Study of Diboson Physics with the ATLAS Detector at LHC

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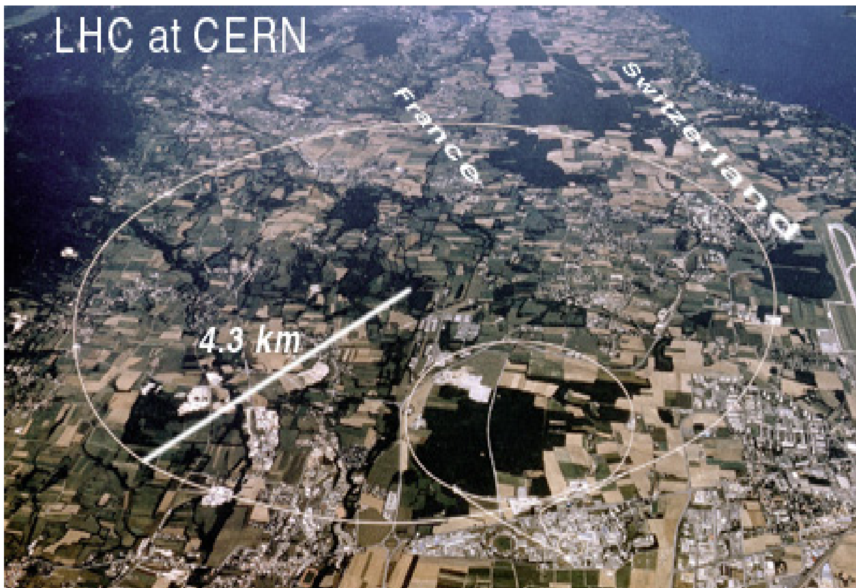
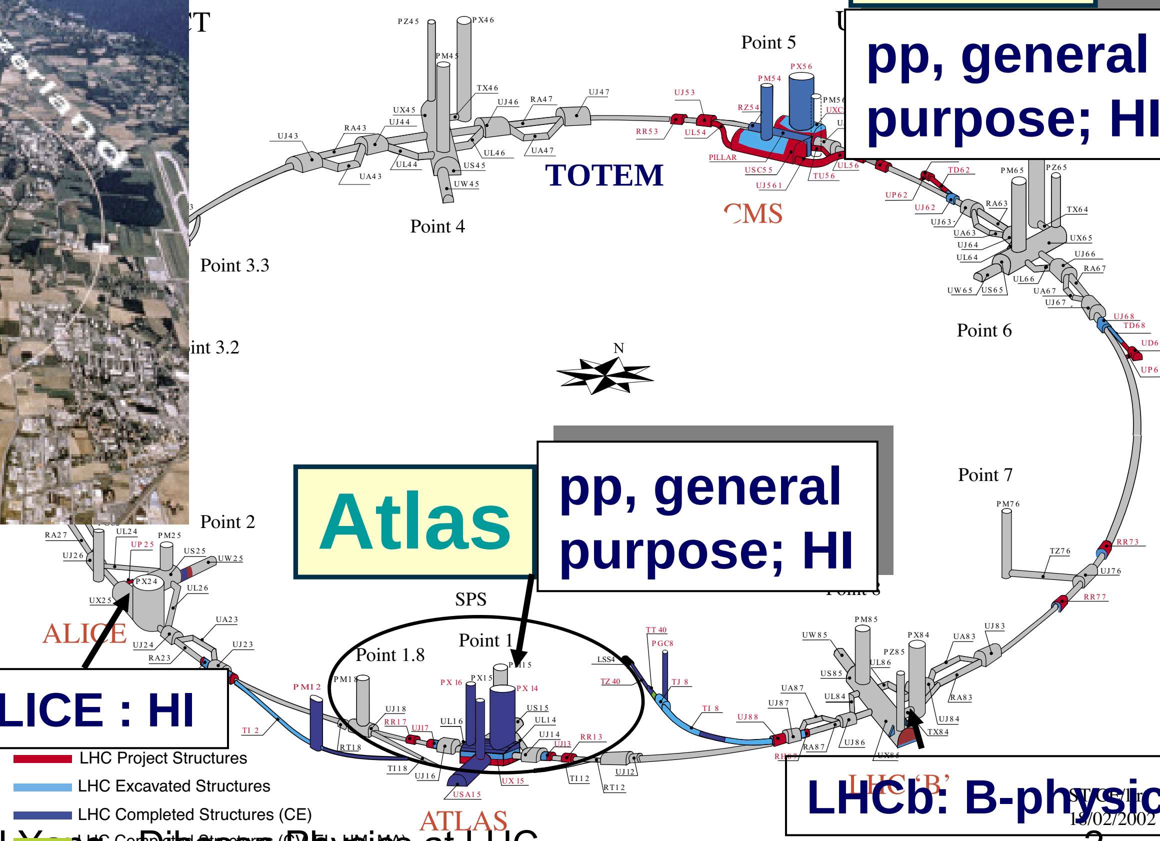
The Large Hadron Collider at CERN

CM = 14 GeV, Lumi = 10^{34} cm^{-2} s^{-1}

- **27 km Tunnel in Switzerland & France**





CMS

pp, general purpose; HI

Atlas

pp, general purpose; HI

ALICE : HI

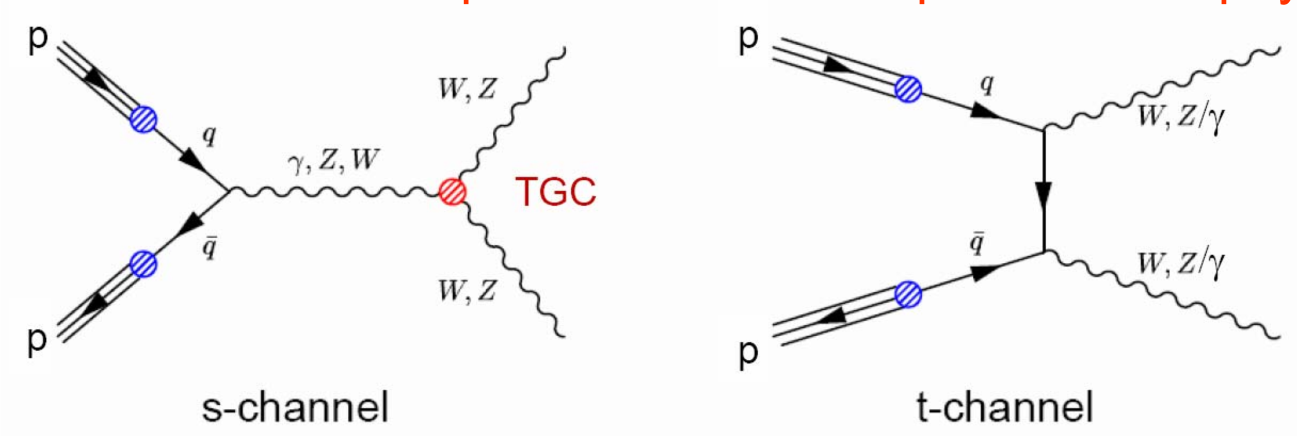
LHCb: B-physics

First Collision: Summer 2008

Physics Motivations - Diboson

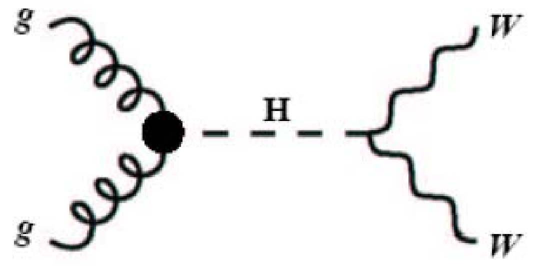
- It's related to some fundamental questions:
  - Why massive bosons?
  - What is the source of the EWSB?

