

Electroweak Physics Current Status

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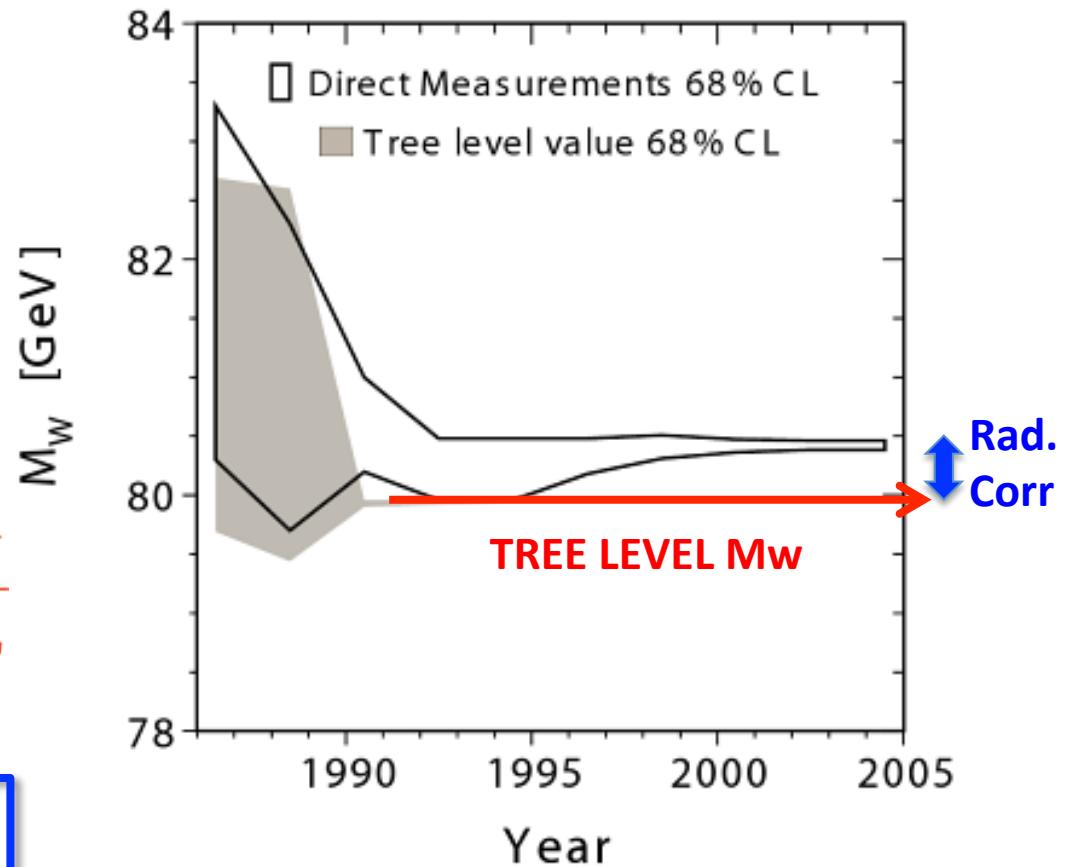
Measurements that probe radiative corrections

- verify consistency of SM
- probe for new physics

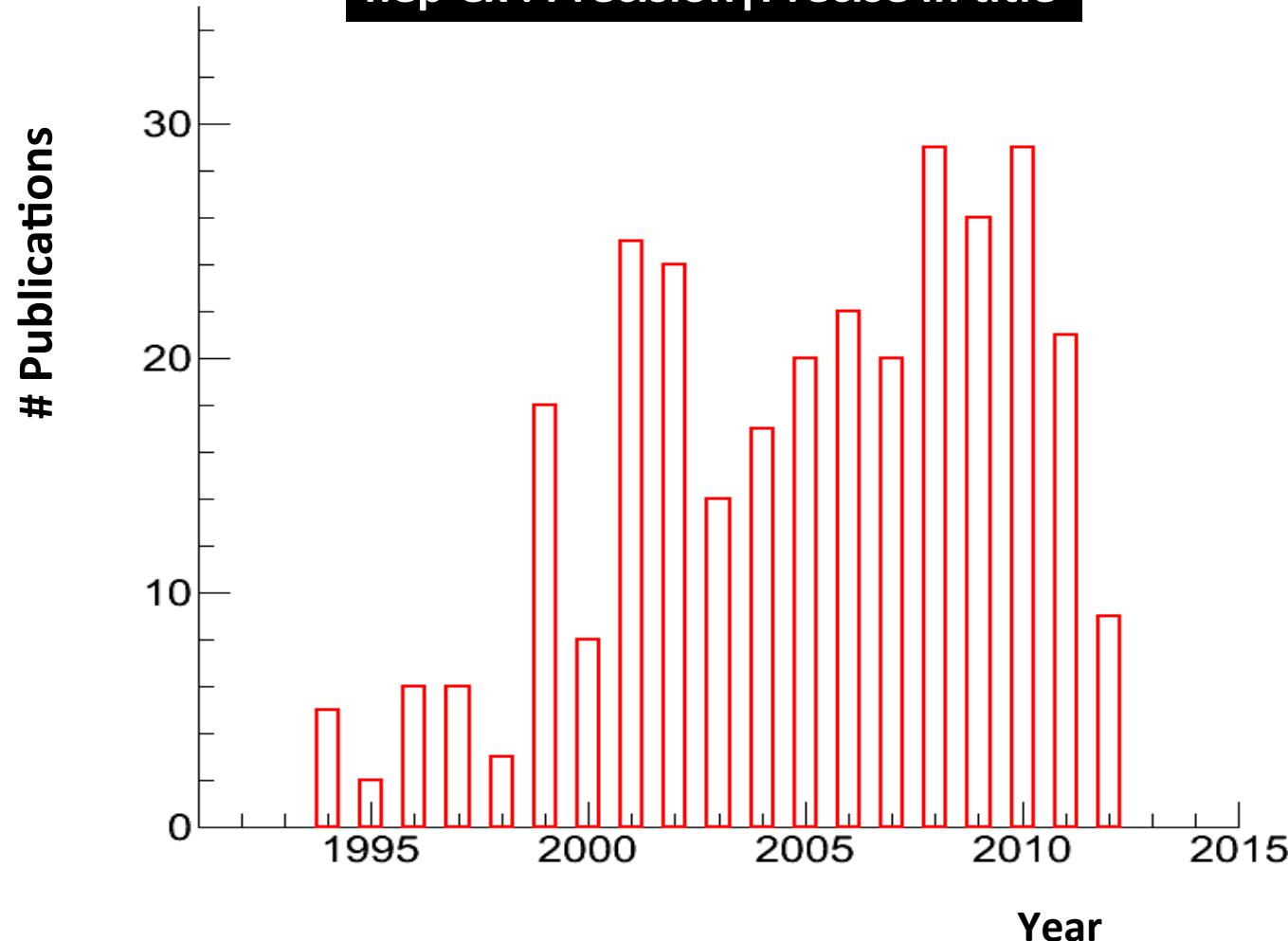
Size of corrections
necessitates “precision”
measurements

$$M_W^2 \left(1 - \frac{M_W^2}{M_Z^2} \right) = \frac{\pi \alpha_{EM}}{\sqrt{2} G_F}$$

Precision means < 0.5%



hep-ex : Precision | Precise in title



Precision in the last month

arXiv.org > hep-ph > arXiv:1204.3898

High Energy Physics – Phenomenology

10% ?

Precision Jet Substructure from Boosted Event Shapes

3%

Phys. Rev. Lett. 108, 171802 (2012) [7 pages]

Precise Measurement of the CP Violation Parameter $\sin 2\phi_1$ in $B^0 \rightarrow (c\bar{c})K^0$ Decays

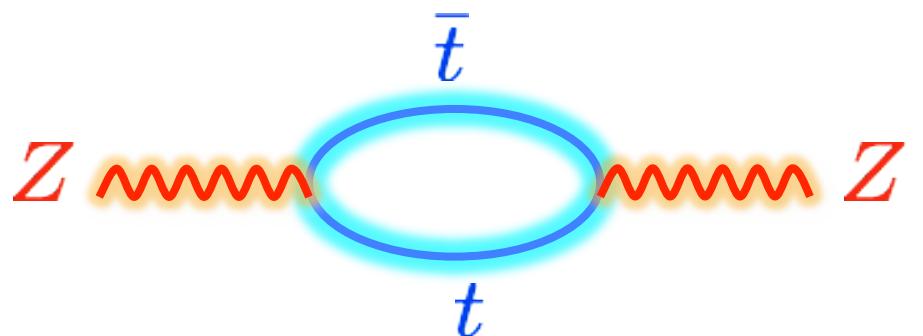
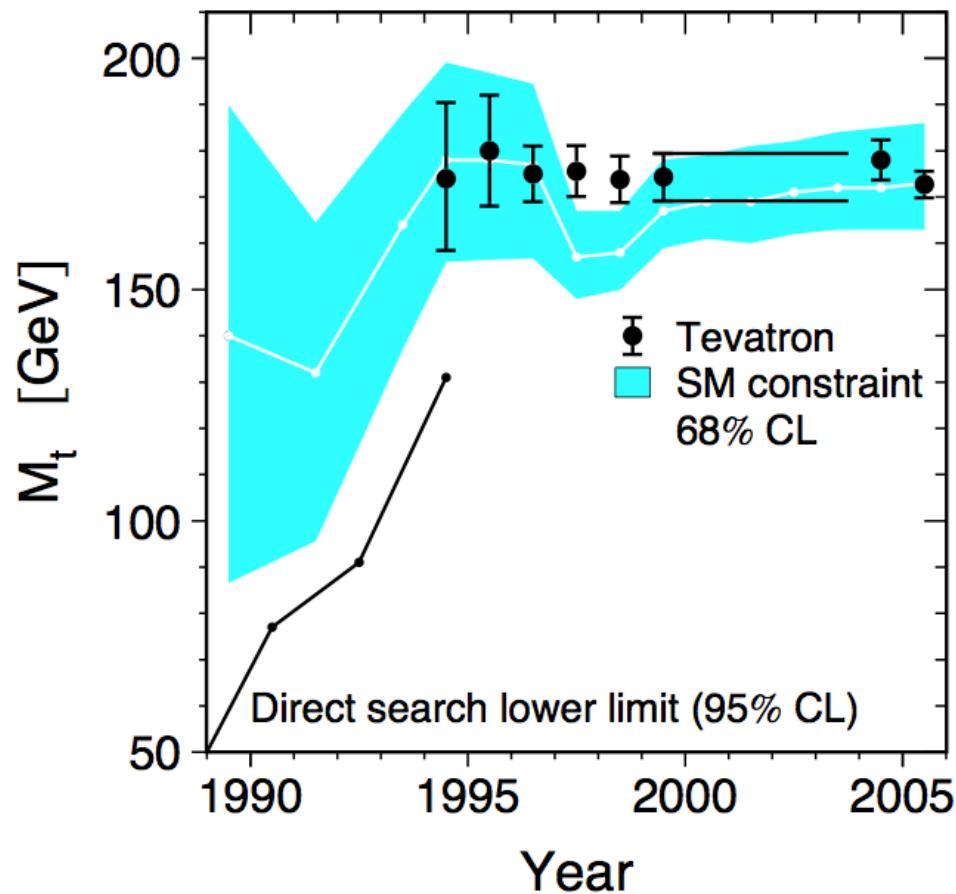
0.5 %

0.02%

Phys. Rev. Lett. 108, 151803 (2012) [8 pages]

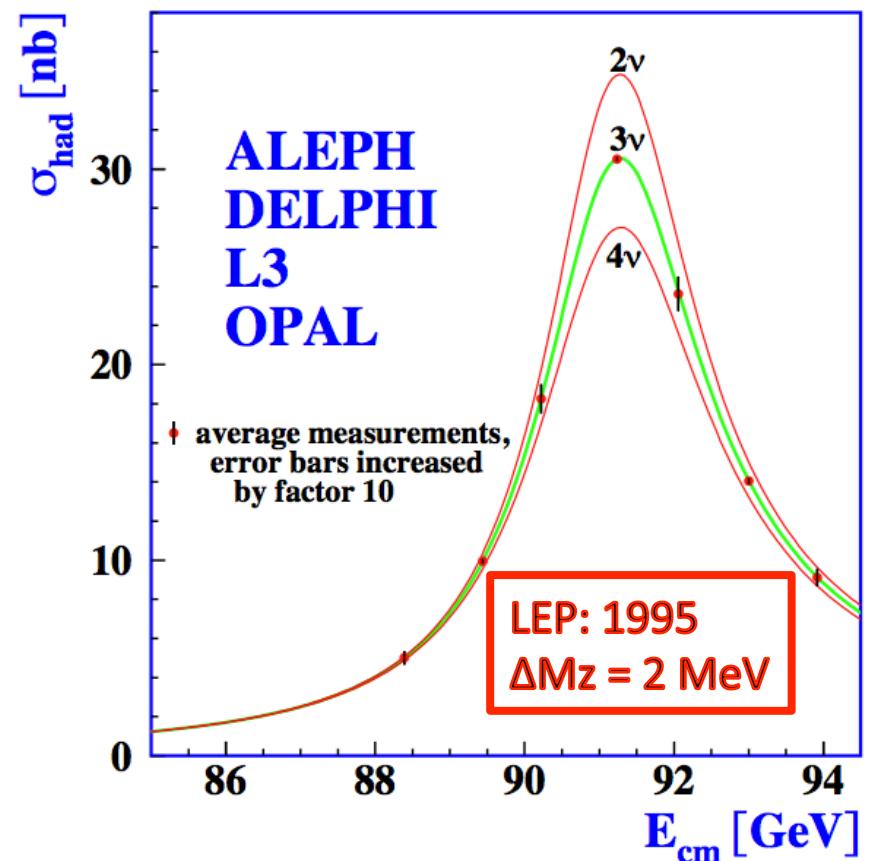
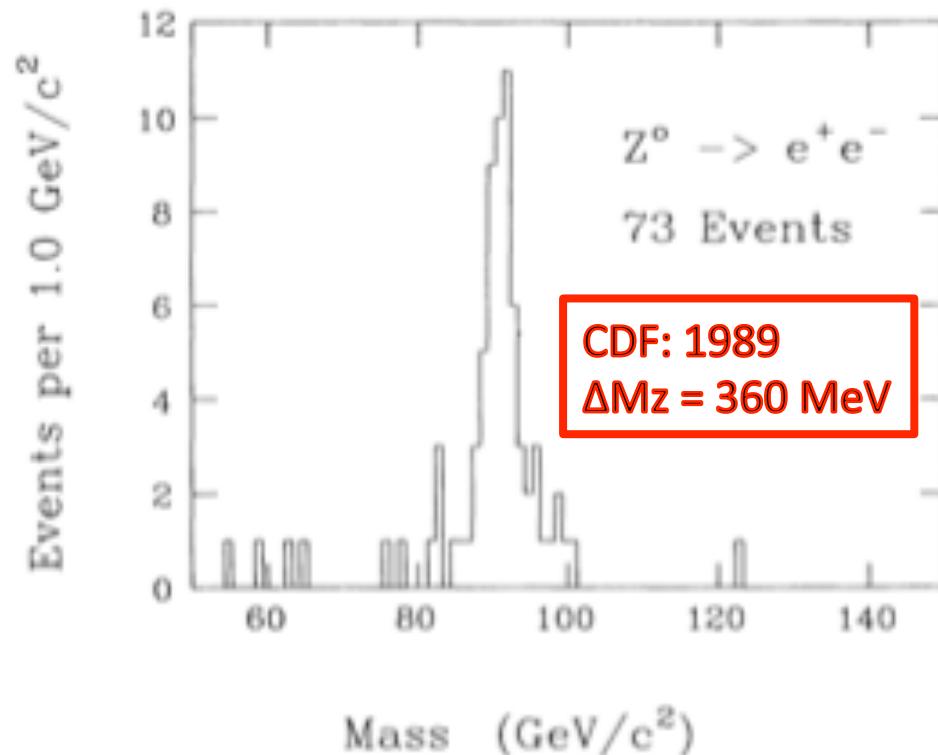
Precise Measurement of the W -Boson Mass with the CDF II Detector

