Diboson production at CDF

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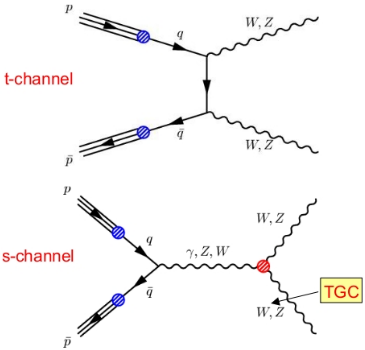
Physics Motivation



Absent at LEP

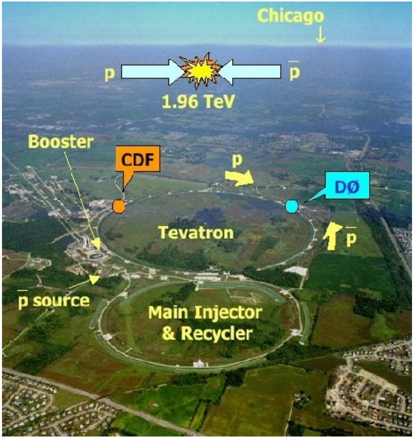
$q\bar{q}' \to W^{(*)}$	$\to W\gamma$	:	$WW\gamma$ only
$q\bar{q}' \to W^{(*)}$	$\to WZ$	:	WWZ only
$q\bar{q} \to Z/\gamma^{(*)}$	$\to WW$	:	$WW\gamma, WWZ$
$q\bar{q} \to Z/\gamma^{(*)}$	$\to Z\gamma$	:	$ZZ\gamma, Z\gamma\gamma$
$q\bar{q} \to Z/\gamma^{(*)}$	$\to ZZ$	:	$ZZ\gamma, ZZZ$

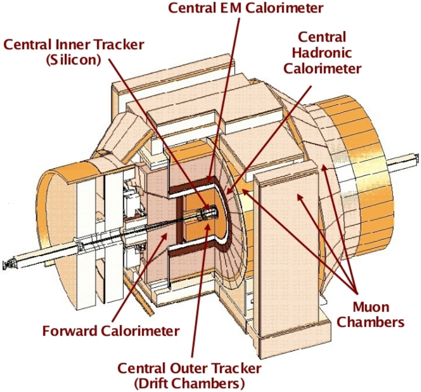
Absent in SM

- Diboson are unique probe of triple gauge couplings:
  1. Sensitive to new physics: ZZZ, $ZZ\gamma$, $Z\gamma\gamma$ absent in SM
  2. TeV with respect to LEP: explores higher energy range
- Significant backgrounds for several interesting processes
- Processes topologically similar to WH, ZH, SUSY.

CDF detector

- Proton-antiproton collision at $\sqrt{s} = 1.96$ TeV
- 36 bunches: crossing time = 396 ns
- Peak luminosity $3.61 \cdot 10^{32}$ cm^{-2} s^{-1}





- Data taking efficiency $\sim 85\%$
- About 5.7 fb^{-1} on tape

Improved Lepton Selection

- Lepton acceptance is a key in final states with 3 or more leptons!
- Try to use all tracks and electromagnetic objects found
- Use as much information as possible for each candidate

Electrons:

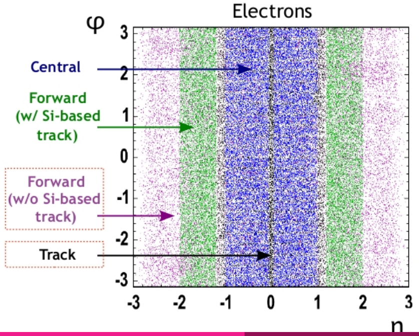
- Central calorimeter
- Forward calorimeter
- w/ or w/o Si-based track

