Electroweak Physics at CDF

- Why Electroweak measurements at the Tevatron?
- CDF-II Detector performance
- Highlights
  - W and Z production cross-sections
  - W Boson mass measurements
  - Di-boson production

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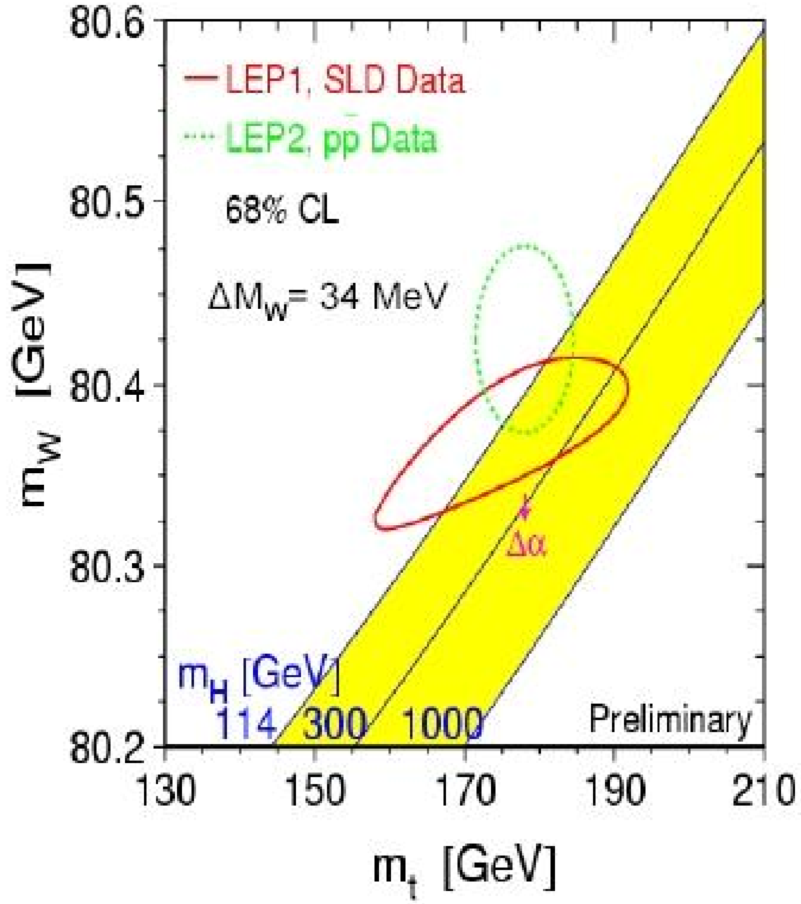
April 17, 2005

Electroweak Physics at the Tevatron

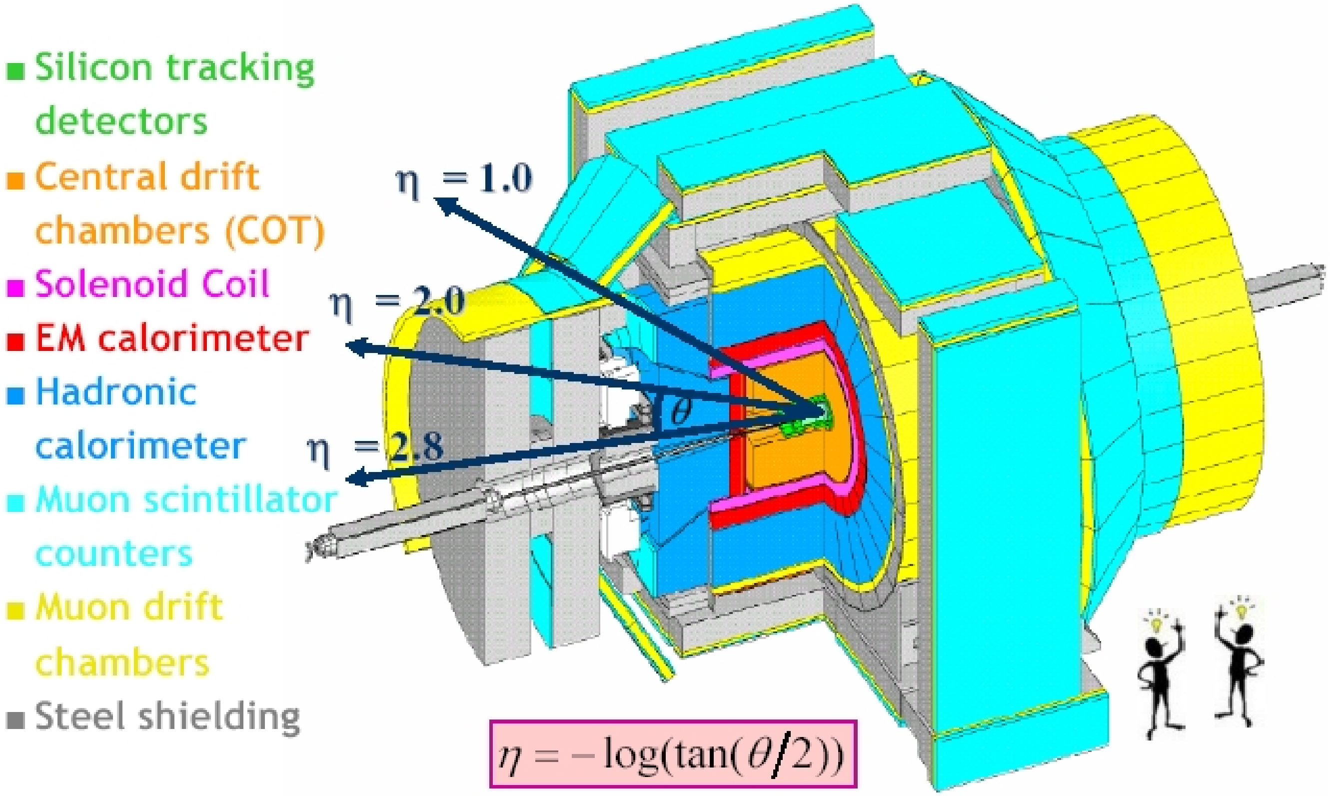


- Z boson properties well known from LEP
- W samples at Tevatron can compete
  - Branching fractions
  - Mass
  - Di-boson correlations
- Only source of electroweak bosons
  - through middle of the decade

The Fermilab Accelerators

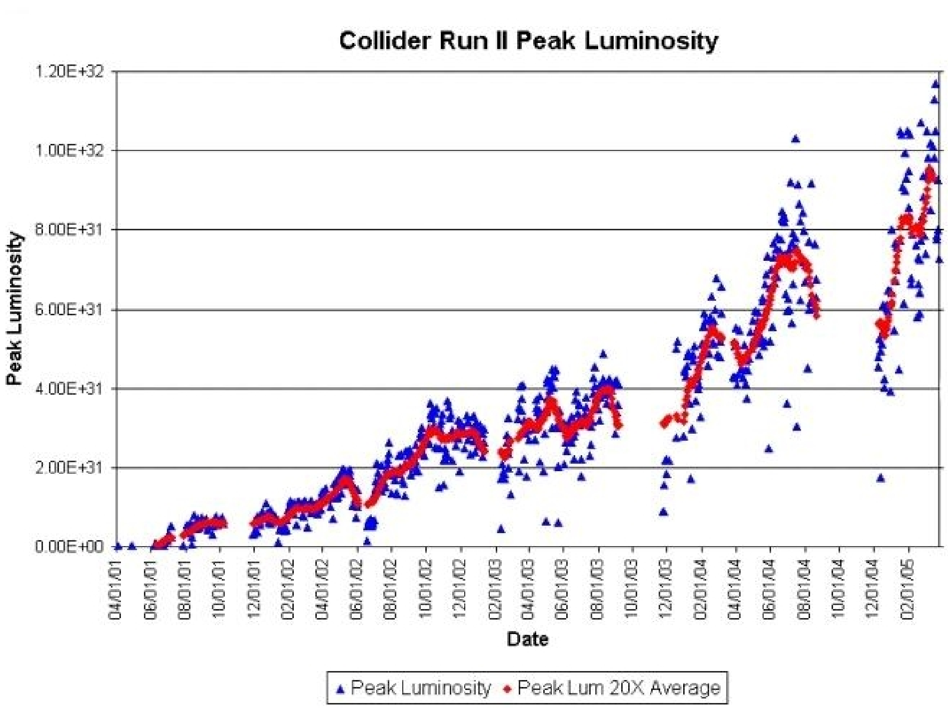
- Luminosity
  - $10^{31} \rightarrow 10^{32}$
- Bunch spacing
  - $3.5\ \mu$s $\rightarrow 396$ ns
- Antiproton stacking
  - Up by factor of 10
- Collision energy
  - $1.8 \rightarrow 1.96$ TeV
- Good data since
  - Spring 2002
  - 600 pb^{-1} in three years

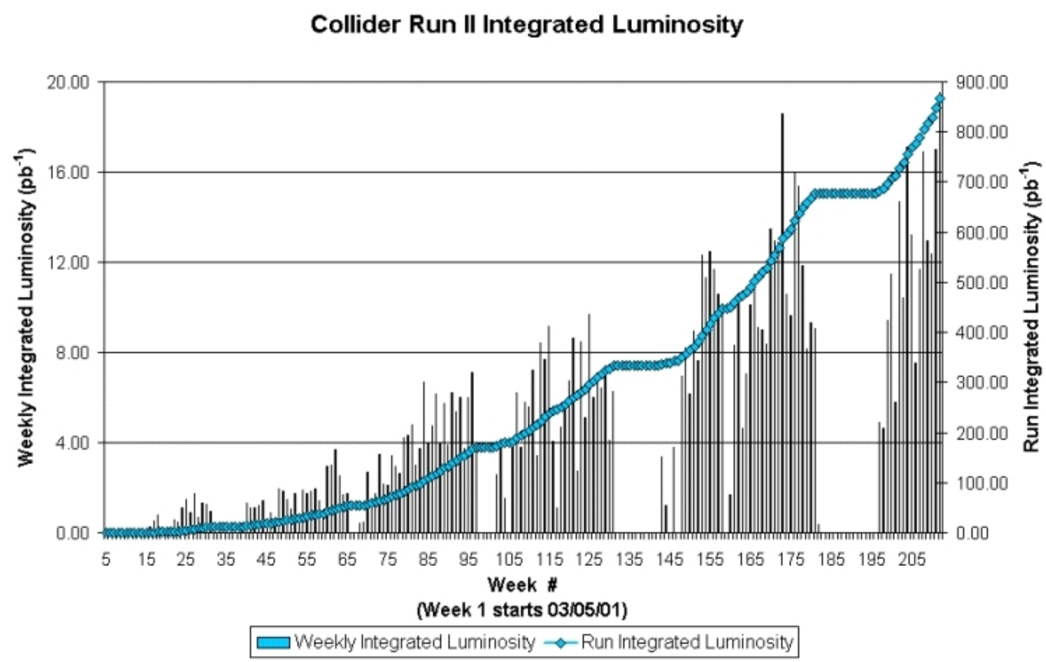
The CDFII Detector



- Completely replaced tracking volume
- Forward calorimetry from gas sampler to scintillator
- Filled in muon coverage to $\eta = 1.5$
- Upgraded all front-end electronics and DAQ for higher rates

