

Review of Theoretical Progresses from before to after Run 1 and Prospects

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Knowledge is in the end based on acknowledgement

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REQUEST: speakers should not try to be exhaustive, but rather describe *what worked better than planned, what was more difficult than planned, and the lessons learnt for the future*

This talk is

- *Not a review*
- *A conclusion held with confidence but not substantiated by proof*
The world is not run by thought, nor by imagination, but by opinion (Elizabeth Drew).
- *A collection of visions, scenarios and approaches*



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 *SM* 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

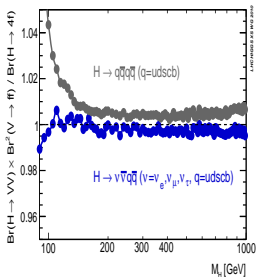
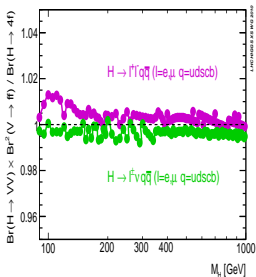
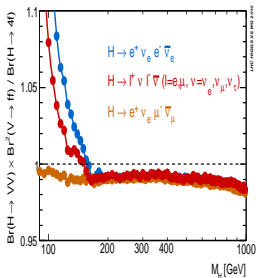
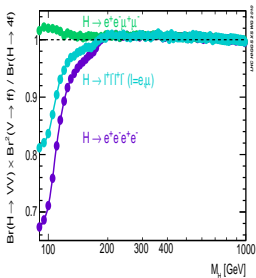
The limits of my language means the limits of my world. Ludwig Wittgenstein

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.

consistency is a game of endless frustration

$$\text{BR}(H \rightarrow \nu\nu) \otimes \text{BR}^2(V \rightarrow \bar{f}f) = \text{BR}(H \rightarrow 4f)?$$



These *plots* are one of the best examples that

$$\begin{array}{ccc} \text{BR}(\mathbf{H} \rightarrow \mathbf{V}\mathbf{V}) & \otimes & \text{BR}^2(\mathbf{V} \rightarrow \bar{\mathbf{f}}\mathbf{f}) \\ & \neq & \\ & & \text{BR}(\mathbf{H} \rightarrow 4\mathbf{f}) \end{array}$$

Trivial but TRUE, $\nexists \mathbf{H} \rightarrow \mathbf{V}\mathbf{V}$ is not a physical Observable, eventually it can be defined as “Pseudo-Observable”

Theorem

$$\nexists \quad \mathbf{H} \rightarrow \mathbf{Z} + \gamma, \mathbf{H} \rightarrow \mathbf{V}\mathbf{V} \quad \text{etc.}$$

$$\text{✂ } \mathbf{V} \notin \quad | \text{in/out} \rangle \quad \text{bases of the Hilbert space}$$

Dalitz Decay?

$$M_H = 125.5 \text{ GeV} \quad \text{BR}(H \rightarrow e^+e^-) = 5.1 \times 10^{-9}$$

while a *naive* estimate gives

$$\text{BR}(H \rightarrow Z\gamma) \text{BR}(Z \rightarrow e^+e^-) = 5.31 \times 10^{-5}$$

4 orders of MAGNITUDE larger

How much is the corresponding PO extracted from full Dalitz Decay?

We could expect $\Gamma(H \rightarrow e^+e^-\gamma) = 5.7\% \Gamma(H \rightarrow \gamma\gamma)$ but photon isolation must be discussed.


Categories

Terminology:

The name **Dalitz Decay** must be reserved for the full process

$$H \rightarrow \bar{f}f\gamma$$

Subcategories:


$$\left\{ \begin{array}{ll} H \rightarrow Z^* (\rightarrow \bar{f}f) + \gamma & \text{unphysical} \\ H \rightarrow \gamma^* (\rightarrow \bar{f}f) + \gamma & \text{unphysical} \\ H \rightarrow Z_c (\rightarrow \bar{f}f) + \gamma & \text{PO}^2 \end{array} \right.$$


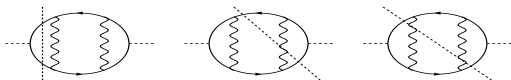
¹ Z^* is the off-shell Z

² Z_c is the Z at its complex pole

Understanding the problem

$$\mathbf{H} \rightarrow \bar{f}f \quad \text{or} \quad \mathbf{H} \rightarrow \bar{f}f + n\gamma?$$

