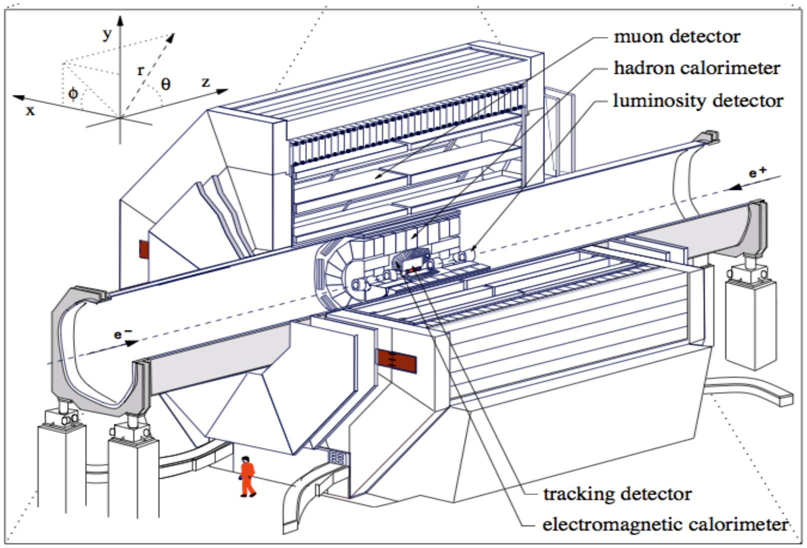
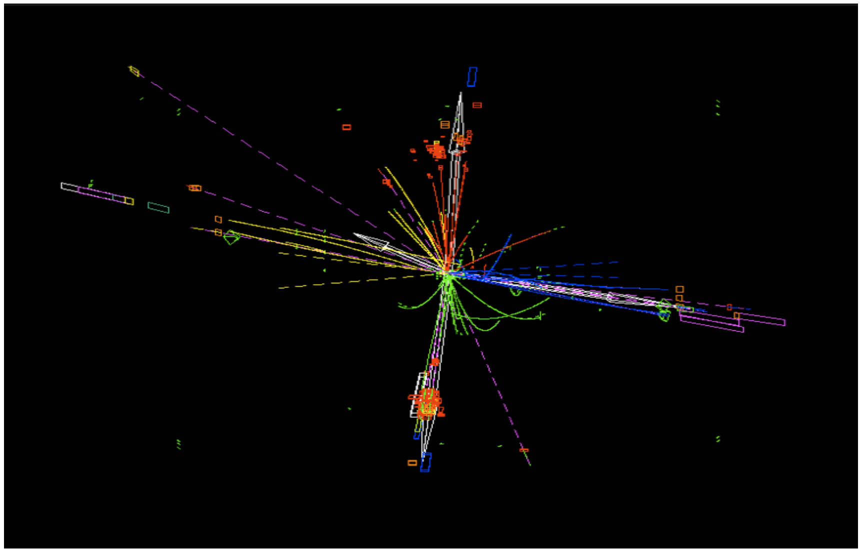
Electroweak Triple Gauge Coupling with Leptonic In-States

