Measuring the W Boson Mass at the Tevatron

XXIInd Rencontres de Blois

17th July 2010

Michiel Sanders

Ludwig-Maximilians-Universität München

For the DØ and CDF Collaborations

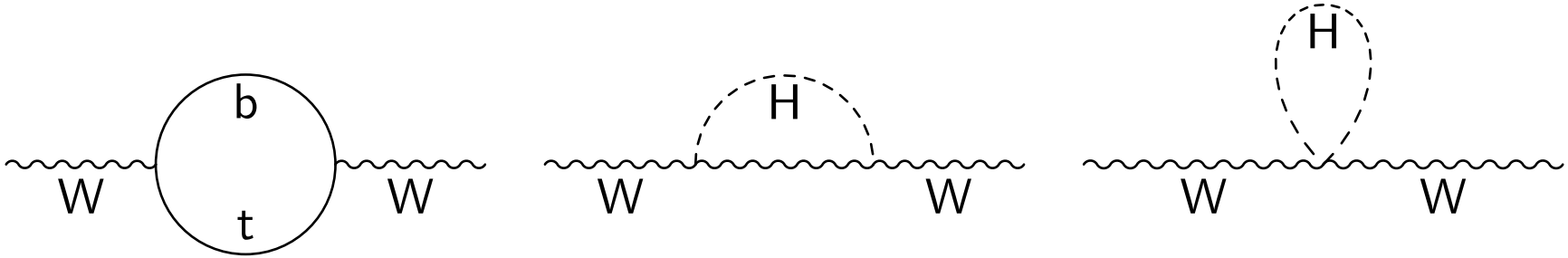
Outline

- Introduction / Motivation
- Tevatron
- Measurement strategy
- Results
- Conclusion & Outlook

Introduction

$$m_{\mathsf{W}}^2\left(1-\frac{m_{\mathsf{W}}^2}{m_{\mathsf{Z}}^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_{\mathsf{F}}}\left(\frac{1}{1-\Delta r}\right)$$

$$\Delta r=\Delta\alpha+\Delta\rho(m_{\mathsf{top}}^2)+\Delta\chi(\ln(m_{\mathsf{H}}))$$



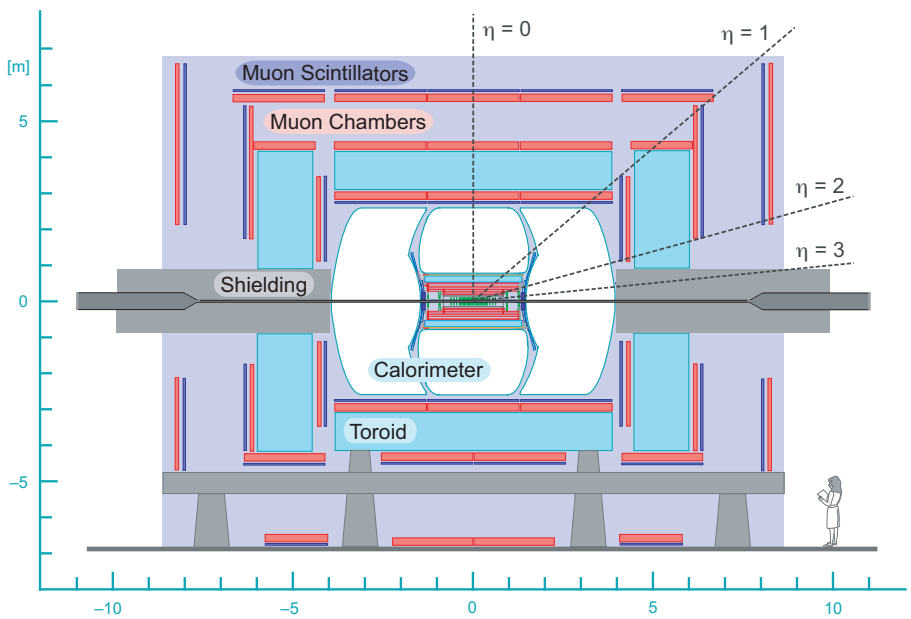
To have equal uncertainty on m_{H}, $\Delta m_{\mathsf{W}} \approx 0.006 \cdot \Delta m_{\mathsf{top}}$

Current $\Delta m_{\mathsf{top}} = 1.1$ GeV $\Rightarrow \Delta m_{\mathsf{W}} = 7$ MeV

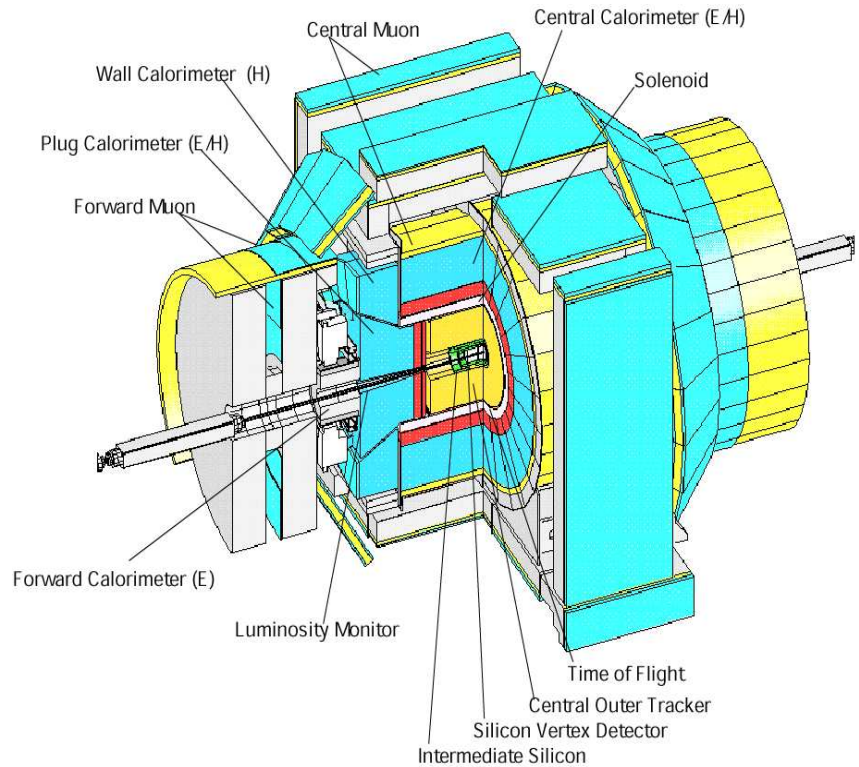
Tevatron

- $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV
- Up to now: $\int \mathcal{L} dt > 9$ fb^{-1} delivered / experiment
- Measurement of m_W: 200 pb^{-1} (CDF), 1 fb^{-1} (DØ)

