Revisiting the Higgs Wishlist

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After a two week long Higgs Identification Rapid Response Workshop in December, 2012, the participants created a Higgs wishlist for future studies. It is of some interest to review this list, to see how far we have come in 3 ½ years, and how many fundamental questions remain unresolved.

Theory Questions

- Is the observable Higgs state at 125 GeV responsible for the unitarization of $W_L W_L$ scattering?

- How close to the alignment limit is the 125 GeV Higgs boson?
  - Are there new Higgs sector phenomena in reach by experiment (alignment without decoupling?)
  - Can we distinguish between tree-level Higgs mixing and loop-induced effects due to BSM physics?

- What if deviations from SM Higgs couplings are found?
  - If large deviations are detected, is there a compelling source of BSM physics that can account for the deviations?
  - If small deviations are eventually established, what are the systematics of the deviations, and do they point to a particular BSM scenario and/or extended Higgs sector?

- Precision Higgs observables as a probe of new physics
  - How well can the LHC do in the asymptotic limit?
  - What is the value added by the ILC?
  - If deviations from SM Higgs couplings are detected can one extract a value for the mass scale of the new physics (Λ_{BSM})?
  - How reliable is the determination of Λ_{BSM}, and how is this quantity related to a measurable quantity?
  - How many standard deviations are required for the deviations to be convincing [cf. $(g-2)_\mu$, A_L , $A_{FB}(b)$]?

- Fate of the Higgs self-coupling $\lambda(Q)$ as $Q \rightarrow M_{PL}$?

  - Is the Higgs vacuum stable or metastable?

  - What is the theoretical origin of λ?

How does BSM physics impact these questions?

  - For example, in the MSSM, λ is determined by gauge couplings, and the Higgs vacuum is therefore stable.

  - In other BSM models, the corresponding answers may not be so straightforward.

- Is the gauge hierarchy problem resolved by TeV-scale physics? If yes, does this new physics provide us with a more fundamental understanding of the origin of electroweak symmetry breaking?

  Supersymmetry remains the favored candidate, but if and when new physics is discovered, avoid the temptation to drive a square peg into a round hole.

  Nevertheless, the SUSY wishlist for Higgs physics includes:

  - A resolution to the μ problem.
  - A more accurate computation of the Higgs mass to reduce the uncertainty below 1 GeV.

Higgs Wishlist for the Experiments

- Is the γγ excess statistically significant?
- Do the $ZZ^{*} \rightarrow$ 4 lepton events provide a consistent story (relative to γγ)?
- Are the ATLAS and CMS Higgs data self-consistent?
- How much tension is there with the SM expectations?

- We are eager for some clarifications…

  - Can custodial symmetry in the Higgs couplings be verified (ultimately with a similar accuracy to the ρ-parameter)?

  - Can we experimentally verify that fermion masses arise from the same mechanism as the gauge boson masses? That is, show the expected dependence of Higgs couplings on masses.

  - Is BR($h \to \gamma Z$) consistent with BR($h \to \gamma\gamma$)?

  - What is BR($h \to$ non-SM channels)?

  - What is BR($h \to$ invisble)?

➢ Further clarifications…

- ❑ Confirm spin and CP quantum numbers of the boson.
- ❑ Measure the htt coupling (better yet: h coupling to the top partners, if they exist!)
- ❑ Double Higgs production: in the far future of a higher luminosity and/or higher energy LHC. Still, beyond the hhh coupling, one can try to detect the WWhh coupling, and identify potential BSM physics effects in the gghh box diagram.
- ❑ Should we perhaps worry about detecting the WWWW quartic vertex and make sure that the gauge structure is preserved?

➢ Beyond the SM Higgs boson---more wishes

- ❑ Find the charged Higgs boson.
- ❑ Measure tan β (if you are absolutely certain that the Higgs sector corresponds to a Type-I or II 2HDM).
- ❑ Even better---if you suspect that the Higgs sector corresponds to a 2HDM, measure the basis-independent Yukawa coupling matrices (since a priori, tan β is a meaningless quantity) and experimentally determine the structure of the Higgs-fermion coupling.
- ❑ Are there two nearly mass-degenerate scalars with mass around 125 GeV?