W Mass and Properties

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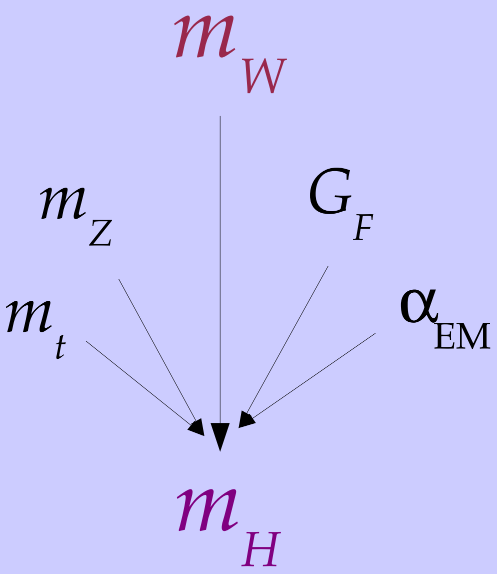
For the CDF and DØ Collaborations

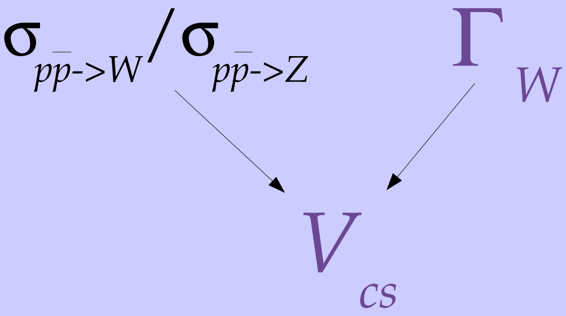


m_W

m_Z G_F

m_t α_{EM}

m_H



$\sigma_{p\bar{p}->W}/\sigma_{p\bar{p}->Z}$ Γ_W

V_{cs}

XIII International Workshop on Deep Inelastic Scattering
University of Wisconsin, Madison
April 27, 2005

W Physics

Study of W bosons at Tevatron provides key SM parameters and constrains physics beyond the SM

W mass: Constrains Higgs mass and new particles coupling to *W*

W width: Input for extracting CKM parameter V_{cs}

W/Z cross section ratio: Sensitive to *W* width and CKM parameter V_{cs}

WVV couplings: Probes new physics coupling to electroweak bosons

W measurements sensitive to parton distributions in proton

- Longitudinal boost affects mass reconstruction and lepton acceptances
- Difference between u(x) and d(x) in proton causes $u\bar{d} \rightarrow W^+$ and $\bar{u}d \rightarrow W^-$ to be boosted in opposite directions

W charge asymmetry
W differential distributions } constrain parton distributions

W Mass in the Standard Model

SM predicts m_W in terms of Z, t masses and electroweak couplings

"On-shell" scheme:

Measured to 0.014% at $Q^2=m_Z^2$

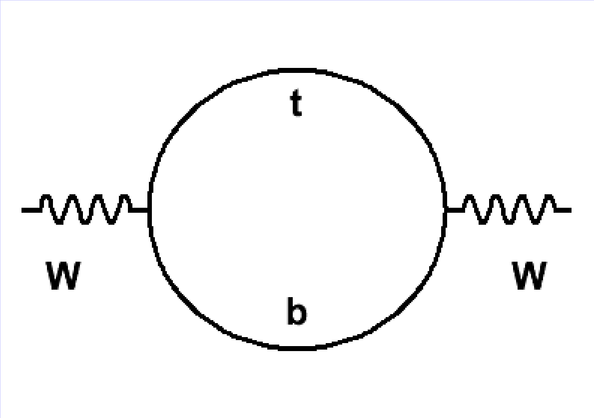
$$m_W^2 = \frac{\pi\alpha_{EM}}{\sqrt{2}G_F\,(1-m_W^2/m_Z^2)(1-\Delta r)}$$

Measured to 0.0009% with muon lifetime

Measured to 0.004% at LEP

Radiative corrections dominated by top, Higgs

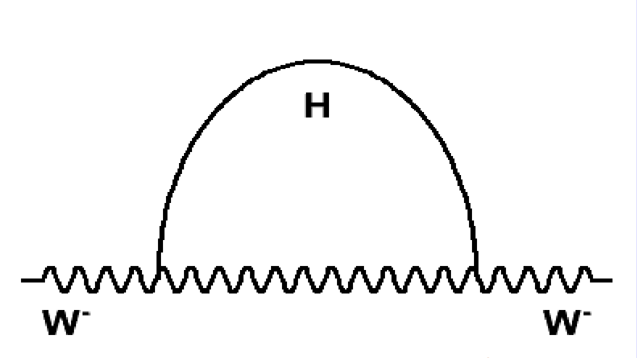
(0.67% correction)



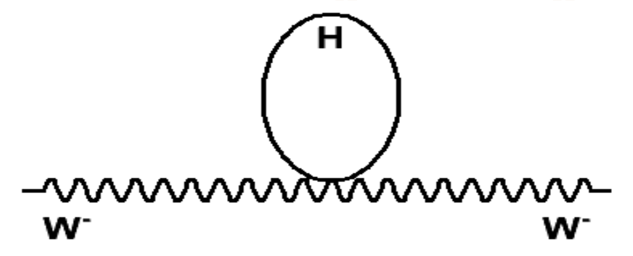
$\Delta m_W \propto m_t^2$

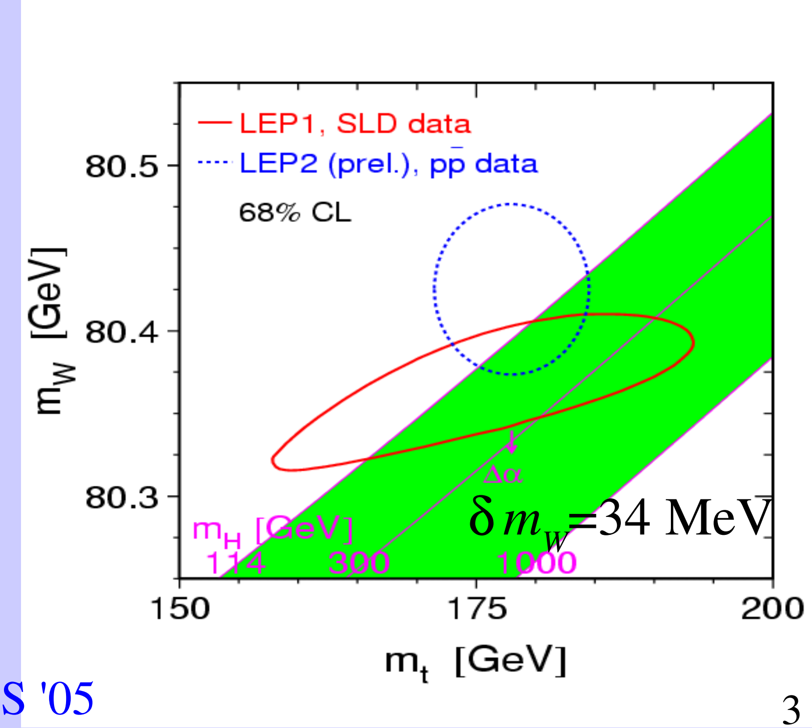
$\delta m_t = 4.3$ GeV →

Need $m_W = 30$ MeV (0.037%)



