Tim Andeen
CERN (and recently Northwestern University)

Recent Electroweak Physics Results from the Tevatron

For the DØ and CDF Collaborations

21st Rencontres de Blois, Windows on the Universe
June 21-26, 2009

New Electroweak Results since January 2009

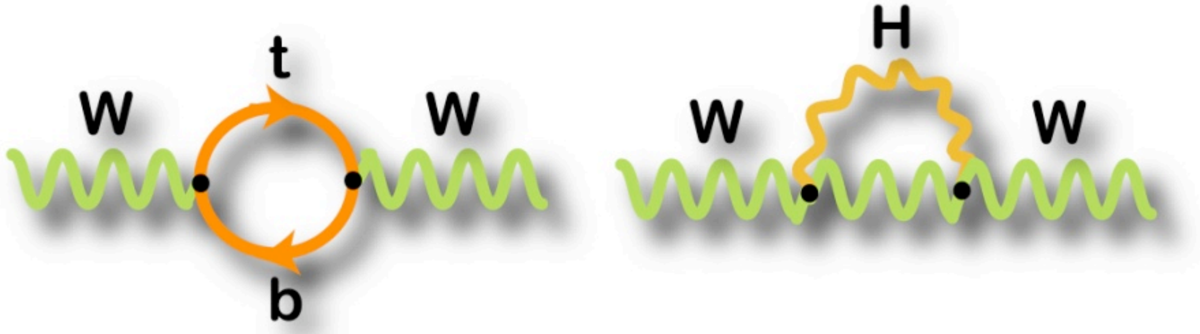
- W Boson Mass (1 fb^{-1}) D0
- W Charge Asymmetry (1 fb^{-1}) CDF
- Di-electron Rapidity from Z/γ^* (2.1 fb^{-1}) CDF
- $Z\gamma \to \nu\nu\gamma$ (3.6 fb^{-1}) D0
- $WW \to l\nu l\nu$ cross section (1 fb^{-1} D0 and 3.6 fb^{-1} CDF)
- $VV \to l\nu jj$ / $\nu\nu jj$ (3.5 fb^{-1}) CDF
- ...and more:

Webpages of results
CDF: www-cdf.fnal.gov/physics/physics.html
DØ: www-d0.fnal.gov/Run2Physics/WWW/results.html

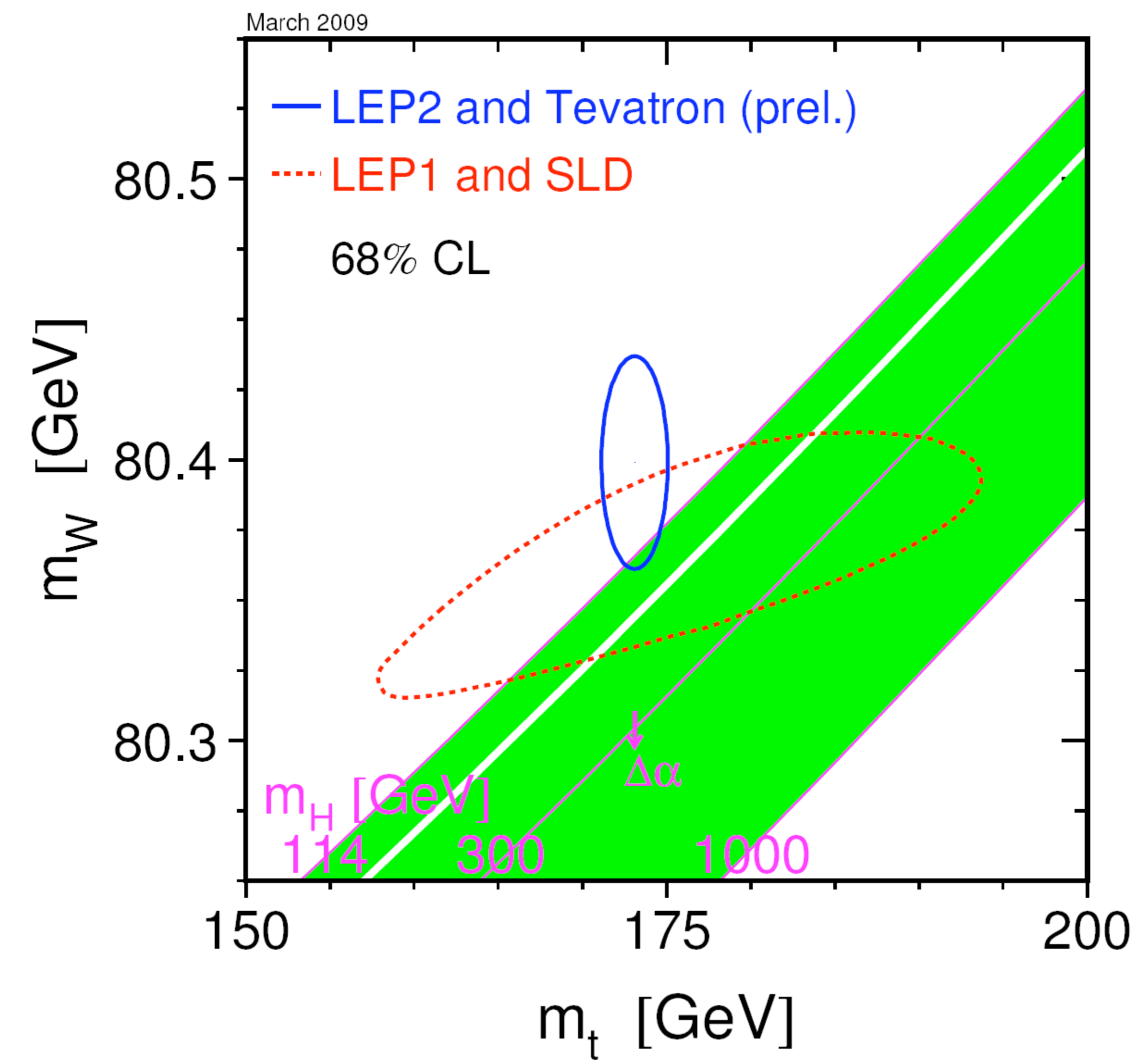
W Boson Mass - Motivation

Precision measurements of M_W and M_t constrain SM Higgs mass.

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



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

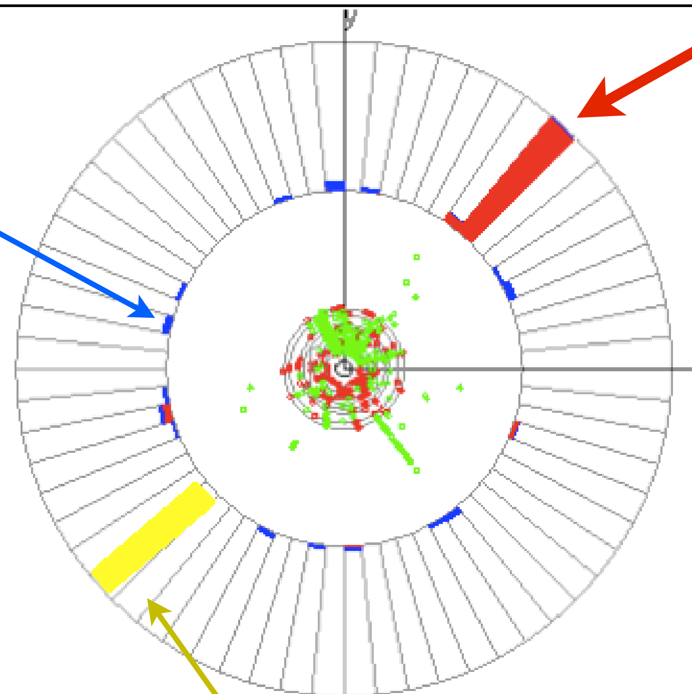


- ΔM_t = 1.3 GeV (currently) means for a comparable constraint...
- We would need ΔM_W = 8 MeV!
- Current have 25 MeV.
- W mass uncertainty is the limiting factor.

W Boson Mass - Measurement Strategy

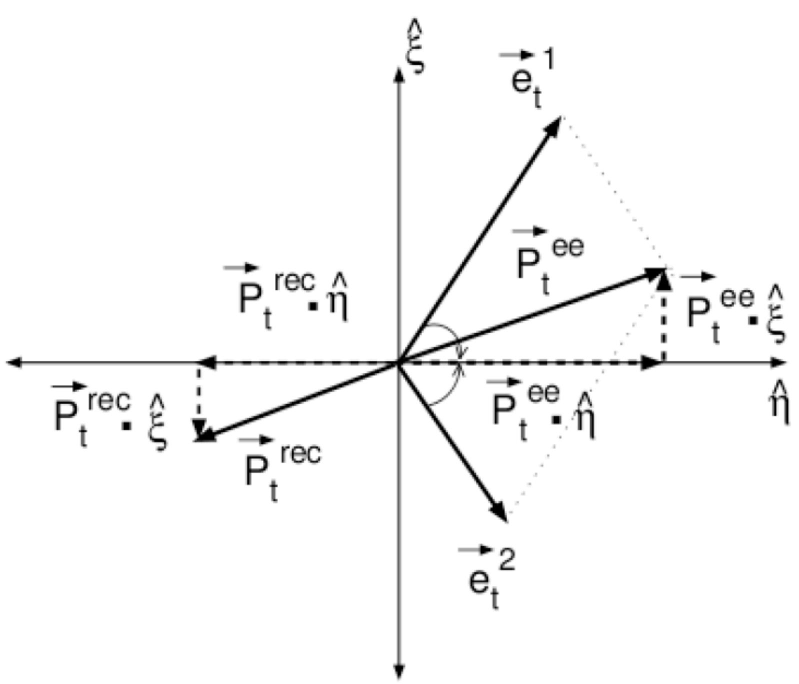
At hadron colliders transverse mass $m_T = \sqrt{2p_T^e p_T^\nu(1-\cos\Delta\phi)}$, electron p_T and neutrino p_T (inferred→MET) distributions are sensitive to the W Mass.

