W Boson Mass

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Results from the
CDF and D0 Collaborations

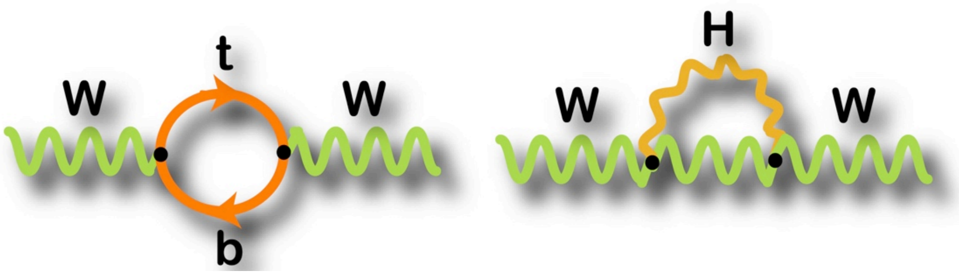
W Boson Mass Measurement

- Loop-level expression for the predicted W mass in terms of other known quantities:

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

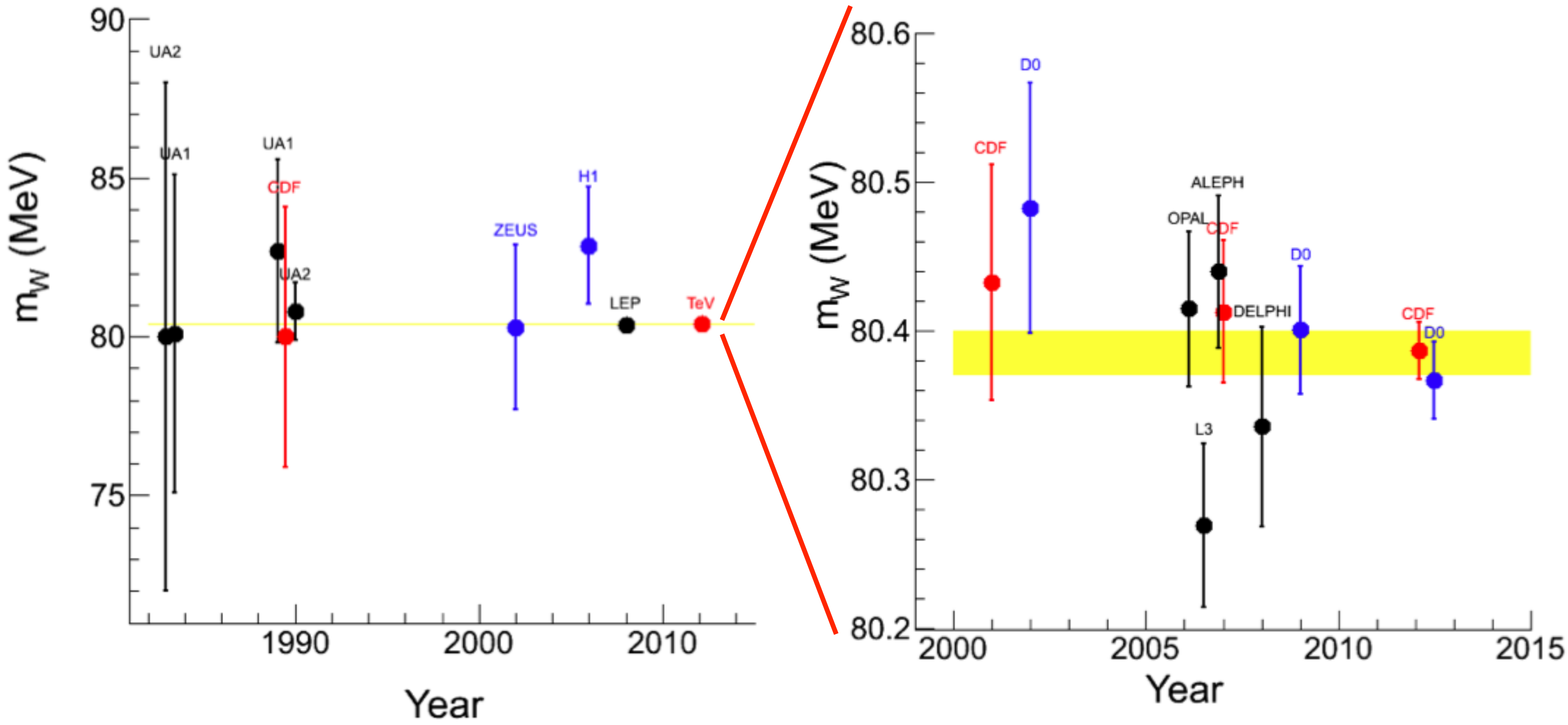
- Loop-induced radiative corrections Δr dominated by
  - Running of α_{em} due to light quark loops
  - Top quark and Higgs loop

⇒allowed indirect constraint on Higgs mass and now comparison to M_H



History of M_W Measurements

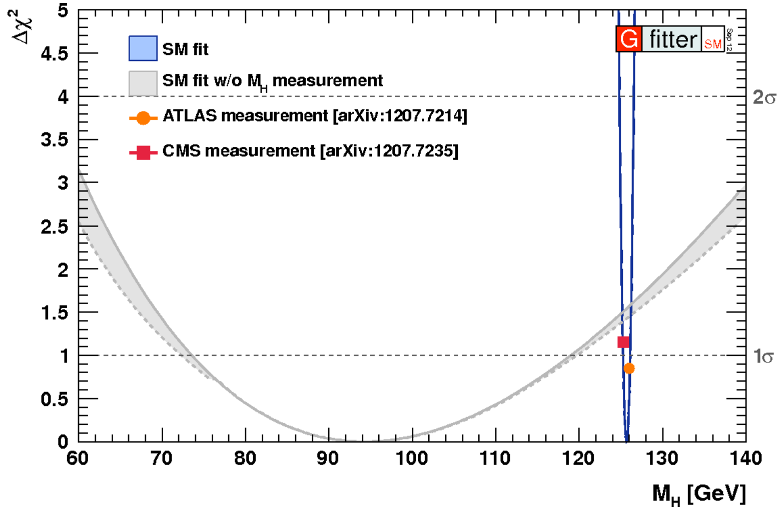
Carried out at several colliders



World average currently dominated by Tevatron

Standard Model Constraints

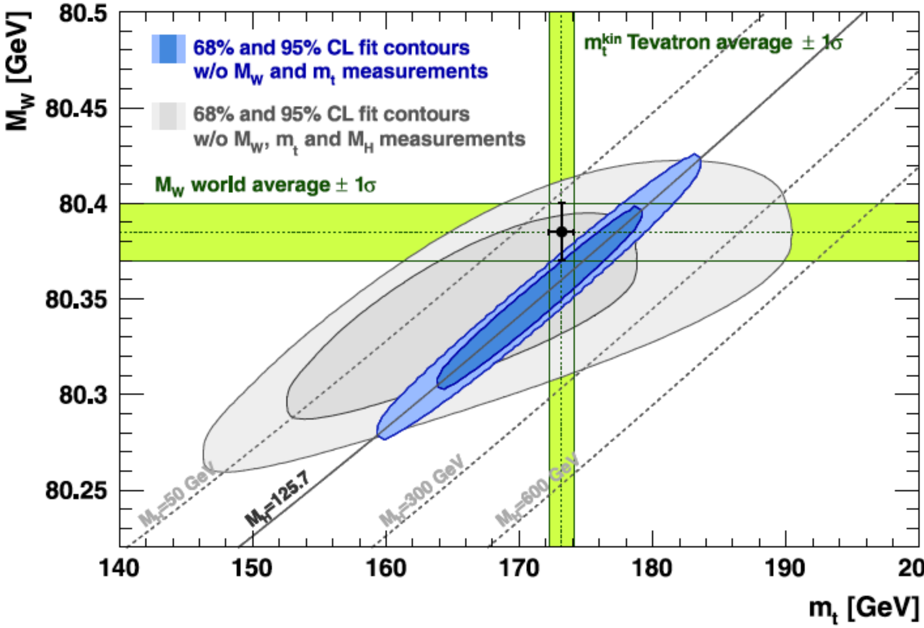
- The direct measurement of the Higgs boson mass has provided the last missing parameter defining the electroweak sector in the SM

