A Brave New Deal:
Charting the Future of US High Energy Physics

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1 Introduction

A detailed study of Higgs boson couplings beyond the HL–LHC program requires a lepton collider. A Higgs factory based on electron-positron linear collider with a center of mass of 250 GeV, proposed by the ILC consortium, is well studied and worthy of US participation.

For TeV-scale Higgs boson physics, for instance, measurement of the triple-Higgs couplings via Higgs boson pair production, probing quartic-Higgs self-coupling or searches for heavy Higgs partners beyond the HL–LHC reach, lepton colliders with muon beams may be more cost effective than a hadron-hadron collider. Amongst the lepton colliders in discussion, for the case of 10-TeV scale physics, muon beams may be the only viable option.

The previous Snowmass process has ensured the US energy frontier community can continue research with its participation in the HL-LHC program in Europe, but has left open its commitment to the ILC in Japan. In order to foster a healthy long term international collider physics program, we believe that in addition to joining the ILC in Japan, the US should conduct intense R&D towards developing a muon-collider on its soil.

A starting point for returning the energy frontier program to the US soil could be a muon-collider at 3 TeV center-of-mass operating at $\approx 1 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Such a machine could be built in a few km ring located on or close to the Fermilab site. This ring could serve as an injector for a 30-km ring for a longer term 30-100 TeV scale discovery machine.

The physics case for a 3-TeV muon collider where several ab^{-1} luminosity are accumulated is very strong. We would be able to measure triple-higgs coupling definitively. We can explore the extended higgs sector to few TeV scale. We can search for weakly coupled new physics more thoroughly, in a cleaner environment with well-defined center-of-mass collisions of muon collider continuing from the HL-LHC.

Remarkably, taming the handling of intense muon beams opens up a very long life for high energy physics, possibly extending human reach to 100-TeV scale physics in our future laboratories. Intense neutrino beams from the muon decays allow good synergy with our current focus on the study of neutrino properties.

2 Proposal

As newcomers to the ILC physics studies, we will have nothing substantial to add on a short time scale. Rather we propose to learn from the existing ILC studies, especially those for 1-TeV case, and extend them to 3-TeV case at a muon collider. We believe such a comparison could be quite useful in defining our plans for the future.

Specifically, we propose the following benchmark processes for a 3-TeV muon collider:

- Higgs boson pair production, $\mu^+\mu^- \rightarrow \nu\nu HH$ and $\mu^+\mu^- \rightarrow ZHH$
- Triple Higgs boson production, $\mu^+\mu^- \rightarrow \nu\nu HHH$
- Detailed measurements of multi-electroweak boson production processes
- Search for extended Higgs sector heavy or light scalars and pseudoscalars
- Higgs portal to dark sector

The physics studies will be conducted using ultrafast delphes-based simulation. However, the true object reconstruction efficiencies and fake object rates are of concern in the muon-collider environment. These aspects will need to be investigated using full simulation detail. The detector that our team is most familiar with is the CMS. The upgraded HL–LHC-version of CMS has 4-D reconstruction capability including time of arrival of signals. The HL-LHC object reconstruction is also well studied and benchmarked in detail in the proton-proton collision environment with 200 collisions per LHC bunch crossing. We would like to understand the capabilities of this upgraded CMS-like detector in reconstructing physics objects and the backgrounds that may be seen at the muon collider. We propose to modify the CMS GEANT4 simulation to replace the forward region detectors with a cone of tungsten shielding. We will use MARS to produce beam induced backgrounds from the decay of the beam muons. CMS software has capabilities to superimpose such backgrounds over the high P_T collision events.

3 The Team

Our team has extensive experience in collider physics, having been engaged in OPAL, SLD, CDF, D0, BaBar, ATLAS and CMS experiments over the past decades. We have been engaged in constructing mechanical structures for the detector, building muon chambers, building electronics for trigger and data acquisition systems, developing firmware and software for data acquisition systems, and developing prompt and offline reconstruction, monitoring, calibration and analysis workflows.