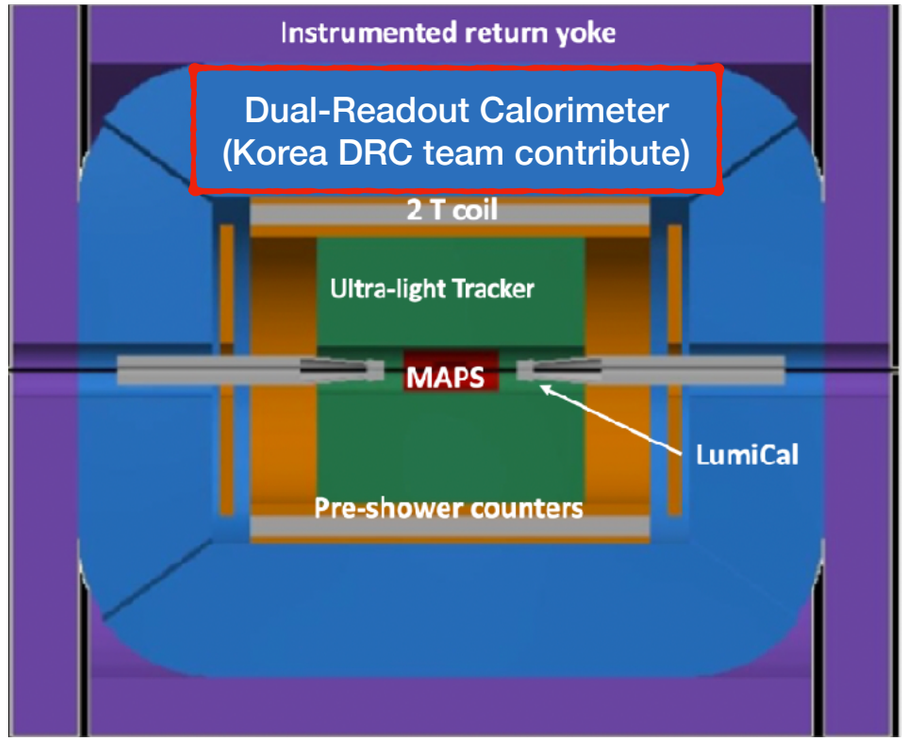
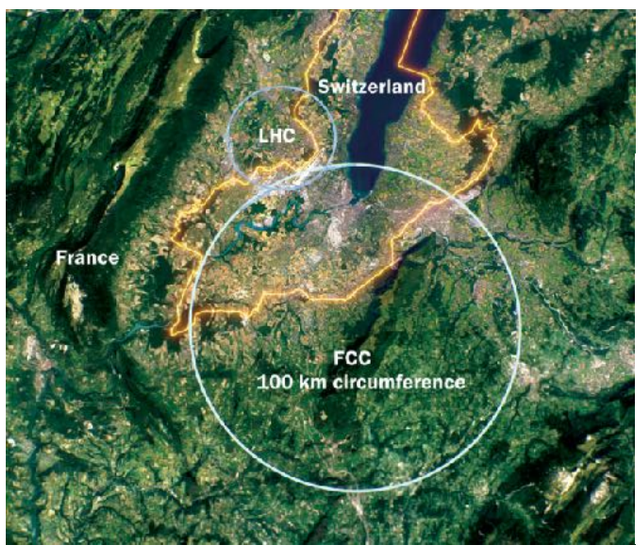
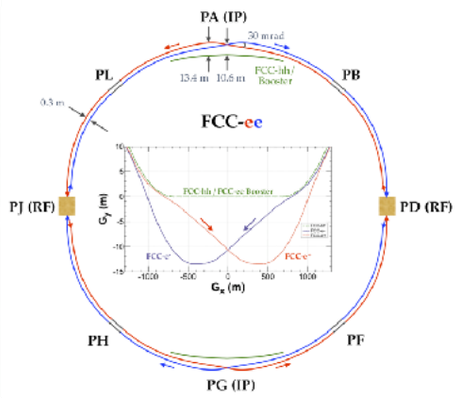
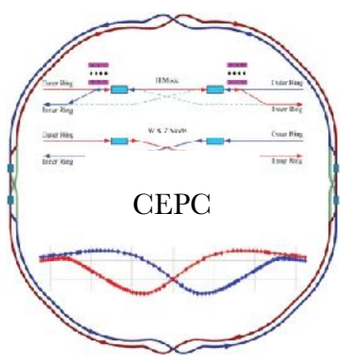
Dual-Readout Calorimeter