Motivation for Precision EWK



Probe the loop corrections

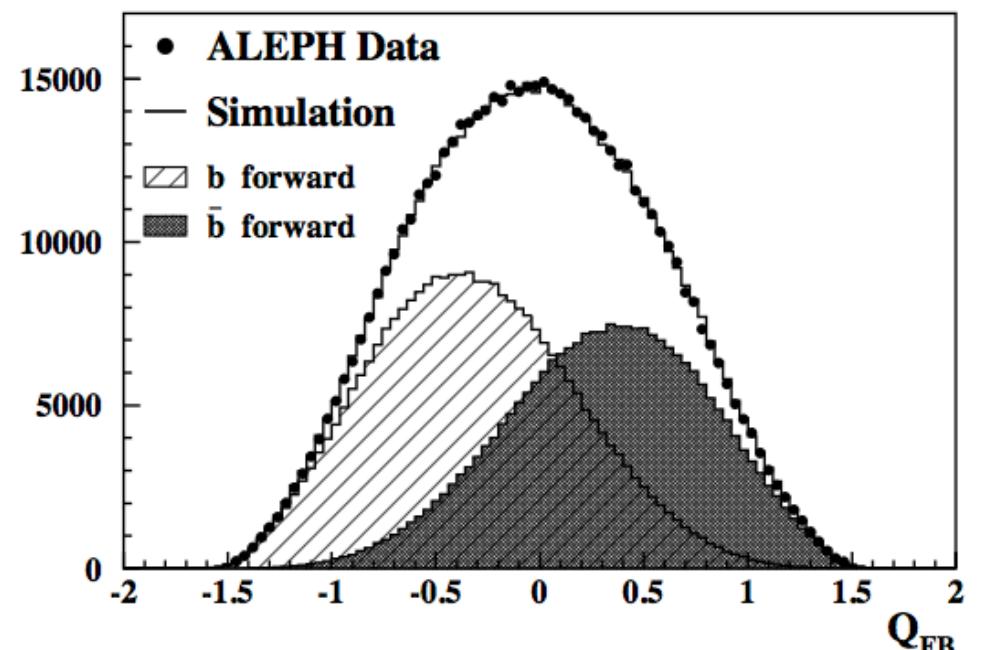
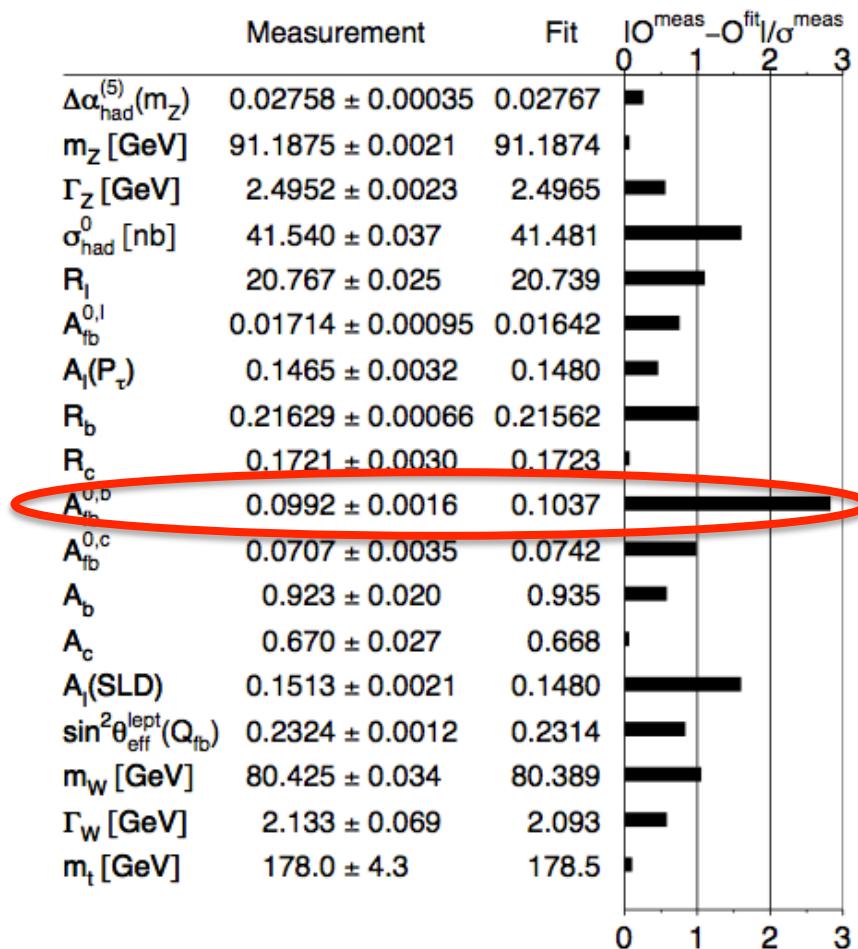
Precision at the Z Pole



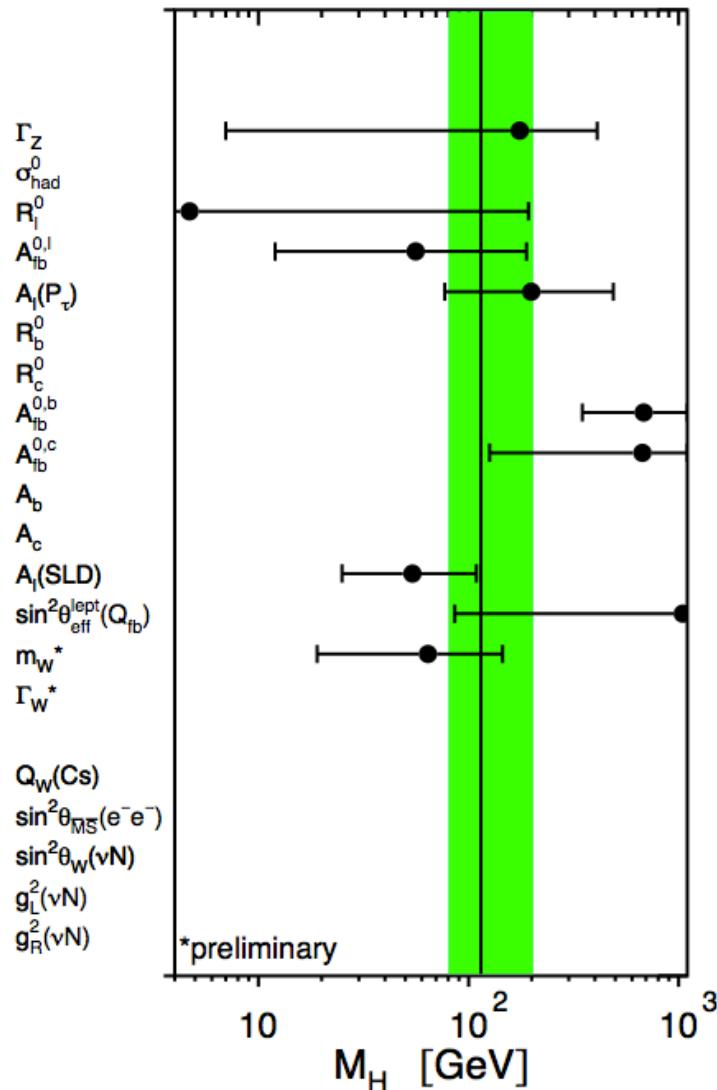
Predicted : Top Mass = 173 ± 20 GeV
light neutrinos = 2.985 ± 0.008

Precision at the Z Pole

From Z pole data alone: $m_H = 111^{+190}_{-60}$ GeV



At the start of Tevatron Run-II



$A_{FB}^b, A_l(SLD), m_W$

had similar weights in constraining m_H

$$m_H = 129^{+74}_{-29} \text{ GeV}$$

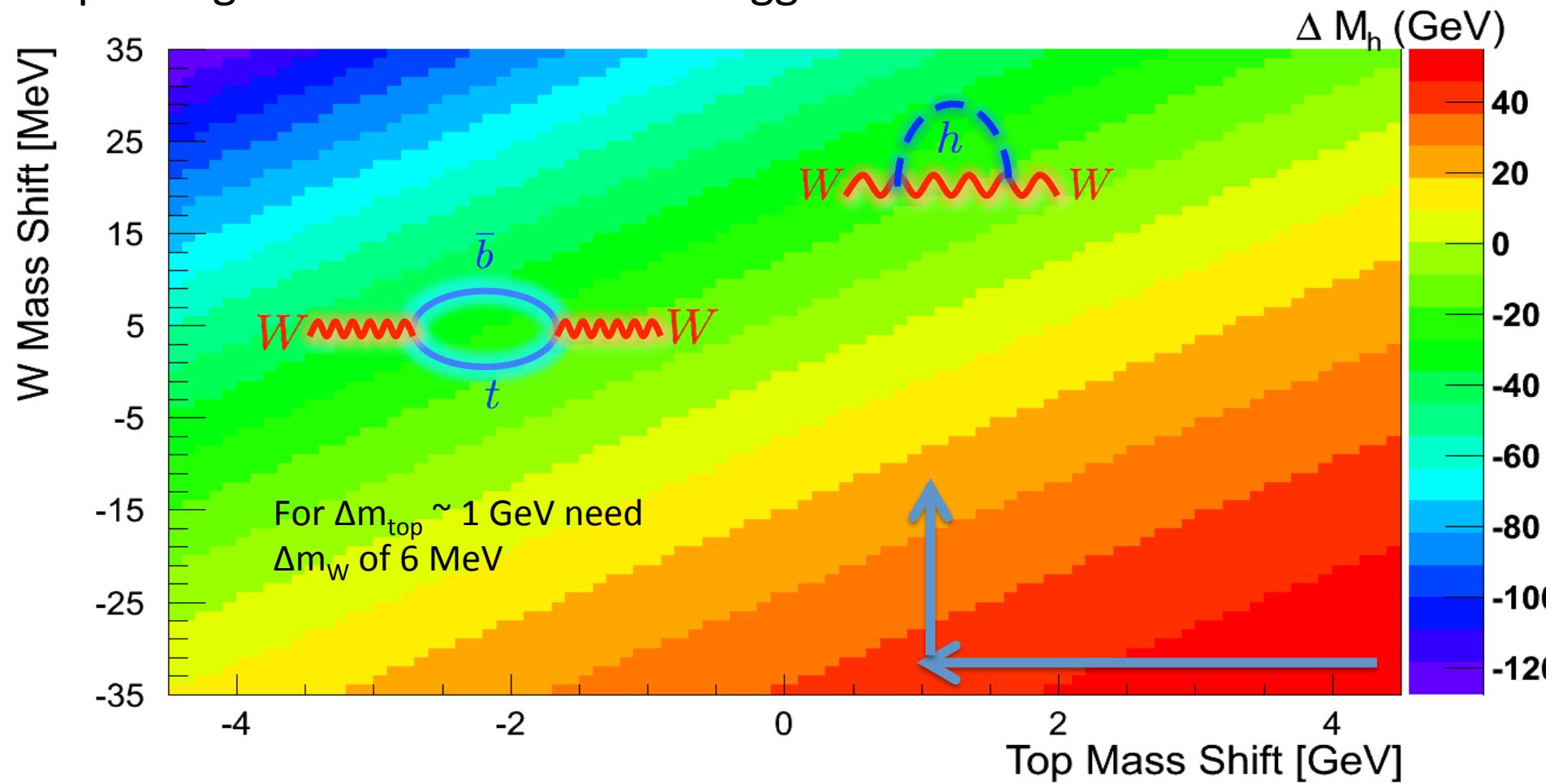
$$m_H < 285 \text{ GeV (95\% CL)}$$

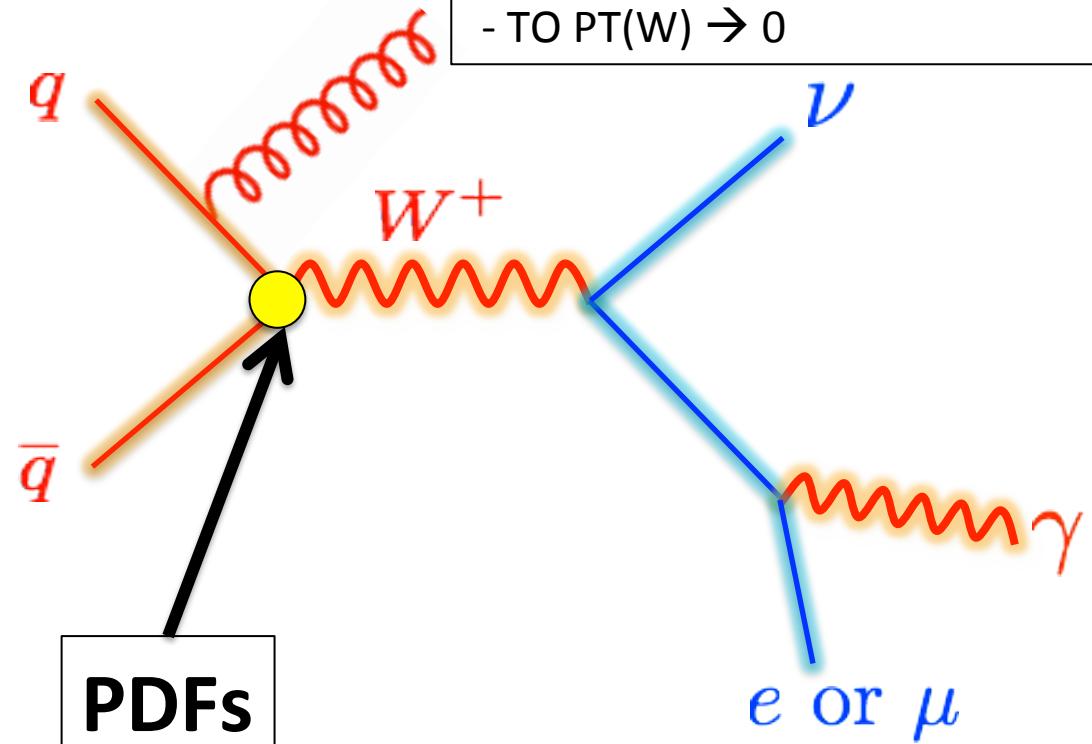
$$\Delta m_W \sim 30 \text{ MeV}$$

$$\Delta m_{top} \sim 4 \text{ GeV}$$

W and Top Mass

Reducing M_W uncertainty was (& still is) the determining factor in improving the constraint on the Higgs mass





INITIAL STATE RADIATION (aka RECOIL)

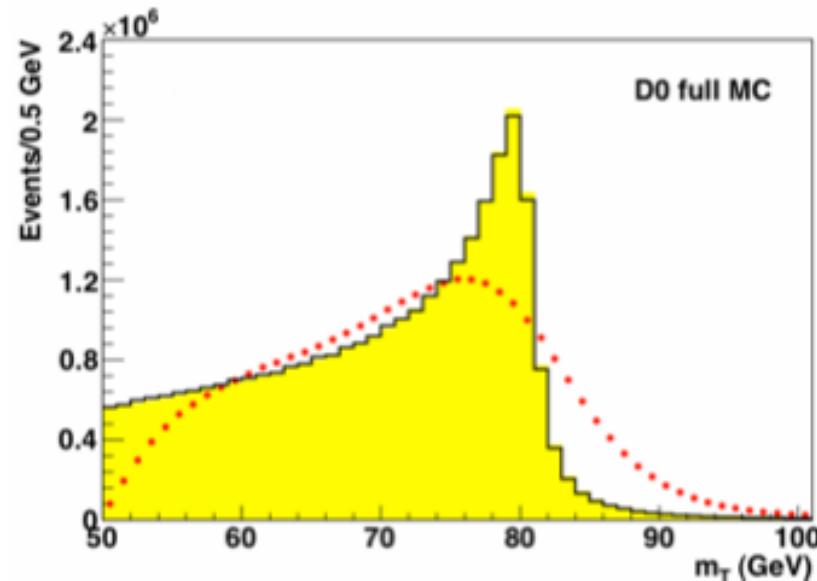
- BOTH QCD AND QED
- TO $PT(W) \rightarrow 0$

PILEUP/UE

FINAL STATE QED

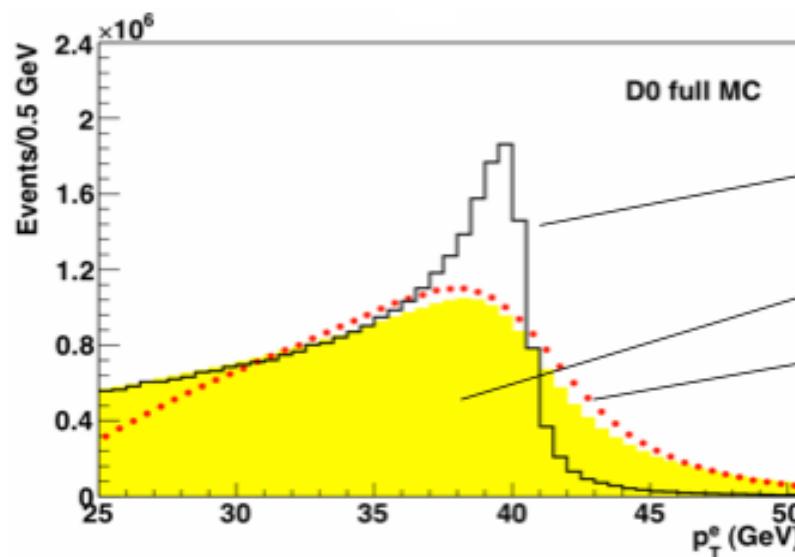
Need to model each of these effects to a precision of ~ 5 MeV
And understand response of detector to a similar level