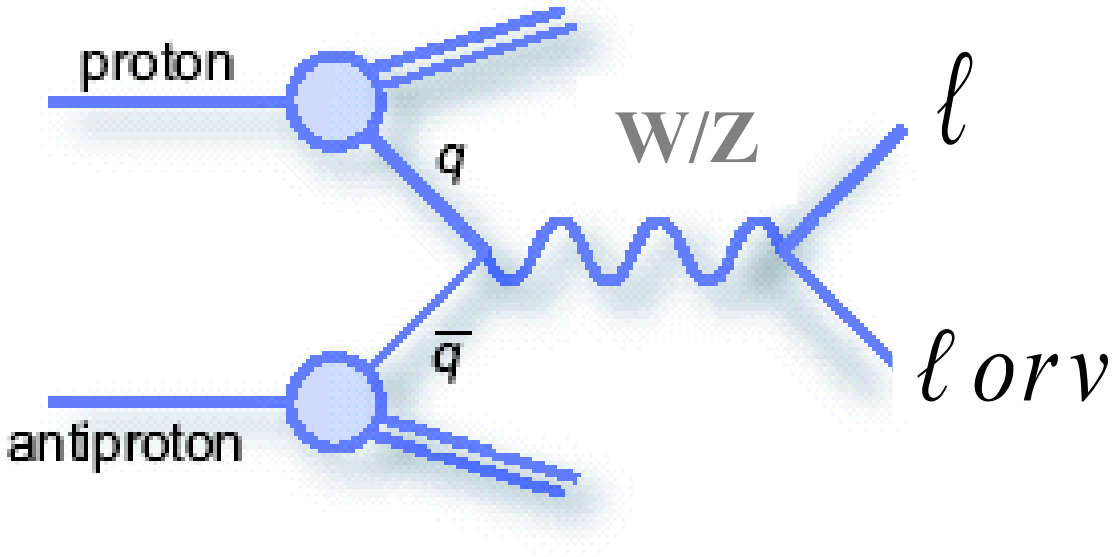
DØ



CDF

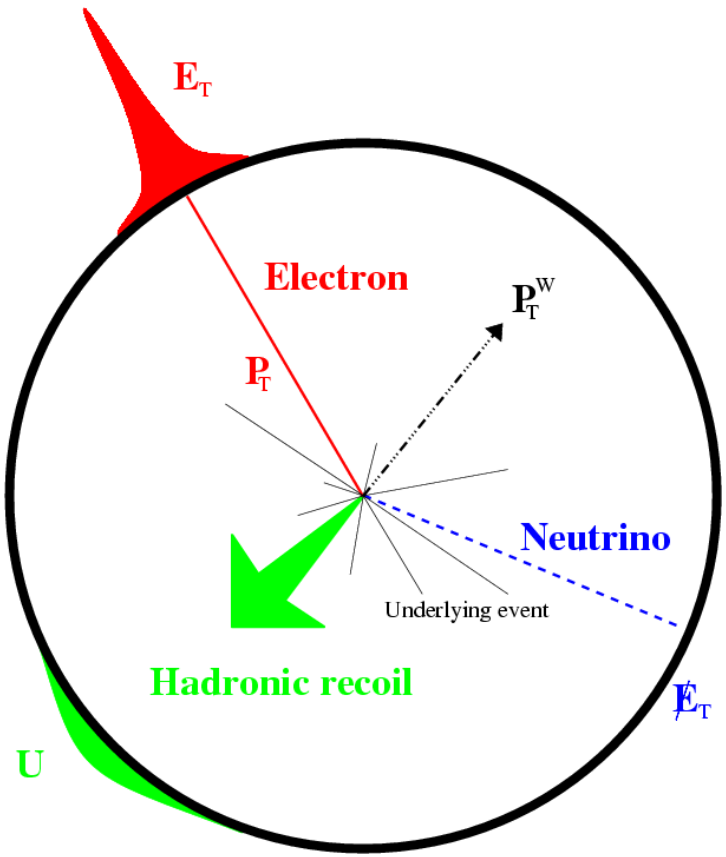


W (& Z) Signature



- High momentum lepton, $|\eta| \lesssim 1$
  DØ: $p_{\mathrm{T}}(e) > 25$ GeV; CDF: $p_{\mathrm{T}}(\ell) > 30$ GeV
- High momentum neutrino $\rightarrow$ Large $\not\!\!E_{\mathrm{T}}$
  DØ: $\not\!\!E_{\mathrm{T}} > 25$ GeV; CDF: $\not\!\!E_{\mathrm{T}} > 30$ GeV
- Small-ish recoil: $u_{\mathrm{T}} < 15$ GeV

