Rencontres de Moriond Electroweak

La Thuile, Italy, 3-10 March 2012

A new measurement of the W boson mass at D0

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on behalf of the D0 Collaboration

Motivation

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

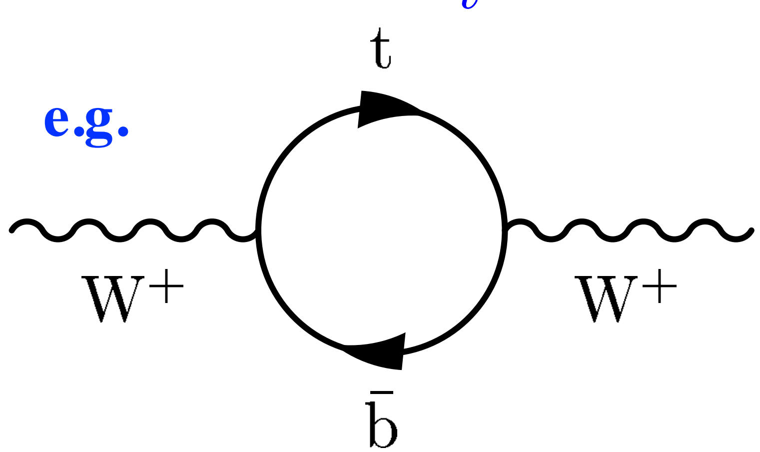
$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}}\frac{1}{\sin\theta_W\sqrt{1-\Delta r}}$$

Radiative corrections Δr

related to the Top quark mass as

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

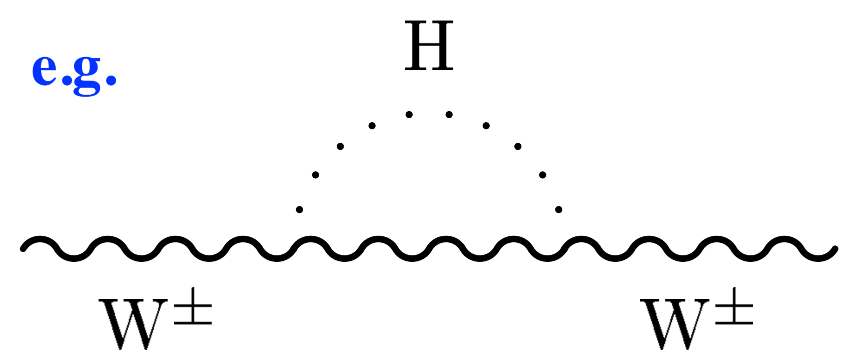
e.g.



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.

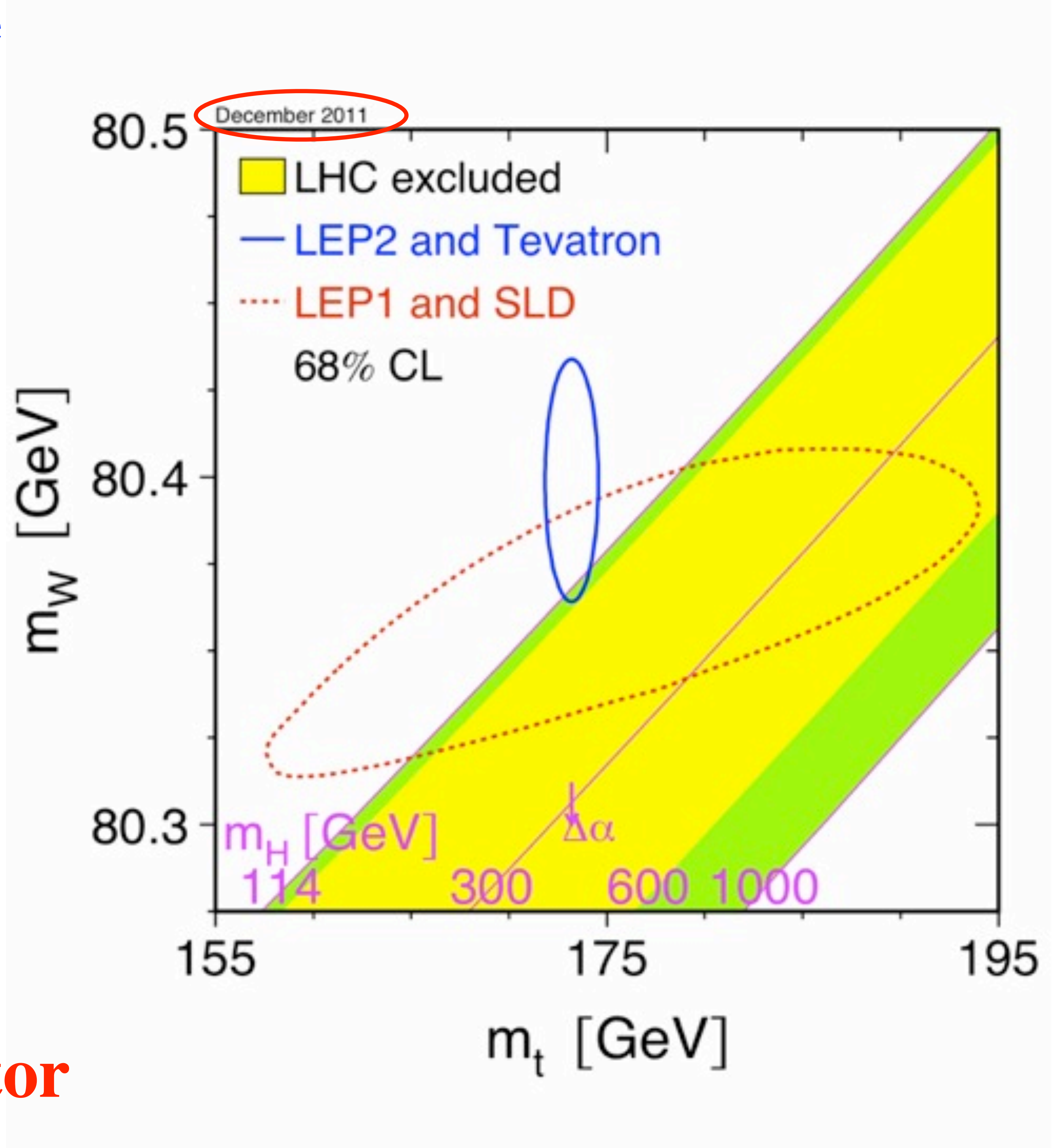
Motivation

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:

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



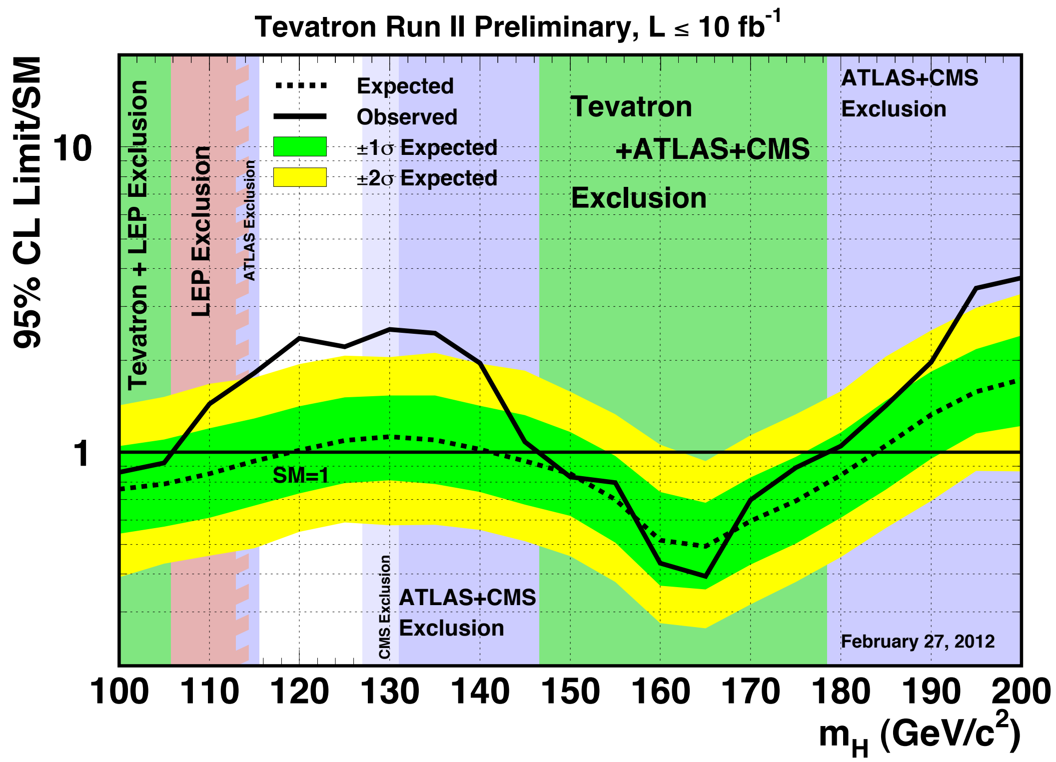
The W mass is the limiting factor in constraining the Higgs mass.

Motivation

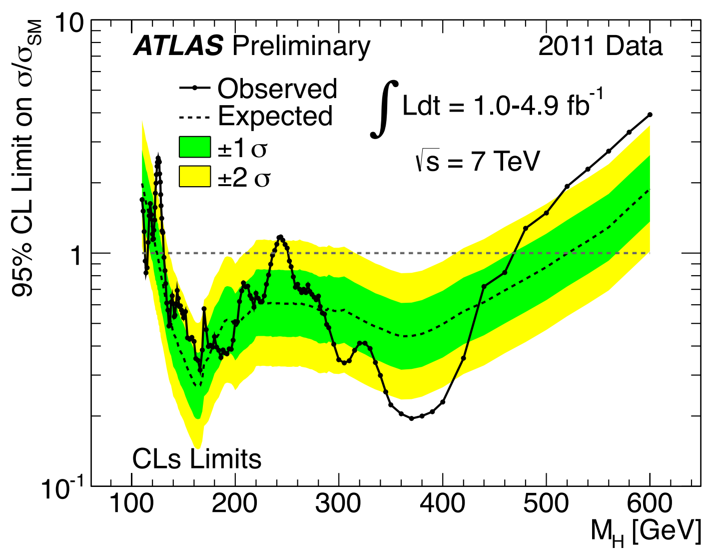
Results from direct searches of Higgs boson

Most likely mass region @ 95% C.L. : Today (7 March 2012)

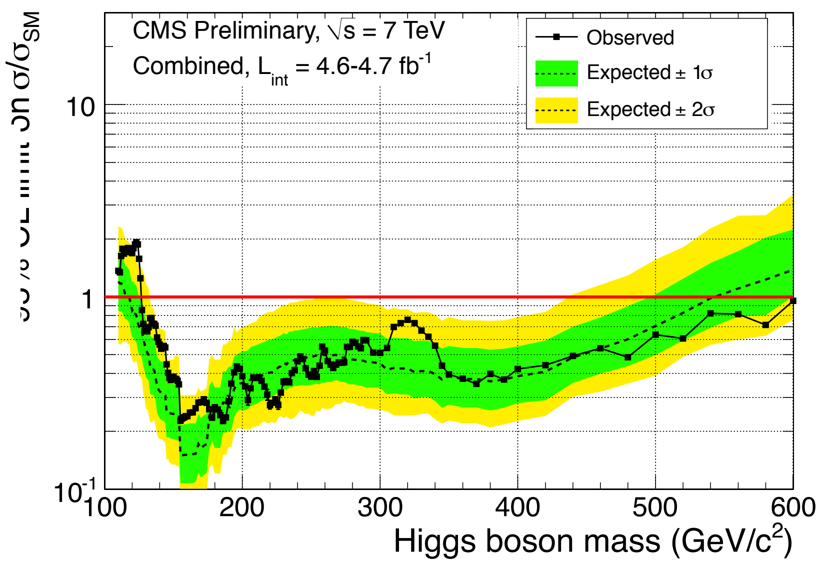
Tevatron Higgs exclusion



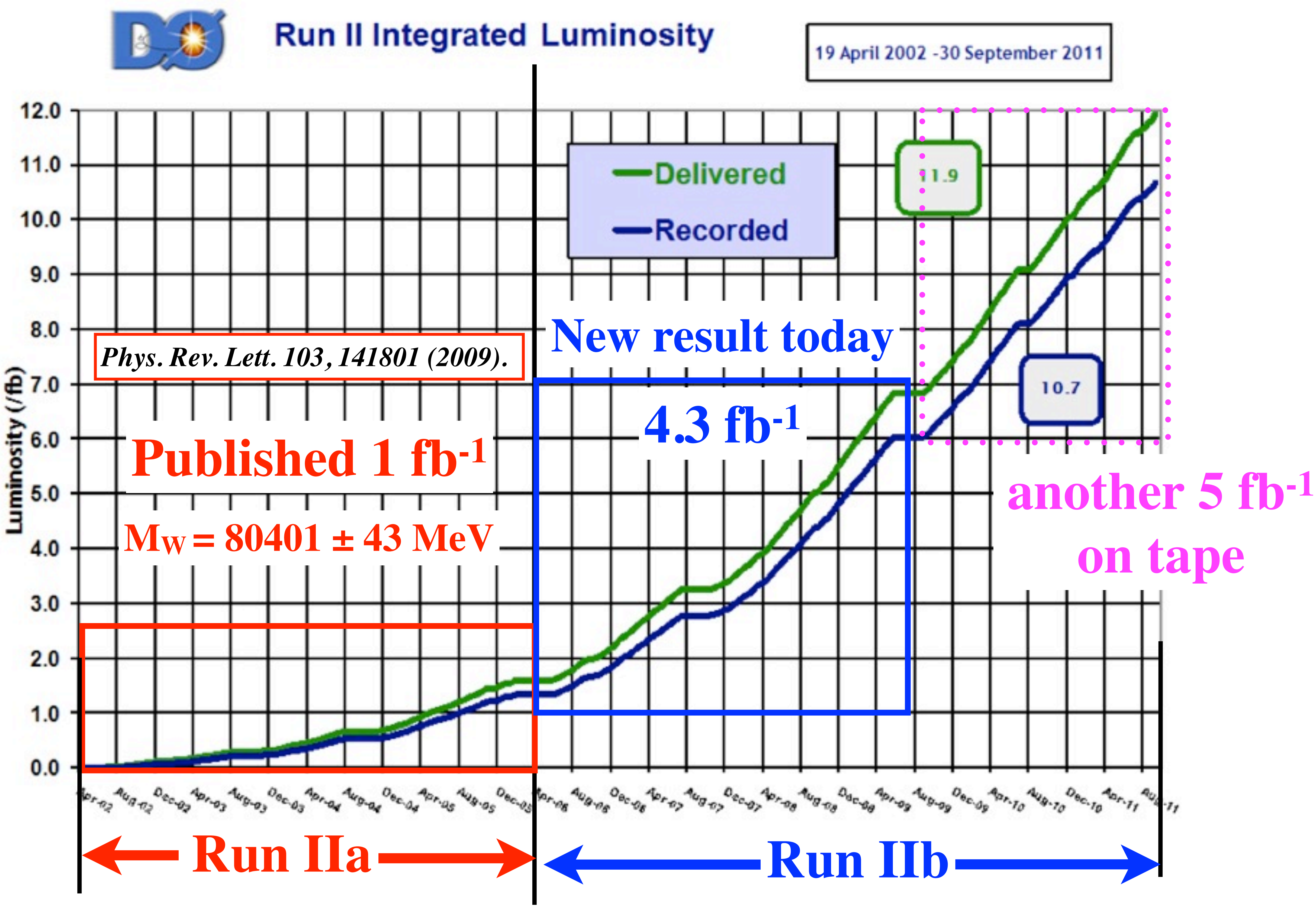
ATLAS:
117.5 - 118.5 GeV
or
122.5 - 129 GeV



CMS:
114.4 - 127.5 GeV



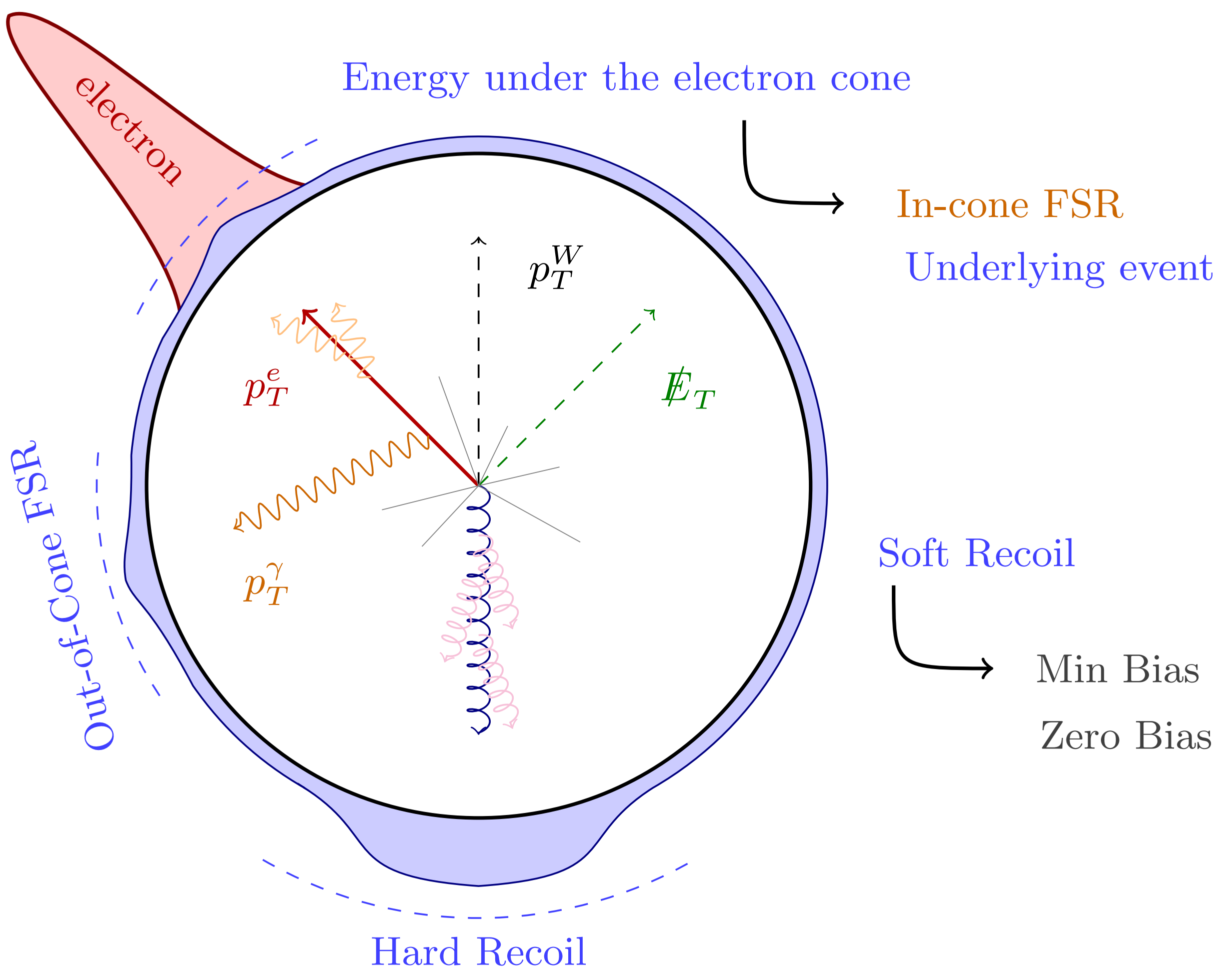
Comparison of indirect constraints and direct searches of Higgs is an important test of the SM.



