Diboson results from the Tevatron

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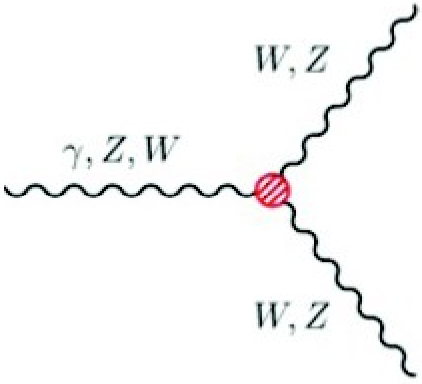
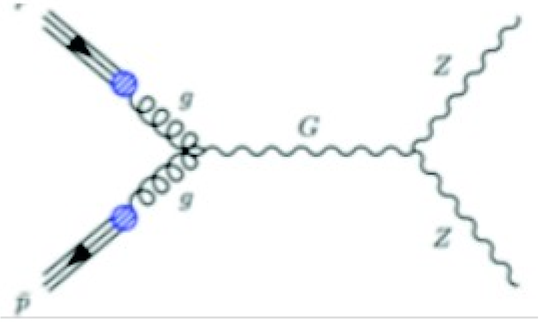
On behalf of the D0 and CDF collaborations

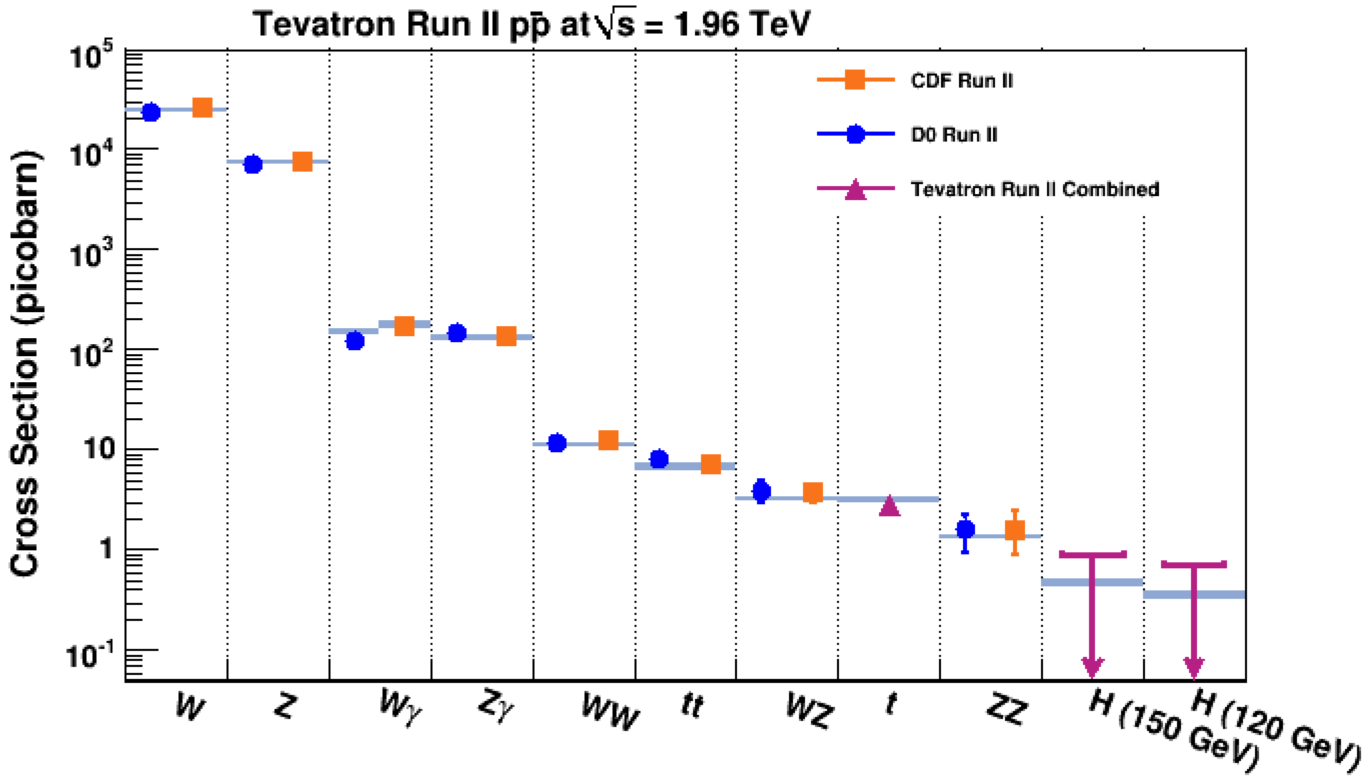
Motivations for diboson physics

- Test of Standard Model
  - SM provides precise predictions of diboson production cross sections
- New physics can enhance diboson production
  - Enhancement of triple gauge couplings (TGCs)
  - Resonances decaying to pairs of bosons
- Measurement of SM diboson production is important step in hunt for Higgs boson
  - $H \rightarrow WW$ / $H \rightarrow ZZ$: Higgs can decay to dibosons
  - Associated WH / ZH production: also diboson events





Diboson production cross sections



Process	D0 measurement [pb]	CDF measurement [pb]	NLO prediction [pb]
WW	11.5 ± 2.2	$12.1^{+1.8}_{-1.7}$	$11.34^{+0.66}_{-0.55}$
WZ	$3.90^{+1.06}_{-0.90}$	4.1 ± 0.7	$3.22^{+0.23}_{-0.19}$
ZZ	$1.35^{+0.52}_{-0.43}$	$1.56^{+0.84}_{-0.68}$	1.4 ± 0.1

(Different measurements use different integrated luminosities, between 1 and 6 fb^{-1})

