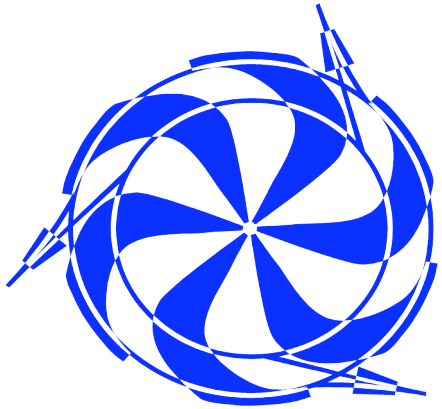
Precision Electroweak Measurements from CDF

Oliver Stelzer-Chilton

TRIUMF

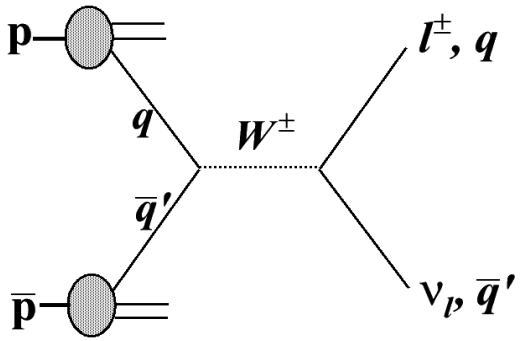


on behalf of the CDF Collaboration

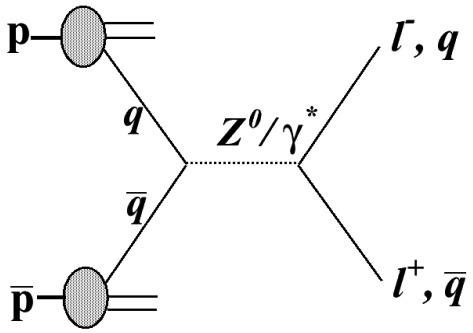
Lake Louise Winter Institute 2009
Alberta, Canada, February 16 – 21, 2009

Introduction

- W→lν and Z→ll have very clean and distinct signatures
  ⇒ low backgrounds, high statistics ⇒ precision measurements



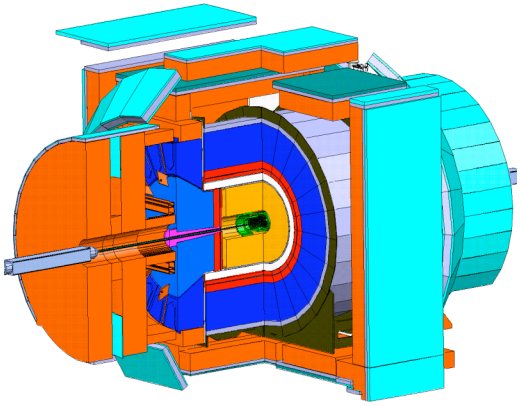
$\sigma(pp \to W^{\pm} \to l\nu) \sim 2775$ pb



$\sigma(pp \to Z^0 \to l^+l^-) \sim 255$ pb

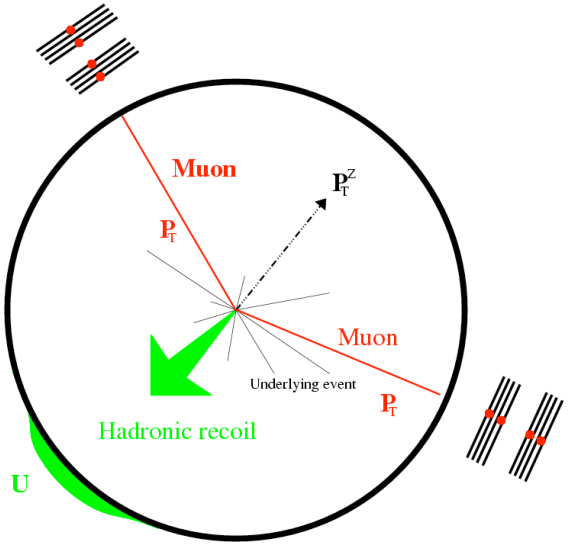
- W and Z boson decays can be used to:
  - ♦ Constrain parton distribution functions (PDF)
    - W charge asymmetry
    - Z rapidity
  - ♦ Make precision measurements of electroweak parameters
    - W boson mass (Higgs mass constraint)
    - W boson width

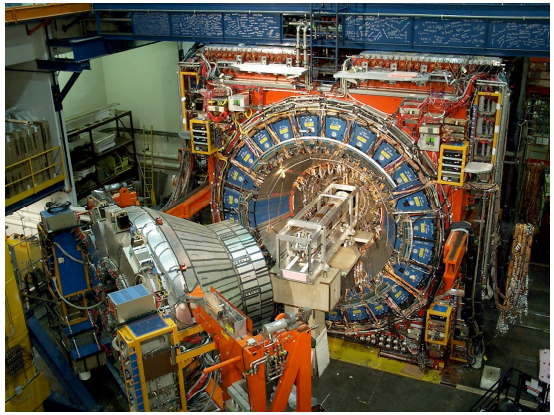
W/Z Bosons at CDF



Z events:

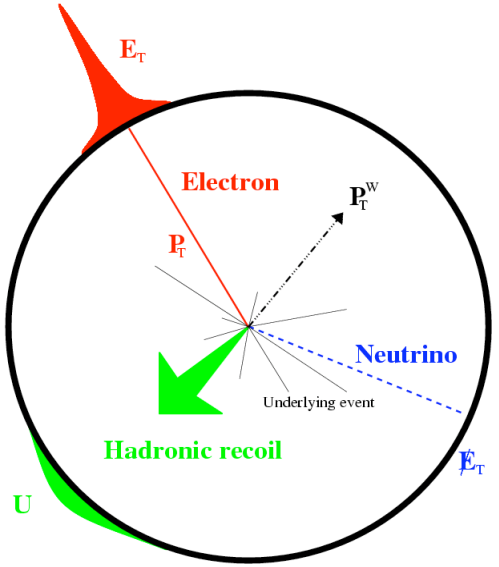
- 2 high p_T charged leptons ($\mu^+\mu^-$ or e^+e^-)
- Both charged leptons are detected and their momenta/energy measured



