Precise Electroweak Measurements at the Tevatron

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Constraining the standard model

- Electroweak sector of the standard model (SM) is constrained by

$$G_F = 1.16637(1) \times 10^{-5}\ \mathrm{GeV}^{-2}$$

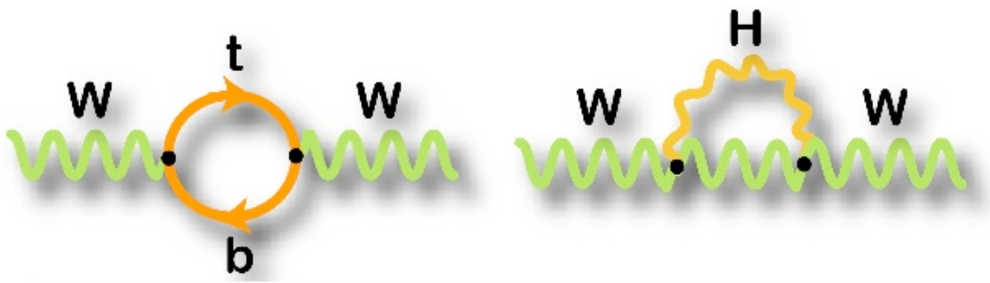
$$\alpha_{EM}(Q^2 = M_Z^2) = 1/127.918(18)$$

$$m_Z = 91.1876(21)\ \mathrm{GeV}/c^2$$

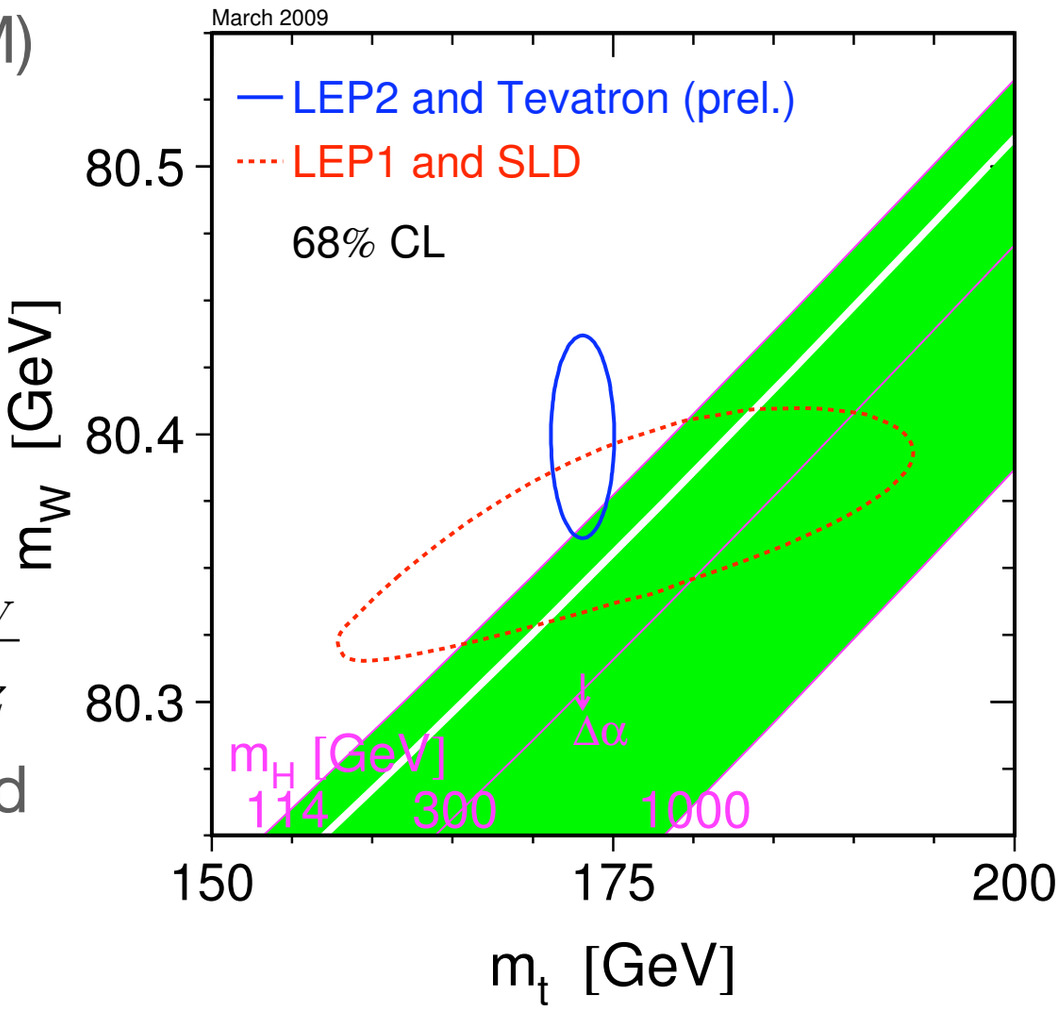
- These constants are all related to m_W by

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

- Radiative corrections Δr dominated by top and Higgs loops

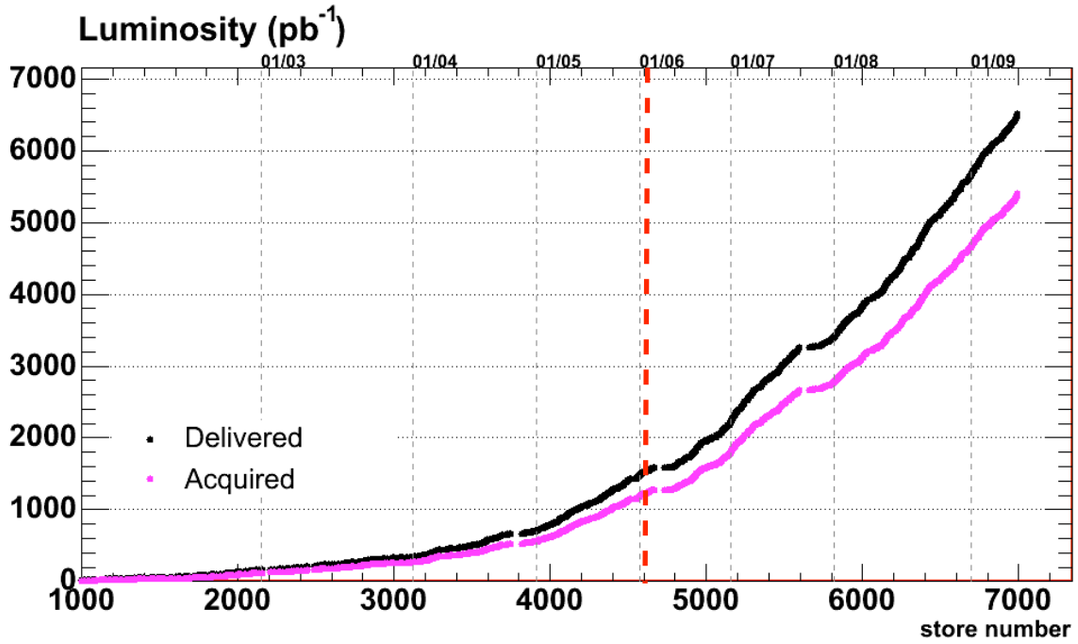


- Precision measurements in m_W and m_{top} constrain SM Higgs mass



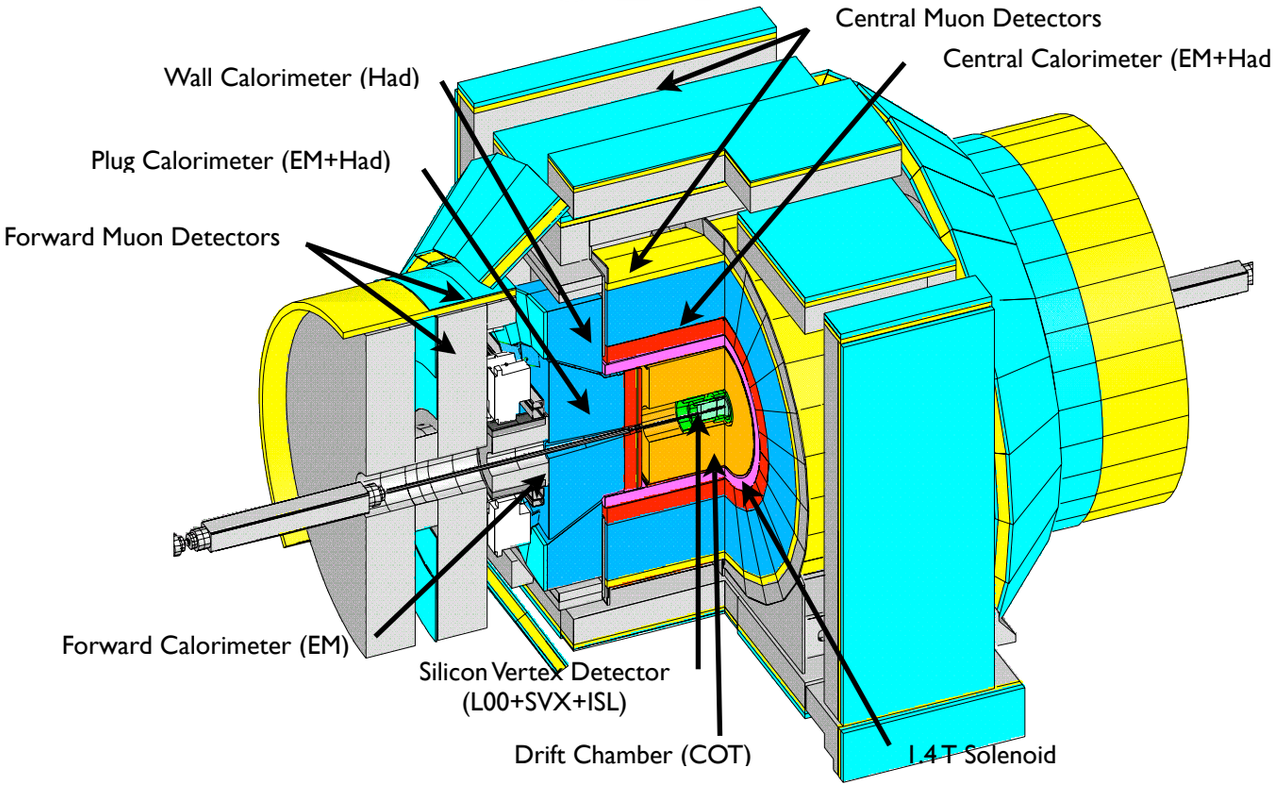
The Fermilab Tevatron

- $p\bar{p}$ collider at $\sqrt{s}$=1.96 TeV
- Excellent accelerator performance
  - Inst. lum. exceeding 3×10^{32} cm^{-2}s^{-1}
  - Over 6 fb^{-1} delivered to each experiment
  - Results shown today use ≤ 1 fb^{-1}
- Every bit of data helps
  - Systematic uncertainties in *W* mass/width measurements reduced by data-based calibrations
- Many thanks to the Fermilab accelerator division!



