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LHCHXSWG

EFT Basis Proposal for LHC Higgs studies

Q&A session, 15/06/15

EFT for Higgs

- Lot of interest to implement model independent EFT approach in LHC BSM searches, including Higgs physics
- Leading NP effects from D=6 BSM operators
- Several bases of D=6 operators proposed (Warsaw, SILH, Higgs Basis). All are equivalent, none is intrinsically better, but some may be more convenient for particular applications
- General difficulty: large number of parameters. 2499 in general case; 76 when flavor blind.
- Higgs observables depend on linear combinations of many parameters. Moreover, several combinations are severely constrained by previous measurements (e.g. LEP-1, W-mass) and LHC cannot be sensitive to these combinations if EFT approach is correct

Inspired by "EFT Primaries" of Gupta et al 1405.0181

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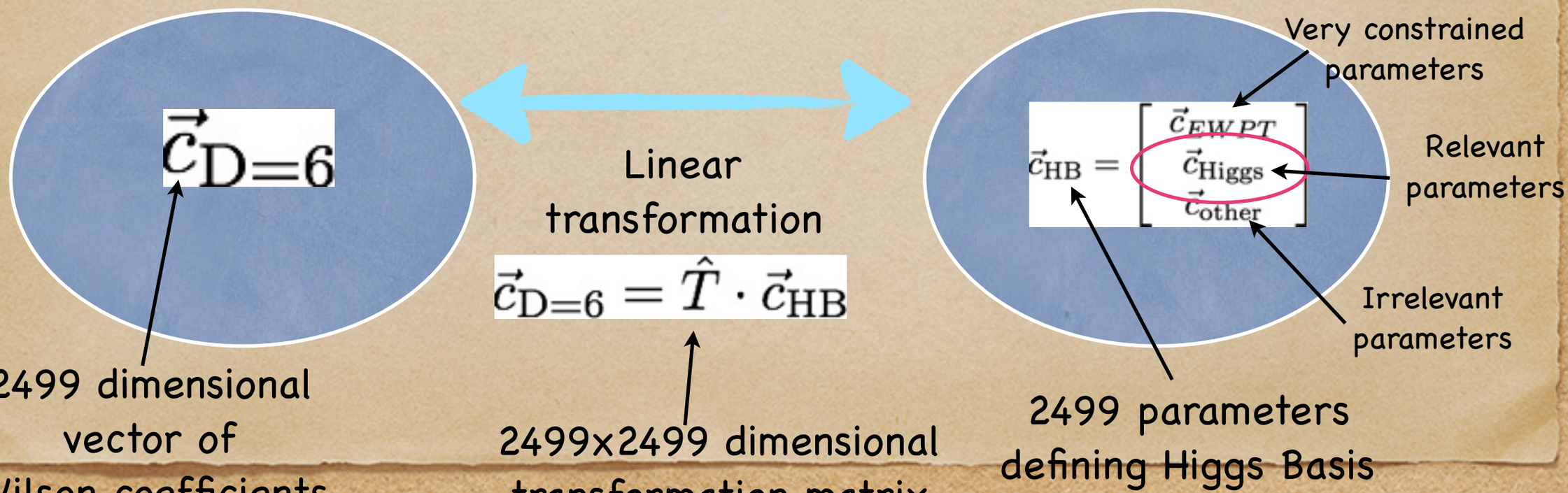
Higgs Basis

- Higgs Basis proposed by LHCHXSWG2 to project out (much smaller) subset of parameters relevant for LHC Higgs studies
- Rotation of any other D=6 basis such that one isolates linear combinations affecting Higgs observables and not constrained severely by precision tests



Higgs Basis: Higgs couplings to matter

- In HB, Higgs couplings to gauge bosons described by 6 CP even and 4 CP odd parameters that are unconstrained by LEP-1