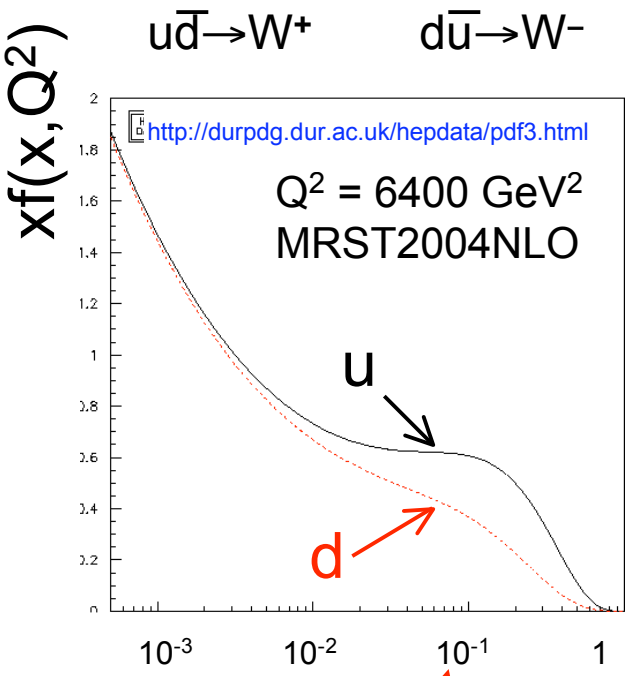


W events:

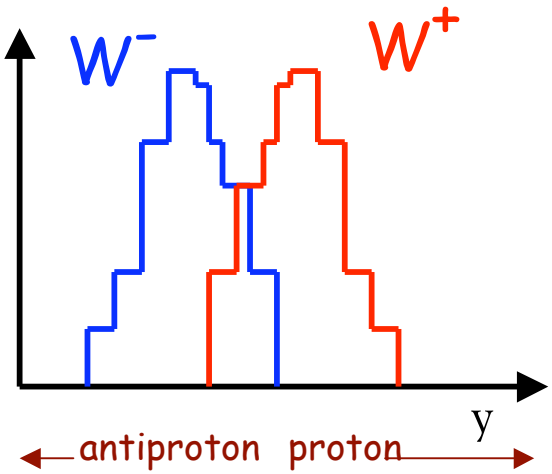
- 1 high p_T charged lepton, 1 high p_T neutrino ($\mu\nu$ or $e\nu$).
- Charged lepton is detected and momentum/energy measured
- Neutrino escapes detection p_T^ν is inferred by the "missing E_T" in the detector.

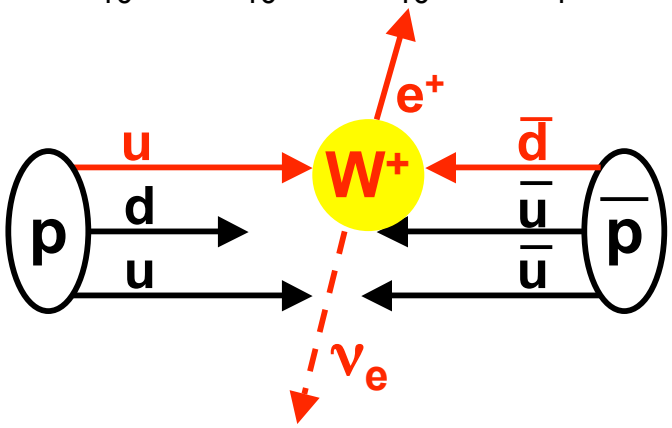


W Boson Charge Asymmetry



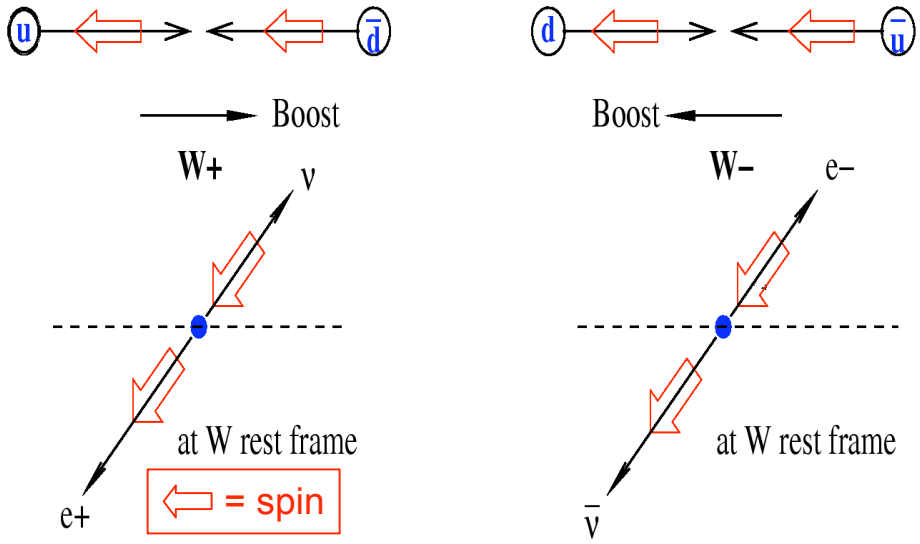
Fraction of proton momentum carried by quark





$$A(y_W) = \frac{d\sigma(W^+)/dy - d\sigma(W^-)/dy}{d\sigma(W^+)/dy + d\sigma(W^-)/dy}$$

