Measurement of W boson mass at DØ

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The Physics of W and Z Bosons
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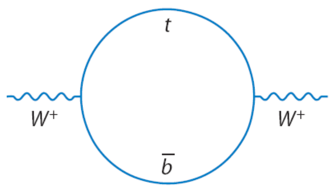
Outline

- Introduction
- Measurement strategy
- Calorimeter calibration
- W mass measurement
- Conclusions

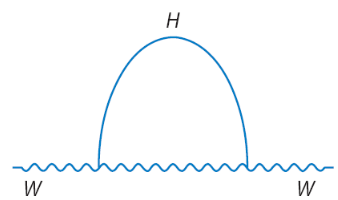
W boson mass

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

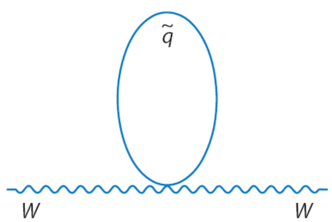
Δ r ~ 3%

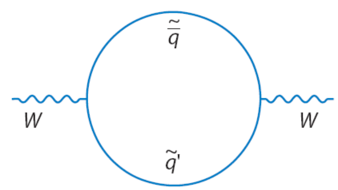


$\Delta r \propto M_t^2$



$\Delta r \propto \log M_H$

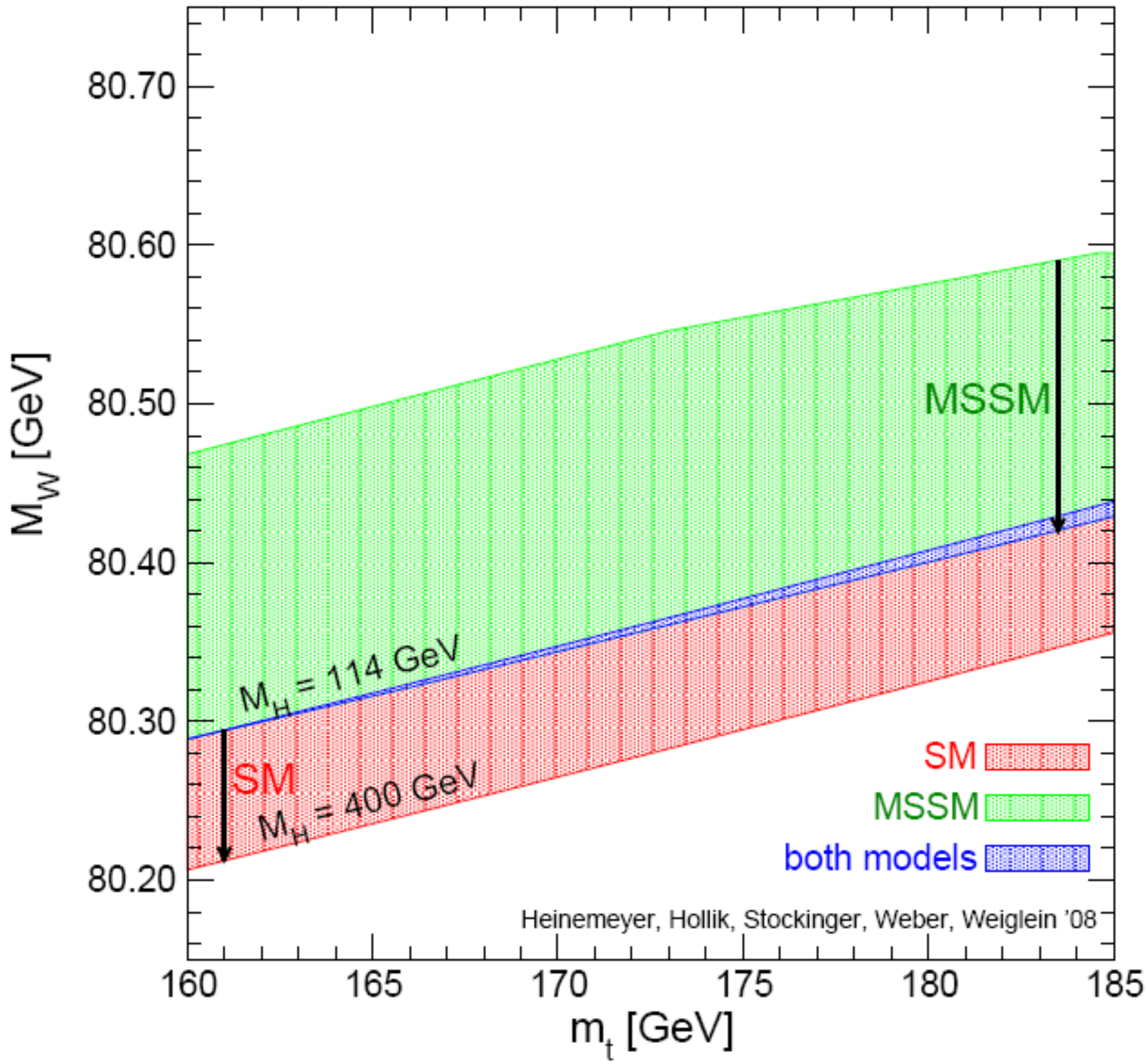




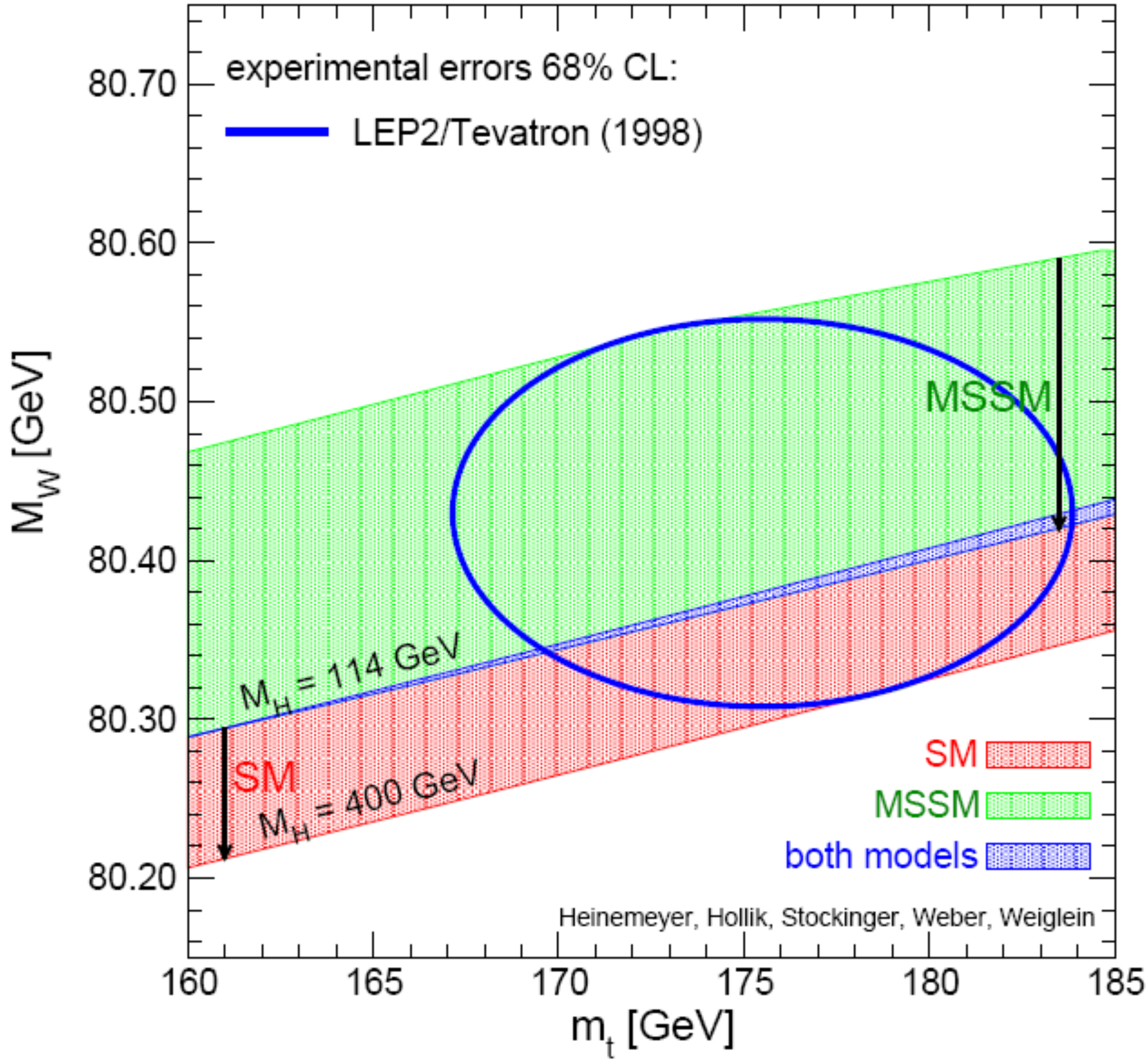
M_W can be increased by up to 250 MeV in MSSM

A precise measurement of M_W can be used to make indirect constraints on M_H and possible new physics

