Diboson Production at DØ

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on the behalf of the DØ Collaboration

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Outline

- ❑ Motivation for studying Diboson Physics
- ❑ Recent DØ results related to Diboson production (cross section measurements, tri-linear coupling limits):
  - γW, γZ
  - ZZ, WZ

- Data (0.8 - 1.0) fb^{-1} from Tevatron Collider
- Up to now, analyzed final states are leptonic (ZZ, WZ) or leptonic with associated photon (γW, γZ)

Studying Diboson production at DØ

- ❑ Test the Standard Model (SM) expectations
- ❑ Search for *New Physics* (EWSB mechanism)
  1. Cross section measurements
  2. Trilinear gauge boson coupling (TGC) measurements

state	TGC vertex
$q\bar{q}' \to \gamma W$	$WW\gamma$
$q\bar{q}' \to WZ$	WWZ
$q\bar{q}' \to \gamma Z$	$\gamma\gamma Z, ZZ\gamma$
$q\bar{q}' \to ZZ$	$ZZZ, ZZ\gamma$
$q\bar{q}' \to WW$	$WWZ, WW\gamma$

Vertices absent in SM

❑ Disagreement with the SM expectation (event yield or TGC value) would indicate the presence of *New Physics*

Charged and Neutral TGCs

- Deviation from the SM can be described via effective Lagrangian
  - *Charged* TGCs (WZ, WW, Wγ production)
  - *Neutral* TGCs (Zγ, ZZ production)

J. Ellison, J. Wudka
hep-ph/9804322v2

Wγ, WW, WZ:
(WWZ and WWγ SM vertices)

SM: $g_1^{\gamma} = \kappa_{\gamma,Z} = 1; \quad \lambda_{\gamma,Z} = 0;$

SM Deviations:

$$\Delta g_1^Z = g_1^Z - 1$$
$$\Delta\kappa_{\gamma,Z} = \kappa_{\gamma,Z} - 1$$
$$\Delta\lambda_{\gamma,Z} = \lambda_{\gamma,Z} - 0$$

Zγ: (Zγγ and ZZγ non-SM vertices)

SM: $h_3^{\gamma,Z} = h_4^{\gamma,Z} = 0;$

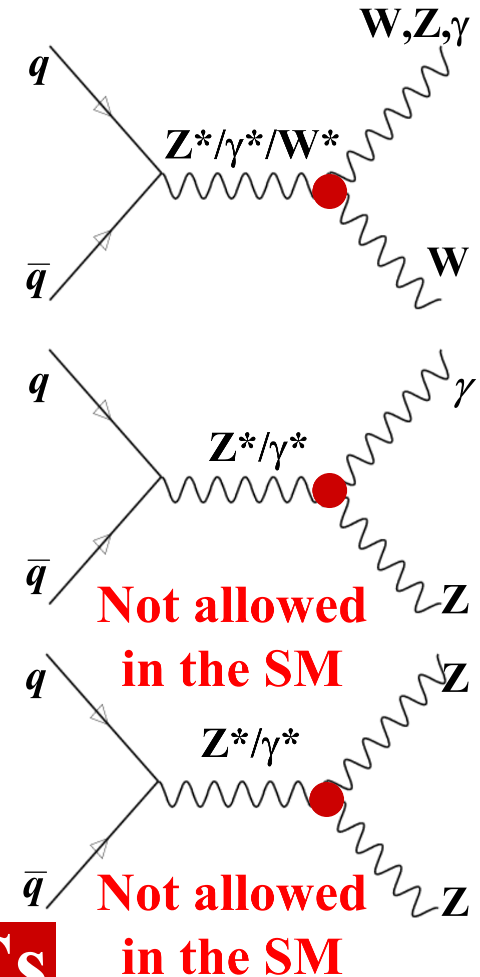
ZZ: (ZZZ and ZγZ non-SM vertices)

SM: $f_4^{\gamma,Z} = f_5^{\gamma,Z} = 0;$

SM Deviations:

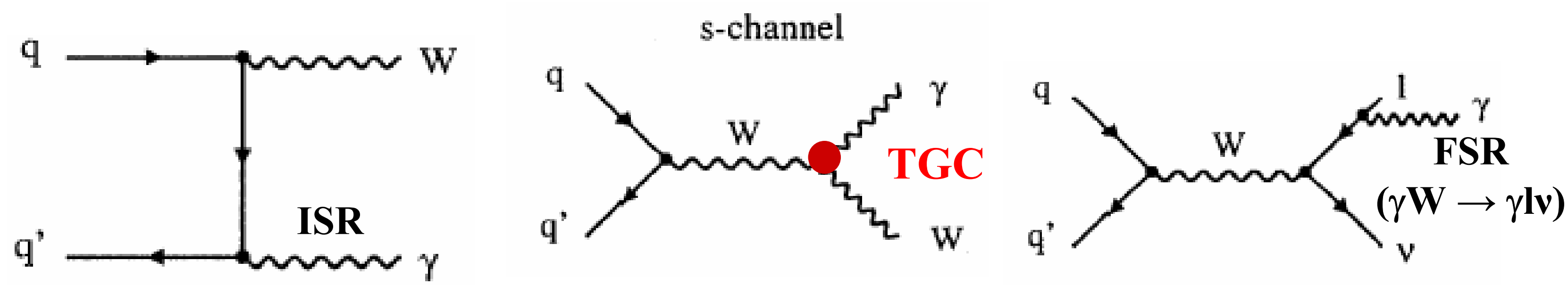
$$\Delta h_{3,4}^{\gamma,Z} = h_{3,4}^{\gamma,Z} - 0$$
$$\Delta f_{4,5}^{\gamma,Z} = f_{4,5}^{\gamma,Z} - 0$$

$$\alpha_i^{\gamma,Z} = \frac{\alpha_{i0}^{\gamma,Z}}{\left(1 + \hat{s}/\Lambda_{FF}^2\right)^n}$$



$\Delta \neq 0 \Rightarrow$ Anomalous TGCs

Wγ Production



- Only *s*-channel contains TGC (WWγ vertex)
- WWγ (g_1^γ, κ_γ, λ_γ) couplings independent of WWZ
- Anomalous TGC cause a deviation from the SM cross section:

  → **Reflected in the photon energy spectrum**

- Interference among tree-level diagrams creates a zero in distribution of θ_{CM} between W boson and incoming quark; (location of zero depends on quark (i.e. W) charge)

$$\rightarrow \gamma W^{\pm} \text{ amplitude goes to zero for } \cos\theta_{CM} = \mp\frac{1}{3}$$

Radiation Amplitude Zero (RAZ)

Baur et al.
hep-ph/9402282

Wγ Production

Analyzed final states: $e\gamma$, $\mu\gamma$ ($\approx 0.9\ fb^{-1}$)

Photon requirements:

$|\eta_\gamma| < 1.1$ or $1.5 < |\eta_\gamma| < 2.5$; $E_T^\gamma > 7$ GeV;

To suppress $W \rightarrow l\nu\gamma$:

$dR_{l\gamma} > 0.7$; $M_T^{l\gamma MET} > 110$ GeV;

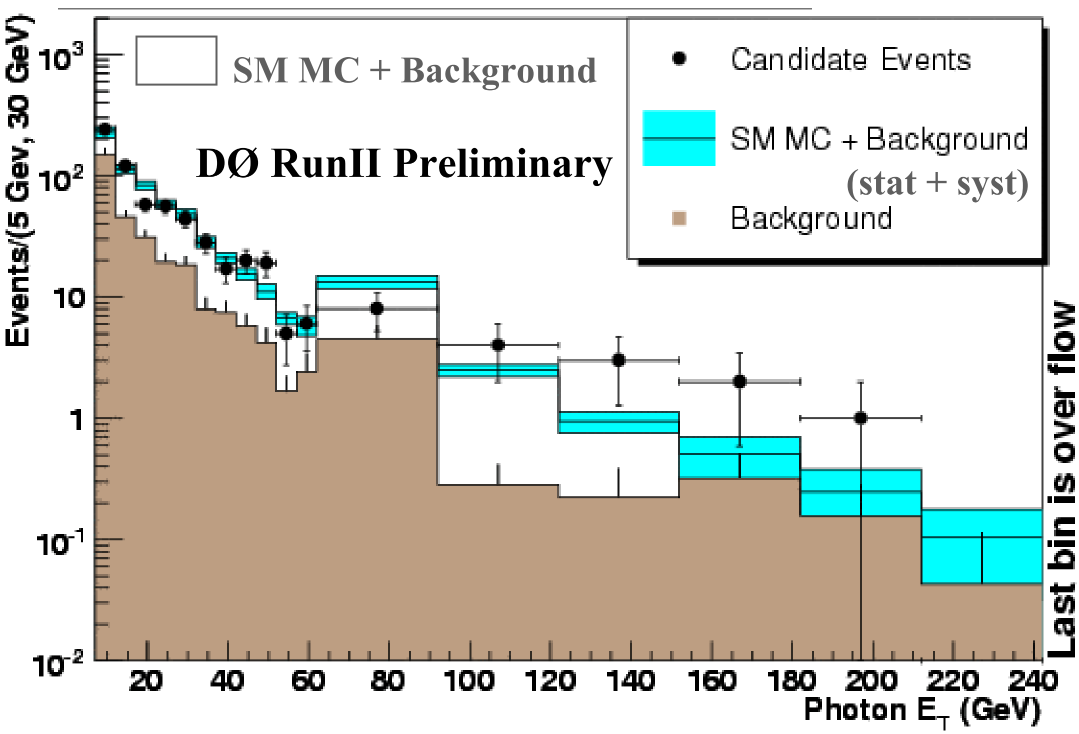
Muon requirements:

$|\eta_\mu| < 2$; $E_T > 20$ GeV; $\not{E}_T > 20$ GeV;

Electron requirements:

$|\eta_e| < 1.1$ or $1.5 < |\eta_e| < 2.5$; $E_T > 25$ GeV;

$\not{E}_T > 25$ GeV; $M_T^W > 50$ GeV;



Dominant background: W + jets

- 634 candidate events
- After background subtraction:

  (335 ± 44) signal events observed

Measured cross sections:

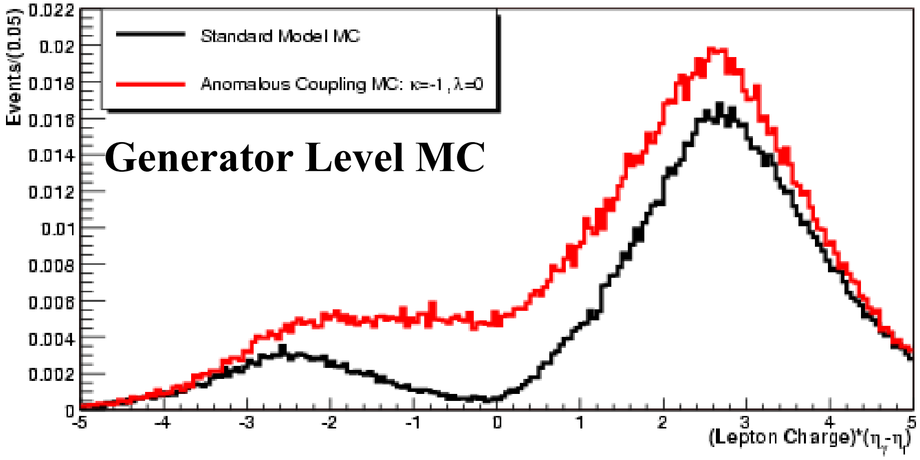
$\sigma_{W\gamma\rightarrow\mu\nu\gamma} = 3.2 \pm 0.5 \pm 0.2$ pb

$\sigma_{W\gamma\rightarrow e\nu\gamma} = 3.1 \pm 0.5 \pm 0.2$ pb

SM NLO: $\sigma_{l\nu\gamma} = 3.21 \pm 0.08$ pb

($E_T^\gamma > 7$ GeV; $dR_{l\gamma} > 0.7$; $M_T^{l\gamma MET} > 90$ GeV)

Radiation Amplitude Zero in Wγ

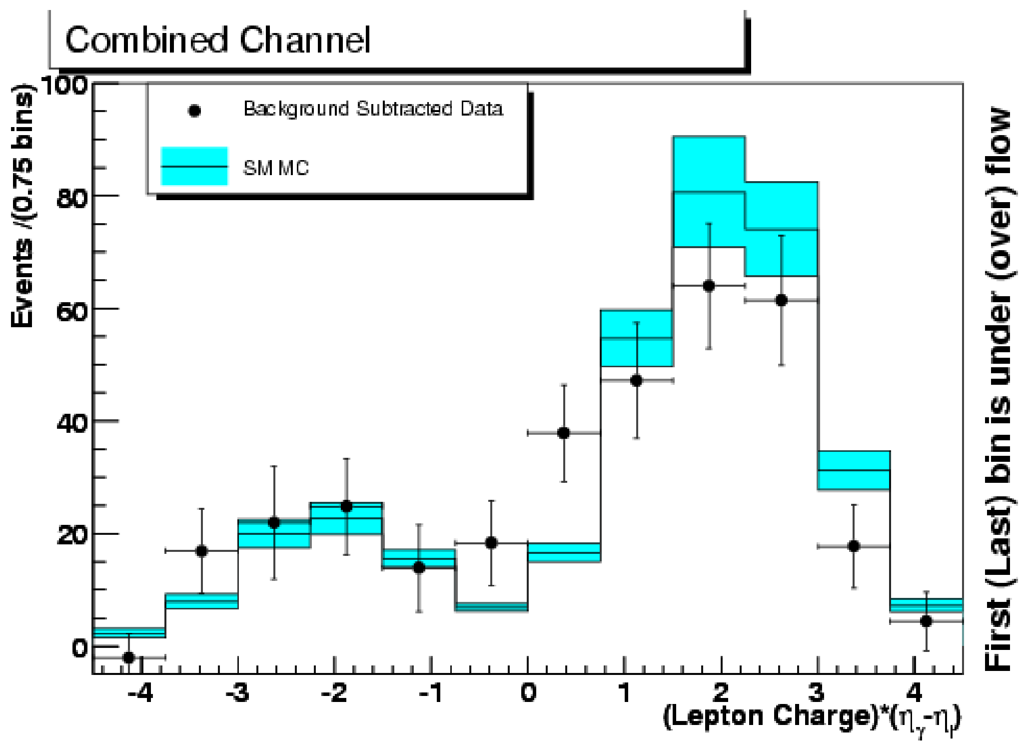


- RAZ evident as a dip around -0.3 (rapidity difference signed by the lepton charge)

