A Boson, a Nobel

the next part of the journey

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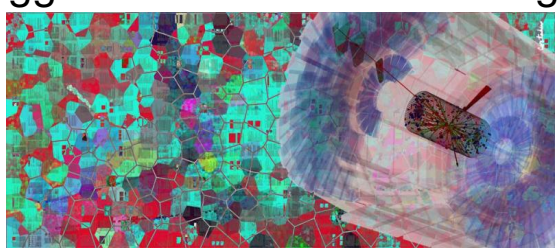
LHC Higgs Cross Sections Working Group

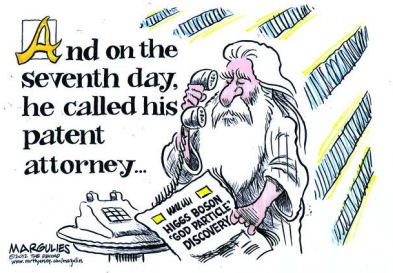


22 October 2013 Torino

Why the Higgs Is Such a Big Deal

But under no circumstances should you call it *the God particle*

(Dave Goldberg)



Nobel Prizes (at least in the sciences) are almost always given out for a discovery rather than a prediction, so it wasn't until last year, when two independent groups at the LHC detected the eponymous particle, that Englert and Higgs were even in contention. This year's announcement represents an incredibly quick turnaround for a committee that has generally been fairly conservative in its awards

Read the full story

http://www.nobelprize.org/nobel_prizes/physics/laureates/2013/advanced-physicsprize2013.pdf

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*

This talk is based on **3** premises and one evidence

P1 *If you don't convince the public that your science matters, your funding will quickly vanish*

P2 *All we need to do is to frequently share passion with a broader audience*

P3 *Scientific outreach doesn't need to be utterly simple*

E *Role of our Institutions in the global effort*

The difference between science and the fuzzy subjects is that science requires reasoning while those other subjects merely require scholarship

(Robert A. Heinlein)

It has become almost a cliche to remark that nobody boasts of ignorance of literature, but it is socially acceptable to boast ignorance of science and proudly claim incompetence in mathematics

(Richard Dawkins)

LEGENDA:

SM The Standard Model of particle physics is a theory concerning the electromagnetic, weak, and strong nuclear interactions, which mediate the dynamics of the known subatomic particles

NP Physics beyond the Standard Model refers to the theoretical developments needed to explain the deficiencies of the Standard Model

Precision Elementary particle physics at highest energy and precision

Hierarchy A hierarchy problem occurs when the fundamental parameters (couplings or masses) are vastly different (usually larger) than the parameters measured by experiment

Running Couplings depend on the energy scale at which one makes the observation

fine tuning The laws of science contain many fundamental numbers. The remarkable fact is that the values of these numbers seem to have been very finely adjusted to make possible the development of life

If you were expecting *snowfall* arguments

Imagine an infinite field of snow extending throughout all of space, flat, featureless, going in all directions ah maybe the middle of Siberia. Now imagine that you are trying to cross this field of snow. So maybe you are a skier, and you skim across the top. That's like a particle that does not interact with the Higgs field. It doesn't sink into the snow. It goes very fast. It's like a particle with no mass, traveling at the speed of light. But maybe you've only got snowshoes. In that case, you sink into the Higgs snowfield. You've got less speed than the skier, less than the speed of light. That's like a particle with mass because you are connecting, interacting with that Higgs snowfield. And then finally, if you've just got boots on, then you sink deeply into the snow. You go very, very slowly, and that's like a particle with a big mass

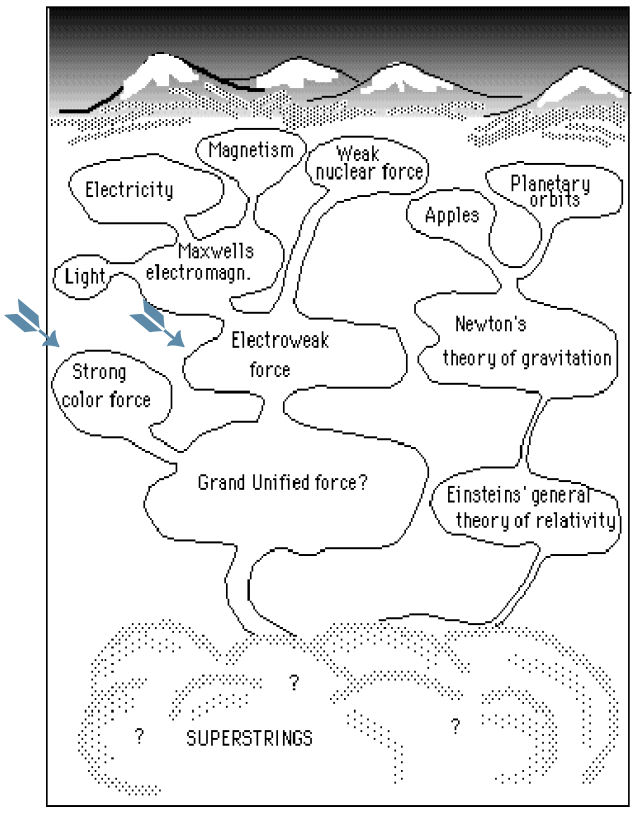
you ended up at the wrong place at the wrong time

Higgs boson outreach from the professionals:

The Higgs boson in your hand. Our new app Collider allows you to play games, view collisions from CERN, and even hunt for the Higgs boson. It features full 3D graphics, event streaming from CERN, tutorials and new games. download for Android phones and tablets, iPhone and iPad

http://www-pnp.physics.ox.ac.uk/barra/media.shtml

Reasons to go Beyond the Standard Model



Theoretical:

SM does not exist without cutoff
(triviality, vacuum stability)
Gauge hierarchy problem
Gauge unification, charge quantization
Strong CP problem
Unification with gravity
Global symmetries & GR anomalies
Why: 3 generations, representations, d=4, many parameters

Experimental facts:

- **Electro weak scale << Planck scale**
- **Gauge couplings almost unify**
- **Neutrinos masses & large mixings**
- **Flavour: Patterns of masses & mixings**
- **Baryon asymmetry of the Universe**
- **Dark Matter**
- **Inflation**
- **Dark Energy**