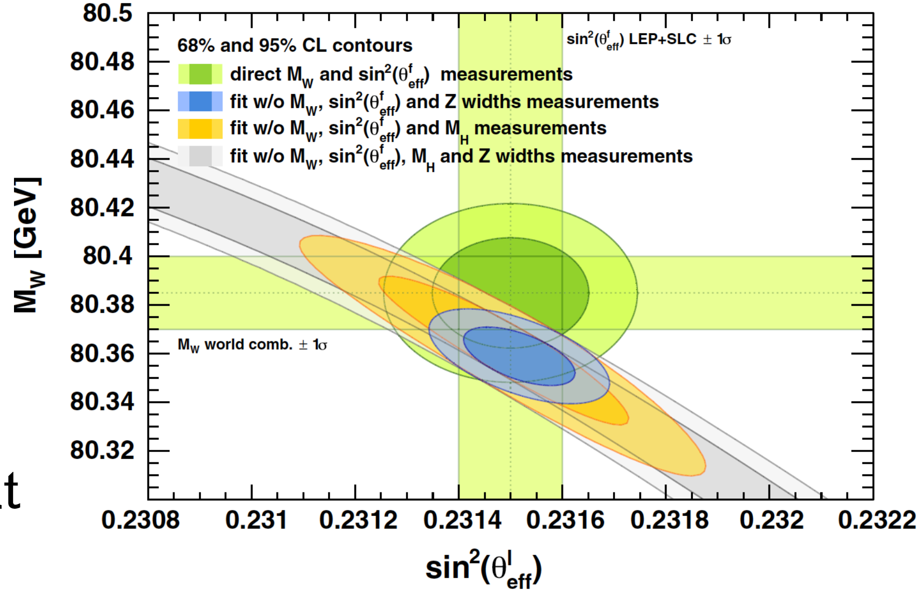


- Therefore the SM can be stringently tested

Good agreement of the electroweak constraint with the Higgs

Eur. Phys. J. C (2014) 74:3046

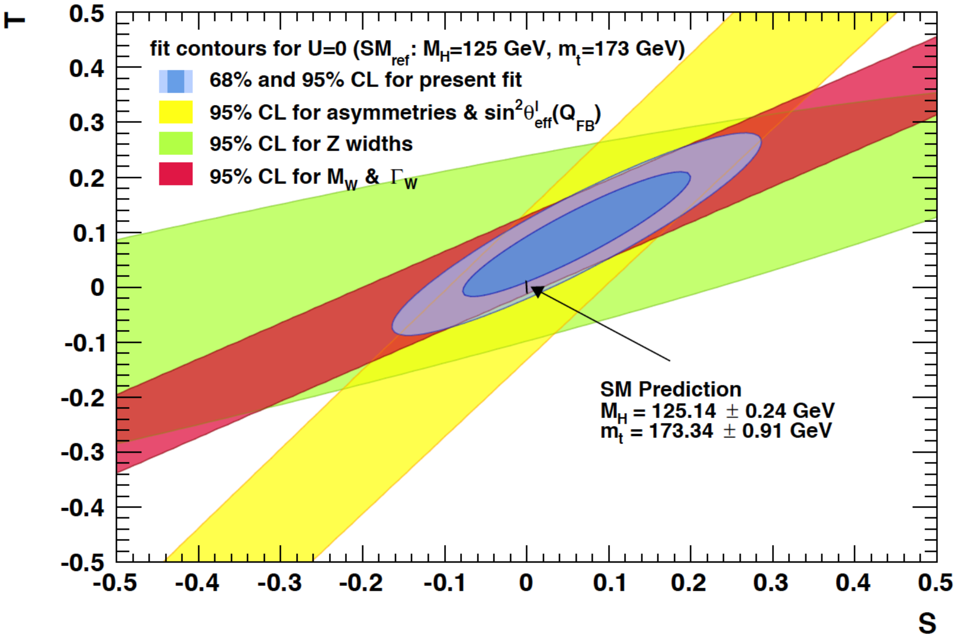




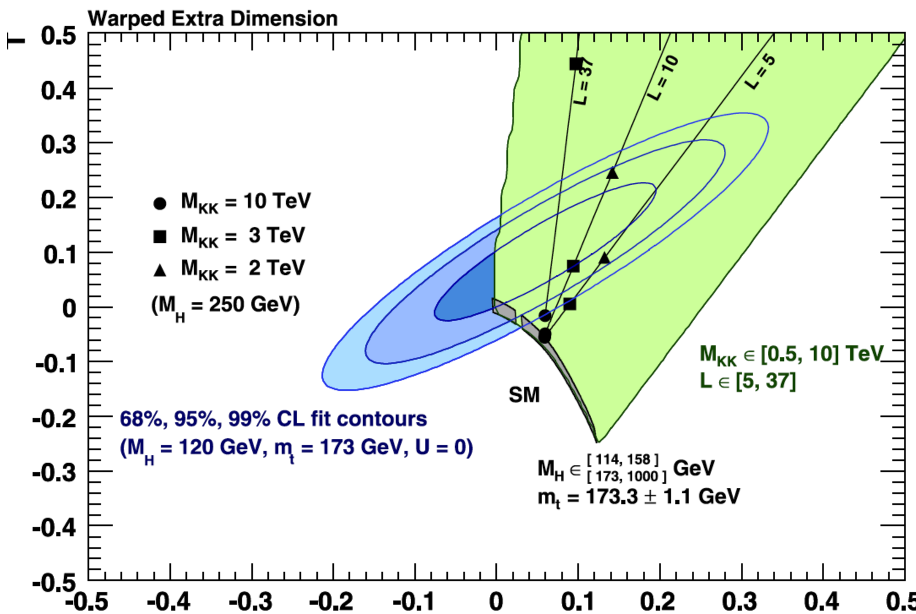
- Improved measurements of $\sin^2(\Theta^l_{eff})$ at colliders provide additional constraints

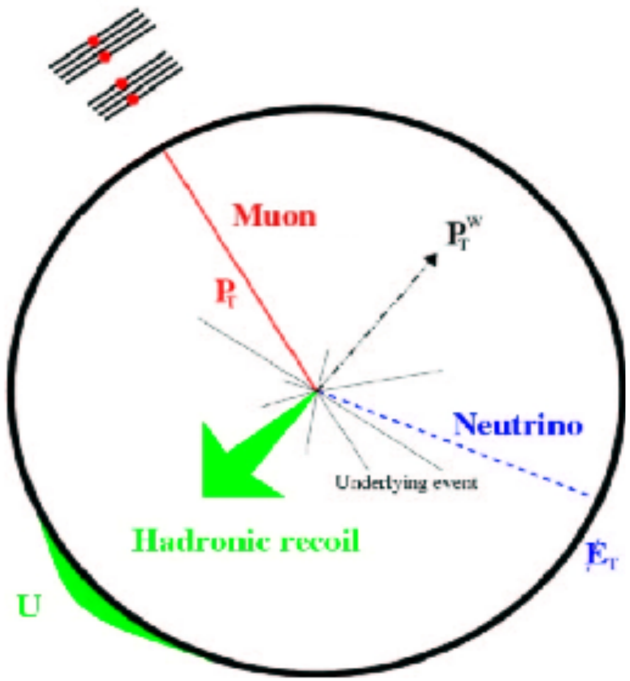
- New physics that contributes to the precision electroweak observables (loop corrections to the gauge-boson self-energies) can be generally described by the S, T, U oblique parameters
- Radiative corrections due to new physics
- The S and T parameters absorb contributions to the neutral and to the difference between neutral and charged weak currents, respectively.

