Disclaimer:

The following draft summary points are based on our current understanding. As white papers with details are still coming in, more information may be added and the numbers may change. These updates may impact the details of the conclusions. Furthermore, we will continue to deliberate the exact wording of the summary.

Higgs Physics Summary

1. Many extensions to the Standard Model predict deviations of Higgs couplings from SM values. The sizes of deviations vary. However for new physics at TeV scale, percent level deviations are expected from many models.

2. Full exploitation of LHC and HL-LHC Higgs measurements will require improvements in theoretical calculations of the gluon fusion Higgs production cross section, both inclusive and with jet vetoes. To match sub-percent experimental uncertainties on Higgs partial widths from Higgs factories will require consistent inclusion of higher order electroweak corrections to Higgs decays, as well as an improvement of the bottom quark mass determination to below ±0.01 GeV.

3. LHC is the place to study Higgs boson in the foreseeable future. The expected precision of Higgs couplings to fermions and vector bosons are estimated to be 5-15% for 300 fb^{-1} and 2-10% for 3000 fb^{-1} at 14 TeV. Better precisions can be achieved for some coupling ratios.

4. Precision tests of Higgs boson couplings to one-percent will require complementary precision programs. Proposed Higgs factories such as linear or circular e^+e^- colliders and potentially a muon collider will be able to achieve these precisions for many of the couplings, and in a more model-independent way than the LHC.

Higgs Physics Summary

5. LHC can measure the Higgs boson mass with a precision of ~100 MeV, however has limited sensitivity to Higgs decay width. Higgs factories such as ILC, LEP3 or TLEP will improve the mass precision to about 35 MeV and measure Higgs decay width up to ~1.3% in precision. Through a line-shape scan, a muon collider can measure the width directly and the mass to sub-MeV precisions.

6. Direct ttH coupling measurements can be done at LHC, ILC, CLIC and muon colliders. The expected precisions are ~8% at HL-LHC, ~4% at ILC and ~3% at CLIC. A high energy muon collider is expected to have the comparable precision as CLIC.

7. Higgs self-coupling is difficult to measure at any of these facilities. A ~20% ultimate measurement is expected from HL-LHC and lepton colliders at 1 TeV. Improvement would need higher energy hadron or lepton colliders such as a CLIC or muon collider, HE-LHC, or VLHC.

8. The spin of the 125 GeV boson will be constrained by the LHC. A limited parameter space of spin-two couplings may be left to be constrained by the data from the future facilities. Potential CP admixture in spin-zero $H \rightarrow ZZ^*$ decay will be measured by LHC to a few percent precision. Lepton colliders operating at ZH maximum can measure this to a greater precision.

Higgs Physics Summary

9. There are strong theoretical arguments for physics beyond the Standard Model. LHC has the highest discovery potential for heavy Higgs bosons as predicted by many Standard Model extensions. Mass reach can be 1 TeV or higher with 3000 fb^{-1} at 14 TeV, but is strongly model dependent. The mass reach is generally limited to less than half the collision energy for e^+e^- colliders and potentially up to the collision energy for a muon collider through s-channel processes.

Facility Comparison

1. LHC or other higher-energy pp colliders will be able to study most aspects of the Higgs physics. The precision achievable at HL-LHC for many couplings is comparable to those of a circular or first-phase linear collider at 250 GeV with 250 fb^{-1}. The hadron colliders generally have the highest discovery potential for heavy Higgs bosons.

2. TeV-scale e^+e^- linear colliders (ILC and CLIC) will offer the full menu of measurements of the 125 Higgs boson, their mass reach for heavy Higgs bosons are generally weaker than high-energy pp colliders. The two linear colliders have different capabilities – the ILC can drop down to the Z peak while CLIC has a higher energy reach and better precision in Higgs self-coupling measurement.

3. TLEP has the best precisions for most of the Higgs coupling measurements. By itself it has no sensitivity to ttH and HHH couplings. However a higher energy pp collider that could potentially be operated in the same tunnel, would have the best sensitivity to the Higgs self-coupling as well as the highest discovery potential for heavy Higgs bosons.

4. A TeV-scale muon collider should have the same physics capability as the ILC and CLIC combined, but this needs to be demonstrated with more complete simulations. The potential polarization is important for testing CP in Higgs-fermion couplings.

Facility Comparison

5. LEP3 has comparable sensitivities with lepton colliders in most of the Higgs coupling measurements, but has no possibility for studying ttH and HHH couplings and no potential for discovering heavy Higgs bosons.

6. A $\gamma\gamma$ collider is ideal to study CP mixture and violation in the Higgs sector. It can significantly improve the precision of the effective $\gamma\gamma$H coupling measurement, therefore more sensitive to potential new physics in the loop.

Conclusion

The discovery of the 125 GeV Higgs boson creates a new dimension for further discoveries in elementary particle physics. An assessment of the Higgs physics reach conducted on a wide range of potential new colliders and collider options shows that deviations in the coupling of the Higgs field to matter can be tested at an order of magnitude higher sensitivity than with the current LHC program. To challenge the precision of the Higgs theory with experiment at these levels will determine the future evolution of the physical vacuum and therefore the fate of the universe and answer the question within our current theoretical understanding as to whether the universe came about under natural conditions.