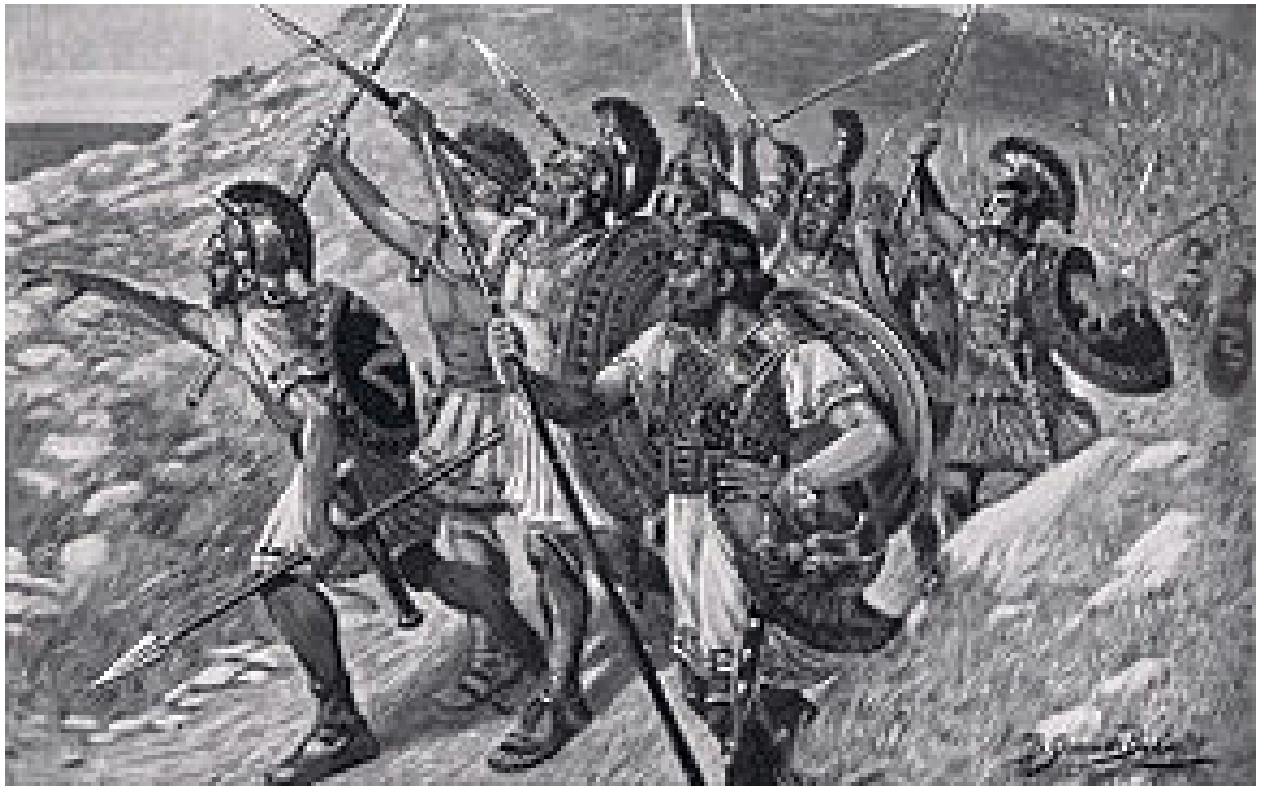
Unless

Nature goes her own way, and all that to us seems an exception is really according to order. . . . When Nature has work to be done, she creates a genius to do it

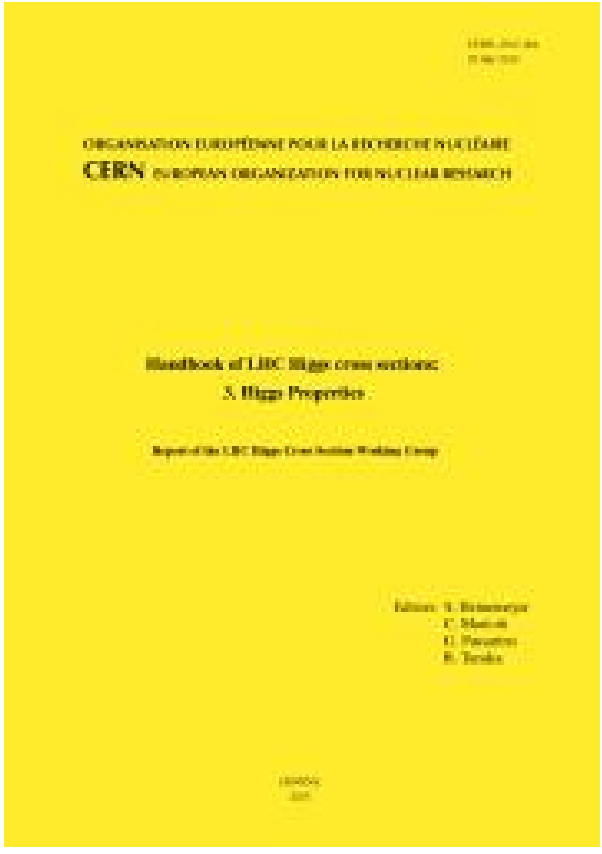
Here we go

THE LHC BOSON: the Xenophon - vision

Θάλαττα Θάλαττα (Anabasis: Book 4, Chapter 7, Section 24).



Time Commercial break: Higgs @ Torino



- Handbook of LHC Higgs Cross Sections: 3. Higgs Properties

Heinemeyer, S (ed.) (Cantabria Inst. of Phys.) ;
Mariotti, C (ed.) (INFN, Turin) ;
Passarino, G (ed.) (INFN, Turin ; Turin U.) ;
Tanaka, R (ed.) (Orsay, LAL)

- Handbook of LHC Higgs Cross Sections: 2. Differential Distributions

Dittmaier, S (ed.) (Freiburg U.) ;
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Passarino, G (ed.) (INFN, Turin ; Turin U.) ;
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- Handbook of LHC Higgs Cross Sections: 1. Inclusive Observables

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Let me remove a stone from my shoe:

for VQR we have been wasting our time

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 NP effects

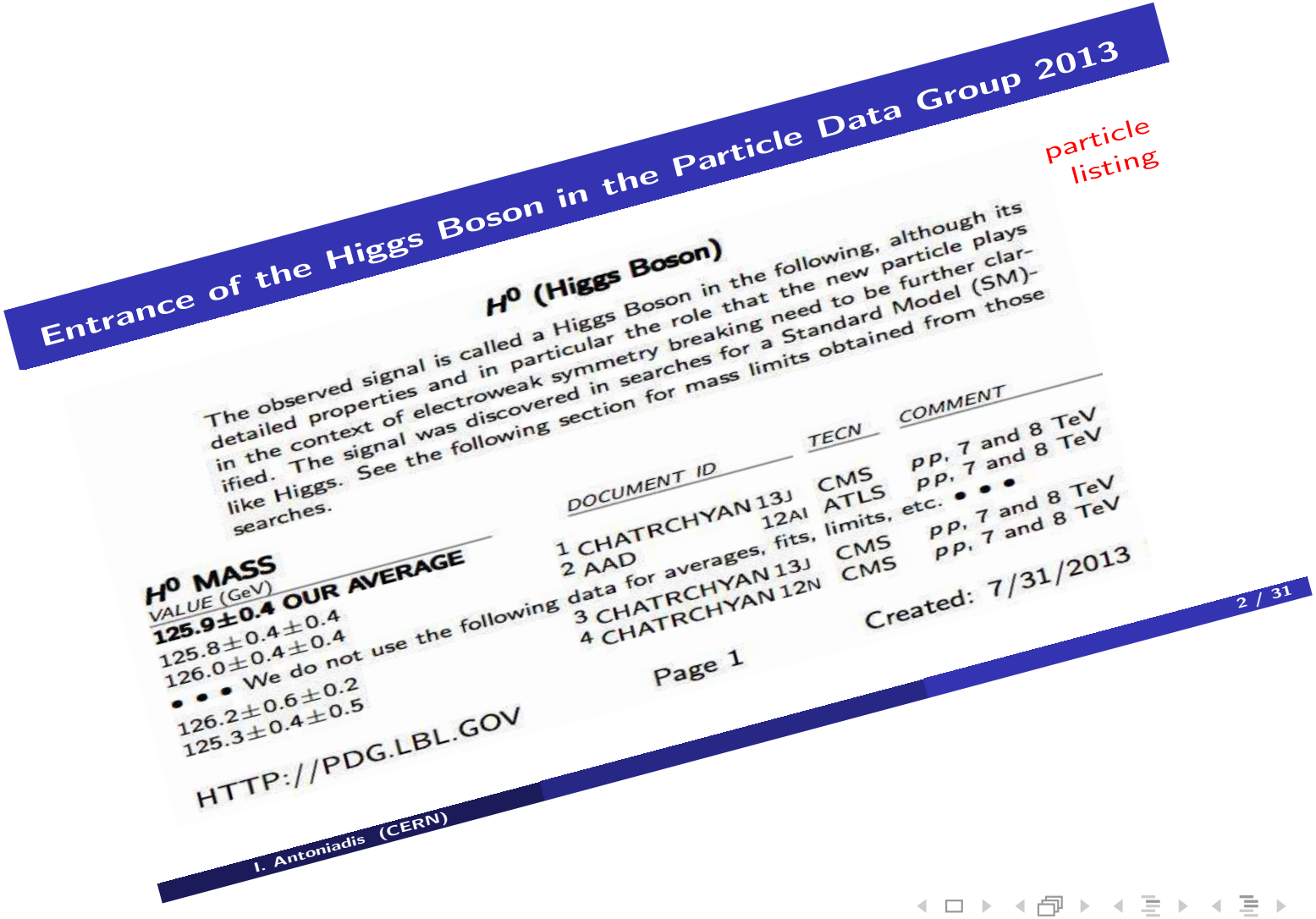
There is nothing either good or bad but thinking makes it so

(William Shakespeare)

Were you expecting NP around the corner?

