Moriond Electroweak
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W/Z boson properties, including W mass, at the Tevatron

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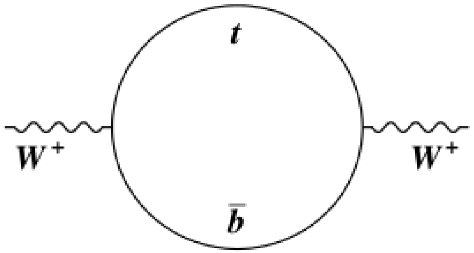
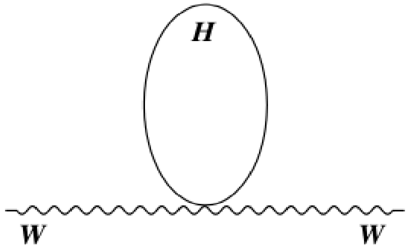
W mass: motivation

W mass is a key parameter in the Standard Model. This model does not predict the value of the W mass, but it predicts this relation between the W mass and other experimental observables:

$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}} \frac{1}{\sin\theta_W \sqrt{1-\Delta r}}$$

Radiative corrections (Δ r) depend on M_t as $\sim M_t^2$ and on M_H as $\sim \log M_H$. They include diagrams like these:



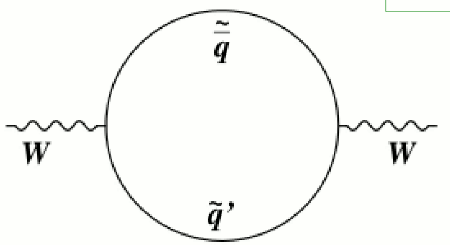


Precise measurements of M_W and M_t constrain SM Higgs mass.

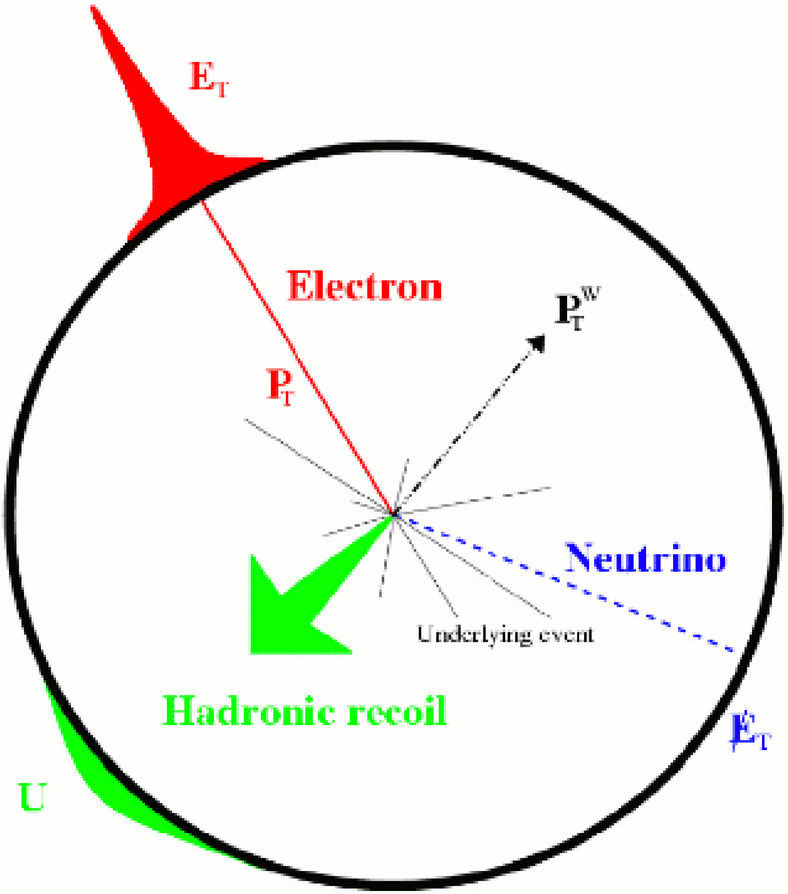
Current Tevatron average:
$\Delta M_t = 1.2$ GeV
$\Rightarrow$ would need: $\Delta M_W =$ 7 MeV
Currently have: $\Delta M_W = 25$ MeV

For equal contribution to the Higgs mass uncertainty need:
$\Delta M_W \approx 0.006 \ \Delta M_t$.

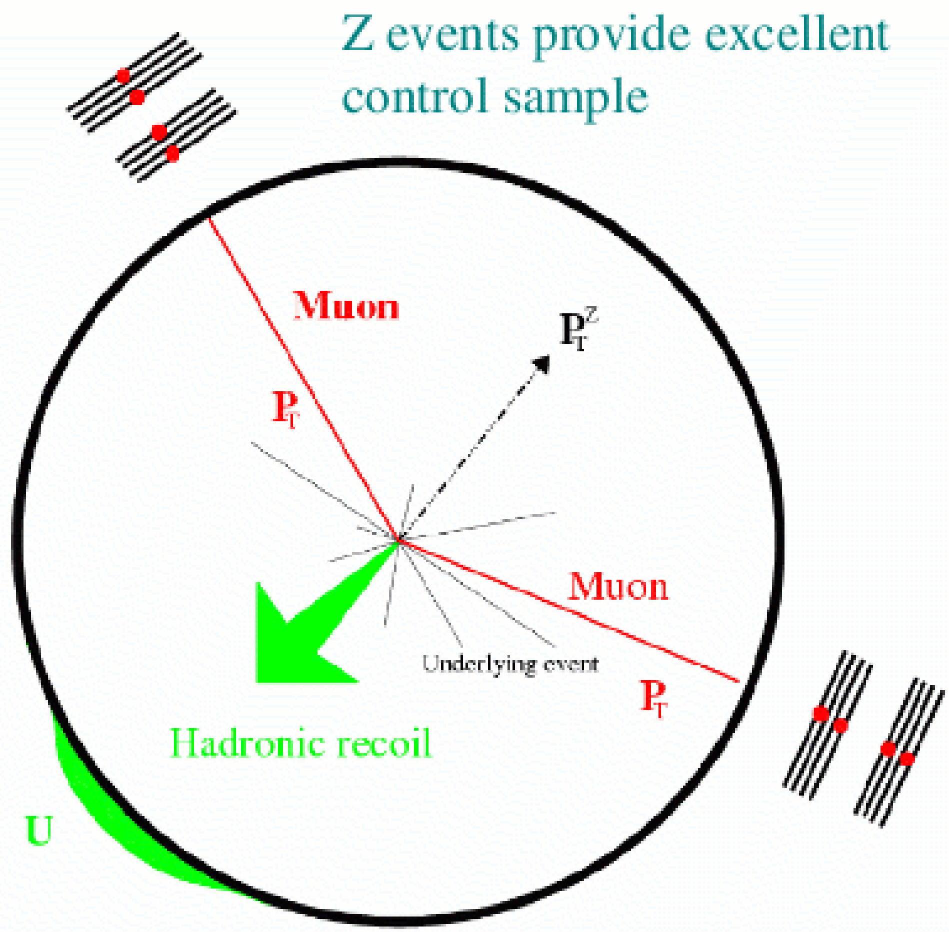
Additional contributions to Δr arise in various extensions to the Standard Model, *e.g.* in SUSY:



Signature in the detector

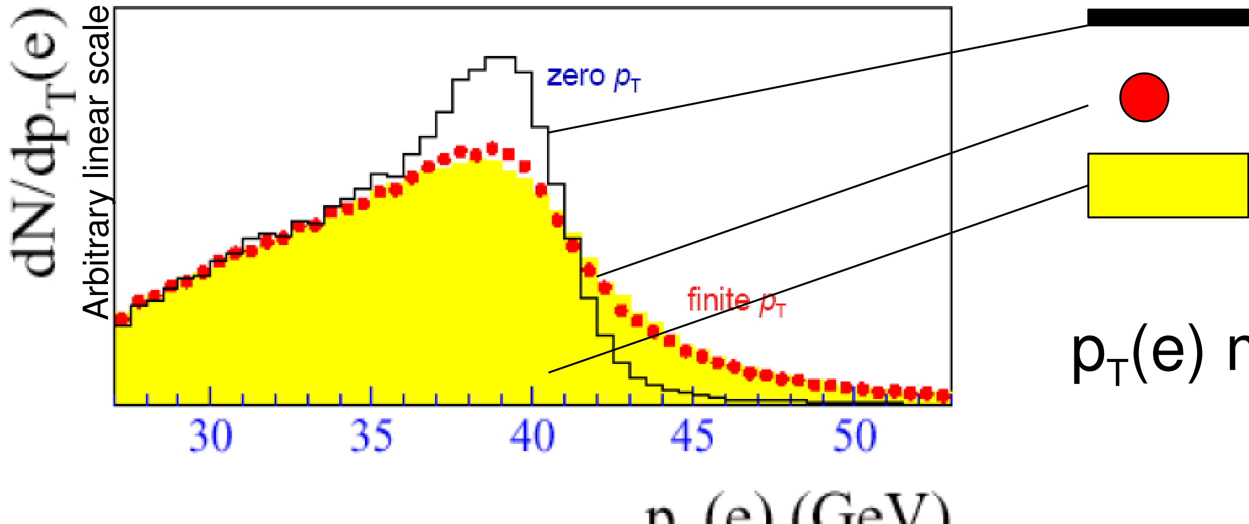


Isolated, high p_T leptons,
missing transverse momentum in W's



In a nutshell, measure two objects in the detector:
- Lepton (e or μ),
  need energy measurement with 0.2 per-mil precision (!!)
- Hadronic recoil, need ~ 1% precision

Experimental observables



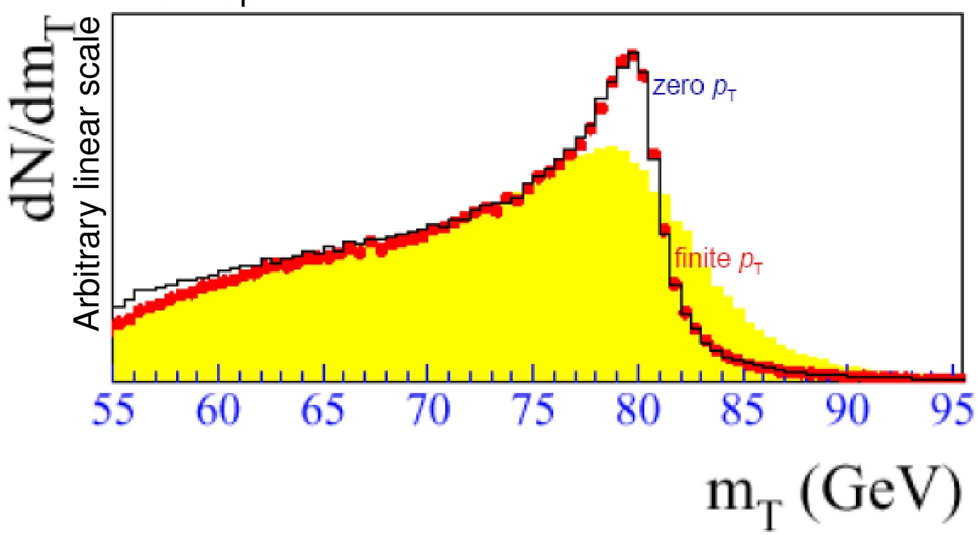
No $P_T(W)$

$P_T(W)$ included

Detector Effects added

$p_T(e)$ most affected by $p_T(W)$

Ref. hep-ex/0011009



$$M_T = \sqrt{2E_T^l \not{E}_T (1 - \cos\Delta\phi)}$$

M_T most affected by measurement of missing transverse momentum

Need Monte Carlo simulation to predict shapes of these observables for given mass hypothesis. DØ use **ResBos** [Balazs, Yuan; Phys Rev D56, 5558] + **Photos** [Barbiero, Was, Comp Phys Com 79, 291] for W/Z production and decay, plus **parameterised detector model**.

First DØ Run II measurement of the W boson mass (preliminary)

1 fb^{-1} of data
using central electrons ($|\eta|<1.05$)

~ 500k W events
~ 19k Z events

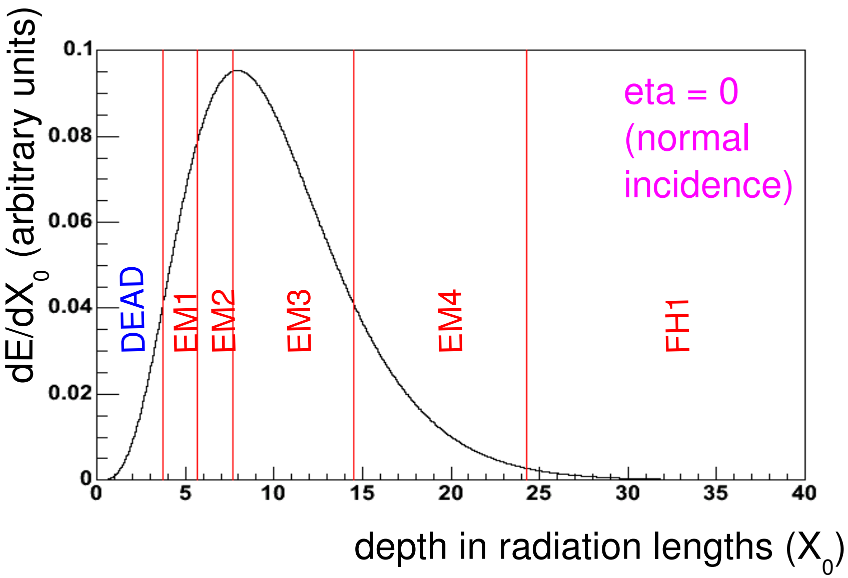
Electrons: energy scale

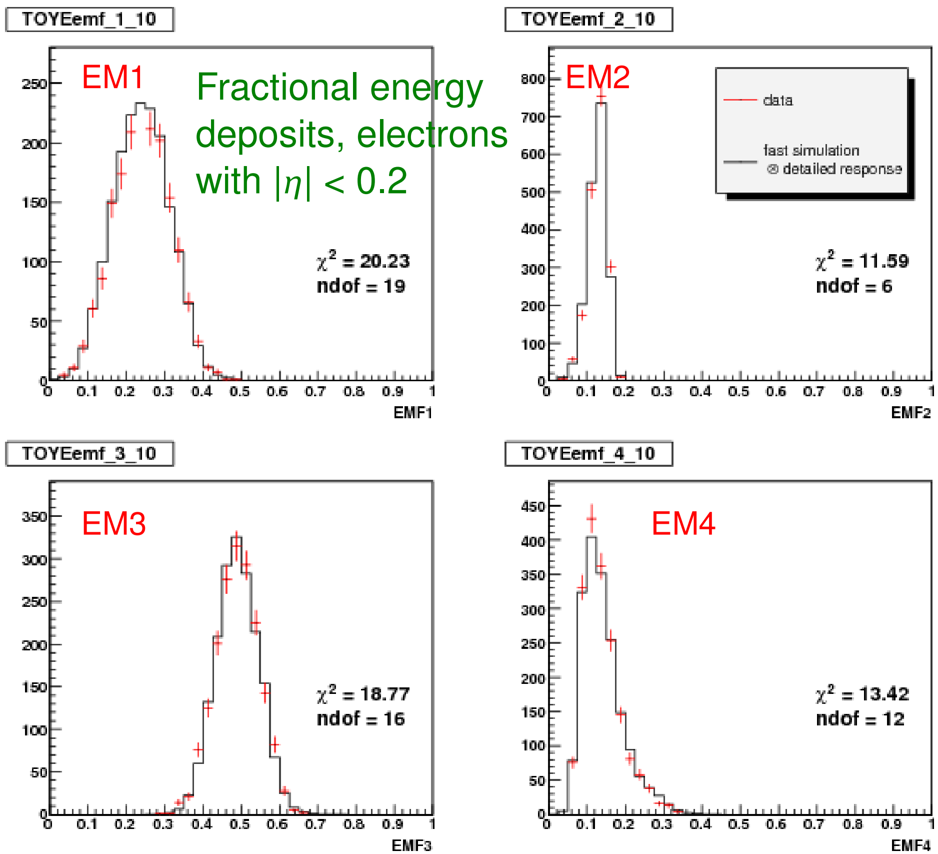
Knowing the amount of dead material is the key to energy response linearity:
Measure amount of dead material *in situ* using electrons from $Z \rightarrow e\, e$.