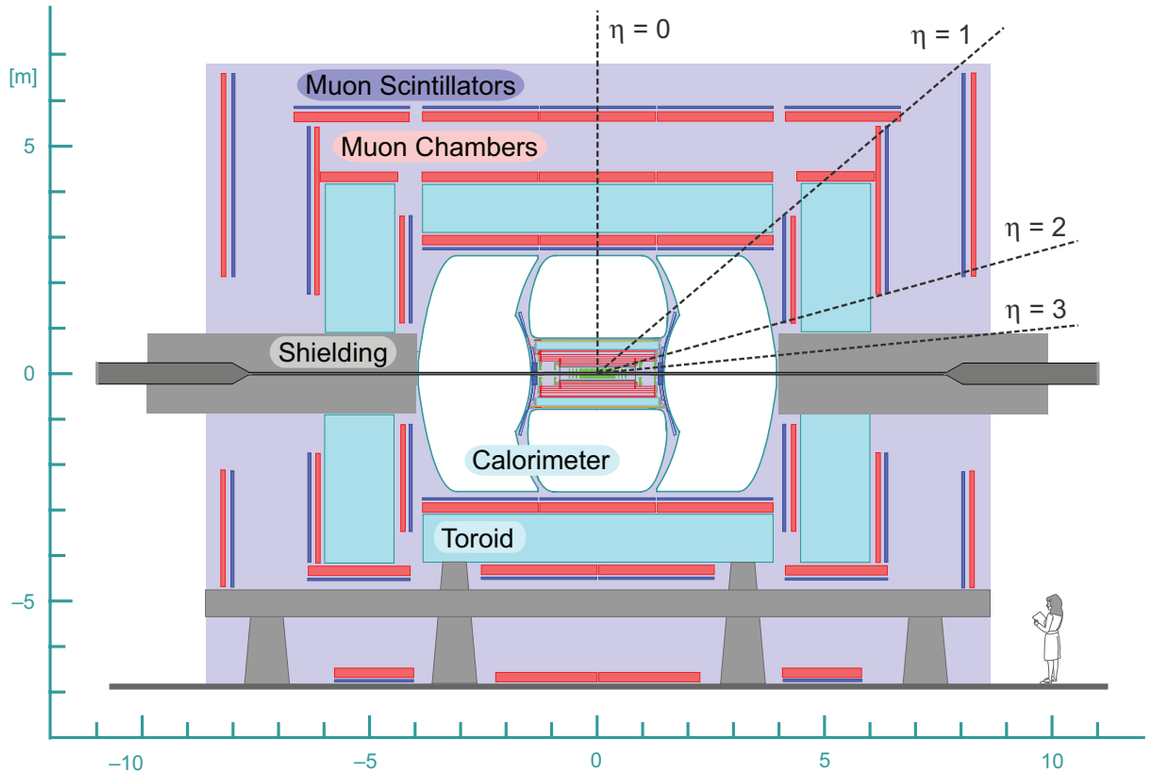
The CDF and DØ detectors

CDF



- Silicon detector and drift chamber
- Pb/Fe-scintillator calorimeters
- Muon detectors
- Superior tracking resolution

DØ



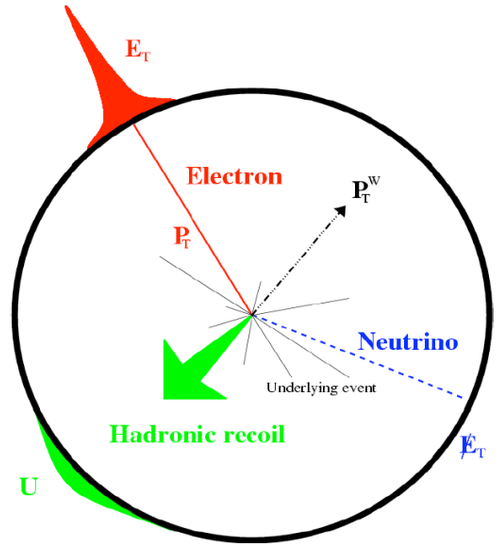
- Silicon and fiber tracker
- Liquid argon/uranium calorimeters
- Muon detetors
- Superior calorimeter resolution

W and Z events at the Tevatron

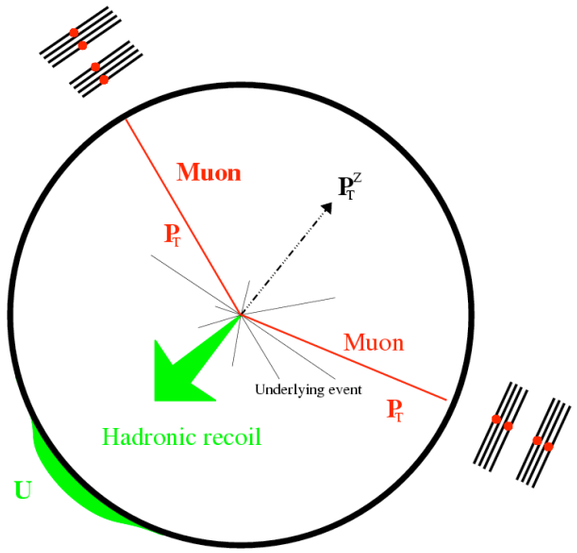
- $W \rightarrow l\nu$
  - 1 isolated high-p_T electron or muon, missing E_T corresponding to neutrino
  - Measure transverse mass

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

  - Non-zero boson p_T results in measurable hadronic recoil
    - Complicates reconstruction of final state

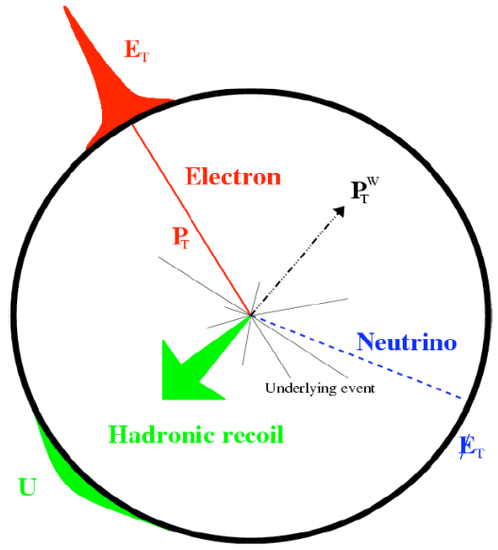


- $Z \rightarrow ll$
  - 2 isolated high-p_T leptons
  - All boson decay products well-measured
    - Perfect tool for calibration (recoil, momentum scales)



Making precision measurements

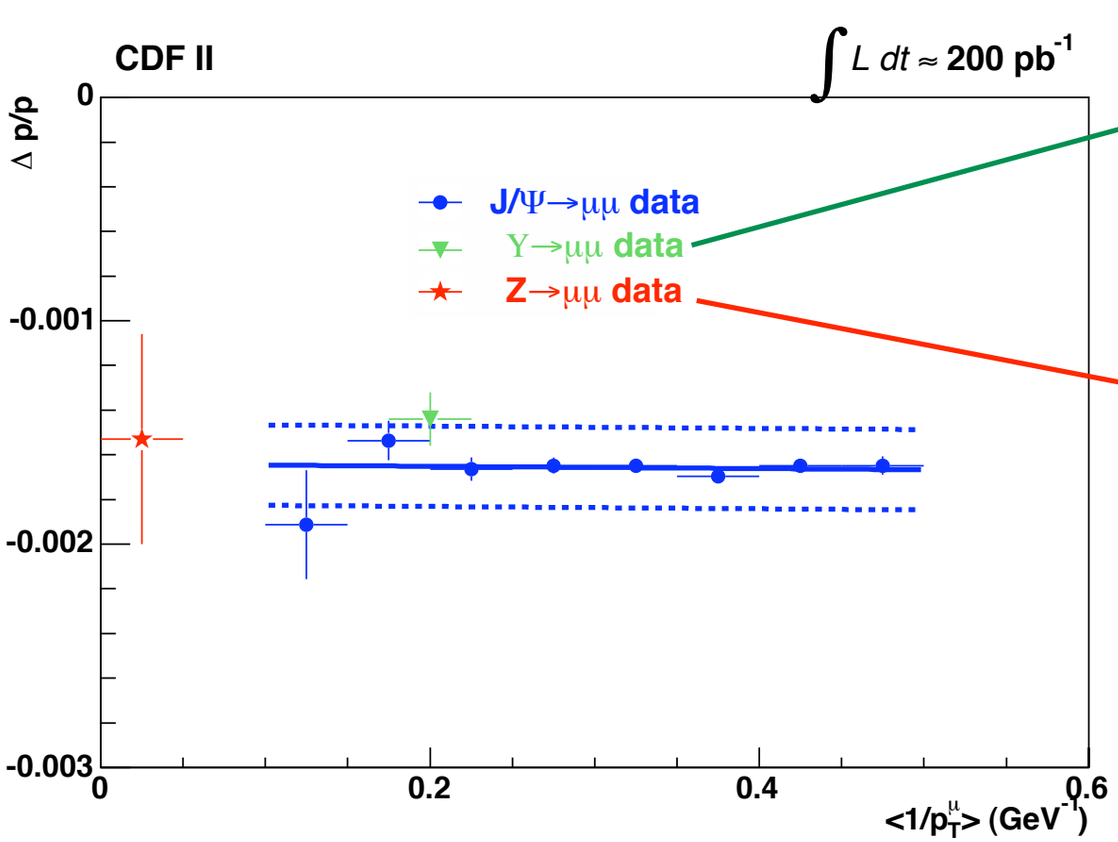
- Lepton p_T carries most information
  - Vital to measure lepton energies to <0.1%
- Hadronic recoil affects inference of neutrino energy
  - Calibrate to ~1%
  - Can reduce impact by requiring $p_T(W) << m_W$
- Need:
  - Tunable **fast simulation**
    - Rely on parameterized descriptions of detectors
    - ~100 times faster than standard detector simulation
  - Large data samples of well-measured states
    - *Z* boson
    - Various dimuon resonances