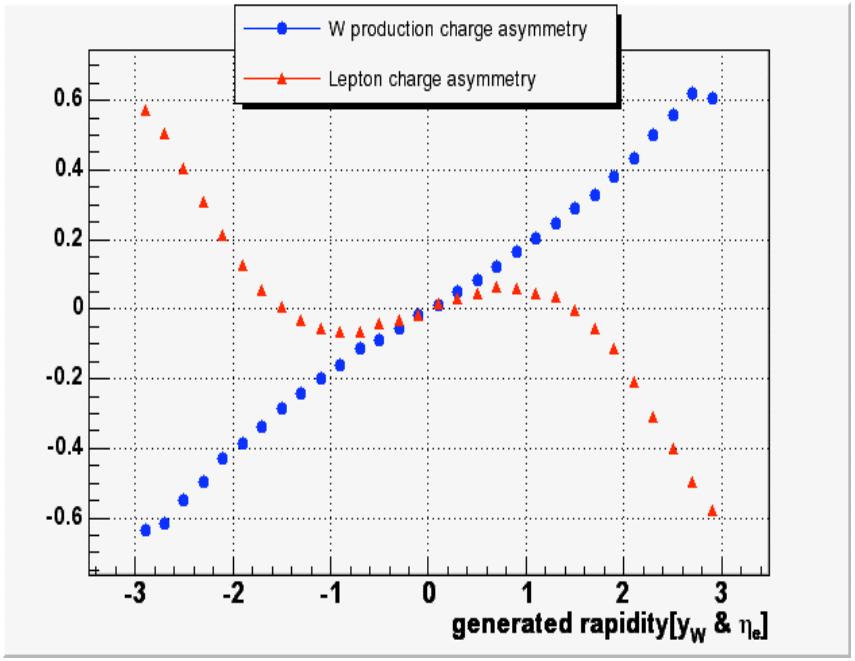
W Boson Charge Asymmetry



- Rapidity distribution of the W boson: Convolution of V-A and PDF's
- Observables, $d\sigma/d\eta_l$, include convolution with V-A structure of the weak decay

$$A(y_W) = \frac{d\sigma(W^+)/dy - d\sigma(W^-)/dy}{d\sigma(W^+)/dy + d\sigma(W^-)/dy}$$

$$A(\eta_l) = \frac{d\sigma(e^+)/d\eta - d\sigma(e^-)/d\eta}{d\sigma(e^+)/d\eta + d\sigma(e^-)/d\eta}$$



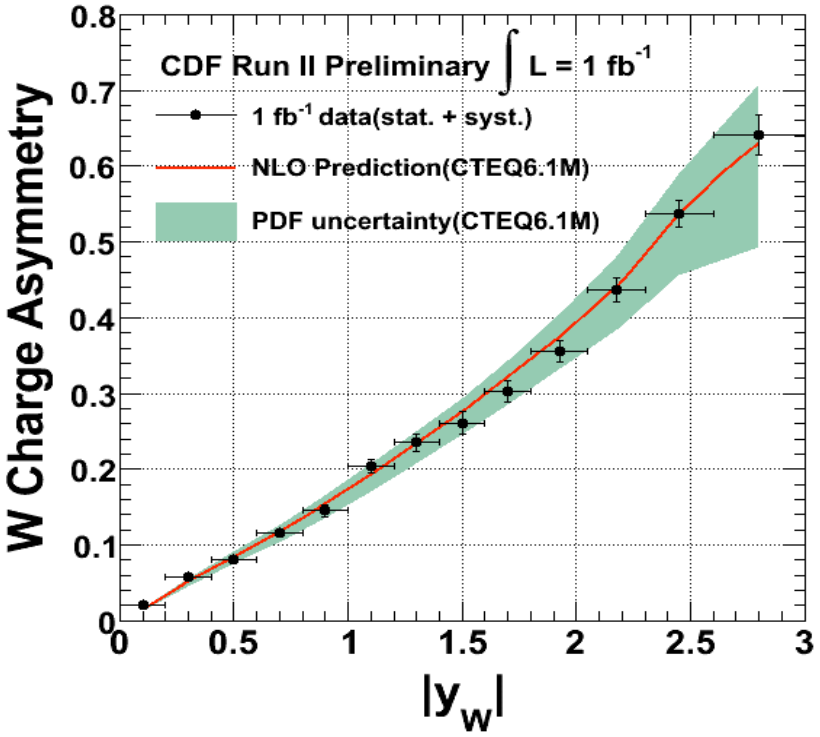
W Boson Charge Asymmetry A(y_W)

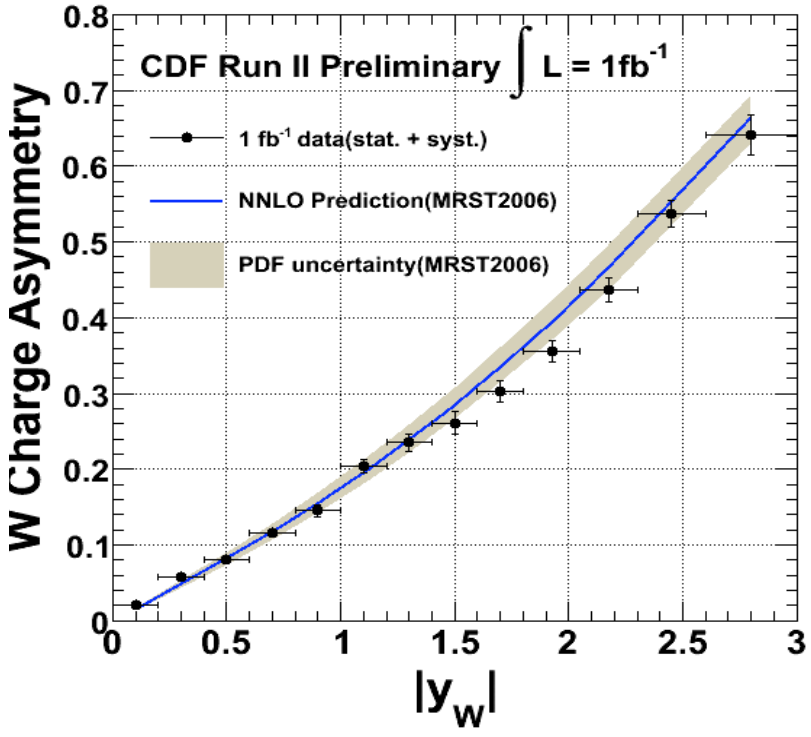
- p_L^{ν} determined by constraining M_W = 80.4 GeV
  - two possible y_W solutions

arXiv:hep-ex/0901.2169

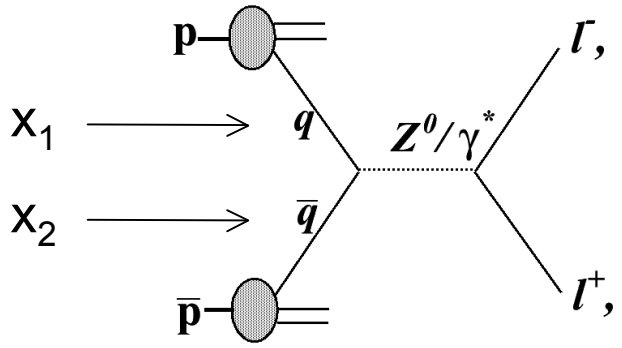
- Each solution receives a weight probability according to:
  - V-A decay structure
  - W cross-section: $\sigma(y_W)$
- Process iterated since $\sigma(y_W)$ depends on asymmetry

