Module assembly of the Dual-Readout Calorimeter for future e+e- colliders

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On behalf of the Korea Dual-Readout Calorimeter Team

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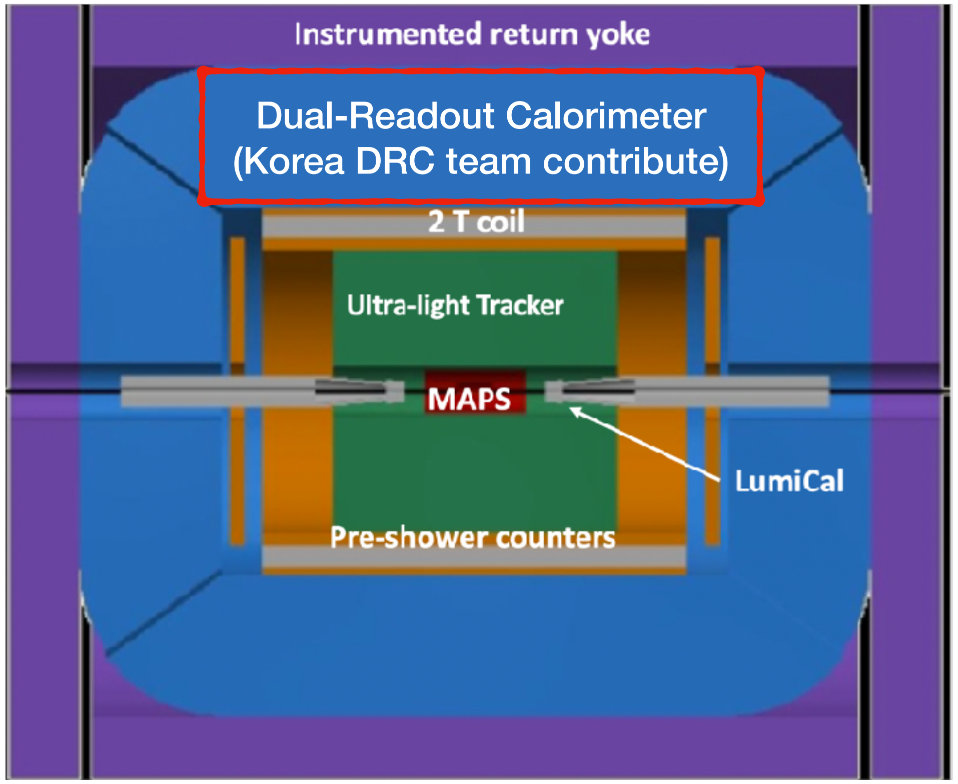
Supported by

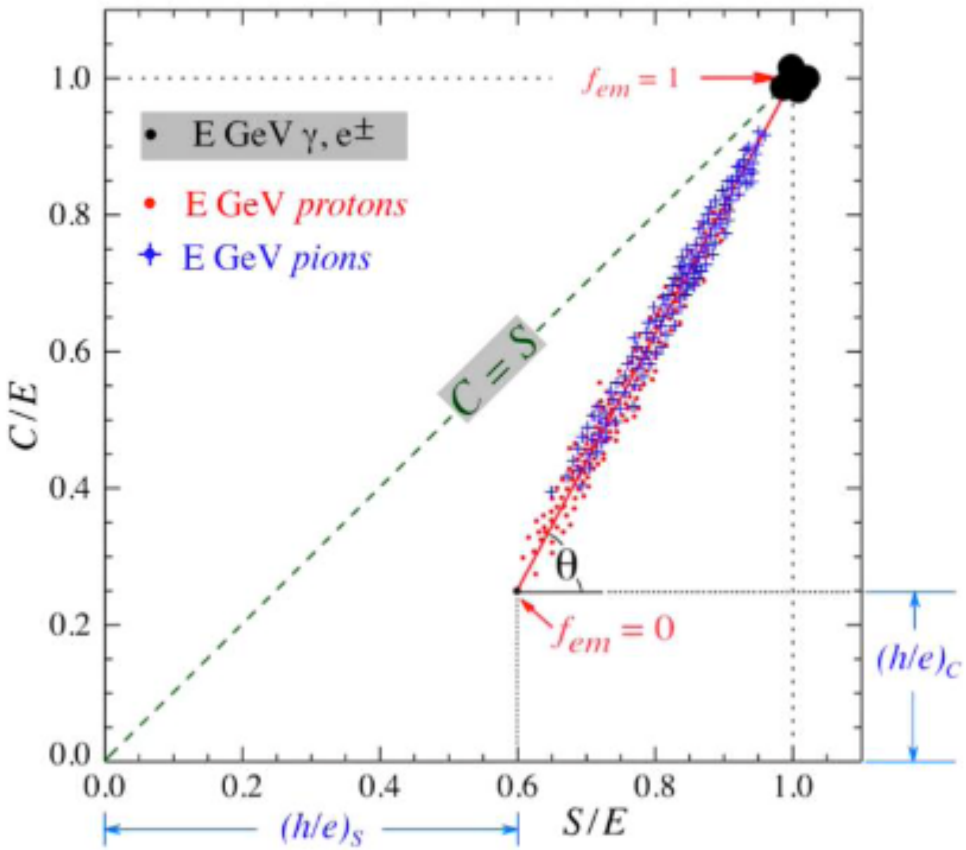
Outline

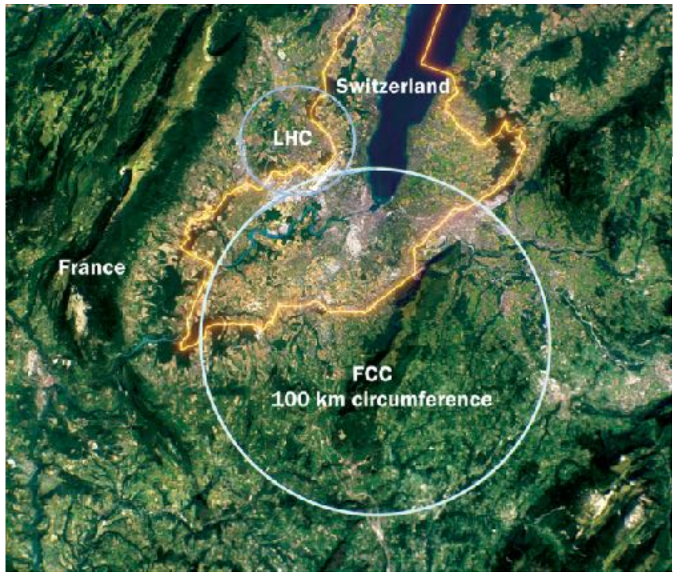
1. Introduction
2. Process of Assembly
    1) Assembly & Bundling Fibers
    2) PMT installation & Cable Connection
    3) Reflector
    4) Lead bricks
3. Summary

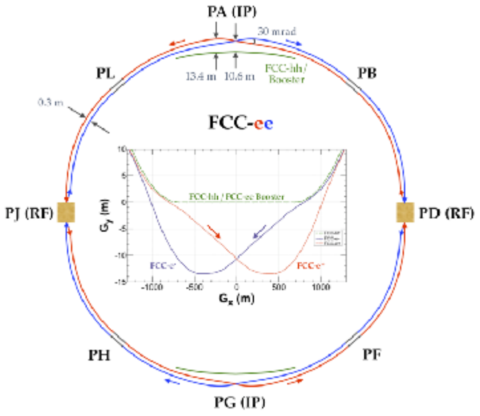
Dual-Readout Calorimeter

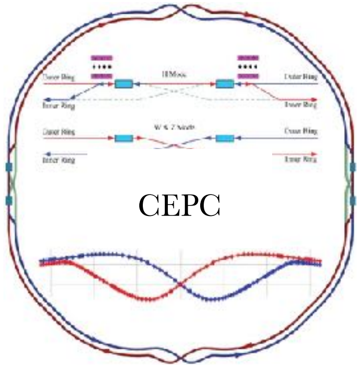
- **Dual-Readout Calorimeter**
  - I) The dual-readout calorimeter has been included in the conceptual design report of both **FCC-ee** and **CEPC**
  - II) **Non-gaussian electromagnetic fluctuations** are a major factor that makes it difficult to measure the energy of hadron shower
  - III) The dual-readout 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**









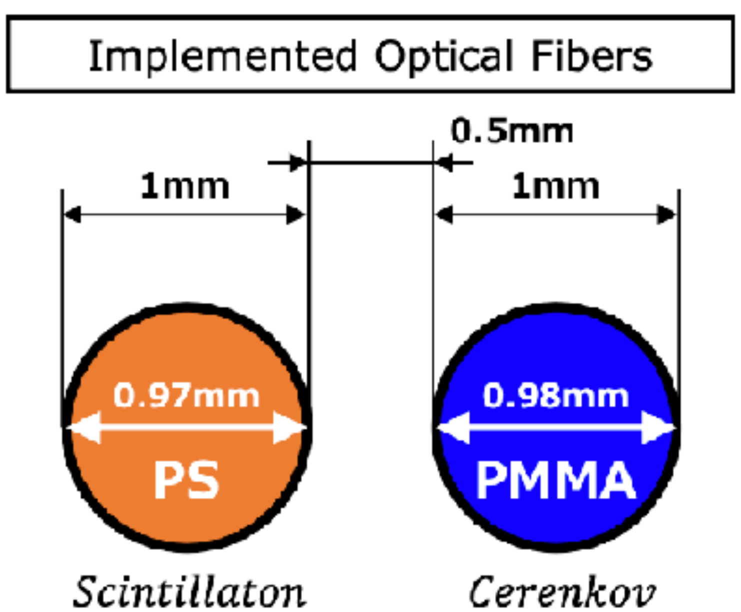


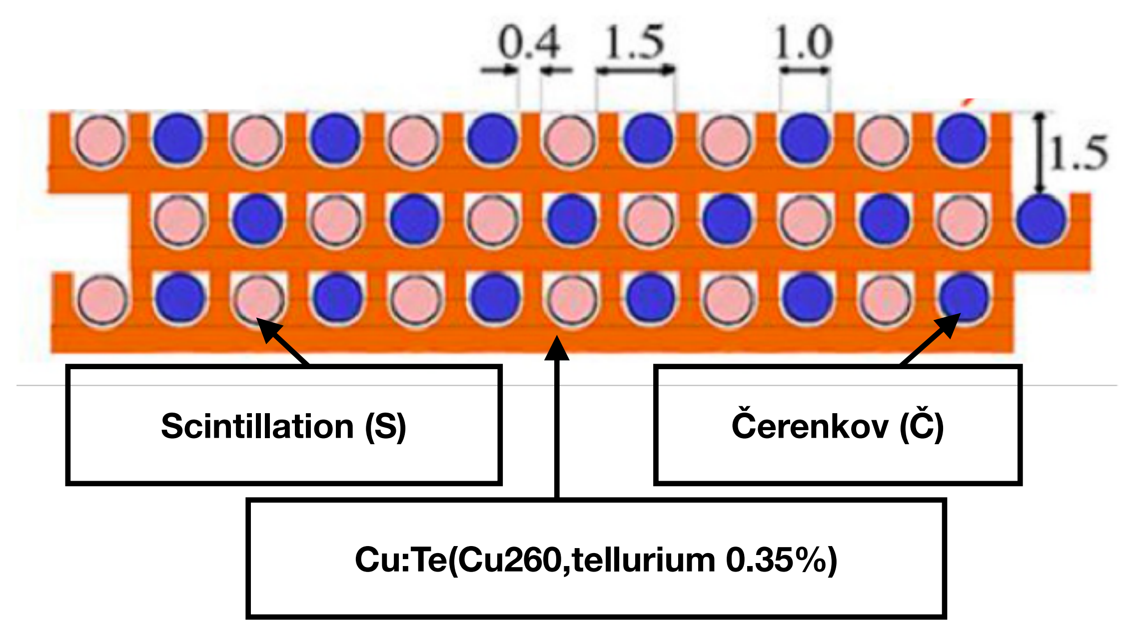
Module Configuration (i)

- The dual-readout calorimeter can be divided by 2 parts in building process
  - i) Copper plate
    - To build calorimeter, we have to disassemble and clean up all plates because they were used in 2016
    - **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

US in 2016

YU in 2020





Module Configuration (ii)

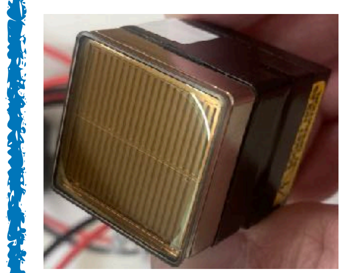
- The dual-readout calorimeter can be divided by 2 parts in building process

- **Module 1**
  - 4 towers
  - MCP-PMT is used in tower 3
  - Different shape & cladding for scintillating fibers
    Shape: Square & Round
    Cladding: Single cladding & Double cladding
  - Generic PMT & **MCP-PMT**

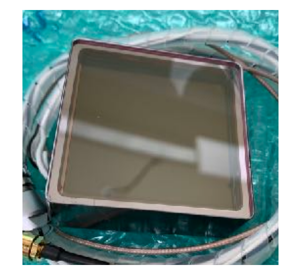
- **Module 2**
  - 9 towers
  - 416 ch SiPM is used in tower 5
  - Generic PMT & **SiPM**

Readout Detector

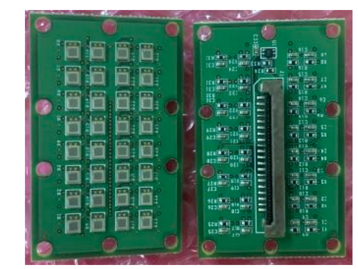
PMT



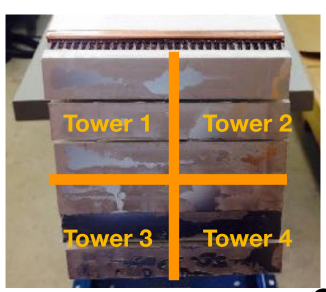
MCP-PMT

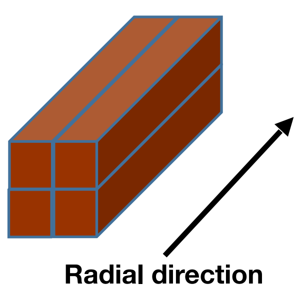


SiPM



Module #1 (2x2)





