Measurement of the W boson mass using 1 fb^{-1} of Dzero data from Run II of the Fermilab Tevatron

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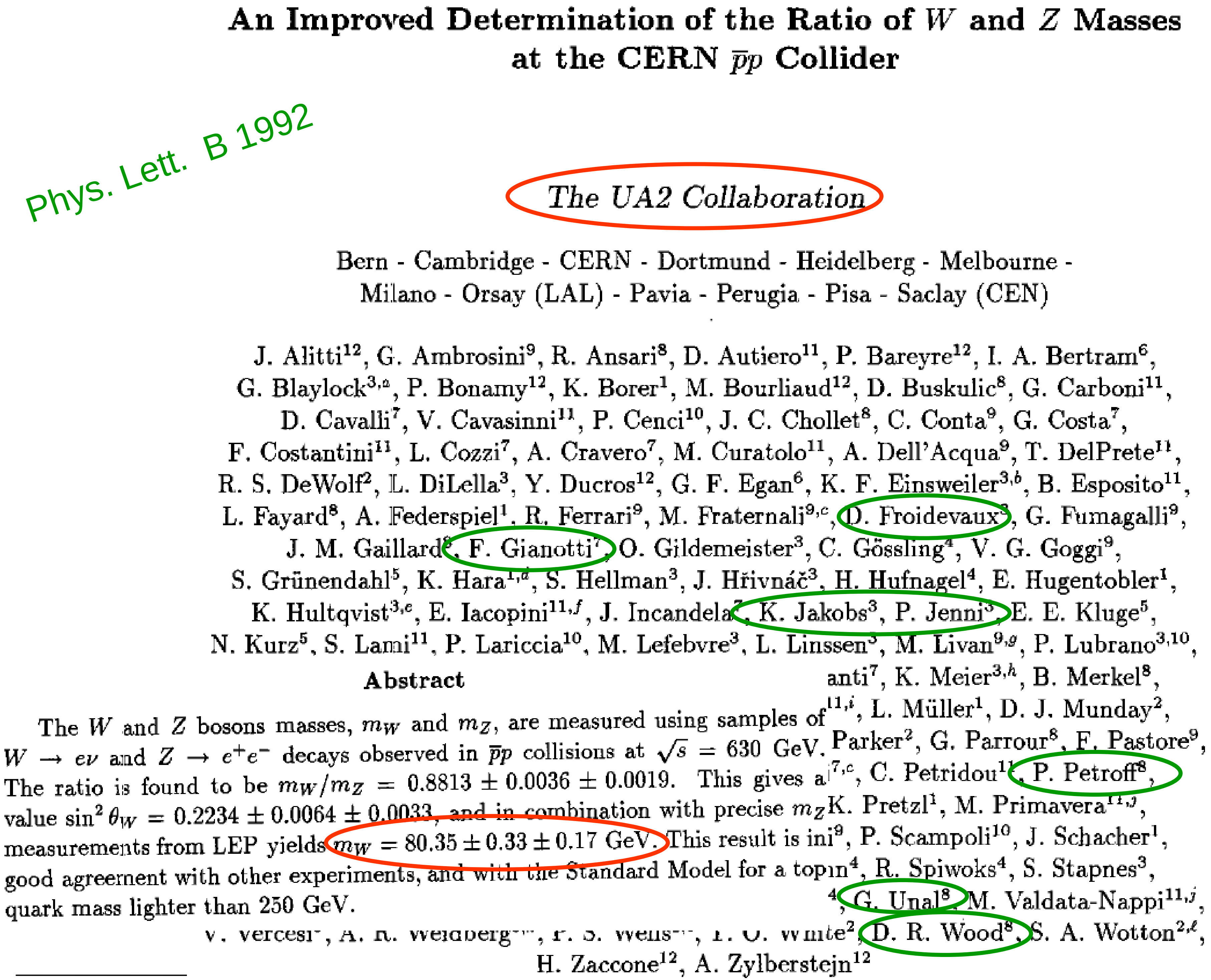
INSTITUT NATIONAL DE PHYSIQUE NUCLÉAIRE
ET DE PHYSIQUE DES PARTICULES



An Improved Determination of the Ratio of W and Z Masses at the CERN $\bar{p}p$ Collider

Phys. Lett. B 1992

The UA2 Collaboration

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Abstract

The W and Z bosons masses, m_W and m_Z, are measured using samples of $W \to e\nu$ and $Z \to e^+e^-$ decays observed in $\bar{p}p$ collisions at $\sqrt{s} = 630$ GeV. The ratio is found to be $m_W/m_Z = 0.8813 \pm 0.0036 \pm 0.0019$. This gives a value $\sin^2\theta_W = 0.2234 \pm 0.0064 \pm 0.0033$, and in combination with precise m_Z measurements from LEP yields $m_W = 80.35 \pm 0.33 \pm 0.17$ GeV. This result is in good agreement with other experiments, and with the Standard Model for a top quark mass lighter than 250 GeV.

Outline

Motivations

Analysis Strategy

Detector Response to electrons

Parametrized Detector Model

- **Electron**
- **Recoil**

Results

Conclusions

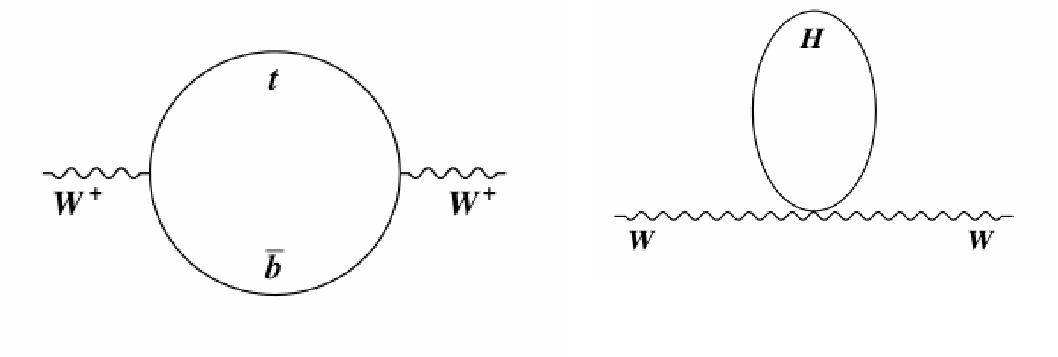
Motivation

W mass is a key parameter in the Standard Model. The model predicts the value of the W mass from measured electroweak quantities

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

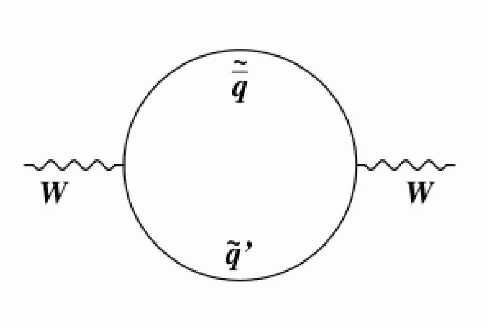
- where $M_W = M_Z \cos\theta_W$
- $\alpha_{EM}(M_Z) = 1/127.918(18)$
- $G_F = 1.16637(1)\ 10^{-5}\ \mathrm{GeV}^{-2}$
- $M_Z = 91.1876(21)$ GeV

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:

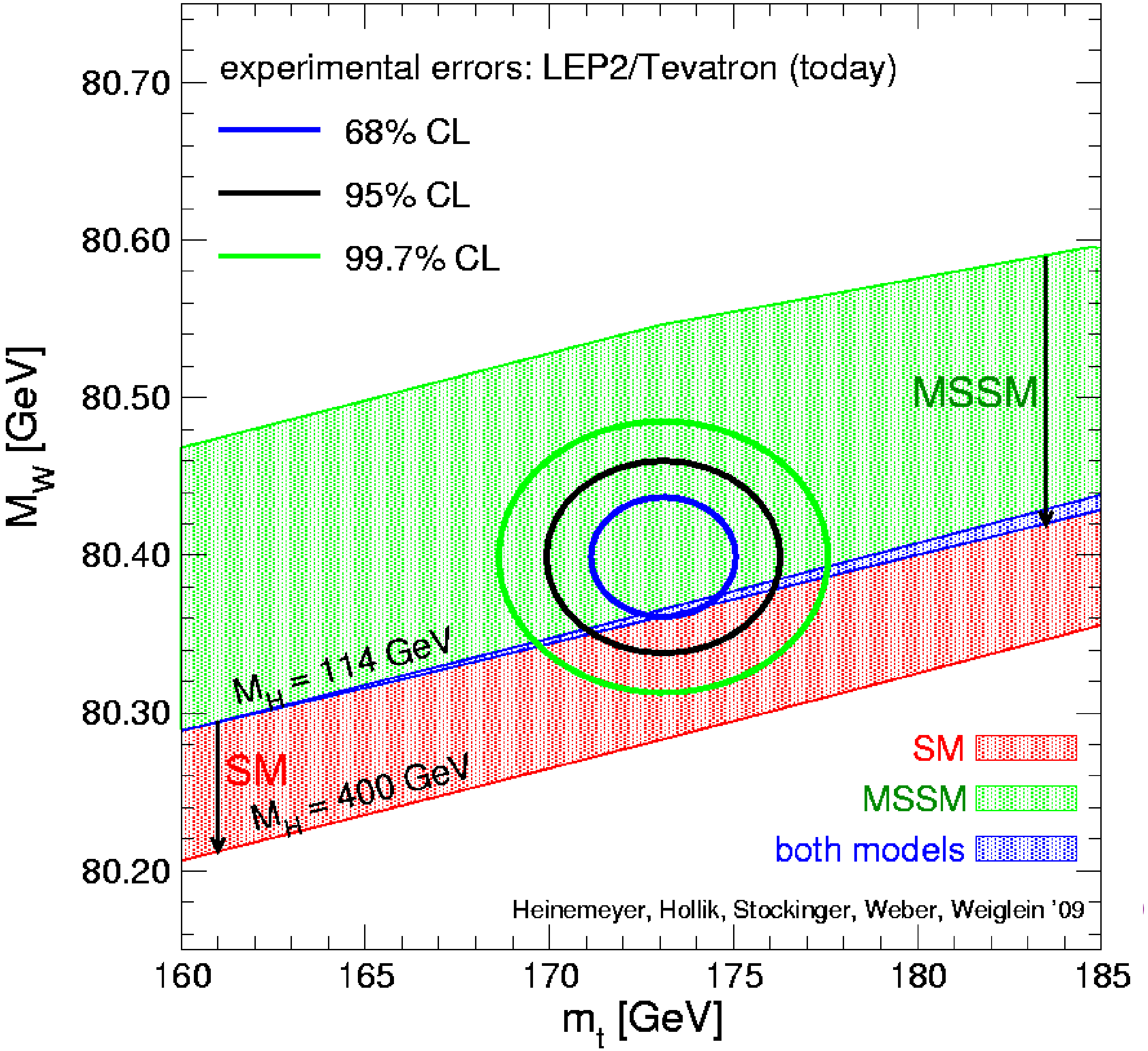


Precise measurements of M_W and M_t constrain SM Higgs mass.

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:

$\Delta M_W \approx 0.006\ \Delta Mt.$

Current Tevatron average:

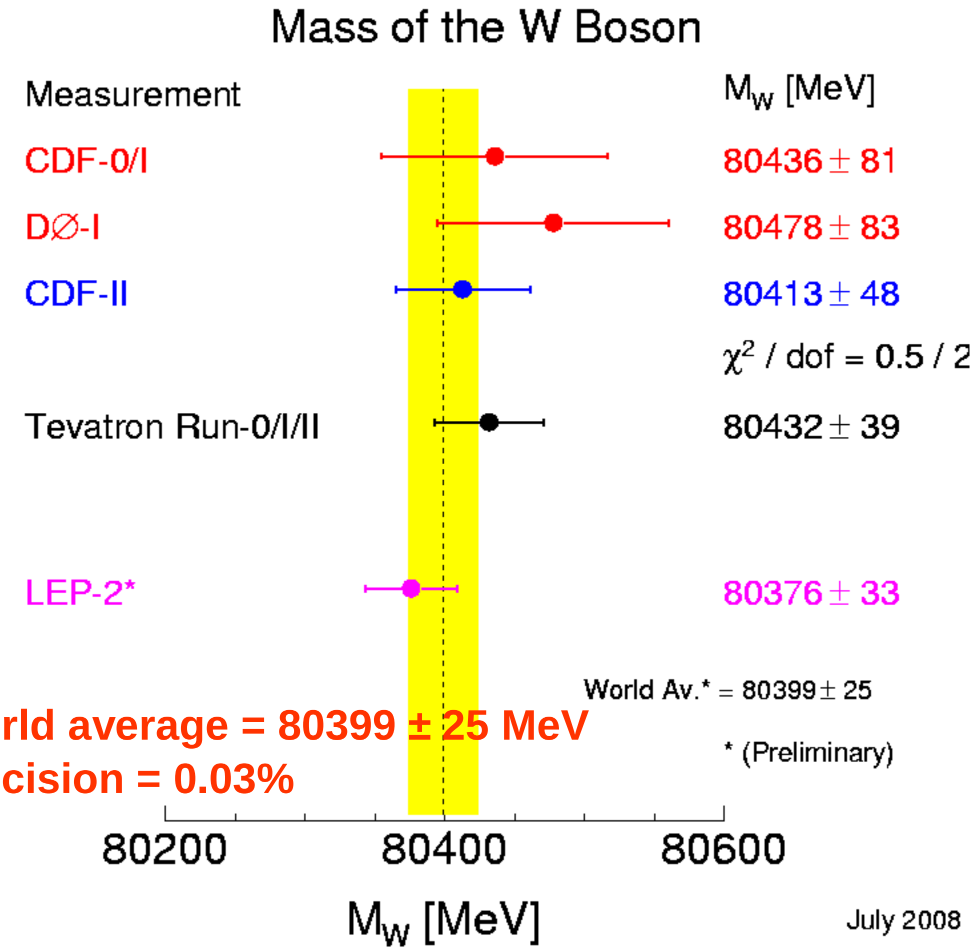
$M_{top} = 173.1 \pm 1.3$ GeV

→ would need: $\Delta M_W =$ 8 MeV

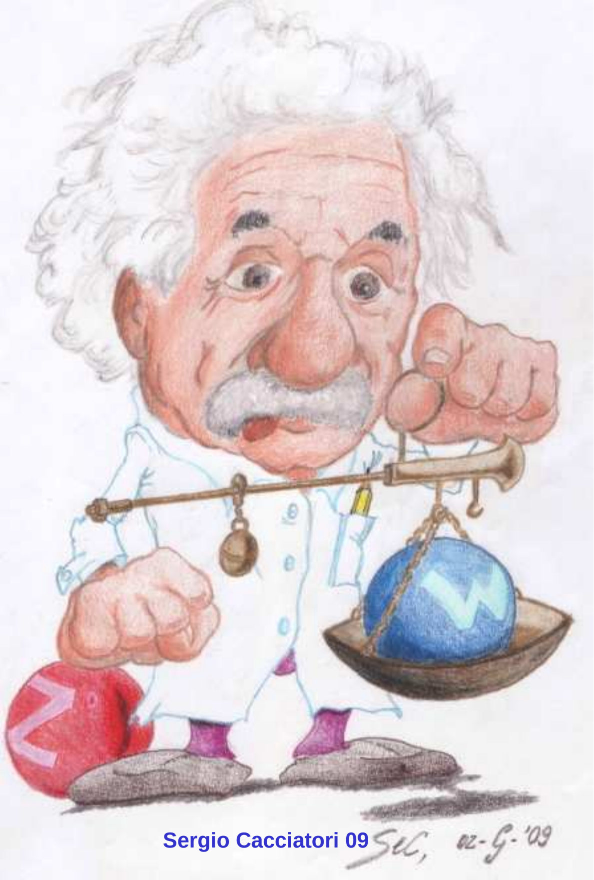
currently have: $\Delta M_W =$ 25 MeV

At this point, i.e. after all the precise top mass measurements from the Tevatron, **the limiting factor here is ΔM_W, not ΔM_t.**

Current precision



World average = 80399 ± 25 MeV
precision = 0.03%



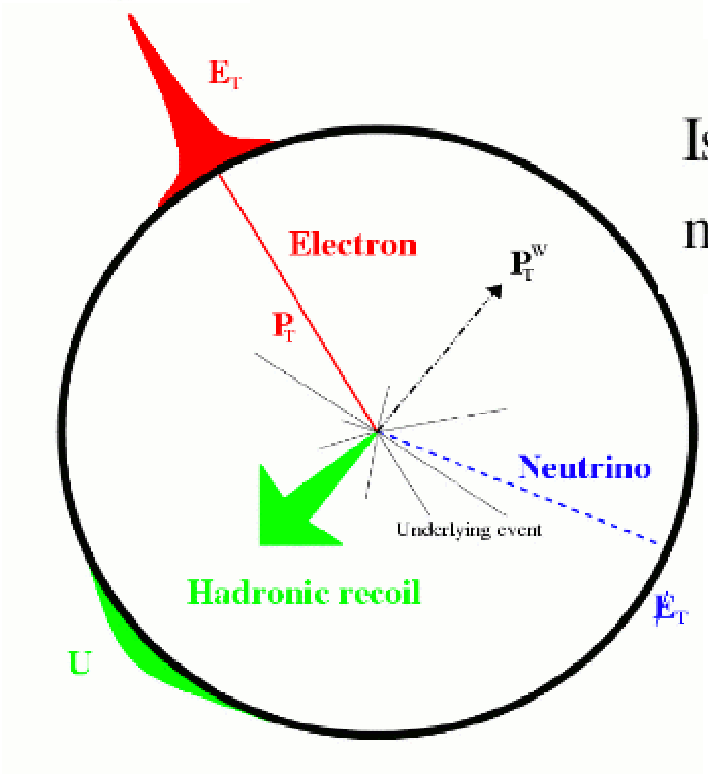
The current world average is still dominated by the final LEP2 results. The Tevatron average is driven by a recent Run II measurement from CDF (200 pb^{-1}) .but the analysis of the Tevatron Run II data is really just starting ...

CDF Run II (200 pb^{-1}):

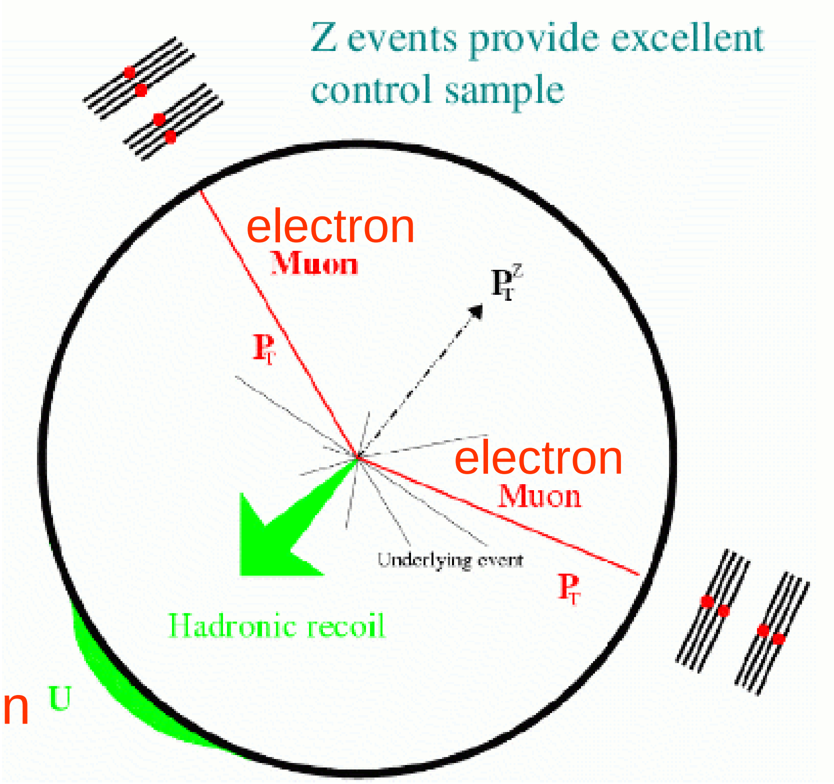
m(W) = 80.413 ± 0.048 GeV

Phys.Rev.Lett.99:151801 (2007)
Phys.Rev.D77:112001 (2008)

Signature in the detector



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

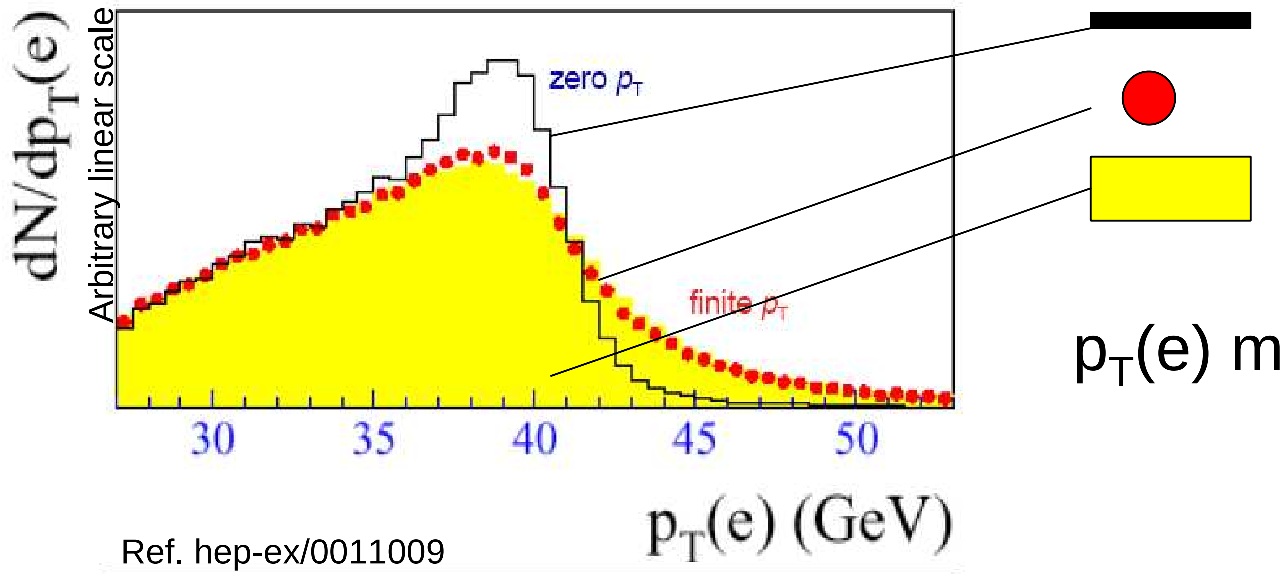

Z events provide excellent control sample

Two objects are measured in the detector:
- Lepton (e or μ) → e in our analysis

need energy measurement with 0.2 per-mil precision
- Hadronic recoil   need ~1% precision

Z → ee used for calibrating electron and hadronic recoil

Experimental observables



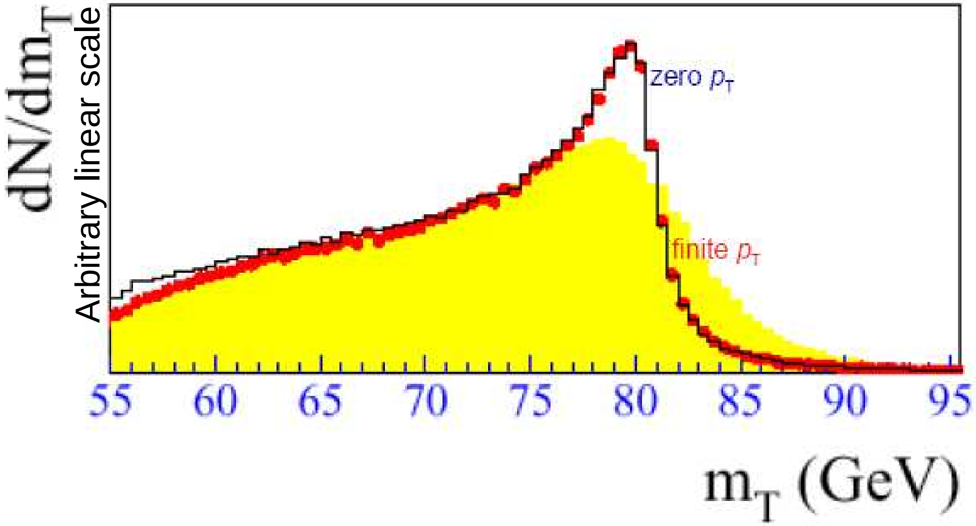
Ref. hep-ex/0011009

▬ No $P_T(W)$

● $P_T(W)$ included

🟨 Detector Effects added

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

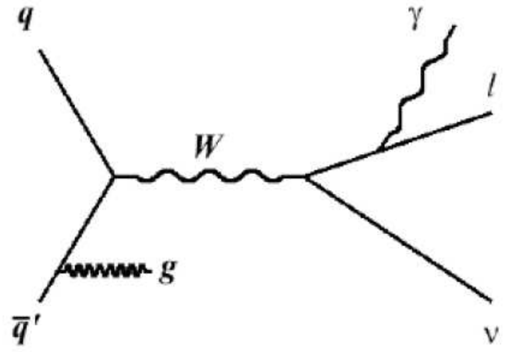


$$M_T = \sqrt{2 E_T^l \not{E}_T (1 - \cos\Delta\phi)}$$

M_T most affected by measurement of missing transverse momentum

Measurement Strategy

W mass is extracted from transverse mass, transverse momentum and transverse missing momentum:
Need Monte Carlo simulation to predict shapes of these observables for given mass hypothesis



NLO event generator : DØ uses **ResBos** [Balazs, Yuan; Phys ReV D56, 5558] + **Photos** {Barbiero, Was; Comp Phys Com 79, 291] for W/Z production and decay

+

Parametrised detector model

↓

W mass templates

+

backgrounds

Detector calibration
- calorimeter energy scale
- recoil

data

binned likelihood fit

↓

W mass

First DØ Run II measurement of the W boson mass (preliminary)

1 fb^{-1} of data

using central electrons (|η|<1.05)

499,830 W → e ν Et (e,ν) > 25 GeV

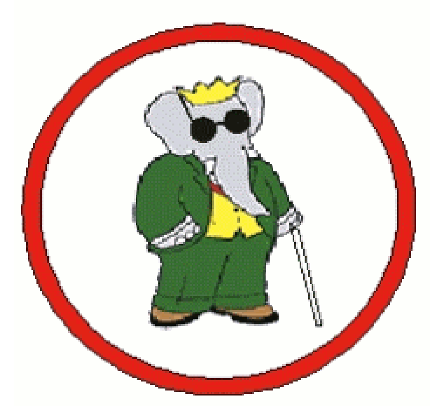
18,752 Z → e e Et (e,e) > 25 GeV

ut(recoil) < 15 GeV

"blind" analysis : central value hidden but not the uncertainties

Standard blinding technique "a la BaBar"

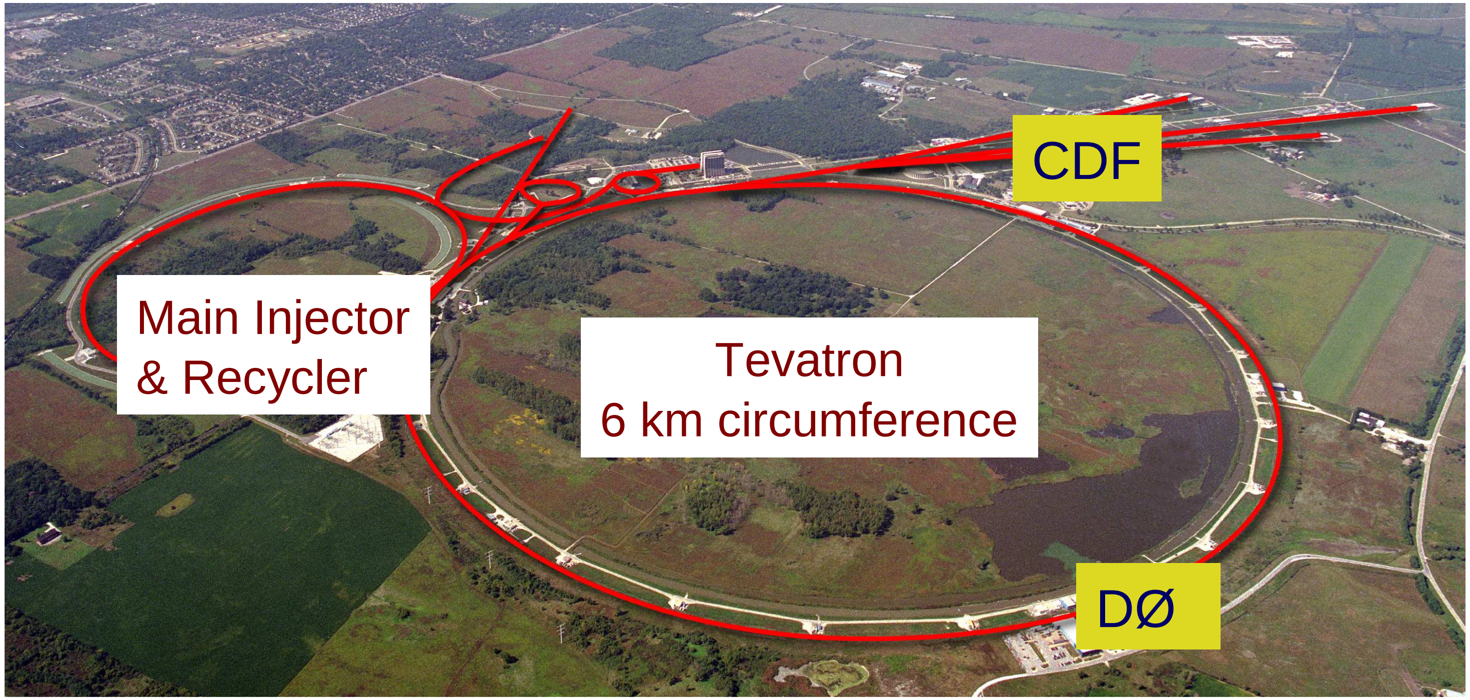
Unblinding has been done only after collaboration approval



