New EWK results from the Tevatron

P.Murat (Fermilab) on behalf of the CDF and D0 collaborations

- W and Z bosons are, in many ways, fundamental for the SM
  - measurements of masses and widths provide high precision tests of the foundations of the SM and its consistency
  - Indirect knowledge about the Higgs boson
  - self-interaction of W and Z at ~TeV scale violates unitarity

- $W \rightarrow l\nu$ and $Z \rightarrow ll$ decays have very clean and distinct experimental signatures
- Use W/Z as probes for precision studies of the low-pt processes
  - $d\sigma(Z \rightarrow ll)/dP_T$: effects of QCD resummation
  - $d\sigma(pp \rightarrow W/Z \rightarrow ll)/dY_{W,Z}$: parton distributions inside a proton

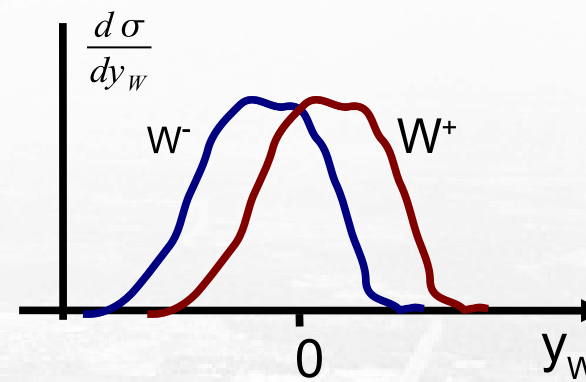
- $W/Z \rightarrow qq$: an important calibration line, also an experimental challenge

PDF's: what drives the need for improving the accuracy?

- Any theoretical calculation of $\sigma(p\bar{p} \to X)$ involves integration over the PDF's
- limit accuracy of the experimental measurements
  - Acceptance calculation for the signal processes
  - Cross section calculations - background predictions
- Uncertainties on the NNLO cross sections at the Tevatron
  - ~ 1% for $\sigma(p\bar{p} \to W)/\sigma(p\bar{p} \to Z)$ - indirect measurement of Γ_W
  - ~2-4% for the total W/Z cross sections
  - ~20% for M~1 TeV
- W mass measurements
  - For 2 fb^{-1} PDF uncertainties become the same as the statistical error

probing parton distributions

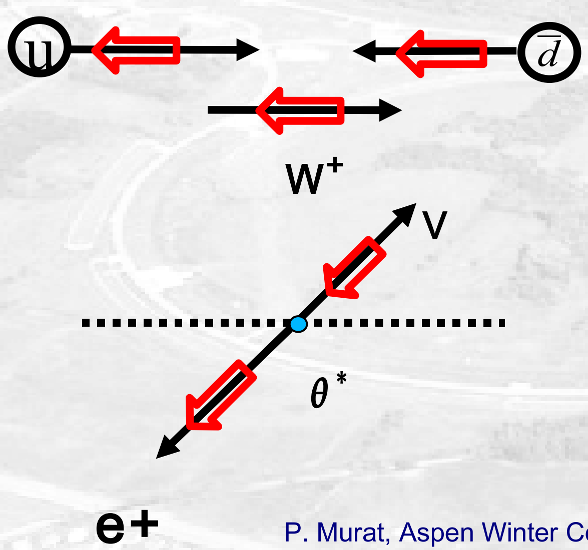
- Measure charge asymmetry in W production $A(y_W) = \dfrac{N^+(y_W) - N^-(y_W)}{N^+(y_W) + N^-(y_W)}$

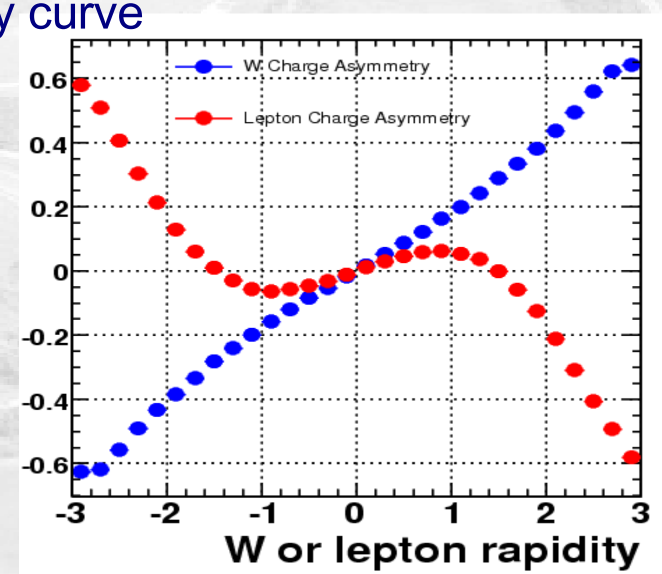


- W+'s produced in $p\bar{p} \to W$ are boosted in the direction of the incoming protons => charge asymmetry increases with y_W

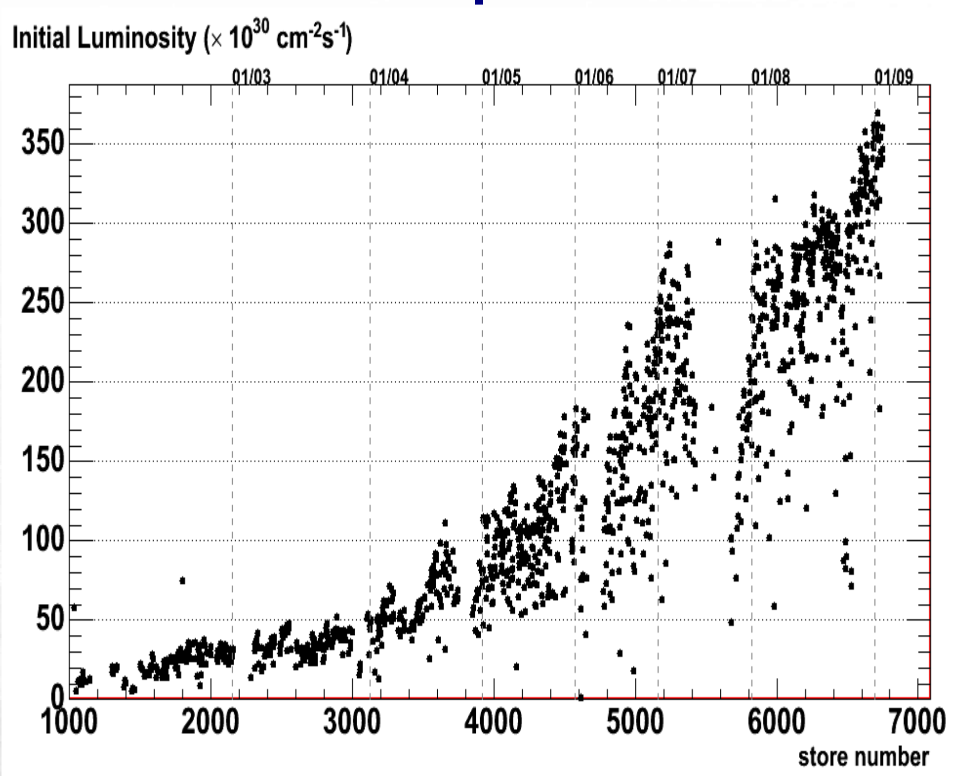
$$A(y_W) \sim \frac{u(x_1)}{d(x_1)} - \frac{u(x_2)}{d(x_2)}; \quad x_1 \cdot x_2 = \frac{M_W^2}{s}; \quad x_1 - x_2 = \frac{2M_W}{\sqrt{s}} \sinh y_W$$

