Diboson Physics in ATLAS

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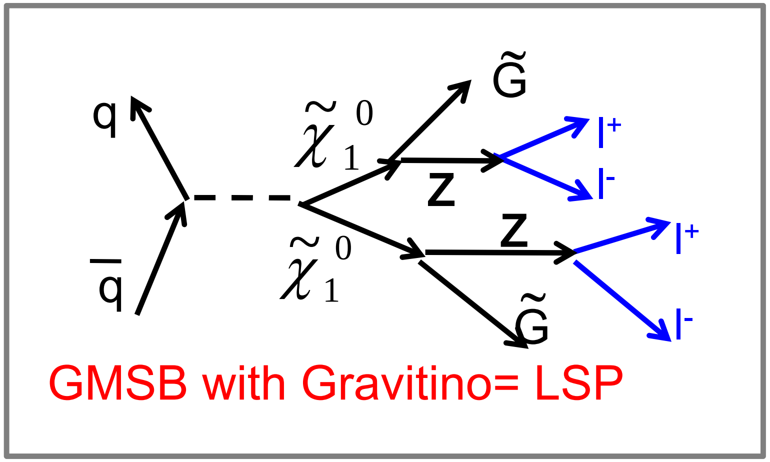
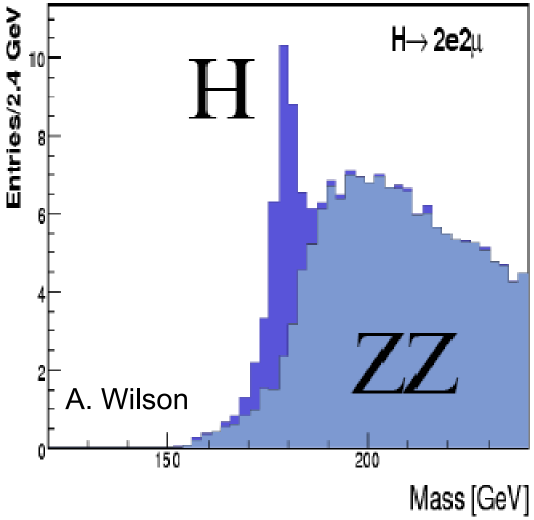
Why are dibosons interesting?

1) an important background to Higgs discovery
2) a signature of new physics



GMSB with Gravitino= LSP



3) a ***gateway*** to beyond the Standard Model via the Triple Gauge boson Couplings. We look for *anomalous TGCs*

Diboson	Signature	Physics
$W^+ W^- \rightarrow l\nu\, l\nu$	2 opposite sign leptons + Missing E_T	Std Model WW production Std Model Higgs Z' decays anomalous charged TGC
$W^\pm Z \rightarrow l\nu\, ll$	lepton+ Missing E_T + Pair of opposite sign leptons	Std Model WZ SUSY , Technicolor anomalous charged TGC
$W^\pm\gamma \rightarrow l\nu\, \gamma$	lepton + photon + ME_T	Std Model $W\gamma$ anomalous charged TGC
$ZZ \rightarrow ll\, ll$ or $ll\, \nu\nu$	2 pairs opposite sign leptons or 1 lepton pair+ME_T	Std Model ZZ & Higgs anomalous neutral TGC GMSB
$Z\gamma \rightarrow ll\, \gamma$	1 lepton pair+ photon	Std Model $Z\gamma$ anomalous neutral TGC GMSB

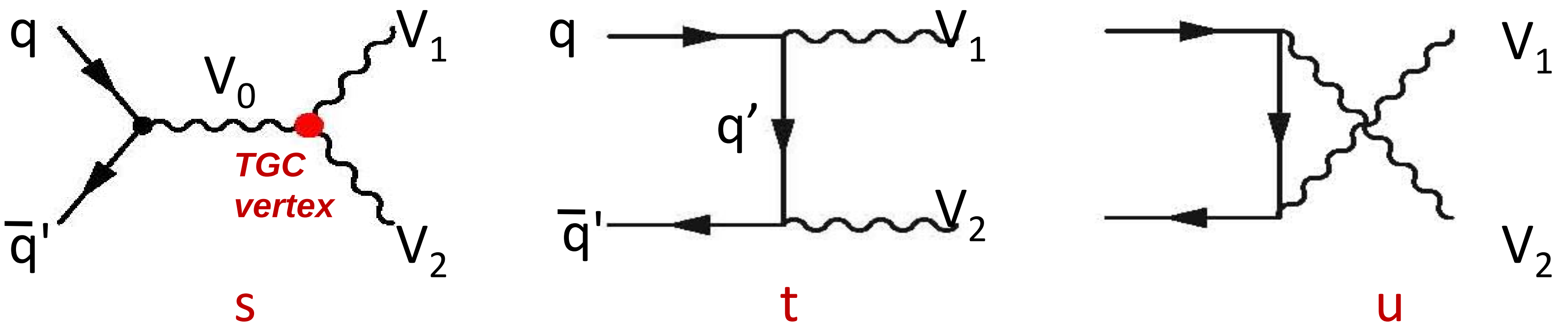
Diboson cross sections: Tevatron and LHC

Process	**conditions**	**Tevatron 1.96 TeV σ(pb)**	**LHC 14 TeV σ(pb)**
WW	W width included	12.4	111.6 total
WZ	W,Z on mass shell	3.7	47.8 total
Zγ	$E_T^{\gamma} > 7\,\mathrm{GeV}, \Delta R > 0.7$		219 total
Wγ	“		451 total
ZZ	Z’s on mass shell	1.43	14.8 total

$$\left.\begin{array}{l} \sigma_{\mathrm{LHC}} \sim 10 \times \sigma_{\mathrm{tevatron}} \\ \\ \mathscr{L}_{\mathrm{LHC}} \geq 10 \times \mathscr{L}_{\mathrm{tevatron}} \\ \\ \sqrt{S_{LHC}} = 7 \times \sqrt{S_{tevatron}} \end{array}\right\}$$

Much higher sensitivity possible at LHC

Standard Model Diboson Production in Hadron Colliders



s t u

SU(2)⊗SU(1) is non-Abelian ➔ TGCs appear (s-channel)

effective Lagrangian for **charged TGC:** **only C & P conserving terms**

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

V = Z/γ & $g_{WW\gamma}$ = -e & g_{WWZ}=-e cotθ_W $V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$

Five Anomalous Charged TGC Parameters

$$L/ig_{WWV} =$$

$$[1+\boldsymbol{\Delta g_1^V}]V^{\mu}(W^{-}_{\mu\nu}W^{+\nu}-W^{+}_{\mu\nu}W^{-\nu})+[1+\boldsymbol{\Delta\kappa_V}]W^{+}_{\mu}W^{-}_{\nu}V^{\mu\nu}+\frac{\boldsymbol{\lambda_V}}{M_W^2}V^{\mu\nu}W^{+\rho}_{\nu}W^{-}_{\rho\mu}$$

K. HAGIWARA, R.D. PECCEI , D. ZEPPENFELD Nucl. Phys B282,253

$\Delta g_1^Z \equiv g_1^Z - 1$ $\Delta\kappa_Z \equiv \kappa_Z - 1$ $\Delta\kappa_\gamma \equiv \kappa_\gamma - 1$ λ_Z λ_γ

all = 0 in Standard Model

Resulting cross-sections become larger for non-zero anomalous terms

Neutral anomalous TGC’s effective Lagrangian:

$$L_{ZZV} = -\frac{e}{M_Z^2}[\, f_4^V(\partial_\mu V^{\mu\beta})Z_\alpha(\partial^\alpha Z_\beta) - f_5^V(\partial^\sigma V_{\sigma\mu})\tilde{Z}^{\mu\beta}(\partial^\alpha Z_\beta))$$

