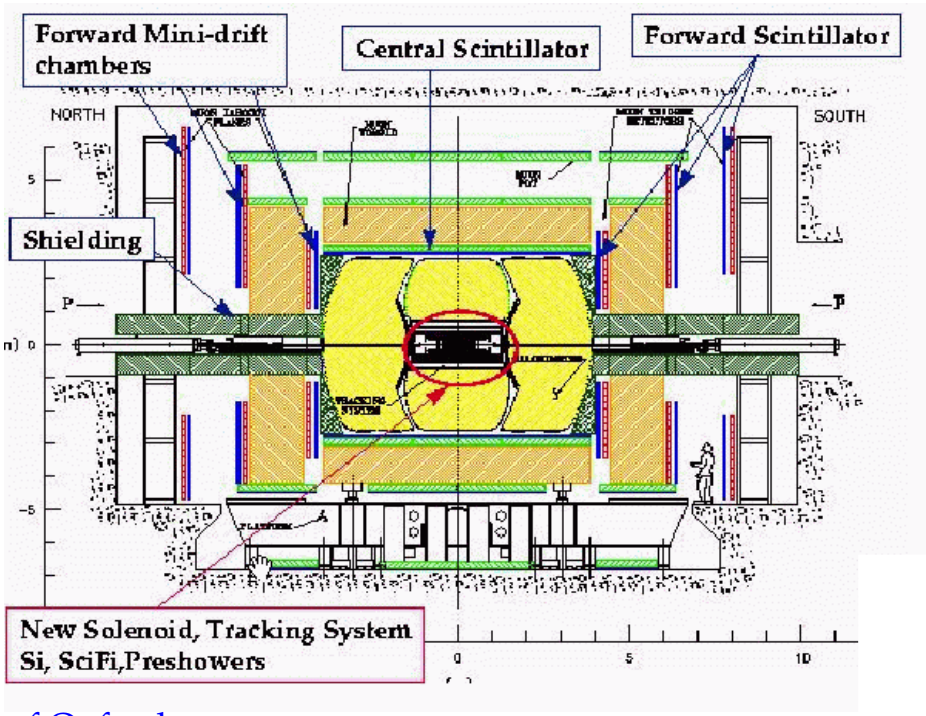


Tevatron has produced **1.6 fb^{-1}** of 1.96 TeV $\sqrt{s}$ $p\bar{p}$ collisions per experiment

CDF:



DØ:



W Mass Measurement

CDF systematic uncertainties determined with **200 pb^{-1}** of Run 2 data:

Systematic Uncertainty	Electrons	Muons	ATLAS
Lepton Scale & Resolution	70	30	15
Recoil Scale & Resolution	50	50	5
W pT model	15	15	5
PDFs	15	15	10
QED	15	20	5
Backgrounds	20	20	5

Constrain with data -- Roughly scale with $\mathcal{L}$

Theoretical inputs -- do not directly scale with $\mathcal{L}$

Must demonstrate luminosity scaling

Potentially a limiting LHC W mass uncertainty

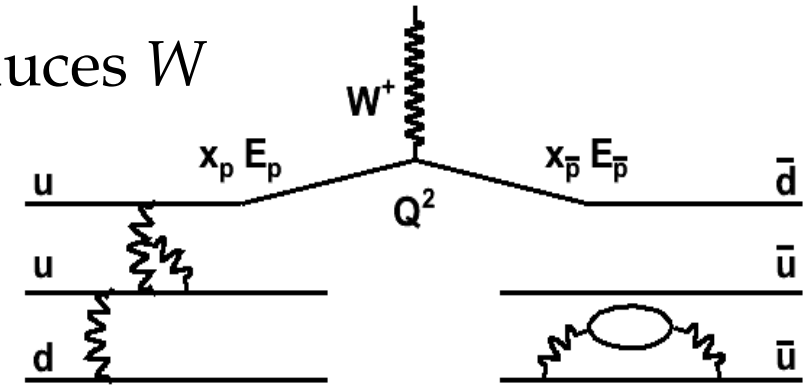
Total uncertainty: 76 MeV

(Expected in **2 fb^{-1}**: 40 MeV)

Precision of <0.1%

W Production

Hard scattering of $q, \bar{q}'$ inside $p, \bar{p}$ produces W



$$\sigma = \sum_{ab} \int dQ\, \delta(Q - 2E_p \sqrt{x_{\bar{p}} x_p}) \int dx_p f_a(x_p, Q) \int dx_{\bar{p}} f_b(x_{\bar{p}}, Q)\, \hat{\sigma}(Q)$$

Sum over quarks, gluons

Kinematic constraint

Parton distribution functions

Calculable hard scattering cross section

Two competing groups (CTEQ & MRST) fit existing data to PDF functions

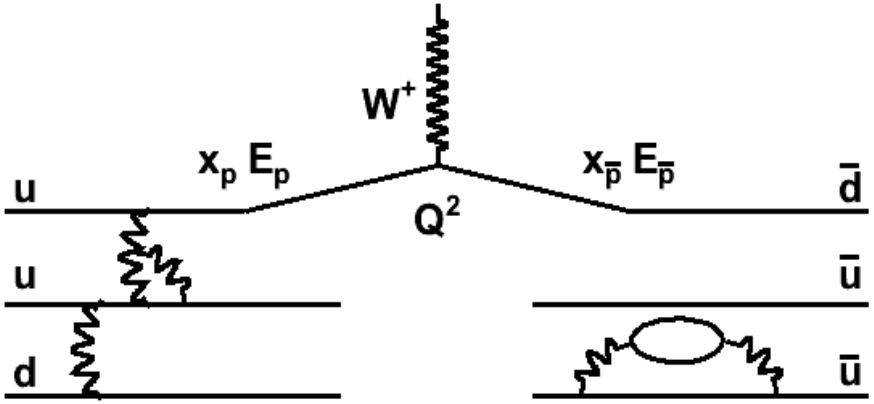
CTEQ parametrization: $xf_a(x,Q_0) = A_0\, x^{A1}\, (1-x)^{A2}\, e^{(A3)x}\, (1 + A_4 x)^{A5}$

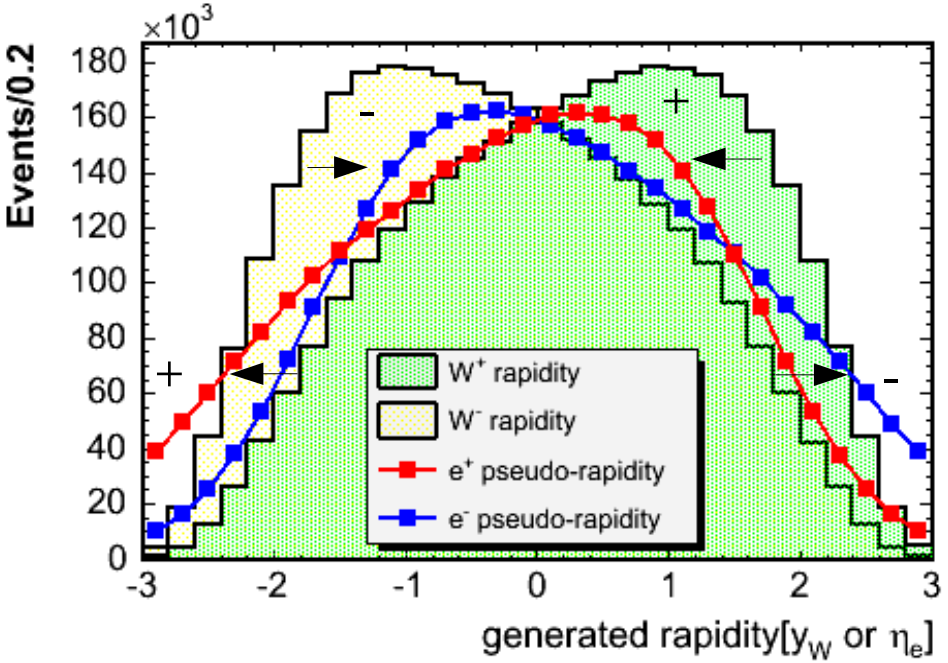
Separate functions for u, d, g, $\bar{u}$, $\bar{d}$: 30 parameters (10 are fixed)

