JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE START PROGRAMME

Develop Laboratory Apparatus for Silicon Photomultipliers testing

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Contents

ABSTRACT

This report is structured into two main sections: the first section focuses on the 3-D design of the MPPC Testing Apparatus and presents the outcomes of dark room testing. Its primary goal is to offer readers a concise understanding of the MPPC's definition and fundamental functionality. It also underscores the imperative need for creating this testing apparatus and display the final design product and its functionality. Furthermore, this section includes an assessment of MPPC performance in a no light environment, to later compare its characteristics before and after radiation exposure.

In the second section of the report, detail the design process and specifications for the connector cover intended for the Luminosity detector and other associated boards within the NICA collider is presented.

This report is divided into 2 parts: 3-D design of MPPC Testing Apparatus and dark room testing result, and 3-D design for cable cover for Luminosity detector BMO for the NICA collider.

Part 1: 3-D design of MPPC Testing Apparatus and dark room testing result.

1.Introduction

1.1 Background

In the realm of photon detection and quantum optics, Multi-Pixel Photon Counters (MPPCs), also known as Silicon Photomultipliers (SiPMs), represent a groundbreaking advancement in the field of low-light-level detection. These innovative devices have revolutionized the way we detect and quantify individual photons, making them invaluable tools in a wide range of scientific, industrial, and medical applications.

MPPCs are semiconductor-based detectors that have emerged as a viable alternative to traditional photomultiplier tubes (PMTs) due to their compact size, low operating voltage, excellent photon detection efficiency, and remarkable insensitivity to magnetic fields. This introduction aims to provide an overview of MPPCs, shedding light on their working principles, applications, and the advantages they offer over other photon detection technologies. [1]

1.2 Motivation

In order to conduct comprehensive studies on the impact of radiation on MPPCs (Multi-Pixel Photon Counters) and ensure accurate calibration, it is imperative to create a dedicated device for the precise delivery of concentrated light to the MPPC and the subsequent observation of its electrical signal. This apparatus will enable us to delve deeper into the behavior of MPPCs under radiation exposure, fostering advancements in our understanding of these sensitive detectors.

1.3 Design section

1.3.1 Objective

To design two distinct 3D models of cable covers, one for single cable configurations and another for dual cable configurations, with the primary goal of ensuring effective and aesthetically pleasing cable management solutions for board connections.

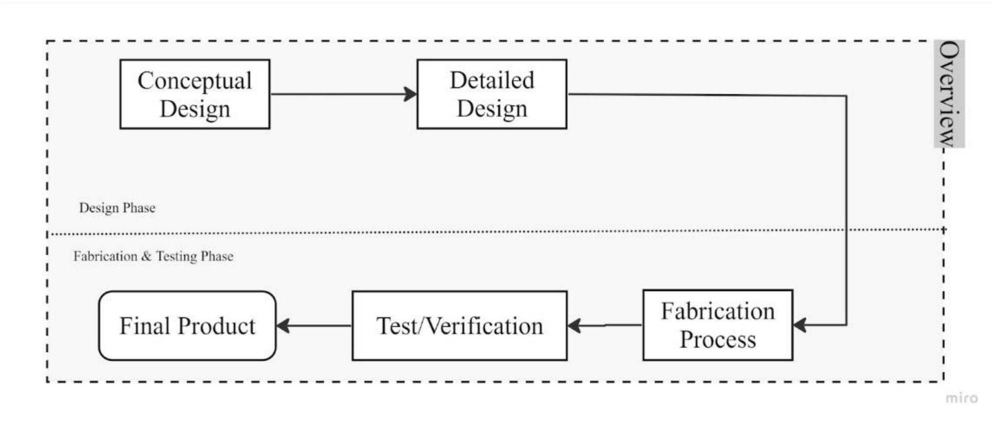


Figure 1: Overview of design process

The design framework for the Multi-Pixel Photon Counter (MPPC) apparatus, as depicted in Figure 1, follows a similar process to the one described in the cable cover design. This process includes conceptualization, detailed design, 3D printing, calibration of critical dimensions, and testing for fit and functionality. If the MPPC apparatus meets the desired criteria, it proceeds to mass production; otherwise, adjustments are made, and the process is iterated to ensure its accuracy and effectiveness.

