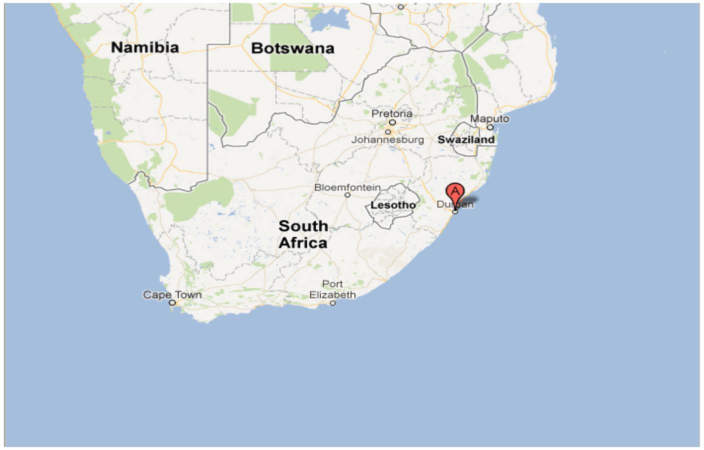
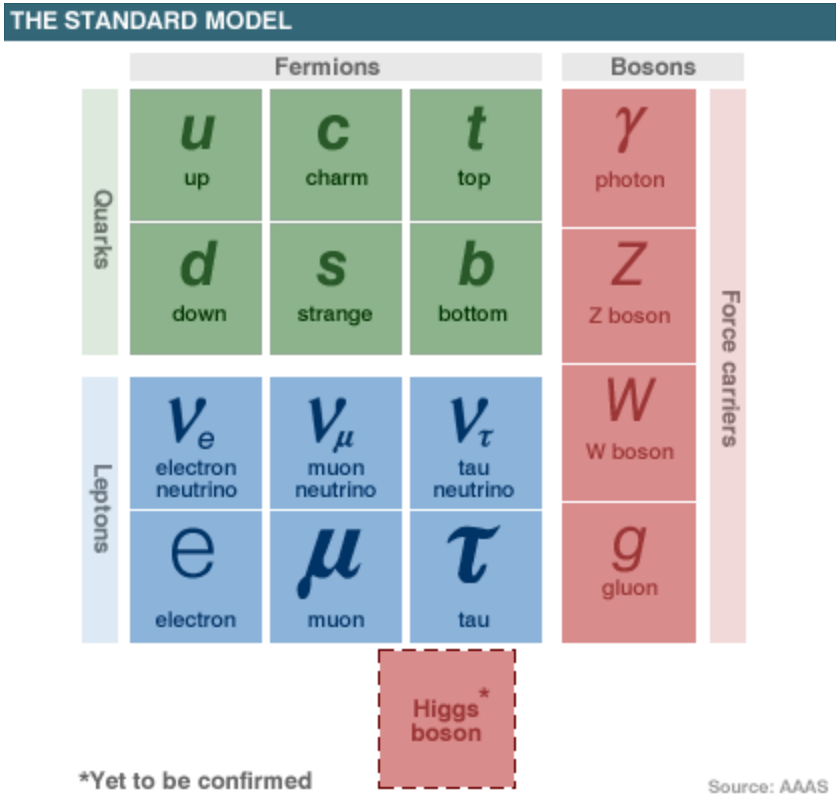
Where is UKZN you ask …



1/6/12

The Standard Model

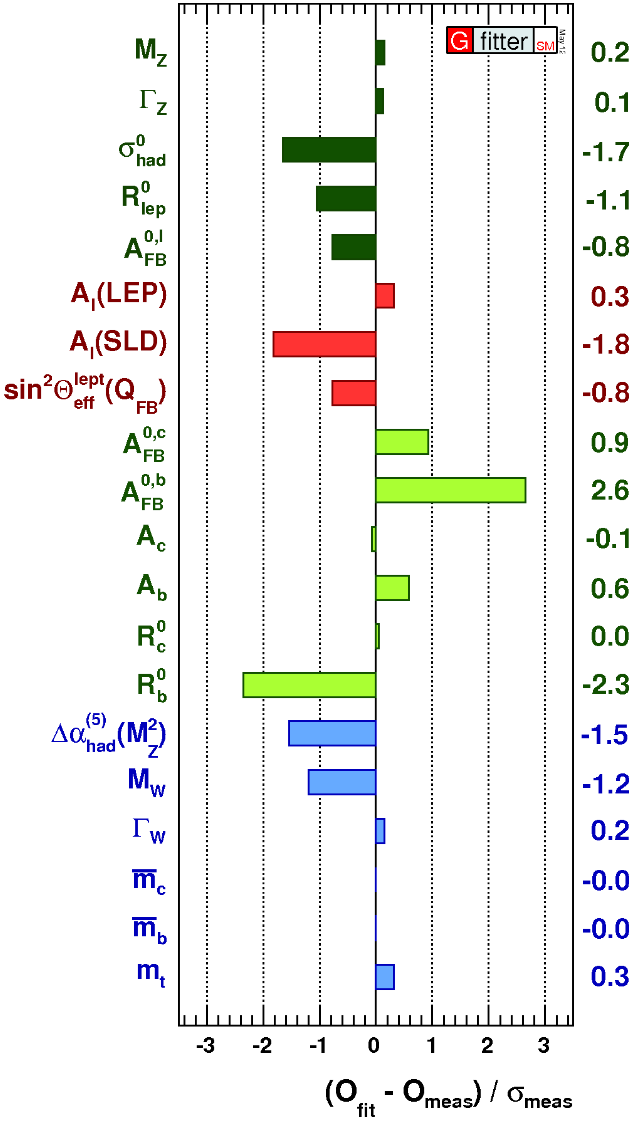


Source: AAAS

- Good description of nature
- Not complete
  - – No verified mechanism for elementary particle mass generation
    - Higgs mechanism is a good candidate
    - Predicts an unobserved scalar boson – The Higgs Boson
  - – Not valid at high energies
- We want to probe for the underlying theory

Testing the Standard Model

- The Standard Model works very well
- Except:
  - Neutrino's have mass
  - The Higgs boson has not been discovered
- To find 'new' physics
  - Direct discovery and study of Higgs boson – LHC
  - Rule out standard model Higgs boson -- W mass



http://arxiv.org/abs/1107.0975

The W Boson Mass cannot be predicted

- The Standard Model relates the mass of the W boson (m_W) to other known quantities:

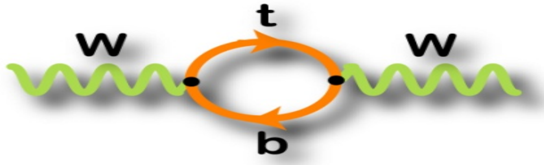
$$m_W = \sqrt{\frac{\pi\alpha}{2G_F}} \frac{1}{\sin\theta_w} \bullet \frac{1}{\sqrt{1-\Delta r}}$$

$$\alpha_{EM}(m_Z)^{-1} = 127.916 \pm 0.015$$

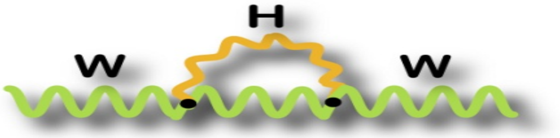
$$G_F = 1.66364(5) \times 10^{-5} \mathrm{GeV}^{-2}$$

$$M_Z = 91.1876(21) \quad \mathrm{GeV}$$

- The 'interesting' term is the radiative correction term which is sensitive to all particles that the W interacts with, this includes:
  - the S.M. Higgs boson
  - Any new particle



$\Delta r \sim m_{top}^2$

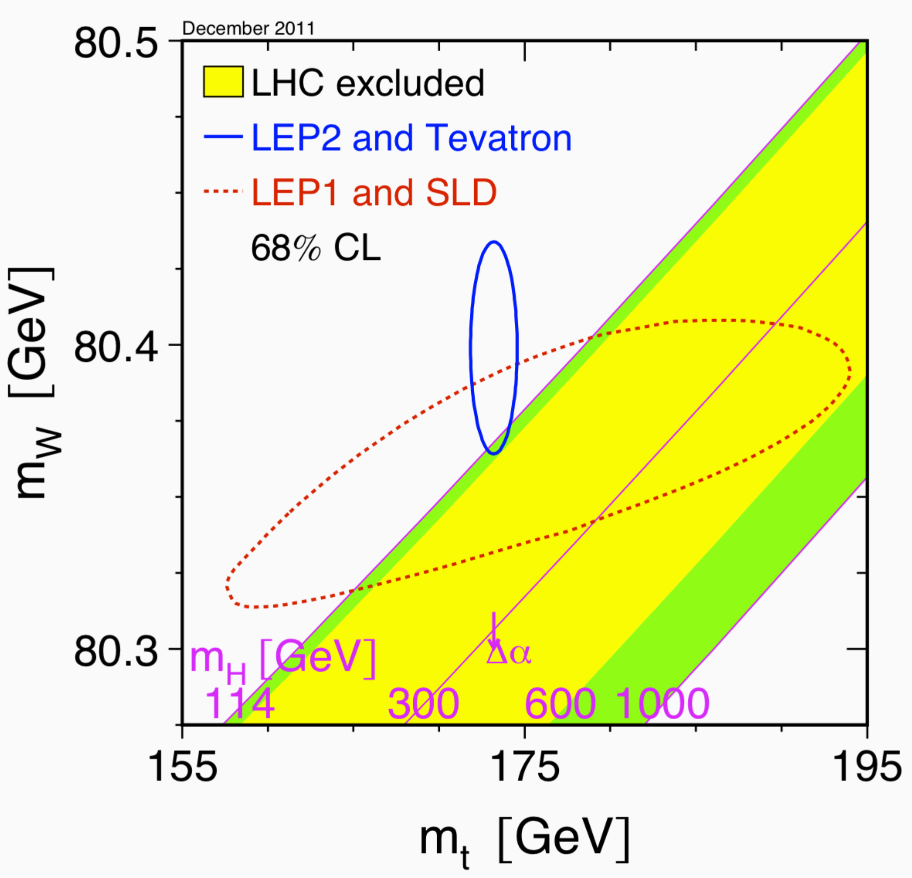


$\Delta r \sim \log m_{Higgs}$

Radiative corrections allow one to constrain the Higgs Boson Mass

- While experiments at the Tevatron and LHC search directly for the Higgs
- Precision measurements of m_t (top quark mass) and m_w constrain the allowed mass of the Higgs boson within the standard model

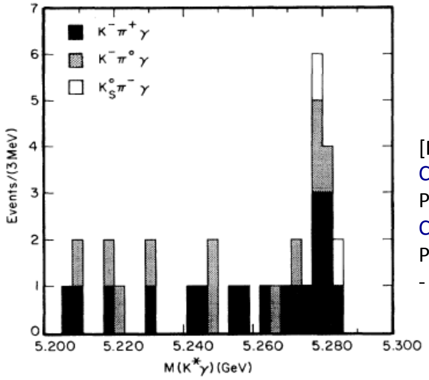
For equal contribution to the Higgs mass uncertainty need:
$\Delta m_w \approx 0.006 \Delta m_t$
Current Tevatron average:
Δm_t = 0.9 GeV (arXiv:1107.5255)
$\Rightarrow$ would need: Δm_W = 5 MeV
Prior to April 2012: Δm_w = 23 MeV



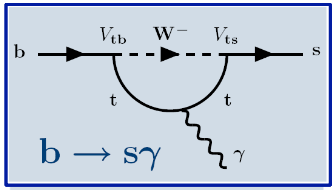
Indirect Evidence for the Top Quark

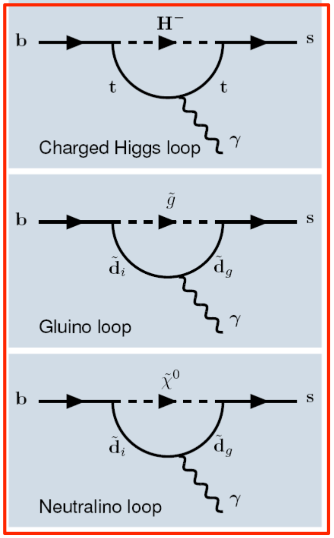
A historical example – $B^0 \to K^{*0}\gamma$

- In SM: occurs through a dominating W-t loop
- Possible NP diagrams:
- Observed by CLEO in 1993, two years before the direct observation of the top quark
  - BR was expected to be (2-4)×10^{-4}
  - → measured BR = (4.5±1.7) ×10^{-4}



[Phys.Rev.Lett. 71 (1993) 674 - Cited by 605 records
Phys.Rev.Lett. 74 (1995) 2885 - Cited by 836 records
Phys.Rev.Lett. 87 (2001) 251807 - Cited by 565 records]

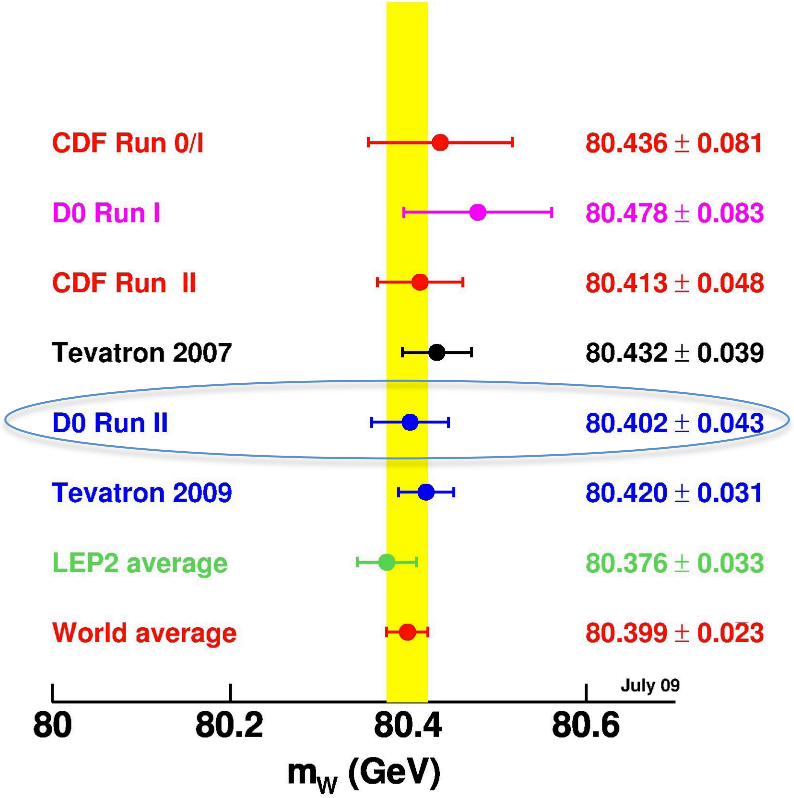




Mitesh Patel (Imperial College) at CERN, about 2 weeks ago

m_W has been measured many times

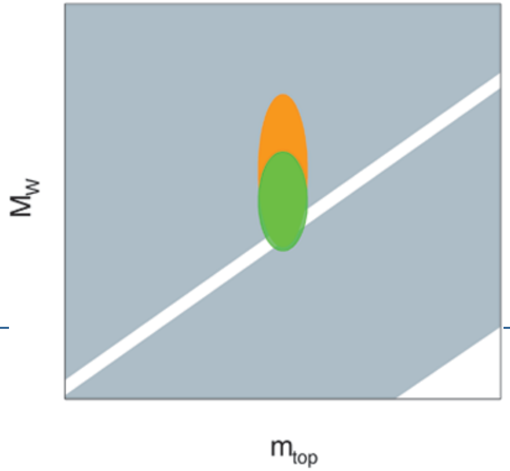
- The LEP average value was the most precise until 2009.
- The 1 fb^{-1} result from D0 lead to the Tevatron combination being more precise than the LEP combination



CDF and D0 updates (PRL 108)

CDF

- e and μ channels
- 2.2 fb^{-1} (including previously analyzed data)
- PRL 108, 151803 (2012)
- $m_W = 80387 \pm 19$ MeV/c^2

