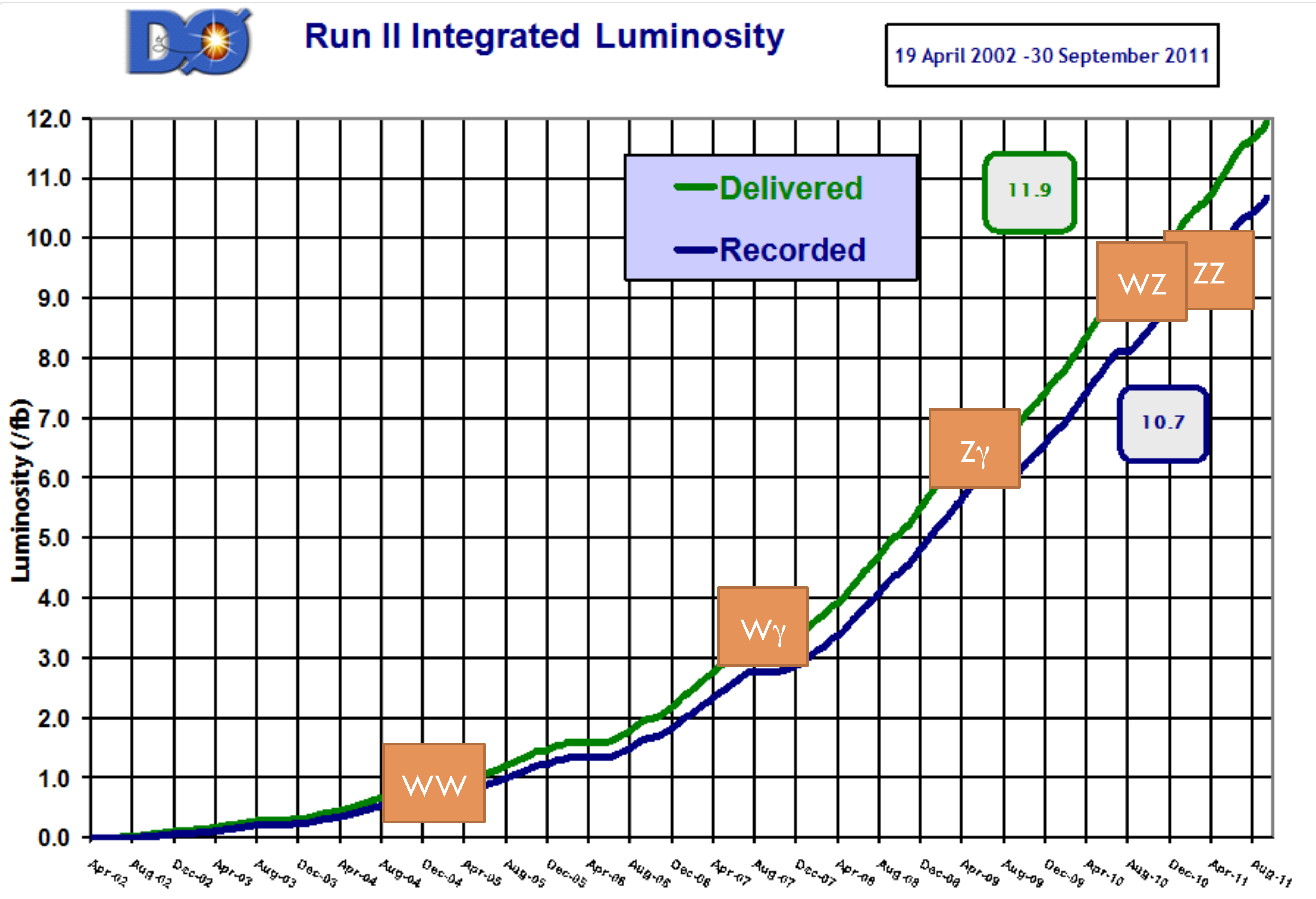
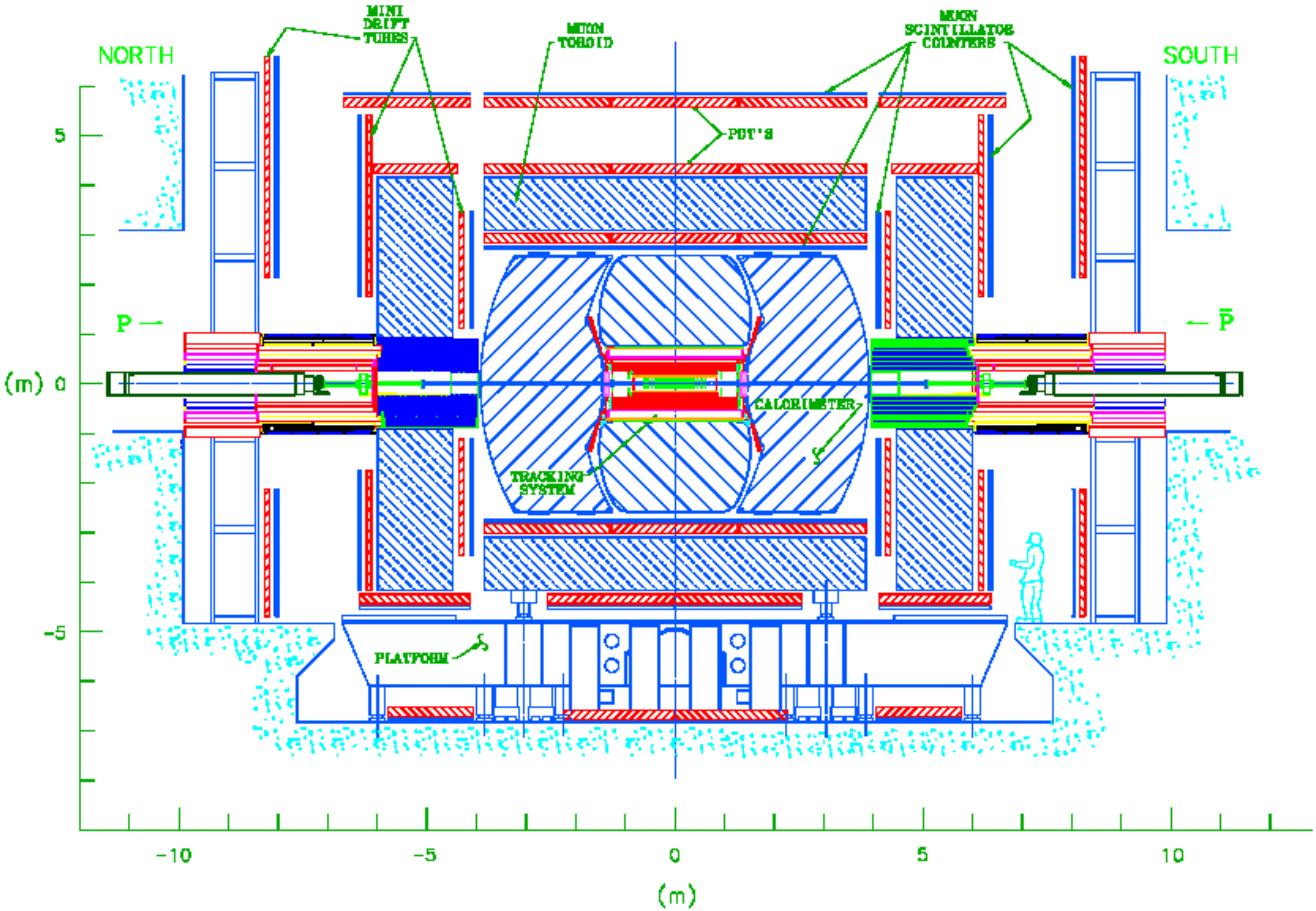
DI-BOSONS AND ANOMALOUS COUPLINGS AT D0

