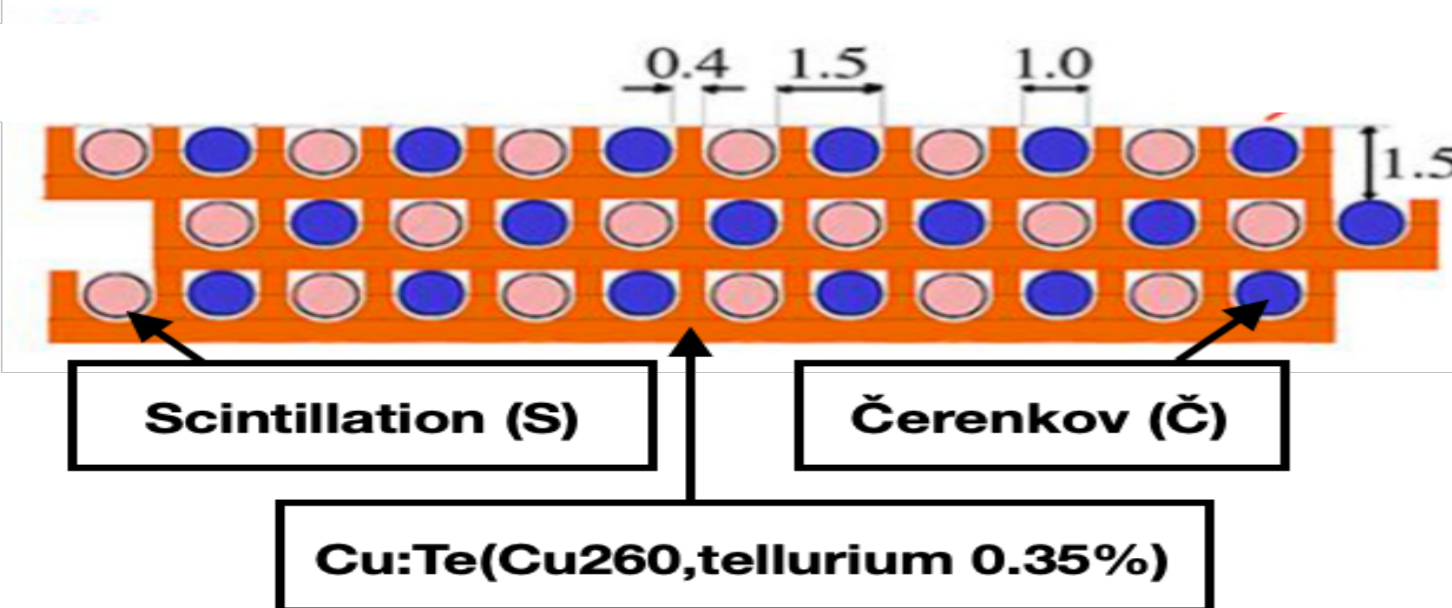


## Dual-readout Calorimeter

- Dual-readout calorimeter has been proposed in IDA detector conceptual report(CDR) for future  $e^+e^-$  collider.
- Dual-readout calorimeter may offer high-quality energy measurement for both EM particles and hadrons.
- Deposited energy of shower components is measured in scintillating and čerenkov fibers.
- The detector uses two different channels; čerenkov fibers respond to mainly EM particles only, and scintillating fibers respond to both EM & hadronic particles.

