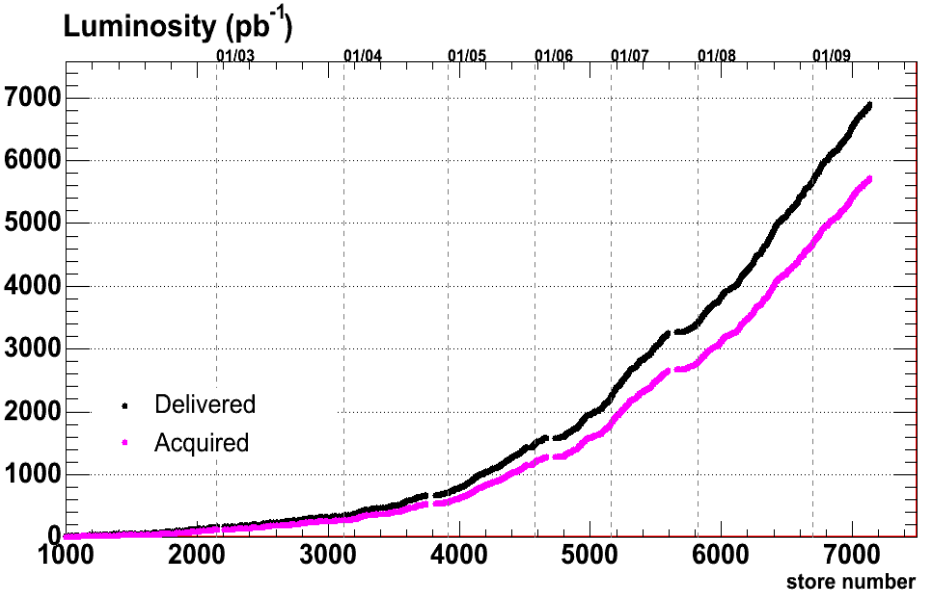
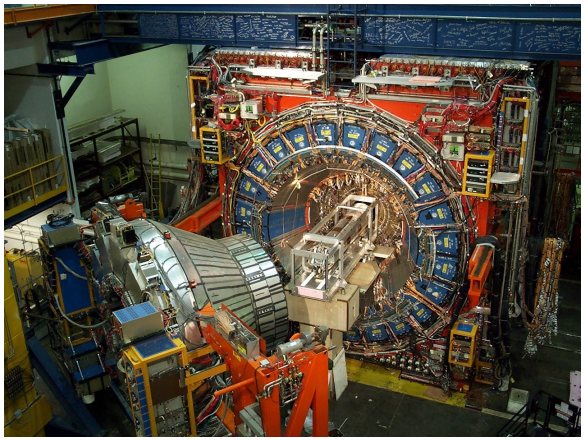
# Observation of WW/WZ → lνjj at CDF

Martina Hurwitz,
*University of Chicago*,
for the CDF collaboration


DPF Electroweak session, July 22 2009

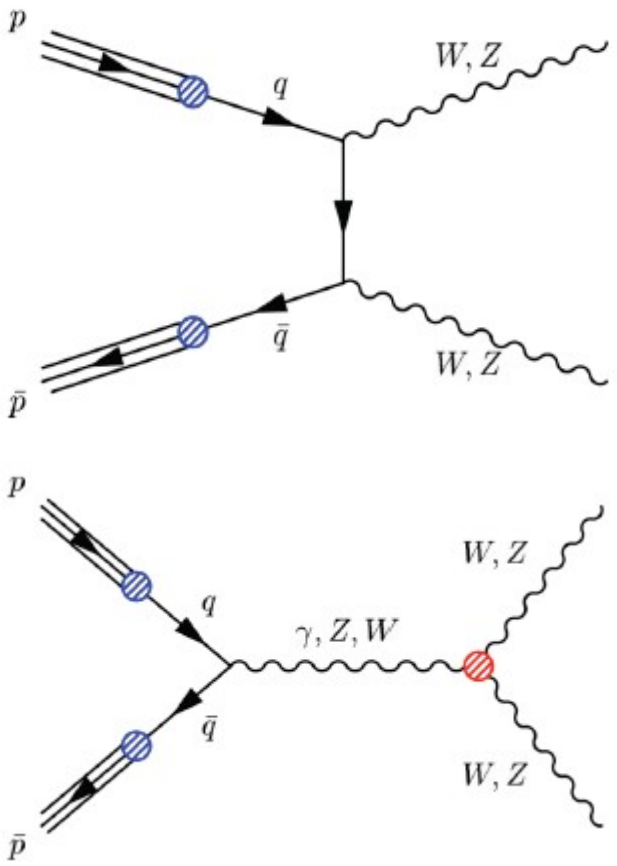
# Tevatron and CDF



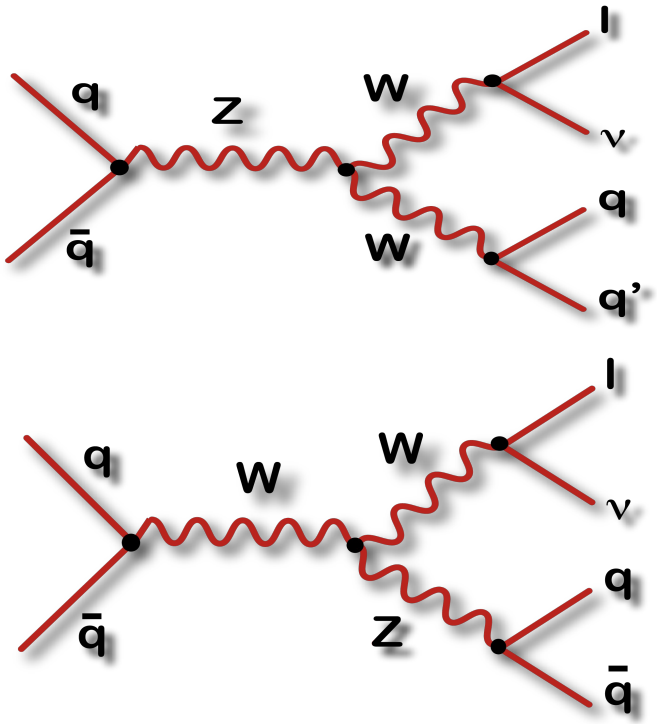
- Tevatron and CDF in stable data-taking mode for several years
- ~6 fb$^{-1}$ of recorded data available