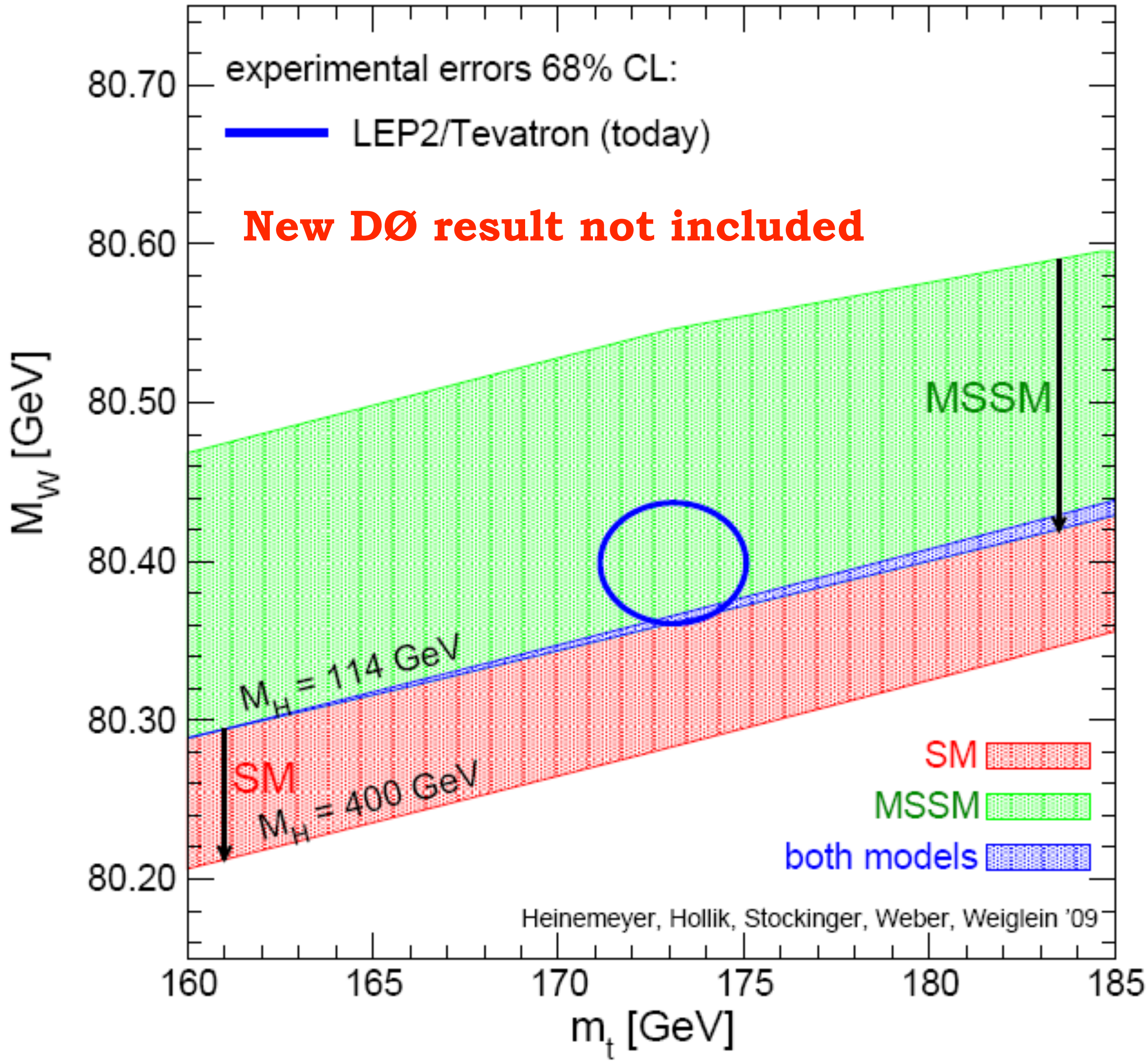
Higgs mass constraint



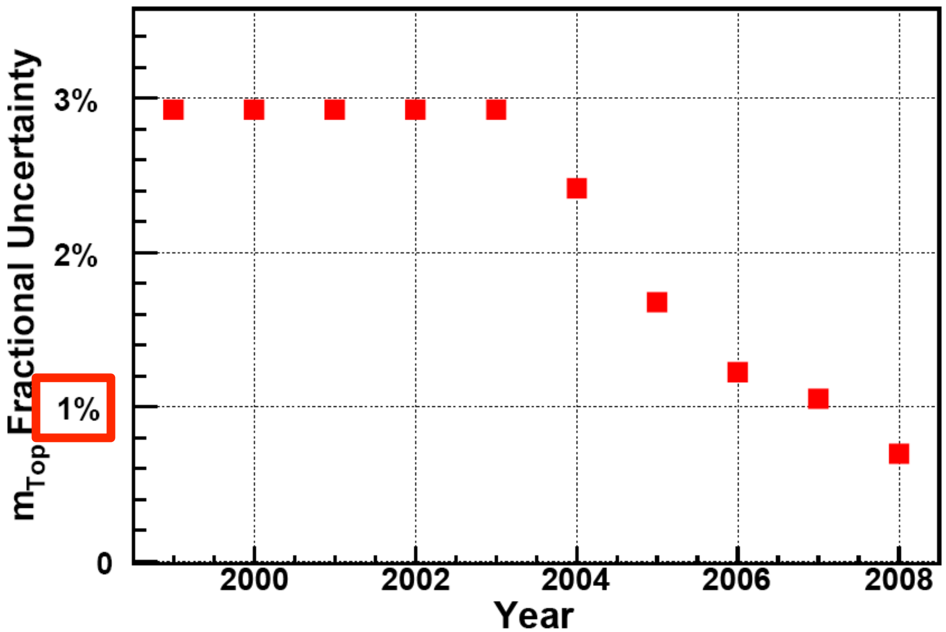
Higgs mass constraint (1998)

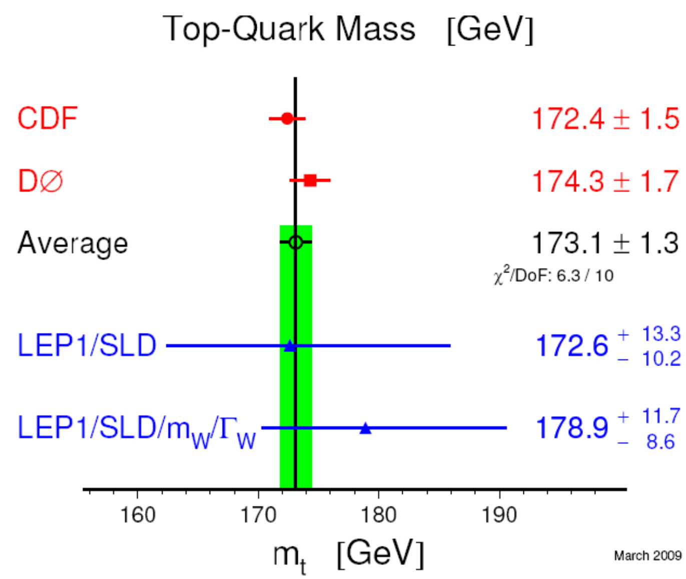


Higgs mass constraint (2009)



M_{top} and M_W uncertainties





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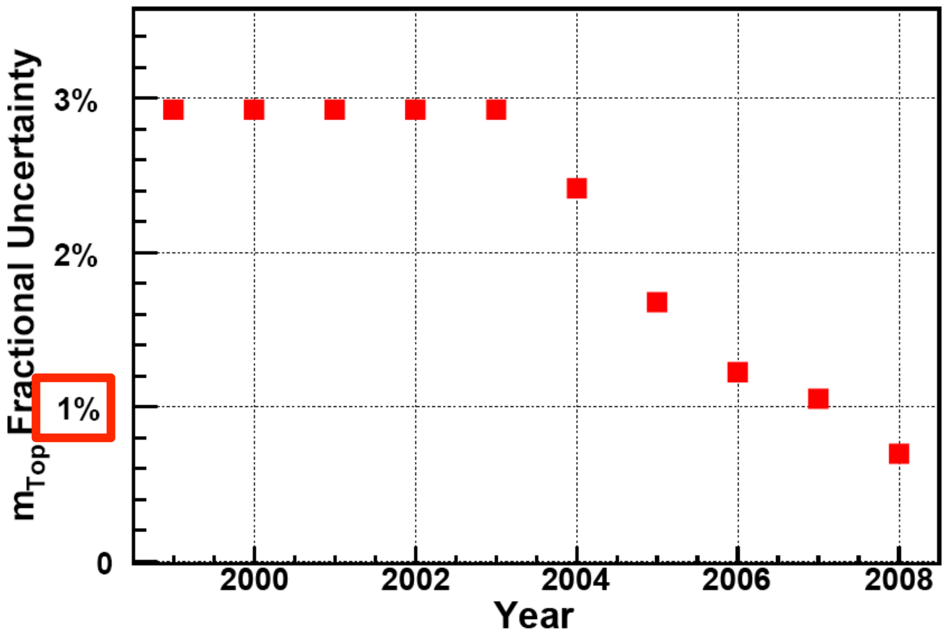
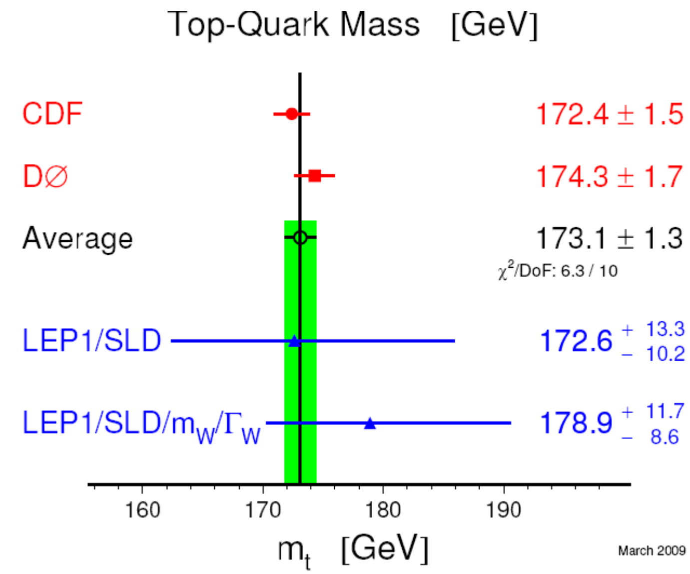
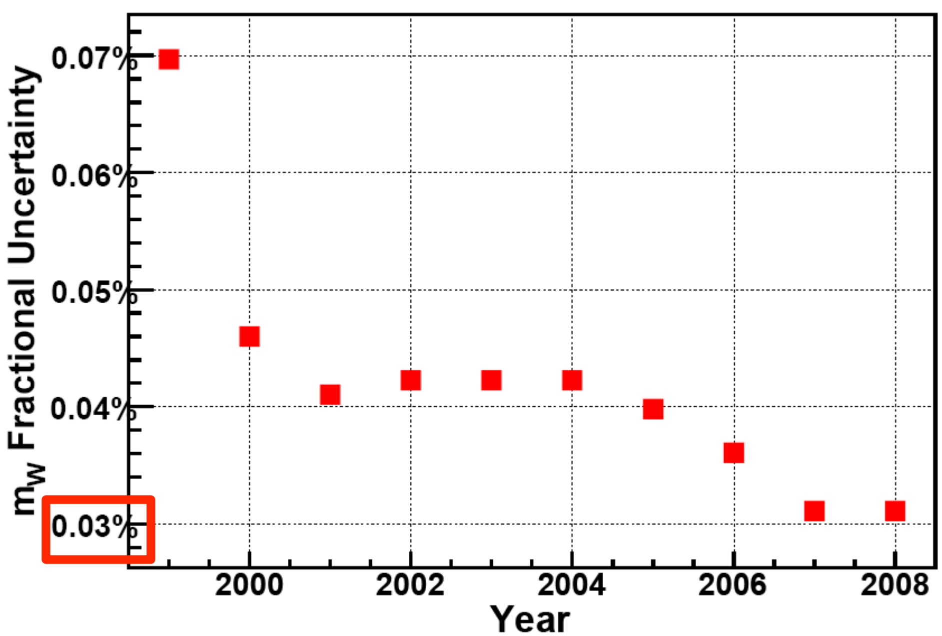
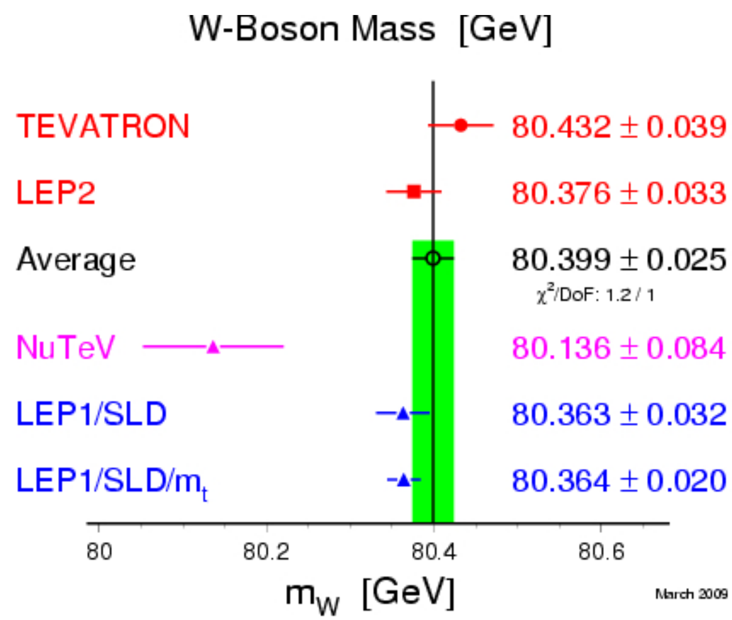
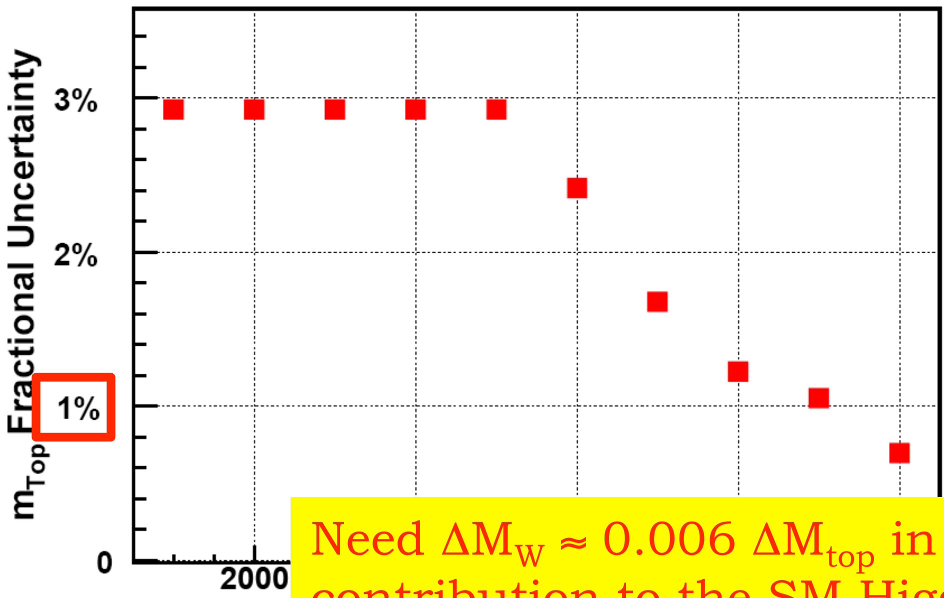