## Dual-Readout Calorimeter

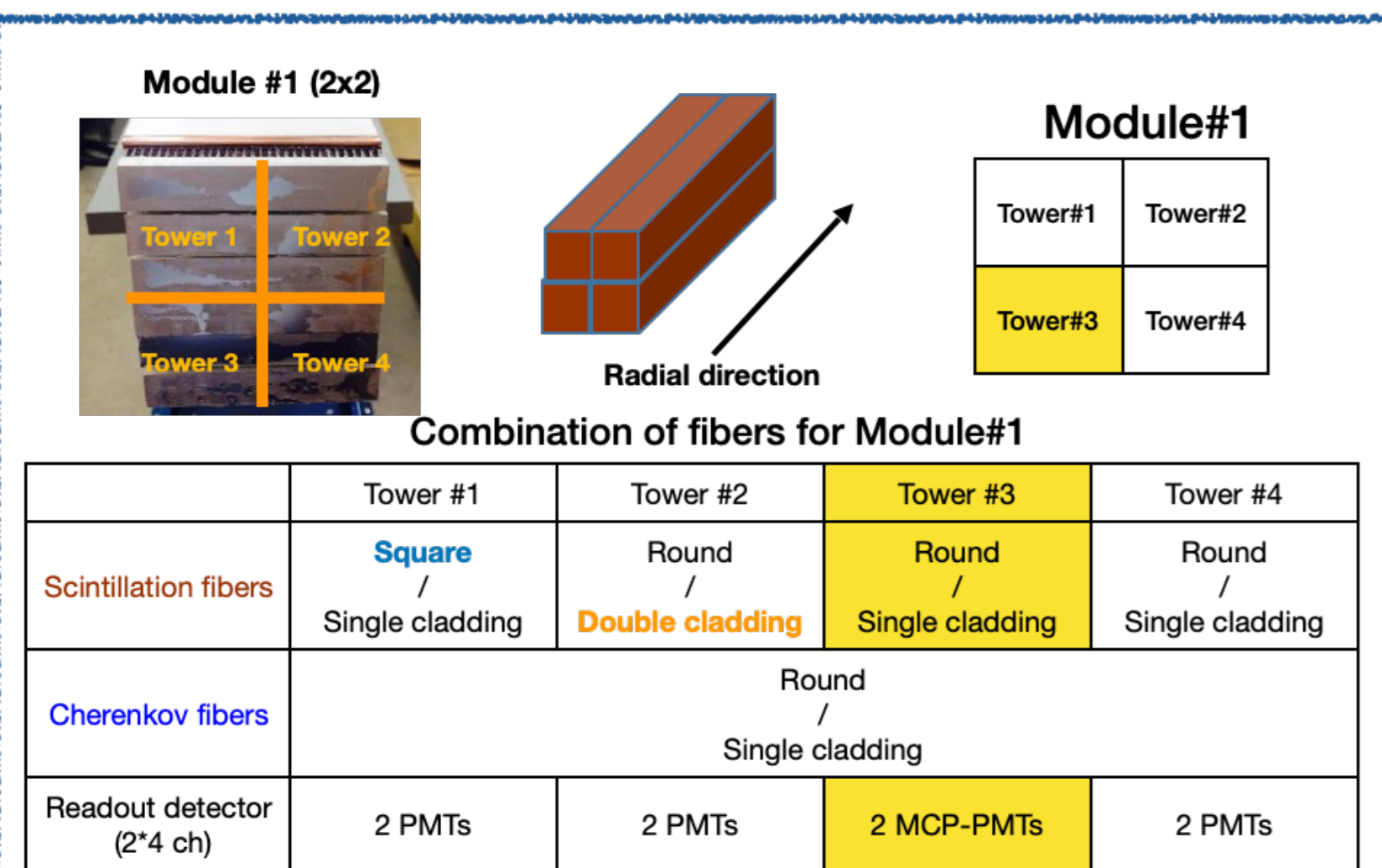
### Cross sectional view of module



- All fibers are installed on stacked copper plates, called tower structures.
- Copper plate: grooving with a milling machine
- Optical fiber
  - Čerenkov fiber: round-shaped with single cladding
  - Scintillating fiber: round-shaped with single cladding & double cladding, square-shaped with single cladding

- Module 1
  - 4 readout towers
  - tower 3 is connected to MCP-PMT
- Module 2
  - 9 readout towers
  - central tower is connected to 416 SiPM ch
- Other towers are equipped with generic PMT

Module #1 (2x2)

