LHCHXSWG, the paradigm shift

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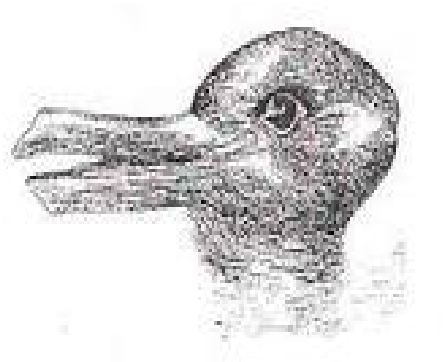

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This will not be a vision talk: as many people (H. Schmidt, K. Jakobs) famously said *if you have a vision see a doctor*.

Before a man studies, to him mountains are mountains and waters are waters; after he gets an insight into the truth, mountains to him are not mountains and waters are not waters; but after this when he really attains to the abode of rest, mountains are once more mountains and waters are waters

Synopsis

① Before the 2012 discovery the hypothesis was the SM and m_H the unknown, therefore bounds on m_H were derived through a comparison with high-precision data.

② At LHC, after the discovery, the unknowns are SM deviations, given that the SM is fully specified and deviations are constrainable. Of course, the definition of SM deviations requires a characterization of the underlying dynamics[1].

[1] every 20 bogus hypotheses you test, one of them will give you a p of < 0.05

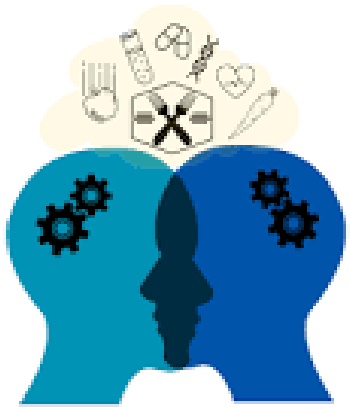
MSM triumph of thinking simple

- ⤇ LHC(**125**) looks very much like the (light) SM Higgs boson The exp. discovery is fundamental but wasn't already clear 20 years ago?
- **NO LHC signal of New Physics**. But ... (debatable) aren't precision Lep data, precision flavour data, etc. pointing in that direction? e.g. consistency with **EW precision data** ↛ no conspiracy between heavy Higgs and New Physics effects

There is nothing either good or bad but thinking makes it so

(William Shakespeare)

Is SM the FINAL THEORY? Certainly no



Additionally, there is no scientific reason to justify the belief that all the big problems have solutions, let alone ones we humans can find.

Building a language

Confusion is a word we have invented for an order which is not understood

Building a common language

Babel of jarring voices

- in order to protect against under-fluctuation in data causing tighter limits than expected, CLs is used, which has as one input the probability of hypothesis given the data
- unstable states lie in a natural extension of the usual Hilbert space that corresponds to the second sheet of the S-matrix; these states have zero norm and, therefore, escape the usual prohibition of having a hermitian Hamiltonian with complex energy

The limits of my language means the limits of my world. Ludwig Wittgenstein

Given the present situation within the two communities it seems reasonable to go back to establishing a common language first

- Even more important, we should try to make sure that our young researchers become fluent in the language. The relation of theory-experiment will have to be two-sided.
- We should make a great effort to capture the progress and changes that happen in the Higgs physics EXP/TH community, assuming a routine role of discussions of short-term and long-term problems. Young researchers should be heavily involved in this process.

Despite the striking fact that a large number of scientists are working , the vast stretches of the unknown and the unanswered and the unfinished still far outstrip our collective comprehension.

OK, what do we do in the meantime?

The problem is not how to imagine wild scenarios, the problem is how to arrive to the correct scenario by making only small steps, without having to make unreasonable assumptions.

Mathematics suffers from some of the same inherent difficulties as theoretical physics: great successes during the 20th century, increasing difficulties to do better, as the easier problems get solved[2].

- ✓ Conventional vision: some very different physics occurs at Planck scale, SM is just an effective field theory.
- ✓ A different vision: is the SM close to a fundamental theory?
- Hope for *conventional* prepare for *different*

[2] The lesson of experiments 1973 - today: extremely difficult to find a flaw in the SM: maybe the SM includes elements of a truly fundamental theory. But then how can one hope to make progress without experimental guidance? One should pay close attention to what we don't understand precisely about the SM even if the standard prejudice is *that's a hard technical problem, and solving it won't change anything* Should we try to better understand links between SM and mathematics?

TH Scenarios in a temporal perspective

- QED alone (with experiments well below the EW scale); the theory has a formal validity above the Planck scale. Correct? Yes. Useful? NO.
- Soon or later new d.o.f. will show up and the (fully consistent) QED will have to be embedded into a larger theory.
- Is it the MSM? Yes, for a while. Once again the MSM is a fully consistent theory but something has to happen before we reach the Planck scale.

➠  Are we at the conclusion that any (fully consistent) QFT is to be used *only* up to the scale dictated by the contemporary experiments (my answer is yes)?

Scenarios

One possible scenario is the one where well below the Planck scale there is a QFT (to be upgraded scale by scale) and where above we have something else

- The *severe* problem with QFT is that quantum gravity is not a strictly renormalizable theory.
- emergence of EFT : EFT is a concept, SMEFT, HEFT are linear and non-linear realizations.

☛ It is worth noting that the HEP journey never contemplated the extension of the Fermi theory with the inclusion of even higher operators; therefore, the MSM represented the beyond-Fermi physics. Comparing with the present: now we are in a beyond-SM desert and we are looking for alternative paths, although the regulative ideal of an ultimate theory remains a powerful aesthetic ingredient. 