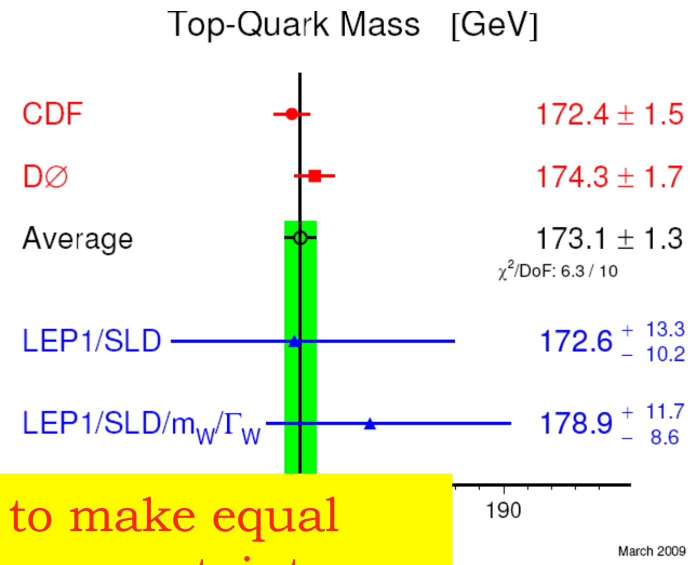






M_{top} and M_W uncertainties

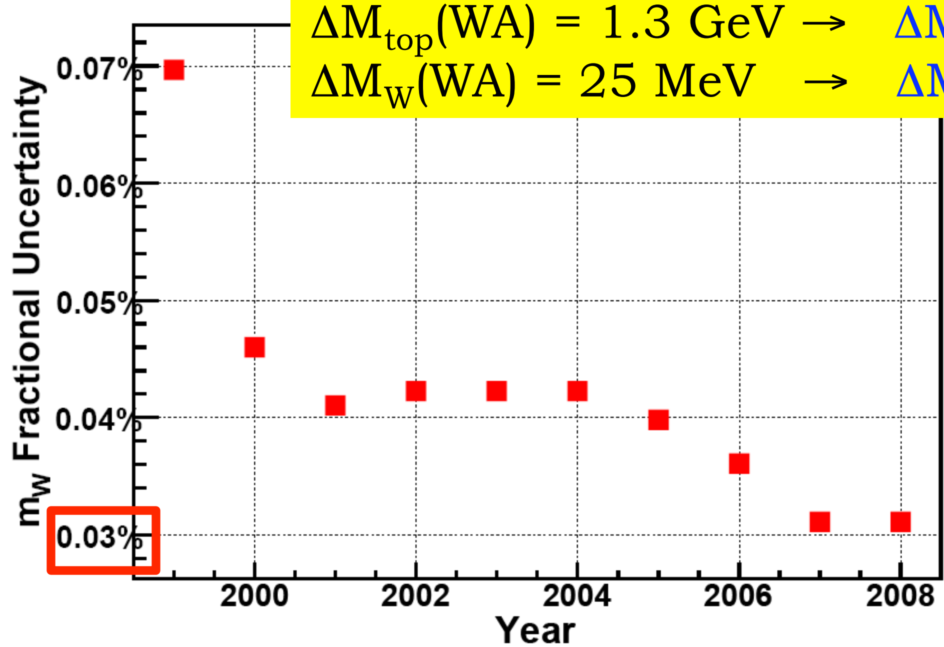


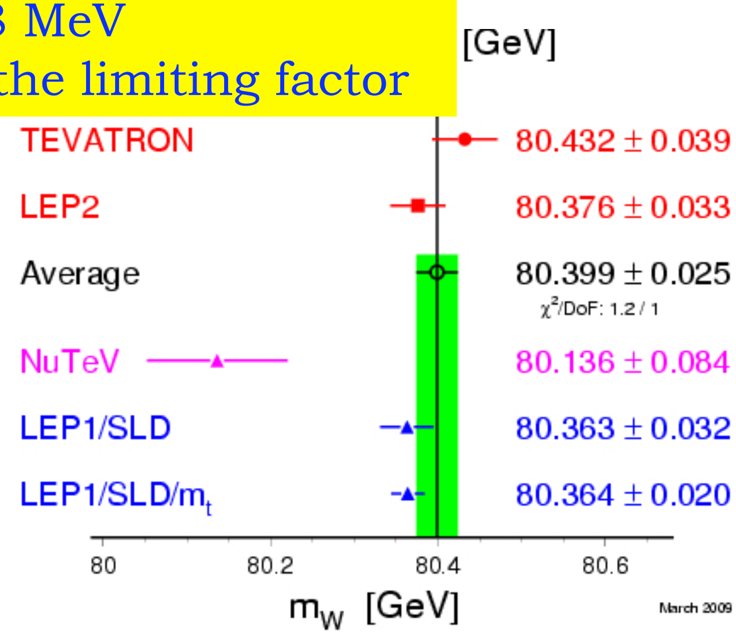


Need $\Delta M_W \approx 0.006\ \Delta M_{top}$ in order to make equal contribution to the SM Higgs mass uncertainty

ΔM_{top}(WA) = 1.3 GeV → ΔM_W = 8 MeV

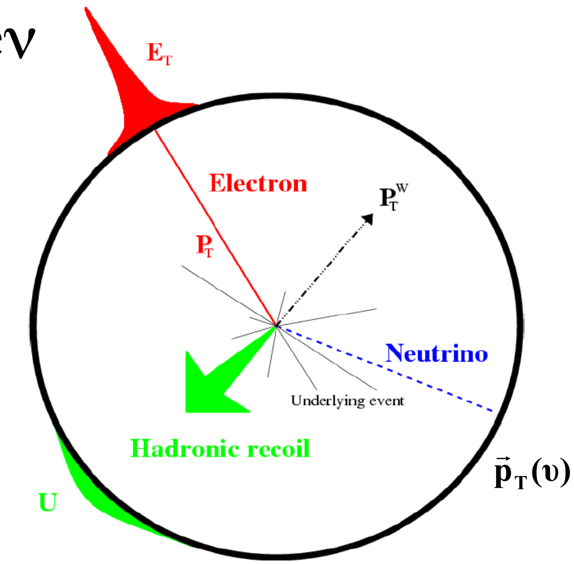
ΔM_W(WA) = 25 MeV → ΔM_W is the limiting factor



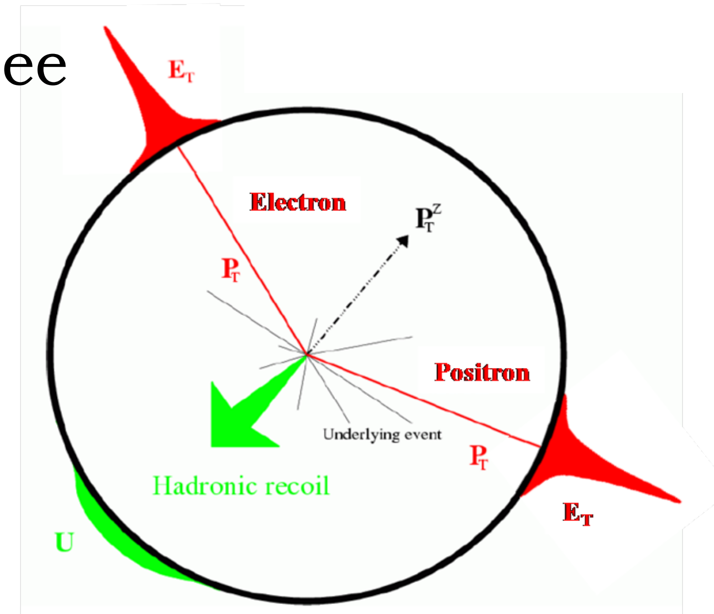


Measurement strategy

W→eν



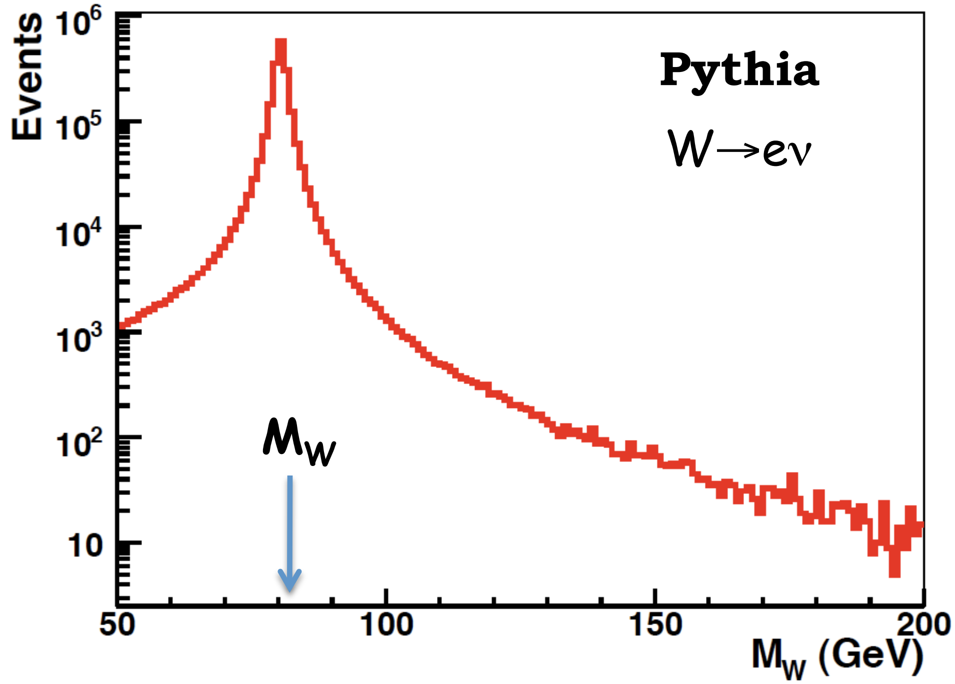
Z→ee



- Three observables: $p_T(e)$, $p_T(\nu)$ (inferred from missing transverse energy), transverse mass $M_T^2=(E_{Te}+E_{T\nu})^2-|\vec{p}_{Te}+\vec{p}_{T\nu}|^2$
- Develop a parameterized MC simulation with parameters determined from the collider data (mainly Z→ee events)
- Generate MC templates with different input M_W, compare with data distributions and extract M_W
- Z →ee events are used to set the absolute electron energy scale, so we are effectively measuring M_W/M_Z

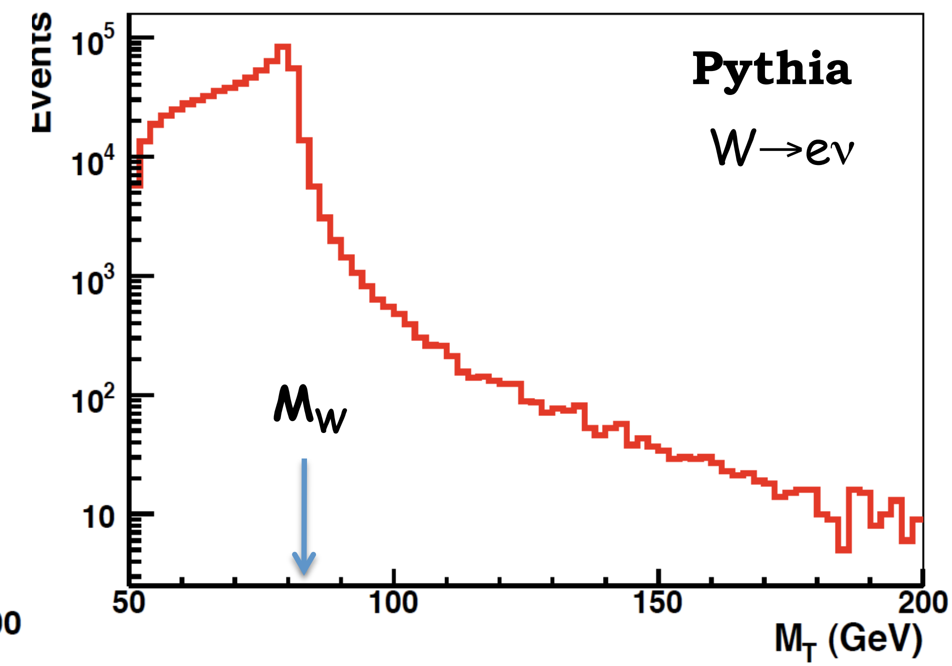
$M(e\nu)$ and $M_T(e\nu)$ in $W \rightarrow e\nu$ events

