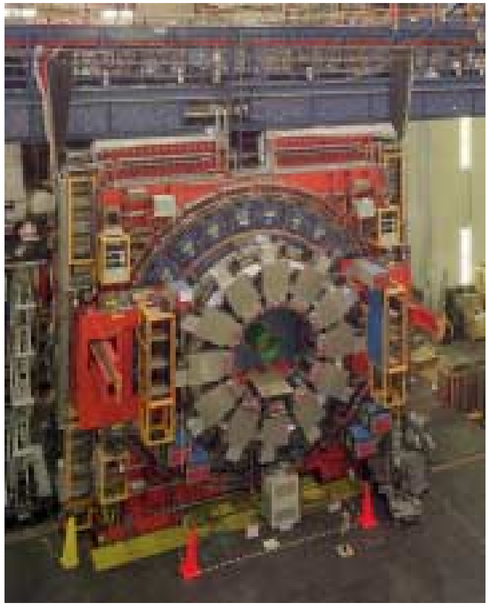
Measurement of Diboson Production at the Tevatron



Ivor Fleck
Universität Freiburg

for the CDF and DØ collaborations

Diboson production
- WW
- WZ/ZZ
- Wγ
- Zγ

anomalous couplings

- all measurements in RunII, i.e. $\sqrt{s}$ = 1.96 TeV
- (nearly) all measurements use only leptonic final states of W and Z bosons

Diboson Production

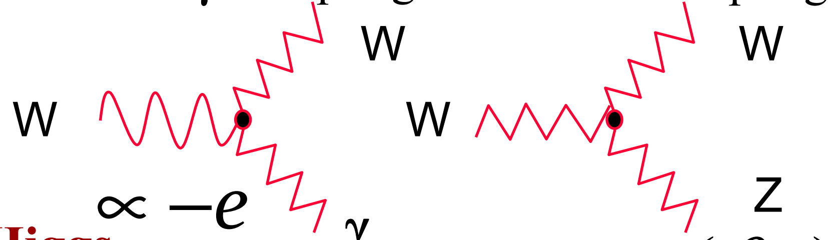
test of non-ablelian component of SM $SU(2)_L \times U(1)_Y$

sensitive for anomalous couplings

background for searches, especially Higgs

→ understanding important

WWγ Coupling WWZ Coupling

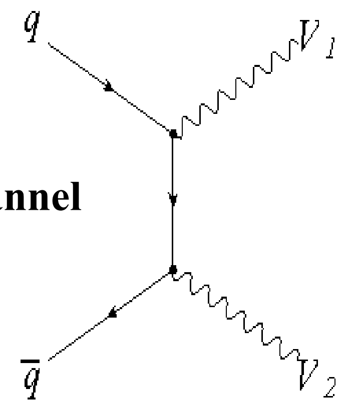


$\propto -e$ $\qquad \propto -e\cot(\theta_w)$

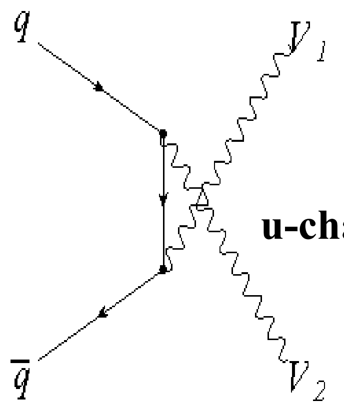
couplings: WWγ, WWZ,

forbidden: ZZγ, Zγγ

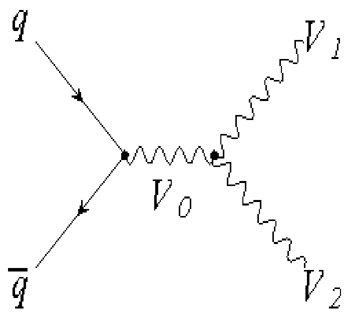
t-channel



u-channel



s-channel



t-channel: cross section violates unitarity for s → ∞

$$\sigma(W^+W^-) \propto \frac{G_F^2 s}{3\pi}$$

(for massless quarks and large s)

s-channel cancels unitarity violation in t- and u-channel for WW, WZ and Wγ production

WWγ and WWZ anomalous couplings

$$L_{WWV}/g_{WWV} = \boxed{g_V^1}\left(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}\right) + \boxed{\kappa_V} W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\boxed{\lambda_V}}{M_W^2} W^\dagger_{\lambda\mu} W^\mu_\nu V^{\nu\lambda}$$

V = Z or γ

$$\lambda(\hat{s}) = \frac{\lambda}{(1+\hat{s}/\Lambda^2)^n}$$

$n = 2$ for $WW\gamma, WWZ$

Λ : form factor to avoid unitarity violation at large s

SM: 5 CP conserving parameters:

$\lambda_Z = 0 \quad \lambda_\gamma = 0$

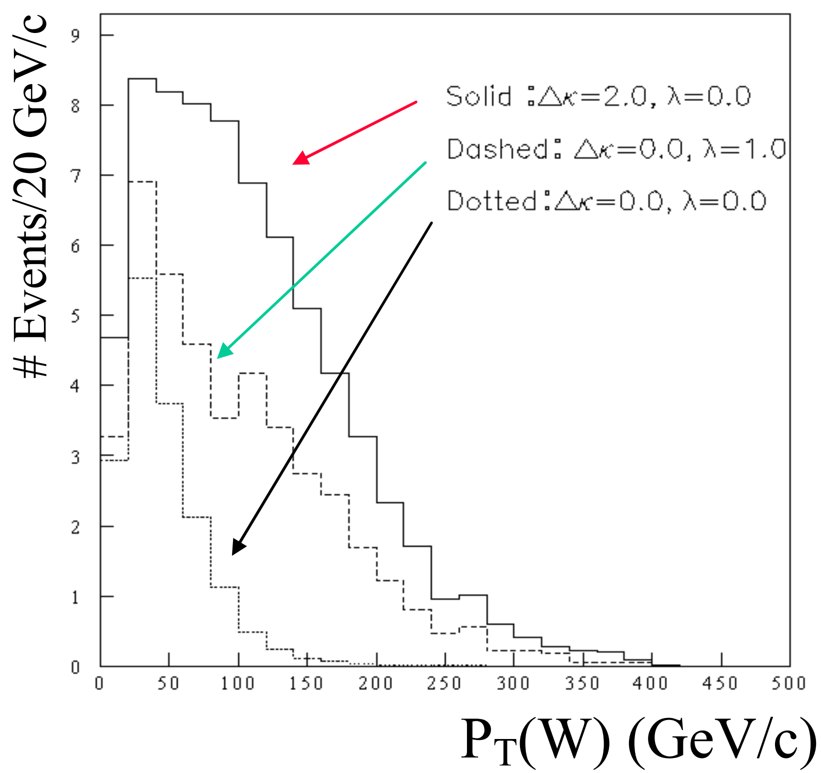
$\Delta\kappa_Z = 0 \quad \Delta\kappa_\gamma = 0 \qquad (\Delta\kappa = \kappa - 1)$