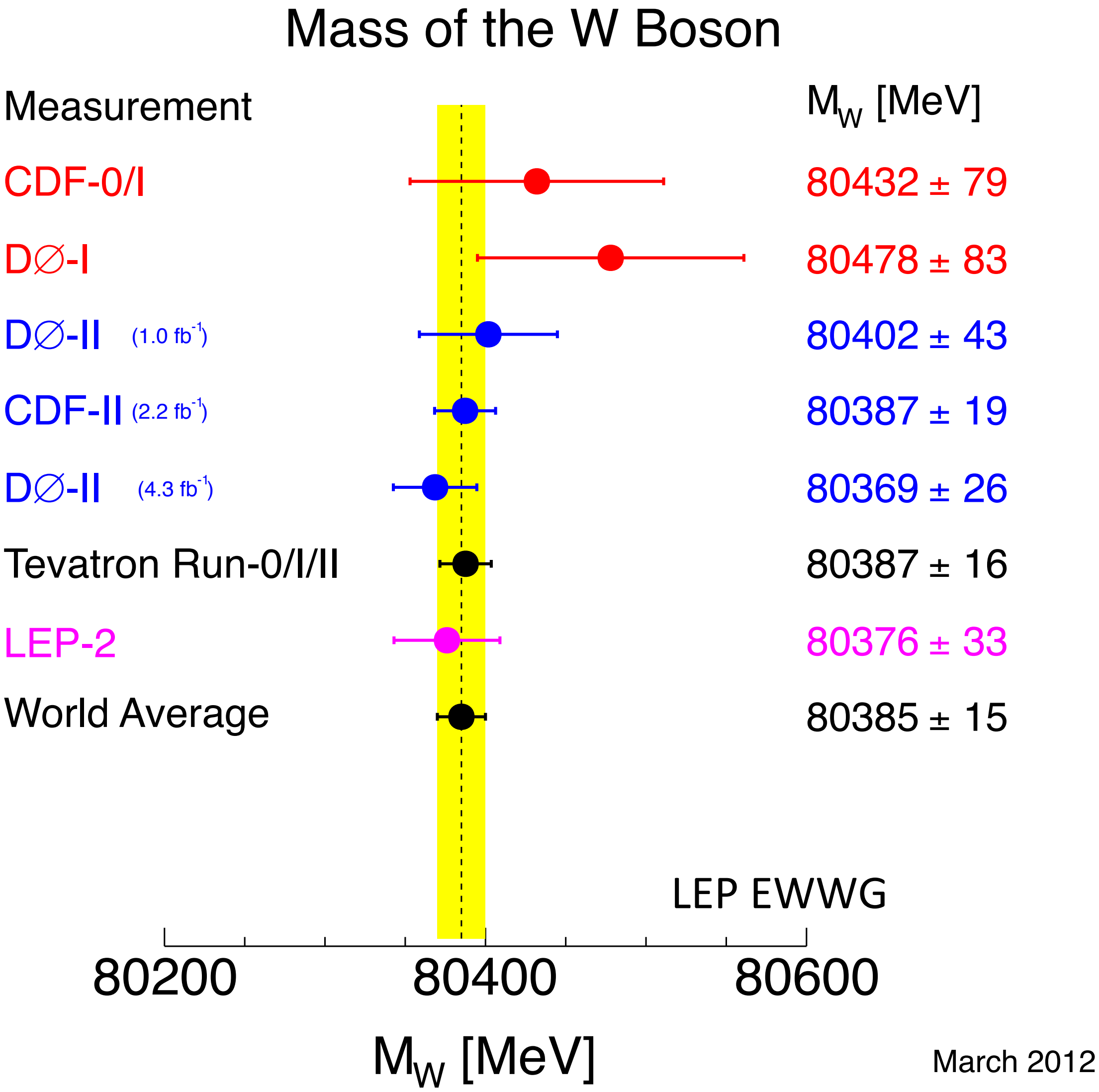


D0

- e channel only
- 4.3 fb^{-1} (in addition to 1 fb^{-1} already analyzed
- PRL 108, 151804 (2012)
- $m_W = 80367 \pm 26$ MeV/c^2 (4.3 fb^{-1})
- $m_W = 80375 \pm 23$ MeV/c^2 (5.4 fb^{-1})

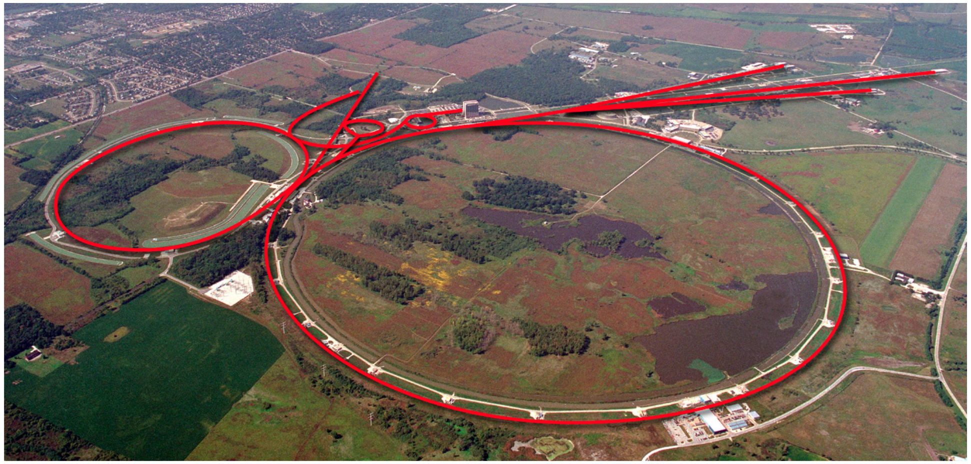
The World Average uncertainty is now 15 MeV / c^2

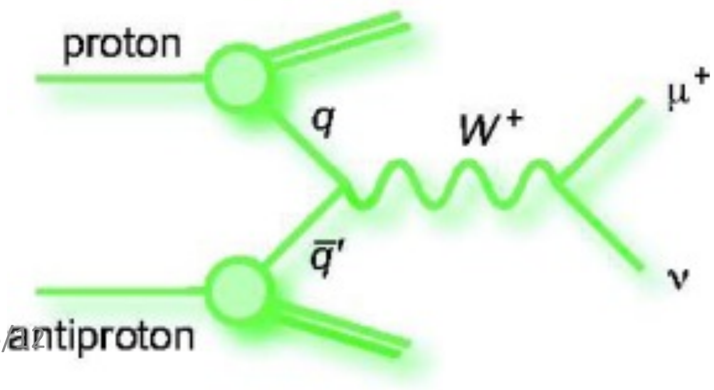
- World Average driven by D0 and CDF measurements
- Results are consistent
- Updates from CDF and D0 in February have driven the Tevatron average uncertainty closer to the current theoretical limit of approximately 6 MeV
- Still the limiting experimental value on the indirect Higgs mass constraint



The Tevatron

- 1. 96 TeV proton anti-proton collider
- 1 km Radius

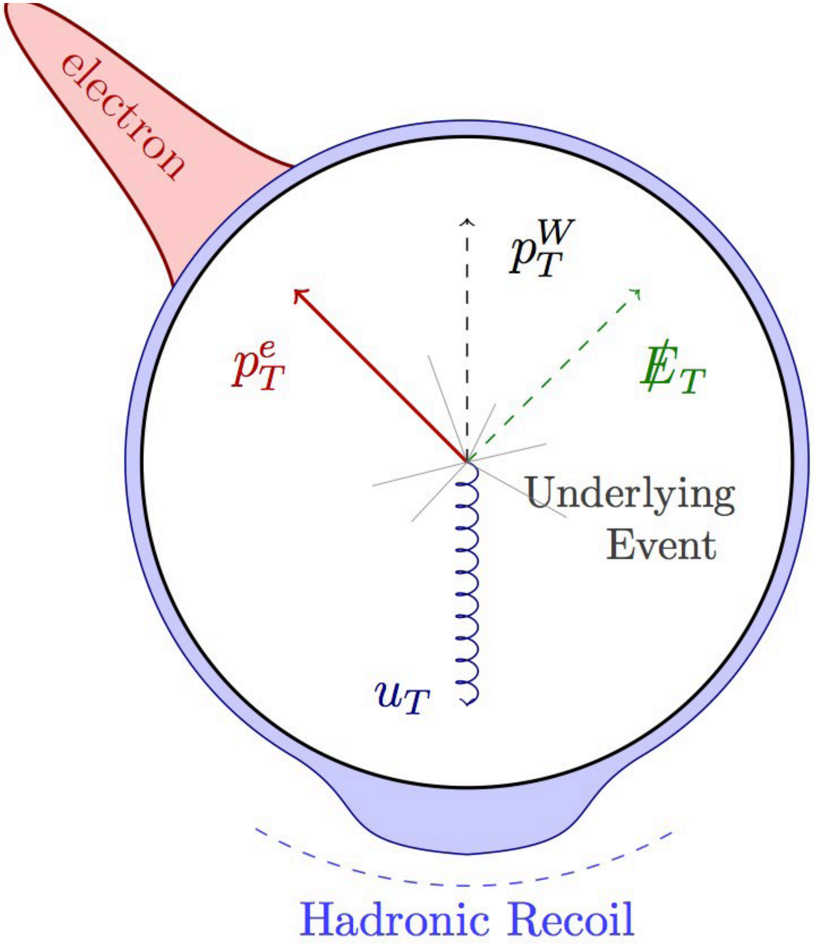




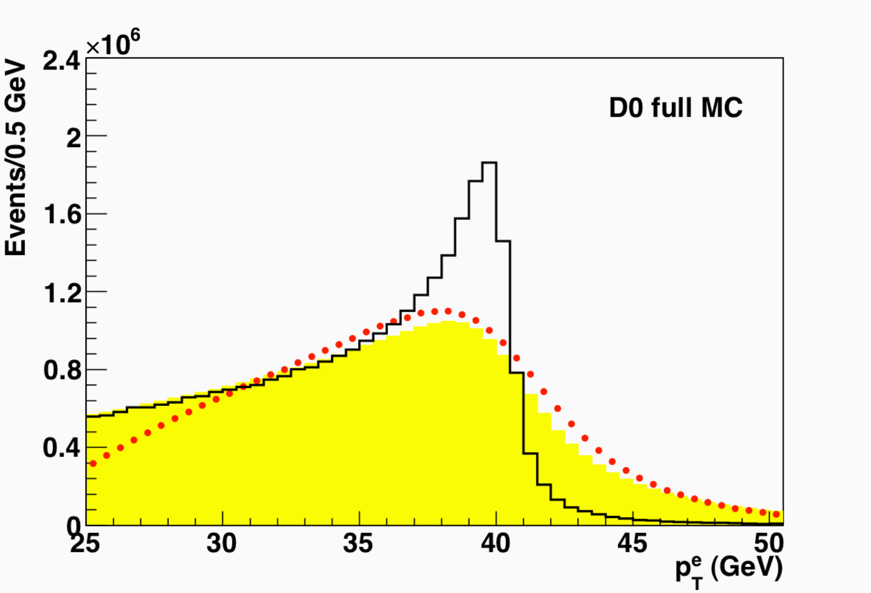
An Event

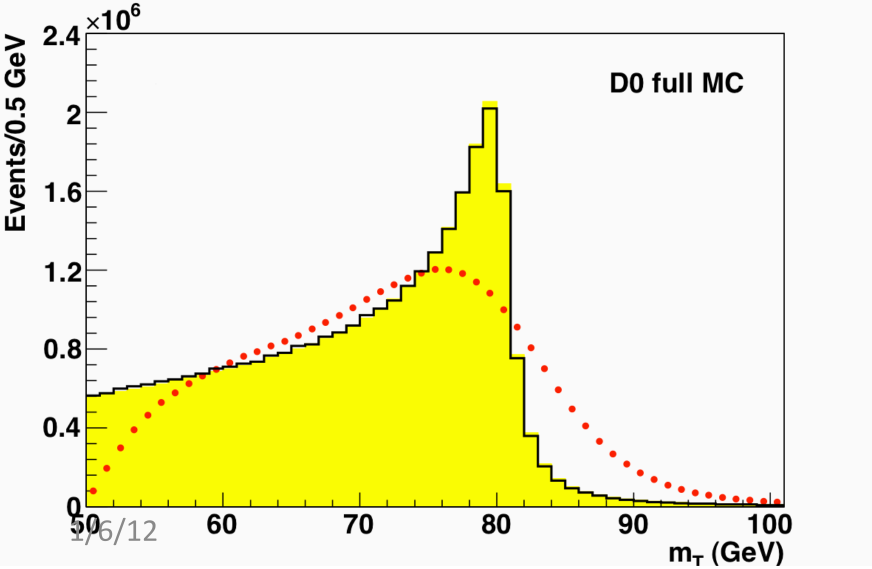
A W Boson Event Representation

- At D0 we measure the W mass in the electron channel.
- For a W candidate event we measure 2 objects
  - The electron
    - Need 0.1 per mil precision
  - The Hadronic recoil
    - Need 1 % precision



Observables





The electron transverse momentum p_T (e) is sensitive to the boson transverse momentum

— No p_T (W) or detector effects

🟨 p_T(W) included

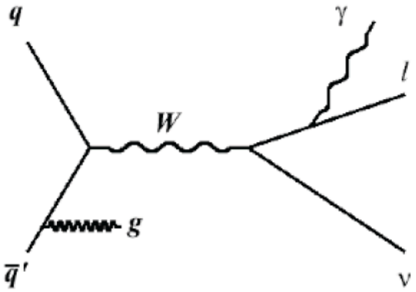
● Detector effects added

The transverse mass (m_T is sensitive to detector effects (via the recoil system)

$m_T^2 = (E_T^e + E_t^\nu)^2 - (\mathbf{p}_T^e + \mathbf{p}_T^\nu)^2$

Rely on Detailed Simulations to compare to Data

- The observables cannot be described analytically, We rely on detailed M.C. And detector response simulations.



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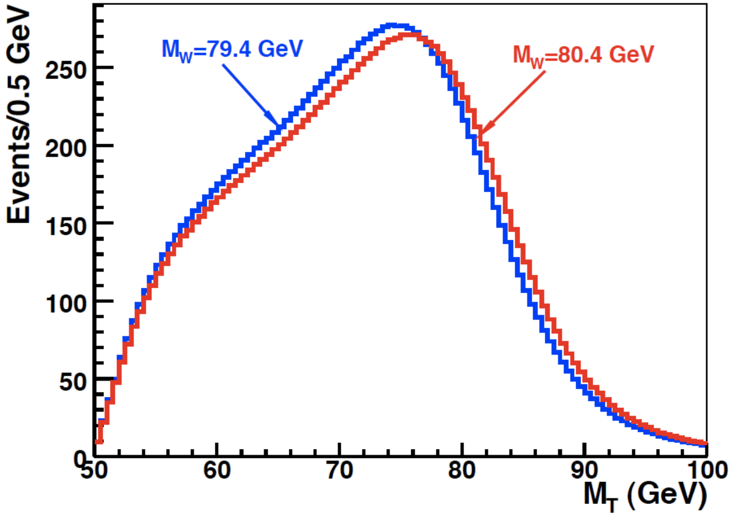
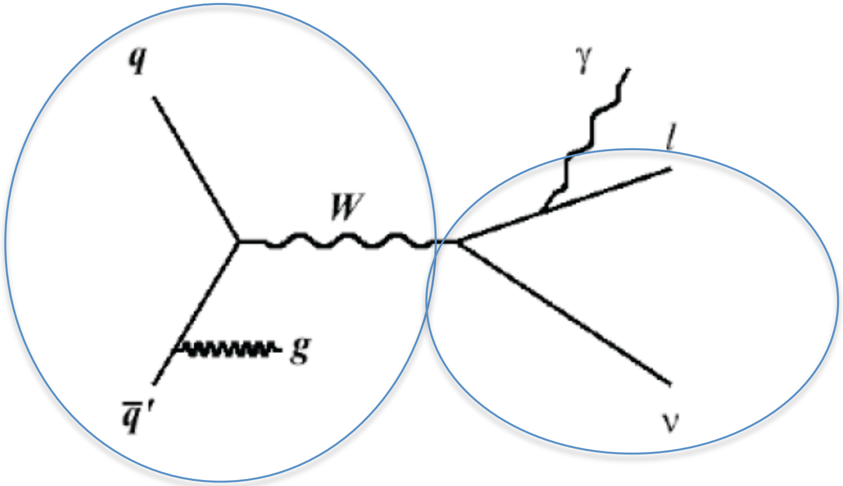
Detector Simulation

=



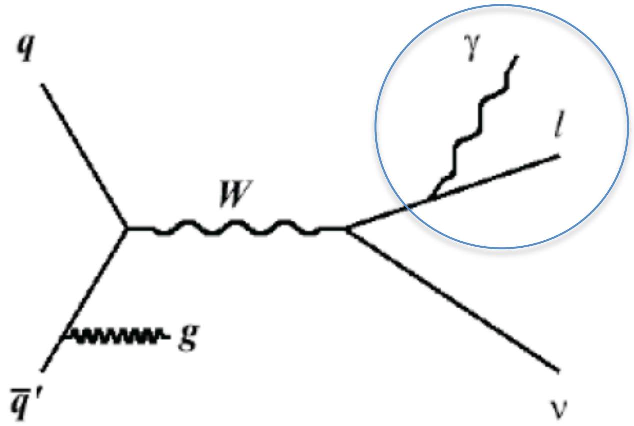
Event Generation – 5-11 MeV

- ResBos:
  - Computes the NLO differential cross-section for pp->B(->*ll*) where B = boson, *l* = electron or neutrino
  - Includes soft-gluon resummed initial state QCD corrections
    - Important for the boson p_T
  - Used with CTEQ 6.6 PDF's