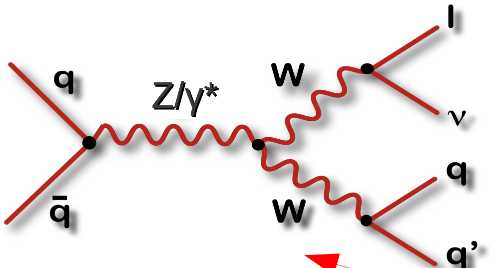
WW/WZ/ZZ decays accessible at Tevatron

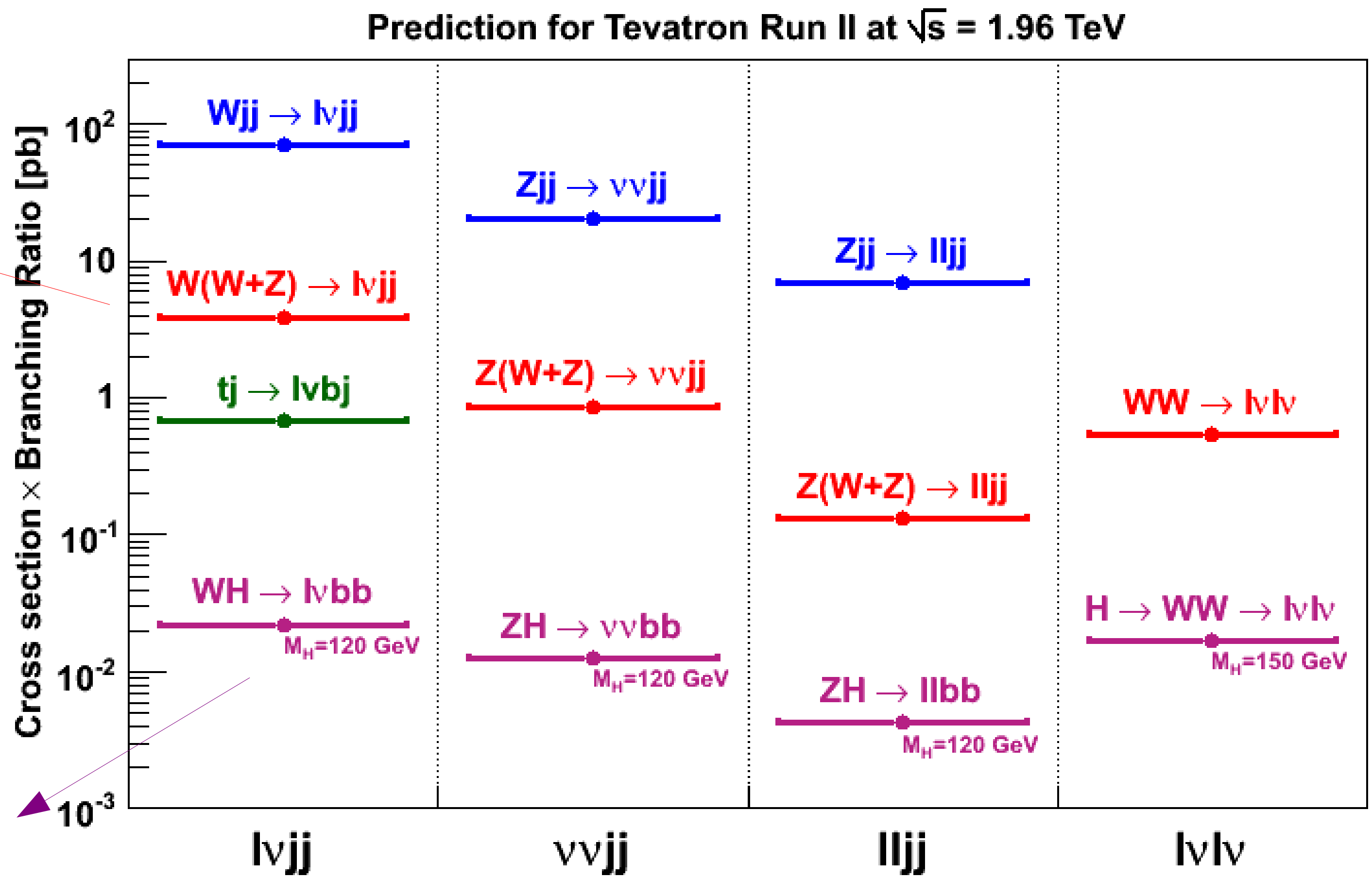
- Fully leptonic modes: both bosons decay leptonically
  (W → lν, Z → ll, Z → νν)
- Low branching fractions
- Presence of multiple charged leptons → low backgrounds from QCD processes
- Usually charged leptons are electrons and muons, taus are not explicitly identified, but tau decaying to electron or muon is part of signal

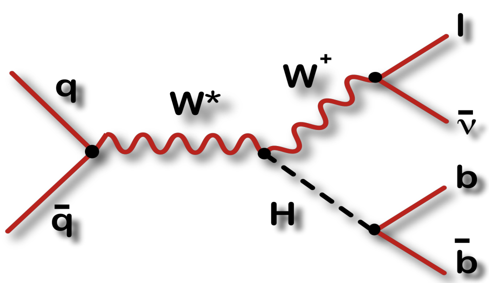
- Semileptonic modes: one of bosons decays hadronically
  (W → qq, Z → qq)
- Larger branching fractions
- Still have something leptonic to trigger on, but much larger backgrounds from W/Z+jets
- W → qq cannot be separated from Z → qq b/c of limited resolution in reconstructing hadronic jets
  - Measure sum of processes, e.g. WW+WZ → lνqq

Dibosons and the Higgs

- Sensitive Higgs search channels at the Tevatron:

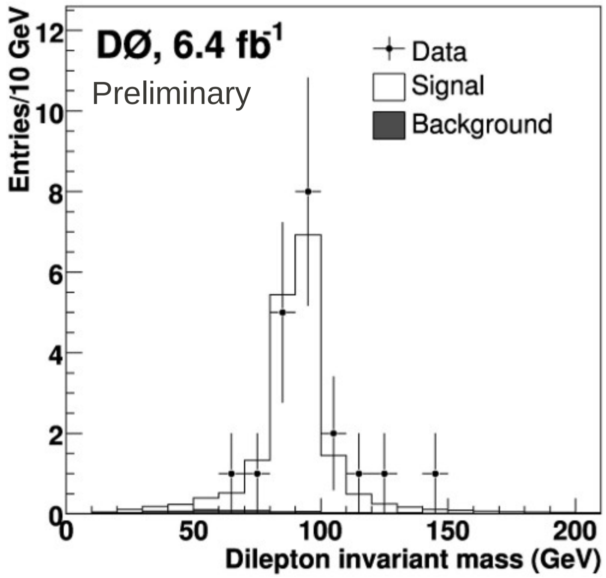


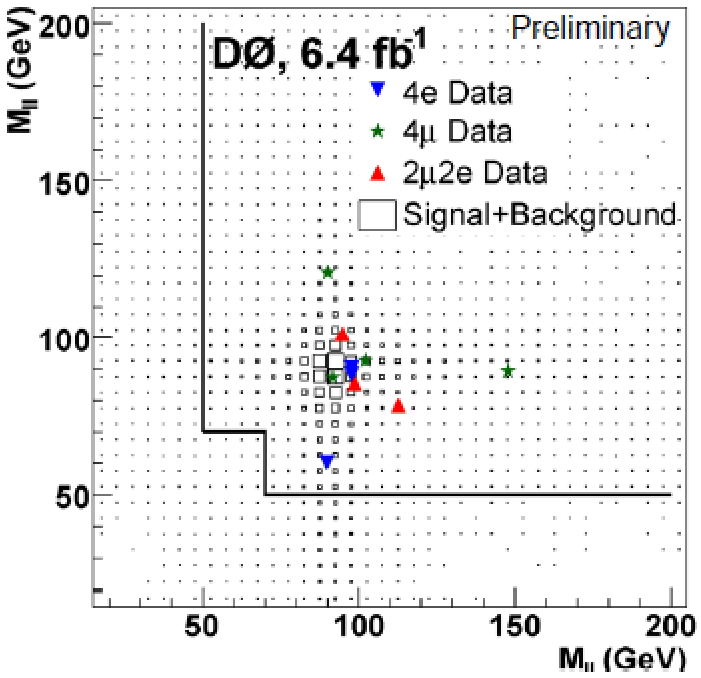




ZZ → llll

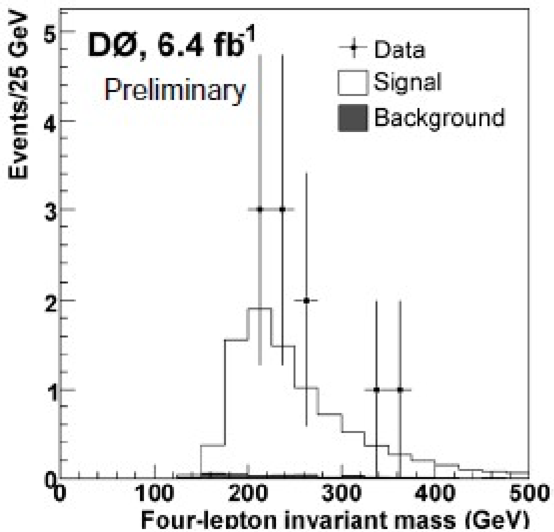
- Two pairs of opposite-sign, same flavor leptons → very clean signature
- First observation of ZZ in 2008 with three four-lepton events
- Now in 6.4 fb^{-1}
  - Expect ~9 signal events, ~0.4 BG events
  - Observe 10 events





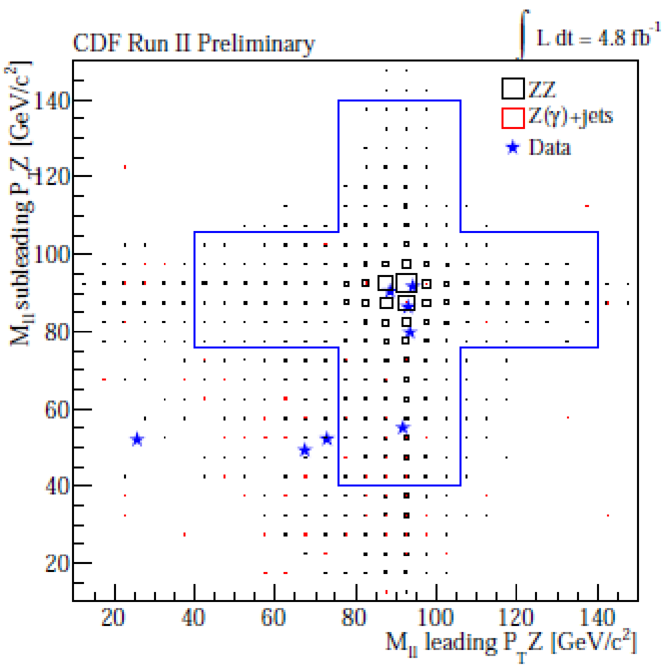
$\sigma(ZZ) = 1.35^{+0.52}_{-0.43}$ pb

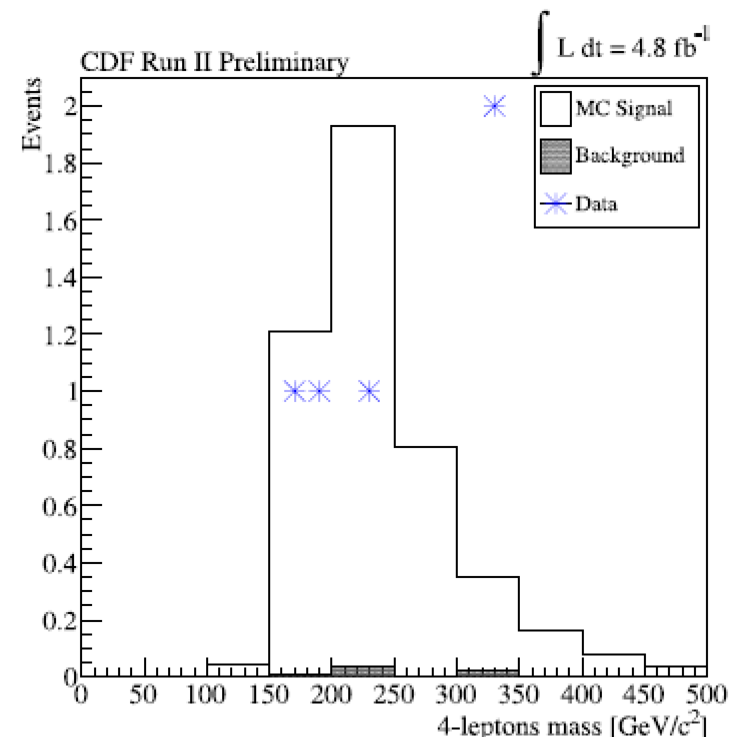
Preliminary result



ZZ → llll

- In 4.8 fb^{-1}, expect ~5 signal events, ~0.04 BG events
- Observe 5 events
- σ(ZZ) = $1.56^{+0.84}_{-0.68}$ pb