Heidi Schellman, Northwestern University

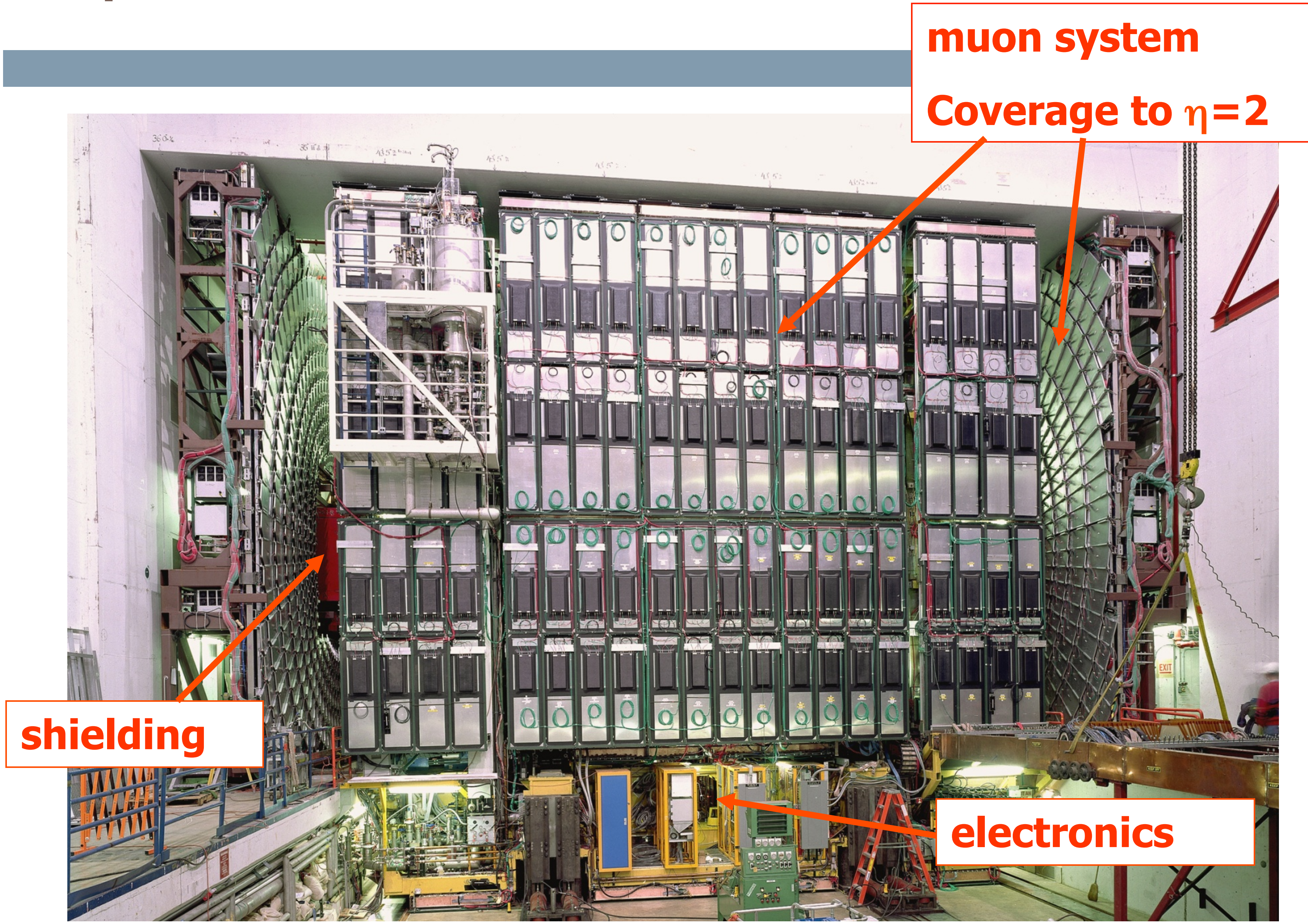

Run II Integrated Luminosity
19 April 2002 -30 September 2011
Delivered
Recorded
11.9
10.7
WW
Wγ
Zγ
WZ
ZZ
Luminosity (/fb)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Apr-02 Aug-02 Dec-02 Apr-03 Aug-03 Dec-03 Apr-04 Aug-04 Dec-04 Apr-05 Aug-05 Dec-05 Apr-06 Aug-06 Dec-06 Apr-07 Aug-07 Dec-07 Apr-08 Aug-08 Dec-08 Apr-09 Aug-09 Dec-09 Apr-10 Aug-10 Dec-10 Apr-11 Aug-11

DØ Detector

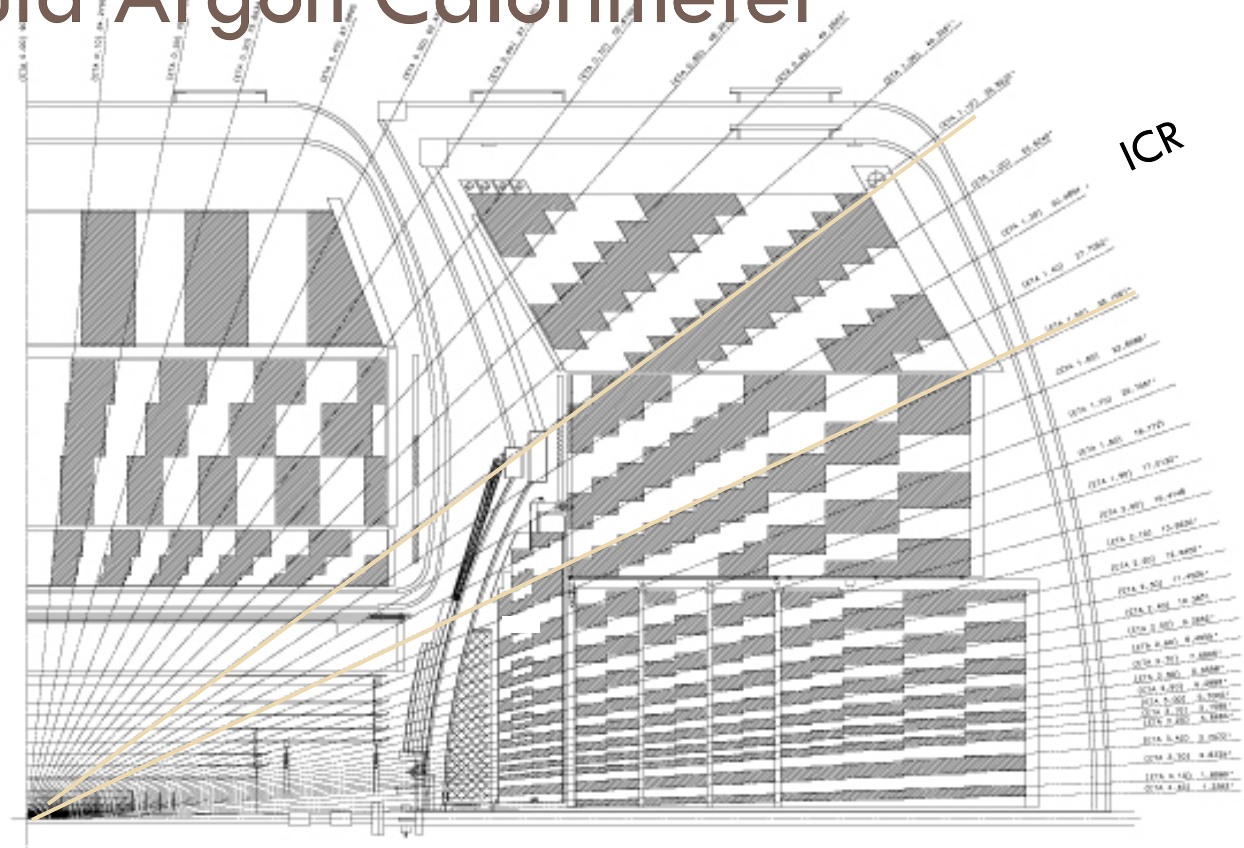


MINI DRIFT TUBES
MUON TOROID
MUON SCINTILLATOR COUNTERS
NORTH
SOUTH
PDT'S
P →
← P̄
CALORIMETER
TRACKING SYSTEM
PLATFORM
5
(m) 0
-5
-10
-5
0
5
10
(m)

Lepton ID in the DØ Detector



Liquid Argon Calorimeter



η=1.1

η=1.5

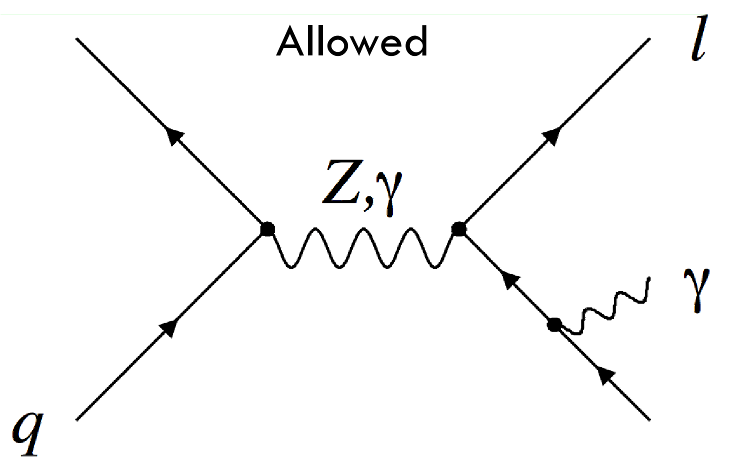
- Liquid argon active medium and uranium/copper absorber
- Hermetic with coverage for: $|\eta| < 4.2$
- Longitudinal and Transverse segmentation $\Delta\eta \times \Delta\varphi \times X^0 = 0.1 \times 0.1 \times \sim 1$

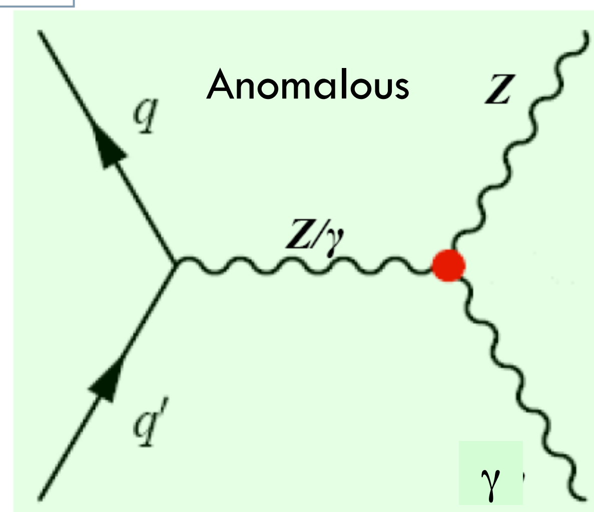
  (0.05x0.05 in third EM layer, near shower maximum)

Lagrangian for neutral (ZZγ/Zγγ)

$$L_{\gamma ZV} = -ie\left[\left(h_1^{\nu}F^{\mu\nu} + h_3^{\nu}\tilde{F}^{\mu\nu}\right)Z_\mu \frac{\left(\square + m_V^2\right)}{M_Z^2} V_\mu + \left(h_2^V F^{\mu\nu} + h_4^V \tilde{F}_{\mu\nu}\right) Z^\alpha \frac{\left(\square + m_V^2\right)}{M_Z^4} \partial_\alpha \partial_\mu V_\nu\right]$$

CP conserving → $h_{3,4}^V$ couplings (V = γ, Z)





$\Delta \neq 0$
ANOMALOUS
COUPLINGS

SM : $h_{3,4}^V = 0$

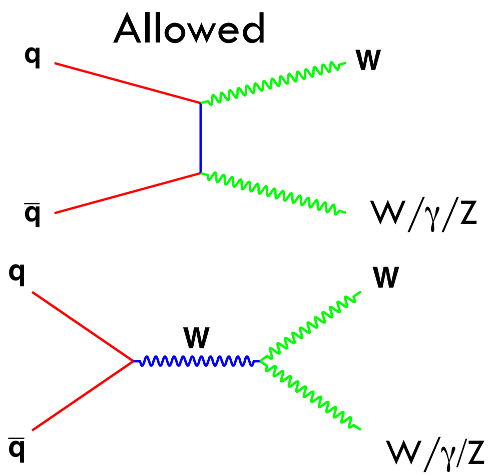
SM Deviations : $\Delta h_{3,4}^V = h_{3,4}^V - 0$

