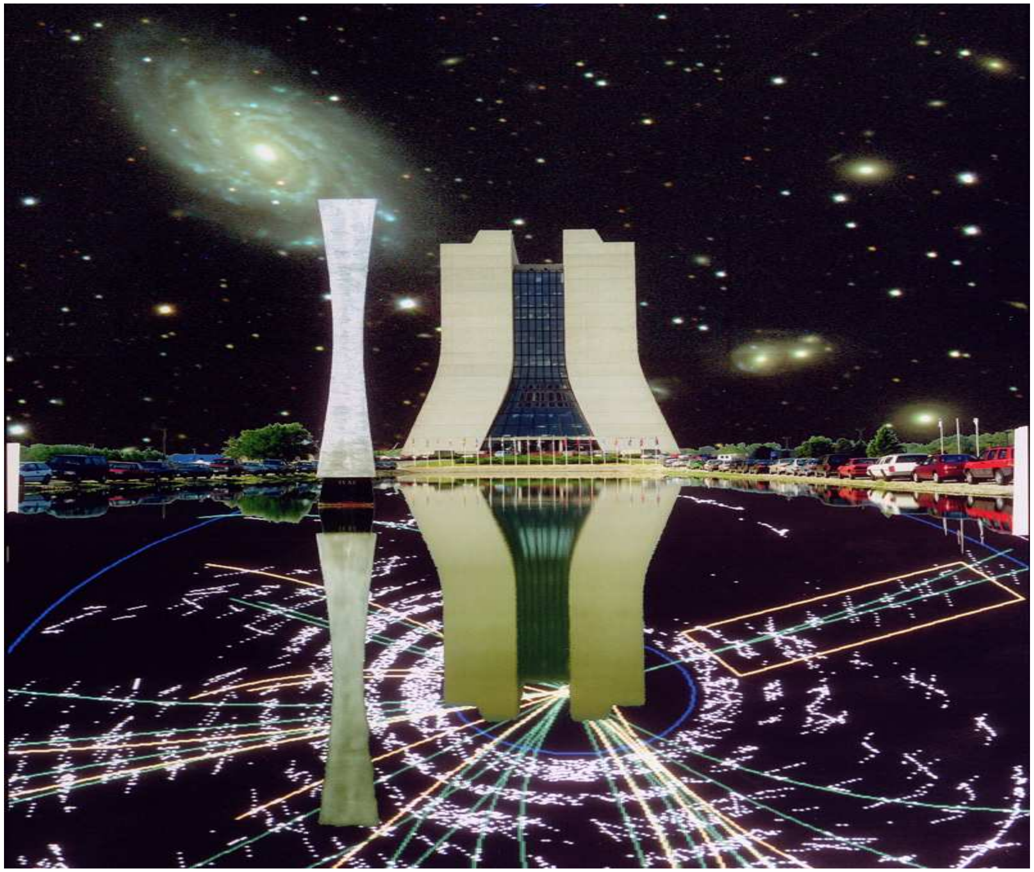
Measurement of the W Boson Mass at the Tevatron

Ashutosh Kotwal
Duke University
for the CDF and D0 Collaborations



34th International Conference on High Energy Physics
University of Pennsylvania
30 July 2008

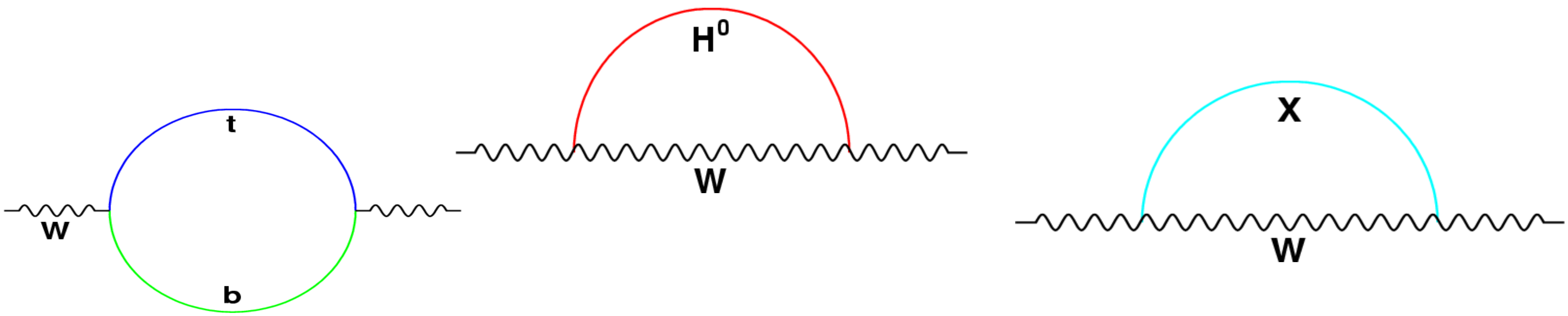
Motivation

- The electroweak gauge sector of the standard model is constrained by three precisely known parameters
  - $\alpha_{EM} (M_Z) = 1 / 127.918(18)$
  - $G_F = 1.16637\ (1) \times 10^{-5}\ \text{GeV}^{-2}$

    $M_Z = 91.1876\ (21)\ \text{GeV}$
- At tree-level, these parameters are related to M_W by
  - $M_W{}^2 = \pi\alpha_{EM} / \sqrt{2} G_F \sin^2\theta_W$
    - Where θ_W is the weak mixing angle, defined by $\cos\theta_W = M_W/M_Z$

Motivation

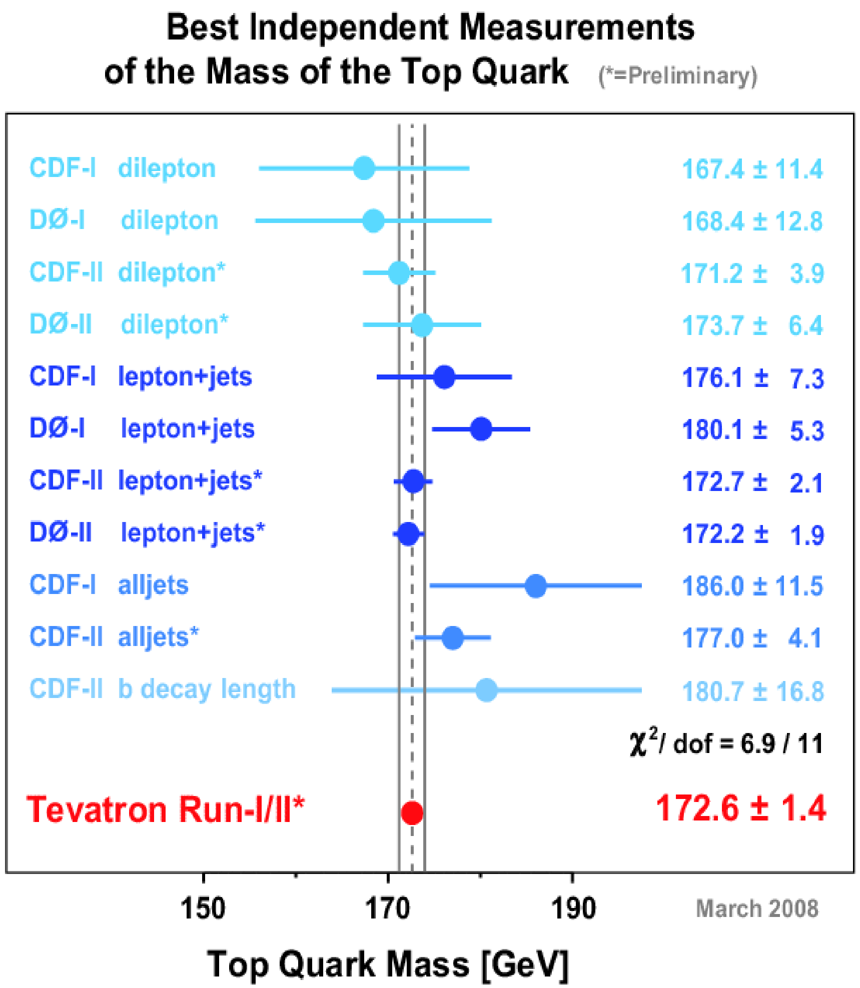
- Radiative corrections due to heavy quark and Higgs loops and exotica



Motivate the introduction of the ρ parameter: $M_W^2 = \rho\,[M_W(\text{tree})]^2$
with the predictions $(\rho - 1) \sim M_{top}^2$ and $(\rho - 1) \sim \ln M_H$

- In conjunction with M_{top}, the W boson mass constrains the mass of the Higgs boson, and possibly new particles beyond the standard model

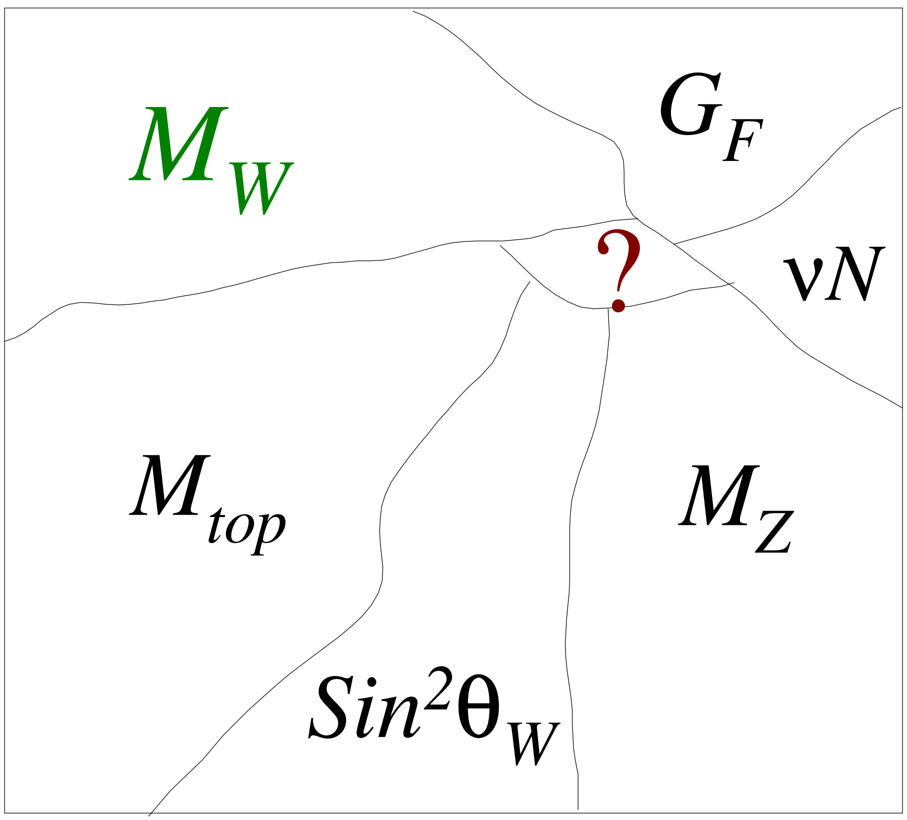
Progress on M_{top} at the Tevatron



- From the Tevatron, δM_{top} = 1.4 GeV => $\delta M_H / M_H$ = 12%
- equivalent δM_W = 8 MeV for the same Higgs mass constraint
- Current world average δM_W = 25 MeV
  - progress on δM_W now has the biggest impact on Higgs constraint!

