Diboson Production at the Tevatron

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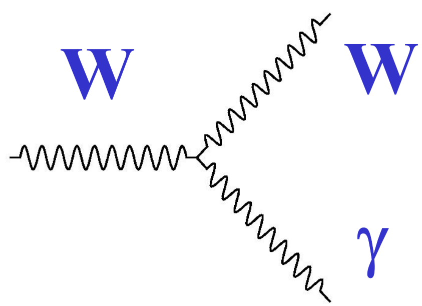
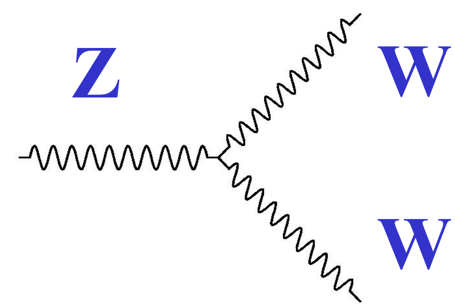
For the CDF and DØ Collaborations

Diboson Production

- $SU(2)_L \times U(1)_Y$ electroweak sector
  - Non-Abelian theory with self-interacting gauge bosons





  - We can study trilinear boson couplings by analyzing events with two (or more) bosons in the final state
- Most of new physics models predict multiple weak bosons in the final state
- Diboson events are a background for other important physics (**H→WW**, $\mathbf{t\bar{t}}$ → dileptons *etc*.)

Boson Reconstruction in CDF and DØ

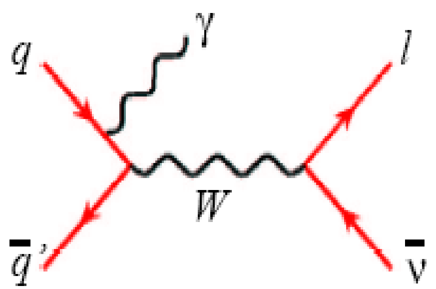
- **W** reconstruction
  - High-p_T lepton candidates, missing E_T
- **Z** reconstruction
  - A pair of two high-p_T lepton candidates
- γ reconstruction
  - Electro-magnetic object reconstructed with a transverse energy of at least **7**(CDF) or **8**(DØ) GeV; object must be isolated and pass shower shape quality requirements
  - Photon candidate is reconstructed in the central region of the calorimeter ($|\eta| < \mathbf{1.1}$)

Photon Reconstruction

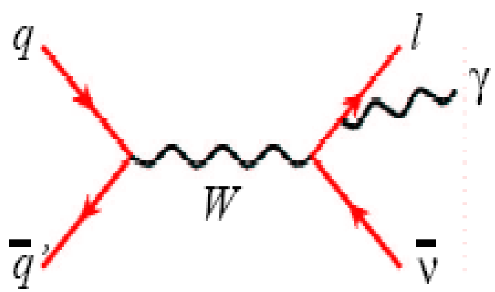
- Photon identification is quite challenging
  - Big background from jets with high energy π^0
    - Use as much information on track isolation and energy deposition as possible
  - No clean photon samples available (sample of **$H\rightarrow\gamma\gamma$** events would be very useful!)
    - Have to use both data and Monte Carlo simulation to measure photon efficiency
    - Photon identification systematic error is one of the dominant in **$W\gamma$** and **$Z\gamma$** analyses