arXiv:1407.3792v1



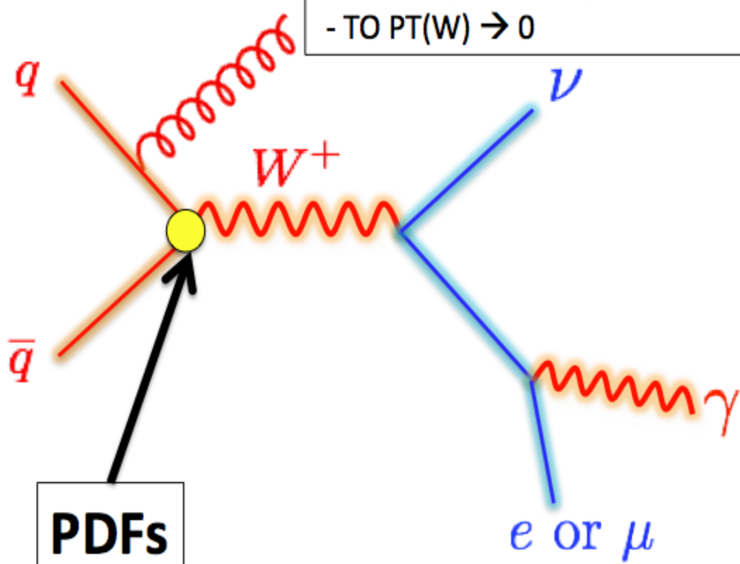
Eur. Phys. J. C (2012) 72:2003





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

INITIAL STATE RADIATION (aka RECOIL)
- BOTH QCD AND QED
- TO PT(W) → 0



PILEUP/UE

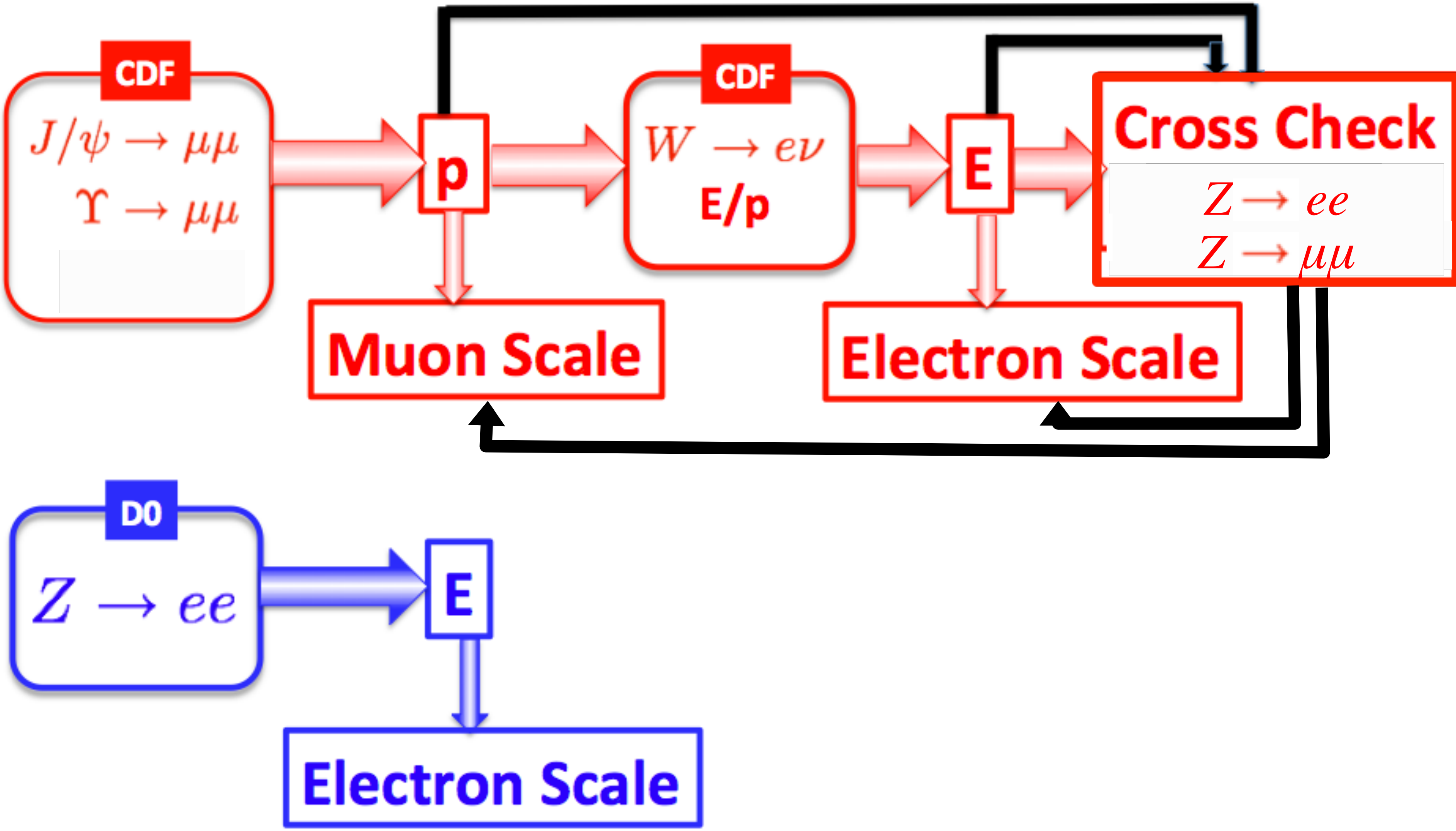
FINAL STATE QED

PDFs

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

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

Lepton Energy Scale



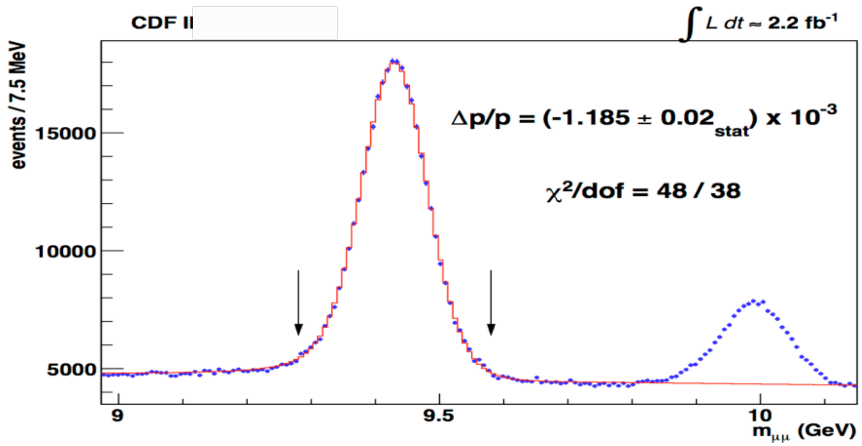
CDF Momentum Scale

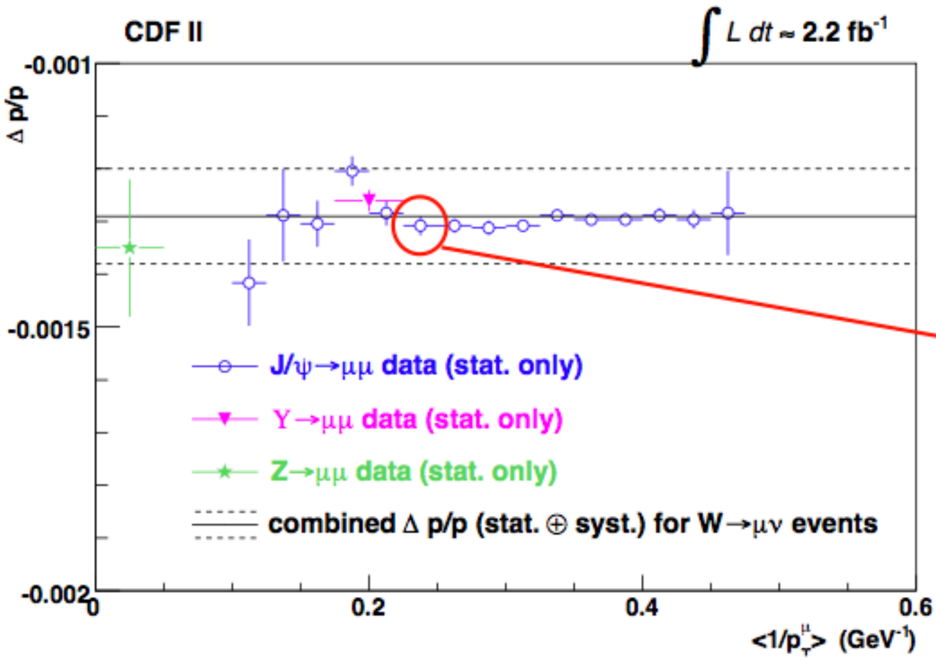
"Back bone" of CDF analysis is track p_T measurement in drift chamber (COT)

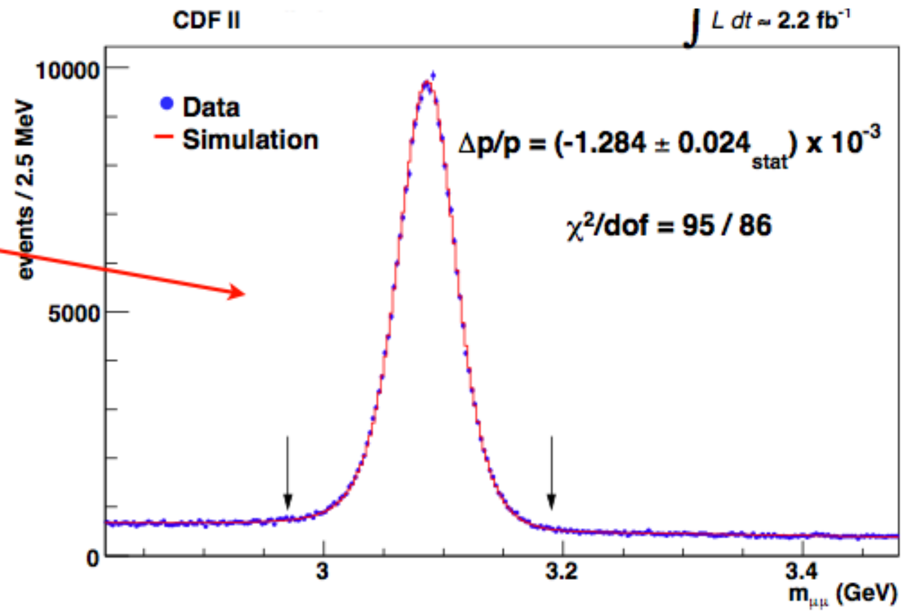
Calibrate momentum scale using samples of dimuon resonances (J/ψ, Υ, Z)

