W Mass Measurement from CDF

Oliver Stelzer-Chilton (TRIUMF)

On behalf of the CDF Collaboration

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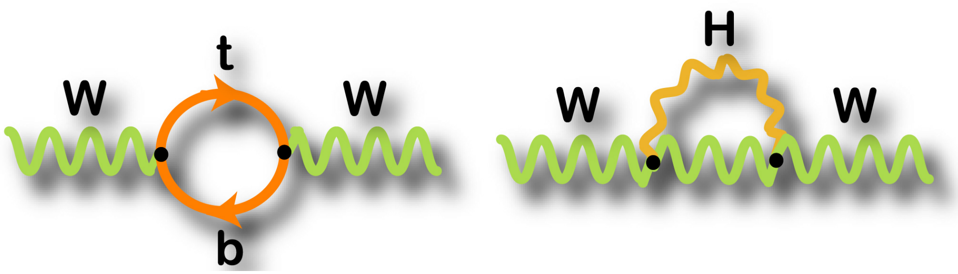
Electroweak Precision Constraints

- Derive W mass from precisely measured electroweak 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 Δr dominated by top quark and Higgs loop
  ⇒allows constraint on Higgs mass

Current top mass uncertainty 0.5% (0.9 GeV)
→ equivalent to 5 MeV on δM_W



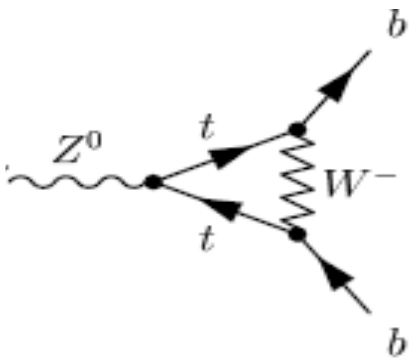
End 2011: W mass uncertainty 0.029% 23 MeV

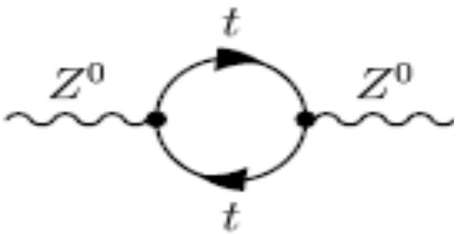
- Progress on W mass uncertainty now has the biggest impact on Higgs mass constraint

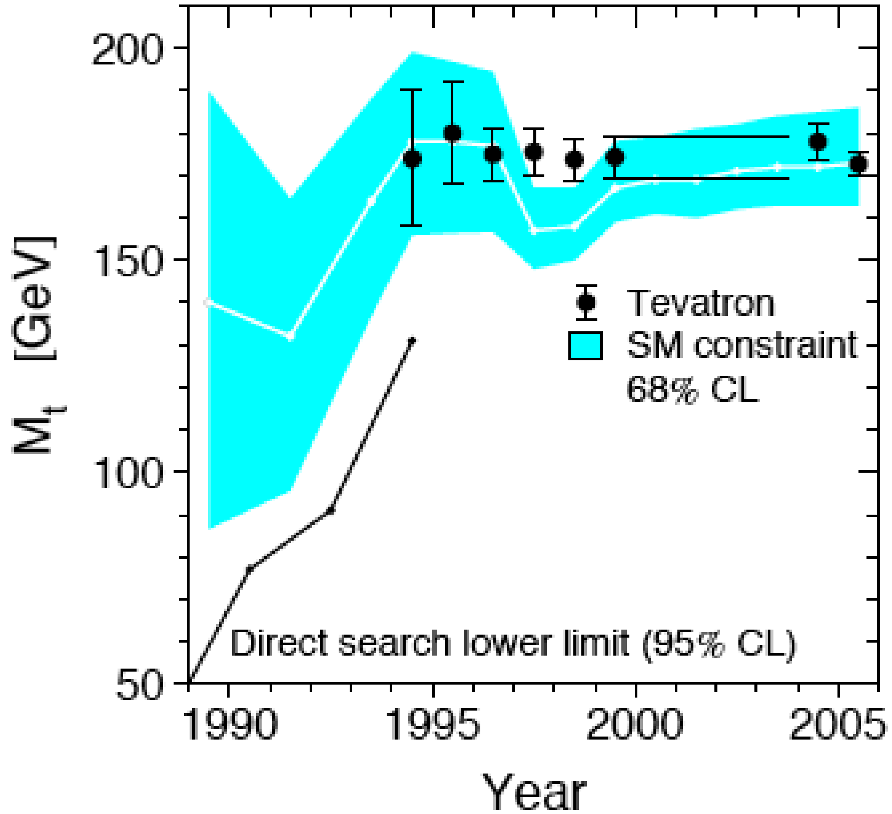
Motivation from the Past

From precision measurements from LEP and SLC on the Z boson pole

- top quark loops in Z^0



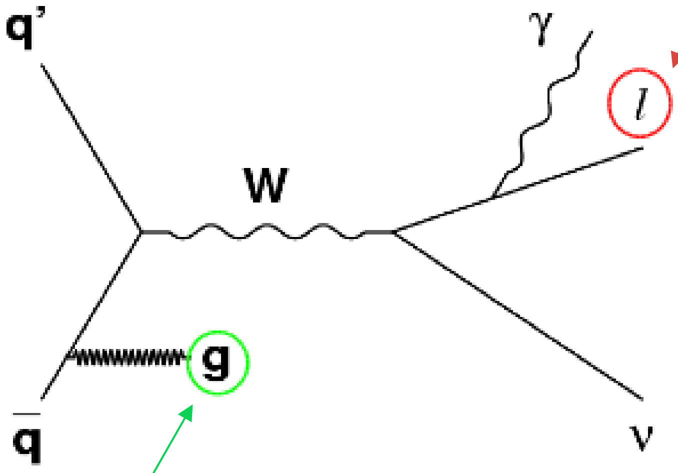


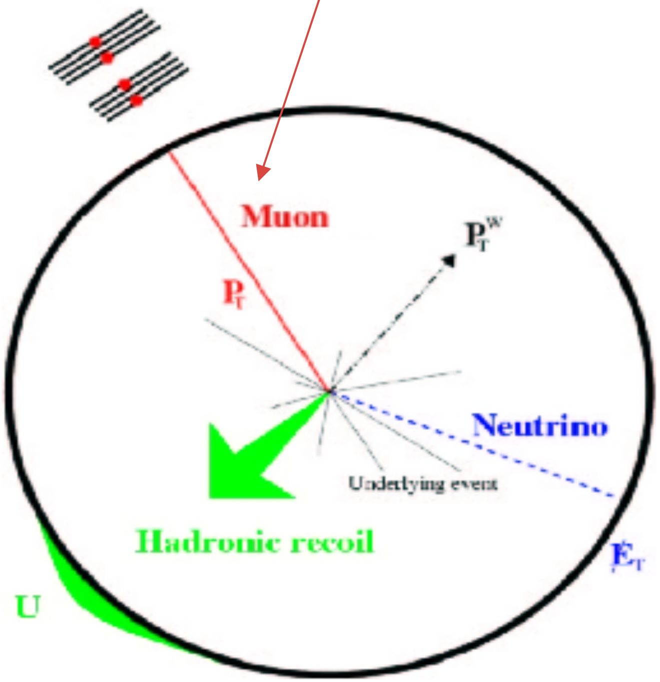


Precision measurements on Z pole constraint top quark mass before its discovery

Quark-antiquark annihilation dominates

precise charged lepton measurement is the key (achieved ~0.01%)





Recoil measurement allows inference of neutrino E_T (restricted to u<15 GeV)

Combine information into transverse mass:

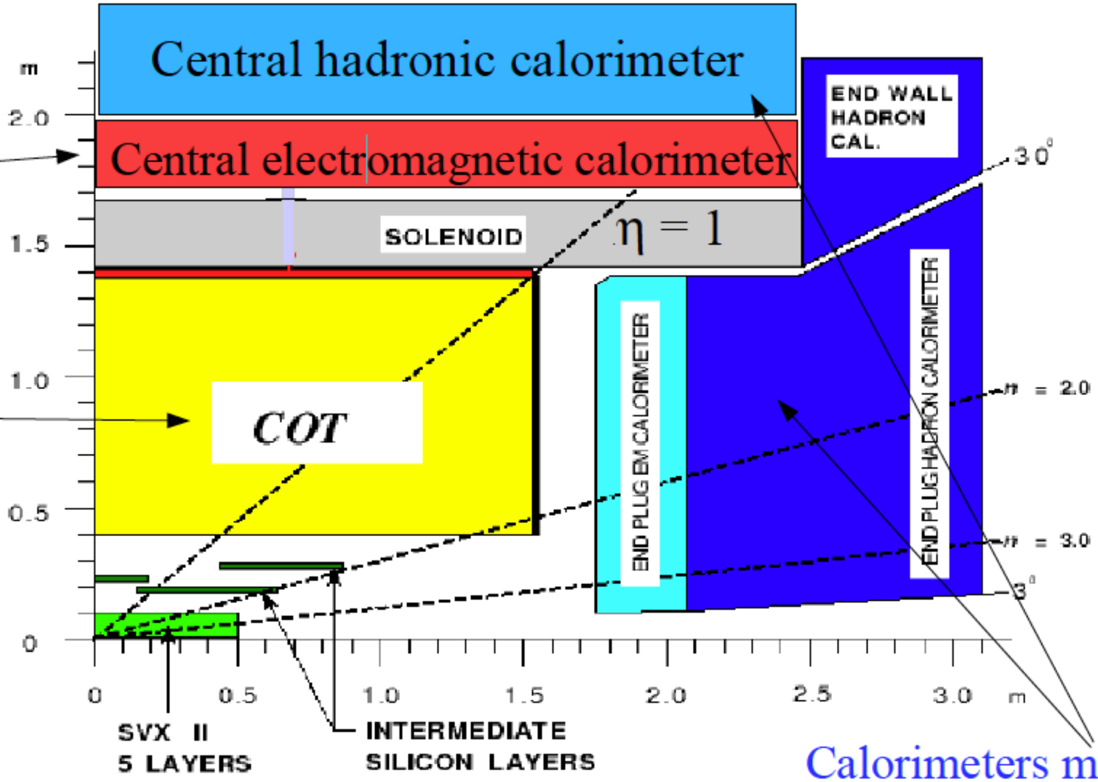
$$m_T = \sqrt{2 p_T^{\,l} p_T^{\,\nu} (1 - \cos\phi_{l\nu})}$$

