Diboson Cross Sections at $\sqrt{s} = 1.96\,\mathrm{TeV}$

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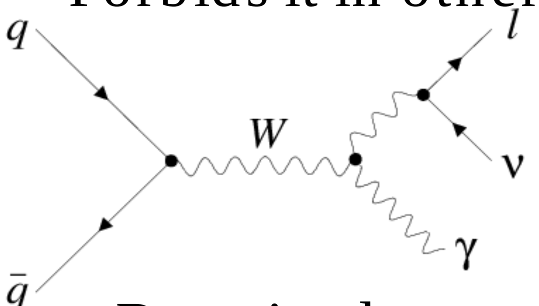
(Florida State University and the
DØ Experiment)
on behalf of the CDF and DØ Collaborations

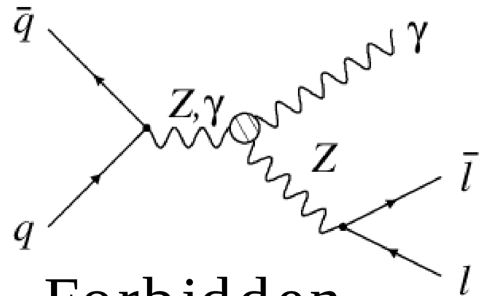
Recontres de Moriond QCD, La Thuile

Diboson Cross Sections

- Cross sections tell us about boson self-coupling.
  - Standard Model is very specific:
    - Requires self coupling in some processes.
    - Forbids it in others.



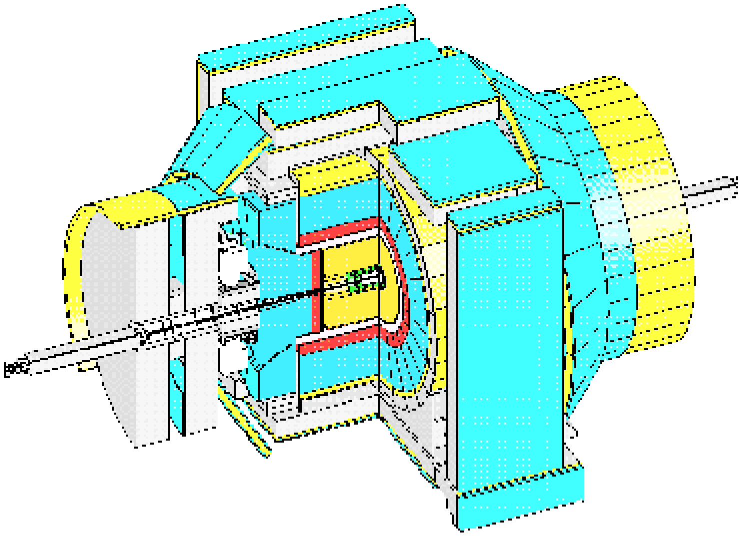
Required.



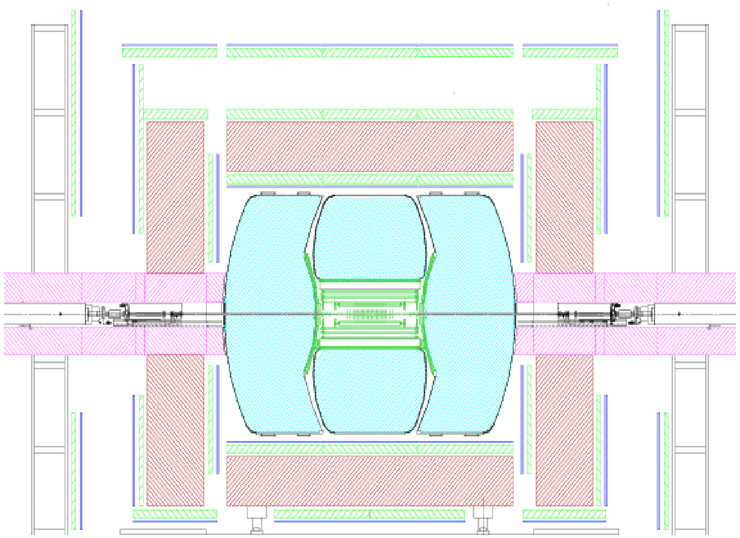
Forbidden.

- Each measurement is thus not only a test of the Standard model, it is also a search for new physics.
  - Wγ
  - Zγ
  - WW
  - ZZ/ ZW

The Experiments:



CDF



DØ

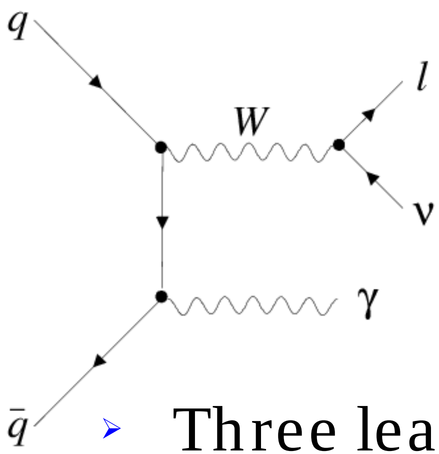
The experiments themselves have been covered earlier this week. I will not do so here (time).

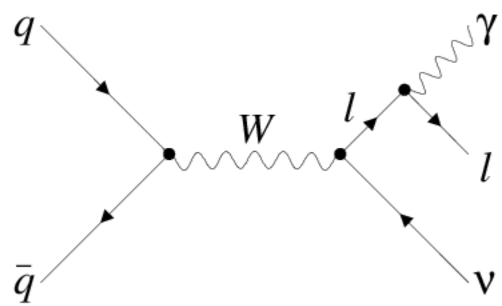
$$p\bar{p},\ \sqrt{s}=1.96\,\mathrm{TeV}$$

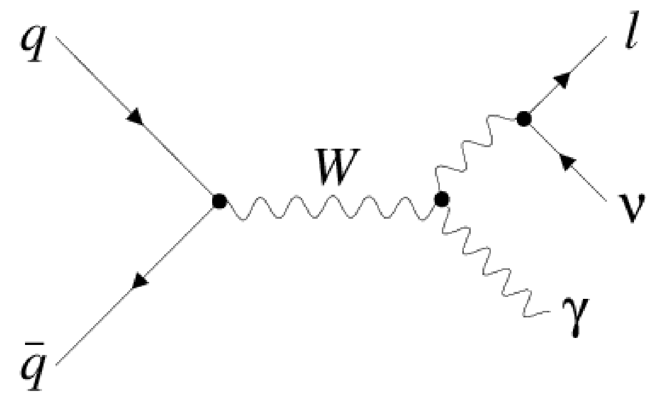
W, Z, and γ Identification

- Analyses presented here are only leptonic decays: e,μ.
  - Clean signals at a hadron collider.
  - Require high p_T, isolated e or μ.
  - Efficiencies measured through inclusive Z->ee (μμ) events in data.
- For photon identification, rely on Monte Carlo:
  - No clean source of isolated photons in data.

