

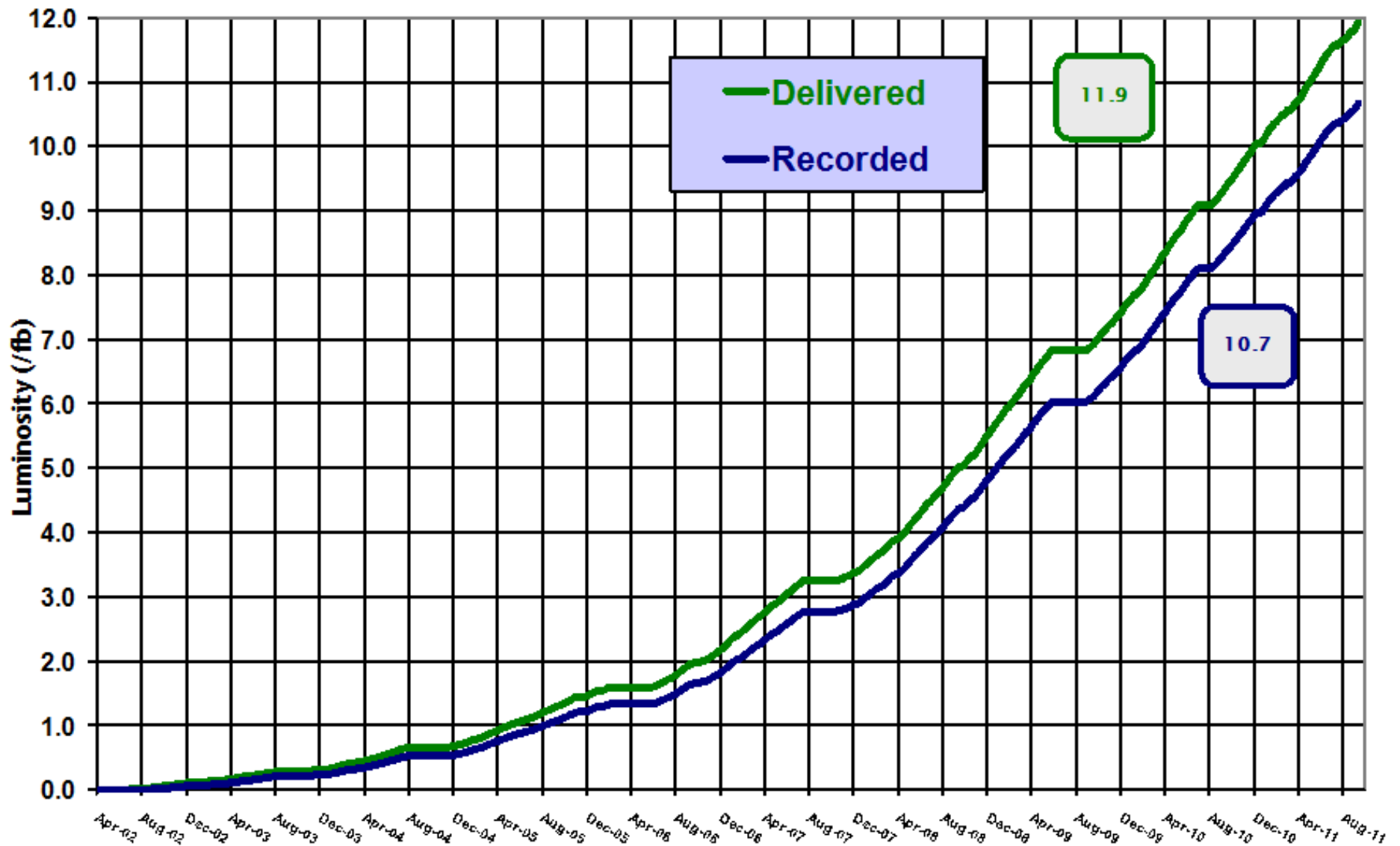
DI-BOSONS AND ANOMALOUS COUPLINGS AT D0

Heidi Schellman, Northwestern University



Run II Integrated Luminosity

19 April 2002 - 30 September 2011



Lepton ID in the DØ Detector

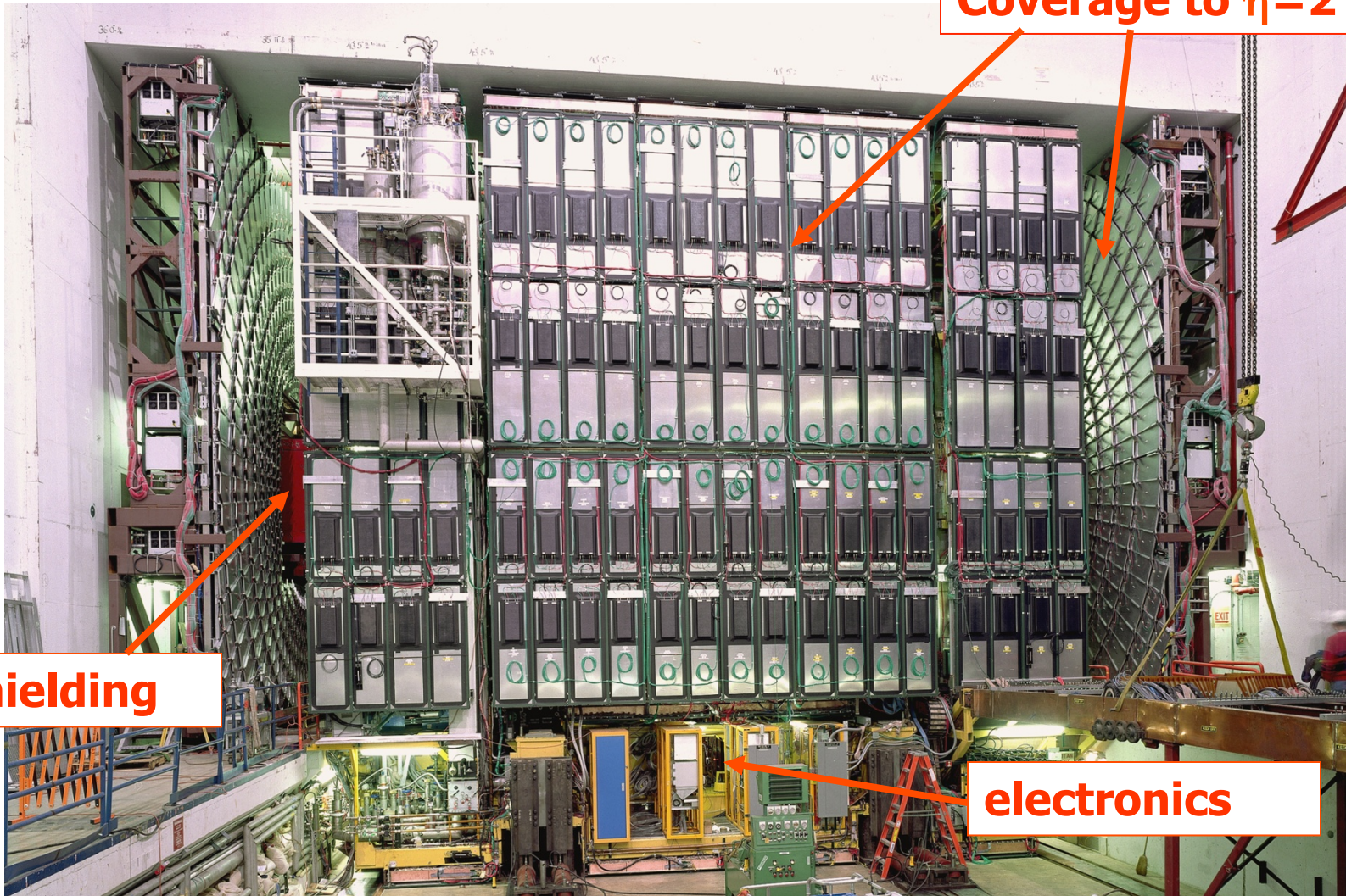
4

muon system

Coverage to $\eta=2$

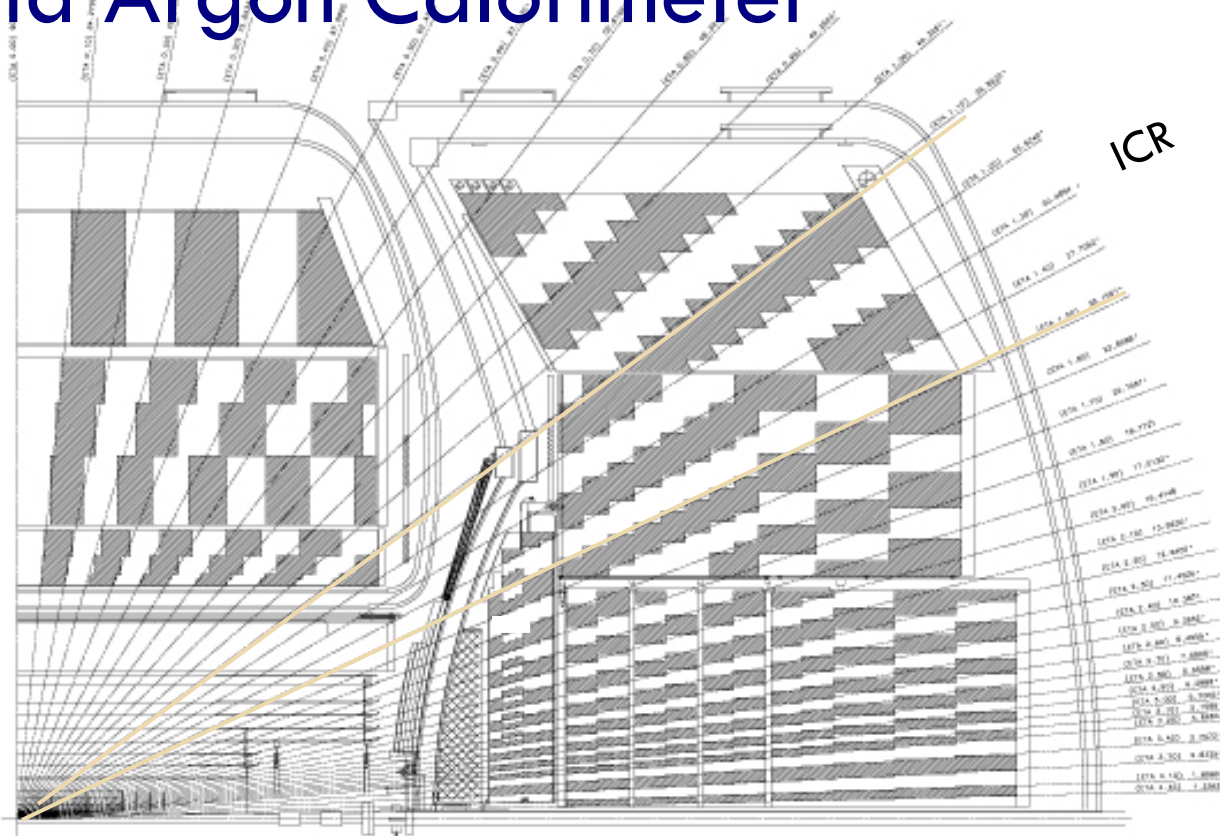
shielding

electronics



Liquid Argon Calorimeter

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ICR

$\eta=1.1$

$\eta=1.5$

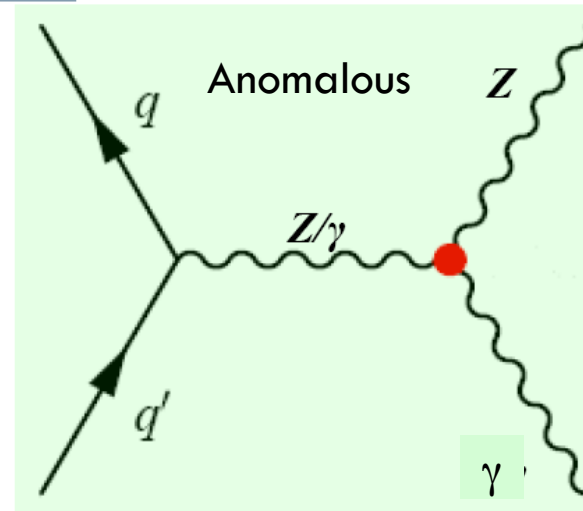
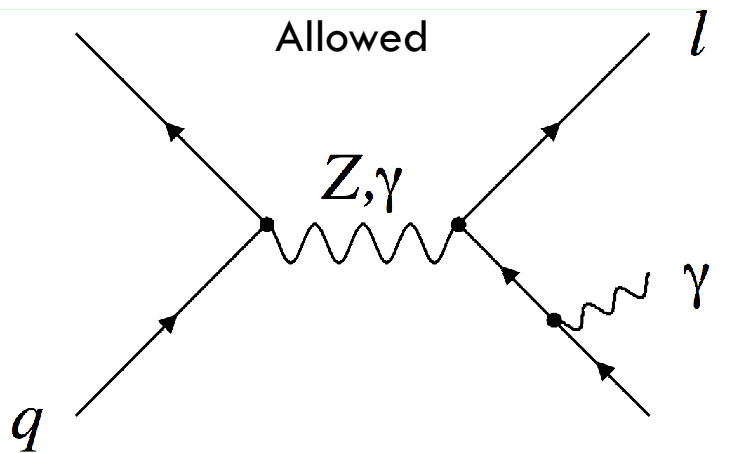
- Liquid argon active medium and uranium/copper absorber
- Hermetic with coverage for: $|\eta| < 4.2$
- Longitudinal and Transverse segmentation $\Delta\eta \times \Delta\phi \times X^0 = 0.1 \times 0.1 \times \sim 1$
(0.05x0.05 in third EM layer, near shower maximum)

Lagrangian for neutral ($ZZ\gamma/Z\gamma\gamma$)

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