- D=6 EFT with linearly realized SU(3)xSU(2)xU(1) enforces relations between Higgs couplings to gauge bosons (otherwise, 5 more parameters)

$$\begin{aligned}
&\text{CP even}: && \delta c_z && c_{z\Box} && c_{zz} && c_{z\gamma} && c_{\gamma\gamma} && c_{gg} \\
&\text{CP odd}: && \tilde{c}_{zz} && \tilde{c}_{z\gamma} && \tilde{c}_{\gamma\gamma} && \tilde{c}_{gg}
\end{aligned}$$

$$\begin{aligned}
\mathcal{L}_{\rm hvv} =& \frac{h}{v}[2(1+\delta c_w)m_W^2 W_\mu^+ W_\mu^- + (1+\delta c_z)m_Z^2 Z_\mu Z_\mu \\
&+ c_{ww}\frac{g_L^2}{2}W_{\mu\nu}^+ W_{\mu\nu}^- + \tilde{c}_{ww}\frac{g_L^2}{2}W_{\mu\nu}^+ \tilde{W}_{\mu\nu}^- + c_{w\Box}g_L^2\left(W_\mu^- \partial_\nu W_{\mu\nu}^+ + \text{h.c.}\right) \\
&+ c_{gg}\frac{g_s^2}{4}G_{\mu\nu}^a G_{\mu\nu}^a + c_{\gamma\gamma}\frac{e^2}{4}A_{\mu\nu}A_{\mu\nu} + c_{z\gamma}\frac{e g_L}{2c_\theta}Z_{\mu\nu}A_{\mu\nu} + c_{zz}\frac{g_L^2}{4c_\theta^2}Z_{\mu\nu}Z_{\mu\nu} \\
&+ c_{z\Box}g_L^2 Z_\mu \partial_\nu Z_{\mu\nu} + c_{\gamma\Box}g_L g_Y Z_\mu \partial_\nu A_{\mu\nu} \\
&+ \tilde{c}_{gg}\frac{g_s^2}{4}G_{\mu\nu}^a \tilde{G}_{\mu\nu}^a + \tilde{c}_{\gamma\gamma}\frac{e^2}{4}A_{\mu\nu}\tilde{A}_{\mu\nu} + \tilde{c}_{z\gamma}\frac{e g_L}{2c_\theta}Z_{\mu\nu}\tilde{A}_{\mu\nu} + \tilde{c}_{zz}\frac{g_L^2}{4c_\theta^2}Z_{\mu\nu}\tilde{Z}_{\mu\nu}]
\end{aligned}$$

- Corrections to Higgs Yukawa couplings to fermions are also unconstrained by EWPT

- Assuming flavor blind Yukawa corrections, LHC Higgs physics parametrized by 9 CP even and 6 CP odd parameters

$$\begin{aligned}
\delta c_w =& \delta c_z + 4\delta m, \quad \leftarrow \text{relative correction to W mass} \\
c_{ww} =& c_{zz} + 2s_\theta^2 c_{z\gamma} + s_\theta^4 c_{\gamma\gamma}, \\
\tilde{c}_{ww} =& \tilde{c}_{zz} + 2s_\theta^2 \tilde{c}_{z\gamma} + s_\theta^4 \tilde{c}_{\gamma\gamma}, \\
c_{w\Box} =& \frac{1}{g_L^2 - g_Y^2}\left[g_L^2 c_{z\Box} + g_Y^2 c_{zz} - e^2 s_\theta^2 c_{\gamma\gamma} - (g_L^2 - g_Y^2)s_\theta^2 c_{z\gamma}\right], \\
c_{\gamma\Box} =& \frac{1}{g_L^2 - g_Y^2}\left[2g_L^2 c_{z\Box} + (g_L^2 + g_Y^2)c_{zz} - e^2 c_{\gamma\gamma} - (g_L^2 - g_Y^2)c_{z\gamma}\right]
\end{aligned}$$

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$$\begin{aligned}
&\text{CP even}: && \delta y_u && \delta y_d && \delta y_e \\
&\text{CP odd}: && \phi_u && \phi_d && \phi_e
\end{aligned}$$

$$\mathcal{L}_{\rm hff} = -\sum_{f=u,d,e} m_f f^c (I + \delta y_f e^{i\phi_f}) f + \text{h.c.}$$

Higgs Basis Proposal

CP even :	δc_z	$c_{z\Box}$	c_{zz}	$c_{z\gamma}$	$c_{\gamma\gamma}$	c_{gg}	δy_u	δy_d	δy_e
CP odd :	$\tilde{c}_{zz}$	$\tilde{c}_{z\gamma}$	$\tilde{c}_{\gamma\gamma}$	$\tilde{c}_{gg}$	ϕ_u	ϕ_d	ϕ_e		

- The LHC should present* results of Higgs searches as simultaneous constraints, including the correlation matrix, on the above 16** parameters ...
- ..or in any other form, as long as the information permitting to translate it to the above form is given.