1.3.2 Conceptual design

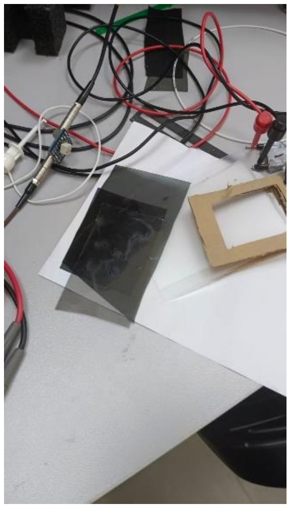


Figure 3 : Prototype of film case

Figure 2 Previously used test bench design

The primary idea behind this design is to create a device capable of securely holding the MPPC in position while also providing the flexibility to introduce varying levels of intense light for testing purposes. Figure 2 illustrates the previous MPPC test design, while Figure 3 showcases the film and film paper case, which serves as a light filter. The motivation for changing the test apparatus stems from the challenges associated with adjusting the position of individual components in the previous design and the need for multiple components to stabilize the device in place. After doing a customer study, customer requirements are obtained as shown in Table 1.

Table 1 : customer requirement of the apparatus

CUSTOMER REQUIREMENT
a separate compartment capable of housing both a light and a battery.
Capable of securely attaching the beam
light source is capable of changing intensity
printable by Creatility Ender 3 V3 with 0.4 mm nozzle
Able to add another device into the beam apparatus if needed

Able to modify beam support type

1.3.3 Detailed design

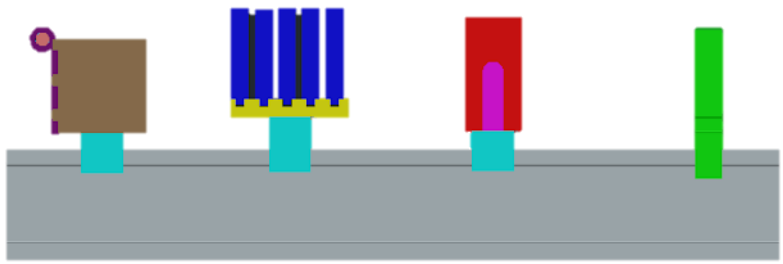


Figure 4 : Assembly of the MPPC test apparatus

To meet the customer's specifications, a box has been designed to house both the light source and its power supply. This box incorporates a compact storage area at its base and is equipped with an attached platform to hold the light bulb. The red component and the pink component are designed to hold MPPC of different size in place with the maximum horizontal length of 50 mm. Additionally, a removable curtain-style film stand has been devised to facilitate adjustments in light intensity. To ensure ease of attachment to the beam, two sizes studs' attachments have been integrated into each component, allowing for effortless removal and reattachment. Moreover, all components have a minimum thickness of 0.2 mm, in accordance with the limitations of the 3D printer. Lastly, all the models are produced using PLA plastic, for ease print and considerable durability. Figure 4 provides a visual representation of the assembly of all components on a beam stand.

The beam stand has a total of 6 components including.

1. Grey Component: I beam

2. Light Blue Component: It has a stud attachment, and it is offered in two sizes: high and low.

3. Intensity adjustment device

    3.1 Yellow Component: This serves as a window stand for a film frame.

3.2 Blue Components: These comprise the film frame for securing a film sheet. Utilize M2.3 screws to affix the film in place, with a maximum length of 7 mm.