Analysis method:
arXiv:hep-ph/0711.2859

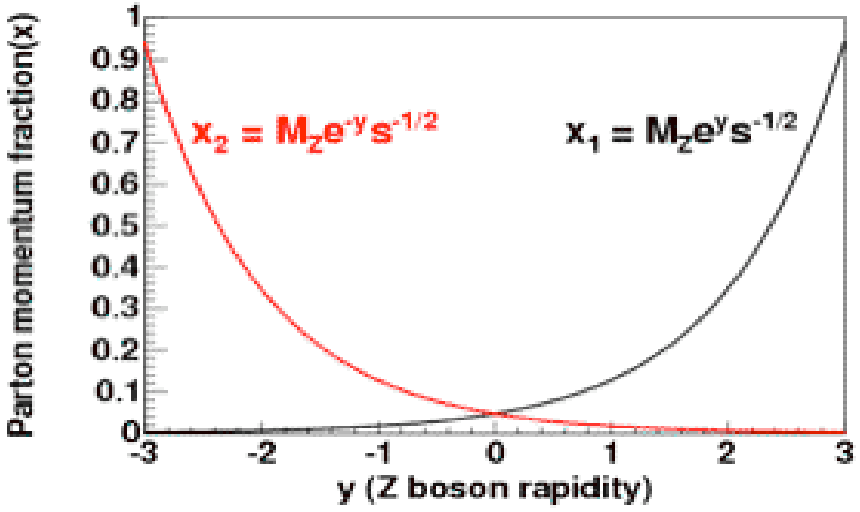




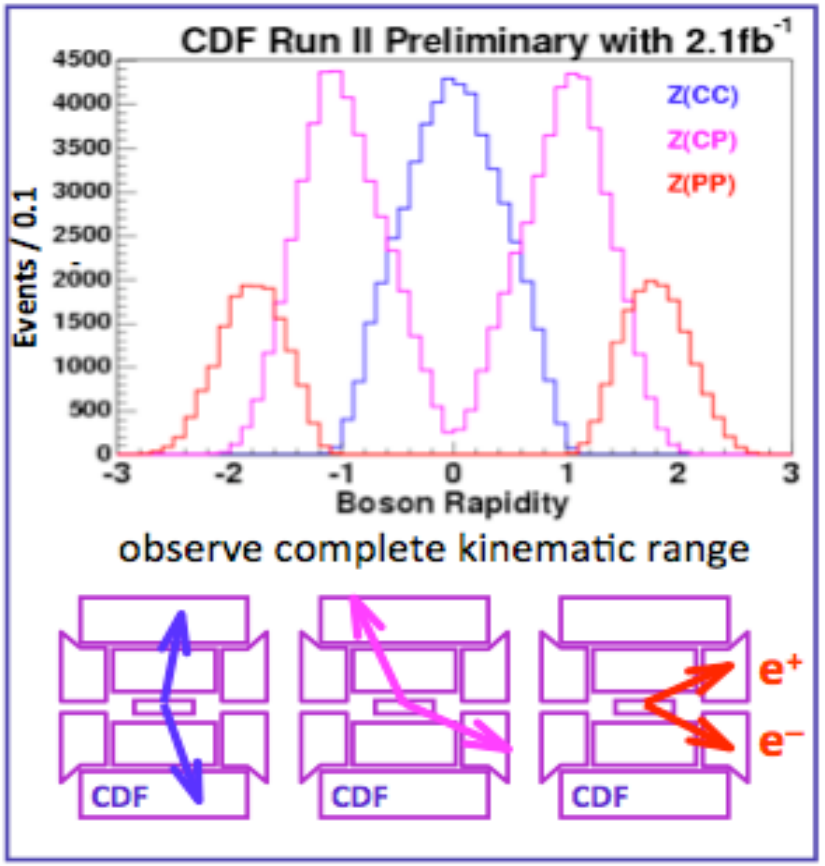
Z Boson Rapidity



Z rapidity (y_Z) is dependant on $x_{1,2}$
A measurement of $d\sigma/dy$ constrains PDFs

