Diboson physics at Tevatron

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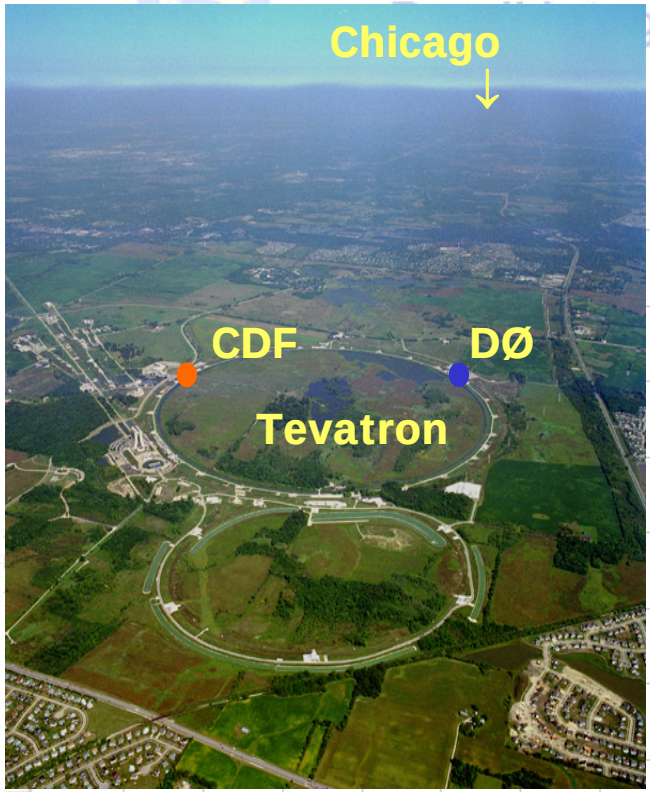
On behalf of the CDF and DØ Collaborations

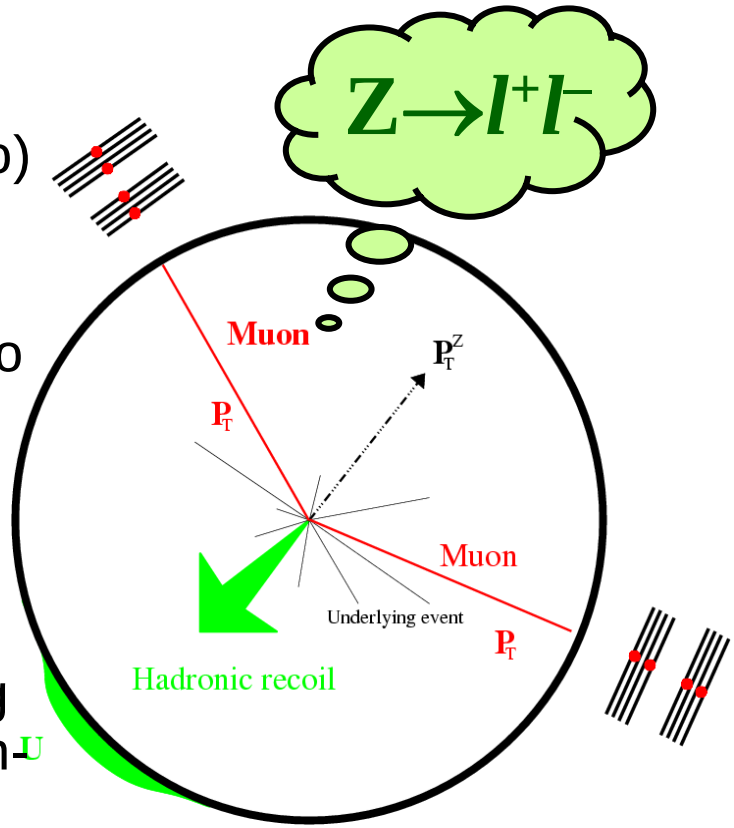


Outline

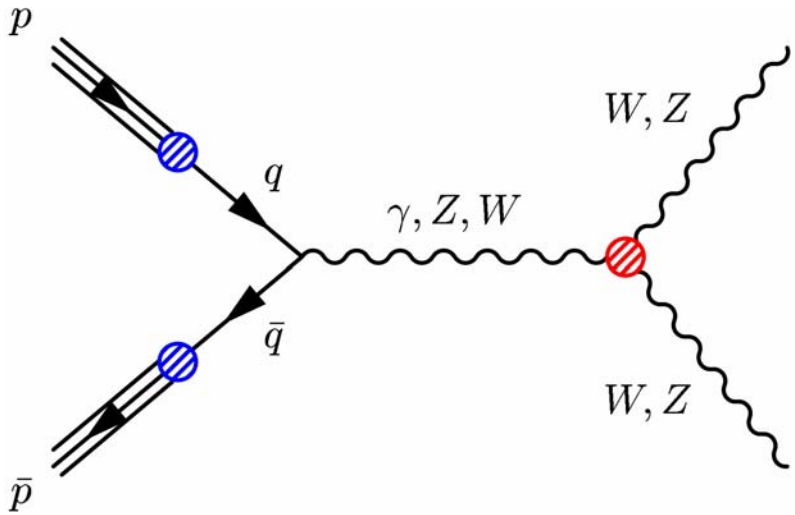
- Tevatron is a “boson factory”:
  - Rate/week (**L** ~ 30 pb^{-1}):
    - 180k $W \rightarrow e/\mu$
    - 16k $Z \rightarrow ee/\mu\mu$
    - 400 WW, 120 WZ, ...
- Spree of new EWK results:
  - http://www-cdf.fnal.gov/physics/ewk/
  - http://www-d0.fnal.gov/Run2Physics/WWW/results/ew.htm
- Single boson production:
  - Measurement of W boson mass and width (Sarah Malik)
  - W and Z measurements (Aidan Robson)
  - W charge asymmetry, Z rapidity, γ + jets (Terry Toole)
  - Studies of associated production of Z + jets (Jochen Cammin)
- Diboson production (WW, WZ, $W\gamma$, $Z\gamma$, ZZ)

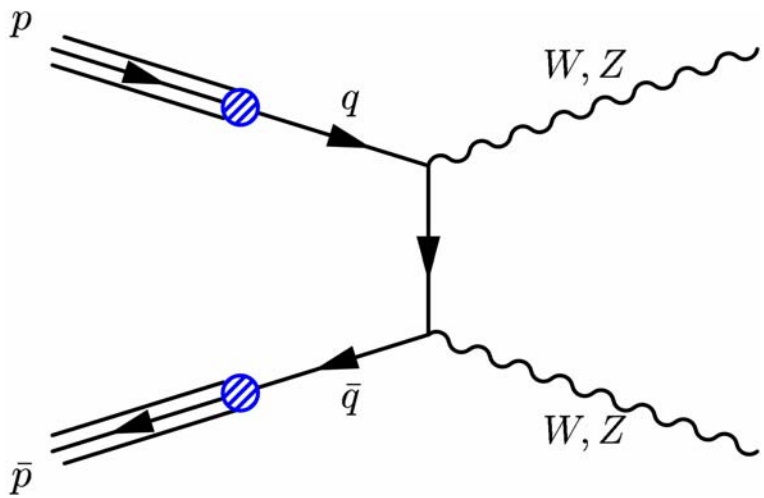
Identification of *Z/W/γ*

- Reconstruction of *Z/W*
  - ***Z :*** two leptons with p_T ~ 35 GeV, little missing E_T (no neutrino)
  - Use “tag and probe” method to measure efficiency, mis-ID rate *etc.*
  - ***W :*** one charged lepton, missing E_T due to unobserved neutrino.
- Photon reconstruction
  - Almost an electron, but no associated charged track
  - Procedure to measure the efficiency using data (electron) and correction for electron-photon shower difference using Monte Carlo simulation