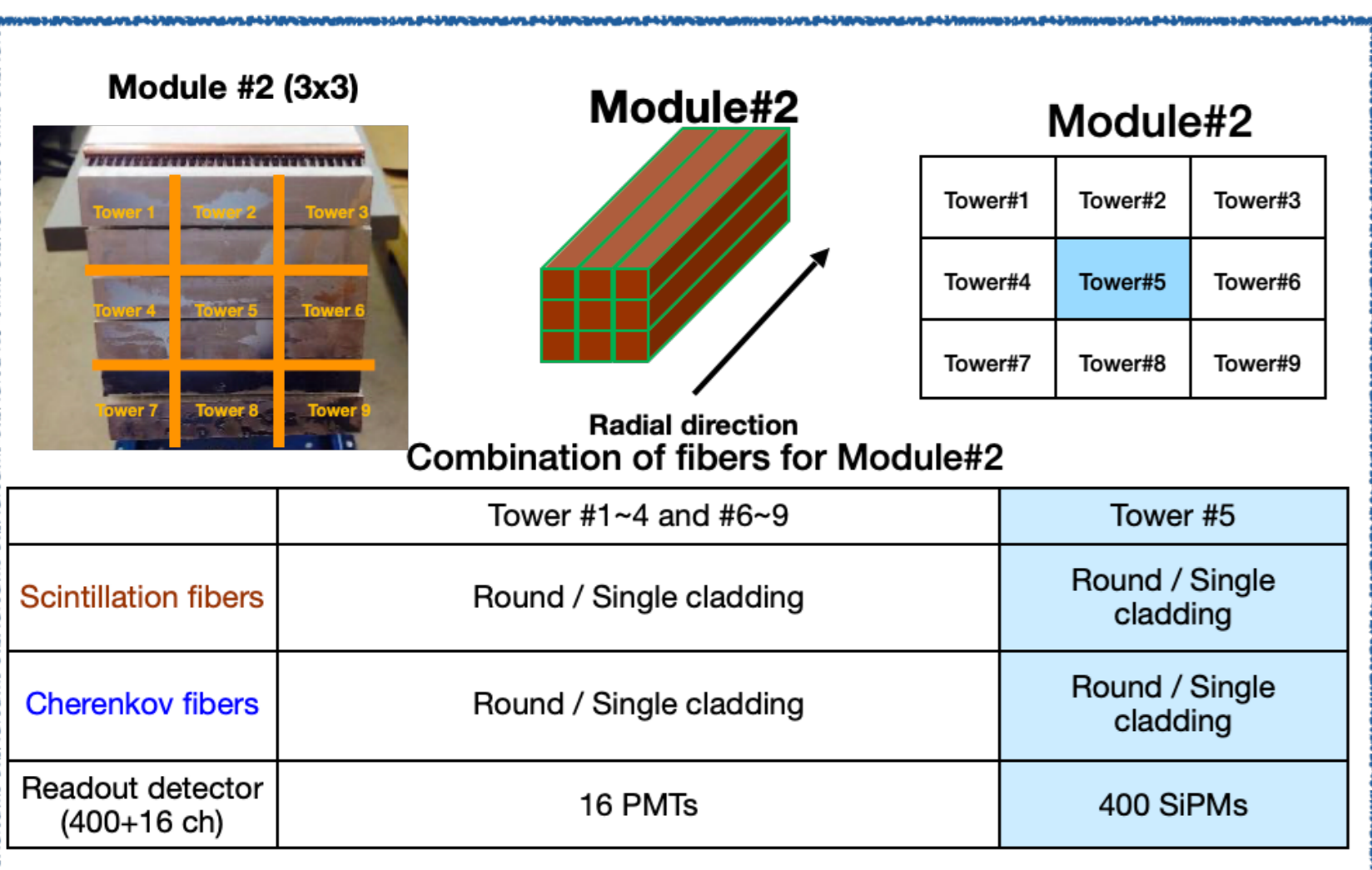


Radial direction

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)