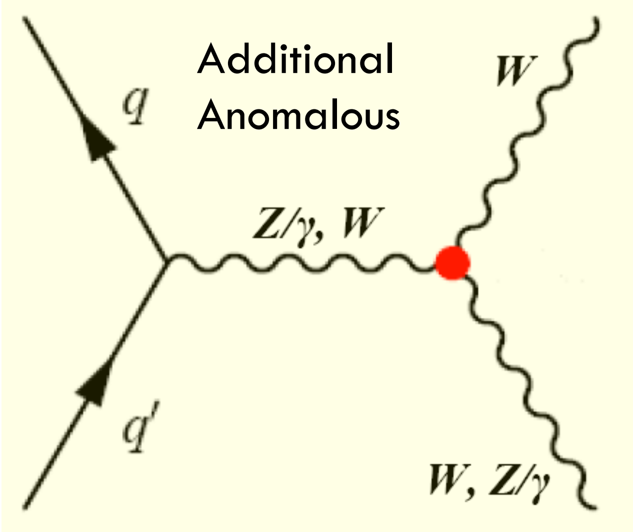
Lagrangian for charged (WWγ/WWZ)

$$\frac{L_{WWV}}{g_{WWV}} = ig_1^V\left(W^*_{\mu\nu}W^\mu V^\nu - W^*_\mu V_\nu W^{\mu\nu}\right) + i\kappa_V W^*_\mu W_\nu V^{\mu\nu} + i\frac{\lambda_V}{M_W^2} W^*_{\lambda\mu} W^\mu_\nu V^{\nu\lambda}$$

$$-g_4^V W^*_\mu W_\nu\left(\partial^\mu V^\nu + \partial^\nu V^\mu\right) + g_5^V \varepsilon^{\mu\nu\lambda\rho}\left(W^*_\mu \partial_\lambda W_\nu - \partial_\lambda W^*_\mu W_\nu\right) V_\rho + i\tilde{k}_V W^*_\mu W_\nu \tilde{V}^{\mu\nu} + i\frac{\tilde{\lambda}_V}{M_W^2} W^*_{\lambda\mu} W^\nu_\mu \tilde{V}^{\nu\lambda}$$

EM gauge inv. ($g_1^\gamma = 1$), C and P conserving ⇒ 5 couplings: κ_V, λ_V, g_1^Z





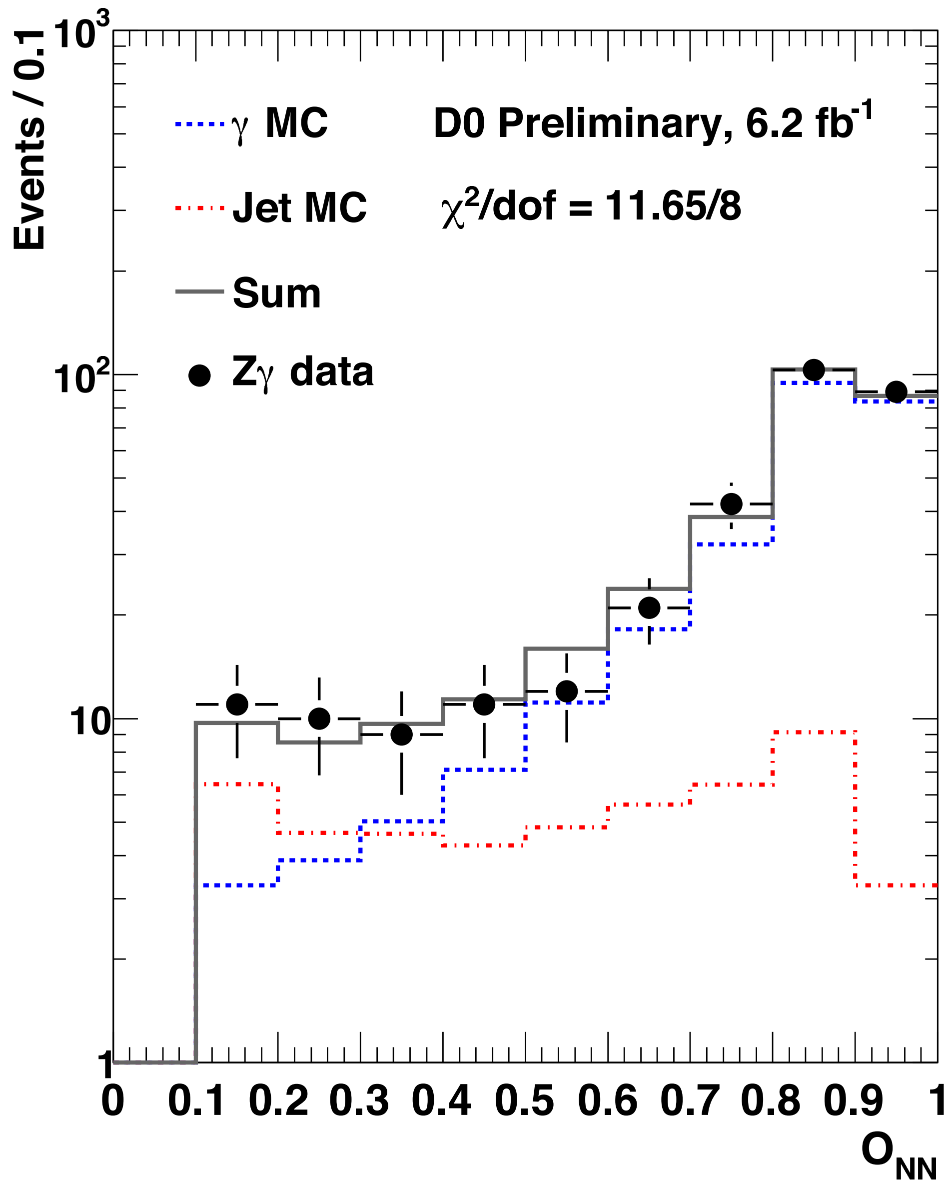
$\Delta \neq 0$
ANOMALOUS COUPLINGS

SM : $g_1^Z = \kappa_V = 1, \ \lambda_V = 0$

SM Deviations: $\Delta g_1^Z = g_1^Z - 1, \ \Delta\kappa_V = \kappa_V - 1, \Delta\lambda_V = \lambda_V - 0$

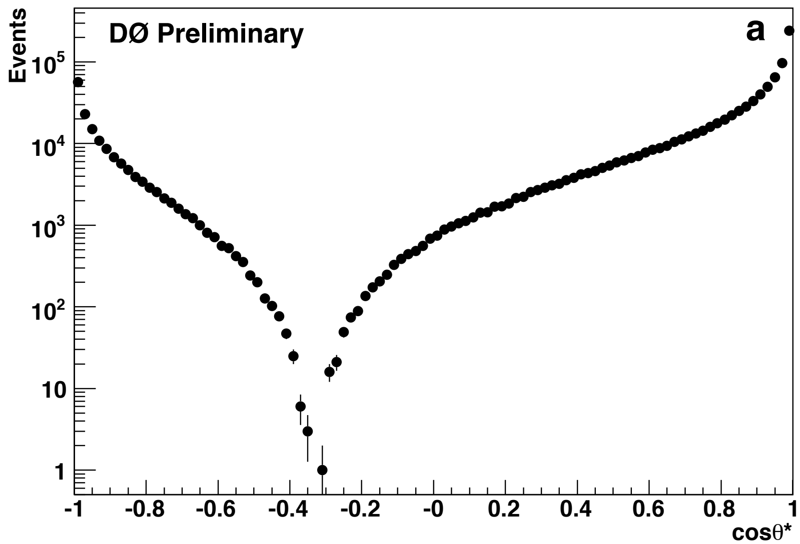
Wγ and Zγ

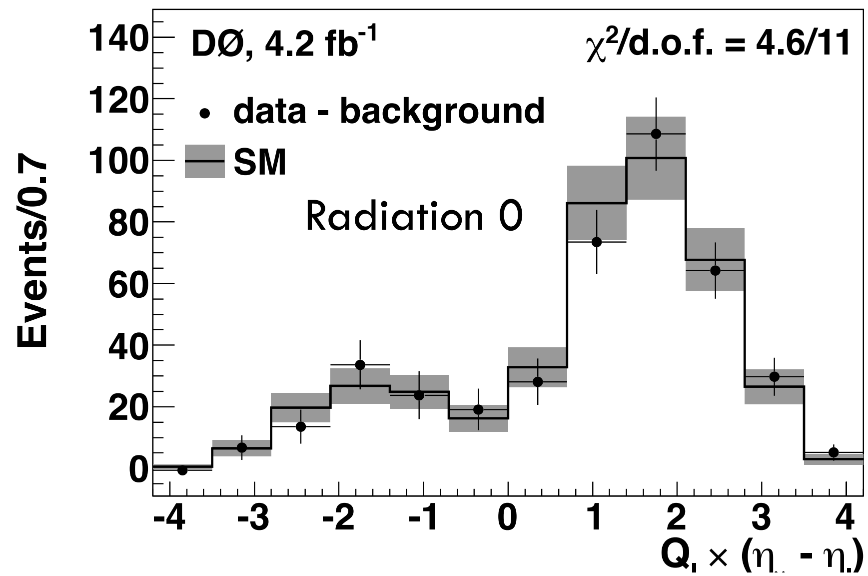
- D0 has excellent photon identification due to fine transverse and longitudinal segmentation in the calorimeter.
- Neural network discriminant yields > 90% purity in Zγ

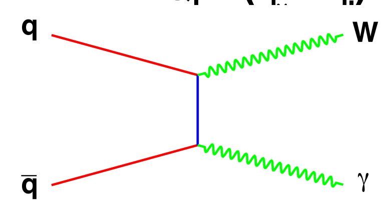


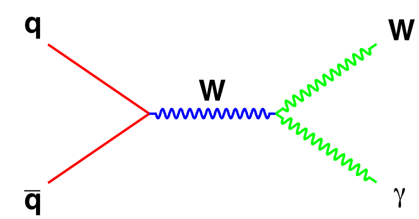
$W\gamma \rightarrow l\nu\gamma$ Production

PRL 107, 241803 (2011)