W Mass



Transverse quantities used and transverse mass is most incisive

$$M_T = \sqrt{2p_T^e E_T (1 - \cos \Delta\phi)}$$



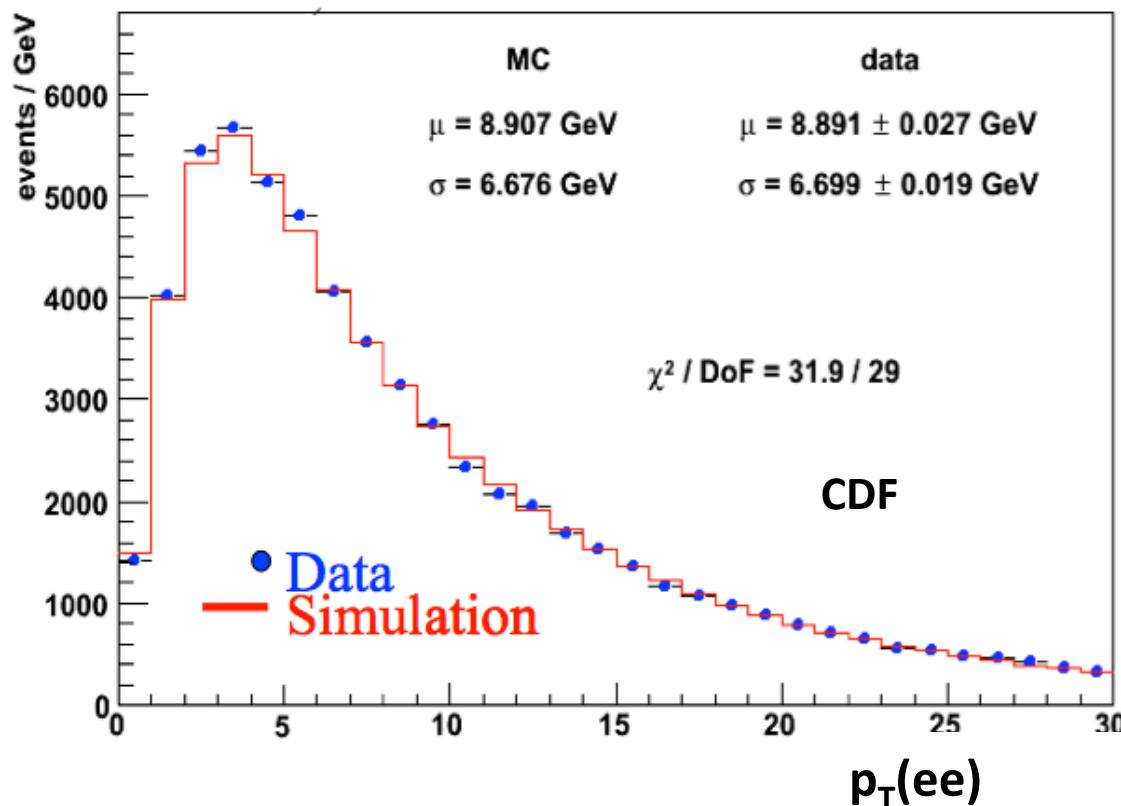
- No $p_T(W)$
- $p_T(W)$ included
- Detector Effects added

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

Use RESBOS : NLO resummation + non perturbative ad-hoc parameterisation at low p_T

The W mass uses data at $p_T(W) < 30$ to reduce the # jets.

Easier to simulate/parameterise “soft” events.



Tune RESBOS / BNLY g_2 parameter from Z events

Assume W / Z pT ratio is accurately defined

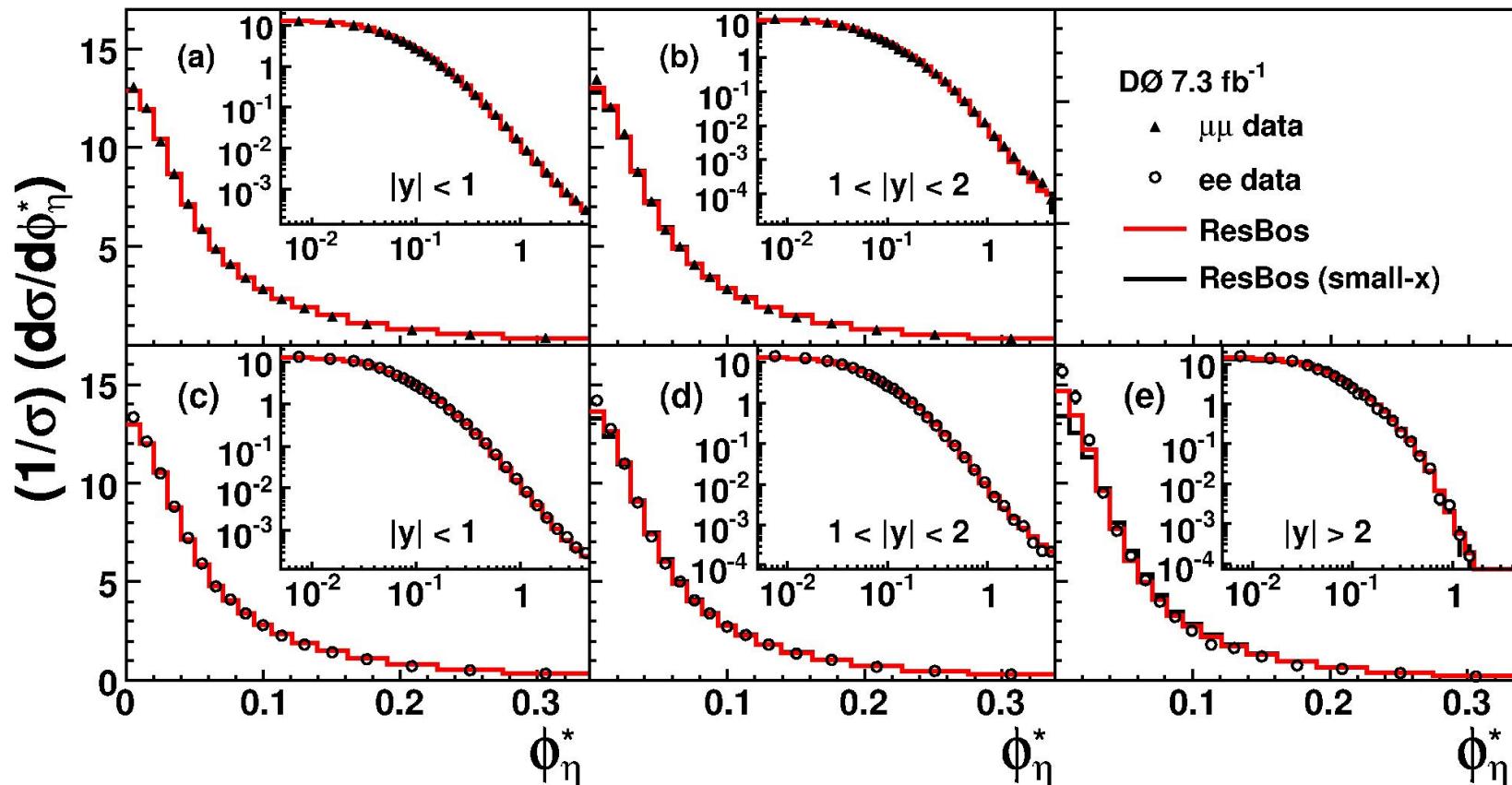
CDF	$\Delta M_W = 5 \text{ MeV}$	2.2 fb^{-1}
D0	$\Delta M_W = 2 \text{ MeV}$	4.3 fb^{-1}



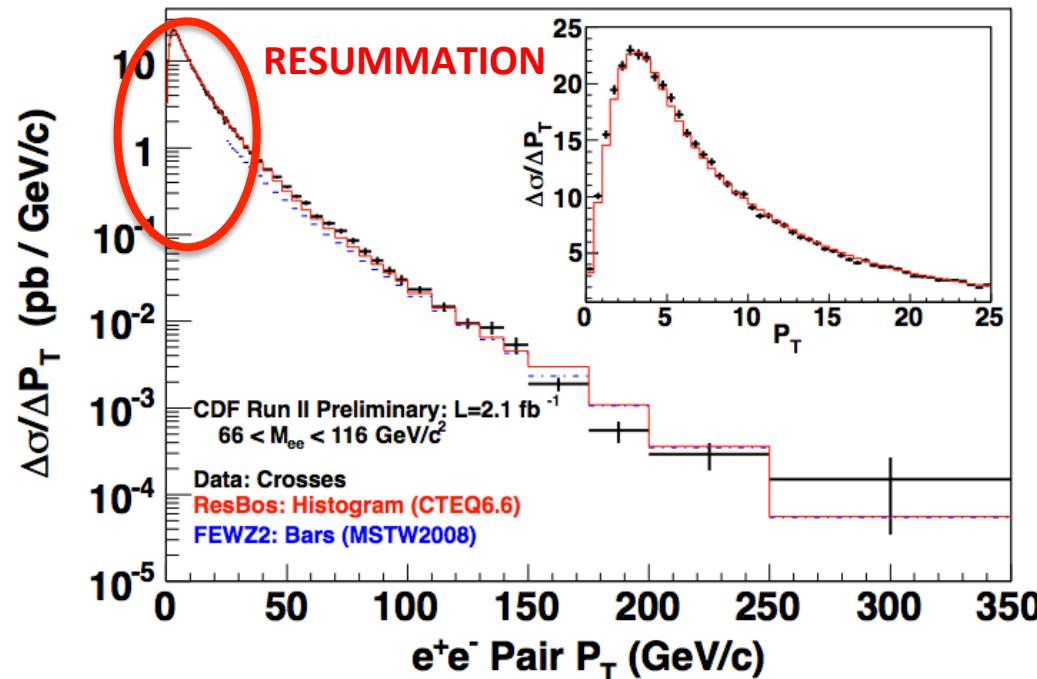
$\Sigma p_T : D0 (\phi^*)$ vs RESBOS

D0 analysis using bespoke variable ϕ^* to minimise detector effects

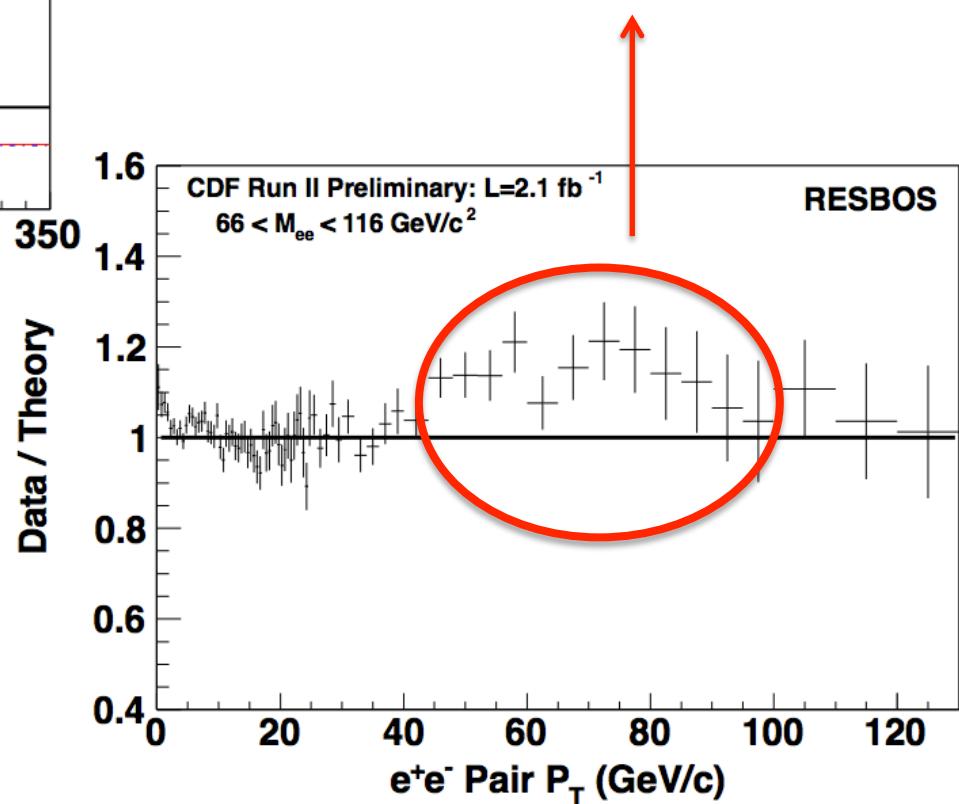
Shows RESBOS to provide very good description of data in Mw region.



Z pT : CDF Unfolded vs RESBOS



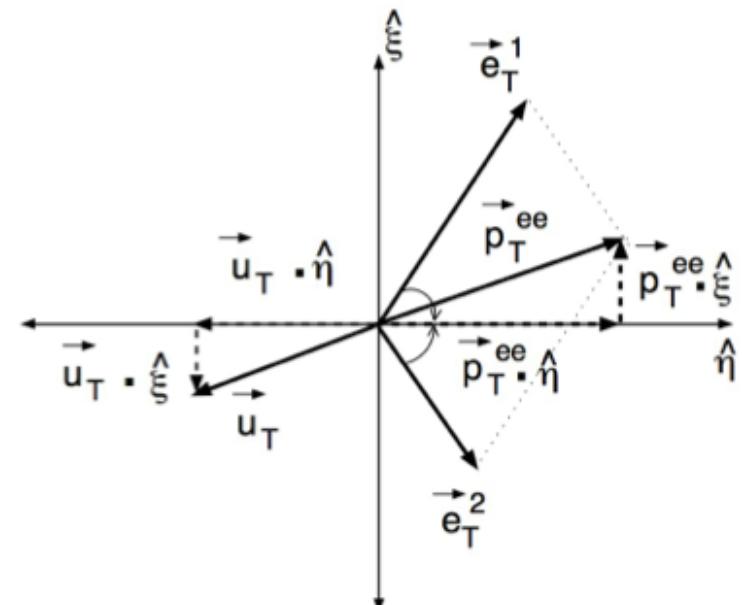
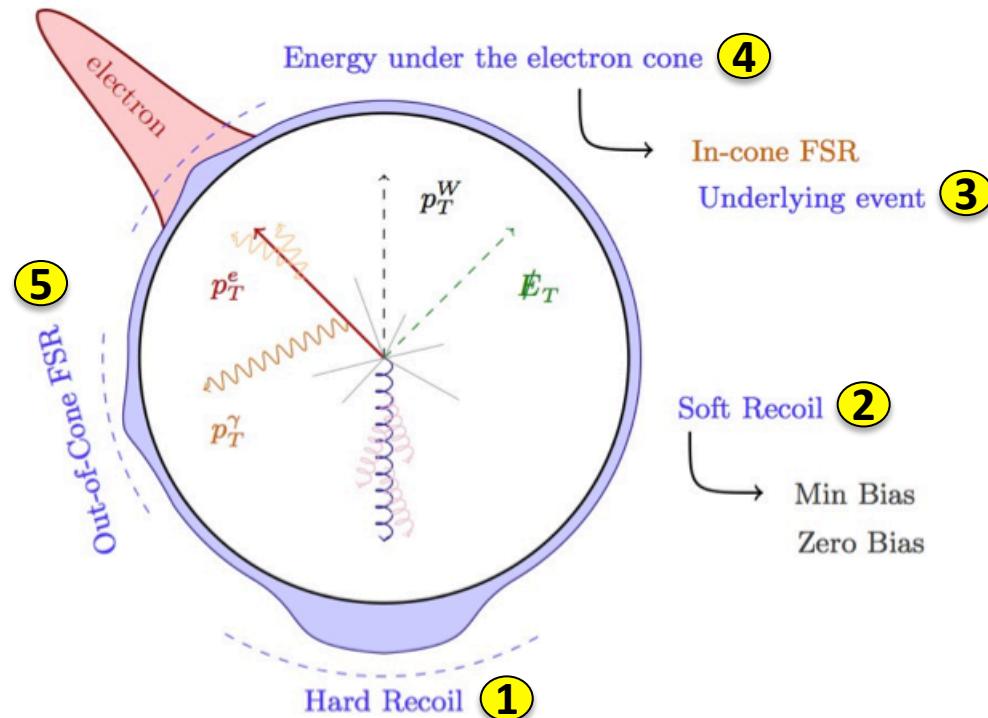
Some issues outside M_W region where resummed calculation is “matched” to NLO.



Detector Response to QCD ISR / UE

Use a parametric model tuned to Z and zero/min-bias events (luminosity dependence)

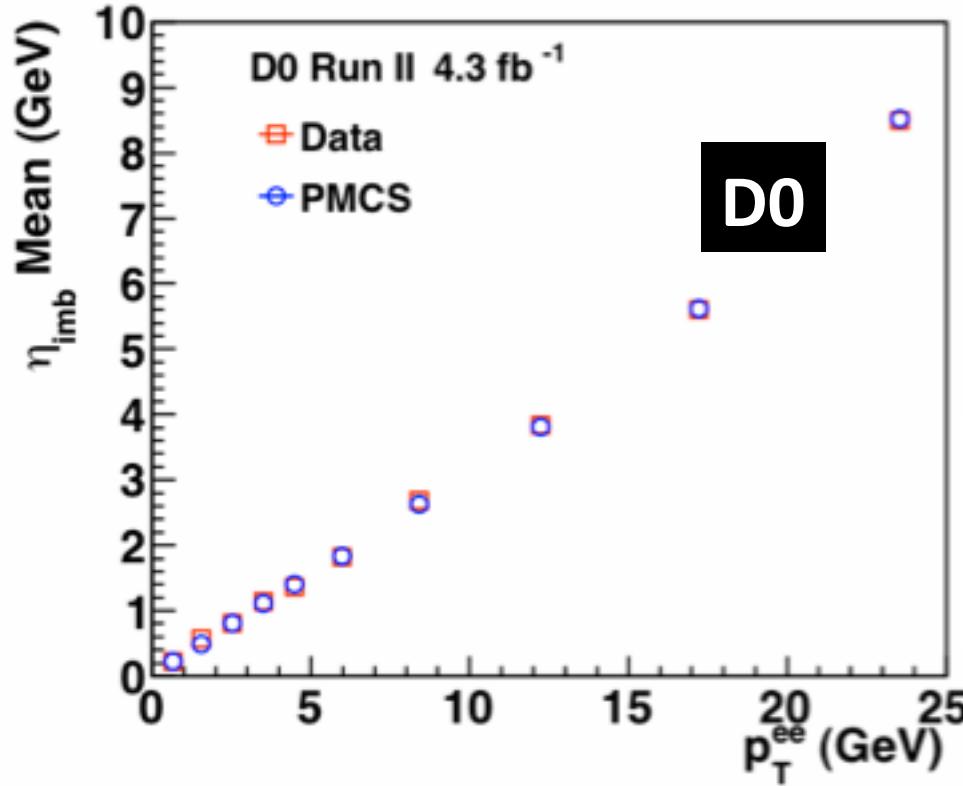
Model separately 5 contributions from.



