Model Independence and the Aim of Explanation

Beyond Models, Bonn

June 13, 2022

Martin King
University of Bonn

Welcome

Welcome

Lunch 12:00-14:00

- June 14 @ Hans im Gluck
- June 15 @ Café Nees
  - not covered

Dinner

- June 14 19:00 @ Oliveto
  - covered for invited speakers

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    - covered for invited speakers
- finger/hand
- nametags
- keyfob
    - Martin: 0049 151 65146770

lhc-epistemologie.uni-wuppertal.de

Stemming from work with P. Bechtle, N. Boddenberg, C. Chall, M. Krämer, P. Mättig, and M. Stöltzner

Shifting Approaches

Synthese
https://doi.org/10.1007/s11229-019-02216-7
S.I.: REASONING IN PHYSICS

Check for updates

From a boson to the standard model Higgs: a case study in confirmation and model dynamics

Cristin Chall[1] · Martin King[1] · Peter Mättig[1] · Michael Stöltzner[2]

Received: 28 March 2018 /

Abstract
Our paper studies th
Collider and its influ
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landscape of elemen
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Higgs discovery th
accepted account o
tion and expose som
discovery as a victo
natives in the face o
a research program
other aspects adapt
landscape of EWSE
model-group, and w

Keywords Model d
programmes · Higg

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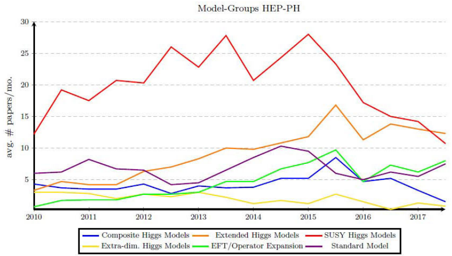

Fig. 2 Overview of model-groups (HEP-PH) from Jan 2010–Dec 2017

are, quite surprisingly, fairly steady over the eight year period, though showing a recent decline. Theoretical studies on the SM Higgs remained fairly constant, primarily focusing on improving the precision of the calculations.

Shifting Approaches

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Bottoms up: The Standard Model Effective Field Theory from a model perspective

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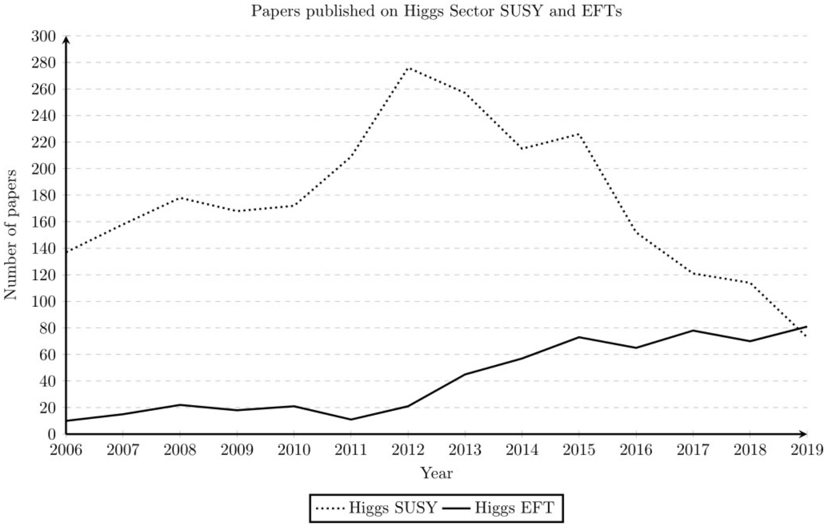
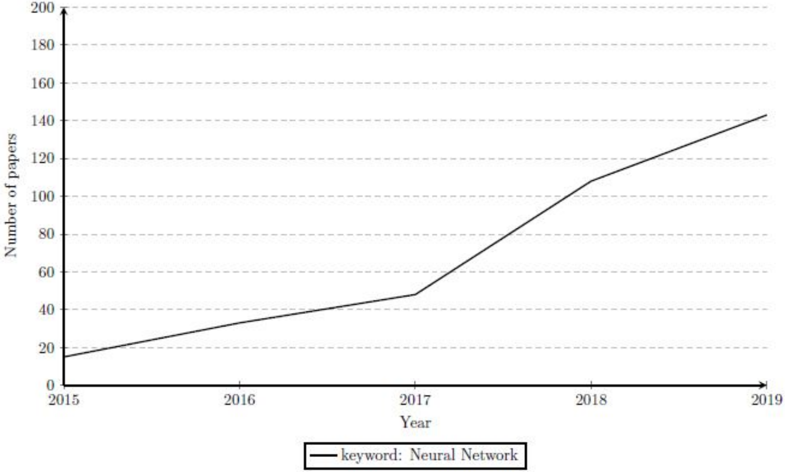
ABSTRACT