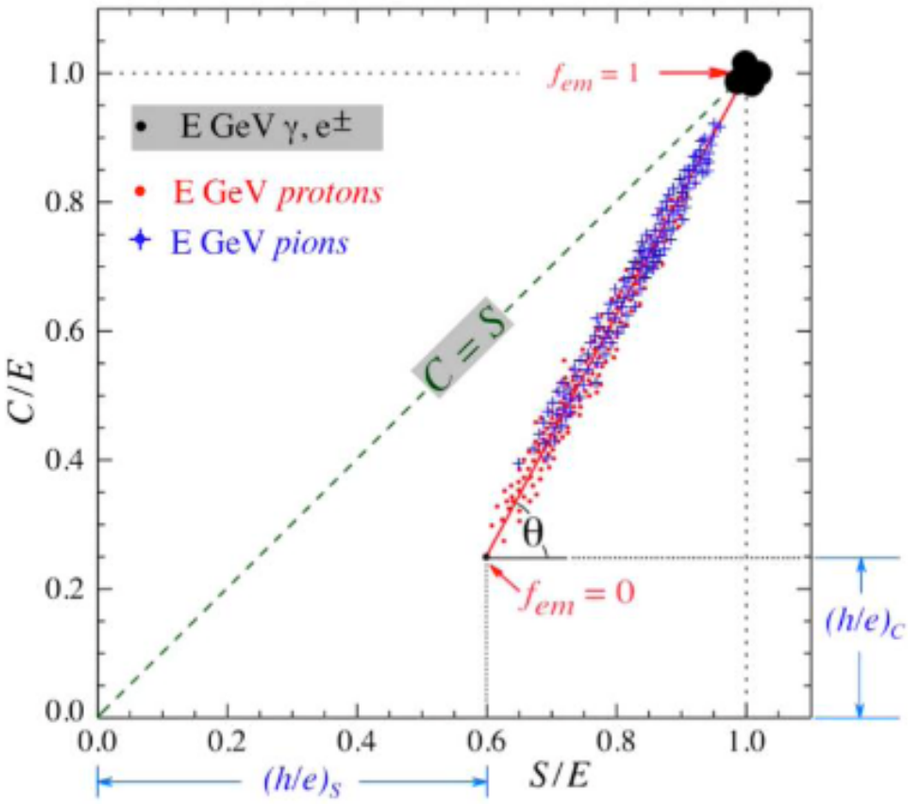
- **Dual-Readout Calorimeter**
  - I) The dual-readout calorimeter has been included in the conceptual design report of both **FCC-ee** and **CEPC**
  - II) **Non-gaussian electromagnetic fluctuations** are a major factor that makes it difficult to measure the energy of hadron shower
  - III) The dual-readout calorimeter offer **high-quality energy measurement** for both EM particles and hadrons simultaneously
  - IV) Outstanding energy resolution can be achieved by **measuring EM component** and **correcting hadron energy event by event**











2. Configuration

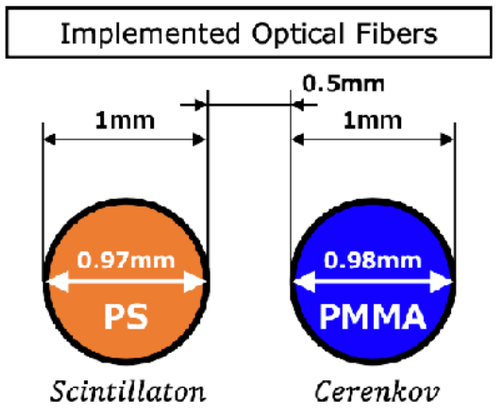
- The dual-readout calorimeter can be divided by 2 parts in building process

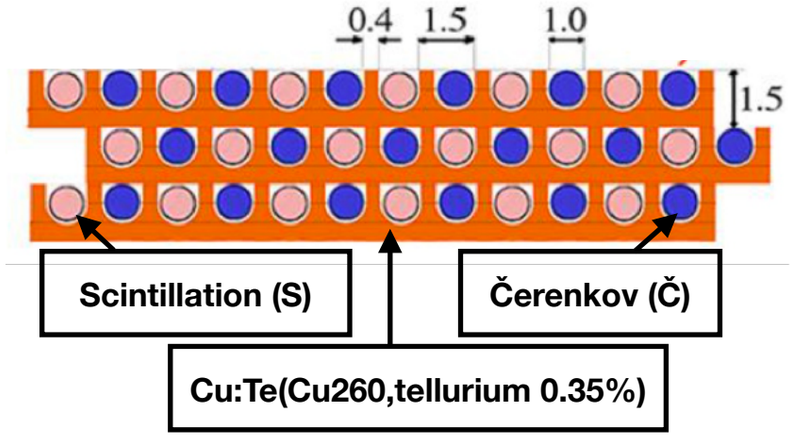
  i) Copper plate
  - **61 plates** are used to build a module

  ii) Optical fibers
  - Čerenkov fibers: round shape and single cladding
    - Made by Mitsubishi, Japan
  - Scintillating fibers: **round** and **square** shape & **single** and **double** cladding
    - Made by Kuraray, Japan