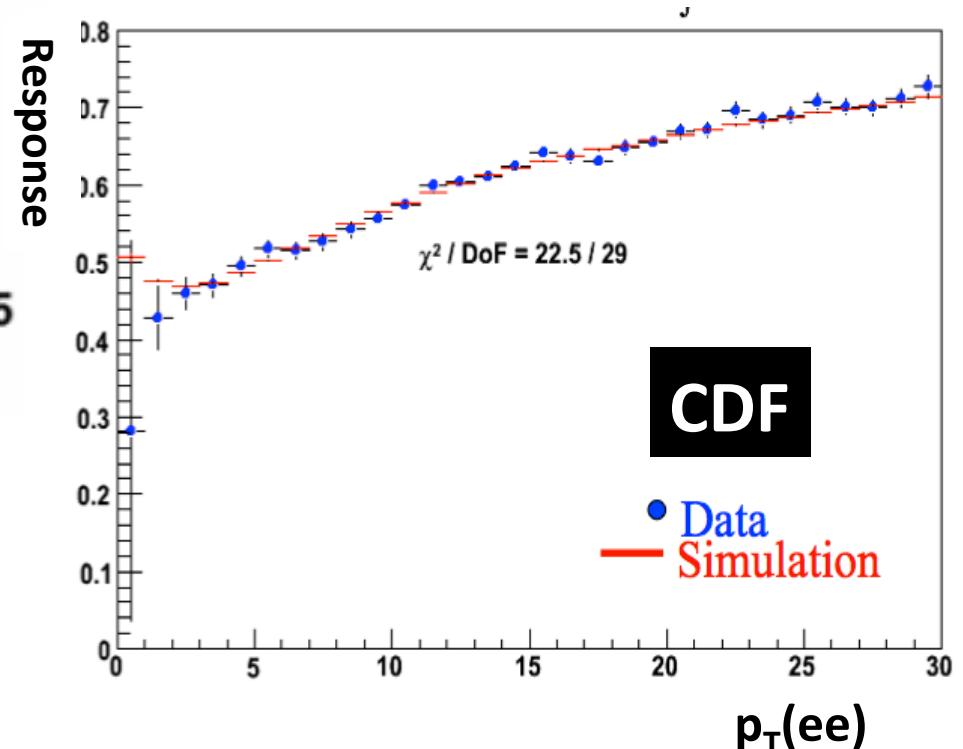
Separate contributions by considering recoil in the “UA2” directions.

Integrity of this model determines how well we model MET.

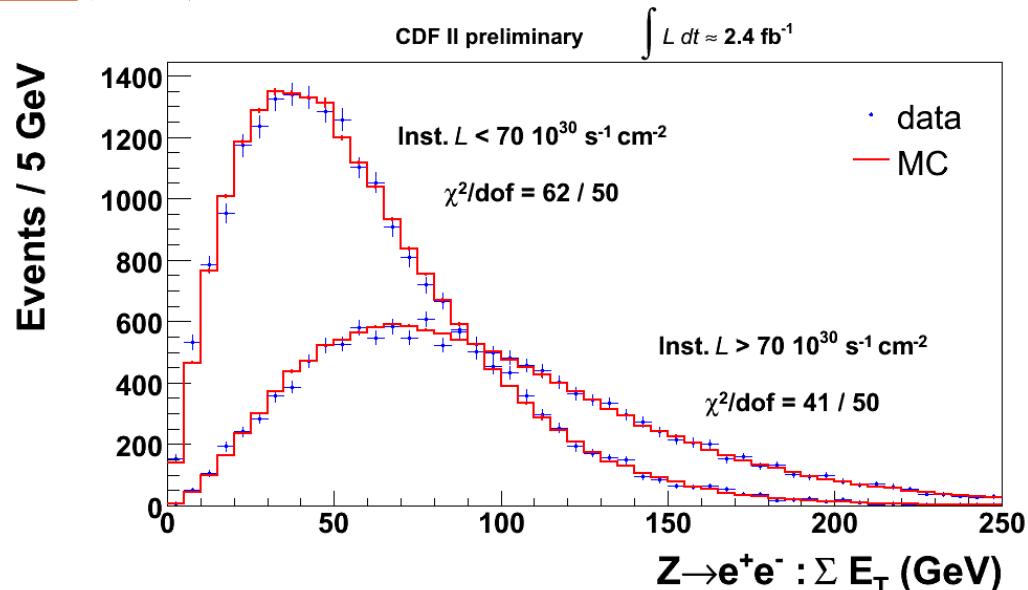
Recoil Response



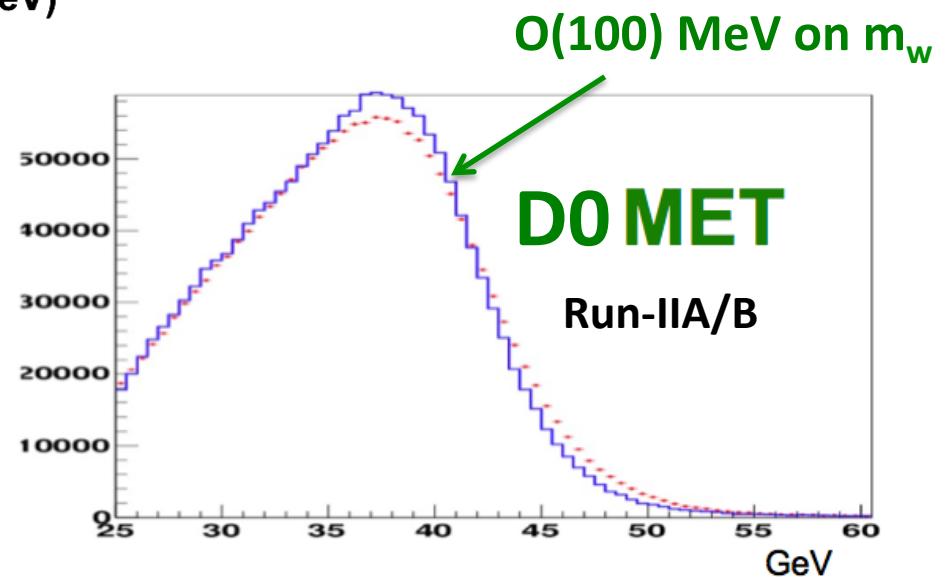
Typically only detect about 50-70% of
“true” QCD radiation



Pileup / Lumi dependence



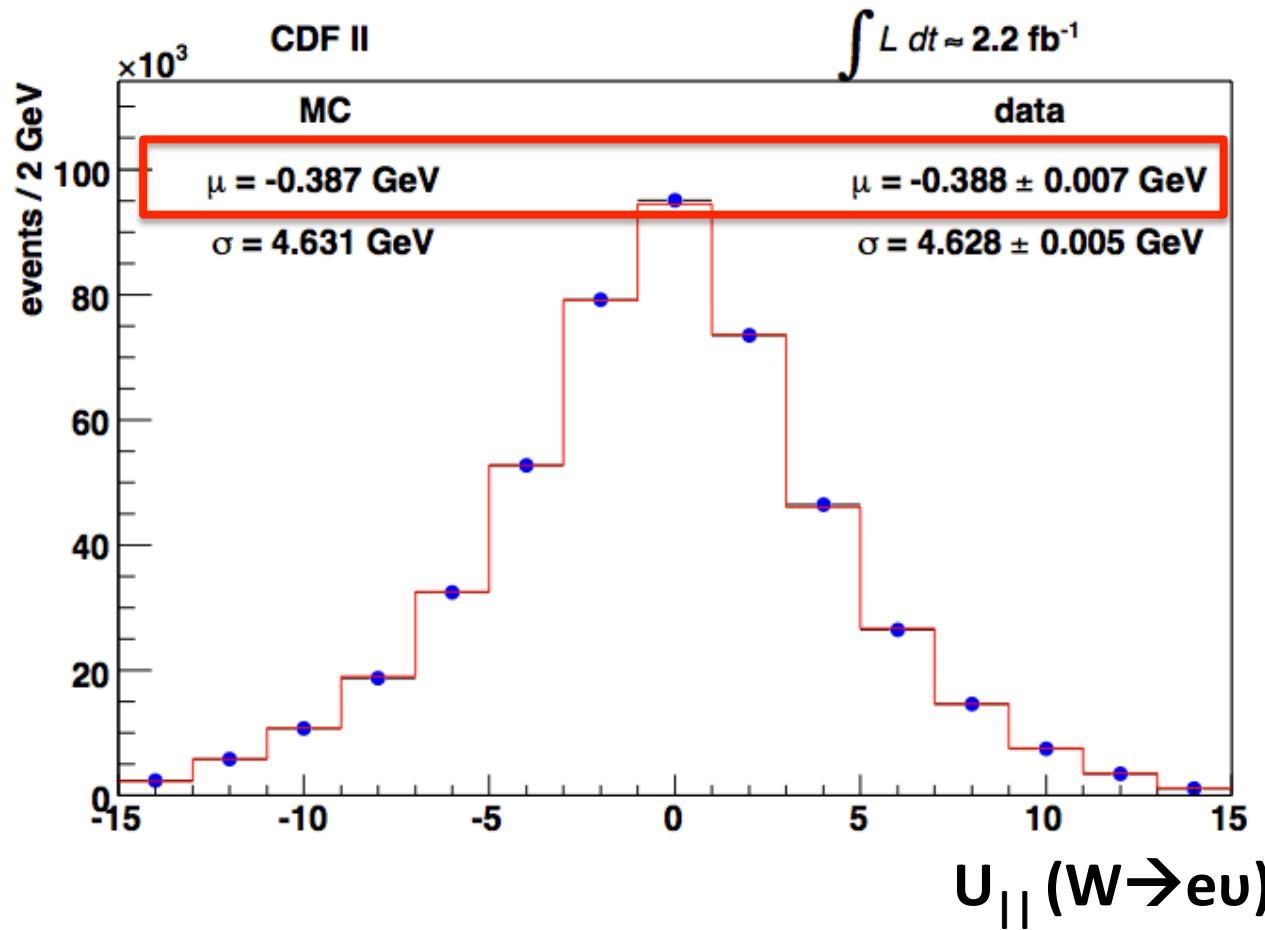
Described well enough by having model have explicit luminosity or ΣE_T dependence





Recoil Response

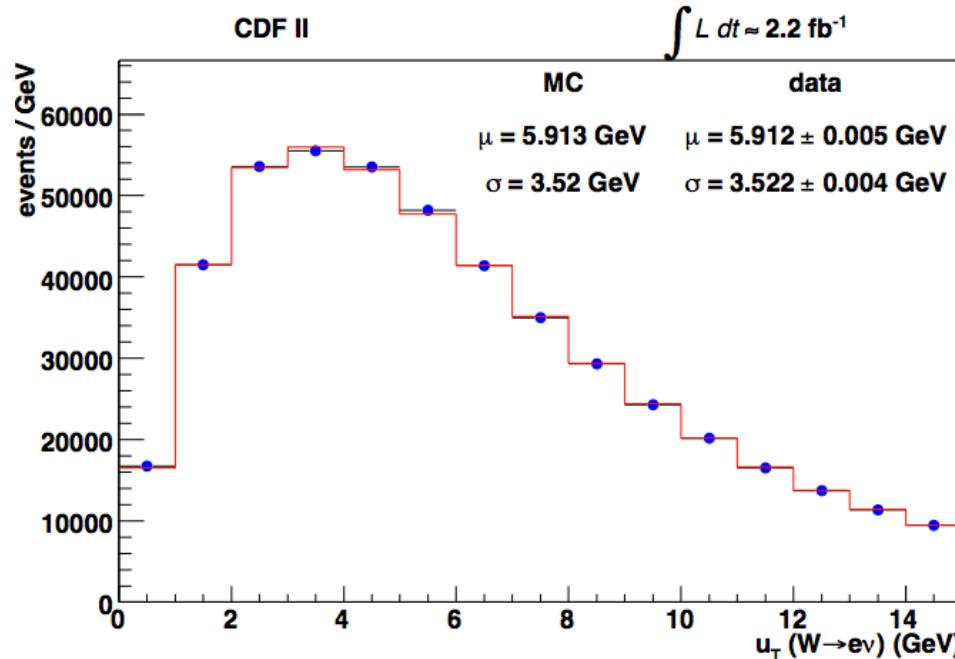
$$m_T \sim 2p_T^l + U_{||} \quad \leftarrow \text{Component of hadronic recoil along charged lepton direction}$$



This is good to 1 MeV !

"How well do you describe MET ?"

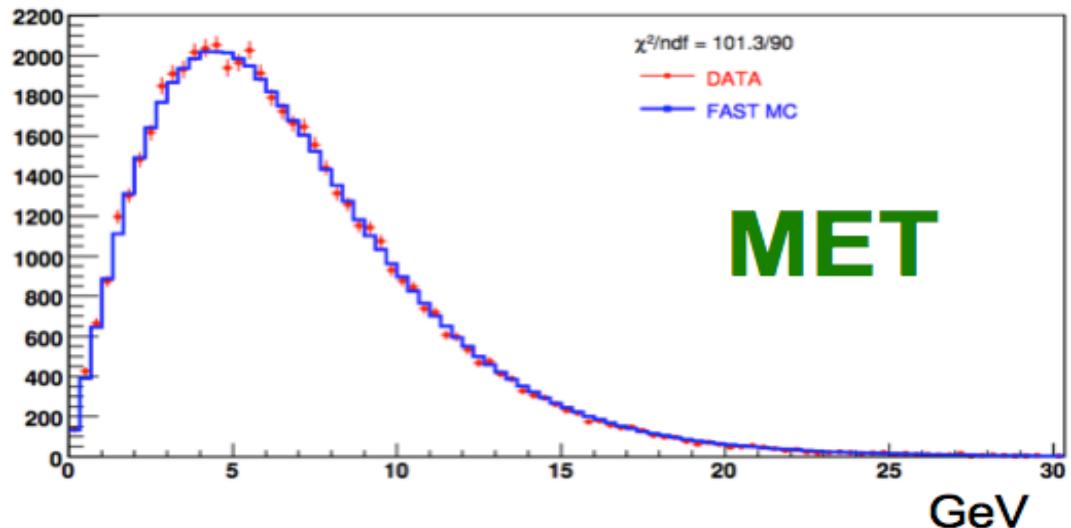
Recoil Response



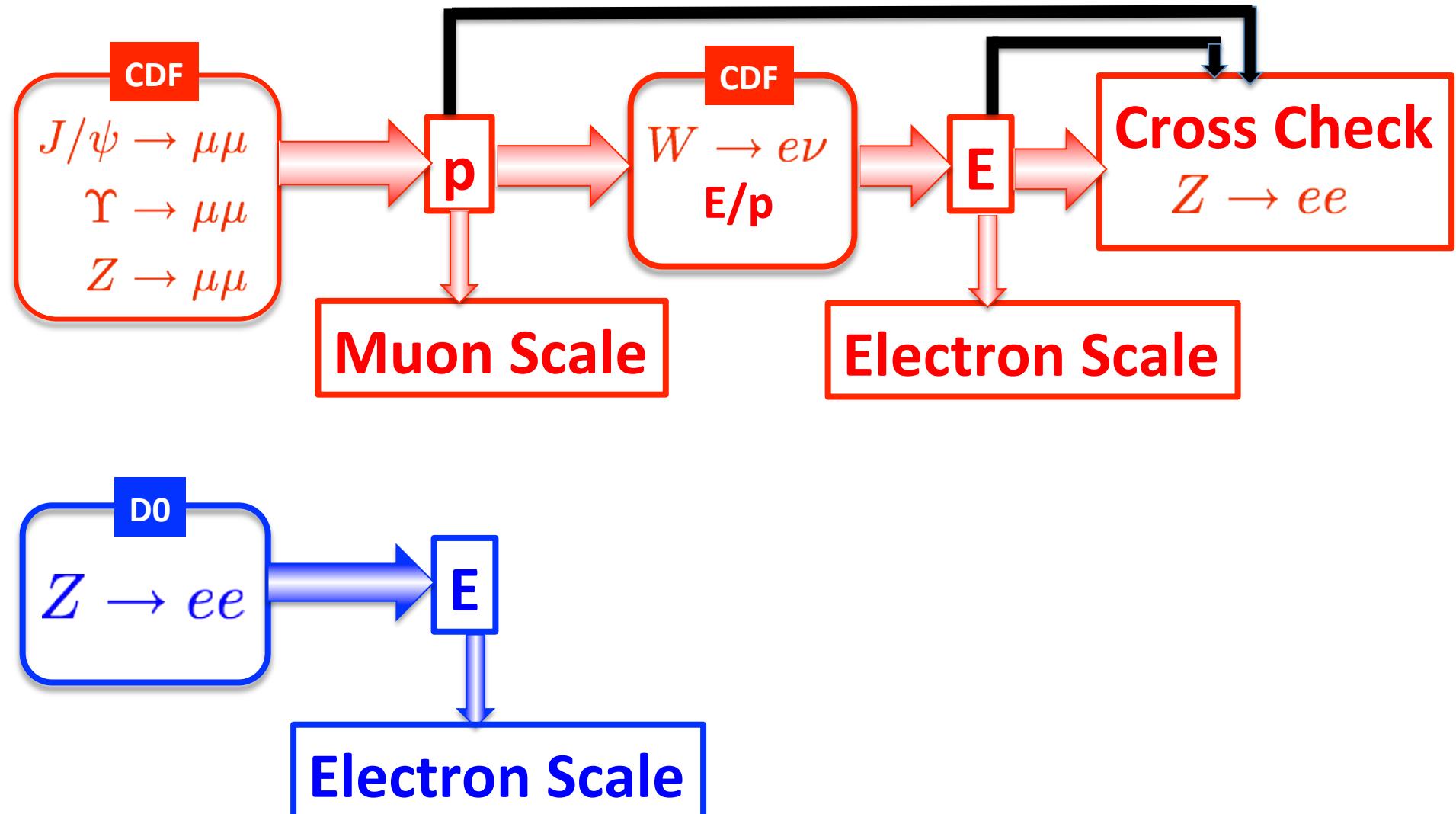
W p_T (from recoil)