A parameters correlated: find eigenvectors to facilitate uncertainty calculations

W Charge Asymmetry

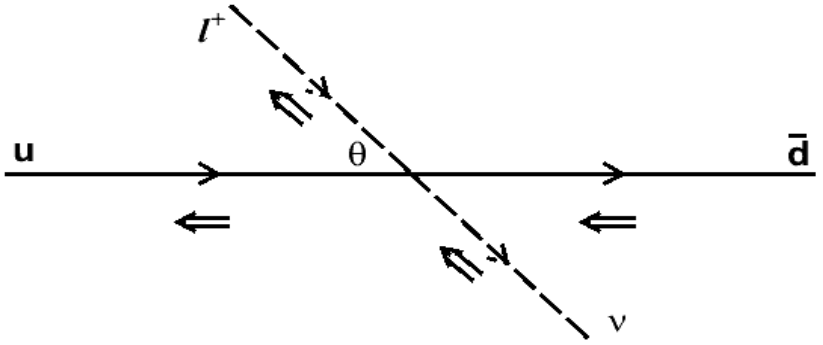
Asymmetric *u*, *d* PDFs ⟶ Asymmetric W^+, W^- rapidity distributions





W decay:

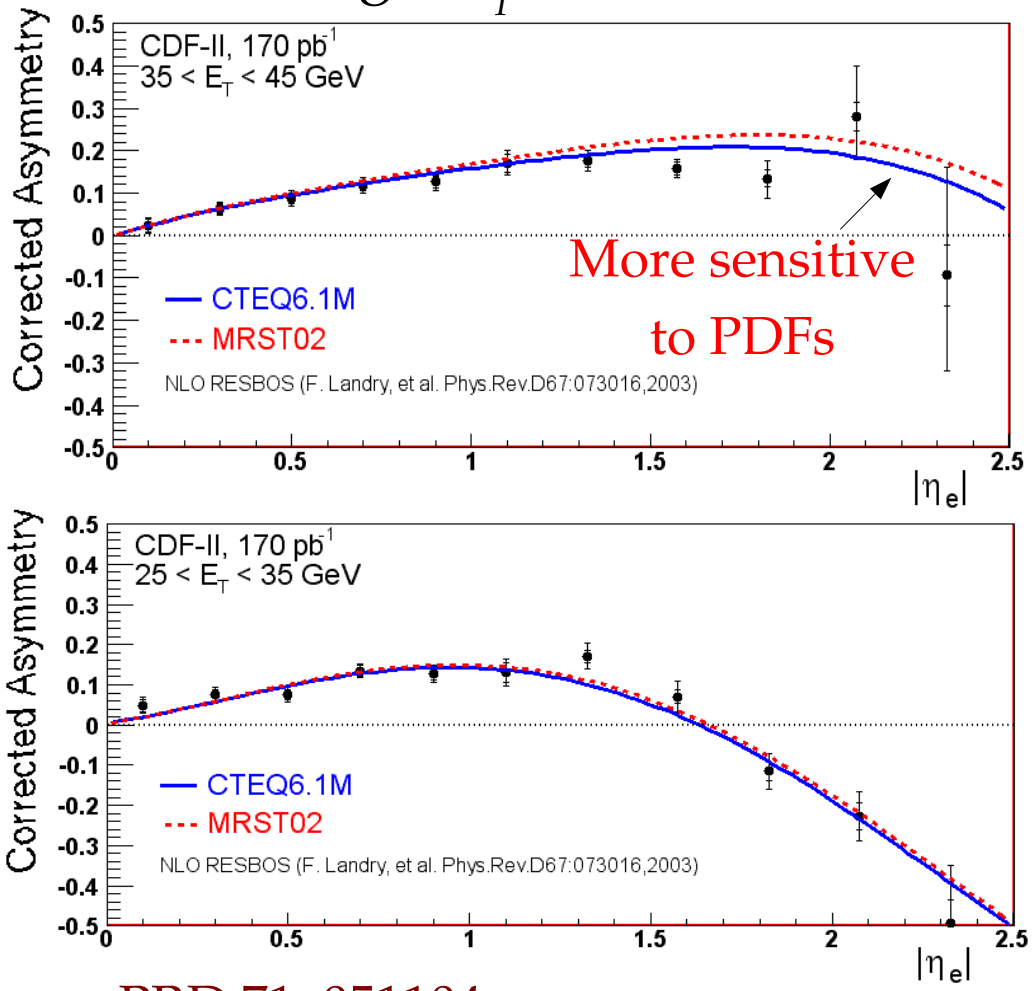
$d\sigma/d\theta \propto (1 + \cos\theta)^2$



$(x_p = x_{\bar{p}})$

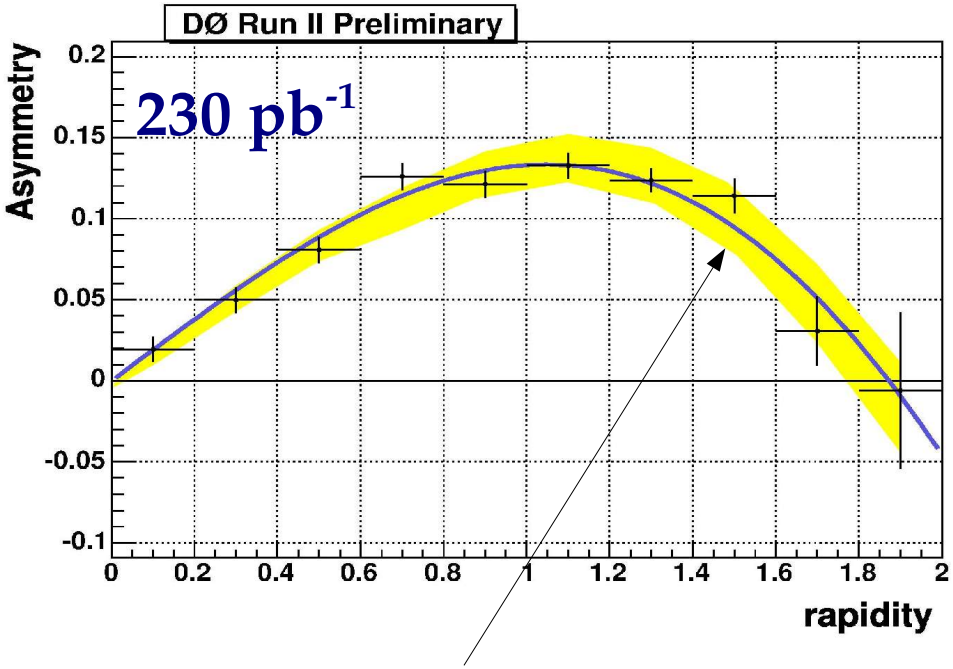
W Asymmetry Measurements

CDF probes asymmetry with high-E_T electrons:



PRD 71, 051104 (2005)

DØ utilizes large μ acceptance:

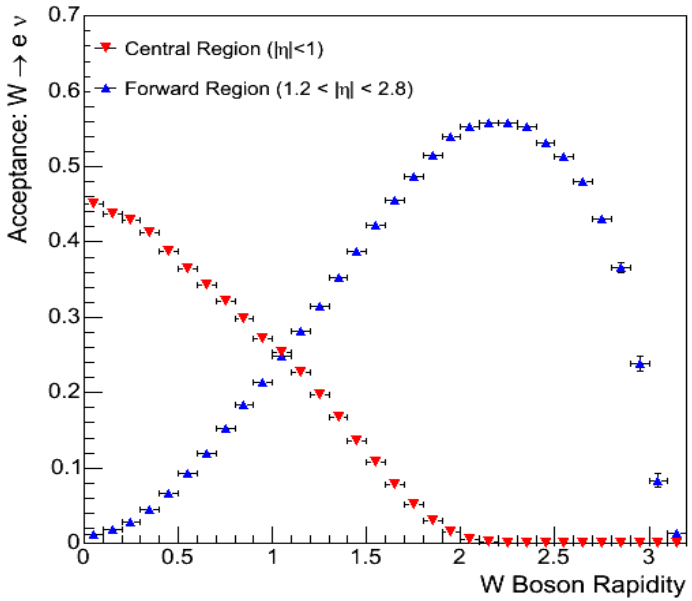


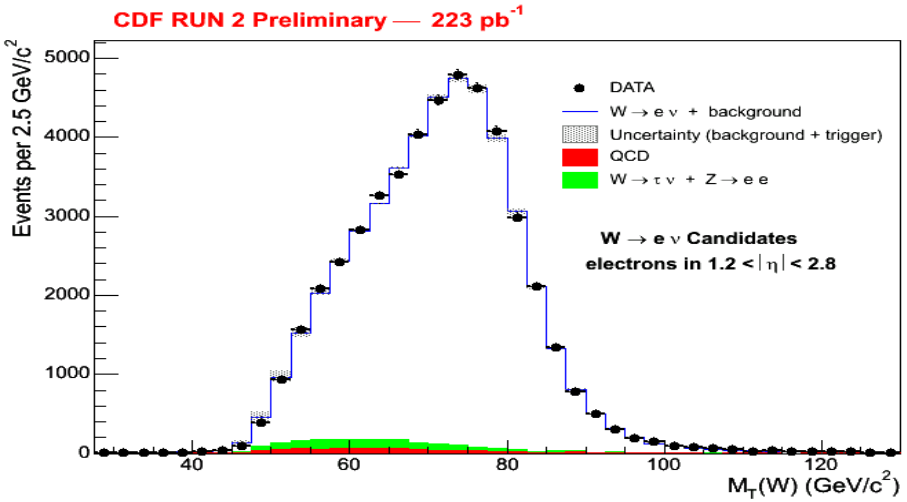
CTEQ uncertainty band

W and Lepton Rapidities

W cross section ratio with forward and central electrons sensitive to $|\eta_W|$

* Separate experimental and theoretical uncertainties





CDF experimental uncertainties:

Electron Identification	± 2.5%
Track Reconstruction	± 1.1%
Luminosity	± 1%
Backgrounds	± 1%

PDF uncertainty:

CTEQ: +2.5%, -3.2%

MRST: +1.2%, -1.6%

Cross section from **central** electrons:

$\sigma_W = 2771 \pm 14\ (\text{stat})\ ^{+62}_{-56}\ (\text{sys}) \pm 166\ (\text{lum})$ pb

Cross section from **forward** electrons:

$\sigma_W = 2796 \pm 13\ (\text{stat})\ ^{+95}_{-90}\ (\text{sys}) \pm 162\ (\text{lum})$ pb

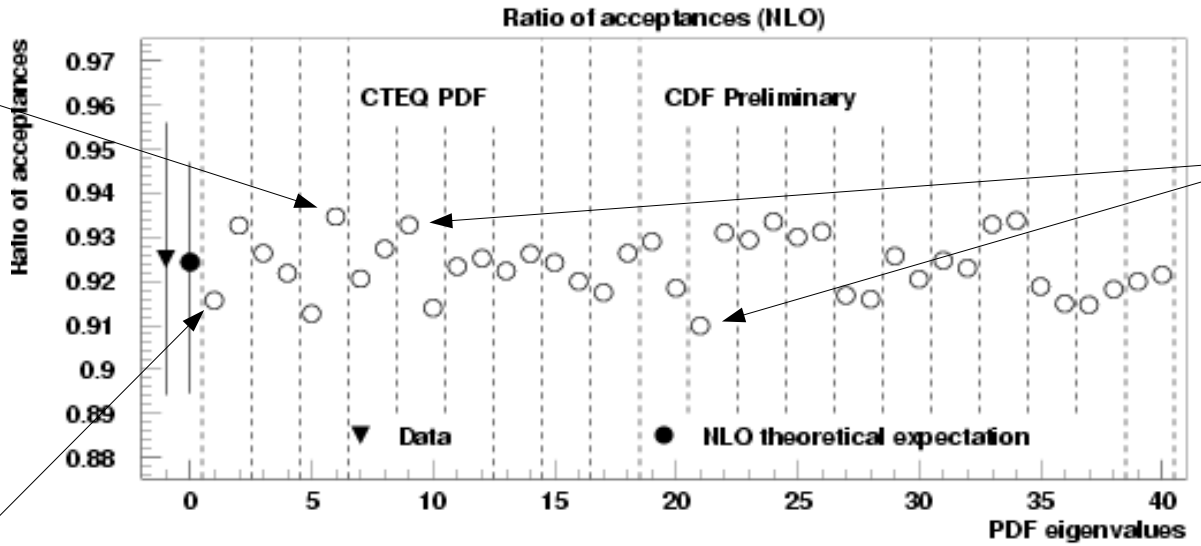
PDF Uncertainty on Ratio

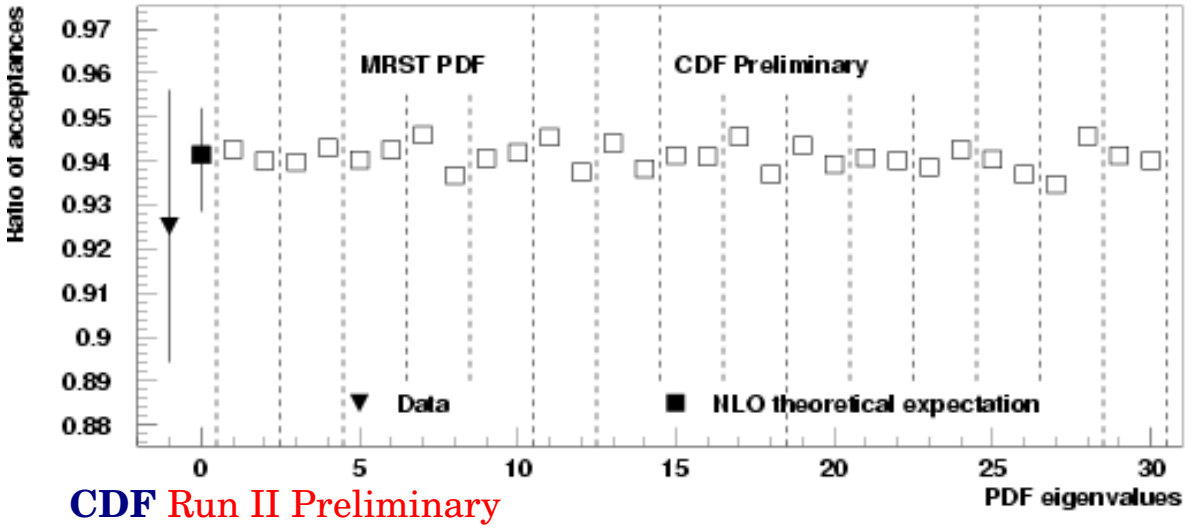
Cross section x Acceptance ratio for ±1σ of each PDF eigenvector:

valence down quark + sea quarks (low x)

gluon (low x)

valence up quark (low x)