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

I'm thrilled that this year's Nobel Prize has gone to particle physics **Rolf Heuer**



Intermezzo As a Physicist I am somewhat ambivalent subdued about the affair.

- **THE SM** *has now got a degree of validity that has extended way beyond what we had before the discovery of a Higgs-like particle*
- *However,* *the one aspect that dominates here* *is that a Higgs could close the last door of the SM that could lead us to a deeper theory*

To love SM is to not always agree with SM . It is usually right, but not always right

Is SM(**125**) the FINAL THEORY ? Maybe no

Problems

- hierarchy problem
- dark matter
- ν-mass, BAU
- inflation
- cosmological constant
- gauge coupling unification
- strong CP

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

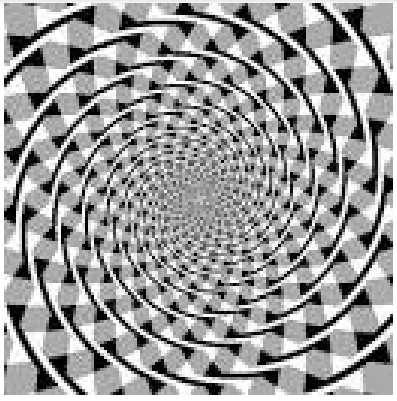
What about Hierarchy? nature choosing fine-tuning? *nothing new*

- CNO - cycle (stars convert hydrogen to helium)
- if gravity stronger or weaker by **1** part in $\mathbf{10^{40}}$, 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 $\mathbf{10^{3-4}}$ 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*



The pessimistic LHC scenario (PS) :

would be nothing but the SM at LHC energies and no detection of dark matter (the recent discovery could complete the Standard Model but the result from the Planck satellite shows that normal matter is only five percent of the energy density of the Universe)

The PTOLEMAIC approach : *forget some of the problems (hierarchy, gauge coupling unification, strong CP). Extend SM*

- Introduce real scalar DM ✓

$$\mathscr{L}_S = -m_S^2 S^2 - g_S \|\Phi^2\| S^2 - \lambda_S^2 S^4$$

- Introduce two ν_R and leptogenesis ✓

$$\mathscr{L}_{\nu R} = -M \overline{N}^c N + y_\nu L \tilde{} \overline{N}$$

- Introduce real scalar inflaton ✓

$$\mathscr{L} = -m^2 \phi^2 - \mu \phi^3 - \kappa \phi^4$$

- Forget about cosmological constant, call it **MBSM** (Minimal Beyond Standard Model)

Do we need more than **MBSM** (also known as Altarelli cocktail* **2**)?

The regulative ideal of an ultimate theory remains a powerful *aesthetic ingredient* (**perhaps too kantian?**) Is it possible to formulate the *ultimate theory* in a finite number of statements? (**Gödel?**)

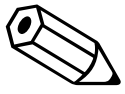
⋆ **2/3** of SM, **1/6** of Majorana neutrinos, **1/6** of axions, add Peccei - Quinn global symmetry, strain the result

The optimistic scenario (OS) :

is the usual picture sold pre-LHC: detection of non-SM Higgs.

Some of us are optimist, but gave no argument for the optimistic scenario beyond the one that it's a good idea in life for a scientist to be an optimist

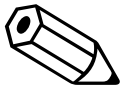
professional only



A concrete (forget gravity) **OS** wish list:

- Systematizing THU in the sense of MHO and MHOU : accuracy over precision. THU in differential form (jets, p_T, η, etc.)
- Beyond **NWA**
- Decays: weird (vector meson) and rare (Dalitz)
- Anything that would use the Higgs as a probe for **BSM**

professional only



- Marrying **EW precision data with Higgs**
- General **EWSB aspects** (dibosons, $\mathbf{VV}$-scattering) and **EW** fits (M_t, M_W, α_s, etc.)
- Predictions/generators to constrain the (finally agreed upon) **EFT coupling space**, esp. using Higgs plus other data (like EW data as mentioned above).

The UTTERLY SIMPLE vision

To my mind, there must be at the bottom of it all, not an utterly simple equation, but an utterly simple IDEA. And to me that idea, when we finally discover it, will be so compelling, and so inevitable, so beautiful, we will all say to each other, "How could it have ever been otherwise?"

(John Wheeler)

PRECISION LHC? or PRECISION ILC?

next step

ILC plans to provide the next significant step in the precision study of Higgs boson properties. LHC precision measurements in the **5–10%** range sould be brought down to the level of **1%**.

But this means that the κ*-language must be updated with the inclusion of* **NLO EW**. *This means*

- ✂ No precision for precision's sake!
- ✌ Precision for a discovery search

ILC plans to measure σ_{ZH}. Once again, this is a pseudo-observable

Precision Physics : *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?

What does the term "Higgs decay" or σ_{ZH} *mean? A mathematical expression? But what does it mean for such an expression to exist in the physical world? Trying to answer that question immediately raises other questions about the correspondence between mathematical objects and the physical world*

Vacuum stability vision

Definition

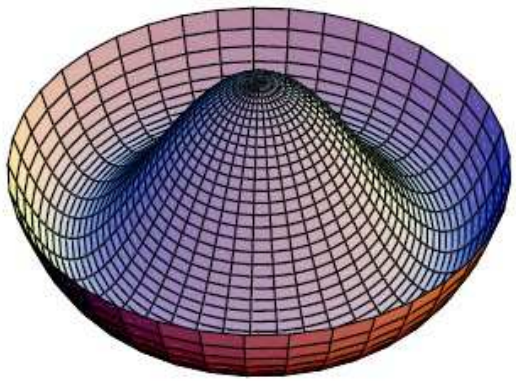
Trivially: in the absence of NP the LHC-boson makes the universe metastable at $\Lambda \approx 10^{10-12}$ ***GeV***

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



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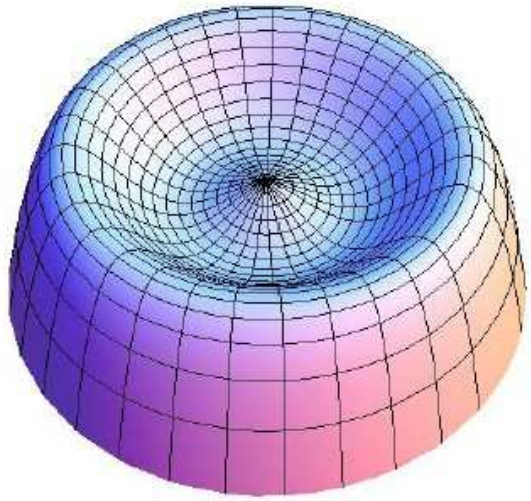


If your mexican hat turns out to be a dog bowl you have a problem...