Run II Integrated Luminosity
19 April 2002 -30 September 2011
Delivered
Recorded
11.9
10.7
Luminosity (/fb)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Apr-02 Aug-02 Dec-02 Apr-03 Aug-03 Dec-03 Apr-04 Aug-04 Dec-04 Apr-05 Aug-05 Dec-05 Apr-06 Aug-06 Dec-06 Apr-07 Aug-07 Dec-07 Apr-08 Aug-08 Dec-08 Apr-09 Aug-09 Dec-09 Apr-10 Aug-10 Dec-10 Apr-11 Aug-11
Phys. Rev. Lett. 103, 141801 (2009).
Published 1 fb-1
Mw = 80401 ± 43 MeV
New result today
4.3 fb-1
another 5 fb-1
on tape
Run IIa
Run IIb

Analysis Strategy at D0

A Typical W→eν Event in DØ Detector



Reconstruct three observables:

$$M_T^W \quad P_T^e \quad \not{E}_T$$

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

using CC electrons with p_T>25GeV

Using Z->ee events for detector calibration

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.

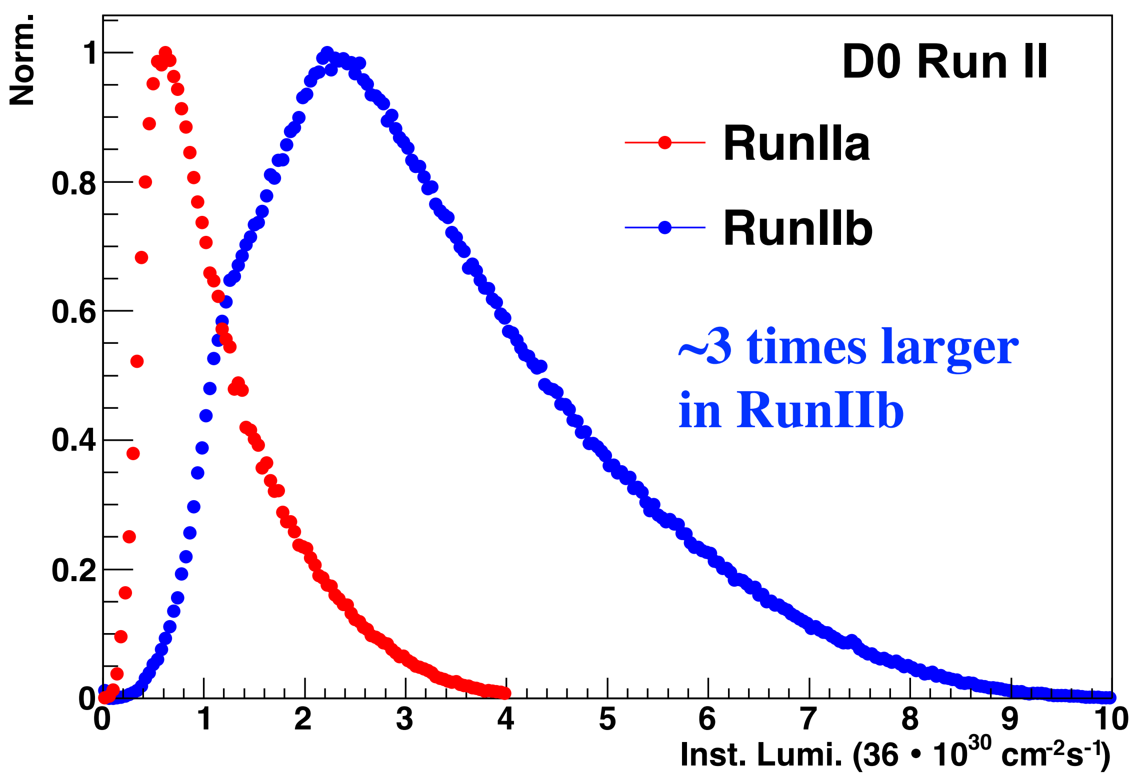
The Fast MC model:

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

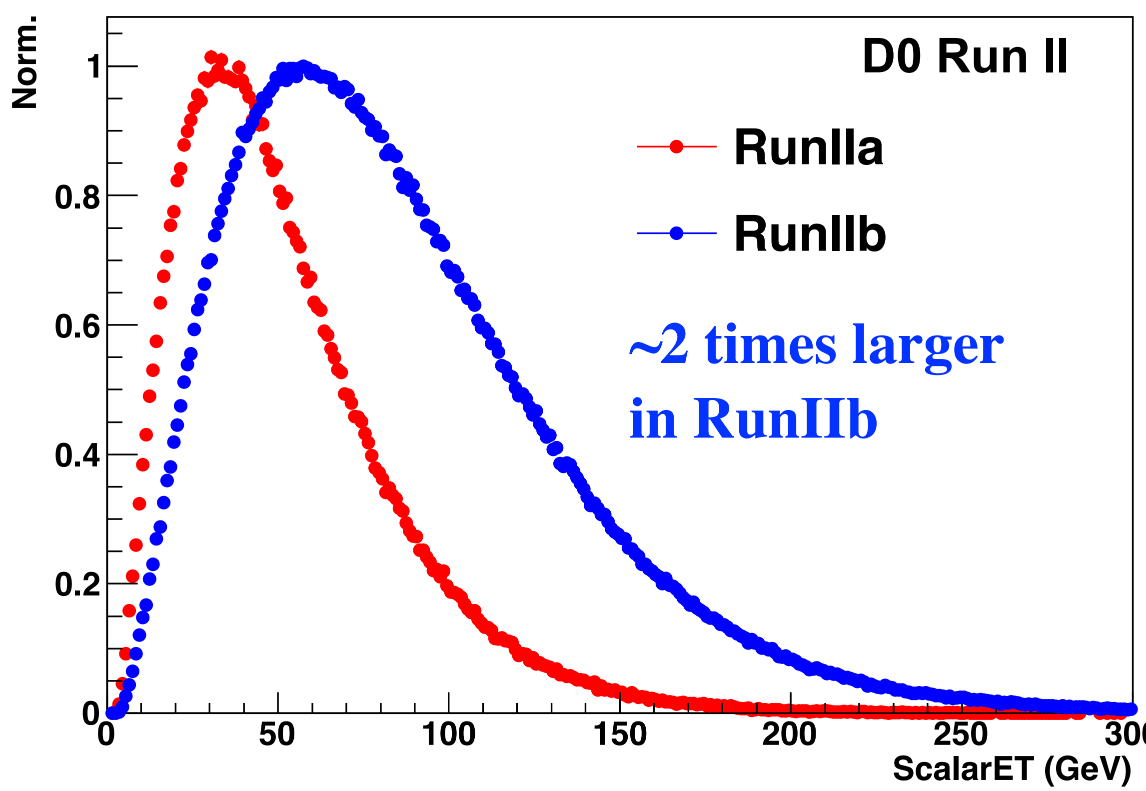
Challenge in Run IIb analysis

RunIIb high instantaneous luminosity results in much higher energy deposition from additional $p\bar{p}$ collisions (pileup) contaminating the detector and complicating the modeling of detector effects.

Inst. Lumi. from W->eν events



Scalar E_T (electron removed) from W->eν events



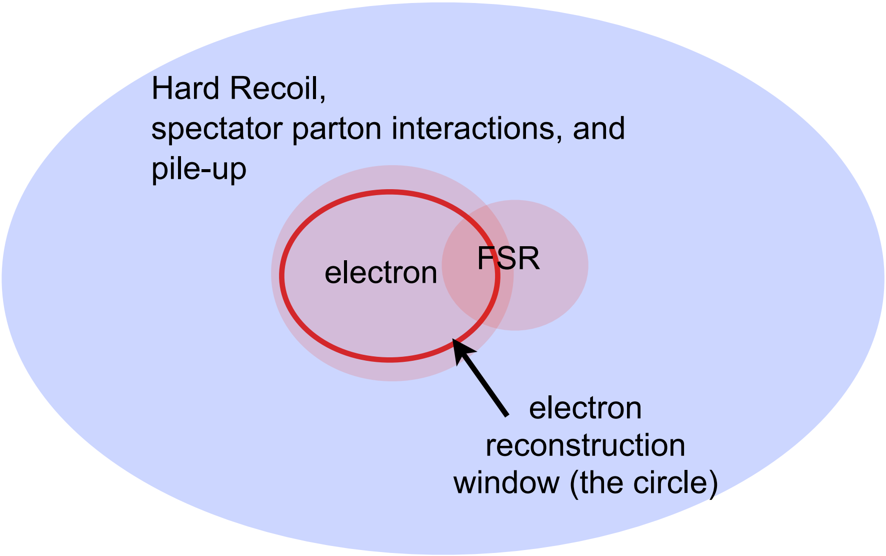
The Parameterized Detector Model for RunIIa analysis is not sufficient to describe RunIIb data!

Example of the RunIIb Updates

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:

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

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.

Final electron energy scale tuning

The art is we firstly correct/model these non-linear energy responses:

- correction of the energy loss due to dead material,
- simulation of effects of instantaneous luminosity,
- modeling of underlying energy flow (as one example shown in the last slide).

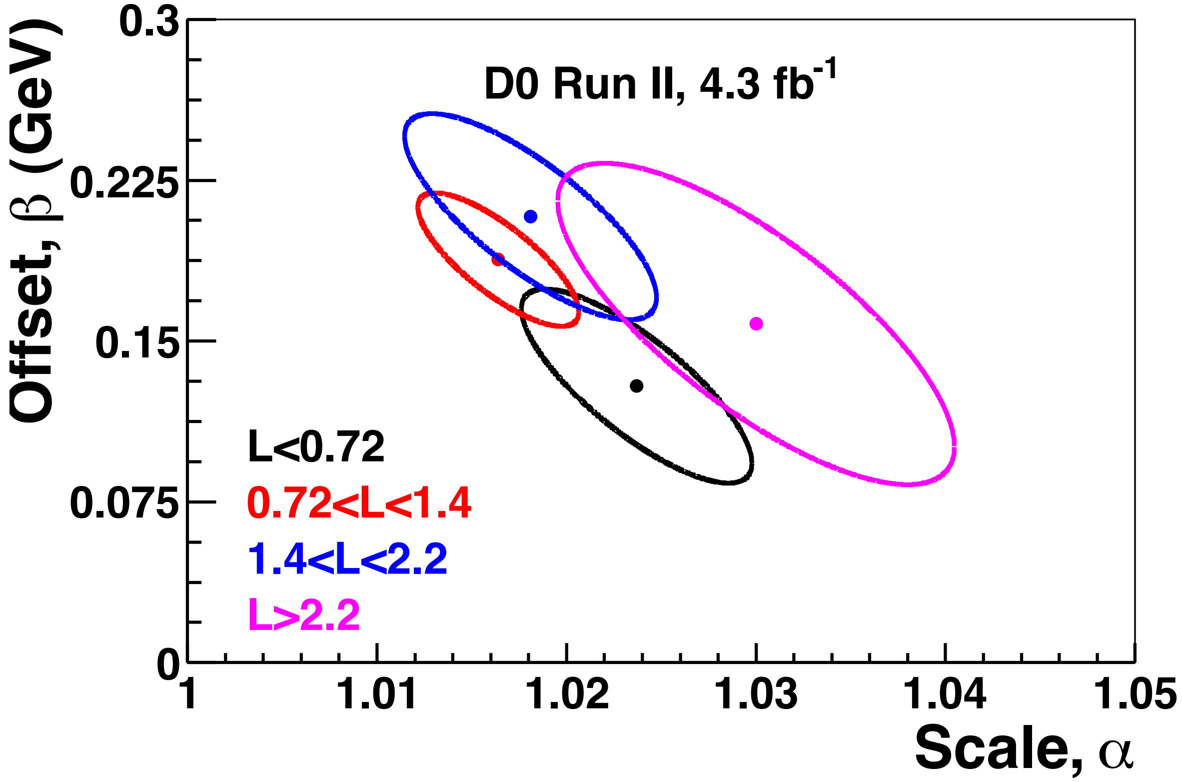
Then, the final electron energy response is assumed to be a linear function of the E_{true} :

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

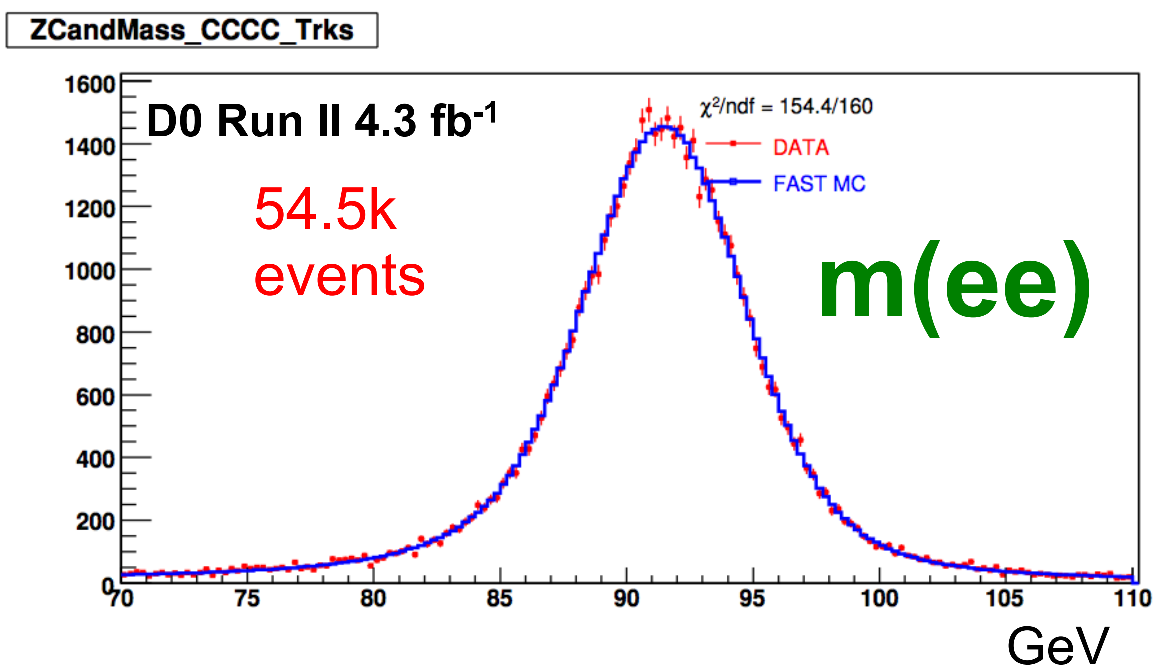
This is calibrated using Z->ee events, with known Z mass value from LEP.

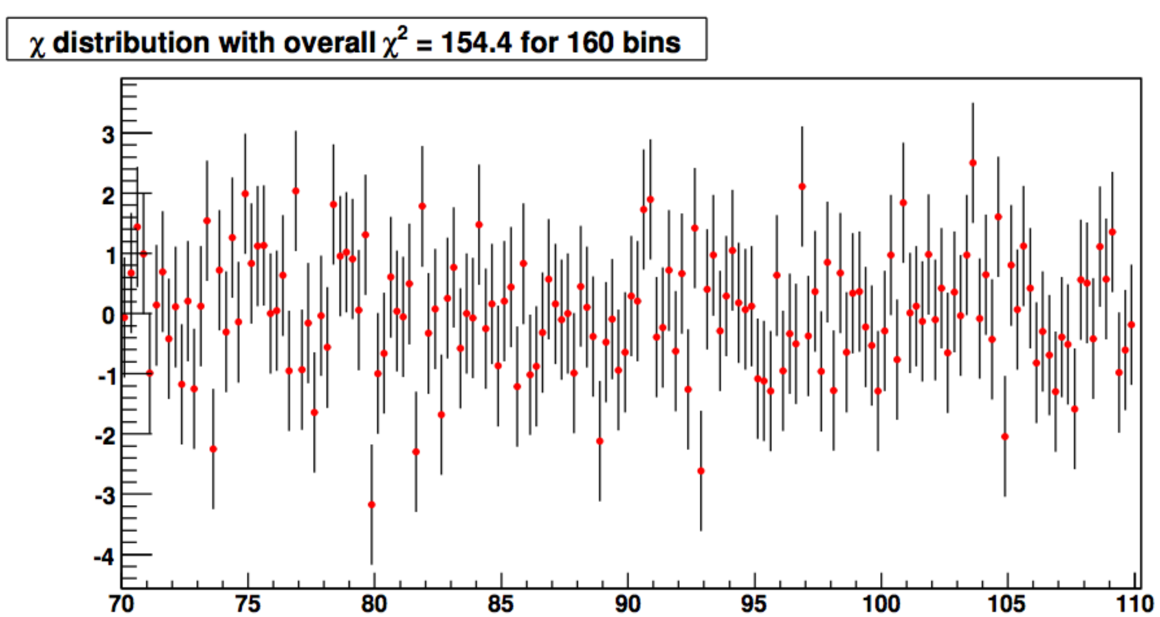
We are actually measuring mW/mZ.

The scale and offset are determined separately for 4 instantaneous luminosity sub-samples.
The good agreement of the 4 contours shows our corrections of non-linear energy response work very well.