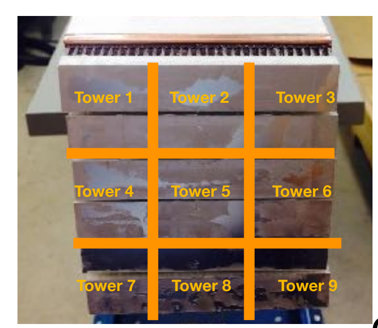
Module#1

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

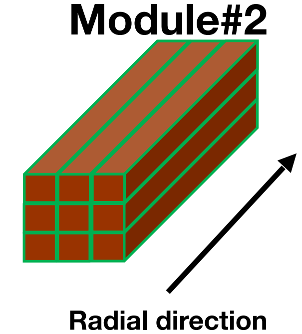
Combination of fibers for Module#1

	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

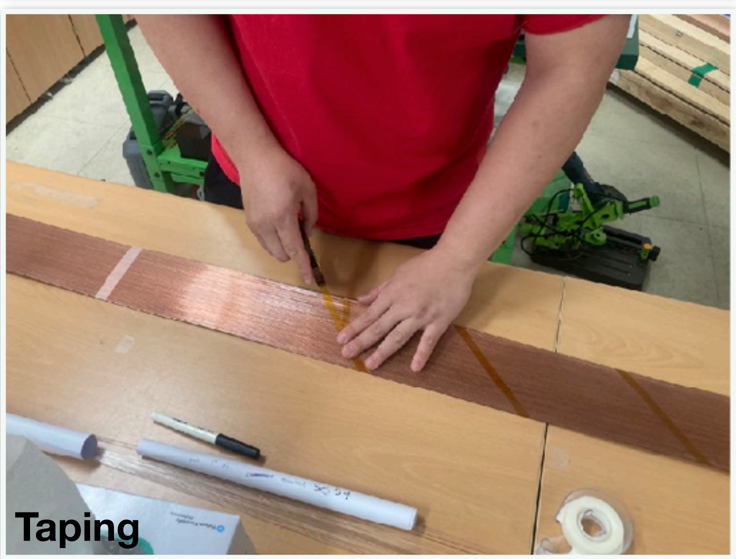
Tower#1	Tower#2	Tower#3
Tower#4	Tower#5	Tower#6
Tower#7	Tower#8	Tower#9

Combination of fibers for Module#2

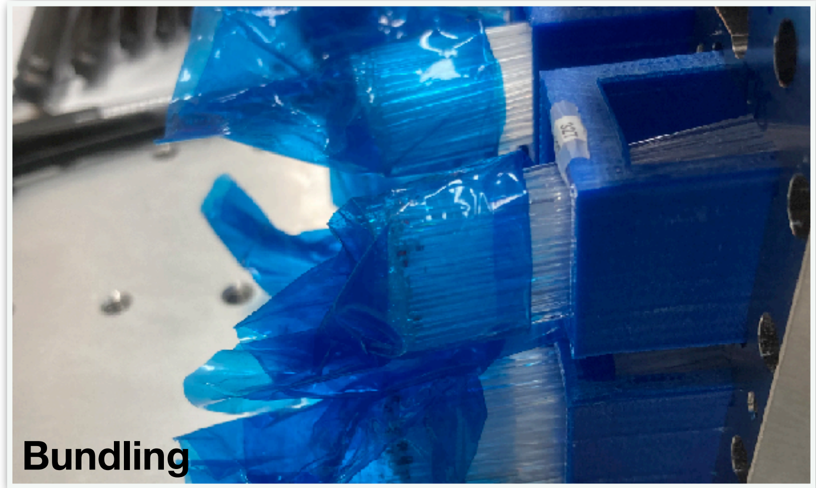
	Tower #1~4 and #6~9	Tower #5
Scintillation fibers	Round / Single cladding	Round / Single cladding
Cherenkov fibers	Round / Single cladding	Round / Single cladding
Readout detector (400+16 ch)	16 PMTs	400 SiPMs

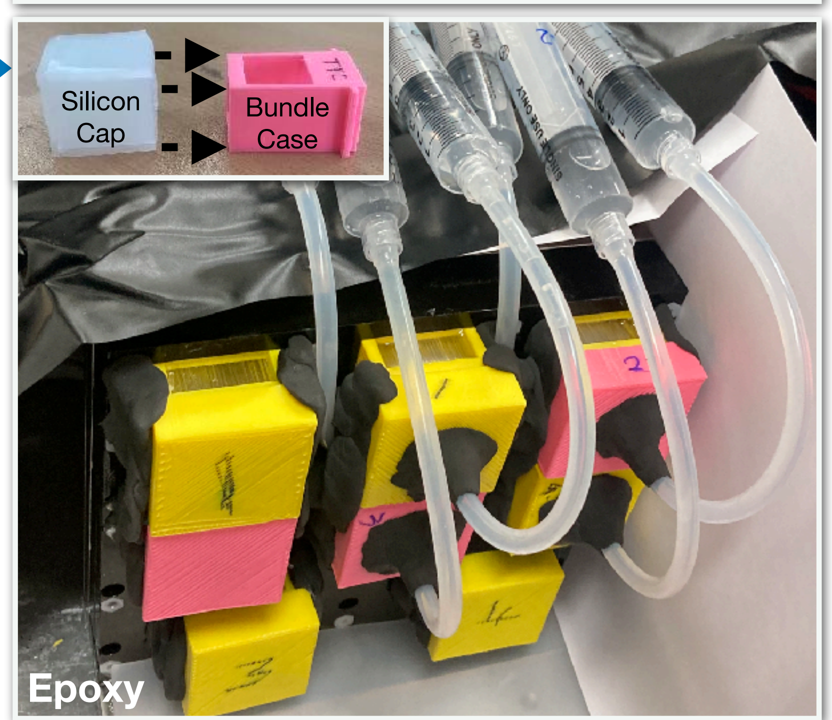
Procedure of Assembly

Step 1. Fiber Assembly

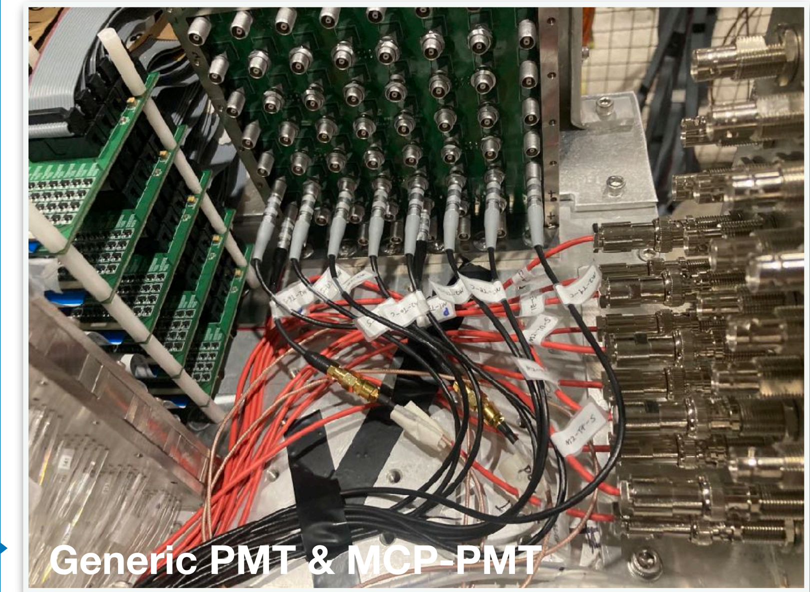


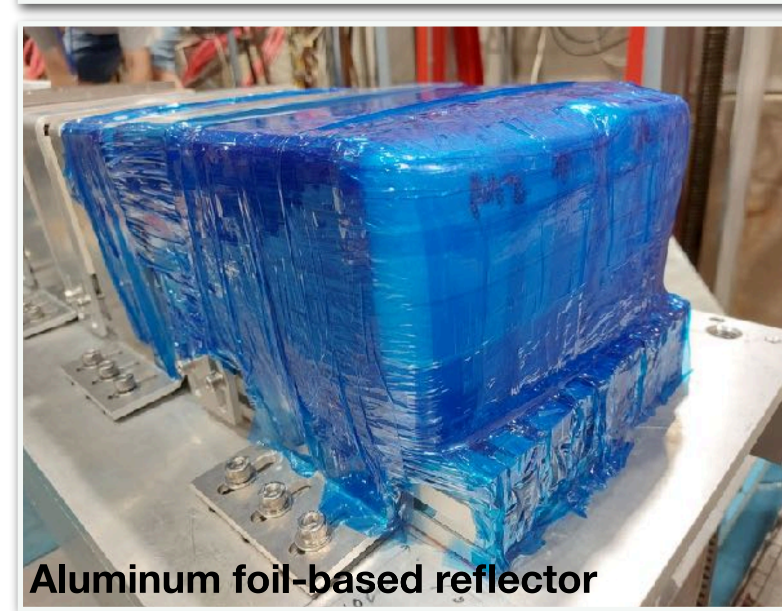
Step 2. Fiber Bundling





Step 3. Install photomultiplier & reflector





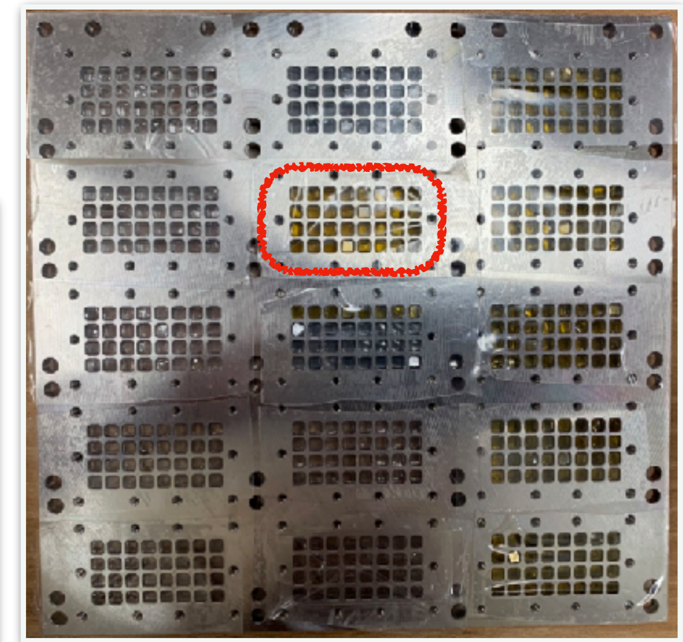
Finished at Yonsei univ. (Steps 1–2)

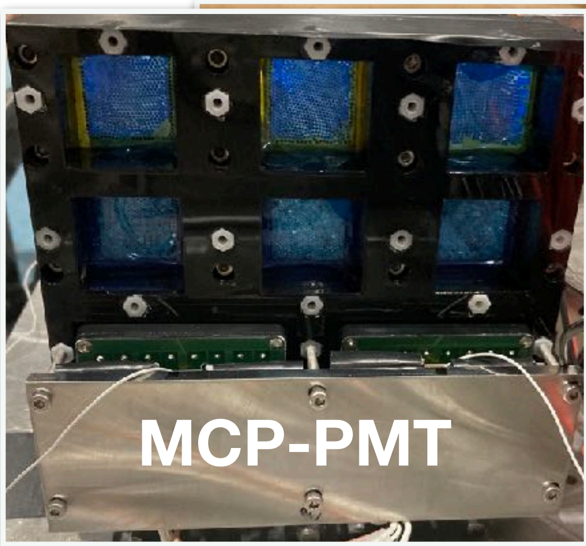
re-installed at CERN (Step 3)

