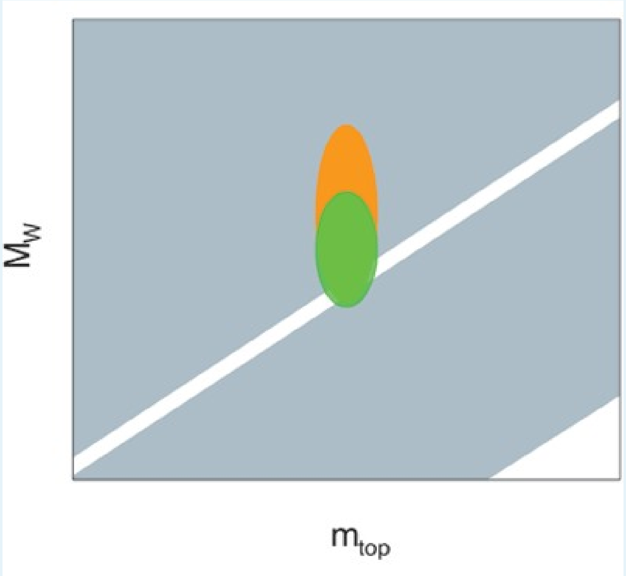
Measurements of the W boson mass at the Tevatron

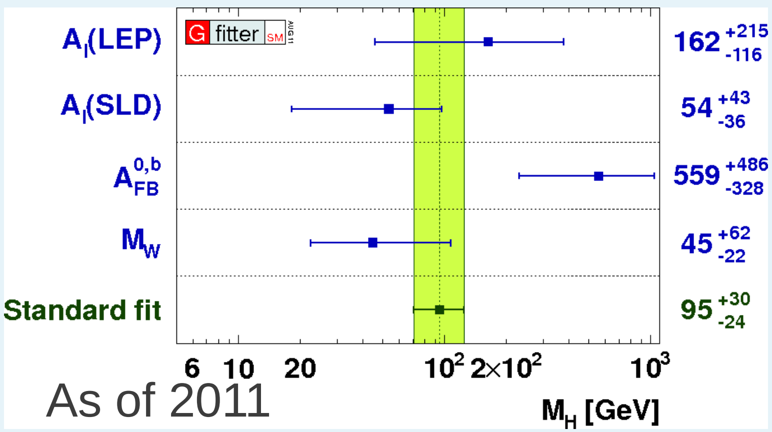
Chris Hays, Oxford University
for the CDF & D0 collaborations



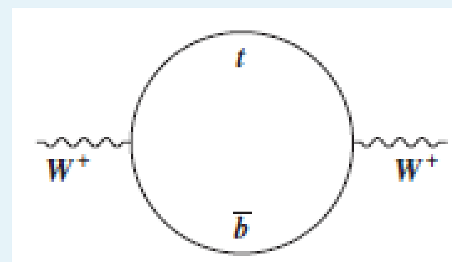
24th Rencontres de Blois
29 May 2012

Electroweak measurements and m_W

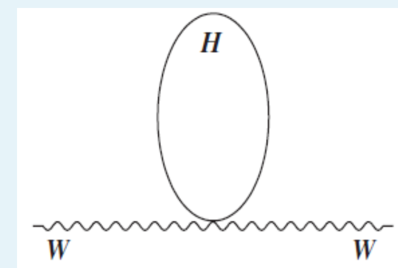
Precision measurements constrain m_H



$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\alpha_{em}}{\sqrt{2}G_F}\frac{1}{1-\Delta r}$$



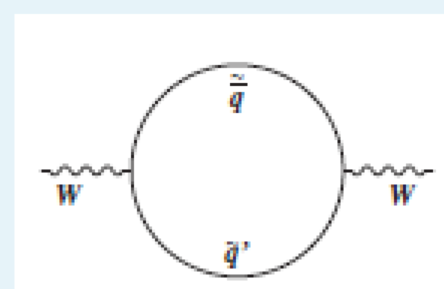
$\Delta r \sim m_t^2$



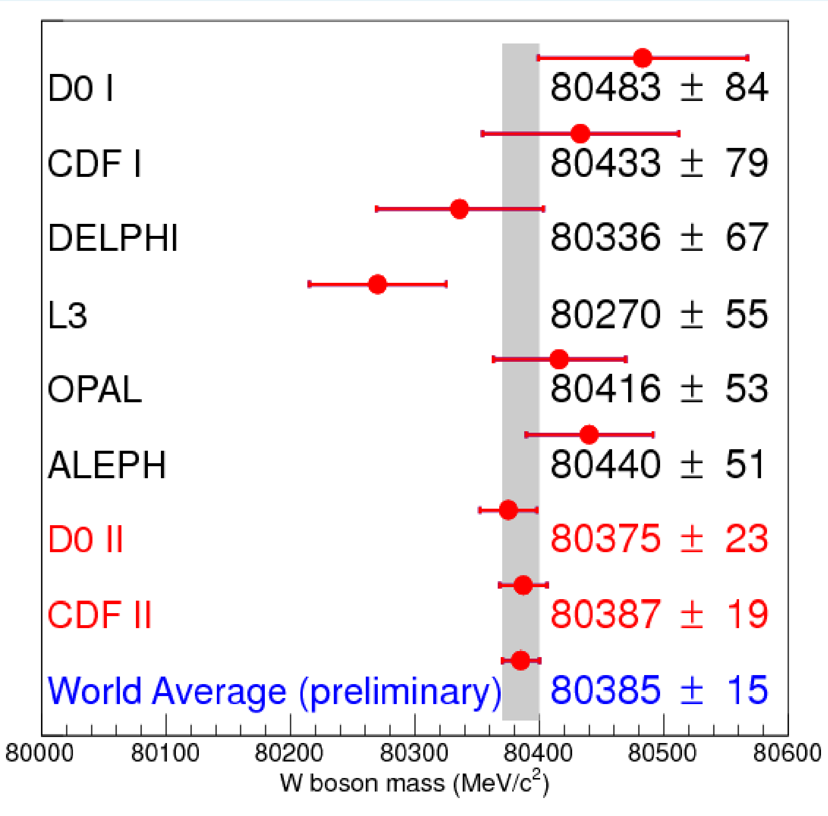
$\Delta r \sim \ln m_H$

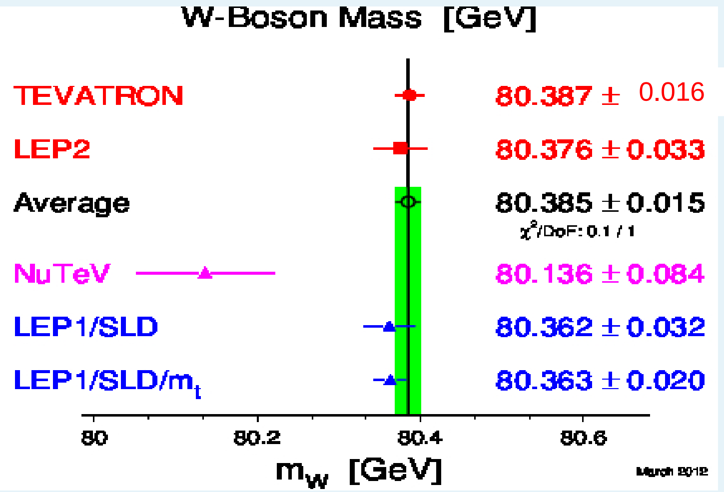
Parameter shift	m_W shift (MeV)
$\Delta(\ln m_H) = +0.693$	-41.3
$\Delta m_t = +0.9$ GeV	5.5
$\Delta\alpha_{em} = +0.00033$	-5.8
$\Delta m_Z = +2.1$ MeV	2.6