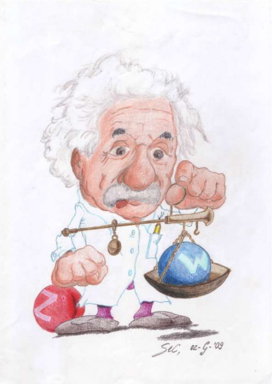
Event Generation – 7 MeV

- Photos
  - Simulates the emission photons
    - Limited to a maximum 2 FSR photons

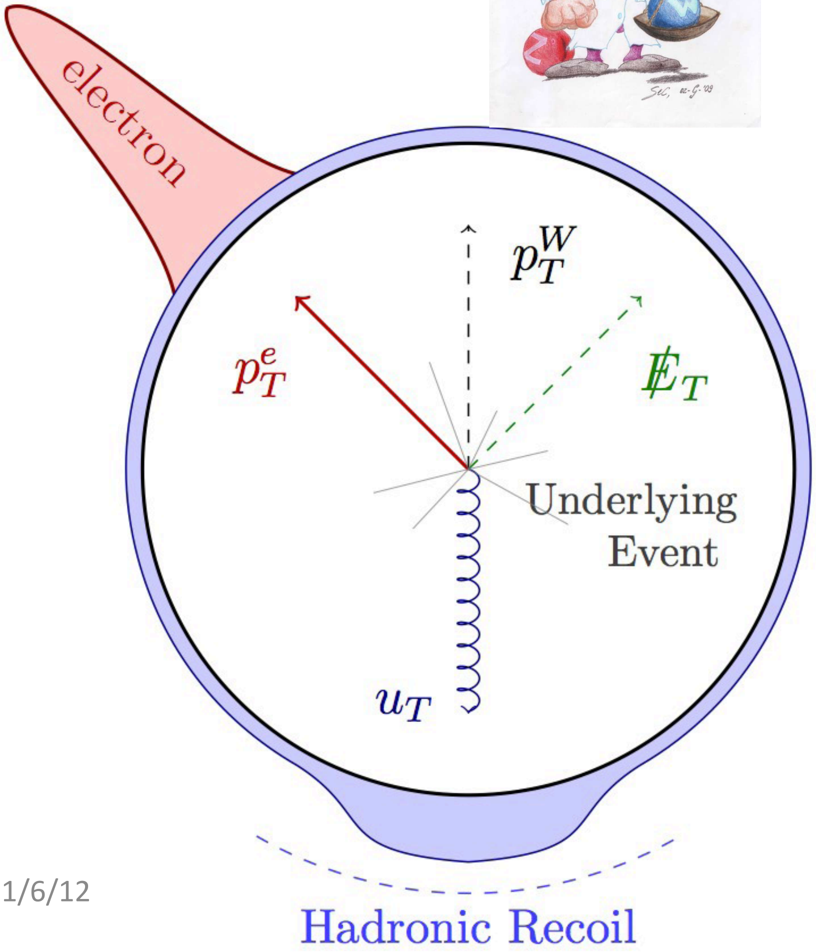


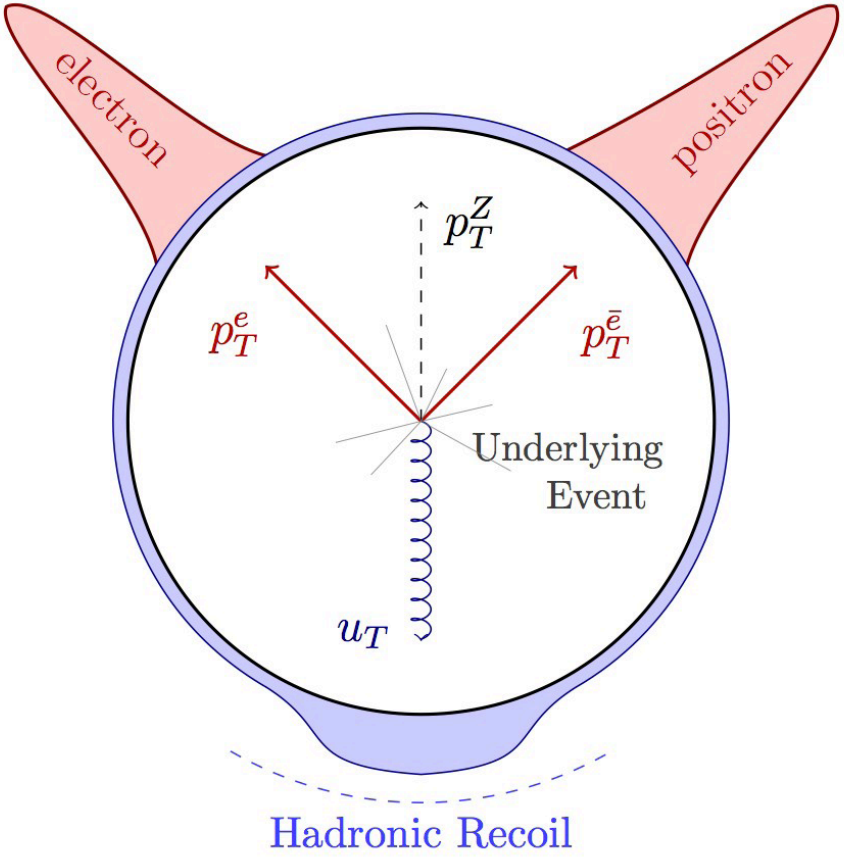
Environment / Detector Response

W → eν Signal



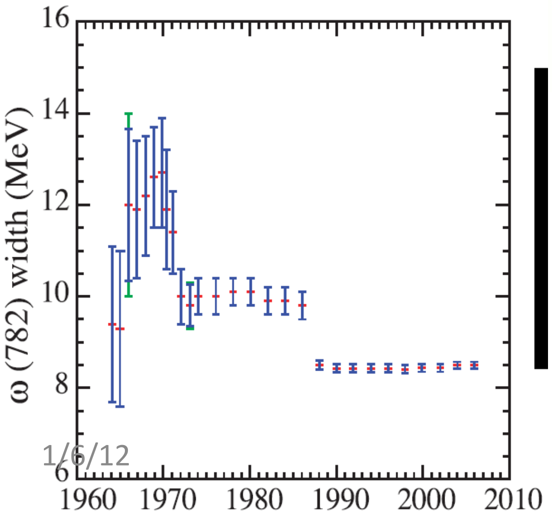
Z → ee control sample
Thank you LEP!

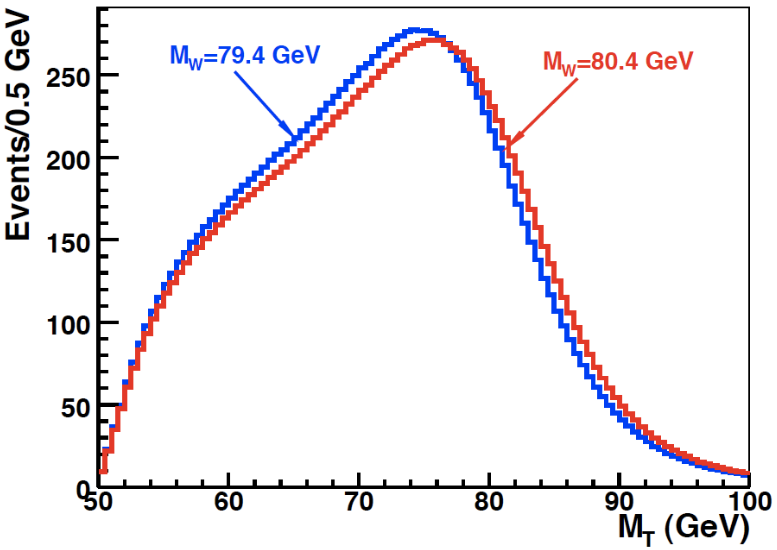




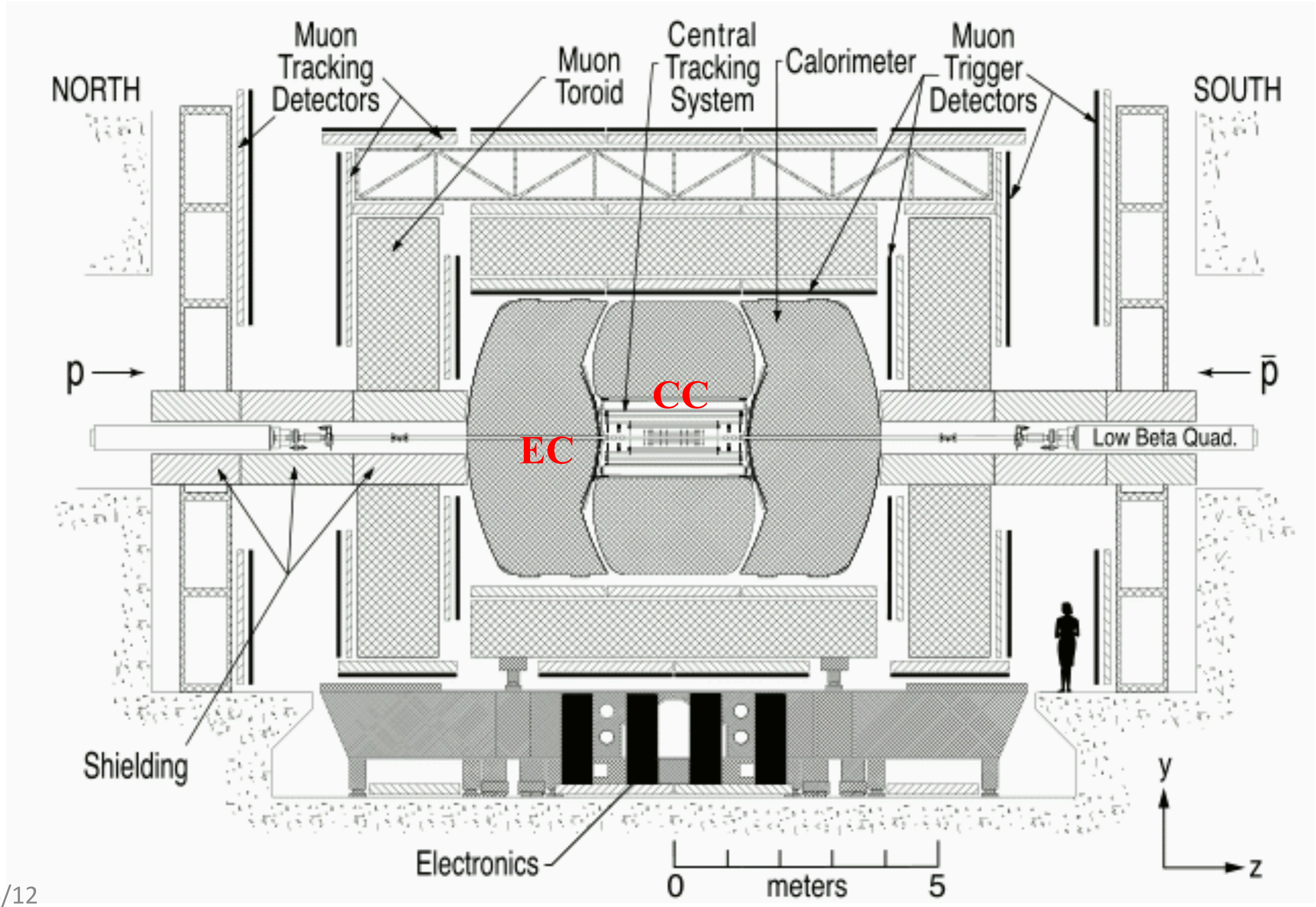
Template Fit

- Finally we fit for the mass using templates
  - Maximise the likelihood
  - Best fit value is hidden : this is a blind analysis

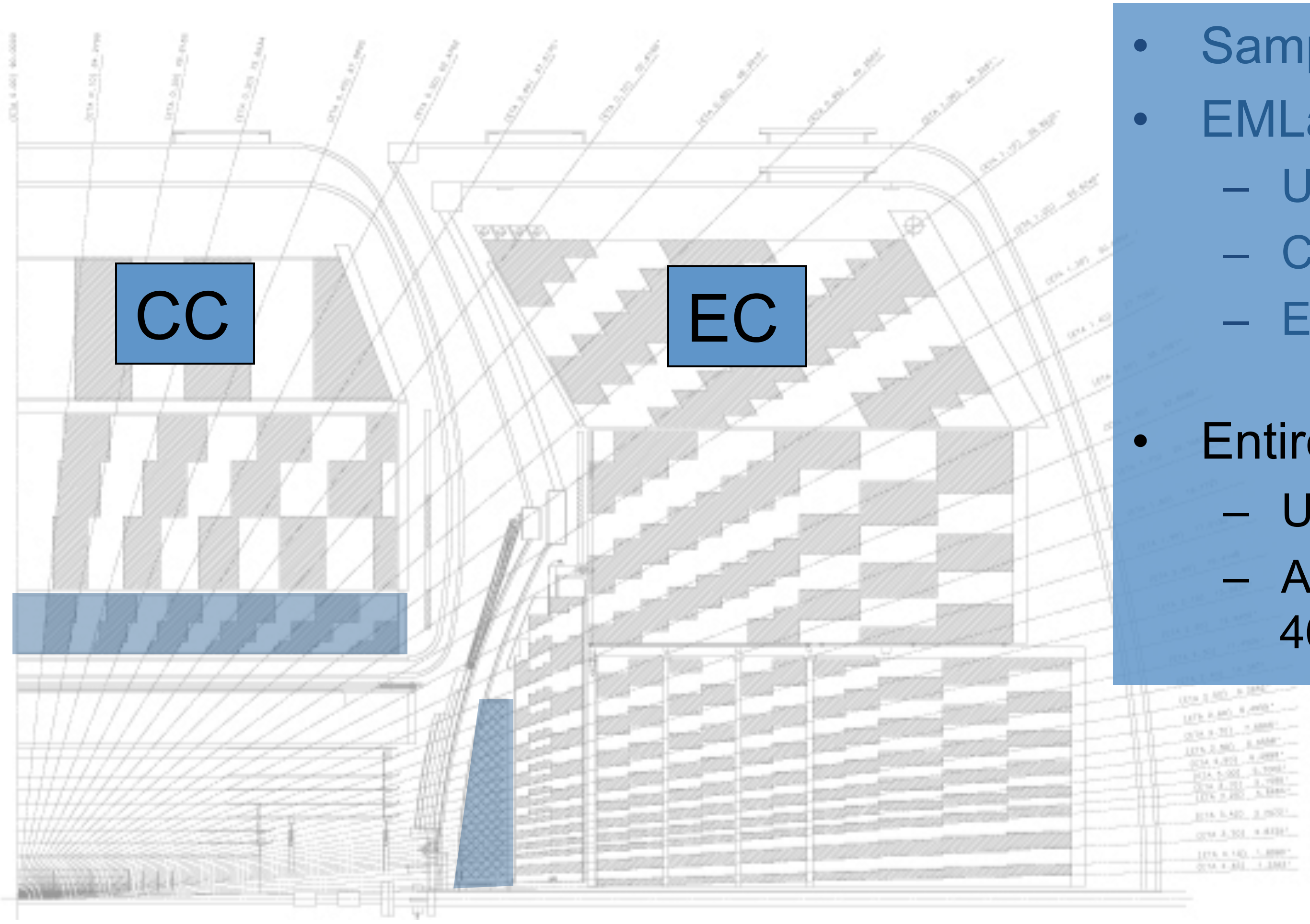




The D0 Detector



Calorimeter



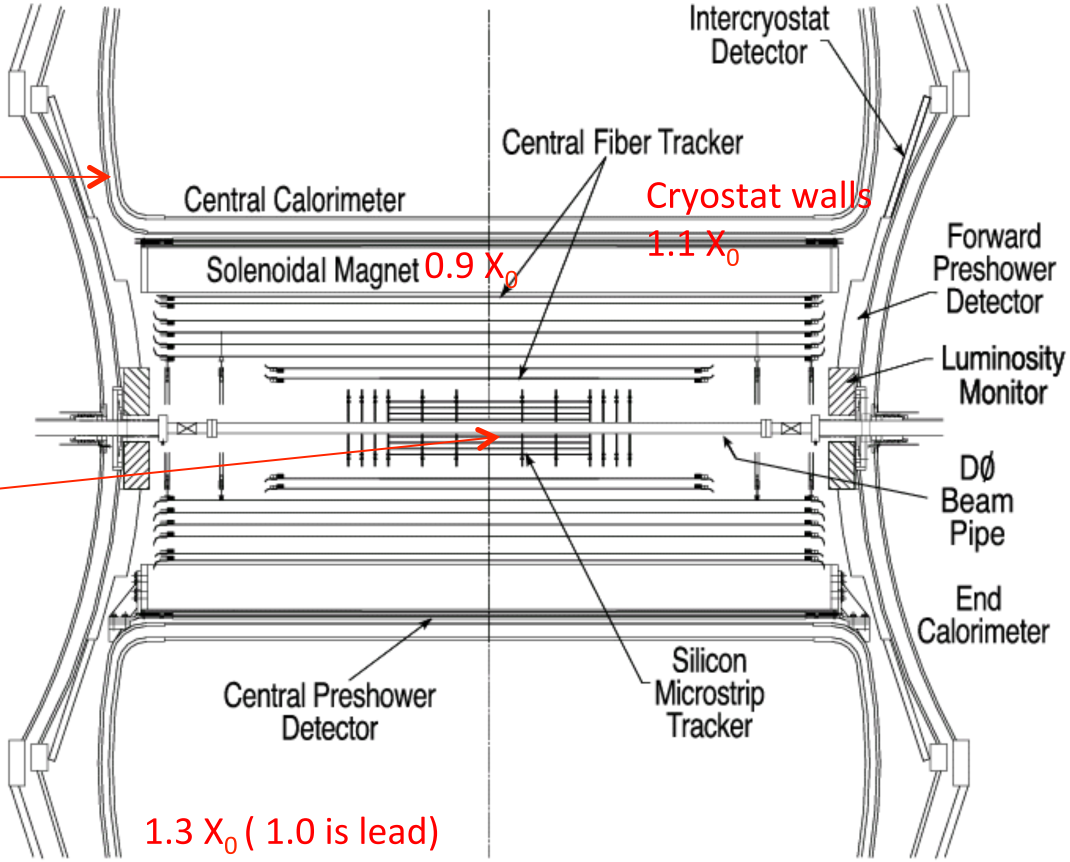
- Sampling Calorimeter
- EMLayers
  - Used for Electron
  - CC |η| < 1.05
  - EC |η| < 2.3
- Entire Calorimeter
  - Used for Recoil
  - Approximately 46,000 channels