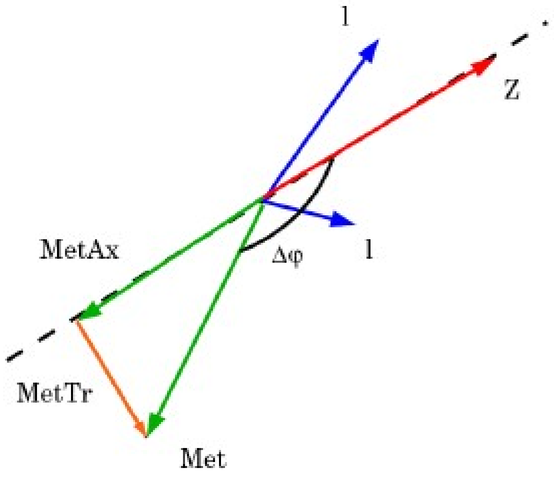


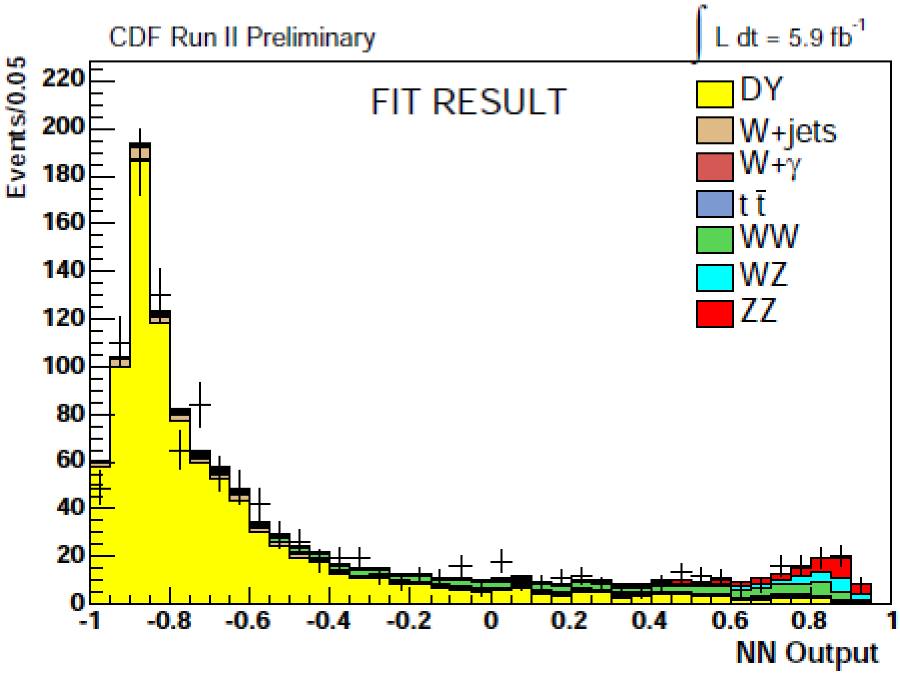


Preliminary result

ZZ → llvv

- Z → l+l- plus high MET
  - Not as clean as Z → llll: background from Drell-Yan production
- To reduce D-Y background, require MET to be back-to-back with Z boson in transverse plane
- 5.9 fb^{-1}
  - Expect ~50 signal events
  - Expect ~1100 BG events
  - Observe 1162 events
- Use neural network to separate signal and background
- σ(ZZ) = $1.45^{+0.92}_{-0.87}$

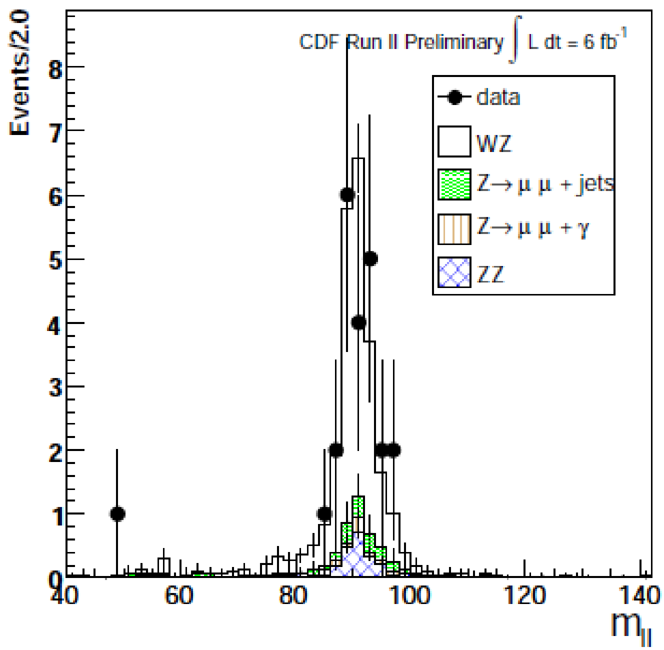


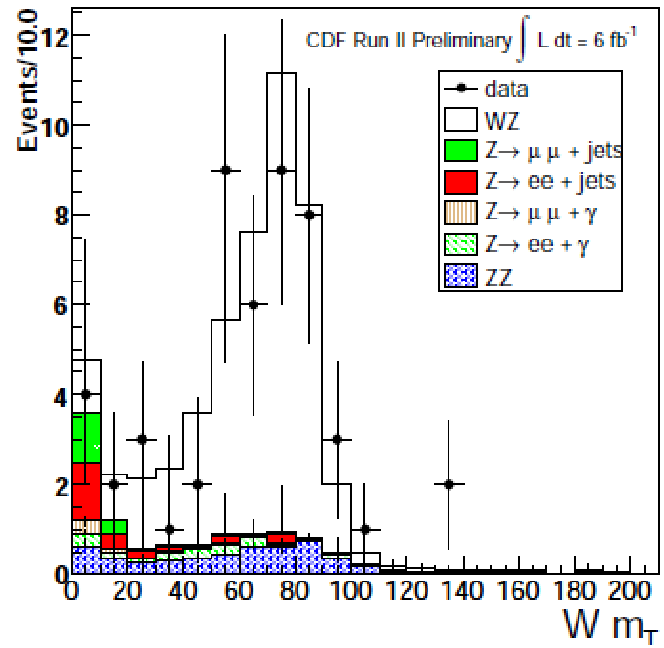


Preliminary result

WZ → lνll

- Signature: three isolated, high-p_T leptons with MET
- Build Z from two opposite-sign, same-flavor leptons, require invariant mass to be close to Z mass



