# Development of a beam-based phase feed-forward demonstration at the CLIC Test Facility (CTF3).

Jack Roberts
New College, Oxford

Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy at the University of Oxford

Trinity Term, 2016

**Abstract**

This is the abstract TeX for the thesis and the stand-alone abstract.

Dedication.

# Acknowledgements

Acknowledgements.

# Contents

# List of Figures

# List of Tables

# Glossary

**Item1** Description.

**Item2** Description.

**Item3** Description.

# Chapter 1

# Introduction

This is the introductory text.

## 1.1 Particle Physics

## 1.2 Particle Colliders

## 1.3 Motivation for Future Linear Colliders

## 1.4 CLIC

## 1.5 FONT

## 1.6 Phase Feedforward for CLIC

## 1.7 Thesis Overview

# Chapter 2

# Design of the PFF Prototype at CTF3

This is the introductory text.

## 2.1 CTF3

### 2.1.1 Goals of CTF3

CLIC and PFF

### 2.1.2 Layout of CTF3

## 2.2 Design of the PFF Prototype at CTF3

### 2.2.1 Schematic Overview of PFF System

;

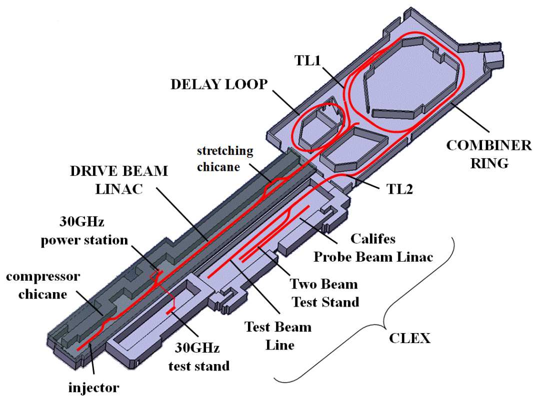


Figure 2.1: CTF3 schematic.

### 2.2.2 Latency

;

## 2.3 PFF Hardware

### 2.3.1 FONT5 Board

### 2.3.2 Amplifier

### 2.3.3 Phase Monitors

### 2.3.4 Kickers

## 2.4 Differences Between PFF at CTF and CLIC

### 2.4.1 Phase Sag

### 2.4.2 Pulse Length

## 2.5 Feedforward Algorithm

### 2.5.1 Theoretical Corrected Jitter

### 2.5.2 Theoretical Optimal Gain

# Chapter 3

# Optics for the PFF Prototype

This is the introductory text.

## 3.1 Introduction to Optics

transverse focusing, dispersion, twiss etc.

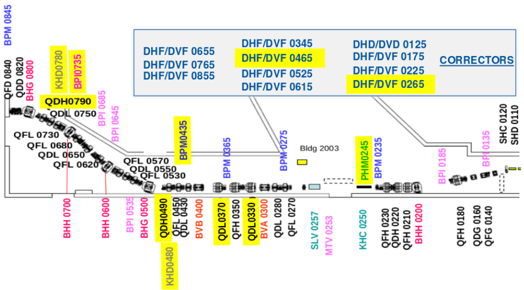


Figure 3.1: New TL2 lattice for PFF. Changes highlighted yellow.

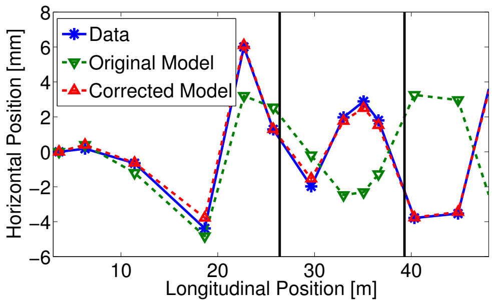


Figure 3.2: Mean phase along.

### 3.1.1 MADX

## 3.2 TL2

### 3.2.1 Lattice

### 3.2.2 Integration of PFF Hardware

### 3.2.3 Optics Constraints

#### Nominal Optics

#### PFF Optics

## 3.3 TL2 Optics Measurements

### 3.3.1 Method

### 3.3.2 Results

### 3.3.3 Sources of Errors in MADX Model

#### Dipole Edge Focusing

#### Quadrupole Strengths

### 3.3.4 Corrections to MADX Model

## 3.4 Matched TL2 Optics

### 3.4.1 MADX Optics Matching

### 3.4.2 Nominal Optics

### 3.4.3 PFF Optics

# Chapter 4

# Phase Monitor Performance

This is the introductory text.