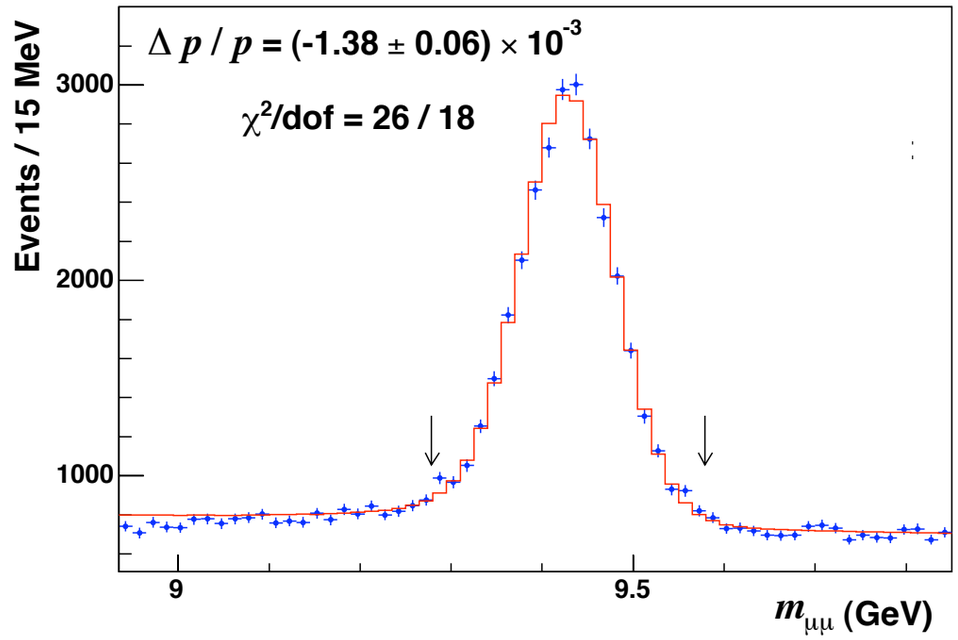


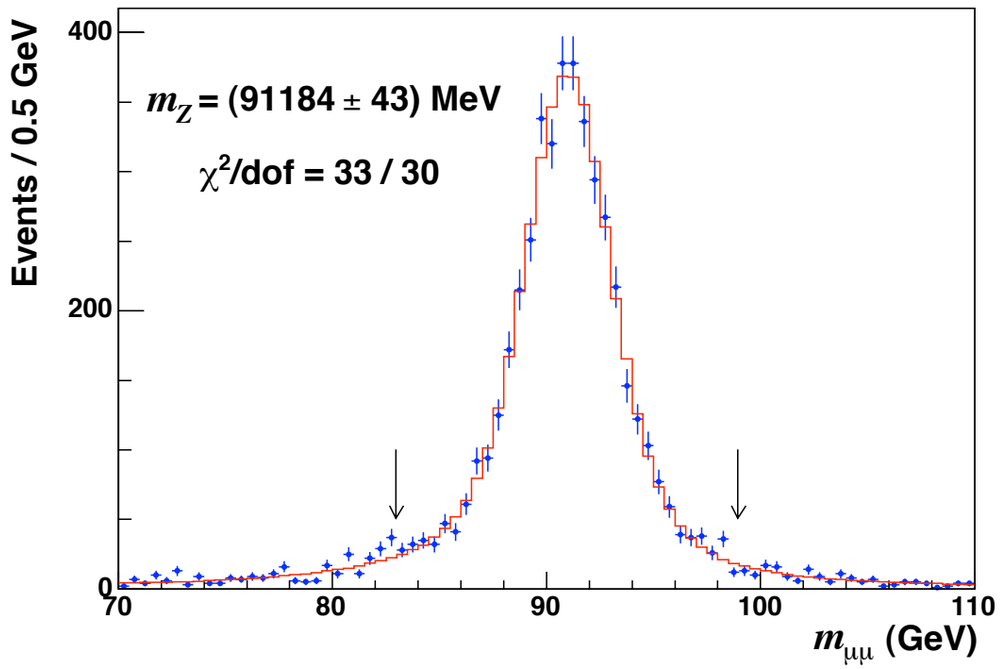
Momentum scale calibration at CDF

- 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

$\Delta m_W = 17$ MeV/c^2





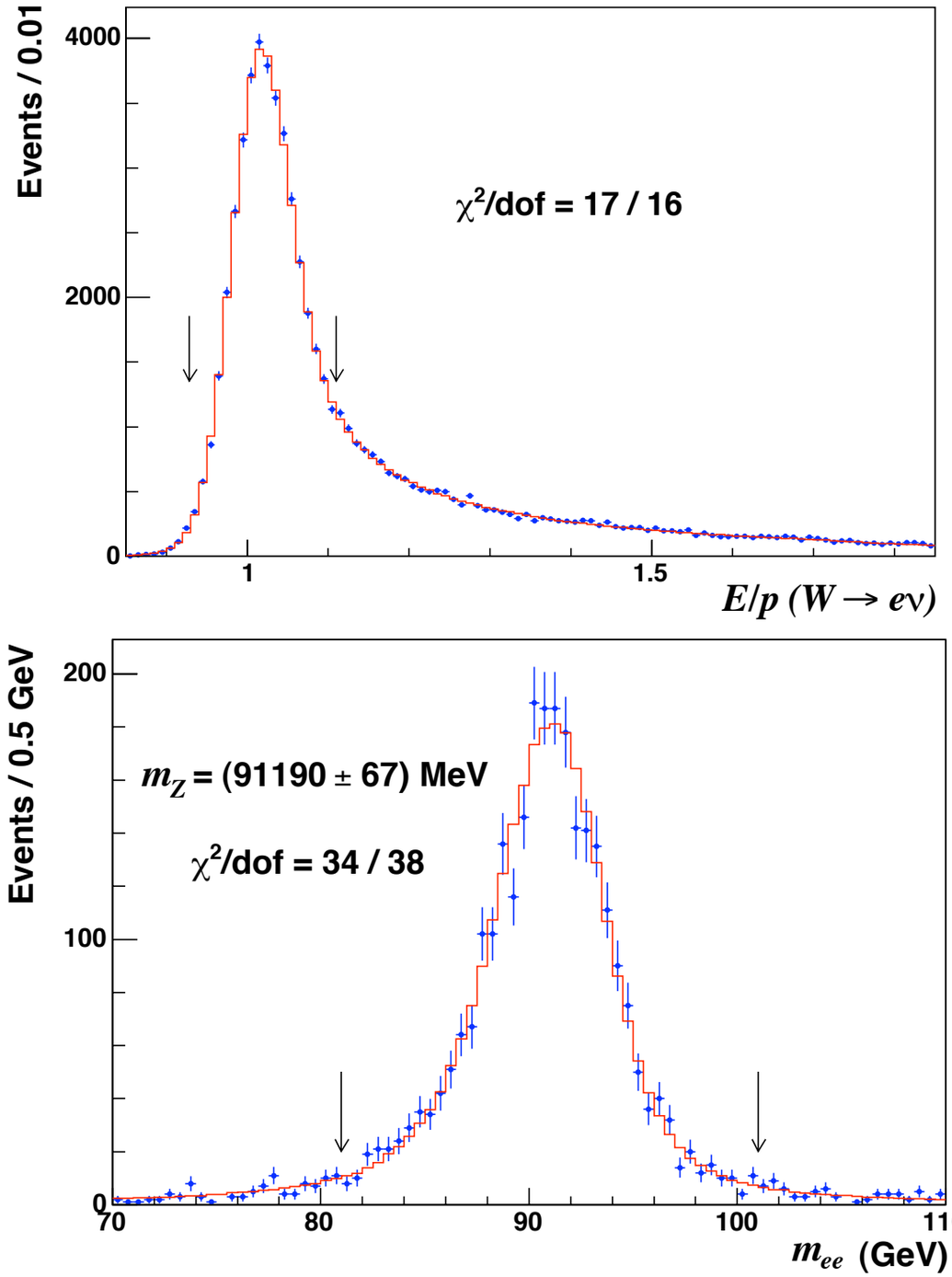


Energy scale determination at CDF

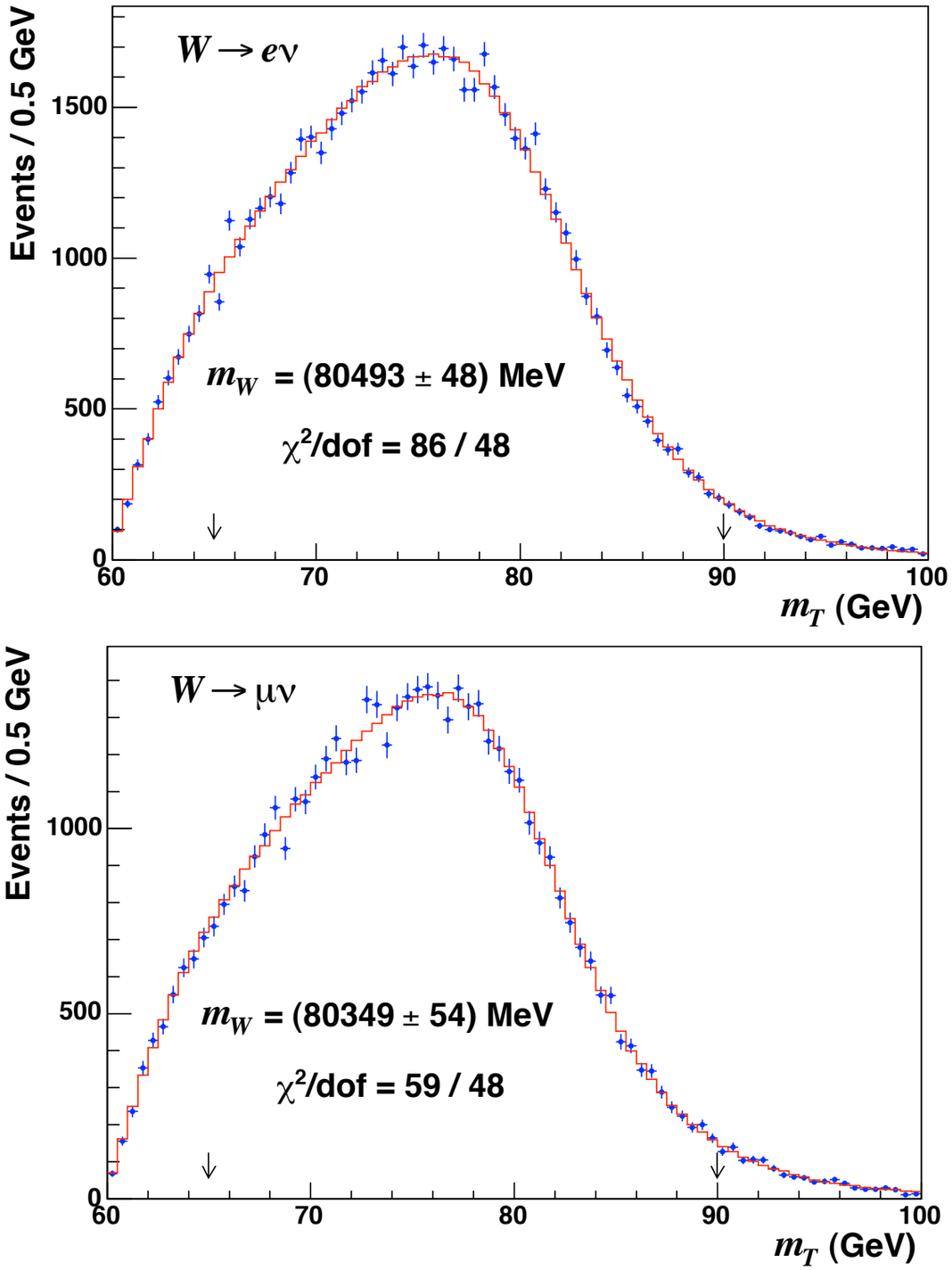
- Calorimeter energy calibrated using peak of electron *E/p* distribution from *W*s
  - Apply calibrated track momentum scale
- Energy loss tuned with high *E/p* tail
- Correct for E_T dependence
- Measure *Z* mass in electrons using calibrated scale

$\Delta m_W = 30$ MeV/c^2

PDG:
m_Z=91188±2 MeV



CDF Measurement (200 pb^{-1})



Systematic Uncertainties (GeV/c^2)

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

Combining fits to m_T, p_T and missing E_T in electrons and muons

m_W=80413±34(stat)±34(syst) MeV/c^2

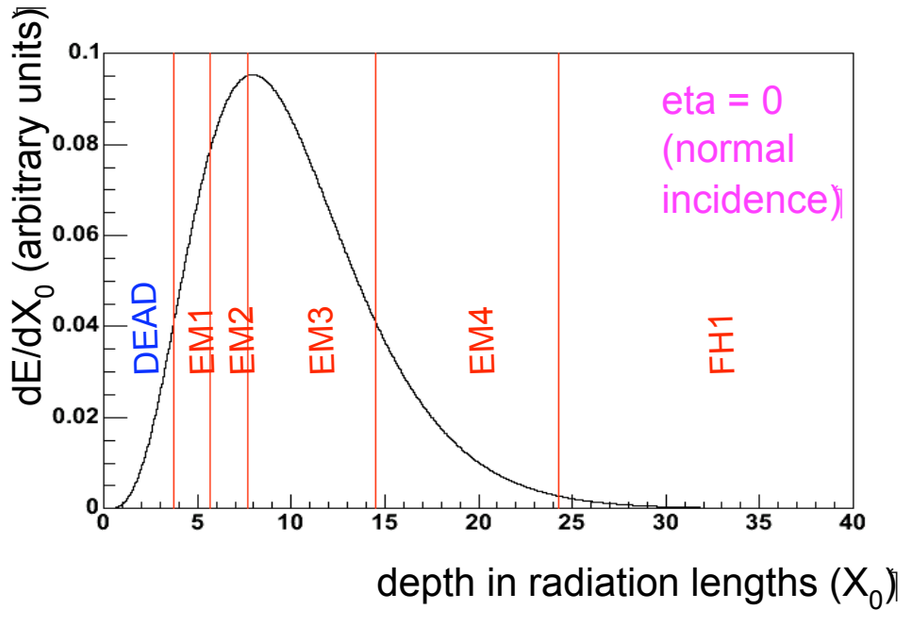
Published:

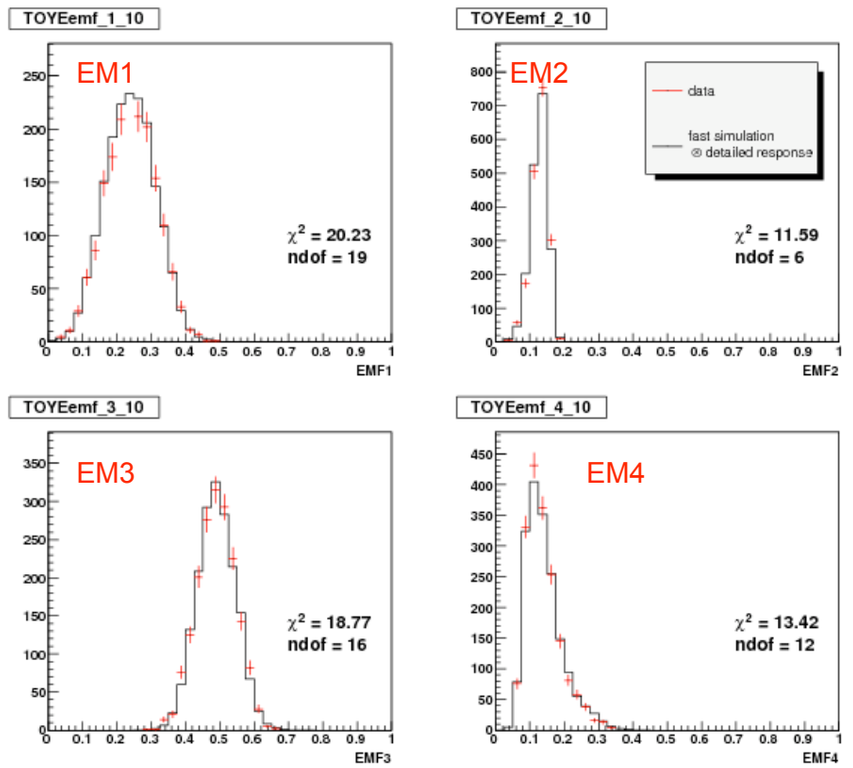
Phys. Rev. Lett. **99**, 151801 (2007)

Phys. Rev. D. **77**, 112001 (2008)

Energy scale at DØ

- Determine amount of dead material in calorimeter *in situ* using $Z \rightarrow ee$ decays
  - Exploit longitudinal segmentation of EM calorimeter
  - Fractional energy deposits in each readout section of EM calorimeter sensitive to amount of dead material
    - Compare fractional deposits in data and simulation
      - Adjust material in simulation to match data
- Amount of dead material in calorimeter determined to less than $0.01X_0$



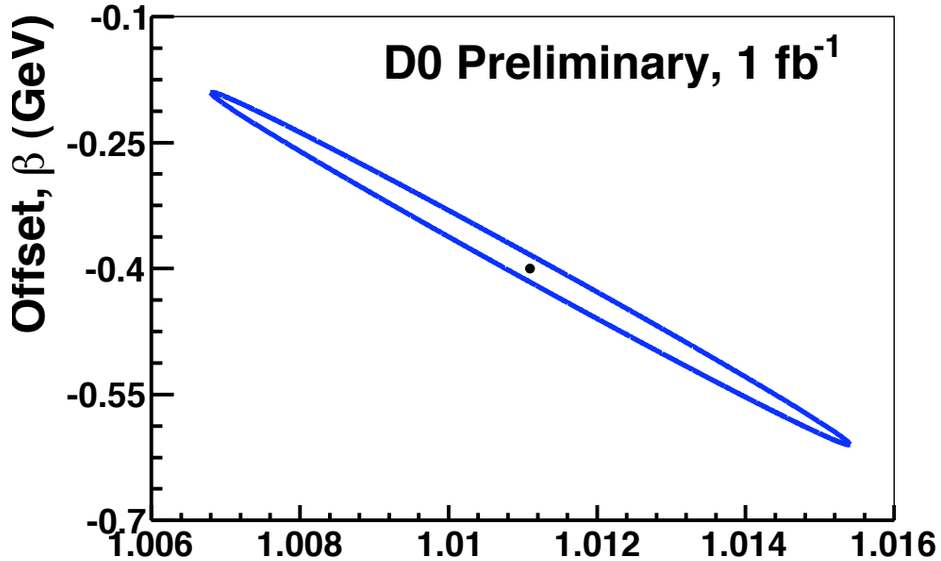


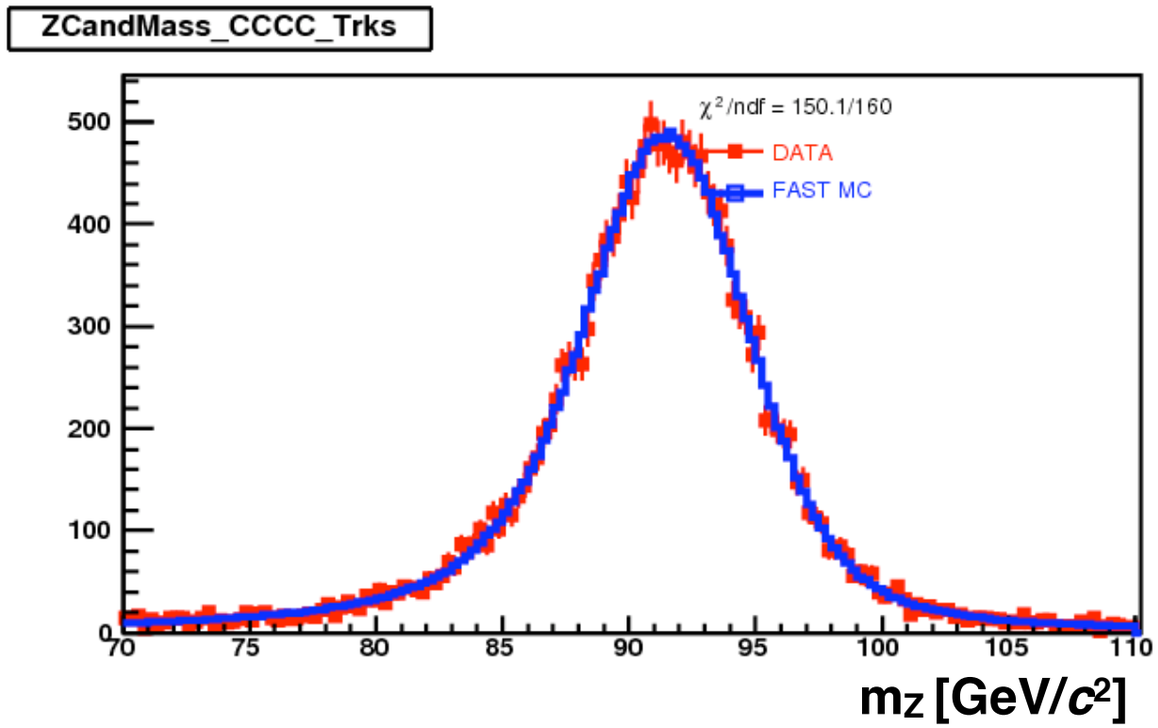
Energy scale and resolution at DØ

- Calibrate EM energy scale using $Z \rightarrow ee$ decays and LEP value for m_Z

$$R_{EM}(R_0) = \alpha \times E_0 + \beta$$

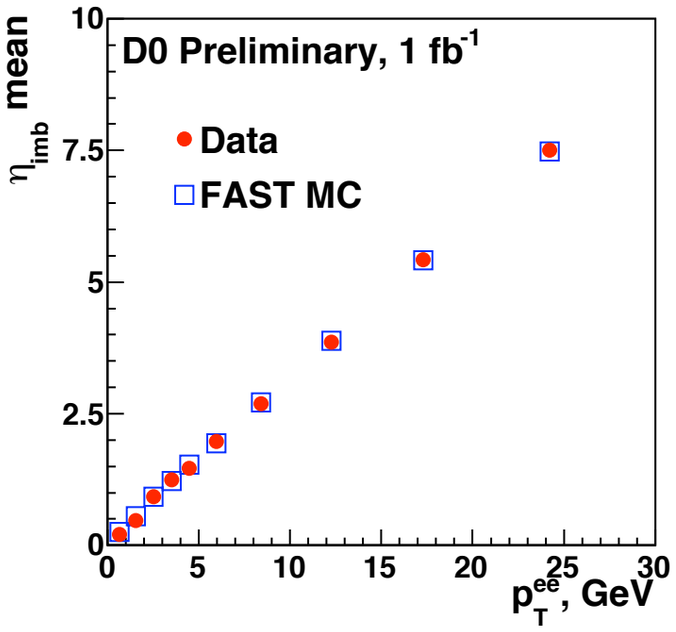
  - Δm_W=34 MeV
    - Dominant systematic, limited by Z statistics
- Parameterize energy resolution as constant term and sampling term
  - Sampling term driven by knowledge of amount of material in CAL
  - Constant term from Z peak
    - Obtain C=(2.05±0.1)%
  - Δm_W=2 MeV

