WW/WZ/ZZ measurements at the Tevatron

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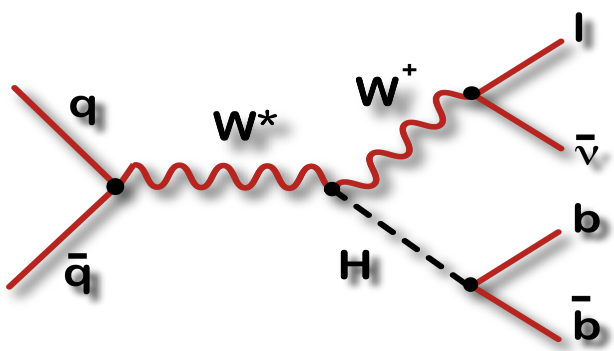
Outline

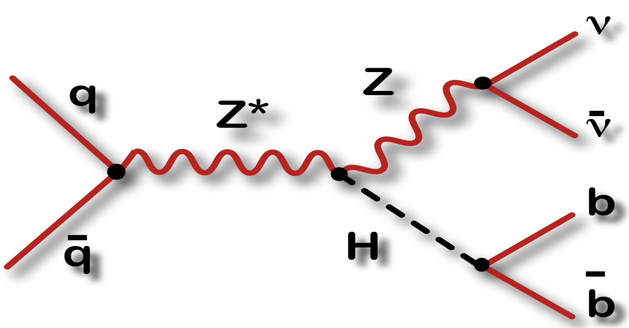
- Motivation
- Tevatron / CDF, D0
- Diboson measurements in fully leptonic decays
- Diboson measurements in semileptonic decays

Dibosons and low-mass Higgs

Most sensitive channels for M_H<135 GeV: Associated production (WH, ZH) with $H \rightarrow b\bar{b}$

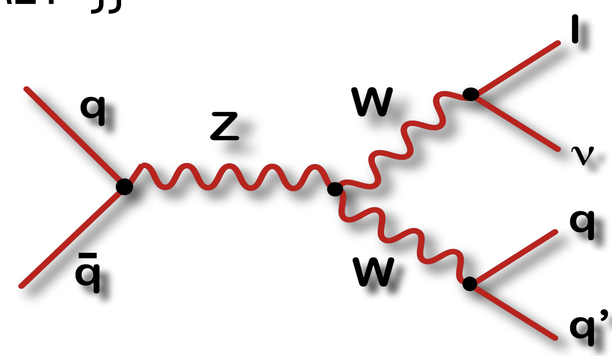
Final states: $l\nu b\bar{b}$, $llb\bar{b}$, and missing tranvserse energy (MET)+$b\bar{b}$

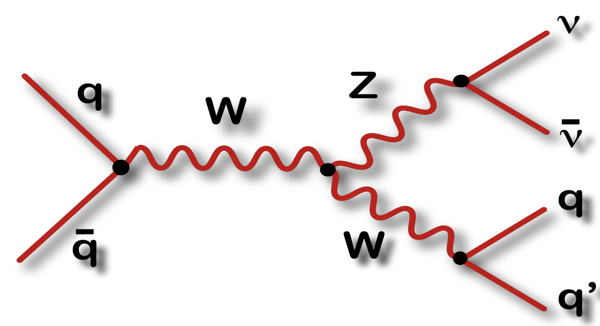




Standard model production of WW, WZ, and ZZ (dibosons)

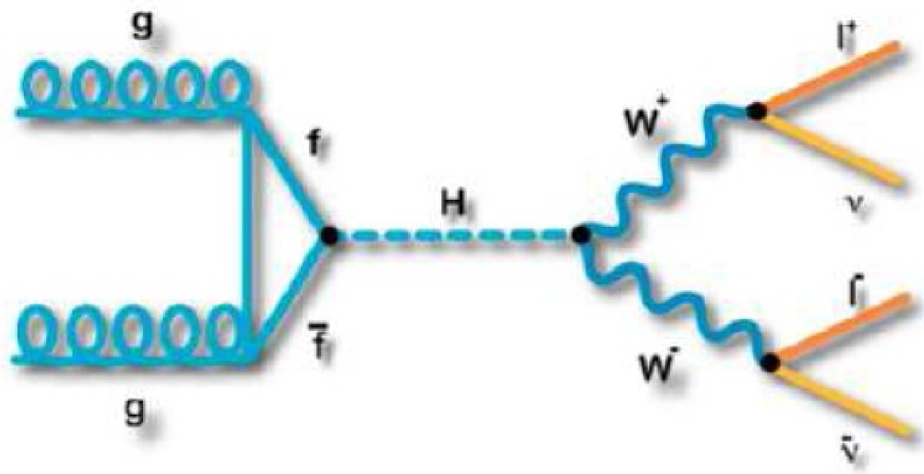
Semileptonic final states: $l\nu jj$, $lljj$, and MET+jj





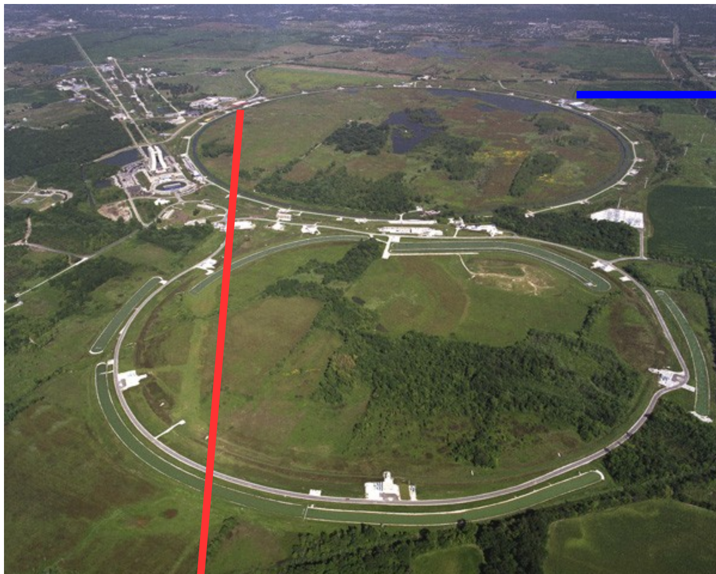
Semileptonic decays of dibosons are good place to test Higgs search techniques

