Measurement of W boson mass at DØ

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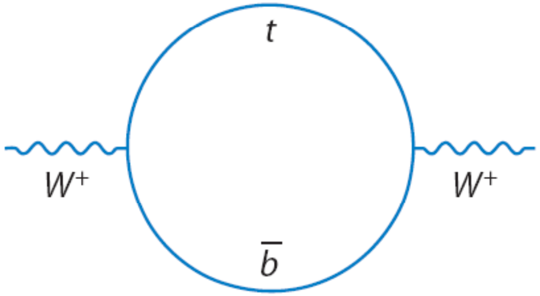
Thank you!

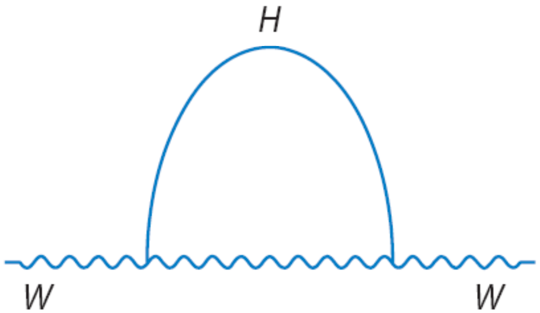
- **An award for the whole DØ collaboration**
  - High precision measurement, needs excellent understanding of the DØ detector
  - Thought it was hopeless to do the DØ W mass measurement in Run II before 2005
  - It took many people many years' hard work to make this measurement possible
- **Special thanks to:**
  - The W mass working group
  - The electroweak physics group
  - The calorimeter operation and calibration groups
  - Mentors and others that I have worked with
  - University of Maryland (Sarah Eno, Nick Hadley, Marco Verzocchi) and Stony Brook (Paul Grannis, John Hobbs, Bob McCarthy)

W boson mass

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



$\Delta r \propto M_t^2$



$\Delta r \propto \log M_H$

W boson mass

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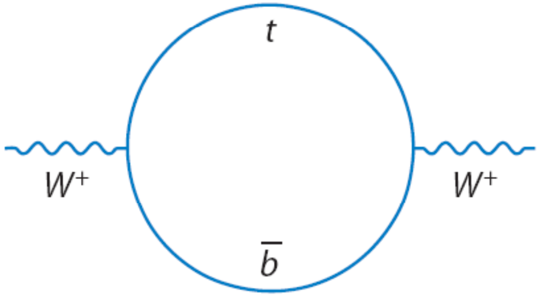
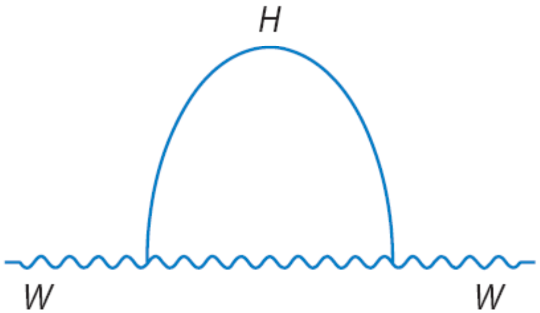
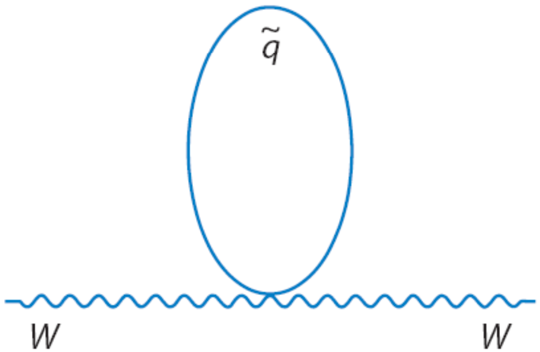
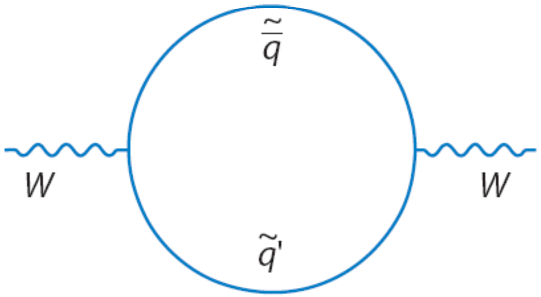




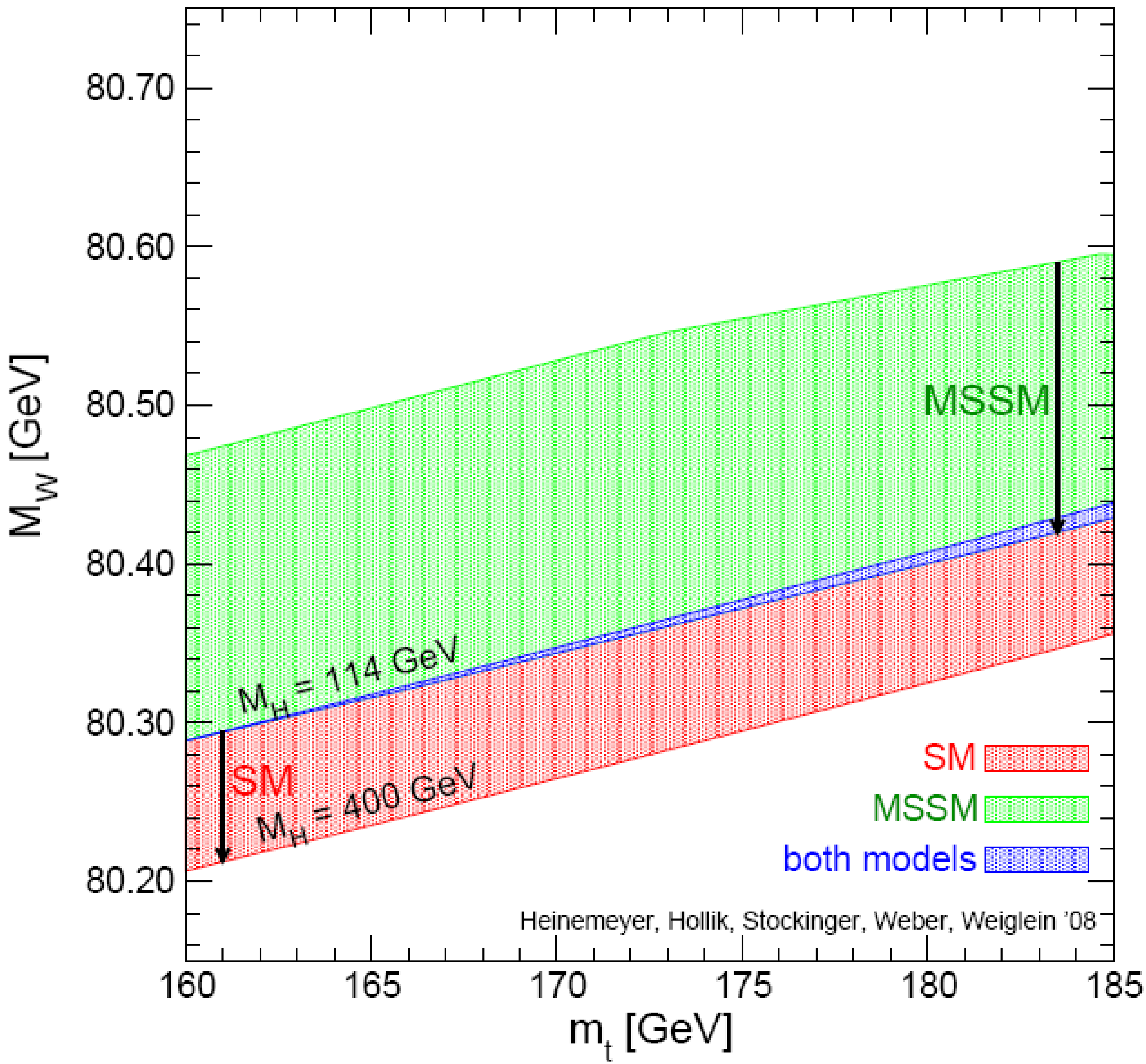
$\Delta r \propto M_t^2$ $\Delta r \propto \log M_H$