Measurement Strategy

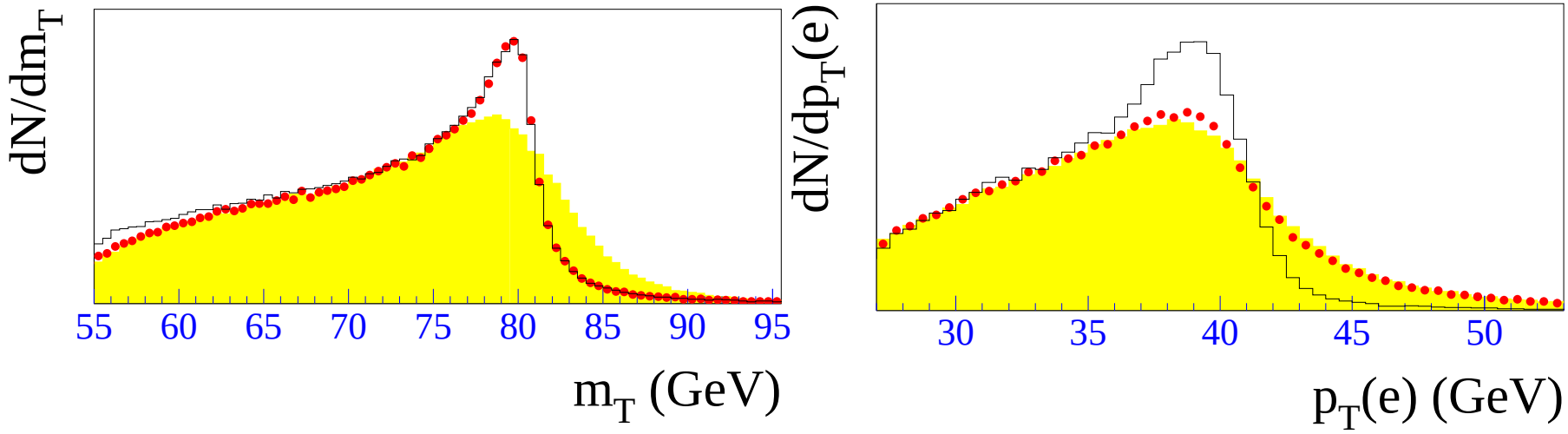


$$\vec{p}_{\mathsf{T}}(\nu) = -\vec{p}_{\mathsf{T}}(\ell) - \vec{u}_{\mathsf{T}}$$

$$m_{\mathsf{T}}^2 = 2p_{\mathsf{T}}(\ell)p_{\mathsf{T}}(\nu)(1 - \cos\Delta\phi_{\ell\nu})$$

- Template fits on parametric simulation of m_{T}, $p_{\mathsf{T}}(\ell)$ and $p_{\mathsf{T}}(\nu)$
- Precision on $p_{\mathsf{T}}(\ell)$: 10^{-4} level; precision on u_{T}: $\%$-level;

W Production

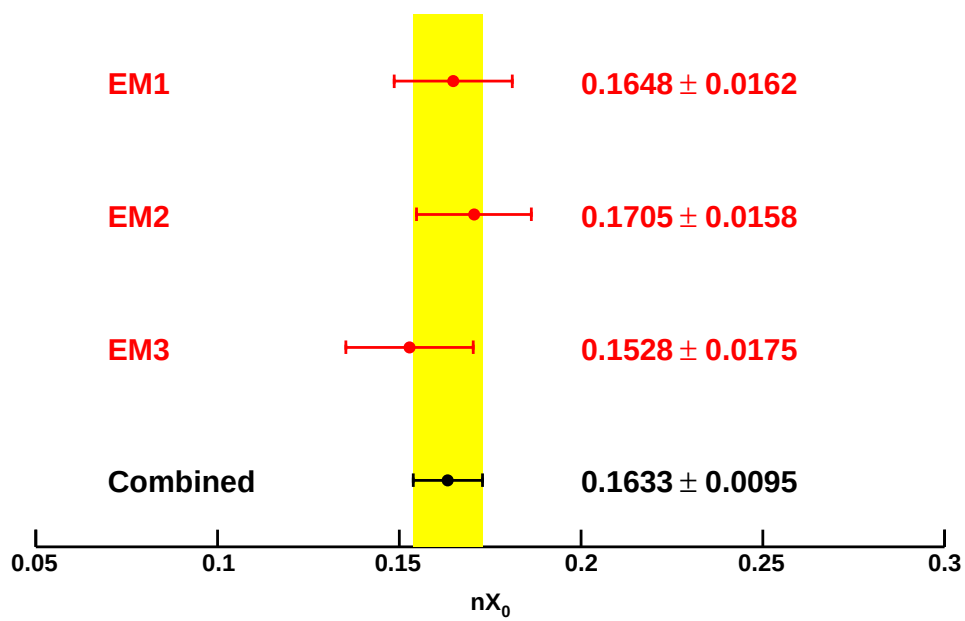


- Production/decay model: RESBOS, PHOTOS/WGRAD
- Dominant uncertainties:
  - PDF: $\approx$ 10 MeV
  - Photon radiation: $\approx$ 11 MeV (CDF), $\approx$ 7 MeV (DØ)

Electron Energy Scale (DØ)

- Calorimeter calibration
- Corrections for energy-loss in uninstrumented regions
  - ∗ Detailed GEANT simulation
  - ∗ Material tuning with 4×15 fractional energy distributions

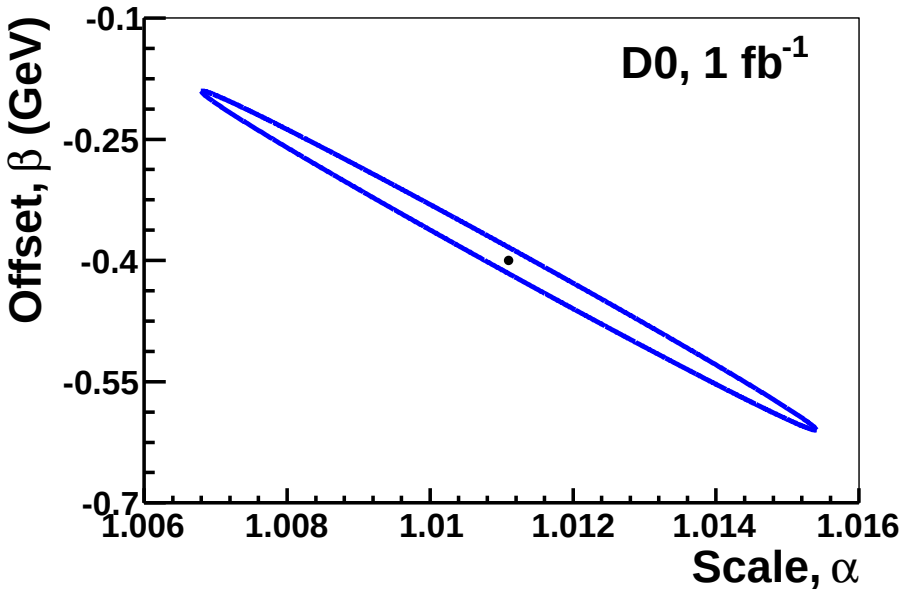
⇒ E and η dependent parameterization of response and resolution

