Anomalous Trilinear Gauge Couplings - ZZ production in ATLAS

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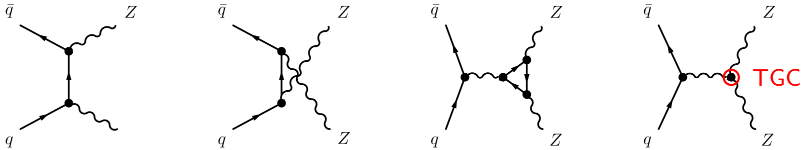
Outline

- Phenomenology on anomalous TGCs in ZZ.
- Methods for measuring TGCs.
- ATLAS results.

Phenomenology on anomalous TGCs in *ZZ*



- ZZV^* vertex not allowed in SM.
- Introduced with generic operator expansion – Effective Lagrangian – keep only lowest order terms.
- On shell requirement gives 4 anomalous TGCs in ZZ:

  f_i^V where $V = \{Z, \gamma\}$ and $i = \{4, 5\}$
- The Lagrangian:

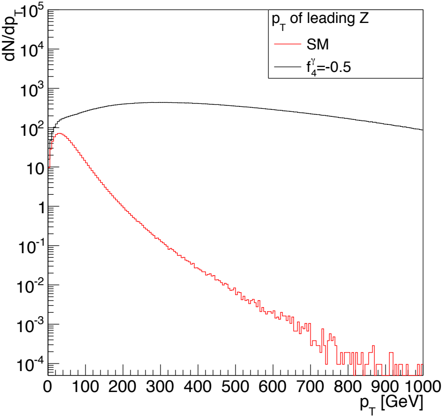
$$\mathcal{L}_{TGC} = \frac{e}{m_Z^2}\left[f_4^V(\partial_\mu V^{\mu\beta})Z_\alpha(\partial^\alpha Z_\beta) + f_5^V(\partial^\sigma V_{\sigma\mu}\tilde{Z}^{\mu\beta}Z_\beta)\right]$$

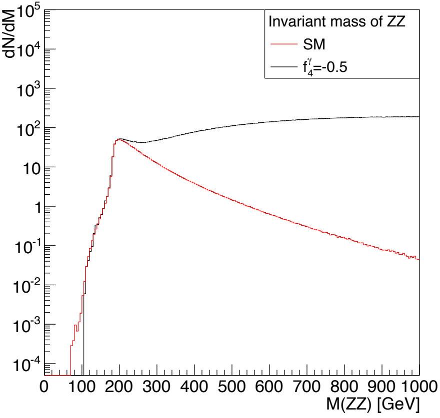
- Traditionally, dipole form factors are introduced to avoid high energy behavior which violates partial wave unitarity:

$$f_i^V(s) = \frac{f_{i0}^Z}{(1+s/\Lambda^2)^n} \quad , \quad n = 3 \quad , \quad \Lambda = 2\text{TeV}$$

Observable effects

The signature of anomalous trilinear gauge couplings is enhanced cross section at high energies ($\hat{s}$) and at large scattering angles. Thus, observables which are proportional to the invariant mass of the diboson system and the gauge boson transverse momentum are particularly sensitive. (Plots made with SHERPA event generator)





Methods for measuring anomalous TGCs

To do a measurement, we need at practical way of parametrizing the observable effects. This is achieved by reweighting Standard Model MC events by recalculating the cross section:

$$\text{weight} \quad = \quad \frac{d\sigma_{\mathrm{SM+TGC}}}{d\sigma_{SM}}$$

- The differential cross section when including TGC is given by (here including only 1 TGC for simplicity)

$$\mathrm{d}\sigma = C_0 + f \cdot C_1 + f^2 \cdot C_2$$

  where $C_0 = \mathrm{d}\sigma_{\mathrm{SM}}$ and $\mathrm{d}\sigma$ denotes $\mathrm{d}\sigma/\mathrm{d}x$ for any observable x.

