Precision Measurements of W and Z Boson Production at the Tevatron

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On Behalf of the CDF and DØ Collaborations

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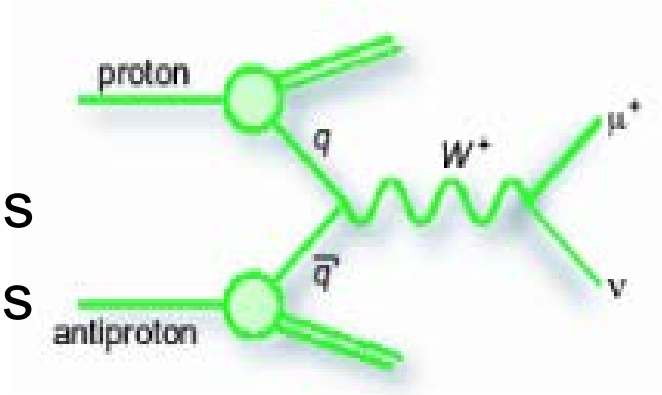
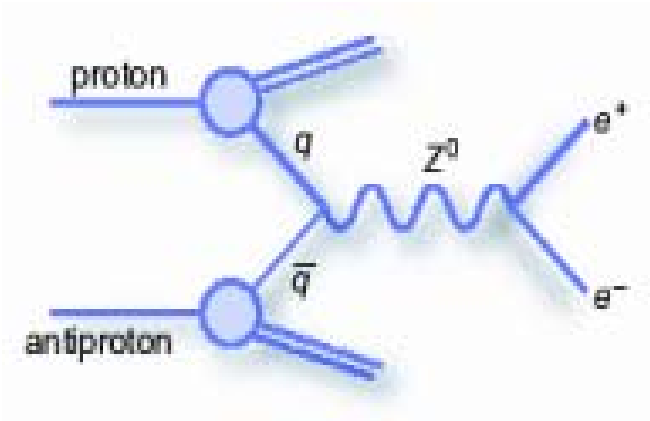
Outline

- Fermilab, CDF and DØ
- Acceptance and PDF uncertainties
- W and Z production cross-sections

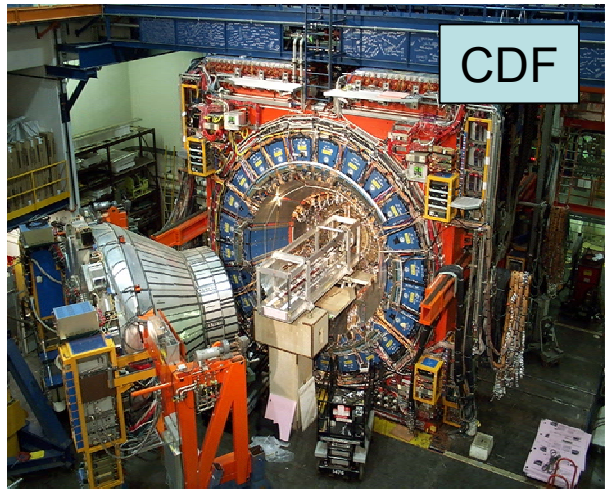




- R - Cross-section ratio measurement
- The future – a new way to measure R
- Summary

Tevatron, CDF and DØ

Delivered luminosity ~ 0.8fb^{-1}



proton anti-proton collider
1.96 TeV, 396 ns bunch spacing
Design lumi: 8fb^{-1} by 2008

Motivation

Precise measurements allow tests of Standard Model predictions

NNLO @ $\sqrt{s}$ = 1.96 GeV: (Stirling, van Neervan)

$\sigma_W \times Br(W \to l\upsilon)$ = 2687 ± 54 pb

$\sigma_Z \times Br(Z \to ll)$ = 251.3 ± 5.0 pb

$R(\sigma_W \times Br(W \to l\upsilon) / \sigma_Z \times Br(Z \to ll))$ = 10.69 ± 0.08

Can be used as a "standard candle" to measure or cross-check luminosity

Ratio of cross-sections give indirect measurement of W width

$$R = \frac{\sigma_W \times Br(W \to l\nu)}{\sigma_Z \times Br(Z \to ll)} = \frac{\sigma_W}{\sigma_Z} \frac{\Gamma_Z}{\Gamma_{Z \to ll}} \frac{\Gamma_{W \to l\nu}}{\Gamma_W}$$

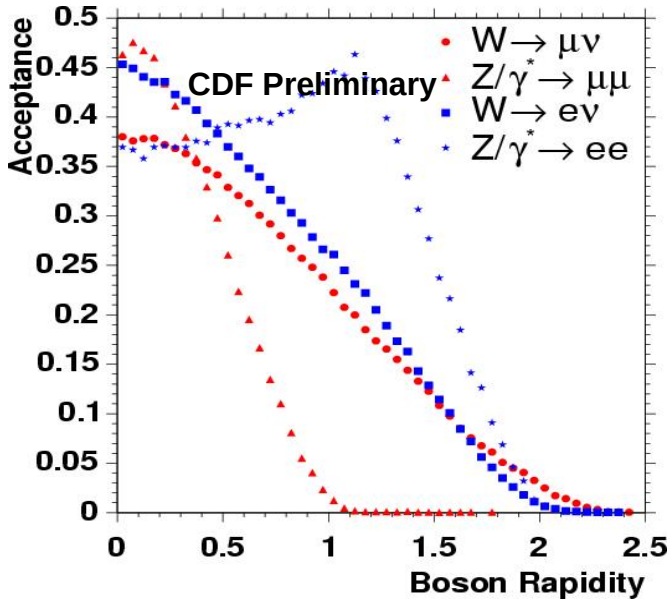
SM: 226.4±0.3MeV

SM: 3.361±0.024

LEP

PDF Uncertainties

- Generally arise in the estimation of the acceptance for these measurements
- Involves counting those events you didn't see
- Need good Monte-Carlo description of the boson production and decay and detector effects



DØ uses a brute force approach

Generate lots of MC for each CTEQ eigenvector set

Calculate error on observable using prescription in:

J.Pumplin et al, JHEP 310 046 (2003)