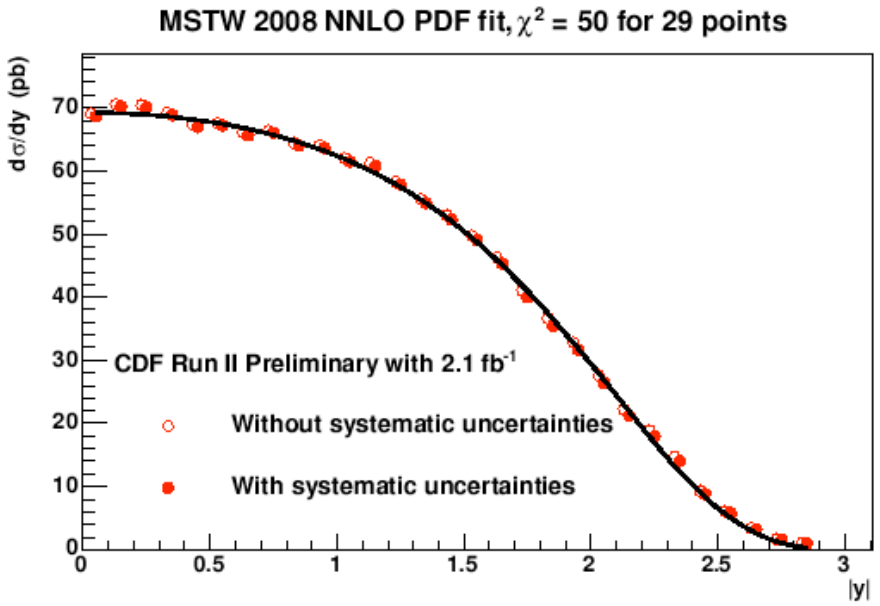


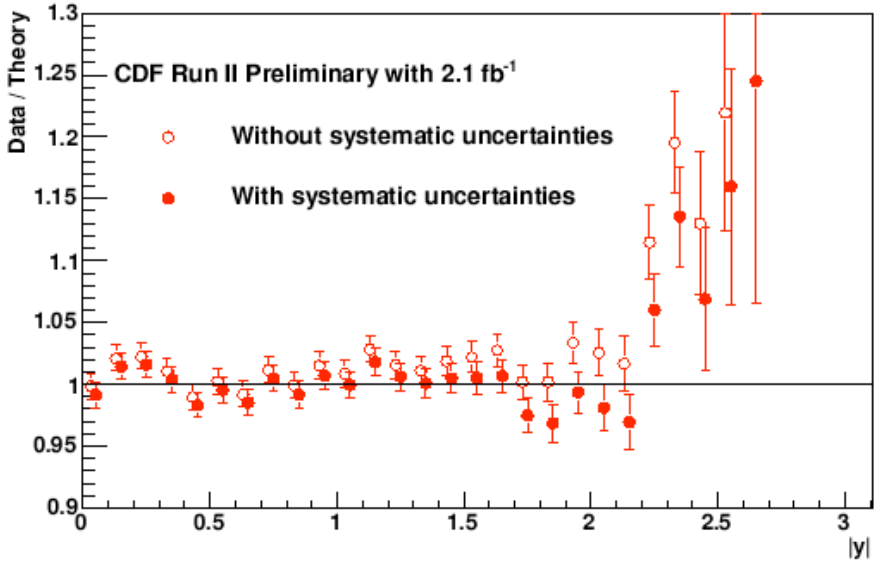
New 2.1 fb^{-1} CDF measurement
(Z→ee events with $|\eta_e|$<2.8)



Z Boson Rapidity

- Jan'09: new PDF fits from MRST group (now MSTW) arXiv:hep-ph/0901.002
  - first fits including the Run II data: electroweak asymmetries, Z→ee rapidity distributions, QCD jet production
- W/Z data constrains mainly up and down quarks
- Extract mainly d(x)





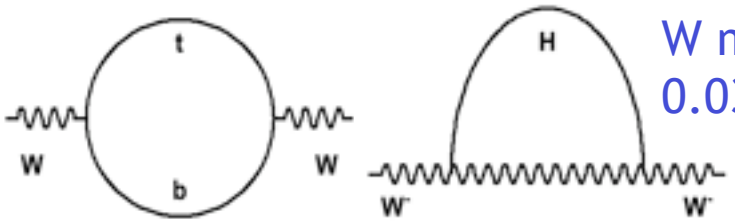
W Boson Mass Motivation

- Derive W mass from precisely measured electroweak quantities

$$m_W^{\,2} = \frac{\pi \alpha_{em}}{\sqrt{2} G_F \sin^2 \theta_W (1 - \Delta r)}$$

- Radiative corrections r dominated by top quark and Higgs loop
  ⇒allows constraint on Higgs mass

Current top mass uncertainty 0.7% (1.2 GeV)
→ equivalent 0.01% (7 MeV) on δM_W

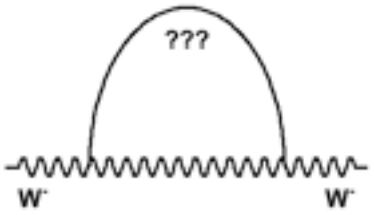


W mass uncertainty 0.031% (25 MeV)

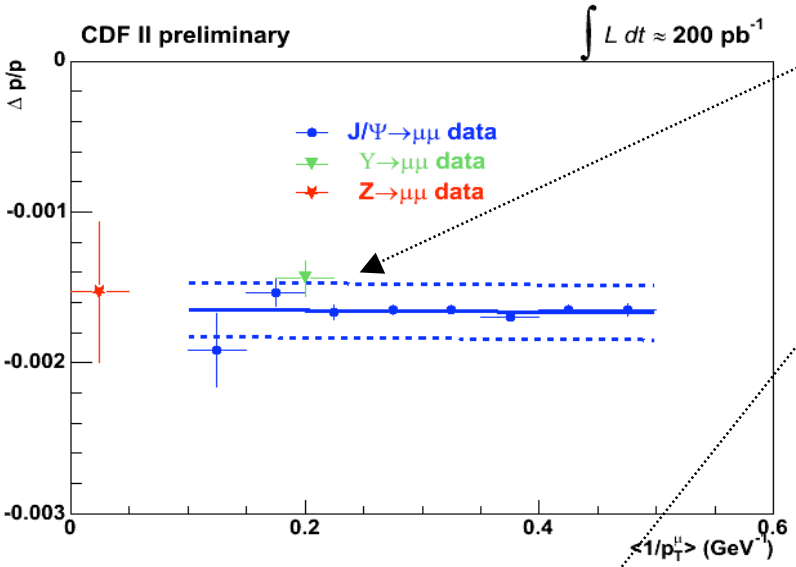
Higgs mass predicted: 84^{+34}_{-26} GeV

- Progress on W mass uncertainty now has the biggest impact on Higgs mass constraint

- With improved precision also sensitive to possible exotic radiative corrections



