D0 1 fb^{-1} *W* Boson Mass Measurement

Jun Guo

SUNY - Stony Brook

on behalf of the D0 Collaboration

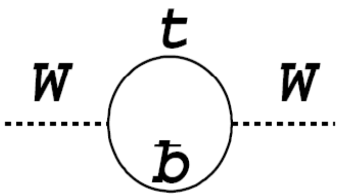
Motivation

- **M_W is a key parameter in the Standard Model**

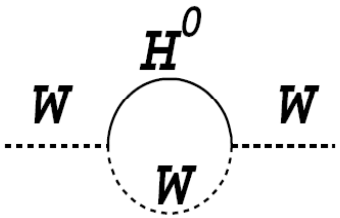
$$\boxed{M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}\frac{1}{\sin\theta_W\sqrt{1-\Delta r}}}}$$

α: Electromagnetic constant
G_F: Fermi constant
θ_W: Weak mixing angle

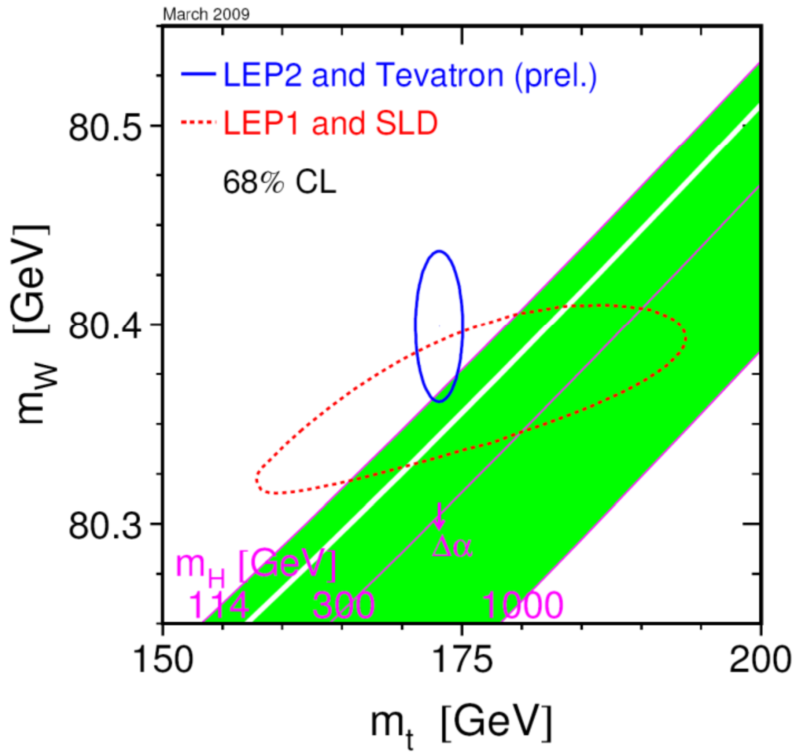
- **In the Standard Model, radiative corrections (Δr) depend on M_t as $\sim M_t^2$ and M_H as $\sim \log M_H$**



$\Delta r \sim M_t^2$

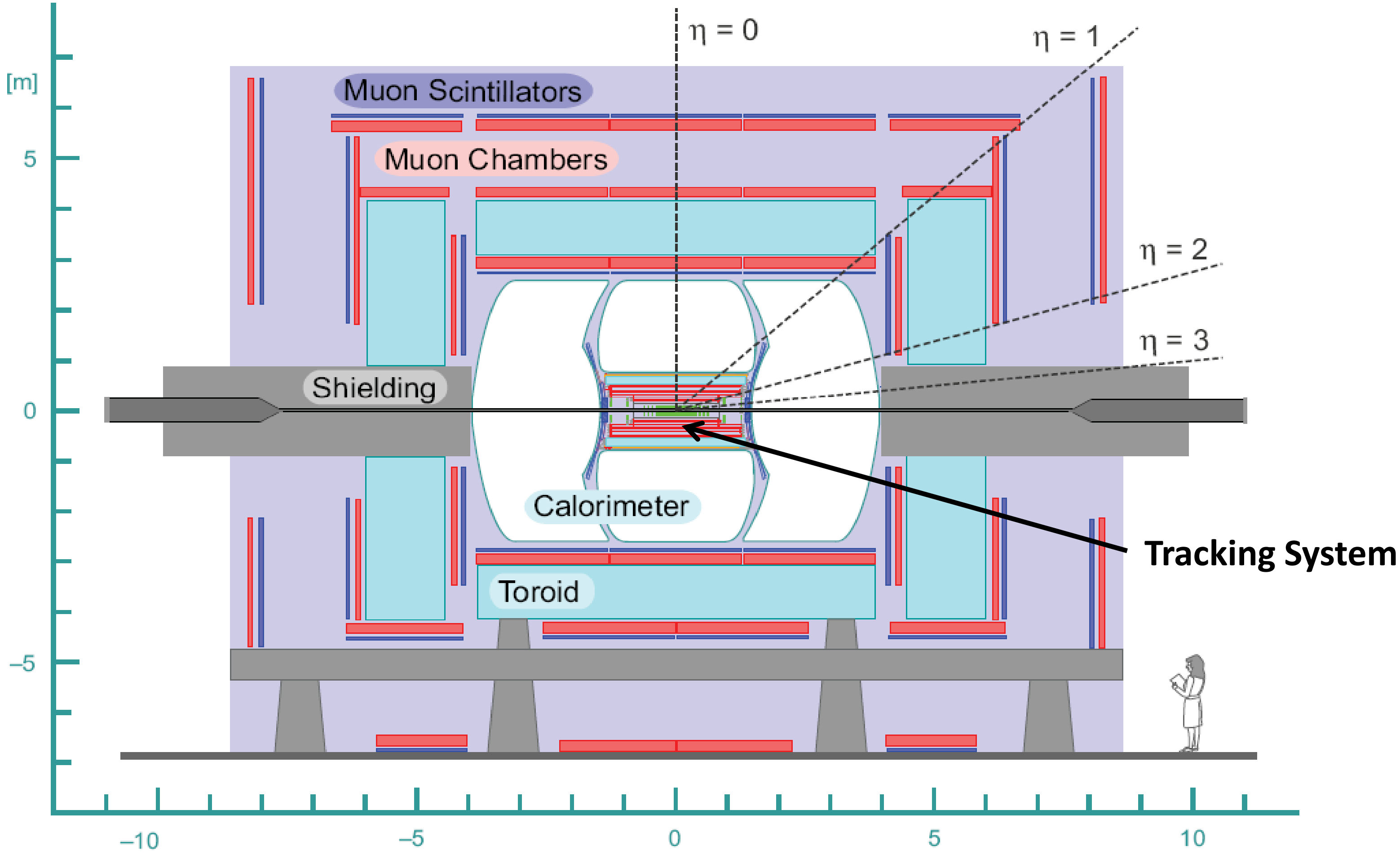


$\Delta r \sim \log M_H$



- **For equal contribution to the Higgs mass uncertainty we need:**
  $\Delta M_W \approx 0.006\ \Delta M_t$
- **Top quark mass is known with an uncertainty ~1.3 GeV, which requires**
  $\Delta M_W \approx 8$ MeV, while currently $\Delta M_W \approx 25$ MeV.
- **M_W is the limiting factor!**

Experimental Setup: D0 Detector



Proton-antiproton collisions with center-of-mass = 1.96 TeV

W Mass Measurement Strategy in *W*->$e\nu$ decays($1fb^{-1}$)

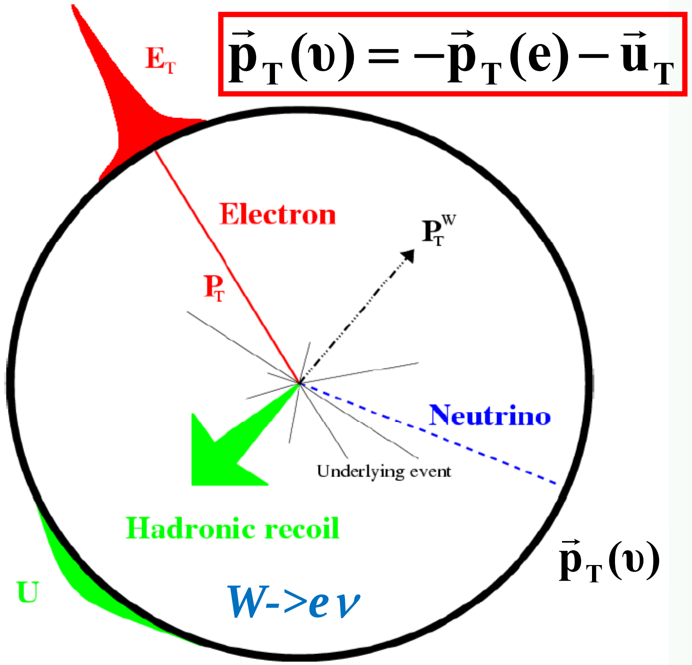
- Transverse Mass(M_T), transverse electron momentum ($p_T(e)$) and missing transverse energy(MET or $p_T(\nu)$) are used to extract *W* mass