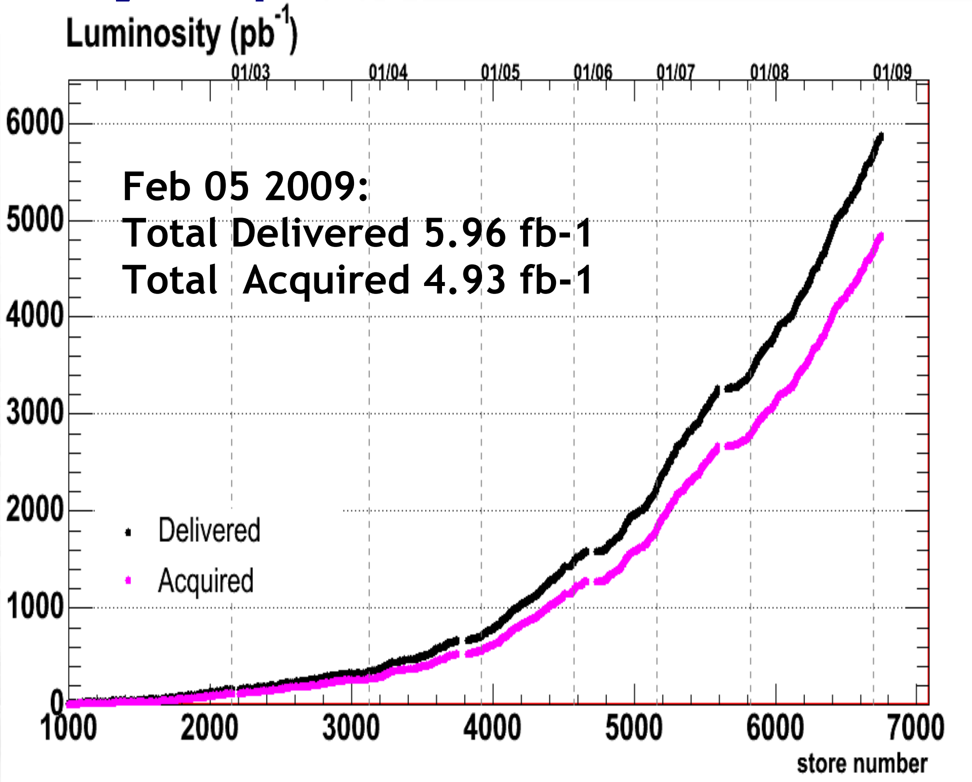
- Can't measure W rapidity directly, measure lepton $W \to l\nu$
- produced W+'s are polarized in the antiproton direction
- V-A structure of the decay current turns over the asymmetry curve





Tevatron performance: steady improvements



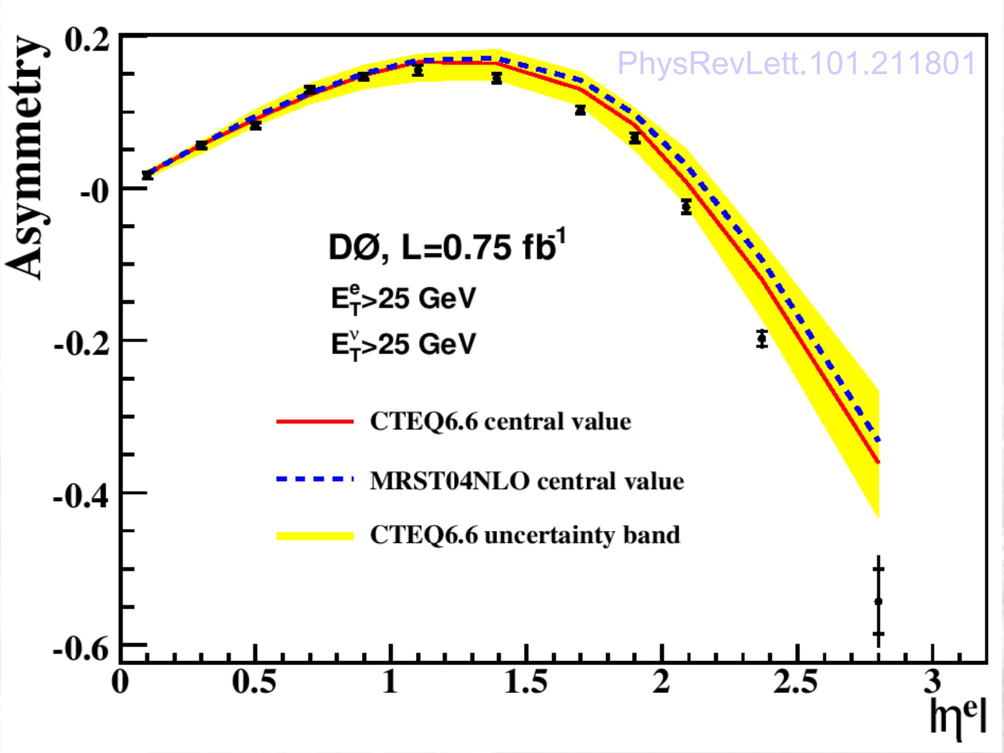


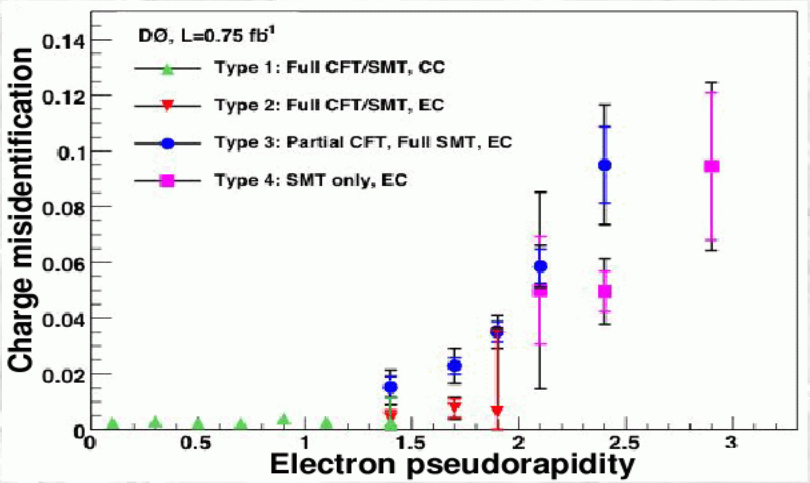
- CDF and D0 are taking data in a very stable mode
- over the last 3 years average L_{inst} increased by a factor of 3
- L > $300*10^{30}/cm^2s^{-1}$ routinely, record: L = $361*10^{30}cm^{-2}s^{-1}$
- ~ 10 MB events per bunch crossing @ 396ns bunch spacing
- Many thanks to Fermilab accelerator division!

Measurement of the lepton charge asymmetry in W->eν

(D0'2008, 0.75/fb)

- W selection: an isolated electron E_T > 25 GeV, |η| < 3.2, $\not{E}_T$ > 25 GeV, M_T > 50 GeV/c^2 ;
  - Total background ~ (4.2+/-0.4)%
    - Z->ee : (2.1+/-01)%
    - W->τν : (1.3 +/- 0.1)%
    - QCD : (0.8 +/- 0.4)%
  - Need to prove that the detector is charge symmetric
    - Trigger, reconstruction efficiencies
    - Charge misidentification rate





- Above |η| > 1 the data points tend to go lower predictions

lepton charge asymmetry: improving sensitivity

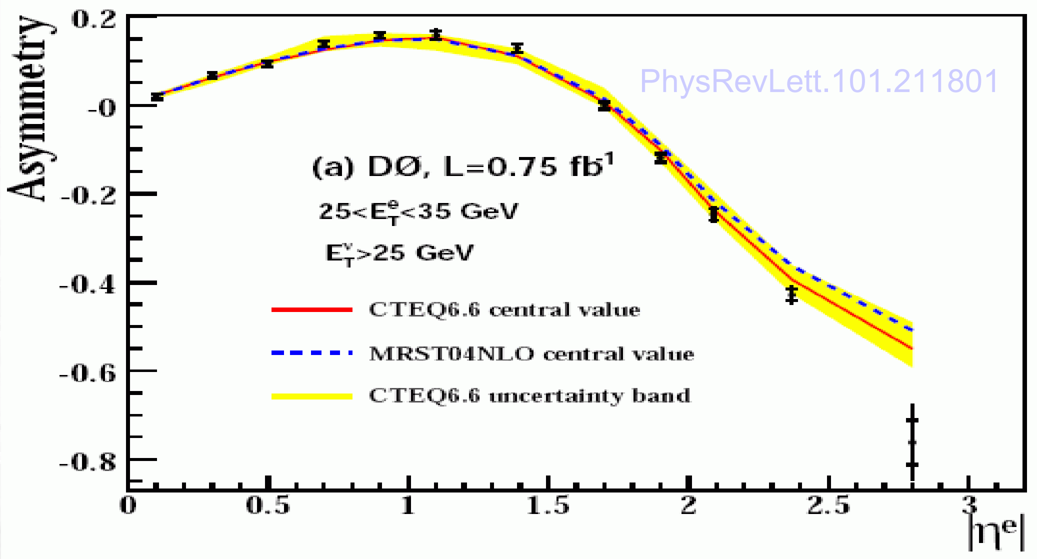
- lepton asymmetry increases with E_T^{lepton}