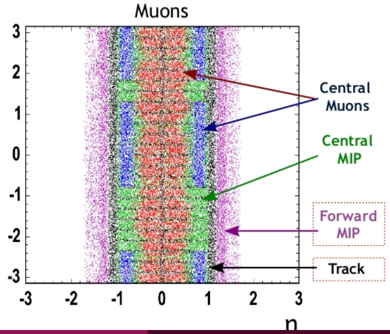
Muons:

- Central muons with matched muon chamber hits
- (MIP): central and forward region

Tracks:

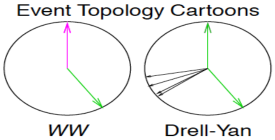
- Fill in regions not fiducial to calorimeters
- No distinction between e and μ.





WW→ $ll\nu\nu$

1. Two leptons (e or μ) with $p_T(l_1) > 20$, $p_T(l_2) > 10\mathrm{GeV}$
2. Dilepton invariant mass $M_{ll} > 16\mathrm{GeV}/c^2$ to reduce heavy flavour backgrounds
3. Njet = 0, with $|\eta| < 2.5$ and $p_T > 15\mathrm{GeV}$ to reduce $t\bar{t}$ and WW/WZ
4. Drell-Yan contamination reduced requiring that the $\not{E}_T$ transverse to each lepton is greater than 25 GeV (15 GeV for e μ)

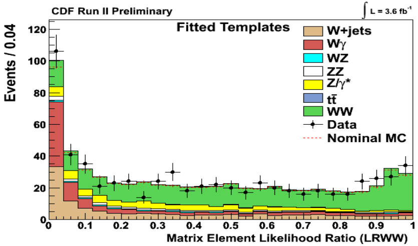


CDF Run II Preliminary $\int \mathcal{L} = 3.6\ \mathrm{fb}^{-1}$

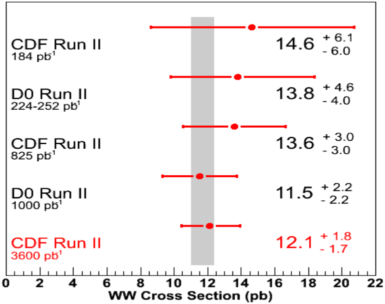
Process	Events
Z/γ^*	79.8 ± 18.4
WZ	13.8 ± 1.9
$W\gamma$	91.7 ± 24.8
W+jets	112.7 ± 31.2
ZZ	20.7 ± 2.8
$t\bar{t}$	1.3 ± 0.2
Total Background	320.1 ± 46.8
WW	317.6 ± 54.1
Signal+Background	637.6 ± 79.6
Data	**654**

WW cross section in 3.6 fb^{-1}

Likelihood ratio formed from Matrix element probabilities



- WW cross section with a precision of less than 15 %.

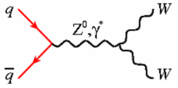


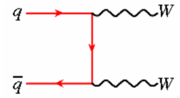
$$\sigma^{NLO}(p\bar{p} \to WW) = 11.7 \pm 0.7\mathrm{pb}$$

$$\sigma(p\bar{p} \to WW) = 12.1^{+1.8}_{-1.6}\mathrm{pb}$$

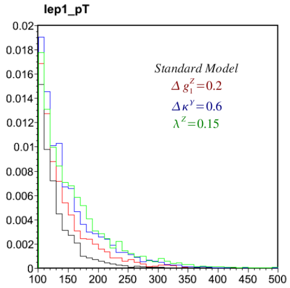
WW a TGC in 3.6 fb^{-1}

- Two diagrams producing WW: s-channel, and t-channel.
- s-channel is susceptible to anomalous triple gauge couplings: $\Delta K^{z}, \Delta K^{\gamma}, \Delta g_1^{z}, \Delta g_1^{\gamma}, \lambda^{z}, \lambda^{\gamma}$
  - HISZ scheme ties these together to make 3 independent parameters





- Analysis strategy:
  1. Take generator level leading lepton p_T distribution from MCFM