The Tevatron

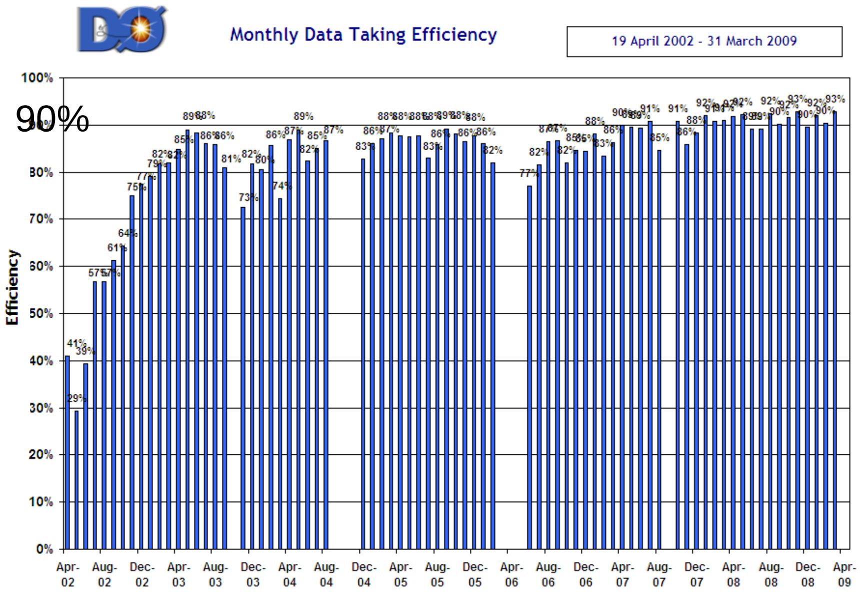
Proton-antiproton
collisions with
center-of-mass = 1.96 TeV

36 p and pbar bunches
396 ns between bunch
crossing



Currently the only place in the world where W and Z bosons can be produced directly

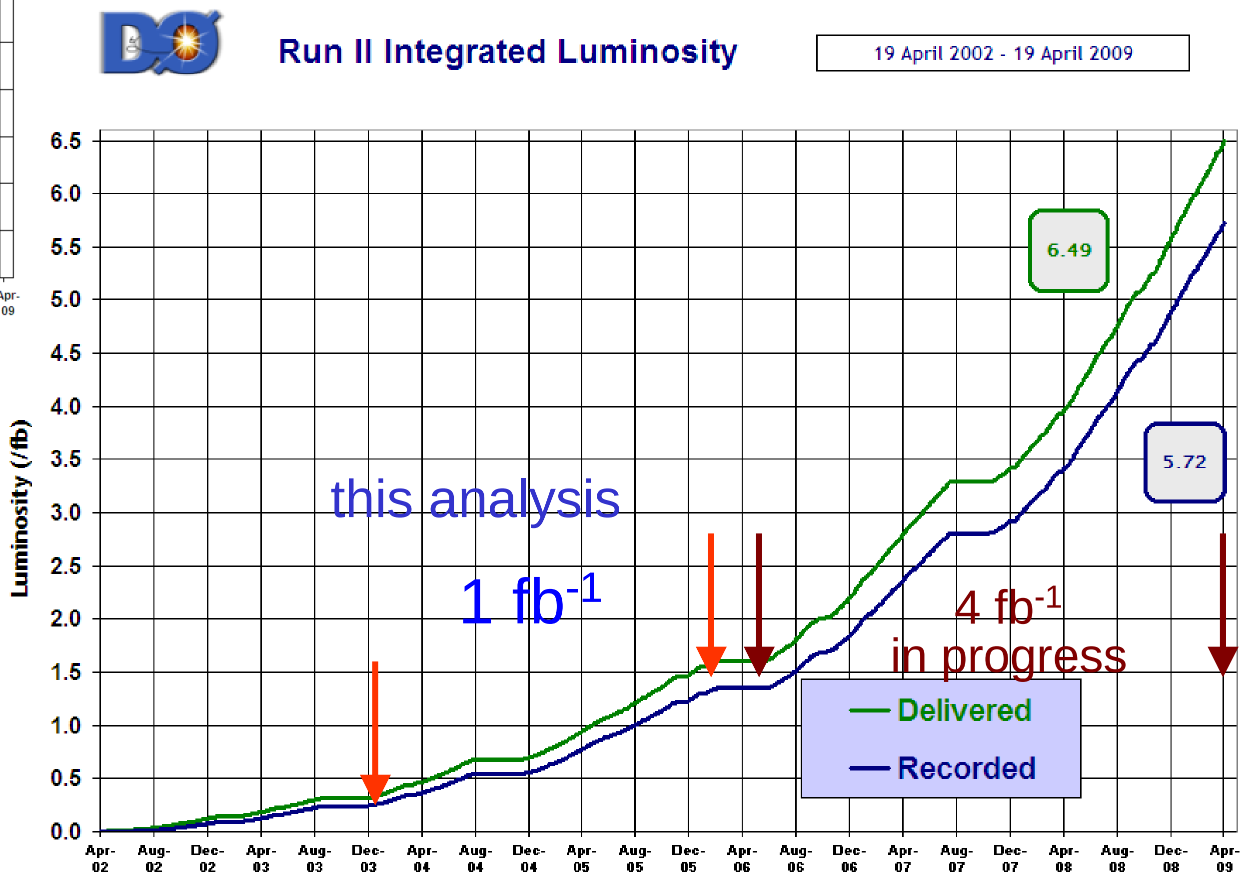
Luminosity



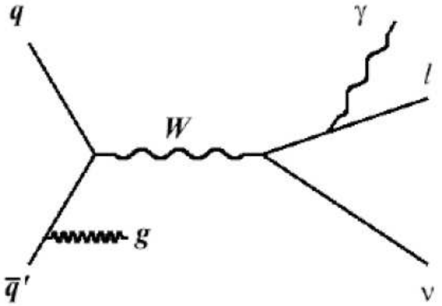
Running extremely well

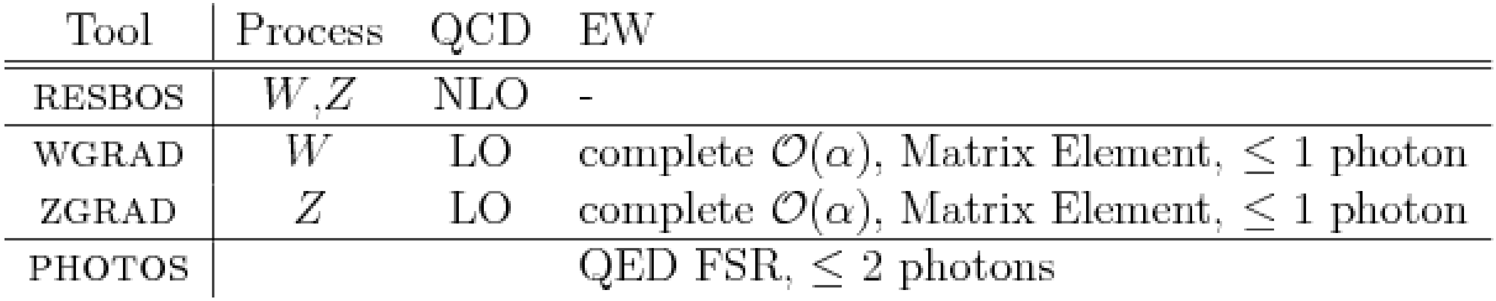
Thanks, FNAL (and Accelerator Division!)

The DØ detector too !



Model of W production and decay





Tool	Process	QCD	EW
RESBOS	W,Z	NLO	-
WGRAD	W	LO	complete $\mathcal{O}(\alpha)$, Matrix Element, ≤ 1 photon
ZGRAD	Z	LO	complete $\mathcal{O}(\alpha)$, Matrix Element, ≤ 1 photon
PHOTOS			QED FSR, ≤ 2 photons

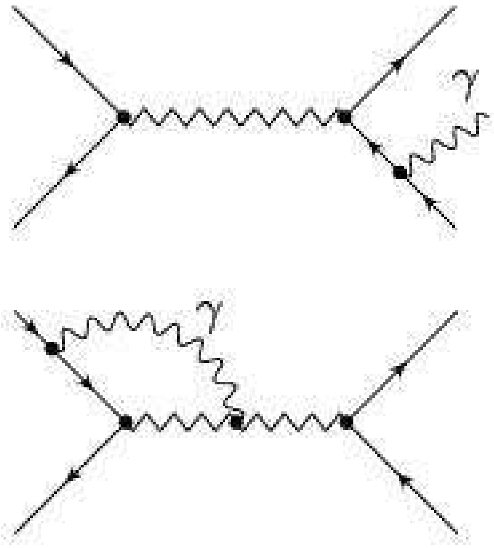
Our main generator is “**ResBos+Photos**”. The NLO QCD in **ResBos** allows us to get a reasonable description of the p_T of the vector bosons. The two leading EWK effects are the first FSR photon and the second FSR photon. **Photos** gives us a reasonable model for both.

We use W/ZGRAD to get a feeling for the effect of the full EWK correct

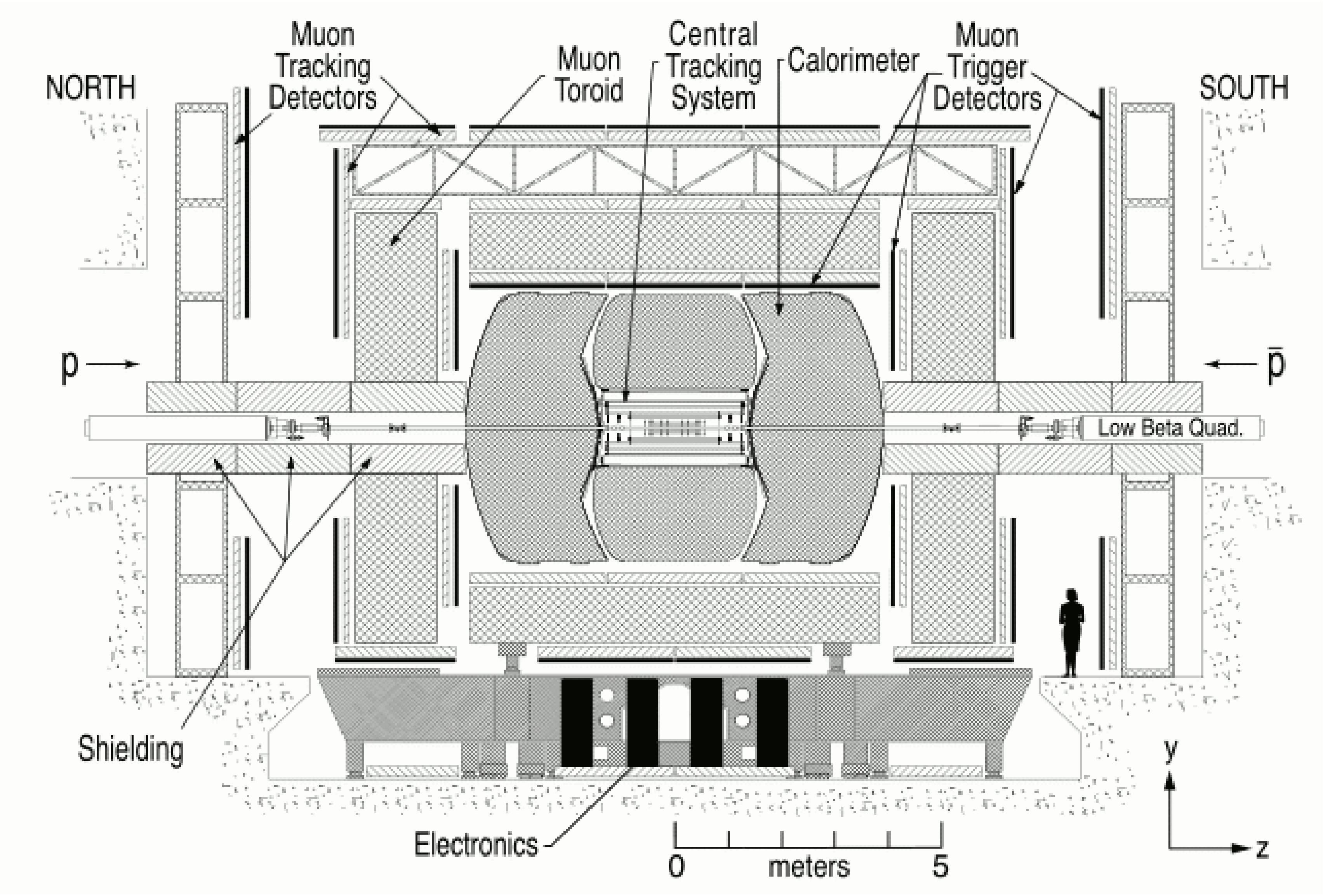
The final “QED” uncertainty we quote is **7/7/9 MeV (m_T,p_T,MET).**

This is the sum of different effects; the two main ones are:

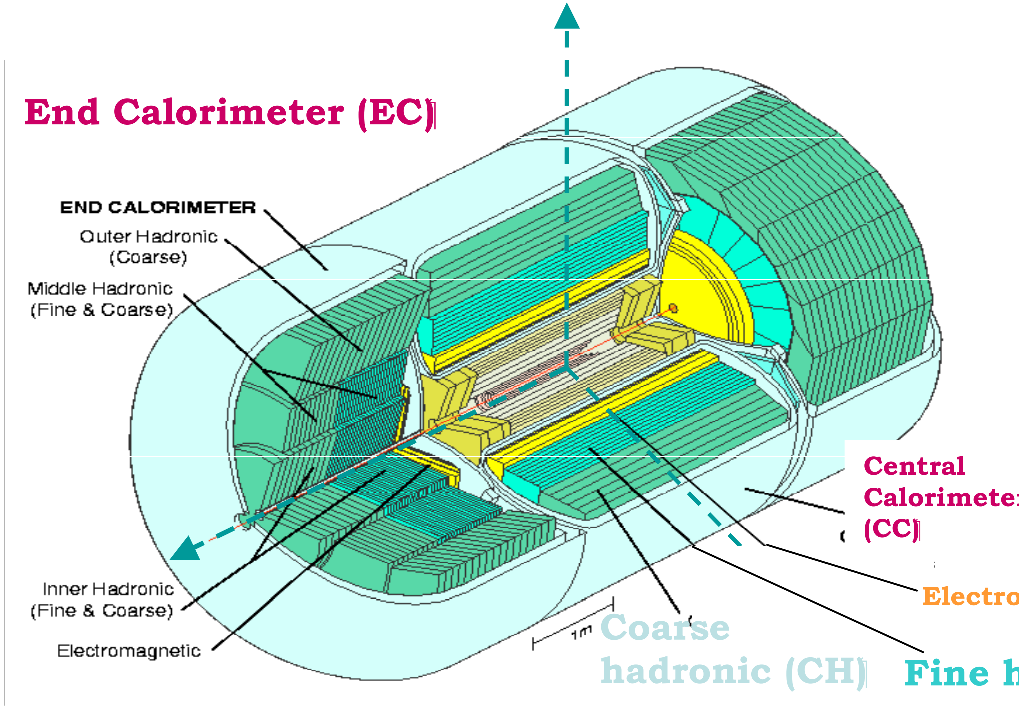
- Effect of full EWK corrections, from comparison of W/ZGRAD in “FSR only” and in “full EWK” modes **(5/5/5 MeV).**
- Very simple estimate of “quality of FSR model”, from comparison of W/ZGRAD in FSR-only mode vs **Photos (5/5/5 MeV).**



The upgraded Dzero detector



Overview of the calorimeter



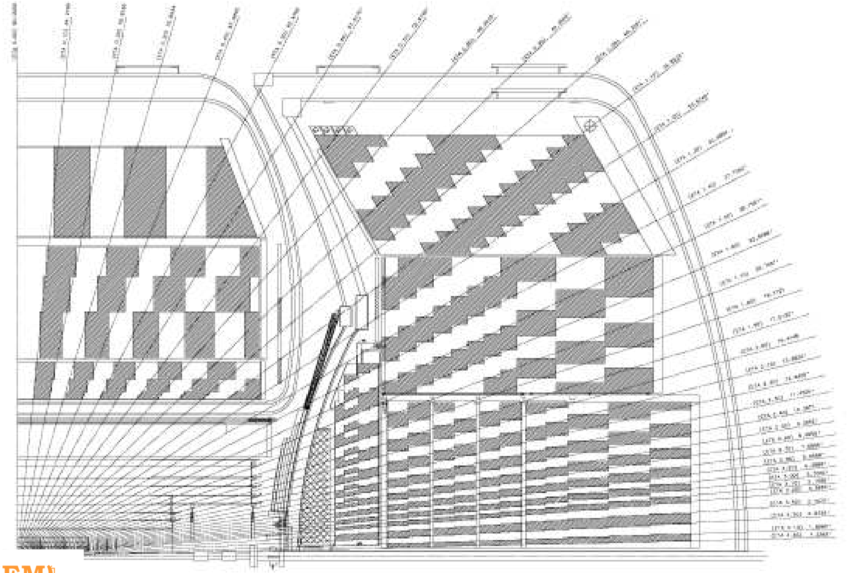
End Calorimeter (EC)

Central Calorimeter (CC)

Electromagnetic (EM)

Coarse hadronic (CH)

Fine hadronic (FH)



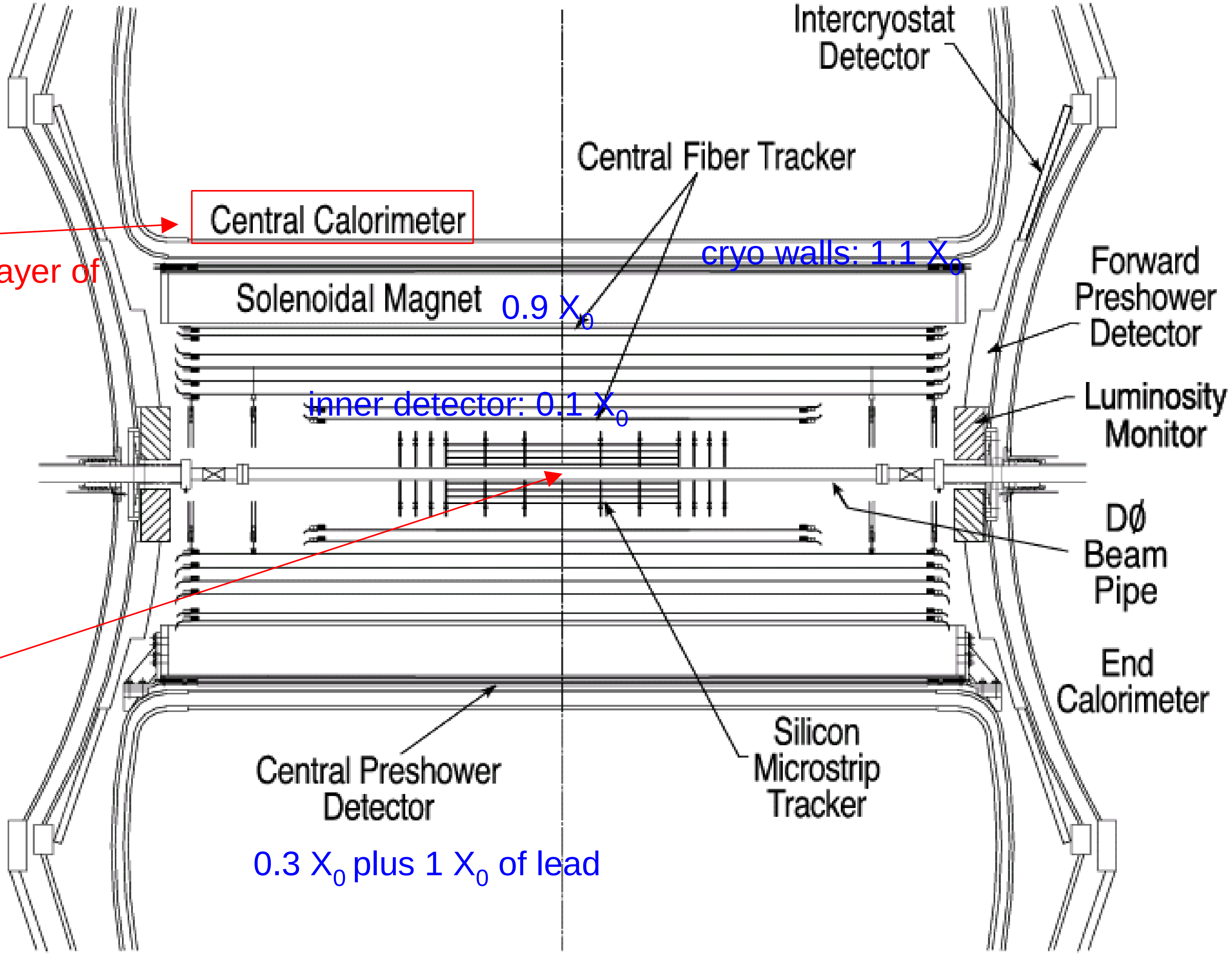
46000 cells

50 dead channels

- Liquid argon active medium and (mostly) uranium absorber
- Hermetic with full coverage :$|\eta| < 4.2$
- Segmentation (towers): $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$

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

Keep in mind: the CAL is not alone !



cryo walls: 1.1 X_0

0.9 X_0

inner detector: 0.1 X_0

0.3 X_0 plus 1 X_0 of lead

First active layer of liquid argon

about 3.7 X_0 in between !

Interaction point

Energy Response Linearity

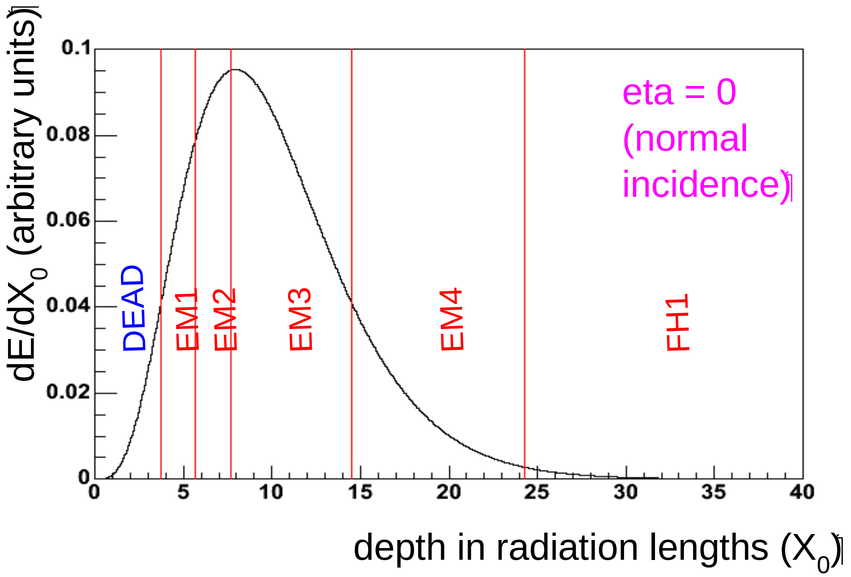
Let us try to understand the effect of the dead material on the energy response linearity

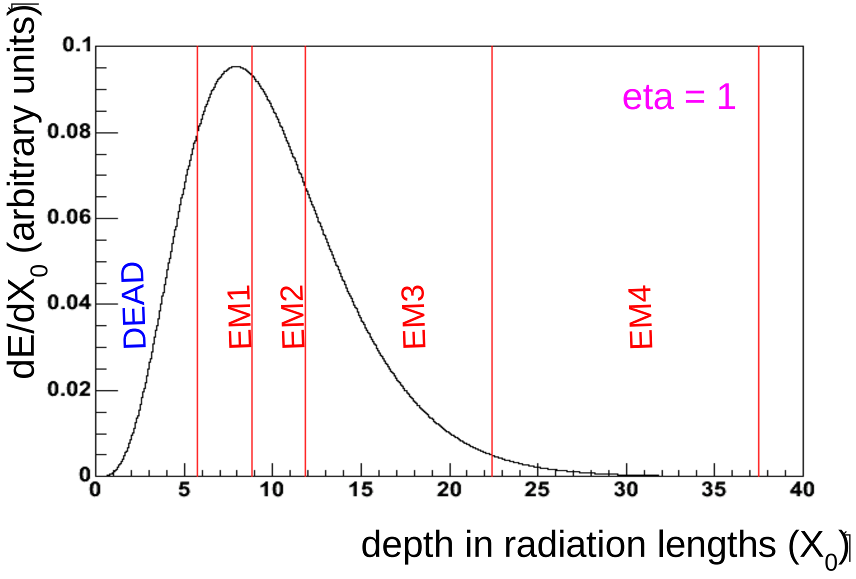
The plot on the right shows the average longitudinal profile of a shower with E = 45 GeV. Assuming normal incidence, the position of the active parts of the CC are also indicated.

In the reconstruction, we apply artificially high weights to the early layers (especially EM1) in an attempt to partially compensate the losses in the dead material:

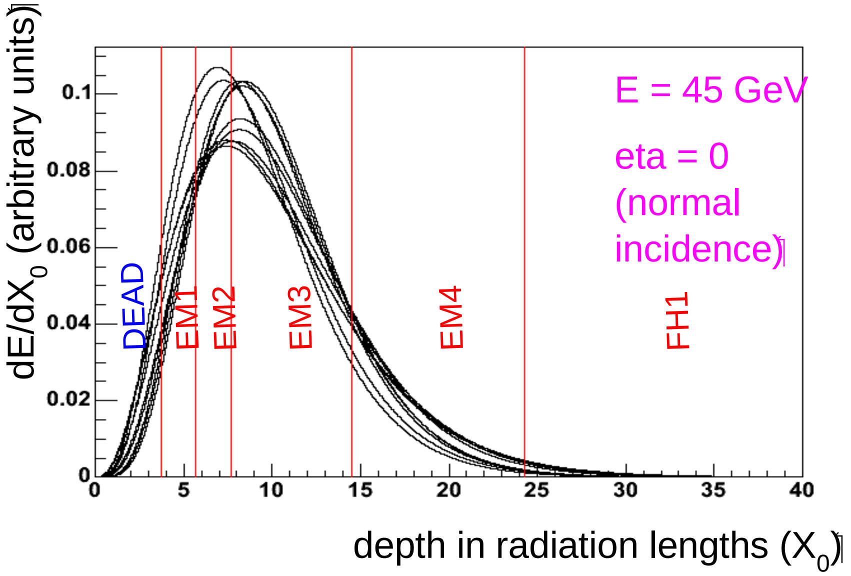
Layer	depth (X_0)	weight (a.u.)	weight/X_0
EM1	2.0	31.199	15.6
EM2	2.0	9.399	4.7
EM3	6.8	25.716	3.8
EM4	9.1	28.033	3.1
FH1	≈ 40	24.885	≈ 0.6

The lower plot illustrates the situation for the same average shower, but this time under a more extreme angle of incidence (physics eta = 1). The shower maximum is now in EM1 !



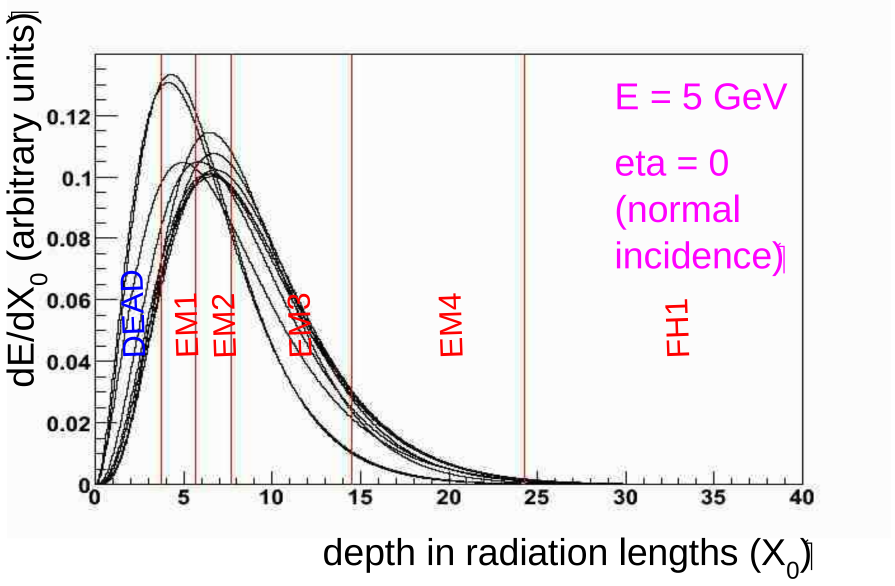


Energy-dependence and fluctuations



The plots on the previous slide show the *average* shower profile at E = 45 GeV.
The plot on the right is basically the same, except that it includes typical *shower fluctuations*.