# WW / WZ production




- WW / WZ production at Tevatron
  - Tests Standard Model predictions
  - Can be enhanced by new physics (Higgs, SUSY, …)
  - Has similar topology to SM Higgs production
- Observation and cross section measurements in leptonic modes
  - WW → lνlν, WZ → lνll
  - Consistent with SM so far
- Semi-leptonic modes suffer from large backgrounds
  - Evidence of WW/WZ → lνjj reported by D0
  - Recent first observation of WW/WZ/ZZ → MET+jj at CDF

# WW+WZ → lνjj




- Require high-$p_T$ electron or muon, large missing transverse energy (MET), and two jets
- Reconstruct W or Z from two-jet system
  - Don't separate W from Z because of detector smearing
- WW is dominant over WZ

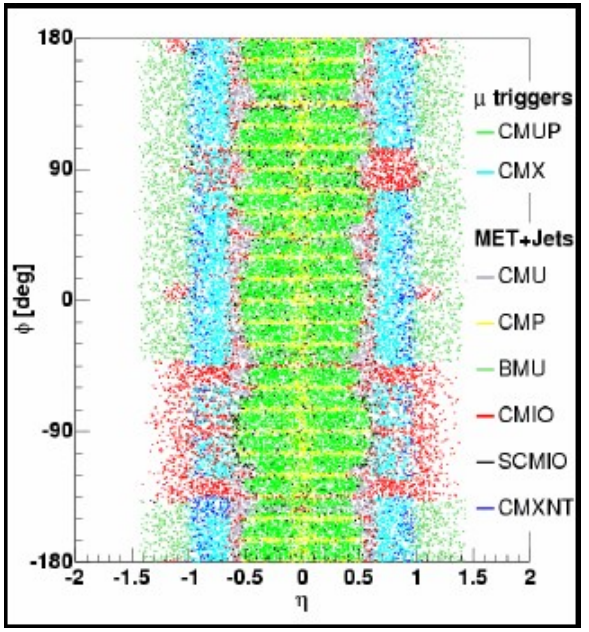
  σ*B.R. (WW) ~ 3.6 pb

  σ*B.R. (WZ) ~ 0.6 pb

- Presenting two recent measurements of WW+WZ → lνjj at CDF
  1) Matrix element analysis in 2.7 $fb^{-1}$ (focus of this talk)
  2) Search for resonance in dijet invariant mass spectrum in 3.9 $fb^{-1}$

# Event selection

- Triggers:
  - High-$p_T$ electron and muon triggers
  - Trigger requiring high MET and exactly two jets
- Four lepton categories: central electrons, central muons, forward muons, muons from MET+jets triggers




- Offline selection
  - Electron or muon with $E_T$ or $p_T$ > 20 GeV
  - MET>20 GeV
  - Two jets with $E_T$>25 GeV
  - Various vetos to reduce backgrounds and improve data / MC agreement