CDF uses re-weighting technique

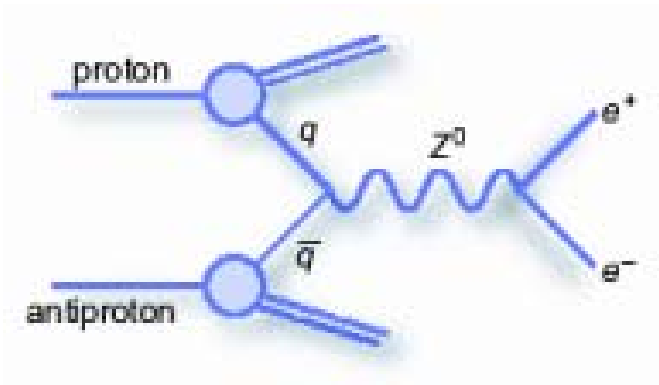
Parameterize acceptance

Generate large ensemble of MC

Re-weight events to correspond to different PDF eigenvector sets

W and Z Boson Production

Look at the leptonic decays of W and Z



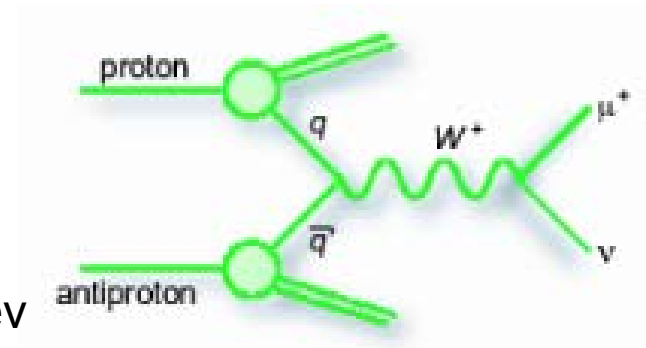
Select Z bosons with:

- single electron/muon triggers
- require two reconstructed leptons
- cut on lepton transverse momentum ~ 20 GeV

Hadronic decays too difficult to pick out from the background

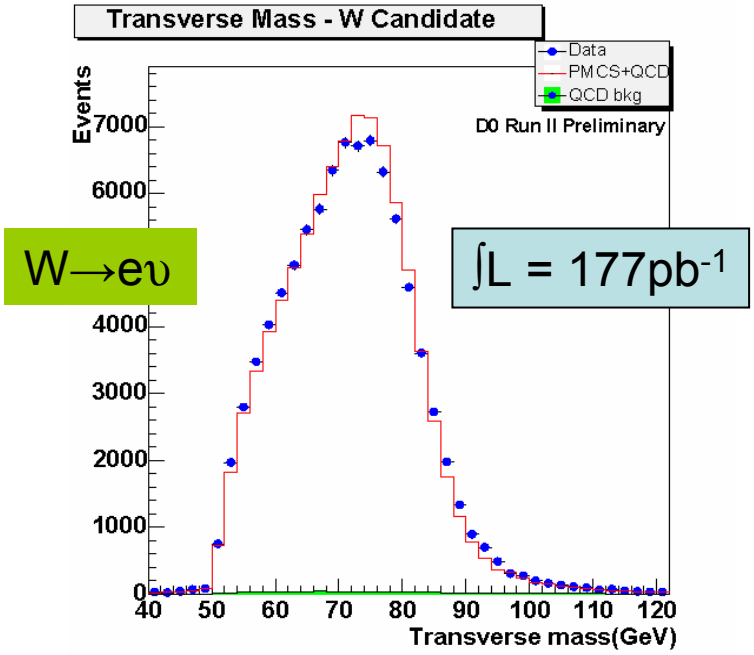
Select W bosons with:

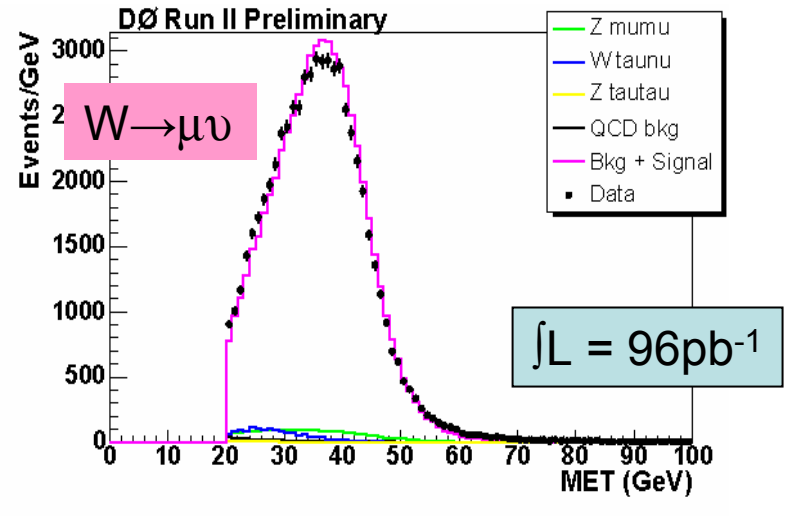
- single electron/muon triggers
- standard lepton identification cuts
- cut on lepton transverse momentum ~20GeV
- cut on missing transverse momentum ~20 Gev



W Production DØ

For W→eυ large contributions to systematics in acceptance calculation
MC-tuning: 1.13%, ID-Eff: 1.43 %, PDFs: 1.41%



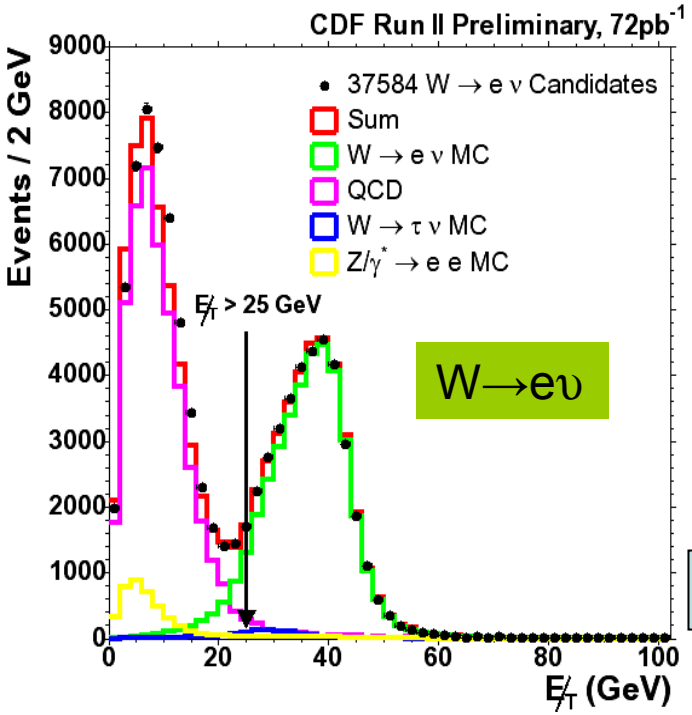


For W→μυ large contributions to systematics from
Acceptance (excl PDF): 1.7%, PDFs: 0.9%