Use $Z \rightarrow \mu\mu$ and $Z \rightarrow ee$ events to derive recoil model

Quadrant of CDF Detector

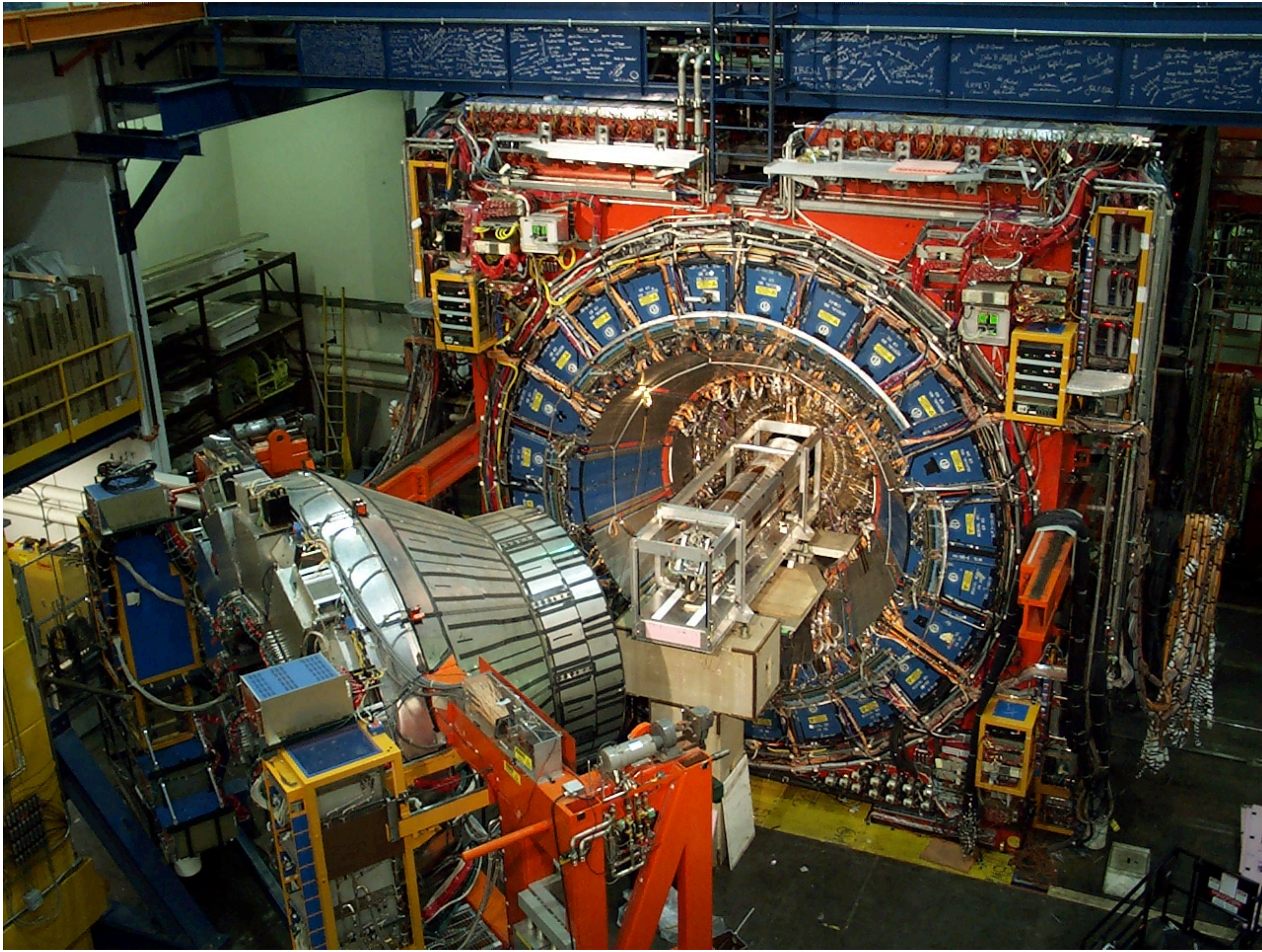
EM calorimeter provides precise electron energy measurement

COT provides precise lepton track momentum measurement



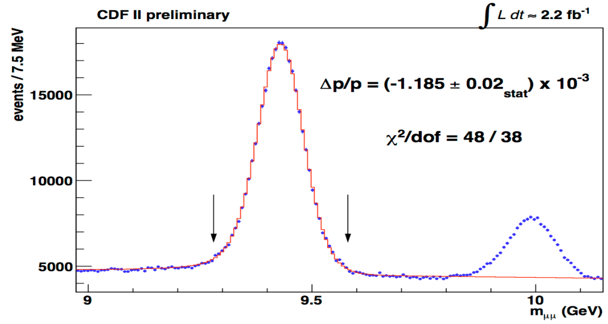
Calorimeters measure hadronic recoil particles

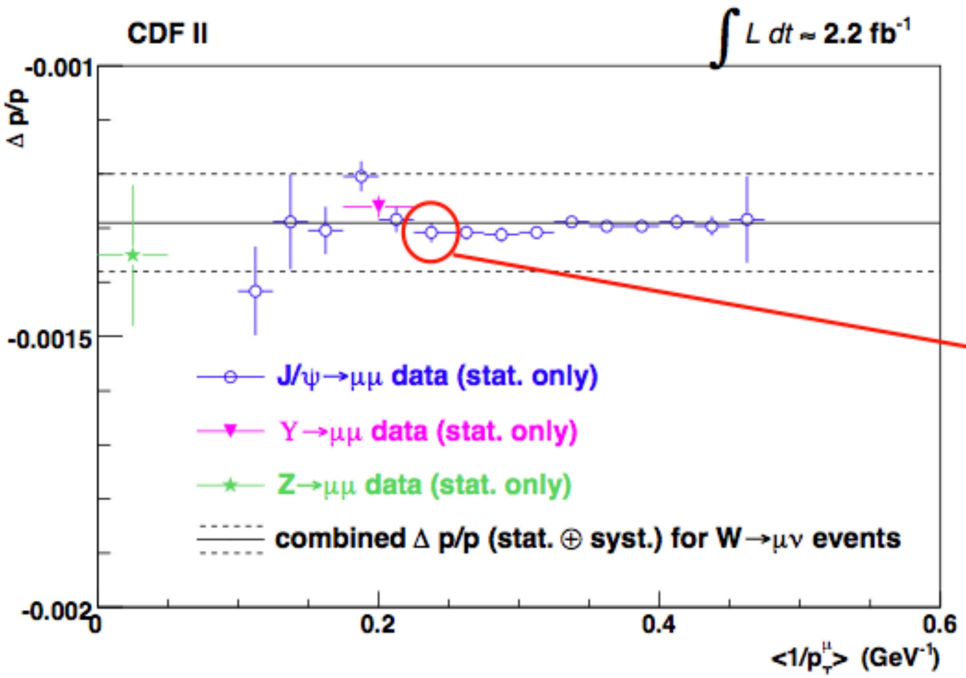
CDF Detector

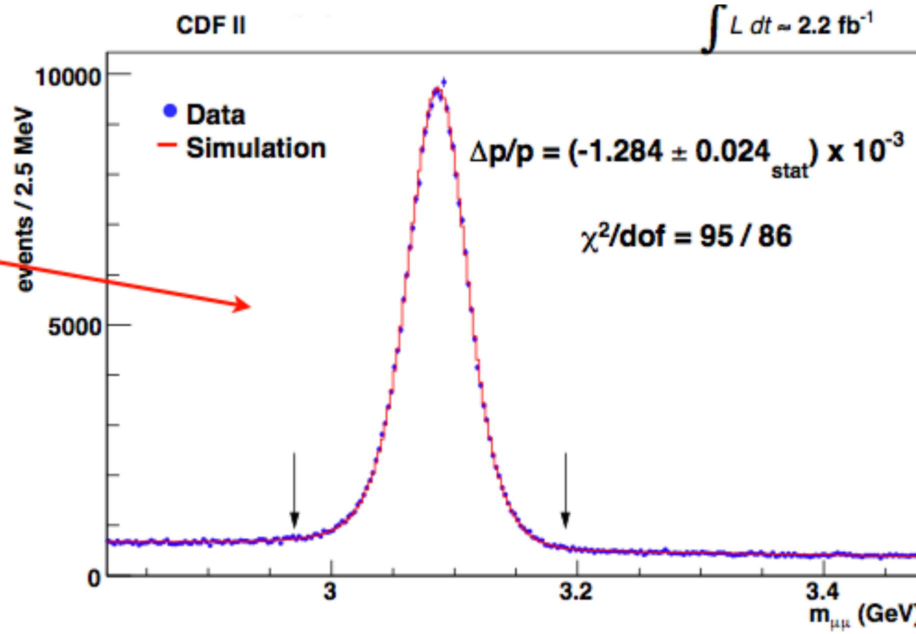


Momentum Scale Calibration

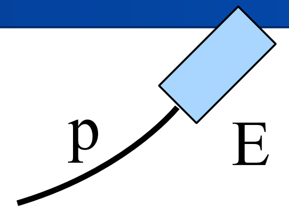
- "Back bone" of CDF analysis is track p_T measurement in drift chamber (COT)
- Perform alignment using cosmic ray data: ~50μm→~5μm residual
- Calibrate momentum scale using samples of dimuon resonances (J/ψ, Υ, Z)
  - Span a large range of p_T
  - Flatness is a test of dE/dx modeling
- Final scale error of 9×10^{-5}: Δm_W = 7 MeV