$\Delta m_W \propto -\ln(m_H) - \ln^2(m_H)$





$\delta m_W = 34$ MeV

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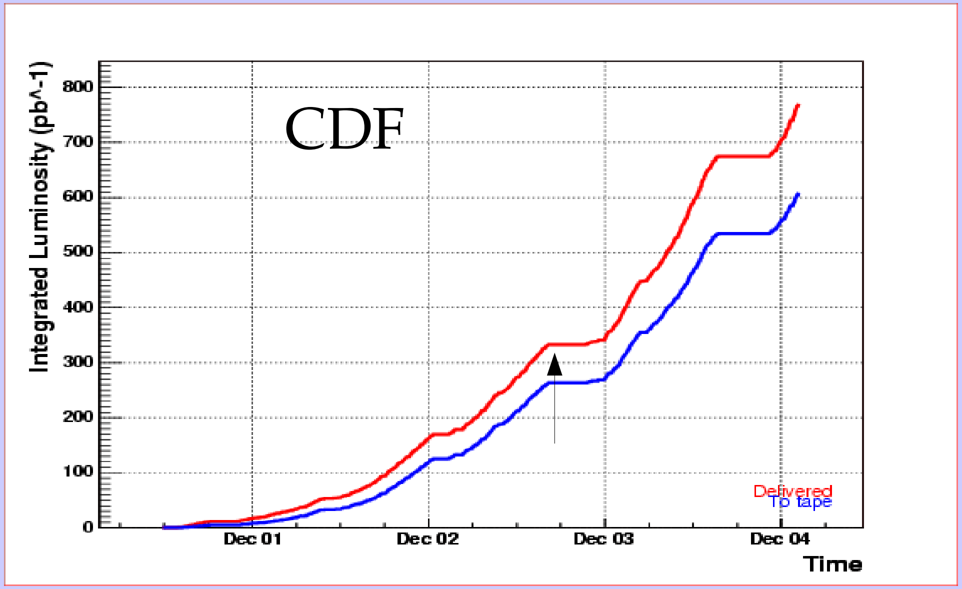
W Mass and Width at the Tevatron

Run 1: Mass: 59 MeV combined uncertainty (79 CDF, 84 DØ),
Width: 105 MeV uncertainty (120 CDF, 175 DØ)

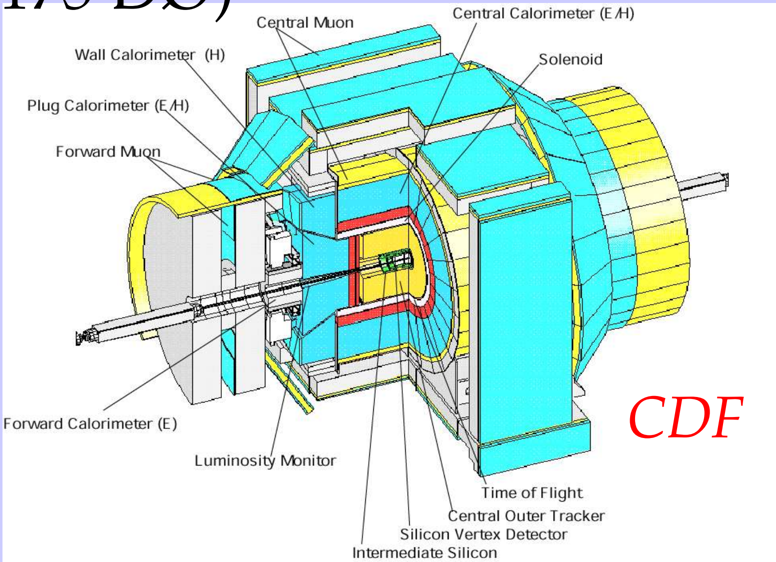
$\mathcal{L}$~120 pb^{-1}

Run 2: $\mathcal{L}$ ~ 600 pb^{-1} recorded per experiment

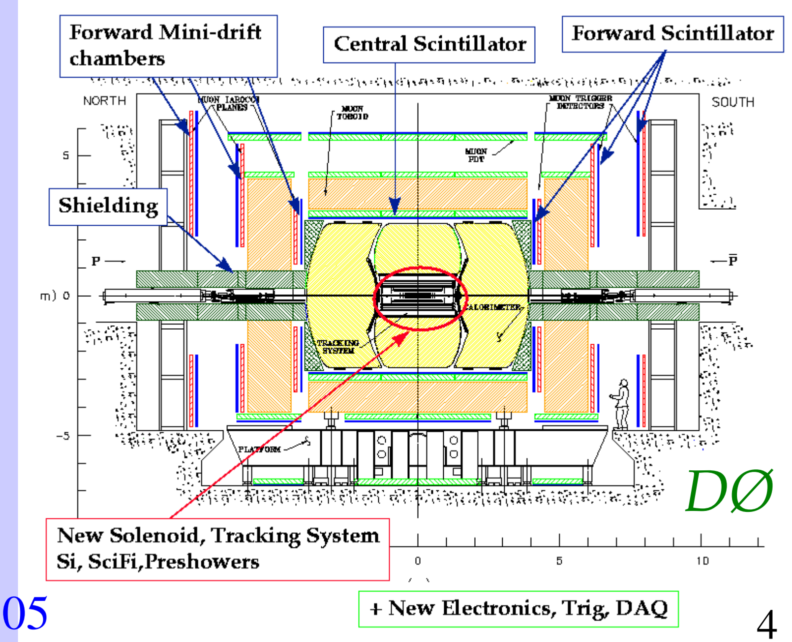


CDF:
Analyzed first 200 pb^{-1}, determined W mass uncertainties in e and μ channels