Bauer, Rainwater Phys Rev D, 62,113011

$$\tilde{Z}^{\mu\beta} = \tfrac{1}{2}\varepsilon_{\mu\nu\rho\sigma}Z^{\rho\sigma}$$

At tree level, no s-channel in SM ➔ $f_4^V = f_5^V = 0$

CP invariance and parity conservation respectively

Objective:

Investigate diboson production cross sections in lepton/photon channel and establish their sensitivity to *anomalous* Triple Gauge Couplings (TGCs)

Method:

Step 1: a: Generation of diboson production with lepton decays only
b: Simulation in ATLAS

Step 2 : a Extract diboson signal (μ, *e*, γ) with kinematic cuts
b: Improved signal/background using *Boosted Decision Trees*

Step 3: Compare pseudo 'observations' of differential cross sections to
expectations from anomalous TGCs ➔

Step 3: cont

Measure diboson production cross sections. Anomalous TGCs amplitudes increase with $\sqrt{\hat{s}}$ or $\hat{s}$

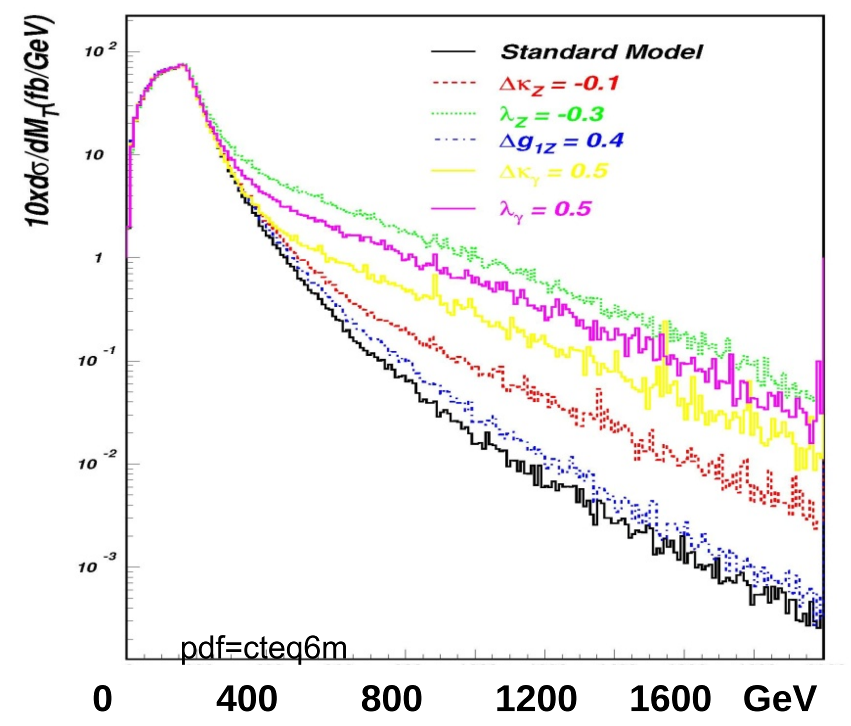
$\sqrt{\hat{s}}$ = diboson invariant mass

We consider: $\frac{d\sigma}{dM_T}$ *and* $\frac{d\sigma}{dP_T}$

These are sensitive to anomalous TGCs , especially at high M_T , p_T

M_T = diboson transverse mass

$$\frac{d\sigma_{WW}}{dM_T} \quad vs \quad M_T$$



MC Generation of diboson signals and backgrounds

SM Diboson Signals:

MC @NLO (v3.1) for WW, WZ, ZZ
Pythia (v6.4) for Wγ, Zγ.
K-factors used to normalize to NLO

Anomalous TGC cross sections:

BHO and BosoMC

Large statistics (> 30 M events) background event samples:

Pythia (with K factors), MC@NLO, Acer, Alpgen

All events run through full detector simulation

Analysis

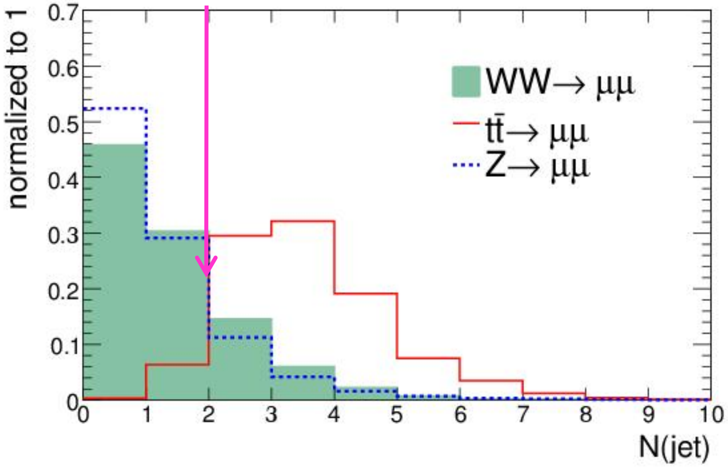
Method 1: Straight Cuts on kinematic variables
Method 2: Multivariate Boosted Decision Tree

Examples: Event Selection for Straight Cuts

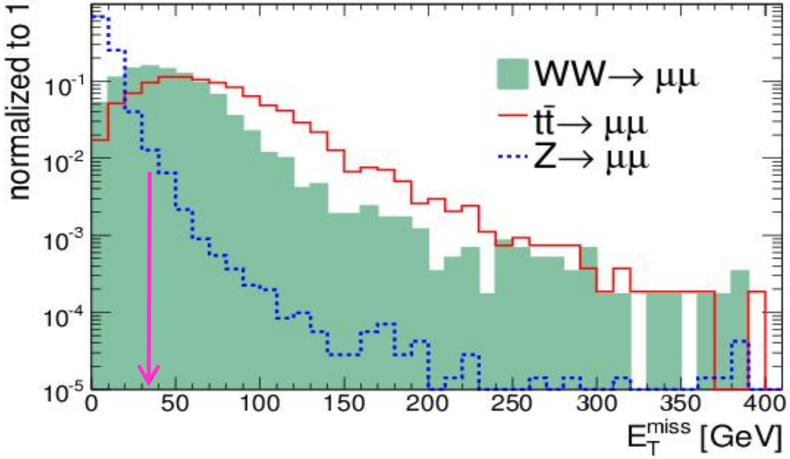
WW→lνlν	2 isolated, opposite charged leptons with P_T>25 GeV $\not\!E_T > 30\,GeV, \quad \lvert M_Z - M_{ll} \rvert > 30\,GeV, \; N_{jet}(E_T > 30\,GeV) < 2$ $\sum(\vec{\not\!E}_T + \vec{P}_T^{leptons}) < 60\,GeV$
WZ→lνll	3 isolated (2 opposite charged) leptons with P_T>25 GeV Vertex cut: ΔA <0.1 mm ΔZ<1mm $\not\!E_T > 30\,GeV, \quad \lvert M_Z - M_{ll} \rvert < 10\,GeV, \; N_{jet}(E_T > 30\,GeV) < 2$ $\sum(\vec{\not\!E}_T + \vec{P}_T^{leptons}) < 60\,GeV, \quad 40 < M_T < 250\,Gev$
ZZ→llll	4 isolated (2 pairs opposite charged) leptons with P_T>20 GeV Vertex cut: ΔA <0.1 mm ΔZ<1mm, no jets

