Studies of WW and WZ production at CDF

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on behalf of the CDF Collaboration

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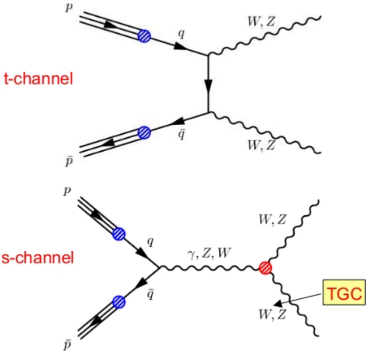
Physics Motivation



Absent at LEP

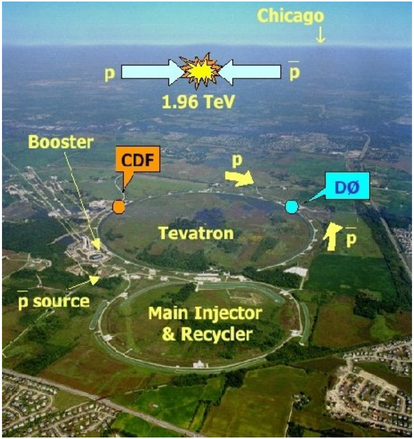
$q\bar{q}'\to W^{(*)}$	$\to W\gamma$:	$WW\gamma$ only
$q\bar{q}'\to W^{(*)}$	$\to WZ$:	WWZ only
$q\bar{q}\to Z/\gamma^{(*)}$	$\to WW$:	$WW\gamma, WWZ$
$q\bar{q}\to Z/\gamma^{(*)}$	$\to Z\gamma$:	$ZZ\gamma, Z\gamma\gamma$
$q\bar{q}\to Z/\gamma^{(*)}$	$\to ZZ$:	$ZZ\gamma, ZZZ$

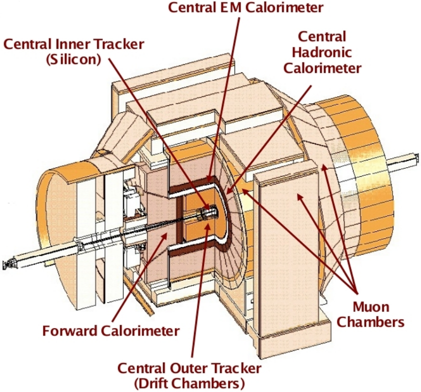
Absent in SM

- Direct probe into the gauge structure of the SM:
  1. S-channel probes triple gauge couplings (TGC)
  2. TeV with respect to LEP: explores higher energy range
- Cross sections can be enhanced by new physics
- Diboson final states close to higgs final states
- Benchmark for experimental capabilities towards Higgs

CDF detector

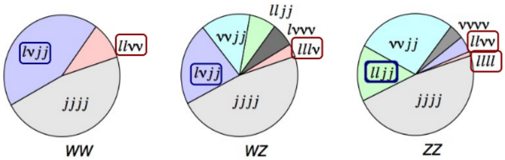
- Proton-antiproton collision at $\sqrt{s} = 1.96$ TeV
- Peak luminosity $4.0 \cdot 10^{32}$ cm^{-2} s^{-1}





- CDF → Multipurpose detector
- Data taking efficiency $\sim 85\%$

Heavy Diboson Production



Leptonic Decay Channels

Small branching fraction and low background

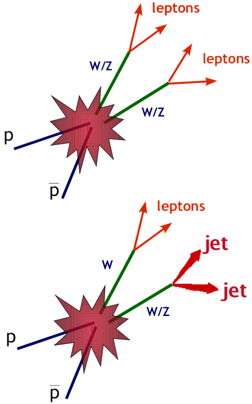
Clean signal but low yields

Key → increase lepton acceptance

Semileptonic Decay Channels

Larger branching fraction and much larger backgrounds

Signal / Background < 0.5%



WW cross section using $3.6\ fb^{-1}$

1. WW→ $\ell\nu$+ $\ell\nu$ production
   - Test SM predictions: x-section, TGC
   - Dominant background for H→ WW (same analysis)
   - Can be enhanced by new physics or Higgs
2. Two isolated leptons and large MET
3. Likelihood ratio formed from Matrix element probabilities

$$\sigma^{NLO}(p\bar{p} \to WW) = 11.7 \pm 0.7pb$$
$$\sigma(p\bar{p} \to WW) = 12.1^{+1.8}_{-1.6}pb$$