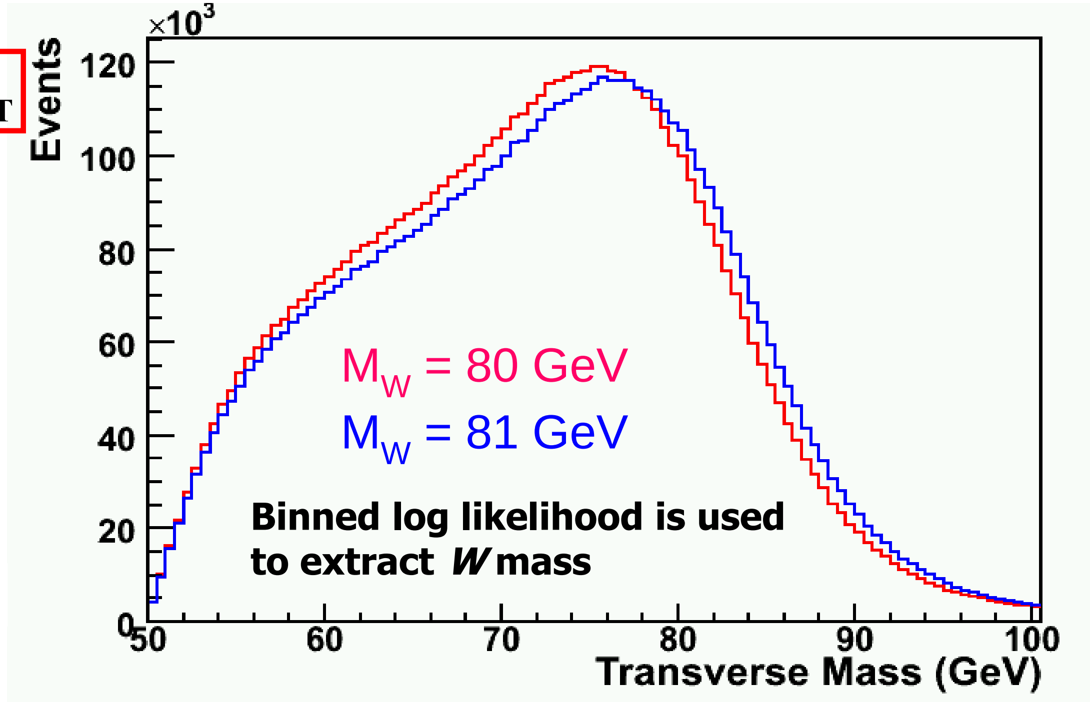
$$M_T = \sqrt{(E_T(e)+E_T(\upsilon))^2 - |\vec{p}_T(e)+\vec{p}_T(\upsilon)|^2}$$

- A fast parameterized simulation(fast MC) is used to model the detector effect and offline selection, which takes the *W* mass as the input

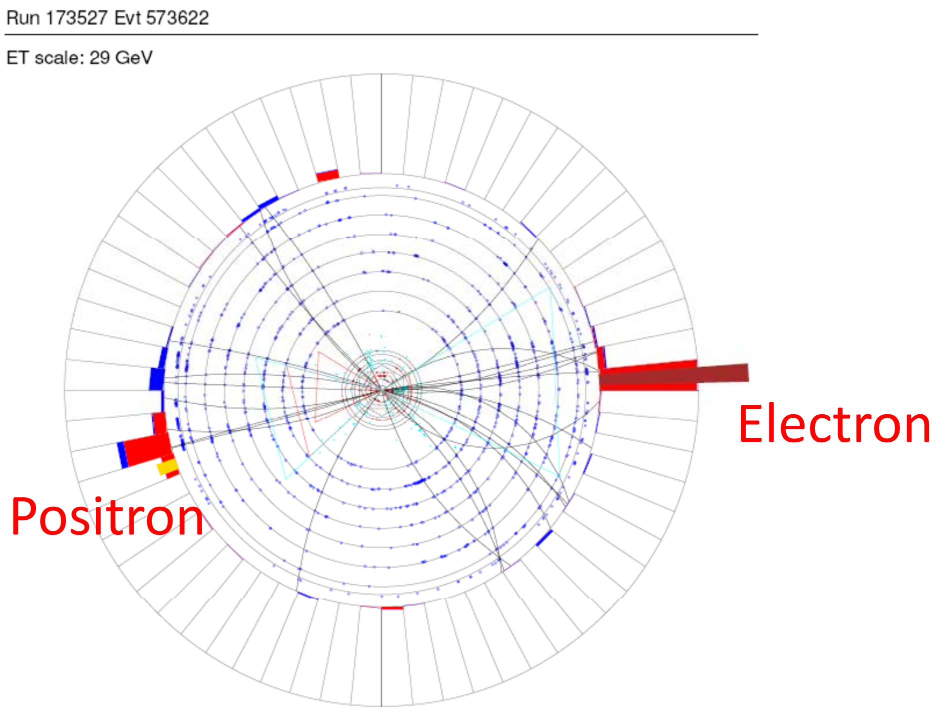
- Do a blind analysis

$$\boxed{\vec{p}_T(\upsilon) = -\vec{p}_T(e) - \vec{u}_T}$$

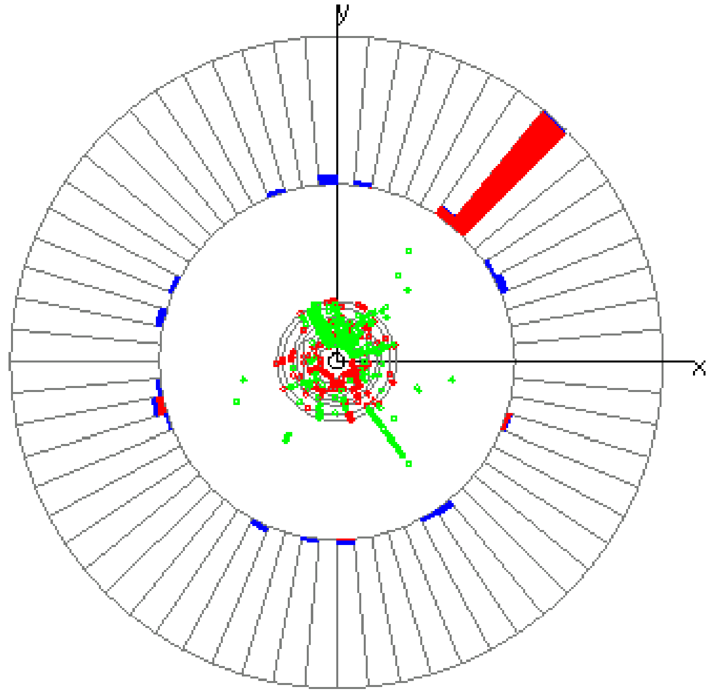




Data Samples:
$1 fb^{-1}$ (2002--2006)



Z->ee : ~18k



W->eν : ~500k

- **For both *Z* and *W*, select isolated high pT electron(s) in the central calorimeter fiducial region**

Generator: RESBOS + PHOTOS

- **QCD process: RESBOS**

  (C. Balazs and C.-P. Yuan, Phys. Rev. D 56, 5558 (1997))

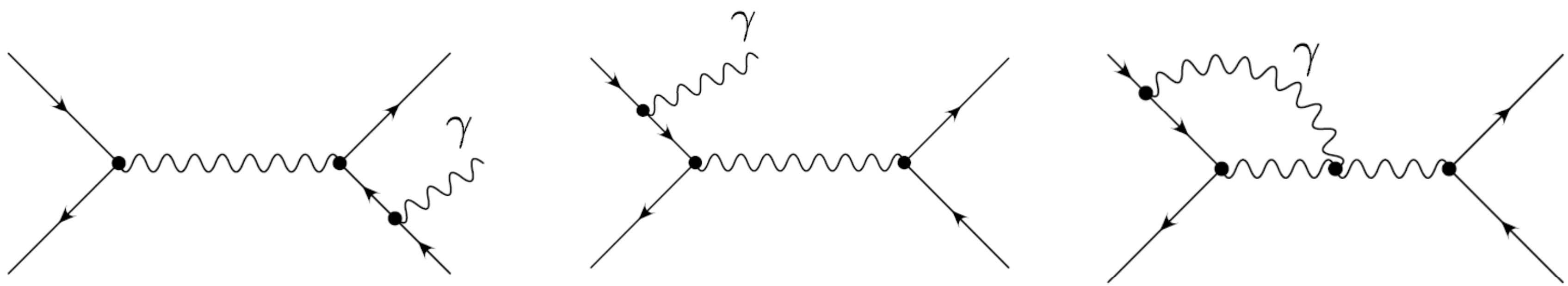
  - **Gluon resummation gives reasonable description of the transverse momentum of the vector bosons at low boson p_T**

- **Photon Radiation: PHOTOS**

  (E. Barbiero and Z. Was, Comp. Phys. Commun. 79, 291 (1994))

  - **It only simulates the final photon radiation(FSR)**
  - **Effect of full EWK correction is studied using W/ZGRAD**

    (U. Baur, S. Keller and D. Wackeroth, Phys. Rev. D 59 013002 (1999))