Experiments in particle physics have hitherto failed to produce any significant evidence for the many explicit models of physics beyond the Standard Model (BSM) that had been proposed over the past decades. As a result, physicists have increasingly turned to model-independent strategies as tools in searching for a wide range of possible BSM effects. In this paper, we describe the Standard Model Effective Field Theory (SM-EFT) and analyse it in the context of the philosophical discussions about models, theories, and (bottom-up) effective field theories. We find that while the SM-EFT is a quantum field theory, assisting experimentalists in searching for deviations from the SM, in its general form it lacks some of the characteristic features of models. Those features only come into play if put in by hand or prompted by empirical evidence for deviations. Employing different philosophical approaches to models, we argue that the case study suggests not to take a view on models that is overly permissive because it blurs the lines between the different stages of the SM-EFT research strategies and glosses over particle physicists' motivations for undertaking this bottom-up approach in the first place. Looking at EFTs from the perspective of modelling does not require taking a stance on some specific brand of realism or taking sides in the debate between reduction and emergence into which EFTs have recently been embedded.

Shifting Approaches



Shifting Approaches



Overview

1. No strong indications in favour of predictions from BSM models
2. No statistically significant deviations from the SM

1. Identify, examine, and minimise the role of **biases**
   - explore new alternatives
   - re-evaluation of principles (e.g., naturalness)
   - model-based $\rightarrow$ model-independent (top-down $\rightarrow$ bottom-up)
2. Shift in cognitive division of labour

- **model-dependent:** full BSM models
  - search for processes and signatures in the context of a particular, well-defined BSM model
    - charged Higgs of Type-II 2HDM with mSUSY
  - Very specific, narrow focus

Spectrum of Model Independence

- **model-dependent:** full BSM models
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    - charged Higgs of Type-II 2HDM with mSUSY
  - Very specific, narrow focus
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  - search for particles common to many BSM models
    - leptoquark, vector triplet, stop
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- **model-independent:** precision measurements, using SMEFT, e.g.
  - not to search for predictions of a model but search for deviations against the background

Changing Methodology

- For decades, hypothesis testing has been king
  - testing SM predictions, BSM predictions

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Some philosophical questions:

- Has the role of hypotheses really changed? How?
- Is it problematic or worrisome? i.e. are there still good prospects for a bottom-up approach?
- What is the role of AI in searches for new physics? What issues does this bring?
- What is ‘model independence’ and how independent from models can one be?
- How does one historically characterise this shift? is it novel?

Model Independence is characterised by:

- a strong reduction of the influence of modelling biases

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For BSM searches:

1. a lack of a well-defined *target model* or *target phenomenon*
2. where there is a well-defined background theory (SM) against which deviations can be observed

Examples:

- Searching for deviations in Higgs production at high p_T
  - not testing a model, but things tend to show up at high Q^2
- Loop corrections to m_W
  - it is precisely constrained in the SM by other parameters, so deviations should be due to BSM physics

"statistical algorithms find patterns where science cannot"

"We usually don't know about causation, and we often don't necessarily care...the objective is more to predict than it is to understand the world...It just needs to work; prediction trumps explanation."

(Kitchin, 2014)

In order for a model to explain some phenomenon:

- empirically adequately capture some feature of the explanandum
- +some further condition that makes this prediction an explanation
  - deduced from true laws of nature, causal realism, unificatory, counterfactual depth, etc.

Local Counterfactual Condition: an explanatory model M provides counterfactual information that shows how the explanandum E depends on M and initial, boundary, and auxiliary conditions C.

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Global Confirmation Condition: an explanatory model M is a part of, or can be fit to, a highly-confirmed scientific theory T.

(King, 2020)

Veridicality:

- Ideally, cite THE reason(s) why

For an effective theory

- given that it is predictive, why should we think it is also explanatory?

What is an EFT?

- low energy theory accurate up to some energy scale Λ (cut-off), where the effects of a higher energy theory (UV-complete) can no longer be ignored
- effects of heavy particles ($m > \Lambda$) are 'encoded' by direct, contact interactions of light particles that *do not occur* in the full theory
- see (Bain, 2013, 2018; Cao and Schweber, 1993; Castellani, 2002; Franklin and Knox, 2018; Hartmann, 2001; Huggett and Weingard, 1995; Rivat and Grinbaum, 2020; Teller, 1989; Wells, 2012; Williams, 2018), etc.