Event selection for: WW→$\mu\nu\mu\nu$

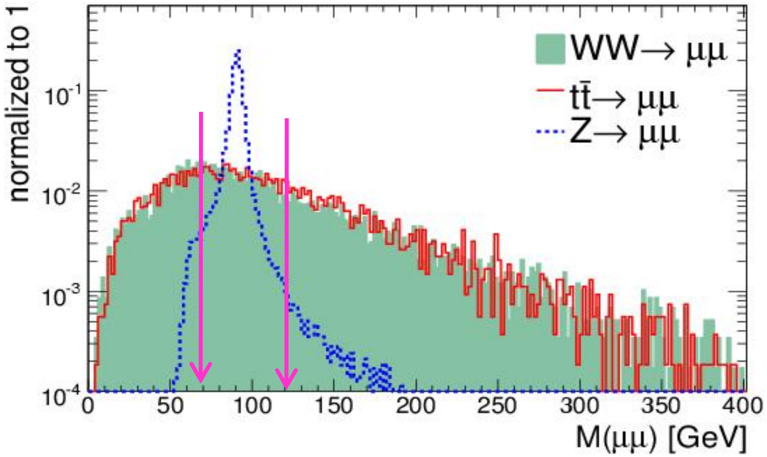
jet cut



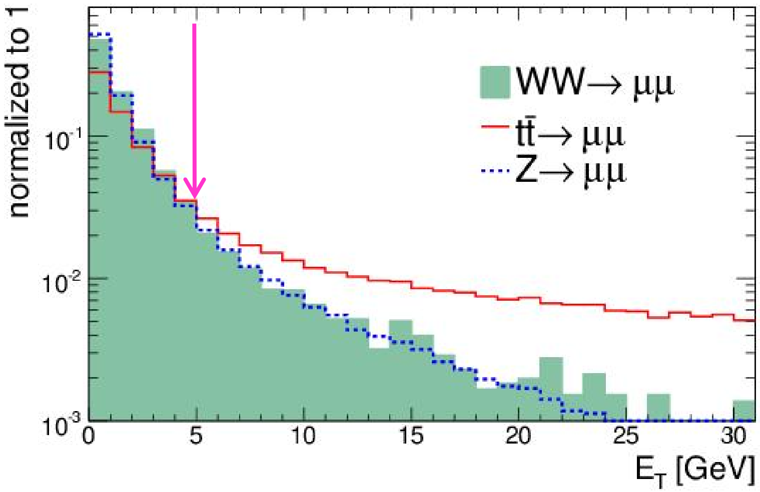
Missing E_T > 30 geV



$|M_Z-M_{ll}|$<30geV

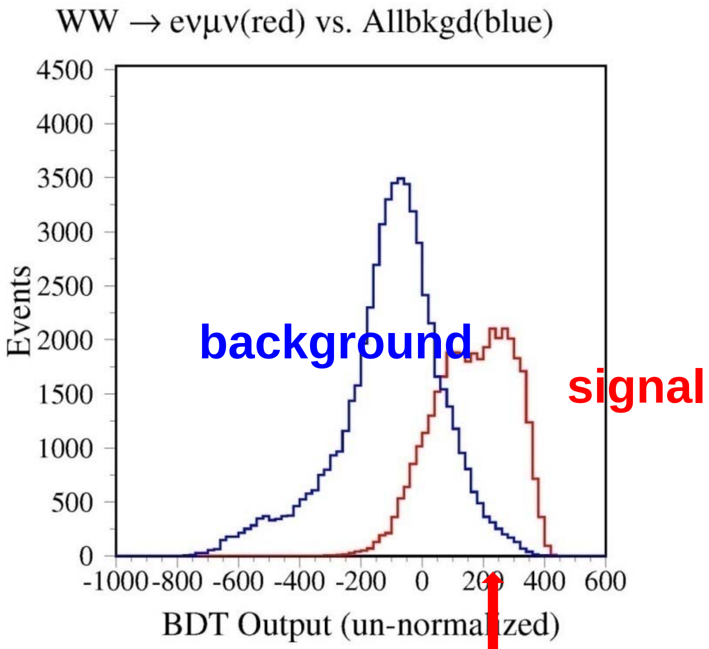


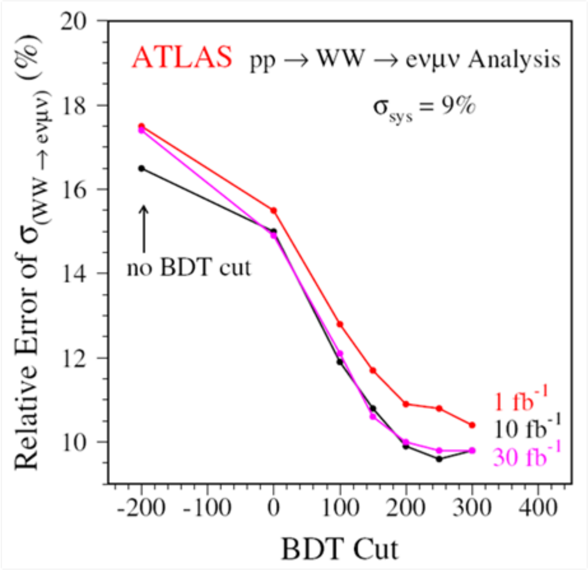
Muon Isolation: E_T(cone=0.45)<5



Boosted Decision Trees

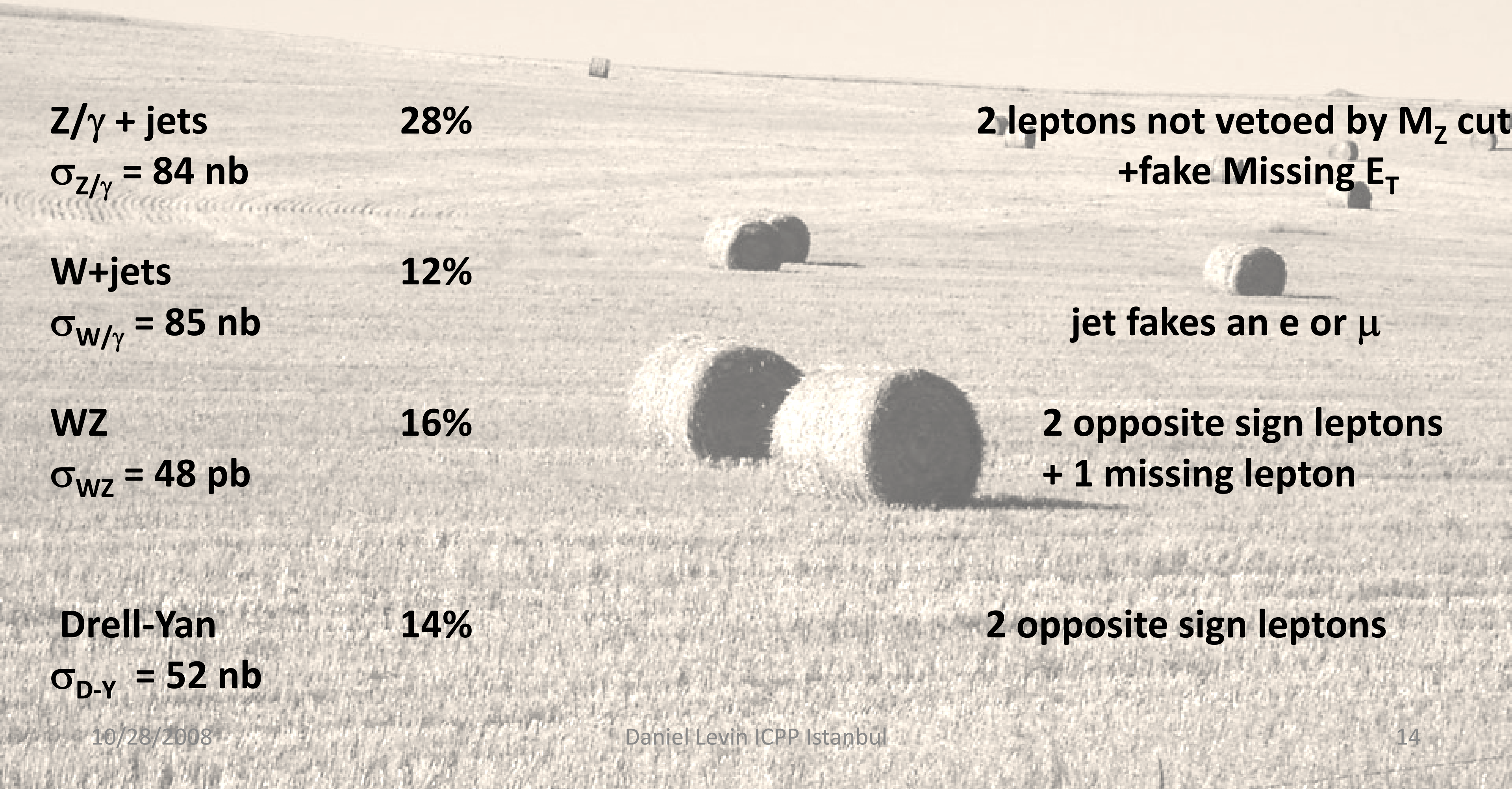
1. Split *training data* recursively using ~20 input variables as classifiers until stopping criterion reached.
2. Each event ends up on either a ***signal leaf*** or ***background leaf***
3. Misclassified events are re-weighted in the next decision tree (boosting)
4. Build a sequence of ~1000 trees with training data
5. Obtain event score = sum of signal-background leaves, over trees.
6. With *test data*: process through tree, apply cut on BDT to get S/B





