Something something something physics

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Abstract

This thesis describes the optimisation of the calorimeter design for collider experiments at the future Compact LInear Collider (CLIC) and the International Linear Collider (ILC). The detector design of these experiments is built around high-granularity Particle Flow Calorimetry that, in contrast to traditional calorimetry, uses the energy measurements for charged particles from the tracking detectors. This can only be realised if calorimetric energy deposits from charged particles can be separated from those of neutral particles. This is made possible with fine granularity calorimeters and sophisticated pattern recognition software, which is provided by the PandoraPFA algorithm. This thesis presents results on Particle Flow calorimetry performance for a number of detector configurations. To obtain these results a new calibration procedure was developed and applied to the detector simulation and reconstruction to ensure optimal performance was achieved for each detector configuration considered.

This thesis also describes the development of a software compensation technique that vastly improves the intrinsic energy resolution of a Particle Flow Calorimetry detector. This technique is implemented within the PandoraPFA framework and demonstrates the gains that can be made by fully exploiting the information provided by the fine granularity calorimeters envisaged at a future linear collider.

A study of the sensitivity of the CLIC experiment to anomalous gauge couplings that effect vector boson scattering processes is presented. These anomalous couplings provide insight into possible beyond standard model physics. This study, which utilises the excellent jet energy resolution from Particle Flow Calorimetry, was performed at centre-of-mass energies of 1.4 TeV and 3 TeV with integrated lumi-

nosities of 1.5ab^{-1} and 2ab^{-1} respectively. The precision achievable at CLIC is shown to be approximately one to two orders of magnitude better than that currently offered by the LHC.

Finally, a study into various technology options for the CLIC vertex detector is described.

Declaration

This dissertation is the result of my own work, except where explicit reference is made to the work of others, and has not been submitted for another qualification to this or any other university. This dissertation does not exceed the word limit for the respective Degree Committee.

Andy Buckley

Acknowledgements

Of the many people who deserve thanks, some are particularly prominent, such as my supervisor…

Preface

This thesis describes my research on various aspects of the LHCb particle physics program, centred around the LHCb detector and LHC accelerator at CERN in Geneva.

For this example, I'll just mention Chapter **??** and Chapter **??**.

Contents

"Writing in English is the most ingenious torture ever devised for sins committed in previous lives."

— James Joyce

Chapter 1

Capacitively Coupled Pixel Detectors for the CLIC Vertex Detector

"There, sir! that is the perfection of vessels!"
— Jules Verne, 1828–1905

1.1 Introduction

Successful identification of heavy-flavour quarks and tau-leptons relies upon precise reconstruction of the secondary displaced vertices produced in the decay of these particles as well as accurate association of the daughter tracks to those vertices. To achieve this for the CLIC experiment very high spatial resolution, of approximately 3 μm and good geometric coverage extending to low θ values are essential. The vertex detector must also have a low material budget, less than 0.2 X_0 per layer, as to not impact the performance of the other sub detectors and a low occupancy, aided by time-tagging to an accuracy of 10 ns, to counteract the high beam-induced backgrounds found near the impact point.

There are no commercially available technology options that fulfil all the criteria for the vertex detector, which had led the CLIC experiment to consider a variety of new technology options. The focus of this chapter is the use of high voltage complementary metal-oxide-semiconductor (HV-CMOS) active sensors coupled to a separate readout ASIC for the CLIC vertex detector.

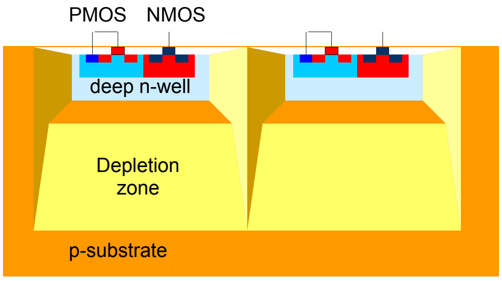

Figure 1.1: HV-CMOS diagram.

1.1.1 HC-CMOS

There are two classifications for pixel detectors; hybrid detectors where a passive sensor is bump-bonded to a separate readout chip and fully integrated where the collection diode is built upon the same wafer as the readout circuitry. Both of these technology options find the CLIC experimental conditions extremely challenging. Hybrid technologies struggle to achieved both the radiation tolerance and the functionality in the readout circuitry, while fully integrated circuits have too slow readout times due to limitations on the applied bias voltage.

HV-CMOS is adapted to the CLIC experimental conditions as the n-MOS and p-MOS transistors forming the integrated amplifier (or generic in-pixel logic operations) for collecting the signal are embedded within a deep n-well, as shown in figure 1.1. This acts as both the collection diode as well as providing shielding to the circuitry from the beam induced radiation. With the integrated circuitry shielded from the p-substrate it becomes possible to apply a large bias voltage to the substrate to widen the depletion region meaning that the main part of any signal deposited in the detector will be transferred via drift as opposed to diffusion, which provides the fast readout times required by the CLIC experiment.

