Standard Model @ LHC
Copenhagen, 10-13 April 2012

Recent W/Z results, including W mass, from the Tevatron

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on behalf of the CDF and D0 collaborations

New W mass results this winter:

Published on PRL today (April 12, 2012)

CDF: 2.2 fb^{-1}, electron and muon channels

Phys. Rev. Lett. 108, 151803 (2012)

D0: 5.3 fb^{-1}, electron channel

Phys. Rev. Lett. 108, 151804 (2012)

W mass: Motivation

The Standard Model (SM) predicts a relationship between the W boson mass and other parameters of electroweak theory:

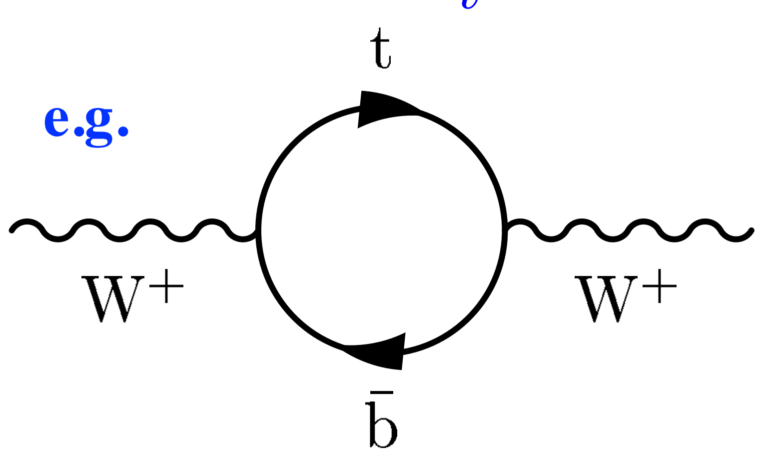
$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}}\frac{1}{\sin\theta_W\sqrt{1-\Delta r}}$$

Radiative corrections Δr

related to the Top quark mass as

$$\Delta r \propto M_t^2$$

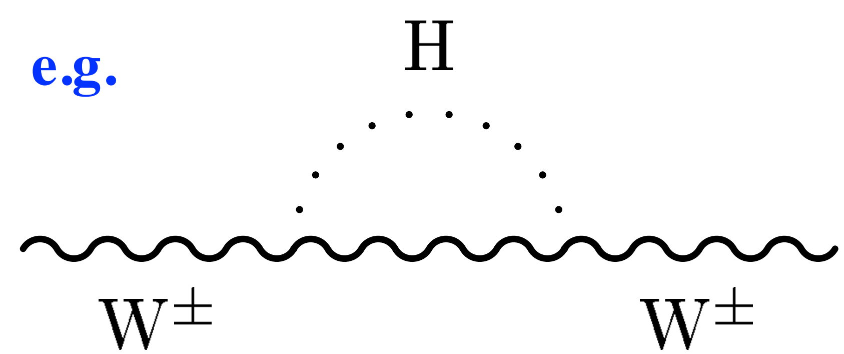
e.g.



related to the Higgs mass as

$$\Delta r \propto \ln M_H$$

e.g.



Precise knowledge of the W mass and top quark mass can indirectly constrain the mass of the hypothetical Higgs boson.

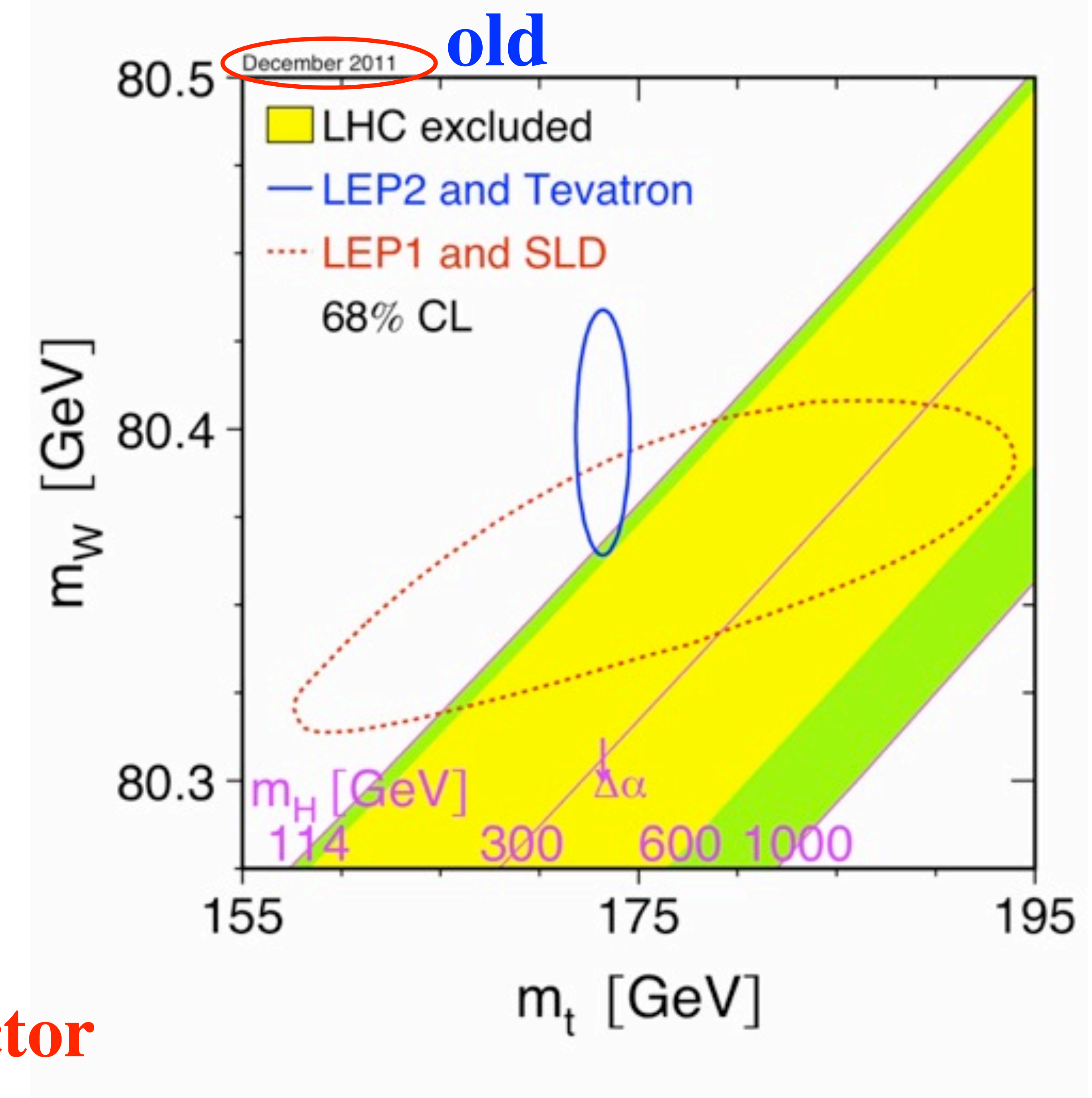
W mass: Motivation

The Higgs mass is much more sensitive to the W mass than the top mass:

$\Delta m_H / \Delta m_W \sim 170 \ \Delta m_H / \Delta m_t$

For equal constraint on the Higgs mass, W mass has to be measured much more precise than the top quark mass:

$\Delta m_W \sim 0.006 \ \Delta m_t$



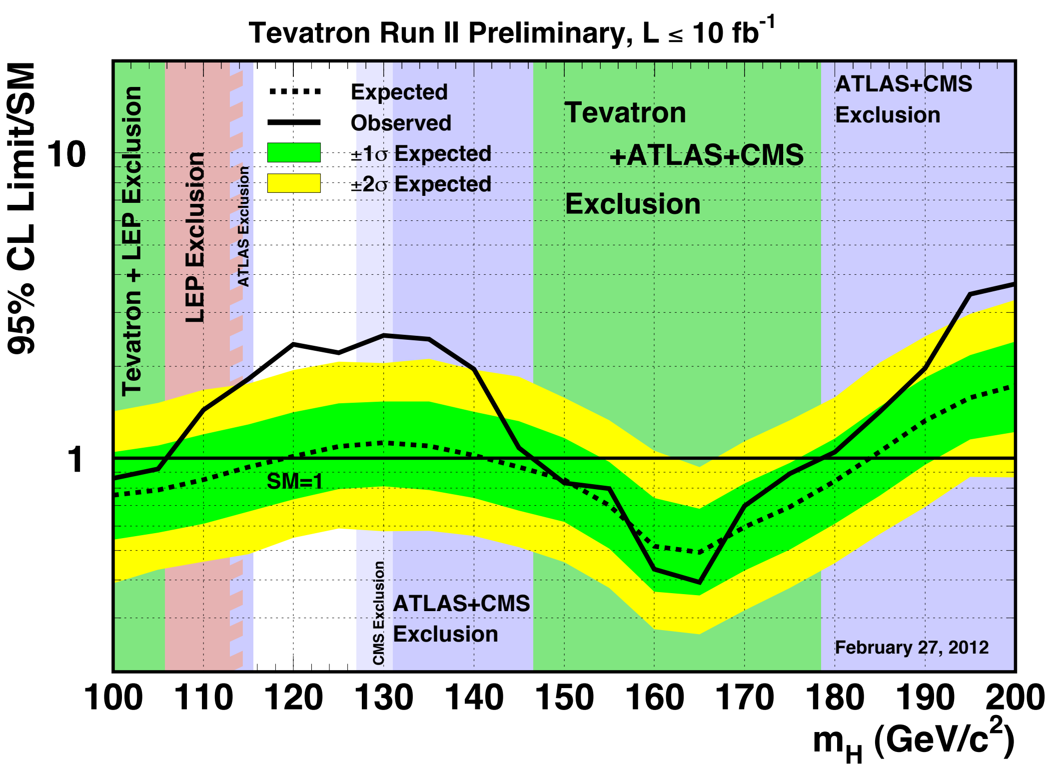
The W mass is the limiting factor in constraining the Higgs mass.

W mass: Motivation

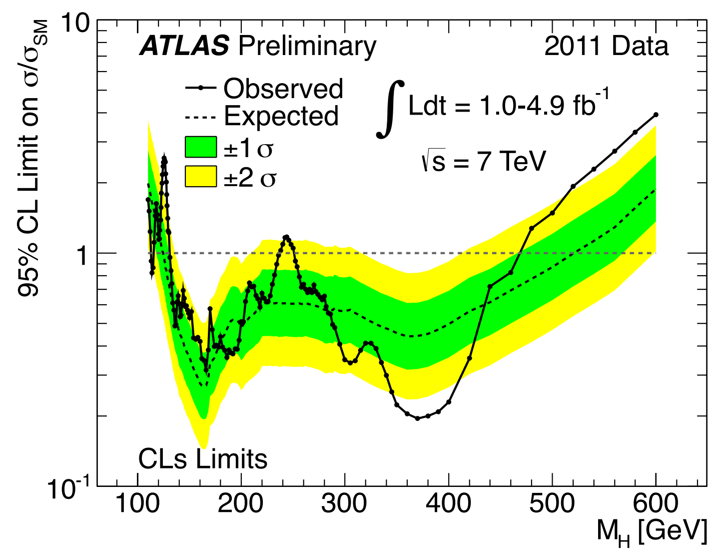
Results from direct searches of Higgs boson

Most likely mass region @ 95% C.L. : Moriond EW 2012

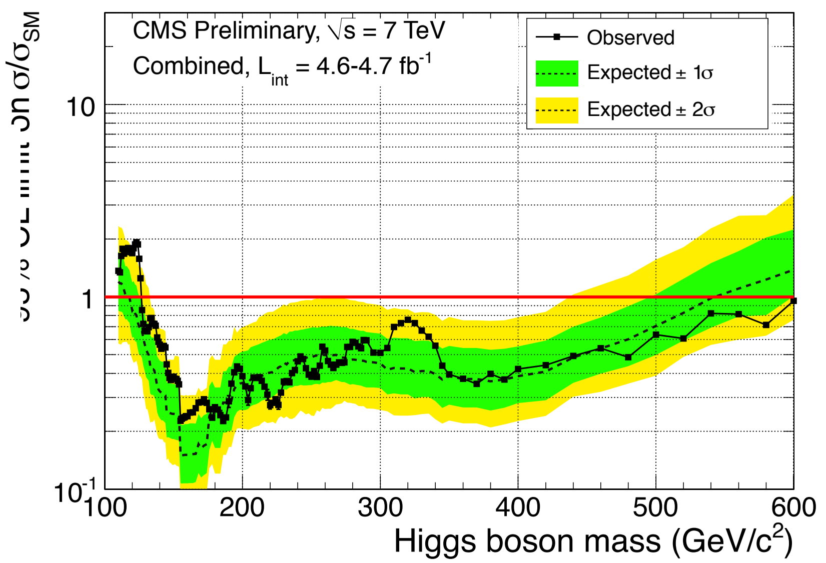
Tevatron Higgs exclusion



ATLAS:
117.5 - 118.5 GeV
or
122.5 - 129 GeV



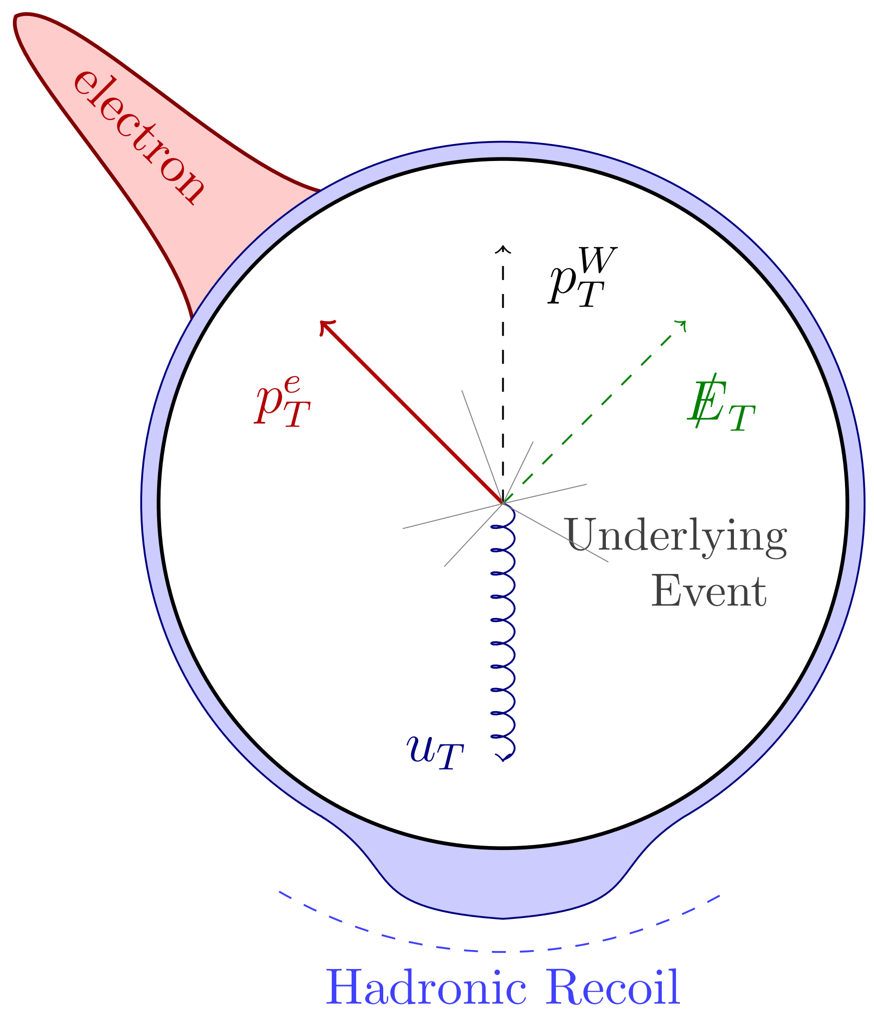
CMS:
114.4 - 127.5 GeV



Comparison of
indirect constraints and direct searches of Higgs
is an important test of the SM.