Motivation

- SM Higgs fit: $M_H = 87^{+36}_{-27}$ GeV (LEPEWWG & TeVEWWG, M. Grunewald)
- LEPII direct searches: $M_H > 114.4$ GeV @ 95% CL (PLB 565, 61)



In addition to the Higgs,
is there another missing piece
in this puzzle?

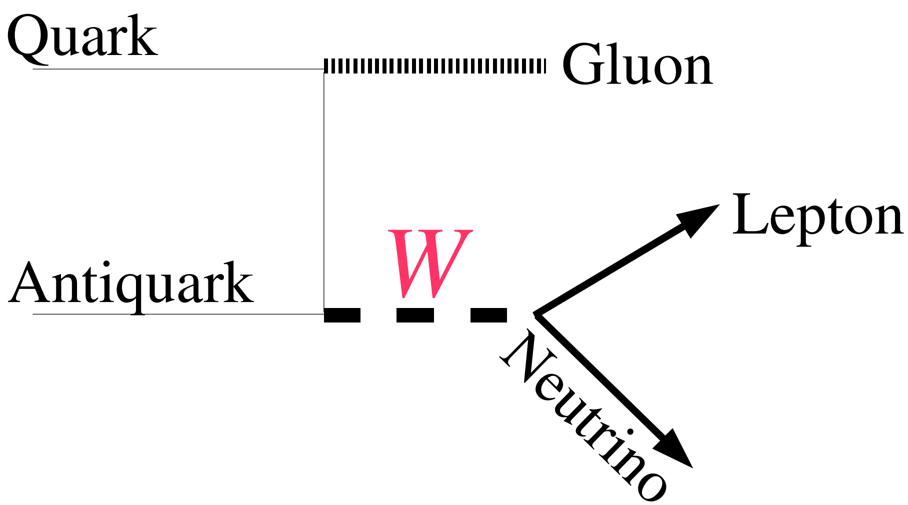
(A_{FB}^b *vs* A_{LR}: 3.2σ)

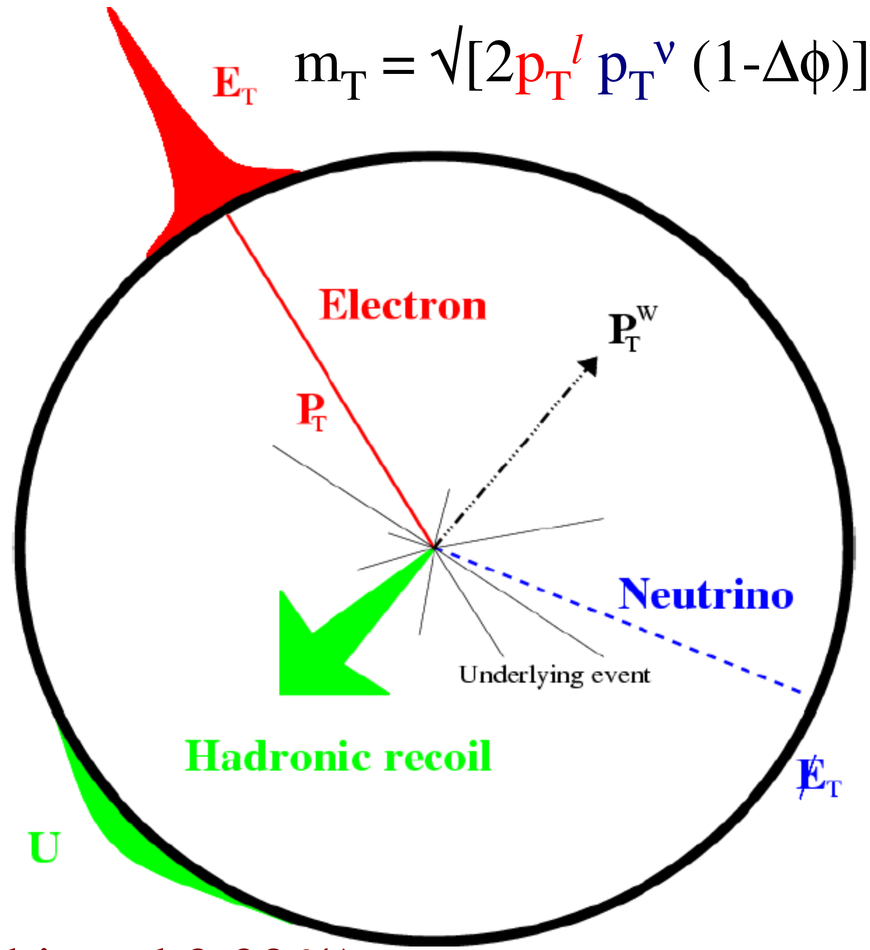
Must continue improving
precision of M_W, M_{top} ...

other precision measurements constrain Higgs, equivalent to $\delta M_W \sim 20$ MeV

Motivate direct measurement of M_W at the 20 MeV level

W Boson Production at the Tevatron





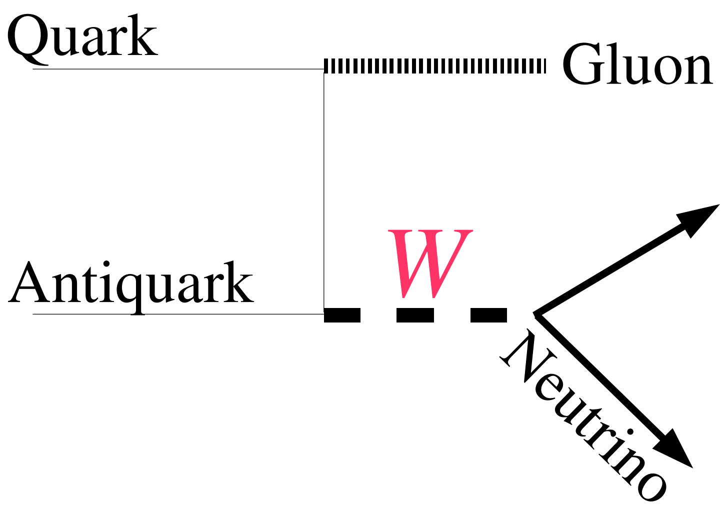
Quark-antiquark annihilation dominates (80%)

Lepton p_T carries most of *W* mass information, can be measured precisely (achieved 0.03%)

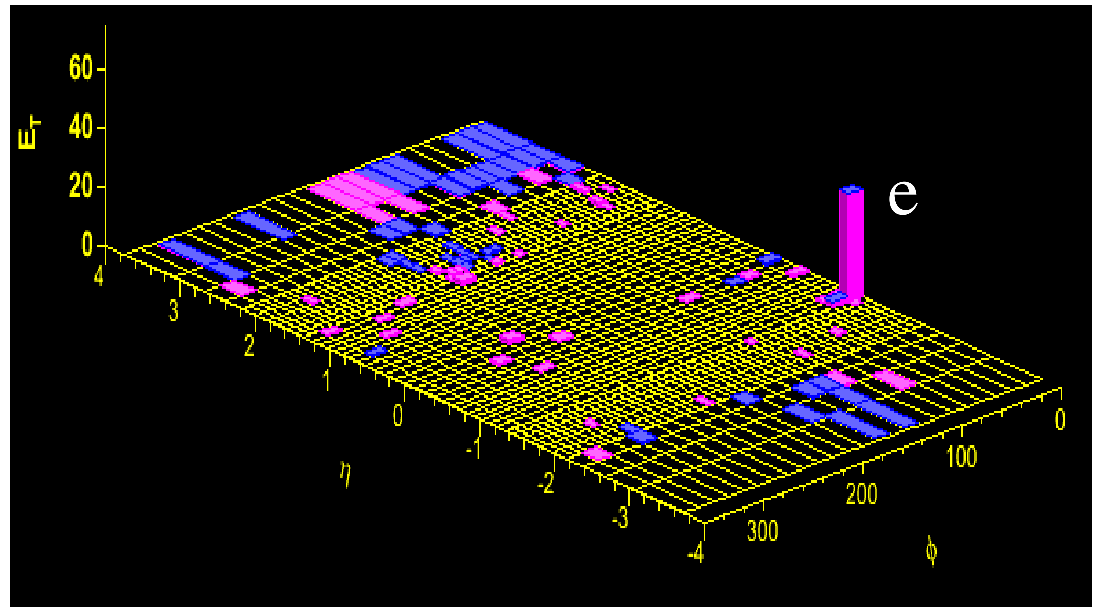
Initial state QCD radiation is *O*(10 GeV), measure as soft 'hadronic recoil' in calorimeter (calibrated to ~1%)