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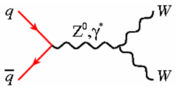

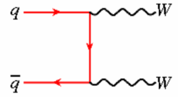

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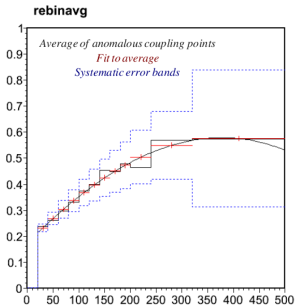

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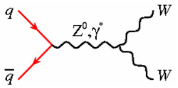

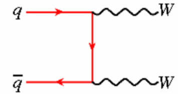

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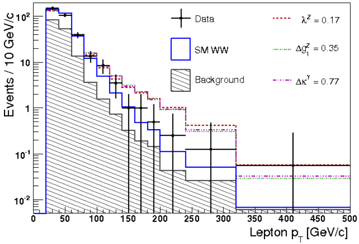

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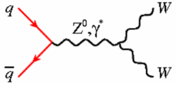

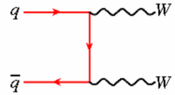

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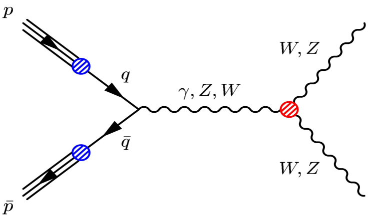
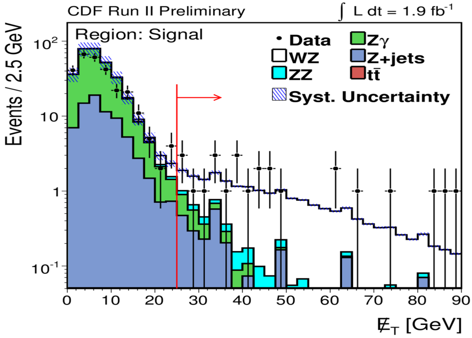
	Λ (GeV)	λ^Z	Δg_1^Z	κ^γ
Expected	1.5	(-0.05,0.06)	(-0.04,0.14)	(-0.17,0.30)
Observed	1.5	(-0.17,0.17)	(-0.26,0.35)	(-0.68,0.77)
Expected	2.0	(-0.05,0.06)	(-0.04,0.13)	(-0.15,0.27)
Observed	2.0	(-0.15,0.15)	(-0.25,0.32)	(-0.62,0.67)

WZ cross section measurement

- Require 3 e or μ leptons and missing transverse energy
- Sensitive to WWZ vertex coupling
- Unique access to WWZ separately from WW γ





$$\sigma\,(p\bar{p} \to WZ) = 4.4 \pm 1.3(\text{stat.}) \pm 0.2(\text{sys.}) \pm 0.3(\text{lum.})\ \text{pb}$$

$$\sigma(WZ)\text{NLO} = 3.7\text{pb}$$

WWZ a TGC

- The Z p_T distribution measured for the observed events is fitted for each of the paramaters: λ, Δg, $\Delta\kappa$. This is done individually as well as two dimensional pairs. The Z p_T distribution is used since it is sensitive to these couplings and it can be measured experimentally.

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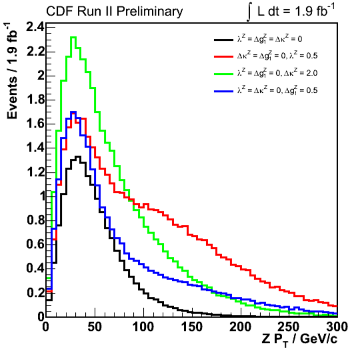

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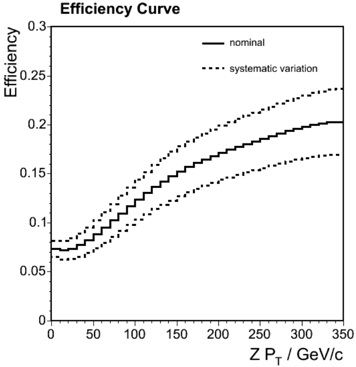