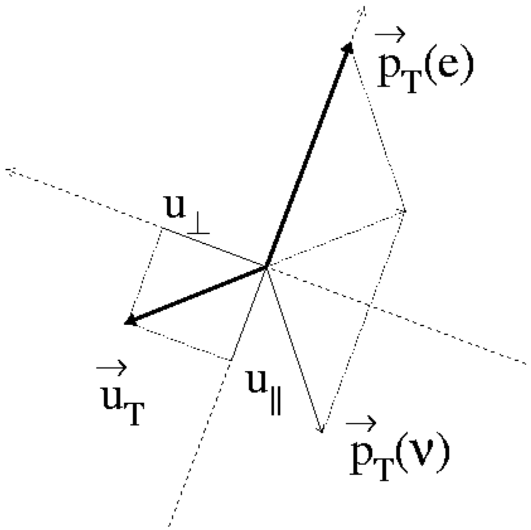
Selection Efficiency

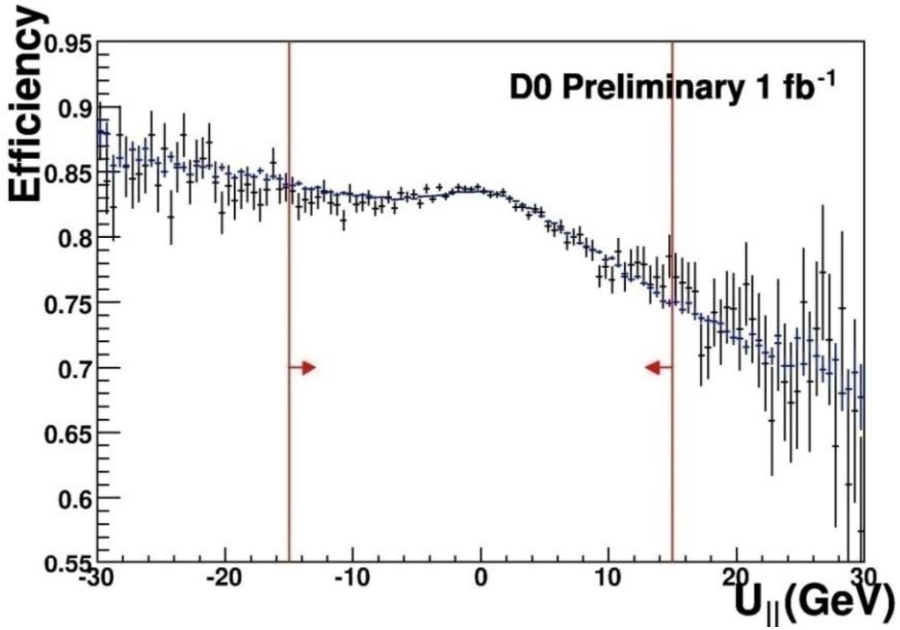
- **Electron selection is subject to multiple factors: detector geometric, electron intrinsic features and contamination from rest of the event**

- **Study the effect from different sources using different methods.**
  - **Geometric dependence(primary vertex and η)**
  - **Intrinsic $p_T(e)$ dependence(internal photon radiation, etc.)**
  - **$u_{||}$ efficiency(relative direction between "e" and "recoil")**
  - **Scalar E_T efficiency(overall hadronic activity effect)**

$u_{||}$ Efficiency

- $u_{||}$ Efficiency is measured using *Z->ee* events
- The recoil of the boson affects electron identification, especially when the recoil is close to the electron





Electrons Energy Response

- Final energy response calibration, using *Z -> e e* :

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

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

  for $\beta \ll E(e1) + E(e2)$:

$$M_{ee} = \alpha \times M_Z + f_Z \beta$$

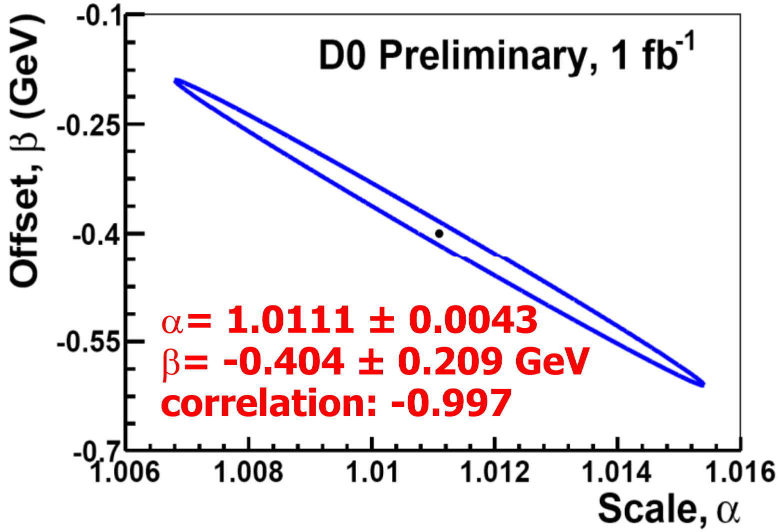
$$f_Z = (E(e1)+E(e2))(1-\cos(\gamma_{ee}))/M_{measured}$$

  γ_{ee} is the opening angle between the two e's

- Templates of M_{ee} vs f_Z are generated for variant α and β values

ΔM_W = 34 MeV, 100% correlated between all three observables

It is the dominant systematic uncertainty in the W mass measurement (limited by *Z* statistics)



Recoil System

Recoil: **everything else in the event except the electron(s).**

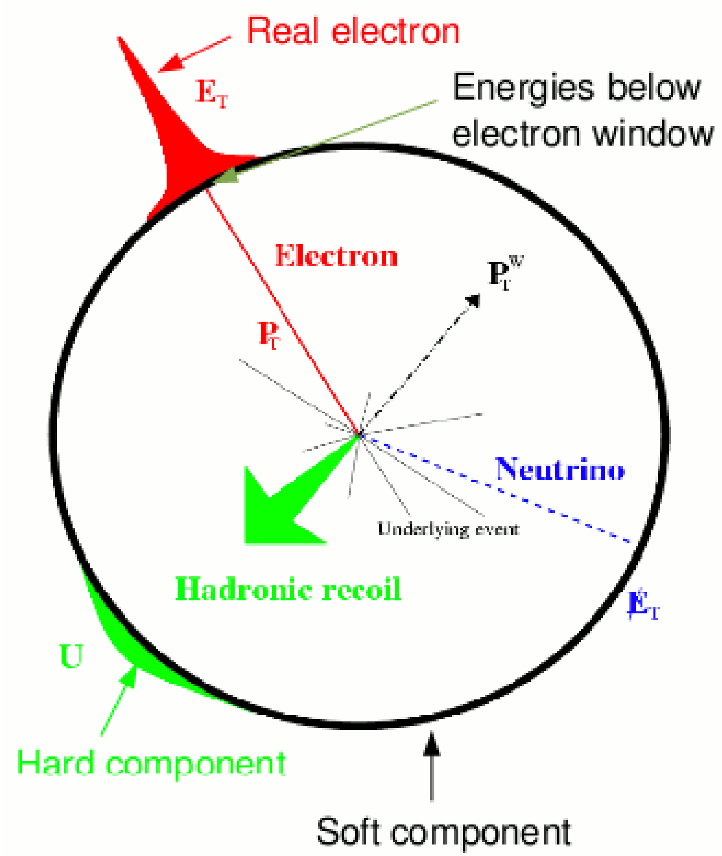
(1) Hard component: from W/Z boson p_T

(2) Soft component:
- **--Spectator parton interactions**
- **--Additional ppbar interactions and electronic noise, etc.**

(3) Recoil energy lost in the electron cones and electron energy leakage outside the electron cluster

(4) FSR outside the electron cones

Additional parameters in the fast simulation are tuned to the data.



Recoil response and resolution

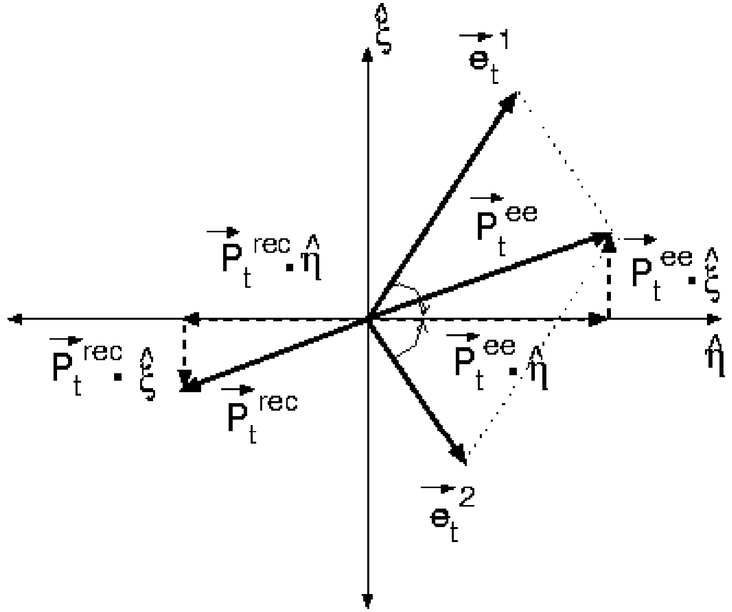
Project the u_T(recoil p_T) and Z boson p_T on η axis (bisector of the two electron directions)