A typical $W \rightarrow e\nu$ event



Recoil

Recoil energy tuned at 1% level by balancing the electron energy and the recoil in $Z \rightarrow e^+e^-$ events using standard UA2 observables:

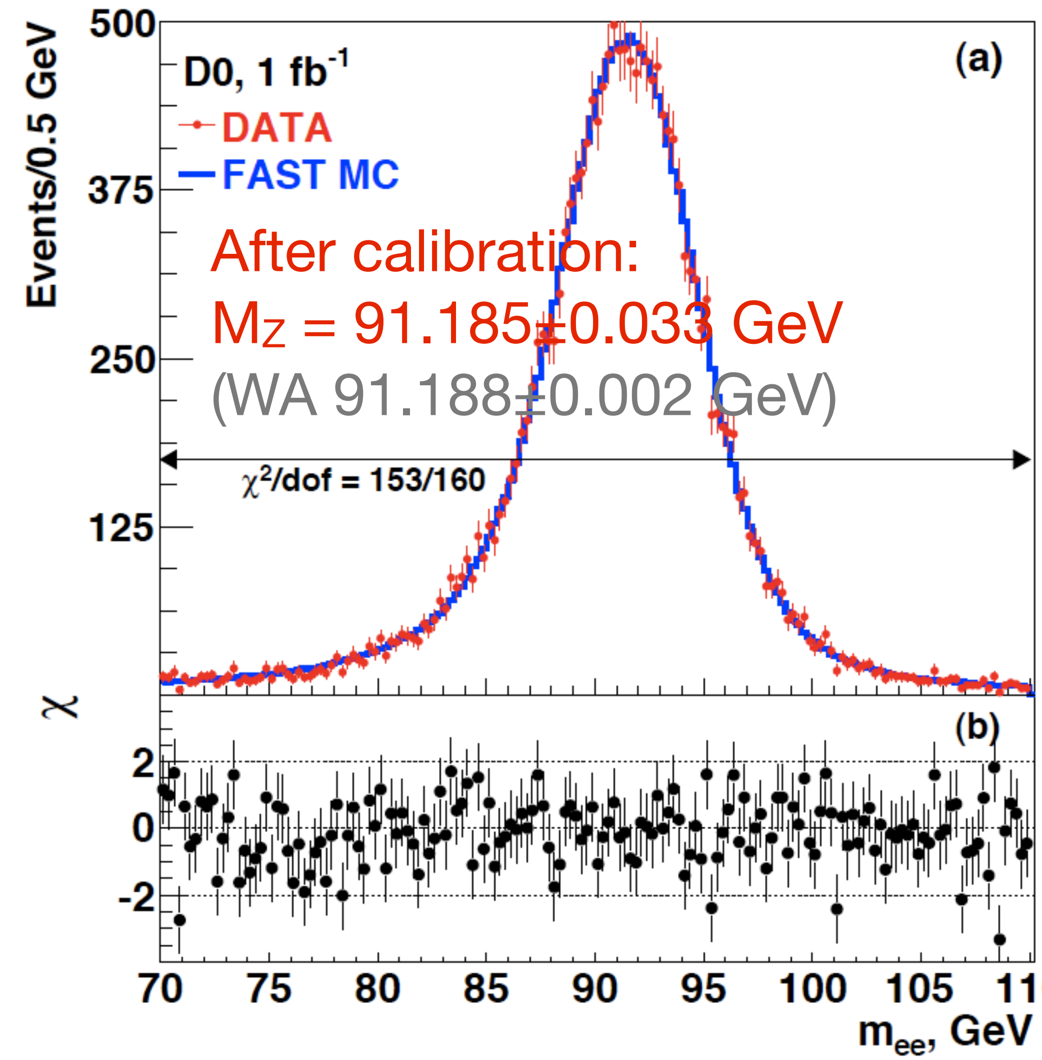


Neutrino

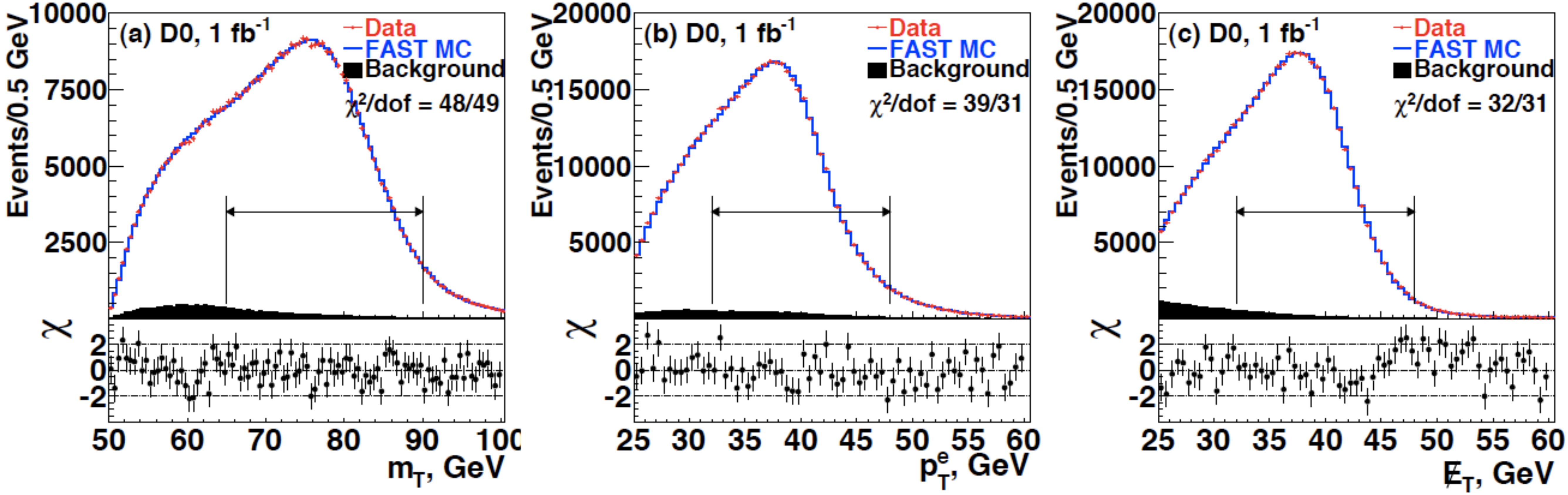
Inferred from recoil and electron energy.

Electron

Calibration of electron energy is derived from $Z \rightarrow e^+e^-$ events. Electron energy calibrated to the 2 per-mil level.



W Boson Mass - Result - 1 fb^{-1}



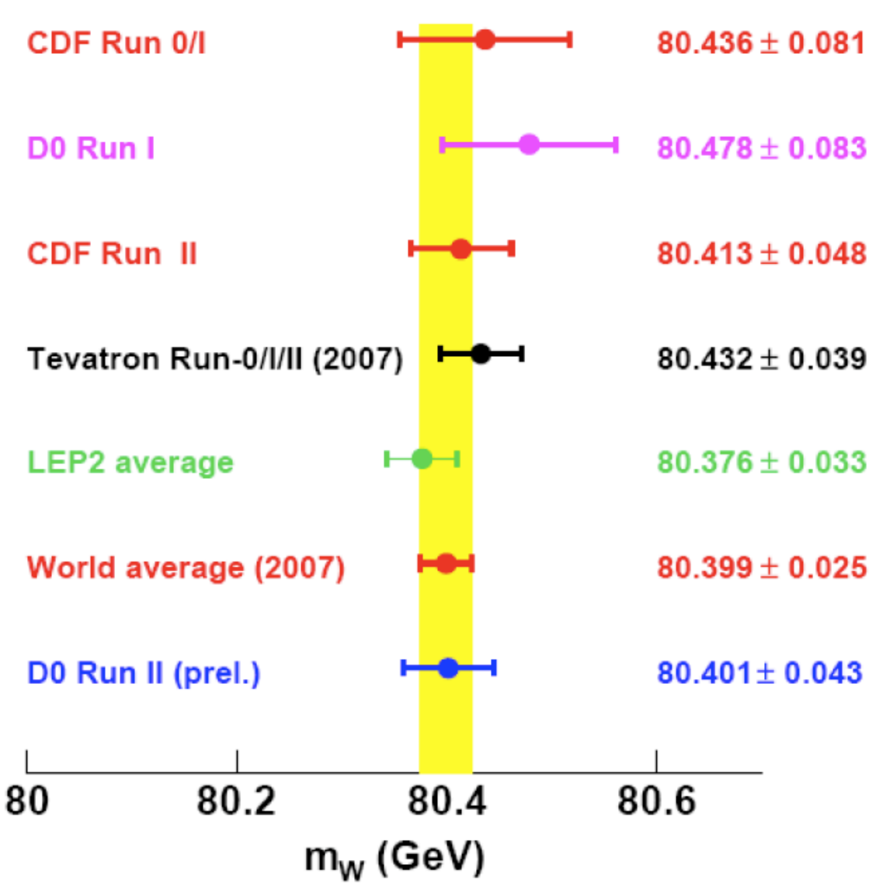
The mass extracted by fitting templates produced by a parameterized Monte Carlo simulation.

Combination of fits from three distributions:

80.401 ± 0.021 (stat) ± 0.038 (sys) GeV

80.401 ± 0.043 GeV

→Most precise measurement from a single experiment.



W Boson Mass - Uncertainty - 1 fb^{-1}

W mass systematic uncertainties in detail:

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	10	11	11
QED	7	7	9
Boson p_T	2	5	2
Production Subtotal	12	14	14
Total	37	40	43

- Energy calibration scales with luminosity (Z statistics).
- CDF is preparing measurement with 2.4 fb^{-1}. Preliminary statistical uncertainties of 16 (15) MeV for muon (electron) channel.

Di-electron rapidity - 2.1 fb^{-1}

Measurement of the shape of the boson rapidity gives us information on the fundamental interactions involved, tests NLO and NNLO predictions.