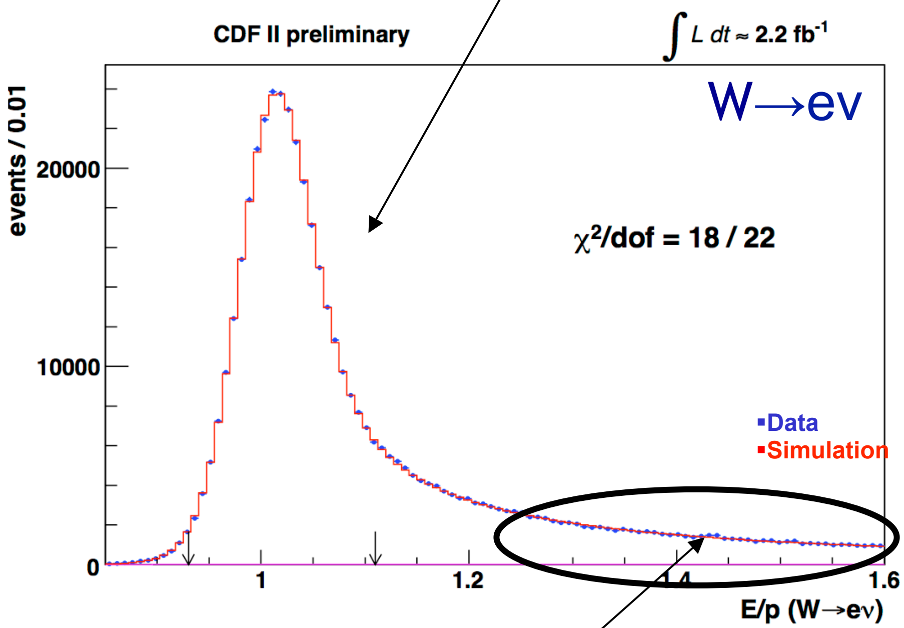


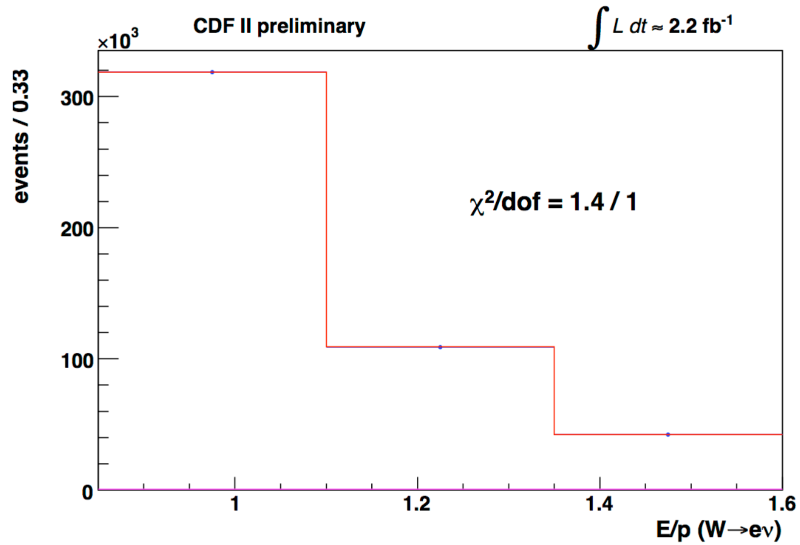


Energy Scale Calibration



Transfer momentum calibration to calorimeter using E/p distribution of electrons from W decay by fitting peak of E/p





Tune number of radiation lengths with E/p radiative tail

Correct for calibration E_T dependence

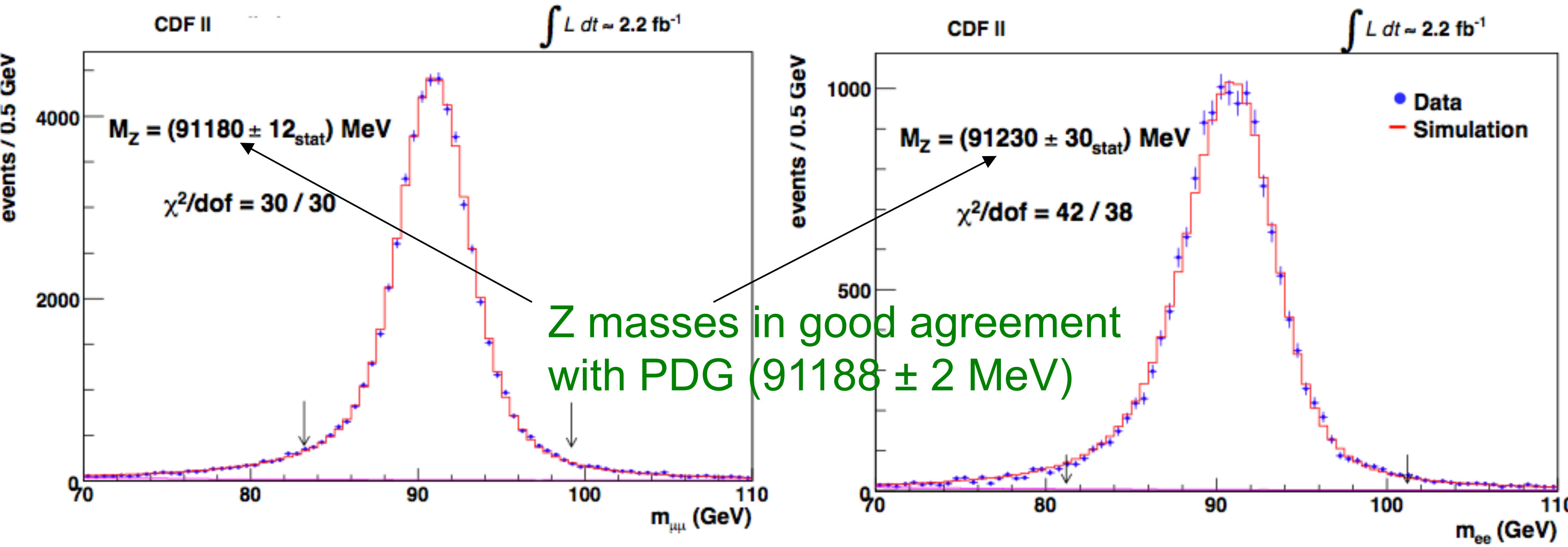
Tune resolution on E/p and Z mass peak

Excellent description of E/p tail

Constraints overall material

Z Boson Masses

- Perform blinded measurement of Z mass using derived scales from independent samples
- Comparison to LEP value of M_Z = 91188 ± 2 MeV is a powerful cross-check of the calibration
- After unblinding, M_Z added as further calibration to both p- and E-scales

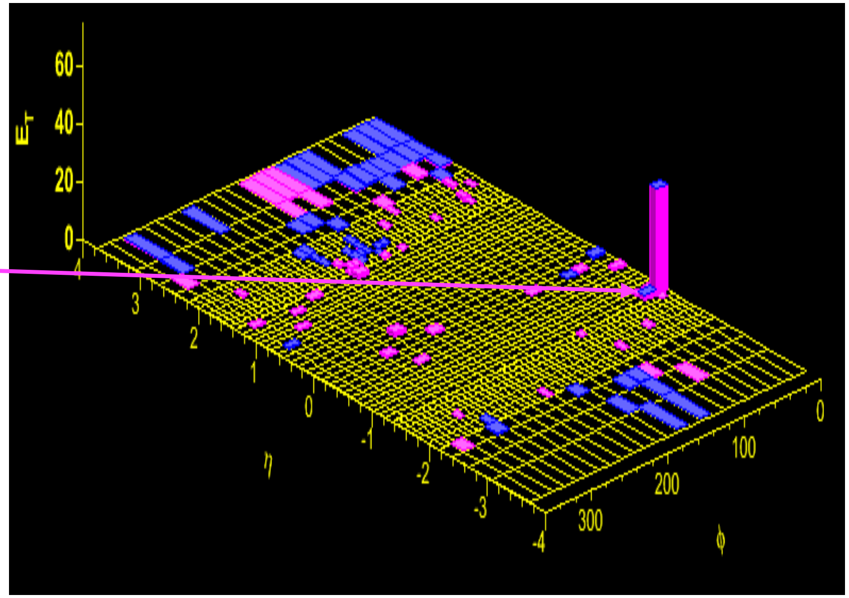


Include Z→ll masses for final momentum scale ΔM_W= 7 MeV
end energy scale ΔM_W= 10 MeV

Hadronic Recoil

Recoil definition:
→ Energy vector sum over all calorimeter towers, excluding:

- lepton towers

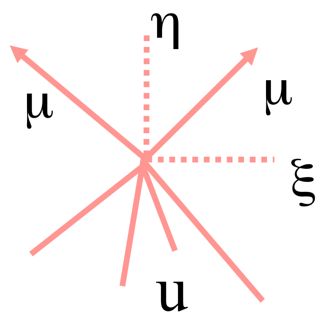


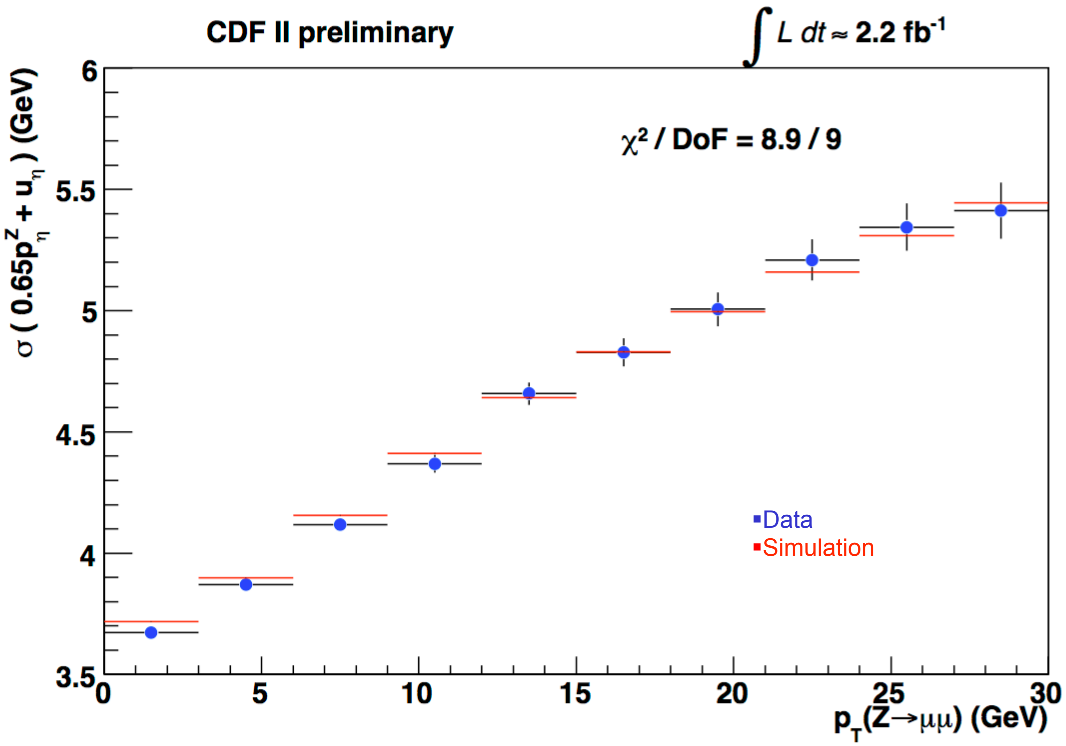
- Measured recoil:
  - hard recoil from hadronic activity in W/Z event
  - underlying event/spectator interaction energy

- Tune using Z and minimum-bias data
- Validate using measured recoil in W events

Recoil Model

- Project vector sum of $p_T(ll)$ and u on orthogonal axes defined by lepton directions
- Use Z balancing to calibrate recoil energy scale
- Mean and RMS of projections as a function of $p_T(ll)$ provide information for model parameters





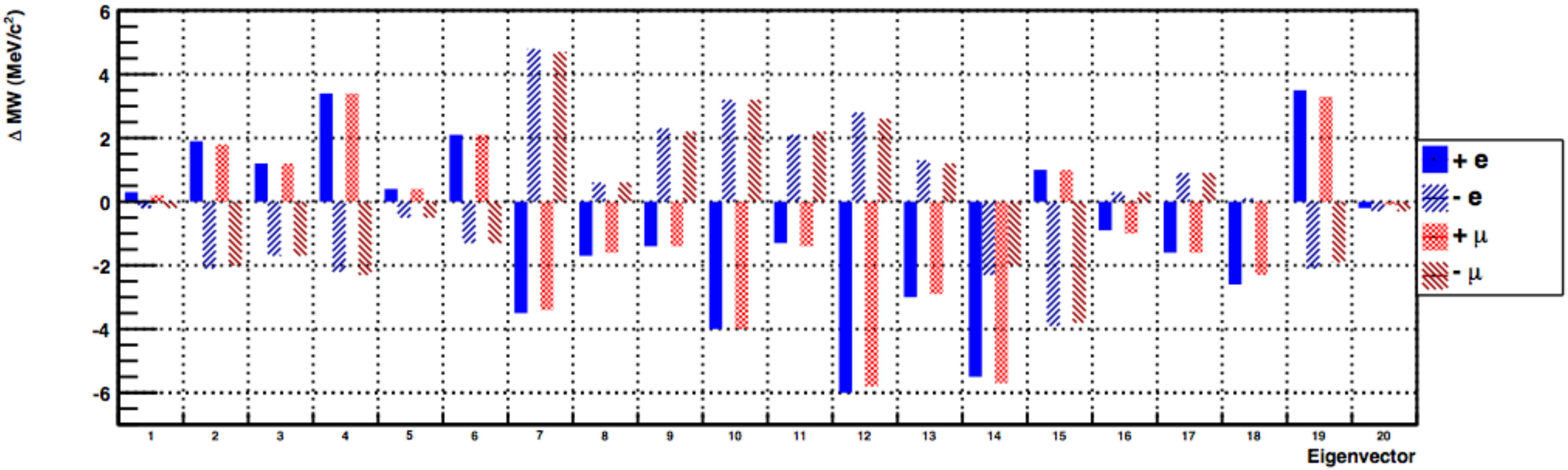
Hadronic model parameters tuned by minimizing χ^2 between data and simulation

ΔM_W= 9 MeV

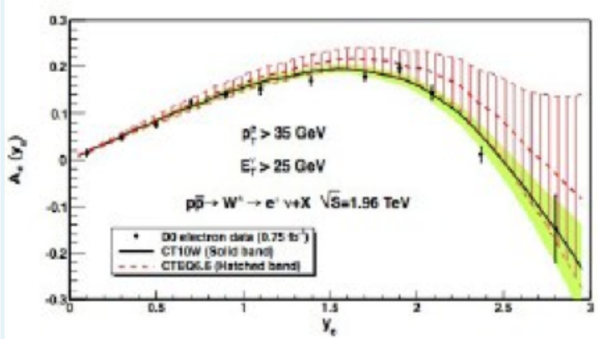
Parton Distribution Functions

Limited lepton acceptance produces dependence on PDFs

Evaluated with CTEQ and MSTW eigenvectors $\Delta M_W = 10$ MeV



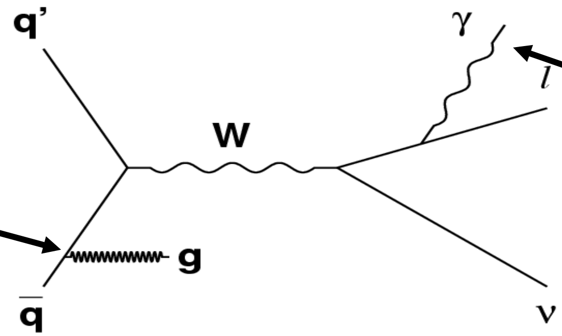
Expect improvement from charge asymmetry measurements



Signal Simulation

- Generator-level input for W&Z simulation provided by RESBOS [Balazs *et.al.* PRD56, 5558 (1997)]

RESBOS



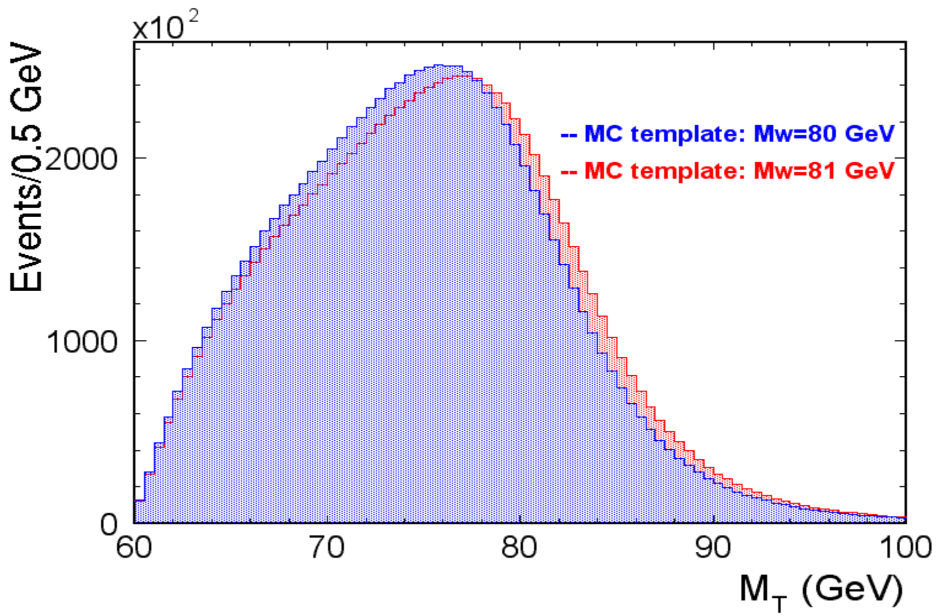
PHOTOS

Multiple radiative photons from PHOTOS
(P. Golonka et.al., Eur. J. Phys. C 45, 97 (2006)

ΔM_W= 3 MeV

ΔM_W= 4 MeV

- Custom fast simulation makes smooth, high statistics templates



Extract the W mass from fit to: m_T, p_T and E_T^{miss} distributions in muon and electron decay channel