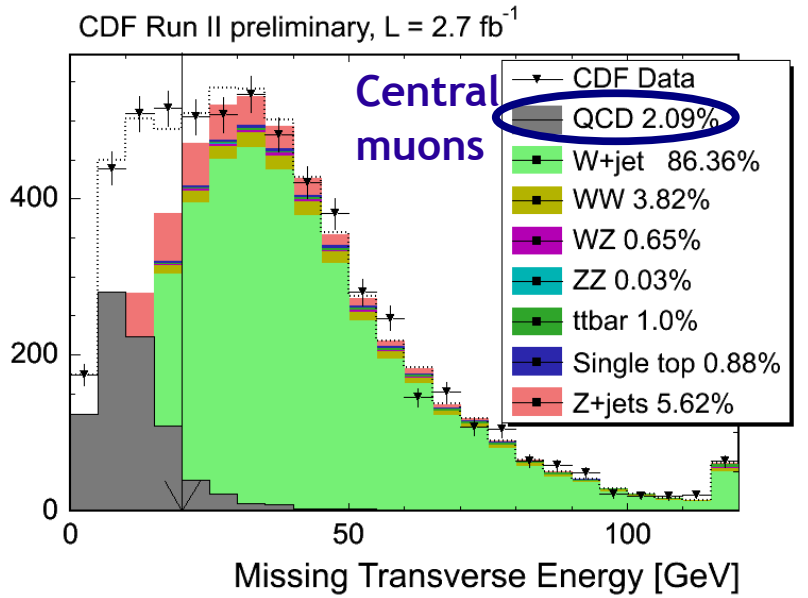
# Backgrounds

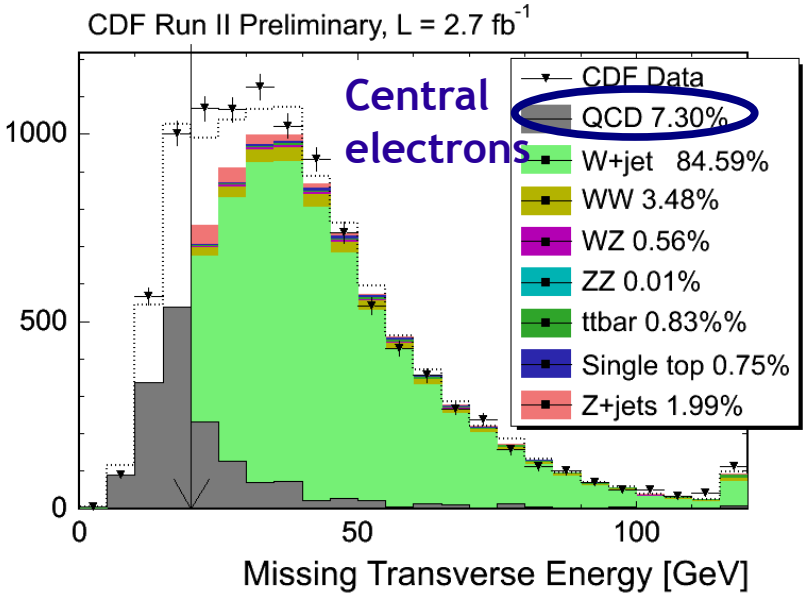
| Process | | Shape modeling | Normalization estimate |
|---|---|---|---|
| W+jets | Large cross section, looks like signal | MC ( Alpgen + Pythia) | Free parameter in final signal extraction |
| Z+jets | Reduce significantly by cutting on additional leptons | MC ( Alpgen + Pythia) | MC (using measured cross section) |
| QCD | Reduce with cuts on MET, $m_T$(W) | Data with loosened lepton ID | Fit to MET spectrum |
| ttbar | Reduce with cuts on additional leptons and jets | MC (Pythia) | MC |
| Single top | Very small cross section | MC (MadEvent + Pythia) | MC |

# QCD multi-jet background

- Jet fakes a lepton and mismeasurement leads to large MET
  - Difficult to model
- Fit to MET spectrum to derive normalization
- Larger contribution in events with electrons
  - Not satisfied with modeling of these events
  - Impose very hard cuts on MET and transverse mass of leptonic W to reduce contribution to ~1%
  - Significantly reduces signal acceptance in electron events

Measurement is dominated by muon events



# Expected event yields

| Process | Event yield |
|---|---|
| $WW$ signal | $441 \pm 28$ |
| $WZ$ signal | $79 \pm 6$ |
| $W$+jets | $9425 \pm 283$ |
| $Z$+jets | $546 \pm 82$ |
| QCD multijet | $252 \pm 101$ |
| $t\bar{t}$ | $111 \pm 15$ |
| single top | $90 \pm 9$ |
| Total predicted | $10944 \pm 313$ |
| Observed | 10948 |

- Observed and predicted total agree by construction
  - W+jets contribution comes from fit to data
  - W+jets estimate used in validation of modeling, but not in final cross section fit
- Small signal-to-background ratio → use matrix element technique to discriminate

# Matrix element method

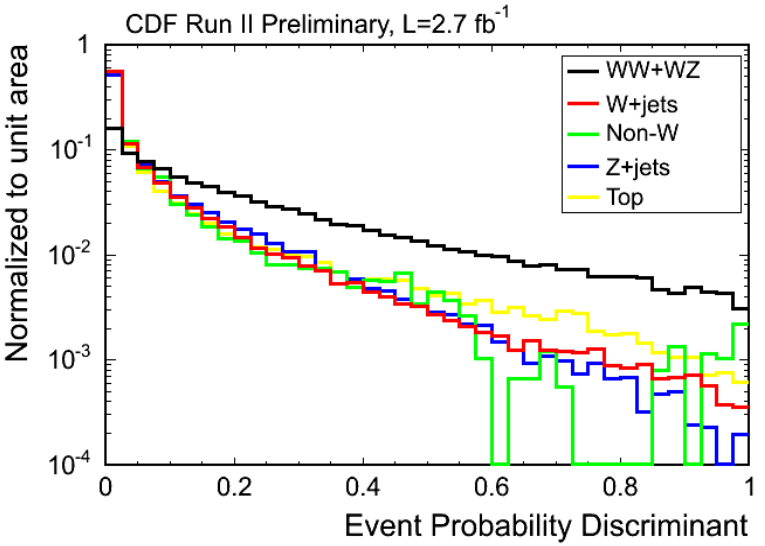
- Can define probability of an event originating from a specific process by evaluating the differential cross section: $P_{evt} \sim \frac{d\sigma}{\sigma}$
  - Integrate over detector response function, initial parton distribution functions, and z-component of missing energy
- Evaluate probabilities for signal and background processes and define Event Probability Discriminant (EPD) as:

$$EPD = P_s/(P_s + P_b)$$

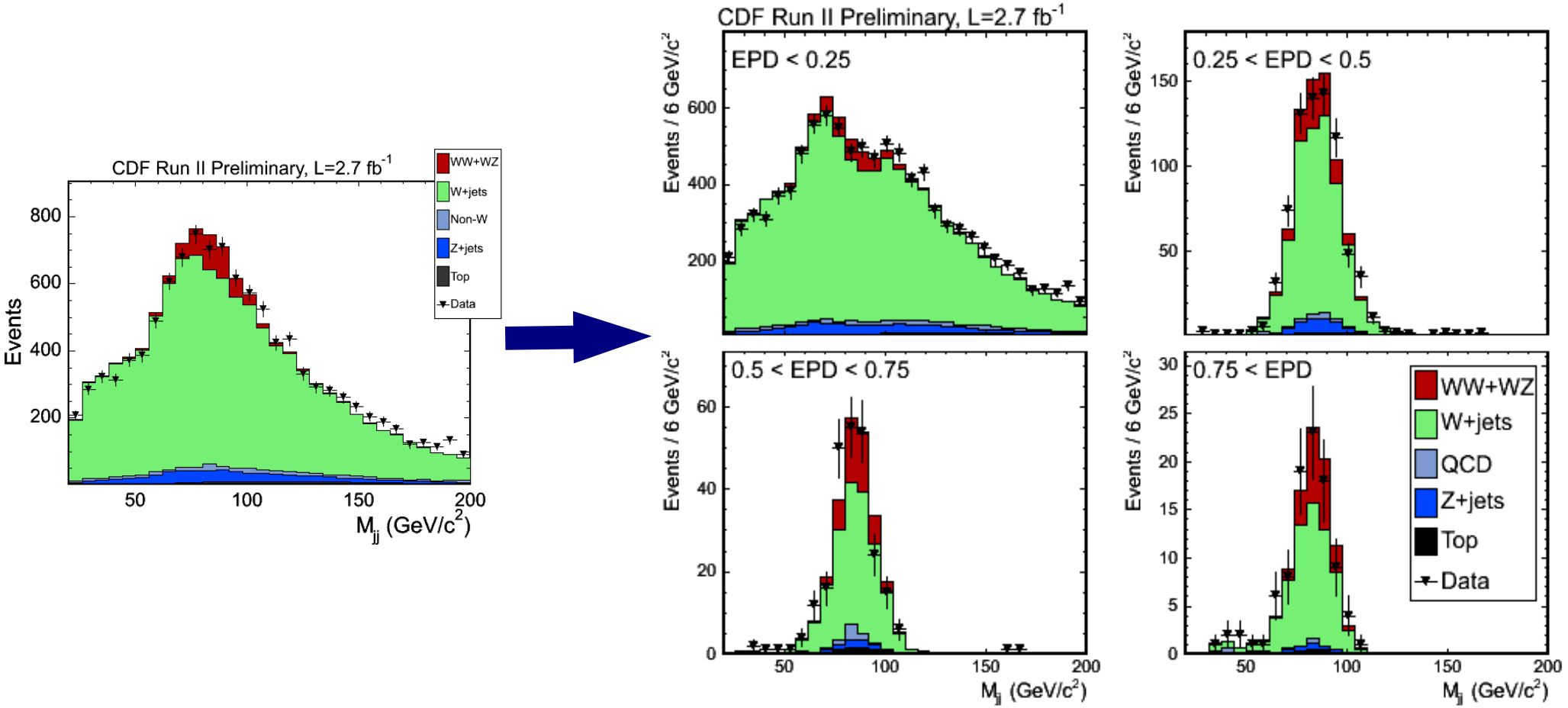
$$EPD = \frac{P_{WW} + P_{WZ}}{P_{WW} + P_{WZ} + P_{schan} + P_{tchan} + P_{Wjj} + P_{Wgj} + P_{Wbb} + P_{Wcc} + P_{Wc}}$$