Wγ







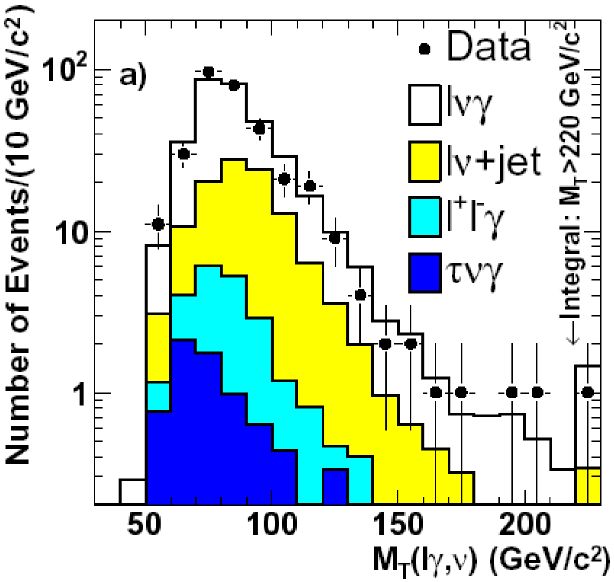
- Three leading order diagrams:
  - Initial State Radiation
  - Final State Radiation
  - Trilinear Vector Boson Vertex
- Cross sections contain all of these:
  - Always measured with respect to a threshold on photon E_T, and lepton photon separation.
- Dominant background is W+j where the jet is misidentified as a photon.

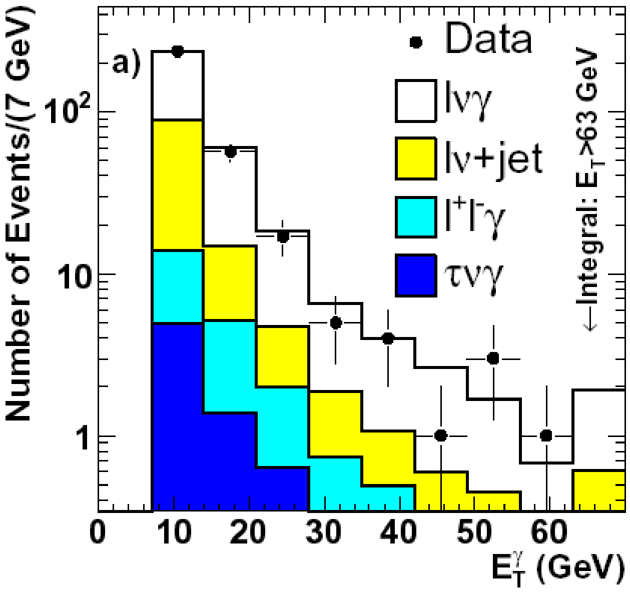
CDF Wγ Cross Section

Channel:	eνγ	μνγ
η^{l}	2.6	1.0
$p_T^{\,l}$	25	20
$\not{E}_T$	25	20
η_γ	1.0	
$p_T^{\,\gamma}$	7	
M_T	$30<M_T<120$	
Lum (pb^{-1})	202	192
Bkg:	67.3±18.1	47.3±7.6
SM exp:	126.8±5.8	95.2±4.9
Observed:	195	128

$\sigma(p\bar{p} \to l\nu\gamma;\ E_T^{\gamma}>7\ \text{GeV},\ dR_{l\gamma}>0.7) = 18.3 \pm 3.1$ pb

PRL 94, 041803 (2005) SM: 19.3 ± 1.4 pb



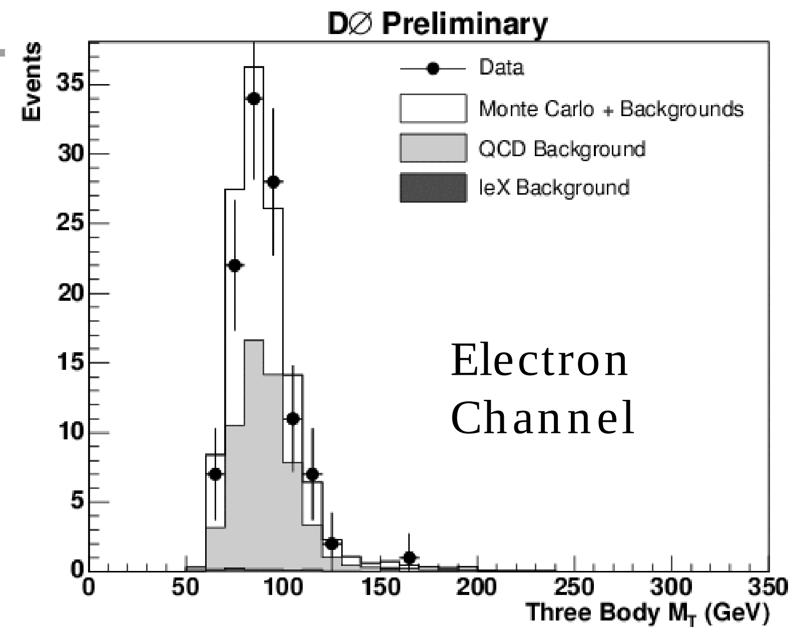


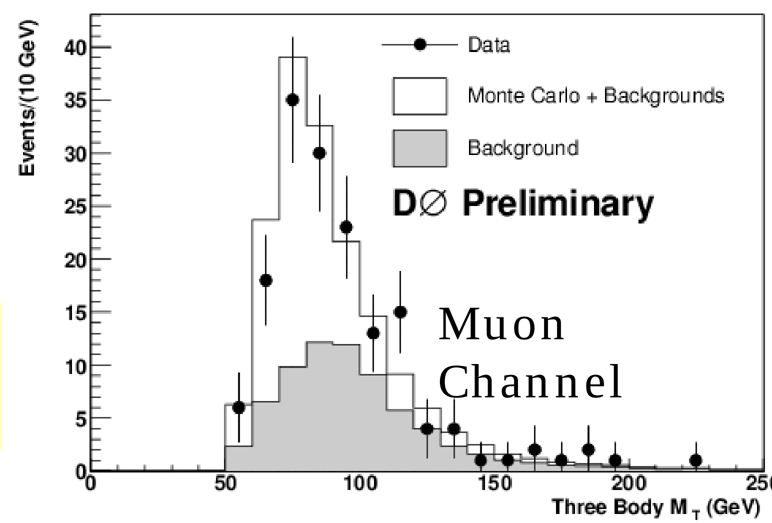
DØ Wγ Cross Section

Channel:	$e\nu\gamma$	$\mu\nu\gamma$
η^l	1.1	2.0
$p_T^{\ l}$	25	20
$\not{E}_T$	25	20
η^γ	1.1	
$p_T^{\ \gamma}$	8	
M_T	$40<M_T$	0
Lum (pb^{-1})	162	134
Bkg:	60.8±4.5	71.3±5.2
SM exp:	59.5±5.4	94.0±7.4
Observed:	112	161