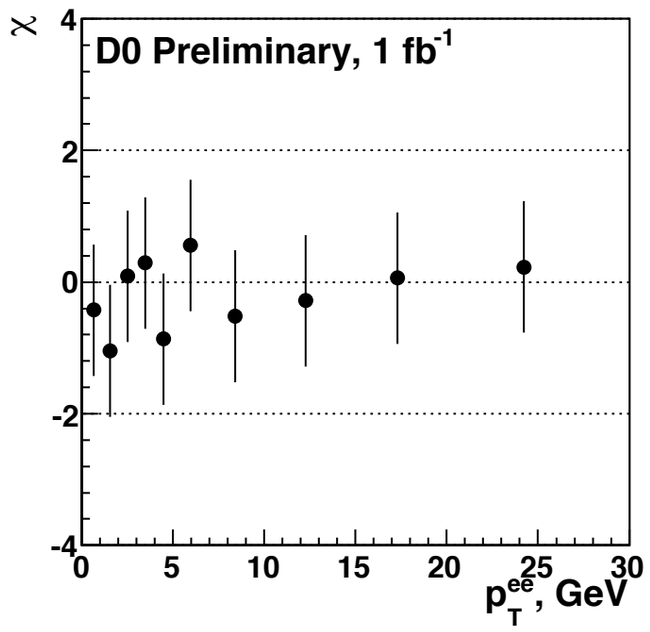


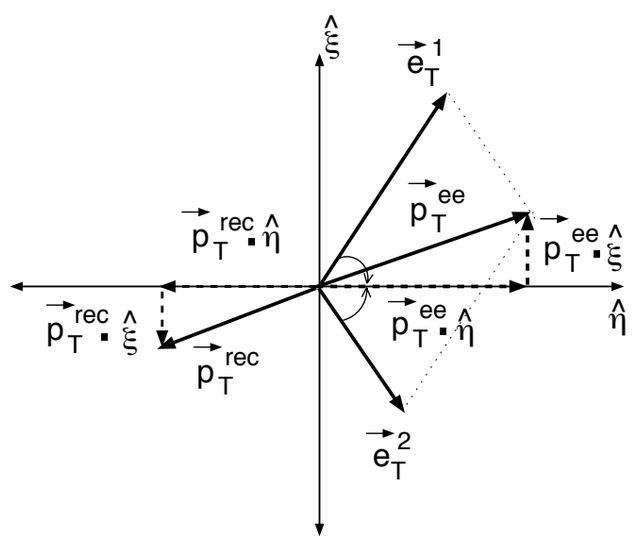


Recoil calibration at DØ

- Adjust parameters in recoil model using $Z \rightarrow ee$ events

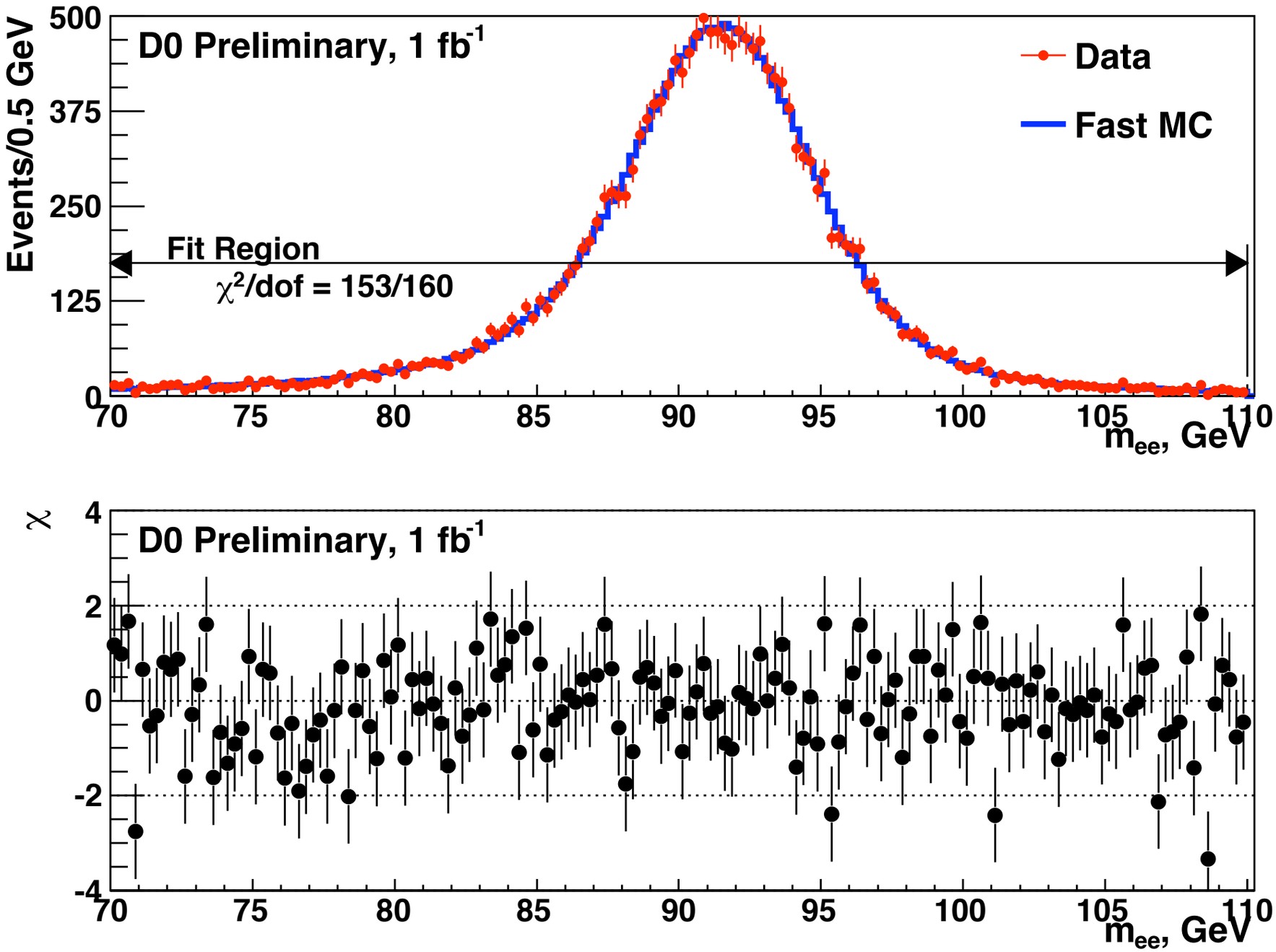






Three components of recoil
1. hard scattering against *W/Z*
2. soft from spectator partons
3. soft additional interactions

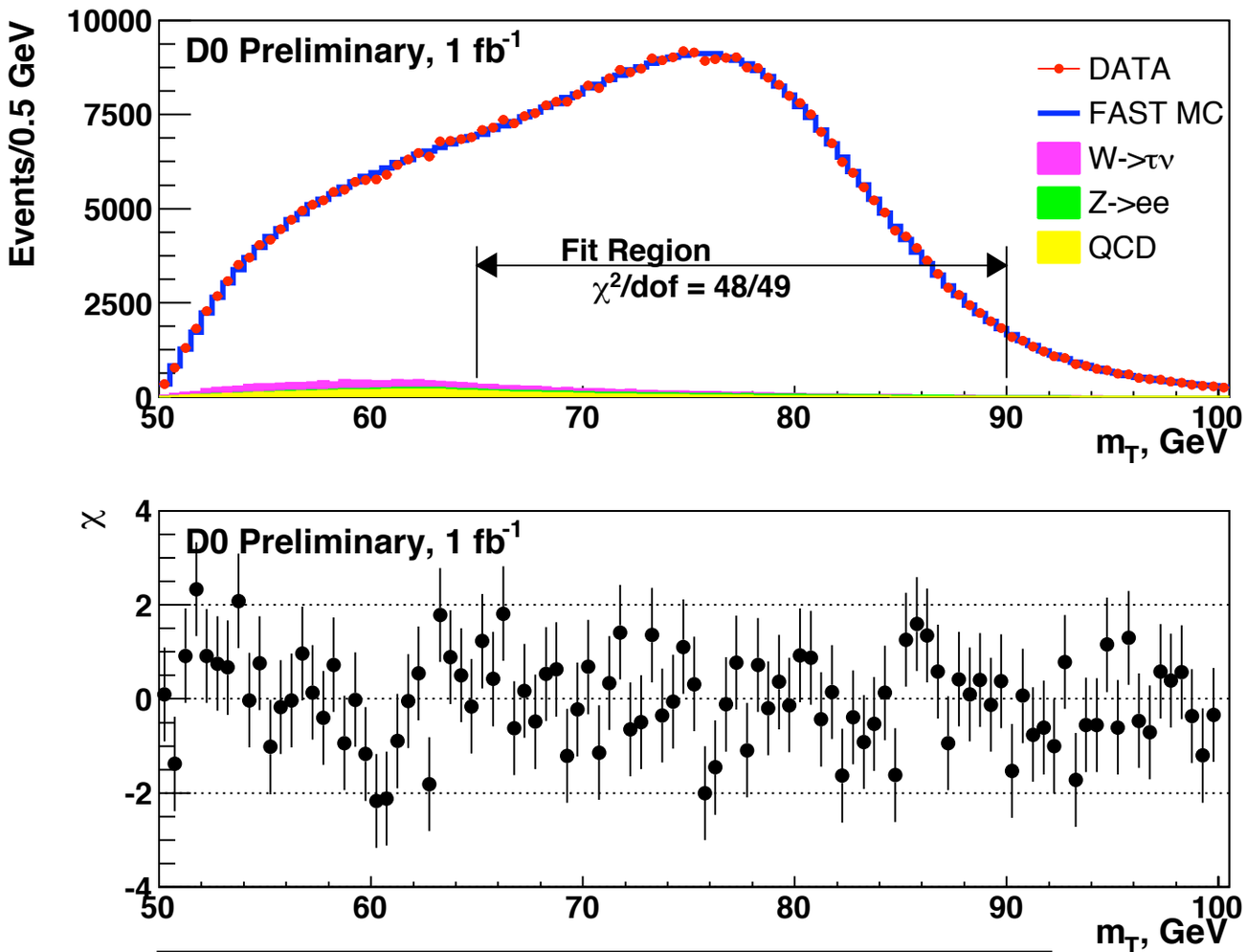
$Z \rightarrow ee$ fit



m_Z=91185±33 MeV/c^2

PDG:
m_Z=91188±2 MeV/c^2

DØ Measurement (1 fb^{-1})



m_T	80.401±0.044 GeV
p_T	80.400±0.048 GeV
$\not\!\!E_T$	80.402±0.050 GeV

Source	$\sigma(m_W)$ MeV m_T
Experimental	
Electron Energy Scale	34
Electron Energy Resolution Model	2
Electron Energy Nonlinearity	4
W and Z Electron energy loss differences	4
Recoil Model	6
Electron Efficiencies	5
Backgrounds	2
Experimental Total	35
W production and decay model	
PDF	9
QED	7
Boson p_T	2
W model Total	12
Total	37

