Diboson Production at DØ

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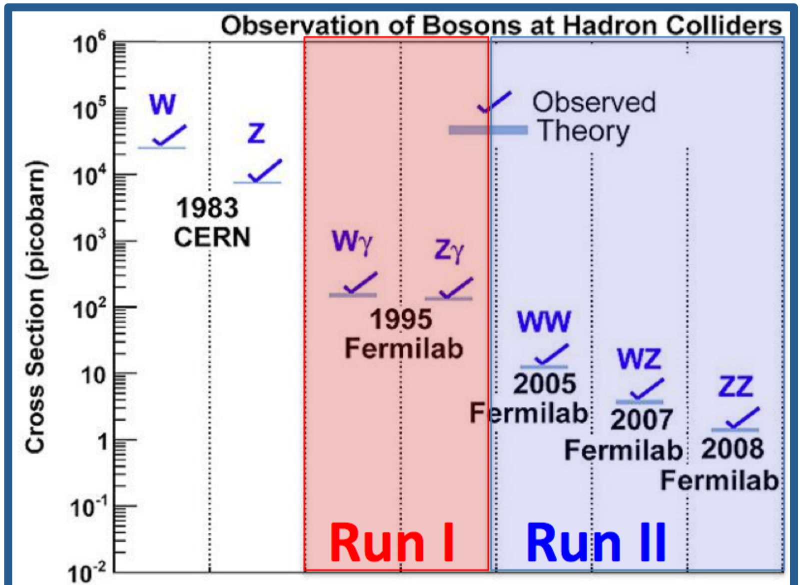
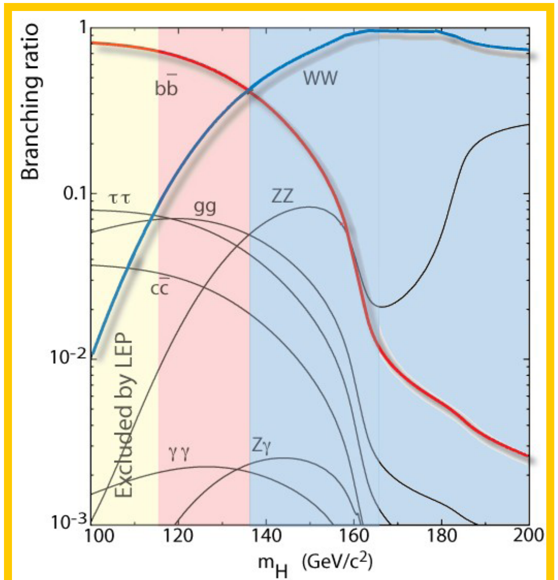
Diboson Production at DØ

- Motivation
  - Triple Gauge Couplings (TGCs)
- The Tevatron and DØ
- $W\gamma \longrightarrow \mu\nu\gamma$
  - Radiation Amplitude Zero and TGCs
- $WZ \longrightarrow \ell\nu\ell\ell$
  - TGCs
- $ZZ \longrightarrow \ell\ell\ell\ell$
  - Kinematics

Motivation

- Precision test of standard model predictions
- Direct window to SM Higgs (*H*→*WW/ZZ/Zγ*)
- Probe for new physics in kinematics
  - Anomalous values of triple gauge boson couplings

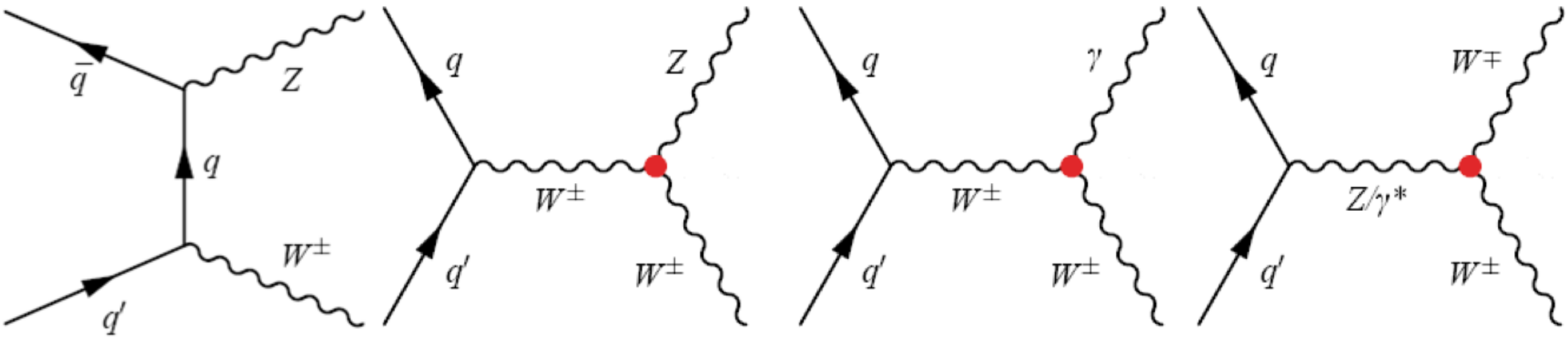




Dibosons at DØ

Triple Gauge Couplings

- SM has two charged TG vertices: *WWZ* & *WWγ*



- With EM gauge invariance and C and P cons., most general Lorentz inv. Lagrangian is:

$$\frac{\mathcal{L}_{WWV}}{g_{WWV}} = i\, g_1^V \left(W^\dagger_{\mu\nu}W^\mu - W^{\dagger\mu}W_{\mu\nu}\right)V^\nu + i\,\kappa_V\, W^\dagger_\mu W_\nu V^{\mu\nu} + i\frac{\lambda_V}{M_W^2} W^{\dagger\,\nu}_{\mu} W_\nu{}^\rho V_\rho{}^\mu$$

...where $V = \gamma$ or Z, $g_{WW\gamma} = -e$, $g_{WWZ} = -e\cot\theta_W$, and $g_1^\gamma = 1$

In SM:
$\lambda_V = 0$
$g_1^V = \kappa_V = 1$
$(\Delta\kappa \equiv \kappa - 1)$

Anomalous TGC Limits

- Anomalous TGCs introduced as dipole form factors to preserve partial-wave unitarity and avoid divergent cross sections