=> The fraction of energy lost in the dead material varies from shower to shower.



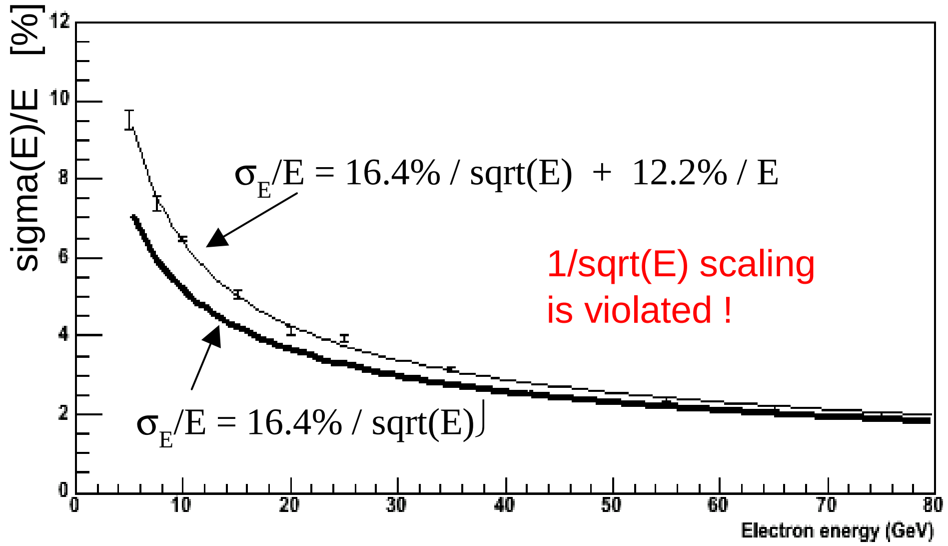
The bottom plot illustrates the situation at a different, lower, energy. The position of the shower maximum (in terms of X_0) varies approximately like ln(E).

=> The average fraction of energy lost in dead material, as well as the relative importance of shower-by-shower fluctuations depend on the energy of the incident electron.

... and fluctuations around the average

Here we show the impact on the energy resolution for electrons. This is again from a detailled detector simulation based on Geant.

Resolution at normal incidence, as a function of electron energy:



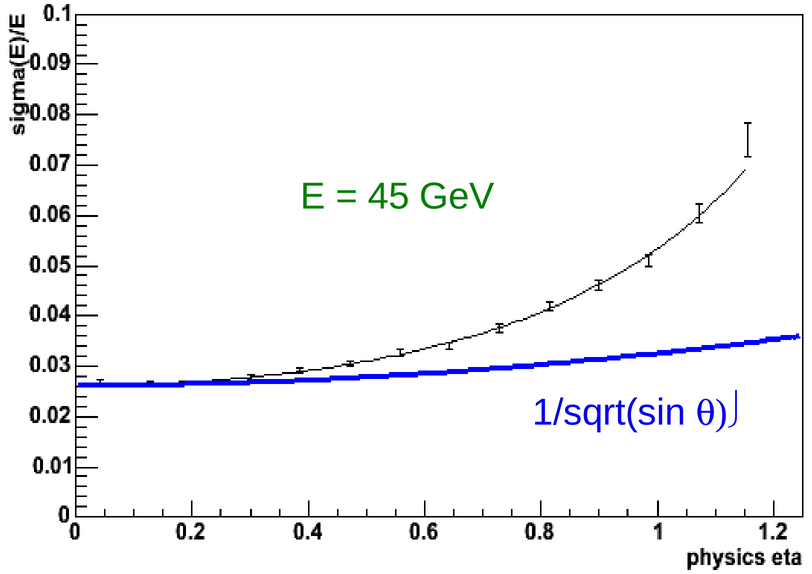
σ_E/E = 16.4% / sqrt(E) + 12.2% / E

1/sqrt(E) scaling is violated !

σ_E/E = 16.4% / sqrt(E)

for an ideal sampling calorimeter (no dead material) one would expect this to scale as 1/sqrt(E)

Resolution at E = 45 GeV, as a function of the angle of incidence (eta):



E = 45 GeV

1/sqrt(sin θ)

for an ideal sampling calorimeter (no dead material) one would expect this to be almost flat

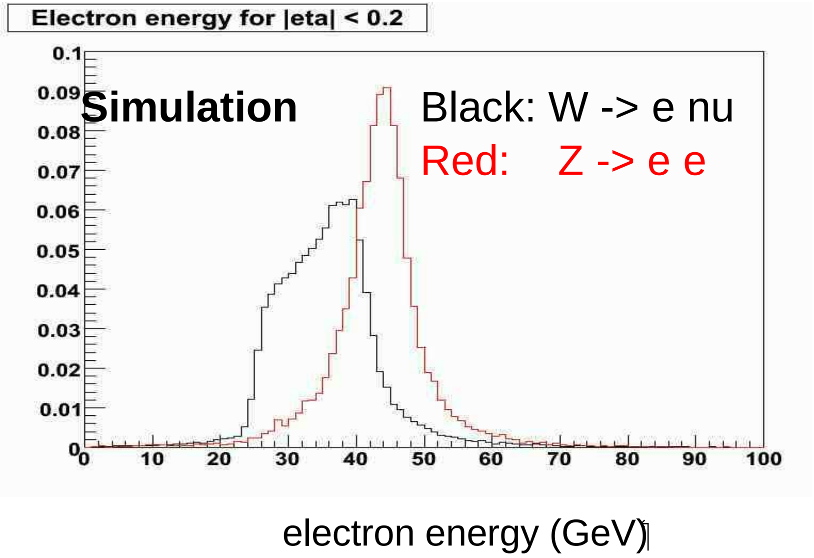
Knowing the amount of dead material is the KEY to energy response linearity

This is done in *situ* using electrons from Z→ ee

How to split our (already small) $Z \rightarrow e\,e$ sample ??

So we need to understand both average response and the resolution as a function of both energy and angle of incidence.

$Z \rightarrow e\,e$ data gives us access to a line in energy/angle space. Consider CC/CC events. At a given angle, the distribution of energies provided by Nature is rather narrow.



How to proceed:

=> Bin electrons in angle (5 bins).

=> Two electrons per Z.

=> 15 distinct combinations of bins - “categories” (no E ordering).

bin 0 : $0 \leq |\eta| < 0.2$
bin 1 : $0.2 \leq |\eta| < 0.4$
bin 2 : $0.4 \leq |\eta| < 0.6$
bin 3 : $0.6 \leq |\eta| < 0.8$
bin 4 : $0.8 \leq |\eta|$

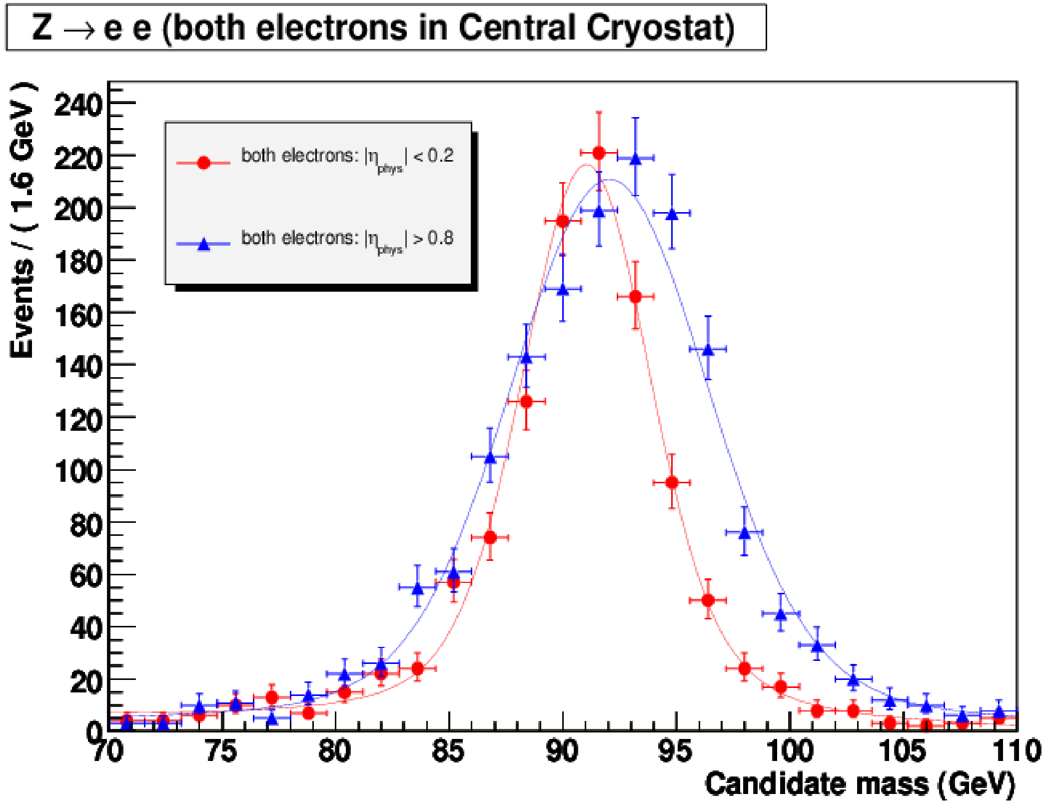
Category	Bins of Each Electron
10	0 – 0
11	0 – 1
12	0 – 2
13	0 – 3
14	0 – 4
15	1 – 1
16	1 – 2
17	1 – 3
18	1 – 4
19	2 – 2
20	2 – 3
21	2 – 4
22	3 – 3
23	3 – 4
24	4 – 4

Split CC/CC $Z \rightarrow e\,e$ sample into the 15 categories and study measured Z mass and mass resolution per category.

Once the information from Z has been harvested, we still need to propagate that down to the lower energies of the W.
Need to understand scaling laws.

Simple plots (after splitting)

Let's start with a few simple plots that are based on the idea of splitting the sample according to eta of the two electrons. Here are the Z mass peaks (early version of data reconstruction) for “both electrons very central” and “both electrons very forward”, i.e. “both electrons at close to normal incidence” and “both electrons at highly non-normal incidence”



We note:

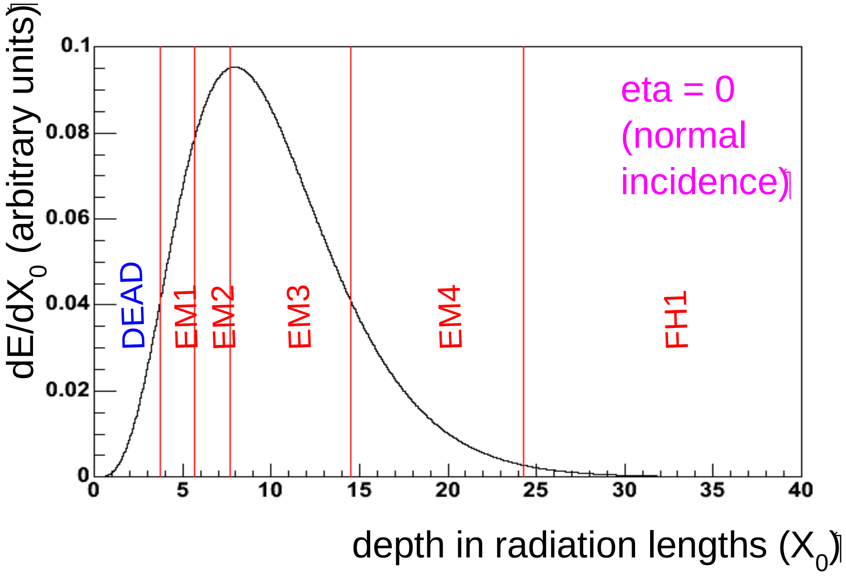
- different resolutions (material !),
- the peaks are not in the same place.

Why aren't the peaks in the same place ? Could be a problem in the MC-based E-loss corrections. But could also be a problem with gain calibrations in different regions of the CAL. This plot alone is not going to tell us, we need more information, new observables.

Need more information: additional observables

Let's go back to one of the plots that we have discussed on an earlier slide.
It clearly suggests that we should try to **exploit the longitudinal segmentation of the EM CAL** to get a handle on dead material:

Imagine we vary the size of the "DEAD" region a little bit
=> the individual layers (EM1 etc) would sample different parts of the shower and therefore see different fractions of the shower energy !!

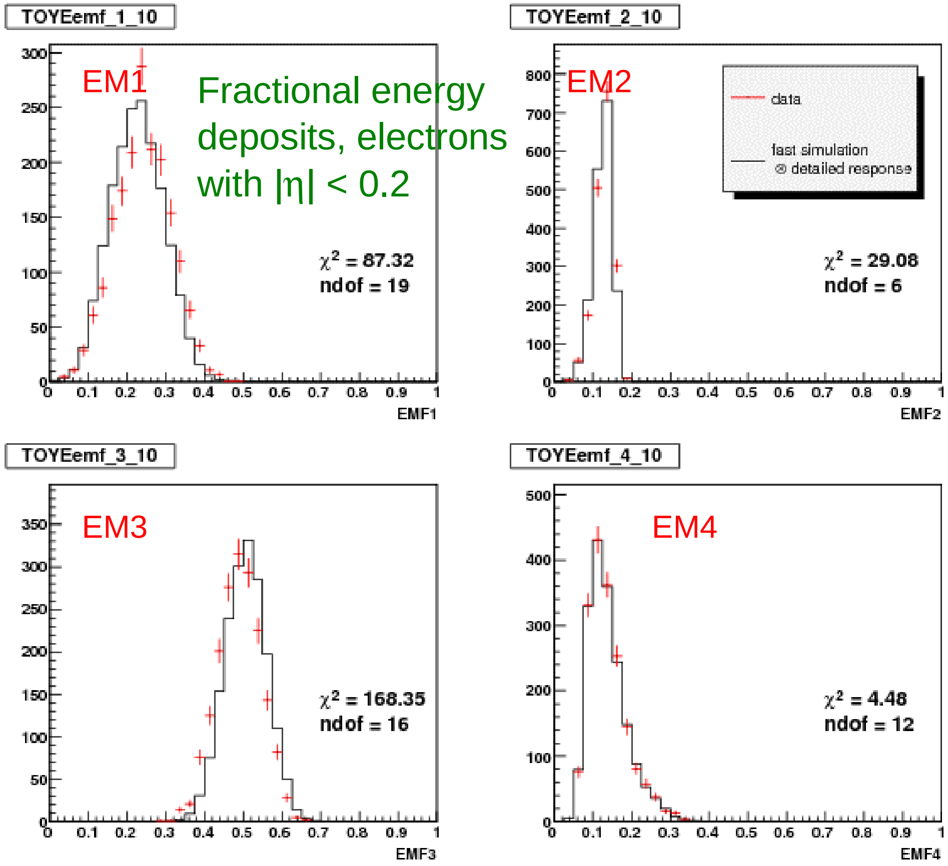


Using the longitudinal segmentation to get a handle on material is a standard technique, it is discussed in the textbooks (e.g. Wigmans).

Back to Dzero. Let's compare data (old reconstruction) and full Monte Carlo (nominal geometry) in terms of the four fractional EM energy deposits. We do this separately in each of the 15 η categories.

Before tuning of material model

Before tuning of material model:
distributions of fractional energy deposits
do not quite match between data and the simulation.

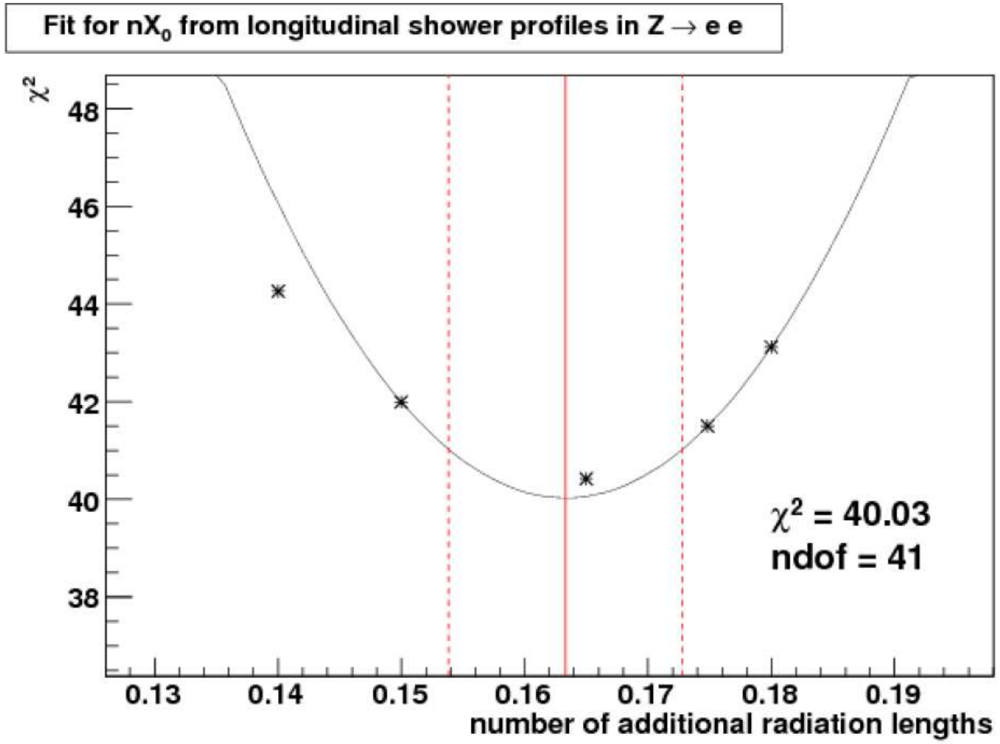


Fractional energy deposits, electrons with $|\eta| < 0.2$

Fit for amount of missing material

"Turn the plots from the previous slides into a fit for the amount of missing material":
Take data/MC ratios per η category for EM1, EM2 and EM3 and fit each one (separately) to a constant. Add the chi-squareds from the three fits. Vary amount of extra material to minimise the global chi-squared.

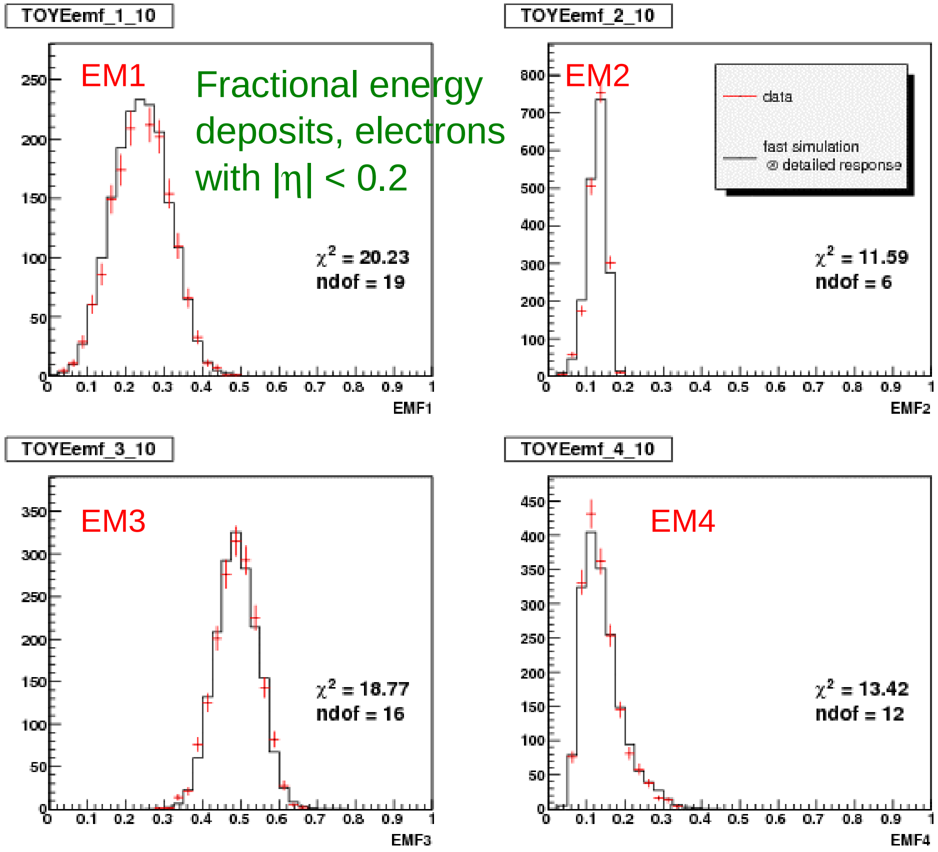
This implies that we leave the absolute energy scale of each layer free to float. This is because this fit is the first time that we have a handle on the intercalibration of the layers.



Amount of fudge material to within less than $0.01X_0$!
With comparatively small systematics from background (underlying event) subtraction and modelling of cut efficiencies.

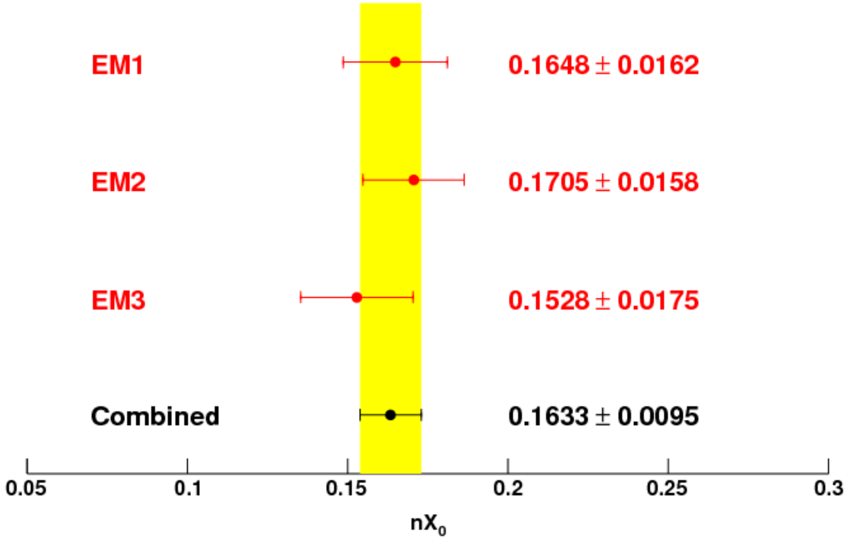
After tuning of material model

After tuning of material model:
distributions of fractional energy deposits are very well described by the simulation.



Fractional energy deposits, electrons with $|\eta| < 0.2$

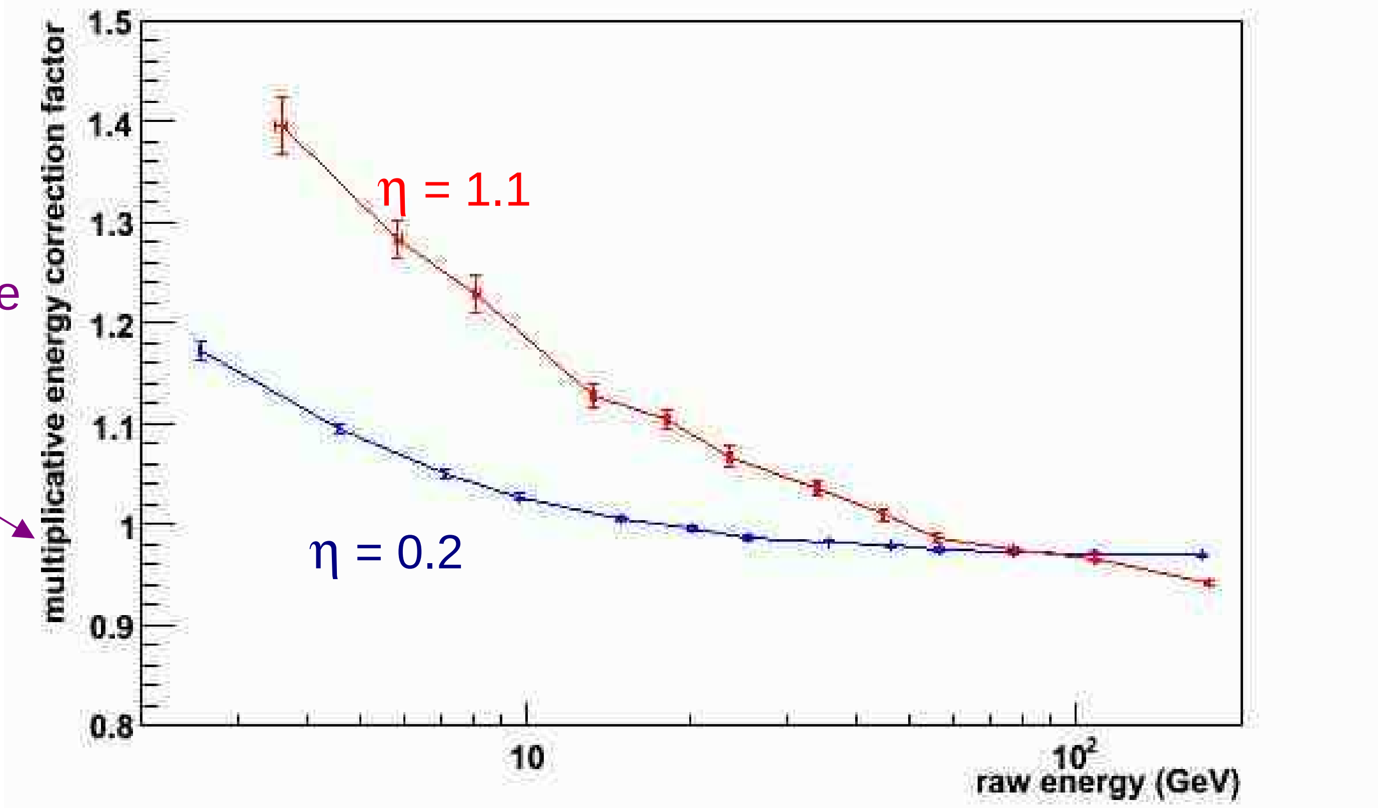
As a cross-check:
Repeat fit for nX_0, separately for each EM layer. Good consistency is found.



Correction to the Raw Energy

An energy-loss correction is applied to our reconstructed electron energies to account for the energy lost in front of the calorimeter. This correction, as a function of energy and angle (η) is estimated using detailed detector simulations based on Geant including the fitted amount of missing material.

This is the energy correction factor that gets us back to the energy of the incident electron.



This is the energy as reconstructed in the CAL.

This energy correction is applied on the data and not parametrized in our fast MC

Electrons: energy scale

After having corrected for the effects of the uninstrumented material:
final energy response calibration, using Z →e e, the known Z mass value from LEP, and the standard "f_z method":

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

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

In a nutshell: the f_Z observable allows you to split your sample of electrons from Z → e e into subsamples of different true energy; this way you can *"scan" the electron energy response as a function of energy*.

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

γ_{ee} is the opening angle between the two electrons

Result:

$\alpha = 1.0111 \pm 0.0043$
$\beta = -0.404 \pm 0.209$ GeV
correlation: -0.997

This corresponds to the dominant systematic uncertainty (by far) in the W mass measurement (but this is really just Z statistics ... more data will reduce it) :

$\Delta m(W) = 34$ MeV, 100 % correlated between all three observables

Electrons: energy resolution

Electron energy resolution is driven by two components:
sampling fluctuations and constant term

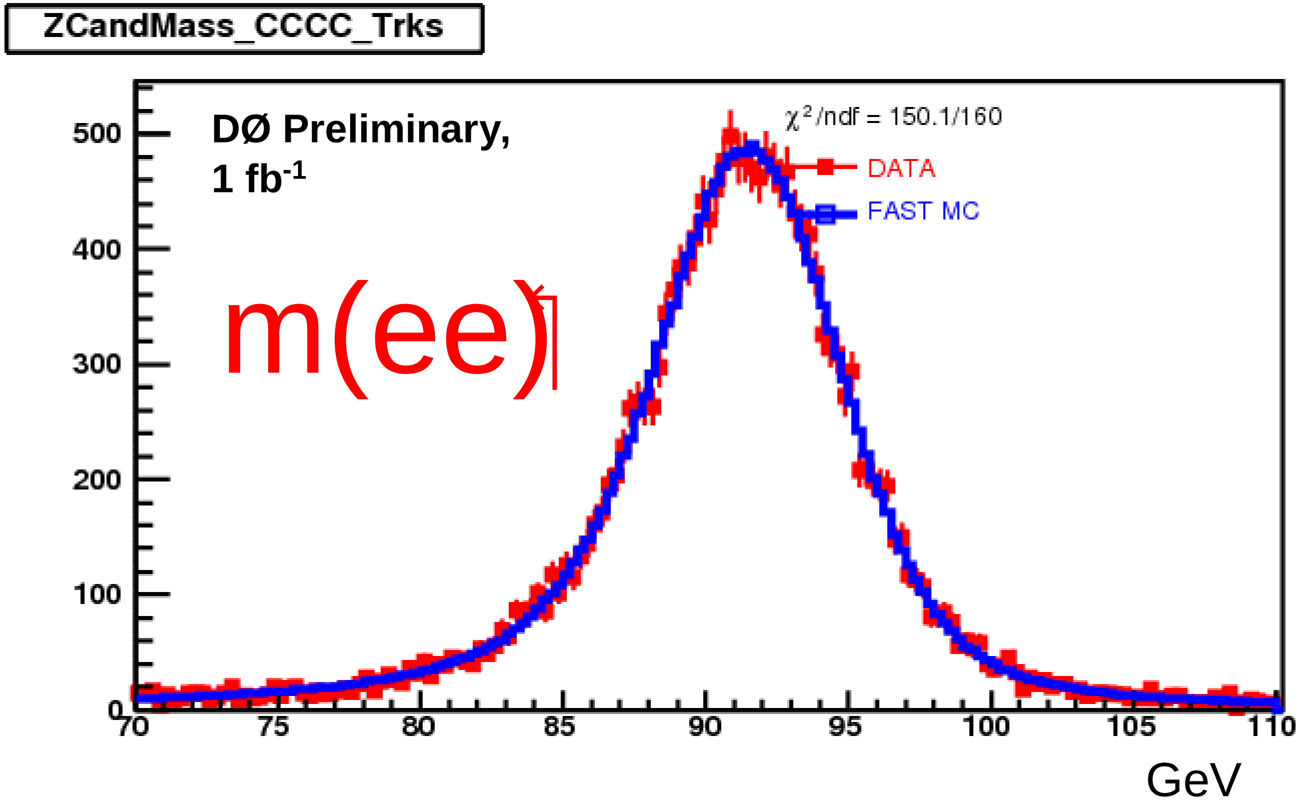
Sampling fluctuations are driven by sampling fraction of CAL modules (well known from simulation and testbeam) and by uninstrumented material. As discussed before, amount of material has been quantified with good precision.