## 4.1 Phase Monitor Electronics

## 4.2 Signal Response Measurements

### 4.2.1 Experimental Setup

### 4.2.2 Saturation

### 4.2.3 Cross-Talk

## 4.3 Calibrations

### 4.3.1 Procedure

### 4.3.2 Single Sample Results

### 4.3.3 Multi-Sample Results

## 4.4 Digitiser Noise

### 4.4.1 On FONT5 Board

### 4.4.2 On SiS Digitiser

## 4.5 Phase Shifter Noise

### 4.5.1 Digital Phase Shifters

### 4.5.2 Mechanical Phase Shifters

## 4.6 Resolution

## 4.7 Linearity

## 4.8 Bandwidth

## 4.9 Dependence on Position

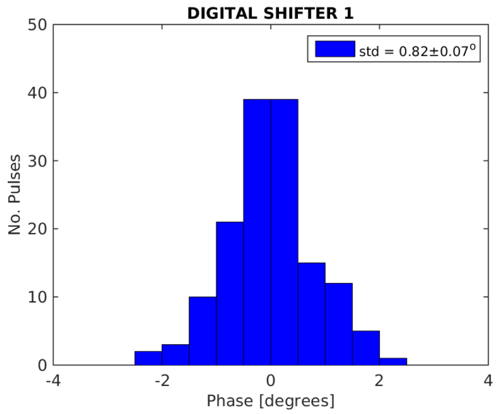


Figure 4.1: Dig shifter 1.

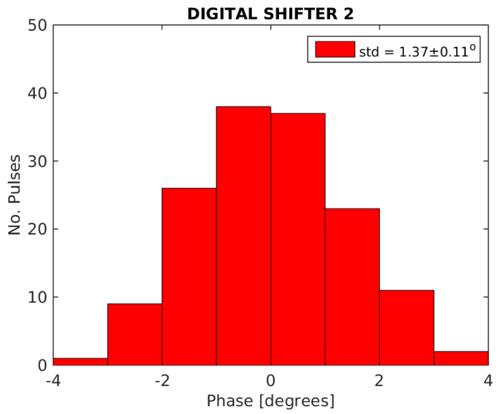


Figure 4.2: Dig shifter 2.

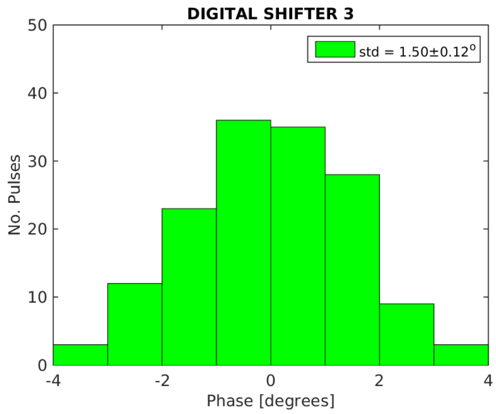


Figure 4.3: Dig shifter 3.

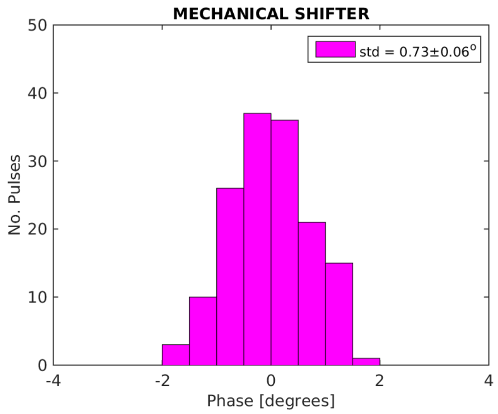


Figure 4.4: Mech shifter.

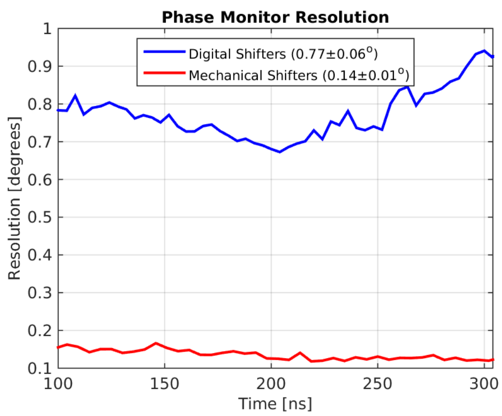


Figure 4.5: Resolution.

# Chapter 5

# Phase Propagation

This is the introductory text.