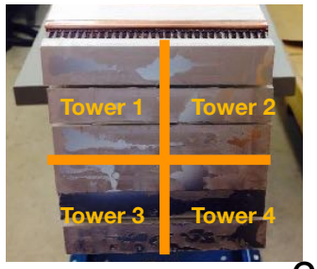
- **Module 1**
  - 4 towers
  - Different shape & cladding for scintillating fibers
  - PMT & **MCP-PMT**

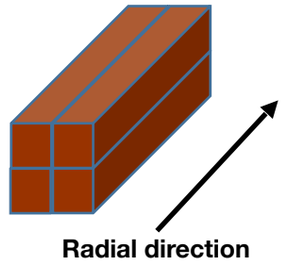
- **Module 2**
  - 9 towers
  - PMT & **SiPM**





Module #1 (2x2)





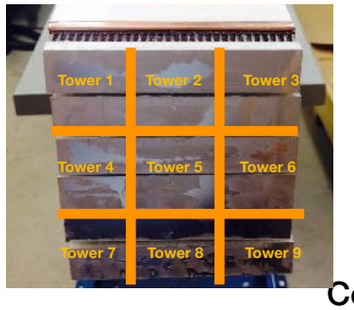
Module#1

Tower#1	Tower#2
Tower#3	Tower#4

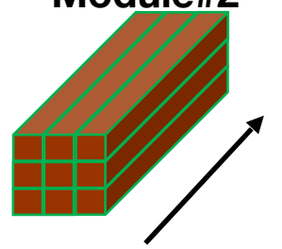
Combination of fibers for Module#1

	Tower #1	Tower #2	Tower #3	Tower #4
Scintillation fibers	**Square** / Single cladding	Round / **Double cladding**	Round / Single cladding	Round / Single cladding
Cherenkov fibers	Round / Single cladding			
Readout detector (2*4 ch)	2 PMTs	2 PMTs	2 MCP-PMTs	2 PMTs

Module #2 (3x3)



Module#2



Module#2

Tower#1	Tower#2	Tower#3
Tower#4	Tower#5	Tower#6
Tower#7	Tower#8	Tower#9

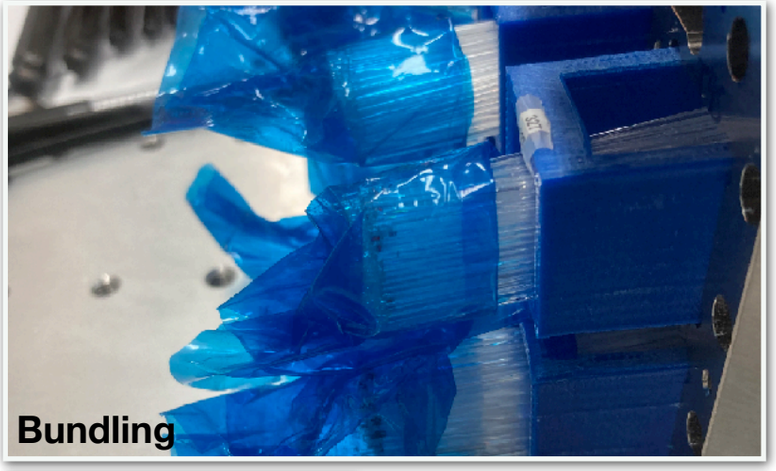
Combination of fibers for Module#2

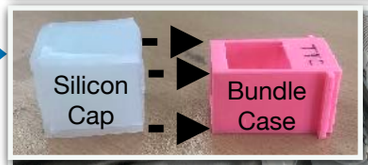
	Tower #1~4 and #6~9	Tower #5
Scintillation fibers	Round / Single cladding	Round / Single cladding
Cherenkov fibers	Round / Single cladding	Round / Single cladding
Readout detector	16 PMTs	400 SiPMs