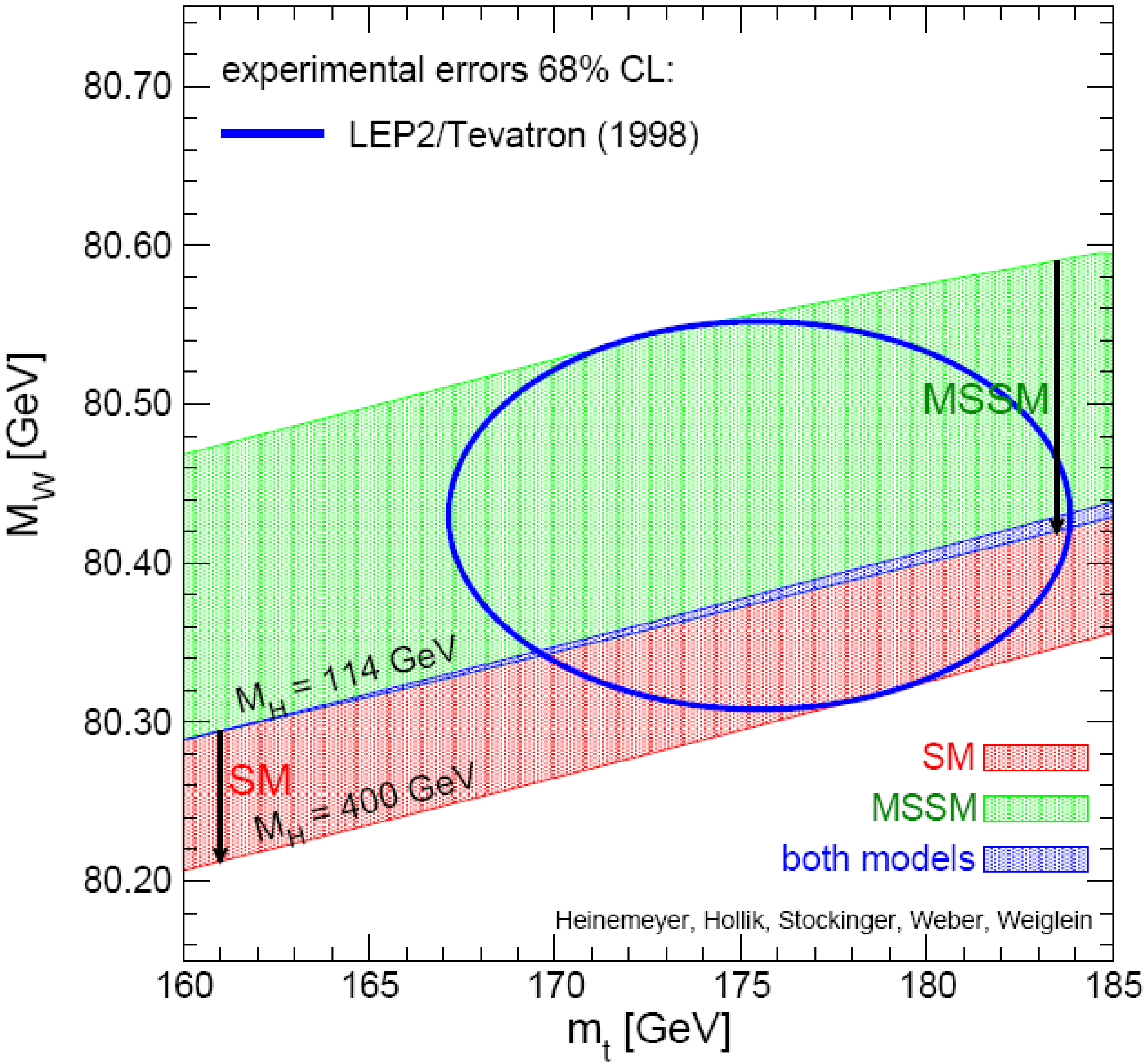


M_W can be increased by up to 250 MeV in MSSM

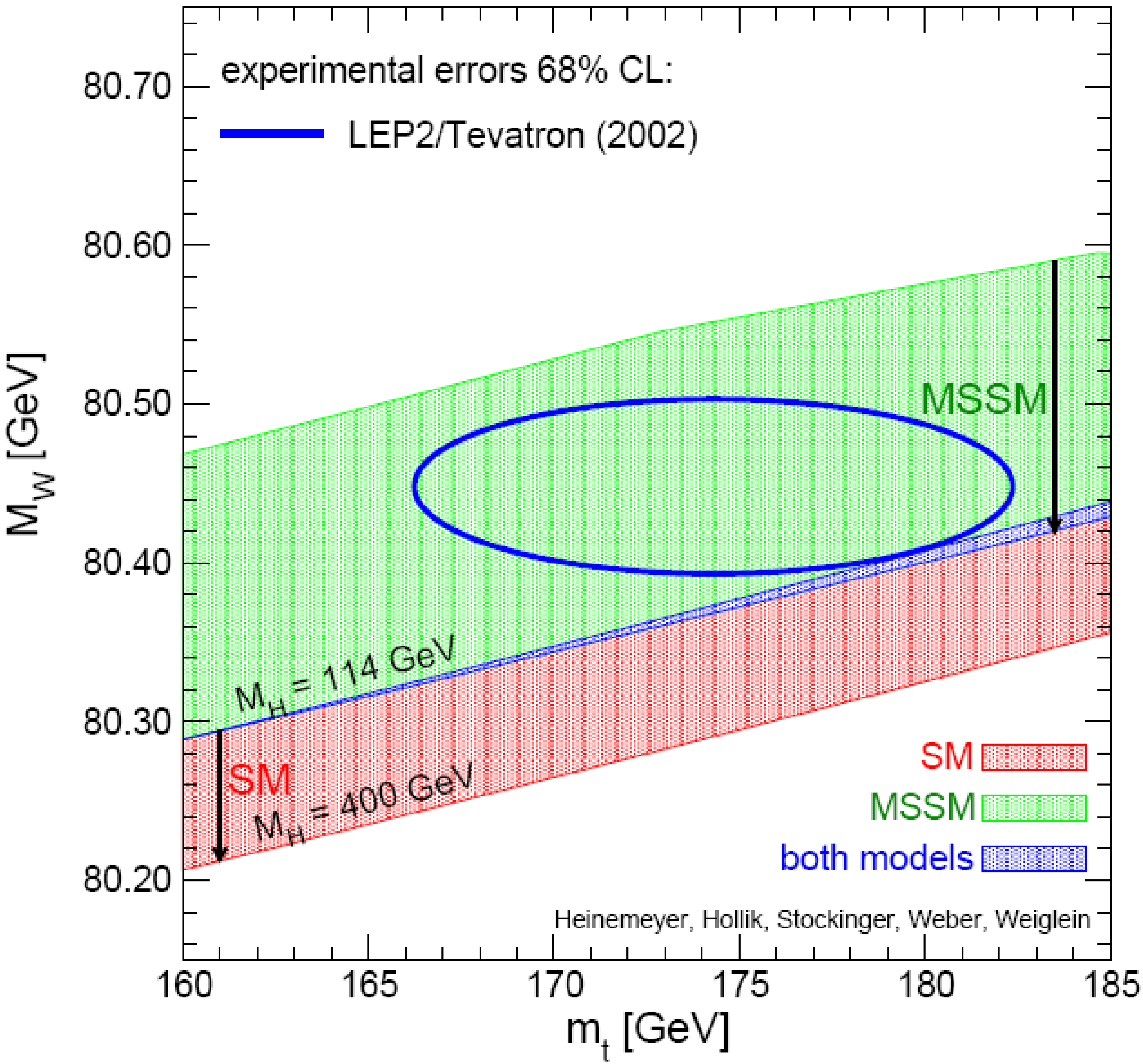
Higgs mass constraints



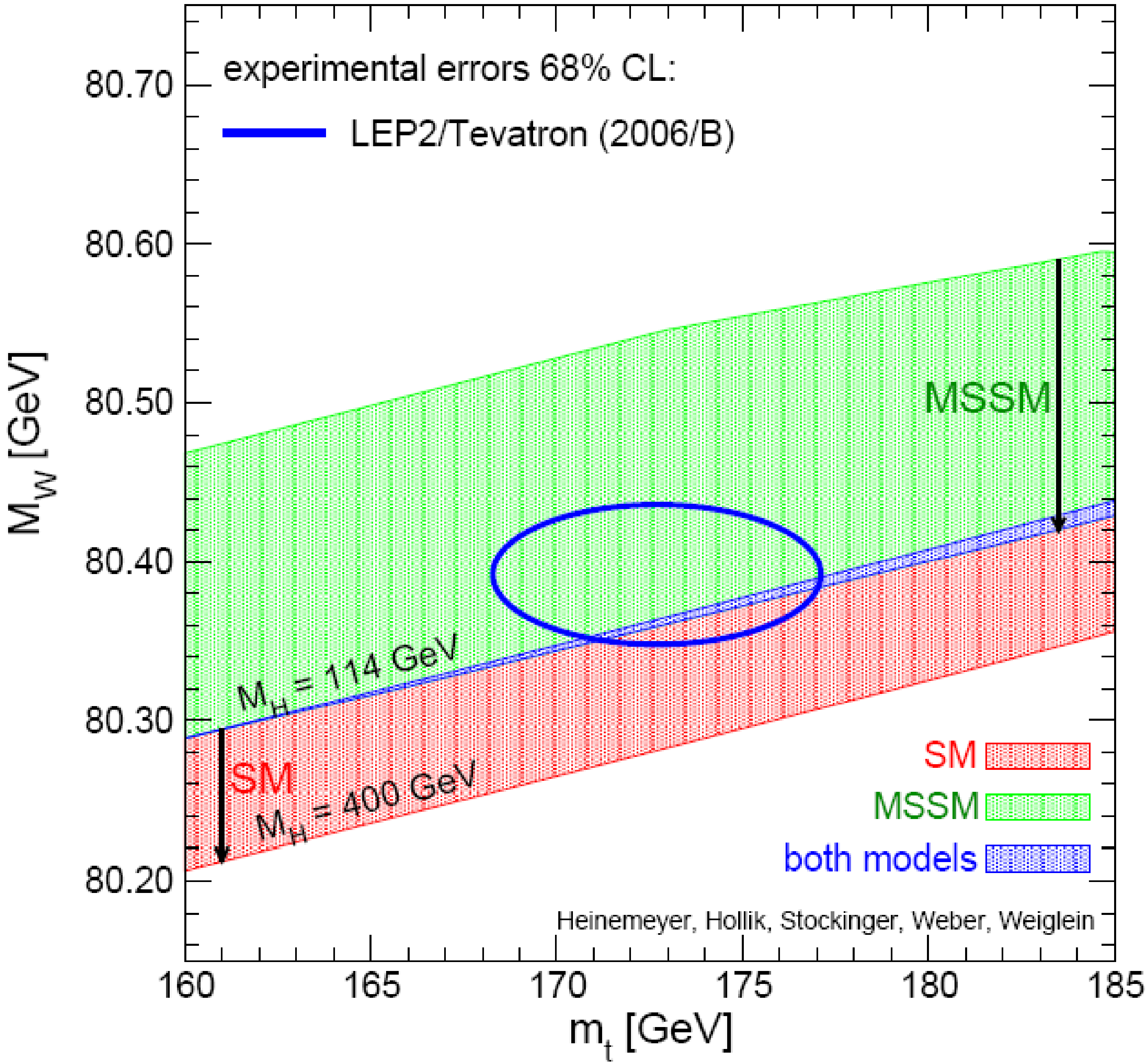
Higgs mass constraints (1998)



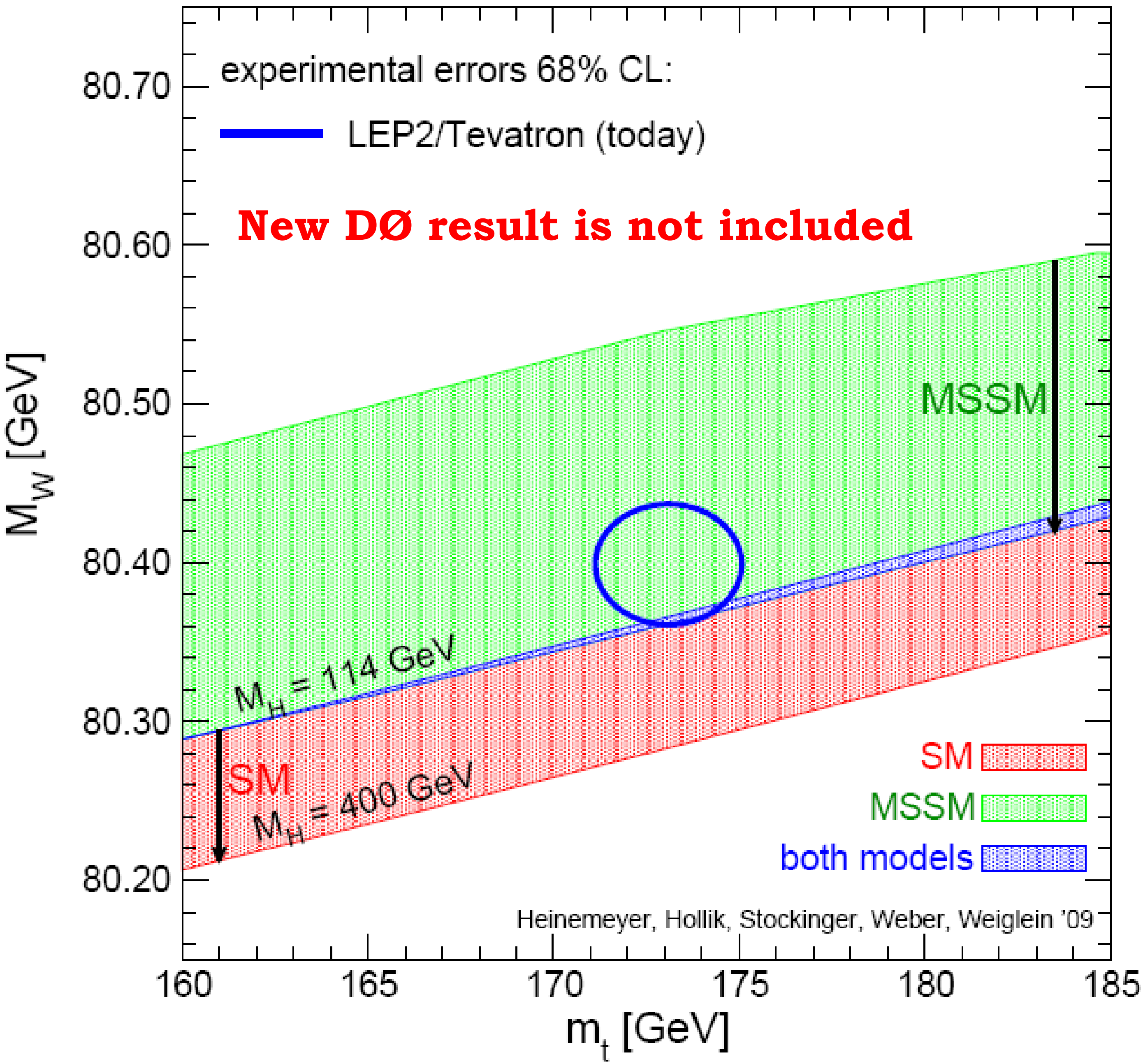
Higgs mass constraints (2002)



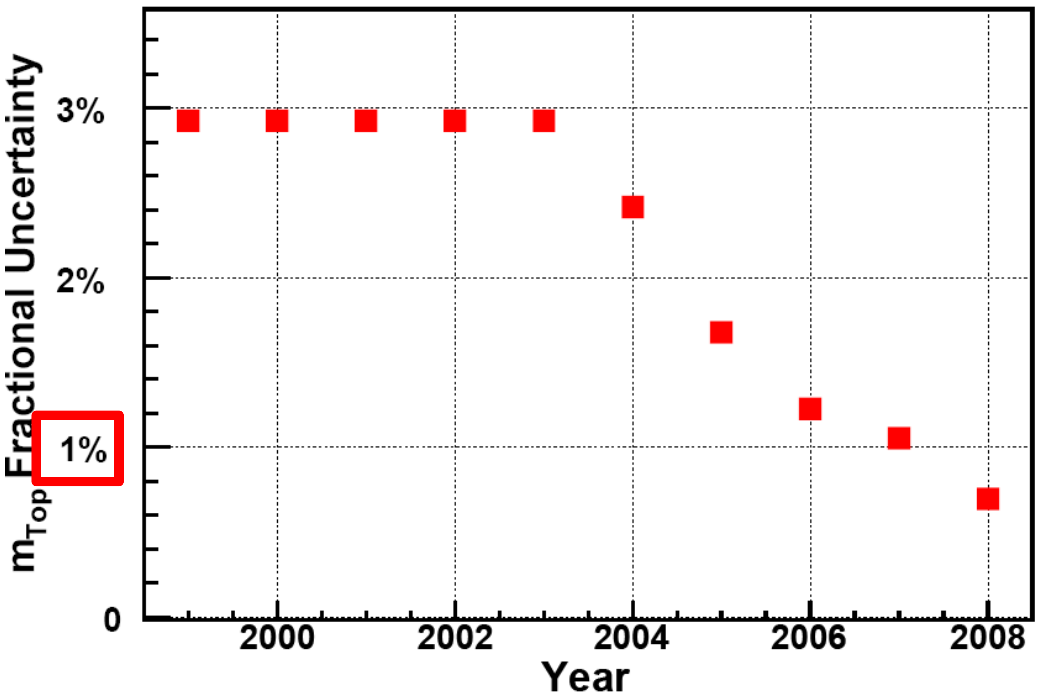
Higgs mass constraints (2006)