$\Delta g_1{}^Z = 0 \qquad (\Delta g_1{}^Z = g_1{}^Z - 1)$

in Wγ production, only WWγ couplings

in WZ production, only WWZ couplings

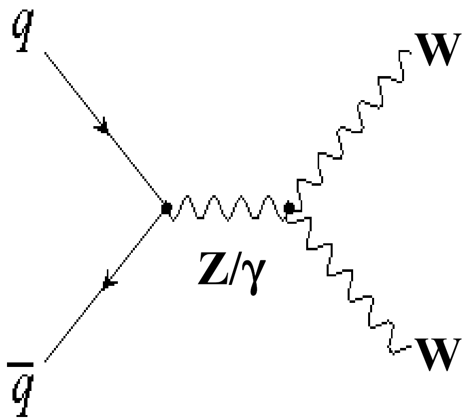
in WW production, both couplings



anomalous couplings lead to excess of events for large E_T of gauge bosons

WW Production

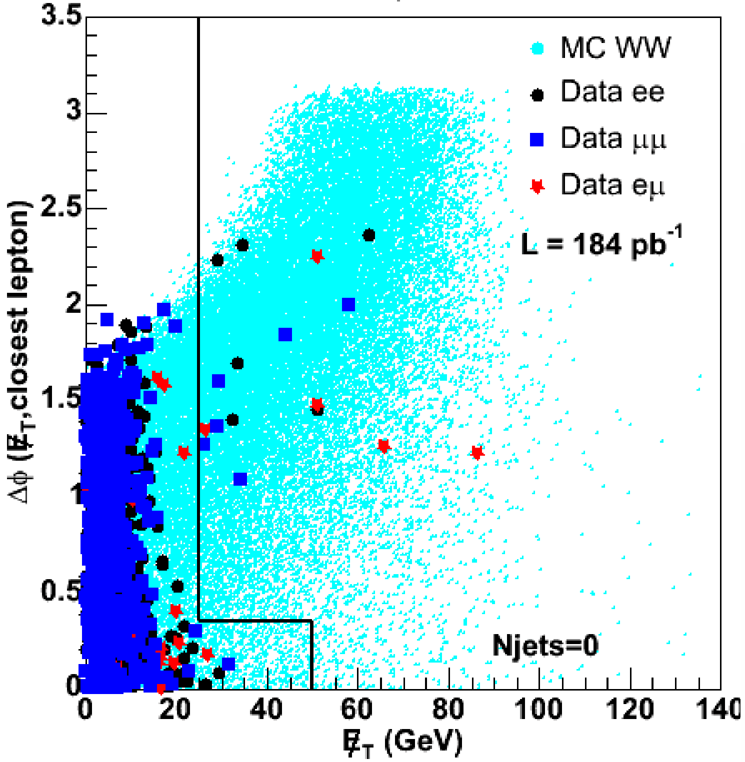
two triple gauge couplings present: WWZ and WWγ
(same final state also in Higgs production)
observed final states: dilepton events (ee, eμ,μμ) + missing E_T



event selection:

- two leptons (e or μ) with p_T > 20 (15) GeV
- $E_{T,miss}$ > 20 - 40 GeV
- Z boson veto

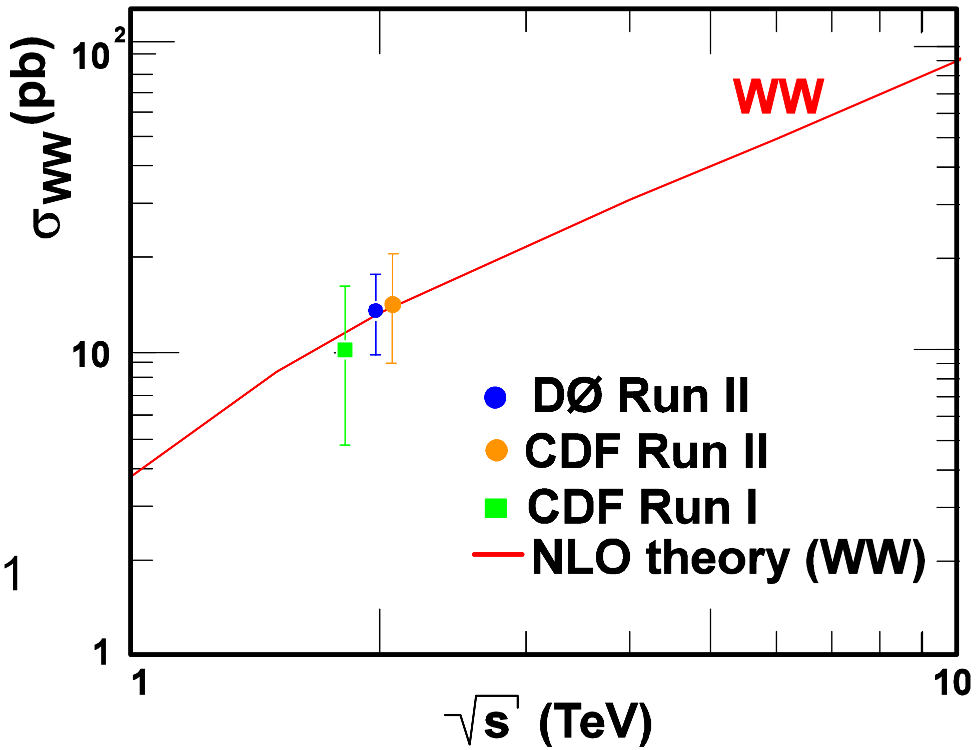
CDF hep-ex/0501050



Process	ee	$e\mu$	$\mu\mu$
WW signal	3.42 ± 0.05	11.10 ± 0.10	2.10 ± 0.05
$Z/\gamma^* \to ee$	0.20 ± 0.06	—	—
$Z/\gamma^* \to \mu\mu$	—	0.28 ± 0.09	1.60 ± 0.40
$Z/\gamma^* \to \tau\tau$	< 0.01	0.0 ± 0.1	< 0.01
$t\bar{t}$	0.18 ± 0.02	0.34 ± 0.03	0.09 ± 0.01
WZ	0.33 ± 0.17	0.38 ± 0.02	0.15 ± 0.08
ZZ	0.19 ± 0.06	0.02 ± 0.02	0.10 ± 0.04
W+jet/γ	1.40 ± 0.07	2.72 ± 0.07	0.01 ± 0.01
Multijet	< 0.05	0.07 ± 0.07	< 0.05
Background sum	2.30 ± 0.21	3.81 ± 0.17	1.95 ± 0.41
Data	6	15	4

WW cross section

NLO cross section: 12.4 ± 0.8 pb
(Campbell,Ellis, Phys.Rev. D60 (1999) 113006)



DØ: $L_{int} = 240\ pb^{-1}$
observe 25 events with
8.1 ± 0.85 ± 0.5(lum) background events

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

5.2 σ significance PhysRevLett **94**, 151801

CDF: $L_{int} = 184\ pb^{-1}$
two analyses: dilepton and lepton plus track, i.e. second lepton identified by track and does not have to meet lepton ID criteria
dilepton has better sensitivity
observe 17 events with 5.0 background events