D0 Tracking and Magnet

First active layer

~3.7 X_0 between

Interaction Point



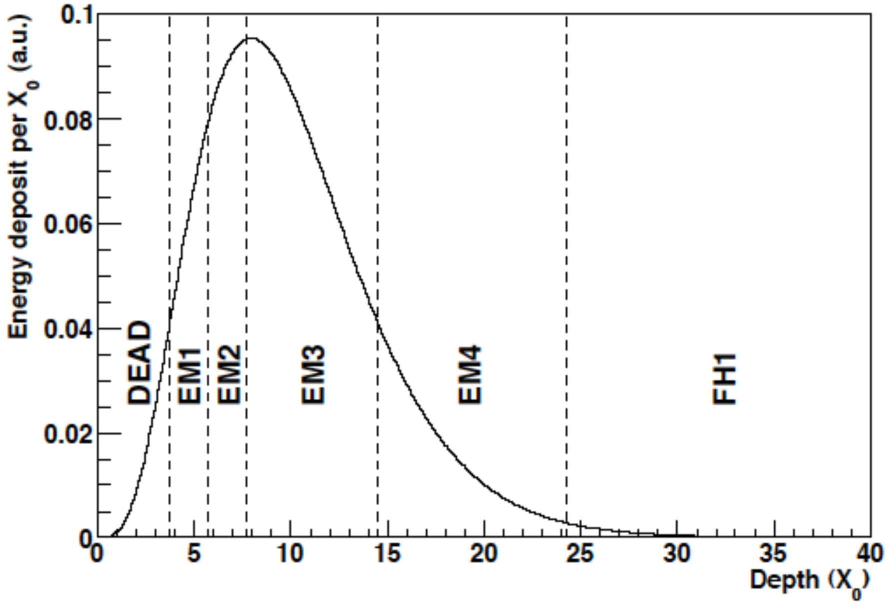
Cryostat walls 1.1 X_0

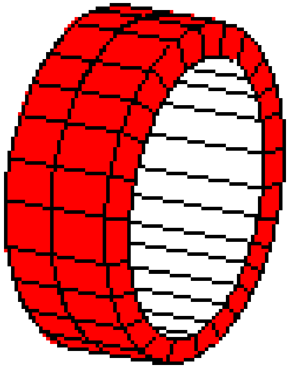
0.9 X_0

1.3 X_0 (1.0 is lead)

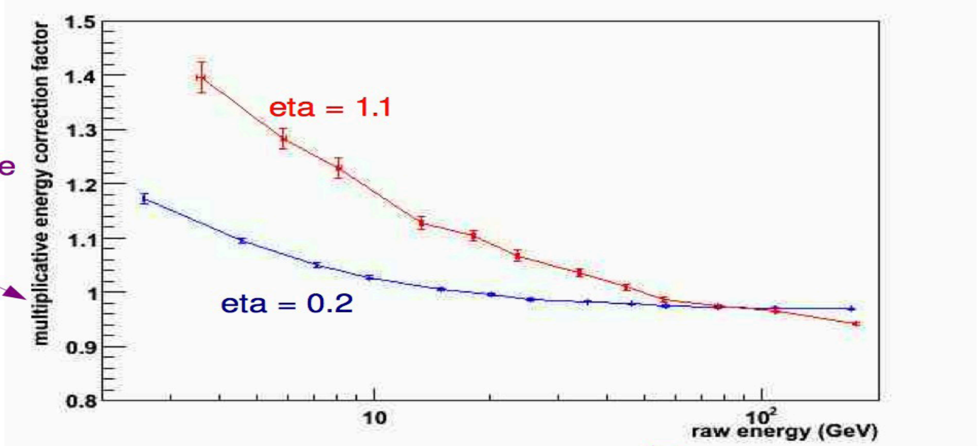
Calorimeter Calibration -- 4 MeV

- Use the azimuthal symmetry of the detector, and physics processes for phi intercalibration at fixed η
- Use Detailed M.C to Calibrate e-loss corrections
- Use the Z Mass peak to calibrate η dependance



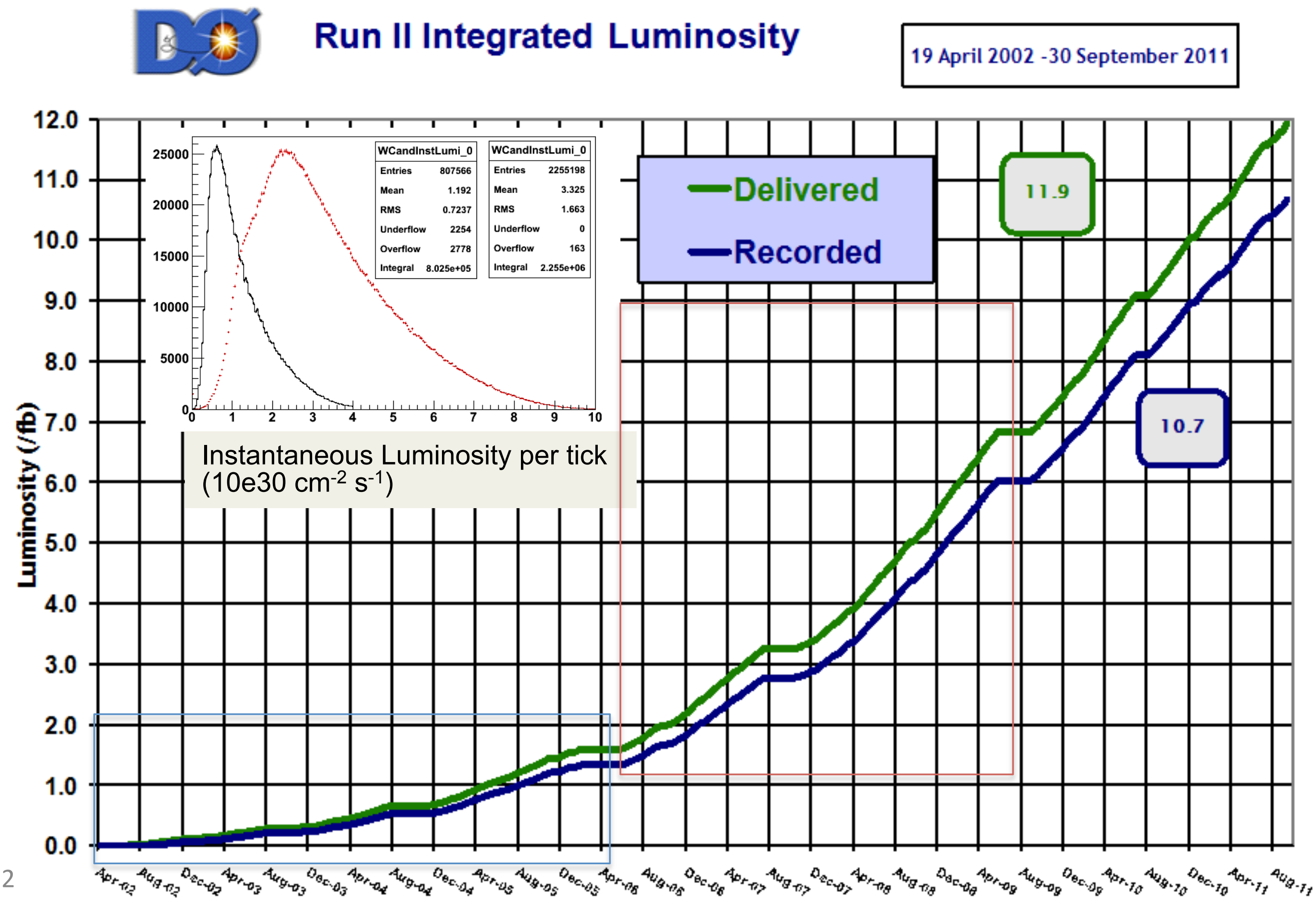


This is the energy correction factor that gets us back to the energy of the incident electron.



This is the energy as reconstructed in the CAL.

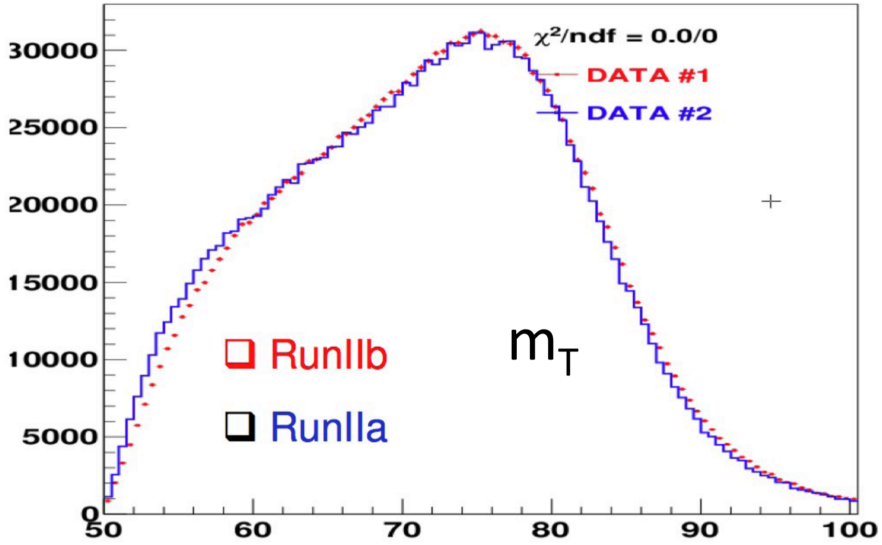
Recorded Luminosity

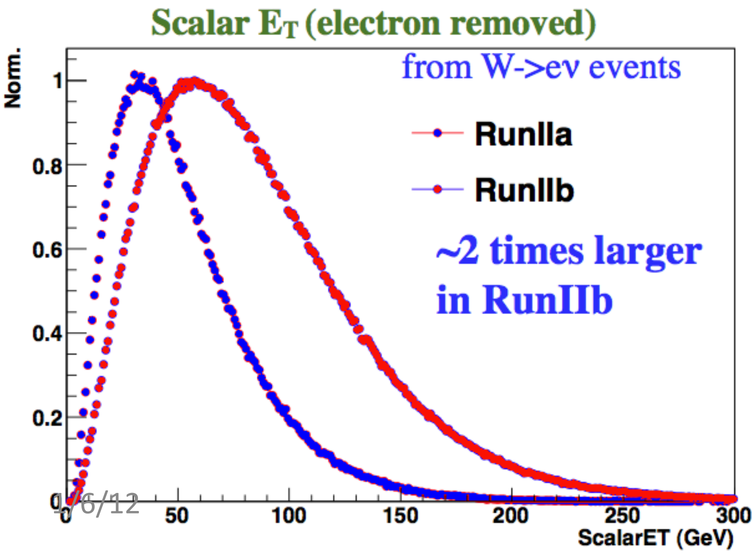


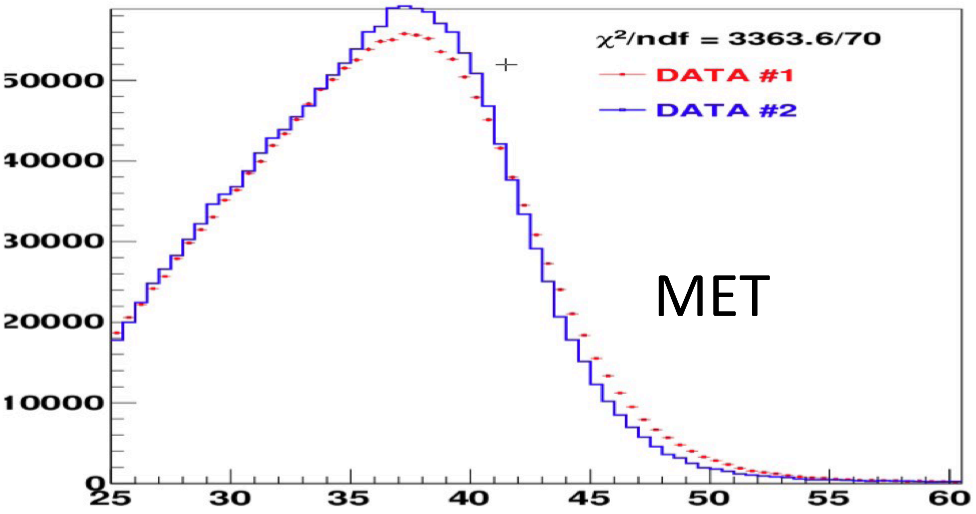
Instantaneous Luminosity per tick
(10e30 cm^{-2} s^{-1})

Higher Luminosity Brings Challenges

More activity in the detector at higher luminosities.
This changes the experimental observables significantly

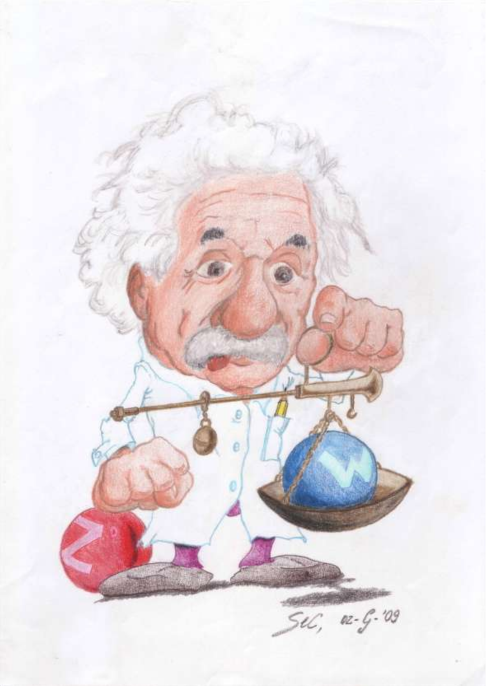






Fast Sim. Tuning

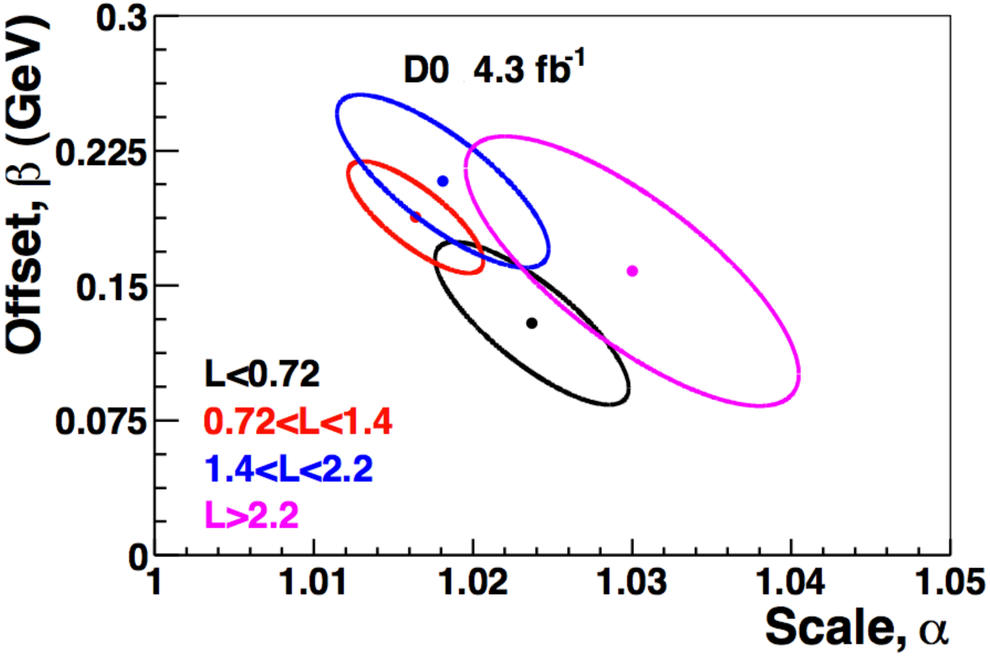
- Parameterised Detector Description Components
  - EM Cluster (electron) Calorimeter Response
    - Response to Electron
    - Effects due to recoil system
      - Hard, and soft recoil
  - Recoil Calorimeter Response
    - Hard Recoil Response
    - Soft Recoil Response
      - Luminosity dependent
    - Correlations with EM Object
  - Efficiencies for selection cuts
    - Evaluated using Tag and Probe method