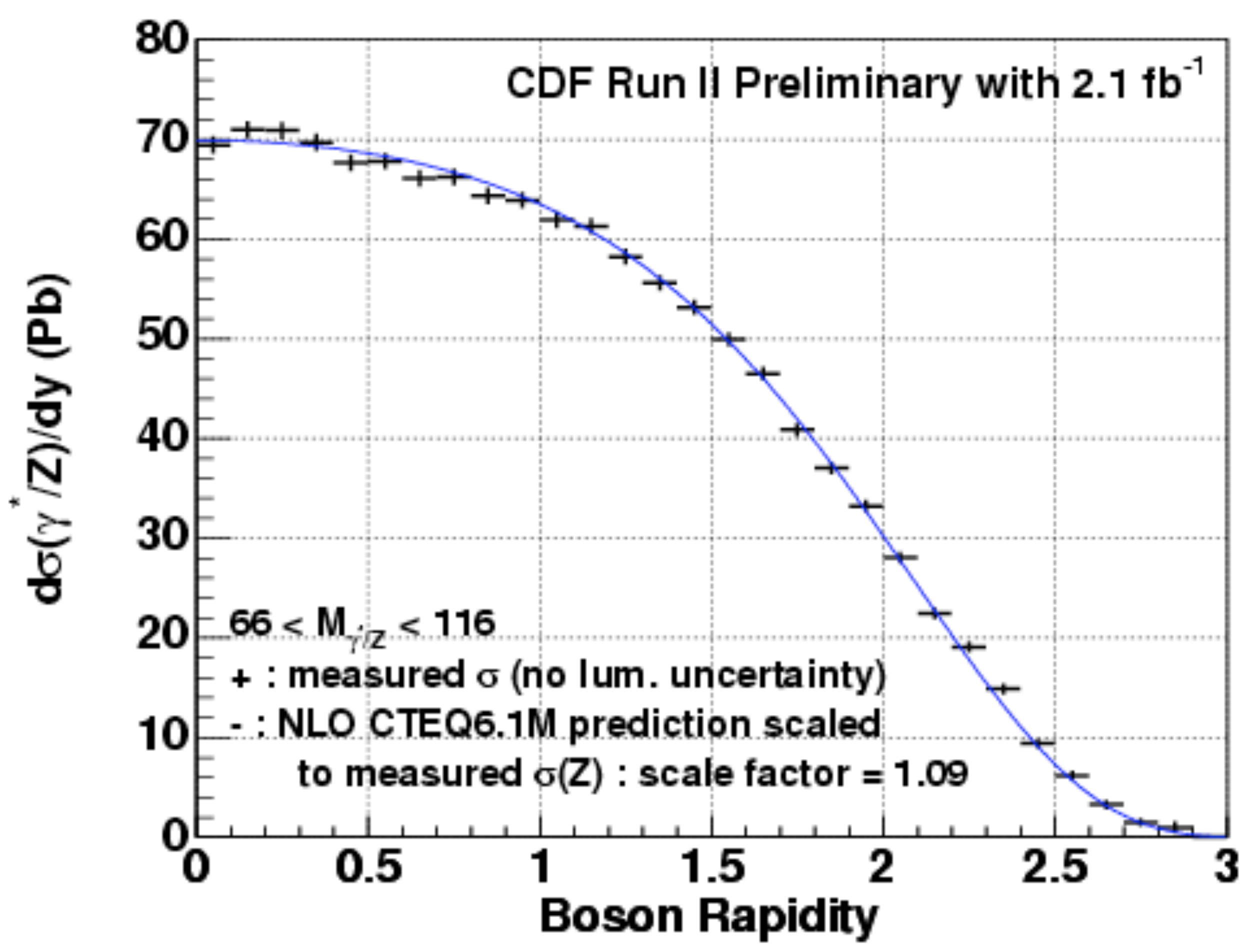
- At LO Z/γ^* is produced from quark/antiquark annihilation. The momentum fraction carried by the (anti)quark is $x_{1(2)}$.
- The rapidity of the boson is defined as : $y = \frac{1}{2}\ln\frac{E+p_L}{E-p_L}$

  is directly related to the momentum fractions: $x_{1,2} = \frac{M_{Z/\gamma^*}}{\sqrt{s}} e^{\pm y}$

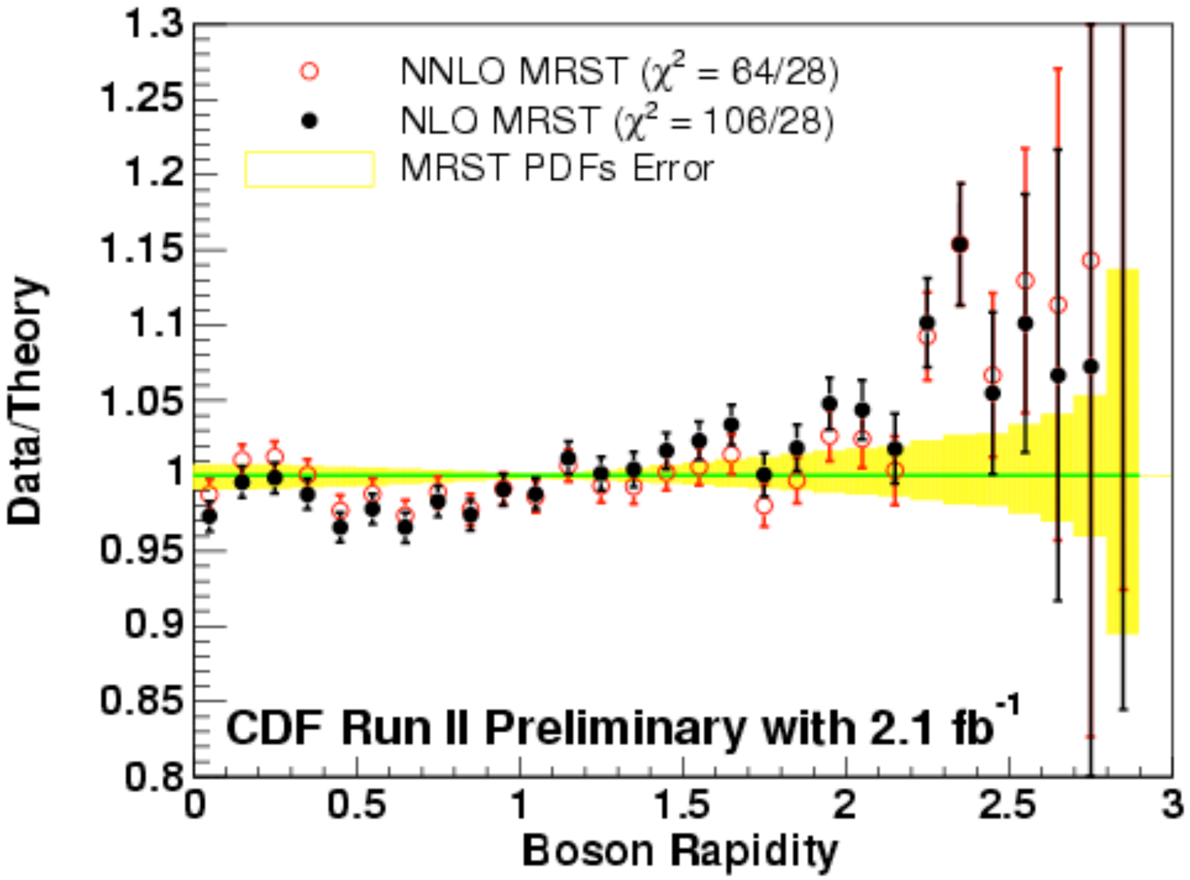
- CDF measures the differential cross section

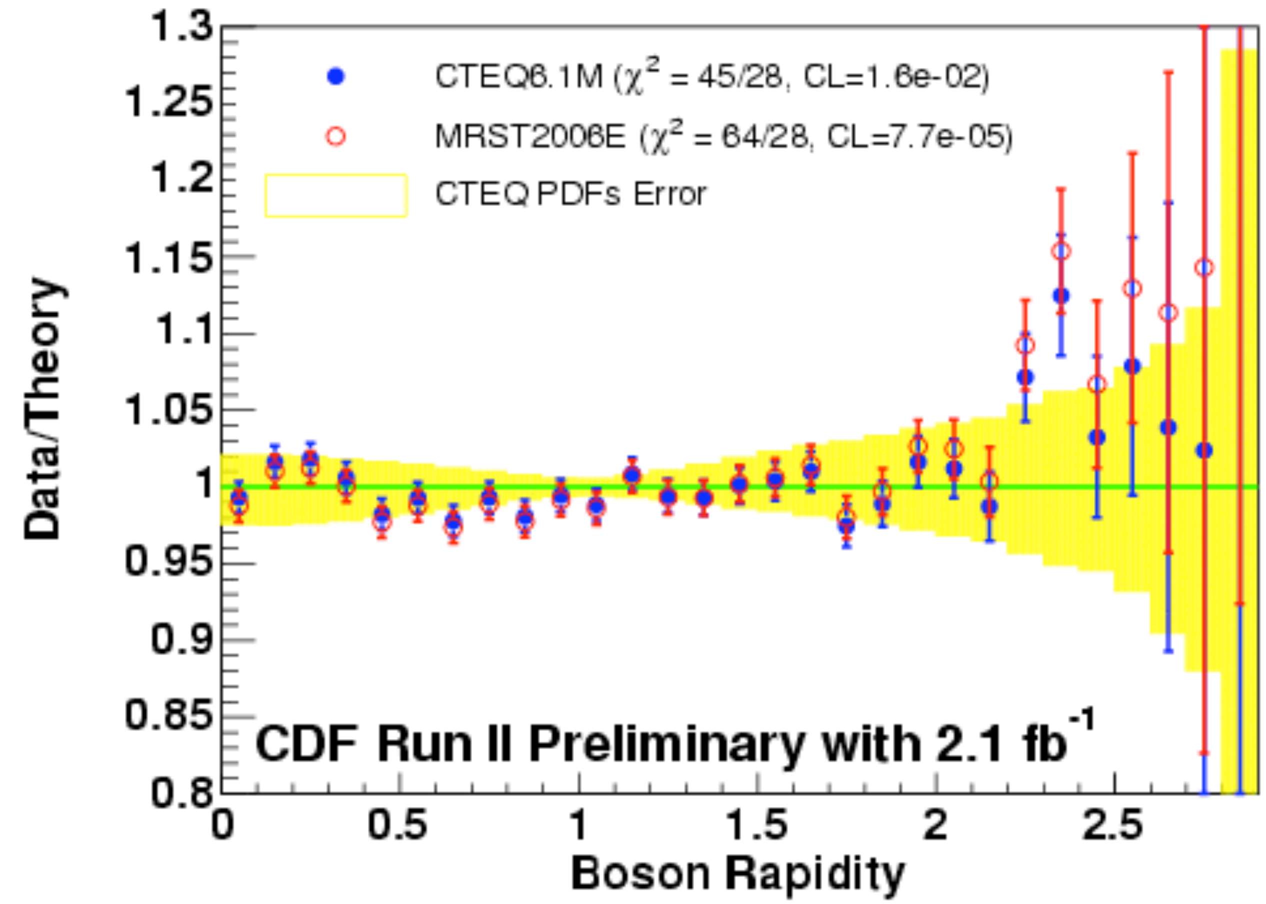
$$\frac{d\sigma(\gamma^*/Z)}{dy}(y) = \frac{N_{sig}(y) - N_{bkg}(y)}{\Sigma_i A \times \epsilon(y) \cdot \epsilon^i_{trig}(y) \cdot \epsilon_{zvtx} \cdot \int Ldt}$$

- Using central ($|\eta|$<1.1) and forward (1.2<$|\eta|$<|2.8|) electrons, in the Z mass region 66 GeV < M_{ee} <116 GeV.



Di-electron rapidity - 2.1 fb^{-1}





CDF compares the rapidity to NNLO (MRST - right) and NLO (CTEQ - left) predictions. Only statistical errors shown, the best agreement is found with CTEQ NLO calculation. Constrains future PDF fits.