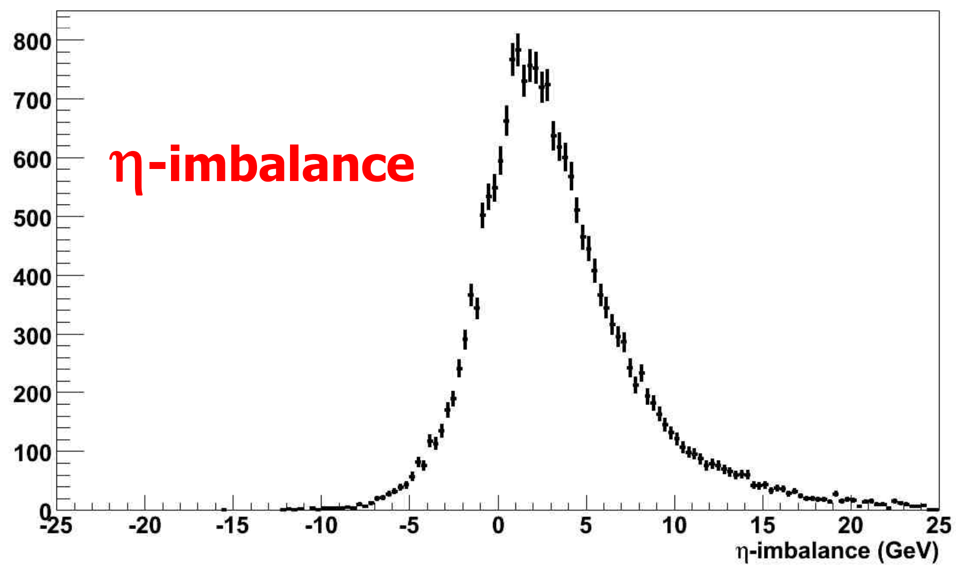
Introduce an optimized variable called η-imbalance: $u_\eta+p_\eta(ee)$

Mean value of η-imbalance: sensitive to hadronic response parameters

Width of η-imbalance: sensitive to hadronic resolution parameters

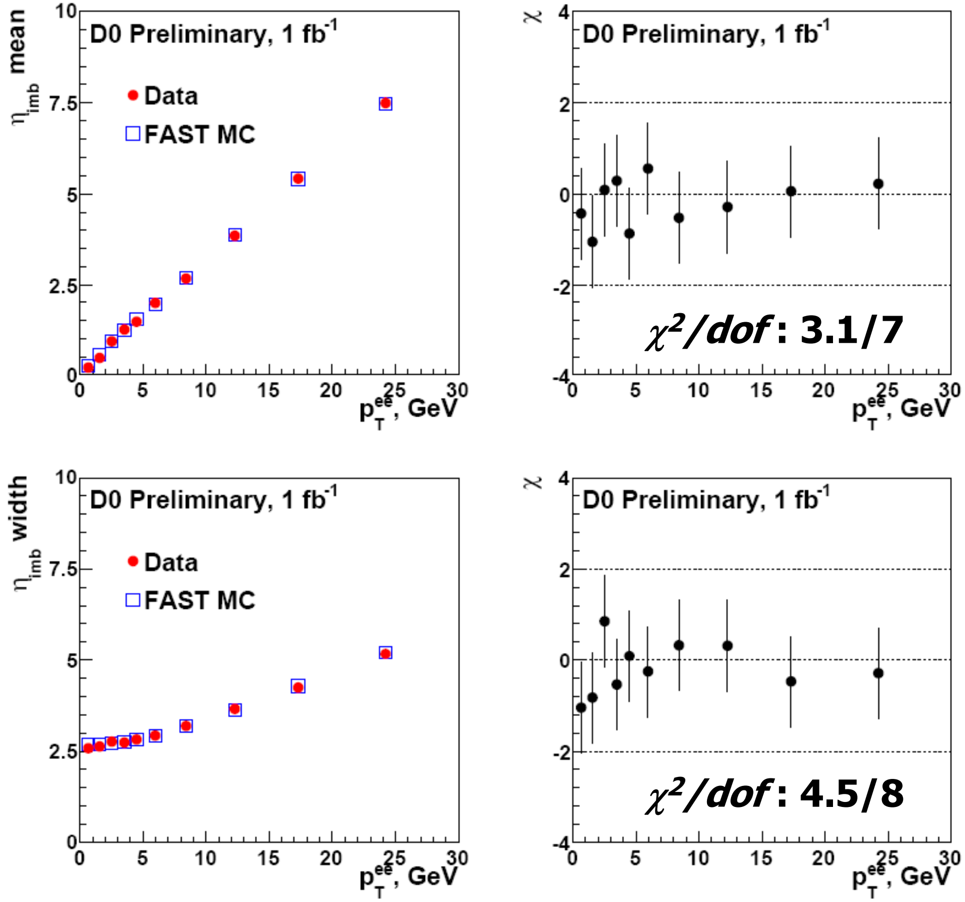
(introduced by UA2)

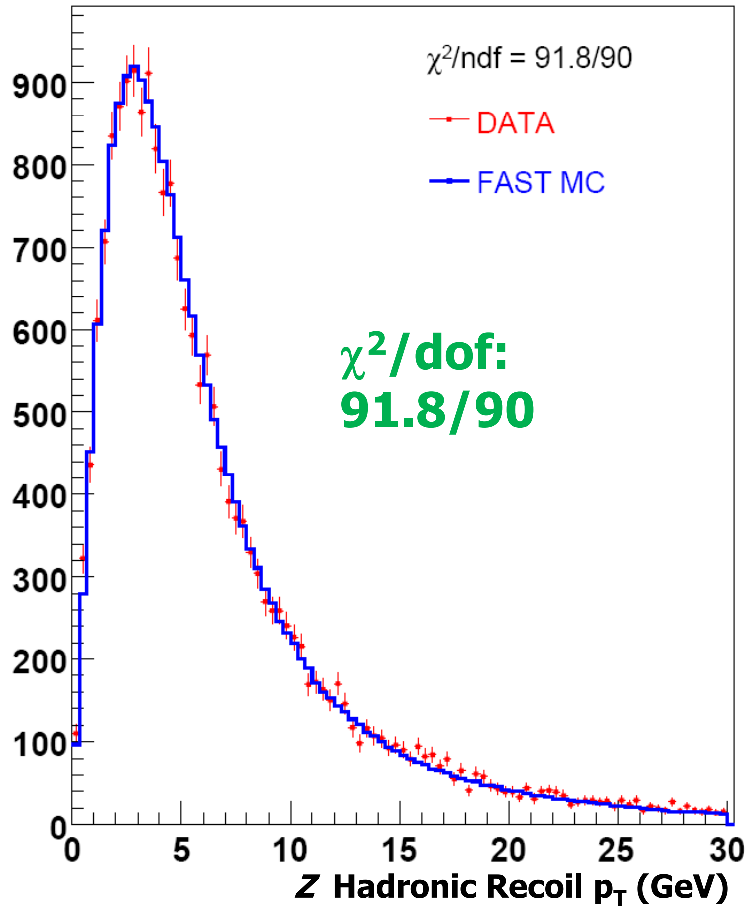




Hadronic Recoil System

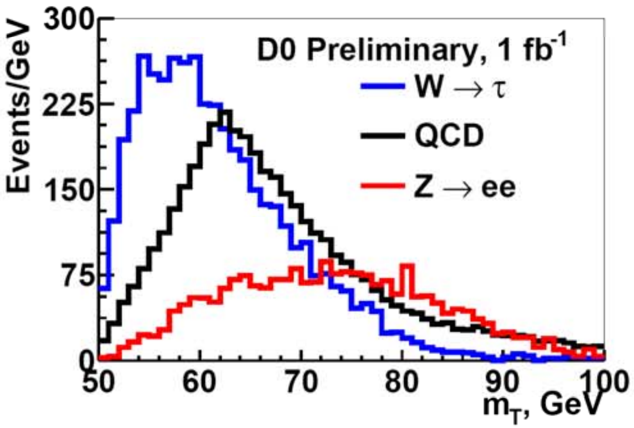
Final adjustment of free parameters in the recoil model is done *in situ* using balancing in *Z -> e e* events and the standard UA2 observables.

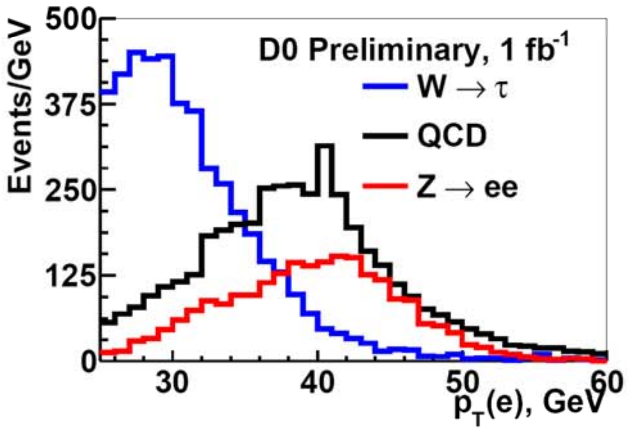


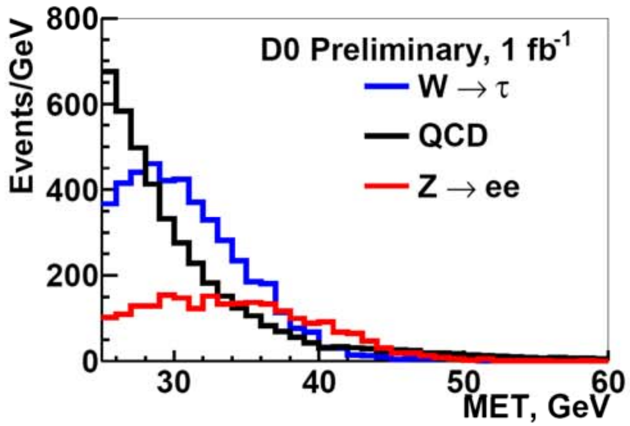


Backgrounds to *W->e*ν

- **QCD (di-jet) ((1.49±0.03)%): one jet faked as electron**
- ***Z -> ee* ((0.80±0.01)%): one electron lost in ICR(between central and forward calorimeter)**
- ***W ->*** $\tau\nu$ **((1.60±0.02)%): mostly from** τ **decays into "e**$\nu\nu$**"**