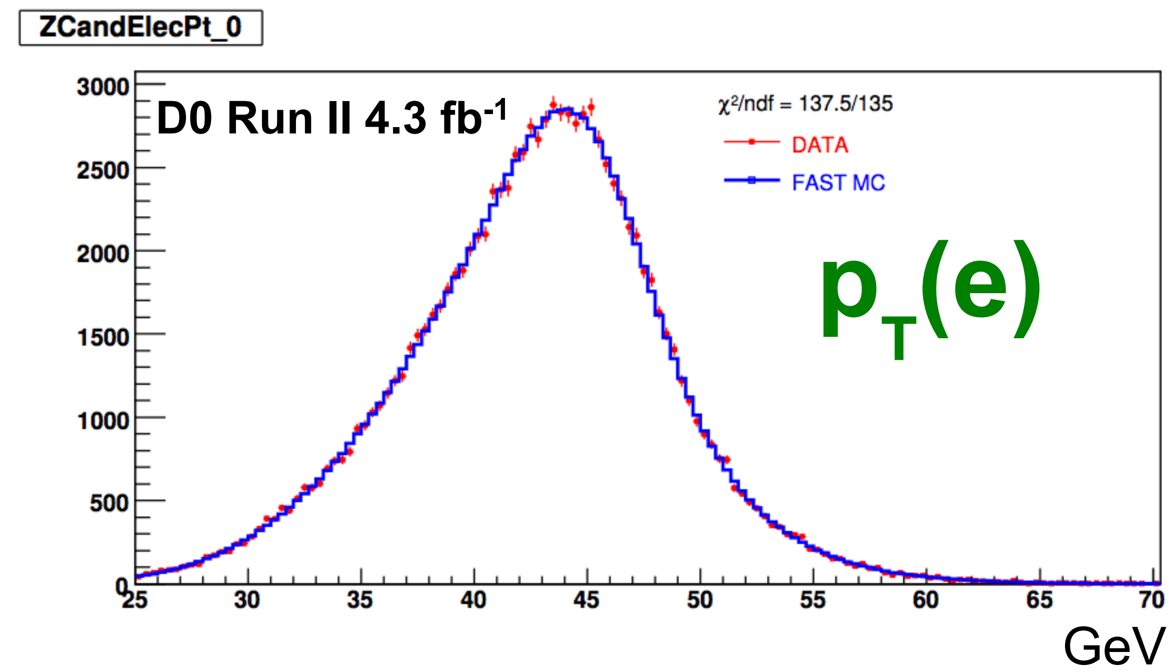


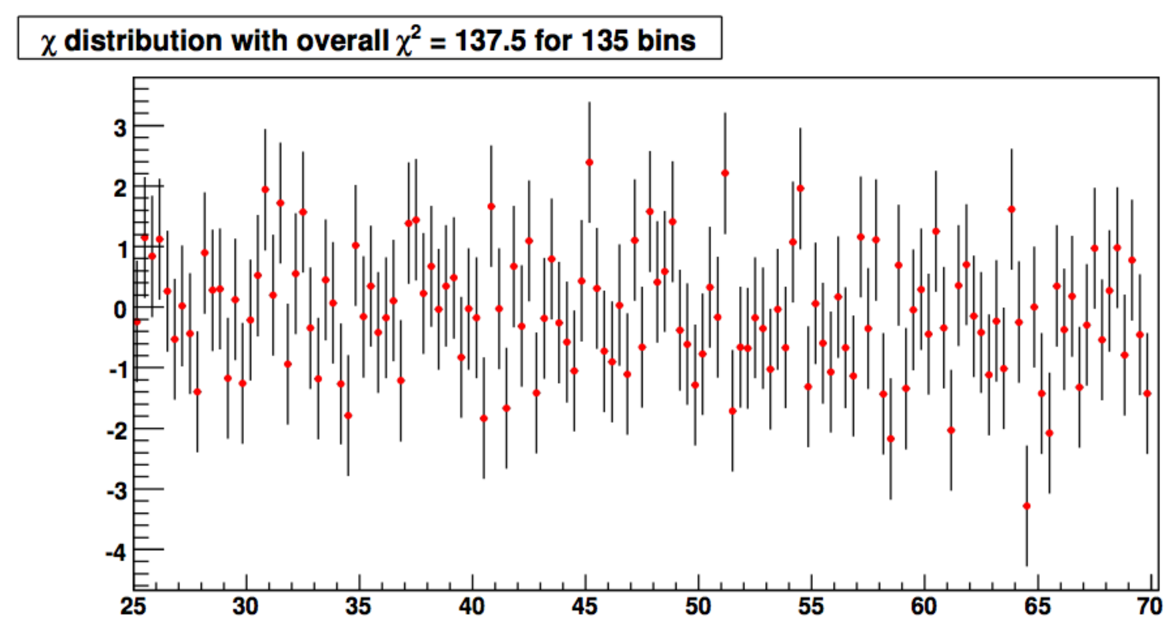
Z data





m(Z) = 91.193 ± 0.017 (stat) GeV



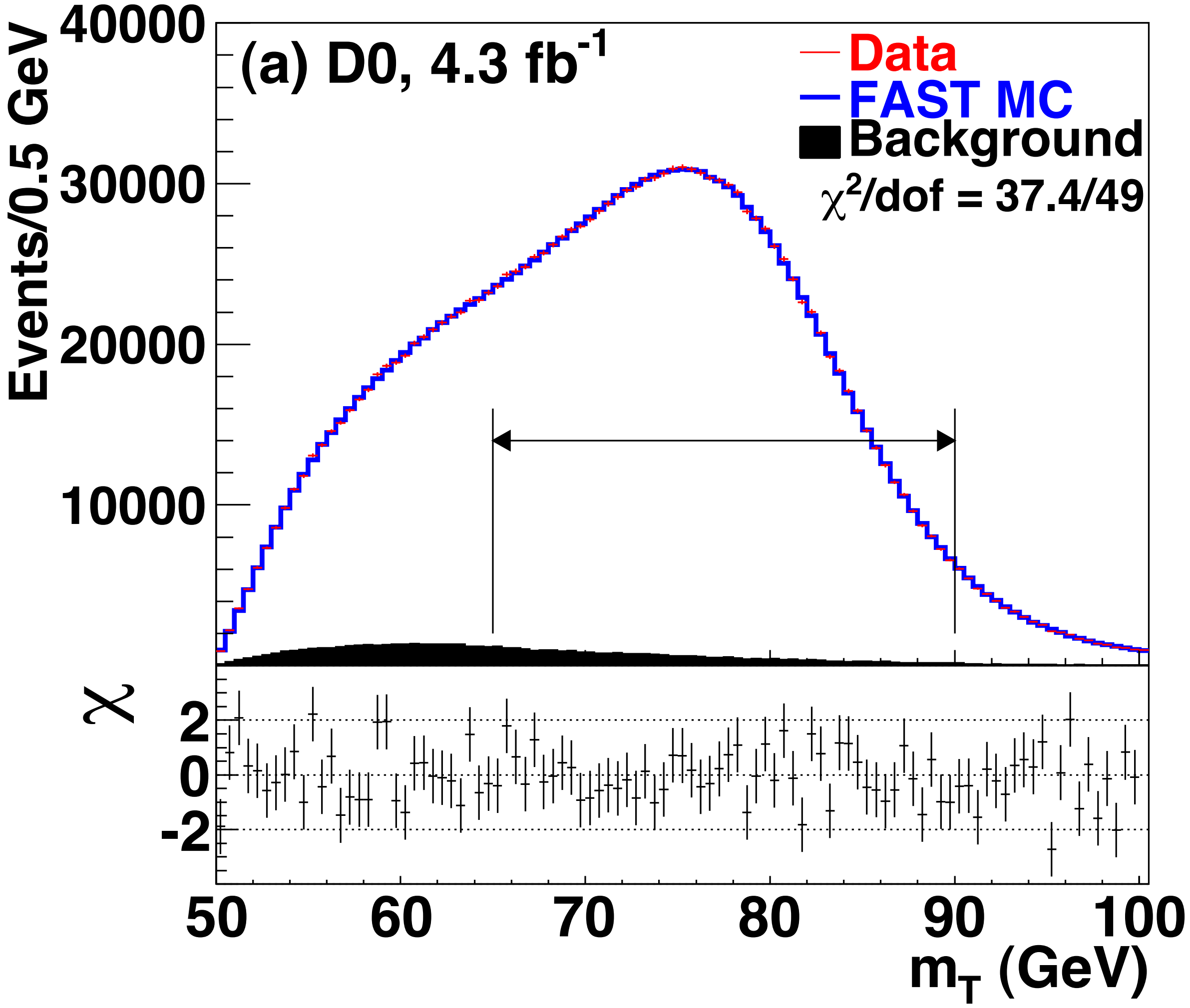


Good agreement between data and parameterised Monte Carlo.

W data

1,677k W events

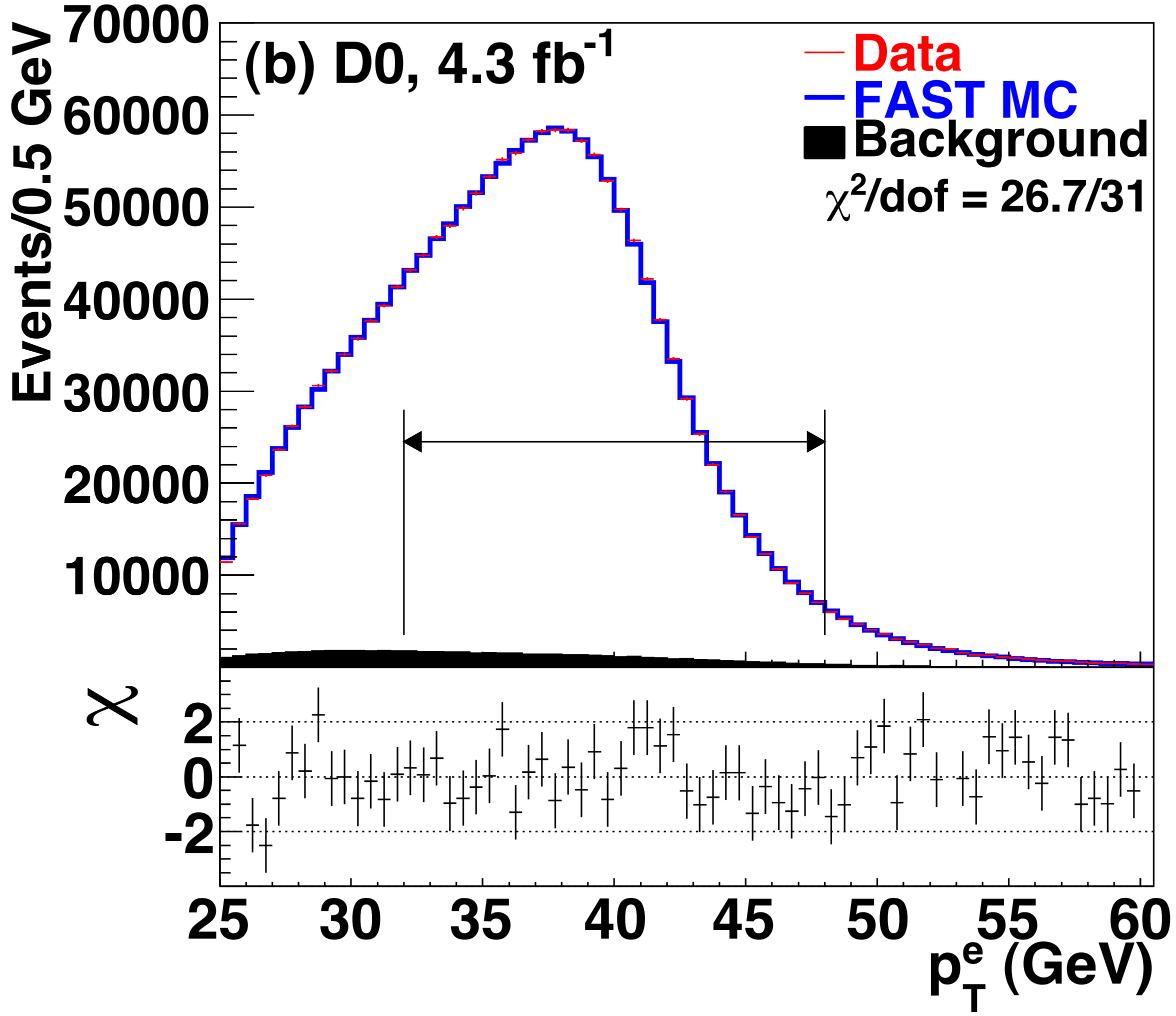
M_T



Fitted result:

m_W = 80371 ± 13 (stat) MeV

$p_T(e)$

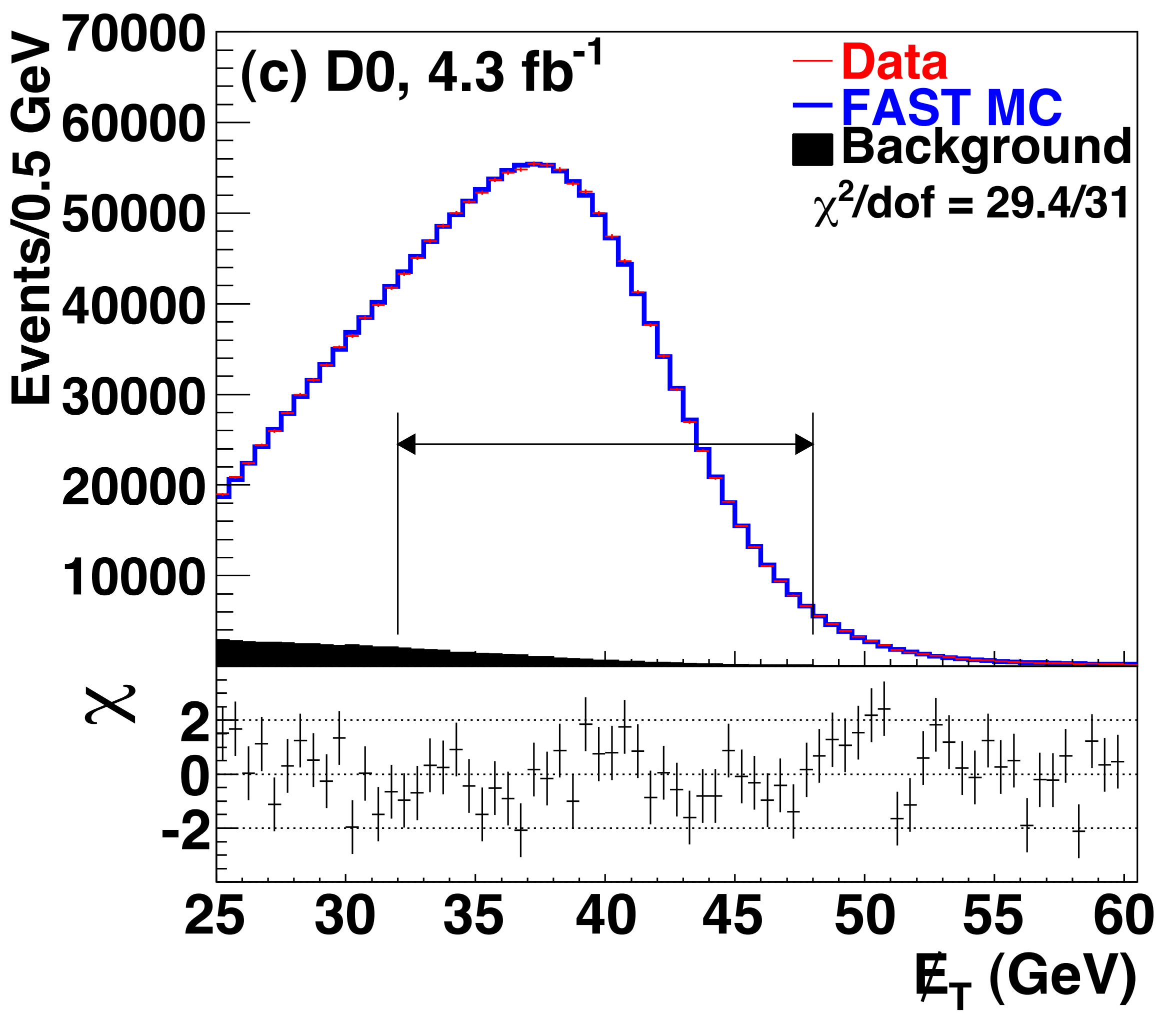


Fitted result:

m_W = 80343 ± 14 (stat) MeV

W data

MET



Fitted result:

m_W = 80355 ± 15 (stat) MeV

Summary of uncertainties

D0 Run II 4.3 fb^{-1}

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
statistical	13	14	15
total	26	28	33

Combination of the measurements

Results from the three observables are highly correlated:

$$\rho = \begin{pmatrix} \rho_{m_T m_T} & \rho_{m_T p_T^e} & \rho_{m_T \not{E}_T} \\ \rho_{m_T p_T^e} & \rho_{p_T^e p_T^e} & \rho_{p_T^e \not{E}_T} \\ \rho_{m_T \not{E}_T} & \rho_{p_T^e \not{E}_T} & \rho_{\not{E}_T \not{E}_T} \end{pmatrix} = \begin{pmatrix} 1.0 & 0.89 & 0.86 \\ 0.89 & 1.0 & 0.75 \\ 0.86 & 0.75 & 1.0 \end{pmatrix}$$

When we consider only the uncertainties which are allowed to decrease in the combination (e.g. not QED), we find that the MET measurement has negligible weight.

We therefore only retain pT(e) and mT for the combination:

Run IIb 4.3 fb^{-1} result:

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

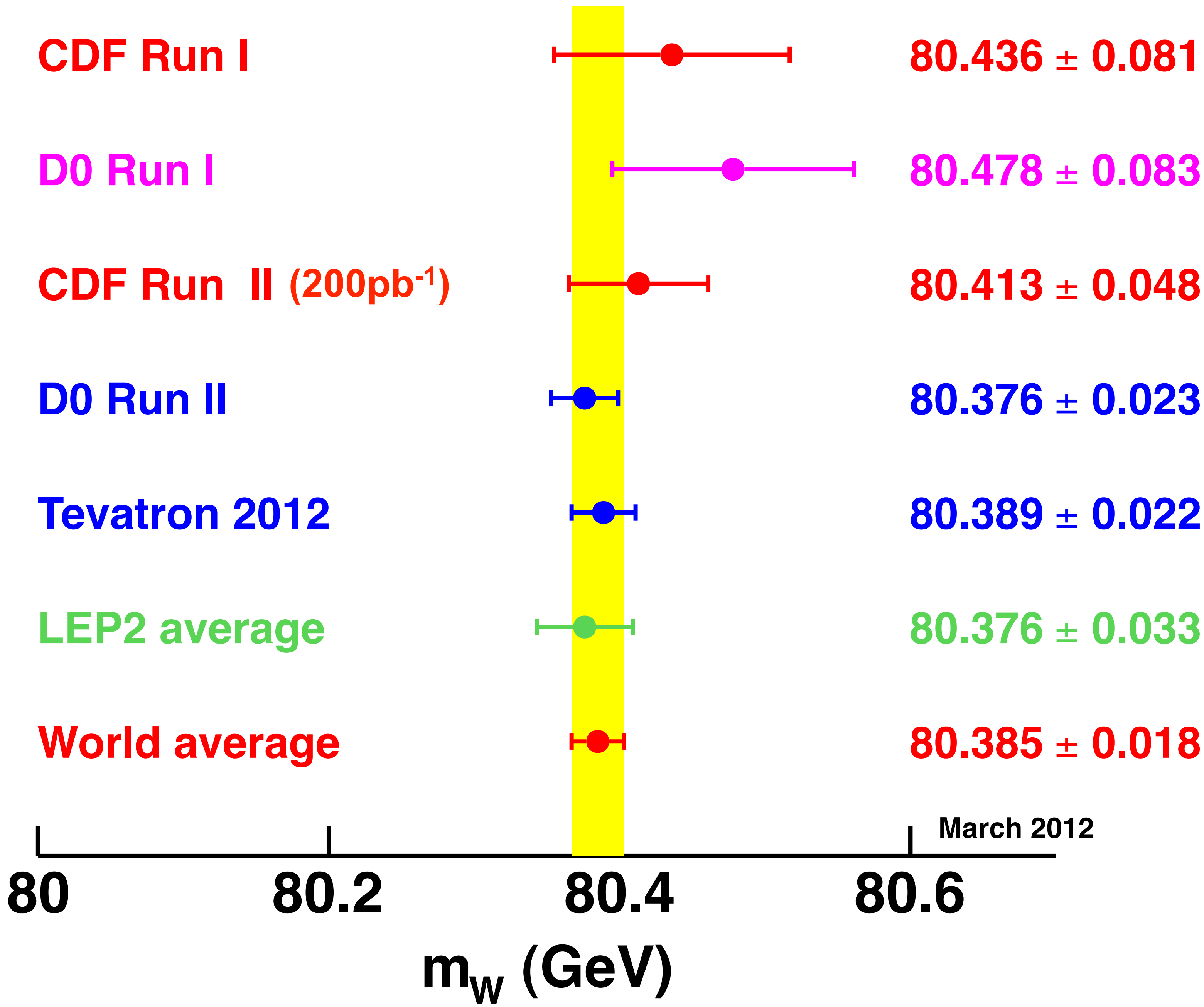
Further combine with Run IIa 1 fb^{-1} result, we obtain the new Run II 5.3 fb^{-1} result:

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

The previous world average uncertainty was just this 23 MeV.