$$sign(l)\times[y(\gamma)-y(l)]\approx -0.3$$

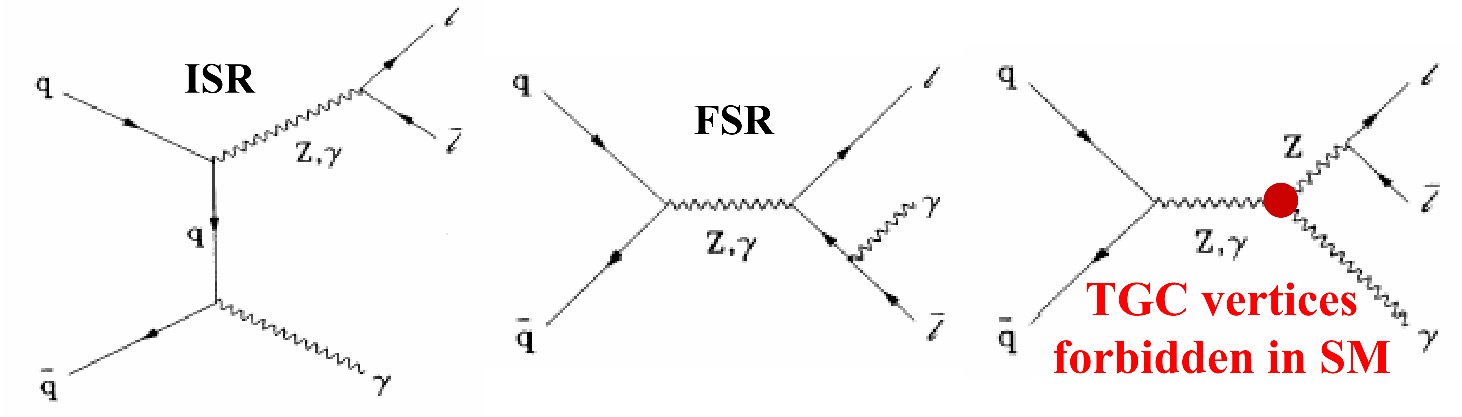
- NLO corrections, FSR and backgrounds obscure the dip

- Wide η coverage essential as well as good signal to background separation and rapidity resolution



Charge-signed rapidity distribution is consistent with the SM

Zγ Production



- Tree-level SM: no γγZ, ZZγ vertices (one-loop SM: $h_{3,4}^{\gamma,Z} \approx 10^{-4}$)
- New Physics predicts the anomalous TGCs:
  → Reflected in the photon energy spectrum
- Analyzed final states: *ee*γ, *μμγ* ($\approx 1\ \text{fb}^{-1}$)

Photon requirements:

$|\eta_\gamma| < 1.1$; $E_T^\gamma > 7$ GeV; $dR_{l\gamma} > 0.7$;

Muon requirements:

$|\eta_\mu| < 2$; $p_T^{(1)} > 20$ GeV; $p_T^{(2)} > 15$ GeV;

Common cuts: $M_{ll} > 30$ GeV;

Electron requirements:

$|\eta_e| < 1.1$ (at least one) and $1.5 < |\eta_e| < 2.5$;

$p_T^{(1)} > 25$ GeV; $p_T^{(2)} > 15$ GeV;

Dominant background: *Z* + jets (misidentification of photon)

Zγ Production at DØ

	$ee\gamma$	$\mu\mu\gamma$
MC Signal	393.4 ± 37.6	410.5 ± 35.9
Background	55.2 ± 8.3	61.3 ± 9.0
Data	453	515

