First Measurement of the *W* Boson Mass with CDF in Run II

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Motivation

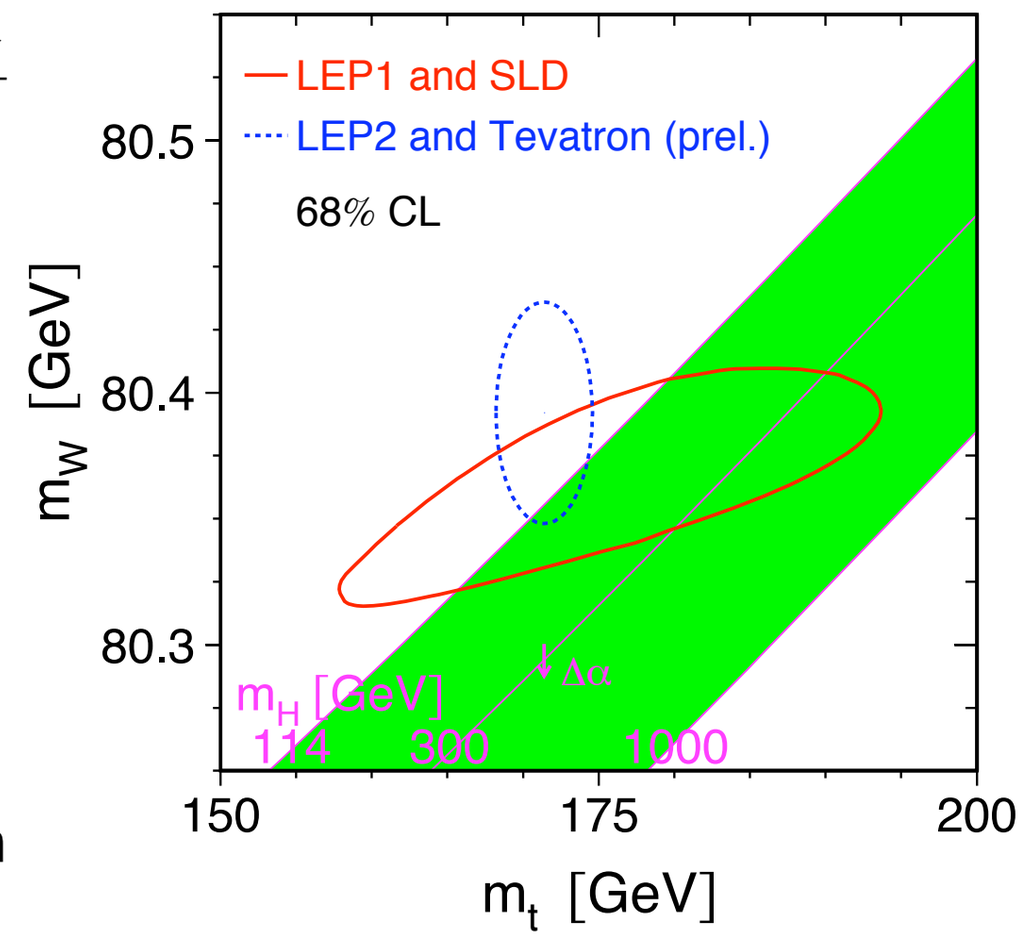
- W boson mass can be derived from precisely measured quantities

$$m_W^2 = \frac{\pi \alpha_{em}}{\sqrt{2} G_F \sin^2\theta_W (1 - \Delta r)} \qquad \sin\theta_W^2 = 1 - \frac{m_W^2}{m_Z^2}$$

- Radiative corrections *r* dominated by top and Higgs loops

  - Precise knowledge of top quark and W boson masses help constrain Higgs boson mass

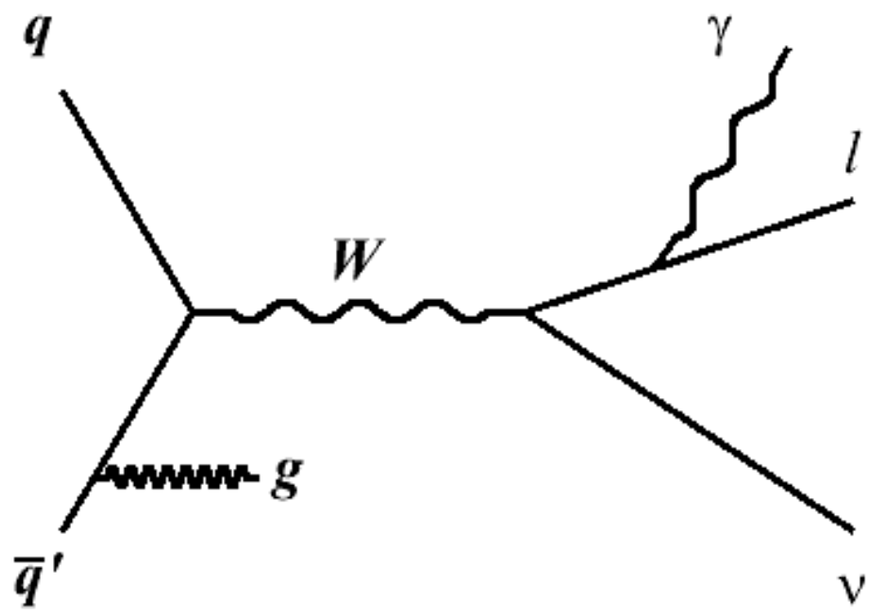
Summer 2006



$M_{Higgs} = 85^{+39}_{-28}$ GeV/c^2

$M_{Higgs} < 166$ GeV/c^2 (95% CL)

W boson production and decay



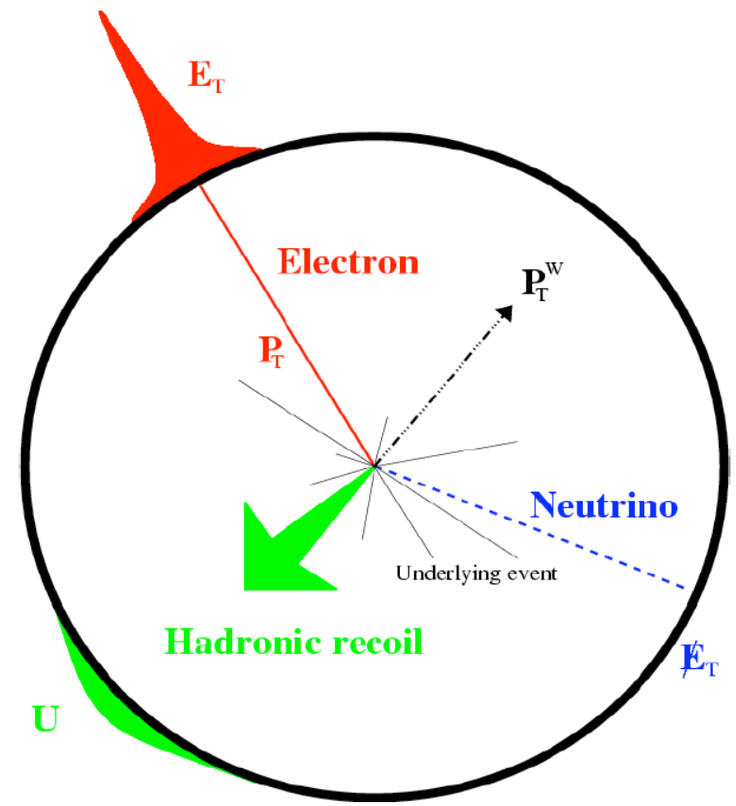
- W production at Tevatron dominated by $q\bar{q}$ annihilation
- Use events with electron or muon in final state
  - $\sigma \cdot BR = 2.749 \pm 0.174$ nb
  - Dataset of 200 pb^{-1}
  - ~100,000 candidate events