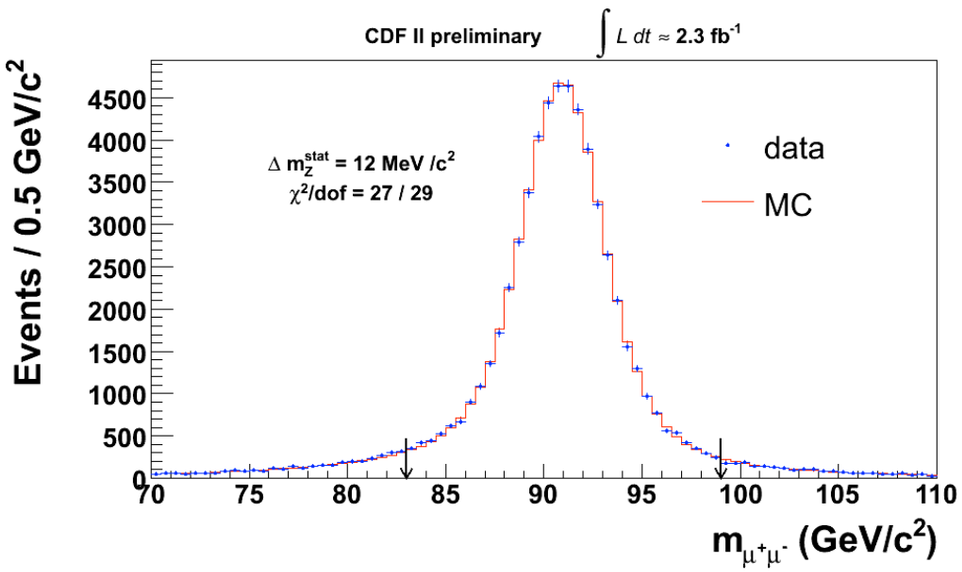
- m_T fit using electrons

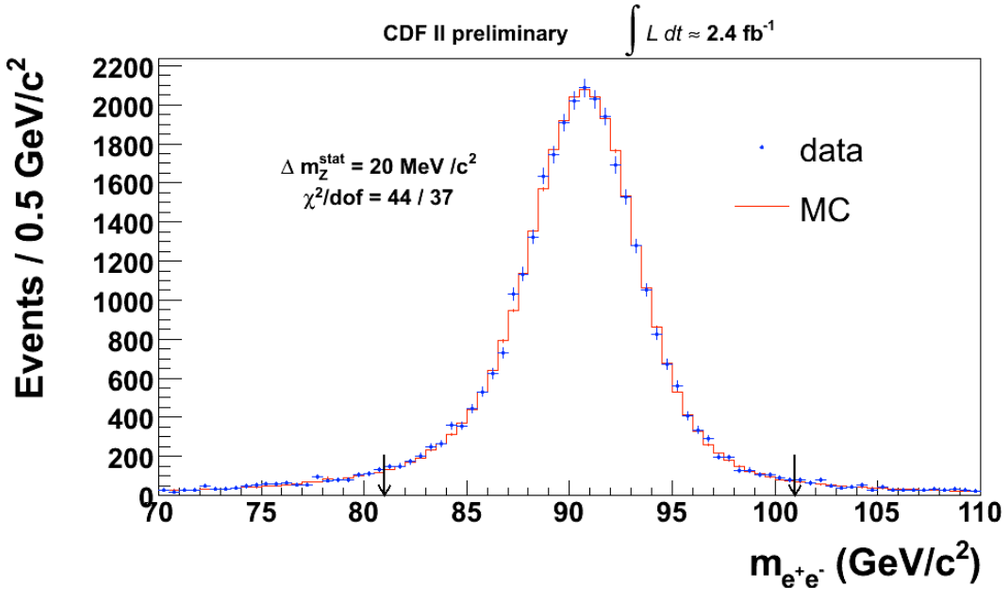
m_W=80401±23(stat)±37(syst) MeV/c^2

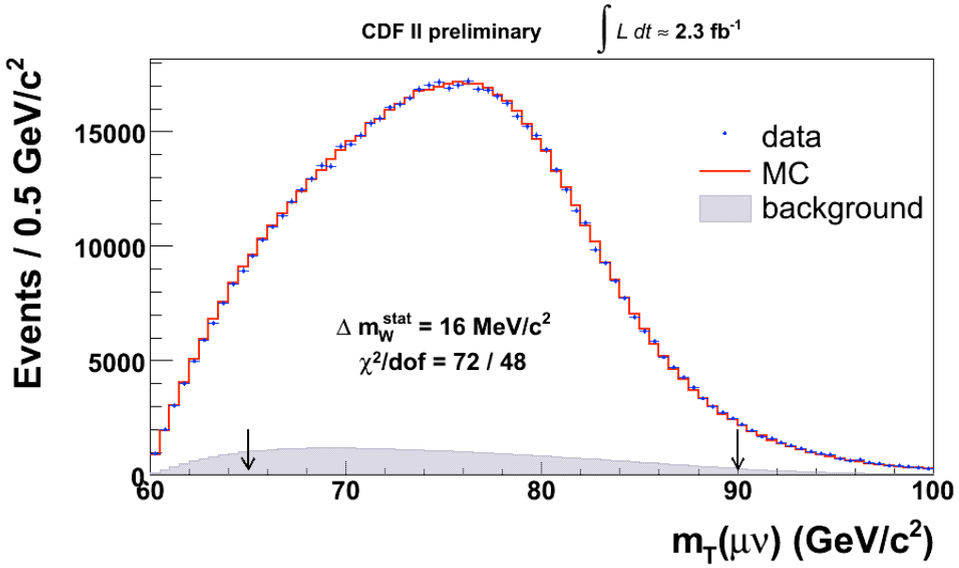
- **Single best** measurement of m_W
- Combination with p_T and missing E_T fits coming soon

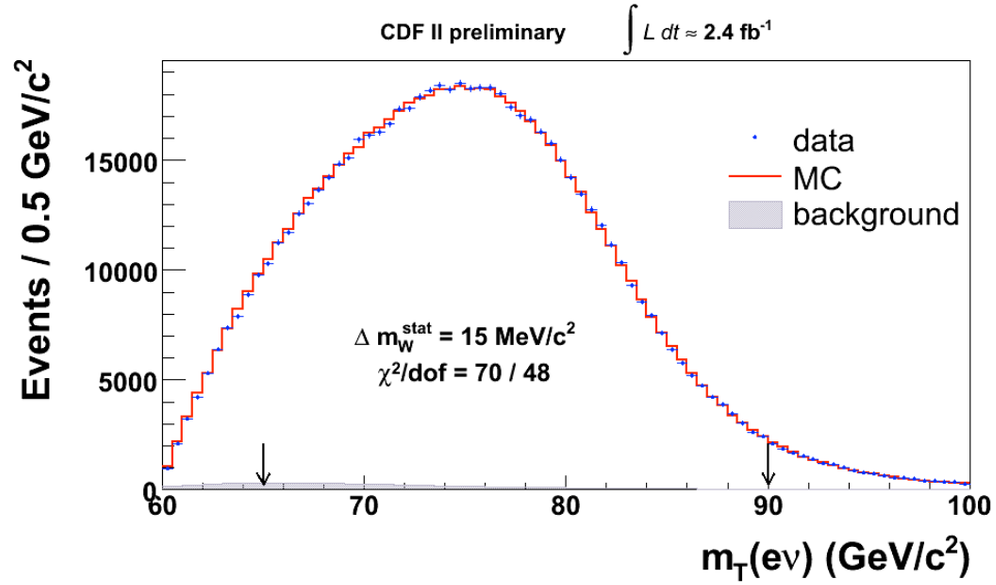
Future *W* mass measurements

- Both experiments working on measurements with larger datasets
  - CDF has analysis of 2.3 fb^{-1} underway
  - Expect total uncertainty of less than 25 MeV

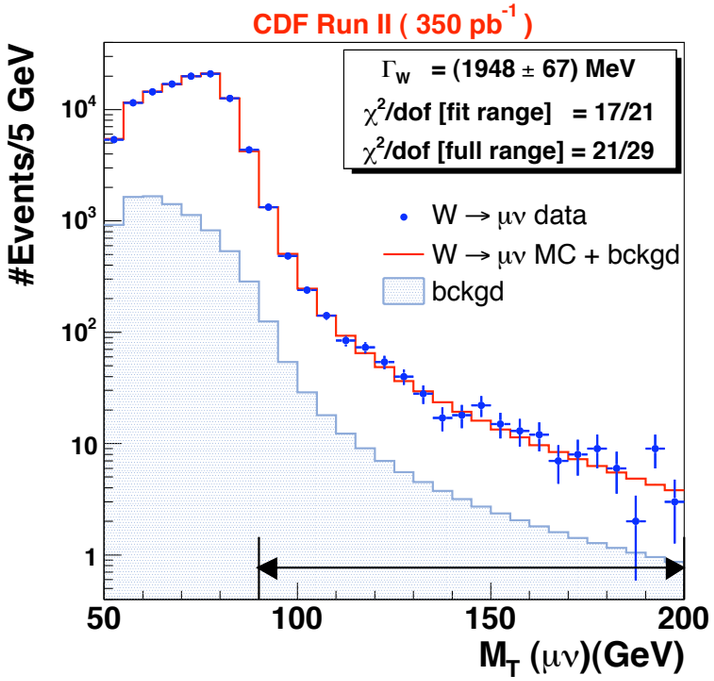


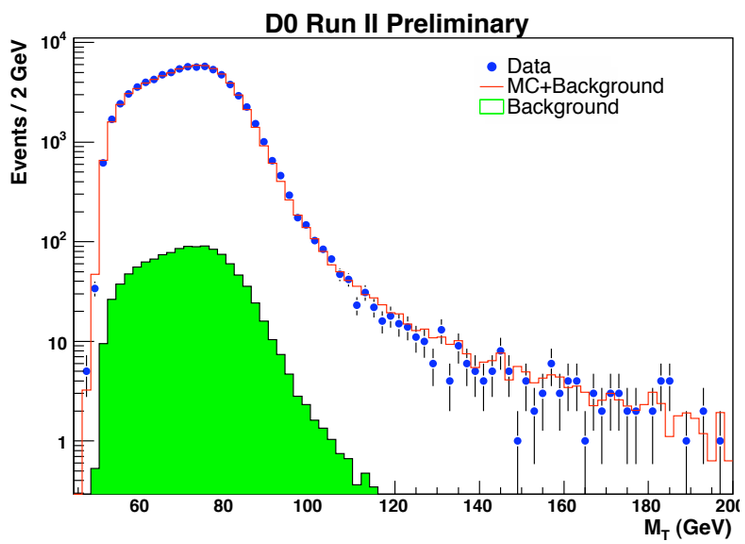


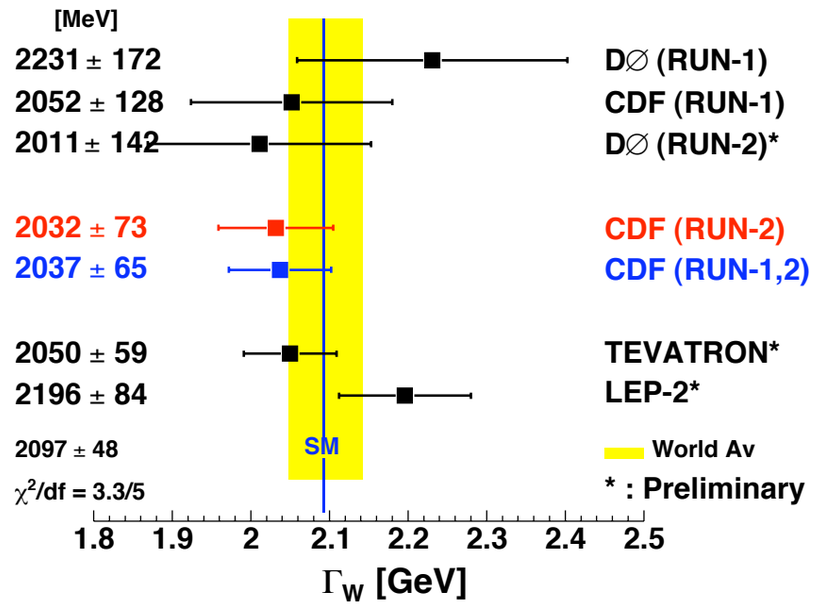




W width measurements







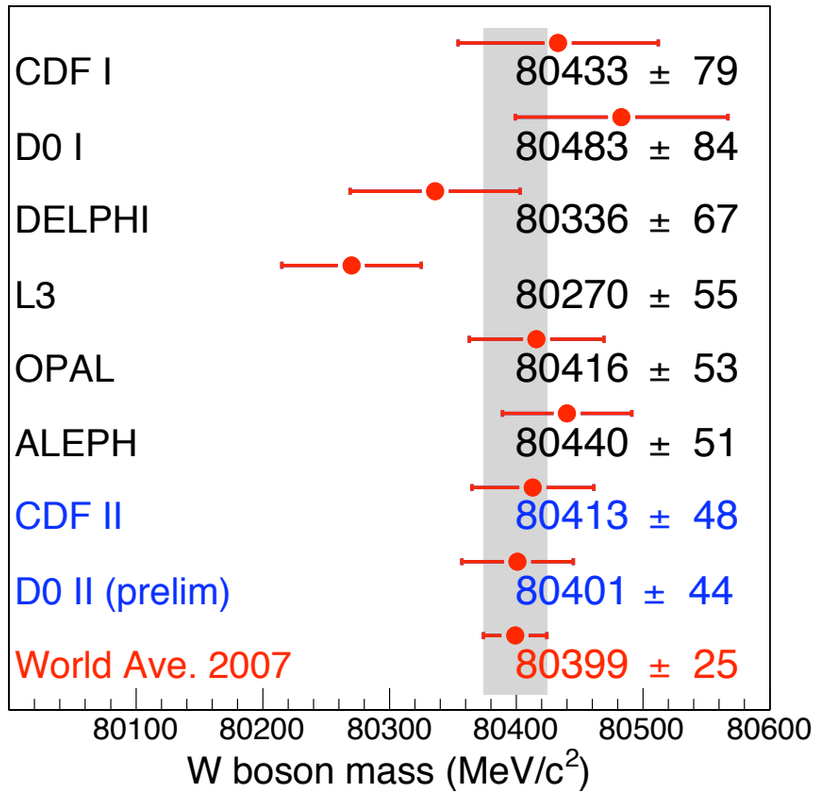
Γ_W=2032±73 MeV/c^2 Γ_W=2011±142 MeV/c^2