Exploit longitudinal segmentation of our EM calorimeter:
fractional electron energy deposits in each of the four readout sections of our EM calorimeter (EM1, ..., EM4) are very sensitive to amount of dead material.

=> compare fractional deposits in data and detailed simulation

adjust material in simulation (5% correction to nominal material model) to match data





Amount of uninstrumented material determined to within less than $0.01X_0$!

Electrons: energy scale

After having corrected for the effects of the uninstrumented material:
final energy response calibration, using $Z \rightarrow e\,e$, the known Z mass value from LEP, and the standard "f_z method":

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

Use energy spread of electrons in Z decay to constrain α and β.

In a nutshell: the f_Z observable allows you to split your sample of electrons from $Z \rightarrow e\,e$ into subsamples of different true energy; this way you can *"scan" the electron energy response as a function of energy*.

$$f_Z = (E(e1)+E(e2))(1-\cos(\gamma_{ee}))/m_Z$$

γ_{ee} is the opening angle between the two electrons

Result: $\alpha = 1.0111 \pm 0.0043$
$\beta = -0.404 \pm 0.209$ GeV
correlation: -0.997

This corresponds to the dominant systematic uncertainty (by far) in the W mass measurement (but this is really just Z statistics ... more data will reduce it) :

Δ m(W) = 34 MeV, 100 % correlated between all three observables

Electrons: energy resolution

Electron energy resolution is driven by two components:
sampling fluctuations and constant term

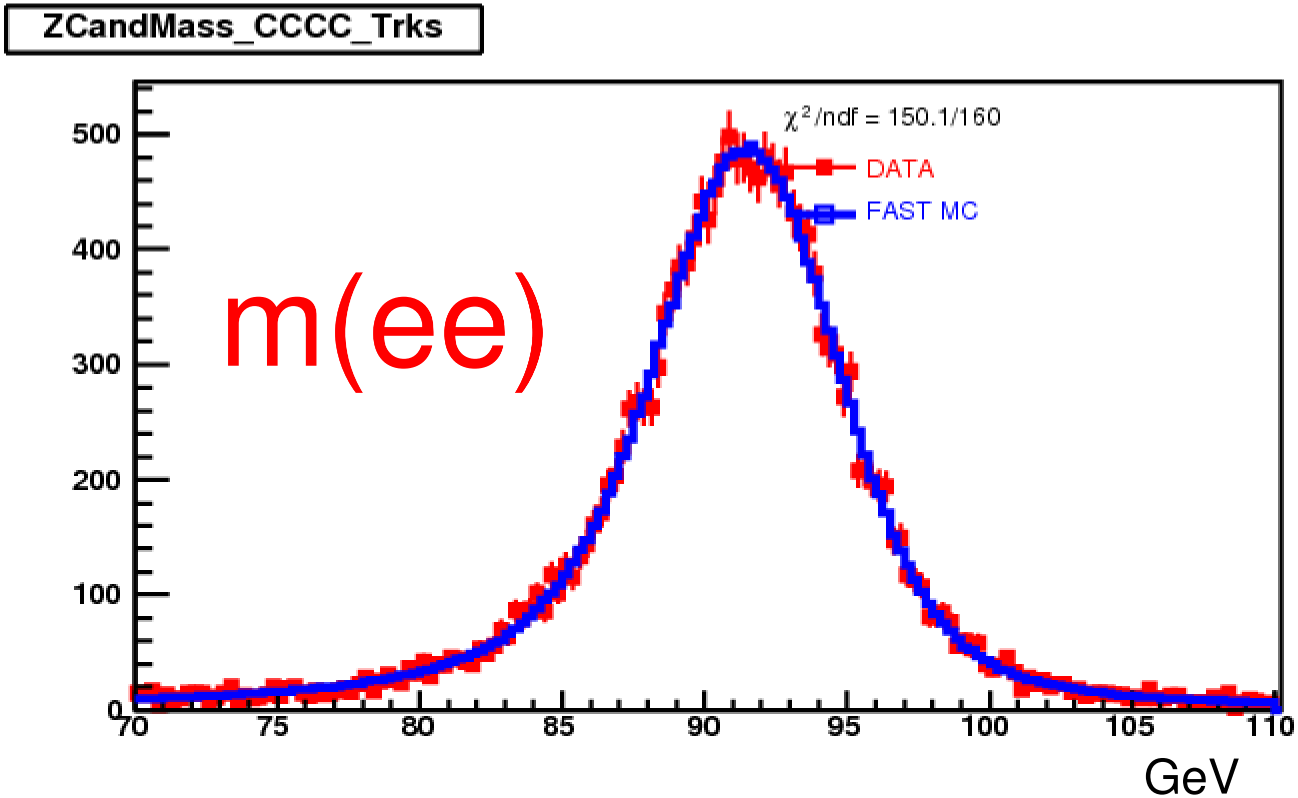
Sampling fluctuations are driven by sampling fraction of CAL modules (well known from simulation and testbeam) and by uninstrumented material. As discussed before, amount of material has been quantified with good precision.

Constant term is extracted from Z -> e e data (essentially fit to observed width of Z peak).

Result:

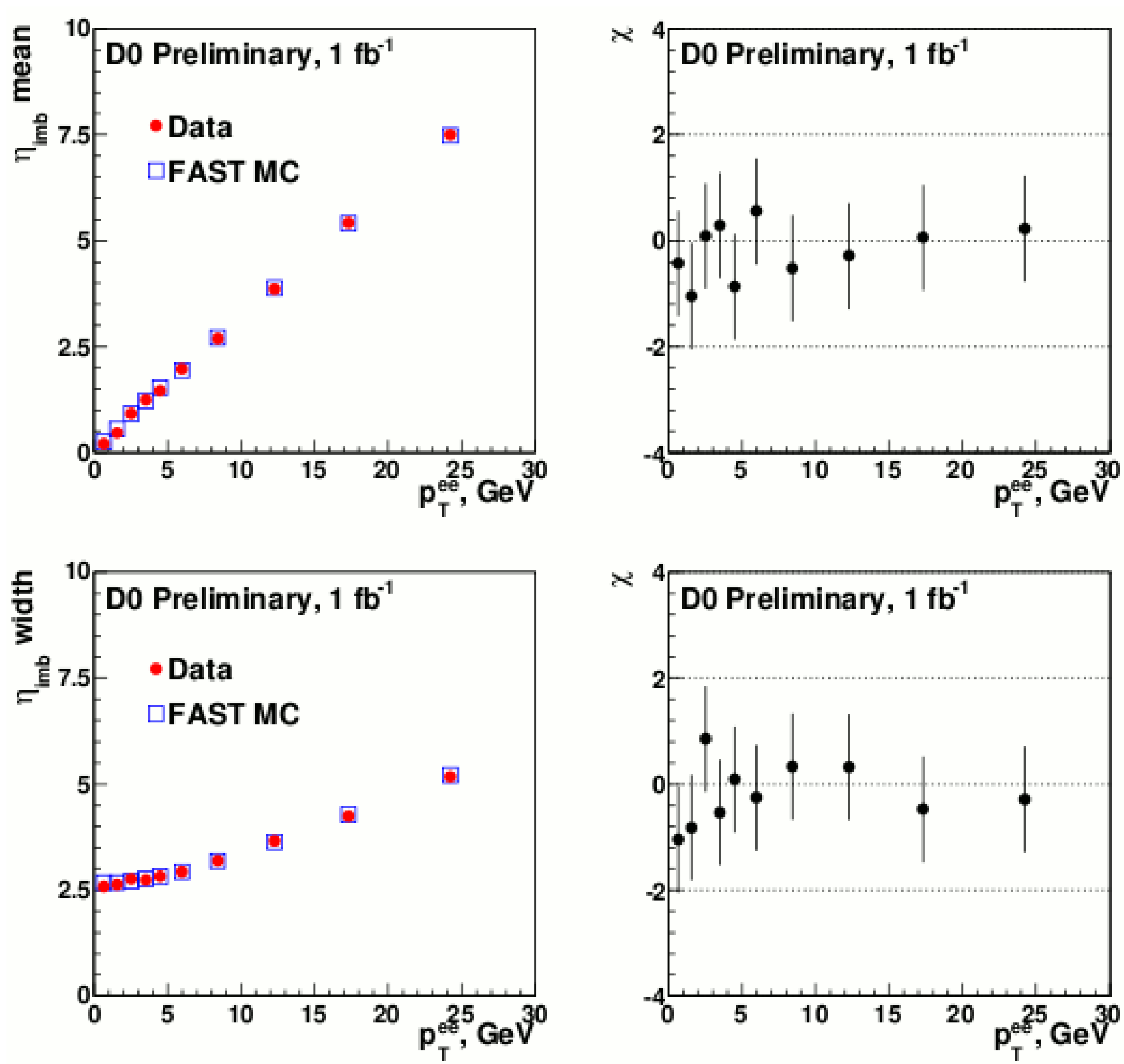
C = (2.05 $\pm$ 0.10) %

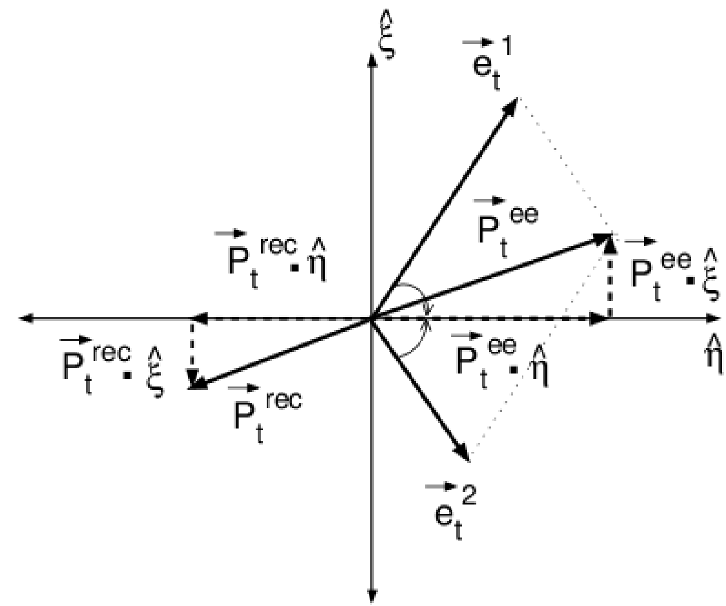
in excellent agreement with Run II design goal (2%)



Recoil calibration

Final adjustment of free parameters in the recoil model is done *in situ* using balancing in Z → e e events and the standard UA2 observables.

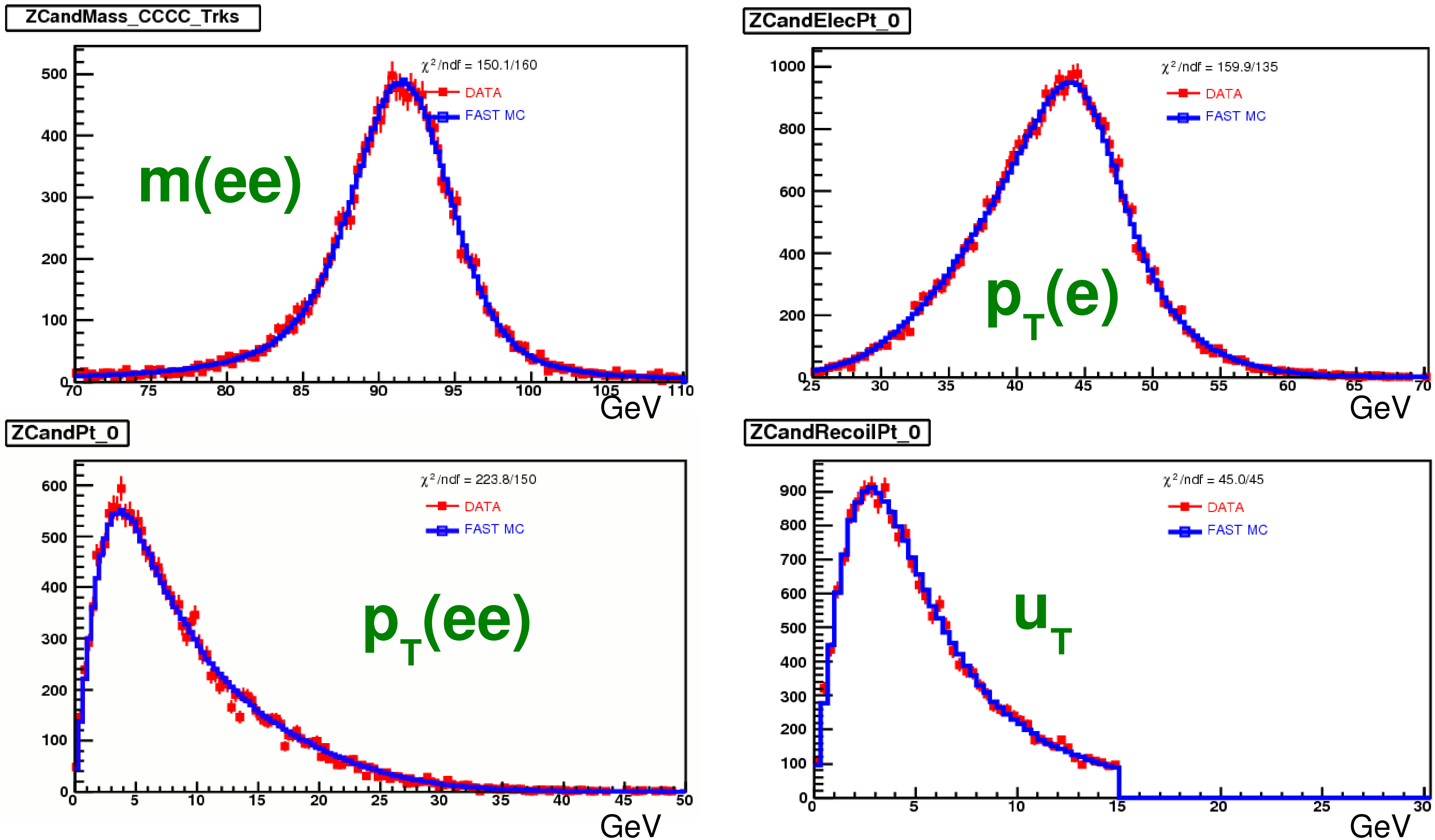




Recoil model has three components:

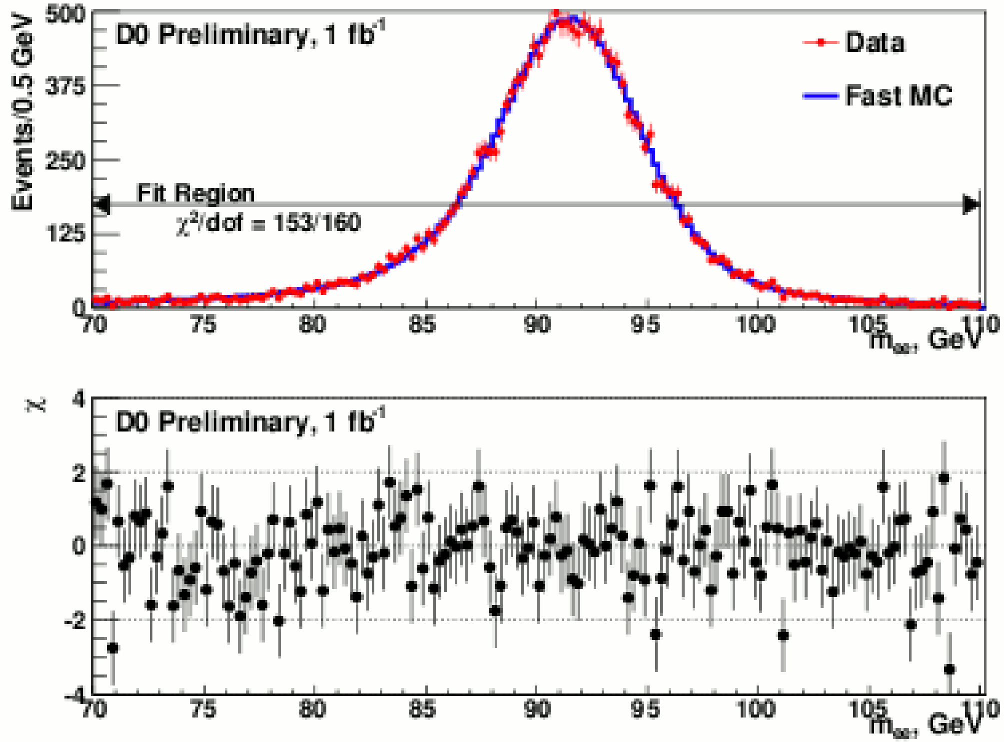
- hard (balances vector boson)
- soft spectator partons
- soft additional interactions

