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Development of FPGA frontend electronics of the scintillating fiber hodoscope of AMBER at CERN

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Bachelor's Thesis

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January 2025

Abstract

Here will be my abstract for thesis Thesis template from the ZNN, updated for Biblatex and Biber.

Contents

CHAPTER 1

Introduction

"Nature will reveal its secrets, but only if we ask the right questions."[Werner Heisenberg]
Progress in particle physics has always been driven by the desire to understand the fundamental building blocks of our universe.
Our current best theory for the innnerworkings of our world, the standart model of particle physics shows us, that the matter we see around us is mostly made up of down and up qurks and electrons. Combinations of these quarks, held together by the strong nuclear force form the proton and neutron,the nuclei of the atoms that make up the matter of the everyday world. Eventhough the Proton was discovered over a hundred years ago by Ernest Rutherford[Pea89], it is still not fully understood.
Since the proton, unlike the electron is a composite particle, it follows that it has an internal structure. The semantic meaning of size in the realm of particele physics is not as straight forward as in the macroscopic world.An answer to the question, what is the size of the proton can be given by looking at the charge distribution of the proton, which defines the charge radius of the proton.
The proton radius measurment at AMBER at CERN aims to reselove a discrepency between the charge radius of the proton as measured by the Lamb shift in muonic and ordinary hydrogen and the electron-proton scattering experiments, the so called proton radius puzzel.
To achieve this, the PRM experiment will measure the cross section of elastic scattering of muons on protons. The scintillating fiber hodoscope is a key component of the PRM experiment, as it provides crucial time measuments of the incoming and scattered mouns, needed for the measurment of the proton radius[Ada19b].

This thesis will focus on the development of the FPGA driven frontend electronics of the scintillating fiber hodoscope for the proton radius measurment at AMBER at CERN, especially on the development of the FPGA firmware required for the control of the CITIROC1A ASIC, a part of the readout and trigger electronic.

CHAPTER 2

Theoretical concepts and AMBER overview

2.1. Measurment of the charge radius of the proton (PRM)

The proton is a baryon, a composite particle made up of one down quark and two up quarks. From this follows that the proton is not a point particle,but has an internal sturucture.
The internal structure can be discribed by the structure functions of the proton, the electric and magnetic form factors G_E and G_M [Ada19b].

2.1.1. Previous measurements of the proton radius

The charge radius of the proton has been massured several times before with different methods. The two premier methods are electron proton scattering experiments and the Lamb shift in muonic and ordinary hydrogen. The results of these measurements differ by five standard deviations as shown in figure 2.1, this has given rise to the so called proton radius puzzle [Ada19b].

2.1.2. Elastic scattering of muons on protons

The AMBER PRM experiment at CERN aims to reslove the proton radius puzzle, by measuring the elastic scattering of muons on protons. The first order cross section,taking

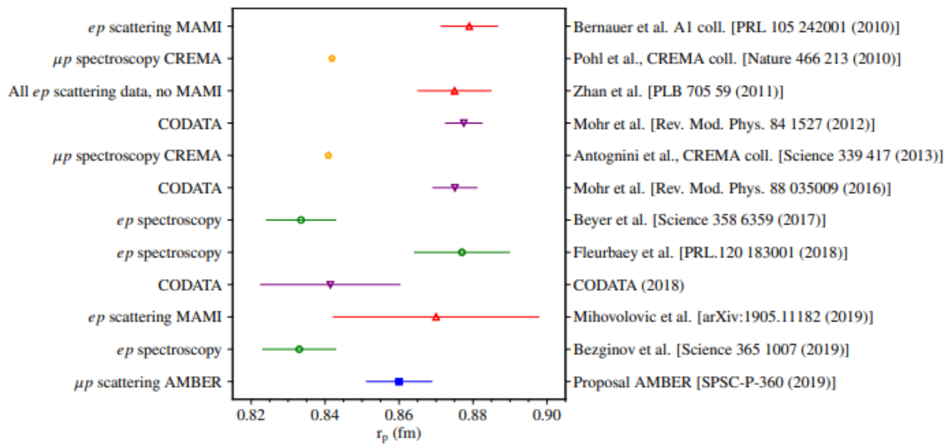

Figure 2.1.: Previous measurements of the proton radius from electron proton scattering experiments and the Lamb shift in muonic and ordinary hydrogen, the measurements differ from each other by five standard deviations. [Ada19b]

into account only interactions where one virtual photon was exchanged, for the elastic scattering of muons on a proton target is [Ada19a]

$$\frac{d\sigma}{dQ^2} = \frac{\pi\alpha^2}{Q^4 m_p^2 p_\mu^2}\left[\left(G_E^2 + \tau G_M^2\right)\frac{4E_\mu^2 m_p^2 - Q^2(s - m_\mu^2)}{1+\tau} - G_M^2\frac{2m_\mu^2 Q^2 - Q^4}{2}\right] \tag{2.1}$$

with $Q^2 = -q^2$ the squared transferred four-momentum, $\tau = Q^2/4m_p^2$, $s = (p_\mu + p_p)^2$, G_E the electric form factor of the proton, G_M the magnetic form factor of the proton and α the fine structure constant.