Diboson production

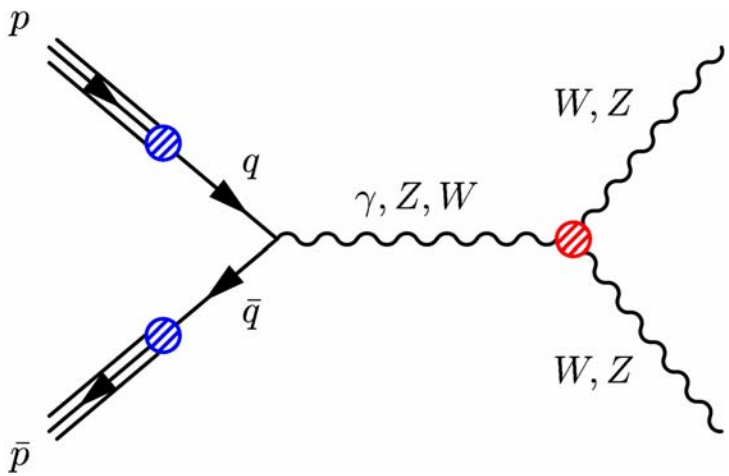




- Important processes for top, Higgs, SUSY physics
- Sensitive to new physics phenomena
  - Most new physics usually involve bosons in final state
  - Self-interacting boson couplings are not known well

First observation of *WZ*

L ~ 1.1 fb^{-1}



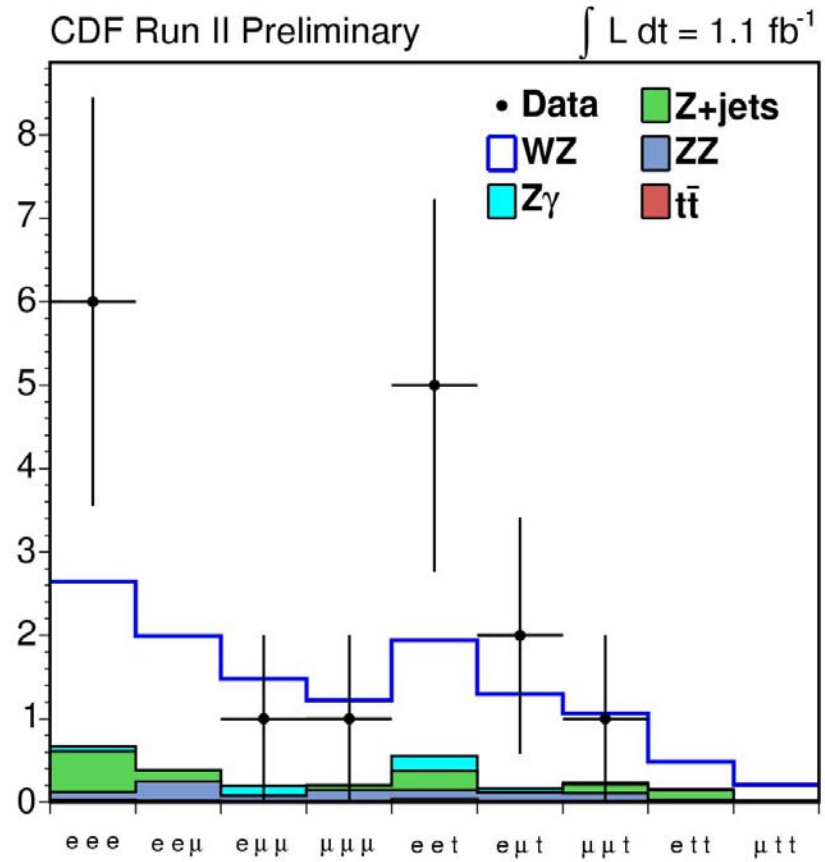
- Unique sensitivity to ***WWZ*** coupling
- Search for a final state with 3 ***e***, μ leptons and missing transverse energy

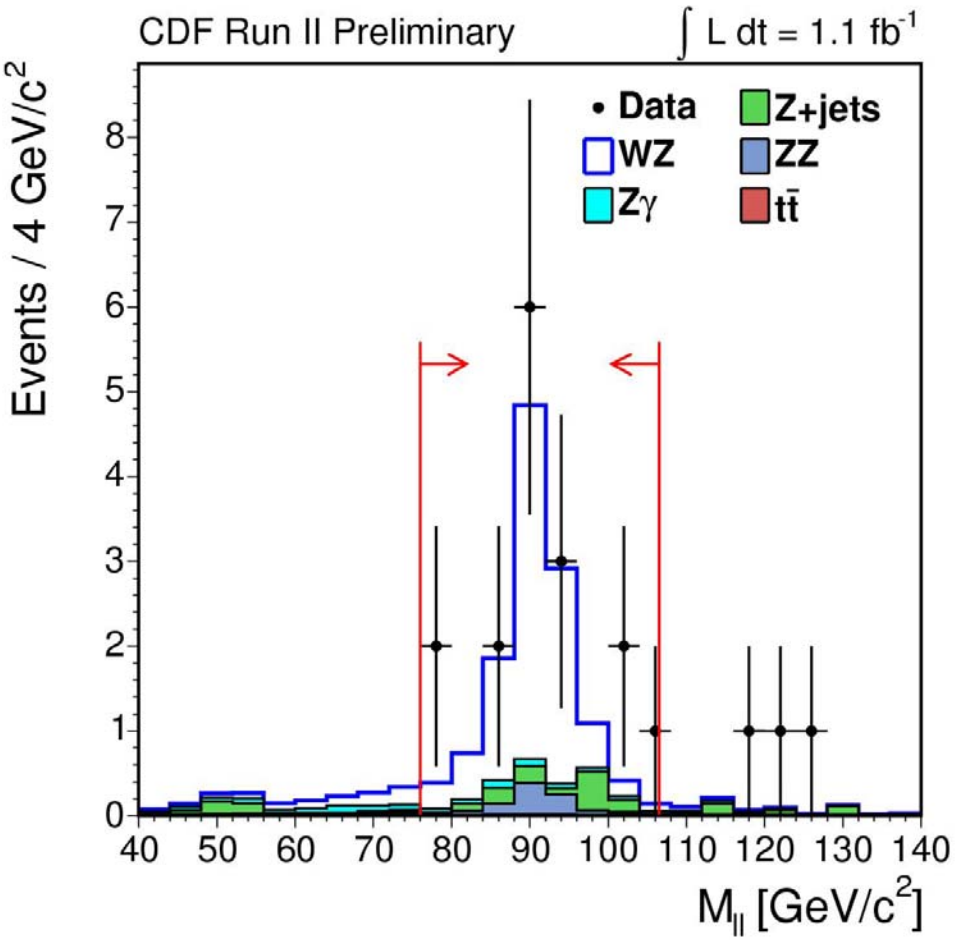
- Observed 16 candidate events with total background of 2.7 ± 0.28 (stat) ± 0.33 (syst) ± 0.09 (lumi) events
  - Background is mostly from ***Z*** + jets production
- Measured cross-section (5.9σ) compares well with theoretical prediction 3.7 ± 0.3 pb

