Module Assembly and the Plan for Full-Size Module of the Dual-Readout Calorimeter for the Future e+e- Colliders

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On behalf of the Korea Dual-Readout Calorimeter Team

February 18, 2024

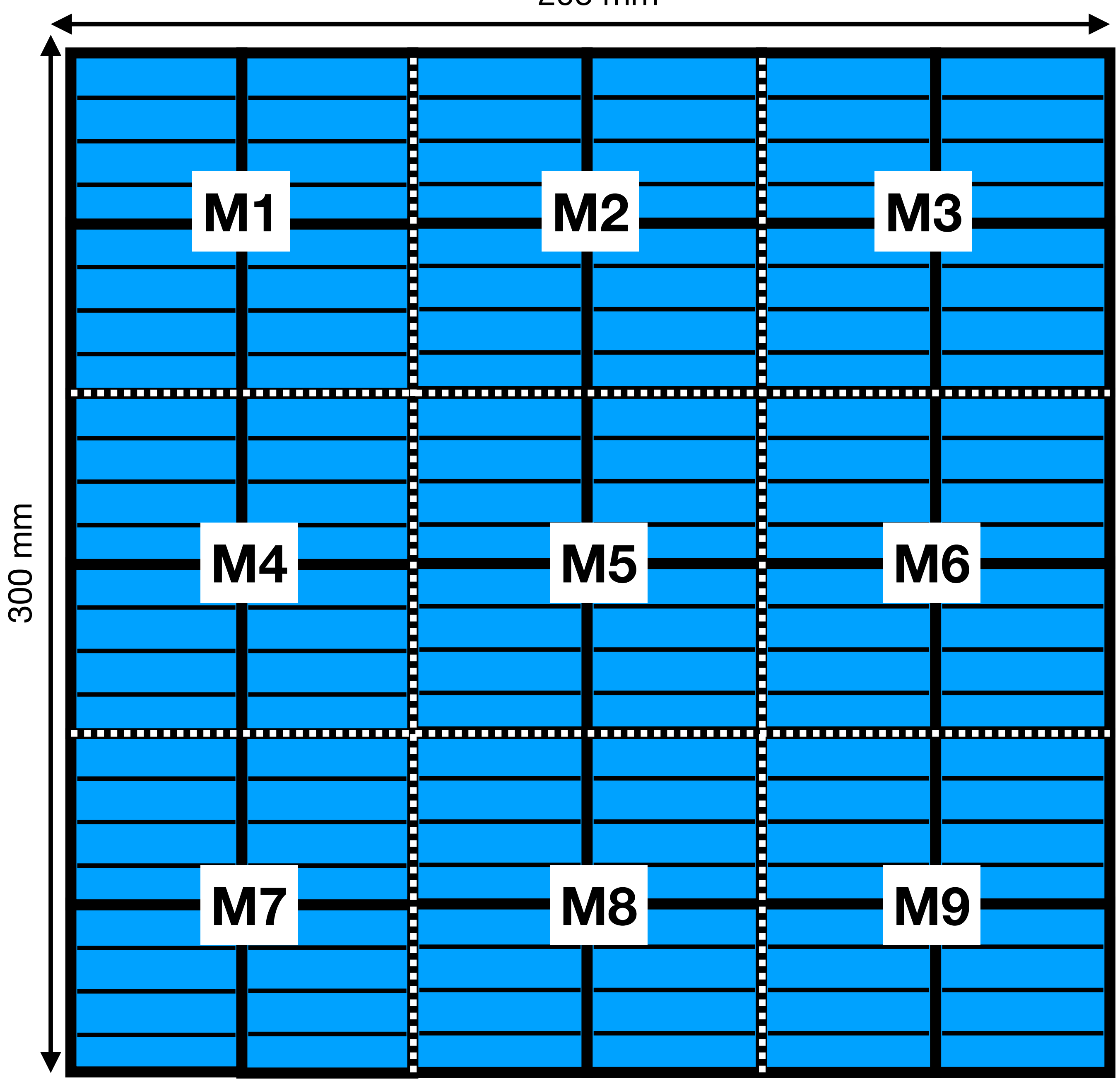
New Prototype for TB2024

- Build a 3x3 size prototype (9 modules)
  - Use SFHS copper forming blocks
  - High granularity readout with MCP-PMT