And possible room for BSM physics



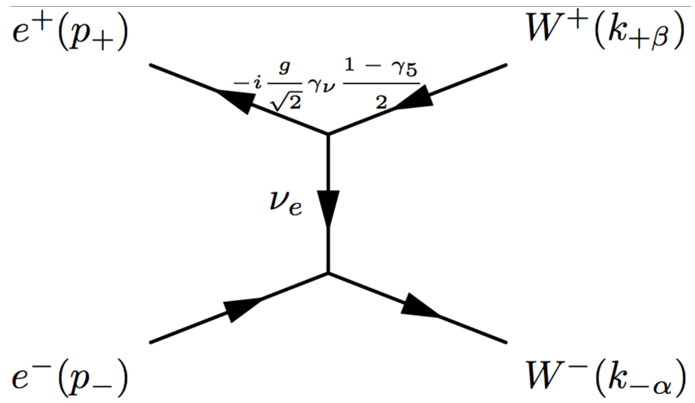
LEP



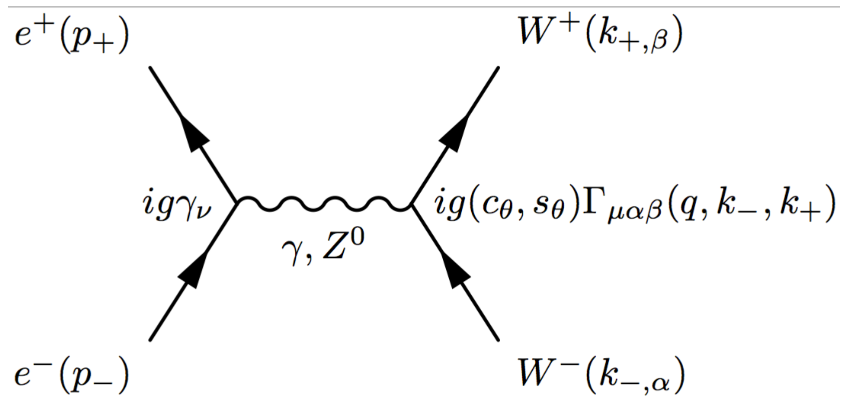
WW > jets at √s = 172 GeV at OPAL

The Process

- ❑ Analyze e+e- > W+ W- > 2l 2ν, 2j l ν, 4j
  - B.R are low in leponic channels, but S/B is good
  - Dimension-6 operators provide SM limits on TGC vertex and multi-parameter analysis.
  - Therefore it is great grounds to look for possible BSM physics



- ❑ Tree level analysis
  - Preserves unitary and gauge invariance
  - RC's increase weak and E.M multipole moments and 1-loop corrections give the value to 10^{-2}



WWZ Lagrangian and Coupling Parameters

$$\mathcal{L} = ig_{WWZ}\Big[g_V^1(W_{\mu\nu}^* W^\mu V^\nu - W^{*\mu}W_{\mu\nu}V^\nu) + k_V W_\mu^* W_\nu V^{\mu\nu} + \frac{\lambda_V}{M_W^2} W_{\alpha\mu}^* W^{\mu\nu} V_\nu^\alpha$$

$$+ig_V^4 W_\mu^* W_\nu(\partial^\mu V^\nu + \partial^\nu V^\mu) - ig_V^5 \epsilon^{\mu\nu\rho\sigma}(W_\mu^* \partial_\rho W_\nu - \partial_\rho W_\mu^* W_\nu)V_\sigma$$

$$+\tilde{k}_V W_\mu^* W_\nu \tilde{V}^{\mu\nu} + \frac{\tilde{\lambda}_V}{M_W^2} W_{\alpha\mu}^* W^{\mu\nu} \tilde{V}_\nu^\alpha\Big]$$

- Adjusting the terms allows a new look at the TGC vertex and other relationships. The λ and κ terms for example fix the magnetic dipole and electric quadrupole.

$$q_W = -\frac{e}{M_W^2}(\kappa_\gamma - \lambda_\gamma) \xrightarrow{SM} -\frac{e}{M_W^2}(1-0)$$

$$\mu_W = \frac{e}{2M_W}(1+\kappa_\gamma+\lambda_\gamma) \xrightarrow{SM} \frac{e}{2M_W}(1+1+0)$$

