University of Zurich[UZH]

The HXSWG2 note on Higgs Pseudo Observables

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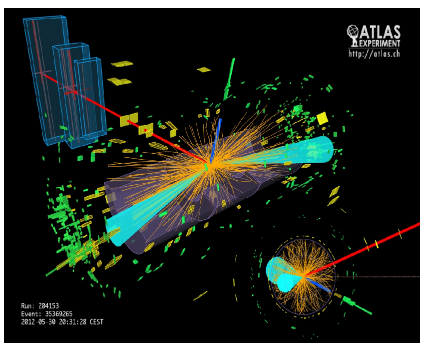
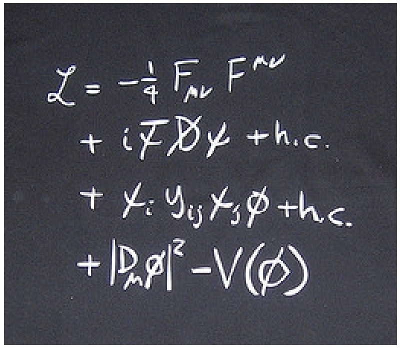
- Introduction
- Effective couplings PO vs. Physical PO
- Some comments on parameter counting
- Some comments about PO vs. EFT
- Conclusions

Introduction

- The goal of the PO is to provide a general encoding of the exp. results in terms of a limited number of "simplified" (idealized) observables of easy th. interpretation [*old idea heavily used since decades in precision-type experiments* e.g.: *LEP, Flavor Physics,…*]





Experimental data — Pseudo Observables — Lagrangian parameters

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LHC Higgs Cross Section Working Group 2 (Higgs Properties)

Pseudo-observables in Higgs physics

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We acknowledge contributions and feedback from (at present. . .):
André David, Michael Duehrssen-Debling, Adam Falkowski, Jonas M. Lindert, Sabine Kraml, Kerstin Tackmann.

The note is ready to be discussed (eventually "frozen" for YR purposes), but of course there is still significant space for improvements if time allows

Introduction

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As it is written in the note, the Higgs PO must be:

I. experimentally accessible,

II. well-defined from the point of view of QFT,

III. capture all relevant NP effects in the limit of no new (non-SM) particles below or close to the Higgs mass.

- For the "QFT fans"... [*QFT compatible definition*]:
  The Higgs PO are defined from a decomposition of on-shell amplitudes based on Lorentz-invariance, unitarity, and crossing symmetry – and a momentum expansion (*on measurable kinematical variables*) based on the analytic properties of the amplitudes under the assumption of no near-by poles (*due to NP*) in the kinematical regime of applicability.

Introduction

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  A detailed pragmatic definition, channel by channel, both for production and decay modes, is presented in the note.

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  A detailed pragmatic definition, channel by channel, both for production and decay modes, is presented in the note... *and PO-based simulation tools starts to be developed:*

An *UFO model* (for MG5_aMC@NLO or Sherpa) is

- fully available for decays (*QED corrections fully accounted by standard shower algorithms, as verified by the comparison with Profecy4f* $\rightarrow$ *PO formalism perfectly match NLO EW accuracy*)
- will soon be available also for EW production, with inclusion of NLO QCD corrections (*work in prog.*)

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Higgs PO

DESCRIPTION DOWNLOAD CONTACTS

http://www.physik.uzh.ch/data/HiggsPO

▶ *Effective couplings PO vs. Physical PO*

A relevant point that is discussed in some detail the note (*and is absent/hidden in the literature on PO*) is the relation between "*effective couplings PO*" and "*Physical PO*"

Two types of PO:

"Physical PO"
Idealized observables with simple physical interpretation

↓

Higgs 2-body partial decay widths than can be seen as the ultimate goal of the exp.

⟷

"Effective couplings PO"
Couplings of a well-defined momentum structure for the amplitude

↓

Essential ingredients to build a MC

one-to-one relation illustrated in the note

Effective couplings PO vs. Physical PO

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Two types of PO:

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"Effective couplings PO"
Couplings of a well-defined momentum structure for the amplitude

E.g.: in h → "ZZ" events we have

$\Gamma(h \to Z_L Z_L)$	←	κ_{ZZ}	[h → ZZ as in SM]
$\Gamma(h \to Z_T Z_T)$	←	ε_{ZZ}	[h → ZZ transv. coupl.]
$\Gamma^{\rm CPV}(h \to Z_T Z_T)$	←	$\varepsilon_{ZZ}^{\rm CP}$	[h → ZZ, CPV coupl.]
$\Gamma(h \to Z f \bar{f})$	←	ε_{Zf}	[h → *Zff* non resonant]

