Measurement of the Properties of Electroweak Bosons at D0

W charge asymmetry measurements
Z boson P_T (Φ^*) measurements

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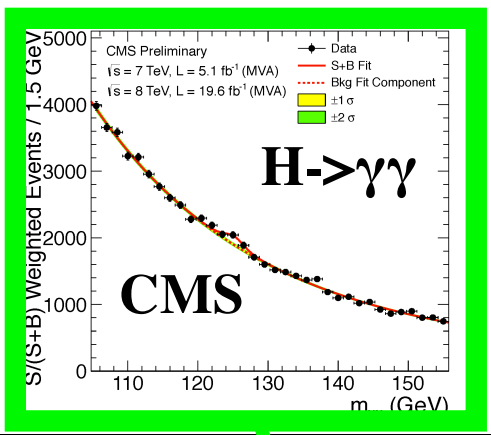
On behalf of the DØ Collaboration

Motivation of W/Z properties measurements

Current "big picture"

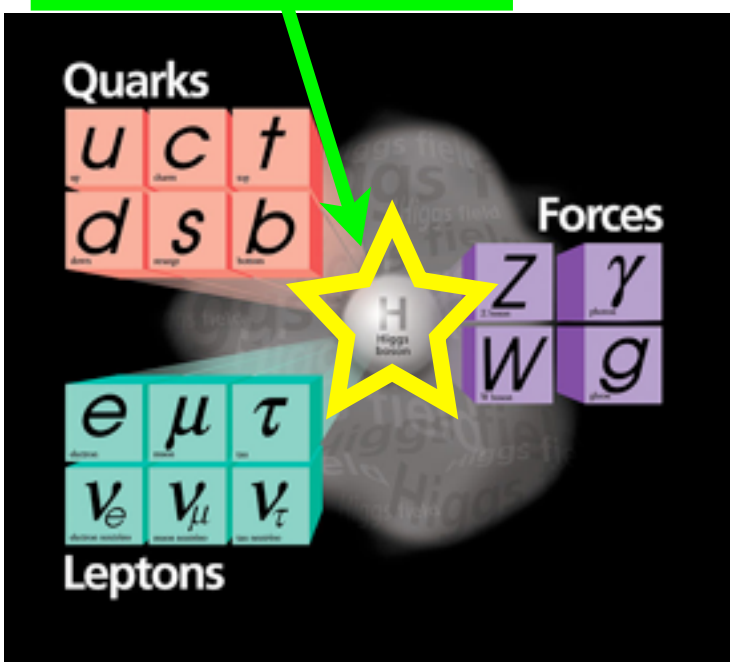
A Higgs discovery.



The SM is now complete!

For the 1st time: we can precisely

Examine a complete SM!



Comparing SM predicted value with directly measured value.

No difference exceeds 3σ.

Eur. Phys. J. C (2012) 72:2205

Pull plot of SM global fit

Motivation of W/Z properties measurement

One example, comparing W boson mass:

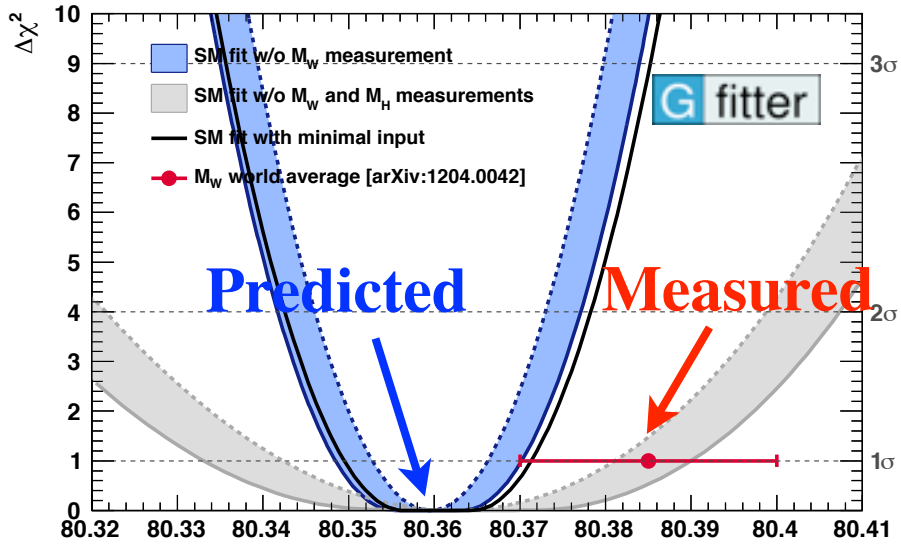
SM predicted:

$M_W = 80359\ \text{MeV} \pm 11\ \text{MeV}$

m_{top} contribution is ± 6 MeV

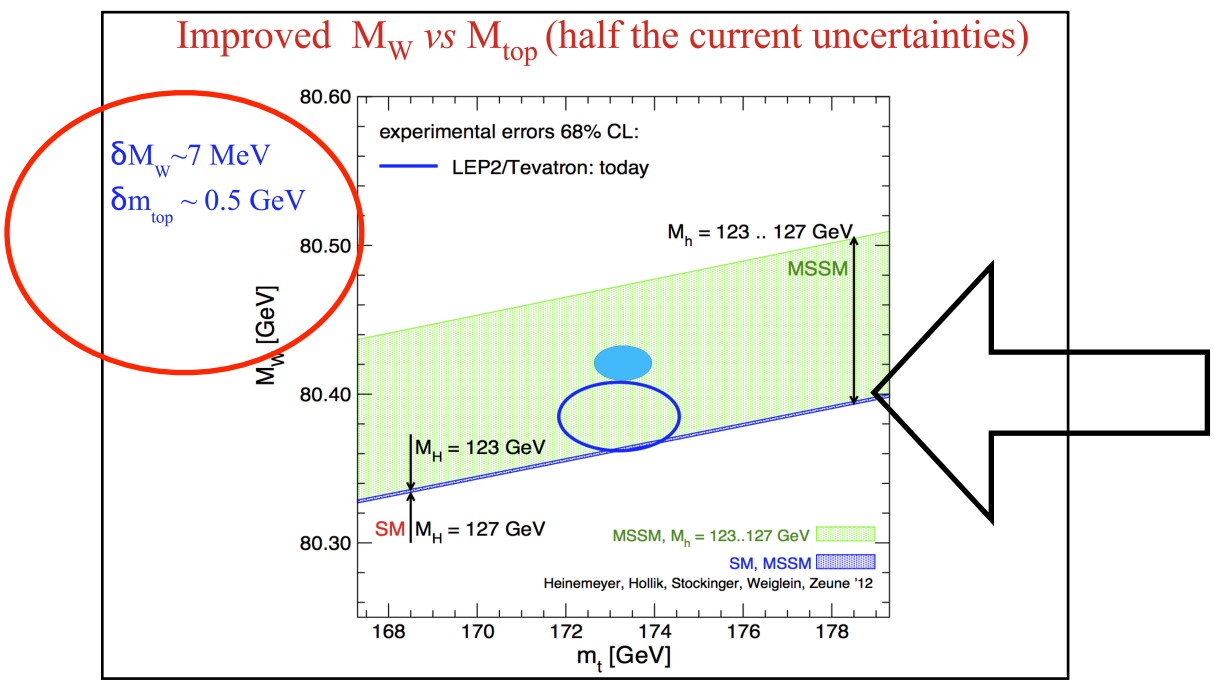
Directly measured:

$M_W = 80385\ \text{MeV} \pm 15\ \text{MeV}$



1.3σ difference

A good agreement!

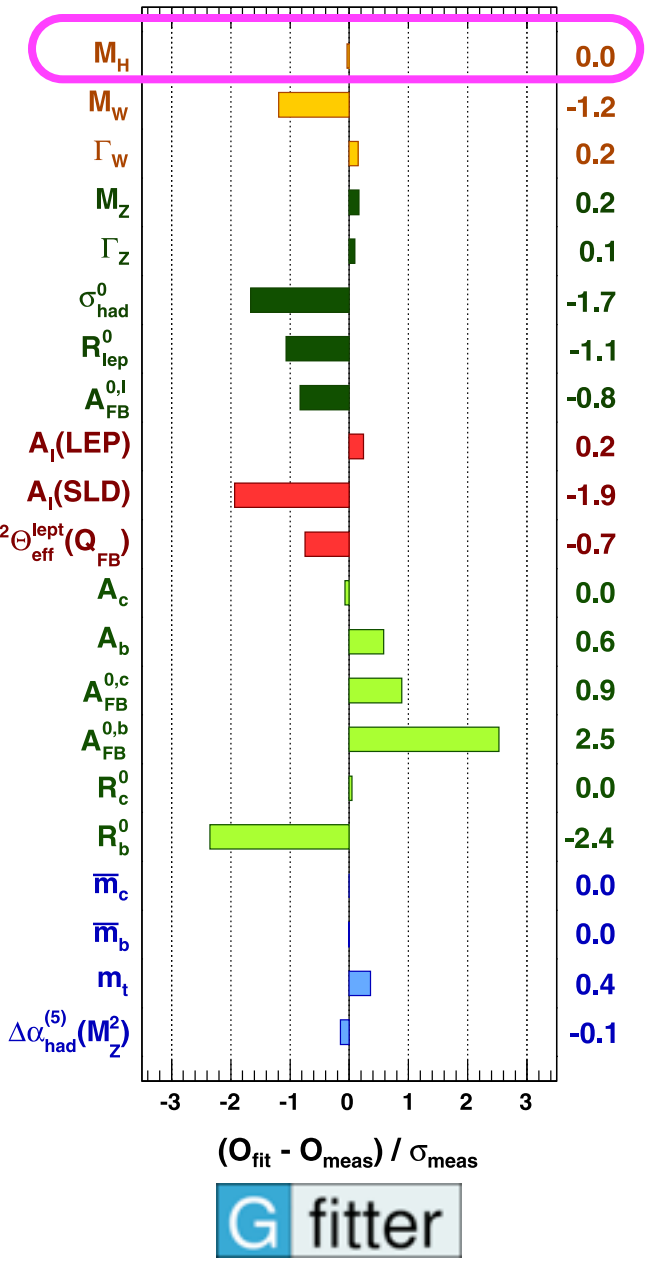


Ashutosh Kotwal's talk early today.

Increasing precision, closer examination, looking for new physics!

Motivation of W/Z properties measurement

Pull plot of SM global fit



EW precision measurements start to be limited by theoretical uncertainties.

E.g. PDF and boson P_T uncertainties are limiting factors for the W mass measurement.

	CDF 2.2 fb^{-1}	D0 4.3 fb^{-1}
Parton distribution functions	10	11
QED radiation	4	7
$p_T(W)$ model	5	2
Production subtotal	12	13
Total systematic uncertainty	15	22
W boson statistics	12	13
Total uncertainty	19	26

Reduce PDF uncertainties:

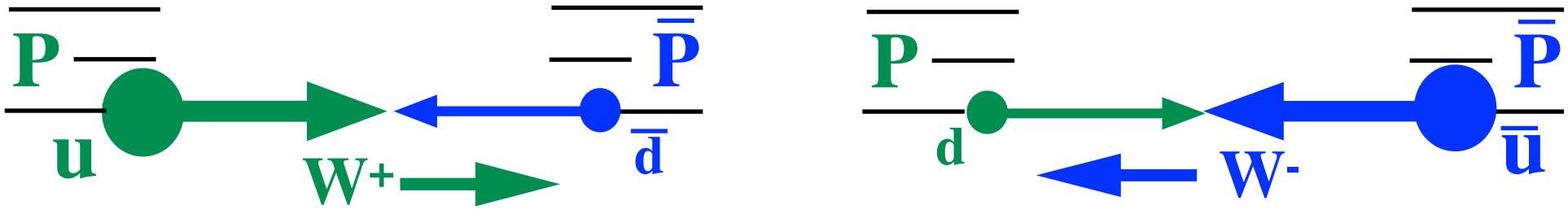
W charge asymmetry measurements

Reduce boson P_T uncertainties:

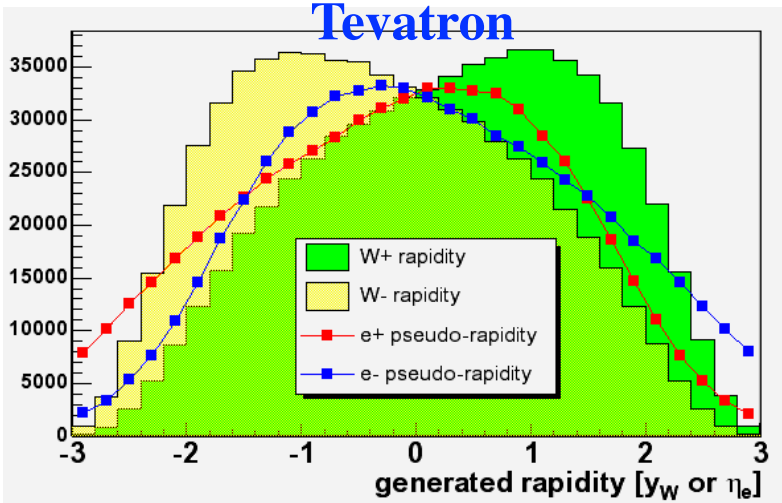
Z boson P_T (Φ^*) measurements

W Charge Asymmetry

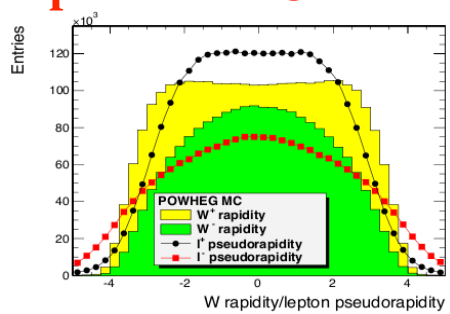
Motivation: Directly constrain valence quark PDFs



Tevatron



compare to LHC:

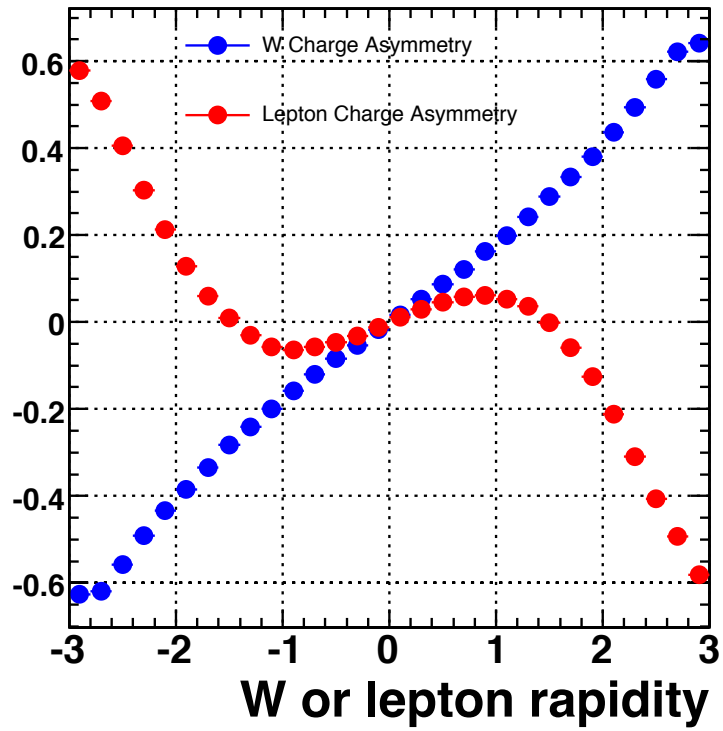


- W Boson is mostly produced by valence quark pairs at Tevatron
- u(ubar) quark carries more momentum than d(dbar) quark
- Thus:
  - W^+ preferentially boosted along proton direction
  - W^- preferentially boosted along anti-proton direction

W Charge Asymmetry

W Charge Asymmetry:

$$A(y_W) = \frac{\frac{d\sigma(W^+)}{dy_W} - \frac{d\sigma(W^-)}{dy_W}}{\frac{d\sigma(W^+)}{dy_W} + \frac{d\sigma(W^-)}{dy_W}} \simeq \frac{u(x_1)/d(x_1) - u(x_2)/d(x_2)}{u(x_1)/d(x_1) + u(x_2)/d(x_2)}$$



- u(x) and d(x) are the PDFs of the valence u quark and d quark in the proton
- x1 and x2 are the momentum fractions in the proton and anti-proton

Directly constrains PDFs, but the 4-momentum of W is not easy to reconstruct, because the neutrino longitudinal momentum (P_z) is not directly measurable at hadron colliders.

Alternative observable is the charge asymmetry of the lepton from the W decay.

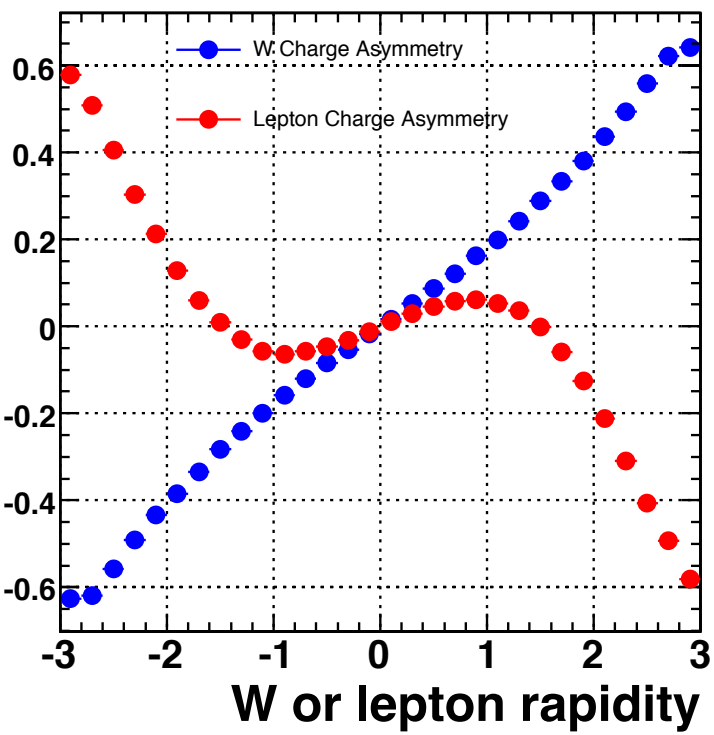
One can of cause try to infer the W longitudinal momentum from the W mass constraint within a two fold ambiguity.