- Inserting three different $f = \{0, 1, -1\}$, the following set of equations is constructed

$$\begin{pmatrix} \mathrm{d}\sigma_1 \\ \mathrm{d}\sigma_2 \\ \mathrm{d}\sigma_3 \end{pmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 1 & 1 & 1 \\ 1 & -1 & 1 \end{bmatrix} \begin{pmatrix} C_0 \\ C_1 \\ C_2 \end{pmatrix}$$

  which can be re-written and manipulated to:

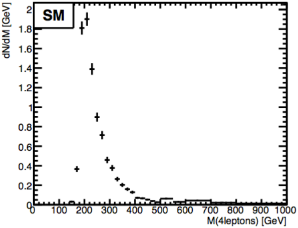
$$\vec{\mathrm{d}\sigma} = \hat{A}\vec{C} \qquad \Rightarrow \qquad \underline{\underline{\vec{C} = \hat{A}^{-1}\vec{\mathrm{d}\sigma}}}$$

- Once the C_i's are determined, the event weights becomes:

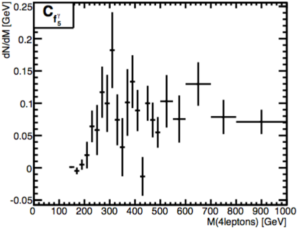
$$\text{weight} \quad = \quad d\sigma_{\mathrm{SM+TGC}}/d\sigma_{SM} \quad = \quad 1 + f \cdot C_1/C_0 + f^2 \cdot C_2/C_0 \qquad (1)$$

- Notice that this works at histogram level for a given observable:

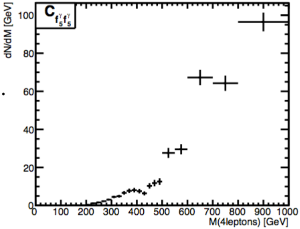
$$\frac{\mathrm{d}N}{\mathrm{d}M(ZZ)}(f) \quad = \quad 1 \cdot$$



$$+ f \cdot$$



$$+ f^2 \cdot$$

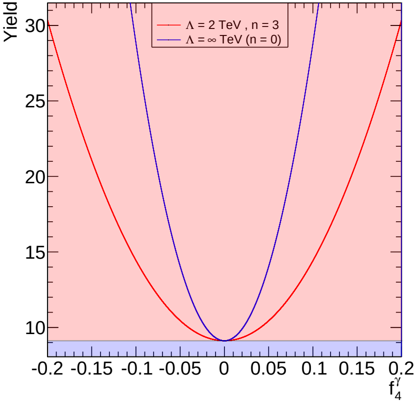


Determining 95% CL

In case we do not see significant signs of anomalous TGCs, we set limits (95% CL).

Determining 95% CL is non-trivial since theory does not cover the case of observing **less events than what SM predicts**. In this case, the fit will be biased towards SM and give **too small confidence intervals**.

EXPERIMENTAL PHASE SPACE

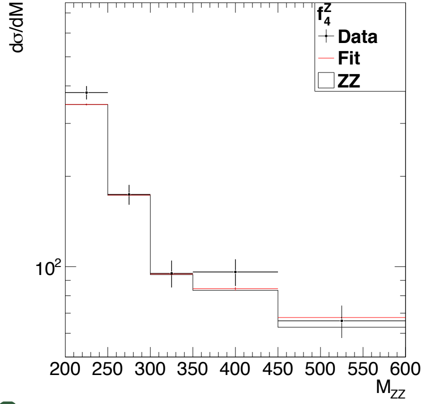


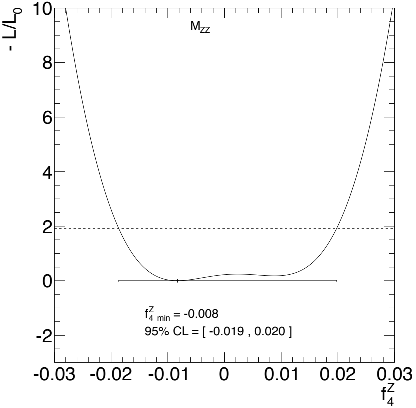
THEORETICAL PHASE SPACE

The question is how to get unbiased confidence intervals?

Determining 95% CL

Example of fitting coupling using pseudo-data (Maximum LogLikelihood estimation). Notice the double minima structure in the Likelihood function. This shows the insignificance of the linear term and thus the difficulties in extracting the sign of the anomalous couplings.

