Fitting EFT coefficients from STXS bins

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Overview

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- Aim:
  - Constrain EFT coefficients with data:
    STXS measurements $\leftrightarrow$ EFT equations.
  - Produce library of EFT equations: can be used for any stat. analysis, publicly available.
- Plan:
  - Define order and truncation of EFT.
  - Choose EFT basis.
  - Use a generator for STXS cross sections.

STXS bins

- Cross sections are measured in each STXS truth bin, with correlations.
- STXS bins are divided into production modes and branching ratios of the decay:
  - production: ttH, WH, ZH, VBF, ggf;
  - decay: hZZ, h$\gamma\gamma$, + others.
- Decay processes are inclusive.
- Decay is expressed as a ratio, e.g. $\frac{\text{BF(H}\rightarrow\gamma\gamma\text{)}}{\text{BF(H}\rightarrow\text{ZZ)}}$.
- Production processes are further divided into kinematic bins.

EFT expansion

- Lagrangian:

$$L = SM + c_i^{(6)} O_i^{(6)} \Lambda^{-2} + c_i^{(8)} O_i^{(8)} \Lambda^{-4}$$

- We take only up to dimension 6 operators:

$$\sigma = |ME_{SM}|^2 + ME_{SM} ME^{(6)} + |ME^{(6)}|^2$$

- We keep $|ME^{(6)}|^2$ because while it has Λ^{-4} dependence it is the leading order term that is not dependent on the SM amplitude.
- Express σ in terms of EFT couplings (quadratic in coefficients):

$$\sigma = SM + B_i c_i^{(6)} + D_{ij} c_i^{(6)} c_j^{(6)}$$

- The $|ME^{(6)}|^2$ term can be dropped by neglecting the D_{ij} coefficients

EFT implementation

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First-pass EFT model:

- HEL model: LO implementation of SILH basis excluding 4-fermion operators
- has 39 operators
- generate with Madgraph
- shower with Pythia8 unless the process is inclusive

Extraction of the equation

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$$\sigma = SM + B_1 c_1 + D_{11} c_1^2 + B_2 c_2 + D_{22} c_2^2 + D_{12} c_1 c_2$$

- Use NP^2== syntax and $c_1 = c_2 = 1$:
  - SM, B_i and D_{ij} for $i = j$ get directly:

$$\begin{cases} NP\hat{}2 == 0 : \sigma_1 = SM \\ NP\hat{}2 == 1 : \sigma_{B1} = B_1,\ \sigma_{B2} = B_2 \\ NP\hat{}2 == 2 : \sigma_{D11} = D_{11},\ \sigma_{D22} = D_{22} \end{cases}$$

  - Extracting D_{ij} for $i \neq j$:
    - generate a sample with NP^2==2 syntax;
    - then $\sigma = D_{11} c_1^2 + D_{22} c_2^2 + D_{12} c_1 c_2$;
    - subtract D_{11} and D_{22} calculated previously.

Bin expressed as a ratio of BFs

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$$\frac{\mathrm{BF}(\mathrm{H}\to\gamma\gamma)}{\mathrm{BF}(\mathrm{H}\to\mathrm{ZZ})}$$

- From MadGraph we get numerator and denominator as a polynomial:

$$\frac{A + B_i c_i + D_{ij} c_i c_j}{F + G_j c_j + H_{ij} c_i c_j}$$

- We may expand as follows:

$$\frac{A + B_i c_i + D_{ij} c_i c_j}{F + G_j c_j + H_{ij} c_i c_j} \approx \frac{A}{F}\left(1 + \frac{B_i c_i}{A} + \frac{D_{ij} c_i c_j}{A} - \frac{G_j c_j}{F} - \frac{H_{ij} c_i c_j}{F} - \frac{G_j B_i c_i c_j}{AF}\right)$$

Data vs MC

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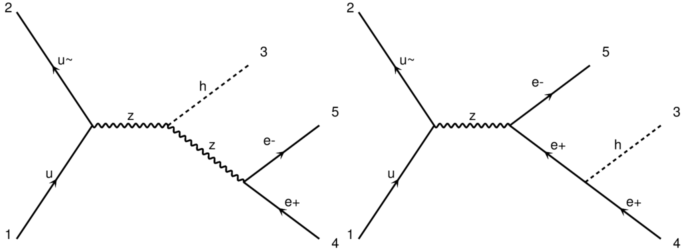
- Detector cannot see intermediate particles while we can specify them in MC. ZH as in Yellow Report (left) vs same final particles (right):



- Effect of removing/ adding diagrams:
  - changes cross-section;
  - changes active BSM couplings (i.e. new diagrams bring new couplings).

