Prospects for Higgs Boson & Top Quark measurments and applications of CMOS MAPS for digital calorimetry at future linear colliders

A. Winter

Thesis submitted for the degree of
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Particle Physics Group,
School of Physics and Astronomy,
University of Birmingham.

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ABSTRACT

X was measured, we showed that $Y \neq Z$ and that $M_{\mathrm{H}} = 126\ \mathrm{GeV}/c^2$.

DECLARATION OF AUTHORS CONTRIBUTION

I did this, and that, and some of the other.

ACKNOWLEDGEMENTS

I would like to thank bla, and bla ...

Motto or dedication

Contents

List of Tables

List of Figures

DEFINITIONS OF ACRONYMS

HL-LHC High Luminosity Large Hadron Collider

LHC Large Hadron Collider
Superconducting collider occupying the 27 km ring at CERN.

QCD Quantum Chromodynamics

SM Standard Model

BSM Beyond the Standard Model

HL-LHC High Luminosity Large Hadron Collider

FCC Future Circular Collider

CLIC Compact Linear Collider

ILC International Linear Collider

CMOS Complimentary Metal-Oxide Semiconductor

MAPS Monlithic Active Pixel Sensors

EM Electromagnetic

ECAL Electromagnetic Calorimeter

DECAL Digital Electromagnetic Calorimeter

CHAPTER 1

INTRODUCTION

With the expected shutdown of the High Luminosity Large Hadron Collider (HL-LHC) in 2038, and the long time scales associated with the construction of any new colliding facility($\tilde{1}$0 years), the time for physicists to agree on what experiments should follow in the post-Large Hadron Collider (LHC) era is rapidly approaching, with initial decisions expected to take place in the early 2020s. However, following the discovery of a Higgs Boson at the LHC [1, 2], with properties in agreement with those predicted by the Standard Model (SM), the particle physics community is left in a situation where there is no definitive course of action through which new physics might be discovered. There are still many open questions remaining; one clear example being the origin of dark matter, which has been observed to make up $\tilde{2}$7% of the universe. Despite being examined through multiple astrophysical observations such as a, b and c (e.g gravitational lensing, galaxy rotation velocity + refs) there is still no proven particle physics explanation for what it is made from or how it is produced. Other notable examples include the matter-antimatter aysmmetry of the universe which is yet to be explained by the levels of CP violation measured in the SM(ref) and the Higgs heirarchy problem / fine tuning problem where it is expected that a precise cancellation of quantum corrections is needed to be able to simultaneously explain the difference in strength between the weak and gravitational forces while allowing for the measured value of the Higgs mass(ref). Currently there is no clear direction for how to answer these questions; as such there are two main approaches that may be taken. The first is to continue to push the boundaries of the "energy frontier" (following the approach of the LHC) and look for new physics at higher energy scales that is not predicted by the SM, but is predicted by many Beyond the Standard Model (BSM) models such as supersymmetry (ref). In this scenario the natural option is to build a circular hadron collider. While hadrons result in more complex interactions due to the fact they are structured, they are well suited for high energy collisions due to their high masses which reduce the amount of synchotron radiation emitted (radiation produced from accelerating a charged body through an Electromagnetic (EM) field, see (1.1)) when accelerating them in a circular path.

$$P = \frac{e^4}{6\pi\varepsilon_0 m^4 c^5} E^2 B^2. \tag{1.1}$$

Where P is power, e is elementary charge, E is particle energy, B is magnetic field, m is mass and all other symbols have their usual meaning.

