The W Mass

In the SM, the W and Z Mass satisfy the relationship

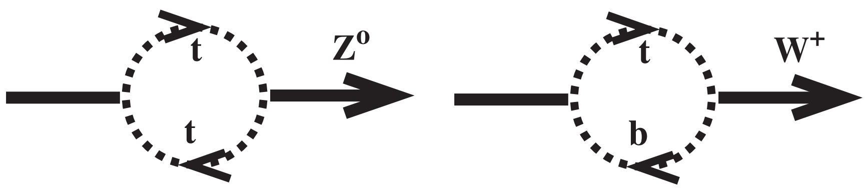
$$\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2}$$

- Defines θ_W based on the physical IVB masses
- but EWK theory is renormalisable
  - Coupling constants are a function of Q^2
  - Have to take "running" into account (introduce Δr)

$$M_W^2 = \frac{1}{2}\left\{1 + \left[1 - \frac{4\pi\alpha(1+\Delta r)}{\sqrt{2}G_F M_Z^2}\right]^{1/2}\right\} M_Z^2$$

SM predicts M_W based on low-energy data

- Existence of split heavy fermions doublet (t, b) affects M_W/M_Z
- effects of top quark and Higgs mass different

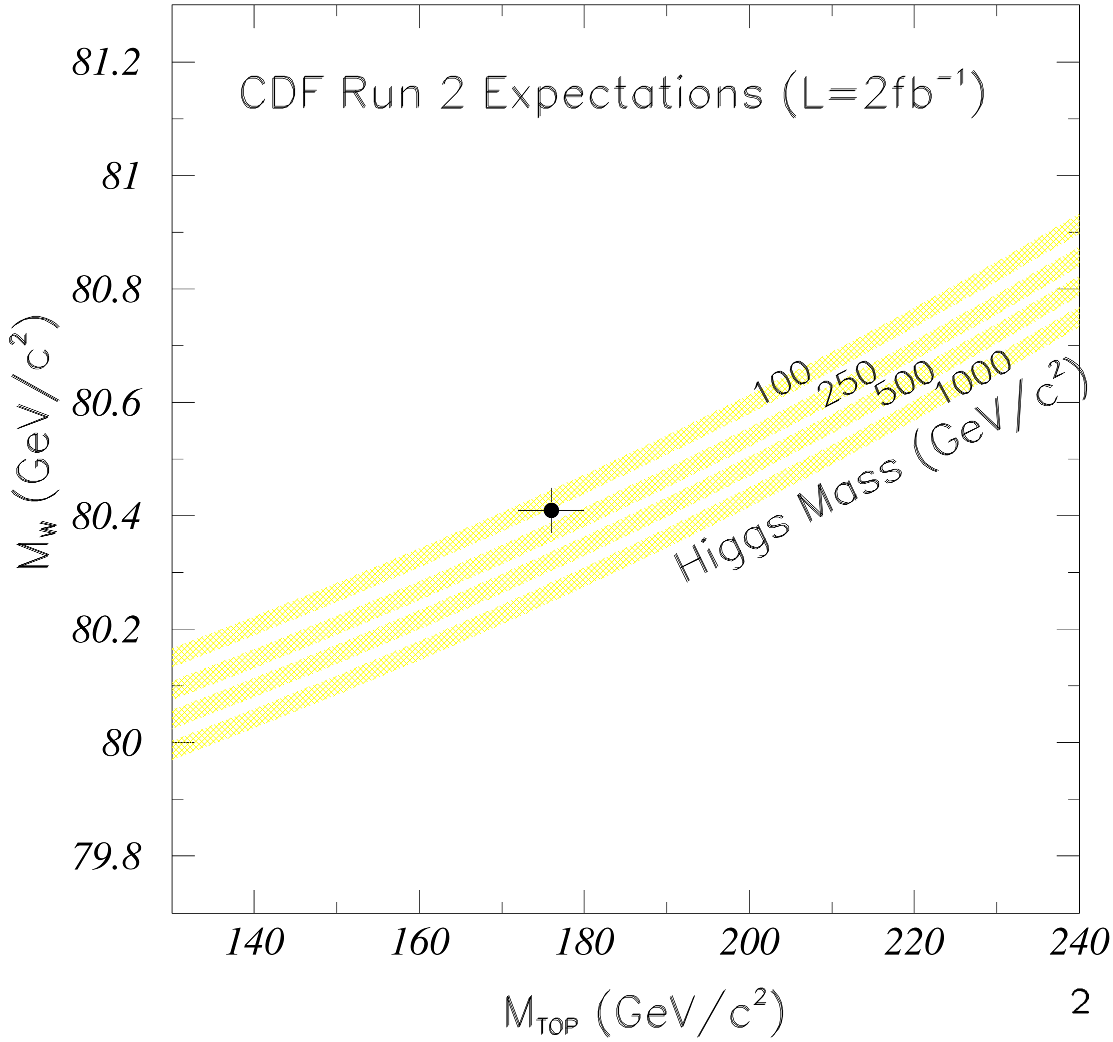


- Introduces
  - quadratic dependence on M_{top}
  - logarithmic dependence on M_{Higgs}

Prediction for M_W vs M_{top}

Can use all LEP data and low-energy data

- Have to assume M_{Higgs}
- Clearly sensitive test!
  - point represents CDF accuracy after Run II



W Mass Measurement

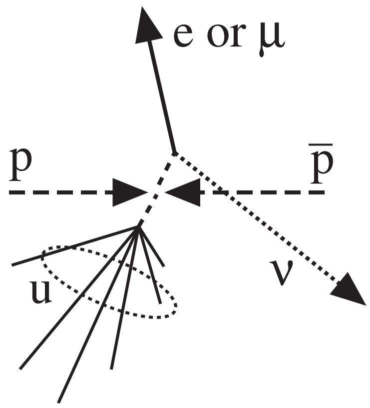
W production cross section is ~ 20 nb at Tevatron

- Can readily observe $W \to e\nu_e$ and $W \to \mu\nu_\mu$
- Select high E_T electron or muon
- Require significant $\not{E}_T$ to tag neutrino

Can infer M_W from transverse mass distribution