HV-CMOS devices are strong candidates for the CLIC vertex detector, however, they do have limitations such as noise from interference between the n and p doped wells of the n-MOS and p-MOS transistors that sit within the deep n well. This noise will grow with the number of n-MOS and p-MOS devices on the wafer and so ultimately restricts the complexity of the in-pixel operations that can be performed. There are also topological difficulties such as the difficulty of applying the CMOS

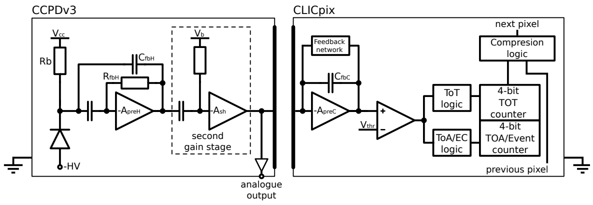

Figure 1.2: Schematic of CCPDv3 and CLICpix pixels.

process to all sizes and the fact that the deep n well does not occupy the full space of the pixel.

To minimise the material budget for the vertex detector, the pixels used are designed to be as thin as possible. This means the signal from the HV-CMOS will be small as the depletion region will be thin. To counter this, in-pixel signal amplification was applied to the HV-CMOS devices, as shown in figure 1.2. This increases the signal going to the readout ASIC, which also counteracts the intrinsically small capacitance between the HV-CMOS and readout ASIC.

1.1.2 CLICpix

The readout ASIC in this study is the CLICpix, which is a charge integrating amplifier connected to a discriminator as shown in figure 1.2. The output to this discriminator is then used as the input for further logic operations that record the magnitude, using a Time over Threshold (ToT) measurement, and time of arrival of the collected charge.

1.2 Construction

Description of construction information based on fabrication note.

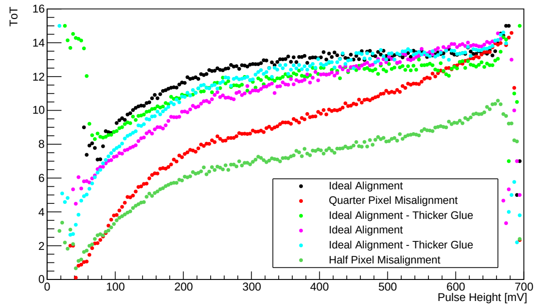

Figure 1.3: Average ToT vs pulse height.

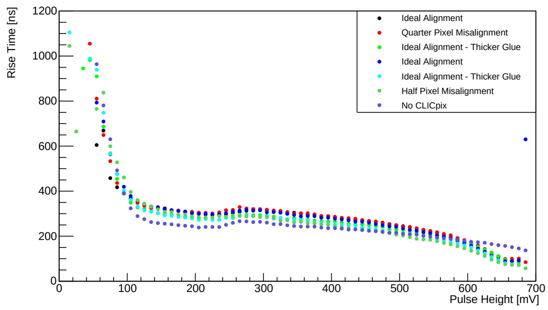

Figure 1.4: Rise time vs pulse height.

1.3 Device Characterisation

1.3.1 CLICPix Calibration

Compare the HV-CMOS pulse height to the ToT recorded on the CLICPix using strontium 90 sources. Gives indication of gluing layer and CLICPix capacitances.

- ToT vs pulse heights.
- ToT vs rise times.

1.3.2 Cross Couplings

ToT on adjacent cells vs pulse heights. No charge sharing apparent except for SET16. Possible issues with manufacturing other offset samples as some charge sharing is expcted.

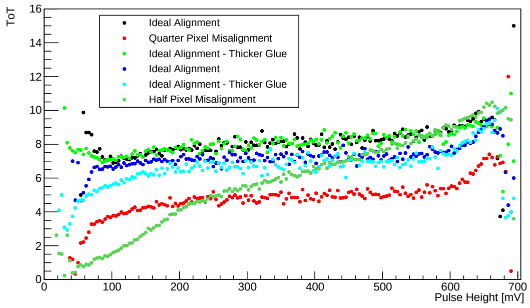

Figure 1.5: Average ToT on adjacent pixel vs pulse height.

1.3.3 Test Pulse Calibration

Inject pulse height of fixed size directly into CLICPix and recored ToT. This cannot be done for the HV-CMOS due to the device construction preventing getting to the relevant input to the HV-CMOS. Plots of average ToT vs pulse height, describe surrogate function fit and column structure.

1.4 Test Beam Analysis

1.4.1 Test Beam Area

Description of test beam, site and telescope.

1.4.2 Efficiency

- Description of masks and why they need to be applied.
- Alignment description.
- Efficiency calculations and conclusions.

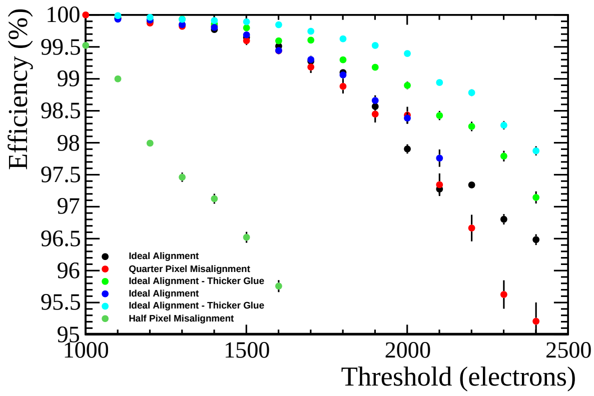

Figure 1.6: Efficiency vs threshold.

Colophon

This thesis was made in $\LaTeX\,2_\varepsilon$ using the "hepthesis" class [1].

Bibliography

[1] Andy Buckley. The hepthesis LaTeX class.

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