$$\sigma = 14{,}6^{+5.8}_{-5.1}(stat)^{+1.8}_{-3.0}(syst) \pm 0.9(lum)\ pb$$

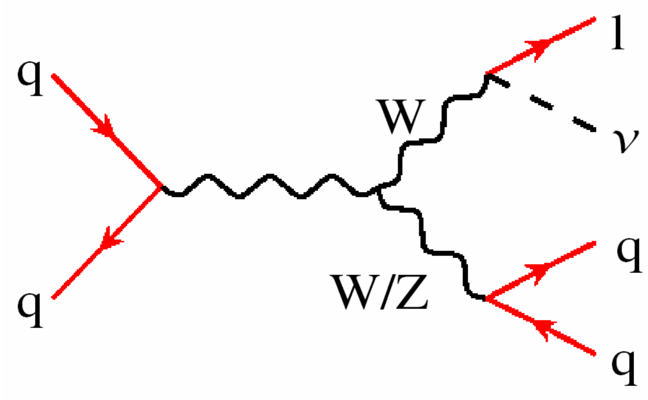
PhysRevLett **94**, 041803

WW in jets plus lepton final states

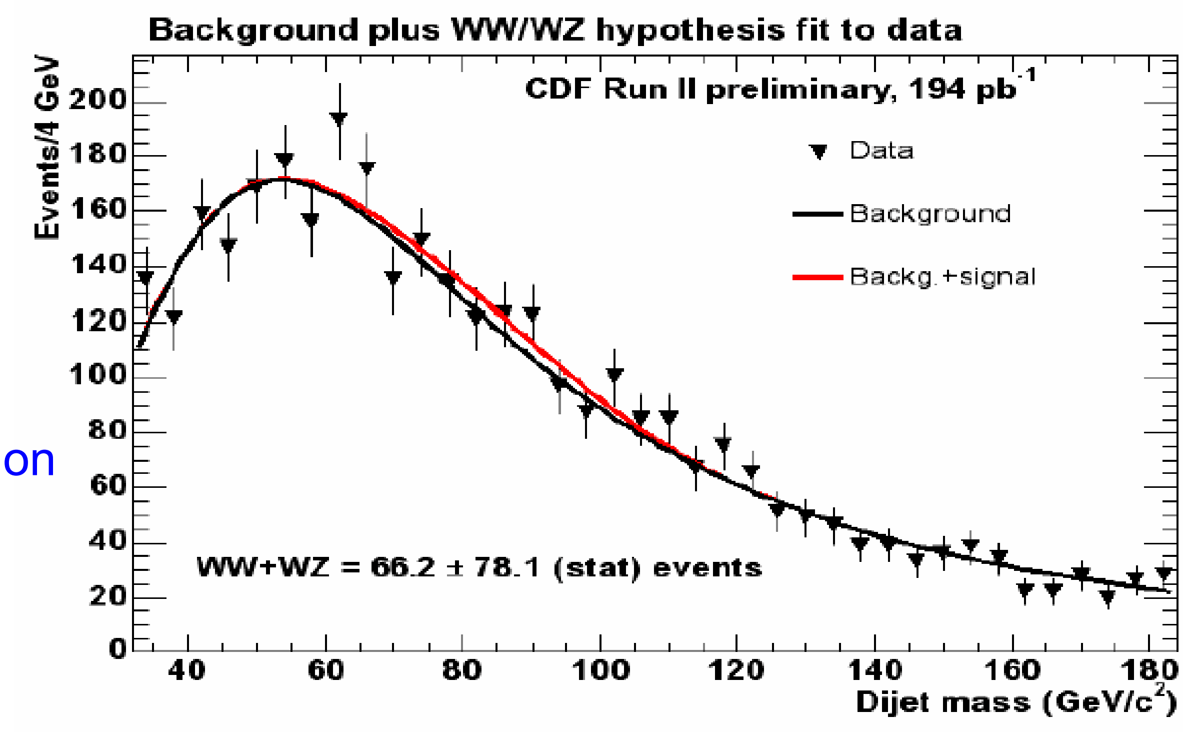
first analysis with W/Z decaying in jets

final state from W→ℓν and W/Z→qq

advantage: much larger branching ratio
disadvantage: much lager backgrounds



main background: W + 2jets production
fit background in sideband



fit in signal region yields:

observed 66 ± 78 ± 34 events
with 91 events signal expectation
σ < 40 pb at 95% CL

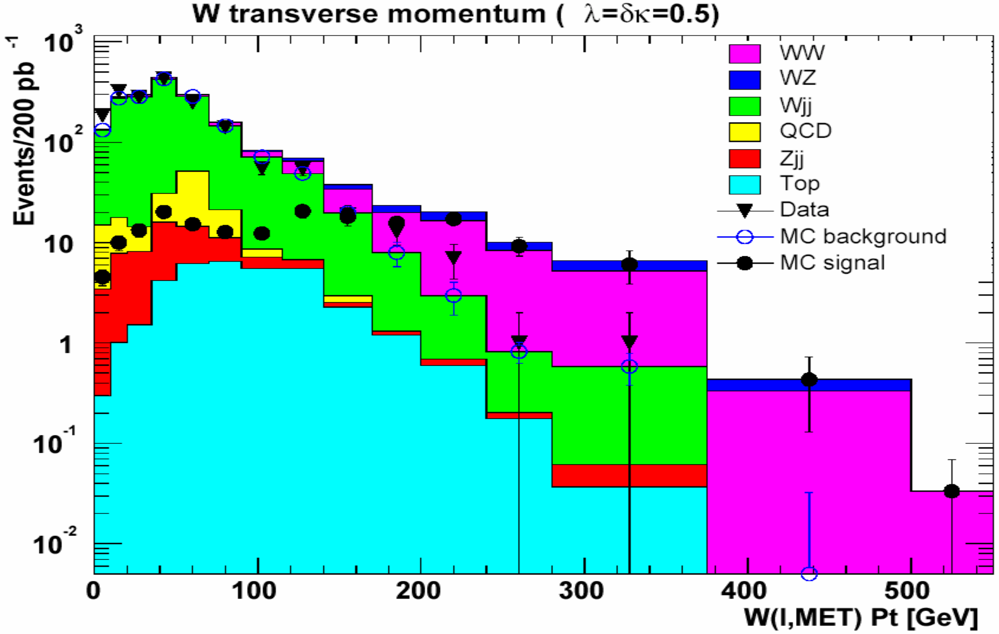
anomalous couplings limits from WW

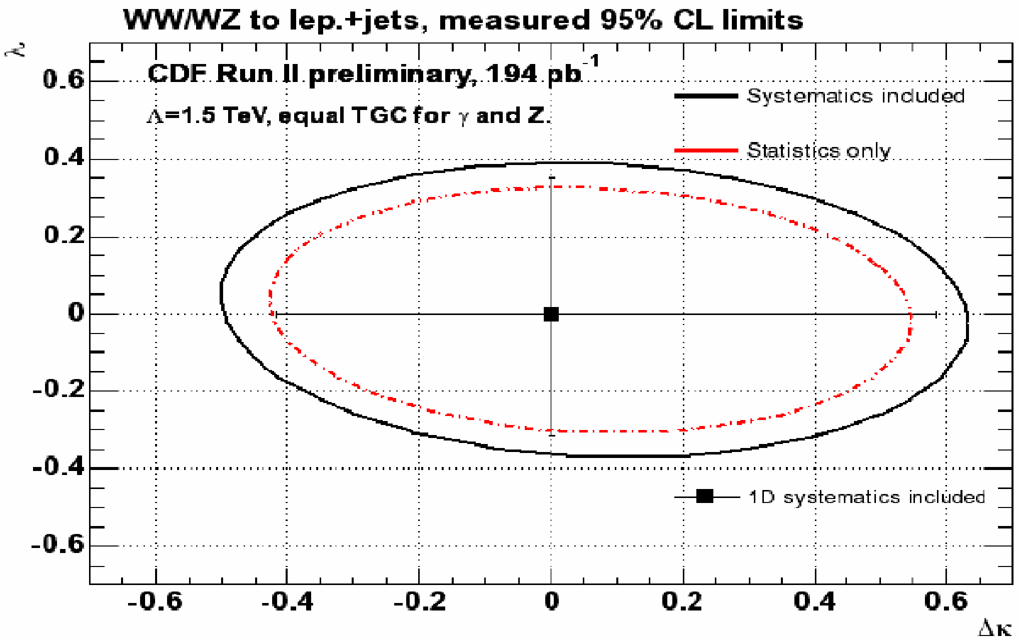
most sensitive variable for anomalous couplings: **p_T of W**