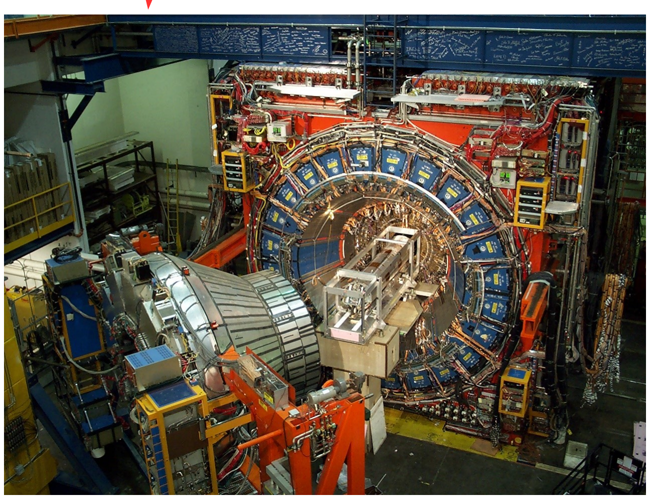
Dibosons and high-mass Higgs



- For M_H>135, most sensitive channel to set limits on Higgs production is gg → H → WW → lνlν
- Can test search techniques by measuring Standard Model WW production cross section

CDF and D0

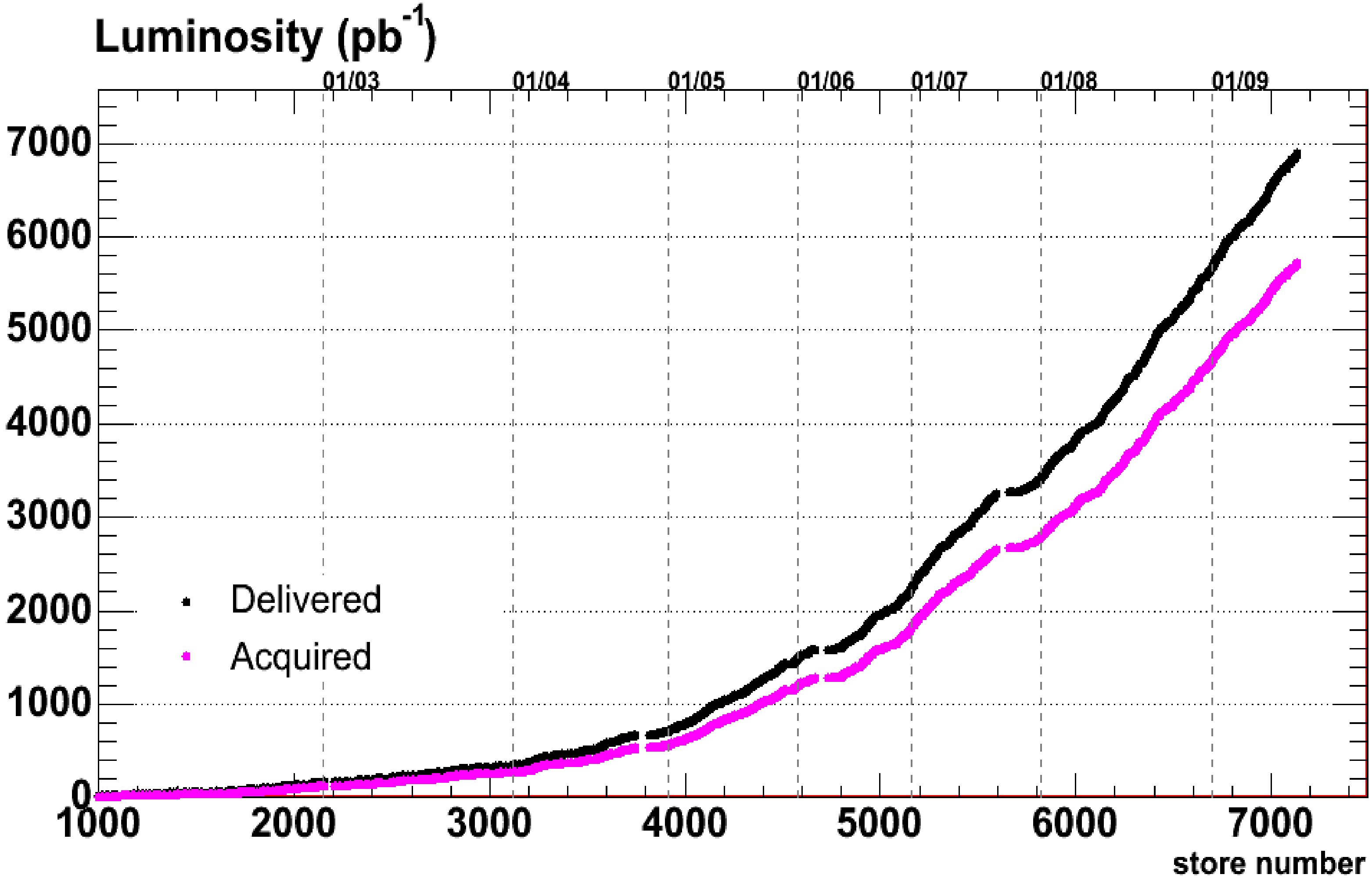




CDF and D0 are similar multi-purpose detectors

- Tracking: particle ID and b-tagging
- Calorimetry: energy measurement
- Muon system