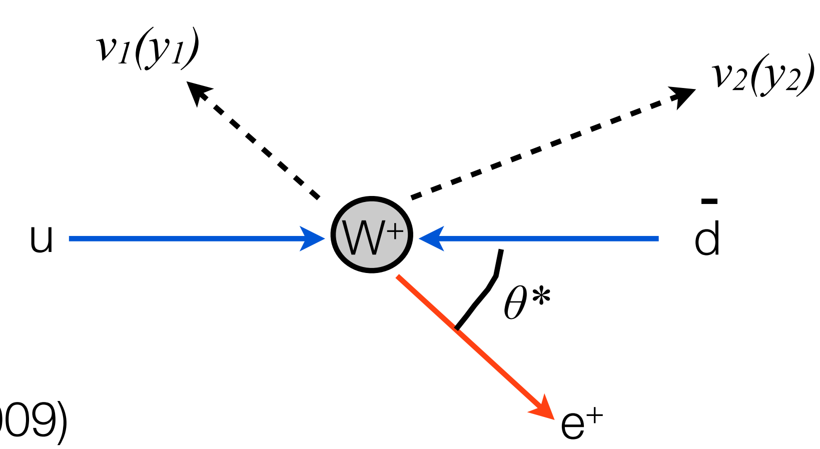
W Charge Asymmetry - 1 fb^{-1}

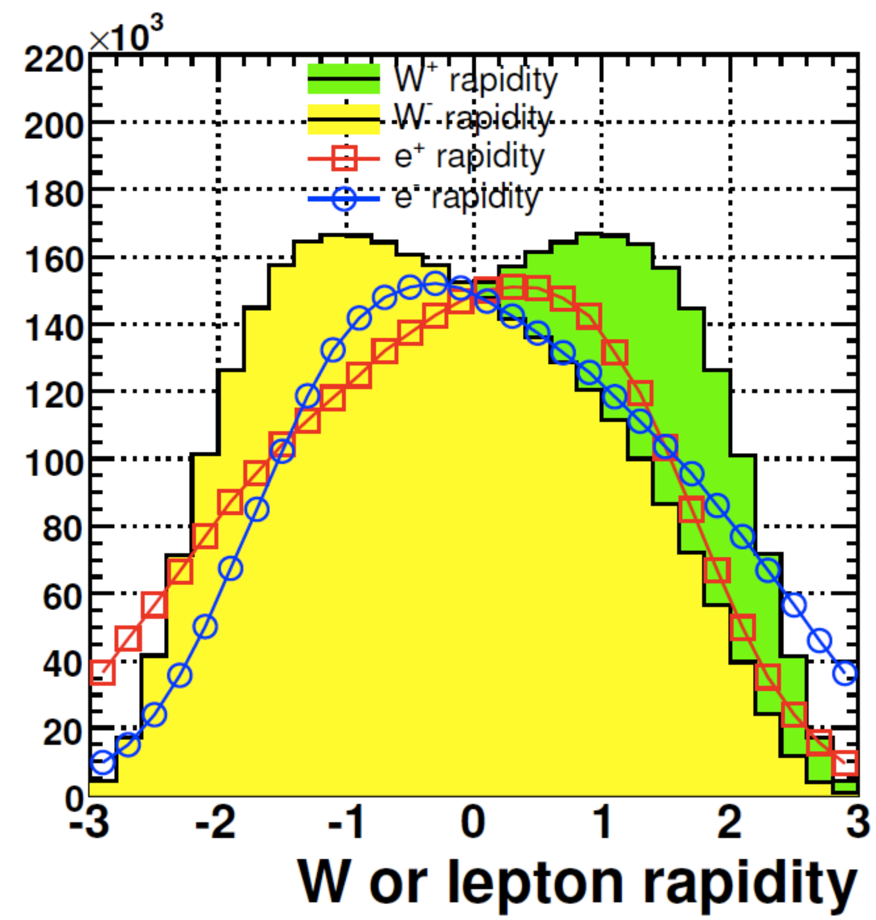
A new analysis technique to measure the W charge asymmetry.

- On average, the u quark carries more momentum than the d quark in the proton. As a result the W^+ (W^-) is, on average, boosted in the (anti) proton direction.

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

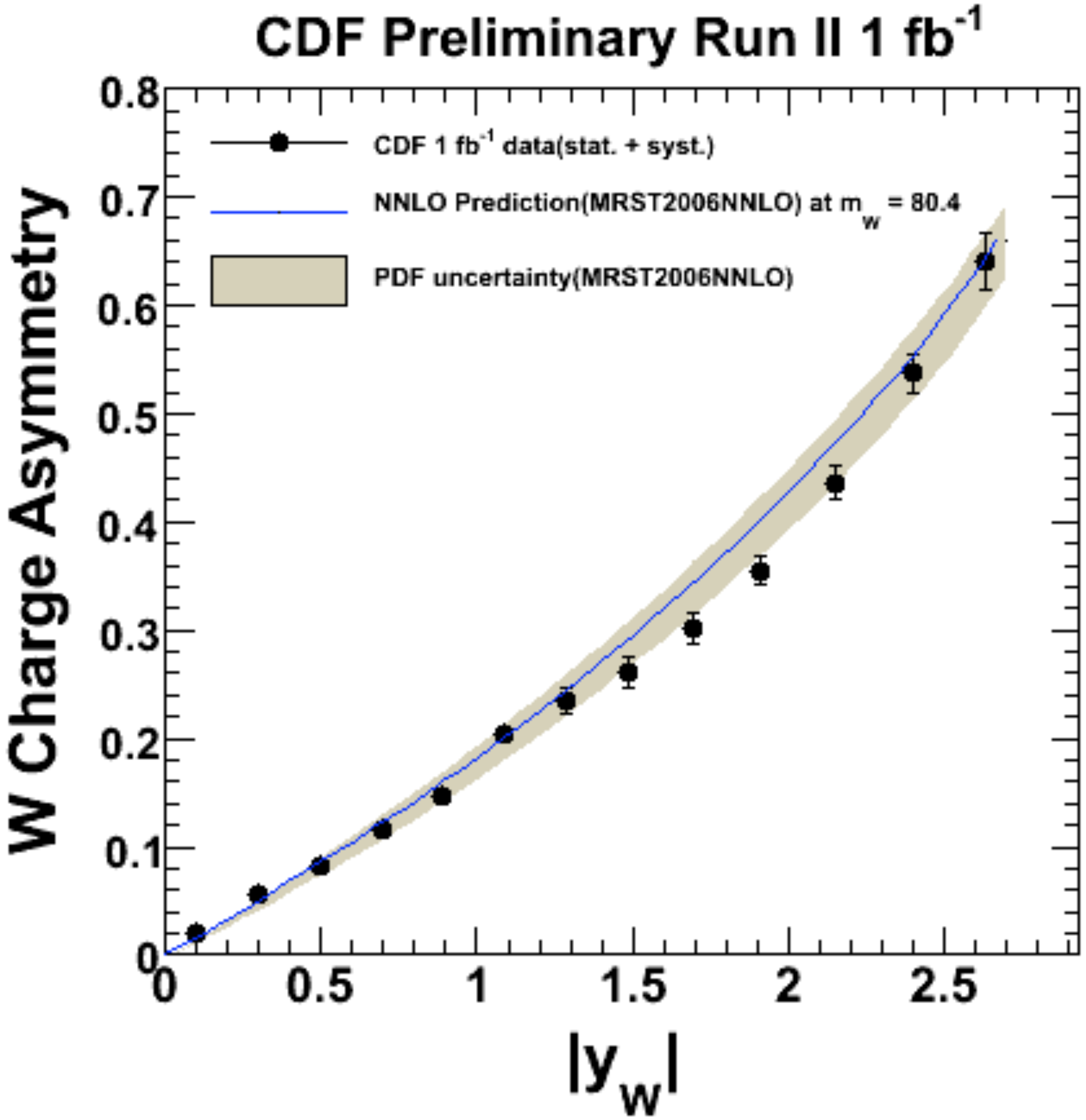
- The asymmetry probes the u/d ratio in the proton.
- CDF measures the W rapidity by constraining the longitudinal momentum of the neutrino using the W mass. Weight the 2 solutions using W production ($\sigma(y_W)$) and decay (V-A structure: $p_T(W)$, y_W, θ^*) predictions and iterate.

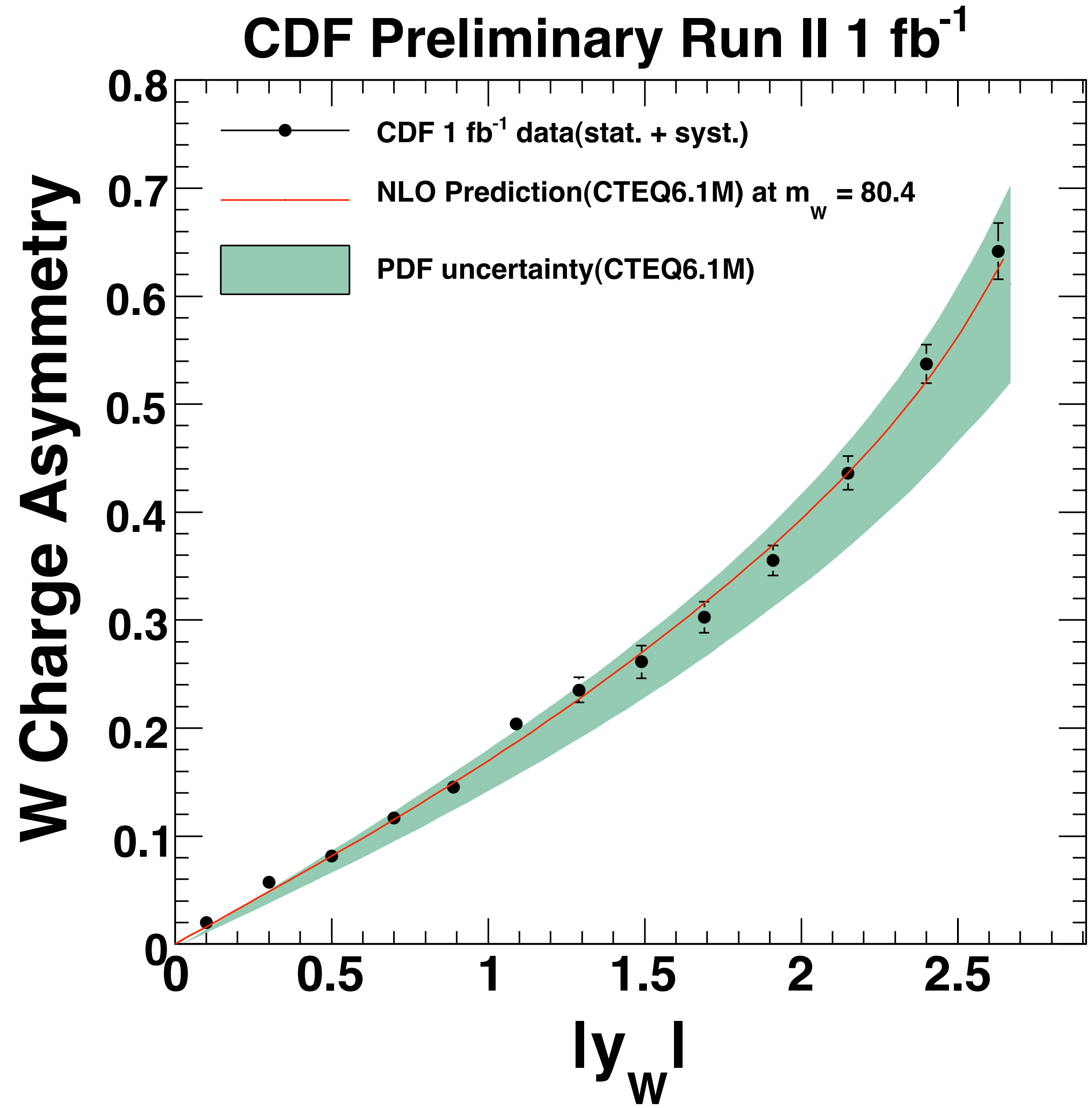




Phys. Rev. Lett. 102, 181801 (2009)
arXiv: 0901.2169 [hep-ex]