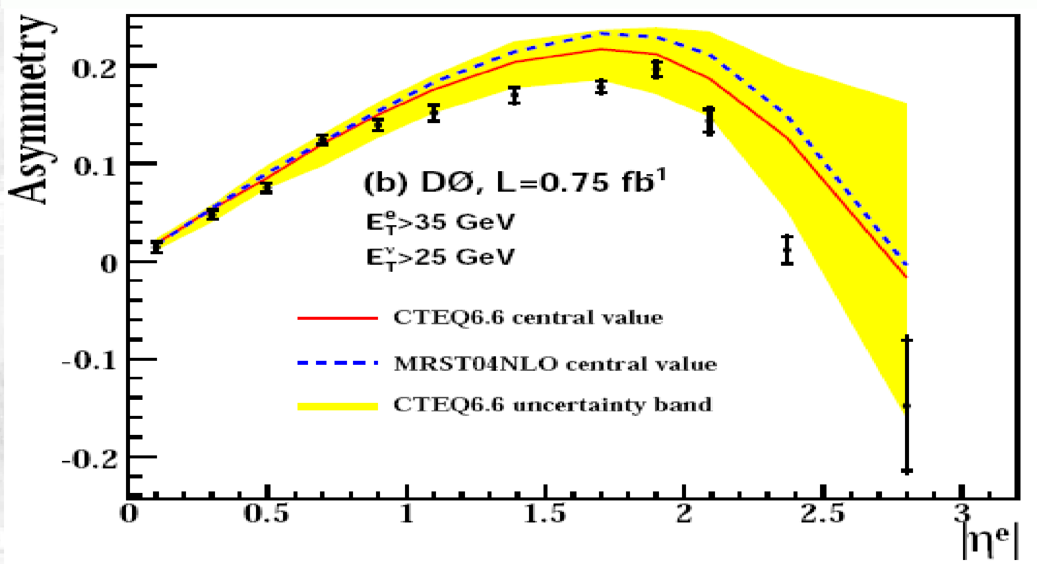
$$\eta_e = y_W + \frac{1}{2}\ln\left(\frac{1+\cos\theta^*}{1-\cos\theta^*}\right) \qquad \cos\theta^* = 1 - 4\,E_T^2/M_W^2$$

- To improve sensitivity use 2 E_T bins

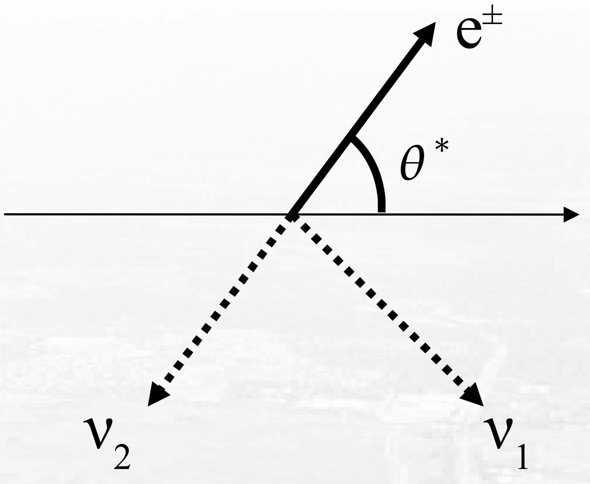
25 GeV < E_T < 35 GeV and E_T > 35 GeV

- Agreement in the low E_T bin much better than in the high E_T bin
- Nominal precision better than current CTEQ6.6 error band
- Potential for constraining u/d





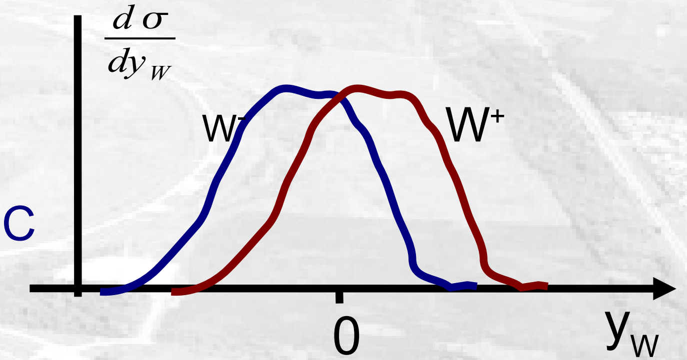
Reconstructing W production asymmetry



- Can distribution in y_W be measured experimentally? -YES!
- Use W mass constraint to reconstruct neutrino P_z
- 2 solutions for P_z and y_W, ϑ^*, lepton angle in W rest system
- In the W rest frame W->lν depends on PDF's only via the sea contribution

$$P_{\pm}(\cos\theta^*, y_W, p_T^W) = (1 \mp \cos\theta^*)^2 + Q(y_W, p_t^W)\cdot(1 \pm \cos\theta^*)^2$$

  - $Q(y,p_T)$ defined using MC@NLO



- An event gets assigned 2 weights, use dσ(pp→W)/dy from MC

$$w_{1,2}^{\pm} = \frac{P(\cos\theta_{1,2}^{\pm}, y_{1,2}, p_t^W)\frac{d\sigma}{dy}(y_{1,2})}{P(\cos\theta_1^{\pm}, y_1, p_t^W)\frac{d\sigma}{dy}(y_1) + P(\cos\theta_2^{\pm}, y_2, p_t^W)\frac{d\sigma}{dy}(y_2)}$$

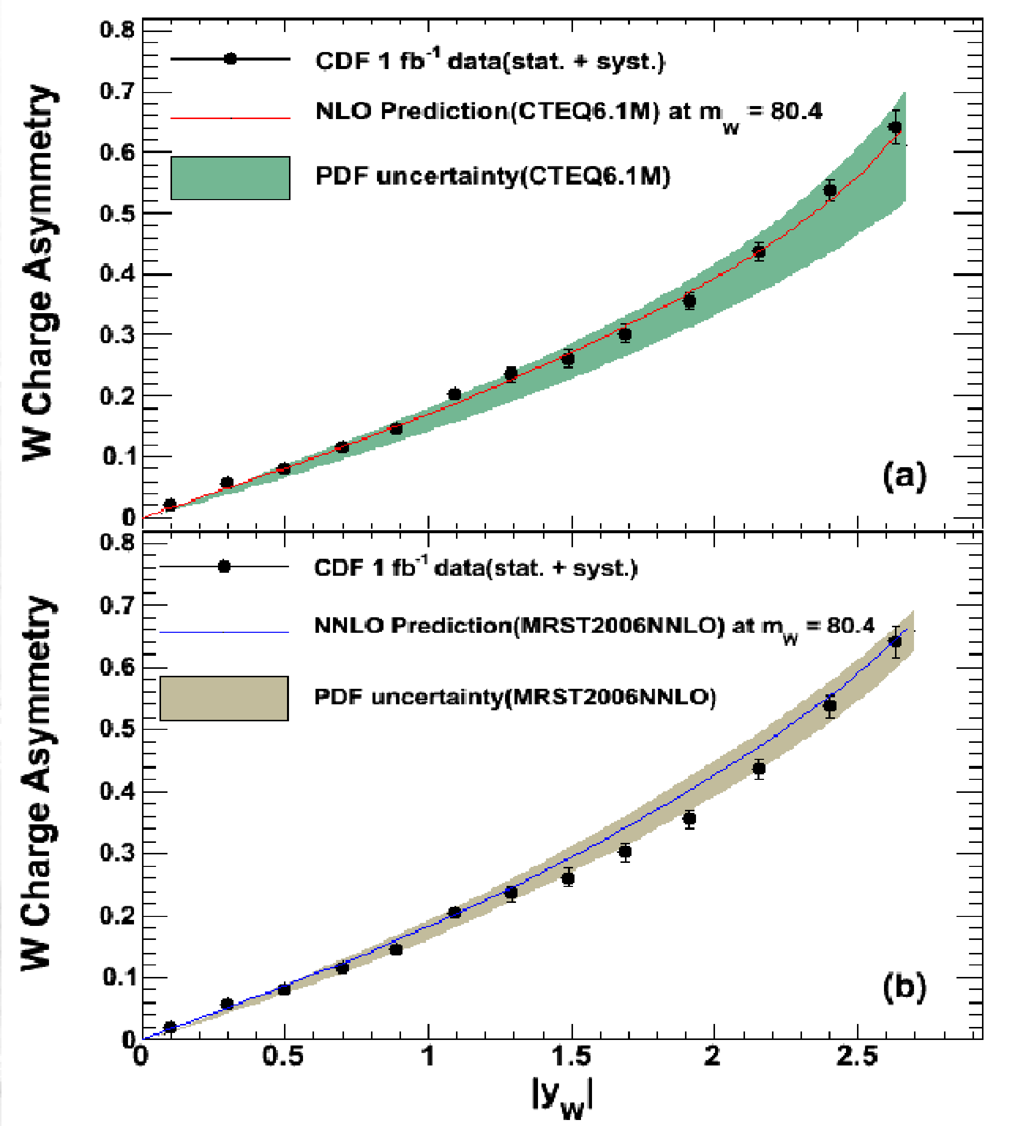
- Reconstruct dσ/dy, iterate
- reconstructed dσ(W)/dy is stable with respect to initial dσ/dy