Wγ Production

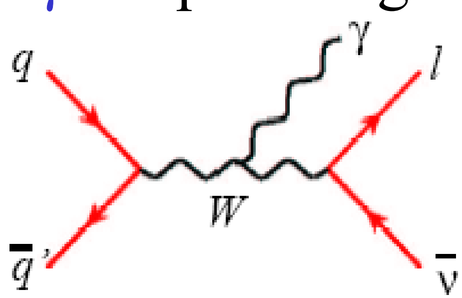
Initial State Radiation



Final State Radiation



WWγ: Triple Gauge Coupling

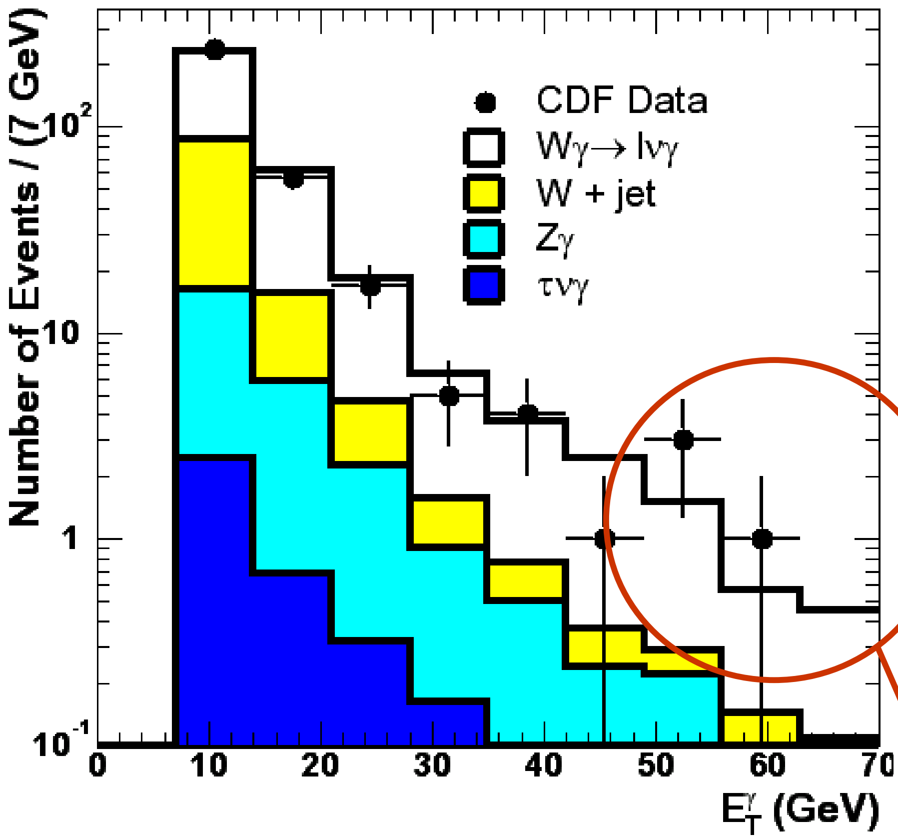


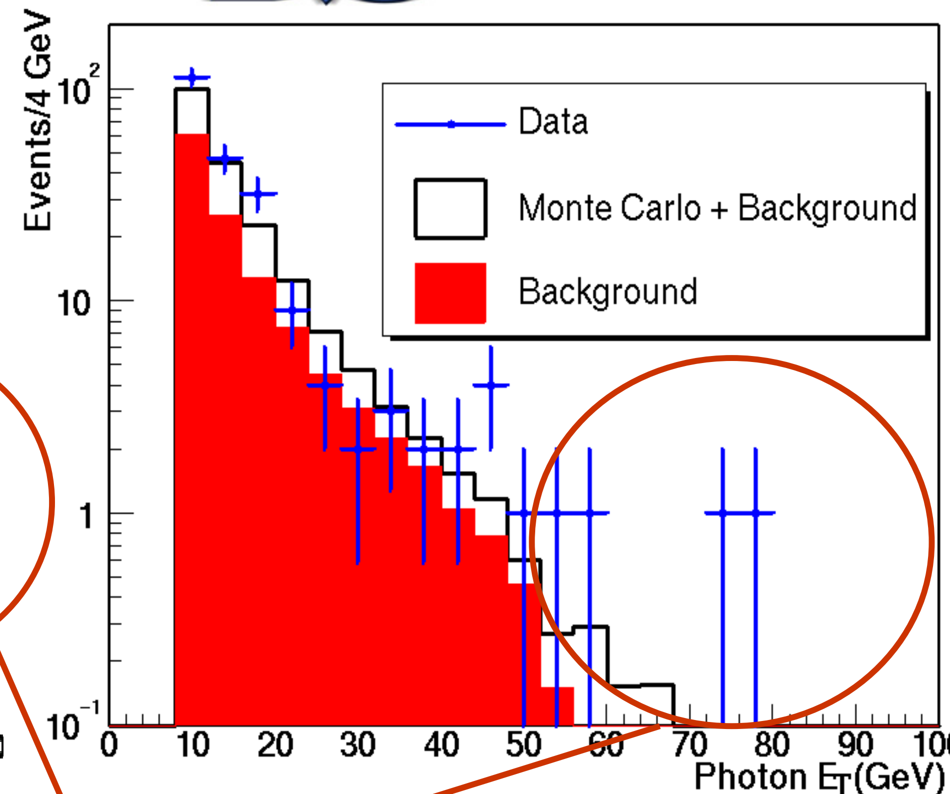
- Require g to be isolated from leptons by at least