$$M_T = \sqrt{2 E_T \not{E}_T (1 - \cos\phi_{l\nu})}$$

- Not totally Lorentz invariant
  - Some sensitivity to W momentum
- Sensitive to structure functions



How Do We Accurately Measure M_W?

We don't know initial state p_z or neutrino p_z

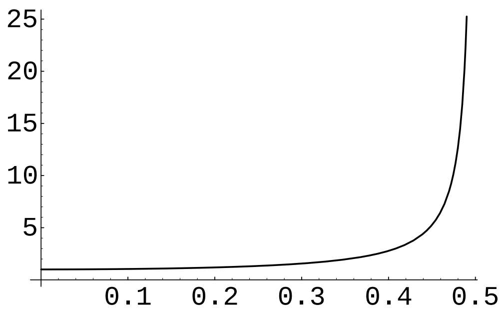
- Cannot reconstruct an invariant mass
- Mass information exists in lepton p_T and $\not{E}_T$

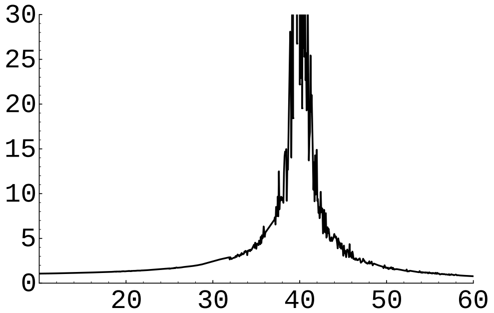
Suppose W decays at rest with $l^{\pm}$ angle θ^*

- Assume decay angular distribution $f(\cos\theta^*)$
- Transform to $p_T = (M \sin\theta^*)/2$

$$\frac{dN}{dp_T} = \frac{1}{1 - 4p_T^2/M^2} \quad f\left(\pm\sqrt{1 - 4p_T^2/M^2}\right)$$

- Has singularity at $p_T = M/2$, moderated by
  - Physical width and p_T of W
  - Detector resolution





$\boxed{\textbf{Reducing Systematics}}$

Can reduce sensitivity to these effects by using M_T

- Much less sensitive to W p_T distribution
- More resolution than p_T (uses more information)

Doesn't get rid of all systematics

- Still residual W p_T dependence
  - Get rid of it by looking only at W's near rest
- Now depend on $\not{E}_T$ measurement
  - Involves entire calorimeter response
- Have to worry about effect of PDF's
- Still have to deal with calibration