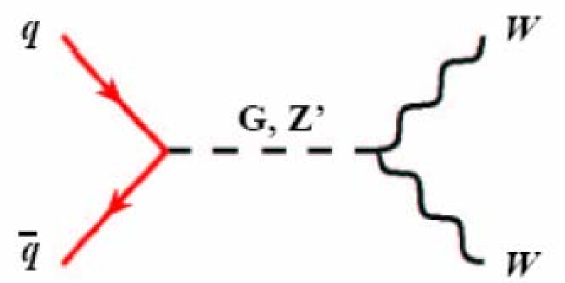
- There should have some new physics leading to EWSB through searching for
  - Direct evidence of new particles (Higgs, SUSY etc.)
  - Indirect evidence of observing anomalous TGCs
  - SM diboson are important control samples for new physics

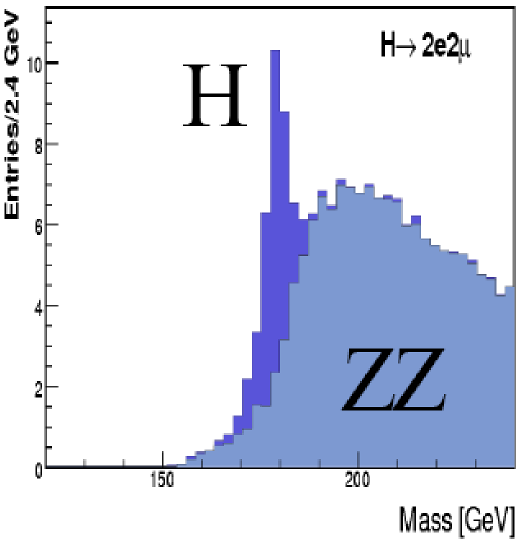


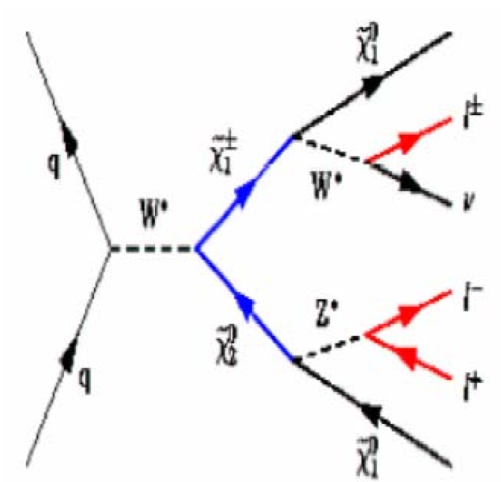
New Physics with Diboson

- WW – Higgs, Z’, G, TGCs
- WZ – SUSY, technicolor, W’, TGCs
- ZZ – Higgs, TGCs
- Wγ – TGCs
- Zγ – TGCs









Cross Sections of Diboson

Diboson mode	Conditions	$\sqrt{s} = 1.96$ TeV $\sigma[pb]$	$\sqrt{s} = 14$ TeV $\sigma[pb]$
W^+W^- [14]	W-boson width included	12.4	111.6
$W^\pm Z^0$ [14]	Z and W on mass shell	3.7	47.8
$Z^0 Z^0$ [14]	Z's on mass shell	1.43	14.8
$W^\pm\gamma$ [15]	$E_T^\gamma > 7$ GeV, $\Delta R(\ell,\gamma) > 0.7$	19.3	451
$Z^0\gamma$ [16]	$E_T^\gamma > 7$ GeV, $\Delta R(\ell,\gamma) > 0.7$	4.74	219

Production rate at LHC will be at least 100x higher at Tevatron.
10x higher cross section and 10-100x higher luminosity.

Probes much higher energy region, so sensitive to anomalous TGCs.

ATLAS diboson Event Selection

$W^+W^- \rightarrow \ell^+\nu\, \ell^-\, \nu$ σ_{WW} = 113.3 pb	2 isolated leptons with P_T > 25 GeV, opposite charges, $\Delta R(\ell\ell)$>0.2, Missing transverse energy > 30 GeV, $\|M_Z$-Mee/$\mu\mu\|$ > 30 GeV N_{jet} (E_T>30 GeV) < 2, |Vector-sum (lep, MET)|<100GeV
$W\, Z \rightarrow \ell\nu\, \ell^+\ell^-$ σ_{W+Z} = 29.4 pb σ_{W-Z} = 18.4 pb	3 isolated leptons with $P_{T(max)}$ > 25 GeV, $\Delta R(\ell\ell)$>0.2 vertex cut for each lepton pair: ΔZ<1mm, ΔA<0.1mm MET > 30 GeV, $\|M_Z$-Mee/$\mu\mu\|$ < 10 GeV, 40GeV < M_T < 250GeV N_{jet} (E_T>30 GeV) < 2, |Vector-sum (lep, MET)|<100GeV
$ZZ \rightarrow \ell^+\ell^-\, \ell^+\ell^-$ σ_{ZZ} = 18.8 pb	4 isolated leptons with at least one P_T > 20 GeV Separation between each lepton pair $\Delta R(\ell\ell)$>0.2 All the lepton come from the same vertex, no hadron jets
$ZZ \rightarrow \ell^+\ell^-\, \nu\nu$ σ_{ZZ} = 18.8 pb	2 lepton with P_T > 20 GeV, and $\|M_Z$-$M_{ll}\|$<10 GeV, $P_T(\ell\ell)$ > 100 GeV veto the 3^{rd} lepton, MET > 50 GeV, N_{jet} (E_T>30 GeV) =0, $\Delta\phi$(Z, MET) > 35 deg, |MET-PT(Z)|/PT(Z) < 0.35
$W\, \gamma \rightarrow \ell\nu\, \gamma$ $\sigma_{\mu\nu\gamma}$=(51.8+38.8)*1.4pb	1 isolated lepton with PT > 20 GeV 1 isolated photon with ET > 20 GeV MET > 30 GeV, 40GeV < M_T < 250Ge, Jet veto, $\Delta R(\ell\gamma)$>0.7
$Z\, \gamma \rightarrow \ell^+\ell^-\gamma$ $\sigma_{\mu\mu\gamma}$ = 20.2*1.4pb	2 isolated leptons with P_T > 20 GeV, opposite charges, $\Delta R(\ell\ell)$>0.2, $\|M_Z$-Mee/$\mu\mu\|$ < 10 GeV, one photon with PT>20GeV, Jet veto $\Delta R(\ell\gamma)$>0.7, $\|M_Z$-Meeγ/$\mu\mu\gamma\|$ > 30 GeV