- Make use of Z Boson to determine parameters

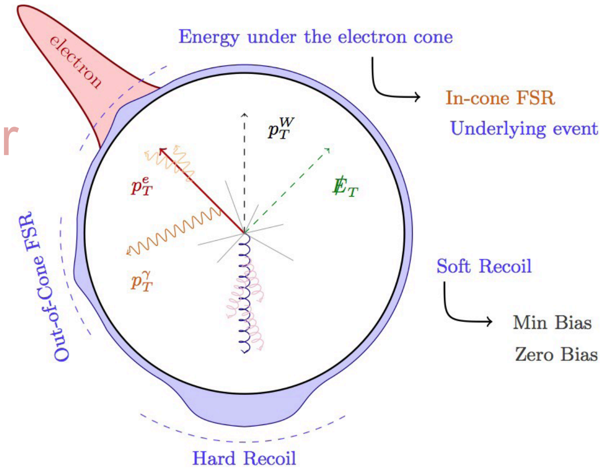
E.M. Response – 16 MeV

- $E_{measured} = \alpha * (E_{true} - 43\text{ GeV}) + \beta + 43\text{ GeV}$
  - β is the offset at 43 GeV, α is the slope
- Determine α,β using 2-D fits to m_Z and f_Z
  - $f_Z = [E(e1)+E(e2)] \times (1-\cos\gamma_{ee}) / M_{measured}$
  - Splits sample into sub-samples
  - Stable over lumi change
- Energy from the recoil system is i event kinematics
  - $u_{||}$, SE_T



Recoil Response – 5 MeV

- $u_T = u_T^{Hard} + u_T^{Soft} + u_T^{Elec}$
  - u_T^{Hard}
    - Hard recoil model based on GEANT Z → v v events
    - Free parameters tuned to Z → ee data
  - u_T^{Soft}
    - Use Library of MB (pythia), and ZB (data) events to model data
  - u_T^{Elec}
    - Leakage of electron energy out of cluster
    - Recoil energy lost in EM cluster
    - FSR Model



Recoil Model has 5 tuneable params.

$$\vec{u}_{T,smear}^{soft} = \sqrt{\alpha_{MB}}\vec{u}_T^{MB} + \vec{u}_T^{ZB}$$

Model of
spectator partons

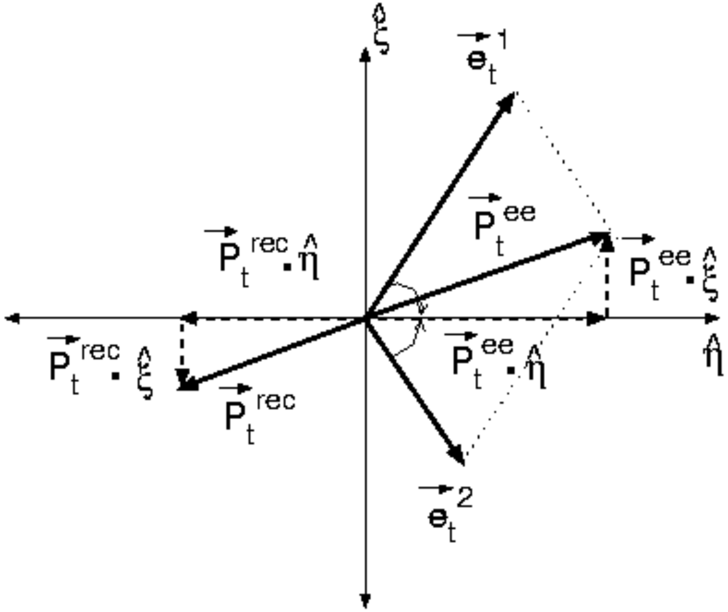
From Data, Random trigger
(takes care of pileup and noise)

Recoil Model has 5 tuneable params.

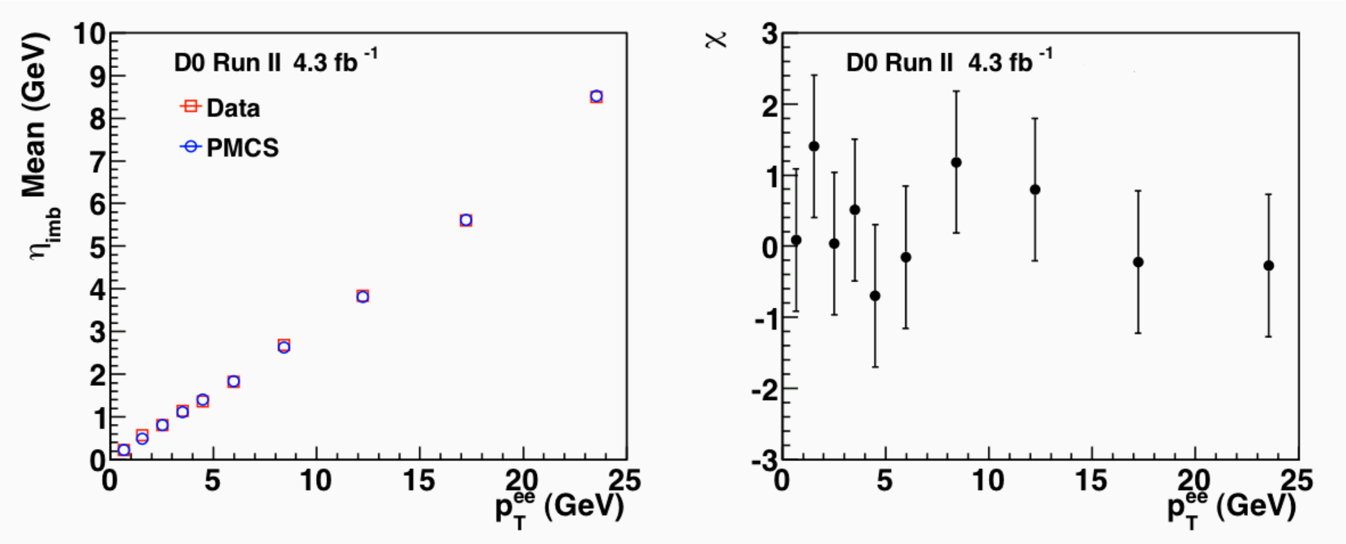
$$\vec{u}^{soft}_{T,smear} = \sqrt{\alpha_{MB}}\,\vec{u}_T^{MB} + \vec{u}_T^{ZB}$$

$$u^{\parallel,hard}_{T,smear} = \left(\mathrm{R}_A + \mathrm{R}_B \cdot e^{-p_T^Z/\tau_{HAD}}\right) p_T^Z \langle \frac{u_T}{p_T^Z} \rangle^{\parallel} + \mathrm{S}_A \left(u_T^{\parallel} - p_T^Z \langle \frac{u_T}{p_T^Z} \rangle^{\parallel}\right)$$

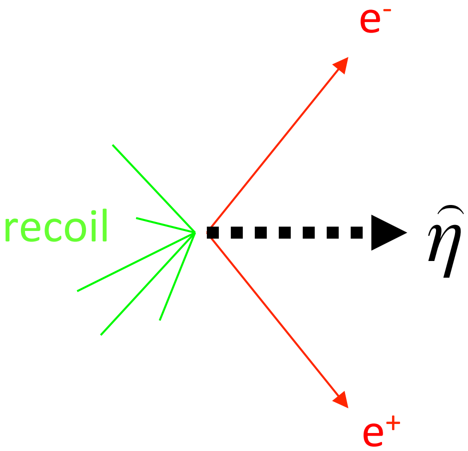
Parameters are tuned using the standard UA2 variables

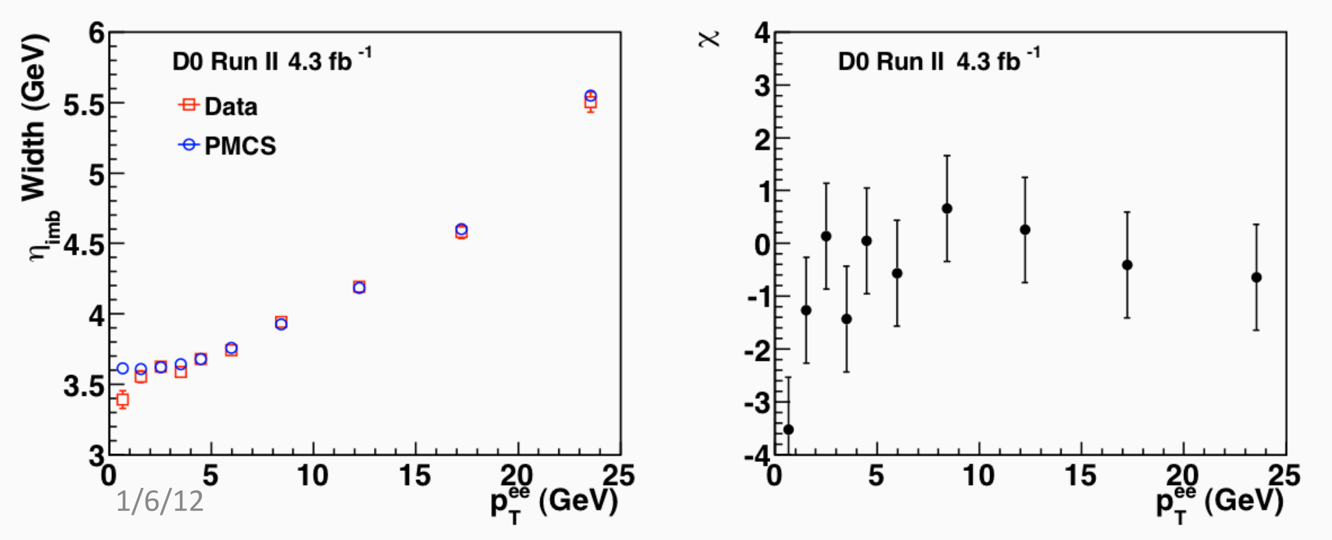


Recoil Tuning



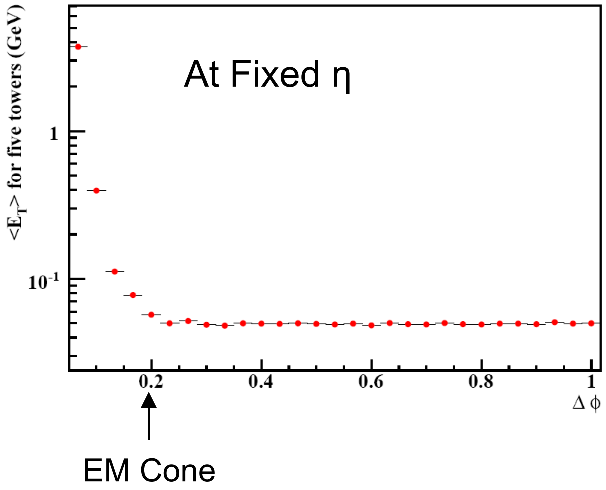
Response

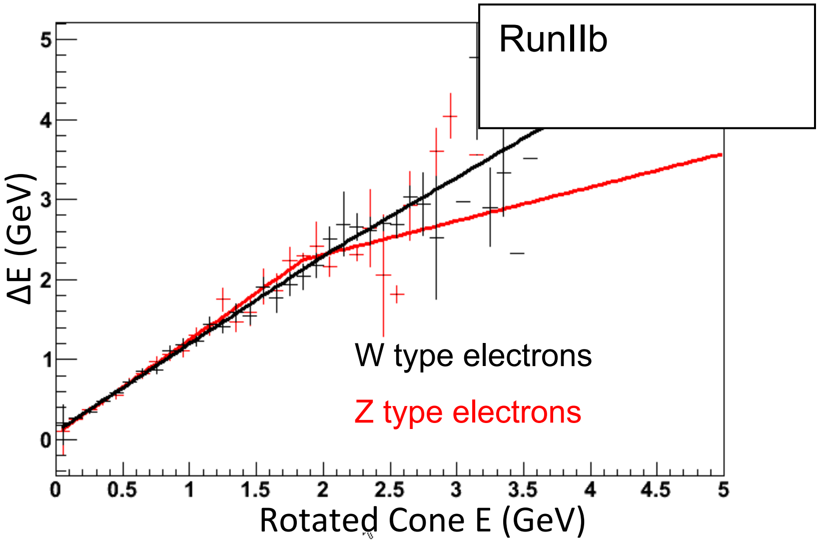


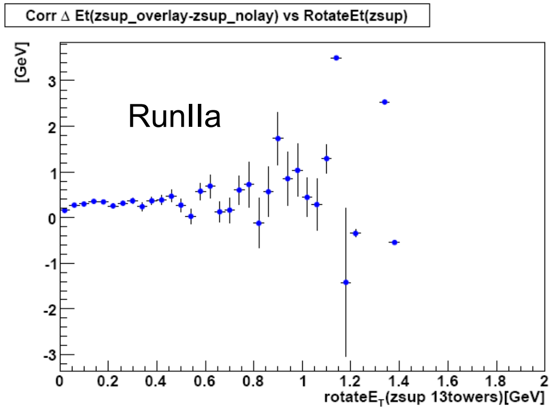


Resolution

Recoil Correction to Energy in EM Cone







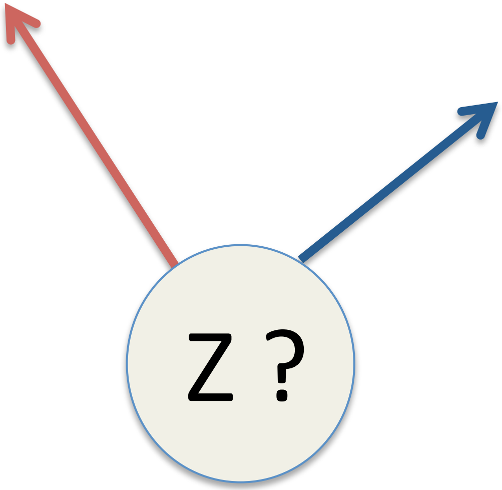
Recoil system contribution to EM cluster energy needs to be determined

Assume Energy in EM Cluster rotated in Φ at fixed η (luminosity, and $u_{||}$) is a good description of the energy added to the cone

Look at change in cluster energy in Geant when rotated energy is overlayed onto single electrons

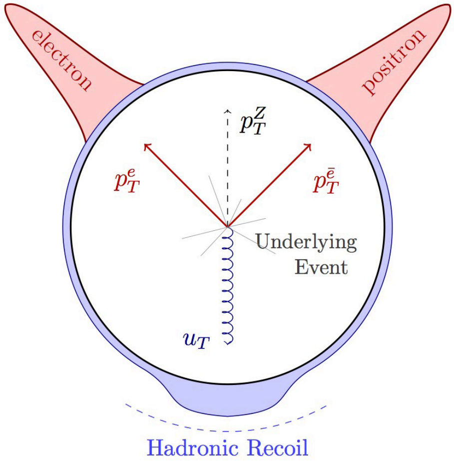
Electron efficiencies -- 3 Mev

- Tag and Probe :
  - Require 1 EM object to pass all selection cuts (Tag)
  - Look for a second EM object (loose cuts)
  - Require invariant mass close to Z pole (Probe)
  - Check probability of other EM object to pass cut under study
  - Evaluates factorized efficiencies