Data Sample from Run 1A

Select events with clean electron or muon

- For muons, require
  - $p_T > 25$ GeV/c
  - satisfies standard muon ID cuts
- For electrons, require
  - $E_T > 25$ GeV
  - satisfies standard electron ID cuts
- Require $\not\!\!E_T > 25$ GeV
- Require no "significant" recoil system
  - $|\vec{u}| < 20$ GeV
  - No jets with $E_T > 30$ GeV
- Left with 4663 $\mu\nu$ and 8067 $e\nu_e$ candidates

Fit $65 < M_T < 100$ GeV to predicted lineshape

- 5718 electron events
- 3268 muon events

Systematic Uncertainties on W Mass

Control of systematics most challenging aspect

1. Energy and momentum scale (120 and 45 MeV/c^2)
   - Determined using $\Upsilon/\psi \to \mu^+\mu^-$ and $Z \to \mu^+\mu^-/e^+e^-$
   - calorimeter scale set by tracking system

2. Resolution function of “detector” ($\sim$ 80 MeV/c^2)
   - Constrained by studies of Z events

3. Uncertainies in “recoil” system physics ($\sim$ 60 MeV/c^2)
   - Limited by statistics on Z sample

4. Structure functions (50 MeV/c^2)
   - Use MRS D_-' as default
   - Check variation caused by other choices

Accounting for correlations in these uncertainties

- Overall systematic uncertainty is 130 MeV/c^2

Momentum and Calorimeter Calibration

CTC was aligned and calibrated *in situ*

- Aligned with zillions of charged particles
- All material accounted for
- Used $J/\psi \to \mu^+\mu^-$ as calibration
- Applied a correction factor of 0.99984 ± 0.00054
- Causes a ±45 MeV/c^2 uncertainty on M_W

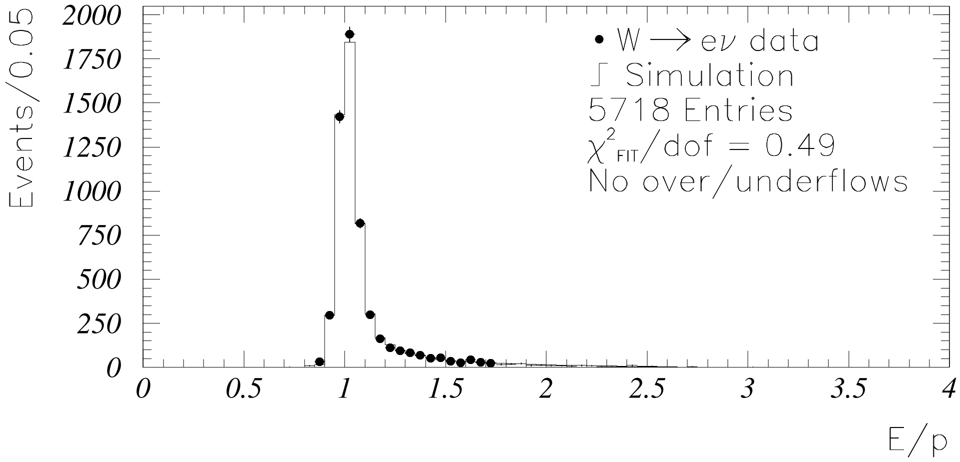
Calorimeter was calibrated by comparing E_{cal} with p

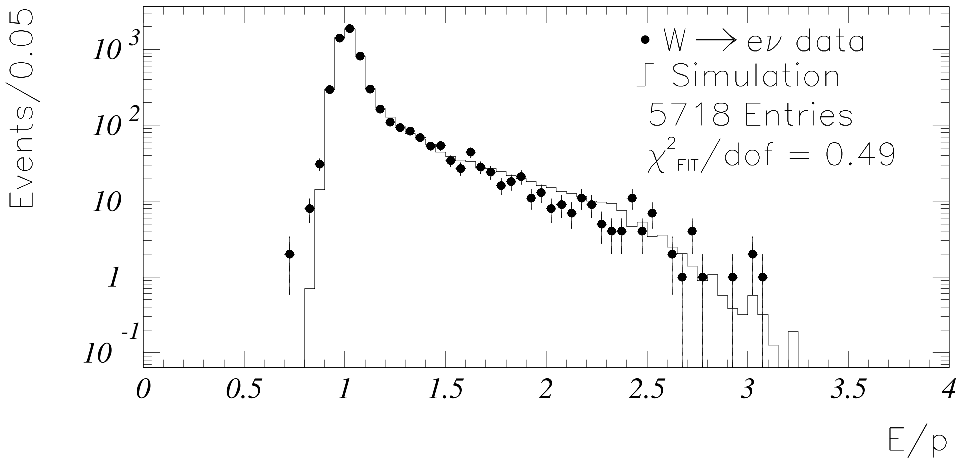
- Use E/p distribution for electrons
- Take into account material in detector (0.09 X_0)
- Limited by statistics, uncertainty in material
  - Statistics gives 0.08% uncertainty
  - Material correction has 0.09% uncertainty
- Overall uncertainty is 0.136% on calorimeter scale