New averages

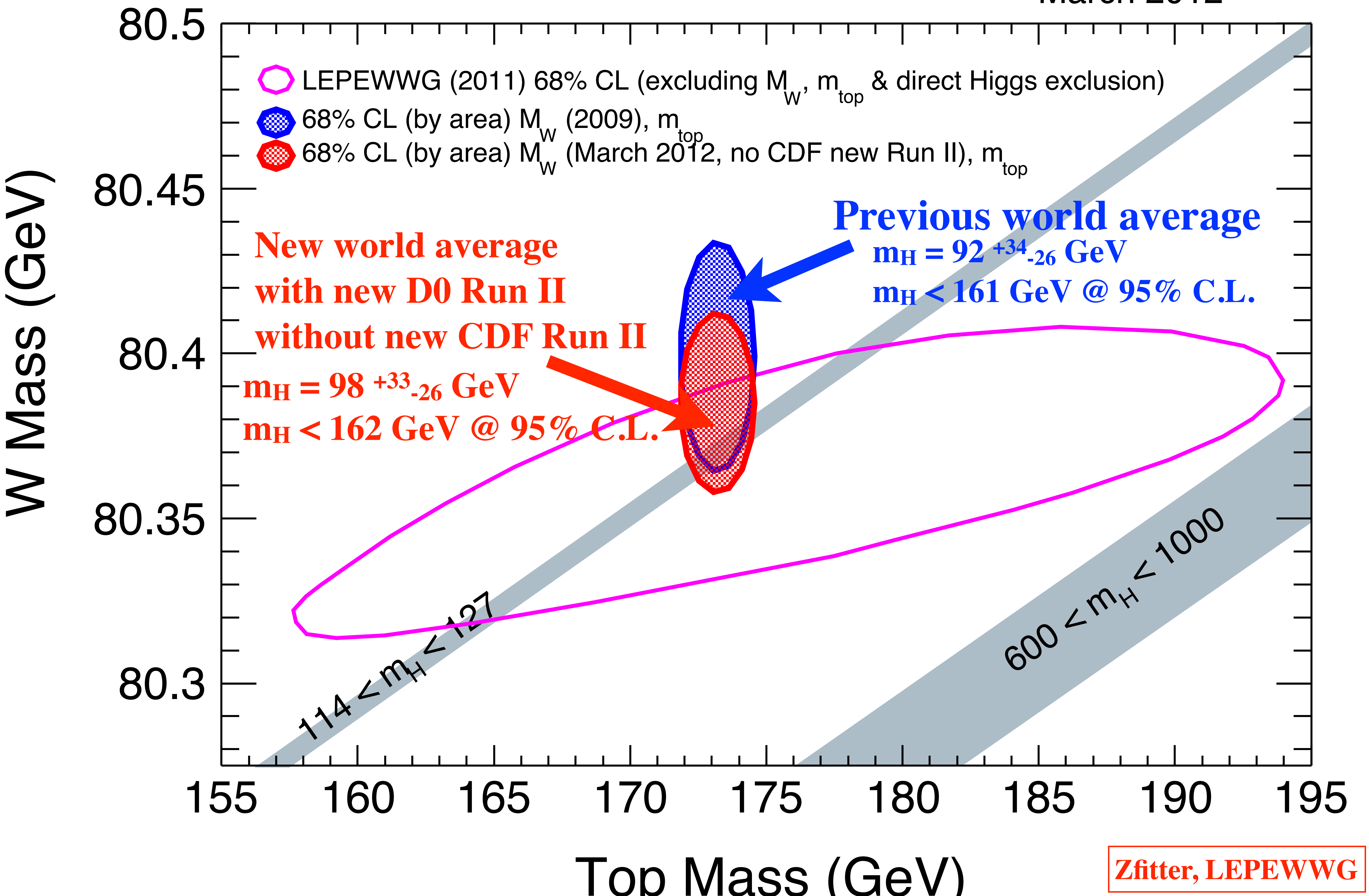
Without new CDF run II result



With only new D0 Run II result, the world average uncertainty is brought down from 23 MeV to 18 MeV

Our new 4.3 fb-1 result assumes a W width of 2100.4 MeV. For the purpose of combination, the width hypothesis has been adjusted to the SM value 2093.2 ± 2.2 MeV.

March 2012


LEPEWWG (2011) 68% CL (excluding M_W, m_{top} & direct Higgs exclusion)
68% CL (by area) M_W (2009), m_{top}
68% CL (by area) M_W (March 2012, no CDF new Run II), m_{top}
New world average
with new D0 Run II
without new CDF Run II
$m_H = 98^{+33}_{-26}$ GeV
$m_H < 162$ GeV @ 95% C.L.
Previous world average
$m_H = 92^{+34}_{-26}$ GeV
$m_H < 161$ GeV @ 95% C.L.
$114 < m_H < 127$
$600 < m_H < 1000$
W Mass (GeV)
80.5
80.45
80.4
80.35
80.3
155
160
165
170
175
180
185
190
195
Top Mass (GeV)
Zfitter, LEPEWWG

Conclusions

We present a new measurement of the W boson mass using 4.3 fb^{-1} of D0 Run II data:

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

Together with our earlier Run II 1 fb^{-1} measurement, the new D0 Run II 5.3 fb^{-1} result:

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

Submitted to Phys. Rev. Lett. on 1 March 2012, arXiv:1203.0293 [hep-ex]

With only the new D0 Run II result, the world average uncertainty is brought down from 23 M to 18 MeV

Higher precision is expected in the future at D0:

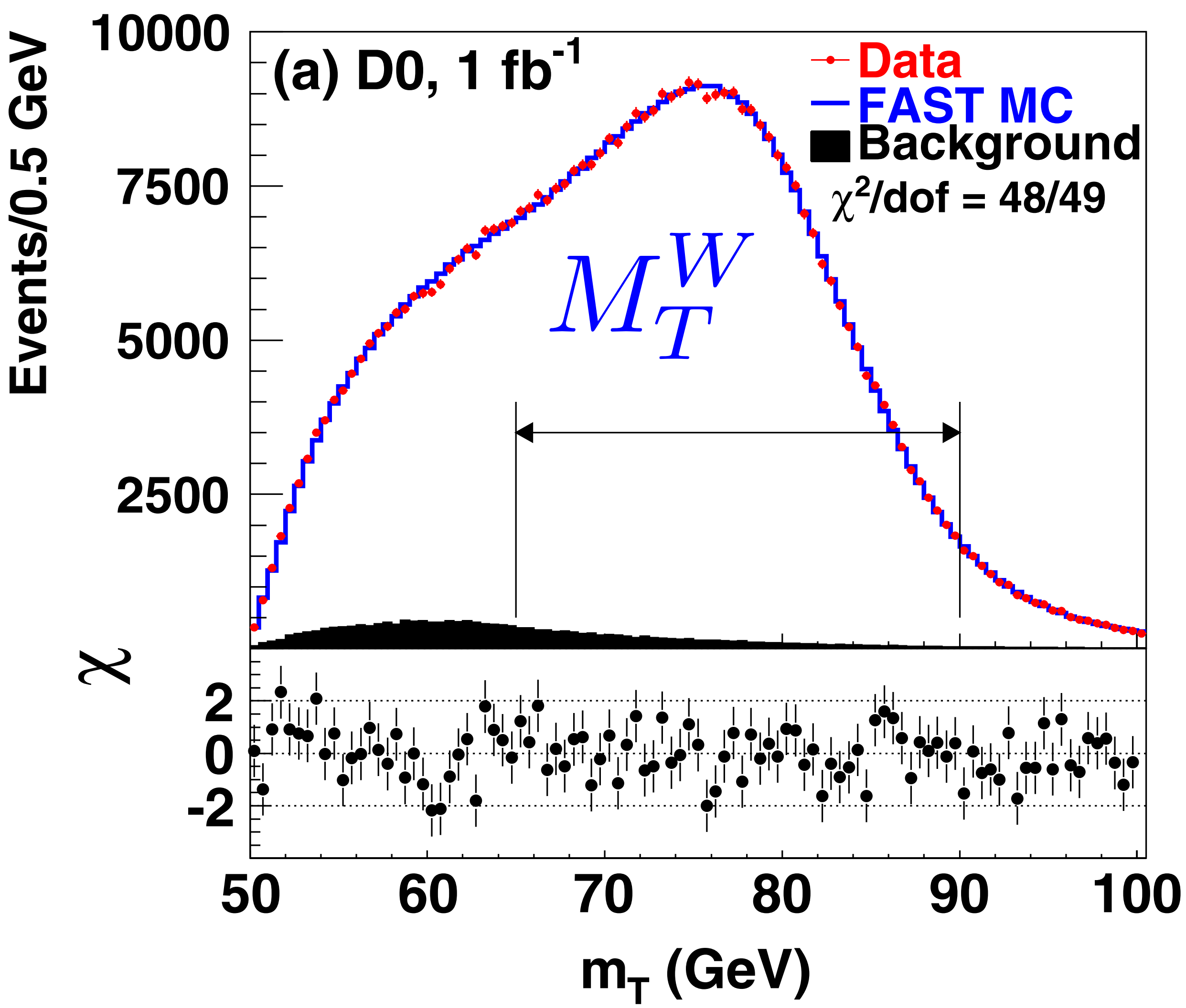
- we still have twice more data to be analyzed,
- working to reduce the sensitivity to the PDF uncertainties,
- working with theory colleagues to reduce uncertainties in the model of W production and decay.

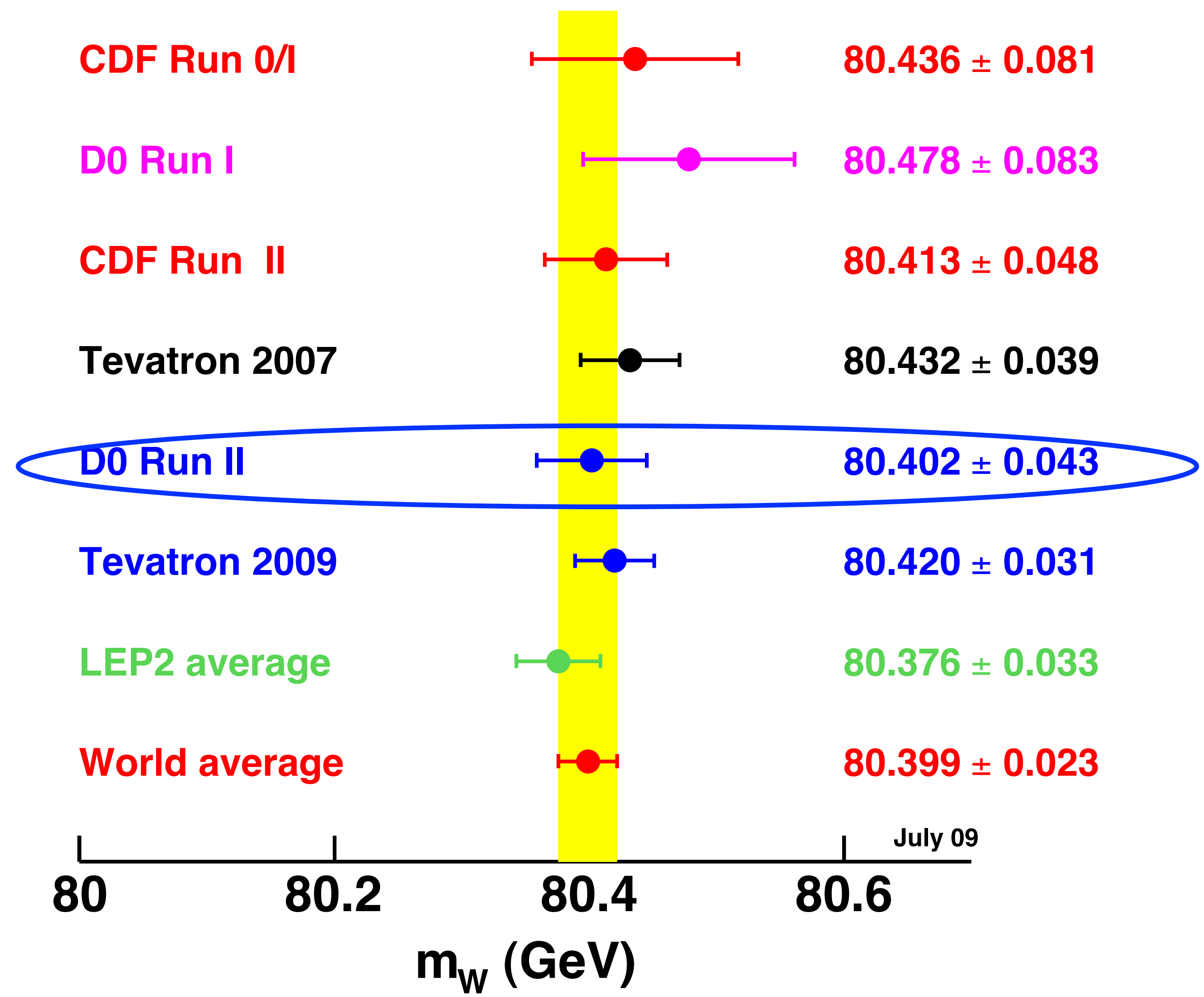
Backups

Published Results DØ RunIIa 1 fb^{-1}

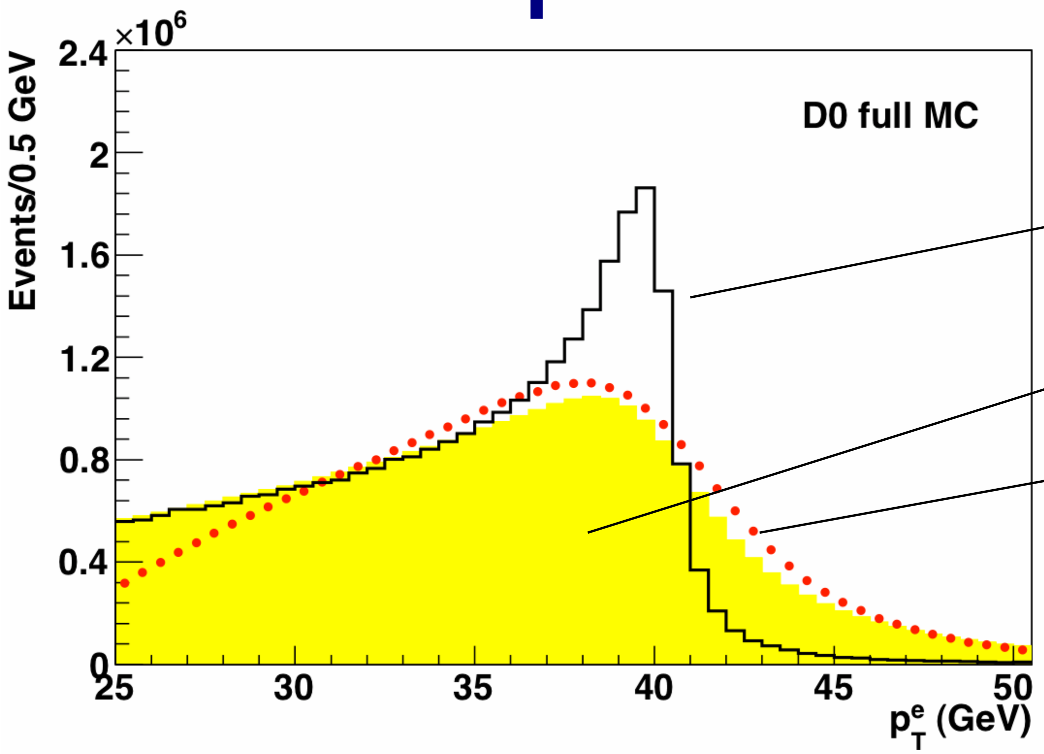
Central Calorimeter (CC) Electrons

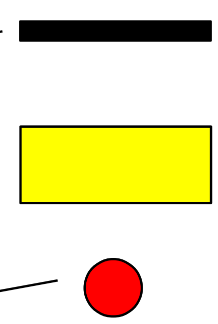
Phys. Rev. Lett. 103, 141801 (2009).



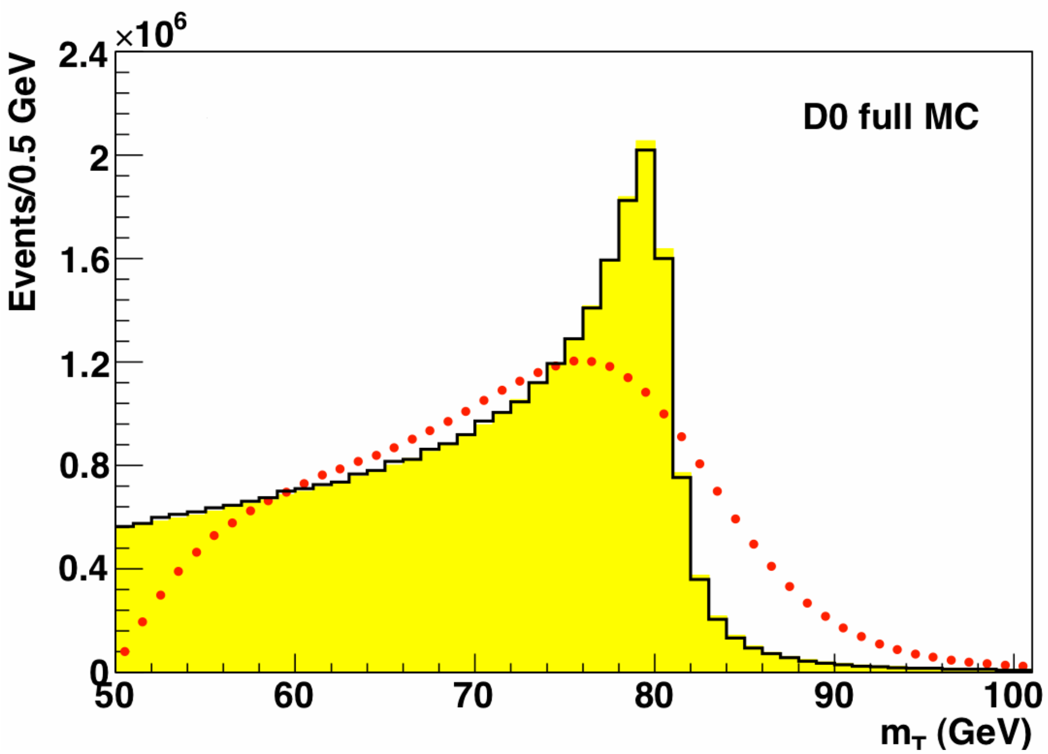


Experimental observables





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

Event selection

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
- $\eta_{\text{det}} < 1.05$ 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

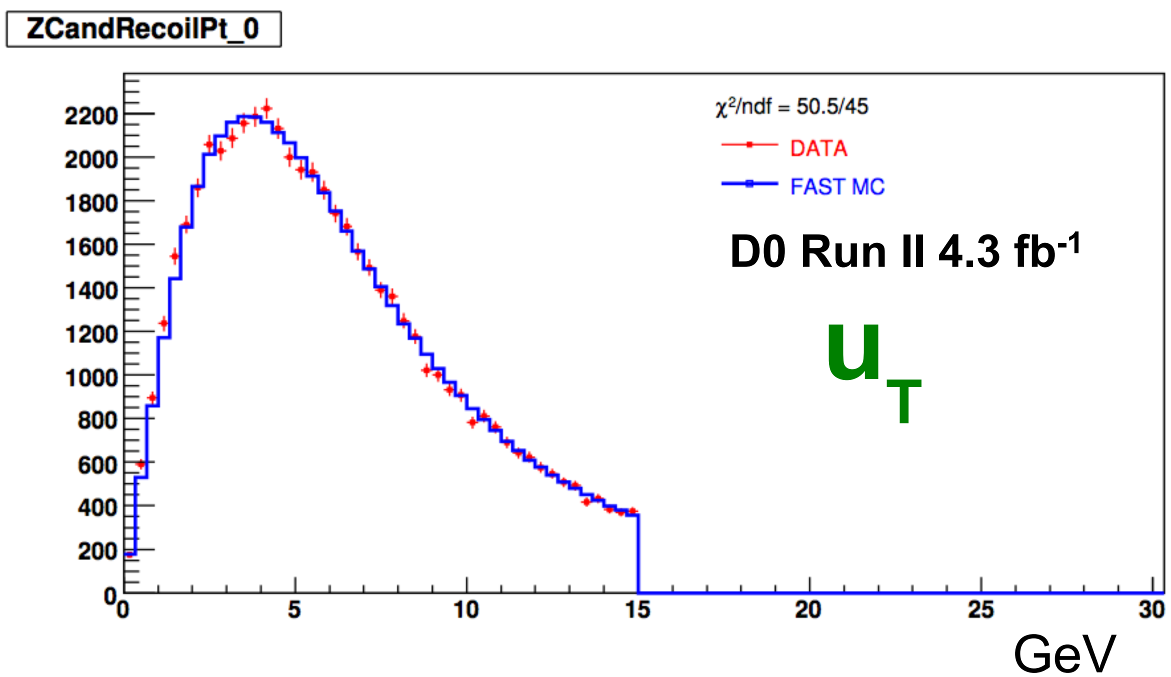
- At least two good electrons
- Hadronic recoil transverse momentum $u_T < 15\,GeV$
- Invariant mass $70 < m_{ee} < 110\,GeV$

