W Boson Mass Measurement at the Tevatron

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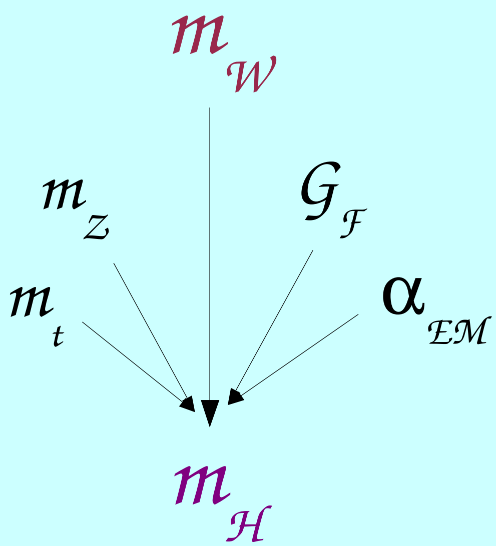
For the CDF and DØ Collaborations



m_W

m_Z

G_F

m_t

α_{EM}

m_H

XLth Rencontres de Moriond -- March 16, 2005

W Mass in the Standard Model

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

"On-shell" scheme:

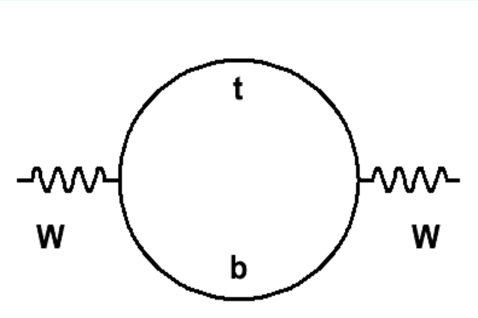
$$m_W^2 = \frac{\pi\alpha_{EM}}{\sqrt{2}G_F\,(1-m_W^2/m_Z^2)(1-\Delta r)}$$

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

Measured to 0.0009% with muon lifetime

Measured to 0.004% at LEP

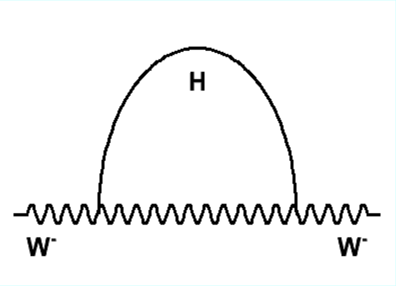
Radiative corrections dominated by top, Higgs (0.67% correction)



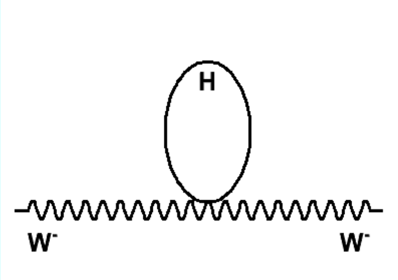
$\Delta m_W \propto m_t^2$

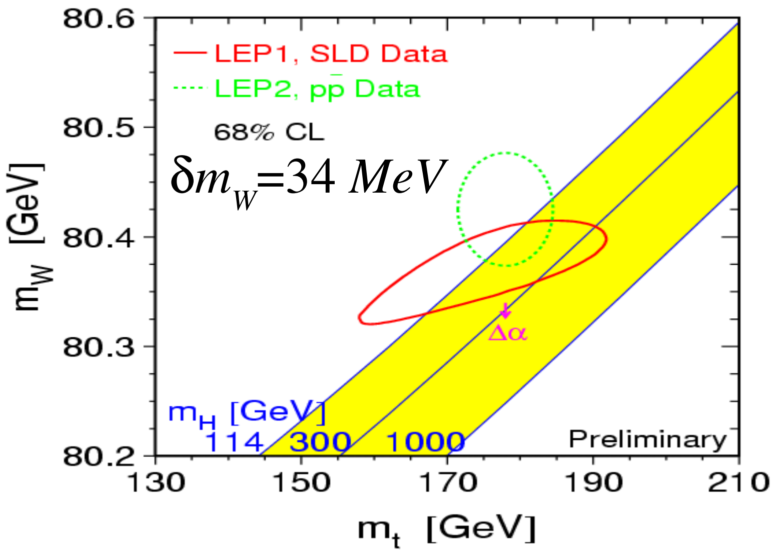
δm_t = 4.3 GeV → *Need*

δm_W = 30 MeV (0.037%)