Table 1: ZWW Lagrangian Couplings

Couplings	Definition	2012 PDG Values
g_Z^1	$1 + c_W \frac{M_Z^2}{2\Lambda^2}$	$0.984^{+0.022}_{-0.019}$
κ_γ	$1 + (c_W + c_B)\frac{M_W^2}{2\Lambda^2}$	$0.973^{+0.044}_{-0.045}$
κ_Z	$1 + (c_W - c_B \tan^2\theta_W)\frac{M_W^2}{2\Lambda^2}$	$0.924^{+0.059}_{-0.056} \pm 0.024$
λ_Z	$c_{WWW}\frac{3g^2 M_W^2}{2\Lambda^2}$	$-0.088^{+0.060}_{-0.057} \pm 0.023$
$\tilde{\kappa}_Z$	$-c_{\tilde{Z}} \tan^2\theta_W \frac{M_W^2}{2\Lambda^2}$	$-0.12^{+0.06}_{-0.04}$
$\tilde{\lambda}_Z$	$c_{\tilde{W}WW}\frac{3g^2 M_W^2}{2\Lambda^2}$	-0.09 ± 0.07

Vertex Corrections

$$\Gamma^{\alpha\beta\mu}(q,k,p) = g^{\alpha\mu}(q+k)^{\beta} + g^{\beta\mu}(p-k)^{\alpha} - g^{\alpha\beta}(p+q)^{\mu} \rightarrow$$

$$\Gamma_V^{\alpha\beta\mu}(q,k,p) = f_V^1(q-k)^{\mu}g^{\alpha\beta} - \frac{f_V^2}{M_W^2}(q-k)^{\mu}p^{\alpha}p^{\beta} + f_V^3(p^{\alpha}g^{\mu\beta} - p^{\beta}g^{\mu\alpha})$$

$$+if_V^4(p^{\alpha}g^{\mu\beta} + p^{\beta}g^{\mu\alpha}) + if_V^5\epsilon^{\mu\alpha\beta\rho}(q-k)_{\rho} - f_V^6\epsilon^{\mu\alpha\beta\rho}p_{\rho}$$

$$-\frac{f_V^7}{M_W^2}(q-k)^{\mu}\epsilon^{\alpha\beta\rho\sigma}p_{\rho}(q-k)_{\sigma}$$

using the definitions:

$$f_V^1 = g_V^1 + \frac{\hat{s}}{2M_W^2}\lambda_V, \quad f_V^2 = \lambda_V, \quad f_V^3 = g_V^1 + \kappa_V + \lambda_V, \quad f_V^4 = g_V^4,$$

$$f_V^5 = g_V^5, \quad f_V^6 = \tilde{\kappa}_V - \tilde{\lambda}_V, \quad f_V^7 = -\frac{1}{2}\tilde{\lambda}_V$$

- Getting the new vertex from the WWZ Lagrangian
- At tree level in the SM, only f^1 and f^3 are nonzero.

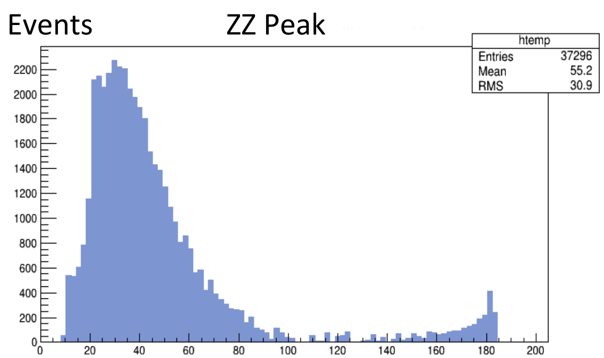
Signals and Background

- Search for TGC via e+ e- > W+ W- > 2l 2ν
  - Pure electroweak process
  - Small branching ratios (~11%) but good S/B
- Backgrounds
  - e+ e- > Z Z
    - Tricky leptonic final state!
  - e+ e- > Z e+ e- , γ f f'
  - ttbar > WWbb
    - Strong signal, but easy to handle