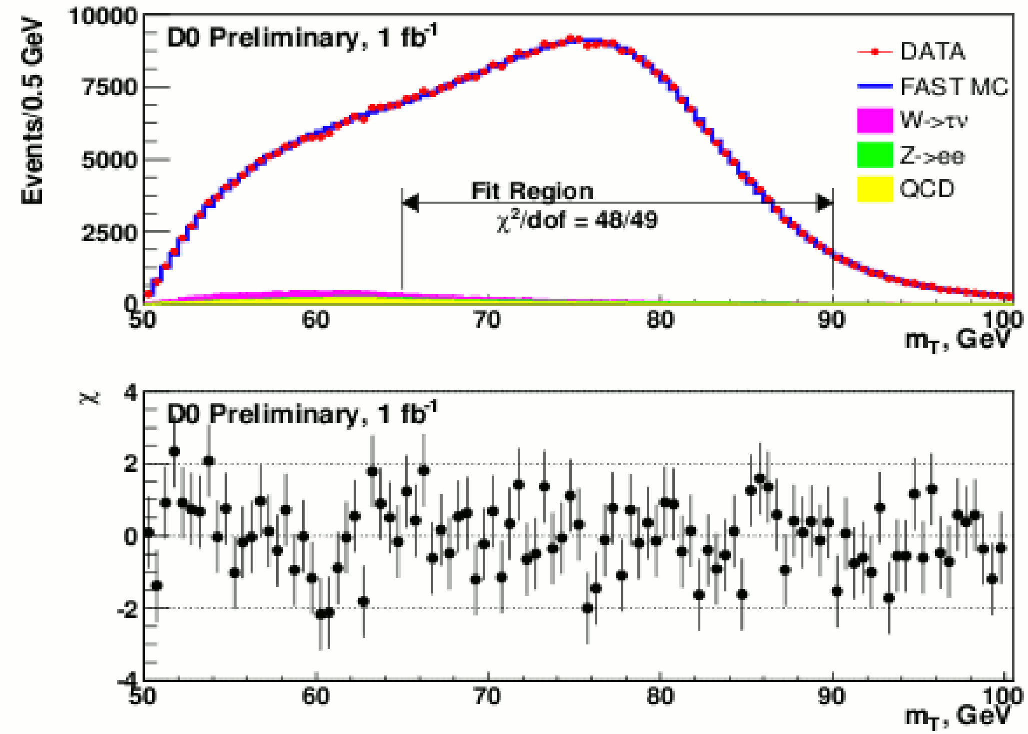
Results: $Z \rightarrow e\,e$ data



✓ **Good agreement between parameterised MC and collider data.**

Mass fits



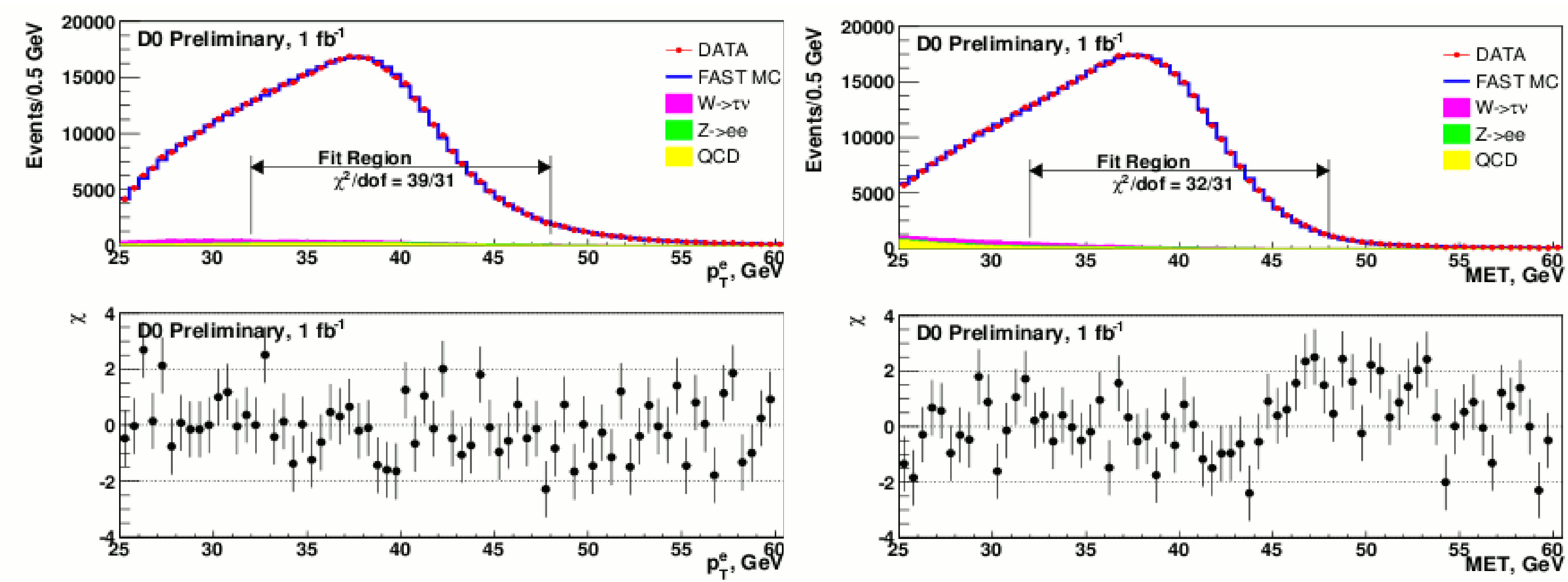


m(Z) = 91.185 ± 0.033 GeV (stat)

(remember that Z mass value from LEP was an input to electron energy scale calibration, PDG: m(Z) = 91.1876 ± 0.0021 GeV)

m(W) = 80.401 ± 0.023 GeV (stat)

Mass fits



m(W) = 80.400 ± 0.027 GeV (stat)

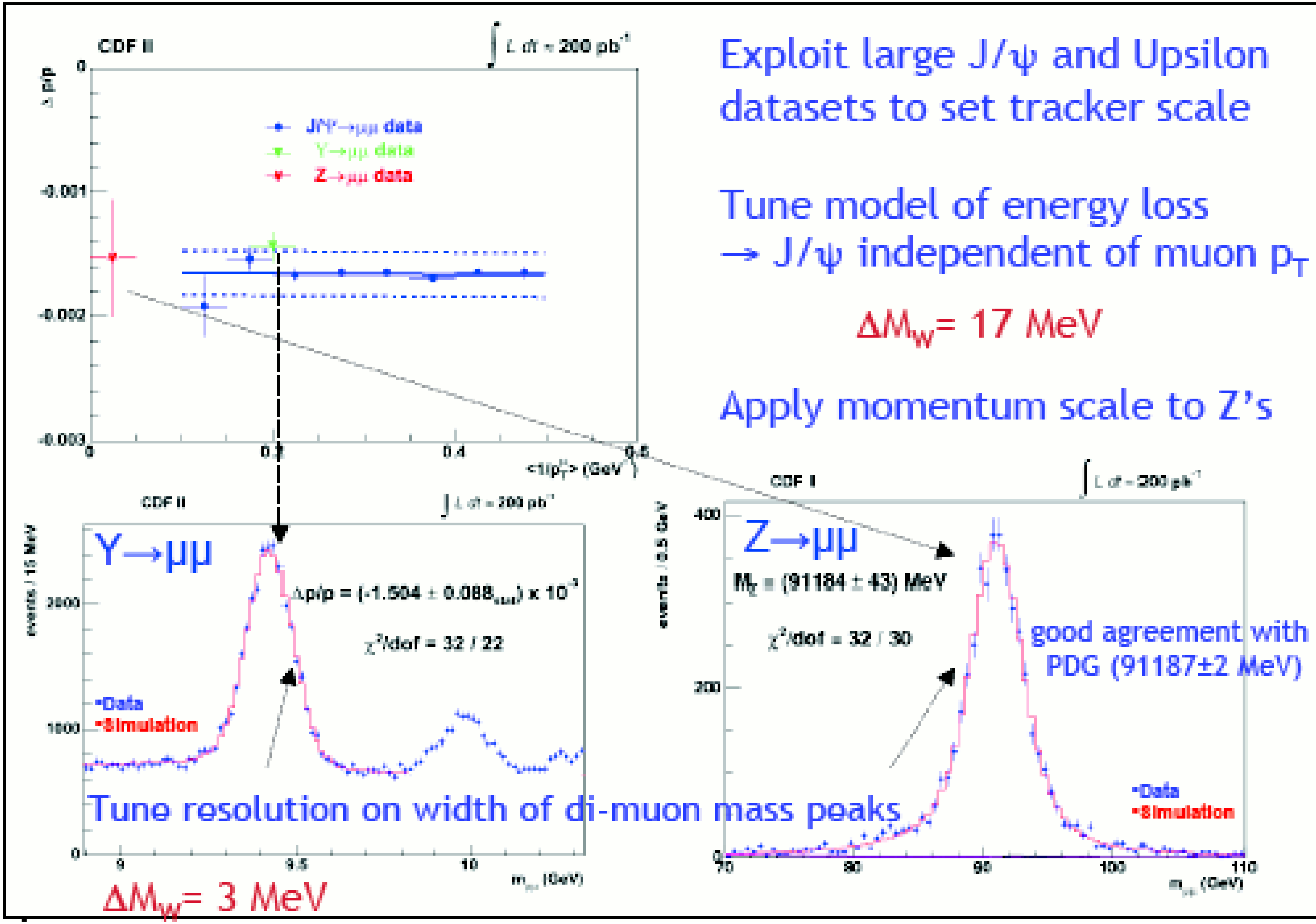
m(W) = 80.402 ± 0.023 GeV (stat)