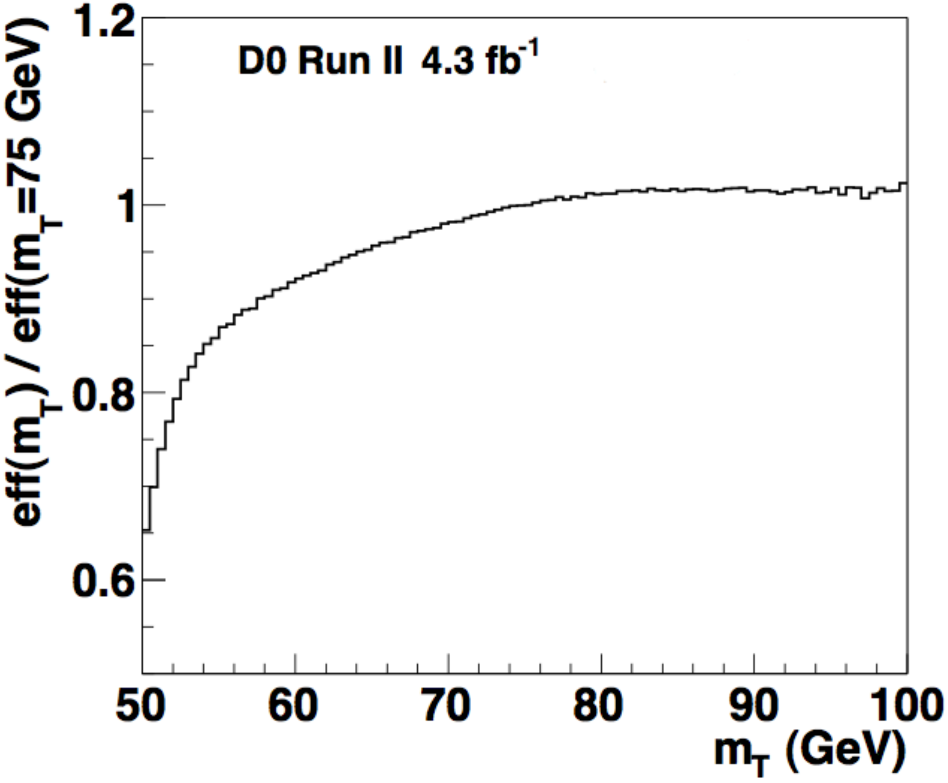


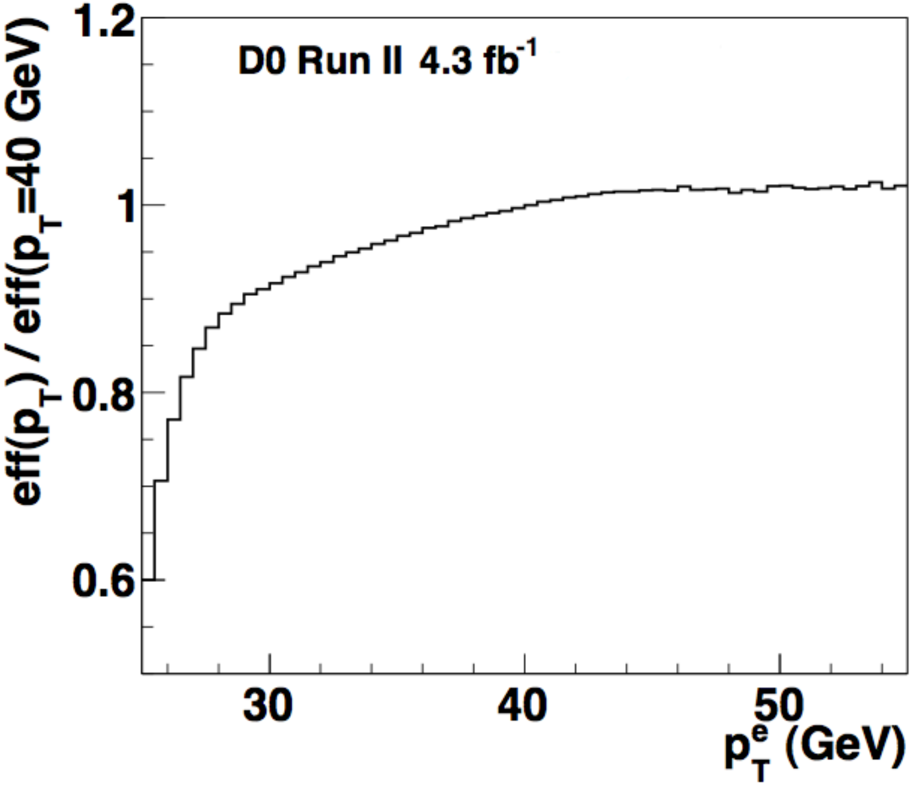
The Tag and Probe method introduces biases

- Consider electron Isolation
  - Require that an electron is ‘clean’
- As detector activity increases the chance of finding the Tag Object is correlated with the chance of the Probe passing
- There are also correlations with the Recoil system:
  - A boosted electron is normally away from the recoil
  - The other electron will overlap
- Resort to Full M.C. studies, and direct fits to the Z Mass peak



Overall efficiency





Analysis Cuts

Event selection

- CAL only trigger (single EM)
- vertex $z < 60\,cm$

Electron selection

- $p_T > 25GeV$
- HMatrix7 < 12, emf > 0.9 and iso < 0.15
- $\eta_{\mathrm{det}} < 1.05$ in the calorimeter fiducial region
- In the calorimeter ϕ fiducial region, as determined from the track
- Spatial track match, track with $p_T > 10GeV$ and at least one SMT hit

$Z \rightarrow ee$ selection

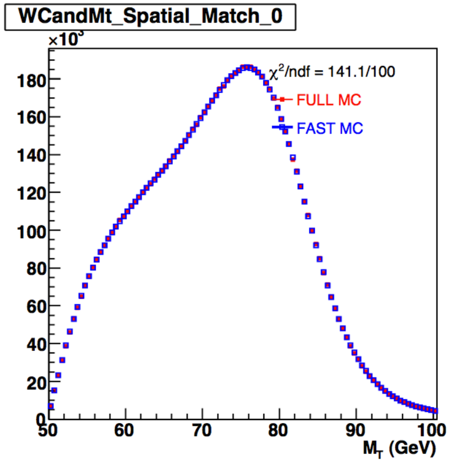
- At least two good electrons
- Hadronic recoil transverse momentum $u_T < 15\,GeV$
- Invariant mass $70 < m_{ee} < 110\,GeV$

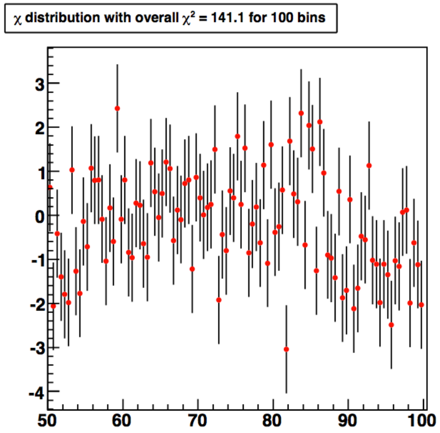
$W \rightarrow e\nu$ selection

- At least one good electron
- Hadronic recoil transverse momentum $u_T < 15\,GeV$
- Transverse mass $50 < m_T < 200\,GeV$
- $\not{E}_T > 25GeV$

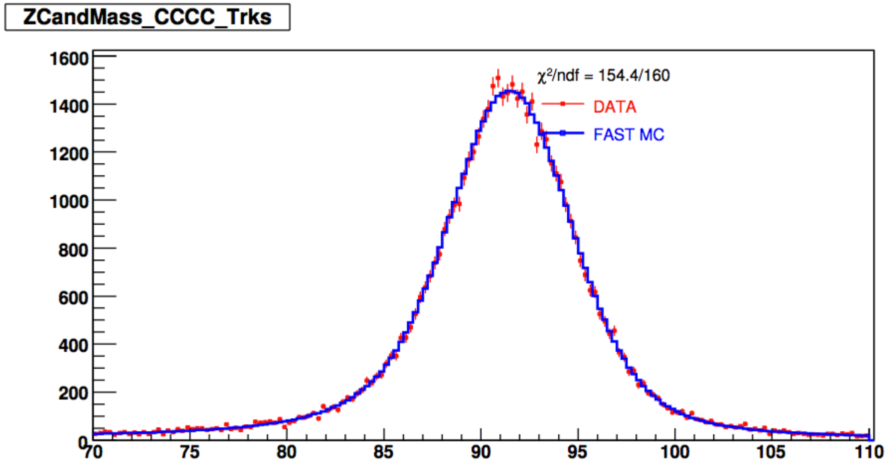
MC Consistency check

- Perform full procedure with GEANT MC
  - Tune fast MC parameters to Z
  - Fit for W Mass
  - Equivalent of 24 fb^{-1}
- Results (80.450 GeV):
  - m_T: 80.448 ± 0.005 (stat) GeV
  - $p_T(e)$: 80.448 ± 0.005 (stat) GeV
  - MET: 80.455 ± 0.006 (stat) GeV

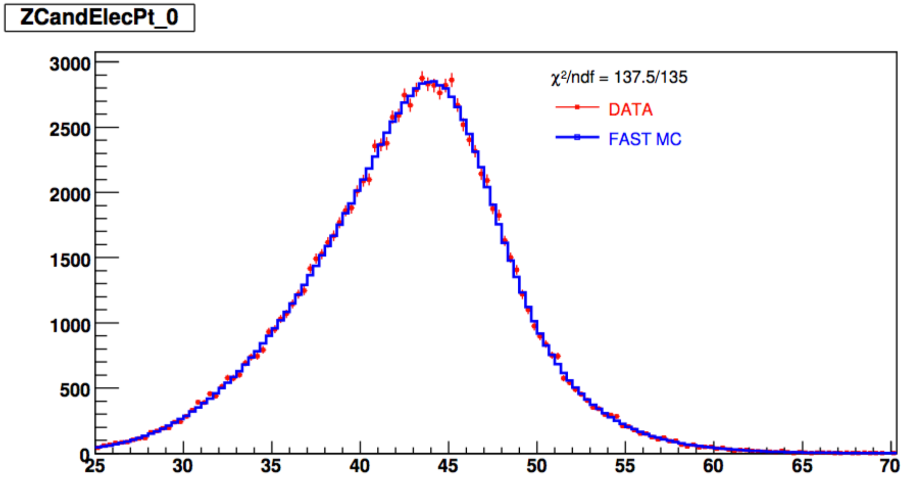


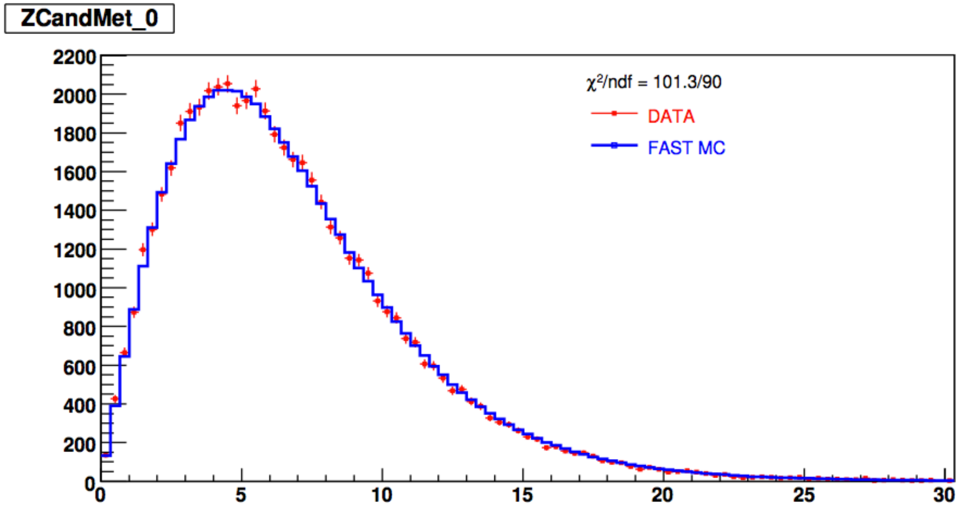


Z Boson Comparison



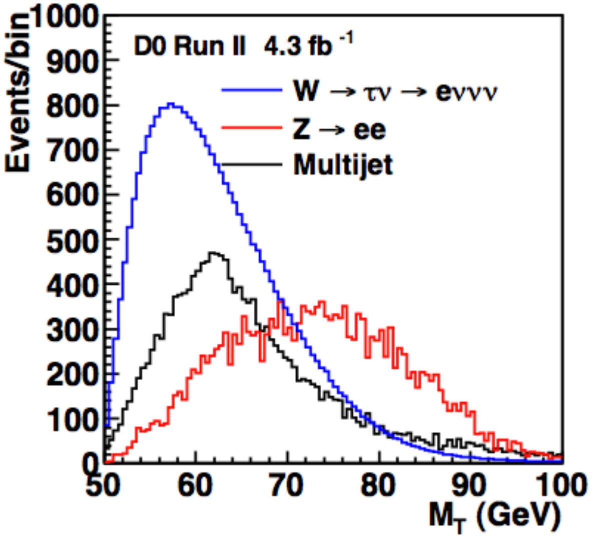
- m_Z = 91.193 ± 0.017 (stat) GeV
  - LEP → 91.188 ± 0.002 GeV
- Good agreement with Data