$\sigma(p\bar{p}\to l\nu\gamma;\ E_T^{\gamma}>8\ \mathrm{GeV},\ \ dR_{l\gamma}>0.7) = 14.8 \pm 2.1\ \mathrm{pb}$

DØ Preliminary SM: 16.0 ± 0.4 pb

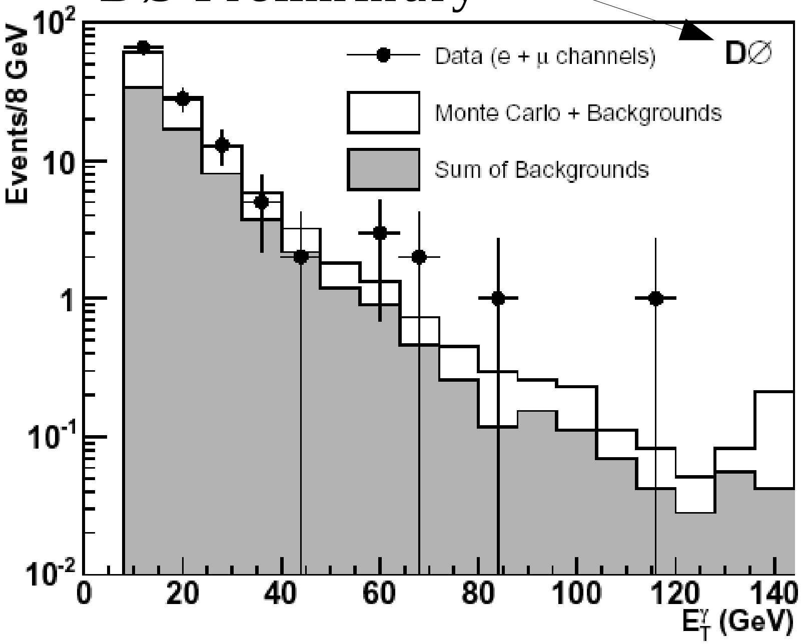




Wγ Anomalous Couplings

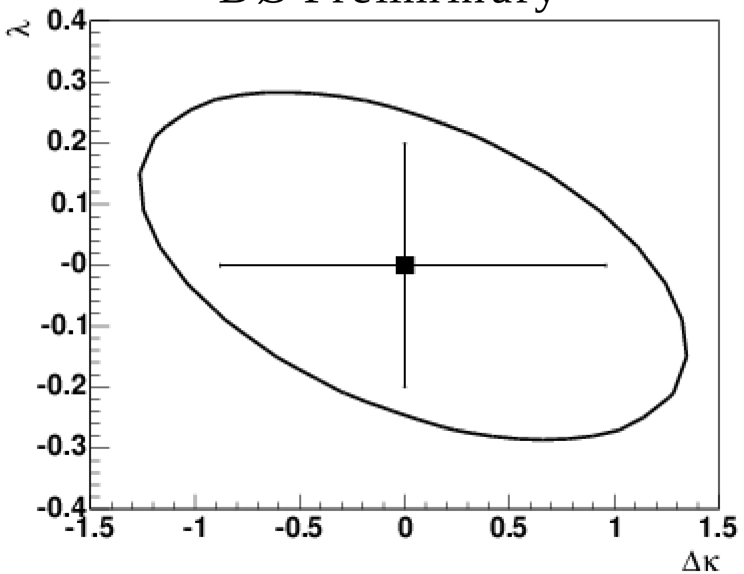
E_T^γ Combined Channels:

DØ Preliminary



- Photon E_T agrees w/ S.M. (last is overflow bin).
- Form a binned-likelihood based on E_T^γ in a λ_γ vs. $\Delta\kappa_\gamma$ grid (including bkgd) on events w/ M_{T3}>90 GeV/c^2.

DØ Preliminary



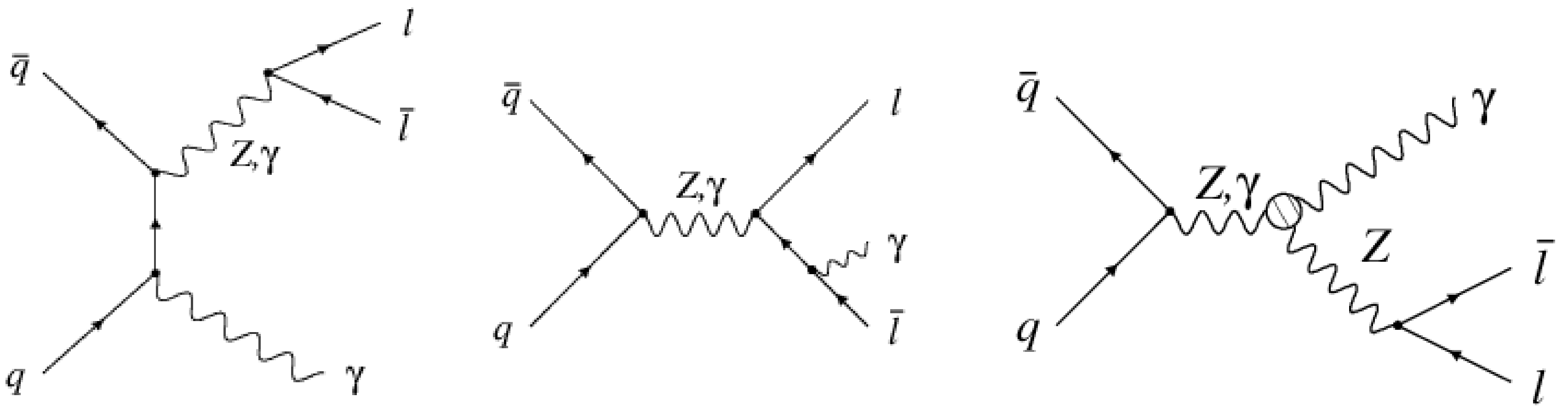
$-0.88<\Delta\kappa_\gamma < 0.96$

$-0.20<\lambda_\gamma<0.20$

DØ Preliminary

1D limits @95% C.L.
Λ=2TeV

Zγ



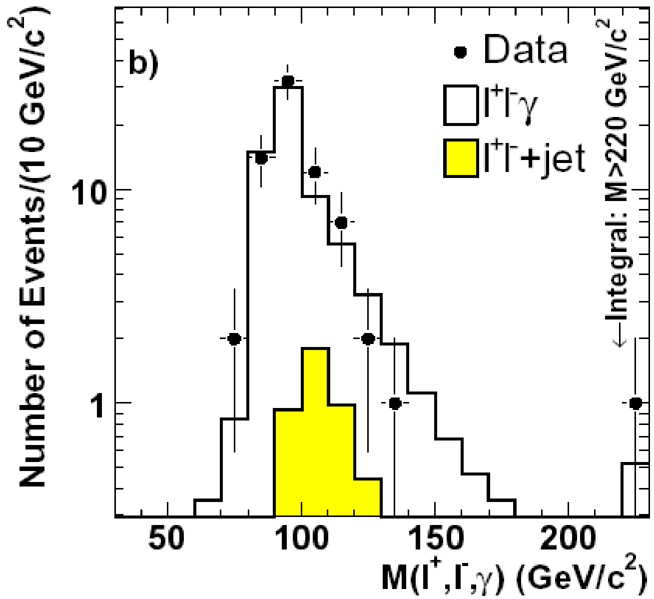
- First two are allowed, final state and initial state radiation.
- In the Standard Model, the last is forbidden.
- For the llγ final state there are contributions from both on-shell Z production, and Drell-Yan.
- Only significant background is Z+j.