Single top

W+jets



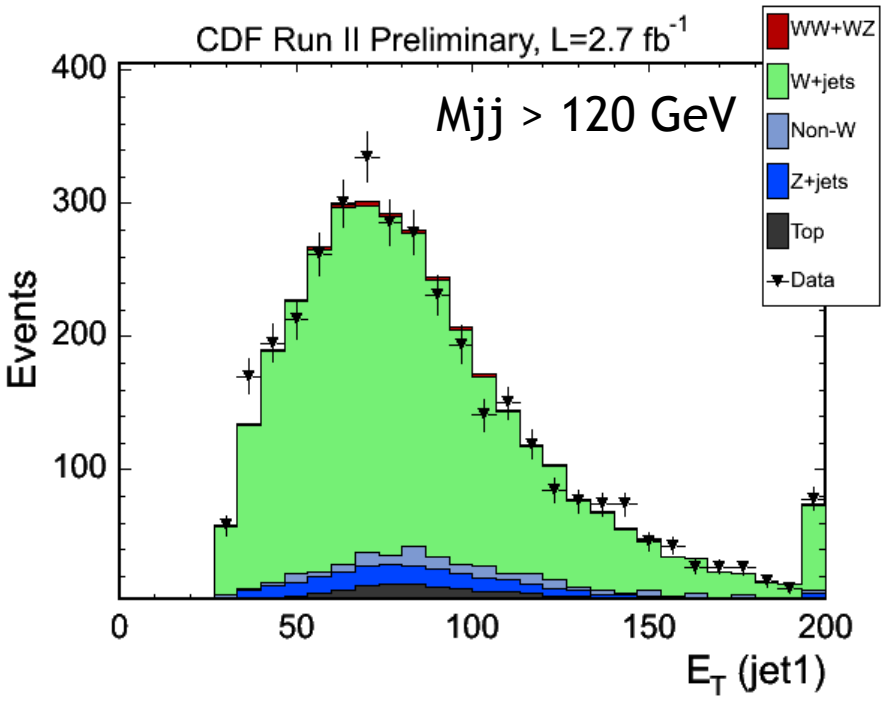
# Effectiveness of matrix element

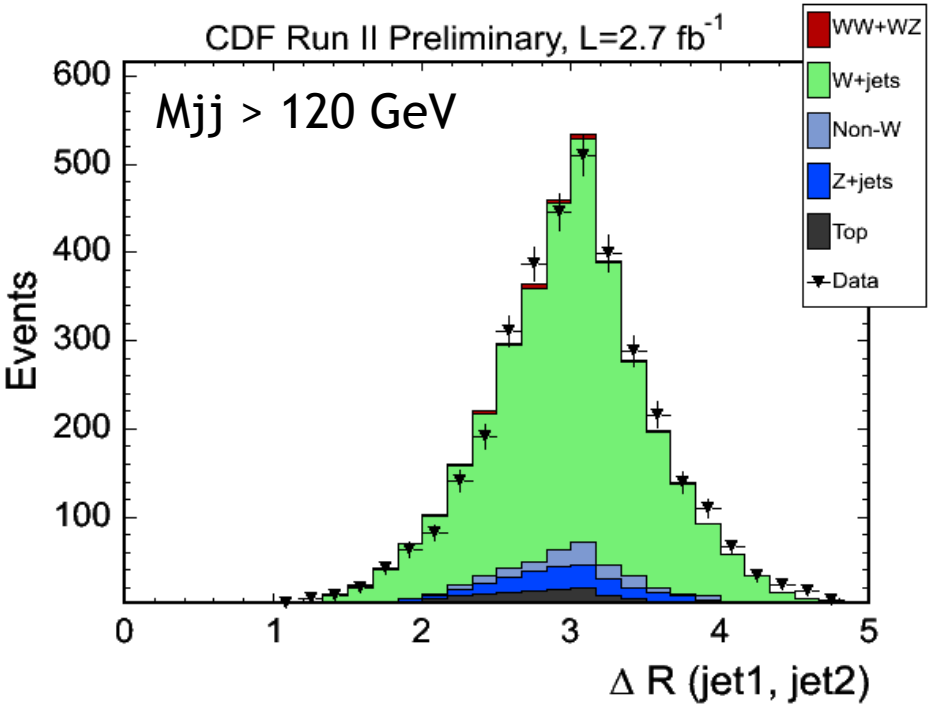



- Dijet mass ($M_{jj}$): resonance in signal at W/Z peak
- Low-EPD events dominated by background, signal-to-background ratio improves with increasing EPD

# Validation of MC modeling

- EPD relies on modeling of background and signal kinematics
- Check modeling of input variables and reconstructed bosons
  - Define control regions with little expected signal contribution according to dijet mass range

