Precision measurements of the W boson mass at the Tevatron

Jan Stark
(LPSC Grenoble, France)

10-25 years of DØ France, October 13-14, 2008, Paris

LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie

IN2P3
Institut National de Physique Nucléaire et de Physique des Particules

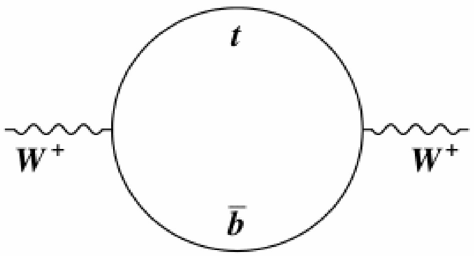
CNRS
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

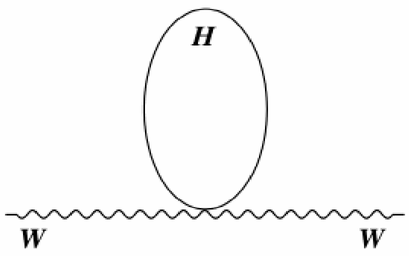
Motivation

W mass is a key parameter in the Standard Model. This model does not predict the value of the W mass, but it predicts this relation between the W mass and other experimental observables:

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

Radiative corrections (Δr) depend on M_t as $\sim M_t^2$ and on M_H as $\sim\log M_H$. They include diagrams like these:



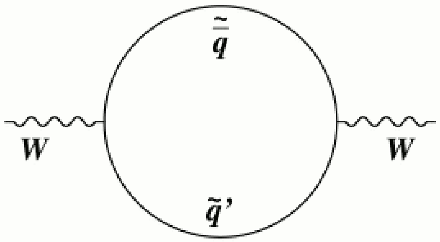


Precise measurements of M_W and M_t constrain SM Higgs mass.

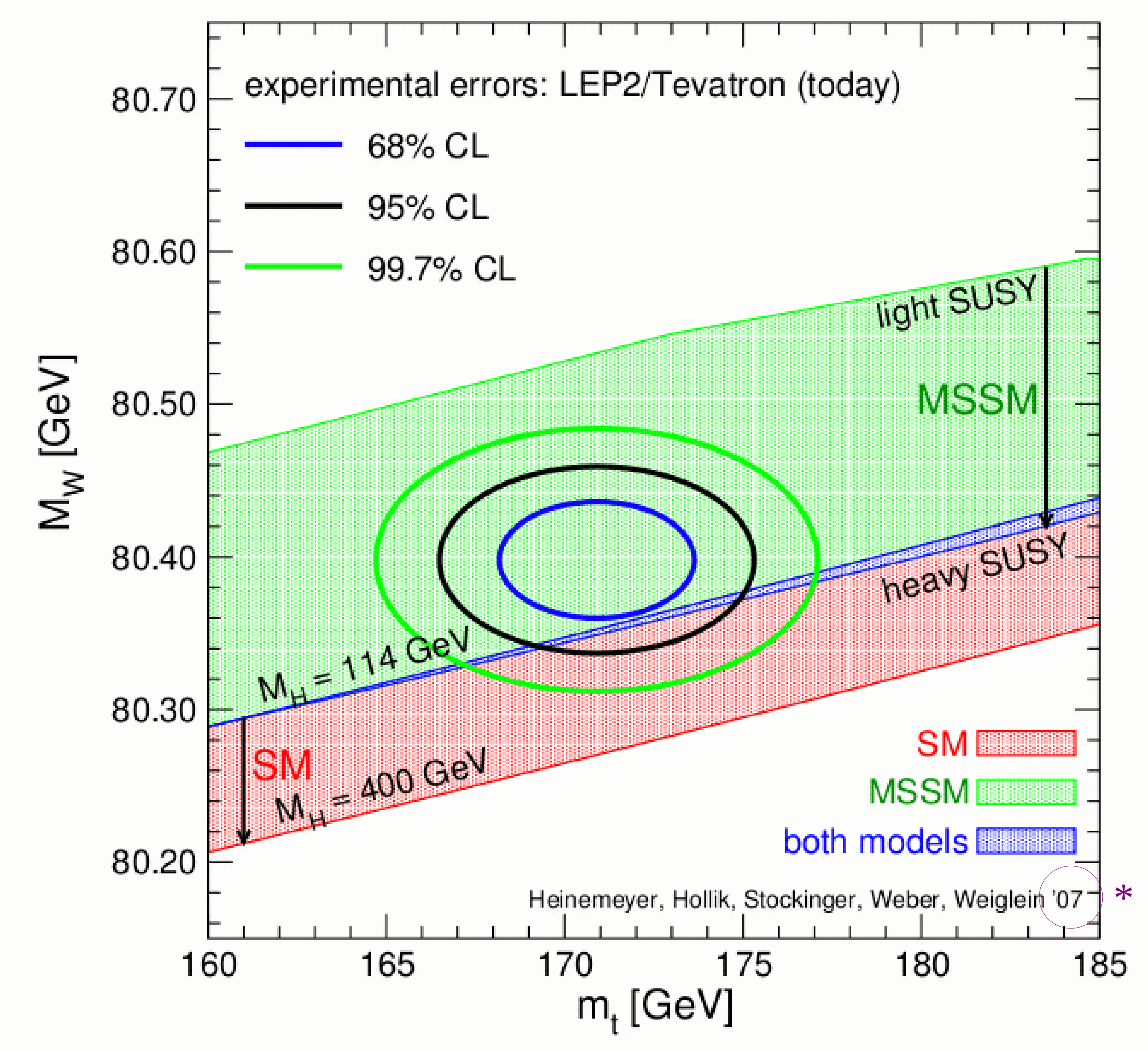
For equal contribution to the Higgs mass uncertainty need: $\Delta M_W \approx 0.006\, \Delta M_t$.

The limiting factor here will be ΔM_W, not ΔM_t !

Additional contributions to Δr arise in various extensions to the Standard Model, *e.g.* in SUSY:



Motivation



*

For equal contribution to the Higgs mass uncertainty need:

$\Delta M_W \approx 0.006\ \Delta M_t$.