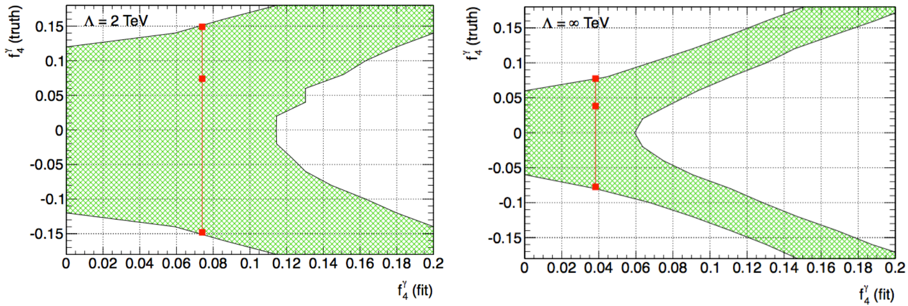




Determining 95% CL

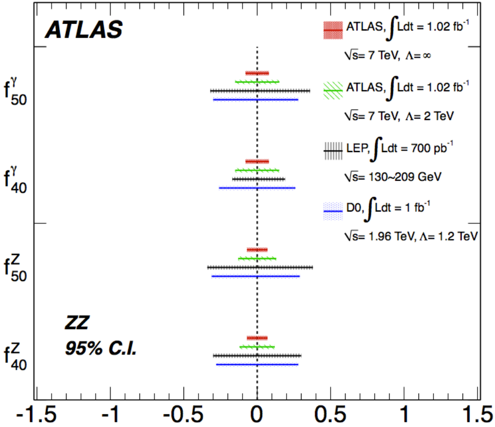
To address the issue of not covering the full experimental phase space, we take a frequentist approach and do a Neyman construction.

- For each input value of the couplings ("truth"), we make 1000 pseudo-experiments (i.e. fluctuating the expected yield at this TGC points with a Poissonian) and fit each of them.
- Each pseudo-experiment produces at point (fit,truth). The 95% of the fits that have the largest Likelihood (Feldman-Cousins ordering) corresponds to the green area in the plots. The limits are then given by the reading off the intersection with the fit to data.



Latest results from ATLAS (summer 2011)

$ZZ \to 4l$, $l = e, \mu$.
9 events expected, 12 events observed (1.02 fb^{-1} data)
Too few events to do shape fit – used total number of events.



Thank you for your attention!

BACKUP SLIDES

Form factor

- **Effective Lagrangians:**
  - The original purpose of aTGCs is an effective Lagrangian for a multiboson interaction expansion in $1/\Lambda^2$:

$$\mathcal{L}_{\text{eff}} = \sum_{d=4}^{\infty} \frac{1}{\Lambda^{d-4}} \mathcal{L}_d = \mathcal{L}_4 + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \dots$$

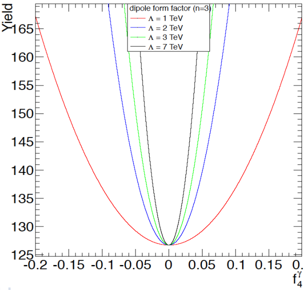
  - With

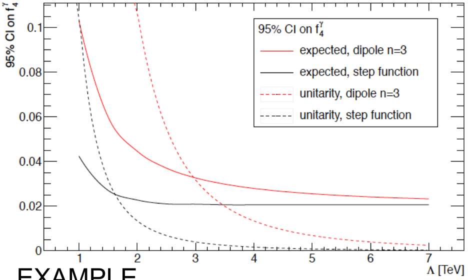
$$\mathcal{L}_i = \sum_j \alpha_{ij} \mathcal{O}_{ij}$$

  - Where Λ is the scale of new physics. (Note: only one Λ!)
  - Standard "two parameter" problem – Λ and α.
  - By construction, (truncated) effective Lagrangians violate unitarity at some scale.
- Current approach of introducing dipole form factor to restore unitarity is ad-hoc and provides (if applied rigorously) different scales to each aTGC – *somewhat destroying the original idea*.
- Using different cutoff scales for different processes and re-determining the scale when more data becomes available makes it difficult to compare to previous results and to other experiments.
- Which cutoff should be used when combining different diboson channels?

Form factor

- **Follow-up on last meeting:**
  - It was discussed that limits could be given as function of Λ (step-function), thus providing results for several Λ scales.
  - Generator study: ZZ, f4G. Using dσ/dpT(Z). SHERPA events reweighted with Baur-Rainwater. Unitarity limits from U. Baur and D. Zeppenfeld, Phys. Lett. B 201 (1988) 383.





EXAMPLE

Kristian Gregersen, LHC EWWG meeting November 30, 2011 10/11

Diagrams included in reweighting code

Born $2 \to 2$ $\longrightarrow$ included

Real emission $2 \to 3$ $\longrightarrow$ included $\longrightarrow$ included $\longrightarrow$ included

Virtual contribution $\longrightarrow$ ignored