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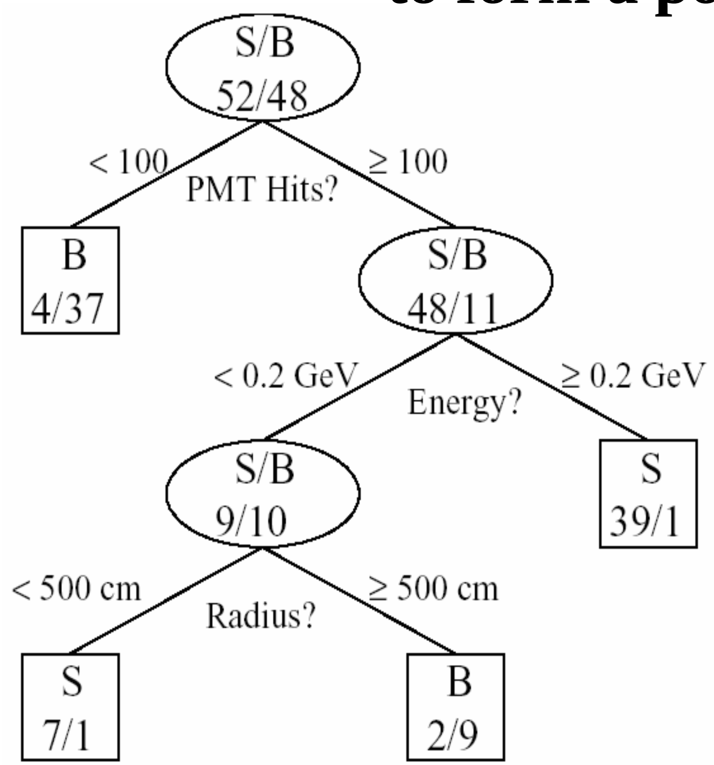
Boosted Decision Trees

➔Relative new in HEP – MiniBooNE, BaBar, D0(single top discovery), ATLAS
➔Advantages: robust, understand 'powerful' variables, relatively transparent, …

"A procedure that combines many weak classifiers to form a powerful committee"

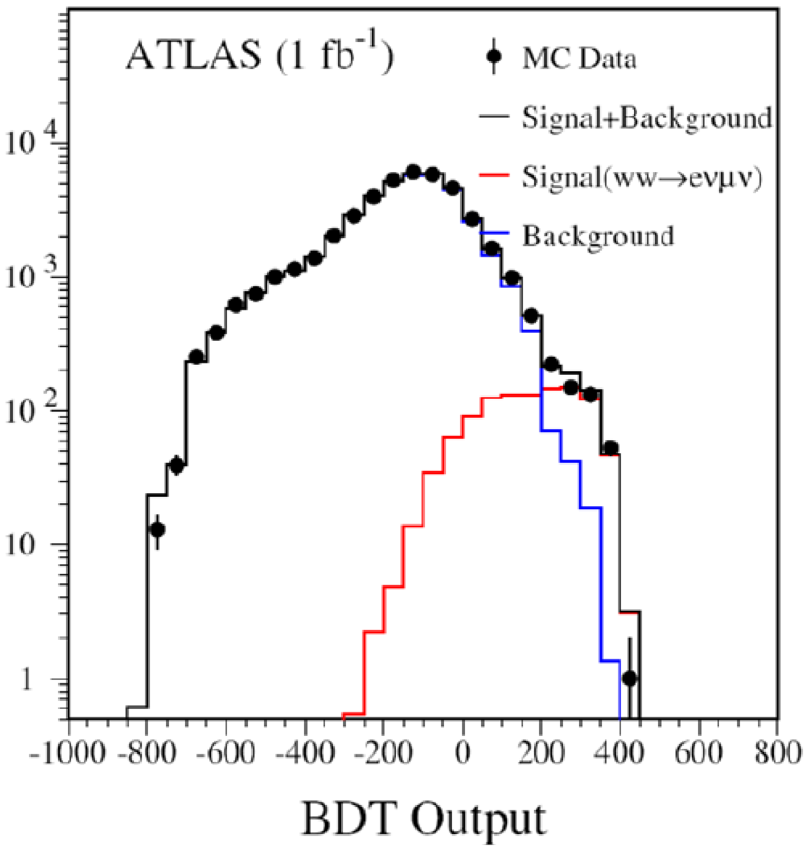


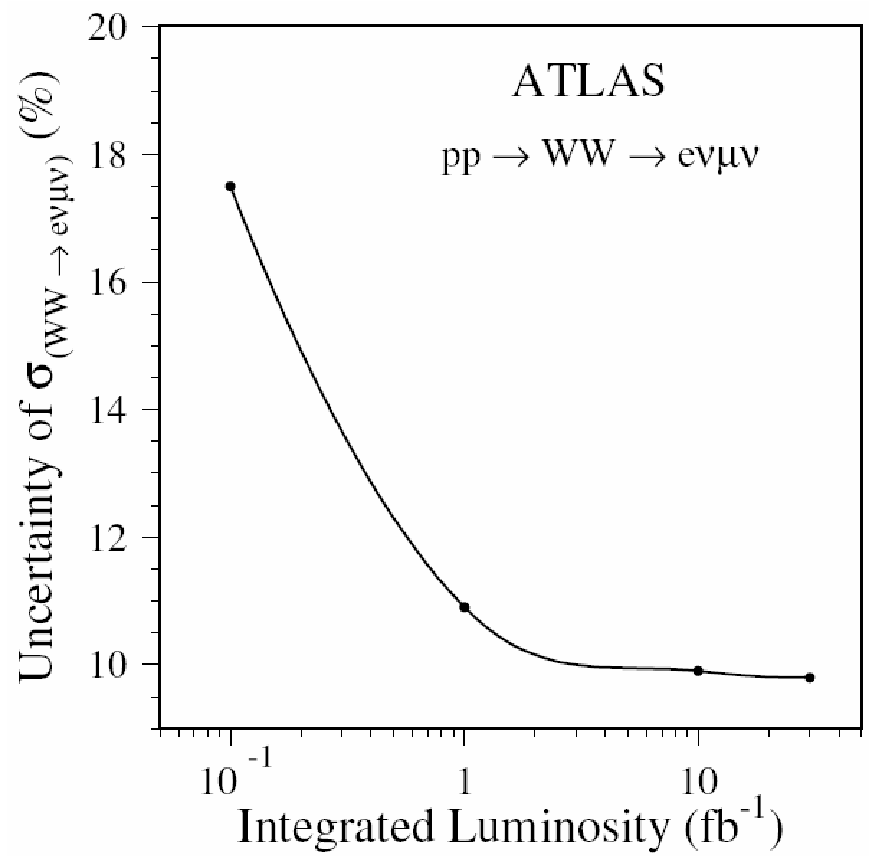
- Split data recursively based on input variables until a stopping criterion is reached (e.g. purity, too few events)
- Every event ends up in a "signal" or a "background" leaf
- Misclassified events will be given larger weight in the next decision tree (boosting)
- Build a set of decisions trees (~100 – 1000)

H.-J. Yang et.al. NIM A555 (2005)370, NIM A543 (2005)577, NIM A574(2007) 342

Analysis with Boosted Decision Trees

PP → WW → eνμν analysis using ATLAS fully simulated MC datasets (~ 30 Million events).