CDF Run II Preliminary

Indirect W Width Measurement

Measure ratio of W to Z cross sections

$$\frac{\sigma(p\bar{p} \to W) \times BR(W \to l\nu)}{\sigma(p\bar{p} \to Z) \times BR(Z \to ll)}, \quad BR(W \to l\nu) = \frac{\Gamma_{W \to l\nu}}{\Gamma_W}$$

Predicted to 0.7%

Measured to 0.07% at LEP

Predicted to 0.1%

Cross section ratio (R) measured to 1.9% by **CDF**

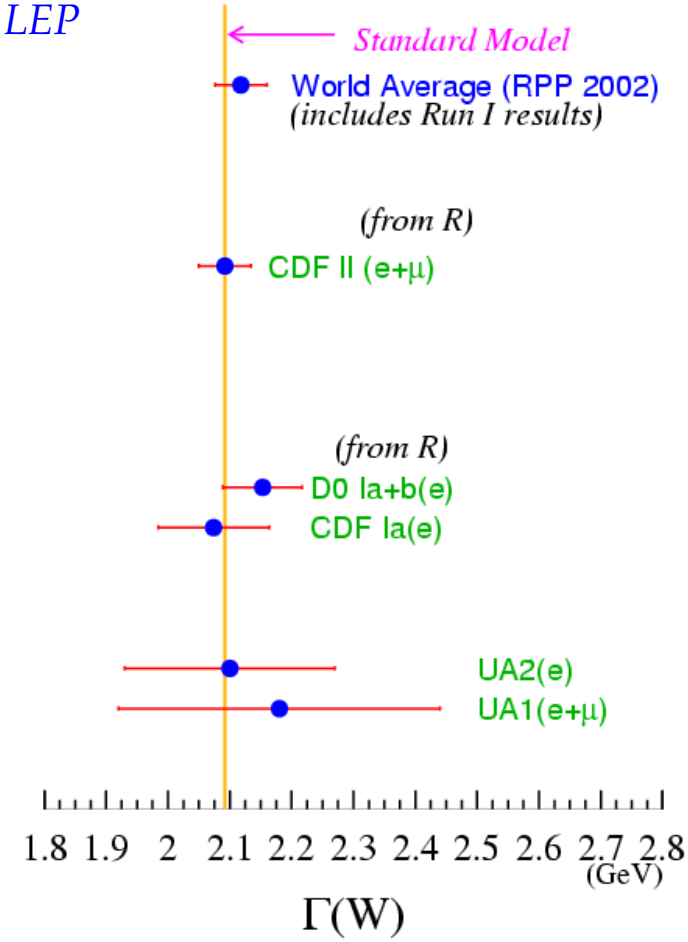
Fractional uncertainties on R (**72 pb^{-1}**):

Uncertainty	Electrons	Muons
Statistics	1.7%	2.4%
Lepton Identification	1.1%	1.0%
PDFs	0.7%	0.8%
Backgrounds	0.4%	0.8%

Measured R: $10.84 \pm 0.15 \pm 0.14$

Extracted Γ_W: 2.092 ± 0.042 GeV

Extracted $|V_{cs}|$: 0.976 ± 0.030



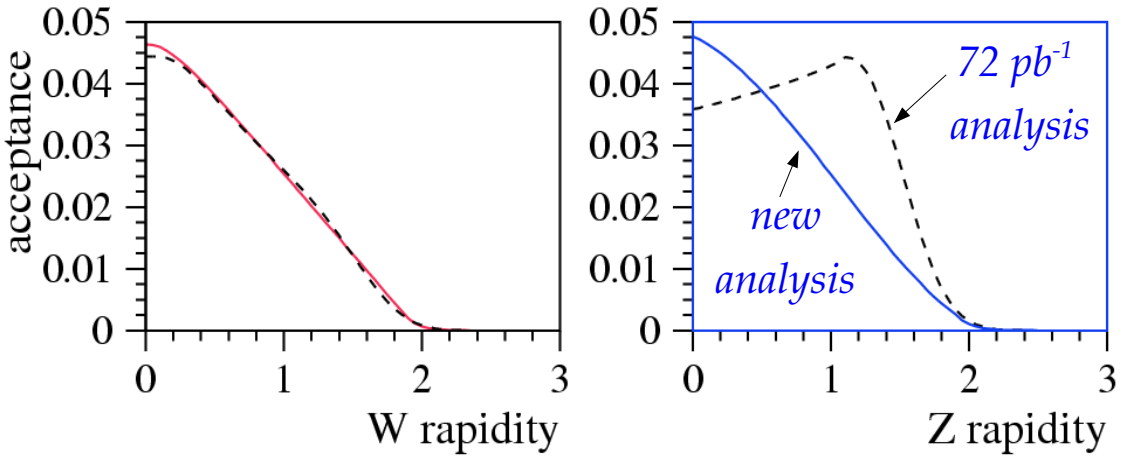
World's most precise measurement of Γ_W

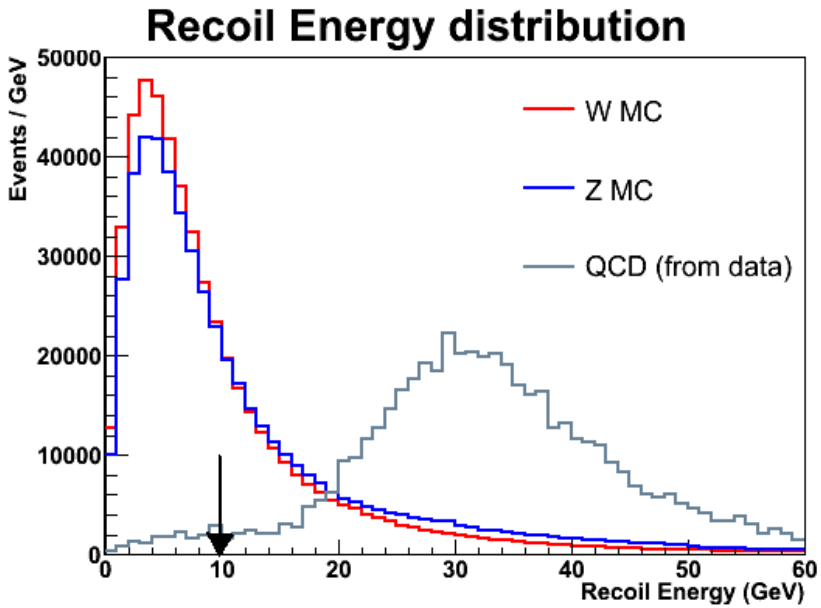
hep-ex/0508029

New Indirect *W* Width

Use uniform boson selection to reduce lepton id and PDF uncertainties

* Require one identified lepton and low hadronic recoil energy





New challenge:

Understand hadronic jet background

Uncertainty	Electrons
Statistics	0.8%
Backgrounds	2.4%
PDFs	0.3%
Lepton Identification	-

