Energy Frontier: Higgs Boson Physics at Hadron Colliders

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Higgs Energy Frontier Charge:

1. Provide a compact summary of the measurements on and searches for the SM Higgs boson, including information from LEP, the Tevatron, and the LHC. Include in this summary a survey of searches for non-minimal Higgs sectors. (Some General Remarks first – the summary of results is straight-forward and informative)

An energy frontier hadron collider provided a compelling and effective search strategy for the Higgs boson:

The LHC cornered the Standard Model with make it or break it capabilities for the Higgs boson search.

Now that a particle has been observed at 125-126 GeV in the SM Higgs search, we need to understand how well we can measure the properties of this particle. Are we in an equally compelling position to continue to investigate this particle, and how should the beam energy and luminosity evolve to keep this program progressing in leaps of sensitivity?

The 1st charge provides the reference point of what we know now (HCP 2012 and Moriond 2013) and we will compare against this reference to quantify the future gains we expect from different scenarios of the hadron collider program.

Higgs Energy Frontier Charge:

2. Provide a compact summary of the theoretical motivations to explore the properties of the Higgs boson to high precision. (The Higgs sector is an avenue for future discovery – how well can we quantify this in the context of what is experimentally possible. We need to establish a strong motivation for this physics.)

a) What is the full phenomenological profile of the Higgs boson? What are the predicted production modes, the final-states, and the experimental observables? (Hadron collider experiments cannot explore the full Higgs phenomenology – but there is an incredible richness at 125 GeV and we need to show what can be done in terms of a diversity of analyses)

b) What are the ranges of predictions for deviations from Standard Model properties that enter from new physics? Which production and decay channels and boson properties are most sensitive to these deviations? (Beyond discovery, can theory guide us to achieve key sensitivities and is there a good match between BSM in the Higgs sector and experiment?)

c) What can be learned from the discovery of bosons from non-minimal Higgs sectors? What is the phenomenology of non-minimal Higgs models? (Are there compelling directions for extended Higgs sector searches?)

d) To what extent are properties of the Higgs boson and the Higgs sector in general important for understanding fundamental physics and the universe?

Higgs Energy Frontier Charge:

3. Organize a set of simulation studies to evaluate the level of precision that can be achieved on Higgs physics measurements for the range of choices of accelerator facilities and detector capabilities under consideration by the Facilities/Instrumentation groups. Include studies of search sensitivities for non-minimal Higgs sectors. (This is the main experimental charge.)

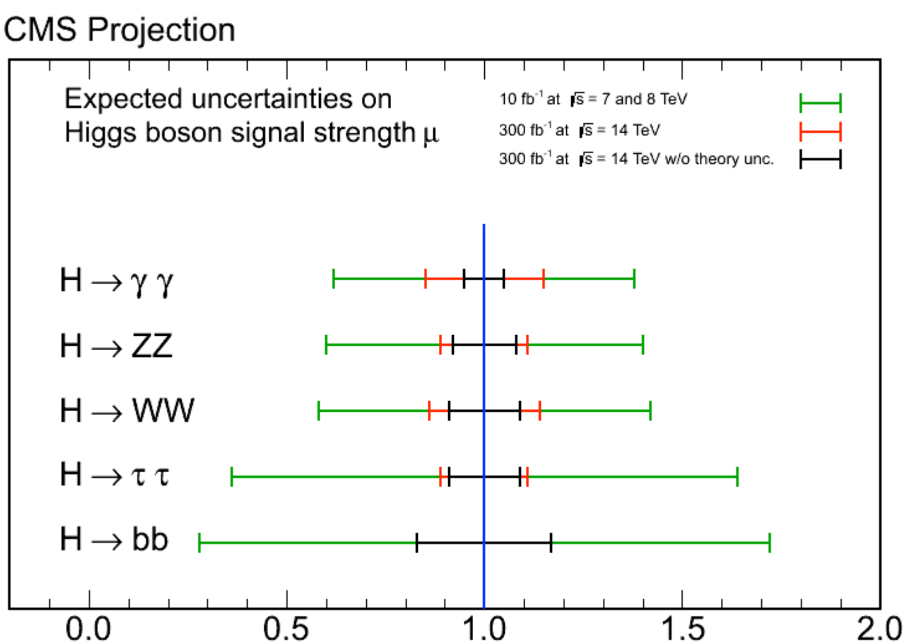
a) To what degree can a particular experimental program ascertain whether the resonance at 125-126 GeV is the Standard Model Higgs boson? To what precision can each of the measured properties of the Higgs boson be determined and tested against SM predictions?