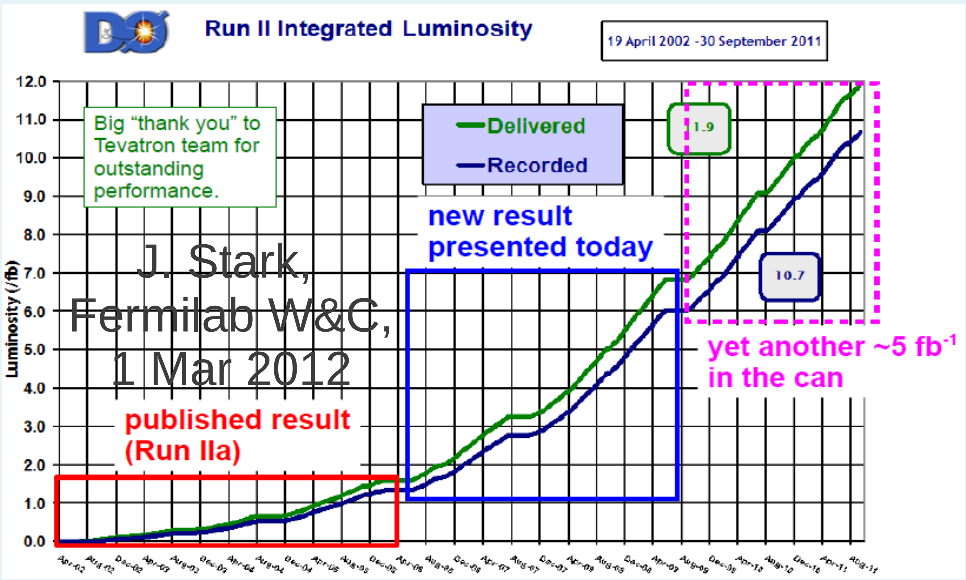
Also constrain hypothetical interactions



m_W measurements







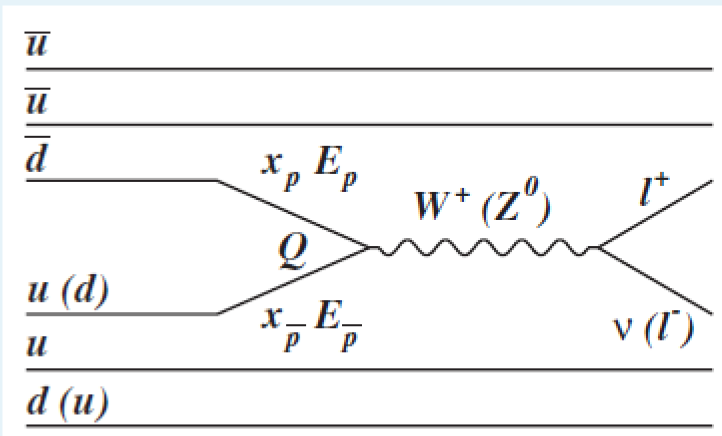
Tevatron Run II measurements:

CDF: first measurement (200 pb^{-1}), superceded by 2.2 fb^{-1} result

D0: combined Run IIA (1 fb^{-1}) & Run IIB (4.3 fb^{-1})

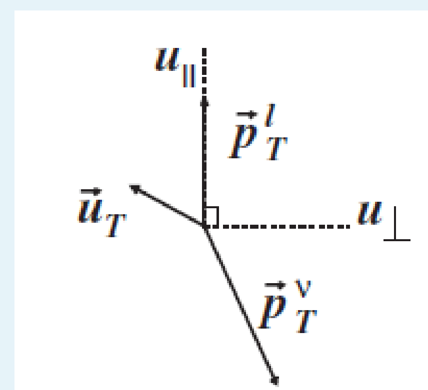
W mass measurement at the Tevatron

High statistics from resonant single W production



Momentum of charged lepton (e or μ) dominates mass information

Neutrino p_T calculated from lepton and recoil measurements



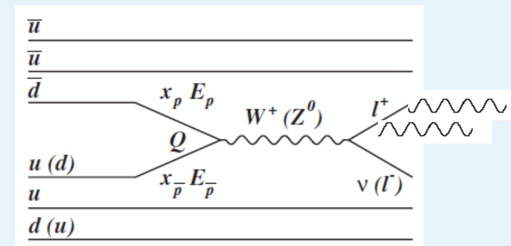
$$m_T = \sqrt{2p_T(l)p_T(\nu)[1-\cos(\phi_l-\phi_\nu)]}$$

In situ calibration of lepton and recoil measurements

Mass determined from fits to charged-lepton p_T, neutrino p_T, and m_T distributions

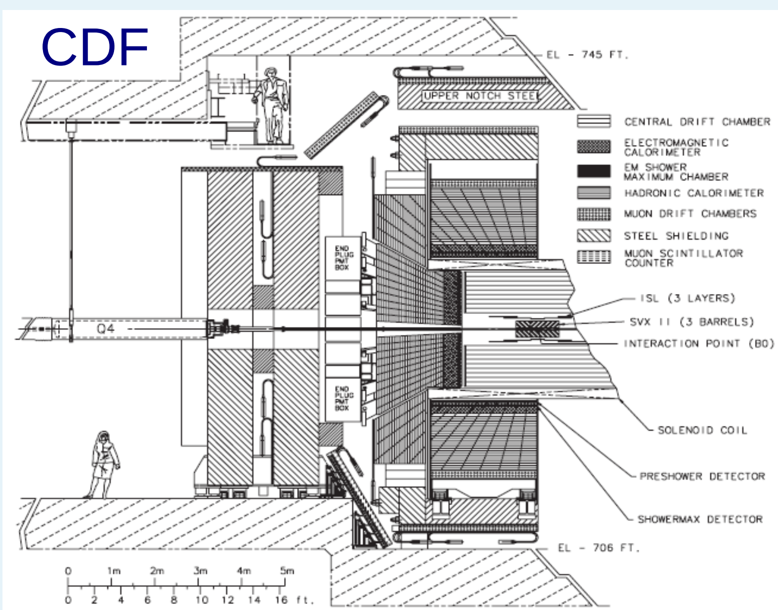
Charged lepton model and calibration

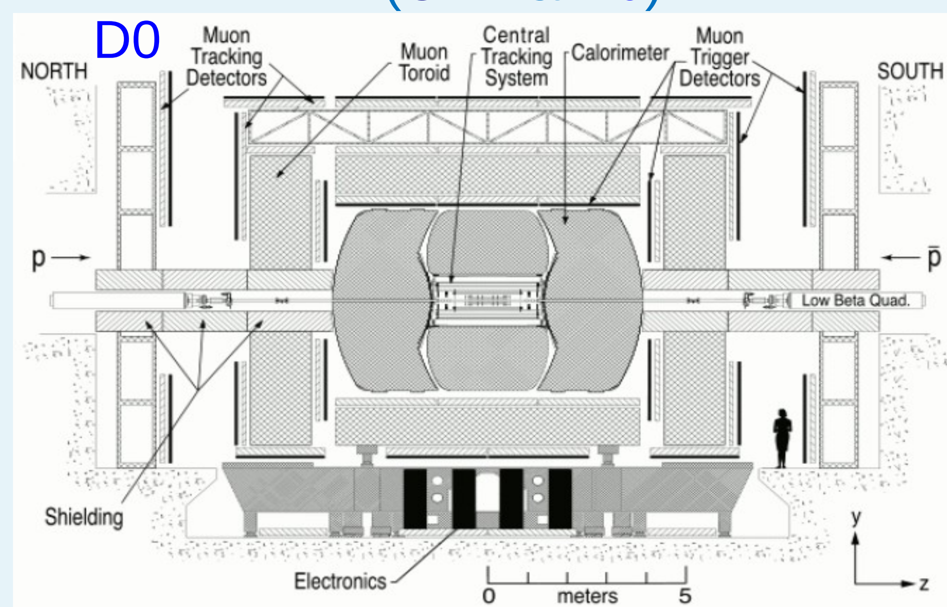
QED radiation in production process



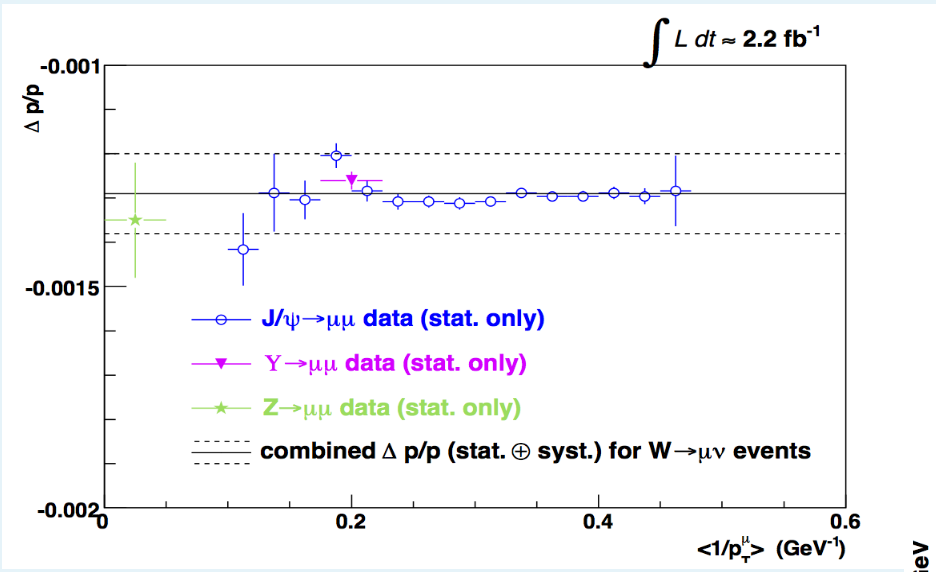
Muon momentum calibration with J/ψ & Υ mesons, Z bosons (CDF)

Electron energy calibration using tracker (CDF) & Z bosons (CDF & D0)





Muon momentum calibration (CDF)