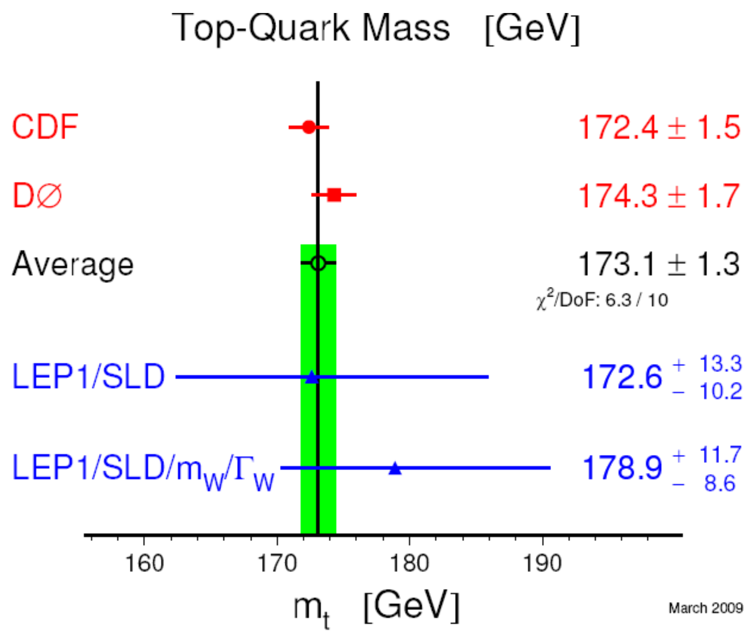


Higgs mass constraints (2009)

