Theory errors in EFT studies

Gauthier Durieux
(CERN)

relevant LHC EFT WG activities:

2021-01-19: Second area 1 meeting (proposals presented)

2021-05-02: Second general meeting (summary note & community comments)

2021-06-28: Third area 1 meeting (further discussion)

Snowmass Energy Frontier Workshop
2 Sept 2021

Theory errors in EFT studies

on SM predictions $\rightarrow$ as usual

on EFT dependences

- missing higher SM orders
- PDF

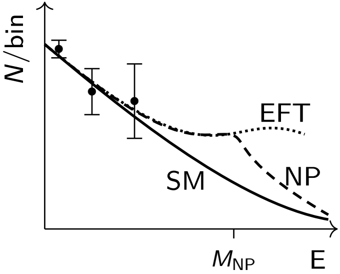
$\Big\}$ $\rightsquigarrow$ as usual (e.g. needs RG in MC)

- inclusion in fits ?? errors depend on c_6/Λ^2 values

from EFT truncation ???

“EFT validity”

Validity of the dim-6 EFT truncation

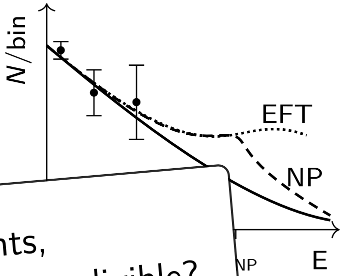


- c_6/Λ^2 extracted from data
- c_8/Λ^4 actually negligible?
- EFT convergent for $E \ll M_{\mathrm{NP}}$

but how is M_{NP} related to c_k/Λ^{k-4}?
how to relate c_6 and c_8 magnitudes?

$\longrightarrow$ additional assumptions are needed
$=$ 'power countings' distinguishing classes of NP

Validity of the dim-6 EFT truncation



- c_6/Λ^2 extracted from data
- c_8/Λ^4 actually negligible?
- EFT

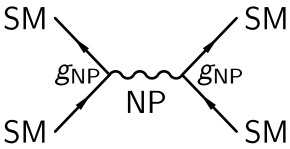
Given c_6 constraints,
in which NP scenarios are c_8 negligible?

c_6 and c_8 magnitudes?

$\longrightarrow$ additional assumptions are needed
$=$ 'power countings' distinguishing classes of NP

Simplest power counting example

One coupling (g_{NP}) and one scale (M_{NP}), in 2-to-2 scattering:



$$\sim \frac{-g_{\mathrm{NP}}^2 E^2}{E^2 - M_{\mathrm{NP}}^2} \longrightarrow \frac{g_{\mathrm{NP}}^2 E^2}{M_{\mathrm{NP}}^2} + \frac{g_{\mathrm{NP}}^2 E^4}{M_{\mathrm{NP}}^4} + \cdots$$

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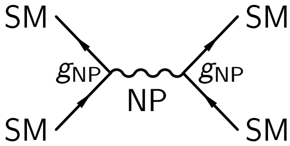

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so

$$c_6/\Lambda^2 \sim g_{\text{NP}}^2/M_{\text{NP}}^2$$

$$c_8/\Lambda^4 \sim g_{\text{NP}}^2/M_{\text{NP}}^4$$

$(\text{couplings})^{\#\text{fields}-2}$

and

$$\begin{aligned} \text{SM*dim-6} &\sim g_{\text{SM}}^2 g_{\text{NP}}^2 E^2/M_{\text{NP}}^2 \\ (\text{dim-6})^2 &\sim g_{\text{NP}}^4 E^4/M_{\text{NP}}^4 \\ \text{SM*dim-8} &\sim g_{\text{SM}}^2 g_{\text{NP}}^2 E^4/M_{\text{NP}}^4 \end{aligned}$$

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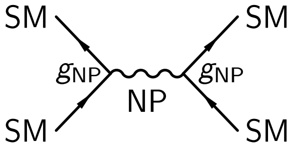

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so
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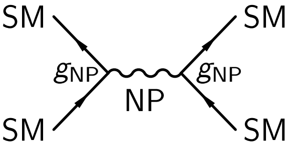
$$\text{SM*dim-6} \Big/ (\text{dim-6})^2 \Big/ \text{SM*dim-8} \sim 1 \Big/ \frac{g_{\text{NP}}^2}{g_{\text{SM}}^2} \frac{E^2}{M_{\text{NP}}^2} \Big/ \frac{E^2}{M_{\text{NP}}^2}$$

$\rightarrow$ $(\text{dim-6})^2 > \text{SM*dim-6}$ only if $g_{\text{NP}}^2 > g_{\text{SM}}^2$

$\rightarrow$ $(\text{dim-6})^2$ / SM*dim-6 suppressed at small E

Simplest power counting example

One coupling ($g_{\rm NP}$) and one scale ($M_{\rm NP}$), in 2-to-2 scattering:



$$\sim \frac{-g_{\rm NP}^2 E^2}{E^2 - M_{\rm NP}^2} \longrightarrow \frac{g_{\rm NP}^2 E^2}{M_{\rm NP}^2} + \frac{g_{\rm NP}^2 E^4}{M_{\rm NP}^4} + \cdots$$

Reduced validity when $(\text{dim-6})^2 >$ SM*dim-6.

Enhanced validity when reducing E.

$$\text{SM*dim-6} \Big/ (\text{dim-6})^2 \Big/ \text{SM*dim-8} \;\sim\; 1 \Big/ \frac{g_{\rm NP}^2}{g_{\rm SM}^2}\frac{E^2}{M_{\rm NP}^2} \Big/ \frac{E^2}{M_{\rm NP}^2}$$

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What (dim-6)^2 ?