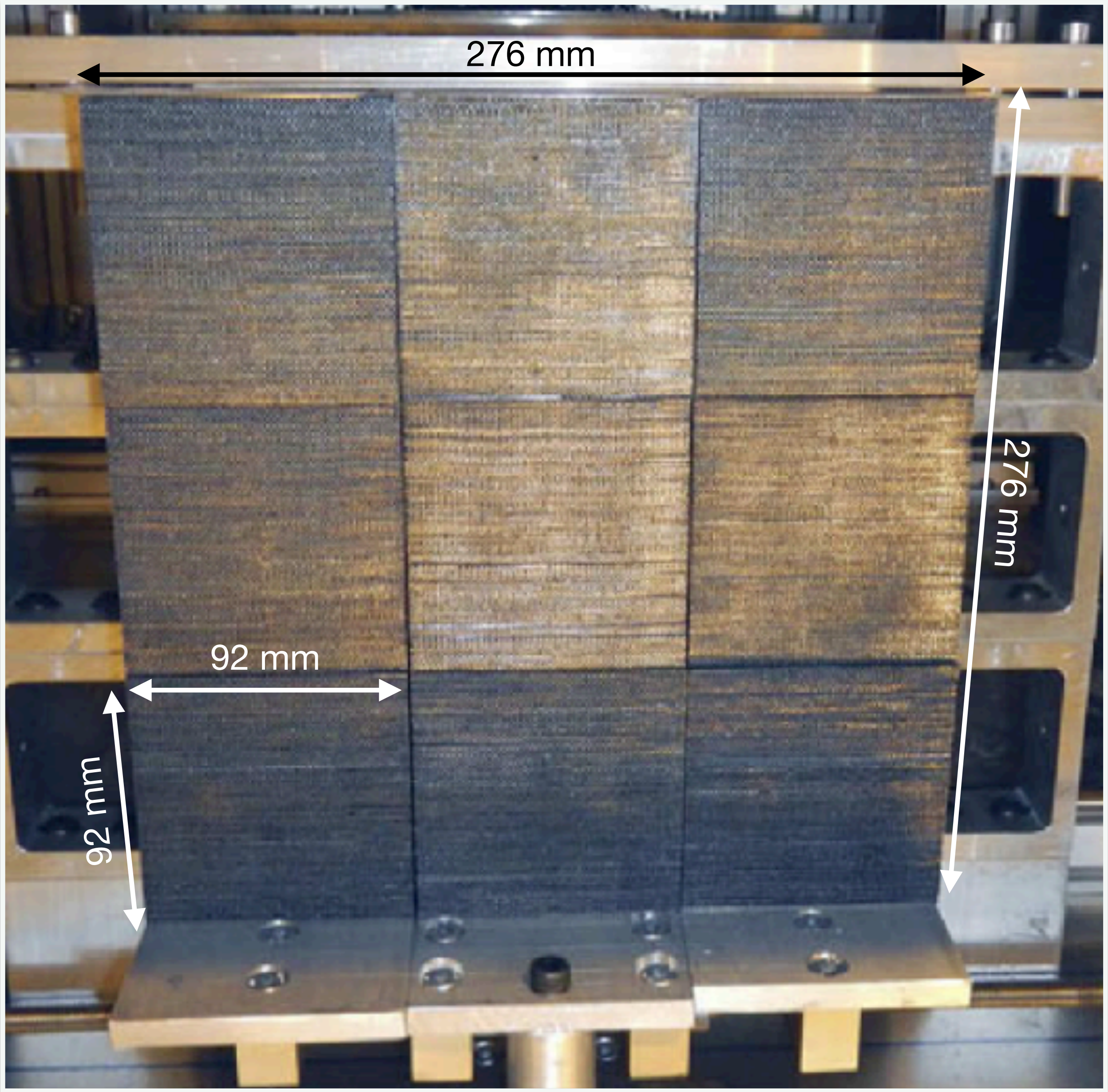
Goal

1. **3x3 size prototype building with copper as an absorber material**
2. **Energy resolution measurement**
3. **High granularity with MCP-PMT**