Go to two-loop, the process is considerably more complex than, say, $\mathbf{H} \rightarrow \gamma\gamma$ (**QED** and **QCD** corrections). Think in terms of cuts of the three-loop \mathbf{H} self-energy 



Moral: *Unless you isolate photons*

you don't know which process you are talking about

$$\mathbf{H} \rightarrow \bar{f}f \text{ NNLO} \quad \text{or} \quad \mathbf{H} \rightarrow \bar{f}f\gamma \text{ NLO}$$

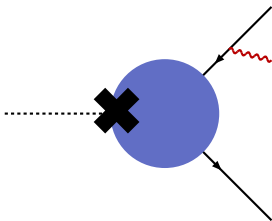
The complete \mathbf{S} -matrix element will read as follows:

$$\begin{aligned}
 \mathbf{S} = & \int d\Phi_2 \left\{ \left| \mathbf{A}^{(0)} (\mathbf{H} \rightarrow \bar{f}f) \right|^2 \right. \\
 & + 2\text{Re} \left[\mathbf{A}^{(0)} (\mathbf{H} \rightarrow \bar{f}f) \right]^\dagger \mathbf{A}^{(1)} (\mathbf{H} \rightarrow \bar{f}f) \\
 & + \left. 2\text{Re} \left[\mathbf{A}^{(0)} (\mathbf{H} \rightarrow \bar{f}f) \right]^\dagger \mathbf{A}^{(2)} (\mathbf{H} \rightarrow \bar{f}f) \right\} \\
 & + \int d\Phi_3 \left\{ \left| \mathbf{A}^{(0)} (\mathbf{H} \rightarrow \bar{f}f\gamma) \right|^2 \boldsymbol{\chi} \right. \\
 & + \left. 2\text{Re} \left[\mathbf{A}^{(0)} (\mathbf{H} \rightarrow \bar{f}f\gamma) \right]^\dagger \mathbf{A}^{(1)} (\mathbf{H} \rightarrow \bar{f}f\gamma) \boldsymbol{\chi} \right\} \\
 & + \int d\Phi_4 \left| \mathbf{A}^{(0)} (\mathbf{H} \rightarrow \bar{f}f\gamma\gamma) \right|^2
 \end{aligned}$$

depending on cuts a term can be N^n LO for one process or N^{n+1} LO for another

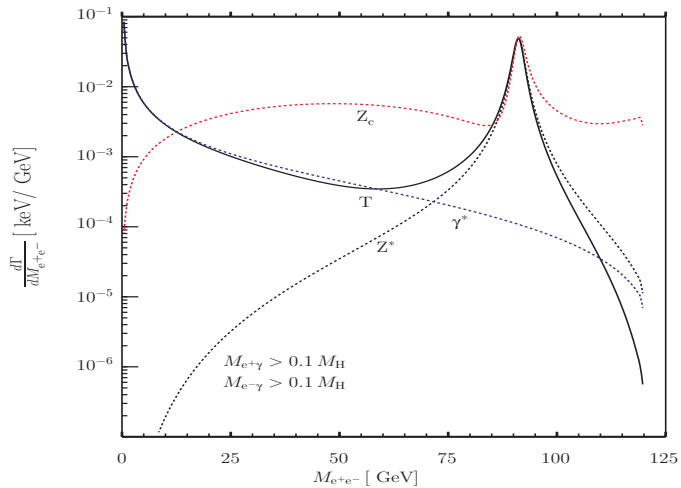
Don't get trapped by your intuition †

- ☞ the **IR/collinear** stuff will not survive in the limit $m_f \rightarrow 0$
- ☞ There are **genuinely non-QED(QCD)** terms surviving the **zero-Yukawa** limit (a result known since the '80s)



2f H-BRs below $10^{-3} - 10^{-4}$
pose additional TH problems
 $\Delta BR \gg BR$

†) don't think in terms of subsets of diagrams!