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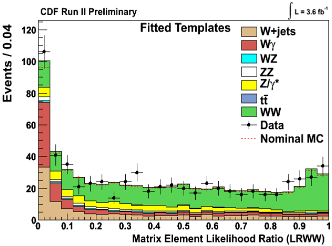
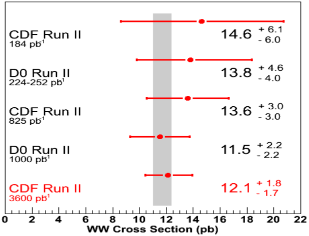
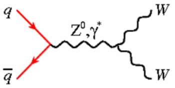
WW cross section with a precision of less than 15 %.

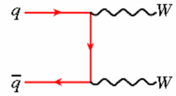




WW and Triple Gauge Couplings

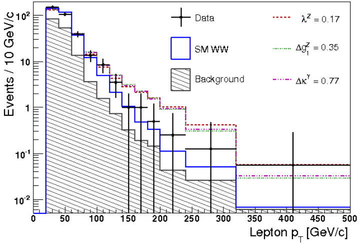
- Two diagrams producing WW: s-channel, and t-channel.
- s-channel is susceptible to anomalous triple gauge couplings: ΔK^z,ΔK^γ,Δg_1^z,Δg_1^γ,λ^z,λ^γ
- HISZ scheme (*Phys. Rev.* **D 48** (1993) 2182) ties these together to make 3 independent parameters



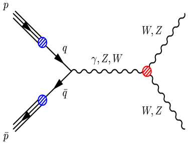


- Fit lepton p_T distribution

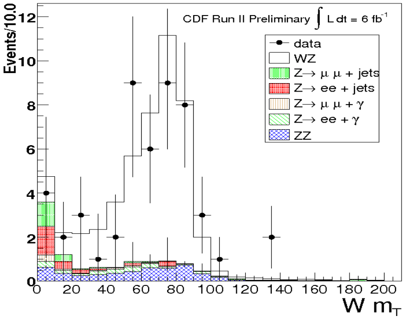
CDF Preliminary Results at 3.6fb^{-1}			
Λ	λ^Z	Δg_1^Z	$\Delta\kappa^\gamma$
2.0TeV	(-0.14,0.15)	(-0.22,0.30)	(-0.57,0.65)
1.5TeV	(-0.16,0.16)	(-0.24,0.34)	(-0.63,0.72)



WZ cross section



- Require 3 e or μ leptons and $\not{E}_T > 25$ GeV
- Lepton ID optimization
  1. Improved electron/muon isolation
  2. Recover central/plug transition
  3. Tight track quality
  4. Normalize to $Z \to \ell\ell$ to reduce the systematic uncertainties

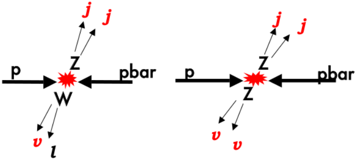


$$\sigma\,(p\bar{p} \to WZ) = 4.1 \pm 0.6(\text{stat.}) \pm 0.4(\text{sys.})\ pb$$

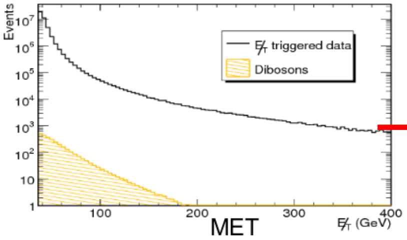
$$\sigma(WZ)NLO = 3.7pb$$

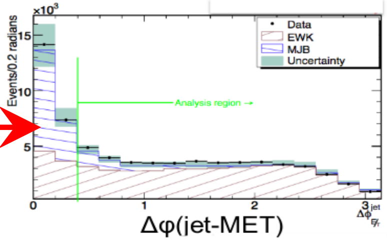
$VV \to \not{E}_T + jets$

- Jet final states are more difficult → Resolution much worse
- Select jj+MET events
  - Acceptance to $\nu\nu$ and $l\nu$ events (WW, WZ, ZZ)
  - Milestone for low mass Higgs searches
  - Similar final state to ZH → $\nu\nu + bb$
- Analysis challenge:
  1. Triggered data dominated by QCD multijet events with fake $\not{E}_T$
  2. After trigger Signal/QCD $\sim 10^{-4}$