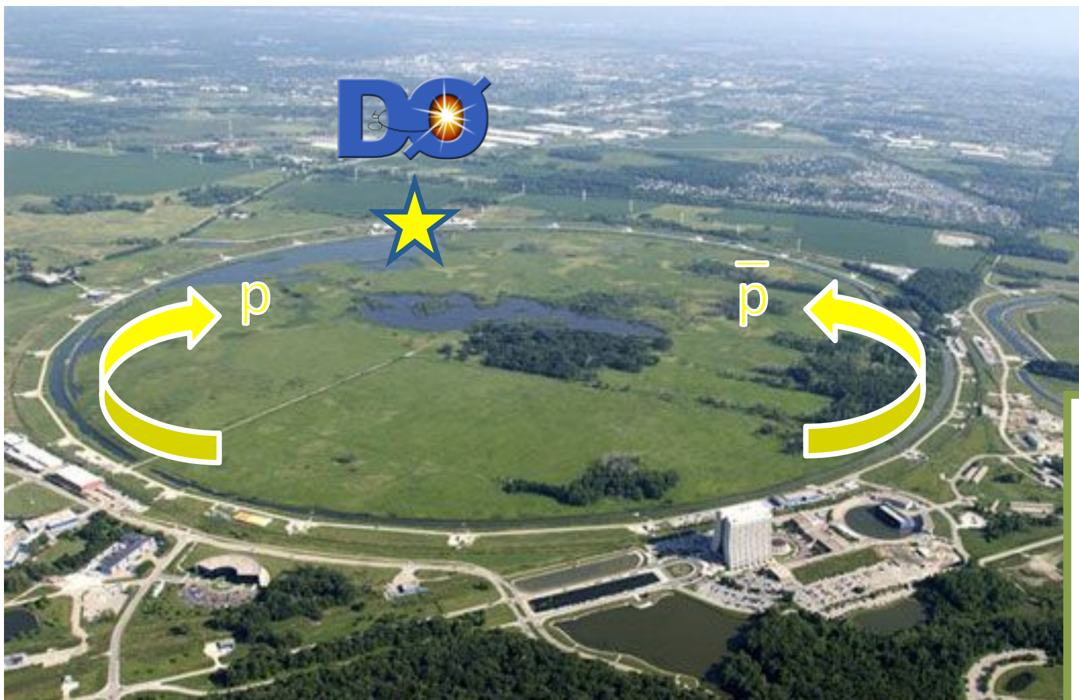
$$A(\hat{s}) = \frac{A_0}{(1+\hat{s}/\Lambda^2)^2}$$

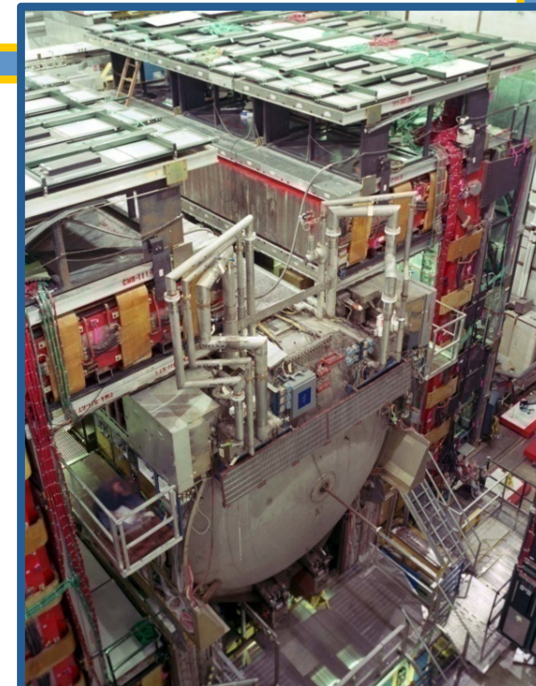
- Constraints may reduce free parameters
  - Hagiwara, Ishihara, Szalapski, Zeppenfeld (HISZ)
    Phys. Rev. D 48, 2182 (1993)
    - Equal coupling between SU(2)×U(1) and Higgs fields

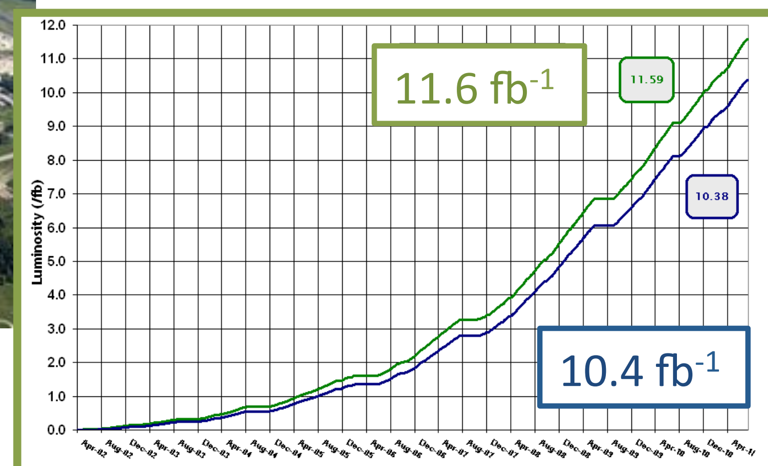
$$\Delta\kappa_Z = \Delta\kappa_\gamma(1-tan^2\theta_W)/2,\ \Delta g_1^Z = \Delta\kappa_\gamma/2cos^2\theta_W,\ \text{and}\ \lambda_Z = \lambda_\gamma$$