Through determining the form factor G_E for small Q^2 , the charge radius of the Proton can be claculated with the following equation [Ada19a]

$$r_p^2 = -6\frac{dG_E}{dQ^2}\bigg|_{Q^2=0} \tag{2.2}$$

2.2. General setup for PRM at AMBER.

2.2.1. Detectors for PRM

To determine the magentic G_M and electric form G_E factors of the proton and thus the charge radius of the Proton, the experimental cross section of the elastic scattering of muons on protons has to be measured.

The general setup of the PRM experiment, with focus on the new detectors needed for the proton radius measurment, is shown in figure 2.2.

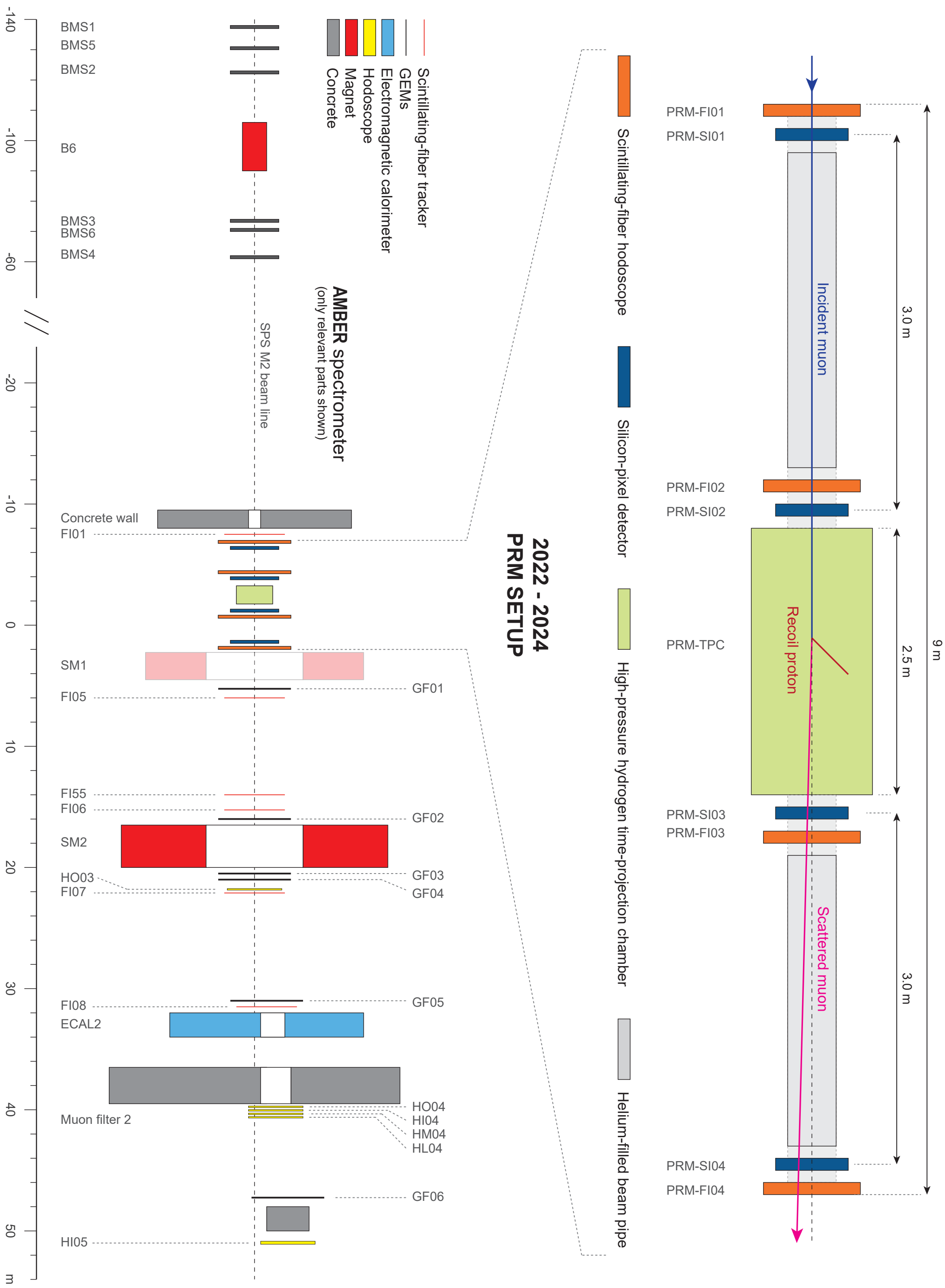

Figure 2.2.: General setup of the Amber experiment with new detectors for PRM. [Eic24]

The incoming muon beam with an energy of 100 GeV[Ada19b] and an beam rate of 2×10^6[Ale24] particles per second is scattered on a pressurized hydrogen gas target, located in the Time Projection Chamber (TPC), which also acts as the detector for the

recoil path of the proton.