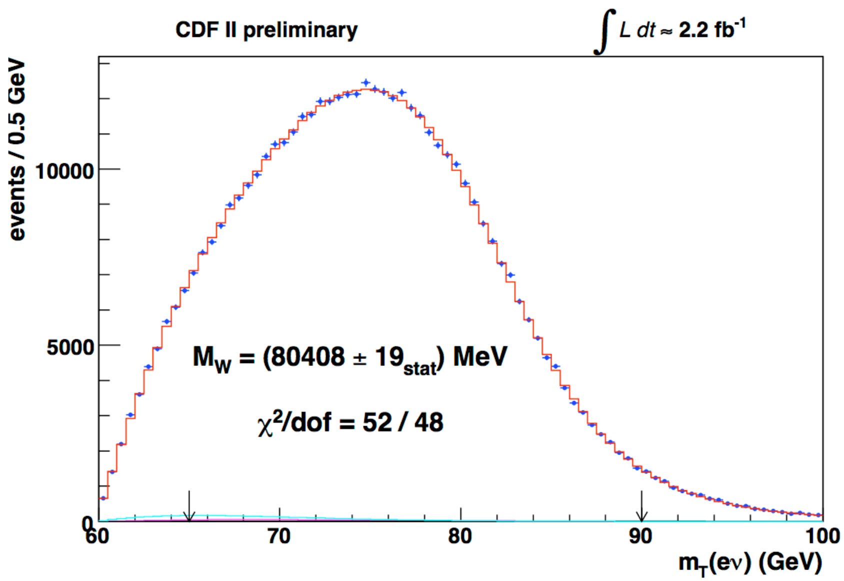
Blind Analysis

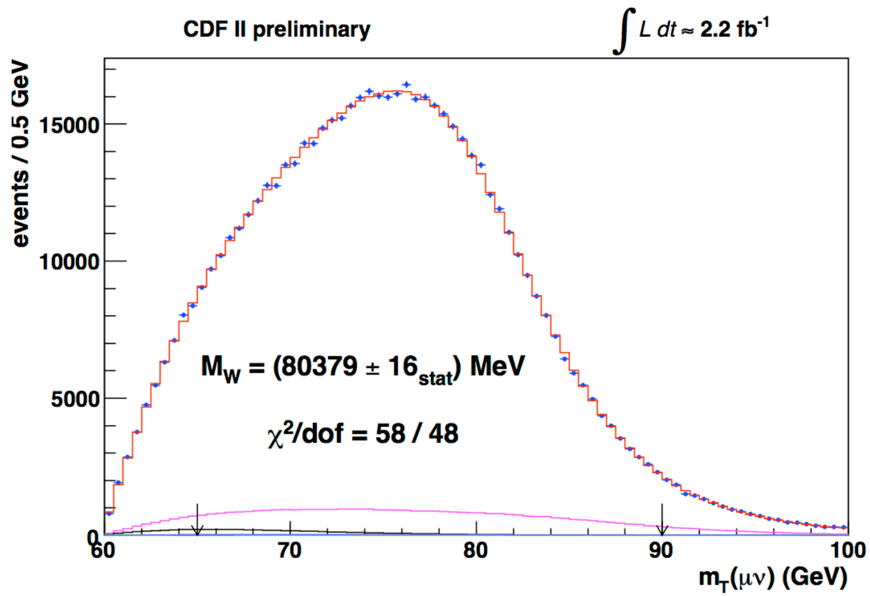
All W and Z mass fit results were blinded with a random [-75,75] MeV offset hidden in the likelihood fitter

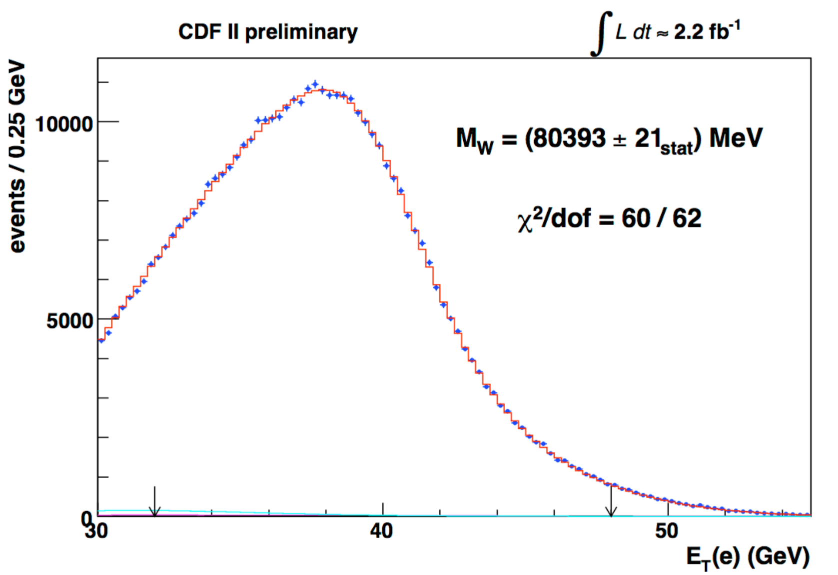
Blinding offset removed after the analysis was declared frozen

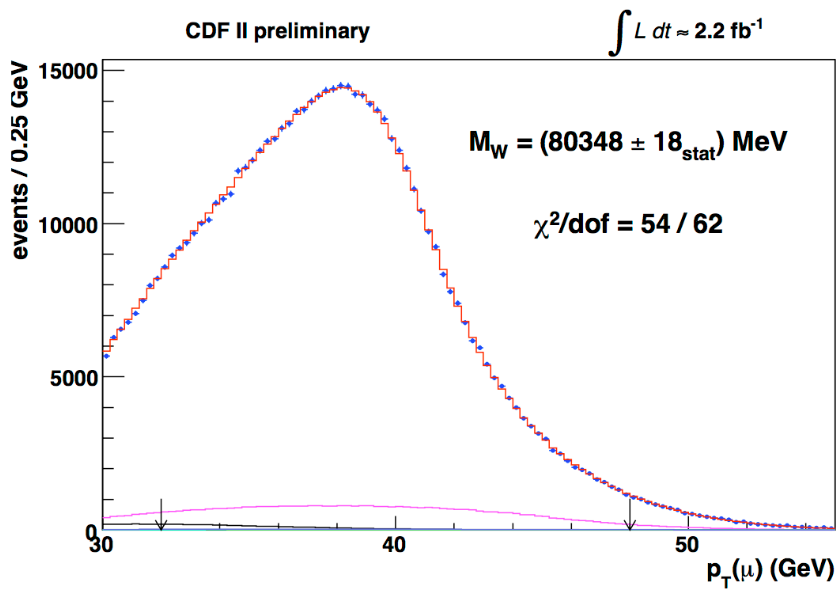
Technique allows to study all aspects of data while keeping Z mass and W mass result unknown within 75 MeV

Fit Results


CDF II preliminary
∫L dt ≈ 2.2 fb^-1
events / 0.5 GeV
$M_W = (80408 \pm 19_{stat})$ MeV
χ^2/dof = 52 / 48
$m_T(e\nu)$ (GeV)


CDF II preliminary
∫L dt ≈ 2.2 fb^-1
events / 0.5 GeV
$M_W = (80379 \pm 16_{stat})$ MeV
χ^2/dof = 58 / 48
$m_T(\mu\nu)$ (GeV)


CDF II preliminary
∫L dt ≈ 2.2 fb^-1
events / 0.25 GeV
$M_W = (80393 \pm 21_{stat})$ MeV
χ^2/dof = 60 / 62
$E_T(e)$ (GeV)


CDF II preliminary
∫L dt ≈ 2.2 fb^-1
events / 0.25 GeV
$M_W = (80348 \pm 18_{stat})$ MeV
χ^2/dof = 54 / 62
$p_T(\mu)$ (GeV)

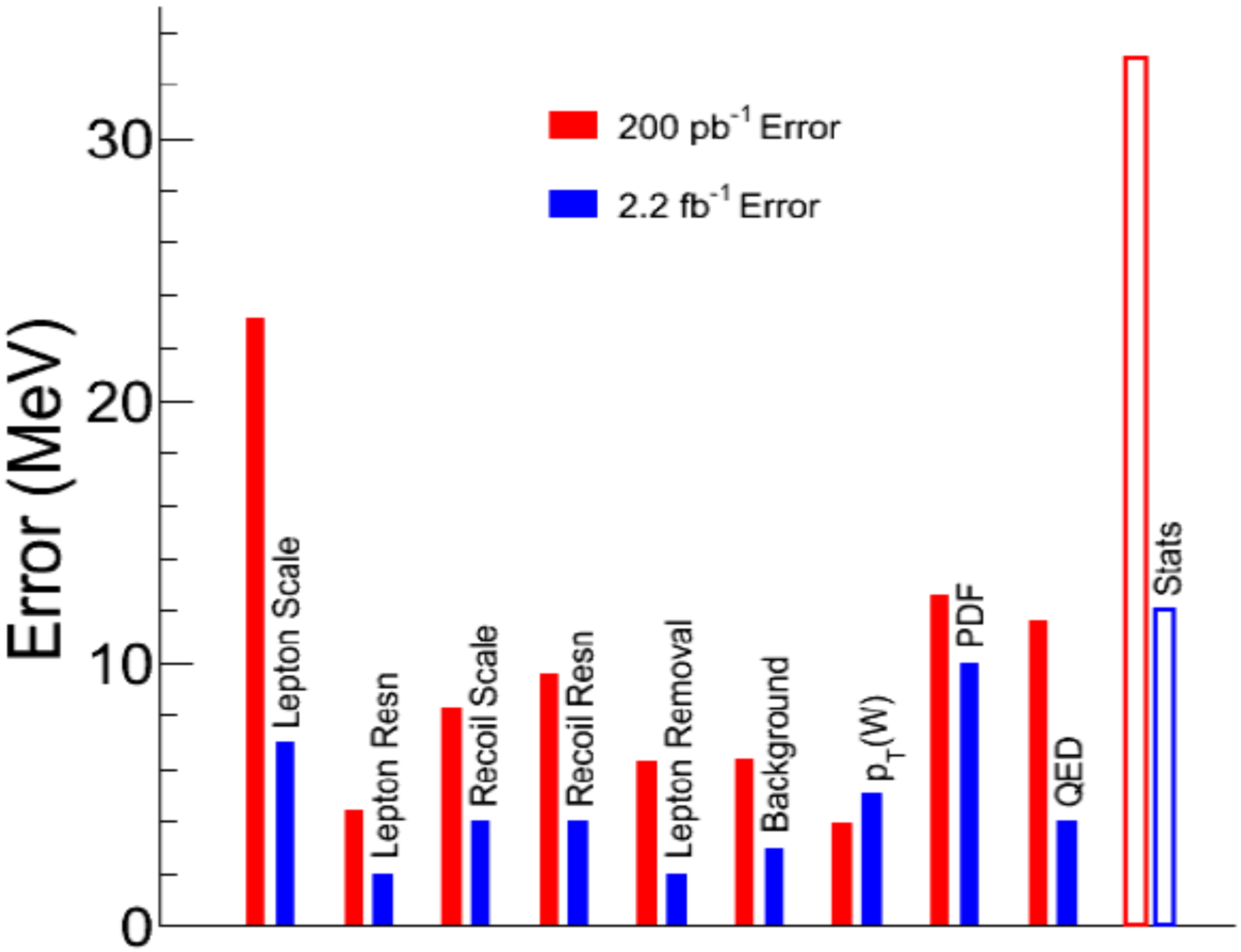
Systematic Uncertainties

New CDF Result (2.2 fb^{-1})
Transverse Mass Fit Uncertainties (MeV)