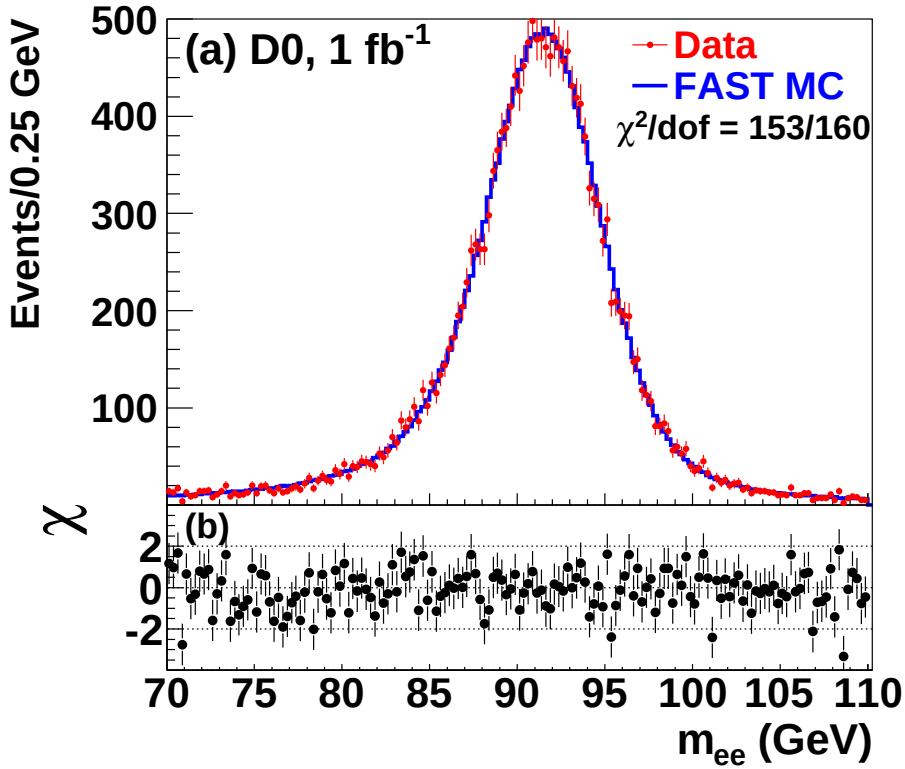


Electron Energy Scale (DØ)

$E_{\text{meas}} = \alpha E_{\text{true}} + \beta \Rightarrow$ fit for α and β in E_{e} bins

Use m_{Z} (LEP) and 18.7k Z $\rightarrow$ e$^+$e$^-$ events

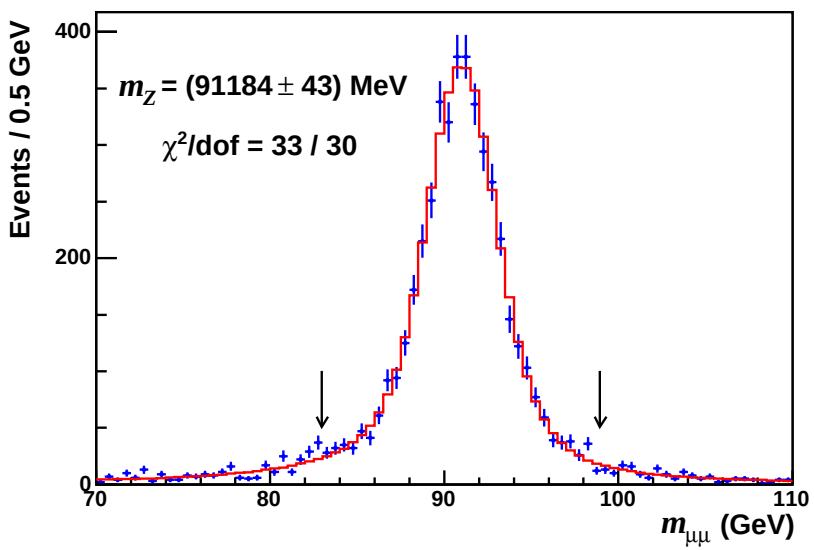


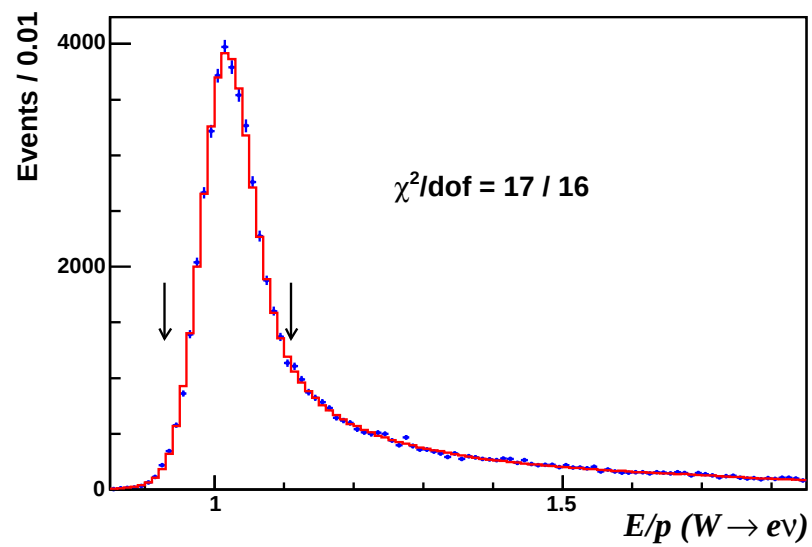


$\Rightarrow$ Largest uncertainty on m_{W}: 34 MeV

Lepton Momentum Scale (CDF)

- Tracker calibration $\Rightarrow$ precise tracker simulation
- Alignment using cosmics
- Momentum scale
  - $*$ Set by fits to 600k J/ψ events
  - $*$ In bins of $1/p_{\mathrm{T}}(\mu)$ and $\cot\theta_\mu$