Accelerator and Detector Performance



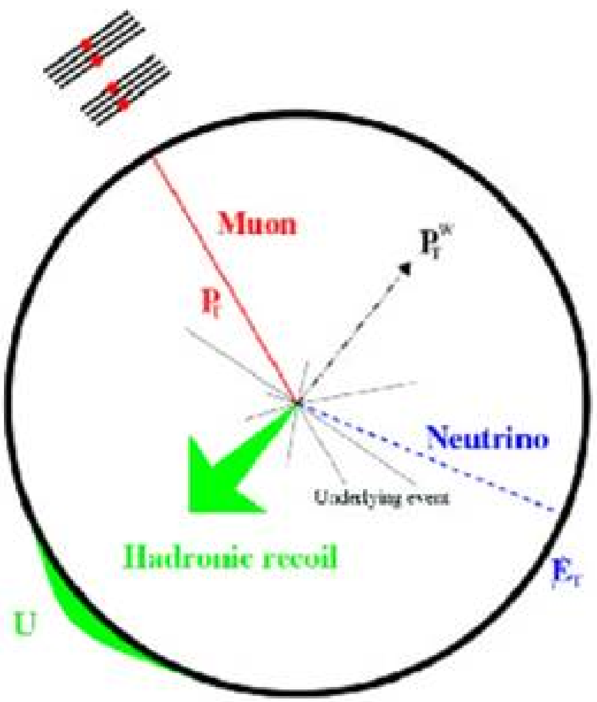


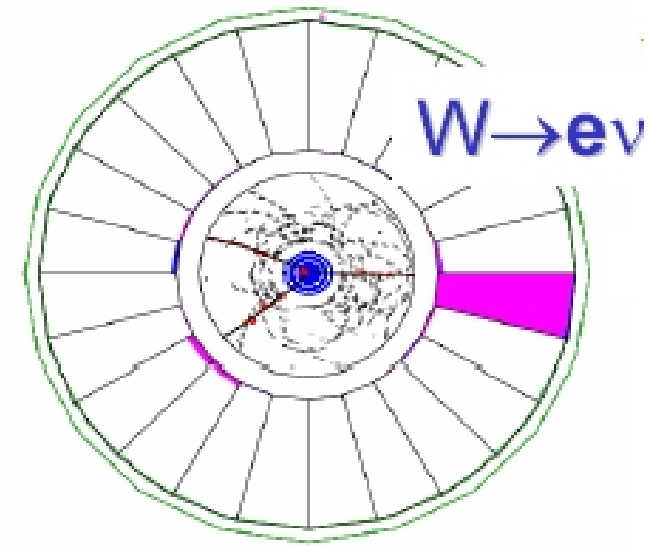
- We are now routinely setting instantaneous luminosity records
- The results presented here range from
  - 70 pb^{-1} for W and Z cross-section measurements
  - 200 pb^{-1} for W mass studies
  - 400 pb^{-1} for measurements this summer

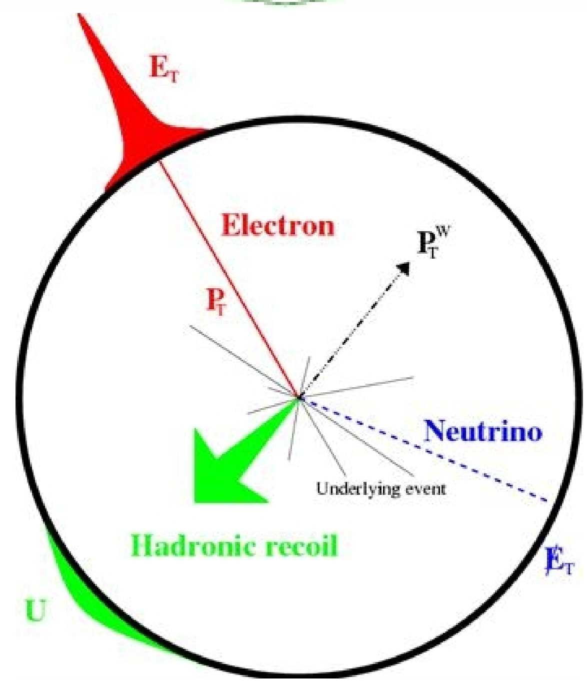
Analysis Strategy

- Concentrate on clean boson decay signatures: charged leptons
  - Only 10% of W decays
  - Only 3% of Z decays

$W \longrightarrow \mu\nu$



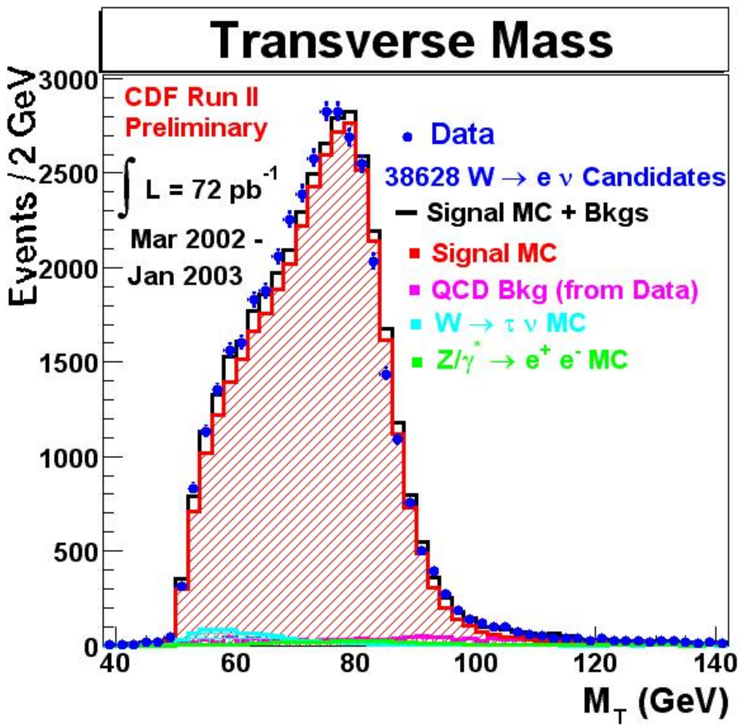




$W^{\pm}$ Boson Production

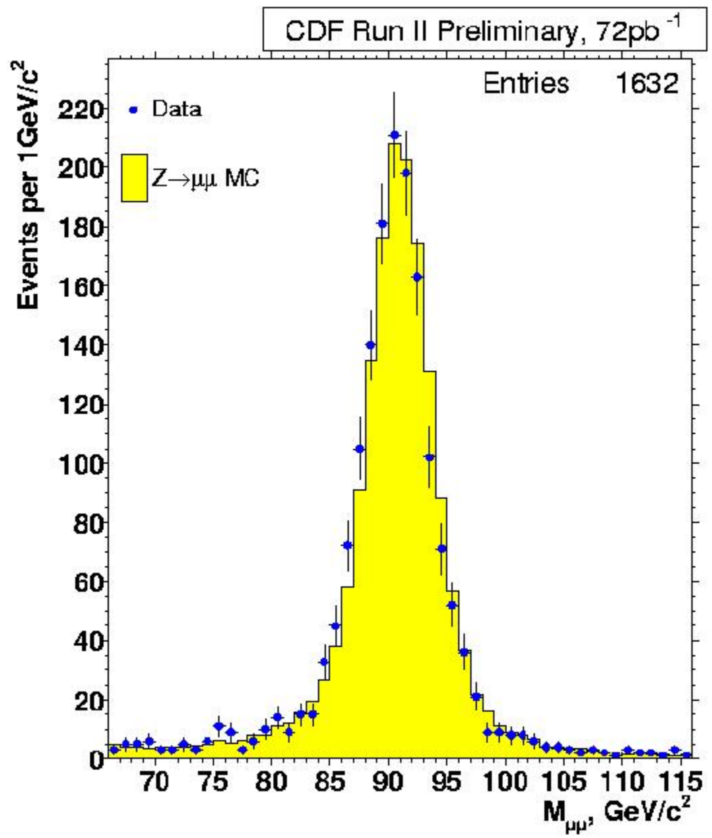
- Vector boson cross-section measurements are systematics limited

Electron Signal



$\sigma \cdot \mathcal{B}(W \to l\nu) =$
$2780 \pm 14(stat) \pm 60(sys) \pm 167(lum)$ pb