Pollutes *W* mass information, fortunately $p_T(W) << M_W$

W Boson Production at the Tevatron



$m_T = \sqrt{[2 p_T^{l}\, p_T^{\nu}\, (1-\Delta\phi)]}$



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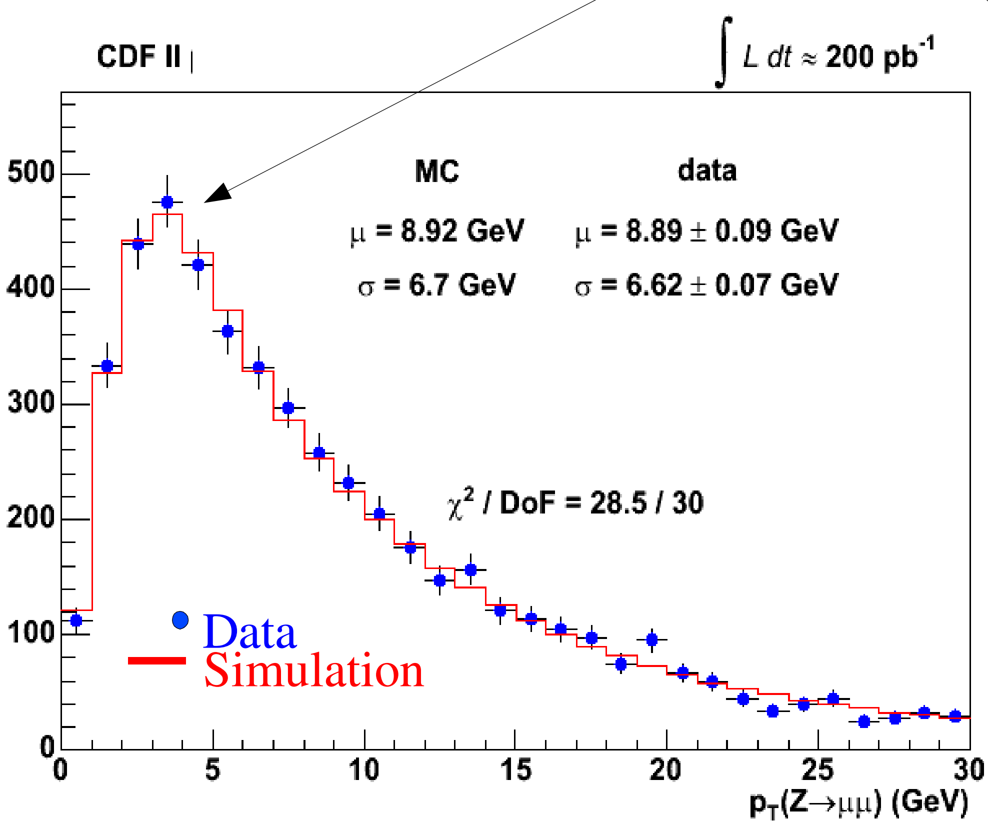
Constraining Boson p_T Spectrum

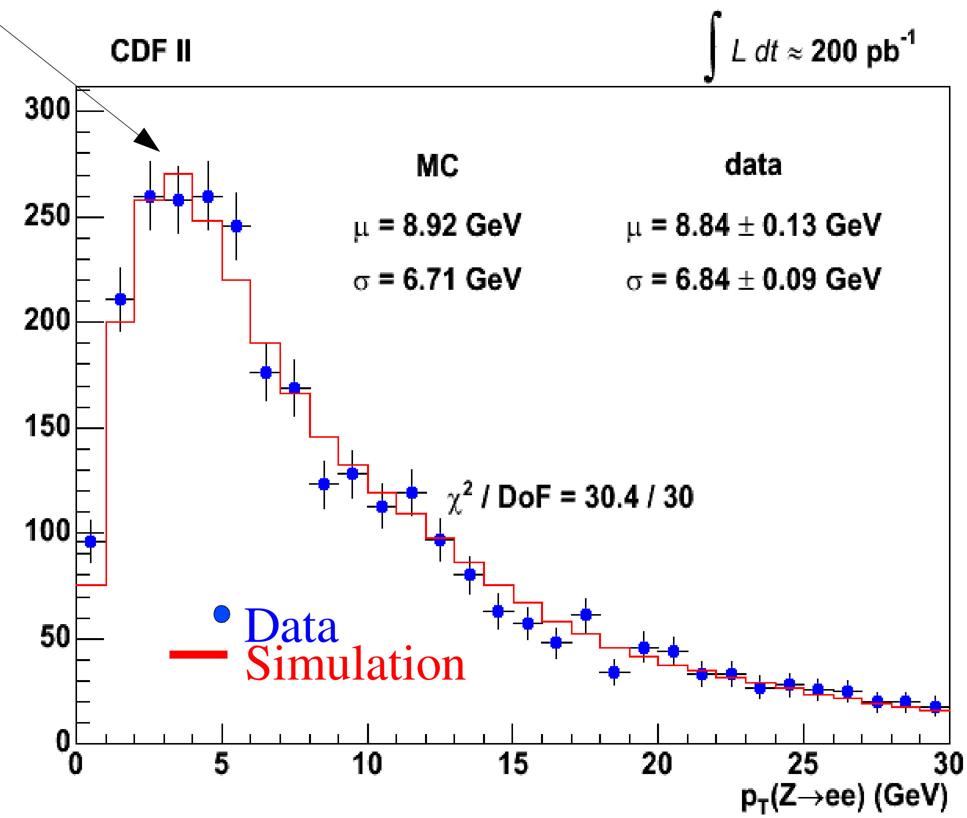
- Fit the well-measured dilepton $p_T(ll)$ spectra for non-perturbative model parameter (D0 Collaboration, PRL 100, 102002; CDF Collaboration, PRD 77:112001)

$\Delta M_W = 3$ MeV

  - Consistent with global fits (Landry *et al*, PRD67, 073016 (2003))

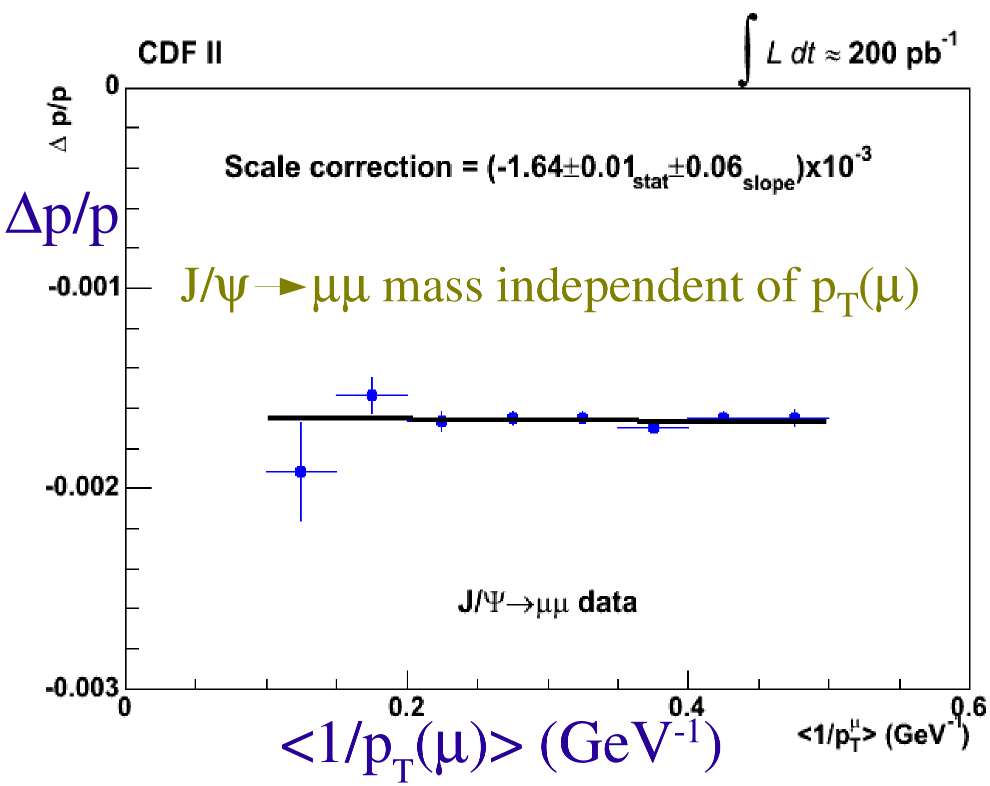
Position of peak in boson p_T spectrum depends on non-perturbative parameter