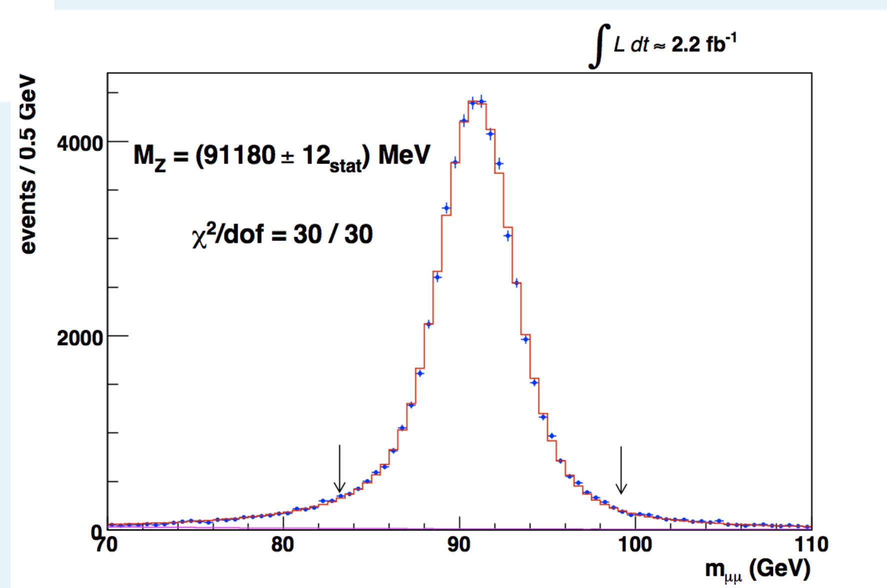


Combine high-statistics measurements of resonant decays of J/ψ & Υ mesons, Z bosons

Confirms tracker linearity over large range of (inverse) momentum

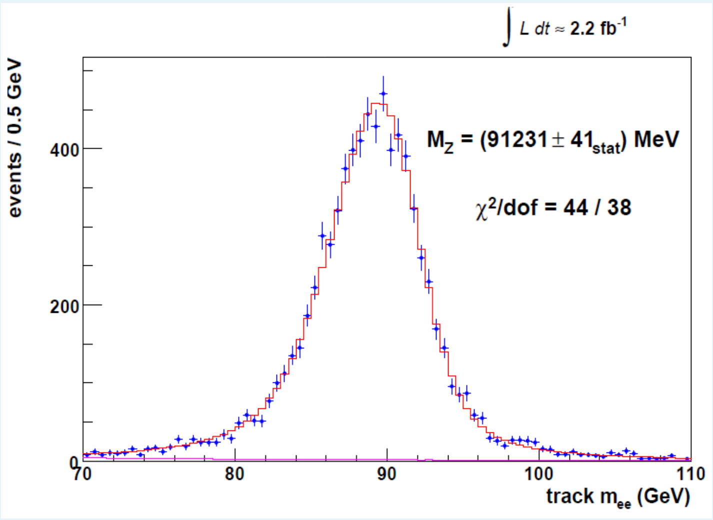
Blind measurement of Z boson mass

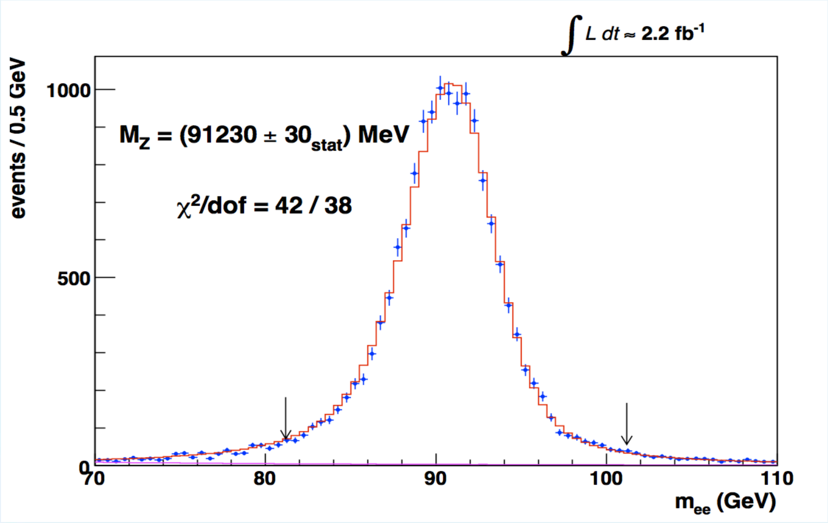
m_Z = 91180 ± 12 ± 10 MeV



Consistency with LEP I a powerful verification of J/ψ & Υ calibrations

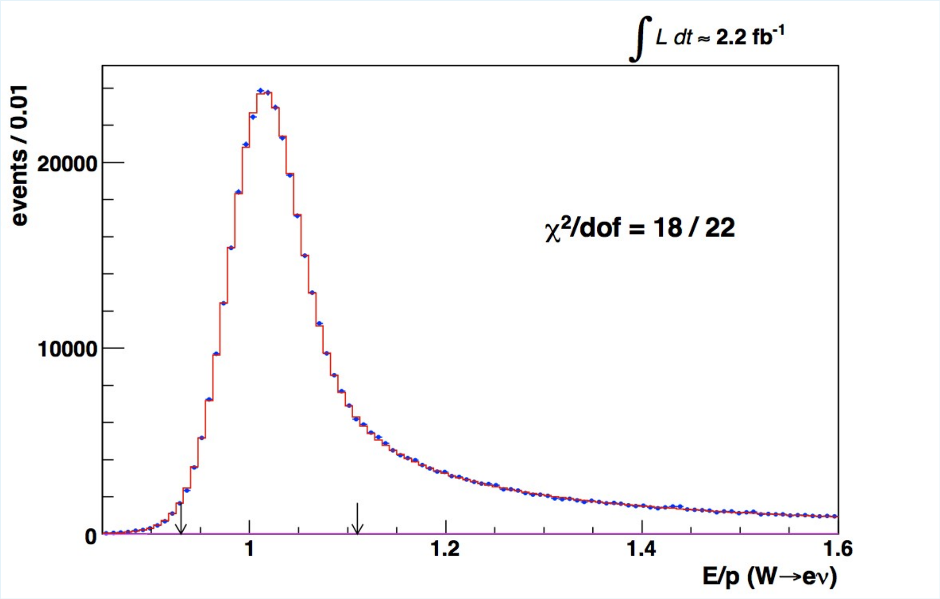
Electron momentum calibration (CDF)





Validate electron track calibration with blinded m_Z measurement using tracks

Transfer track calibration to calorimeter using ratio of measurements (E/p)



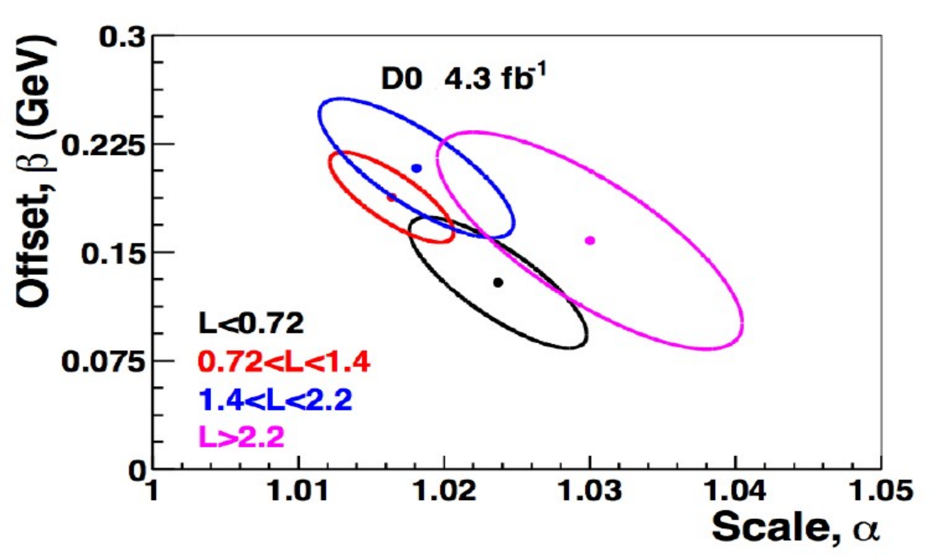
Blind calorimeter m_Z measurement:

m_Z = 91230 ± 30 ± 14 MeV

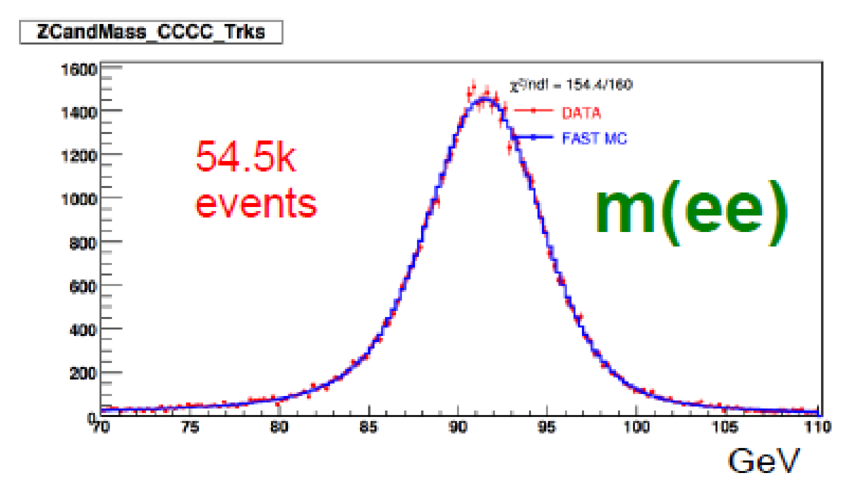
Electron momentum calibration (D0)