$M_W^2=(E_e+E_\nu)^2-|\vec{p}_e+\vec{p}_\nu|^2$



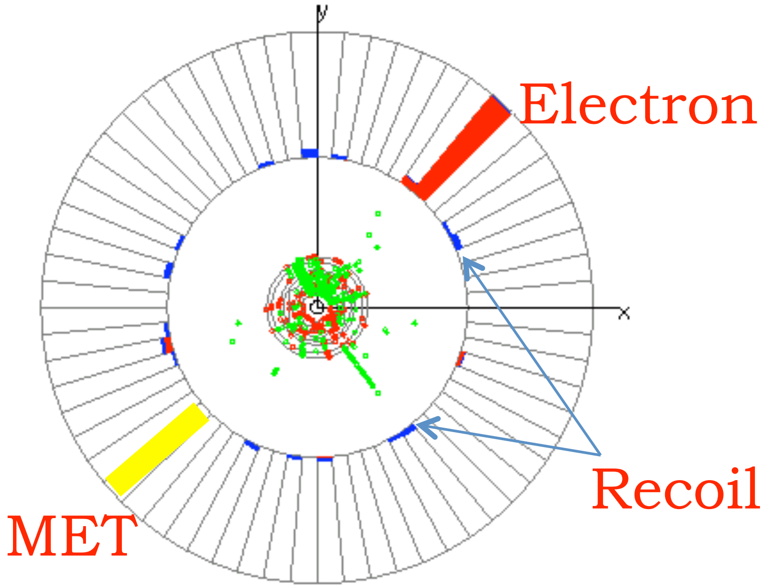
$M(e\nu)$

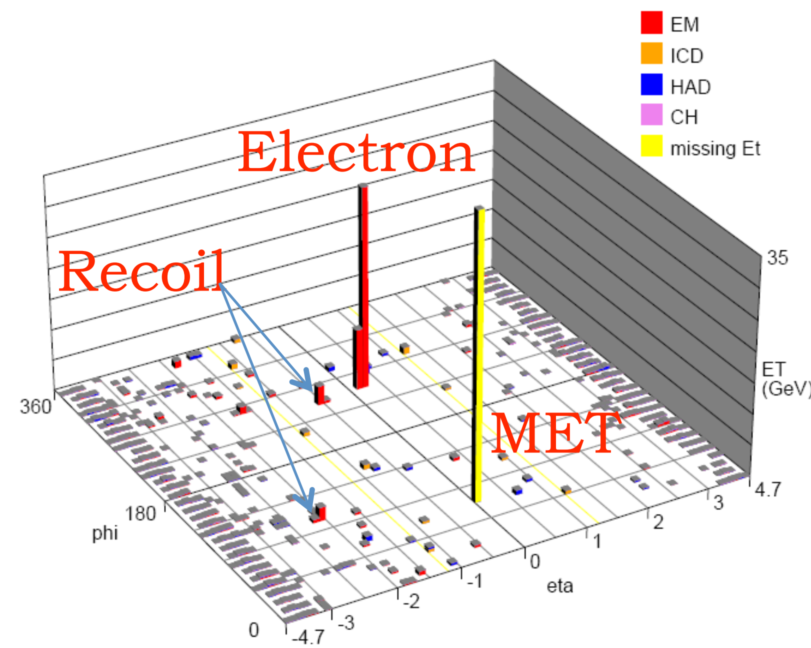
$M_T^2=(E_{Te}+E_{T\nu})^2-|\vec{p}_{Te}+\vec{p}_{T\nu}|^2$



$M_T(e\nu)$

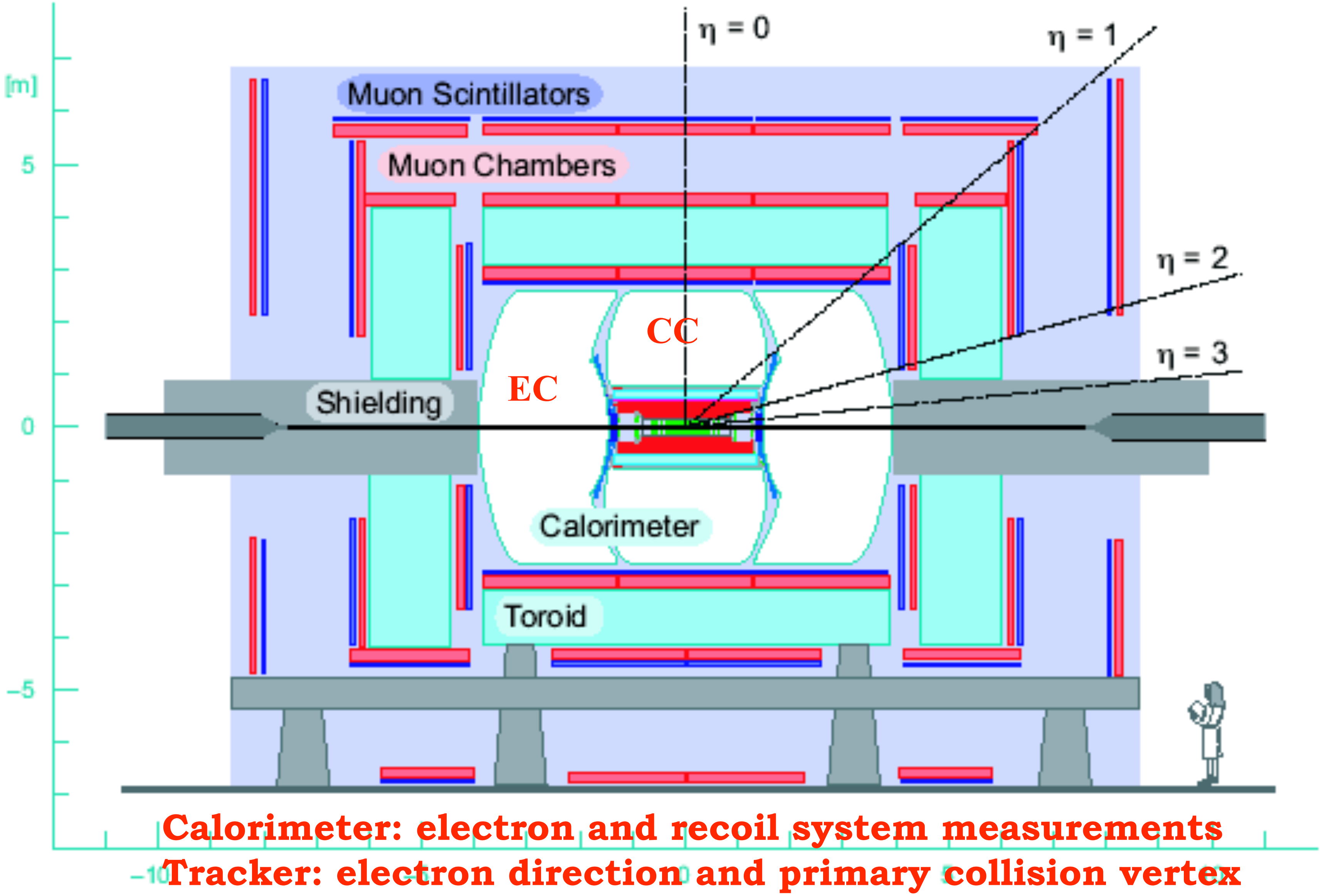
W→eν candidate





- Crucial to understand the calorimeter response to the electron (~40 GeV) and the recoil system (everything else except the electron, ~ 5 GeV)
- To measure M_W with an uncertainty of 50 MeV:
  - Need to understand the electron energy scale to 0.05%
  - Need to understand the recoil system response to <1%