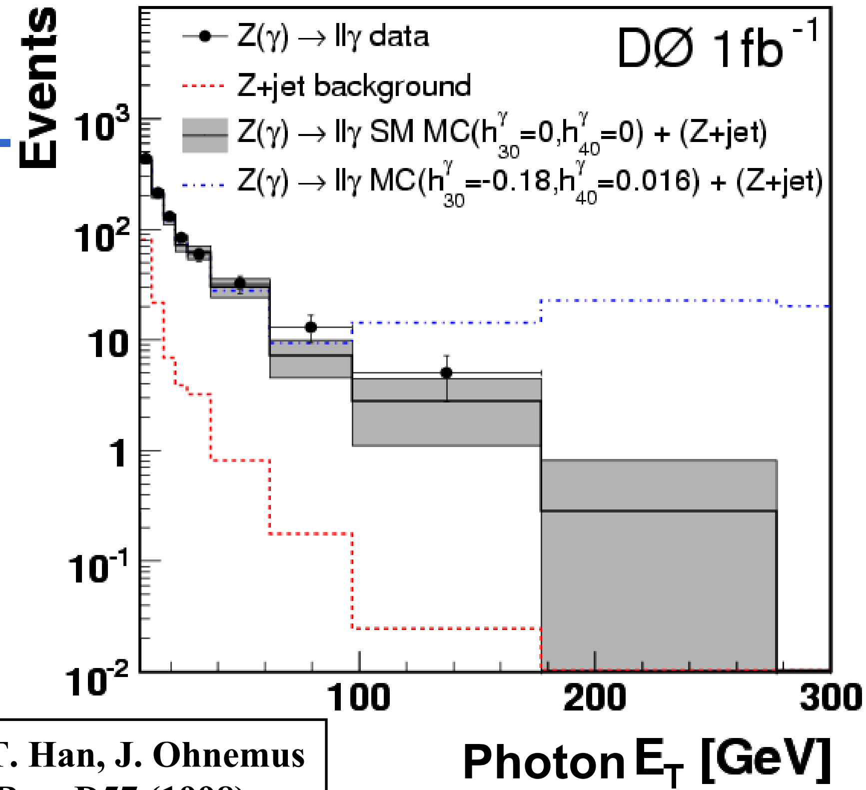
Measured cross section:

$\sigma_{\gamma Z} = 4.96 \pm 0.30_{(stat+syst)} \pm 0.30_{(lumi)}$ pb

SM NLO: $\sigma_{Z\gamma} = 4.74 \pm 0.22$ pb

($E_T^{\gamma} > 7$ GeV; $dR_{\gamma l} > 0.7$; $M_{ll} > 30$ GeV)

U. Baur, T. Han, J. Ohnemus
Phys. Rev. D57 (1998)



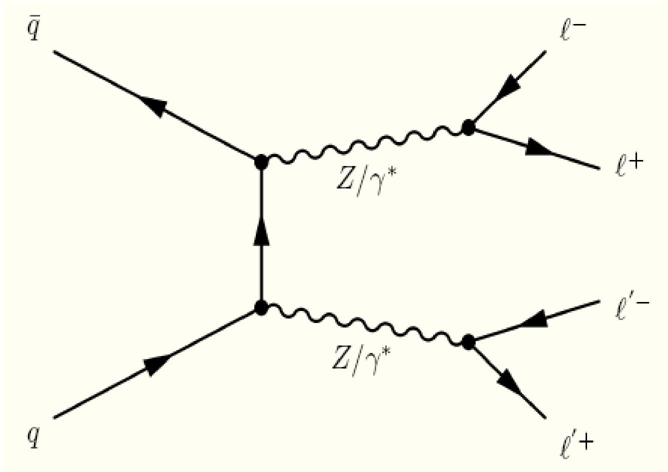
Photon candidate E_T spectrum: comparison with the expected distributions (MC) in the presence of anomalous ZZγ/γγZ couplings

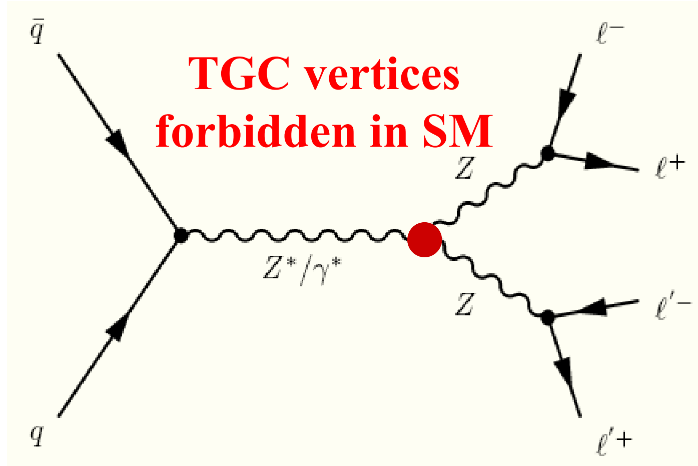
95% C.L. $h_{30,40}^{\gamma,Z}$ limits ($h_{10,20}^{\gamma,Z} = 0$):

h^{γ} ($h^Z = 0$)	h^Z ($h^{\gamma} = 0$)
$-0.085 < h_{30} < 0.084$	$-0.083 < h_{30} < 0.082$
$-0.0053 < h_{40} < 0.0054$	$-0.0053 < h_{40} < 0.0054$

Tightest $h_{40}^{\gamma,Z}$ limits to date!