Procedure of Assembly

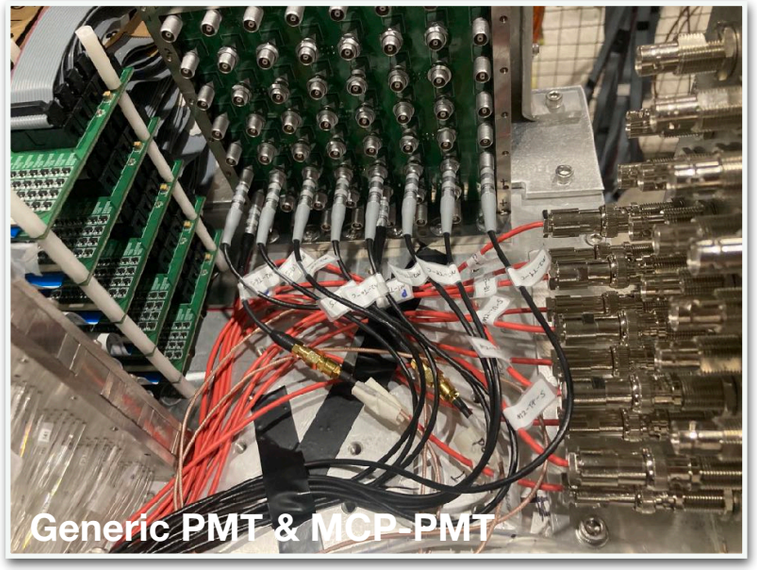
Step 1. Fiber Assembly

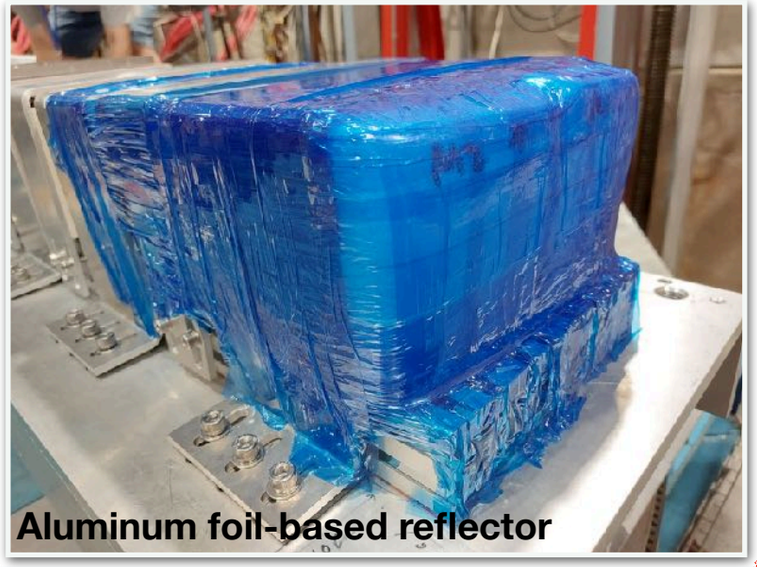
Step 2. Fiber Bundling





Step 3. Install photomultiplier & reflector



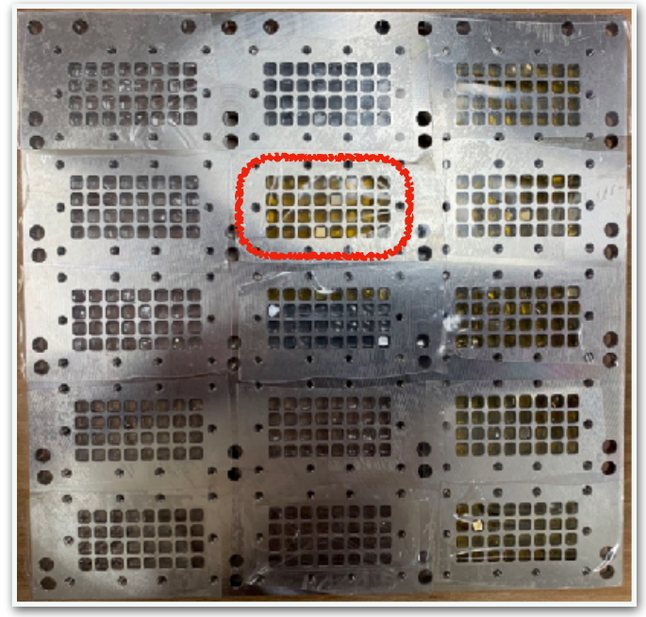


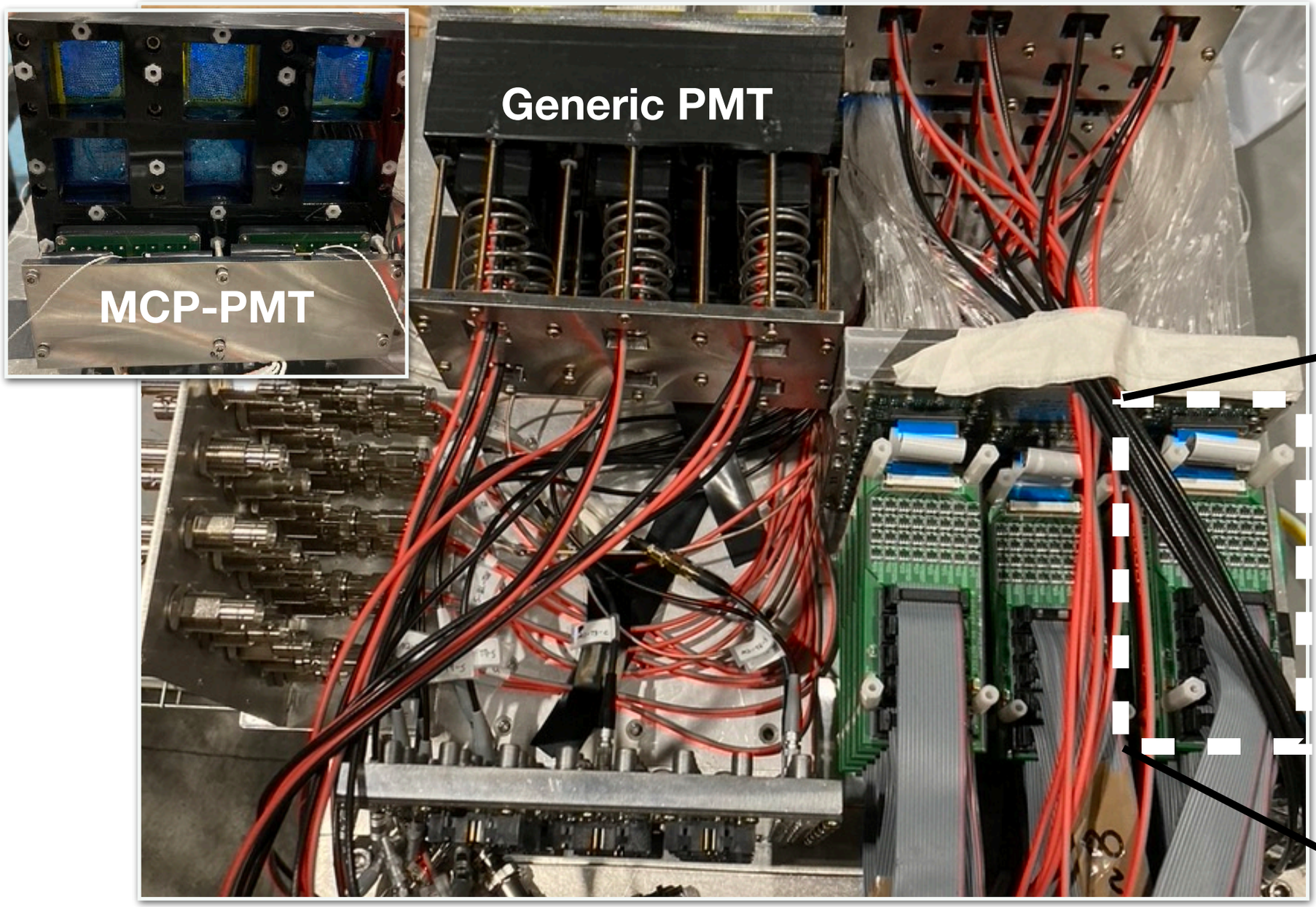
Finished at Yonsei univ.

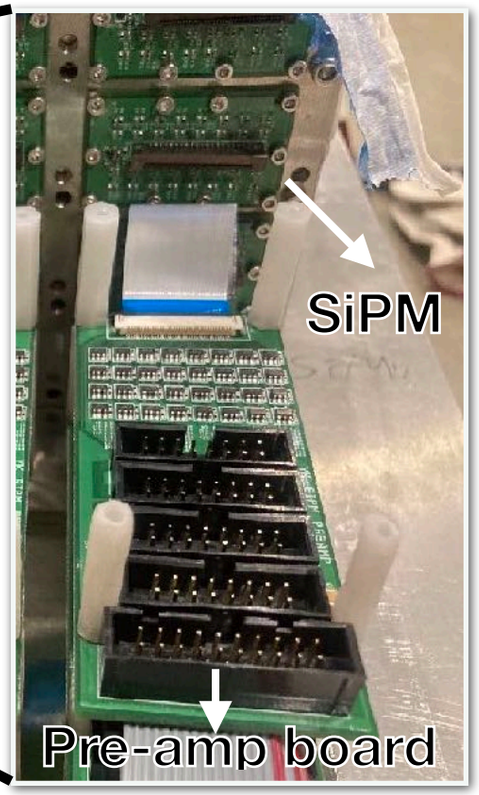
Readout Installation

- **Readout: Generic PMT, MCP-PMT, SiPM**
  - **In SiPM installation case**, we assembled SiPM very carefully to prevent the optical cookie from escaping and, connected it to the pre-amp board
  - **In other case**, installation and cable connection are assembled at the same time
  - **MCP-PMT** has 2 types of cable: negative & positive signal line