Current Tevatron average:

$\Delta M_t = 1.2$ GeV

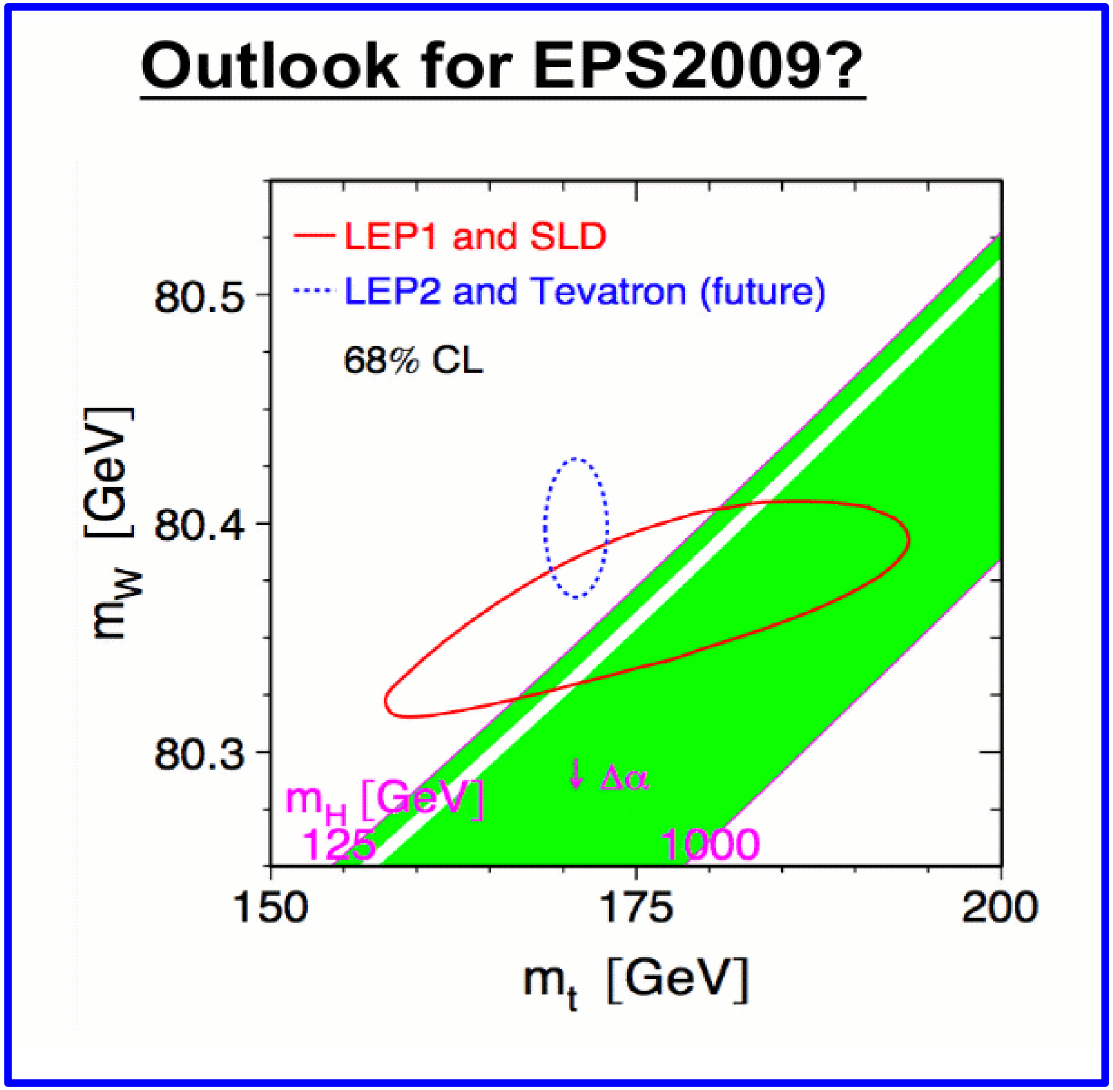
$\Rightarrow$ would need: $\Delta M_W = 7$ MeV

Currently have: $\Delta M_W = 25$ MeV

The limiting factor here is ΔM_W, not ΔM_t !

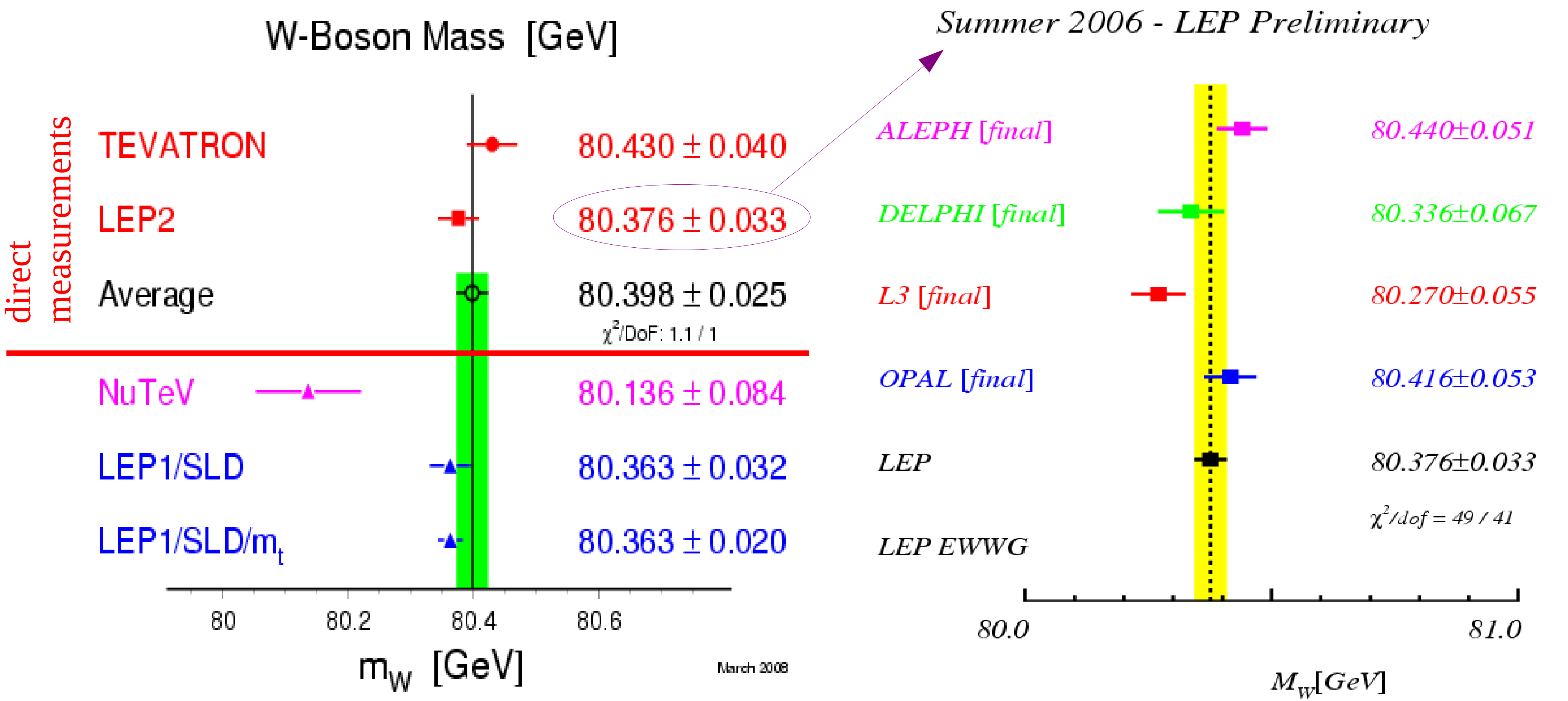
* This plot does not use the latest number for the top mass, but as I said, it does not really matter.