$$\sigma(WZ) = 5.0^{+1.8}_{-1.6}\ (\text{stat.} + \text{syst.})\ \text{pb}$$

First observation of *WZ*

L ~ 1.1 fb^{-1}



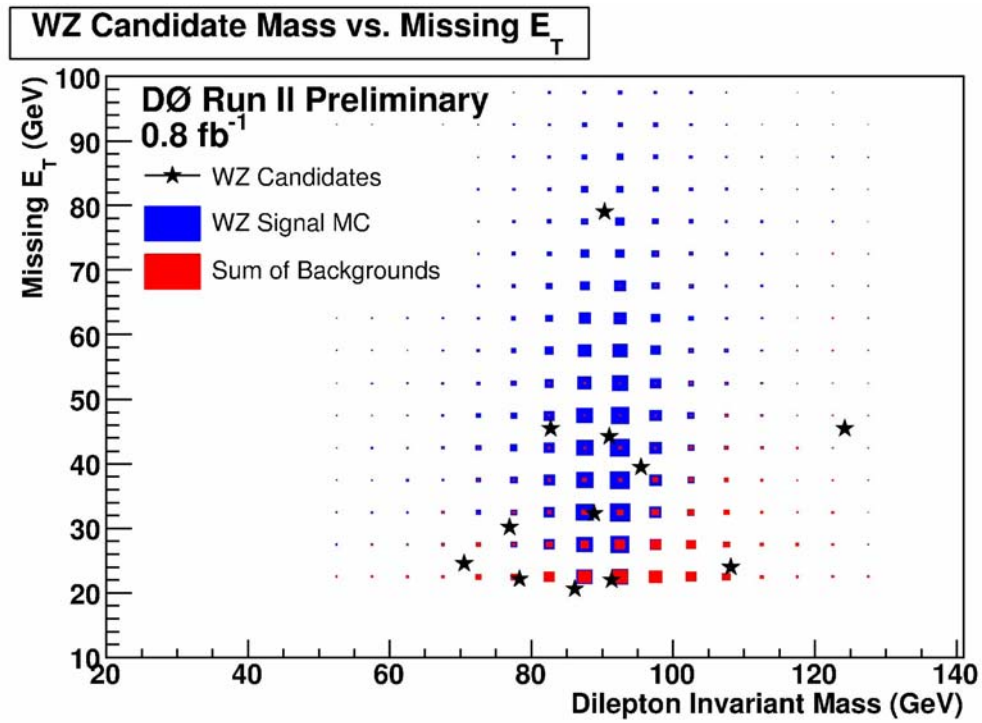


Evidence for *WZ*

L ~ 0.8 fb^{-1}

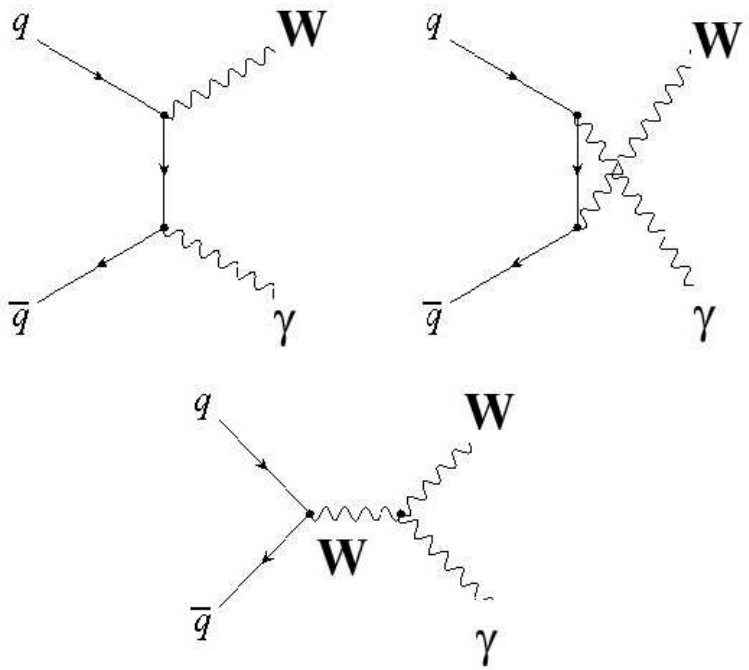
- Observed 12 candidate events in 4 decay channels: *eee* (2), *ee*μ (1), *e*$\mu\mu$ (7), $\mu\mu\mu$ (2)
- Estimated background (major contribution is from ***Z*** + jets) is 3.61 $\pm$ 0.21 events
  - P (bkg fluctuation) = 4.2 x 10^{-4}, 3.3σ
- Cross-section calculated by combining likelihoods for each channel
  - SM: 3.68 $\pm$ 0.25 pb