Tune BDT cut to minimize error on cross section measurement

Major Background: example WW→$e\nu\mu\nu$



$t\bar{t} \rightarrow l + x$ σ_{tt} = 830 pb	**28%**	**1 lepton + jets fakes lepton +fal** **missing E_T**
Z/γ + jets $\sigma_{Z/\gamma}$ = 84 nb	**28%**	**2 leptons not vetoed by M_Z cut** **+fake Missing E_T**
W+jets $\sigma_{W/\gamma}$ = 85 nb	**12%**	**jet fakes an e or μ**
WZ σ_{WZ} = 48 pb	**16%**	**2 opposite sign leptons** **+ 1 missing lepton**
Drell-Yan $\sigma_{D\text{-}Y}$ = 52 nb	**14%**	**2 opposite sign leptons**

Signal & Background for 1 fb^{-1}

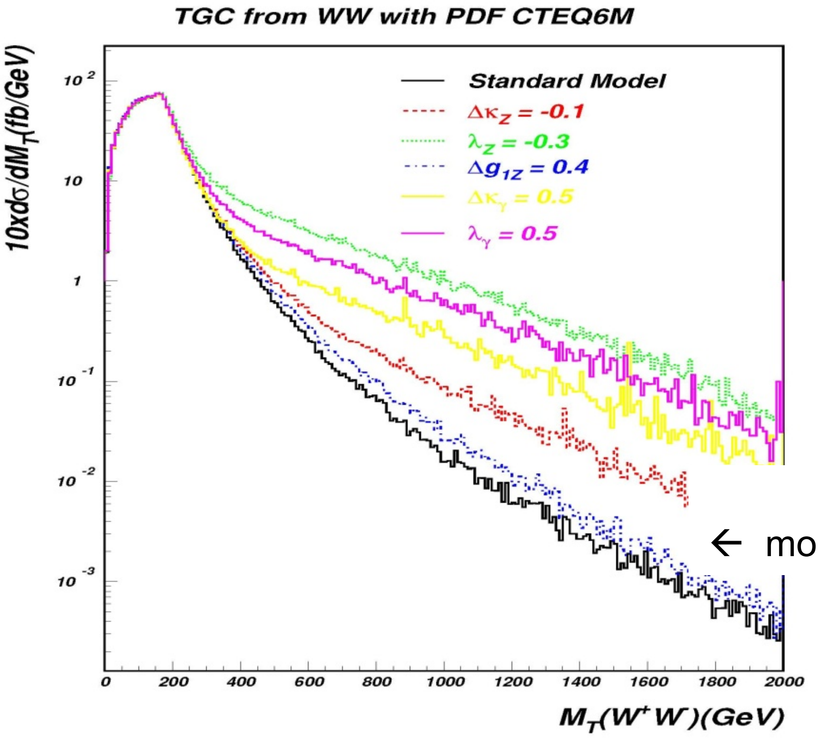
(includes 20% systematic error)

Process		Signal Events	Background Events	Signal Efficiency	Significance
WZ→lνll	BDT cuts	128 ±2 53 ±2	16 ±3 8 ±1	15.2% 6.3 %	18 11.4
WW→lνlν	BDT cuts	469 ± 6 231 ± 4	92 ± 8 223 ± 21	4.9% 2.4%	23 15.5
ZZ→4l ZZ→2l	cuts cuts	17 ± 0.5 10 ± 0.2	1.9 ± .2 5 ± 2	7.7% 2.6%	6.8 3.2
Wγ→lνγ	BDT	3770 ±153	2520 ± 250	6.6%	>30
Zγ→llγ	BDT	1118 ± 35	616 ± 62	9.2%	25.3

Computation of TGC limits

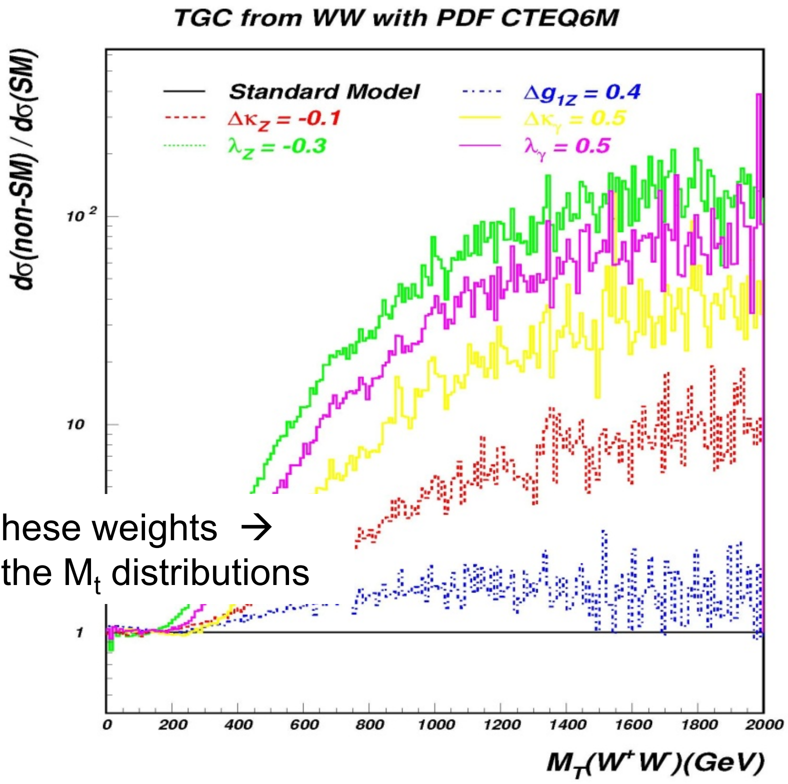
1. Generate events in anomalous TGC space, get weights: w= $d\sigma_{anom}/d\sigma_{SM}$
2. Fully simulated events are reweighted