Summary of uncertainties

systematic uncertainties

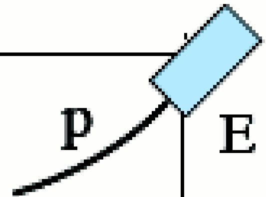
Source	$\sigma(m_W)$ MeV m_T	$\sigma(m_W)$ MeV p_T^e	$\sigma(m_W)$ MeV $\not{E}_T$
Experimental			
Electron Energy Scale	34	34	34
Electron Energy Resolution Model	2	2	3
Electron Energy Nonlinearity	4	6	7
W and Z Electron energy loss differences (material)	4	4	4
Recoil Model	6	12	20
Electron Efficiencies	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
statistical	23	27	23
total	44	48	50

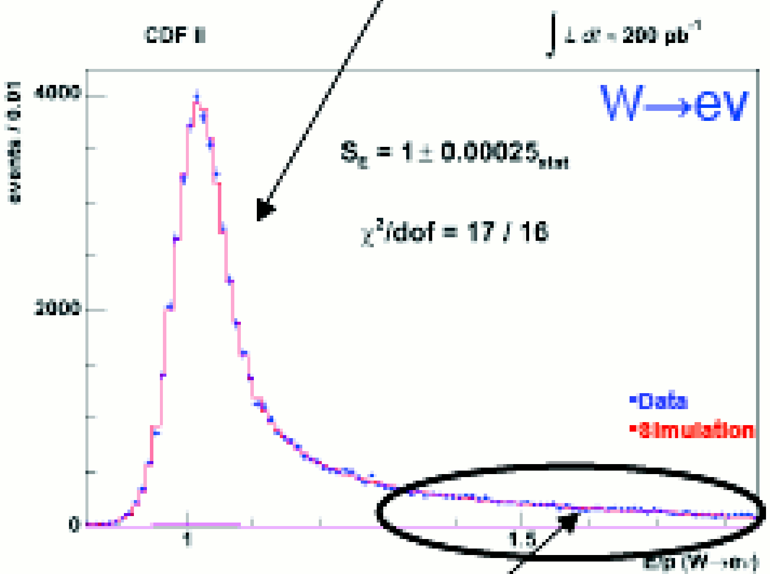
Comparison to CDF: Lepton scale



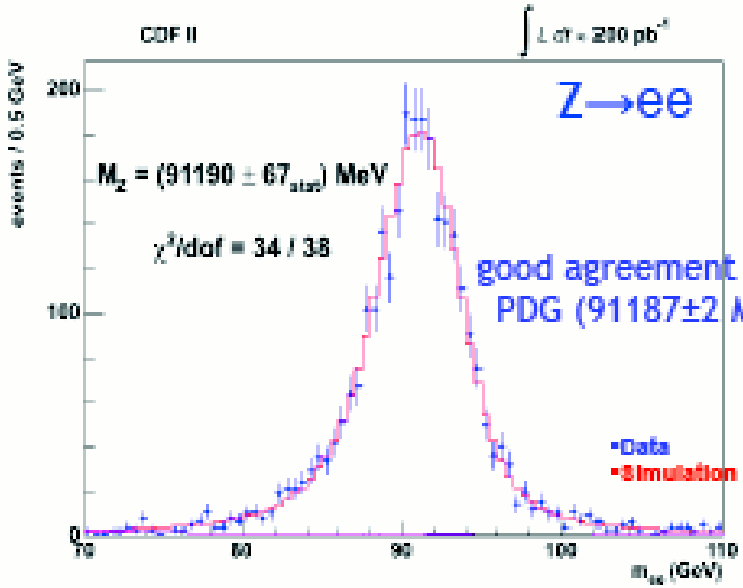
CDF: Lepton energy scale

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





Apply energy scale to Z's



good agreement with PDG (91187±2 MeV)

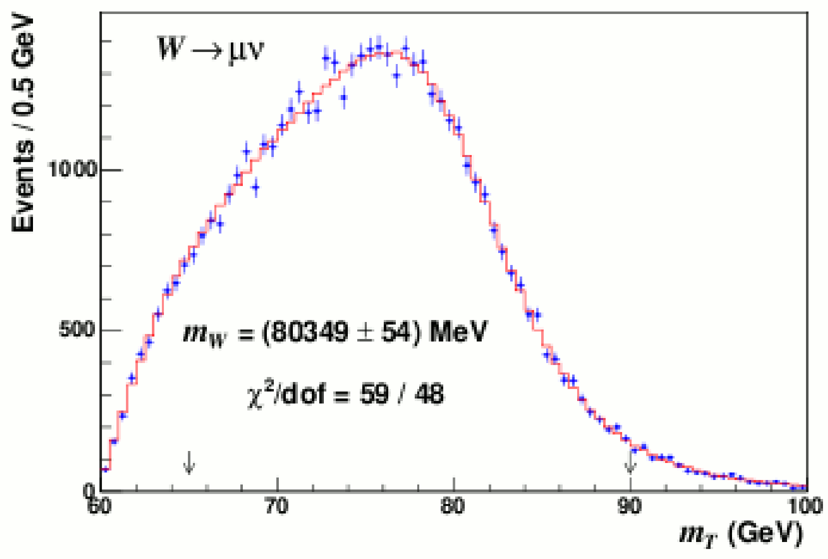
Tune number of radiation lengths with E/p radiative tail

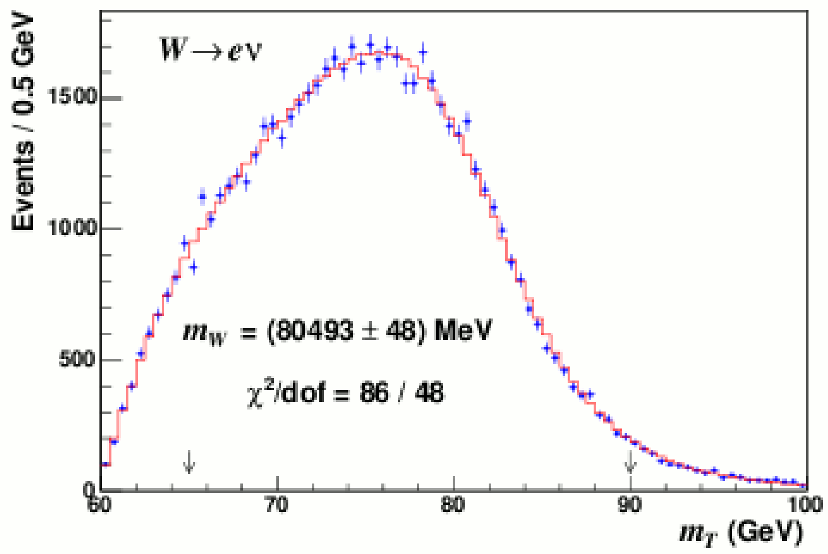
Add Z Mass fit to calibration (30% weight) ΔM_W= 30 MeV