The reconstruction of the path of the muon is achieved through the usage of two detector types, combined into one unified tracking station (UTS) as shown in figure 2.3.
Each UTS consists of three layers of pixilized silicon detectors (ALPIDEs),for precises positional measurments (spacial resolution of about 8 µm [Fri22]) of the incoming and scattered muons, but lacking the time resolution(5 µs[Fri22]) required for the PRM experiment. For this reason each UTS includes a scintillating fiber hodoscope (SFH),the detector of intrest for this thesis, which provides the time precision(300 ps[Fri22]) for the measurment.
Four of these unified tracking stations,two before and two after the active target, are placed in the beamline as shown in 2.2. The measurment of the momentum of the scattered moun is done by existing COMPASS detectors located after the, for the PRM newly included, detectors[Ada19b].

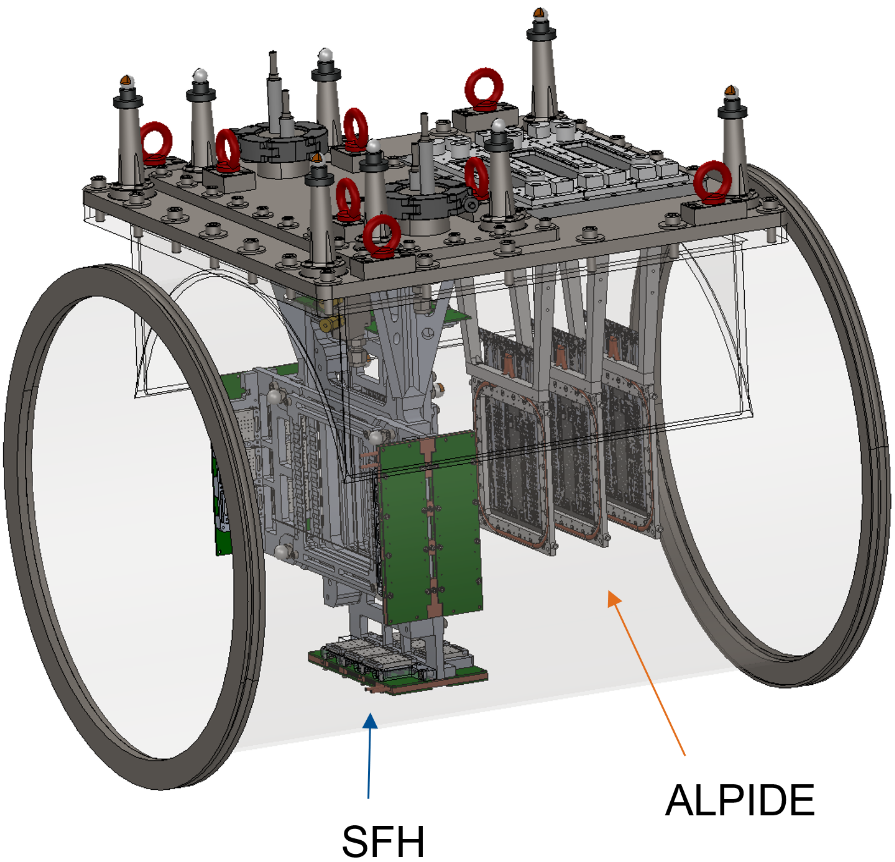

Figure 2.3.: Unified tracking station (UTS) with three layers of pixilized silicon detectors (ALPIDEs) and the scintillating fiber hodoscope (SFH). [Eic24]