First direct measurement of the W charge asymmetry

(CDF'2008, 1/fb)

– W → eν selection: an isolated electron $E_T > 25$ GeV/c, $|\eta| < 2.8$

- $\not{E}_T > 25$ GeV,
- $M_T > 50$ GeV/c^2
- W -> τν : part of the signal
- **Total background: 0.7-1.2%**



- Results consistent with the NLO/NNLO PDF parametrizations (CTEQ6, MRST2006)
- will further constrain PDF fits when included into analysis
- Submitted to PRL Jan'09

MSTW'2008: new PDF fits from MRST group (now MSTW)

- first fits including the Run II data (hep-ph/0901.002)
  - W charge asymmetries, excluding the 2 measurements reviewed in this talk
  - $d\sigma(Z \to ee)/dy_Z$
  - QCD jet production

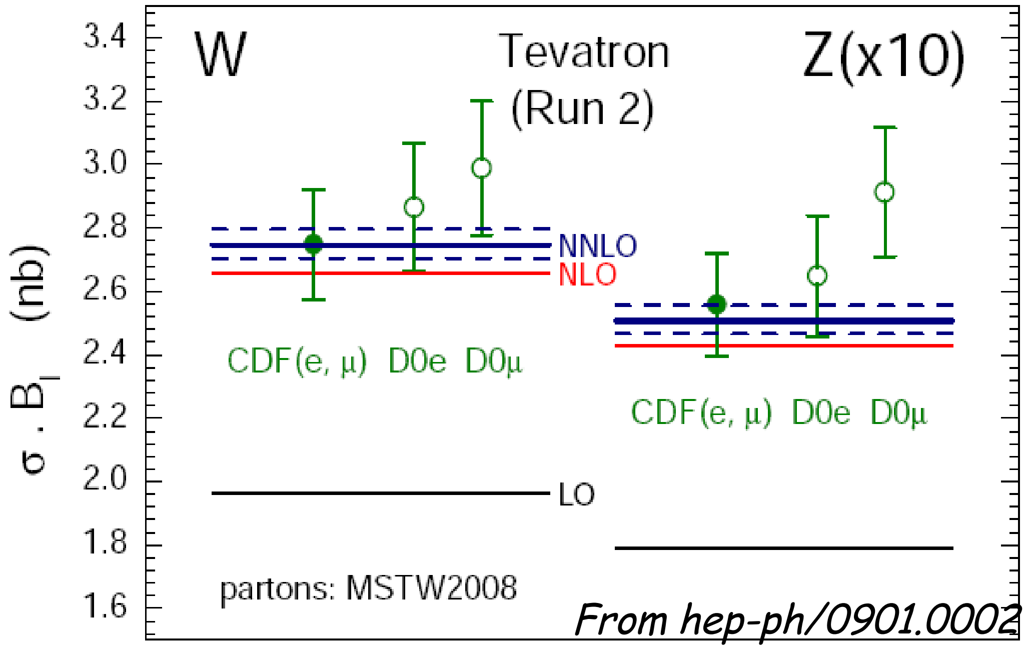


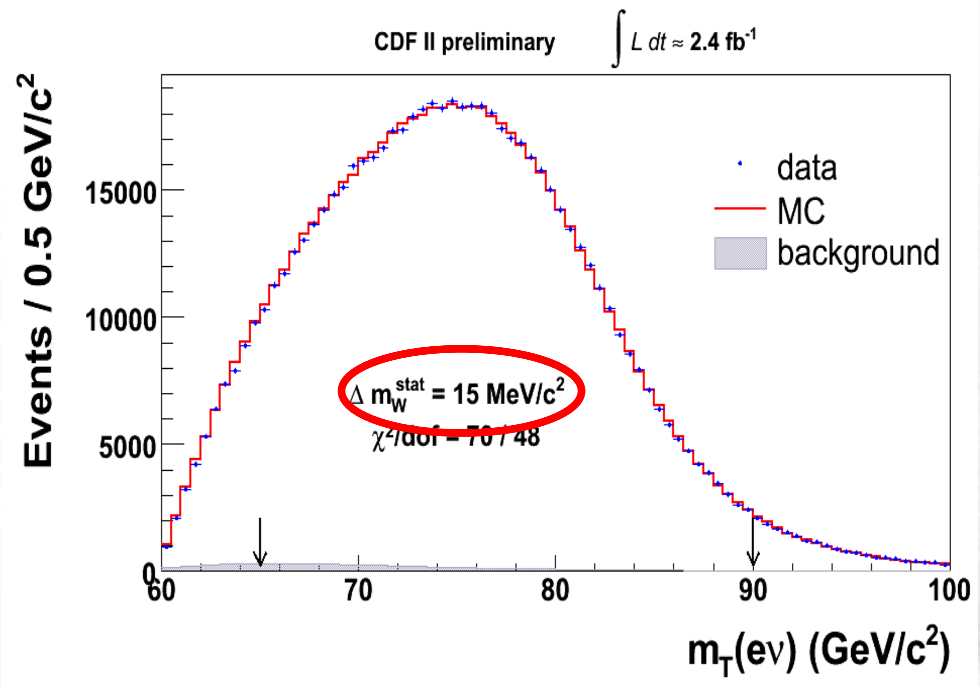
Figure 65: $W \equiv W^+ + W^-$ and Z total cross sections compared to Tevatron data [189, 190], where the dashed lines show the one-sigma PDF uncertainties on the NNLO predictions. The luminosity uncertainty of $\sim 6\%$ is not included on the experimental data points.

- MSTW2008 NNLO: σ*B(pp->W->lv) = 2.747 +0.049-0.042 (~ 2% up)
- Accuracy of the calculation: +1.8% -1.5%

PDF's and uncertainties on the W mass measurement

Source	$W \to \mu\nu$	$W \to e\nu$	Common
Lepton Scale	17	30	17
Lepton Resolution	3	9	0
Lepton Efficiency	1	3	0
Lepton Tower Removal	5	8	5
Recoil Energy Scale	9	9	9
Recoil Energy Resolution	7	7	7
Backgrounds	9	8	0
PDFs	11	11	11
W Boson p_T	3	3	3
Photon Radiation	12	11	11
Statistical	54	48	0
Total	60	62	26

CDF, 200 pb-1 (PRD 77, 112001)



- Expect most uncertainties to scale as 1/sqrt(L), studies in progress confirm this
- For 2 fb^{-1} statistical uncertainty ~ 11 MeV/c^2, same as current PDF contribution
- Improvement in PDF uncertainties will reduce total error on W mass