and BDT selection cut applied to get reference distributions: $d\sigma/dM_T$



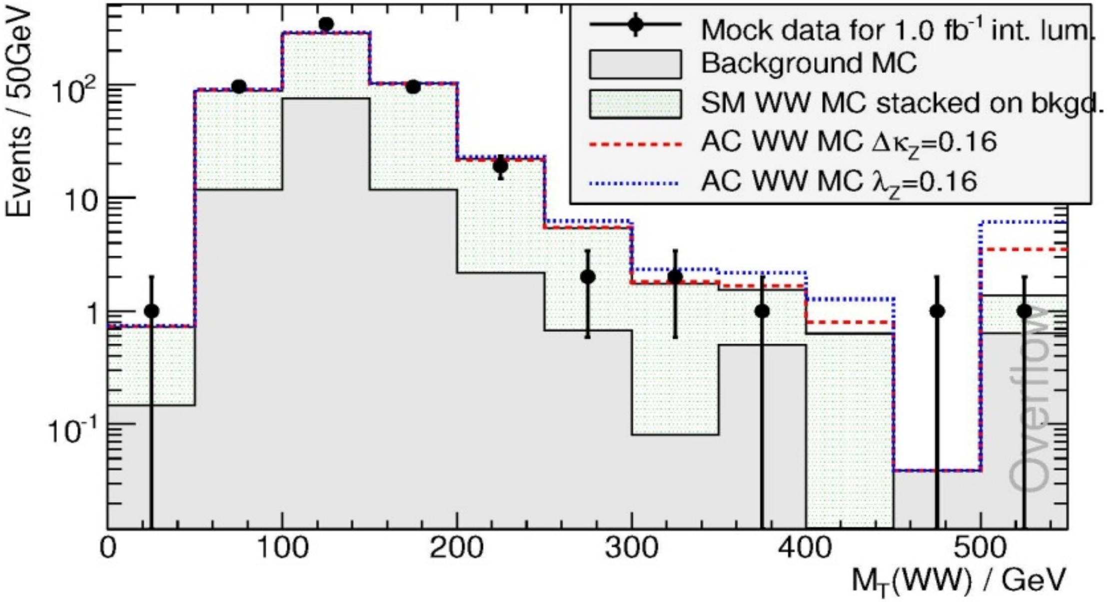
These weights →

← modify the M_t distributions

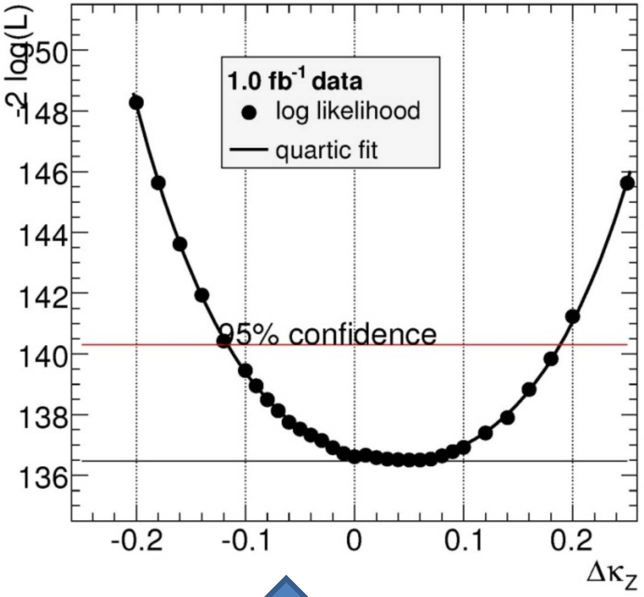


3. Poisson sample an ‘observation’ from Standard Model (signal + background) M_T distributions. In 1-dimensional case, set all but one TGC parameter to zero.

A mock observation for 1 fb^{-1}



Log (Likelihood) vs $\Delta\kappa_Z$



4. Extract 95% CL limits from fit of binned Log Likelihood vs anomalous TGC

Anomalous charged TGCs: Expected 1-D 95% CL limits

Source	**Lumi fb^{-1}**	λ_Z **WZ**	$\Delta\kappa_1^Z$ **WW**	Δg_1^Z **WZ**	$\Delta\kappa_1^\gamma$ **WW**	λ_γ **Wγ**
ATLAS	**0.1**	**[-.062,.056]**	**[-.44,.61]**	**[-.063,.119]**	**[-.47,0.51]**	**X**
ATLAS	**1**	**[-.028,.024]**	**[-.117,.187]**	**[-.021,.054]**	**[-.24,.25]**	**[-.09,.04]**
CDF/D0	**1.9/.16**	**[-.13,.14]**	**[-.82,1.27]**	**-**	**[-.88,.96]**	**[-.2,.2]**

Anomalous charged TGCs: Expected 1-D 95% CL limits

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ATLAS	**0.1**	**[-.062,.056]**	**[-.44,.61]**	**[-.063,.119]**	**[-.47,0.51]**	**X**
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CDF/D0	**1.9/.16**	**[-.13,.14]**	**[-.82,1.27]**	**-**	**[-.88,.96]**	**[-.2,.2]**
	10	**[-.015,.013]**	**[.035,.073]**	**[-.011,.034]**	**[-.26,.07]**	**[-.05,.02]**
	30	[-0.012,.008]	[-.026,.0048]	[-.005,.023]	[-.056,.054]	[.02,.01]

Anomalous neutral TGC 95% CL limits

Lumi	f_4^Z	f_5^Z	f_4^γ	f_5^γ
1	[-.018,.018]	[-.018,.019]	[-.022,.022]	[-.022,.022]
30	[-.006,.006]	[-.006,.007]	[-.008,.008]	[-.008,.008]
LEP	[-.3,.3]	[-.34,.38]	[-.27,.19]	[-.32,.36]

Summary

Vector boson self couplings are fundamental prediction of the SM

Measurements of diboson production rates can test these couplings and probe physics, beyond the Standard Model

With first 0.1 fb^{-1} can establish WW, WZ, Wγ, Zγ diboson signals with 5 sigma

This talk represents efforts of:

Kostantinos Bachas
Tom Barber
Richard Batley
Andrea Bocci
Ilectra Christidi
Tiesheng Dai
Al Goshaw

Liang Han
Chris Hays
Suen Hou
Yi Jiang
Ashutosh Kotwal
Mark Kruse
Xuefei Li
Zhijung Liang

Hong Ma
Chara Petridou
Dragan Popovic
Dusan Reljic
Dimos Sampsonidis
Ljiliana Simic
Nenad Vranjes
Song-Ming Wang

Pat Ward
Alan Wilson
Haijun Yang
Yi Yang
Pei Zhang
Zhengguo Zhou,
Jiahang Zhong
Bing Zhou

backup

Matrix Element Dependence on Q^2

$$L / g_{WWV} = i g_1^V \left(W^*_{\mu\nu} W^\mu V^\nu - W^*_\mu V_\nu W^{\mu\nu} \right) + i \kappa^V W^*_\mu W_\nu V^{\mu\nu} + i \frac{\lambda_V}{M_W^2} W^*_{\rho\nu} W^\mu_\nu V^{\rho\nu}$$

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At tree level: $g_1^Z = g_1^\gamma = 1$ $\kappa^Z = \kappa^\gamma = 1$ $\lambda_Z = \lambda_\gamma = 0$

define 5 anomalous charged TGCs:

$\Delta g_1^Z \equiv g_1^Z - 1$ $\Delta\kappa_1^Z \equiv \kappa_1^Z - 1$ $\Delta\kappa_1^\gamma \equiv \kappa_1^\gamma - 1$ λ_Z λ_γ

anomalous TGCs: Matrix Element Q^2 dependence

Final state	$\Delta\kappa_1^Z$	$\Delta\kappa_1^\gamma$	Δg_1^Z	λ_Z	λ_γ
WW	Ŝ	Ŝ	Ŝ½	Ŝ	Ŝ
WZ	Ŝ½	Ŝ½	Ŝ	Ŝ	Ŝ
Wγ	Ŝ½	Ŝ½	Ŝ	Ŝ	Ŝ