Overall uncertainties on W mass from calibration are

- Momentum scale: ±45 MeV/c^2
- Calorimeter scale: ±110 MeV/c^2

E/p Comparison

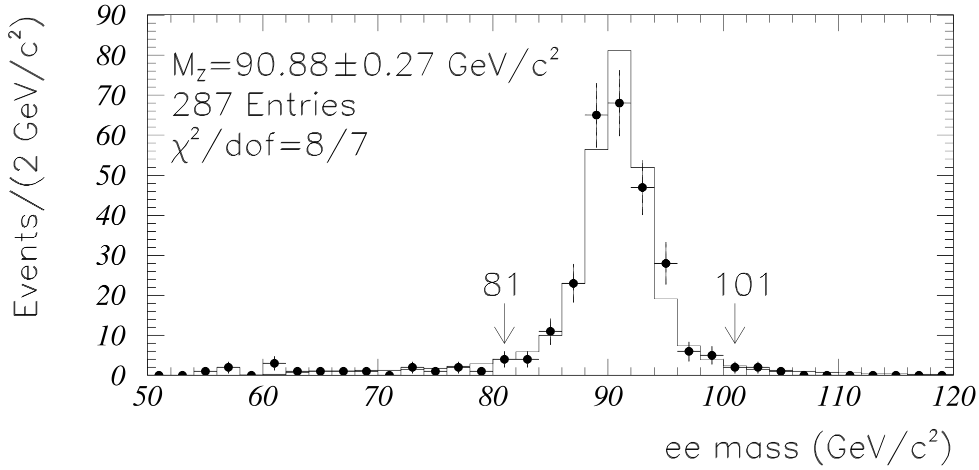




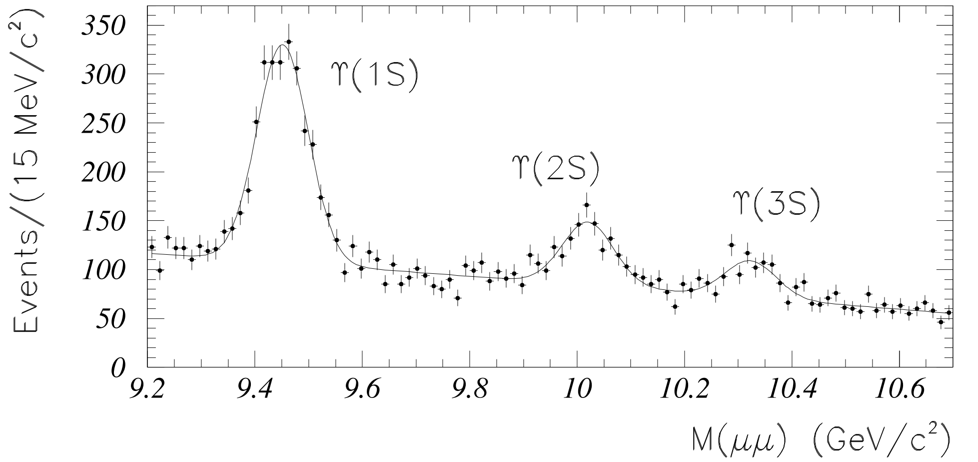
Checks of CTC Calibrations

Z mass from electrons a good check

- Use tracks to determine absolute calorimeter E_T



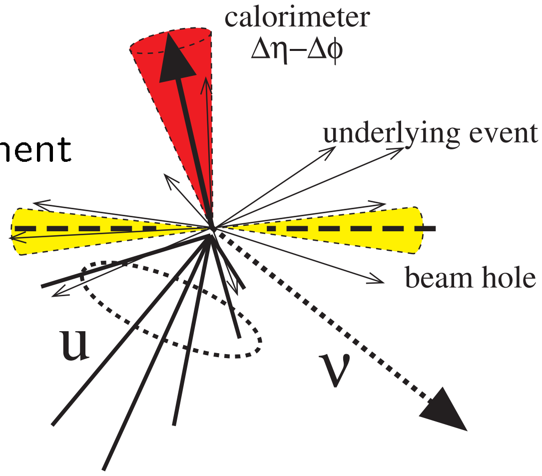
Dimuon mass distribution absolute check of p_T