A short History of beyond ZWA (don't try fixing something that is already broken in the first place)

- ① There is an enhanced Higgs tail Kauer - Passarino (arXiv:1206.4803):
away from the narrow peak the propagator and the off-shell H width behave like ➡

$$\Delta_H \approx \frac{1}{\left(M_{VV}^2 - \mu_H^2\right)^2},$$

$$\checkmark \frac{\Gamma_{H \rightarrow VV}(M_{VV})}{M_{VV}} \sim G_F M_{VV}^2$$

- ② Introduce the notion of ∞ -**degenerate** solutions for the Higgs couplings to SM particles Dixon - Li (arXiv:1305.3854), Caola - Melnikov(arXiv:1307.4935)

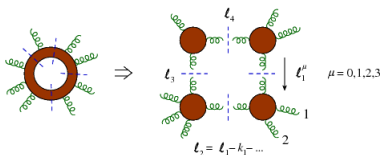
- ③ Observe that the enhanced tail is obviously γ_H -independent and that this could be exploited to constrain the Higgs width model-independently
- ④ Use a matrix element method (e.g. MELA) to construct a kinematic discriminant to sharpen the constraint Campbell, Ellis and Williams (arXiv:1311.3589)

What progresses were (not) done by theorists during the run 1
time lap?

*In the middle of the journey of our life I found myself within a dark woods where
the straight way was lost* Dante Alighieri, Inferno

This relation has been known for fifty years
 efficient evaluation of the coefficients
 that's the name of the game

$$A_n^{1\text{-loop}} = \sum_i d_i \text{[Square Diagram]} + \sum_i c_i \text{[Triangle Diagram]} \\
 + \sum_i b_i \text{[Bubble Diagram]} + R_n + O(\varepsilon)$$



NEW LOOP TECHNIQUES

For the calculation of one-loop matrix elements, several methods are now established :

- **Generalized Unitarity (ex. BlackHat, Rocket,...)**

[Bern, Dixon, Dunbar, Kosower, hep-ph/9403226 +; Ellis, Giele, Kunszt 0708.2398, +1 0806.3467]

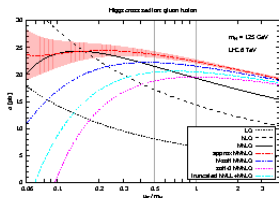
- **Integrand Reduction (ex. CutTools, Samurai)**

[Ossola, Papadopolulos, Pittau, hep-ph/0609007; del Aguila, Pittau, hep-ph/0404120; M Ossola, Reiter, Tramontano, 1006.0710]

- **Tensor Reduction (ex. Golem, GoSam)**

[Passarino, Veltman, 1979; Denner, Dittmaier, hep-ph/0509141, Binoth, Guillet, Heinrich, Reiter 0810.0092]

Fantastic achievements in multi-loop, at the price of privileging SIGNAL, from Spira & Zerwas to Anastasiou (to appear)



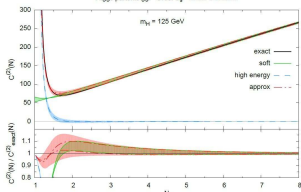
Trust but check: NNLO

Harlander et al. hep-ph/0201206

Anastasiou et al. hep-ph/0207204

Mazzanti et al. arXiv:0801.2544

Higgs partonic gg. Order α_s^2 Mellin transform



$$C_{\text{approx}}(N, \alpha_s) = C_{\text{soft}}(N, \alpha_s) + C_{\text{h.e.}}(N, \alpha_s).$$

Meanwhile ([arXiv:1404.3204](https://arxiv.org/abs/1404.3204)) and in view of the recent full computation of the result in the soft limit for infinite top mass (which determines a previously unknown constant) there is an estimate of the cross section for Higgs production in gluon fusion at **next - to - next - to - next - to - leading** order

$$\sum_{ij} \sigma_{ij \rightarrow H(\rightarrow ZZ)+X}(\zeta, \kappa, \mu_R, \mu_F) = \sigma_{gg \rightarrow H} \delta\left(1 - \frac{z}{V}\right) + \frac{\sigma}{\kappa} \left(\Delta\sigma_{gg \rightarrow Hg} + \Delta\sigma_{qg \rightarrow Hq} + \Delta\sigma_{\bar{q}q \rightarrow Hg} + \text{NNLO} \right)$$

$$\sigma_{gg \rightarrow ZZ} = \sigma_{gg \rightarrow ZZ}^{\text{LO}}$$

MHO here!