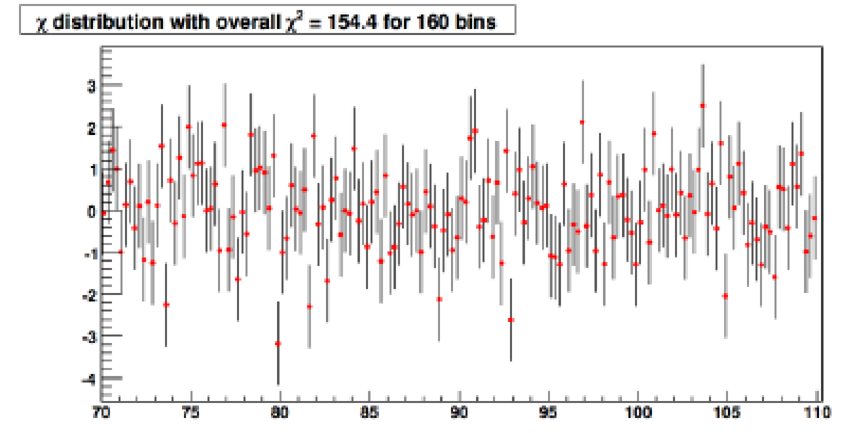
$E_{measured}$ = scale * (E_{true} – 43 GeV) + offset + 43 GeV

Calibrate momentum scale and offset using Z boson decays



Measure parameters in several luminosity ranges



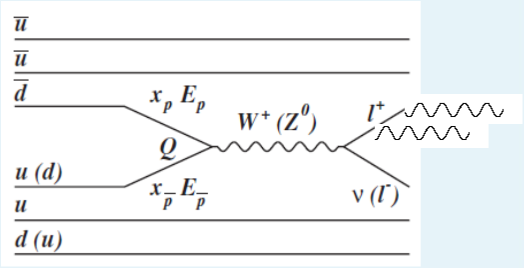


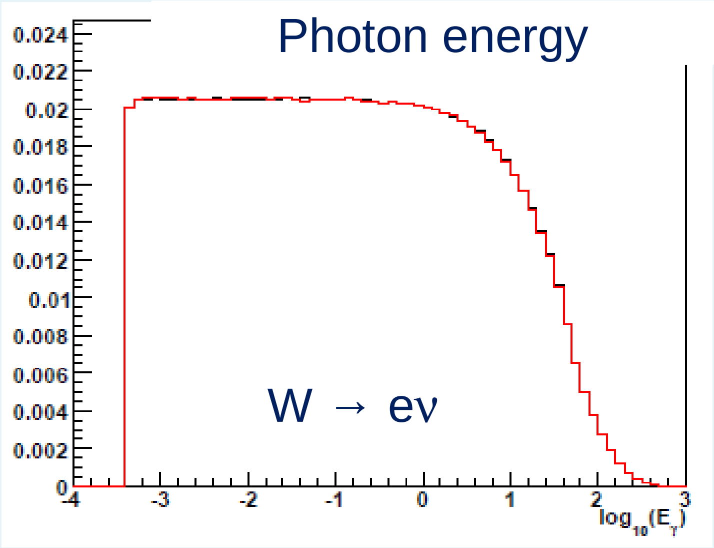
m(Z) = 91.193 ± 0.017 (stat) GeV

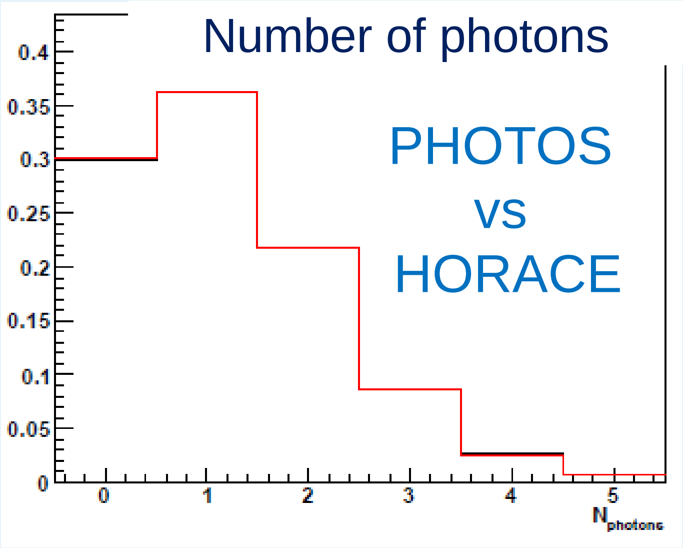
QED final-state radiation

Model using PHOTOS: leading log FSR calculation matched to matrix-element calculation at all orders, including interference effects

Cross-check using
W/ZGRAD (D0): full NLO electroweak calculation and
HORACE (CDF): matched leading log ISR + FSR





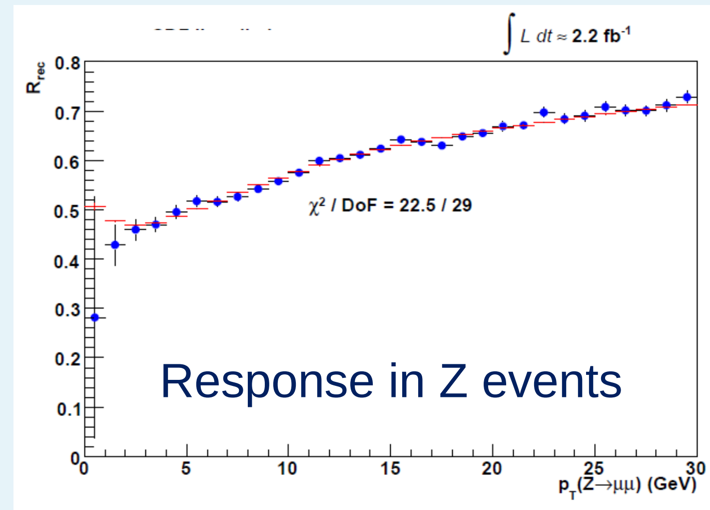


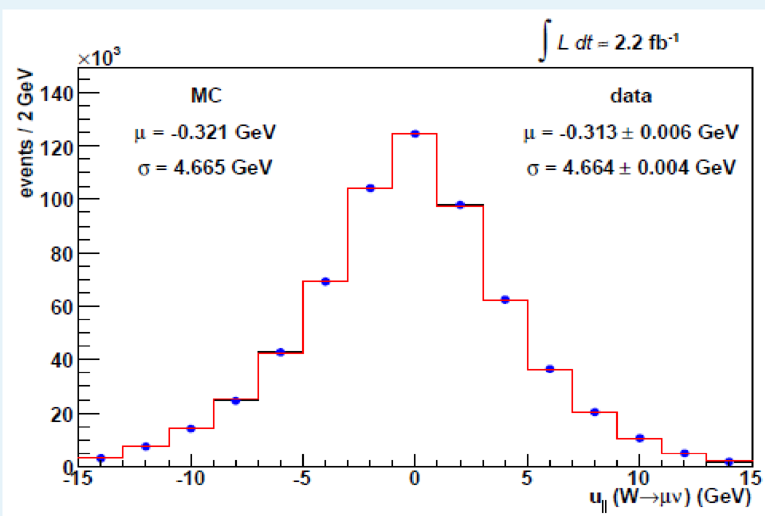
Neutrino momentum calibration (CDF)

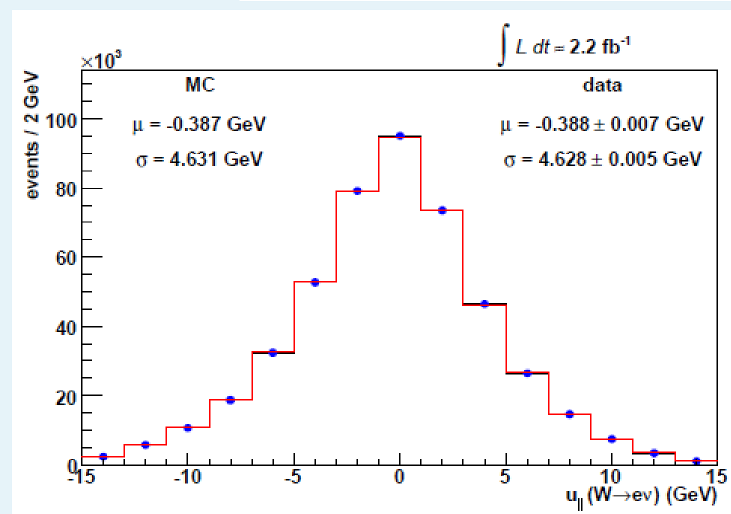
Calibrate detector response and resolution to initial-state QCD using Z boson events