CP conserving $\rightarrow h_{3,4}^V$ couplings ($V = \gamma, Z$)



$\Delta \neq 0$
ANOMALOUS
COUPLINGS

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

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

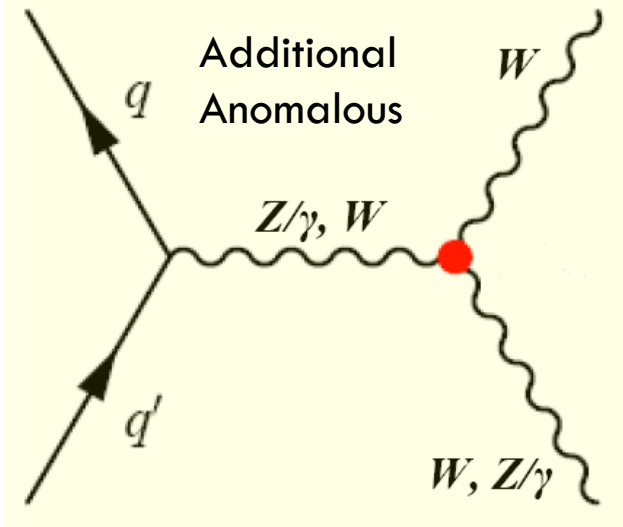
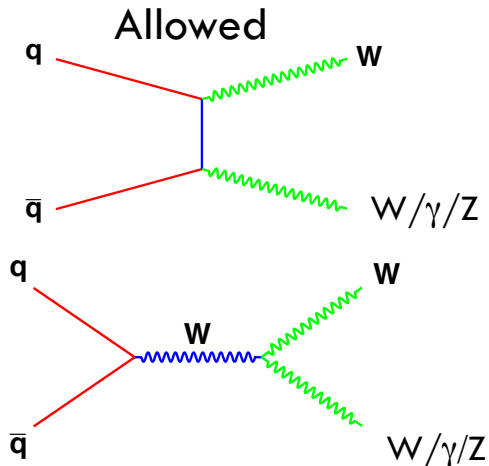
Lagrangian for **charged** (WW γ /WWZ)

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

$$-g_4^V W_\mu^* W_\nu (\partial^\mu V^\nu + \partial^\nu V^\mu) + g_5^V \epsilon^{\mu\nu\lambda\rho} (W_\mu^* \partial_\lambda W_\nu - \partial_\lambda W_\mu^* W_\nu) V_\rho + i\tilde{\kappa}_V W_\mu^* W_\nu \tilde{V}^{\mu\nu} + i\frac{\tilde{\lambda}_V}{M_W^2} W_{\lambda\mu}^* W_\nu^{\mu\nu} \tilde{V}^{\lambda\rho}$$

EM gauge inv. ($g_1^V = 1$), C and P conserving \Rightarrow 5 couplings: $\kappa_V, \lambda_V, g_1^Z$



$\Delta \neq 0$
ANOMALOUS
COUPLINGS

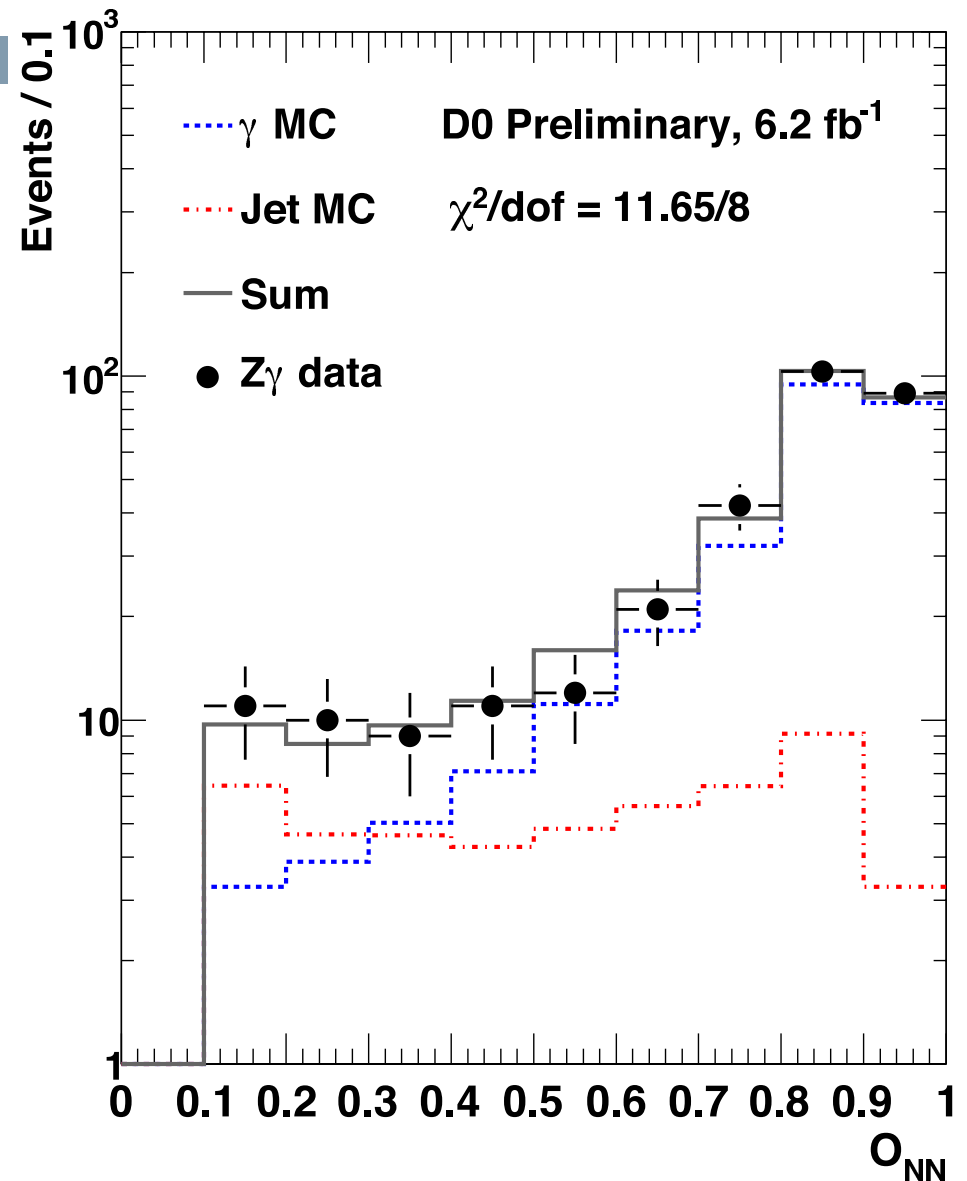
SM : $g_1^Z = \kappa_V = 1, \lambda_V = 0$