CDF preliminary result in **300 pb^{-1}**

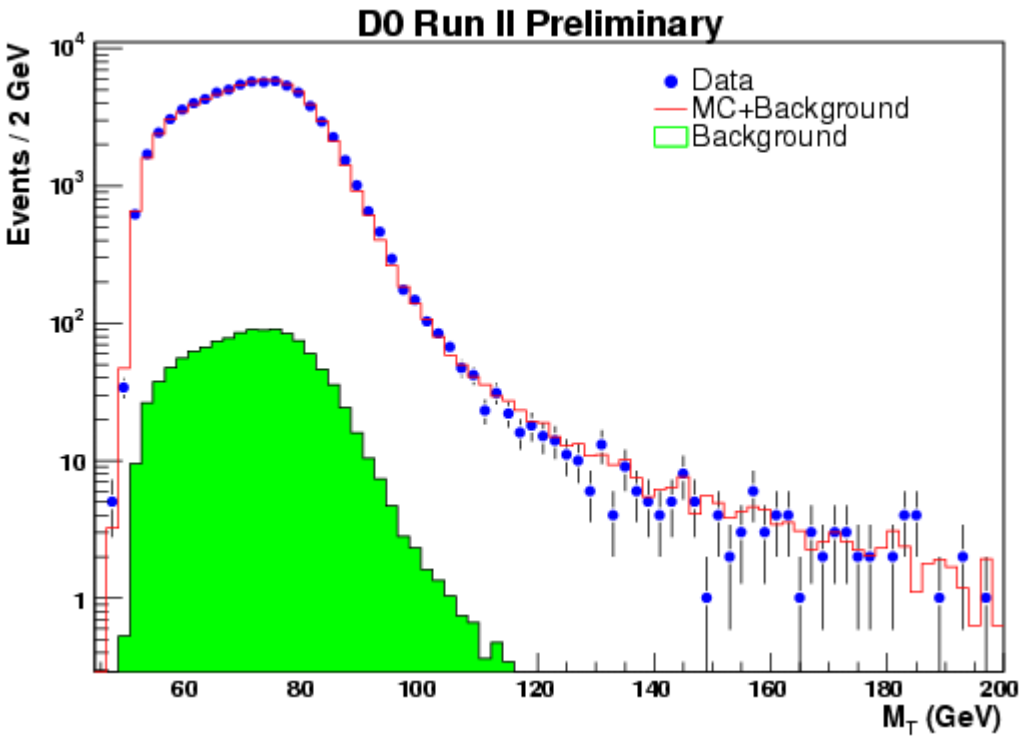
Measured *R*: 10.55 ± 0.09 ± 0.27

Direct *W* Width Measurement

DØ directly measured *W* width using **177 pb^{-1}**

- *Fit 625 candidate W→ eν events in region*

  100 GeV < m_T < 200 GeV



$\Gamma_W = 2.011 \pm 0.093 \pm 0.107$ GeV

Dominant systematic uncertainties:

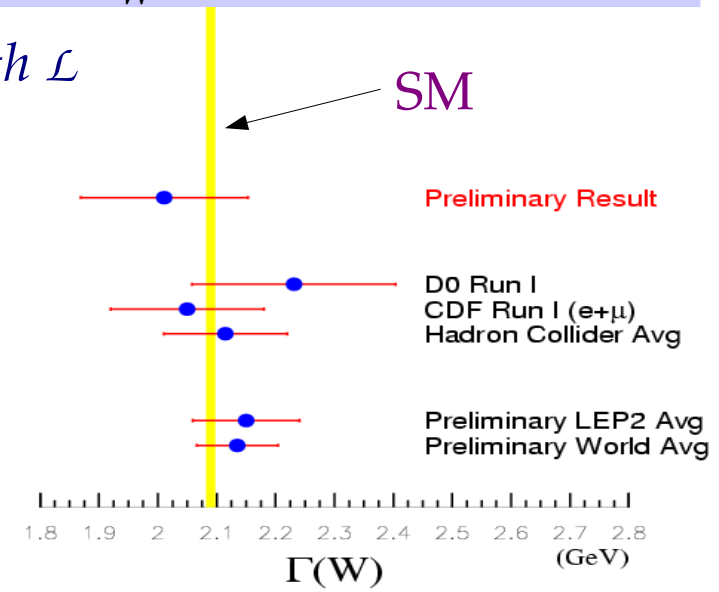
* Electron scale and resolution

  $\delta\Gamma_W = \pm 55$ MeV

* Recoil scale and resolution

  $\delta\Gamma_W = \pm 80$ MeV

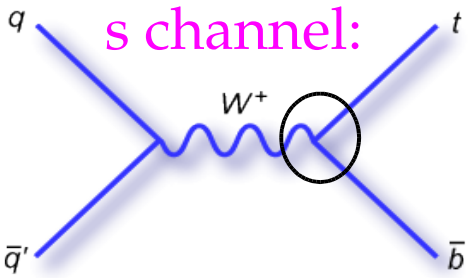
Scale with $\mathcal{L}$

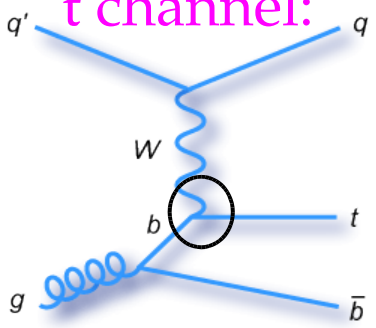


W Coupling to *t*

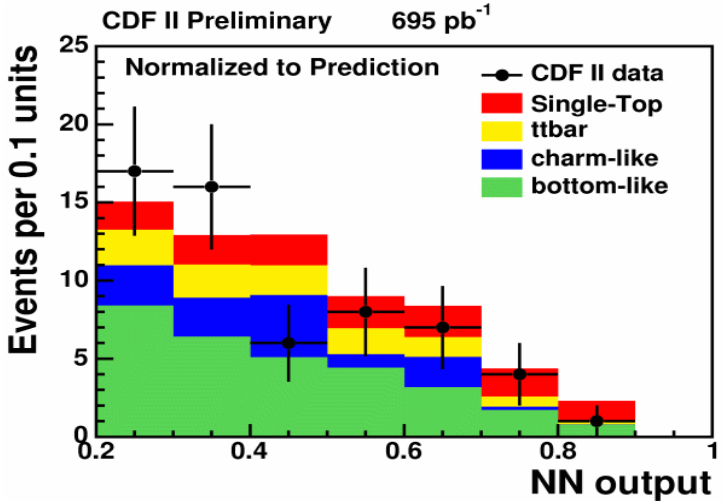
Probe V_{tb} with study of single top production

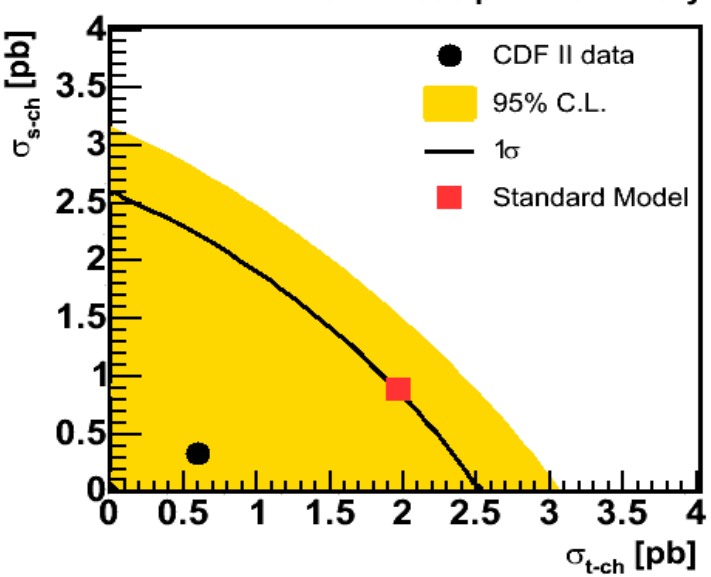
* Use advanced analysis techniques to separate from large $W\bar{b}b$ background