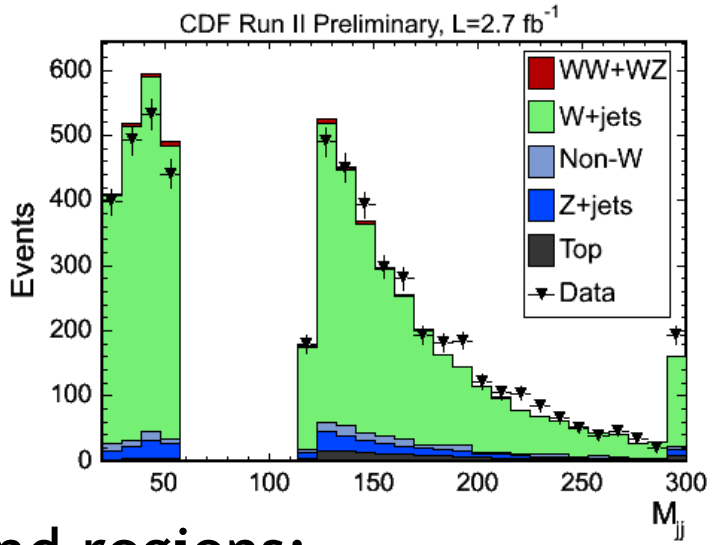


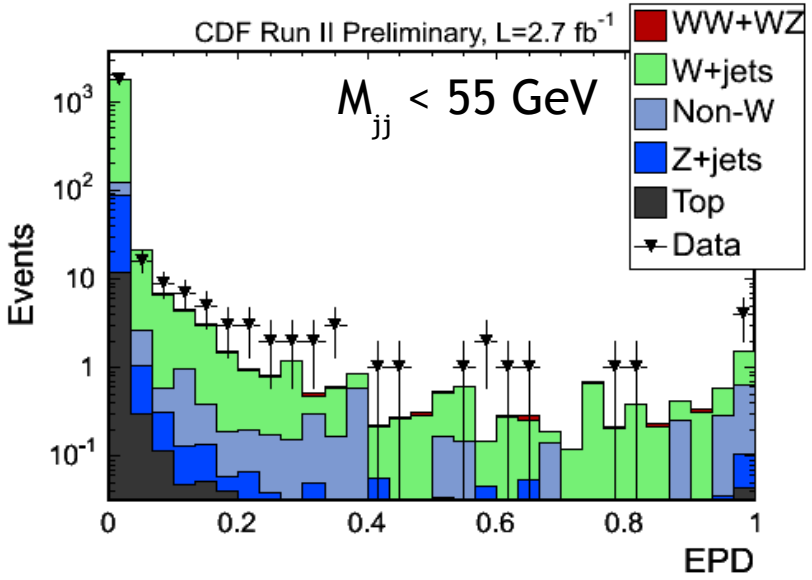
# Validation of MC modeling

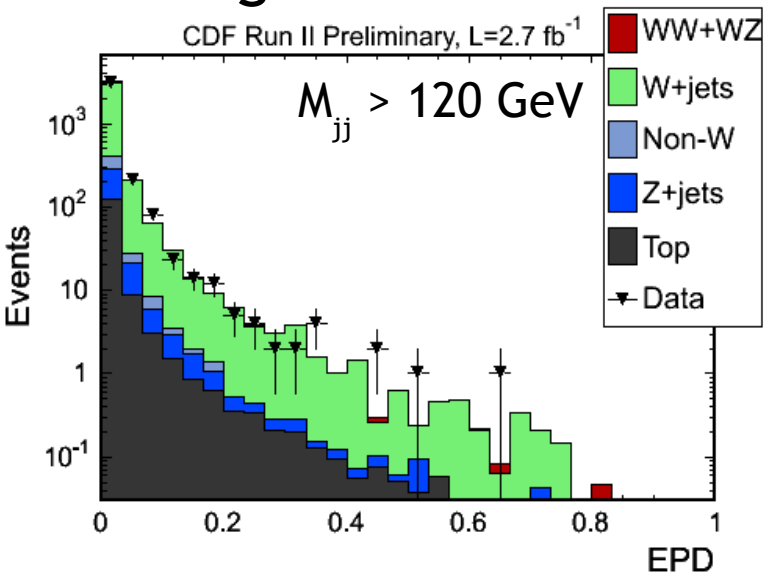
Small discrepancy in sidebands of dijet mass

- Assign systematic uncertainty
- Derived in sidebands, extrapolated through signal region




Validation of discriminant in sideband regions:



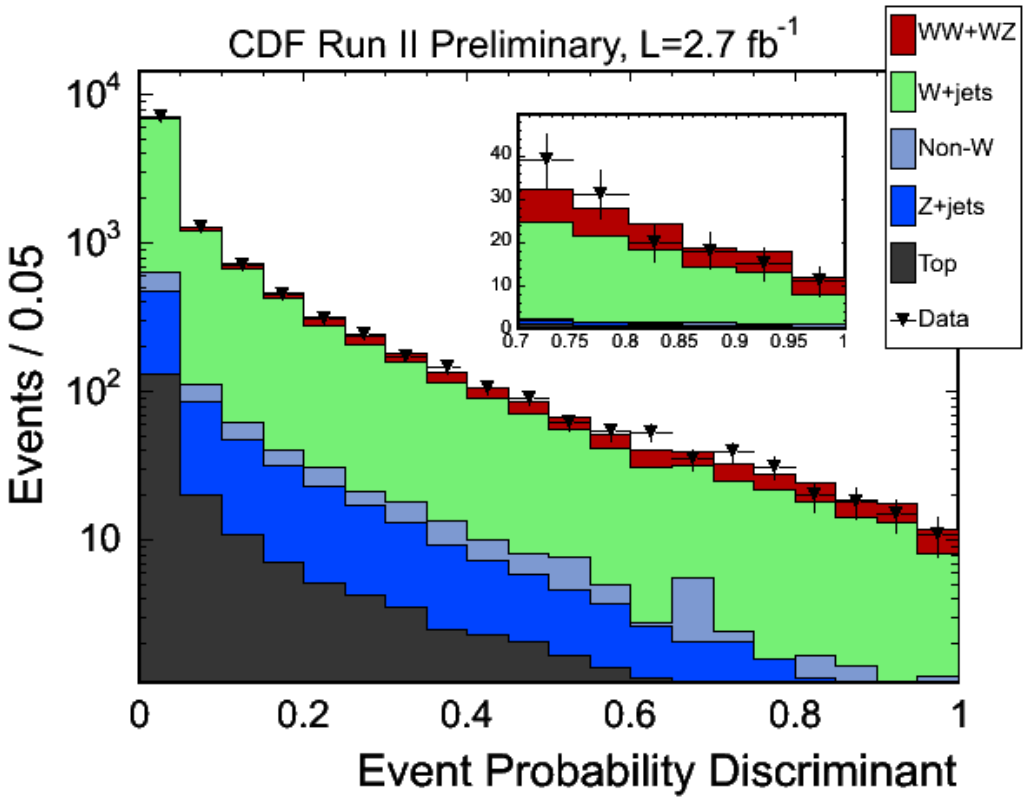
# Fit to extract cross section

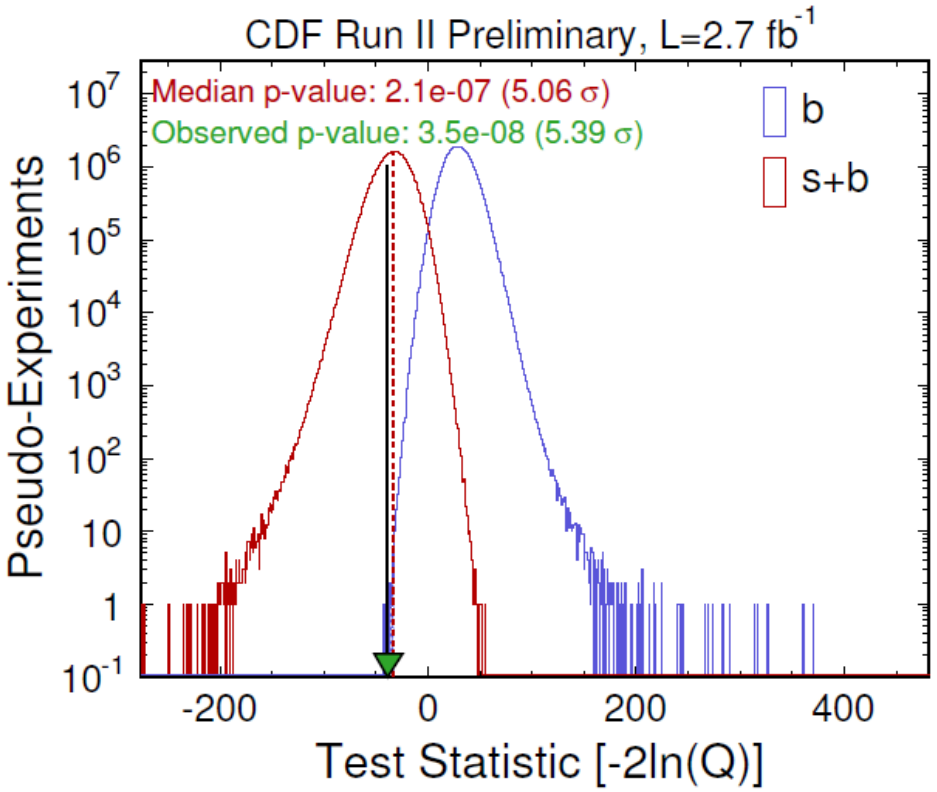
- Binned maximum likelihood fit
  - Signal cross section and W+jets normalization are free parameters
- Bayesian approach: systematic uncertainties treated as nuisance parameters with Gaussian priors
  - Jet energy scale and resolution (shape and rate)
  - Background normalizations
  - Monte Carlo statistical uncertainties on templates
  - ISR / FSR and PDF uncertainties
  - Shape uncertainty in W+jets background: from uncertainty in factorization and renormalization scales in Alpgen and small mismodeling observed in dijet mass control regions
  - 6% uncertainty in integrated luminosity