Secret hopes



... as shown by Terry Wyatt at the EPS 2007 conference.

Current precision



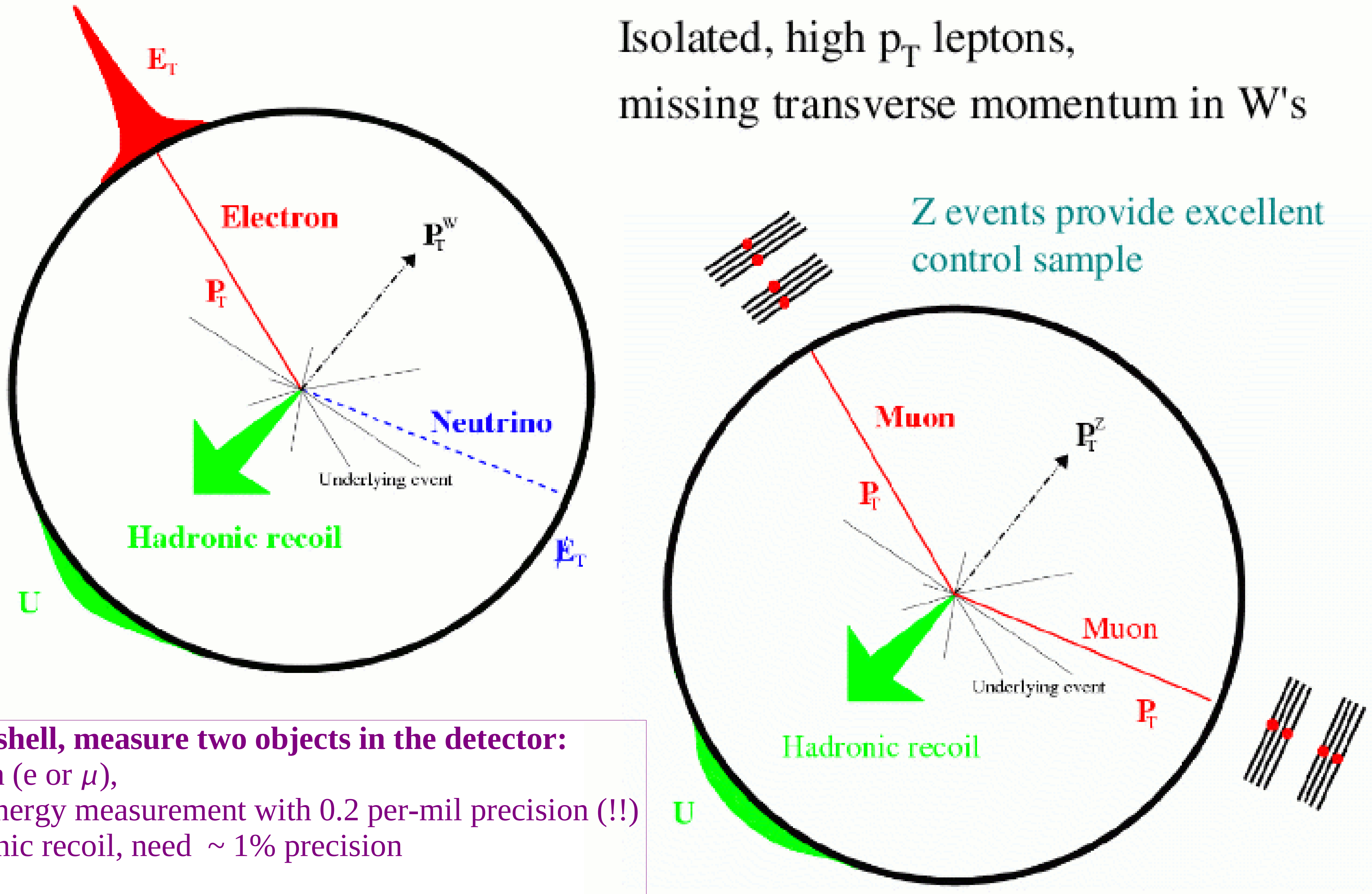
The current world average is still dominated by the final LEP2 results.

The Tevatron average is driven by a recent Run II measurement from CDF (200 pb^{-1}), but the analysis of the Tevatron Run II analyses is really just starting ...

CDF and DØ: signatures in the detector

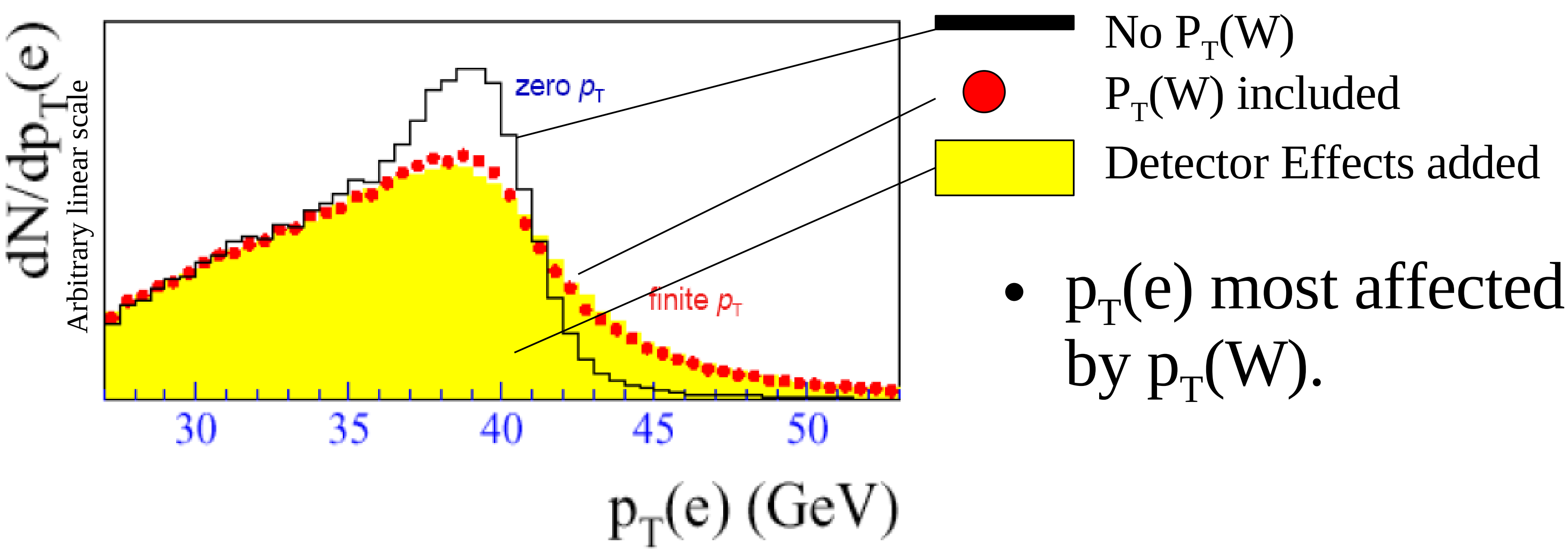
Isolated, high p_T leptons,
missing transverse momentum in W's