W Charge Asymmetry - 1 fb^{-1}





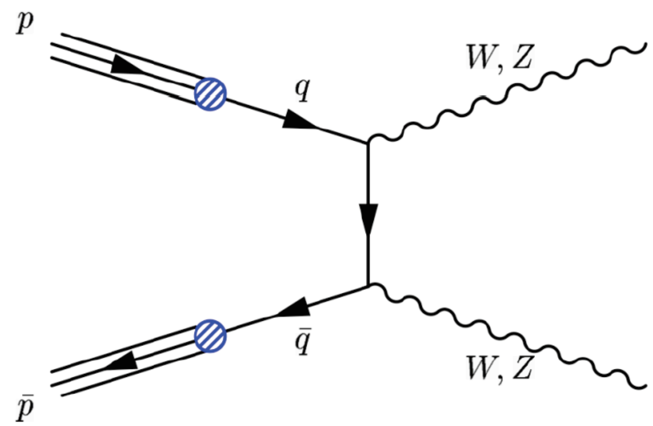
CDF compares the asymmetry to NNLO (MRST) and NLO (CTEQ) predictions.

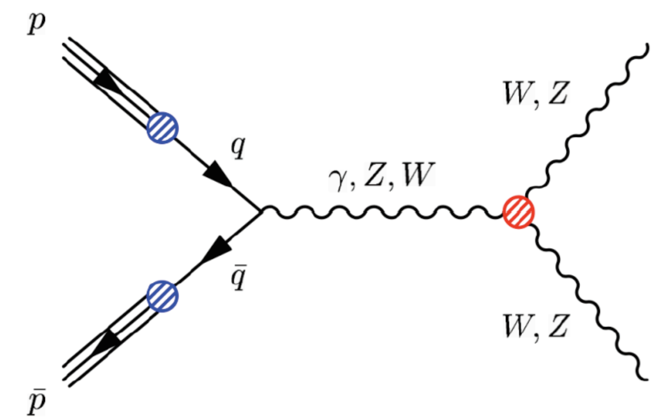
Statistical and systematic uncertainty less than PDF uncertainty.

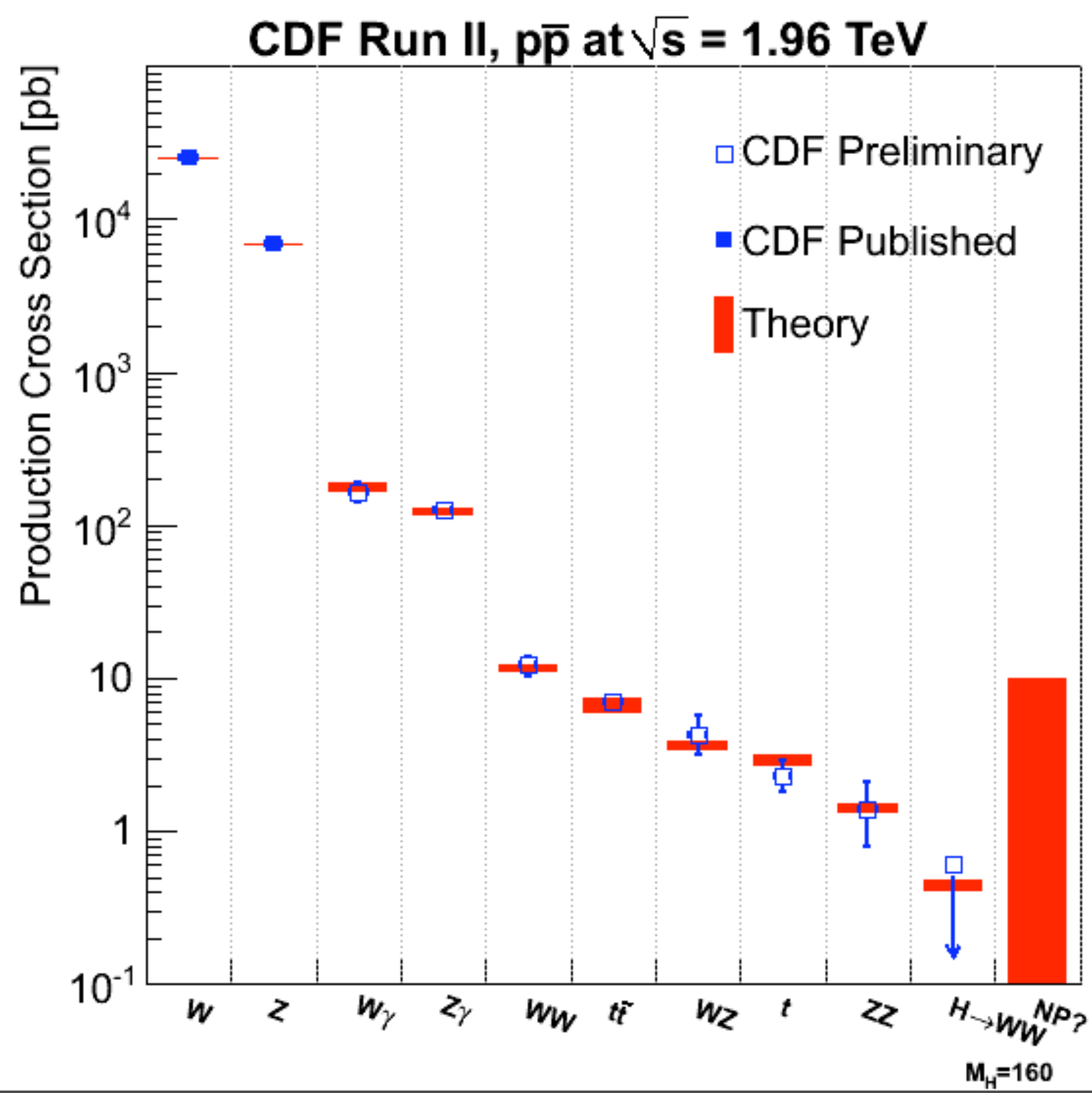
Phys. Rev. Lett. 102, 181801 (2009)
arXiv: 0901.2169 [hep-ex]

Diboson Processes

- A test of the Standard Model and a "road" to the Higgs.
    - WW, WZ and ZZ all observed at the Tevatron with >5σ significance.
    - Production rate would be changed by anomalous, non-Standard Model triple gauge couplings such as WWZ, WWγ → test of SM.
    - The final state is similar to the Higgs → proving analysis methods and determining backgrounds.
- Tevatron complements LEP results, probing higher center of mass energies, and different coupling combinations.



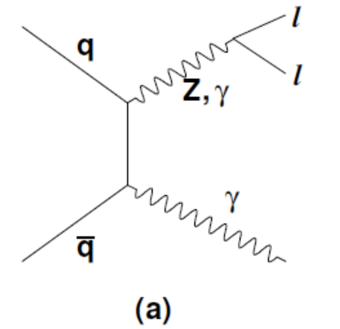




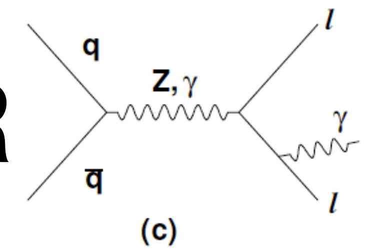
$Z\gamma \rightarrow \nu\nu\gamma$ 3.6 fb^{-1} →NEW←

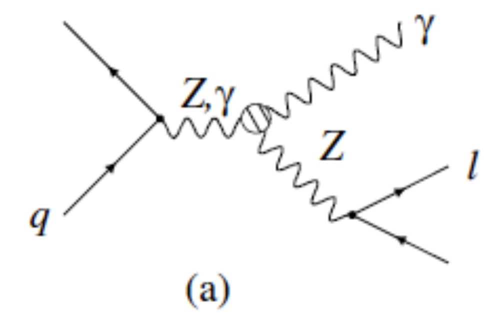
- First observation (5.1σ) of process at the Tevatron.
  - ✦ Search for single photon E_T > 90 GeV in the central calorimeter,
  - ✦ neutrinos indicated by MET > 70 GeV.
  - ✦ no second EM object, no jet object.