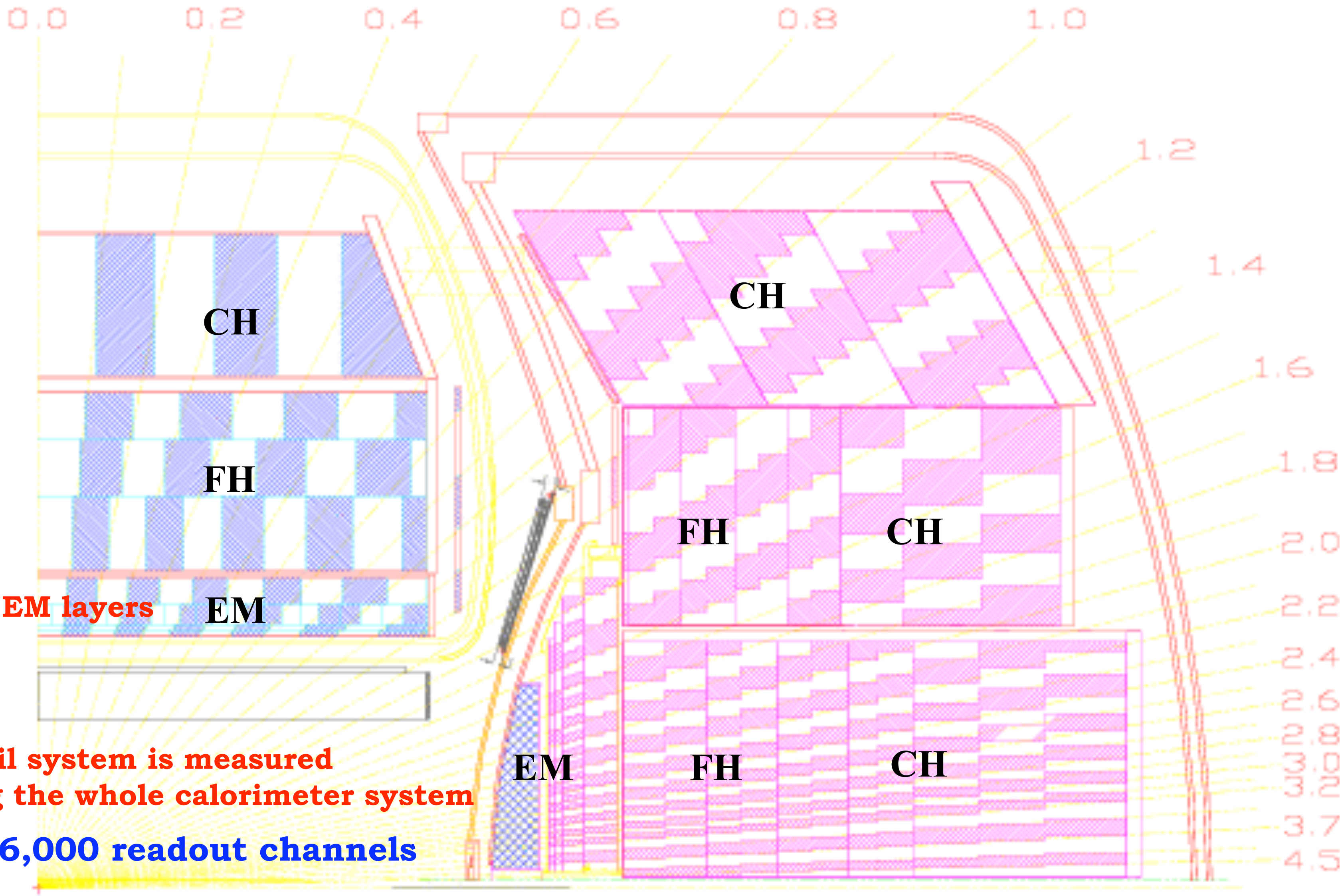
DØ detector



Calorimeter: electron and recoil system measurements

Tracker: electron direction and primary collision vertex

Uranium-LAr calorimeters



Four EM layers

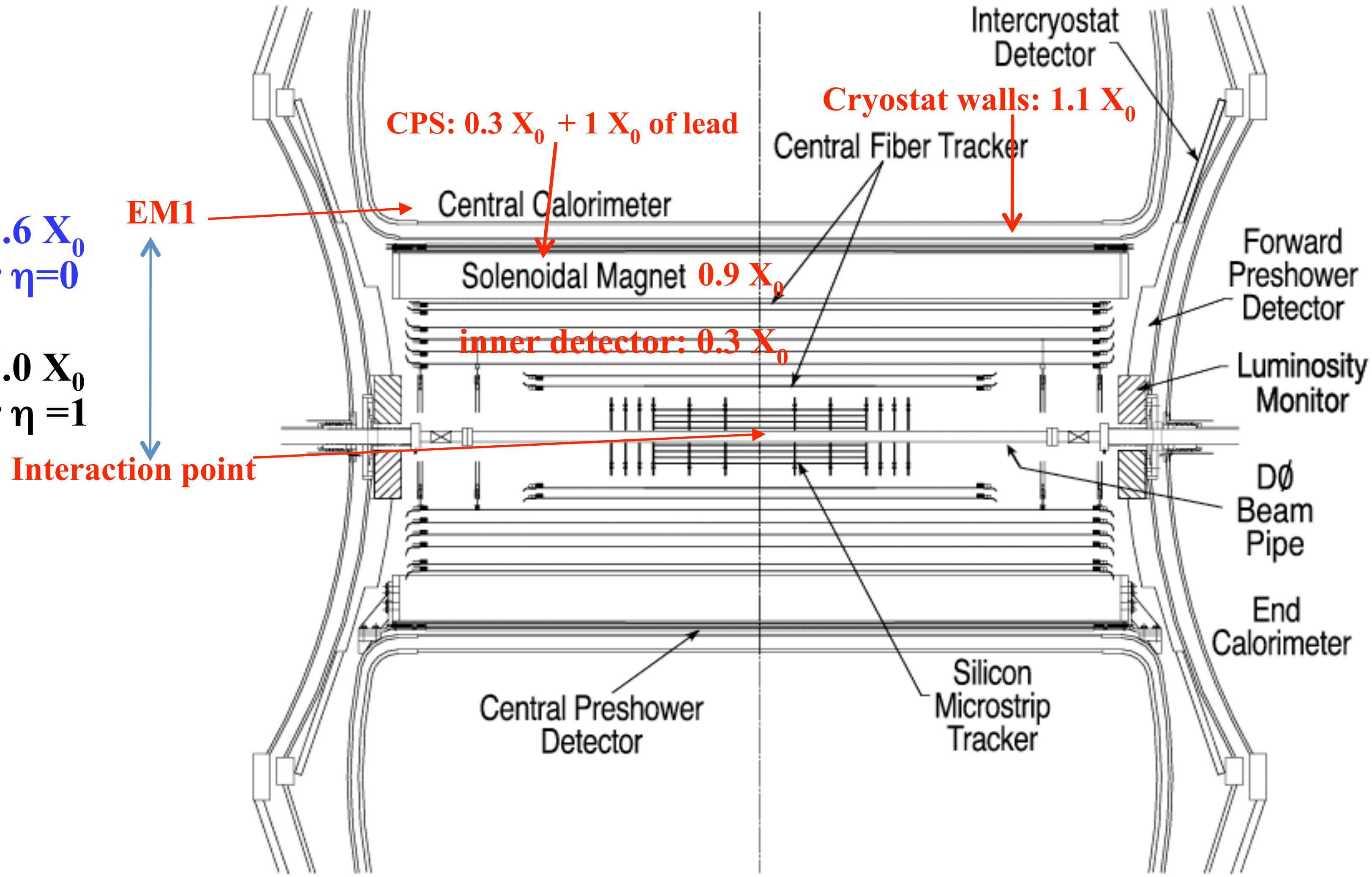
Recoil system is measured using the whole calorimeter system

~ 46,000 readout channels

Material in front of the calorimeter

~ 3.6 X_0 for η=0

~ 5.0 X_0 for η =1

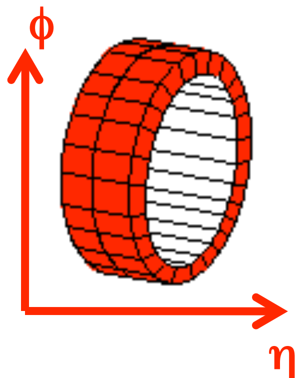


Detector calibration

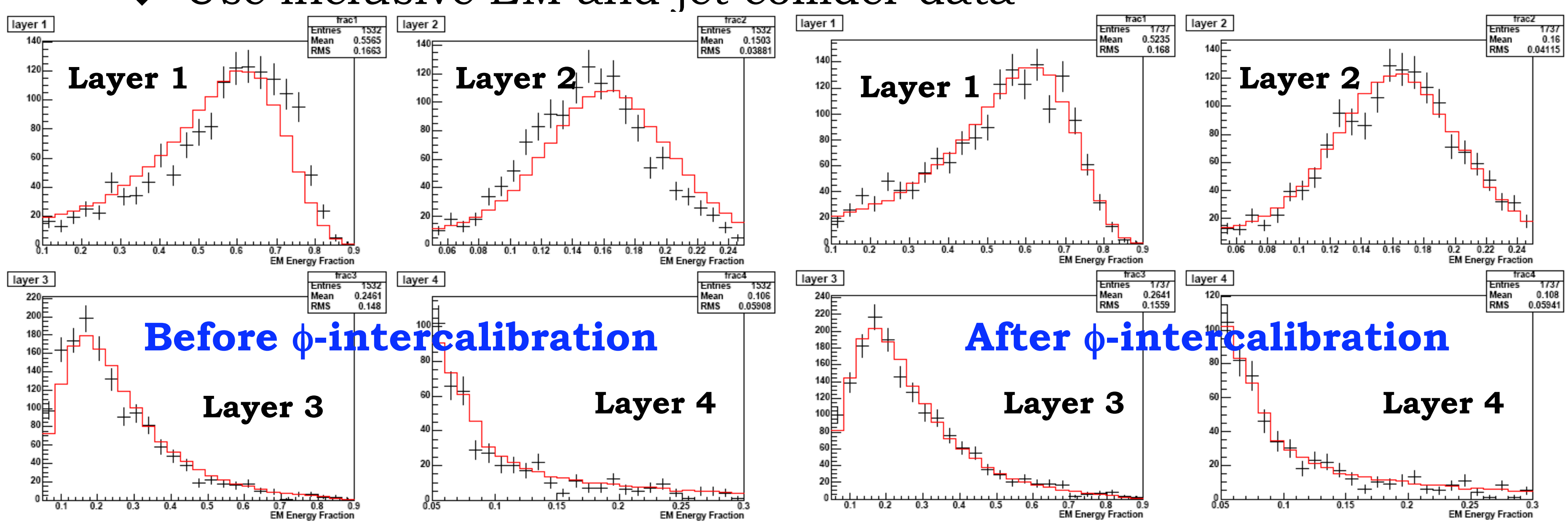
- CDF calibration (0.2 fb^{-1}):
  - ~4% energy (momentum) resolution for e (μ) at p_T=45 GeV
  - Use $J/\psi \rightarrow \mu\mu$ (0.6 M), $\Upsilon \rightarrow \mu\mu$ (70 k), $Z \rightarrow \mu\mu$ (5 k) to calibration the tracking system
  - Use E/p distribution for electron from W decays to calibrate the calorimeter system
  - See Ashutosh Kotwal's talk
- D0 calibration (1 fb^{-1}):
  - ~4% (10%) energy (momentum) resolution for e (μ) at p_T=45 GeV
  - Only 18 k $Z \rightarrow ee$ events
  - Similar electron p_T distributions for Z and W events
  - Stable and uniform calorimeter response

Calorimeter calibration (I)

- Calorimeter calibration: ADC → GeV
- **Electronics calibration using pulsers:**
  - inject known electronics signal into preamplifier and equalize readout electronics response
- **ϕ-intercalibration for both EM and HAD calorimeters**
  - Unpolarized beams at the Tevatron
  - Energy flow in the transverse plane should not have any azimuthal dependence
  - Use inclusive EM and jet collider data

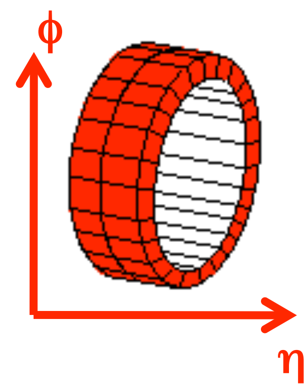


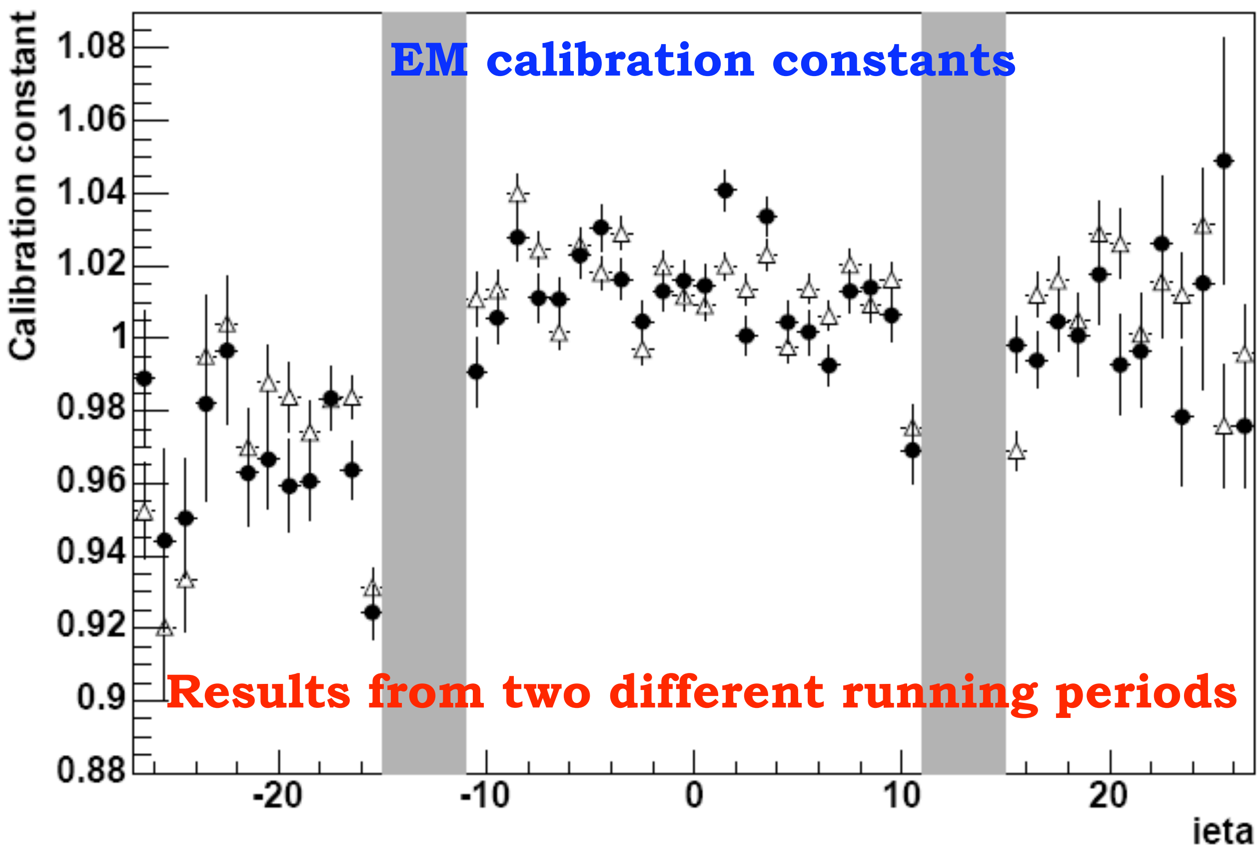
Red: average
Black: one cal tower



Calorimeter calibration (II)