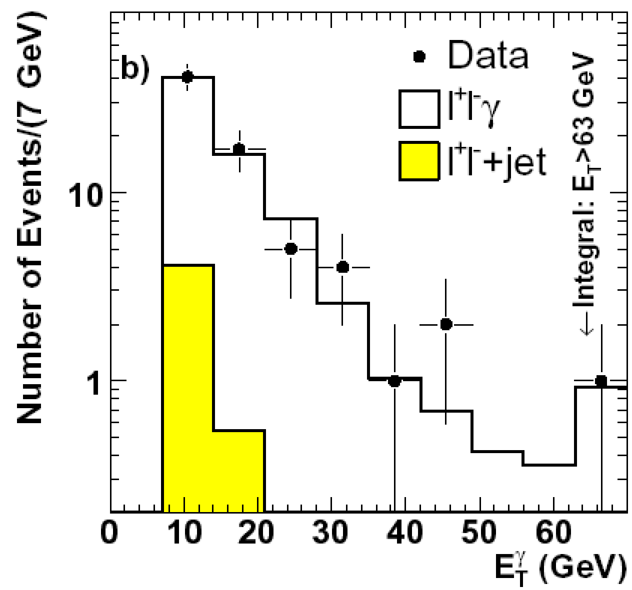
CDF Zγ Cross Section

Channel:	eeγ	μμγ
η^l	2.6	1.0
$p_T^{\ l}$	25	20
η^γ	1.0	
$p_T^{\ \gamma}$	7	
M_{ll}	$40<M_{ll}<130$	
Lum(pb^{-1})	202	192
Bkg:	2.8±0.9	2.1±0.6
SM exp:	31.3±1.6	33.6±1.5
Observed:	36	35

$\sigma(p\bar{p}\text{->}ll\gamma;\ E_T^\gamma>7$ GeV, $dR_{l\gamma}>0.7) = 4.6 \pm 0.6$ pb

PRL 94, 041803 (2005) SM: 4.5 ± 0.3 pb



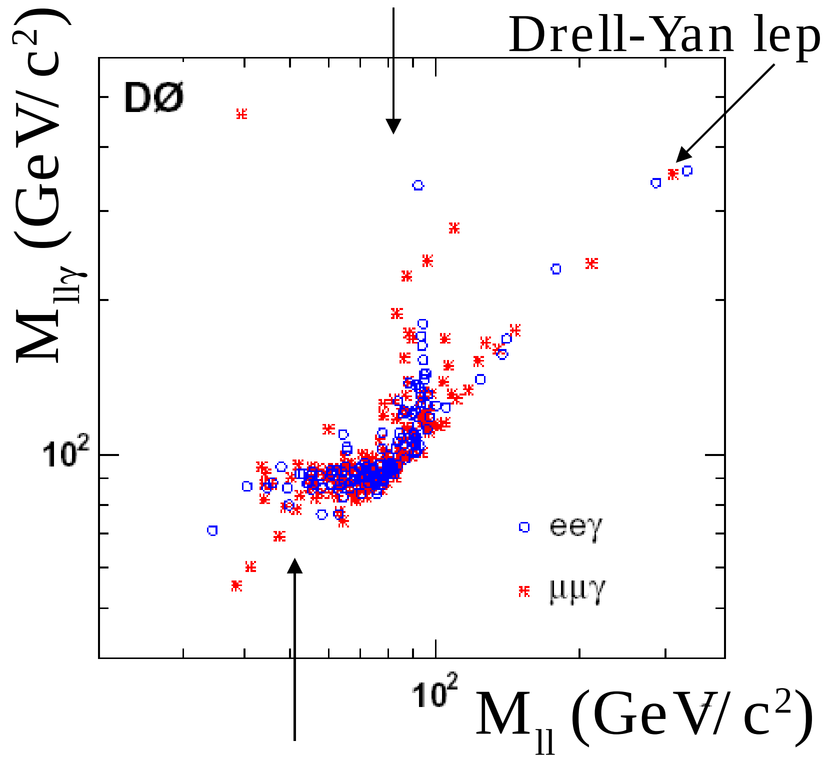


DØ Zγ Cross Section

Channel:	eeγ	μμγ
η^l	1.1 (2.5)	2.0
p_T^l	25	15
η^γ	1.1	
p_T^γ	8	
M_{ll}	$30<M_{ll}$	
Lum (pb^{-1})	320	290
Bkg:	23.6±2.3	22.4±3.0
SM exp:	95.3±4.9	126.0±7.8
Observed:	138	152

Initial State Radiation

Drell-Yan leptons



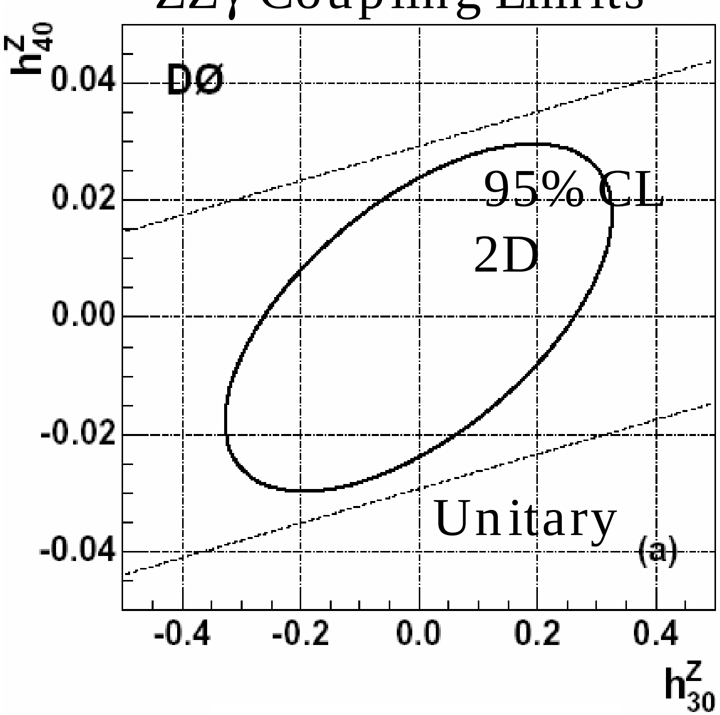
Final State Radiation

$\sigma(p\bar{p}\to ll\gamma;\ E_T^\gamma>8$ GeV, $dR_{l\gamma}>0.7) = 4.2 \pm 0.5$ pb