Muon Signal

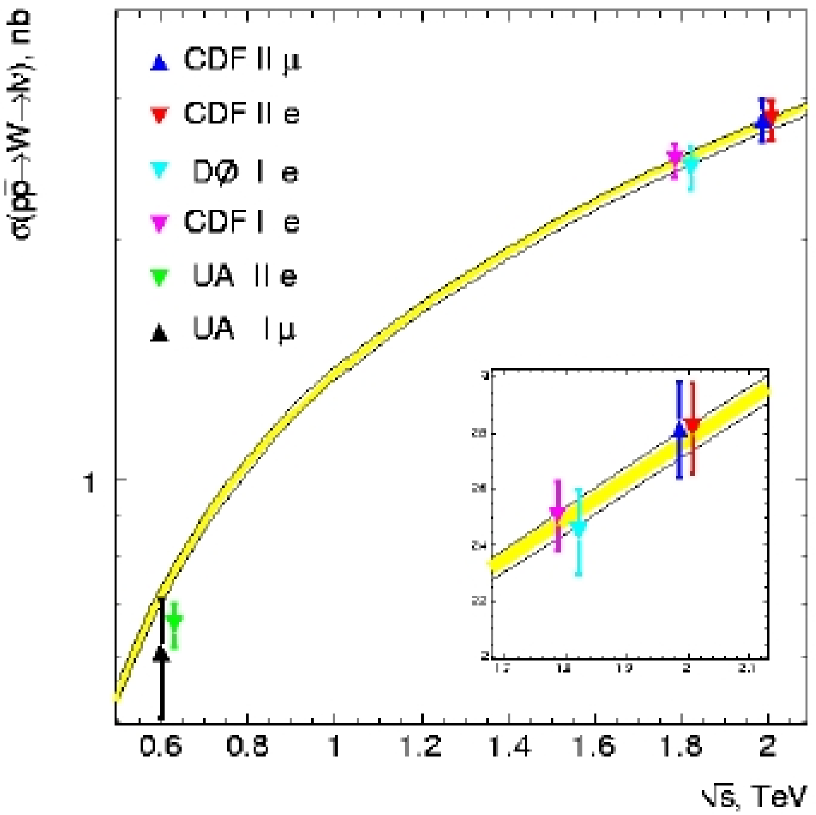


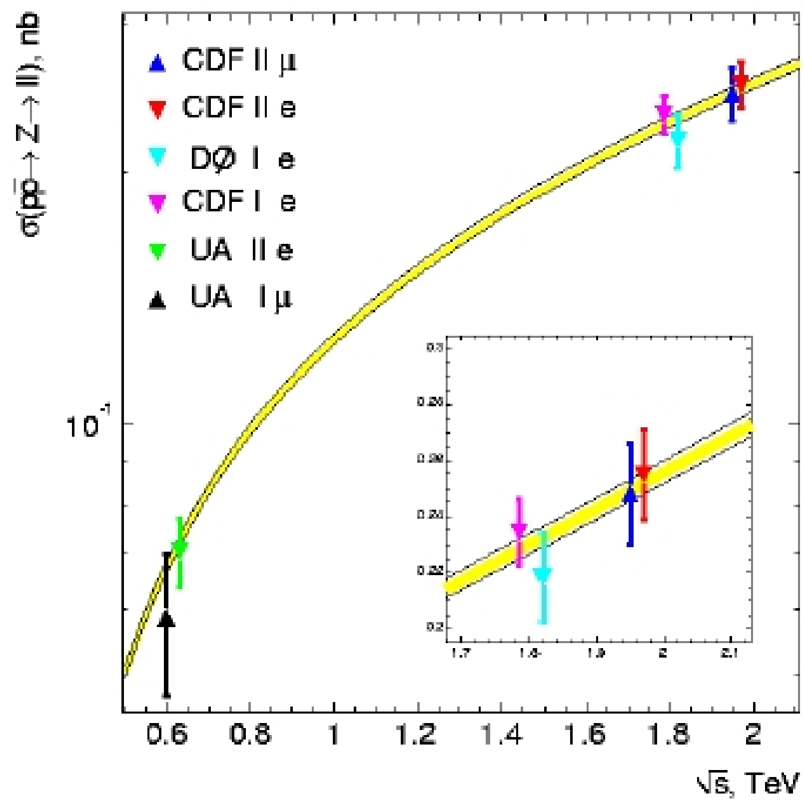
$\sigma \cdot \mathcal{B}(Z \to l^+l^-) =$
$254 \pm 3(stat) \pm 5(sys) \pm 15(lum)$ pb

70 page PRD in preparation describing these measurements

Summary of Cross-Sections

- Measurements provide impressive confirmation of Standard Model

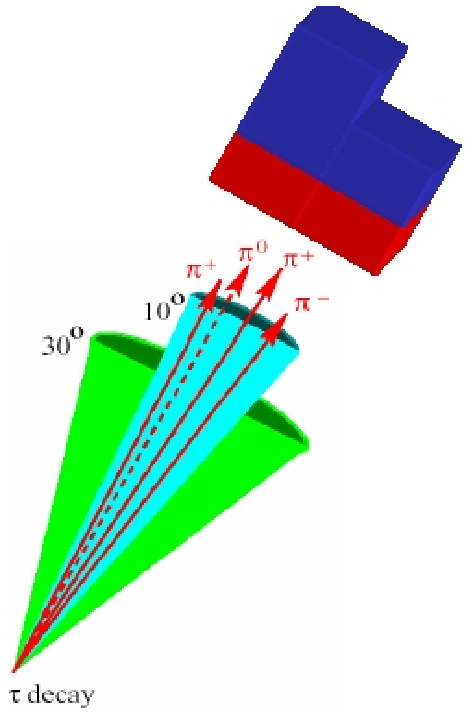


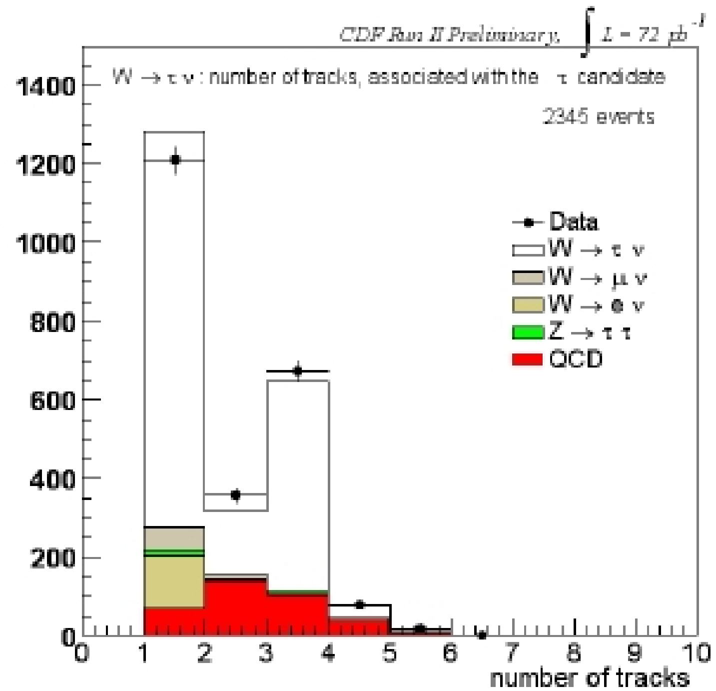


- Theory predicts σ scaling
- LHC proposes to make $W^{\pm}$ and Z^0 the basis for $\mathcal{L}$ normalisation
- Working to improve techniques see Kathy Copic: Session E7

W to τ Branching Ratio

- Identify $W \to \tau\nu$ candidates with
  - One or three isolated charged tracks
  - Charged track mass less than m_τ





- 2345 $W \to \tau\nu$ candidates with 26 % background
- $\sigma \cdot \mathcal{B}(W \to \tau\nu) = 2620 \pm 70(stat) \pm 210(sys) \pm 160(lum)$ pb

Weak Decay Lepton Universality

- Determine coupling of W to different leptons

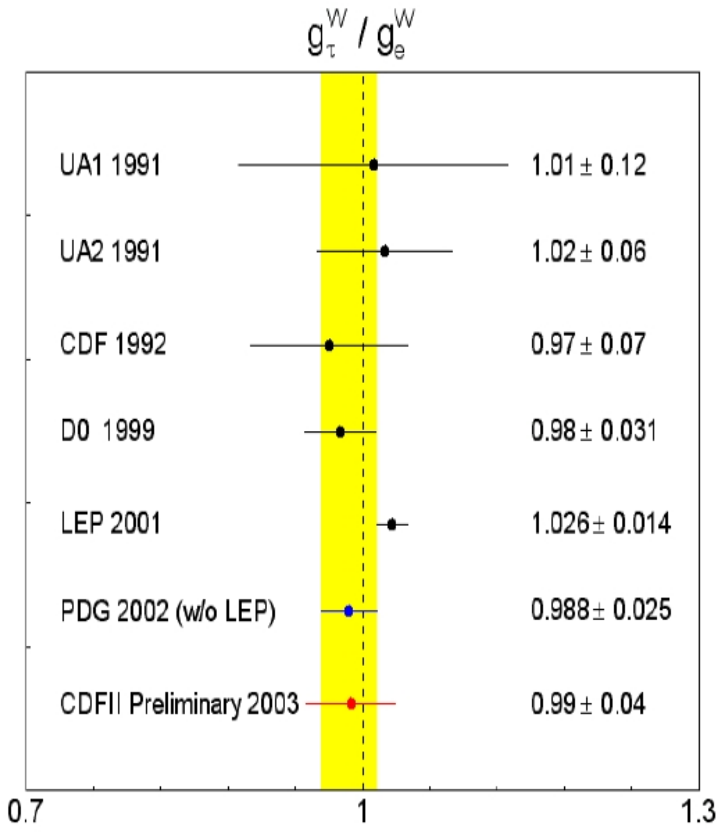
$$\frac{\sigma \cdot \mathcal{B}(W \to l_x \nu)}{\sigma \cdot \mathcal{B}(W \to e\nu)} = \frac{\Gamma(W \to l_x \nu)}{\Gamma(W \to e\nu)} = \frac{g_x^2}{g_e^2}$$

- Many systematics cancel in ratio

$$\frac{g_\mu}{g_e} = 0.998 \pm 0.012$$

- This is competitive with LEP (0.993 ± 0.013)
- Similar for $W \to \tau$

$$\frac{g_\tau}{g_e} = 0.99 \pm 0.04$$



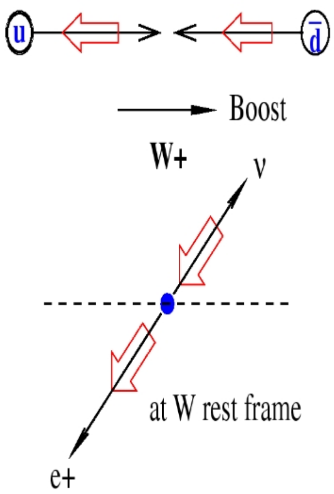
W Charge Asymmetry

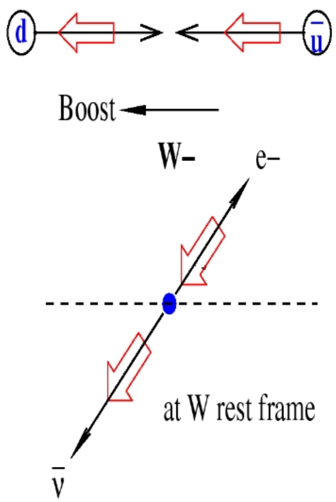
- Use W bosons to probe proton structure(u/d ratio)