Measurement strategy

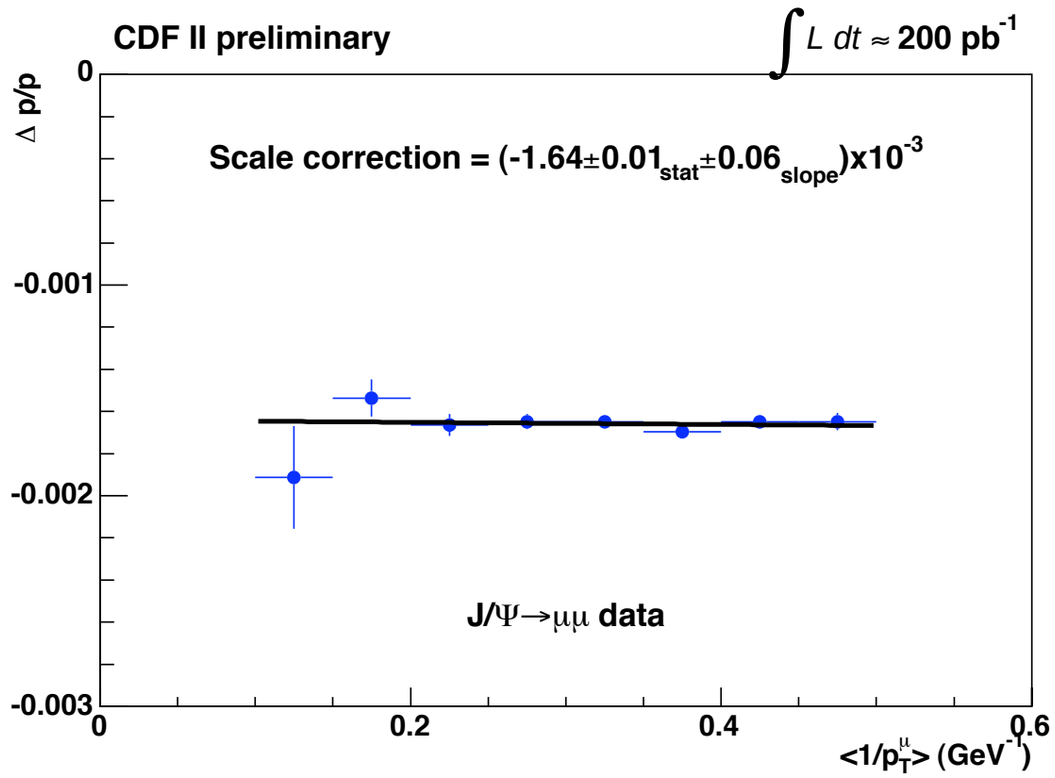
- Use transverse mass

$$m_T = \sqrt{2p_T^\ell p_T^\nu (1 - \cos\Delta\theta_{\ell\nu})}$$

- Precise measurement of charged lepton
  - Calibrate track momentum measurement
  - Calibrate calorimeter energy measurement
  - Use *Z* boson as cross-check and additional calibration
- Hadronic recoil - allows inference of neutrino
  - Calibrate using *Z* boson events
  - Cross-check with *W* boson events
- Perform final fit using *W* mass templates
  - Parameterized fast simulation to model detector effects

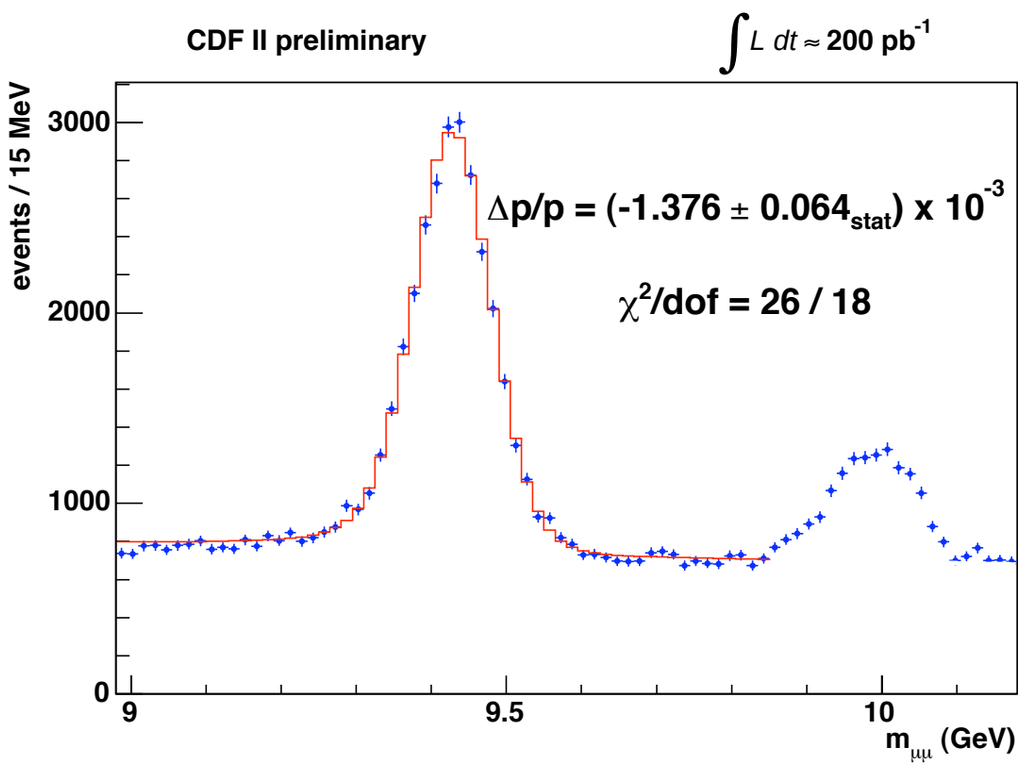


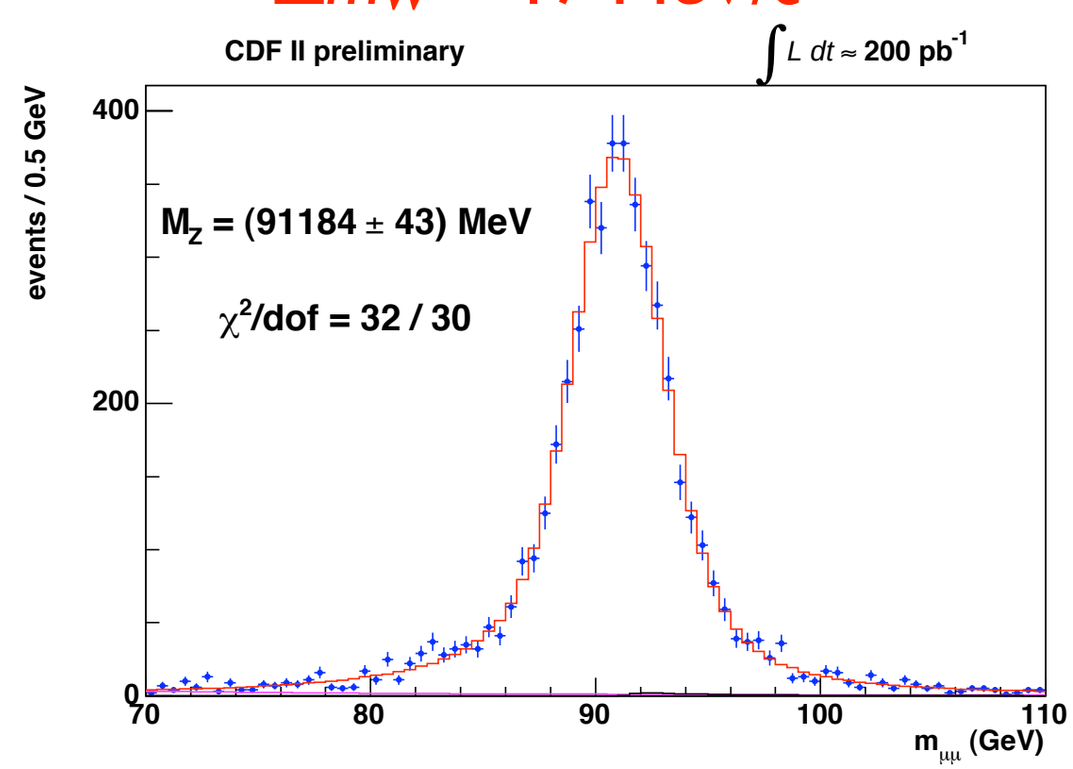
Track momentum scale



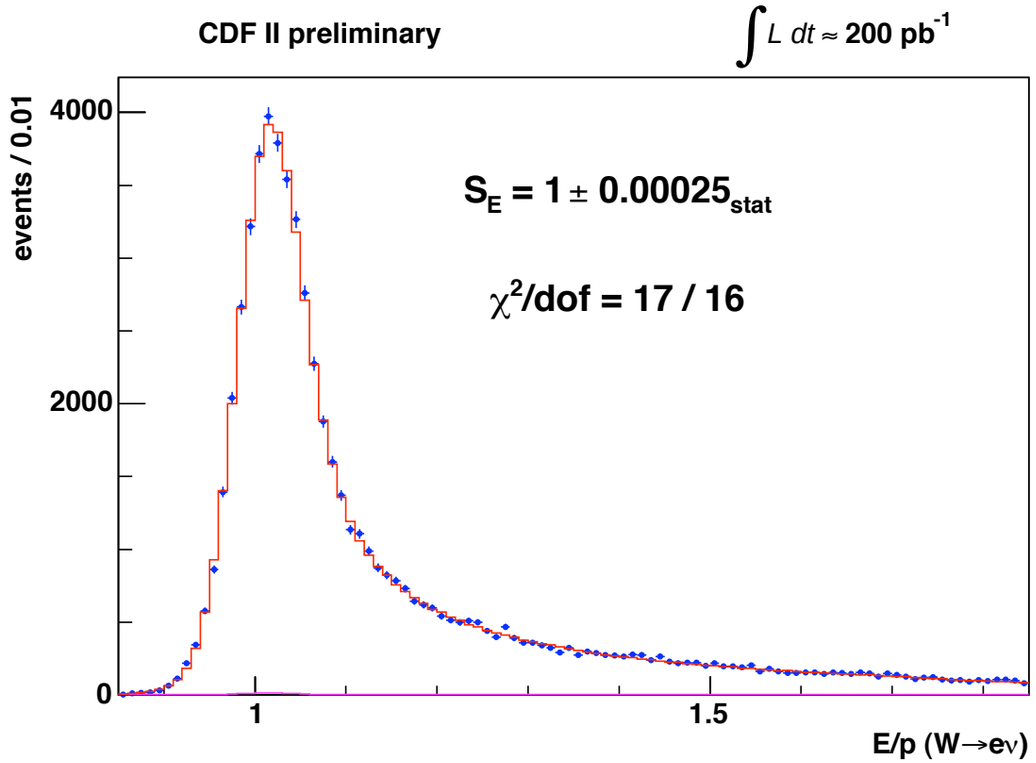
- Large sample of J/ψs and Υs are used
  - Tune model of energy loss→ J/ψ mass independent of muon p_T
  - Tune track resolution using Υ decays
- Apply momentum scale to Z decays
  - Use world avg. Z mass as additional calibration