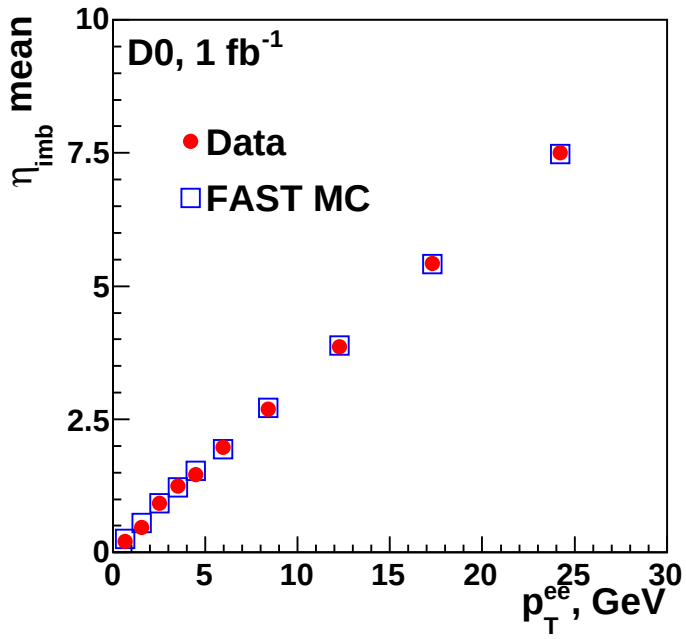


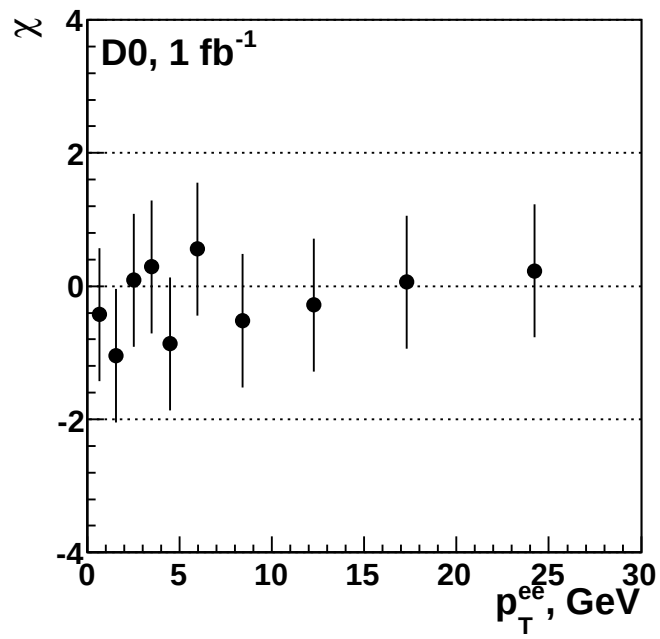


$\Rightarrow$ Uncertainty on m_{W}: 17/30 MeV (muon/electron)

Recoil Momentum Scale

$\vec{u}_{\mathrm{T}} = \vec{u}_{\mathrm{T}}^{\,\mathrm{hard}} + \vec{u}_{\mathrm{T}}^{\,\mathrm{soft}} + \vec{u}_{\mathrm{T}}^{\,\mathrm{electron}}$ Scale set by η_{imb} in $\mathrm{Z} \to \ell\ell$ events





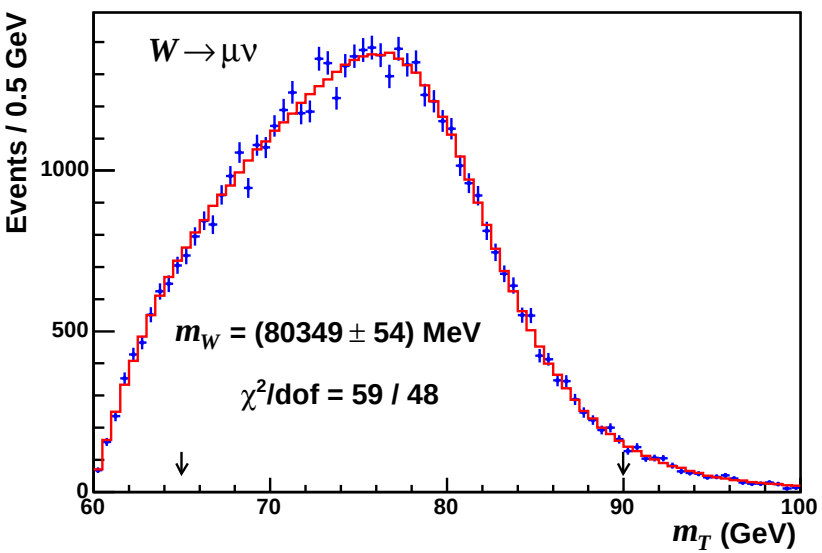
Uncertainty on m_{W}:

– DØ: 6 MeV (m_{T}), 12 MeV (p_{T}), 20 MeV ($\not{E}_{\mathrm{T}}$)

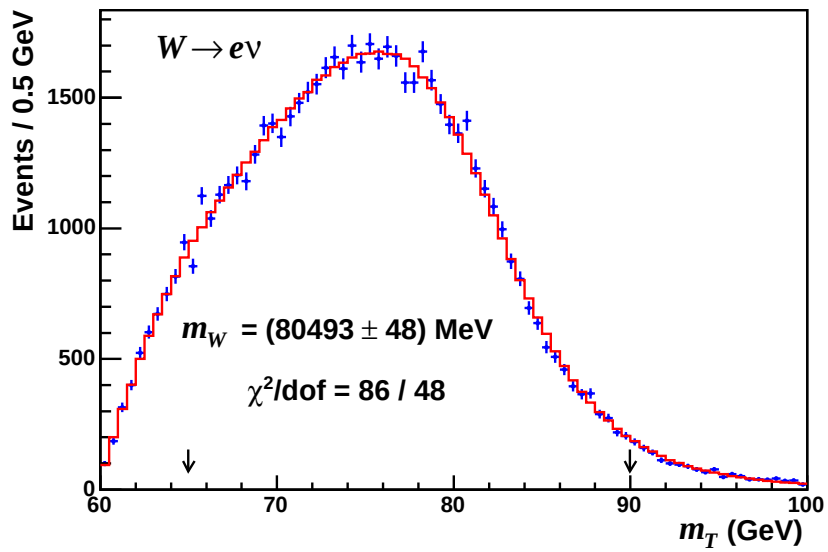
– CDF: 9 MeV (m_{T}), 17 MeV (p_{T}), 30 MeV ($\not{E}_{\mathrm{T}}$)

Results (CDF)