Tevatron



Large data sample allows us to probe very small cross sections

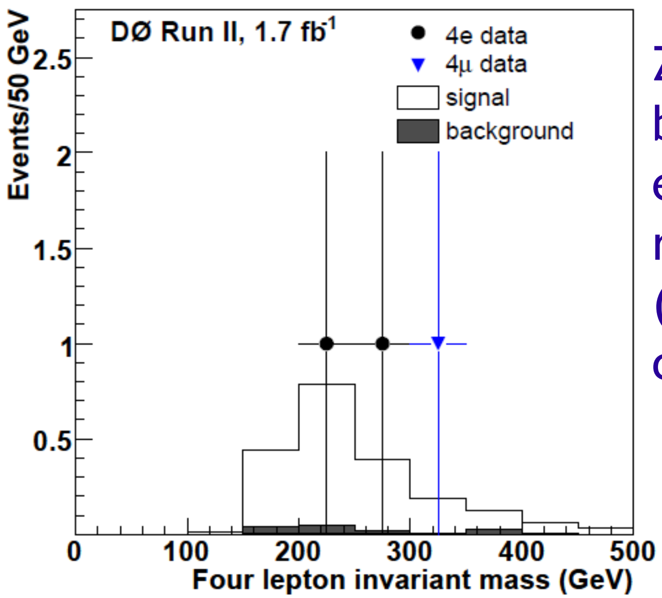
Fully leptonic diboson measurements

- Cleanest channels to test standard model predictions
- WW, WZ, and ZZ production have all been observed at the 5σ level at the Tevatron
  - Cross sections compatible with Standard Model predictions
  - Now placing limits on new physics (aTGC)

Process	Channel used for measurement	Cross section measured at CDF (pb)	Cross section measured at D0(pb)	Predicted NLO cross section (pb)
WW	lvlv	$12.1^{+1.8}_{-1.7}$	11.5 ± 2.2	11.7 ± 0.7
WZ	lvll	$4.3^{+1.3}_{-1.1}$	$2.7^{+1.7}_{-1.3}$	3.7 ± 0.3
ZZ	llll and llvv	$1.4^{+0.7}_{-0.6}$	1.6 ± 0.65	1.4 ± 0.1

(Measurements use different integrated luminosities between 1.0 and 3.6 fb^{-1})

ZZ production in leptonic decays



ZZ → llll: small backgrounds, count events in signal region (More sensitive channel)