$$\sigma(WZ) = 3.98^{+1.91}_{-1.53}\ \text{pb}$$



Measurement of $W\gamma$ cross section

L ~ 1.0 fb^{-1}

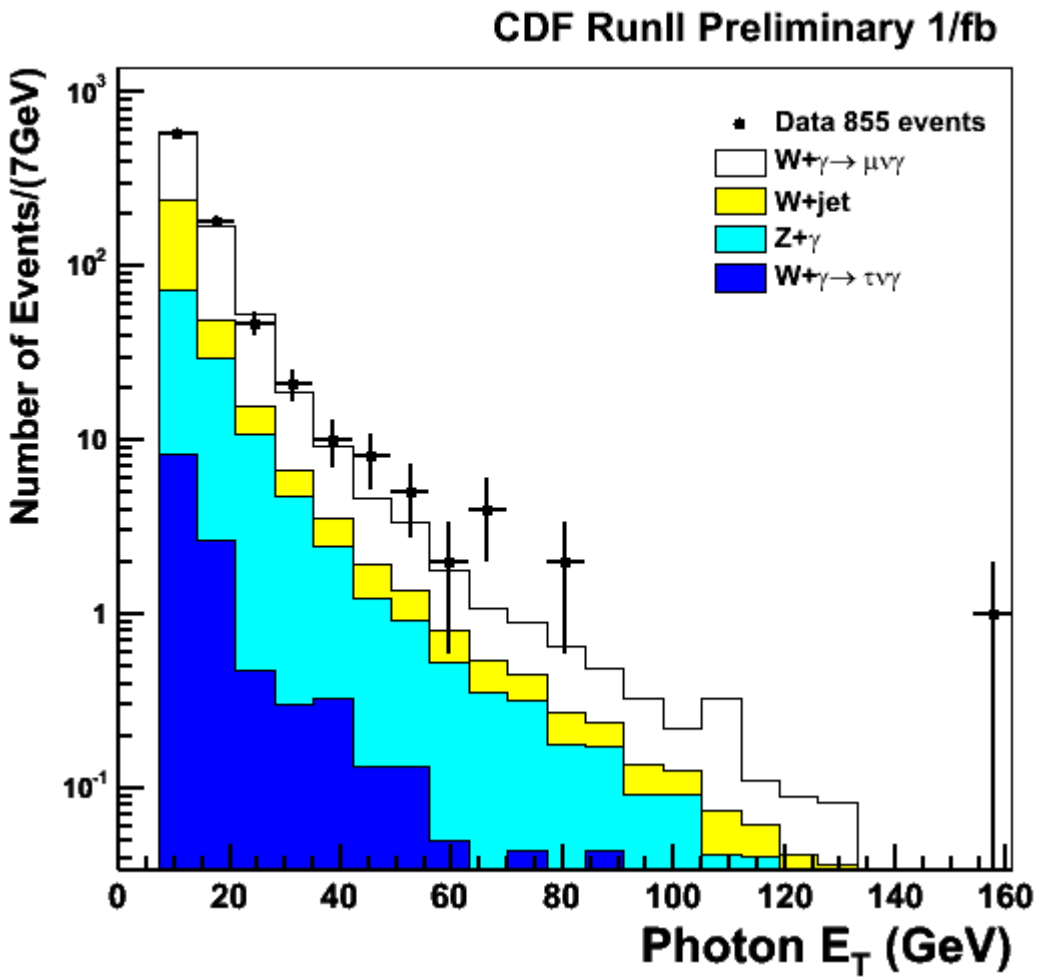


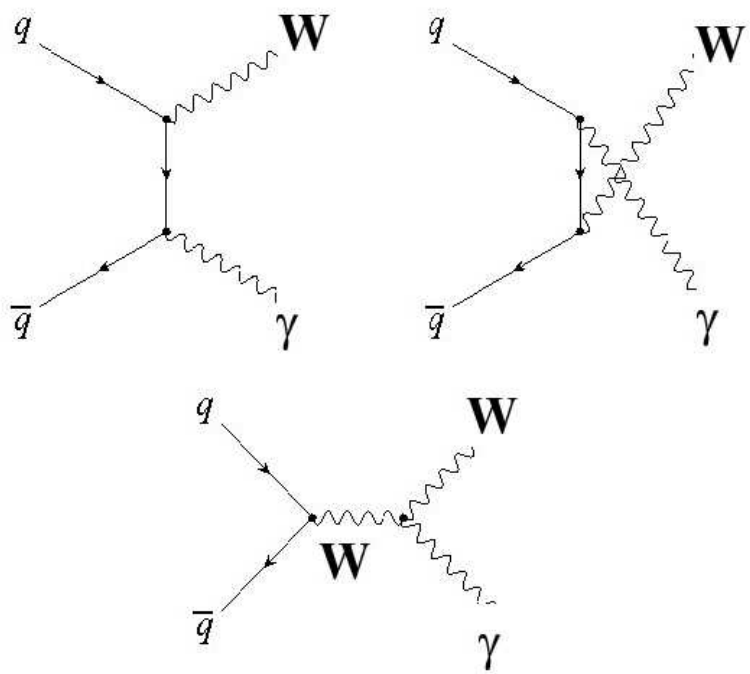
- Reconstruct in $W \rightarrow \mu\gamma\nu$ decay mode
- Observed 850 candidate events with expected background of 331.1 ± 0.7 ± 66.9 events
  - mostly W+jet and $Z\gamma$ processes
- SM predicts 19.3 ± 1.4 pb

$$\sigma(W\gamma)\times BR(W\rightarrow\mu\nu)=19.11\pm1.04(\text{stat.})\pm2.40(\text{syst.})\pm1.11(\text{lumi.})\ \text{pb}$$

Measurement of $W\gamma$ cross section

L ~ 1.0 fb^{-1}





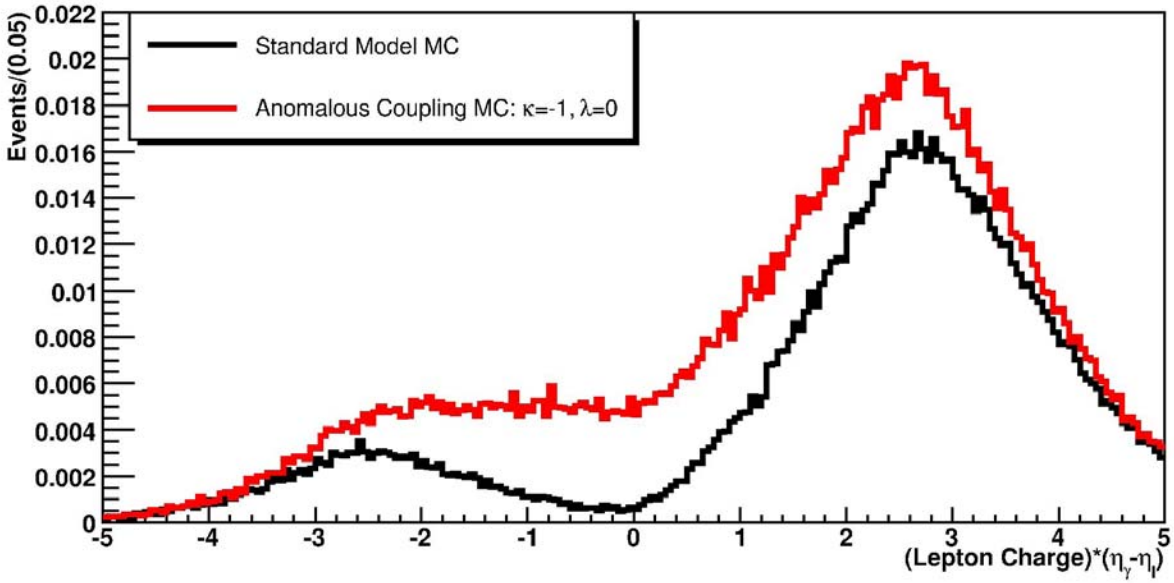
Study of $W\gamma$ production

$L \sim 0.9\ fb^{-1}$

- Interference among tree-level diagrams creates zero in the center-of-mass distribution of angle between ***W*** and incoming quarks
- Radiation Amplitude Zero Baur *et al.*: hep-ph/9402282

$$\mathrm{sign}(l)\times(Y(\gamma)-Y(l))\approx -0.3$$

- Sensitive to anomalous $WW\gamma$ couplings

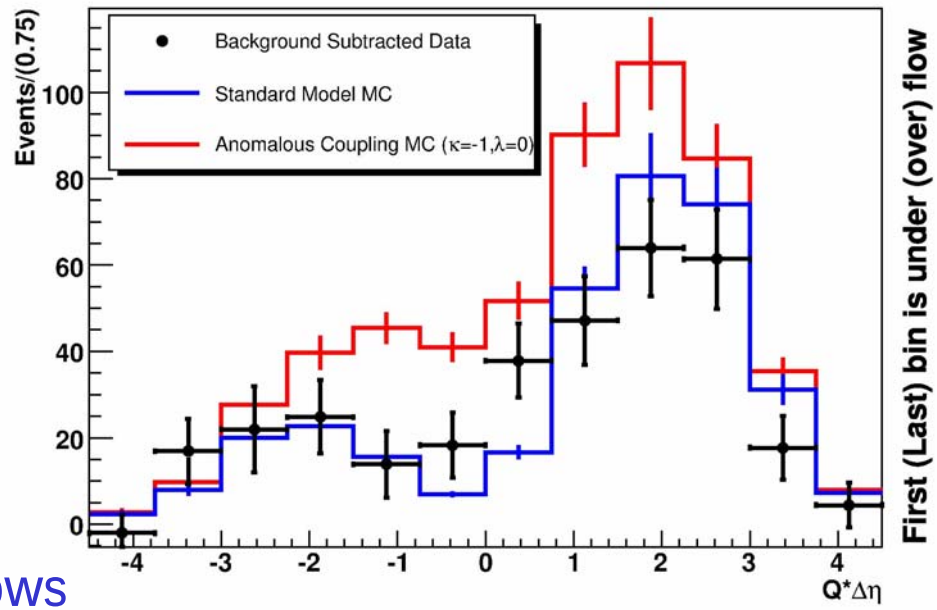


Study of $W\gamma$ production

L ~ 0.9 fb^{-1}

- Reduce contribution from Bremstrahlung by threshold imposed on the transverse mass of lepton-photon-neutrino (missing E_T)
- Observed 130 ($\mu\gamma$) and 205 ($e\gamma$) candidate events
  - Purity is ~50%, major backgrounds are W+jet and Z production

$$\sigma(W\gamma \to e\gamma\nu) = 3.21 \pm 0.49 \pm 0.20 \text{ pb}$$
$$\sigma(W\gamma \to \mu\gamma\nu) = 3.12 \pm 0.49 \pm 0.19 \text{ pb}$$