2.2.2. Scintillating fiber hodoscope(SFH)

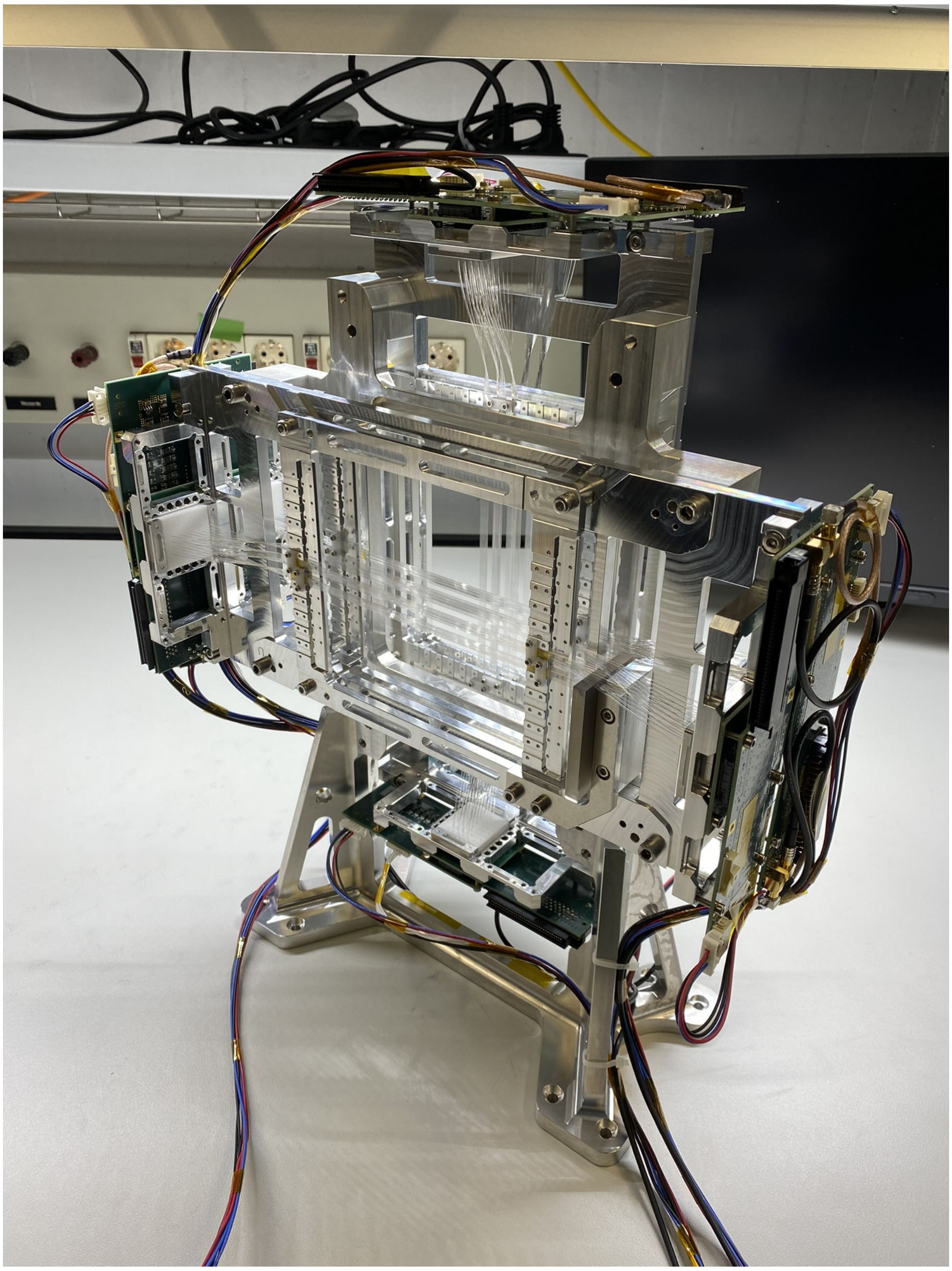

Figure 2.4.: Scintillating fiber hodoscope (SFH) with some of the scintillating fibers of the four layres installed.The frontend electronics are not attached.[Eic24]

The scintillating fiber hodoscope shown in figure 2.4, the detector for which the FPGA driven frontend electronics are developed in this thesis, is used to measure the precise timing(300 ps[Fri22]) of the incoming and scattered muons.Every SFH contains four layers of scintillating fibers, two in x and two in y direction. Each layer is made up of 192[Fri22], 500 μm thick[The24] fibers, in total 768[Fri22] fibers per SFH. When charged particels, muons in this case, pass through a scintillating fiber they excite the scintillating material, which then emits photons.Both ends of every fiber are conected to a silicon photomultiplier (SiPM) which converts the photons into an electrical signal, that is then proccesed by the frontend electronics.