Z events provide excellent
control sample

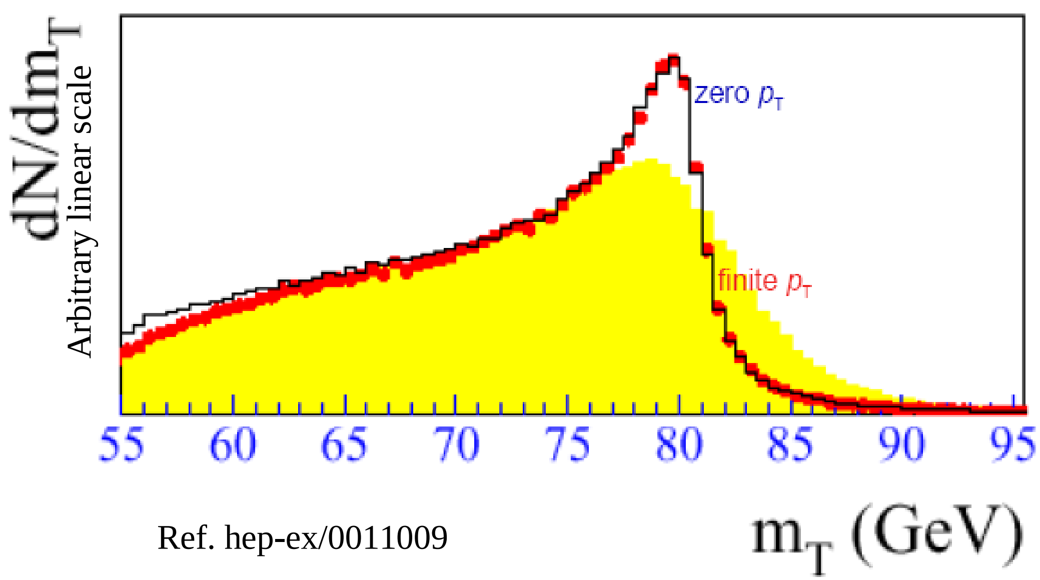


In a nutshell, measure two objects in the detector:
- Lepton (e or μ),
  need energy measurement with 0.2 per-mil precision (!!)
- Hadronic recoil, need ~ 1% precision

Experimental observables



- p_T(e) most affected by p_T(W).



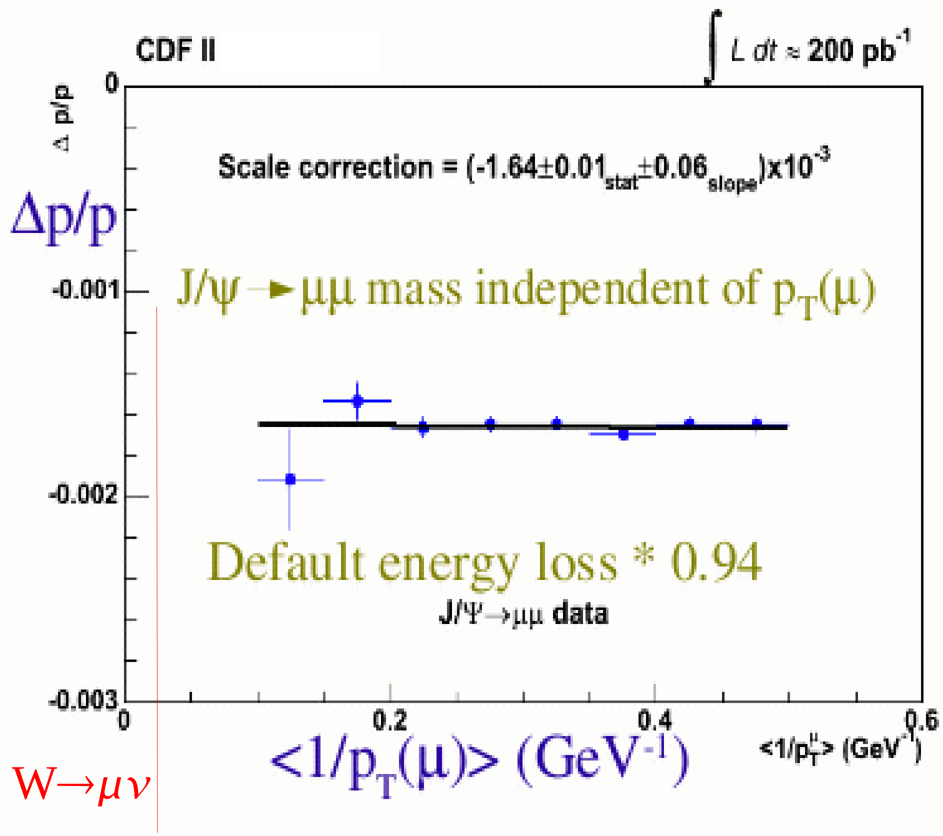
$$M_T = \sqrt{2E_T^l \not{E}_T (1 - \cos\Delta\phi)}$$

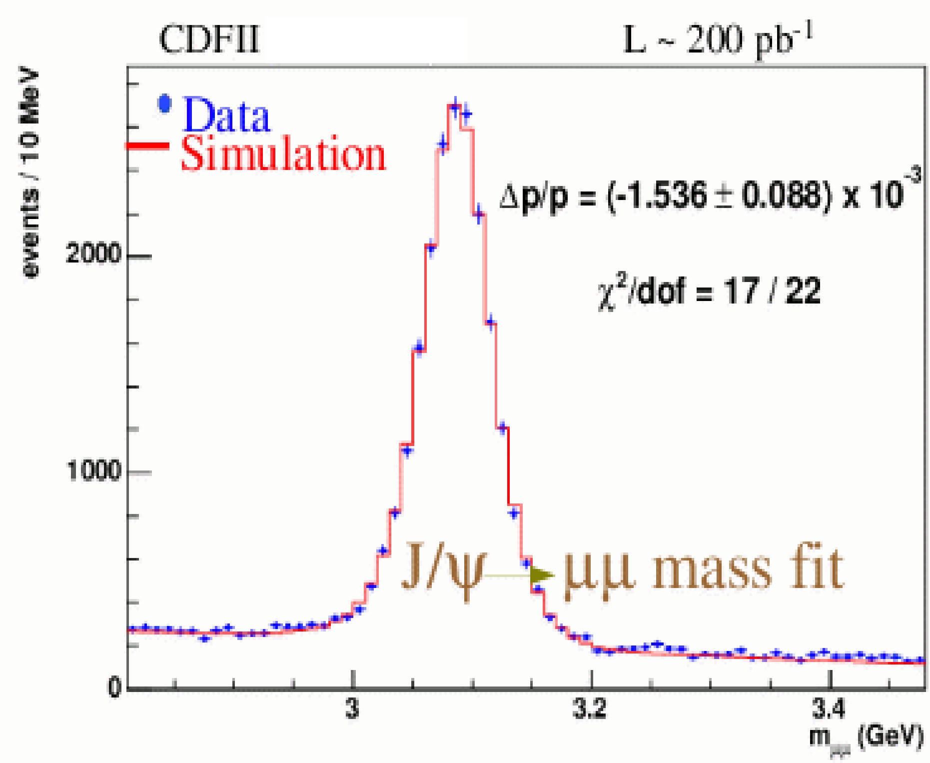
- M_T most affected by missing transverse momentum measurement.