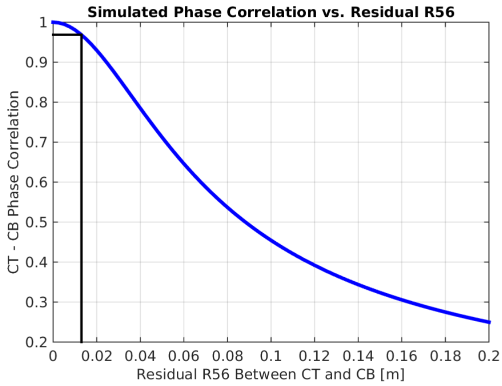


Figure 5.1: Phase correlation vs. residual R56 between monitors.

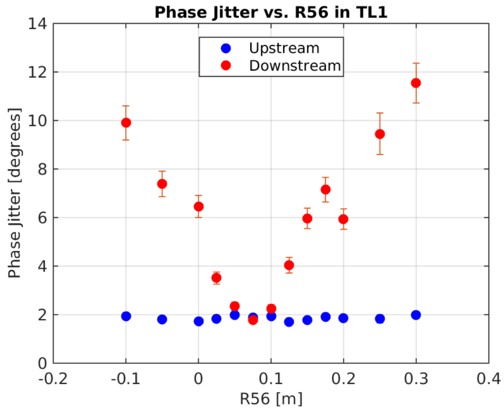


Figure 5.2: Phase jitter for different R56 whilst wiggling gun current.

## 5.1 Characteristics of Uncorrected Phase Jitter

## 5.2 First Order Energy Dependencies

### 5.2.1 Correlation between Phase and Energy

### 5.2.2 Expected Dependence due to Optics

## 5.3 Mitigation of First Order Energy Dependence

### 5.3.1 TL1

### 5.3.2 Matched Optics for TL1

### 5.3.3 Scans of R56 in TL1

## 5.4 Higher Order Energy Dependencies

### 5.4.1 Expected Dependence due to Optics

### 5.4.2 Energy Variation Along the Pulse

### 5.4.3 R56 Scans whilst Varying Beam Energy

### 5.4.4 Effect on PFF Operation

## 5.5 Other Sources of Phase Jitter

### 5.5.1 Combiner Ring Septum

### 5.5.2 TL1 & Combiner Ring Bends

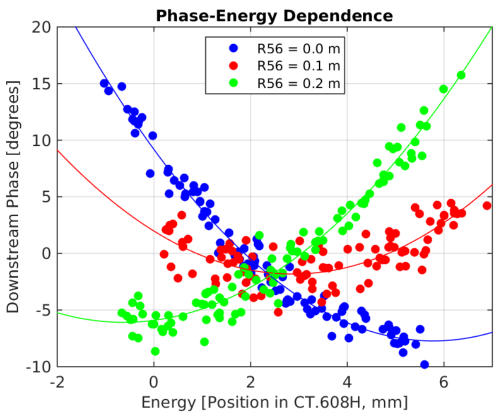


Figure 5.3: Phase vs. energy for different R56 in TL1.

# Chapter 6

# Setup and Commissioning of the PFF System

This is the introductory text.

## 6.1 Experimental Setup

### 6.1.1 Implementation of PFF Algorithm in Firmware

### 6.1.2 FONT5 and Amplifier Setup

### 6.1.3 SiS and CERN Control System Setup

## 6.2 Droop Correction

The droop in the response of the FONT5 ADCs, as most clearly seen in the output of the diode channel in Figure 6.1 (although it also effects the mixer channel), is not an issue for the work the FONT group does at ATF2 where the signals are well approximated by delta functions separated by $\sim$100 ns. Although the droop has been seen previously, its significance for the continuous microsecond length pulse at CTF3 had not been considered because of this.

The droop emerges as a result of the use of AC coupling on the ADC input transformers for electrical isolation. This involves using a capacitor, the current across which is dependent on $dV/dt$ ($V$ being voltage and $t$ time), to remove the DC component from a signal. In particular for the diode channel, which should be a square wave, the output is increasingly well described by a DC signal on the flat top as you move away from the leading edge of the pulse, with the capacitor causing droop in the response as a result.

