ATLAS DIM-8 SMEFT

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LHC EFT WG
July 3, 2023
Quartic Electroweak Couplings

- Vector Boson Scattering (VBS) and triboson (VVV) productions are sensitive to Quartic Gauge boson Couplings (QGC).
- Rare processes which are at reach of LHC.

(ANI-PHYS-PUB-2022-009)
Model considered for aQGC interpretation

- Allows to probe for deviations introduced by physics beyond the SM.
- Extension of the SM Lagrangian with additional dimension-8 operators:

\[ \mathcal{L}_{EFT} = \mathcal{L}_{SM} + \sum_{d>4} \sum_{i} \frac{\tilde{c}_i}{\Lambda^{d-4}} \mathcal{O}_i \]

- Dimension-8 operators are the lowest-dimension operators inducing only QGCs without TGC vertices:

<table>
<thead>
<tr>
<th>Operator(s)</th>
<th>WWWWW</th>
<th>WWZZ</th>
<th>WWγZ</th>
<th>WWγγ</th>
<th>ZZZZ</th>
<th>ZZγγ</th>
<th>Zγγγ</th>
<th>γγγγ</th>
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<tr>
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</tr>
</tbody>
</table>

(T3 and T4 also available)
Overview of ATLAS measurements sensitive to aQGC

- Published ATLAS Run 2 analyses sensitive to aQGC:
  - VBS (Full Run 2):
    - $Z(\nu\nu)\gamma jj$ [JHEP 06 (2023) 082] *
    - $Z(\ell\ell)\gamma jj$ [arXiv:2305.19142]
    - $ZZ(4\ell)jj$ [ATLAS-CONF-2023-024] *
    - $W^\pm W^\pm jj$ [ATLAS-CONF-2023-012] *
  - Triboson (Full Run 2):
    - $WZ\gamma$ [arXiv:2305.16994, submitted to PRL]
    - $W\gamma\gamma$ [ATLAS-CONF-2023-005]
    - $Z\gamma\gamma$ [Eur.Phys.J.C 83 (2023) 539] *
  - Combined EFT interpretation of $WZjj$ and $W^\pm W^\pm jj$ (36 fb$^{-1}$) [ATL-PHYS-PUB-2023-002] *

- Analyses above marked with a “*” include an aQGC interpretation
EFT limits setting

Assumptions and challenges (1/2)

- **EFT decomposition**: extra operators are added to the SM Lagrangian such that, for one given operator, the squared amplitude is sum of SM, SM-EFT interference, and EFT quadratic terms:

\[
|A_{SM} + \sum_i c_i A_i|^2 = |A_{SM}|^2 + \sum_i c_i^2 \text{Re}(A_{SM}^* A_i) + \sum_i c_i^2 |A_i|^2 + \sum_{i,j,i\neq j} c_i c_j \text{Re}(A_i A_j^*)
\]

→ Usual case: assuming one non-zero wilson coefficient at a time. Also 2D limits.

- **Prediction accuracy**: \(\sigma_{EFT} = \sigma_{SM}^{best} \times \frac{\sigma_{EFT}^{LO}}{\sigma_{LO}^{SM}}\)

→ Assume higher-order corrections factorize, not always good assumption
EFT limits setting

Assumptions and challenges

- **Validity of EFT model:**
  - Impact of higher-dimensional operators is expected to be suppressed by powers of cut-off scale.
  - EFT model is not complete and can violate unitarity at very high parton centre-of-mass energies (requires unitarization).

- **EFT Limit setting:**
  - From particle-level (unfolded) differential measurements
    - Assume EFT acceptance and efficiency are similar as in SM.
  - From detector-level measurements
    - Less easy to reinterpret, potentially allows to use more complex multivariate discriminant that are non-trivial to unfold.
EFT limits unitarization

**Principle**

- **Clipping technique:**
 Introduced to preserve unitarity at high energy by setting the EFT prediction to zero when the energy of the process is above a given clipping energy \( E_c \). EFT limits are derived for a scan of different clipping energies.

- **Unitarized limit:**
  Unitarity bounds (arXiv:2004.05174) for a given limit value are calculated from partial-wave unitarity constraints. The unitarized limit is chosen given the intersection of the clipping scan and the unitarity bounds.
**EFT limits unitarization**

*Clipping examples*

- Example of $Z\gamma\gamma$ analysis [Eur.Phys.J.C 83 (2023) 539]

- Below: limits are clipped given upper bounds on $E_c = m_{\ell\ell\gamma\gamma}$. The last bin corresponds to no clipping.
**EFT limits unitarization**

*Examples of unitarized 1D limits (1/2)*

- Example of $Z(\nu\nu)\gamma jj$ analysis [JHEP 06 (2023) 082]

- Limits are clipped given upper bounds on $E_c = m_{Z\gamma}$. Discontinuity corresponds to a change of event selection.

- Unitarity bounds are compared with limits to derive unitarized limits.
EFT limits unitarization

Examples of unitarized 1D limits (2/2)

- Example of ZZ(4\ell)jj analysis [ATLAS-CONF-2023-024].
- Limits are clipped given upper bounds on $E_c = m_4\ell$.
- Example of case (here for T9) where unitarity bounds are always below limits.
EFT limits unitarization

Examples of unitarized 2D limits

- Example of $W^\pm W^\pm jj$ analysis [ATLAS-CONF-2023-012].
- Limits are clipped given upper bounds on $E_c = m_{WW}$.
- Unclipped limits (more stringent)
- Clipped limits with $E_c = 1.5$ TeV, and unitarity bounds

\[ \text{ATLAS Preliminary} \]
\[ \sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1} \]
EFT limits unitarization

**Examples of unitarized 2D limits**

- Example of $W^±W^±jj$ analysis [ATLAS-CONF-2023-012].
- Limits are clipped given upper bounds on $E_c = m_{WW}$.
- Unclipped limits (more stringent)
- Clipped limits with $E_c = 1.5$ TeV, and unitarity bounds
EFT limits combination

*Examples of combined 2D limits*

- Example of combined EFT interpretation of $WZjj$ and $W^\pm W^\pm jj$ ($36 \, fb^{-1}$) [ATL-PHYS-PUB-2023-002].
- Limits shown are not unitarized (published 1D limits are).
- 2D results show the complementarity of the channels.
Summary

- VBS and triboson productions are sensitive to aQGC
- Limits on EFT coefficients (Eboli model) have been derived by analyzing these processes (using decomposition method).
- To address the validity of the model at high energy, limits have been computed given upper bounds on the energy of the processes (clipping), and further compared to unitarity bounds in order to derive unitarized limits.