W mass: Analysis Strategy

A typical W→eν event in CDF and D0 detectors



Reconstruct three observables:

$$M_T,\ P_T^l,\ \not{E}_T$$

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

using central (eta<1) electrons/muons with p_T>25GeV

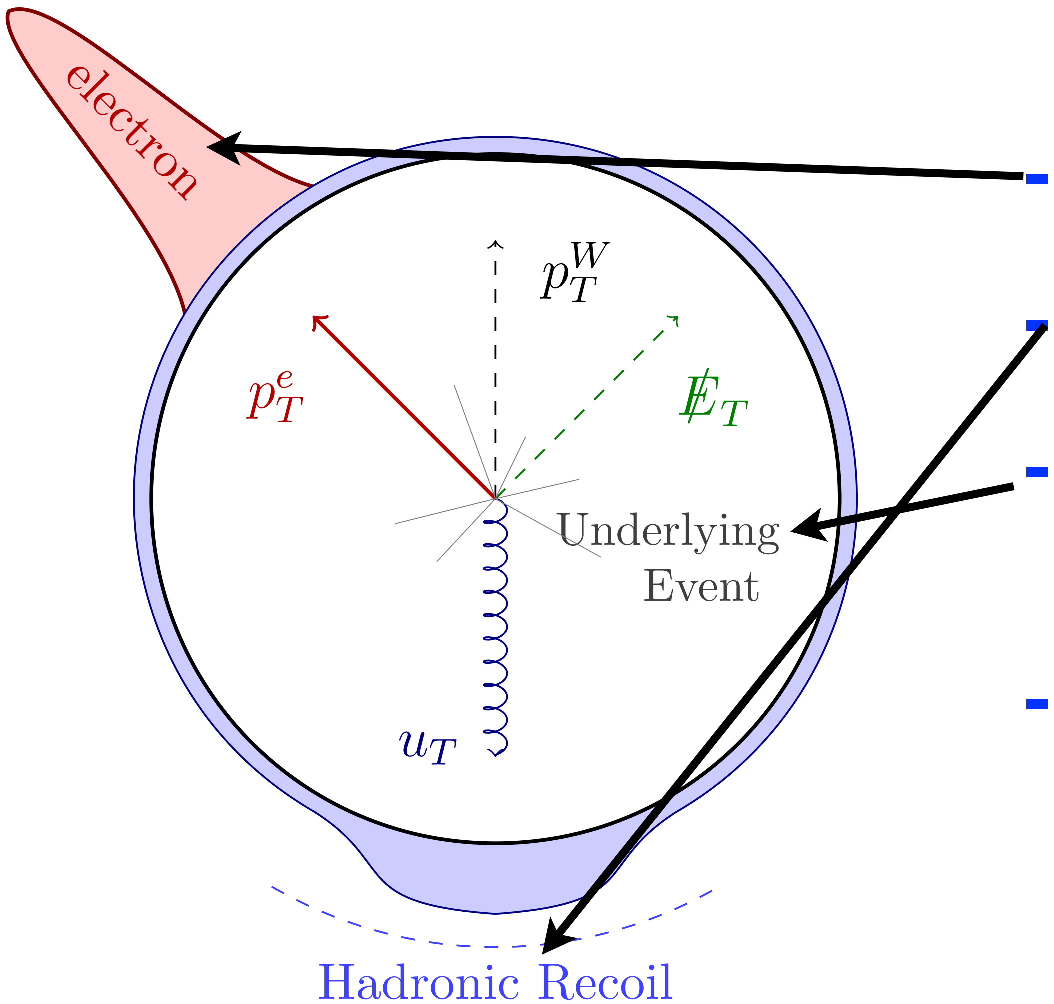
A Fast MC model to generate templates of the 3 observables with different W mass hypotheses. Fit the templates to the data to extract W mass.

The Fast MC model:

- **Event Generator: Resbos(CTEQ6.6)+Photos**
- **Parametrized Detector Model**

W mass: Analysis Strategy

The parametrized detector model has to simulate:



- **electron/muon energy response and smearing**
- **hadronic recoil energy response and smearing**
- **underlying energy: additional ppbar interactions (pileup) and spectator parton interactions**
- **electron/muon selection efficiency**

W mass: Analysis Strategy

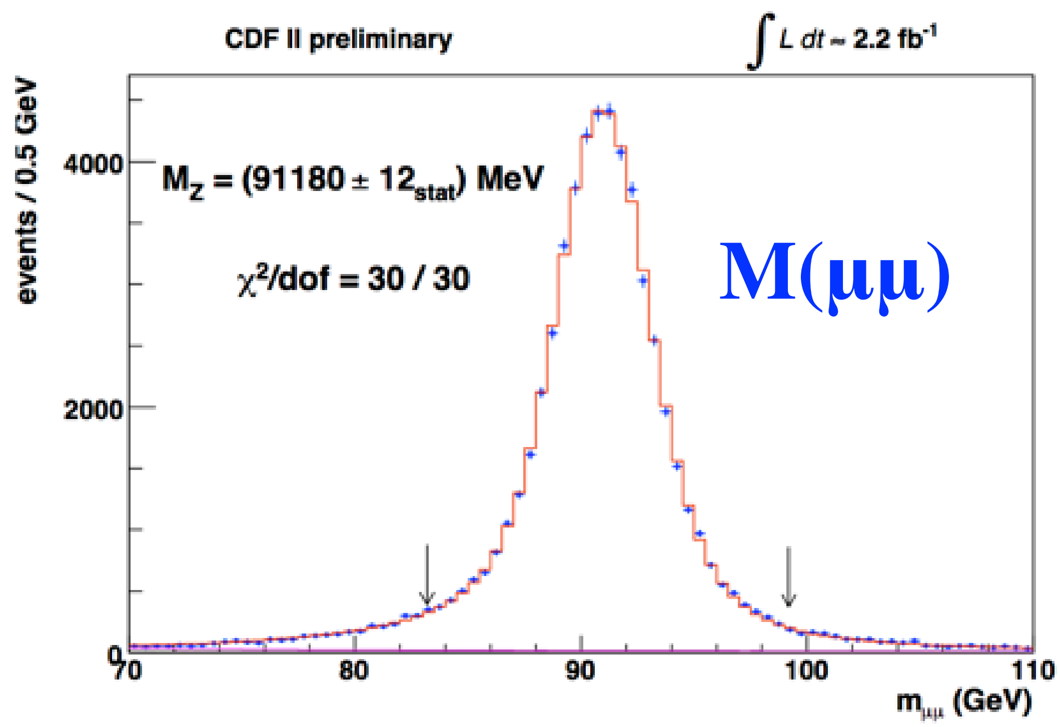
Lepton energy calibration at CDF:

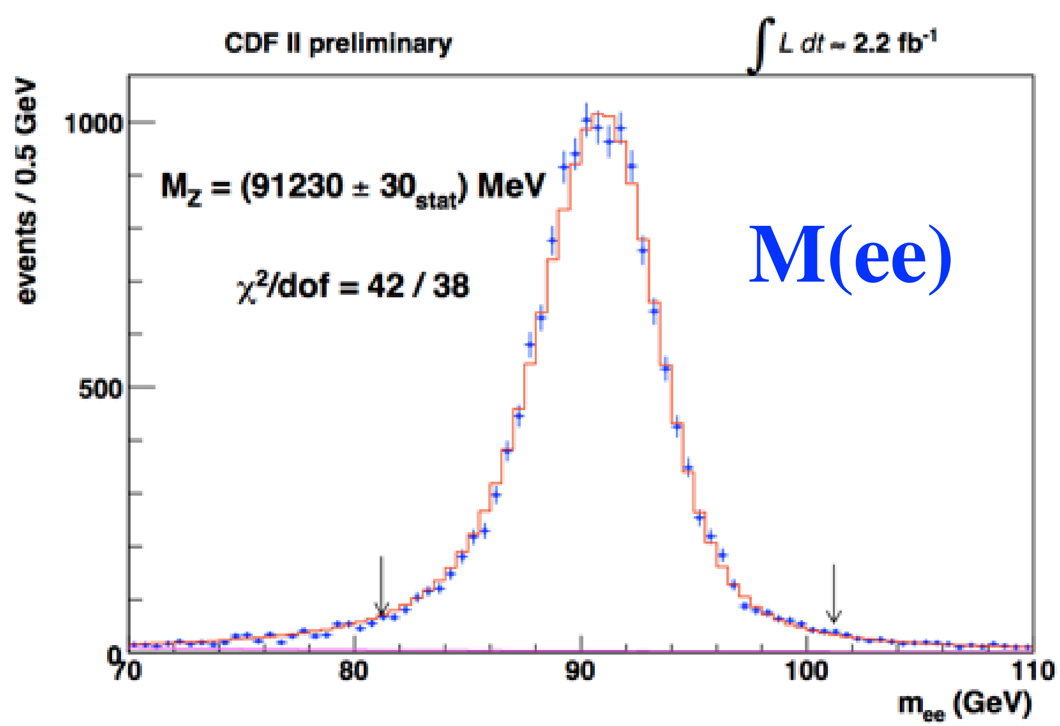
Tracker calibration:

- tracker alignment using cosmic rays
- tracker momentum scale and non-linearity constrained using J/ψ->μμ and Υ->μμ events
- confirmed using Z->μμ fits

EM calorimeter calibration:

- Transfer tracker momentum scale to EM calorimeter energy scale using fits to the E/p spectrum using W->eμ events
- confirmed using Z->ee fits

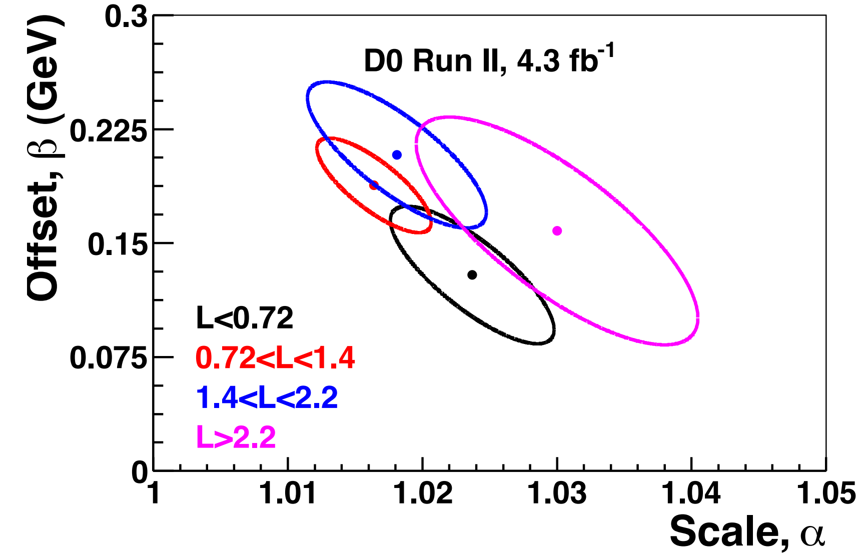




W mass: Analysis Strategy

Lepton energy calibration at D0:

(Based solely on calorimeter)

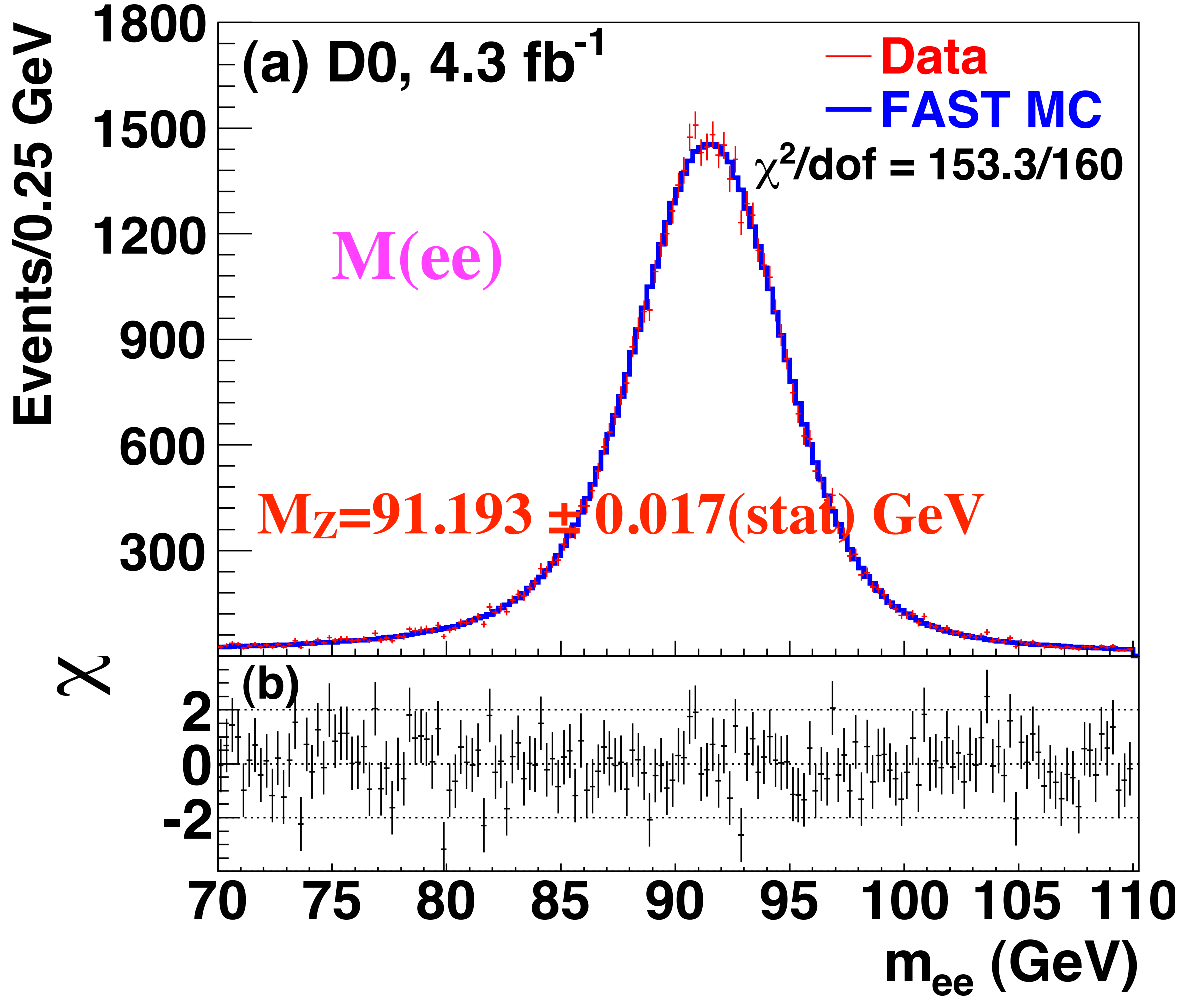


Correct/model non-linear energy responses:

- the energy loss due to dead material,
- underlying energy contamination from pileup and hadronic recoil

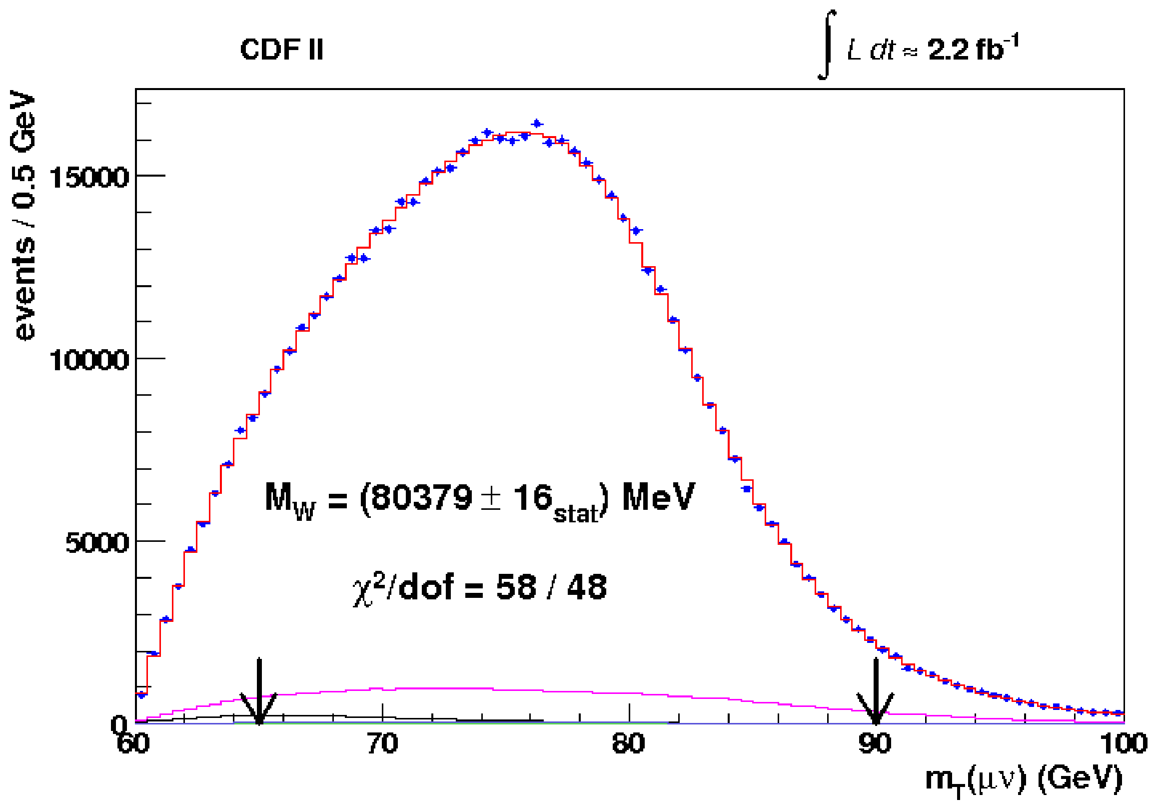
Final electron energy response is calibrated using Z->ee events assuming a linear response:

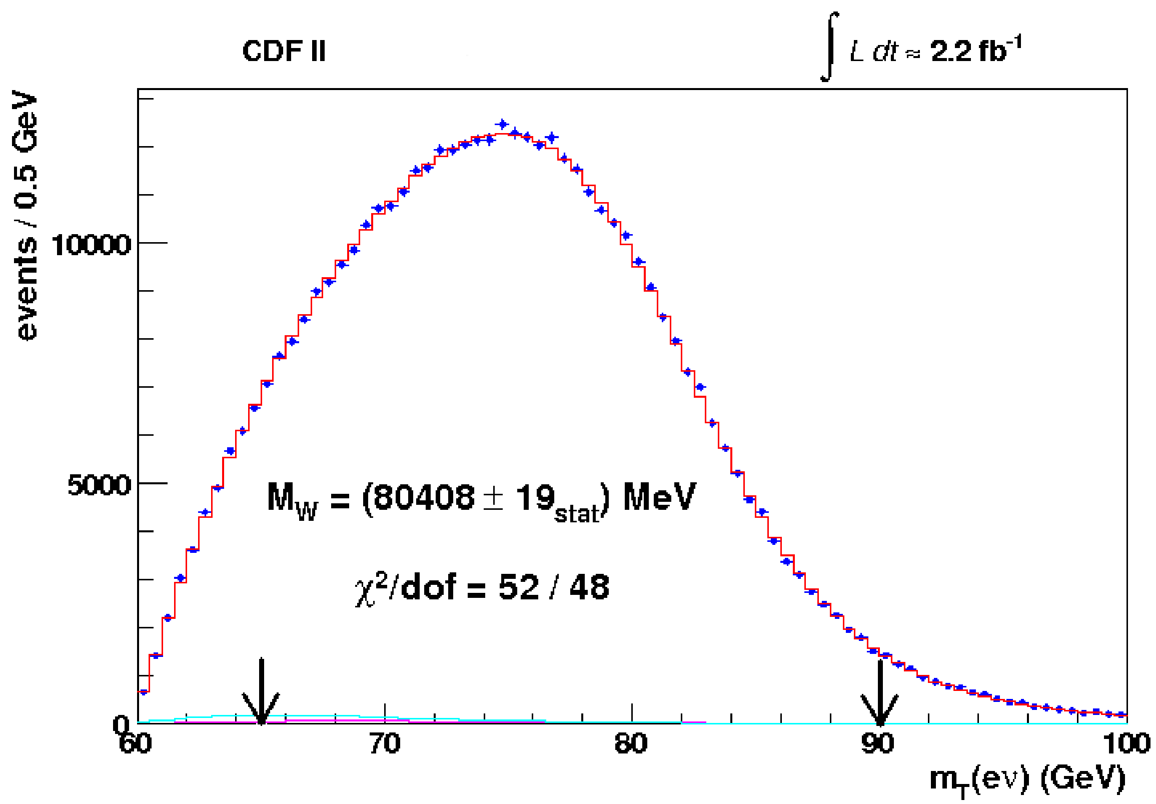
$$R_{EM}(E_{true}) = \alpha \cdot (E_{true} - \bar{E}_{true}) + \beta + \bar{E}_{true}$$



W mass: Results

Results from CDF:





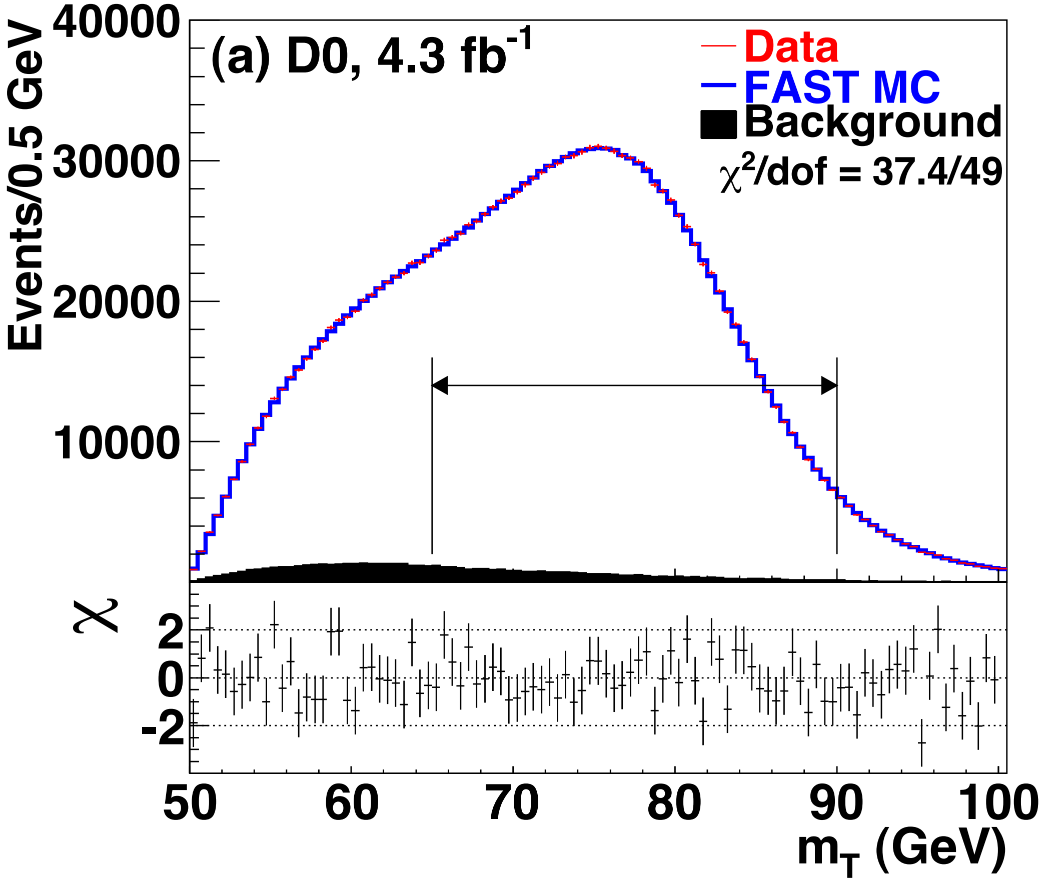
Method $(2.2\ fb^{-1})$	M_W (MeV)	Method $(2.2\ fb^{-1})$	M_W (MeV)
$m_T(\mu,\nu)$	80379 ± 16(stat)	$m_T(e,\nu)$	80408 ± 19(stat)
$p_T(\mu)$	80348 ± 18(stat)	$p_T(e)$	80393 ± 21(stat)
$\not{E}_T(\mu,\nu)$	80406 ± 22(stat)	$\not{E}_T(e,\nu)$	80431 ± 25(stat)
Combination $(2.2\ fb^{-1})$		**80387 ± 19** MeV (syst + stat)	

Most precise single experiment result!

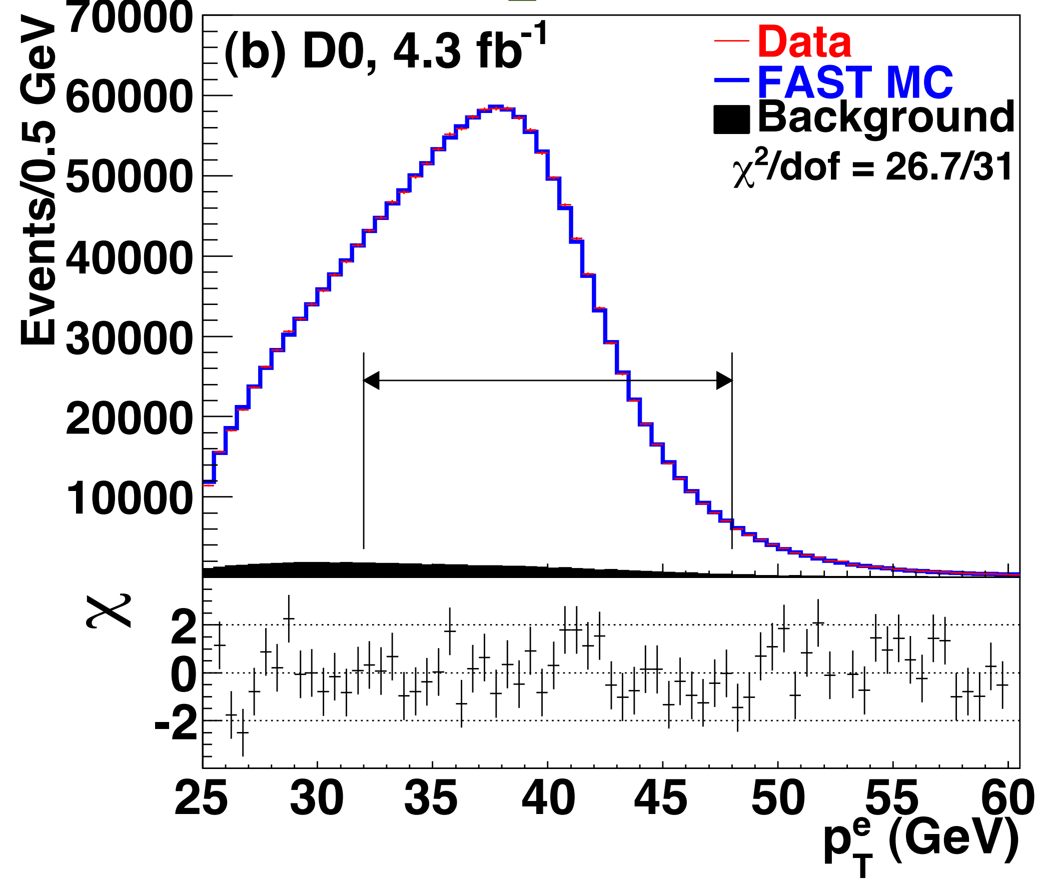
W mass: Results

Results from D0:

M_T



$p_T(e)$



Method $(4.3\ fb^{-1})$	M_W (MeV)
$m_T(e,\nu)$	80371 ± 13(stat)
$p_T(e)$	80343 ± 14(stat)
$\not{E}_T(e,\nu)$	80355 ± 15(stat)
Combination $m_T \oplus p_T$ $(4.3\ fb^{-1})$	80367 ± 26(syst + stat)
Combination $(5.3\ fb^{-1})$	**80375 ± 23**(syst + stat)

23 MeV was the previous world average!

W mass: Systematic uncertainties

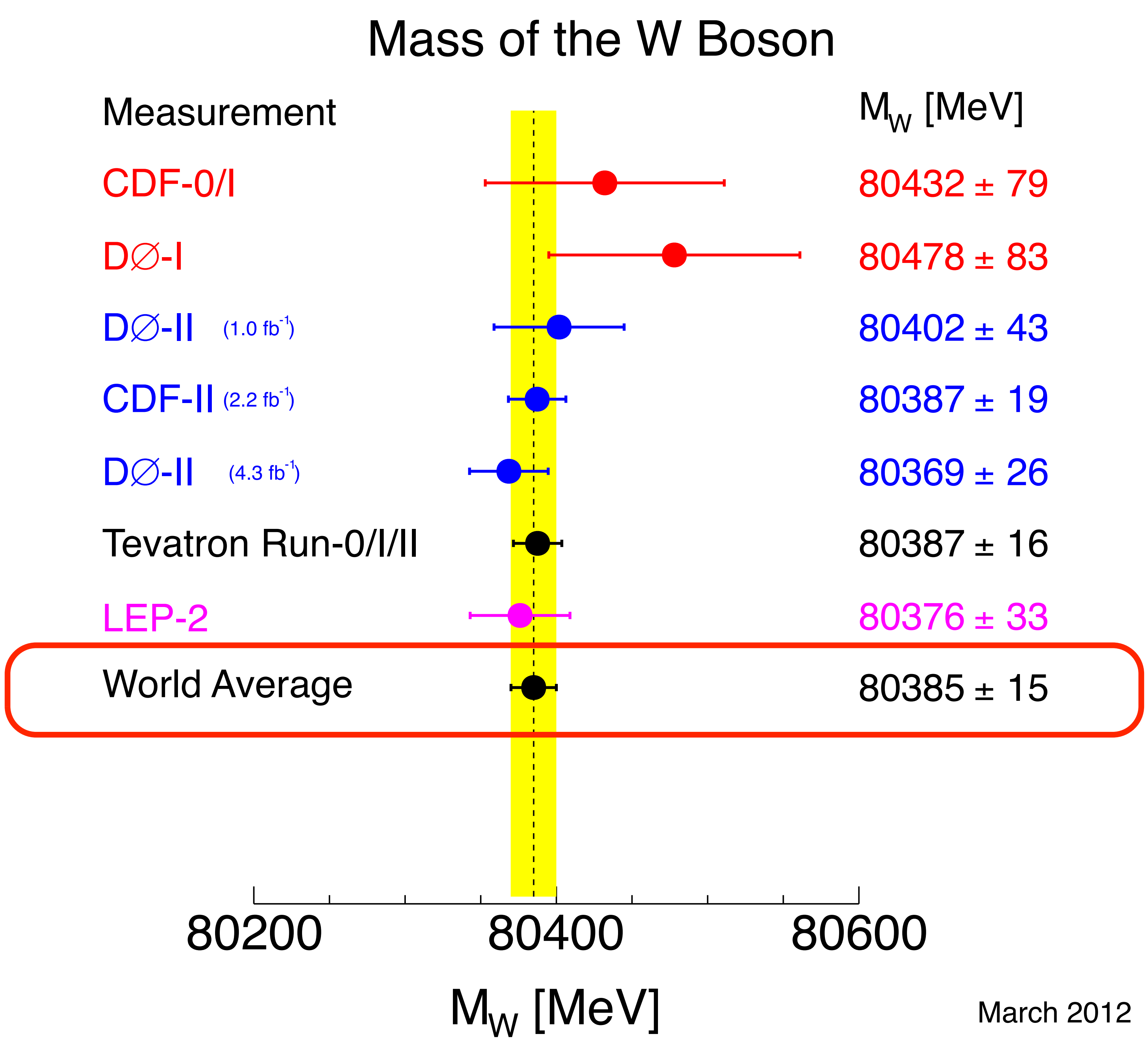
CDF 2.2 fb-1, e- and μ-channels

Source	Uncertainty (MeV)
Lepton energy scale and resolution	7
Hadronic recoil energy scale and resolution	6
Lepton removal	2
Backgrounds	3
Experimental subtotal	10
Parton distributions	10
QED radiation	4
$p_T(W)$ model	5
Production subtotal	12
Total systematic uncertainty	15
W-boson statistics	12
Total uncertainty	19