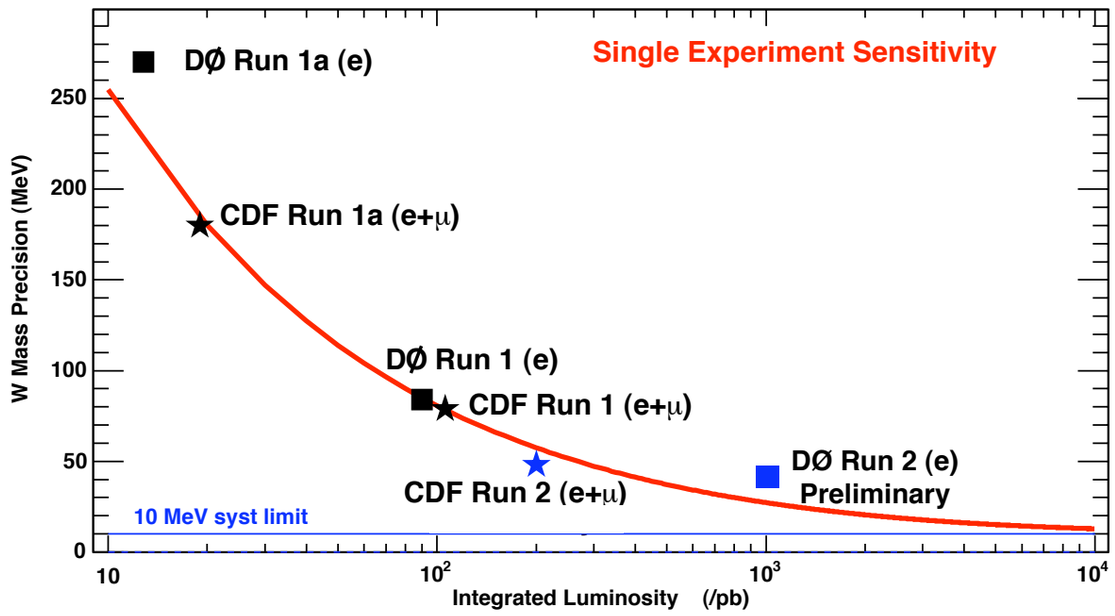
- Machinery and tools used for measuring *W* mass can also be used to measure *W* width
  - Tevatron results more precise than LEP
  - CDF result published in Phys. Rev. Lett **100**, 071802 (2008)

Conclusions

- Tevatron experiments continue to lead in precision electroweak physics
  - Both CDF and D0 measure m_W to greater precision than any LEP experiment
  - D0 combination (imminent) of 3 fits will further improve new result
  - CDF analysis with 2.3 fb^{-1} with projected total uncertainty of 25 MeV/c^2
  - Most precise measurement of *W* width
- TEVEWWG combination soon
  - gFitter* gives us a preview
    - m_W=80.399±0.023 GeV/c^2
    - m_H<155 GeV/c^2 @95% CL