$\sigma_W \times Br(W \to e\upsilon) = 2865.2 \pm 8.3_{(stat)} \pm 62.8_{(sys)} \pm 40.4_{(pdf)} \pm 186.2_{(lum)}$ pb

$\sigma_W \times Br(W \to \mu\upsilon) = 2989 \pm 15_{(stat)} \pm 81_{(sys)} \pm 194_{(lum)}$ pb

W Production at CDF



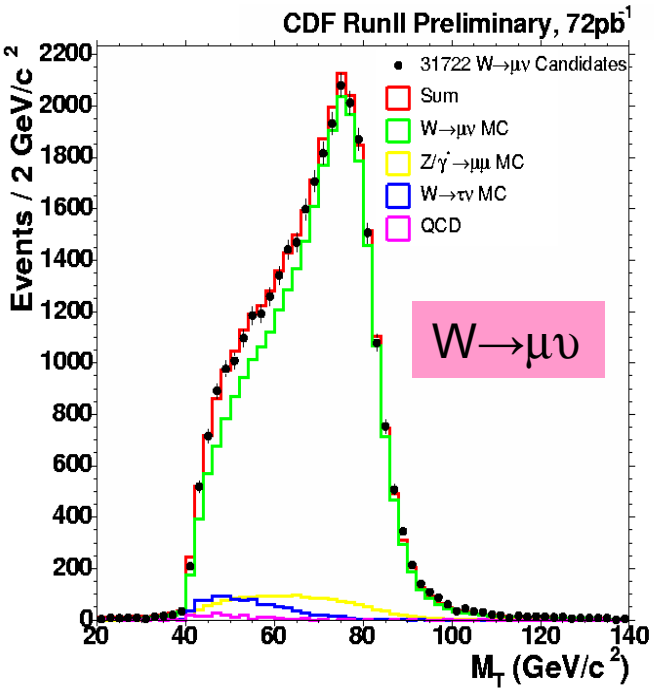
W→eυ

∫L = 72pb^{-1}

$\sigma_W \times Br(W \to e\upsilon) = 2768 \pm 14_{(stat)} \pm 60_{(sys)} \pm 167_{(lum)}$ pb

PRL 94 091803 (2005)

$\sigma_W \times Br(W \to \mu\upsilon) = 2768 \pm 14_{(stat)} \pm 60_{(sys)} \pm 167_{(lum)}$ pb

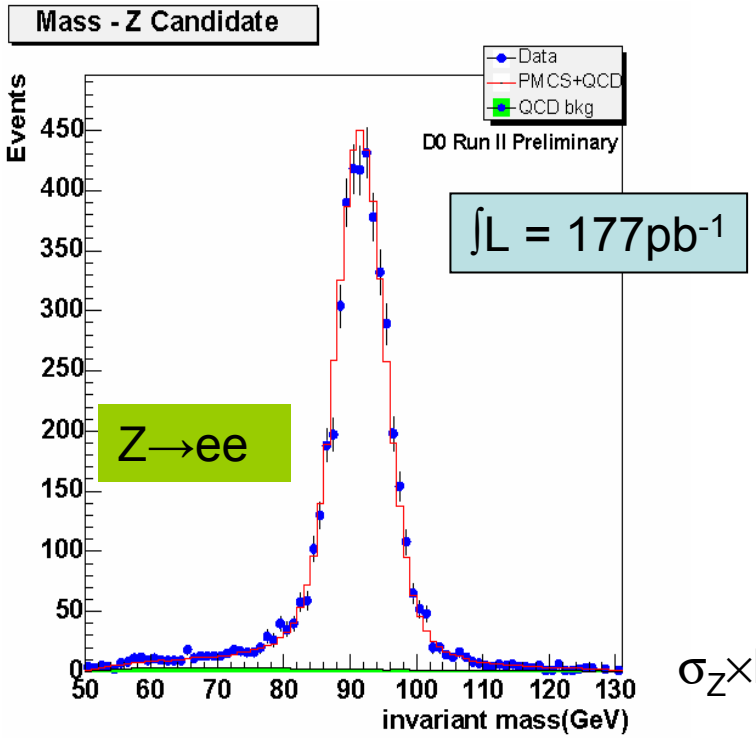


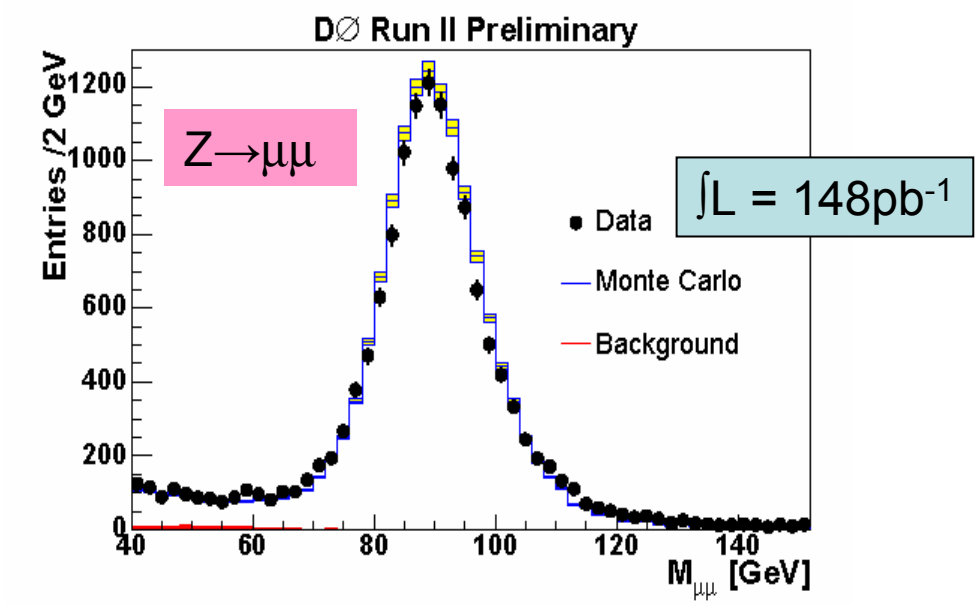
W→μυ

$\sigma_W(e+\mu) = 2775 \pm 10_{(stat)} \pm 53_{(sys)} \pm 167_{(lum)}$pb

Dominant contributions to systematics from acceptance (PDFs) and the efficiencies