Effect of Underlying Event

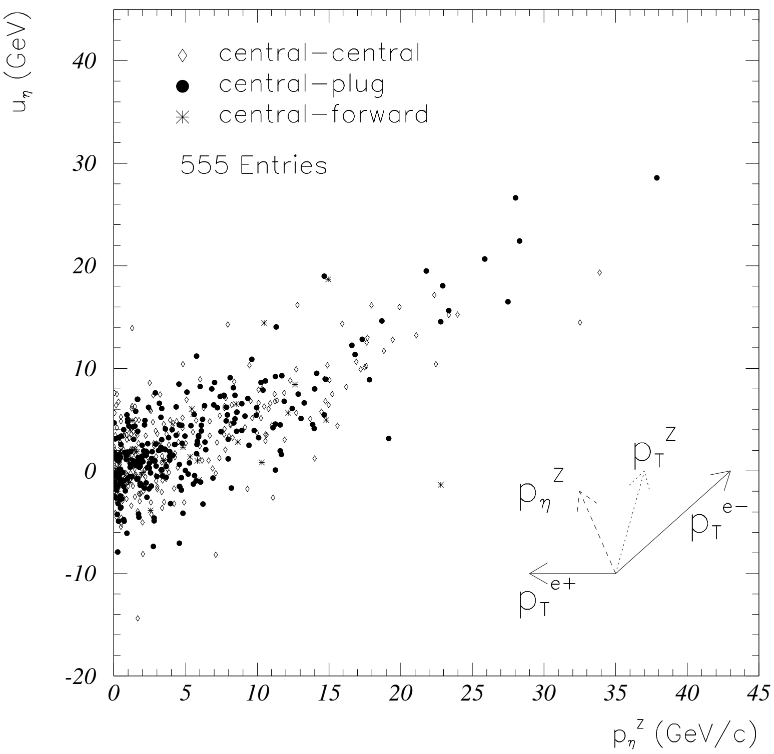
Have to understand effect of underlying event on M_T

- Enters in two ways:
  1. Modifies $\vec{u}$ (and therefore $\not\!\!E_T$)
  2. Modifies electron energy measurement



Can study $\vec{u}$ effects by looking at Z events

- Z momentum well measured by dilepton final state
- Can determine calorimeter response to given recoil



Combining Channels

To combine channels, have to understand uncertainties

- Some uncertainties unique to each channel, others correlated
- Uncorrelated ones are reduced by averaging
- Correlated uncertainties effect average result