51k W $\longrightarrow \mu\nu$ events



64k W $\longrightarrow$ eν events



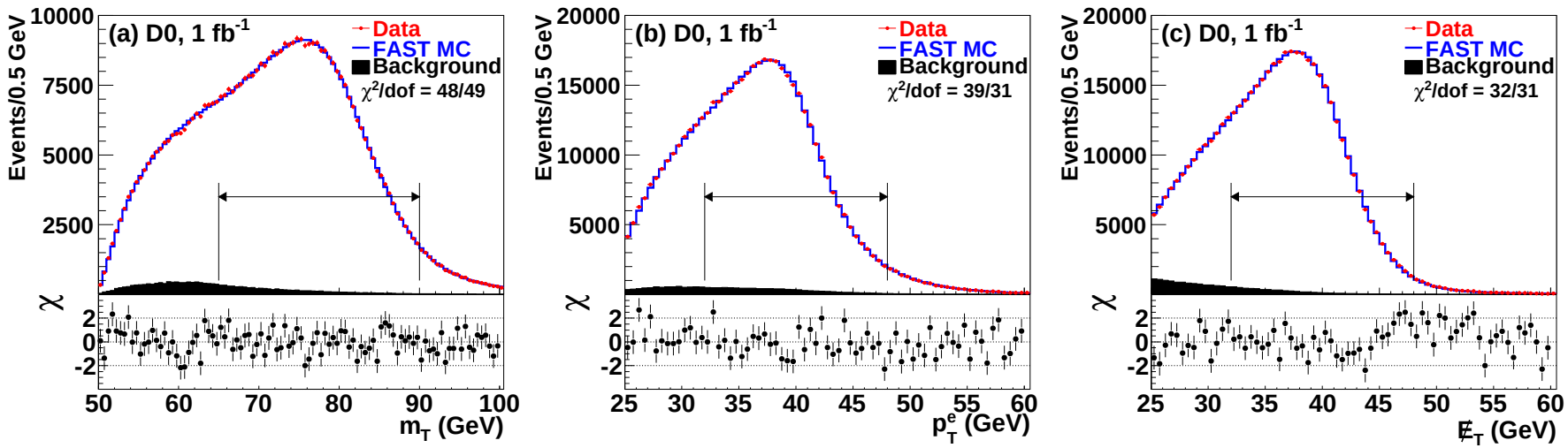
Combination of six measurements:

$$m_{\mathrm{W}} = 80.413 \pm 0.034_{\mathrm{stat}} \pm 0.034_{\mathrm{syst}} \text{ GeV}$$

$$m_{\mathrm{W}} = 80.413 \pm 0.048 \text{ GeV } (200 \text{ pb}^{-1})$$

Results (DØ)

500k W $\longrightarrow$ eν events



80.401 ± 0.023 GeV $\quad$ 80.400 ± 0.027 GeV $\quad$ 80.402 ± 0.023 GeV

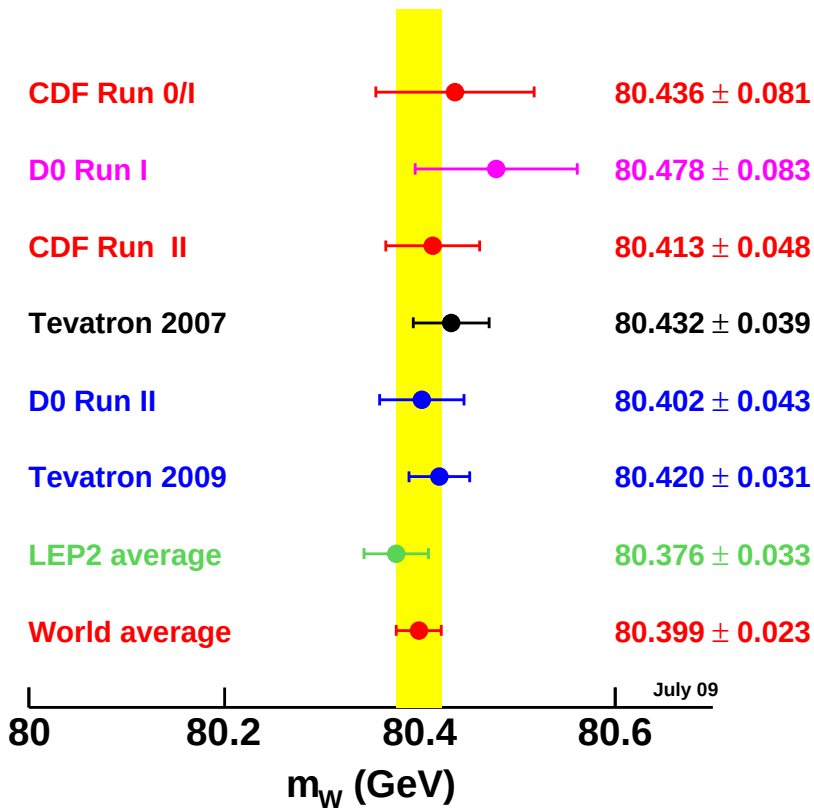
Combination of three measurements:

$$m_W = 80.401 \pm 0.021_{\text{stat}} \pm 0.038_{\text{syst}} \text{ GeV}$$

$$m_W = 80.401 \pm 0.043 \text{ GeV } (1 \text{ fb}^{-1})$$

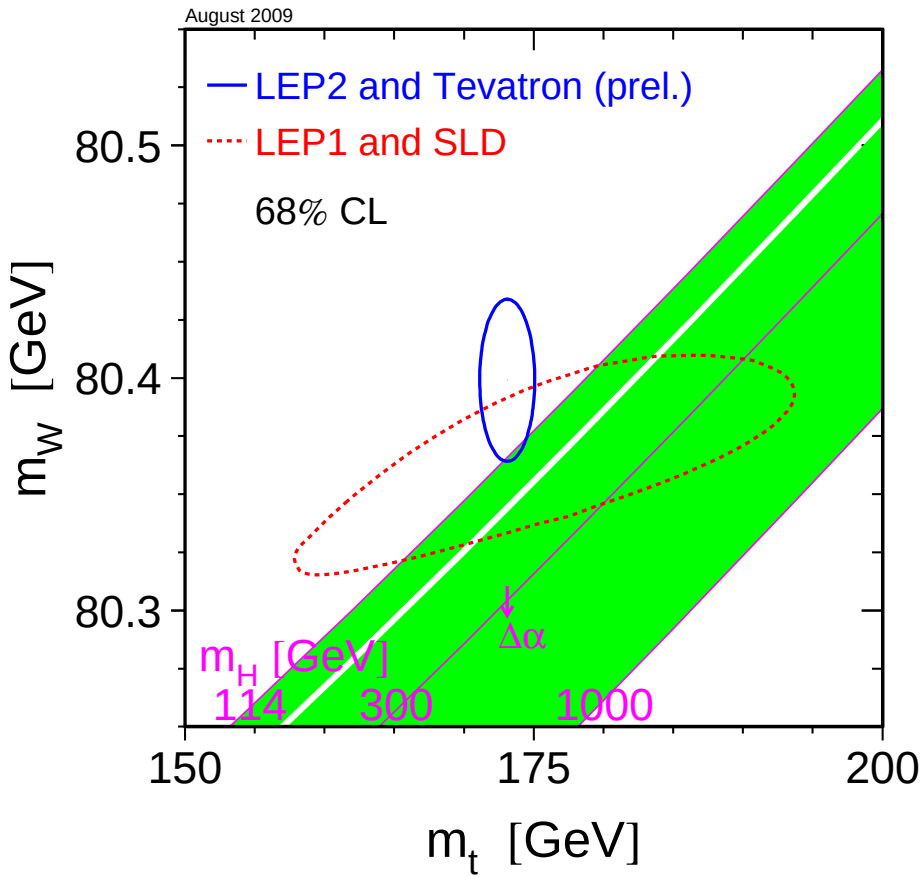
Combination

- Correct old CDF measurements to modern PDF
- Correct to the same Γ_W value
- PDF, QED, Γ_W uncertainties correlated

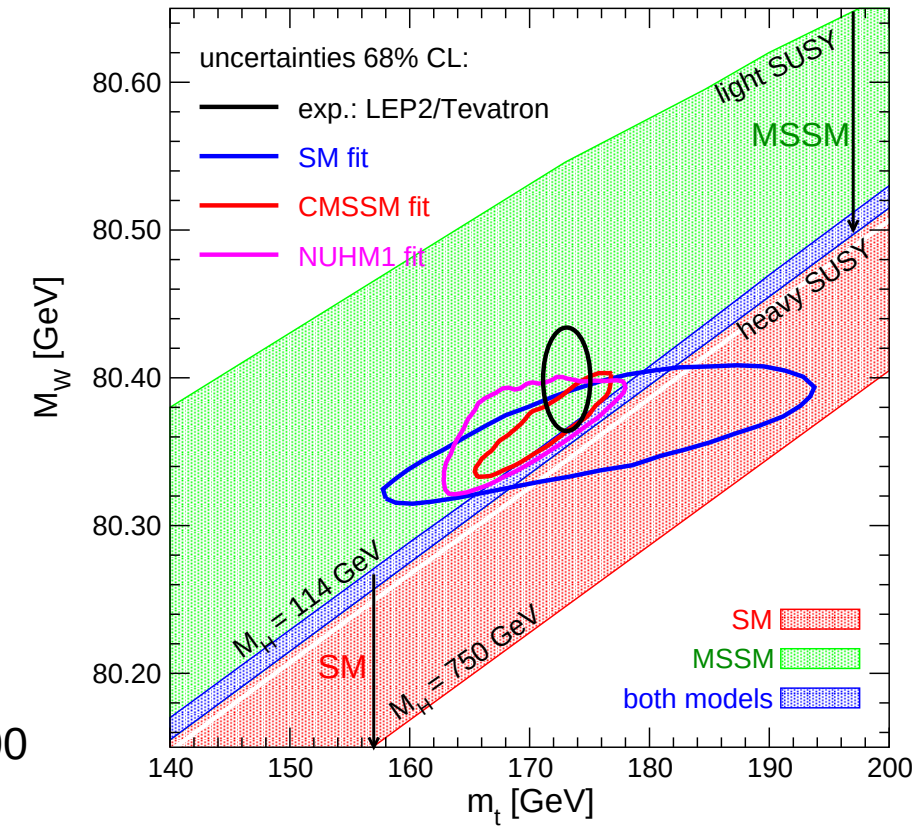


Interpretation

Standard Model LEPEWWG



SUSY PRD **81**, 035009 (2010)