hep-ex/0502036 SM: 3.9 ± 0.2 pb

Zγ Anomalous Couplings

ZZγ Coupling Limits



$|h^Z_{10,30}|<0.23$

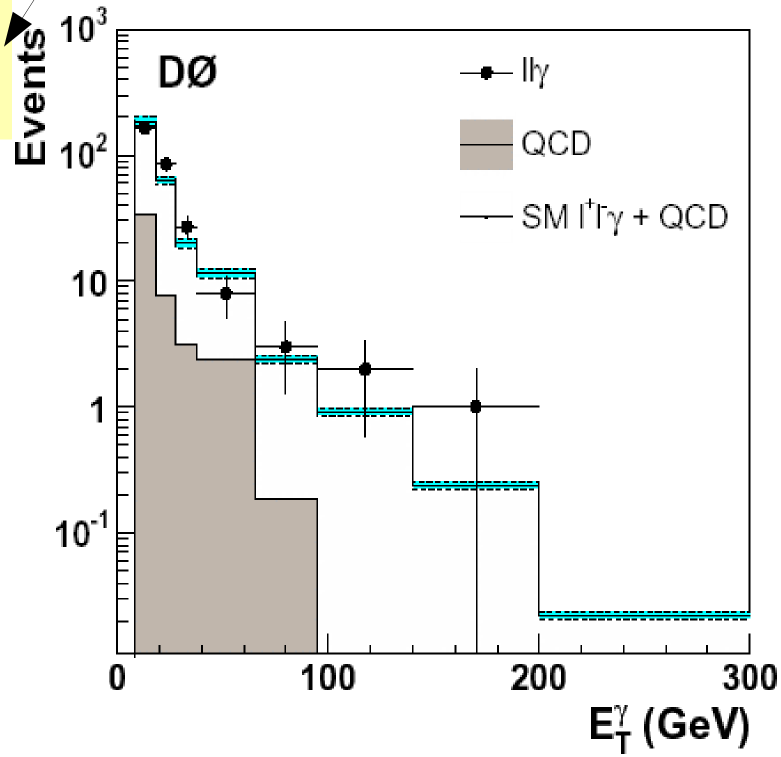
$|h^Z_{20,40}|<0.020$

$|h^\gamma_{10,30}|<0.23$

$|h^\gamma_{20,40}|<0.019$

Most stringent limits to date.

hep-ex/0502036

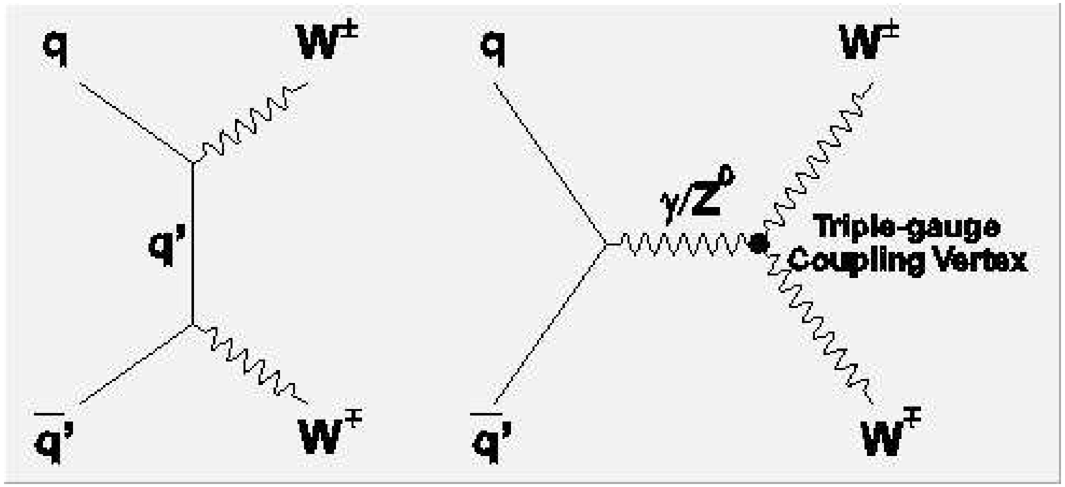


$\Lambda = 1000$ GeV

The ZZγ and Zγγ

AC contours are similar.

WW



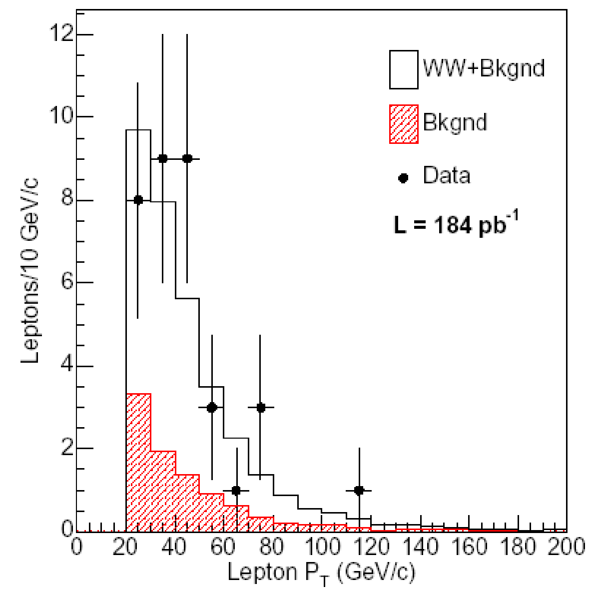
- Final state has couplings to both γ and Z.
  - Highly constrained by studies at LEP.
  - Backgrounds: DY, WZ, ZZ, top...
- Favored discovery channel:
  - Higgs (covered later this week).
  - Heavy resonances.