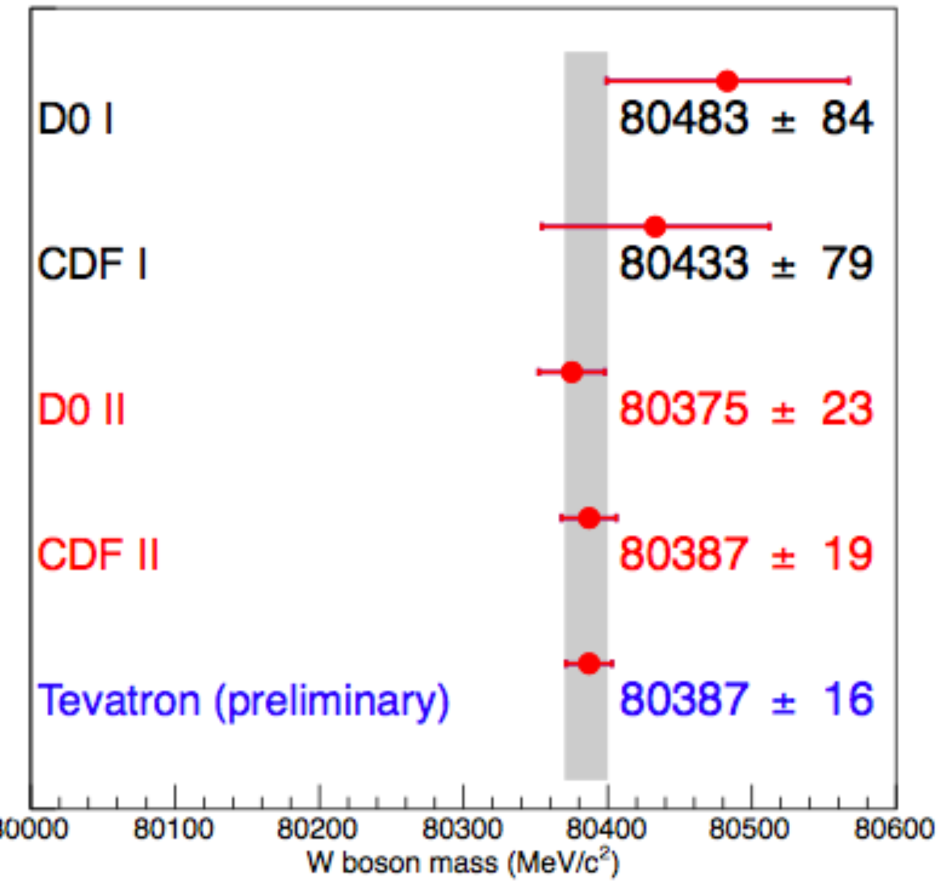
	electrons	*muons*	*common*
W statistics	19	16	0
Lepton energy scale	10	7	5
Lepton resolution	4	1	0
Recoil energy scale	5	5	5
Recoil energy resolution	7	7	7
Selection bias	0	0	0
Lepton removal	3	2	2
Backgrounds	4	3	0
pT(W) model	3	3	3
Parton dist. Functions	10	10	10
QED rad. Corrections	4	4	4
Total systematic	18	16	15
Total	26	23	

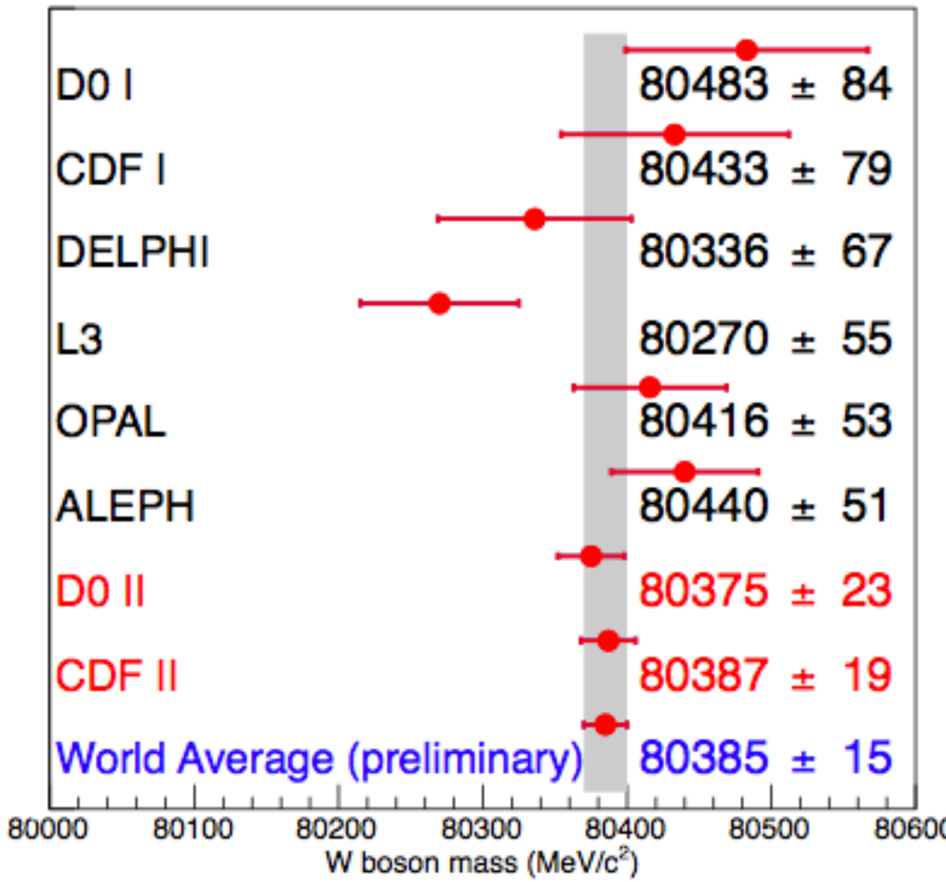
Systematic uncertainties shown in green: statistics-limited by control data samples

Uncertainty Scaling



Results: W Mass Combination





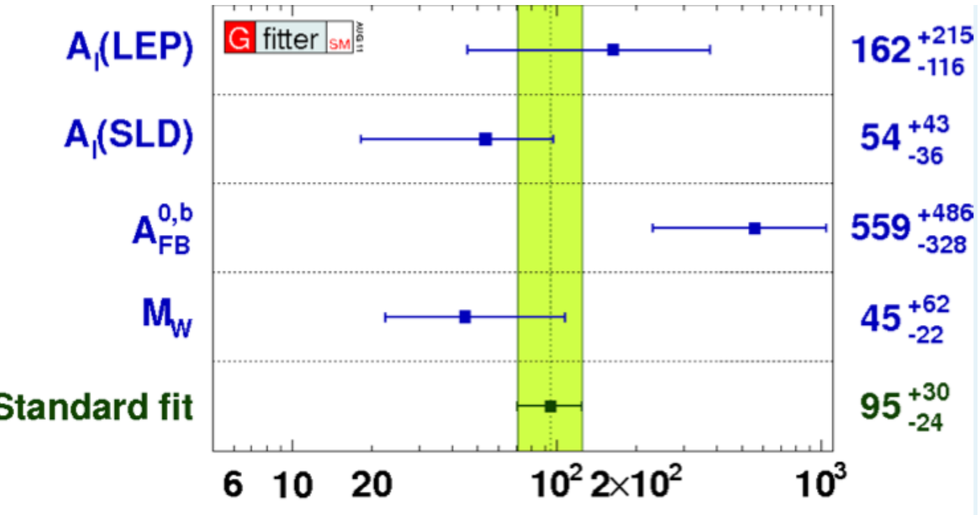
Previous world average: 80398 ± 23 MeV

New CDF result is significantly more precise than previous world average

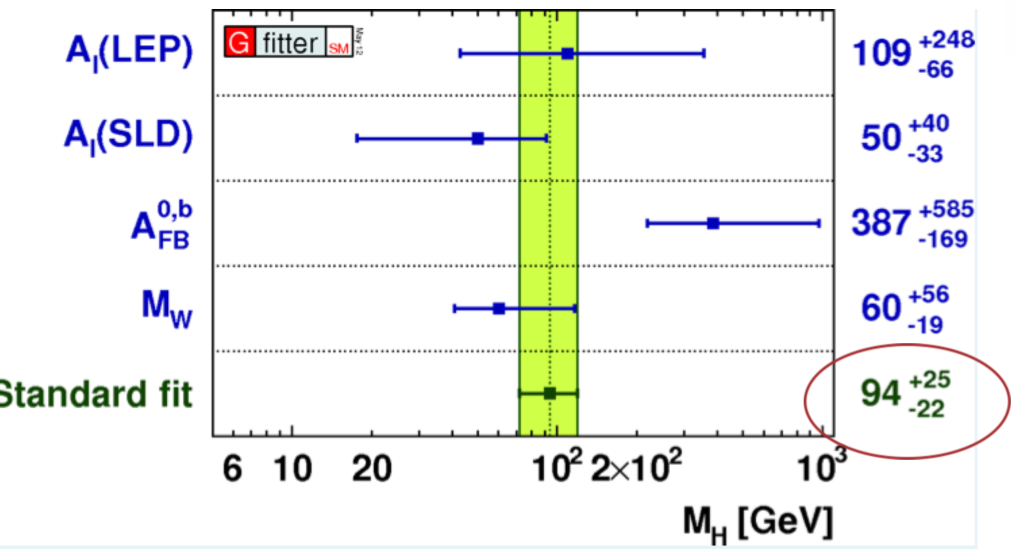
$M_W = 80387 \pm 12_{stat} \pm 15_{syst}$ MeV = 80387 ± 19 MeV