Simulation Cuts at 200 GeV CM Energy

- Leading leptons have pT > 20 GeV
- Secondary leptons have pT > 10 GeV
- Expect a large MET in fully leptonic decays, MET ≥ 20 GeV
- Leptons have $|\eta| < 2.4$
- $\Delta R < 0.4$ in $\eta \times \varphi$ plane
  - Will show ΔR dependence on WWZ couplings
- Jet: pT > 30 GeV and $|\eta|<5.0$
- SM Tree level designation of WWZ couplings
- ~80% of electron energy must come from a cone of half-angle 15°

A Quick Look at Backgrounds and MET



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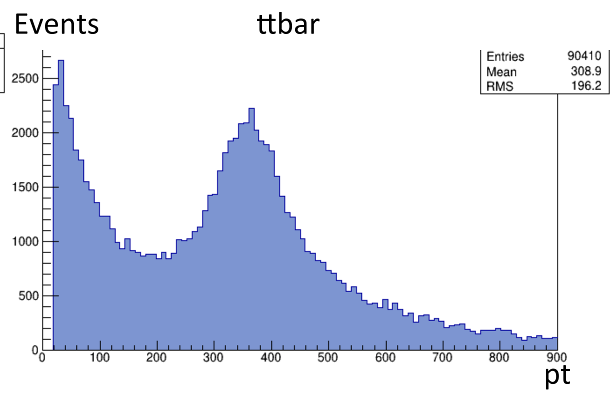

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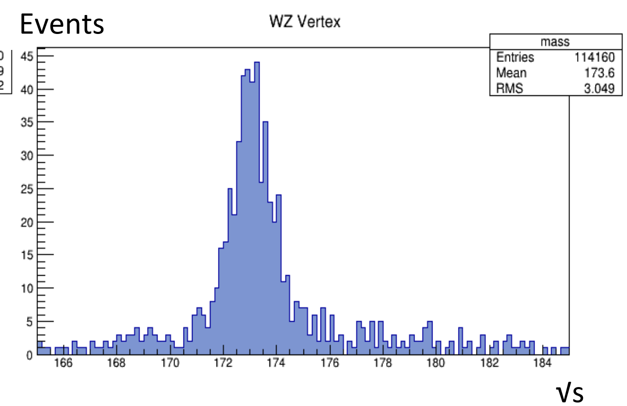

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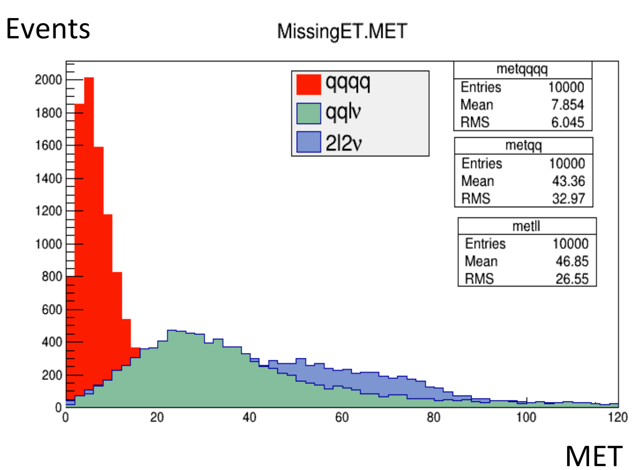

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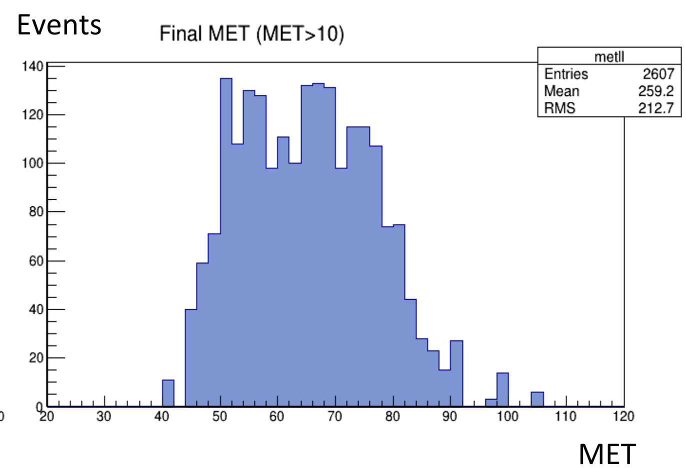