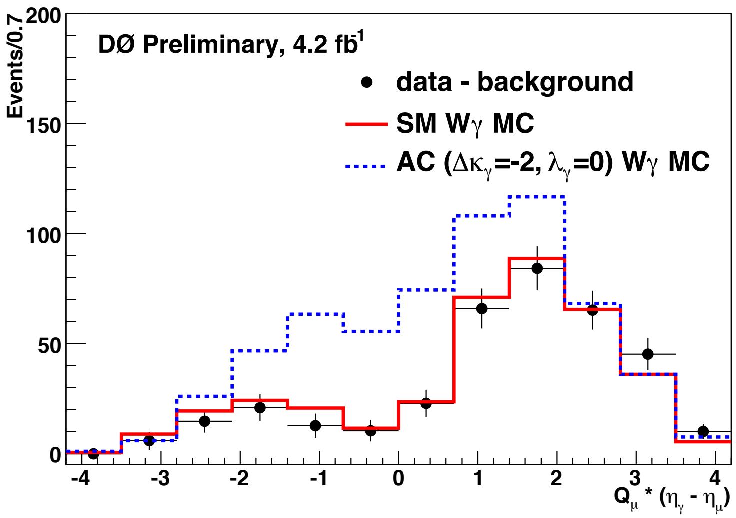


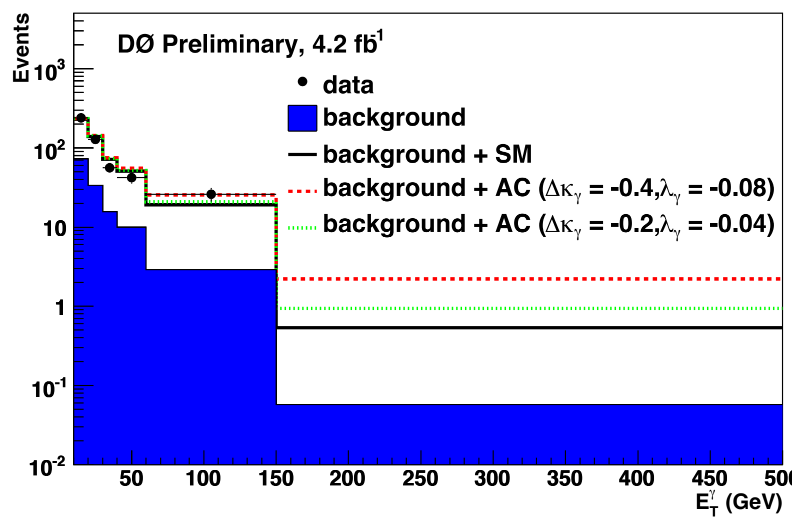
$$\sigma_{W\gamma} \times \mathbf{BR}(\mathbf{W} \rightarrow \mathbf{l}\upsilon) = \mathbf{7.6} \pm \mathbf{0.4}_{(\text{stat})} \pm \mathbf{0.6}_{(\text{syst})}\ \mathbf{pb}$$

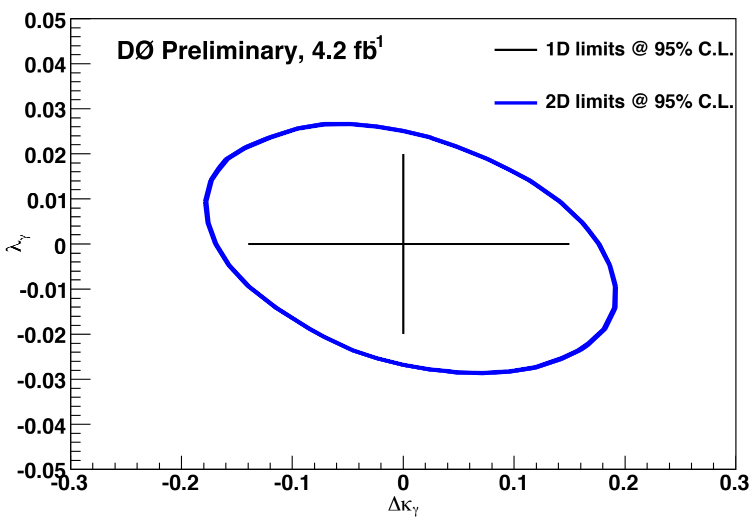
$$\text{SM@NLO}: \sigma = 7.6 \pm 0.2\,\text{pb}$$

(photon E_T > 15 GeV, $dR_{(l\gamma)}$ > 0.7)

Anomalous Wγ couplings







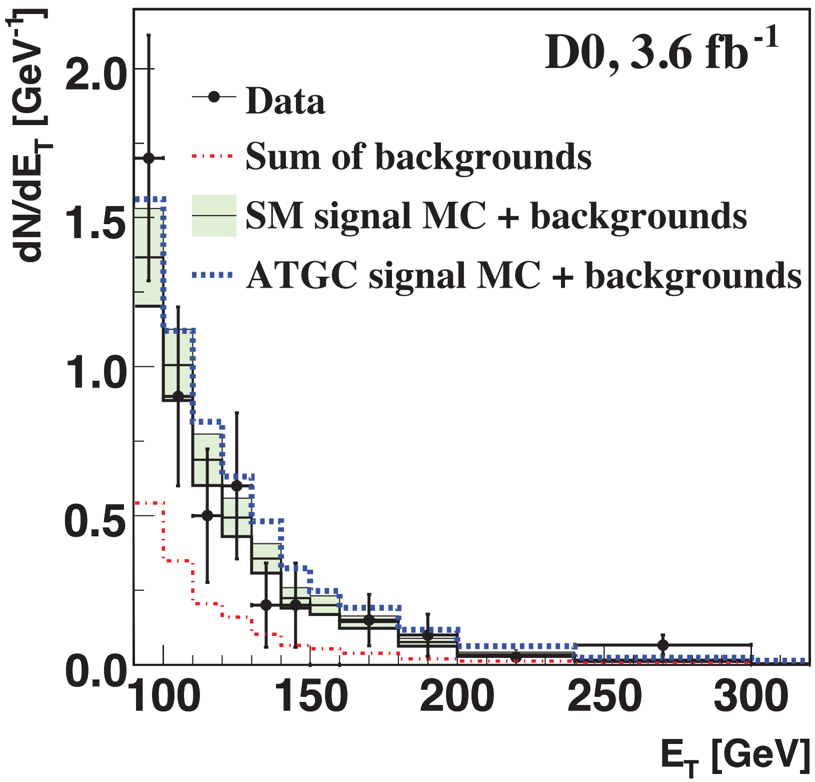
95% CL limits on TGCs:

$$-0.4 < \Delta\kappa_\gamma < 0.4, -0.08 < \lambda_\gamma < 0.07$$

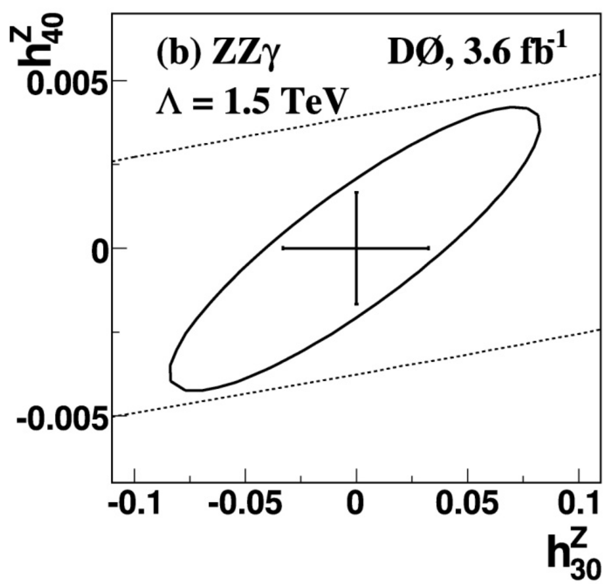
$Z\gamma \rightarrow \nu\nu\gamma$

Phys. Rev. Lett. 102, 201802 (2009)

Select interactions with large, significant Missing transverse momentum



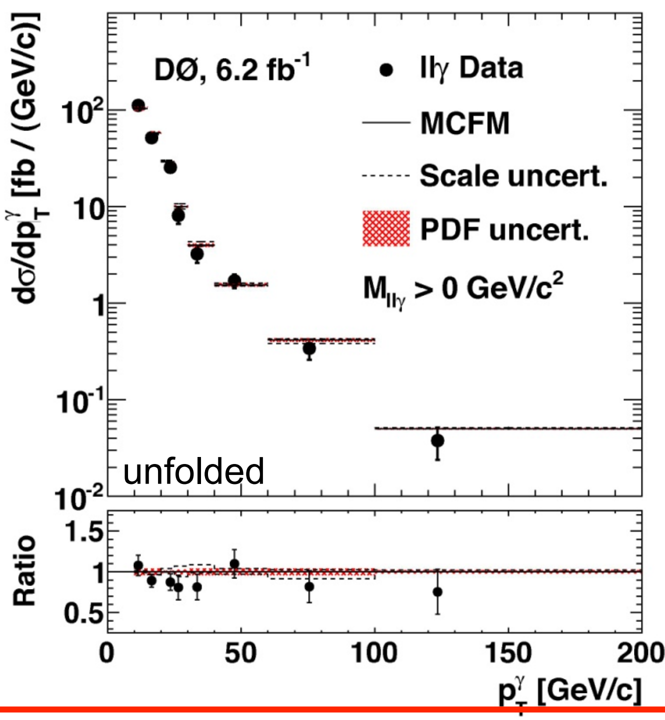
$Z\gamma \rightarrow \nu\nu\gamma$ avoids radiation off of the Z!

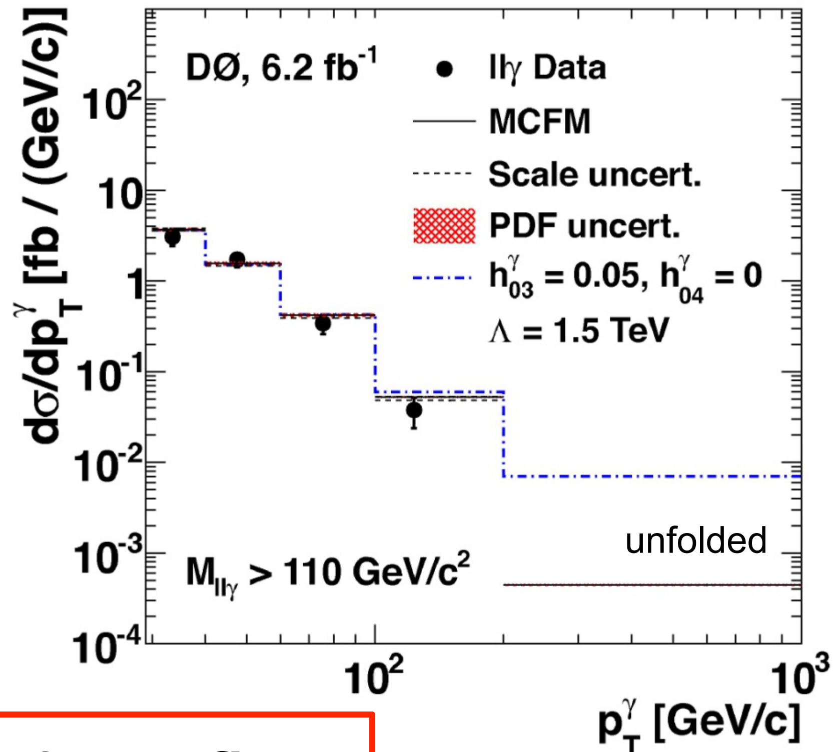


Limits on the anomalous couplings of Z's to photons.