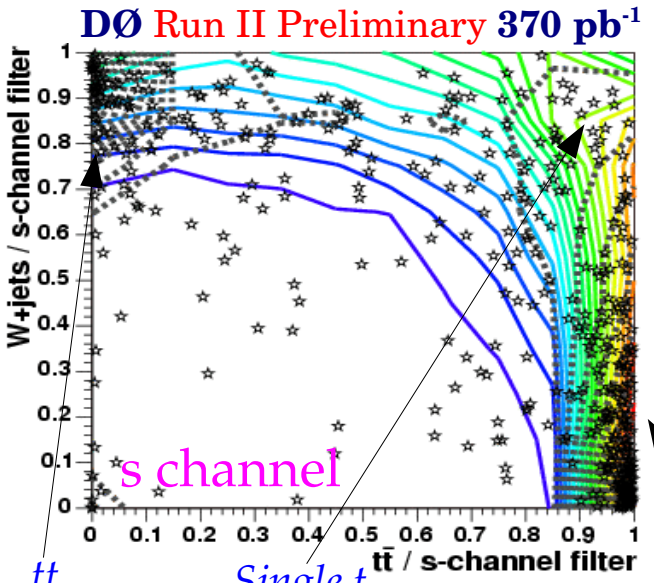


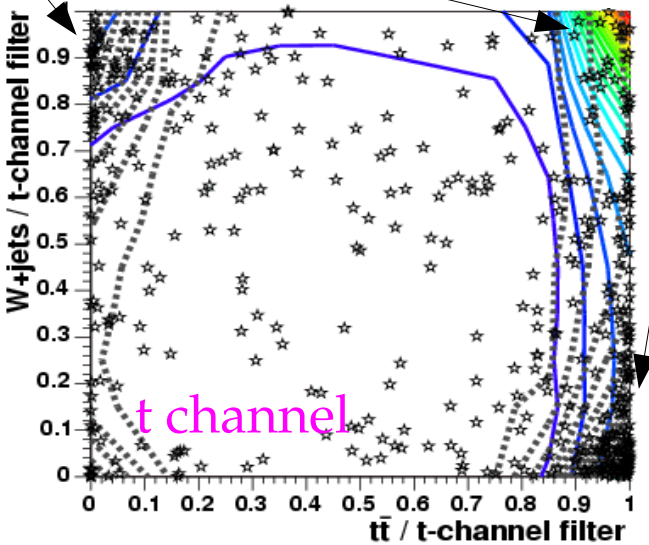


$\sigma(p\bar{p} \rightarrow tb) = 2.9$ pb







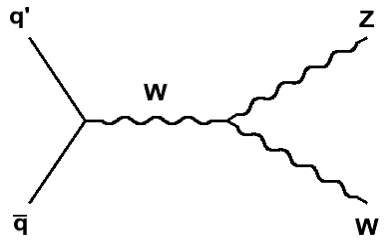


tt *Single t* *W + jets*

WZ Production

Direct probe of *WWZ* vertex unique to Tevatron

* Low background in trilepton decay channel



CDF: Expect 4.6 events, observe **2**

Signal:

WZ: 3.72 ± 0.02 (stat.) ± 0.15 (syst.)

Backgrounds:

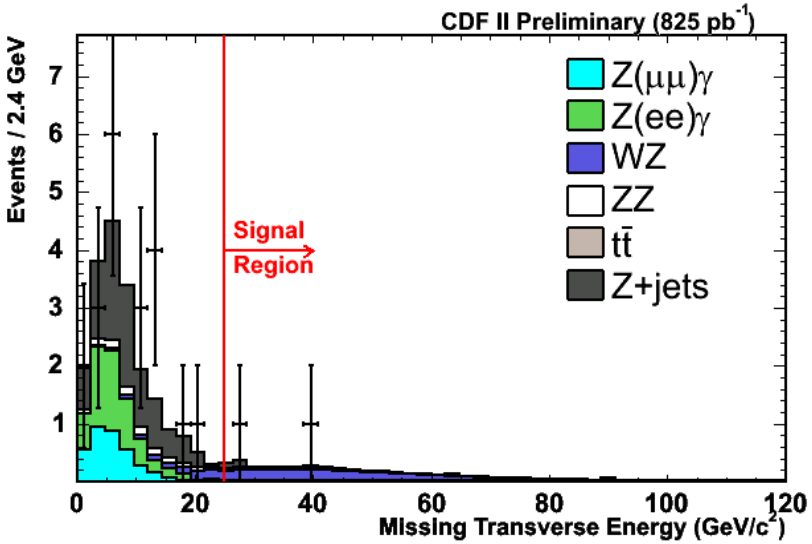
ZZ: 0.50 ± 0.01 (stat.) ± 0.05 (syst.)

Zγ: 0.03 ± 0.01 (stat.) ± 0.01 (syst.)

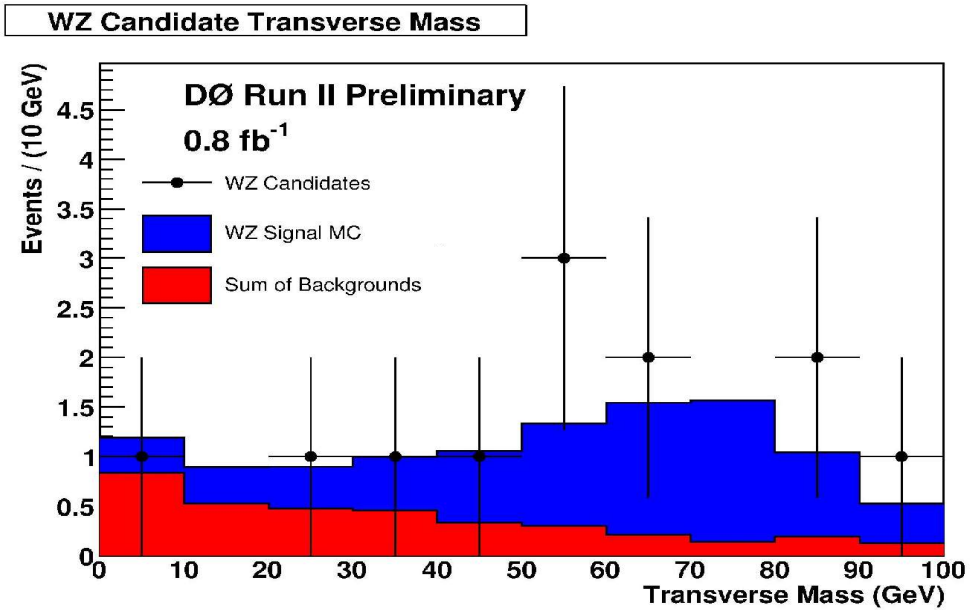
$t\bar{t}$: 0.05 ± 0.01 (stat.) ± 0.01 (syst.)

Z+jets: 0.34 ± 0.07 (stat.) $^{+0.15}_{-0.09}$ (syst.)

Total: 0.92 ± 0.07 (stat.) $^{+0.16}_{-0.10}$ (syst.)



DØ: Expect 11.1 events, observe **12**



$\sigma_{WZ} = 4.0\ ^{+1.9}_{-1.5}$ pb

3.3σ significance

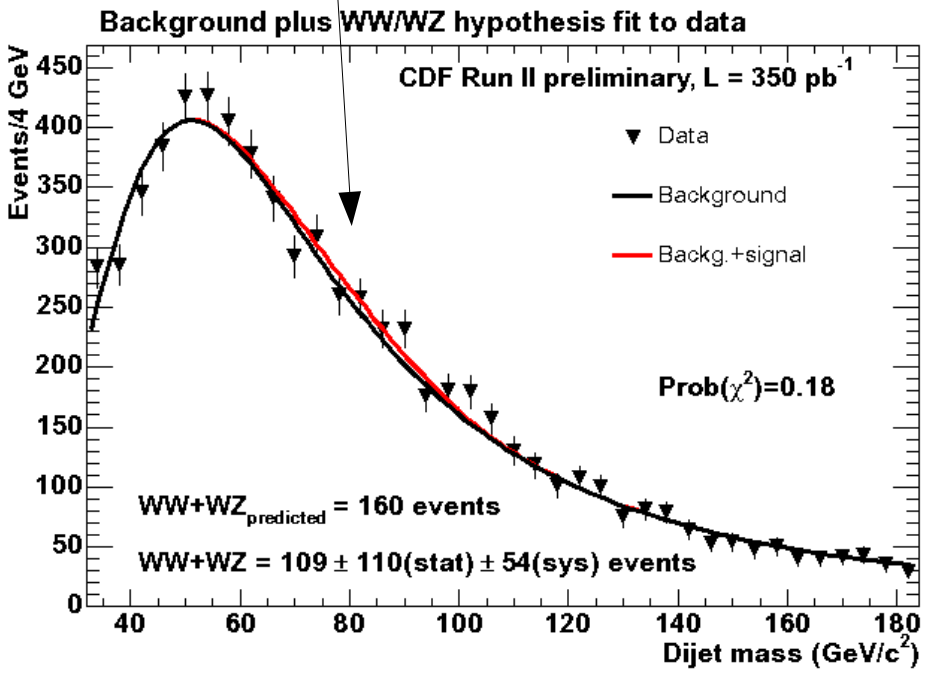
First evidence of *WZ* production at the Tevatron