Z Production at DØ





$\sigma_Z \times Br(Z \to \mu\mu) = 291 \pm 3.0_{(stat)} \pm 6.9_{(sys)} \pm 18.9_{(lum)}$ pb

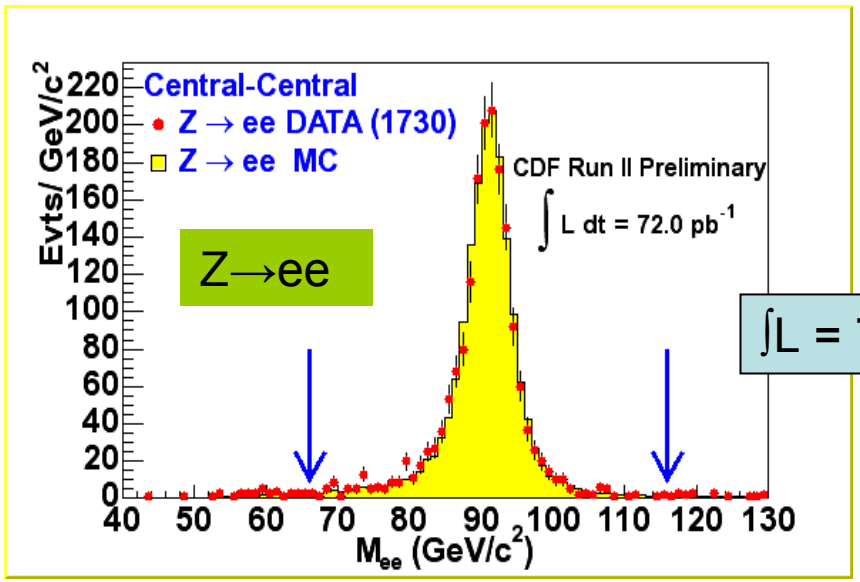
$\sigma_Z \times Br(Z \to ee) = 264.9 \pm 3.9_{(stat)} \pm 8.5_{(sys)} \pm 5.1_{(pdf)} \pm 17.2_{(lum)}$ pb

Large contributions to systematics from acceptance (PDF 1.7%) and understanding detector efficiencies

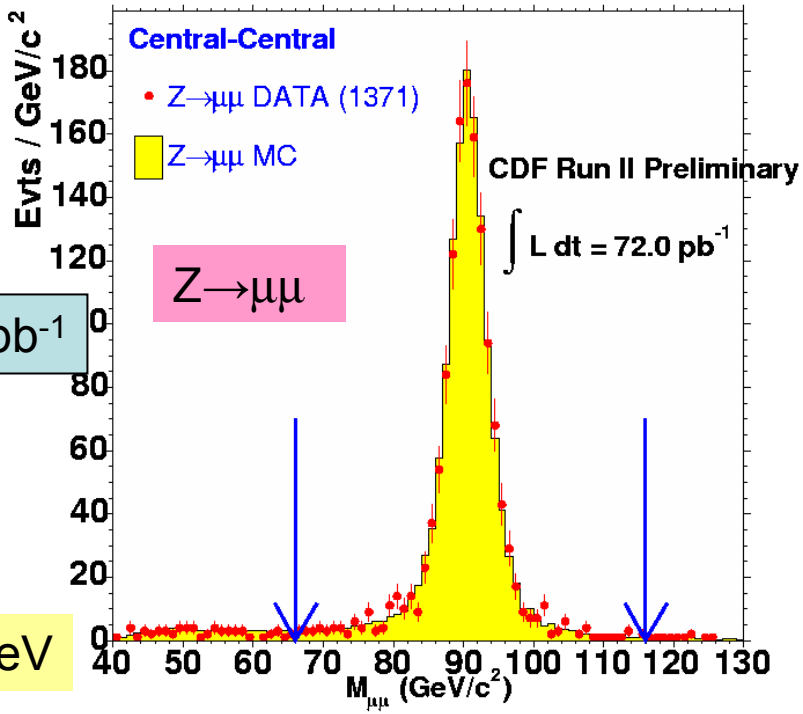
Z Production at CDF

$\sigma_Z \times Br(\gamma^*/Z \rightarrow ee) = 255.8 \pm 3.9_{(stat)} \pm 5.5_{(sys)} \pm 15.4_{(lum)}$ pb

PRL 94 091803 (2005)



$\int L = 72 pb^{-1}$



Mass window: $66 \leq M_Z \leq 116$ GeV

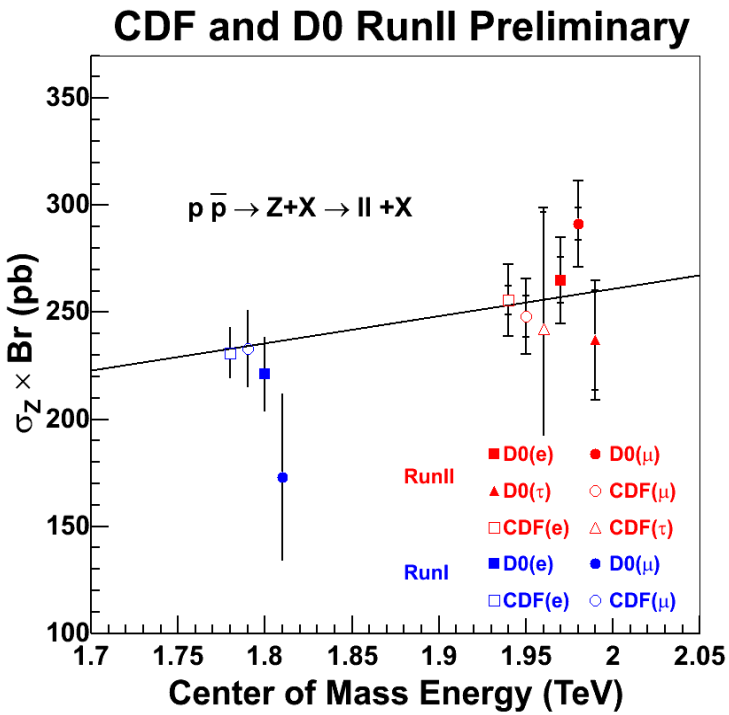
$\sigma_Z \times Br(\gamma^*/Z \rightarrow \mu\mu) = 248.0 \pm 5.9_{(stat)} \pm 7.6_{(sys)} \pm 14.9_{(lum)}$ pb