formed using lepton and $E_{T,miss}$ (ν)

anomalous couplings most visible at large p_T of W

figure shows signal with anomalous couplings $\lambda = \Delta\kappa = 0.5$





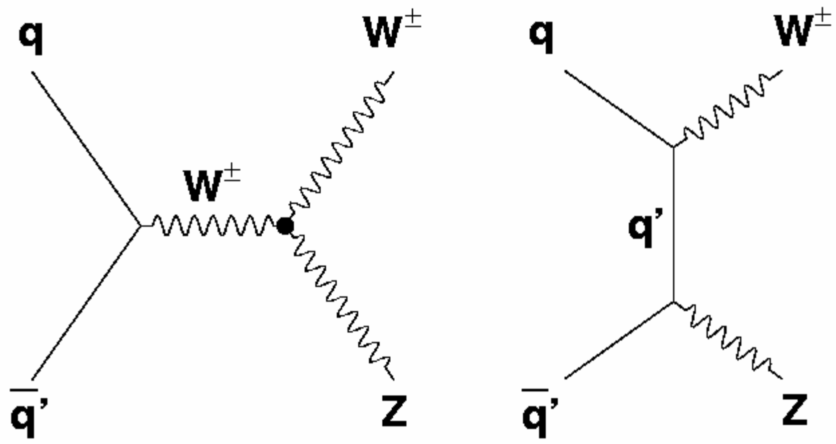
limits at 95% CL:

$-0.42 < \Delta\kappa < 0.58$

$-0.32 < \lambda < 0.35$

WZ Production

- -only single triple gauge coupling **WWZ**
- -LEP did not measure this vertex independently of WWγ vertex
- -Final state not observed elsewhere



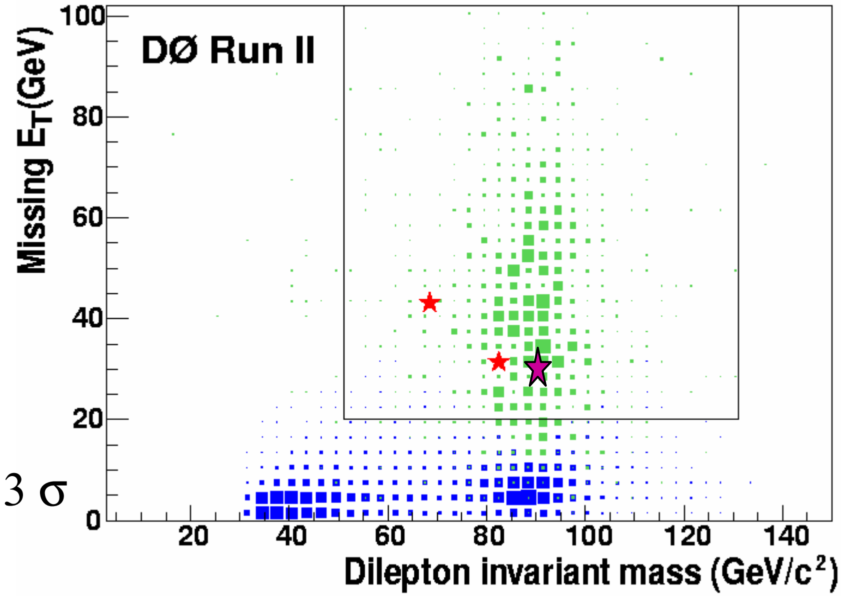
NLO cross section: 3.7 ± 0.1 pb

trilepton final states: eee, eeμ,μμe,μμμ
very low background, very low BR~1,5%

DØ: $L_{int} \approx 300\ pb^{-1}$, lepton p_T>15 GeV, missing E_T>20 GeV, lepton pair mass consistent with Z mass
observe: 3 events with 0.71 ± 0.08 background events and 2.04 signal expectation
main backgrounds:
- Z+jets: 0.35±0.02, Z+γ: 0.15±0.02, ZZ: 0.20±0.07

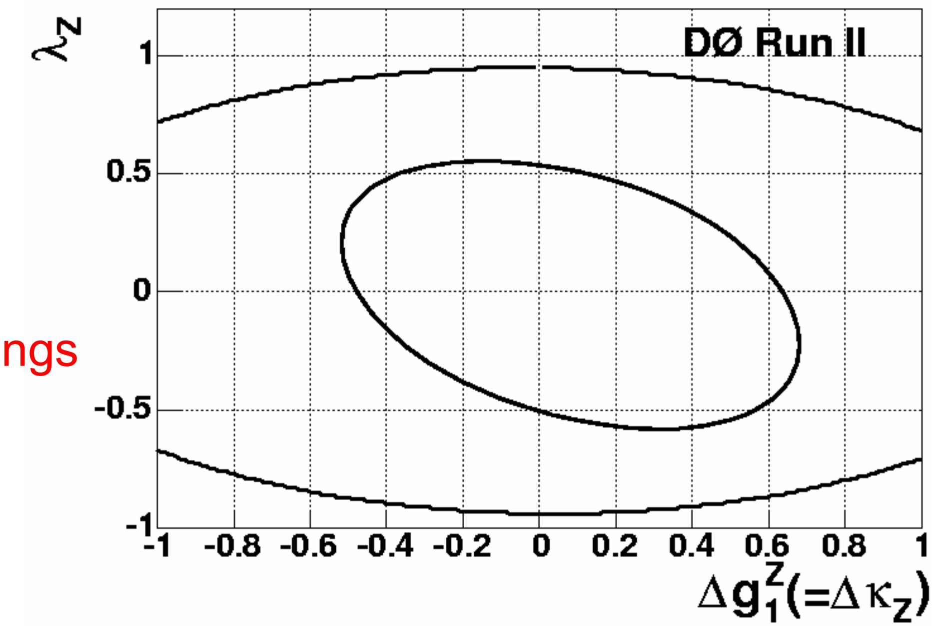
$$\sigma = 4{,}5^{+3{,}8}_{-2{,}6}(\text{stat}+\text{syst})\ \text{pb}$$

σ < 13.3 pb at 95%CL
probability of fluctuation 0.71 → 3 is 3.5 %, less than 3 σ
hep-ex/0504019, submitted to PRL



WZ Anomalous Couplings Limits

As no deviation from the SM expectation observed:
set limit on anomalous couplings