Making Dibosons at Fermilab

The Tevatron produces $p\bar{p}$ collisions at CM energy ($\sqrt{s}$) 1.96 TeV

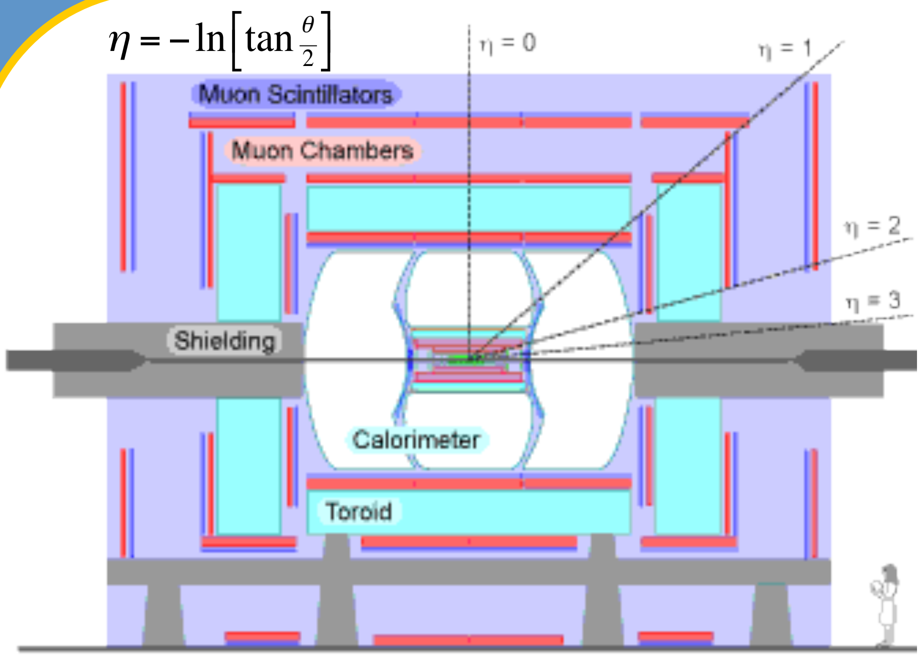


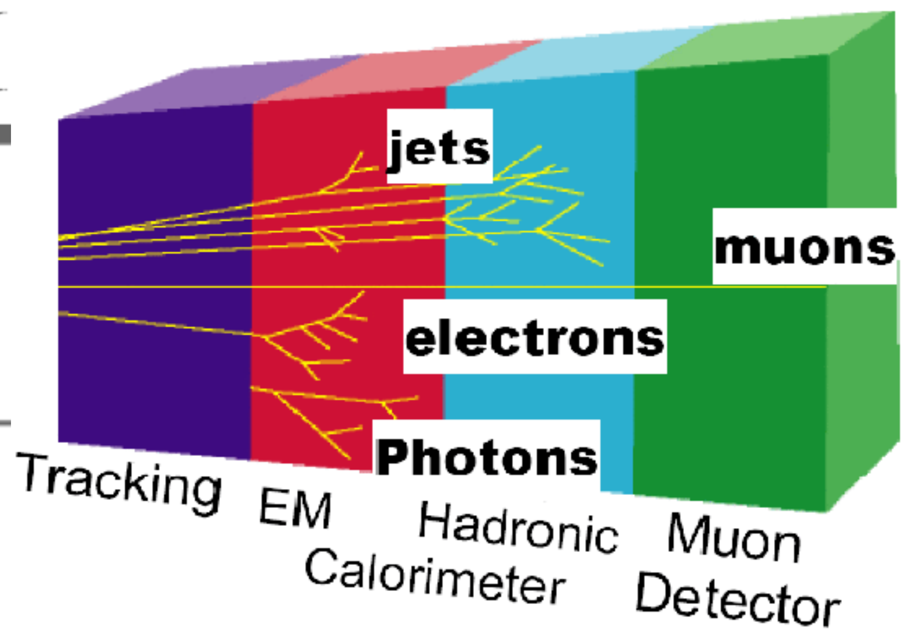




Thanks to the Accelerator Division for providing excellent performance!

The DØ Detector

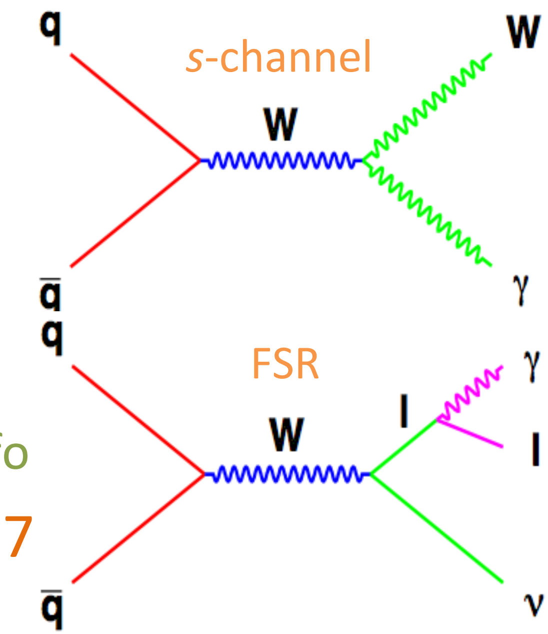




- Silicon vertex detector
- Scintillating fiber tracking & preshower detectors
- LAr-U calorimeter
- Muon chambers