TB2024



3x3 size module
Copper-fiber calorimeter



RD52 fiber calorimeter(2017)
lead-fiber calorimeter

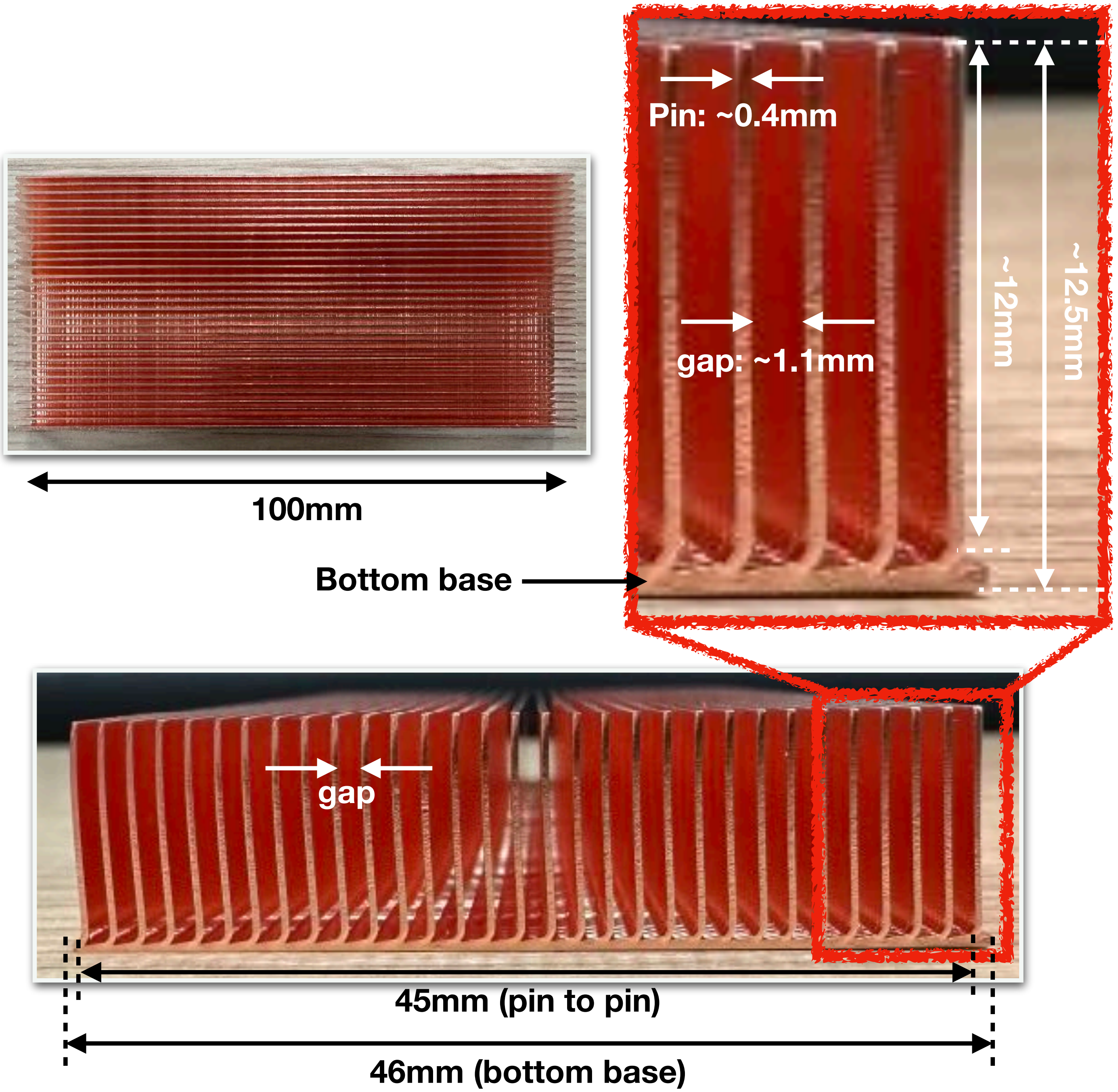
Beam Test Programs for TB 2024

- 36 tower calibration with 20 GeV electrons (0 deg. (rotation angle), 0 deg. (tilting angle))
- The EM performance
  - the energy scan (6, 10, 20, 30, 40, 60, 80, 100, 120 GeV) (1.5 deg., 1.0 deg.)
  - the uniformity scan with 9 points (0 deg., 0 deg.)
- The Hadronic performance (all runs with the interaction target)
  - pions and jets (20, 40, 60, 80, 100, 120 GeV) (0 deg., 0 deg.) and (1.5 deg., 0 deg)
  - protons (20, 40, 60, 80, 100, 120 GeV) without interaction target (0 deg., 0 deg.) and (1.5 deg., 0 deg)
- Additional programs
  - positron resolution measurement with 10, 20, 40, 60, 80, 100, 120 GeV
  - particle identification (e, mu, pi)
  - lateral shower profile measurement with pions
  - light attenuation measurement