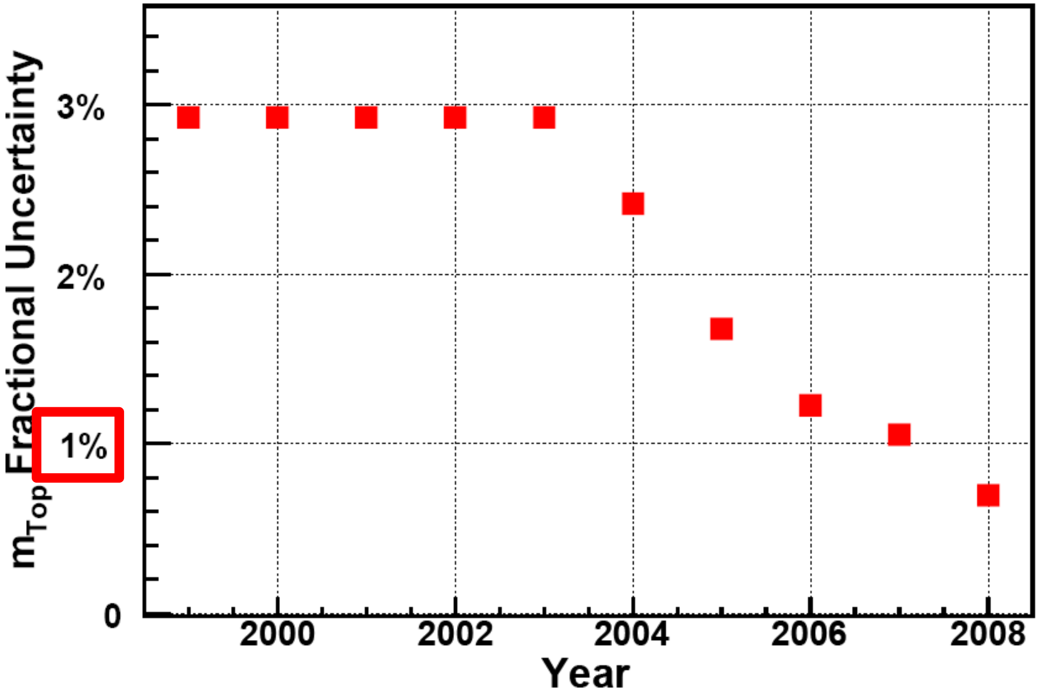


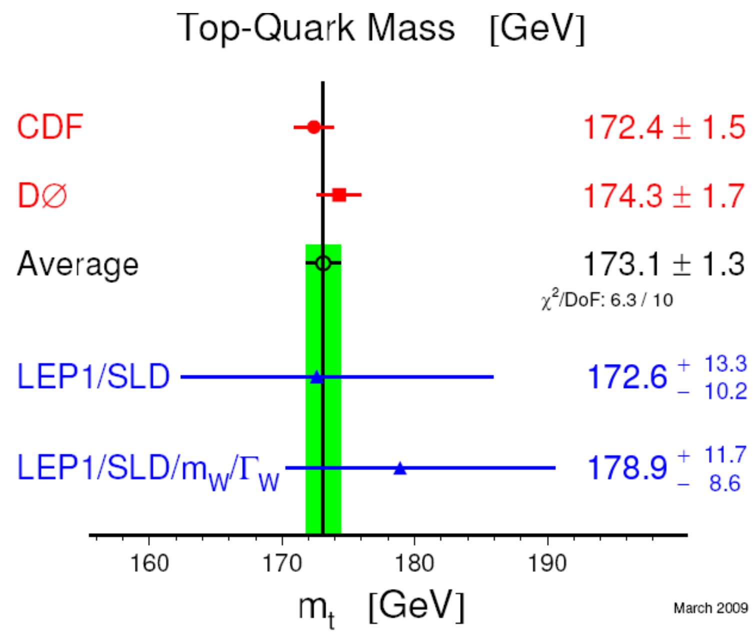
M_W and M_{top} uncertainties

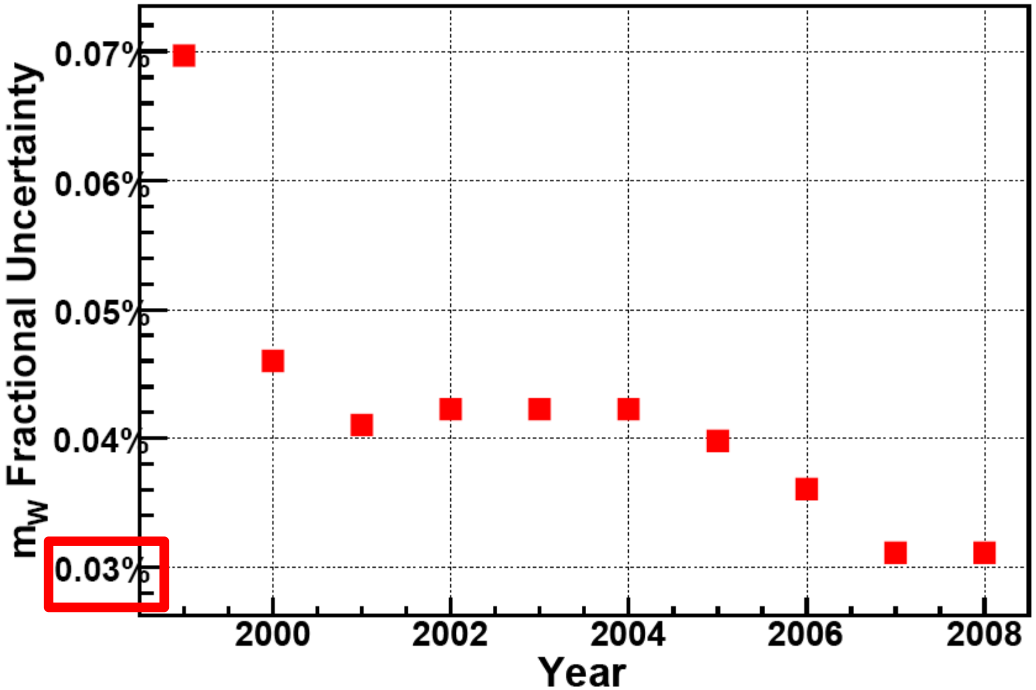


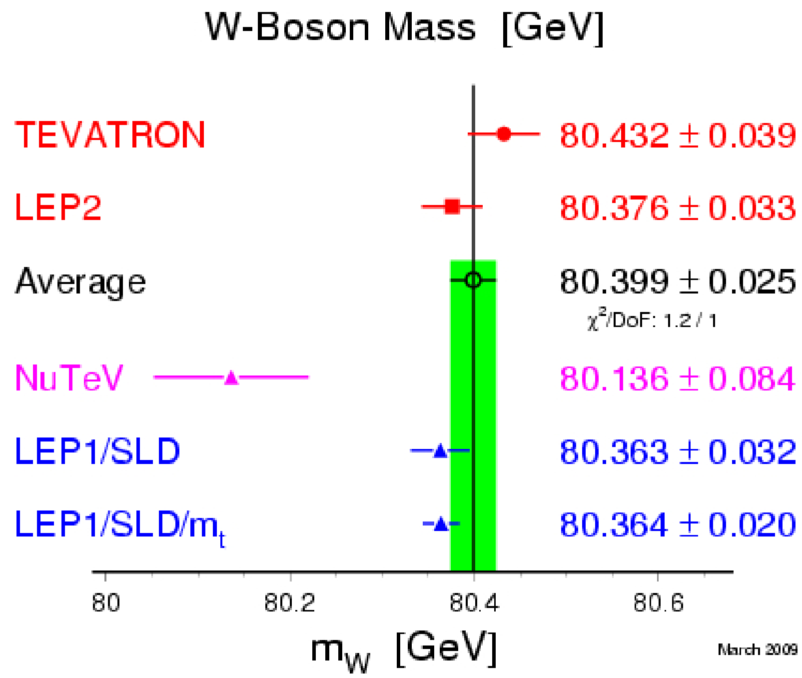


M_W and M_{top} uncertainties

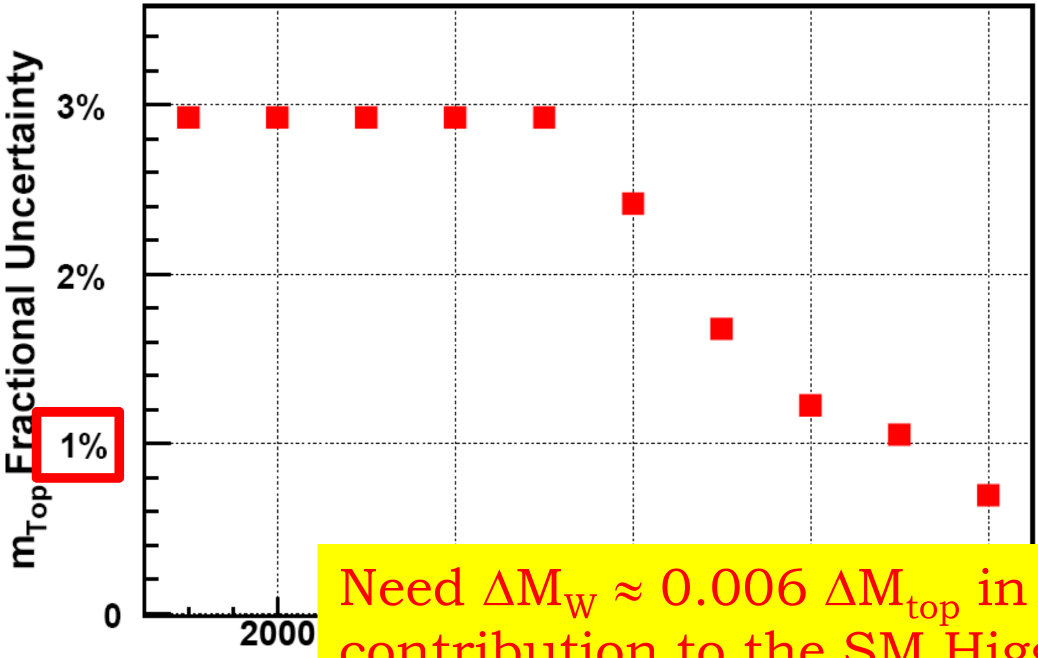


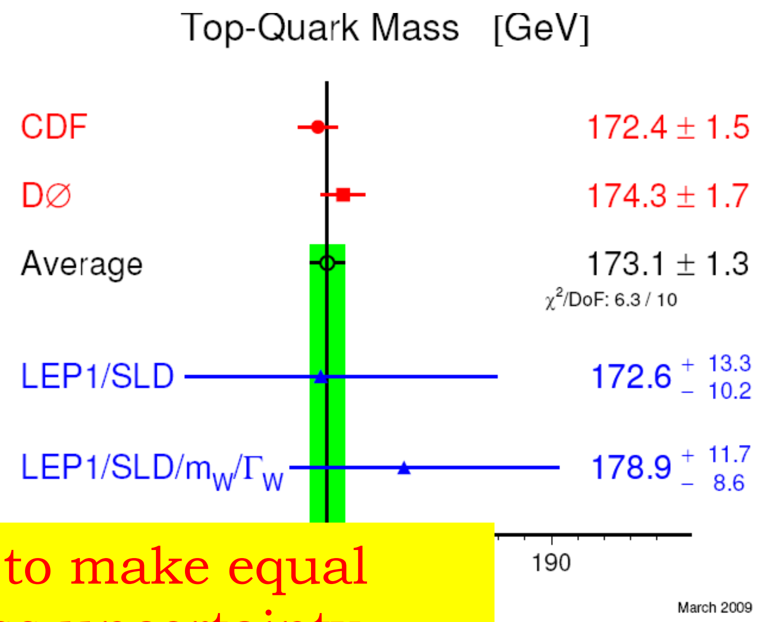






M_W and M_{top} uncertainties

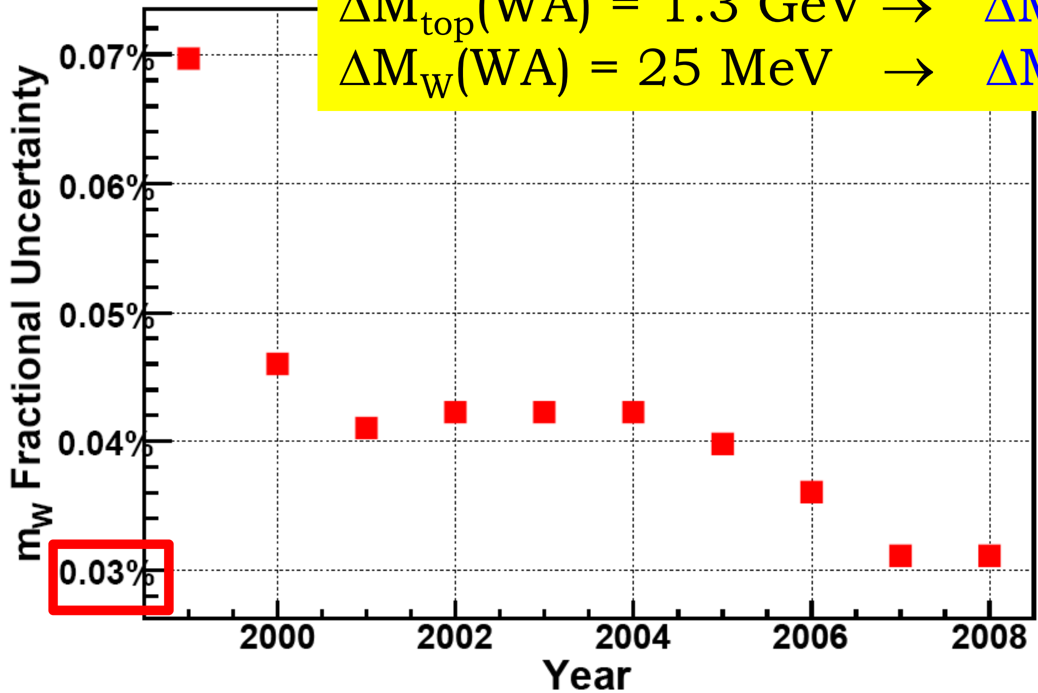


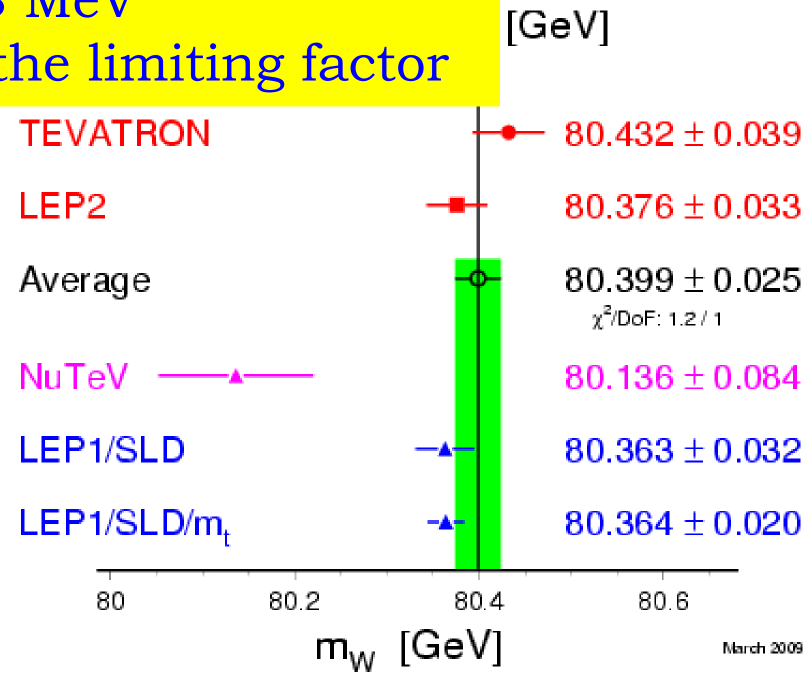


Need $\Delta M_W \approx 0.006\ \Delta M_{top}$ in order to make equal contribution to the SM Higgs mass uncertainty

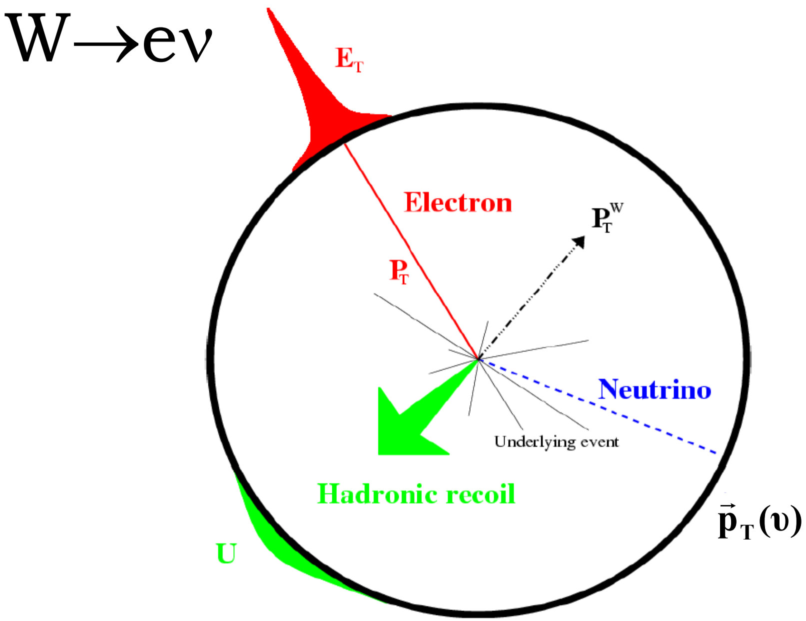
ΔM_{top}(WA) = 1.3 GeV $\rightarrow$ ΔM_W = 8 MeV

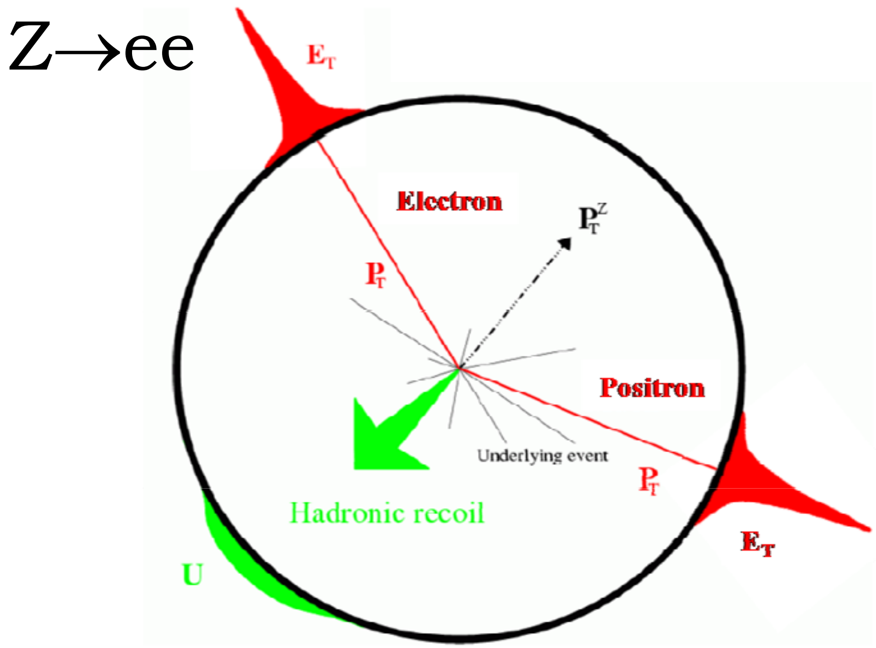
ΔM_W(WA) = 25 MeV $\rightarrow$ ΔM_W is the limiting factor





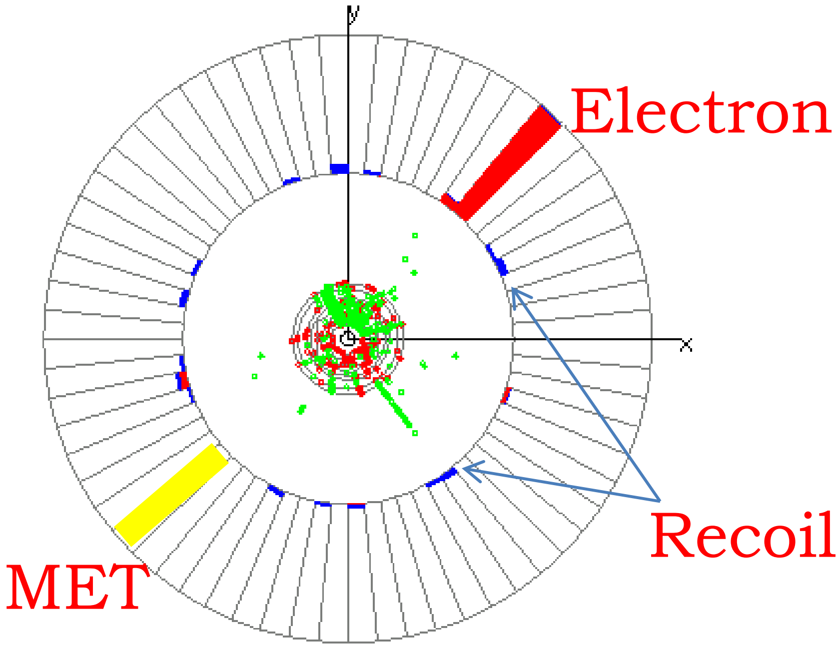
Measurement strategy

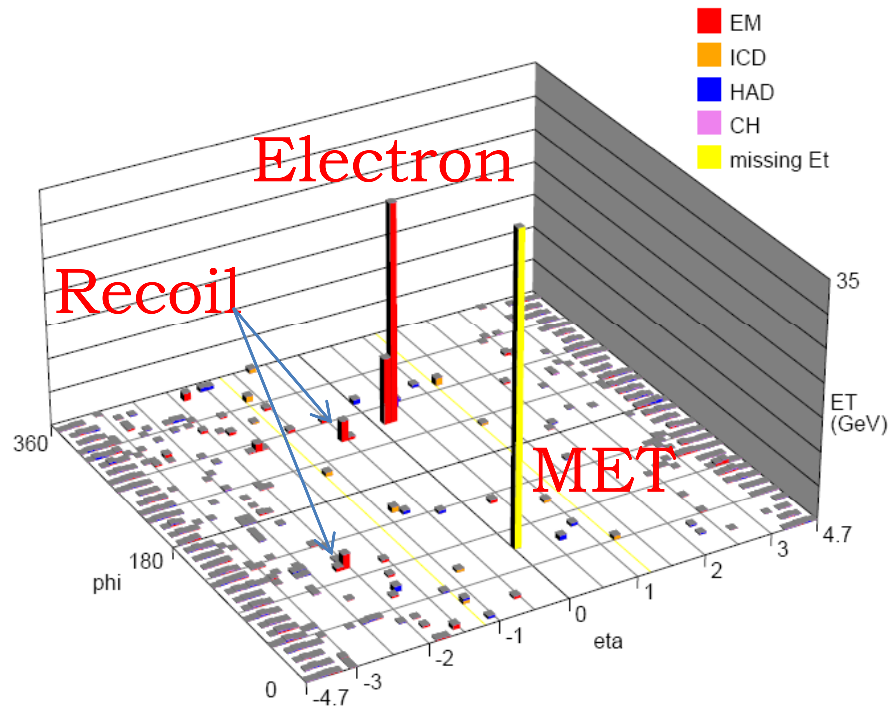




- Three observables: $p_T(e)$, $p_T(\nu)$ (inferred from missing transverse energy), transverse mass $M_T^2=(E_{Te}+E_{T\nu})^2-|\vec{p}_{Te}+\vec{p}_{T\nu}|^2$
- Develop a parameterized MC simulation with parameters determined from the collider data (mainly Z→ee events)
- Generate MC templates with different input W mass values, 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