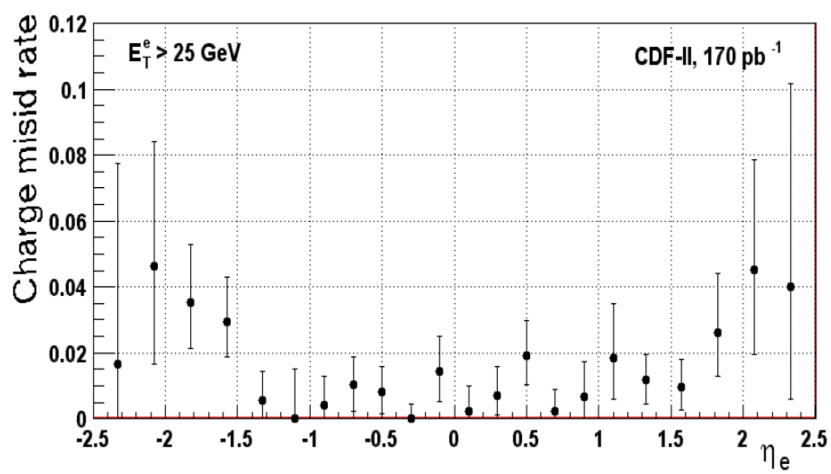
$$A(y_W) = \frac{d\sigma(W^+)/dy - d\sigma(W^-)/dy}{d\sigma(W^+)/dy + d\sigma(W^-)/dy}$$

- Measure charged lepton asymmetry: inverted by V - A coupling

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



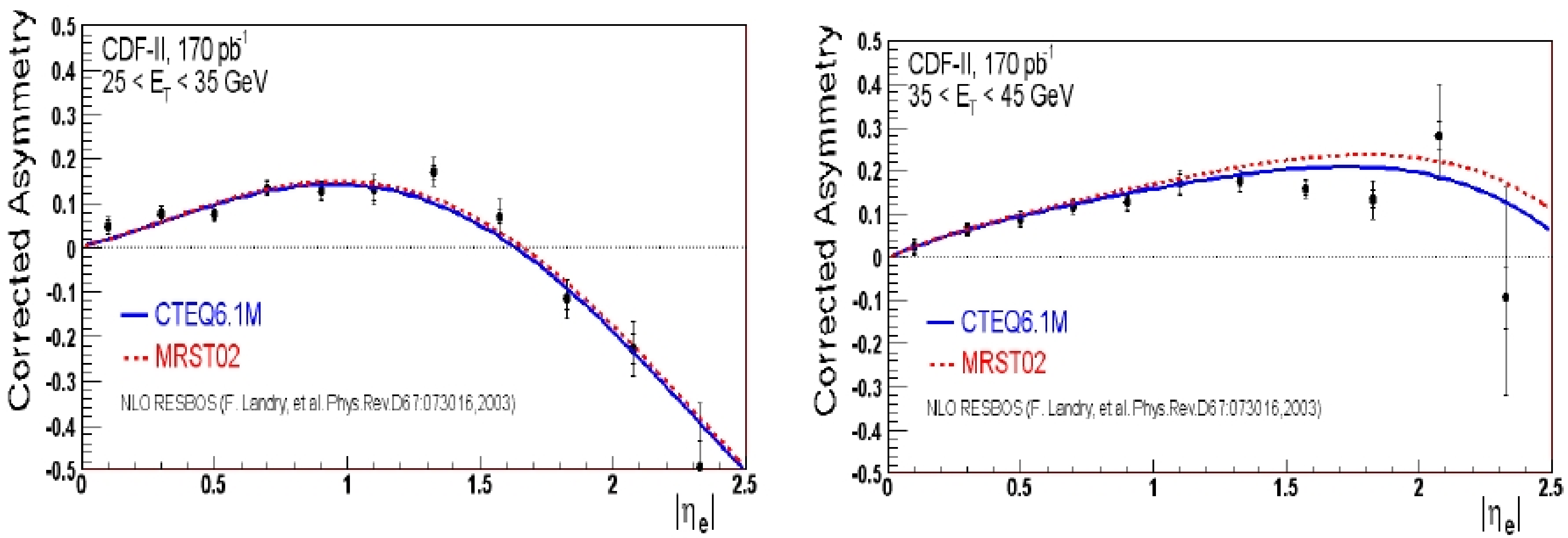




- Must minimise and quantify charge misID rate (4 % at $|\eta| \approx 2$)
- Extend charge identification with silicon stand-alone tracking

Constraints on Proton Parton Densities

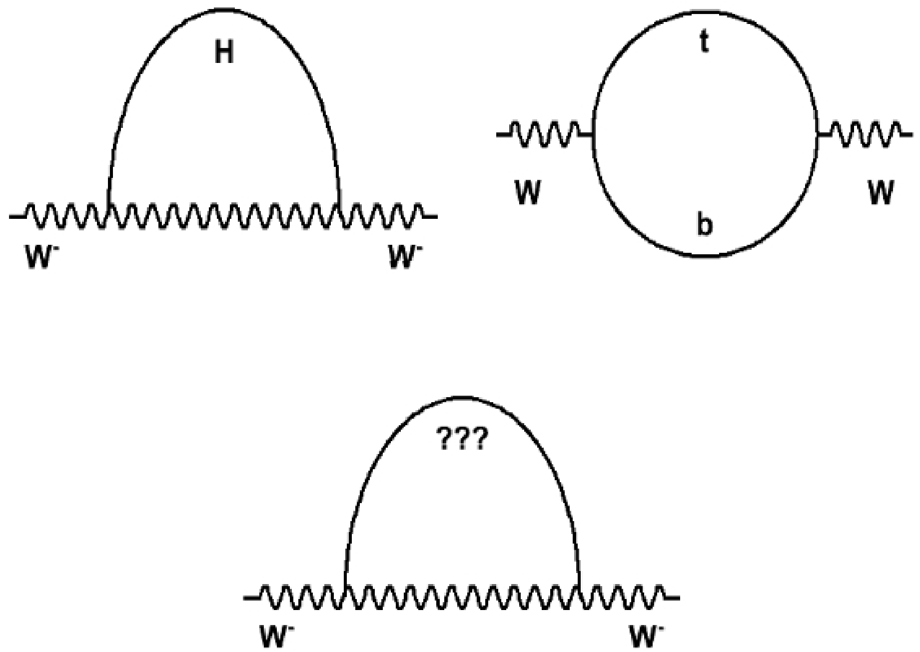
- Deconvolute lepton asymmetry
- Through V-A decay inversion
- To extract information on parton momentum distributions



- Published in hep-ex/0501023
- Results being incorporated in PDF fits
- More information in talk by Boyoung Han: Session E7

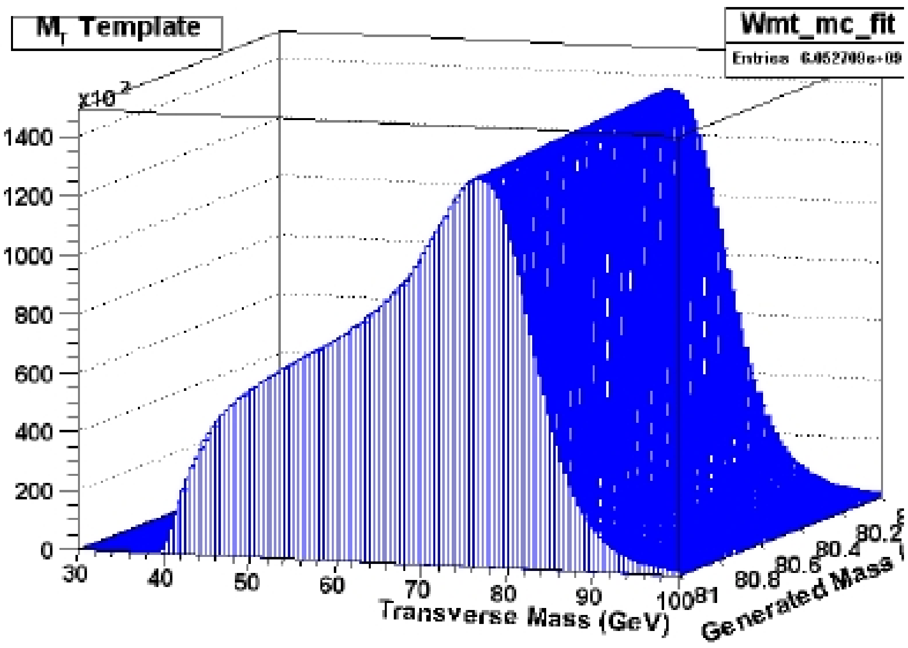
The W Mass

- $W^{\pm}$ mass related to
  - t quark and H^0 mass
  - through radiative corrections
- The state of the art is currently
  - LEP: $80,447 \pm 42$ MeV
  - Tevatron: $80,454 \pm 59$ MeV
- Eventually get several 40 MeV
  - from the Tevatron experiments



Measuring the W Mass

- Clean signals for both $W \rightarrow e, \mu\, \nu$
  - Don't measure neutrino directly
  - Infer its transverse momentum
  - Measure the transverse mass
- Cannot calculate analytically
  - Simulate production kinematics
  - Detector resolution
  - Lepton radiation and energy loss