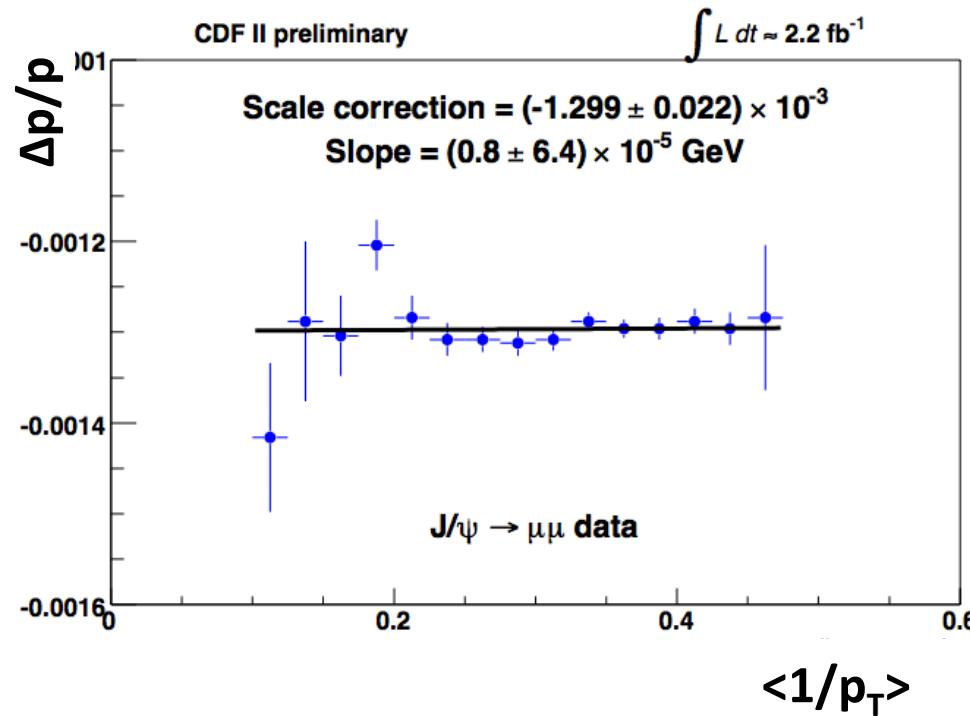
CDF
 $\Delta M_W = 6 \text{ MeV}$

D0
 $\Delta M_W = 5 \text{ MeV}$

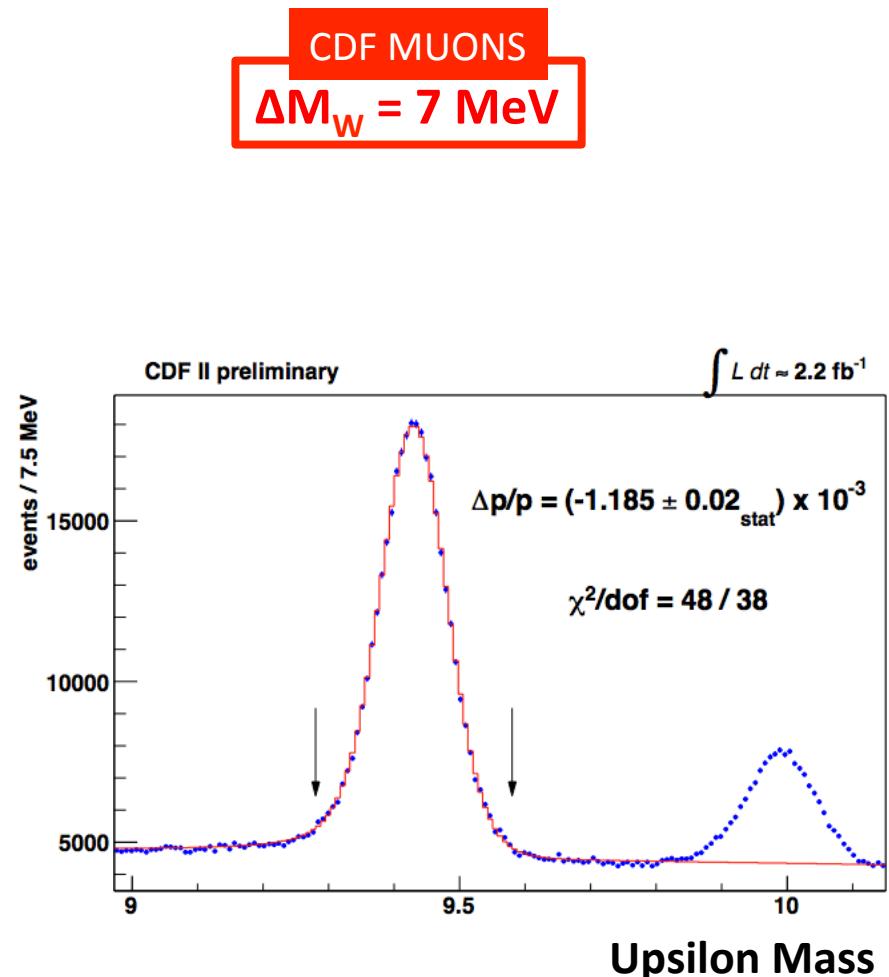


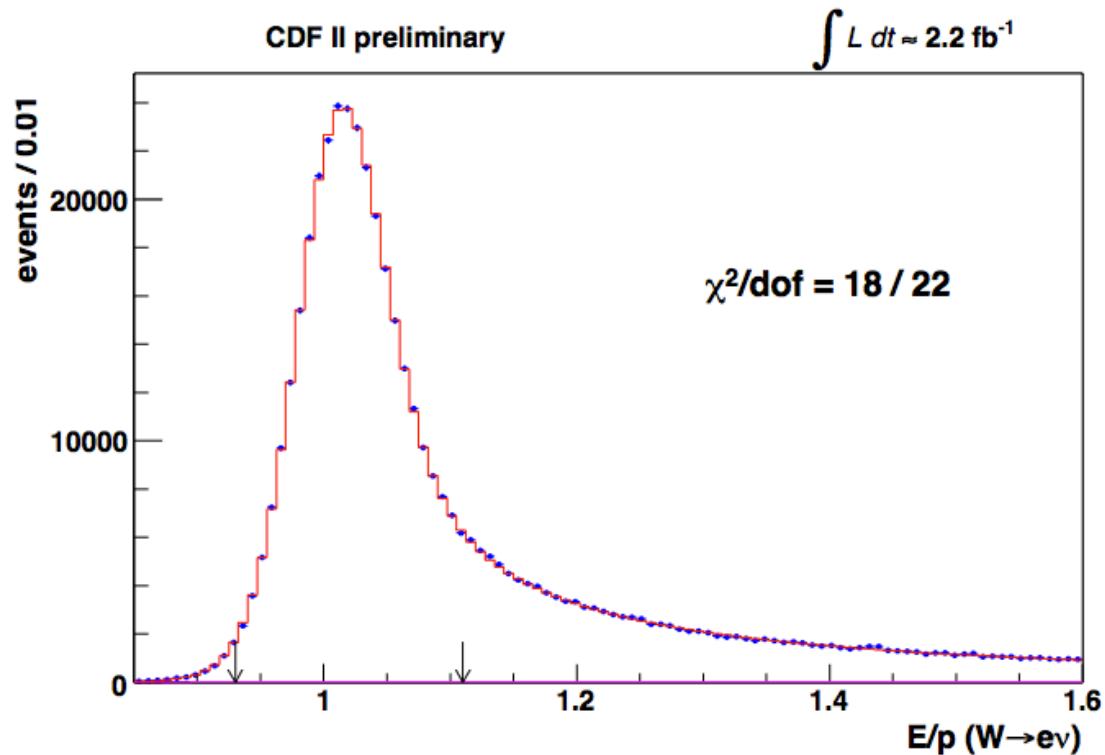
Lepton Energy Scale





With this p-scale measured $Z \rightarrow \mu\mu$
mass is: $7 \pm 12 \text{ MeV}$ below PDG

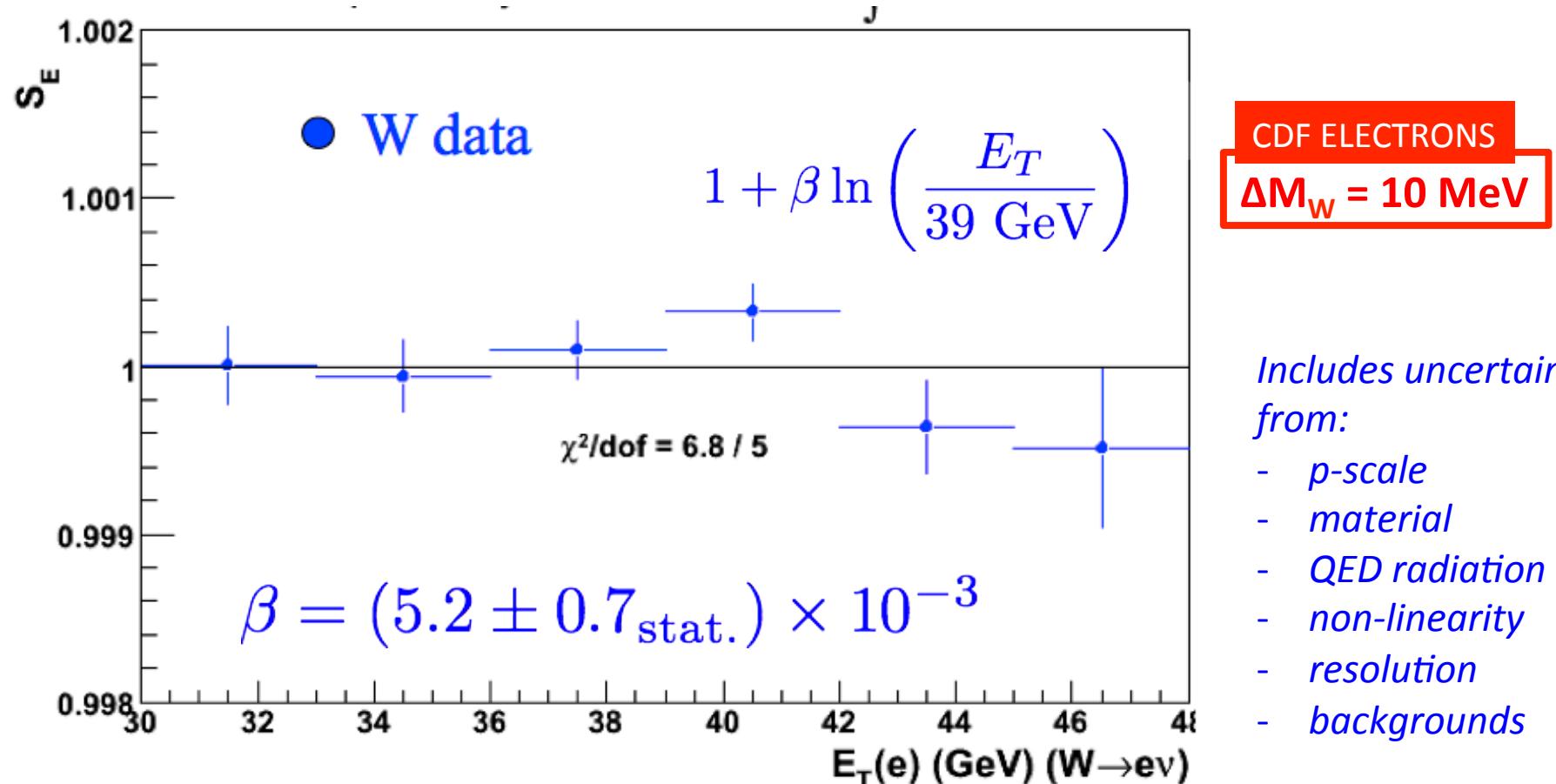




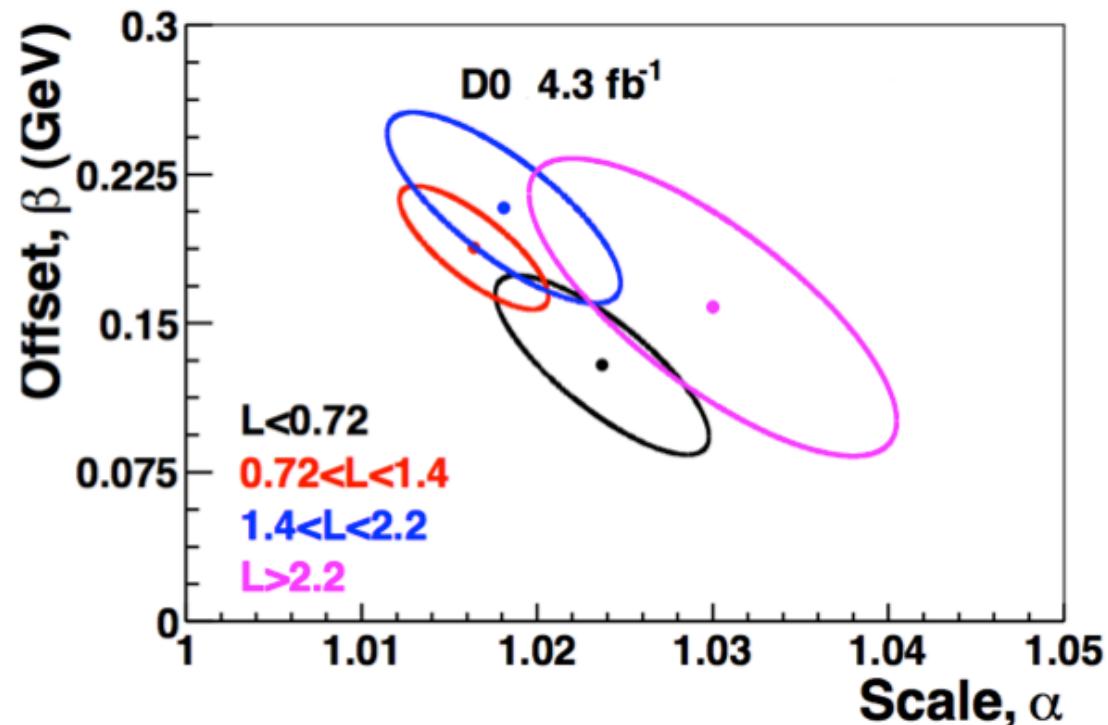
Tail of distribution used to constrain detector material X_0

With this E-scale measured $Z \rightarrow ee$
mass is: 43 ± 30 (stat.) MeV above PDG