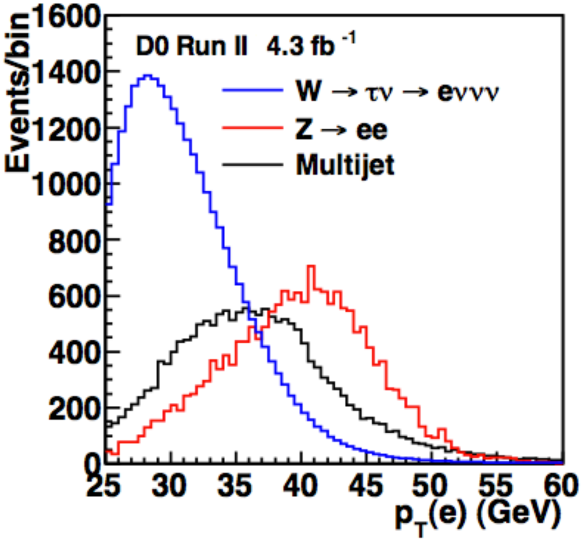


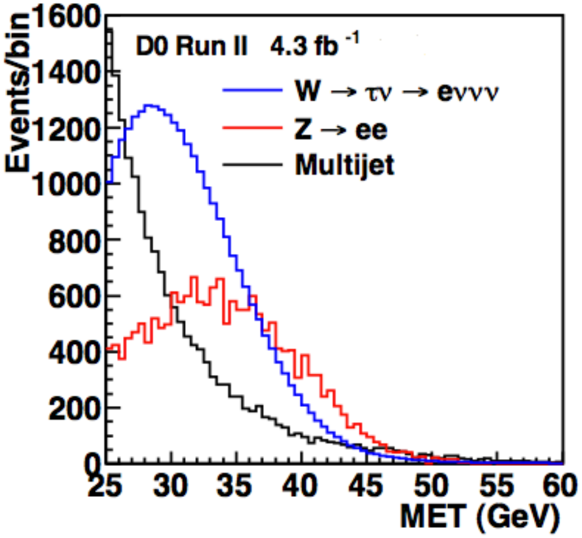


Backgrounds

- Multijet and Z→ ee determined from data
- W → τν from Resbos

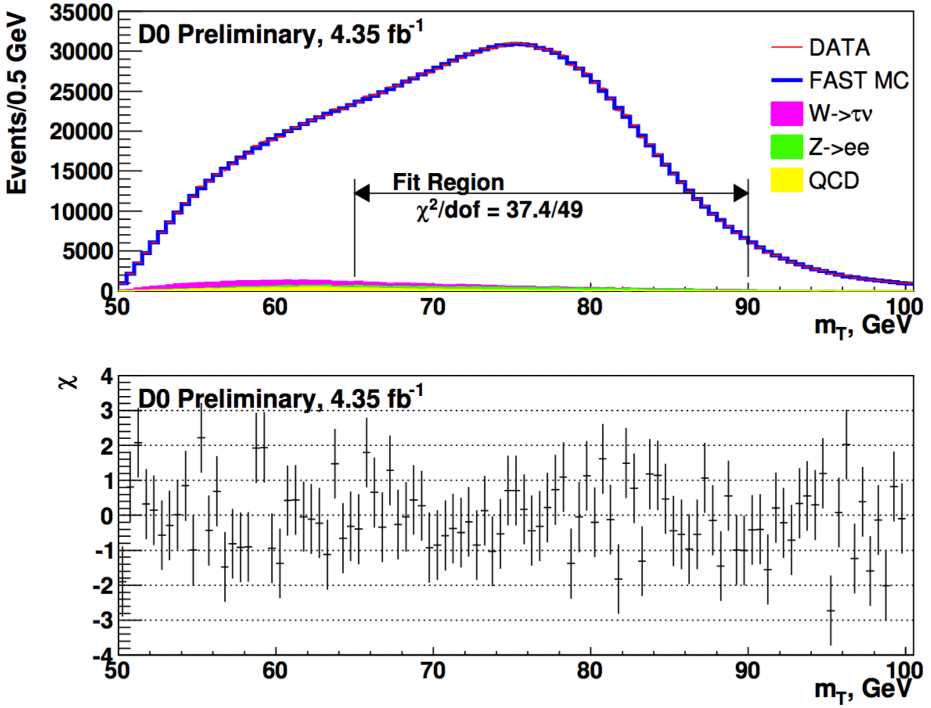




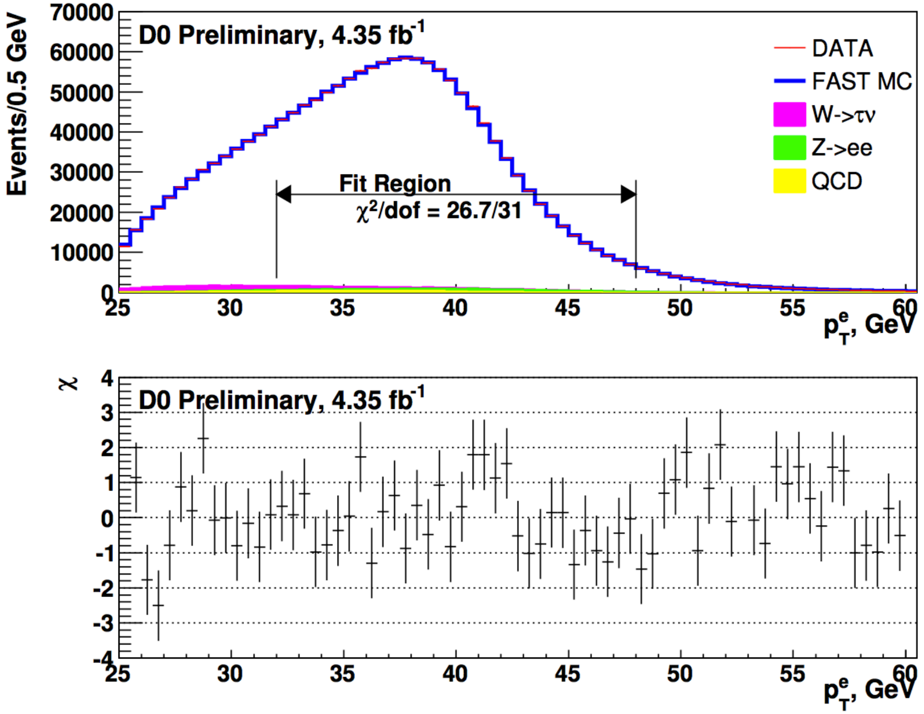


W Data

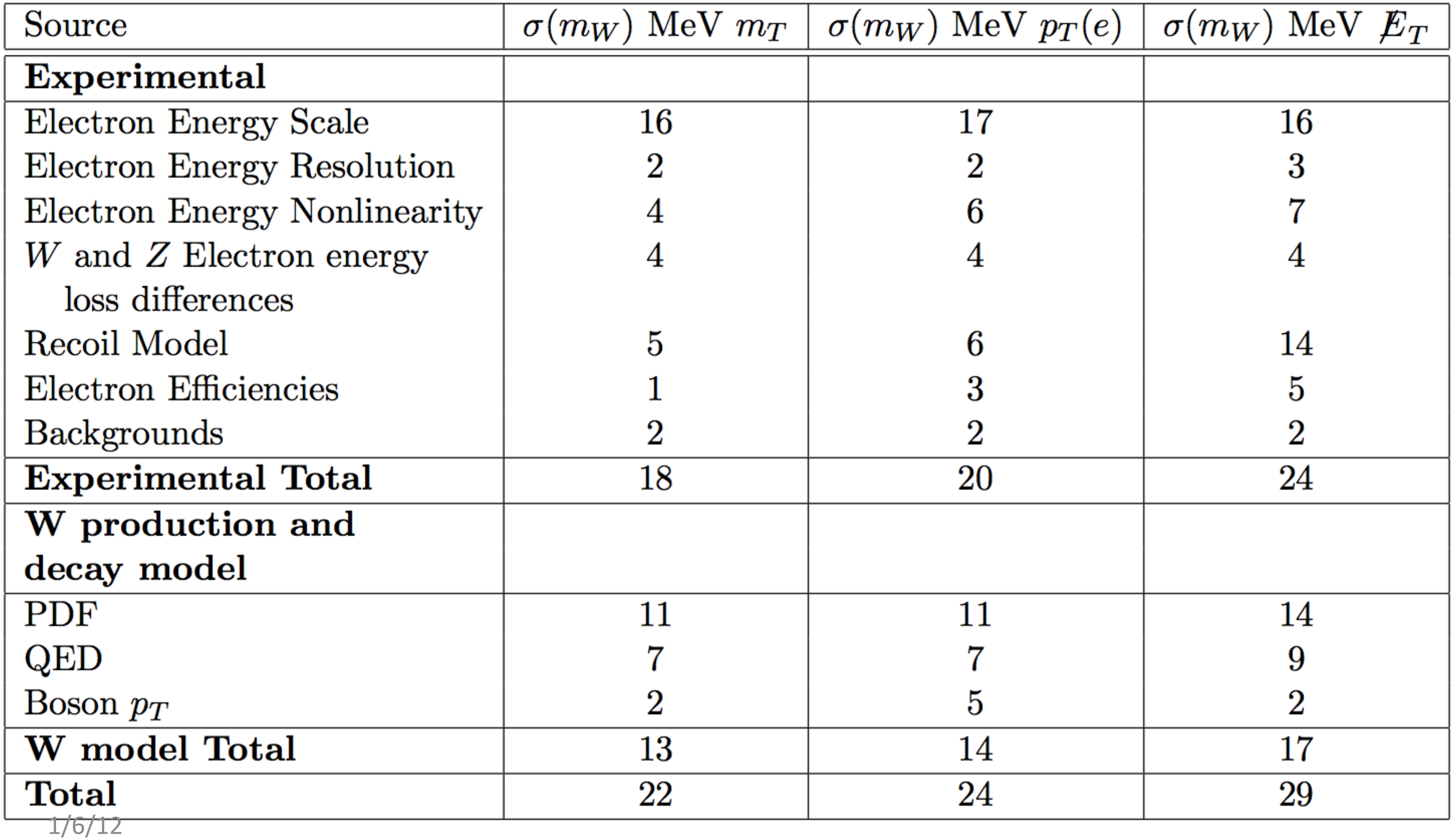
m_W = 80371 ± 13 MeV (stat)



m_W = 80343 ± 14 MeV (stat)



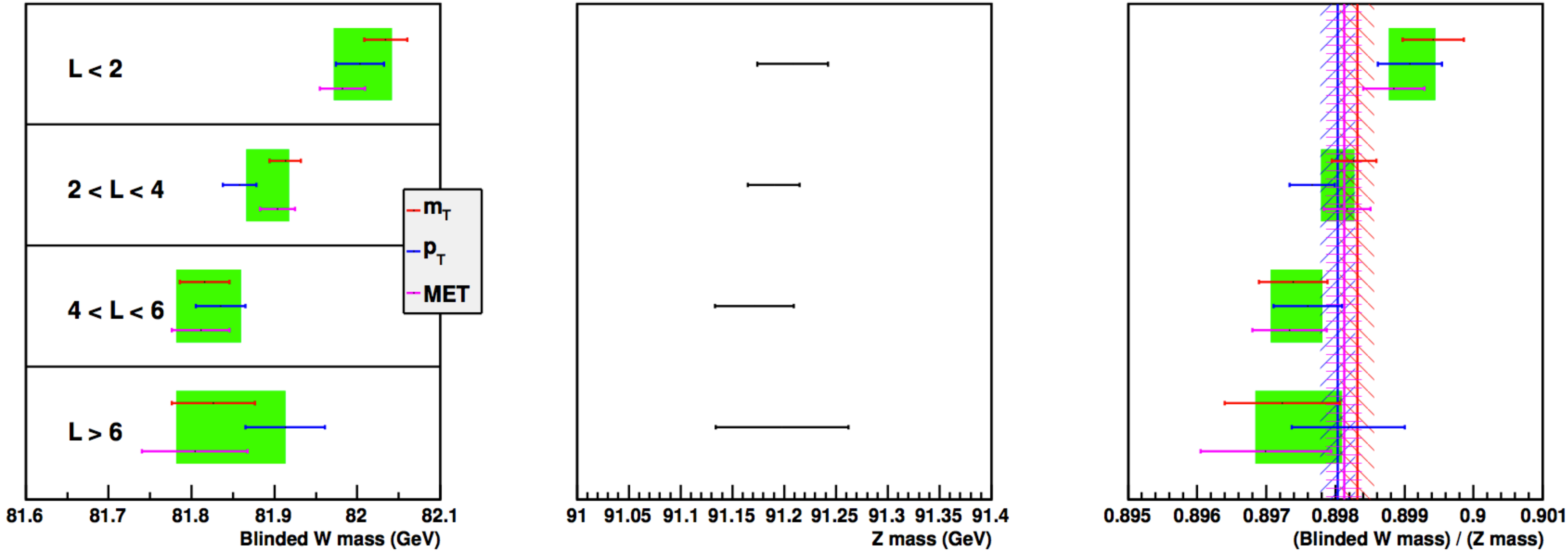
Systematic Uncertainties



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	16	17	16
Electron Energy Resolution	2	2	3
Electron Energy Nonlinearity	4	6	7
W and Z Electron energy loss differences	4	4	4
Recoil Model	5	6	14
Electron Efficiencies	1	3	5
Backgrounds	2	2	2
Experimental Total	18	20	24
W production and decay model			
PDF	11	11	14
QED	7	7	9
Boson p_T	2	5	2
W model Total	13	14	17
Total	22	24	29

W Consistency Check

- Stable in Time and Luminosity



Results

- m_T: 80.371 ± 0.013 (stat) ± 0.022 (syst)
- $p_T(e)$: 80.343 ± 0.014 (stat) ± 0.024 (syst)
- MET: 80.355 ± 0.015 (stat) ± 0.029 (syst)
- Combined :

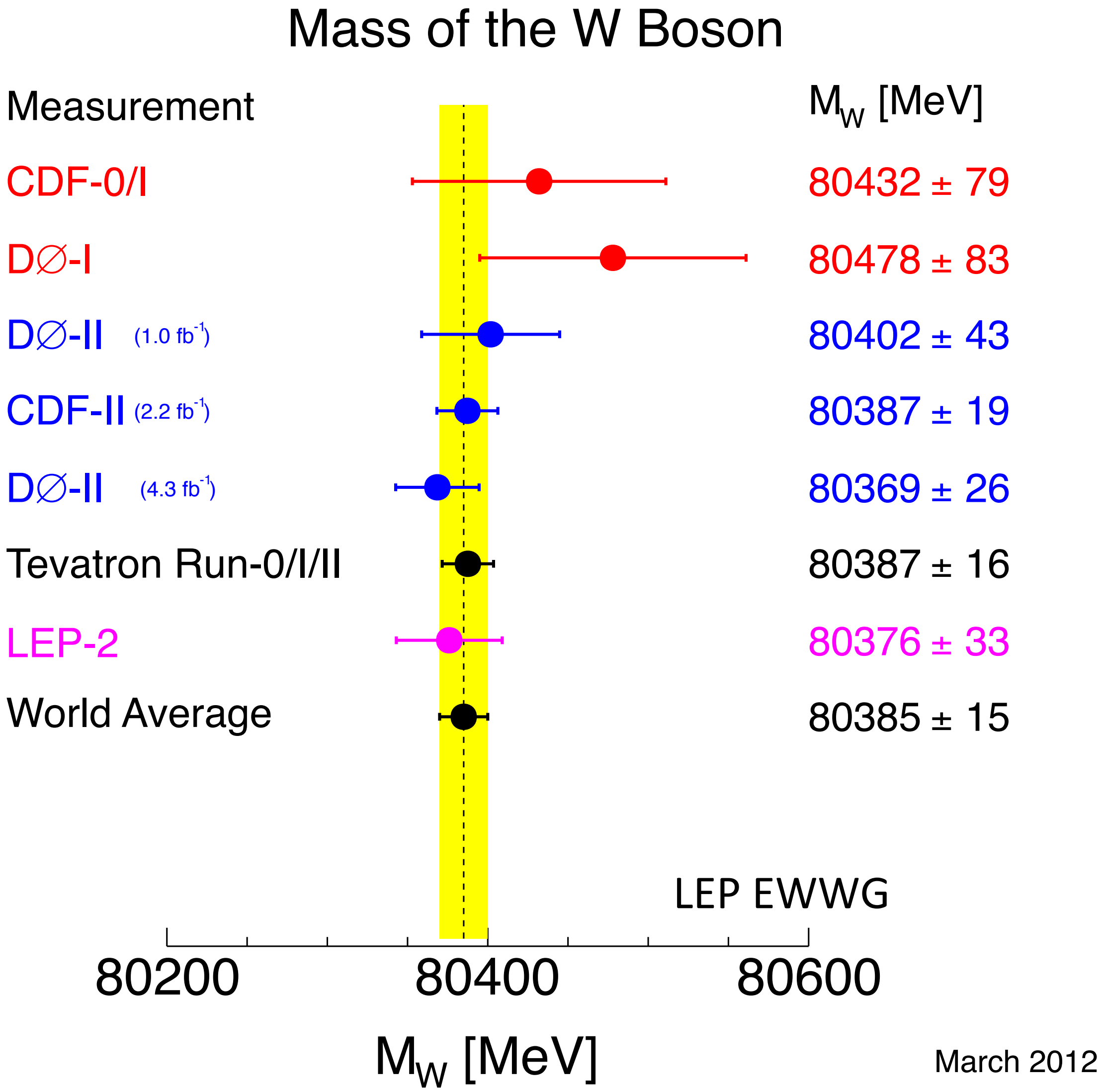
$$\begin{aligned} M_W &= 80.367 \pm 0.013 \text{ (stat)} \pm 0.022 \text{ (syst) GeV} \\ &= 80.367 \pm 0.026 \text{ GeV.} \end{aligned}$$

Combined with earlier measurement:

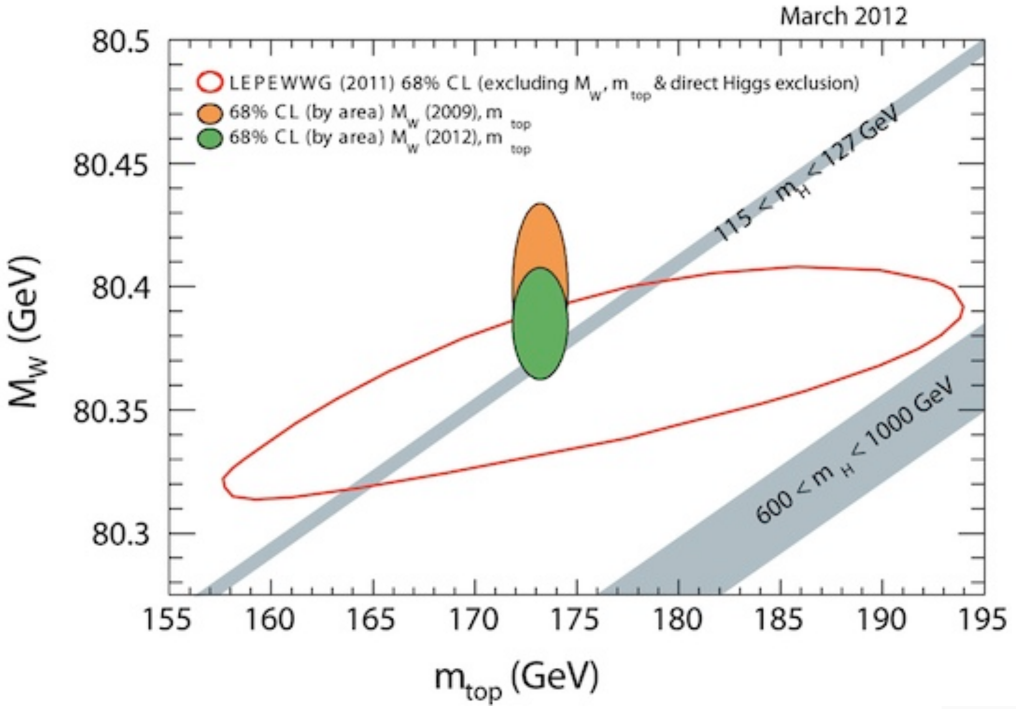
$$\boxed{\begin{aligned} M_W &= 80.375 \pm 0.011 \text{ (stat)} \pm 0.020 \text{ (syst) GeV} \\ &= 80.375 \pm 0.023 \text{ GeV.} \end{aligned}}$$