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

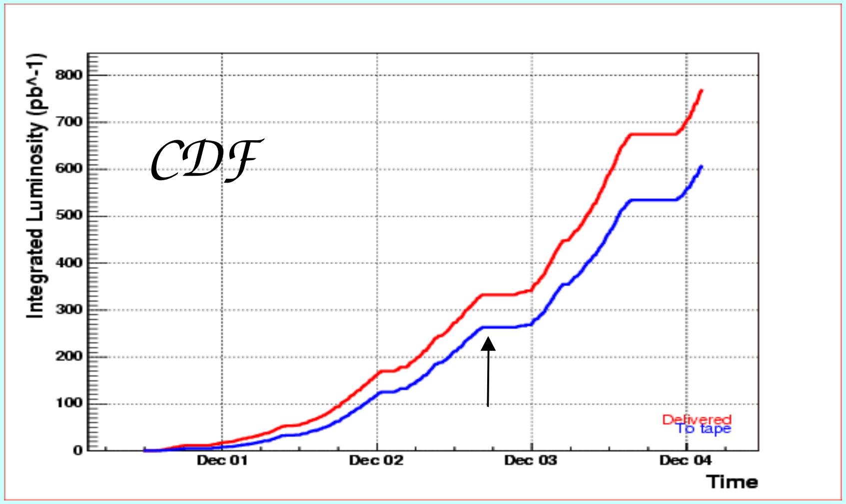


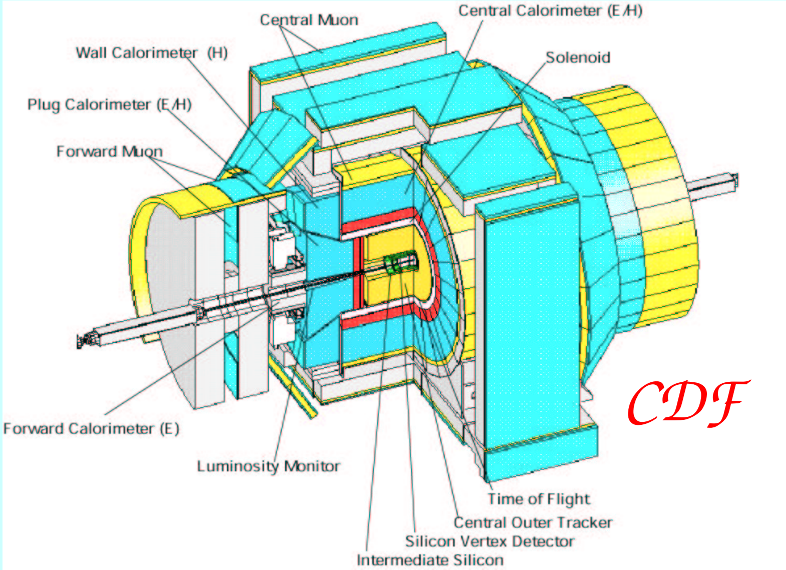


W Mass at the Tevatron

Run 1: 59 MeV combined uncertainty (79 CDF, 84 DØ), L~120 pb^{-1}

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





CDF:

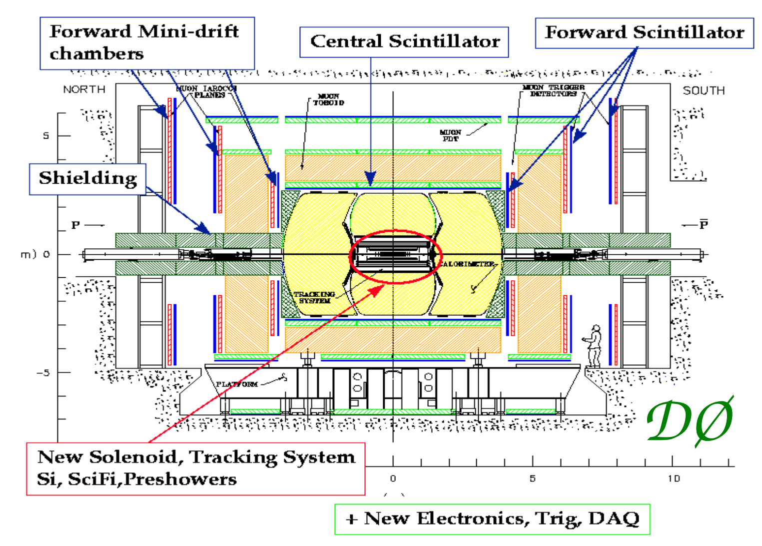
Analyzed first 200 pb^{-1},

determined uncertainties in e and μ channels

DØ:

Finishing precision calorimeter calibration,

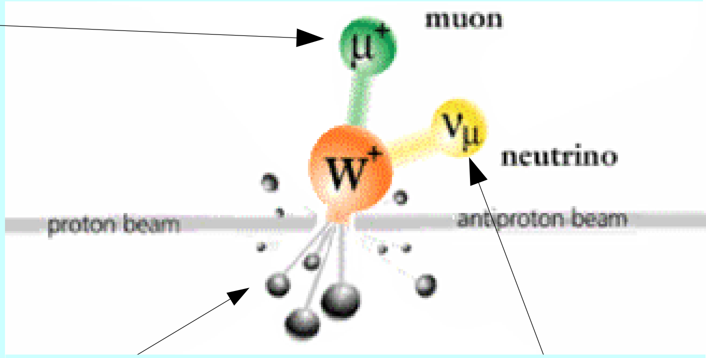
finalizing data sample selection

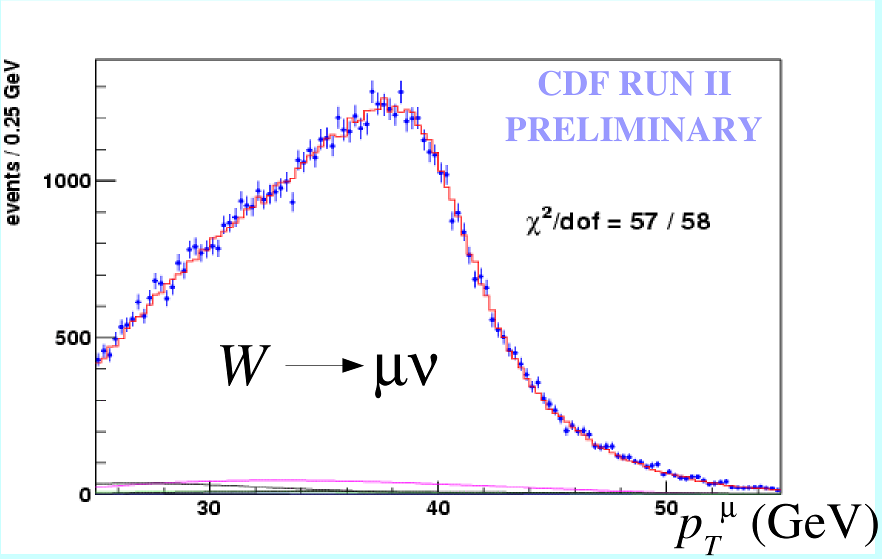


W Mass at the Tevatron

Mass information comes primarily from lepton p_T

- *Run 2 goal: calibrate p_T to ~0.01%*

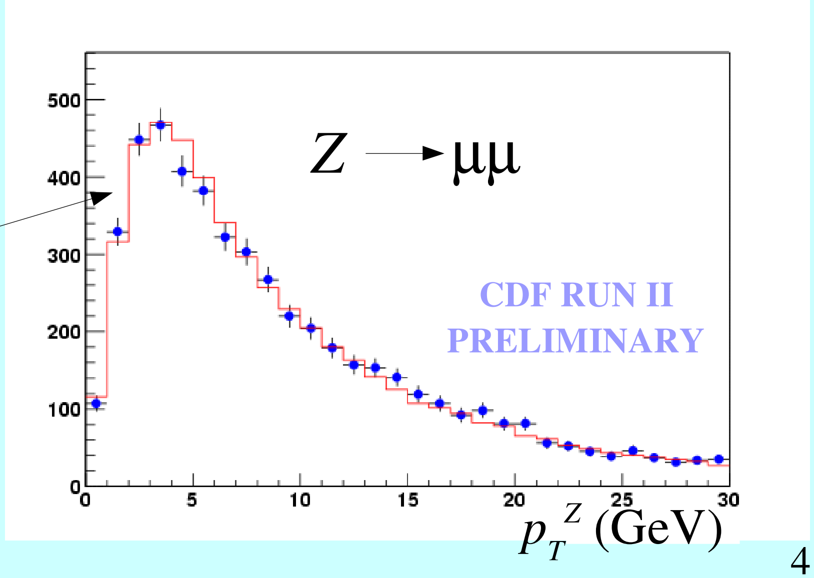




Additional information from ν p_T

(inferred through measurement of hadronic recoil energy)

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

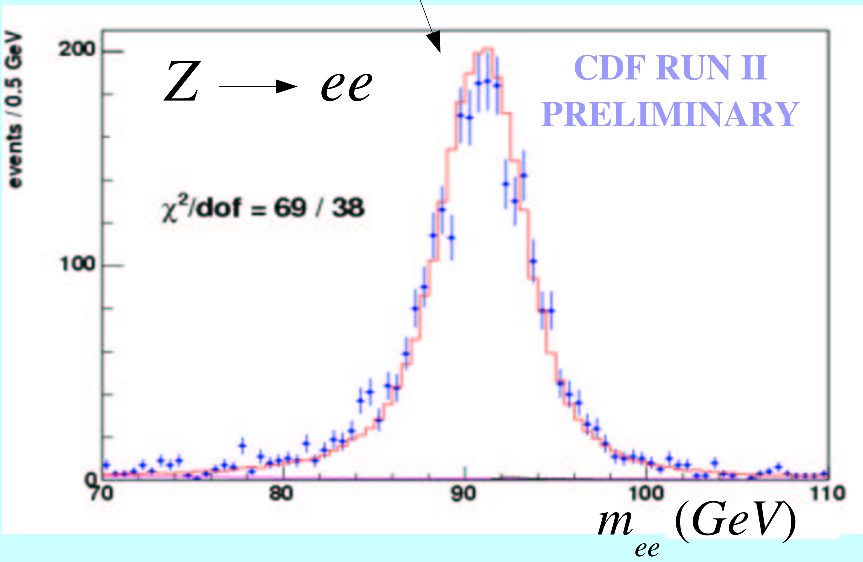


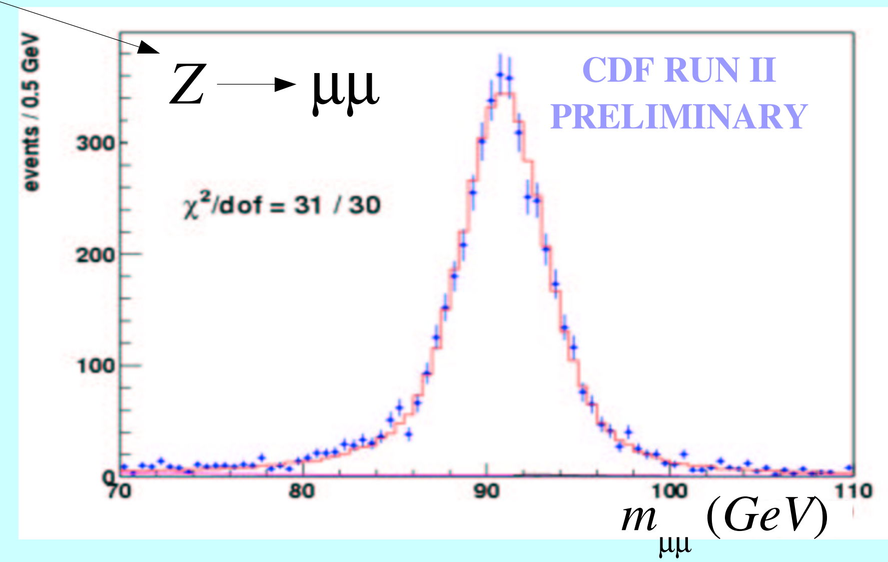
Combine lepton and neutrino p_T to form transverse mass (m_T) for best statistical power

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

W Mass at CDF

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

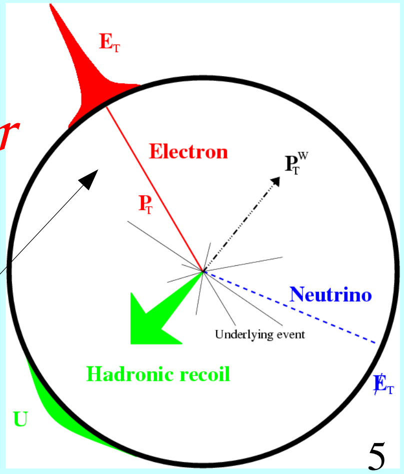




Combine electron and muon channels to increase statistical power

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 → ll events*



CDF Event Generation and Simulation

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

QCD corrections to W/Z production:

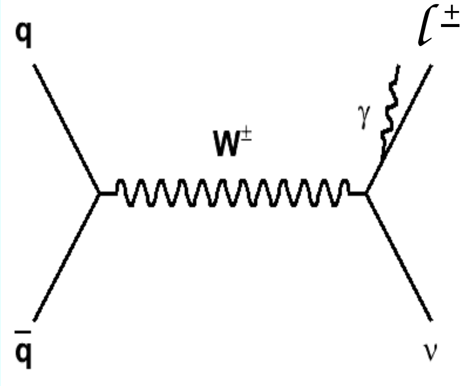
$\delta m_W = \pm$ 13 MeV

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

QED corrections to W/Z decay:

Radiate final-state photons according to energy and spatial distributions from NLO event generator (WGRAD)

$\delta m_W = \pm$ 15-20 MeV



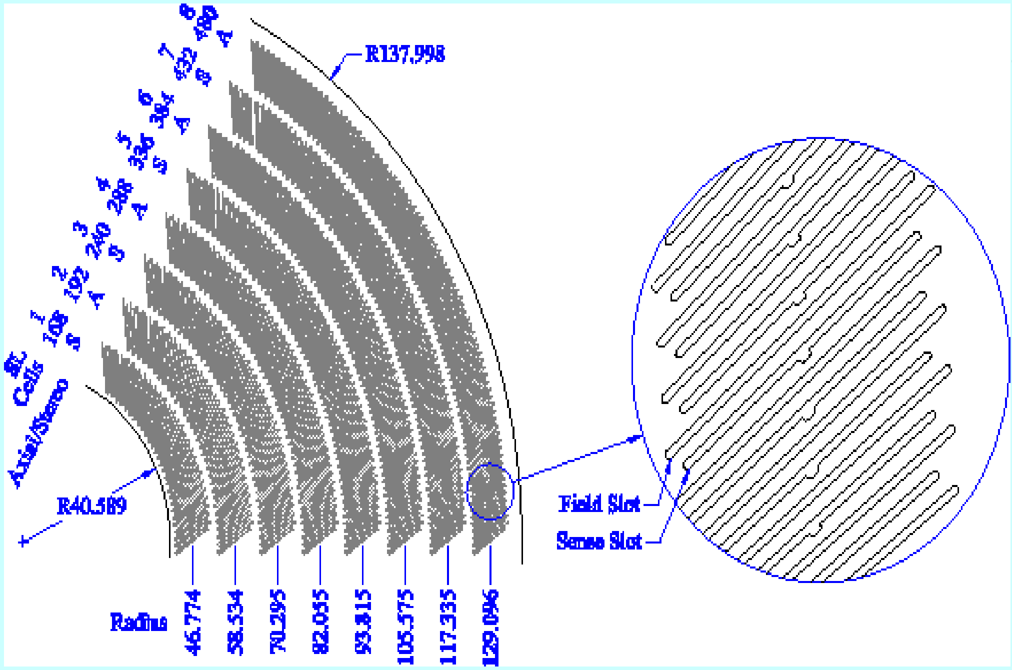
Detector simulation and reconstruction:

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

CDF RUN II
PRELIMINARY

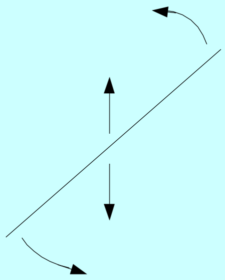
CDF Tracker Alignment

Correct for chamber nonuniformities when fitting tracks

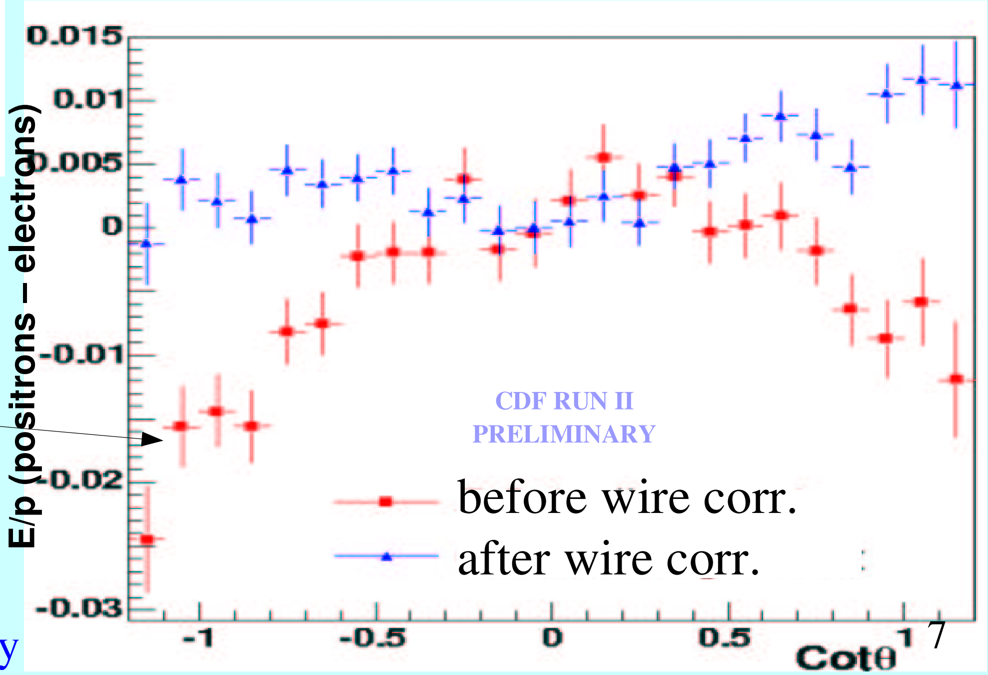


Drift chamber has wires strung between two endplates

- *Use cosmic ray data to fit for endplate cell positions and wire displacement from electrostatics*