ISR



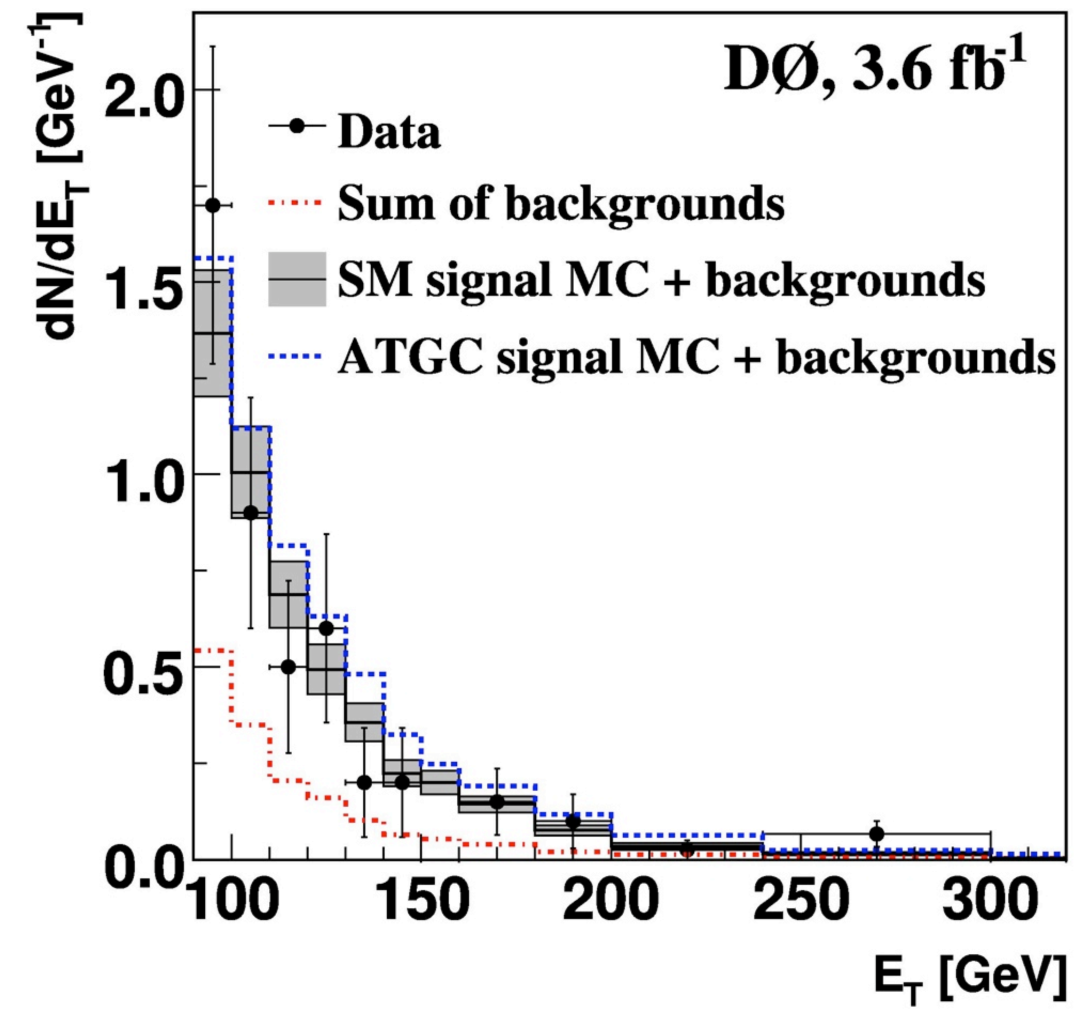
FSR





Non-SM

	Number of events
$W \rightarrow e\nu$	$9.67 \pm 0.30(\text{stat.}) \pm 0.48(\text{syst.})$
non-collision	$5.33 \pm 0.39(\text{stat.}) \pm 1.91(\text{syst.})$
W/Z + jet	$1.37 \pm 0.26(\text{stat.}) \pm 0.91(\text{syst.})$
$W\gamma$	$0.90 \pm 0.07(\text{stat.}) \pm 0.12(\text{syst.})$
Total background	$17.3 \pm 0.6(\text{stat.}) \pm 2.3(\text{syst.})$
$N^{\text{SM}}_{\nu\bar{\nu}\gamma}$	33.7 ± 3.4
N_{obs}	51



- σ($Z\gamma \rightarrow \nu\nu\gamma$) = 32 ±9(stat.+sys.) ±2(lum.) fb

  (SM NLO 39±4 fb)

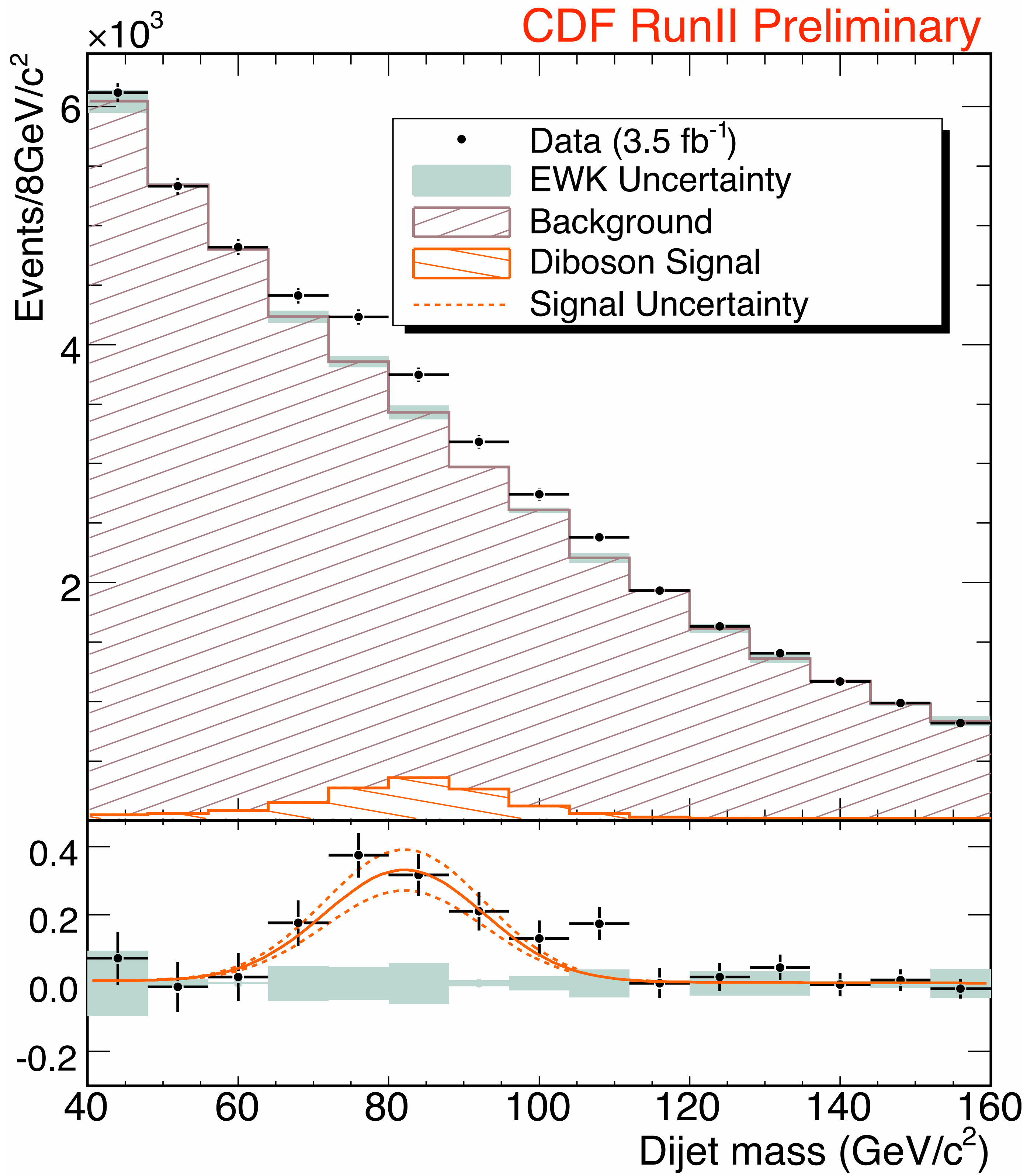
Phys. Rev. Lett. 102 , 201802 (2009)
arXiv: 0902.2157 [hep-ex]

$VV \rightarrow l\nu jj$ or $\nu\nu jj$ →NEW←

Final state 2 jets p_T>25 GeV, MET>60 Gev, no lepton required.

- WW dominates the signal.
    - Measured by CDF (3.6 fb^{-1})
    - $\sigma(WW \rightarrow l\nu l'\nu) = 12.1^{+1.8}_{-1.7}$ pb
    - Measured by D0 (1 fb^{-1})
    - $\sigma(WW \rightarrow l\nu l'\nu) = 11.5 \pm 2.2$ pb
- Difficult channel with large backgrounds. Similar signal to low mass SM Higgs. (for example ZH, WH).
- 1516±239(stat.)±144(syst.) diboson events observed in 3.5 fb^{-1}.

- $\sigma(VV) = 18.0 \pm 2.8(\text{stat}) \pm 2.4(\text{syst}) \pm 1.1(\text{lumi})$ pb
- Significance 5.3σ
- SM: $\sigma(VV) = 16.8 \pm 0.5$ pb



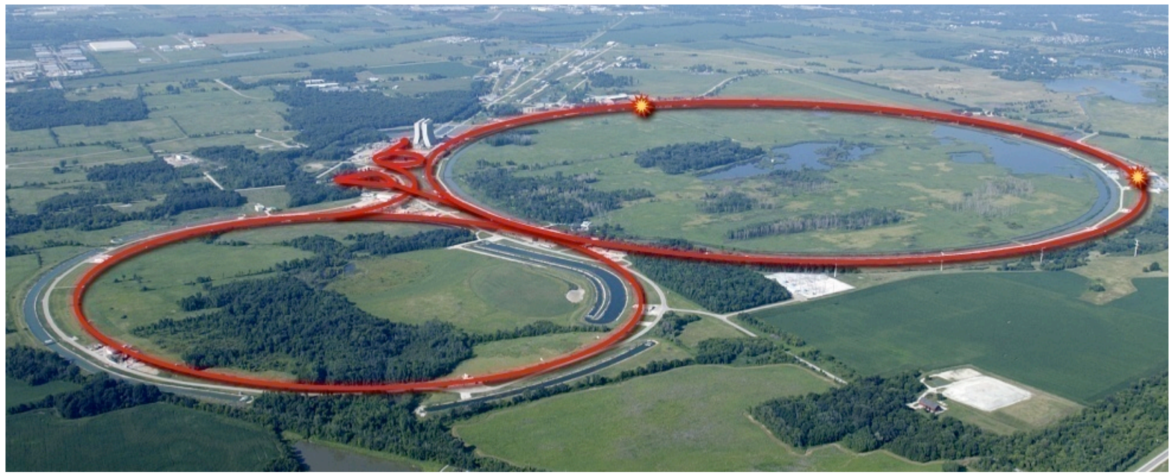
arXiv: 0905.4714

Summary and Prospects

- Most precise W mass measurement to date : 0.05%. Provides greater constraints on the Higgs mass.
- First direct measurement of W change asymmetry, and di-electron rapidity measurement constrain PDFs.
- Most precise measurement of WW and VV cross sections (along with the broad diboson program) show path to the Higgs.
- First observation of $Z\gamma \rightarrow \nu\nu\gamma$ provides increasingly tight limits on TGCs.

- Many other interesting analyses, this was just a sample.
- These analyses range from 1 to 3.6 fb^{-1}. More than 6 fb^{-1} *recorded* by each experiment!
  - for diboson analyses that means more events to measure smaller cross sections.
  - for precision measurements we have a chance to further understand and reduce the systematic uncertainties.
- *Many* analyses in the pipeline. The Tevatron remains an exciting place.