Model underlying event with unbiased data, tuned to model Z boson events with $p_T^Z \sim 0$

Validate model in W boson events



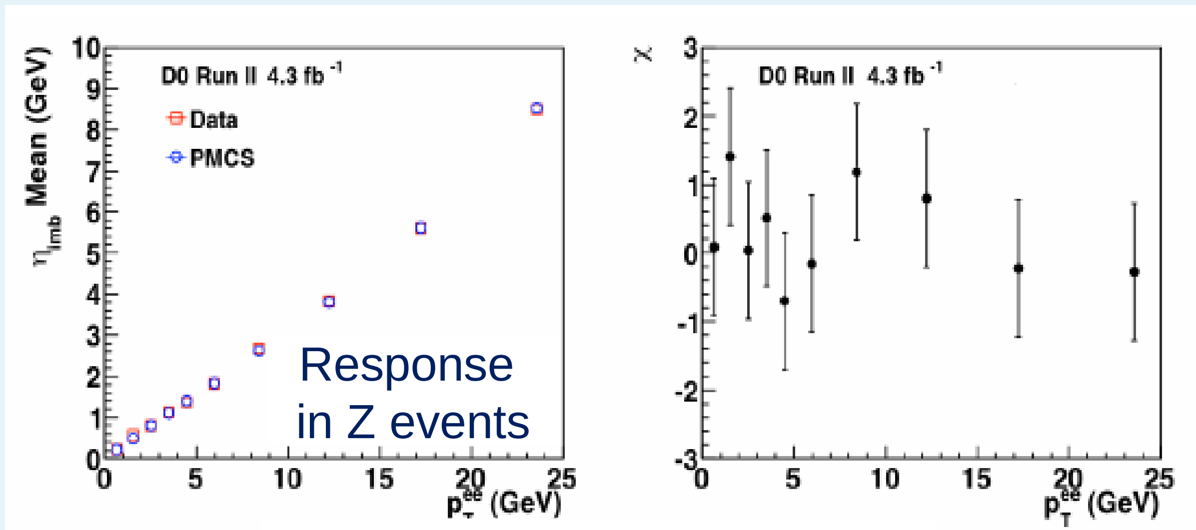


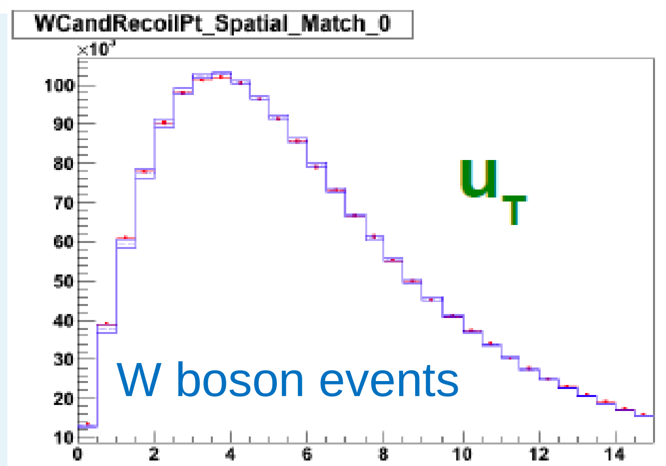


$$m_T \approx 2p_T\sqrt{1 + u_{||}/p_T} \approx 2p_T + u_{||}$$

Neutrino momentum calibration (D0)

Similar calibration samples and procedures to CDF



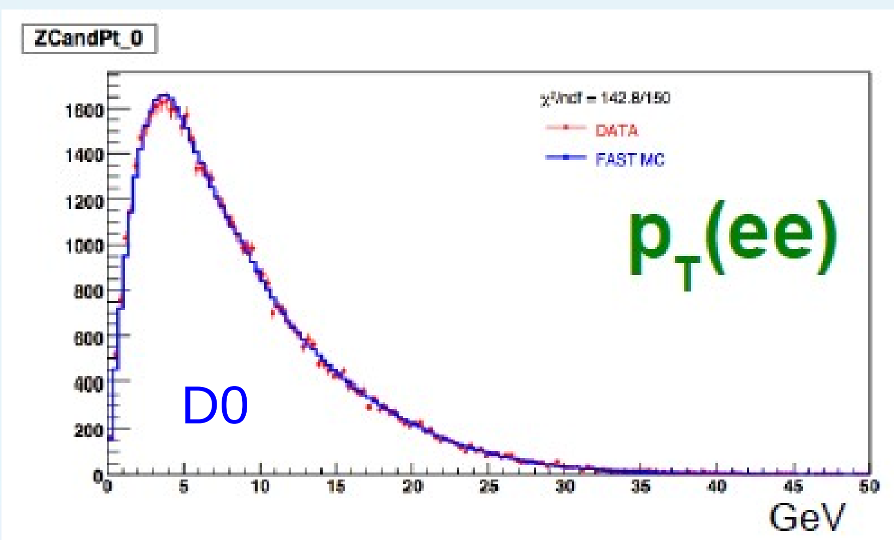


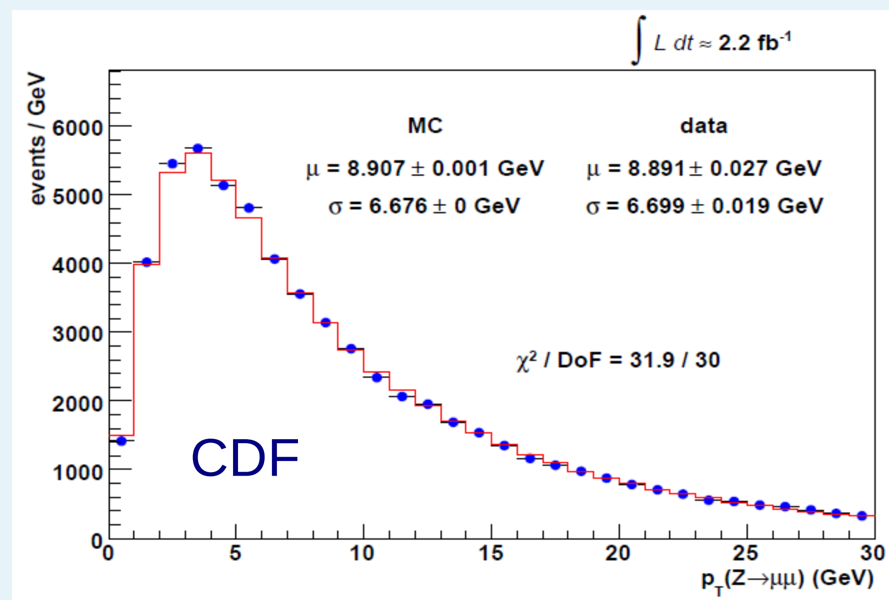
W boson p_T

Model boson p_T with RESBOS (NNLL + NNLO QCD calculation), tuned with Z boson data