$Z\gamma \rightarrow ll\gamma$

Phys. Rev. D **85**, 052001 (2012)





$$\sigma_{Z\gamma} \times BR(Z \rightarrow ll) = 1089 \pm 40(\text{stat}) \pm 65(\text{syst})\ \text{fb}$$

$$\text{SM@NLO}: \sigma = 1096 \pm 34\ \text{fb}$$

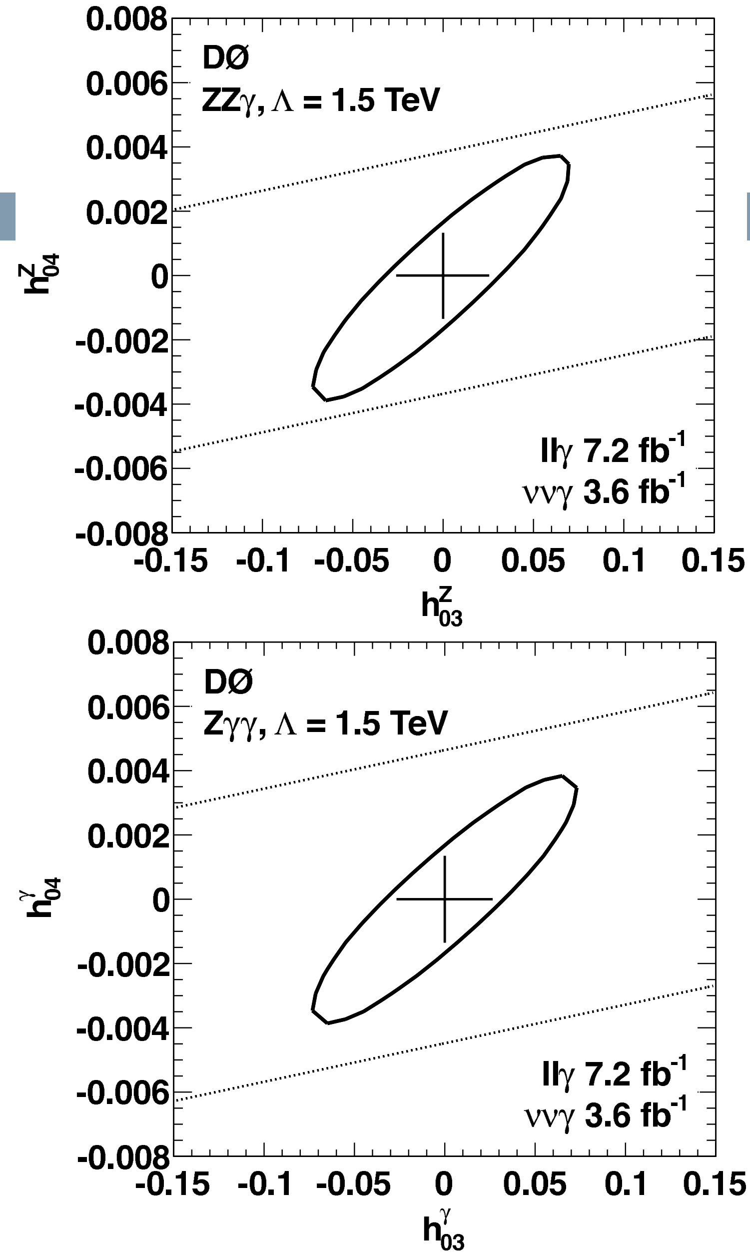
$$\sigma_{Z\gamma} \times BR(Z \rightarrow ll) = 288 \pm 15(\text{stat}) \pm 11(\text{syst})\ \text{fb}$$

$M_{ll\gamma}$ > 110 GeV (FSR removal): $\text{SM@NLO}: \sigma = 294 \pm 10\ \text{fb}$

$Z\gamma \rightarrow \mu\mu\gamma$

	$\ell\ell\gamma$ 7.2 fb^{-1} $\nu\nu\gamma$ 3.6 fb^{-1} $\Lambda = 1.5$ TeV
$\lvert h_{03}^{Z}\rvert <$	0.026
$\lvert h_{04}^{Z}\rvert <$	0.0013
$\lvert h_{03}^{\gamma}\rvert <$	0.027
$\lvert h_{04}^{\gamma}\rvert <$	0.0014

Fit the pt distribution to limit anomalous couplings
Combine with the $\nu\nu\gamma$ channel for improved limits.

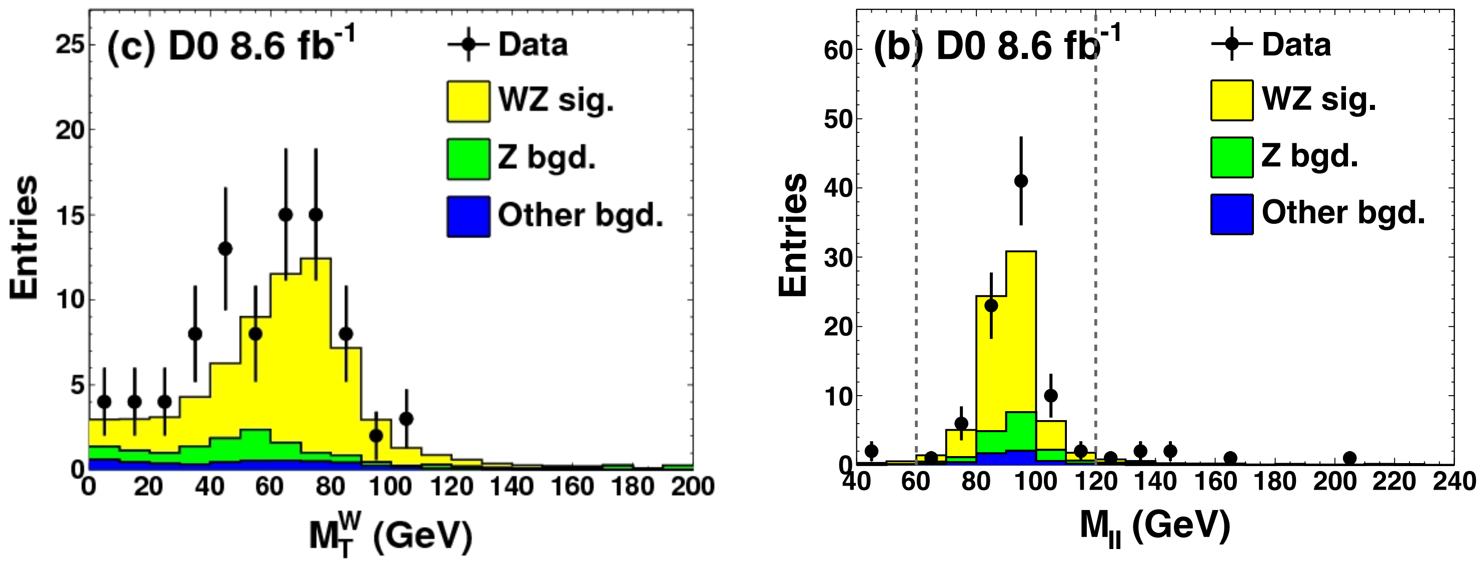


Combine with $\nu\nu\gamma$

WZ→ lνll

Phys. Rev. D 85, 112005 (2012)

Three high p_T (isolated) leptons (μμμ, eee, eeμ, μμe) +MET



$$\sigma_{WZ} = 4.5^{+0.6}_{-0.7}\,(\text{stat} + \text{syst})\ \text{pb}$$

SM@NLO: $\sigma = 3.21 \pm 0.19$ pb
($60 < M_{ll} < 120$ GeV)

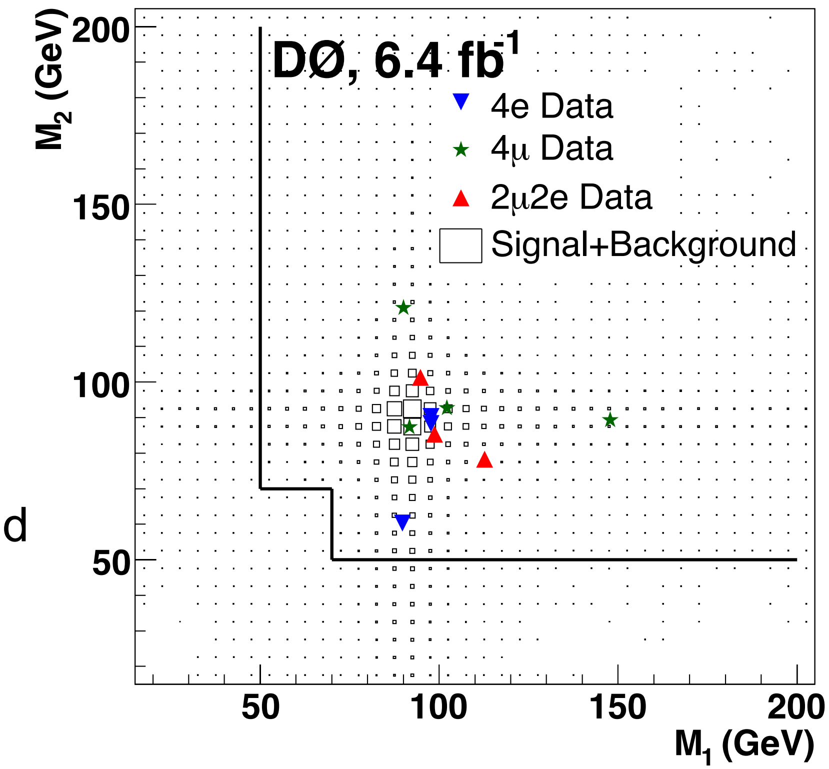
Phys.Rev.D84:011103,2011

ZZ → llll Production

Cross section for the ZZ production using fully leptonic final states

- Four high p_T leptons (μμμμ, eeee, eeμμ)