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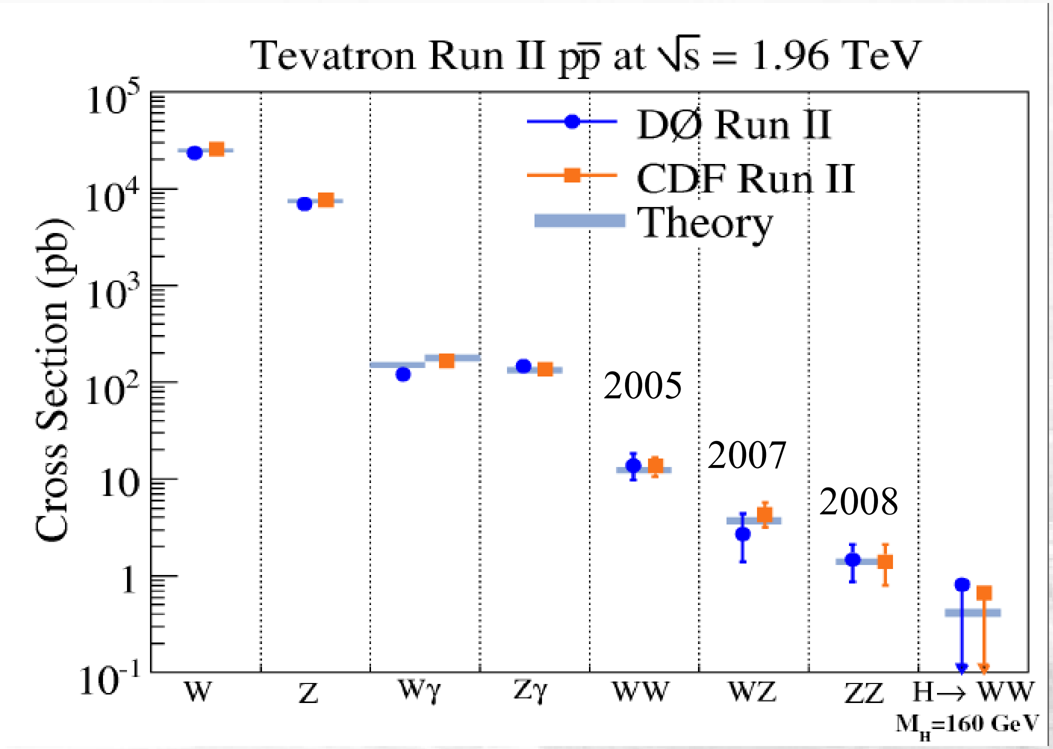
Diboson production at the Tevatron

- All the diboson production processes (VV,Vγ) have been measured
- Heavy dibosons:
  - WW: 2005
  - WZ : 2007
  - ZZ : 2008
- only in leptonic channels
- W/Z → qq was remaining a challenge

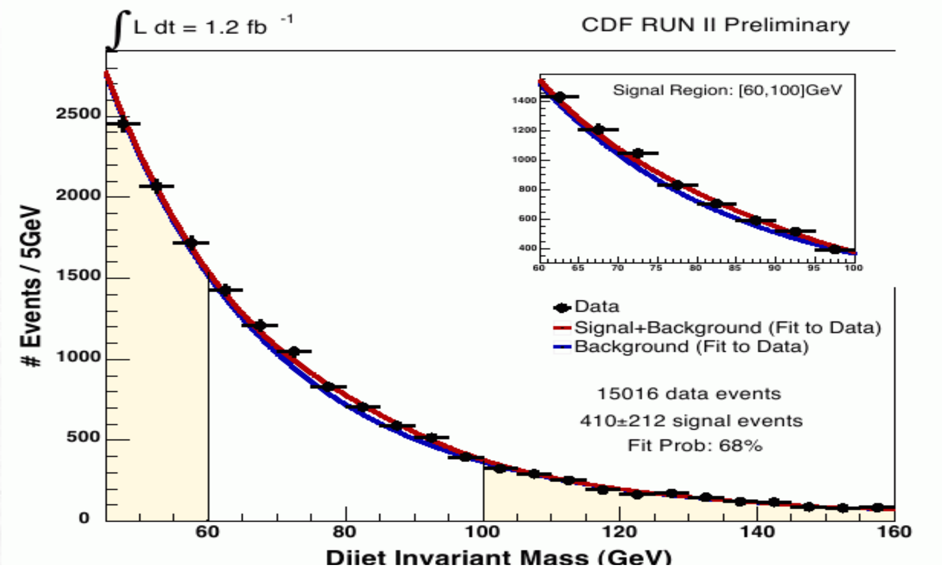


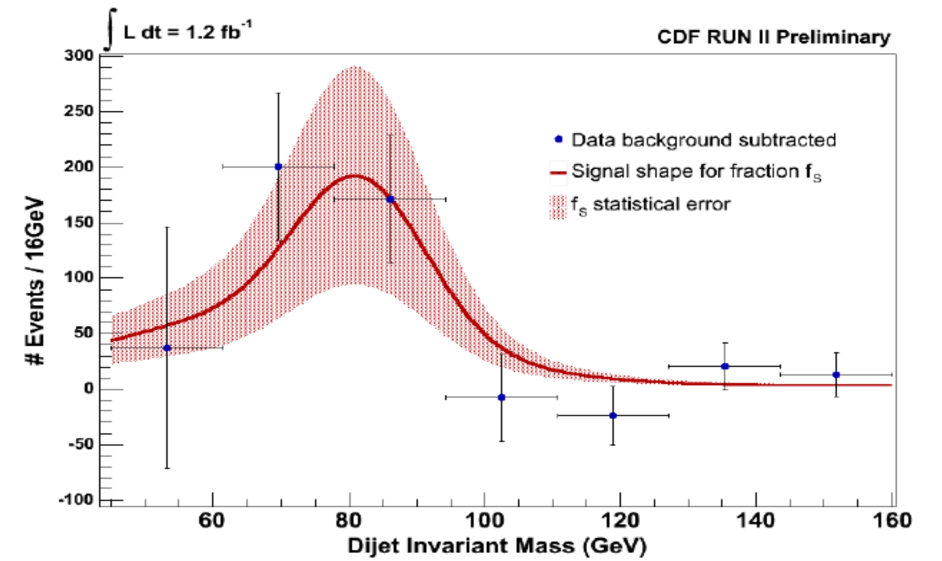
- Low-mass Higgs searches are based on the reconstruction of a H→bb signal
- Establishing "calibration lines" : W/Z → qq, Z → bb a priority

Searches for WW/WZ->lvjj

- Most recent search by CDF'2008 (1.2/fb)
- W→lv selection:
  - Isolated e,μ : E_T > 20 GeV, eta < 1.1(1.2)
  - $\not{E}_T$ > 25 GeV/c
  - 30 GeV/c^2 < M_T(l,v) < 120 GeV/c^2
- W/Z→qq:
  - 2 jets E_T > 15 GeV, |η| < 2.4, Δη(jj) < 2.5
- NN-based cut improves S/B to ~5%
- Bgr model:
  - fit sidebands: M(jj) < 60, M(jj) > 100

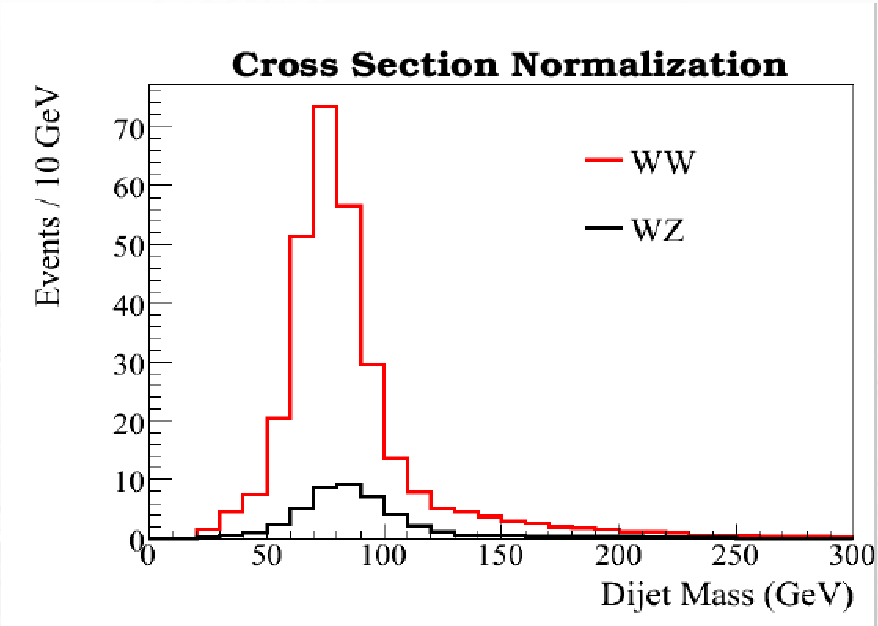
signal	410 ± 212 ± 102
measured σ	1.47 ± 0.77± 0.38 pb
limit	σ < 2.88 pb @95% CL
σ(theory)	2.09 ± 0.14