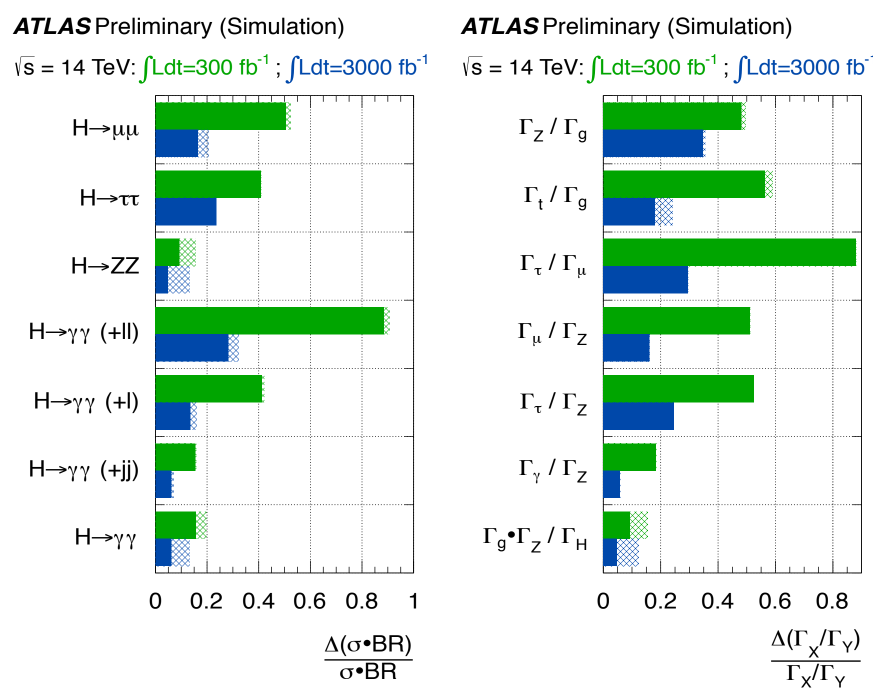
This is a statement primarily for the Atlas and CMS experiments to address through simulation and guided by what has been achieved so far. There is the basic approach which is to take the current searches for SM final states and push them to the benchmarks of 300/fb at 14 TeV, 3000/fb at 14 TeV, and 300/fb at 33 TeV – bringing in Upgrades that are central to Higgs search sensitivities.

Detailed dissection of these final states and coherence of the Higgs properties are enumerated in parts c) and d) - part a) is a base understanding.

Example Analyses

- Initial work has been done on σ•BR for Present→300fb^{-1}@14TeV→3000fb^{-1}@14TeV
- HE-LHC option needs study (and what the are specific benefits for Higgs physics and extended sectors)
- Mass, Parity, Spin, Tables of σ•BR precisions for all final states





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b) What are the search sensitivities for bosons in non-minimal Higgs sectors?

This is taken to be opportunistic, not comprehensive. What can be discovered in Higgs sectors beyond the SM over the wide mass range probed by a hadron collider?

There are natural extensions to the SM Higgs that predict additional particles in the Higgs sector. The leading production modes can be different, the decay chains can be different, and some combinations of these could be best addressed at hadron colliders. SUSY Higgs (A, H, H +/-), nMSSM-specific decays (H→aa), and other extensions are part of the rich phenomenology that hadron colliders can explore – especially from the wide-band mass range (125 GeV is on the lowest end of what the LHC was built for)