DØ:
Measured W width in 177 pb^{-1} of electron data



CDF



Forward Mini-drift chambers

Central Scintillator

Forward Scintillator

Shielding

New Solenoid, Tracking System
Si, SciFi, Preshowers

+ New Electronics, Trig, DAQ

DØ

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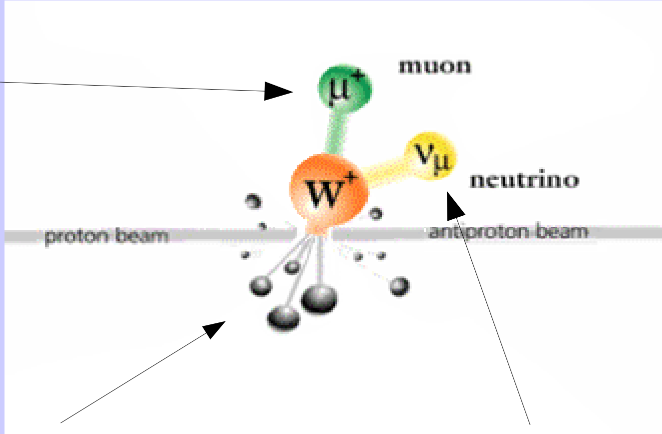
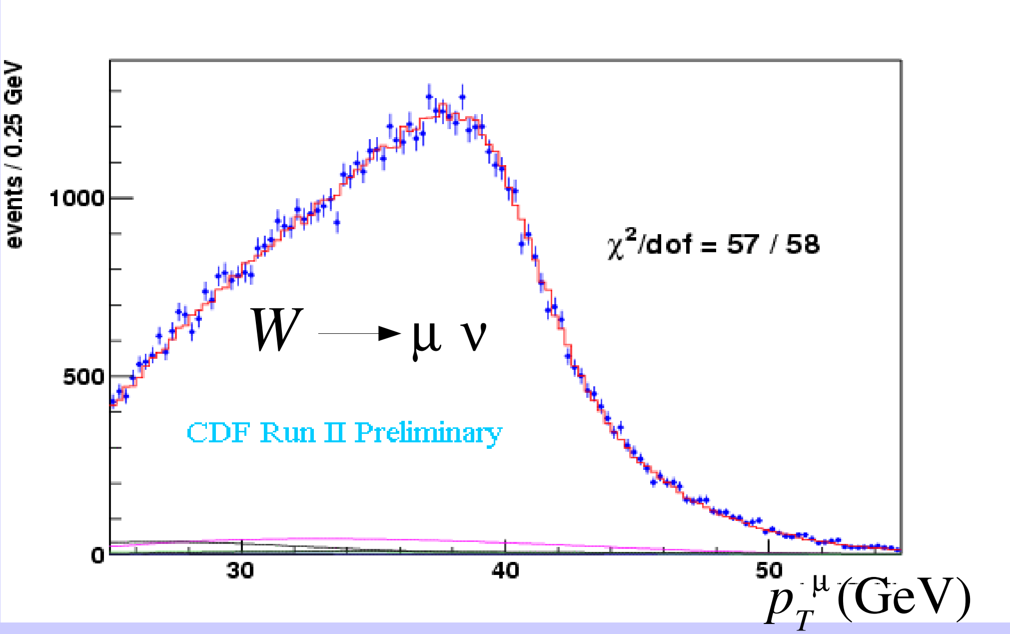
W Mass at the Tevatron

Mass information comes primarily from lepton p_T

- Run 2 goal: calibrate p_T to ~0.01%

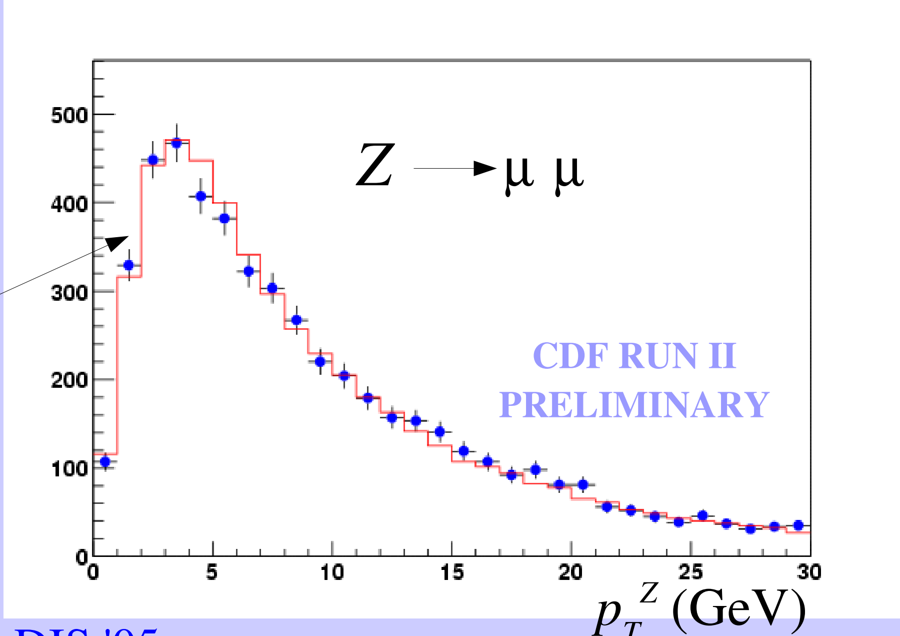




Additional information from ν p_T

(inferred through measurement of hadronic recoil energy)

Use *Z* decays to model boson p_T distribution, detector response to hadronic recoil energy