ZZ Production





- **Only *s* - channel contains Z/γZZ vertex**
- **SM NLO: $\sigma_{ZZ} = 1.6 \pm 0.1$ pb**
- **Up to recently not observed at a hadron collider**
- **Tree-level SM: no ZZZ or γZZ vertices (one-loop SM: $f_{4,5}^{\gamma,Z} \approx 10^{-4}$)**
- **Analyzed final states: *eeee* , *μμμμ* , *μμee*, (≈ 1 fb^{-1})**
- **Analysis depends on optimizing the single lepton cuts**

J.M. Campbell, R.K. Ellis, Phys. Rev. D60 (1999)

Muon requirements:

$|\eta_\mu| < 2$; $p_T > 15$ GeV; $\cos\alpha < 0.96$; $|\Delta z_{vtx}| < 3$ cm;

Electron requirements:

$|\eta_e| < 1.1$ or $1.5 < |\eta_e| < 3.2$; $E_T > 15$ GeV;

Common cuts: $dR_{e\mu} > 0.2$; $M_{ll} > 30$ GeV;

ZZ Production

Dominant backgrounds:

$t\bar{t}(\mu\mu\mu\mu/\mu\mu ee)$; QCD (eeee)

Channel	Background	Signal	N
$\mu\mu\mu\mu$	0.057 ± 0.017	0.46 ± 0.05	0
eeee	0.080 ± 0.017	0.44 ± 0.03	0
$\mu\mu ee$	0.034 ± 0.014	0.81 ± 0.09	1
Total	**0.17 ± 0.04**	**1.71 ± 0.11**	**1**

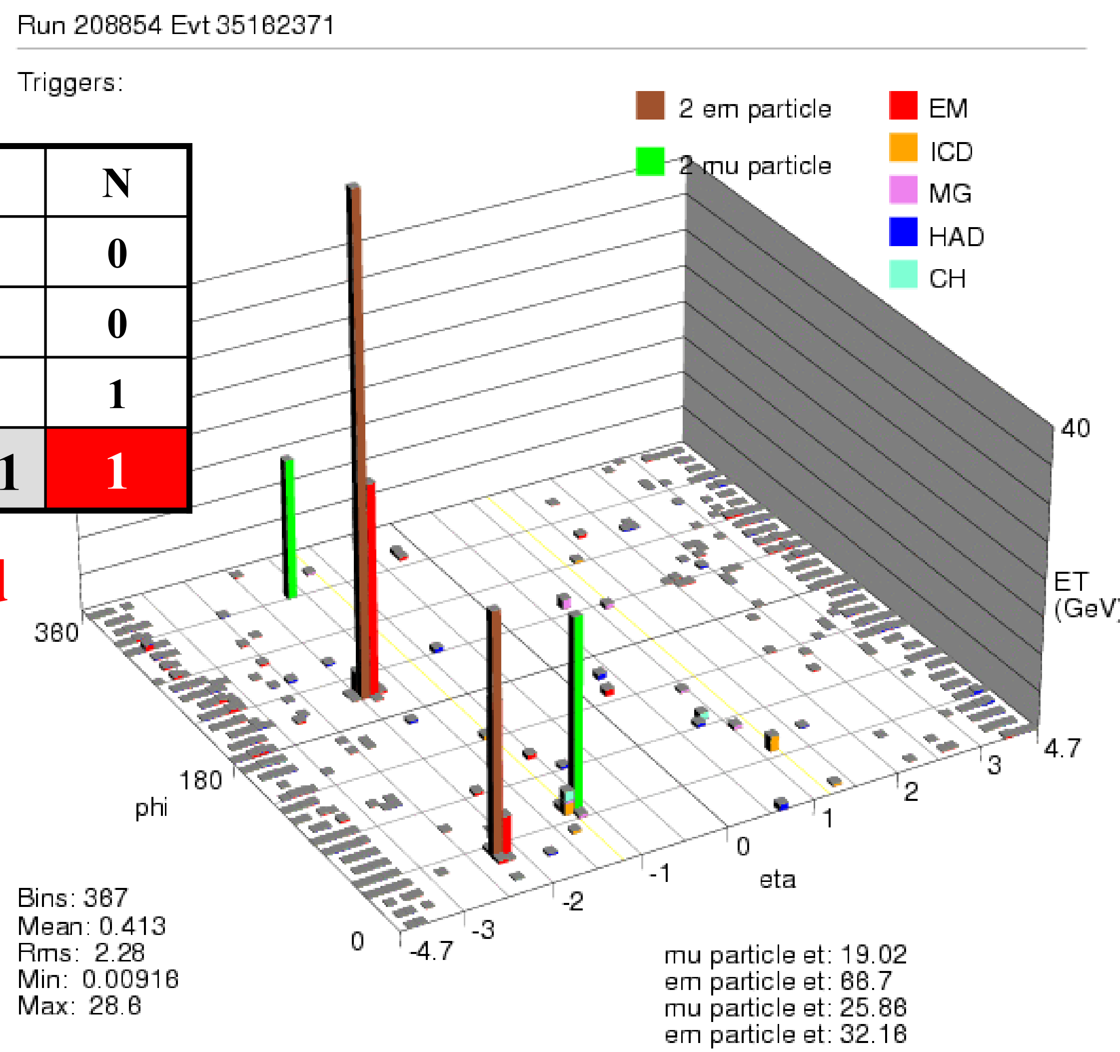
1 candidate event is found in the $\mu\mu ee$ channel