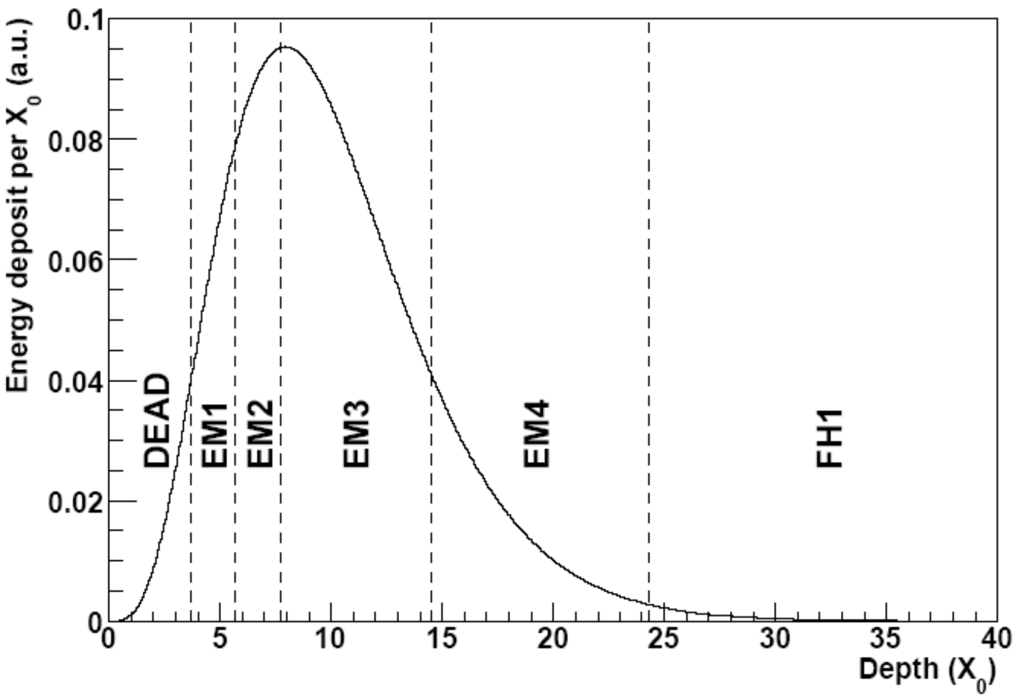
- **η-intercalibration for both EM and HAD calorimeters**
  - EM: Use Z→ee events (minimize Z mass resolution and give the correct (LEP) measured value)
  - HAD: Use γ+jet and di-jet events



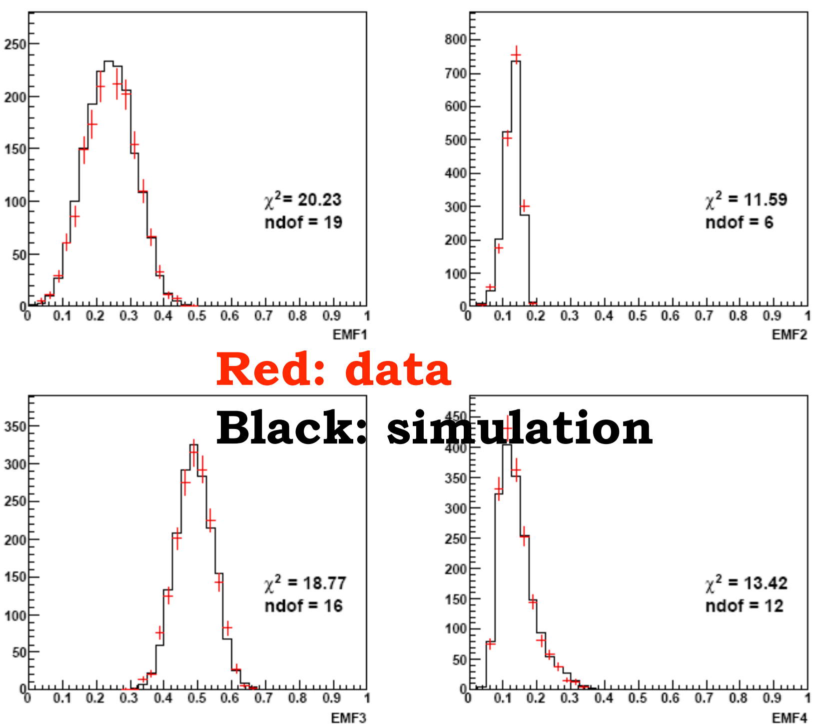


Calorimeter calibration (III)

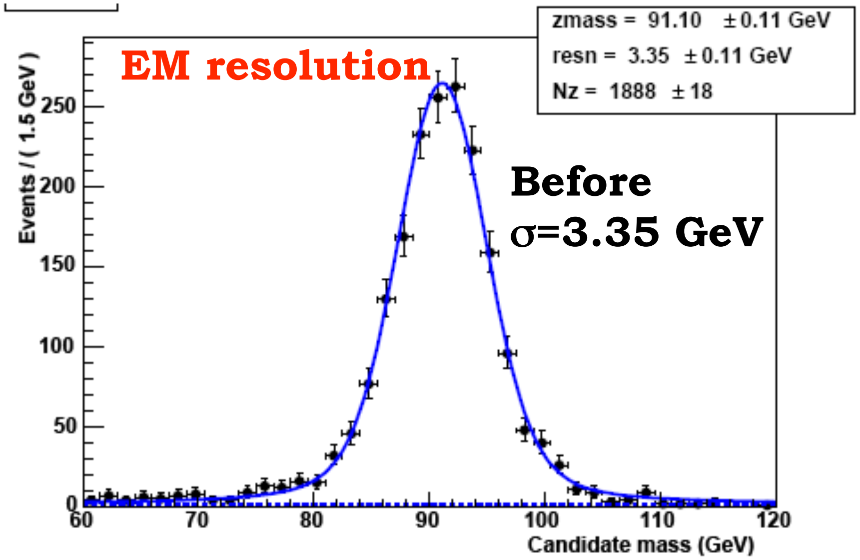
- Electrons lose ~15% of energy in front of the calorimeter
- **Amount of material before the calorimeter (using electron EMFs):**
  - Exploit longitudinal segmentation of EM calorimeter
  - Fraction energy depositions (EMFs) in each EM layer are sensitive to the amount of dead material
- **Amount of missing material in the Geant MC simulation: (0.16 ± 0.01) X_0**