- =

An induced approach: The *put money where mouth is* approach

- No matter how challenging it may be to see BSM
- Precision Higgs Physics looks now like a must! ✓

❝ Science can only be understood backwards; but it must be lived forwards ❞

(paraphrasing Soren Kierkegaard)

- QUINTESSENTIAL PRECISION: we find ourselves in a *just-so* situation, the vacuum is at the verge or being stable or metastable. A sub-percent change of $\sim$ **1** ***GeV*** in either M_t or M_H is all it takes to tip the scales

The *Missing Guiding Principle* scenario

- Have we lost our motivation (e.g. no guiding principle from naturalness)?
- Maybe yes, maybe no if motivation remains *derive* **EWSB** and/or *compute parameters in a deeper theory*

After all, naturalness is a vague concept and the **SM** is a renormalizable theory

❝ *If one ignores the hierarchy problem it is completely fine and predictive* ❞ (G. Altarelli)

Only when you try to predict **EW** observables from a deeper theory you face naturalness It is plausible to assume that Nature has a way, still hidden to us, to realize *a deeper form of naturalness at a more fundamental level*

Feynmanian versus Wilsonian visions, i.e. Λ cutoff versus scale of NP

$$\mathscr{L}_{\rm ESM} = \mathscr{L}_{\rm SM} + \sum_{n>4}\sum_{i=1}^{N_n} \frac{a_i^n}{\Lambda^{n-4}}\,\mathscr{O}_i^{(d=n)} + \sum_{i=1,2,4} b_i\,\Lambda^i\,\mathscr{O}'_i$$

- SM *not embedded* means $b_{1,2} = 0$, *it's renormalization*!
- SM *embedded* (Wilsonian scenario), b_2 not suppressed by any symmetry
  - $M_{\rm H}$ should be $\mathscr{O}(\Lambda)$ and it is light, thus $\delta M_{\rm H}^2 \sim \Lambda^2$
  - $M_{\rm H} \approx 125\ GeV$ which means $\Lambda \approx 1\ TeV$ (which doesn't seem to be the case) or FINE TUNING (**not a theorem!**)

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 :

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

Now we know where we stand ✓

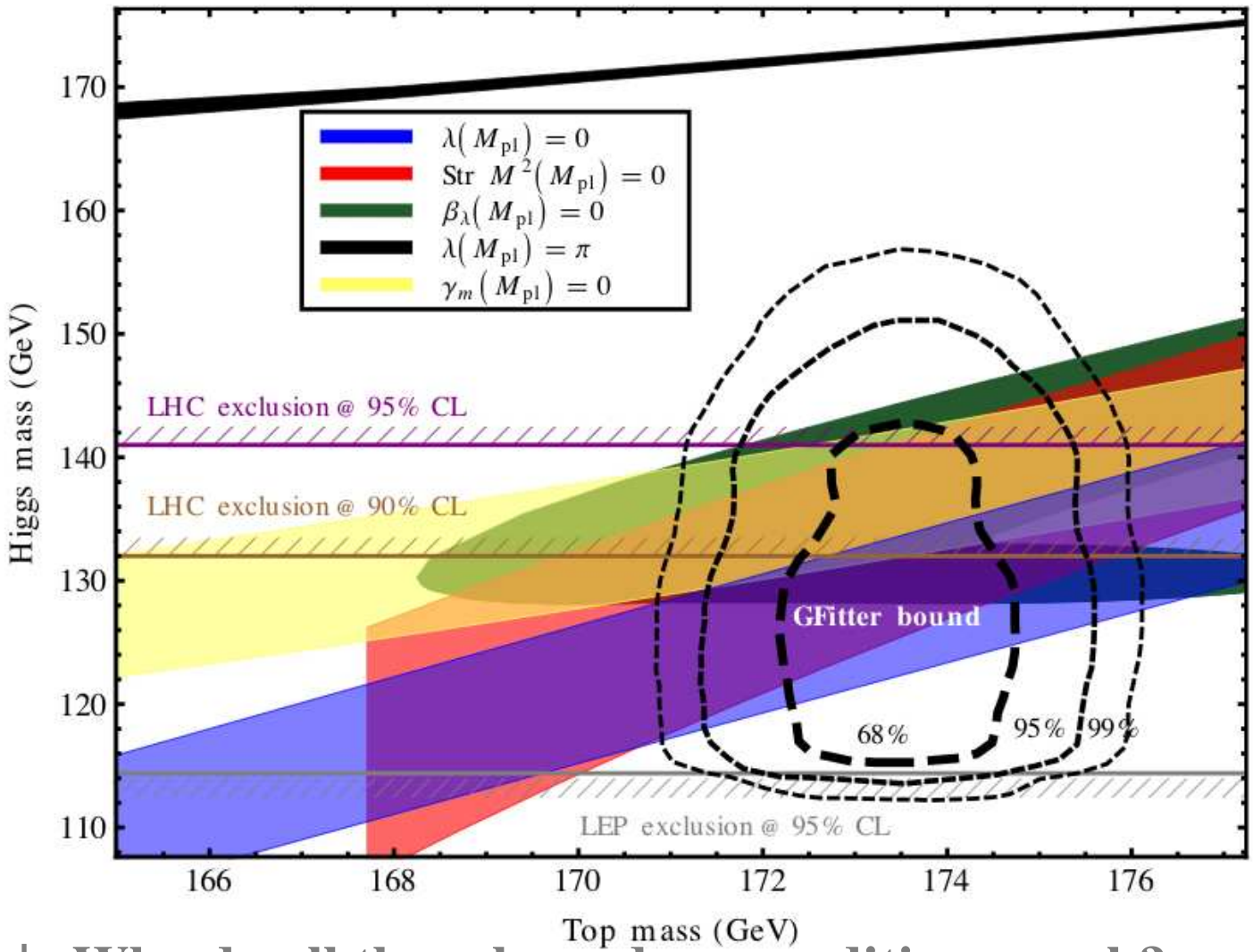
Why all of a sudden questions like *a special value of* $\boldsymbol{\lambda}$ *at* $\boldsymbol{M_{\text{plank}}}$*?* are becoming a popular tune?

$$V = \frac{1}{4}\,\lambda(\mu)\,\mathrm{H}^4, \qquad \lambda_0 = \frac{1}{4}\,\frac{M_{\mathrm{H}}^2}{v^2}$$

Conceivable special scenarios

- Vacuum stability, $\boldsymbol{\lambda\left(M_{\text{plank}}\right) = 0}$
- vanishing of $\boldsymbol{\beta}$-function, $\boldsymbol{\beta_\lambda\left(M_{\text{plank}}\right) = 0}$
- the *Veltman* condition (cancellation of quadratic divergencies)

From M. Lindner talk at SCALARS 2013



m_H
!
exc

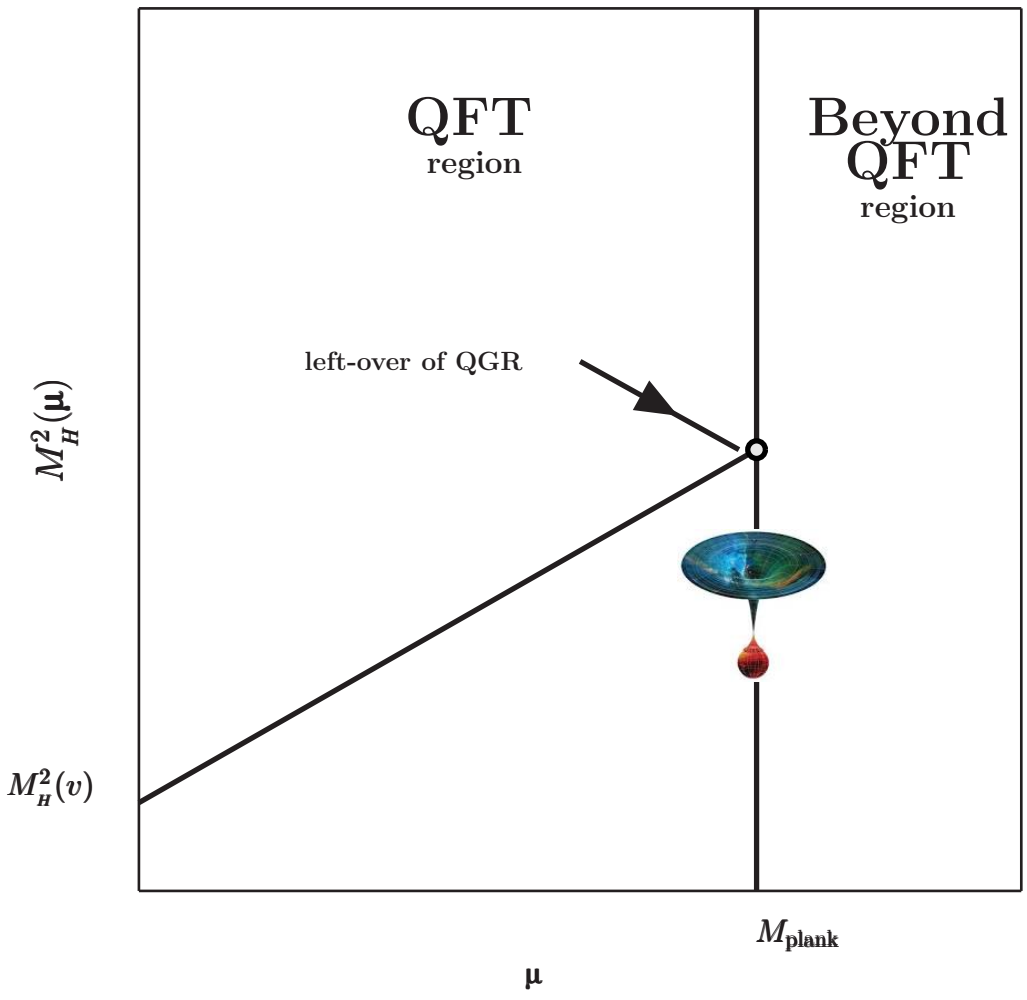
- ! **Why do all these boundary conditions work?**
  - suppression factors compared to random choice = O(1