Using $m_{\text{top}} = 173.1 \pm 1.3$ GeV

$$\Rightarrow m_{\text{H}} = 87^{+35}_{-26} \text{ GeV}$$

Future

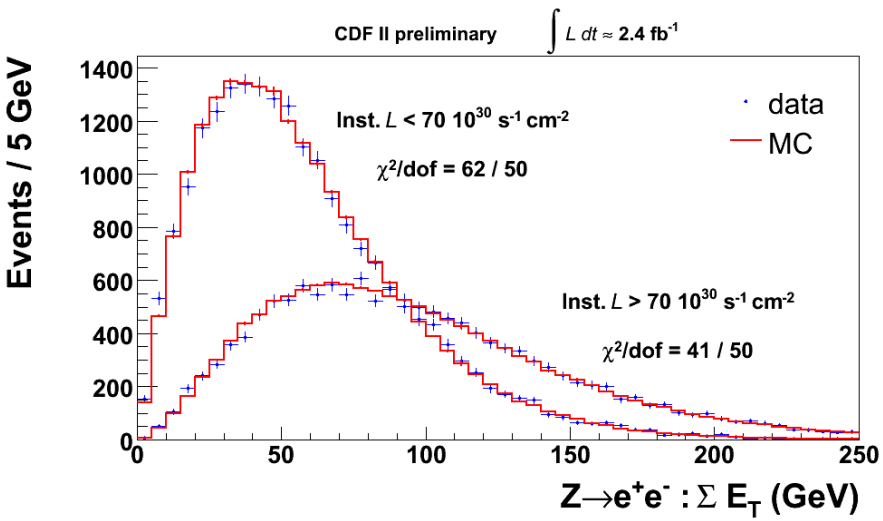
More data, at higher $\mathcal{L}$

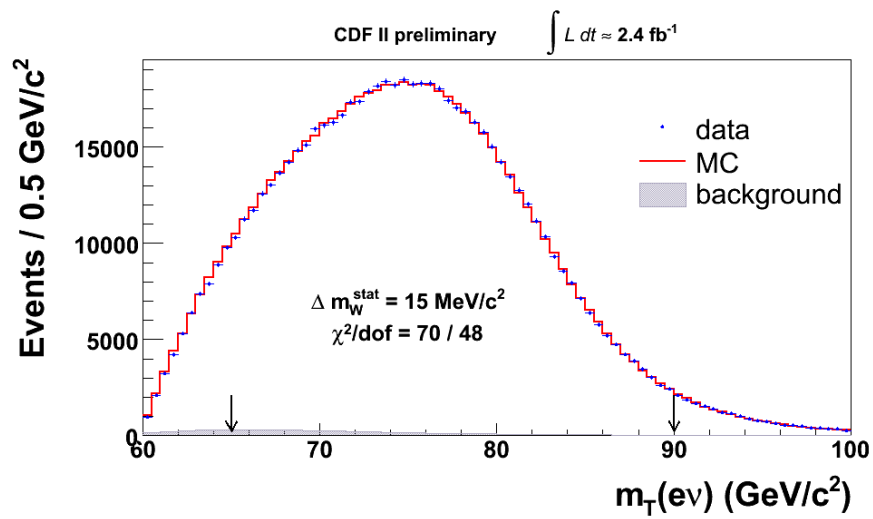
– Smaller statistical uncertainty

– Better determination of momentum scale

– Better constraints on production model

– More energy in the detector





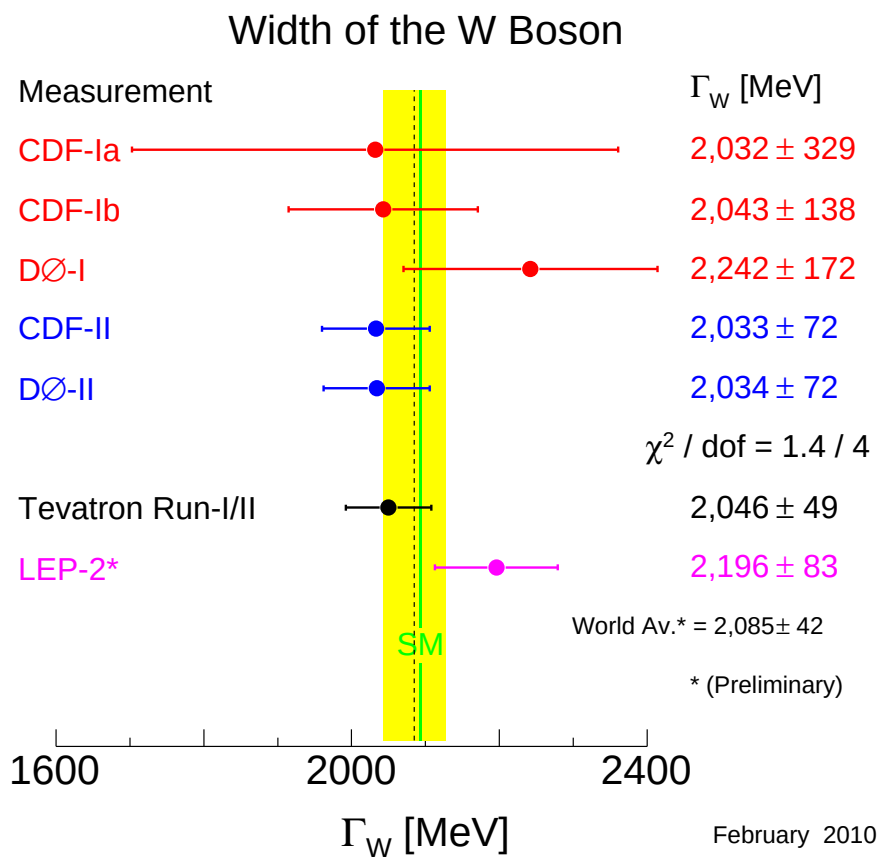
Conclusion

- $m_{\mathrm{W}} = 80.420 \pm 0.031$ GeV (Tevatron)
  $m_{\mathrm{W}} = 80.399 \pm 0.023$ GeV (Tevatron & LEP)
- Precision from Tevatron better than LEP
- Goal: get down to 15 MeV uncertainty
- Find the Higgs boson . . .

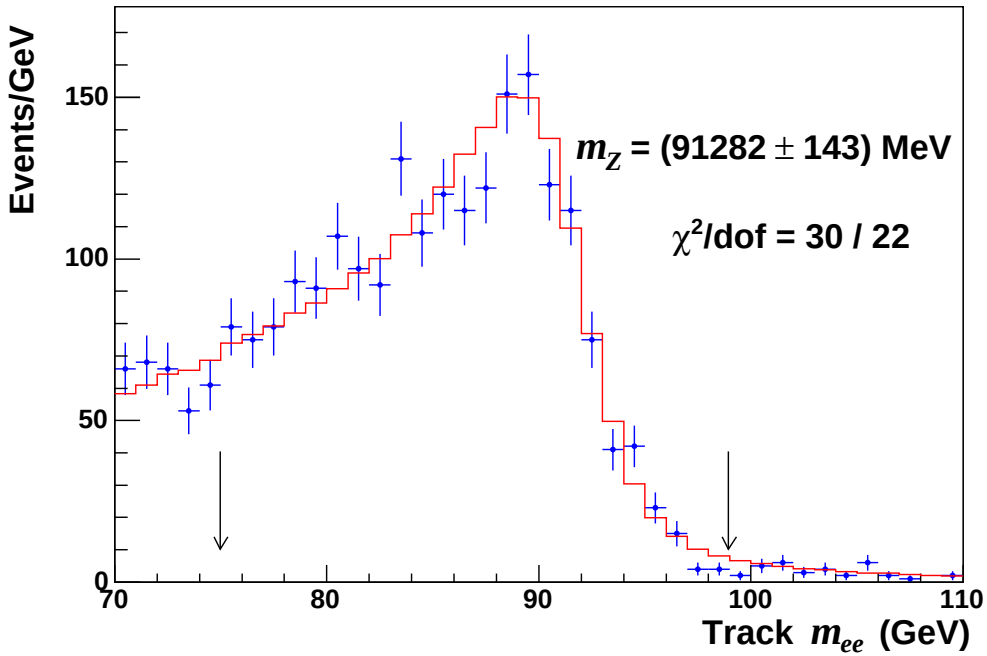
W Boson Width

Sensitive to decays to non-SM particles

New Tevatron combination: $\Gamma_W = 2.046 \pm 0.049$ GeV



CDF Electron Tracking



Selection & Background

Very small background

W $\rightarrow \tau\nu_\tau$

Z $\rightarrow \ell\ell$

Electron/muon-like jets

DØ $\leq$ 6 MeV selection, $\leq$ 5 MeV background

CDF $\approx$ 9 MeV background (large Z $\rightarrow \mu\mu$ contribution)