CMS EFT efforts

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On behalf of the CMS Collaboration

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Introduction

• Current CMS EFT efforts summarized by A. Grohsjean in the 1st general meeting: link

• This talk focus on the convention/basis choices and related questions

• TOP, EW and Higgs all have ongoing analyses, questions in common, though most examples given in Higgs
EFT parameters: general approach

- Higgs differential distributions
  - Parameterization on SILH basis
  - Xsec: linear and quadratic terms
- Multi-dimensional cross section extractions: STXS
  - Parameterization on SILH basis
  - Xsec: linear and quadratic terms
**EFT parameters: general approach**

- **Top process xsec**
  - $\ell\nu, t\ell\ell, t\ell q, t\ell H,$ and $t\ell\nu,$ leptonic final state
  - Warsaw basis, LO (dim6TopEFT model)
  - Linear and quadratic terms
    \[
    w_t(c_t) = s_{0t} + \sum_j s_{1lj} \frac{c_j}{\Lambda^2} + \sum_j s_{1lj} c_j^2 + \sum_{j,k} s_{3ljk} \frac{c_j c_k}{\Lambda^2}
    \]

- **Top differential measurement**
  - $t\ell Z$ differential $p_T(Z)$ and $\cos(\theta_Z^*)$
  - Warsaw basis, LO (dim6TopEFT model)
  - Linear and quadratic terms
EFT parameters: dedicated approach

\[ A(HVV) = \frac{1}{v} \left[ a_1^{VV} q_1^2 + \frac{\kappa_1^{VV} q_1^2 + \kappa_2^{VV} q_2^2}{(\Lambda_1^{VV})^2} + \frac{\kappa_3^{VV}(q_1 + q_2)^2}{(\Lambda_Q^{VV})^2} \right] m_{V1}^2 \epsilon_{V1}^* \epsilon_{V2}^* \]

+ \frac{1}{v} a_2^{VV} f_{\mu \nu}^{(1)} f_{(2) \mu \nu}^{*} + \frac{1}{v} a_3^{VV} f_{\mu \nu}^{(1)} f_{(2) \mu \nu}^{*},

- • HVV anomalous coupling measurements
- • Designed observables sensitive to each anomalous coupling
- • General EFT mass-eigenstate basis
- • SMEFT with SU(2)xU(1) symmetry -> map to Higgs parameterization
- • Linear + quadratic terms
• Anomalous triple and quartic gauge couplings
• Dedicated final states, sensitive to different aTGC and aQGC
• Conversion to EFT, HISZ basis
Choice of model /basis

- Current choices of models/basis are quite diverse
  - transparent expressions of analysis observables
    - aTGC/aQGC in HISZ, anomalous HVV and Hff couplings map to Higgs parameterization
  - Availability of the tools
  - Direct comparison to previous results
- For grand combination across LHC, easier to use the same language
  - given the correct tool, most analyses could be related in different bases
  - HIG STXS combination plans to move to Warsaw basis: public tool "EFT2Obs" by A.Gilbert and CMS HIG Combination experts
  - Dedicated AC: mass eigenstates to perform analysis and report results, map to any basis rotation in combination
  - Top: SMEFT Warsaw basis
  - EW: mainly in HISZ, for combination could be rotated
Analysis in different base

Whatever basis chosen, analysis will be sensitive to the same physics, just in different combinations of operator

\[
\begin{align*}
AC & \quad Higgs & \quad Warsaw basis \\
- \frac{2s_w^2 c_w^2}{v^2} a_2 & \quad & \\
\frac{g^4 c_{WW} + 4g^2 g'^2 c_{WB} + g'^4 c_{BB}}{(g^2 + g'^2)^2} & \quad &
\frac{g^2 c_{WW} - 2(g^2 - g'^2)c_{WB} - g'^2 c_{BB}}{g^2 + g'^2}, \\
\frac{c_{\gamma\gamma} = c_{WW} + c_{BB} - 4c_{WB}}{ } & \quad & \\
\frac{2}{g^2 - g'^2} \left[ g'^2 c_{WB} - c_T + \delta v \right] & \quad &
\frac{2}{g^2} \left[ c_T - \delta v \right], \\
\frac{c_{\gamma\gamma}}{ } & \quad &
\frac{2}{g^2 - g'^2} \left[ (g^2 + g'^2)c_{WB} - 2c_T + 2\delta v \right].
\end{align*}
\]

\begin{align*}
AC & \quad Warsaw basis \\
g_{4}^{Z\gamma} & = -2 \frac{v^2}{\Lambda^2} \left( s_w^2 w_{\phi B} + c_w^2 w_{\phi B} + s_w c_w w_{\phi B} \right), \\
g_{4}^{\gamma\gamma} & = -2 \frac{v^2}{\Lambda^2} \left( c_w^2 w_{\phi B} + s_w^2 w_{\phi B} - s_w c_w w_{\phi B} \right), \\
g_{4}^{Z\gamma} & = -2 \frac{v^2}{\Lambda^2} \left( s_w c_w (w_{\phi B} - w_{\phi B}) + \frac{1}{2} (s_w^2 - c_w^2) w_{\phi B} \right), \\
g_{4}^{\gamma\gamma} & = -2 \frac{v^2}{\Lambda^2} w_{\phi G}.
\end{align*}

Questions

• Linear or linear+quadratic terms

\[ w_i(\vec{c}) = s_{0i} + \sum_j s_{1ij} \frac{c_j}{\Lambda^2} + \sum_j s_{2ij} \frac{c_j^2}{\Lambda^4} + \sum_{j,k} s_{3ijk} \frac{c_j c_k}{\Lambda^2} \]

• Most CMS analyses consider linear+quadratic terms
  • positive definite
  • sensitive to operators (e.g. CP-odd) does not enter linear terms
  • allow to access EFT validity
• Aware of possible issues
  • D8 operators neglected in both cases
  • dependence on quadratic terms indicates poor sensitive to EFT effects
• Pros usually outweighs cons in experimental analyses
Questions

- Operator double insertion

- VBF/ZH/WH, $H \rightarrow ZZ/WW$

\[
 w_i(c) = \left( s_{0i} + \sum_j s_{1ij} \frac{c_j}{\Lambda^2} + \sum_j s_{2ij} \frac{c_j^2}{\Lambda^4} + \sum_{j,k} s_{3ijk} \frac{c_j c_k}{\Lambda^2 \Lambda^2} \right) \times \left( s_{0i} + \sum_j s'_{1ij} \frac{c_j}{\Lambda^2} + \sum_j s'_{2ij} \frac{c_j^2}{\Lambda^4} + \sum_{j,k} s'_{3ijk} \frac{c_j c_k}{\Lambda^2 \Lambda^2} \right)
\]

- Up to $1/\Lambda^8$

- What to include in this case? Currently keep all for positive definite
Questions

• CP-odd operators
  • no strict reason why CP-odd should be prohibited
  • so far not many analyses extracting CP-odd WC
  • overall xsec=0 in linear term
  • observables could be designed to be sensitive to the linear term
  • dedicated measurements in combination with general ones
As more EFT analyses ongoing, some common questions come up

- EFT expansions to be used
  - double insertion operators
- CP-odd operators

For a grand combination, analyses explore expressing results in different bases