($\text{MC}_{gg \rightarrow (H^* \rightarrow) ZZ}^{\text{SM}}$) using the following weighting function:

$$\text{MC}_{gg \rightarrow (H^* \rightarrow) ZZ}(\mu_{\text{off-shell}}) = K^{H^*}(m_{ZZ}) \cdot \mu_{\text{off-shell}} \cdot \text{MC}_{gg \rightarrow H^* \rightarrow ZZ}^{\text{SM}} \quad (4)$$

induces some guesswork

for including THU

$$+ \sqrt{K^{H^*}(m_{ZZ}) \cdot K^B(m_{ZZ}) \cdot \mu_{\text{off-shell}}} \cdot \text{MC}_{gg \rightarrow ZZ}^{\text{Interference}}$$

$$+ K^B(m_{ZZ}) \cdot \text{MC}_{gg \rightarrow ZZ}^{\text{cont}}, \quad \text{''}$$

$$\text{MC}_{gg \rightarrow ZZ}^{\text{Interference}} = \text{MC}_{gg \rightarrow (H^* \rightarrow) ZZ}^{\text{SM}} \text{MC}_{gg \rightarrow H^* \rightarrow ZZ}^{\text{SM}} \text{MC}_{gg \rightarrow ZZ}^{\text{cont}}, \quad (5)$$

where $\text{MC}_{gg \rightarrow ZZ}^{\text{Interference}}$ represents a MC sample for the interference term between signal and background as defined in Equation (5). The K-factors are calculated inclusively without any selections.

As a direct simulation of an interference MC sample is not possible, Equation (5) and $R_{H^*}^B$ are used to obtain:

$$\text{MC}_{gg \rightarrow (H^* \rightarrow) ZZ}(\mu_{\text{off-shell}}) = \left(K^{H^*}(m_{ZZ}) \cdot \mu_{\text{off-shell}} \quad K_{gg}^{H^*}(m_{ZZ}) \cdot \sqrt{R_{H^*}^B \cdot \mu_{\text{off-shell}}} \right) \cdot \text{MC}_{gg \rightarrow H^* \rightarrow ZZ}^{\text{SM}} \quad (6)$$

$$+ K_{gg}^{H^*}(m_{ZZ}) \cdot \sqrt{R_{H^*}^B \cdot \mu_{\text{off-shell}}} \cdot \text{MC}_{gg \rightarrow (H^* \rightarrow) ZZ}^{\text{SM}}$$

$$+ K_{gg}^{H^*}(m_{ZZ}) \cdot \left(R_{H^*}^B \quad \sqrt{R_{H^*}^B \cdot \mu_{\text{off-shell}}} \right) \cdot \text{MC}_{gg \rightarrow ZZ}^{\text{cont}},$$

3.2 $q\bar{q} \rightarrow ZZ$ and $q\bar{q} \rightarrow WZ$ background

The $q\bar{q} \rightarrow ZZ$ and $q\bar{q} \rightarrow WZ$ background are simulated with Powheg [27, 28] in NLO QCD using dynamic QCD renormalisation and factorisation scales of m_{VZ} and the CT10 NLO PDF set. Parton showering and hadronization is done with Pythia8. The interference with the $q\bar{q} \rightarrow WW$ process for the $2\ell 2\nu$ final state is neglected [28].

3.2.1 NNLO QCD correction to $q\bar{q} \rightarrow ZZ$

improve TH bckg!



TH progress: pick at random ...

The characteristic of scientific progress is our knowing that we did not know

- ✓ inclusive production of vector-boson pairs in hadron collisions
- ✓ **ZZ** production at hadron colliders in NNLO QCD
- ✓ resummation of the transverse-energy distribution in Higgs boson production
- ✓ Real-virtual contributions to the inclusive Higgs cross-section
- ✓ soft triple-real radiation for Higgs production at N3LO
- ✓ NNLO phase space master integrals for two-to-one inclusive cross sections in dimensional regularization
- ✓ Combining Resummed Higgs Predictions Across Jet Bins
- ✓ NNLO QCD corrections to single-top production at the LHC
- ✓ Non-planar master integrals for the production of two off-shell vector bosons in collisions of massless partons

Improved calculations for Higgs processes

- ✓ Inclusive Higgs cross section

scales: \hat{s} , m_h ; m_t , m_b , m_w

- ✓ Higgs plus jet

scales: \hat{s} , m_h , p_T^h , E_T^j , R ; m_t , m_b , m_w

- ✓ Higgs plus more jets

scales: \hat{s} , m_h , p_T^h , E_T^{j1} , E_T^{j2} , E_T^{j3} , \dots , R , $\Delta\eta_{j_1 j_2}$; m_t , m_b , m_w