Adding/removing diagrams: σ change

SM samples σ/pb comparison: σ/pb of all intermediate particles vs σ/pb with intermediate particles written in the brackets:

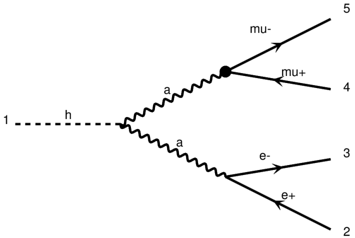
- tth: 0.400 vs 0.413 (g).
- wh: 0.0719 vs 0.0729 (W).
- zh: 0.0507 vs 0.0516 (Z).
- h$\gamma\gamma$: $1.04 \cdot 10^{-5}$ - no other diagrams.
- hzz: $4.72 \cdot 10^{-8}$ vs $4.23 \cdot 10^{-8}$ (Z).

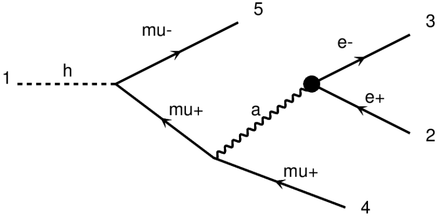
Fractional uncertainty: 0.004.

Adding/removing diagrams: hZZ

- Full sample: $4.72 \cdot 10^{-8}$ GeV
- Only Z in s-channel: $4.23 \cdot 10^{-8}$ GeV
- Only Z and γ in s-channel: $4.55 \cdot 10^{-8}$ GeV

Fractional uncertainty: 0.004.





Adding/removing diagrams: BSM couplings change

Number of BSM couplings: removed intermediate particles vs all:

- Production:
  - tth: 9 vs 28.
  - wh: 10 vs 13.
  - zh: 23 vs 29.
- Decay:
  - h$\gamma\gamma$: 2 in both.
  - hzz: 17 in both.

Example of the equation

- Process: H$\rightarrow \gamma\gamma$:

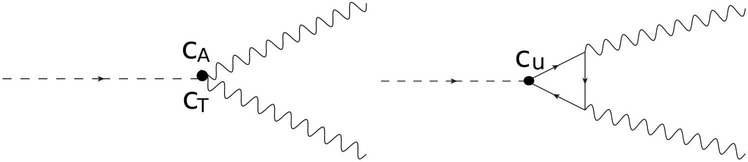
$$\Gamma/GeV = 1.042\cdot 10^{-5}(\pm 4\cdot 10^{-8}) - 0.00953(\pm 4\cdot 10^{-5})\cdot cA + 2.178(\pm 0.009)\cdot cA\cdot cA + 2.178(\pm 0.009)\cdot tcA\cdot tcA$$

- Process: H$\rightarrow$ZZ:

$$\Gamma/GeV = 4.75\cdot 10^{-7}(\pm 2\cdot 10^{-9}) + 1.365\cdot 10^{-6}(\pm 5\cdot 10^{-9})\cdot cHW + 4.09\cdot 10^{-7}(\pm 2\cdot 10^{-9})\cdot cHB + 9.75\cdot 10^{-7}(\pm 4\cdot 10^{-9})\cdot cHL + 9.75\cdot 10^{-7}(\pm 4\cdot 10^{-9})\cdot cpHL + 1.555\cdot 10^{-7}(\pm 6\cdot 10^{-10})\cdot tcHW + 4.58\cdot 10^{12}(\pm 2\cdot 10^{10})\cdot cT\cdot cT + 2.58\cdot 10^{12}(\pm 2\cdot 10^{10})\cdot cH\cdot cT + 5.82\cdot 10^{12}(\pm 3\cdot 10^{10})\cdot cT\cdot cHe + \text{ smaller terms}$$

Small contributions to σ

- Remove small contributions that are smaller than expected NLO uncertainties, e.g. 0.1% of the highest contribution.



- H$\rightarrow$4l cT quadratic terms are too large.
  - H$\rightarrow$ZZ, cT$=$1: small Γ
  - H$\rightarrow$Zll, cT$=$1: small Γ
  - H$\rightarrow$4l, cT$=$1, only H in s-channel: small Γ
  - H$\rightarrow$4l, cT$=$1, all particles or only Z and H: large Γ

Summary

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- Our aim is to produce a library with EFT mapping to STXS bins s.t.:
  - include leading operators that appear in the process;
  - provide information about effects due to added/ removed diagrams.
- We will produce a note documenting the results.