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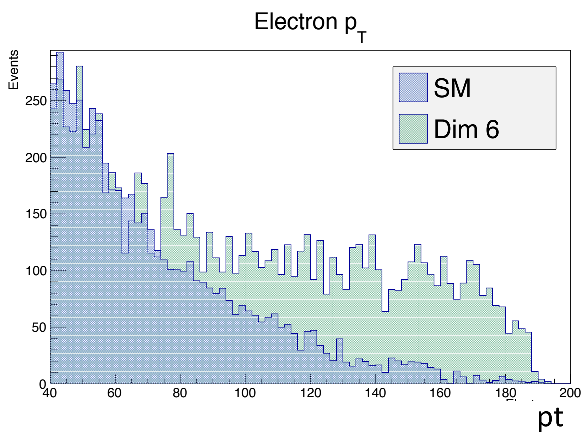
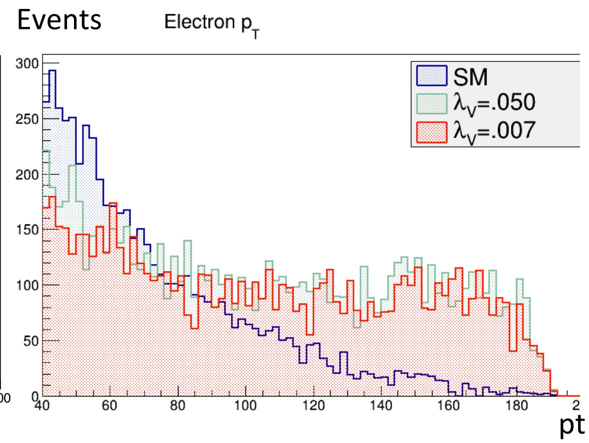
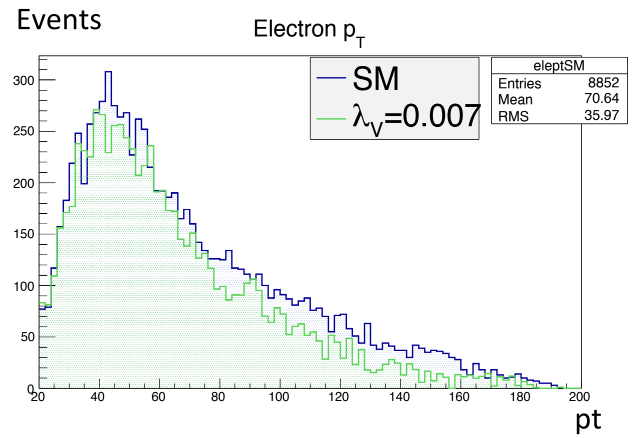
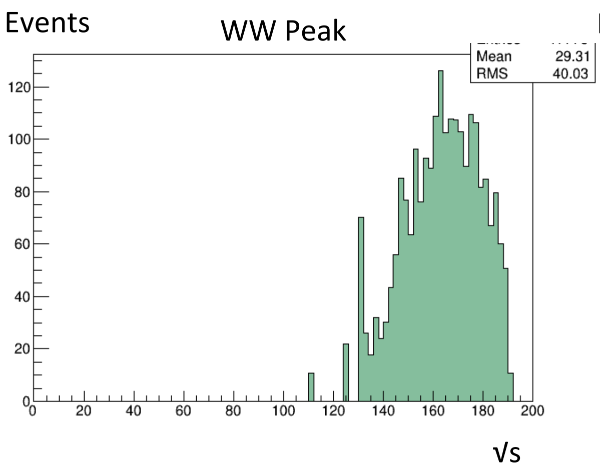
- Isolation of the primary background signals and the MET in the fully leptonic channel