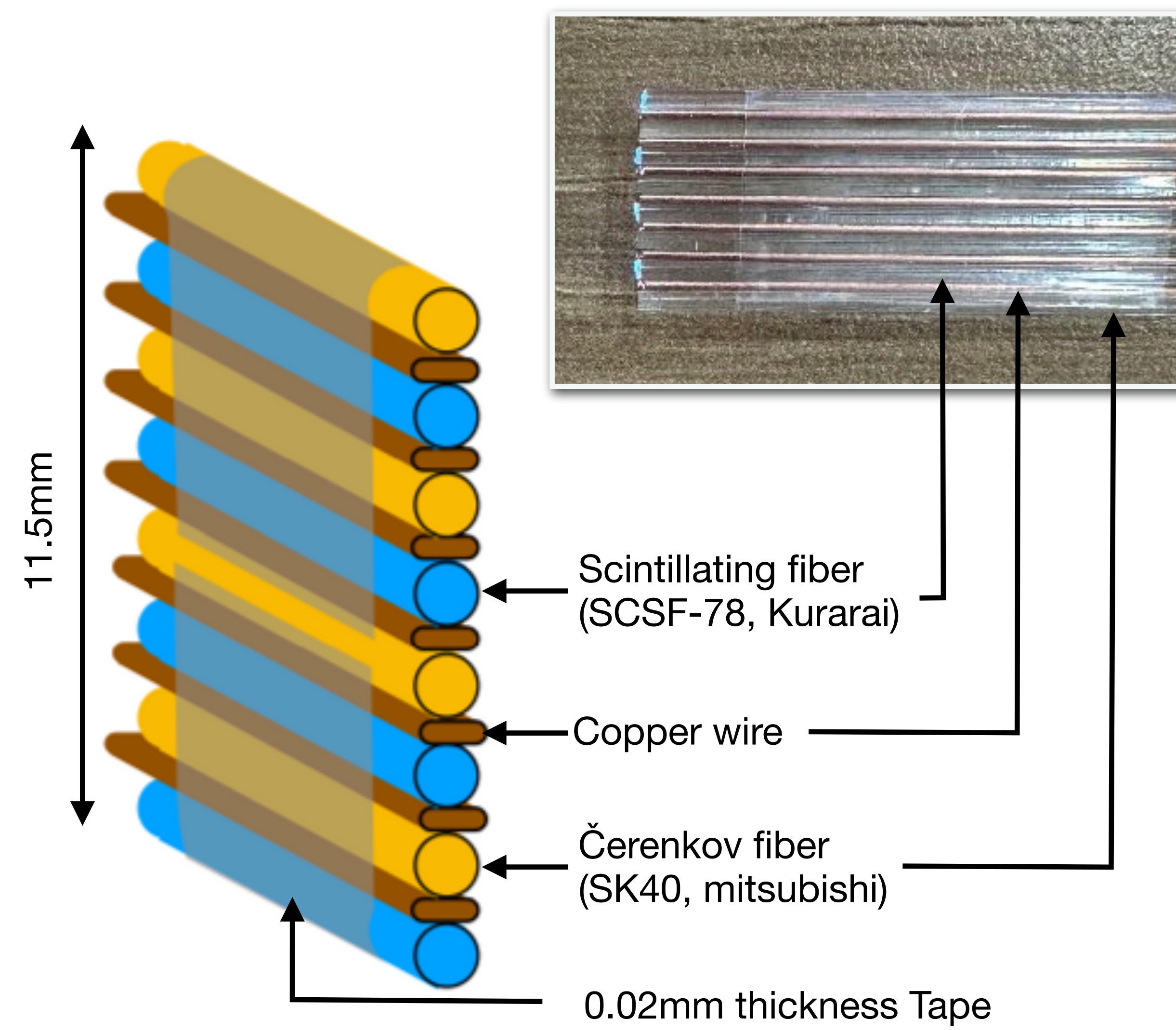
Module Assembly

- New module assembly can be divided by 2 parts

i) SFHS Copper block