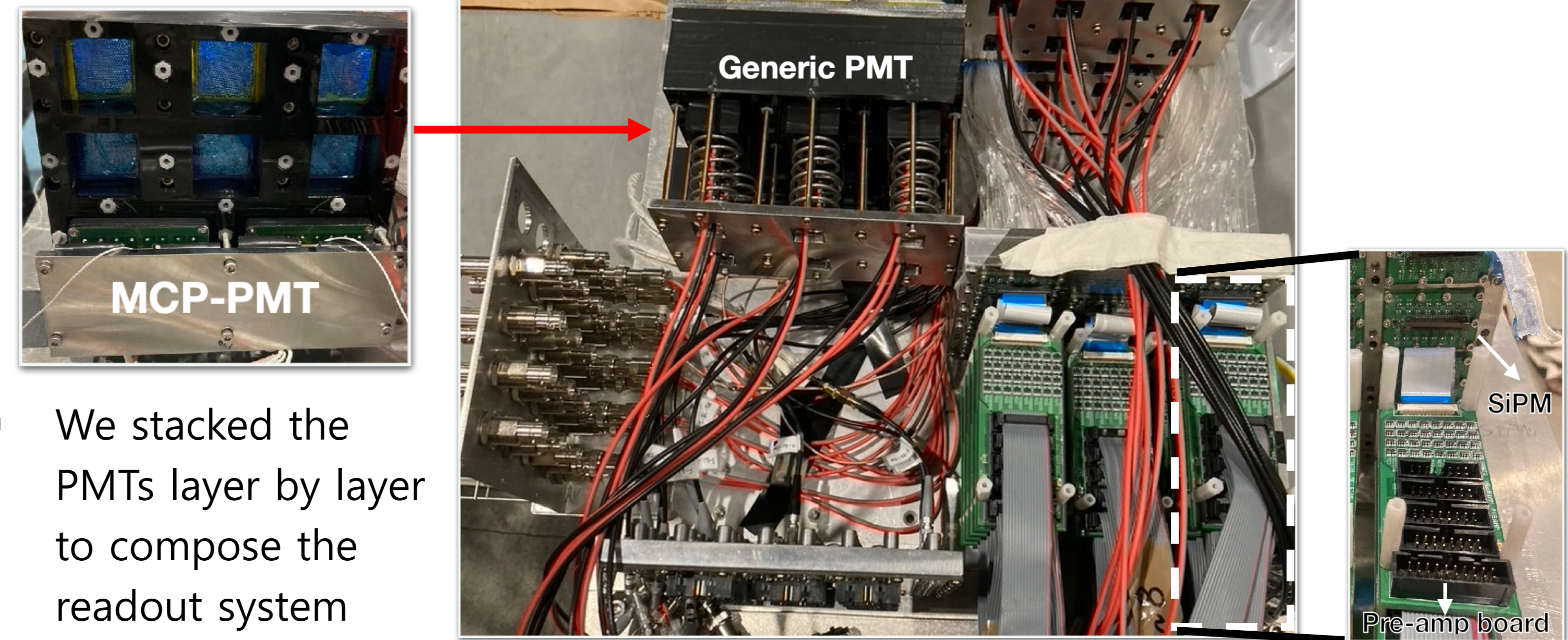
Radial direction

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

## Readout System Installation

- We used 3 types of photomultiplier for checking the characteristic of dual-readout calorimeter
  - Generic PMT (22 ch), MCP-PMT (4 ch), SiPM (400 ch)



- We stacked the PMTs layer by layer to compose the readout system

## DAQ Connection

- We made **mapping** for cable connection with DAQ team
- Also, auxiliary detectors are connected to PMT sensor board with LEMO cable