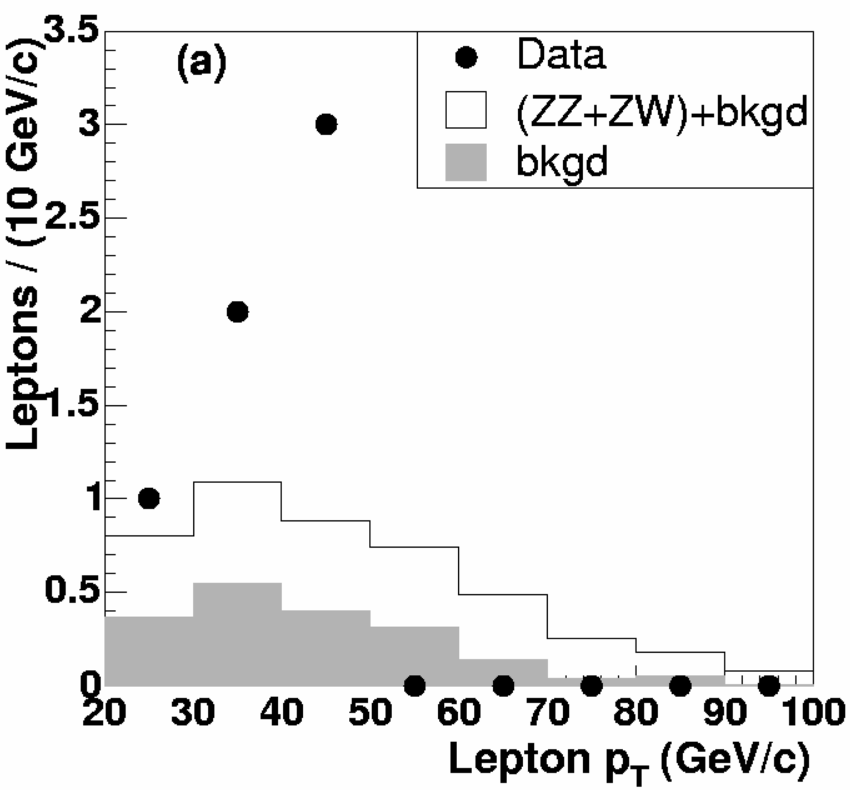
- inner limit from analysis at 95%CL for Λ = 1.5 TeV

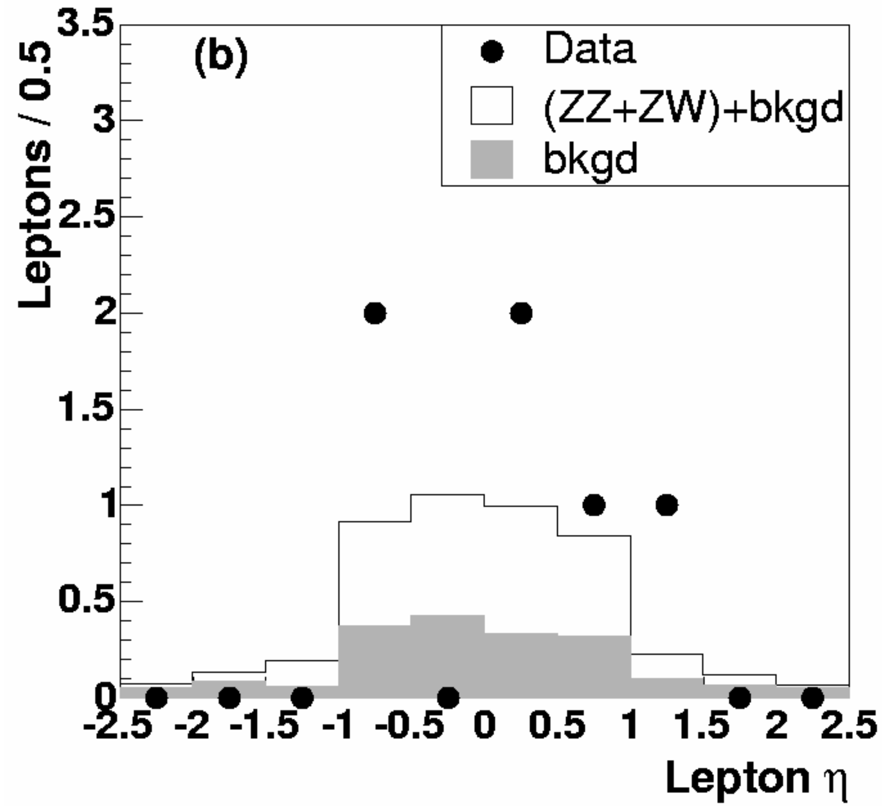
- outer limit from S-matrix unitarity

	$\Lambda = 1$ TeV	$\Lambda = 1.5$ TeV
$\Delta g_1^Z = \Delta\kappa_Z = 0$	$-0.53 < \lambda_Z < 0.56$	$-0.48 < \lambda_Z < 0.48$
$\lambda_Z = \Delta\kappa_Z = 0$	$-0.57 < \Delta g_1^Z < 0.76$	$-0.49 < \Delta g_1^Z < 0.66$
$\lambda_Z = 0$	$-0.49 < \Delta g_1^Z = \Delta\kappa_Z < 0.66$	$-0.43 < \Delta g_1^Z = \Delta\kappa_Z < 0.57$
$\lambda_Z = \Delta g_1^Z = 0$	$-2.0 < \Delta\kappa_Z < 2.4$	-

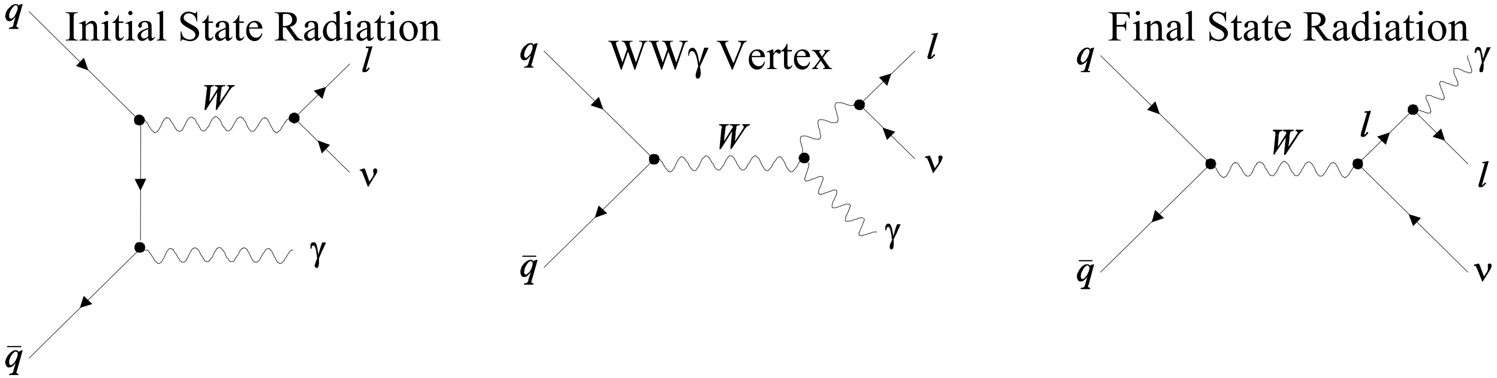
WZ/ZZ Production

CDF: search for ZW and ZZ combined with $L_{int} = 194\ pb^{-1}$
final states: $\ell\ell\ \nu\nu$, $\ell\ell\ \ell\ell$, $\ell\ell\ \ell\nu$
observe 3 events with background expectation of 1.0 ± 0.2 events and signal expectation of 2.3 ± 0.3 events
limit σ < 15.2 pb at 95%CL (PhysRev **D71**,091105)
(SM: σ = 5.0 ± 0.4 pb, σ(ZZ) = 1.39 ± 0.10pb, σ(ZW) = 3.65 ± 0.26 pb)
sensitive to neutral triple-gauge-couplings and WWZ couplings