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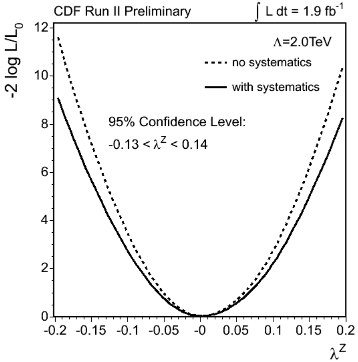
  3. A -2log L is then formed for a binned distribution in data to come from an expected Z pT distribution given any coupling value



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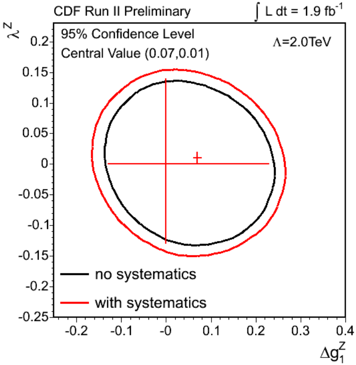
  4. 2D limits



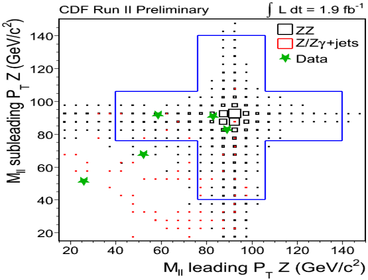
ZZ production

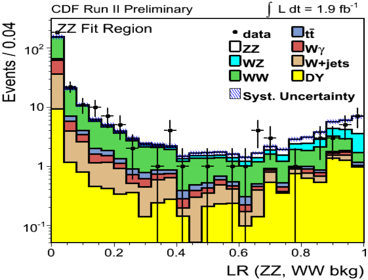
- Very small cross section (1.4 ± 0.1 pb Campbell, Ellis, PRD 60 (1999) 113006)
- Two decays mode considered
  1. $llll$: ~ 0.5%
     - Small BR
     - Clean Sample
  2. $ll\nu\nu$: ~ 3%
     - 6 times larger BR
     - Large Backgrounds (WW, WZ,Drell-Yan)

Observed Results

P-Value	0.12	1.1×10^{-5}	5.1×10^{-6}
Significance	1.2 σ	4.2 σ	4.4 σ

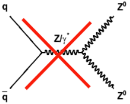
Measured Cross-Section	$1.4^{+0.7}_{-0.6}(stat. + syst.)$ pb (NLO prediction is 1.4 pb)

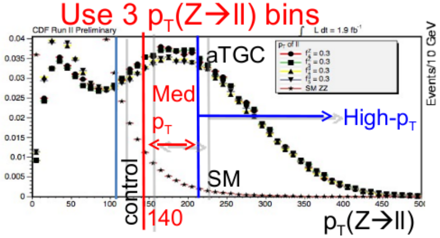


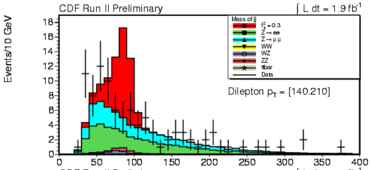


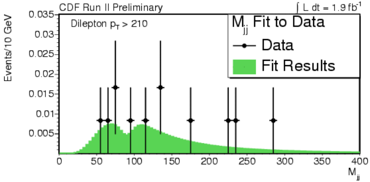
TGC: ZW and ZZ

- Trigger Lepton with $E_T > 20\mathrm{GeV}$
- Second lepton with $E_T > 10\mathrm{GeV}$
- $76 < M_{ll} < 106$ GeV :suppress non Z production
- 2 jets (cone $\Delta R < 0.4$, $|\eta|<2.5$)