The most interesting question: *is the Higgs potential at* M_{plank} *flat? Why?*

- ⇝ V flat means no Higgs self-interaction
- ⇝ Is the **SM** *directly embedded* into gravity …?

In this case

- We do not have a renormalizable **QFT** of gravity
- we need to move beyond QFT ! *It means new non-QFT Plank-scale concepts* !


QFT
region
Beyond
QFT
region
left-over of QGR
$M_H^2(\mu)$
$M_H^2(v)$
M_{plank}
μ

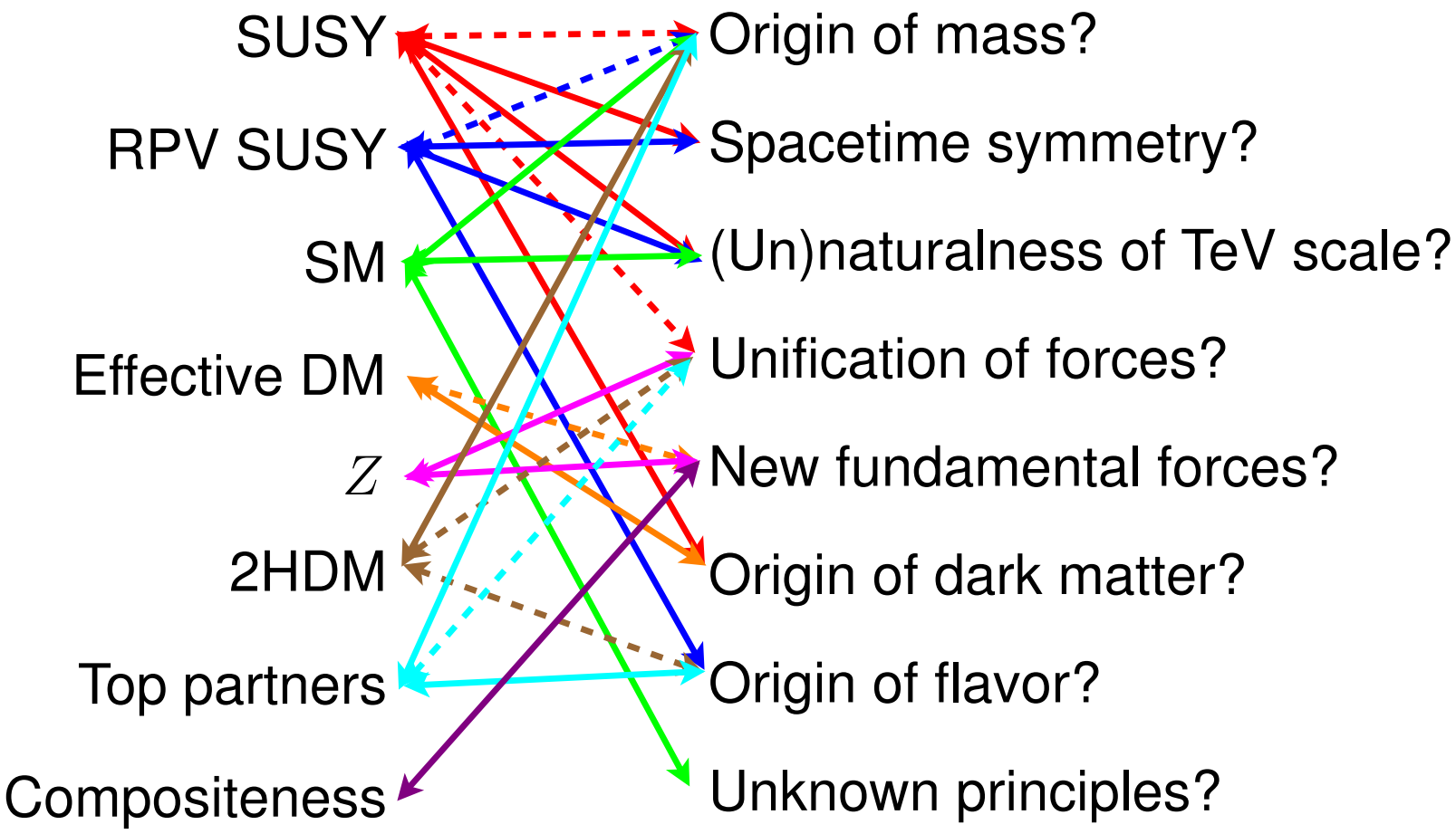
The *Set your preferences* scenario

1. New **QFT**
2. Beyond **QFT**

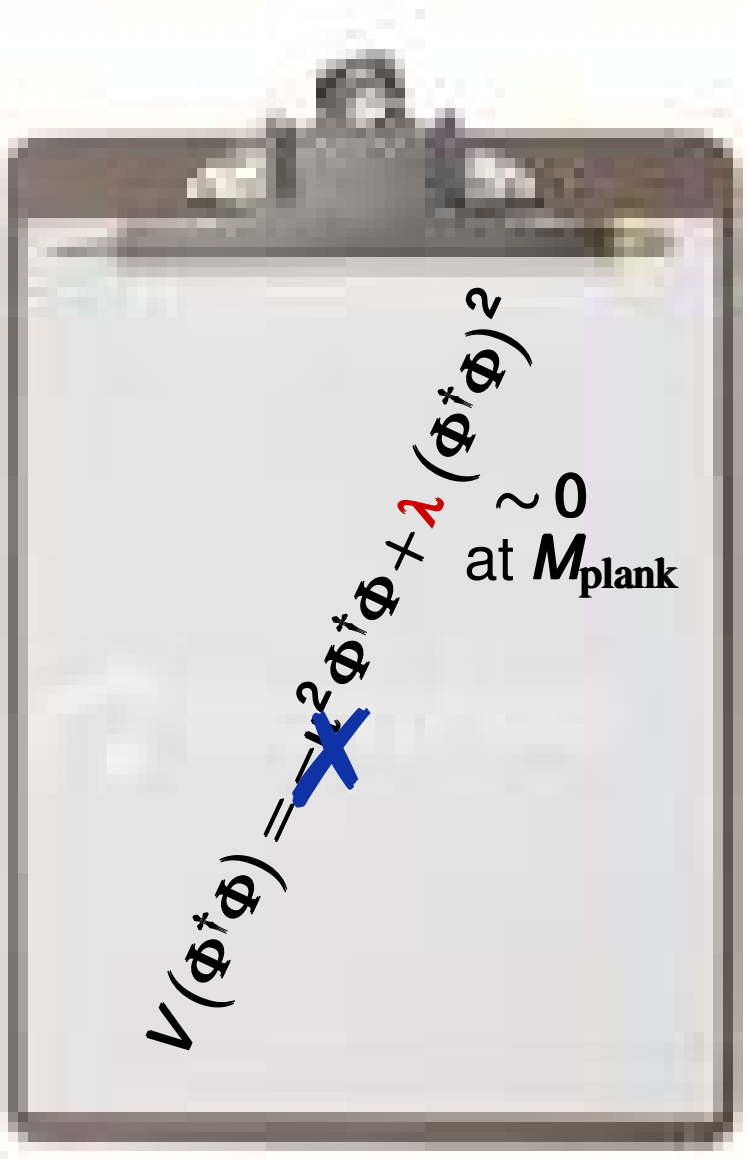
The second scenario is relatively new and avoids hierarchy problem by shifting it to the unknown region, the first is the traditional one where one plays with

- more representations, new groups, inclusion of **XXXSSM**
- and ... runs into hierarchy problem
- or set NP-scale above M_{plank} ...