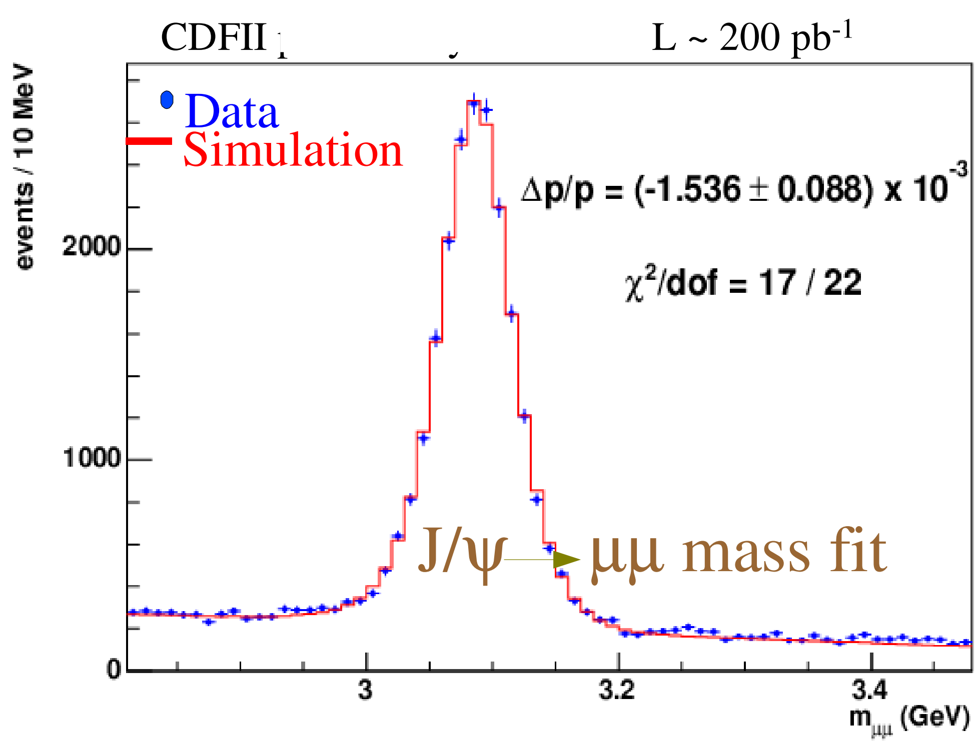




Tracking Momentum Scale

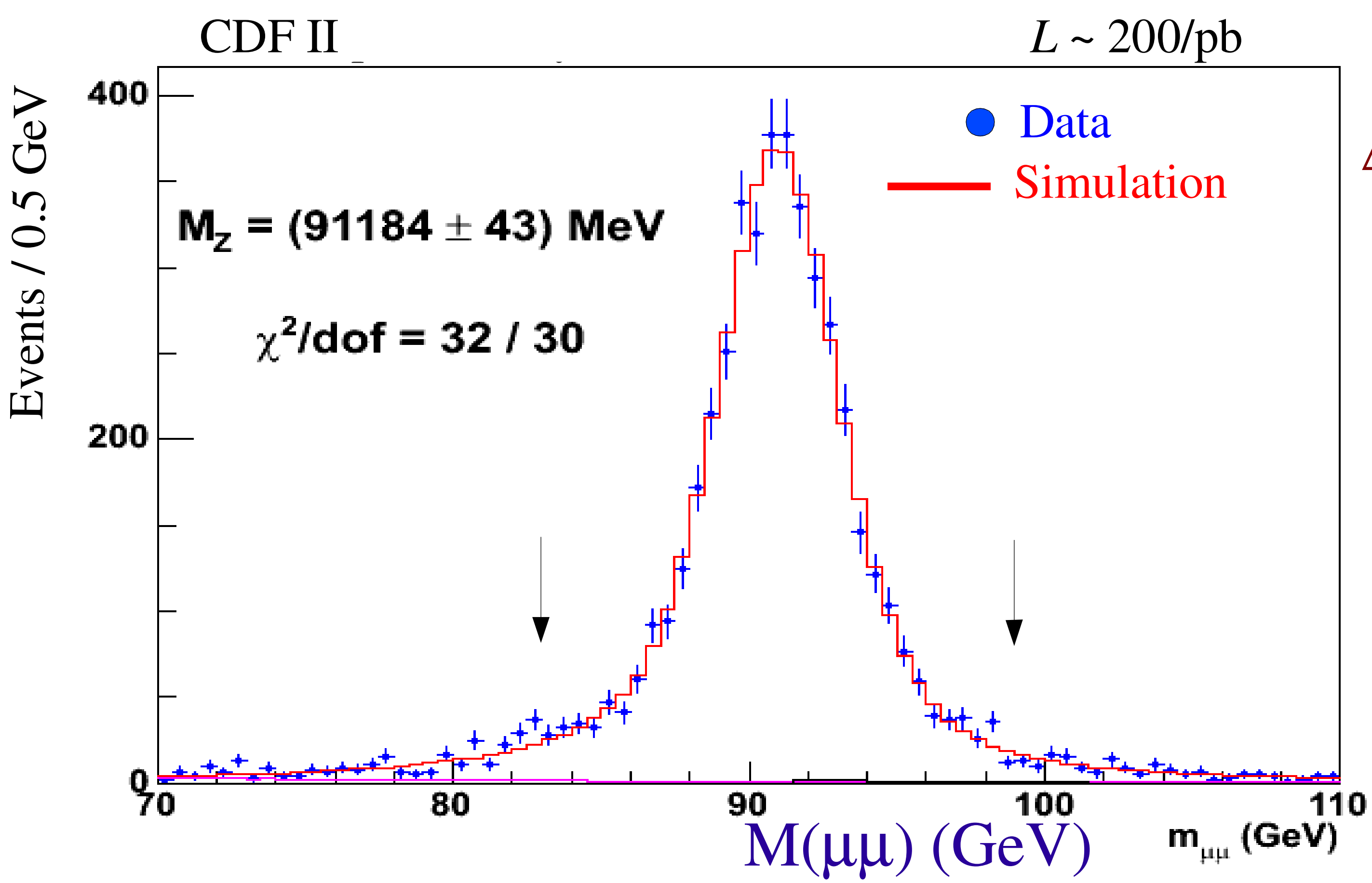
- Set using $J/\psi \to \mu\mu$ and $Y \to \mu\mu$ resonance and $Z \to \mu\mu$ masses
  - All are individually consistent with each other
- J/ψ: $\Delta p/p = (-1.64 \pm 0.06_{stat} \pm 0.24_{sys}) \times 10^{-3}$
  - Extracted by fitting J/ψ mass in bins of $<1/p_T(\mu)>$, and extrapolating momentum scale to high momentum





$Z \to \mu\mu$ Mass Cross-check & Combination

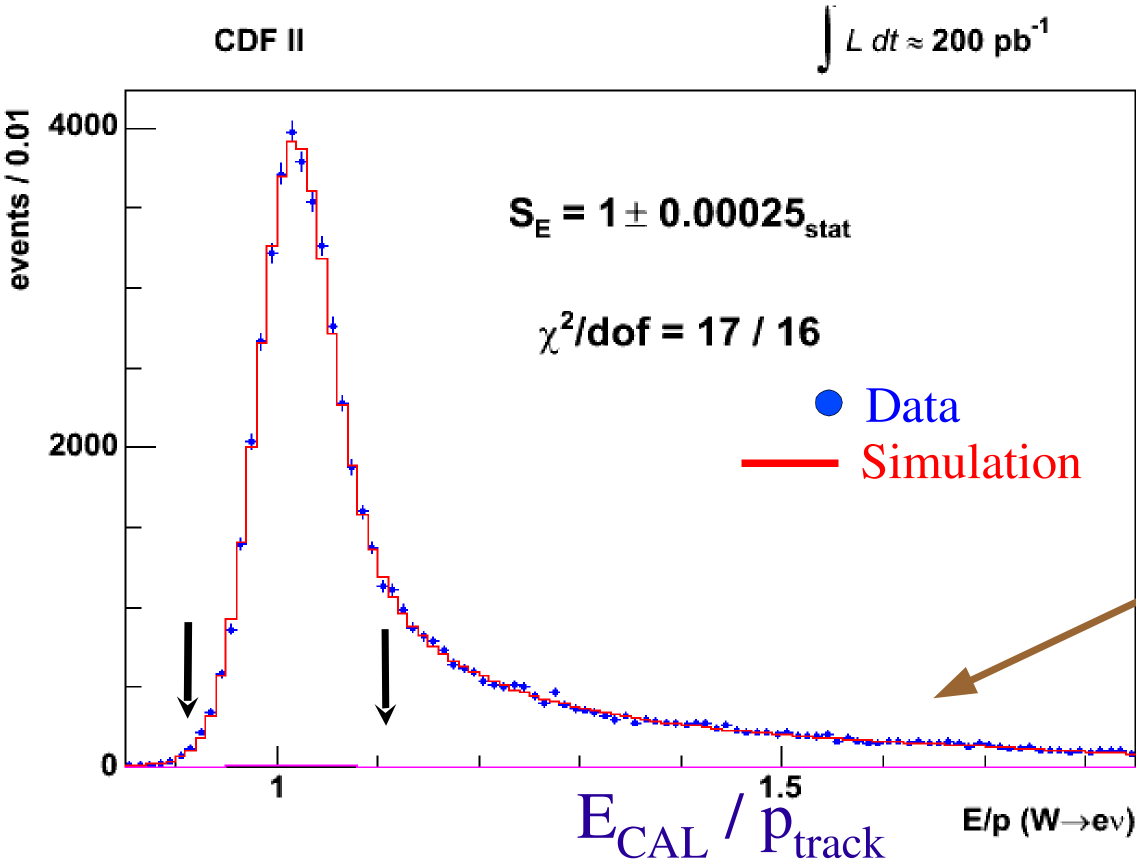
- Using the J/ψ and Υ momentum scale, measured *Z* mass is consistent with PDG value
- Final combined: $\Delta p/p = (-1.50 \pm 0.15_{independent} \pm 0.13_{QED} \pm 0.07_{align}) \times 10^{-3}$



$\Delta M_W = 17$ MeV

EM Calorimeter Scale

- E/p peak from $W \rightarrow e\nu$ decays provides measurements of EM calorimeter scale and its (E_T-dependent) non-linearity
  - $S_E = 1 \pm 0.00025_{stat} \pm 0.00011_{X0} \pm 0.00021_{Tracker}$
- Setting S_E to 1 using E/p calibration