D0 4.3 fb-1, e-channel

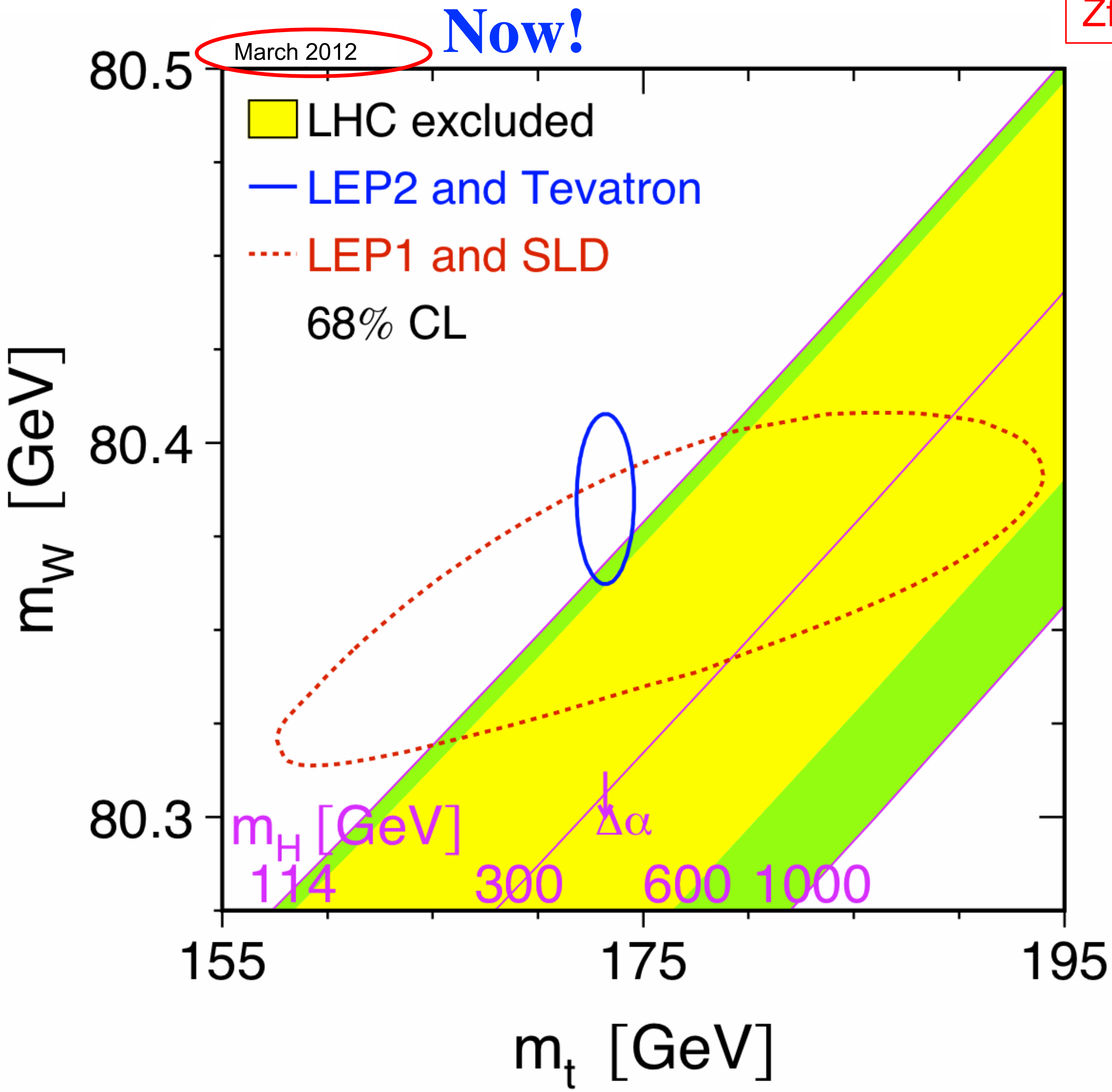
Source	Uncertainty (MeV)
Electron energy calibration	16
Electron resolution model	2
Electron shower modeling	4
Electron energy loss model	4
Hadronic recoil energy scale and resolution	5
Electron efficiencies	2
Backgrounds	2
Experimental subtotal	18
Parton distributions	11
QED radiation	7
$p_T(W)$ model	2
Production subtotal	13
Total systematic uncertainty	22
W-boson statistics	13
Total uncertainty	26

W mass: New world average

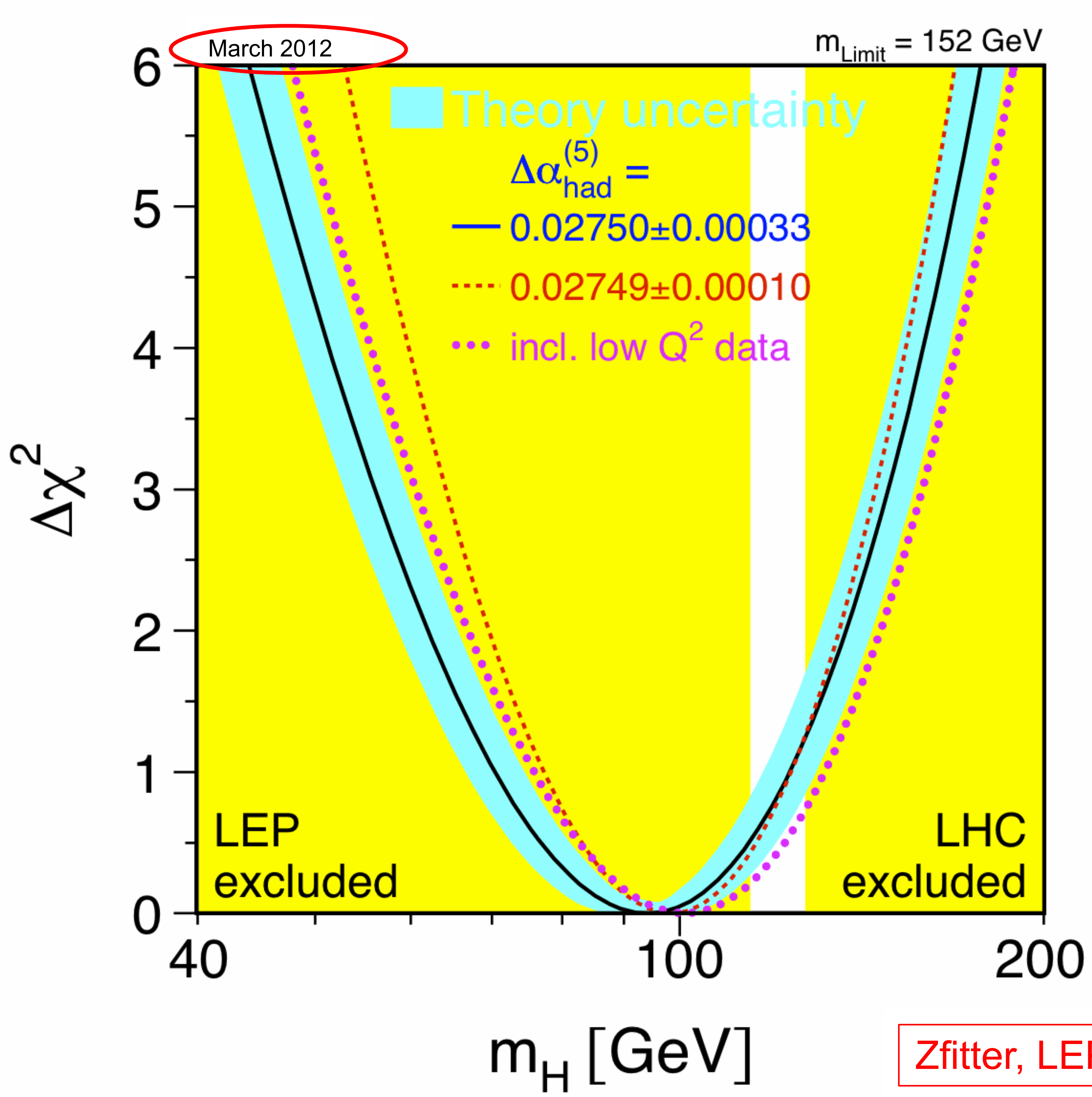


W mass: New world average

Zfitter, LEPEWWG



W mass: Constraint on Higgs mass



Zfitter, LEPEWWG

Previous (Dec. 2011) SM Higgs fit:

$m_H = 92^{+34}_{-26}$ GeV

$m_H < 161$ GeV @ 95% C.L.

New prel. SM Higgs fit:

$m_H = 94^{+29}_{-24}$ GeV

$m_H < 152$ GeV @ 95% C.L.

Other recent W/Z results:

Z P_T

Multibosons: (see e.g. talk J. Sekaric, Moriond EW 2012)

W/Z + jets: (see e.g. talk D. Bandurin, Moriond QCD 2012)

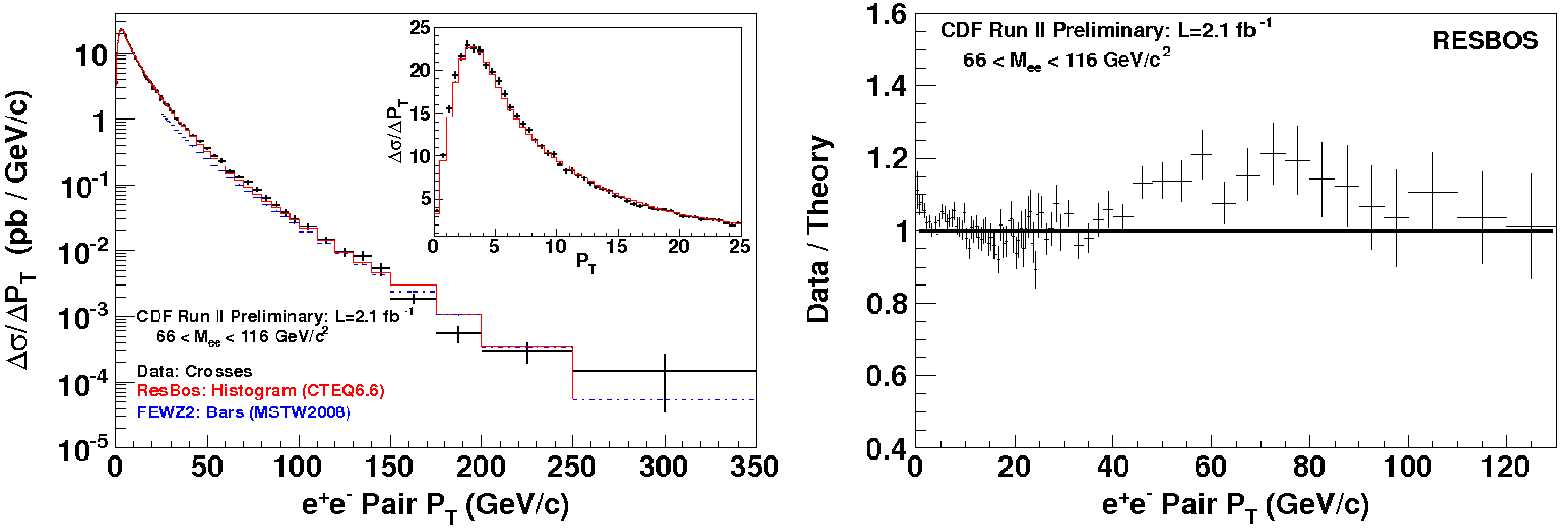
In the early age of the Tevatron (as the age now for LHC), these measurements provided essential results for understanding the W/Z productions at the Tevatron.

Z/γ* pT measurements

In the SM, the Z/γ* pT is calculated by high order QCD corrections in the Z/γ* production. The lowest order does not predict any pT for the Z /γ*.

- **Constrains the theoretical prediction of the boson pT**
- **Benefitted by many precision measurements, including the W boson mass.**

Results from CDF:

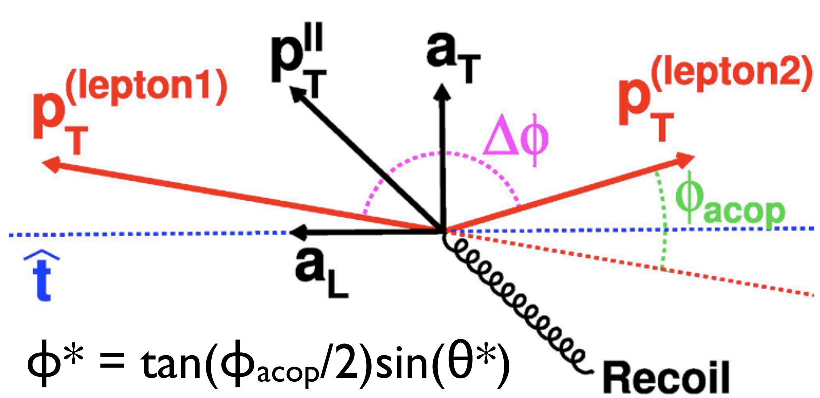


Z/γ* pT measurements

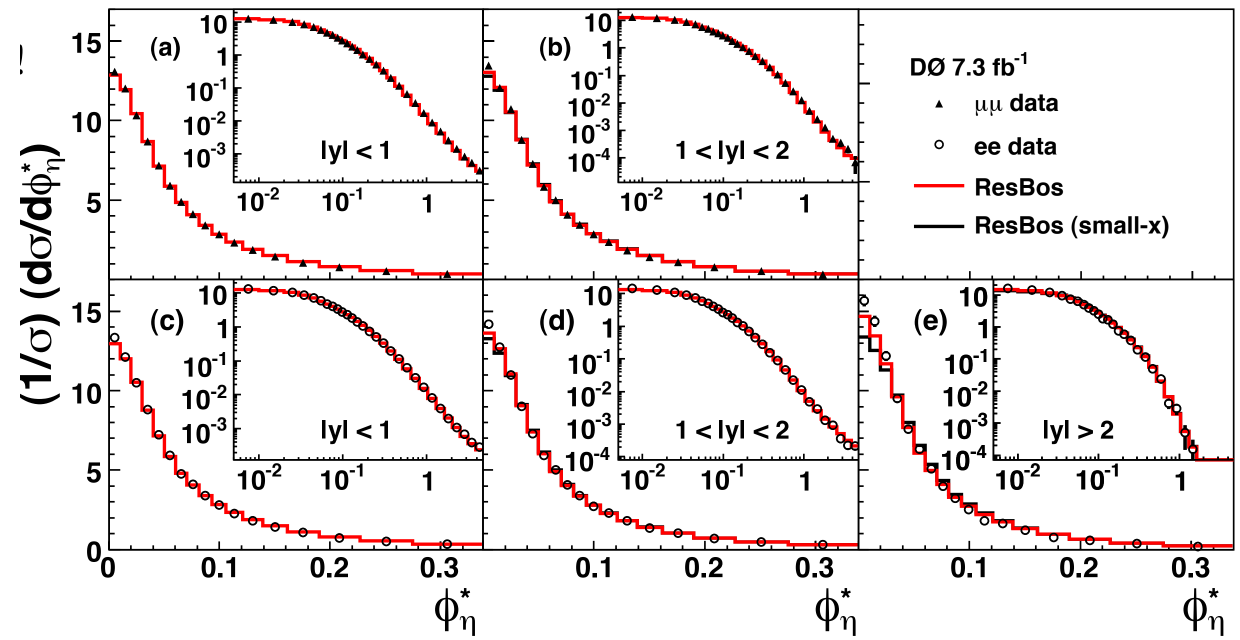
Results from D0:

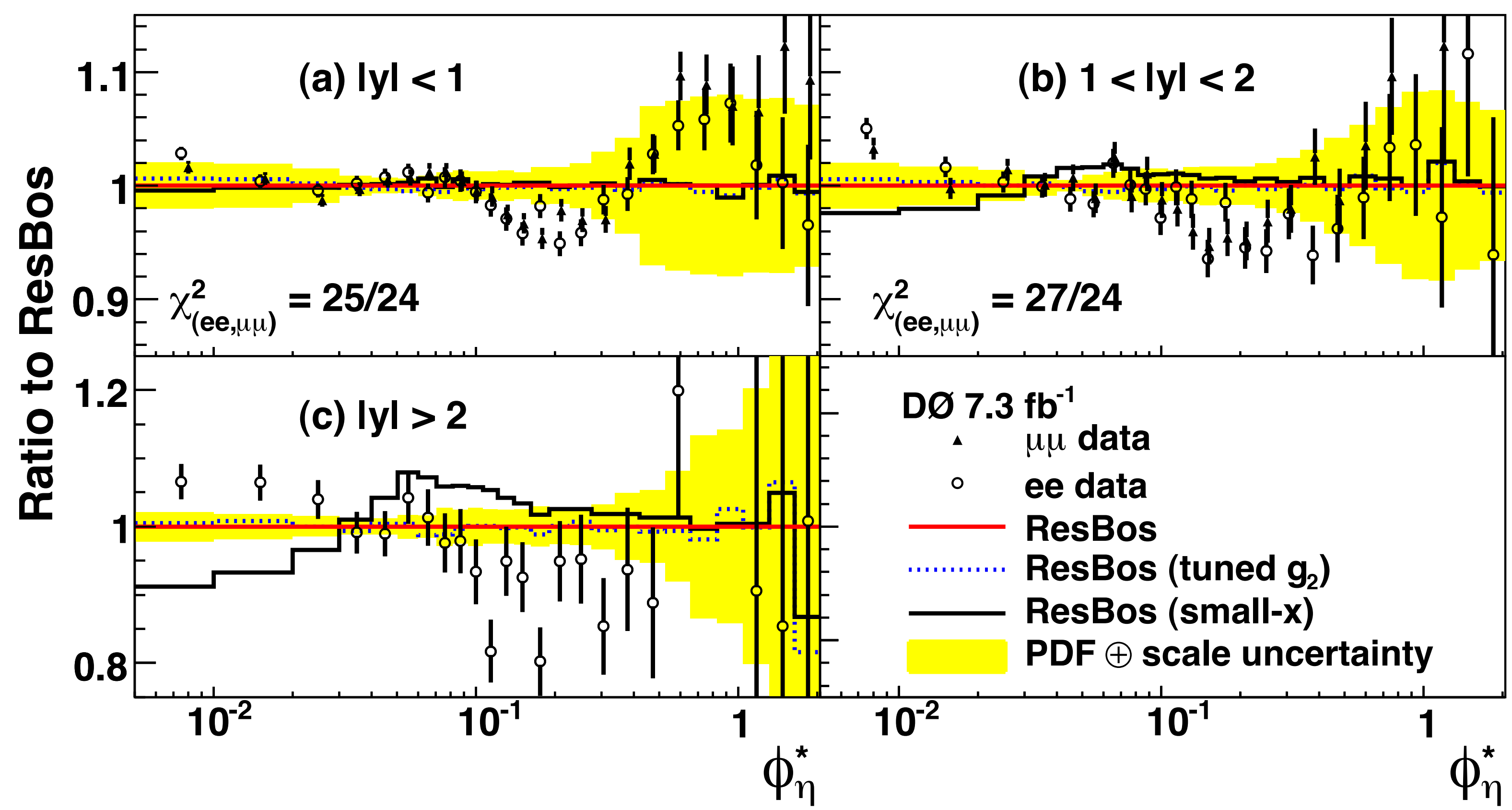
Alternative variable to study the Z/γ* pT : Φ^*

- **Less sensitive to the detector resolution and selection efficiency**
- **Equivalent power to constrain the boson pT prediction**



$\phi^* = \tan(\phi_{acop}/2)\sin(\theta^*)$





Summary and outlook

- New results from CDF and D0 this winter bring down the world average W boson mass uncertainty from 23 MeV to 15 MeV!

  New world average : $M_W = 80.385 \pm 0.015$ GeV
  Constraints on the SM Higgs boson: $M_H = 94^{+29}_{-24}$ GeV
  $M_H < 152$ GeV @ 95% C.L.

- Theoretical uncertainties started to play an important role in the W boson mass measurement:
  - PDF uncertainty: can be reduced by including EC electrons and by other analysis e.g. W change asymmetry measurement
  - With the full Tevatron data sets and reduction of PDF uncertainties, eventually higher precision can be achieved.

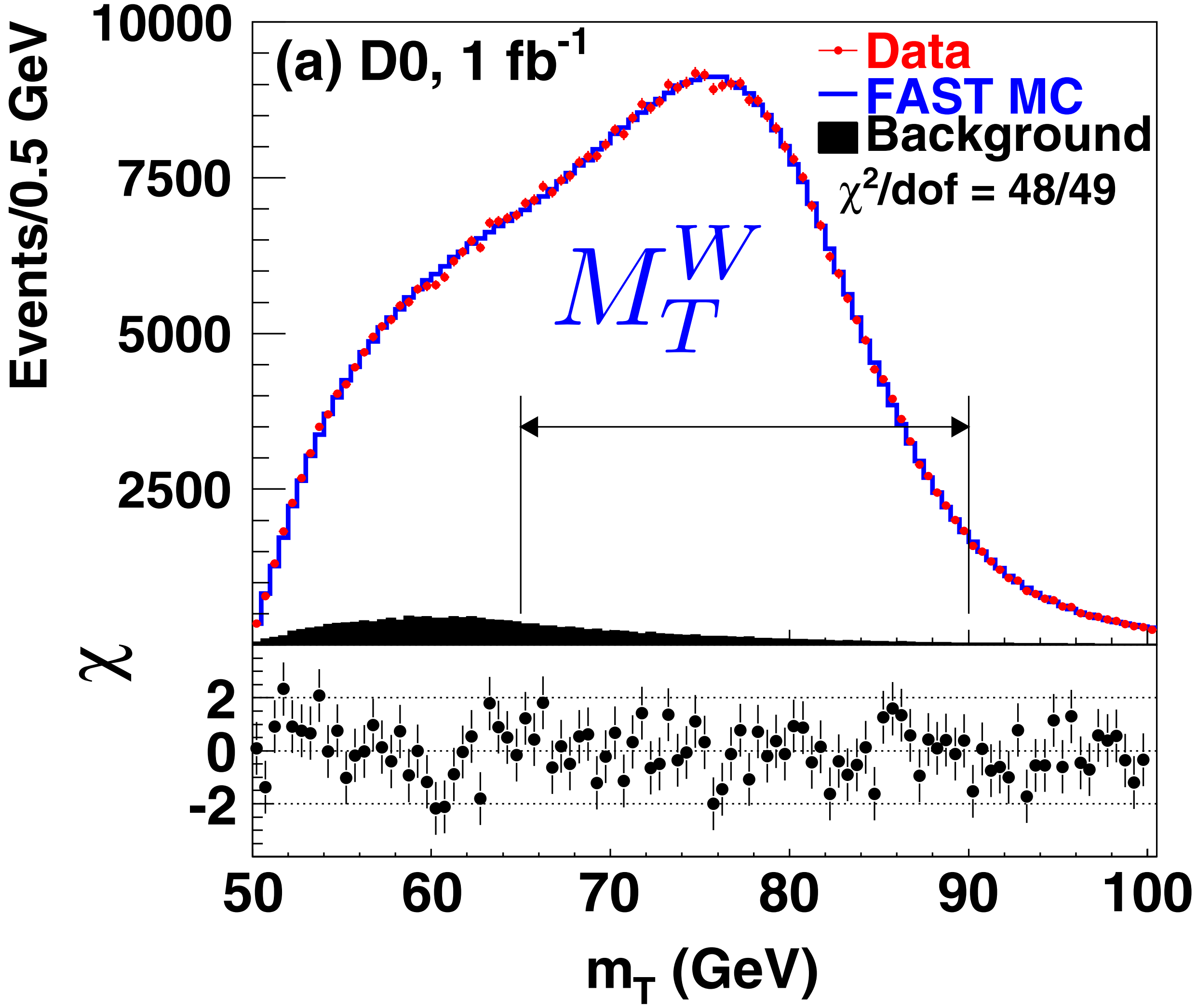
- Many other new W/Z results came this winter!

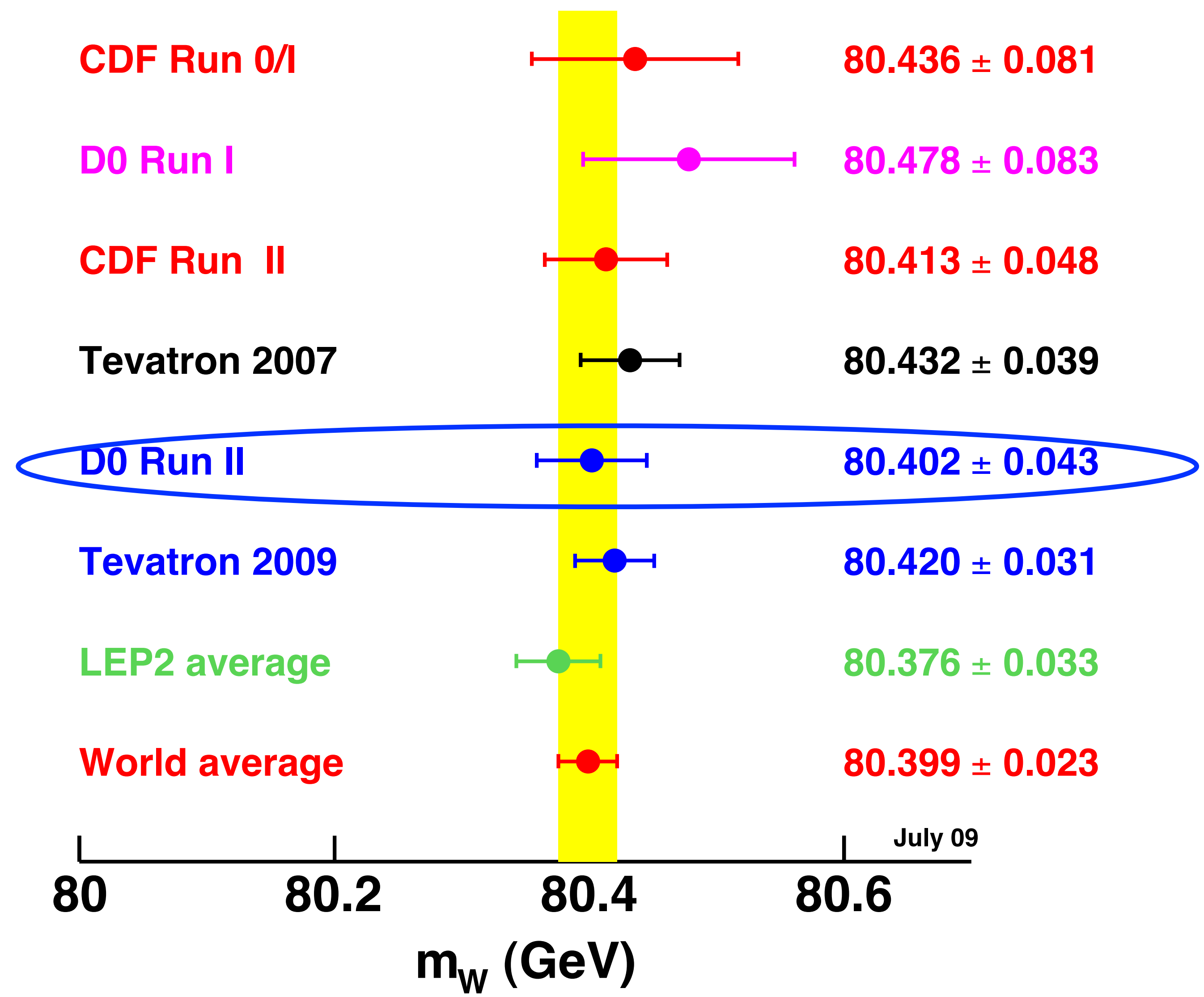
Backups

Published Results DØ RunIIa 1 fb^{-1}

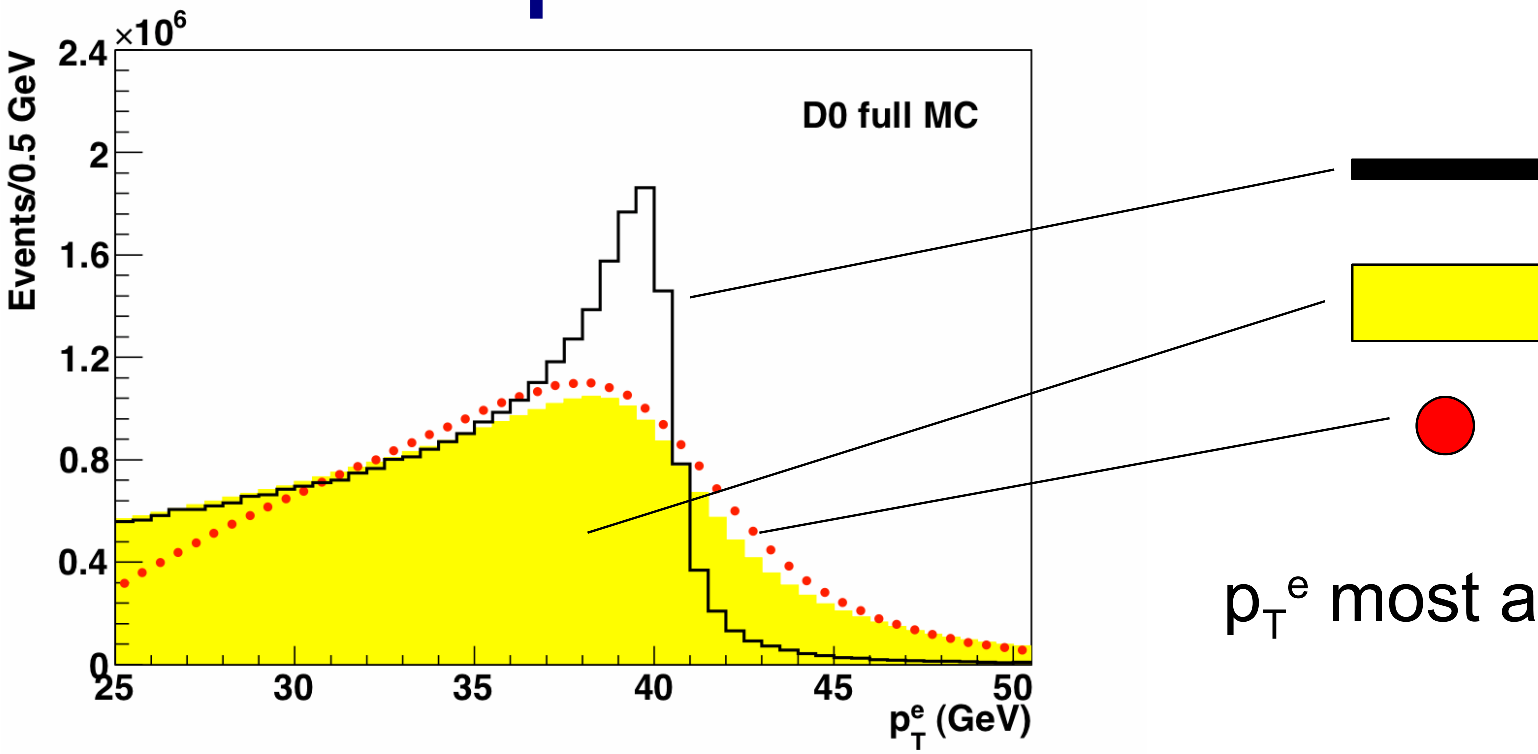
Central Calorimeter (CC) Electrons

Phys. Rev. Lett. 103, 141801 (2009).