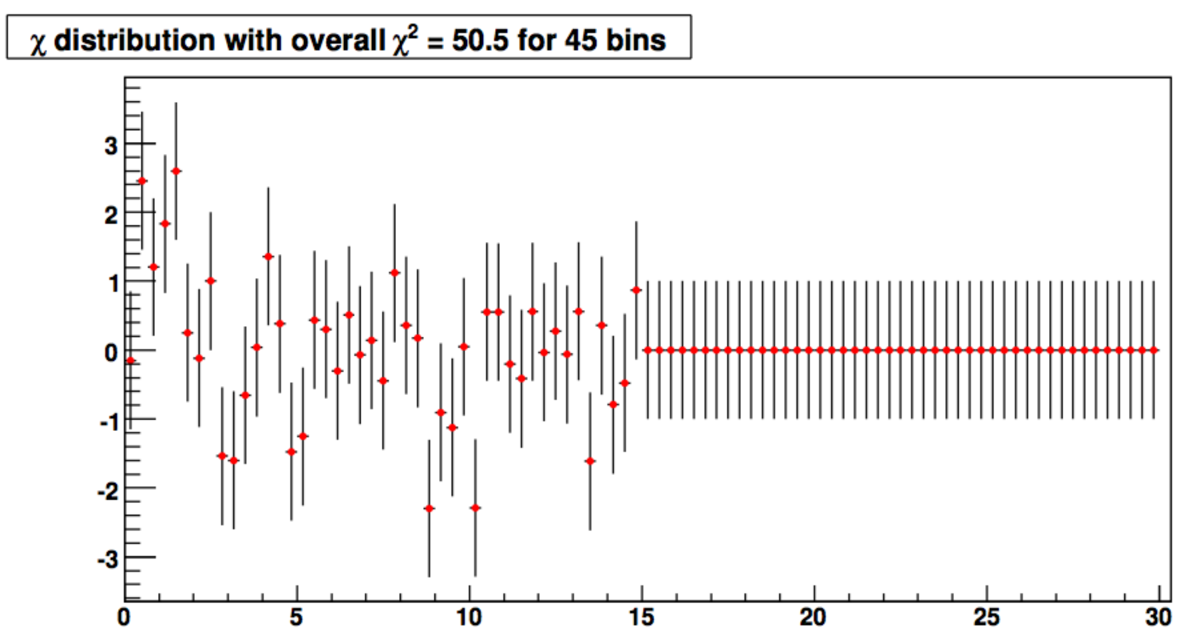
$W \rightarrow e\nu$ selection

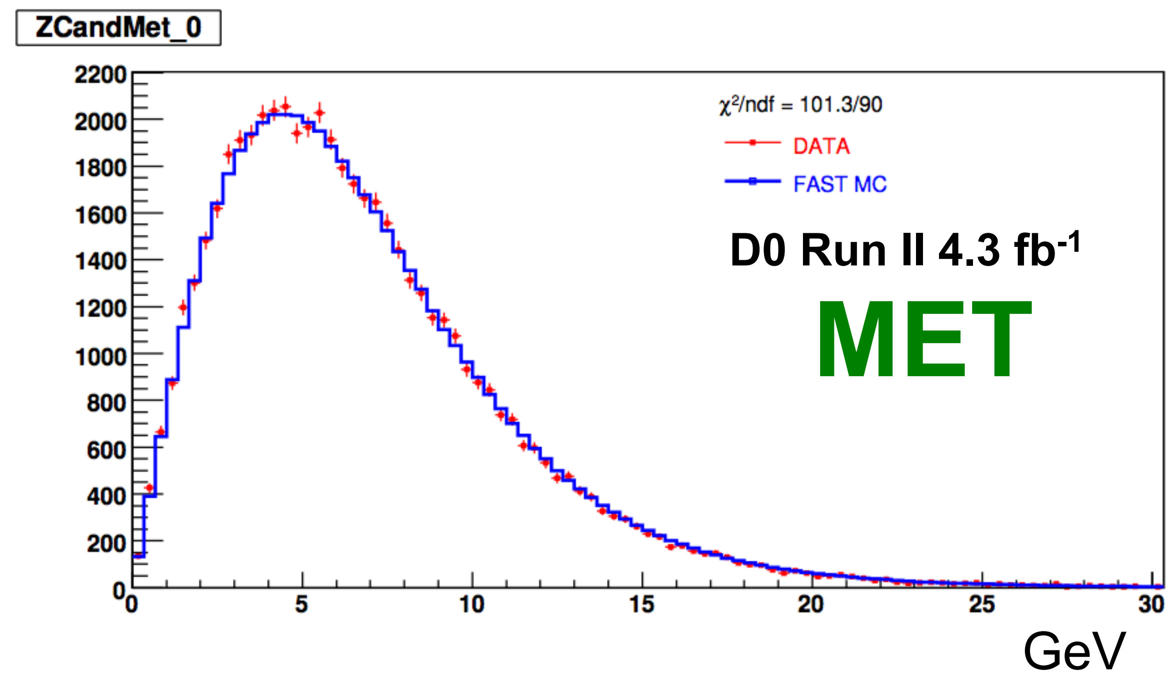
- At least one good electron
- Hadronic recoil transverse momentum $u_T < 15\,GeV$
- Transverse mass $50 < m_T < 200\,GeV$
- $\not\!\!E_T > 25GeV$

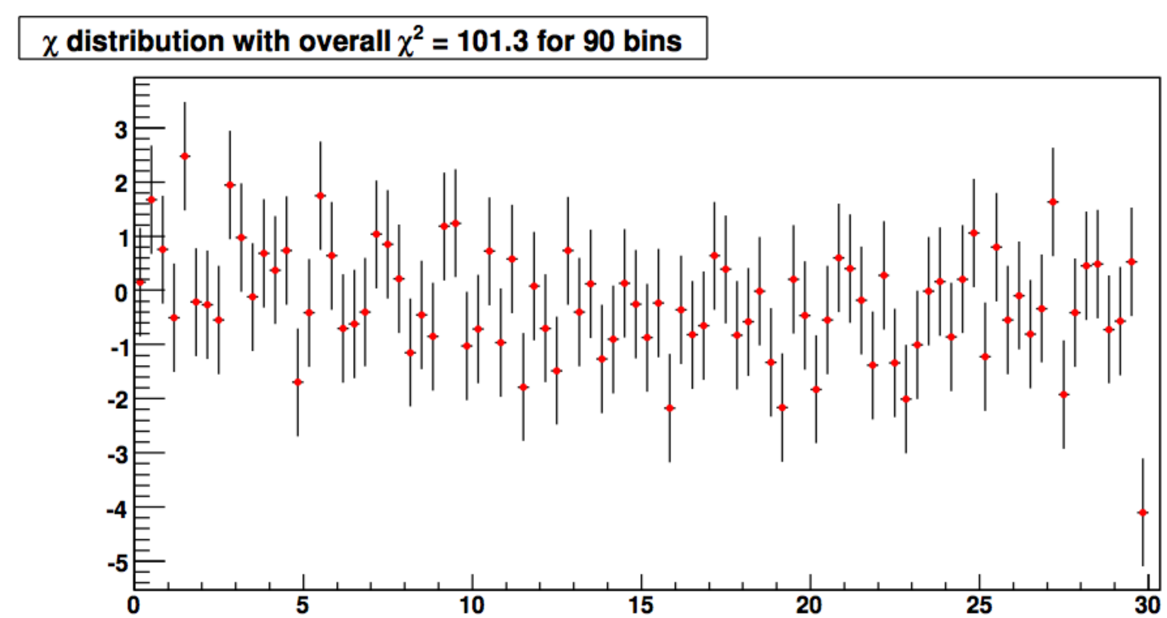
Number of candidates after selection: 54,512 (Z → e e)
1,677,394 (W → e nu)

Z data









Good agreement between data and parameterised Monte Carlo.

Recoil model

Have five tunable parameters in the recoil model that allow us to adjust the response to the hard recoil as well as the resolution (separately for hard and soft components):

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

model of spectator partons (based on soft collisions in collider data)

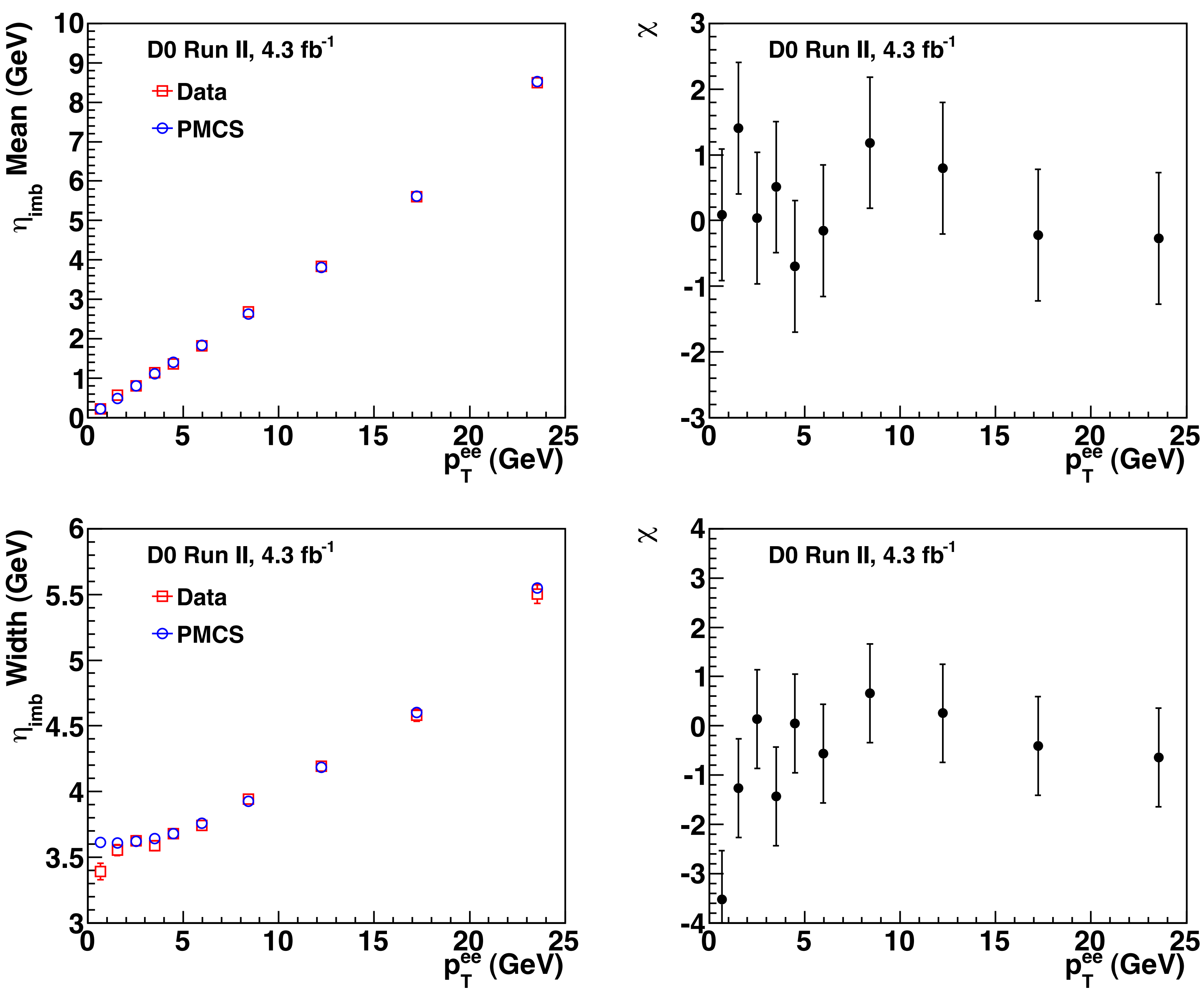
model of pileup/noise (from collider data, random trigger)

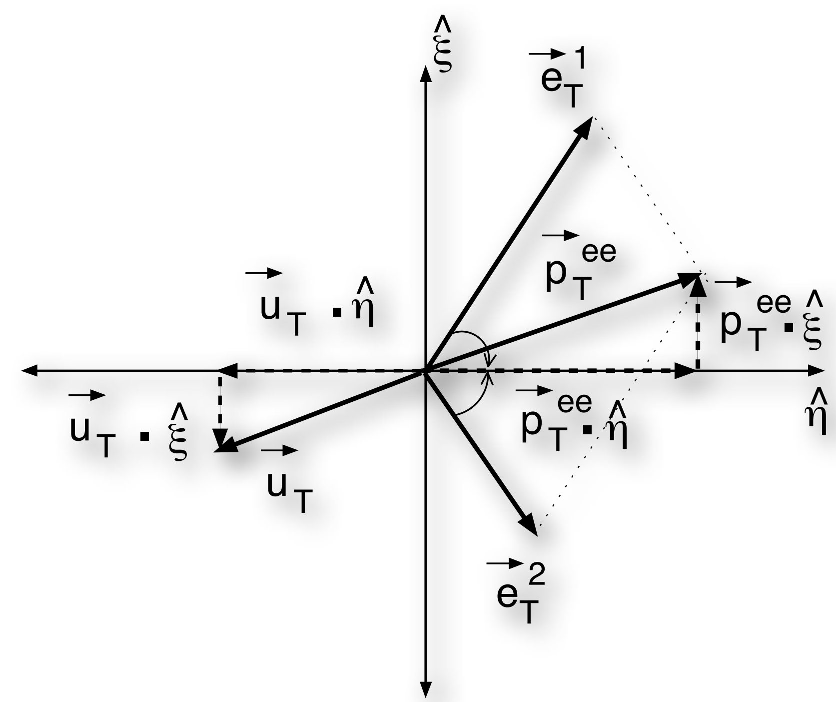
$$u_{T,smear}^{\parallel,hard} = \left(\mathrm{R}_A + \mathrm{R}_B \cdot e^{-p_T^Z/\tau_{HAD}}\right) p_T^Z \langle \frac{u_T}{p_T^Z} \rangle^{\parallel} + \mathrm{S}_A \left(u_T^{\parallel} - p_T^Z \langle \frac{u_T}{p_T^Z} \rangle^{\parallel} \right)$$

model of hard recoil response (from detailed first-principles simulation)

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:





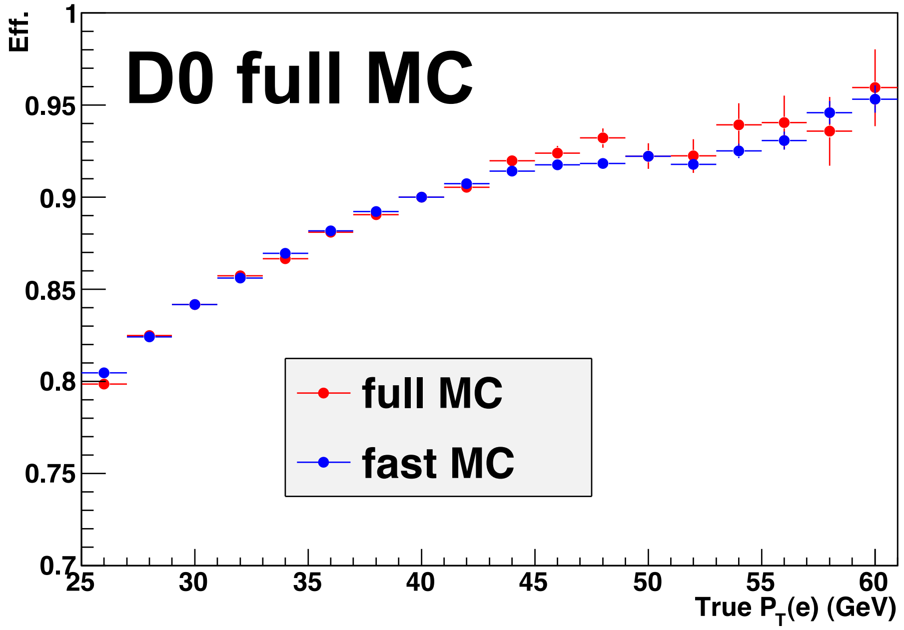
Electron efficiency model

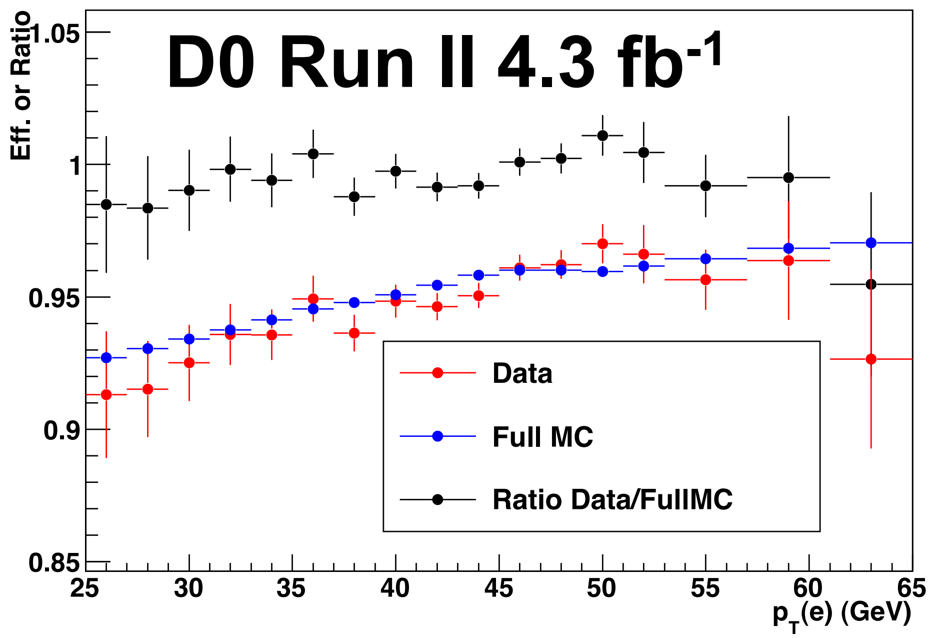
Efficiency modeling in the high inst. lumi. condition is challenging:

- **pileup and hard recoil contaminate the electron reconstruction window,**
- **correlations with electron kinematics.**

A two-step modeling:

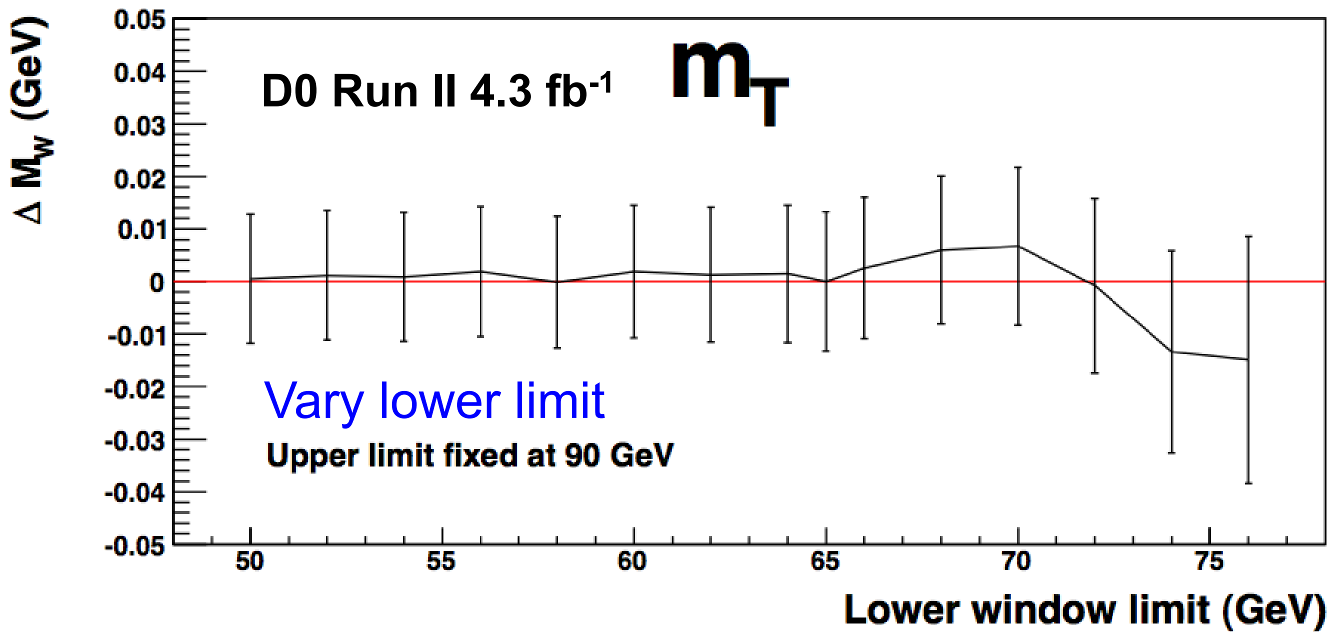
- **model the efficiency in a detailed simulation overlaid with pileup from collider data.**
- **check efficiency dependences using Z->ee events comparing data and detailed simulation.**