Span a large range of p_T

Final scale error of 9×10^{-5}

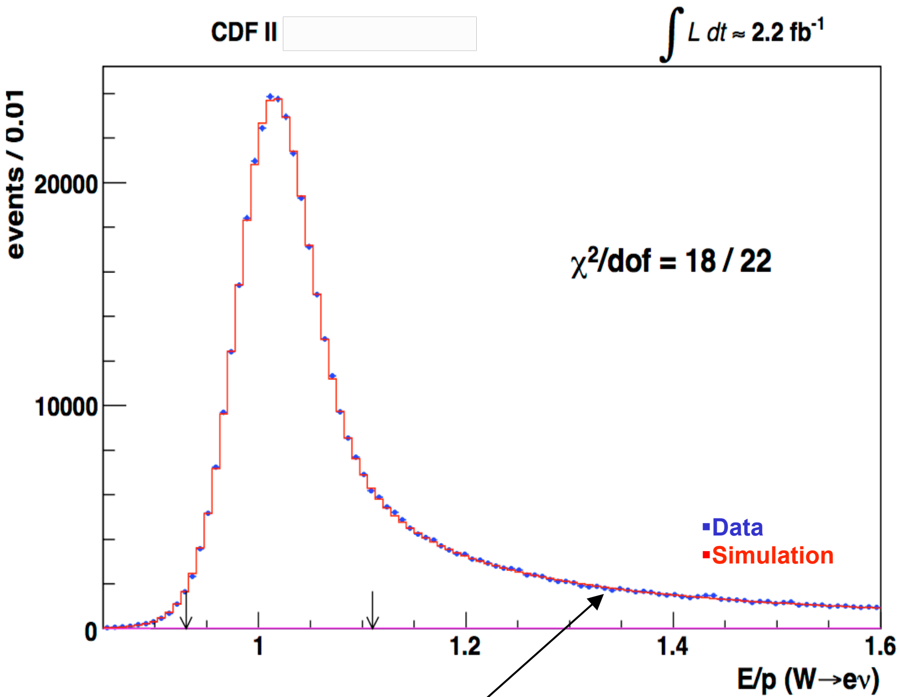


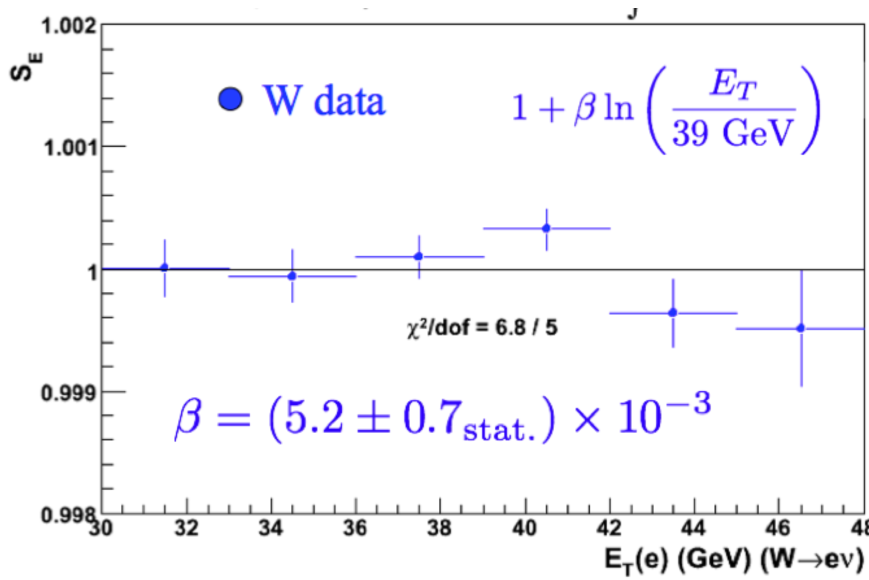




CDF Energy Scale

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



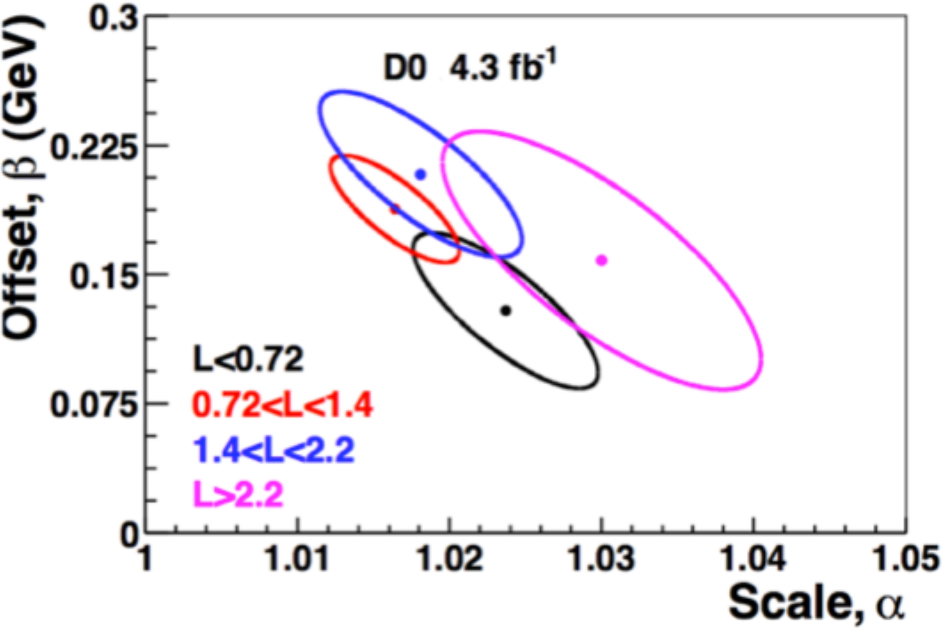


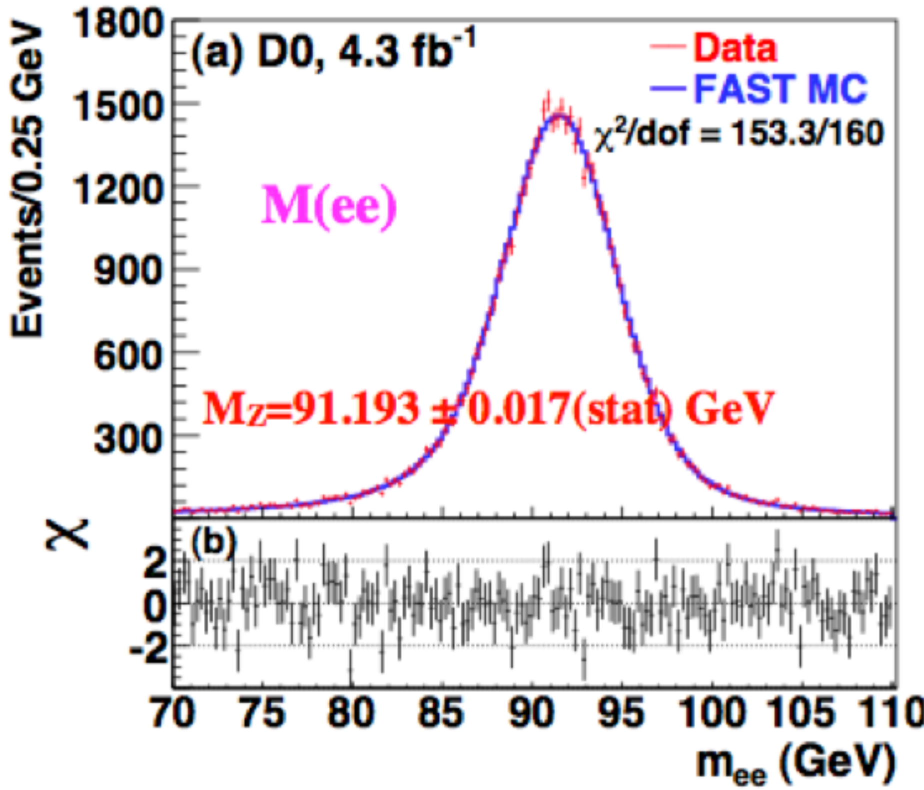
Excellent description of E/p tail
Constraints overall material