PMT sensor board mapping

Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel	Channel
MCP_1A_1	MCP_1A_2	MCP_1A_3	MCP_1A_4	MCP_1A_5	MCP_1A_6	MCP_1A_7	MCP_1A_8	MCP_1A_9	MCP_1A_10
MCP_1B_1	MCP_1B_2	MCP_1B_3	MCP_1B_4	MCP_1B_5	MCP_1B_6	MCP_1B_7	MCP_1B_8	MCP_1B_9	MCP_1B_10
MCP_2A_1	MCP_2A_2	MCP_2A_3	MCP_2A_4	MCP_2A_5	MCP_2A_6	MCP_2A_7	MCP_2A_8	MCP_2A_9	MCP_2A_10
MCP_2B_1	MCP_2B_2	MCP_2B_3	MCP_2B_4	MCP_2B_5	MCP_2B_6	MCP_2B_7	MCP_2B_8	MCP_2B_9	MCP_2B_10
MCP_3A_1	MCP_3A_2	MCP_3A_3	MCP_3A_4	MCP_3A_5	MCP_3A_6	MCP_3A_7	MCP_3A_8	MCP_3A_9	MCP_3A_10
MCP_3B_1	MCP_3B_2	MCP_3B_3	MCP_3B_4	MCP_3B_5	MCP_3B_6	MCP_3B_7	MCP_3B_8	MCP_3B_9	MCP_3B_10
MCP_4A_1	MCP_4A_2	MCP_4A_3	MCP_4A_4	MCP_4A_5	MCP_4A_6	MCP_4A_7	MCP_4A_8	MCP_4A_9	MCP_4A_10
MCP_4B_1	MCP_4B_2	MCP_4B_3	MCP_4B_4	MCP_4B_5	MCP_4B_6	MCP_4B_7	MCP_4B_8	MCP_4B_9	MCP_4B_10

Auxiliary detector

Preamp board mapping

Channel	Channel	Channel
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

Down stream side

## Procedure of Assembly

- 3 steps to build dual-readout calorimeter
- All steps are performed at Yonsei university
- Installation readout system & reflector is disassembled after working test and re-assembled in H8 at CERN

### Step 1. Fiber Assembly



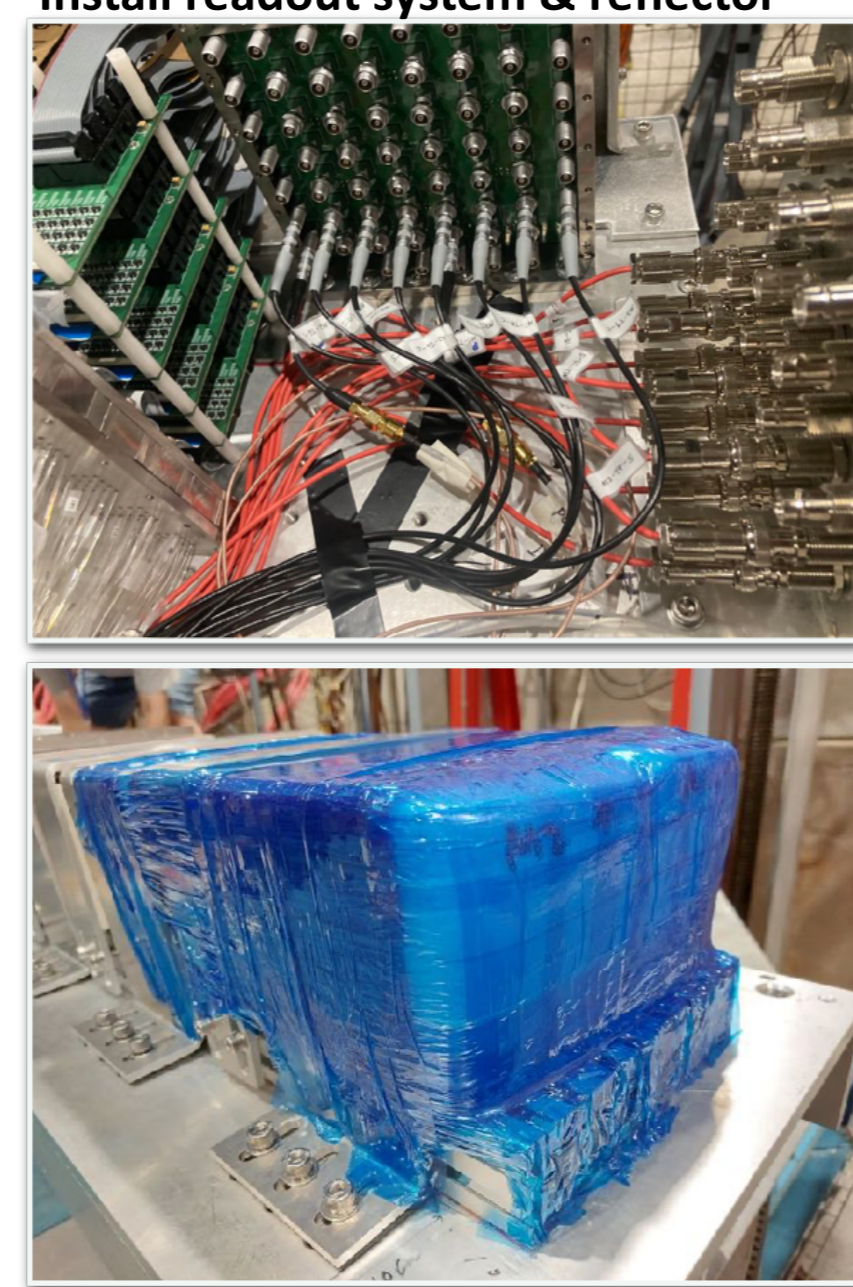
- Fibers are put in the grooves of the copper plate
- Taping to block the escaping fibers