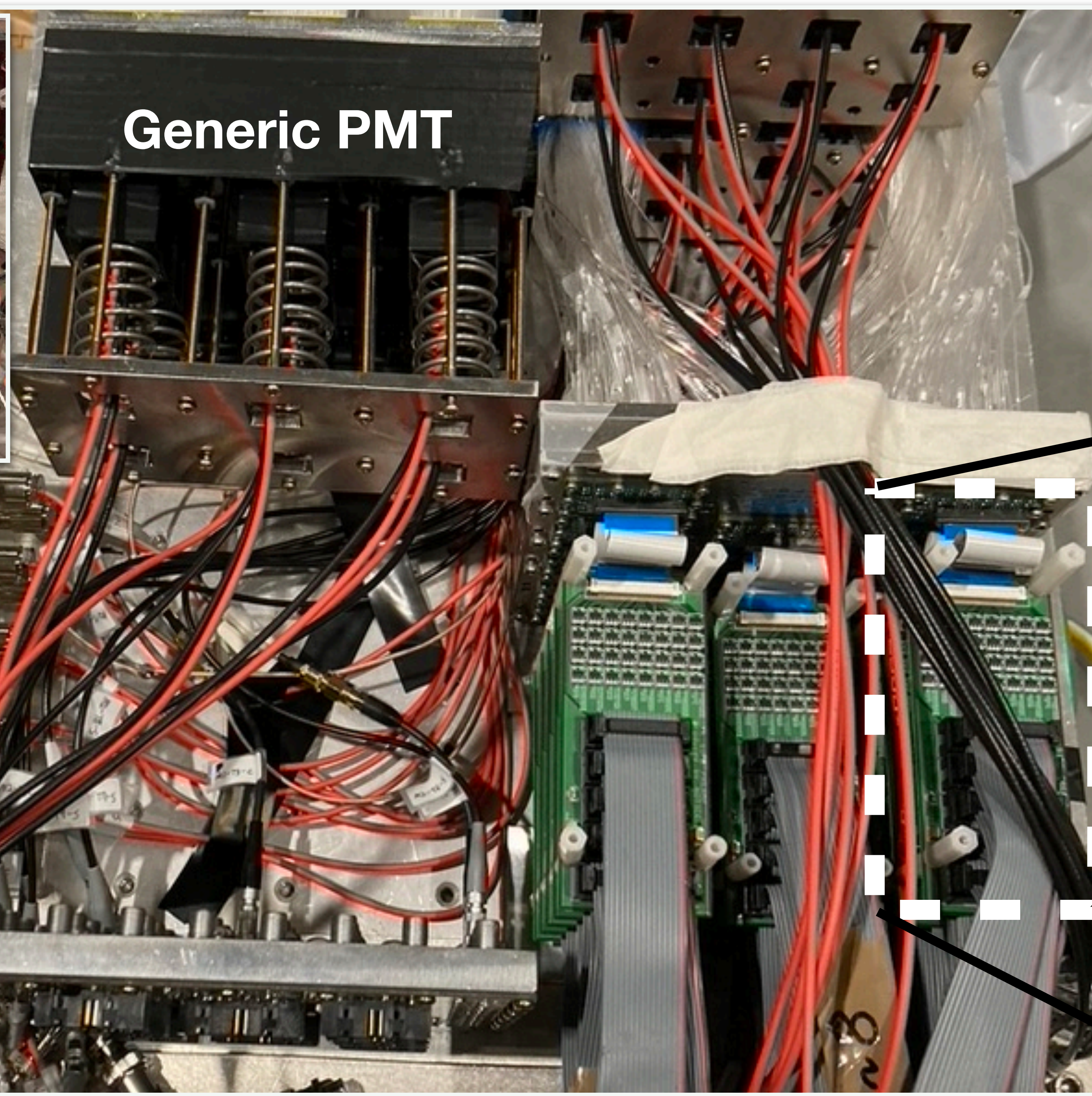
Readout Installation

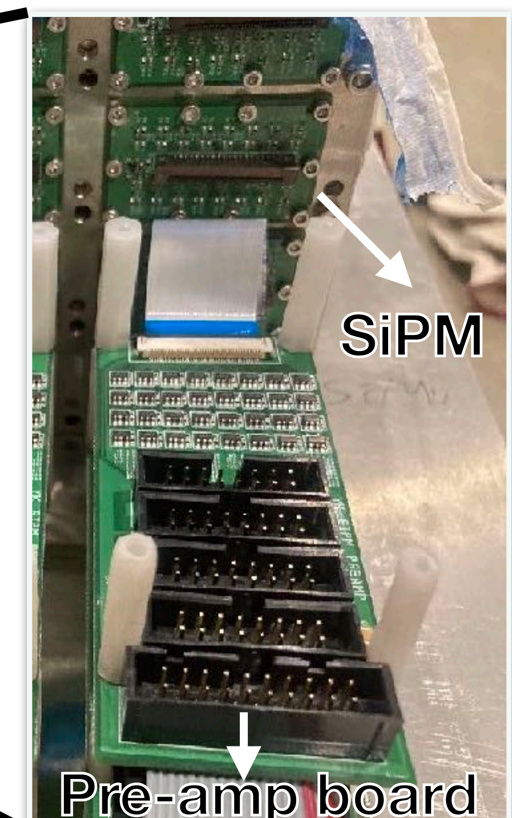
- **Readout: Generic PMT, MCP-PMT, SiPM**
  - **In SiPM installation case**, we assembled SiPM very carefully to prevent the optical cookie from escaping and, connected it to the pre-amp board
  - **In other case**, installation and cable connection are assembled at the same time
  - **MCP-PMT** has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

SiPM Frame









DAQ Connection

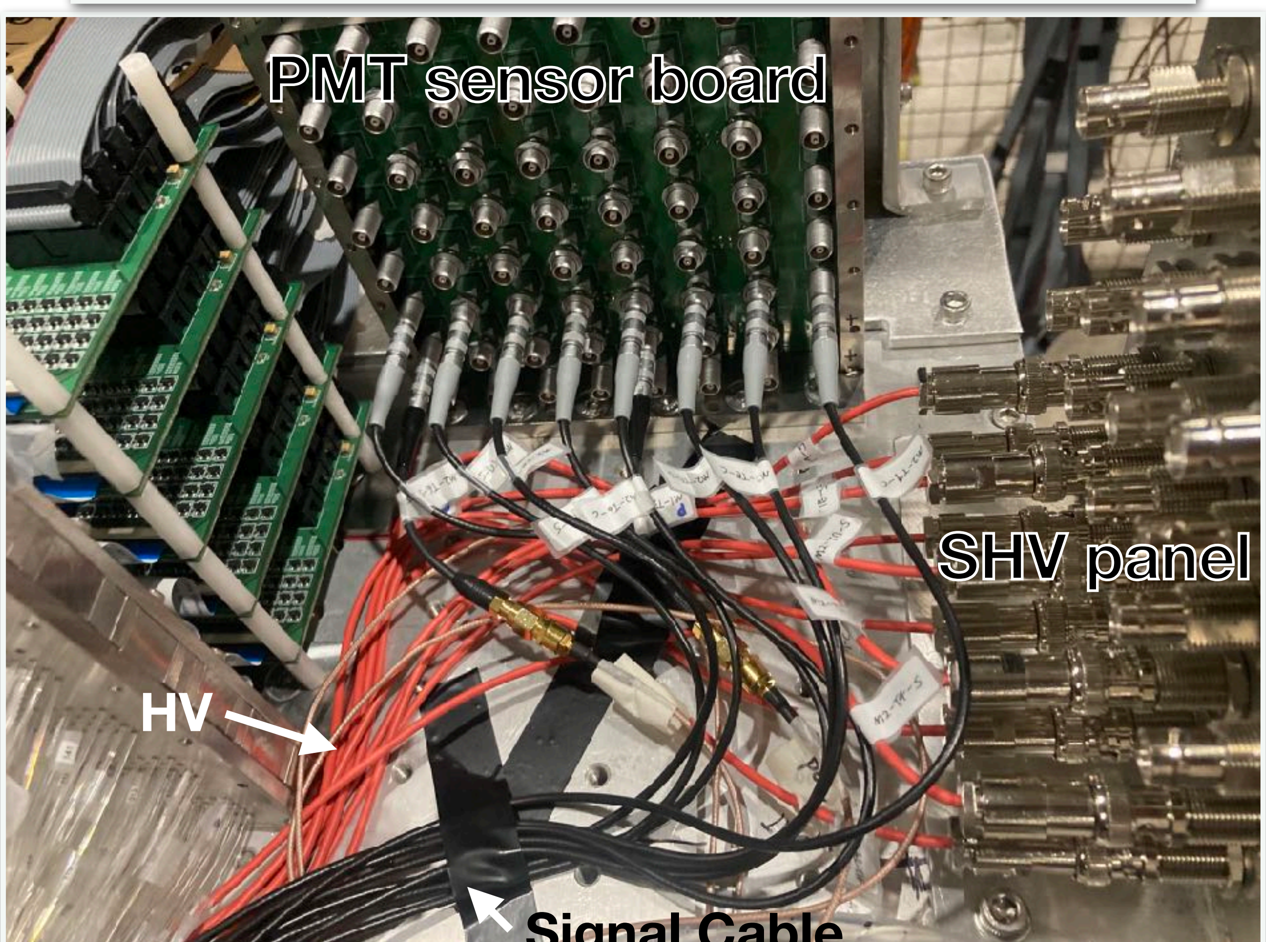
Generic PMT & MCP-PMT

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

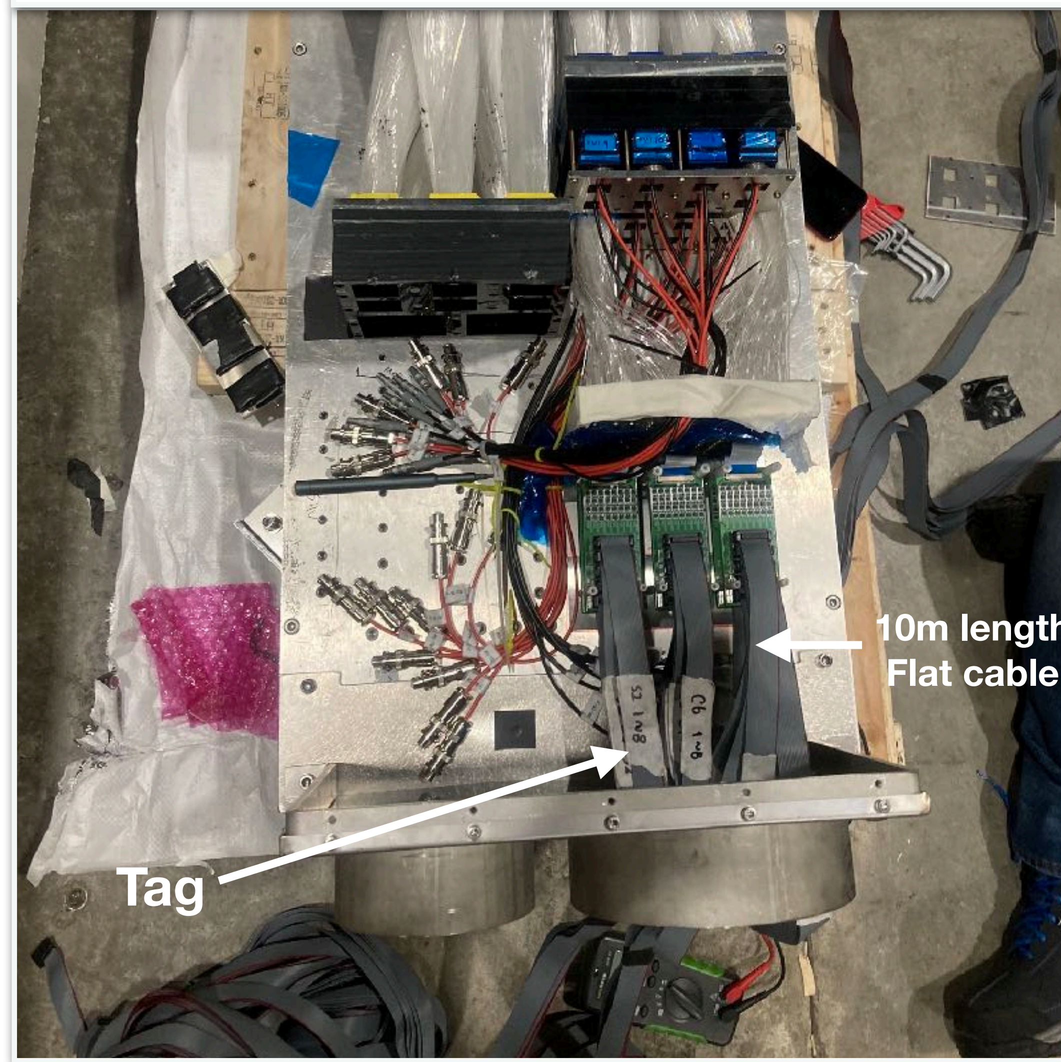


SiPM

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



- **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**

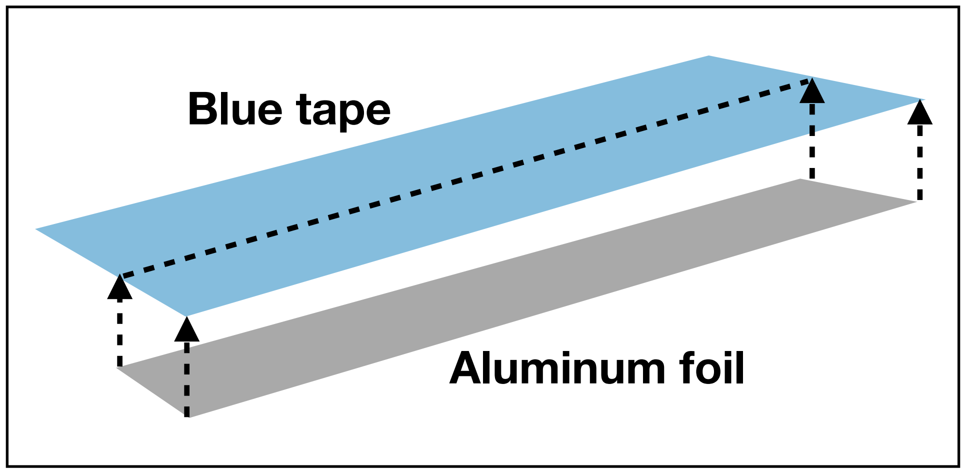
Aluminum foil

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

Reflector: Aluminum Foil (ii)