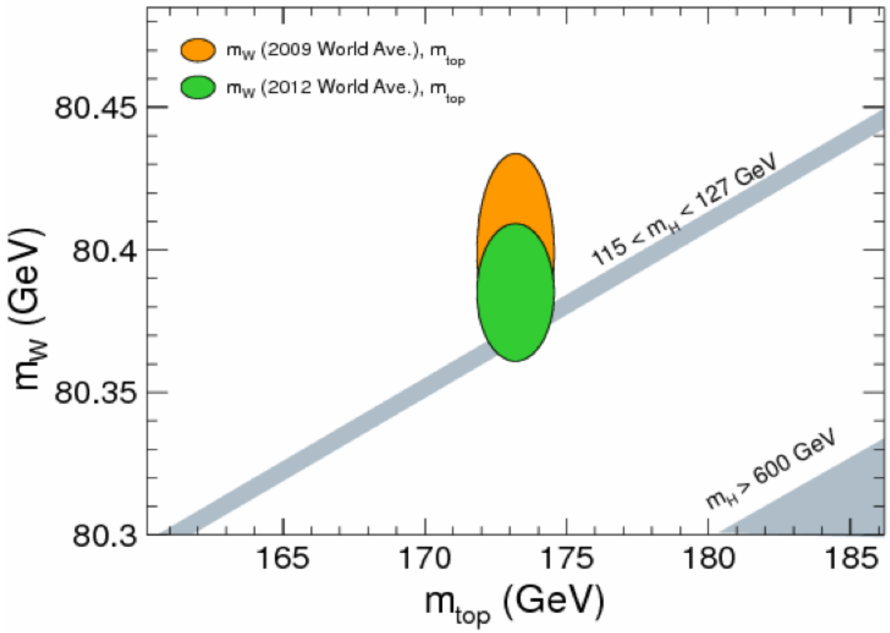
Results: Higgs Constraints

End 2011:



Today:





Without M_W:

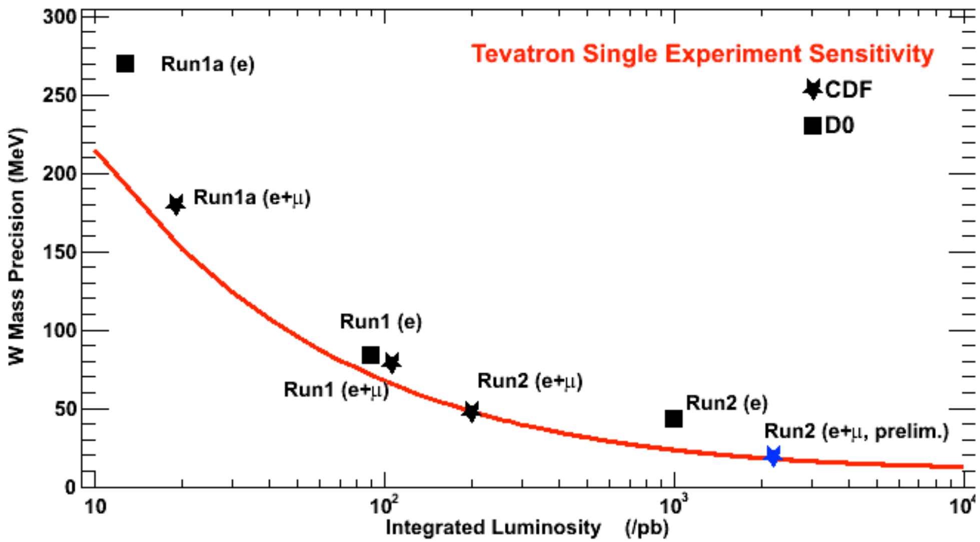
$M_H = 106^{+71}_{-32}$ GeV

Conclusion

New CDF result is significantly more precise than previous world average

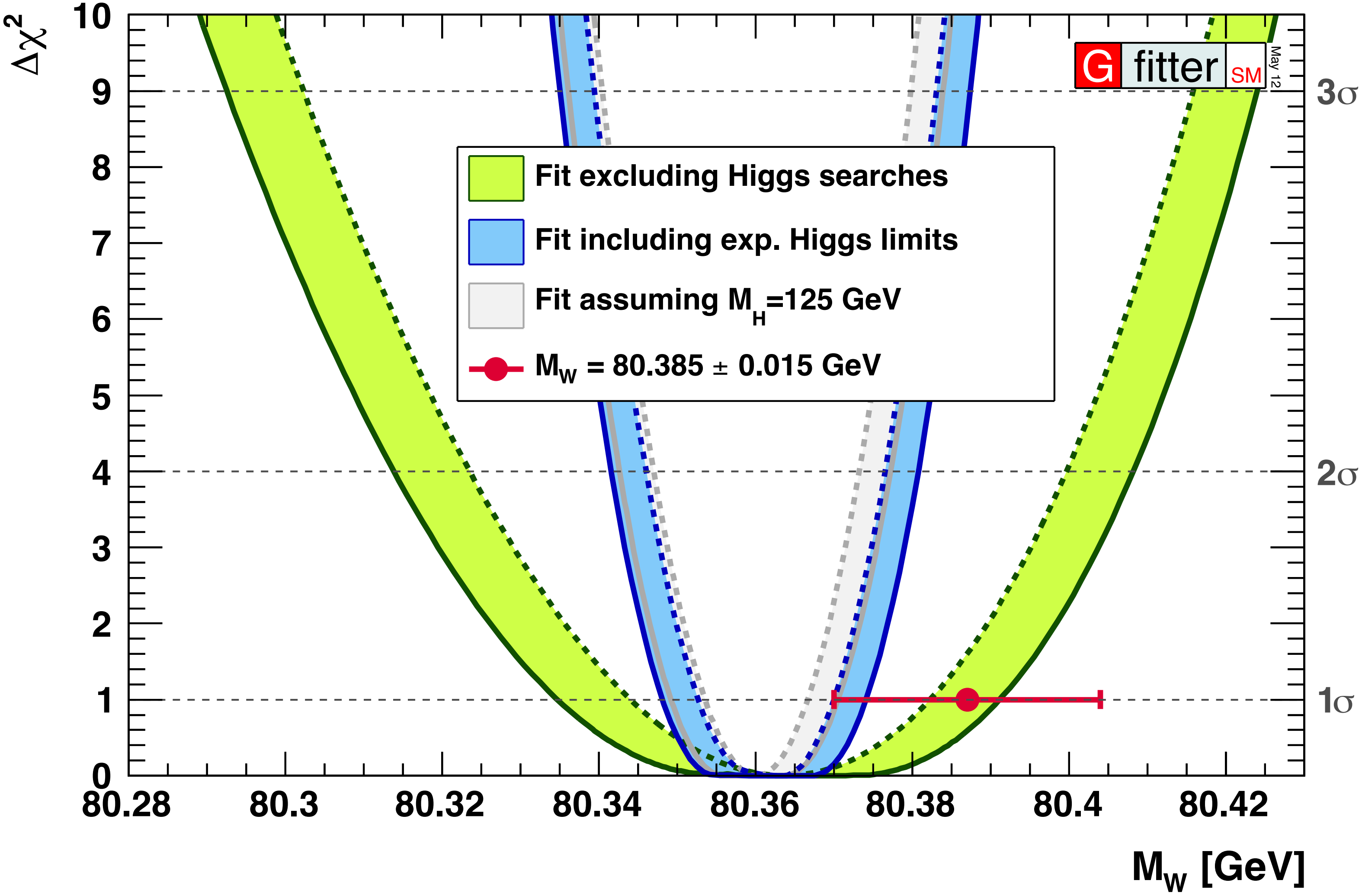
M_W = 80387 ± 19 MeV

PRL 108 (2012) 151803

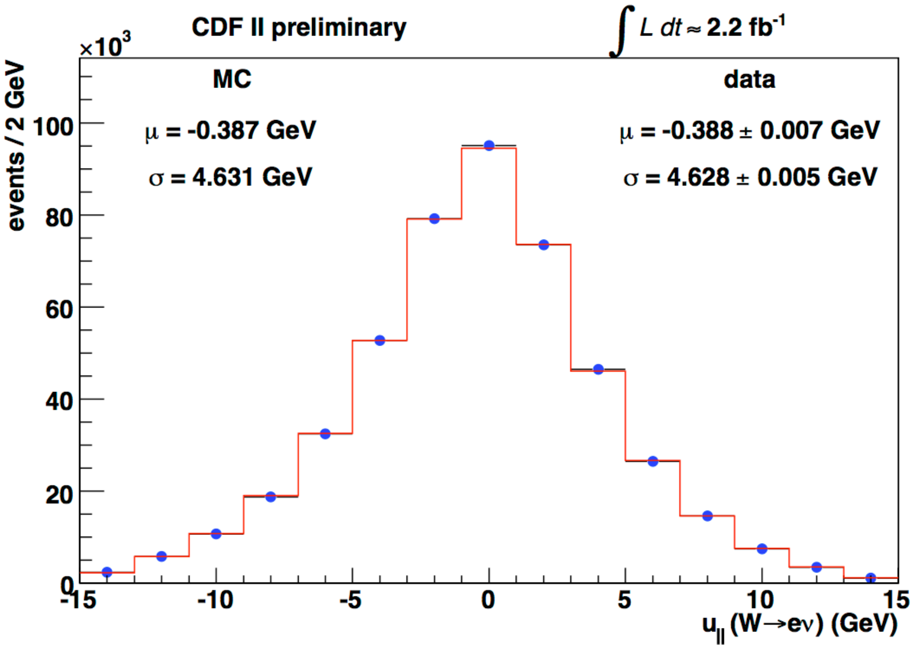


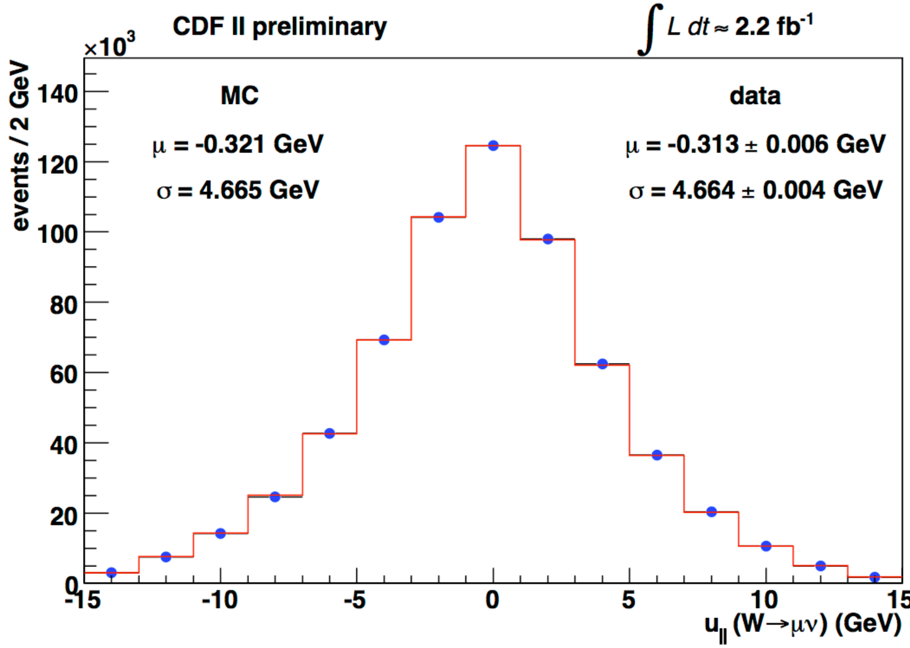
The W boson mass will continue to play An important role as a stress test of the Standard Model.

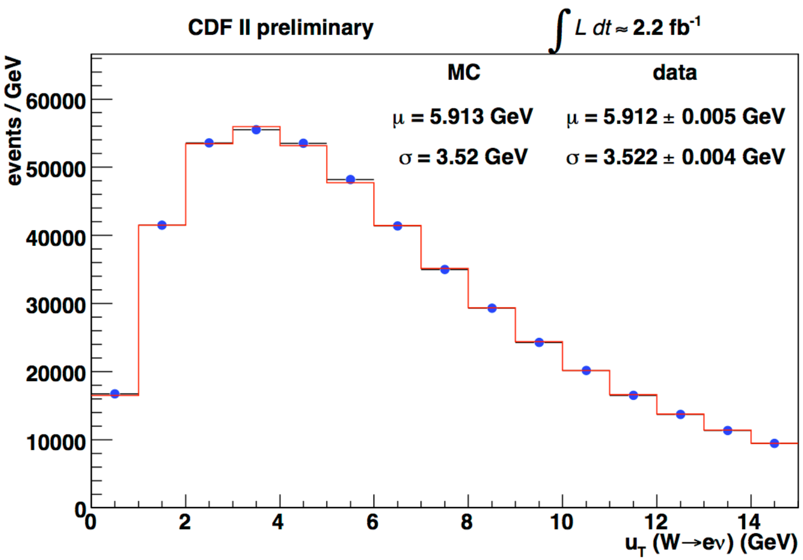
Direct and Indirect M_W

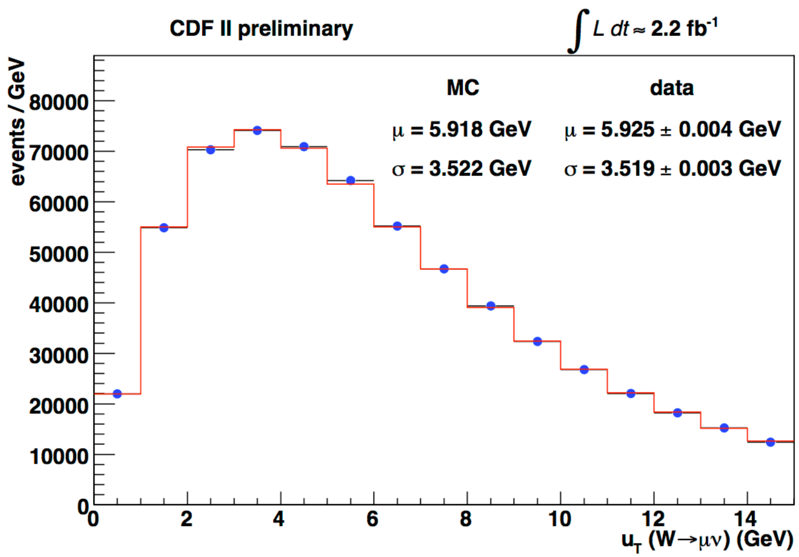


Recoil Checks

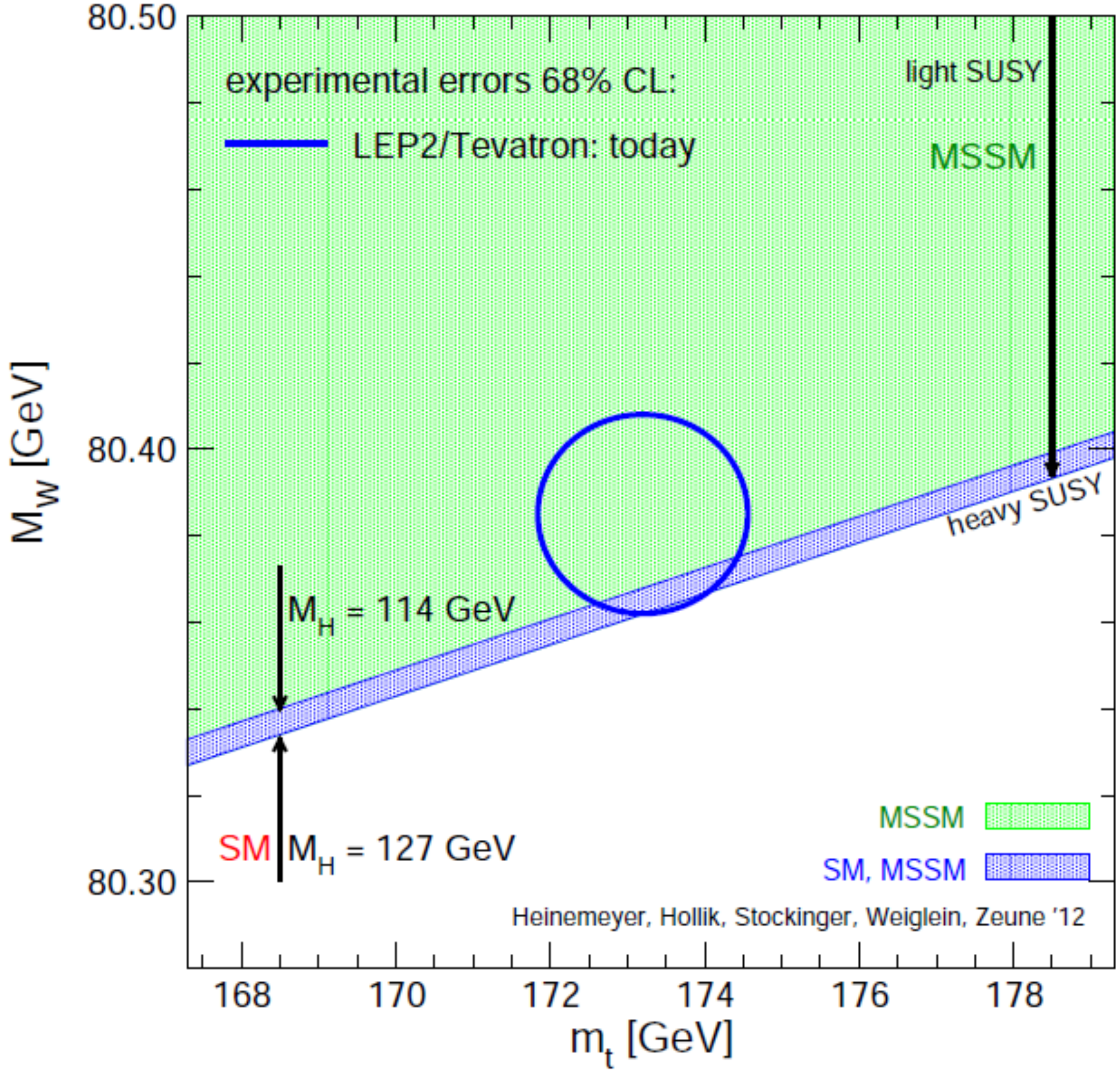








SUSY


experimental errors 68% CL:
LEP2/Tevatron: today
light SUSY
MSSM
heavy SUSY
M_H = 114 GeV
SM
M_H = 127 GeV
MSSM
SM, MSSM
Heinemeyer, Hollik, Stockinger, Weiglein, Zeune '12
80.50
80.40
80.30
168
170
172
174
176
178
M_W [GeV]
m_t [GeV]