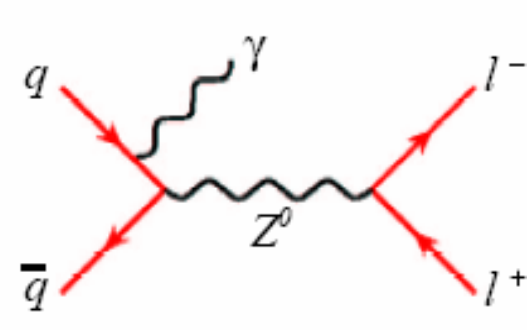


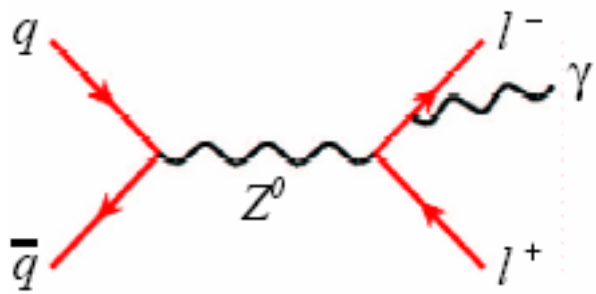
- Rapidity difference distribution shows the first hint of radiation amplitude zero

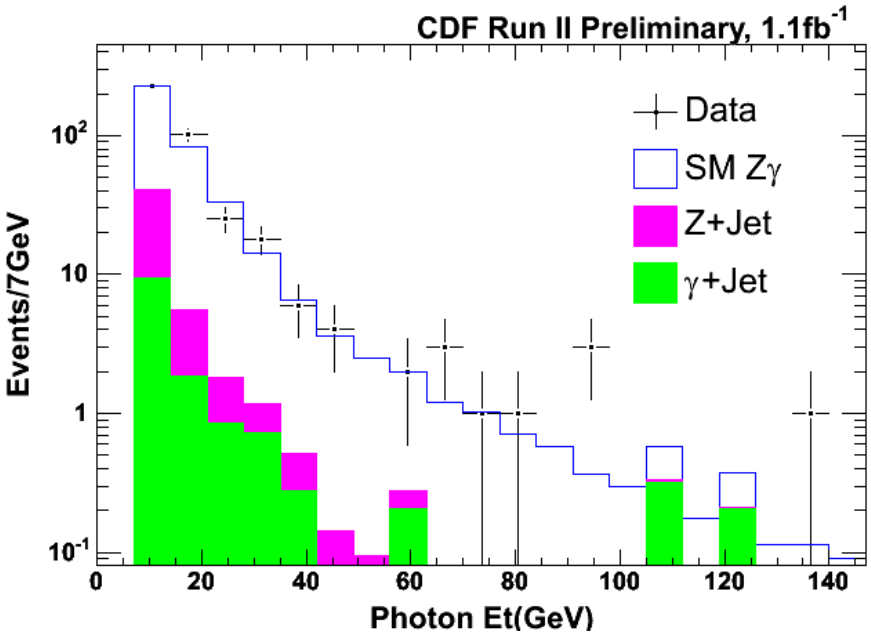
$$\chi^2/\text{n.d.f.} = 16/12$$

Measurement of $Z\gamma$ cross section

L ~ 1.0 fb^{-1}







- Reconstruct in ***Z(γ) →eeγ*** decay mode
- Observed 390 candidate events with expected background of 51.0 ± 15.7 events
  - mostly ***Z***+jet process
- SM predicts 4.7 ± 0.4 pb

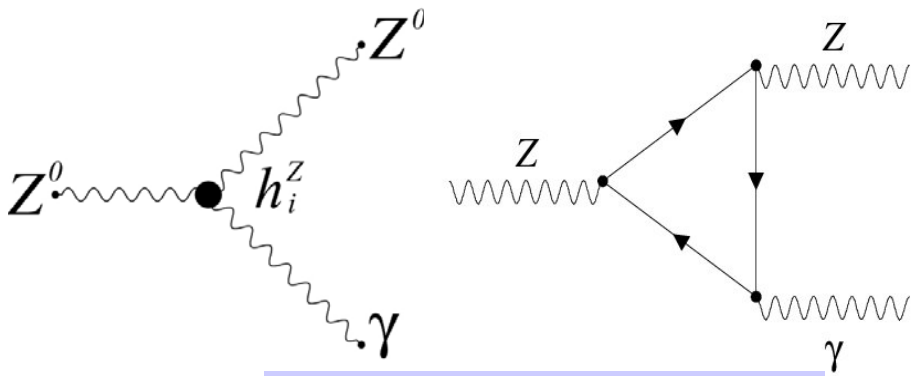
$$\sigma(Z\gamma \to ee\gamma) = 4.9 \pm 0.3(\text{stat.}) \pm 0.3(\text{syst.}) \pm 0.3(\text{lumi.})\,\text{pb}$$

Study of $Z\gamma$ production

L ~ 1.1 fb^{-1}

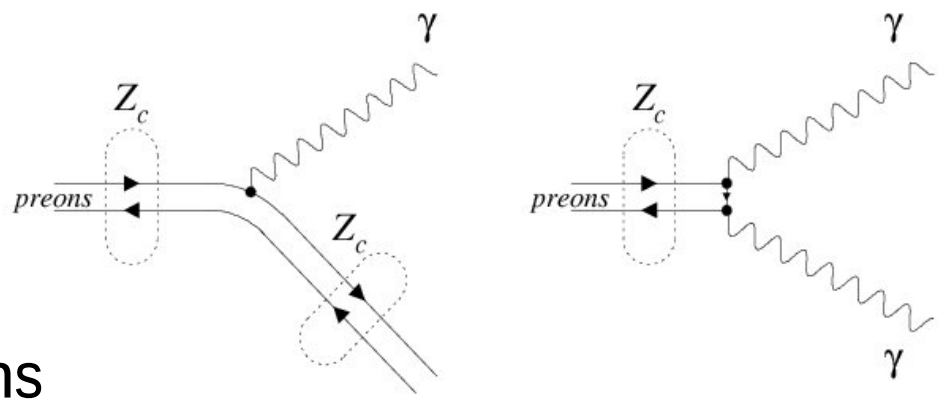
- Within standard model, Z boson and photon cannot couple at tree level
  - Theory predicts ~10^{-4} correction due to loop processes

