Investigating Anomalous Trilinear Gauge Couplings

Geoffrey Fatin & Joseph Flanigan
LHC Facts

- Proton-proton collisions
- Current collision energy: 8TeV
- Expected maximum collision energy: 14TeV
- 27km in circumference (Fermilab: 6.3km)
The CMS Detector

- **Silicon Tracker**
  - 65 million pixels in each silicon pixel detector
  - Maps positioning of most particles originating from the collision

- **Electromagnetic Calorimeter (ECAL)**
  - Dense crystals of lead tungstate
  - Accurately detects and measures energies of photons and electrons

CMS Detector (Continued)

- Hadronic Calorimeter (HCAL)
  - Brass/steel interwoven with plastic scintillators
  - Measures energies of hadrons
- Muon Detectors
  - Muons are not stopped by other detector parts
- Solenoid Magnet
  - Superconducting, cooled to -268.5°C
  - 4 Tesla

http://rdms-cms.jinr.ru/docs/rdms_1/setup.gif
Trilinear Gauge Couplings (TGC)

- Simply put, when three gauge bosons couple to each other
- Typically this occurs when a $W^+$ and $W^-$ boson couple to a $Z^0$-boson or photon
- Primary Feynman Diagrams versus less important ones

**FIG. 1:** In this Feynman Diagram an electron-positron pair annihilate producing either a photon or Z-boson coupled to a WW pair.

**FIG. 2 (right):** A diagram that shows the elementary particles that are a part of the Standard Model.
TGC Lagrangian

\[
\mathcal{L}_{\text{TGC}} = \text{i} e g_1^Z (A_\mu (\partial_\mu W_{-\nu} - \partial_\nu W_{-\mu}) W^+_{\nu} - A_\mu (\partial_\mu W_{+\nu} - \partial_\nu W_{+\mu}) W^-_{\nu}) + \text{i} e \kappa_\gamma (\partial_\mu A_\nu - \partial_\nu A_\mu) W^{+\mu} W^{-\nu} \\
+ \text{i} e \cot \theta_w g_1^Z (Z_\mu (\partial_\mu W_{-\nu} - \partial_\nu W_{-\mu}) W^+_{\nu} - Z_\mu (\partial_\mu W_{+\nu} - \partial_\nu W_{+\mu}) W^-_{\nu}) + \text{i} e \cot \theta_w \kappa Z (\partial_\mu Z_\nu - \partial_\nu Z_\mu) W^{+\mu} W^{-\nu} \\
+ \frac{\lambda_\gamma}{M_W^2} ((\partial_\mu A_\rho - \partial_\rho A_\mu) (\partial^\rho W_{+\nu} - \partial_\nu W_{+\rho} (\partial_\nu W_{-\mu} - \partial_\mu W_{-\nu})) \\
+ \text{i} e \cot \theta_w \frac{\lambda Z}{M_W^2} ((\partial_\mu Z_\rho - \partial_\rho Z_\mu) (\partial^\rho W_{+\nu} - \partial_\nu W_{+\rho} (\partial_\nu W_{-\mu} - \partial_\mu W_{-\nu})) - e g_4^Z W^+_{\nu} W^-_{\mu} (\partial^\mu A_\nu + \partial_\nu A_\mu) \\
+ \text{e} \cot \theta_w g_4^Z W^+_{\nu} W^-_{\mu} (\partial^\mu Z_\nu + \partial_\nu Z_\mu) + \text{e} g_5^Z \epsilon_{\mu
u\rho\sigma} ((\partial^\rho W_{-\mu}) W^{+\nu} - (\partial^\nu W^{+\mu}) W^{-\mu}) A^\sigma \\
+ \text{e} \cot \theta_w g_5^Z \epsilon_{\mu
u\rho\sigma} ((\partial^\rho W_{-\mu}) W^{+\nu} - (\partial^\nu W^{+\mu}) W^{-\mu}) Z^\sigma + \text{i} e \kappa_\gamma W^+_{\nu} W^-_{\mu} \frac{1}{2} \epsilon_{\mu\nu\rho\sigma} (\partial_\rho A_\sigma - \partial_\sigma A_\rho) \\
+ \frac{\tilde{\lambda}_\gamma}{M_W^2} ((\partial_\mu W_{+\nu} - \partial_\nu W_{+\mu}) (\partial_\rho W_{-\mu} - \partial_\mu W_{-\rho}) \frac{1}{2} \epsilon_{\nu\rho\sigma\ell} (\partial_\sigma A_\ell - \partial_\ell A_\sigma) \\
+ \text{i} e \cot \theta_w \tilde{\kappa} Z W^+_{\nu} W^-_{\mu} \frac{1}{2} \epsilon_{\mu
u\rho\sigma} (\partial_\rho Z_\sigma - \partial_\sigma Z_\rho) \\
+ \text{i} e \cot \theta_w \frac{\tilde{\lambda}_Z}{M_W^2} ((\partial_\mu W_{+\nu} - \partial_\nu W_{+\mu}) (\partial_\rho W_{-\mu} - \partial_\mu W_{-\rho}) \frac{1}{2} \epsilon_{\nu\rho\sigma\ell} (\partial_\sigma Z_\ell - \partial_\ell Z_\sigma)
The Monte-Carlo (MC) Method:

- Method for determining characteristics based on probability
- Example: determining the area of a shape
- More “events”, greater accuracy

FIG 1: In order to calculate the area of an odd shape using the Monte-Carlo, we cover it in evenly spaced dots.

\[ \frac{n}{N} \approx \frac{A_o}{A_s} \]

\[ A_o = \lim_{N \to \infty} \left( \frac{n}{N} \right) \cdot A_s \]
How Jets Form:

- Bosons are short-lived, difficult to study/detect
- Can study jets from boson decay
- Color-charged particles from decay hadronize
- Hadronization creates more color-charged particles
- A “jet” of hadronic matter is created
- Can measure energy contained in this jet, determine which boson formed it

Parameter Adjustment

- One way of testing for anomalous trilinear gauge couplings is to vary the parameters in the TGC Lagrangian to detect deviations from SM predictions.
- We can use the MC method to predict how our particles collided or to determine which boson decay we are seeing.
- We can adjust parameters in the detector (one-to-one correspondence with LGC parameters), which produces different MC’s.
- Some are more valuable than others (too much background, elimination of important signals, etc.)
Signals

- We are looking for a signal composed of:
  - Two jets produced from $W$-boson decay
  - One leptonic decay of a $W$-boson (the neutrino produced here is not detectable, except through calculating the missing energy)
- Specifically, we are looking for “merged jets”

http://www-cdf.fnal.gov/physics/ewk/2008/wwwz/plots/WW_WZ_ALL.gif
Merged Jets

- Extremely high energy collisions, jets have little time to separate. Results in what looks like a single jet.
- We must find algorithms that can help us determine which hadronic matter detections are from which boson decays
- Reduction in background noise and ensuring we don’t eliminate good data are also important factors

Fig 1: Depiction of collimation of two jets in a high energy collision.

Fig 2: Depiction of merged jets inside a detector.
Distinct Jets & Background Noise

- One of our primary tasks is to investigate the most efficient means of reducing background noise.
- It is necessary to maximize signal events and minimize background events.

Other Possible Anomalous Interactions

- Diboson production combined with the emission of a highly energetic photon
- This is a rare event and is indicative of a more massive particle involved in the interaction
- There also exist quartic couplings of gauge bosons

http://arxiv.org/abs/0908.1061
Relation to the Higgs and Sensitivity to New Physics

- Higgs decay versus non-Higgs decay
- If the Higgs does not exist, these kinds of phenomena are sensitive to new physics.