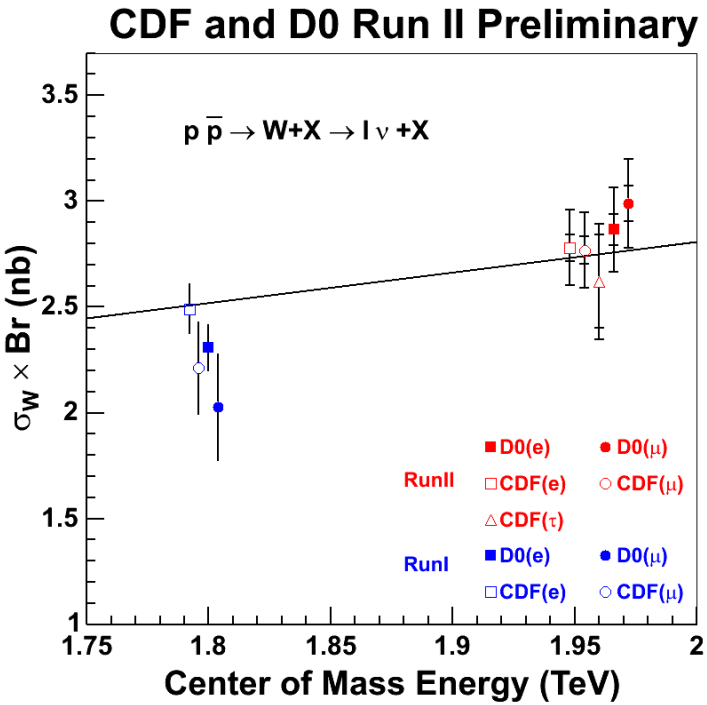
$\sigma_Z(e+\mu) = 254.9 \pm 3.3_{(stat)} \pm 4.6_{(sys)} \pm 15.2_{(lum)}$ pb

Dominant contributions to systematics from acceptance (PDFs) and the efficiencies

Cross sections Summary

Benchmark analyses for all high pT lepton analyses





Systematics limited measurements ~2-3% level (excl luminosity)

Dominant contributions from acceptance (large contributions from PDF uncertainties) and efficiencies

Cross-section Ratios

Ratio of cross-sections provides an indirect measurement of the W width

$$R = \frac{\sigma_W \times Br(W \to l\nu)}{\sigma_Z \times Br(Z \to ll)} = \frac{\sigma_W}{\sigma_Z} \frac{\Gamma_Z}{\Gamma_{Z \to ll}} \frac{\Gamma_{W \to l\nu}}{\Gamma_W}$$

Luminosity essentially cancels in ratio
Efficiencies and acceptance also cancel to a degree → reduced errors

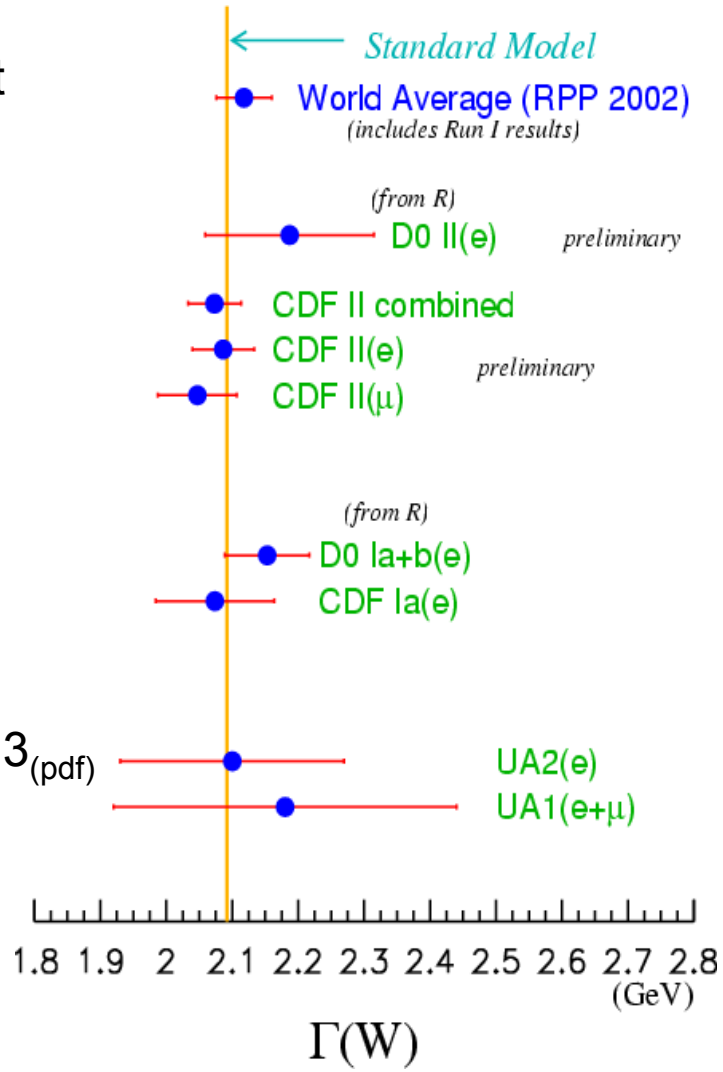
DØ preliminary:

$R(e) = 10.82 \pm 0.16_{(stat)} \pm 0.25_{(syst)} \pm 0.13_{(pdf)}$

CDF PRL 94 091803 (2005)