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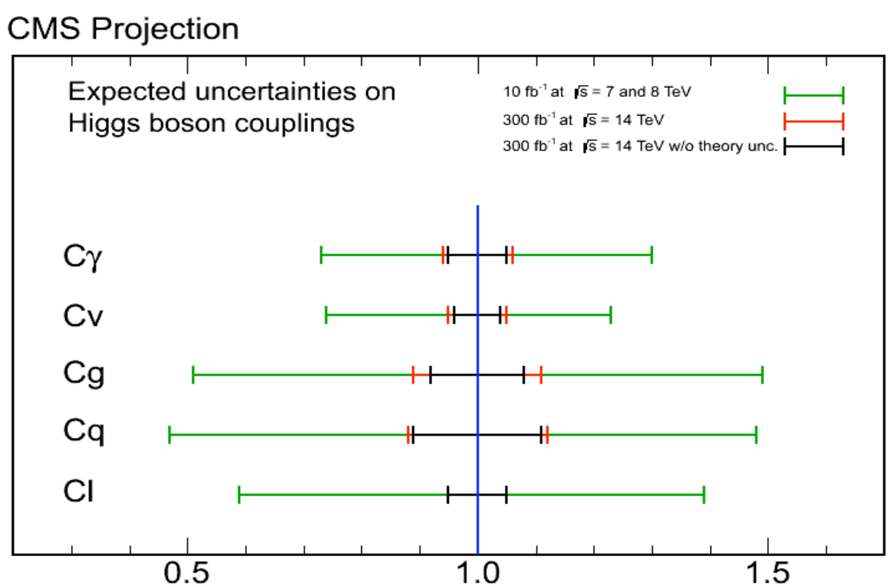
c) The studies should summarize their results in terms of these areas:
   i. Mass and width measurements
   ii. "Couplings" in terms of production cross section by process and branching fractions by decay mode, including searches for non-SM couplings
   iii. "Tensor structure" in terms of quantum numbers (JCP) and effective couplings in the Lagrangian
   iv. Couplings and properties governing the Higgs potential

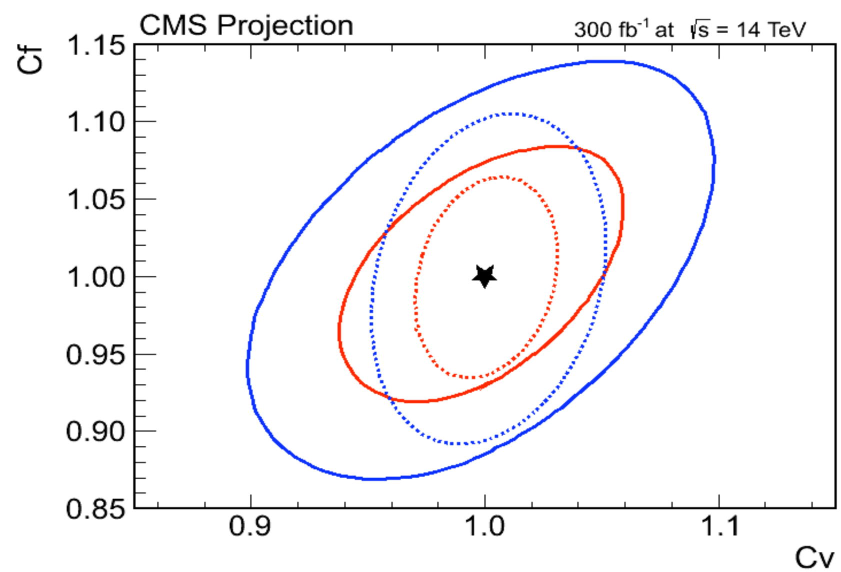
This is the detailed quantitative approach to dissecting the Higgs sector. There is an embedded indirect energy frontier search here that is potentially the farthest reaching mass scale that we can hope to probe at the LHC. The sensitivity to large mass scale needs to be quantified.

Direct observation of the Higgs potential properties will bring the Higgs theory together in full circle – but how well can we really do this.

Example Analyses

- Initial work couplings has been done for Present→300fb^{-1}@14 TeV
- More final states need to be included for HL-LHC and HE-LHC options
- Final states for Triple-Higgs couplings under study (&Higgs pair rate)
- Differential decay rates/tau-polarization correlations in H→ττ
- Alternative presentations of results and the evolution of the sensitivity on these quantities may also be helpful