Ref. hep-ex/0011009

Momentum scale calibration

- J/ψ: $\Delta p/p = (-1.64 \pm 0.06_{stat} \pm 0.24_{sys}) \times 10^{-3}$
  - Extracted by fitting J/ψ mass in bins of $<1/p_T(\mu)>$, and extrapolating momentum scale to zero curvature



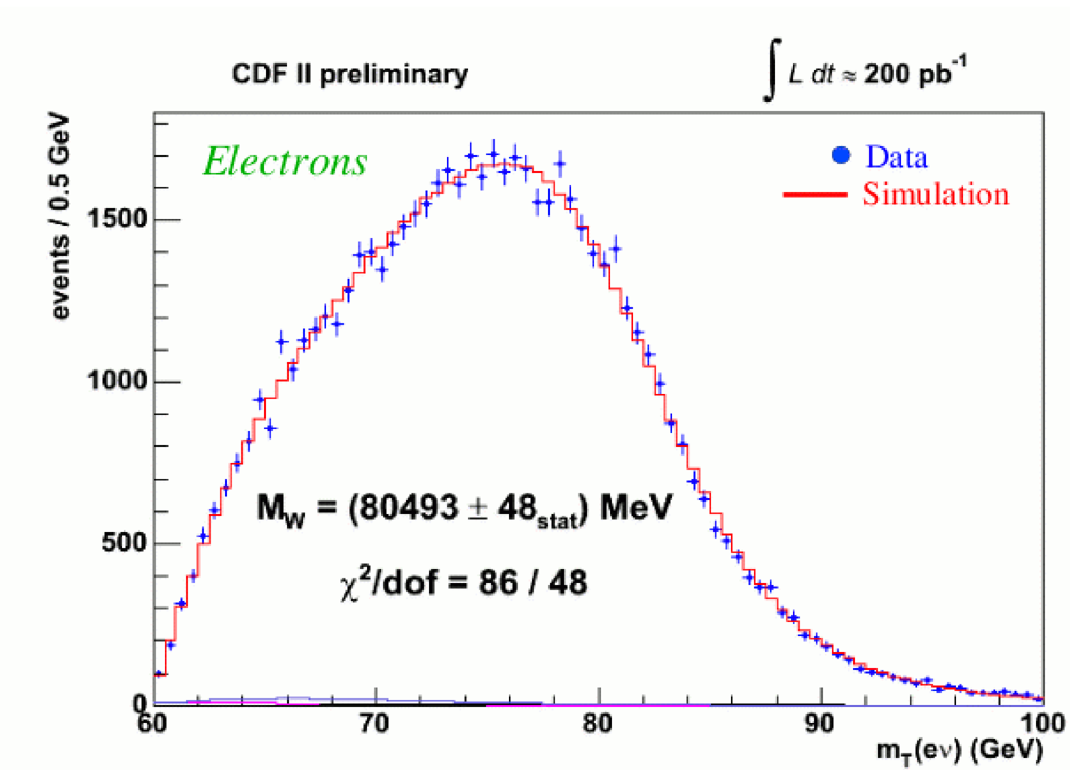


After this calibration of tracking momentum scale:
transfer of calibration to calorimeter using E/p observable for electrons from $W \to e\, \nu$.

First CDF Run II result

Based on only 200 pb^{-1} of low luminosity data.

Here we show results from transverse mass only;
$p_T(e)$ and $p_T(\nu)$ observables give consistent results.



Transverse Mass Fit Uncertainties (MeV)

	electrons	muons	common
W statistics	48	54	0
Lepton energy scale	30	17	17
Lepton resolution	9	3	-3
Recoil energy scale	9	9	9
Recoil energy resolution	7	7	7
Selection bias	3	1	0
Lepton removal	8	5	5
Backgrounds	8	9	0
pT(W) model (g2,g3)	3	3	3
Parton dist. Functions	11	11	11
QED rad. Corrections	11	12	11
Total systematic	39	27	26
Total	62	60	

Preparations for a measurement

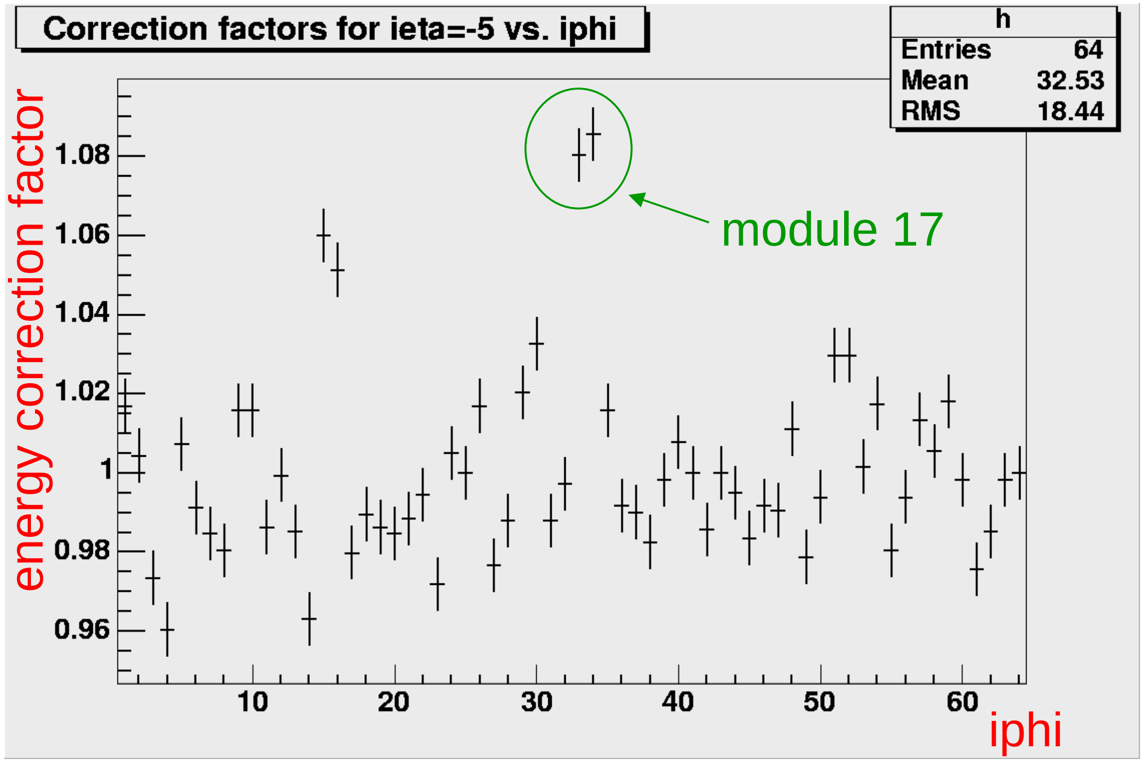
The first DØ Run II measurement (based on the full Run IIa dataset) is not quite ready yet.