Constant term is extracted from Z -> e e data (essentially fit to observed width of Z peak).

Result:

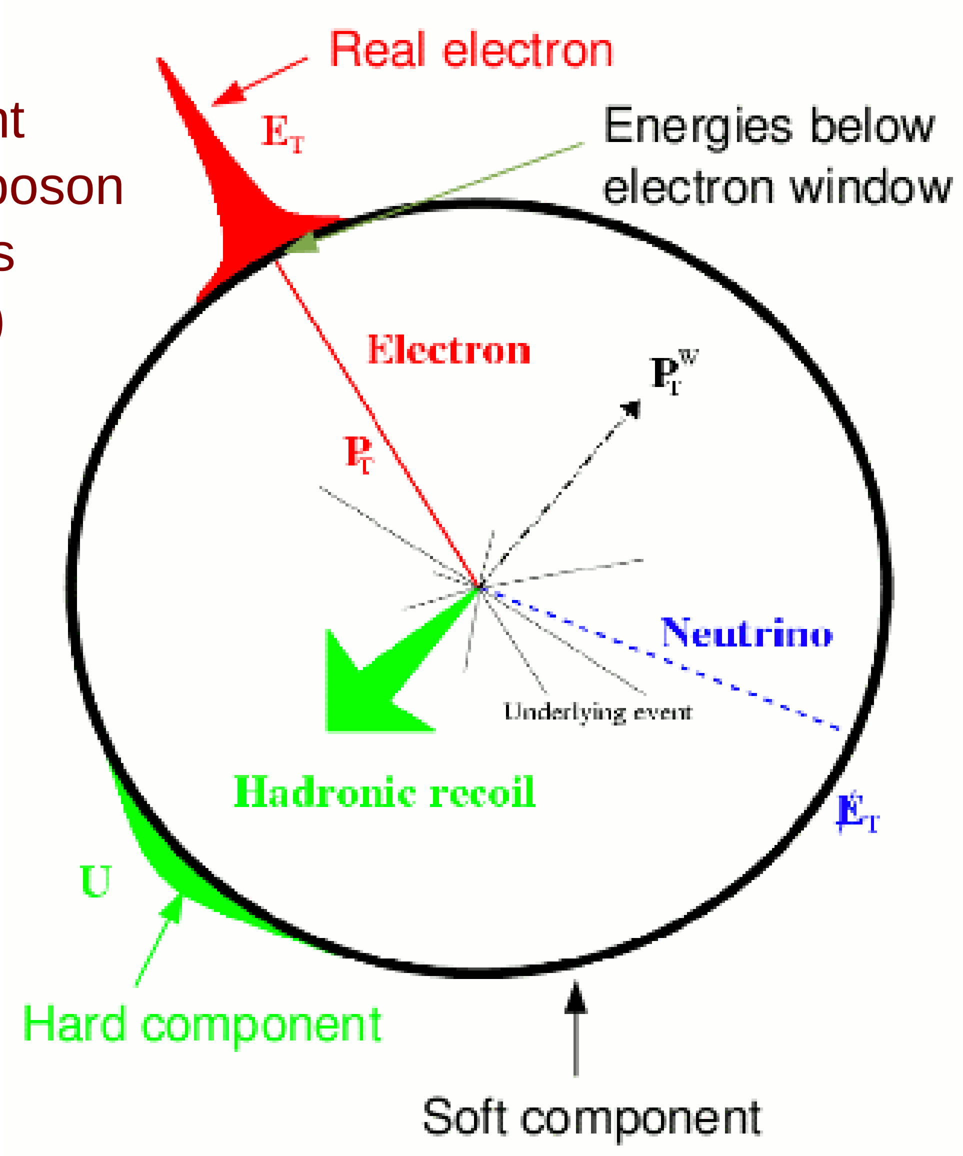
C = (2.05 ± 0.10) %

in excellent agreement with Run II design goal (2%)



Switching gears: recoil model

Everything in the event except for the vector boson and its decay products (e for W and e e for Z)



Recoil model

Recoil vector in parameterised MC: $\vec{u}_T = \vec{u}_T^{\,\mathrm{Hard}} + \vec{u}_T^{\,\mathrm{Soft}} + \vec{u}_T^{\,\mathrm{Elec}} + \vec{u}_T^{\,\mathrm{FSR}}$

$$\vec{u}_T^{\,\mathrm{Hard}} = \vec{f}(\vec{q}_T)$$

Hard component that balances the vector boson in transverse plane.
Ansatz from full Z → νν MC; plus free parameters for fine tuning,
e.g. multiplicative scale adjustment as function of q_T:

$$\mathtt{RelResp} = \mathtt{RelScale} + \mathtt{RelOffset} \cdot \exp\frac{-q_T}{\tau_{\mathtt{HAD}}}$$

$$\vec{u}_T^{\,\mathrm{Soft}} = \alpha_{\mathrm{MB}} \cdot \vec{E}_T^{\,\mathrm{MB}} + \alpha_{\mathrm{ZB}} \cdot \vec{E}_T^{\,\mathrm{ZB}}$$

Soft component,
not correlated with vector boson.

Two sub-components; - additional ppbar interactions and detector noise: from ZB events, plus parameter for fine tuning
- spectator partons: from MB events, plus parameter for fine tuning

$$\vec{u}_T^{\,\mathrm{Elec}} = -\sum_e \Delta u_{\parallel} \cdot \hat{p}_T(e)$$

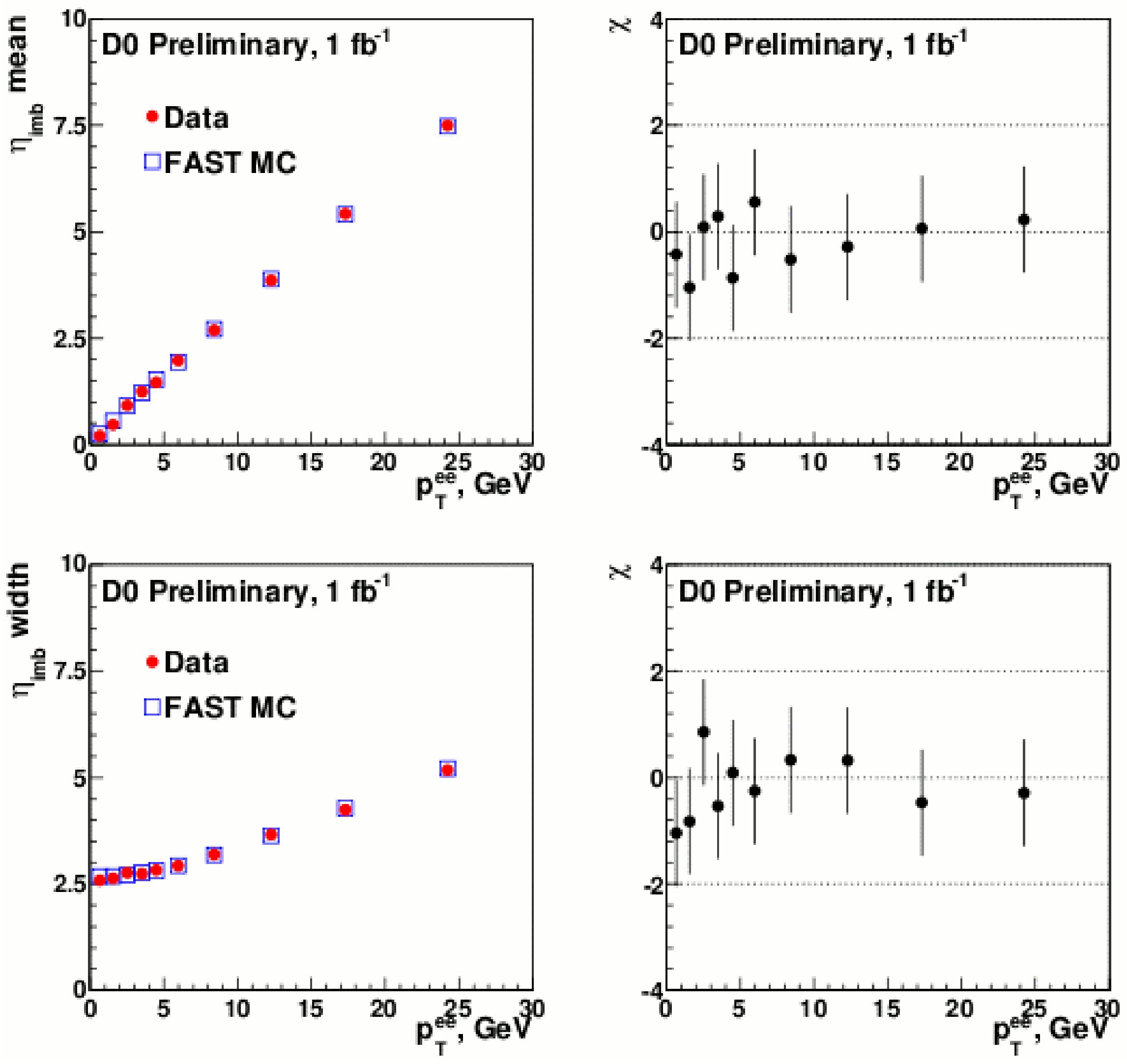
Recoil energy "lost" into the **electron cones**.
Electron energy leakage outside cluster.

$$\vec{u}_T^{\,\mathrm{FSR}} = \sum_\gamma \vec{p}_T(\gamma)$$

FSR photons (internal bremsstrahlung) outside cone;
includes detailed response model.

Recoil calibration

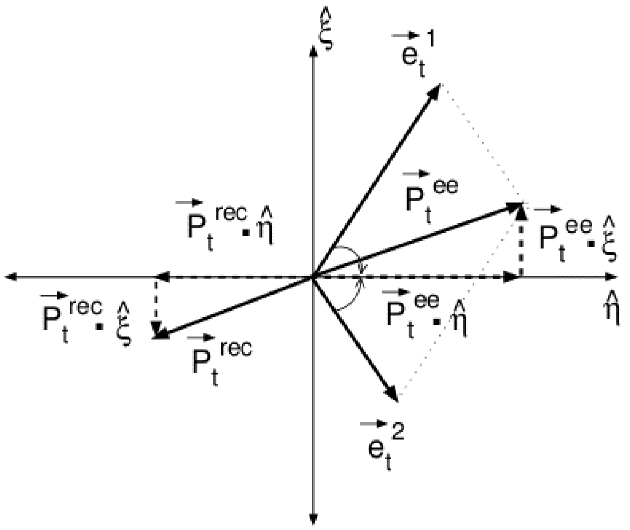
Final adjustment of free parameters in the recoil model is done *in situ* using balancing in Z → e e events and the standard UA2 observables.



UA2 observables:
In transverse plane, use a coordinate system defined by the bisector of the two electron momenta.

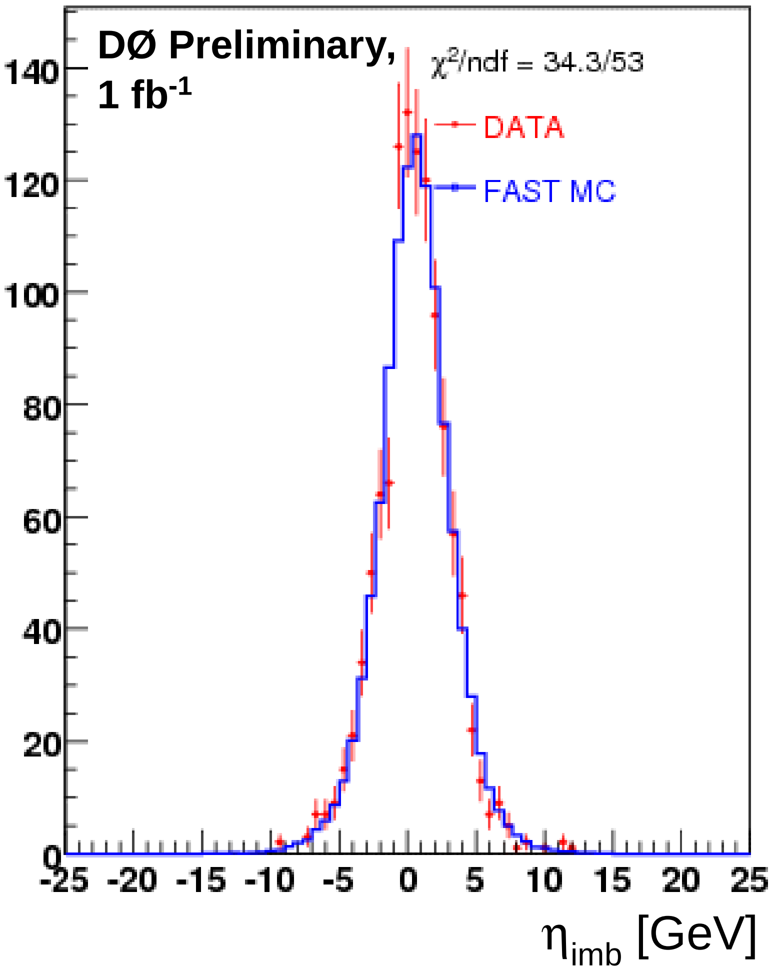
η-imbalance : $(\vec{P}_t^{ee} + \vec{P}_t^{rec}) \cdot \hat{\eta}$

ξ-imbalance : $(\vec{P}_t^{ee} + \vec{P}_t^{rec}) \cdot \hat{\xi}$

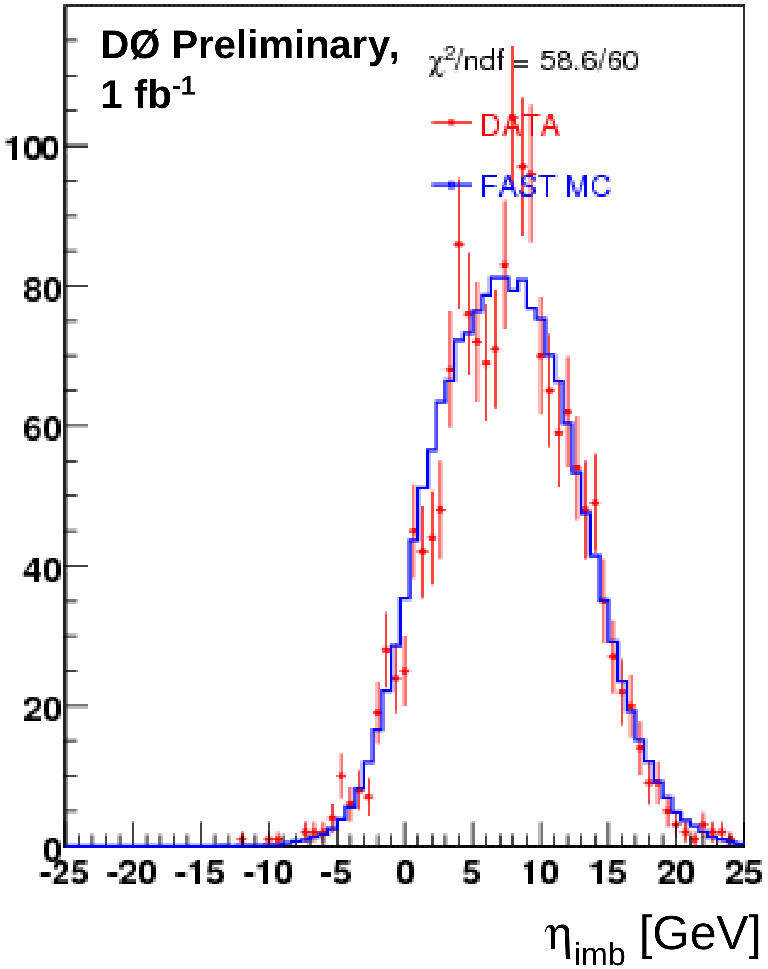


Examples: η_{imb} distributions

$1 < p_T(ee) < 2$ GeV



20 GeV $< p_T(ee)$

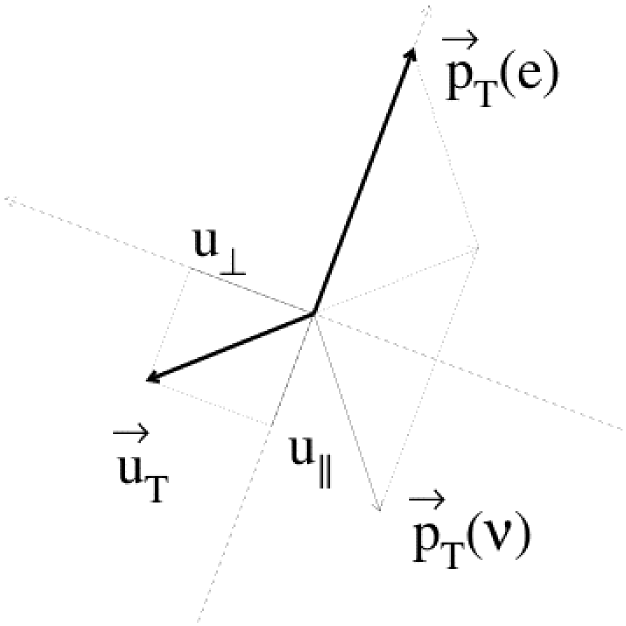


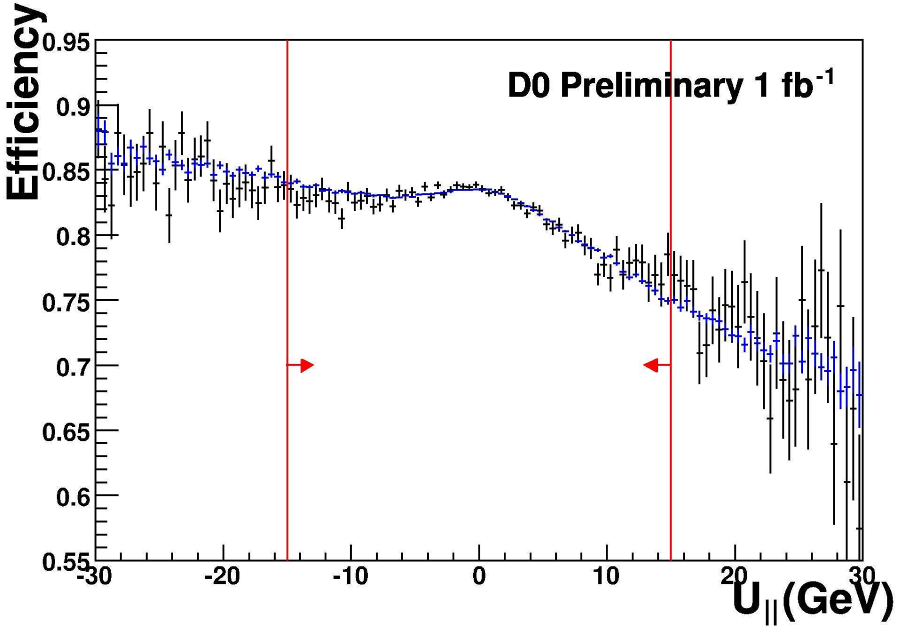
Electron reco efficiency model

Efficiency model also takes into account relative orientation of electron and “rest of the event” (hadronic activity). For example:

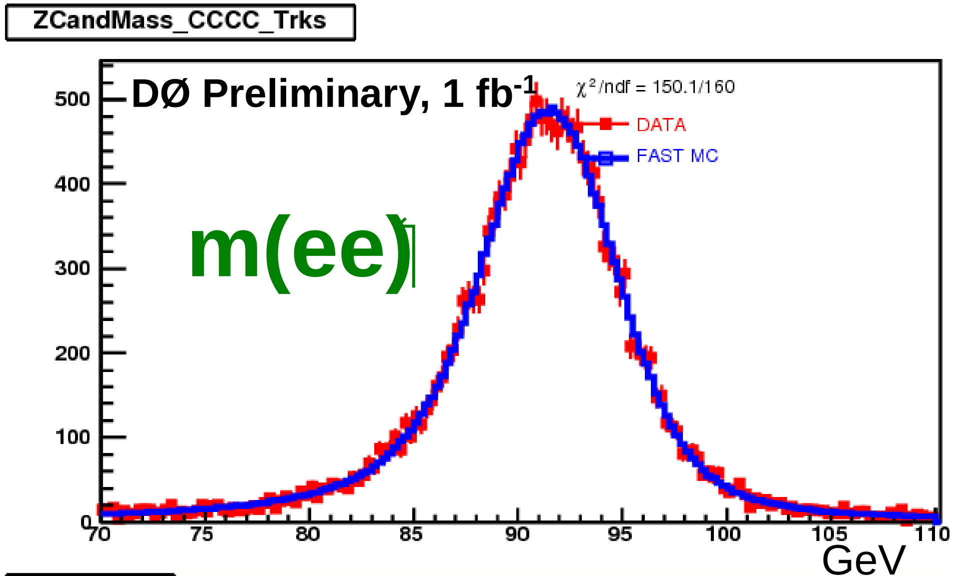
- Efficiency corrections vs. $p_T(e)$ and scalar E_T.
- Efficiency corrections vs. $u_{||}$.

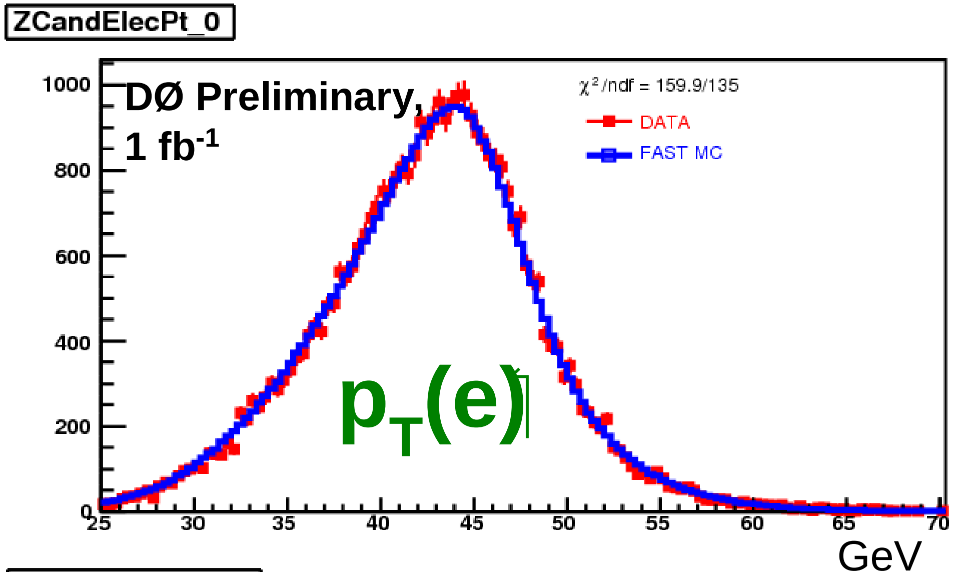
Much of this level of detail is only necessary for a measurement of the W width, not the mass.

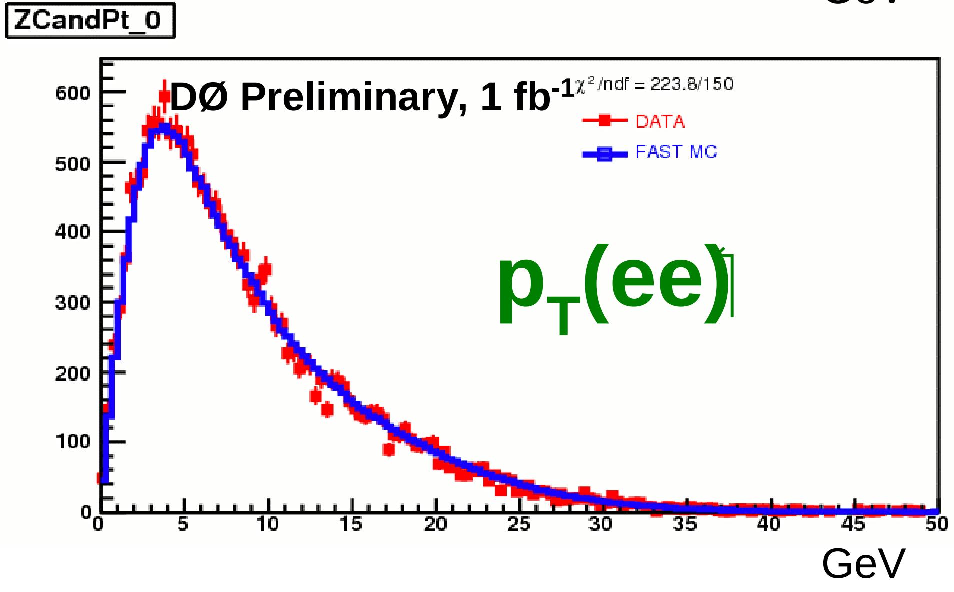


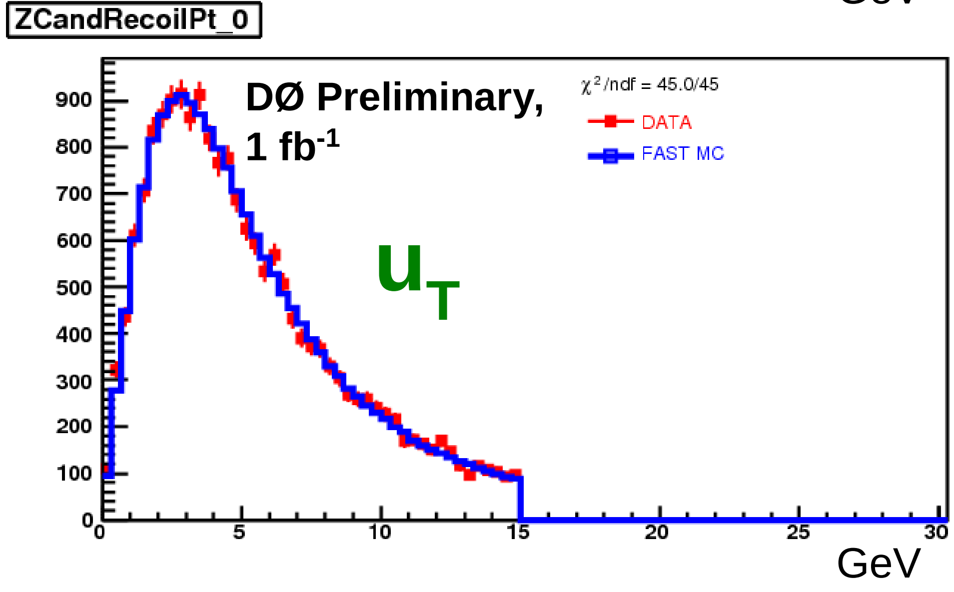


Results: Z → e e data



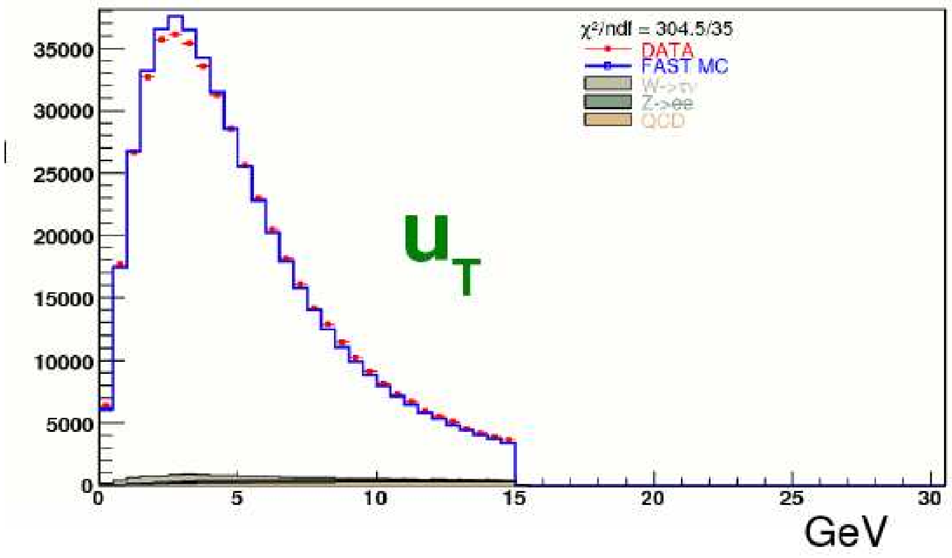






Good agreement between parameterised MC and collider data.