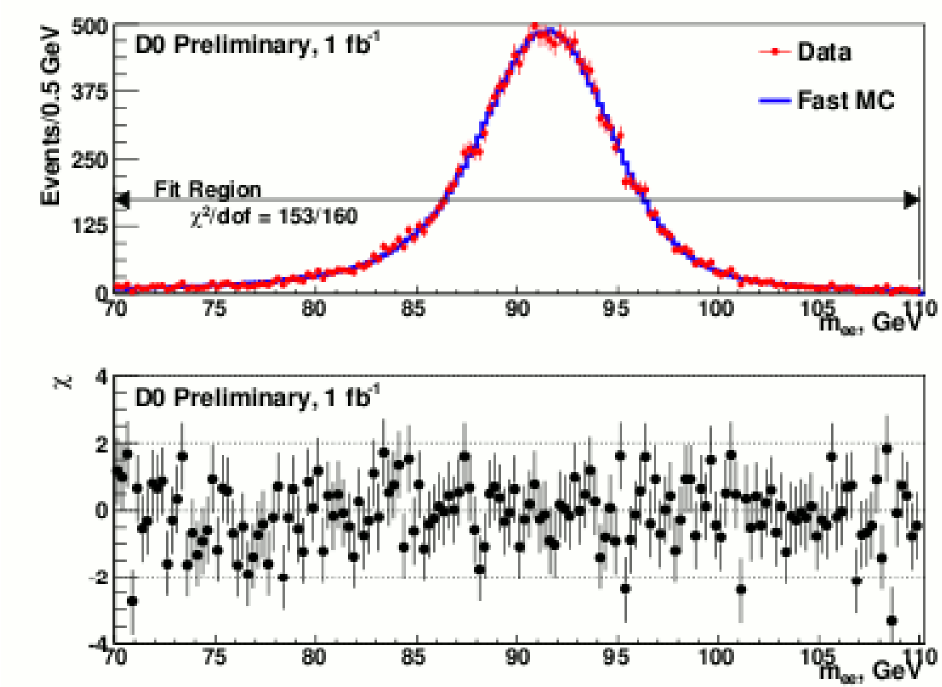






Mass fits

Z Mass

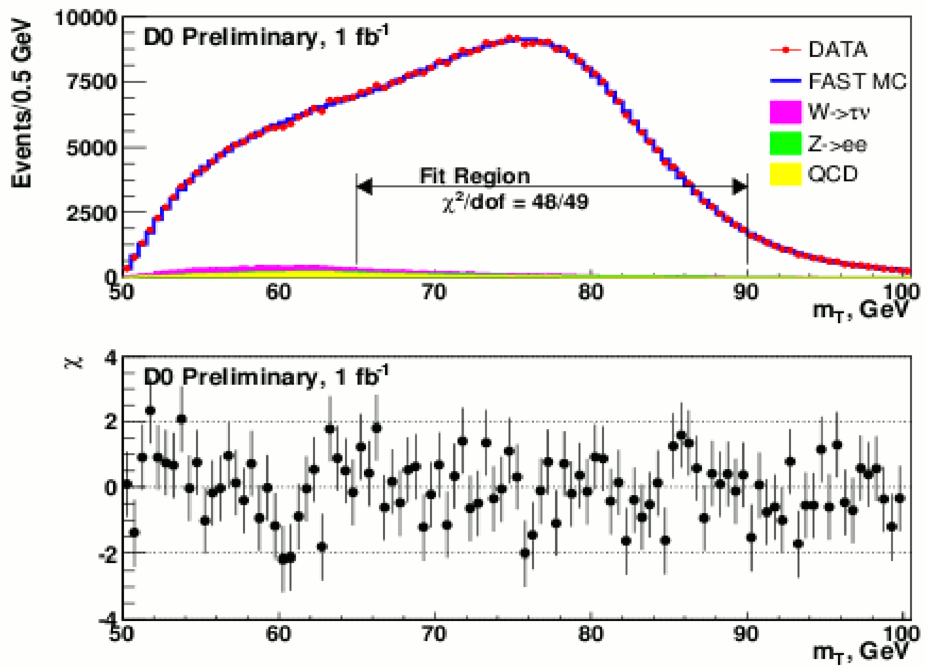


Z->ee : ~18k

M_Z = 91.185 ± 0.033 GeV (stat)