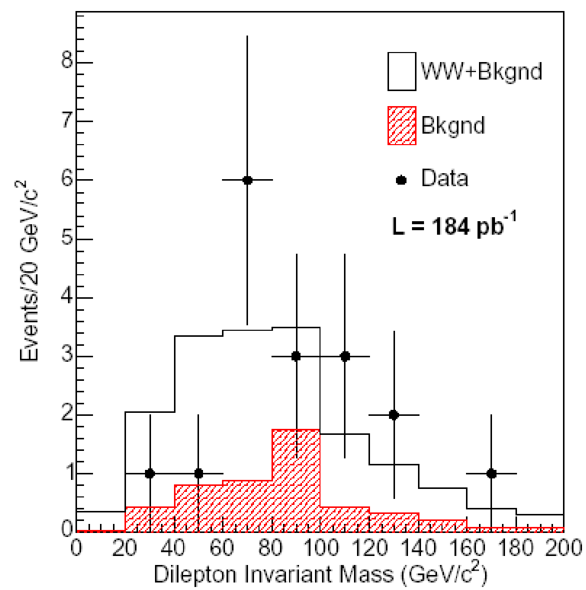
CDF WW Cross Section

Channel:	ee	eμ	μμ
η^l	2	2(1)	1
$p_T^{\,l}$		20	
$\not{E}_T$		25 ($\Delta\phi_{ll}$ > 20° if E_T<50)	
$\not{E}_T^{\,sig}$		3	
Jet Veto		E_T > 15, |η|<2.5	
Lum	184	184	184
Bkg:	$4.5^{+1.4}_{-0.5}$	1.9±0.4	$1.3^{+1.6}_{-0.5}$
SM exp:	$4.5^{+1.4}_{-0.5}$	7.0±0.8	$3.8^{+1.6}_{-0.5}$
Observed:	6	5	6

$\sigma(p\bar{p}\to W^+W^-)=14.6^{+5.8}_{-5.1}(\text{stat})^{+1.8}_{-3.0}(\text{sys})\pm0.6(\text{lum})$ pb

hep-ex/0501050 SM: 12.4 ± 0.8 pb



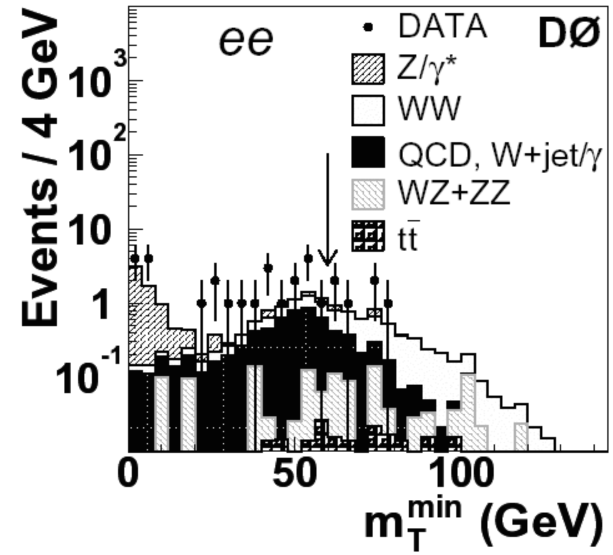


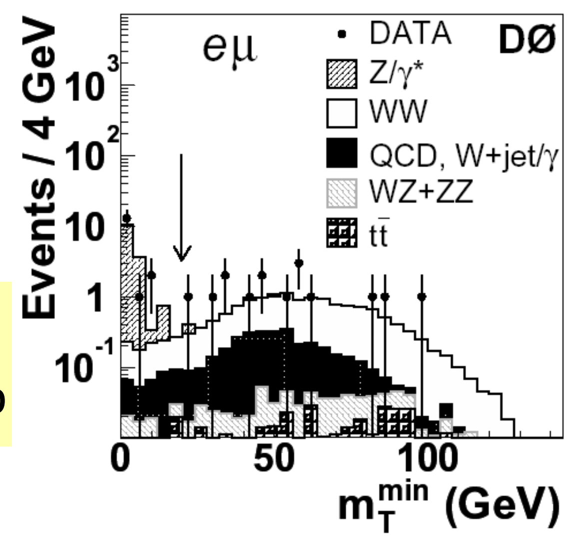
DØ WW Cross Section

Channel:	ee	eμ	μμ
η^l	3	3(2)	2
p_T^l		20(15)	
$\not{E}_T$	30	20	40
$\not{E}_T^{sc}$	15	15	----
$H_{T_{E_T>20,\ \lvert\eta\rvert<2.5}}$	50	50	100
Lum	252	235	224
Bkg:	2.30±0.21	3.81±0.17	1.95±0.41
SM exp:	3.42±0.05	11.10±0.10	2.10±0.05
Observed:	6	15	4

$\sigma(p\bar{p}\to W^+W^-) = 13.8^{+4.3}_{-3.8}(\text{stat})^{+1.2}_{-0.9}(\text{sys}) \pm 0.9(\text{lum})$ pb

hep-ex/0410066 (accepted by PRL) SM: 12.4 ± 0.8 pb





WZ/ZZ Limit (CDF)

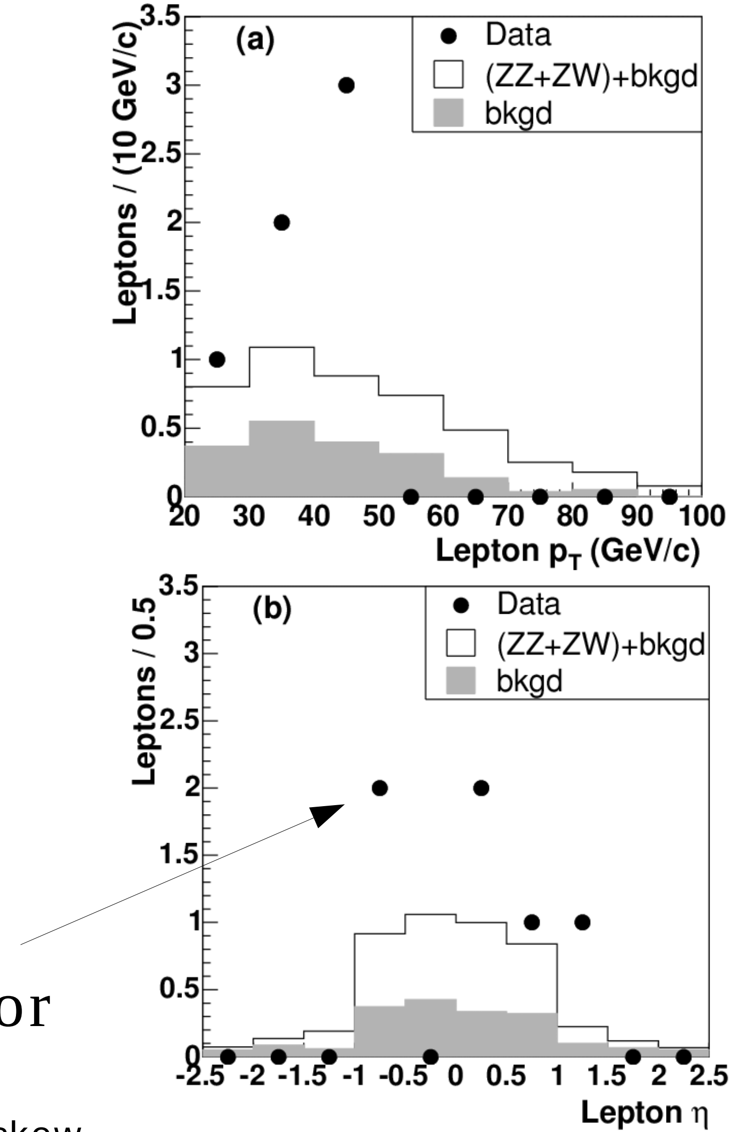
- Set an upper limit on WZ/ZZ production combined.
- Identify two leptons to resolve the Z, and then make additional requirements (which can be looser to gain efficiency).
- Small backgrounds from DY, WW, top.
- Three Channels considered:
  - Two leptons plus missing E_T.
  - Three leptons plus missing E_T.
  - Four leptons.