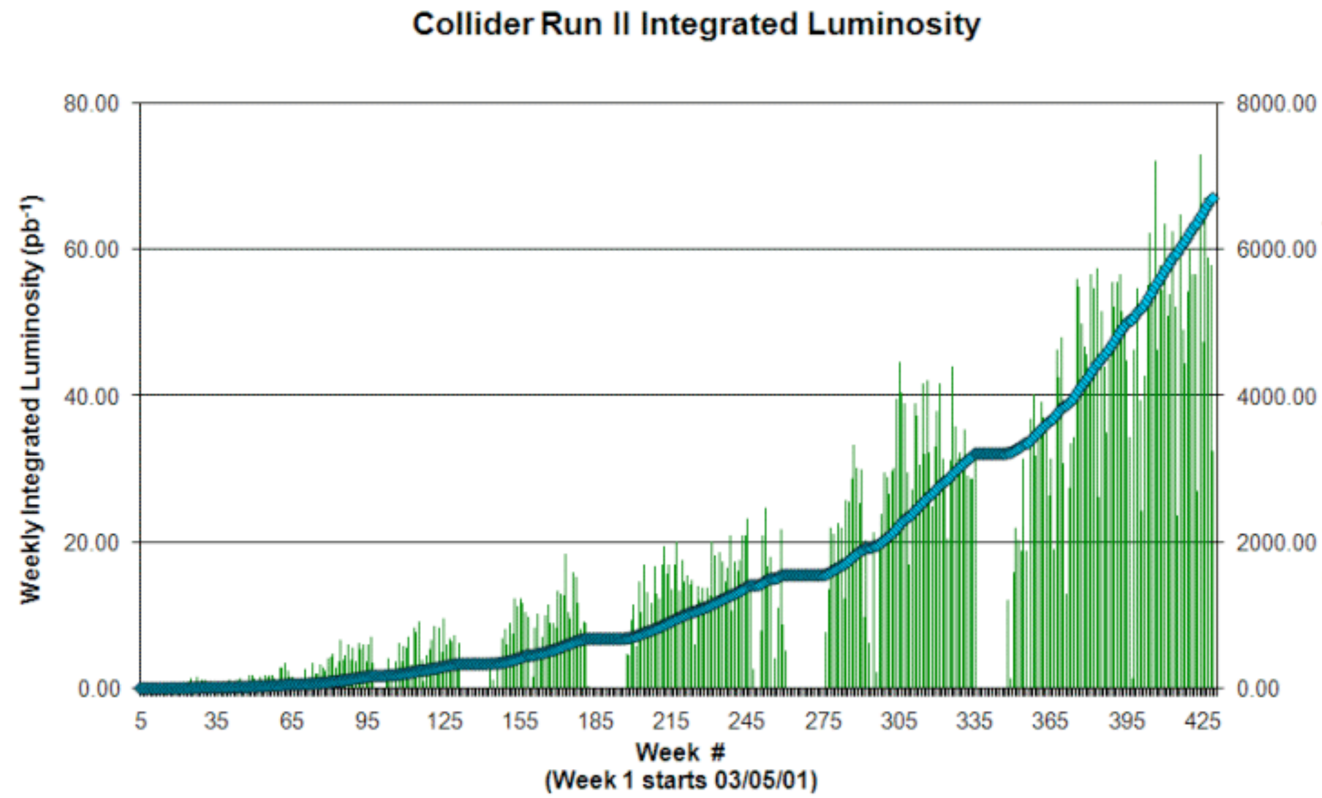
The Accelerators

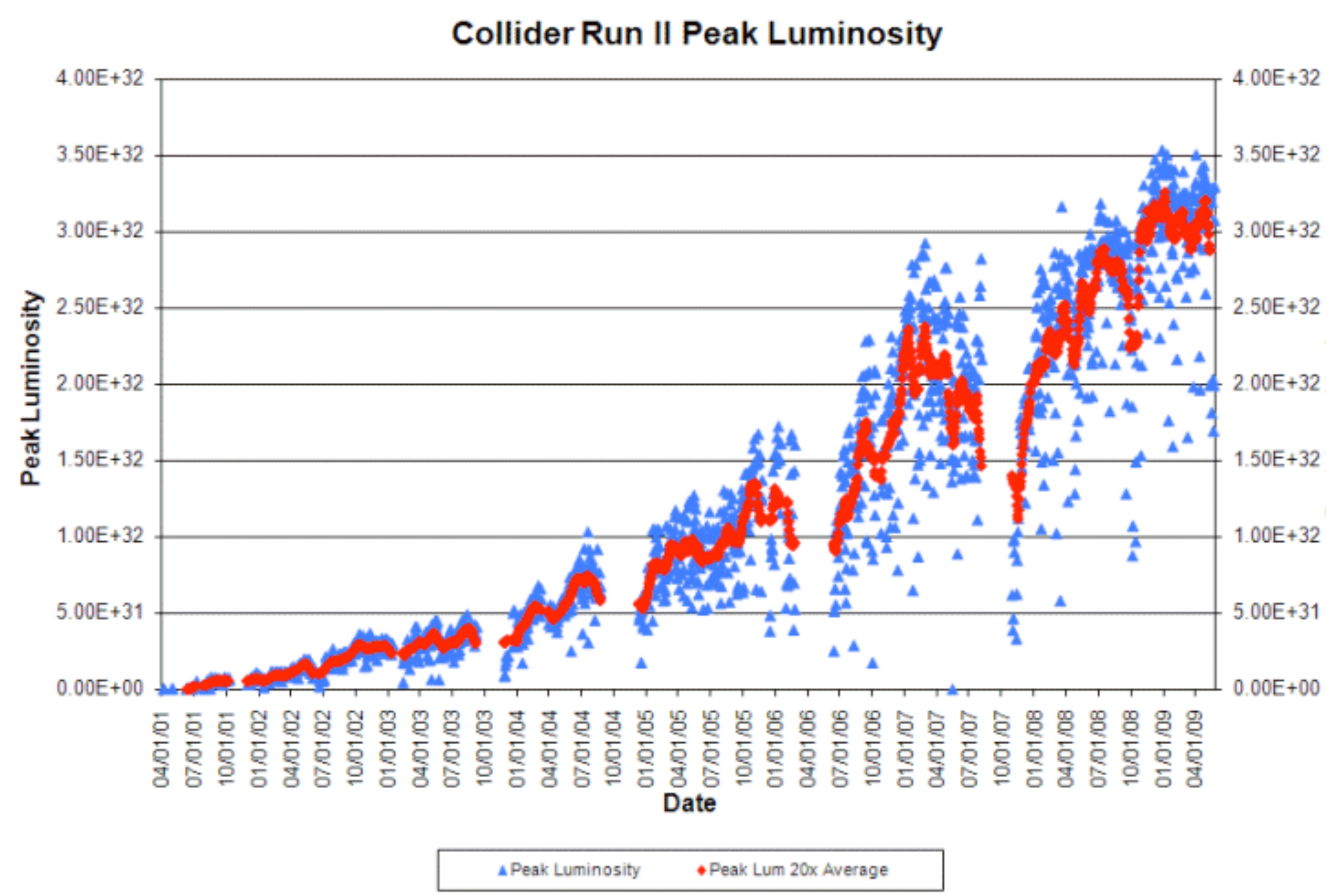


- > 6 fb^{-1} delivered to each experiment. Smooth and efficient operation thanks to the accelerator division.

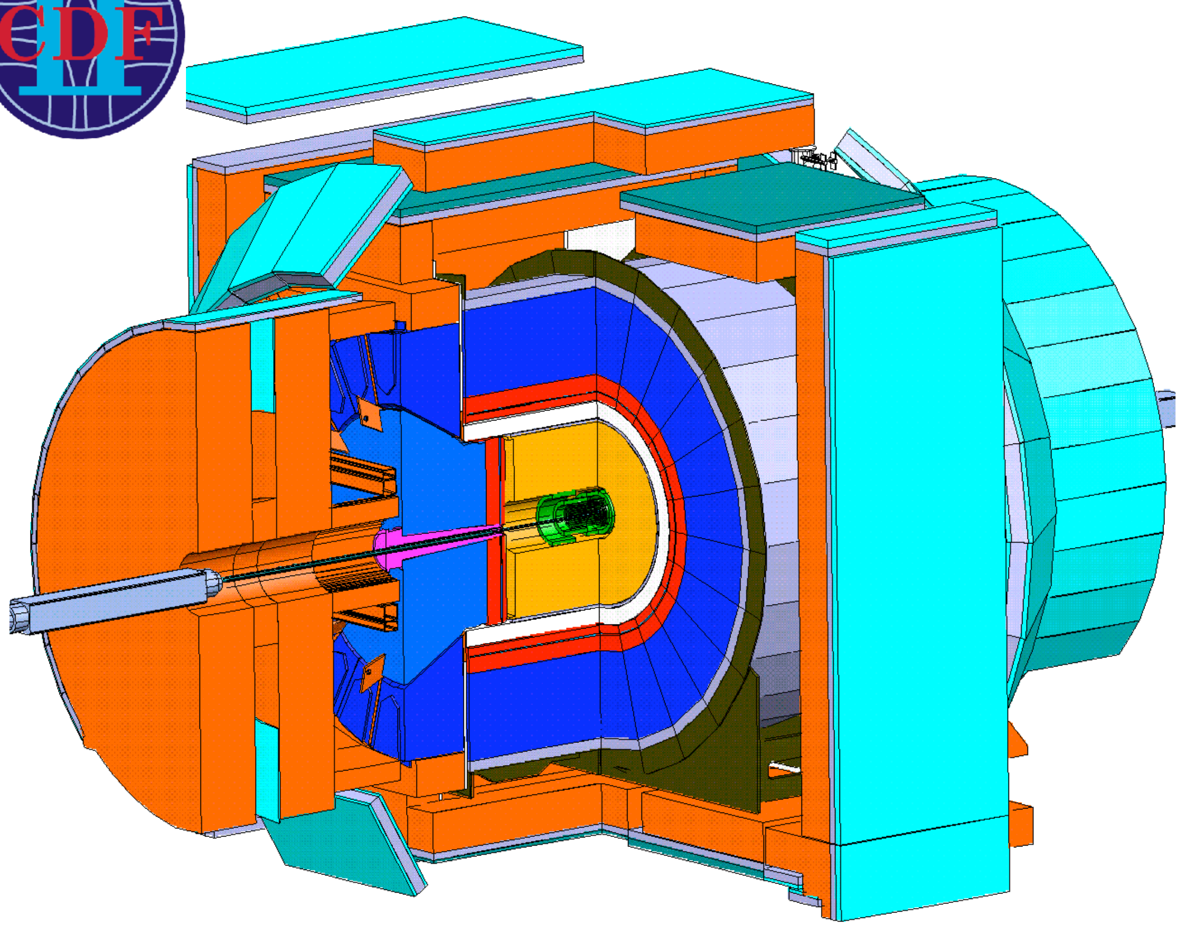
- Peak luminosity of 355 x 10^{30} cm^{-2} s^{-1}. Record week of 72 pb^{-1} delivered.