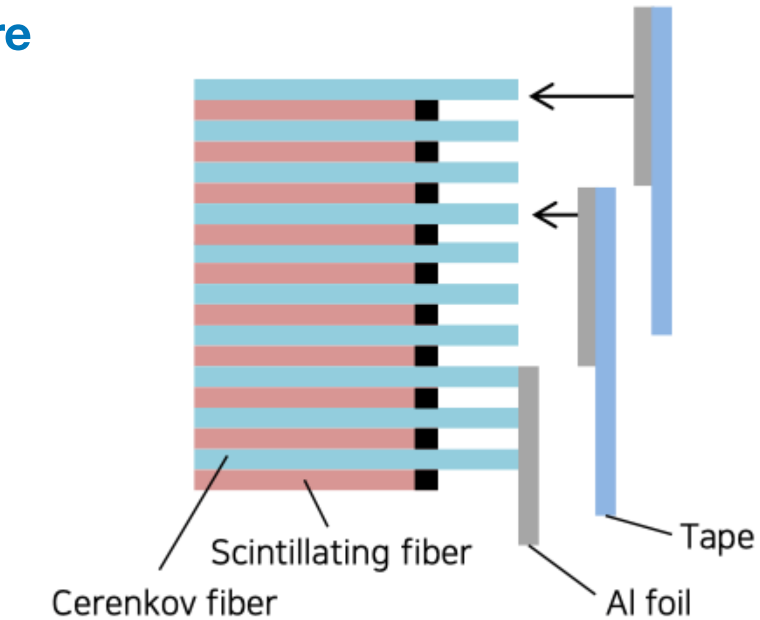
1. Making reflector

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



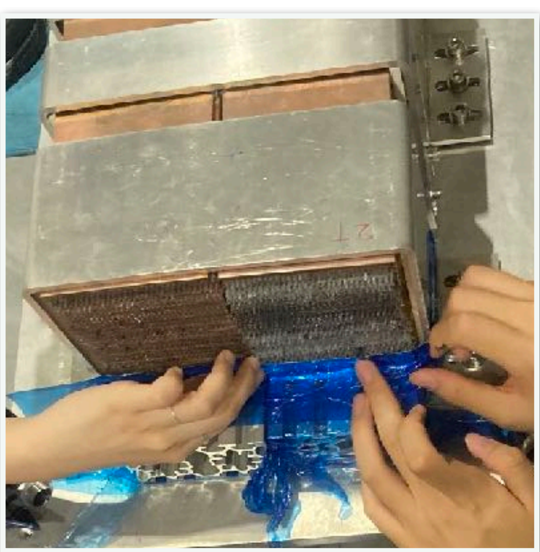
2. Attaching reflector

- 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

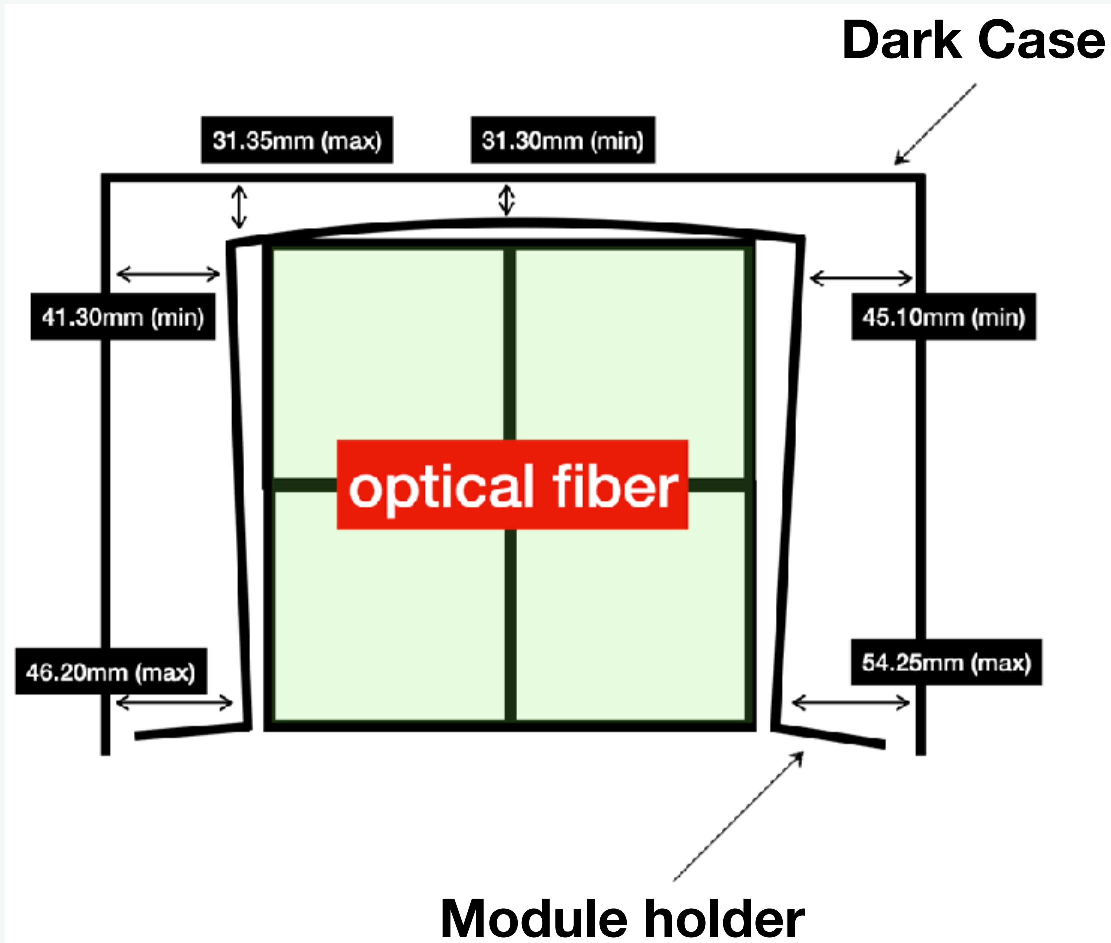


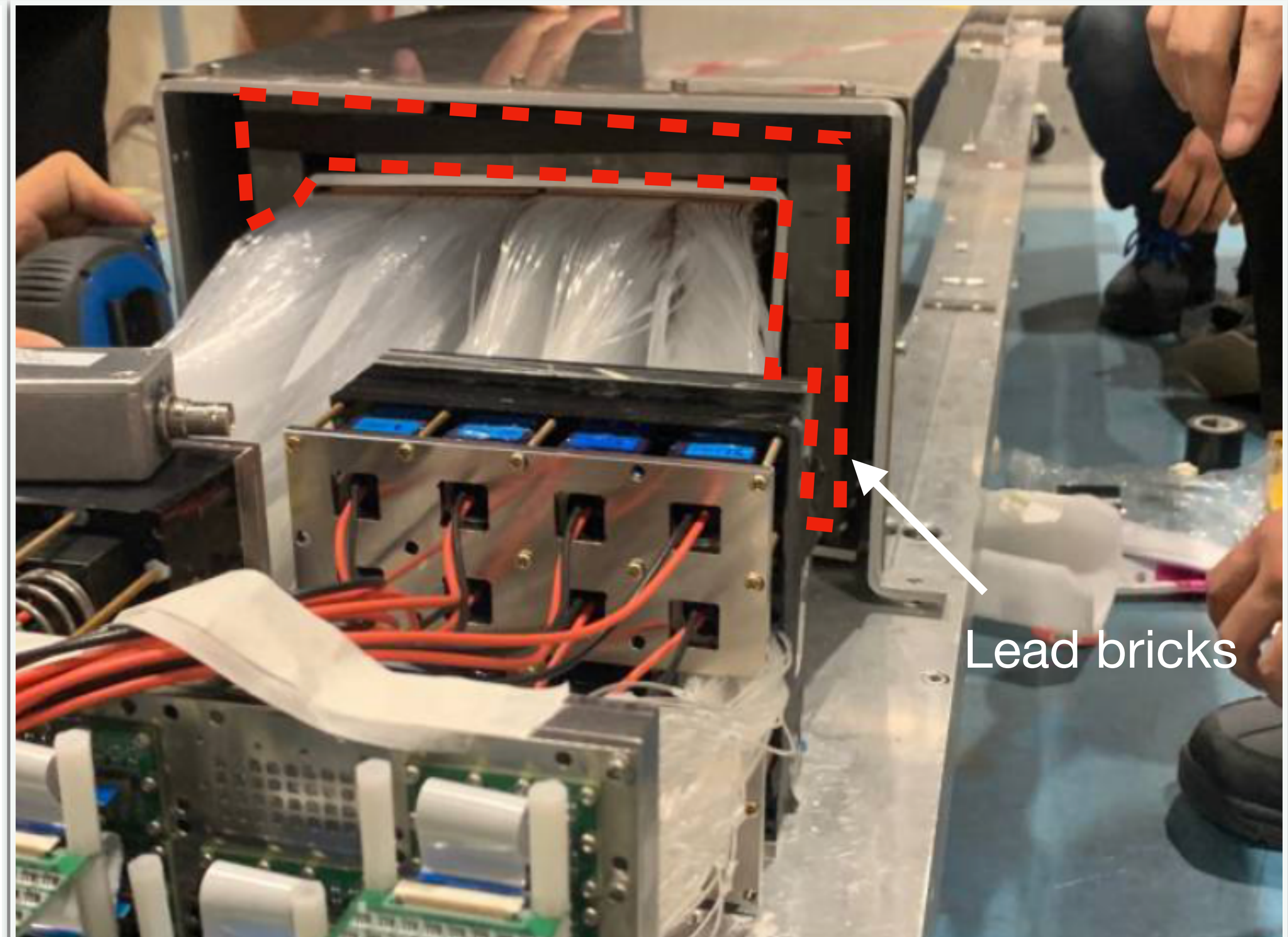
4. Fixation & pressure

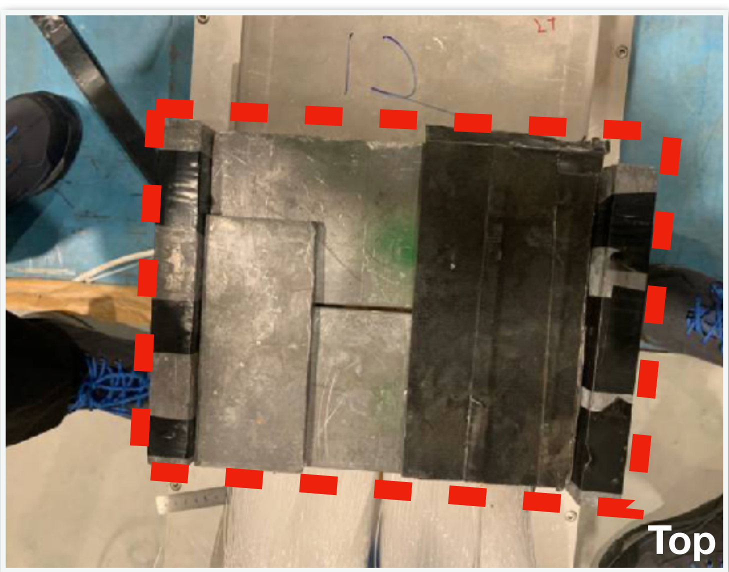
- We use buffer material again to **fix** and **press reflector**

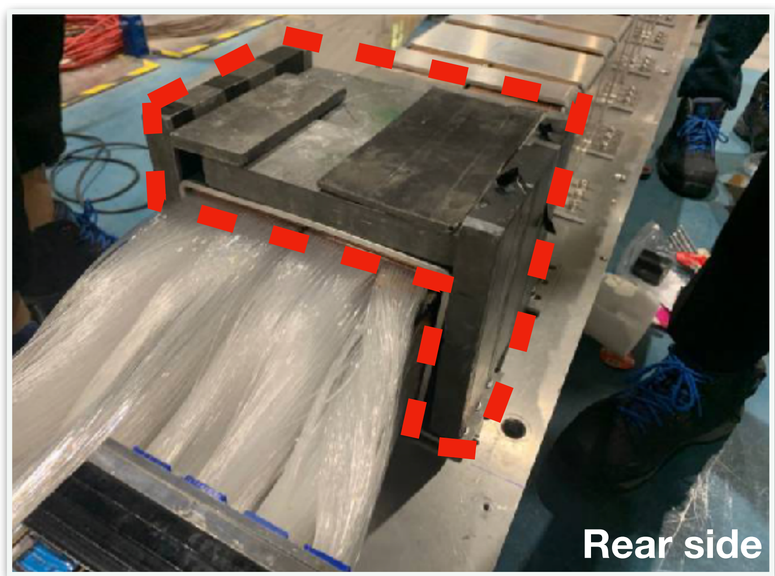
Shielding PMT

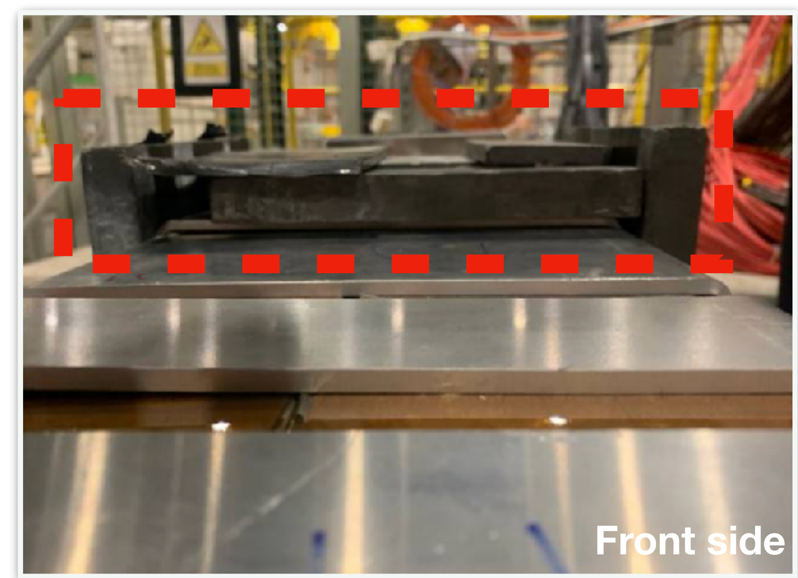
- We put lead bricks in dark case to **protect PMTs from beam**