e^+/e^- track momentum difference as function of polar angle



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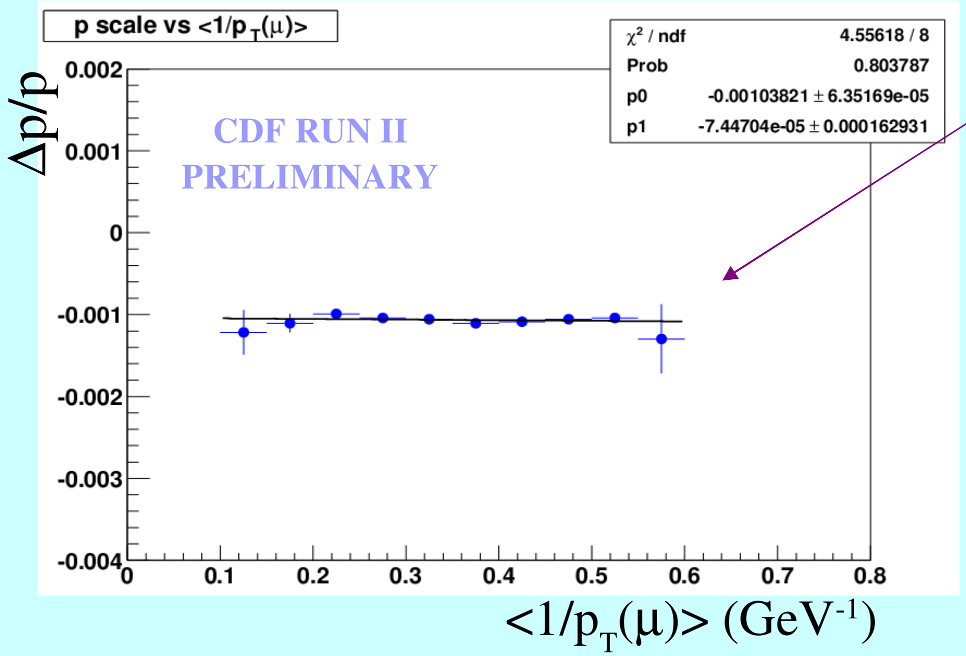
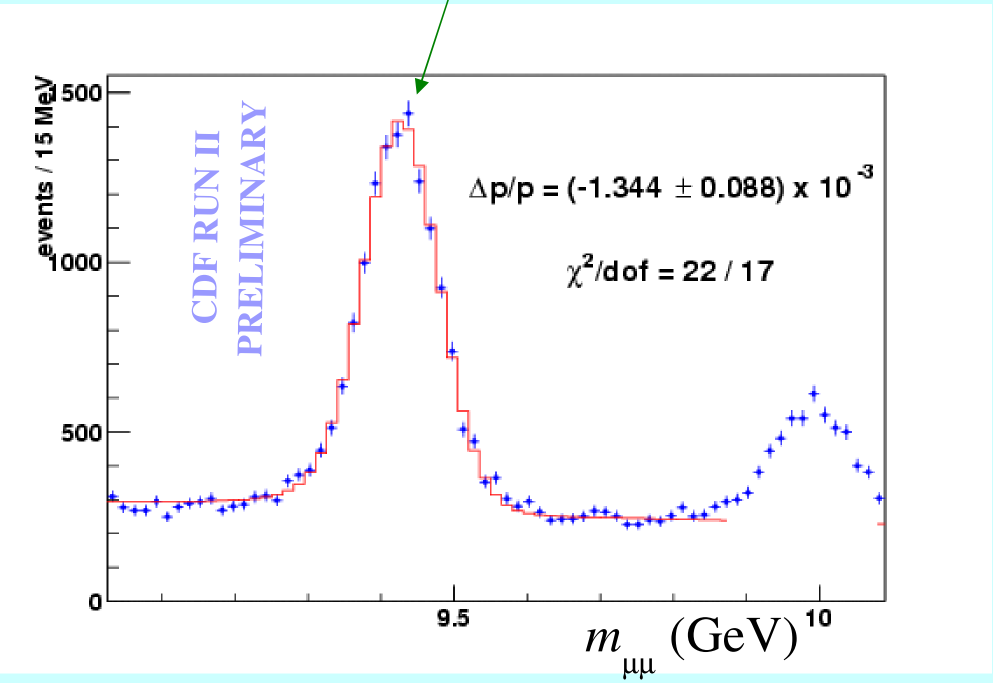
CDF Muon Momentum Calibration

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 beam constraining bias

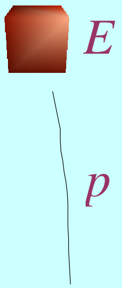


momentum determined to
3 parts in 10000:

$\delta m_W = \pm 25\ \text{MeV}$

CDF Electron Energy Calibration

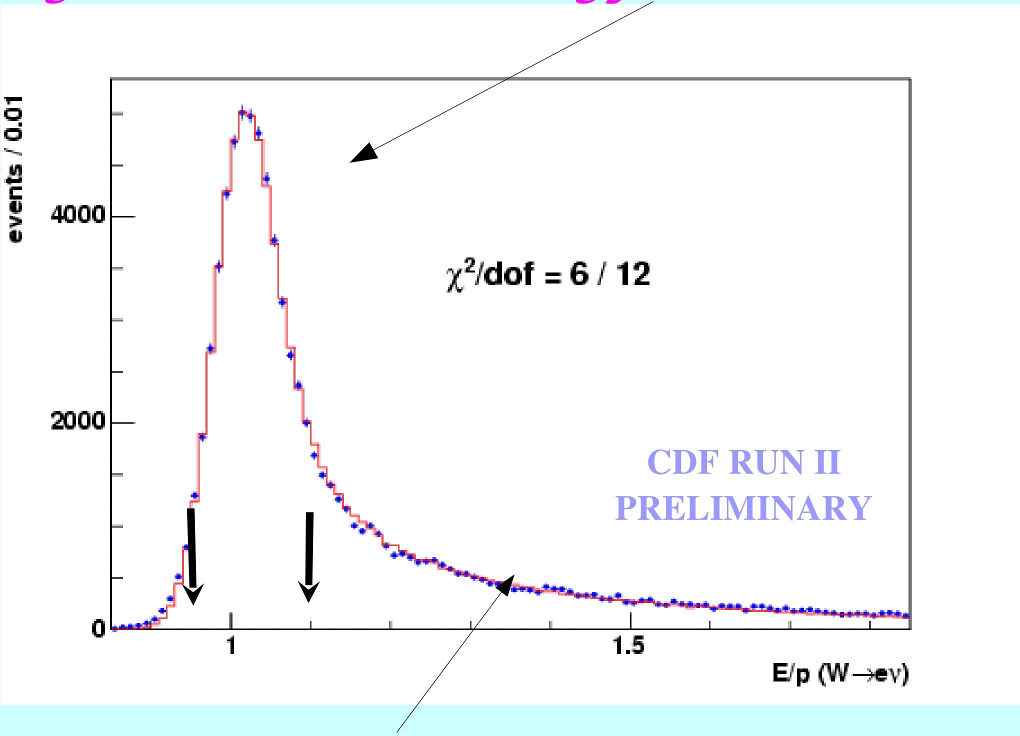
Use calibrated tracks to set calorimeter electromagnetic energy scale



E/p peak in W ⟶ eν events determines energy scale

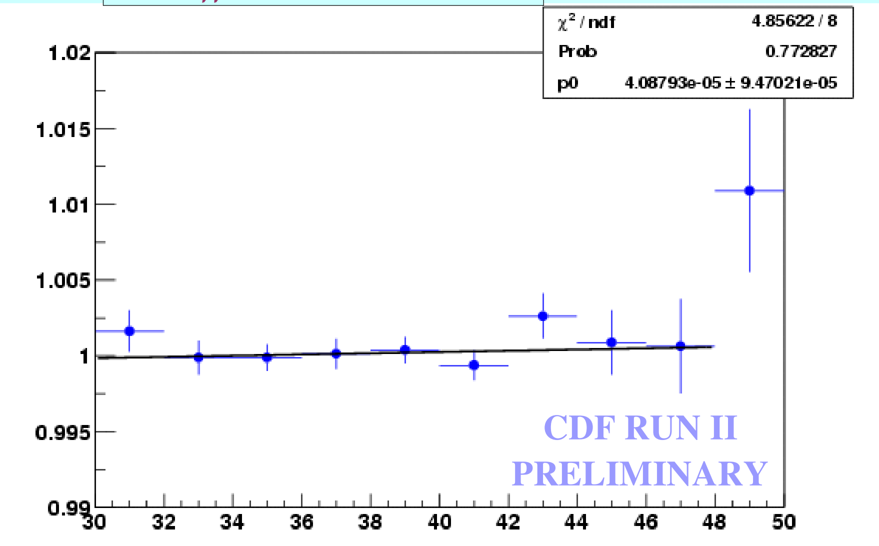
High statistics, similar energy distribution to measurement sample