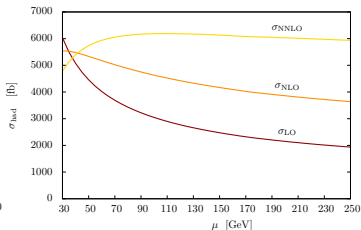
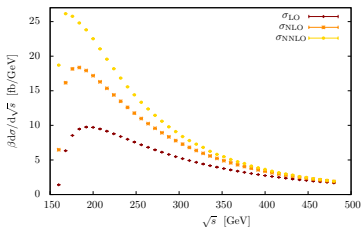
whenever large ratios of scales can be produced, then resummation of the large logarithms may be necessary

- small transverse momentum
- threshold logarithms
- large transverse momentum
- large rapidity separations
- **A hot example - outside Higgs - of log resummation is 1407.4537**

$$(1 + \delta_{QCD}^{NLO} + \delta_{EW}^{NLO}) \quad \text{or} \quad (1 + \delta_{QCD}^{NLO}) \times (1 + \delta_{EW}^{NLO})$$

courtesy of N. Glover

pp \rightarrow H + jet (gluons only) at NNLO $m_t \rightarrow \infty$



- ✓ large effects near partonic threshold
- ✓ large K -factor

$$\sigma_{NLO}/\sigma_{LO} \sim 1.6$$

$$\sigma_{NNLO}/\sigma_{NLO} \sim 1.3$$

- ✓ significantly reduced scale dependence $\mathcal{O}(4\%)$
- ✓ gg-channel is dominant for phenomenological studies: at NLO gg(70%), qg (30%)
- ⚠ other channels needed at this level of precision - in progress

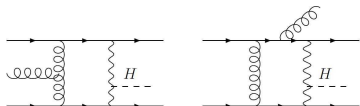
courtesy of N. Glover

VBF pp \rightarrow H + 3 jets at NLO

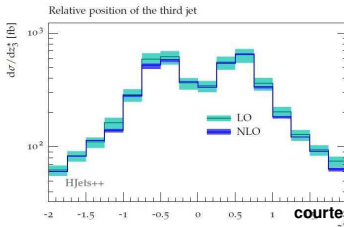
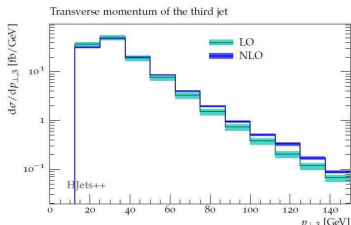
Campanario, Figy, Platzer and Sjodahl

Observe

- ✓ NLO corrections are moderate for inclusive cuts
- ✓ scale uncertainty significantly decreases
- ✓ third jet tends to accompany the tagging jet

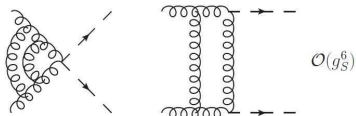


Uses **HERWIG++** for real contribution

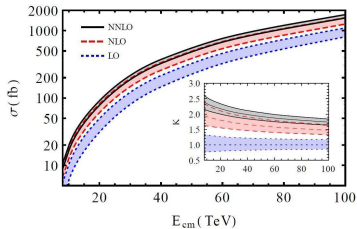


courtesy of Ni Glover

pp \rightarrow HH at NNLO $m_t \rightarrow \infty$



de Florian, Mazzitelli



Observe

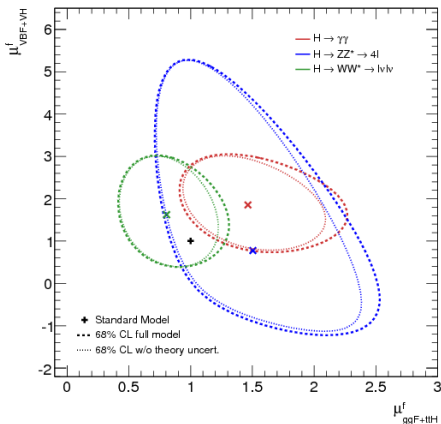
- ✓ NLO/LO ~ 1.9
- ✓ NNLO/NLO ~ 1.2
- ✓ scale uncertainty significantly decreases

courtesy of N. Glover

* *interpretation techniques*



New techniques have been developed to present Higgs coupling measurements, which decouple the poorly defined theoretical uncertainties associated to inclusive and exclusive cross section predictions. These techniques simplify the combination of multiple measurements and can be used in a more general setting ([arXiv:1401.0080](https://arxiv.org/abs/1401.0080))





The measured properties of the Higgs boson are in good agreement with predictions from the SM.