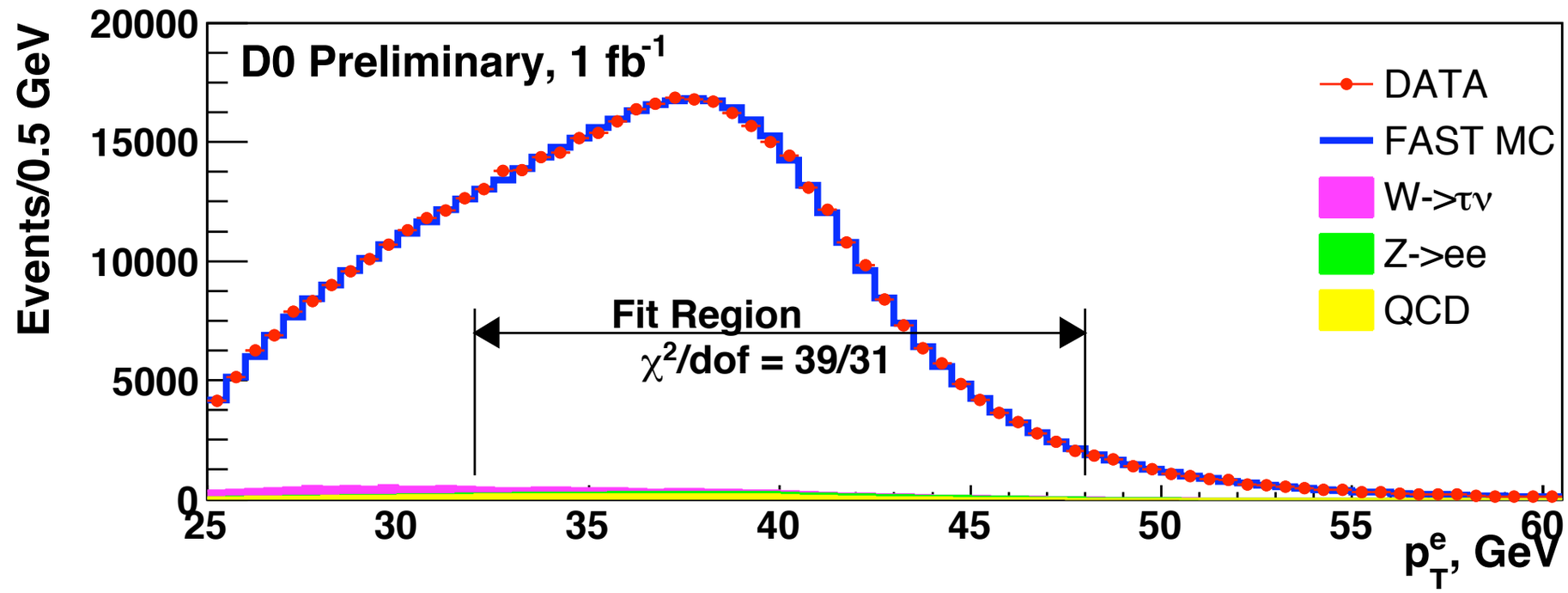
*http://gfitter.desy.de

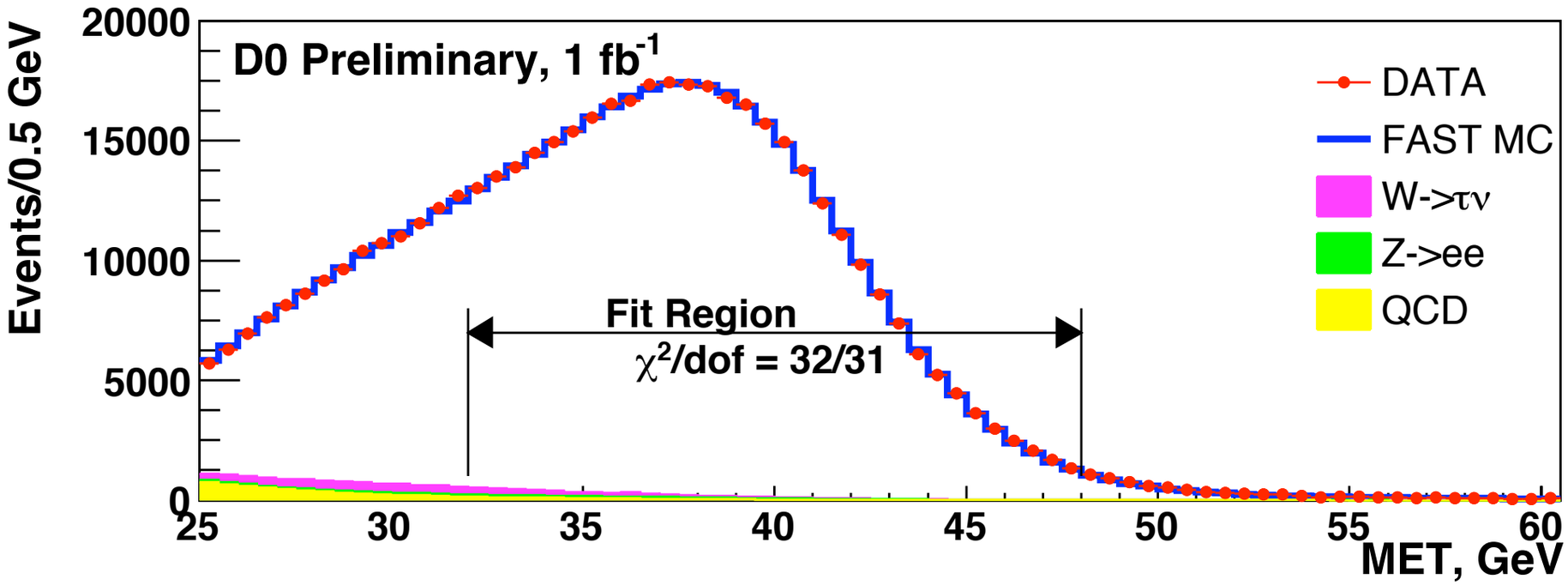




Backup

Lepton p_T and $\not\!\!E_T$ fits

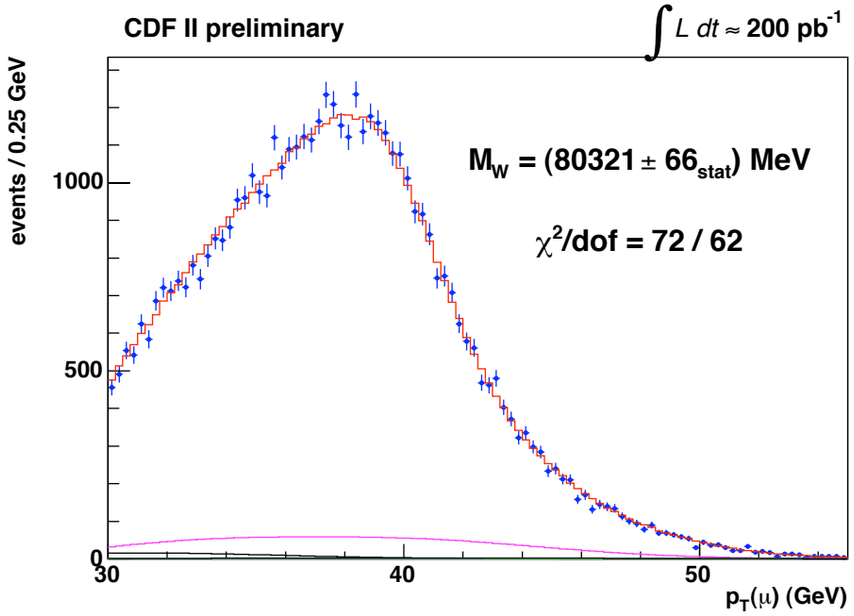


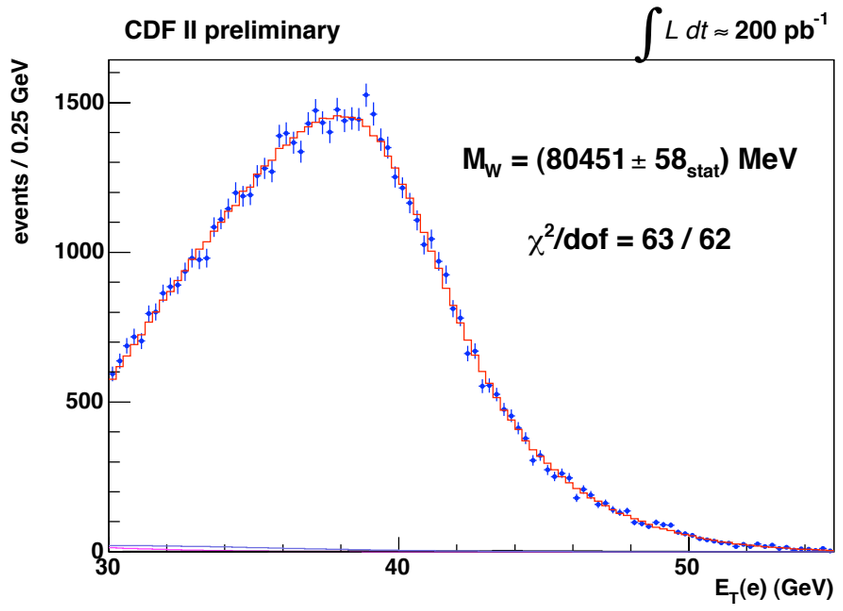


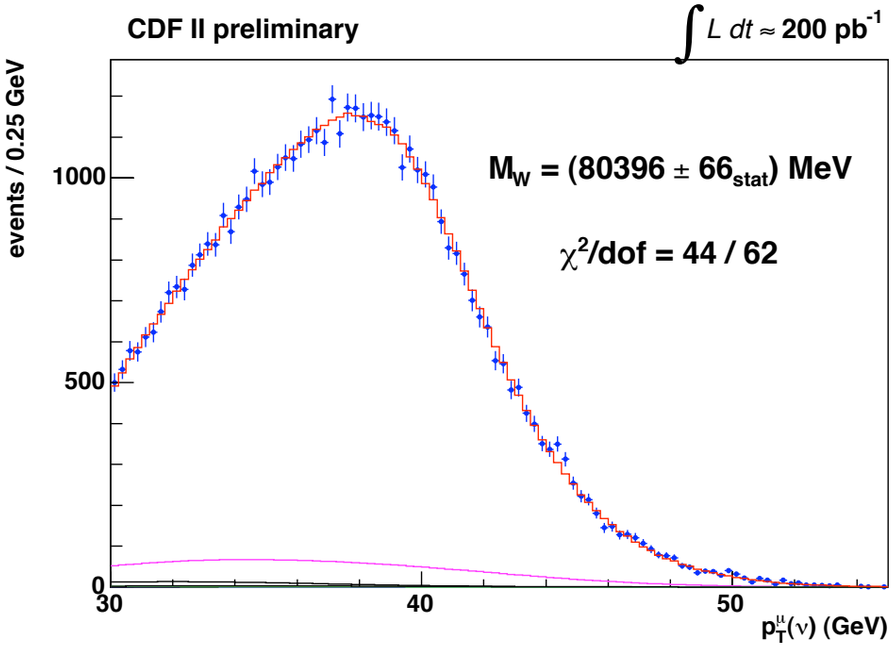
Systematic uncertainties

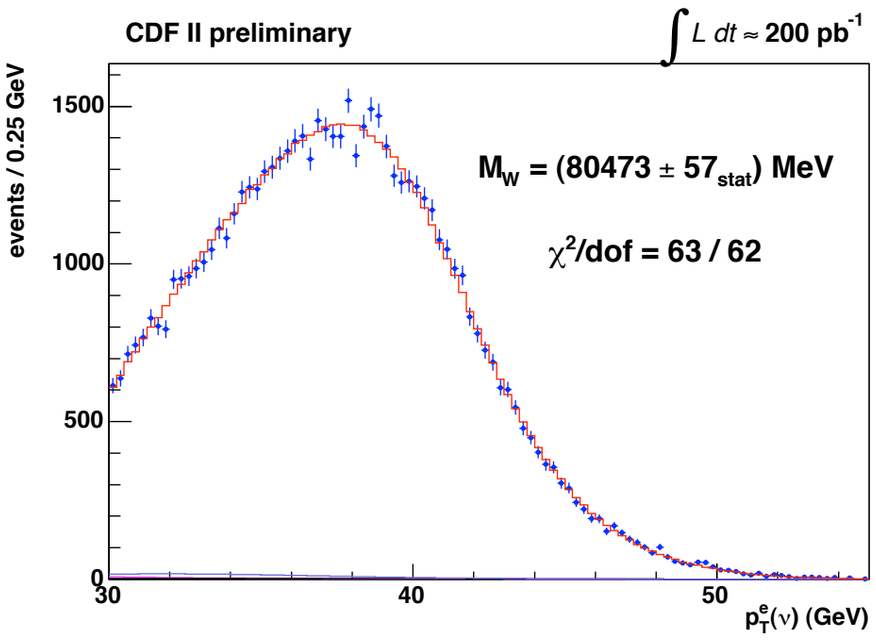
Source	$\sigma(m_W)$ MeV m_T	$\sigma(m_W)$ MeV p_T^e	$\sigma(m_W)$ MeV $\not\!\!E_T$
Experimental			
Electron Energy Scale	34	34	34
Electron Energy Resolution Model	2	2	3
Electron Energy Nonlinearity	4	6	7
W and Z Electron energy loss differences	4	4	4
Recoil Model	6	12	20
Electron Efficiencies	5	6	5
Backgrounds	2	5	4
Experimental Total	35	37	41
W production and decay model			
PDF	9	11	14
QED	7	7	9
Boson p_T	2	5	2
W model Total	12	14	17
Total	37	40	44

Lepton p_T and $\not\!\!E_T$ fits

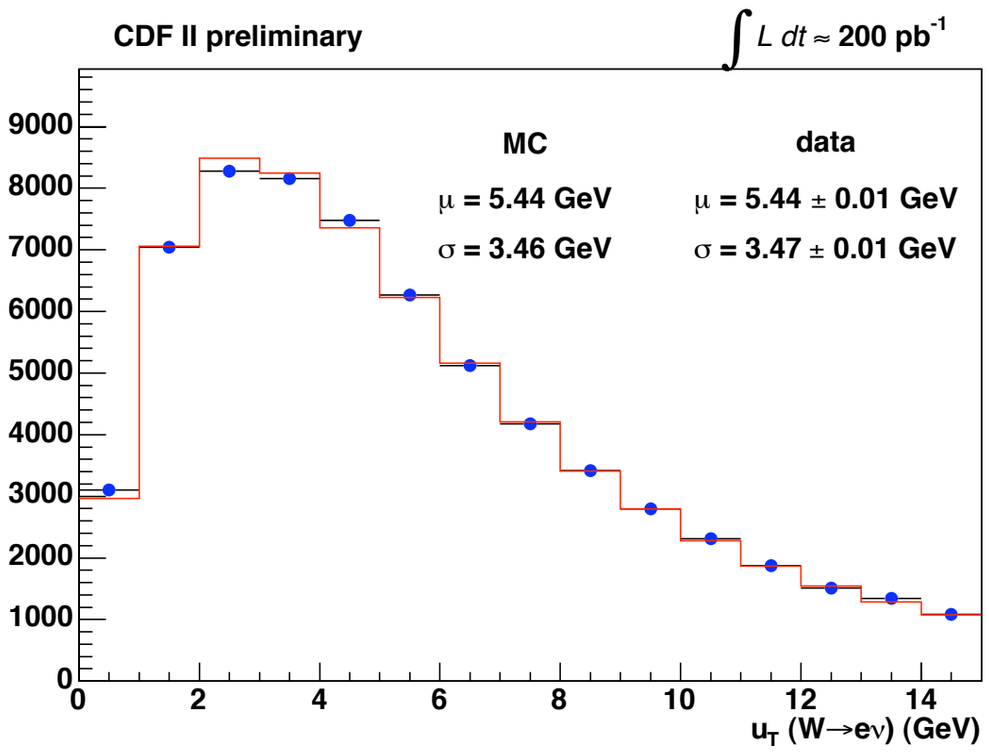




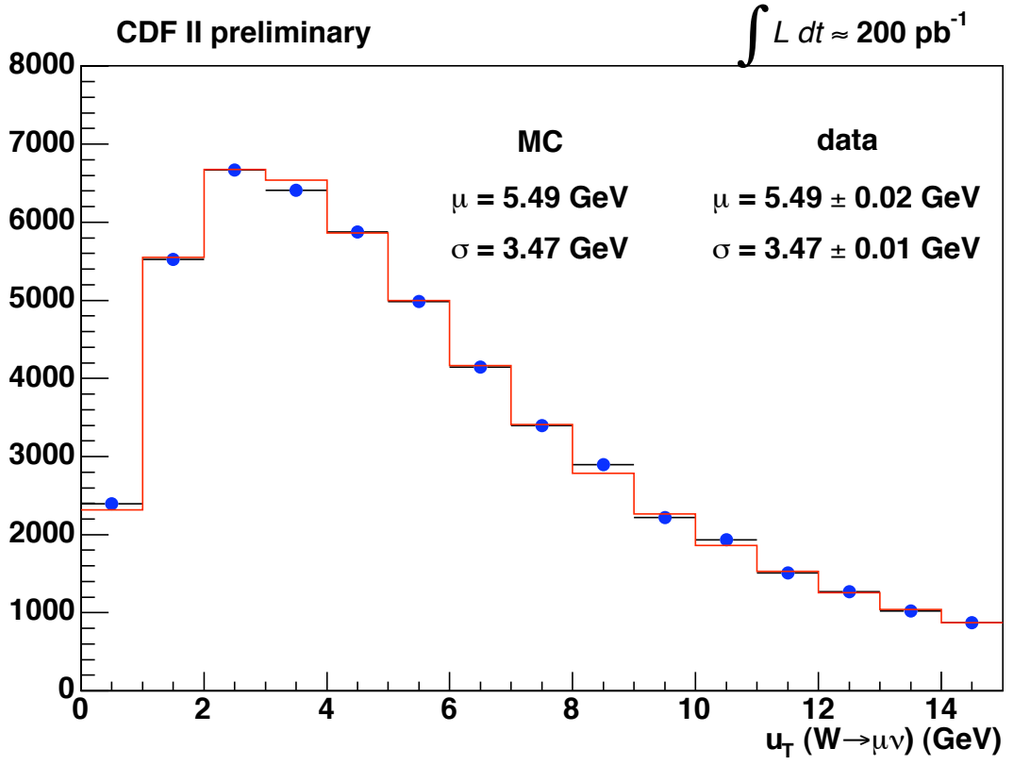




Recoil validation



Electrons



Muons

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