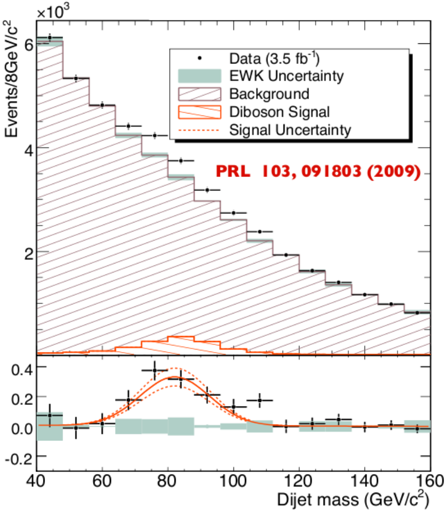


- Reject QCD based on sophisticated $\not{E}_T$ resolution model [arXiv:0910.5170]
- After QCD rejection: Signal/QCD~0.2





$VV \rightarrow met + jets$



- Fit M_{jj} distribution
- EWK M_{JJ} shape: checked with γ+jj $\rightarrow$ significantly reduces systematics
- Fitted Jet Energy scale compatible with 1

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

SM: $16.8 \pm 0.5pb$ (MCFM + CTEQ6M)

First observation in hadronic final state: 5.3 σ significance

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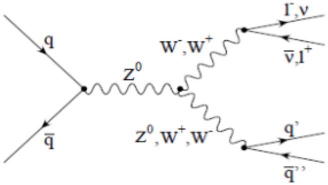
$WW/WZ \rightarrow l\nu$ +jets



- Require high p_T lepton, large $\not{E}_T$, and two jets
- Build W or Z from two-jet system:
  - Dijet mass resolution doesn't allow to distinguish between W and Z
- WW is dominant (WZ has lower cross section, branching ratio)

Two measurements of WW/WZ → lvjj have been carried out at CDF

- Matrix element analysis in 4.6 fb^{-1} (2.7 fb^{-1} published)
- Search for resonance in dijet invariant mass spectrum in 4.3 fb^{-1} (3.9 fb^{-1} published)

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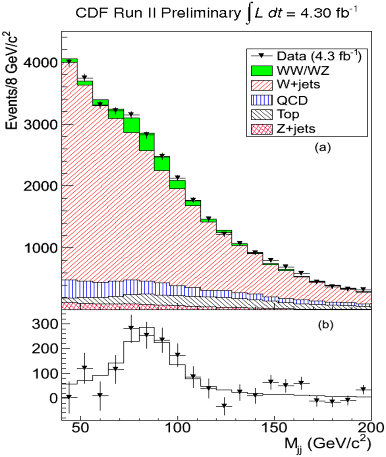
M_{jj} method in $4.3\ fb^{-1}$

- 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
- Fit to extract ths signal : 1582 $\pm$ 275 (stat.) $\pm$ 107 (syst) $WW/WZ \to l\nu jj$ events

$$\sigma_{WW/WZ} = 18.1 \pm 3.3(\text{stat.}) \pm 2.5(\text{syst.})\ \text{pb}$$

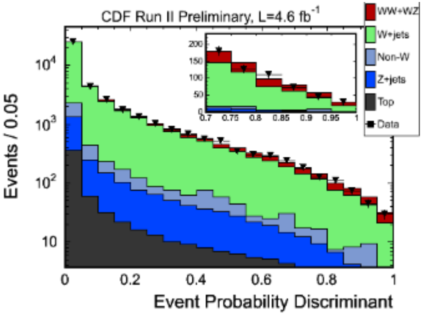
- Compatible with SM cross section: (15.9 $\pm$ 0.9 pb)
  - Significance 5.2 σ (5.1 expected)

Matrix Element method in 4.6 fb^{-1}

1. Second approach uses a multivariate technique to exploit all the information in the event.
   - Use matrix element calculation to build discriminant (EPD) to separate signal and background

$$EPD = P_{sig}/(P_{sig} + P_{BG})$$

   - Likelihood fit to extract signal.