Top-Down

- Use the SM as UV-complete theory and construct models that effectively give the same results for some phenomenon, below a certain energy Λ

Bottom-Up

- Assume that the SM is a low-energy effective description of some unknown UV-complete theory
  - to identify the effects of new physics and constrain possible BSM models

Building an Effective Field Theory

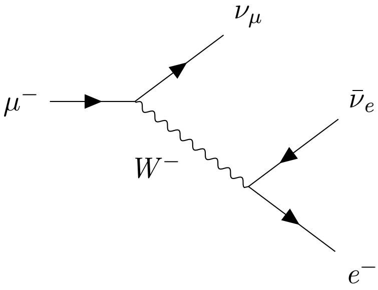
1. Specify energy scale Λ
2. Specify the content
   - all fields with $m < \Lambda$
   - all possible interactions between the fields at all orders
3. Impose symmetries
   - SM gauge symmetries, Lorentz, flavour, etc.
4. Define a power counting scheme
   - truncate expansion to focus on leading effects

(Brehmer, 2016; Georgi, 1993; Kaplan, 2016)

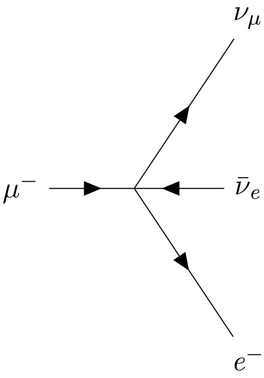
1. $\Lambda < m_W$
2. particles less than m_W
   - leptons and quarks (not top)
   - simplicity: $m > \Lambda_{QCD}$
3. Lorentz invariance, electric charge, lepton & baryon number
4. only lowest dimension operators
   - have four fermion fields (dim-6)

$$\mathcal{L}_{eff} = i\bar{\psi}_i\gamma^\mu\partial_\mu\psi_i - m_i\bar{\psi}_i\psi_i + \frac{C}{\Lambda^2}\left(\bar{\psi}_i(1-\gamma_5)\gamma_\mu\psi_j\right)\left(\bar{\psi}_k(1-\gamma_5)\gamma^\mu\psi_l\right) \tag{1}$$

SM:



Fermi Theory ($\Lambda = m_W$)



Step 3:

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \sum_i \frac{C_i^6}{\Lambda^2}\mathcal{O}_i^6 + \sum_j \frac{C_j^8}{\Lambda^4}\mathcal{O}_j^8 + \sum_k \frac{C_k^{10}}{\Lambda^6}\mathcal{O}_k^{10} + \dots \tag{2}$$

- $\mathcal{O}^n$ is a dim-n operator; C^n is a dimensionless Wilson coefficient

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Step 4:

- dim-6 SM-EFT $\rightarrow$ 2499 different operators, interactions, free parameters

(Alonso et al., 2014)

Down-selection

5. Make some preferential cuts:
   - make assumptions/focus on sectors of interest (CP conservation; Higgs sector)
   - look at promising non-zero coefficients (analyses have been done)
   - properties of interest (e.g. compositeness)
6. If statistically significant deviations:
   - focus on one operator, representing a real SM-deviation
   - hint that it effectively represents/describes some new physics

This last stage allows to go beyond SM-EFT

7. Construct a matching simplified model (new field)
   - assume: one particle and decoupled
   - match quantum numbers
8. Embed simplified model in UV-complete BSM model
   - allows for top-down reconstruction of the step-6 EFT

Can a top-down EFT explain?

- Predictively accurate within a well-defined energy scale
  - the full theory is known and the calculations can be shown to match
  - EFT error calculated to be on order of ratio of the energy scales
- Optimised in terms of explanatory relevance
  - what is relevant (for E) is highlighted and what is irrelevant is excluded

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An EFT can be the appropriate explanatory framework

- Where the full theory is known (explanatory), a top-down EFT can 'stand in' for it

The same cannot be said for the SM-EFT

1–4 instead of 2 terms, 2499 terms

- there is still Laplacean blindness

5–6 2499 $\rightarrow$ 1 based on preferences and external motivations

- arbitrary and underdetermined reduction of parameters

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7–8 with new fields describing some deviations

- ✓ satisfaction of the local adequacy condition
- ✓ fit into global explanatory theory
  - essentially you have an top-down EFT of a higher energy theory

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    - move away from aiming to explain the world
- a shift in methodology (not by choice) that may not be transitive

"To say that prediction is the purpose of a scientific theory is to confuse means with ends. It is like saying that the purpose of a spaceship is to burn fuel...Passing experimental tests is only one of many things a theory has to do to achieve the real purpose of science, which is to explain the world."

(Deutsch, 1997, p. 7)

Thank you

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