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

$W\gamma$ and $Z\gamma$

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

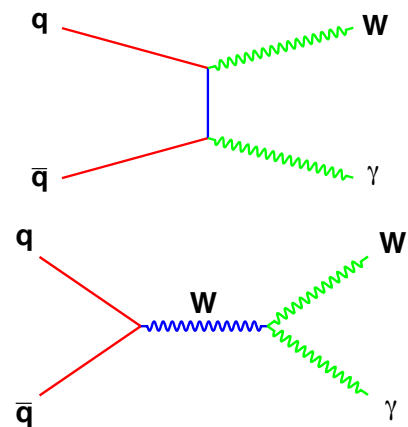
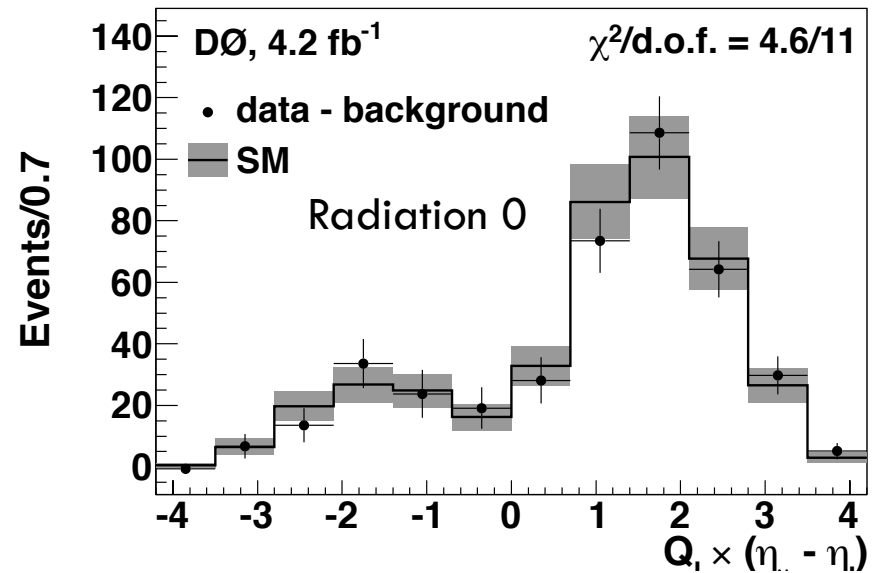
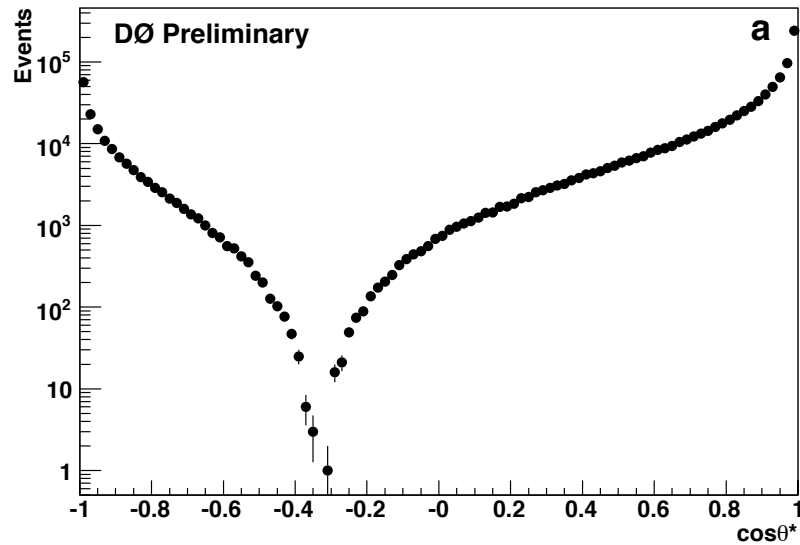


$W\gamma \rightarrow l\nu\gamma$ Production



[PRL 107, 241803 \(2011\)](#)

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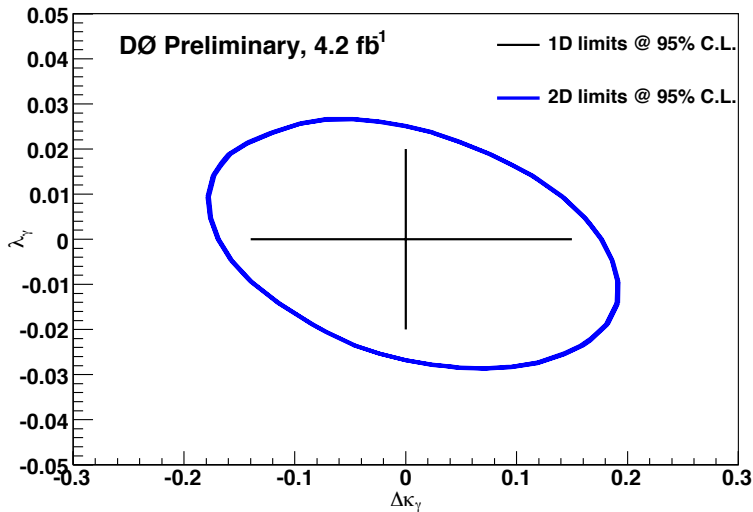
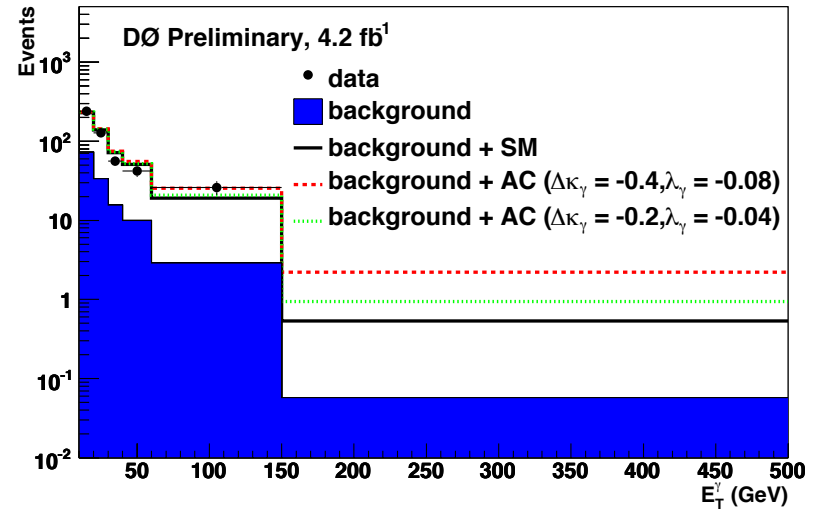
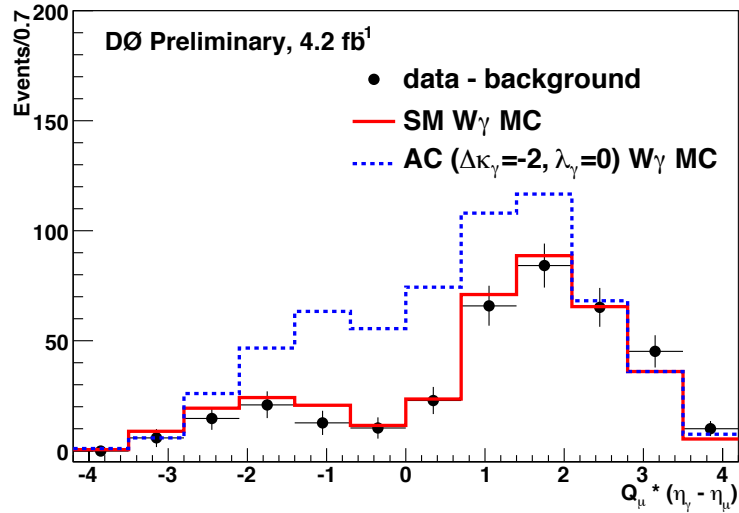


$$\sigma_{W\gamma} \times \text{BR}(W \rightarrow l\nu) = 7.6 \pm 0.4(\text{stat}) \pm 0.6(\text{syst}) \text{ pb}$$

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

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

Anomalous $W\gamma$ couplings



95% CL limits on TGCs:

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

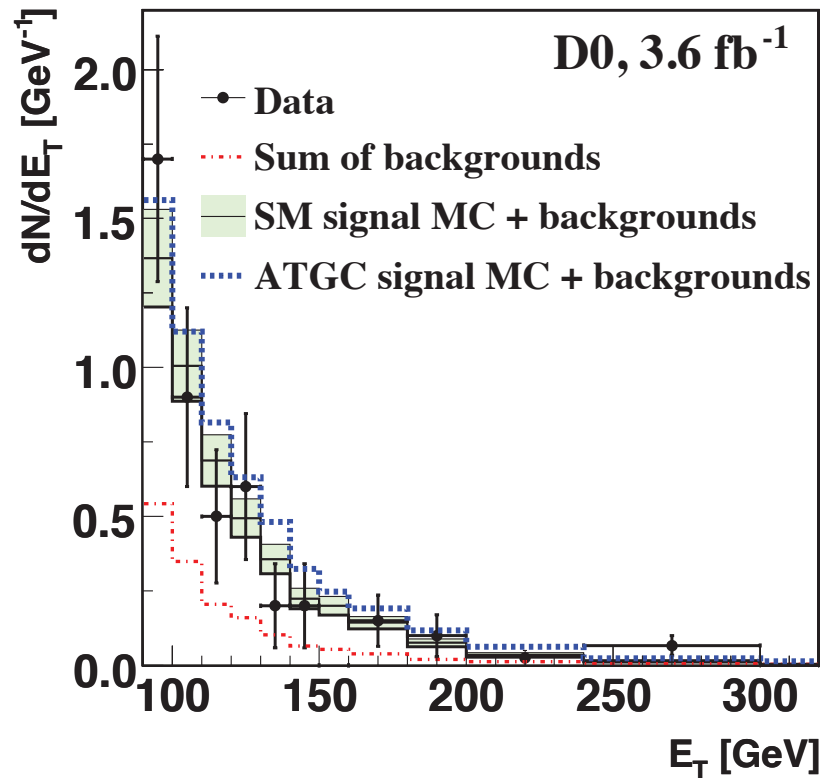
$$Z\gamma \rightarrow \nu\nu\gamma$$

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

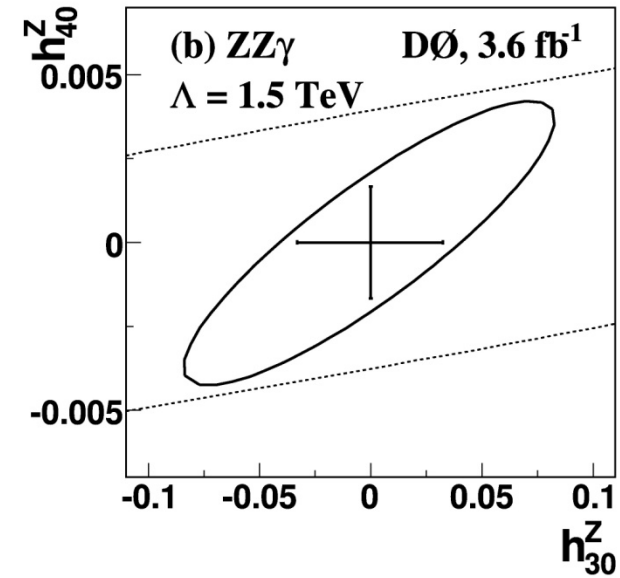


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Select interactions with large, significant Missing transverse momentum



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



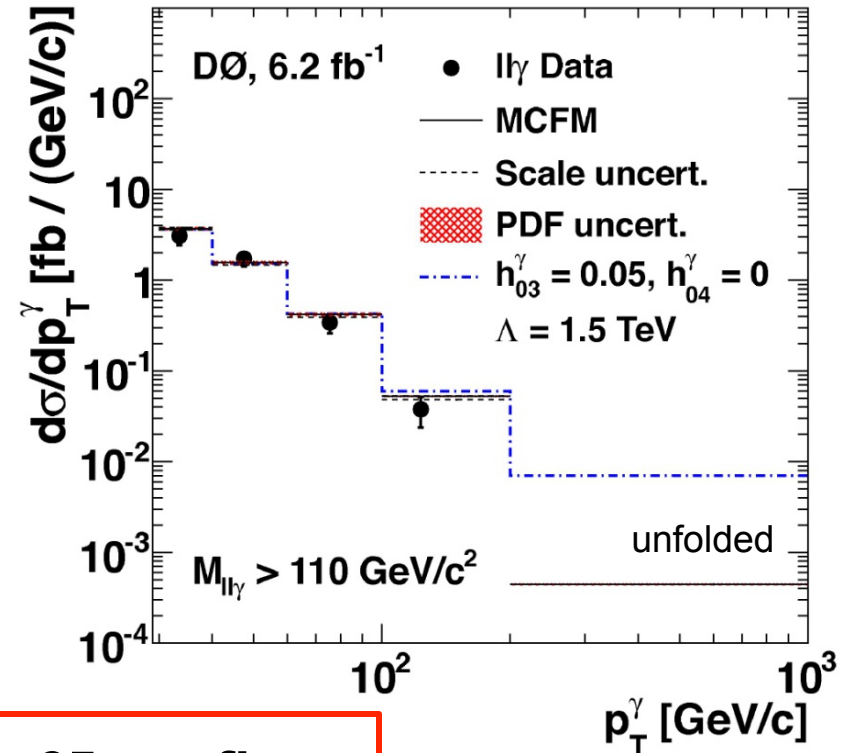
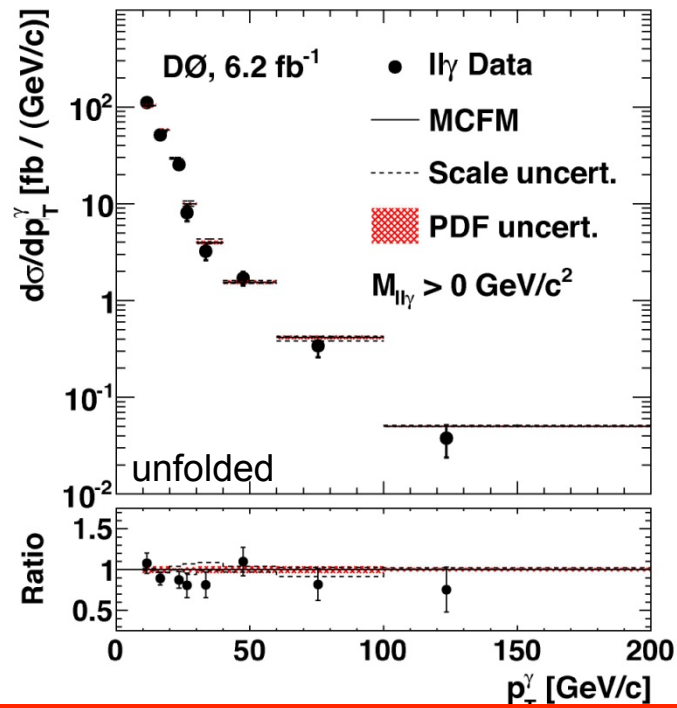
Limits on the anomalous couplings of Z's to photons.

$Z\gamma \rightarrow \ell\ell\gamma$ Production



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

12



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

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

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

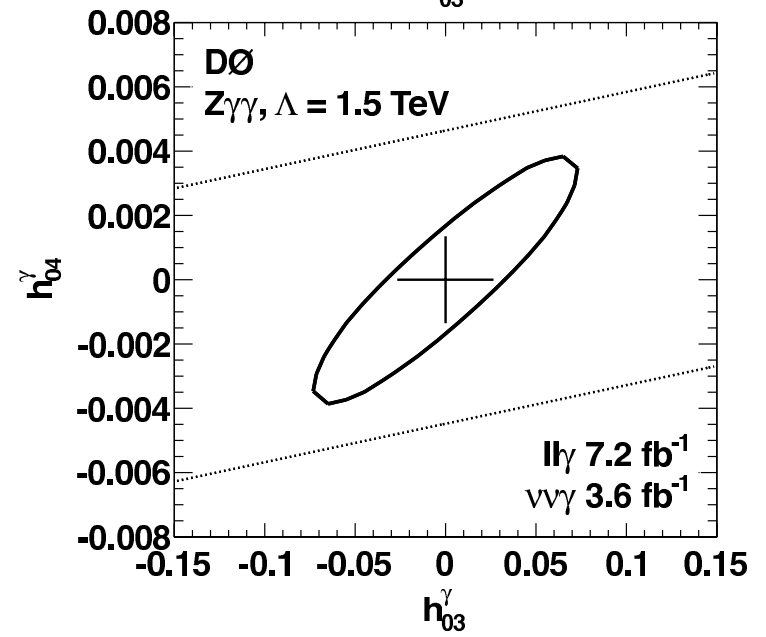
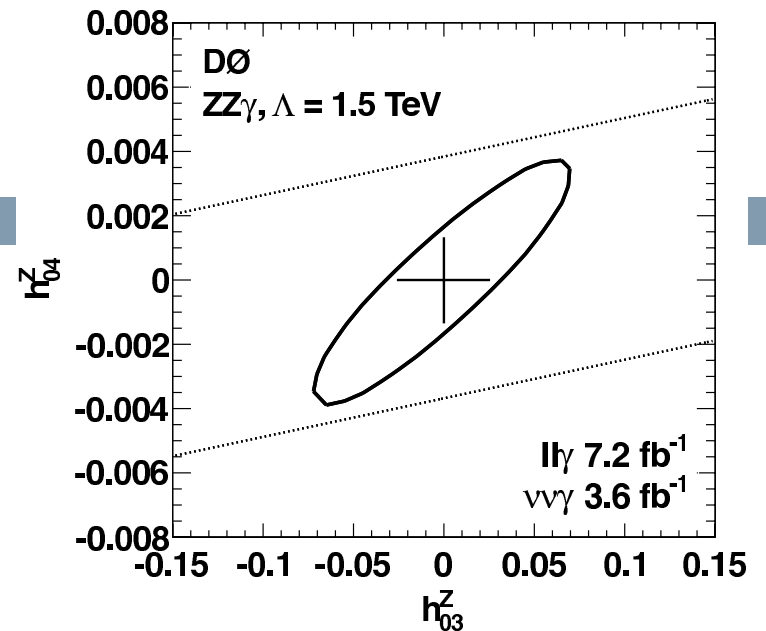
$$M_{\ell\ell\gamma} > 110 \text{ GeV (FSR removal)} : \text{SM@NLO} : \sigma = 294 \pm 10 \text{ fb}$$