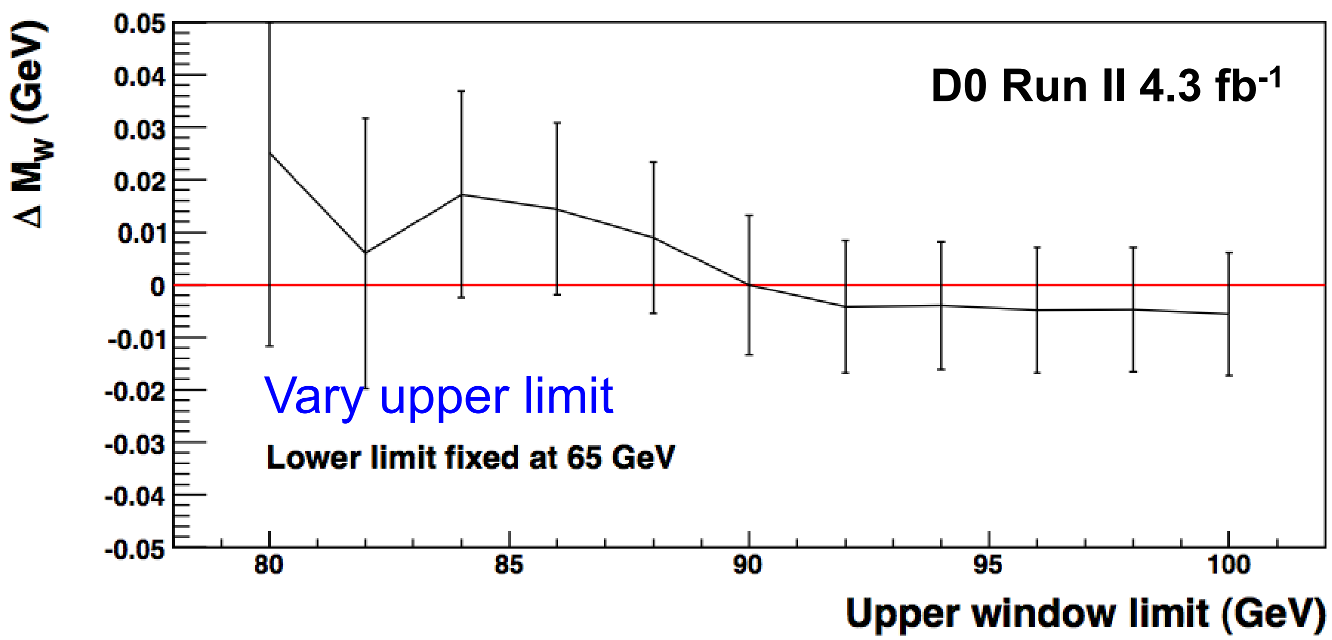




Consistency checks

Vary the range used in the m_T fit:

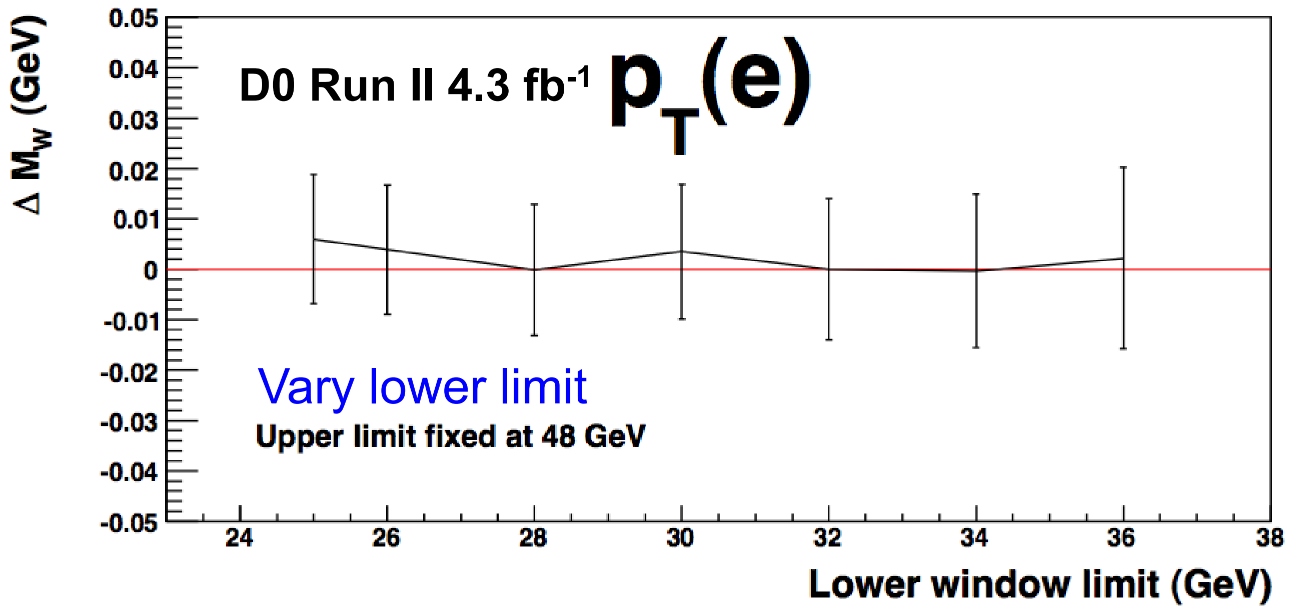


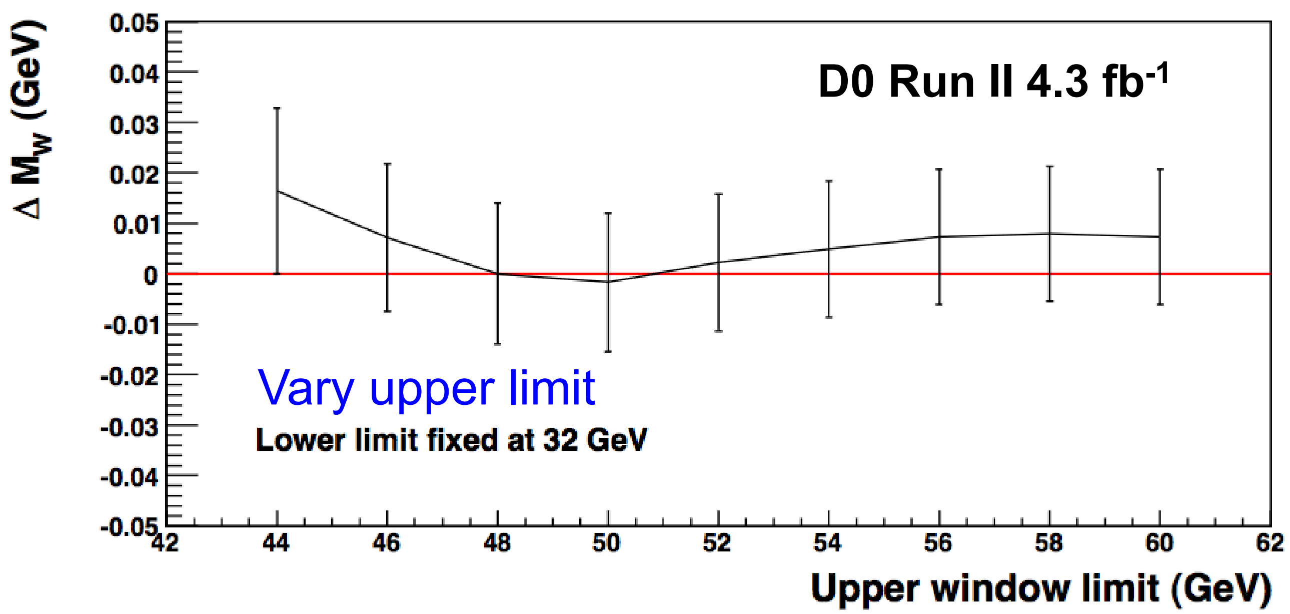


Measurement is stable

Consistency checks

Vary the range used in the $p_T(e)$ fit:

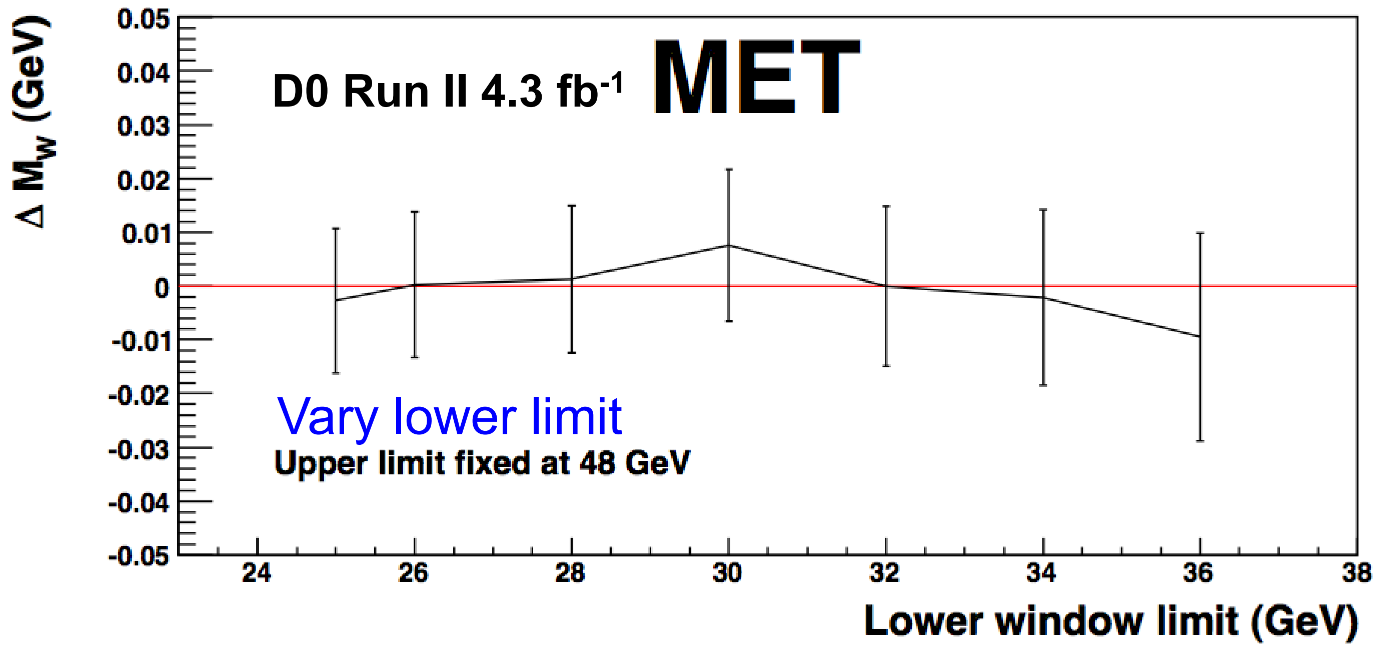


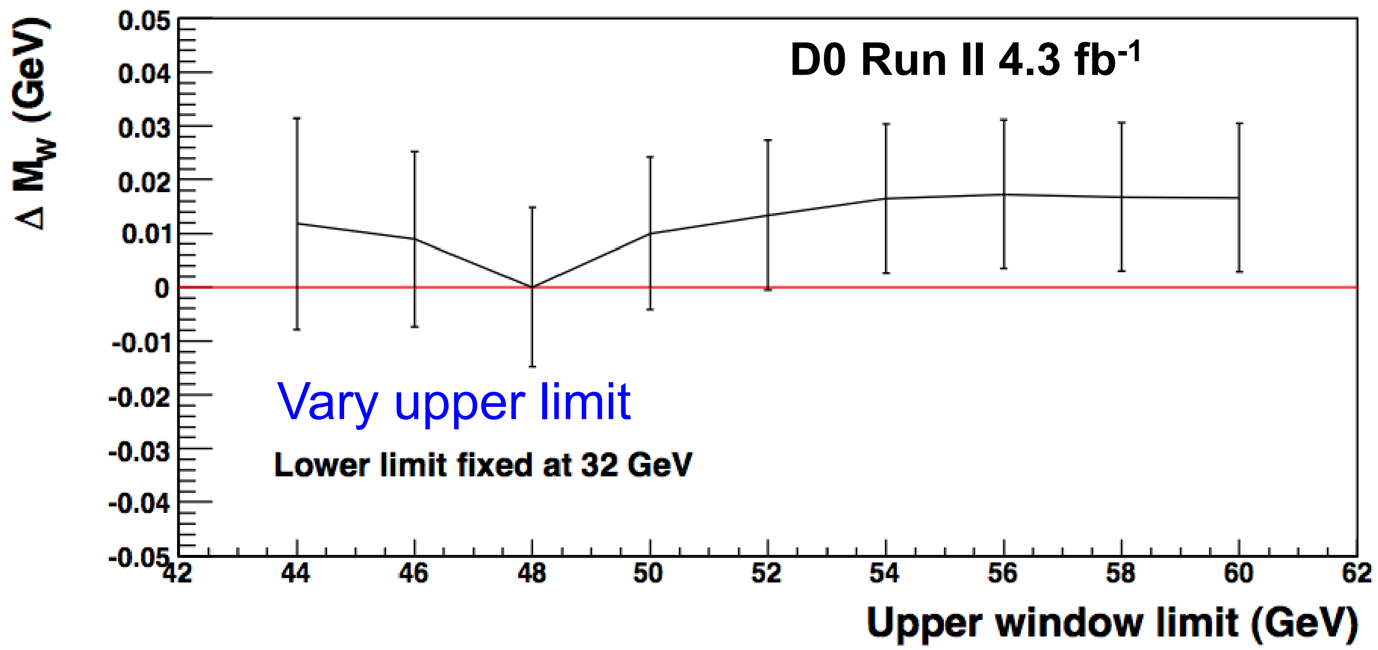


Measurement is stable

Consistency checks

Vary the range used in the MET fit:



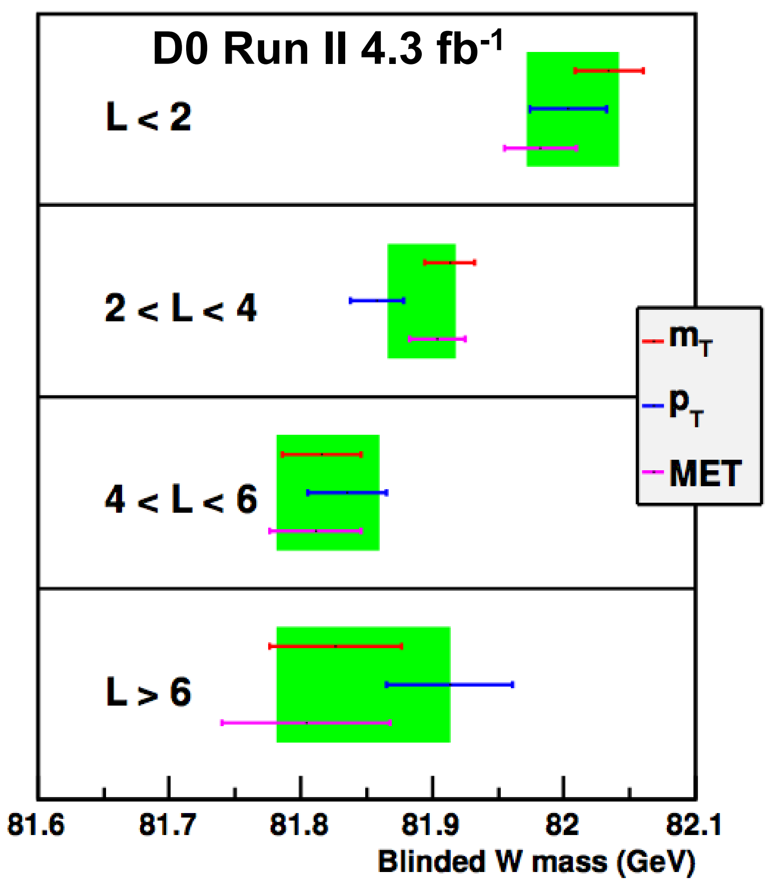


Measurement is stable

Consistency checks

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

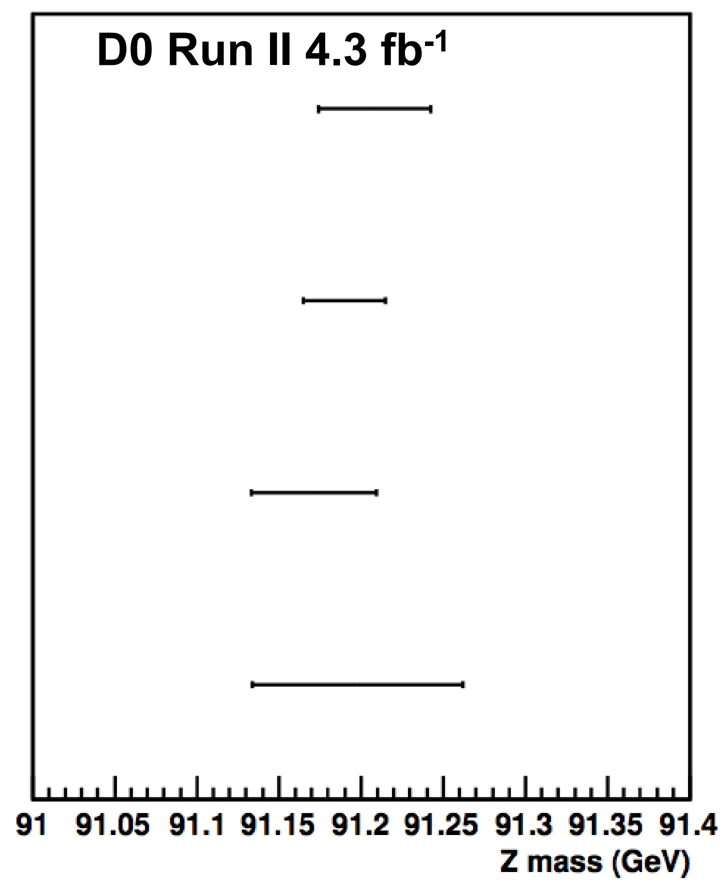
W



Error bars represent W statistics.

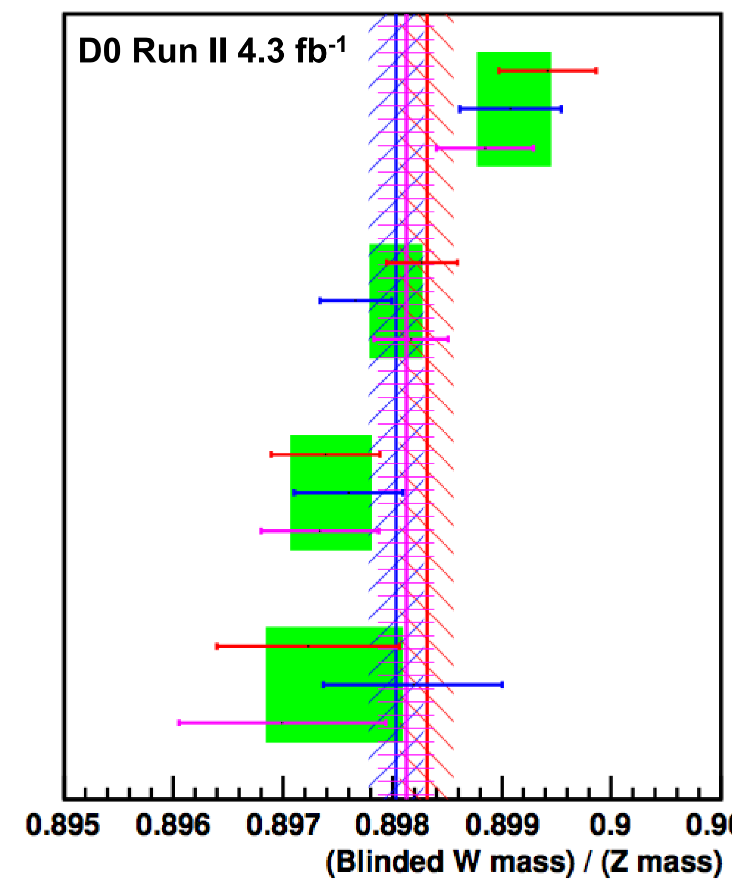
Green bands represent EM scale uncertainty (100 % correlated for m_T, p_T and MET).