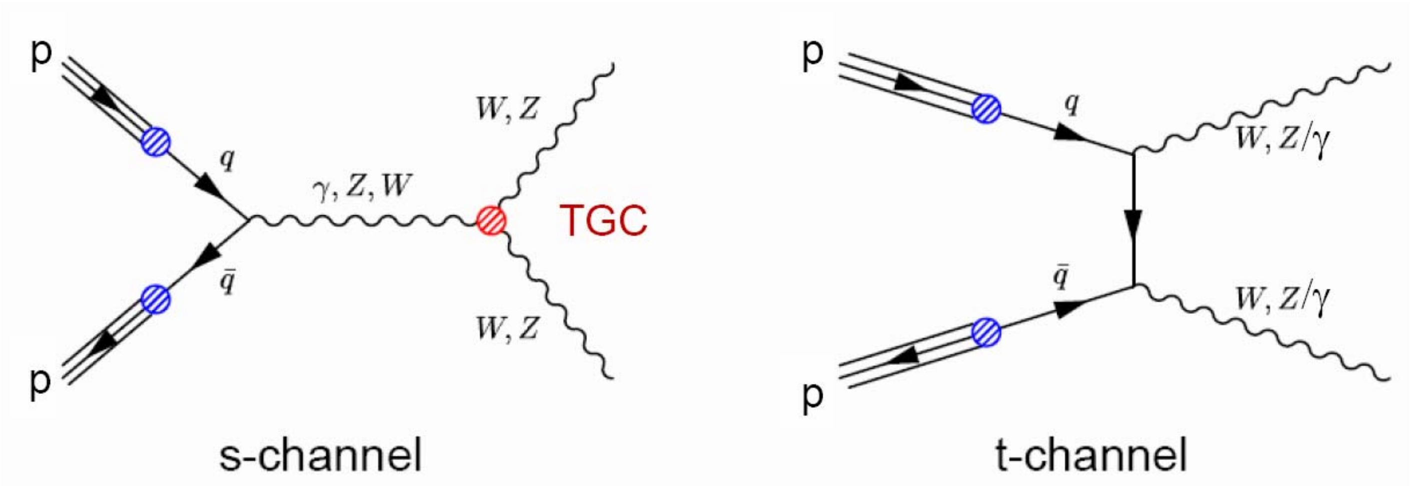




Diboson Results with $1fb^{-1}$ Int. Lumi

Diboson mode	Signal	Background	N_σ	Analysis (signal eff.)	σ_{stat}^{signal}
$W^+W^- \to e^\pm \nu \mu \mp \nu$	419.9 ± 3.5	80.8 ± 8.0	47	BDT (eff=15.2%)	4.9%
$W^+W^- \to \mu + \nu \mu^- \nu$	90.3 ± 1.6	20.2 ± 2.8	20	BDT (eff=6.6%)	10.5%
$W^+W^- \to e^+ \nu e^- \nu$	78.0 ± 1.6	35.4 ± 3.6	13	BDT (eff=5.7%)	11.3%
$W^+W^- \to \ell^+ \nu \ell^- \nu$	103.1 ± 2.6	16.6 ± 2.0	25	Cut based (eff=2.0%)	9.9%
$W^\pm Z \to \ell^\pm \nu \ell^+ \ell^-$	152.6 ± 1.7	16.1 ± 2.5	38	BDT (eff=17.9%)	8.1%
	53.4 ± 1.6	8.0 ± 1.1	19	Cut based (6.3%)	13.7%
$ZZ \to 4\ell$	16.5 ± 0.1	1.9 ± 0.2	7.2	Cut based (eff=7.7%)	24.6%
$ZZ \to \ell^+ \ell^- \nu \bar{\nu}$	10.2 ± 0.2	5.2 ± 2.0	3.7	Cut based (eff=2.6%)	31.3%
$W\gamma \to e\nu\gamma$	1901 ± 77	1474 ± 147	50	BDT (eff=6.7%)	2.3%
$W\gamma \to \mu\nu\gamma$	2976 ± 121	2318 ± 232	62	BDT (eff=10.5%)	1.8%
$Z\gamma \to e^+ e^- \gamma$	337.4 ± 12	187.2 ± 19	25	BDT (eff=5.5%)	5.4%
$Z\gamma \to \mu^+ \mu^- \gamma$	774.8 ± 25	466.7 ± 47	36	BDT (eff=12%)	3.6%

SM Diboson Production at LHC



- Model independent effective Lagrangian for charged triple gauge boson interactions with anomalous couplings (C & P Conservation)

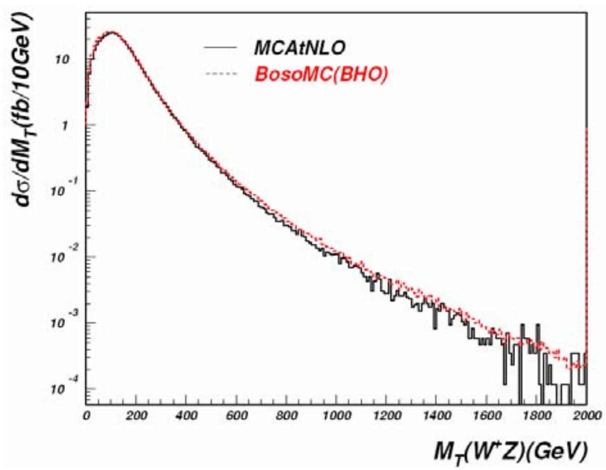
$$L/g_{WWV} = ig_1^V(W^*_{\mu\nu}W^\mu V^\nu - W_{\mu\nu}W^{*\mu}V^\nu) + i\kappa^V W^*_\mu W_\nu V^{\mu\nu} + \frac{\lambda^V}{M_W^2} W^*_{\rho\mu} W^\mu_\nu V^{\nu\rho}$$

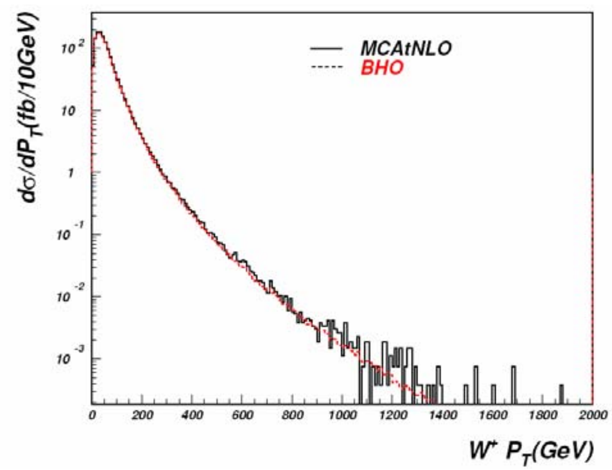
where V = Z, γ.

