Next Generation Hadron Colliders

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Chapter 1

Introduction

The Nature of an Historic Science: Probing the Extremes of Spacetime and Energy. What are the Next Steps?

The science of studying matter and energy at the smallest physical scales has a century-old history beginning with the discovery of the electron in 1895. Variously called Elementary Particle Physics and High Energy Physics (HEP), it is a subfield of Physics made up of 5000 physicists from most industrialized countries in the world. "HEP" tells the operational story: In order to uncover the details of the sub-nuclear world, projectiles of particles are produced and collided. The higher the energies of the projectiles, the further into the quantum mechanical world the probes see.

Construction of the devices necessary to create these energies are massive projects of now international scope. These laboratories are funded in as many ways as there are nations contributing, but they are all funded by public funds. Every physicist making use of these devices is grateful for the opportunity and mindful of the privilege inherent as ambassadors to these unknown regions of space and time. Currently, we are enjoying the full use of of facilities in Illinois, California, Northern Germany, Switzerland, and Japan. This collection of laboratories is collectively pointing the way to the next steps, each lab focussed on particular questions. In previous years, the next steps were often clear and numerous, designed around the variety of directions suggested by the previous research. Now we are at a unique point in five decades as the number of concrete plans is limited to one facility, the Large Hadron Collider (LHC) in Switzerland. The complexity of these facilities and the devices constructed to make use of them have lengthened the leadtimes required to design and construct them and increased the investments required.

1.1 Some Facts and Vocabulary

Traditionally, experiments in High Energy Physics have been done with three general kinds of particle accelerators:

"fixed target" facilities in which beams of protons, neutrons, photons, neutrinos, pions, and other more exotic particles have been produced externally to the parent proton source;

lepton collider facilities in which electrons are collided with their antiparticle partners, positrons, within a single accelerator; and

hadron colliders in which counter-rotating beams of protons/antiprotons/ions are collided within a single acclerator.

It has been useful from the perspective of both enhancing discovery potential and precision determination of parameters to have bootstrapped generations of both lepton colliders and hadron colliders running in parallel, upgrading in parallel, and planning for future upgrades in parallel. This synergy has been especially fruitful during the years of planning, building, and running of the CERN SPS, Fermilab Tevatron, SLAC PEP, DESY, PETRA,CERN LEP, KEK, Tristan, SLAC SLC, and CERN LHC. Currently this tradition continues with the upgraded Tevatron, SLAC B-Factory, and KEK B-Factory and the future points directly to the CERN Large Hadron Collider (LHC). The hope is that the world's plans for the future will include a next generation electron-positron collider and a next generation hadron collider.

The recognition that a lepton partner to the CERN LHC would be required led to the beginning of planning for a Next Linear Collider (NLC) in the late 1980's. This work began to mature such that in May of 1993, the International Committee for Future Accelerators recognized a collaborative venture of DESY, KEK, and SLAC to coordinate the worldwide R&D of linear colliders and to develop the accelerator physics and engineering along with the development of the physics case. This effort has recently led to recommendations for various possible sitings and technical implementations for a linear collider facility of electrons and positrons to be operational in Europe, the US, or Japan by the second decade of the 21st century. The planning will therefore have preceeded actual implementation by nearly a quarter of a century. Likewise, the planning for the LHC preceeded its construction by a similar leadtime.

The subsequent facility will likely be a post-LHC hadron collider. Realistically, its implementation is unlikely before the middle of the next decade. Work on accelerator concepts began roughly five years ago, primarily at Fermilab but also at CERN. Using the above experience as a guide, realization of such a device is then conceivable on a timescale of approximately 2015-2020. The accelerator physics and engineering is maturing at both laboratories, but the physics case has not yet matured to the point of being able to help drive parameter and/or staging choices. Recognizing that it is time to begin, the first real effort in this regard was begun at the Snowmass workshop in 2001.

This document is meant to be a follow-on report of progress in both the physics case and the detector issues for such a facility. It is organized in a modular fashion and can hopefully be read by a variety of audiences: from those who simply want a broad, but timely introduction to those who are concerned with the details of the latest R&D and simulations. As an e-document it can be navigated according to taste, with the depth of the links probing to the more detailed results.

Chapter 2

Higgs Physics

Inherent in the assumptions of the Standard Model is a mechanism for breaking of the symmetry presumed to have held in the hottest periods of the Universe's evolution. The working assumption surrounding this symmetry breaking is that, just as is true in the descriptions of many-body descriptions of various phase transitions such as ferromagnetism, superconductivity, etc., the formation of a macroscopic, quantum mechanical "quasi particle" occurs which is a manifestation of a measurable disturbance in the ground state of the system. In traditional bulk materials, these quasi particles are sometimes loosely-bound states of component objects of the unbroken system (Cooper electron pairs in superconductivity). In the Standard Model, in which the ground state is the vacuum, this manifestation is a spinless, massive hadron named for its inventor, Peter Higgs. The Higgs boson, then, has been increasingly anticipated as the Standard Model's successes have multiplied over now nearly 3 decades.

There are inherent difficulties with this naive picture. These difficulties are of a technical and mathematical nature and depending on how the eventual story turns out, may affect the eventual nature of the Higgs boson, it's properties and decays, as well as the actual number of them. Searching for it's manifestation and unravelling of its properties is at the heart of the most fundamental searches ongoing today. The task for the next higher energy machines will be to further study its properties and to be prepared for surprises and odd features which may challenge low-energy facilities. Of particular importance is the complete characterization of how the Higgs boson(s) couples to matter and to other Higgs bosons. This critical investigation may require considerable center of mass energy, as the Higgs boson is guaranteed to be more than 100 GeV/c^2 in mass. Multiple Higgs boson scenarios may involve particles which are significantly more massive than this.

The production of Higgs bosons at hadron colliders can be of a variety of forms, depending on the mass of the boson itself. For intermediate masses (100-150 GeV/c^2), the most promising channel | is through association with a W boson.

Bibliography

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