# Results

Measured cross section:
σ(WW+WZ) = 17.7 ± 3.9 pb
(NLO: 16.1 ± 0.9 pb)

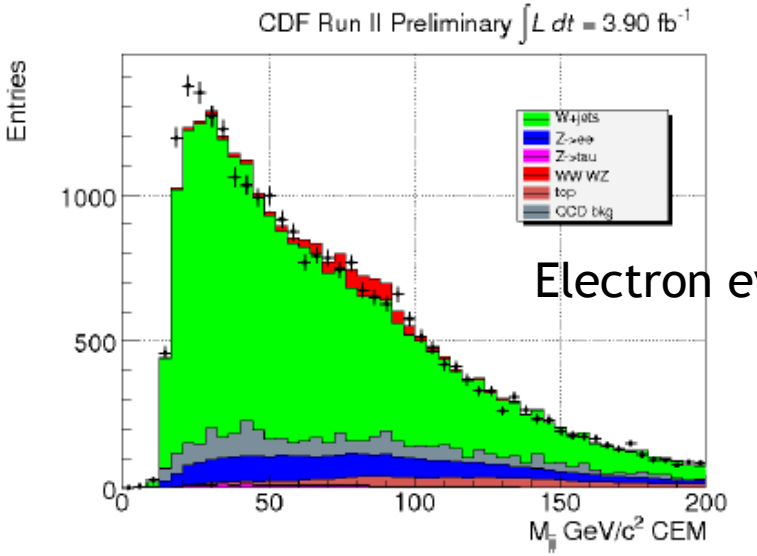
p-value = 3.5 x $10^{-8}$
5.4σ signifiance
(5.1σ expected)



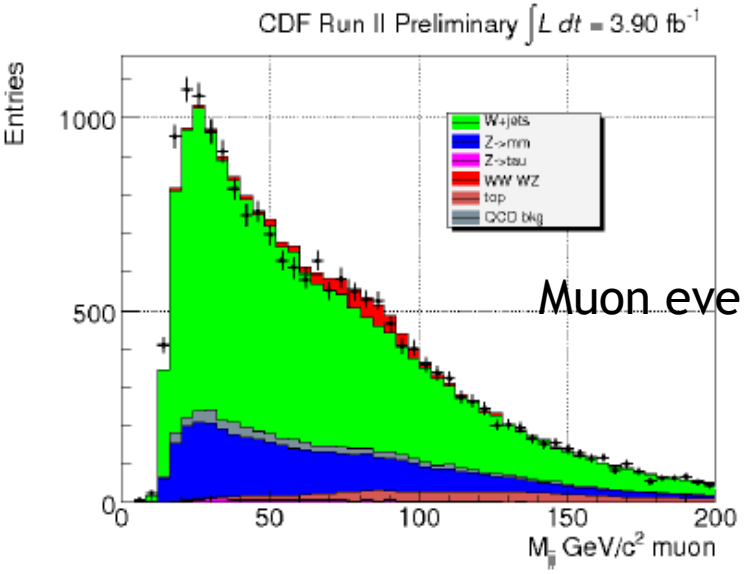



# Search using dijet mass

- Search for resonance in $M_{jj}$
  - Intuitive search technique, but lower sensitivity expected
- Event selection different than in matrix element analysis to achieve smoothly falling distribution in background
  - Cut on $p_T$ of hadronic W candidate ($p_T$>40 GeV)
  - Different QCD veto
    - Less strict veto in electrons → ~equal acceptance in muon and electron events