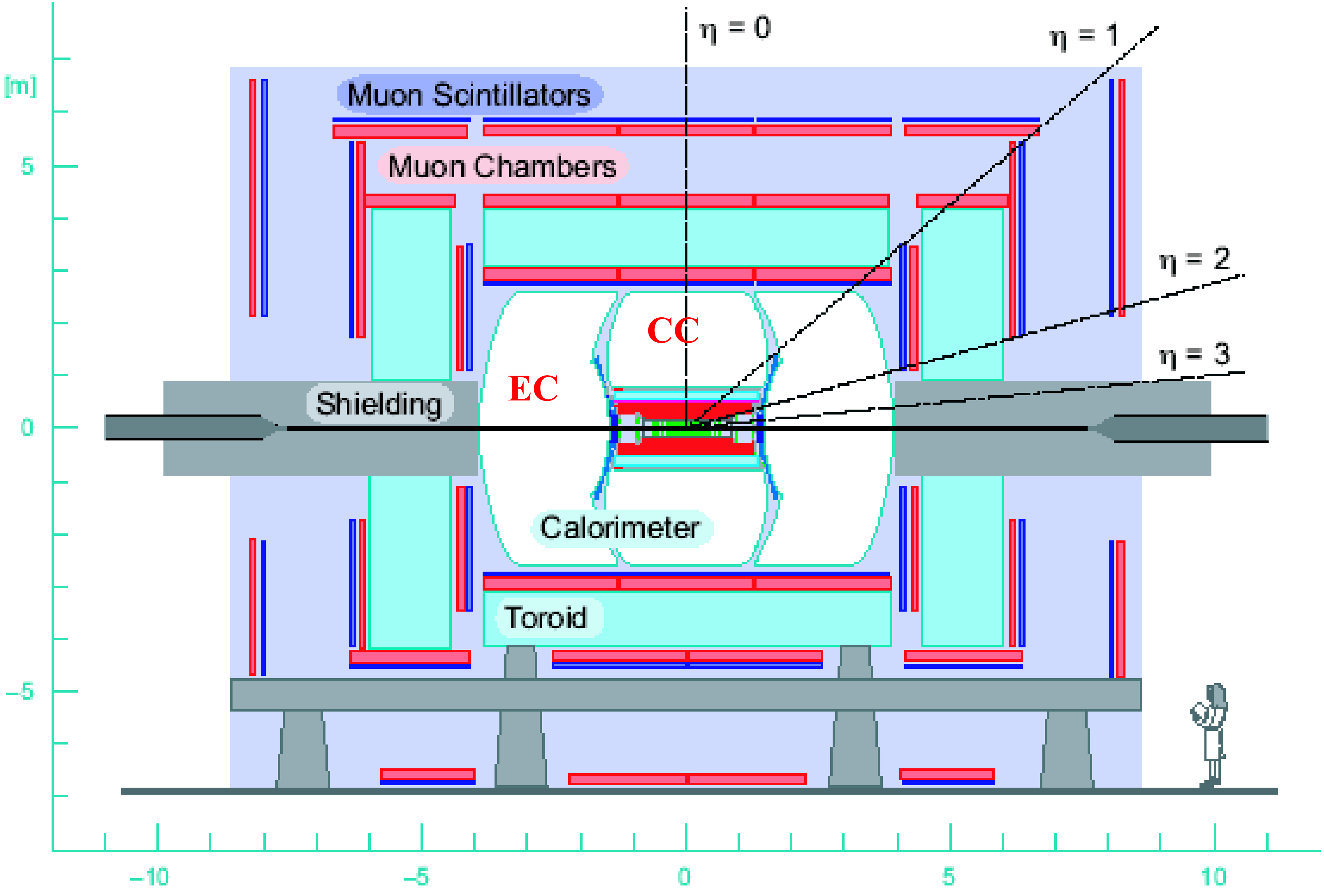
W→eν candidate





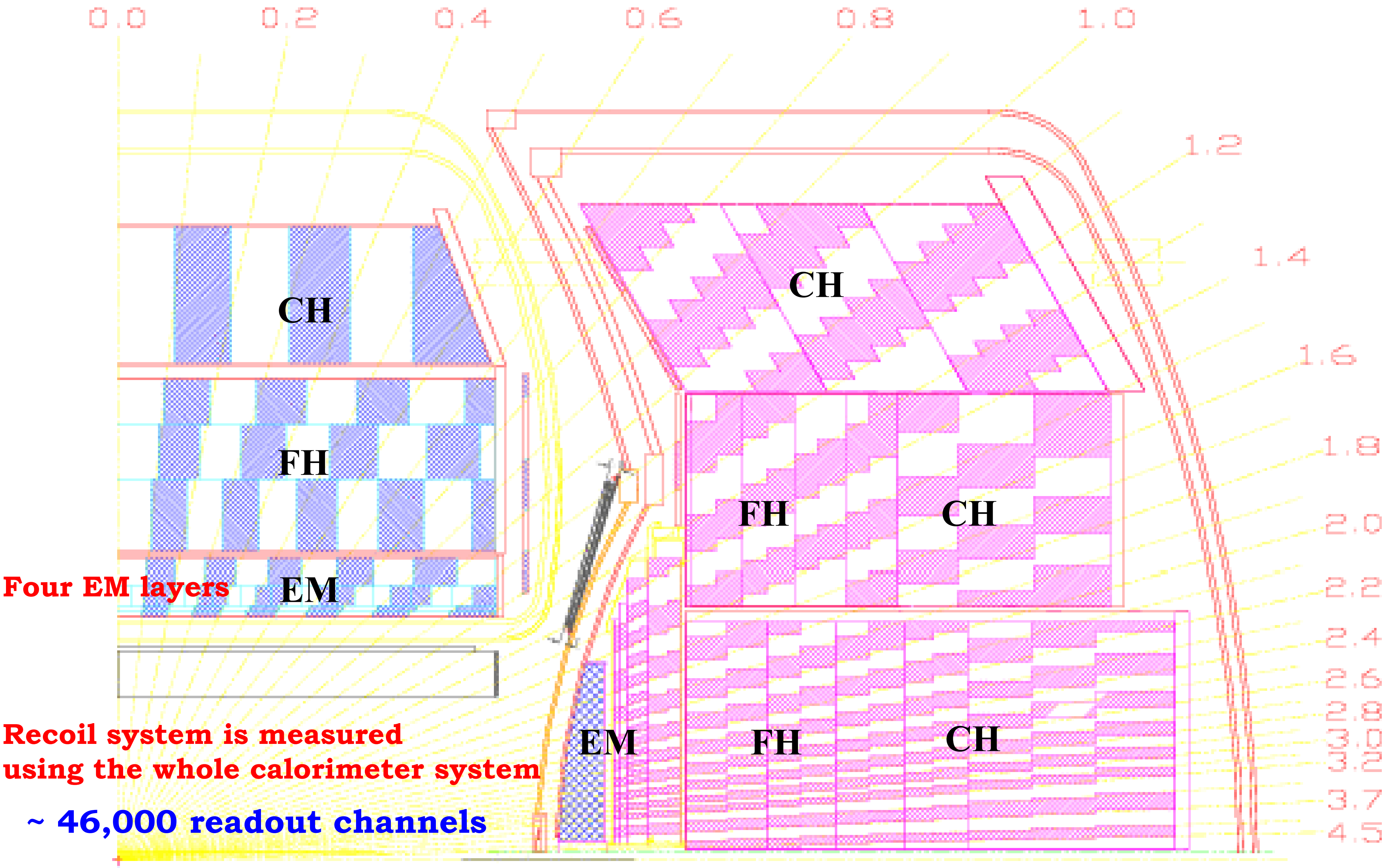
- Crucial to understand the calorimeter response to the electron (~40 GeV) and the recoil system (~ 5 GeV)
- To measure M_W with an uncertainty of 50 MeV:
  - Need to understand the electron energy scale to 0.05%
  - Need to understand the recoil system response to <1%

DØ detector



η = 0
η = 1
η = 2
η = 3
[m]
Muon Scintillators
Muon Chambers
CC
EC
Shielding
Calorimeter
Toroid
5
0
–5
–10
–5
0
5
10

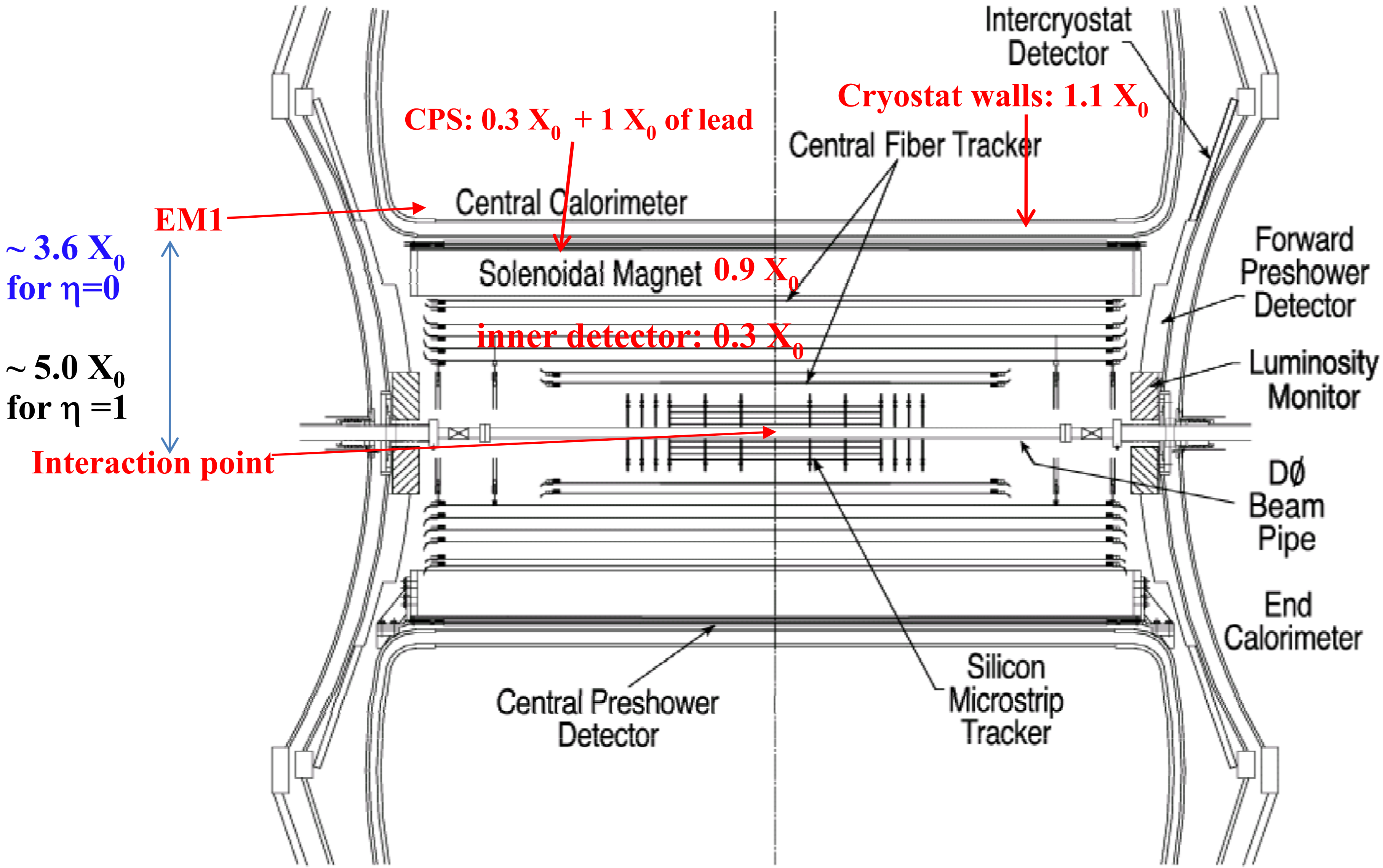
Uranium-LAr calorimeters



Recoil system is measured using the whole calorimeter system

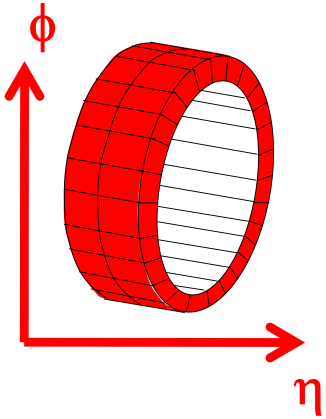
~ 46,000 readout channels

Material in front of the calorimeter



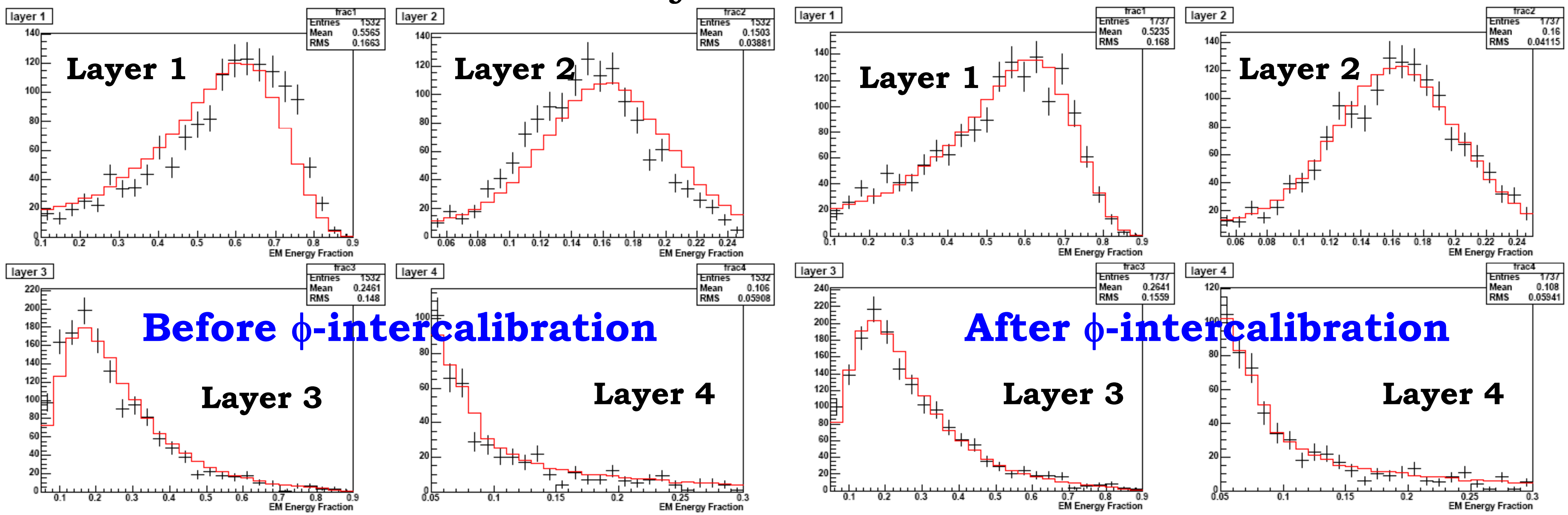
Calorimeter calibration (I)