5. Summary

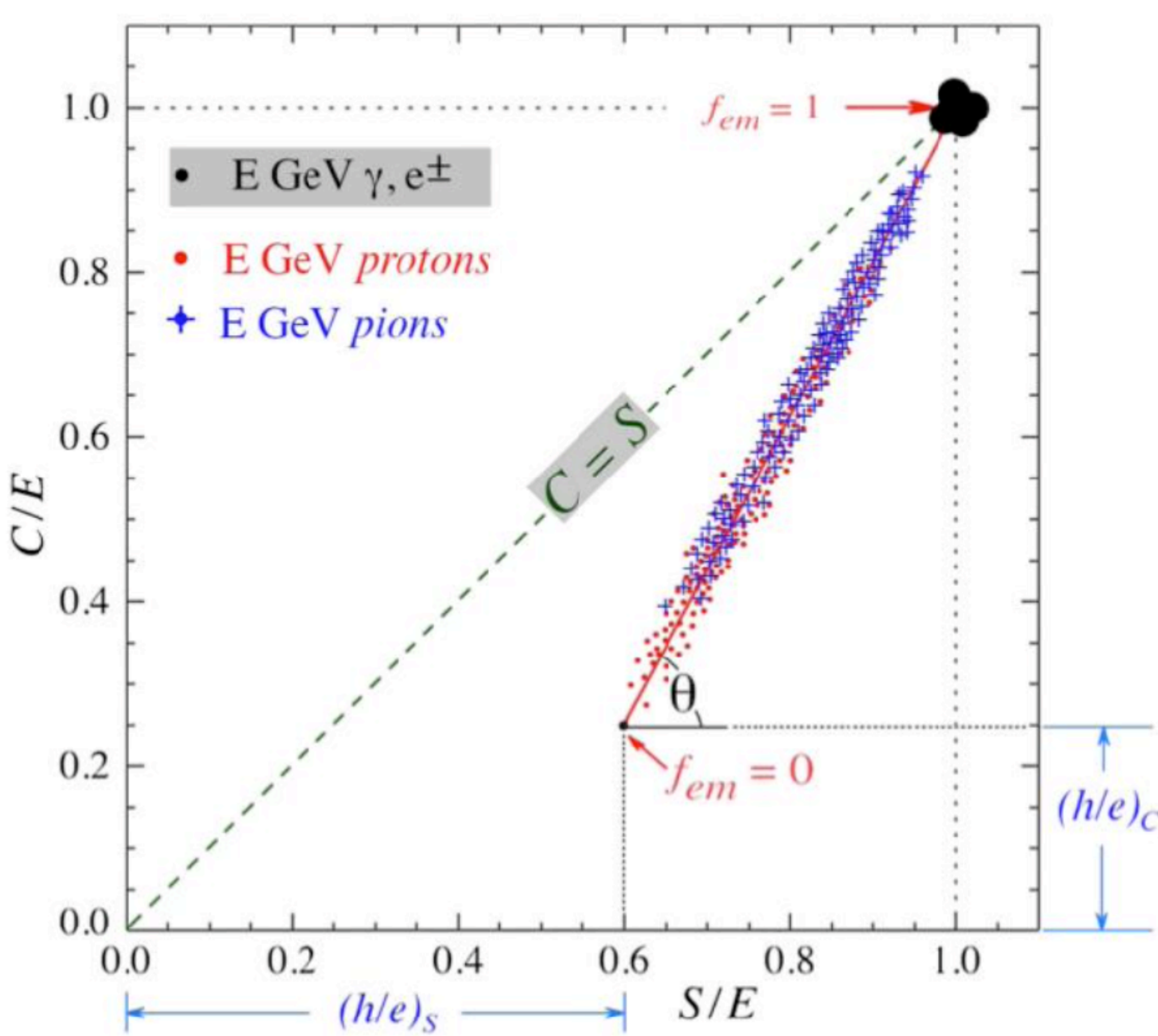
- We tested the dual-readout calorimeter we firstly built in H8 at CERN
- The first importance is **optical contact between readout and fiber**
- The second importance is **readout protection from beam**

Back up

Dual-Readout Calorimeter

KyuyeongHwang's slide, 2021.01.22, Saga-Yonsei workshop

- Čerenkov and scintillating fibers which are implemented on copper plate can measure EM particles and hadronic particles at the same time
- f_{EM} can be measured by implemented two different type of fibers with different h/e responses in a calorimeter



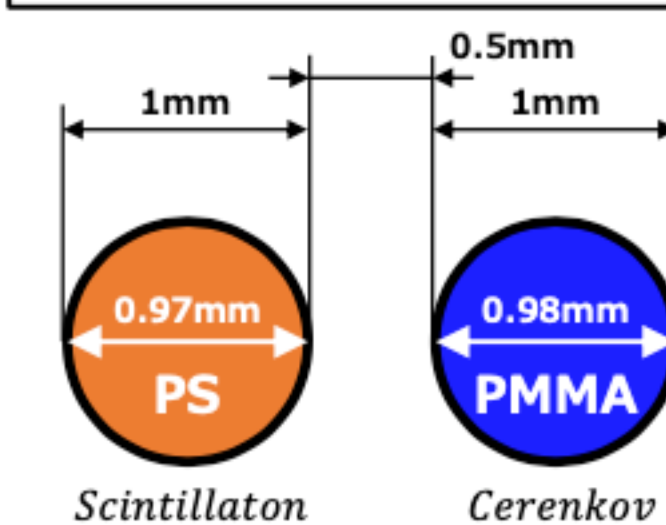
1. $C = E\left[f_{EM} + \frac{1}{(e/h)_C}(1 - f_{EM})\right]$ 2. $S = E\left[f_{EM} + \frac{1}{(e/h)_S}(1 - f_{EM})\right]$

3. $f_{EM} = \frac{(h/e)_C - (C/S)(h/e)_S}{(C/S)[1-(h/e)_S] - [1-(h/e)_C]}$

4. $\chi \equiv \cot\theta = \frac{1-(h/e)_S}{1-(h/e)_C}$

5. $E = \frac{S - \chi C}{1 - \chi}$

Implemented Optical Fibers

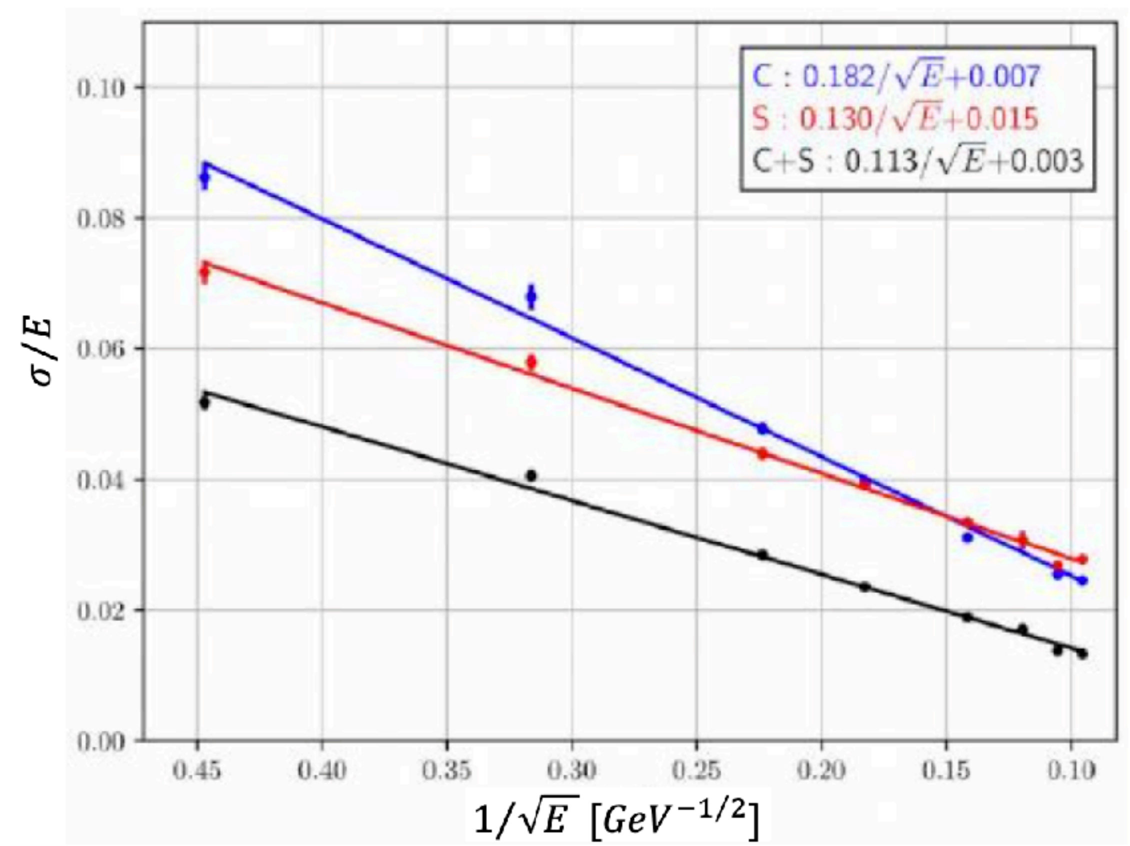


KyuyeongHwang's slide, 2021.01.22, Saga-Yonsei workshop

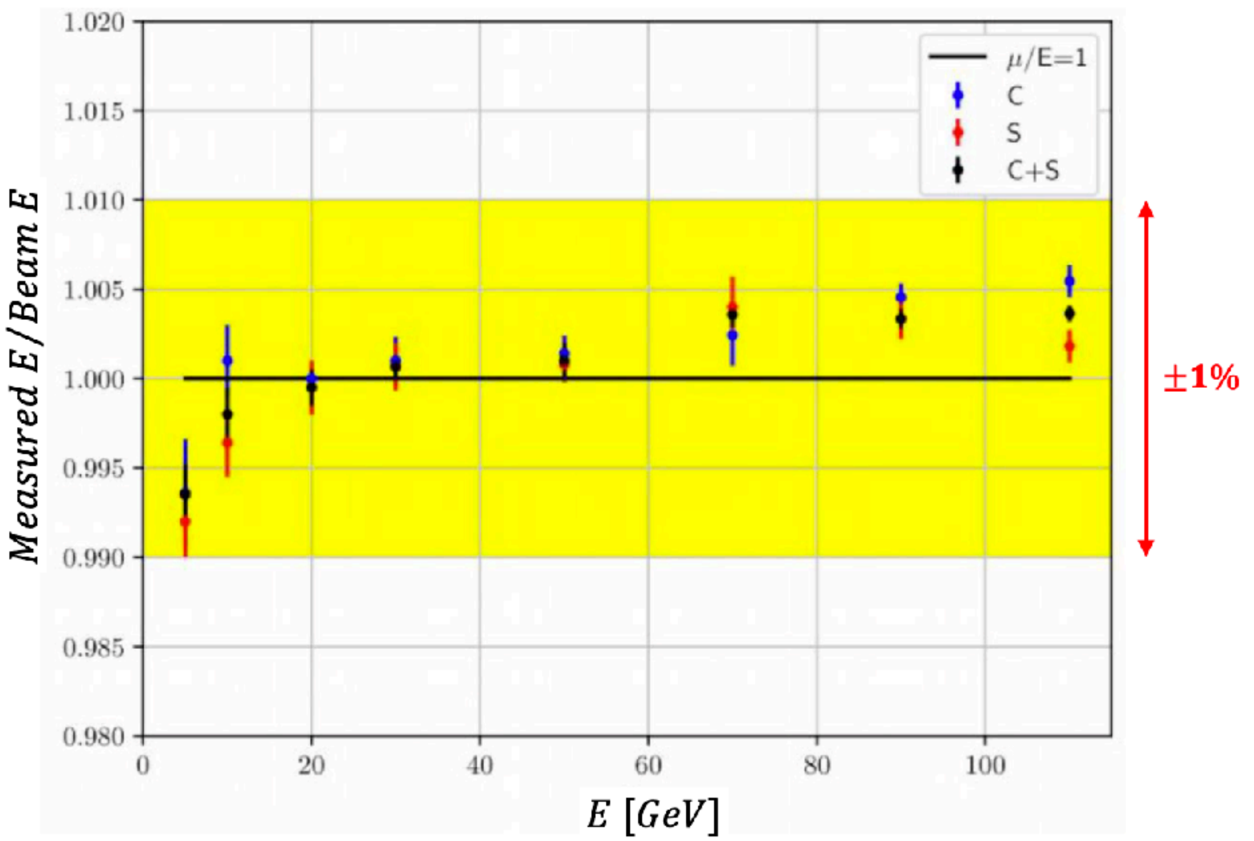
EM Energy Resolution

- EM energy resolution is measured with different 8 energy points electron and scaled with $1/\sqrt{E}$.
- Stochastic & constant term of energy resolution can be obtained by linear fitting.

EM Energy Resolution



EM Energy Linearity



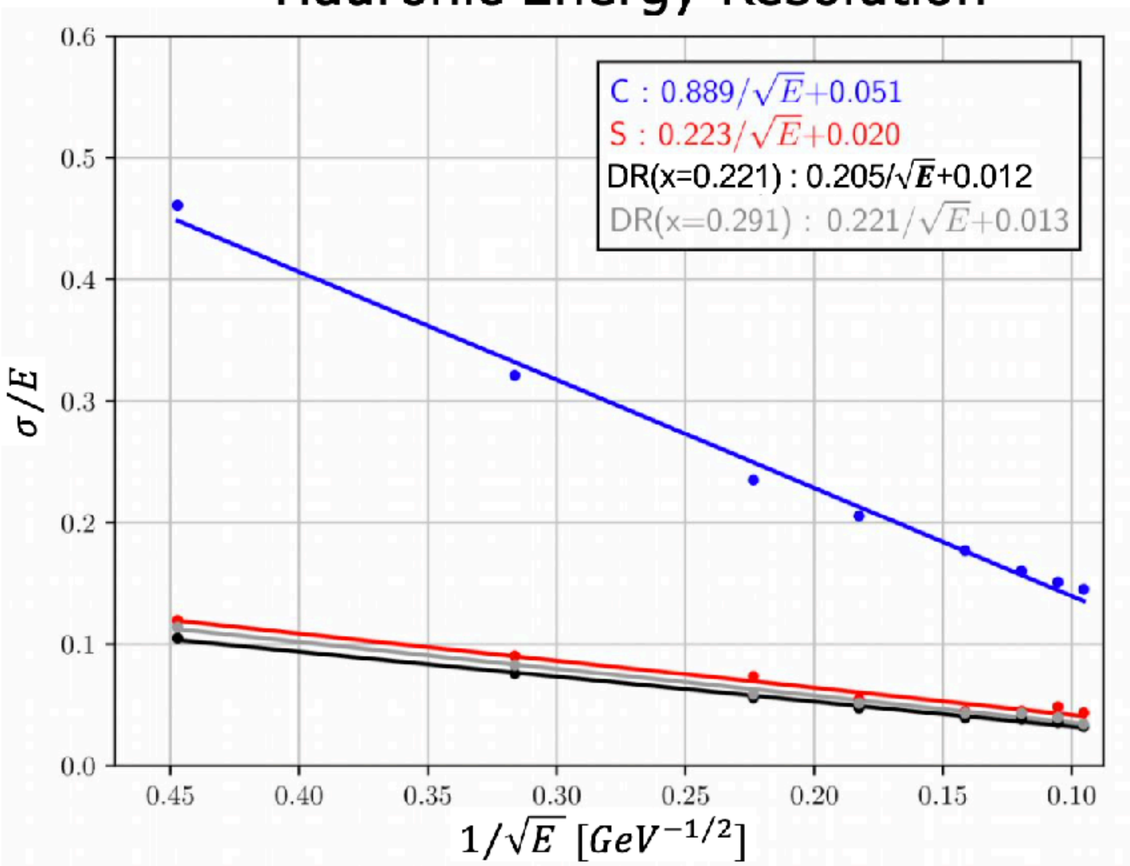
- Stochastic term for EM energy resolution is ~11%.
- Measured EM energy satisfies linearity within 1% level at both scintillation and Cerenkov channels.