*) in addition to other ways of presenting them
(mu, fiducial, pseudo-observables, non-linear EFT, ...)
**) 17 if double Higgs production analyses include;
more than 16 if more generic flavor structure assumed

Since January meeting

Higgs Basis - what's new

$\delta g(1+h/v)^2 V_\mu \bar{f}\gamma_\mu f$

- Switched to a representation where all coefficients of hVff interactions are proportional to respective coefficients of Vff interactions. Possible after introducing 3 additional 2-derivative Higgs couplings to gauge bosons in Lagrangian. $c_v \Box \frac{h}{v} V_\mu \partial_\mu V_{\nu\mu}$
  Then hVff couplings can be neglected in practice given LEP-1 constraints
- More couplings in Lagrangian explicitly listed: triple and quartic gauge couplings, double Higgs coupling, dipole-type Higgs couplings
- Basis definition extended to 4-fermion terms. Independent couplings now span complete non-redundant dimension-6 basis
- Complete translation from Warsaw basis; added translation from SILH basis and HISZ operators. Translations to other bases and notation can be provided on request
- Monte Carlo implementation "Rosetta" almost ready
- Coordination with diboson and double Higgs groups
- Many bugs and typos fixed (though they're still being found). Most formulas independently cross-checked and tested in combat

Developed by B.Fuks, F.Maltoni, K.Matawari, K.Mimasu,V. Sanz, F. Riva

Rosetta

- Interface of effective couplings Lagrangian defined in LHCHXSWG note to aMC@NLO (tree-level only so far)
- Modular architecture, easy to add user-defined extensions
- Accepts input in any popular basis (currently Higgs, SILH, or Warsaw basis) and provides translation between any pair
- Planning to add functionalities to determine compatibility of input parameters with previous measurements (LEP-1, LEP-2, LHC)
- Planning interface to other existing Higgs tools: eHDECAY, HiggsBounds, Lilith, ...

Recent feedback (1)

From T. Plehn

- Problem of correlations among the Higgs basis parameter (or any other D=6 bases) that may hinder experimental determination
- Indeed, all 9 CP even parameter affect e.g. the total Higgs width. Thus, measured Higgs signal strength depends on all the parameters in a complicated way. Also other sources of correlations (czz vs cz□, cgg vs δyu, δyb vs everbody else).
- My take: correlations is fact of life; we need to work hard to disentangle them (more measurements, differential distributions, combine with diboson studies); unlikely this can be improved by smart basis choice.
- More feedback welcome.

Recent feedback (2)

From G. Buchalla, O. Cata, A. Celis C. Krause,

- Organization of the note: Warsaw basis should be introduced before Higgs basis
- My take: indeed, organization can be improved for better clarity, though simple swapping will not work and more rewriting is needed
- My proposal: Section 3 == effective coupling Lagrangian (without relations between dependent and independent parameters; Section 4 == matching Warsaw basis to effective coupling Lagrangian; Section 5 == Higgs Basis: pick a set of couplings defining the basis and relate others to that set using relations following from Section 4
- More feedback needed

Recent feedback (3)

From G. Buchalla, O. Cata, A. Celis C. Krause,

- Add separate section on non-linear EFT, with 1504.01707 as starting point
- My take: there is no complete formulation and consensus concerning non-linear EFT realizations yet. Discussion and techniques to a large degree orthogonal to that used in linear formulation
- Thus preparing recommendations will take much more time and effort.
- My proposal: current note restricted to linear EFT realizations. Discuss at July meeting whether non-linear EFT recommendations are feasible/needed. If yes, start a separate task force on this topic.

More feedback

Send us your feedback
before or during July meeting

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