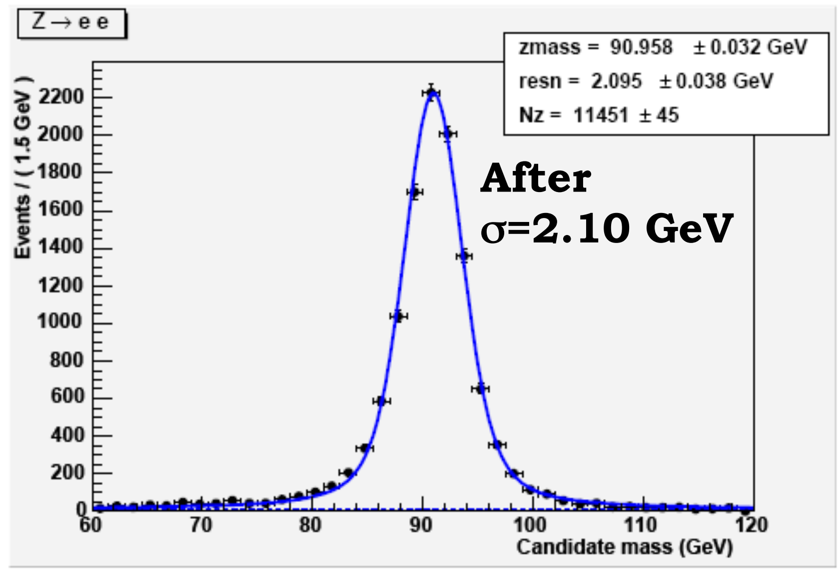


Electron EMFs

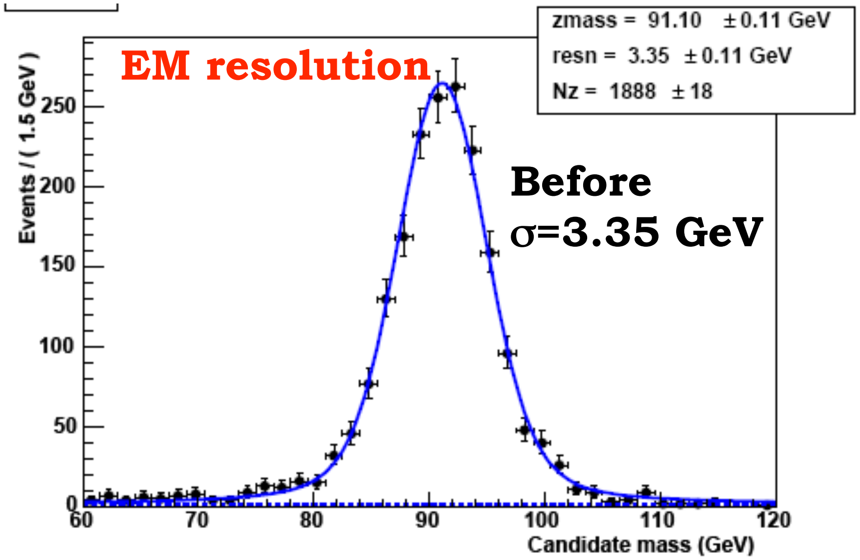


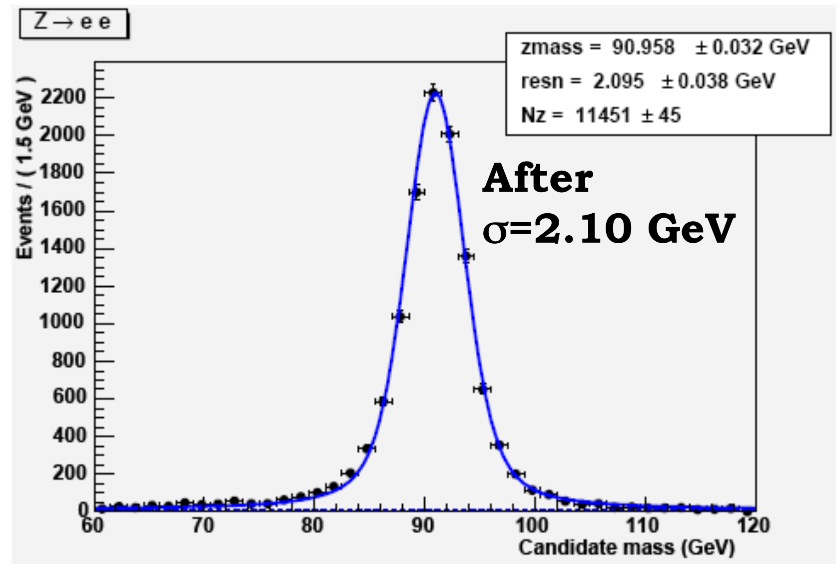
Calibration results

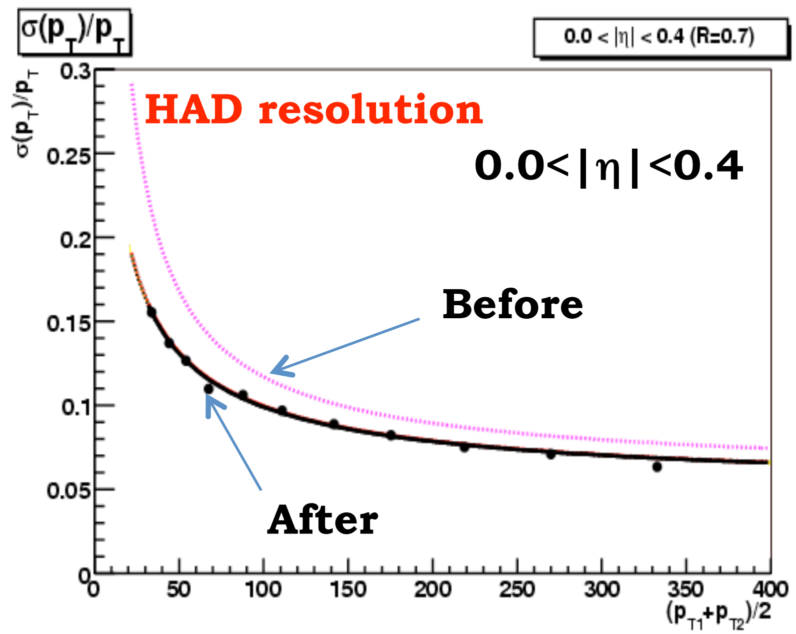


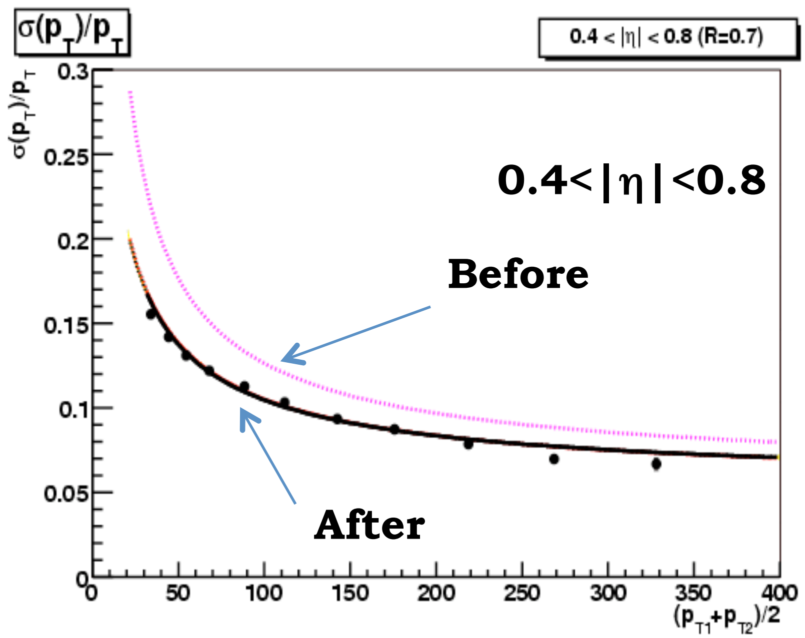


Calibration results







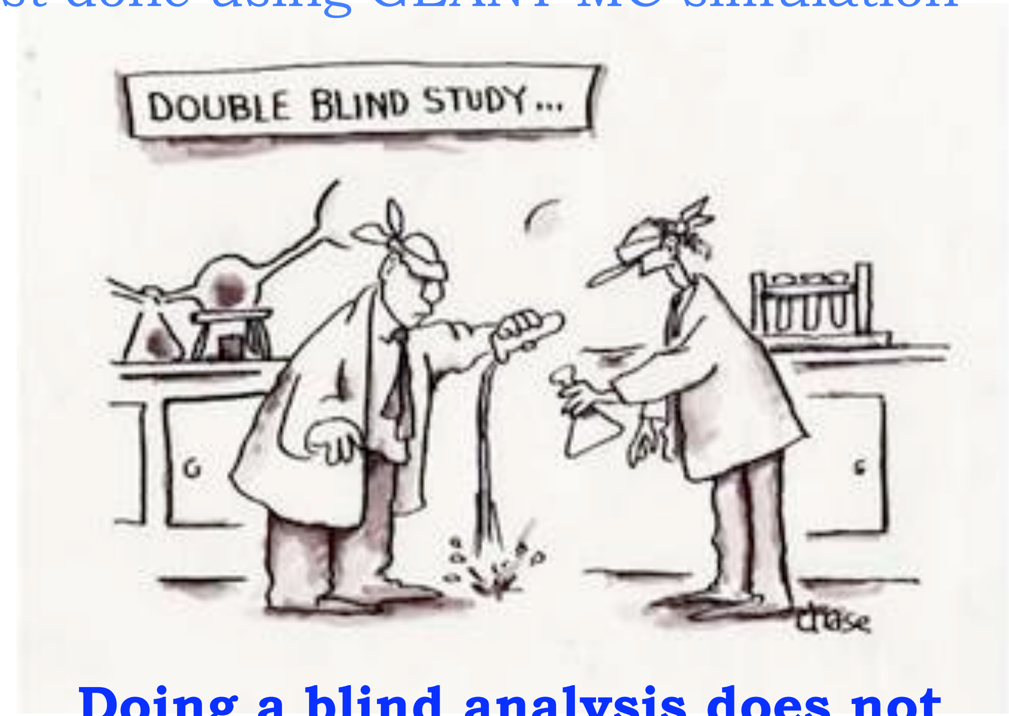


Parameterized MC simulation

- Interfaced with latest MC event generators (ResBos+PHOTOS, see Jan Stark's talk)
- Detector simulation: Electron/Recoil system simulation, Correlations between electron and the recoil system
- Mass templates generation

Parameterized MC simulation

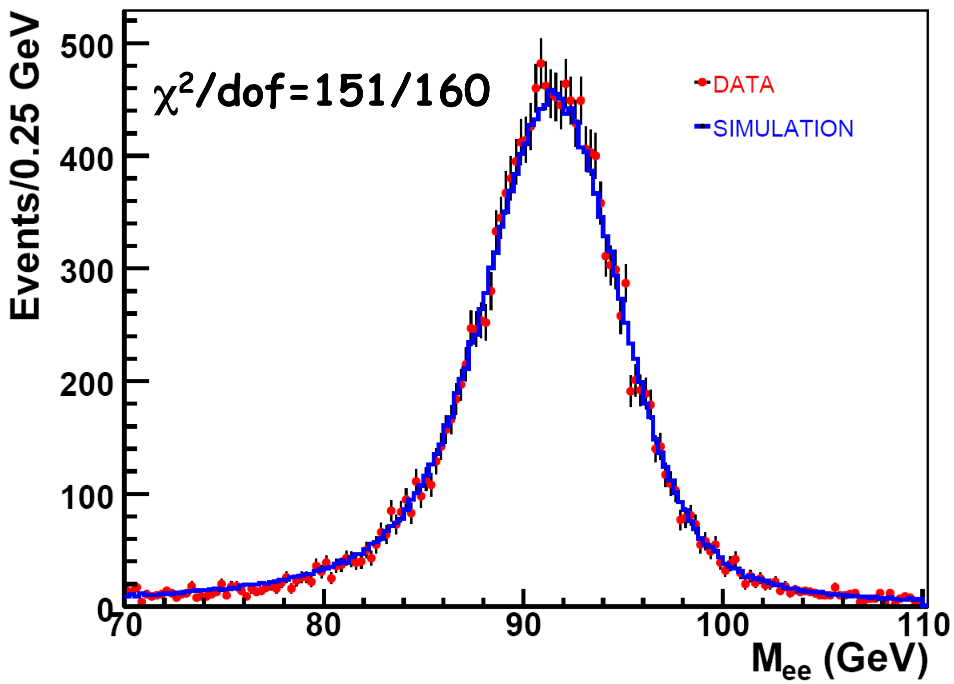
- Interfaced with latest MC event generators (ResBos+PHOTOS, see Jan Stark's talk)
- Detector simulation: Electron/Recoil system simulation, Correlations between electron and the recoil system
- Mass templates generation
- Central value blinded until the analysis was approved by D0
- Closure test done using GEANT MC simulation



Doing a blind analysis does not mean doing an analysis blindly...

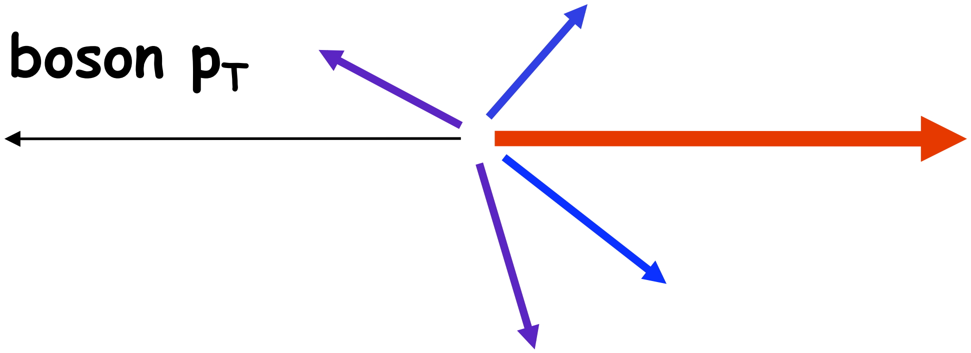
Electron simulation

- Electron energy scale and resolution parameters are determined using Z→ee collider data
- Dominant uncertainty on M_W is due to electron energy modeling (limited Z statistics)

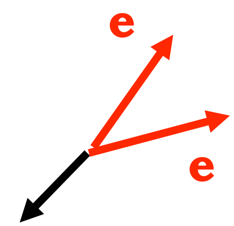


Recoil simulation

boson p_T

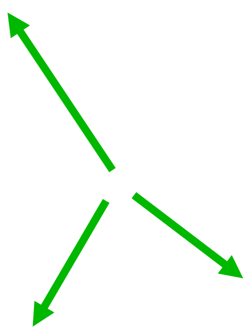


"Hard Recoil": quarks or gluons (recoiling against the boson) that were produced in the hard-scattering



Underlying event: energy content from additional interactions between spectator and sea quarks in the same ppbar collision

"Soft Recoil"



Energy content from additional ppbar collisions

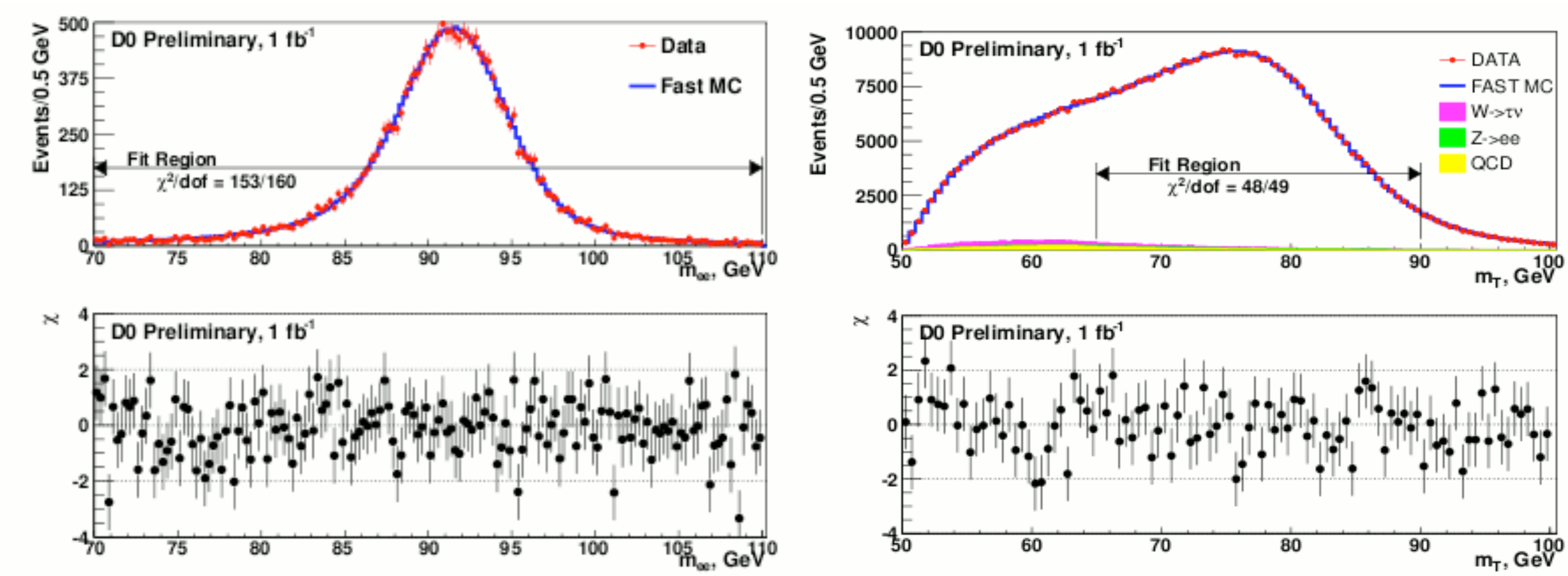
minbias and zerobias events

Final adjustment of free parameters in the recoil model is done **in situ** using $Z \to ee$ events