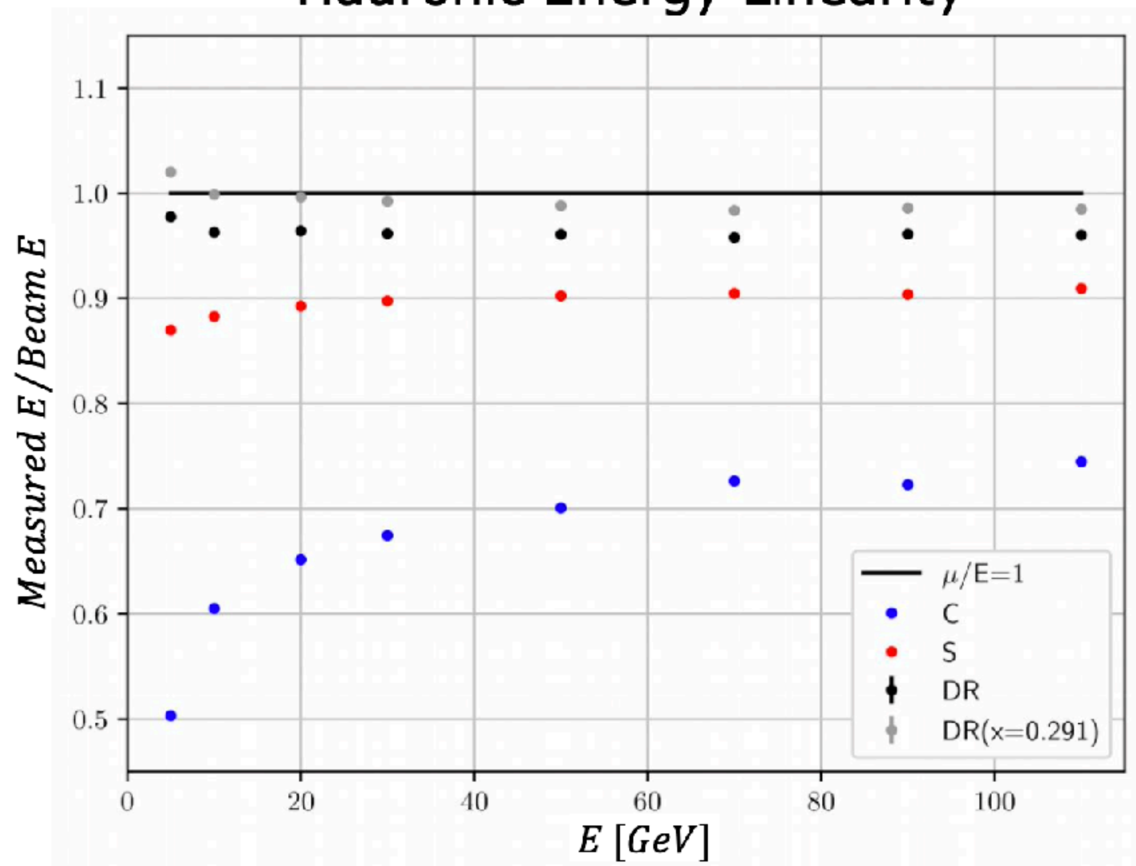
Energy Resolution

KyuyeongHwang's slide, 2021.01.22, Saga-Yonsei workshop

Hadronic Energy Resolution

- Hadronic energy resolution is measured with 8 different energy single pion beams.
- Two chi values(0.221 and 0.291) are used for DR correction.



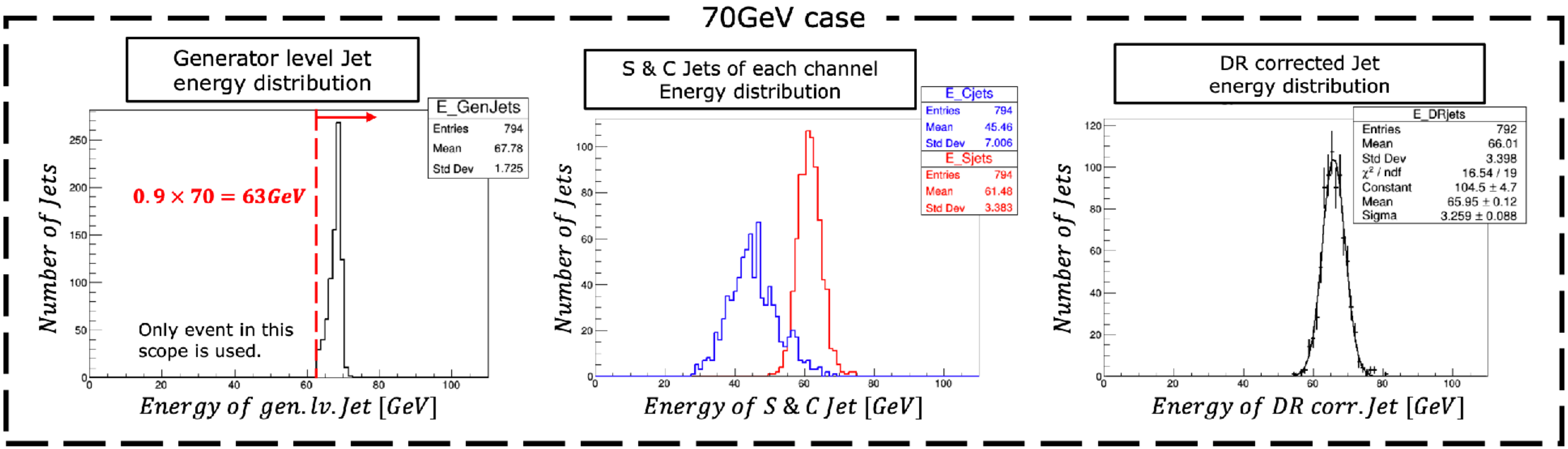


- Stochastic term for hadronic energy resolution is ~21%.
- Energy resolution differs with chi values.

KyuyeongHwang's slide, 2021.01.22, Saga-Yonsei workshop

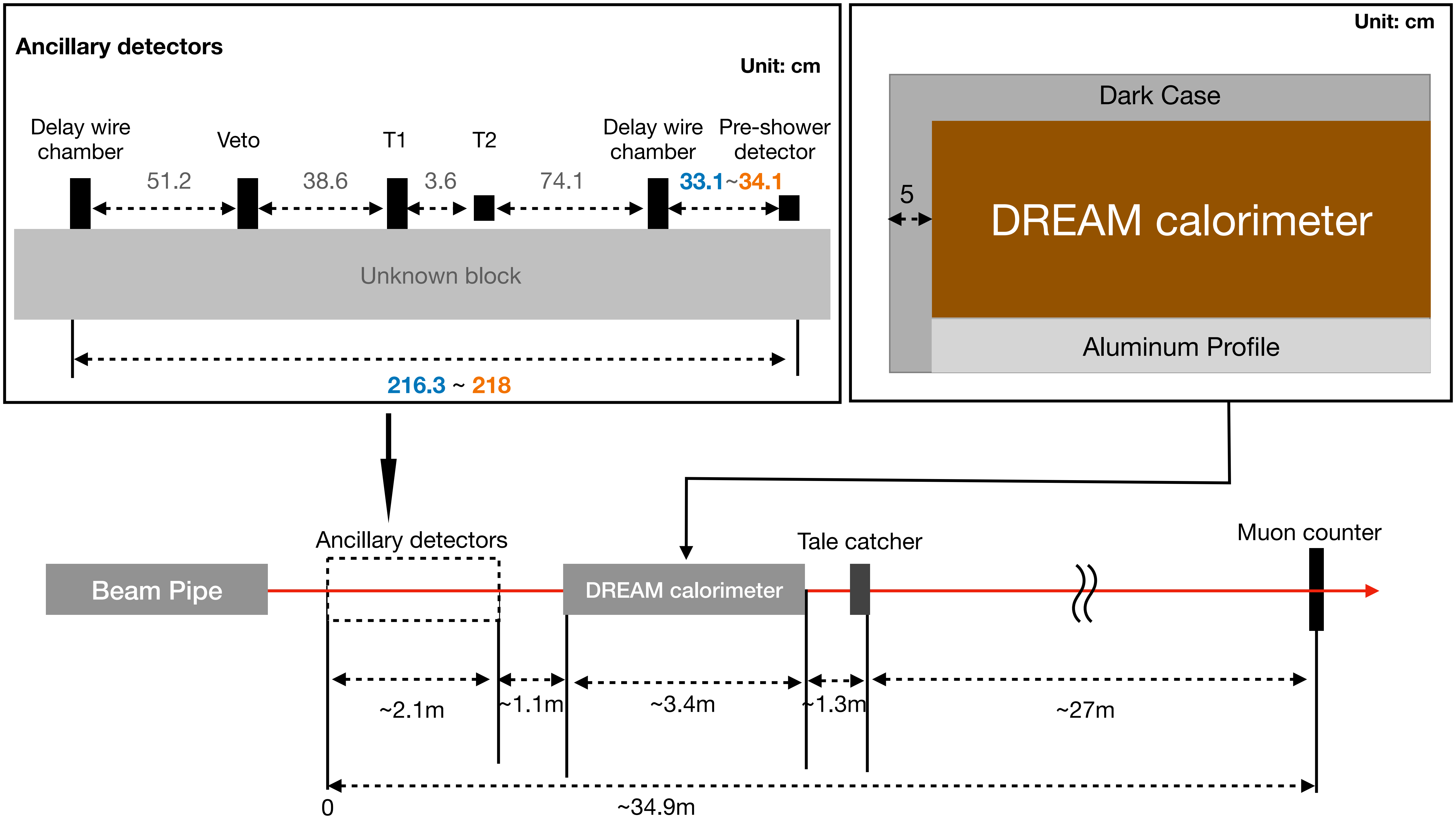
Jet Energy Resolution

- Jet energy resolution is measured with 4 different energy u quar. (50, 70, 90, 110 GeV)
- Jet is reconstructed with anti-kt algorithm(R=0.8) and chi value for DR correction is 0.221.



- Missing energy from neutrino and neutron during simulatation makes resolution worse.
- Only events are used for jet energy resolution measurement whose Gen. lv. Jet has an energy over 90% of generated jet.