$$\Delta R(\gamma,\ell) = \sqrt{\Delta\eta^2 + \Delta\phi^2} > \mathbf{0.7}$$

  - reduce FSR processes
- Sensitive to WWγ trilinear coupling
- Anomalous coupling would
  - Change the shape of γ E_T distribution (more high-E_T photons)
  - Enhance the cross-section

Photon E_T Spectrum





Sensitive region to anomalous couplings

Wγ Cross-section Results

	Electron(Muon)	Electron(Muon)
Luminosity, pb^{-1}	202(192)	162(82)
E_T^{γ}	> 7 GeV	> 8 GeV
Total background	94.7 ± 23.6	124.1 ± 12.5
Candidates	323	223
σ, pb	**$19.7 \pm 2.8^{stat+syst} \pm 1.1^{lumi}$**	**$19.3 \pm 6.7^{stat+syst} \pm 1.2^{lumi}$**
NLO Theory, pb	**19.3 ± 1.4**	**16.4 ± 0.4**

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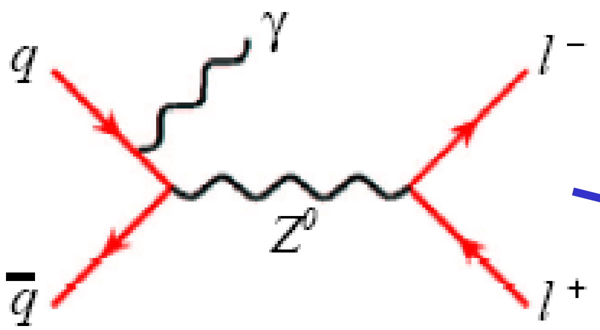
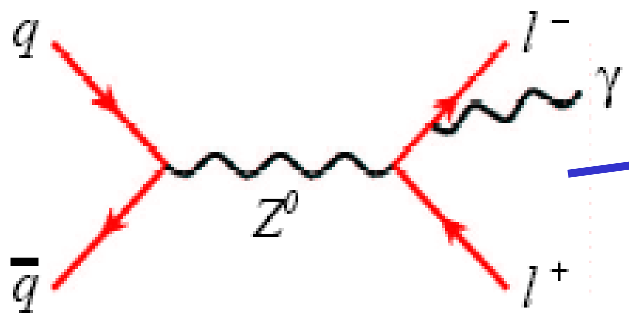
$Z\gamma$ Production