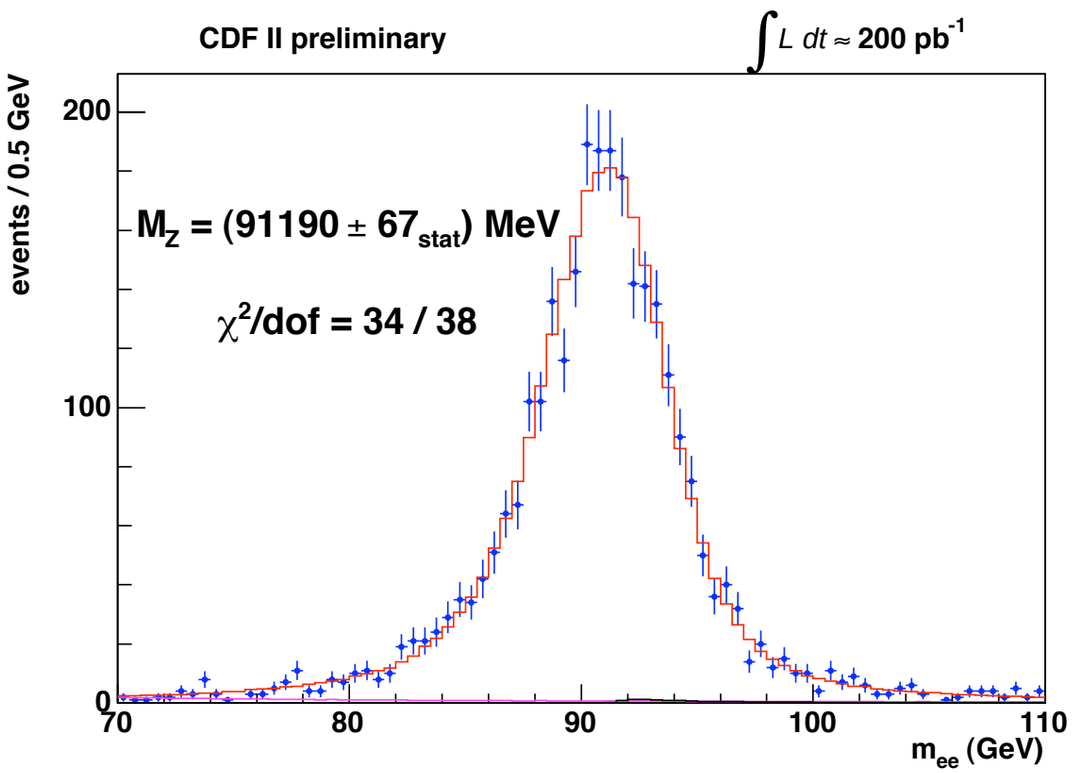
Δm_W = 17 MeV/c^2





Calorimeter energy scale





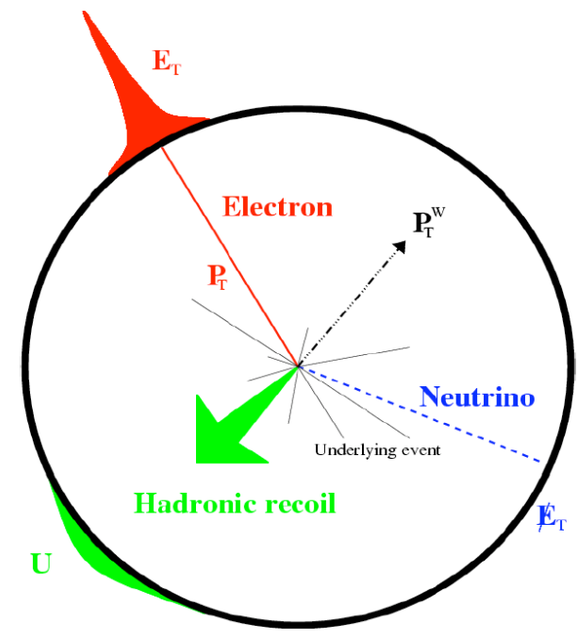
- Calibration of calorimeter energy scale vital for electron measurement
- Calorimeter energy calibrated using peak of electron *E/p* distribution from *W*s
  - Apply calibrated track momentum scale
- Energy loss tuned with high *E/p* tail
- Correct for E_T dependence
- Measure *Z* mass in electrons using calibrated scale