W Charge Asymmetry

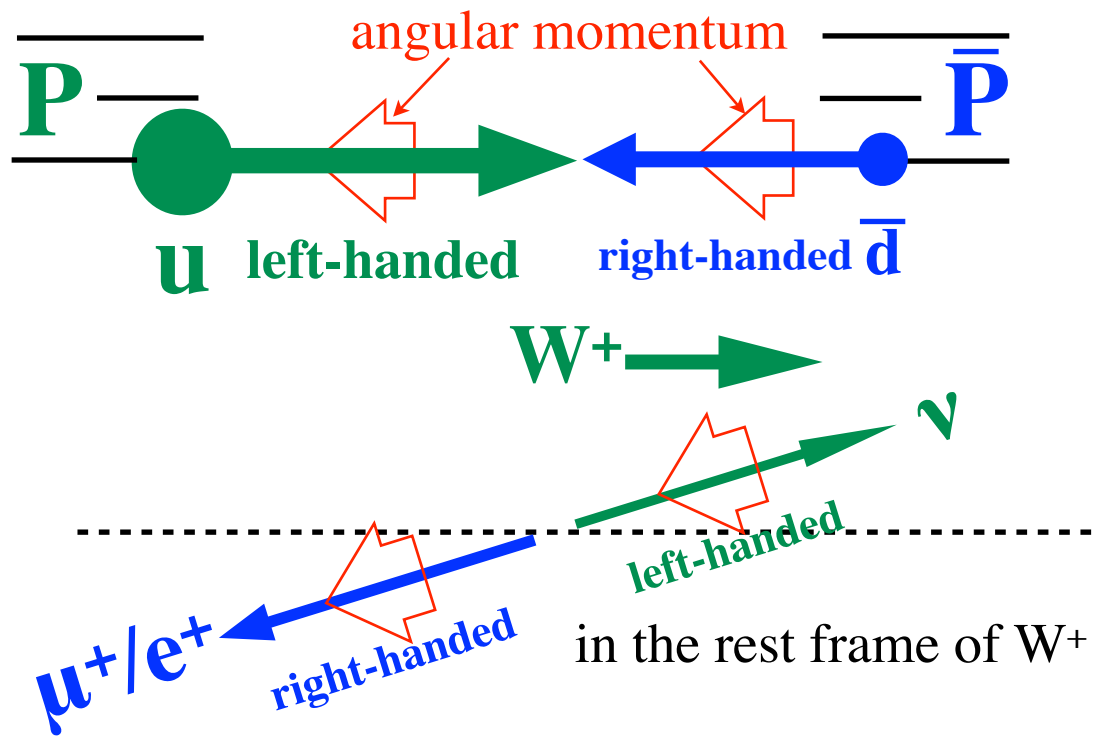
Lepton Charge Asymmetry:

$$A(\eta_\mu) = \frac{\frac{d\sigma(\mu^+)}{d\eta_\mu} - \frac{d\sigma(\mu^-)}{d\eta_\mu}}{\frac{d\sigma(\mu^+)}{d\eta_\mu} + \frac{d\sigma(\mu^-)}{d\eta_\mu}}$$

Directly observable but counterbalances the W charge asymmetry, due to the V-A asymmetry and angular momentum conservation.



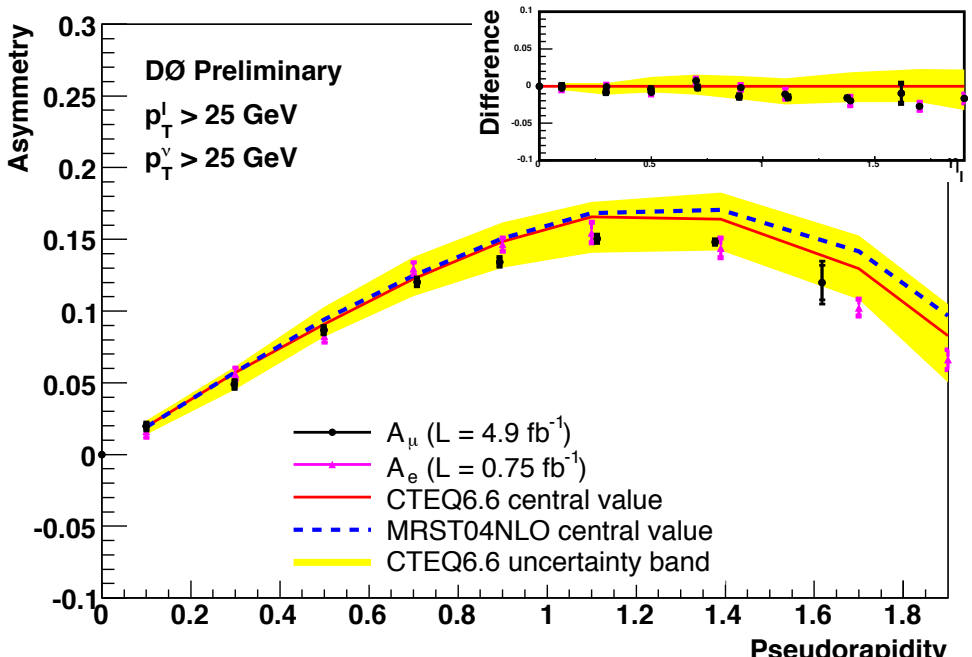
E.g. for W+:



W Charge Asymmetry

- **Strong constraint power on PDFs: Much smaller uncertainty from measurement than theoretical (PDF) prediction.**
- **Some tension at high lepton P_T.**

Overall

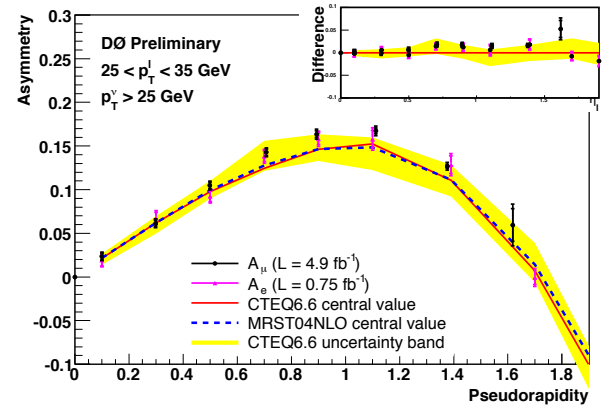


Data points:

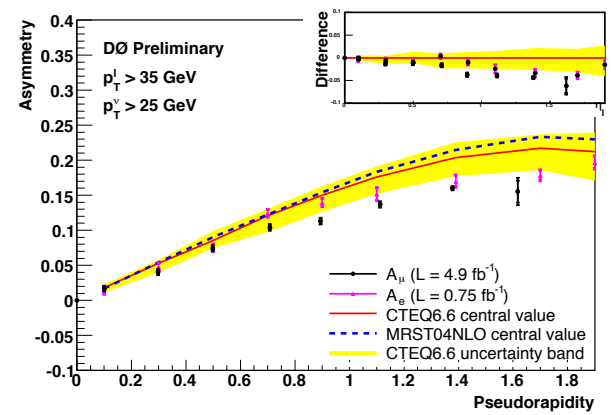
Pink: W->eν, *0.75 fb^{-1}, PRL 101, 211801 (2008)*

Black: W->μν, *4.9 fb^{-1} , DØ Note 5976-CONF (2009)*

Low Lepton P_T



High Lepton P_T



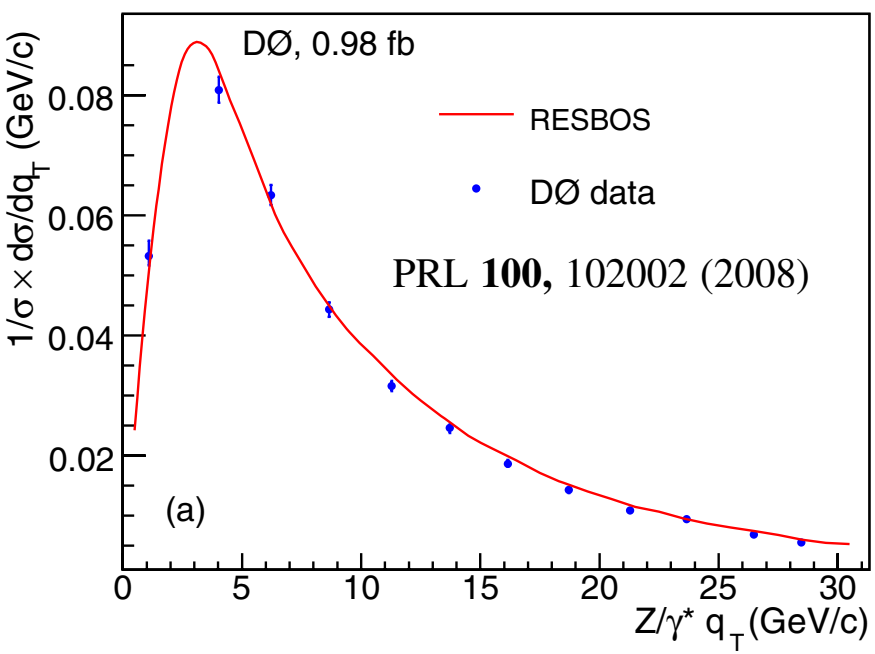
Full data set results are coming.

P_T distribution of Z bosons, Φ* measurement

Theoretical modeling of $P_T(Z)$ requires soft gluon resummation with additional non-perturbative form factors determined by experimental data.

Benefitted by many precision measurements, including the W boson mass.

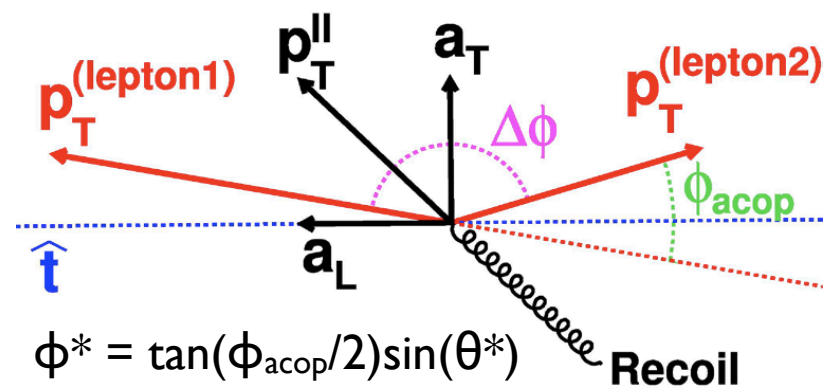
Typical $P_T(Z)$ distribution at D0



Systematical uncertainty is dominant already at 1 fb^{-1} due to experimental resolution on $P_T(Z)$.

Alternative variable to study $P_T(Z)$: Φ*

- **Using only angular variables**
- **Less sensitive to the detector resolution and selection efficiency**
- **Equivalent power to constrain the boson P_T prediction**