E/p also used to constrain calorimeter non-linearity

D0 Energy Scale

$$E_{measured} = \alpha \times E_{TRUE} + \beta$$





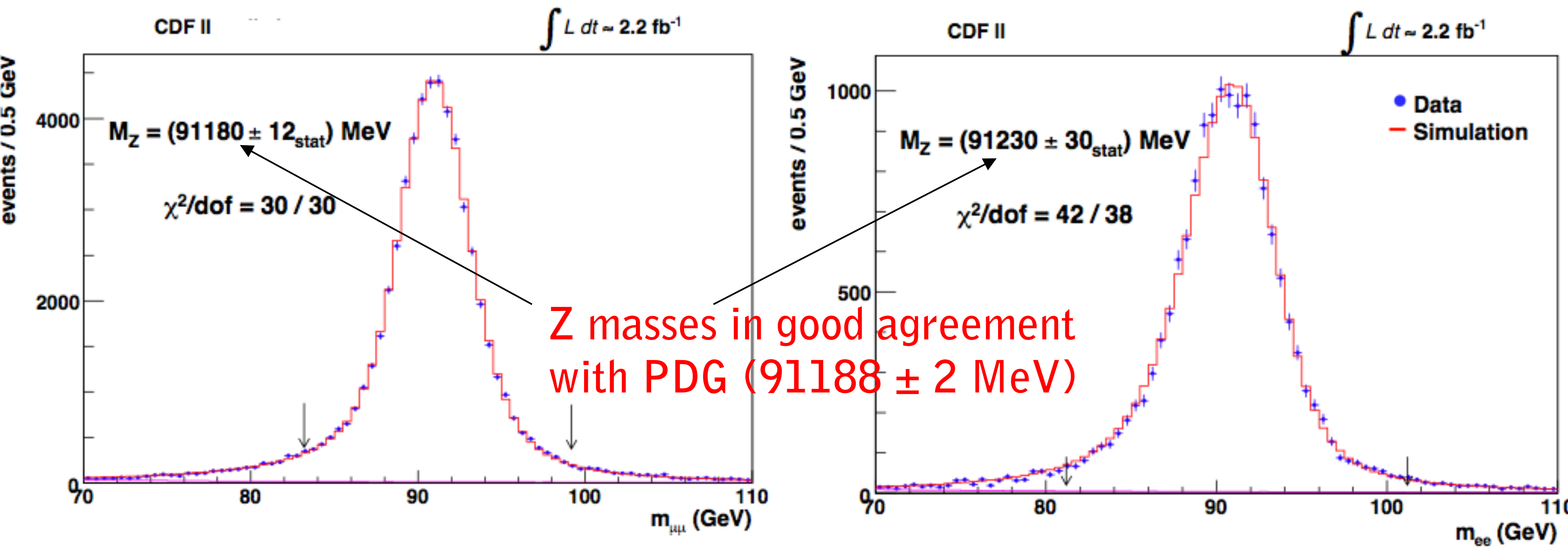
Measured in luminosity and energy bins

Consistent with PDG by construction

D0 is measuring M_W/M_Z

CDF Z Boson Masses

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

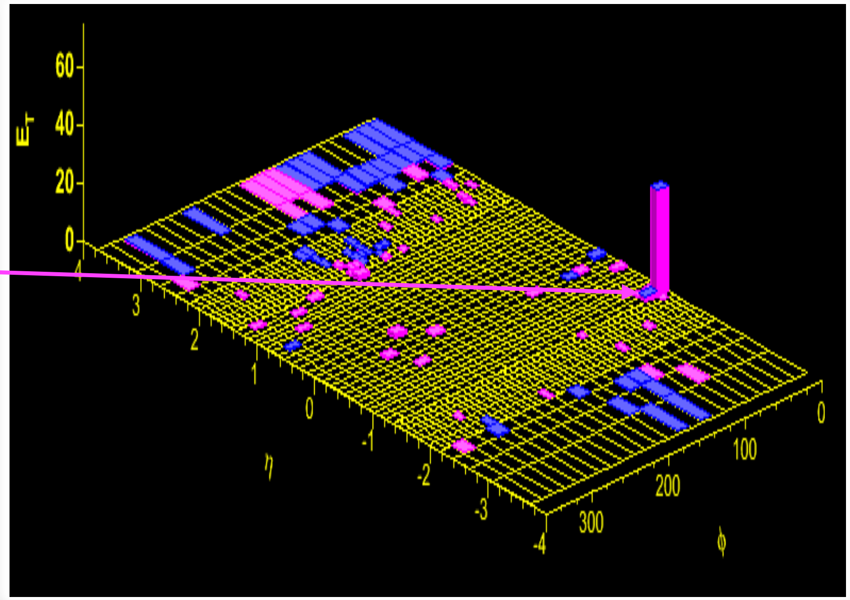


Include Z→ll masses for final momentum scale and energy scale

Hadronic Recoil

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

- lepton towers



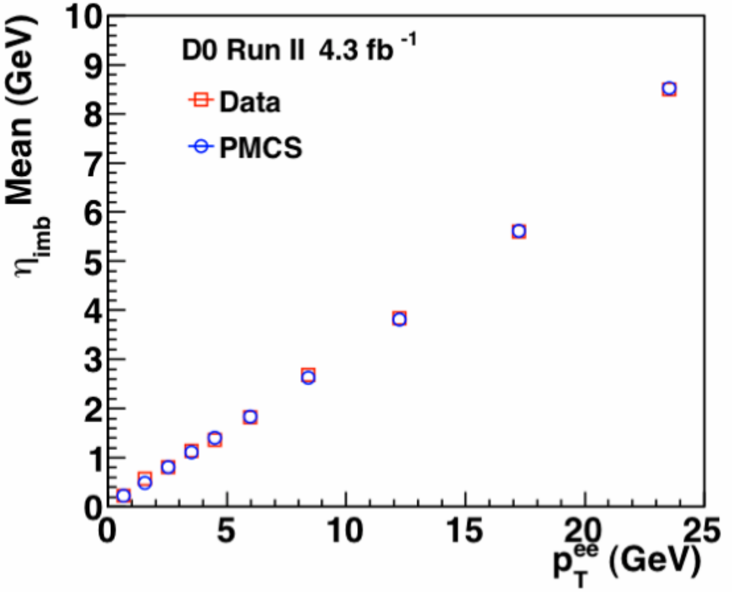
- Measured recoil:
  - hard recoil from initial state **QCD** in W/Z event
  - underlying event/spectator interaction energy

- Calibrate detector response and resolution using Z and minimum-bias data

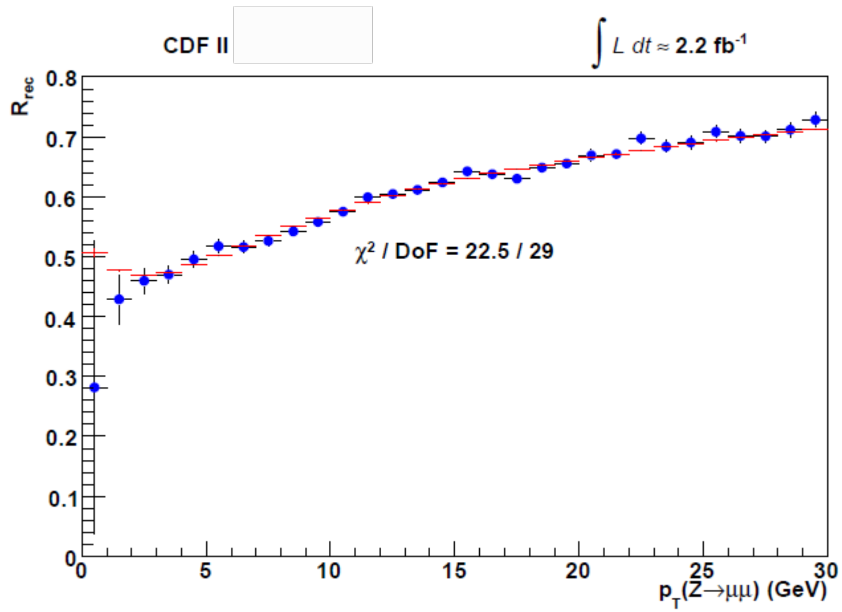
- Validate using measured recoil in W events