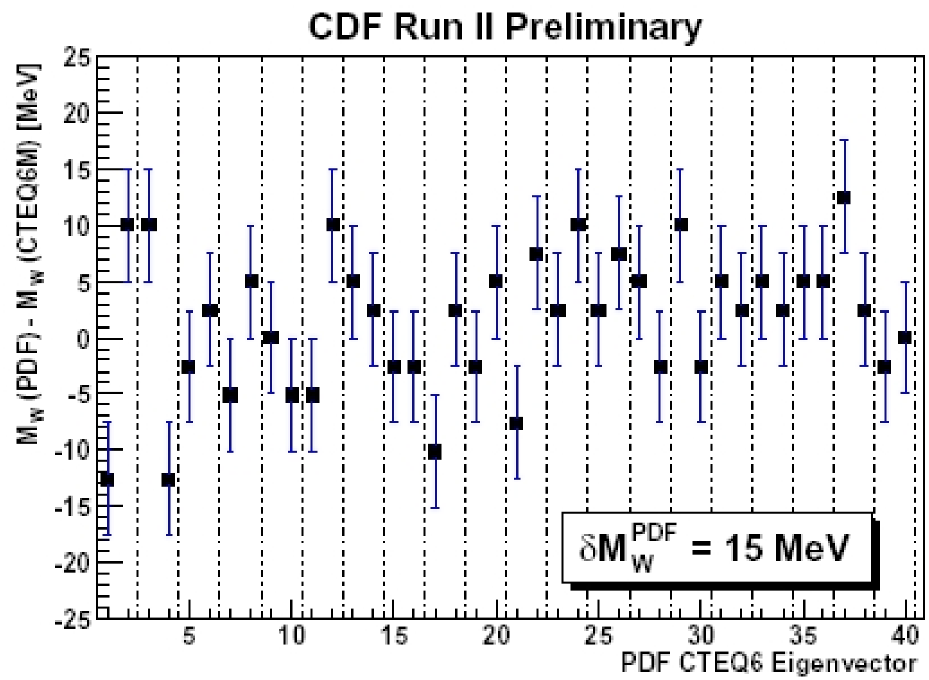


$$m_T = \sqrt{[E_T(l) + E_T(\nu)]^2 + [p_T(l) + p_T(\nu)]^2}$$

$$m_T = \sqrt{2 p_T(l) p_T(\nu) \{1 - \cos[\phi(l) - \phi(\nu)]\}}$$

W Boson Production

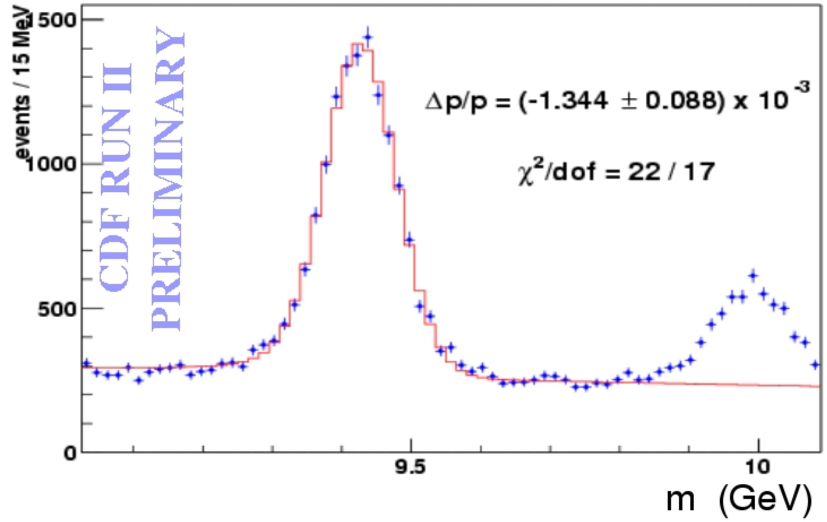
- W fitting lineshapes sculpted by longitudinal momentum distribution from parton distribution functions
  - CTEQ provides Error PDFs
  - 90 % coverage of input data
- Lineshape prediction also models
  - Gluon radiation W polarisation (RESBOS, NLO QCD)
  - Photon radiation (internal, external) (WGRAD, NLO QED)
  - Detector's response to these – at better than 0.1 % !
- More information in talk by Ian Vollrath: Session E7

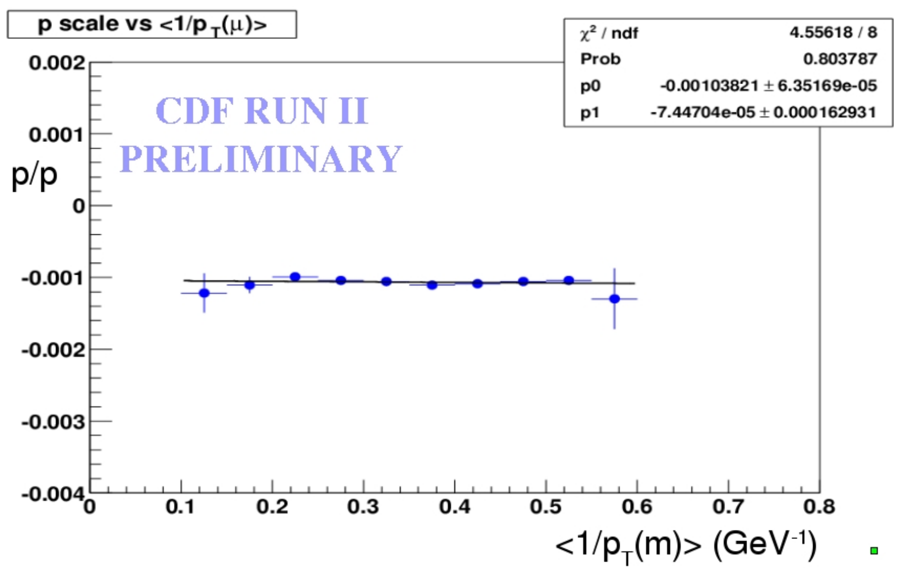


Systematic Uncertainty: ΔM_W = 30 MeV

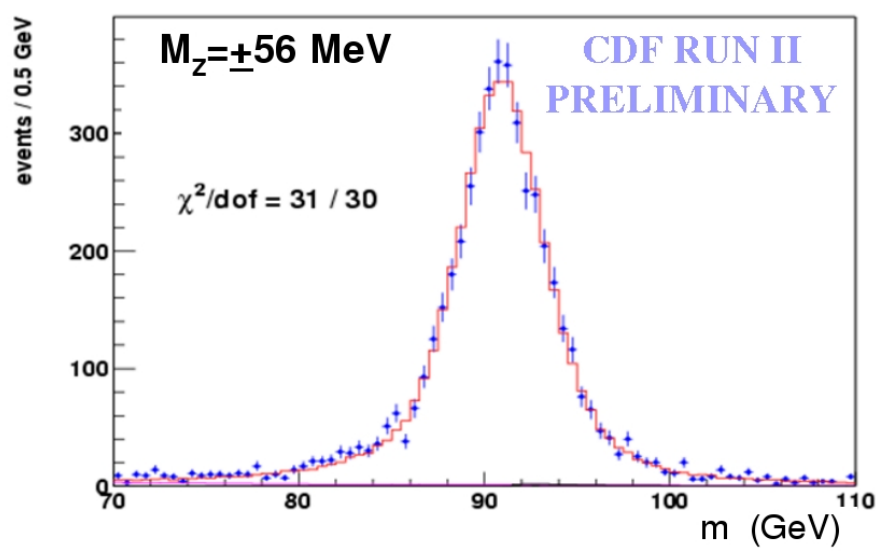
Tracker Calibration

- Momentum scale calibration
- Largest systematic for muons
- Constrain/Calibrate with
  - $J/\psi \rightarrow \mu^+\mu^-$
  - $\Upsilon(1S) \rightarrow \mu^+\mu^-$
  - Cross-check with $Z \rightarrow \mu^+\mu^-$