### Step 2. Fiber Bundling



- We used **3d-printed bundle case**
- Fiber bundle of each tower is glued by **epoxy**

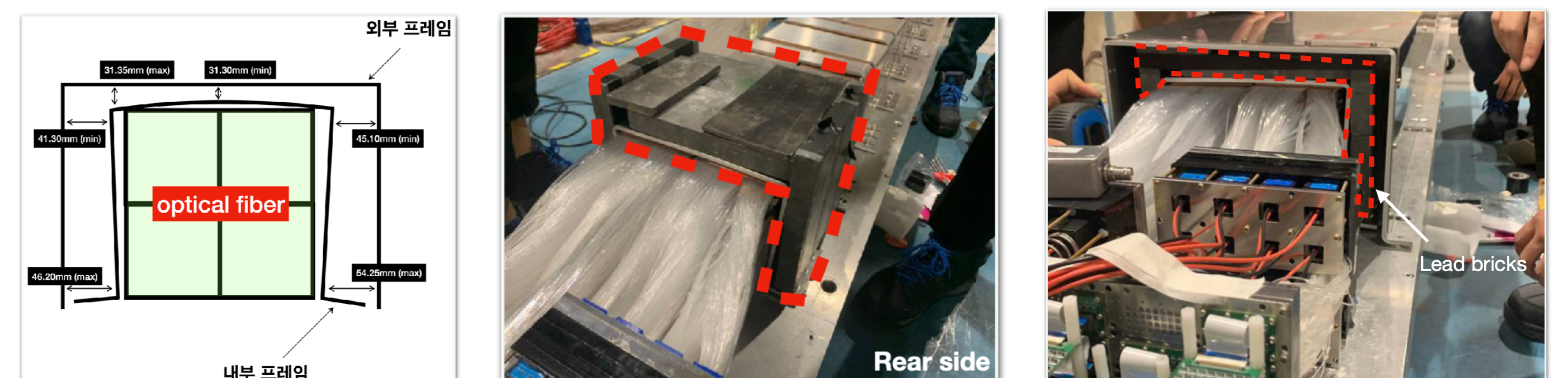
### Step 3. Install readout system & reflector



- All readout systems are **installed on towers & connected to the DAQ system**

## Shielding PMT

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



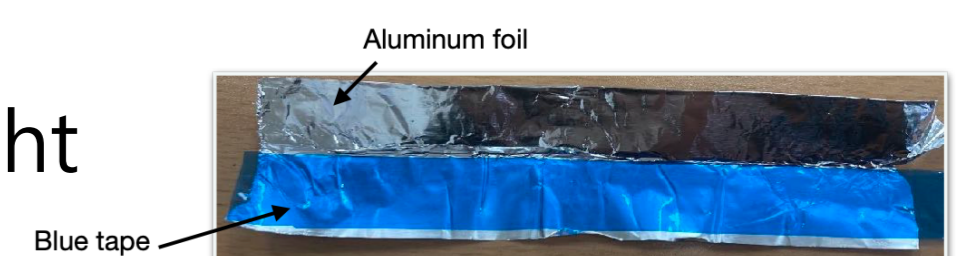
## Reflector

- Čerenkov light is nearly exactly prompt, so reflected light retains good time information.
- Čerenkov light also has no signal penalty in the longer path length of the reflected light because attenuation length is long.