Sensitivity of the couplings to various process

Δg_1^Z $\sim$ s in WZ ; $\sim s^{1/2}$ in WW

$\Delta\kappa_1^Z$ & $\Delta\kappa_1^\gamma$ $\sim$ s in WW; $\sim s^{1/2}$ in WZ/Wγ

λ_Z & λ_γ $\sim$ s

Where $\sqrt{\hat{s}}$ is the diboson invariant mass

➔ Limits on Δg_1^Z should be smaller from WZ

➔ Limits on $\Delta\kappa_1^Z$ & $\Delta\kappa_1^\gamma$ should be smaller from WW

➔ Limits on λ_Z & λ_γ same from any process

Preserving unitarity

The 5 anomalous charged TGC couplings are defined as:

$\Delta g_1^Z \equiv g_1^Z - 1$ $\Delta\kappa_1^Z \equiv \kappa_1^Z - 1$ $\Delta\kappa_1^\gamma \equiv \kappa_1^\gamma - 1$ λ_Z λ_γ

Unitarity is preserved via a cut-off scale Λ (set to 2 TeV):

$$\Delta\kappa(\hat{s}) = \frac{\Delta\kappa_0}{(1+\hat{s}/\Lambda^2)^n}$$

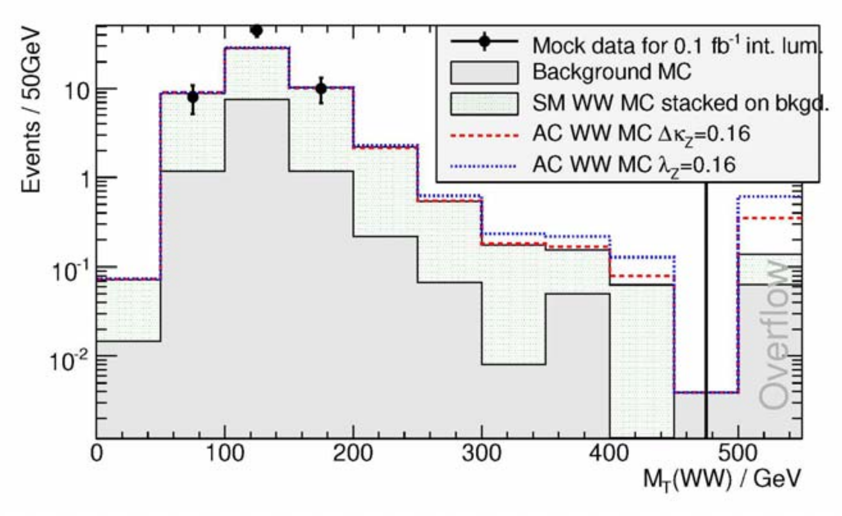
$\Delta\kappa_0$=value in low energy limit