- 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



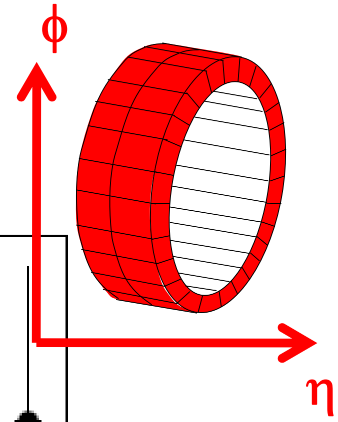
Red: average

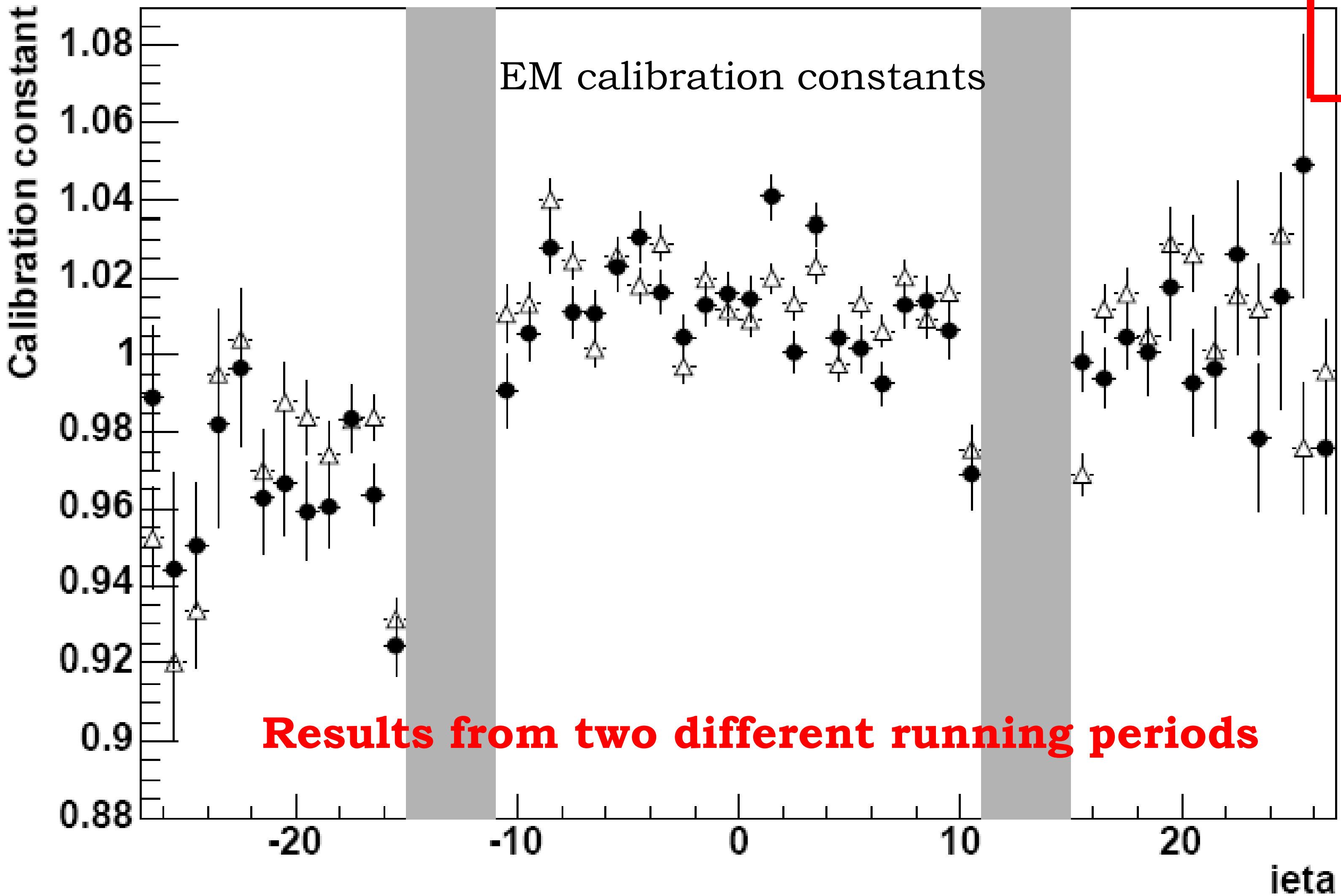
Black: one cal tower



Calorimeter calibration (II)

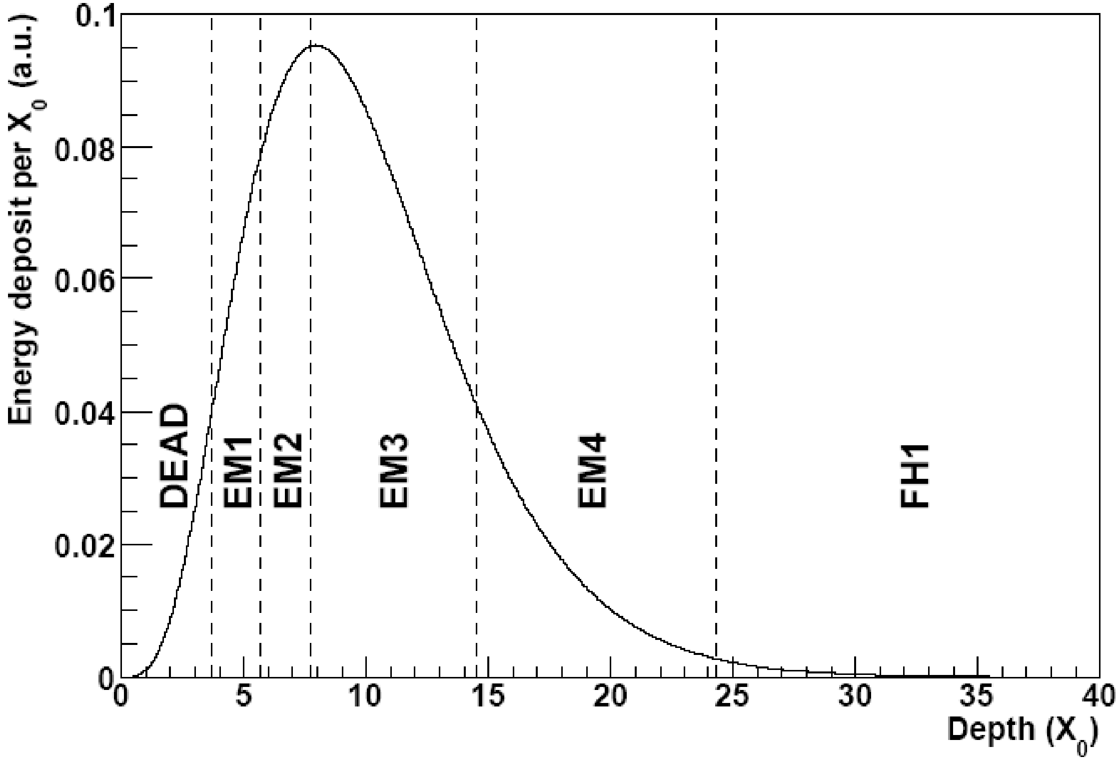
- **η-intercalibration for both EM and HAD calorimeters**
  - EM: Use Z→ee events
  - HAD: Use γ+jet and di-jet events



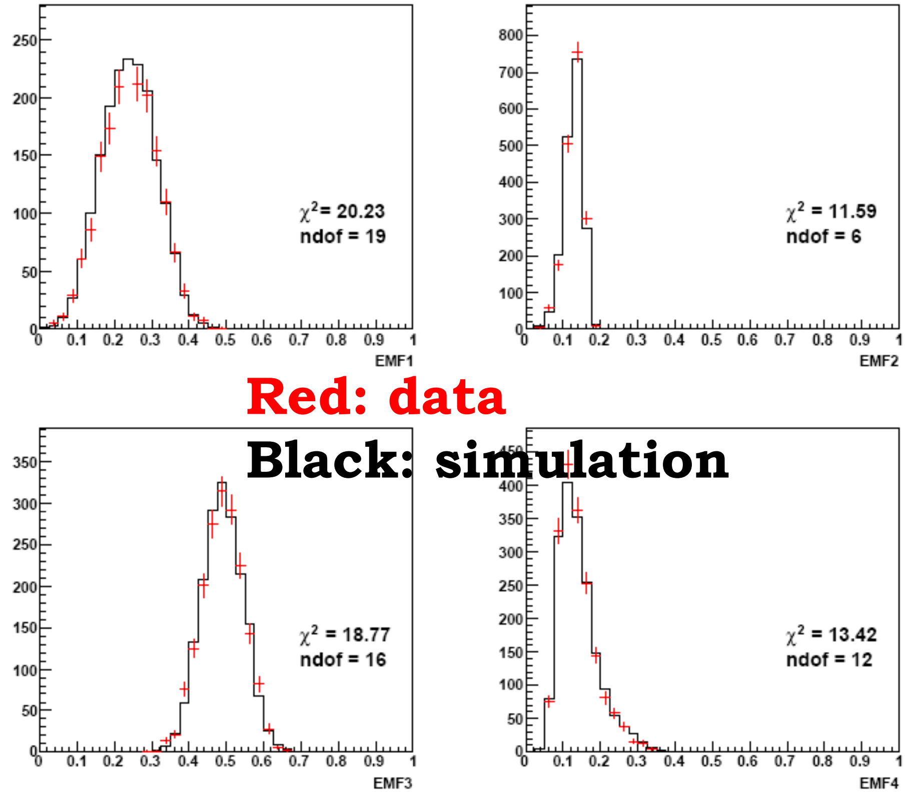


Calorimeter calibration (III)

- Electrons lose ~15% of energy in front of the calorimeter
- **Amount of dead material determined 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: $(0.16 \pm 0.01)\ X_0$**