Correct for calibration E_T dependence

Tune resolution on E/p and Z mass peak ΔM_W= 9 MeV

CDF: Result and uncertainties





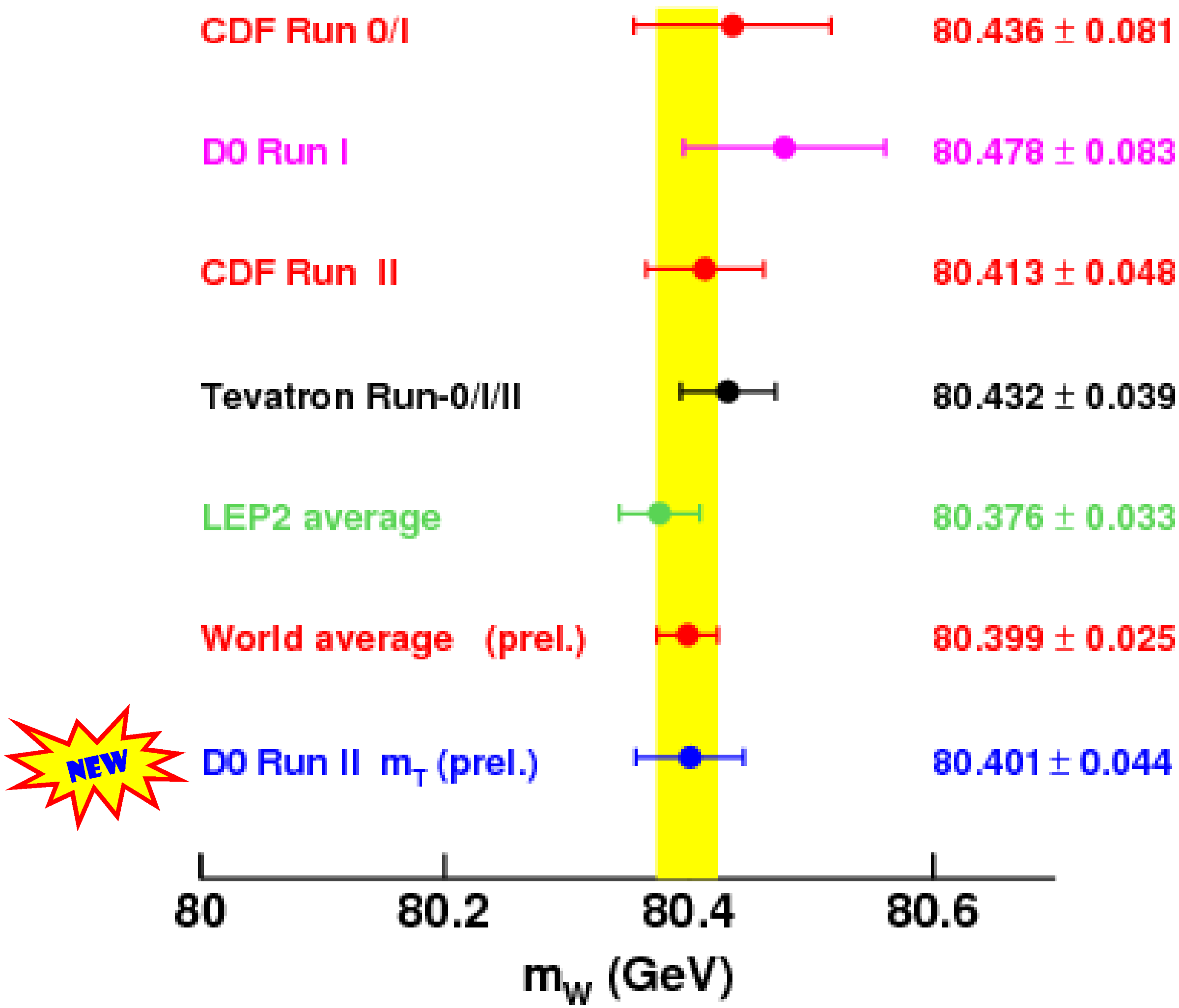
m_T Fit Uncertainties			
Source	$W \rightarrow \mu\nu$	$W \rightarrow e\nu$	Correlation
Tracker Momentum Scale	17	17	100%
Calorimeter Energy Scale	0	25	0%
Lepton Resolution	3	9	0%
Lepton Efficiency	1	3	0%
Lepton Tower Removal	5	8	100%
Recoil Scale	9	9	100%
Recoil Resolution	7	7	100%
Backgrounds	9	8	0%
PDFs	11	11	100%
W Boson p_T	3	3	100%
Photon Radiation	12	11	100%
Statistical	54	48	0%
Total	60	62	-

Combined result (electrons, muons; three observables):

m(W) = 80.413 ± 0.048 GeV

Phys.Rev.Lett.99:151801 (2007)
Phys.Rev.D77:112001 (2008)

W mass: summary of results



The new result from DØ is the single most precise measurement of the W boson mass to date.

So far, we quote our m_T result as the main result. Will combine results from the three observables; expect ~ 10 % improvement in total error over m_T alone.

The new result is in good agreement with previous measurements.

W charge asymmetry

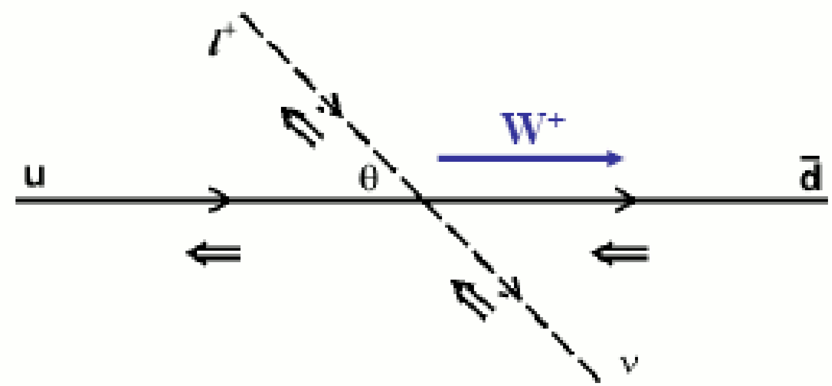
$W^{\pm}$ rapidity measurement constrains PDF of u and d quarks.

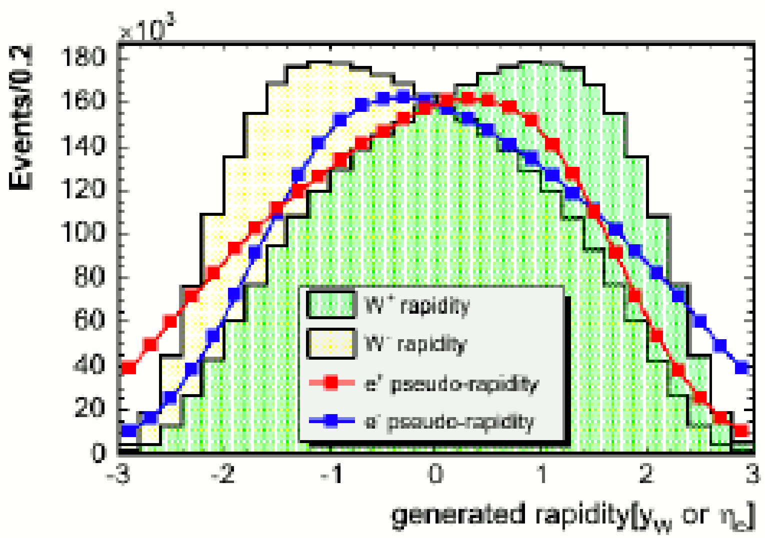
$$x_{1,2} = \frac{M_W}{\sqrt{s}} e^{\pm y}$$

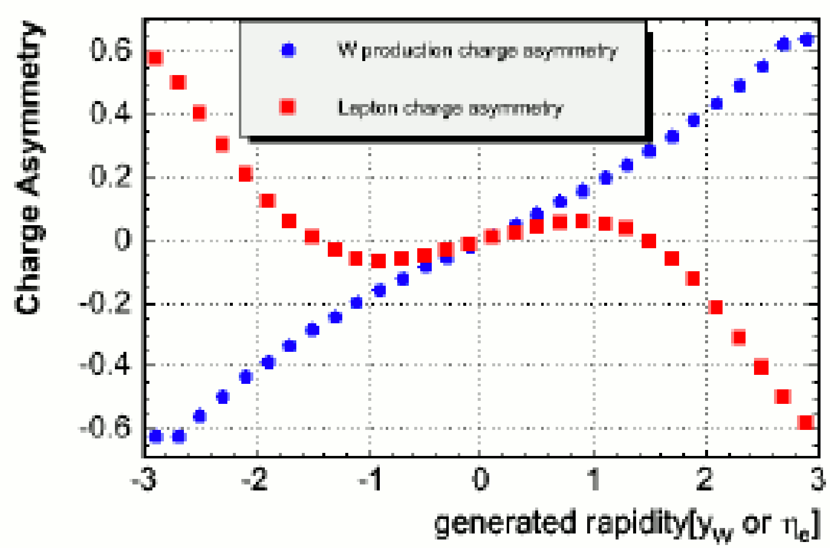
Different u, d momentum:
$W^{\pm}$ produced asymmetrically.