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.

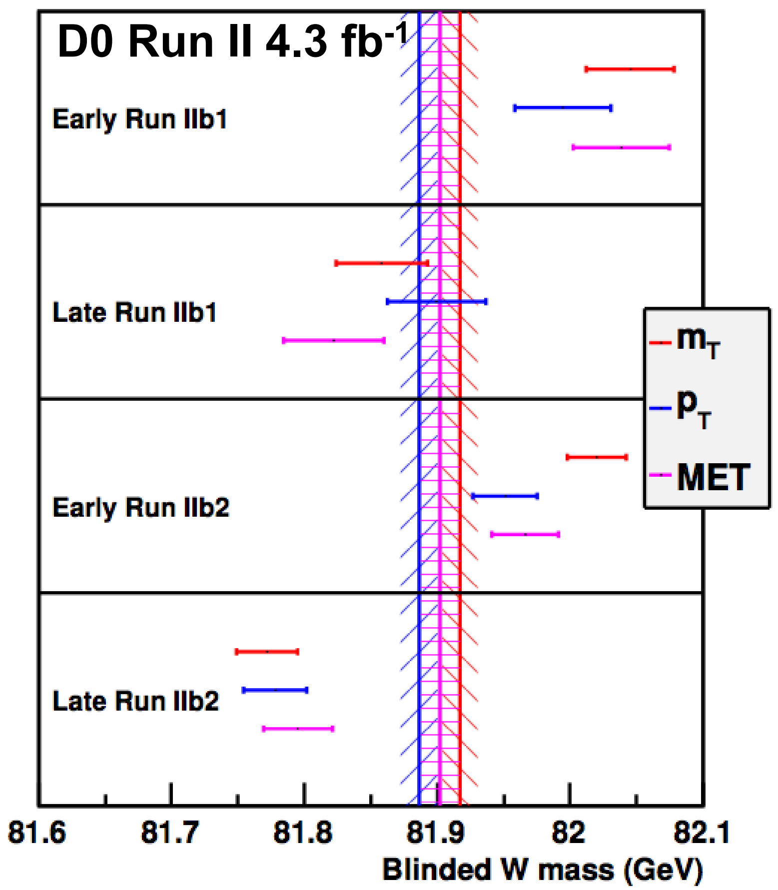
Green bands represent contribution from Z alone (100 % correlated for m_T, p_T and MET).

mass ratio is stable vs. lumi.

Consistency checks

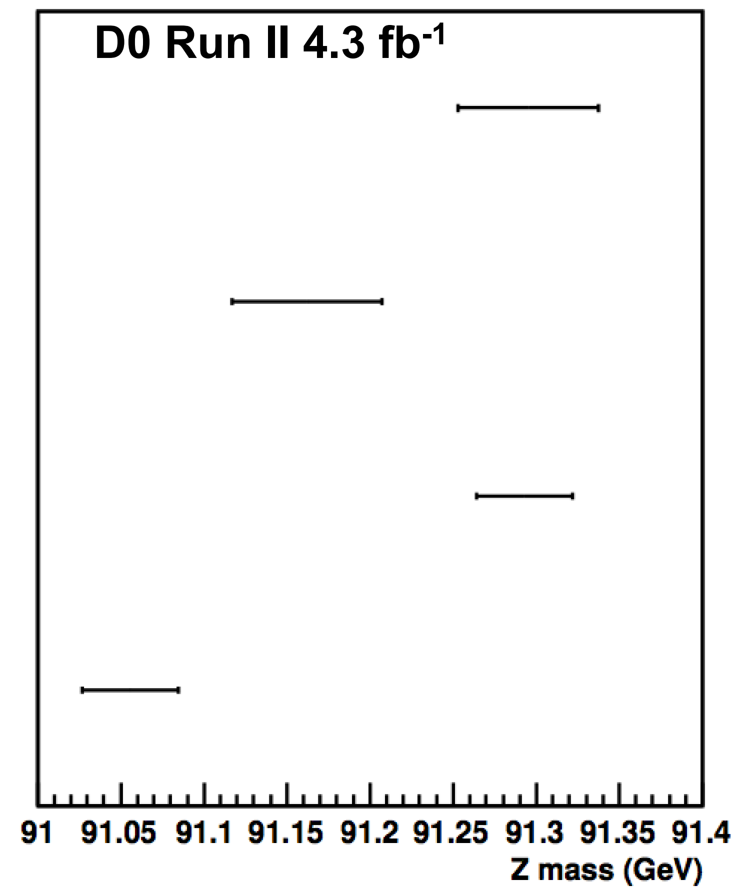
Split data sample into four data taking periods and measure W mass separately for each period:

W

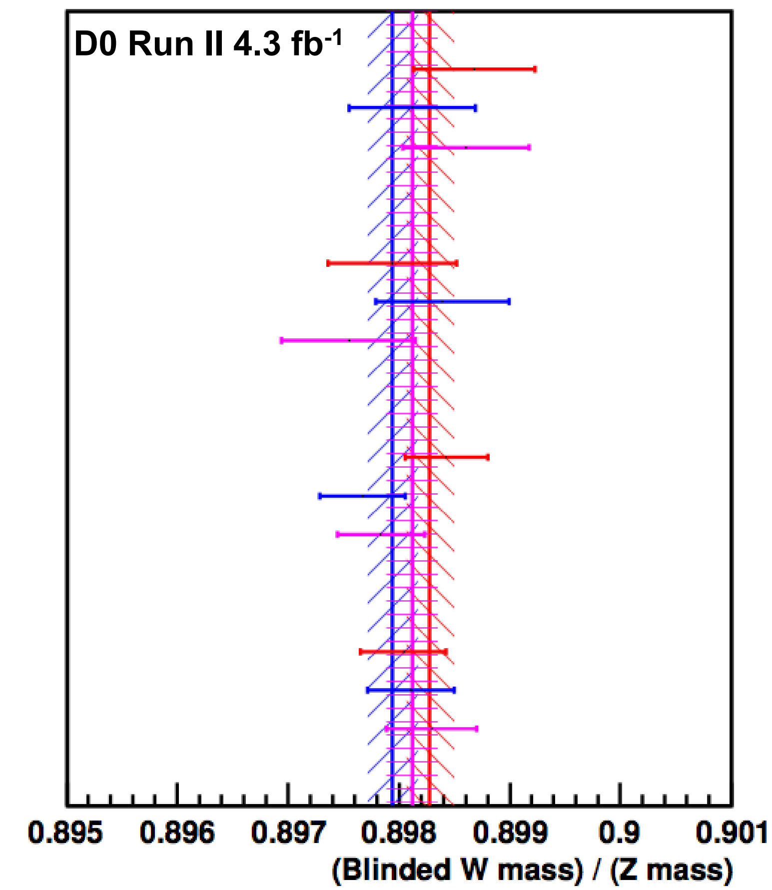


Error bars represent W statistics.

Z



“W/Z”



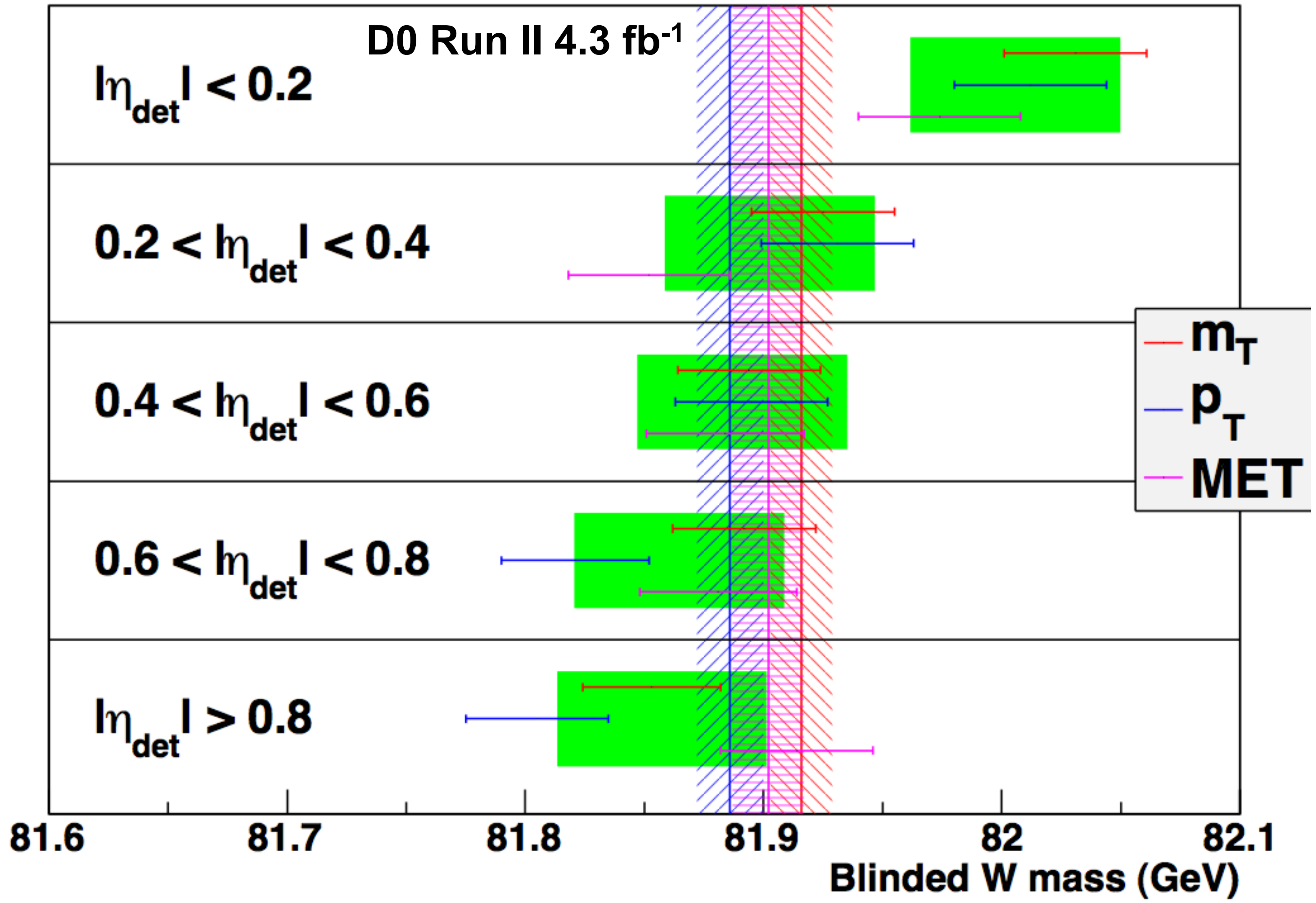
Error bars represent W *and* Z statistics.

Mass ratio is stable over time.

Consistency checks

Split data sample into five bins of detector eta and measure W mass separately for each bin:

W



Error bars represent W statistics.

Green bands represent the part of the EM scale uncertainty that is uncorrelated from one eta bin to another (100 % correlated for m_T, p_T and MET).

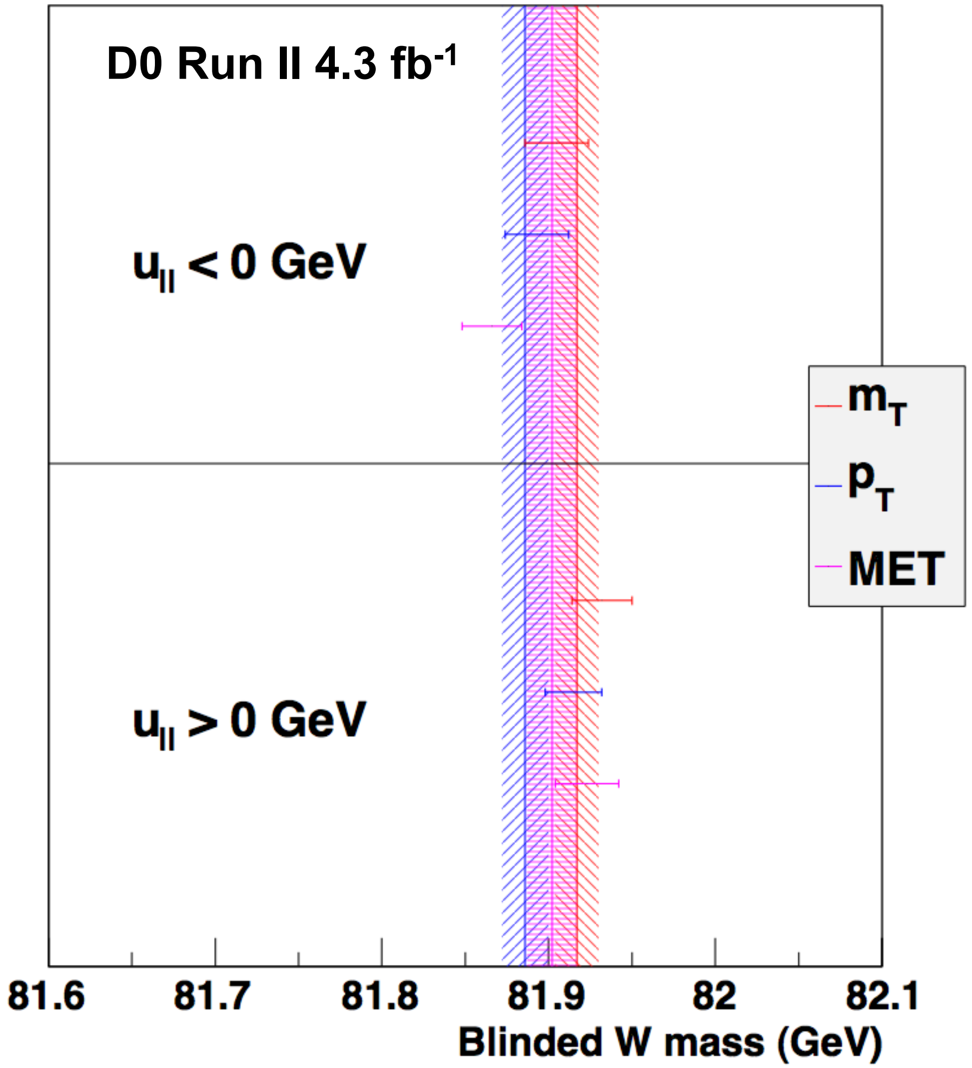
Sorry, still using blinded mass in these plots.
But it does not matter here …
differences between observables and subsamples are preserved by the blinding.

Mass is stable with eta.

Consistency checks

Split data sample into two bins of $u_{||}$ and measure W mass separately for each bin:

W



Error bars represent W statistics.

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

Mass is stable with $u_{||}$.

Towards the future

The bigger picture:

- "In our first Run II measurement (1 fb^{-1}), we have learned how to use our Run II detector to achieve the necessary precision on electron and recoil energy measurements".

  Uninstrumented material, …

- "In the the Run II measurement presented today (4.3 fb^{-1}), we have learned how to deal with the effect of high instantaneous luminosity and therefore to exploit large Run II datasets".

- We still have roughly another factor two more data in the can.

  Dominant experimental systematic uncertainty (electron energy scale) is expected to scale with statistics.

  To be able to *fully* benefit from this sample, we will have to beat down the uncertainties in the model of W production and decay.

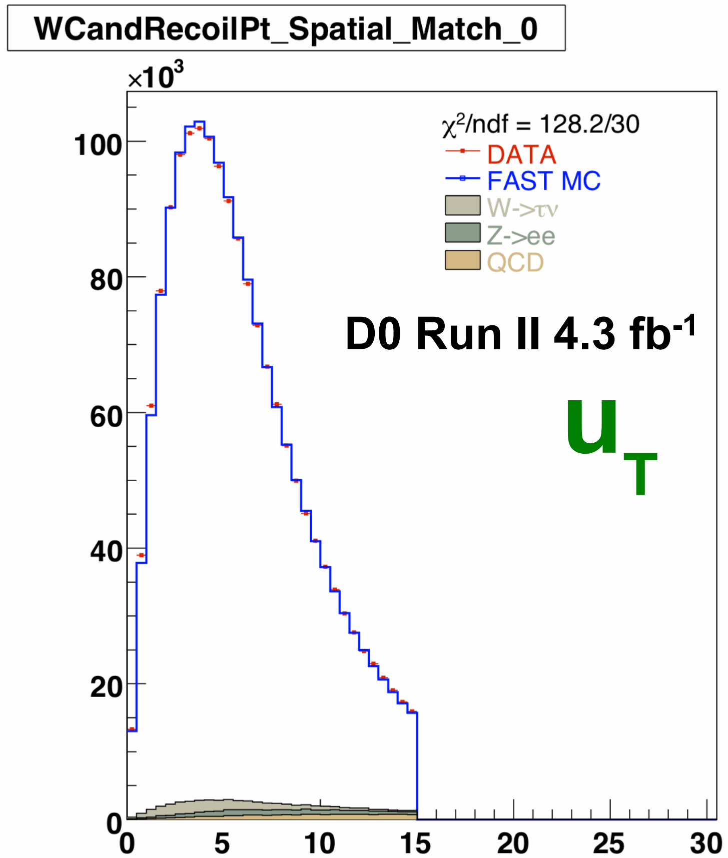
  QED uncertainty and PDF uncertainty !

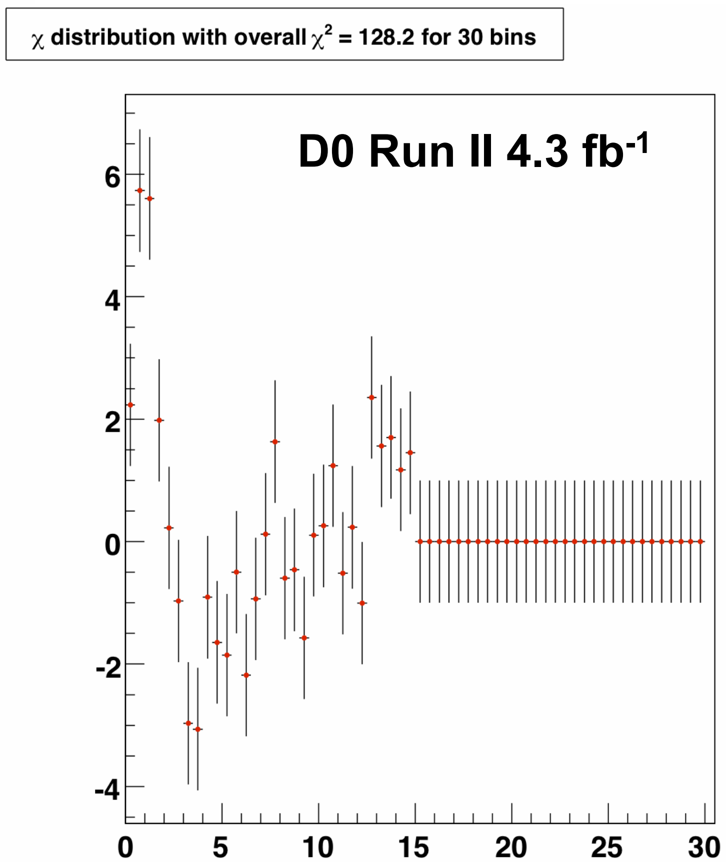
Fortunately, our theory friends are also very active !