W → e ν data WARNING !



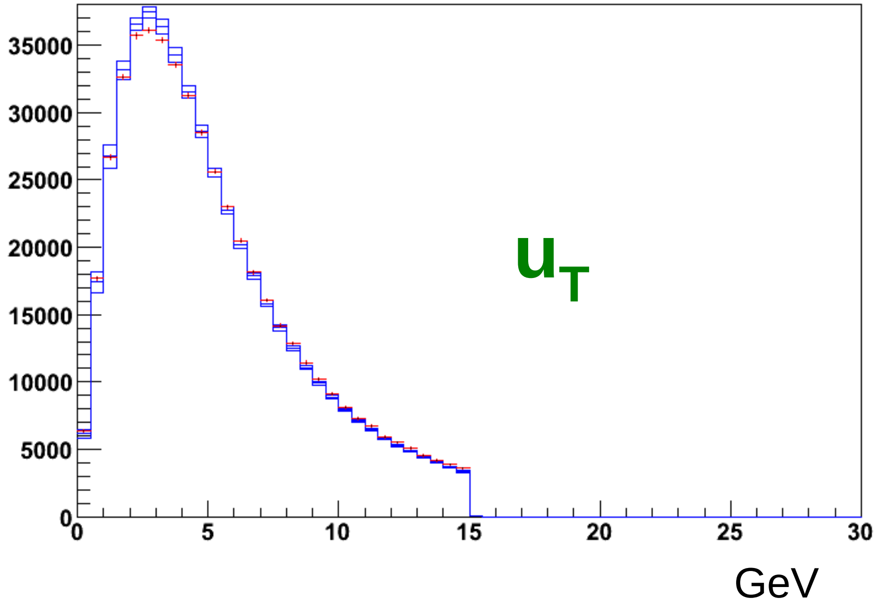
Data-MC not in good agreement !

Error bars only reflect limited W statistics they do not reflect the much more limited **Z statistics** that have been used to calibrate the recoil model !

The blue band in the bottom plot reflects one sigma excursions in the recoil parameters.

→ **agreement is not so bad !**

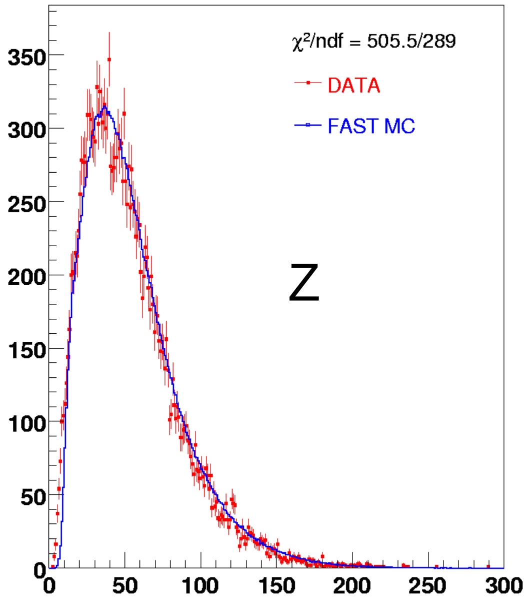
Compared to Run I we do need much more parameters to describe the recoil:
This significantly increases the importance of the effect discussed above

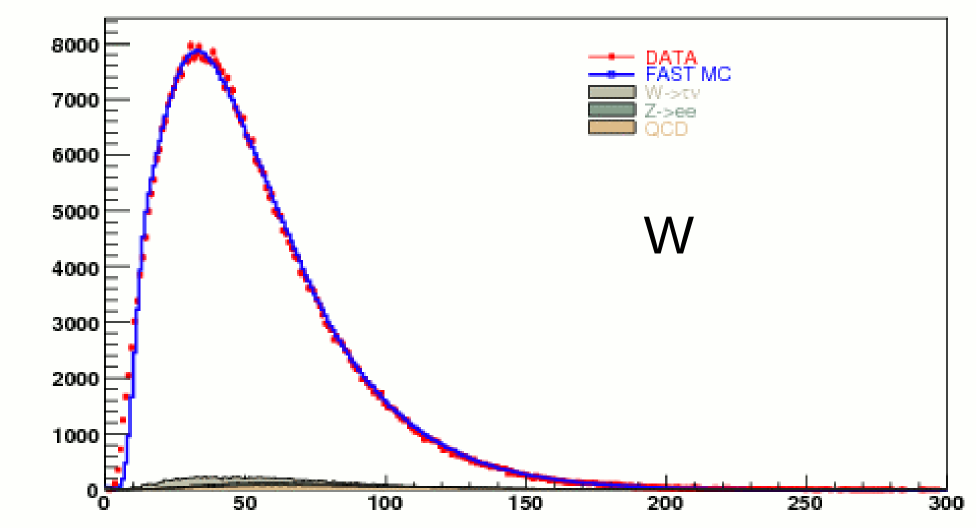


Z→e e and W → e ν

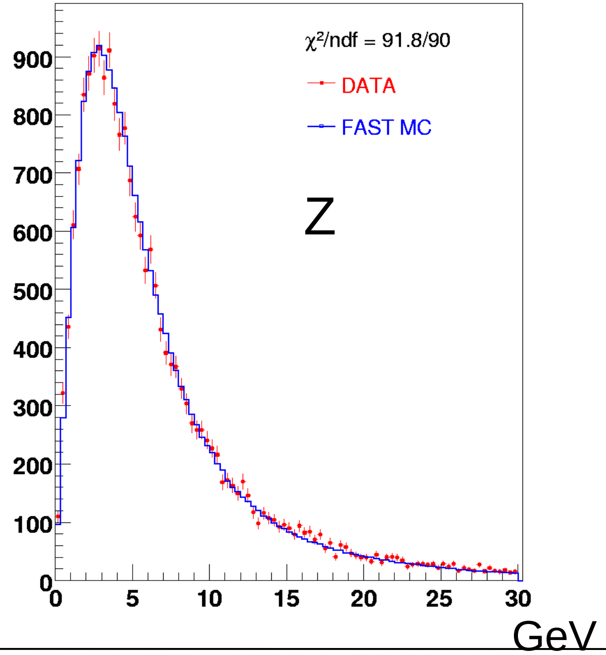
Data in red
MC in blue

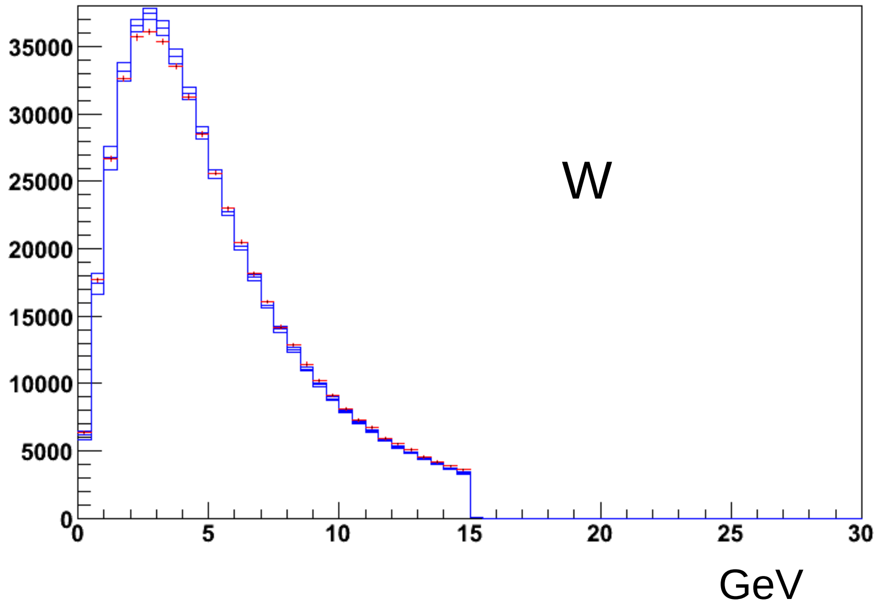
SET





u_T

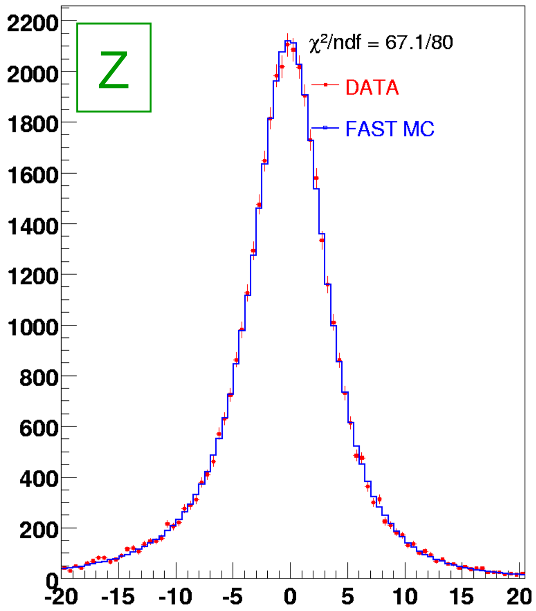




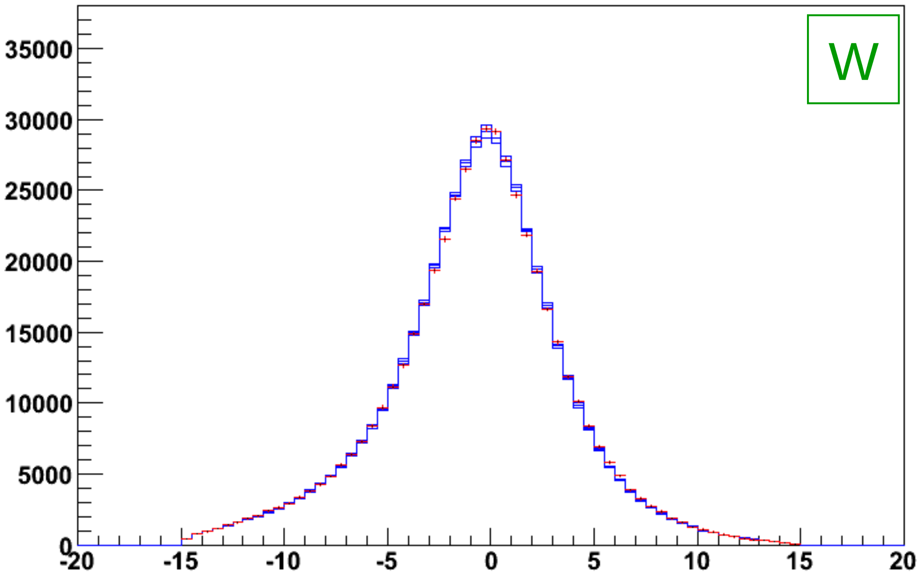
Z→e e and W → e ν

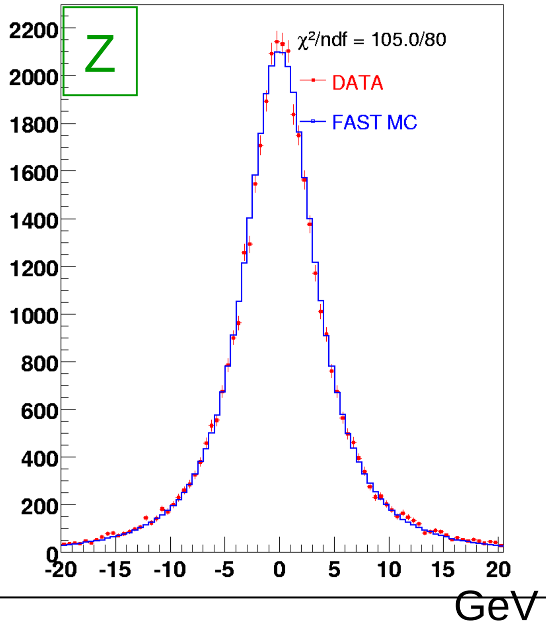
Data in red

MC in blue

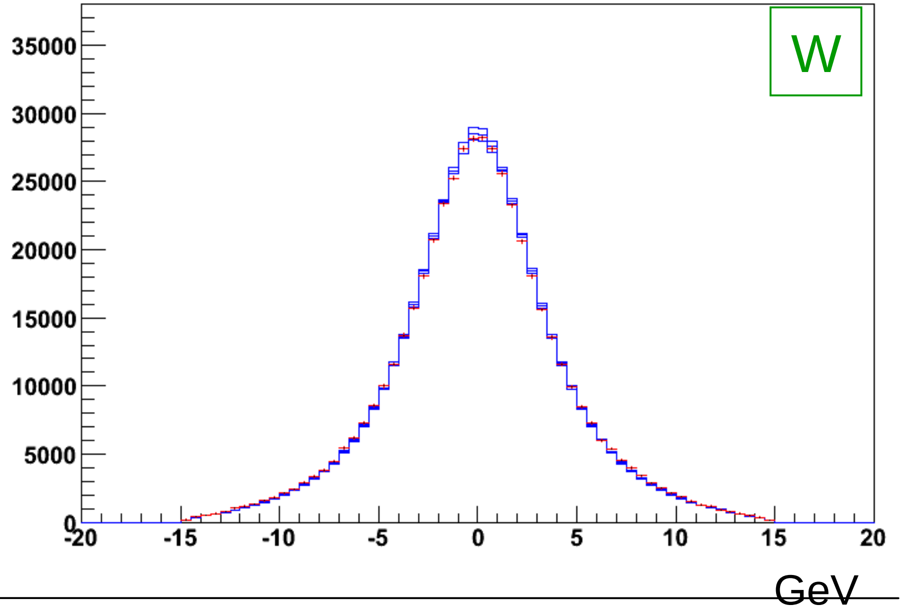


u_{para}

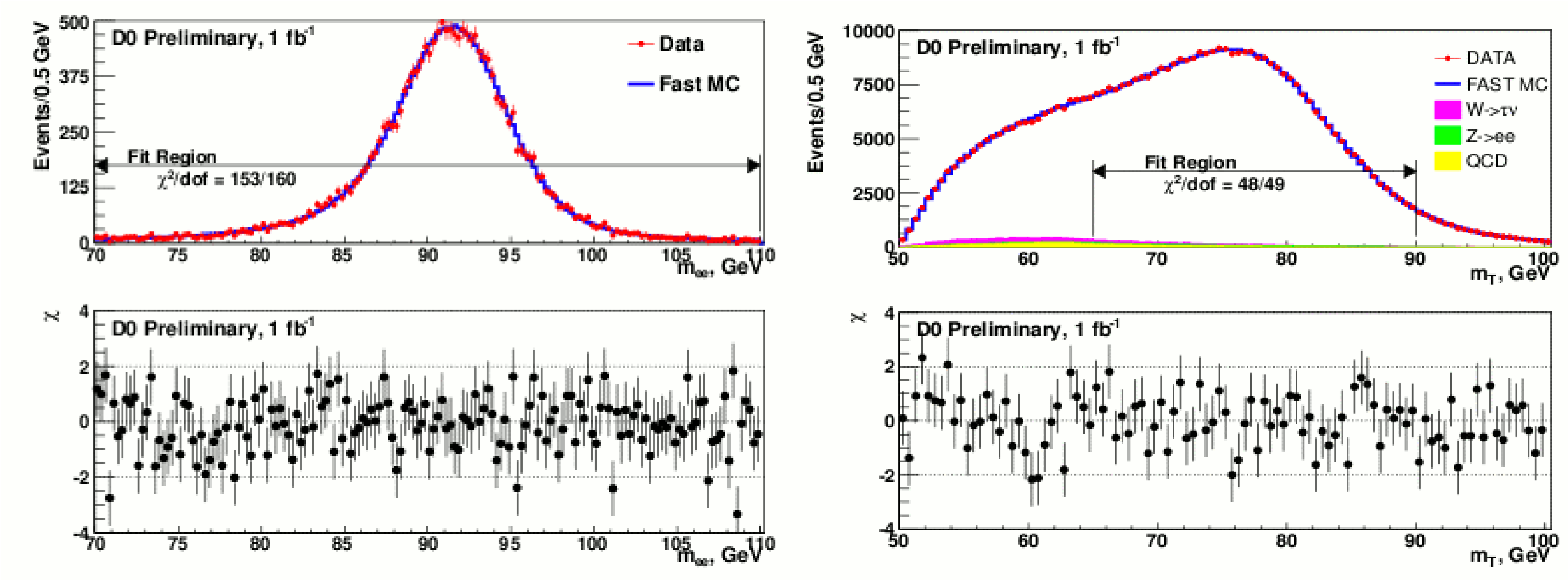




u_{perp}



Mass fits

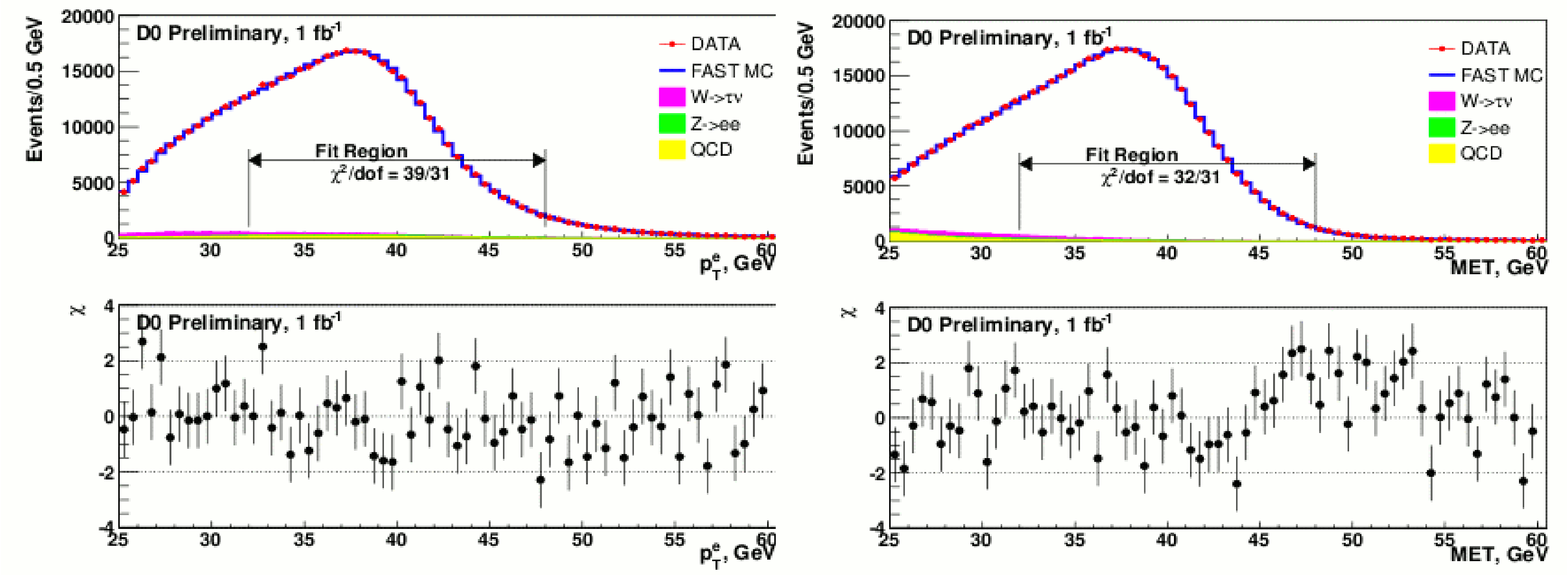


m(Z) = 91.185 ± 0.033 GeV (stat)

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

m(W) = 80.401 ± 0.023 GeV (stat)

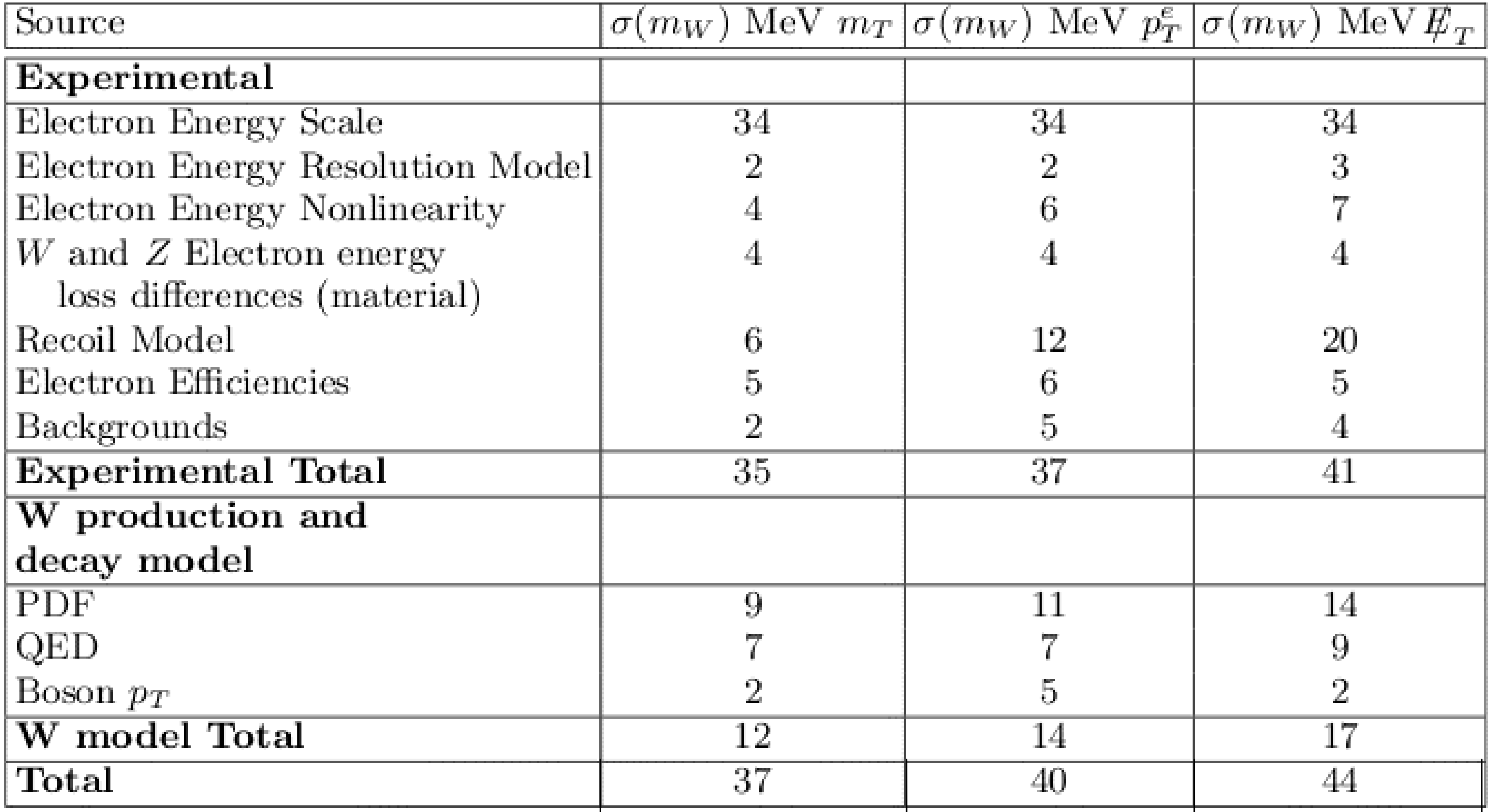
Mass fits



m(W) = 80.400 ± 0.027 GeV (stat) **m(W) = 80.402 ± 0.023 GeV (stat)**

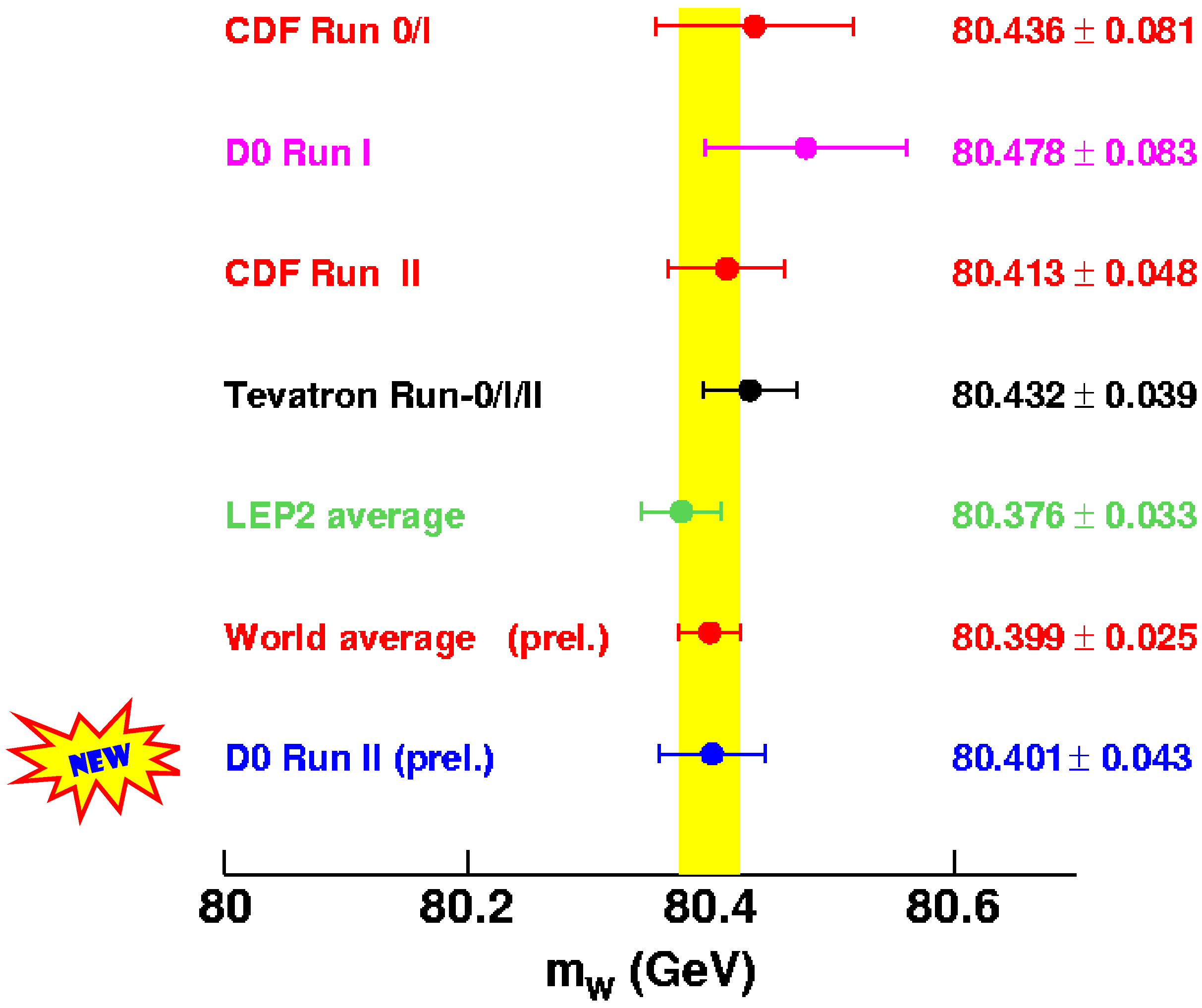
Summary of uncertainties

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	34	34	34
Electron Energy Resolution Model	2	2	3
Electron Energy Nonlinearity	4	6	7
W and Z Electron energy loss differences (material)	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

Comparison to previous results



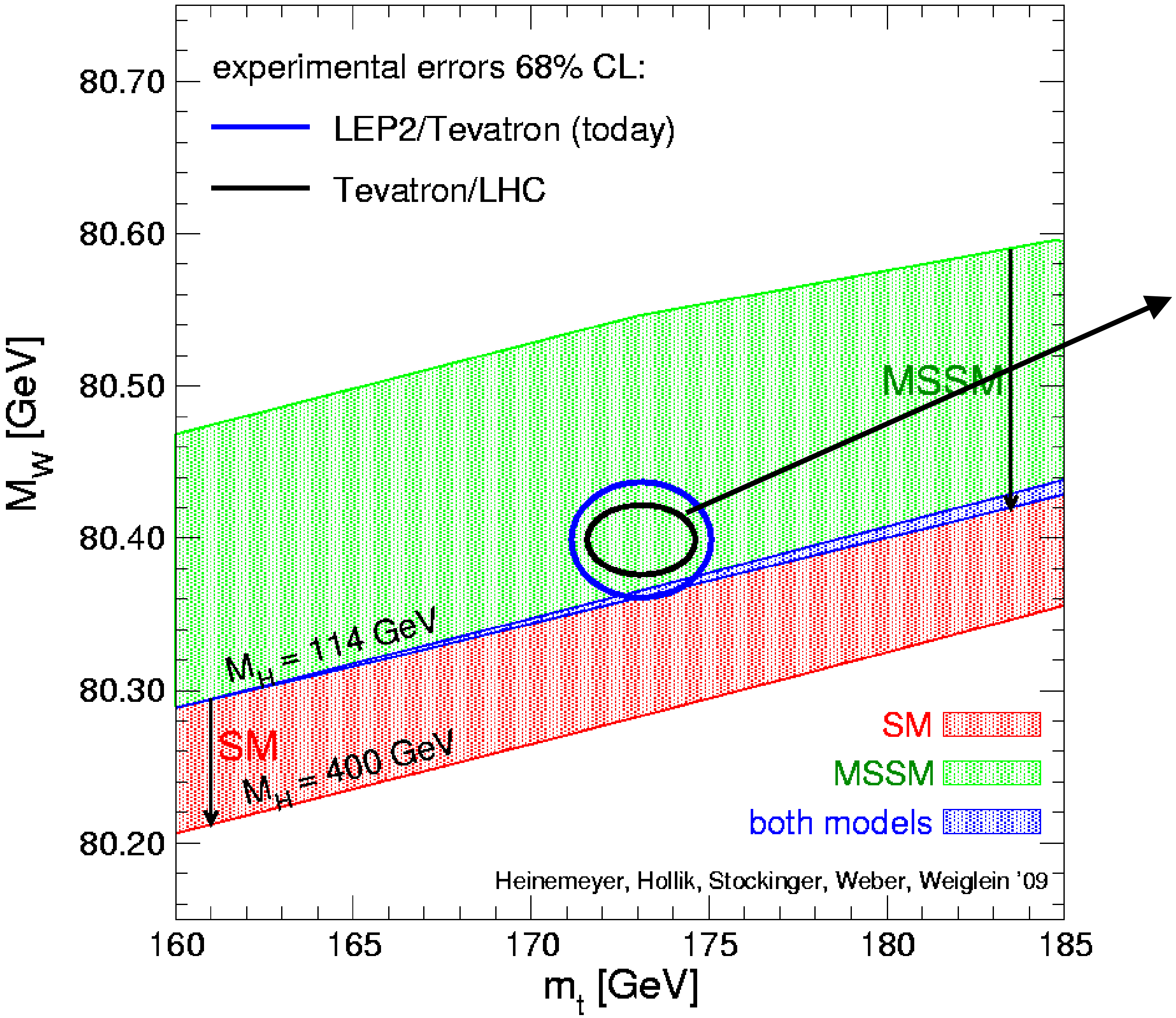
The new result from DØ is the **single most precise measurement** of the W boson mass to date.