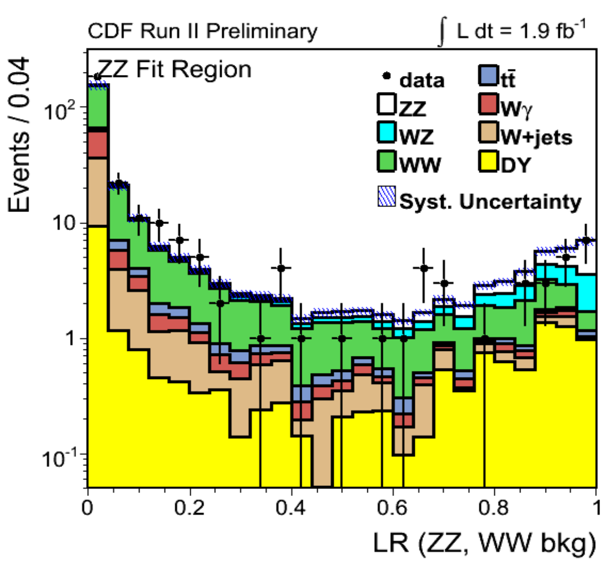
- D0

  ZZ → llll (1.7 fb^{-1}): 5.3σ

  ZZ → llνν (2.7 fb^{-1}): 2.6σ

  σ(ZZ) = 1.6 ± 0.65 pb

  → *first observation!*



ZZ → llνν: larger backgrounds, use multivariate technique

- CDF

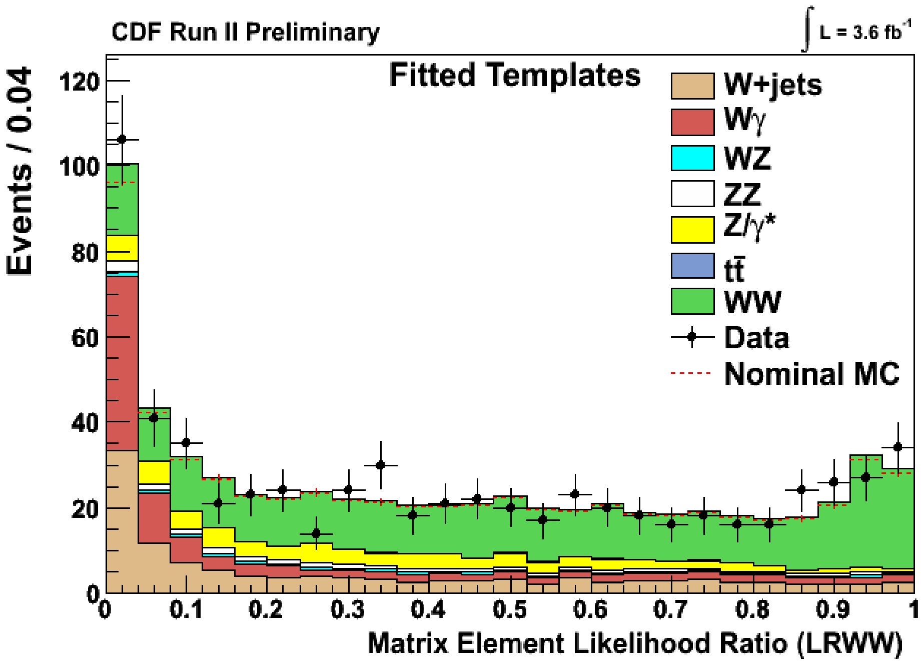
  ZZ → llll (1.9 fb^{-1}): 4.2σ

  ZZ → llνν (1.9 fb^{-1}): 1.2σ

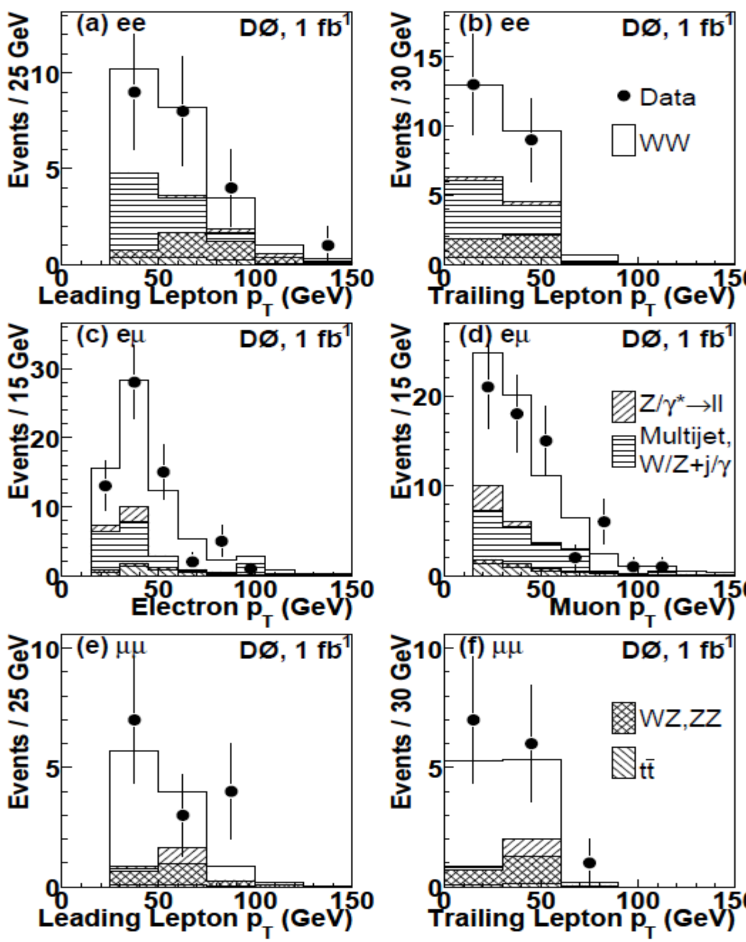
  σ(ZZ) = $1.4^{+0.7}_{-0.6}$ pb

WW → lνlν

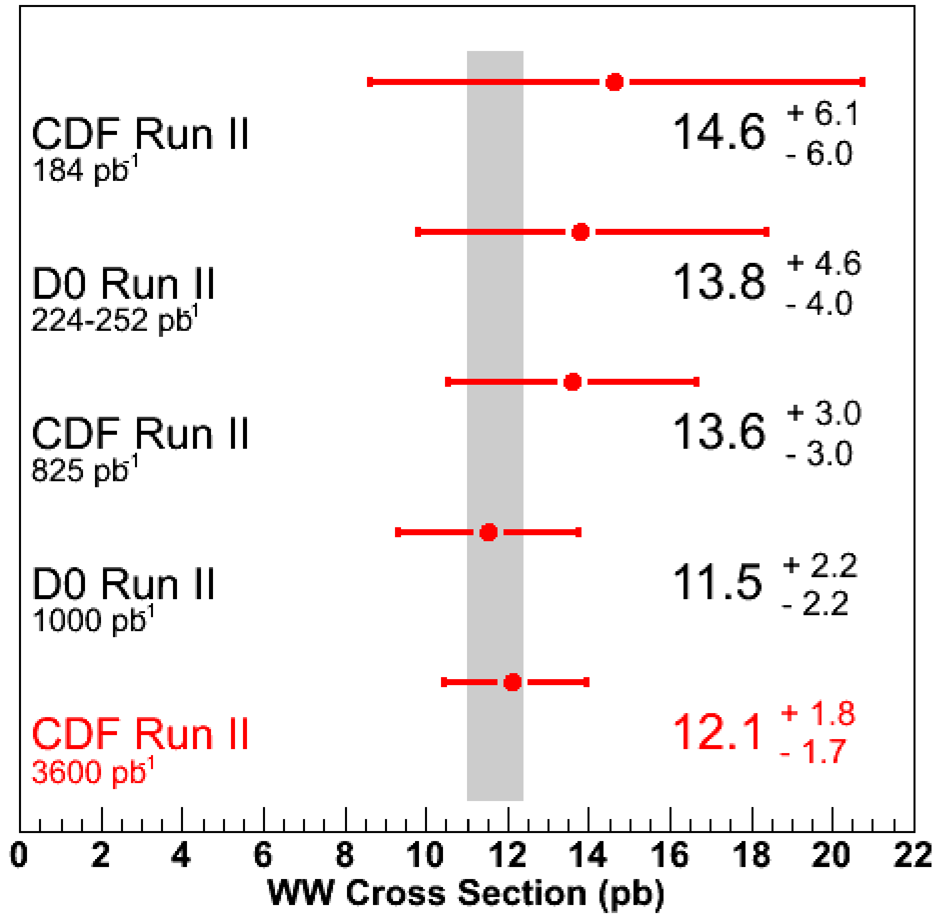
- CDF: differential cross sections of signal and background processes used to build likelihood ratio
  - Same analysis technique as used in H → WW search