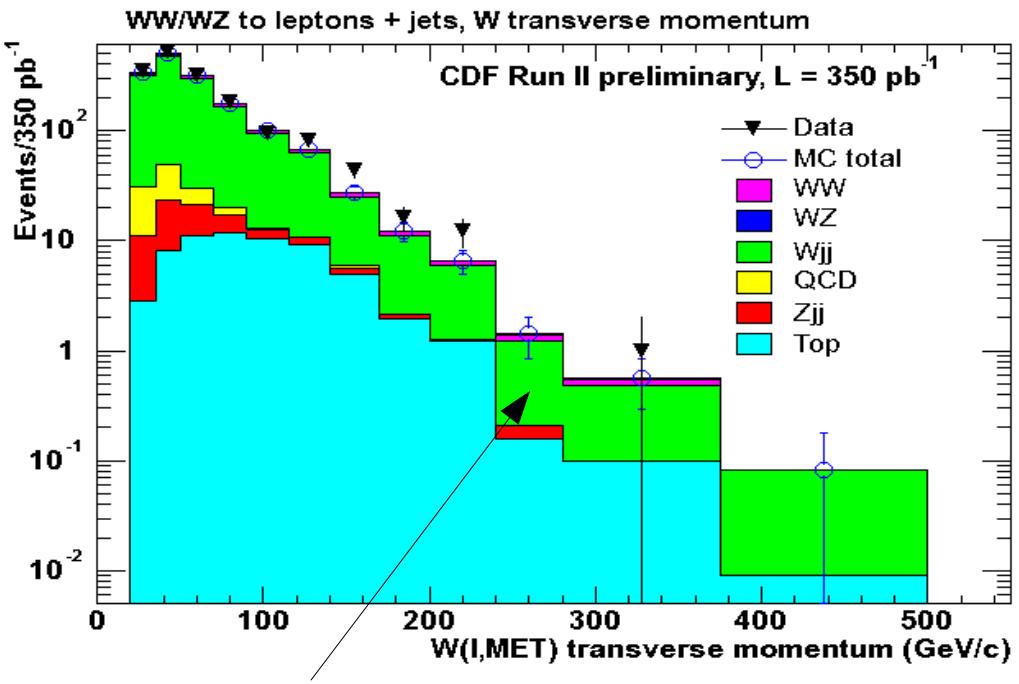
(*WZ* + *ZZ* significance : 4.2σ)

WW + *WZ* Search

Increase sensitivity to anomalous couplings with high BR channel

* *W* or *Z* hadronic decay: **4-7x** all-lepton branching ratio
* Large background makes direct observation difficult





Potential for new physics at high W p_T

CDF sets Tevatron's strongest anomalous coupling limits for this channel

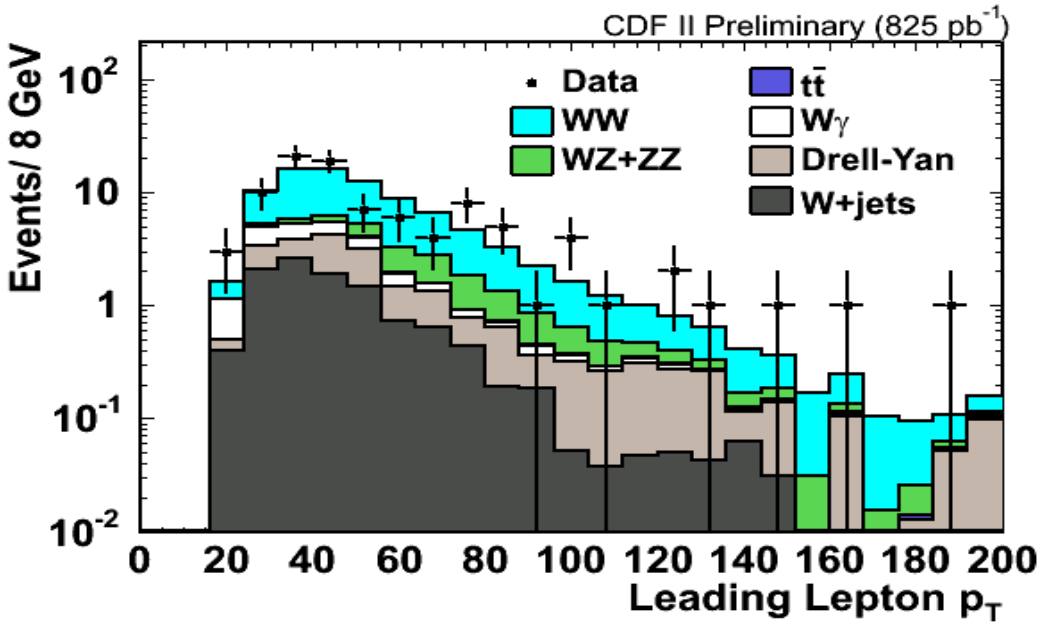
WW Cross Section Results

Measure *WW* cross section in low-background dilepton channel

CDF: 20% measurement accuracy in **825 pb^{-1}**

$$\sigma_{WW} = 13.6 \pm 2.3\ (\text{stat}) \pm 1.6\ (\text{sys}) \pm 1.2\ (\text{lum})\ \text{pb}$$

Mode	*ll*
WW	52.4 ± 0.1 ± 4.3
Drell-Yan	11.8 ± 0.8 ± 3.1
W+jets	11.0 ± 0.5 ± 3.2
$WZ+ZZ$	7.9 ± 0.0 ± 0.8
$W\gamma$	6.8 ± 0.2 ± 1.4
$t\bar{t}$	0.2 ± 0.0 ± 0.0
Sum Bkg	37.8 ± 0.9 ± 4.7
Expected	90.2± 0.9 ± 6.4
Data	95



DØ uses **250 pb^{-1}** to set Tevatron's strongest anomalous coupling limits for this channel

Summary

W boson unique physics probe:

* Constrains Higgs mass
* Sensitive to supersymmetric & other new particles
* Window into generational structure

Hadron colliders provide unique opportunities for precision *W* physics

Current limiting systematic uncertainties at the Tevatron:

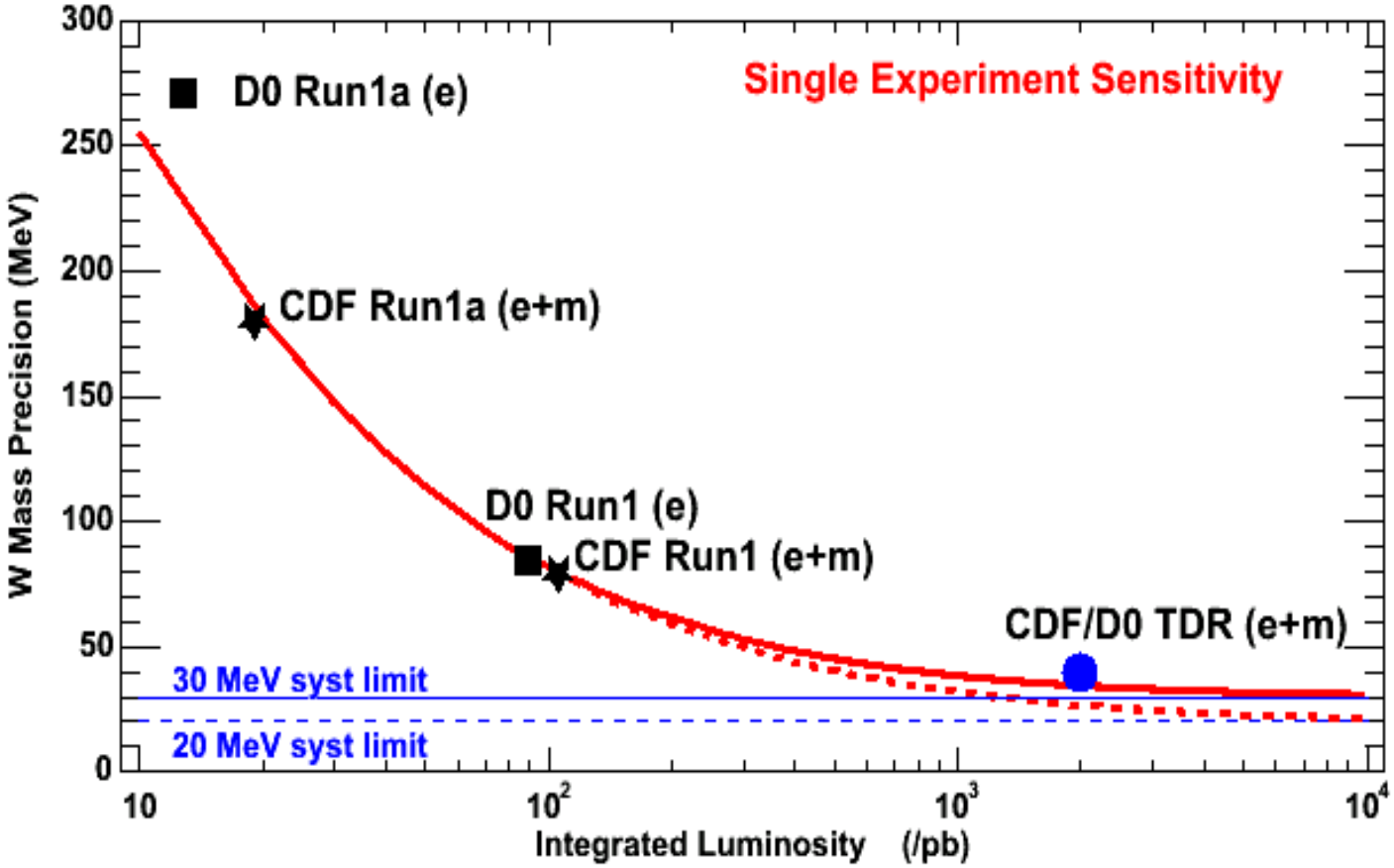
* *W* mass and direct width: Lepton scale, recoil model
* Indirect width: Lepton identification, PDFs, backgrounds

All W production and decay details need careful understanding at LHC

Backup

W Mass Measurement Projections

Projected Tevatron precision as a function of luminosity:



Measurement will be systematics-limited at 4 fb^{-1}: $\delta m_W^{\text{stat}} \sim 10$ MeV

Anomalous Couplings

Parametrize new physics in effective Lagrangian:

$$L_{WWV}/g_{WWV} = ig_1^V(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + i\kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + i\lambda_V/M_W^2\, W^\dagger_{\lambda\mu}W^\mu{}_\nu V^{\nu\lambda}$$

SM: $g_1^\gamma = g_1^Z = 1$

AC: Δg_1^Z ($= g_1^Z - 1$)

SM: $\kappa_\gamma = \kappa_Z = 1$

AC: $\Delta\kappa_Z$, $\Delta\kappa_\gamma$ ($= \kappa_V - 1$)

SM: $\lambda_\gamma = \lambda_Z = 0$

AC: λ_Z , λ_γ

Impose unitarity by introducing a 'new physics' energy scale:

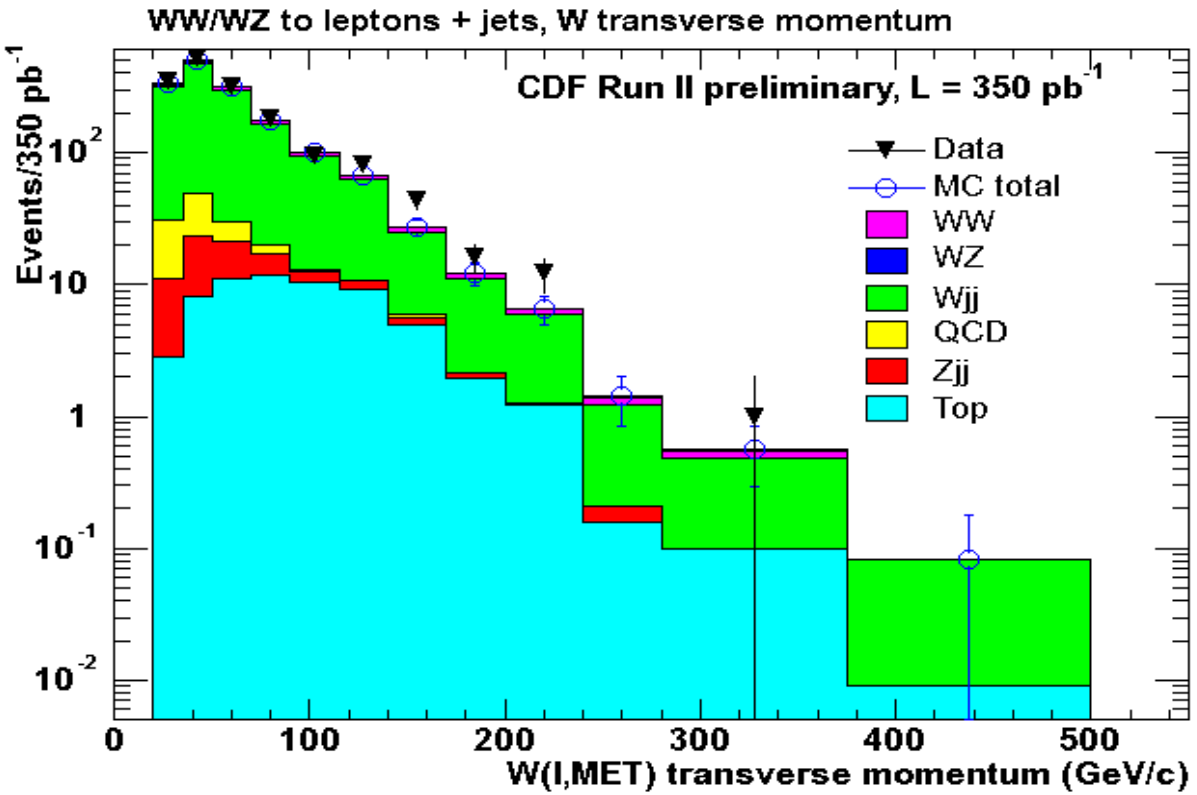
$$\alpha(s) = \alpha_0 \,/\, (1 + s/\Lambda^2)^2$$

Anomalous couplings increase as new physics scale approaches

Manifested in additional cross section at high boson p_T in WW/WZ events

Anomalous Coupling Search

No significant excess observed at high boson p_T



Limits on anomalous couplings: $|\lambda_V| < 0.28$, $-0.51 < \Delta\kappa_V < 0.44$ ($\Lambda = 1.5$ TeV)

(c.f. DØ Run 1 in this channel: $-0.36 < \lambda_V < 0.39$, $-0.47 < \Delta\kappa_V < 0.63$ ($\Lambda = 1.5$ TeV))