Diboson Physics at the Tevatron

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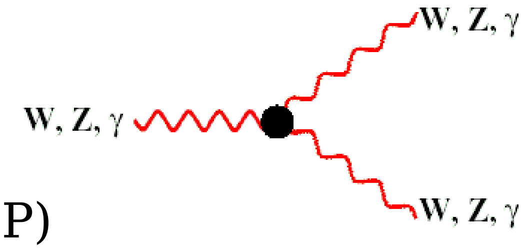
for the CDF and D0 Collaborations

Why Study Diboson Production?



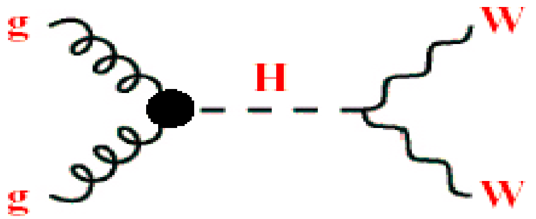
- Probe non-Albelian nature of $SU(2)_L \otimes U(1)_Y$ → gauge boson self-interactions (triple, quartic)

  → Diboson production a sensitive probe of new physics (NP) (anomalous trilinear gauge couplings)

- Tevatron (pp) complementary to LEP (e^+e^-)

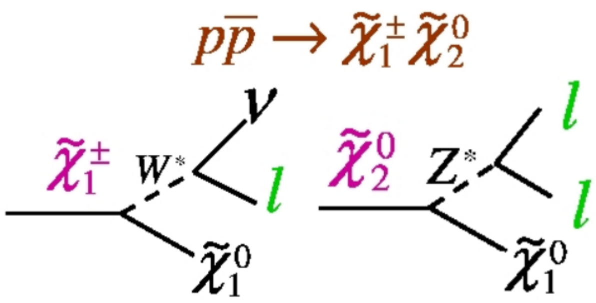
  → Tevatron has sensitivity to different coupling combinations compared to LEP (e.g. direct WWZ)

  → Tevatron explores higher $\hat{s}$, where one might expect NP effects to become evident



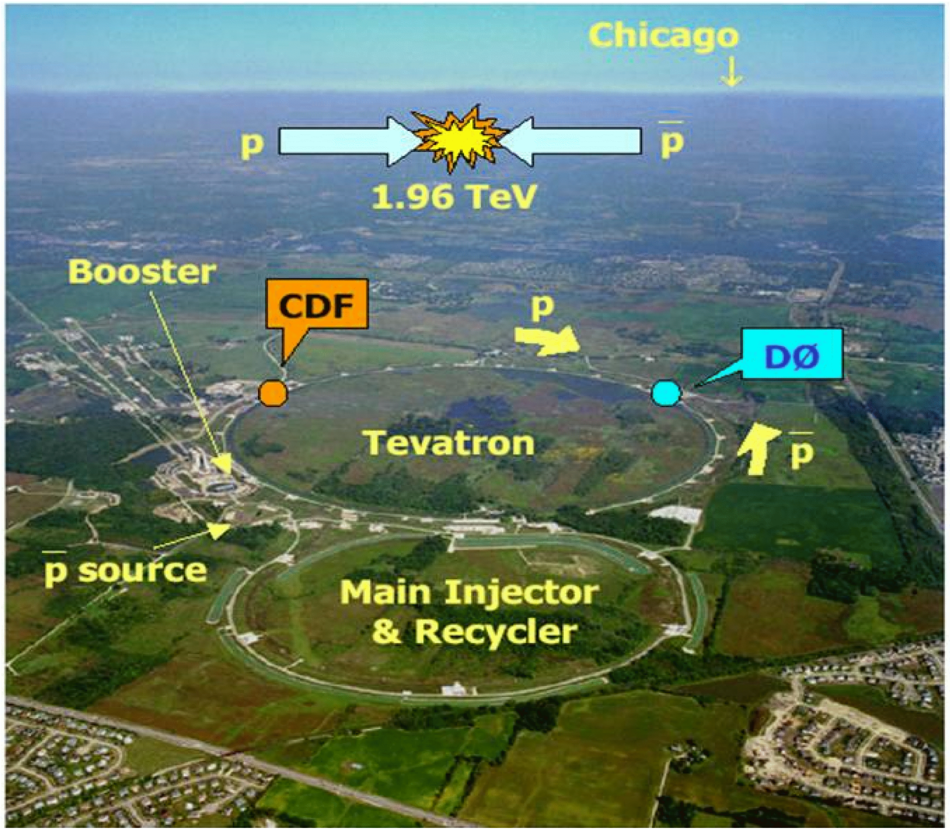
- SM diboson production important background for many high pt analyses (e.g. $H \to WW^{(*)}$, SUSY, tt)

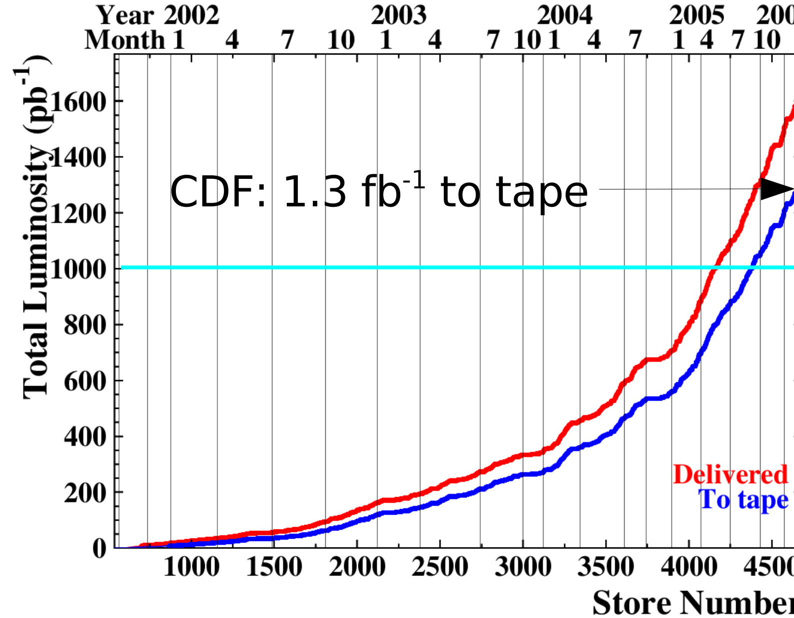
  → Demonstrates experimental sensitivity to multi-lepton final states (e.g. pp → $W^{\pm}Z^0$ → trileptons + E_t similar to pp → $\chi_2^{\pm}\chi_1^0$ → trileptons + E_t SUSY signal)

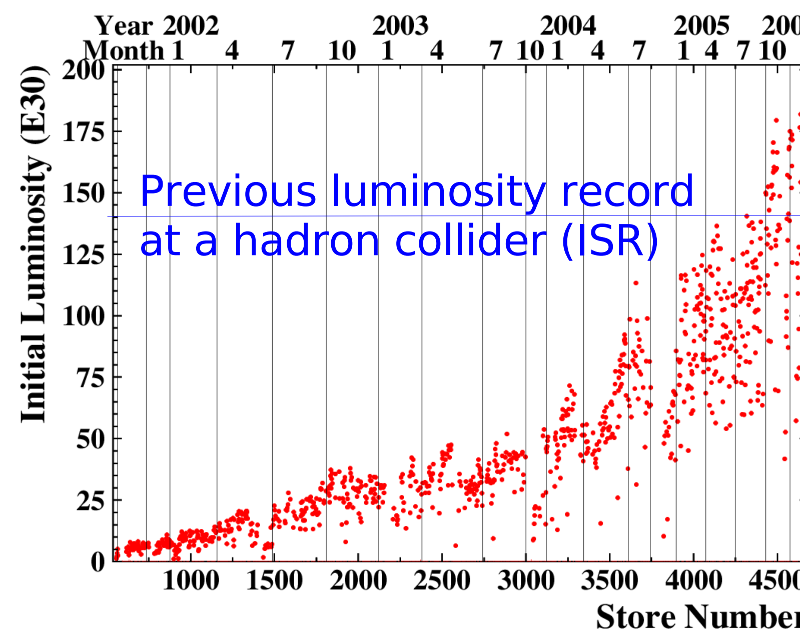


The Fermilab Tevatron

World's highest energy particle collider
until turn-on of LHC @ CERN





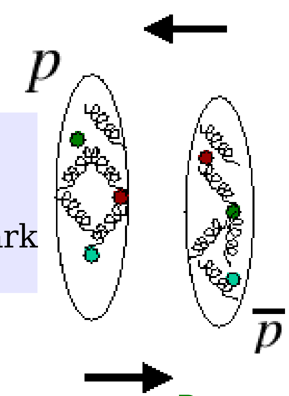


Run II Started 2001:

- $\sqrt{s}$=1.96 TeV
- L_{inst} = 181.8×10^{30} cm^{-2}s^{-1} (record luminosity)
- $\int L\,dt$ = ~1.6 fb^{-1}
  $\rightarrow$ 4 – 8 fb^{-1} expected by 2009

Collisions:

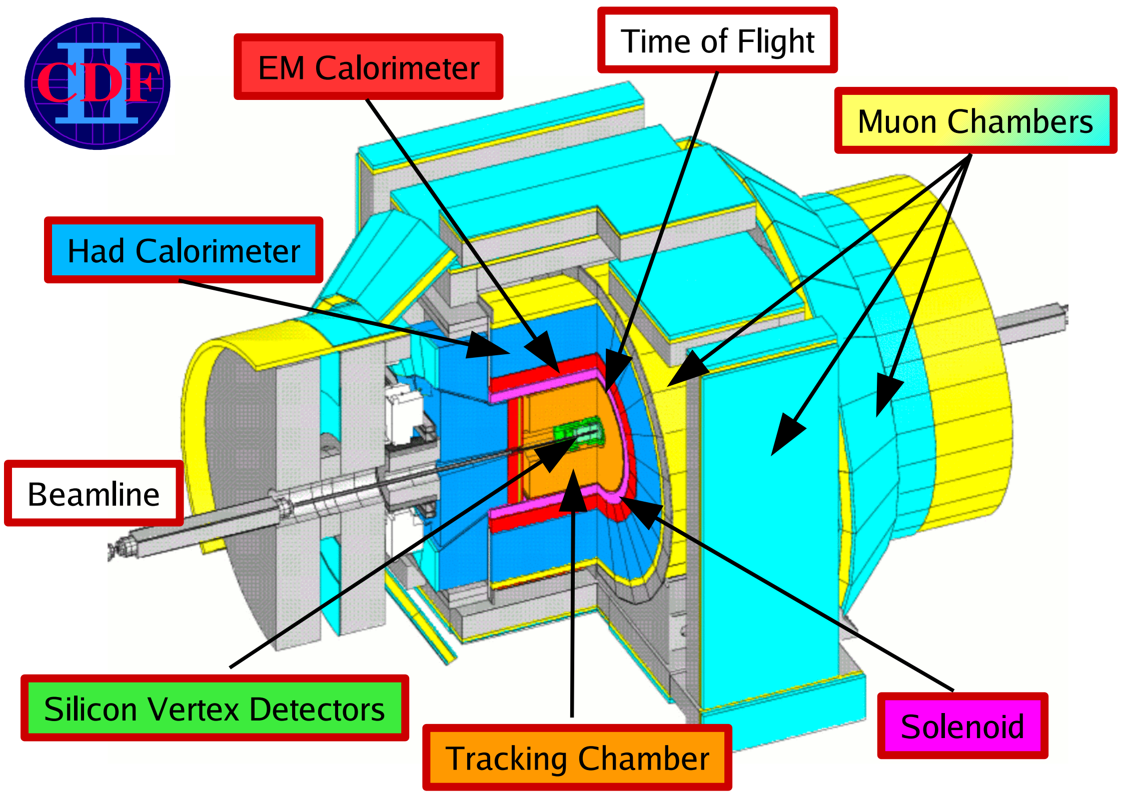
- gluon-gluon
- quark-antiquark
- gluon-quark

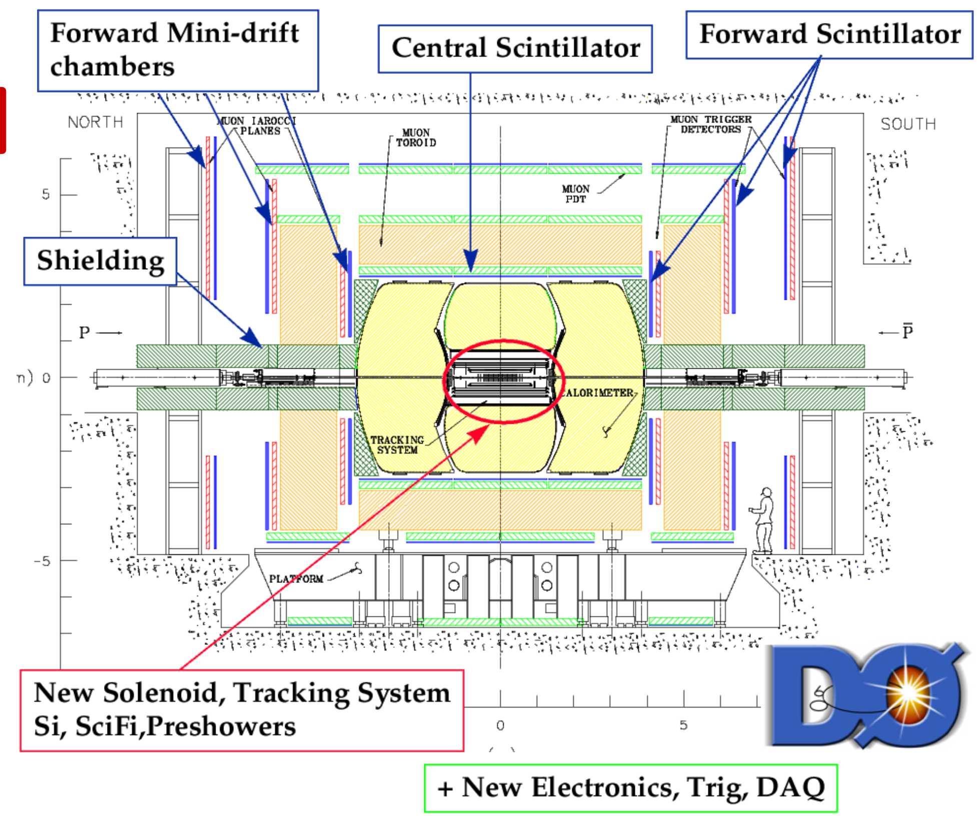


The Detectors: CDF and D0

Detectors upgraded for Run II for improvements in:

- Trigger & Data Acquisition
- Charged Particle Tracking
- Electron and muon coverage
- Particle identification





WWγ and WWZ Anomalous Couplings

Parameterize NP in terms of coupling parameters in an effective Lagrangian:

$$L_{WWV}/g_{WWV} = i g_1^V (W_{\mu\nu} W^{\mu} V^{\nu} - W_{\mu} V_{\nu} W^{\mu\nu}) + i k_V W_{\mu} W_{\nu} V^{\mu\nu} + \frac{i\lambda_V}{M_W^2} W_{\lambda\mu} W^{\mu}_{\nu} V^{\nu\lambda}$$

$$V \equiv Z, \gamma$$

$$\alpha \Rightarrow \alpha(\hat{s}) = \frac{\alpha_0}{(1+\hat{s}/\Lambda^2)^2}$$

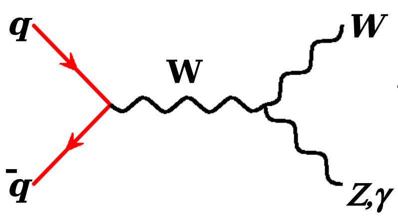
$\sqrt{\hat{s}}$ = CM energy of subprocess

Λ = scale of NP (form factor)

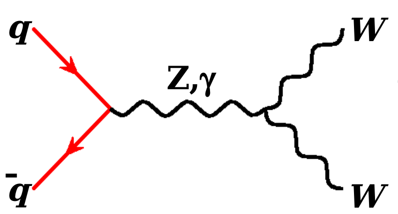
5 CP conserving coupling parameters

SM at tree level: $g_1^Z = g_1^{\gamma} = k_Z = k_{\gamma} = 1, \quad \lambda_Z = \lambda_{\gamma} = 0$

Trilinear gauge couplings:

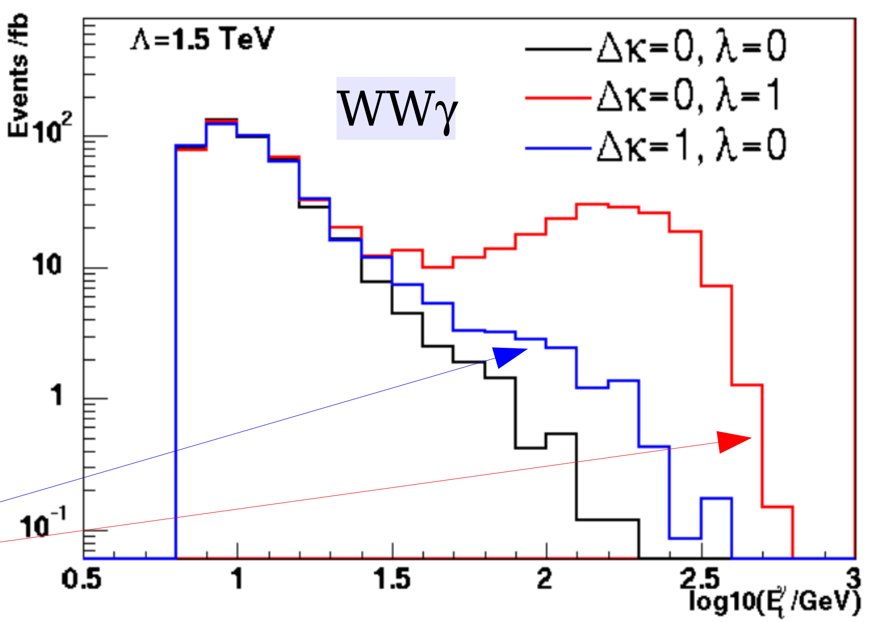


WW: both WWγ and WWZ

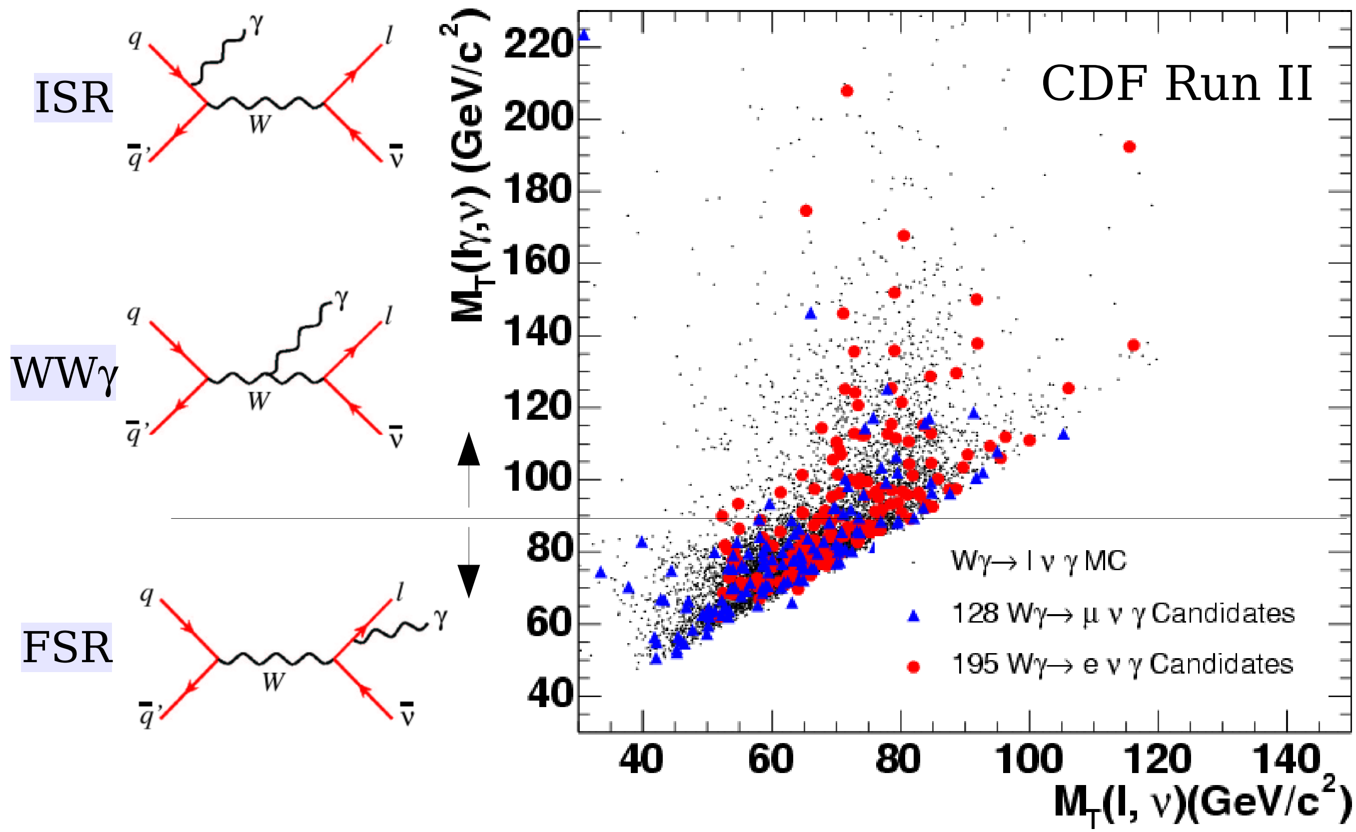


Wγ (WZ): only WWγ (WWZ)

Anomalous couplings enhance cross-section at high gauge boson E_t

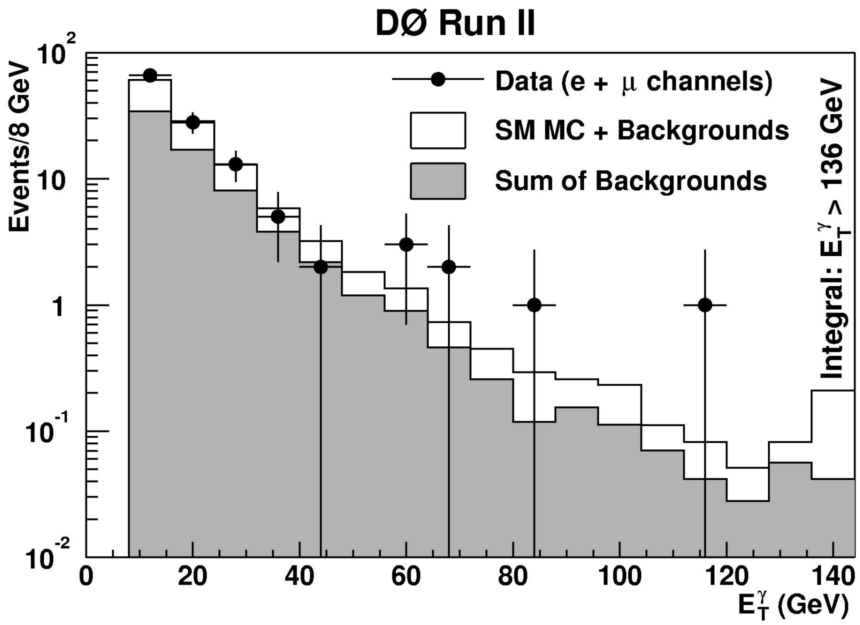


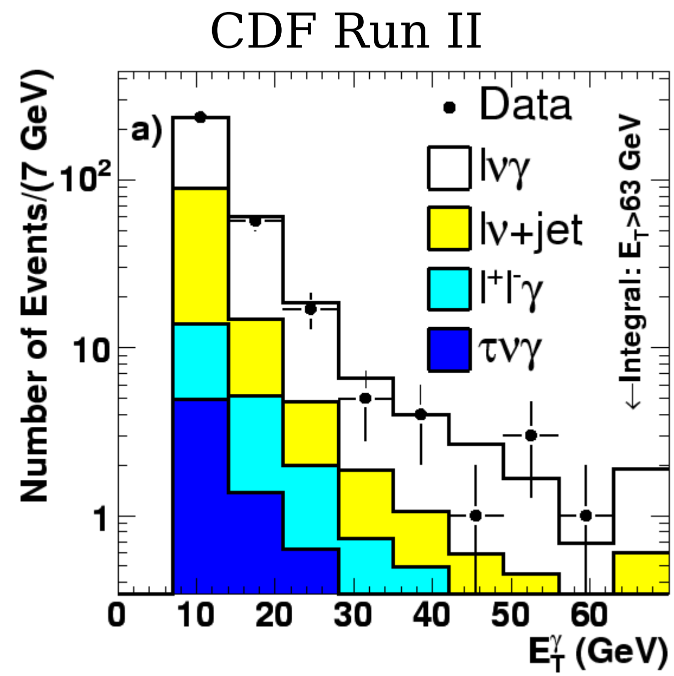
Wγ



	σ(pp->Wγ)	SM, pb	E^{γ}_{T}
CDF	18.1 ± 1.6 ± 2.4 ± 1.2	19.3 ± 1.4	7
DØ	14.8 ± 1.6 ± 1.0 ± 1.0	16.0 ± 0.4	8

WWγ Anomalous Couplings



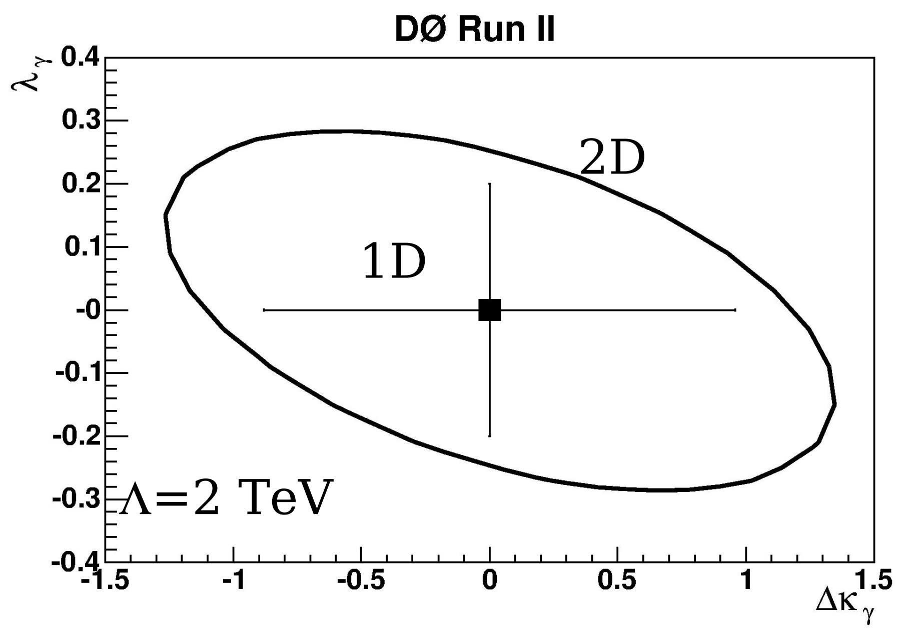


D0: limits for anomalous couplings:

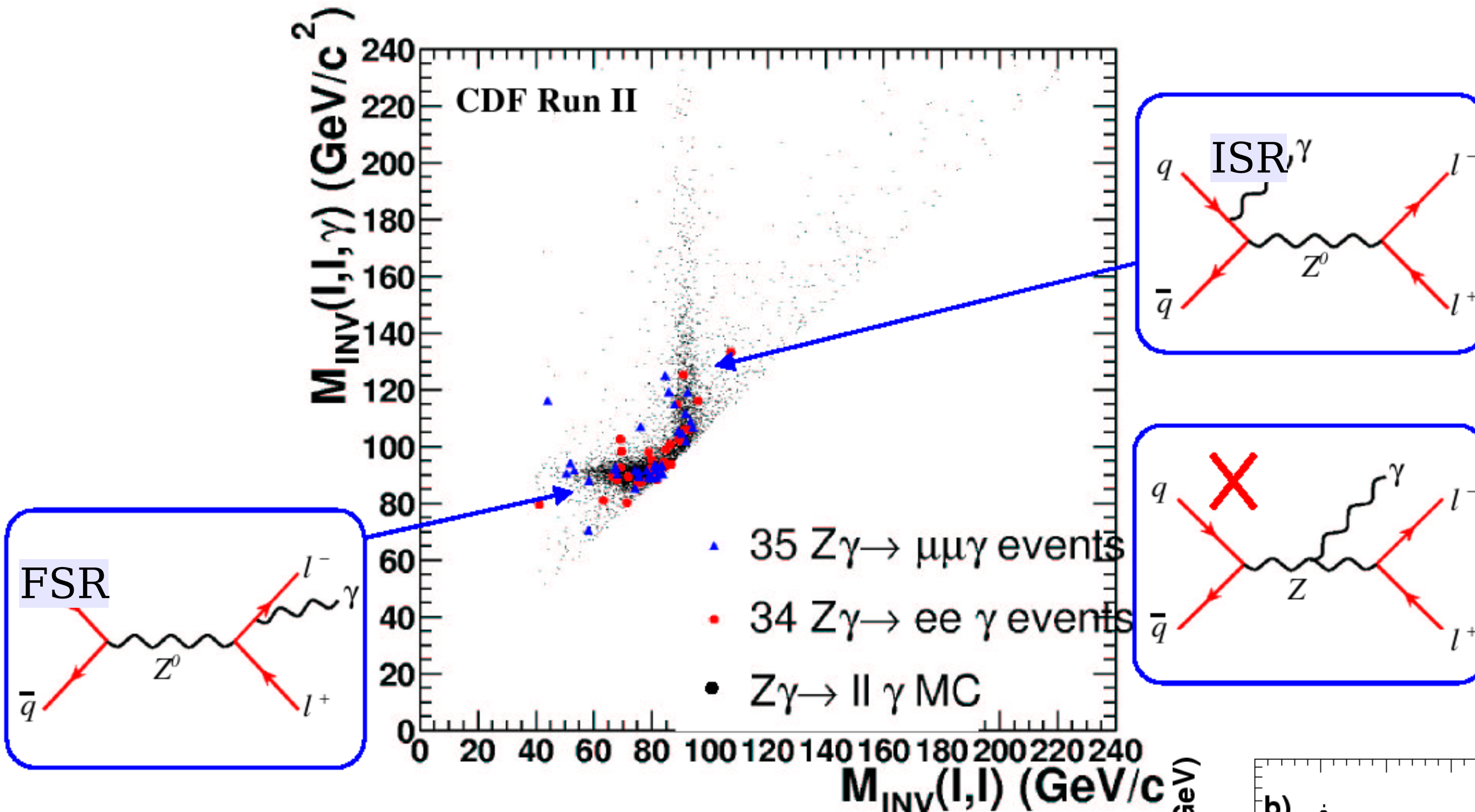
1D limits at 95% CL

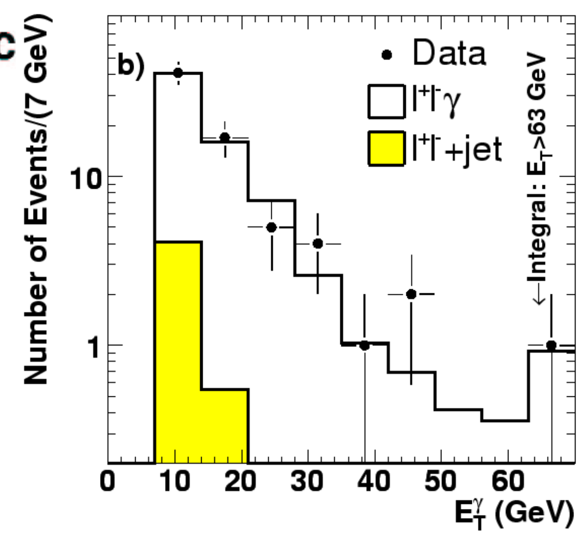
$$-0.88 < \Delta\kappa_\gamma < 0.96$$

$$-0.20 < \lambda_\gamma < 0.20$$



Zγ





	N_{data} (e + μ)	σ($l\,l\,\gamma$) exp.	σ($l\,l\,\gamma$) theory	$E_T(\gamma)$ GeV	M($l\,l$) GeV/c^2
CDF	71	4.6±0.6	4.5±0.3	> 7	> 40
DØ	290	4.2±0.5	3.9±0.2	> 8	> 30

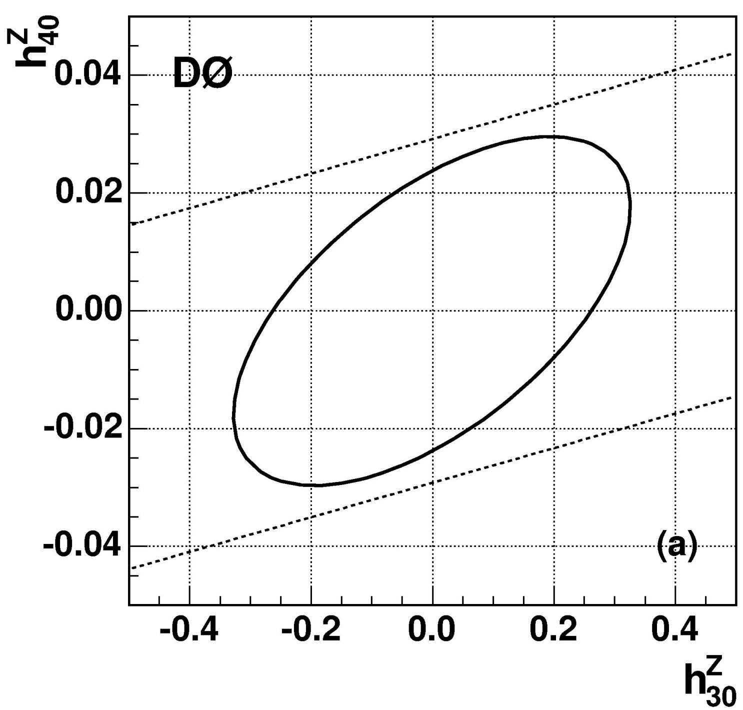
ZZγ and Zγγ Anomalous Couplings

Non-SM characterized by an effective Lagrangian with 8 form-factor coupling parameters called h_1^V, h_2^V, h_3^V, and h_4^V where V stands for **γ** and Z.

CP violating h_1^V and h_2^V

CP conserving h_3^V and h_4^V

SM: all couplings equal to zero



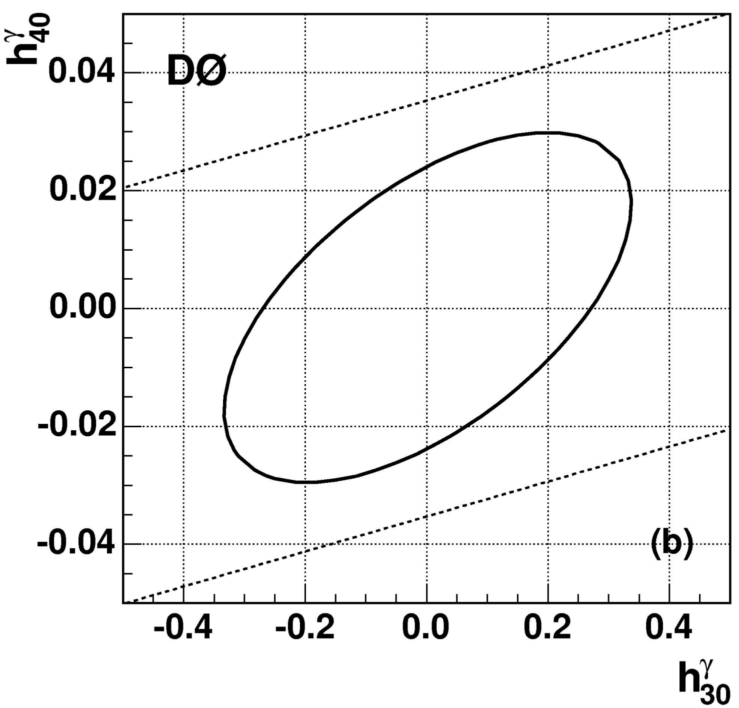
ZZγ limits 2D at 95%CL

$$|h_{10,30}^Z| < 0.23$$

$$|h_{20,40}^Z| < 0.020$$

$$|h_{10,30}^\gamma| < 0.23$$

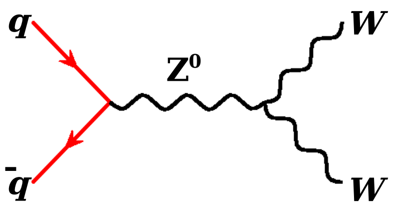
$$|h_{20,40}^\gamma| < 0.019$$

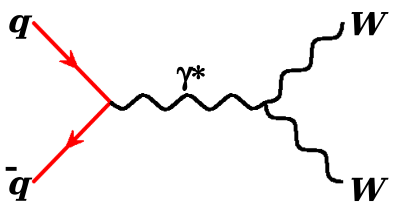


Zγγ limits 2D at 95%CL

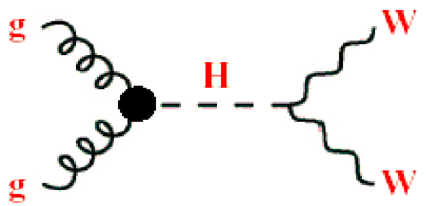
WW Production

Involves 2 triple gauge couplings





Same final state in Higgs decay



NLO cross section: 12.4 ± 0.8 pb

(Campbell,Ellis, Phys.Rev. D60 (1999) 113006)