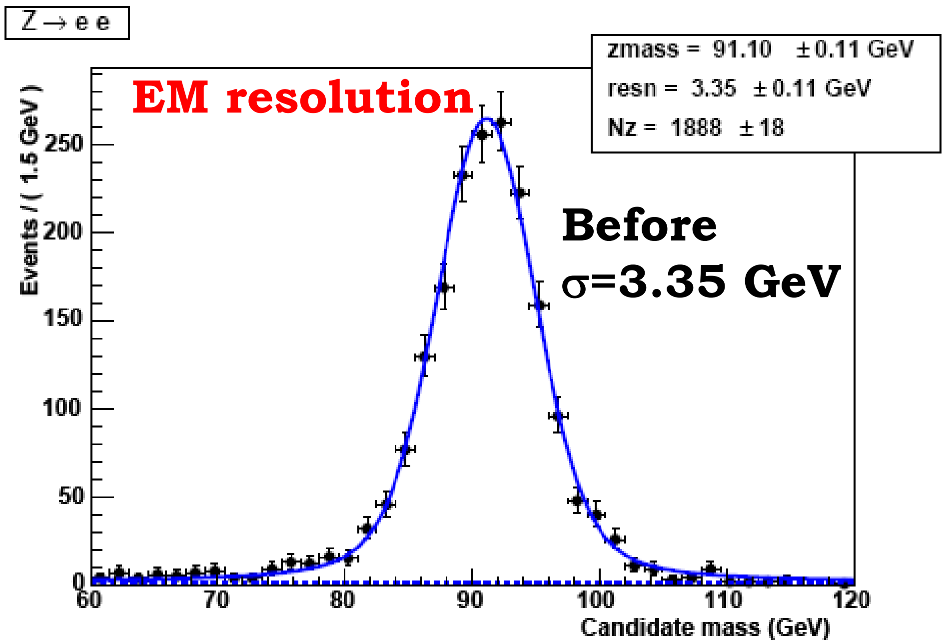
Electron EMFs

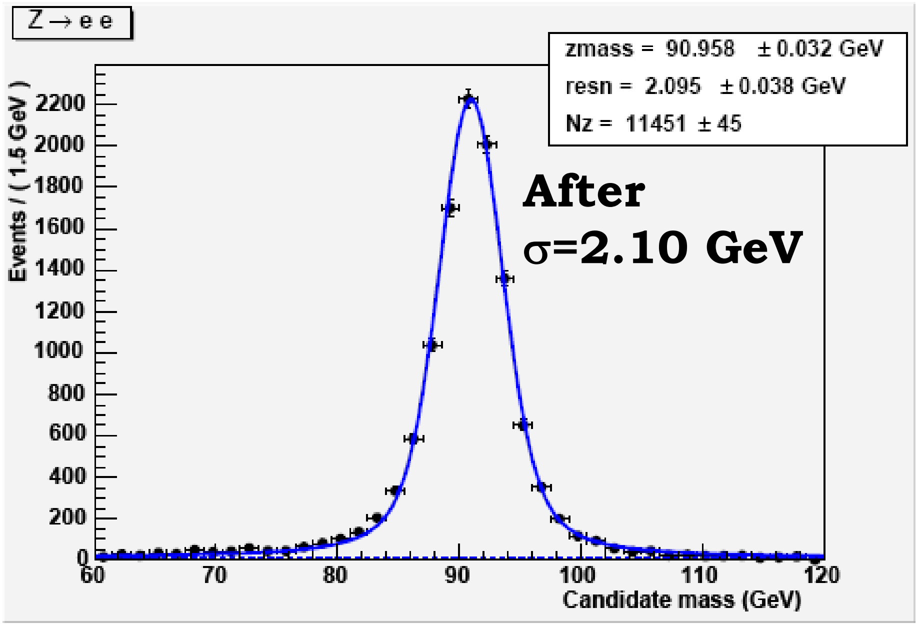


Red: data

Black: simulation

Calibration results





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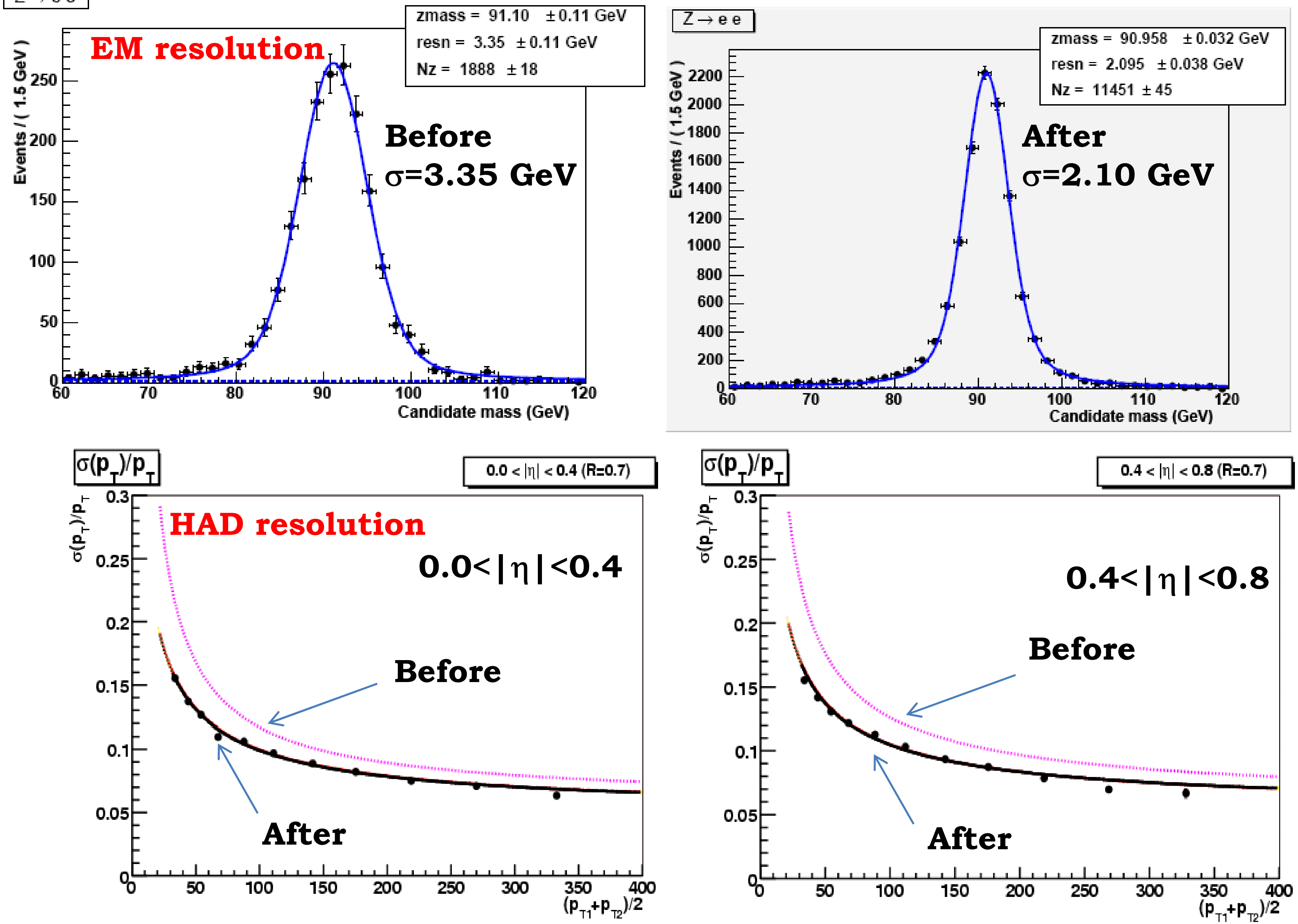


Parameterized MC simulation

- Interfaced with latest MC event generators (ResBos+Photos)
- Detector simulation: Electron simulation, Recoil system simulation, Correlations between electron and the recoil system
- Mass templates generation
- Make sure we understand Z events before we look at W events

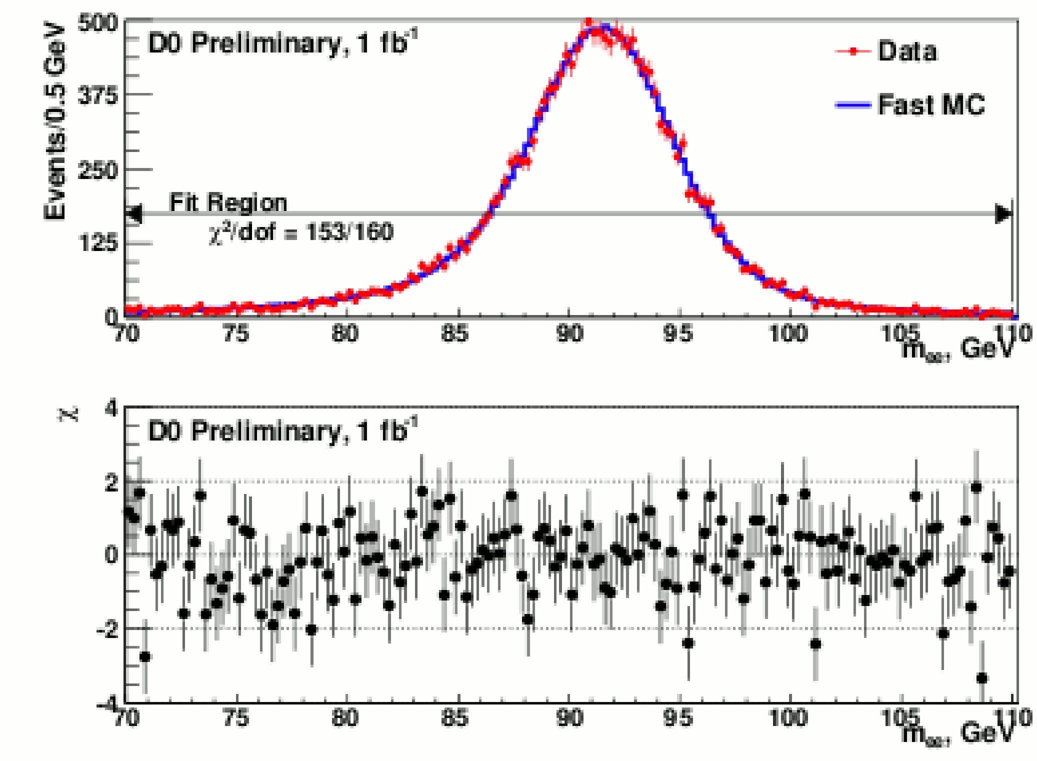
Parameterized MC simulation

- Interfaced with latest MC event generators (ResBos+Photos)
- Detector simulation: Electron simulation, Recoil system simulation, Correlations between electron and the recoil system
- Mass templates generation
- Make sure we understand Z events before we look at W events
- Central value blinded until the analysis was approved by D0
- Closure test done using full MC simulation

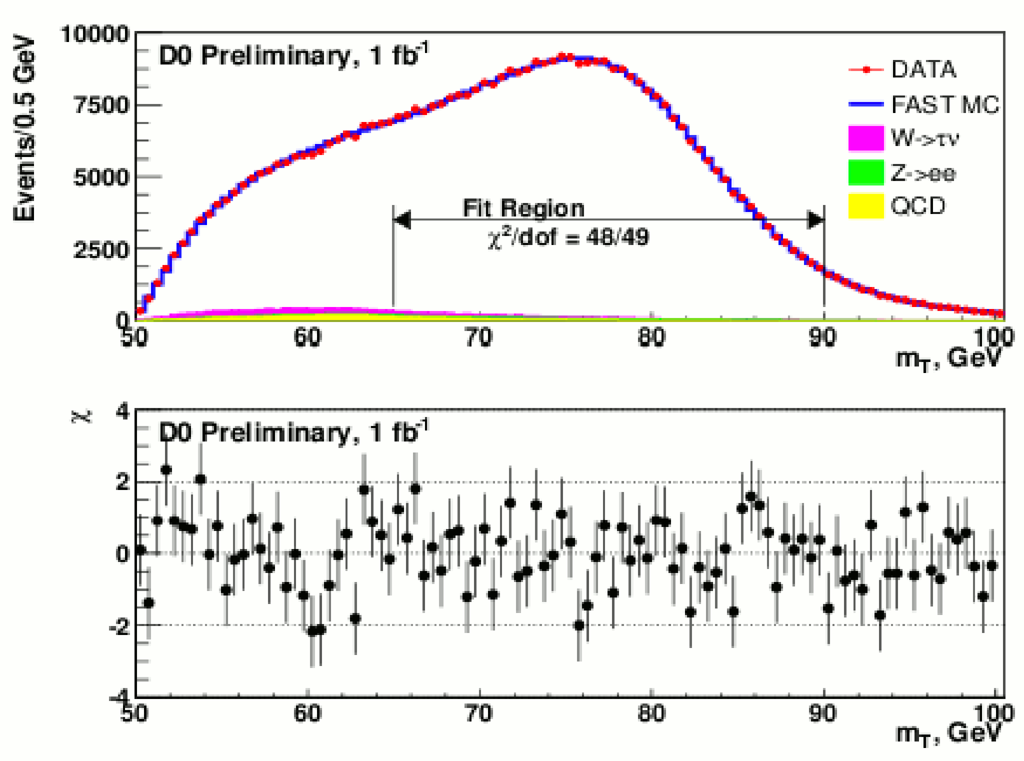
Doing a blind analysis does not mean doing an analysis blindly…