SiPM Frame







DAQ Connection

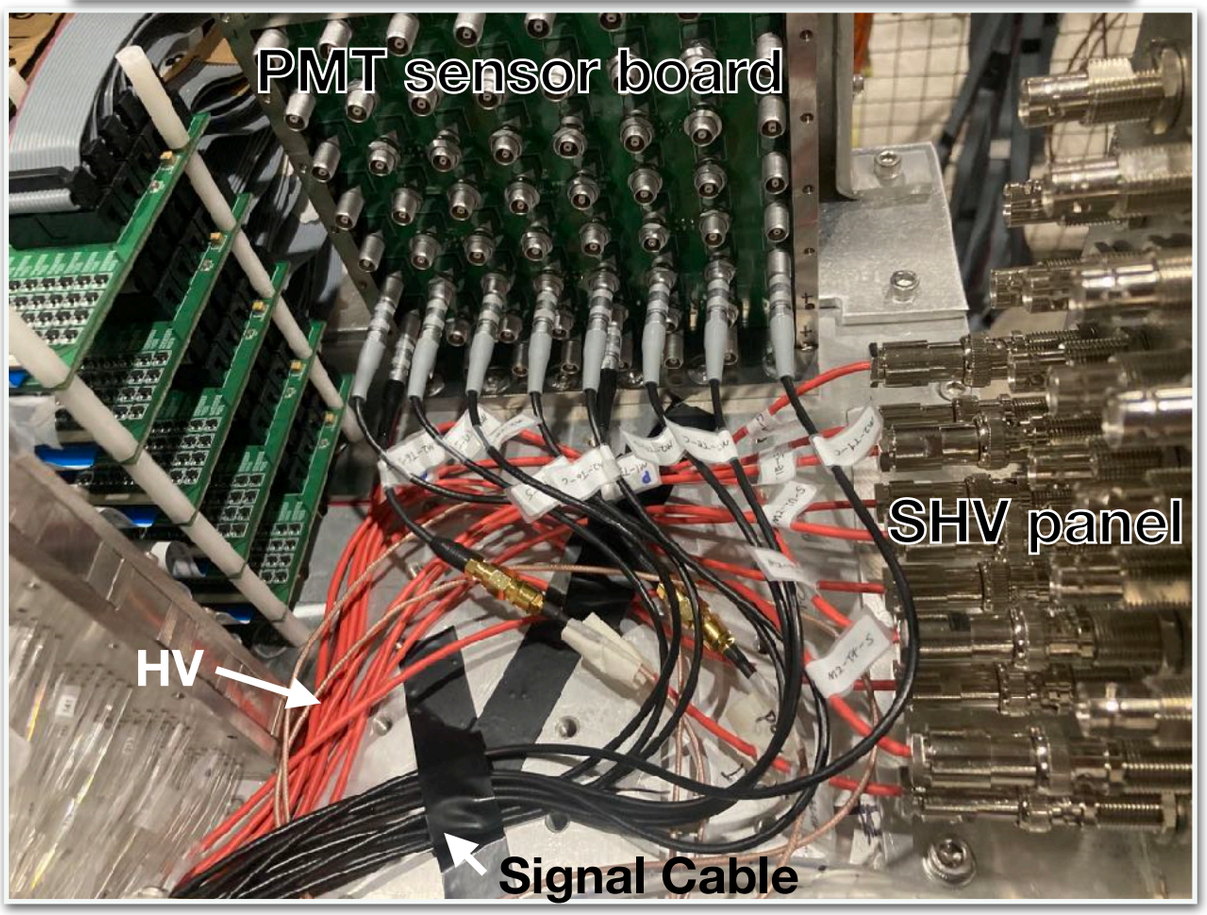
Generic PMT & MCP-PMT

PMT sensor board mapping

lemo cable connect side

mid 1	mid1 ch1 M1_T1_S	mid1 ch3 M1_T2_S	mid1 ch5 M1_T4_S	mid1 ch7 M1_T3_S MCP(-)	mid1 ch9 M1_T1_C	mid1 ch11 M1_T2_C	mid1 ch13 M1_T4_C	mid1 ch15 M1_T3_C MCP(-)
	mid1 ch2	mid1 ch4	mid1 ch6	mid1 ch8	mid1 ch10	mid1 ch12 PS	mid1 ch14 TC	mid1 ch16 Muon
	mid1 ch17 DWC1 (digital1) **right**	mid1 ch19 DWC1 (digital2) **left**	mid1 ch21 DWC1 (digital3) **up**	mid1 ch23 DWC1 (digital4) **down**	mid1 ch25 DWC2 (digital1) **right**	mid1 ch27 DWC2 (digital2) **left**	mid1 ch29 DWC2 (digital3) **up**	mid1 ch31 DWC2 (digital4) **down**
	mid1 ch18	mid1 ch20	mid1 ch22	mid1 ch24	mid1 ch26	mid1 ch28	mid1 ch30	mid1 ch32
mid 2	mid2 ch1 M2_T1_S	mid2 ch3 M2_T2_S	mid2 ch5 M2_T3_S	mid2 ch7 M2_T4_S	mid2 ch9 M2_T1_C	mid2 ch11 M2_T2_C	mid2 ch13 M2_T3_C	mid2 ch15 M2_T4_C
	mid2 ch2 M2_T6_S	mid2 ch4 M2_T7_S	mid2 ch6 M2_T8_S	mid2 ch8 M2_T9_S	mid2 ch10 M2_T6_C	mid2 ch12 M2_T7_C	mid2 ch14 M2_T8_C	mid2 ch16 M2_T9_C
	mid2 ch17 M1_T3_S MCP(+)	mid2 ch19	mid2 ch21	mid2 ch23	mid2 ch25 M1_T3_C MCP(+)	mid2 ch27	mid2 ch29	mid2 ch31
	mid2 ch18	mid2 ch20	mid2 ch22	mid2 ch24	mid2 ch26	mid2 ch28	mid2 ch30	mid2 ch32