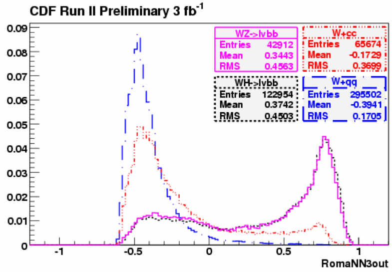
- Significance 5.4 σ (5.1 expected)

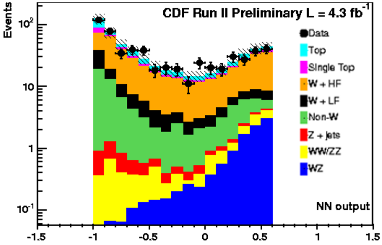
$$\sigma_{WW/WZ} = 16.5^{+3.3}_{-3.0}(stat. + syst.)pb$$

$WZ \to \ell\nu + b\bar{b}$

- Cross section $\sigma(WZ \to l\nu b\bar{b}) = 0.12pb$
- Important benchmark toward higgs searches
- Event selected requiring one lepton (tight and central), $\not{E}_T > 20$ GeV and two jets.
- The two b-jets identfied with NN algorithm :
  1. Uses both the lifetime information as well as the lepton information.
  2. Per-jet output value $\to 1$ = more b-jet like.
  3. Jet tagged if output > 0.0
- Another is NN used to discriminate between WZ and other backgrounds
- Set a limit with 4.3 fb^{-1}:

$\sigma_{obs} < 3.9 \cdot$SM $(3.9$ expected) at 95 % CL

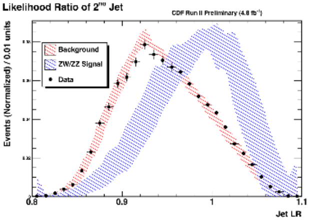


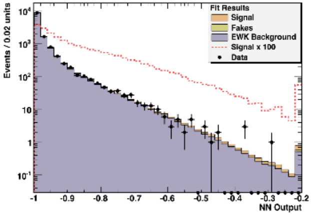


$ZW + ZZ \rightarrow ll + jj$

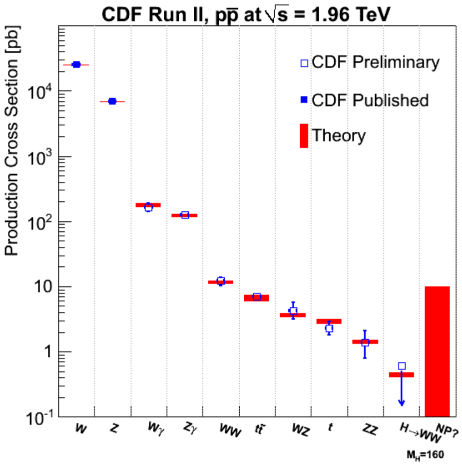
- Combination of WZ and ZZ still unobserved:
  - Expected cross section 5.0 ± 0.4 pb
  - Branching ratio of Z $\longrightarrow$ leptons small
  - Z+jets background is very large
  - Motivates new quark-gluon discriminant
- Jet Likelihood Ratio: Quark/Gluon Discriminant
  - Energy in q jets less spatially spread than in g jets $\rightarrow$ quantified as Jet LR: larger = more quark-like
- Build NN discriminant
- Fit of 4.8 fb^{-1} data to S+B template yields:
  - set a limit on σ_{ZW+ZZ} of

$$\sigma_{ZZ+ZW} < 2.9 \cdot \text{SM at 95 \% CL}$$





Conclusion



- Diboson physics a rich and interesting place
  - SM tests
  - Higgs benchmark
  - New physics searches
- Larger Tevatron datasets allows for more targeted searches
- Most interesting results are yet to come!!