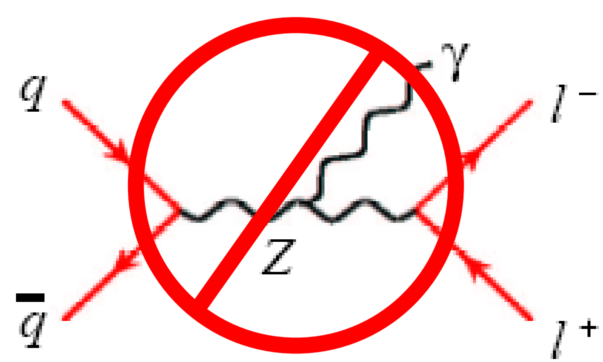
Initial State Radiation

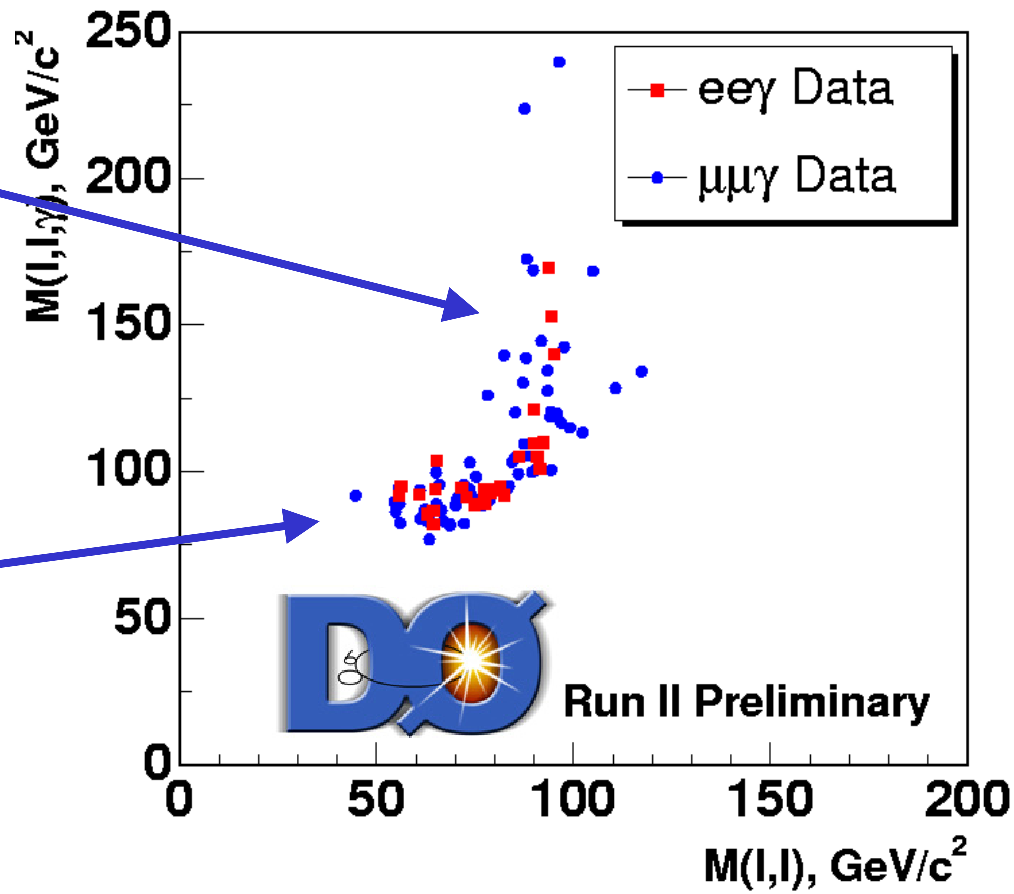


Final State Radiation



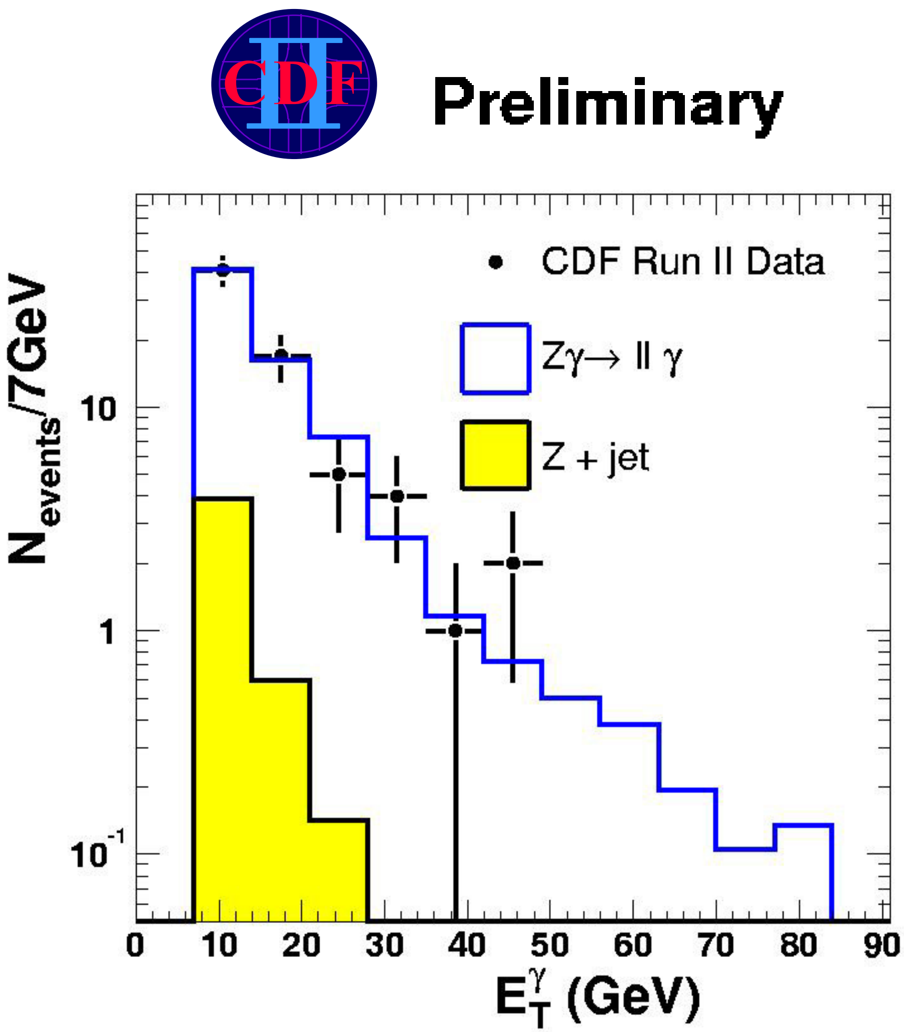
ZZg: Triple Gauge Coupling

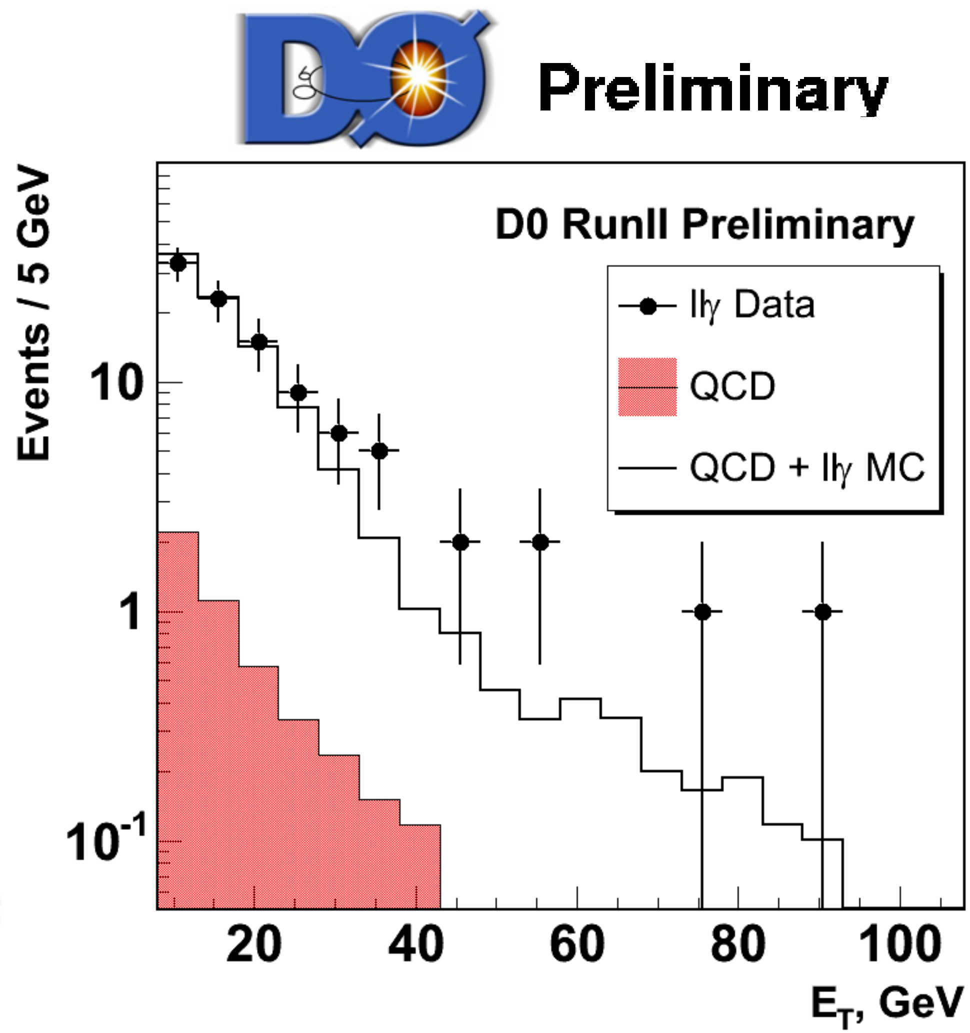