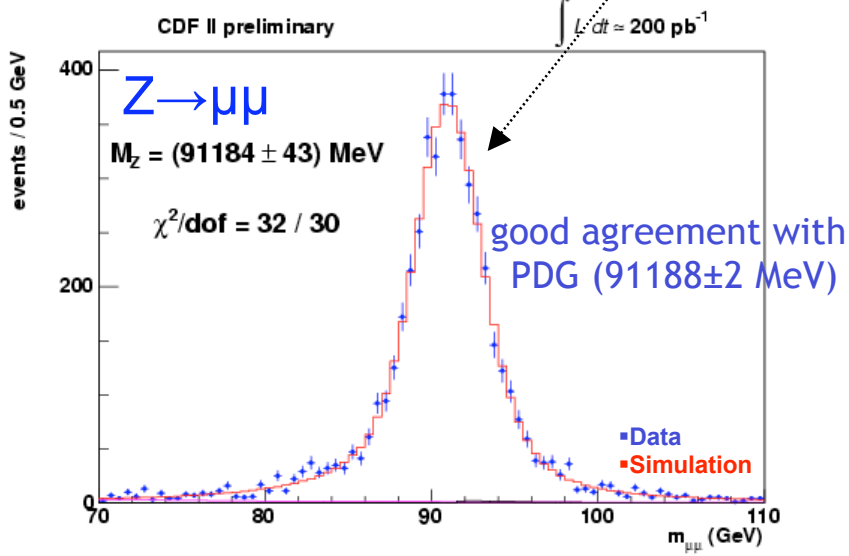
W Boson Mass Momentum Scale Calibration



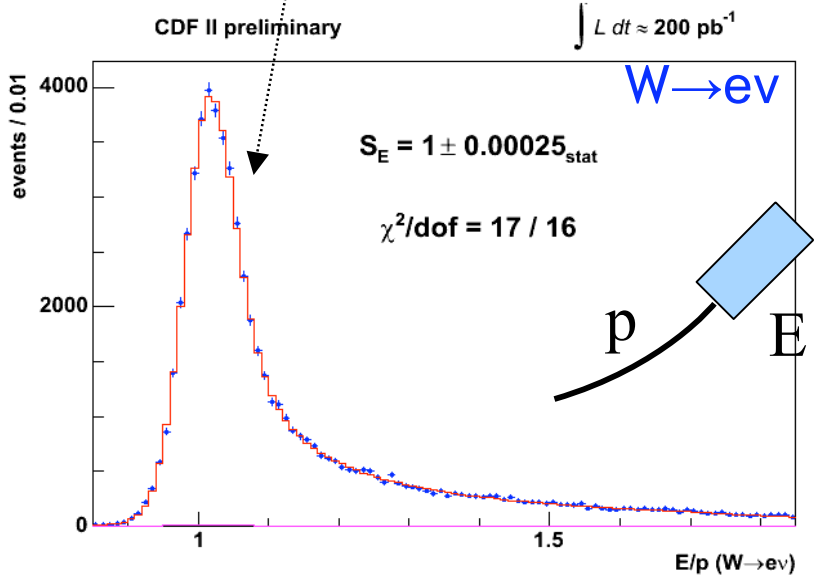
Exploit large J/ψ and Upsilon datasets to set momentum scale

Tune resolution on width of di-muon mass peaks

Transfer momentum scale to energy Scale using E/p



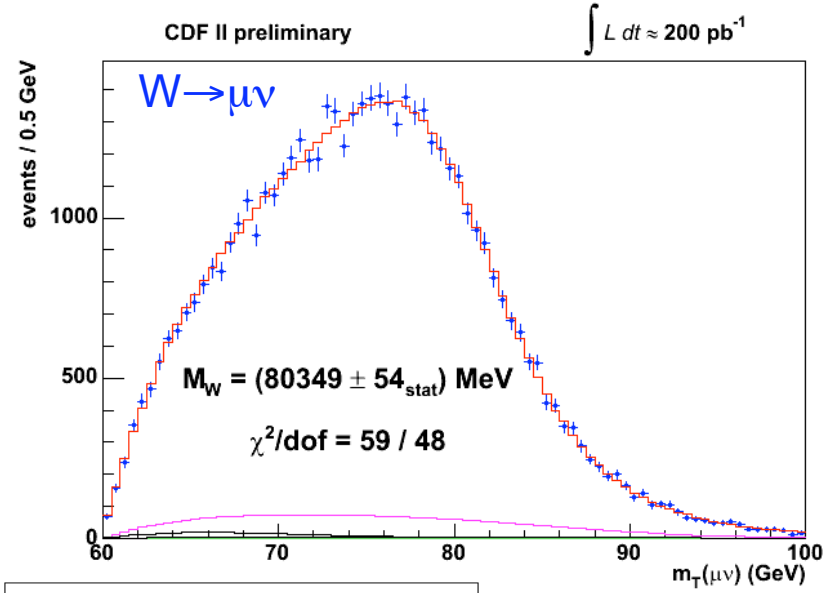
good agreement with PDG (91188±2 MeV)

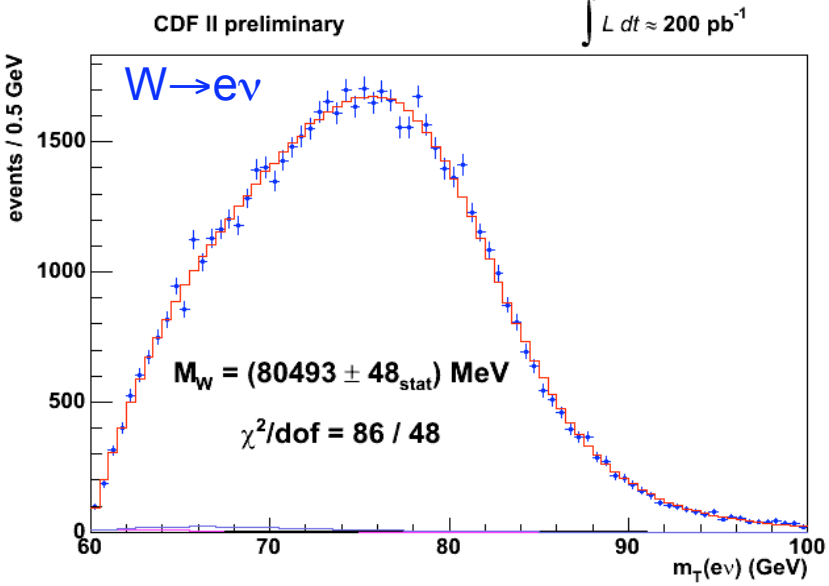


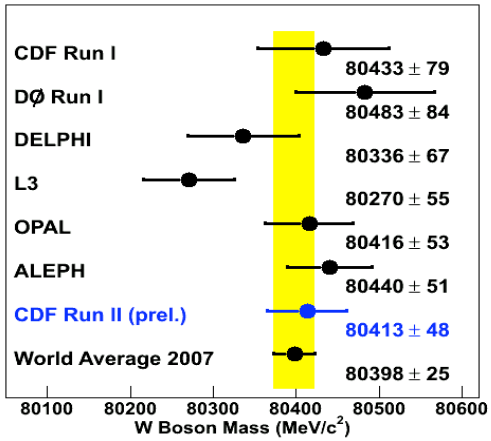
W Boson Mass Fits and Results

- Fit to transverse mass, momentum and missing energy distributions

Phys. Rev. Lett. 99, 151801 (2007)
Phys. Rev. D 77, 112001 (2008)