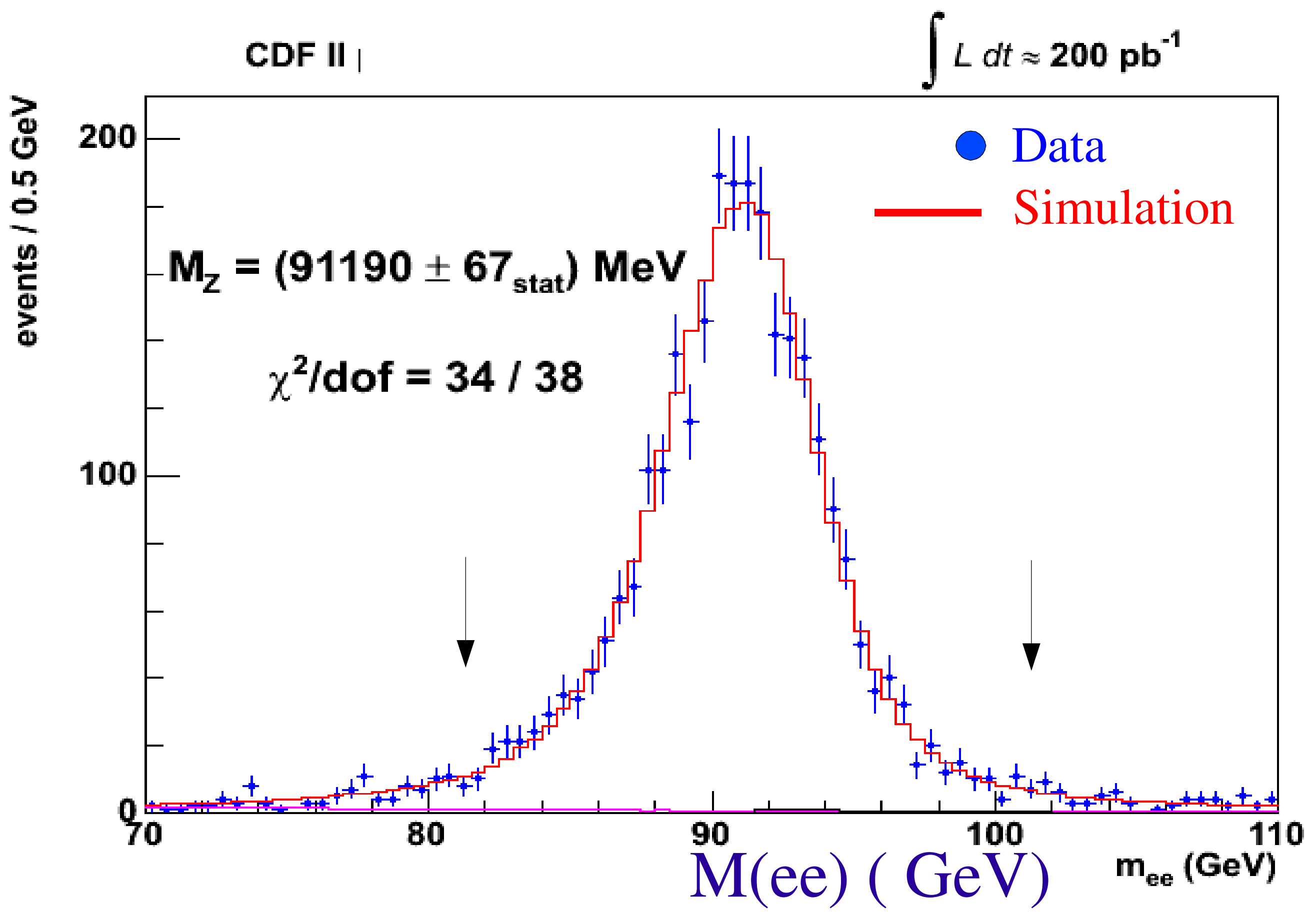


Tail region of E/p spectrum used for tuning model of radiative material

$Z \rightarrow$ ee Mass Cross-check and Combination

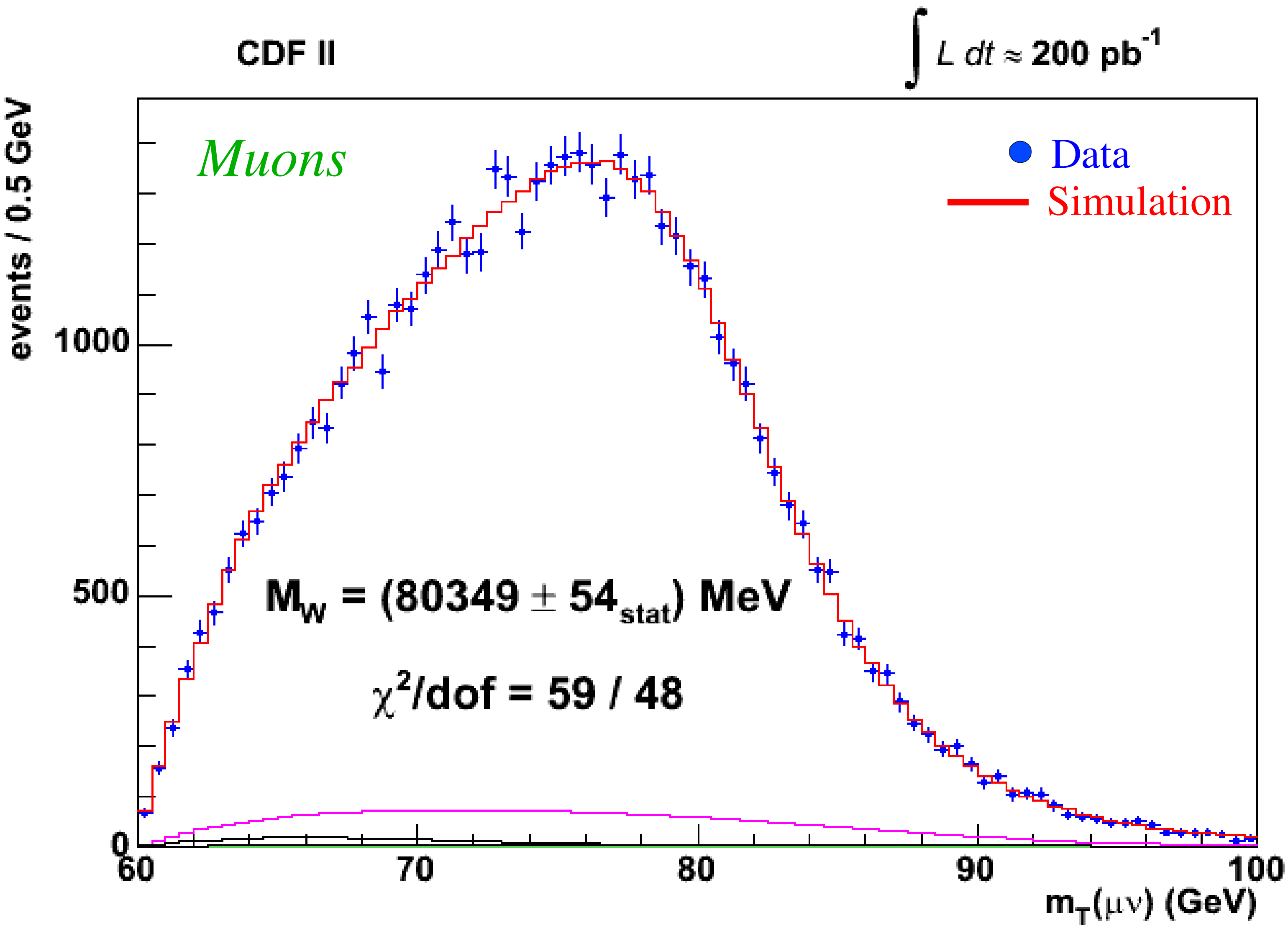
- Z mass consistent with E/p-based measurements
- Combining E/p-derived scale & non-linearity measurement with $Z \rightarrow ee$ mass yields the most precise calorimeter energy scale:
  - $S_E = 1.00001 \pm 0.00037$

$\Delta M_W = 30$ MeV



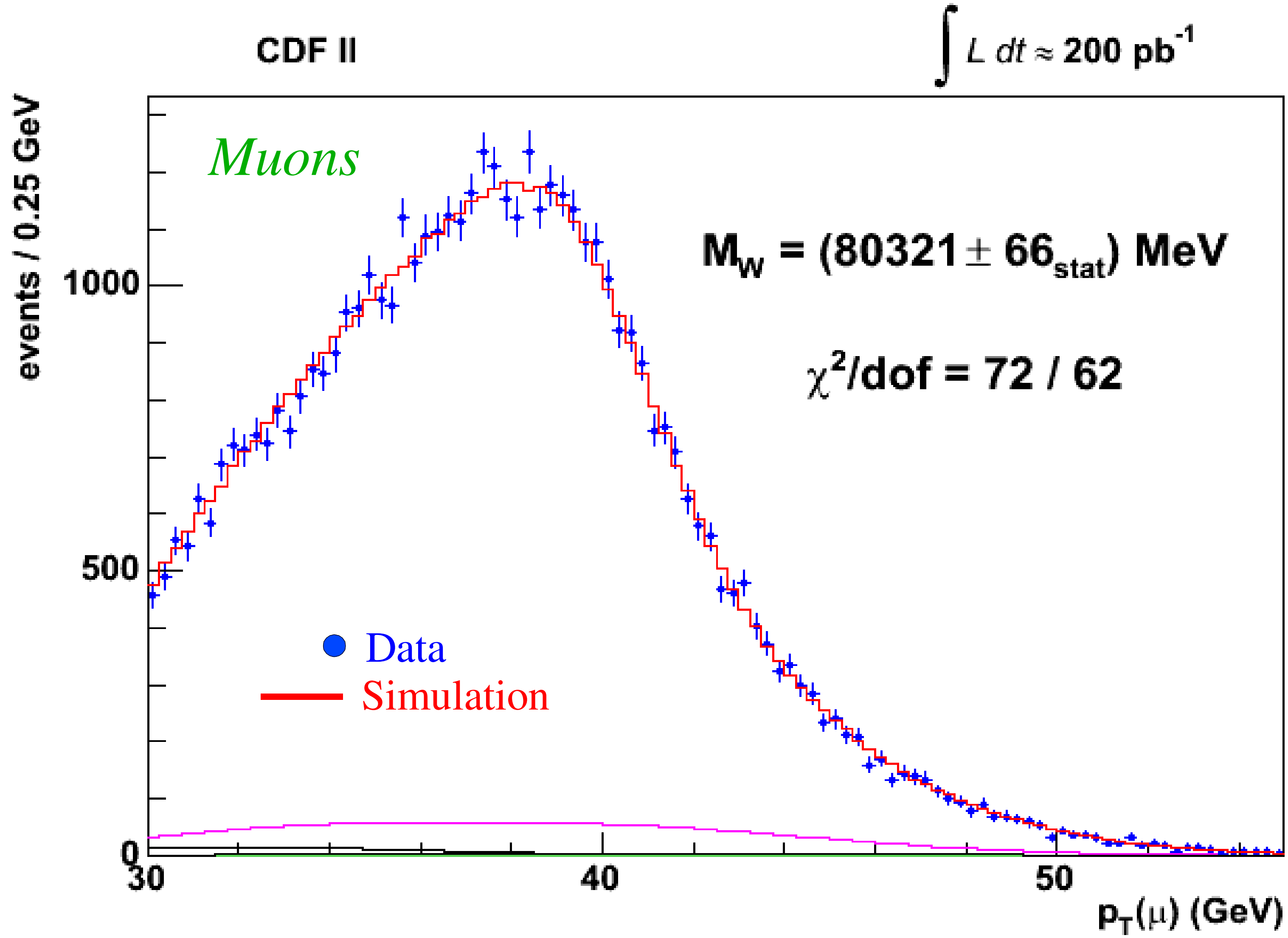
W Boson Mass Fits

(CDF, PRL 99:151801, 2007; Phys. Rev. D 77:112001, 2008)



W Lepton p_T Fits

(CDF, PRL 99:151801, 2007; Phys. Rev. D 77:112001, 2008)



Transverse Mass Fit Uncertainties (MeV)