4. MPPC holder

4.1 Red Component: This is the specimen (MPPC) frame.

4.2 Pink Components: These are size adjustment keys. I

5. Light Box Components:

5.1. Front Plate: Place the power supply horizontally and direct the wire out through a side opening. Secure the light source in the upper holder.

5.2. Back Plate: Align it with the front plate.

5.3. Lid.

5.4. Rotating Column.

6. Green component(optional): use for fitting single cell censor.

1.3.4 Fabrication

Once the design was finalized, I utilized the CURA application to create the model and fine-tune parameters like infill and wall thickness. The aim was to balance time efficiency and the durability of the apparatus. Consequently, an infill of 20% and a wall thickness of 0.8 mm were chosen. This configuration ensures the design's flexibility in the solid sections and decreases the time needed to print.

1.3.5 Test/Verification

Following a test print, it's essential to scrutinize and fine-tune the dimensions using a sanding tool if there are slight discrepancies. However, if the functionality is completely compromised, it becomes necessary to revisit the conceptual design.

1.3.6 Final Product

Once the 3D printer completes each component in the design, a range of sanding tools are employed to enhance the precision and fit of the cover's features. This refining process ensures that all the components meet the desired specifications and provides a secure fit for its intended components. The complete assembly are shown in Figure 5.

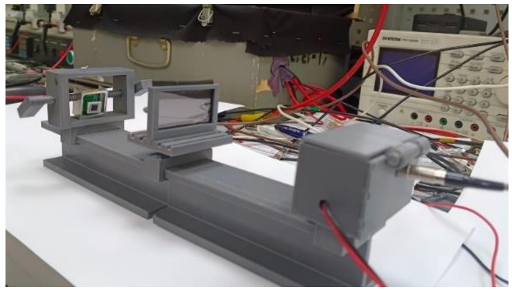
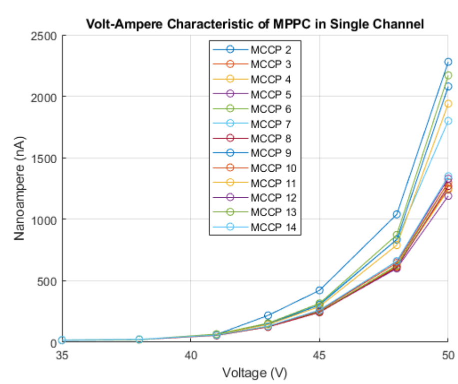


Figure 5: Final assembled product of test apparatus

1.4 Experimental section

In order to observe the characteristics of MPPC before and after radiation, one experiment is conduct om MPPCs before they are transported to CERN to be tested. The experiment is conduct in the dark where MPPC is connect to KEITHLEY 6487, a highly accurate instrument used for measuring extremely low currents (in the picoampere range) and providing precise voltage sources for testing and characterizing electronic components and materials, voltage and. The design apparatus will be used later to observe the characteristics of MPPC after radiation in the next stage of experiment. The goal, functional form, and graphical representation are shown in table 2.

Table 2 : goal,functional form,and graphic representation of the experiment

Goal	Functional form	Graphical representation
To observe a volt-ampere characteristic of each individual MPPC before radiation.	*I = f(Voltage;MPPC;T,LV,t)* *I* = current (nA) *Voltage* = input current (V) *MPPC* = the number of MPPC *T* = temperature (constant =20 C) *L*= Luminance *t* = waiting time (s)	

1.4.1 Experimental Principle

When the MPPC detects individual photons, it initiates an avalanche breakdown, leading to a measurable current. By applying varying voltages, often referred to as bias voltages, to the MPPC terminals, researchers can measure the corresponding current. This data is then used to create a graph that illustrates the relationship between the applied voltage and the resulting current (I). Such a graph provides essential insights into the MPPC's characteristics, including its dynamic range, threshold voltage, breakdown voltage, and gain. [1]
However, the primary focus of this experiment is quality control and recorded data to compare with radiation MPPCs in later stages. Specifically, it concentrates on assessing the performance of 13 MPPCs, labeled as MPPC numbers 2 to 14. The primary objective is to identify any inconsistencies or undesirable characteristics in these MPPCs. In cases where an MPPC exhibits performance issues that cannot be remedied, it may be necessary to either discontinue its use or attempt to repair it to meet the required specifications. This stringent quality control process ensures that only reliable and consistent MPPCs are utilized in experiments involving photon detection and radiation.