Recoil Response

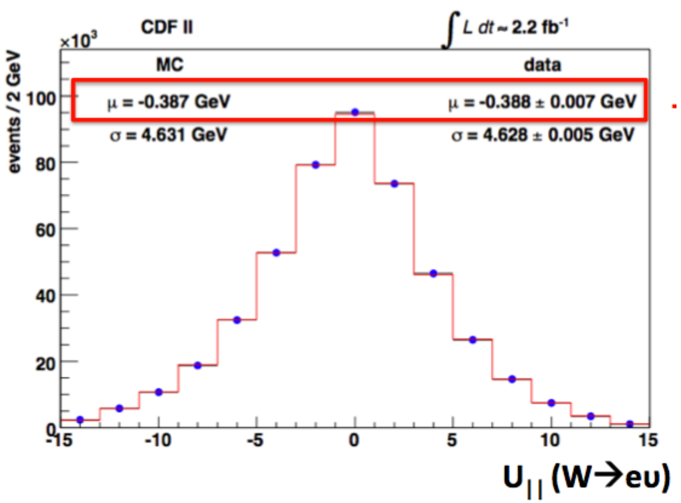
Similar calibration samples and procedures between D0 and CDF



Typically only detect 50-70% of "true" QCD readiation



Validate model in W events

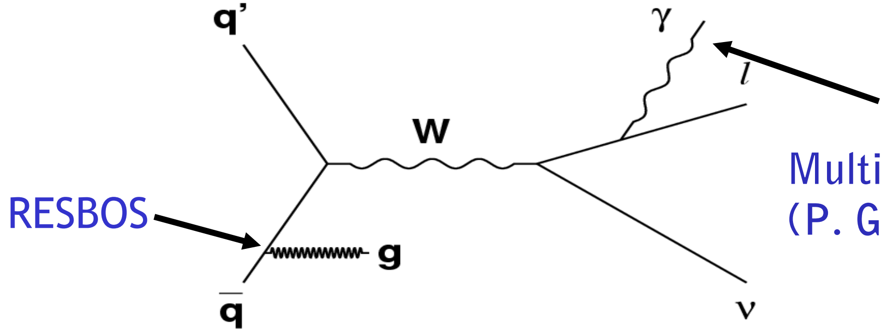


$$m_T \sim 2p_T^l + U_{||}$$

← Component of hadronic recoil along charged lepton direction

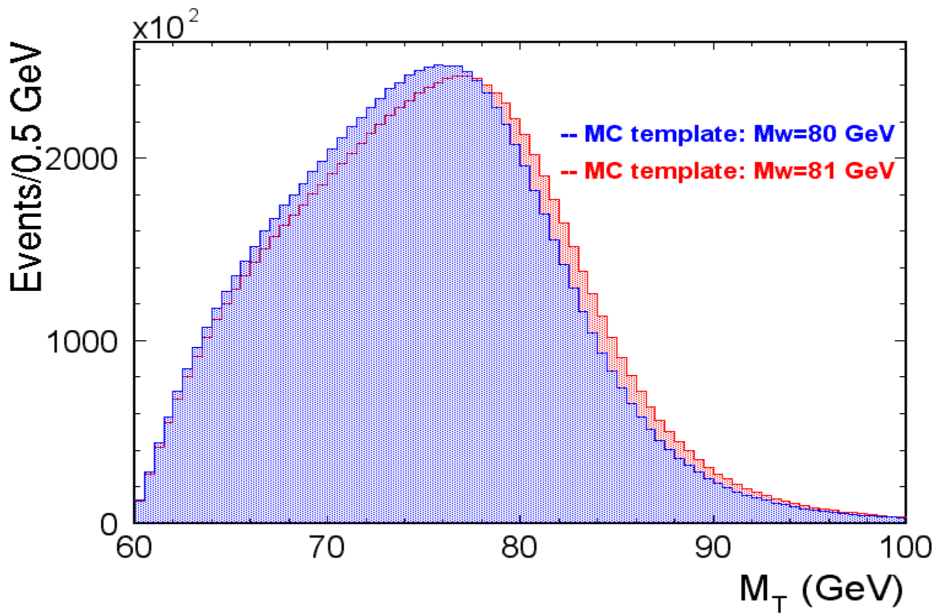
Signal Simulation

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



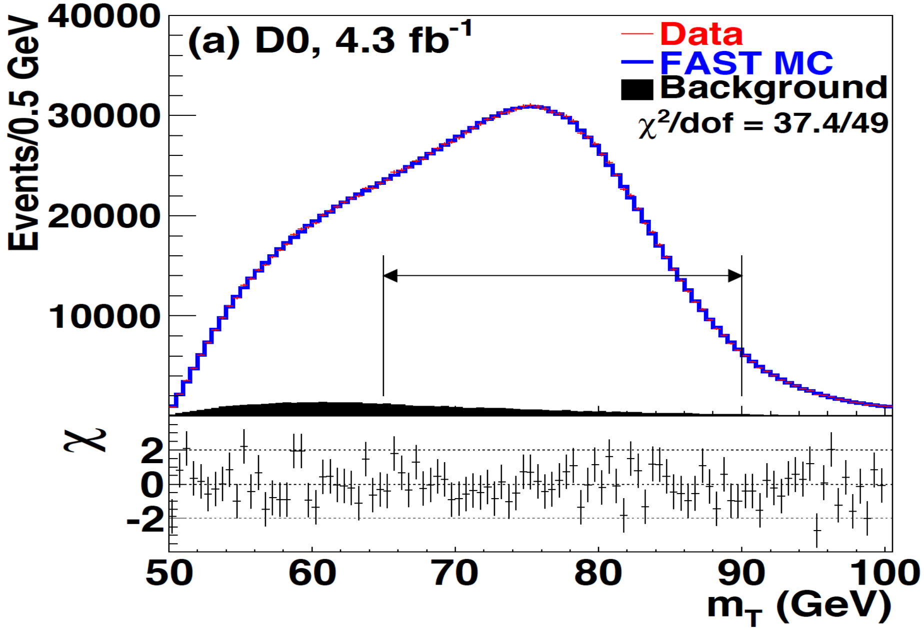
Multiple radiative photons from PHOTOS (P. Golonka et.al., Eur. J. Phys. C 45, 97 (2006)

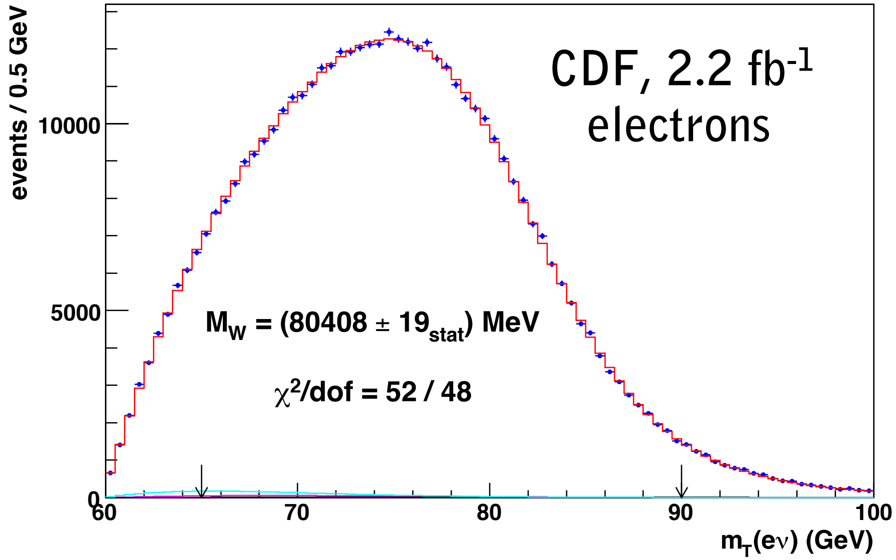
Custom fast simulation makes smooth, high statistics templates