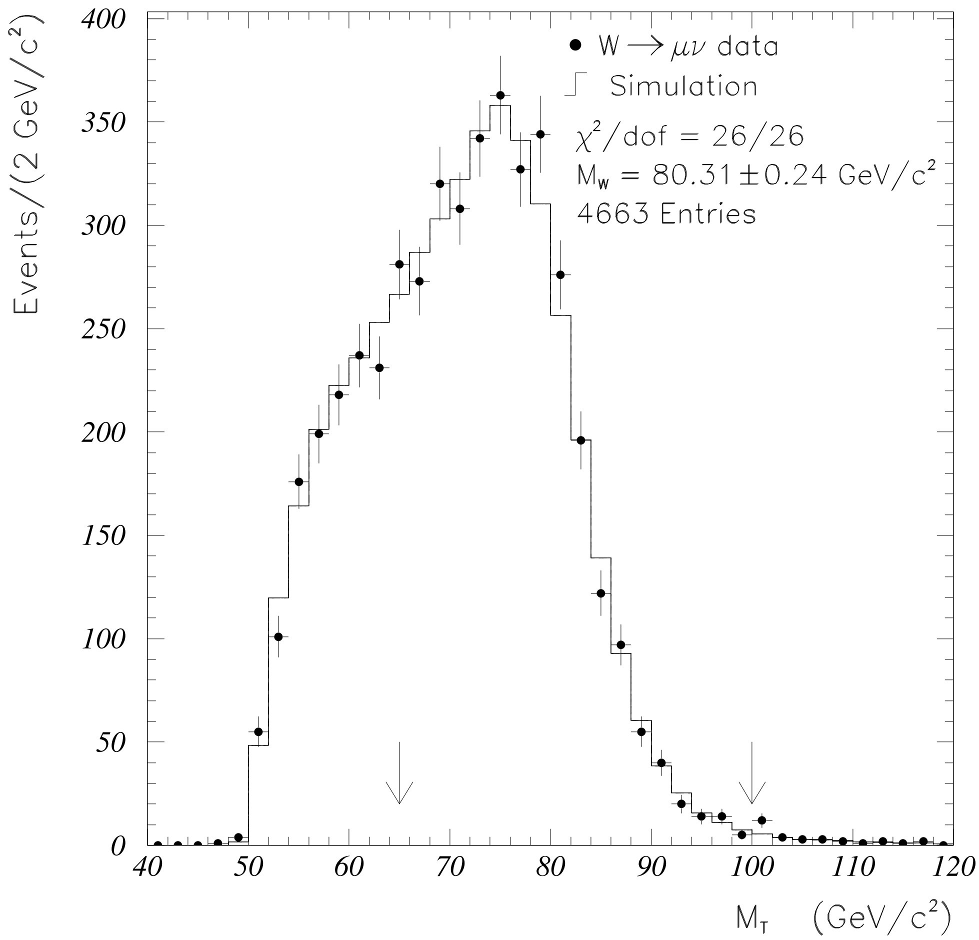
Uncertainty	ΔM_W^e	ΔM_W^μ	Common
Statistical	145	205	
Energy Scale	120	45	45
Resolution	80	60	0
p_T model	45	45	25
Recoil model	60	60	60
PDF	50	50	50
Total	230	240	100

Fit to Muon Data

Results of fit to muon data

- Fit data to predicted shape
  - function of M_W, Γ_W
- Use only most sensitive M_T range

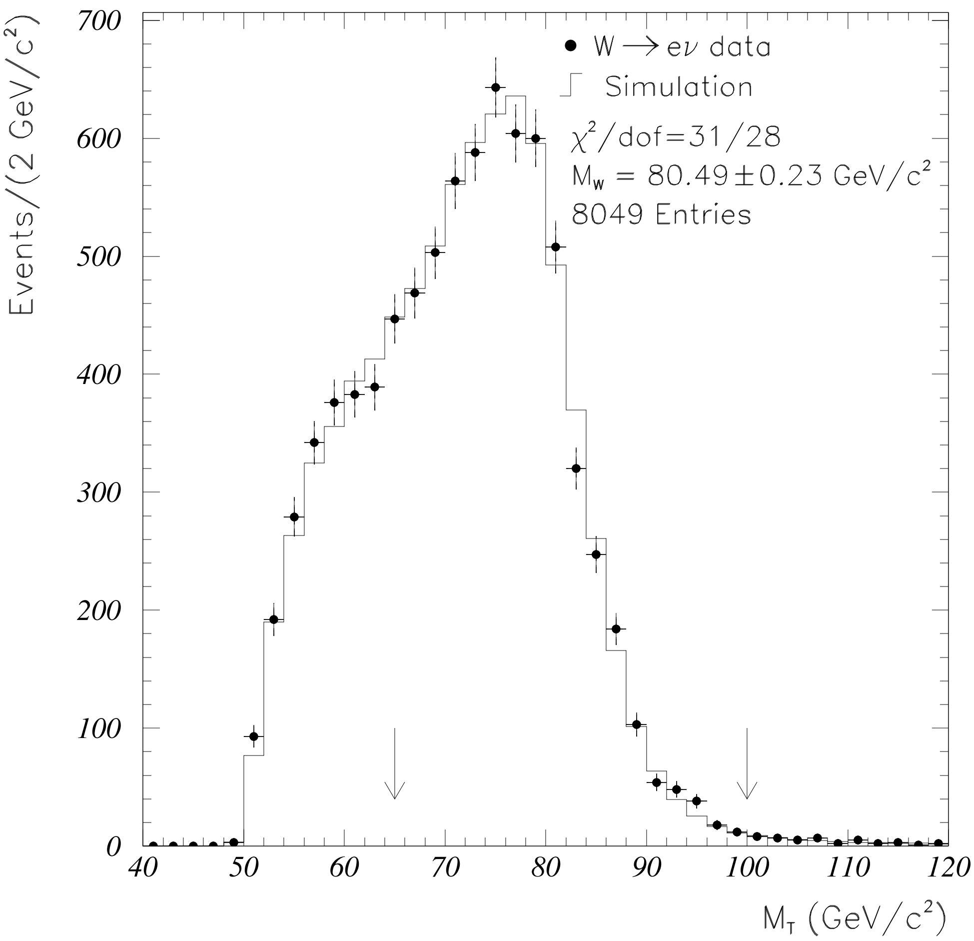
$$M_W = 80.310 \pm 0.205 \pm 0.130 \text{ GeV/c}^2$$