Effective couplings PO vs. Physical PO

A relevant point that is discussed in some detail the note (*and is absent/hidden in the literature on PO*) is the relation between "*effective couplings PO*" and "*Physical PO*"

PO	Physical PO	Relation to the eff. coupl.
$\kappa_f,\ \lambda_f^{\rm CP}$	$\Gamma(h\to f\bar f)$	$= \Gamma(h\to f\bar f)^{\rm (SM)}[(\kappa_f)^2+(\lambda_f^{\rm CP})^2]$
$\kappa_{\gamma\gamma},\ \lambda_{\gamma\gamma}^{\rm CP}$	$\Gamma(h\to \gamma\gamma)$	$= \Gamma(h\to \gamma\gamma)^{\rm (SM)}[(\kappa_{\gamma\gamma})^2+(\lambda_{\gamma\gamma}^{\rm CP})^2]$
$\kappa_{Z\gamma},\ \lambda_{Z\gamma}^{\rm CP}$	$\Gamma(h\to Z\gamma)$	$= \Gamma(h\to Z\gamma)^{\rm (SM)}[(\kappa_{Z\gamma})^2+(\lambda_{Z\gamma}^{\rm CP})^2]$
κ_{ZZ}	$\Gamma(h\to Z_L Z_L)$	$= (0.209\ {\rm MeV})\times\lvert\kappa_{ZZ}\rvert^2$
ϵ_{ZZ}	$\Gamma(h\to Z_T Z_T)$	$= (1.9\times 10^{-2}\ {\rm MeV})\times\lvert\epsilon_{ZZ}\rvert^2$
$\epsilon_{ZZ}^{\rm CP}$	$\Gamma^{\rm CPV}(h\to Z_T Z_T)$	$= (8.0\times 10^{-3}\ {\rm MeV})\times\lvert\epsilon_{ZZ}^{\rm CP}\rvert^2$
ϵ_{Zf}	$\Gamma(h\to Z f\bar f)$	$= (3.7\times 10^{-2}\ {\rm MeV})\times N_c^f\ \lvert\epsilon_{Zf}\rvert^2$
κ_{WW}	$\Gamma(h\to W_L W_L)$	$= (0.84\ {\rm MeV})\times\lvert\kappa_{WW}\rvert^2$
ϵ_{WW}	$\Gamma(h\to W_T W_T)$	$= (0.16\ {\rm MeV})\times\lvert\epsilon_{WW}\rvert^2$
$\epsilon_{WW}^{\rm CP}$	$\Gamma^{\rm CPV}(h\to W_T W_T)$	$= (6.8\times 10^{-2}\ {\rm MeV})\times\lvert\epsilon_{WW}^{\rm CP}\rvert^2$
ϵ_{Wf}	$\Gamma(h\to W f\bar f')$	$= (0.14\ {\rm MeV})\times N_c^f\ \lvert\epsilon_{Wf}\rvert^2$

Some comments on parameter counting

Number of independent PO for EW Higgs decays [$h \to 4\ell$ (ℓ=e,μ,ν) + $\ell\ell\gamma$ + $\gamma\gamma$]:

EW decay modes	*flavor +CP symm.*	*flavor non univ.*	*CP violation*
$h \to \gamma\gamma, 2e\gamma, 2\mu\gamma$ $4e, 4\mu, 2e2\mu$	$\kappa_{ZZ}, \kappa_{Z\gamma}, \kappa_{\gamma\gamma}$ $\epsilon_{ZZ}, \epsilon_{Ze_L}, \epsilon_{Ze_R}$ (6)	$\epsilon_{Z\mu_L}, \epsilon_{Z\mu_R}$ (2)	$\epsilon^{CP}_{ZZ}, \epsilon^{CP}_{Z\gamma}, \epsilon^{CP}_{\gamma\gamma}$ (3)
$h \to 2e2\nu, 2\mu2\nu, e\nu\mu\nu$	κ_{WW} $\epsilon_{WW}, \epsilon_{Z\nu_e}, \mathrm{Re}(\epsilon_{We_L})$ (4)	$\epsilon_{Z\nu_\mu}, \mathrm{Re}(\epsilon_{W\mu_L})$	$\epsilon^{CP}_{WW}, \mathrm{Im}(\epsilon_{We_L})$ $\mathrm{Im}(\epsilon_{W\mu_L})$ (5)
all EW decay modes *with custodial symmetry*	$\kappa_{ZZ}, \kappa_{Z\gamma}, \kappa_{\gamma\gamma}$ $\epsilon_{ZZ}, \epsilon_{Ze_L}, \epsilon_{Ze_R}$ $\mathrm{Re}(\epsilon_{We_L})$ (7)	$\epsilon_{Z\mu_L}, \epsilon_{Z\mu_R}$	$\epsilon^{CP}_{ZZ}, \epsilon^{CP}_{Z\gamma}, \epsilon^{CP}_{\gamma\gamma}$