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

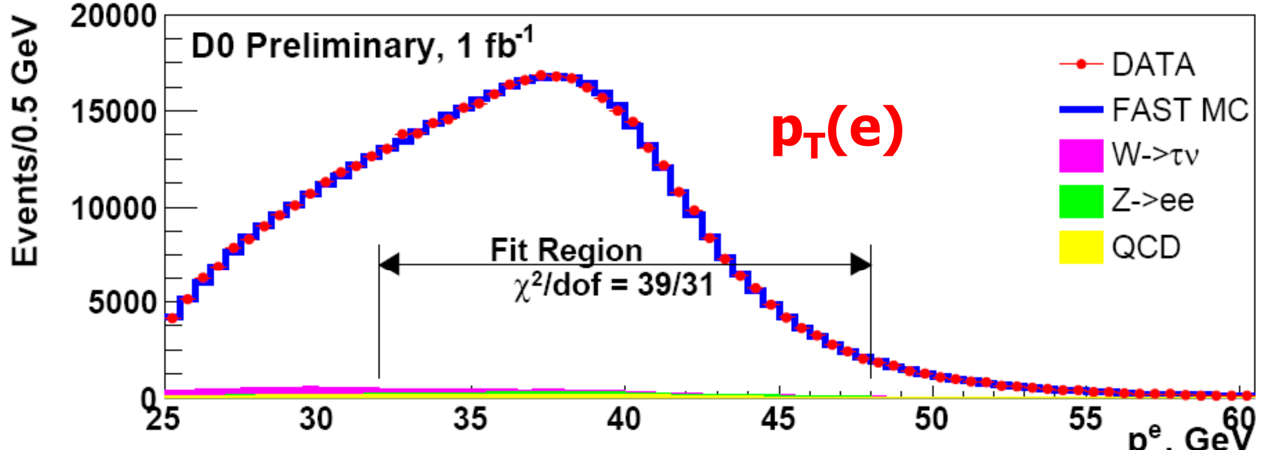
M_T



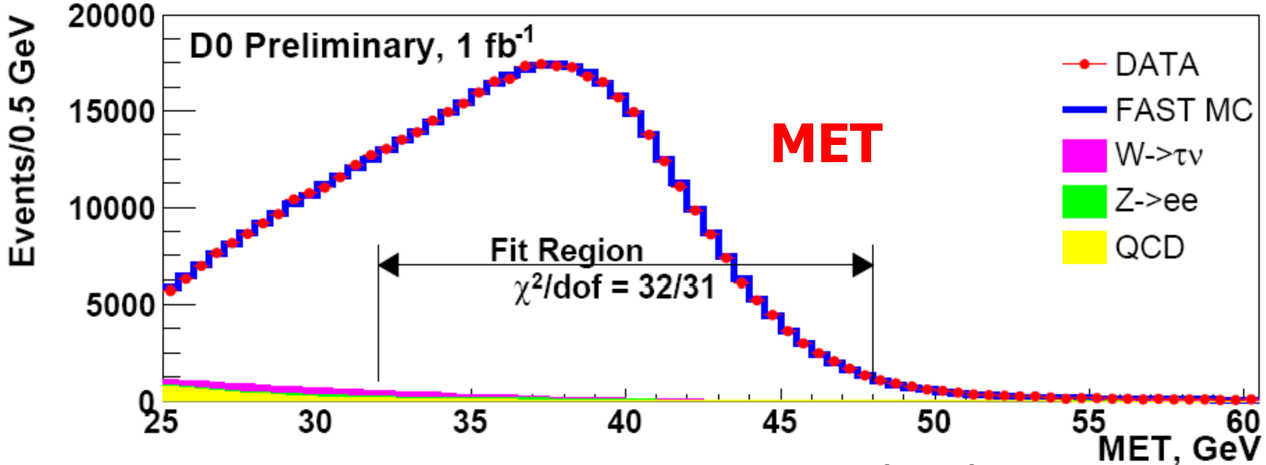
W->eν : ~500k

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

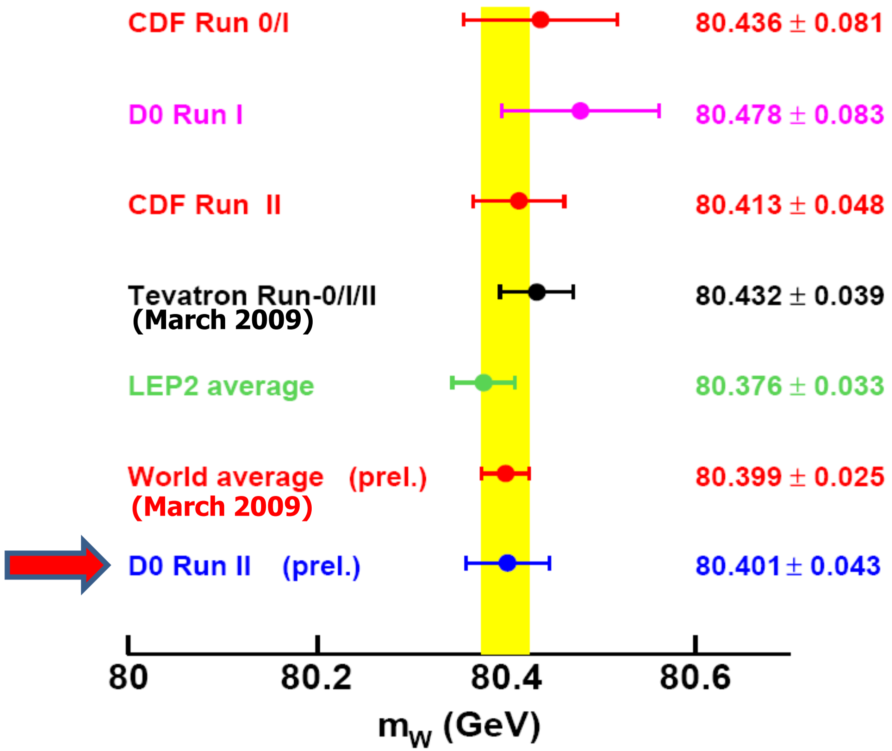
Source	$\sigma(m_W)$ MeV m_T	$\sigma(m_W)$ MeV p_T^e	$\sigma(m_W)$ MeV $\not{E}_T$
Experimental			
Electron Energy Scale	$\boxed{34}$	$\boxed{34}$	$\boxed{34}$
Electron Energy Resolution Model	2	2	3
Electron Energy Nonlinearity	4	6	7
W and Z Electron energy loss differences	4	4	4
Recoil Model	6	12	20
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

M_W : 80.401 ± 0.043 GeV (Combined)

Conclusion

M_W :

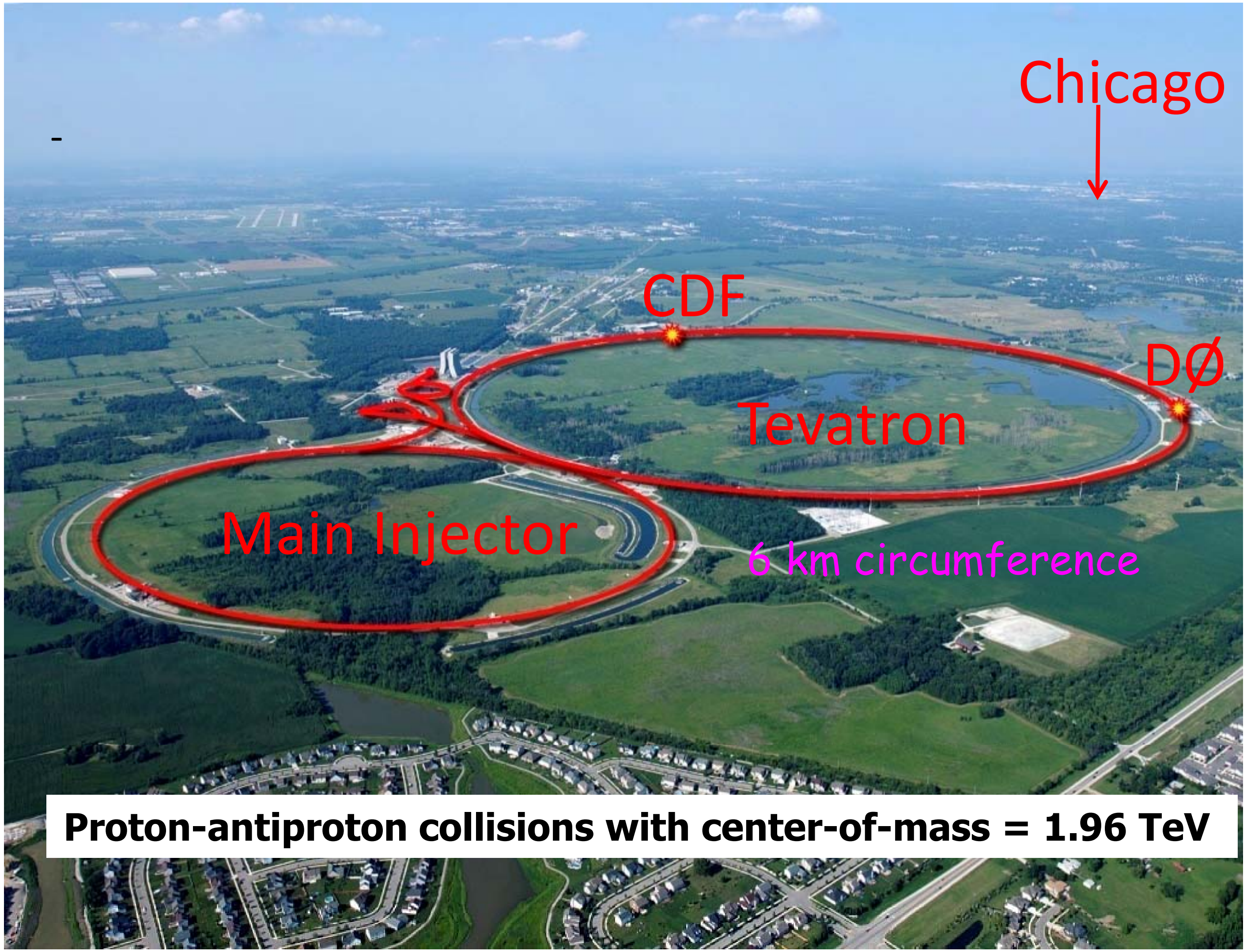
80.401 ± 0.023(stat) ± 0.037(syst) GeV= 80.401 ± 0.044 GeV (M_T)
80.400 ± 0.027(stat) ± 0.040(syst) GeV= 80.400 ± 0.048 GeV (p_T(e))
80.402 ± 0.023(stat) ± 0.044(syst) GeV= 80.402 ± 0.050 GeV (MET)
80.401 ± 0.043 GeV (Combined)



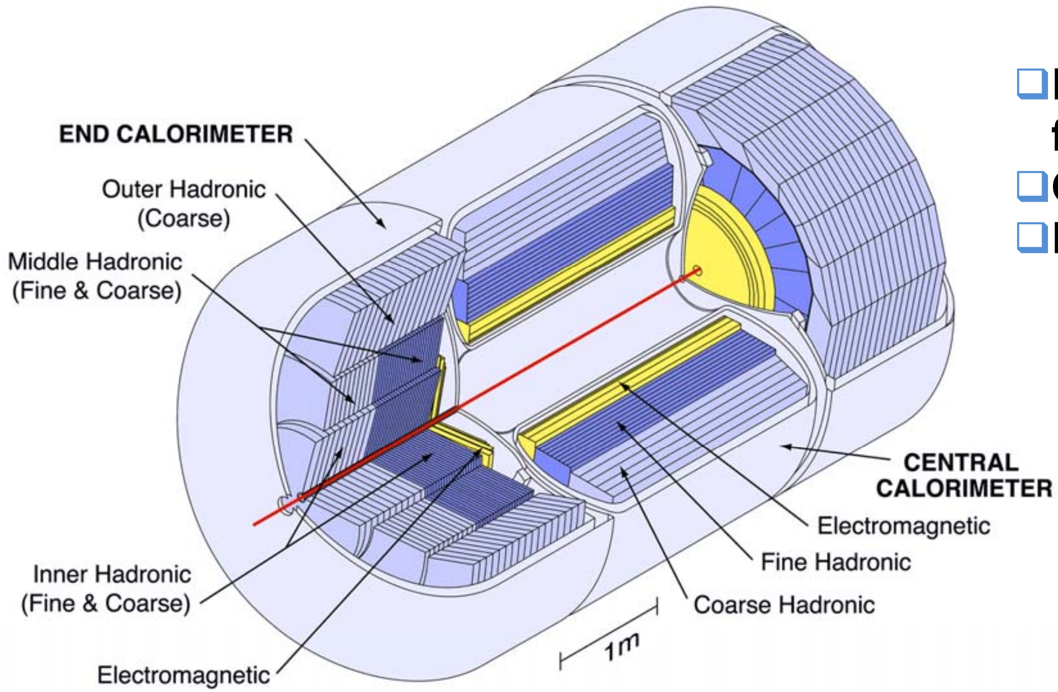
- **D0 group measured W boson mass using 1 fb^{-1} Run II data with a precision of 0.05%, which is in good agreement with previous measurements.**
- **Single most precise measurement of the *W* boson mass to date**
- **Expect ~ 25 MeV uncertainty with 5 fb^{-1} D0 data**