- D0: Combine most sensitive cuts in several channels



WW → lνlν



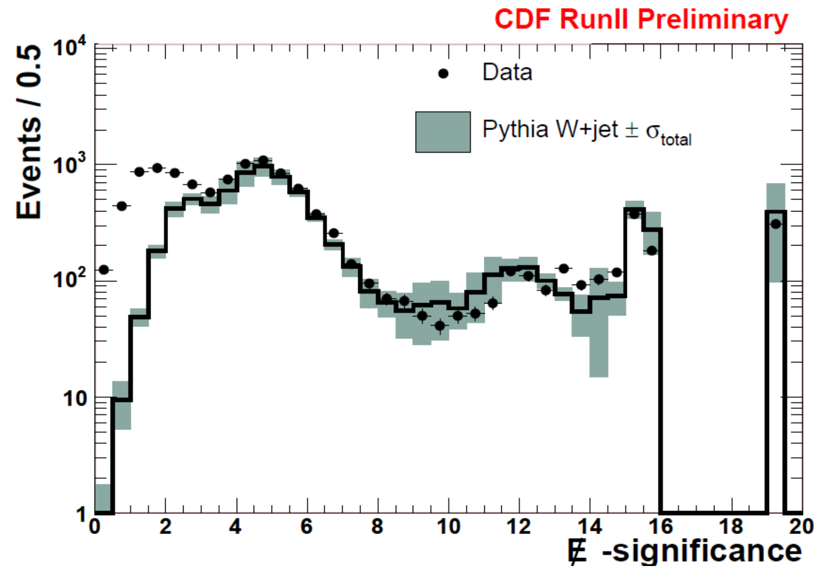
CDF Run II
184 pb-1
14.6 + 6.1 - 6.0
D0 Run II
224-252 pb-1
13.8 + 4.6 - 4.0
CDF Run II
825 pb-1
13.6 + 3.0 - 3.0
D0 Run II
1000 pb-1
11.5 + 2.2 - 2.2
CDF Run II
3600 pb-1
12.1 + 1.8 - 1.7
0 2 4 6 8 10 12 14 16 18 20 22
WW Cross Section (pb)

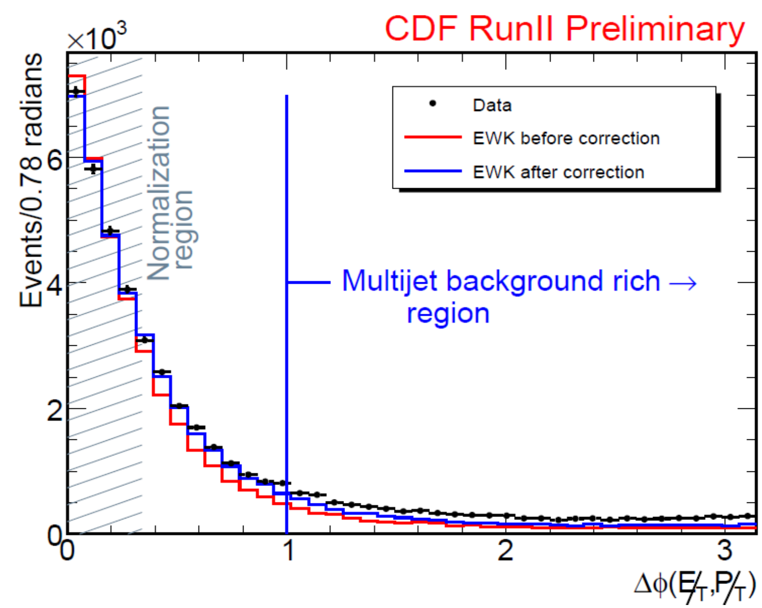
Semileptonic diboson decays

- One boson decays leptonically (W→lν, Z→ll, Z→νν) and the other hadronically (W→jj, Z→jj)
  - Separating Z→jj from W→jj is difficult because of detector resolution, so signal is sum of diboson processes
- Will present recent results in two channels:
  - Large MET and two jets (WW+WZ+ZZ → MET+jj)
    - (Dedicated talk in Thursday's electroweak session)
  - One lepton, large MET, and two jets (WW+WZ → lνjj)
    - (Dedicated talk on CDF results in Thursday's electroweak session)
- Challenging searches because of large backgrounds
  - W/Z + jets (large)
  - QCD multijet (from mismeasurement, difficult to model)
  - Top (small)

WW/WZ/ZZ → MET+jj

- Require MET>60 GeV and exactly two jets
  - No veto on events with identified leptons
- Signal is combination of
  - WW → lνjj (dominant)
  - WZ/ZZ → jjνν
  - WZ/ZZ → jjll
- QCD multi-jet background can be large, difficult to model
  - Remove as much as possible
  - Model rest by finding data sample enriched in QCD multi-jet events