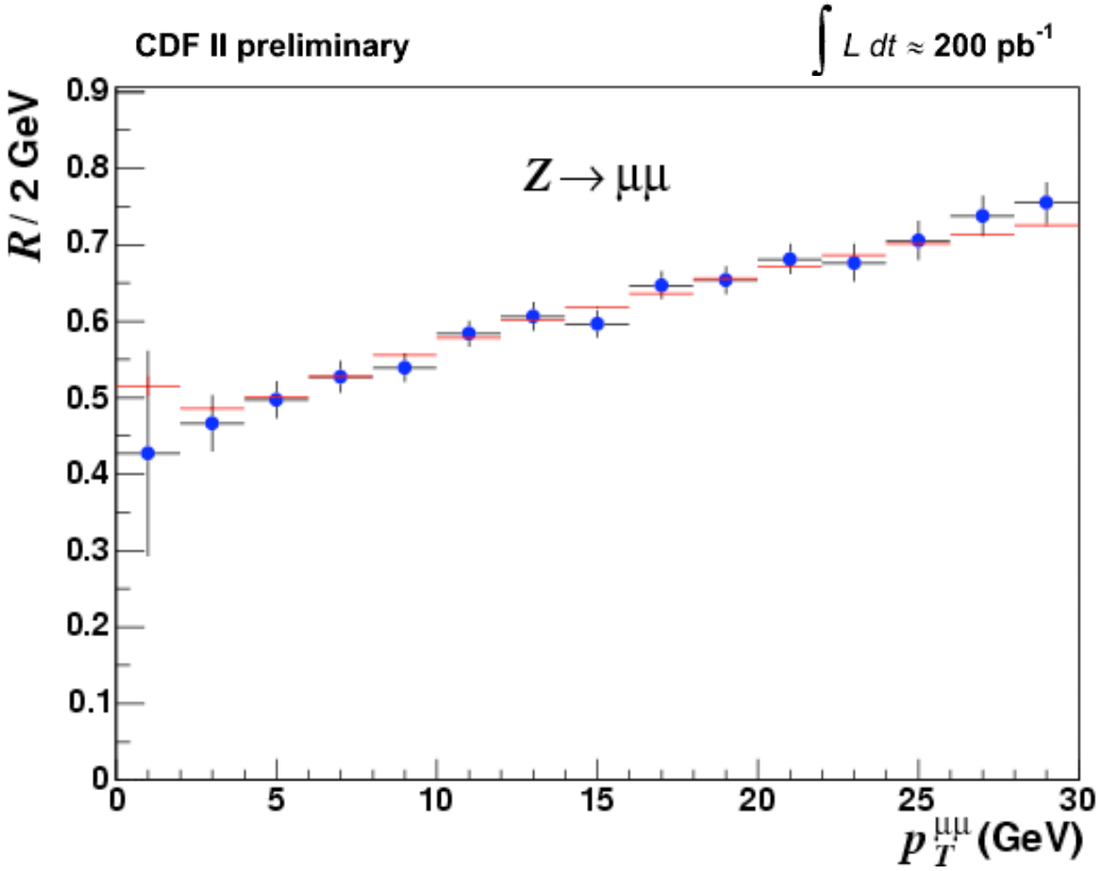
$\Delta m_W = 30\ \mathrm{MeV}/c^2$

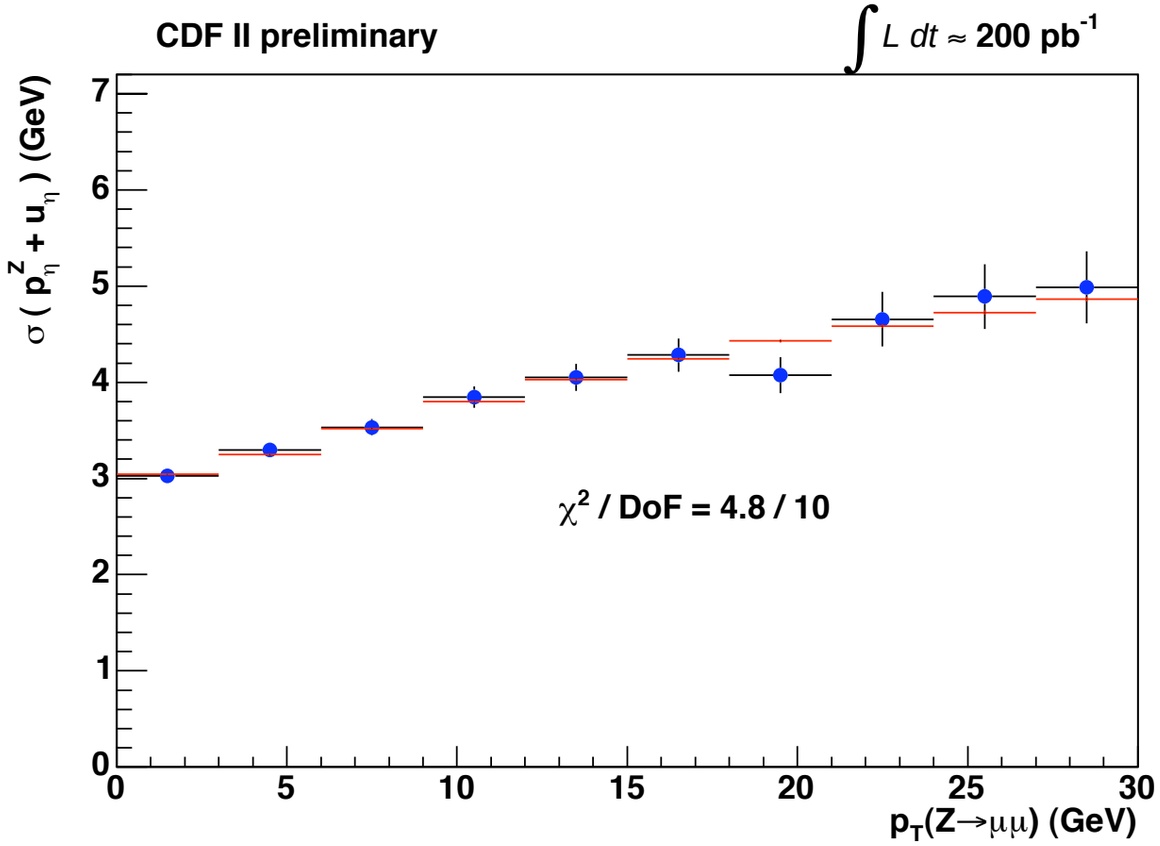
Recoil

- Hadronic recoil (u): energy in calorimeter excluding measured lepton
- Calibrate model for u using Z boson events
  - Recoil energy scale $R=u_{meas}/u_{true}$
  - Recoil energy resolution