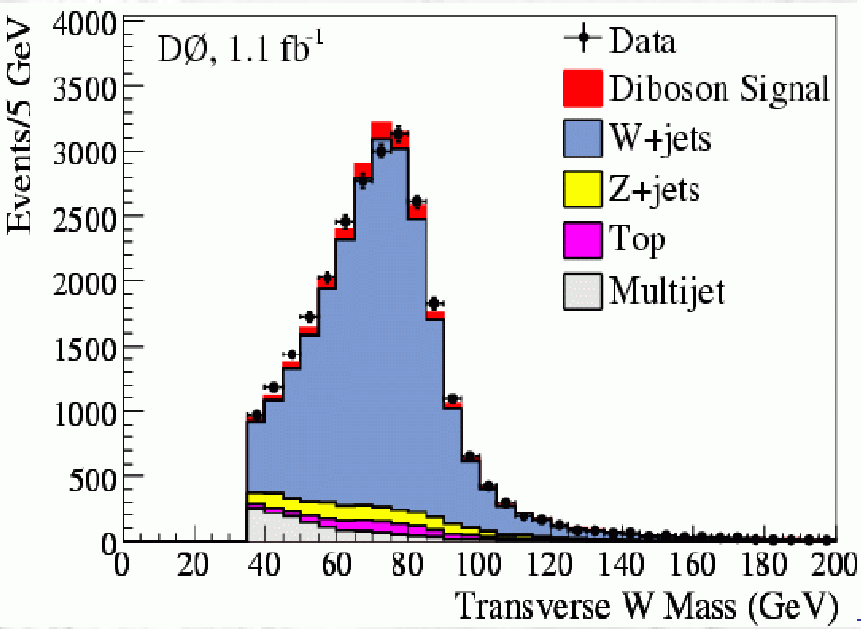


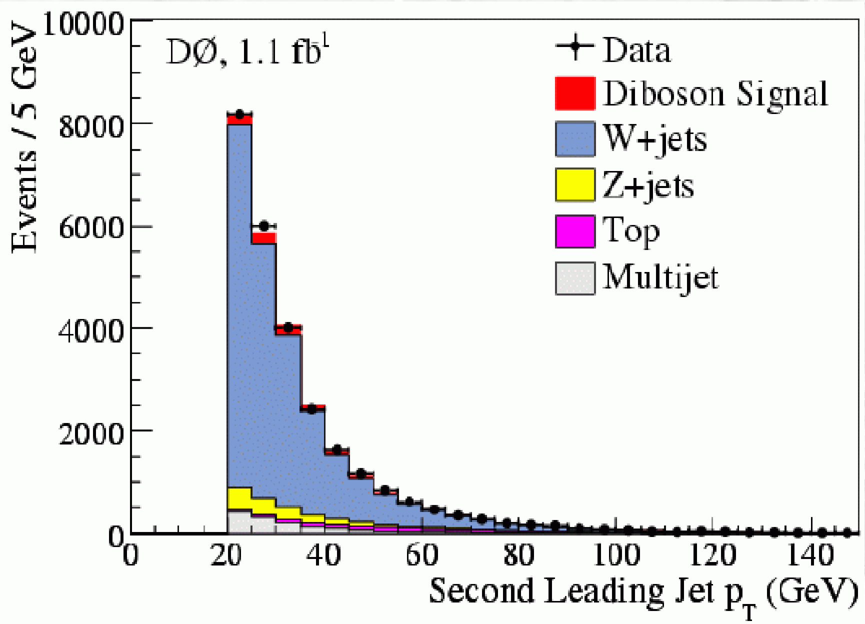


Evidence for WZ/ZZ->lνjj (D0'2008, hep-ex/0810.3873)

- W->lν selection:
  - Isolated e,μ : Et > 20 GeV, $|\eta_e| < 1.1$, $|\eta_\mu| < 2$
  - $\not{E}_T$ > 20 GeV/c, $M_T(l,\nu)$ > 35 GeV/c^2
- Do not distinguish between WW and WZ
- W/Z→qq selection:
  - 2 jets with Et > 20 GeV, $|\eta| < 2.5$
  - Leading jet E_T > 30 GeV
  - No veto on N_{jets}