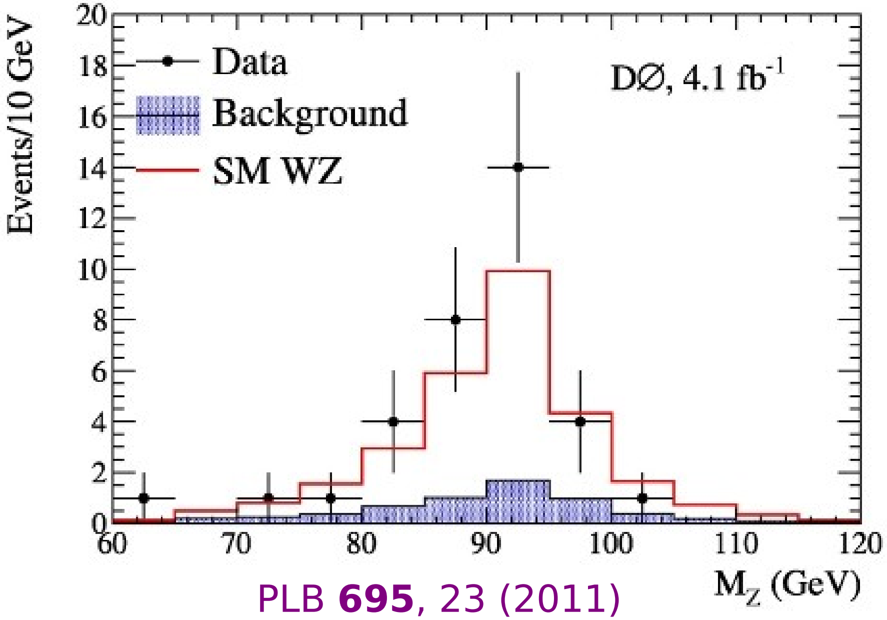


Preliminary result

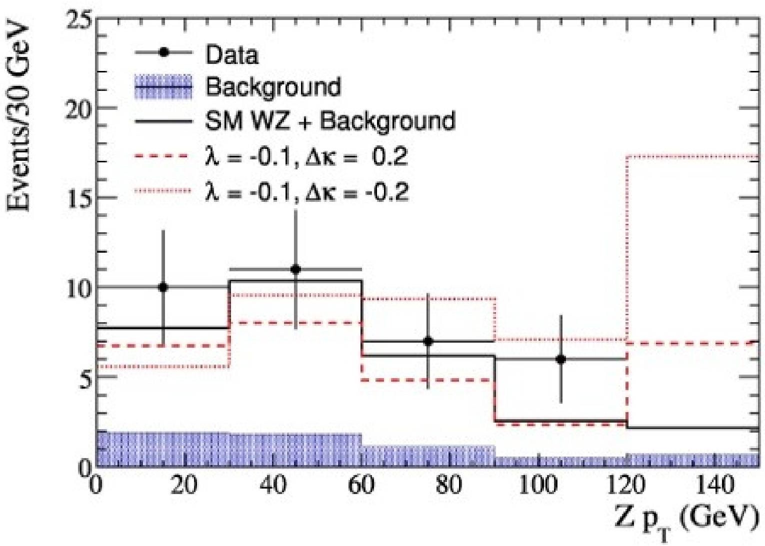
- In 6 fb^{-1}, ~50 signal and ~11 BG events
- σ(WZ) = 4.1 ± 0.7 pb

WZ → lνll (D0)

- In 4.1 fb^{-1}, expect ~23 signal and ~6 BG events, observe 34
- σ(WZ) = $3.90^{+1.06}_{-0.90}$ pb
- Use p_T of Z boson to set limit on aTGCs: best limit from direct measurement of WWZ vertex



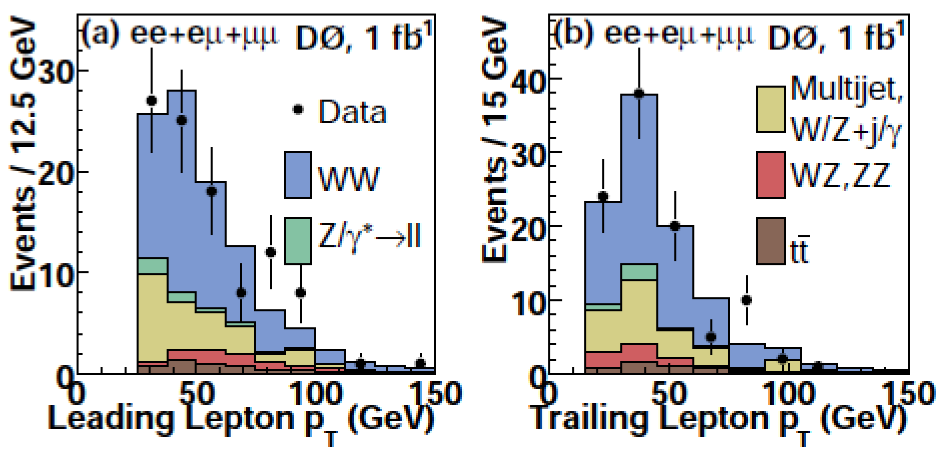
PLB **695**, 23 (2011)



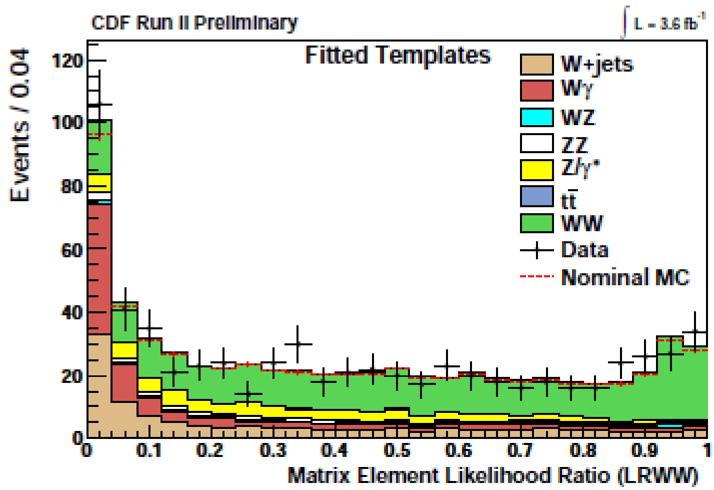
Coupling relation	95% C.L. Limit
$\Delta g_1^Z = \Delta\kappa_Z = 0$	$-0.077 < \lambda_Z < 0.093$
$\lambda_Z = \Delta\kappa_Z = 0$	$-0.056 < \Delta g_1^Z < 0.154$
$\lambda_Z = \Delta g_1^Z = 0$	$-0.400 < \Delta\kappa_Z < 0.675$
$\Delta\kappa_Z = 0$ (HISZ)	$-0.077 < \lambda_Z < 0.093$
$\lambda_Z = 0$ (HISZ)	$-0.029 < \Delta\kappa_Z < 0.080$

WW → lνlν

- Signature: two opposite-sign, isolated, high-p_T leptons and large MET
- Major BGs from Drell-Yan, Wγ, W+jets
- D0: count events, combine ee eμ and μμ channels
  - ~65 signal, ~40 BG events in 1 fb^{-1}
  - σ(WW) = 11.5 ± 2.2 pb
- CDF: matrix element probabilities to separate signal and BG
  - ~300 signal, ~300 BG events (3.6 fb^{-1})
  - σ(WW) = $12.1^{+1.8}_{-1.7}$ pb



PRL **103**, 191801 (2009)



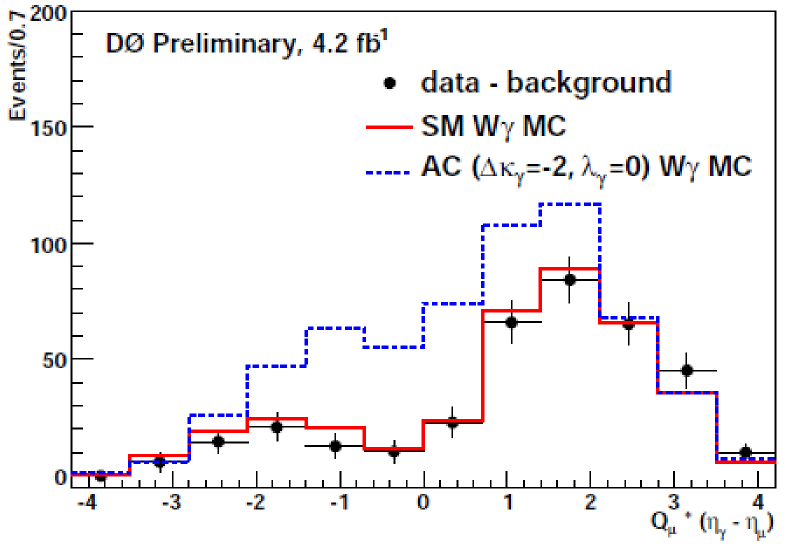
PRL **104**, 201801 (2010)