- Any indication of non-zero trilinear couplings indicates new physics

Photon E_T Spectrum





$Z\gamma$ Cross-section Results

	CDF Electron(Muon)	DØ Electron(Muon)
Luminosity, pb^{-1}	202(192)	177(144)
E_T^γ	> 7 GeV	> 8 GeV
Background	4.5 ± 0.8	14.8 ± 1.5
Candidates	70	101
σ, pb	$5.3 \pm 0.7^{stat+syst} \pm 0.3^{lumi}$	$3.9 \pm 0.5^{stat+syst} \pm 0.3^{lumi}$
NLO Theory, pb	5.4 ± 0.4	4.3 ± 0.4

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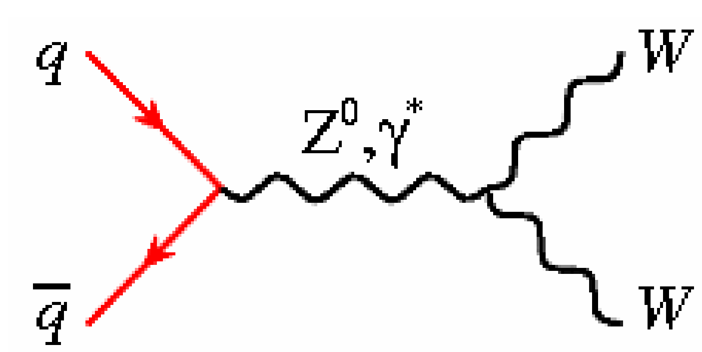
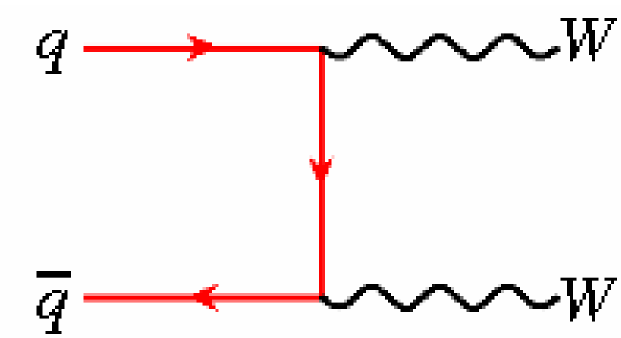
WW Production