As an example, two very recent publications that should help with the QED uncertainty:

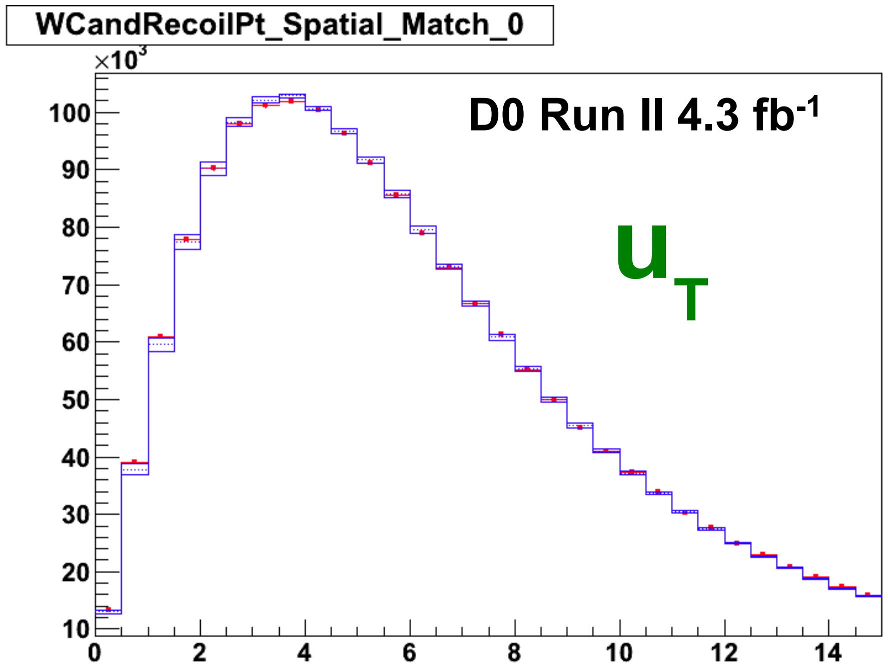
- Implementation of electroweak corrections in the POWHEG BOX: single W production arXiv:1202.0465
- Combining NLO QCD and Electroweak Radiative Corrections to W-boson Production at Hadron Colliders in the POWHEG Framework arXiv:1201.4804

W data





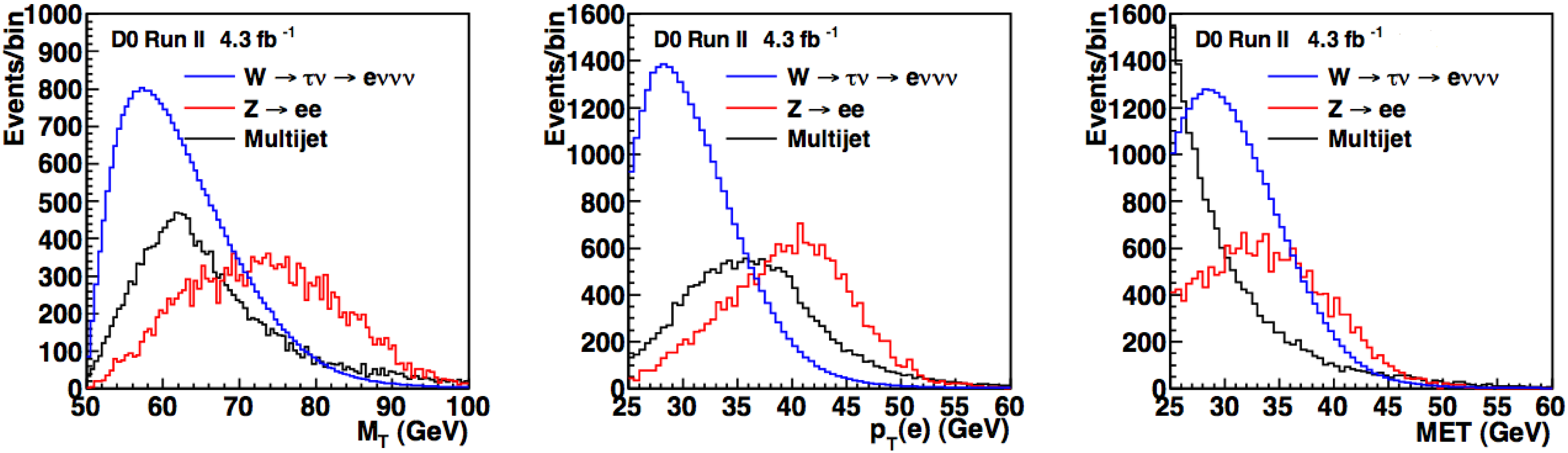
Here the error bars only reflect the finite statistics of the W candidate sample.



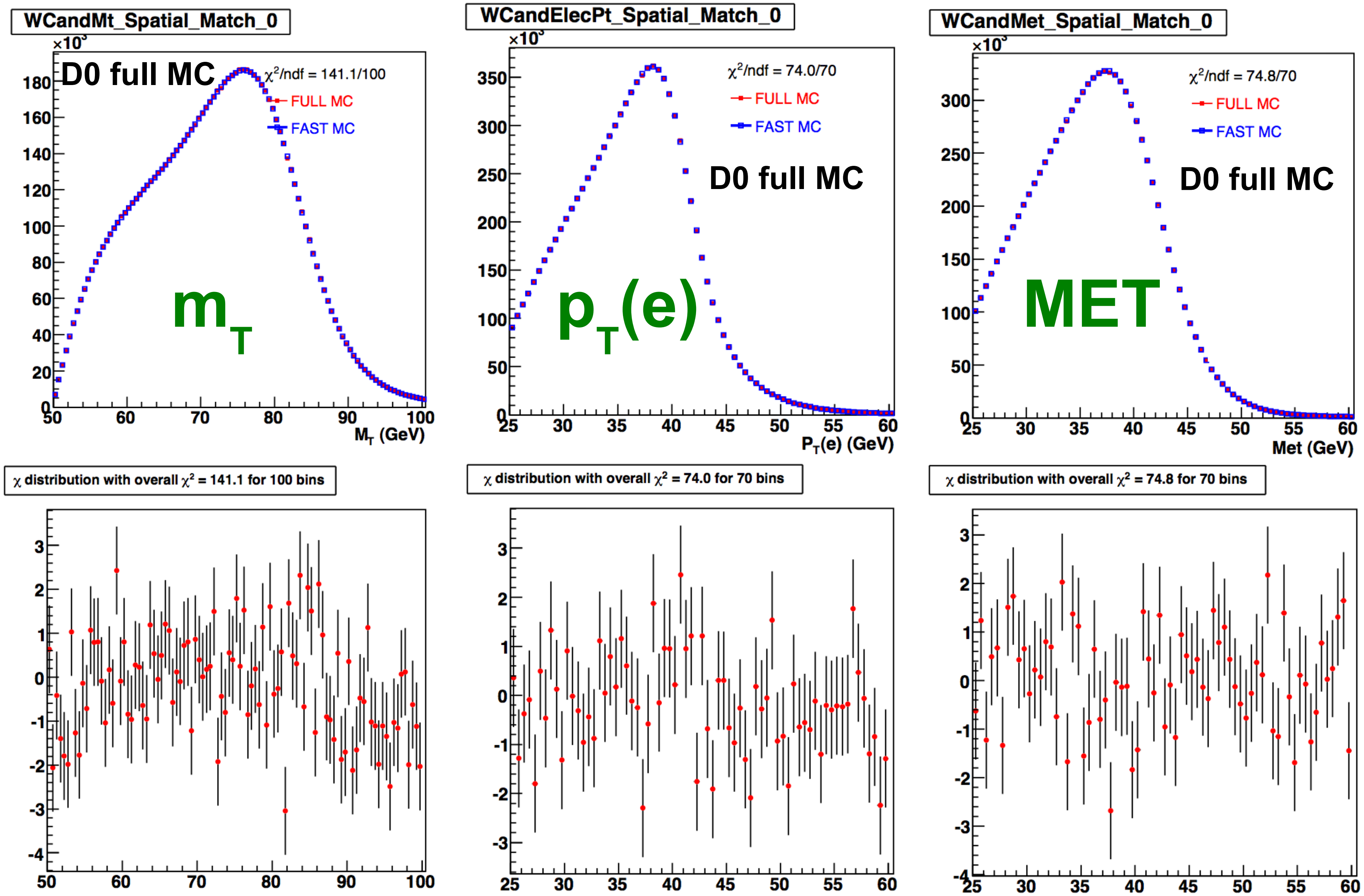
These are the same W candidates in the data. The blue band represents the uncertainties in the fast MC prediction due to the uncertainties in the recoil tune from the finite Z statistics.

Good agreement between data and parameterised Monte Carlo.

Backgrounds



MC closure test



9.8 M events after selection

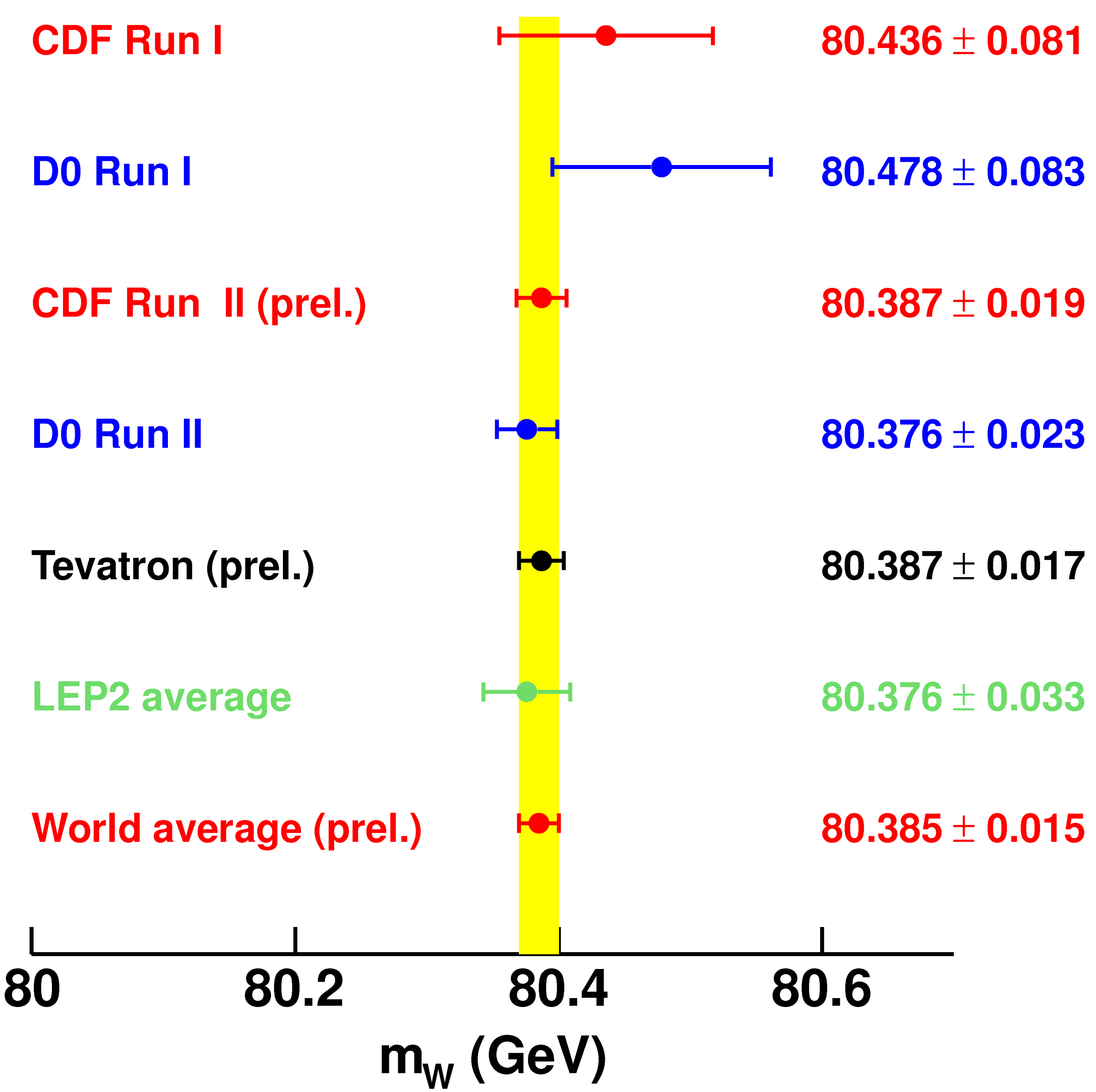
m_T: 80.448 ± 0.005 (stat) GeV

$p_T(e)$: 80.448 ± 0.005 (stat) GeV

Met: 80.455 ± 0.006 (stat) GeV

Input value: 80.450 GeV

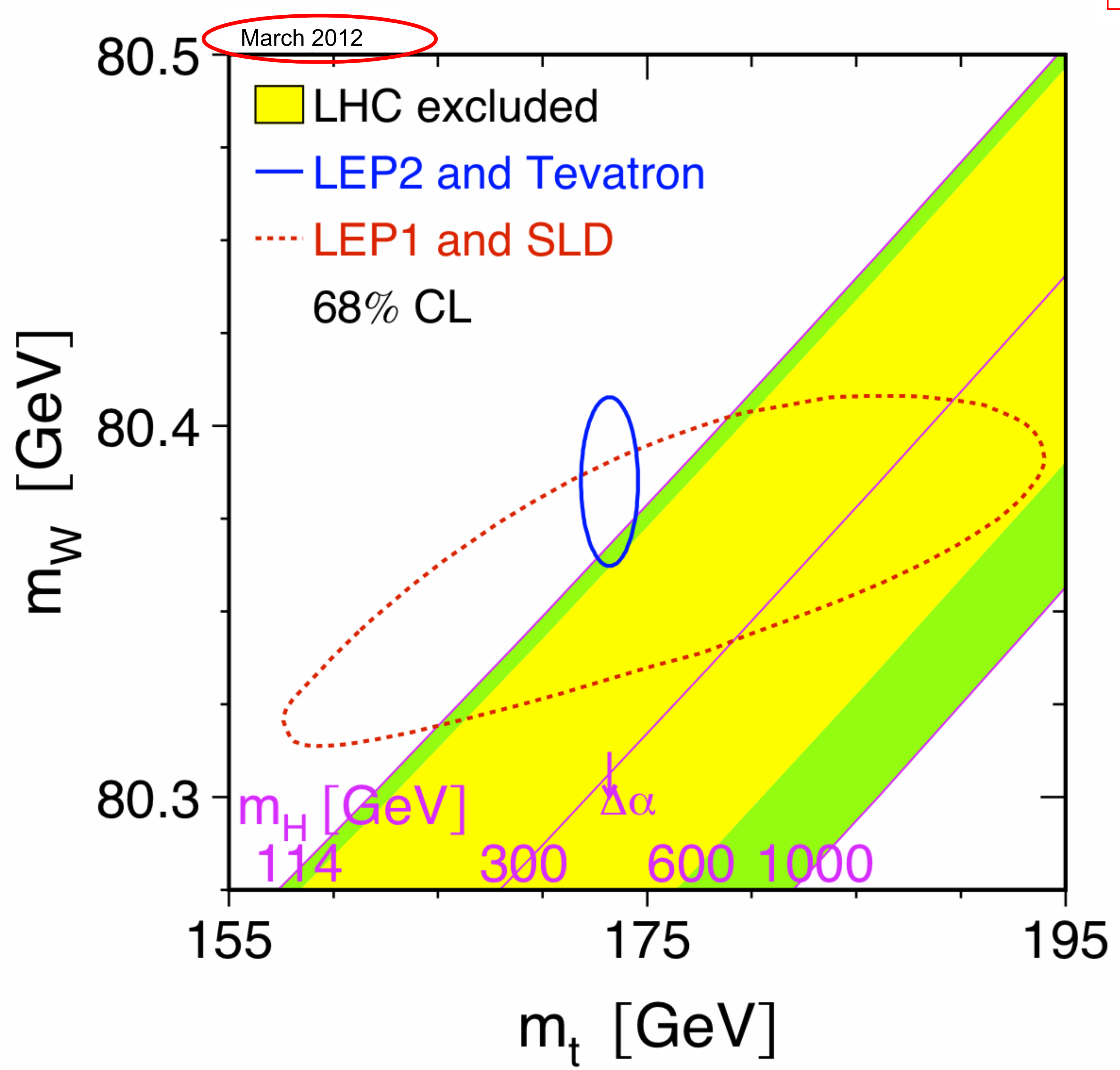
New averages



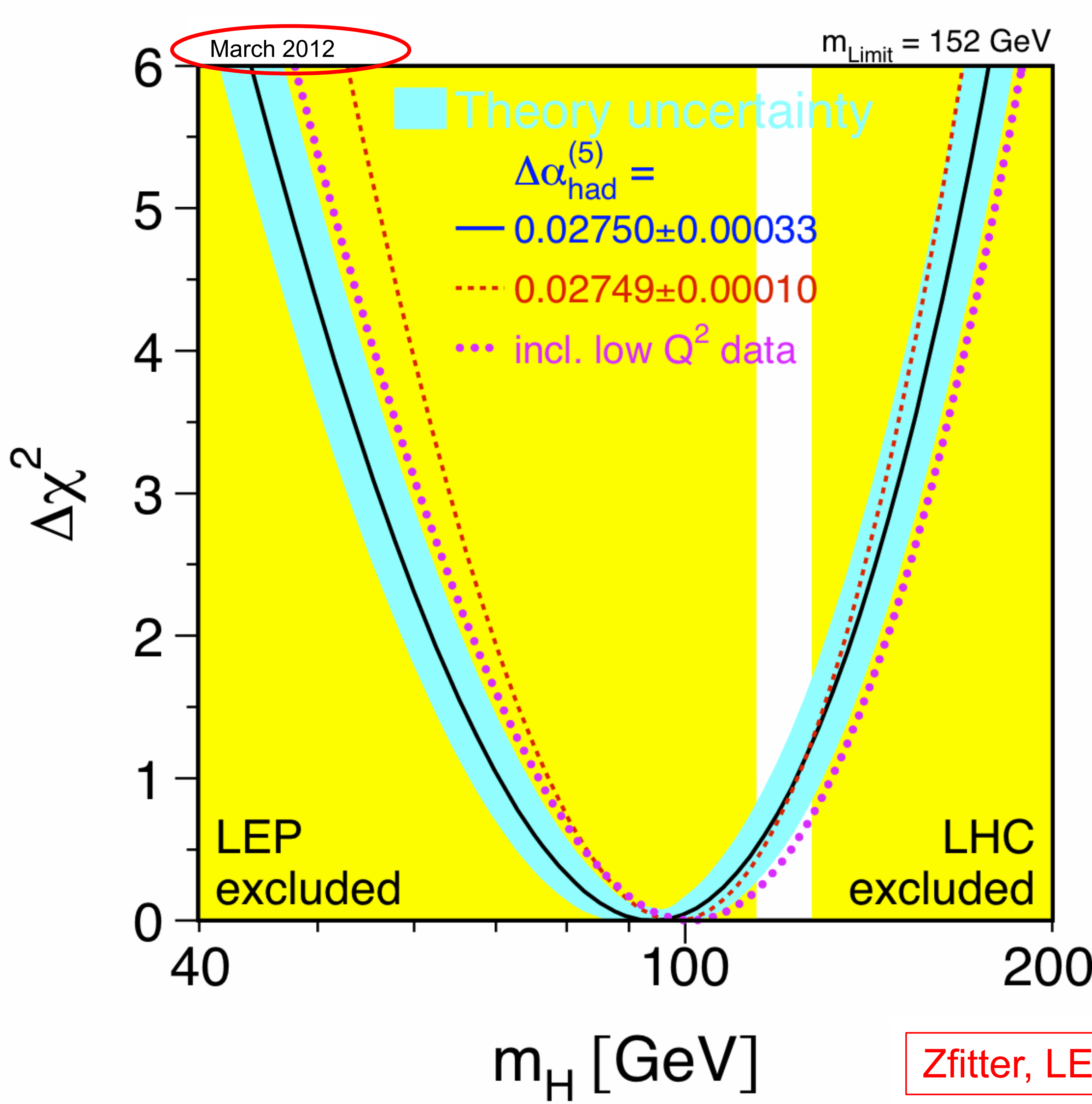
Our new 4.3 fb-1 result assumes a W width of 2100.4 MeV. For the purpose of combination, the width hypothesis has been adjusted to the SM value 2093.2 ± 2.2 MeV.

Now!

Zfitter, LEPEWWG



Constraint on the Higgs boson 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.