Big Questions



The Try something new *conformal* vision



Almost CS!

broken CS?

$\mu = 0$ + Coleman-Weinberg? ✗

M_H too low (from CW), too high (from Veltman condition)

Perturbatively natural conformal extension?

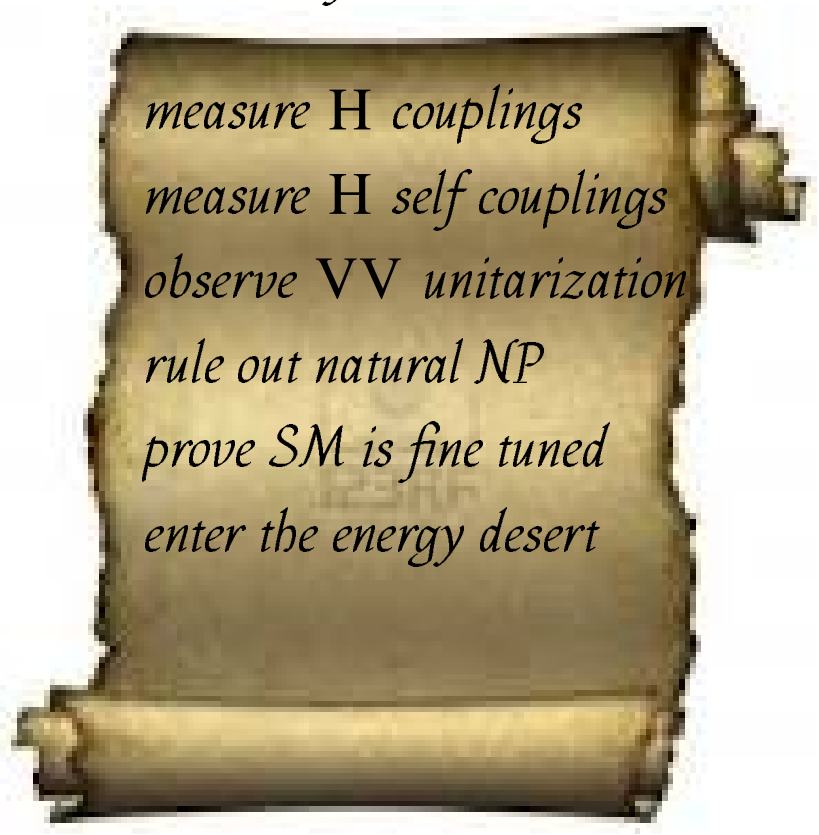
Lindner, Sannino, . . .

The where to put money vision

If the LHC boson alone contributes to **EWSB** $\mathbf{V_L V_L}$ -scattering does not grow at high energies

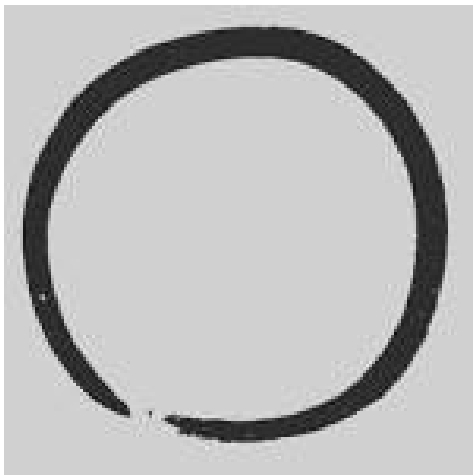
- New Physics also means that the LH boson is not alone but
- NP non-observability at **1** ***TeV*** tells us that the rest is heavy. *Then the scattering could get strong for a range of energies, until the high-energy UV physics starts unitarizing*
- LHC experiments can/could reveal this interesting possibility

The Lost Book of Nostradamus



MY OPINION?

Before a man studies, to him mountains are mountains and waters are waters; after he gets an insight into the truth through the instruction of a good master, 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



(Paraphrasing Essays in Zen Buddhism First Series 24)

Conclusions

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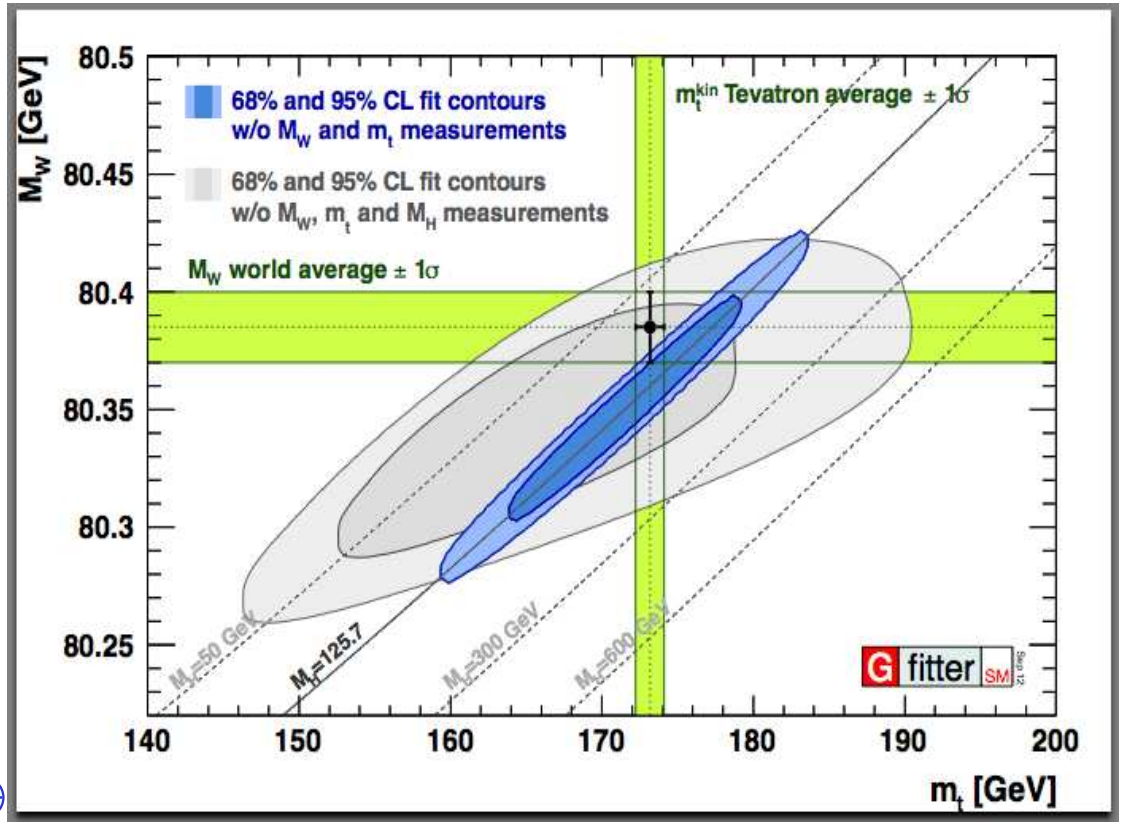
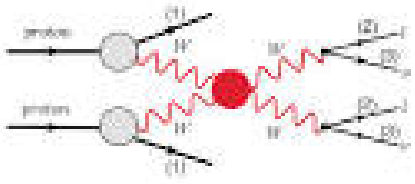
- Are you Popper-like (progress is through testing falsifiable ideas) or Kuhn-like (progress is through producing results that fit in with the established view point)?
- “ A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it ”