E/p also used to constrain E-scale non-linearity



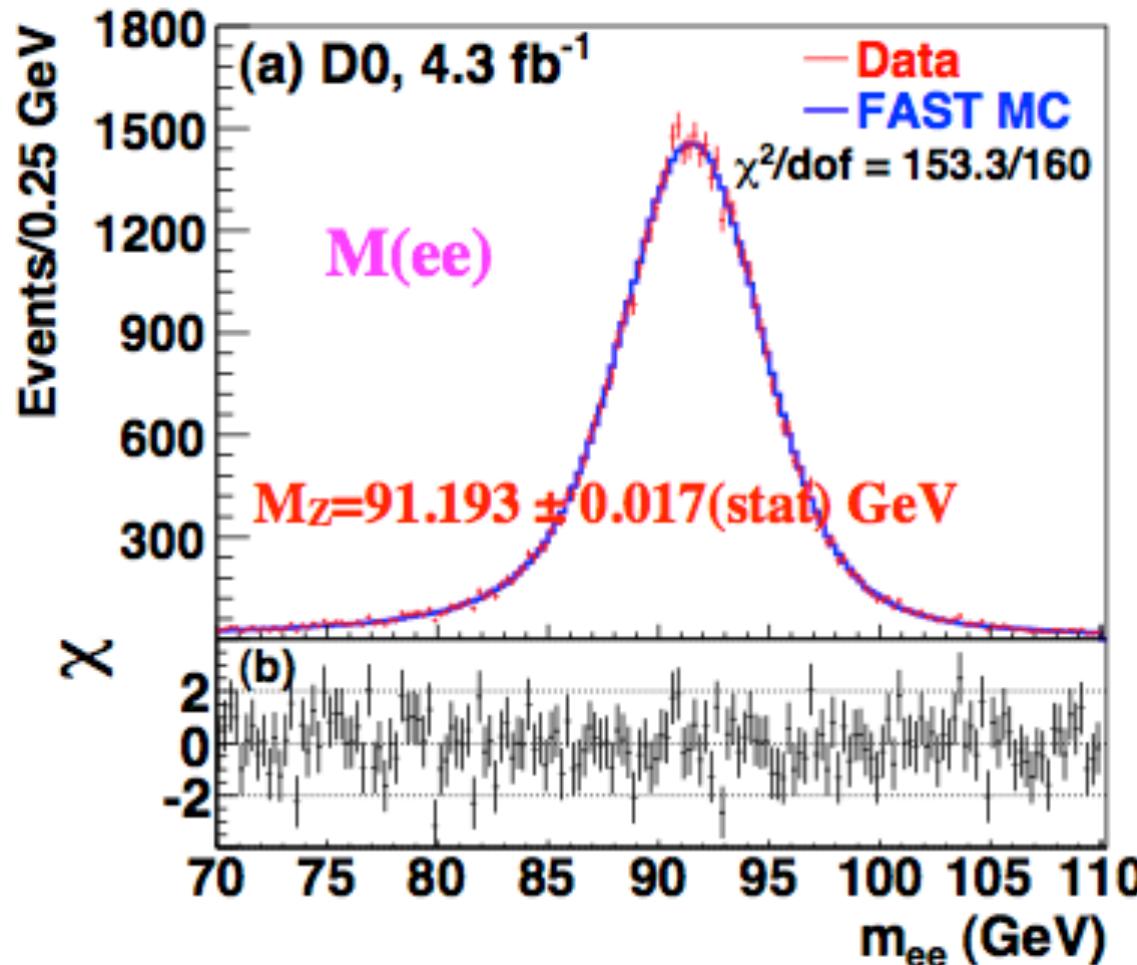
$$E_{\text{MEAS}} = \alpha (E_{\text{TRUE}} - 43 \text{ GeV}) + \beta + 43 \text{ GeV}$$



Model

- energy loss due to dead material
- UE due to pileup and recoil

In luminosity and energy bins



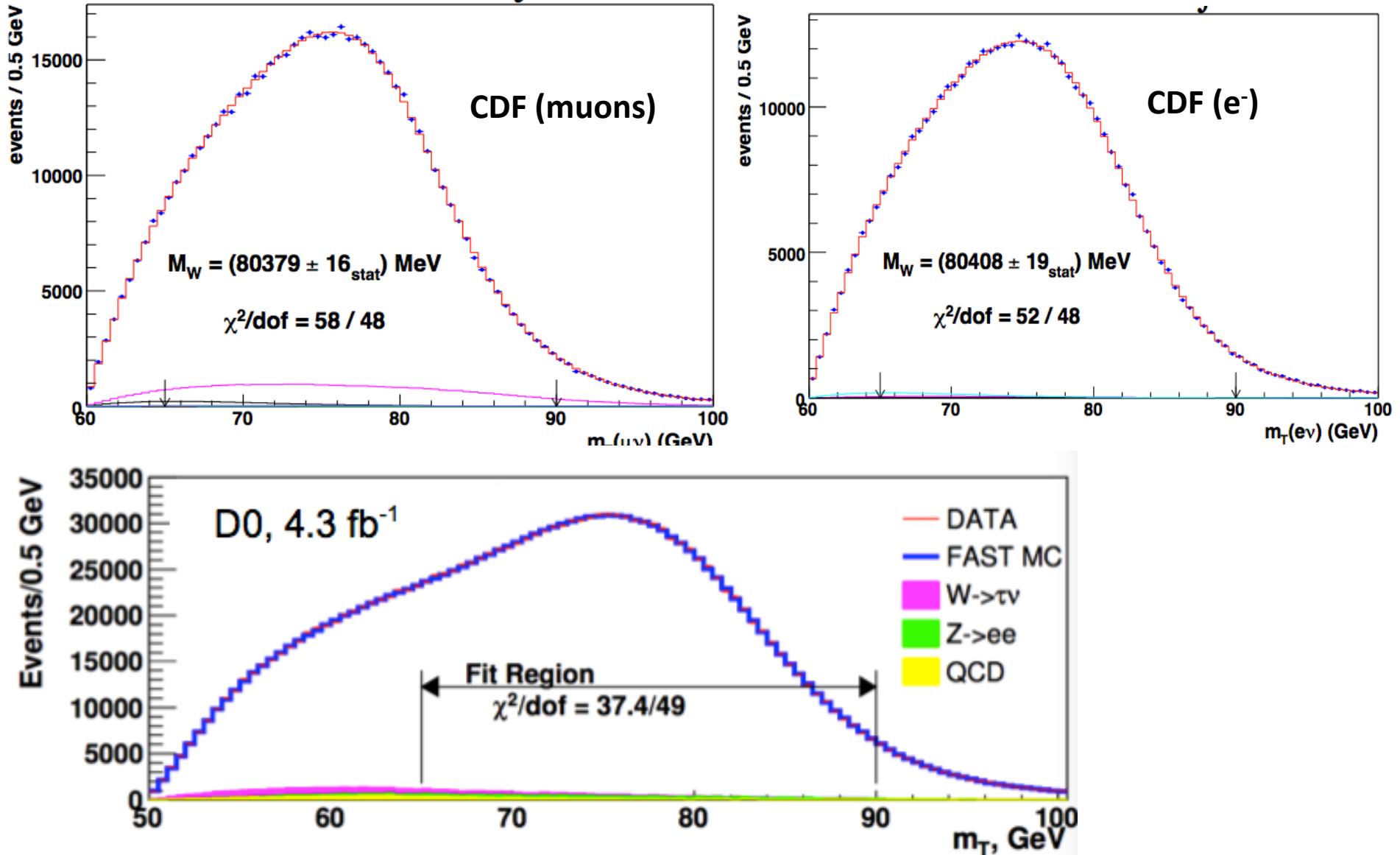
Consistent with PDG by construction.

D0 measuring M_W/M_Z

DO ELECTRONS
 $\Delta M_W = 17 \text{ MeV}$

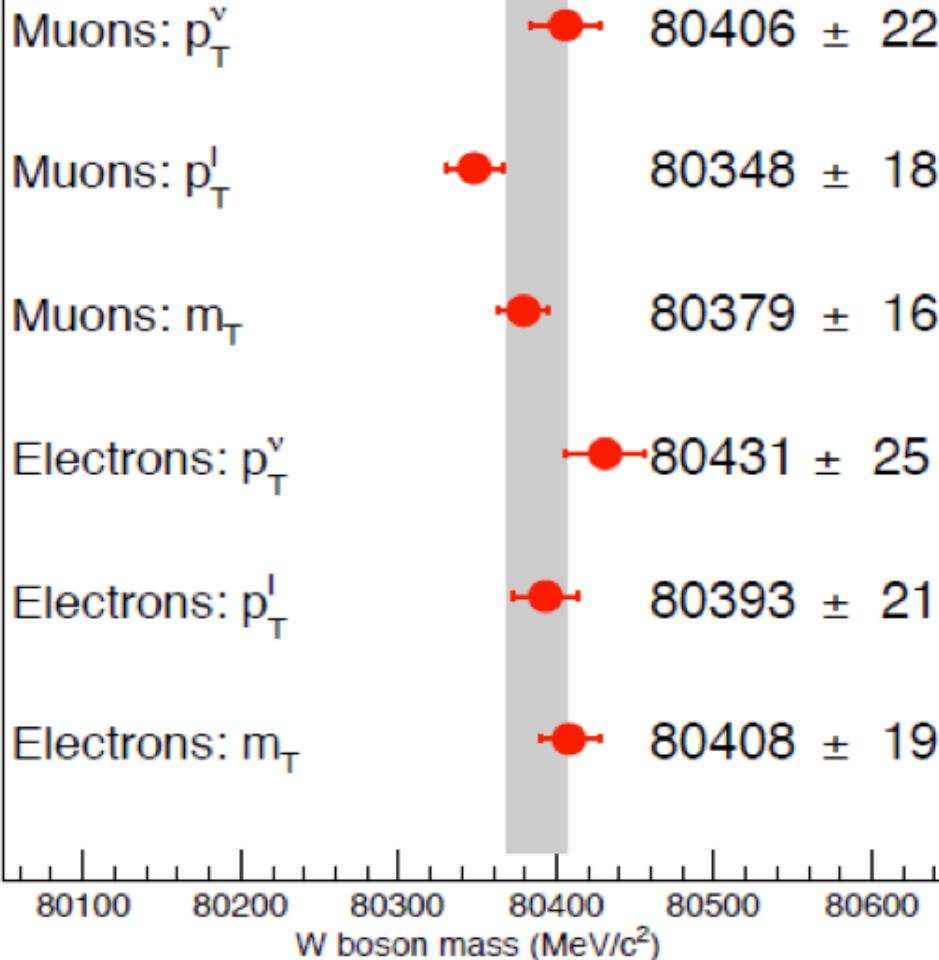
Nearly all statistical

Transverse Mass Fits



Mass Fits

CDF



Possible to do many cross checks
with different fits

D0 only use m_T , p_T
CDF use m_T , p_T and MET

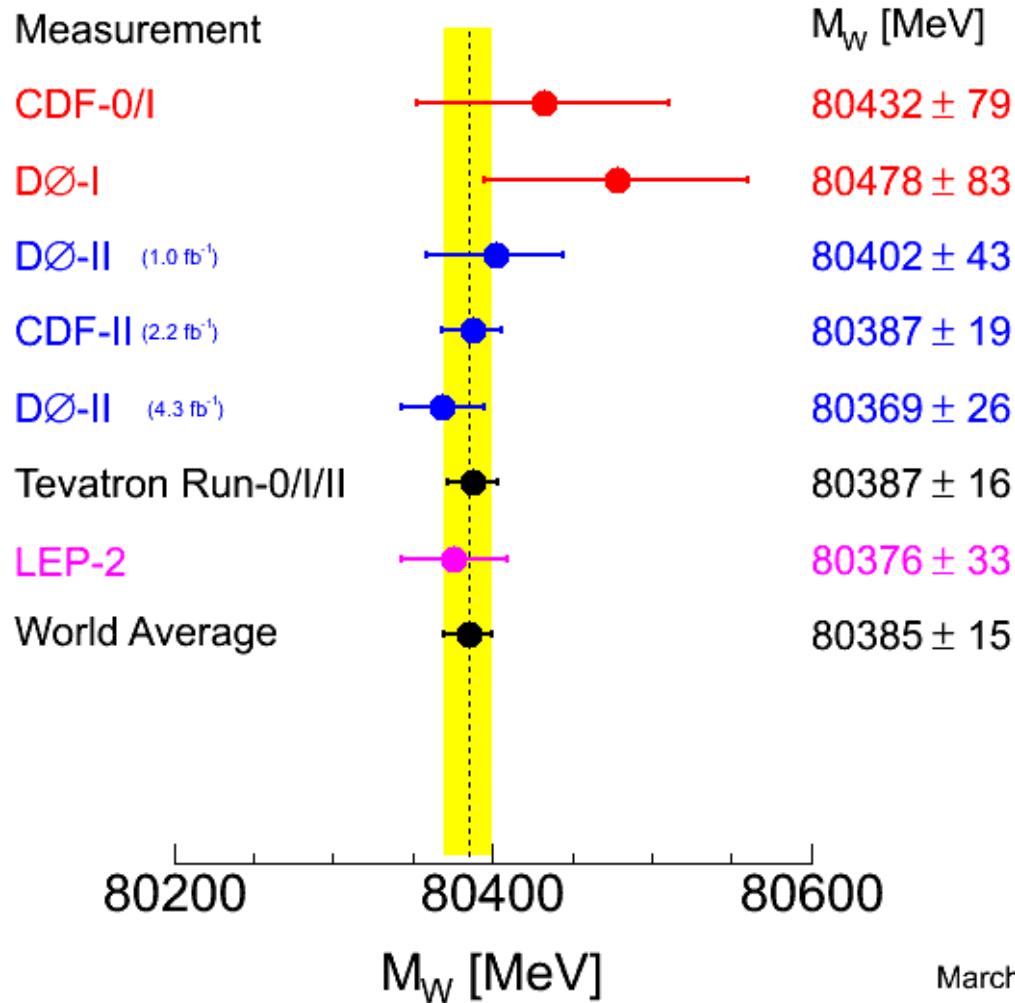
90% of M_W information is in m_T .

Uncertainties

Uncertainty	D0	CDF	
Lepton energy scale/resn/modelling	17	7	<i>Largely stat. in origin</i>
Hadronic recoil energy scale and resolution	5	6	10 MeV
Backgrounds	2	3	
Parton distributions	11	10	<i>Largely theory in origin</i>
QED radiation	7	4	12 MeV
$p_T(W)$ model	2	5	
Total systematic uncertainty	22	15	
W -boson statistics	13	12	
Total uncertainty	26 MeV	19 MeV	

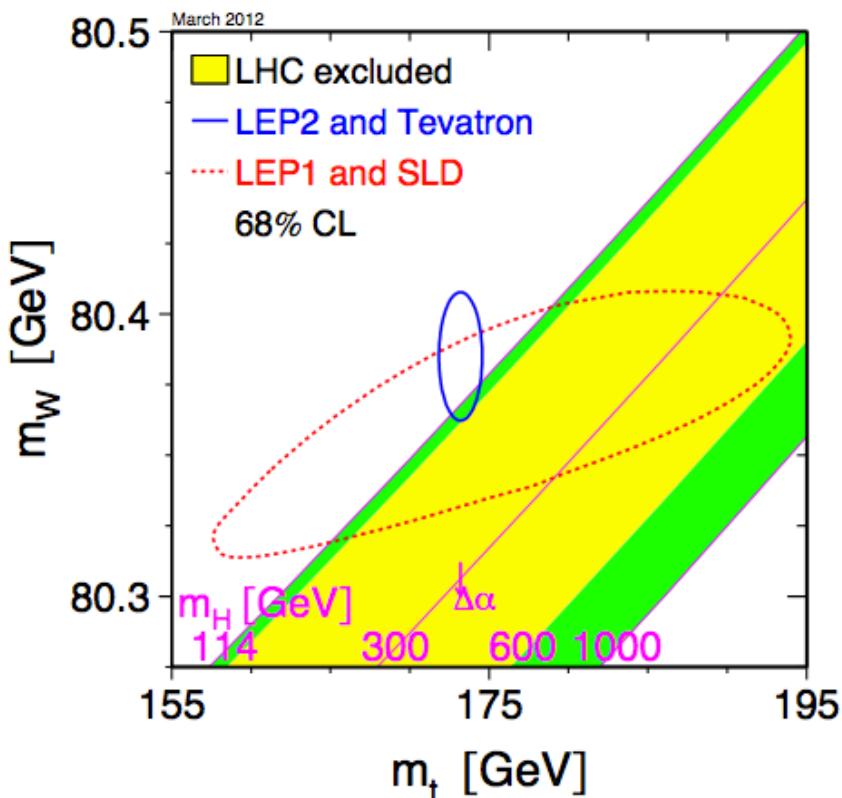
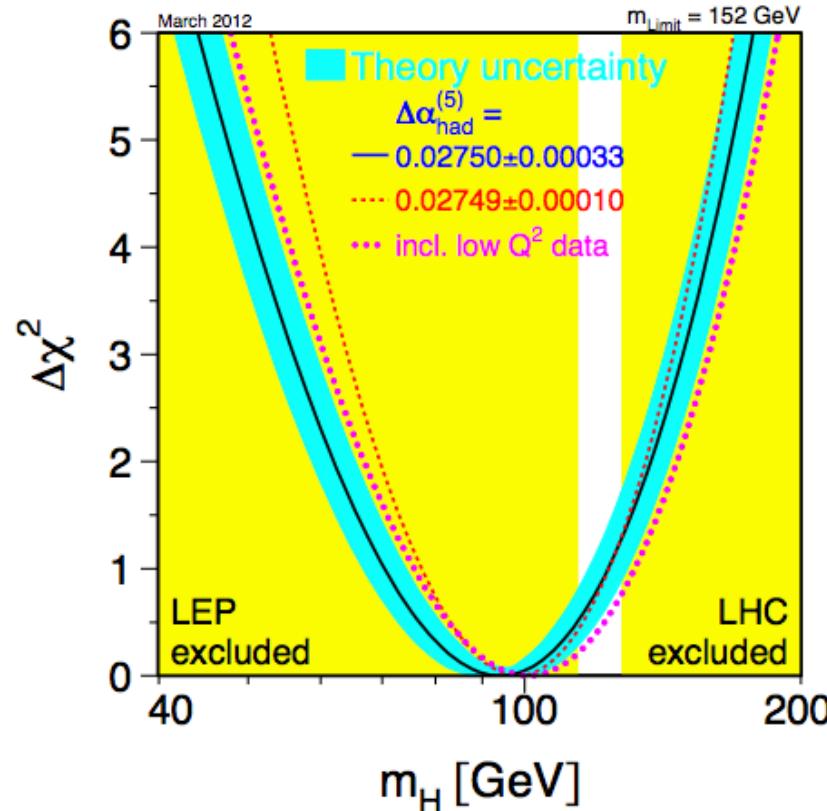
World Average