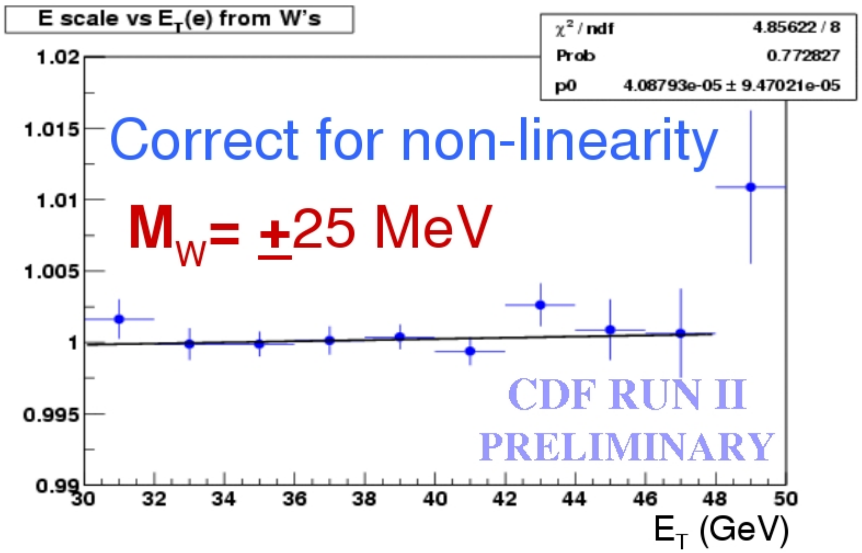
Muons

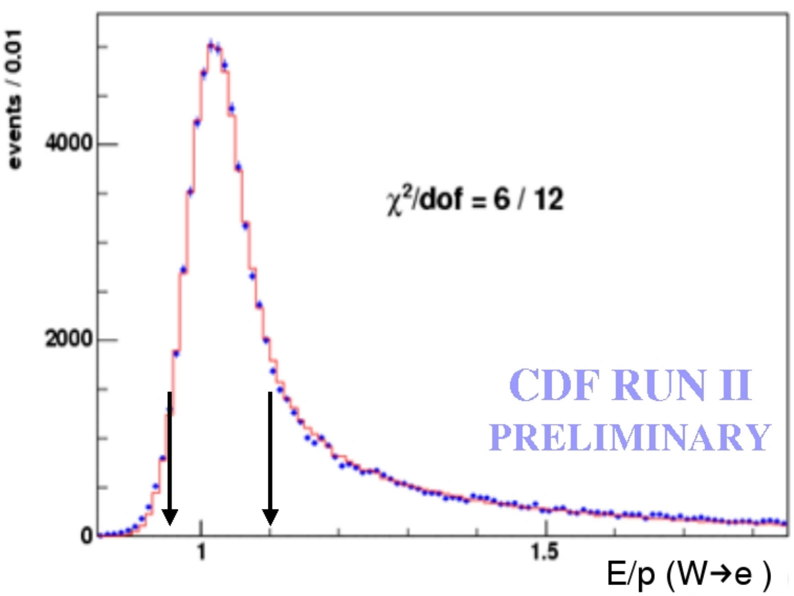


Systematic Uncertainty: ΔM_W = 30 MeV

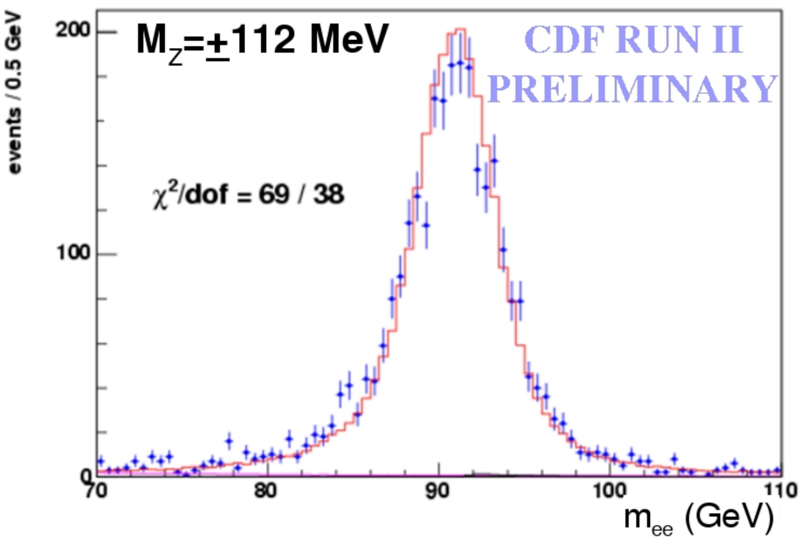
Calorimeter Calibration

- Energy Scale calibration
- Constrain/Calibrate with
  - $B \to e\nu$ to equalise tower gains
  - E/p from W electrons





Electrons



- Cross-check with $Z \to e^+e^-$

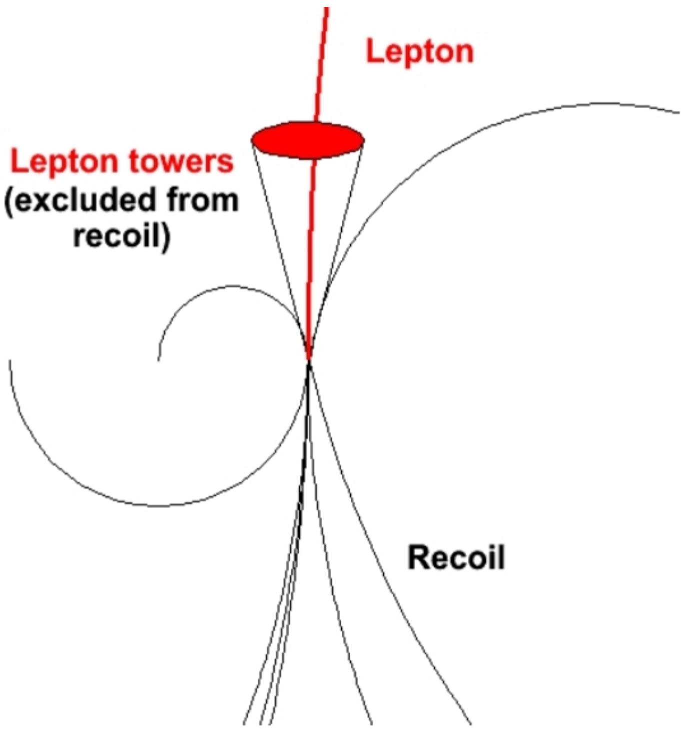
Systematic Uncertainty: ΔM_W = 65 MeV

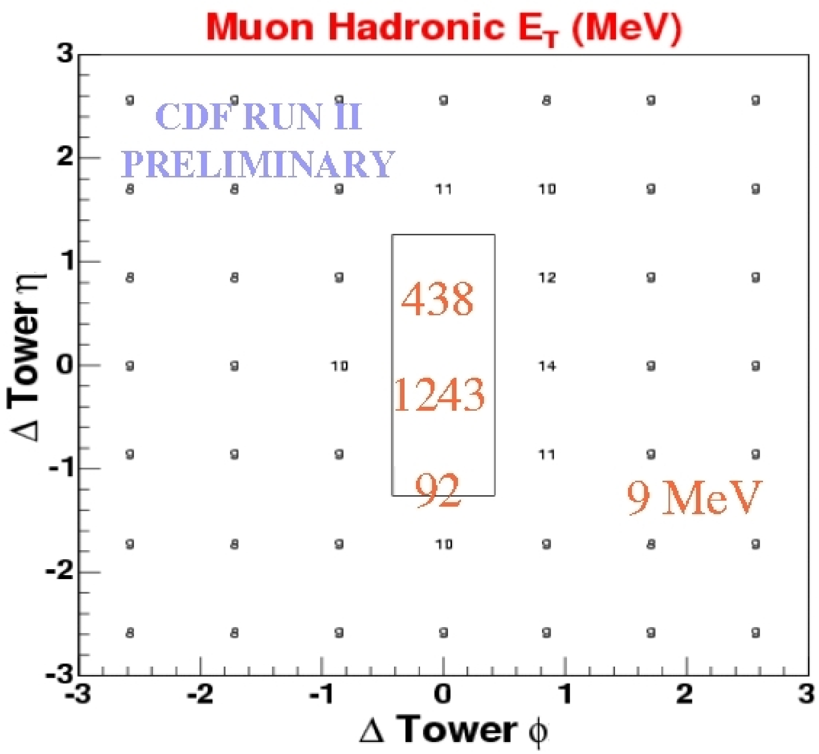
Subtleties Measuring Neutrino

- Measure neutrino as observed momentum imbalance

$$\vec{p}_T(\nu) = \vec{u} - \vec{p}_T(l^{\pm})$$

- Measure $\vec{u}$ from recoil energy seen in calorimeter



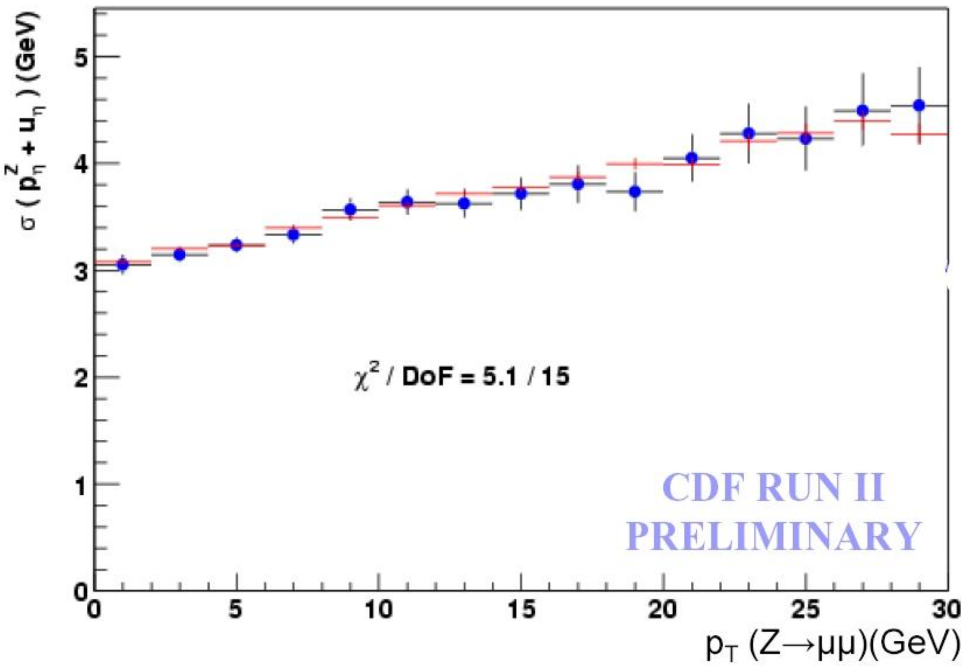


Systematic Uncertainty: ΔM_W = 10 MeV

Constraints on Underlying Event Model

- Use $Z \rightarrow l^+l^-$ events to measure detector response to $\vec{u}$

- At low p_T dominated by
  - underlying event resolution
- At high p_T dominated by
  - jet resolution
- Resolution contributes 40 MeV
- Bias contributes 20 MeV