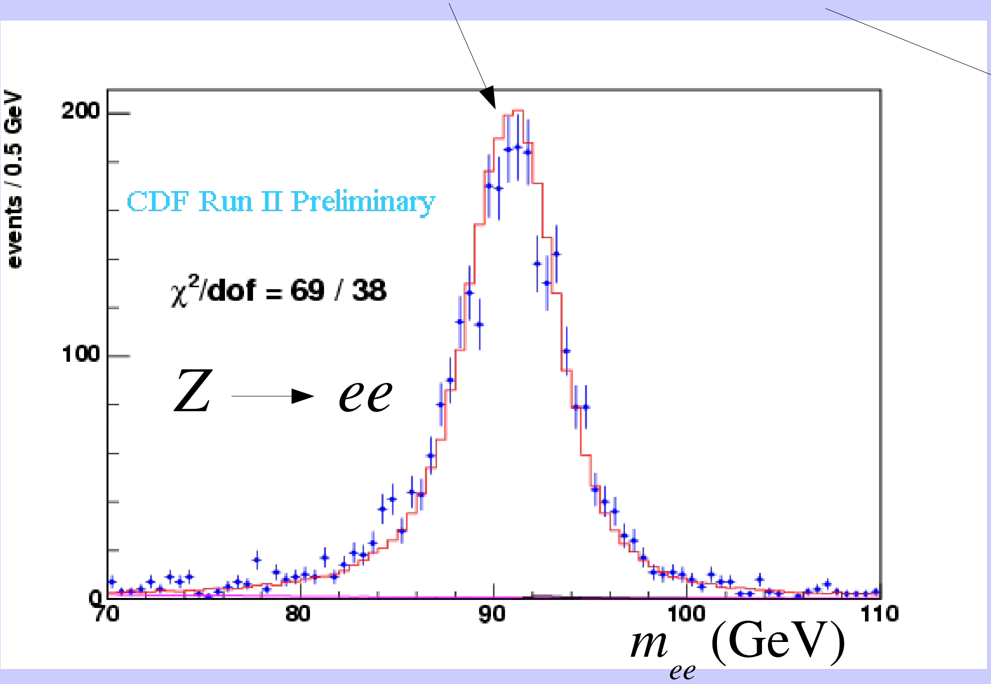


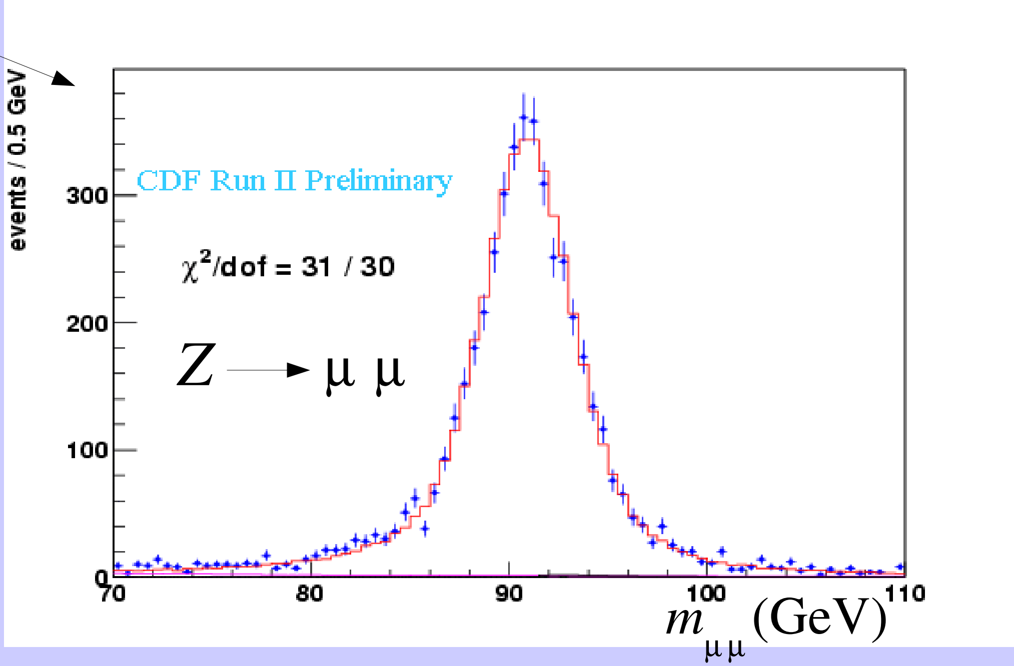
Combine lepton and neutrino p_T to form transverse mass (m_T) for best statistical power

$$m_T^2 = 2p_T^l p_T^\nu(1-\cos\Delta\phi)$$

W Mass at CDF

Similar calorimeter and tracker resolutions for e and μ from *W*/*Z* decays

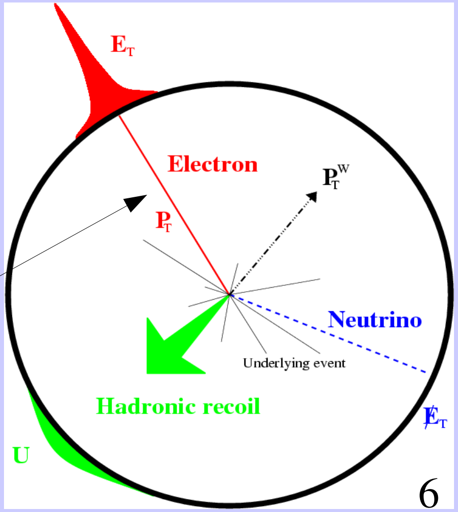




Combine electron and muon channels to increase statistical power

Strategy:

- *Use muons from decays of low-mass resonances to calibrate tracker*
  - *Linear momentum response allows extrapolation to high masses*
- *Use electrons from W decays to calibrate calorimeter with track*
- *Model hadronic response using $Z \rightarrow ll$ events*



W Mass Uncertainties at CDF

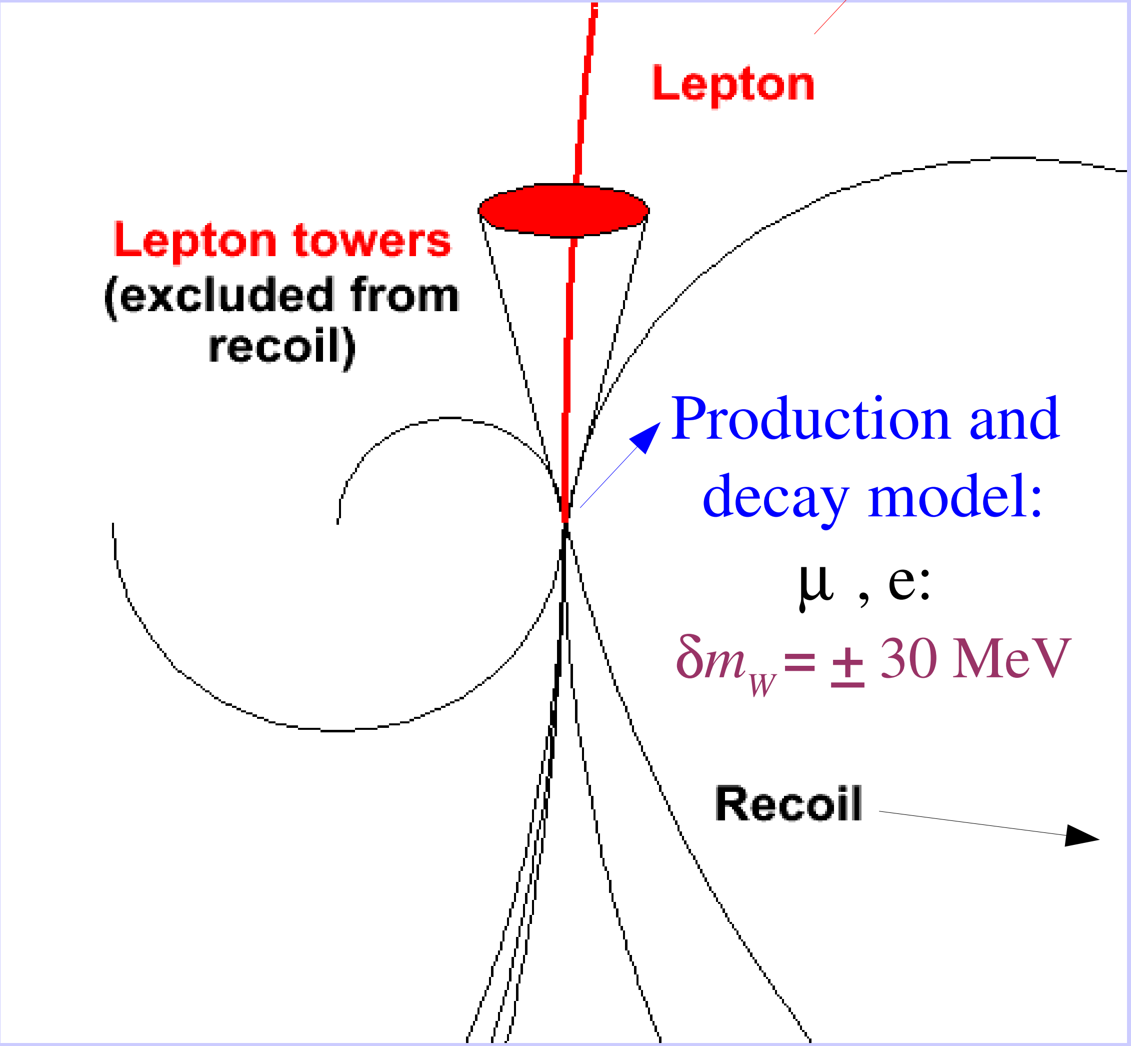
Backgrounds:

μ , e: $\delta m_W = \pm 20$ MeV

Scale and resolution:

μ : $\delta m_W = \pm 30$ MeV

e: $\delta m_W = \pm 70$ MeV



Statistics:

μ :

$\delta m_W = \pm 50$ MeV

e :

$\delta m_W = \pm 45$ MeV

Production and decay model:

μ , e:

$\delta m_W = \pm 30$ MeV

Transverse mass fit

CDF RUN II PRELIMINARY

Scale and resolution:

μ ,e: $\delta m_W = \pm 50$ MeV

CDF Event Generation

Precision of few parts in 10^4 requires detailed model of measured line shapes

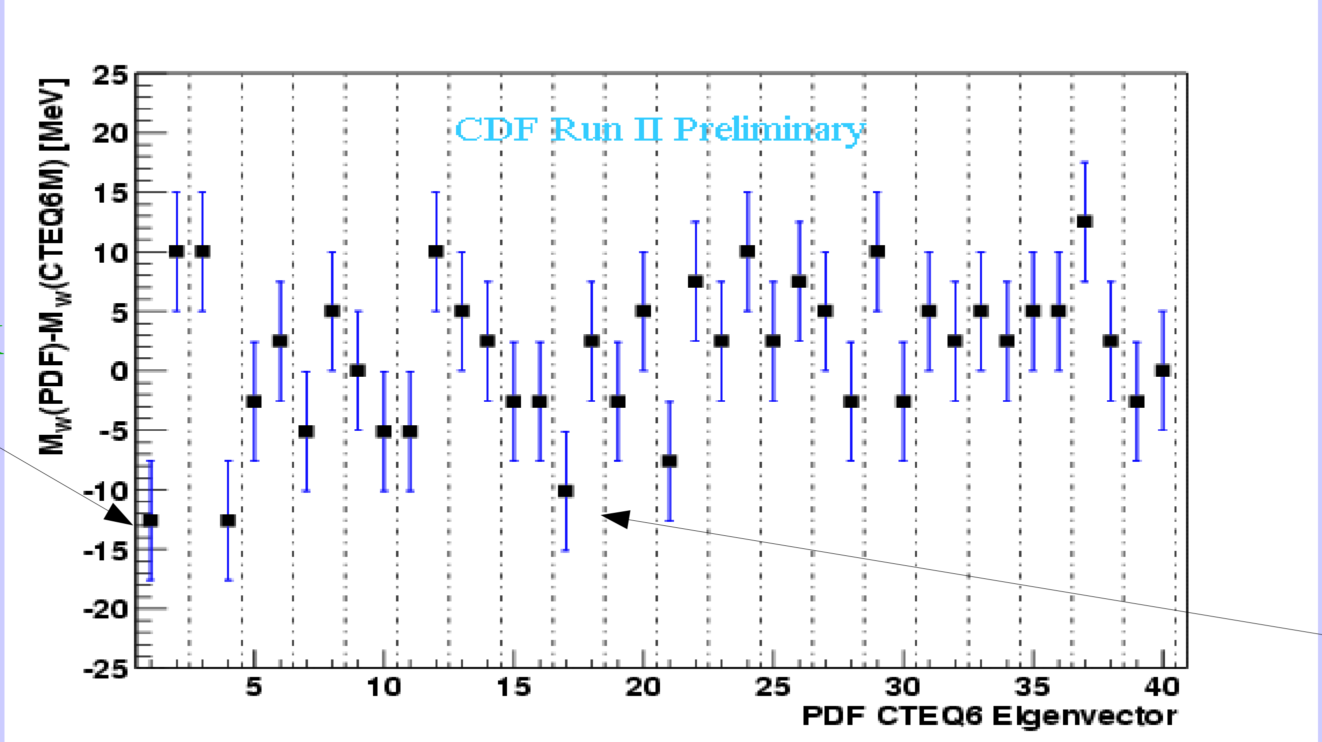
W/Z production:

Parton distribution functions determine boson η distribution

m_T and p_T fits rely on accurate model of lepton η

$\delta m_W = \pm 15$ MeV

Determined using CTEQ eigenvectors, cross-checked with MRST



Valence quark eigenvectors

Gluon eigenvectors

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CDF Event Generation and Simulation

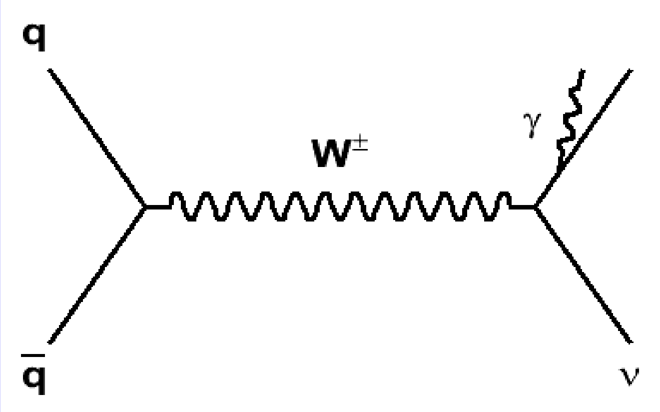
QCD corrections to W/Z production:

Model boson p_T using event generator (RESBOS) with next-to-leading log calculation, non-perturbative parameters constrained with Run 1 Z p_T data

$\delta m_W = \pm 13$ MeV ← 27 MeV for lepton p_T fit

QED corrections to W/Z decay:

Simulate radiation of final state photons according to energy and spatial distributions from NLO event generator (WGRAD)



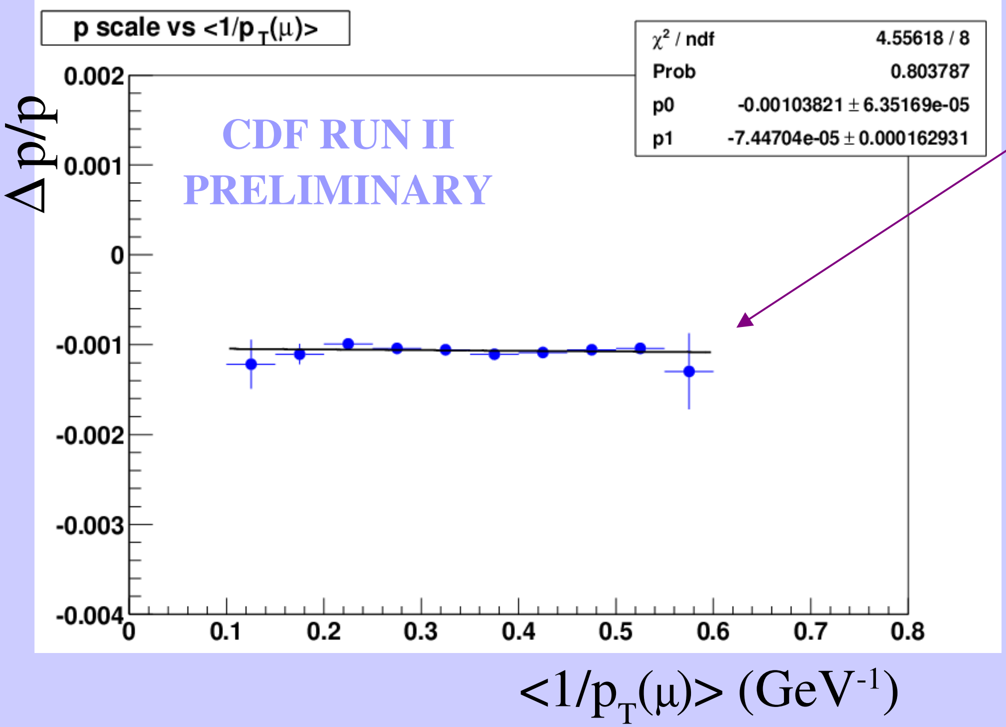
$\delta m_W = \pm 15\text{-}20$ MeV

Detector simulation and reconstruction:

- Fast hit-level tracker simulation
- Model bremßtrahlung, ionization energy loss, γ conversion

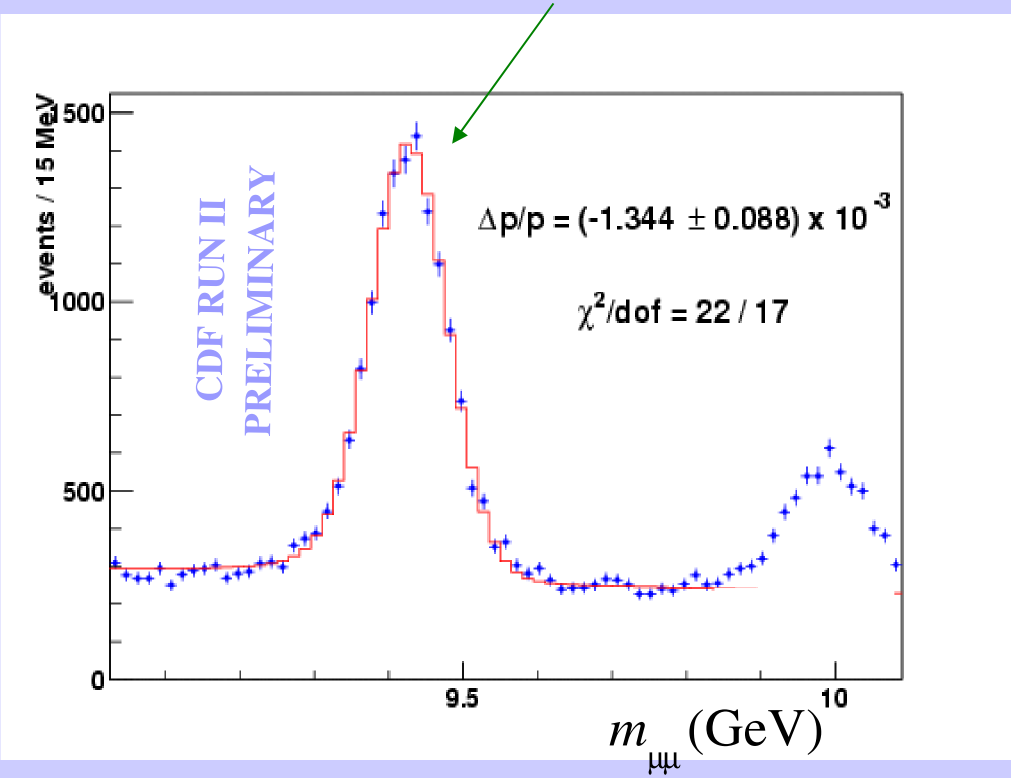
CDF Muon Momentum Calibration

Set momentum scale using J/ψ and upsilon decays to muons



J/ψ mass independent of muon momentum

Upsilon mass constrains tracker non-linearity and tests prompt track fit



momentum determined to
3 parts in 10000:

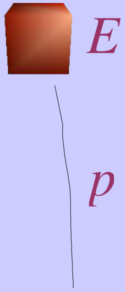
$\delta m_W = \pm 25$ MeV

CDF Electron Energy Calibration

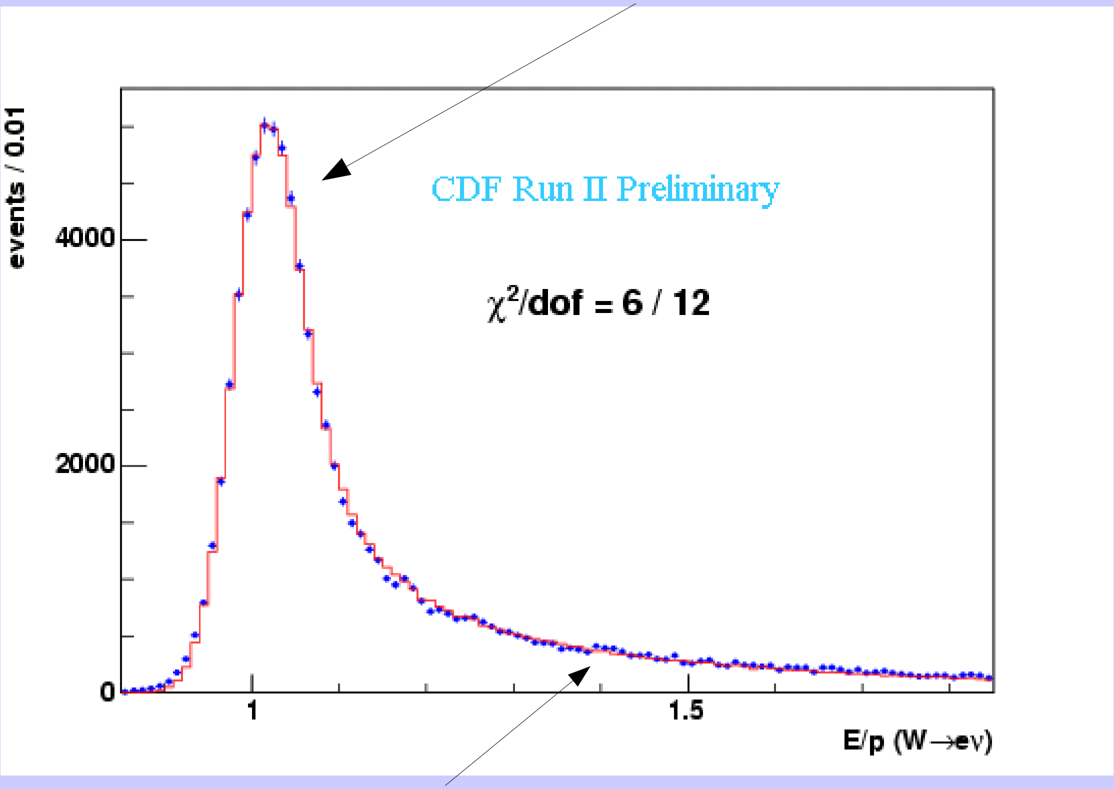
Use calibrated tracks to set calorimeter electromagnetic energy scale