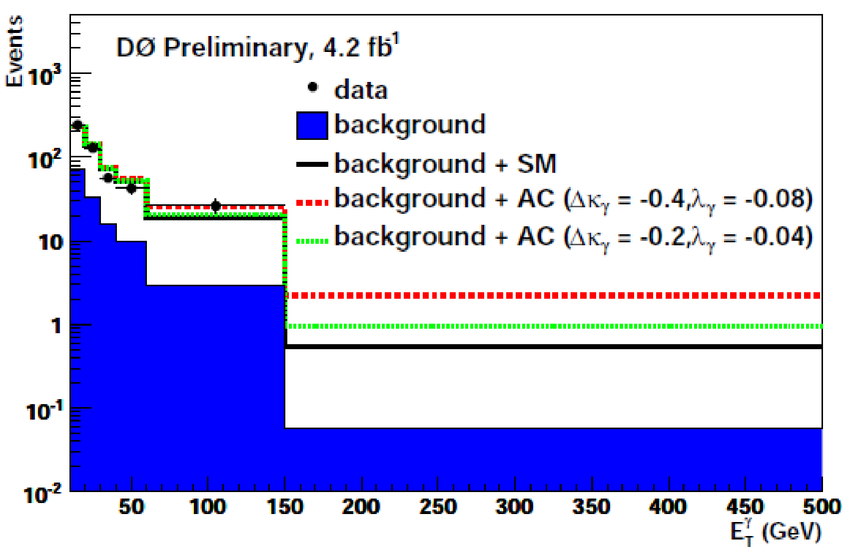
$W\gamma \to \mu\nu\gamma$

- High-p_T isolated muon, high MET, and photon
  - Use neural network to optimize separation between photons and hadronic jets
- Expect ~750 signal events, ~270 BG events
  - BG mostly due to W+jets with jet faking a photon
- Set limits on TGCs using E_T^γ comparable with LEP's

ALEPH	$-0.1 < \Delta\kappa_\gamma < 0.029$	$-0.043 < \lambda_\gamma < 0.014$
L3	$-0.049 < \Delta\kappa_\gamma < 0.095$	$-0.062 < \lambda_\gamma < 0.019$
OPAL	$-0.1 < \Delta\kappa_\gamma < 0.018$	$-0.097 < \lambda_\gamma < -0.024$
LEP2 combined	$-0.072 < \Delta\kappa_\gamma < 0.017$	$-0.049 < \lambda_\gamma < 0.008$
DØ 4.2 fb^{-1}	$-0.07 < \Delta\kappa_\gamma < 0.07$	$-0.012 < \lambda_\gamma < 0.011$

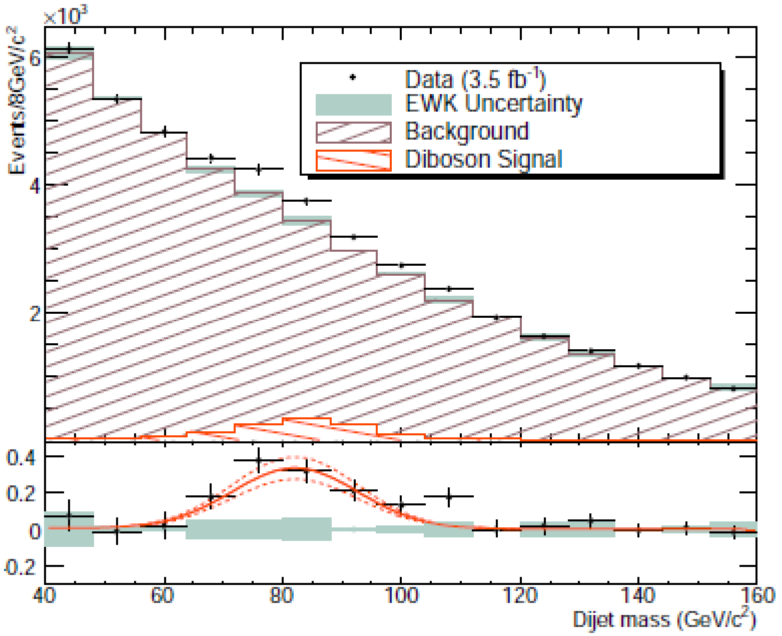
Preliminary result



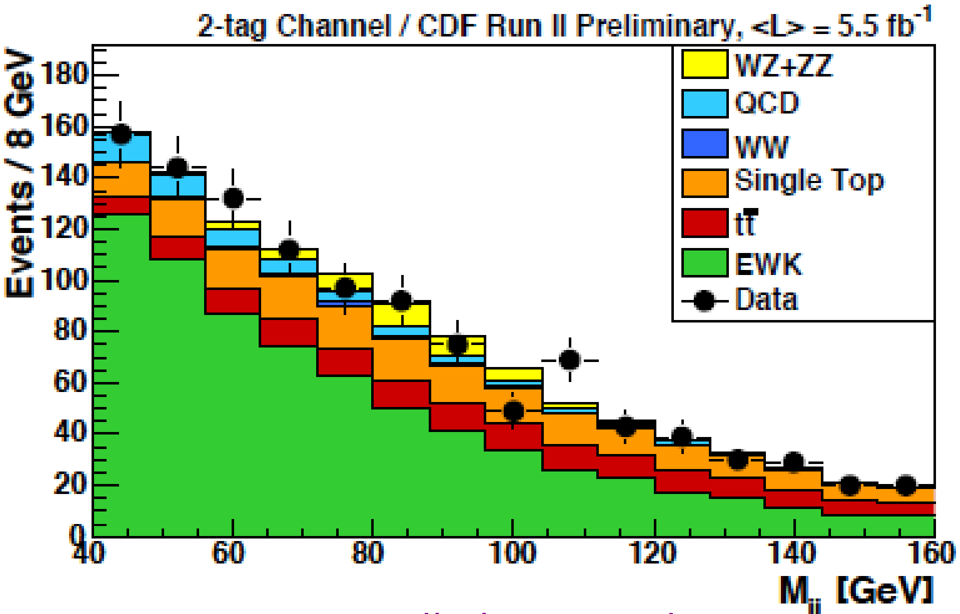


WZ+ZZ → MET+bb (CDF)

- WW+WZ+ZZ → MET+jets observed and measured in 2009
  - Two jets and large MET → developed smart ways to reduce multijet background and model W+jets
- Add b-tagging: sensitive only to WZ+ZZ
  - Smaller signal cross section
  - B-tagging → smaller signal acceptance
  - Very similar to situation in Higgs searches
  - sigma(WZ+ZZ) = $5.0^{+3.6}_{-2.5}$ pb