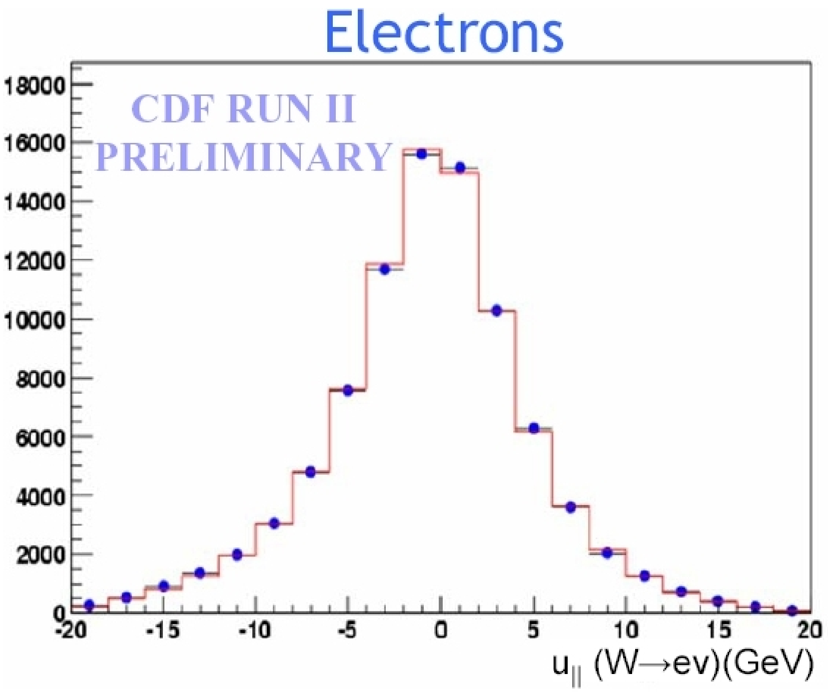


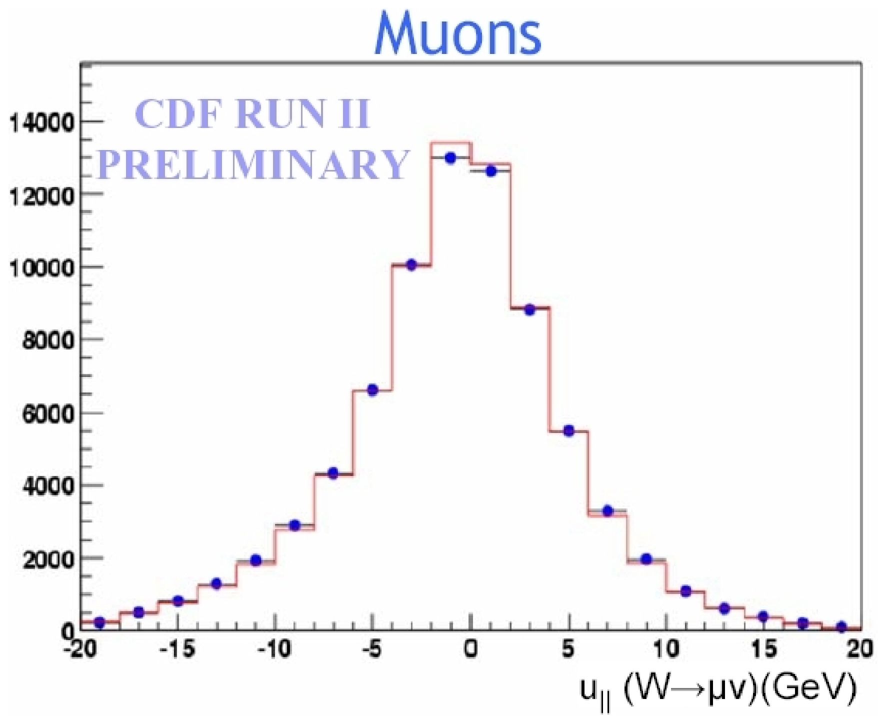
Systematic Uncertainty: ΔM_W = 50 MeV

Underlying Event Bias in Model

- Bias in $u_{parallel}$ feeds directly in W mass

$$m_T = \sqrt{2p_T(l)p_T(\nu)\{1-\cos[\phi(l)-\phi(\nu)]\}}$$



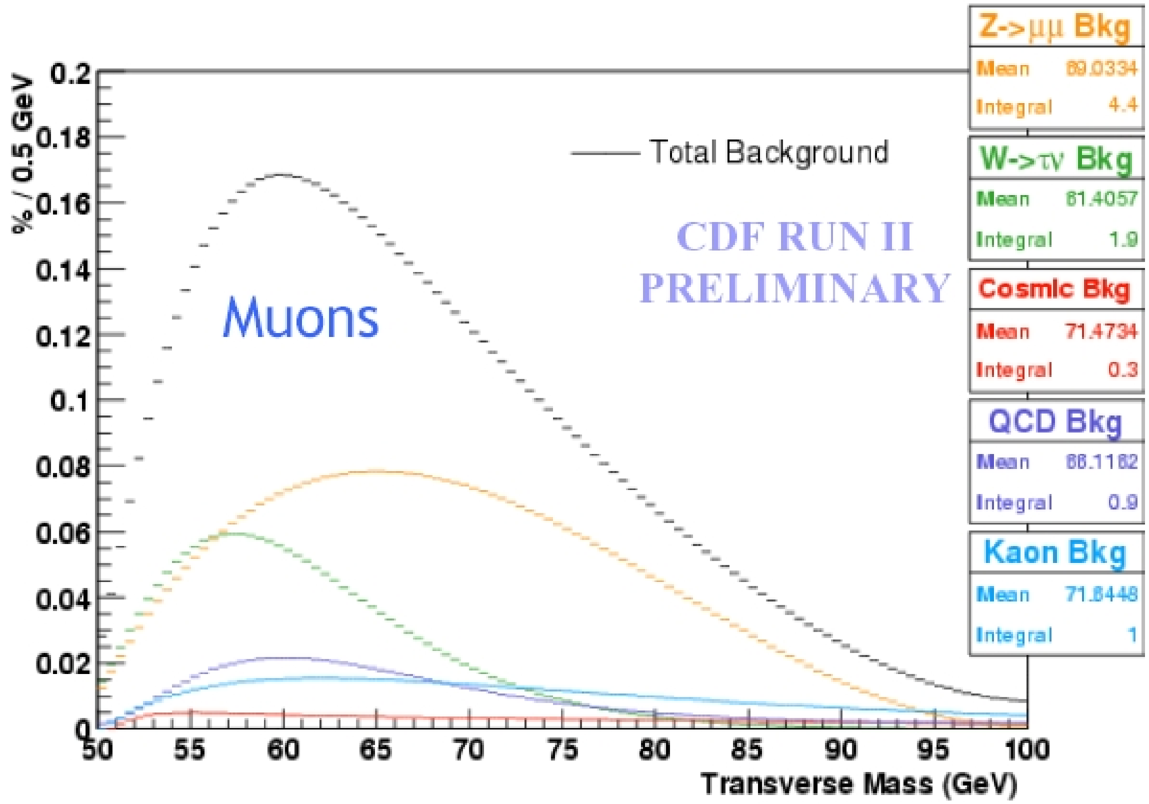


- Model agrees with data within statistical uncertainties

Backgrounds in *W* Samples

Muons

Background	%
Hadronic Jets	0.9 ± 0.5
Kaons	1.0 ± 1.0
Cosmic Rays	0.3 ± 0.1
$Z \rightarrow \mu\mu$	4.4 ± 0.2
$W \rightarrow \tau\nu$	1.9 ± 0.1



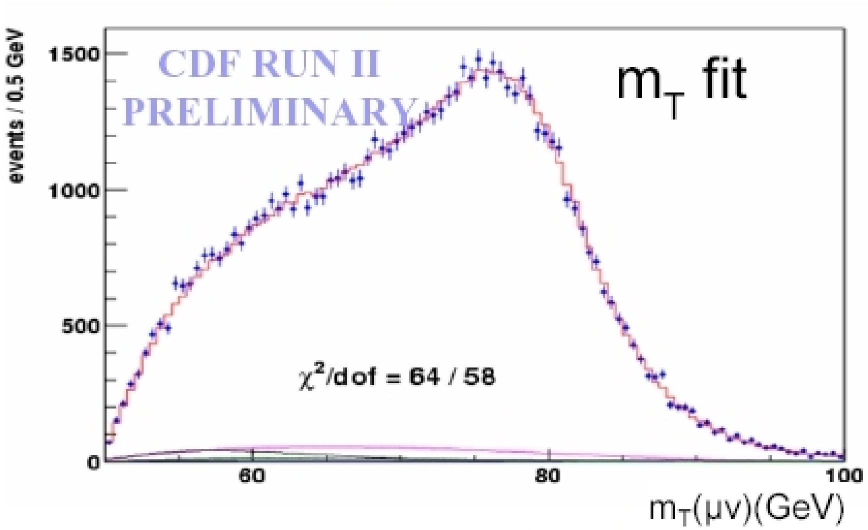
Electrons

Background	%
Hadronic Jets	1.1 ± 0.4
$Z \rightarrow ee$	0.27 ± 0.03
$W \rightarrow \tau\nu$	1.9 ± 0.1