ZZ → llll
10 events
.37 background



$$\sigma_{ZZ} = \mathbf{1.26^{+0.47}_{-0.37}\,(stat + syst)\,pb}$$

SM@NLO: σ = 1.40 ± 0.10 pb

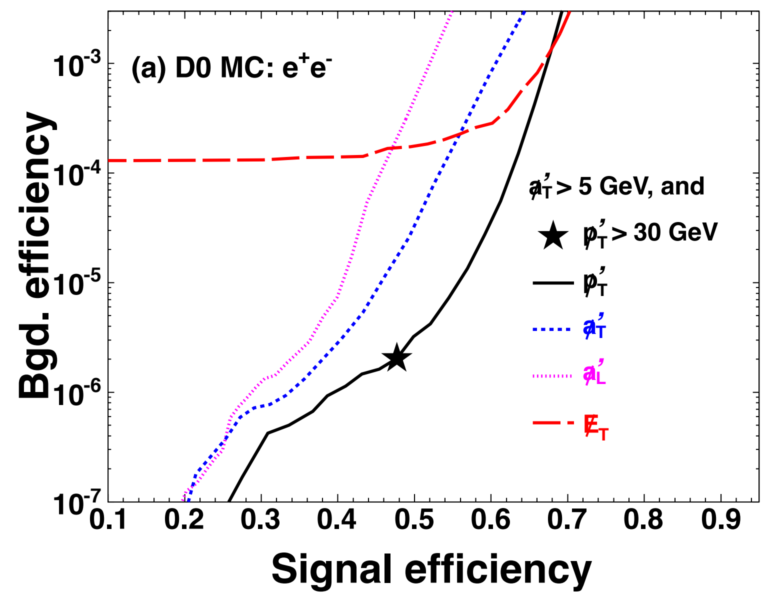
ZZ→ llνν

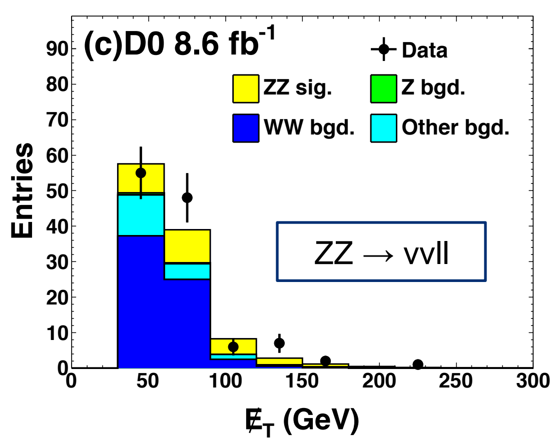
Phys. Rev. D 85, 112005 (2012)

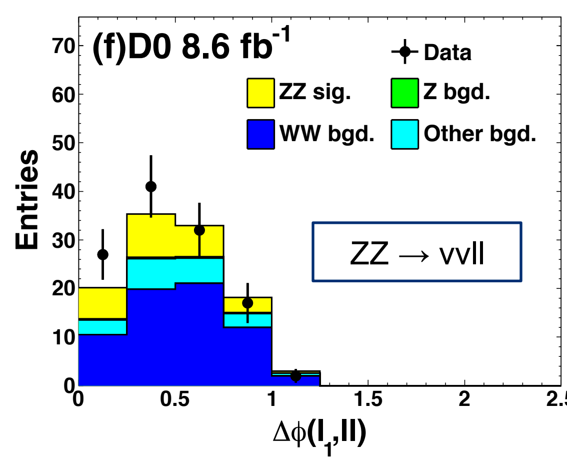
Challenges in vvll final states:
- MET reconstruction
- WW background

$$\not{p}'_T = p_T^{\ell\ell} + 2[p_T^{\delta} + p_T^{\mathrm{recoil}} + p_T^{\mathrm{trkjets}}]$$

Optimal variable is a modified p_T with negative corrections proportional to resolutions (ie. $p_T^{\delta} < 0$)







Result:

vvll (8.6 fb^{-1}):

$$\sigma_{ZZ} = 1.64^{+0.46}_{-0.46}\text{(stat+syst) pb}$$

SM@NLO: σ = 1.40 ± 0.10 pb

ZZ→ llνν

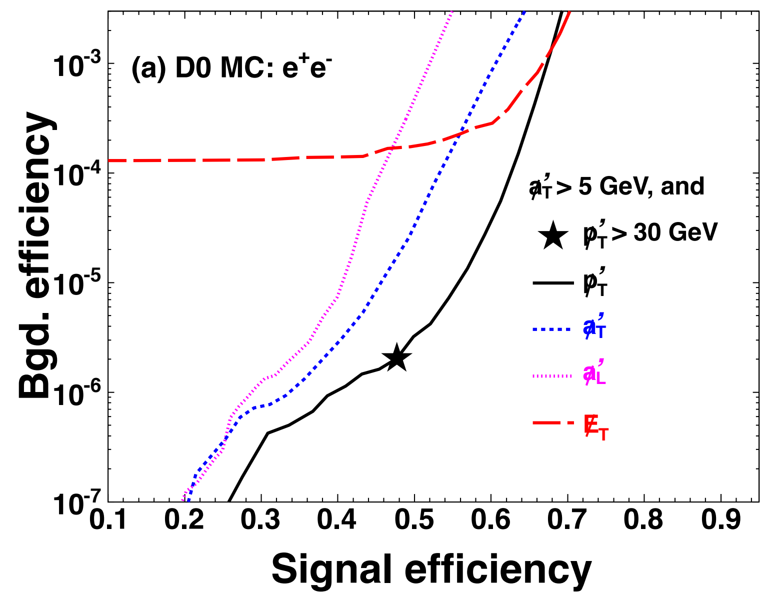
Phys. Rev. D 85, 112005 (2012)

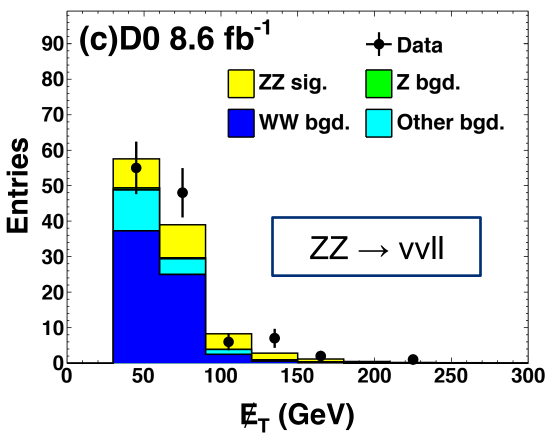
Challenges in ννll final states:

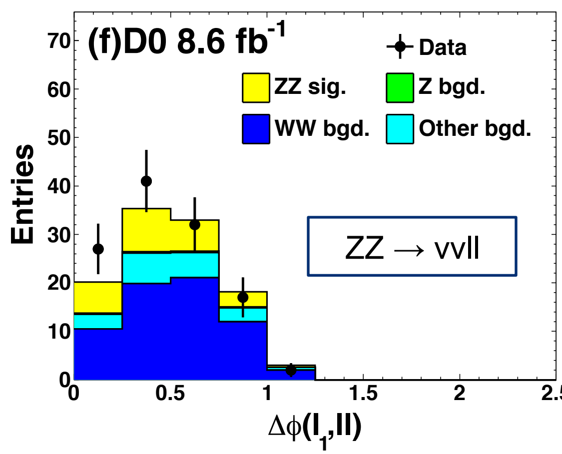
- MET reconstruction
- WW background

$$\not{p}'_T = p_T^{\ell\ell} + 2[p_T^{\delta} + p_T^{\rm recoil} + p_T^{\rm trkjets}]$$

Optimal variable is a modified p_T with negative corrections proportional to resolutions (ie. $p_T^{\delta} < 0$)







Combined:

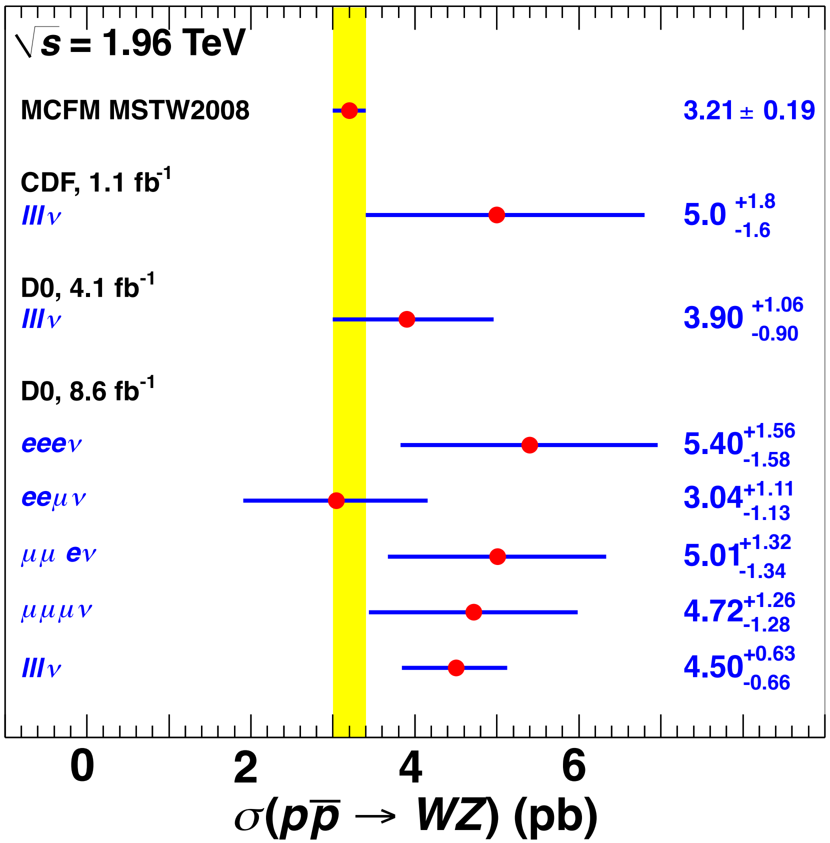
llll (6.4 fb^{-1})+ννll (8.6 fb^{-1}):