But the years and years of the necessary groundwork are behind us. In this short talk we can only give a small glimpse of the exciting work that has been done.

For example (plot on the right): calorimeter calibration.

These developments already contribute significantly to the quality of many published DØ Run II analyses.

Example of results from phi intercalibration



$Z \rightarrow e^+ e^-$ in Run IIa data:

# of primary vertices	$<$scalar $E_T>$ per event (excluding electrons)
1	33 GeV
2	53 GeV
3	74 GeV
4	92 GeV
...	....

Also, this is **not** a simple "redo" of the DØ Run I analysis:

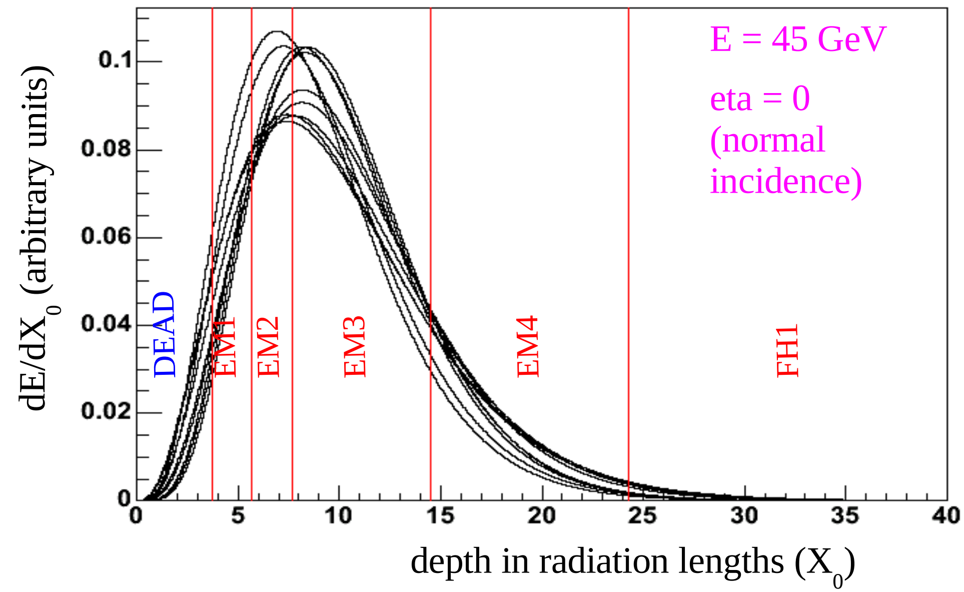
- in Run II we are going for completely new levels of precision ("now every detail counts"),
- Run II running conditions are much less favourable (e.g. energy flow from multiple interactions [was negligible in Run I]).

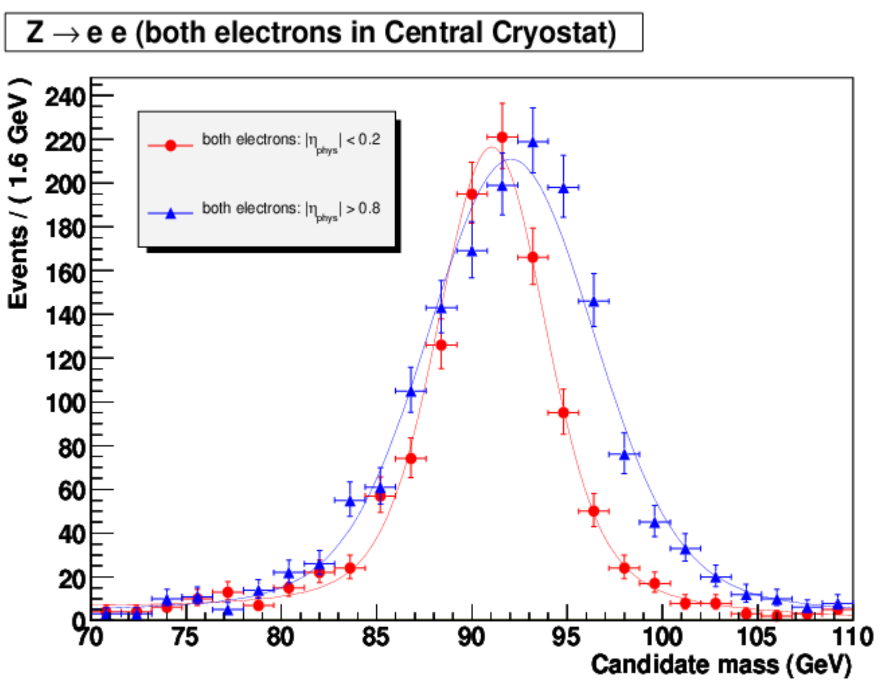
(Unexpected ?) issues

Maybe not all Run II – specific issues have been fully appreciated immediately by everybody in the Collaboration.

For example: the effect of dead material in front of the CC.

The plot on the right shows 10 typical profiles of showers from 45 GeV electrons, and how they are sampled by DØ.





This has very significant consequences for our energy measurements, as illustrated by the two $Z \to e^+ e^-$ mass peaks from Run IIa data (before final calibration):

red: both electrons at ~ normal incidence on CC
blue: both electrons at highly non-normal incidence on CC

Dead material is a significant contributor to energy resolution (especially at non-normal incidence [blue peak] ....)