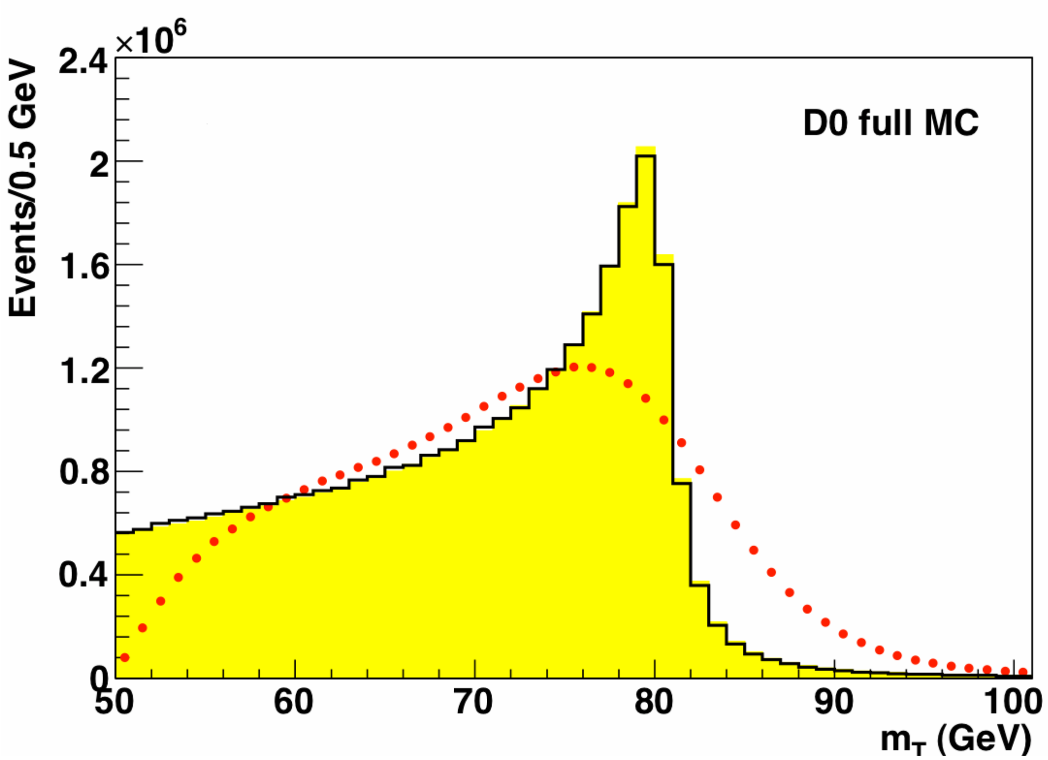




Experimental observables



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



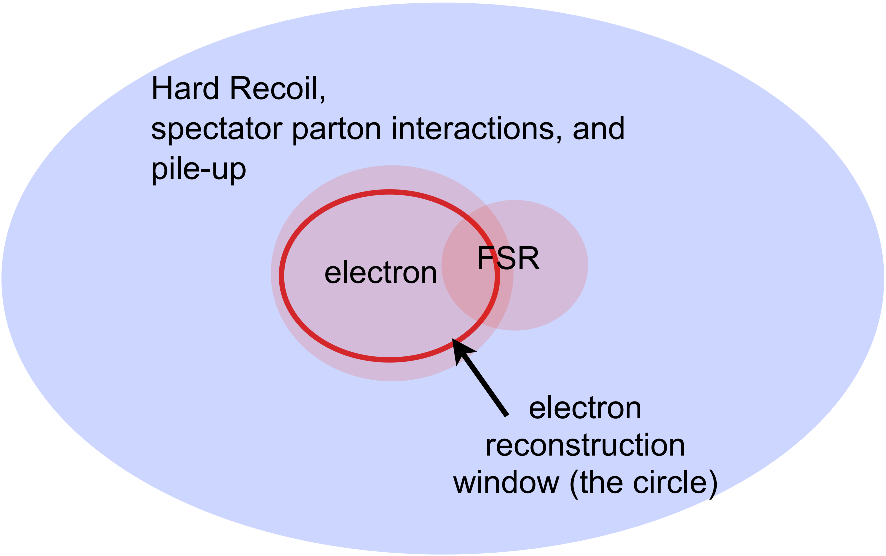
$$m_T = \sqrt{2\, p_T^e\, \not{E}_T (1 - \cos\Delta\phi)}$$

m_T most affected by measurement of recoil transverse momentum

Electron Model:

$$E_{reco} = R_{EM}(E_{true}) \otimes \sigma_{EM}(E_{true}) + \Delta E_{corr}$$

Response — Resolution — (RunIIb Challenge)



ΔE_{corr} Model: Model Update in RunIIb

1. Energy loss due to FSR
2. Recoil, spectator partons interactions and pile-up contamination inside electron reconstruction cone
3. Effects due to electronics noise subtraction and baseline subtraction (to subtract residue energy deposition from previous bunch crossings)

Recoil Model:

$$\vec{u}_T = \vec{u}_T^{\,\text{Hard}} + \vec{u}_T^{\,\text{Soft}} + \vec{u}_T^{\,\text{Elec}} + \vec{u}_T^{\,\text{FSR}}$$

Recoil P_T

"pure" Hard Recoil balancing W or Z boson

Soft Recoil: pile-up and spectator parton interactions

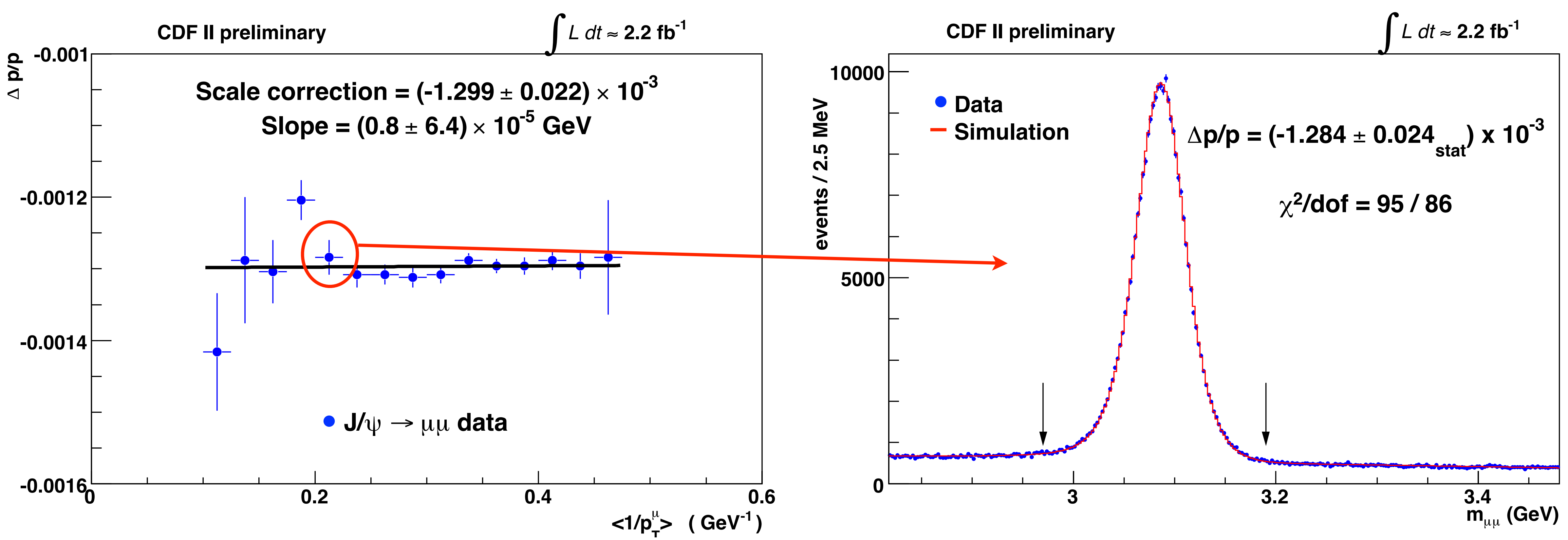
Model Update in RunIIb

In the same framework of ΔE_{corr} Modeling

What has been added to (subtracted from) the electron has to be subtracted from (added to) the recoil.

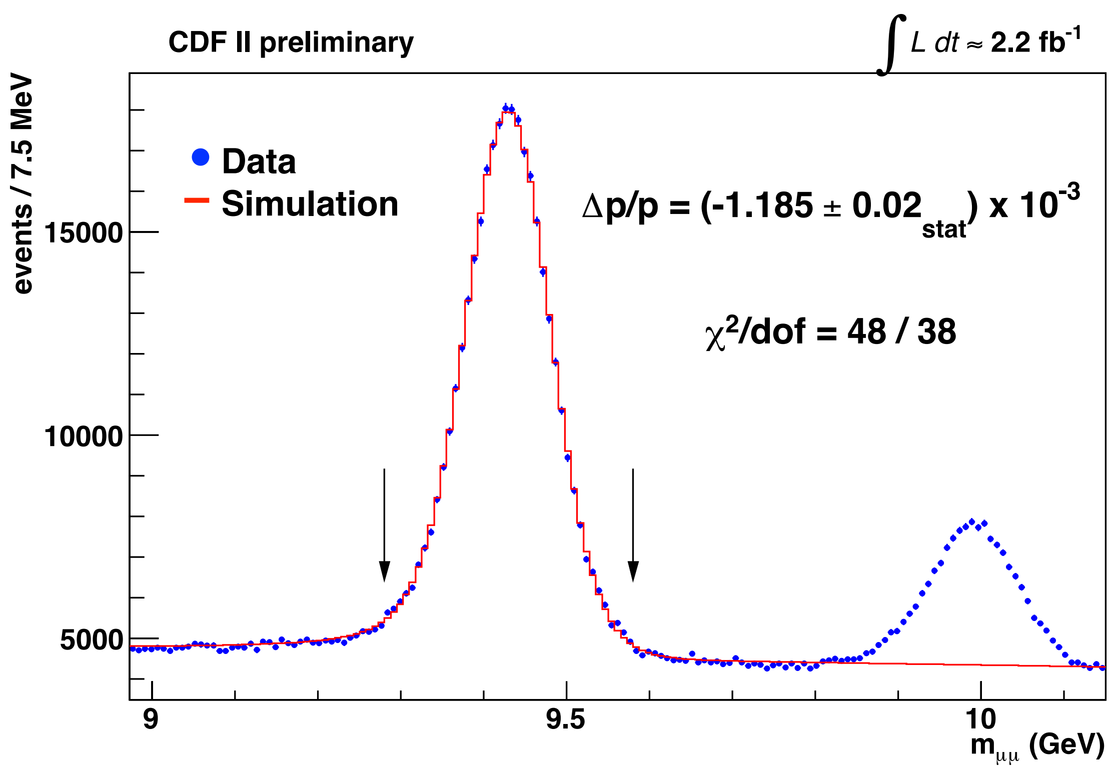
Track momentum scale: J/ψ

- Utilize large μμ resonances (J/ψ, Y, Z) to set overall momentum scale
- Size of J/ψ sample allows subsample fits
  - Correct for non-uniformities in B-field
  - Fit J/ψ mass in bins of $<1/p_T(\mu)>$ and apply material scale (4%) to remove depedence
- Apply calibration from J/ψ to Y

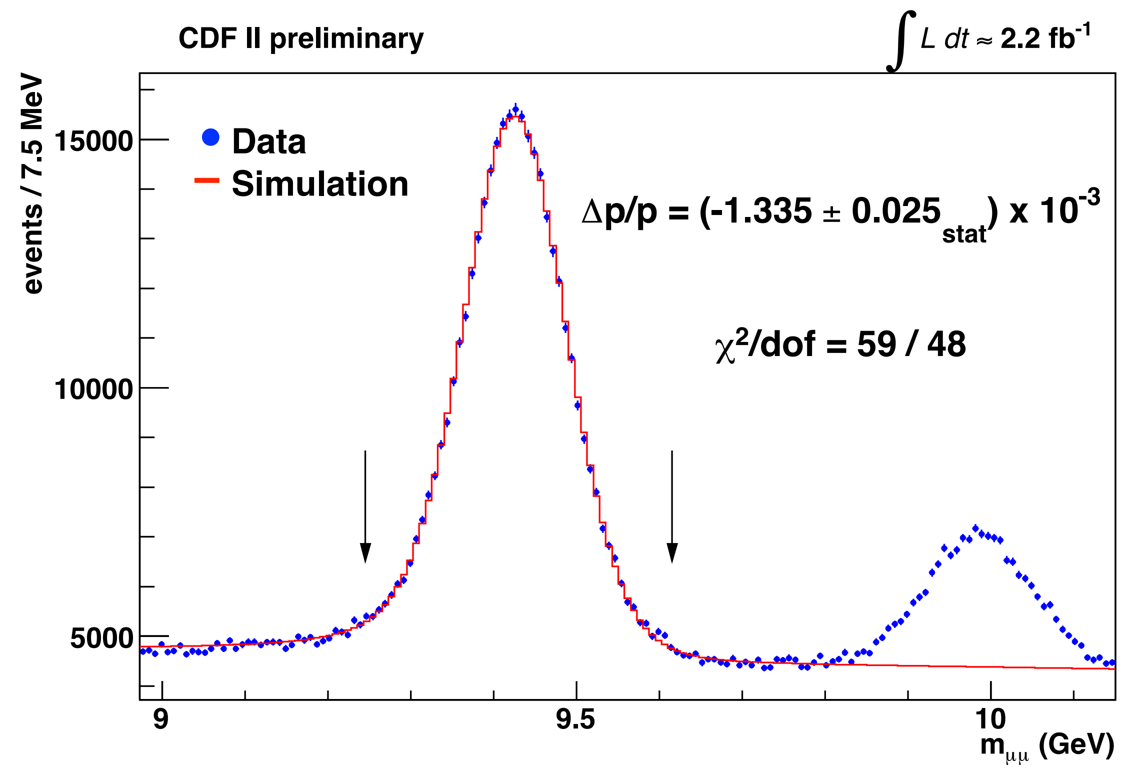


Track momentum scale: Υ

- Υ sample provides higher-p_T sample to tune scale
  - Υs produced promptly: validation of beam-constraining (BC) procedure
  - Perform fit with BC and non-BC tracks
    - Take average of two fits, assign systematic
- Combine *J*/ψ and Υ scales and apply to *Z*s