- Block has 30 gaps

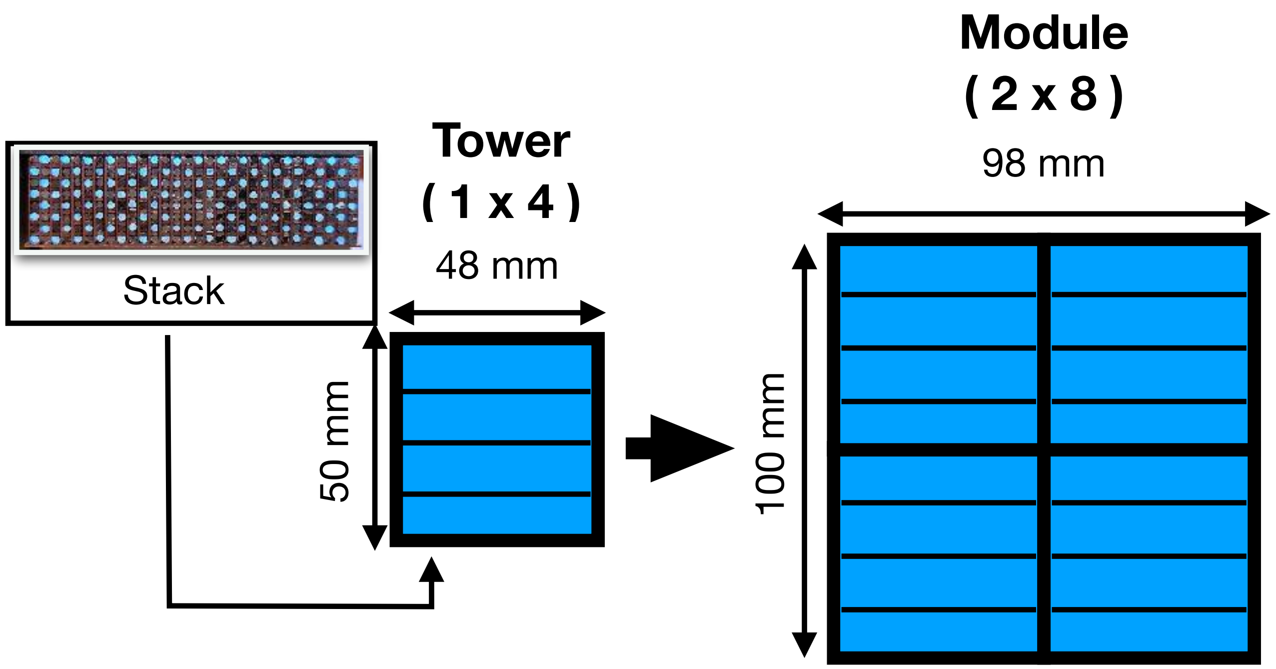


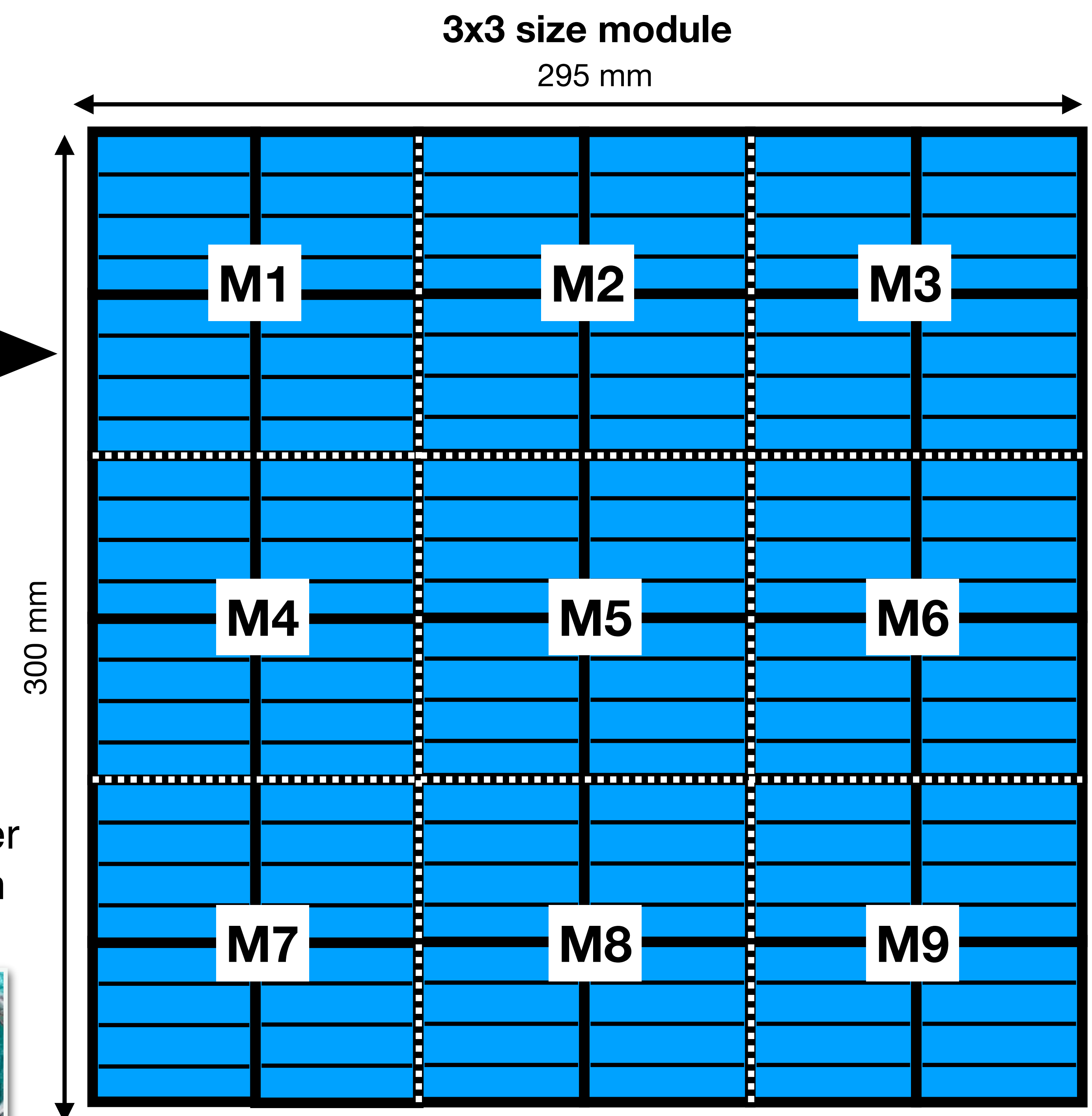
ii) Fiber layer unit
- Consists of fibers and copper wires
  - 4 scintillating fibers (1ϕ, 2.9m)
  - 4 cerenkov fibers (1ϕ, 3m)
  - 14 copper wires (1mm * 0.5mm * 1250mm)