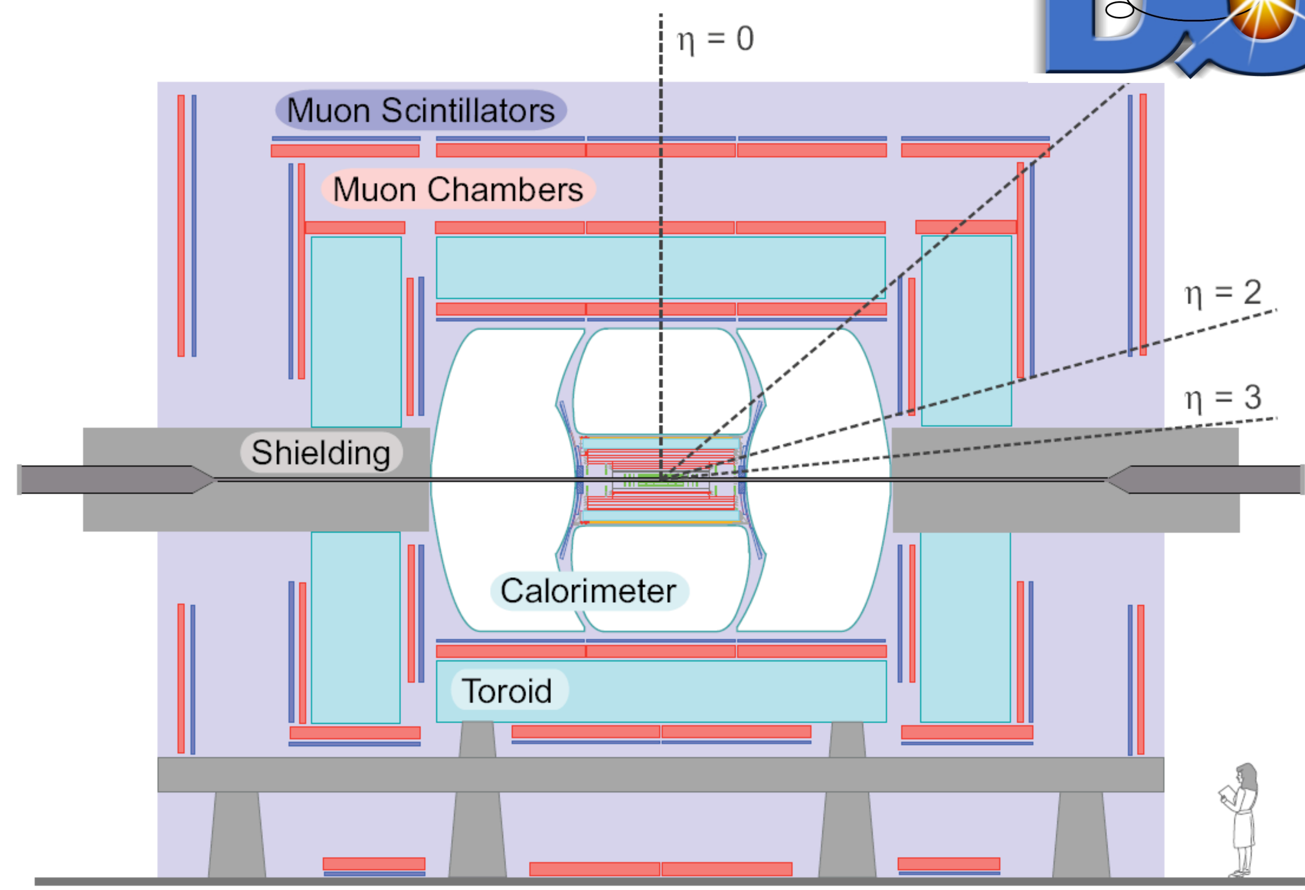
- Expect to reach 9 fb^{-1} in 2010. Today's results include up to 3.6 pb^{-1}.





The Experiments



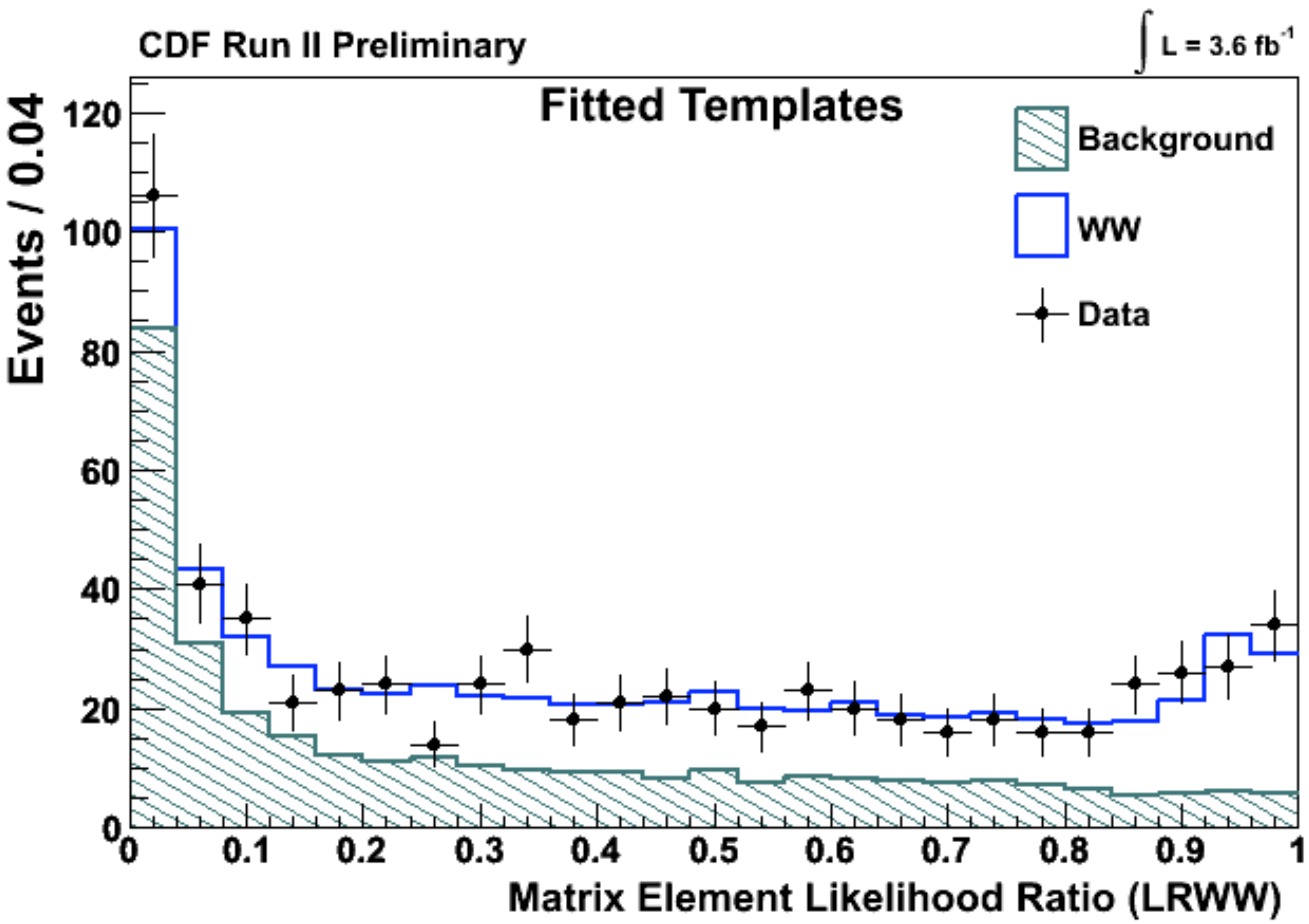


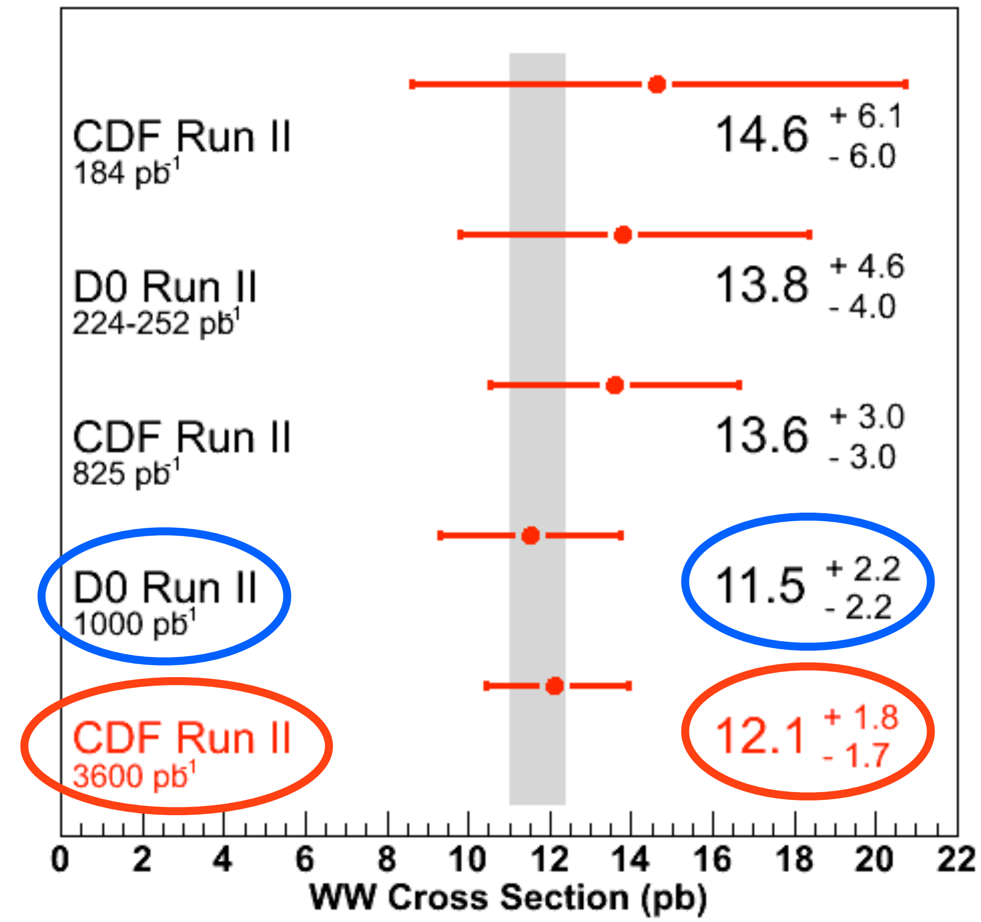
CDF and D0 are stable and well understood general purpose detectors. Nearly all sub-detectors are used in electroweak analyses.

- Silicon and drift chamber trackers
- Pb/Fe Scintillating Calorimeters
- Muon detectors

- Silicon and fiber trackers
- Uranium/Liquid Argon Calorimeters
- Muon detectors

$WW \rightarrow l\nu l'\nu$





- Final state: 2 leptons, missing transverse energy from neutrinos.
- D0: 1 fb^{-1}. Cross section is determined in a counting experiment. Electron, muon, or electron/muon final states allowed. Cut on a maximum $p_T(WW)$. arXiv:0904.0673
- CDF: Larger sample (3.6 fb^{-1}) and new analysis method calculating the probability the event was WW using event kinematics and LO ME cross sections.

  Cross section is determined with a binned maximum likelihood method using the shape of the likelihood ratio (LR) spectrum. → Most precise to date. ←