Does it make sense to extend the $\varkappa$ framework to off-shell effects?

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$\varkappa$'s: ``Interim framework" for analyses so far

Simplified framework for analysis of LHC data so far; deviations from SM parametrised by tree-level inspired ``scale factors" $\varkappa_i$

Based on several assumptions, in particular:

[arXiv: 1209.0040]

The width of the assumed Higgs boson near 125 GeV is neglected, i.e. the zero-width approximation for this state is used. Hence the signal cross section can be decomposed in the following way for all channels:

$$(\sigma \cdot \mathrm{BR})\,(ii \to \mathrm{H} \to f\!f\,) = \frac{\sigma_{ii} \cdot \Gamma_{f\!f}}{\Gamma_{\mathrm{H}}} \tag{1}$$

where σ_{ii} is the production cross section through the initial state ii, $\Gamma_{f\!f}$ the partial decay width into the final state $f\!f$ and Γ_{H} the total width of the Higgs boson.

$\Rightarrow$ Zero-width approximation

$\varkappa$'s are defined for on-shell Higgs production and decay

The on-shell definition was chosen for good reasons

- On-shell matrix elements are closely related (in the zero-width approximation) to physical observables (more precisely: pseudo-observables)

- Off-shell Higgs contributions:

    - part of a full process

    - in general not gauge-invariant by themselves

Limitations of the $\varkappa$ framework (not an exhaustive list)

- The $\varkappa$'s are tree-level inspired scaling factors for testing (small) deviations from the SM predictions

- Their most important property is that the best (including all relevant higher-order QCD and electroweak corrections) SM prediction has to be recovered in the limit $\varkappa_i = 1$

- The interpretation of the $\varkappa$'s as scaling factors of Higgs couplings would a priori only hold if all higher-order corrections were neglected. Fortunately the dominant QCD corrections factorise, so that this interpretation holds in an approximate sense, up to electroweak effects

- The $\varkappa$ framework breaks down once electroweak effects become relevant. Once electroweak higher-order corrections are taken into account, it makes no sense anymore to think of scaling a coupling by a certain factor. This would destroy UV finiteness, gauge invariance, etc.

How about off-shell $\varkappa$'s?

One could think about defining an off-shell $\varkappa$ like $\varkappa(M_{VV})$. Technical complication: need to determine this quantity for every value of M_{VV}

Why do $\varkappa$(on-shell) and $\varkappa$(off-shell) differ from each other in the first place?

- Electroweak higher-order contributions give rise to a running of the Higgs couplings

- The most important contributions come from threshold effects, if / when at sufficiently high M_{VV} the (off-shell) Higgs decay into a pair of new particles opens up. There is no reason to disregard this possibility a priori

⇒ The difference between on-shell and off-shell $\varkappa$'s is due to electroweak effects: this is precisely where the whole $\varkappa$ framework breaks down

⇒ From my point of view it makes no sense to attempt an extension of the $\varkappa$ framework to off-shell effects

If no off-shell ϰ's, what else?

- One could formally define a ϰ factor multiplying the whole process g g → 4 f, however this ϰ would no longer have an interpretation in terms of a Higgs coupling

- An effective field-theory (EFT) approach based on a well-defined effective Lagrangian is capable of dealing with off-shell (and on-shell) effects. Caveat: in this approach it is assumed from the start that the scale of new physics Λ is heavy, i.e. there are no light states of new physics present. This is an important limitation regarding (off-shell) Higgs decays into states of new physics

- I propose to study off-shell effects both within an EFT approach and within specific models (appropriate benchmark scenarios)