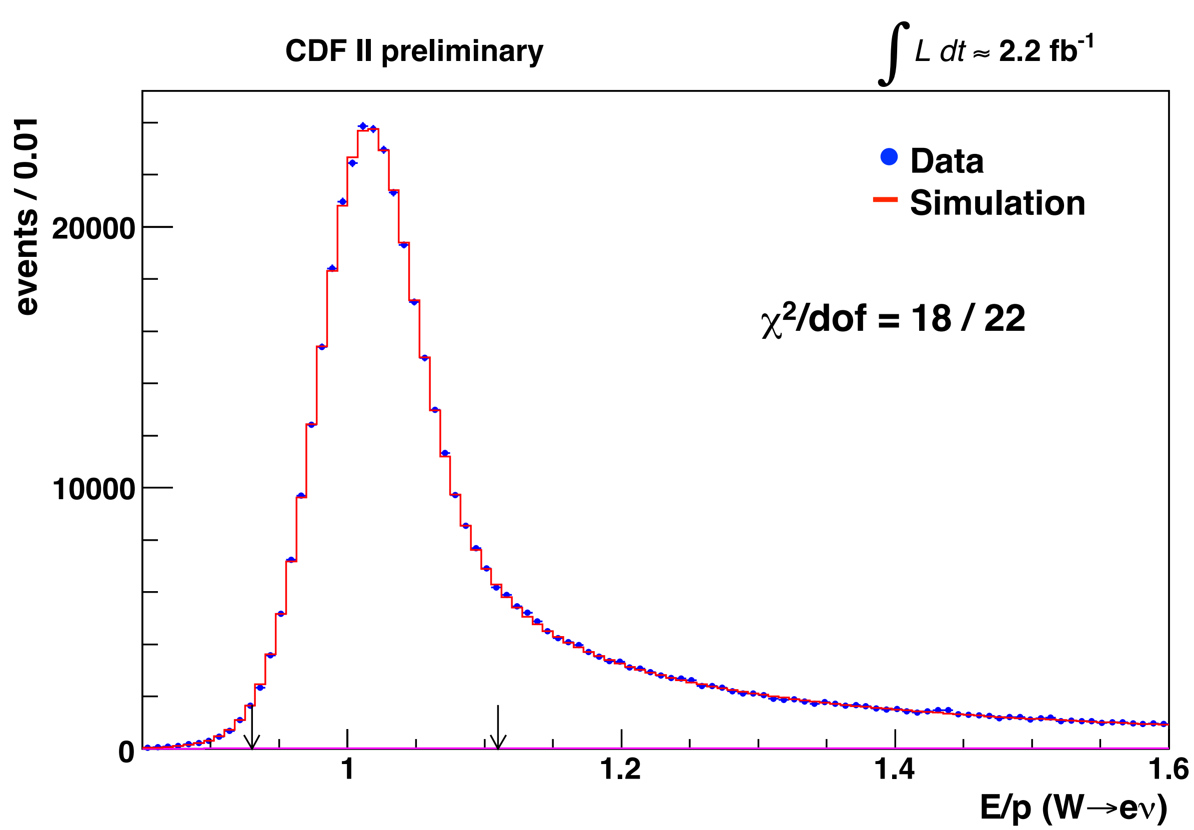
Beam constrained tracks

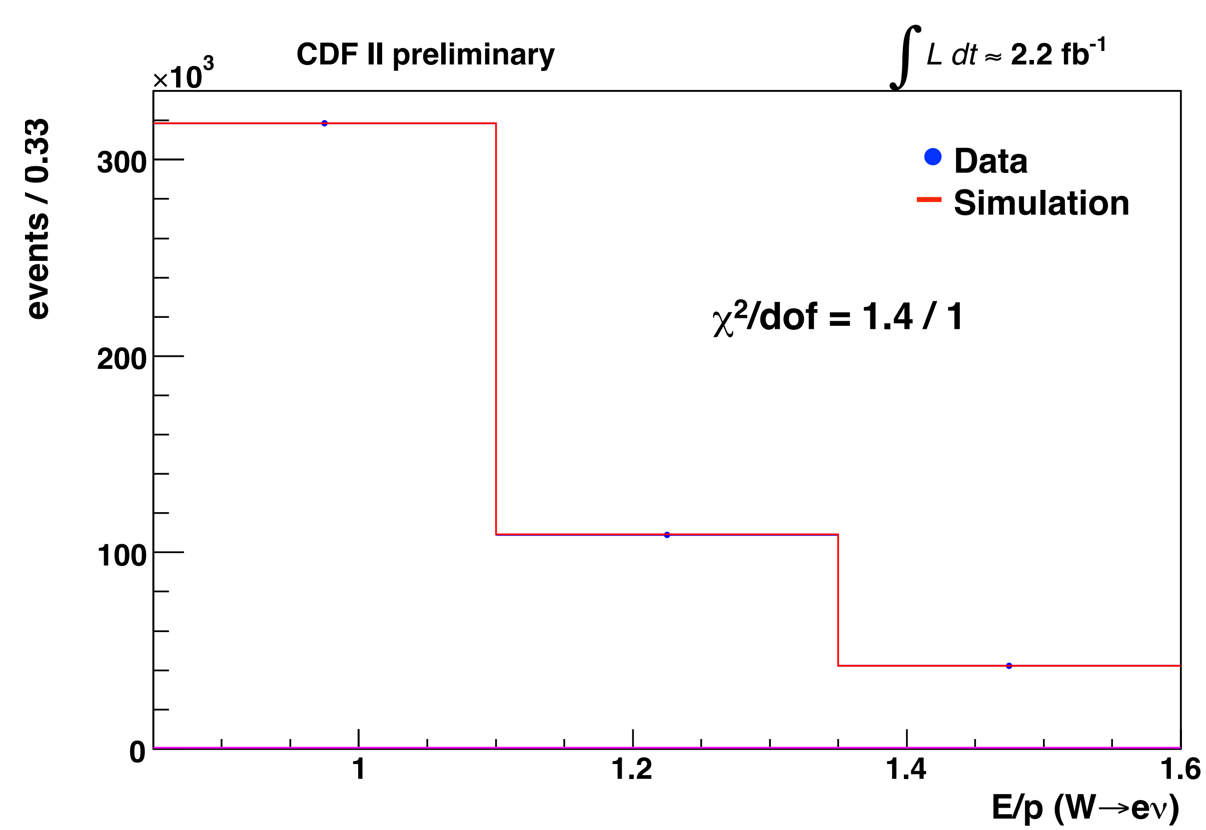


Non-beam constrained tracks

Energy scale calibration

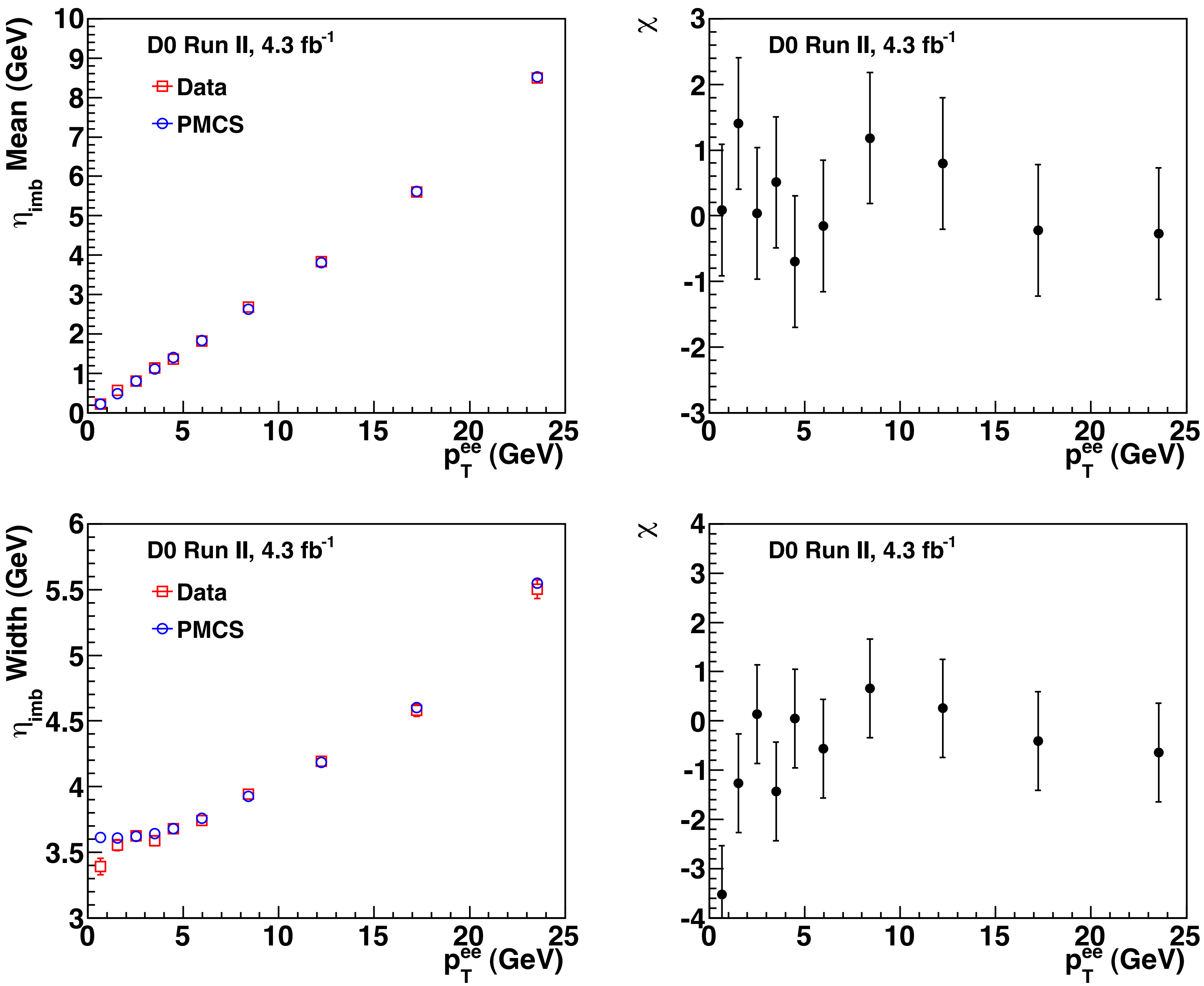
- Simulate energy loss with custom GEANT4-based simulation
  - Simulate coil absorption, leakage into had. calorimeter, E_T dependence
- Calibrate EM calorimeter response using *W* and *Z* *E/p* distributions
  - Fit to peak to obtain scale and non-linearity (E_T dependent)
    - $\Delta S_E = (9_{stat} \pm 5_{non\text{-}linearity}) \times 10^{-5}$
  - Fit to tail to tune amount of radiative material
    - $S_{X0} = 1.026 \pm 0.003_{stat} \pm 0.002_{bkg}$
- Systematic uncertainty ΔM_W=13 MeV

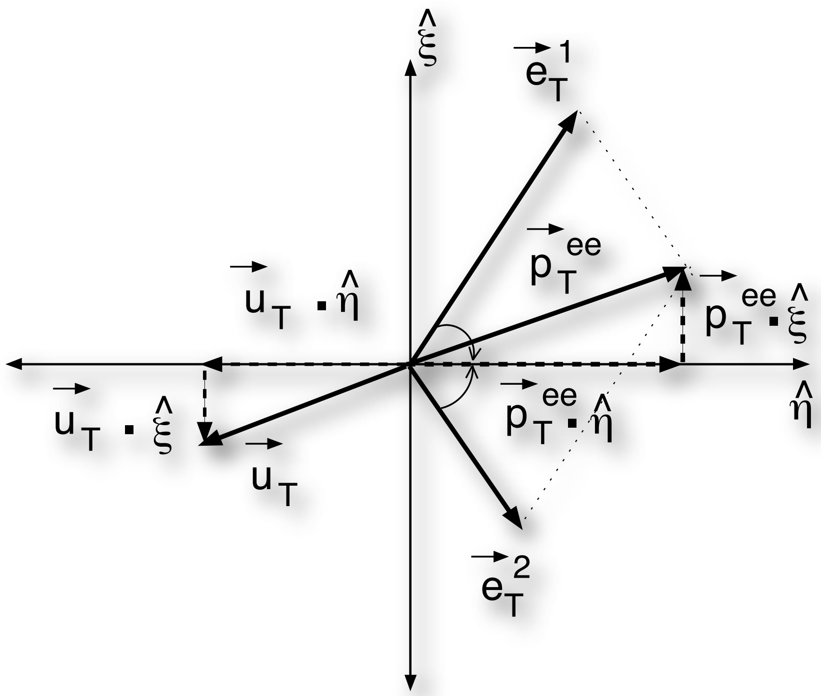




Recoil Calibration

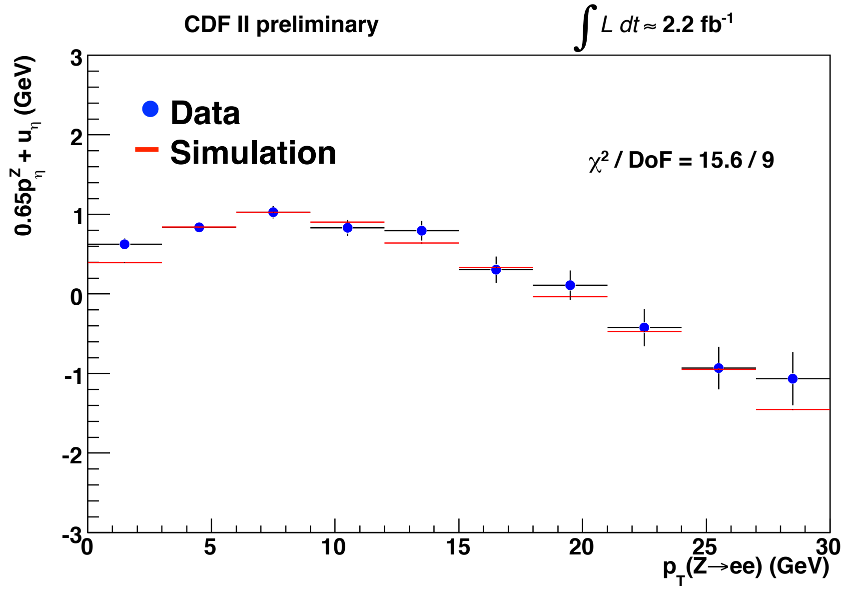
We have certain free parameters in the recoil model for tuning the fast MC to agree with Z->ee data events, using the standard UA2 observables:



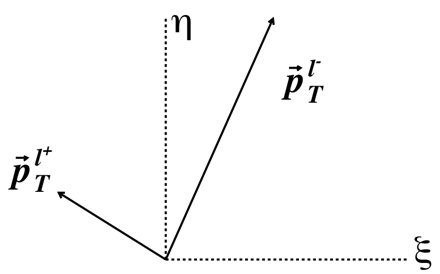


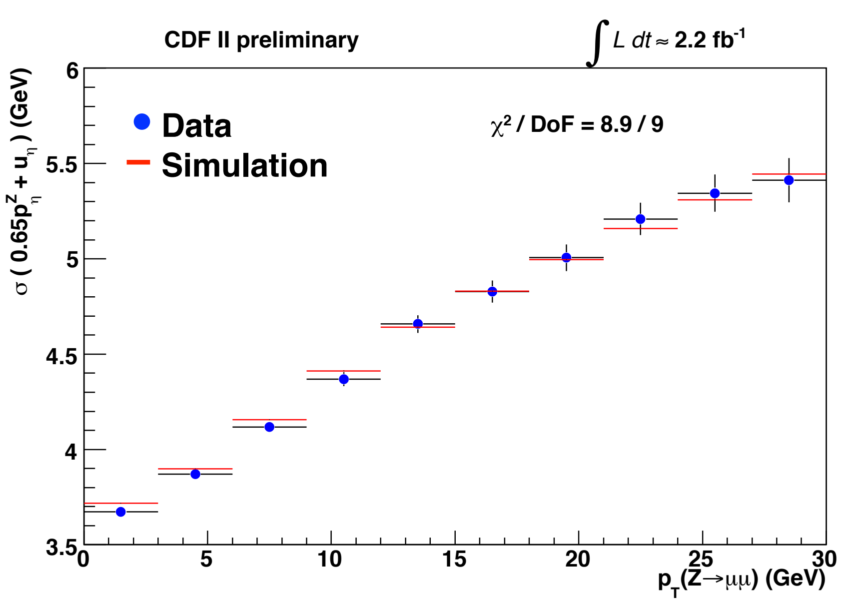
Recoil calibration

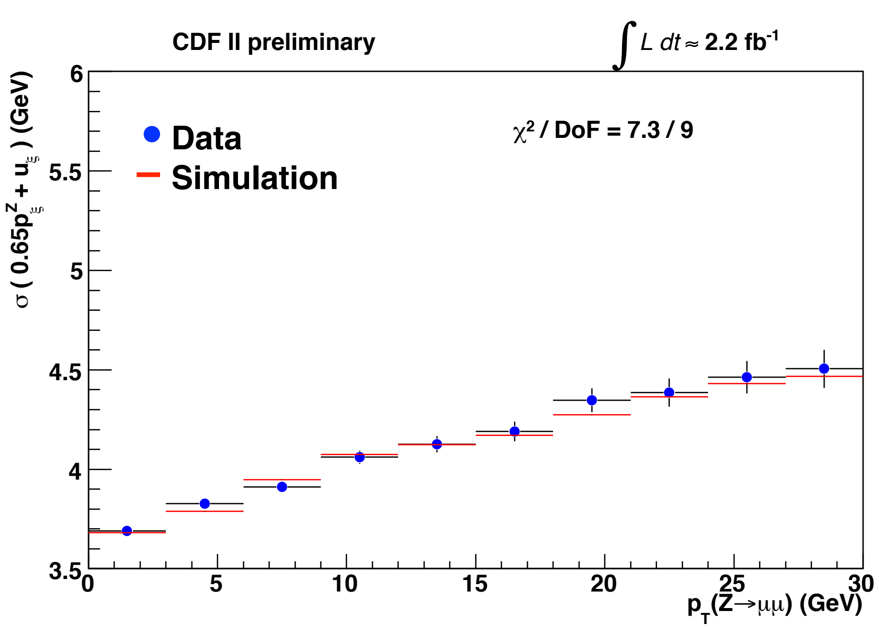
- Recoil scale $R=u_{meas}/u_{true}$
  - Calibrate by balancing Z p_T against p_T+u along eta axis ΔM_W = 4 MeV



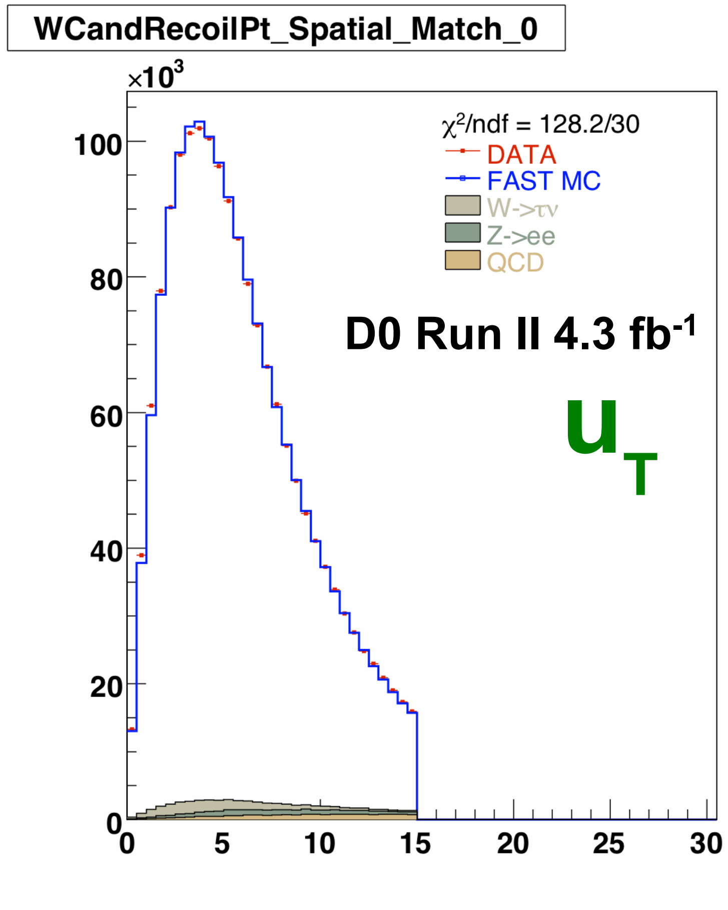
- Recoil resolution
  - Calibrate balancing Z p_T against rms(p_T+u) along both axes ΔM_W = 4 MeV