DØ Note 6172-CONF, 4.2 fb^{-1}

$W\gamma \longrightarrow \mu\nu\gamma$ Production

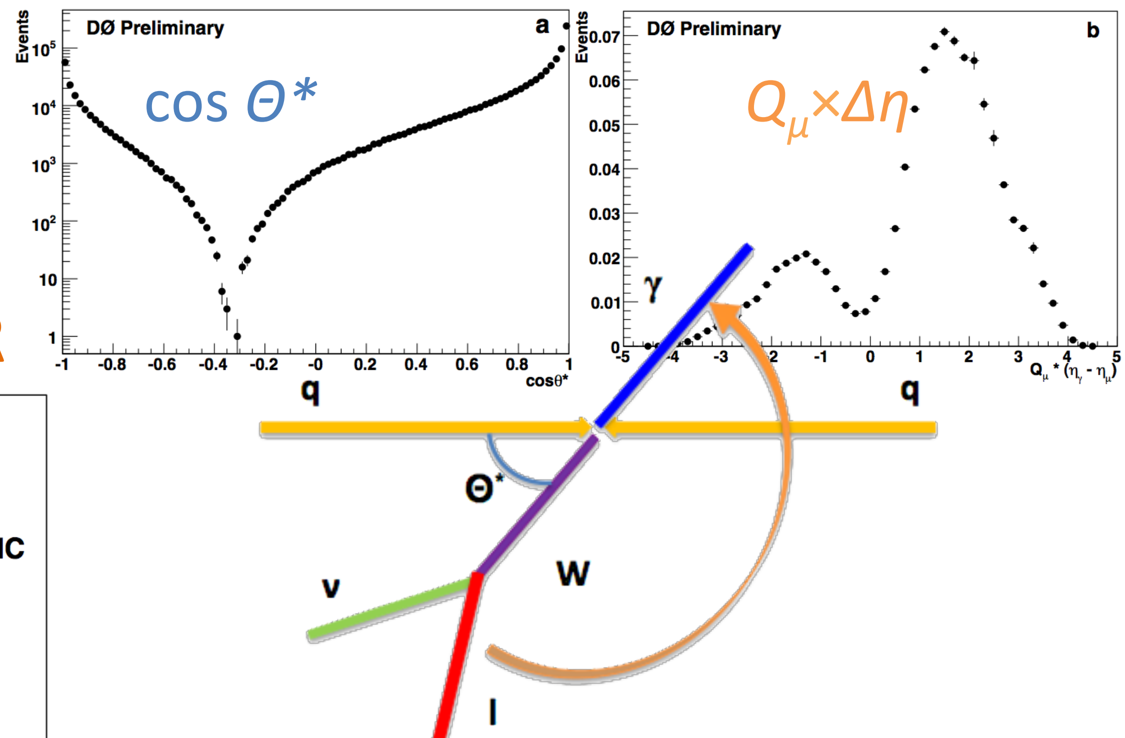


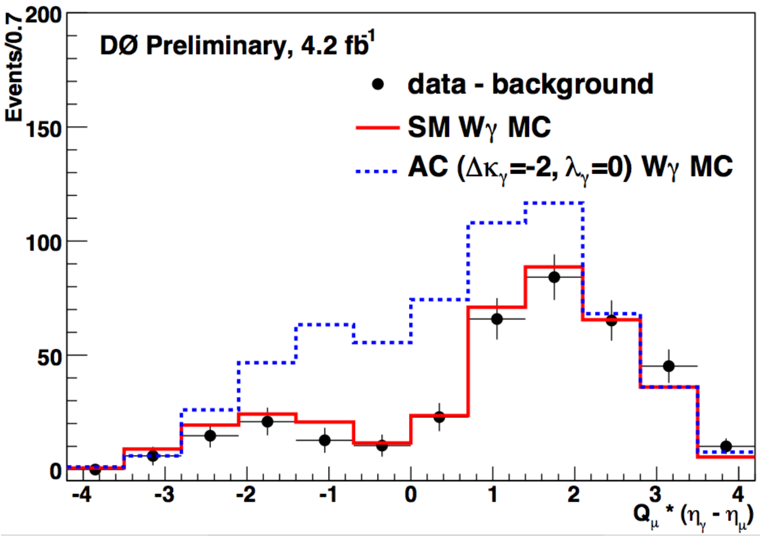
- Event selection suppresses FSR
  - 1 Isolated μ, $p_T > 20$ GeV, $|\eta| < 1.6$
  - Missing $E_T > 20$, MET+μ $M_T > 40$ GeV
  - γ $E_T > 10$ GeV, $|\eta| < 1.1$ or $1.5 < |\eta| < 2.5$
    - NN reduces fakes using CAL, CPS & tracker info
  - 3-body (μ,MET,γ) $M_T > 110$ GeV, $\Delta R_{\mu\gamma} > 0.7$
- $e\mu+X$, W+jet bkgds from data
  - $Z_{\mu\mu}\gamma$ and $W_{\tau\nu}\gamma$ from MC
- SM ($p_T^\gamma > 8$): σ = 16 ± 0.4 pb
  - σ = 15.2 ± 0.4 (stat) ± 1.6 (syst) pb

	Total
$e\mu$+X	5.2 ± 1.9
$Z_{\mu\mu}\gamma$	21.3 ± 2.6
$W_{\tau\nu}\gamma$	6.2 ± 0.8
W+jet	101.5 ± 7.7
total background	134.2 ± 8.6
data	492
data - background	357.8 ± 23.8
signal	375.6 ± 41.5

Radiation Amplitude Zero

- From interference between tree level diagrams
  - Zero ➛ dip for observables in lab frame
  - Obscured by FSR