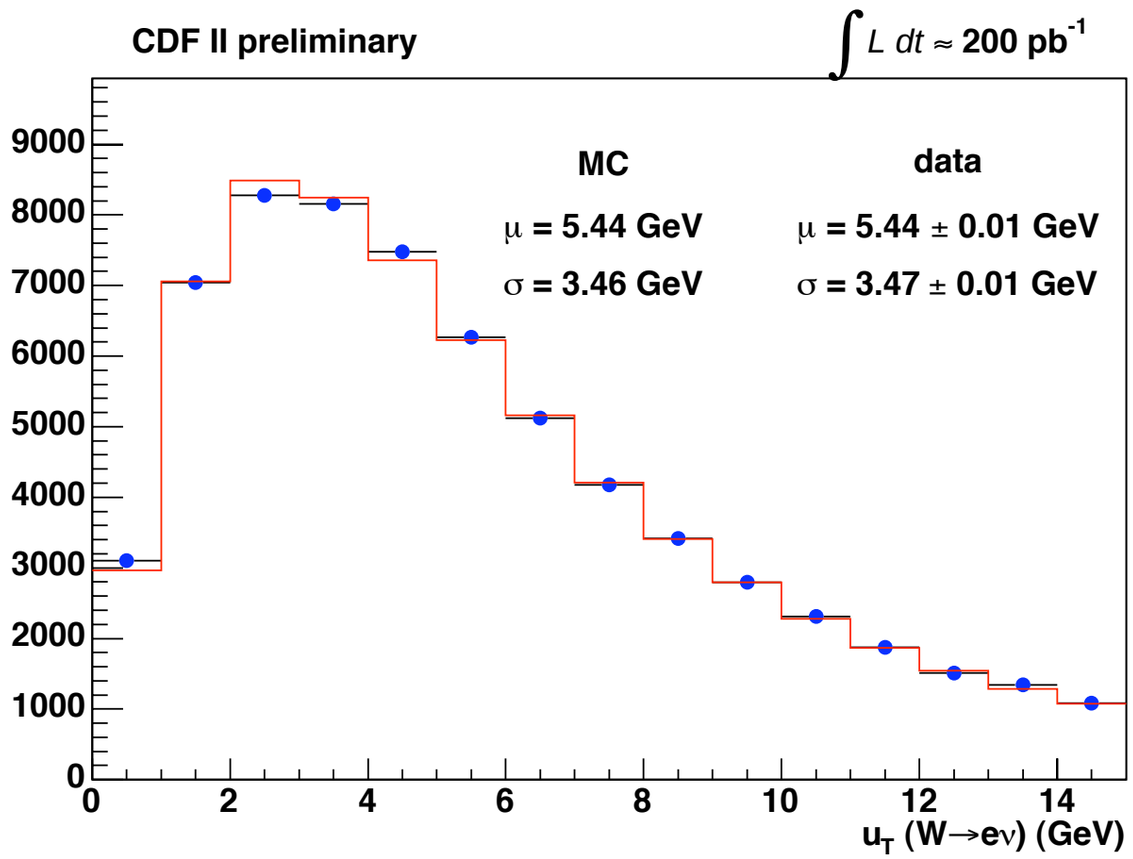
$$\Delta m_W = 11 \text{ MeV}/c^2$$



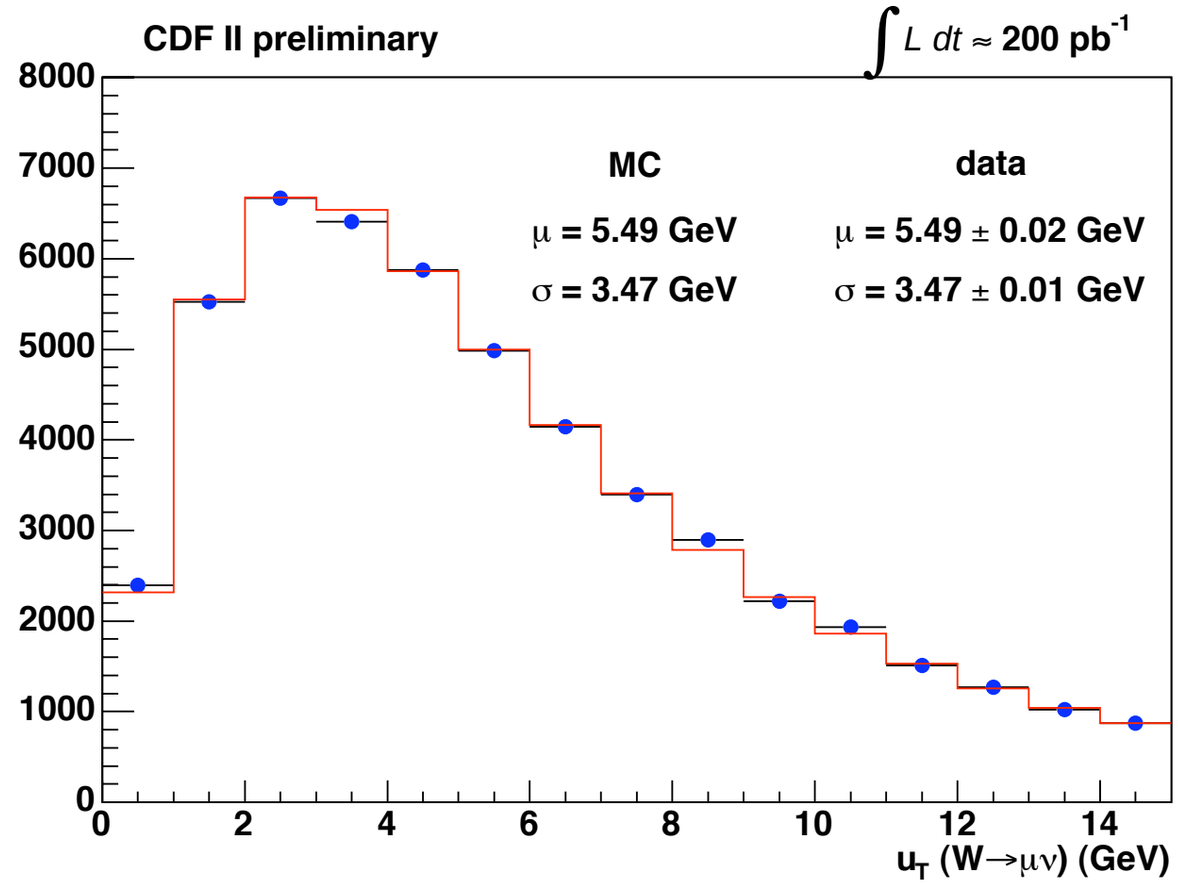




Recoil validation



Electrons



Muons

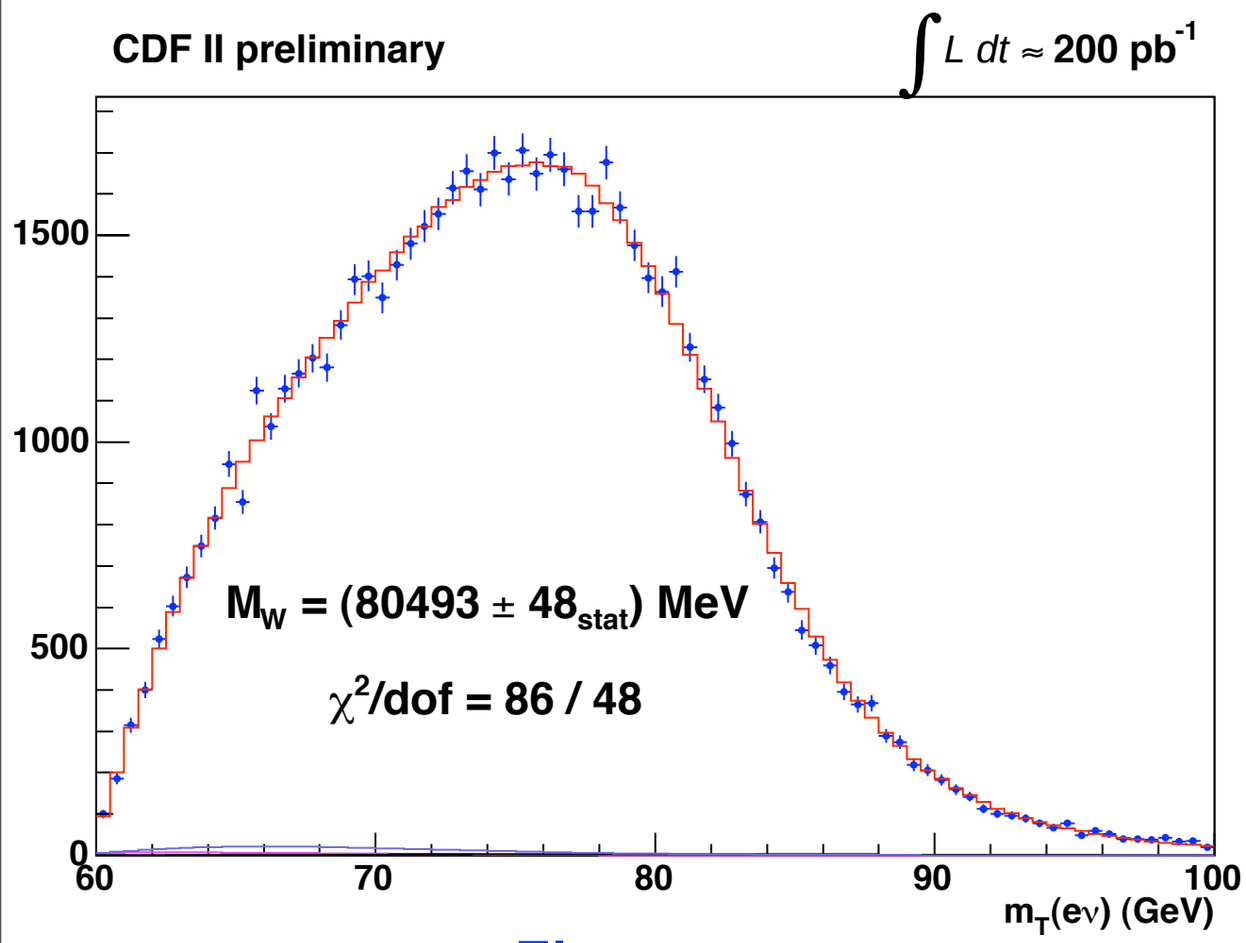
- Compare recoil distribution between simulation and data for *W* boson events

Systematic uncertainties

Source	$W \to \mu\nu$	$W \to e\nu$	Common
Lepton Scale	17	30	17
Lepton Resolution	3	9	0
Lepton Efficiency	1	3	0
Lepton Tower Removal	5	8	5
Recoil Energy Scale	9	9	9
Recoil Energy Resolution	7	7	7
Backgrounds	9	8	0
PDFs	11	11	11
W Boson p_T	3	3	3
Photon Radiation	12	11	11
Statistical	54	48	0
Total	60	62	26

- Systematic uncertainties for transverse mass fits shown (units of MeV/c^2)

Transverse mass fits



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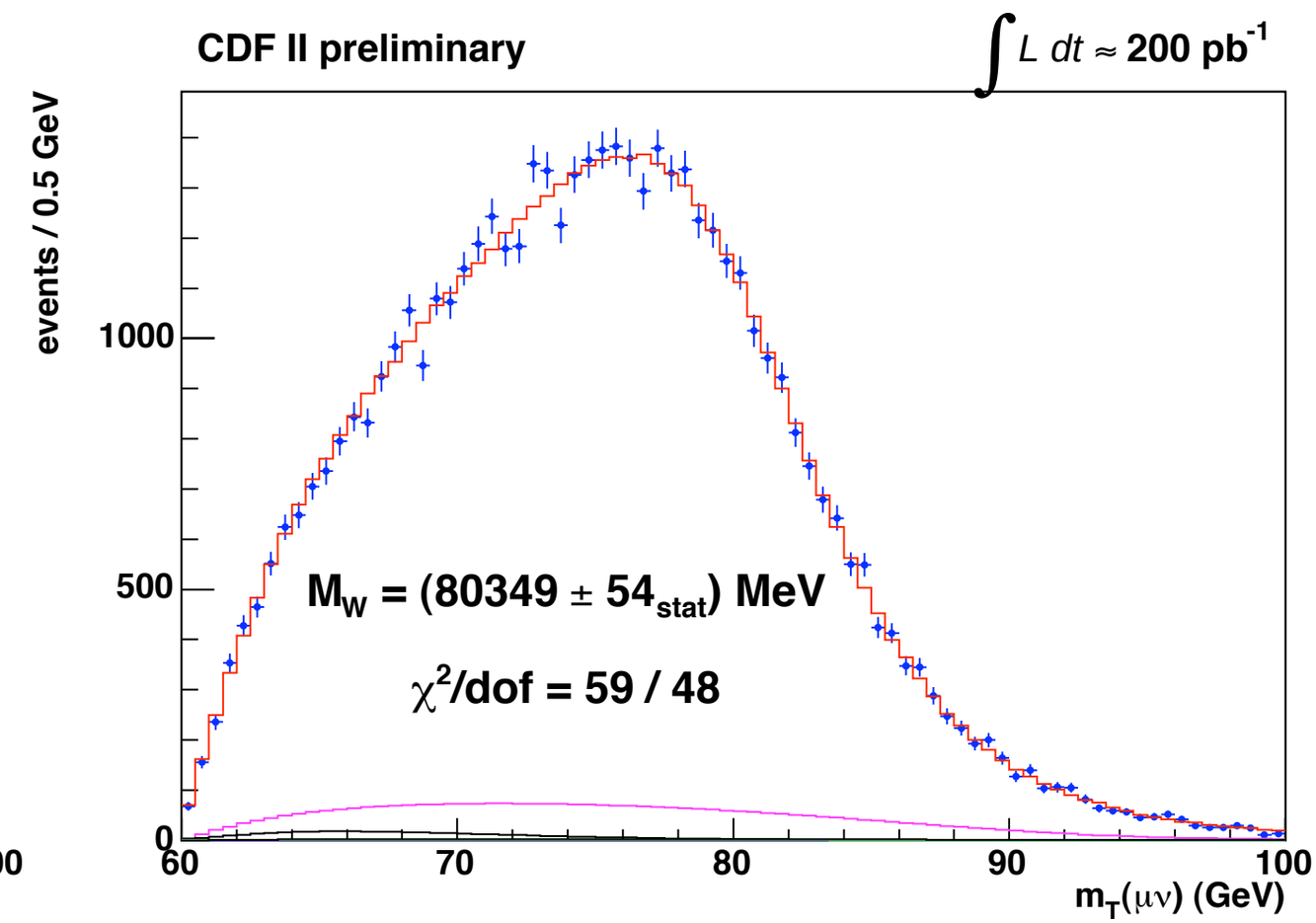