E/p peak in *W* → eν events determines energy scale

High statistics, similar energy distribution to measurement sample

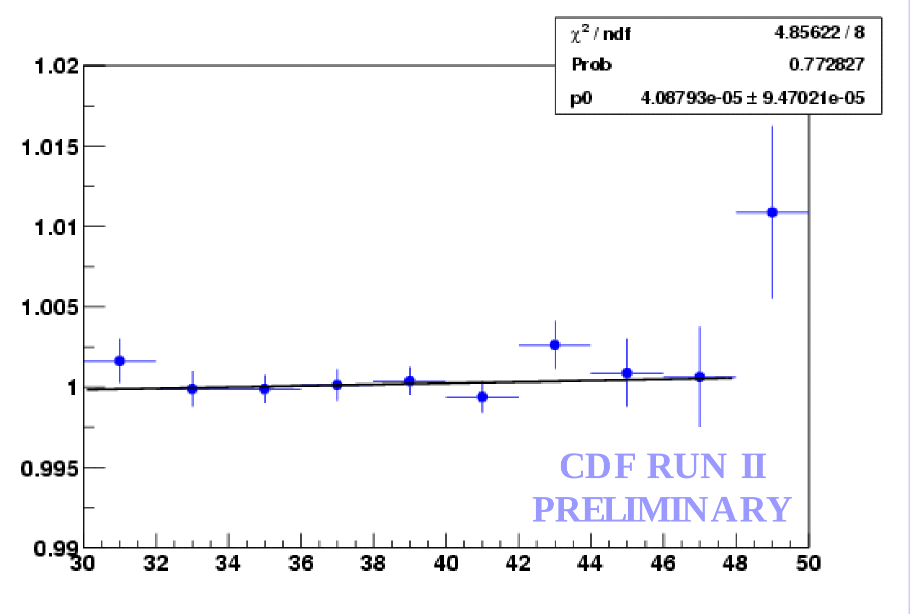


$\delta m_W = \pm\ 35$ MeV



Measure calorimeter non-linearity using E/p distribution in bins of E_T

$\delta m_W = \pm\ 25$ MeV



*Significant amount of passive material (silicon) in CDF detector

$\delta m_W = \pm\ 55$ MeV

Tune upstream passive material model using tail of E/p distribution

CDF Hadronic Recoil Measurement Model

* Parametrize hadronic response: $R = \mathbf{u}_{\text{meas}} / \mathbf{u}_{\text{true}}$

* Resolution model combines terms from underlying event and jet resolution

$\mathbf{u}_{\text{true}}$ given by $p_T(Z)$

$\delta m_W = \pm 20$ MeV

Underlying event:

* independent of recoil

* resolution model tuned on minimum bias events

$\delta m_W = \pm 37$ MeV

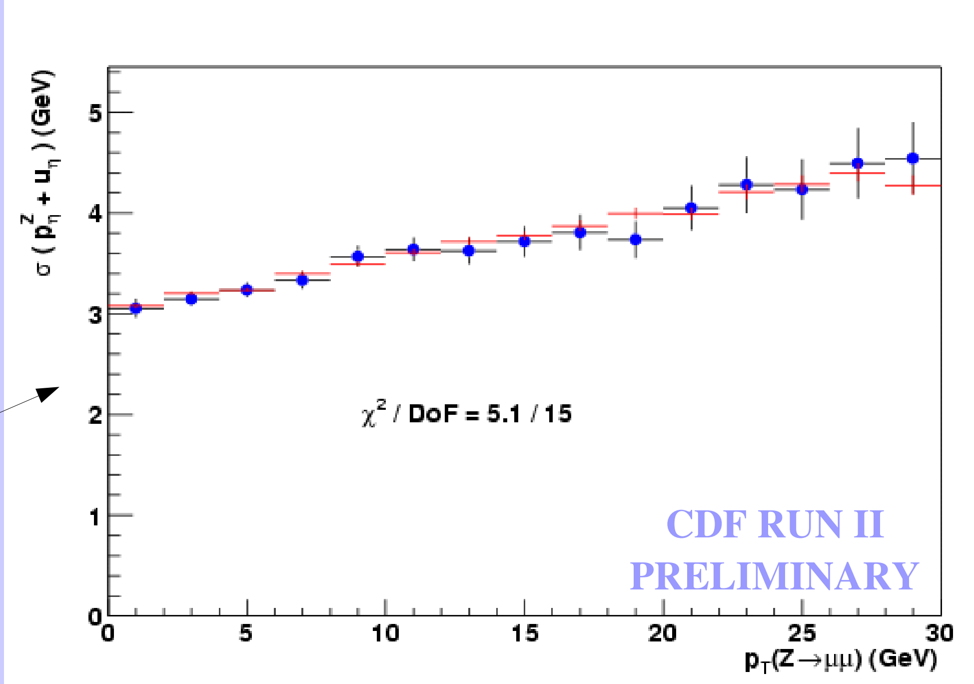
Jet resolution:

* accounts for resolution $p_T(Z)$-dependence

* resolution ~ $[\, p_T(Z)\,]^{1/2}$

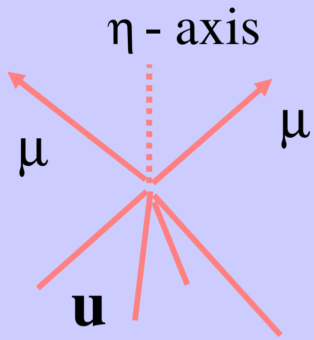
$\delta m_W = \pm 20$ MeV

Resolution as a function of p_T

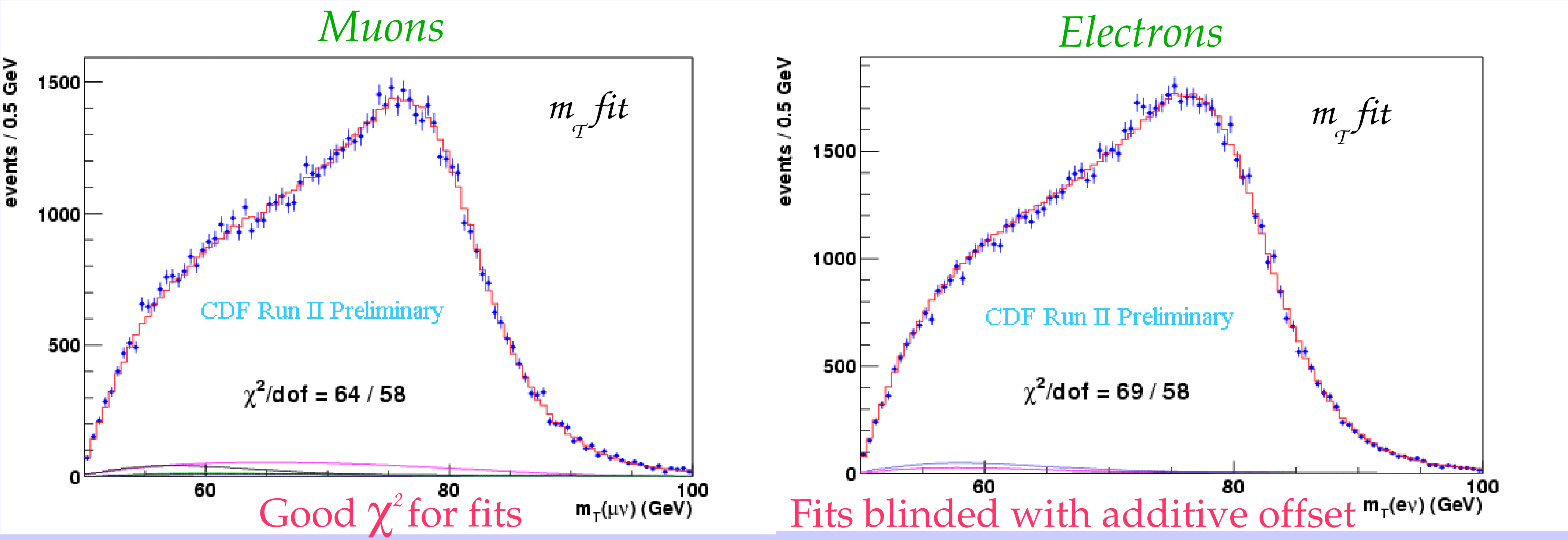


Tune parameters using

$Z \longrightarrow \mu\mu$ events



CDF *W* Mass Fits and Systematics



Muons

Electrons

Good χ^2 for fits

Fits blinded with additive offset

Systematic	Electrons (Run 1b)	Muons (Run 1b)	Common (Run 1b)
Production and Decay Model	30 (30)	30 (30)	25 (16)
Lepton Energy Scale and Resolutic	70 (80)	30 (87)	25 (0)
Recoil Scale and Resolution	50 (37)	50 (35)	50 (0)
Backgrounds	20 (5)	20 (25)	
Statistics	45 (65)	50 (100)	
Total	105 (110)	85 (140)	60 (16)

Total uncertainty 76 MeV (cf Run 1: 79 MeV)

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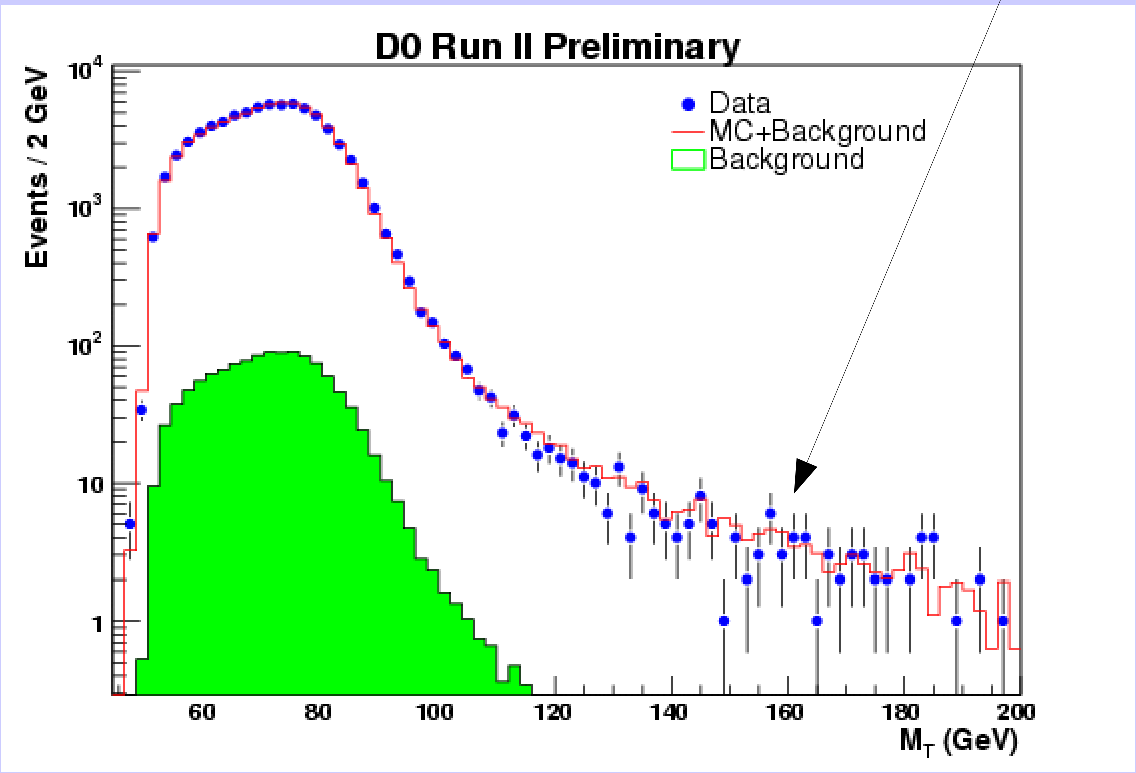
DØ *W* Width Measurement

Width information in events with high m_T

- *Fit 625 candidate $W \rightarrow e\nu$ events in region $100\ \text{GeV} < m_T < 200\ \text{GeV}$*

$$\Gamma_W = 2.011 \pm 0.093 \pm 0.107\ \text{GeV}$$



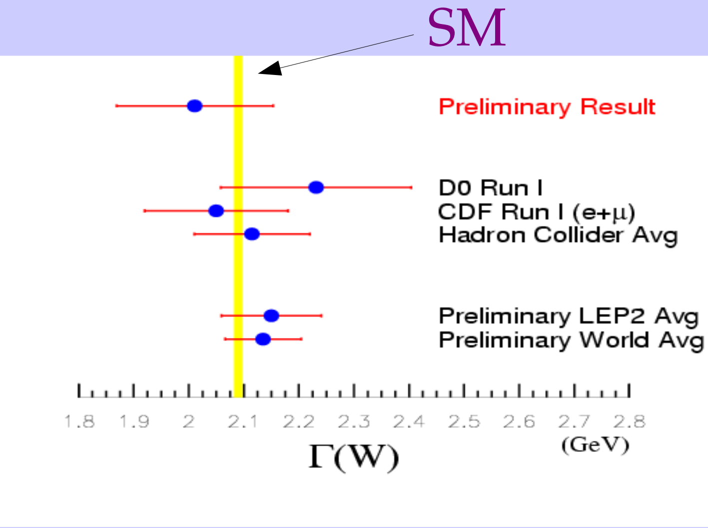
Dominant systematic uncertainties:

* Electron scale and resolution

$$\delta\Gamma_W = \pm 55\ \text{MeV}$$

* Recoil scale and resolution

$$\delta\Gamma_W = \pm 80\ \text{MeV}$$



Summary and Outlook

Tevatron W studies providing important SM measurements and constraints

W mass and width measurements key components

Run 2 analyses in advanced stages

- *200 pb^{-1} analyzed at CDF and W mass uncertainties determined*
  - ***Run 2 W mass uncertainty: 76 MeV (Run 1: 79 MeV)***
- *DØ width measurement complete with 177 pb^{-1}*
  - ***Run 2 W width uncertainty: 142 MeV (Run 1: 173 MeV)***

Run 2 will integrate 4 - 8 fb^{-1}

- *Expect to provide significant reduction in uncertainties*
  - *Mass: 40 MeV per experiment in Run 2*
    (current single most precise experiment: ALEPH, 58 MeV)
  - *Width: 50 MeV per experiment in Run 2*
    (current single most precise experiment: DELPHI, 120 MeV)