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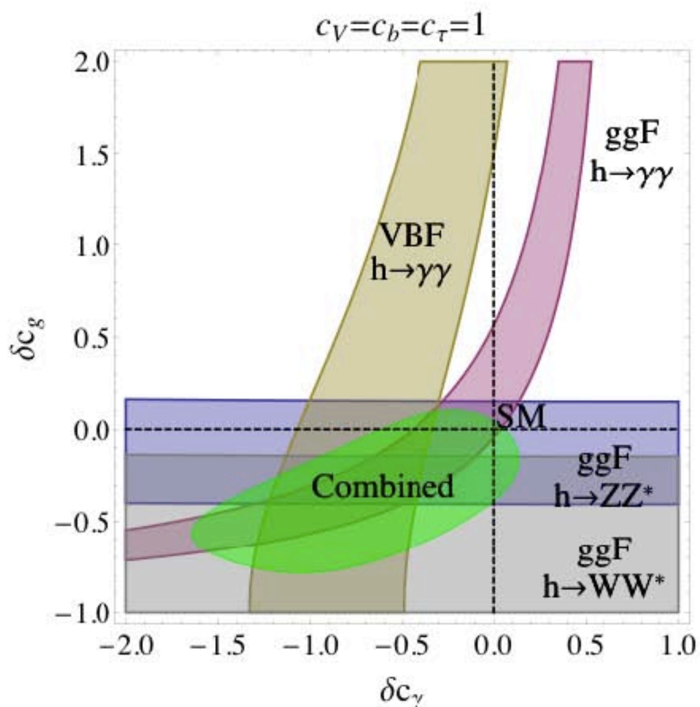
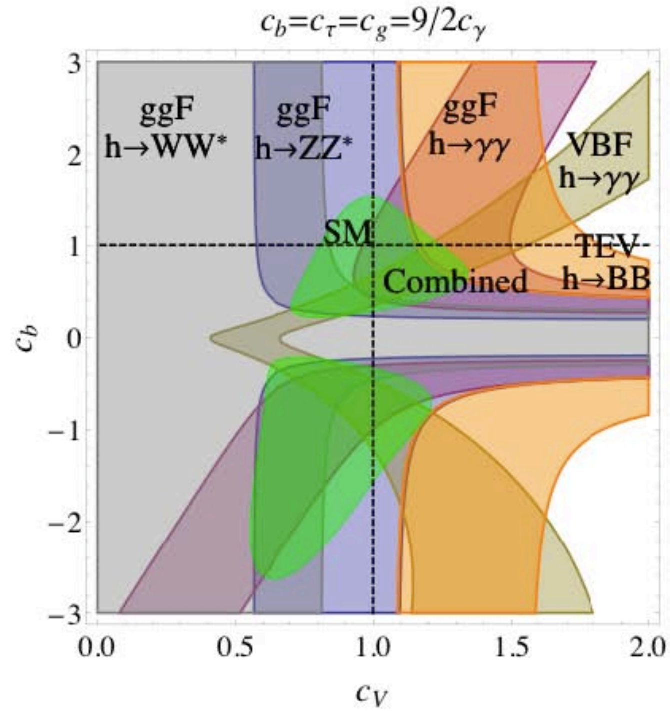
Alternative Presentation of Results

$$\mathcal{L}_{eff} = c_V \frac{2m_W^2}{v} h W_\mu^+ W_\mu^- + c_V \frac{m_Z^2}{v} h Z_\mu Z_\mu - c_b \frac{m_b}{v} h\bar{b}b - c_\tau \frac{m_\tau}{v} h\bar{\tau}\tau + c_g \frac{\alpha_s}{12\pi v} h G^a_{\mu\nu} G^a_{\mu\nu} + c_\gamma \frac{\alpha}{\pi v} h A_{\mu\nu} A_{\mu\nu} + \ldots$$