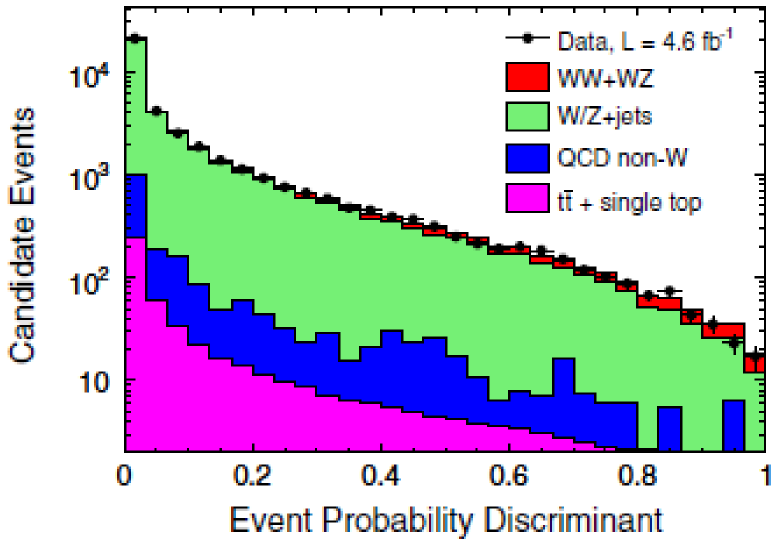
PRL **103,** 091803 (2009)



Preliminary result

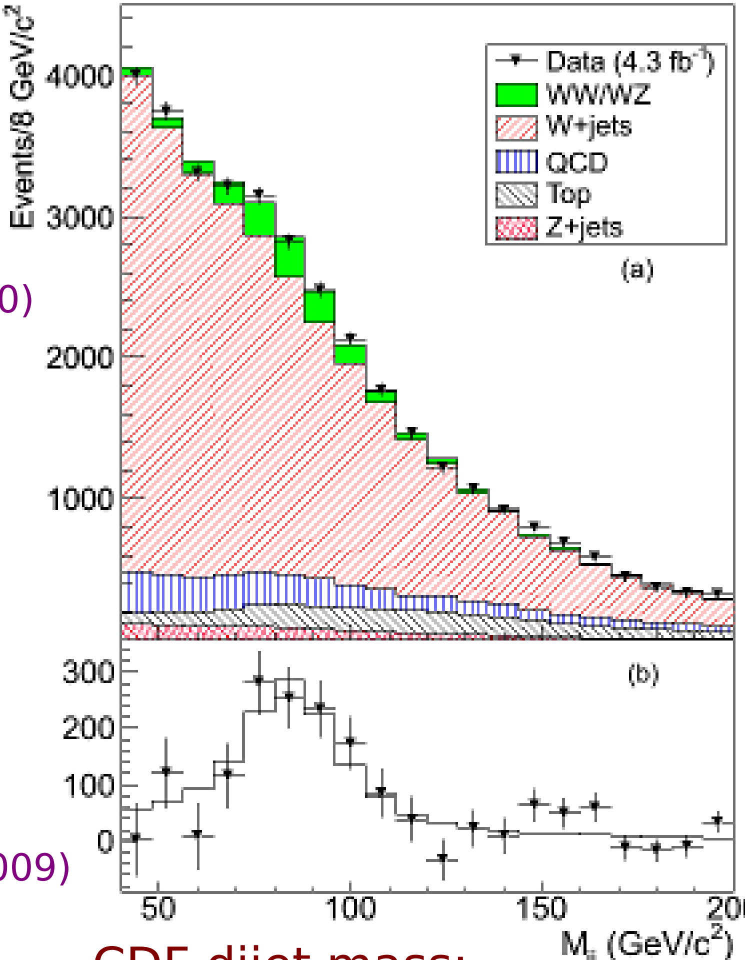
WW+WZ → lνjj

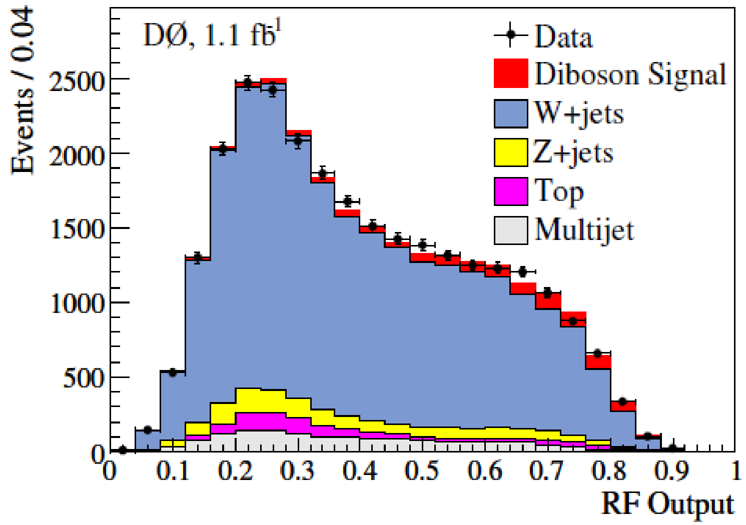
- One trigger lepton, two jets and MET → large W+jets background
- Challenge is to separate signal and BG; model BG well



CDF matrix element: σ(WW+WZ) = 17.4 ± 3.3 pb

PRD **82**, 112001 (2010)





D0 random forest: σ(WW+WZ) = 20.2 ± 4.5 pb

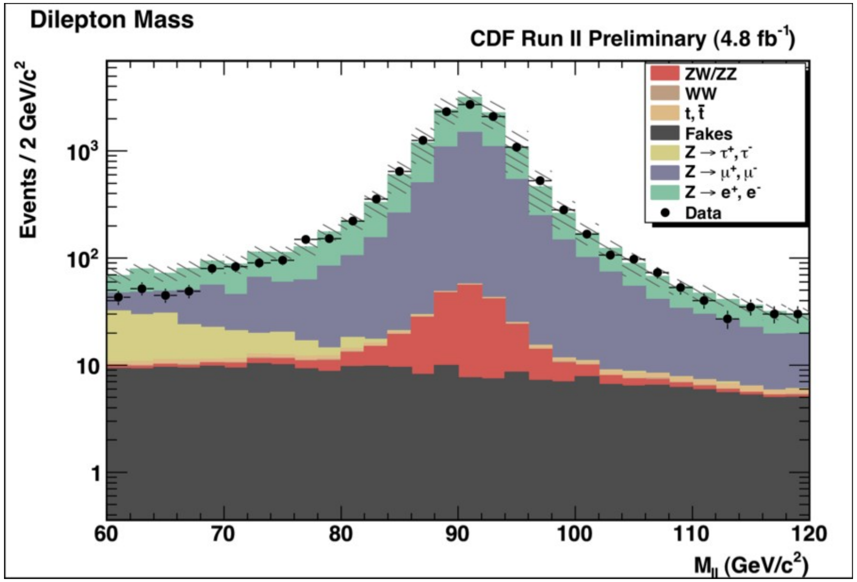
PRL **102**, 161801 (2009)