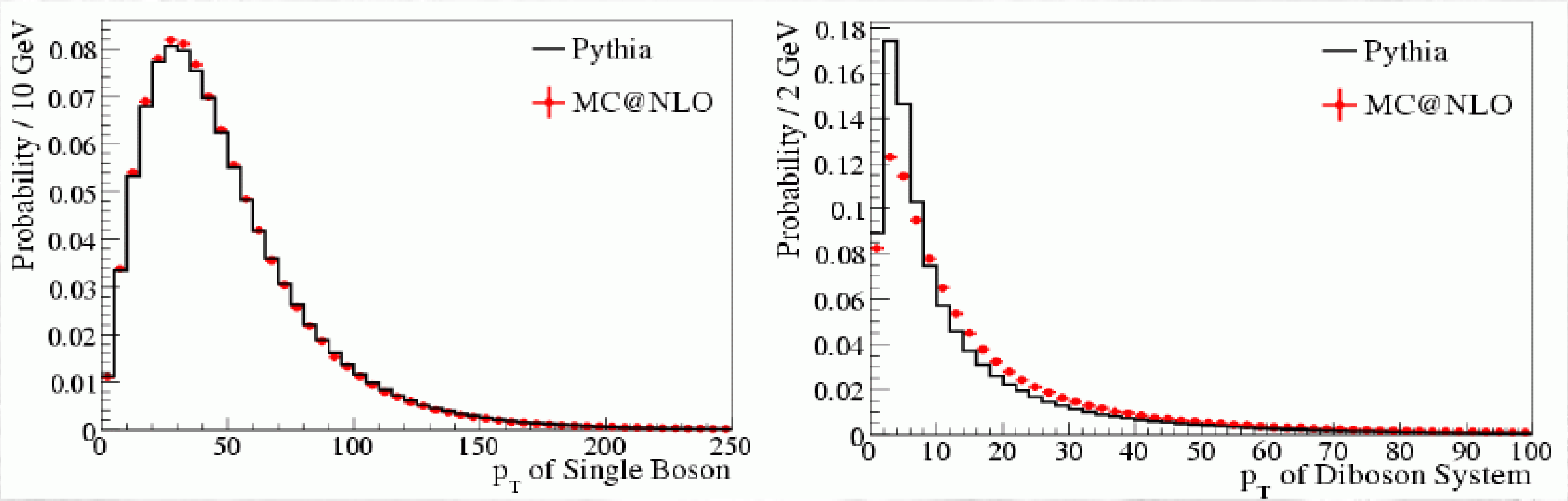






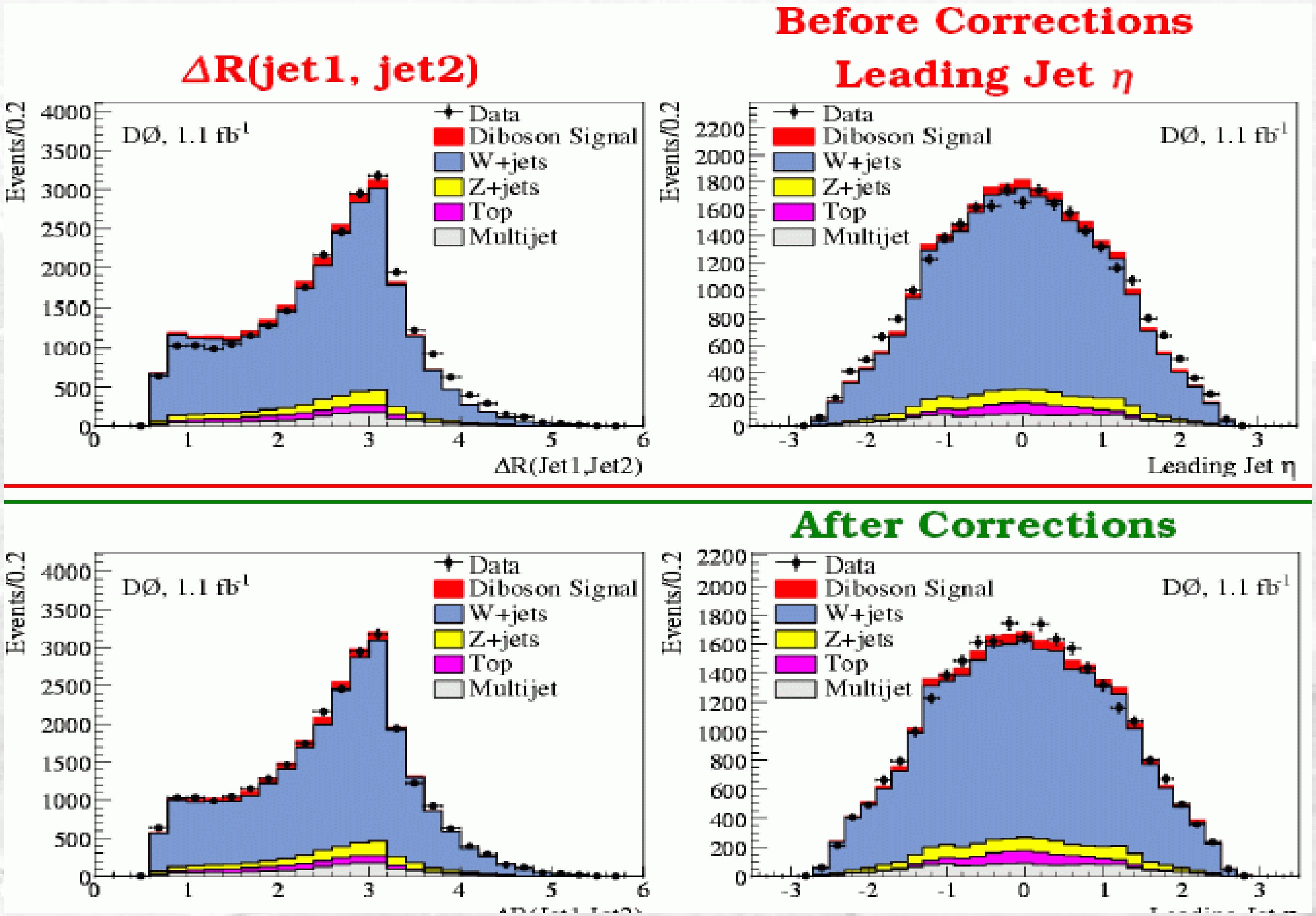
WZ/ZZ->lvjj: signal modelling

- Use Pythia (LO) to model the WW/WZ signal
- Comparison to NLO (MC@NLO) :
  - differences in modeling parameters of the diboson system, affecting acceptance
- correct Pythia at a generator level



WZ/ZZ->lvjj: background modeling

- W/Z+jets, ttbar simulated with ALPGEN (+MLM matching)
- Differences between the data and MC in jet angular distributions
  - due to W+jets background modeling
- MC tuned at event level

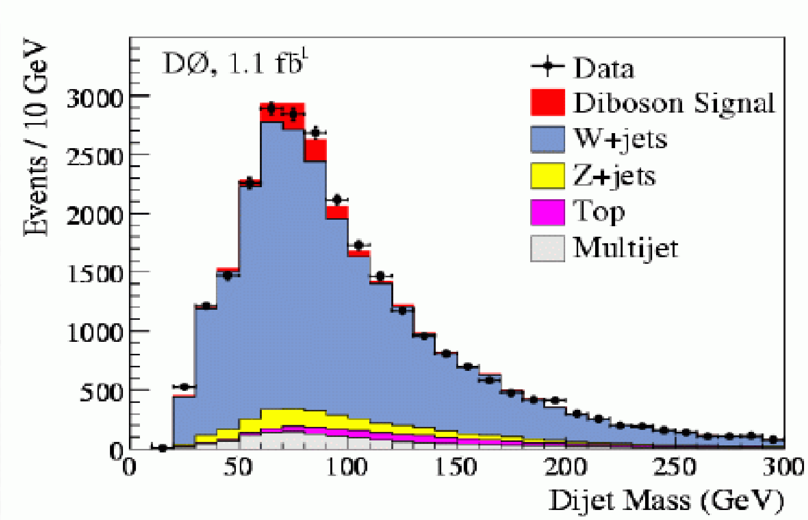


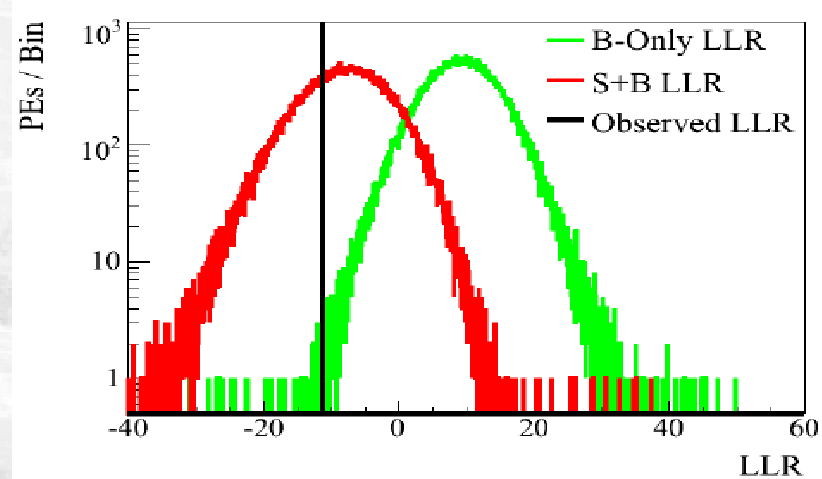
WZ/ZZ->lvjj: signal significance

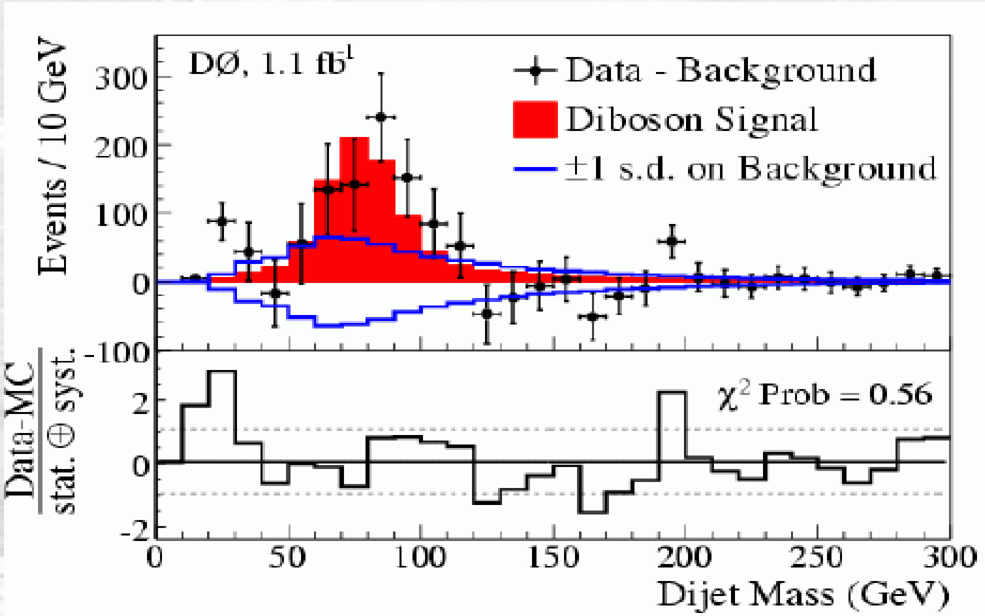
- Normalize all backgrounds except W+jets to NLO/NNLO cross sections,
  - let W+jets normalization float
- fit M(jj) spectrum with no signal hypothesis

  $1\text{-}CL_B$ = 2.5*10^-4 => 3.5σ (1-sided)
- Allow signal (WW/WZ) rate to float:

σ(WW+WZ) = 18.5±2.8(stat)±4.9(sys)±1.1(lum)