$$\phi^* = \tan(\phi_{acop}/2)\sin(\theta^*)$$

$$\cos(\theta_\eta^*) = \tanh\left(\frac{\eta^- - \eta^+}{2}\right)$$

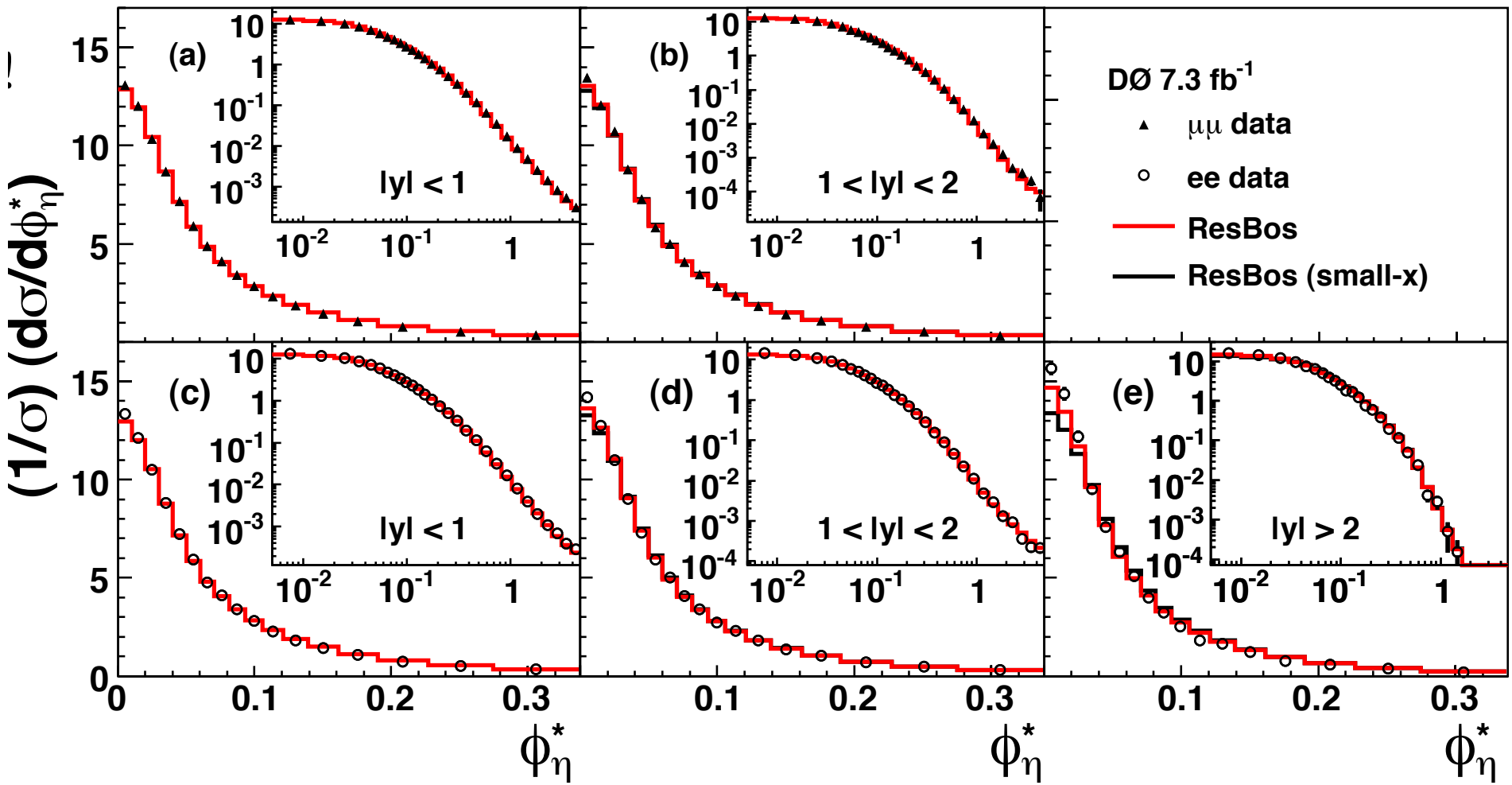
NIM P.R. A 602, 432 (2009)
Eur.Phys.J. C71, 1600 (2011)

P_T distribution of Z bosons, Φ* measurement

D0 7.3 fb^{-1}
455k Z->ee events
511k Z->μμ events

The first measurement using this method.

PRL 106, 122001 (2011)



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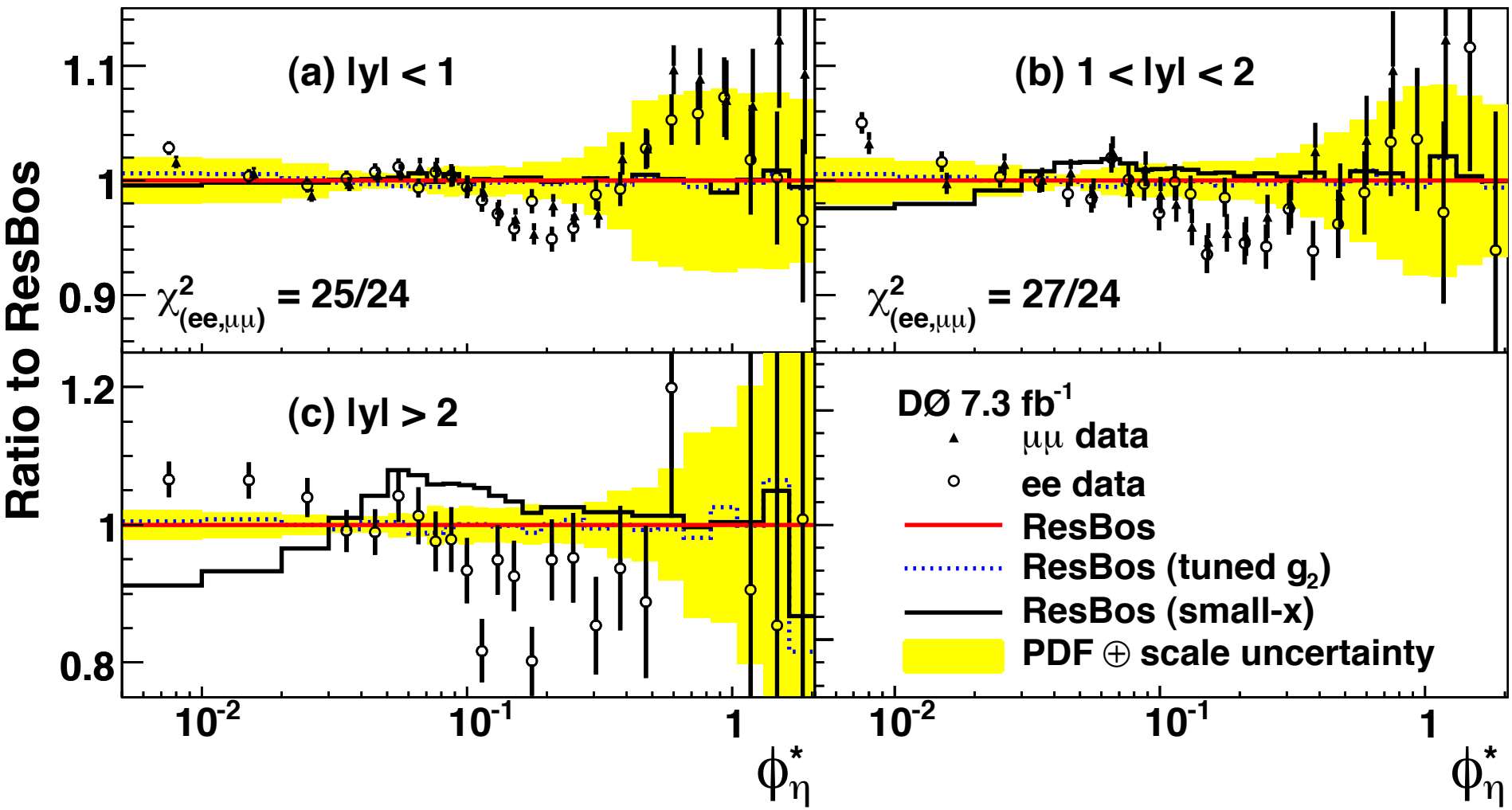