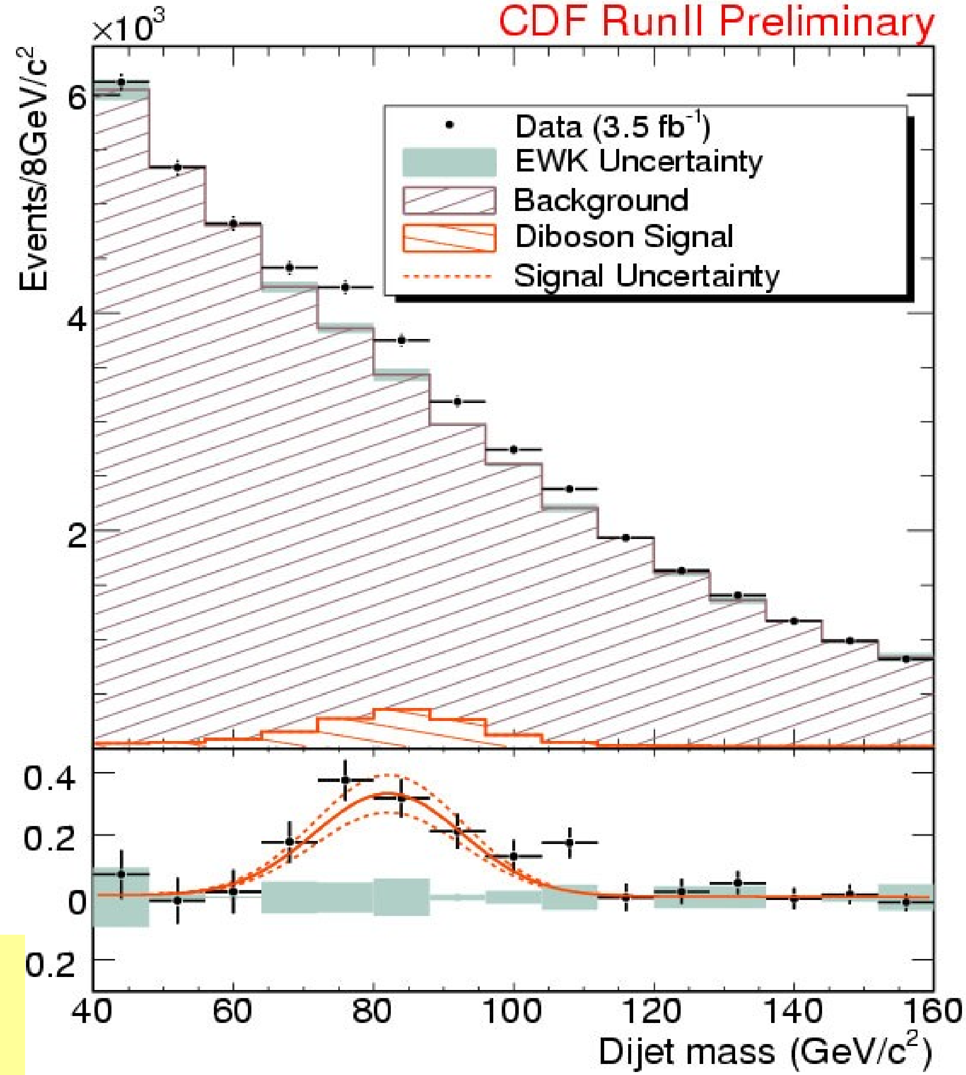




WW/WZ/ZZ → MET+jj

- Electroweak background
  - Modeled with Monte Carlo
  - γ+jet events used to assess uncertainty in MC modeling
- Fit invariant mass of two-jet system to sum of signal and background templates
  - Jet energy scale and electroweak background shape are dominant systematic uncertainties
- Result

5.3σ observation
σ(WW+WZ+ZZ) =
18±2.8(stat)±2.4(syst)±1.1(lumi) pb



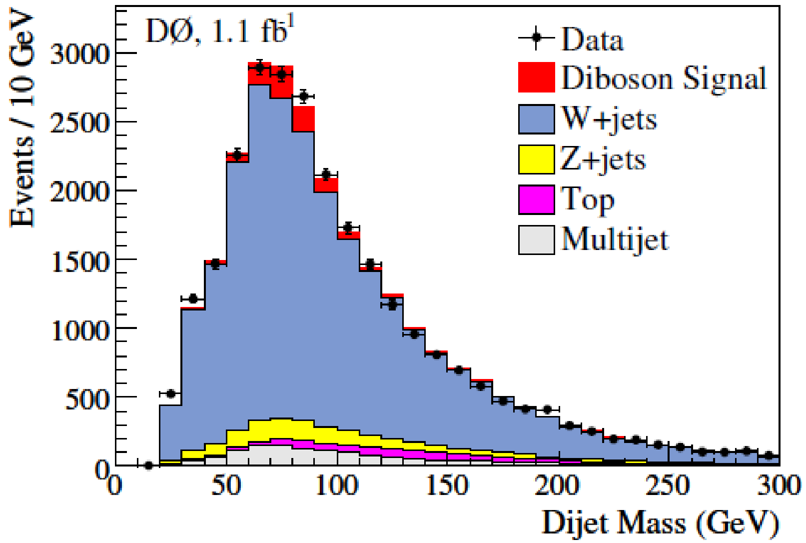
Standard model: 16.8±0.5 pb

WW/WZ → lνjj

- Will present three recent searches using different strategies to discriminate signal and background
  1) RF: Random forest classifier (D0, 1.1 fb^{-1})
  2) Mjj: Dijet mass (CDF, 3.9 fb^{-1})
  3) ME: Discriminant based on matrix elements (CDF, 2.7 fb^{-1})

WW/WZ → lνjj (RF)

	$e\nu q\bar{q}$ 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



- Signal comprises ~3% of total events
- Dominant background is W+jets, so need good modeling
  - Use Alpgen simulation
  - Carefully compare kinematics in simulation to measured kinematics in data
  - Small discrepancies in jet angles between data and Monte Carlo are observed: MC corrected to data and systematics assigned

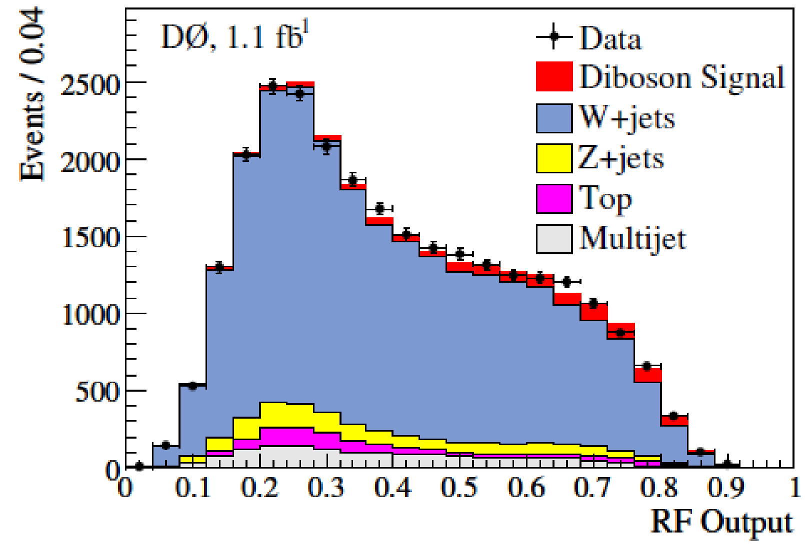
WW/WZ → lvjj (RF)