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

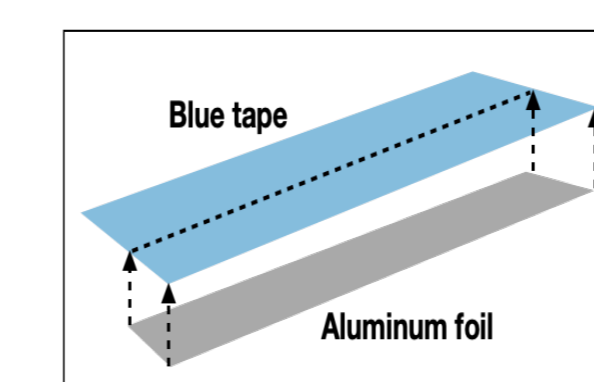
Scintillating fiber: **block the light**  
Čerenkov fiber: **reflect the light**  
which gives the depth of light in the module

- Aluminum foil is a good material to reflect čerenkov light
- Procedure of aluminum foil reflector



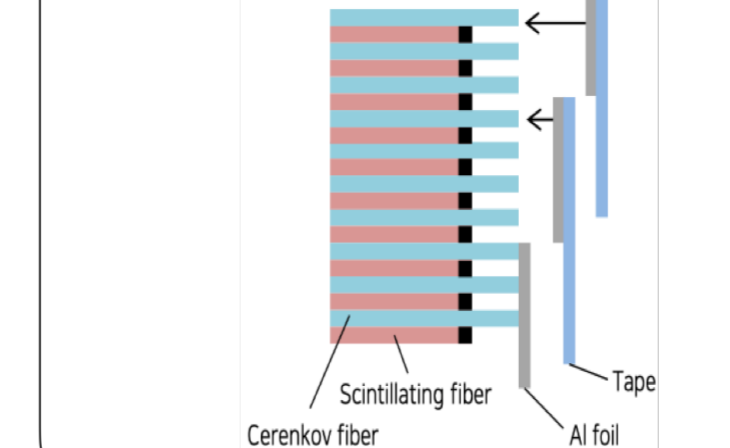
### 1. Making reflector

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



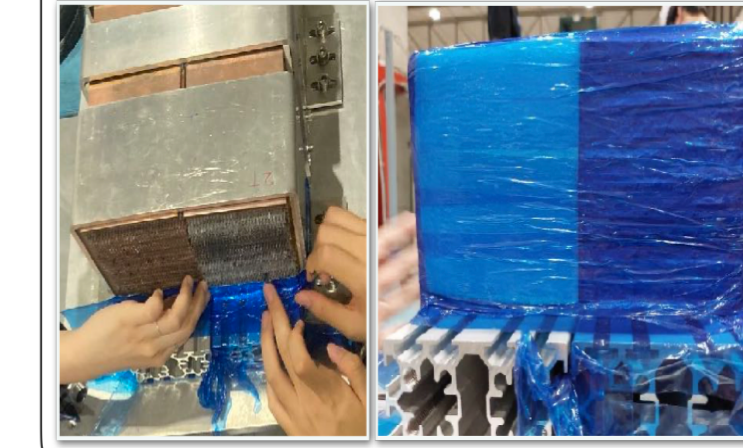
### 2. Attaching reflector

- 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**



## Conclusions & Next Step

- Dual-readout calorimeter is a **novel, innovative, possibly more cost-effective design** for the future collider.
- We **built 2** dual-readout calorimeter modules & **tested** them in August at CERN
- The first importance is **optical contact between fiber and readout system**
- Shielding readout system** is the second importance