CDF WZ/ZZ Limit

Channel:	ee	μμ
η^l	2.5	1.0
p_T^l	20	20
M_{ll}	$76<M_{ll}<106$	
Lum (pb^{-1})	194	194
Bkg:	1.02±0.24	
SM exp:	2.31±0.29	
Observed:	2	1

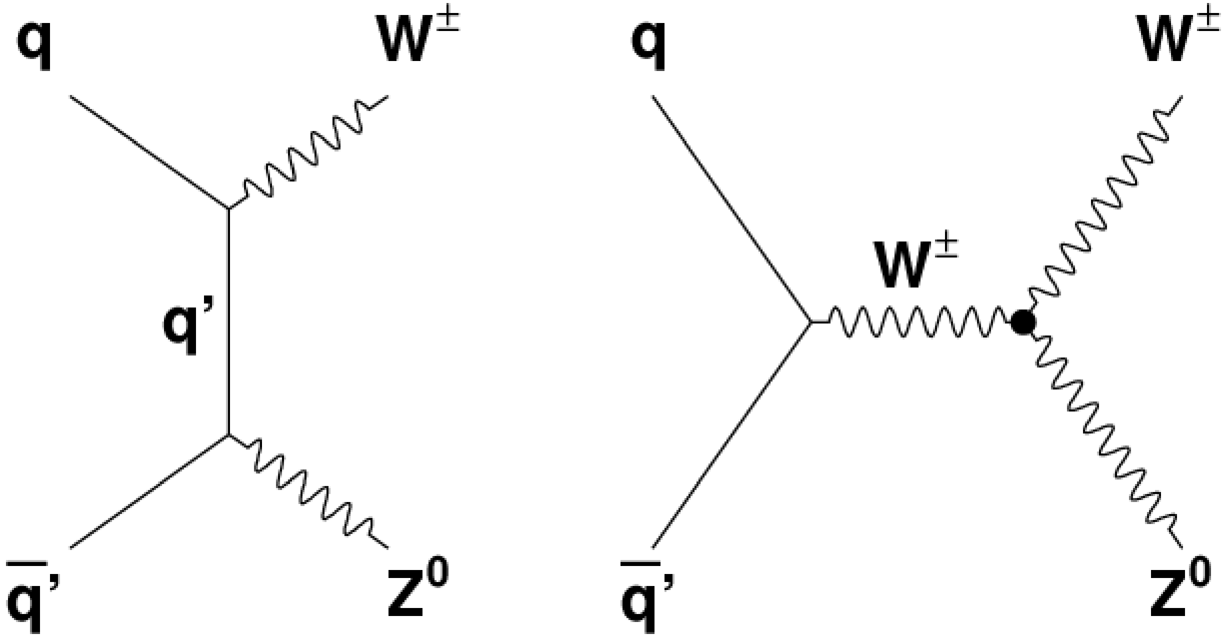
All observed events are in $ll\not{E}_T$ channel.

$\sigma(p\bar{p}\to ZW/ZZ)<15.2$ pb
hep-ex/0501021 SM: 5.0 ± 0.4 pb



Error bars omitted for clarity.

WZ

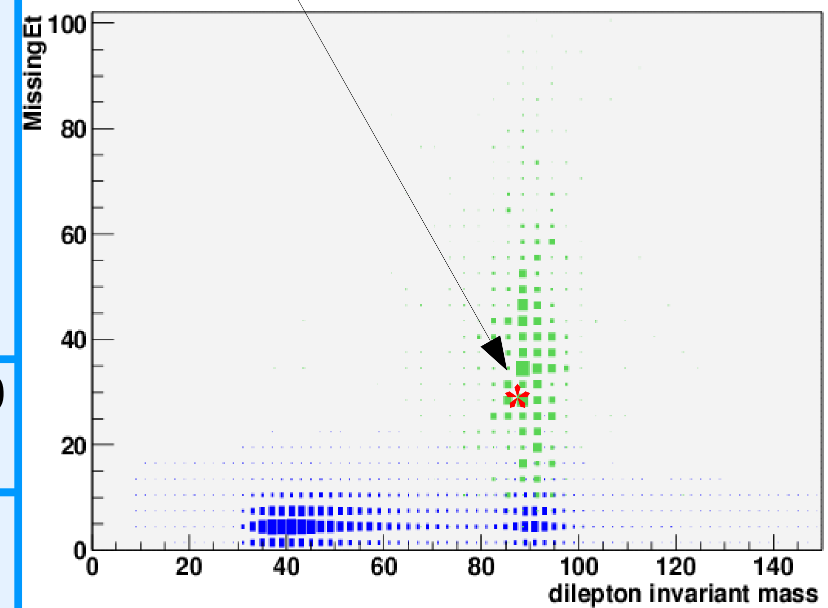


- DØ performed a search exclusively for WZ to three leptons plus missing transverse energy.

DØ WZ Analysis

Tri-electron candidate

Channel:	eee	eeμ	μμe	μμμ
η^l	2.5	2.5(2)	2.5(2)	2
p_T^l	15			
$\not{E}_T$	20			
M_{ll}	$71 < M_{ee} < 111$		$51 < M_{\mu\mu} < 131$	
E_{THAD}	50			
Lum	320	292	285	289
Bkg:	0.71±0.08			
SM exp:	2.04±0.13			
Observed:	1	0	0	2



$\sigma(p\bar{p} \to WZ) < 13.3$ pb

or, interpreted as cross section: $\sigma(p\bar{p} \to WZ) = 4.5^{+3.8}_{-2.6}$ pb