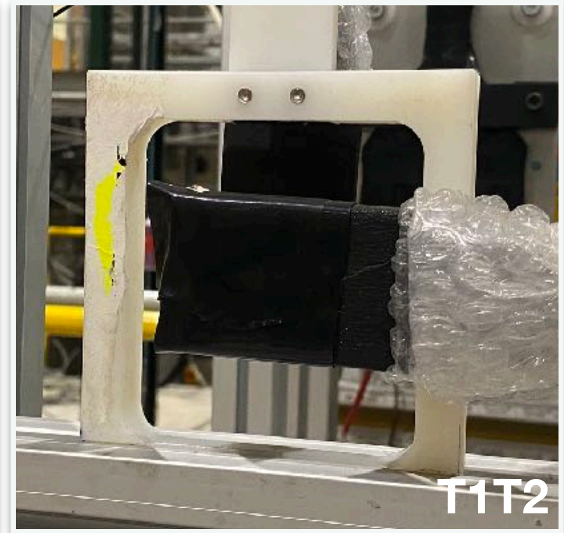
Geometry

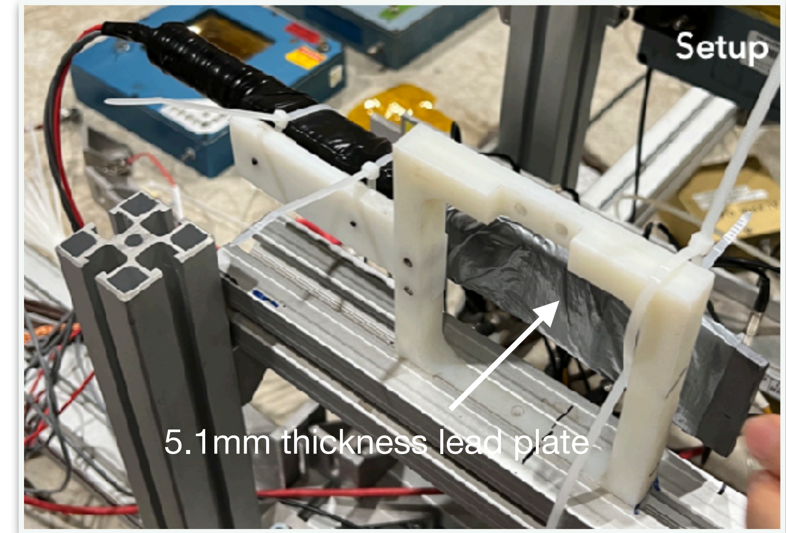


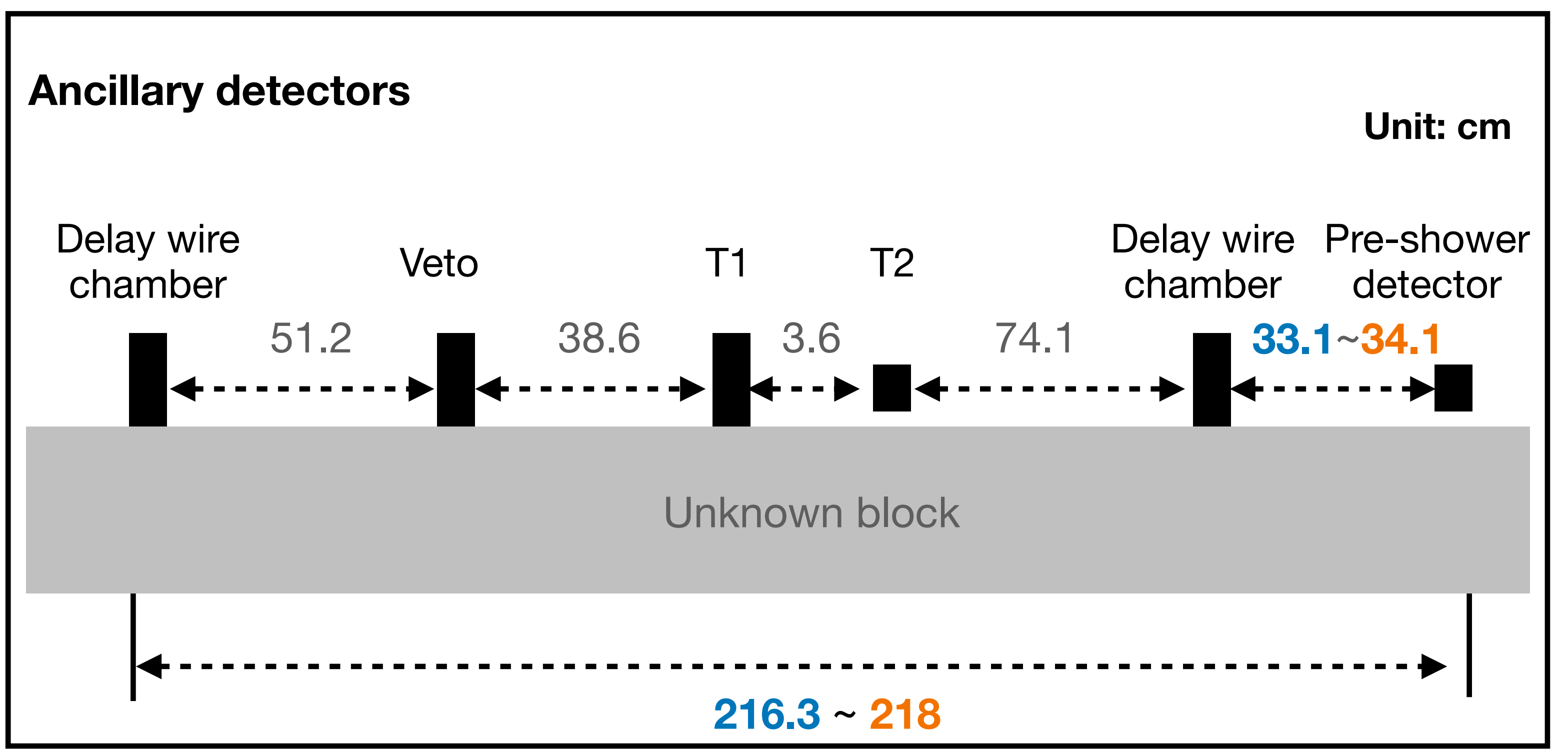
Ancillary detectors
Unit: cm
Delay wire chamber
Veto
T1
T2
Delay wire chamber
Pre-shower detector
51.2
38.6
3.6
74.1
33.1~34.1
Unknown block
216.3 ~ 218
Unit: cm
Dark Case
5
DREAM calorimeter
Aluminum Profile
Ancillary detectors
Tale catcher
Muon counter
Beam Pipe
DREAM calorimeter
~2.1m
~1.1m
~3.4m
~1.3m
~27m
0
~34.9m

Ancillary detectors

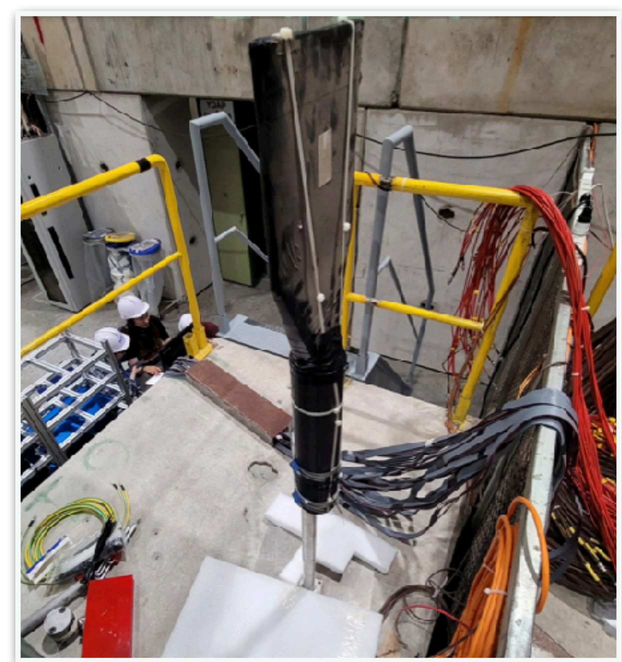
- **Delay wire chamber: x,y position measurement**
- **T1T2+veto: trigger**
- **Pre-shower detector: for obtaining various types of particles by shower**







- **Tale catcher: to detect particles that are through the DRC**
- **Muon counter: to detect muon**



* See Changgi Huh's talk for more details of ancillary detectors - presentation no. G1.05

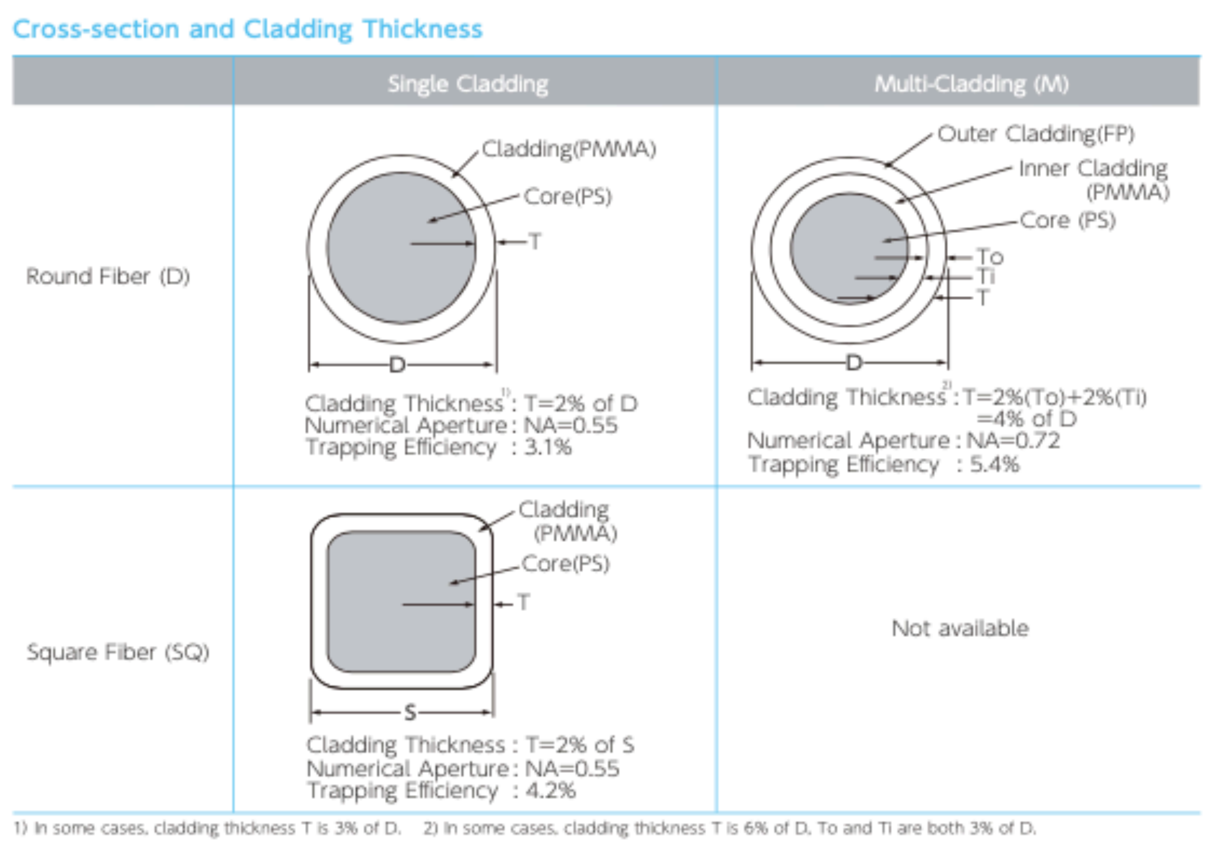
Fiber Specification

- **Čerenkov fiber**

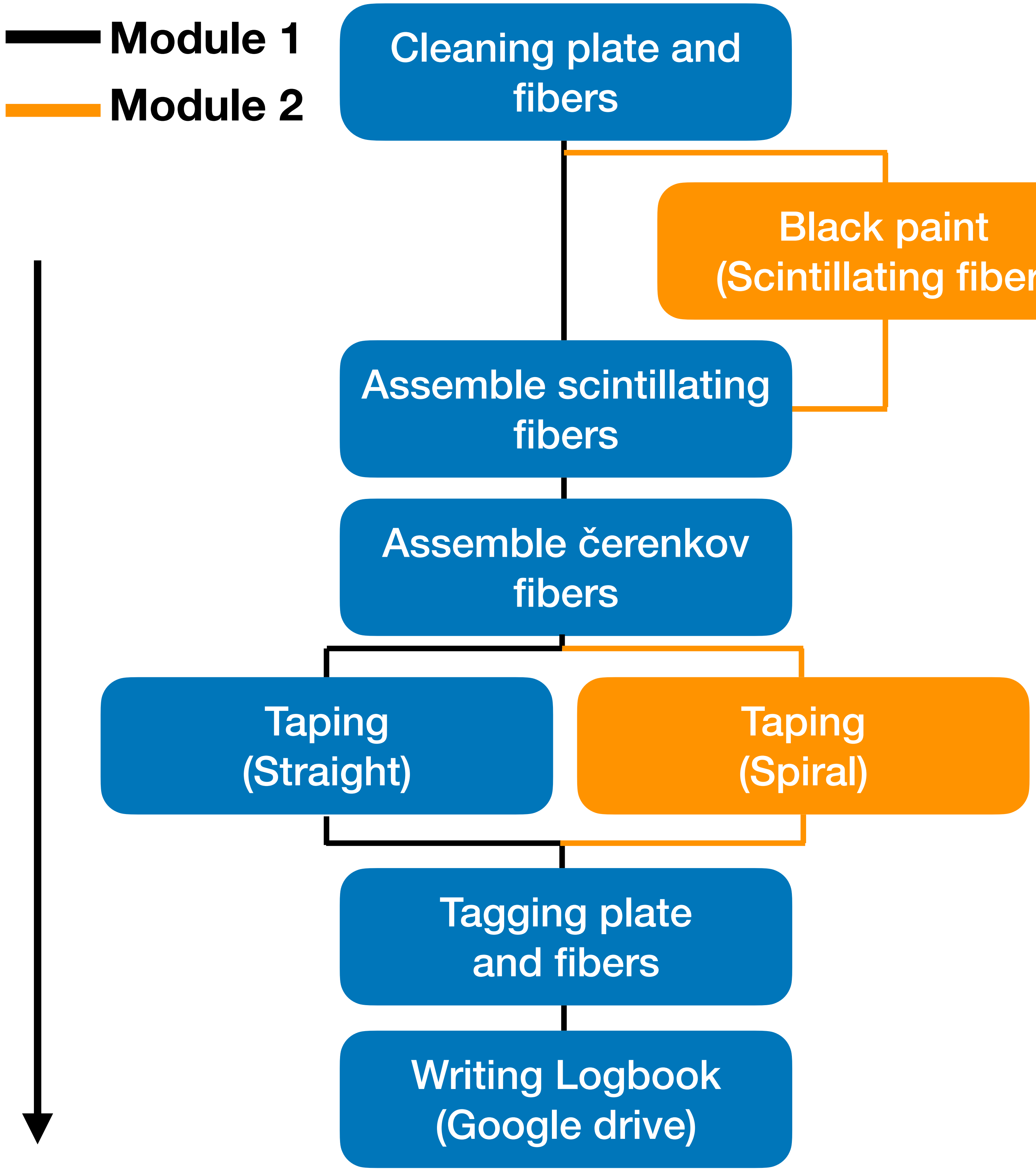
Table 1

Item		SK-40 Specification			
		Unit	Min.	Typ.	Max.
Optical Fiber	Core Material	–	Polymethyl-Methacrylate Resin		
	Cladding Material	–	Fluorinated Polymer		
	Core Refractive Index	–	1.49		
	Refractive Index Profile	–	Step Index		
	Numerical Aperture	–	0.5		
	Core Diameter	μm	920	980	1,040
	Cladding Diameter	μm	940	1,000	1,060
Approximate Weight		g/m	1		

- **Scintillating fiber**



Assembly

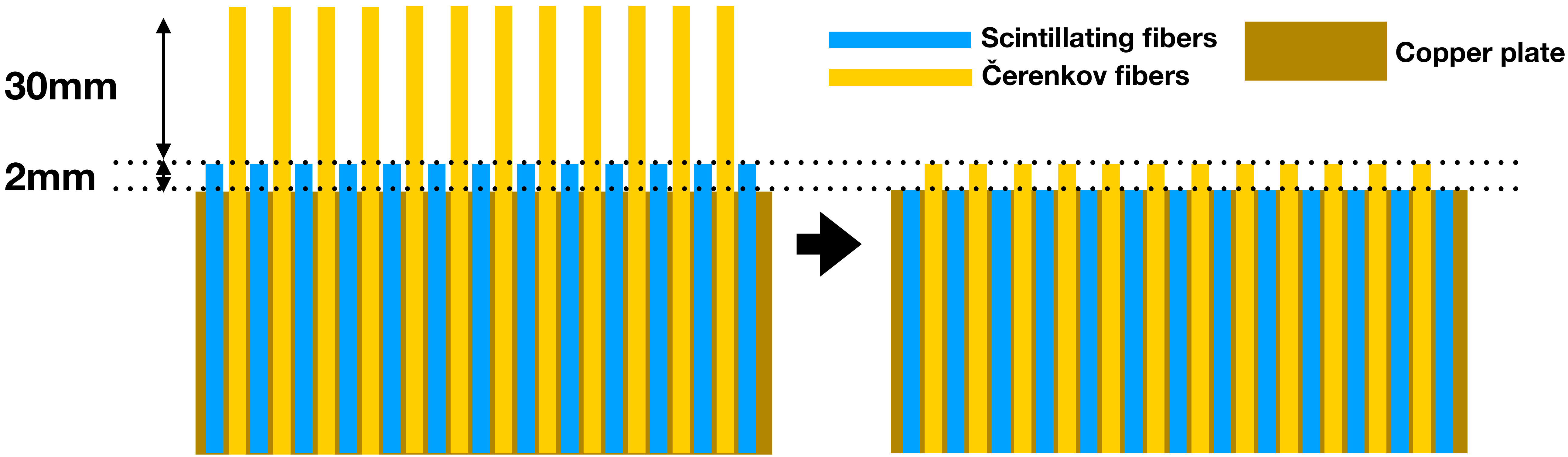


- The process of assembly for module 1&2 is the same
- However, there are differences in **alignment**, **taping**, and **painting scintillating fibers**