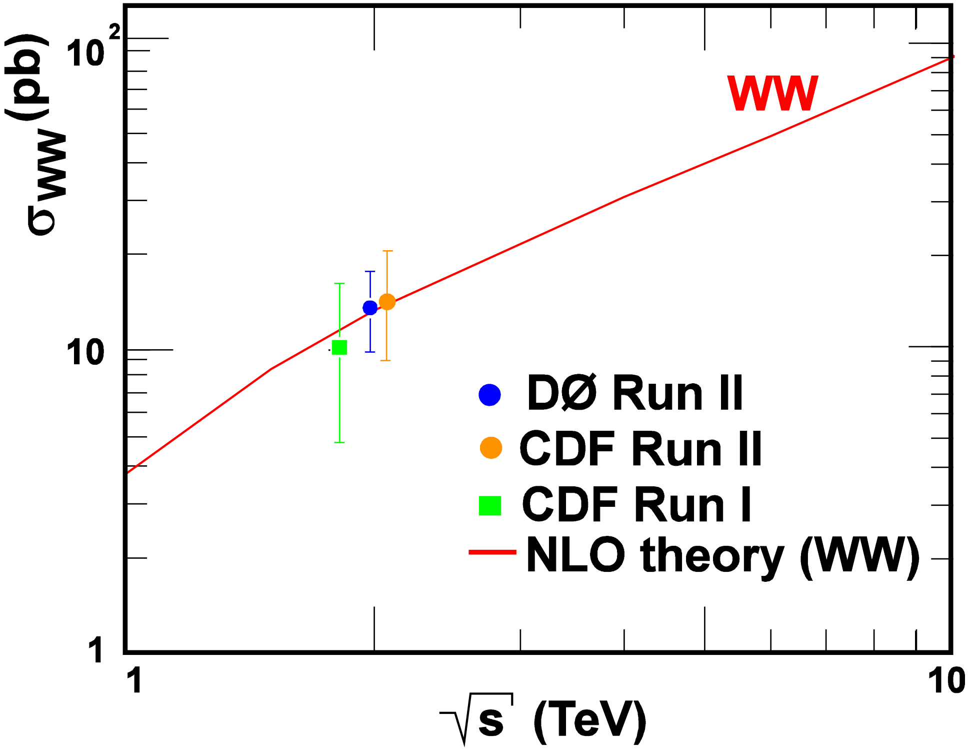
Previous Run II measurements:

CDF: $\int L\,dt$ = 184 pb^{-1}
Observe 17 with expected background of 5.0 events PRL 94 (2005) 211801

$$\sigma = 14.6^{+5.8}_{-5.1}(\text{stat})^{+1.8}_{-3.0}(\text{syst}) \pm 0.9\,(\text{lum})\text{ pb}$$

D0: $\int L\,dt$ = 240 pb^{-1}
Observe 25 with expected background of 8.1 events PRL 94 (2005) 151801

$$\sigma = 13.8^{+4.3}_{-3.8}(\text{stat})^{+1.2}_{-0.9}(\text{syst}) \pm 0.9\,(\text{lum})\text{ pb}$$



WW Cross Section

New measurement from CDF using ∫L dt = 825 pb^{-1}

WW → dileptons + MET:

- Two OS leptons (e,μ) with Pt > 20 GeV
- Z veto (76 < Mll < 106) if MET/ΣE_t < 3 for ee, μμ
- MET > 25 GeV
- Δφ(lepton,jet) > 20^o if 25 < MET < 50 GeV
- 0 jets with Et > 15 GeV and |η| < 2.5

New!

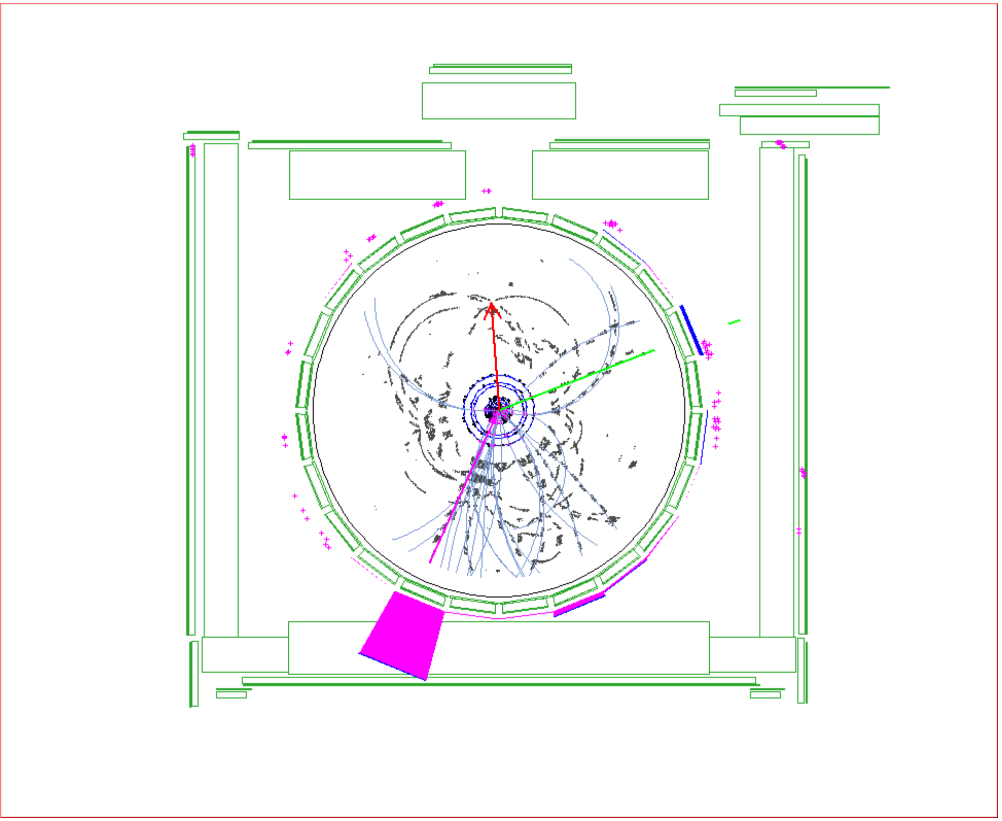
Mode	ee	$e\mu$	$\mu\mu$	ll
WW	12.82 ± 0.06 ± 1.06	28.82 ± 0.09 ± 2.39	10.71 ± 0.05 ± 0.89	52.36 ± 0.12 ± 4.35
Drell-Yan	4.83 ± 0.52 ± 1.26	3.56 ± 0.43 ± 0.93	2.82 ± 0.37 ± 0.73	11.21 ± 0.77 ± 2.91
$t\bar{t}$	0.05 ± 0.01 ± 0.01	0.11 ± 0.01 ± 0.01	0.04 ± 0.01 ± 0.00	0.20 ± 0.01 ± 0.02
$WZ+ZZ$	3.62 ± 0.02 ± 0.36	0.93 ± 0.01 ± 0.09	3.39 ± 0.01 ± 0.34	7.93 ± 0.02 ± 0.79
$W\gamma$	3.57 ± 0.12 ± 0.71	3.25 ± 0.10 ± 0.65	0.02 ± 0.01 ± 0.00	6.83 ± 0.16 ± 1.37
W+jets	2.96 ± 0.23 ± 0.71	6.69 ± 0.41 ± 1.98	1.33 ± 0.17 ± 0.53	10.99 ± 0.50 ± 3.20
Sum Bkg	15.03 ± 0.58 ± 1.65	14.54 ± 0.60 ± 2.28	7.60 ± 0.41 ± 0.97	37.16 ± 0.93 ± 4.61
Expected	28± 0.59 ± 1.96	43± 0.61 ± 3.31	18± 0.41 ± 1.31	90± 0.94 ± 6.33
Data	29	47	19	95