$R(e+\mu) = 10.92 \pm 0.15_{(stat)} \pm 0.14_{(syst)}$

$\Gamma_W = 2.079 \pm 0.042$ GeV



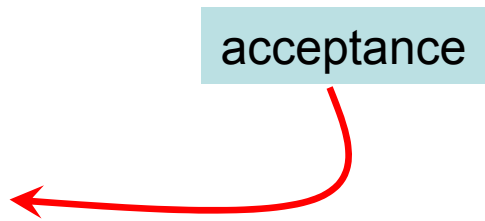
Systematics For R(W/Z) at CDF

K.Copic (UMich), V.Martin, M.Schmitt (Northwestern)

Presented recently at APS (K.Copic) and joint CTEQ/CDF/DØ W/Z Workshop (D.Waters)

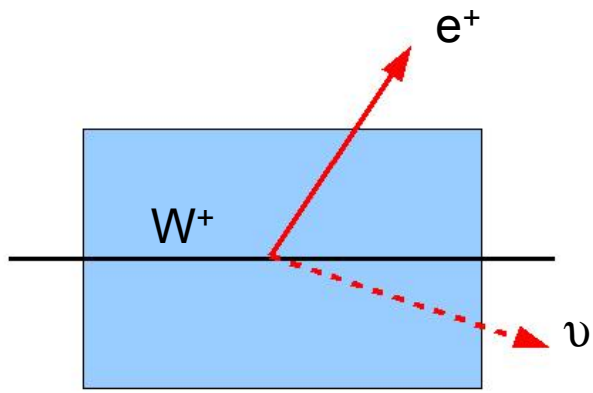
(http://www.uic.edu/~varelas/wz_workshop.html)

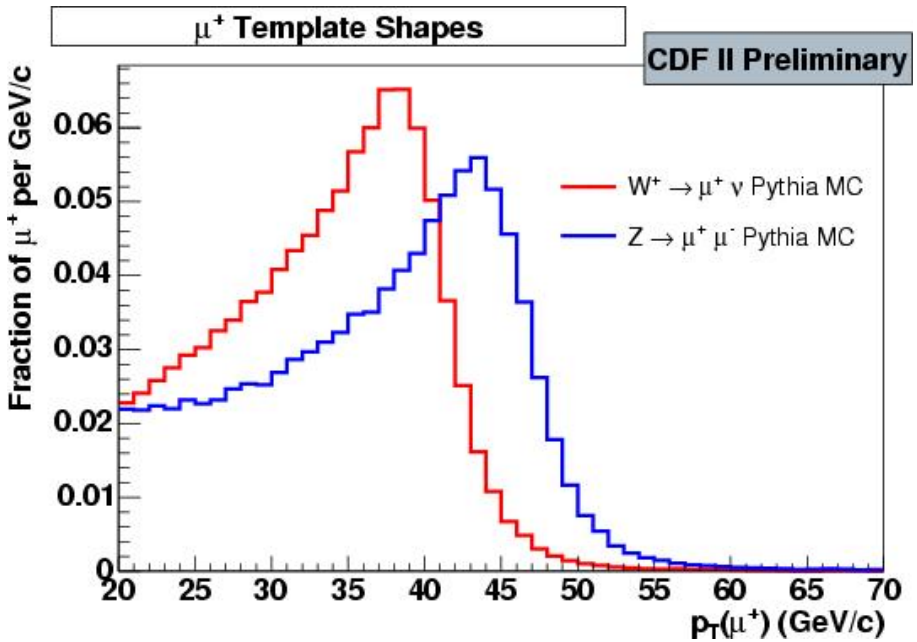
category	Electrons	muons
Central value	10.82 ± 0.16	11.12± 0.18
PDF	0.07	0.09
Material	0.03	0.00
Recoil	0.03	0.04
Efficiency	0.12	0.11
Backgrounds	0.04	0.09

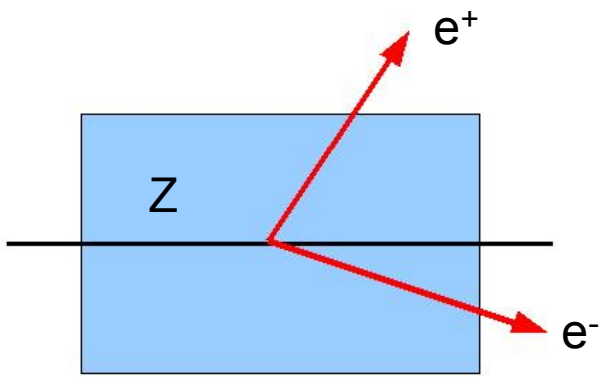


A New Way to Measure R at CDF

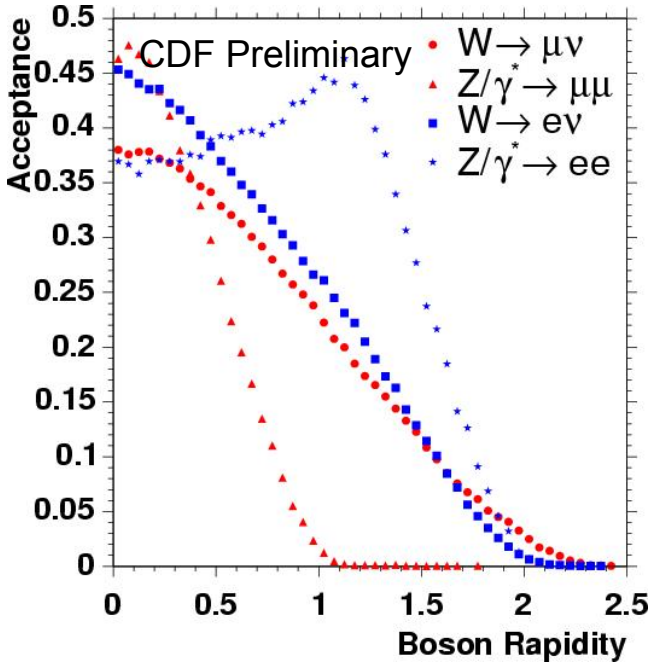
- Select W and Z events with identical cuts
  - Require a single lepton passing trigger and full lepton ID selection
  - Fit the transverse momentum (for μ) or transverse energy (for e) spectra to determine relative fraction of W or Z in sample