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

Transverse mass fits

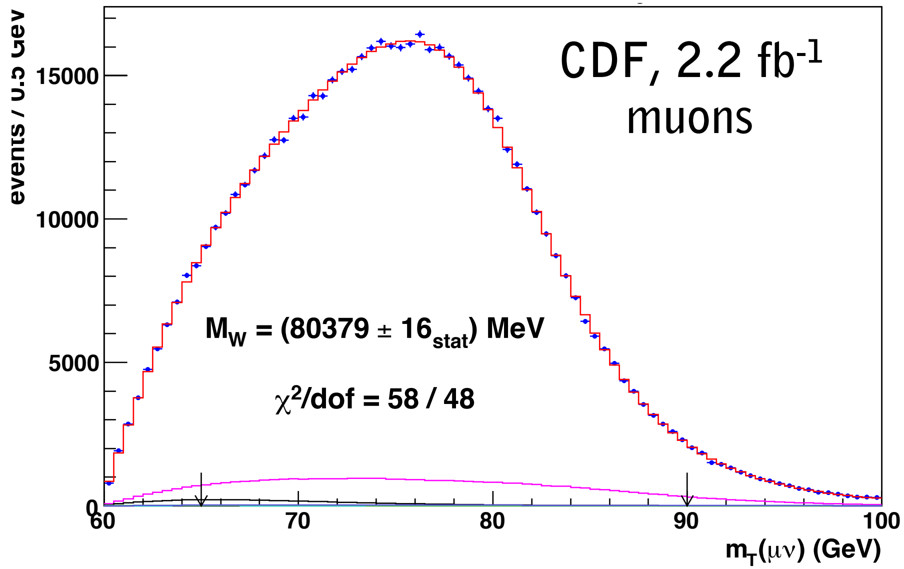




D0: Phys. Rev. D89 (2014) 1, 012005

CDF: Phys. Rev. Lett. 108 (2012) 151803

CDF: Phys. Rev. D89 (2014) 7, 072003



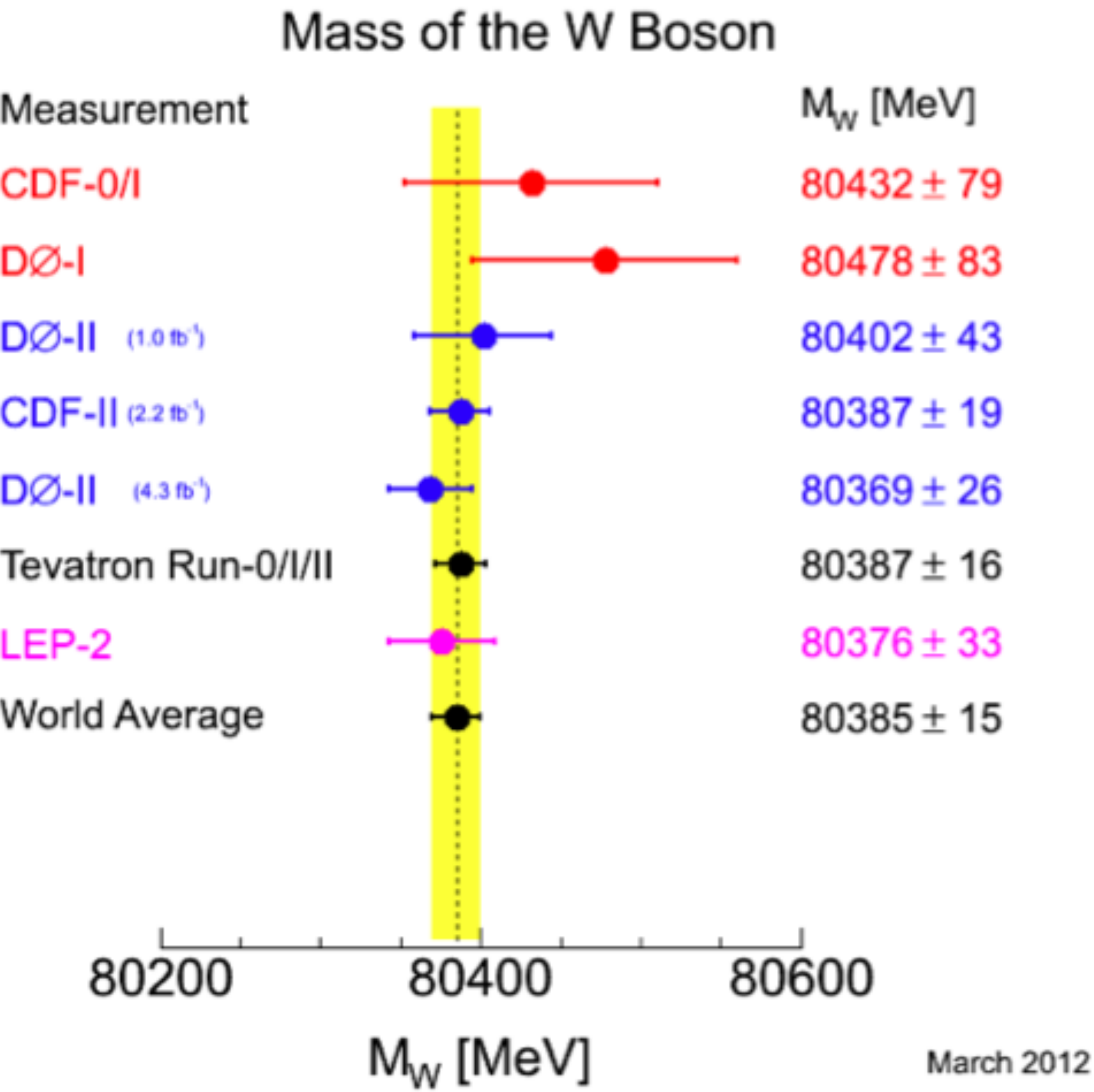
Uncertainties

Uncertainty	D0	CDF
Lepton energy scale/resn/modelling	17	7
Hadronic recoil energy scale and resolution	5	6
Backgrounds	2	3
Parton distributions	11	10
QED radiation	7	4
$p_T(W)$ model	2	5
Total systematic uncertainty	22	15
W-boson statistics	13	12
Total uncertainty	26 MeV	19 MeV