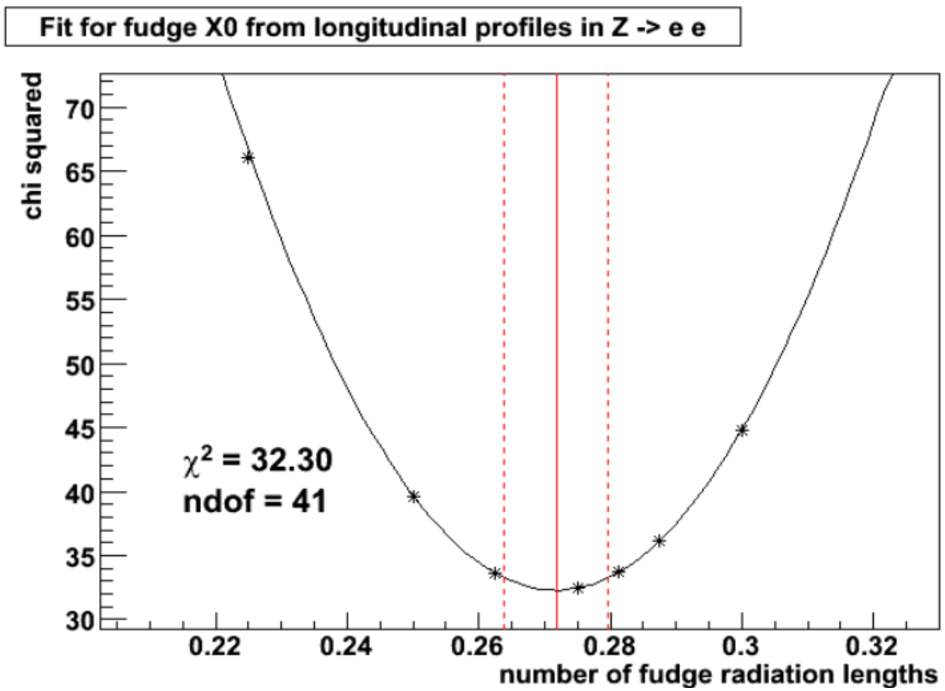
Energy losses in dead material need to be corrected for (using detailed MC simulations). As the (wrong) position of the blue peak shows, these corrections derived from standard DØ MC are not correct.

Solutions

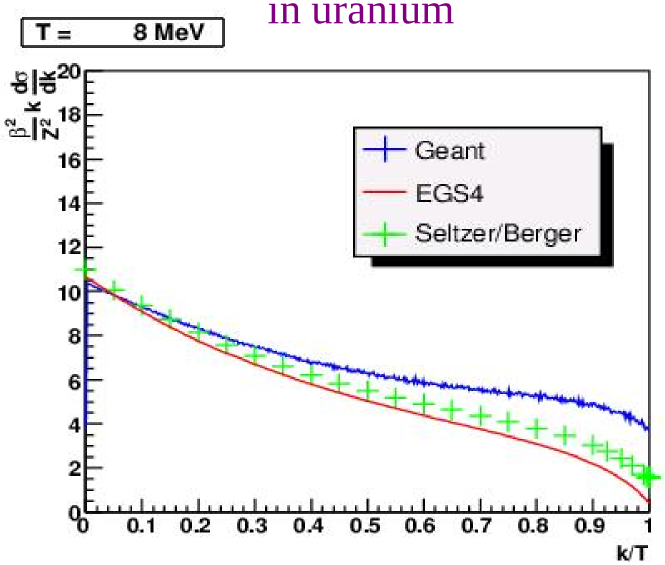
We have developed the techniques needed to deal with these issues.

For example, exploit the longitudinal segmentation of the calorimeter to measure the amount of material missing in the simulation using electrons from $Z \rightarrow e^+ e^-$ data.

=> very precise fit, as shown on the right.



Example: Bremsstrahlung in by electrons in uranium



The material accounting is not the only ingredient of detailed MC simulations.

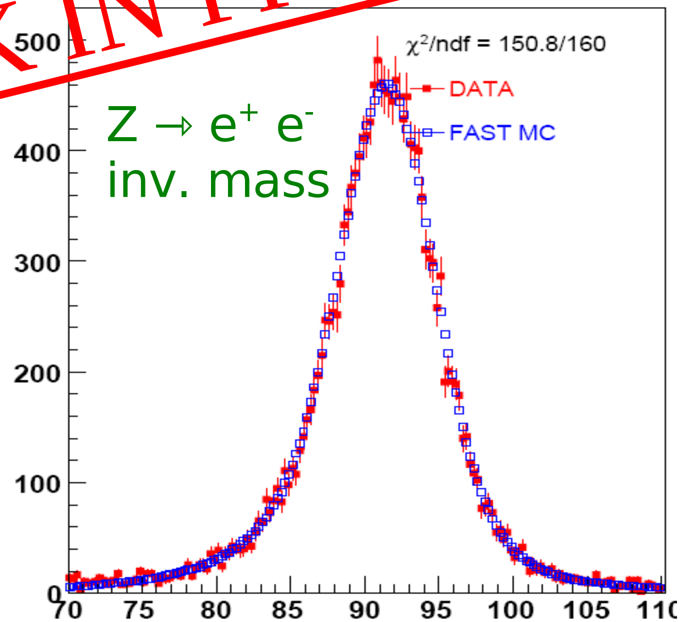
Also had to work on some other ingredients like:

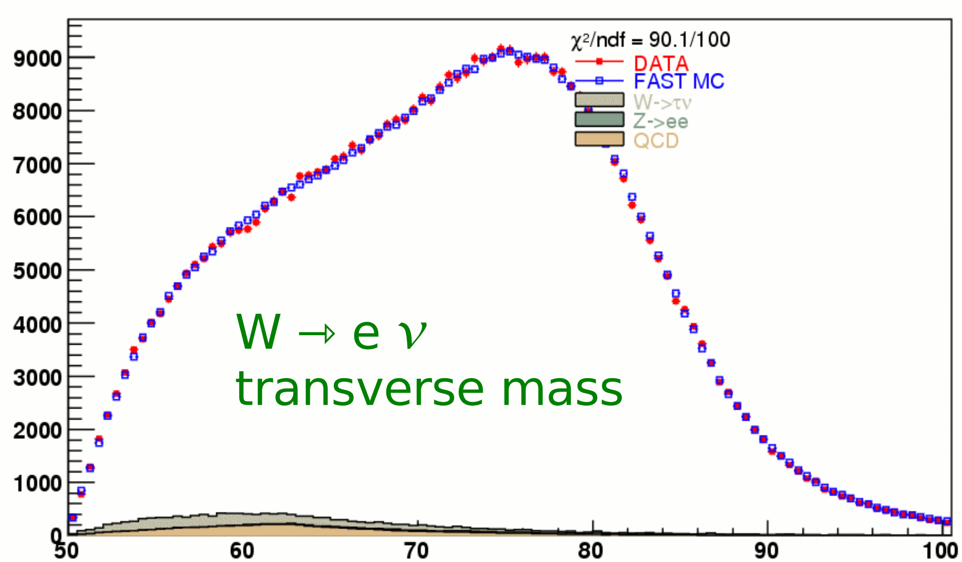
- cross sections of EM processes in Geant (plot on the left),
- details of the Geant tracking parameters chosen by DØ.