In the simplest case the droop should be well described by an exponential decay of the form $A\exp\left(-t/T\right)$. The droop makes it difficult to perform calibrations and measurements

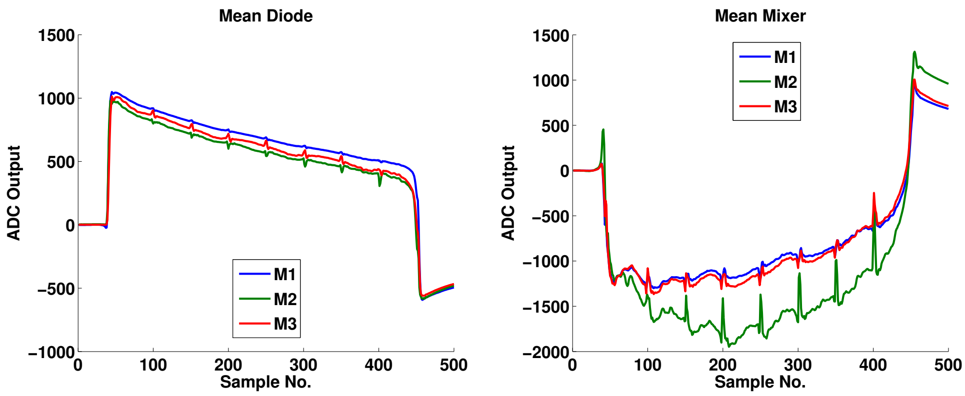


Figure 6.1: Mean diode and mixer output with no filter.

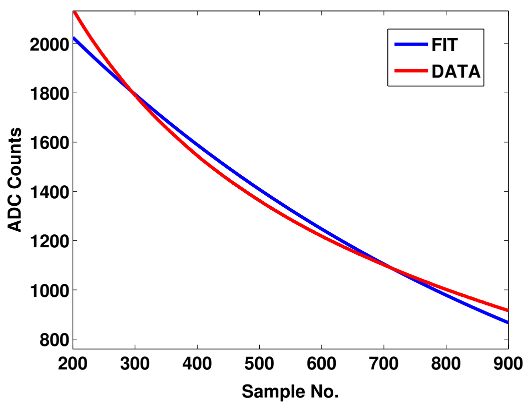


Figure 6.2: Attempted exponential fit to the ADC droop.

on the data and one way in which it could be removed in offline analysis is by determining the decay constants, $T$, for each of the ADCs on the FONT5 board. To avoid the influence of beam effects tests were done in Oxford using a generated 10 $\mu$s DC pulse.

Unfortunately, as can be seen in Figure 6.2 which shows an example of an exponential fit for one ADC, although the fits return good $R^2$ values it is clear that the slope of the exponential curve is not a good match for the slope of the data. This is perhaps not unexpected as the ferrite cores used in the transformers have many non-linear properties. In fact, by using a fit with two exponential terms it is possible to obtain a perfect match to the data but at this point the complexity of the fit would make any attempt to remove the droop in real beam data in this way spurious.

Instead, changes will be made to the currently in development FONT5a board hardware and firmware to greatly reduce the scale of the droop. Different transformers will be used to reduce the droop rate by up to a factor of fifty and in addition digital filtering will be implemented in firmware to smooth out and reduce the remaining droop component even further. It is expected that after these changes the droop will be small enough to not have a detrimental effect on the performance of the phase feedforward system.

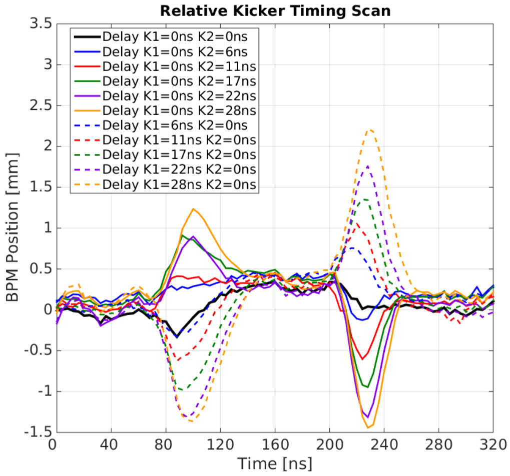


Figure 6.3: Traces relative timing scan.

## 6.3 Kicker and Optics Performance Verification

### 6.3.1 Correction Range

Scan and comparison to expectation from optics.