- **Backup Slides**

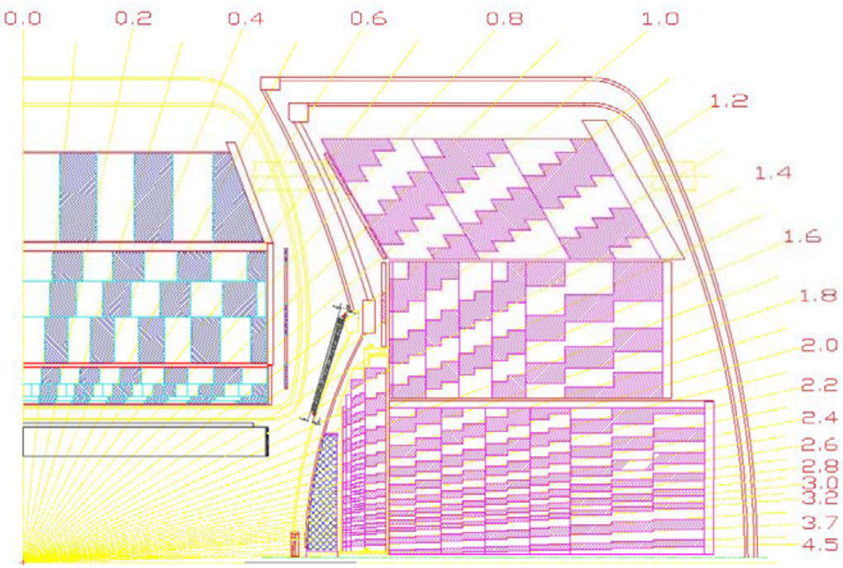
Experimental Setup: Tevatron



Uranium/Liquid-argon Calorimeter



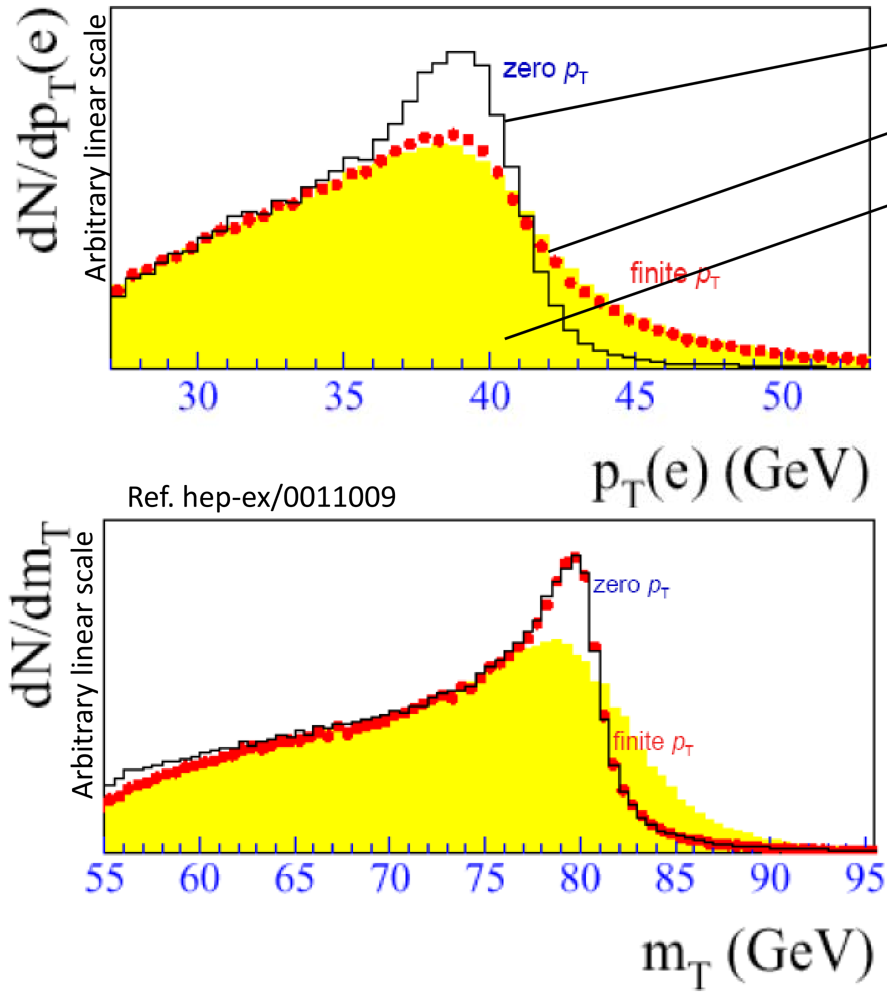
- Energy measurement and identification for electrons, photons and jets
- Central and Forward
- Electromagnetic and Hadronic



- **Full coverage** : $|\eta| < 4.2$
- **~46,000 channels**
- **Fine segmentation(towers): $\Delta\eta \times \Delta\varphi = 0.1\text{x}0.1$**

(0.05x0.05 in third EM layer, near shower maximum)

Observables Sensitivities



No $P_T(W)$

$P_T(W)$ included

Detector Effects added

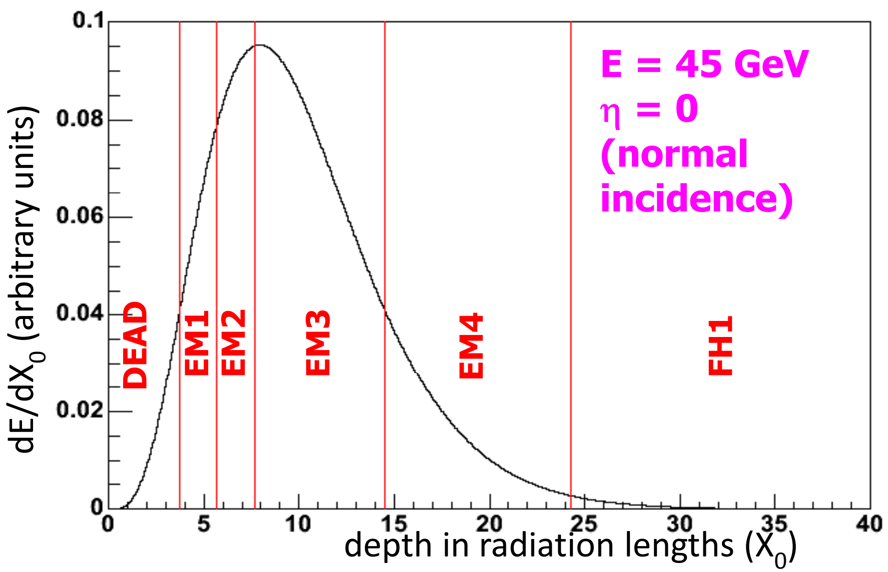
$p_T(e)$ most sensitive to $p_T(W)$

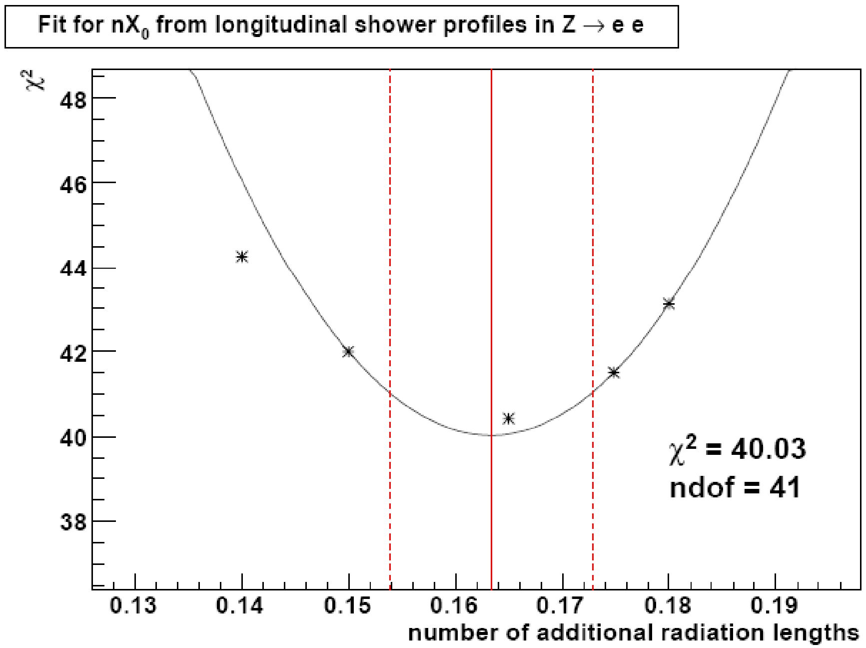
$$M_T = \sqrt{2E_T^l \not{E}_T (1 - \cos\Delta\phi)}$$

M_T most affected by measurement of missing transverse momentum

Material in front of calorimeter

- ~4X0 dead materials in front of the calorimeter
- Need to know number of X0 in front of calorimeter precisely
- Measurement method:
  - electron energy fraction in each layer is sensitive to the material in front of calorimeter
  - Construct a model to predict EMF distribution for different nX0
  - Compare predictions with data





Additional material by fitting for three EM layer together:
n=0.1633 +- 0.0095

Data Samples:
$1fb^{-1}$(2002--2006)

- **Common Selection for both *Z->ee* and *W->eν*:**
  - $|Vtx_{primary}|<60$ cm
  - Single electron trigger fired
  - Electron in central calorimeter: $|\eta_{det}|<1.05$
  - Fiducial region
  - $p_T(e) > 25$ GeV, iso<0.15, emfrac>0.9, shower shape, track match
  - Recoil $p_T < 15$ GeV