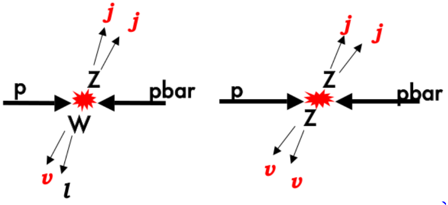


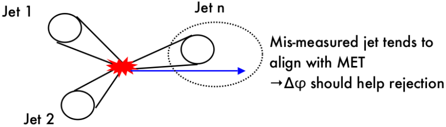
	limits
σ (WZ) 140 < $Z^0(p_T)$	234 fb
σ (WZ) 210 < $Z^0(p_T)$	135 fb
σ (ZZ) 140 < $Z^0(p_T)$	280 fb
σ (ZZ) 210 < $Z^0(p_T)$	77 fb

$VV \to$ met + jets

First observation

- Selection:
  1. $\not\!\!E_T > 60$ GeV
  2. exactly two jets with $E_T > 25$ Gev and $\eta < 2.0$
  3. $\not\!\!E_T$ significance > 4
  4. $\Delta\phi(\not\!\!E_T, \text{jet}) > 0.4$
- Select jj+MET events
  1. Benefited from L2 met/cal trigger upgrade (doi: 10.1109/NSSMIC.2006.354160)
- Acceptance to $\nu\nu$ and $l\nu$ events (WW, WZ, ZZ)
- QCD rejection: MetModel
  1. Reduced to only 16% out of selected events

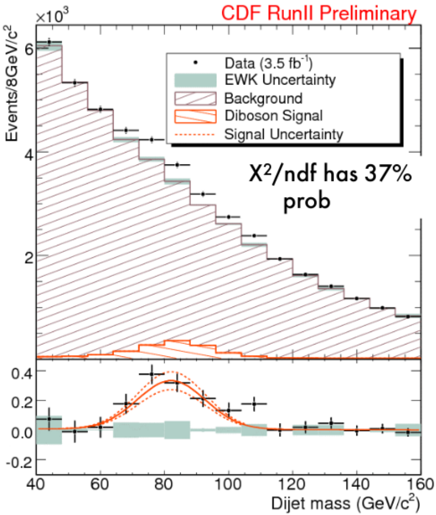




- Remaining QCD: based on $\Delta\phi(calMET - trkMET)$
- EWK mJJ shape: checked with γ+jj $\to$ significantly reduces systematics

VV → met + jets

First observation



Parameter	Fitted value
Jet energy scale, JES	0.985 ± 0.019
Yield of EWK background events	$36,140 \pm 1230$
Yield of MJB background events	7249 ± 1130
Yield of Diboson candidates	1516 ± 239

$\sigma(WW + WZ + ZZ) = 18.0 \pm 2.8(stat) \pm 2.4(syst) \pm 1.1(lumi)pb$

SM: 16.8 ± 0.5pb (MCFM + CTEQ6M)

5.3 σ significance

PRL just submitted: arXiv:0905.4714

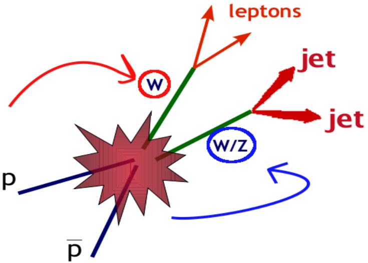
$WW/WZ \to l\nu$ +jets

Leptonic W candidate:

- one tight lepton (electron or muon) with $E_T > 20$ GeV, $\eta < 1.2$ and $\not{E}_T > 25$ GeV
- $M_T(W) > 30$ GeV/c^2 to get rid of large part of the QCD background