Muons

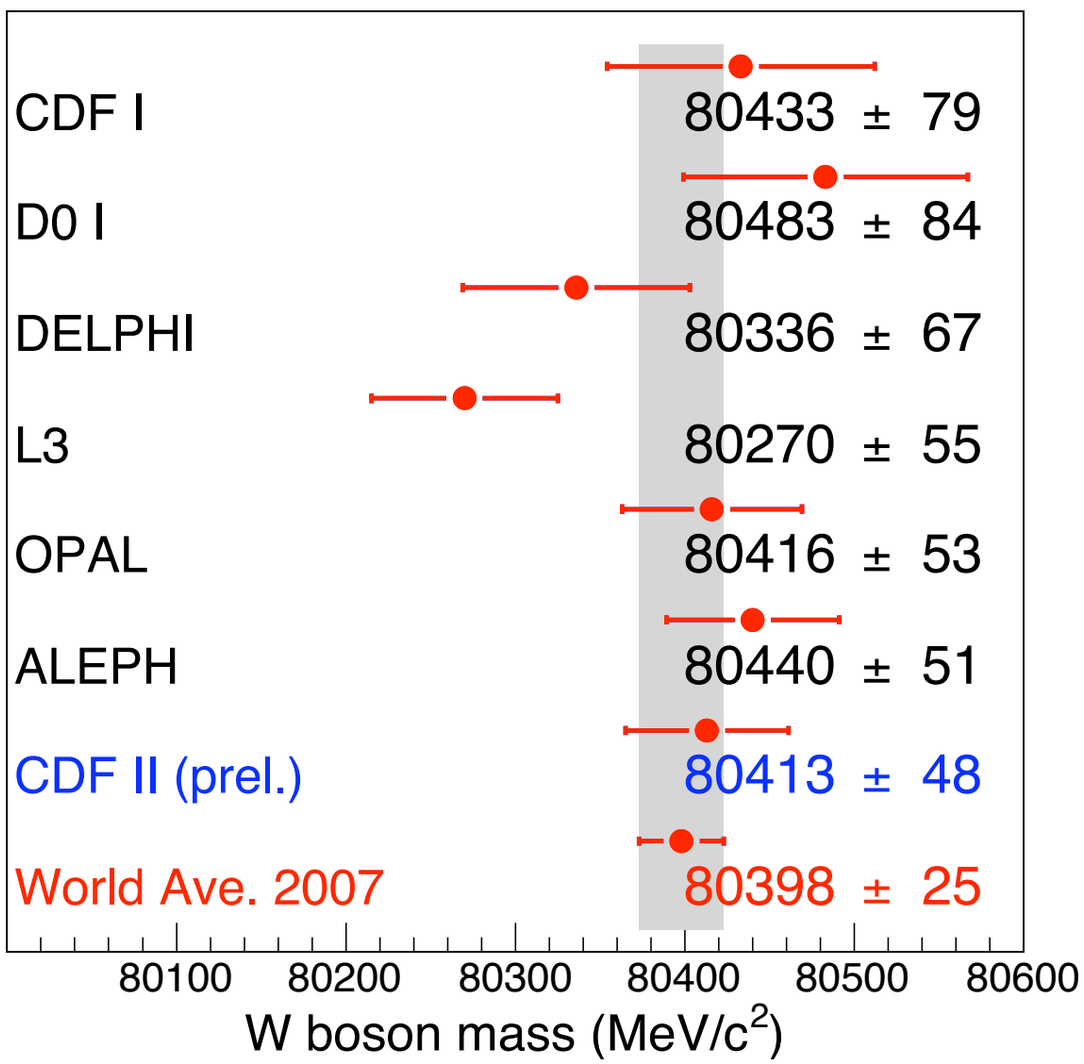
- Transverse mass (m_T) fits provide most precision
  - Charged lepton p_T and missing E_T (neutrino p_T) fits also performed and included in final measurement

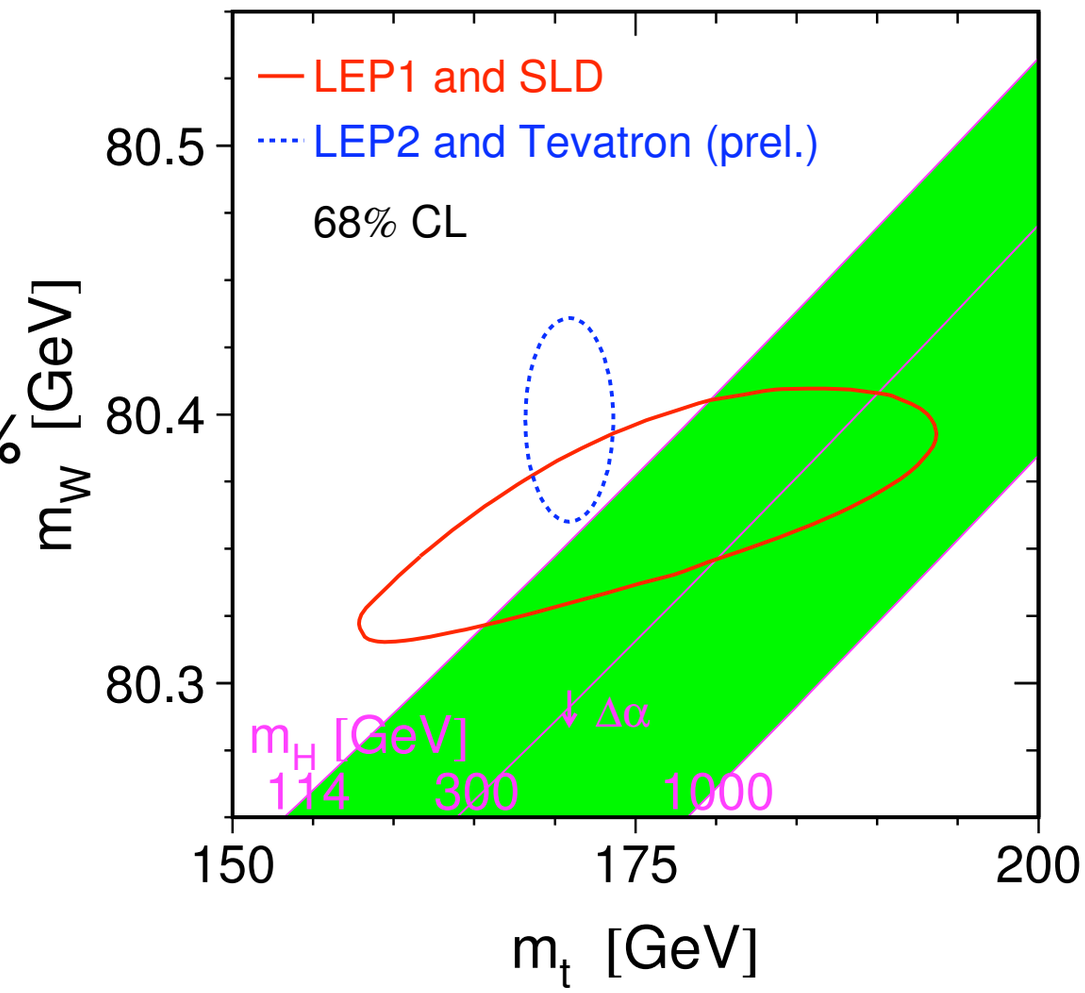
Result

- Combined electron and muon fit:

m_W=80413±48 MeV/c^2

  - Single most precise measurement of W boson mass in the world
  - Reduces uncertainty of world avg. by ~15%





Combined with newest m_t average:

$M_{Higgs} = 76^{+33}_{-24}$ GeV/c^2

M_{Higgs} < 144 GeV/c^2 (95% CL)