Mass fits

Z invariant mass (M_{ee}), 18k



W transverse mass (M_T), 500k

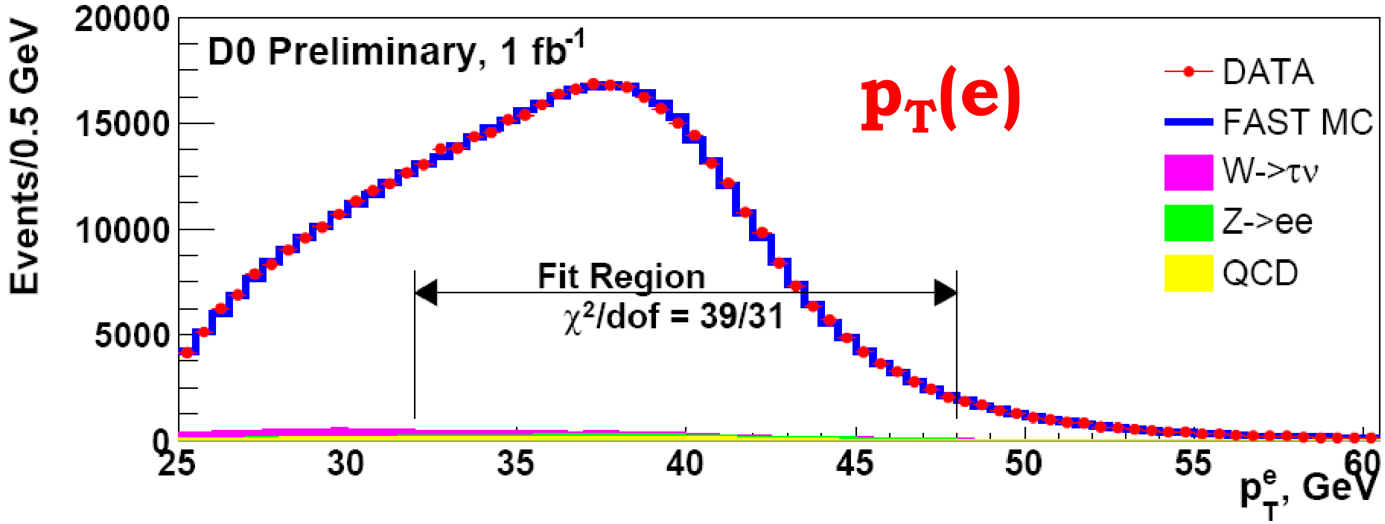


M_Z = 91.185 ± 0.033 (stat) GeV

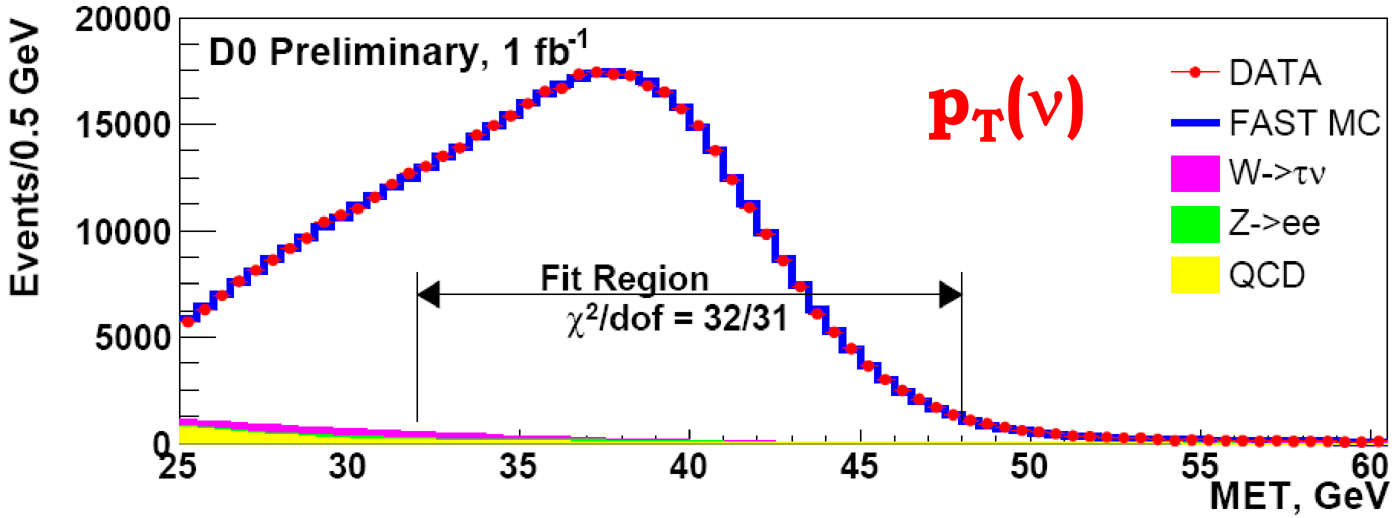
M_W = 80.401 ± 0.023 (stat) GeV

(WA M_Z=91.188 ± 0.002 GeV)

Mass fits



M_W = 80.400 ± 0.027 (stat) GeV



M_W = 80.402 ± 0.023 (stat) GeV

Uncertainties

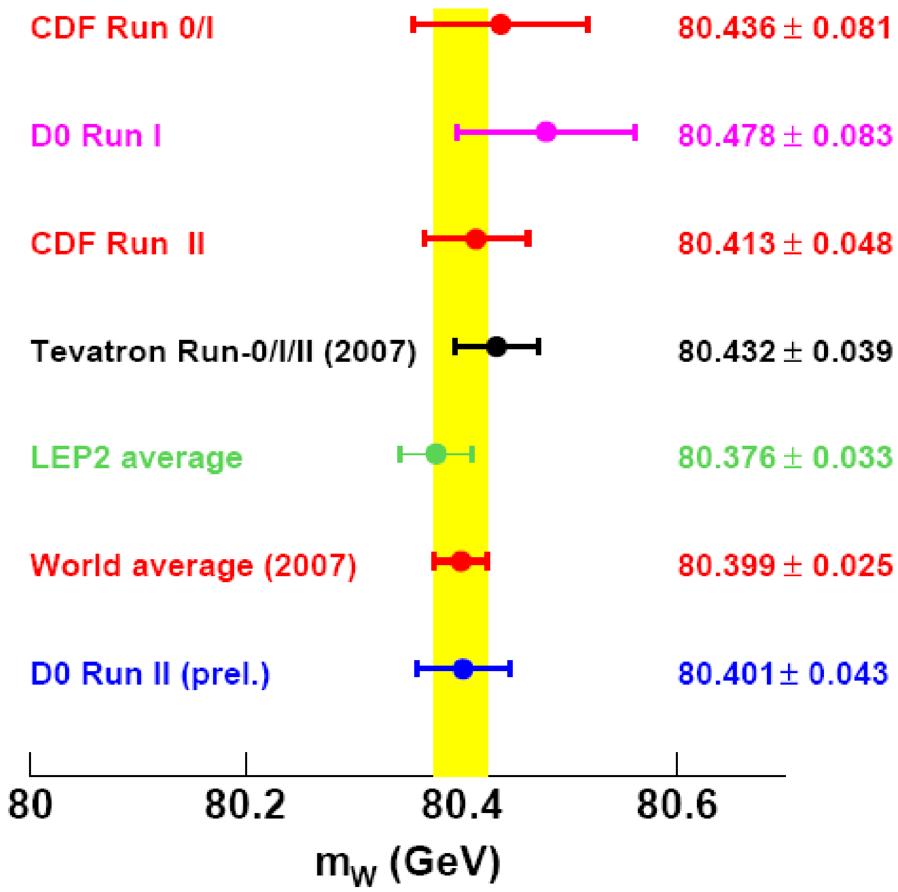
Source	$\sigma(m_W)$ MeV m_T	p_T^e	$\not{E}_T$
Electron energy calibration	34	34	34
Electron resolution model	2	2	3
Electron energy offset	4	6	7
Electron energy loss model	4	4	4
Recoil model	6	12	20
Electron efficiencies	5	6	5
Backgrounds	2	5	4
Experimental Subtotal	35	37	41
PDF	9	11	14
QED	7	7	9
Boson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

- Use BLUE method to combine three results

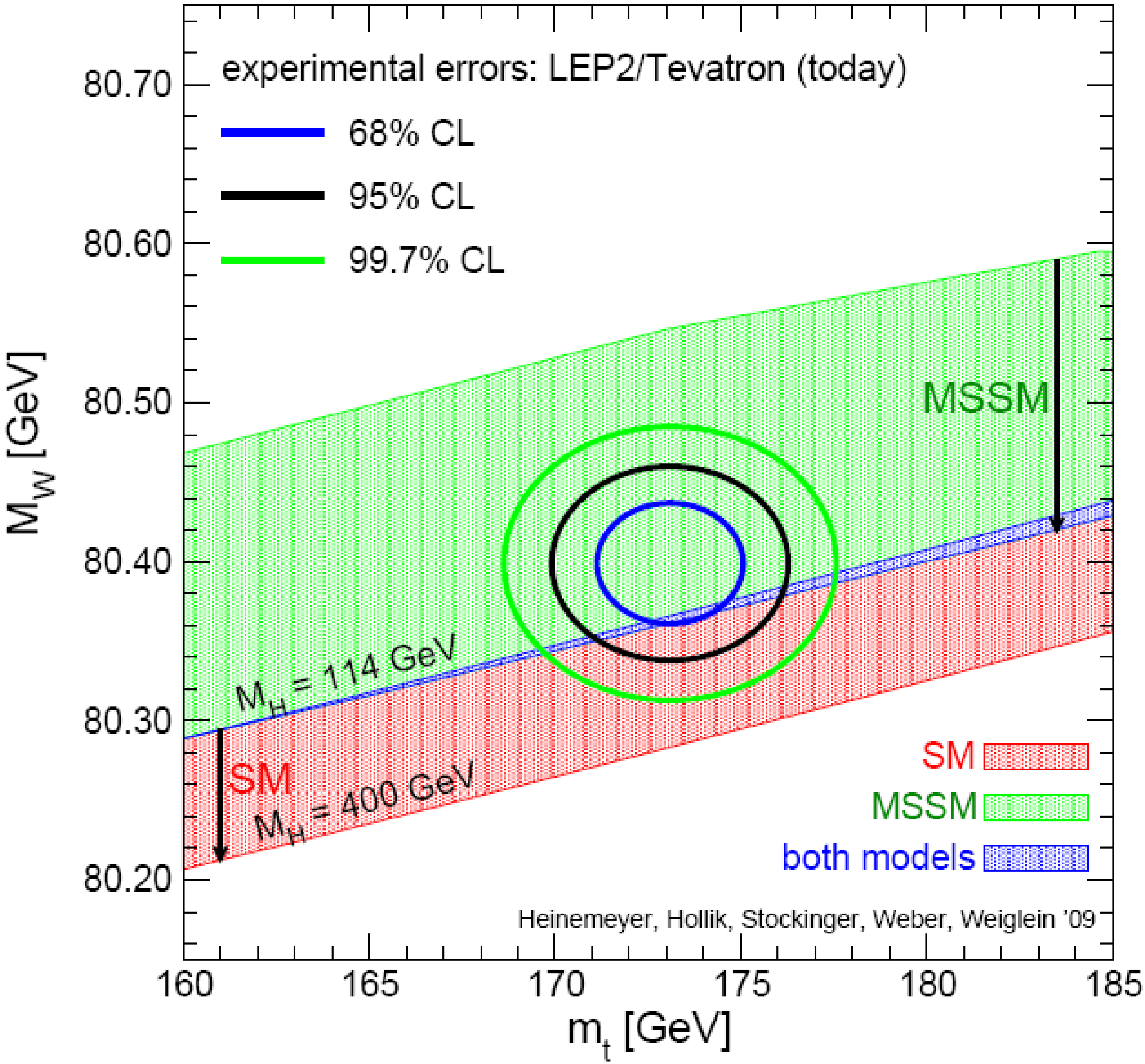
  M_W=80.401 ± 0.043 GeV

- Most precise measurement from one single experiment to date
- Expect the Tevatron combined uncertainty to be smaller than the LEP combined uncertainty for the first time
- Expect the world average uncertainty to be reduced by ~10%
- Expect the upper limit on the SM Higgs mass to be reduced by ~ 5 GeV
- Expect ΔM_W=15 MeV for the ultimate Tevatron M_W uncertainty



Backup Slides

Higgs mass constraints (2009)



Calorimeter calibration

- CDF calibration:
  - Use $J/\psi \to \mu\mu$, $\Upsilon \to \mu\mu$, $Z \to \mu\mu$ to calibration the tracking system
  - Use E/p distribution for electrons from W decays to calibrate the calorimeter system
- D0 calibration:
  - Worse tracker momentum resolution
  - Only ~20k $Z \to ee$ events
  - Similar electron p_T distributions for Z and W events

η-equalization and absolute EM scale

- Once ϕ degree of freedom is eliminated, use $Z \rightarrow$ ee events to absolutely calibrate each ϕ-intercalibrated η ring
- Reconstructed Z mass: $m = \sqrt{2E_1E_2(1-\cos\omega)}$
- The electron energies are evaluated as:

$$E_{1(2)} = E^{raw} + K(E^{raw}, \theta)$$

Raw energy measurement from the calorimeter

Parameterized energy-loss corrections from Geant MC simulation

- Raw EM cluster energy:

$$E^{raw} = \sum_{cells} C_{i\eta} \cdot E'$$

One (unknown) calibration constant per η ring

Cell energy after electronics calibration, ϕ-nitercalibration and sampling weights

- Determine the set of calibration constants $C_{i\eta}$ that minimize the experimental resolution on the Z mass and give the correct (LEP) measured value