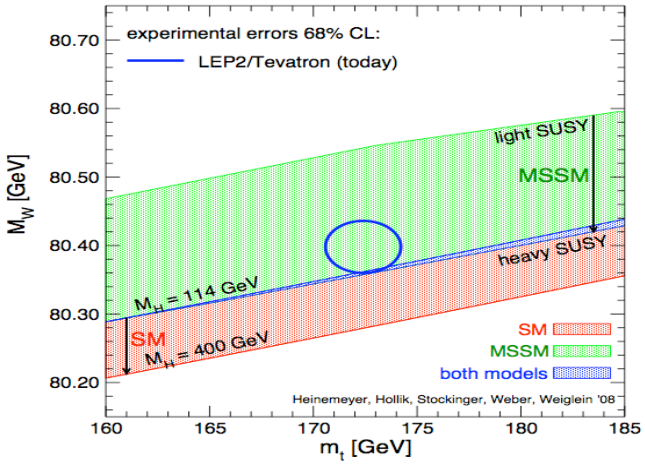






$m_W = 80413 \pm 34_{stat} \pm 34_{syst}$ MeV

- Total uncertainty of 48 MeV
  → worlds most precise single measurement
- Uncertainty reduced ~15% (29 to 25 MeV)



W Boson Mass Systematic Uncertainty

Systematic uncertainty on transverse mass fit

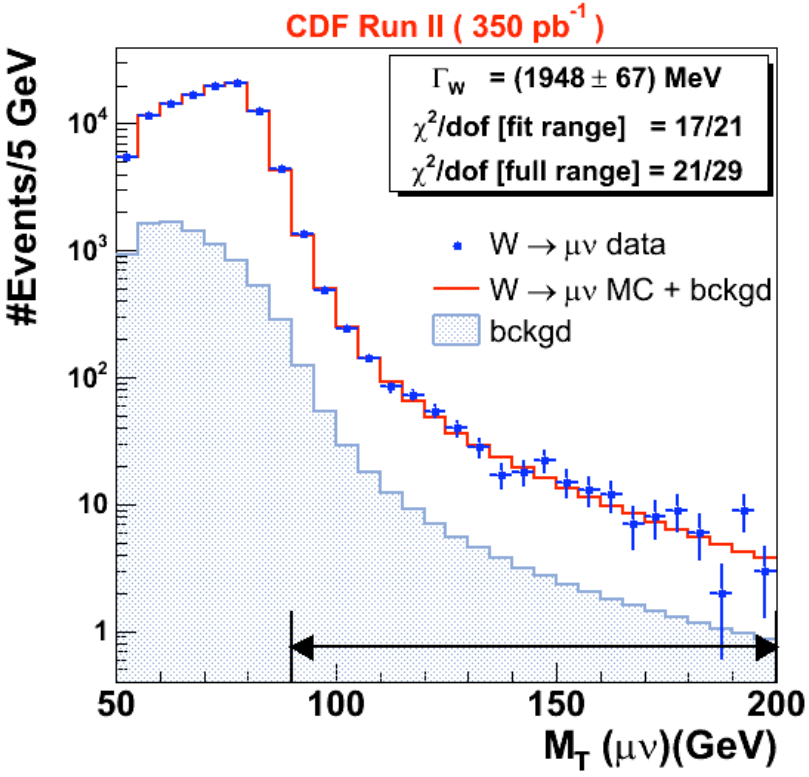
CDF II preliminary **$L = 200\ pb^{-1}$**

m_T Uncertainty [MeV]	Electrons	Muons	Common
Lepton Scale	30	17	17
Lepton Resolution	9	3	0
Recoil Scale	9	9	9
Recoil Resolution	7	7	7
$u_{\parallel}$ Efficiency	3	1	0
Lepton Removal	8	5	5
Backgrounds	8	9	0
$p_T(W)$	3	3	3
PDF	11	11	11
QED	11	12	11
Total Systematic	39	27	26
Statistical	48	54	0
Total	62	60	26

- Have a large statistical component
- Scale partially with statistics
- External input → new PDF's very timely!

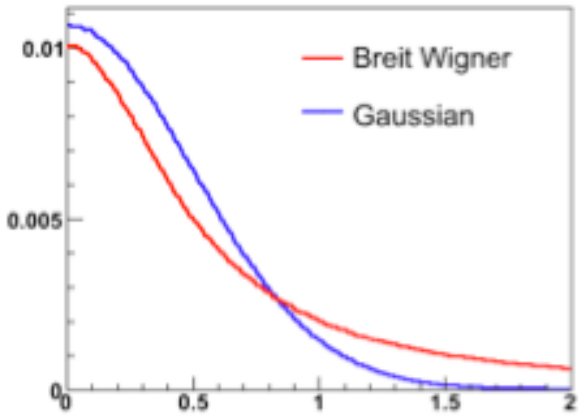
W Boson Width

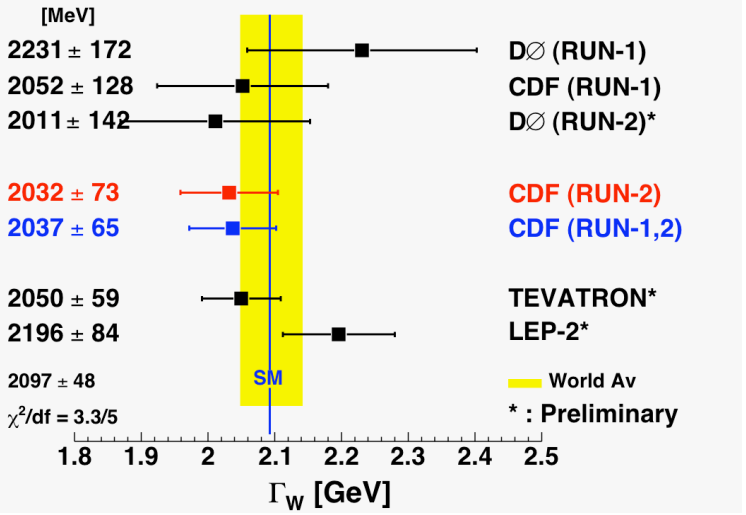
Fit for Γ_W in the high transverse mass tail for $W \to e\nu$ and $W \to \mu\nu$ channel



Γ_W = 2032 ± 73 (stat + syst) MeV

Phys. Rev. Lett. 100, 071801 (2008)