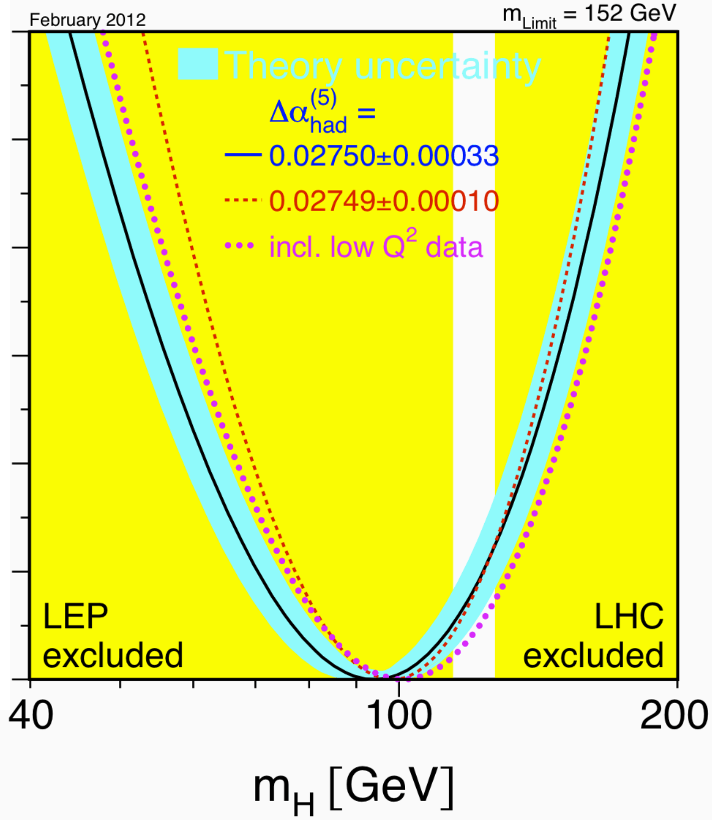
The World Average uncertainty is now 15 MeV / c^2

- World Average driven by D0 and CDF measurements
- Results are consistent
- Still the limiting experimental value on the indirect Higgs mass constraint



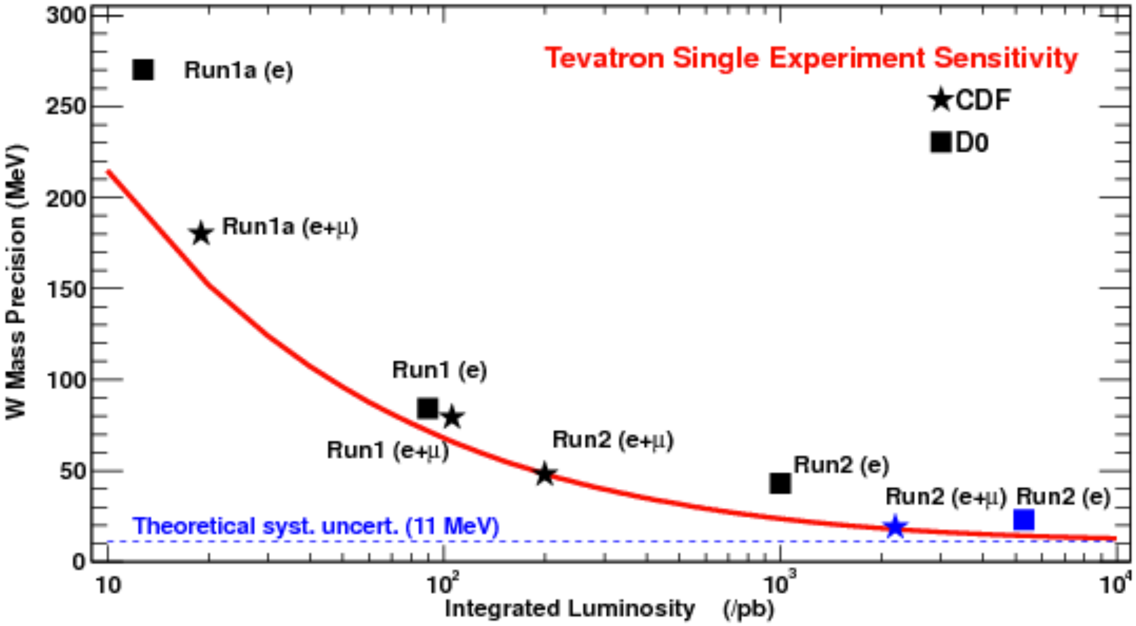
Higgs Constraint





Future

- 5 fb^{-1} data to be analyzed
  - Plans to extend η coverage
- Recent advances with theory
  - POWHED (QED implementation)
  - CTEQ10W (better PDF uncertainty)



Backup

Yields

- 54,512 (Z → e e)
- 1,677,394 (W → e nu)

Calorimeter Cell

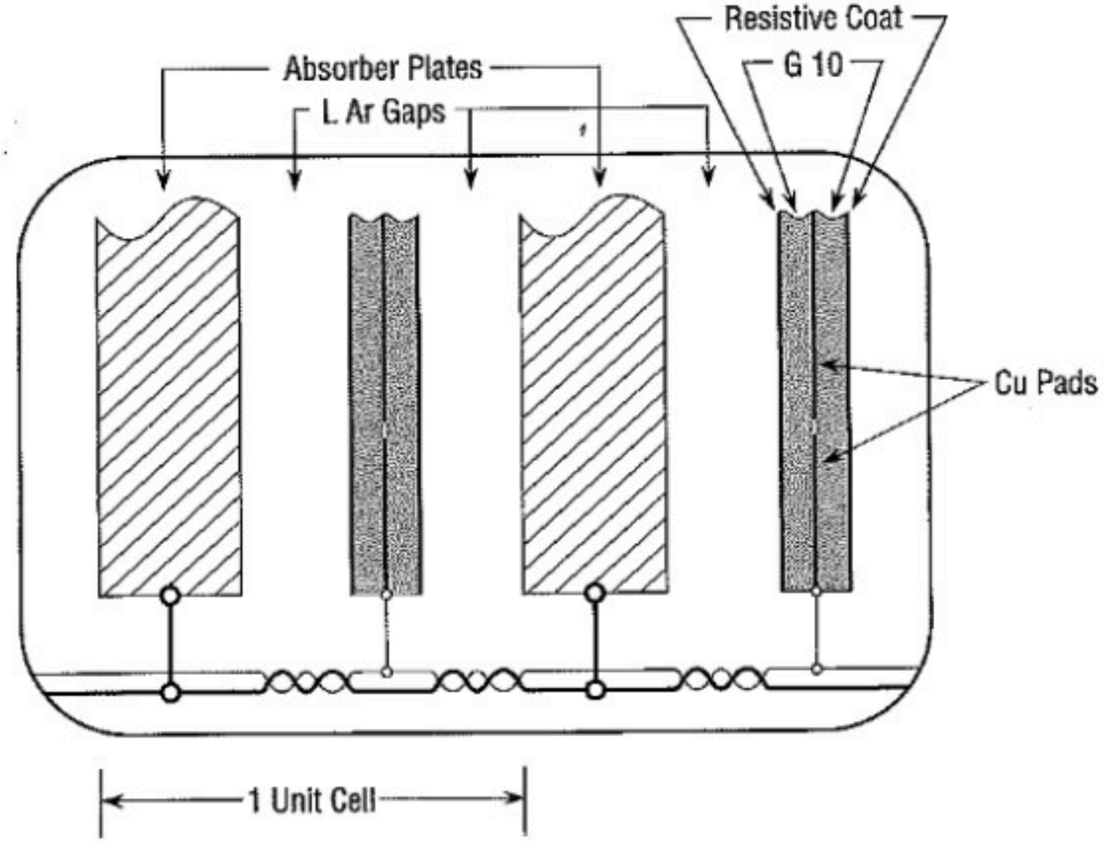
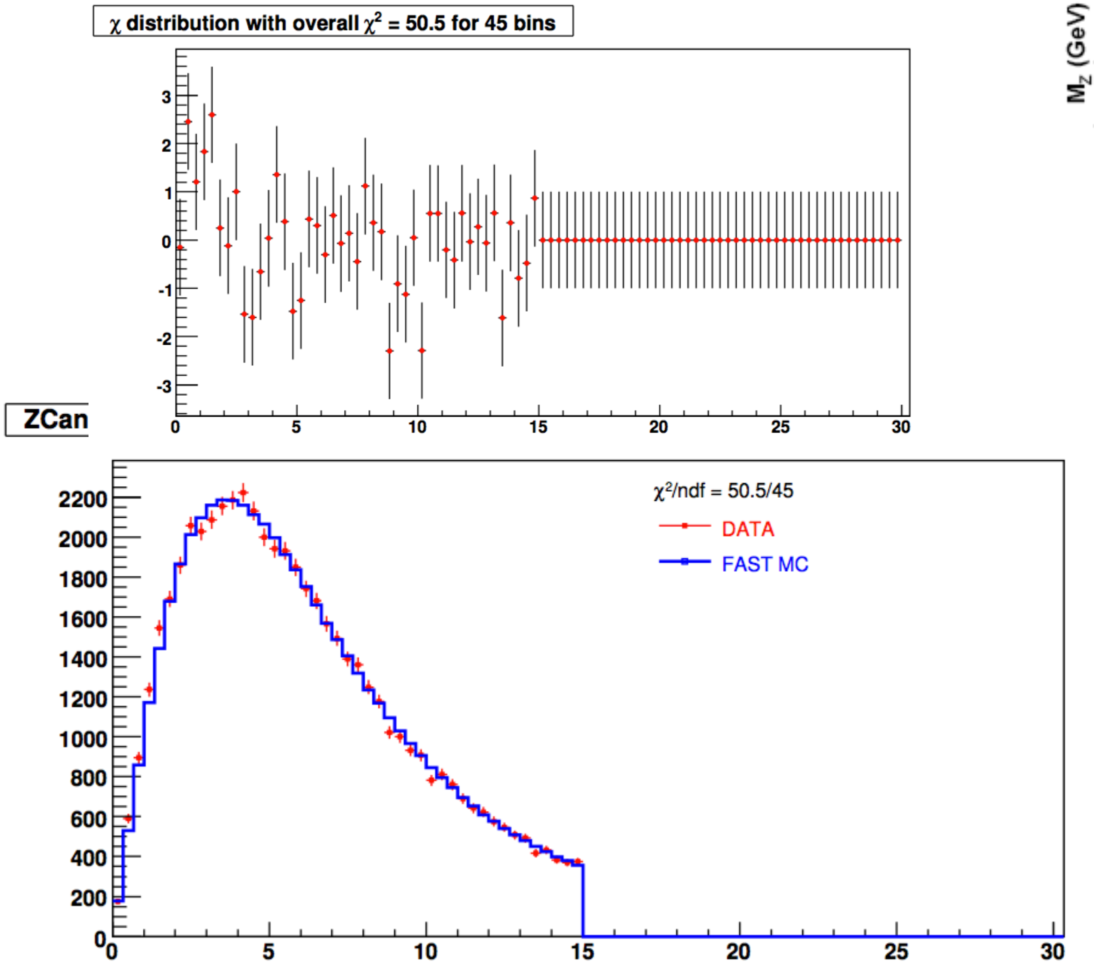
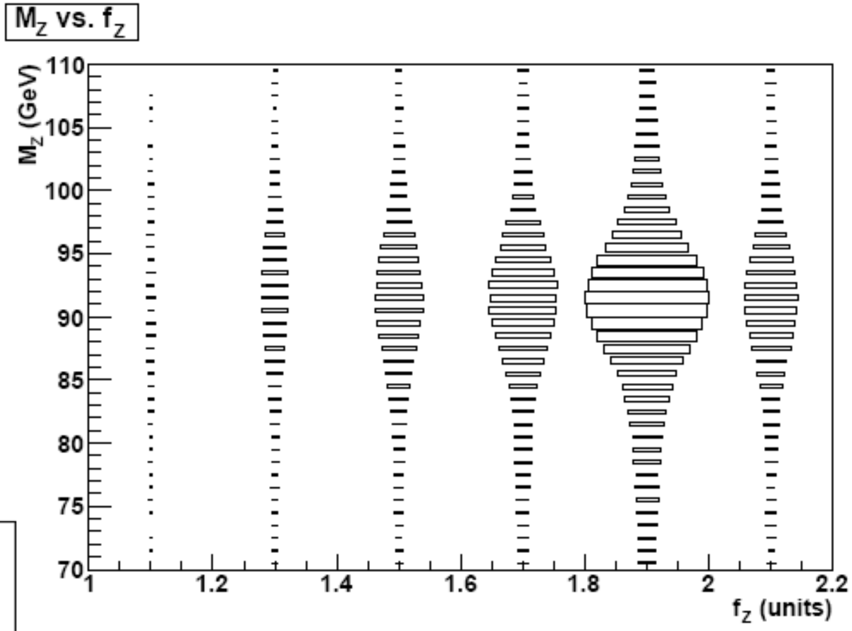


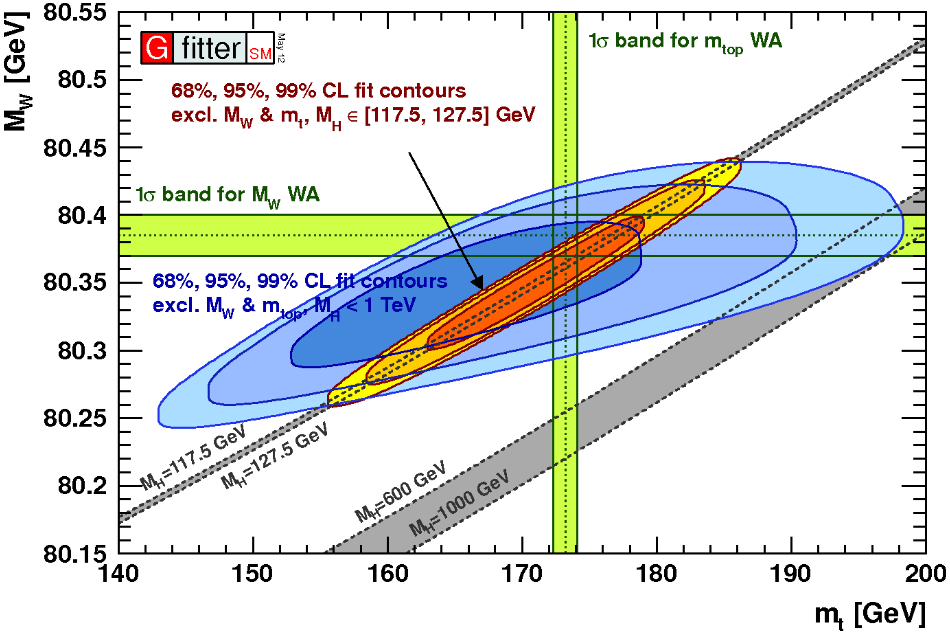
Fig. 27. Schematic view of the liquid argon gap and signal board unit cell.

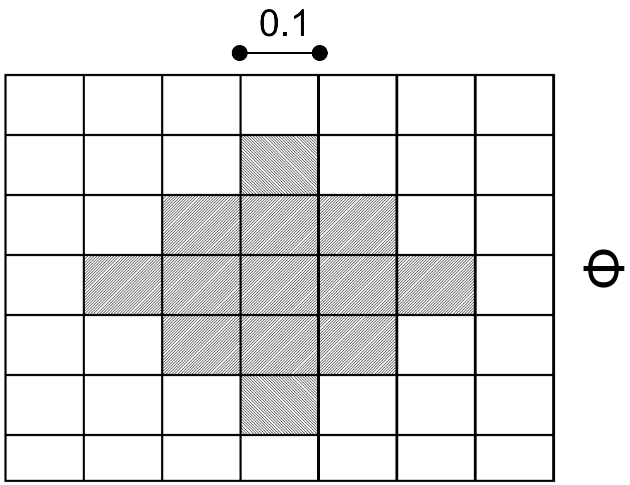
Z Boson Fits


χ distribution with overall χ^2 = 50.5 for 45 bins
3
2
1
0
-1
-2
-3
0
5
10
15
20
25
30
ZCan
χ^2/ndf = 50.5/45
DATA
FAST MC
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30

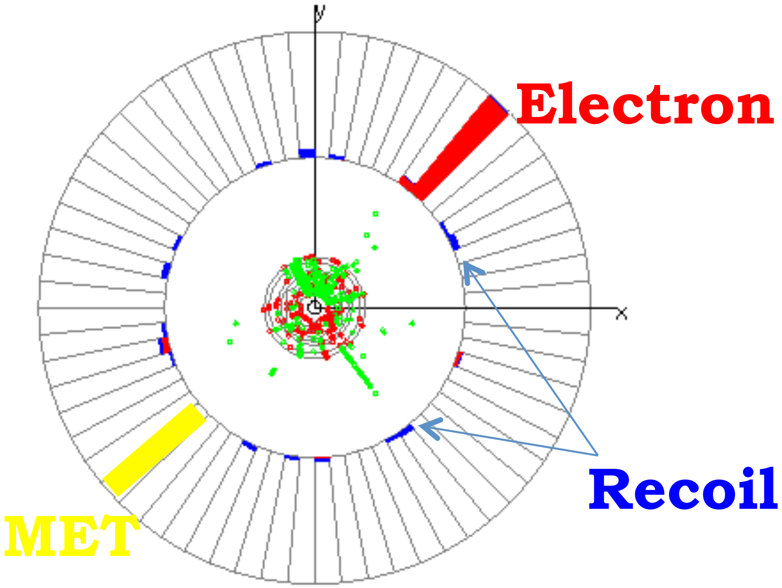

M_Z vs. f_Z
M_Z (GeV)
110
105
100
95
90
85
80
75
70
1
1.2
1.4
1.6
1.8
2
2.2
f_Z (units)

Gfitter Constraint





EM Cluster of Cal Towers η



Typical W Event