1.4.2 Experimental Set Up and Method

To acquire data for this graph, the MPPC is connected to two channels: the first channel being the Triple SiPM(T/H), and the second channel being the Single SiPM. These two probes are linked to a specialized instrument, the Keithley 66487. Subsequently, the MPPC is positioned inside a controlled environment—a dark box situated in a room with regulated humidity and temperature, as visually represented in Figure 6.

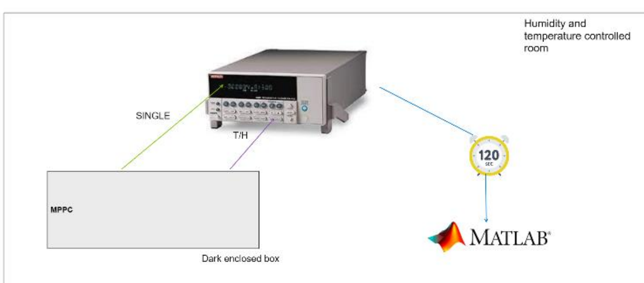


Figure 6: Experimental set up

Following this setup, the individual currents corresponding to each MPPC are measured after a designated time interval, typically t = 120 seconds, to mitigate the effects of voltage fluctuations and ensure stable measurements.

1.4.3 Experimental Results

Table 3:Volt-Ampere of Single channel MPPC

No. Matrix /V	*10*	*15*	*20*	*25*	*30*	*35*	*38*	*41*	*43*	*45*	*48*	*50*
2	4	5	8	9	12	17	21	63	218	422	1040	2280
3	6	7	9	10	14	18	22	57	127	248	615	1250
4	5	6	8	10	14	18	22	57	127	248	620	1240
5	4	6	8	10	14	19	23	58	126	246	600	1190
6	5	7	8	10	14	19	23	56	125	247	625	1300
7	5	6	7	9	12	16	20	63	151	313	833	1800
8	5	7	8	10	13	17	21	55	124	243	609	1270
9	5	6	7	9	12	16	20	61	147	303	836	2080
10	6	7	9	11	14	19	22	58	129	255	645	1300
11	5	7	8	10	13	18	21	62	144	290	790	1940
12	6	7	9	11	15	19	23	58	131	260	658	1330
13	5	7	8	10	14	19	22	66	155	316	873	2170
14	6	7	9	11	15	19	24	58	131	262	660	1350