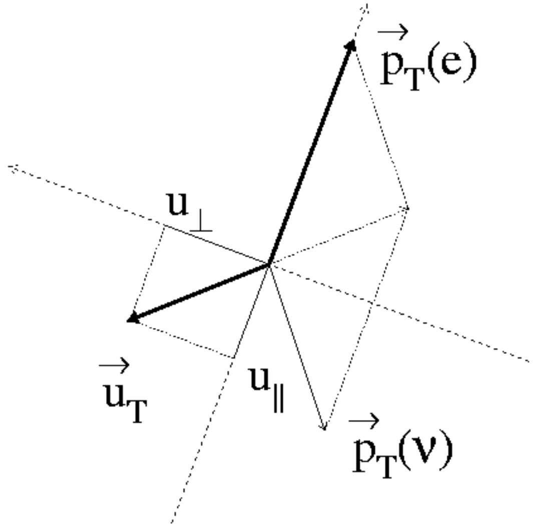
- **Additional Selection for *Z->ee* (~18k):**
  - 70 GeV < Invariant Mass(e,e) < 110 GeV

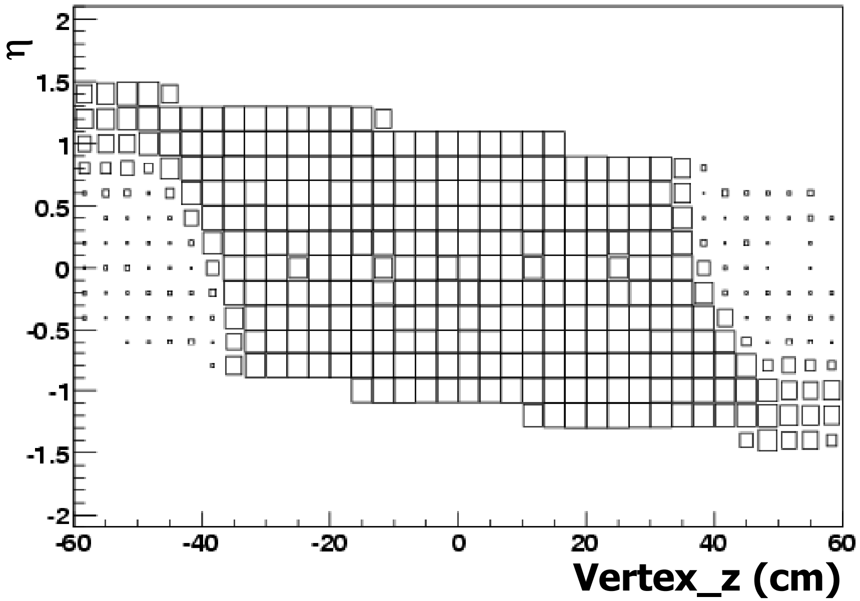
- **Additional Selection for *W->eν* (~500k):**
  - 50 GeV < M_T < 200 GeV
  - MET > 25 GeV

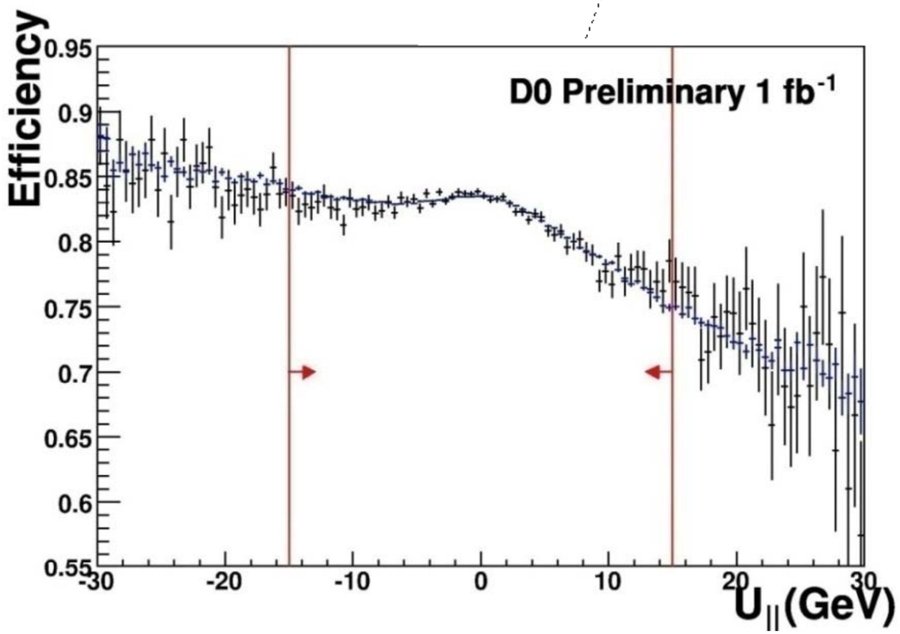
Geometric dependence and $u_{||}$ Efficiency

- **Efficiency is measured using the tag-and-probe method on *Z->ee* events**

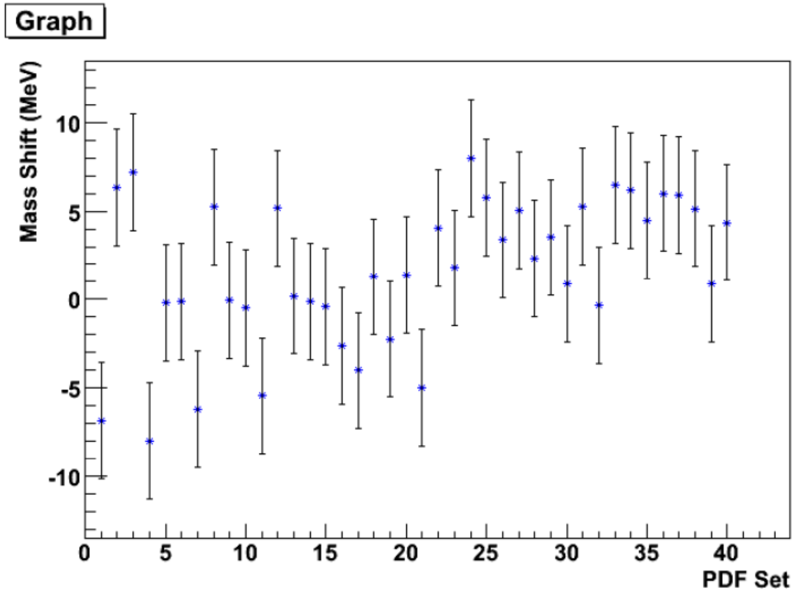
- **The recoil of the boson affects electron identification, especially when the recoil is close to the electron**



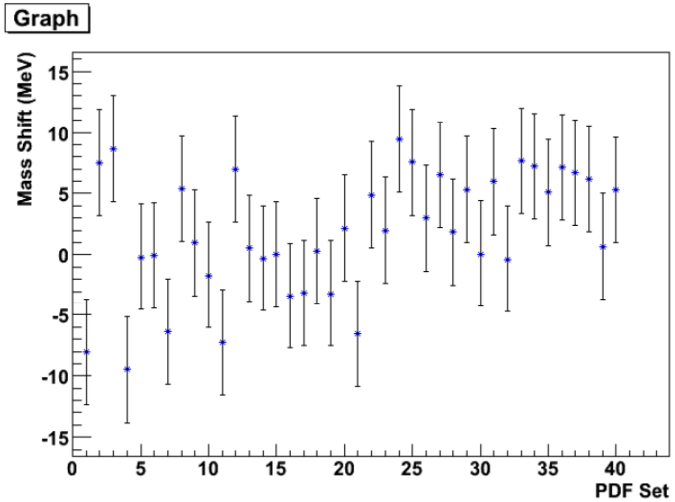




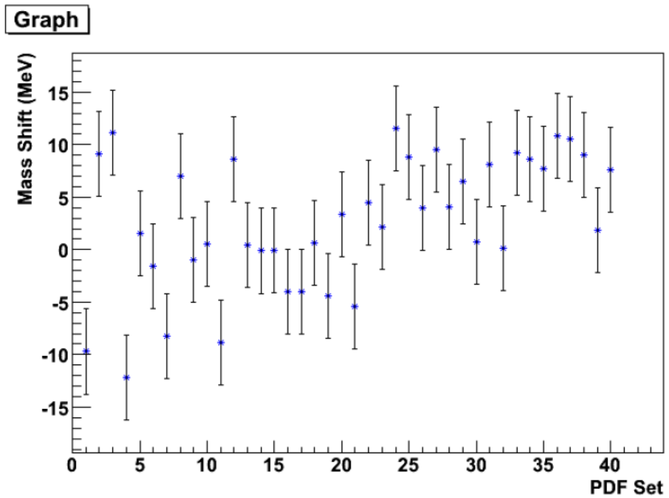
PDF Uncertainties



$\Delta M_W(M_T)$: 9 MeV



$\Delta M_W(p_T(e))$: 11 MeV



$\Delta M_W(MET)$: 14 MeV

Final Efficiency Check

- **The SET and pure $p_T(e)$ dependence of efficiency is studied in details using full MC(6 fb^{-1}) truth, which cannot be performed in data due to the method and limited statistics**
- **Use tag-and-probe method to measure $p_T(e)$ dependence in full MC and data as a final check**