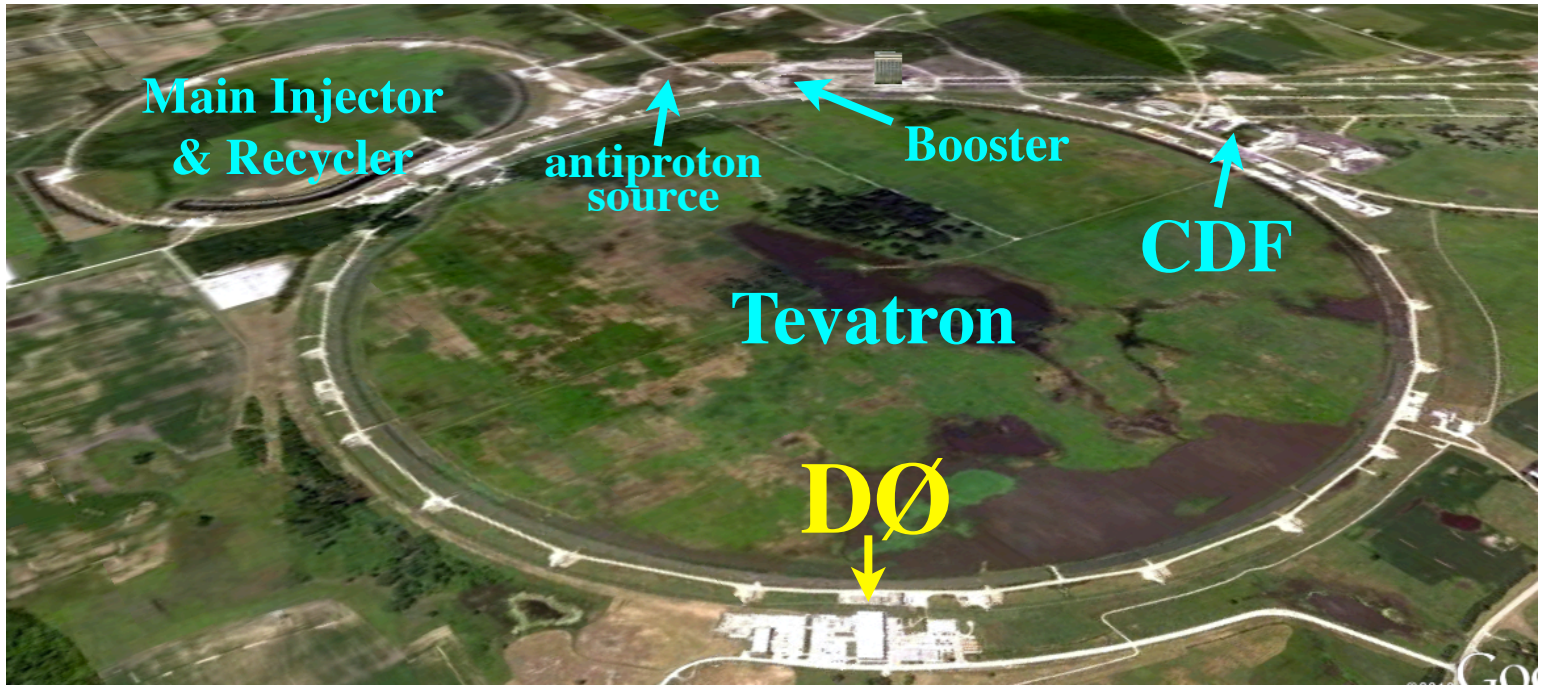
Full data set (10 fb^{-1}) Z->μμ is now in internal review!

Summary

- **The Higgs discovery=> we can precisely examine a completed SM.**
- **Precision EW measurements start to be theoretically limited.**
- **W/Z properties measurements:**
  - **W charge asymmetry:**
    - **Direct constraint on the valence quark PDFs**
  - **Z boson P_T (Φ^*) measurements:**
    - **Improve modeling of boson P_T**
- **New results are coming from D0!**