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

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

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



Combine with $\nu\nu\gamma$

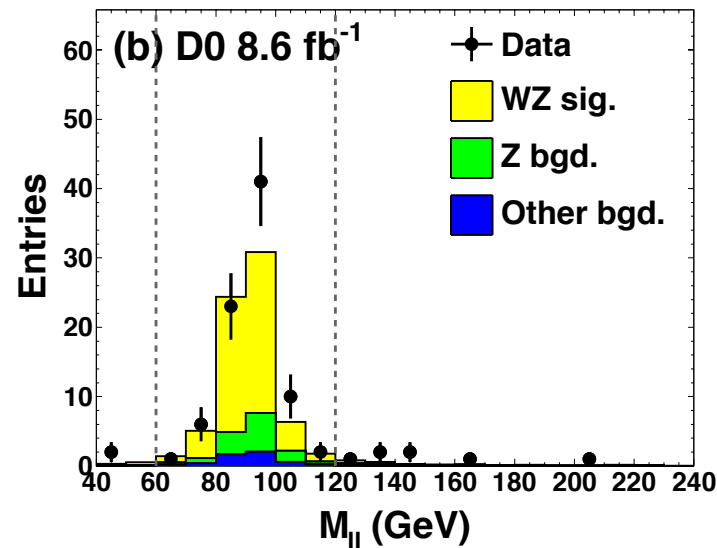
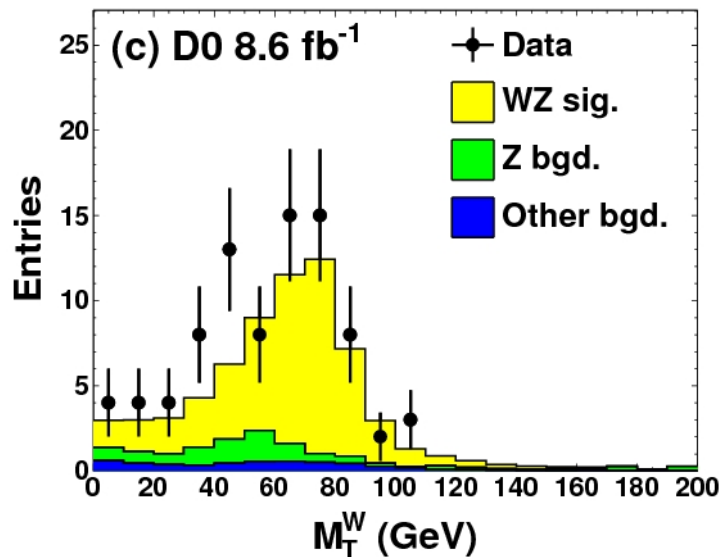


WZ \rightarrow $l\nu ll$ Production

Phys. Rev. D 85, 112005 (2012)

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Three high p_T (isolated) leptons ($\mu\mu\mu$, eee , $ee\mu$, $\mu\mu e$) +MET



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

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



ZZ → IIII Production

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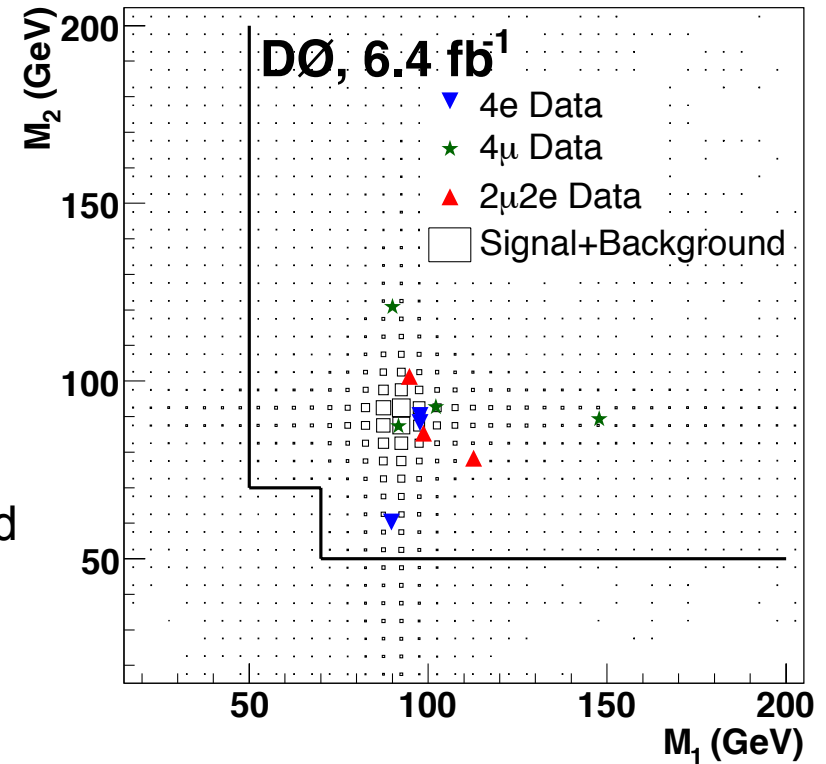
Cross section for the ZZ production using fully leptonic final states

- Four high p_T leptons ($\mu\mu\mu\mu$, $eeee$, $ee\mu\mu$)

ZZ → IIII
 10 events
 .37 background

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

$$\text{SM@NLO: } \sigma = 1.40 \pm 0.10 \text{ pb}$$



ZZ \rightarrow $\nu\nu\ell\ell$ Production



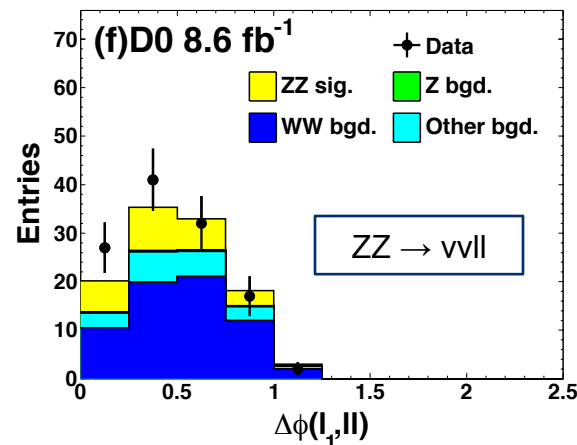
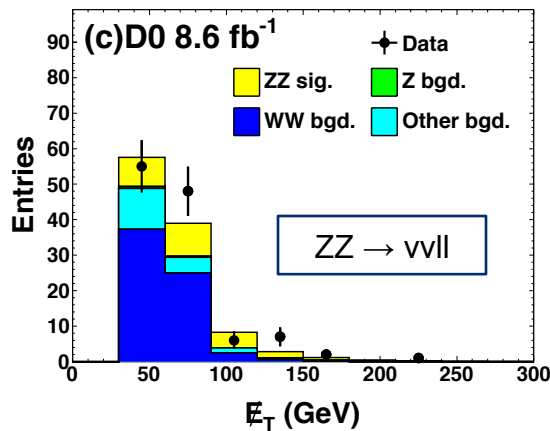
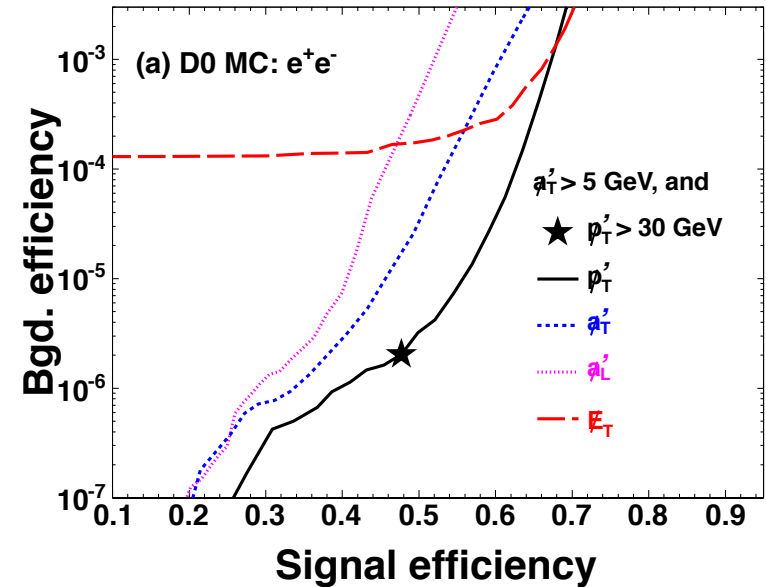
Phys. Rev. D 85, 112005 (2012)

Challenges in $\nu\nu\ell\ell$ final states:

- MET reconstruction
- WW background

$$\vec{p}_T^l = \vec{p}_T^{\ell\ell} + 2[\vec{p}_T^\delta + \vec{p}_T^{\text{recoil}} + \vec{p}_T^{\text{trkjets}}]$$

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



Result:

$\nu\nu\ell\ell$ (8.6 fb^{-1}):