Procedure of Module Assembly

- **3x3 size module**





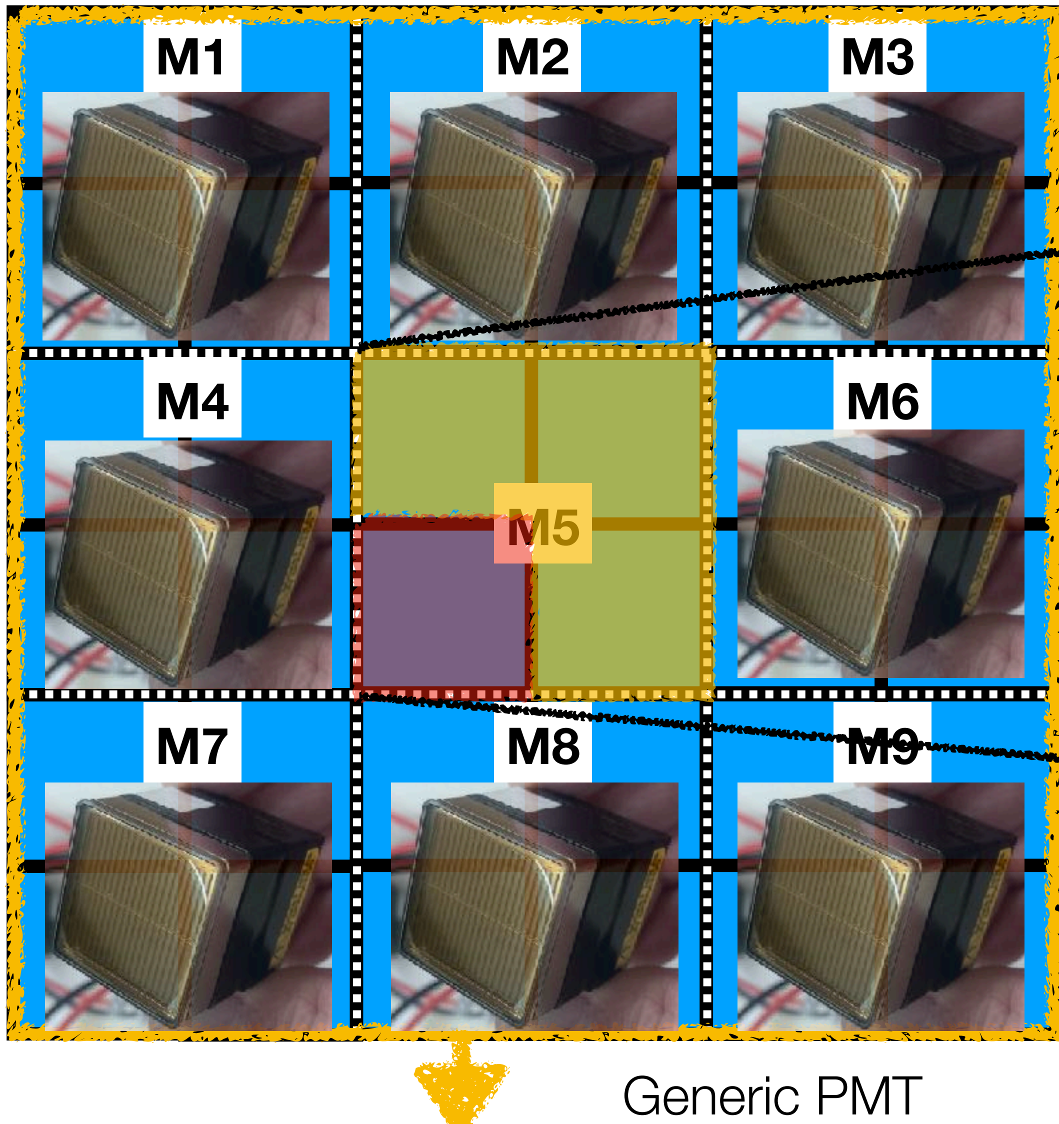
- Necessary number of fiber layer units for
  - Stack = 30 fiber layer units
  - Tower = 4 stacks = 120 fiber layer units
  - Module = 4 towers = 16 stacks = 480 fiber layer units
  - 3x3 size prototype = 9 modules = **4608** fiber layer units (including layers placed in the gap between copper block)