The amplitude, before squaring,

$$A = A_{\text{SM}} + \frac{c_6 \cdot A_6}{\Lambda^2} + \frac{c_8 \cdot A_8}{\Lambda^4} + \frac{c_6 \cdot A_{8'} \cdot c_6}{\Lambda^4} + \cdots$$

single ins.

double ins.,
$1/\Lambda^4$ field redef.,...

- From the *equivalence* theorem, $1/\Lambda^2$ terms can be translated exactly and linearly from one dim-6 basis to the other:

$$\tilde{c}_6 \cdot \tilde{A}_6 = c_6 \cdot A_6 \qquad \text{with } \tilde{c}_6 = L \cdot c_6$$

- From renormalizability order by order, $1/\Lambda^2$ terms only require dim$\leq$6 counterterms. They are gauge invariant too.

$\longrightarrow$ $|c_6 \cdot A_6|^2/\Lambda^4$ also well defined and unambiguous among all $1/\Lambda^4$ terms of $|A|^2$

Theory proposals' summary

here

Common ground

1. dim-6 truncation in the near future
   EFT validity = dim-6 matches full model

2. well-defined squares of single dim-6 insertions
   translatable exactly between dim-6 bases

3. required UV assumptions to compare dim-6 and -8 magnitudes
   UV-dependent EFT validity (e.g. using a *power counting*)

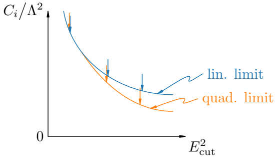
Theory proposals A & B

based on [HXSWG '16], [LHC TOP WG '18]
A: proposal, video, slides, Contino, Falkowski, Goertz, Grojean, Maltoni, Panico, Riva, Wulzer
B: proposal, video, Degrande, Maltoni, Mimasu, Vryonidou, Zhang

1. multi-dimensional information in EFT space
   $\to$ proper re-interpretability required for validity

2. quadratic [default] vs. linear comparison
   $\to$ qualitative validity: *broad* or *restricted*
   $\to$ more quantitative?

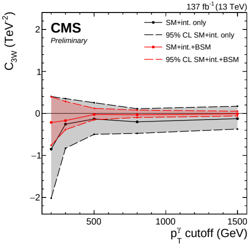
3. control over probed scales (e.g. sliding upper cut=E_{cut}=M_{cut}=clipping, double differential, etc.)
   $\to$ re-design analyses, also for sensitivity
   $\to$ cut values and variables across processes?



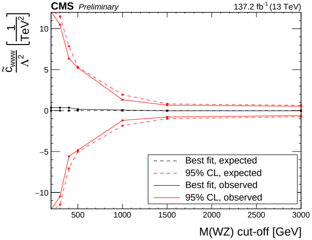
4. validity assessed *a posteriori*
   $\to$ retain UV independence till then
   $\to$ applicable to different classes of models

Clipping examples

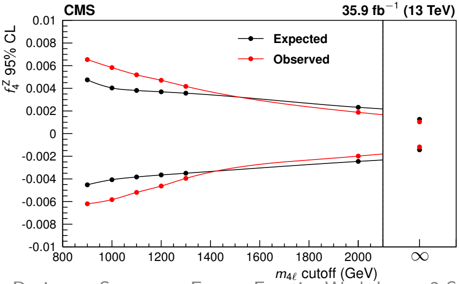
$W\gamma$ [CMS-SMP-20-005]



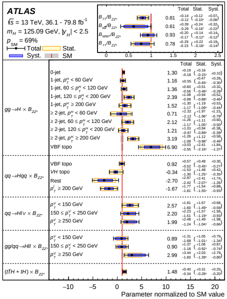
WZ [CMS-SMP-20-014]



ZZ [CMS-SMP-16-017]



STXS [ATLAS]



Theory proposal C

1. $(\text{dim-6})^2$ as proxies for dim-8 interferences

2. many models encompassed in one power counting rule
   $\rightarrow$ models to be covered?

3. signal: linear dim-6
   unc.: known $(\text{dim-6})^2 +$ dim-8 estimates

4. unc. fed into EXP analyses
   $\rightarrow$ folding-in UV assumption for dim-8 estimate

5. unc. $= \pm(\text{dim-6})^2 \times \left(1 + \sqrt{N_8}\,\frac{g_{\text{SM}}^2}{\mathfrak{C}_6\Lambda^2}\sqrt{1 + \frac{1}{\mathfrak{C}_6^2\Lambda^4}}\right)$

Further discussions

last meeting here

community comments here

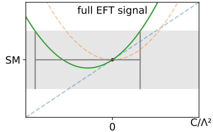
Experimental considerations

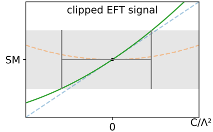
work load/person power

- run II analyses not possibly redone for EFT combinations
    - combine first analyses with existing control over E?
    - new strategies possible for run III?
- expensive to re-run analyses for different clipping values

clipping the EFT signal instead of the data?

- equivalent when the clipped variable is actually measured
- otherwise comparing prediction and data in different phase spaces
- conservative when data matches the SM?
- on any variable, so easier combination of processes?
- introducing a spurious feature in the signal
- sensitivities from different observables after clipping





linear fits often fail?

cumbersome c/Λ^2-dependent uncertainties?

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How to treat EFT truncation errors in EXP analysis?

Community input: here

LHC EFT WG agenda: here