n=2 for charged TGC parameters

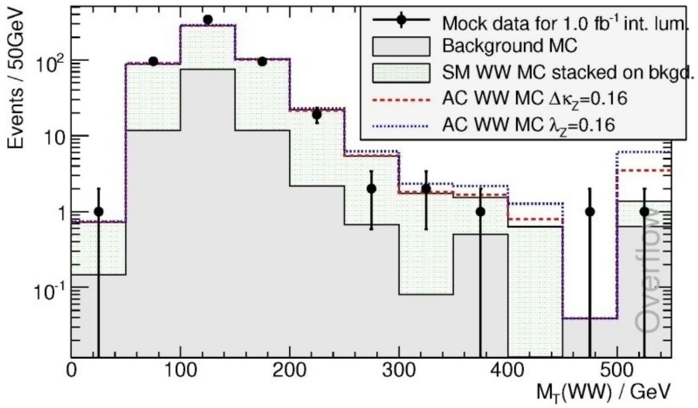
n=3 for neutral TGC

Mock observation in WW channel for increasing luminosity

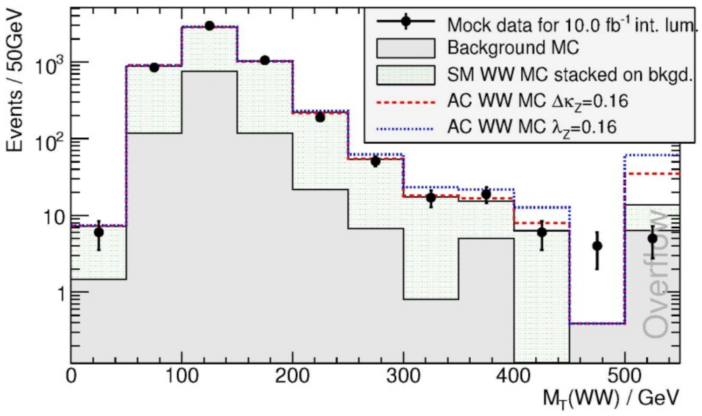
0.1 fb^{-1}



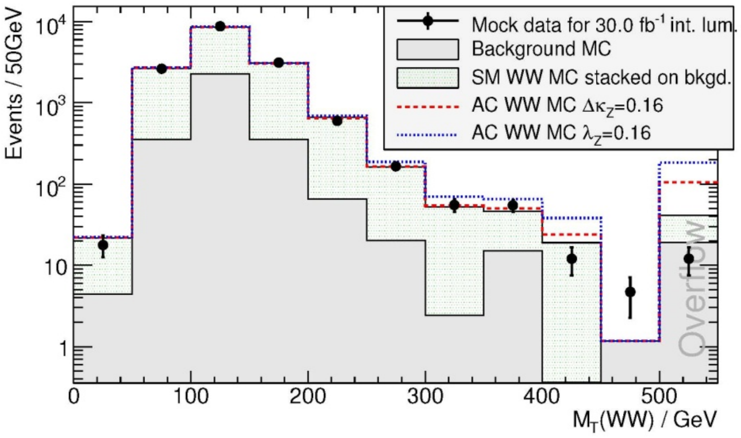
1 fb^{-1}



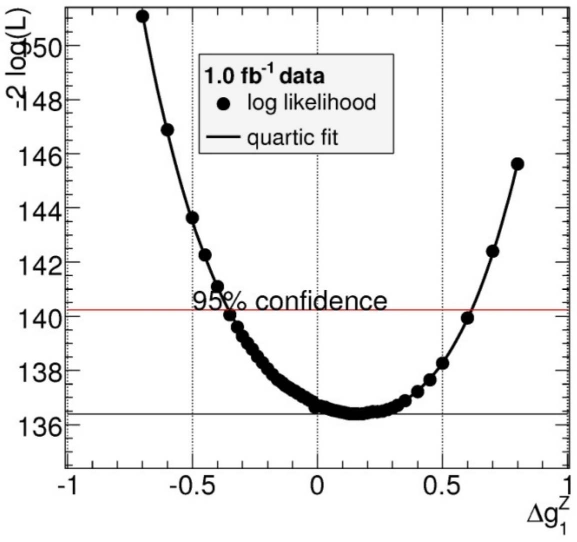
10 fb^{-1}

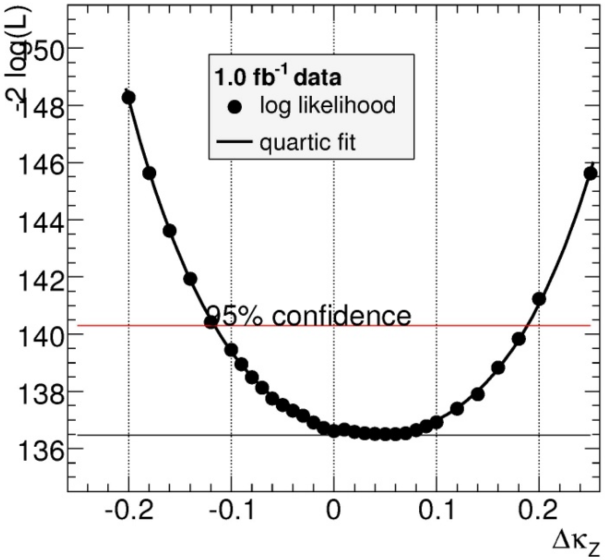


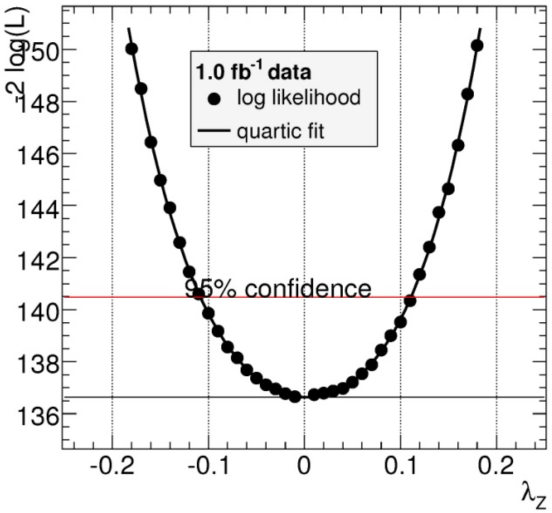
30 fb^{-1}

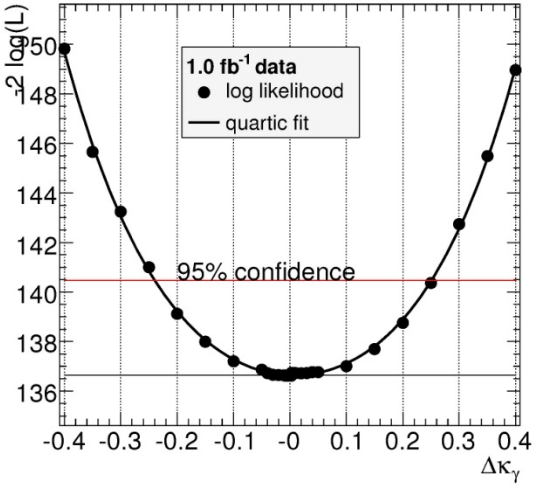


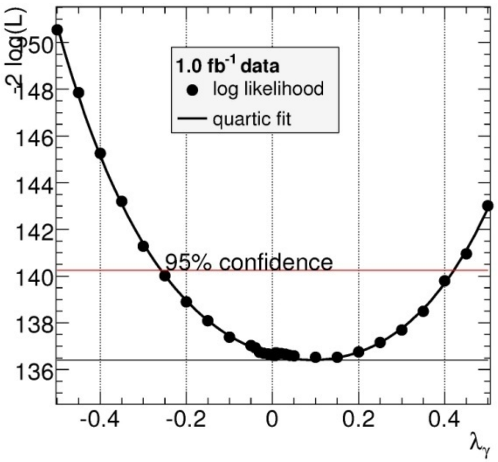
TGC Results for 1 fb^{-1} all charged TGC anomalous parametrs











Likelihood for an observation of n events in a bin:

$$L = \int_{1-3\delta_b}^{1+3\delta_b} \int_{1-3\delta_s}^{1+3\delta_s} g_s g_b \frac{(f_s\nu_s + f_b\nu_b)^n e^{-(f_s\nu_s + f_b\nu_b)}}{n!} df_s df_b$$

$\nu=\mathscr{L}\sigma\,\epsilon$ expected # of signal/background events for luminosity $\mathscr{L}$, cross section σ, acceptance ϵ

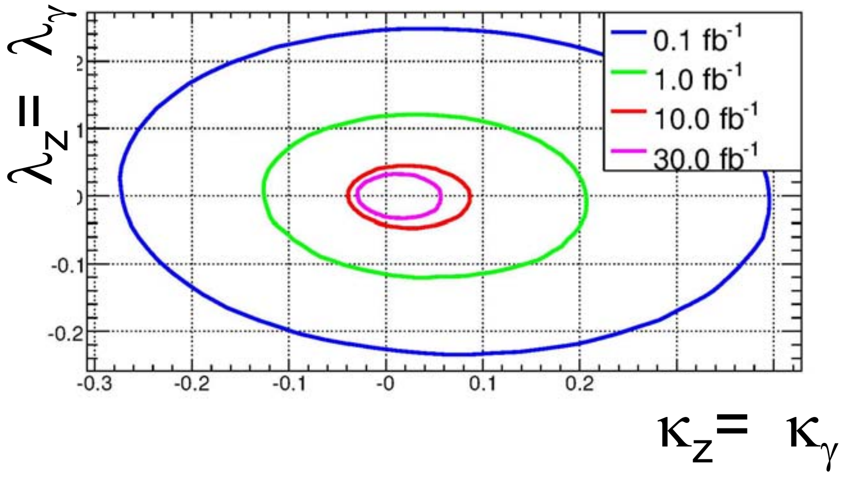
Systematic uncertainty δ

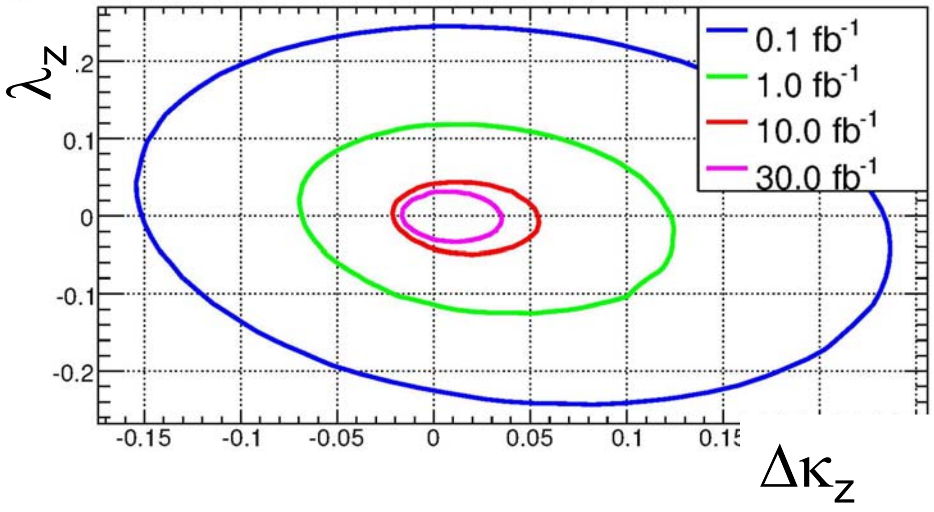
$g_{i=}$=gaussian probability of signal/background in bin