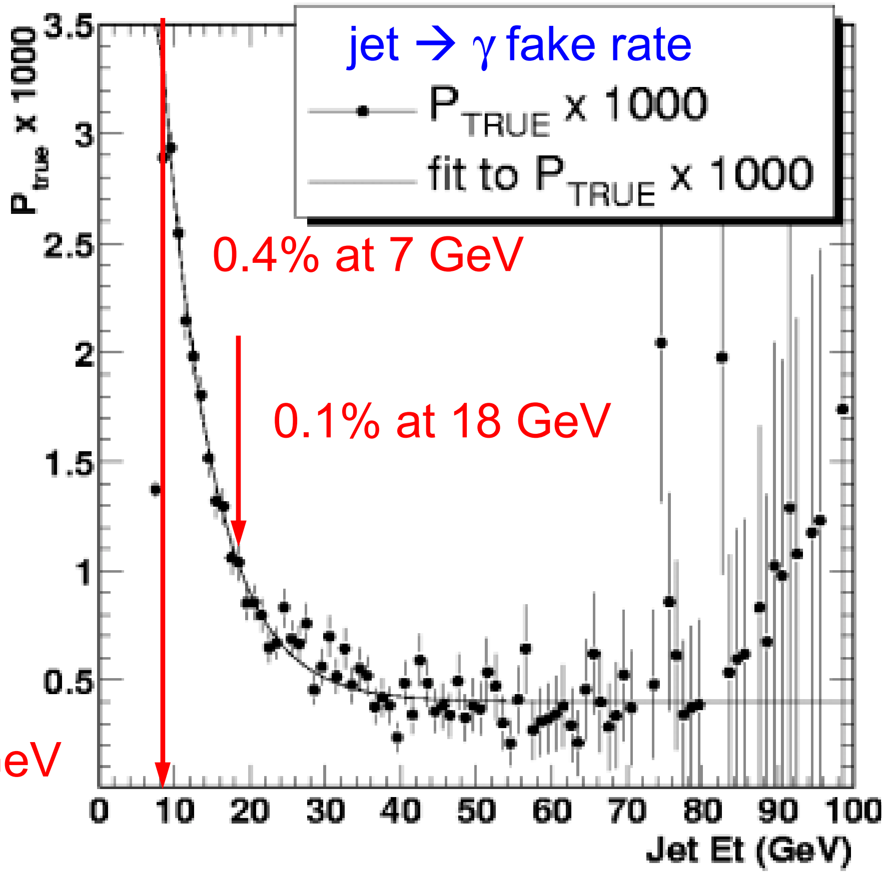
Wγ Produktion



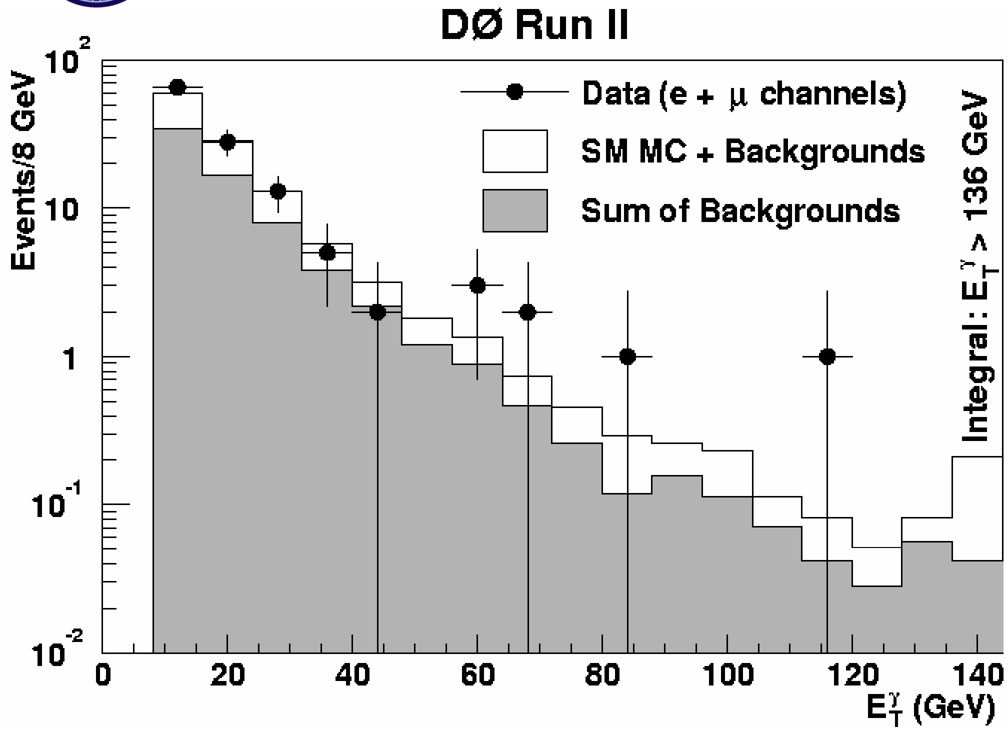
CDF: L_{int} = 200 pb^{-1}, W → eν, μν
$E_T(\gamma) > 7$ GeV, $|\Delta R(\ell,\gamma) > 0{,}7$
observe 323 events with
114 events background expectation

Theory (NLO): σ • BR (W→ ℓν) = 19,3 ± 1,4 pb
σ • BR (W→ ℓν) = 18,1 ± 3,1 pb
PhysRevLett **94**, 211801

main background source:
W+jet events: 87.1 of 114 background events
jet → γ fake rate:
0.4% at 7 GeV, 0.1% at 18 GeV, 0.04% >40 GeV



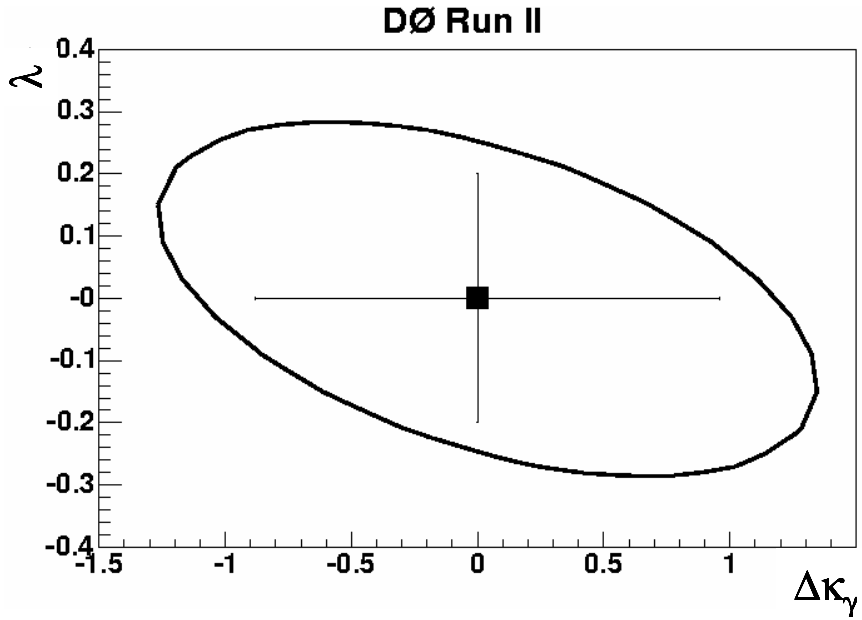
anomalous couplings limits from Wγ



DØ: $L_{int} \approx 150\ pb^{-1}$, W → eν, μν
E^γ_T > 8 GeV, ΔR(ℓγ) > 0.7
Theory: σ • BR (W→ ℓν) = 16.0 ± 0.4 pb
σ • BR (W→ ℓν) =
14.8 ± 1.6(stat) ± 1.0(syst) ± 1.0(lumi) pb
PhysRev D**71**, 091108

limits on anomalous couplings using binned likelihood on photon E_T spectrum

limits calculated for $M_T(W,\gamma)$ > 90 GeV



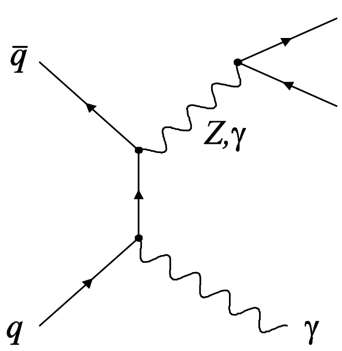
only single triple gauge coupling **WWγ**