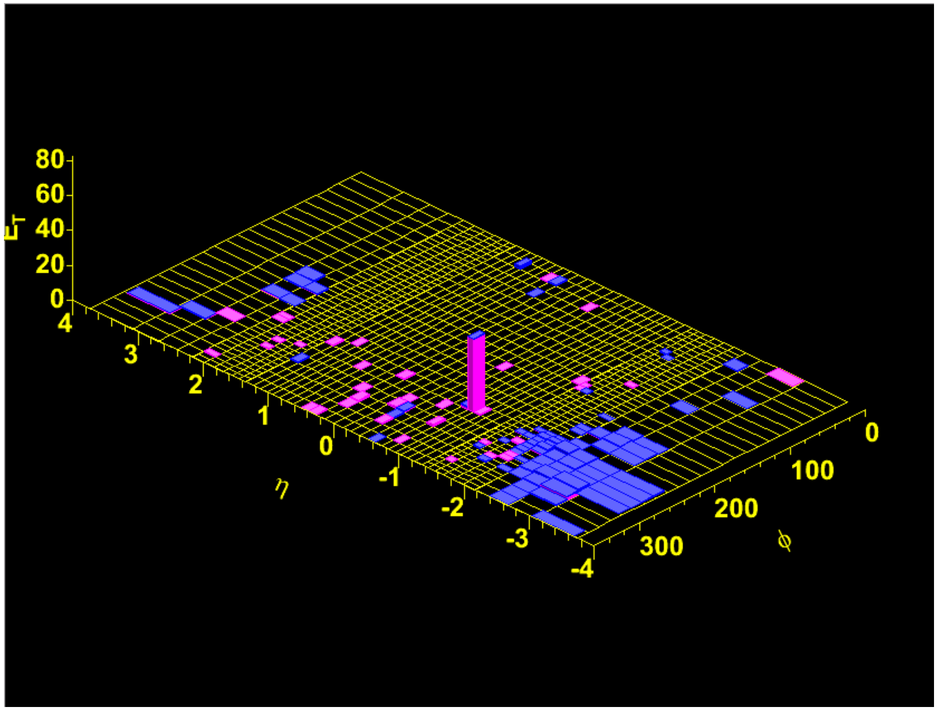
Expect:
37.2 background

Observe:
95 events

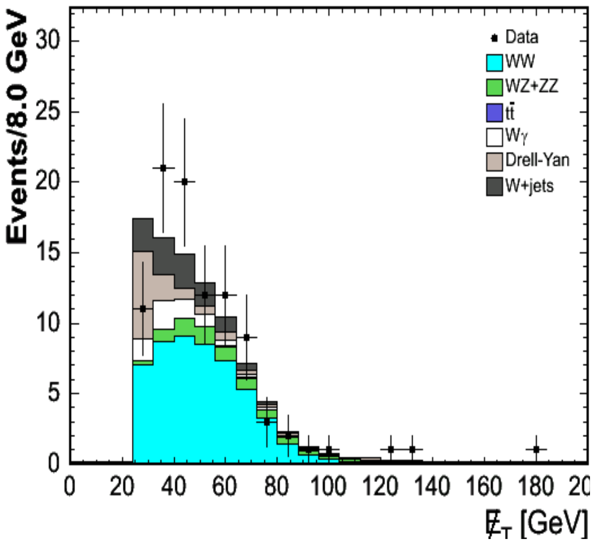
$$\sigma(p\bar{p}\rightarrow WW)=13.7\pm2.3\,(\mathrm{stat})\pm1.6\,(\mathrm{syst})\pm1.2\,(\mathrm{lum})\ \mathrm{pb}$$

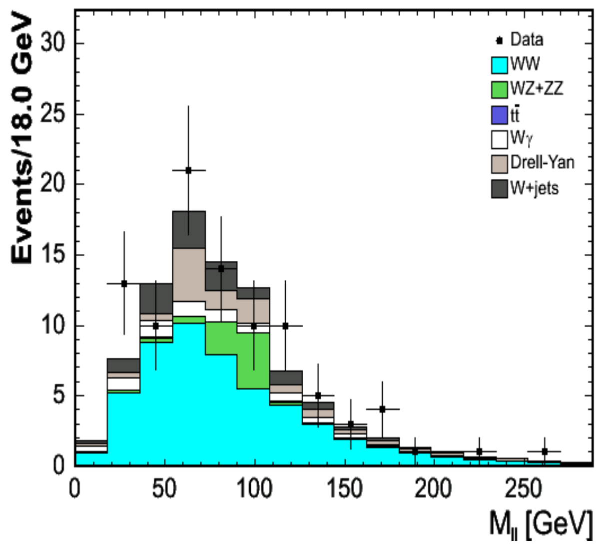
WW Candidate Event

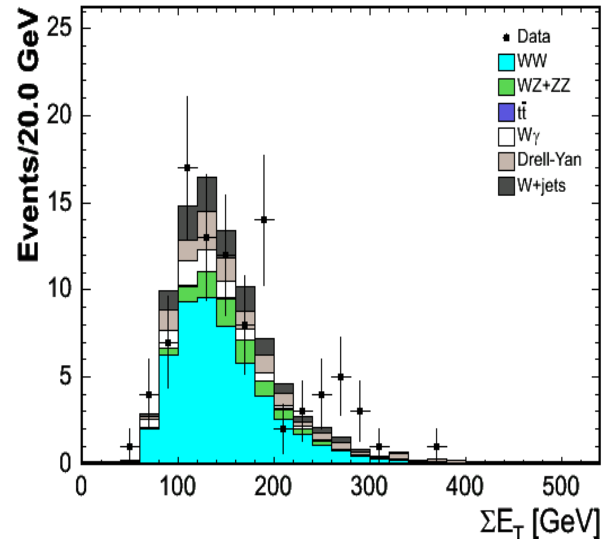


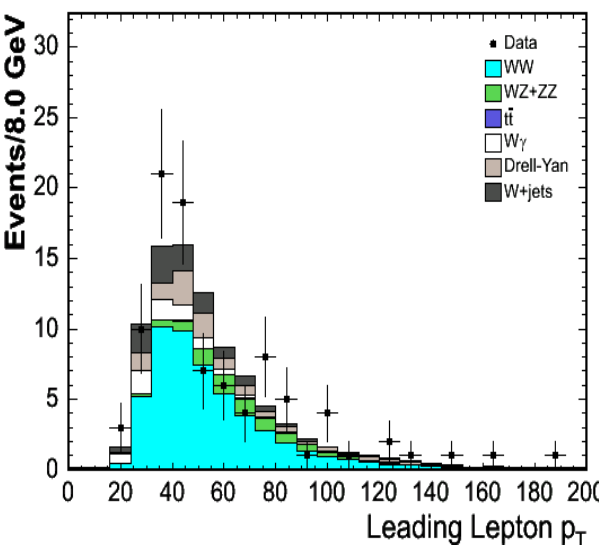


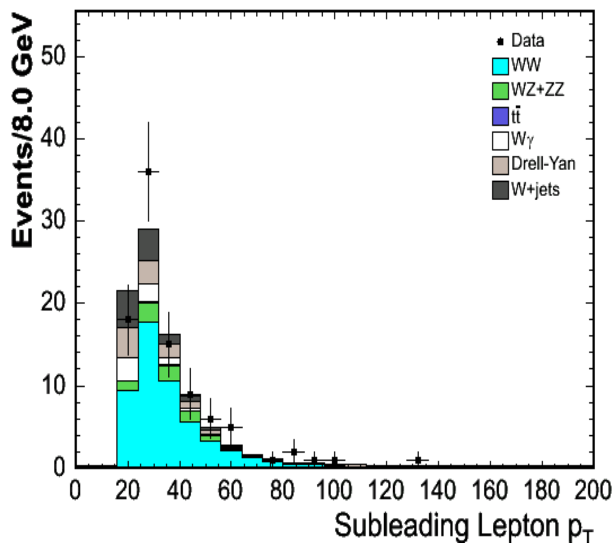
WW Kinematic Distributions











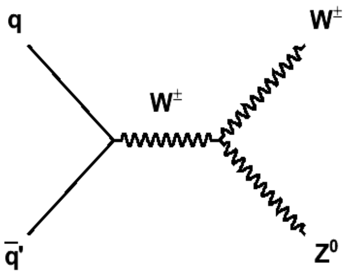
Just observing WW signal

↓

Study WW kinematics
in search of Higgs,NP!

WZ Production

Involves a single triple gauge coupling:



- Not available @ LEP
- Measure WWZ coupling independent of WWγ
- WZ→ trileptons rare but distinct signiture
- Yet to be conclusively observed

NLO cross section: 3.7 ± 0.1 pb

(Campbell,Ellis, Phys.Rev. D60 (1999) 113006)

CDF (WZ+ZZ): ∫L dt = 194 pb^{-1}
Observe 3 events with expected background of 1.0±0.2 and signal of 2.3±0.3 in 2,3, and 4 lepton final states