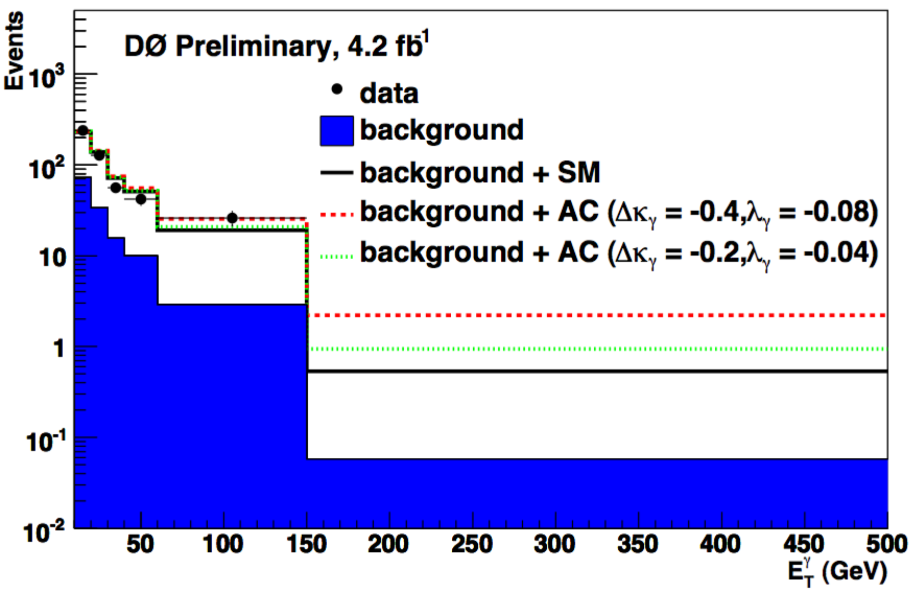


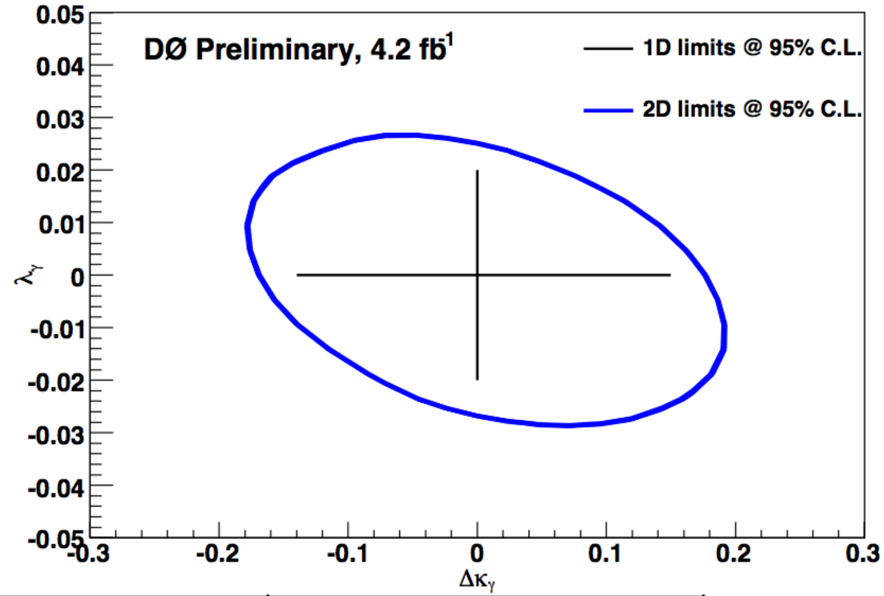


- Observe dip consistent with the SM prediction

Anomalous $WW\gamma$ TGCs

- Limits set using E_T^γ spectrum (Λ = 2 TeV)
  - Improves previous 0.7 fb^{-1} DØ limits by factor of 3
  - Sensitivity comparable to the LEP experiments





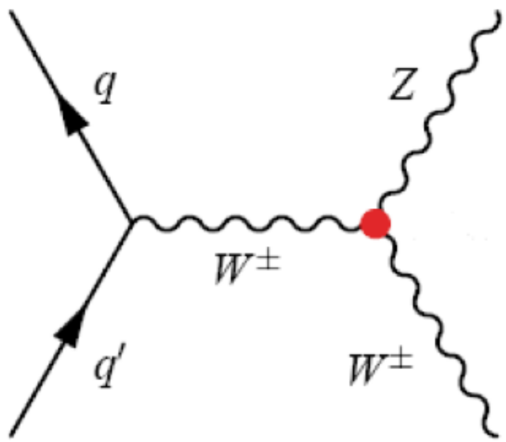
68% C.L. Limits:

LEP2 combined	$-0.072 < \Delta\kappa_\gamma < 0.017$	$-0.049 < \lambda_\gamma < 0.008$
DØ 4.2 fb^{-1}	$-0.07 < \Delta\kappa_\gamma < 0.07$	$-0.012 < \lambda_\gamma < 0.011$

Phys. Lett. B 695, 67 (2011), 4.1 fb^{-1}

$WZ \longrightarrow \ell\nu\ell\ell$ Production

- Four channels ($\ell = e, \mu$) with similar selection
  - Three isolated ℓ with $p_T > 15$ GeV
    - ICR e ($1.1 < |\eta| < 1.6$) allowed as part of Z decay
  - MET > 20 GeV
  - Best M_Z from like-flavor opposite-sign leptons make Z
    - Other lepton considered as W decay product
    - 92% correct for eee, 89% correct for $\mu\mu\mu$
- V+jets, $Z\gamma$ est. from data; ZZ, $t\bar{t}$ from MC

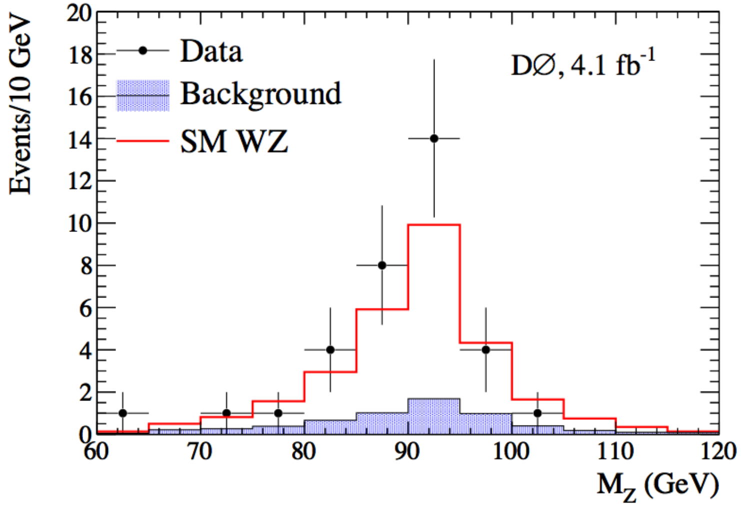


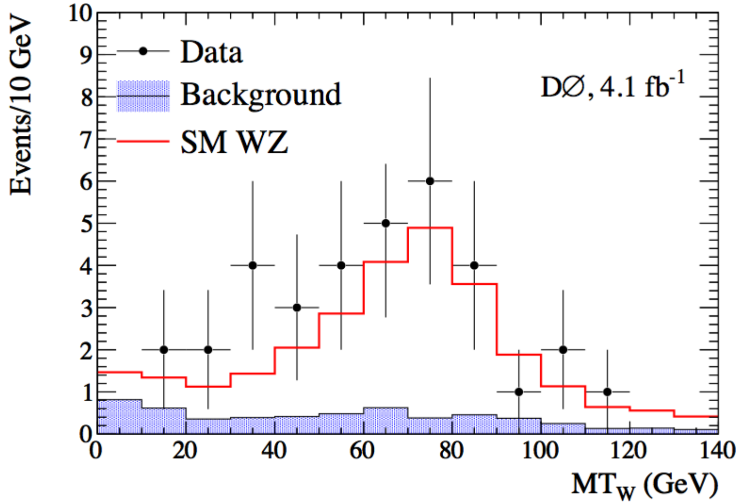
$WZ \to \ell\nu\ell\ell$ Production

- 34 candidates
  - 23.3 ± 1.5 *WZ*
  - 6.0 ± 0.6 bkgd

Source	eee	$ee\mu$	$e\mu\mu$	$\mu\mu\mu$
Total bkg.	1.33 ± 0.21	2.11 ± 0.31	1.13 ± 0.35	1.46 ± 0.24
WZ signal	5.9 ± 0.8	6.9 ± 0.8	4.7 ± 0.6	5.8 ± 0.8
Observed	9	11	9	5

- SM $\sigma = 3.25 \pm 0.19$ pb
  - Observed $\sigma = 3.90^{+1.01}_{-0.85}$ (stat+syst) $\pm$ 0.31 (lumi) pb