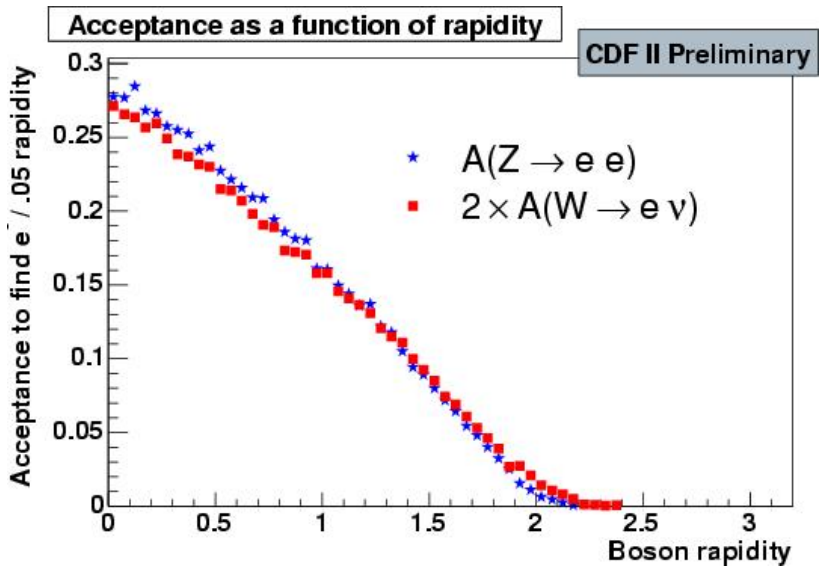






A New Way to Measure R at CDF



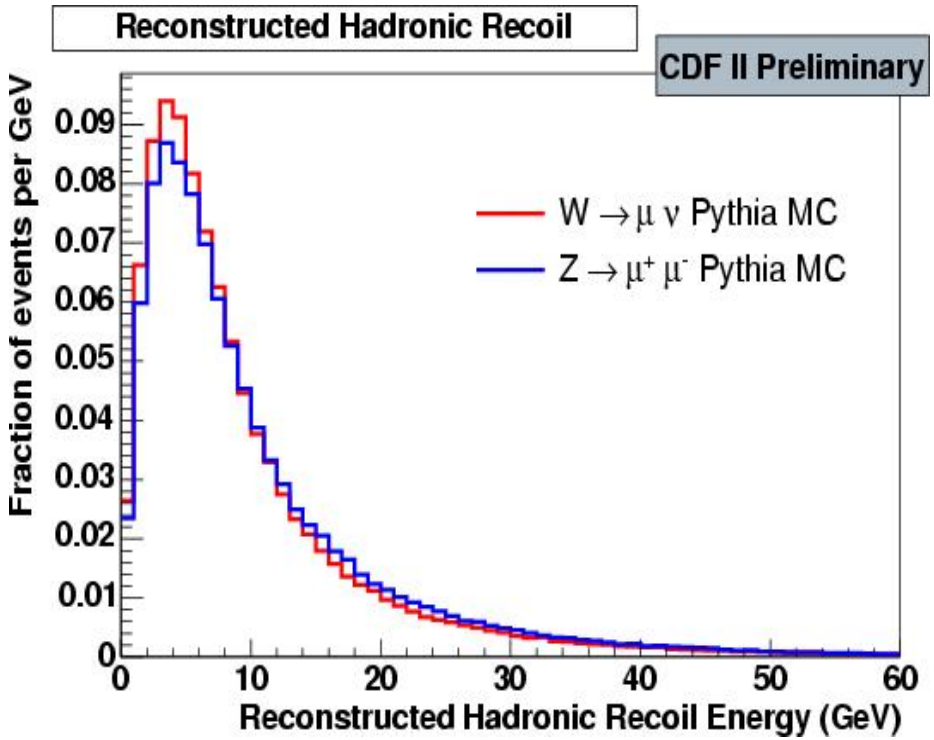


- Efficiencies now cancel almost exactly in the ratio
- Construct samples carefully → acceptances very similar for W and Z
- Evaluate PDF uncertainties on the acceptance using 40 CTEQ PDF eigenvector sets and re-weighting method