$$\sigma_{ZZ} = 1.44^{+0.35}_{-0.34} \text{(stat+syst) pb}$$

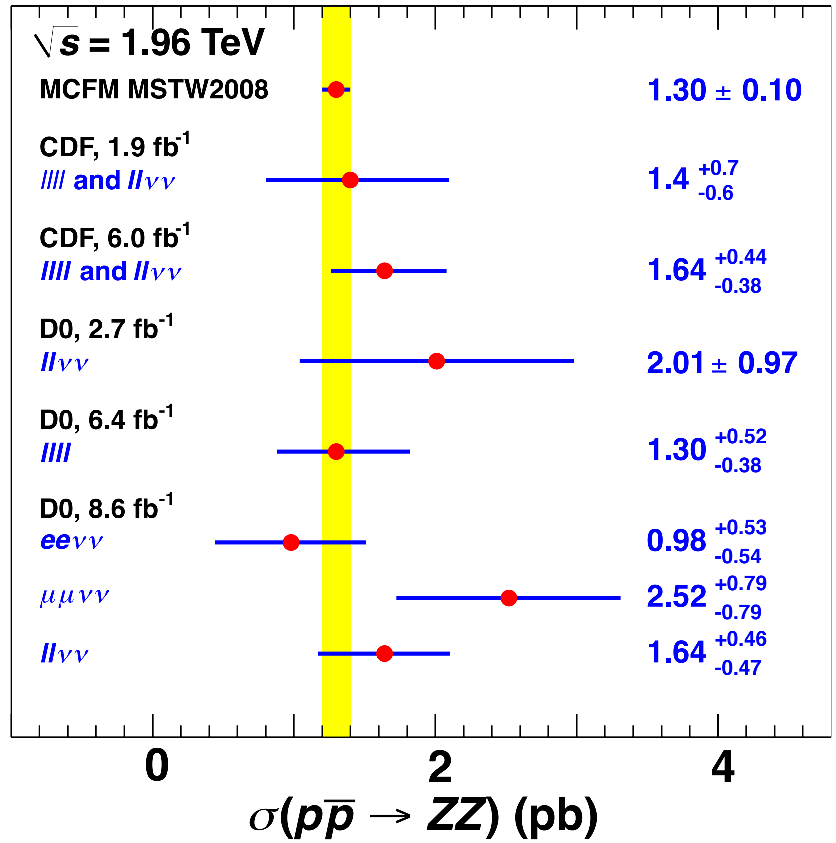
SM@NLO: σ = 1.40 ± 0.10 pb

Tevatron WZ and ZZ cross sections

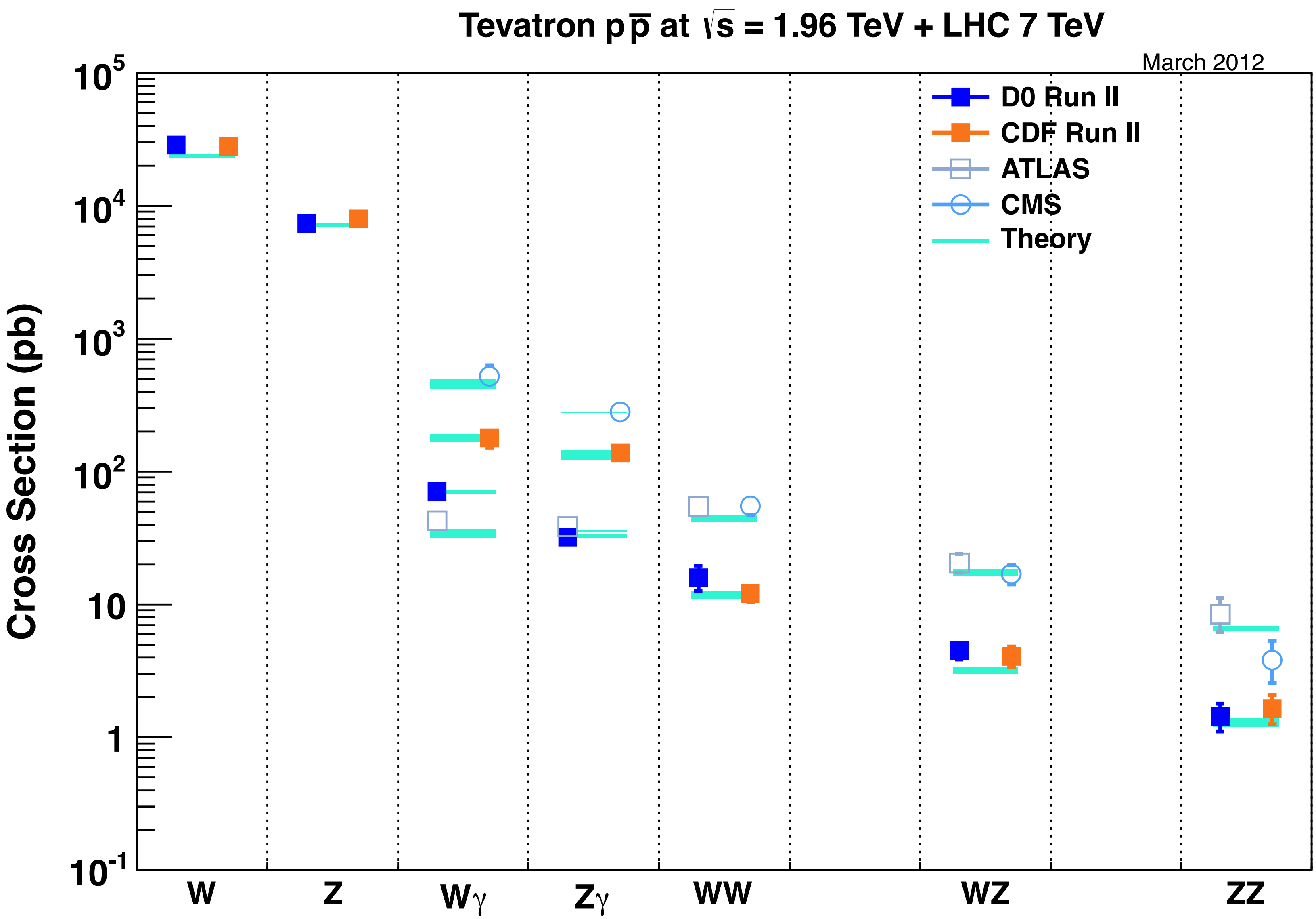
WZ



ZZ



Summary of Bosons at the Tevatron + friends

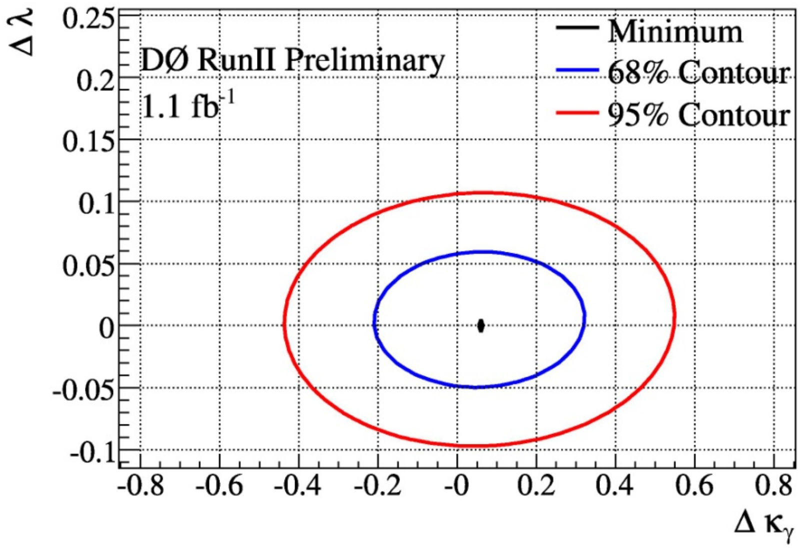


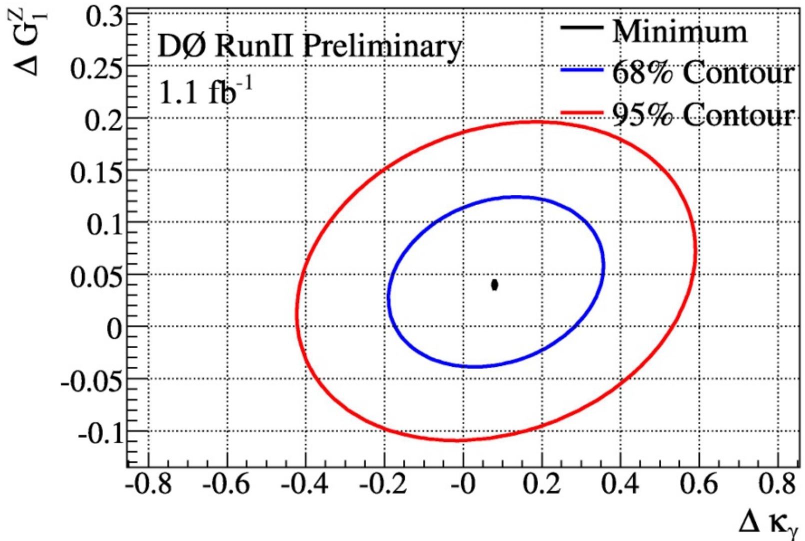
Summary

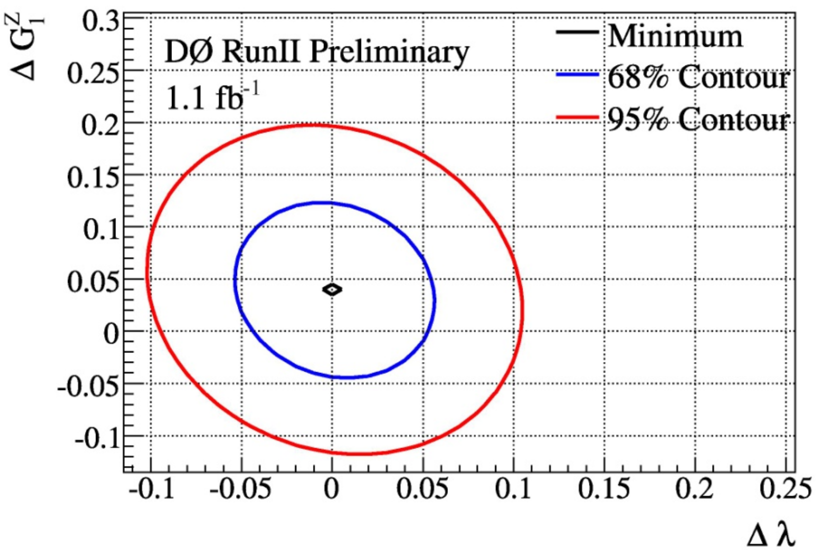
- Diboson cross sections have been measured in many all-leptonic channels
- Future updates
  - Full statistics ZZ
  - Full statistics WW
  - Anomalous couplings using all channels

BACKUP SLIDES

Older D0 limits on anomalous couplings from Wγ, WW, WZ







Can be interpreted as measurements of the magnetic dipole and quadrupole moments.