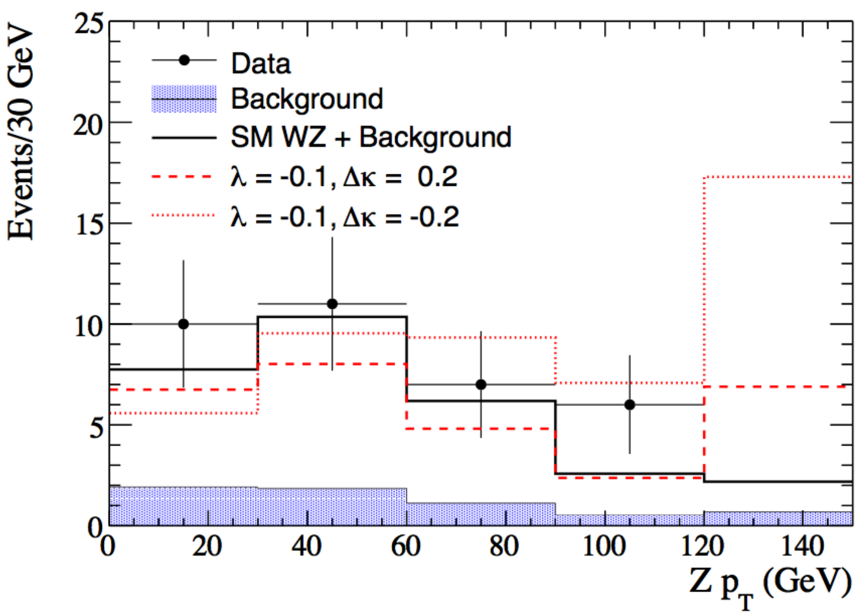


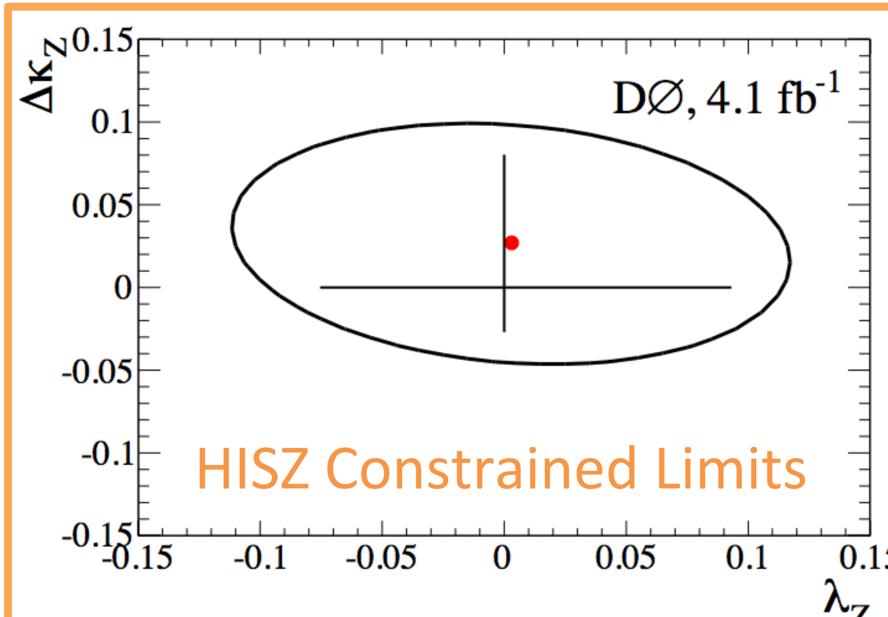
Dibosons at DØ

WZ Anomalous TGCs

- Z p_T spectrum used to set TGC limits
  - Most stringent limits from direct *WZ* study

Coupling relation	95% C.L. Limit
$\Delta g_1^Z = \Delta\kappa_Z = 0$	$-0.075 < \lambda_Z < 0.093$
$\lambda_Z = \Delta\kappa_Z = 0$	$-0.053 < \Delta g_1^Z < 0.156$
$\lambda_Z = \Delta g_1^Z = 0$	$-0.376 < \Delta\kappa_Z < 0.686$
$\Delta\kappa_Z = 0$ (HISZ)	$-0.075 < \lambda_Z < 0.093$
$\lambda_Z = 0$ (HISZ)	$-0.027 < \Delta\kappa_Z < 0.080$

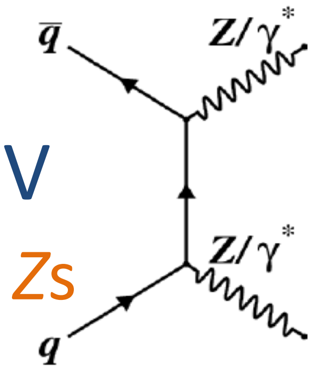


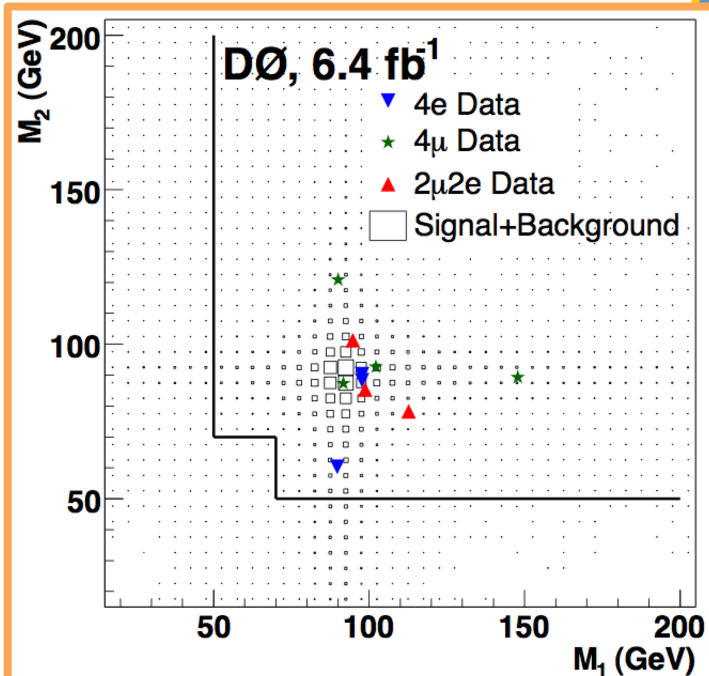


Phys. Rev. D 84, 011103 (2011), 6.4 fb^{-1}

$ZZ \longrightarrow \ell\ell\ell\ell$ Production

- Smallest SM diboson σ before Higgs
- Selection requires $M_{Z1} > 70$, $M_{Z2} > 50$ GeV
  - Same-flavor opposite-sign ℓs used to make Zs
    - 1 flavor: $p_T^{1,2,3,4} > 30, 25, 15, 15$
    - 2 flavors: $p_T^{\ell:1,2} > 20, 15$ each ℓ
- Largest bkgd. ($W/Z/\gamma$+jets) estimated from data
  - $t\bar{t}$ background from MC
  - Cosmic ray μ contribution considered for $ee\mu\mu$, $\mu\mu\mu\mu$



