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

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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*

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# DEFINITIONS OF ACRONYMS

**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

The Higgs discovery is cited [1]

# CHAPTER 1

# INTRODUCTION

Following the discovery of a Higgs Boson at the Large Hadron Collider (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 phsyics might be discovered. There are many open questions remaining such as the nature of dark matter or the origins of matter-antimatter asymmetry, but no clear direction for how to answer them. As such there are two main approaches that may be taken- the first would be 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. The second option is to advance in the "precision frontier" to search for small deviations from the SM and harder to detect processes. Both approaches come with their own advantages and disadvantages. Going to higher energies is more likely to allow direct detection of new particles and is supported by the fact that the majority of BSM models predict that new physics effects should exist at energies beyond what has been explored so far, however the problem is that the scale at which new physics should appear is unknown. This makes designing a future high energy collider difficult as without a clear idea of what energy is needed it is possible the collision energy will be below the new physics scale and so no new phenomenum will be observed. Pushing the precision frontier has the drawback that it may only serve to reinforce confidence in the SM and has a smaller chance of direct discovery of new physics, however even in this worst case scenario it will still provide precise measurements of SM properties which are beneficial both for constraining BSM models and for reducing uncertainties on future measurements at high energy colliders.

The choice in which the community decides to proceed will greatly influence the design options for the next generation of particle colliders. For high energy measurments the obvious choice will be a circular hadron collider similar to the LHC. The circular design allows for particles to be accelerated over as large a time as necessary without the need for a large collider which facilitates reaching higher energies. It also allows for collisions to occur at multiple sites simultaneously allowing for more experiments to take place at the facility. For a circular design, hadrons (most likely protons due to their stability and charge) are needed as their high mass minimises energy loss from synchotron radiation. This is radiation produced by a charged particle undergoing a transverse acceleration and is described by equation (1.1):

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

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.

While protons allow for high energy collisions, they are not suitable for precision measurements as their composite nature means that the initial four monentum and quantum numbers of the collision cannot be known. This means that all information must be extracted purely from a collisions decay products which are subject to uncertainties from detector resolutions/acceptances and the decay products visibility e.g. neutrinos/dark matter cannot be detected. For precision physics the better choice is to collide electron-positron pairs. This is an annihilation reaction where all quantum numbers will cancel out and the initial energy and momentum are only limited by the quality of the colliding beams. This allows conservation laws to be used to infer the properties of missing particles such as neutrinos or new particles. For colliding electrons, a circular collider is no longer feasible as the electrons low mass result in energy being lost through synchotron radiation at $10^{16}$ times the rate of protons. Instead, lepton colliders are traditionally built as linear colliders. This prevents synchotron radiation occuring but limits the maximum collision energy achievable as the path over which a particle can be accelerated is limited to just one length of the collider and it is expensive and impractical to produce longer colliders. That being said, because a lepton collider provides an annihilation interaction rather than a parton interaction it is possible to build a lepton collider with a lower beam energy but still have a higher average collision energy.

With the High Luminosity Large Hadron Collider (HL-LHC) expected to finish taking data in the 2030s and the long construction times associated with super colliders, a decision on what form the next generation of colliders should take is expected to occur by the early 2020s. 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. 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 by the Japanese government 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 electromagnetic calorimeter based on Complimentary Metal-Oxide Semiconductor (CMOS) Monlithic Active Pixel Sensors (MAPS) technology for use in future detectors.

# CHAPTER 2

# Theory

Moriond talk should be useful for deciding content here!!

Physics program for colliders- three main areas will be higgs top and BSM physics

## 2.1 Higgs

Plot of Higgs production cross sections vs energy

### 2.1.1 HiggsStrahlung

Model independent measurements Mass Width Couplings

## 2.2 Top

Mass Width AFB EW Couplings

## 2.3 BSM

Predictions for SUSY

# CHAPTER 3

# Experiments

Mainly take from midterm!!!

## 3.1 CLIC

## 3.2 ILC

## 3.3 Framework

Shared analysis framework

### 3.3.1 Particle Flow

## 3.4 Detectors

### 3.4.1 ILD

mention difference between ILD and CLIC_ILD

### 3.4.2 SiD

Leave description of DECAL concept to DECAL chapter but mention it as one of the ECAL alternatives here

# CHAPTER 4

# Higgs Analysis

Reinforce context for measurement as part of the higgs width measurement

Take everything from analysis note!!

lepton finding

jet finding- higgs and W mass plots

btagging

describe BDTs

final selection and uncertainty

Impact of this on the overall higgs measurements at CLIC & compare to Higgs to qqqq channel

CHAPTER 5

# Top Tagging

Generic top tagger, explain overall approach of using 6 BDTs

Overall analysis method

If we end up with cut on the energy, start with full energy range analysis to highlight problems

Explain it will be tested in terms of AFB. Explain importance of AFB measurement

## 5.1 lepton finding

Method- based on using Pandora ID and jet isolation

Lepton finding efficiency Asymmetry Gamma correction for electrons Charge tagging efficiency QbyP

## 5.2 jet finding

Concept of fat jets reconstruction efficiency in terms of theta Compare alogrithms in terms of top mass and angle for reconstruction Compare methods picking the correct

### 5.2.1 fat jet properties

Multiplicity- systematic uncertainty Angular relations nSubjettiness

## 5.3 ISR effects

Photon energy vs angle Inability to reconstruct leptonic top Boost introduced to $t\bar{t}$ system Imact on reconstrcuted angle

## 5.4 event selection

No need to re-explain BDTs but should explain why and how we use 6 bdts Final selection results for a particular working point

## 5.5 AFB determination

Methods for calculating it and variation between them- Effect of ISR Effect of BDT selection Background modelling

Potentially adding cuts on acceptance- need to add in extrapolation??

# CHAPTER 6

# DECALStudies

General concept- energy proportional to nParticles

Explain potential benefits- cheape, same tech as inner detectors, granularity could improve particle flow

Description of Mokka & Geant4

Detector changes implemented for simulations- smaller pixel size, active silicon replaced with thinner active silicon layer and passive silicon layer

## 6.1 DigiMAPs

Various effects on resolution Charge Spread Background Noise Signal Noise Clustering Threshold

## 6.2 Design Optimization

Aspect Ratio for resolution Linearity Leakage= do studies based on change in radiator- tungsten vs lead

## 6.3 Hardware studies

Assuming this ever works....

# CHAPTER 7

## Conclusion

# 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...