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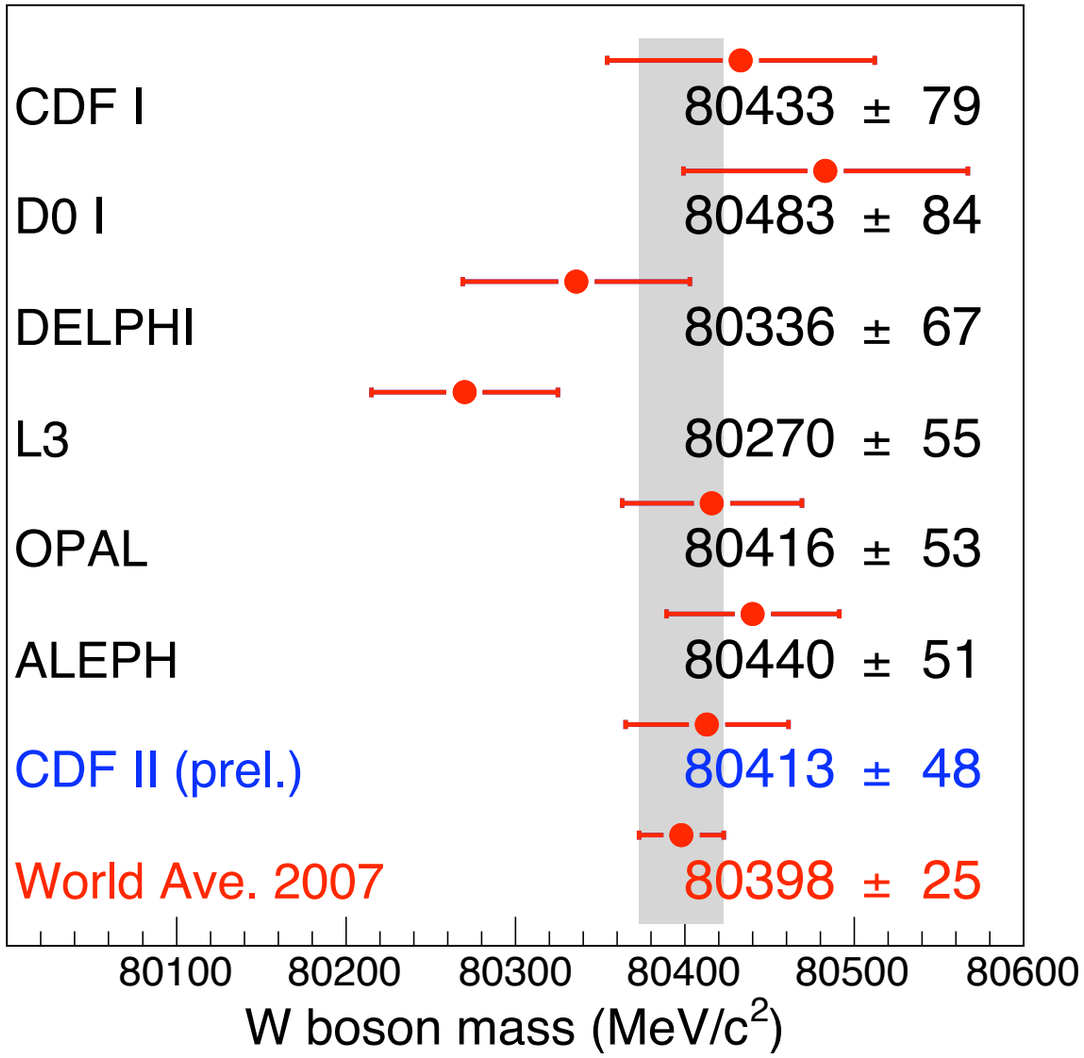

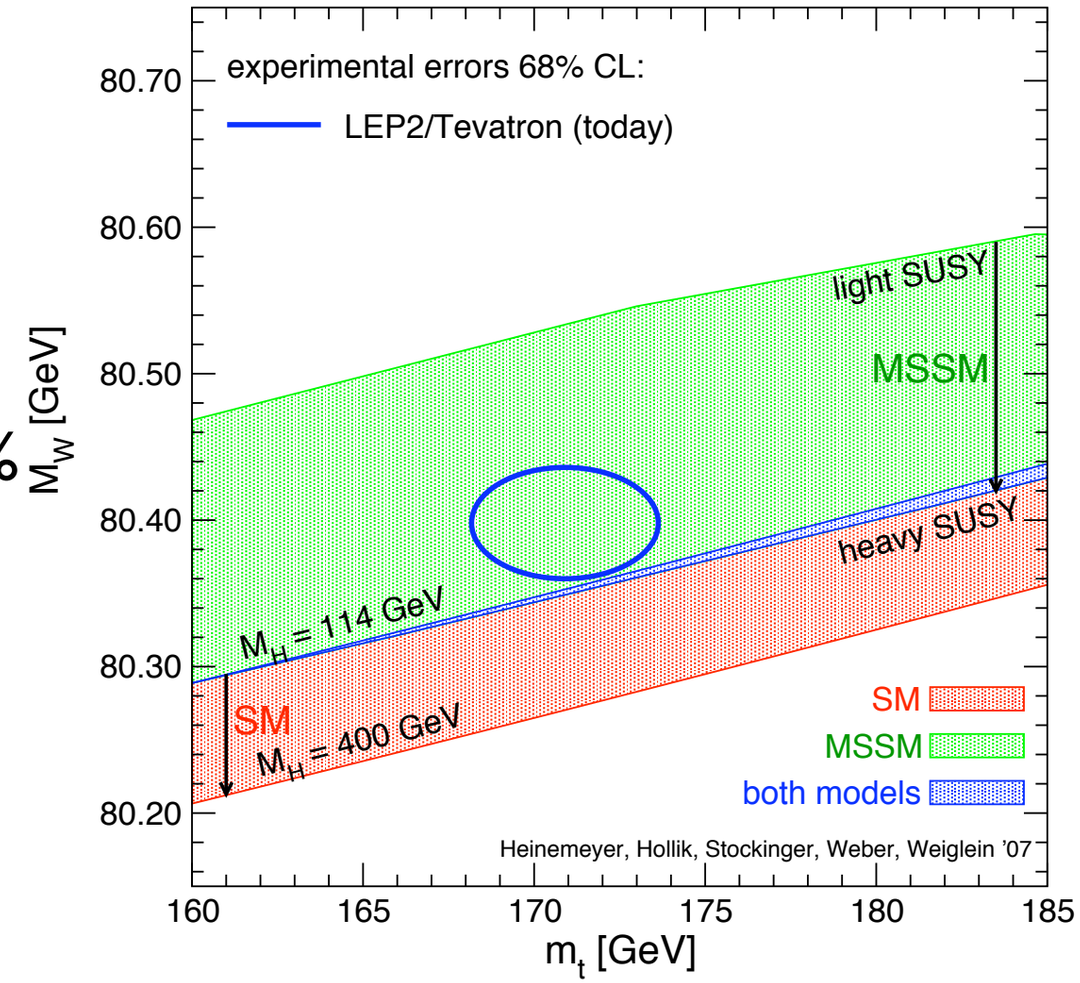

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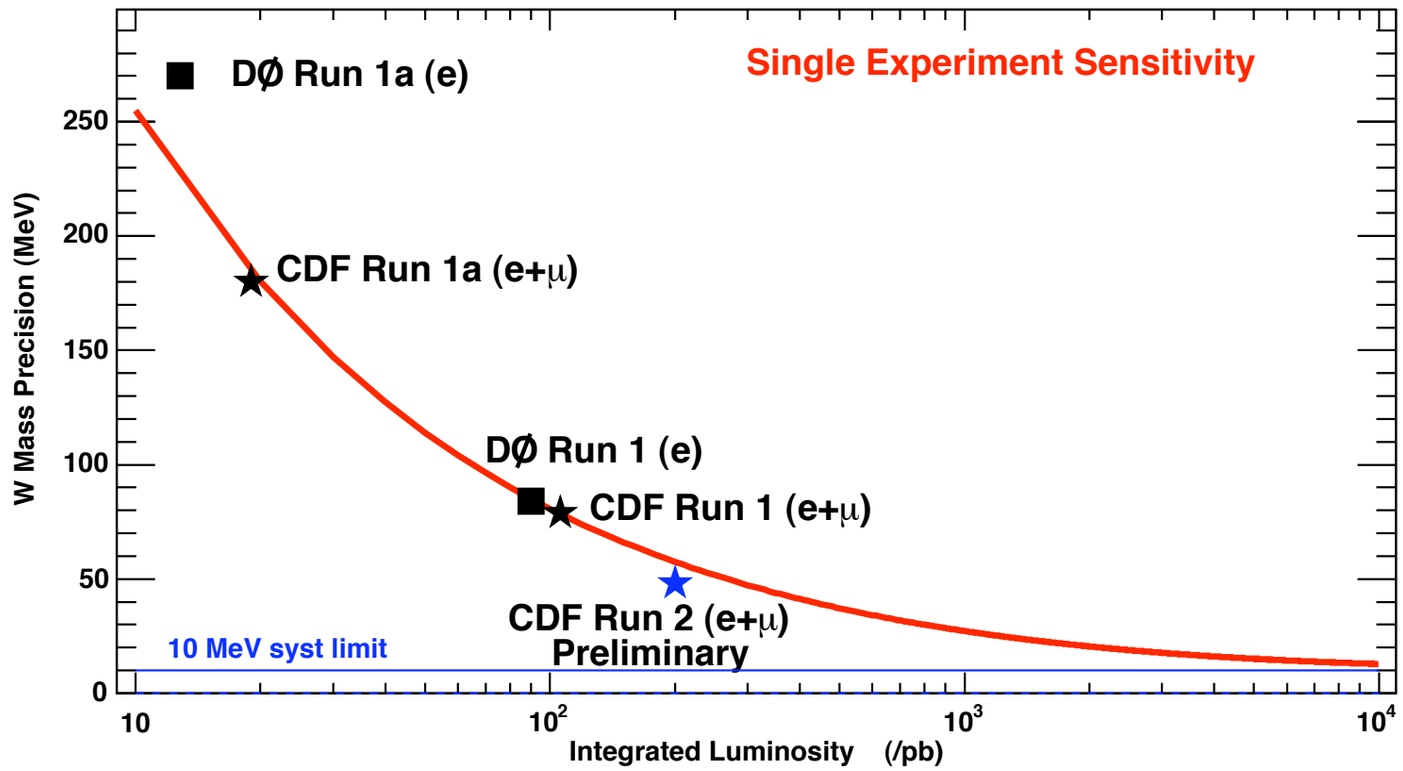
Conclusion