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

$$\text{SM@NLO: } \sigma = 1.40 \pm 0.10 \text{ pb}$$

ZZ → ννll Production



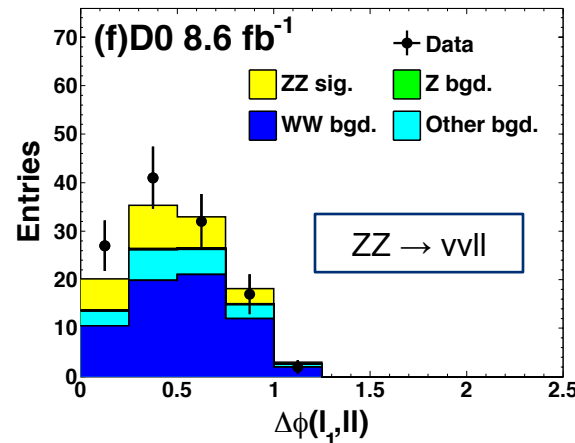
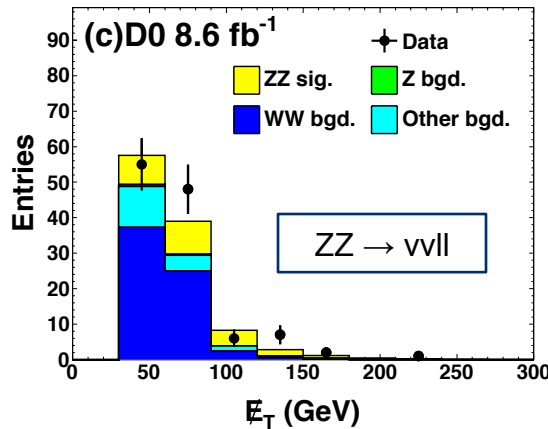
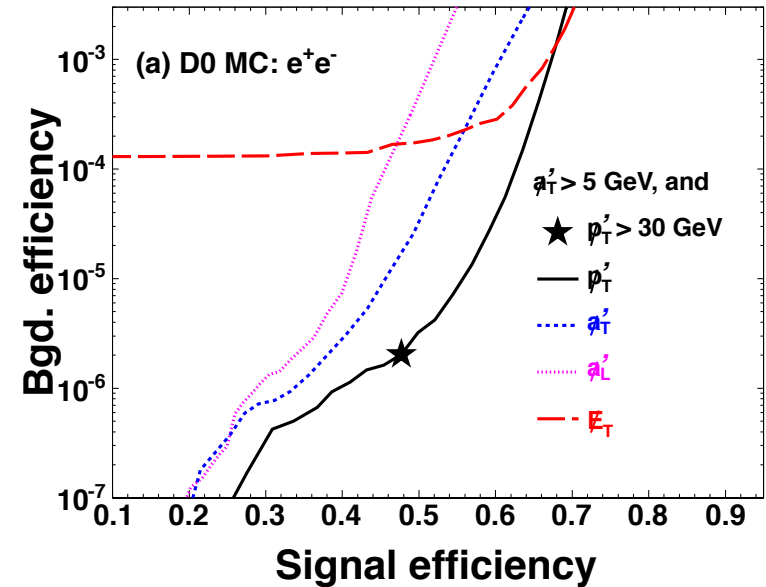
Phys. Rev. D 85, 112005 (2012)

Challenges in ννll final states:

- MET reconstruction
- WW background

$$\vec{p}_T^l = p_T^{\ell\ell} + 2[p_T^\delta + p_T^{\text{recoil}} + p_T^{\text{trkjets}}]$$

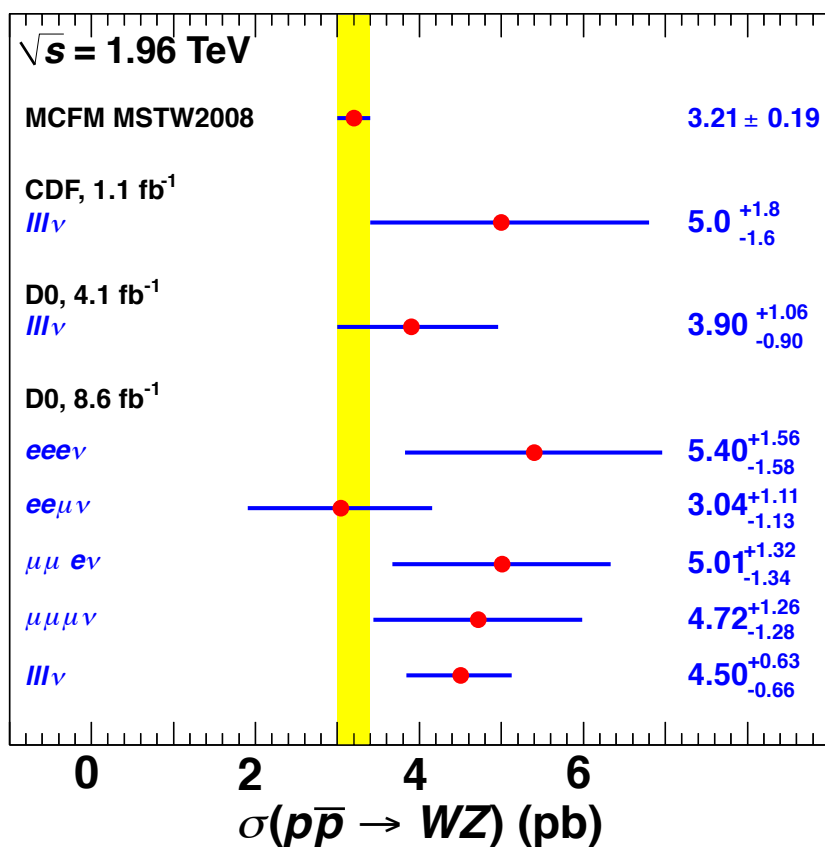
Optimal variable is a modified p_T with negative corrections proportional to resolutions (ie. $p_T^\delta < 0$)



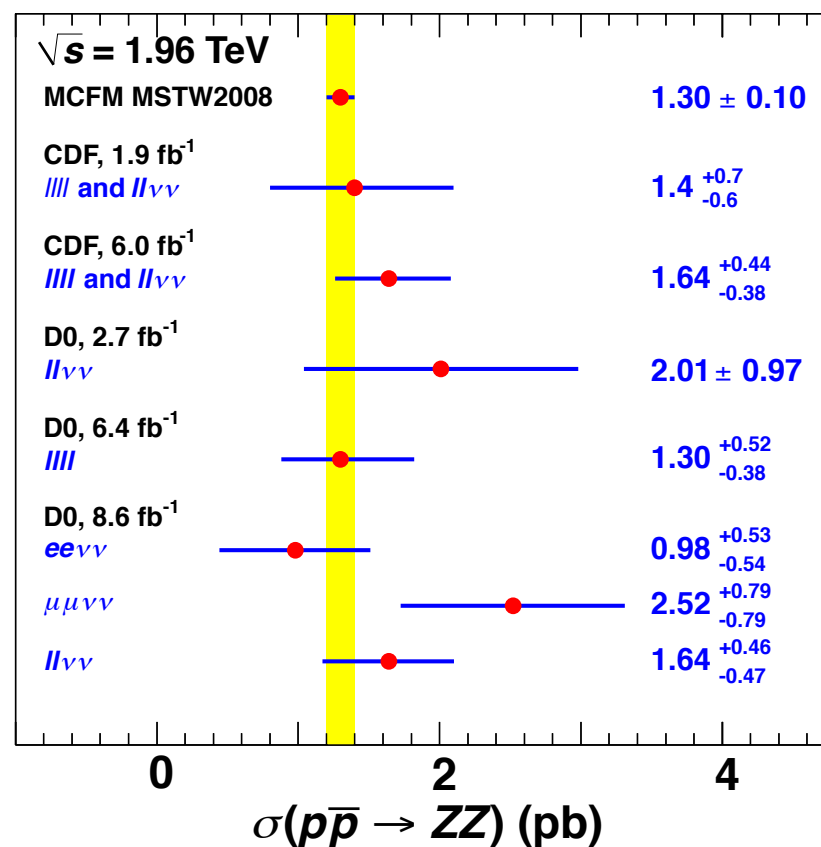
Combined:
 ll ll (6.4 fb⁻¹) + ννll (8.6 fb⁻¹):
 $\sigma_{ZZ} = 1.44^{+0.35}_{-0.34}$ (stat+syst) pb
 SM@NLO: $\sigma = 1.40 \pm 0.10$ pb