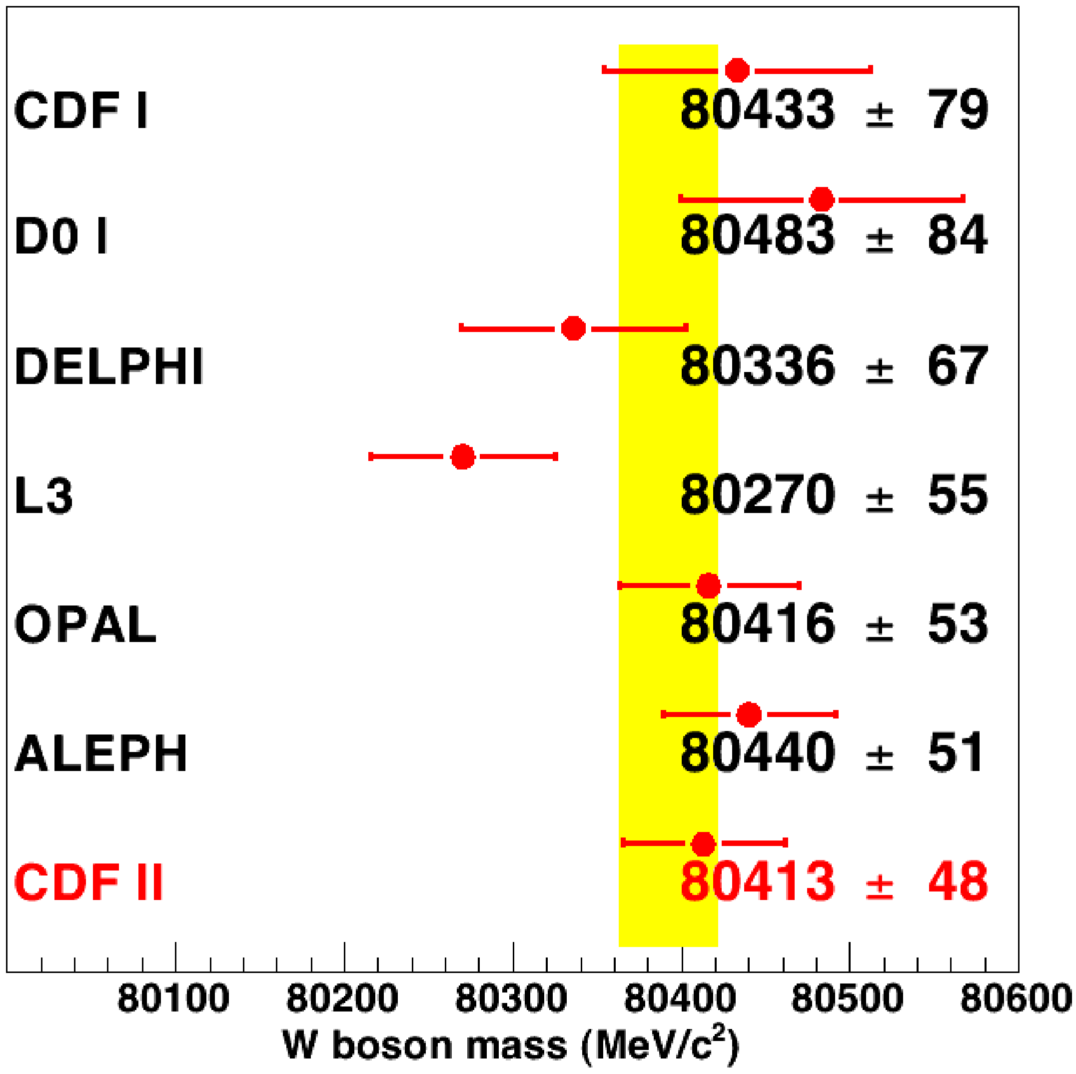
(CDF, PRL 99:151801, 2007; Phys. Rev. D 77:112001, 2008)

	electrons	*muons*	*common*
W statistics	48	54	0
Lepton energy scale	30	17	17
Lepton resolution	9	3	-3
Recoil energy scale	9	9	9
Recoil energy resolution	7	7	7
Selection bias	3	1	0
Lepton removal	8	5	5
Backgrounds	8	9	0
pT(W) model	3	3	3
Parton dist. Functions	11	11	11
QED rad. Corrections	11	12	11
Total systematic	**39**	**27**	**26**
Total	**62**	**60**	

W charge asymmetry from Tevatron helps with PDFs → Parton dist. Functions

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

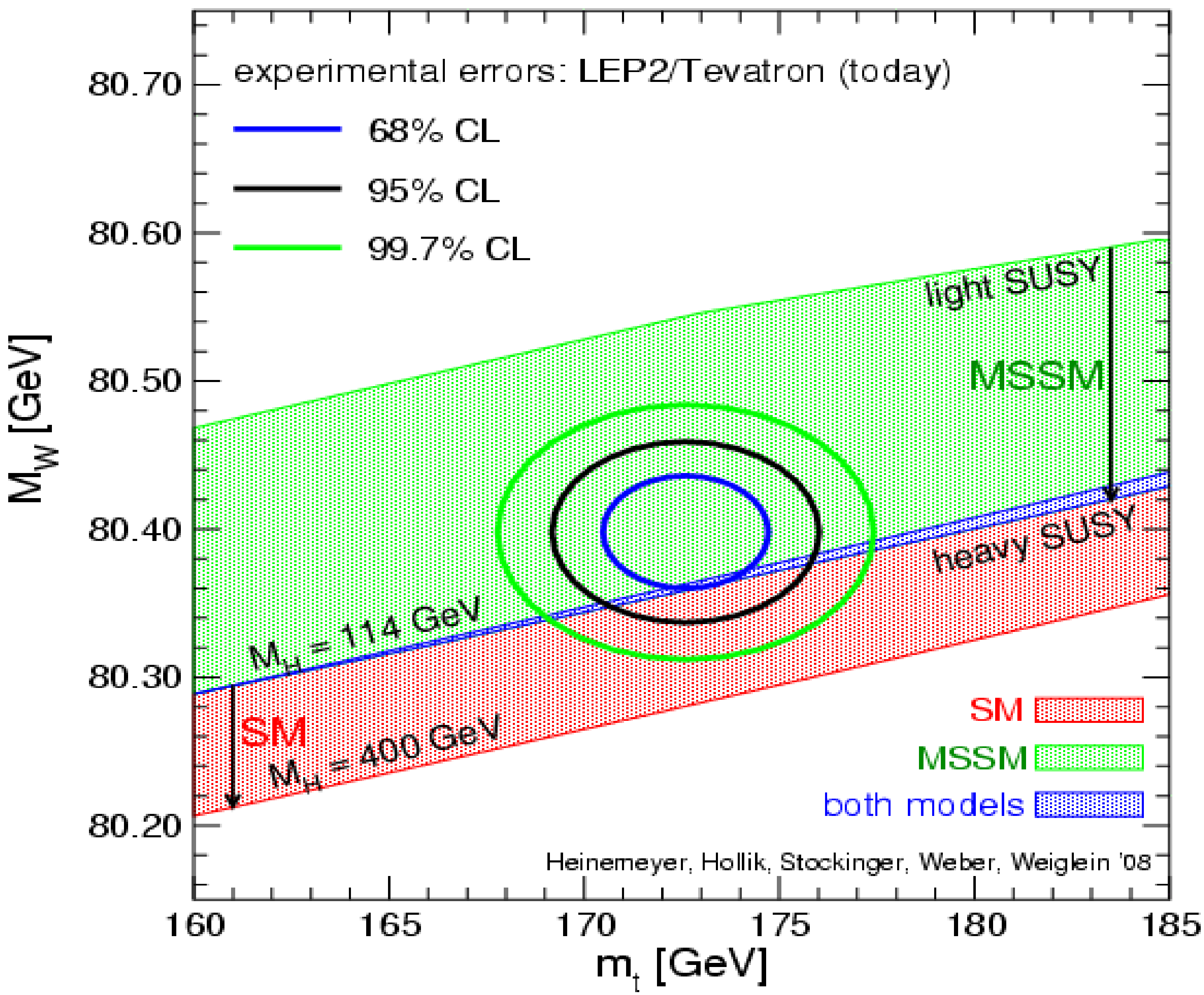
Comparisons



The CDF Run 2 result is the most precise single measurement of the W mass

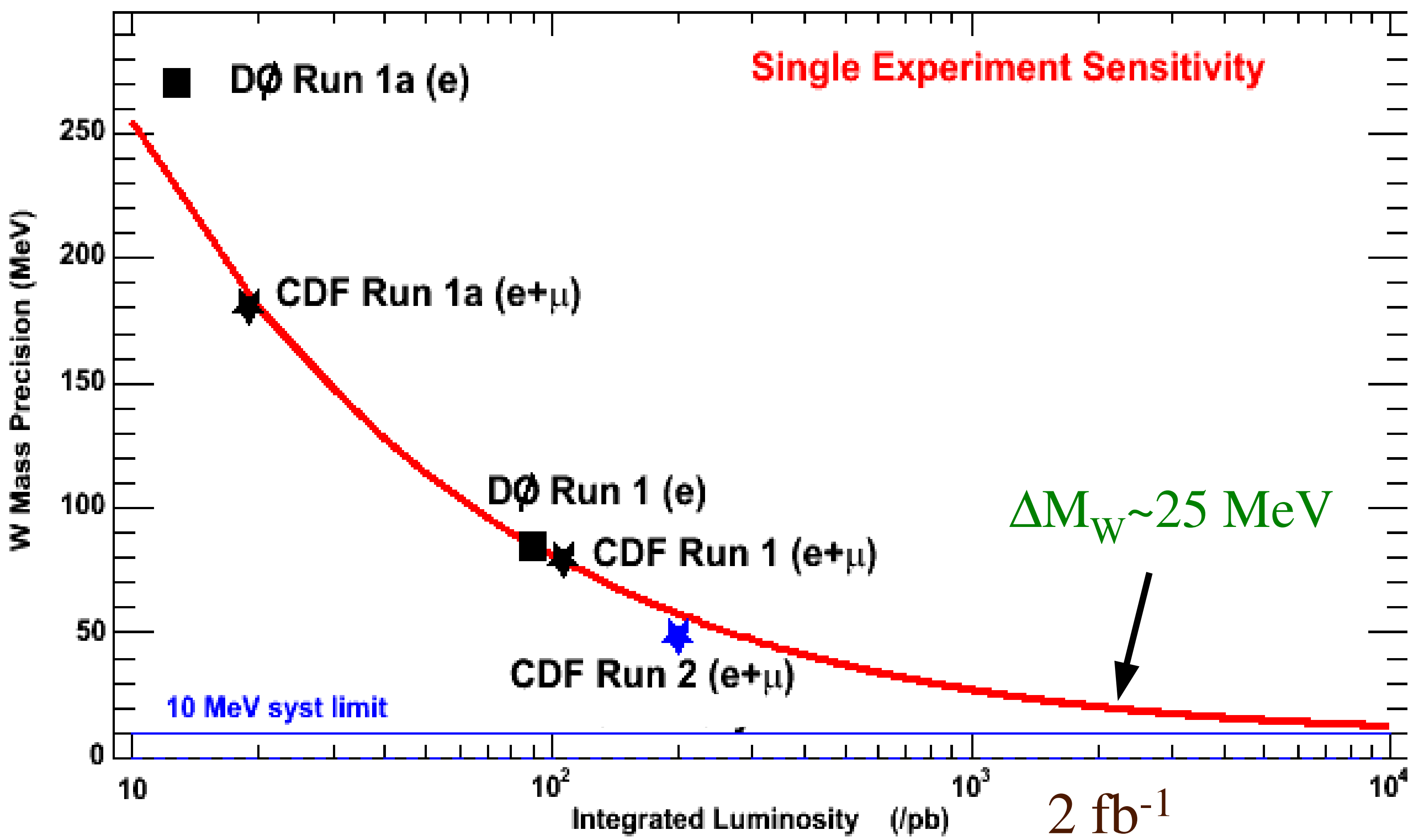
(PRL 99:151801, 2007; Phys. Rev. D 77:112001, 2008)