- CDF has performed single most precise measurement of *W* boson mass

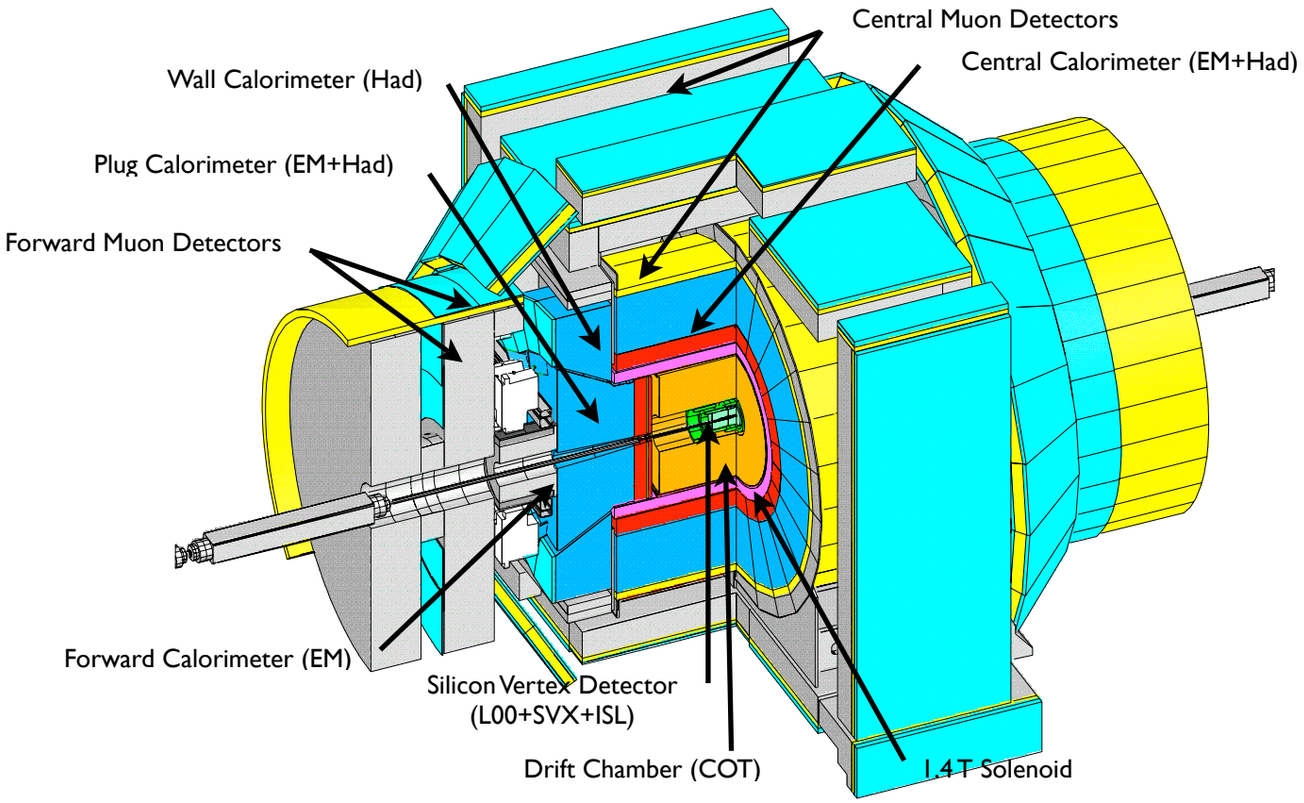
$$m_W = 80413 \pm 34(\text{stat}) \pm 34(\text{sys})\ \text{MeV}/c^2$$
$$= 80413 \pm 48(\text{stat+sys})\ \text{MeV}/c^2$$

  - Impact on world average has moved most likely Higgs mass further into LEP excluded region

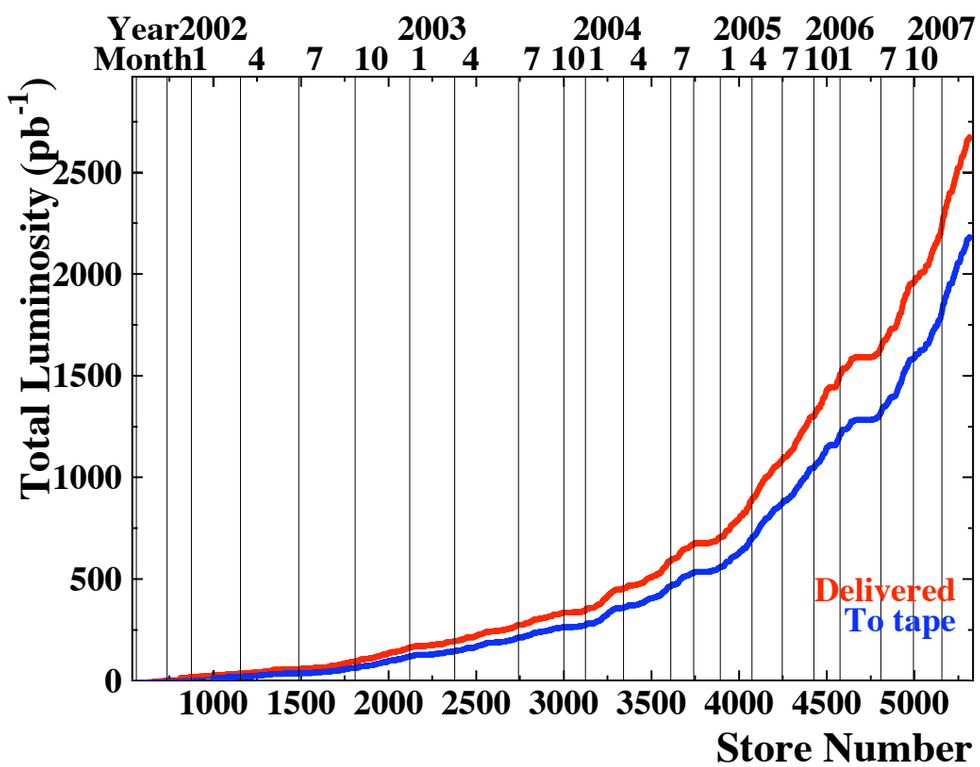
- Expect CDF $\Delta m_W < 25\ \text{MeV}/c^2$ with ~2 fb^{-1} already recorded

Backup Slides

The Tevatron and CDF detector



- Tevatron
  - Peak luminosity >2.8×10^{32} $cm^{-2}s^{-1}$
  - 2.5 fb-1 delivered to experiments
- CDF Detector - General purpose detector
  - Precision tracking (Silicon + COT)
  - EM and Hadronic calorimeters
  - Muon detectors (extended for Run II)
- >2.0 fb-1 recorded at CDF



Backgrounds

Electrons

Source	*% of W data*	*Uncertainty on m_W*
Tau decays	0.93±0.02	1 MeV/c^2
Hadronic jets	0.25±0.15	7 MeV/c^2
Z decays	0.24±0.01	2 MeV/c^2

Muons

Source	*% of W data*	*Uncertainty on m_W*
Tau decays	0.89±0.02	1 MeV/c^2
Hadronic jets	0.1±0.1	2 MeV/c^2
Z decays	6.6±0.3	6 MeV/c^2
Decays in flight	0.3±0.2	5 MeV/c^2
Cosmic rays	0.05±0.05	2 MeV/c^2