$\delta m_W = \pm 35$ *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*

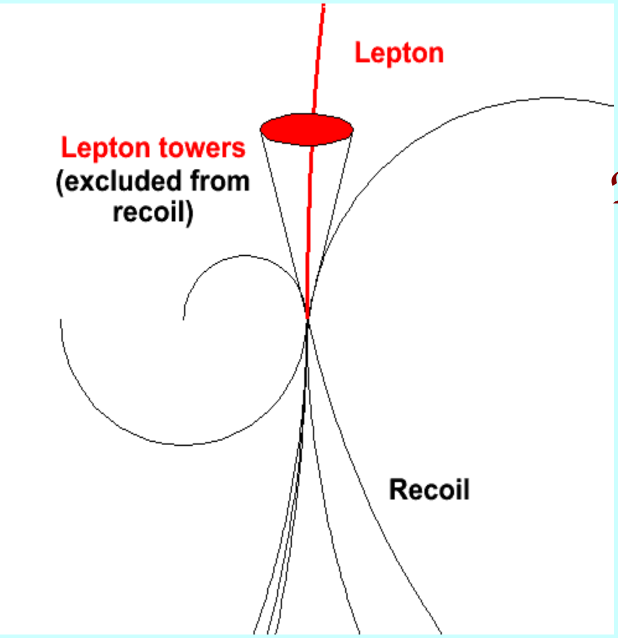
$\delta m_W = \pm 55$ *MeV*

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

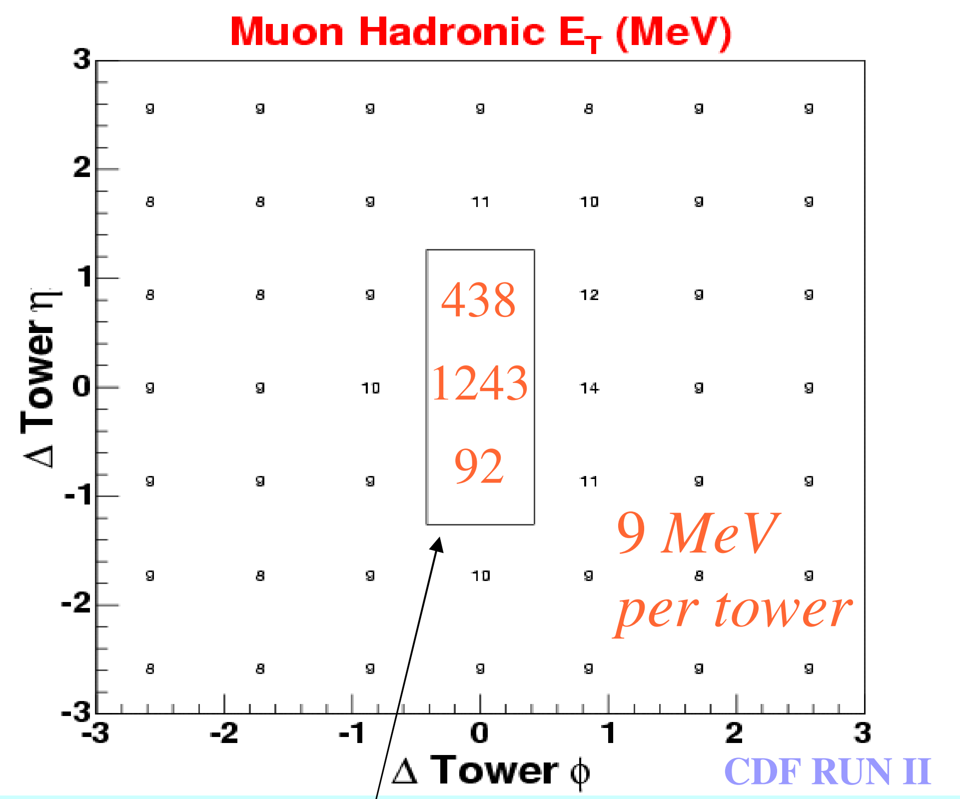
Hadronic Recoil Measurement

Measure hadronic recoil (u) by summing over all calorimeter towers ← *0.1 x 0.25 η-φ*

* *Remove towers with energy deposited by lepton*



Estimate removed recoil energy using towers separated in φ



CDF RUN II
PRELIMINARY

Removed muon towers

Measure removed energy as a function of recoil energy along the lepton direction

$$\boxed{\delta m_W = \pm 10\ MeV}$$

Hadronic Recoil Measurement Model

- * Parametrize hadronic response: $\mathcal{R} = u_{meas}/u_{true}$ ← u_{true} given by $p_T(Z)$

$\delta m_W = \pm 20$ MeV

- * Resolution model combines terms from underlying event and jet resolution

Underlying event:

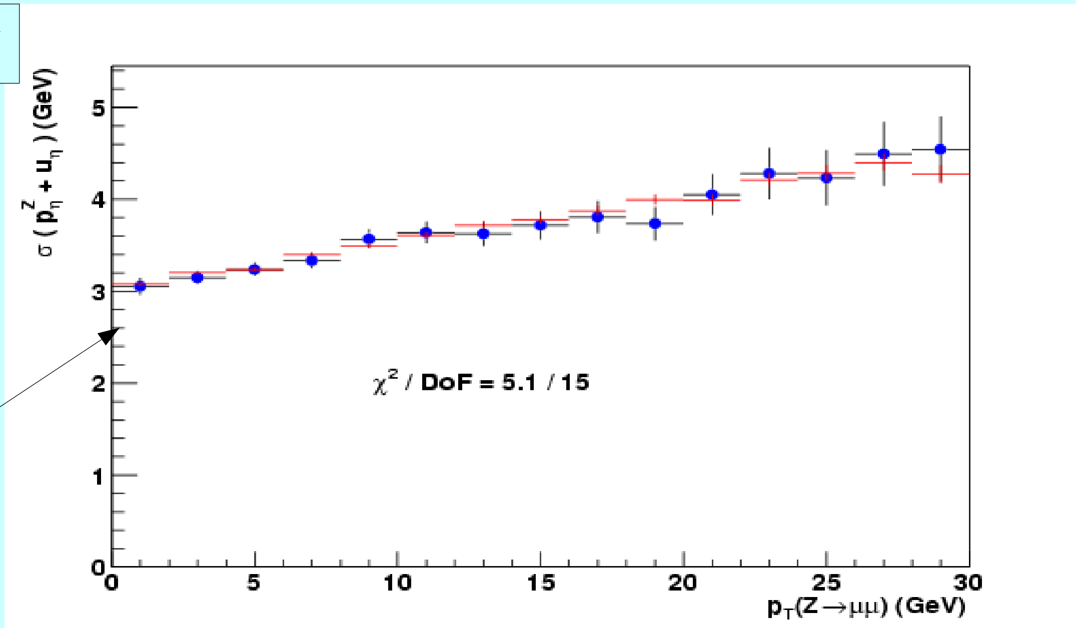
- * independent of recoil
- * resolution model tuned on minimum bias events

Jet resolution:

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

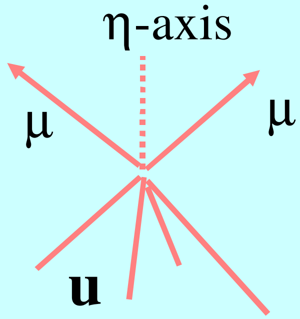
$\delta m_W = \pm 20$ MeV

$\delta m_W = \pm 37$ MeV



Resolution as a function of p_T

Tune parameters using $Z \rightarrow \mu\mu$ events



Backgrounds

Muons

Use data to estimate decays-in-flight → μ, hadronic jets → μ, and cosmic ray muons