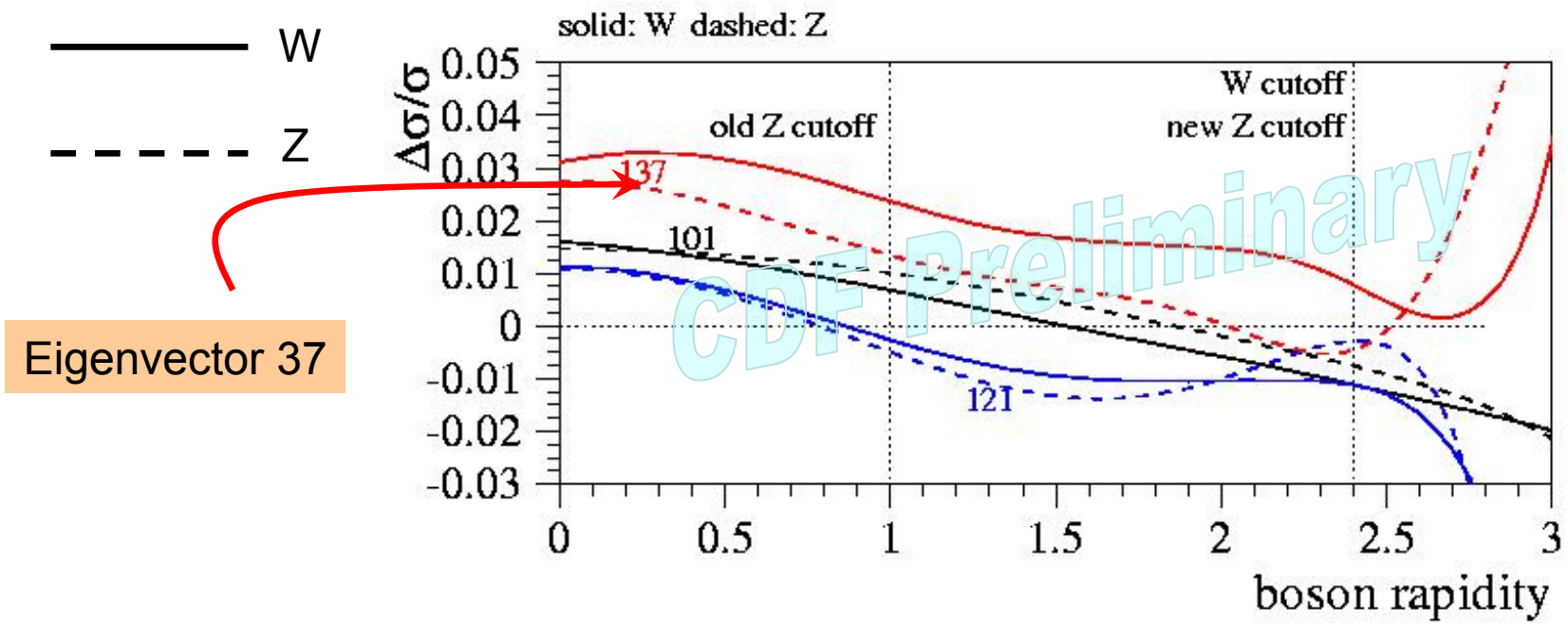
A New Way to Measure R at CDF

Removing cuts to make selections identical → increased backgrounds

- Cut on hadronic recoil
  - softer for W and Z events compared with QCD
  - Works well with muons
  - For electrons need to be careful to avoid biases
- Need well understood background shapes for template fit



Acceptance revisited PDF uncertainties



- Only sensitive to the difference in the acceptance for W and Z
- For a typical pair of PDF error sets the difference is very small
  - Though for a couple the differences are significant (eg 37,38)
- Estimated systematics from PDFs on R ≤ 0.5%

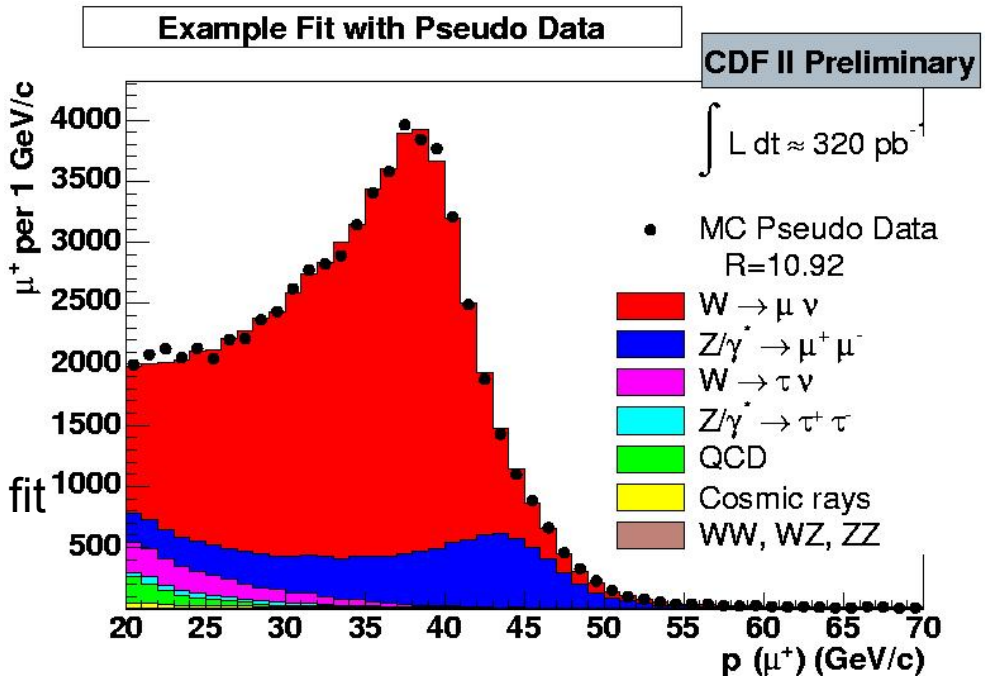
A New Way to Measure R at CDF

Trading one set of systematics:

- Efficiency
- PDFs in acceptance

For:

- statistical errors in the template fit
- Systematics from quality of Monte-Carlo description



- Initial studies of the sensitivity estimate with 400-500 pb^{-1} can achieve similar statistical power to current measurement (72pb^{-1}) but with significantly reduced systematics!

Summary

Presented results on the precise measurement of W and Z boson production

DØ preliminary

$\sigma_W \times Br(W \to e\upsilon) = 2865.2 \pm 8.3_{(stat)} \pm 62.8_{(sys)} \pm 40.4_{(pdf)} \pm 186.2_{(lum)}$ pb

$\sigma_W \times Br(W \to \mu\upsilon) = 2989 \pm 15_{(stat)} \pm 81_{(sys)} \pm 194_{(lum)}$ pb

$\sigma_Z \times Br(Z \to ee) = 264.9 \pm 3.9_{(stat)} \pm 8.5_{(sys)} \pm 5.1_{(pdf)} \pm 17.2_{(lum)}$ pb

$\sigma_Z \times Br(Z \to \mu\mu) = 291 \pm 3.0_{(stat)} \pm 6.9_{(sys)} \pm 18.9_{(lum)}$ pb

$R(e) = 10.82 \pm 0.16_{(stat)} \pm 0.25_{(syst)} \pm 0.13_{(pdf)}$

Results systematics limited at 2-3% level (+6.5% lumi)

CDF **PRL 94 091803 (2005)**

$\sigma_W(e+\mu) = 2775 \pm 10_{(stat)} \pm 53_{(sys)} \pm 167_{(lum)}$pb

$\sigma_Z(e+\mu) = 254.9 \pm 3.3_{(stat)} \pm 4.6_{(sys)} \pm 15.2_{(lum)}$ pb

$R(e+\mu) = 10.92 \pm 0.15_{(stat)} \pm 0.14_{(syst)}$

$\Gamma_W = 2.079 \pm 0.042$ GeV

Dominant systematics come from acceptance and efficiency – includes large contributions from PDF uncertainties

Which underlying physical aspects of the PDFs contribute to uncertainties?
Which measurements (e.g. W charge asymmetry, inclusive jets) at the Tevatron can help?

Though we may come up with clever ideas to reduce systematics, PDF and other production uncertainties could still play a significant role both in these measurements and other precision measurements such as the W boson mass