☞ However, small deviations in the Higgs couplings may manifest themselves once the currently large uncertainties will be improved as part of the LHC program and at a future Higgs factory. There are typical new physics scenarios that lead to observable modifications of the Higgs interactions. They can be divided into two broad categories:

- ① mixing effects as in portal models or extended Higgs sectors,
- ② vertex loop effects from new matter or gauge fields.






In each model it is possible to relate coupling deviations to their effective new physics scale. It turns out that with percent level precision the Higgs couplings will be sensitive to the multi-TeV regime (**arXiv:1403.7191**).

Madgraph vision



AUTOMATION

-  **Cost saving**
Trade human time and expertise spent on computing process at the time with time on physics and pheno.
-  **Robustness**
Programs are modular and computations based on that can be systematically and extensively checked. Tr easily built.
-  **Wide accessibility**
One framework for all. Available to everybody for an u set of applications for **Augmented TH/EXP** collaboration.

Augmented TH/EXP collaboration

Prisma Colloquium, Mainz, 20 Nov 2013 Fabio Maltoni

Monday 23 December 2013



Generalized Unitarity
(ex. BlackHat, Rocket,...)

Integrand Reduction
(ex. CutTools, Samurai)

Tensor Reduction
(ex. GoSam)



Prisma Colloquium, Mainz, 20 Nov 2013

Monday 23 December 2013

Fabio Maltoni

also called Toyota vision, which is fine as long as Ferrari vision is still allowed
concept cars are followed by production vehicles in the mass production ...

Which run 1 experimental results had a positive feedback towards theory?

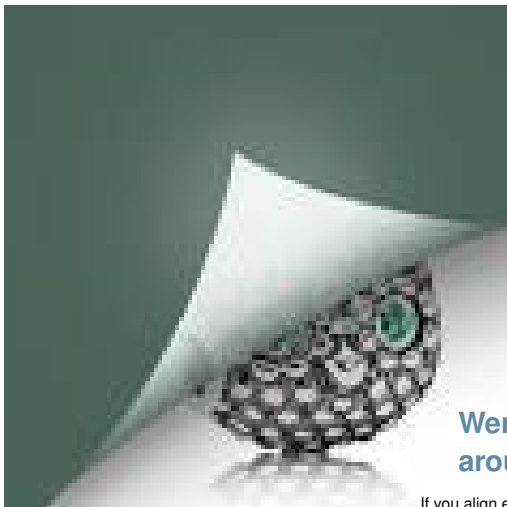
This mountain is so formed that it is always wearisome when one begins the ascent, but becomes easier the higher one climbs Dante Alighieri, Purgatorio

Of course the discovery, the absence (so far) of NP, first measurements of Higgs couplings, bounding the Higgs width.
But, most importantly,



LHC has been (is) a model cleaner, models dying by the dozens
for each new inverse **femtobarn**

Good tests kill flawed theories; we remain alive to guess again. Karl Popper



**Were you expecting NP
around the corner?**

If you align expectations with reality, you will never be disappointed

What about Hierarchy? nature choosing fine-tuning? *nothing new*

- CNO - cycle (stars convert hydrogen to helium)
- if gravity stronger or weaker by **1** part in **10^{40}** , then life-sustaining stars like the sun could not exist

If we nudge one of the constants just a few percent in one direction, stars burn out within a million years of their formation, and there is no time for evolution. If we nudge it a few percent in the other direction, then no elements heavier than helium form. No carbon, no life. Not even any chemistry. No complexity at all (D. D. Deutsch)

- size of sun-moon from earth . . . , many more in the **10^{3-4}** ballpark (neutron/proton mass ratio, initial explosion of big bang, etc.)