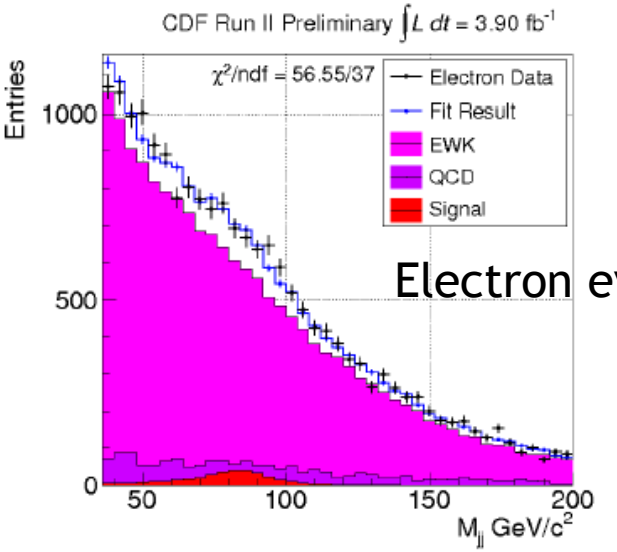

Electron events



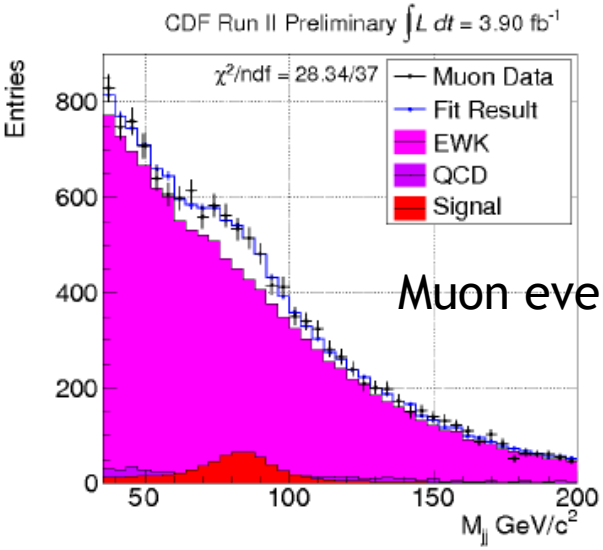

Muon events

# Signal extraction in dijet mass

- Create three templates
  - Electroweak (EWK) = W+jets, Z+jets, and top backgrounds
  - QCD
  - Signal = WW and WZ
- Perform binned likelihood fit to sum of three templates
  - EWK normalization, signal normalization, overall normalization are free parameters
  - QCD is constrained by MET fit
- Muon and electron events fit separately, results combined at end

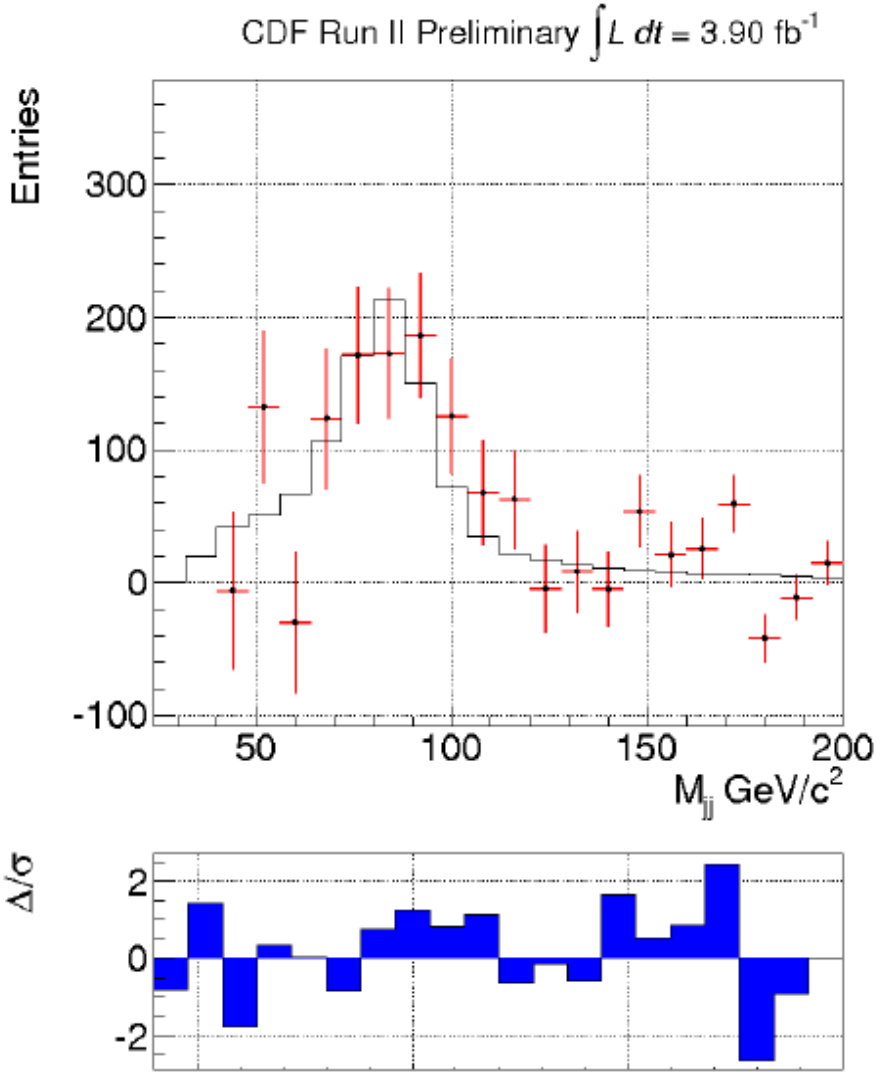



Electron events




Muon events

# Results from fit to dijet mass




σ(WW+WZ) = 14.4±3.1(stat)±2.2(sys) pb
(NLO: 16.1 ± 0.9 pb)

Significance: 4.6σ
(4.9σ expected)

# Conclusions

- We have observed WW/WZ events in channel with lepton (electron or muon), MET, and two jets
  - Challenging search with large W+jets background
  - Interesting topology analogous with Higgs searches
- Search using matrix element discriminant with 2.7 $fb^{-1}$ of luminosity finds signal with significance of 5.4σ
- Two separate measurements of cross section give compatible results and are in good agreement with SM
  - σ(WW+WZ) = 17.7 ± 3.9 pb (Matrix element technique)
  - σ(WW+WZ) = 14.4 ± 3.8 pb (Dijet mass technique)

  [σ(WW+WZ) = 16.1 ± 0.9 pb (Standard model at NLO)]