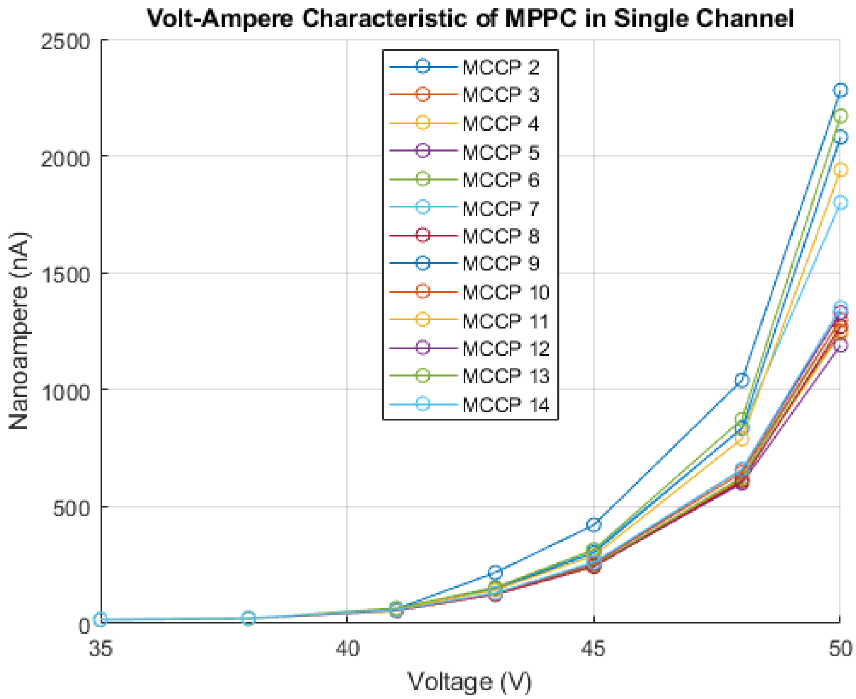


Chart 1 :Volt-Ampere characteristics of MPPC using Single channel

Table 4:Volt-Ampere of T/H channel MPPC

No. Matrix / V	*10*	*15*	*20*	*25*	*30*	*35*	*38*	*41*	*43*	*45*	*48*	*50*
2	16	20	26	29	37	47	53	194	19500	24000	32000	39000
3	18	21	28	38	43	53	62	371	980	2000	5300	9000
4	16	22	27	34	43	53	63	355	960	2000	5300	9000
5	13	18	24	30	40	53	64	340	913	1900	4800	8100
6	7	14	19	23	32	47	60	317	854	1800	4700	7500
7	13	15	18	23	30	42	49	280	747	1500	3800	6500
8	15	18	23	26	34	43	51	293	766	1700	4080	6900
9	14	17	21	25	37	46	53	340	903	1870	4600	7880
10	14	16	21	26	35	46	53	192	551	1200	3000	5100
11	13	19	25	28	39	50	62	490	1250	2600	6400	11000

12	17	20	23	30	40	53	63	353	925	1926	4750	8130
13	18	21	26	31	41	57	66	485	1270	2650	6580	11350
14	16	19	25	29	36	46	53	452	1238	2600	6420	1095

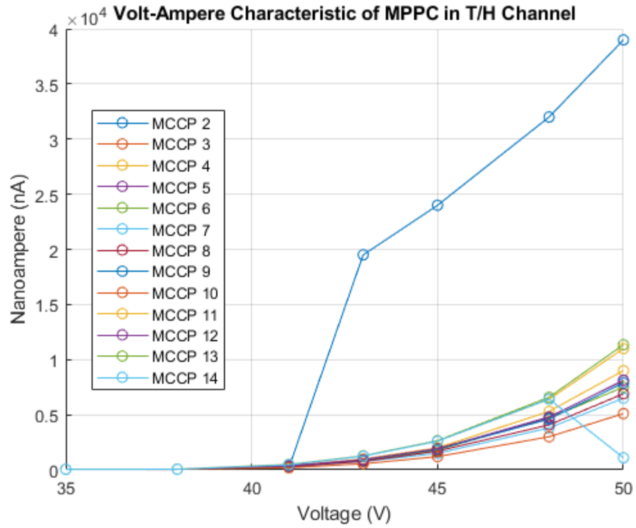


Chart 2: Volt-Ampere characteristics of MPPC using T/H channel

The graph in chart 2 analysis clearly indicates that MPPCs number 2 and 14 may have experienced malfunctions within the T/H (Triple SiPM) cell, as evidenced by their significantly divergent current readings compared to the others. However, in the case of the single cell, all MPPCs appear to be operating normally without any noticeable issues as shown in chart 1.

1.4.4 Conclusion & Discussion

In conclusion, as current directly varies with input voltage, and MPPC 2,14 need to be investigated for any error or malfunction before next testing.