Background: $P_{fluctuation} \approx 16\%$

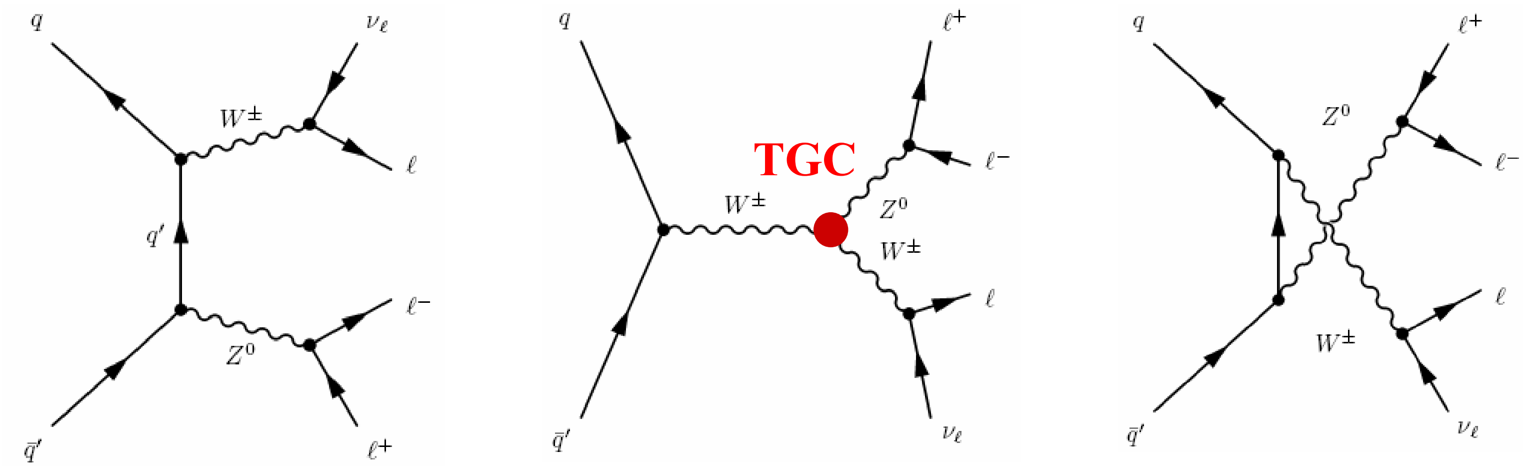
Cross section limit:

$\sigma_{ZZ} < 4.3$ pb at 95% C.L.

(for $M_{Z/\gamma^*} > 30$ GeV)



WZ Production



- **Only *s* - channel contains TGC (WWZ vertex)**
- **WWZ couplings (g_1^Z, κ_Z, λ_Z) independent of WWγ**
- **Analyzed final states: *eeμ*, *μμe*, *eee*, *μμμ* (≈ 1 fb^{-1})**
- **Analysis dependent on single lepton cuts**

Muon:
$|\eta_\mu| < 2$; $\not{E}_T > 20$ GeV; $E_T > 15$ GeV;

Electron requirements:
$|\eta_e| < 1.1$ or $1.5 < |\eta_e| < 2.5$; $\not{E}_T > 20$ GeV; $E_T > 15$ GeV;

Common cuts: **$dR_{ll} > 0.2$; M_{ll} = (51-131)/(71-111) GeV; $\Sigma_{vector}(E_T + \not{E}_T) < 50$ GeV;**

Dominant backgrounds: Z(→ *ee*) + jets (*eee*); ZZ (*eeμ*);
Z(→ *μμ*) + jets (*μμe*); ZZ (*μμμ*);