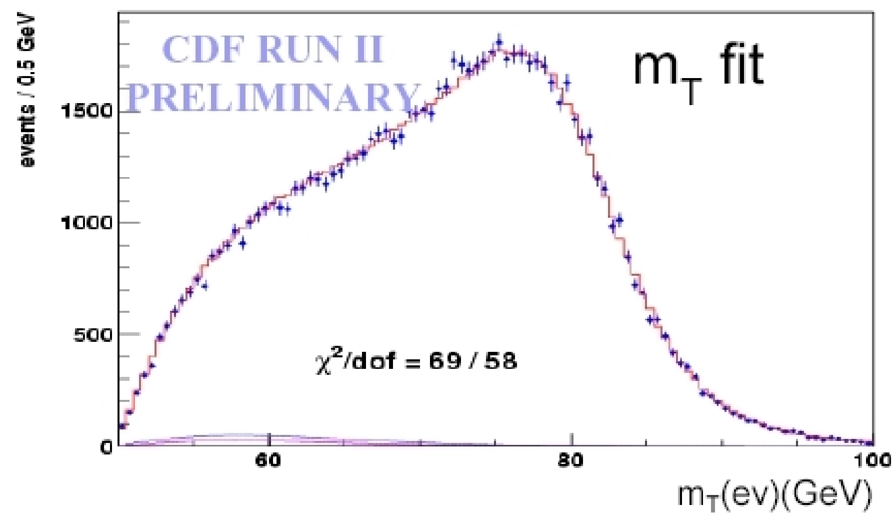
$\Delta M_W = \underline{+}\ 20$ MeV

W Mass Fits

Muons

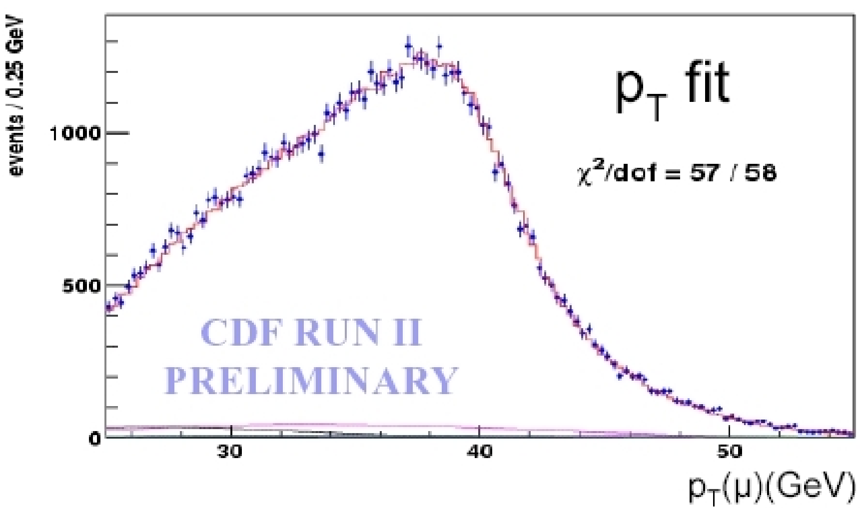


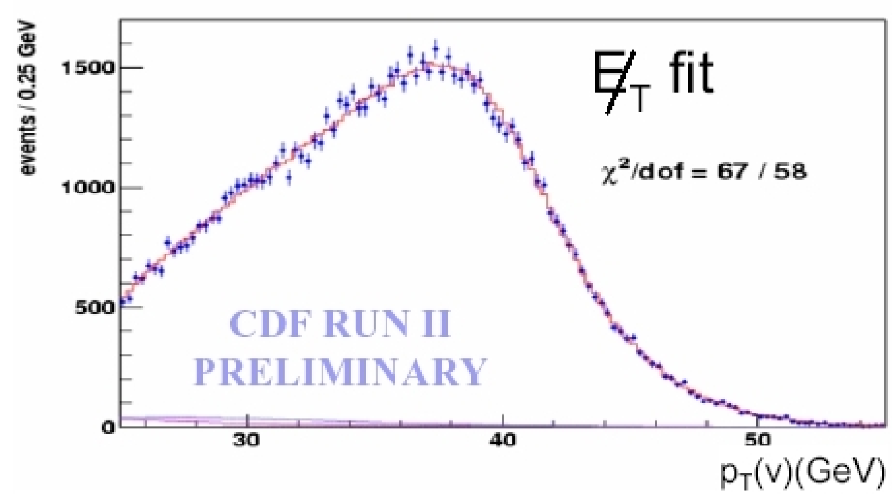
Electrons



Good x^2/dof for fits

Fits still blinded

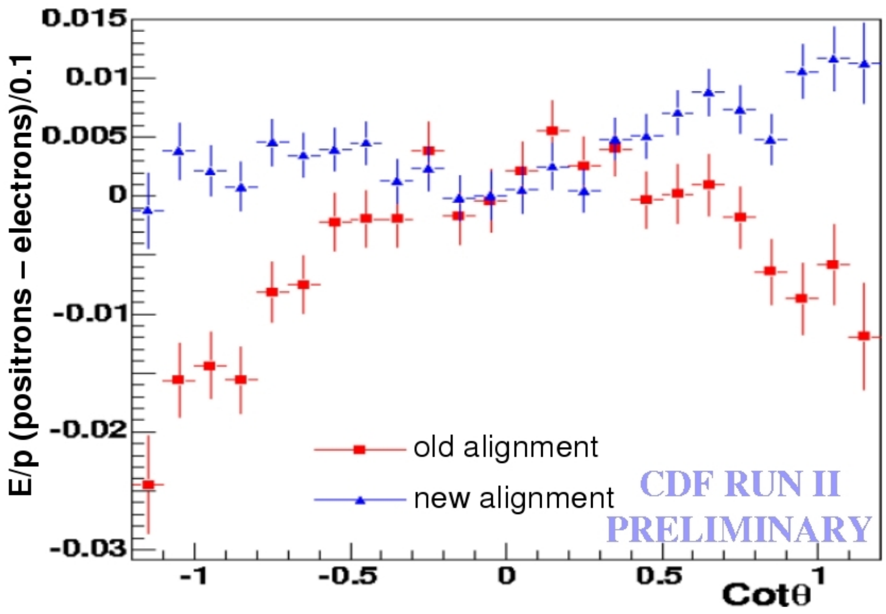




The Bottom Line (for now)

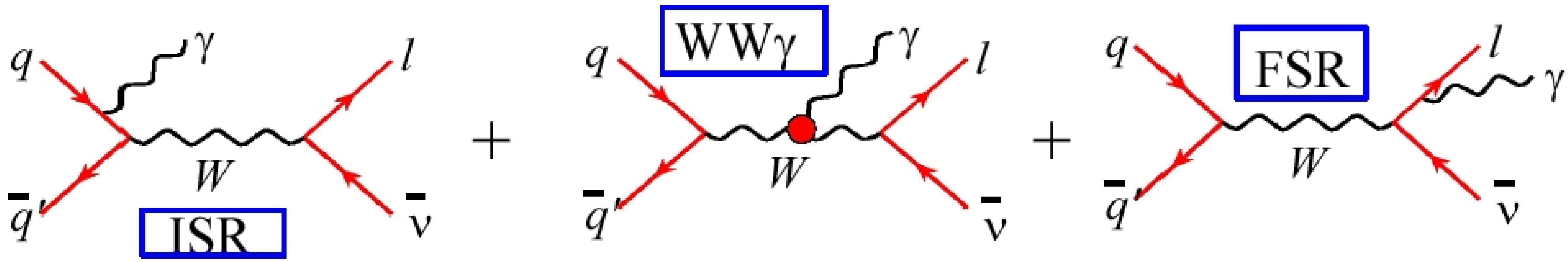
- Working to reduce systematics
  - Alignment of tracker (charge bias)
  - Recoil resolution and $p_T(W)$
  - Passive material and radiation

Uncertainty	Electrons	Muons
Statistics	45	50
Mom Scale	70	30
Recoil	50	50
Bkgnds	20	20
W Model	30	30
Total	105	85

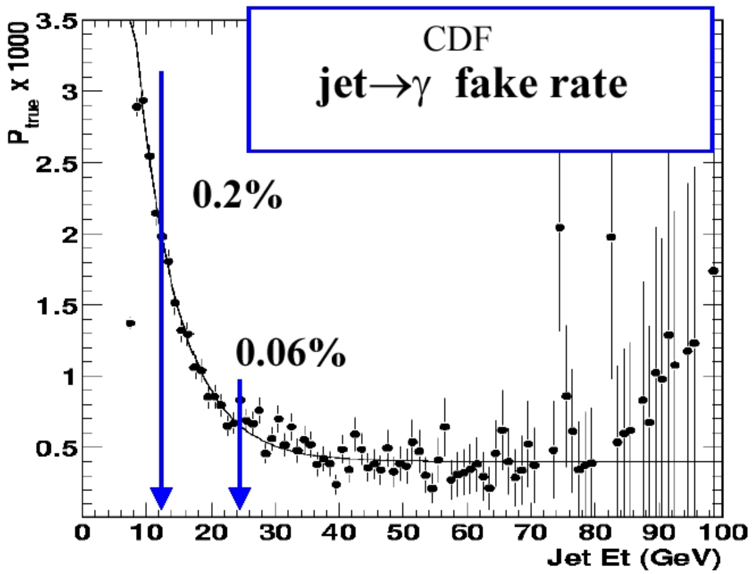


- Combining two results (including correlations)
- Overall uncertainty ΔM_W = 76 MeV
- Already better than CDF-I

$p\bar{p} \rightarrow W\gamma$ Production



- Probe $WW\gamma$ coupling
- Select W with high p_T leptons
- Photon identification:
  - $|\eta| \leq 1.1$ and $R(\gamma l^{\pm}) \geq 0.7$



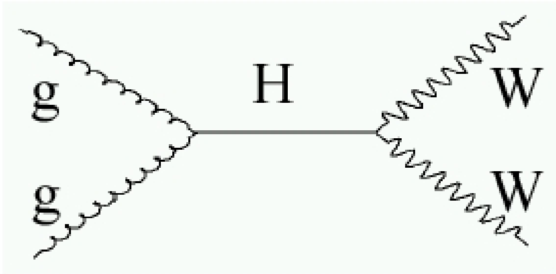
- $\sigma(p\bar{p} \rightarrow W\gamma) = 18.1 \pm 1.6(stat) \pm 2.4(sys) \pm 1.2(lum)$ pb; $E_\gamma \geq 7$ GeV
- SM predicts 19.3 ± 1.4 pb
- Insufficient statistics for angular analysis at this stage

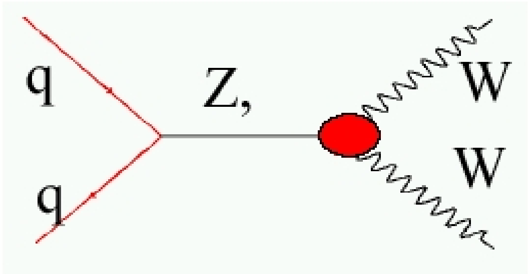
$p\bar{p} \rightarrow WW$ Production

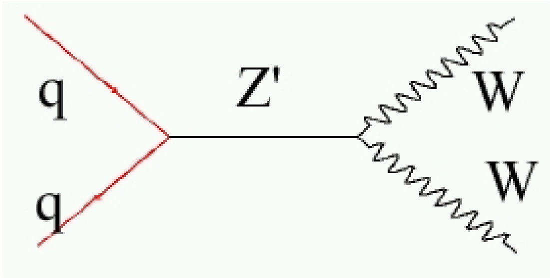
- LEP-2 experiments have large statistics
- Tevatron production well beyond threshold
- An even more interesting background

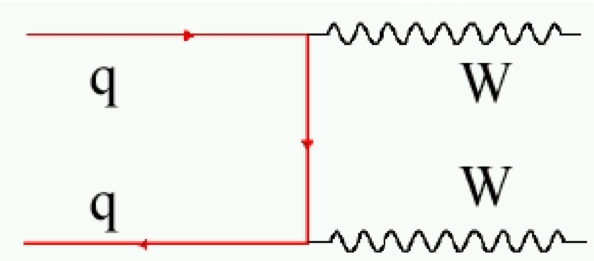
$$gg \rightarrow H \rightarrow WW$$

- A first step to WWZ coupling measurements
- Non-SM heavy boson states









$p\bar{p} \to WW$ Cross-Section

- Published result based on 200 pb^{-1}
- Signal established
- Studies of $W(l\nu)W(jj)$ underway

Luminosity	200pb-1
WW signal	11.3+/-1.3
Background	4.8+/-0.7
Expected total	16.1+/-1.6
Observed	17

- $\sigma(p\bar{p} \to WW) = 14.6 \pm 5.5(stat) \pm 2.4(sys) \pm 0.9(lum)$ pb
- SM predicts 12.4 ± 0.8 pb
- No obvious inconsistency with SM here either
- More information in talk by Jorgen Sjolin: Session E7

Summary and Prospects

- Have surpassed LEP precisions in W couplings
  - Establishing the foundation for future Electroweak measurements
- Making progress on the W mass
  - Statistics sufficient to make sub-40 MeV measurement
  - Should have control samples to improve systematics to this level
- Just embarking on di-Boson measurements
  - Should improve precision on triple boson couplings
- 600 pb^{-1} data on tape now
- Expect at least another factor of four before LHC starts