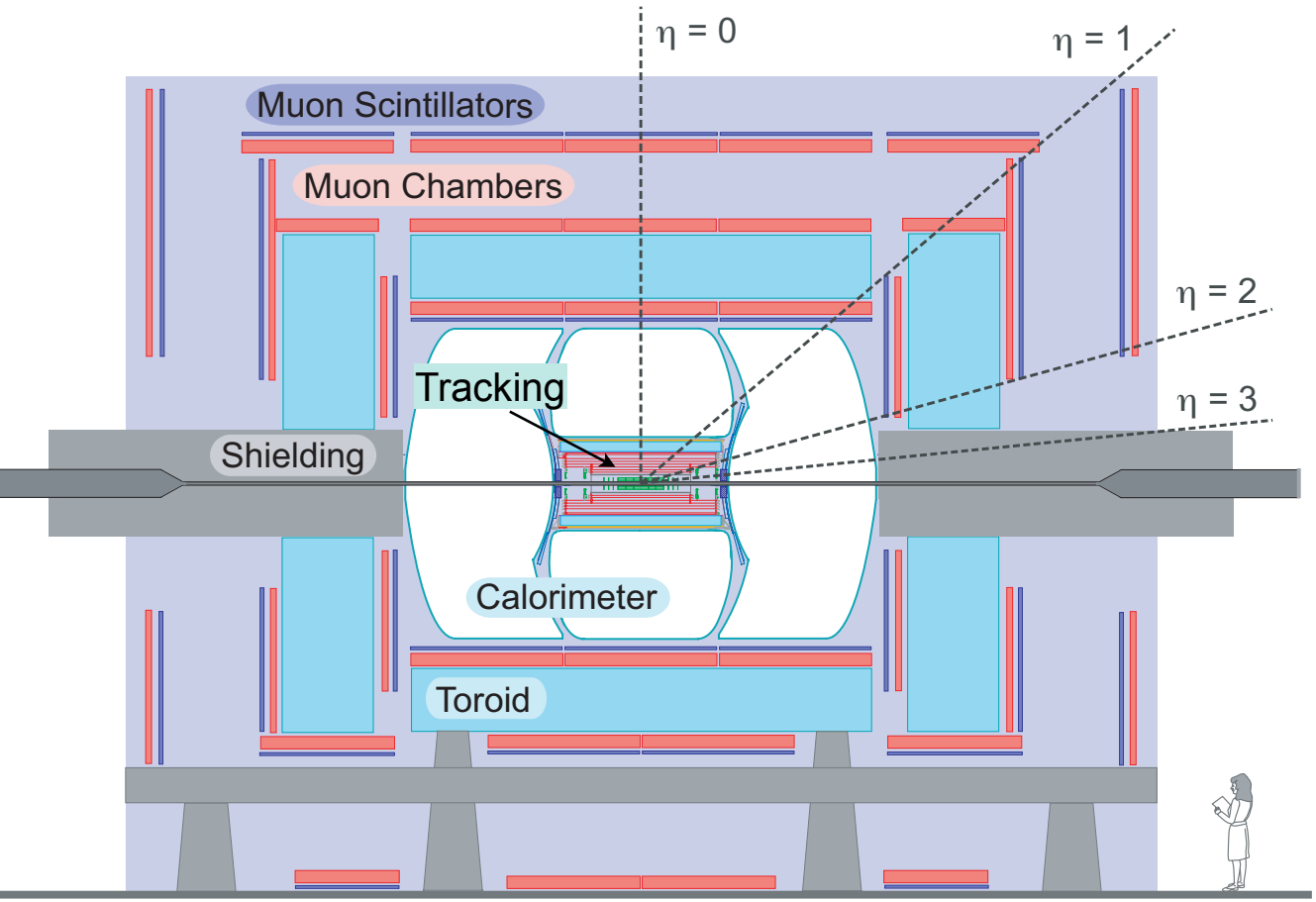
Backup slides

The Tevatron



- The Tevatron is a Proton-Antiproton Collider at 1.96 TeV
  - CP symmetric initial states
  - Low pileup ! N(vertex) ~ 5 .
- W and Z bosons are produced mainly by valence quarks (compared to LHC)
  - Low PDF uncertainties
  - Ideal for asymmetry measurements

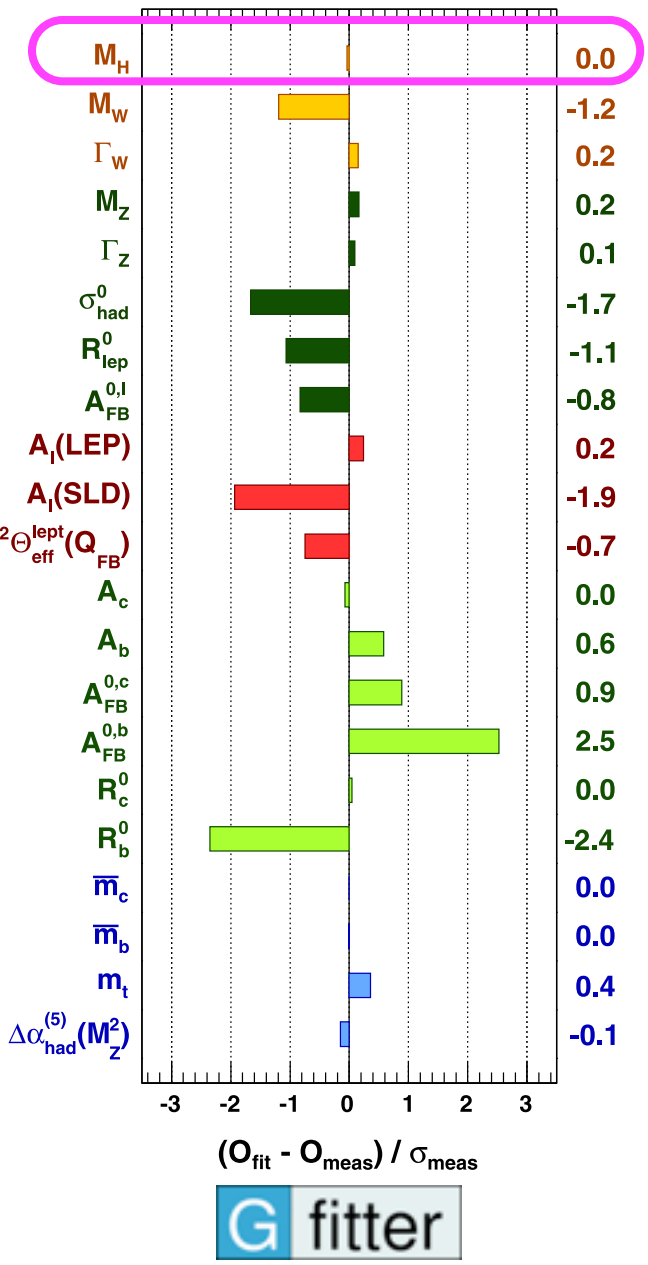
The DØ Detector



- Tracking
  - 2 T magnet
  - $\delta P_T/P_T \sim 10\%$ @ 45 GeV
  - $\delta\eta \sim 1.5\times10^{-3}$
  - $\delta\phi \sim 4\times10^{-4}$
- Calorimeter
  - η coverage up to 4.2
  - $\delta E/E \sim 4\%$ @ 45 GeV
  - Thickness ~ 20 X_0
  - Granularity $\phi\times\eta \sim 0.1\times0.1$
- Muon System
  - η coverage up to 2

Motivation of W/Z properties measurement

Pull plot of SM global fit



W mass uncertainties:

D0 W->eν 4.3 fb^{-1}

Source	Uncertainty (MeV)
Electron energy calibration	16
Electron resolution model	2
Electron shower modeling	4
Electron energy loss model	4
Recoil energy scale and resolution	5
Electron efficiencies	2
Backgrounds	2
Experimental subtotal	18
Parton distribution functions	11
QED radiation	7
$p_T(W)$ model	2
Production subtotal	13
Total systematic uncertainty	22
W boson statistics	13
Total uncertainty	26

CDF W->eν + W->μν 2.2 fb^{-1}

Source	Uncertainty (MeV)
Lepton energy scale and resolution	7
Recoil energy scale and resolution	6
Lepton removal from recoil	2
Backgrounds	3
Experimental subtotal	10
Parton distribution functions	10
QED radiation	4
$p_T(W)$ model	5
Production subtotal	12
Total systematic uncertainty	15
W boson statistics	12
Total uncertainty	19