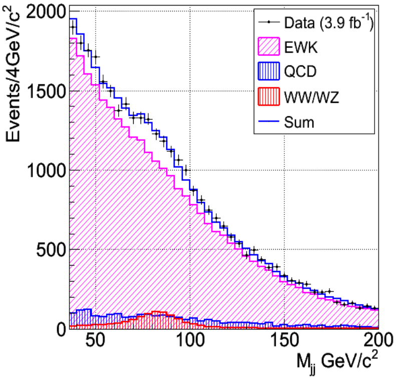
Hadronic W candidate:

- At least 2 jets (reconstructed using JETCLU,$R = 0.4$) with:
  1. $E_T > 20\text{GeV}$ corrected for detector effects.
  2. $|\eta| < 2.4$
  3. $\Delta\eta < 2.5$
  4. Electron removal



M_{jj} method in 3.9 fb^{-1}

- Two different approaches used:
  1. First approach uses the shape of M_{jj} of the two leading jet to look for a clear resonance



- Use $p_T > 40$ GeV/c cut to smoothen mjj distribution
- Binned fit to extract signal: template EWK, QCD and signal.
- We estimate combining the two decays: 1070 $\pm$ 232 (stat.) $\pm$ 86 (syst) $WW/WZ \to l\nu jj$ events, for 4.61 σ where 4.9 was expected.
- Finally, we measure:

$$\sigma_{WW/WZ} = 14.4 \pm 3.1(stat.) \pm 2.2(syst.)pb$$

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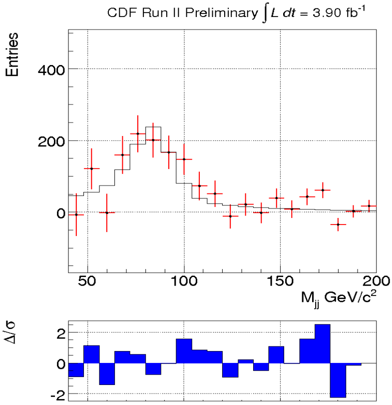

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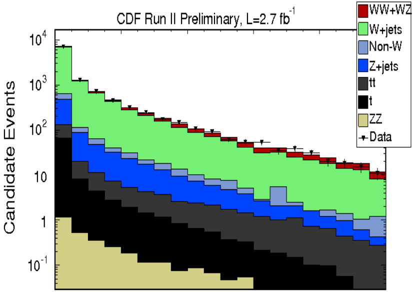
Matrix Element method in 2.7 fb^{-1}

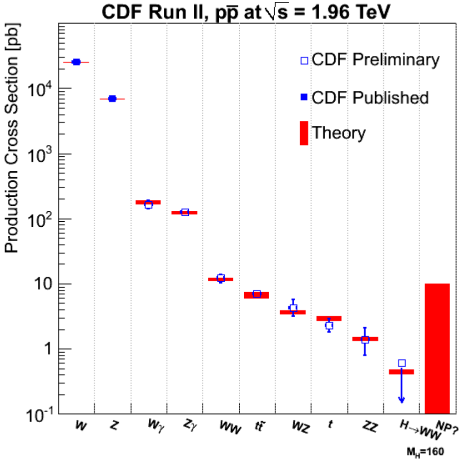
1. Second approach uses a multivariate technique to exploit all the information in the event: expect more sensitivity
2. Different selection since the shapes of the two discriminants are different:
   - Exactly two tight jets with $E_T > 25$ GeV and $\eta < 2.0$
   - Harder cut on $M_T(W) > 70\text{GeV}/c^2$ and $\not{E}_T > 40$ GeV
   - Use matrix element calculation to build discriminant (EPD) to separate signal and background
   - Likelihood fit to extract signal.



- Found a significance of 5.4 σ where 5.1 was expected : First observation

$$\sigma_{WW/WZ} =$$
$$17.7 \pm 3.1(\text{stat.}) \pm 2.4(\text{syst.})\text{pb}$$

Conclusion



- Measuring processes with cross sections similar to Higgs!
- New limits set on anomalous couplings
- First observation of diboson with leptons+jets:
  1. Opens the way to diboson studies with jets