As expected DØ Run II combined results improve by ~ 10 % only the total error over m_T alone.

The new result is in good agreement with previous measurements.

Ref: Tevatron ElectroWeak Working Group http://tevewwg.fnal.gov

Projection



CDF/DØ combined
10 fb^{-1} 2011 (?)

ΔmW ~ 10 MeV
Δmtop ~ 1GeV

Summary and outlook

We have presented, for the first time, a new preliminary measurement of the W boson mass from the DØ Collaboration. It is based on central electrons in 1 fb^{-1} of Run II data:

$$\boxed{\begin{aligned} m_W &= 80.401 \pm 0.023(\text{stat}) \pm 0.037(\text{syst})\ \text{GeV} = 80.401 \pm 0.044\ \ \text{GeV}\ \ (\text{m}_\text{T}) \\ &\ 80.400 \pm 0.027(\text{stat}) \pm 0.040(\text{syst})\ \text{GeV} = 80.400 \pm 0.048\ \ \text{GeV}\ \ (p_T^e), \\ &\ 80.402 \pm 0.023(\text{stat}) \pm 0.044(\text{syst})\ \text{GeV} = 80.402 \pm 0.050\ \ \text{GeV}\ \ (\not{E}_T). \end{aligned}}$$

NEW

A combination of the results from the three observables gives:

80.401 ± 0.021 (stat.) ± 0.038 (syst.) = 80.401 ± 0.043 GeV

This is the most precise single measurement of the W boson mass to date.

This measurement is in good agreement with a previous Run II measurement from CDF (electron and muons in 200 pb^{-1} of data), as well as with the LEP average.

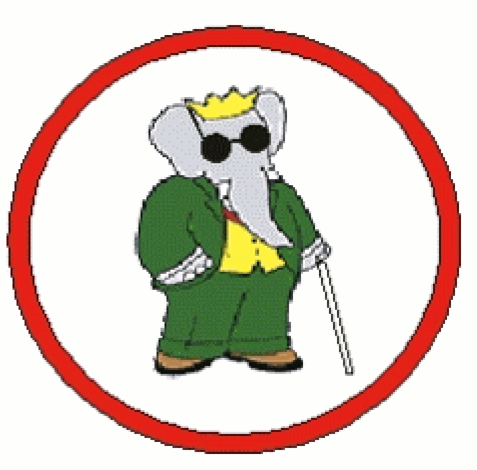
DØ and CDF use very different techniques for the main ingredient of the measurement, namely to establish the lepton energy scale. Their systematic uncertainties are uncorrelated to a large extent, which is good for cross-checks and combination. Similar comments apply to (non-)correlation with LEP results.

For both D0 and CDF these measurements are just the beginning. Both collaborations are analysing larger datasets. CDF predict 25 MeV total uncertainty with 2.3 fb^{-1}. DØ expect similar or better uncertainties with the 5 fb^{-1} in the can.

Backup slides

Comments on analysis strategy

Before analysing the collider data, we perform a **Monte Carlo closure test**. This means we treat simulated events from a detailed Pythia/Geant simulations as collider data and perform a full W mass/width analysis. Goal: develop and test analysis procedures and code with known input values. At each analysis step, check that predictions from parameterised MC match MC truth.



We perform our measurements as a **blind analysis**. This means that the central values (but not the uncertainties) are deliberately hidden from the analysers and reviewers until the analysis is considered complete. The blinding technique we used is a standard technique that is routinely used by other collaborations, *e.g.* BaBar:

> Simply change your mass fitting program in such a way that
> it reports the fitted mass, offset by some hidden offset.
> The offset is the same for all three observables (=> allow comparisons),
> no uncertainties, neither statistical nor systematic are ever obscured by the blinding.

“Unblinding” has been done only after collaboration approval.

Measurement strategy

Three physical observables: $M_{T,}$ $p_T(e)$ and $p_T(\nu) = \not{E}_T$

MC simulation to predict shapes of these observables for given mass hypothesis
- generator
- parametrized MC →models detector effects using parameters tuned on collider data

Templates at different M_W are generated using this parametrized MC

The best value of M_W is determined using likelihood method in the fitting program.

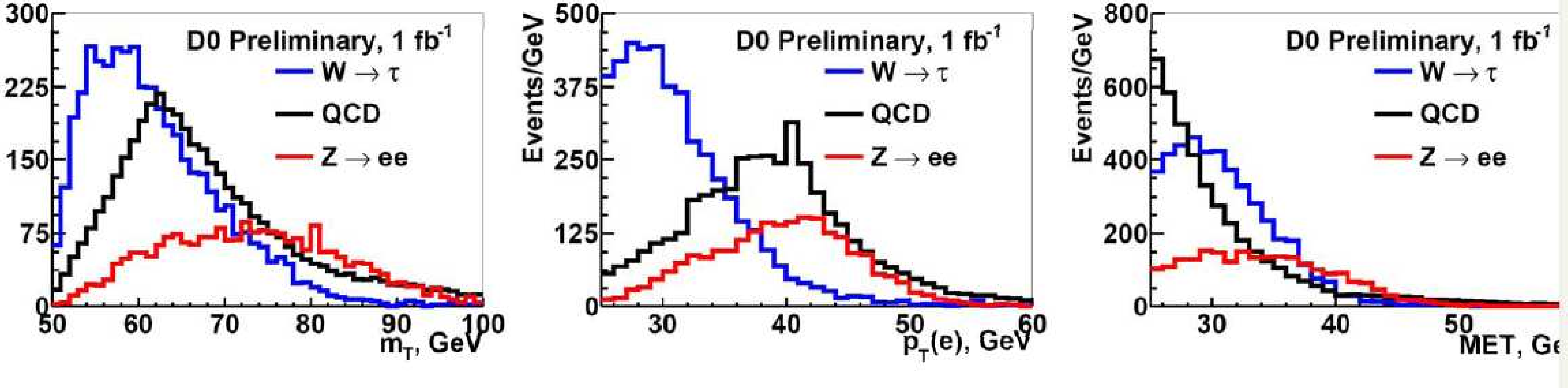
Selection Efficiency

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

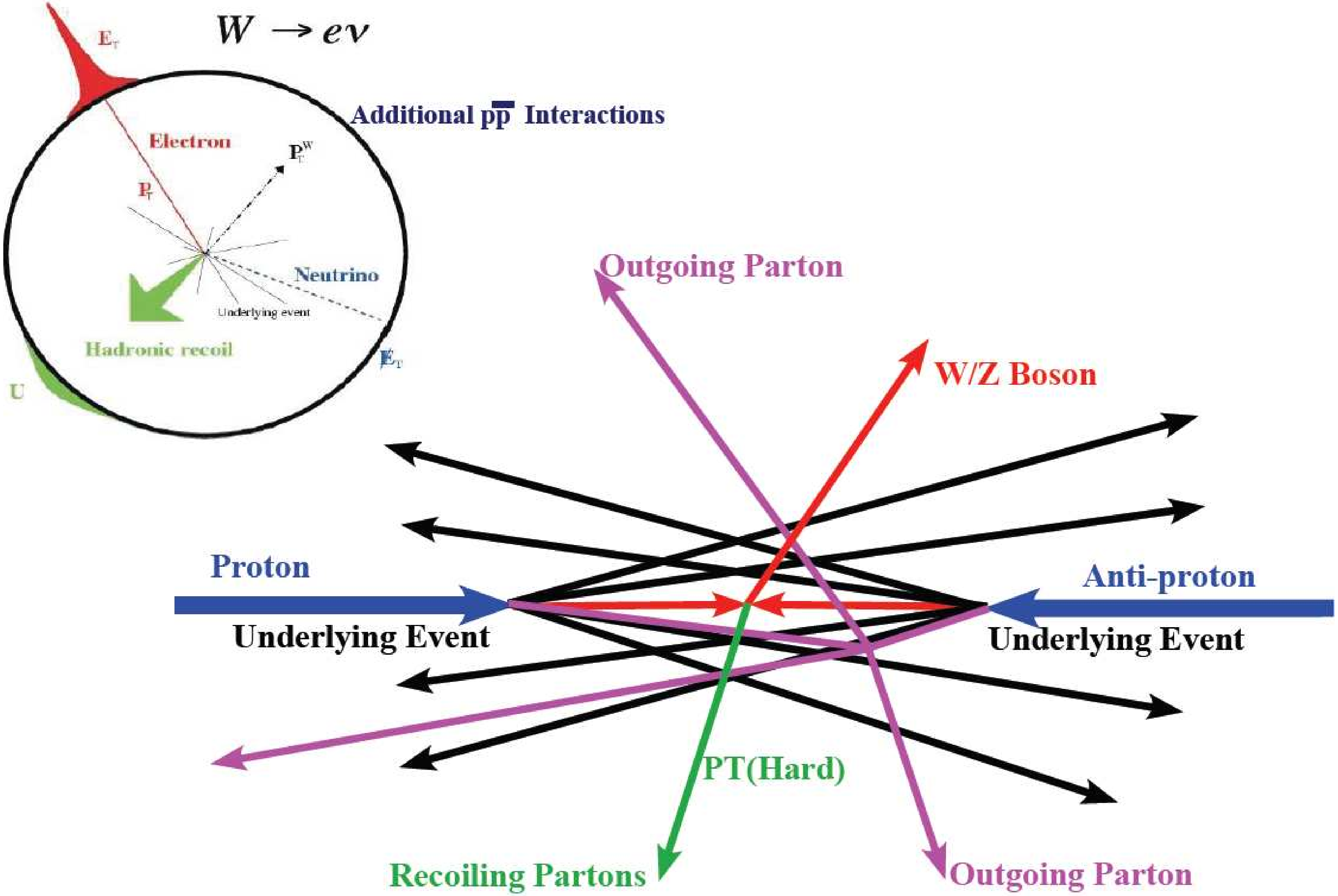
- **Study the effect from different sources using different methods.**
  - **Geometric dependence(primary vertex and η)**
  - **Intrinsic $p_T(e)$ dependence(internal photon radiation)**
  - **$u_{||}$ efficiency(relative direction between "e" and "recoil")**
  - **Scalar E_T efficiency(overall hadronic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

Backgound to $W \rightarrow e\,\nu$

- QCD (di-jet) ((1.49±0.03)%): one jet faked as electron
- *Z -> ee* ((0.80±0.01)%): one electron lost in ICR(between CC and EC CAL)
- *W ->* $\tau\nu$ ((1.60±0.02)%): mostly from τ decays into “eνν”

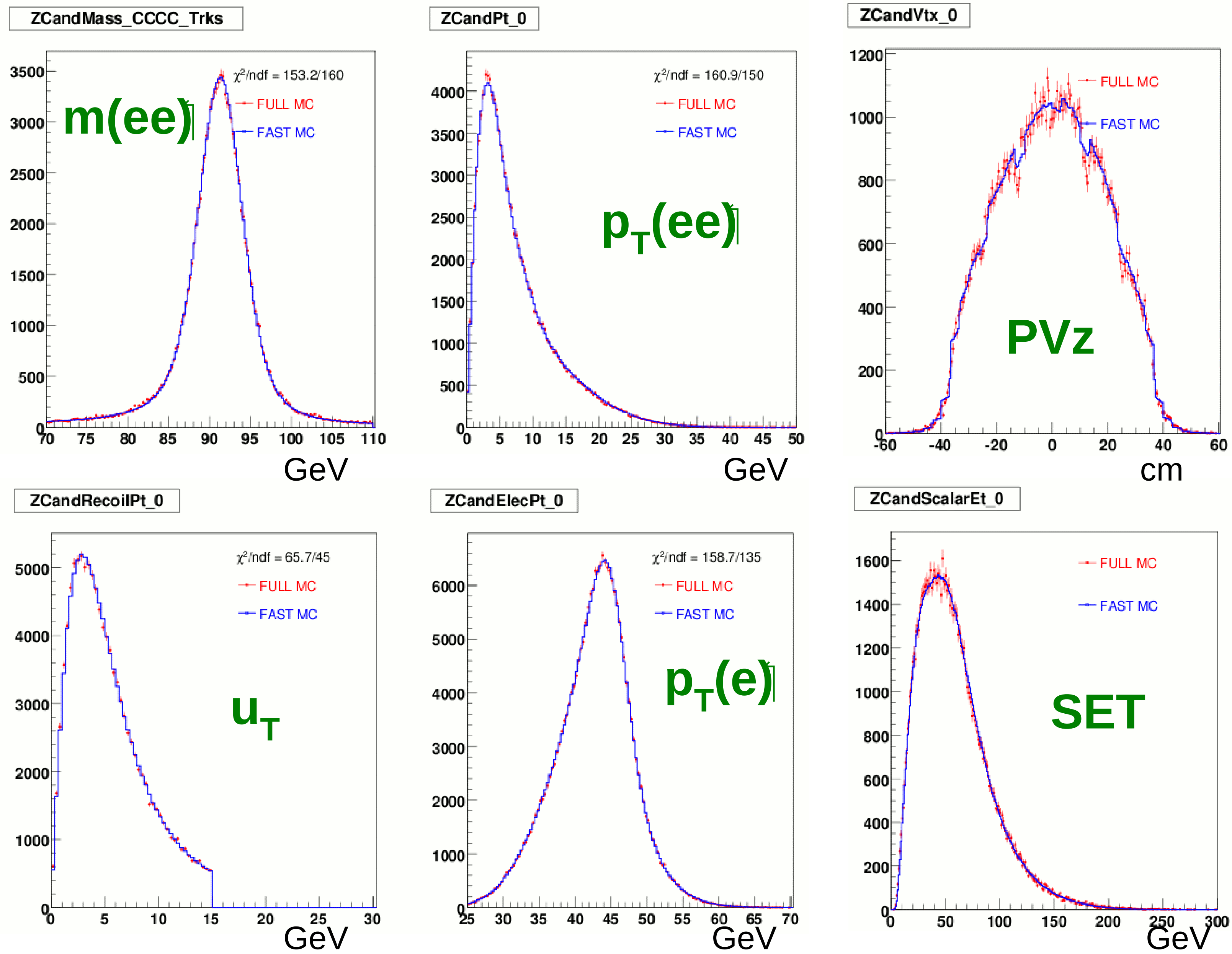


Hadronic Recoil Simulation – Additional $p\bar{p}$ Interactions

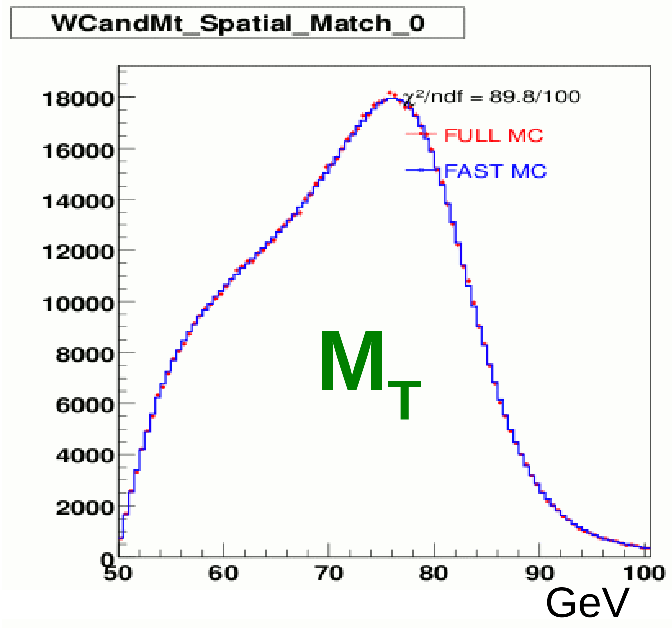


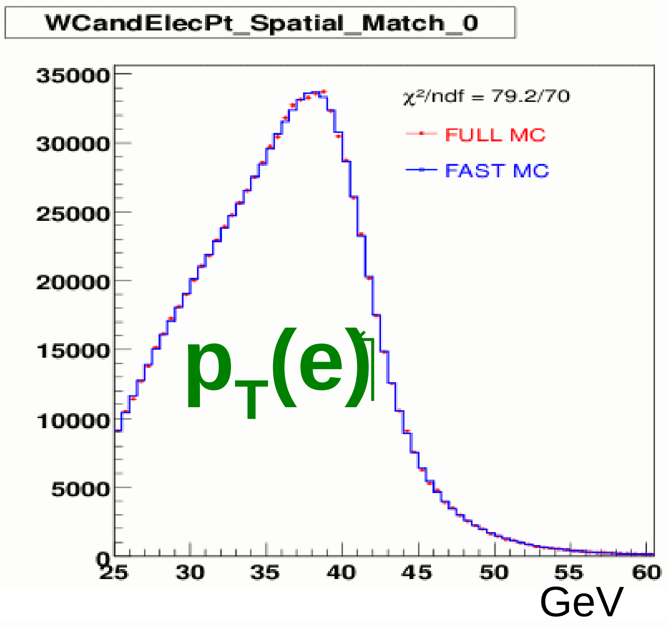
MC closure test: Z → e e

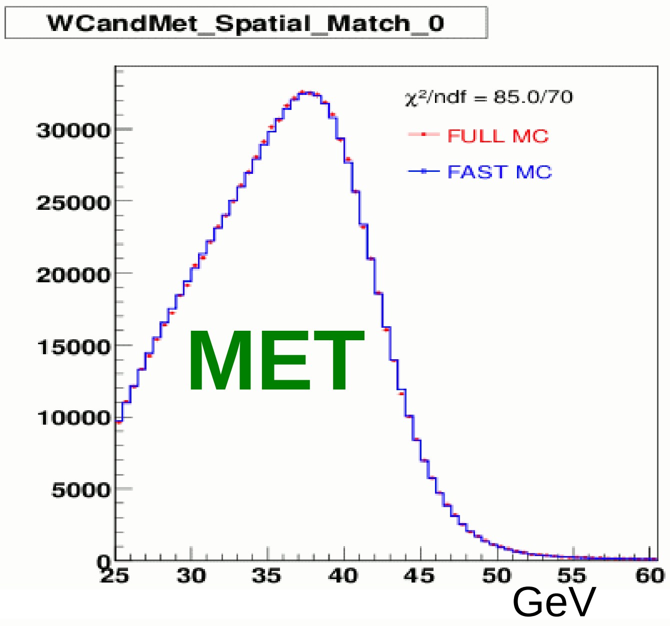
- Good agreement between full and parameterised MC.

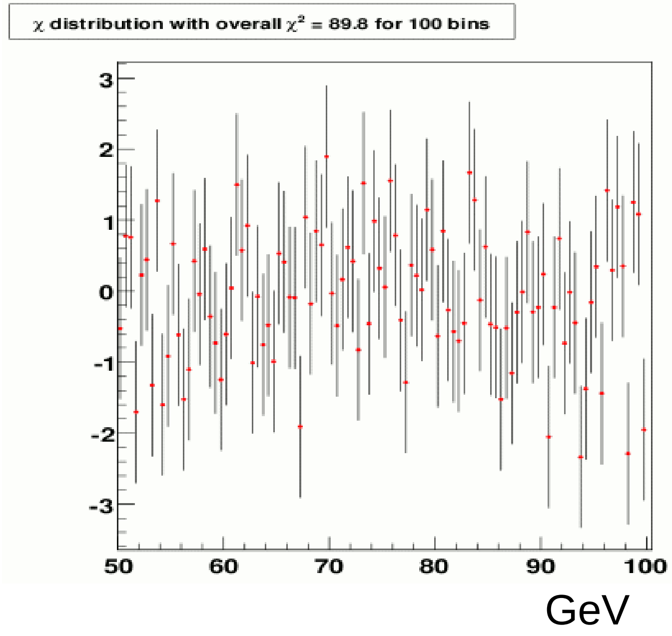


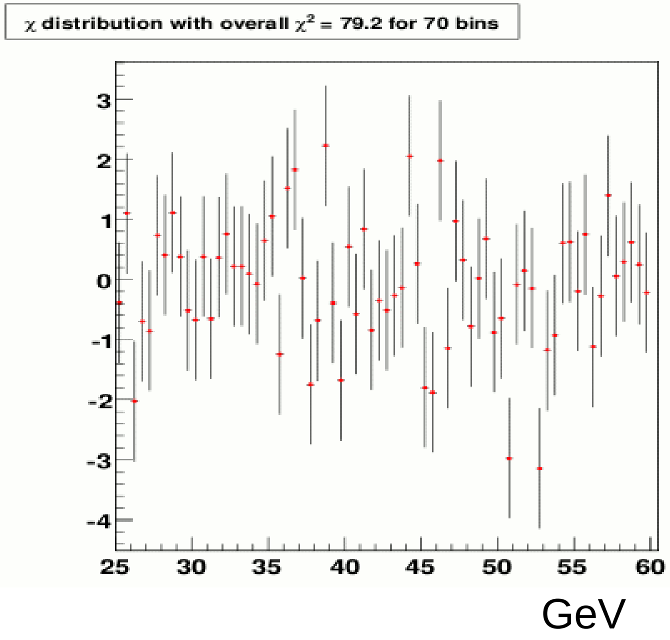
MC closure test: W → e ν

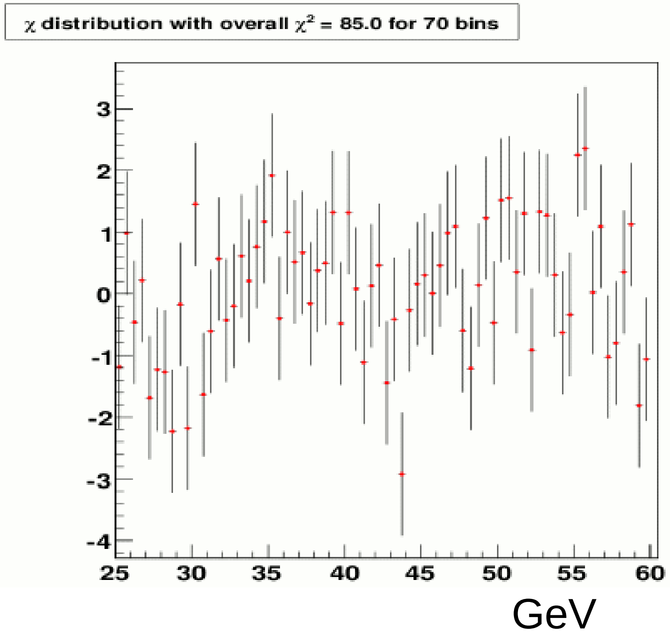




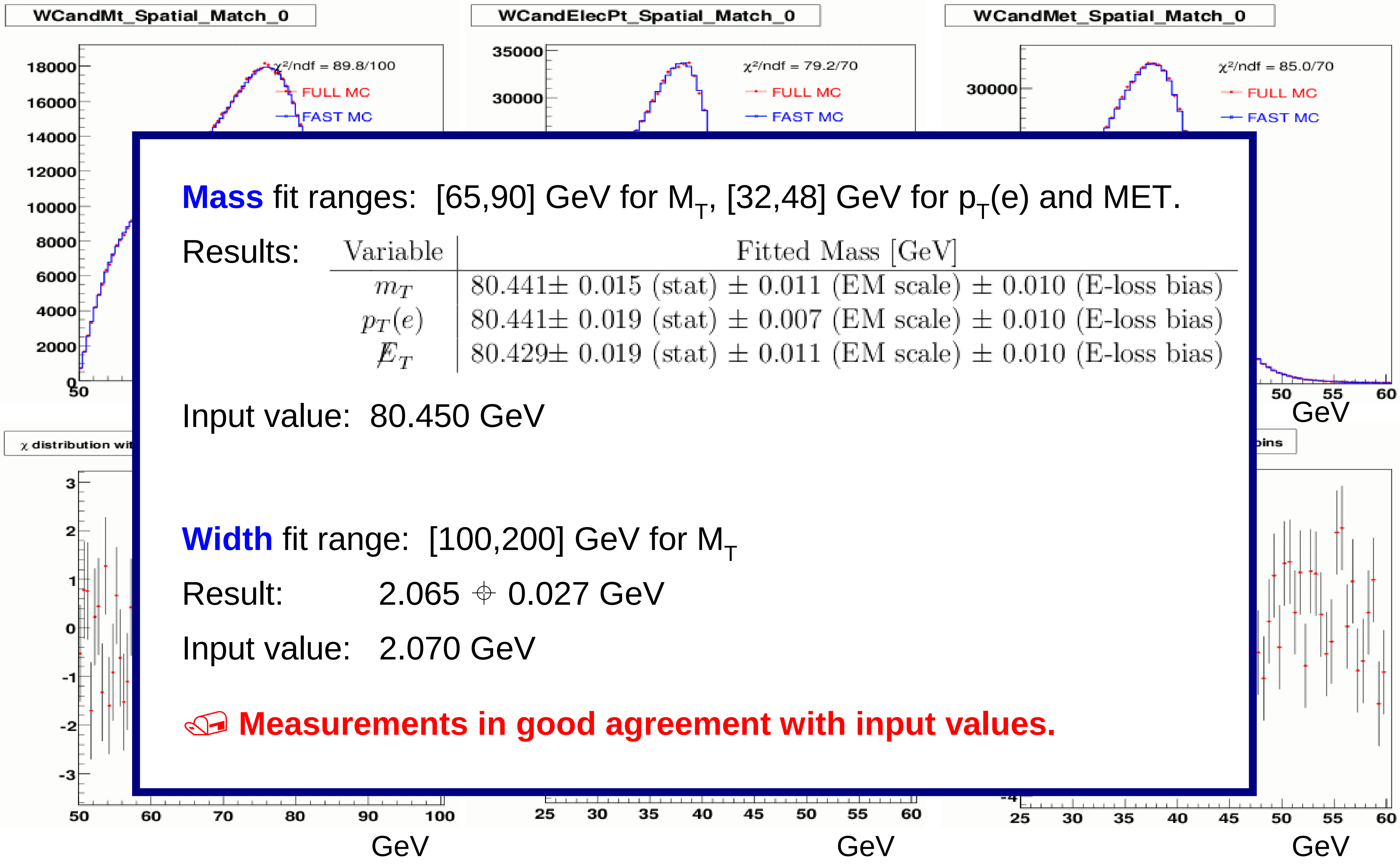








MC closure test: W → e ν



Mass fit ranges: [65,90] GeV for M_T, [32,48] GeV for p_T(e) and MET.