Tevatron WZ and ZZ cross sections

WZ

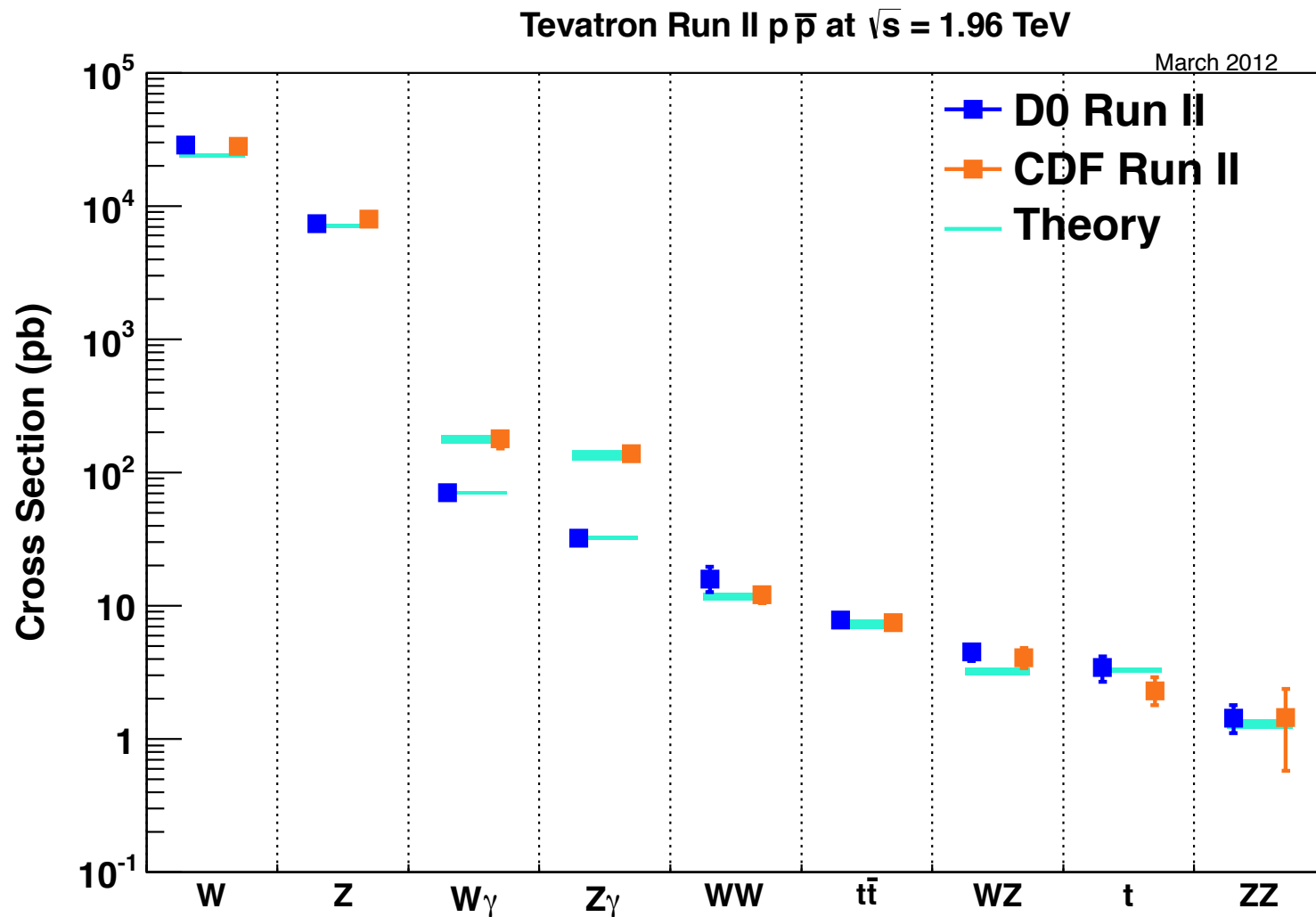


ZZ



Summary of Bosons at the Tevatron

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Summary

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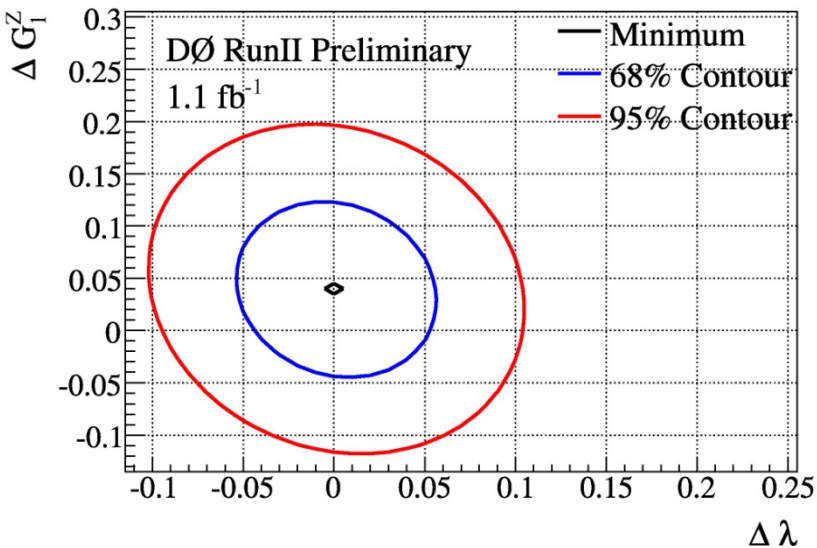
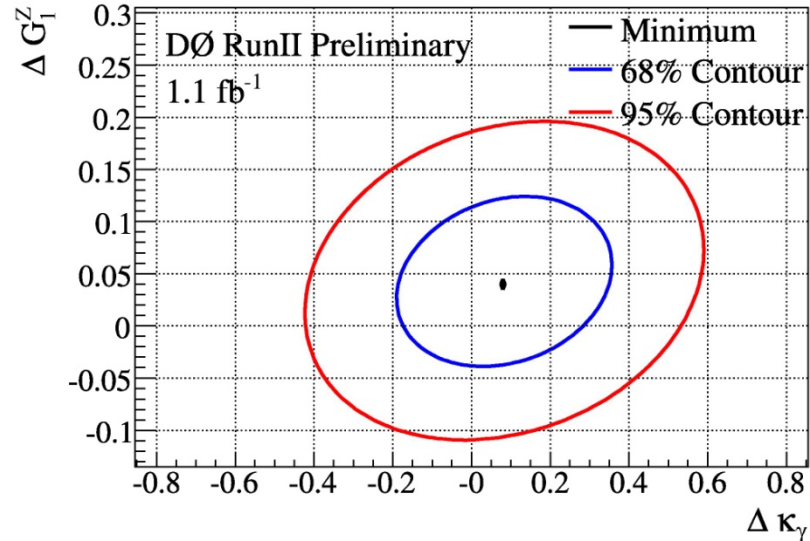
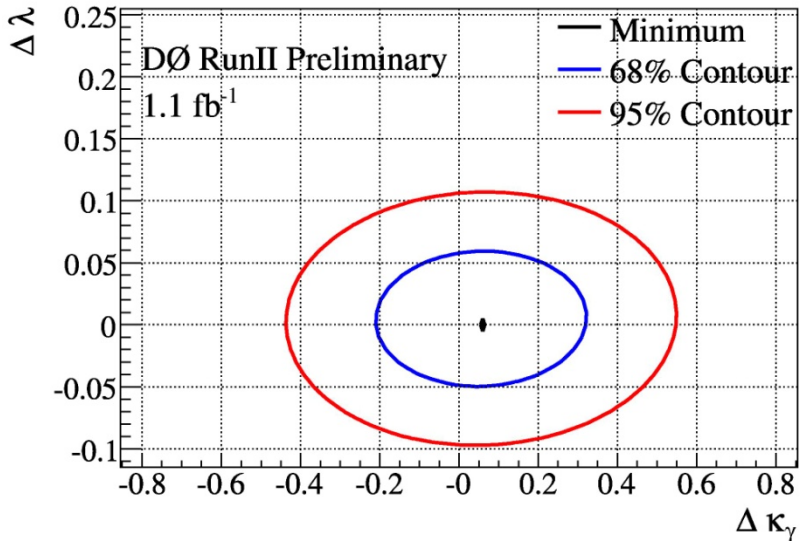
- Diboson cross sections have been measured in many all-leptonic channels
- Future updates
 - ▣ Full statistics ZZ
 - ▣ Full statistics WW
 - ▣ Anomalous couplings using all channels

BACKUP SLIDES

Older D0 limits on anomalous couplings from $W\gamma$, WW , WZ



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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

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- 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 $\rightarrow 10 \text{ fb}^{-1}$ of data \rightarrow factor of 10 in statistics and 3 in sensitivity.

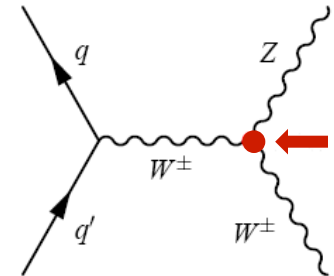
Motivation for Diboson Studies



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:

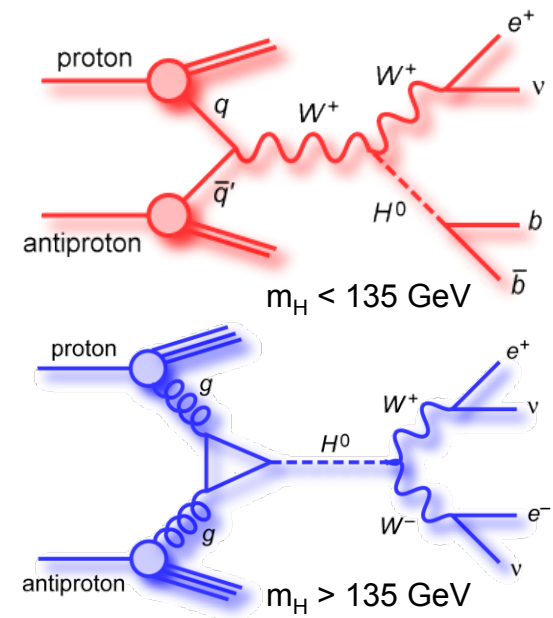
- Top
- Higgs
- Beyond the SM

Good understanding is highly valuable

Proving ground for analysis techniques and statistical treatment used in the

Tevatron Higgs searches

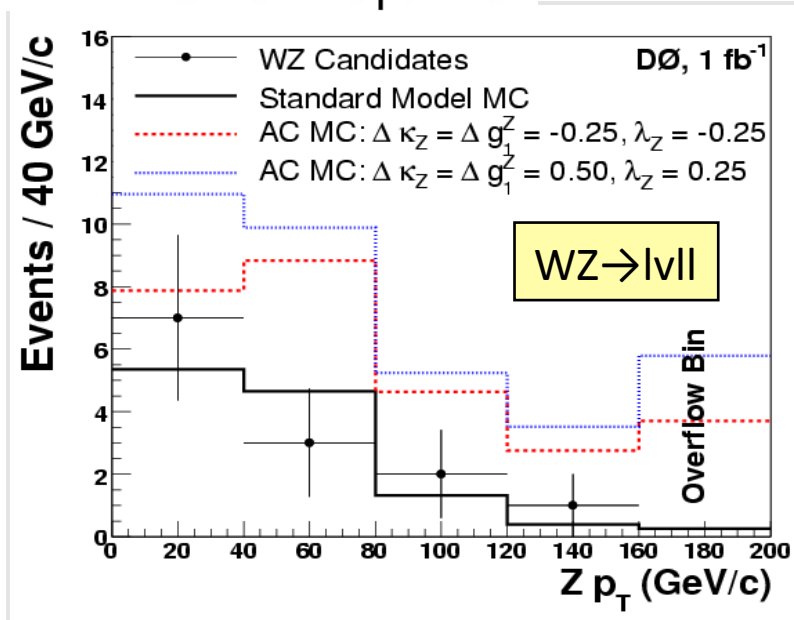
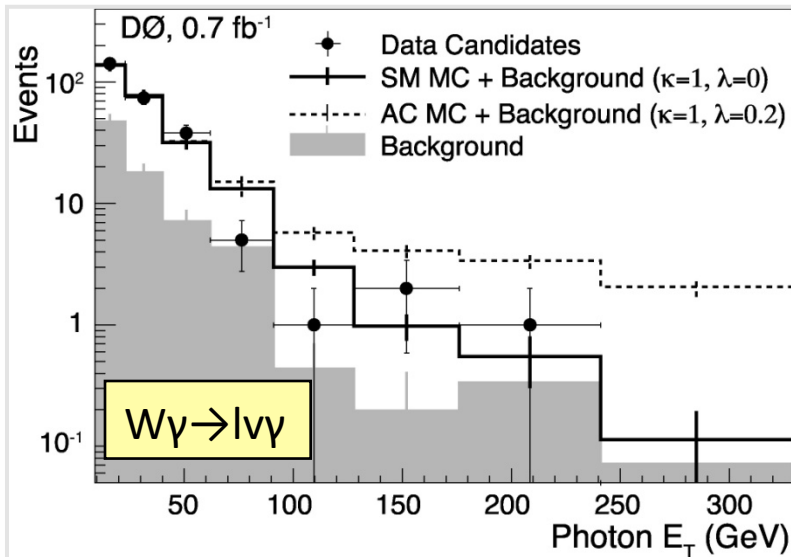
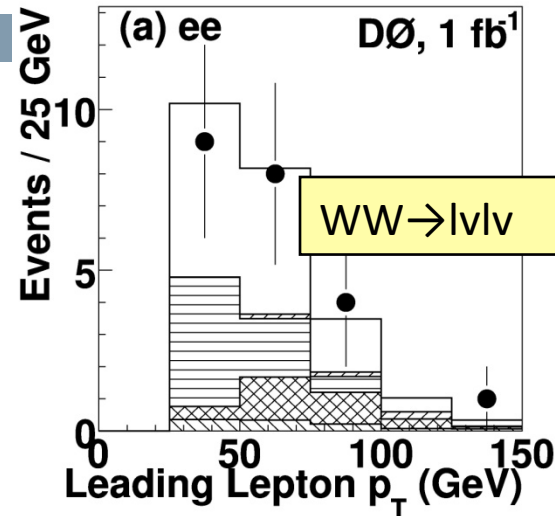
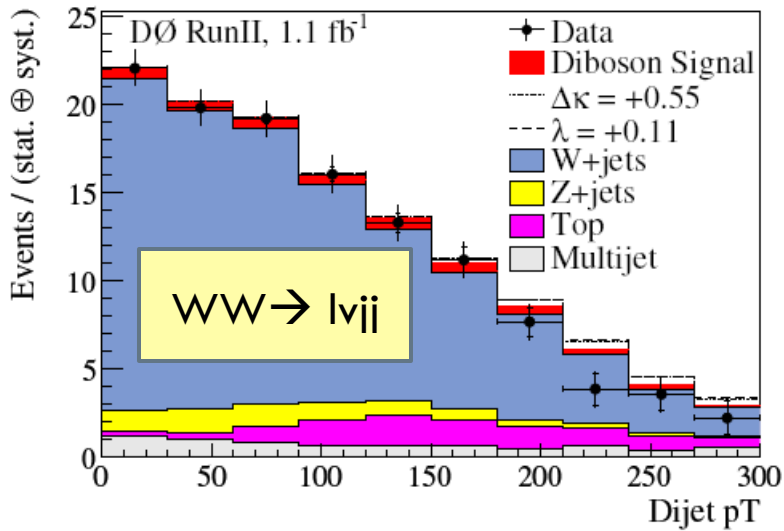
Complementary to Higgs production (same final states/challenges)



DØ – set charged TGC limits using pt in 4 channels



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Charged Triple Gauge Couplings

Probed by WW , WZ , and $W\gamma$ production

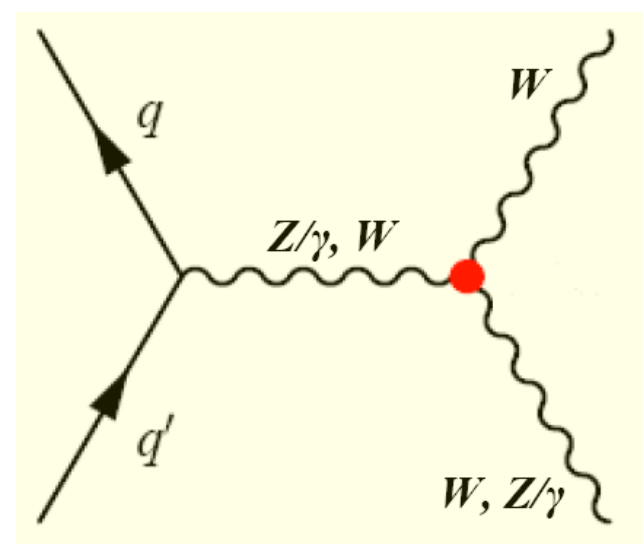
General Lagrangian has **14** parameters

Assume EM gauge invariance and C and P conservation

\Rightarrow 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

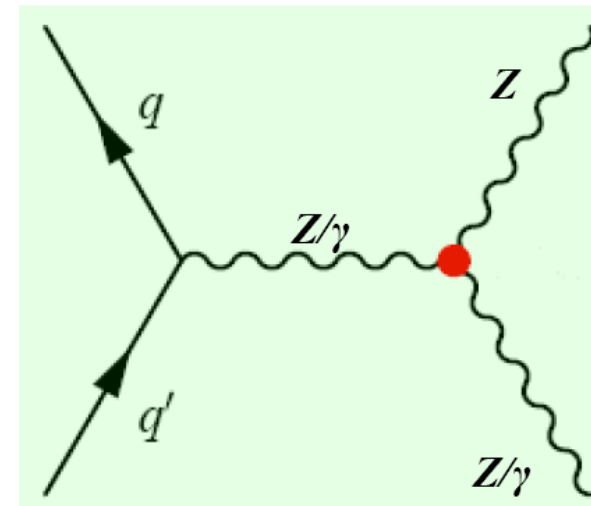
Probed by ZZ and $Z\gamma$ production

General Lagrangian has **8** TGC parameters

Assume CP conservation

\Rightarrow 4 non-SM TGC parameters:

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



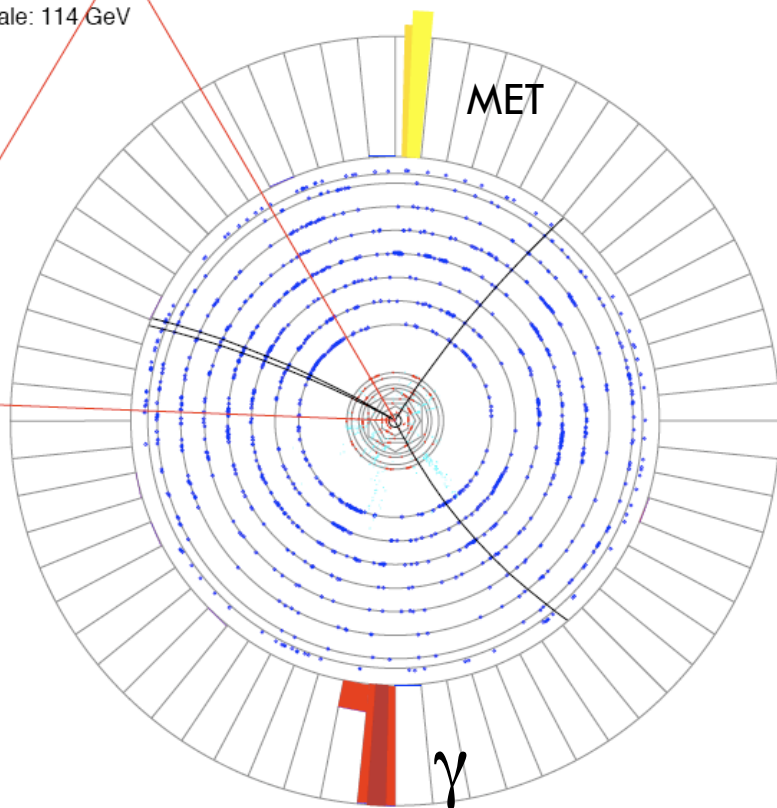
$\nu\nu\gamma$ candidate event



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Run 225055 Evt 44315577 Sun Sep 10 03:18:04 2006

ET scale: 114 GeV



Run 225055 Evt 44315577 Sun Sep 10 03:18:04 2006

E scale: 130 GeV