→ charge asymmetry of l, ν from W decay

But V-A interaction: **reduces** the observable **asymmetry** in the lepton rapidity distributions.







First direct measurement of $A(y_W)$

First direct measurement of W charge asymmetry from CDF

Find the two neutrino four-vectors which are solutions for $m(l\ \nu) = M(W)$.

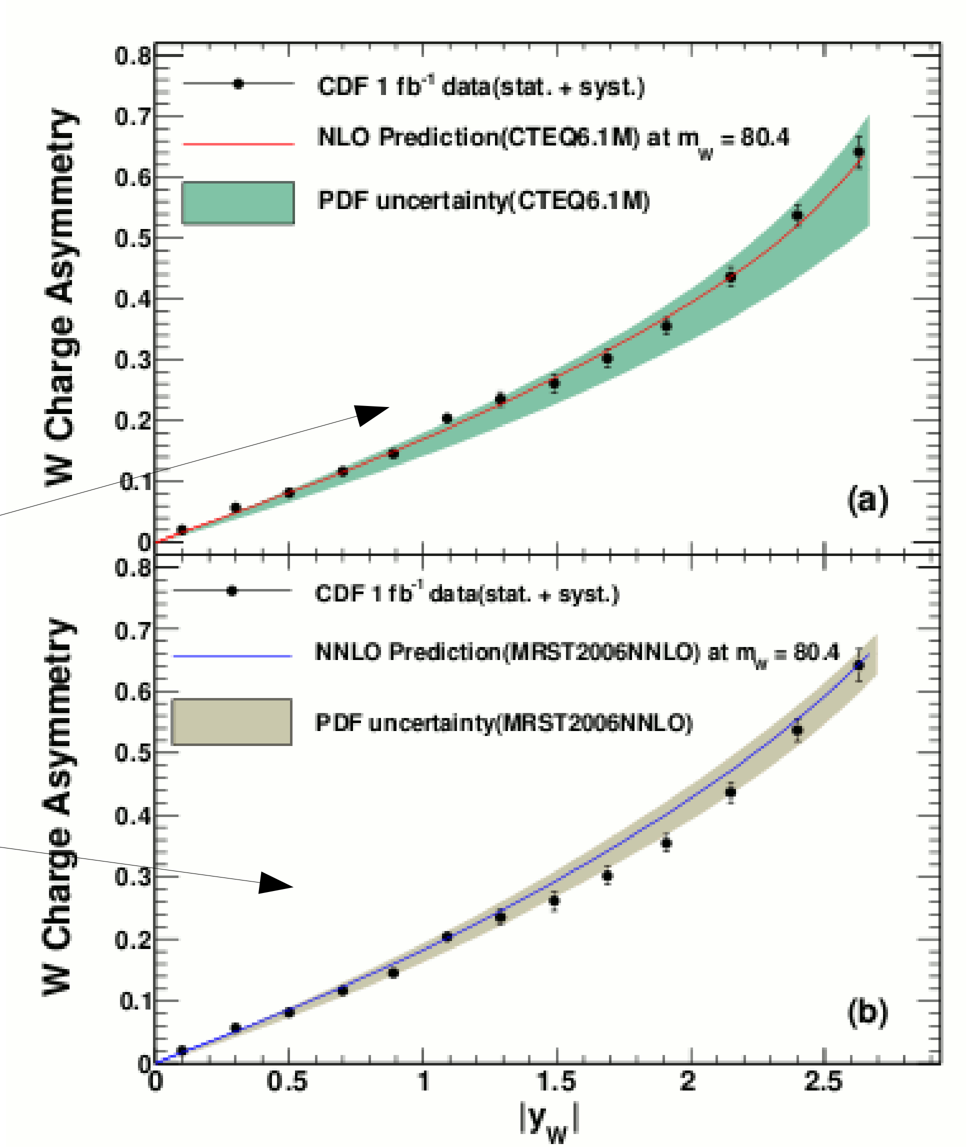
Despite additional complication of multiple solutions, it works !

Systematics < 1.5 % for $|y_W| > 2.0$

Appears that it will have impact on d/u of proton.

Compare to CTEQ6.1M (NLO) and MRST2006 (NNLO) PDFs and their uncertainties.

Working with fitting groups to incorporate results into future PDF sets.



NNLO Prediction: C. Anastasiou et al., Phys. Rev. D69 , 094008 (2004)
MRST 2006 PDFs: A. D. Martin et al., hep-ph/0706.0459, Eur. Phys. J., C28 , 455 (2003)
CTEQ6M PDFs: J. Pumplin et al., hep-ph/0201195

Summary and outlook

We have presented, for the first time, a new preliminary measurement of the W boson mass from the DØ Collaboration. It is based on central electrons in 1 fb^{-1} of Run II data:

$$\begin{aligned} m_W \;=\; & 80.401 \pm 0.023(\text{stat}) \pm 0.037(\text{syst})\ \text{GeV} = 80.401 \pm 0.044\ \ \text{GeV}\ \ (m_T) \\ & 80.400 \pm 0.027(\text{stat}) \pm 0.040(\text{syst})\ \text{GeV} = 80.400 \pm 0.048\ \ \text{GeV}\ \ (p_T^e), \\ & 80.402 \pm 0.023(\text{stat}) \pm 0.044(\text{syst})\ \text{GeV} = 80.402 \pm 0.050\ \ \text{GeV}\ \ (\not{E}_T). \end{aligned}$$

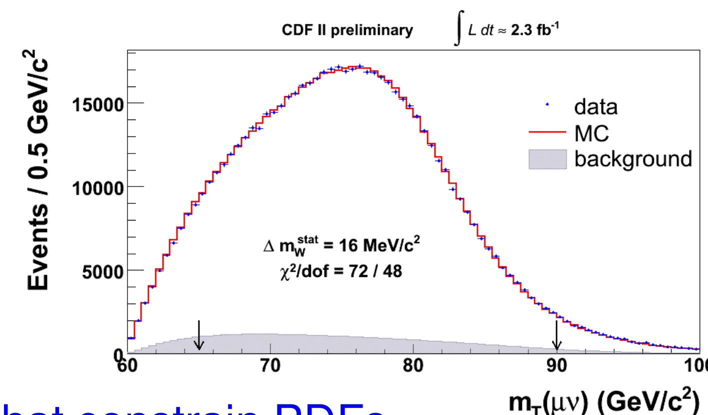
NEW

This is the most precise single measurement of the W boson mass to date.

This measurement is in good agreement with the previous Run II measurement from CDF (electron and muons in 200 pb^{-1} of data), as well as with the LEP average.

DØ and CDF use very different techniques for the main ingredient of the measurement, namely to establish the lepton energy scale. Their systematic uncertainties are uncorrelated to a large extent, which is good for cross-checks and combination. Similar comments apply to (non-)correlation with LEP results.

For both D0 and CDF these measurements are just the beginning. Both collaborations are analysing larger datasets. CDF predict 25 MeV total uncertainty with 2.3 fb^{-1}. DØ expect similar or better uncertainties with the 5 fb^{-1} in the can.



At the same time, progress is made on other measurements that constrain PDFs . PDFs are a source of uncertainties in the W mass which *are* correlated bewteen DØ and CDF.