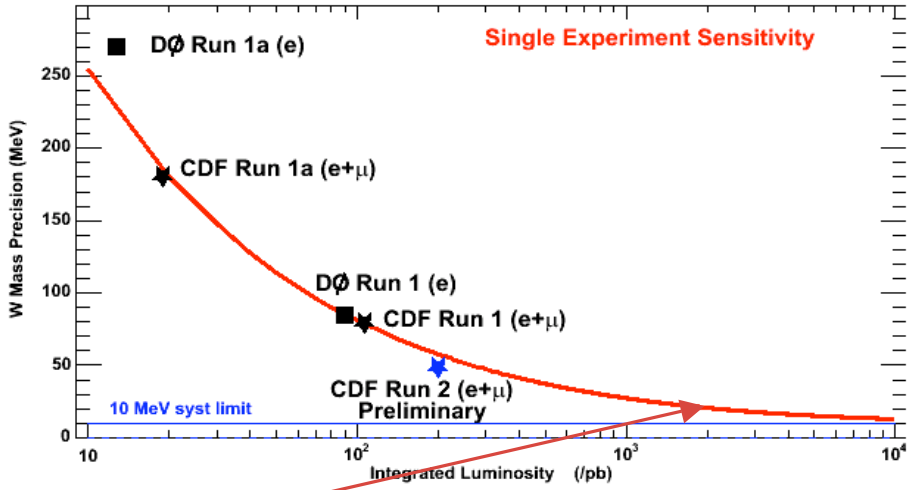


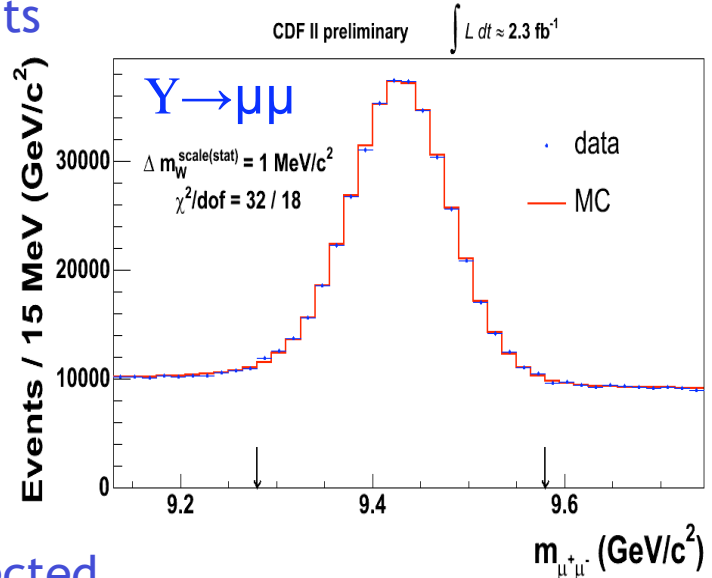
World's most precise measurement! (reduces average uncertainty by 20%)

(Γ_W^{SM} = 2091 ± 2 MeV)

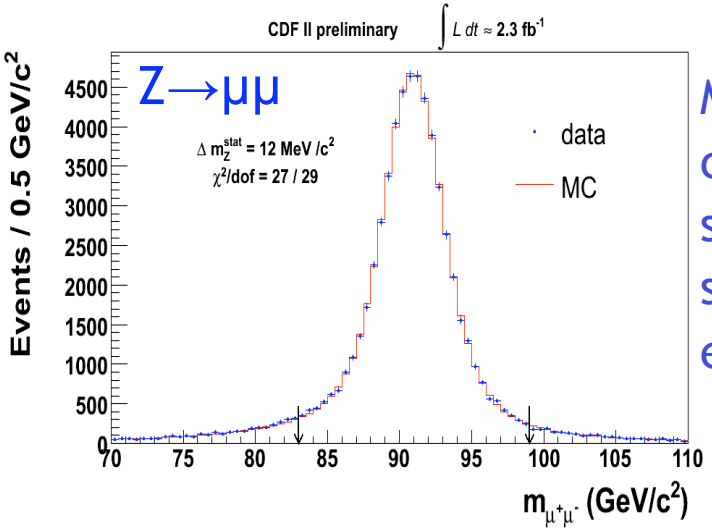
W Boson Mass Outlook

- Projection from previous Tevatron measurements

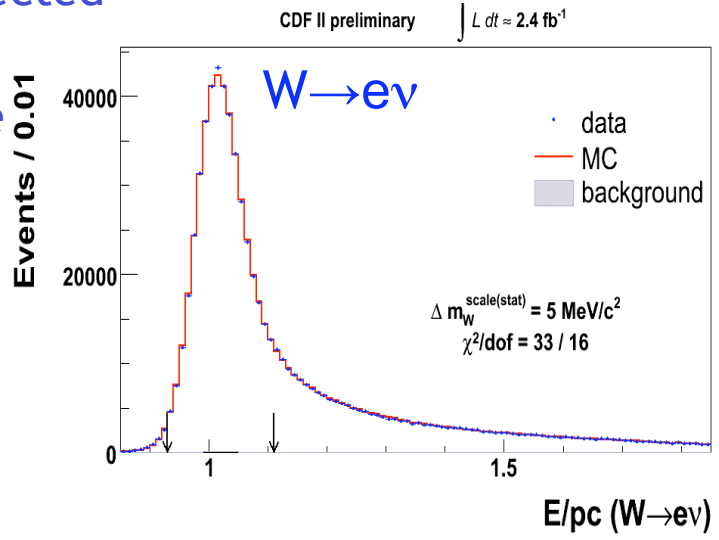




- Expect ΔM_W < 25 MeV with ~2 fb^{-1} already collected



Momentum scale control samples scale as statistically expected



Summary

- New precision measurements of the W/Z asymmetries start testing accuracy of our knowledge of the proton structure
  - Latest Z boson $d\sigma/dy$ measurement now included in MSTW2009

- Precision measurements of the W boson mass and width are the single most precise for one experiment
  - $m_W = 80413 \pm 48$ (stat + syst) MeV
  - $\Gamma_W = 2032 \pm 73$ (stat + syst) MeV

- Global electroweak fits favour low Higgs mass
  - $m_H = 84^{+34}_{-26}$ GeV, $m_H < 154$ GeV @ 95% C.L.

- A W boson mass measurement from CDF with 25 MeV uncertainty will significantly improve the Higgs constraint