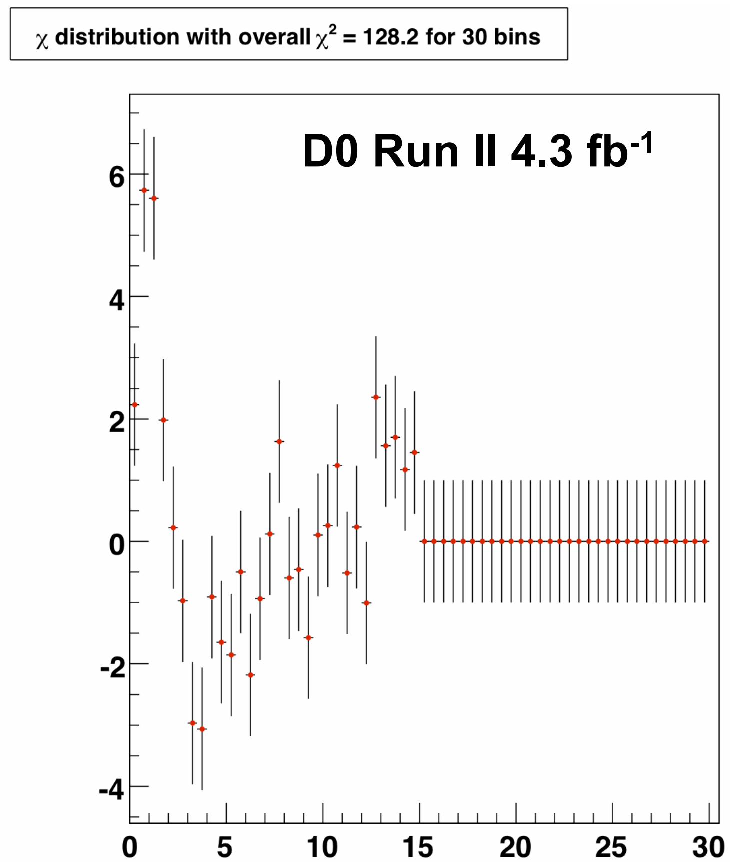




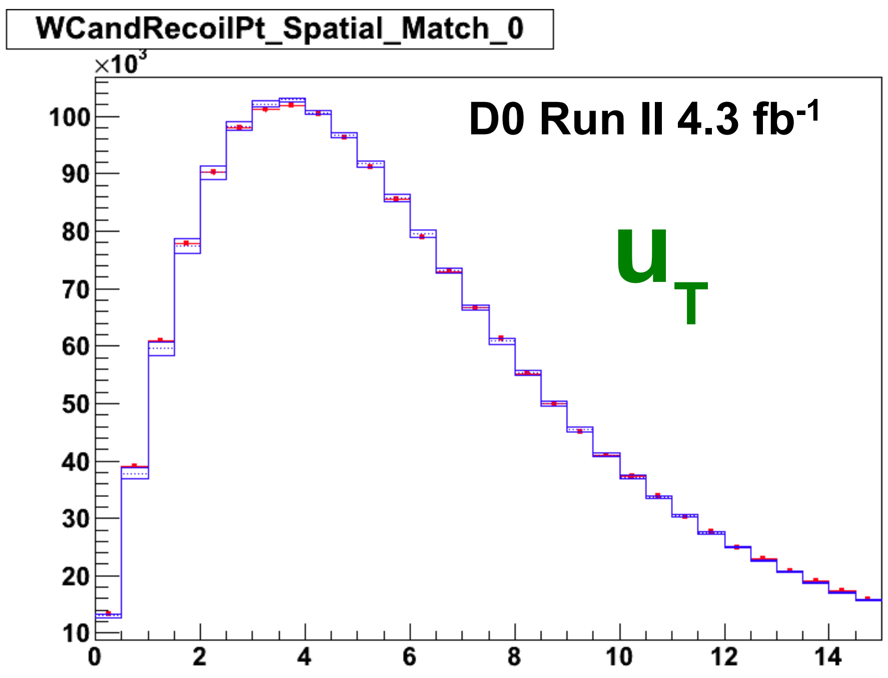


W data





Here the error bars only reflect the finite statistics of the W candidate sample.



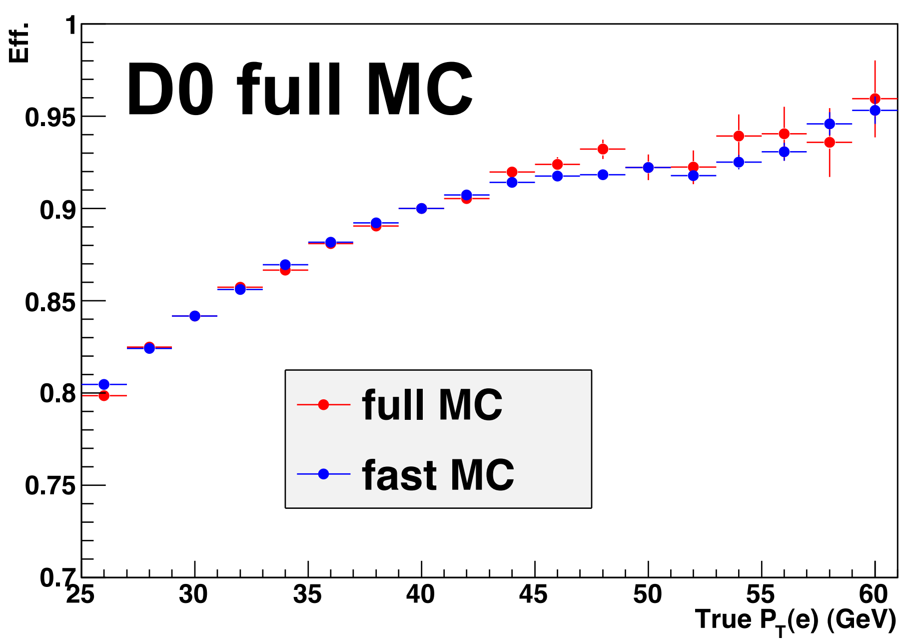
These are the same W candidates in the data. The blue band represents the uncertainties in the fast MC prediction due to the uncertainties in the recoil tune from the finite Z statistics.

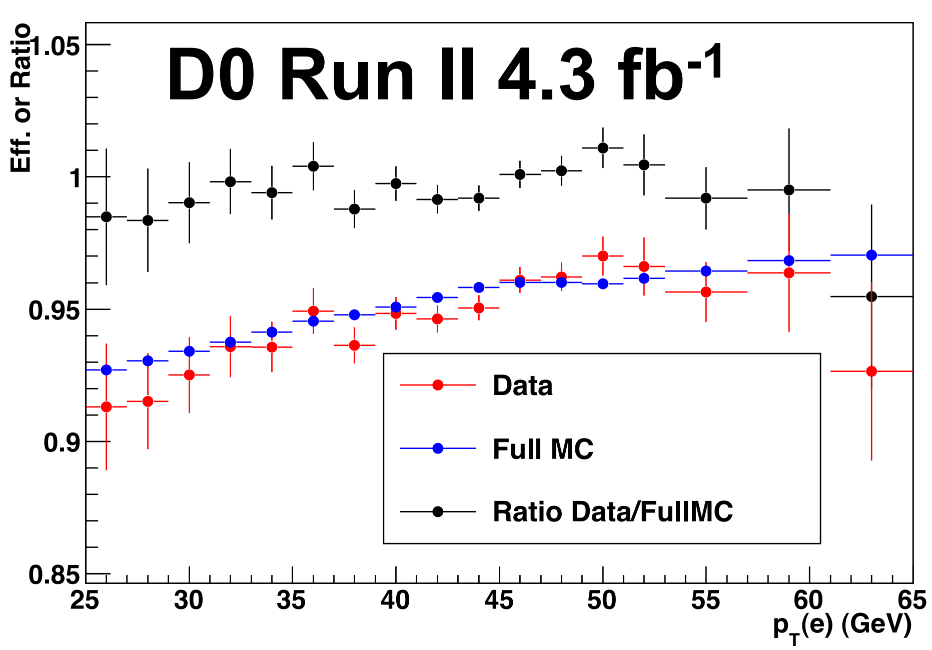
Good agreement between data and parameterised Monte Carlo.

Electron efficiency model

Efficiency modeling in the high inst. lumi. condition is challenging:
- **pileup and hard recoil contaminate the electron reconstruction window,**
- **correlations with electron kinematics.**

A two-step modeling:
- **model the efficiency in a detailed simulation overlaid with pileup from collider data.**
- **check efficiency dependences using Z->ee events comparing data and detailed simulation.**

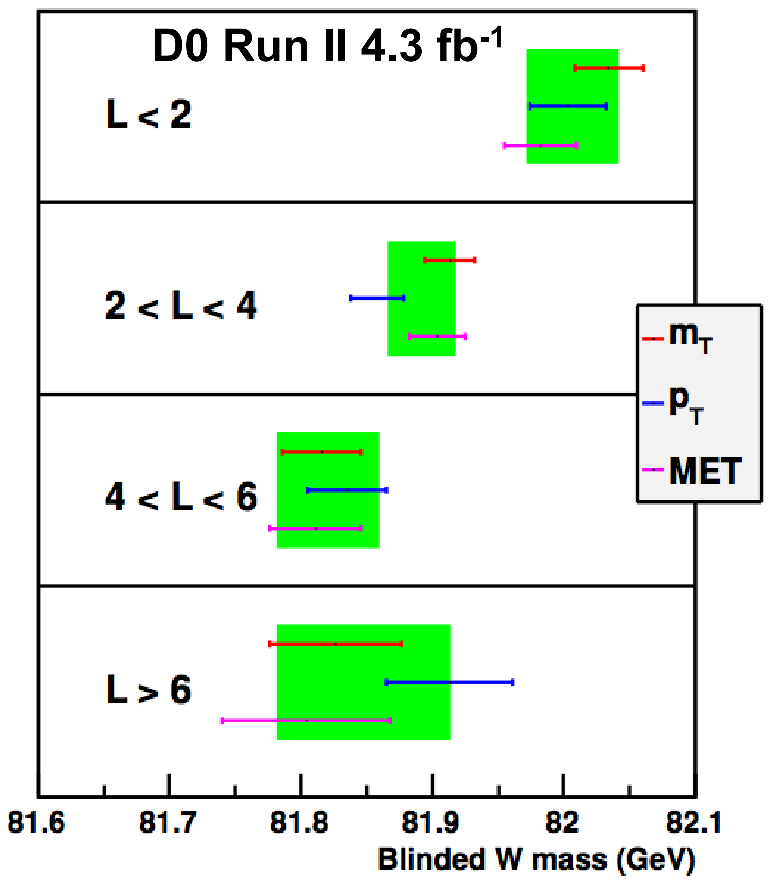




Consistency checks

Split data sample into four bins of instantaneous luminosity and measure W mass separately for each bin:

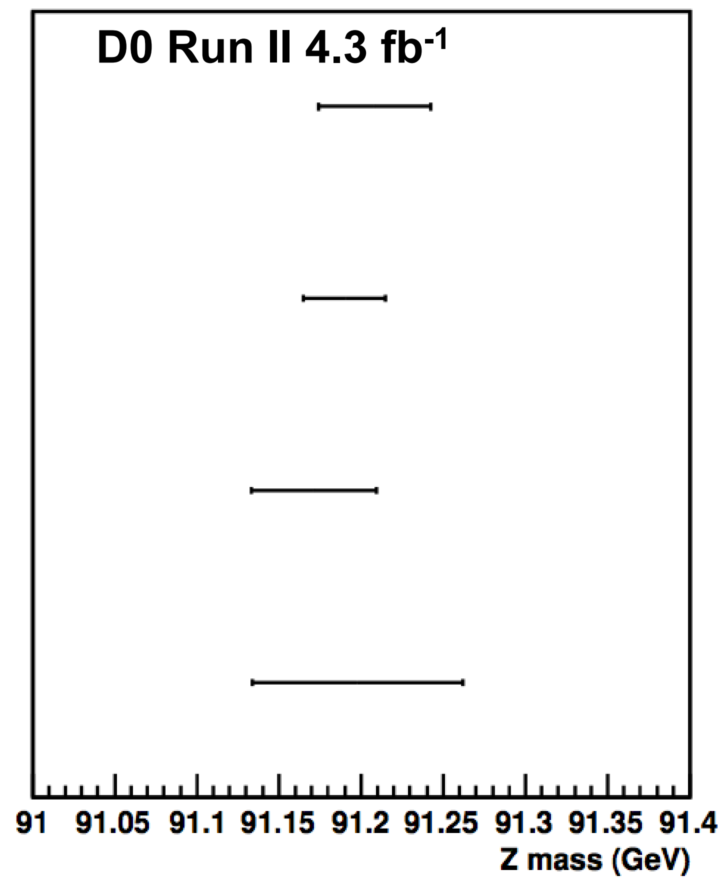
W



Error bars represent W statistics.

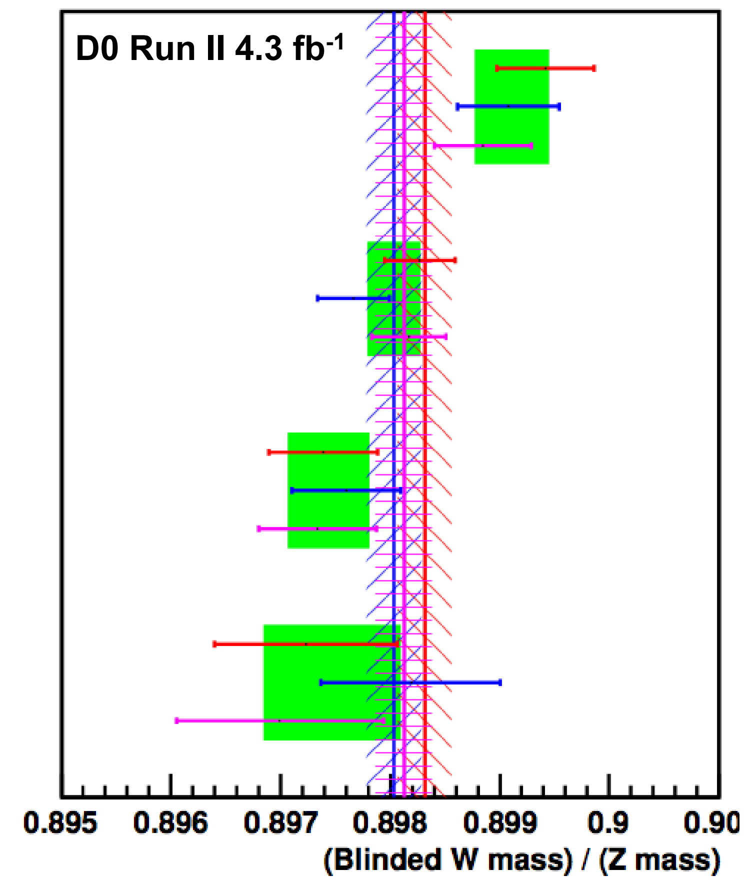
Green bands represent EM scale uncertainty (100 % correlated for m_T, p_T and MET).

Z



Sorry, still using blinded mass in these plots.
But it does not matter here …
differences between observables and subsamples are preserved by the blinding.

"W/Z"



Error bars represent W *and* Z statistics.

Green bands represent contribution from Z alone (100 % correlated for m_T, p_T and MET).

mass ratio is stable vs. lumi.

Backgrounds