Baur *et al.*: PRD57, 2823 (1998)



SM: h ~ 10^{-4}

- Several extensions of the standard model predict enhancement due to
  - New particles in the loop
  - Direct interaction with preons (composite ***Z*** boson models)



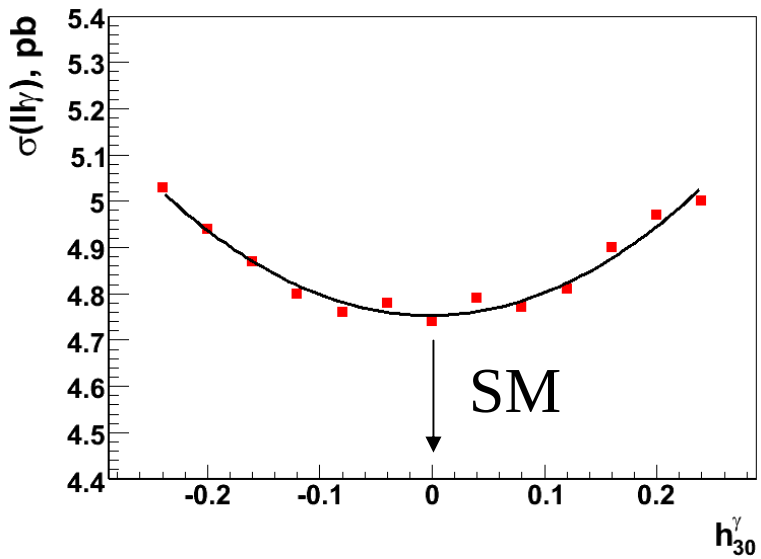
NP: h ~ 10^{-1} – 10^{-3}

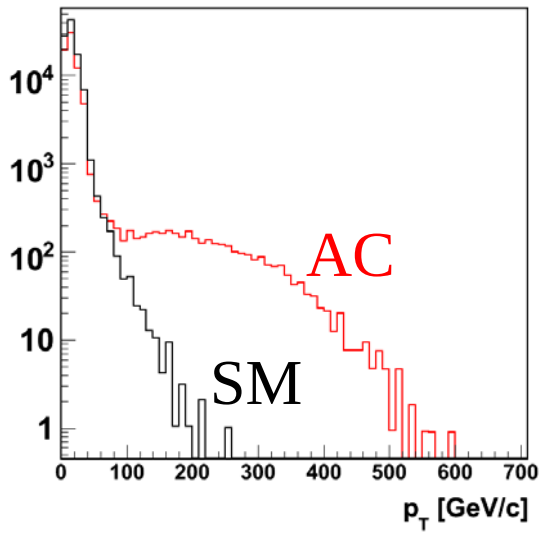
$Z\gamma$ anomalous couplings

- Most general parameterization of couplings is done using Baur formalism (8 complex parameters h_i)

$$h_i^0(\hat{s}) = \frac{h_{i0}^{Z,\gamma}}{(1 + \hat{s}/\Lambda^2)^n}$$

- Non-zero values would manifest through increased cross section and increase of high energy photons





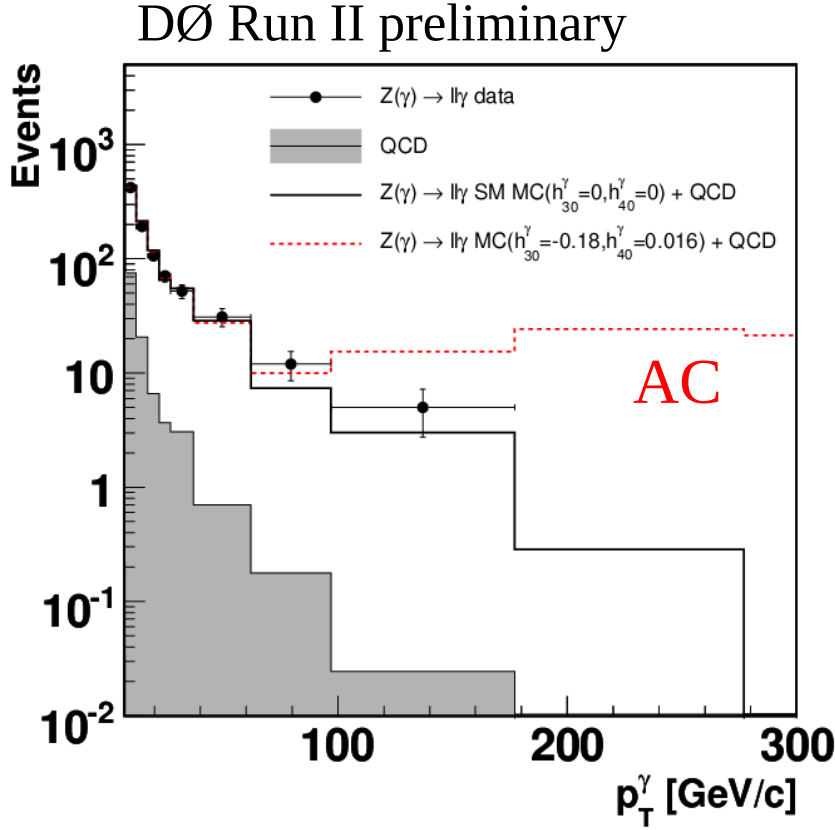
Measurement of $Z\gamma$ cross section

L ~ 1.1 fb^{-1}

- Observed 890 candidate events in 2 decay channels: $ee\gamma$ (453), $\mu\mu\gamma$ (437)
- Estimated background (major contribution is from Z + jets) is 110.4 ± 11.7 events
- Cross-section calculated by combining likelihoods for each channel

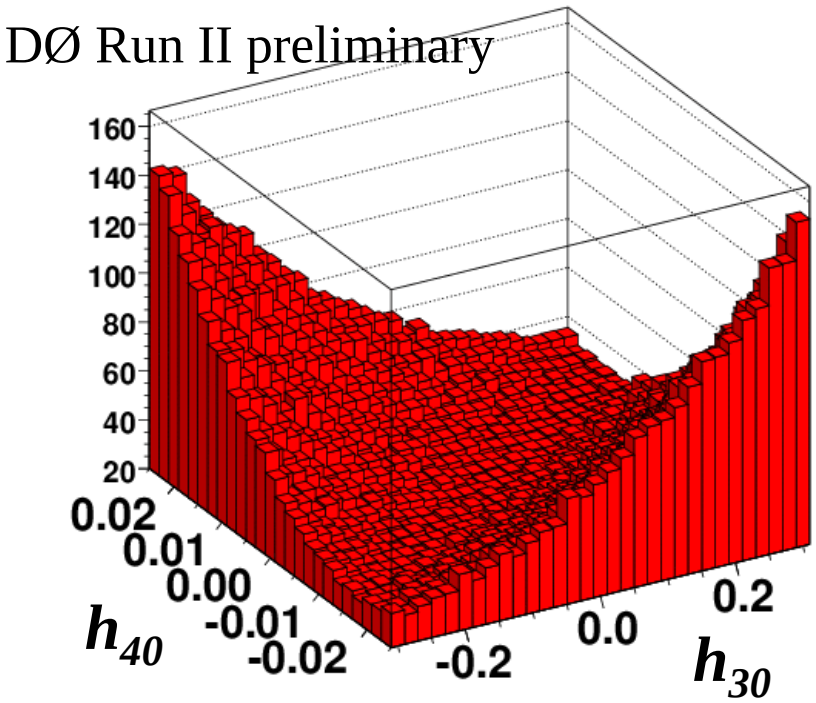
$$\sigma(Z\gamma) = 4.43 \pm 0.27 \pm 0.27 \text{ pb}$$