D0: limits for anomalous couplings:
1D limits at 95% CL

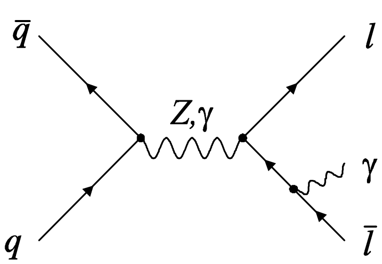
$$-0.88 < \Delta\kappa_\gamma < 0.96$$
$$-0.20 < \lambda_\gamma < 0.20$$

Zγ Produktion

Initial State Radiation

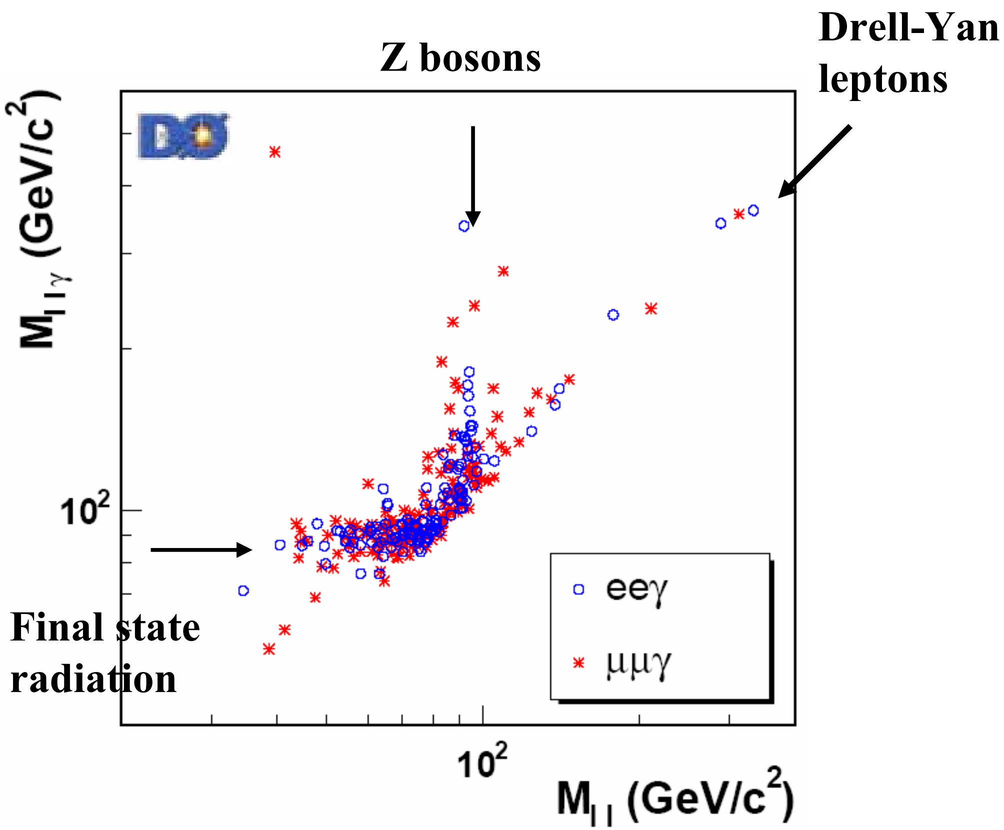


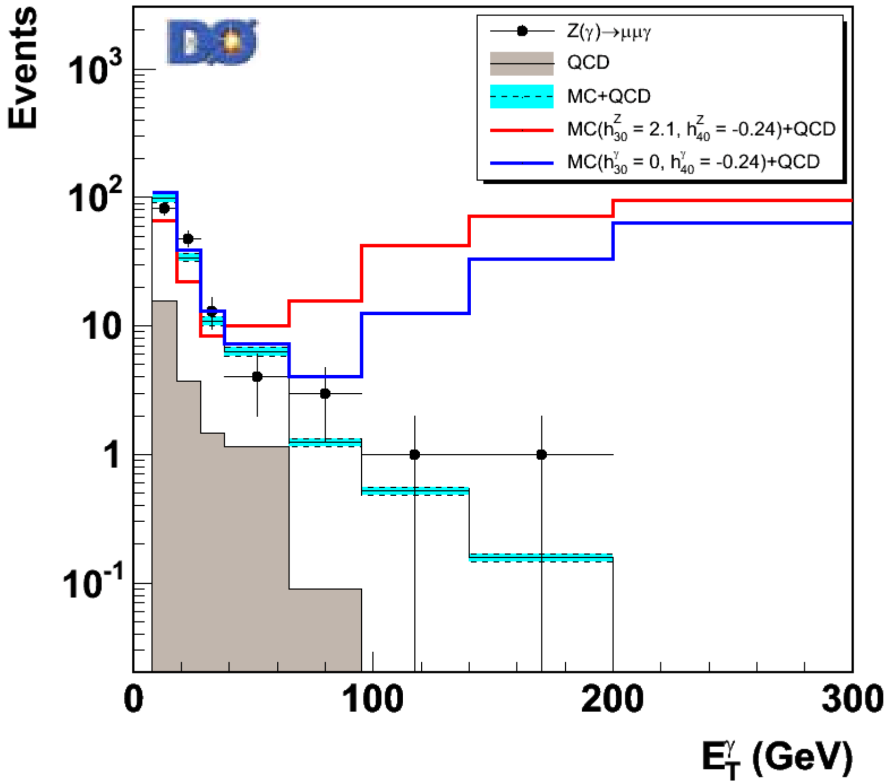
Final State Radiation



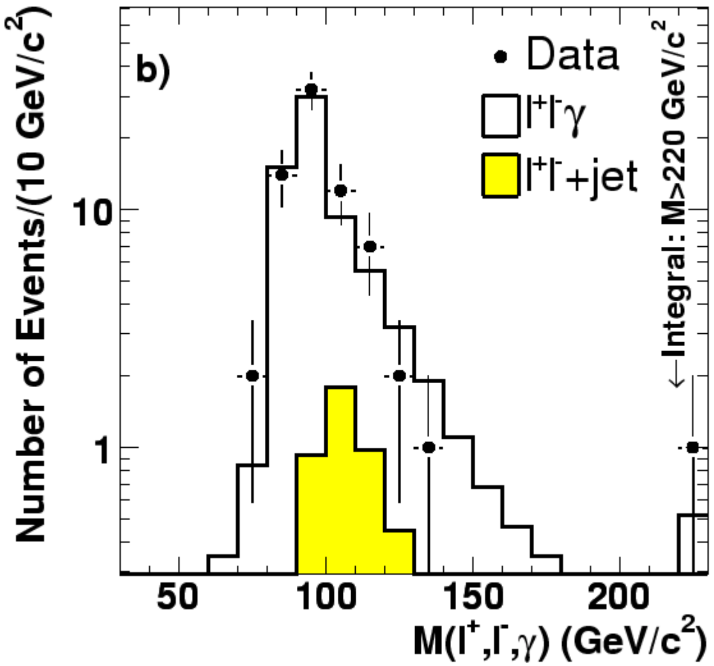
neutral triple gauge couplings
(ZZZ, ZZγ, Zγγ, γγγ)
are forbidden in SM