It is worth remembering how well *classical Ptolemaic epicycles* could predict astronomical positions *despite being based on false (but highly-tuned) Roman science*

Vacuum stability vision



Definition

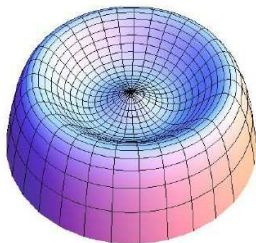
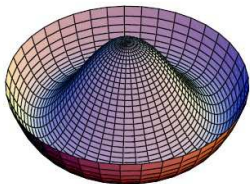
Trivially: in the absence of NP the LHC-boson makes the universe metastable at $\Lambda \approx 10^{10-12} \text{ GeV}$

God plays not only dice but also russian roulette

Precision striking back : But ... small deviations from SM couplings is a guess based on absence of NP so far with more data the properties of the LHC-boson could get even closer to the SM predictions which is very challenging (more than rushing now to too quick conclusions): deviations may be of the order of the present SM uncertainties

Illustrative

It's the shape that matters



If your mexican hat turns out to be a dog bowl you have a problem...

- =

QFT: infinities, renormalization, predictions. **Status OK** (but Landau poles are there and, possibly, instability is present), many things remain unexplained. **SM** is **QFT**, as it is **QED** (not embedded into **SM**)

QFT with **embedding**: requires a cutoff scale for the embedding, the physics of that scale is **unknown**. Keywords are triviality and vacuum stability

Lindner CLASSIFICATION:

- $M_H = 125\text{--}126 \text{ GeV}$ → instability → new physics
- $M_H = 126\text{--}157 \text{ GeV}$ SM ... non-minimal Susy perfect
- $M_H > 157 \text{ GeV}$ real BSM required

LHC data and Higgs imposters



- ① Example: an EW singlet scalar can couple to $\mathbf{V}\mathbf{V}$ through loop-induced $\mathbf{d} = \mathbf{5}$ operators. Compared to a SM Higgs boson, the singlet decay widths in the diphotons and $\mathbf{Z}\gamma$ channels are generically enhanced, while decays into massive final states like $\mathbf{W}\mathbf{W}$ and $\mathbf{Z}\mathbf{Z}$ are kinematically disfavored.
- ② Current LHC data already strongly disfavor both the dilatonic and non-dilatonic singlet imposters. On the other hand, a generic Higgs doublet give excellent fits to the measured event rates of the newly observed scalar resonance, while the SM Higgs boson gives a slightly worse overall fit ([arXiv:1207.1093](https://arxiv.org/abs/1207.1093)).



Higgs couplings **measurement** and **interpretation**

they are consistent \iff there is at least one possible situation in which they are all true

- ☞ Despite Wightman Axioms (a separable Hilbert space etc..) QFT is full of assumptions (Yang-Mills existence and mass gap, etc.) but, once you accept them, QFT is a non flexible working environment: you cannot rescale the theory as you wish and pretend to get meaningful results

Measurement without theory?

☞ NO, theory and measurements are *dual* in the sense that a testable theory is associated with a set of data accounts that correspond to that theory.

☞ unfortunately the partnership between theory and measurements proved far from equal. Why are the data not better? The facts themselves are not in dispute. However, measurements without theory is a conceptual ingenuity

☞ Best known example is a Higgs boson of spin **2**:

- ① An effective theory of spin **2** has an UV cutoff which is approximately of the same order of the mass. Indeed, in a fixed external EM background charged spinions show pathological behavior like superluminality and/or acausality and/or strong coupling at finite energy scale.
- ② One could start from a linearized Einstein-Hilbert Lagrangian and then Kaluza-Klein reduce it. However, this approach does not seem realistic either since such a set-up with the light Higgs as a KK-graviton will also implies KK W and Z around 100 GeV, which is in much contradiction with data.

What are the future (run 2 and longer term) prospects?

My course is set for an uncharted sea Dante Alighieri, Paradise



Today strategy in NP searches is the following:



search for signals in arbitrary models that give limits on some parameter of the model with the demoralizing conclusion that there is no signal. When working for the first time at unexplored energies it is good practice to perform a quick search for the most popular models; however, if you do not find something, this is not the best practice for two reasons: *we are not changing our prejudices and the search becomes depressing*



Comparing complementary approaches

Space of SIGNALS(signatures) (P. Nason)

- ☞ It looks more promising to group signals by studying a *generic signal*, sensitive to different models of NP, and to compare the measurements to the SM predictions.
 - ☞ The study of a *generic signal* is to understand whether the signal itself is well explained within the SM framework, to observe possible deviations that suggest NP. It could lead us to some relevant discovery and it will stimulate our understanding of SM processes at colliders.
- ☞ Consider all BSM analyses and group them according to signals and not to BSM models. The question will not be *have we been missing a corner in the space of theories?* but *have we been missing a corner in the space of measurable signals?*

Space of THEORIES arXiv:1209.5538

- ☞ At the same time one should look for any indication leading to a consistent theory at higher scales. From this point of view the goal remains to bring BSM physics at the SM level of technology.
- ☞ The new phase can be summarized as follows:
 - ① assume that there is a weakly coupled UV completion and study signal and background within an effective theory, which is as model-independent as possible
 - ② alternatively we could imagine some UV completion based on a hierarchy of effective theories. We introduce **dim = 6** (or higher) operators, taking into accounts bounds from high precision EW physics, and study on/off resonance processes with the point of view of the 14 TeV.