- In the Standard Model: $g_1^V = \kappa_V = 1$ and $\lambda_V = 0$.
- Five anomalous coupling parameters: Δg_1^Z, $\Delta\kappa_Z$, λ_z, $\Delta\kappa_\gamma$, and λ_γ

Probing Anomalous TGCs in ATLAS

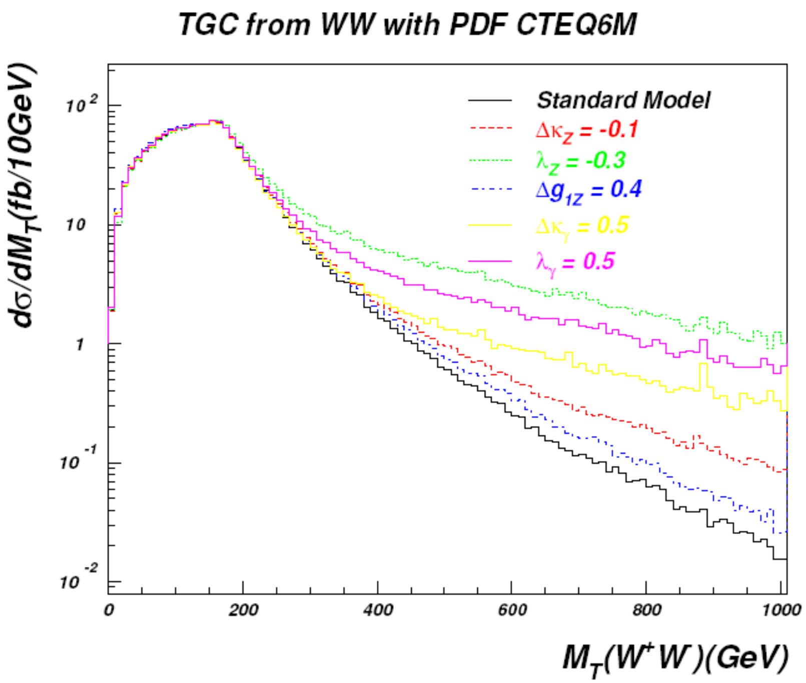
- To probe the anomalous couplings we need a model of the kinematic distributions for various couplings. We use:
  - NLO generators
    - MC@NLO produces events that are fully simulated in ATLAS
    - BHO MC generates events with anomalous couplings

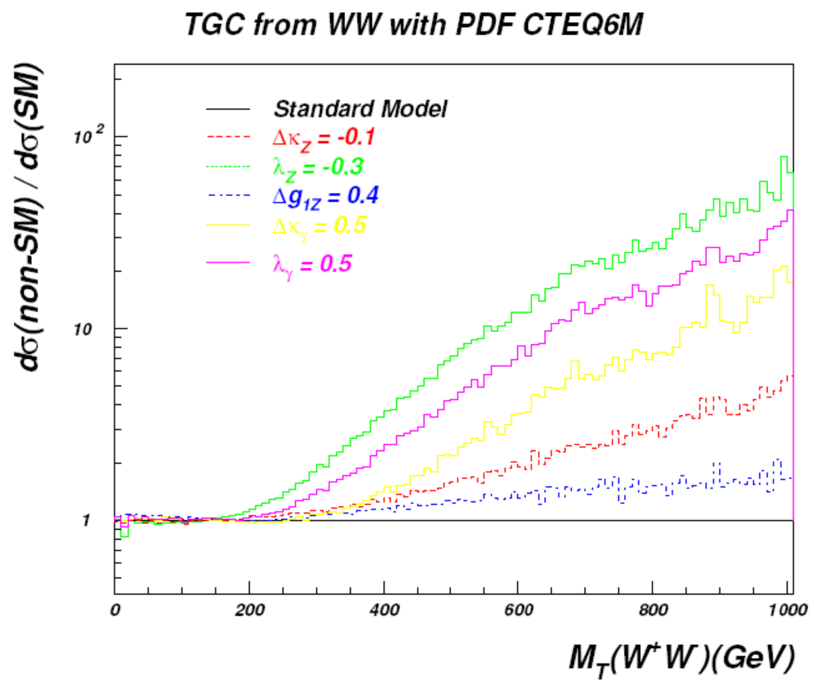




  - Reweighting
    - Using kinematic distributions from BHO we reweight the fully simulated MC@NLO events to produce expected distributions for a range of anomalous couplings.

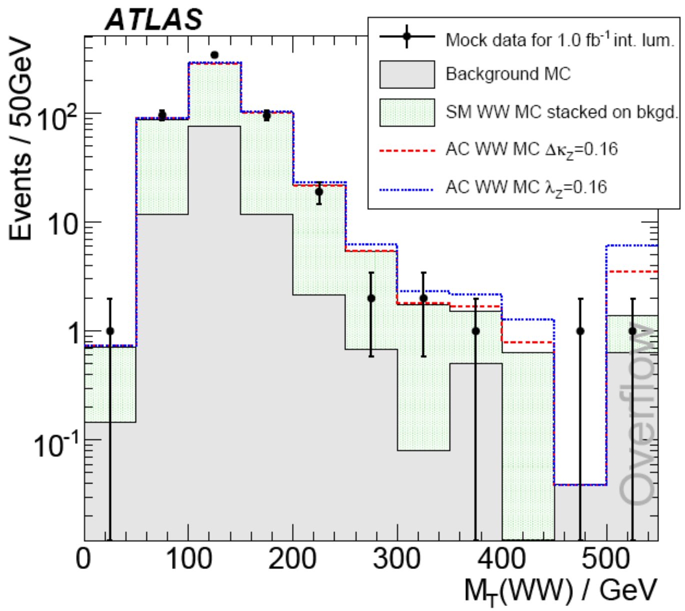
Anomalous spectra and reweighting ratio

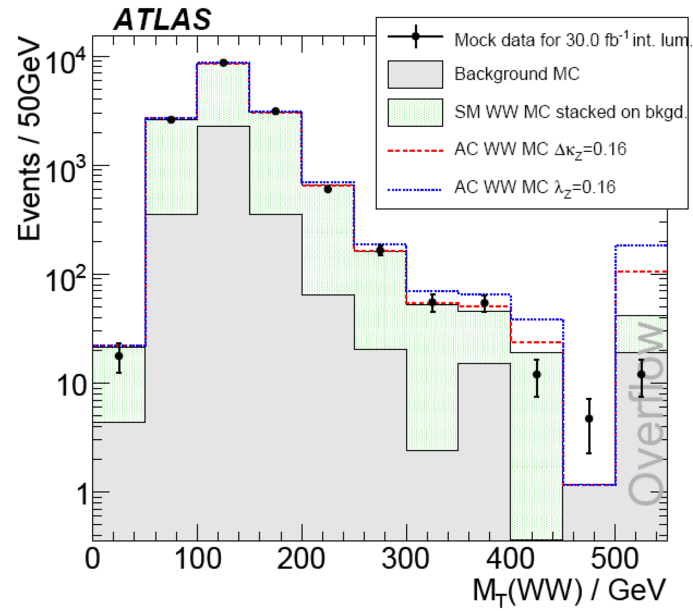




- The $M_T(WW)$ spectrum for W^+W^- events with anomalous coupling parameters using the BHO Monte Carlo.
- At right are the 'weights = dσ(non-SM)/dσ(SM)' used to reweight fully simulated events.