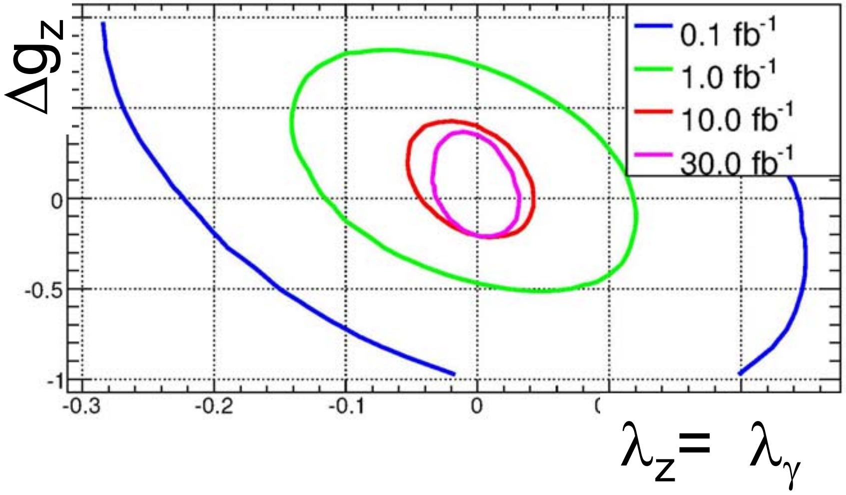
Total log Likelihood over all decay channels, all bins

$$LL = -2 \sum_{channels=k} \sum_{bins=i} \log(L_i^k)$$

2-D limits on anomalous TGC parameters, various luminosity







Systematic errors

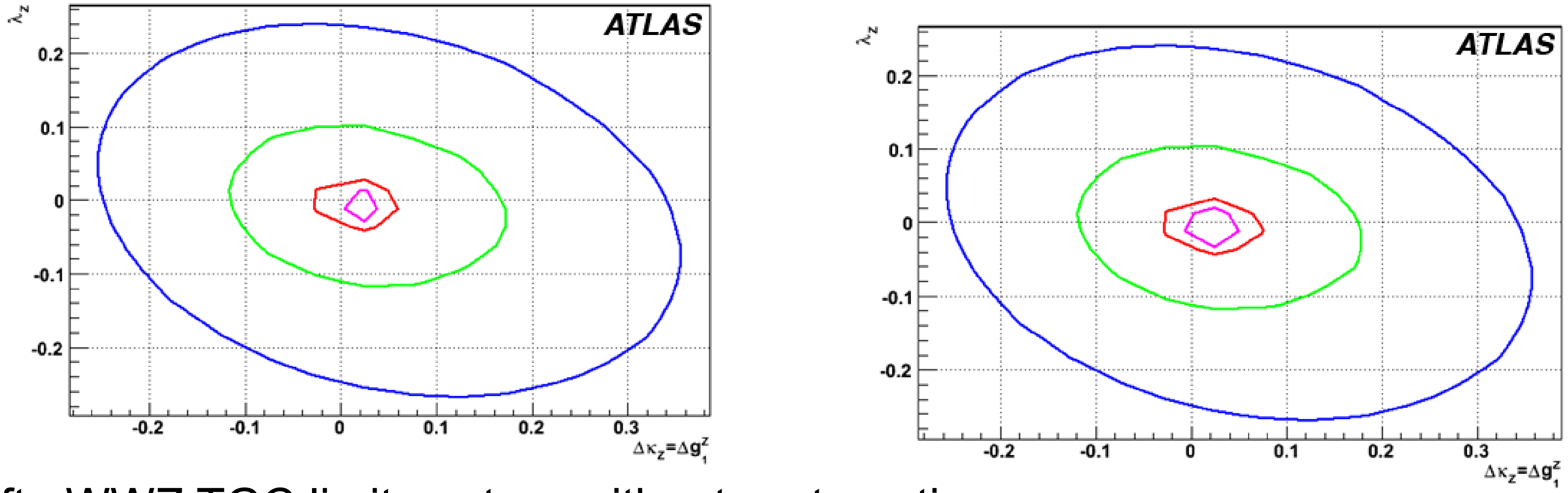
Experimental:

Luminosity: (from Tevatron) …………………………….. 6.5%
Efficiency: …………………………………………………. 3%
Jet energy scale ………………………………………….. 5%

Theoretical:

background uncertainty from limited MC statistics …… 15%
PDF errors ………………………………………. ……… 3%
NLO Scaling ………………………………………………. 5%

2-D 95 % CL limits on anomalous TGC parameters with and without systematic error



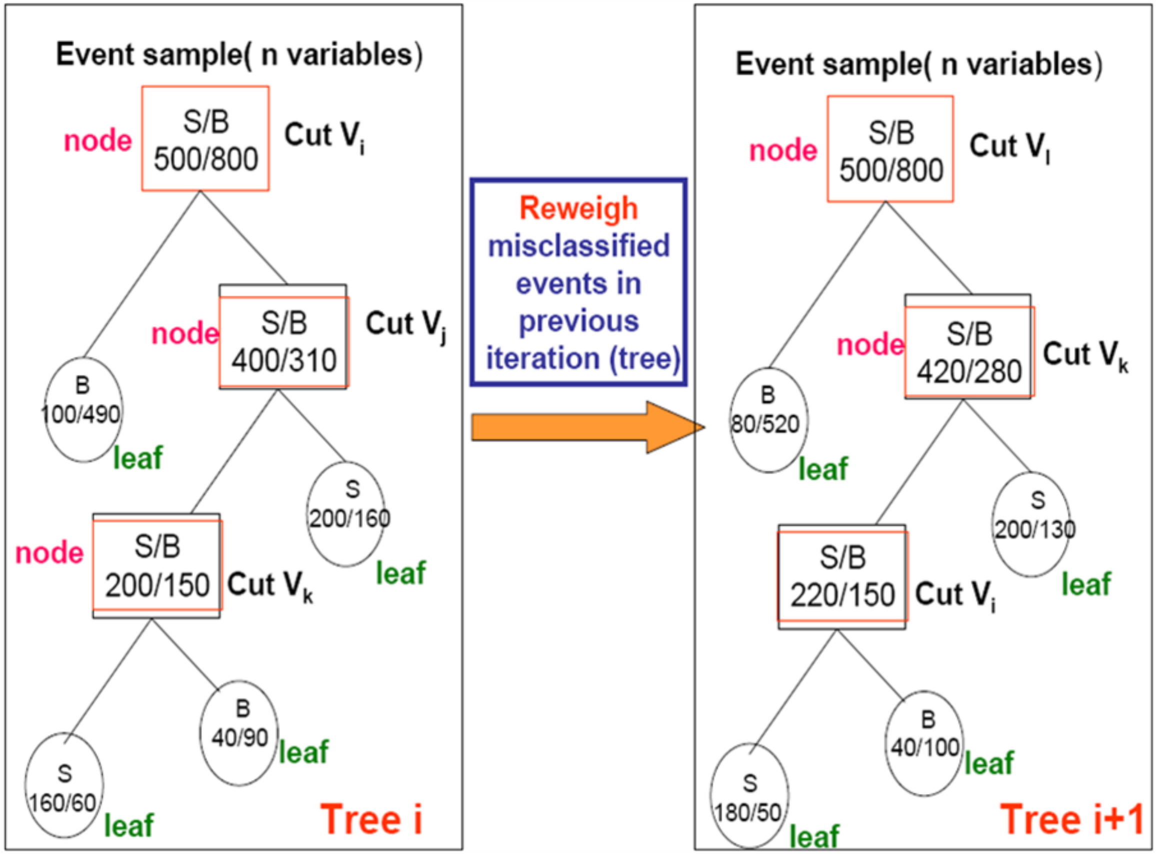
Left: WWZ TGC limit contour without systematic errors
for λ_z vs. $\Delta g_z = \Delta\kappa_z$

Right : WWZ TGC limit contour with
the systematic errors (σ_{Signal} = 9.2%, $\sigma_{\text{Background}}$ = 18.3%)

Integrated luminosities of 0.1, 1.0, 10.0 and 30.0fb^{-1},

Systematic errors become significant at 30fb^{-1}.

Boosted Decision Trees



Split data recursively using ~20 input variables until stopping criterion reached

All events settle on "signal" or "background" leaf

Misclassified events are weighted in the next decision tree (boosting)

Build a sequence of 100-1000 trees

Final score from all trees.

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