Ancillary detector

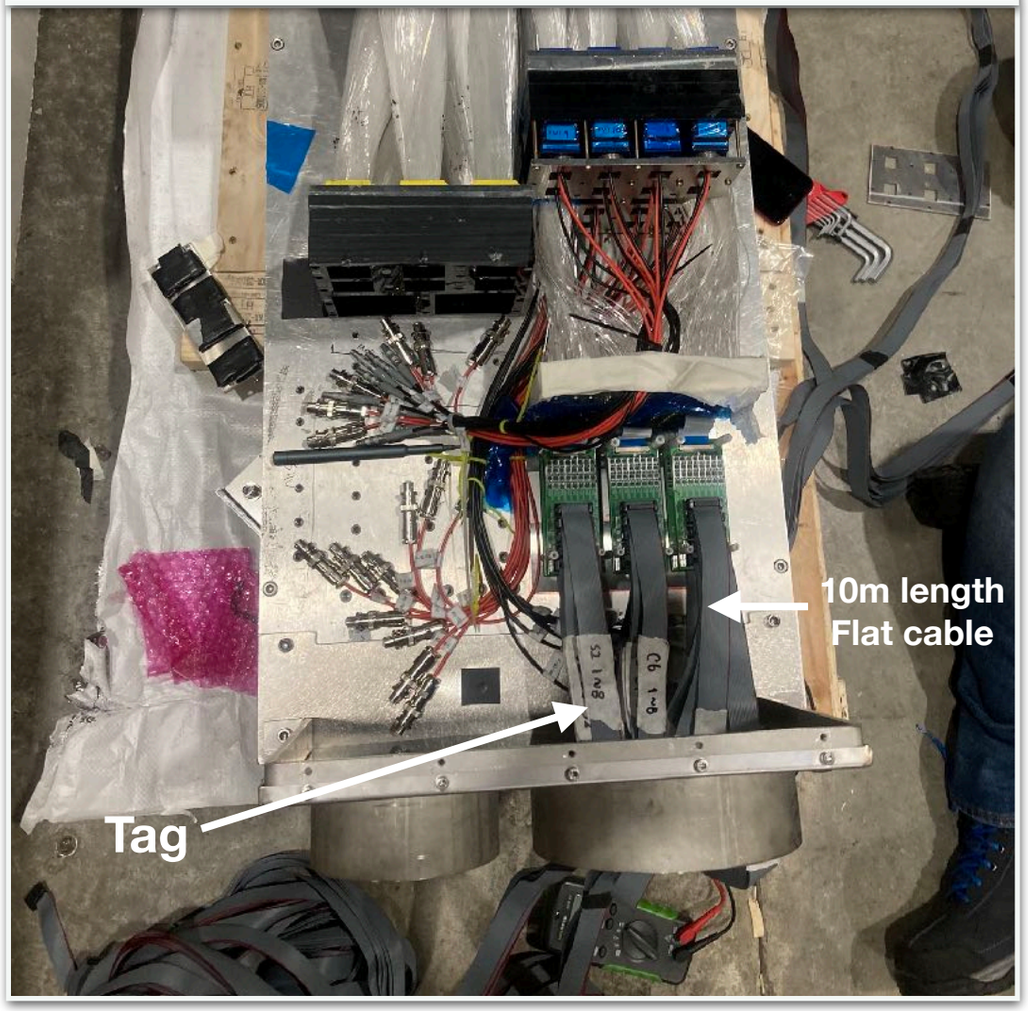


SiPM

Preamp board mapping

Down steam side

S5-mid15		C5-mid7
S4-mid14	S6-mid10	C4-mid6
S3-mid13	SC-mid11	C3-mid5
S2-mid12	C6-mid8	C2-mid4
S1-mid9		C1-mid3



Reflector: Aluminum Foil (i)

- **Reflectors**
  - The characteristics of lights

Light	Scintillating light	Čerenkov light
Quantity	Bright	Not bright
Speed	Slow (~2 ns)	Fast (~0 ns)
Attenuation lengths	Small (~3m)	Long (6~10m)

At the front side of copper plate,

- Scintillating fiber: **block** the light
- Čerenkov fiber: **reflect** the light which gives **the depth of light** in the module

  - Reflector material
    - We changed the material as a reflector from the aluminum mirror to an **aluminum foil**