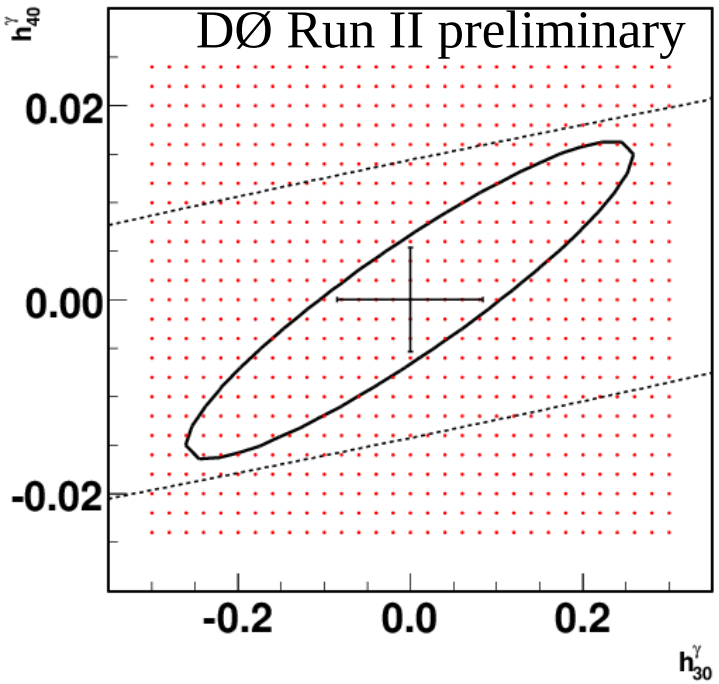
  - SM: 4.74 ± 0.22 pb



Limits on anomalous $Z\gamma$ couplings

- Use photon E_T distribution and compare it with Monte Carlo simulation for a given pair of values of h_i





- Set world's tightest limits on anomalous $ZZ\gamma$ and $Z\gamma\gamma$ couplings (Λ=1.2 TeV)

$$|h_{30}^{V}| < 0.085,\ V = \gamma, Z \qquad |h_{40}^{V}| < 0.0054,\ V = \gamma, Z$$

First evidence for *ZZ* production

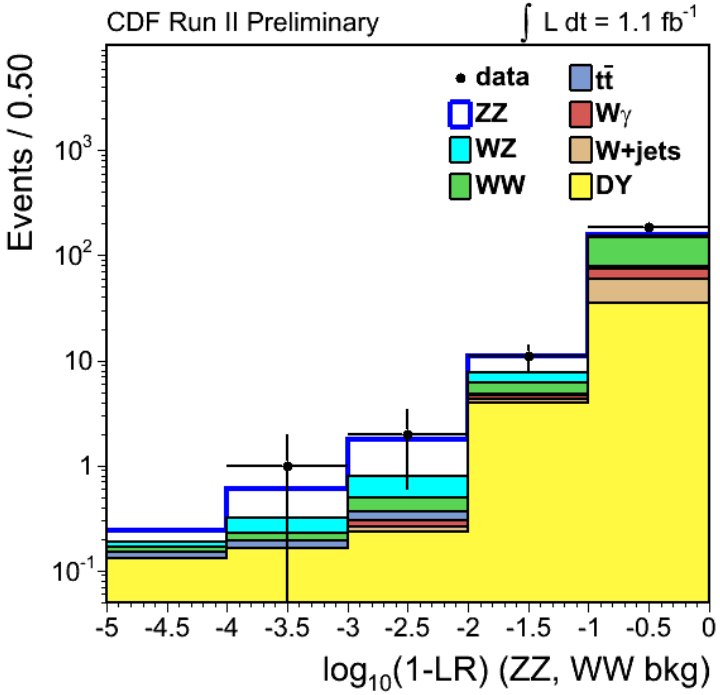
L ~ 1.5 fb^{-1}

- Search using combination of the four charged (***e***, μ) leptons and two charged lepton two neutrino final state
- 4 charged lepton final state:

Z+jets	0.026 ± 0.021 (stat.) ± 0.004 (syst.) ± 0.000 (lumi.)
$Z\gamma\gamma$	0.003 ± 0.001 (stat.) ± 0.000 (syst.) ± 0.000 (lumi.)
ZZ	2.516 ± 0.020 (stat.) ± 0.032 (syst.) ± 0.151 (lumi.)
Total Bkg	0.029 ± 0.021 (stat.) ± 0.004 (syst.) ± 0.000 (lumi.)
Total	2.545 ± 0.029 (stat.) ± 0.032 (syst.) ± 0.151 (lumi.)
Observed	**1**

First evidence for *ZZ* production

L ~ 1.5 fb^{-1}



- 2 charged lepton final state:
  - Observed 182 events, with expected signal of 10.7 events

	$ll\nu\nu$	4 lepton	Combined
prob 2σ	0.50	0.92	0.88
prob 3σ	0.27	0.71	0.77
prob 5σ	0.05	0.24	0.51
Observed Significance	1.9 σ	2.2 σ	3.0 σ
95% CL Limit	3.4 pb	2.6 pb	2.1 pb

- Observed cross-section is $\sigma(ZZ) = 0.75^{+0.71}_{-0.54}$ pb
  - SM predicts 1.4 $\pm$ 0.1 pb