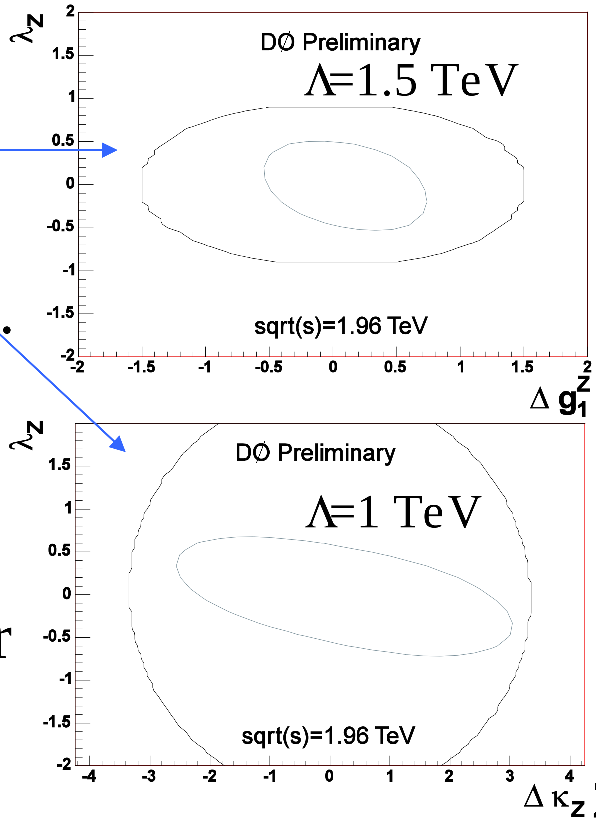
DØ Preliminary SM: 3.7 ± 0.1 pb

Probability of background to fluctuate up to 3 events: 3.5%

WZ Anomalous Couplings

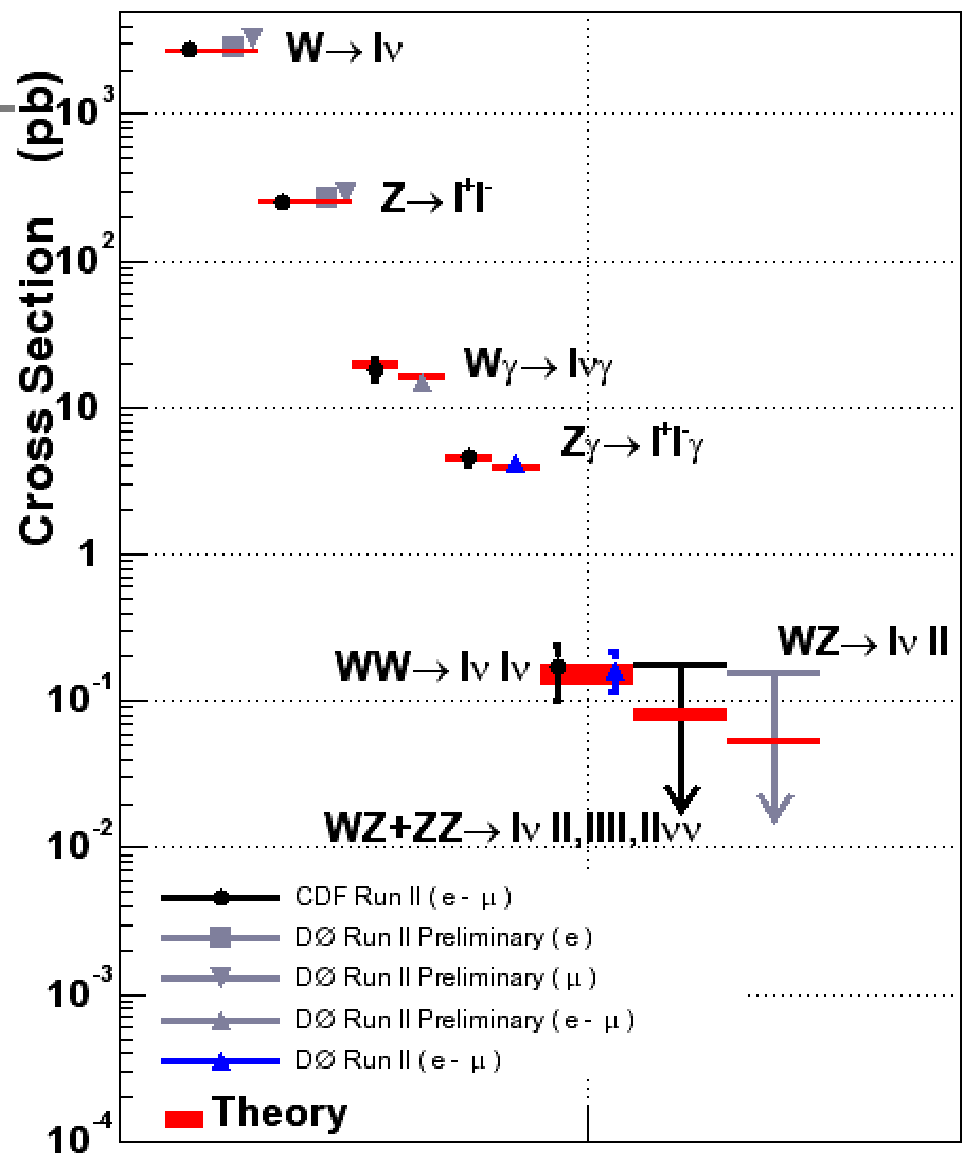
$\Lambda = 1.0$ TeV	DØ Preliminary	$\Lambda = 1.5$ GeV
$-0.53 < \lambda_Z < 0.56$		$-0.48 < \lambda_Z < 0.48$
$-0.57 < \Delta g_1^Z < 0.76$	95% C.L.	$-0.49 < \Delta g_1^Z < 0.66$
$-2.0 < \Delta\kappa_Z < 2.4$		-

- Inner contours: 2D limits. Outer contours are from unitarity.
- Best limits in WZ final states.
- First 2D limits in $\Delta\kappa_Z$ vs. λ_Z using WZ.
- Best limits available on Δg_1^Z, $\Delta\kappa_Z$, and λ_Z from direct, model-independent measurements.
- The DØ Run II 1D limits are ~ factor of 3 better Run I limits.



Summary

- Many new results on Diboson production and coupling strengths.
  - All results represent a subset of current Run II Data :
    - You'll be hearing from us soon!



The following is a backup slide.

Previous Coupling results:

- DØ and CDF put limits on anomalous WWγ and WWZ Couplings in Run 1.
  - WWγ and WWZ couplings from WW
  - WWγ couplings from Wγ analyses
  - WWZ couplings from WZ
- DØ Combined Wγ, WW, WZ

$$-0.25 < \Delta\kappa_\gamma = \Delta\kappa_Z < 0.39$$

$$-0.18 < \lambda_\gamma = \lambda_Z < 0.19$$

95% C.L. $\Lambda = 2$ TeV

Tightest from the Tevatron

- LEP Combined (1D 95% CL)

LEP EWK Working Group hep-ex/0412015

$$-0.105 < \Delta\kappa_\gamma < 0.069$$

$$-0.059 < \lambda_\gamma < 0.026$$

$$-0.051 < \Delta g_1^Z < 0.034$$

"HISZ" SU(2)xU(1) coupling relations

$$\lambda_\gamma = \lambda_Z \text{ and } \kappa_Z = g_1^Z - \tan^2\theta_w(\kappa_\gamma - 1)$$

Didn't use a form-factor dependence in their couplings.

(complementary in several ways)