M_W *vs* M_{top}



experimental errors: LEP2/Tevatron (today)
68% CL
95% CL
99.7% CL
light SUSY
MSSM
heavy SUSY
M_H = 114 GeV
SM
M_H = 400 GeV
SM
MSSM
both models
Heinemeyer, Hollik, Stockinger, Weber, Weiglein '08
80.70
80.60
80.50
80.40
80.30
80.20
M_W [GeV]
160
165
170
175
180
185
m_t [GeV]

Preliminary Studies of 2.4 fb^{-1} Data

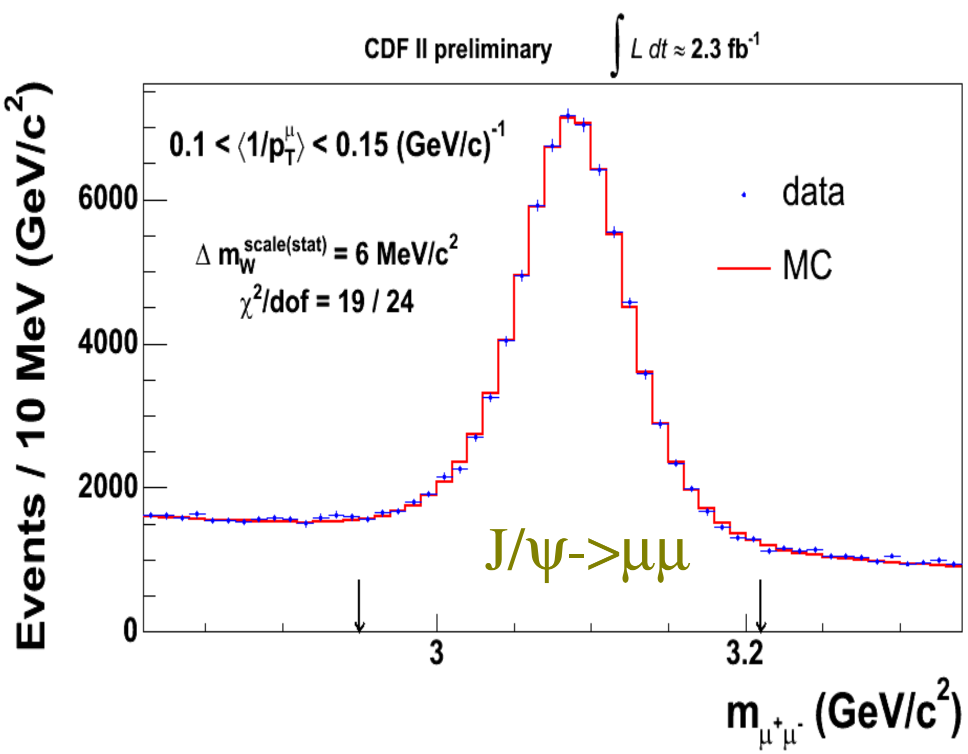


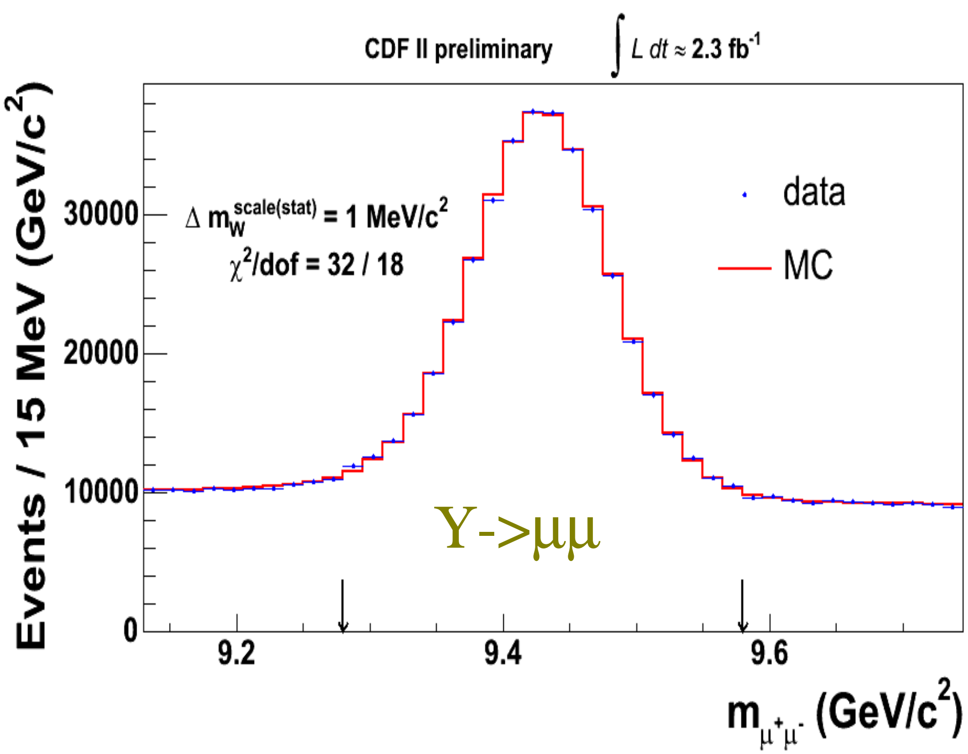
Preliminary Studies of 2.4 fb^{-1} Data

CDF has started the analysis of 2.3 fb^{-1} of data, with the goal of measuring M_W with precision better than 25 MeV