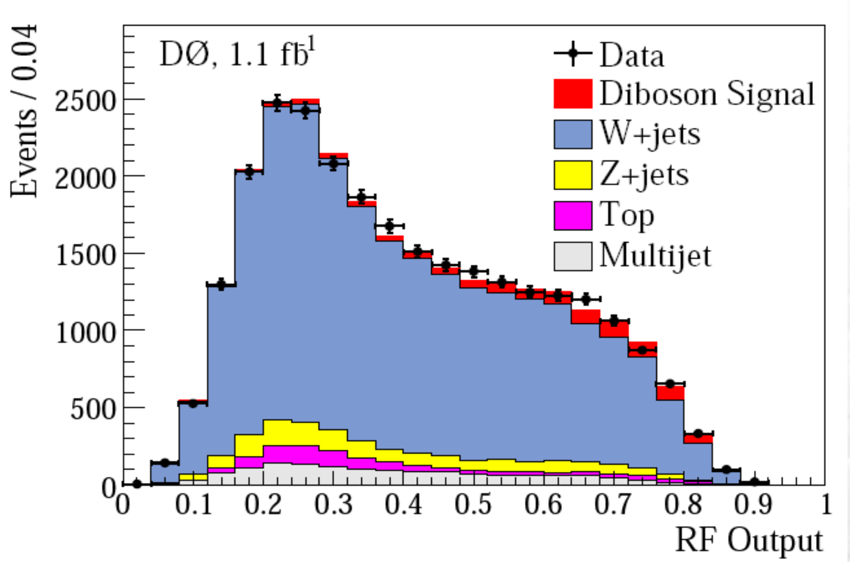






WZ/ZZ->lvjj: improving signal significance

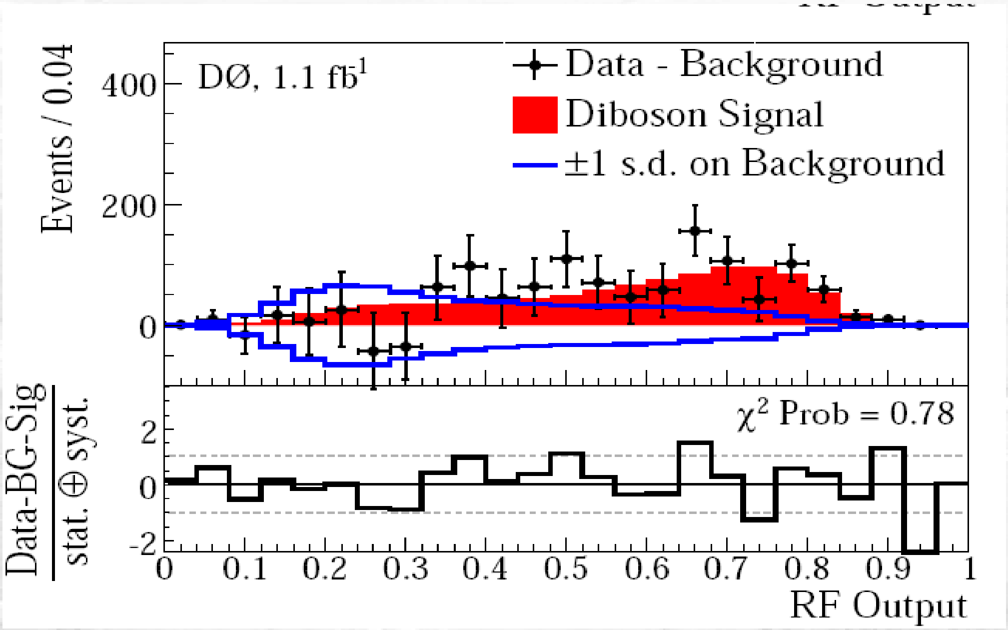
- Use multivariate technique 'Random Forest' (arXiv:physics/0507143)

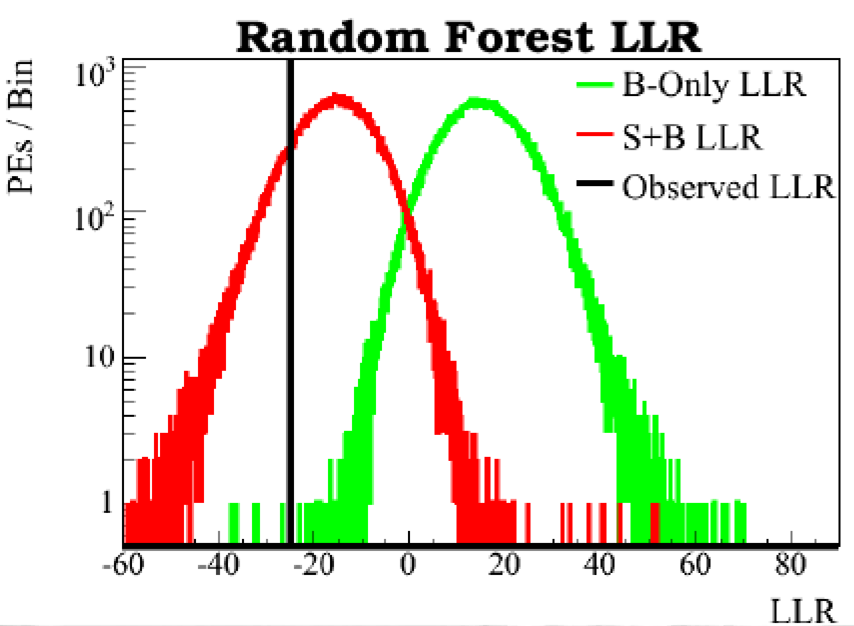


- Background-only hypothesis:

  $1\text{-}CL_B = 1.8 \cdot 10^{-6} \Rightarrow 4.6\sigma$ (1-sided)

- Improvement in sensitivity due to RF ~32%





- cross check:
  - W+jets SF = 1.53 ± 0.12, consistent with the calculation of the NLO K-factor

WZ/ZZ->lvjj : cross sections

- Sample composition (S/B ~3-4%)

	$e\nu q\bar{q}$ channel	$\mu\nu q\bar{q}$ channel
Diboson signal	436 ± 36	527 ± 43
W+jets	10100 ± 500	11910 ± 590
Z+jets	387 ± 61	1180 ± 180
$t\bar{t}$ + single top	436 ± 57	426 ± 54
Multijet	1100 ± 200	328 ± 83
Total predicted	12460 ± 550	14370 ± 620
Data	12473	14392

- Cross sections in muon and electron channels consistent with each other and with NLO

Channel	Fitted signal σ (pb)	Expected p-value (significance)	Observed p-value (significance)
$e\nu q\bar{q}$ RF Output	18.0±3.7(stat)±5.2(sys)±1.1(lum)	6.8×10^{-3} (2.5 s.d.)	3.2×10^{-3} (2.7 s.d.)
$\mu\nu q\bar{q}$ RF Output	22.8±3.3(stat)±4.9(sys)±1.4(lum)	1.8×10^{-3} (2.9 s.d.)	5.2×10^{-5} (3.9 s.d.)
Combined RF Output	20.2±2.5(stat)±3.6(sys)±1.2(lum)	1.5×10^{-4} (3.6 s.d.)	5.4×10^{-6} (4.4 s.d.)
Combined Dijet Mass	18.5±2.8(stat)±4.9(sys)±1.1(lum)	1.7×10^{-3} (2.9 s.d.)	4.4×10^{-4} (3.3 s.d.)

Combined result (e+mu): σ (pp->WV) = 20.2 +/- 4.5 pb

NLO prediction: σ (pp->WV) = 16.1 +/- 0.9 pb

submitted to PRL

Summary

- precision Run II measurements of the probe accuracy of our knowledge of the proton structure
- Improved PDF fits using the Run II data available
- Diboson measurements map a road for the Higgs searches
  - evidence for $p\bar{p} \rightarrow WW/WZ \rightarrow l\nu jj$

Outlook

- new indirect limits on Higgs mass from upcoming W mass measurements
  - M_H < 154GeV @95%CL adds scienticic excitement
- New diboson measurements, $p\bar{p} \rightarrow WZ \rightarrow l\nu bb$ is a priority
- Time to start normalizing measurements to W/Z inclusive cross sections:
  - ±6%(lum) term could already be hiding important features in the data

Tevatron has already delivered ~6/fb of data per experiment.