T = kinetic energy of incident electron k = energy of the radiated photon

WORK IN PROGRESS

Current status

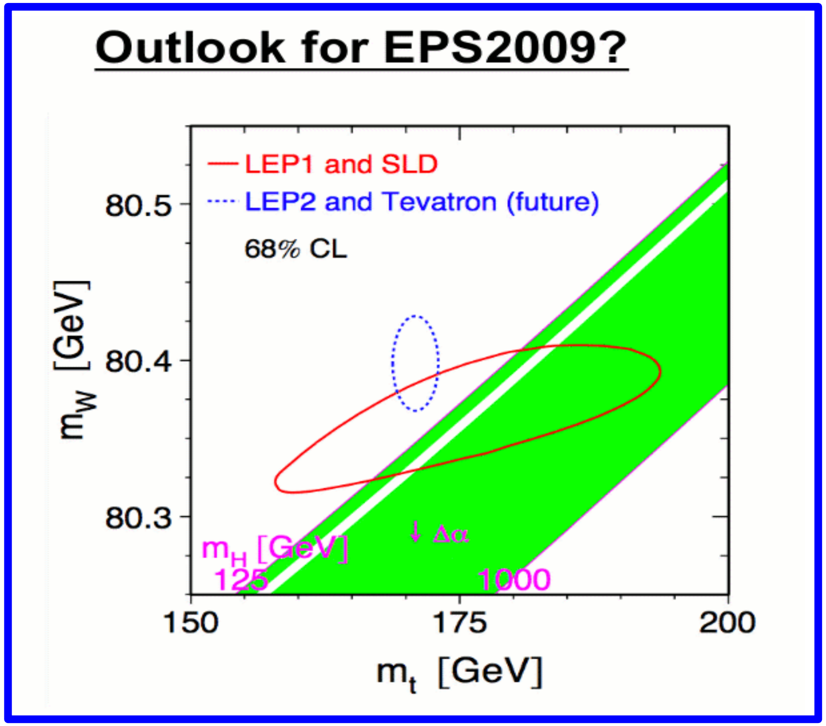




1 fb^{-1}

source	M_t	$ElecP_t$
W stat	19	23
e resp	29	29
e linea.	7	6
e resol	2	2
had resp	17	14
had resol	12	2
bkgd	2	2
efficiencies	5	6
pdf	15	24
P_tW	2	5
QED	8	10
W width	<5	<5
Total	45	48

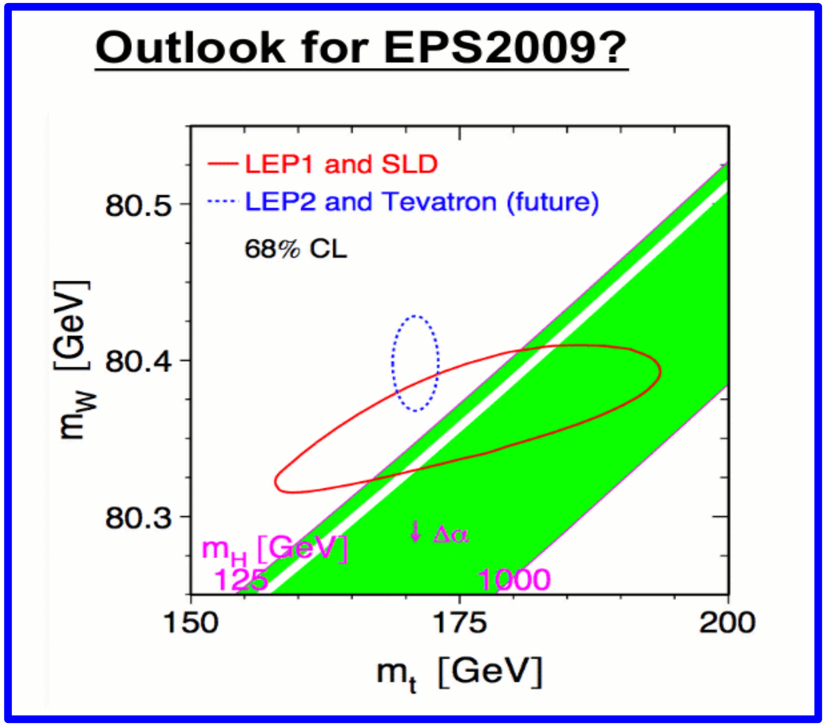
Back to Terry's hopes



... as shown at the EPS 2007 conference.

Are such expectations reasonable ?

Back to Terry's hopes



... as shown at the EPS 2007 conference.

Are such expectations reasonable ?

Yes ! And you can read it in detail in the following article.

When the authors of

"Measurement of the W Boson Mass at the Tevatron"
Ashutosh V. Kotwal , Jan Stark
Annual Review of Nuclear and Particle Science, November 2008

http://arjournals.annualreviews.org/toc/nucl/forthcoming

wrote that 25 MeV per experiment are around the corner, and that a final combined error of 15 MeV is realistic, they really meant it.

WORK IN PROGRESS

Extrapolation to 4 fb^{-1}

4 fb^{-1} (extrapolated from 1 fb^{-1})

Extrapolation from 1 fb^{-1} to 4 fb^{-1} is not that difficult; leading systematics are really just a reflection of the cruel lack of $Z \rightarrow e^+ e^-$ events:

In 1 fb^{-1}, we have just
18k $Z \rightarrow e^+ e^-$ events
to calibrate our
485k $W \rightarrow e \nu$ events.

That is a problem and the solution is straightforward: **add more data**.

At least in the case of DØ, all Run II – specific issues are addressed in the first round of analysis. Specifically, the first 1 fb^{-1} already contain very high inst. luminosities. Can simply add more data, with small losses due to a possible veto on the highest lumi events.

source	M_t	$ElecP_t$
W stat	9	12
e resp	15	15
e linea.	4	3
e resol	2	2
had resp	9	7
had resol	6	2
bkgd	2	2
efficiencies	5	6
pdf	10 ?	12 ?
P_tW	2	5
QED	8	10
W width	<5	<5
Total	25	27

Conclusion

The mass of the W boson is a crucial parameter in the Standard Model.
A precision measurement of this quantity will be one of the most important legacies of Run II.

First DØ Run II measurement of W boson mass is close to finalisation.

This will be the conclusion of many years of hard work on things like the calorimeter, dead material and such.
Many other precision measurements (e.g. Top mass, precision electroweak, QCD, ...) already benefit from many of these developments.

Strong involvement of DØ France in the detector work that was needed to achieve this.
Lesser involvement in the final analysis (e.g. zero French students except for Tim Andeen [Northwestern University] with co-advisors Schellman/Stark).

The next round of analysis [~ 4 fb^{-1}] should be even more fun (and much simpler).
Anybody want to have some fun and contribute to Science before the LHC starts up (and long before it provides a measurement of the W mass) ?