WZ Production

Channel	Background	Signal	N
eee	0.960 ± 0.069	1.83 ± 0.35	2
$ee\mu$	0.485 ± 0.053	1.84 ± 0.52	1
$\mu\mu e$	0.963 ± 0.080	1.80 ± 0.63	7
$\mu\mu\mu$	1.203 ± 0.143	2.07 ± 0.56	2
Total	**3.61 ± 0.20**	**7.54 ± 1.21**	**12**

- **12 candidate events**
- **3.6 ± 0.2 background estimated**

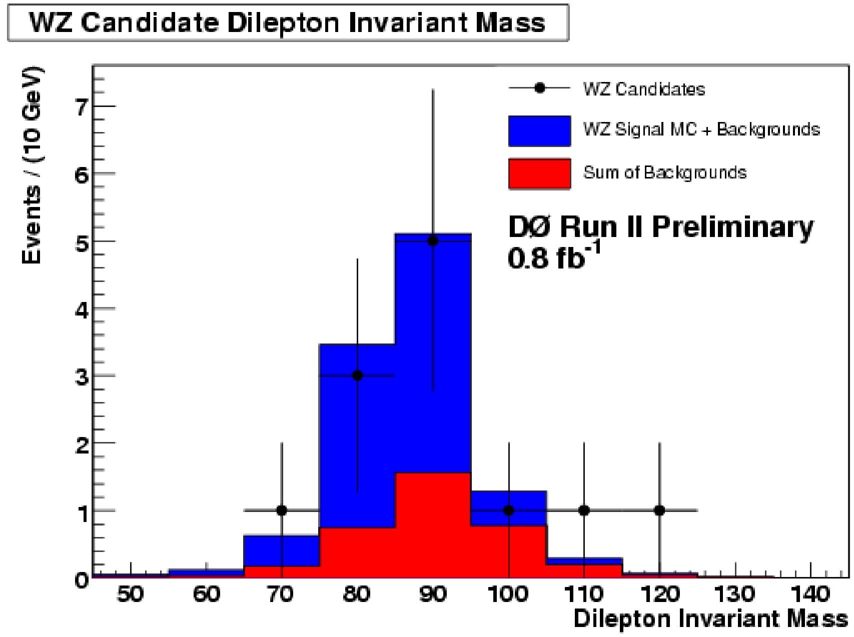
($P_{fluctuation} = 4.2 \cdot 10^{-4}$)

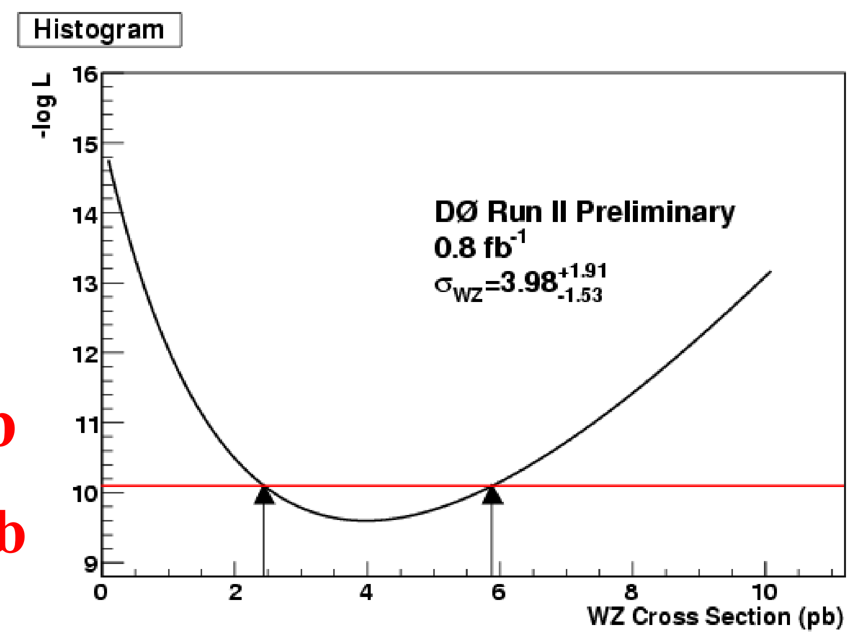
→ 3.3 σ significance

Cross section is calculated by combining likelihoods ($f(\sigma)$) for each channel →

$$\sigma_{WZ} = 3.98^{+1.91}_{-1.53}\,\text{pb}$$

SM NLO: $\sigma_{WZ} = 3.68 \pm 0.34$ **pb**





EPS 2007, J. Sekaric

Summary

- Diboson production cross sections consistent with the NLO SM
- Best limits on h_{40}^{V} in Zγ to date
- Charge signed rapidity difference in Wγ is in agreement with the SM
- Evidence of WZ production at DØ
- New results (Wγ, WZ, ZZ, WW) with more data are on the way!
  ($L \approx 2.64$ fb^{-1} on June 24th, 07)