Results:

Variable	Fitted Mass [GeV]
m_T	80.441± 0.015 (stat) ± 0.011 (EM scale) ± 0.010 (E-loss bias)
$p_T(e)$	80.441± 0.019 (stat) ± 0.007 (EM scale) ± 0.010 (E-loss bias)
$\not{E}_T$	80.429± 0.019 (stat) ± 0.011 (EM scale) ± 0.010 (E-loss bias)

Input value: 80.450 GeV

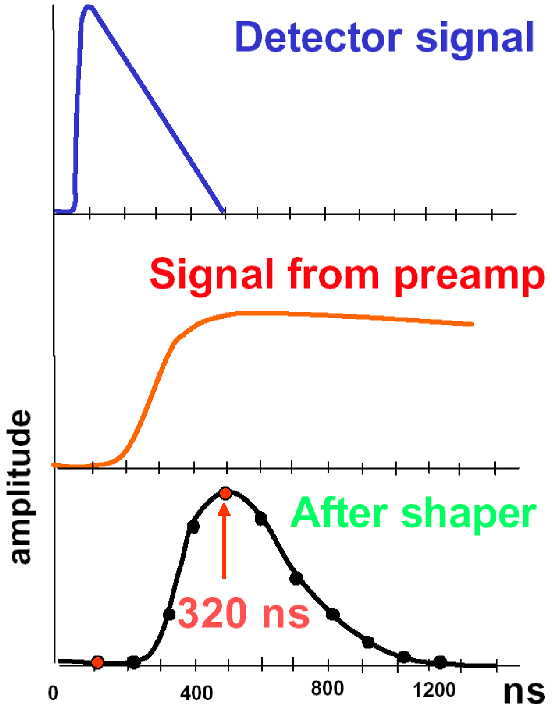
Width fit range: [100,200] GeV for M_T

Result: 2.065 ⌖ 0.027 GeV

Input value: 2.070 GeV

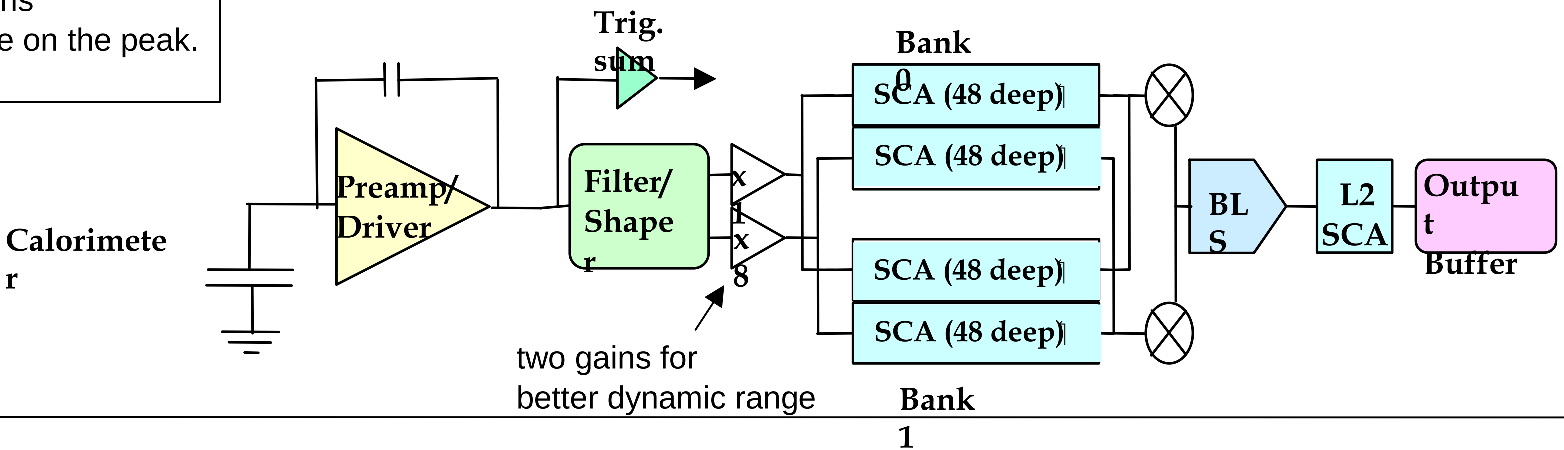
☞ **Measurements in good agreement with input values.**

Basics of the readout



- Detector signal ~ 450 ns long
  (bunch crossing time: 396 ns)
- Charge preamplifiers
- BLS (baseline subtraction) boards
  - short shaping of ~2/3 of integrated signal
  - signal sampled and stored every 132 ns in analog buffers (SCA) waiting for L1 trigger
  - samples retrieved on L1 accept, then baseline subtraction to remove pile-up and low frequency noise
  - signal retrieved after L2 accept
- Digitisation

Have ability to sample and
record the shaped signal
also at (320 ± 120) ns
to make sure we are on the peak.



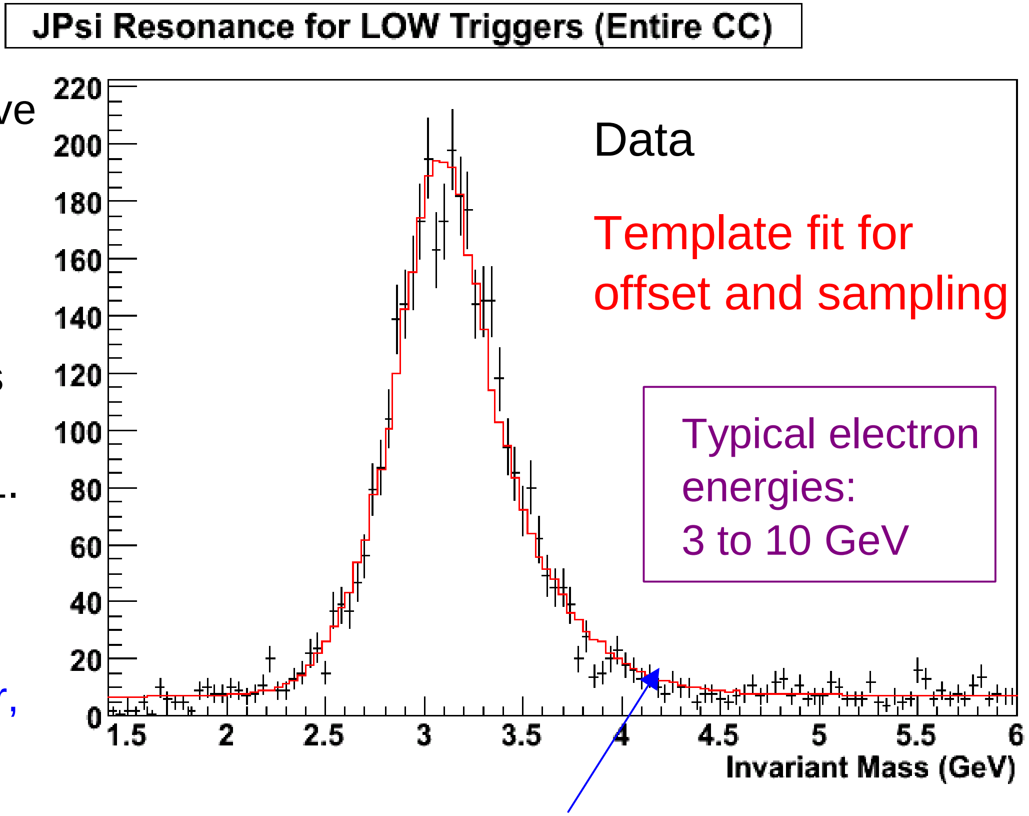
two gains for
better dynamic range

J/Ψ → $e^+ e^-$

Fortunately, when I said “*extrapolation*” down to the W, that was not the whole story. We also have another di-electron resonance that sits **lower** in energy than the W: the J/Ψ.

At a hadron collider, such a sample is *extremely* hard to obtain. One of the keys to our success is D0's excellent *Central Track Trigger*. It allows us to trigger on isolated tracks already at Level 1. We typically require two tracks of $p_T > 3$ GeV.

It took us many many person-months to obtain this sample: design/implementation of the trigger, understanding efficiencies, etc, etc.



Data

Template fit for offset and sampling

Typical electron energies:
3 to 10 GeV

Psi(2S) contribution

In contrast to the Z, the energy resolution at J/Ψ energies is practically insensitive to issues with gain calibration (the constant term in the energy resolution is irrelevant). The J/Ψ is a nice probe for sampling fluctuations and scale issues related to dead material.

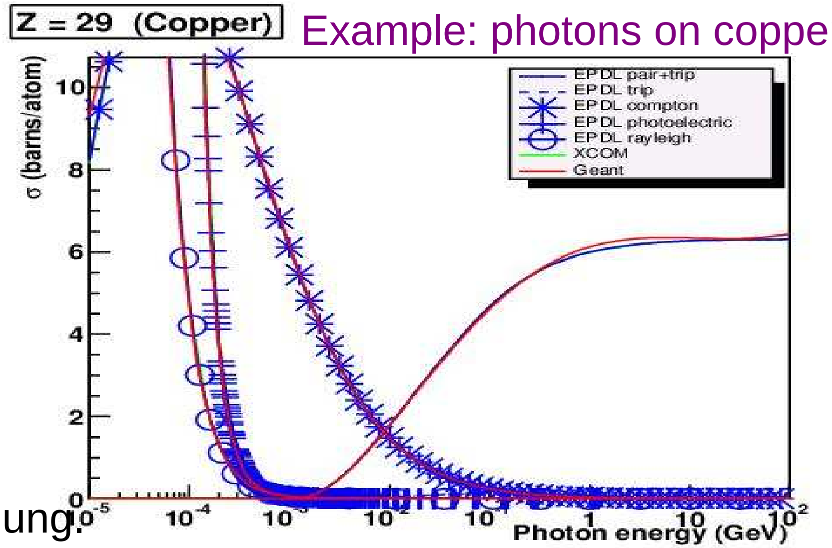
Cross-sections: QED is easy, right ?

But in practice these calculations involve time-consuming Hartree-Fock calculations, partial wave expansions, etc, etc.

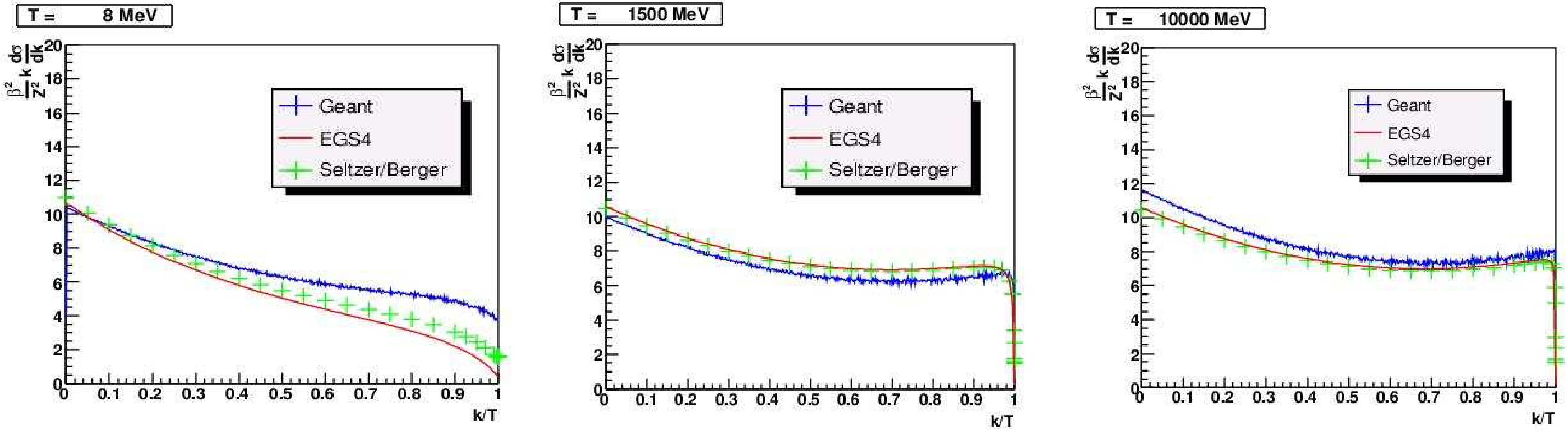
In addition, popular simulation programs (like Geant or EGS) often use simplified models or simple parameterisations of cross sections in order to avoid large look-up tables and to implement fast random number techniques.

A detailed comparison of Geant and EGS to state-of-the-art cross section calculations is striking, especially for Bremsstrahlung.

Example: photons on copper

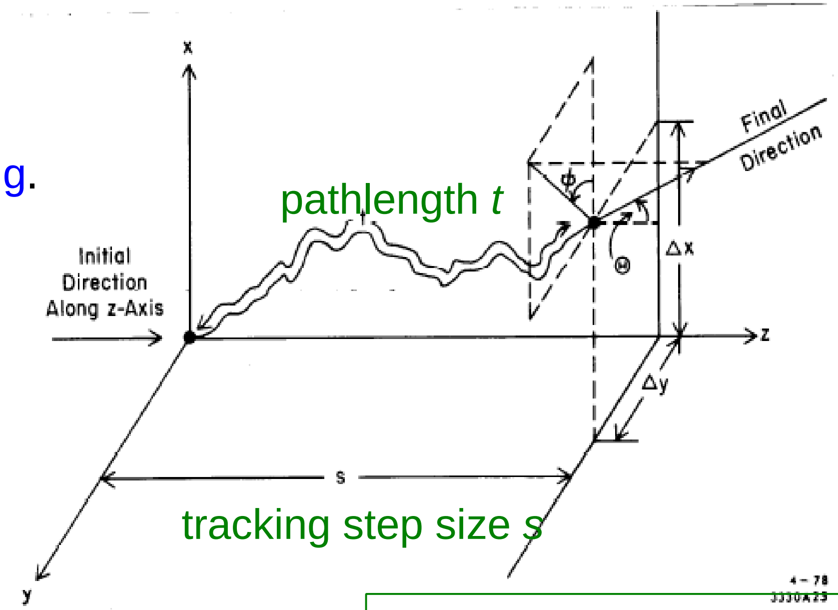


Example: Bremsstrahlung in by electrons in uranium



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

Pathlength correction in e-tracking



The tracking algorithm "thinks" in terms of *s*, but for dE/dx it calculates *t*.

In a nutshell:

- There are various parameters in Geant particle tracking. These include things like the "maximum fractional energy loss in one step" and the "shortest step size Geant is willing to take".

- We use Geant in AUTO mode, *i.e.* Geant choses the values of the parameters for us.

- Mulitiple scattering is simulated using Molière theory. That theory provides predictions (PDFs) for things like the scattering angles defined in the plot on the right. It also provides the *pathlength correction* (predict *t* for a given *s*).

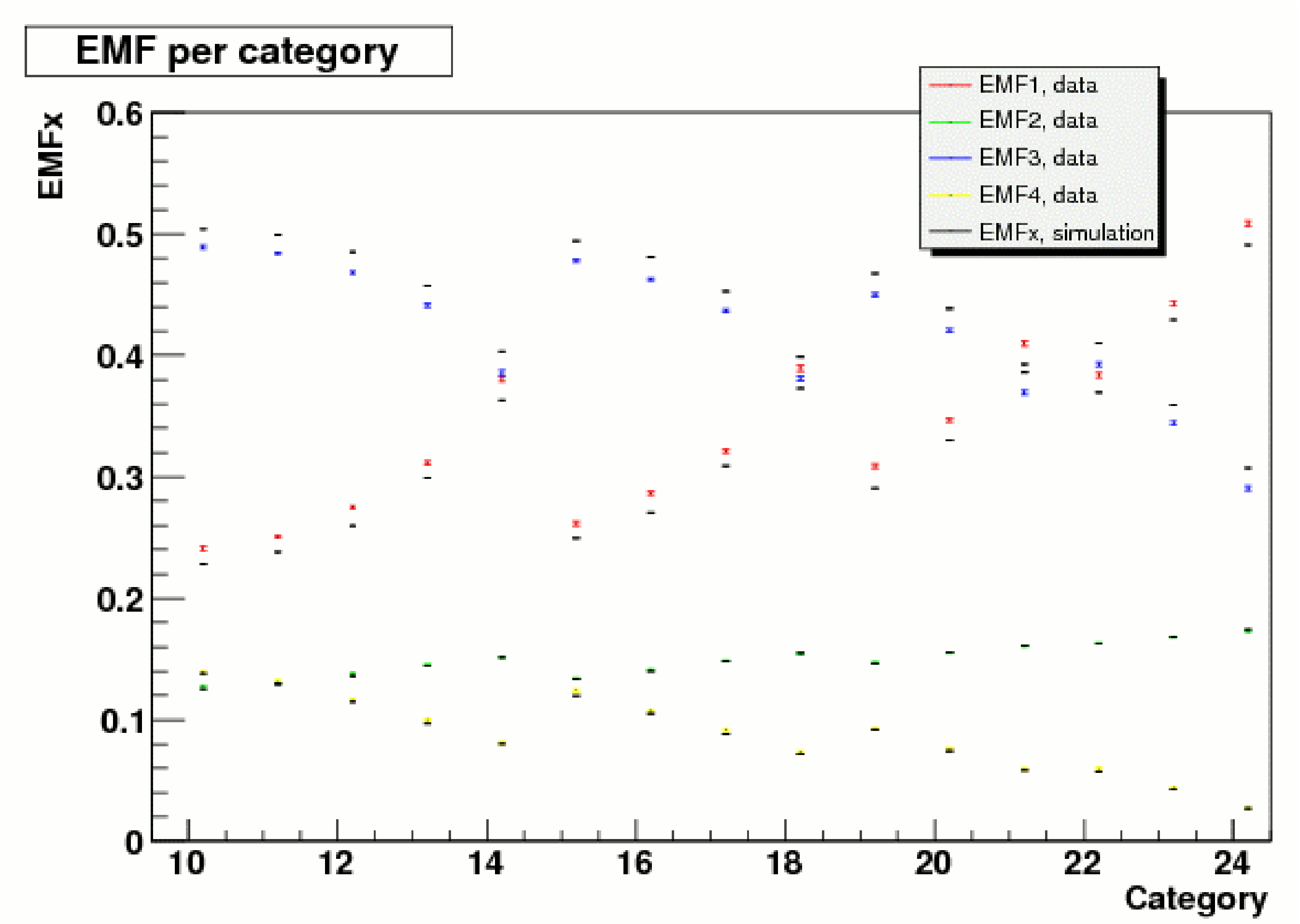
- The formula for the pathlength correction is only valid for small steps *s* (a precise definition for "small" is provided by the theory).

- As it turns out, already at high energies (1 MeV level), the upper limit on *s* from Molière theory is **inconsistent** with the lower limit on *s* chosen by Geant (to conserve CPU).

- Geant choses to not say anything, take the large step anyway, and not apply the pathlegth correction. At 400 keV the correction should be of the order of 3; it rises for lower energies.

EM fractions in Z → $e^+ e^-$ events

Use electrons from Z -> e e, plot mean fractional energy deposit in each one of the EM layers. Separate the events into the standard categories in physics eta. The plot below shows each of the four EM fractions for each of the 15 categories.



Data:

EM1

EM2

EM3

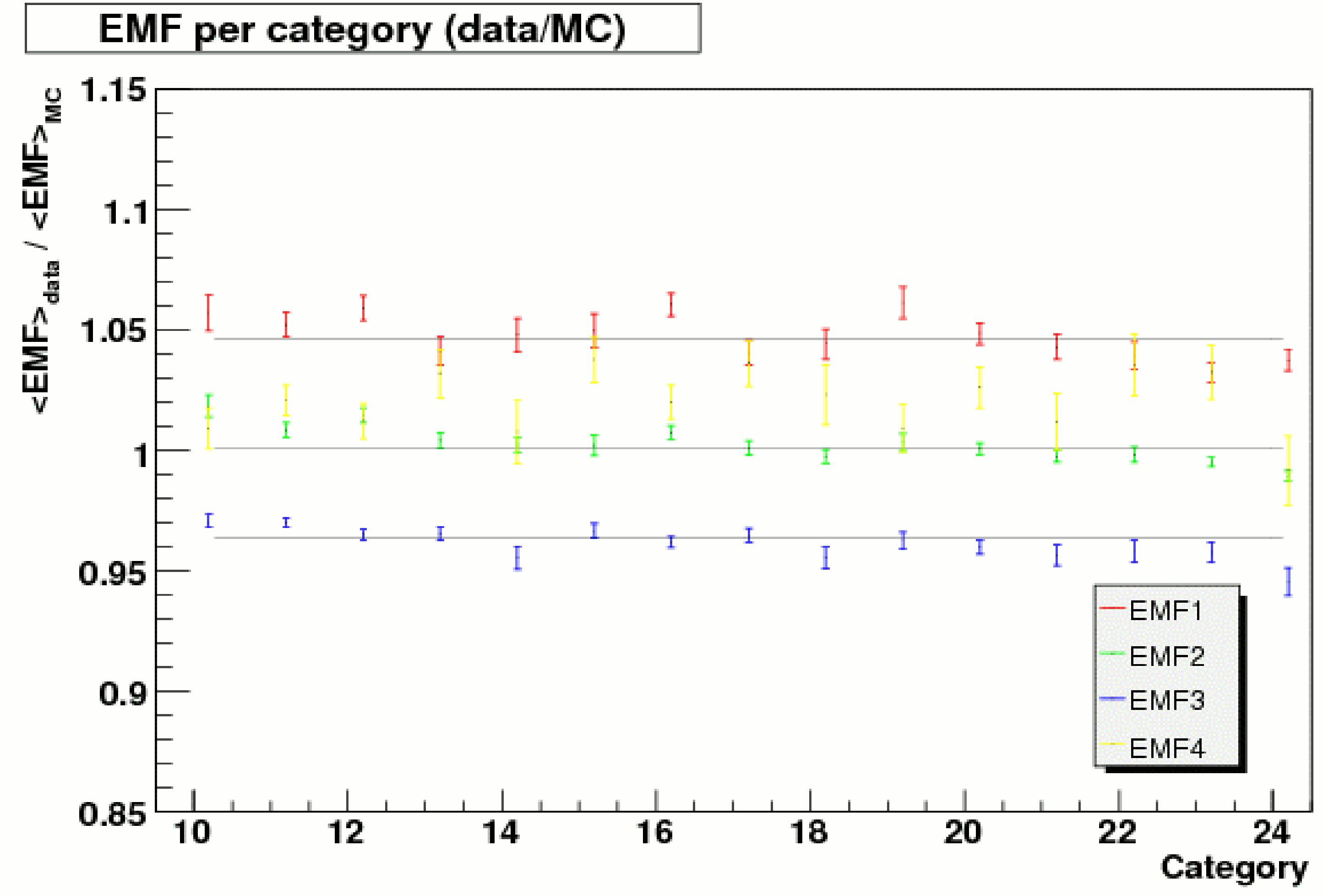
EM4

Monte Carlo (no fudge material):

black

This is a busy plot that can be tricky to read. Let's look at the data/MC ratios instead (on the next slide).

EM fractions in Z → $e^+ e^-$ events

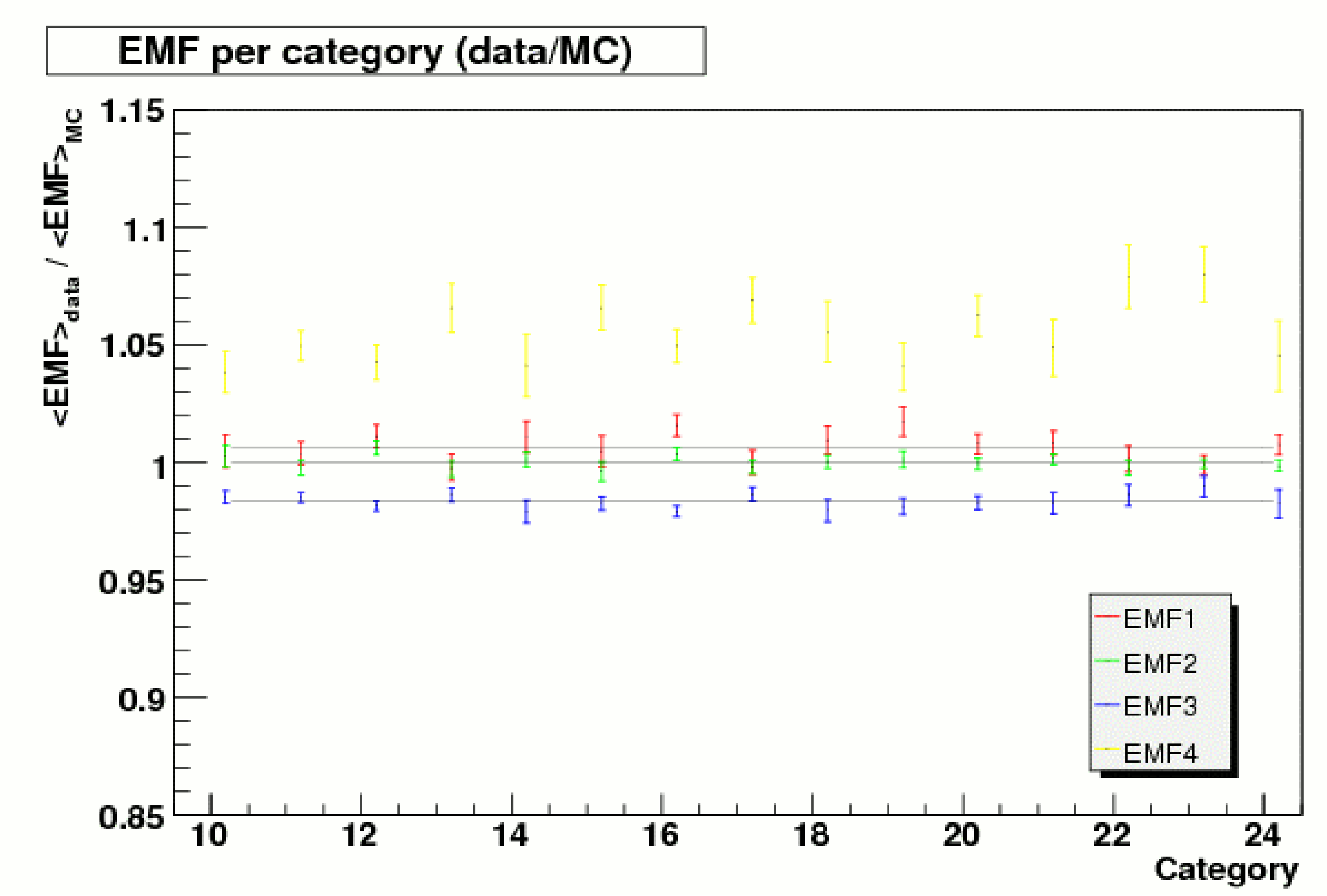


Data / Monte Carlo (MC without fudge material):

- EM1
- EM2
- EM3
- EM4

Clear trends are visible, especially for EM1 and EM3.
Also, the excursions away from unity are pretty large. Part of the mean per-layer excursion could be explained by the layers not being properly calibrated with respect to each other, but deviations of O(5 %) are not really expected.

EM fractions in Z → $e^+ e^-$ events



Data / Monte Carlo (MC with 0.16 X_0 fudging):

EM1

EM2

EM3

EM4

Certainly less trendy than with the nominal detector geometry.

The layers that receive the bulk of the energy (EM1, EM2 and EM3) are also much closer to unity.

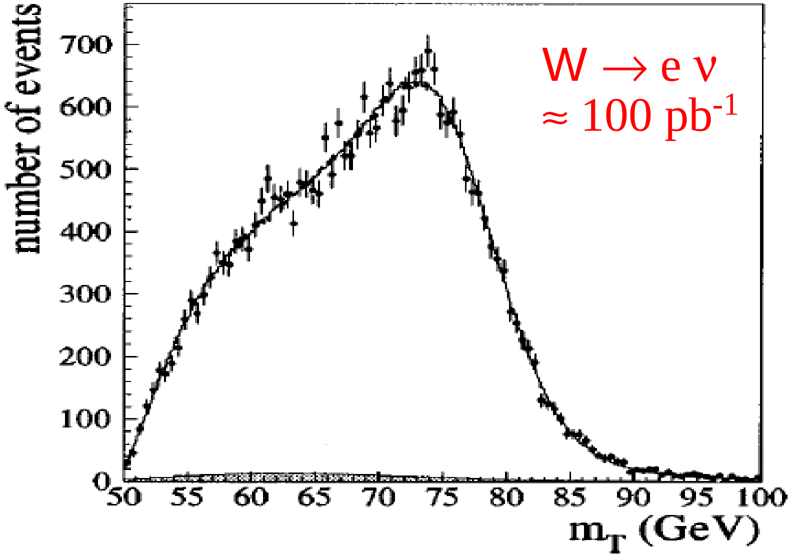
Dzero Run I

DØ Collaboration, PRD 58, 092003 (1998)

Observable: “transverse mass”

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

Relatively robust against uncertainties in physics model.