- Sensitive to **ZWW** and **γWW** couplings
- Select events with two high-p_T leptons, large missing E_T
  - (**ee**) and (**$\mu\mu$**) channels have large background from **Z** decays; (**eμ**) is much cleaner, major background from **Wγ** process.
- CDF: "lepton+track" – require only one reconstructed high -p_T lepton and a charged track
  - increases efficiency,
  - includes **$W\rightarrow\tau\nu$** decays

WW Production

CDF II	**ee**	**μμ**	**eμ**	All
Expected signal	2.90 ± 0.34	2.75 ± 0.32	5.69 ± 0.66	11.3 ± 1.3
Background	1.97 ± 0.40	1.14 ± 0.28	1.66 ± 0.31	4.77 ± 0.7
Candidates	6	6	5	**17**

DØ	**ee**	**μμ**	**eμ**	All
Expected signal	3.26 ± 0.05	2.01 ± 0.05	10.8 ± 0.1	16.1 ± 0.1
Background	2.30 ± 0.26	1.94 ± 0.43	3.81 ± 0.30	8.05 ± 0.7
Candidates	6	4	15	**25**

WW Cross-section Results

NLO Theory: 13.5 pb (CTEQ5L)
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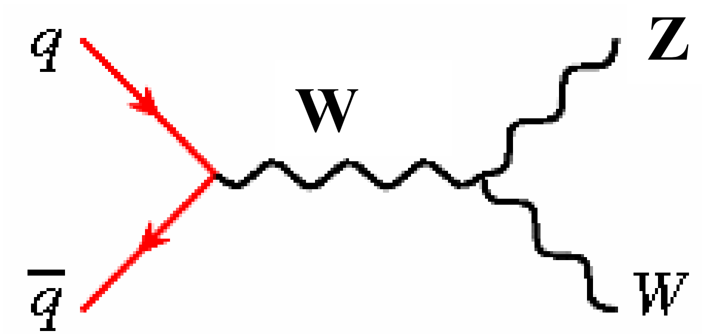
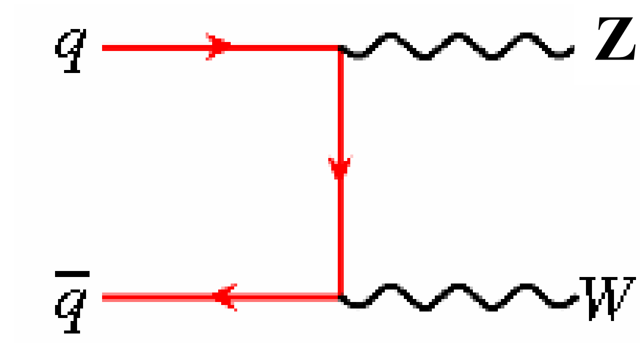
- Dilepton final state
  - CDF: $\sigma(pp\to WW) = 14.3\,^{+5.6}_{-4.9}(\text{stat}) \pm 1.6(\text{syst}) \pm 0.9(\text{lumi})$
  - DØ: $\sigma(pp\to WW) = 13.8\,^{+4.3}_{-3.8}(\text{stat}) \pm 1.0(\text{syst}) \pm 0.9(\text{lumi})$
- Lepton+track
  - CDF: $\sigma(pp\to WW) = 19.4 \pm 5.1(\text{stat}) \pm 3.5(\text{syst}) \pm 1.2(\text{lumi})$

- Cross-sections are consistent with SM prediction
- Work on extracting **ZWW** and γ**WW** trilinear couplings is in progress.