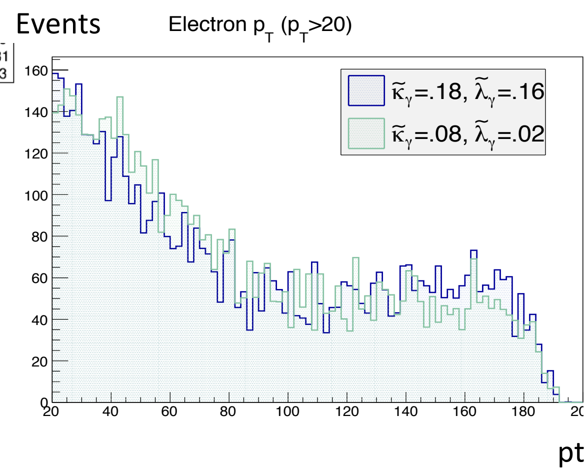
Probing the TGC Vertex

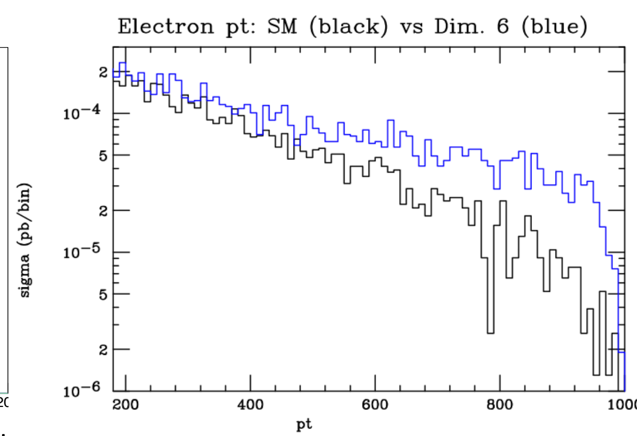




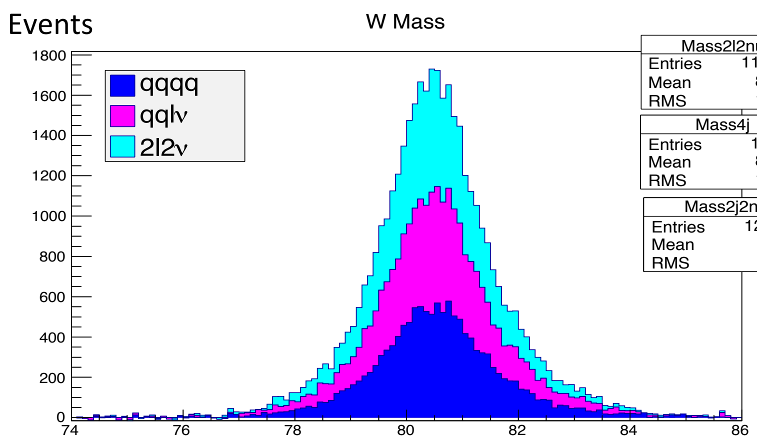








Predicting the W Mass



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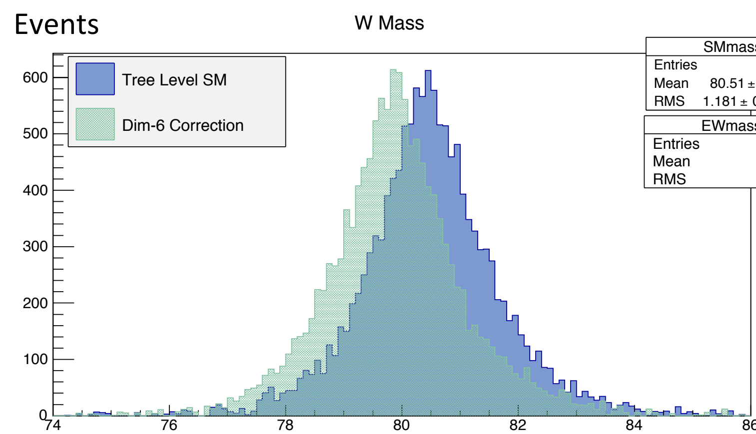