Mass of the W Boson



Run-II has halved the M_W uncertainty

Higgs Constraint

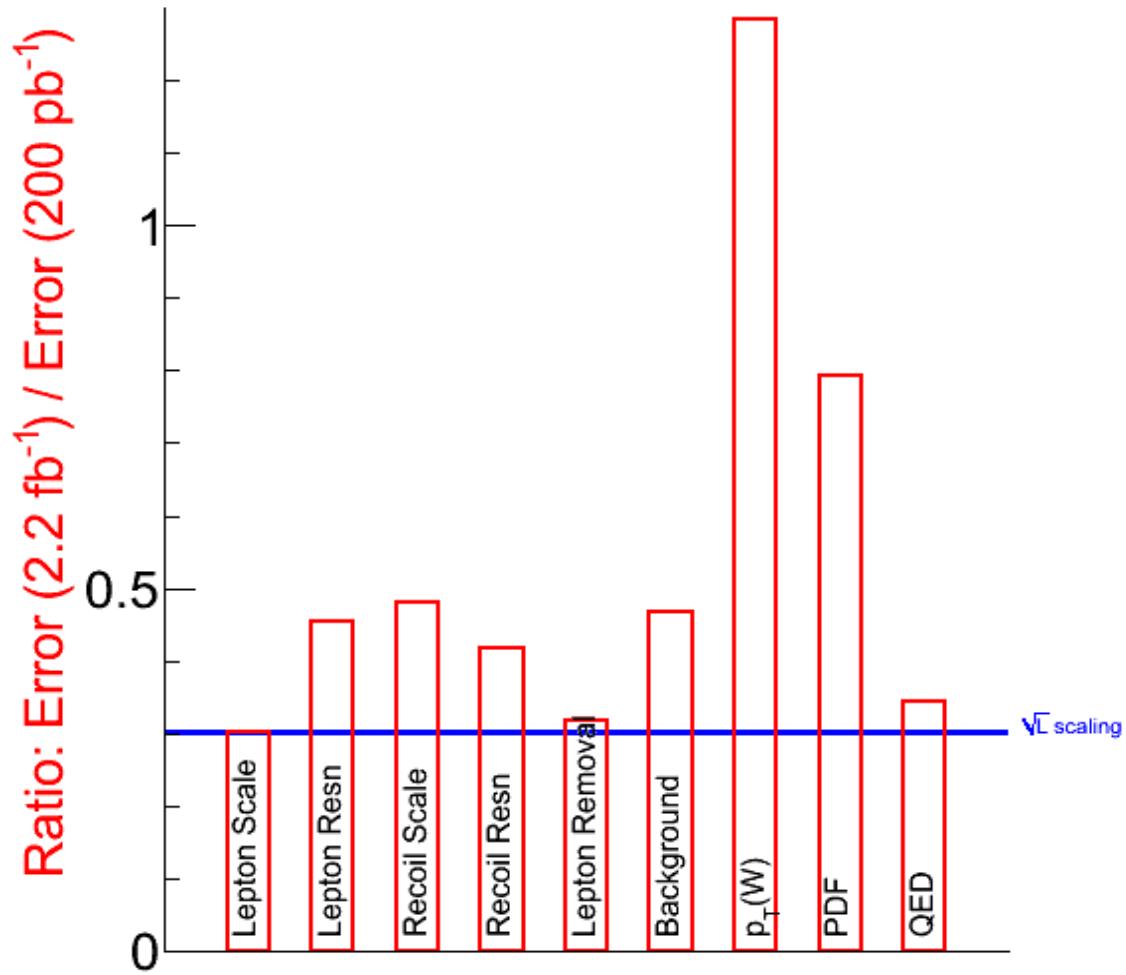


As of March 2012:

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

$m_H < 152 \text{ GeV} @ 95\% \text{ CL}$

Going Below 15 MeV



Can expect some errors
to scale with stats.

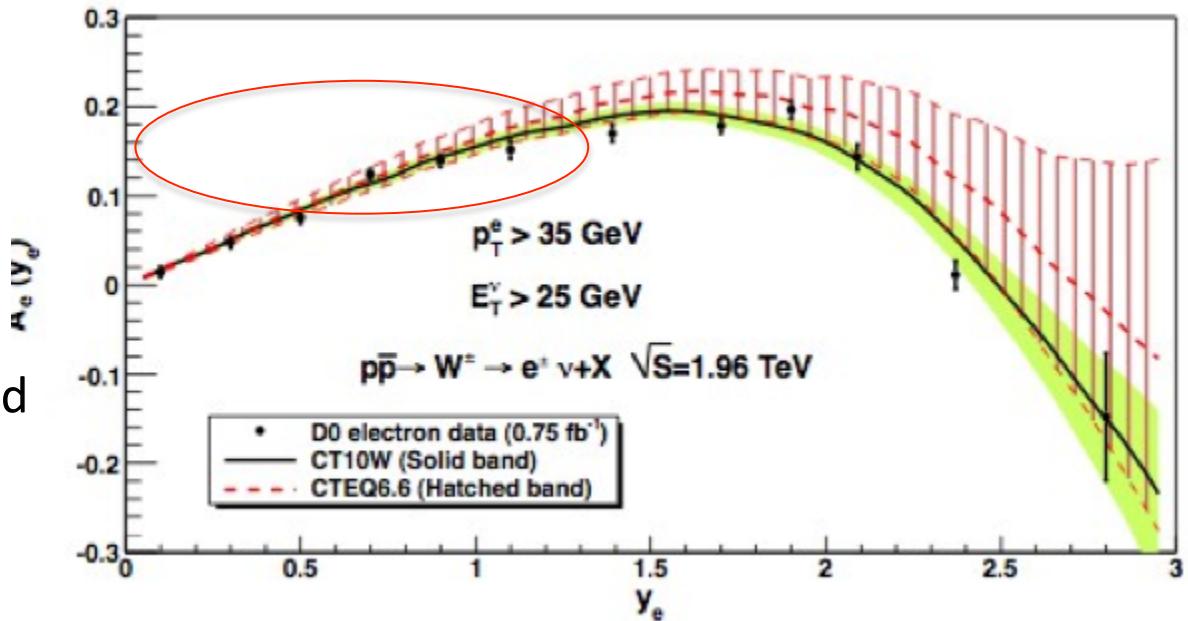
BUT

QED, PDFs, PT(W) will
need more work/ideas.

Going Below 15 MeV

PDFs

- include new data in fits (e.g. SEAQUEST)
- extend rapidity range of M_W measurement
- use m_T variant with reduced PDF uncertainty



QED

- investigate new NLO QCD+QED MCs e.g. POWHEG'

LHC



Is Below 15 MeV interesting ?

World average uncertainty of 15 MeV

- 10 MeV from PDFs
- 4 MeV from QED

This will require some serious work to reduce even a small amount.

If Higgs is discovered then constraint that $m_H < 152 \rightarrow m_H < 145$ GeV is arguably irrelevant.

If Higgs isn't discovered then we know that 150 MeV of radiative correction is coming from somewhere i.e.

If $m_H \rightarrow \infty$ then $M_w = 80219$ vs 80385 ± 15 MeV measured.

Any EWK symmetry breaking model needs to provide $O(150$ MeV) correction.

Could a more precise M_w in conjunction with m_H give additional information ?

If we get 10 MeV uncertainty

$M_w (\text{MEAS}) - M_w (\text{SM}) = 24 \pm 15 \text{ (MEAS)} \pm 9 \text{ (SM) MeV.}$

Current SM M_w uncertainty of ~ 9 MeV (with 10 GeV uncertainty on m_H)

If measure Higgs mass to 1 GeV then this reduces to ~ 8 MeV

Top mass ($\Delta m = 0.9$ GeV) = 5.4 MeV

Unknown/not calculated HO corrections = 4 MeV

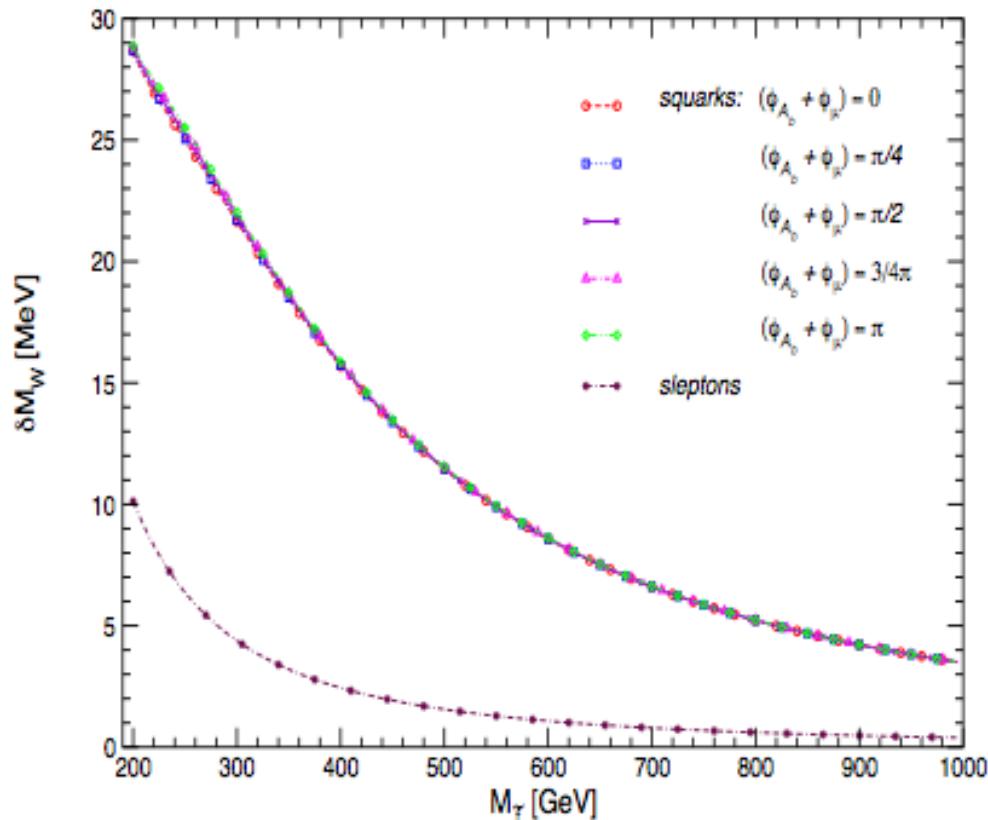
$\alpha_{\text{EM}}(\text{HAD}) (1 \times 10^{-4})$ = 1.8 MeV

$M_z (\Delta M = 2.1$ MeV) = 2.7 MeV

$\alpha_s (0.003)$ = 1.8 MeV

There is not a lot of room for new physics in this....

What about BSM uncertainties



SUSY drives M_W up by $O(20$ MeV)
but with a large $O(20$ MeV) variance
from e.g. unknown mass scale, complex
phase in stop mass matrix

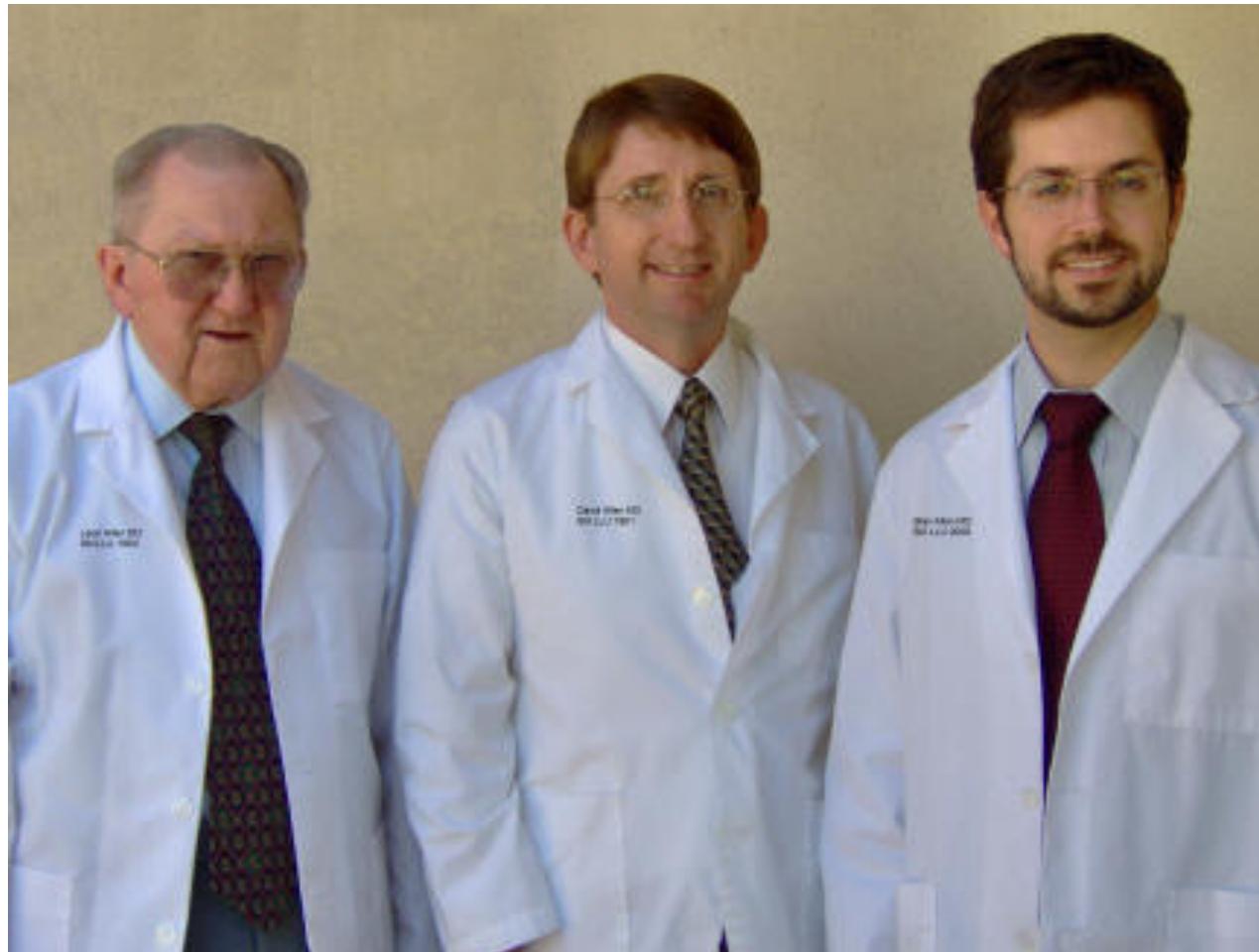
If SUSY is sighted then $O(20$ MeV)
uncertainty reduced but LHC
cannot determine all SUSY
parameters.

So we have: ΔM_W (THEORY : SM + BSM) ~ 15 MeV.
 ΔM_W (EXP) ~ 15 MeV now.....

Gestation period of an M_W measurement is 2-5 years.

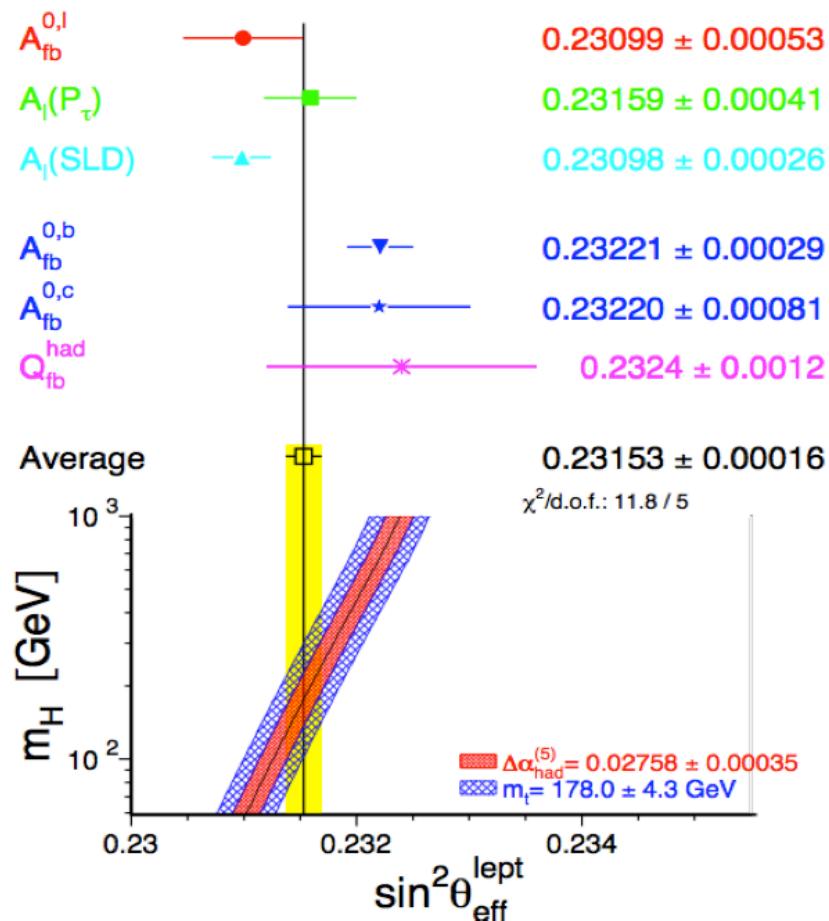


Check your meeting rooms....