Pushing the energy frontier has the appeal that it allows direct detection of particles at new energy scales and is supported by the fact that many BSM models rely on new particles appearing in ¿multiTeV energy range e.g. supersymmetry (ref (maybe of CLIC 3TeV bsm plot?), however it does have drawbacks and risks. Due to the composite structure of hadrons they provide collision energies that are often significantly below the provided beam energy and that are challenging to measure. This limits the type of measurement that can be performed as the initial state of the interaction is poorly defined and so all measurments must rely on measurement of the final state particles. This increases the effect of uncertainties intorduced by detector accpetances and resolutions and makes it highly challenging to identify particles that can't be measured by the detector e.g. neutrino/ dark matter candidates. Due to fragmentation of the hadrons, there are also significant Quantum Chromodynamics (QCD) backgrounds produced which can dominate over interesting signal channels. While these do make measurements more challenging, the real risk with pushing the energy frontier is that the constraints on the scale of at which new physics might be observed are currently very poor (give examples of BSM models predicting very different energy ranges.) This makes it extremely challenging to choose what collision energy any future collider should operate at as choosing too low an energy will result in no new phenomena being seen.

The second option is to advance in the "precision frontier" and search for small deviations from the SM or harder to detect processes. In this case the more natural choice is to use a lepton collider as the fact the interaction is an annihilation of fundamental particles rather than composite particles means that the initial conditions of the interaction can be known to a high level of precision determined entirely by the quality of the colliding beams. For leptons it is also possible produce polarised beams which opens up a new range of potential measurements when examining interactions that couple differnetly to left and right handed objects. Doing this we can probe areas of the SM that are less well measured such as the Higgs and Top quark sectors and search for evidence of physics beyond the standard model. The worst case scenario for a lepton collider is to simply reinforce the SM, however even in this case the new levels of precision on many of the SM parameters will be beneficial for constraining BSM theories and reducing systematic uncertainties on measurements being made at hadron colliders. While allowing for precision measurements of the SM, lepton colliders do also provide opportunities for both direct and indirect discoveries of new physics through channels that are either unavailable at hadron colliders or that are challenging due to QCD backgrounds. The main draw back of colliding leptons is that currently the only viable option is to use electrons and positrons (though there is effort underway to use muons(ref)) which have extremely low masses and so produce considerable levels of synchotron radiation (10^{16} as much as protons) when used in a circular collider. The usual solution to this is to use a linear collider instead. This prevents losses from synchotron radiation, however it limits the maximum collision energy that can be achieved as the path over which the particles can be accelerated is limited to the length of the accelerator which is limited by the increasing cost of extending the footprint of the machine. It is worth noting however, that for leptons the collision uses the full beam energy each time and so higher energy interactions can be produced from lower energy beams than for hadrons.

Considerable work has already been carried out into designing both high energy and high precision colliders. On the high energy side is the Future Circular Collider (FCC), a 100 TeV circular proton collider propsed as a project for CERN. It is possible to alos use this device as an ee collider operating above the Higgs theshold so as to act as a "Higgs factory". On the precision side there are multiple proposed projects (REFERENCE SMALLER PROJECTS), however the most mature of these are the linear electron-positron colliders: Compact Linear Collider (CLIC) **??** and International Linear Collider (ILC) **??**. The ILC is a 500 GeV collider proposed as a joint endeavour between the Japanese government and the international community while CLIC is a multi-TeV machine being proposed by CERN. Due to the large cost of these devices it unlikely that CERN will build both FCC and CLIC together.

The focus of this thesis will be on the prospects of the proposed high precision colliders. In particular we discuss the prospects for measuring properties of the Higgs Boson and Top quark at CLIC which are relatvely poorly measured when compared to other standard model particles, while also examining a novel design for a digital calorimeter based on Complimentary Metal-Oxide Semiconductor (CMOS) Monlithic Active Pixel Sensors (MAPS) technology for use in future detectors as an extremely high granularity Electromagnetic Calorimeter (ECAL).

REFERENCES

[1] G. Aad *et al.*, "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC," *Phys. Lett. B*, 2012.

[2] S. Chatrchyan *et al.*, "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC," *Phys. Lett.*, vol. B716, pp. 30–61, 2012.

APPENDIX A

FIRST APPENDIX

Tables of datapoints...