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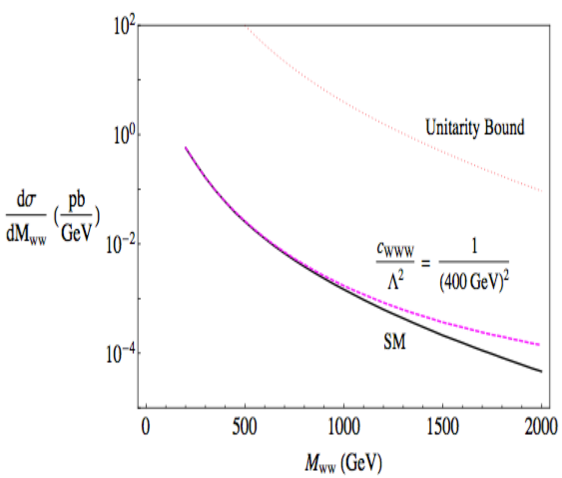

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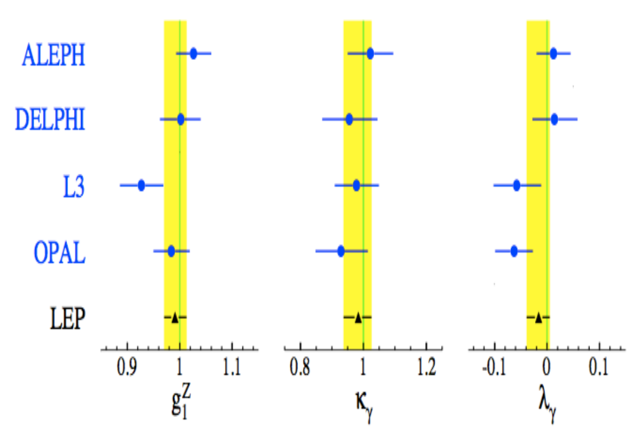

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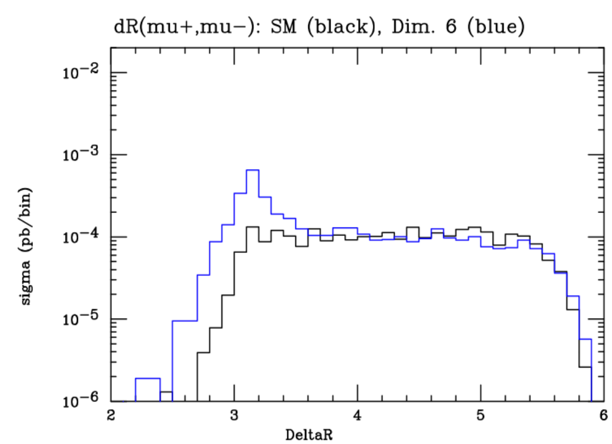

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Results

- Multi-parameter fits test whether a single-parameter fit masks an anomalous coupling
- The Lagrangian parameters used fall within a 68% CL. Terms not observed in the SM have values very near zero
- Non-Abelian gauge theories work!
- Future experiments will determine what “ very near zero” means

Summary

- An effective QFT approach to the $SU(2)_L xU(1)_Y$ Non-Abelian gauge symmetry group is rich and versatile
- There's still room for new physics
- Electroweak triple gauge couplings (like ggg) are already highly involved, never mind quartic and beyond! Perhaps we will discover that the Lagrangian is more predictive than we think.

Thank you for your attention!