WZ Production





- Select events with three high-p_T lepton (electron or muon) candidates and missing E_T
- We expect 1.02 ± 0.07 signal events with estimated background of 0.39 ± 0.02 events
- Observe one event with three muon candidates
  - Set an upper-limit on **WZ** cross-section of **15.1 pb** at 95% C.L.
  - NLO Theory predicts 3.7 ± 0.1 pb

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WZ and **ZZ** Production

- Statistics is not sufficient, try to set limit on combined **WZ** and **ZZ** production
- Require a **Z** candidate decaying in either electrons or in muons in the event and
  - large missing transverse energy (**Z**$\rightarrow\nu\nu$) or
  - a third lepton (**e** or μ) and missing E_T or
  - two leptons
- Expect **2.72 ± 0.33** signal events with estimated background of **2.29 ± 0.42** events
- Observe 4 candidate events in data (all in **Z**+missing E_T)
- Set an upper limit on **WZ+ZZ** production of **13.9 pb**
  - NLO Theory prediction is **5.2 ± 0.4 pb**.

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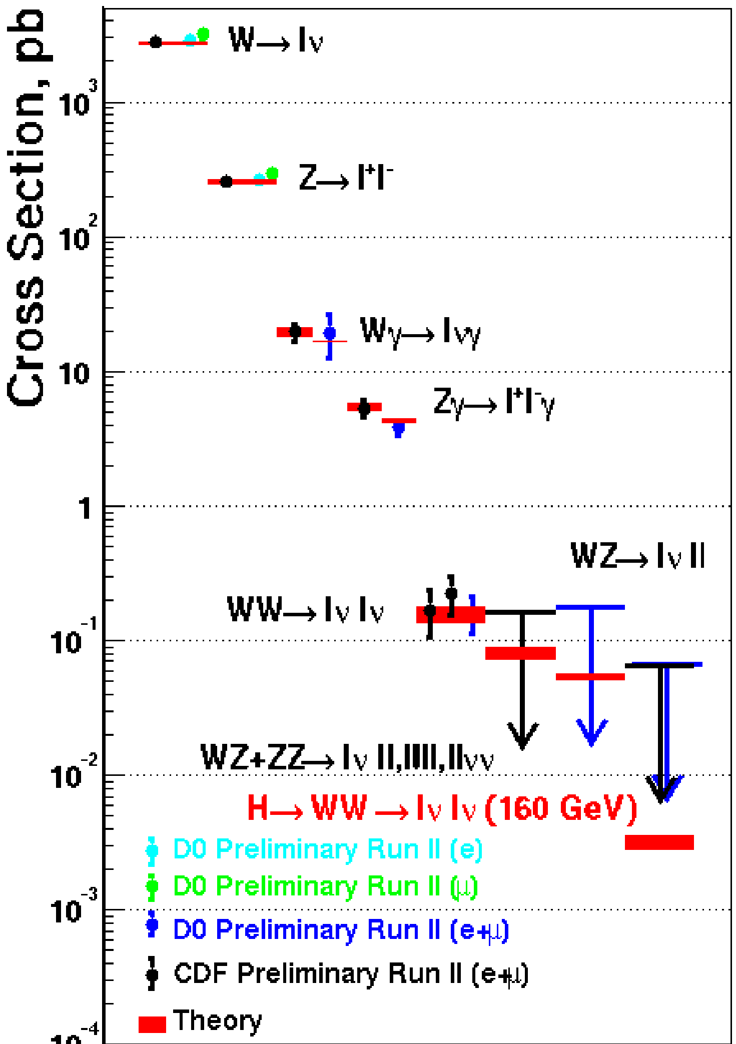
Conclusions



- We report measurements of **Wγ**, **Zγ**, and **WW** cross-sections.
  - First observation of **WW** production
- Results are consistent with the Standard Model predictions
- Limits are set on **WZ** and **ZZ** processes
- Measurements are being interpreted in the framework of anomalous coupling
- Expect final results and publications soon…