Largely stat. in origin → **10 MeV**

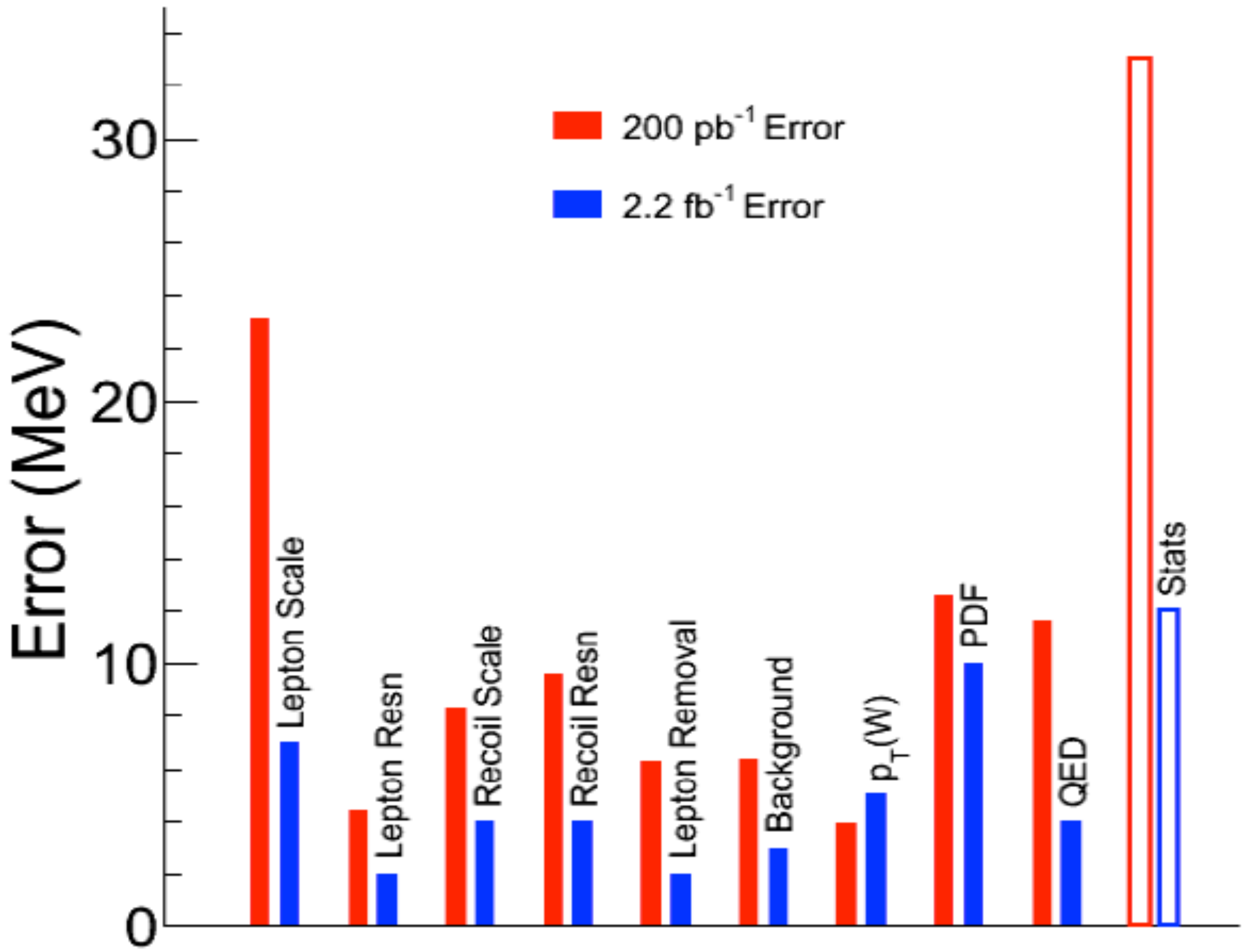
Largely theory in origin → **12 MeV**

World Average



Tevatron Run-II has halved the Mw uncertainty

Going Below 15 MeV at the Tevatron

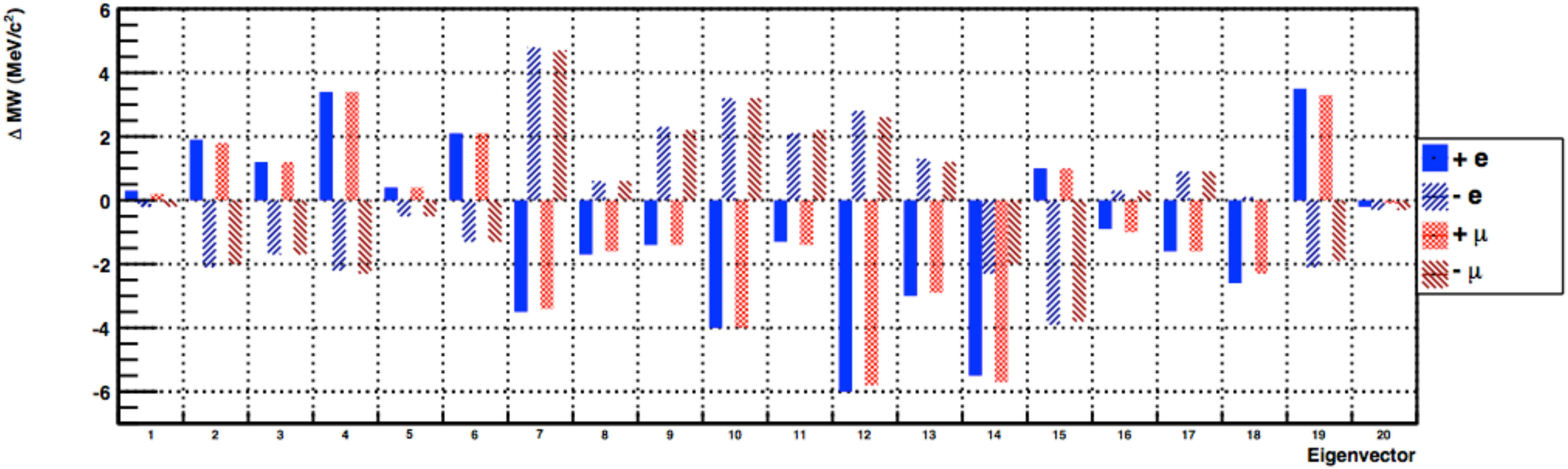


Going Below 15 MeV on M_W

Limited lepton acceptance produces dependence on PDFs

Will likely be the limiting factor in reducing uncertainty

Evaluated with CTEQ and MSTW eigenvectors



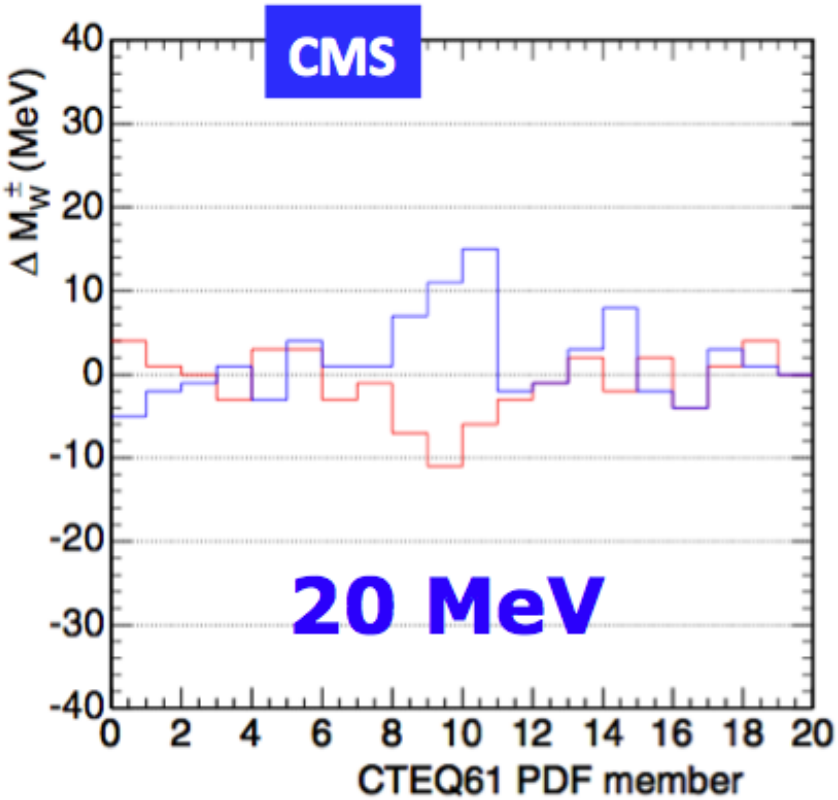
Tevatron and LHC measurements that can further constrain PDFs:

- Z boson rapidity distribution
- W boson charge asymmetry
- Z boson AFB

PDF's at LHC

At LHC (unlike TeV) significant contribution from "cs" production.

Affects:
- acceptance via rapidity and kinematic cuts
- contribution to $p_T(W)$ (m_C mass)



Constraints from W and Z data will reduce uncertainty of course

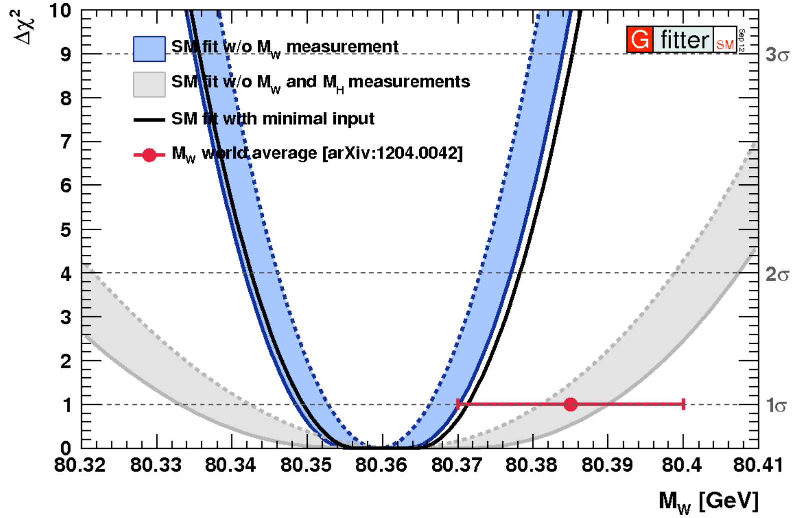
Unique forward acceptance of LHCb can potentially allow for significant reduction for ATLAS and CMS through anti-correlation

arXiv:1508.06954v1

Conclusions

Program of precision physics with W and Z bosons well established

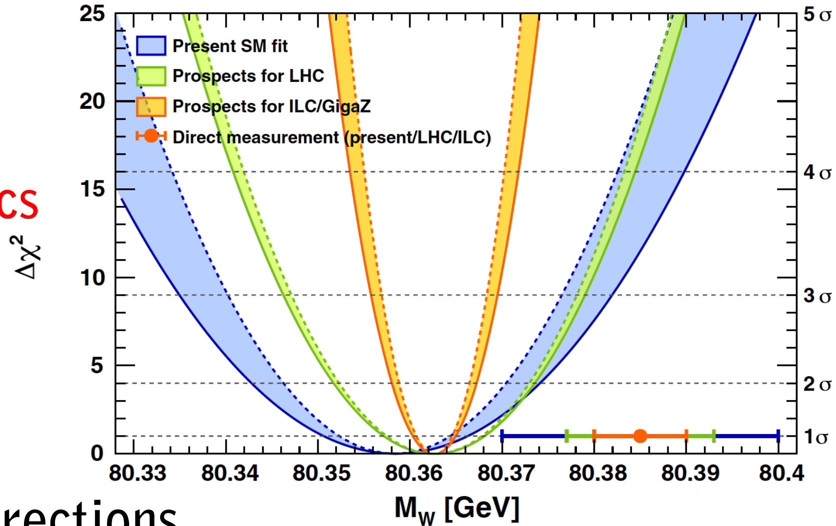
Tevatron currently leading precision measurements of W boson mass, 10 MeV measurement possible



LHC, lot's of W's and Z's, systematics is key!

Constraints on PDF's critical

EW precision measurements in a good agreement with 125 GeV Higgs boson



SM over-constrained - constraints New Physics

Indirect m_W uncertainty 8 MeV needs to be matched with direct measurement

Improve indirect measurements: m_{top}, HO corrections, ...