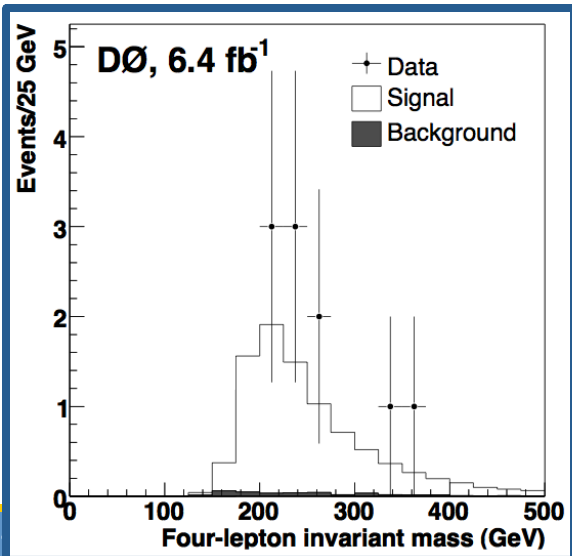


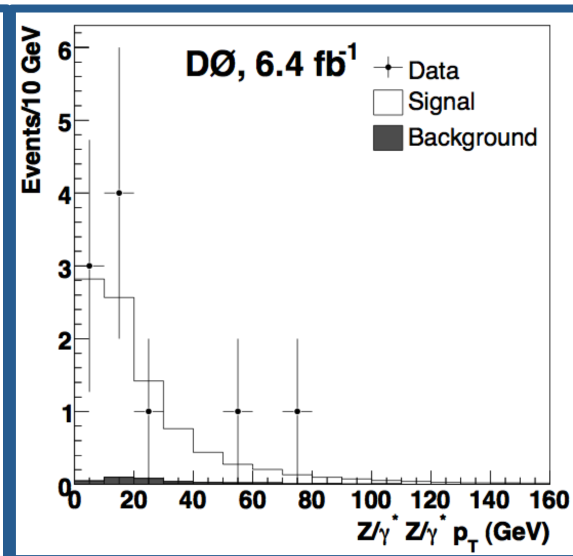
Dibosons at DØ

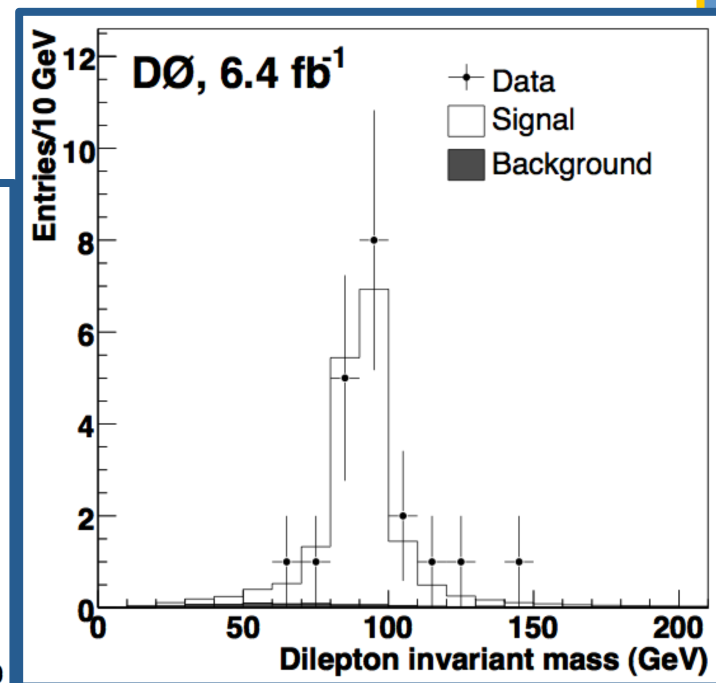
ZZ→ℓℓℓℓ Production

- Observe 10 events with 0.37 ± 0.13 background
- SM NLO prediction: σ(*Z*/γ* *Z*/γ*) = 1.4 ± 0.1 pb
  - Obs. $\sigma = 1.33\,^{+0.50}_{-0.40}$ (stat) ± 0.12 (syst) ± 0.09 (lumi) pb
  - Combined with 2.7 fb^{-1} *ℓℓνν*:

$\sigma(ZZ) = 1.40\,^{+0.43}_{-0.37}$ (stat) ± 0.14 (syst) pb



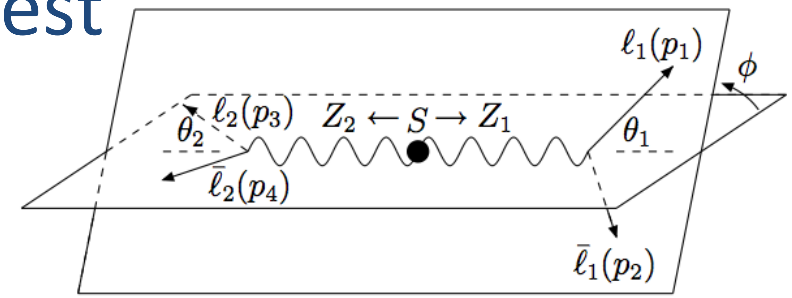




Dibosons at DØ

ZZ Decay Plane Angle

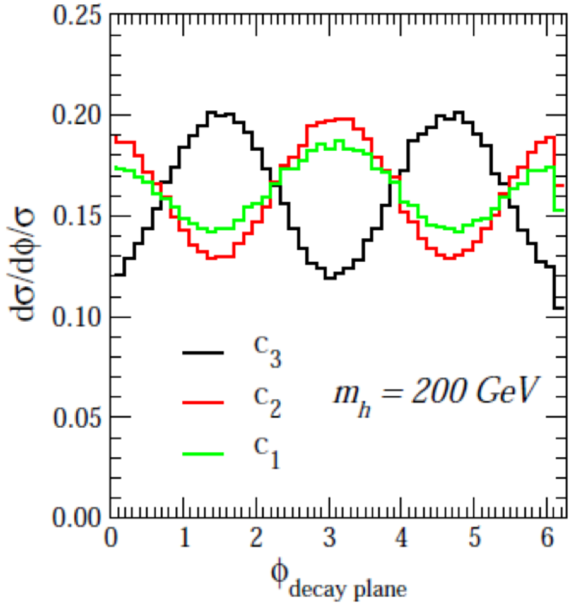
- Decay plane angle of interest for Higgs/BSM search
  - Rotates Z_2 decay plane into Z_1 decay plane