new couplings would show as high E_T bosons





Zγ Production Cross Sections



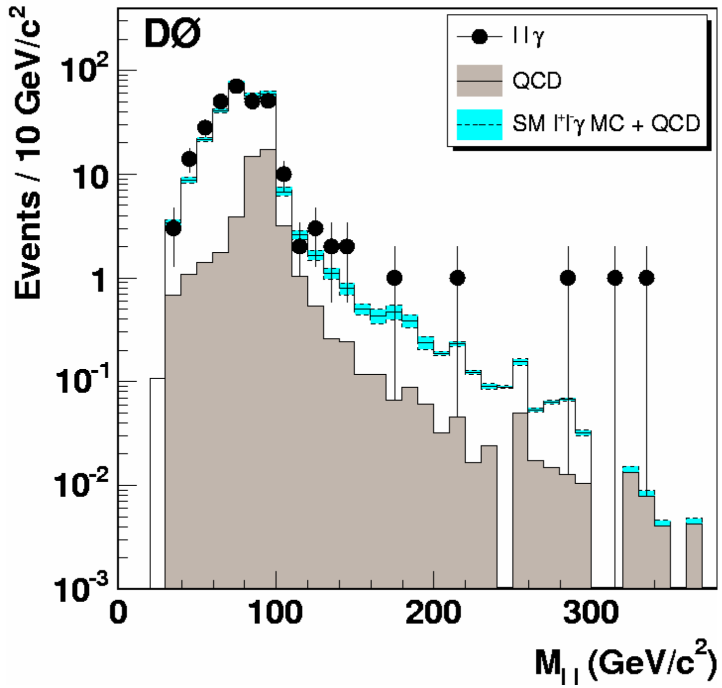
CDF: Z→ ee, μμ L_{int} ~ 200 pb^{-1}
$M_{\ell\ell}$> 40 GeV/c^2
$E_T(\gamma)$ > 7 GeV, ΔR (ℓγ) > 0.7

MC: σ x BR(Z→$\ell^+\ell^-$) = 4.5 ± 0.3 pb
(Baur and Berger)
71 events with 4.9 events background
measurement: σ = 4.6 ± 0.6 pb
PhysRevLett **94**, 211801

DØ: Z→ ee, μμ L_{int} ~ 300 pb^{-1}
$M_{\ell\ell}$> 30 GeV/c^2
$E_T(\gamma)$ > 8 GeV, ΔR (ℓγ) > 0.7

MC: σ x BR(Z→$\ell^+\ell^-$) = 3.9 ± 0.15 pb
(Baur and Berger)

290 events with 45 events background
σ = 4.2 ± 0.4 (stat +syst) ± 0.3 (lumi) pb
hep-ex/0502036



$Z\gamma$ Anomalous Coupling Limits

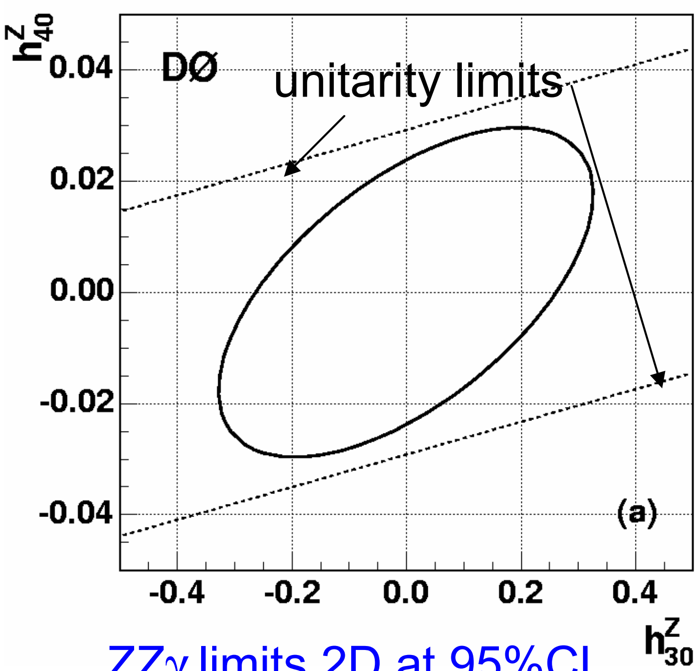
Non-SM characterized by an effective Lagrangian with 8 form-factor coupling parameters called h_1^V, h_2^V, h_3^V, and h_4^V where V stands for γ and Z.

CP violating h_1^V and h_2^V

CP conserving h_3^V and h_4^V

SM: all couplings equal to zero

Limits on CP conserving and CP violating couplings found to be similar, same for real and imaginary part



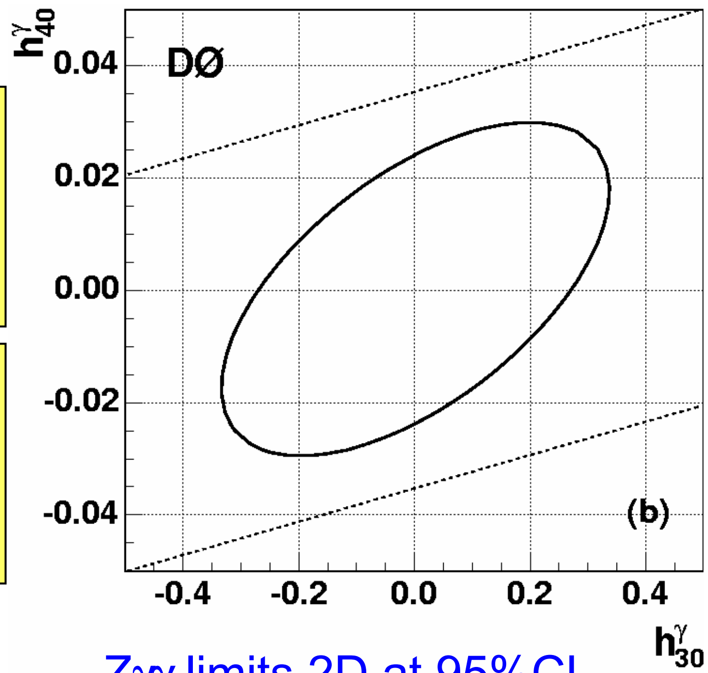
ZZγ limits 2D at 95%CL

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

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

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

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



Z$\gamma\gamma$ limits 2D at 95%CL

Comparison with LEP

LEP: $e^+ e^- \rightarrow Z/\gamma^* \rightarrow Z\gamma$

$$-0.056 < h_{10}^{\gamma} < 0.055$$
$$-0.045 < h_{20}^{\gamma} < 0.025$$
$$-0.049 < h_{30}^{\gamma} < 0.008$$
$$-0.002 < h_{40}^{\lambda} < 0.034$$

$$-0.13 < h_{10}^{Z} < 0.13$$
$$-0.078 < h_{20}^{Z} < 0.071$$
$$-0.20 < h_{30}^{Z} < 0.07$$
$$-0.05 < h_{40}^{Z} < 0.12$$

LEP: 2001 results

2005 results slightly different, but no limits calculated

$$0.944 < g_1^Z < 1.035$$
$$0.786 < \kappa_\gamma < 1.009$$
$$-0.069 < \lambda_\gamma < 0.026$$

limits for couplings WWZ and WWγ from LEP much stronger than from Tevatron

DØ has most restrictive limits in "h_2" and "h_4"

LEP has most restrictive limits in "h_1" and "h_3"

Summary

- cross sections in diboson production of
- **WW**
- **WZ/ZZ**
- **Wγ**
- **Zγ**

have been measured in leptonic final states

- first studies of lepton plus jets final states started

- limits on anomalous couplings

some better than results from LEP