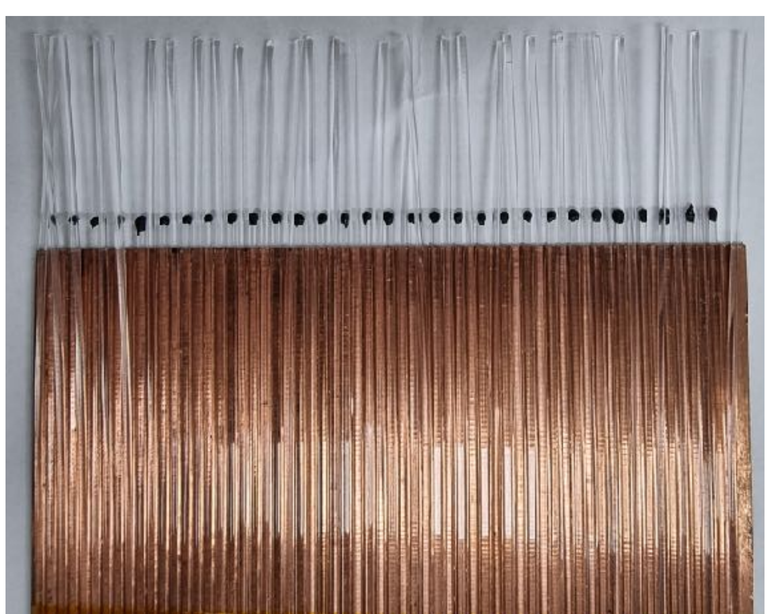
	Module 1	**Module 2**
Alignment	C: 30mm S: 2mm	C: **2mm** S: **0mm**
Taping	Straight	**Spiral**
painting	After inserting fibers	Before inserting fibers

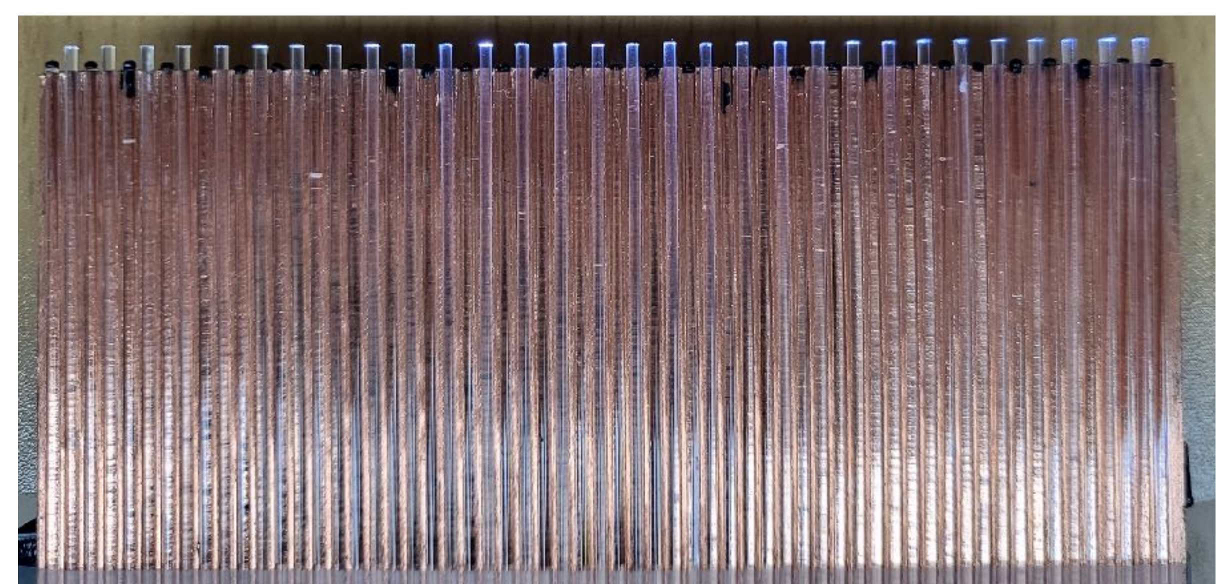
The alignment of Fibers

- **Differences between module 1 and 2**
  1) **The alignment of fibers**



Module 1 **Module 2**

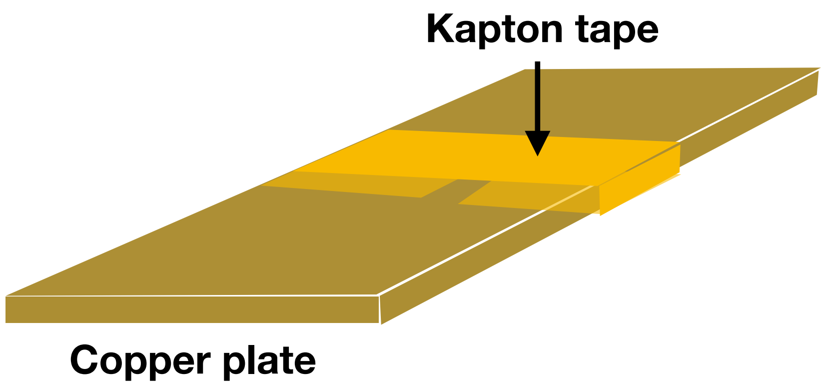


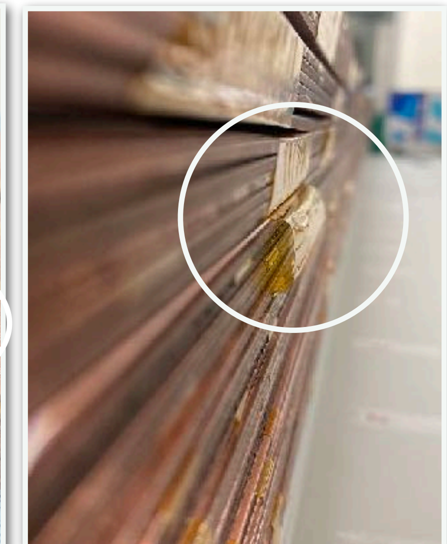


Taping Methods

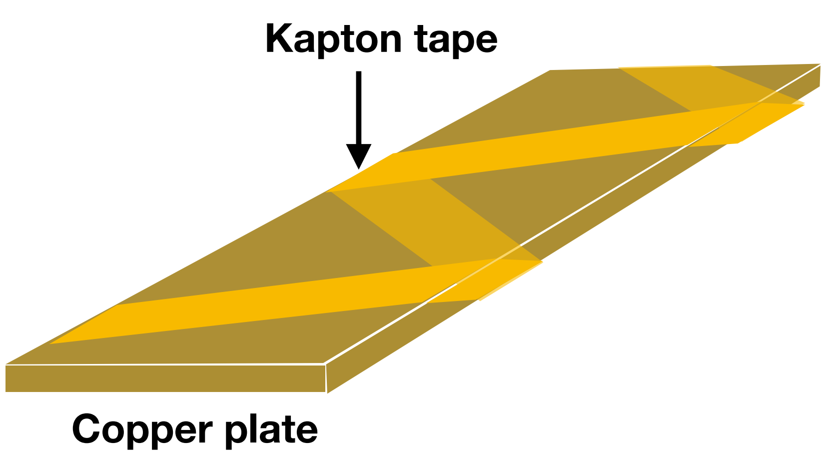
- **Differences between module 1 and 2**
  2) **Taping**

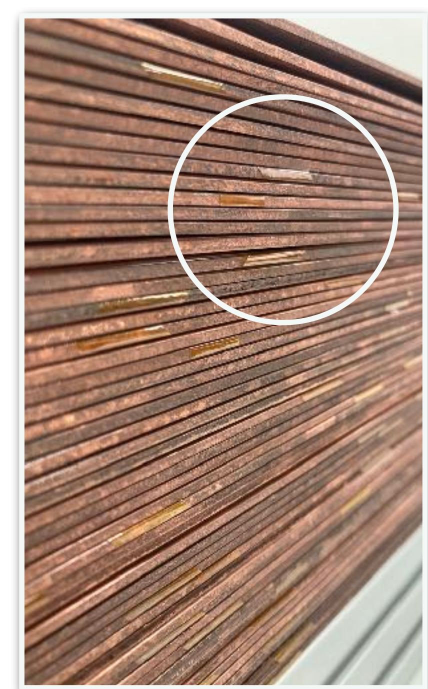
Module 1

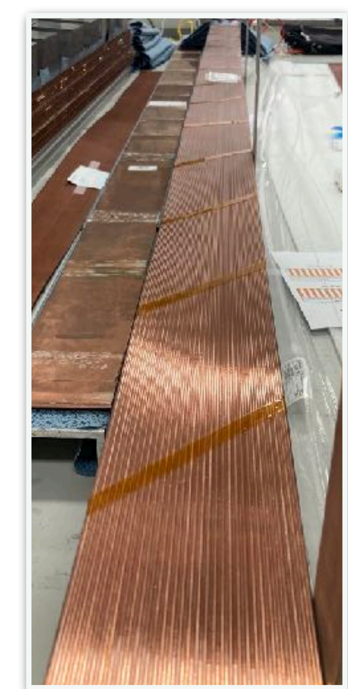




Module 2

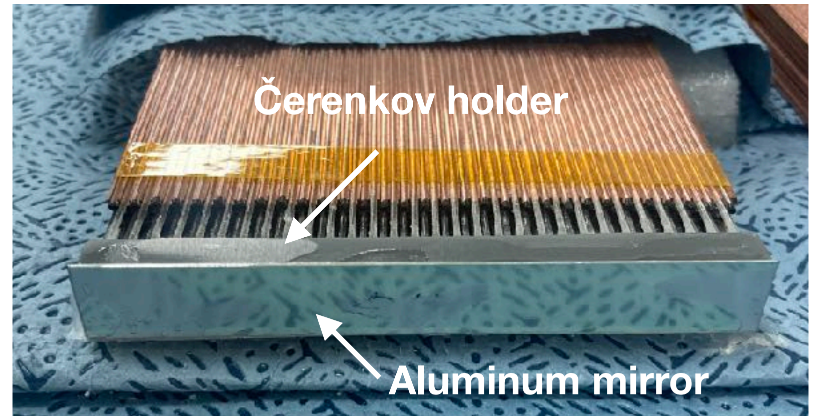




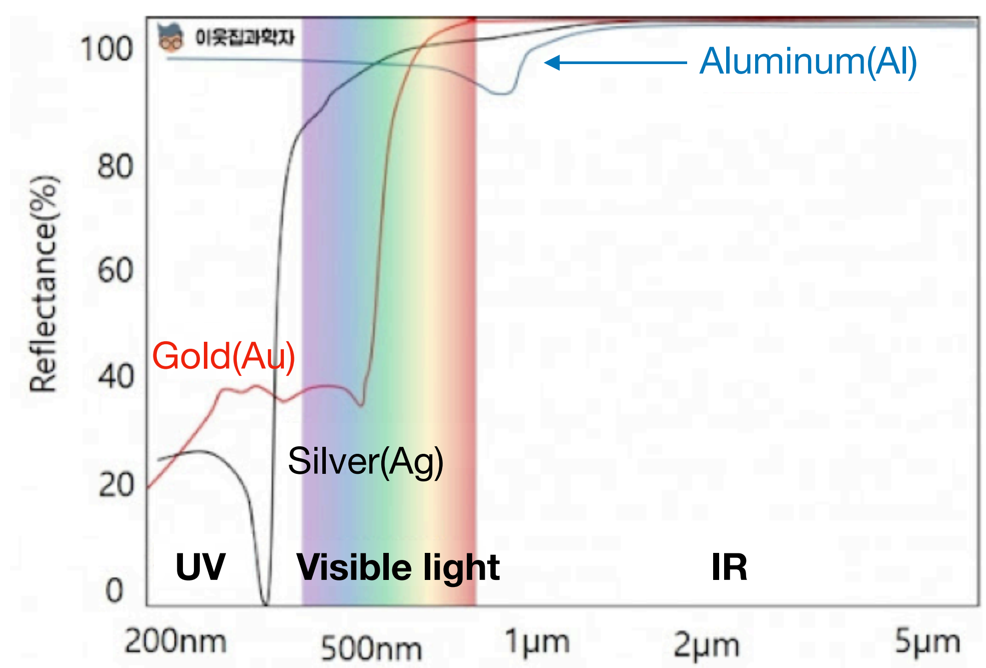


Reflector: Aluminum Foil

- The material as a reflector is changed from aluminum mirror to aluminum foil



- **Aluminum Foil**
  - We choose aluminum foil as a reflector
  - Aluminum foil has advantages
    1) high reflectance: over **~90%**
    2) availability: easy to get
    3) low cost



- Method and key point
  - The key point is **how well it adheres to the fiber**
  - Procedure (plan)
    - Cutting fibers at the front side using a grinder
    - Polishing fibers by hand
    - Attaching aluminum foil