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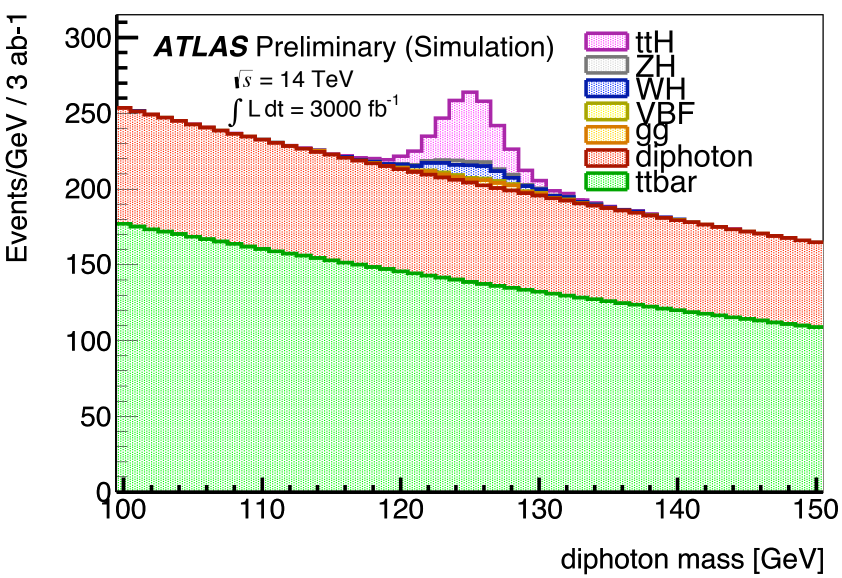
d) What are intrinsic advantages of particular experimental programs? Are there unique capabilities to reconstructing particular decays or unique sensitivities to particular rare decay rates? Are there properties that can be determined in some experimental programs and not in others? To what extent can complementary programs enhance the overall Higgs physics program?

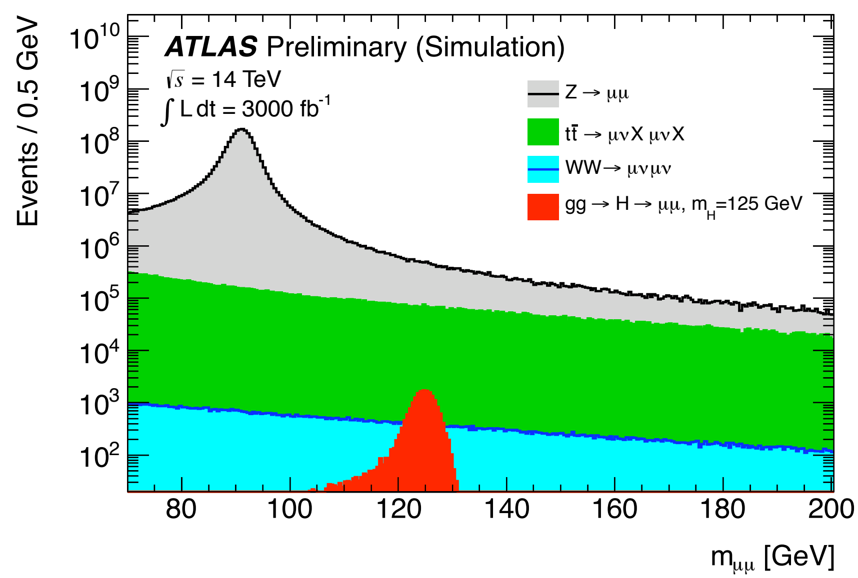
This part comes out of the comparison and combination with the lepton collider approach (or gamma gamma or other potential colliders).

Hadron colliders have high production rates – so processes like top +diphoton can be observed. Decay fraction sensitivity have a starting point of 10^8 Higgs bosons.

Example Analyses

- Rare SM Final States
  - ttH (H→γγ)
  - H→μμ
  - H→Zγ
  - H→ZZ→4ν
  - VBF produced





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e) Provide cross-calibration for the simulation tools to provide a record of what intrinsic performances and assumptions went into these results.

Here we want to make sure there is no question about the validity or assumptions that go into these studies. Atlas and CMS approve these results, so this is mostly covered on detector performance. For backgrounds and other assumptions (including out-of-time pile-up, etc.), these need to be documented.

Workshops and Planning

- The committee recognizes that the simulation work is substantial and organization of this work must begin in advance of the end of 2012
  - We propose a January meeting (Jan. 14-15th at Princeton) to report on the progress and plans for completing these studies – will be well advertized and open to all experimental and theory groups studying the future of Higgs physics
  - Compare hadron, lepton and other collider and detector options to see where there are expected to be big gains and differences
  - Verify the timeline for analysis sample production by experimental groups
  - Identify the analyses that the experiments plan to undertake
  - Monthly meetings with experimental contacts to understand what studies are to be organized and address open questions