A_{FB} / sin²(θ_W)

Other current “precision” measurement with some bearing on SM consistency is A_{FB}.

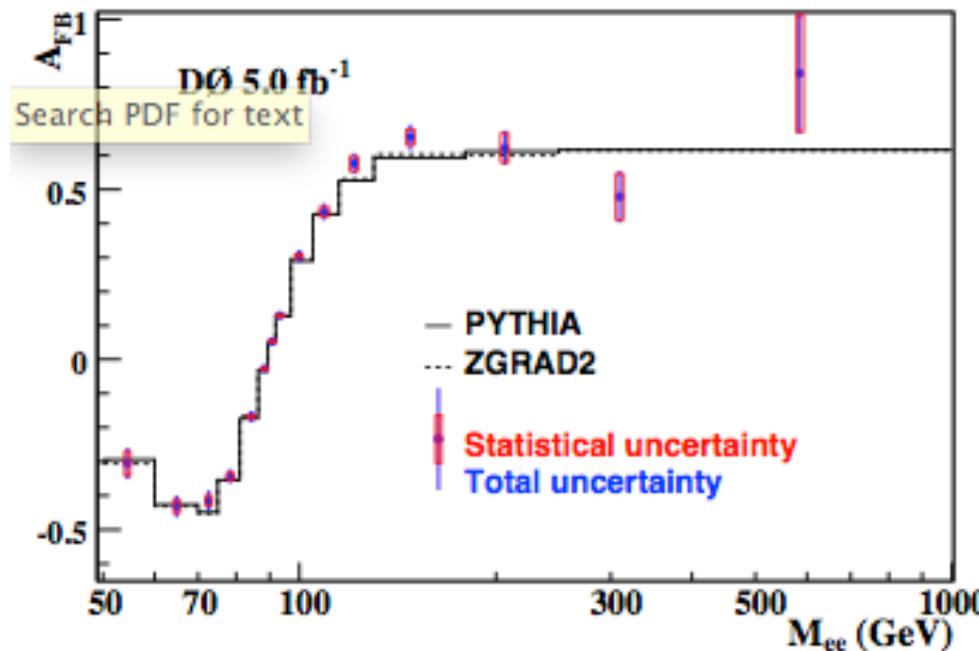


Existing tension in LEP/SLD values

Since most of Tevatron Zs are from u, d quarks can measure A_{FB} from light quarks better than LEP

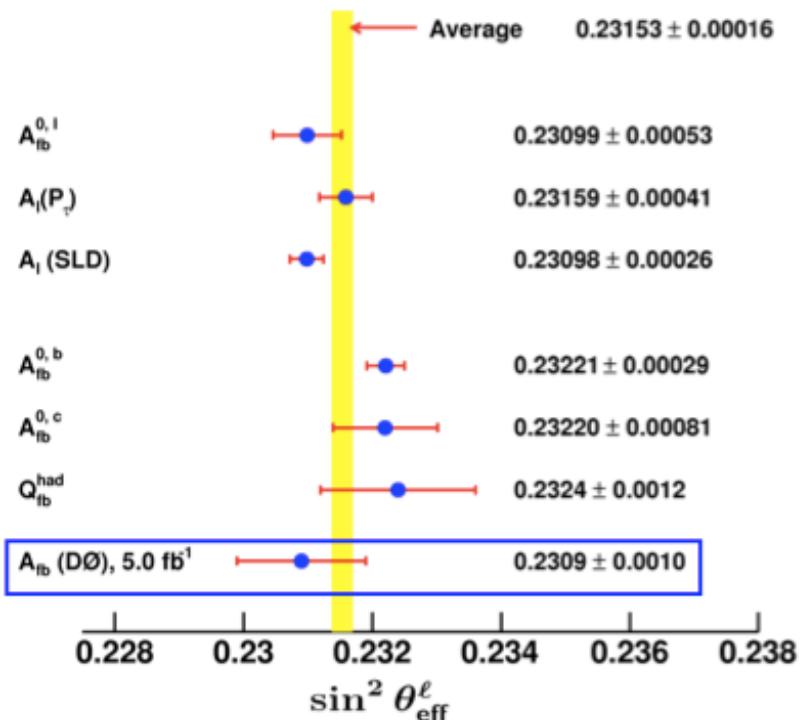
Measure light-quark couplings

A_{FB} / sin²(θ_W)

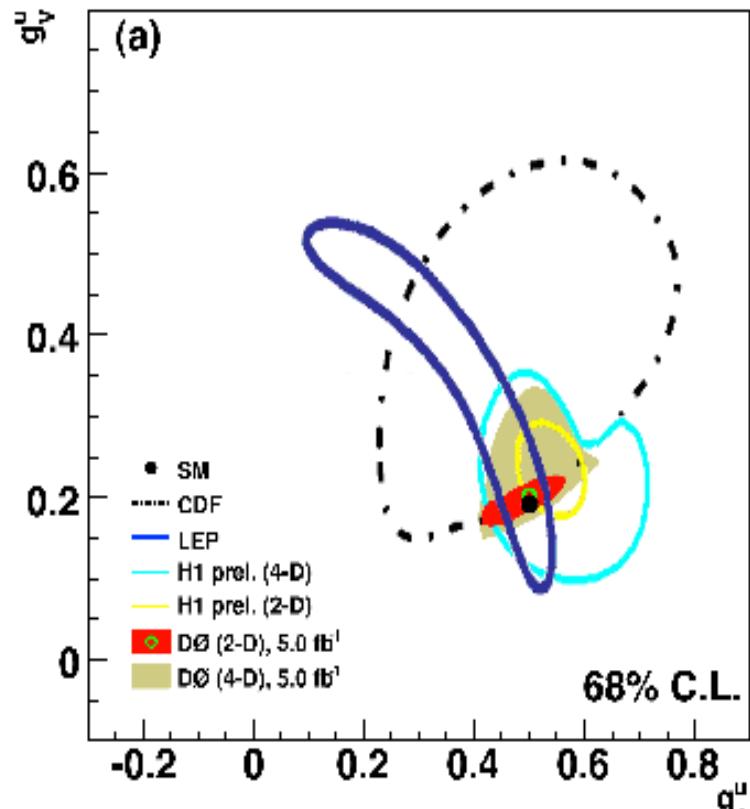


Uncertainty 0.0010 dominated
by statistics 0.0008 and then PDF 0.0005.

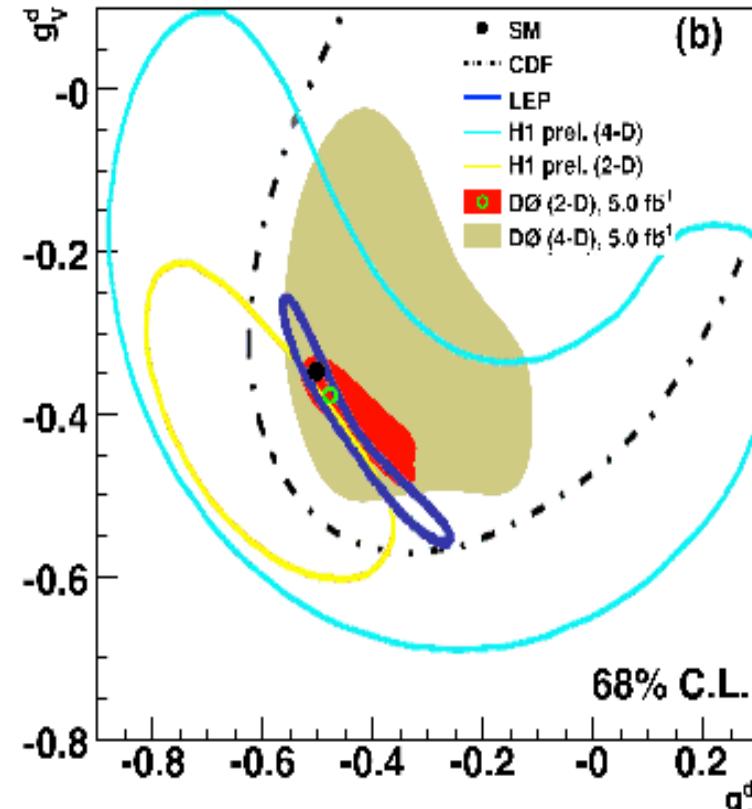
Expect final Tevatron uncertainty ½ this



Quark couplings



Z-u quark couplings



Z-d quark couplings



Conclusion

LEP/SLD and Tevatron have been hugely successful in establishing and probing the consistency of the SM.

Sadly there are no bona-fide cracks yet.

We have measured M_w and M_{top} with precisions (15 MeV, 0.9 GeV) that few would have predicted 10 years ago.

But we know M_w has 150 MeV of new radiative corrections
– is this the Higgs ?

Backup

20 MeV

4 MeV

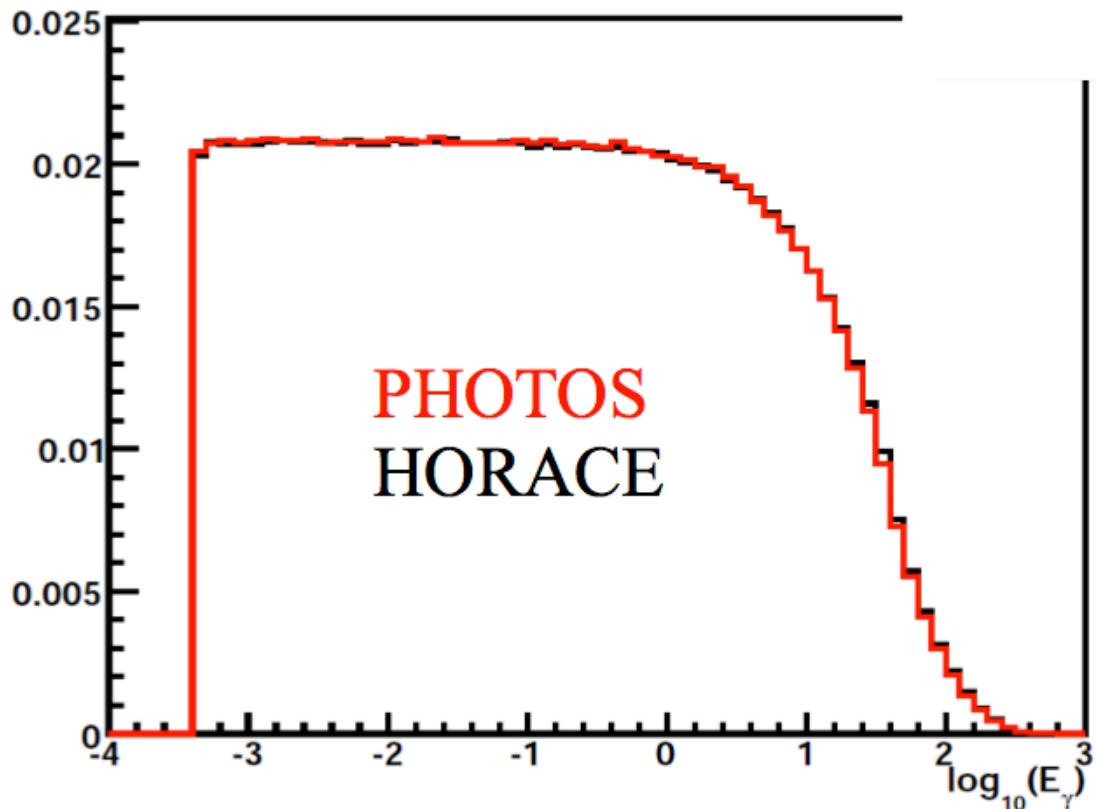
	CDF0	CDFIa	CDFIb	CDFII 200pb ⁻¹	CDFII 2.3fb ⁻¹	DØ 1fb ⁻¹
effects:						
single photon	✓	✓	✓	✓	✓	✓
exact $\mathcal{O}(\alpha)$	—	—	—	✓	✓	—
multi-photon	—	—	—	—	✓	✓
ISR	—	—	—	—	✓	—
uncertainties:						
2γ emission	✓	✓	✓	✓	✓	✓
ISR	—	—	✓	✓	✓	✓
$\alpha\alpha_s$	—	—	—	✓	✓	—
SV cut-off	—	—	—	✓	✓	✓
Z/W correl.	—	—	—	✓	✓	✓
beyond 2γ	—	—	—	—	✓	—
H.O. SV corr.	—	—	—	—	✓	—
pair creation	—	—	—	—	✓	—
Breit-Wigner	—	—	—	—	✓	—
EWK scheme	—	—	—	—	✓	—

Mw QED Uncertainty

Default is PHOTOS.

But extensive cross-checks with HORACE

- comparison of multi-photon algorithms and to exact $O(\alpha)$
- impact of ISR



Uncertainties from

- leading log approx
- multi-photon calculation
- HO soft/virtual corrections
- e+e- pair creation
- QED/QCD interference
- dependence on EWK scheme
- dependence on cut-offs



Mw PDF Uncertainty

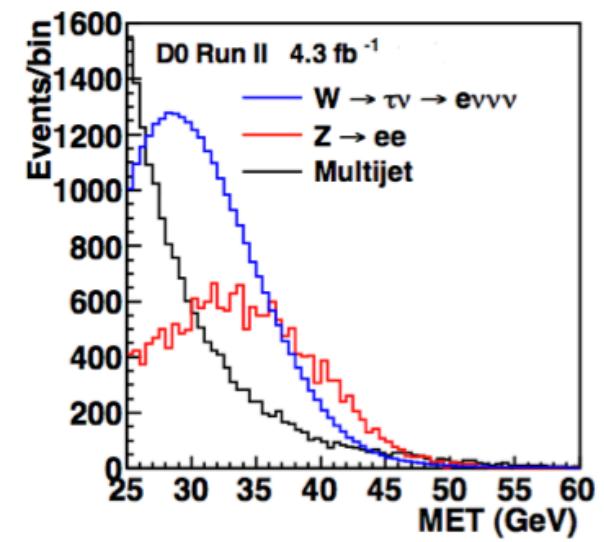
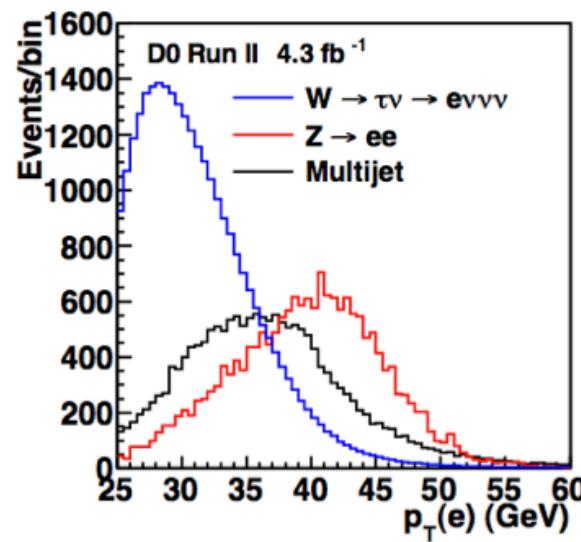
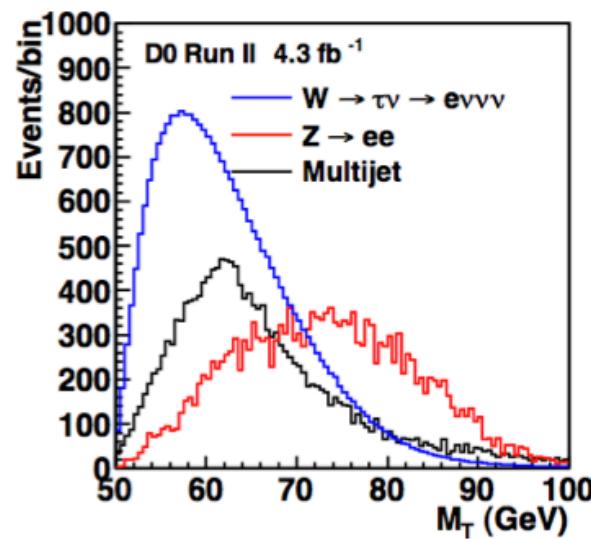
Default PDF is CTEQ6.6

Central value agrees with MSTW within quoted 10 MeV uncertainty

CDF use MSTW (68% CL) as error and D0 use CTEQ6.1 (90% CL scaled to 68% CL)

CTEQ error is 10% (1 MeV) larger

Mw Backgrounds





D0 Mass Fits vs Luminosity

“W/Z”