20 (no symmetries) → 7 (CP + Lepton Univ + Custodial)

Some comments on parameter counting

Number of independent PO for EW Higgs decays + EW production + Yukawa modes (h → ff):

	PO with maximal symmetry [CP + Lepton Univ + Custodial]:
Production & decays	$\kappa_{ZZ}, \kappa_{Z\gamma}, \epsilon_{ZZ}$
EW decays only	$\kappa_{\gamma\gamma}, \epsilon_{Ze_L}, \epsilon_{Ze_R}, \mathrm{Re}(\epsilon_{We_L})$
EW productions only	$\epsilon_{Zu_L}, \epsilon_{Zu_R}, \epsilon_{Zd_L}, \epsilon_{Zd_R}$
	(11) [→ 32 with no symm.]
Yukawa modes	$\kappa_b, \kappa_c, \kappa_\tau, \kappa_\mu$ (4) [→ 8 with no symm.]
	(*as in the original κ-formalism*)

Some comments about PO vs. EFT

PO and couplings in EFT Lagrangians are *intimately related but are not the same thing* (on-shell amplitudes vs. Lagrangians parameters) → full complementarity

When discussing EFT approaches to Higgs physics it is worth stressing there is not a unique way to proceed:

I. Nature of the "light fields" →

Linear EFT
h(125) embedded in the $SU(2)_L$ doublet ϕ
(SM limit for $\Lambda \to \infty$)

Non-linear EFT
h(125) is $SU(2)_L$ singlet + 3 Goldstones
($\Lambda \lesssim$ few TeV)

II. Symmetries of the theory →

Custodial symmetry, CP invariance, Flavor symmetries,...
(all the accidental symmetries of the SM)

III. Validity regime of the EFT →

Hopefully dictated by data, but so far unclear
(relevant to address importance of NLO vs. LO)

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- The PO are calculable in any EFT approach (*linear, non-linear, LO, NLO...*)
  - In the limit where we work at the tree-level in the EFT there is a simple linear relation between PO and EFT couplings: each PO represent a unique linear combination of couplings of the most general Higgs EFT.
  - This does not hold beyond the tree-level (the PO do not change, but their relation to EFT couplings is more involved....)

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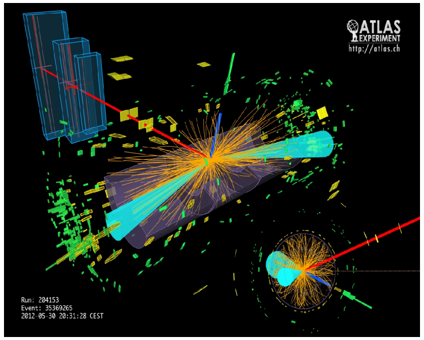
  - This does not hold beyond the tree-level (the PO do not change, but their relation to EFT couplings is more involved....)
- For Higgs production also the PO involve an expansion in momenta; however, this is different that the operator expansion employed within the EFT
  - To define the PO we expand only on a measurable kinematical variables, this is why the validity of the *expansion can be checked directly by data* (on the same process used to determine the PO)
- In each process the PO are the maximum number of independent observables that can be extracted by that process only → naturally optimized for data analyses
- Contrary to the EFT, the PO do not allow to relate process with different external states (e.g. Higgs physics and EWPO)

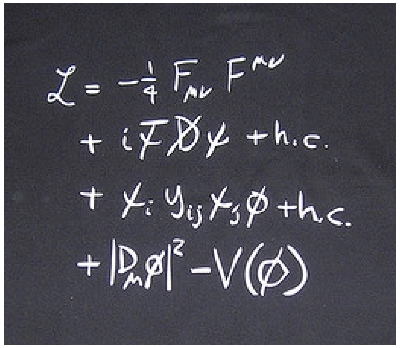
Conclusions

- The Higgs PO represent a general tool for the exploration of Higgs properties (in view of high-statistics data), with minimum loss of information and minimum theoretical bias → *full complementary to EFT* (and explicit BSM)

- The formalism is now fully developed and a 1st version of the note for YR4 is basically ready

- We already had several discussion about PO in the WG, but further feedback, especially on the note, is very welcome...





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