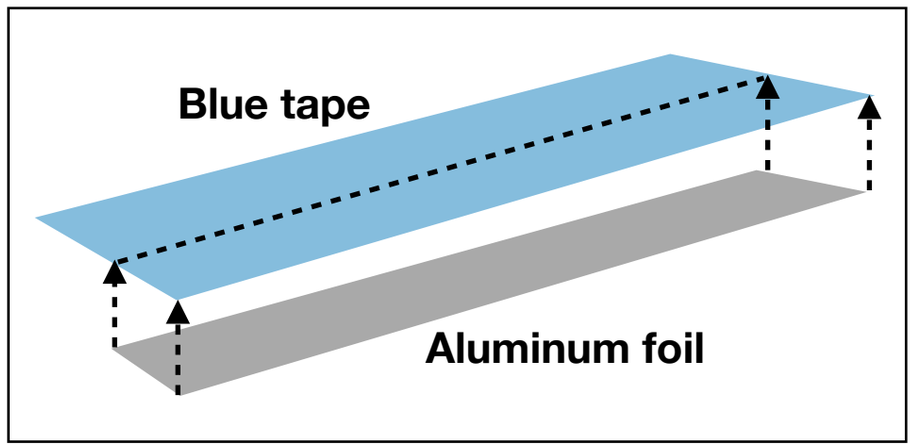
Aluminum foil

- Method
  - Aluminum reflectors are made by inserting blue tape between them and folding foil

Reflector: Aluminum Foil (ii)

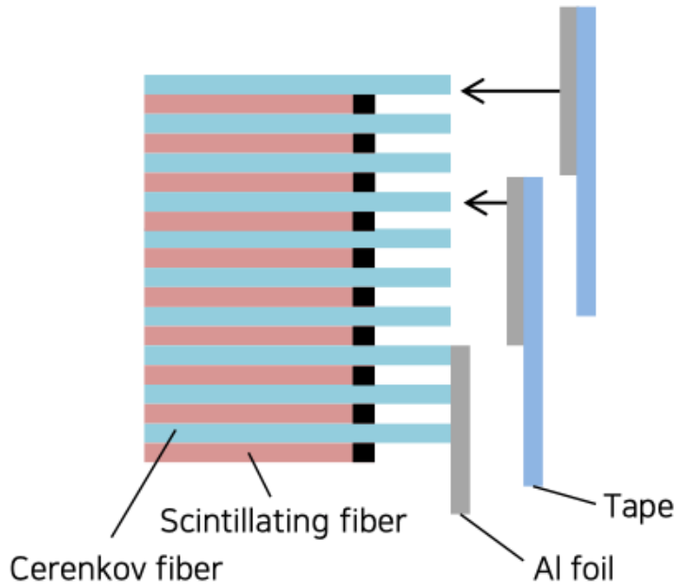
1. Making reflector

- Reflector was made by that **aluminum foil** is attached on the half of blue tape



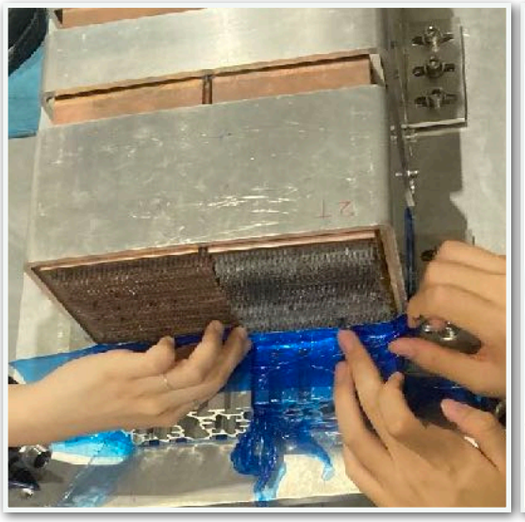
2. Attaching reflector

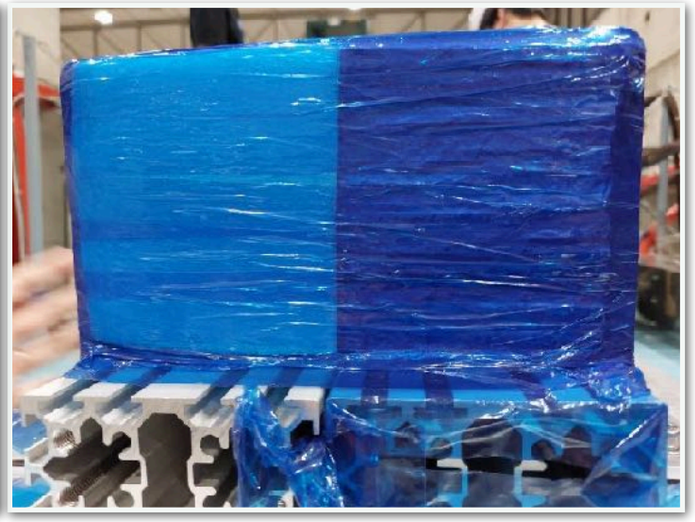
- Reflector is attached using tapes in **stair-shaped structure**



3. Buffer material

- We used buffer material to **make up for different distance** between module 1 & 2





4. Fixation & pressure

- We use buffer material again to **fix** and **press reflector**

Shielding PMT

- We put lead bricks in dark case to **protect PMTs from beam**