$M_T(WW)$ sensitive to WWZ & WWγ couplings



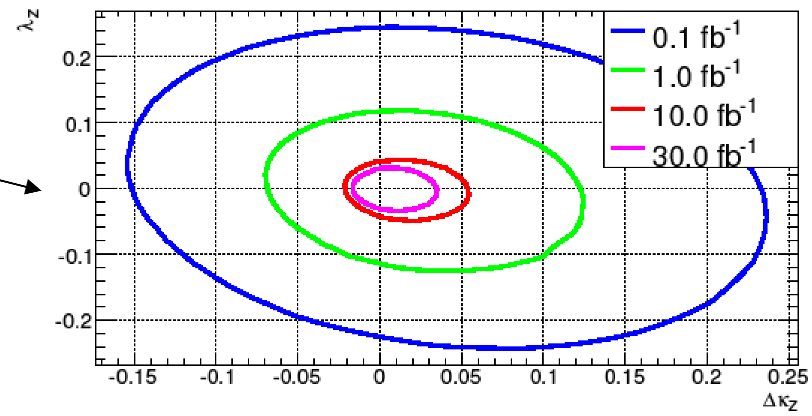


- Binned likelihood comparing mock SM observations to a SM profile & two reweighted anomalous profiles
- Using 10 bins from 0-500GeV and one overflow bin.
- In addition, the three decay channels, ee, eμ, and $\mu\mu$, are binned separately for a total of 33 bins.

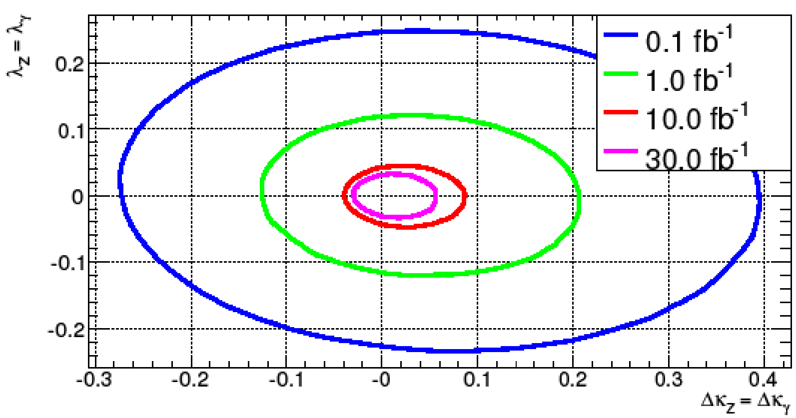
2D anomalous TGC sensitivity using $M_T(WW)$

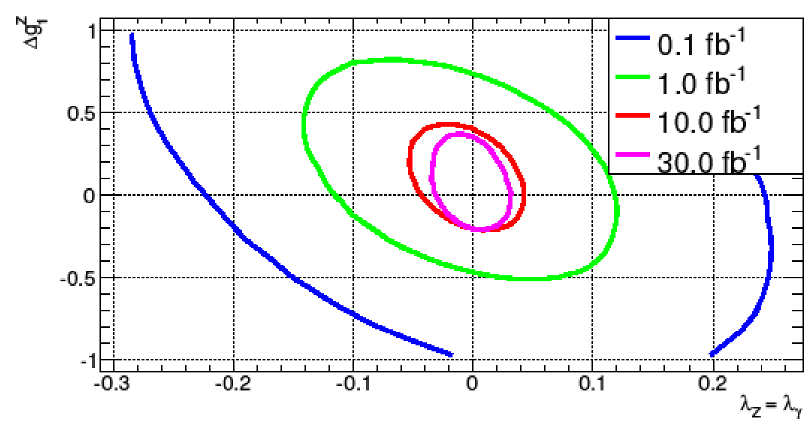
95% confidence contours for 0.1, 1, 10, and 30 fb^{-1} integrated luminosity

Right: HISZ assumption (2 parameters)



Bottom: "Standard" assumption, Z param. = γ param. (3 parameters)





ATLAS TGC sensitivity for 1.0 fb^{-1}

95% CL intervals for anomalous TGCs, cutoff Λ = 2 TeV

Diboson	λ_z	$\Delta\kappa_z$	Δg_1^z	$\Delta\kappa_\gamma$	λ_γ
WZ(ATLAS) 1.0 fb^{-1}	[-0.028,0.024]	[-0.203,0.339]	[-0.021,0.054]		
WZ(D0) 1.0 fb^{-1}	[-0.17,0.21]	[-0.12,0.29]	$\Delta g_1^z = \Delta\kappa_z$		
WW(ATLAS) 1.0 fb^{-1}	[-0.108,0.111]	[-0.117,0.187]	[-0.355,0.616]	[-0.240,0.251]	[-0.259,0.421]
WW(LEP)	$\lambda_z = \lambda_\gamma$	$\Delta\kappa_z = \Delta g_1^z - \Delta\kappa_\gamma \tan^2\theta_w$	[-0.051,0.034]	[-0.105,0.069]	[-0.059,0.026]
$W\gamma$(ATLAS) 1.0 fb^{-1}				[-0.43,0.20]	[-0.09,0.04]
$W\gamma$(D0) 0.16 fb^{-1}				[-0.88, 0.96]	[-0.2,0.2]

Summary

- The Diboson analyses use ~ 30 M ATLAS fully simulated datasets.
- WW, WZ, Wγ and Zγ signal can be established with statistical sensitivity better than 5σ for the first 0.1 fb^{-1} integrated luminosity, and ZZ signal can be established with 1.0 fb^{-1} data.
- The anomalous triple gauge boson coupling sensitivities from LHC/ATLAS can be significant improved over the results from Tevatron and LEP using the first 1.0 fb^{-1} data.
- SM Diboson productions are important control samples for Higgs, SUSY, Technicolor, G, Z' particle searches with diboson final states.

LHC will start collisions in 2008 , please still tuned !