In this experiment, my primary responsibility lies in the acquisition of I-V graphs and the quality control assessment of the MPPCs. Meanwhile, my supervisor and his team have conducted additional experiments related to the MPPC characteristics, including gain measurements with and without a shaper, to gather more comprehensive information about the individual qualities of each MPPC before subjecting them to radiation testing. Currently, they are conducting further testing at CERN, Switzerland. In the later stage of the project, the designed apparatus will be in use.

Part 2: 3-D design for cable cover for Luminosity detector BMO for the NICA collider

2.1. Introduction

The cable cover framework as shown in Figure 1 can be divided into two primary phases: the design phase and the manufacturing & testing phase. The design phase includes conceptual design, and detailed design. The manufacturing and testing phase includes the fabrication process, testing and verification, and then the final product.

In conceptual design is a guide in the development of cable cover designs. It evaluates the possibility of design requirements from customer study product: customer requirement shown in Table xx which allows us to define the functional concept of operation which will be further define in conceptual design. In the Detailed design phase, all the detailed such as the dimension, material are defined.

Table 5: cable cover customer requirement

CUSTOMER REQUIREMENT
Tightly fit cable
able to fit in narrow socket of 9 mm wide socket
comfortable to hold
able to accommodate connector grip
strong enough to protect the board

Moving to the manufacturing and testing phase, it starts with fabrication step. In this step the 3-D model file in fusion 360 is put into CURA program to create a support structure needed to print with a 3d printer, and to specify the durability of the model by modifying infill pattern, density, and wall thickness. After that the file is sent to the 3-D printer to get the final product.

2.2 Conceptual design

Figure 7: Initial design of similar connector cover

The primary idea behind this design is to encase the board, which has been soldered with a pin connector, within an enclosed space. This enclosure is designed to have a dedicated area for securely holding the board and an opening at one end to accommodate a 9 mm cable. Figure 7 provided depicts the initial design of the cable cover, showcasing its key features, such as a heat-resistant section, a gap for wire soldering, additional space for securing the board, a compartment for the cable, and a hole for securely fastening screws.

2.3 Detailed design

Analyzing the customer requirement table, we can infer that the cable's opening hole should have a diameter of 8.8 millimeters for a secure fit. The gap between the two plates must be narrower than 8.3 millimeters, and the wall thickness should be at least 2 millimeters to ensure durability. Additionally, the cover should feature rounded edges, eliminating sharp corners. Lastly, the widest dimension should exceed 2.5 centimeters, approximately the width of an average thumb, for comfortable user grip.

Given that there are two types of boards, one designed to accommodate a single cable and the other with a thickness of 1.63 mm, it's important to note that the circular region on the board is where wires will be soldered. Hence, a 2 mm gap needs to be allocated for this purpose. The protruding section of the board will serve as the location for the grip. The protruding part of the board will function as a grip location, as illustrated in Figure 10 and Figure 11. The protruding pole serves to secure the board in place; once the screw is fastened, the excess pole can be removed, and the plastic can be melted to firmly affix the board. A square grid is incorporated to precisely center the board between two planes, ensuring a symmetrical appearance for the cover and allowing for precise placement of the pin connector, which will be soldered onto the wider end of the board.The cross section of the cover are illustrated by Figure 8 and Figure 9.