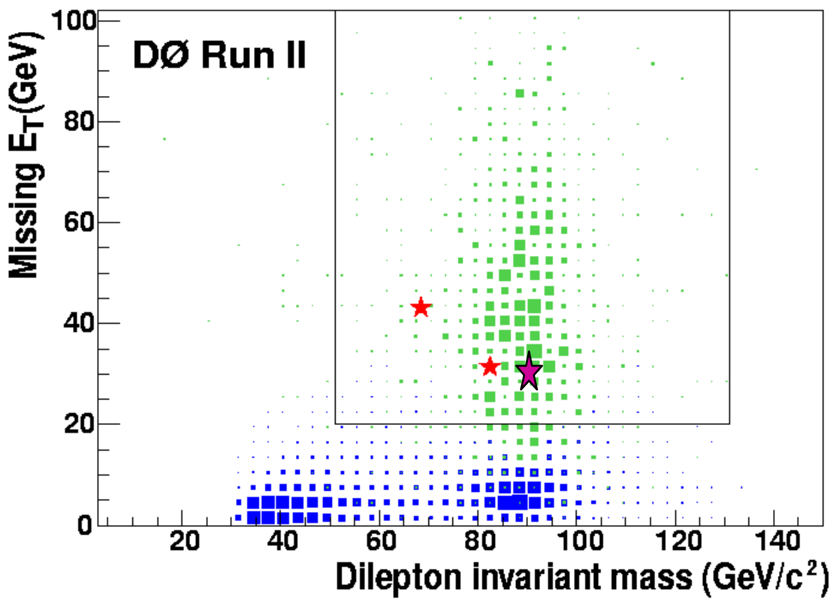
PR D71, 091105

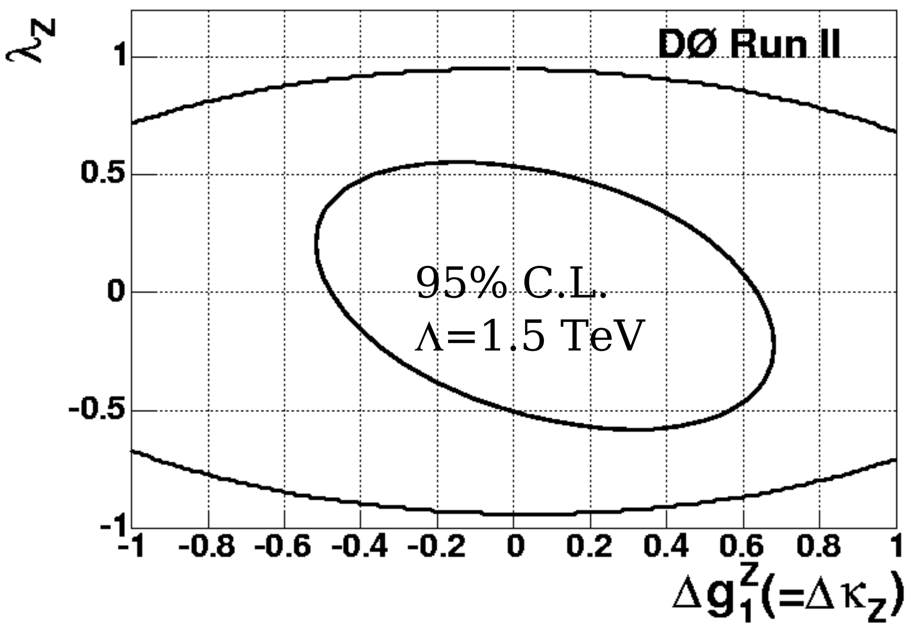
$$\sigma < 15.2\,\text{pb @ 95 C.L (SM: } 5.0 \pm 0.4\,\text{pb)}$$

D0 (WZ): ∫L dt = 300 pb^{-1}
Observe 3 events (1eee, 2μμμ) with expected background of 0.71±0.08 and signal of 2.04 in 3 lepton final state

hep-ex/0504019

$$\sigma < 13.3\,\text{pb @ 95 C.L} \qquad \sigma = 4.5^{+3.8}_{-2.6}\,\text{(stat+syst) pb}$$





WZ→trileptons + MET

New from CDF using $\int L\, dt = 825\ pb^{-1}$

WZ → trileptons + MET:

- 3 leptons (e,μ) with Pt > 20,10,10 GeV
- Z region (76 < Mll < 106)
- MET > 25 GeV

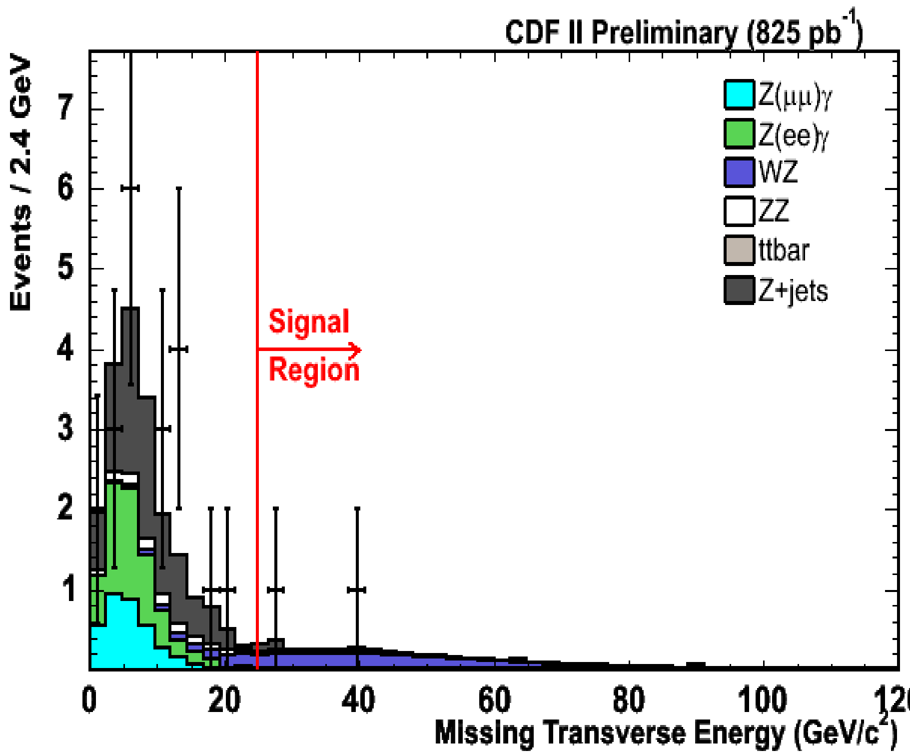
Observe 2 events with expected background of 0.9±0.2 and signal of 3.7±0.3

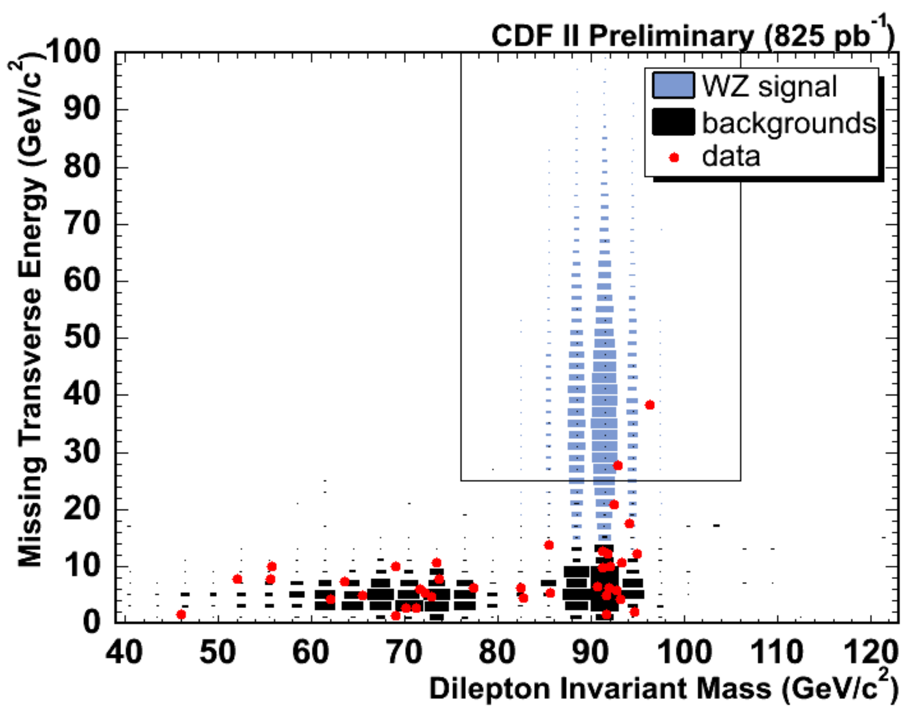
New!

σ(WZ) < 6.34 pb (95% C.L.)

Signal and Background Expectations (825 pb^{-1})

Signal:					
WZ:	3.72	± 0.02	(stat.)	± 0.15	(syst.)
Backgrounds:					
ZZ:	0.498	± 0.007	(stat.)	± 0.050	(syst.)
Zγ:	0.025	± 0.011	(stat.)	± 0.005	(syst.)
ttbar:	0.047	± 0.010	(stat.)	± 0.005	(syst.)
Z+jets (fakes):	0.34	± 0.07	(stat.)	$^{+0.15}_{-0.09}$	(syst.)
Total:	0.91	± 0.07	(stat.)	$^{+0.16}_{-0.10}$	(syst.)