Fit to Electron Data

Results of fit to electron data

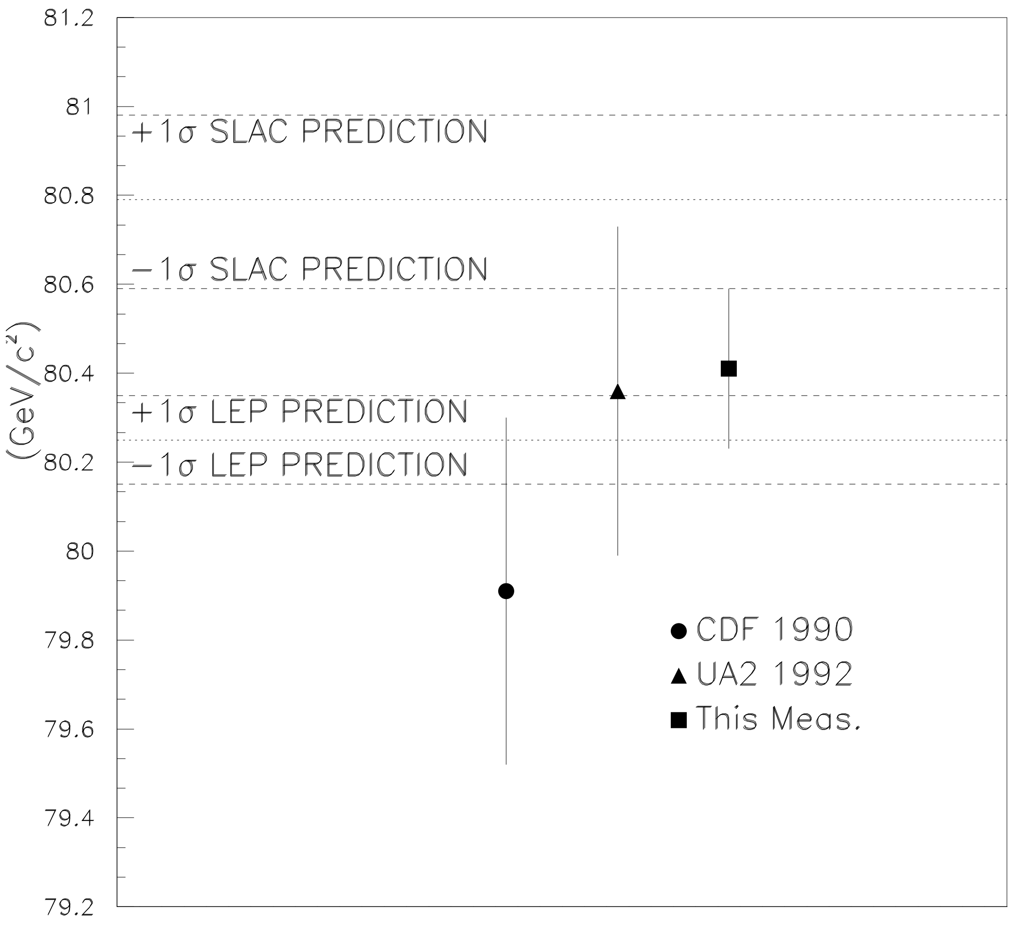
$$M_W = 80.490 \pm 0.145 \pm 0.175 \text{ GeV/c}^2$$



Summary of W Mass

Combined mass from both channels is

$$M_W = 80.41 \pm 0.18 \text{ GeV/c}^2$$



How Well Can We Do?

The statistical errors will decrease $\times 2$

- Already have $\times 5$ more data
- Will come done to $\lesssim$ 100 MeV/channel

Systematic uncertainties are the challenge

- Experience has shown them to also scale with sample size
  - All determined by other data
- Should hope to get to $\lesssim$ 50 MeV/c^2