2.3. Field Programmable Gate Arrays (FPGAs)

CHAPTER 3

Frontend electronic of the scintillating fiber hodoscope

3.1. Overview of the frontend electronics

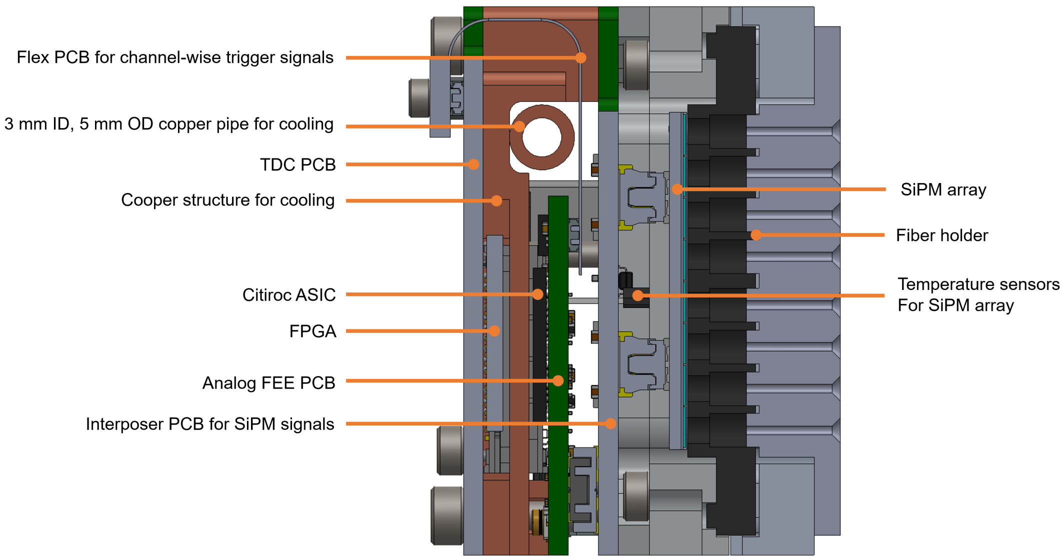

Figure 3.1.: Sideview of the frontend electronics that will be attached on the sides of the SFH, the fiber holders will be attached to the fibers. The SiPM arrays transform the incoming photons into electric signals that are then transferred to the frontend electronics by the PCB interposer.[Eic24]

3.1.1. Proccesing of the SFH signal

The frontend electronics of the scintillating fiber hodoscope process the signals from the scintillating fibers. They can be attached on all four sides of the SFH, as can be seen in figure 2.4. The fibers are conected to the fiber holders on both ends as shown in figure 3.1. There are in total 768[Fri22] fibers per SFH. Since both ends produce an electric signal, a total of 1546 signals or 384 signals, for every attached electonics unit have to be proccesed.
The incoming photons are transformed into electric signals by the SiPM arrays. The SiPM signals are then transmitted to the analog frontend electronics (FEE) PCB by the interposer PCB also shown in figure 3.1.[Eic24]