W → e ν

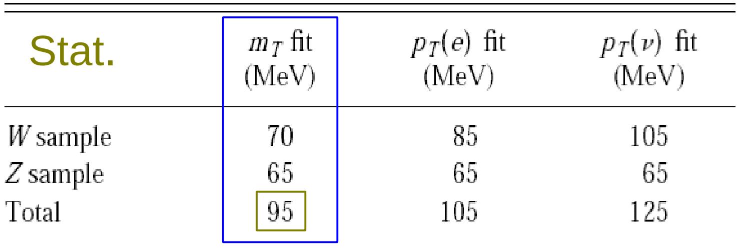
≈ 100 pb^{-1}

Model detector effects using parameters “from data” (and a lot of hypotheses).

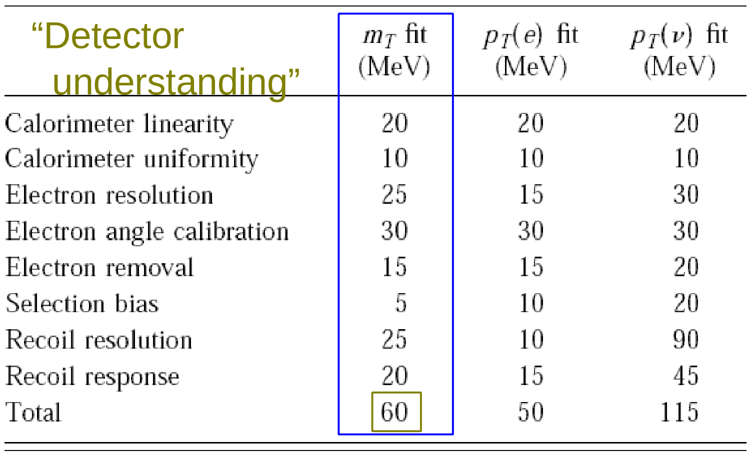
Generate M_T templates for different M_T points -> likelihood fit.

Understanding the detector behaviour, based mainly on Z → e e and Ψ → e e calibration samples, is crucial.

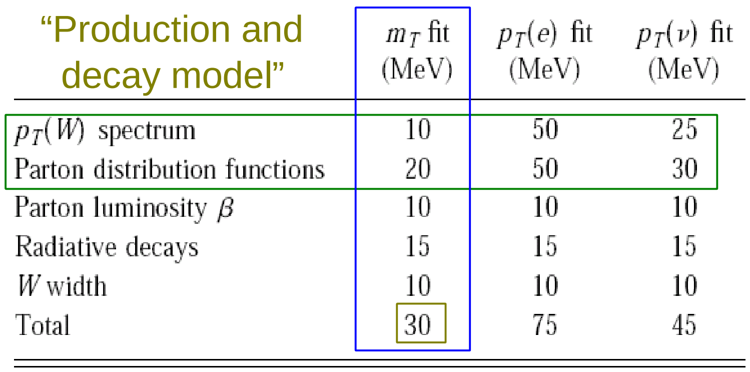
Uncertainties



Stat.	m_T fit (MeV)	$p_T(e)$ fit (MeV)	$p_T(\nu)$ fit (MeV)
W sample	70	85	105
Z sample	65	65	65
Total	95	105	125



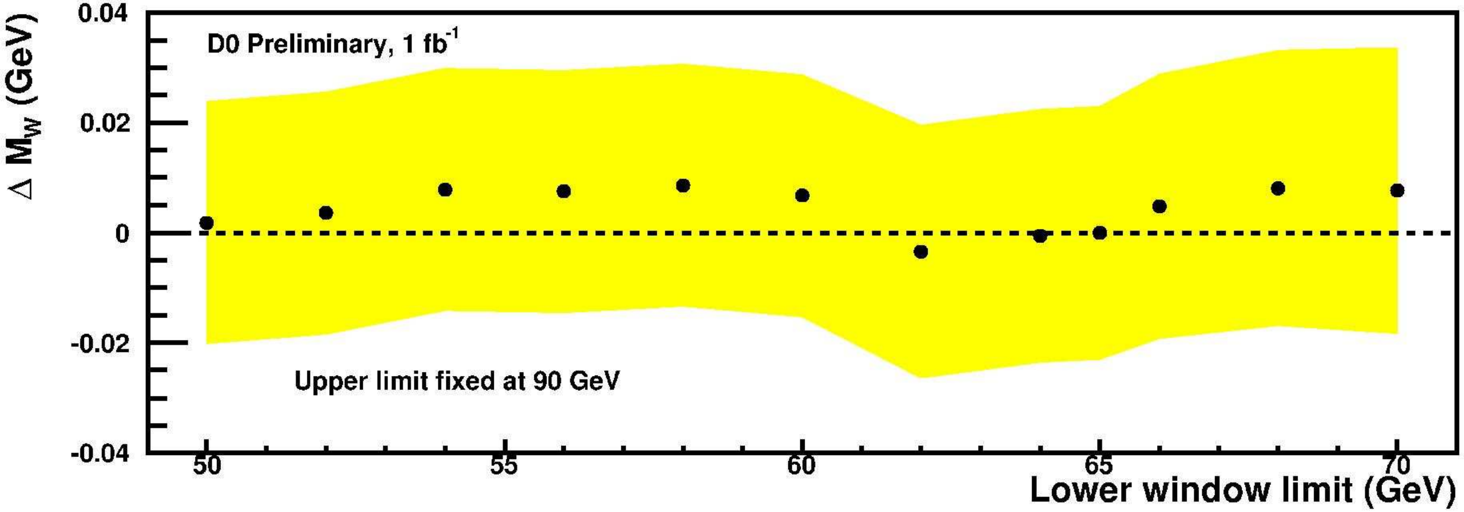
“Detector understanding”	m_T fit (MeV)	$p_T(e)$ fit (MeV)	$p_T(\nu)$ fit (MeV)
Calorimeter linearity	20	20	20
Calorimeter uniformity	10	10	10
Electron resolution	25	15	30
Electron angle calibration	30	30	30
Electron removal	15	15	20
Selection bias	5	10	20
Recoil resolution	25	10	90
Recoil response	20	15	45
Total	60	50	115

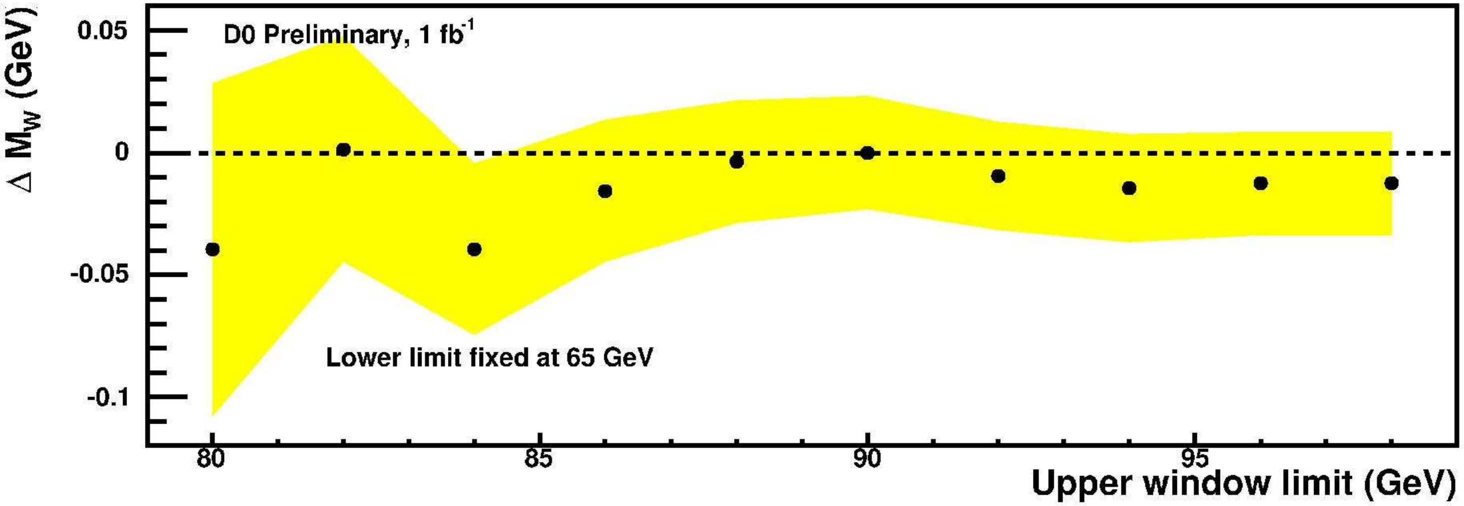


“Production and decay model”	m_T fit (MeV)	$p_T(e)$ fit (MeV)	$p_T(\nu)$ fit (MeV)
$p_T(W)$ spectrum	10	50	25
Parton distribution functions	20	50	30
Parton luminosity β	10	10	10
Radiative decays	15	15	15
W width	10	10	10
Total	30	75	45

Stability checks

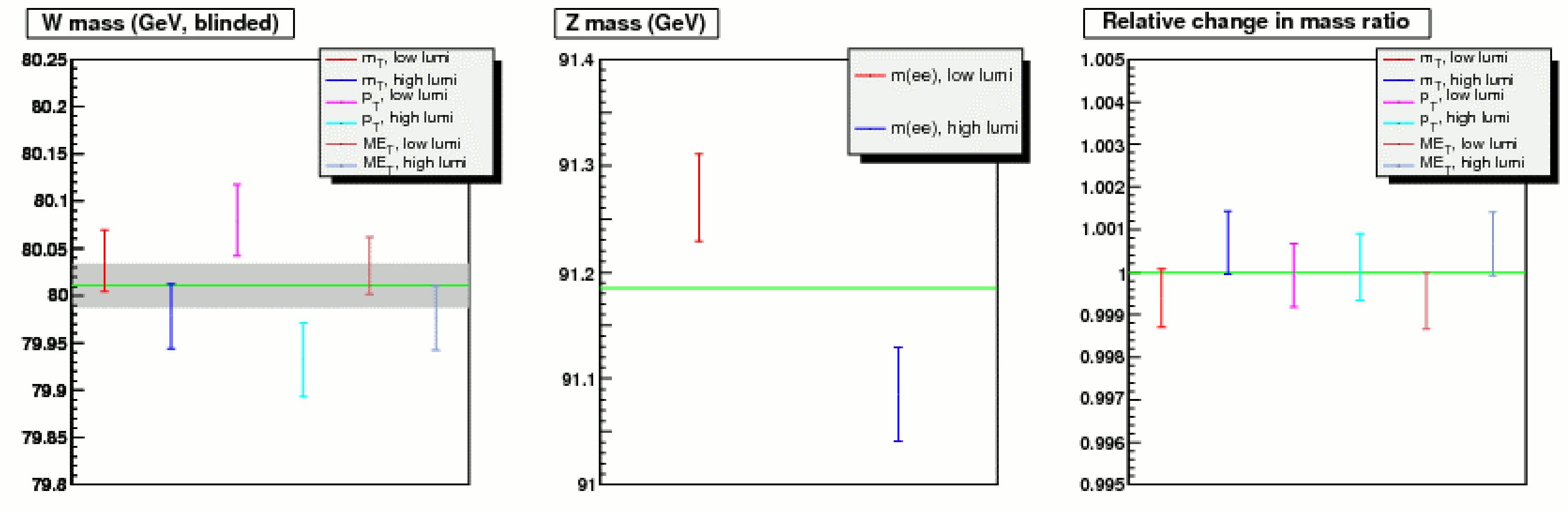
Changes in the fitted m_W when the fitting range (m_T observable) is varied.



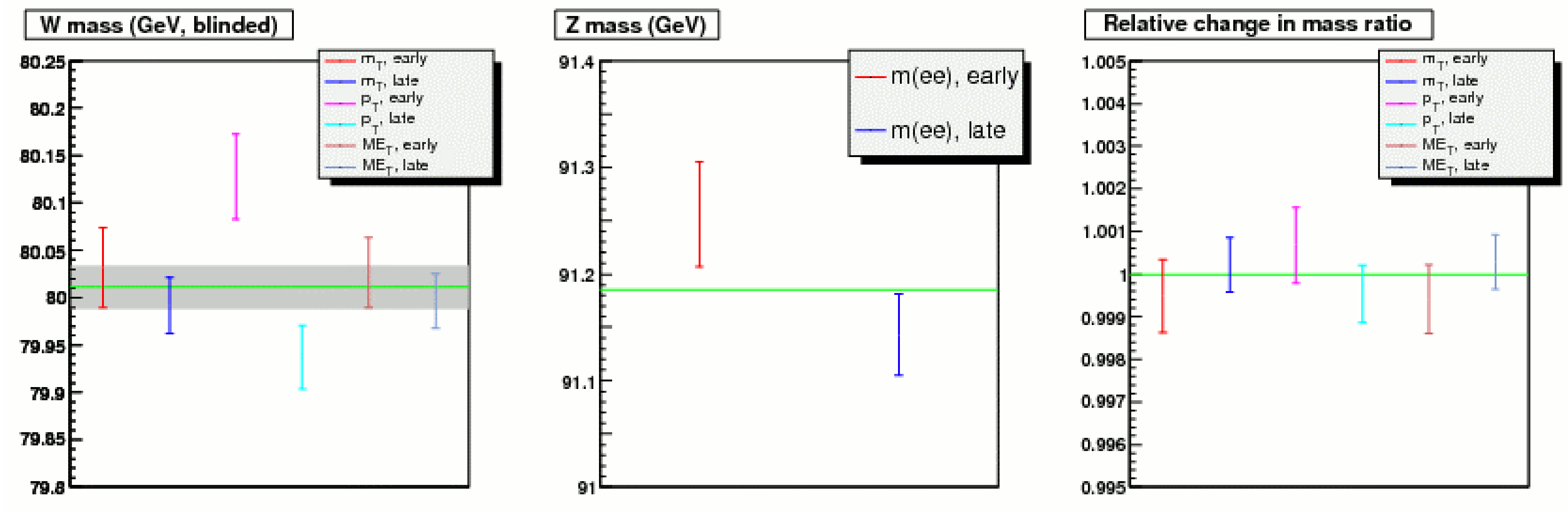


Stability checks

Instantaneous luminosity (split data into two subsets – high and low inst. luminosity)



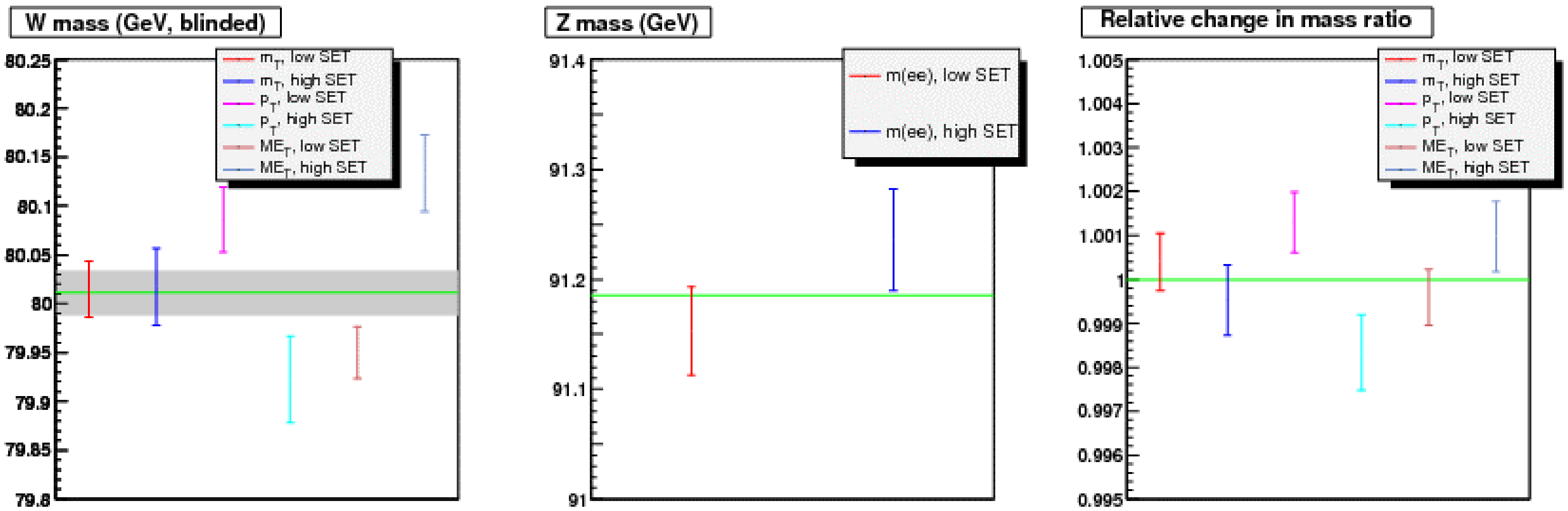
Time (i.e. data-taking period)



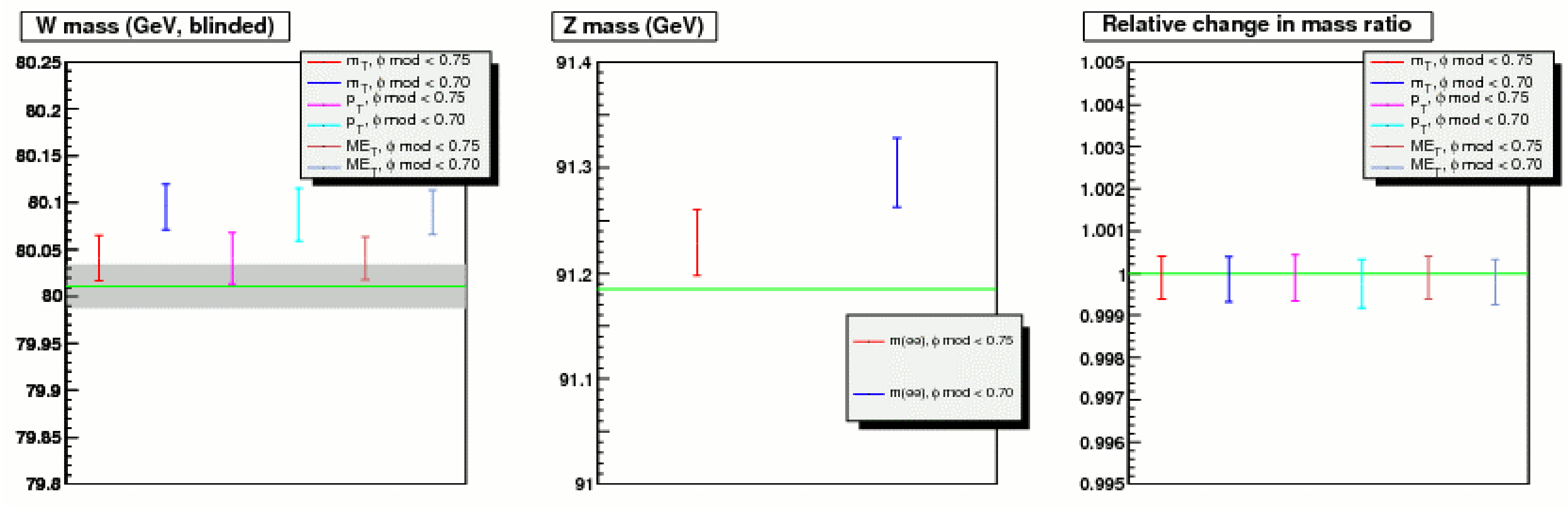
Sorry, plots still in terms of blinded mass, but it does not matter here.

Stability checks

Scalar E_T (“global event activity as seen by calorimeter”)



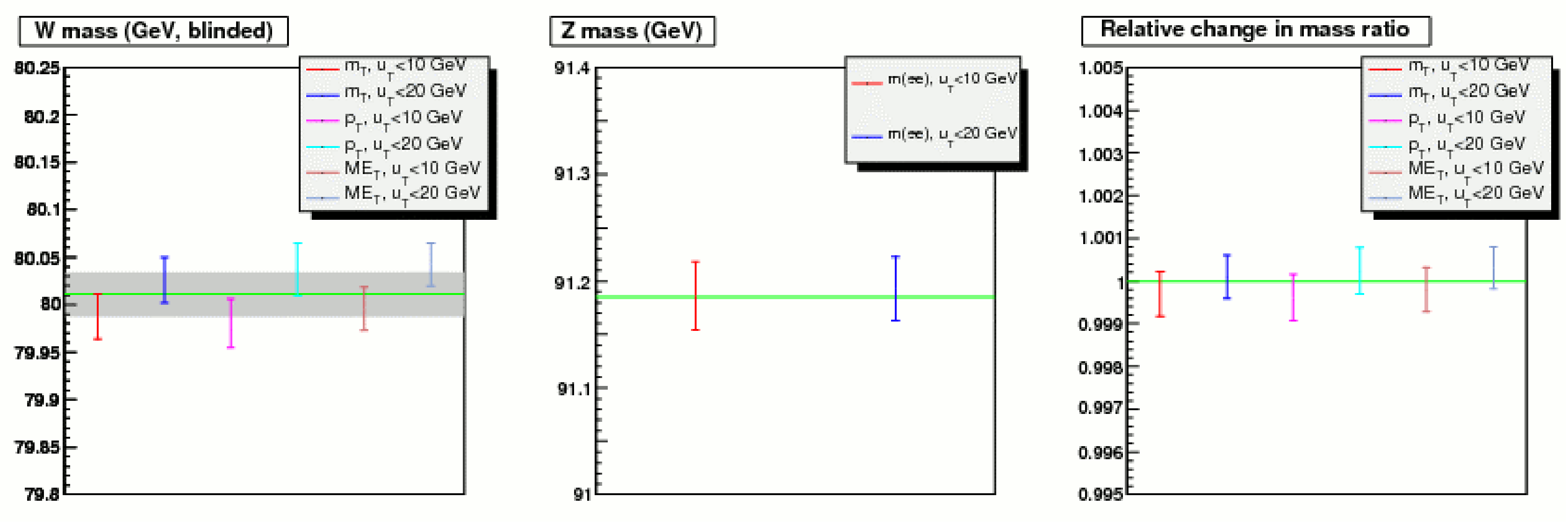
Electron distance from phi cracks



Sorry, plots still in terms of blinded mass, but it does not matter here.

Stability checks

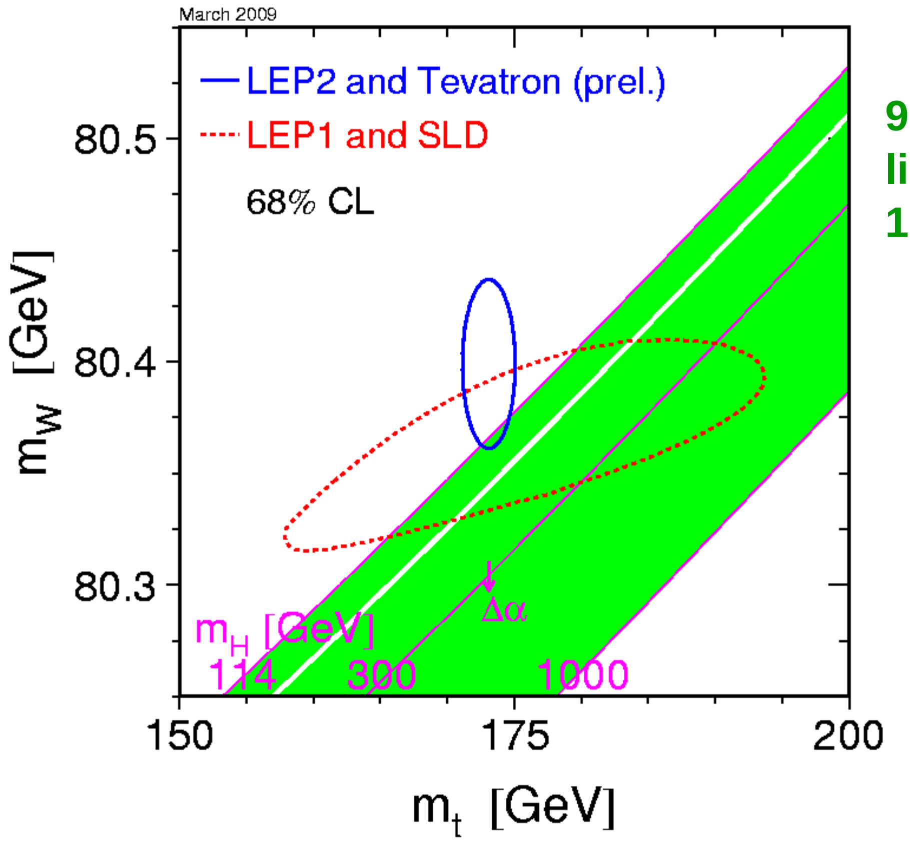
Cut on u_T ("length of recoil vector")



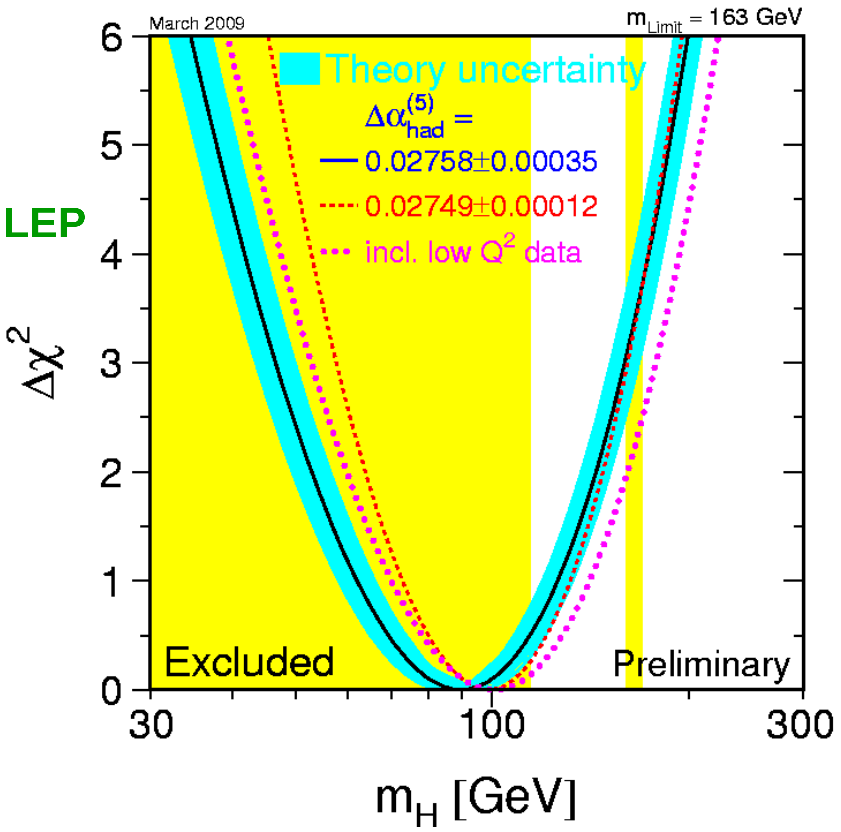
Sorry, plots still in terms of blinded mass, but it does not matter here.

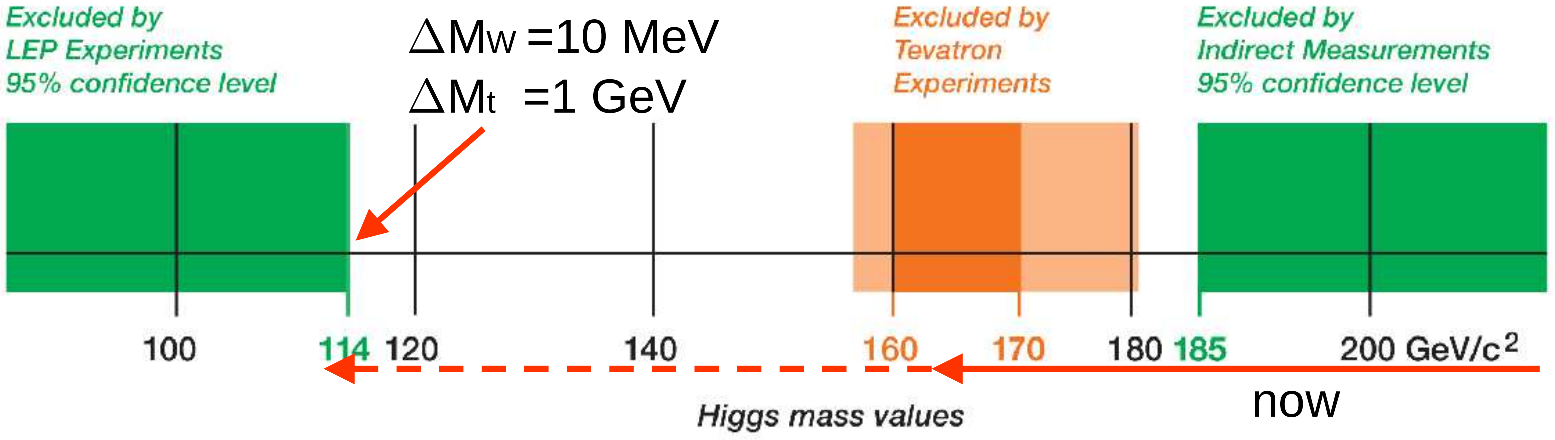
http://lepewwg.web.cern.ch/LEPEWWG/

Top mass = 173.1 + 1.3 GeV



95% CL
limit 163 GeV
191 GeV with LEP





ΔM_W =10 MeV
ΔM_t =1 GeV

now

Indirect
no LEP