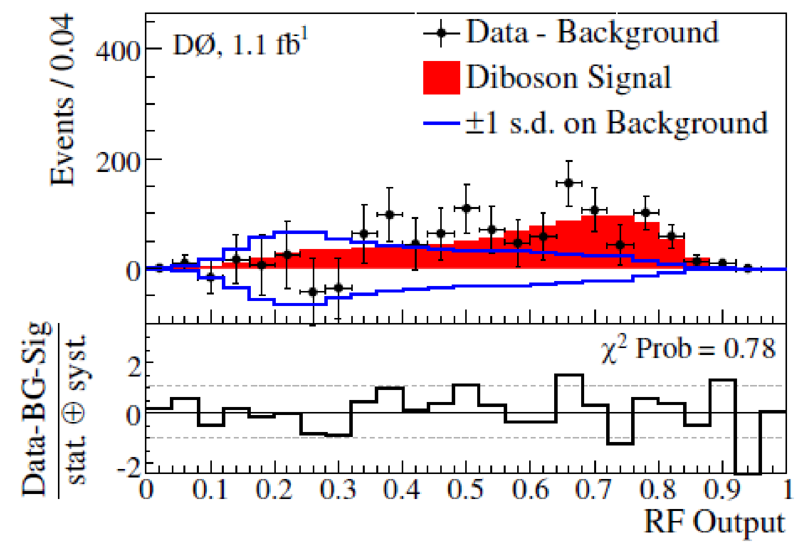
- Random Forest classifier used to separate signal from background
  - Forest of decision trees
  - Input several well-modeled kinematic variables
  - Output classification
- Fit to sum of templates
  - Dominant systematic uncertainties from jet energy scale, W/Z+jets shape
- Result:

  4.4σ evidence

  σ(WW+WZ) = 20.2 ± 4.5 pb

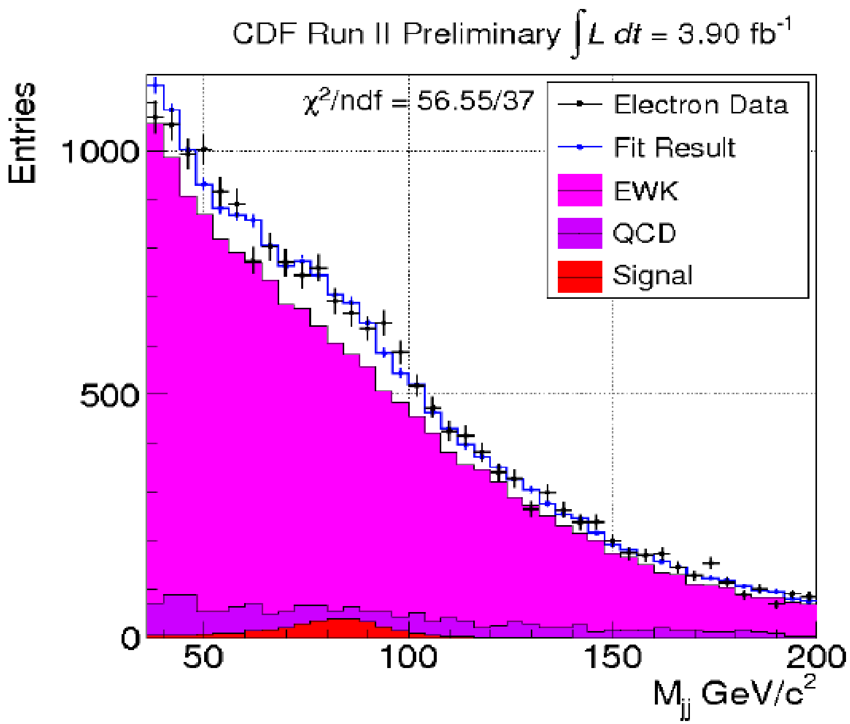
  (Standard model: 16.1 ± 0.9 pb)

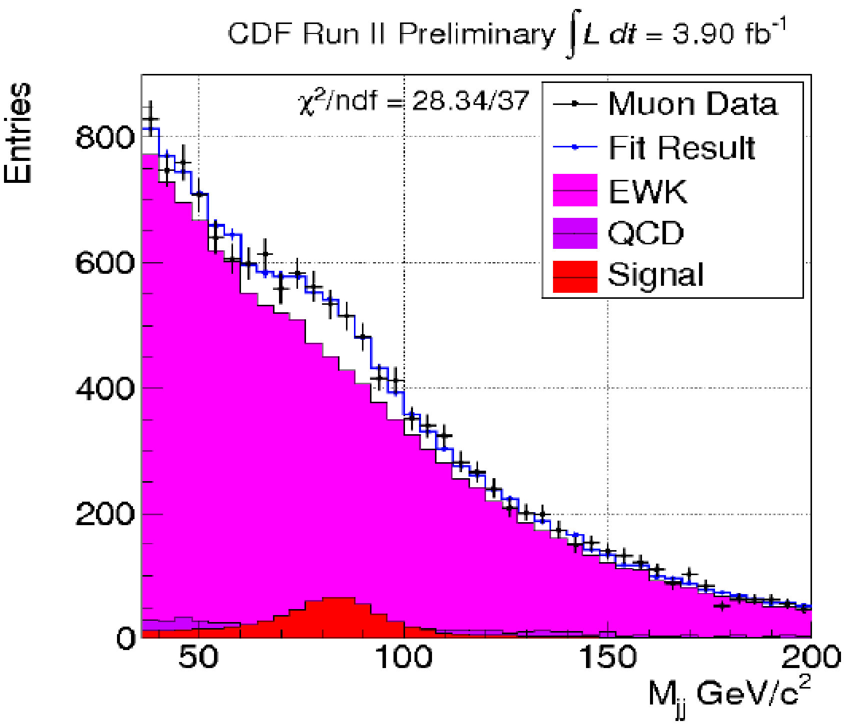




WW/WZ → lvjj (Mjj)