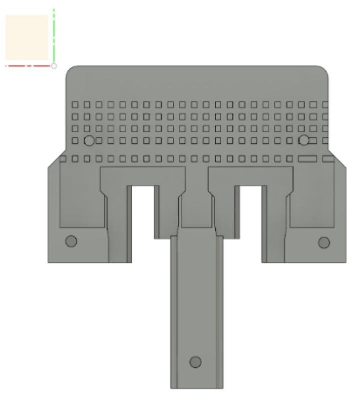


Figure 8 : Inside of 2 cable style

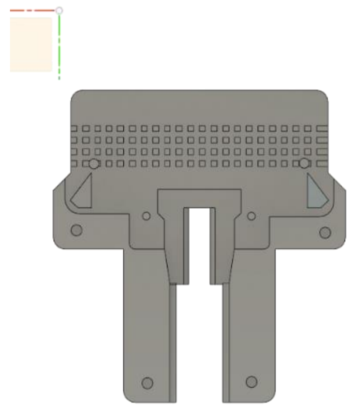


Figure 9: Inside of 1 cable style

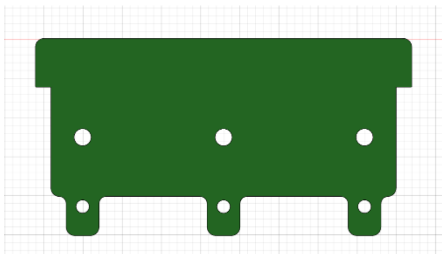


Figure 10: 2 cable board

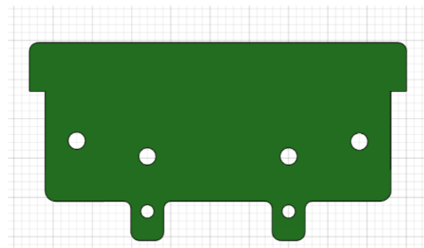
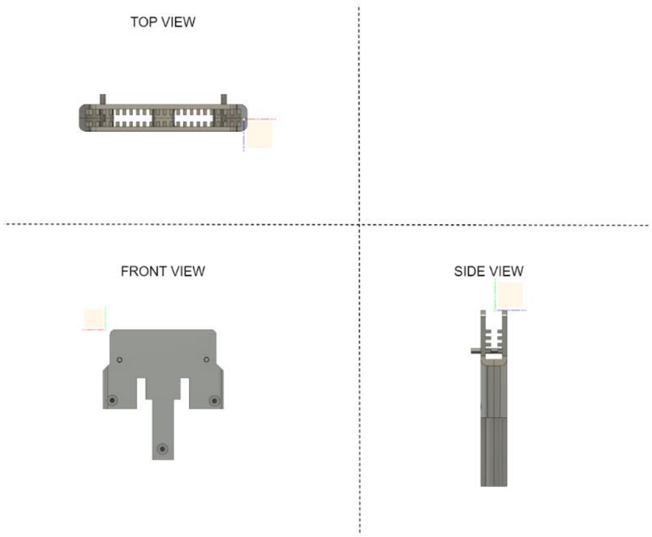


Figure 11: 1 cable board

2.4 Final Design



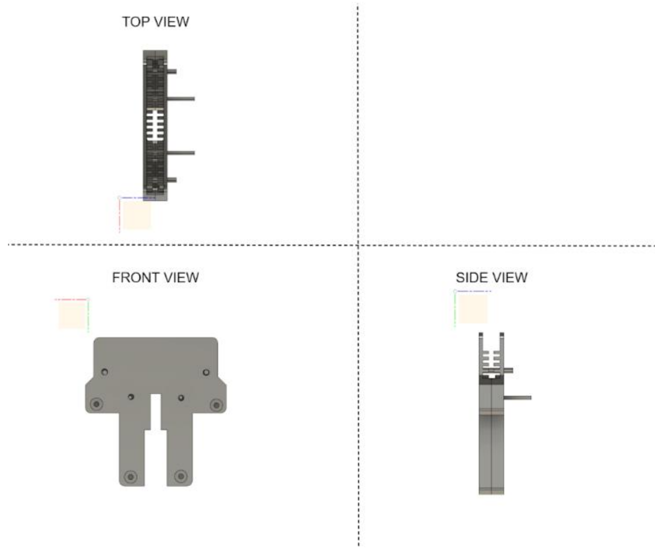


Figure 13: Final design of 2 cable case

Figure 12: Final design of 1 cable case

Figure 12, and Figure 13 display the top view, front view, and side view of two cable case designs.