Backup slides

Systematic Uncertainties

- Signal systematics ~9%
  - Luminosity measurement 6.5%
  - PDF assumption 3%
  - NLO scaling 5%
  - Particle ID 3%
- Background systematics ~18%

  (in addition to the above)
  - MC sample statistics 15% (may drop to 10%)
  - Calibration on lepton, jet energy 5%
- The systematic errors start to dominate the cross-section measurement uncertainties after 5-10 fb^{-1}.

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ATLAS TGC sensitivity for 10 fb^{-1}

95% CL intervals for anomalous TGCs compare with Tevatron and LEP, cutoff Λ = 2 TeV

Diboson, (fit spectra)	λ_Z	$\Delta\kappa_Z$	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
WZ, (M_T)	[-0.015, 0.013]	[-0.095, 0.222]	[-0.011, 0.035]		
$W\gamma$, (p_T^γ)				[-0.26, 0.07]	[-0.05, 0.02]
WW, (M_T)	[-0.040, 0.038]	[-0.035, 0.073]	[-0.149, 0.309]	[-0.088, 0.089]	[-0.074, 0.165]
WZ, (D0) (1.0fb^{-1})	[-0.17, 0.21]	[-0.12, 0.29] ($\Delta g_1^Z = \Delta\kappa_Z$)			
$W^\pm\gamma$ (D0), (0.16fb^{-1})				[-0.88,0.96]	[-0.2,0.2]
WW, (LEP) ($\lambda_\gamma = \lambda_Z, \Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma \tan^2\theta_W$)			[-0.051,0.034]	[-0.105,0.069]	[-0.059,0.026]

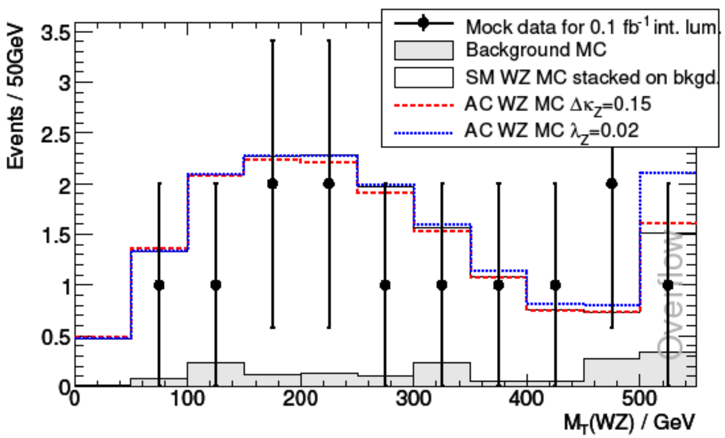
Neutral TGCs Sensitivity (10 fb^{-1})

$$g_{ZZV}\Gamma_{ZZV}^{\alpha\beta\mu} = e\frac{P^2 - M_V^2}{M_Z^2}\left[\, i f_4^V (P^\alpha g^{\mu\beta} + P^\beta g^{\mu\alpha}) + i f_5^V \varepsilon^{\mu\alpha\beta\rho}(q_1 - q_2)_\rho \,\right]$$

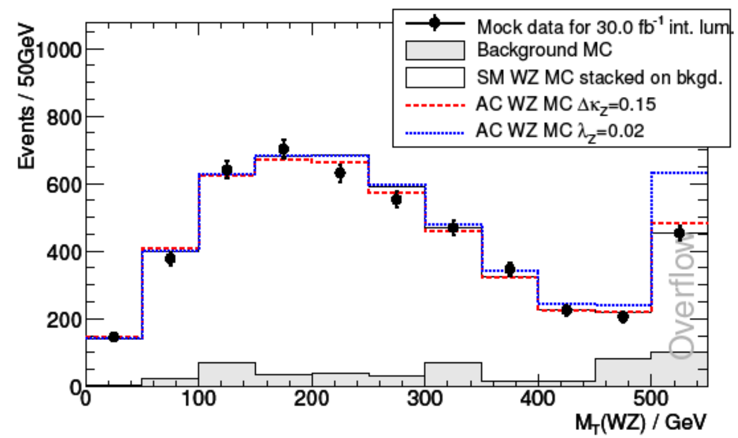
	f_4^Z	f_5^Z	f_4^γ	f_5^γ
$ZZ \to \ell\ell\ell\ell$	[–0.010, 0.010]	[–0.010, 0.010]	[–0.012, 0.012]	[–0.013, 0.012]
$ZZ \to \ell\ell\nu\nu$	[–0.012, 0.012]	[–0.012, 0.012]	[–0.014, 0.014]	[–0.015, 0.014]
Combined	[–0.009, 0.009]	[–0.009, 0.009]	[–0.010, 0.010]	[–0.011, 0.010]
LEP Limit	[–0.30, 0.30]	[–0.34, 0.38]	[–0.17, 0.19]	[–0.32, 0.36]

M_T(WZ) spectrum sensitive to WWZ couplings

$0.1\ fb^{-1}$

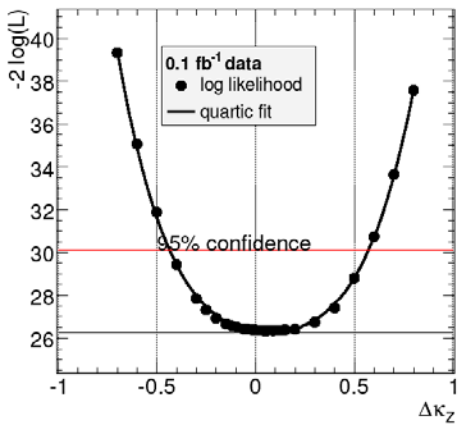


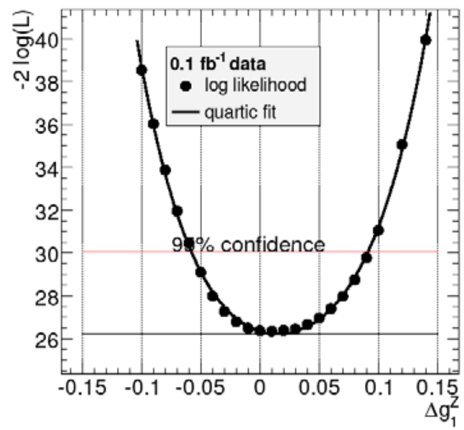
$30\ fb^{-1}$

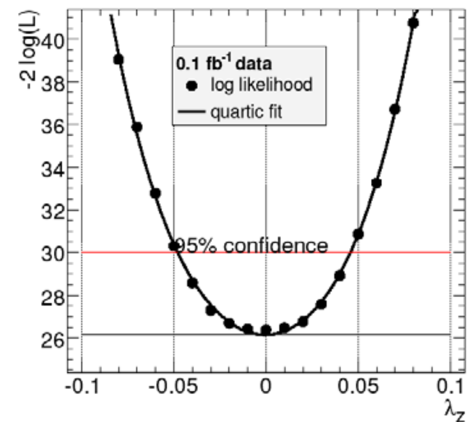


- Binned likelihood comparing mock SM observations to a SM profile and two reweighted anomalous profiles
- M_T(WZ) was found to be the most sensitive kinematics quanitity (P_T(Z), M(ll), and others are also useful, but not as sensitive).
- Using 10 bins from 0-500GeV and one overflow bin.