see Jan Stark's talk

Mass fits

Z invariant mass (M_{ee}), 18k **W transverse mass (M_T), 500k**

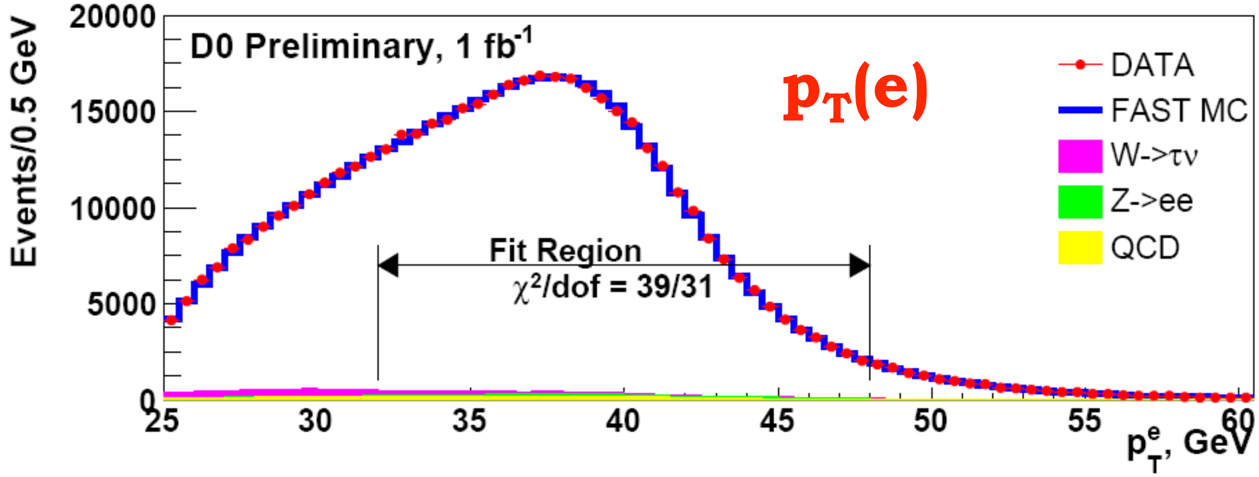


M_Z = 91.185 ± 0.033 (stat) GeV **M_W = 80.401 ± 0.023 (stat) GeV**

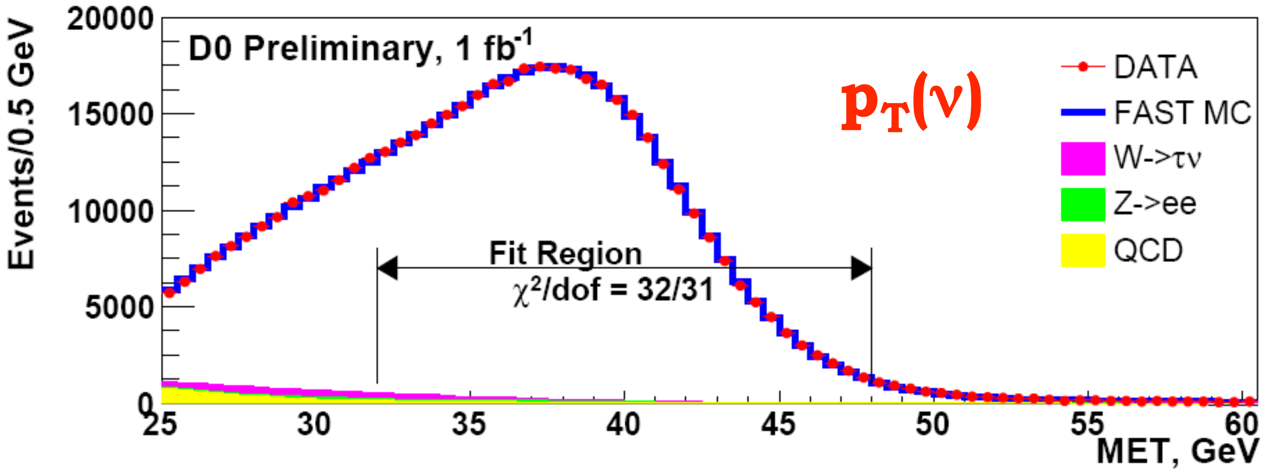
(WA M_Z=91.188 ± 0.002 GeV)

PRL 103, 141801 (2009)

Mass fits



M_W = 80.400 ± 0.027 (stat) GeV



M_W = 80.402 ± 0.023 (stat) GeV

Uncertainties

Source	$\sigma(m_W)$ MeV m_T	p_T^e	$\not{E}_T$
Electron energy calibration	34	34	34
Electron resolution model	2	2	3
Electron energy offset	4	6	7
Electron energy loss model	4	4	4
Recoil model	6	12	20
Electron efficiencies	5	6	5
Backgrounds	2	5	4
Experimental Subtotal	35	37	41
PDF	9	11	14
QED	7	7	9
Boson p_T	2	5	2
Production Subtotal	12	14	17
Total Systematic	37	40	44
Statistical	23	27	23
Total	44	48	50

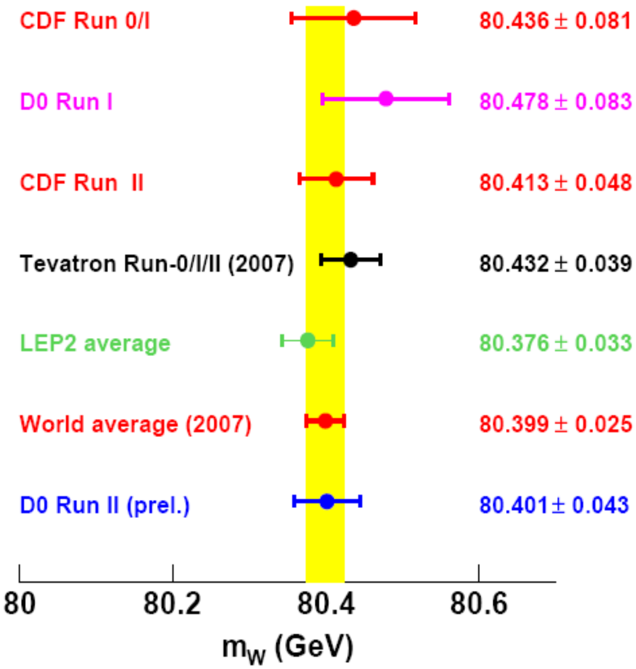
W boson mass

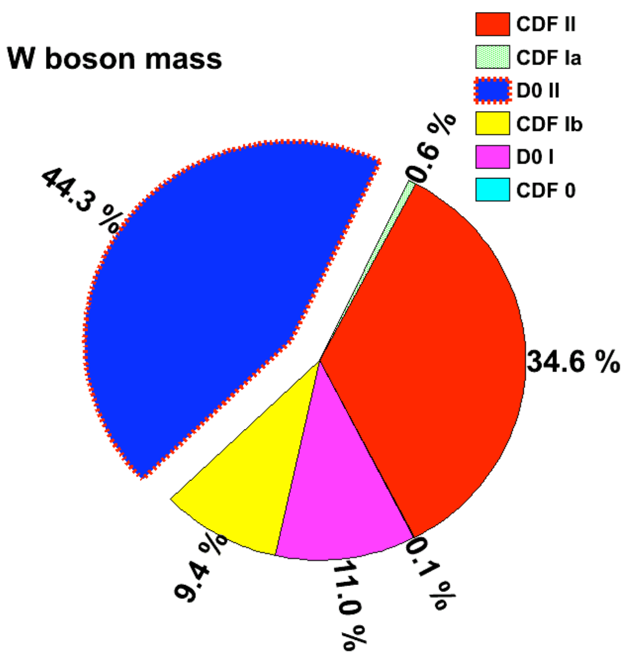
arXiv: 0908.1374

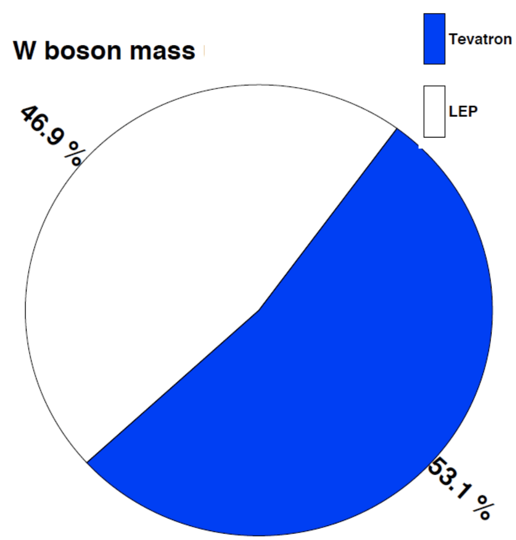
- Use BLUE method to combine three results

  M_W=80.401 ± 0.043 GeV

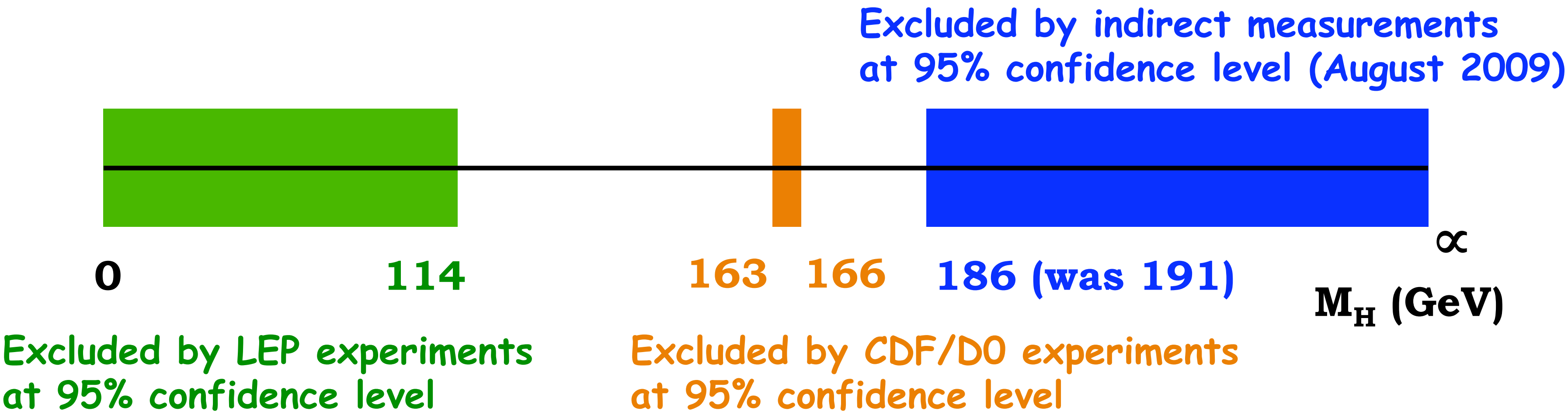
- Most precise measurement from one single experiment to date
- Tevatron combined uncertainty to be smaller than the LEP combined uncertainty
- World average uncertainty reduced by ~10% to 23 MeV







Indirect constraints on M_H (w/ D0's M_W result)



$$M_H = 87^{+35}_{-26}\,\mathrm{GeV}$$

If ΔM_W = 15 MeV (23 MeV now), Δm_{top} = 1 GeV (1.3 GeV now) and M_W=80.400 GeV, M_{top}=172.5 GeV, then

M_H < 117 GeV @ 95% C.L.

(P. Renton, ICHEP 2008)