3.1.2. The analog frontend electronics (FEE) PCB

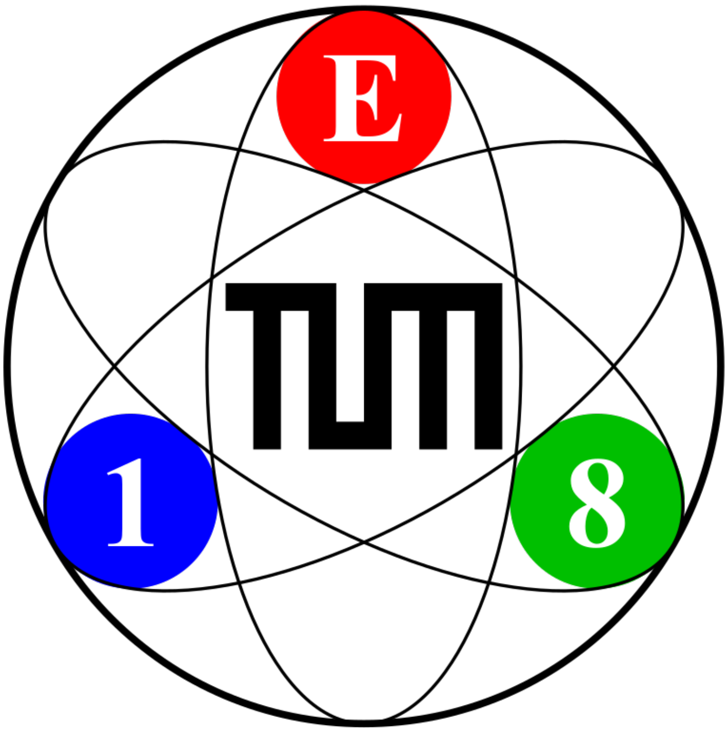

Figure 3.2.: The analog frontend electronics (FEE) PCB with the six CITIROC1A ASICs, on the left cite you can see the region where the power supply is connected.The output of the CITIROC1A is transmitted to the iFTDC over three flex PCBs.[Eic24]

The analog frontend electronics (FEE) PCB, shown in figure 3.2, together with the iFTDC form the heart of the frontend electronics. It contains six CITIROC1A ASICs, which are used to amplify and process the signals,32 by each CITIROC1A ASIC , from the SiPM arrays.The output of the CITIROC1A is then transmitted to the iFTDC over three flex

PCBs. The power supply is connected to the FEE PCB on the left side.Two CITIROC1A ASICs are each controlled by one Artix-7 FPGA located on the iFTDC.[Kon24]

3.1.3. The iFTDC

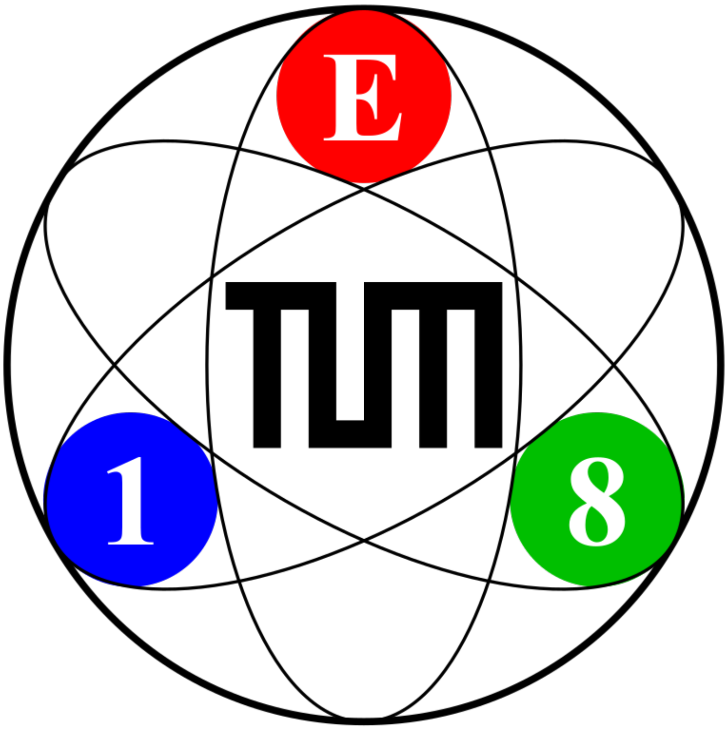

Figure 3.3.: The iFTDC with three Artix-7 FPGA, the three flex PCBs that connect the iFTDC with the FEE PCB and the power supply.[Kon24]

The iFTDC is a FPGA based time-to-digital converter depicted in figure 3.3.It is made up out of three Artix-7 FPGA, who each control two CITIROC1A ASICs. The FPGA handels the readout as well as the configuration of the CITIROC1A ASICs[Kon24]. The focus of this thesis is the devolopment of FPGA firmware for the configuration of the CITIROC1A ASICs, but a provisional readout firmware will also be developed.
INSERT: here stil hast to be includes how ethernet works how ipbus works and how jtag is implemented ans stuff analong this line

3.2. The CITIROC1A ASIC

CHAPTER 4

Development of the FPGA firmware for CITIROC ASIC

Here i describe the development of the FPGA firmware for the CITIROC ASIC.

CHAPTER 5

Results

CHAPTER 6

Discussion

Discussion

CHAPTER 7

Conclusion and Outlook

7.1. Conclusion

Conclusion

7.2. Outlook

Outlook

APPENDIX A

Code

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Acknowledgement

I want to thank:

Tutor .

Professor .

Eidesstattliche Erklärung

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