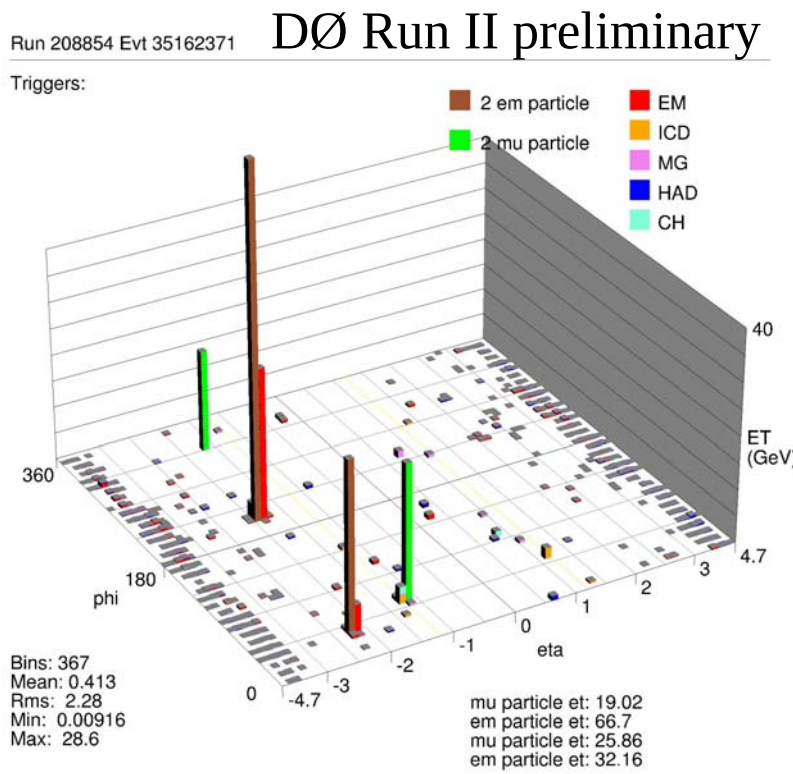
Search for ZZ production

$\mathbf{L} \sim 1.0\ \mathrm{fb}^{-1}$

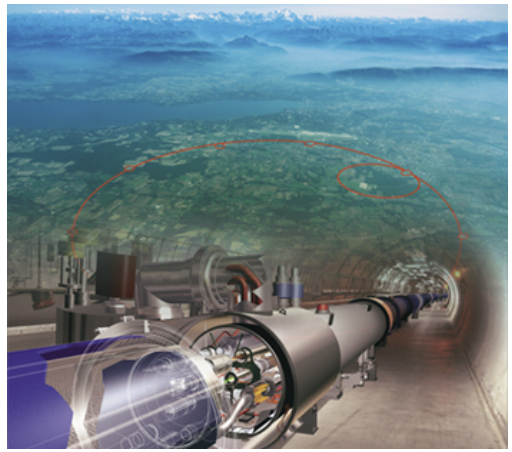
- Observed 1 candidate events in 3 decay channels:
  $eeee$ (0), $ee\mu\mu$ (1), $\mu\mu\mu\mu$ (0)
- Estimated background (major contribution is top and QCD processes) is
  0.17 ± 0.04 events
- Set a limit:

$$\sigma(ZZ) < 4.3\ \mathrm{pb\ at\ 95\%\ C.L.}$$

  – SM: 1.6 ± 0.1 pb



Conclusion

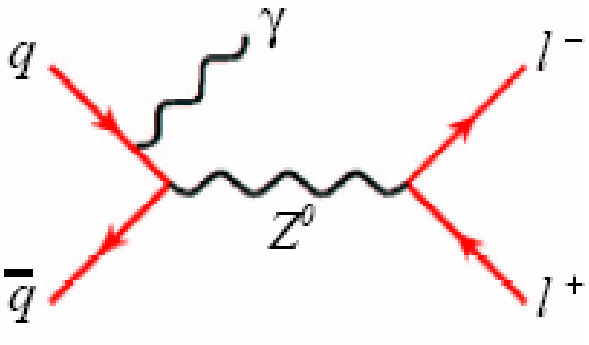


- Run II of Tevatron is at its peak
  - Have more than 25x of Run I data on tape
  - Data keeps coming!
- A very strong electroweak program at the electroweak boson factory
  - Single boson physics
  - ***WZ, Wγ, Zγ, ZZ***
    - Measurements of cross-sections, trilinear gauge boson couplings (quadrilinear are on horizon)
  - Important testing grounds for LHC physics program

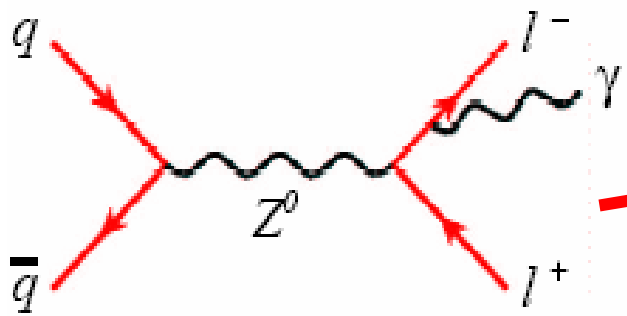
Backup slides

$Z\gamma$ production

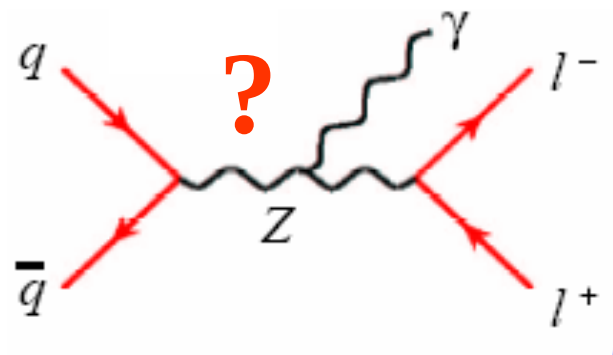
Initial State Radiation

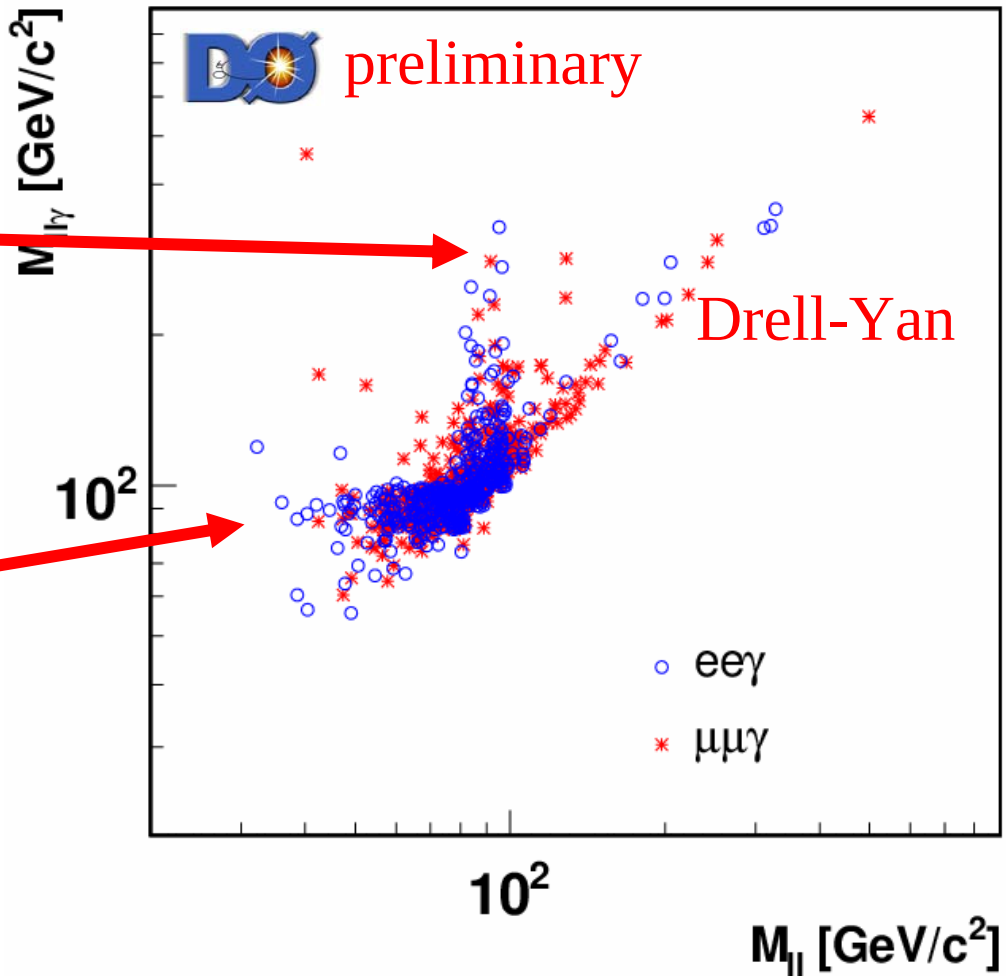


Final State Radiation



ZZγ: Triple Gauge Coupling





The DØ Detector