D0: dedicated measurement of non-perturbative component

CDF: tune non-perturbative and perturbative components in situ



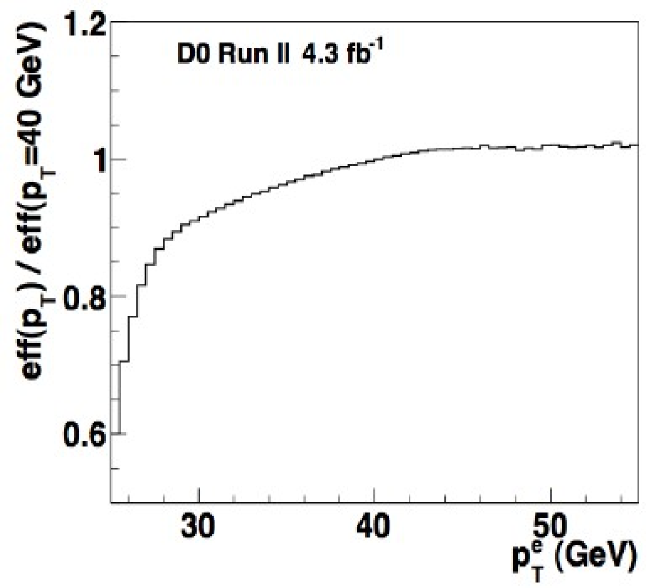


W boson selection & backgrounds

Kinematic selection aims to maximize mass information
& minimize background

Require lepton p_T > 25 (D0) or 30 (CDF) GeV, recoil (u_T) < 15 GeV

Correct for identification efficiencies

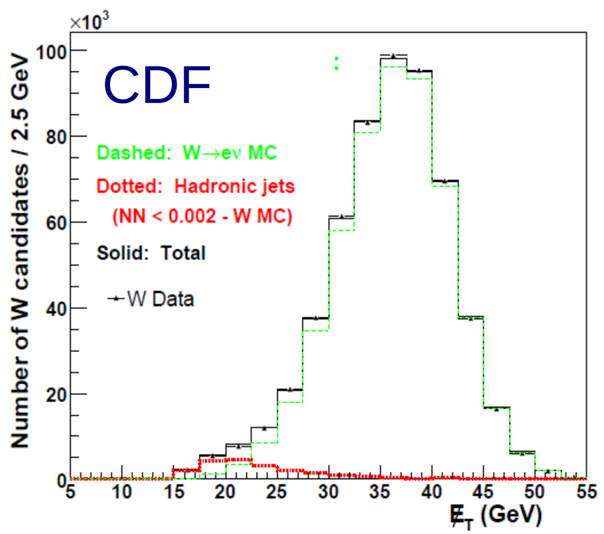


Electroweak backgrounds:
$W \to \tau\nu$ & $Z \to ll$

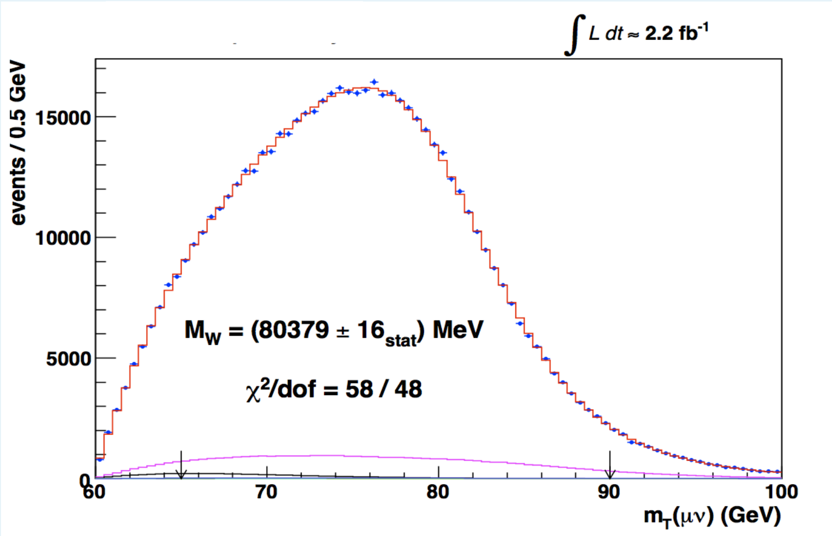
Background	% of $W \to e\nu$ data
$Z \to ee$	0.139 ± 0.014
$W \to \tau\nu$	0.93 ± 0.01
QCD	0.39 ± 0.14
Total	

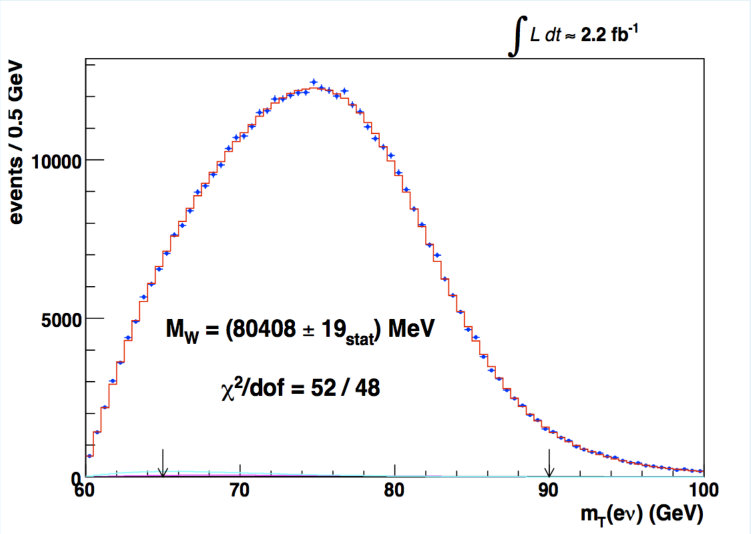
QCD backgrounds:
jets and π/K DIF

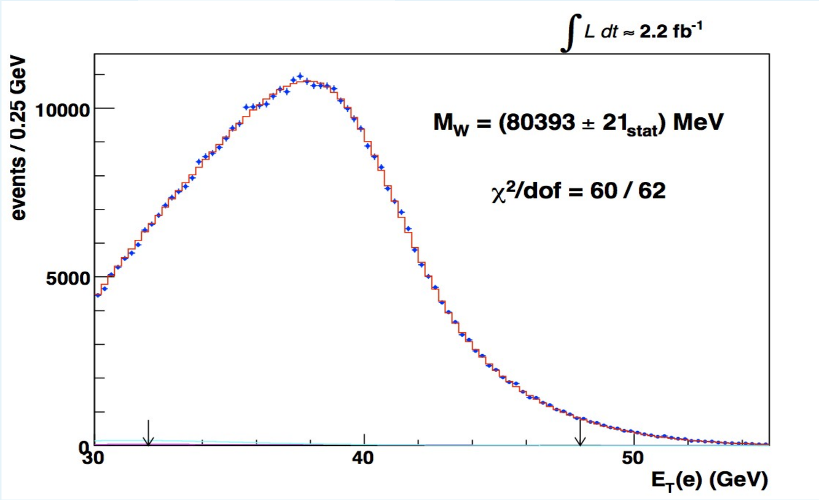
Background	% of $W \to \mu\nu$ data
$Z \to \mu\mu$	7.35 ± 0.09
$W \to \tau\nu$	0.880 ± 0.004
QCD	0.035 ± 0.025
DIF	0.24 ± 0.08
Cosmic rays	0.02 ± 0.02
Total	

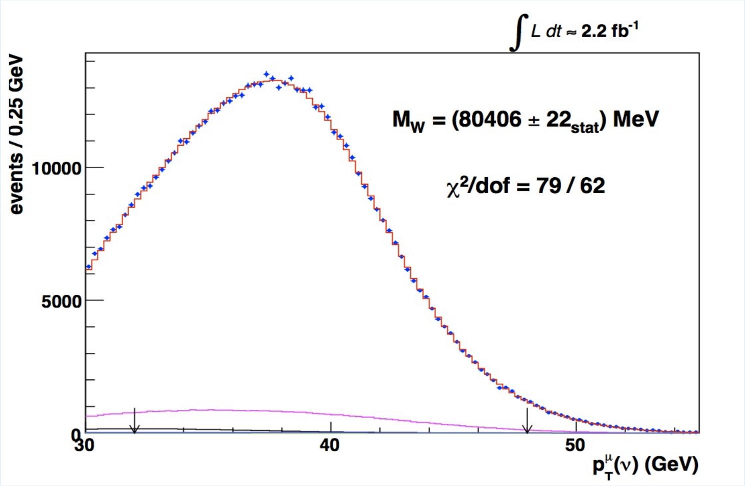


W boson mass fits (CDF)



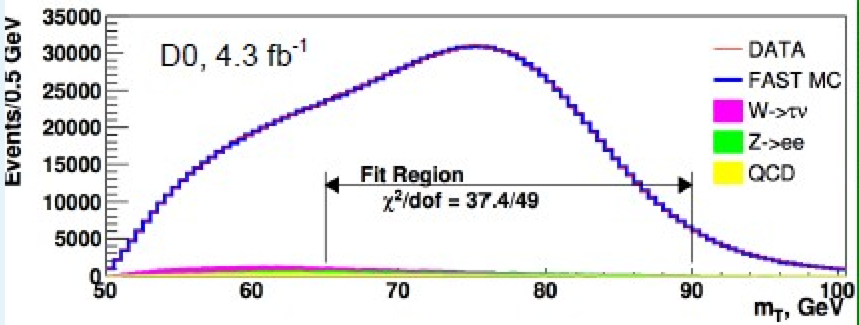






W boson mass fits (D0)

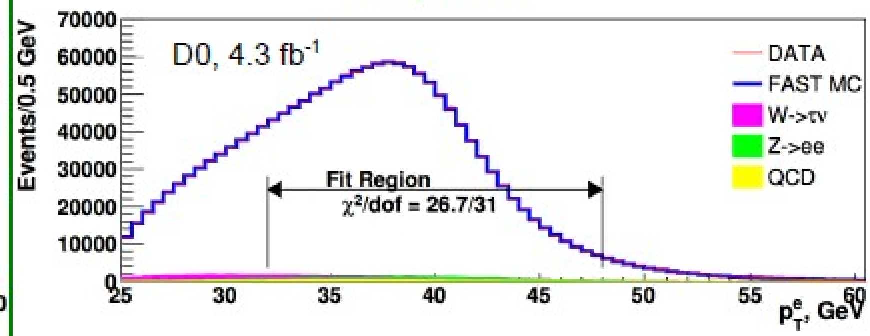
m_T



Fit results:

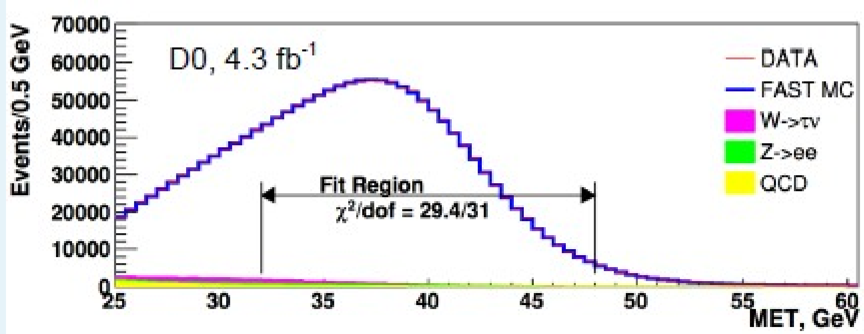
m(W) =
80371 ± 13 MeV (stat)

$p_T(e)$



m(W) =
80343 ± 14 MeV (stat)

MET



Fit results:

m(W) =
80355 ± 15 MeV (stat)

Results

Source	Uncertainty (MeV)
Lepton energy scale and resolution	7
Recoil energy scale and resolution	6
Lepton removal	2
Backgrounds	3
$p_T(W)$ model	5
Parton distributions	10
QED radiation	4
W-boson statistics	12
Total	19

CDF: All systematic uncertainties <10 MeV, except for PDFs

$$M_W = 80\ 387 \pm 12_{\mathrm{stat}} \pm 15_{\mathrm{syst}}$$

Source	Uncertainty (MeV)
Electron energy calibration	16
Electron resolution model	2
Electron shower modeling	4
Electron energy loss model	4
Hadronic recoil energy scale and resolution	5
Electron efficiencies	2
Backgrounds	2
Experimental subtotal	18
Parton distributions	11
QED radiation	7
$p_T(W)$ model	2
Production subtotal	13
Total systematic uncertainty	22
W-boson statistics	13
Total uncertainty	26

D0: dominant systematic uncertainty (energy scale) limited by Z → ee statistics

$$M_W = 80.367 \pm 0.013\ (\mathrm{stat}) \pm 0.022\ (\mathrm{syst})\ \mathrm{GeV}$$

(new measurement)

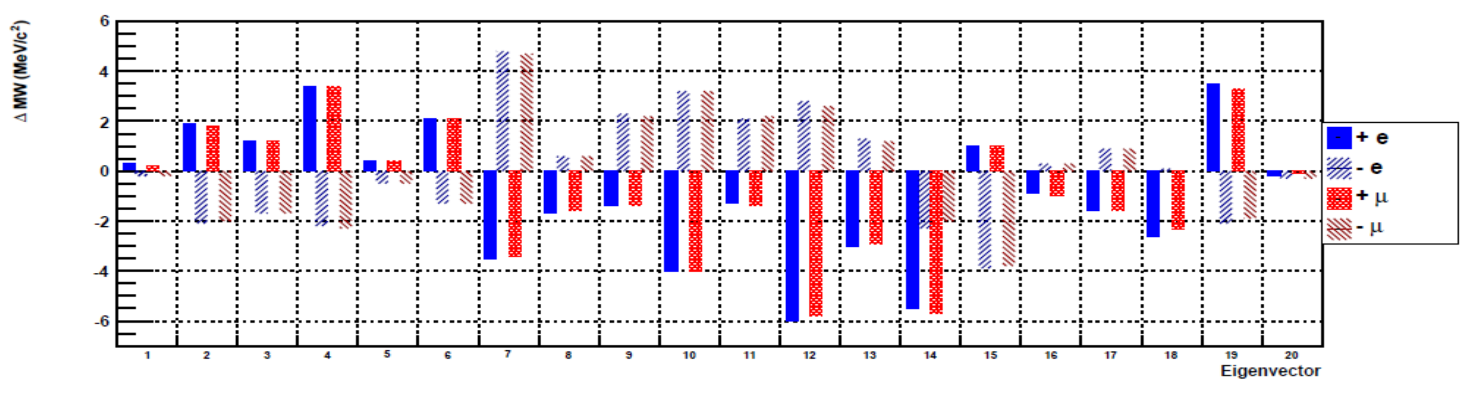
$$M_W = 80.375 \pm 0.011\ (\mathrm{stat}) \pm 0.020\ (\mathrm{syst})\ \mathrm{GeV}$$

(combined Run II)

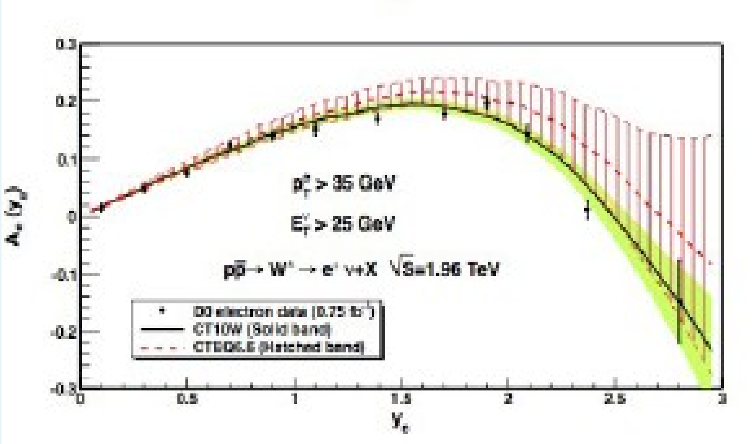
Parton distribution functions

Limited lepton acceptance produces dependence on PDFs

~10 MeV variation with CTEQ or MSTW eigenvectors



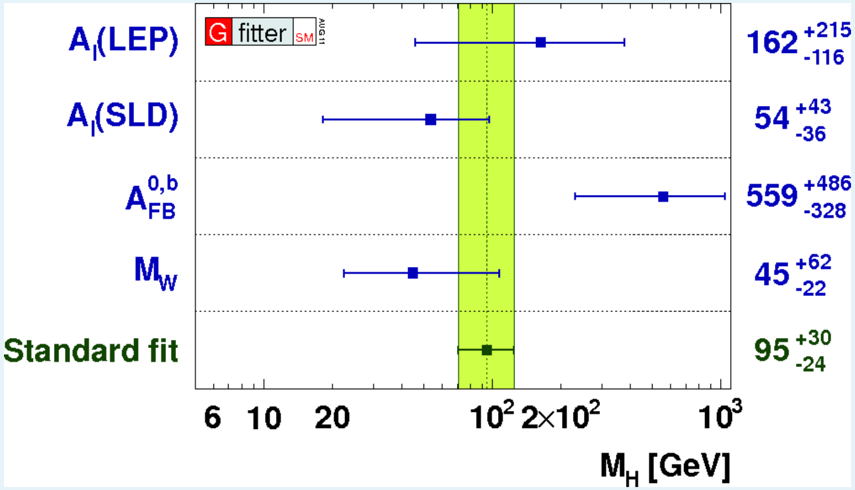
Expect improvement from charge asymmetry measurements



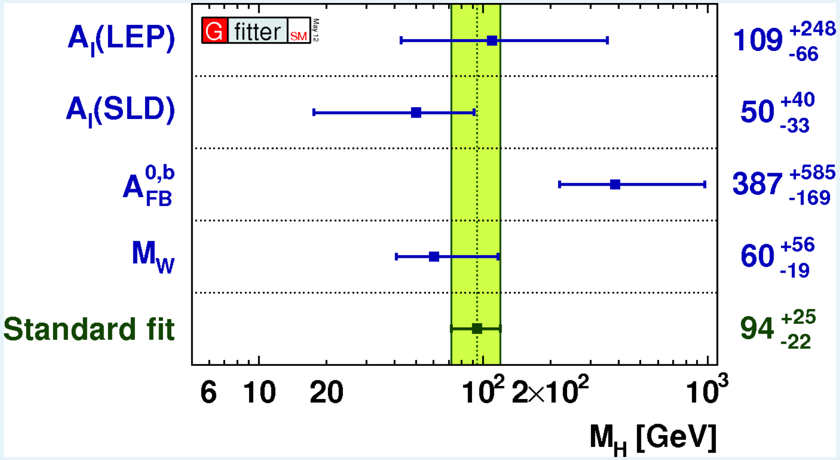
Also LHC data / new variables?