2.5 Fabrication

Once the design was finalized, I utilized the CURA application to create the model and fine-tune parameters like infill and wall thickness. The aim was to balance time efficiency and the durability of the cable cover. Consequently, an infill of 30% and a wall thickness of 1.6 mm were chosen. This configuration ensures the design's rigidity in areas with a thickness of ≤ 2mm while providing flexibility in the solid sections. The total printing time is 1 hour for 1 set of covers. The anticipated product and its fitting are depicted in Figure 14 below.

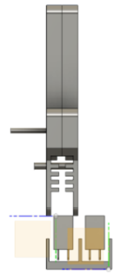


Figure 14:Model aessembly on real plate

2.6 Test / Verification

After the 3-d print product is done, the critical dimensions of the cable cover are calibrated, specifically focusing on the width between the two plates, and the cable opening. Subsequently, a test is conducted to verify whether the cable cover can effectively accommodate the specimens' board and socket. If the cable cover fits these components as intended, the production process advances to mass production, with 20 pieces manufactured for the single cable version and 15 pieces for the double cable version. However, if any fit issues arise during testing, the process is iterated, starting over from the conceptual design phase.

2.7 Final product

Once the 3D printer completes the cable cover design, a range of 3D modeling and sanding tools are employed to enhance the precision and fit of the cover's features. This refining process ensures that the cable cover meets the desired specifications and provides a secure fit for its intended components as shown in Figure 15, and Figure 16.

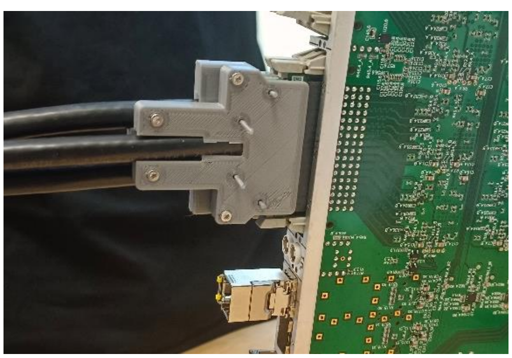


Figure 16: 2 connector connect to narow sockets

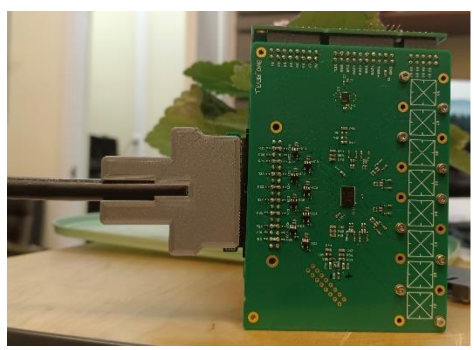


Figure 15: single connector on Luminosity Detector box

References

[1] HAMAMATSU, "HAMAMATSU," [Online]. Available: https://www.hamamatsu.com/eu/en/product/optical-sensors/mppc/what_is_mppc.html. [Accessed 20 September 2023].

Acknowledgment

I would like to extend my heartfelt gratitude to Mikhail Buryakov and Svetaslavl Buzin for their invaluable guidance and support throughout my journey. Their expertise, dedication, and unwavering commitment have been instrumental in shaping the success of my endeavors. Their insightful advice and mentorship have not only enriched my understanding but also fueled my passion for the subject matter.

Mikhail Buryakov and Svetaslavl Buzin's willingness to share their knowledge, provide critical insights, and offer solutions to challenges have been a source of inspiration for me. Their guidance has significantly contributed to the quality and depth of my work.

I am truly fortunate to have had the privilege of working alongside such exceptional mentors, and I express my deepest appreciation for their contributions to my personal and professional growth. Their influence will undoubtedly resonate in my future endeavors, and I look forward to continuing our collaborative journey.

Once again, thank you, Mikhail Buryakov and Svetaslavl Buzin, for your unwavering guidance, wisdom, and support.

Sincerely,
Nattiya Duangprateep