Space of THEORIES cont.

- ☞ The (almost) model independent approach is based on the following (additional) assumption:
 - ☞ all new degrees of freedom are heavy with decoupling. No model independent approach can be designed if decoupling is missing or we have light d.o.f.
- ☞ Therefore we will have a complementary approach between EFT measurements and analysis in specific BSM benchmark models with light d.o.f.
- ☞ Our goal is start of the work for an EFT approach to Higgs (couplings) measurements in Run II, allowing a consistent treatment of a wide range of measurements. This requires going beyond LO and including EW corrections. This is uncritical as long as experimental precision is $> 10\%$ (Run I) but it is expected to be below 10% at Run II and beyond.

Improving TH uncertainty

- ☞ Move from QCD scale-variation uncertainty to MHOU (Missing Higher Order Uncertainty); there are obvious reasons for that, including the fact that non-QCD uncertainties cannot be simulated by scale variations. Move from

- ① plotting σ at central values of μ_R, μ_F with a band $[\mu/\xi, \xi\mu]$ to
- ② plotting $d\sigma/\sigma - 1$ on the x -axis and the corresponding pdf (probability distribution function, small) on the y -axis.



In my view, there is no sense in motivating an interpretation of MHOU that assume constraints privileging some values over others. A Bayesian analysis looks more solid, you write down your assumptions: **a)** the prior, **b)** the profile and you derive a posterior. Assumptions are there, open for criticism.

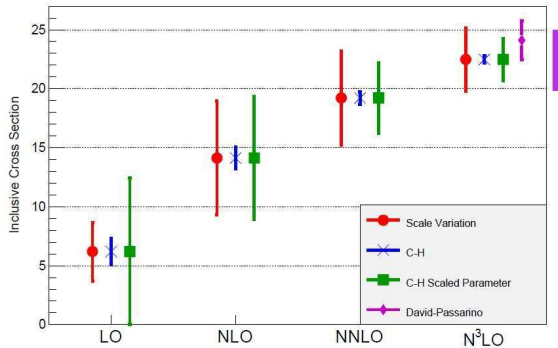
- ☞ gluon fusion is giving a strong support to the Bayesian approach simply because the perturbative expansion

$$\theta \asymp \sum_{n=0}^{\infty} c_n g^n$$

is converging much slower than what expected by scale variation arguments and the behavior, order-by-order, is (more or less) what is suggested by the previous orders

- ☞ when dealing with a slowly converging (?) series, known up to the first three terms, stating that next order, most probable, value is equal to the one in previous order (Gaussian pdf), doesn't make much sense

Theoretical error on σ_H revisited



Forte, Isgro, Vita

Drawing conclusions pre-conclusions

(restricting our attention to the relative merits of realism and instrumentalism)

Do we have a way of knowing whether “unobservable” theoretical entities really exist, or that their meaning is defined solely through measurable quantities?

Leplin (1984), **Sokal** (2001)

- ✳ Now we must move on to the next step, melting BSM-physics with high-precision SM-technology. The question has been repeated many times but answers are still converging around *Not yet*
- ✳ Meanwhile, it came dangerously close to realizing a nightmare, of Physics done by sub-sets of diagrams instead of cuts. *Well, several years ago we avoided that fate, may be the history will repeat itself?*

CONCLUSIONS: *don't mistake activity with achievement*

- ☛ The LHC runs at **7** and **8 TeV** have led to the discovery of the Higgs boson at **125 GeV** which will remain as one of the major physics discoveries of our time.
- ☛ Another very important result was the surprising absence of any signals of new physics that, if confirmed in the continuation of the LHC experiments, is going to drastically change our vision of the field.
- ☛ At present the indication is that Nature does not care too much about our our theoretical prejudices, excessive success of the Standard Model?

Merely to adopt the more powerful assumption is no more than to assume the more powerful conclusion