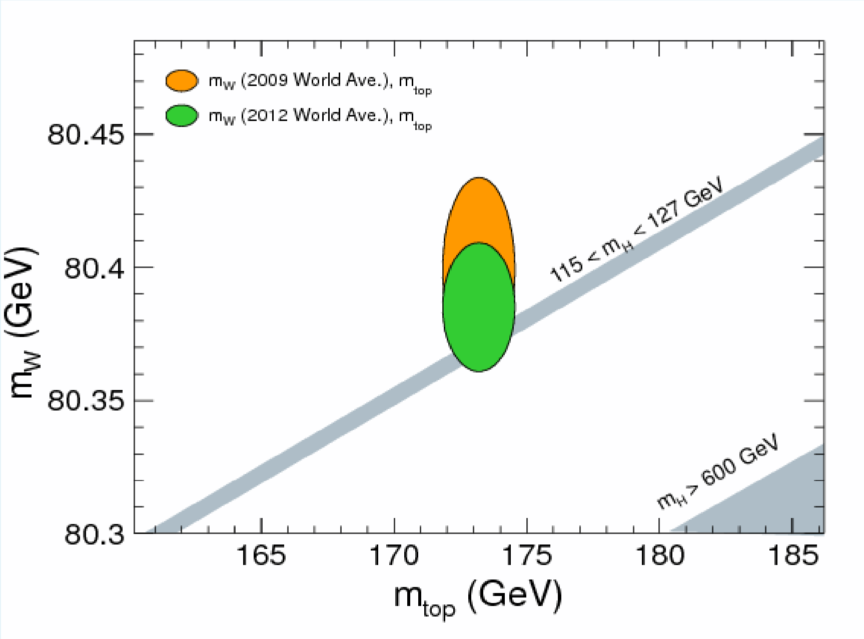
To Higgs-inity...

2011:



Today:

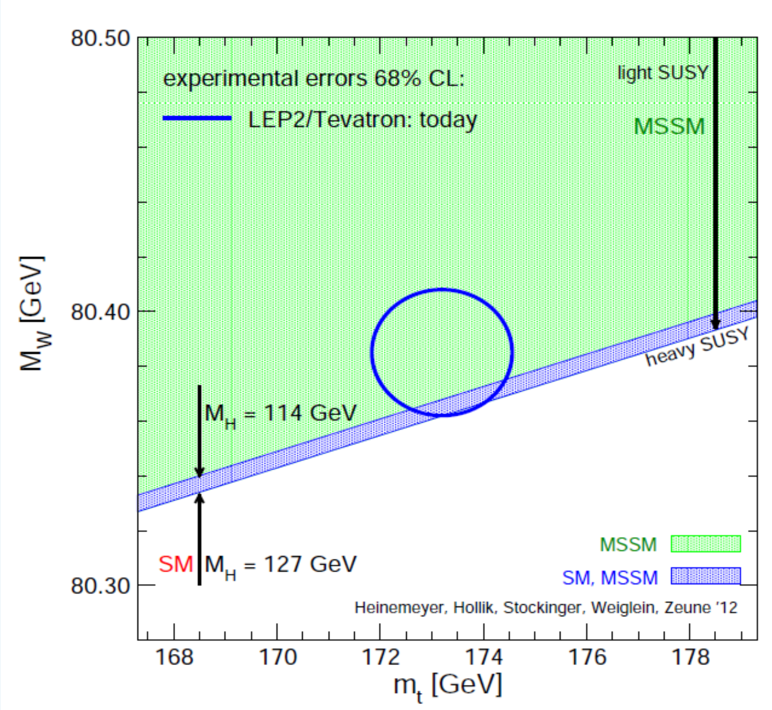




Without m_W: $m_H = 106^{+71}_{-32}$ GeV

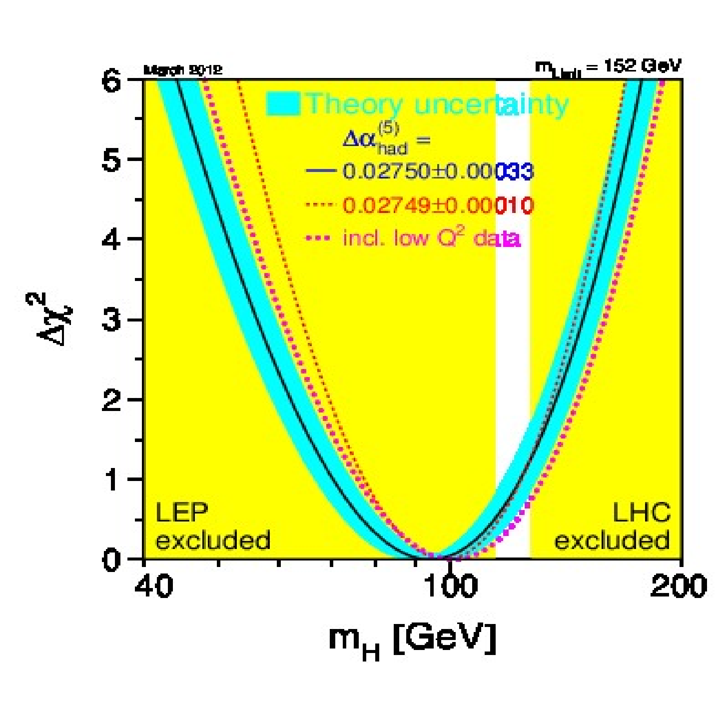
...and beyond

Discover light Higgs



m_W provides significant constraint on new physics

Exclude light Higgs



m_W provides many-sigma demonstration of new physics

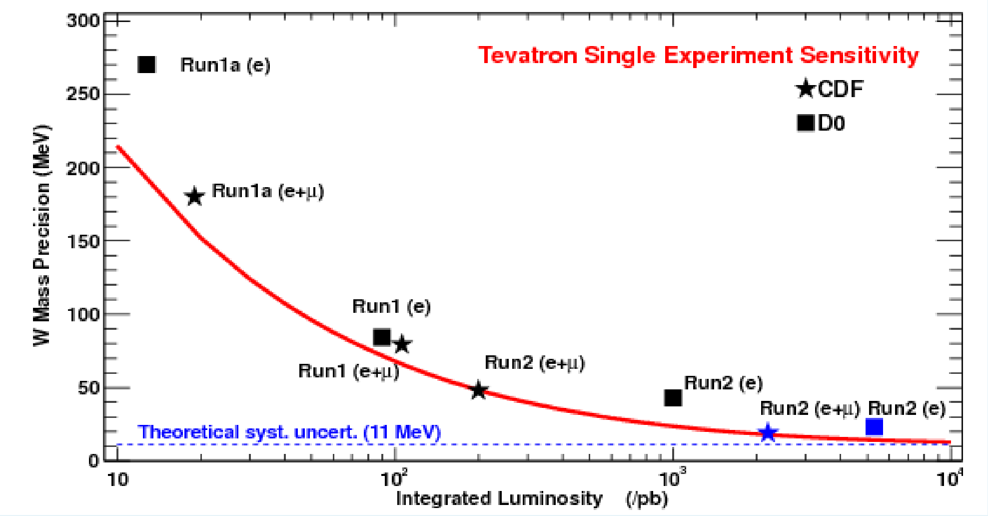
Summary

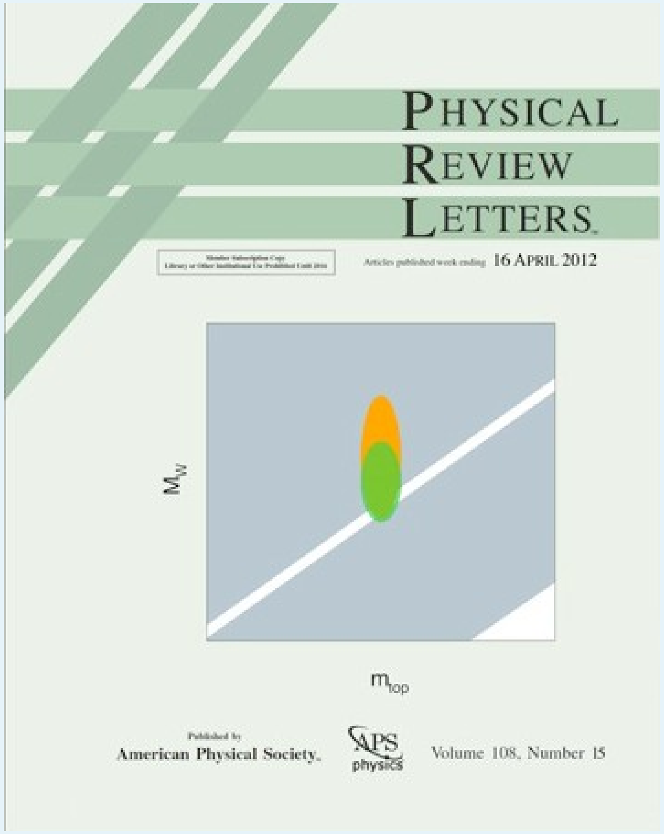
Combined CDF + D0 measurement achieves 16 MeV precision

Factor of 2 improvement over LEP

More precise than indirect m_W determinations

CDF measurement alone more precise than the previous world average





Results published in PRL and highlighted on PRL cover

Further precision possible with complete Tevatron data set