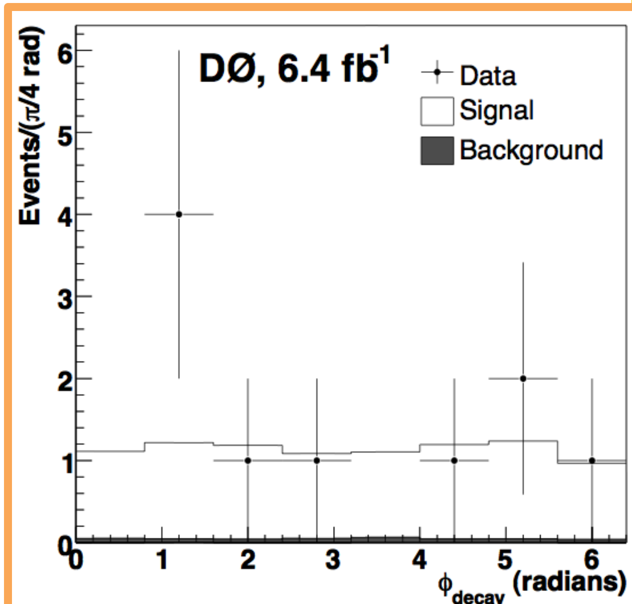


Higgs-like scalar

Heavy scalar

CP-odd scalar

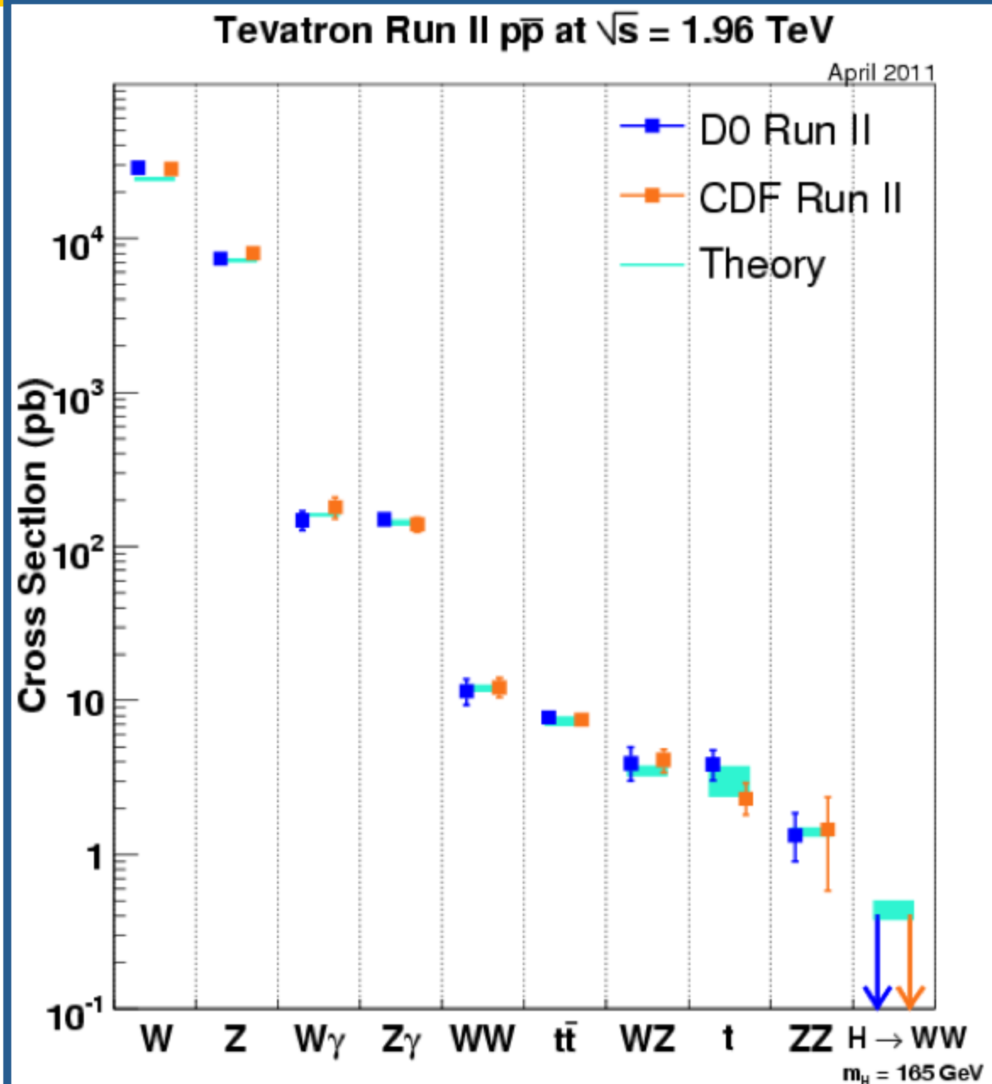




Diboson Production at DØ

- Up to 6.4 fb^{-1} used to measure dibosons
  - No deviation from SM in kinematics & TGCs
- Many analyses will have twice the data by the end of RunII

$W\gamma \longrightarrow \mu\nu\gamma$	4.2 fb^{-1}	15.2 ± 1.6 pb
$WZ \longrightarrow \ell\nu\ell\ell$	4.1 fb^{-1}	$3.90^{+1.06}_{-0.90}$ pb
$ZZ \longrightarrow \ell\ell\ell\ell$	6.4 fb^{-1}	$1.33^{+0.52}_{-0.43}$ pb



Diboson Production

at DØ

Dibosons at DØ

MVA Validation (*WW/WZ*)

- *WW/WZ*⟶*ℓνjj* used to verify MVA techniques
  - SM signal with same signature as WH⟶*ℓνjj*
  - MVA gives superior results vs. dijet mass