- Achieve smoothly falling background distribution by requiring p_T of the hadronic W boson to be larger than 40 GeV
- Fit dijet mass distribution to sum of templates

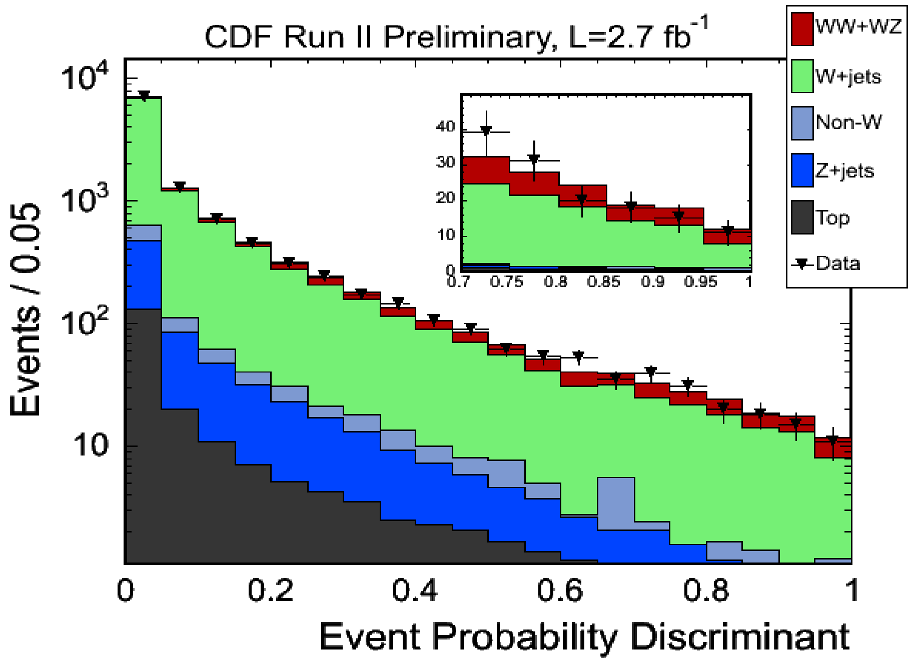


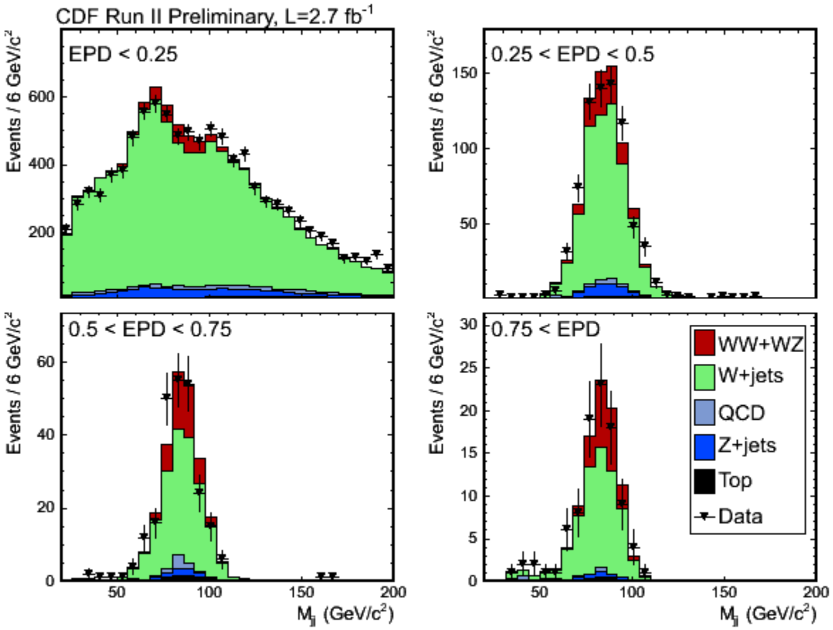


$\sigma(WW+WZ) = 14.4 \pm 3.1(\text{stat}) \pm 2.2(\text{sys})$ pb → 4.6σ

WW/WZ → lνjj (ME)

- Differential cross sections to find probability of event originating from certain signal and background processes
- Event probability discriminant (EPD) built from probabilities: $EPD = P_{sig} / (P_{sig} + P_{BG})$





σ(WW+WZ) = 17.7 ± 3.9 pb → 5.4σ observation

Conclusions

- Many recent interesting diboson measurements at the Tevatron
  - Observation of very low cross-section processes (ZZ)
  - Precise measurement of WW cross section in channel used for high-mass Higgs search
  - Observation of small signals in high-background semi-leptonic modes (analogous to low-mass Higgs searches)
- Proof that we understand data coming from the Tevatron
  - Many different channels
  - Many different analysis techniques
- Possible future diboson studies to validate Higgs techniques: add b-tagging (WZ → lvbb, ZZ → llbb, WZ/ZZ → MET+bb)
  - Z → bb has lower branching ratio than H → bb
  - Z has lower mass than Higgs