Max Planck, Scientific Autobiography and Other Papers

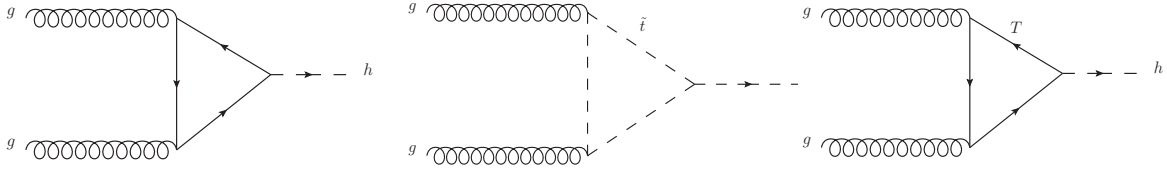
Thanks for your attention

Backup

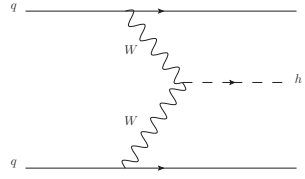

80.5
80.45
80.4
80.35
80.3
80.25
M_W [GeV]
140
150
160
170
180
190
200
m_t [GeV]
68% and 95% CL fit contours
w/o M_W and m_t measurements
68% and 95% CL fit contours
w/o M_W, m_t and M_H measurements
M_W world average ± 1σ
m_t^{kin} Tevatron average ± 1σ
M_H=50 GeV
M_H=125.7
M_H=300 GeV
M_H=600 GeV
G fitter SM



- For most models, except for the FP Higgs, gluon fusion is the dominant production mechanism ($\sigma(gg \to h_{SM}) \sim 20$ pb for 125 GeV Higgs at LHC8). But the gluon fusion can involve other exotic colored particles:

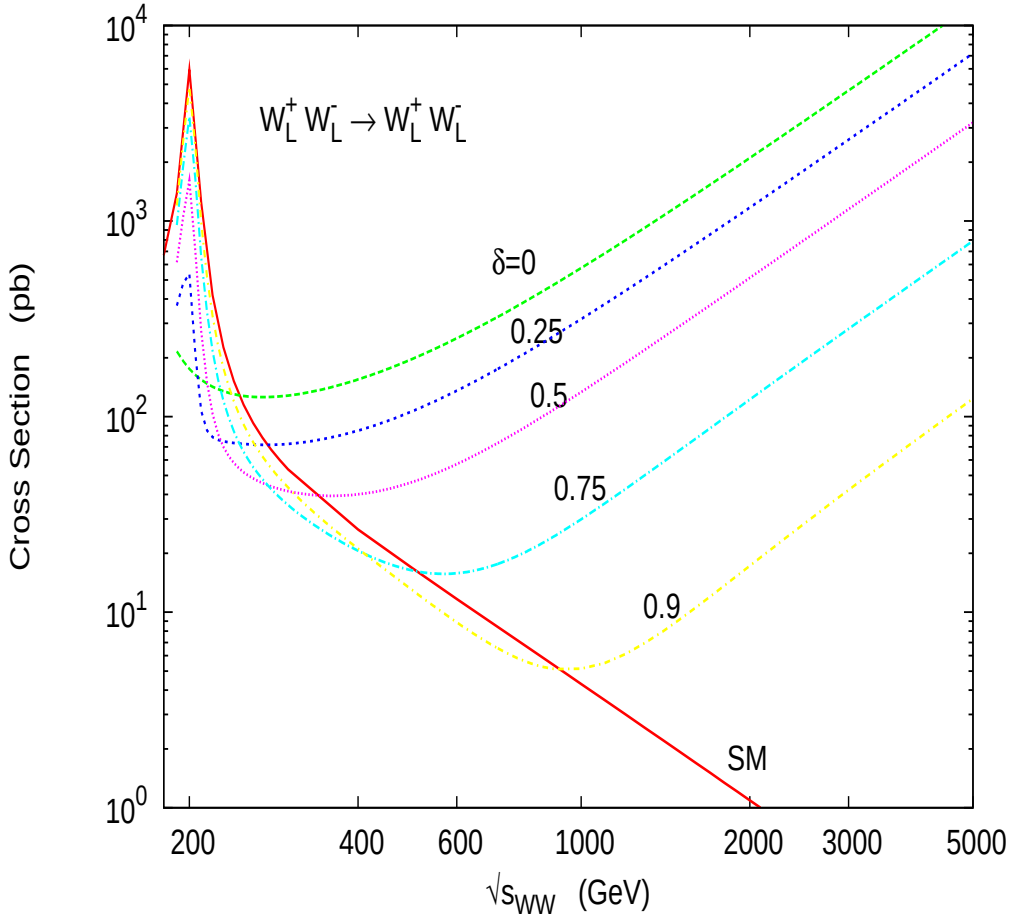


- On the other hand, VBF is the cleanest channel to probe EWS hVV couplings:



which gives two energetic forward jets which can be tagged experimentally.

- Before kinematical cuts, VBF cross section is 8% of gluon fusion for 125 GeV Higgs at LHC8, while Higgs-strahlung is 5%.



Cheung, Chiang, Yuan

Partially-strong scattering: THDM

$$g_{hVV} = \sin(\beta - \alpha)\, g^{SM}_{H^0VV} \qquad g_{HVV} = \cos(\beta - \alpha)\, g^{SM}_{H^0VV}$$

- Energy growing behavior tamed above M_H
- growing behavior expected *if there is space enough between* M_h *and* M_H

Warning ☛

the measurement of the VV scattering at the Atlas and CMS experiment is very challenging and statistically limited. Experimentally, all final states can be studied; while the fully leptonic ones have very little background, but a very small statistics, the semi-leptonic ones suffer from a very large background coming from $t-t$, VV + jets , V + jets production

Signal strengths

LHC projections

Different scenarios assumed by the two experiments

- ATLAS: with and without th error (same exp. syst. as
- CMS: Scenario 1 and Scena

EWK production modes (st theory error) allow overc large theory uncertainty fusion production

Aim at 5% for the main fiv analyses

5%

ATLAS

$\Delta\mu/\mu$	300 fb^{-1}		3000 fb^{-1}	
	All unc.	No theory unc.	All unc.	No theory unc.
$H \to \mu\mu$ (comb.)	0.39	0.38	0.15	0.12
(incl.)	0.47	0.45	0.19	0.15
(ttH-like)	0.73	0.72	0.26	0.23
$H \to \tau\tau$ (VBF-like)	0.22	0.16	0.19	0.12
$H \to ZZ$ (comb.)	0.12	0.06	0.10	0.04
(VH-like)	0.32	0.31	0.13	0.12
(ttH-like)	0.46	0.44	0.20	0.16
(VBF-like)	0.34	0.31	0.21	0.16
(ggF-like)	0.13	0.06	0.12	0.04
$H \to WW$ (comb.)	0.13	0.08	0.09	0.05
(VBF-like)	0.21	0.20	0.12	0.09
(+1j)	0.36	0.17	0.33	0.10
(+0j)	0.20	0.08	0.19	0.05
$H \to Z\gamma$ (incl.)	1.47	1.45	0.57	0.54
$H \to \gamma\gamma$ (comb.)	0.14	0.09	0.10	0.04
(VH-like)	0.77	0.77	0.26	0.25
(ttH-like)	0.55	0.54	0.21	0.17
(VBF-like)	0.47	0.43	0.21	0.15
(+1j)	0.37	0.14	0.37	0.05
(+0j)	0.22	0.12	0.20	0.05

CMS: [Scenario2, Scenario1]