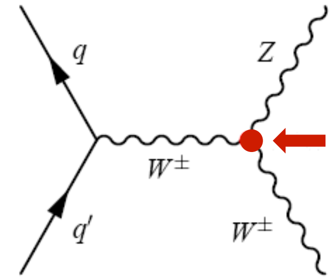
$$\mu_W = (1+\kappa+\lambda)\frac{e}{2M_W} = 2.02^{+0.08}_{-0.09}\ \frac{e}{2M_W}$$

$$q_W = -(\kappa-\lambda)\frac{e}{M_W^2} = 1.00 \pm 0.09\ \frac{e}{M_W^2}$$

Prospects for the future

- D0 and CDF are updating to the full statistical sample.
  - Done for WZ and ZZ channels
- Combining channels and experiments will increase the TGC sensitivity by a factor of 3-5.
- LHC experiments have 10 times the cross section → 10 fb^{-1} of data → factor of 10 in statistics and 3 in sensitivity.

Motivation for Diboson Studies

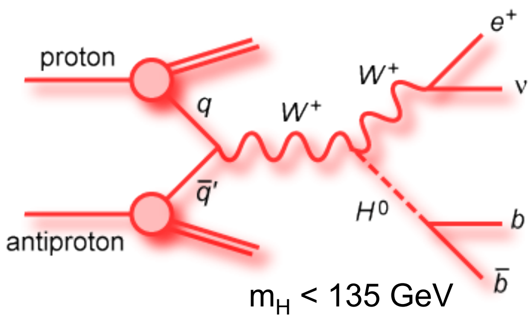


Probe of the EWSB mechanism
- Test of the SM
- Indirect searches for New Physics

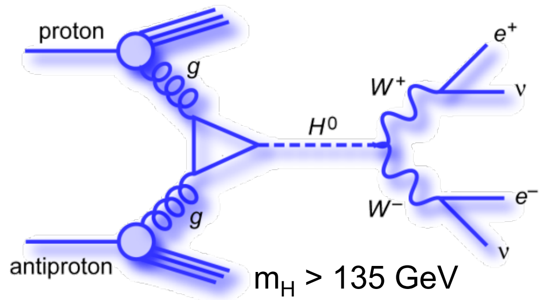
Cross sections, Kinematic distributions, Trilinear Gauge Boson Couplings (TGCs)

Important background to:
- Top
- Higgs
- Beyond the SM

Good understanding is highly valuable

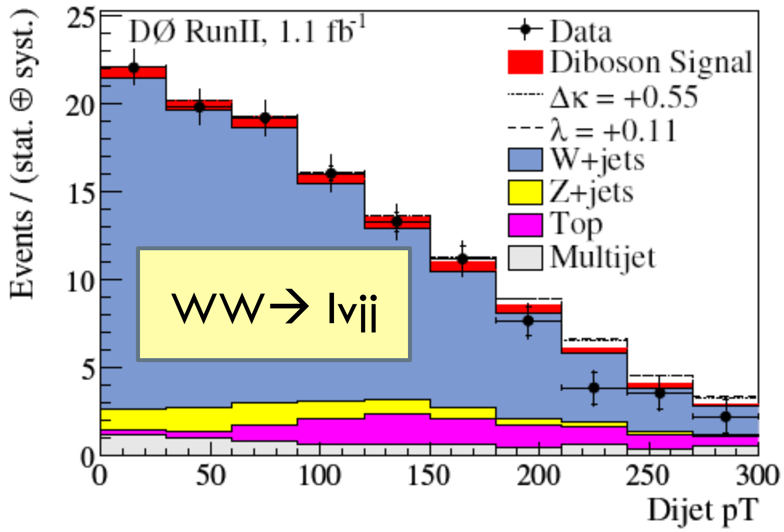


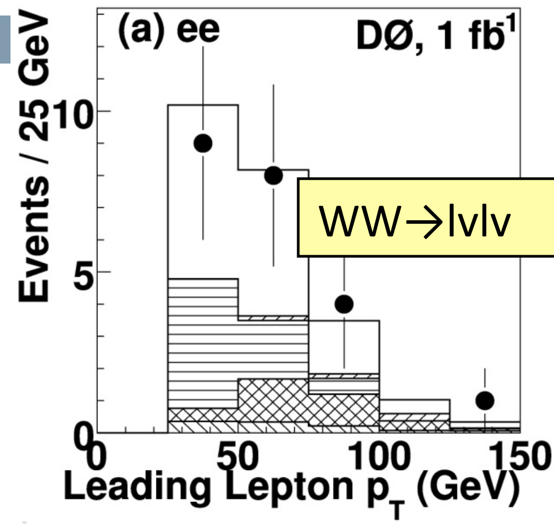
Proving ground for analysis techniques and statistical treatment used in the Tevatron **Higgs searches**

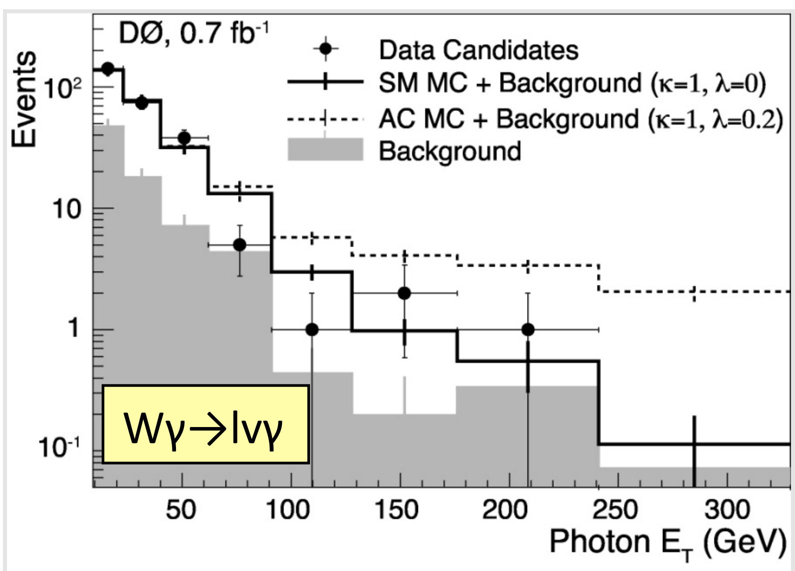


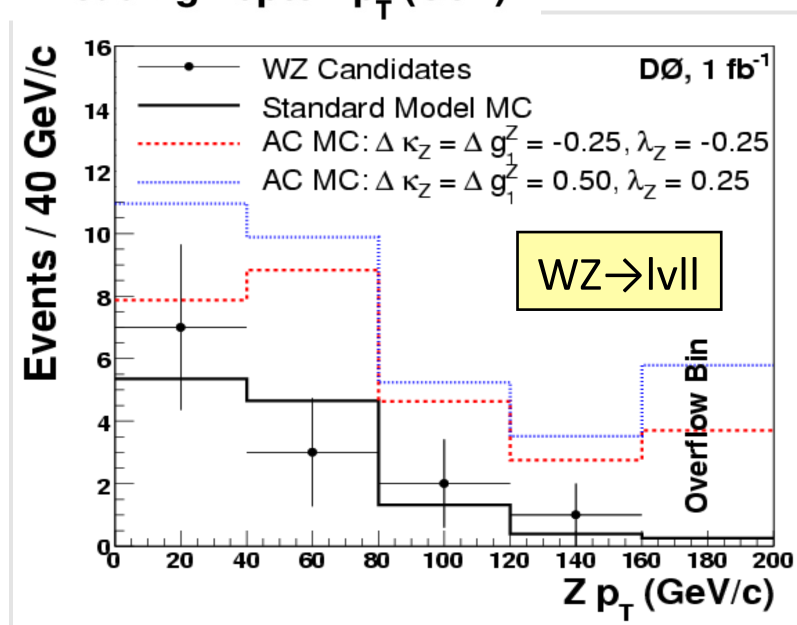
Complementary to Higgs production
(same final states/challenges)

D0 – set charged TGC limits using pt in 4 channels









Charged Triple Gauge Couplings

Probed by ***WW, WZ, and W γ production***

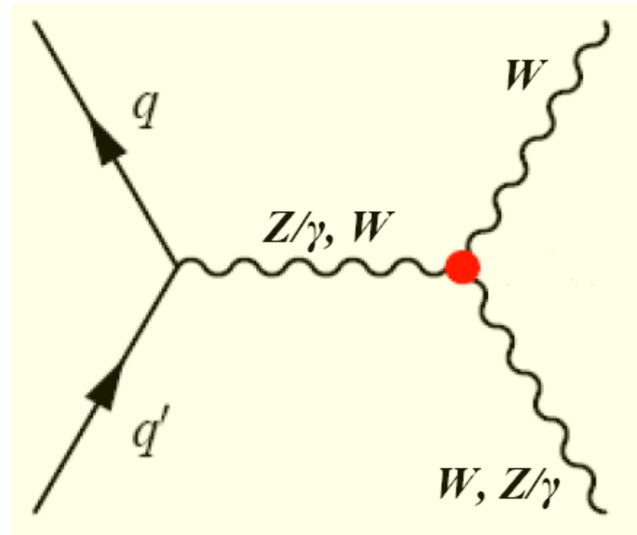
General Lagrangian has **14** parameters

Assume EM gauge invariance and C and P conservation

⇒ 5 TGC parameters:

$$g^1_Z, \kappa_\gamma, \kappa_Z, \lambda_\gamma, \lambda_Z$$

g^1 and κ are 1 in the SM, the rest are zero



Neutral Triple Gauge Couplings

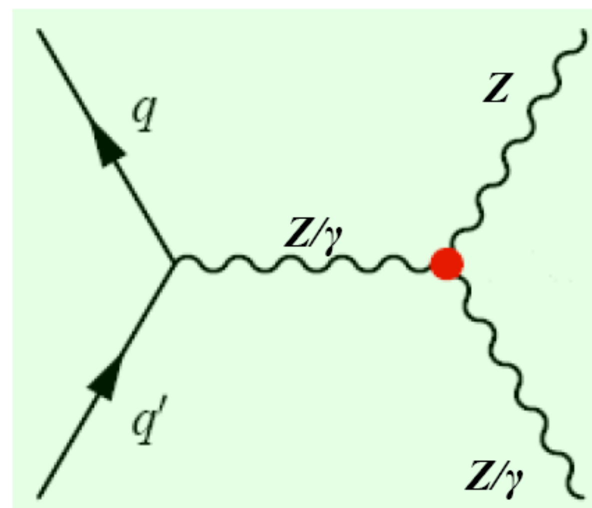
Probed by ***ZZ and Zγ production***

General Lagrangian has **8** TGC parameters

Assume CP conservation

⇒ 4 non-SM TGC parameters:

$$h^3_\gamma, h^3_Z, h^4_\gamma, h^4_Z \text{ all 0 in SM}$$



$\nu\nu\gamma$ candidate event