* *Cosmic ray background:*

- *determined using track hit timing information*

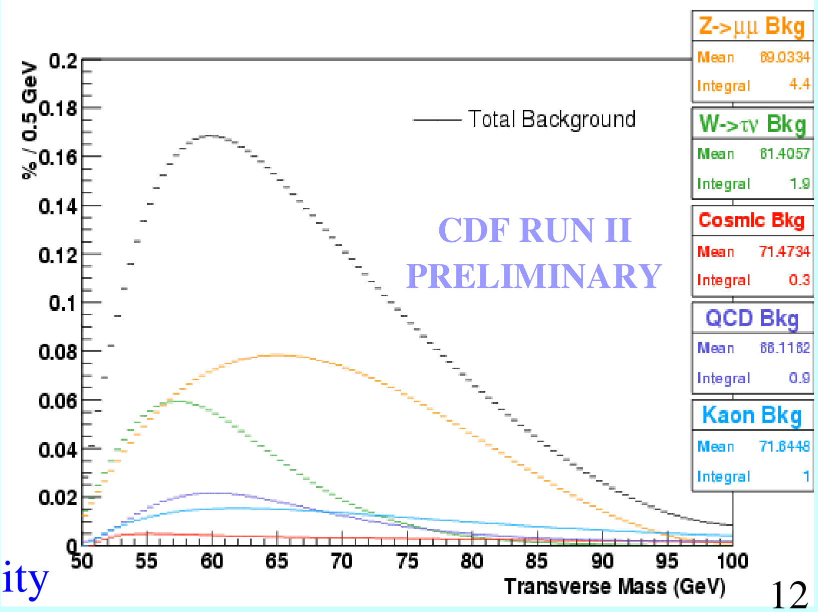
Background	%
Hadronic Jets	0.9 ± 0.5
Kaons	1.0 ± 1.0
Cosmic Rays	0.3 ± 0.1
$Z \rightarrow \mu\mu$	4.4 ± 0.2
$W \rightarrow \tau\nu$	1.9 ± 0.1

* *Kaon background:*

- *decay in COT leads to track mismeasurement → $\not{E}_T$ opposite to track*
- *use $\Delta\phi(l, \not{E}_T)$ distribution to estimate background*

* *Hadronic jet background:*

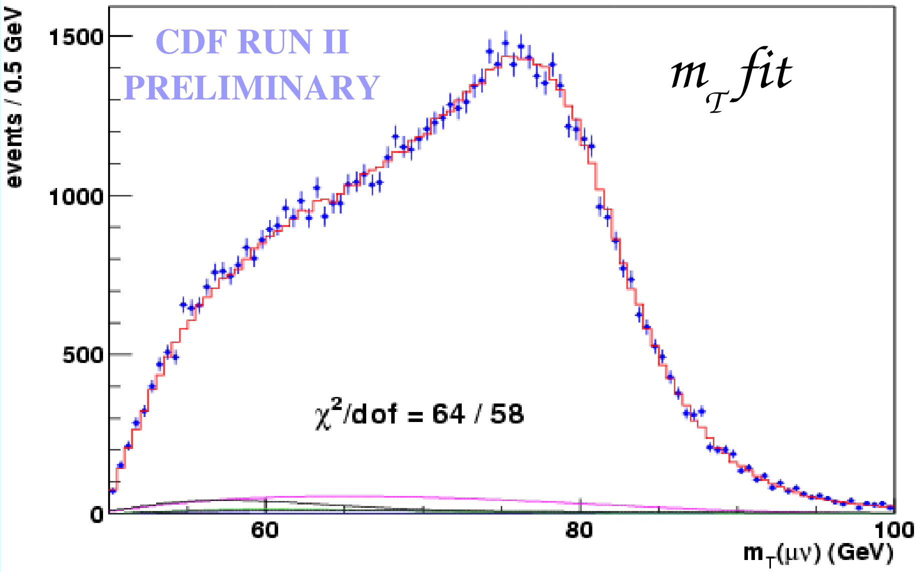
- *obtain QCD $\not{E}_T$ distribution using events with significant energy surrounding muon*
- *fit data $\not{E}_T$ distribution to obtain background normalization*



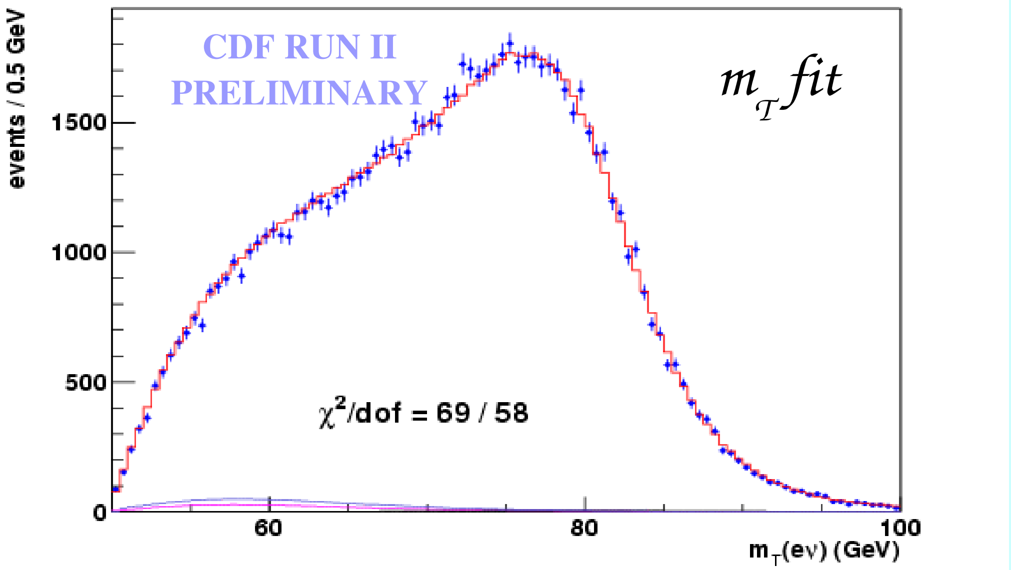
$$\boxed{\delta m_W = \pm 20\ MeV}$$

W Mass Fits and Systematics

Muons



Electrons



Good χ^2 for fits

Fits blinded with additive offset

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

Summary and Outlook

Tevatron data pointing us toward the Higgs

W mass measurement key component

Run 2 analyses in advanced stages

- 200 pb^{-1} analyzed at CDF and uncertainties determined
  - Total uncertainty (76 MeV) already lower than Run 1 (79 MeV)
  - Full analysis cross-check in progress with GEANT tracker simulation
- DØ finalizing calorimeter calibrations

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

- Expect to provide significant reduction in uncertainty
  - 40 MeV per experiment in Run 2
    (current single most precise experiment: ALEPH, 58 MeV)