TGC sensitivity using $M_T(WZ)$ with $0.1 fb^{-1}$ integrated luminosity







One parameter limits (assuming other couplings are SM)

$-0.4 < \Delta\kappa_Z < 0.6$

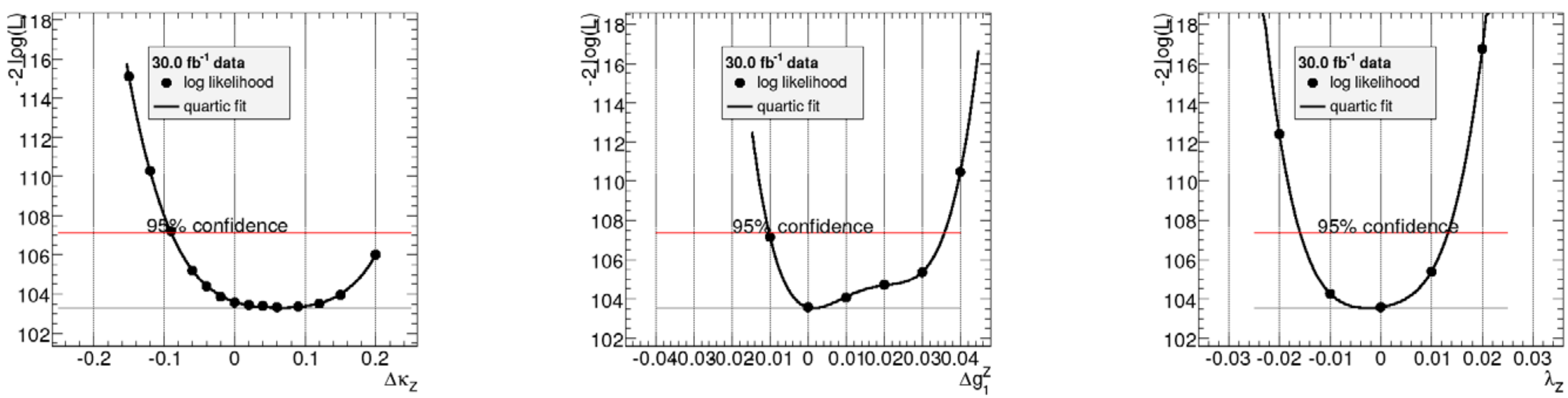
$-0.06 < \Delta g_1^Z < 0.1$

$-0.06 < \lambda_Z < 0.05$

Tevatron results

$-0.12 < \Delta\kappa_z < 0.29$	2 TeV	D0 with 1.0 fb^{-1}
$-0.17 < \lambda_z < 0.21$		
$-0.82 < \Delta\kappa_z < 1.27$	2 TeV	CDF with 1.9 fb^{-1}
$-0.13 < \lambda_z < 0.14$		

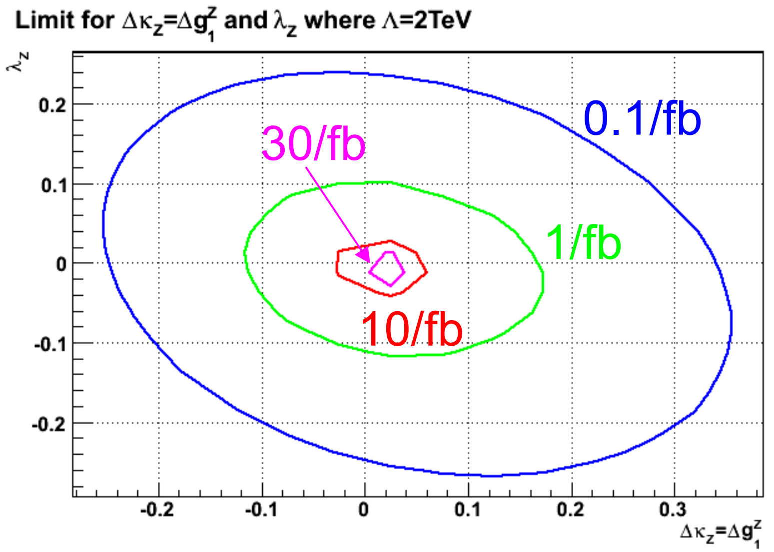
TGC sensitivity using $M_T(WZ)$ with $30fb^{-1}$ integrated luminosity



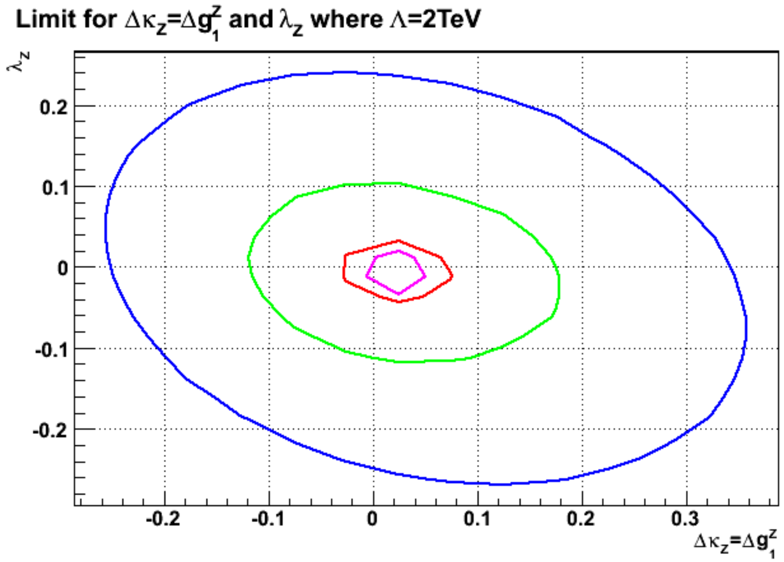
One parameter limits (assuming other couplings are SM)

Λ=2 TeV	Λ=3 TeV
$-0.08 < \Delta\kappa_Z < 0.17$	$-0.07 < \Delta\kappa_Z < 0.13$
$-0.01 < \Delta g_1^Z < 0.008$	$-0.003 < \Delta g_1^Z < 0.018$
$-0.005 < \lambda_z < 0.023$	$-0.008 < \lambda_z < 0.005$

Systematic Error Effect on TGCs
2D Limits, Λ=2TeV, using $P_T(Z)$



No systematic errors



9.2% signal, 18.3% background

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Experimental Advantages

- W's and Z's leptonic decay final states provide experimentally clean signals.
- Identification of W and Z bosons are well established.
- W and Z masses provide a valuable constraint.
- They are good sources of high Pt leptons
  - Efficient observation with low background
  - Trigger at low momentum threshold