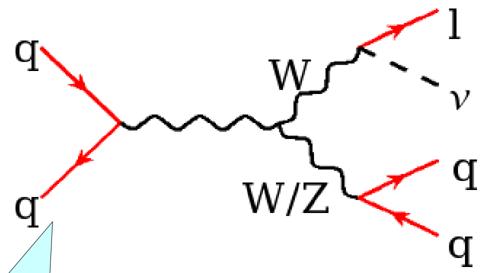


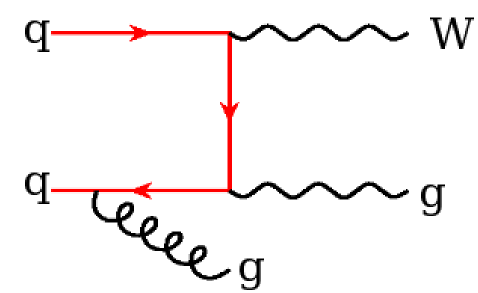
WW/WZ→lνjj

Pro: much larger branching fraction
Con: much larger backgrounds, mainly from W+jets

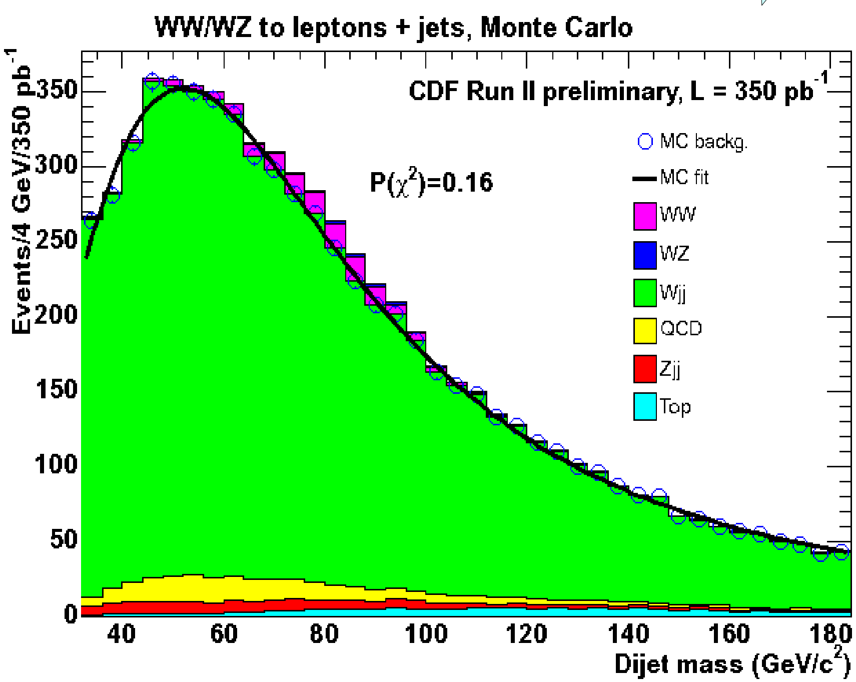
- Lepton E_T > 25 GeV, |η| <
- E_T > 25 GeV.
- At least 2 jets E_T > 15 GeV
- Dijet mass 32-184 GeV

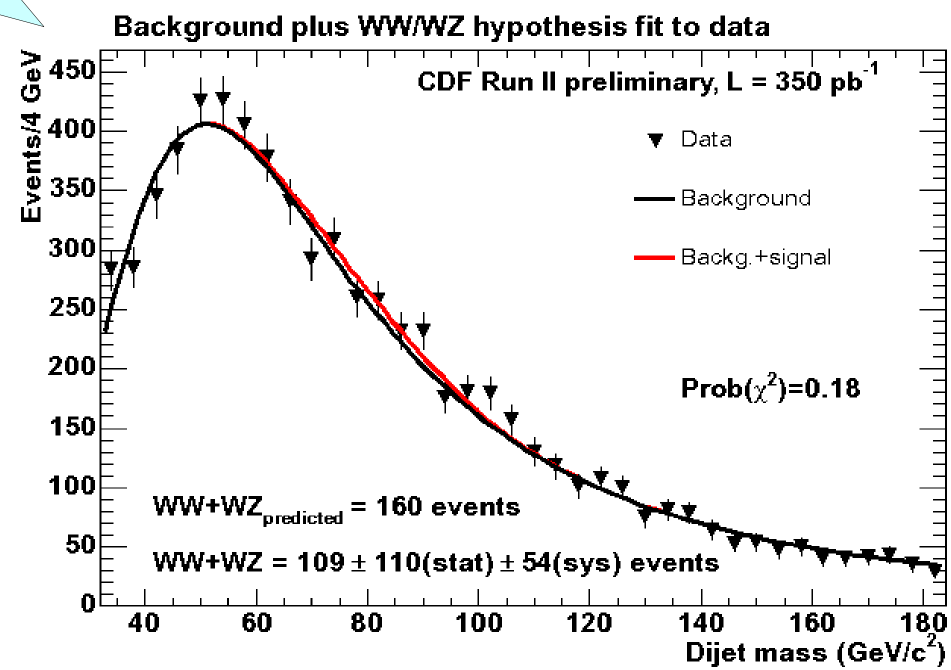
New!





- Fit signal and background di-jet mass shape to data.





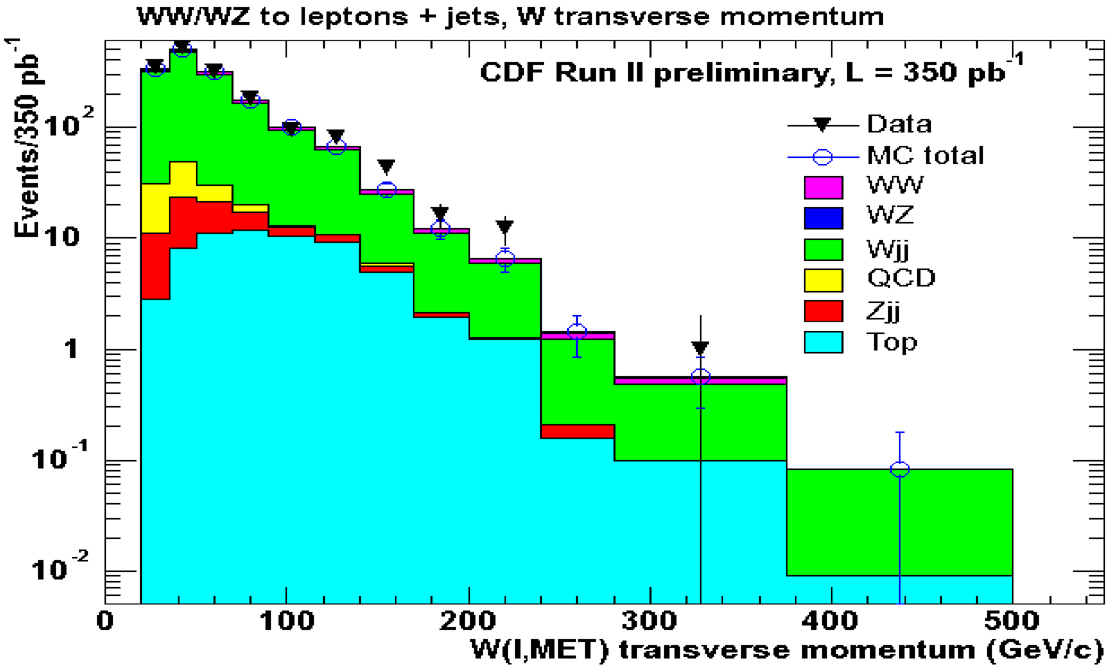
σ(WW+WZ) < 36 pb (95% C.L.)

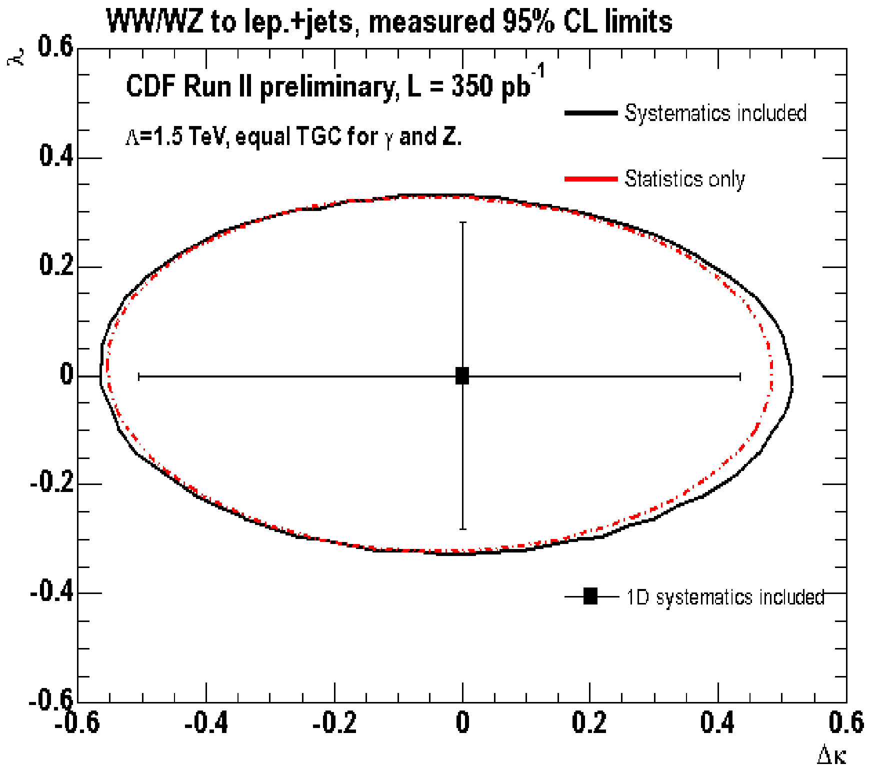
Anomalous Couplings: WW/WZ→lνjj

W pt found to be most sensitive for anomalous coupling limits

W pt formed using lepton pt and MET (ν)

Full spectrum fit for AC hypothesis and used in setting limits





Determined 1D 95% C.L. limits:

$(\Delta\kappa,\lambda)$=([-0.51,0.44],[0.28,0.28])

Summary/Outlook

Diboson cross section studied in:

- WW
- WZ/ZZ
- Wγ
- Zγ

in mainly leptonic channels, but also final states with jets

Limits on anomalous trilinear gauge couplings were determined
-> more on the way

Dibosons interesting on their own in studying EWK physics

but...

Looking forward to more diboson physics aiding in the search for higgs and NP