### 6.3.2 Linearity

### 6.3.3 Orbit Closure

### 6.3.4 Shape

Shape of FF kick on BPMs vs. shape of upstream phase

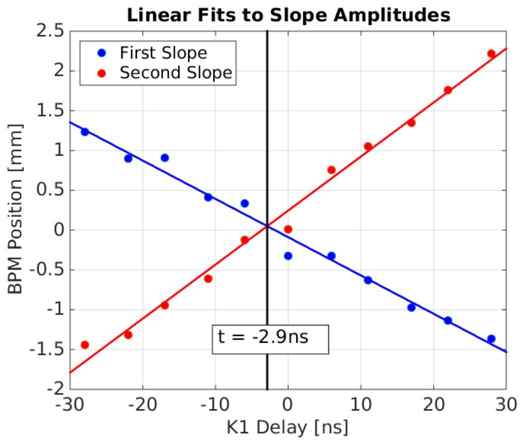


Figure 6.4: Relative timing scan - fit to rising/falling edge.

## 6.4 Absolute Kicker Timing

### 6.4.1 Latency

### 6.4.2 Using Beam Pickup

### 6.4.3 Using BPMs

## 6.5 Relative Kicker Timing

## 6.6 Correction Bandwidth

# Chapter 7

# Feedforward Results

This is the introductory text.

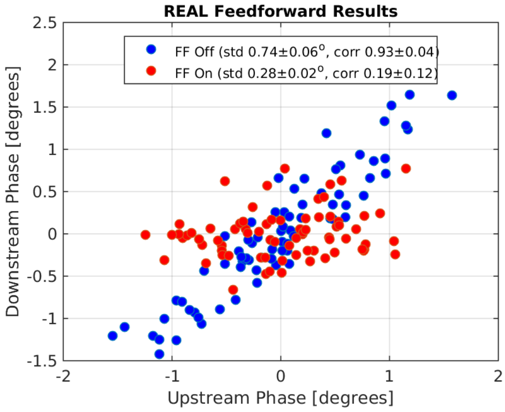


Figure 7.1: Mean phase.

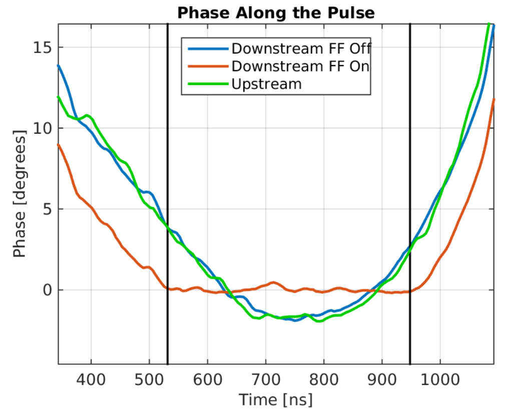


Figure 7.2: Mean phase along.

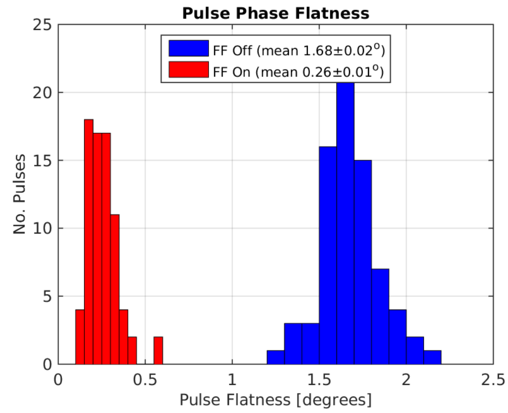


Figure 7.3: Flatness.

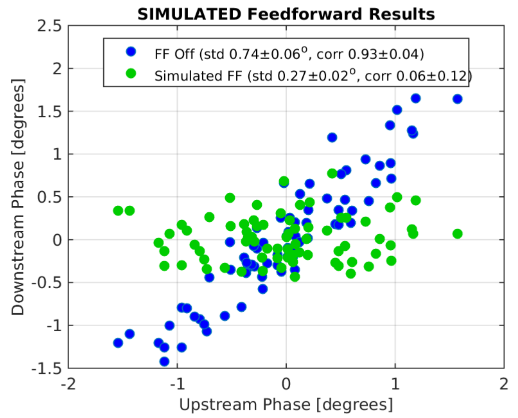


Figure 7.4: Simulated PFF.

## 7.1 Gain Scans

## 7.2 Correction at Optimal Gain

## 7.3 Simulated PFF Results

## 7.4 Correction on Longer Timescales

## 7.5 Correction with Additional Jitter Source

## 7.6 Slow Correction

### 7.6.1 Implementation

### 7.6.2 Results

# Chapter 8

# Conclusions

This is the introductory text.

## 8.1 Summary

## 8.2 Future Work