EFT 

① There is a EFT, T_1 , representing the physics at some energy scale Λ_1, say the MSM which is, despite being UV-complete, considered to be an EFT.

② At higher energies new phenomena might happen to show up, and T_1 does not account for them

③ From T_1 to T_2 (valid up to $\Lambda_2 > \Lambda_1$), T_2 some BSM model

④ One possibility: no new particles between Λ_1 and Λ_2, therefore we can use the low-energy limit of T_2. In other words, starting with T_2 is top-down. The bottom-up corresponds to use T_1 + higher-order operators, i.e. EFT(T_1). One example is LEFT, the low-energy EFT below the EW scale.

EFT again

⑤ New particles between Λ_1 and Λ_2. All new particles have to be identified . Fermions or bosons? What is their mass and charge, how they couple to other particles etc This procedure has two components

- a priori (TH), i.e. selecting T_2
- a posteriori (EXP), i.e. quantum numbers in T_2 have to be determined on the basis of experiments

❶ Repeat, $\mathrm{T}_i \to \mathrm{T}_{i+1}$. EFTs provide a local account of a given phenomenon in terms of the d.o.f. which are relevant at the energy scale under consideration

Constructing an EFT

- Experiments occur at some finite energy and measure $\mathrm{S_{eff}}(\Lambda)$
- There is no fundamental scale above which $\mathrm{S_{eff}}(\Lambda)$ is not defined
- $\mathrm{S_{eff}}(\Lambda)$ loses its predictive power if a process at $\mathrm{E} = \Lambda$ requires ∞ renormalized parameters
- When $\mathrm{T_1}$ is the MSM we have the SMEFT . The corresponding Lagrangian gives the leading amplitudes in an exactly unitary S- matrix below the scale Λ. The theory is not strictly renormalizable.
- Nevertheless SMEFT gives a consistent expansion of amplitudes in powers of vev/Λ (on-shell) and of E/Λ (off-shell) where E is the typical scale at which we measure the process.

Executive summary (so far) After the LHC results, the SM has been completed, raising its status to that of a full theory. Despite its successes, this SM has shortcomings vis-à-vis cosmological observations. At the same time, there is presently a lack of direct evidence for new physics phenomena at the accelerator energy frontier. From this state of affairs arises the need for a consistent theoretical framework in which deviations from the SM predictions can be calculated. Such a framework should be applicable to comprehensively describe measurements in all sectors of particle physics: LHC Higgs measurements, past electroweak precision data, etc.

By simultaneously describing all existing measurements, this framework then becomes an intermediate step toward the next SM, hopefully revealing the underlying symmetries

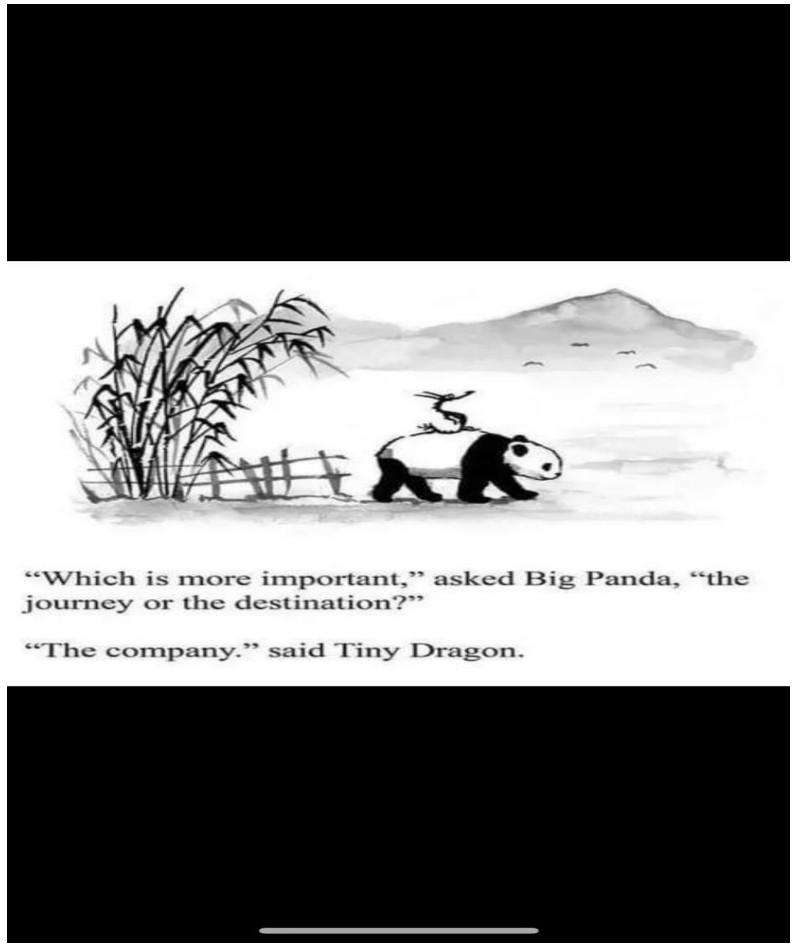
We choose to go beyond the SM straits. We choose to do that and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too.

Ideas that require people to reorganize their picture of the world provoke hostility

To conclude, the journey to the next SM may require crossing narrow straits of precision physics. If that is what nature has in store for us, we must equip ourselves with both a range of concrete BSM models as well as a general SMEFT. Both will be indispensable tools in navigating an ocean of future experimental results.

Each paradigm will be shown to satisfy more or less the criteria that it dictates for itself and to fall short of a few of those dictated by its opponent

T. S. Kuhn



Thank you Chiara, Reisaburo, Stefan, Sven ...

Thank you for your attention