L (fb^{-1})	$\gamma\gamma$	WW	ZZ	bb	$\tau\tau$	$Z\gamma$	$\mu\mu$	inv.
300	[6, 12]	[6, 11]	[7, 11]	[11, 14]	[8, 14]	[62, 62]	[40,42]	[17, 28]
3000	[4, 8]	[4, 7]	[4, 7]	[5, 7]	[5, 8]	[20, 24]	[20,24]	[6, 17]

Not with LO κ-language

Lagrangian

$$\mathscr{L}_{\text{eff}} = \mathscr{L}^{(4)}_{\text{SM}} + \frac{1}{\Lambda^2}\sum_k \alpha_k \mathscr{O}_k,$$

$$\begin{aligned}\mathscr{L}^{(4)}_{\text{SM}} = & -\frac{1}{4}G^A_{\mu\nu}G^{A\mu\nu} - \frac{1}{4}W^I_{\mu\nu}W^{I\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} \\ & + (D_\mu\Phi)^\dagger(D^\mu\Phi) + m^2\Phi^\dagger\Phi - \frac{1}{2}\lambda(\Phi^\dagger\Phi)^2 \\ & + i\bar{l}\not{D}l + i\bar{e}\not{D}e + i\bar{q}\not{D}q + i\bar{u}\not{D}u + i\bar{d}\not{D}d \\ & - (\bar{l}\Gamma_e e\Phi + \bar{q}\Gamma_u u\tilde{\Phi} + \bar{d}\Gamma_d d\Phi + \text{h.c.}),\end{aligned}$$

Operators

Φ^6 and Φ^4D^2	$\psi^2\Phi^3$	X^3
$\mathscr{O}_\Phi = (\Phi^\dagger\Phi)^3$	$\mathscr{O}_{e\Phi} = (\Phi^\dagger\Phi)(\bar{l}\Gamma_e e\Phi)$	$\mathscr{O}_G = f^{ABC}G^{A\nu}_\mu G^{Bp}_\nu G^{C\mu}_\rho$
$\mathscr{O}_{\Phi\Box} = (\Phi^\dagger\Phi)\Box(\Phi^\dagger\Phi)$	$\mathscr{O}_{u\Phi} = (\Phi^\dagger\Phi)(\bar{q}\Gamma_u u\tilde{\Phi})$	$\mathscr{O}_{\widetilde{G}} = f^{ABC}\widetilde{G}^{A\nu}_\mu G^{Bp}_\nu G^{C\mu}_\rho$
$\mathscr{O}_{\Phi D} = (\Phi^\dagger D^\mu\Phi)^*(\Phi^\dagger D_\mu\Phi)$	$\mathscr{O}_{d\Phi} = (\Phi^\dagger\Phi)(\bar{q}\Gamma_d d\Phi)$	$\mathscr{O}_W = \varepsilon^{IJK}W^{Iv}_\mu W^{Jp}_\nu W^{K\mu}_\rho$
		$\mathscr{O}_{\widetilde{W}} = \varepsilon^{IJK}\widetilde{W}^{Iv}_\mu W^{Jp}_\nu W^{K\mu}_\rho$
$X^2\Phi^2$	$\psi^2X\Phi$	$\psi^2\Phi^2D$
$\mathscr{O}_{\Phi G} = (\Phi^\dagger\Phi)G^A_{\mu\nu}G^{A\mu\nu}$	$\mathscr{O}_{uG} = (\bar{q}\sigma^{\mu\nu}\frac{\lambda^A}{2}\Gamma_u u\tilde{\Phi})G^A_{\mu\nu}$	$\mathscr{O}^{(1)}_{\Phi l} = (\Phi^\dagger i\overleftrightarrow{D}_\mu\Phi)(\bar{l}\gamma^\mu l)$
$\mathscr{O}_{\Phi\widetilde{G}} = (\Phi^\dagger\Phi)\widetilde{G}^A_{\mu\nu}G^{A\mu\nu}$	$\mathscr{O}_{dG} = (\bar{q}\sigma^{\mu\nu}\frac{\lambda^A}{2}\Gamma_d d\Phi)G^A_{\mu\nu}$	$\mathscr{O}^{(3)}_{\Phi l} = (\Phi^\dagger i\overleftrightarrow{D}^I_\mu\Phi)(\bar{l}\gamma^\mu\tau^I l)$
$\mathscr{O}_{\Phi W} = (\Phi^\dagger\Phi)W^I_{\mu\nu}W^{I\mu\nu}$	$\mathscr{O}_{eW} = (\bar{l}\sigma^{\mu\nu}\Gamma_e e\tau^I\Phi)W^I_{\mu\nu}$	$\mathscr{O}_{\Phi e} = (\Phi^\dagger i\overleftrightarrow{D}_\mu\Phi)(\bar{e}\gamma^\mu e)$
$\mathscr{O}_{\Phi\widetilde{W}} = (\Phi^\dagger\Phi)\widetilde{W}^I_{\mu\nu}W^{I\mu\nu}$	$\mathscr{O}_{uW} = (\bar{q}\sigma^{\mu\nu}\Gamma_u u\tau^I\tilde{\Phi})W^I_{\mu\nu}$	$\mathscr{O}^{(1)}_{\Phi q} = (\Phi^\dagger i\overleftrightarrow{D}_\mu\Phi)(\bar{q}\gamma^\mu q)$
$\mathscr{O}_{\Phi B} = (\Phi^\dagger\Phi)B_{\mu\nu}B^{\mu\nu}$	$\mathscr{O}_{dW} = (\bar{q}\sigma^{\mu\nu}\Gamma_d d\tau^I\Phi)W^I_{\mu\nu}$	$\mathscr{O}^{(3)}_{\Phi q} = (\Phi^\dagger i\overleftrightarrow{D}^I_\mu\Phi)(\bar{q}\gamma^\mu\tau^I q)$
$\mathscr{O}_{\Phi\widetilde{B}} = (\Phi^\dagger\Phi)\widetilde{B}_{\mu\nu}B^{\mu\nu}$	$\mathscr{O}_{eB} = (\bar{l}\sigma^{\mu\nu}\Gamma_e e\Phi)B_{\mu\nu}$	$\mathscr{O}_{\Phi u} = (\Phi^\dagger i\overleftrightarrow{D}_\mu\Phi)(\bar{u}\gamma^\mu u)$
$\mathscr{O}_{\Phi WB} = (\Phi^\dagger\tau^I\Phi)W^I_{\mu\nu}B^{\mu\nu}$	$\mathscr{O}_{uB} = (\bar{q}\sigma^{\mu\nu}\Gamma_u u\tilde{\Phi})B_{\mu\nu}$	$\mathscr{O}_{\Phi d} = (\Phi^\dagger i\overleftrightarrow{D}_\mu\Phi)(\bar{d}\gamma^\mu d)$
$\mathscr{O}_{\Phi\widetilde{W}B} = (\Phi^\dagger\tau^I\Phi)\widetilde{W}^I_{\mu\nu}B^{\mu\nu}$	$\mathscr{O}_{dB} = (\bar{q}\sigma^{\mu\nu}\Gamma_d d\Phi)B_{\mu\nu}$	$\mathscr{O}_{\Phi ud} = i(\tilde{\Phi}^\dagger D_\mu\Phi)(\bar{u}\gamma^\mu\Gamma_{ud}d)$

Examples & Details

What is the *best* question that an amateur could ask now?

Why is the Higgs boson decaying?

Disappointing ANSWER: because it can (**Quantum Mechanics**), if it can happen it will happen

- We describe the Higgs boson as a particle, which implies that it is a real thing, an object, and thus when we are told it undergoes 'decay' we summon analogies with other objects we know to decay, like
  - organic matter (because of chemical influences from outside) or perhaps
  - radioactive decay (because a nucleus is in an unstable state, and the energy required to allow it to remain in existence is less if it spits out energy in the form of a photon or something
- When we talk about any "fundamental" particle such as the Higgs, the reason for its decay is actually much more simple. Such a particle is not an "object" in the sense we usually imagin, it is more accurately described as a "possibility"