Tracker alignment with cosmic rays has been completed for this dataset

Lepton resolutions as good as they were in 200 pb^{-1} sample



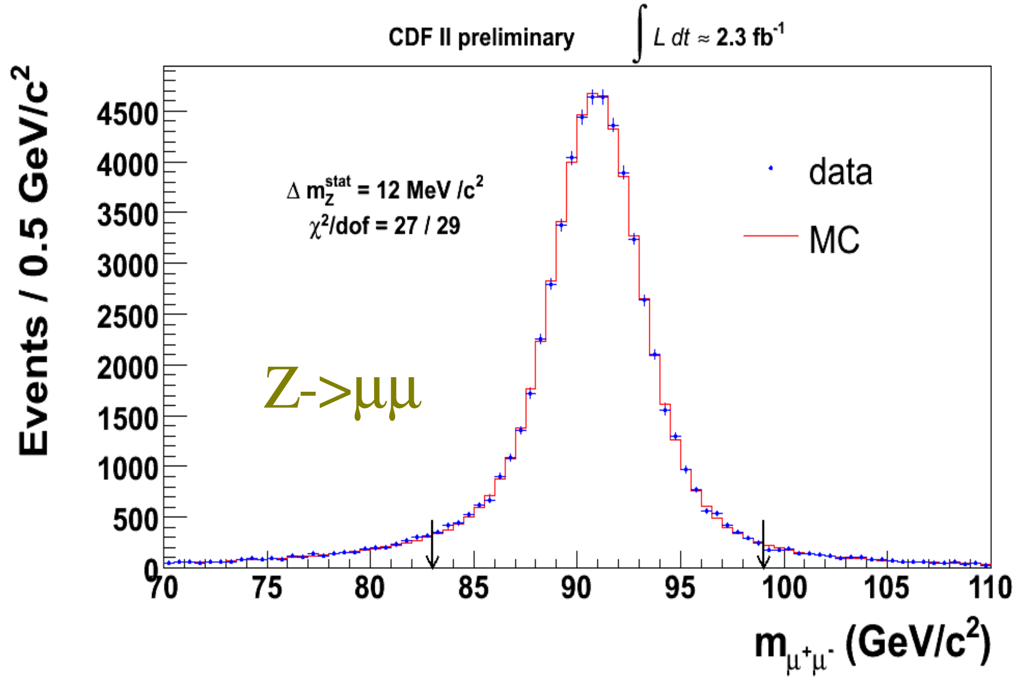


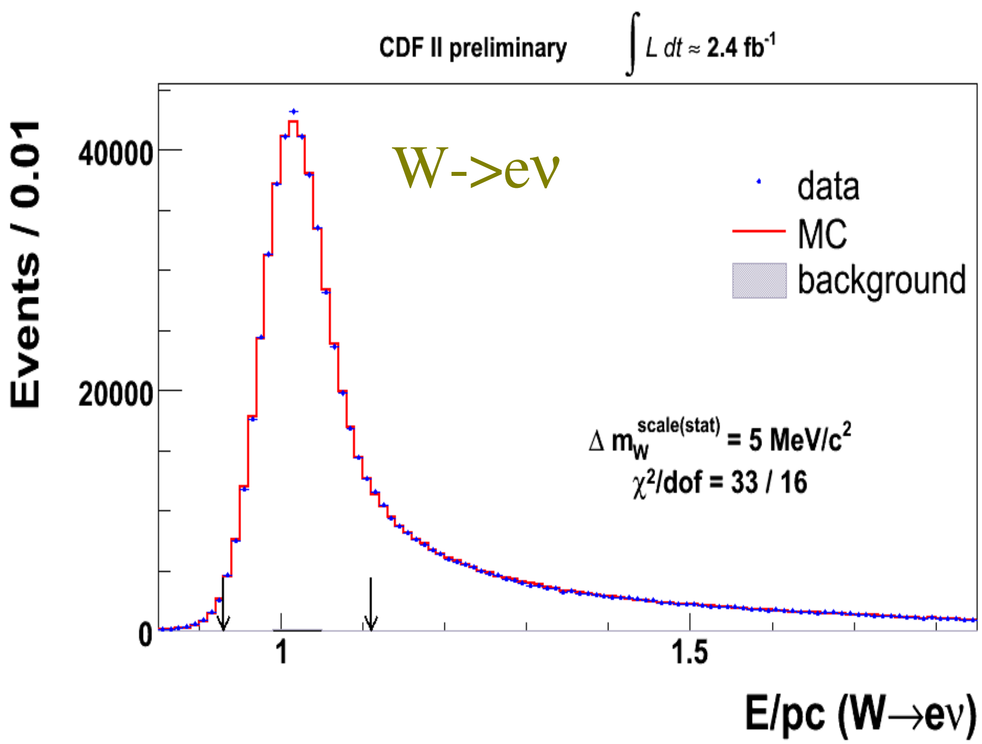
Preliminary Studies of 2.4 fb^{-1} Data

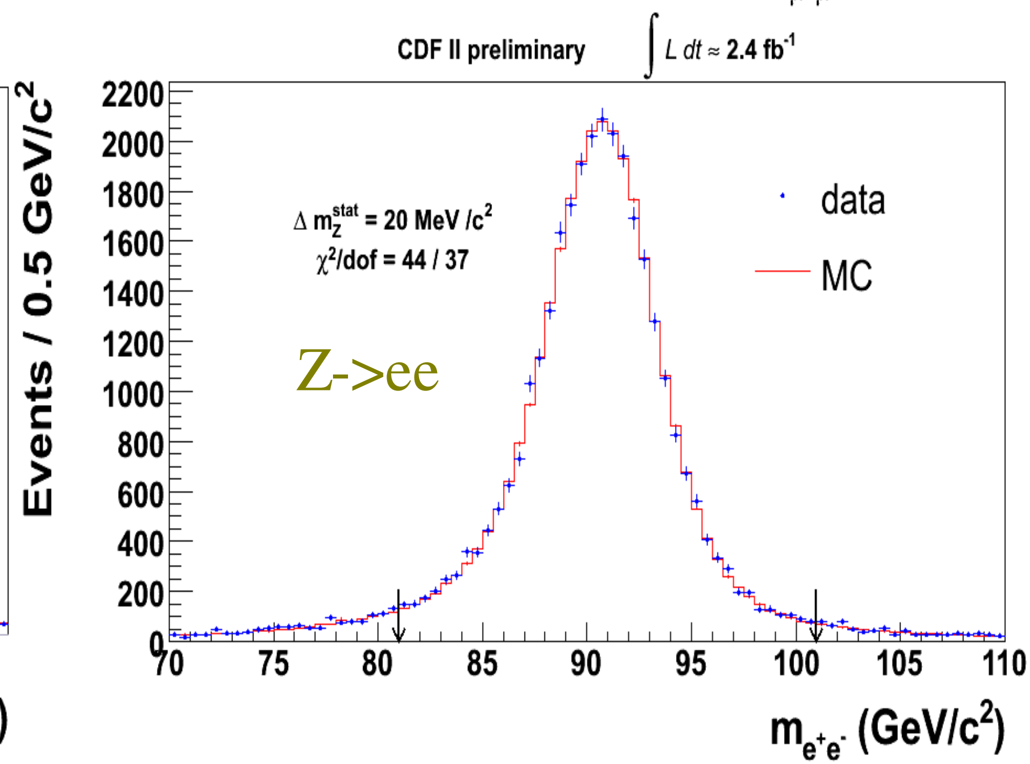
Statistical errors on all lepton calibration fits have scaled with statistics

Detector and data quality maintained over time

detailed calibrations in progress

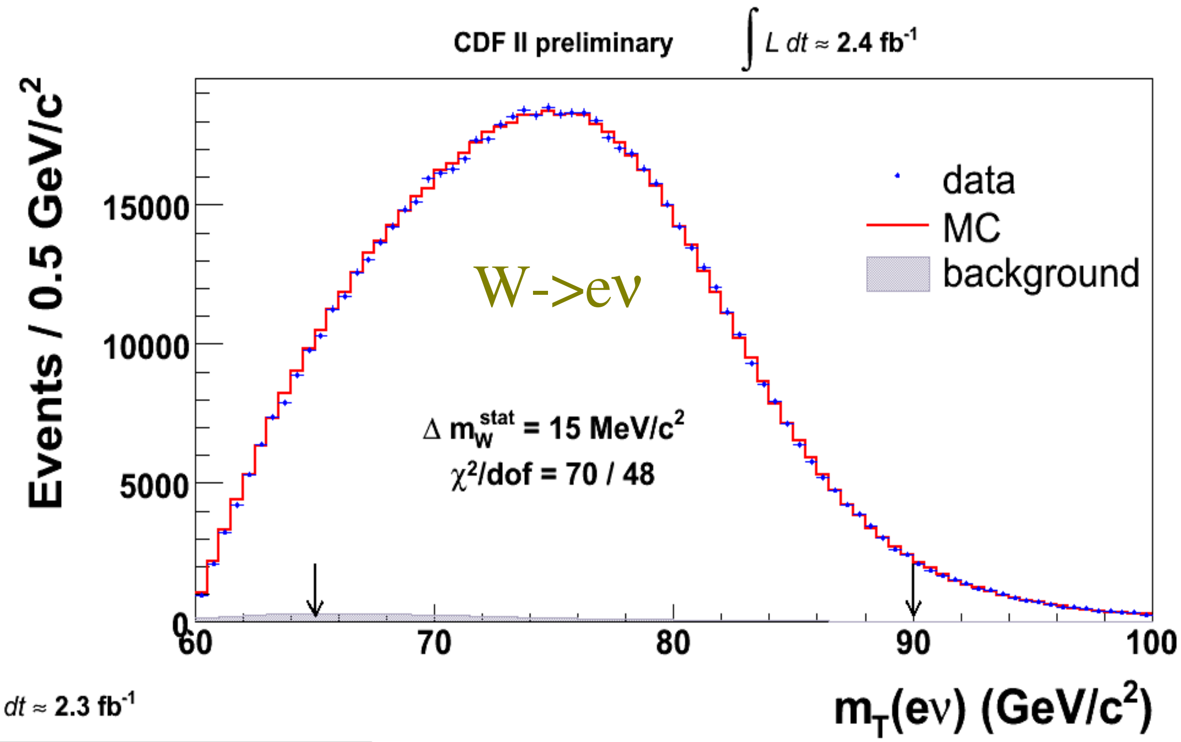


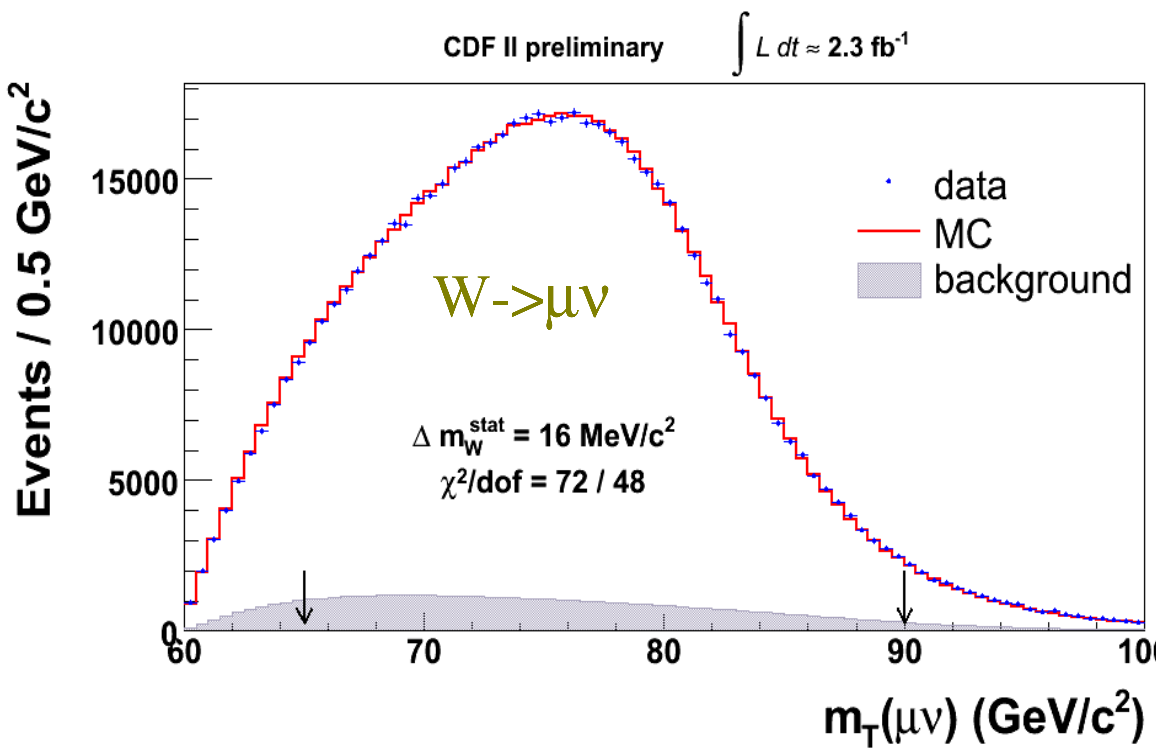




Preliminary Studies of 2.4 fb^{-1} Data

Recoil resolution not significantly degraded at higher instantaneous luminosity





statistical errors on transverse mass fits are scaling with statistics

Summary

- The *W* boson mass is a very interesting parameter to measure with increasing precision
- CDF Run 2 W mass result is the most precise single measurement:
  - $M_W = 80413 \pm 34_{stat} \pm 34_{syst}$ MeV
    $= 80413 \pm 48$ MeV

Summary

- The *W* boson mass is a very interesting parameter to measure with increasing precision
- CDF Run 2 W mass result is the most precise single measurement:
  - $M_W = 80413 \pm 34_{stat} \pm 34_{syst}$ MeV
    $= 80413 \pm 48$ MeV
- Most systematics limited by statistics of control samples
  - Looking forward to $\delta M_W < 25$ MeV from ~ 2 fb^{-1} of CDF data
- Measurement from D0 imminent in the electron channel with 1 fb^{-1} data sample

Combined Results

- Combined electrons (3 fits): $M_W = 80477 \pm 62$ MeV, $P(\chi^2) = 49\%$
- Combined muons (3 fits): $M_W = 80352 \pm 60$ MeV, $P(\chi^2) = 69\%$
- All combined (6 fits): $M_W = 80413 \pm 48$ MeV, $P(\chi^2) = 44\%$

Lepton p_T and Missing E_T Fit Uncertainties

CDF II preliminary

Uncertainty (p_T)	Electrons	Muons	Common
Lepton Scale	30	17	17
Lepton Resolution	9	3	0
Recoil Scale	17	17	17
Recoil Resolution	3	3	3
Lepton Removal	0	0	0
$u_{\parallel}$ Efficiency	5	6	0
Backgrounds	9	19	0
$p_T(W)$	9	9	9
PDF	20	20	20
QED	13	13	13
Total Systematic	45	40	35
Statistical	58	66	0
Total	73	77	35

CDF II preliminary

Uncertainty (MET)	Electrons	Muons	Common
Lepton Scale	30	17	17
Lepton Resolution	9	5	0
Recoil Scale	15	15	15
Recoil Resolution	30	30	30
Lepton Removal	16	10	10
$u_{\parallel}$ Efficiency	16	13	0
Backgrounds	7	11	0
$p_T(W)$	5	5	5
PDF	13	13	13
QED	9	10	9
Total Systematic	54	46	42
Statistical	57	66	0
Total	79	80	42