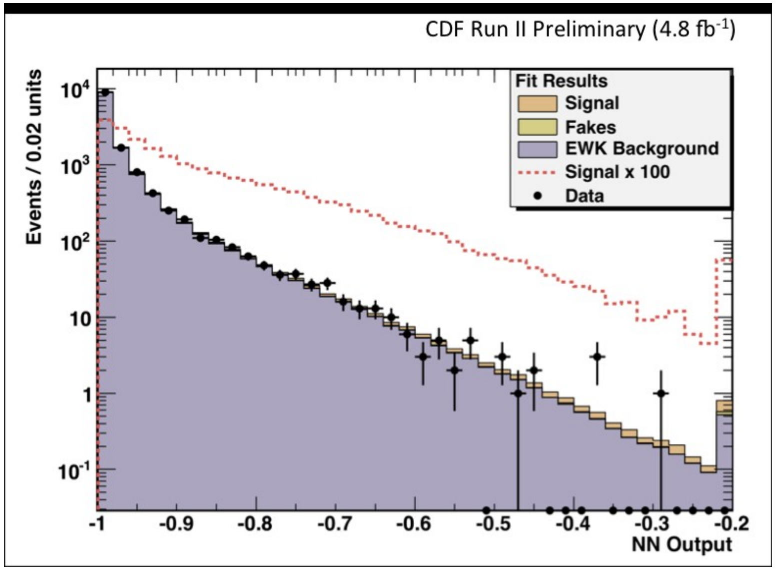
CDF dijet mass: σ(WW+WZ) = 18.1 ± 4.1 pb

Preliminary result

ZW+ZZ → lljj

- 2 electrons or muons from Z decay, two jets, low MET
  - Major background is from Z+jets
- In 4.8 fb^{-1}, expect ~202 signal events, ~13000 BG events
- Neural network used for discrimination
  - Includes variables to separate quark and gluon jets
- Analysis not yet sensitive enough to find signal
  - Expect and observe ~1σ deviation from BG-only hypothesis

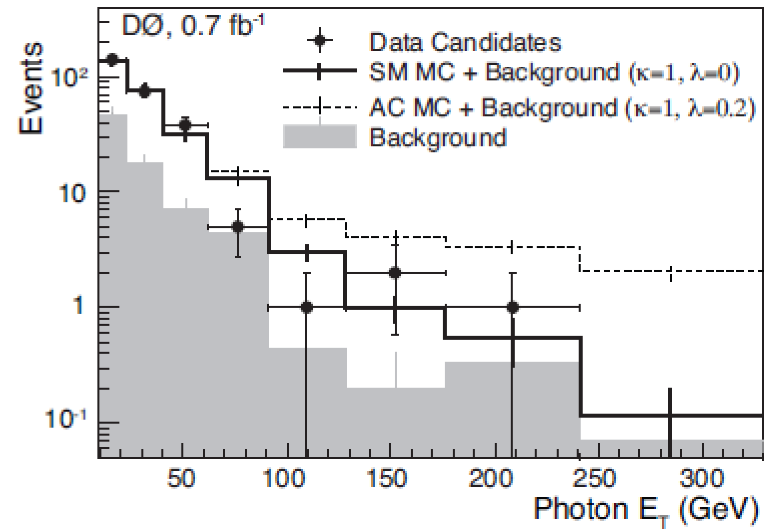


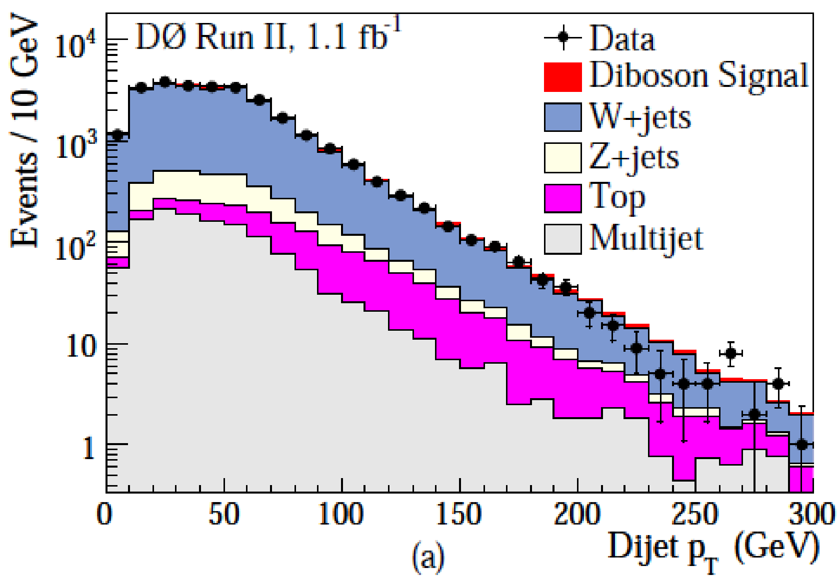


Preliminary result

Combined WWγ / WWZ limit

- Combine four measurements
  - $W\gamma \to l\nu\gamma$: $p_T(\gamma)$
  - $WW \to l\nu l\nu$: $p_T(l_1)$ vs $p_T(l_2)$
  - $WZ \to l\nu ll$: $p_T(Z)$
  - $WW/WZ \to l\nu jj$: $p_T(jj)$
- Best limits from hadronic collider





Results respecting $SU(2)_L \otimes U(1)_Y$ symmetry			
Parameter	Minimum	68% C.L.	95% C.L.
$\Delta\kappa_\gamma$	0.07	[−0.13, 0.23]	[−0.29, 0.38]
Δg_1^Z	0.05	[−0.01, 0.11]	[−0.07, 0.16]
λ	0.00	[−0.04, 0.05]	[−0.08, 0.08]
μ_W	2.02	[1.93, 2.10]	[1.86, 2.16]
q_W	−1.00	[−1.09, −0.91]	[−1.16, −0.84]
Results for equal-couplings			
Parameter	Minimum	68% C.L.	95% C.L.
$\Delta\kappa$	0.03	[−0.04, 0.11]	[−0.11, 0.18]
λ	0.00	[−0.05, 0.05]	[−0.08, 0.08]
μ_W	2.02	[1.94, 2.09]	[1.88, 2.15]
q_W	−1.02	[−1.09, −0.94]	[−1.16, −0.87]

arXiv:0907.4952v2

Conclusions

- Diboson measurements are rich area of physics
  - Careful probe of standard model
  - Stepping-stone to finding Higgs boson
- Many exciting results from the Tevatron
  - Precise cross section measurements
  - Stringent limits on TGCs
  - Searches and measurements in difficult topologies
- So far, see excellent agreement with Standard Model
  - Across experiments, decay modes, and analysis styles
- Still room for improvement!
  - Many analyses done with ~1/2 of full Tevatron dataset
  - Combinations of analyses and experiments
  - Employ sophisticated analysis techniques similar to those used in Higgs searches