- Channel information
  - 2 MCP-PMT
    - PLANACON XP85012, XP85112
  - 35 Square shape PMT (Generic PMT)
    - Hamamastu R11265-100

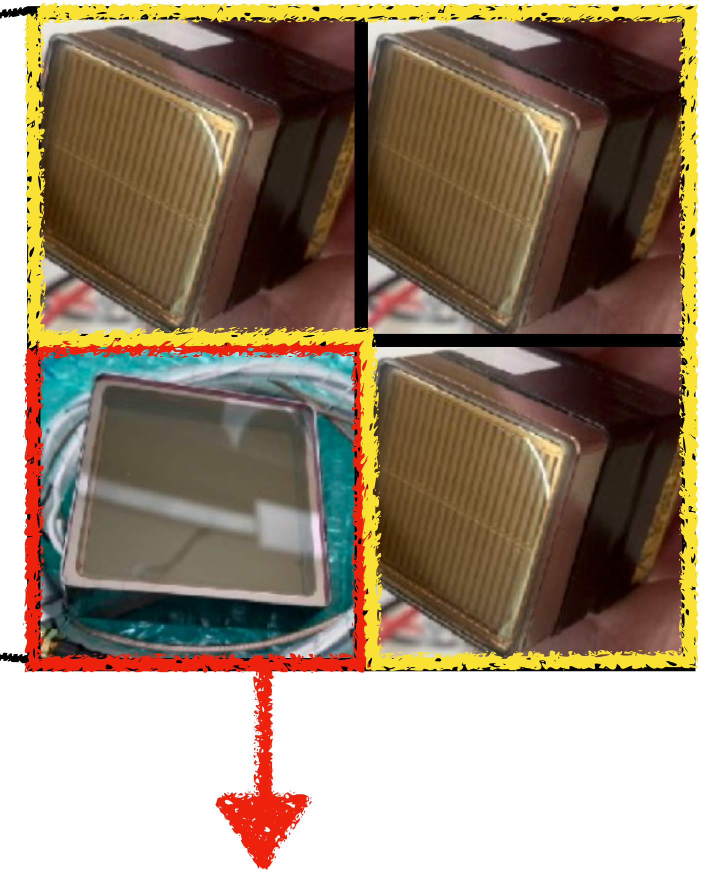
We called them as generic PMT

Module 5 Configuration & Readout Configuration

3x3 size module



Module 5



Generic PMT

Module		M1	M2	M3	M4	M5	M6	M7	M8	M9
Model		R11265-100								
# ch	C	4	4	4	4	3	4	4	4	4
	S	4	4	4	4	3	4	4	4	4

Total: 70 channels

MCP-PMT

	C	S
Model	PLANACON XP85112	PLANACON XP85012
# channel	64	64

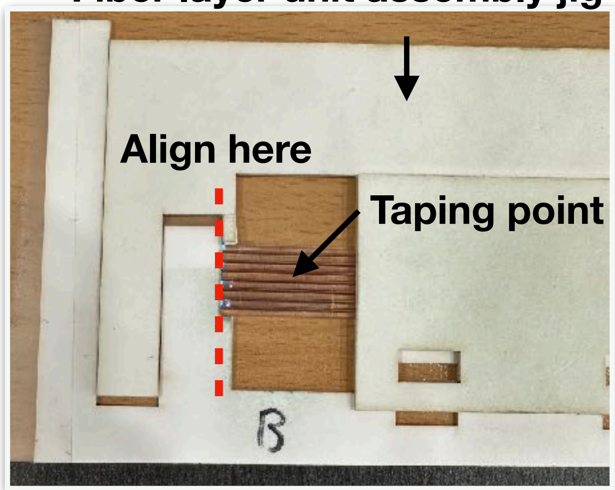
Total: 128 channels

3x3 size module has 198 channels

Assembly of Fiber Layer Unit

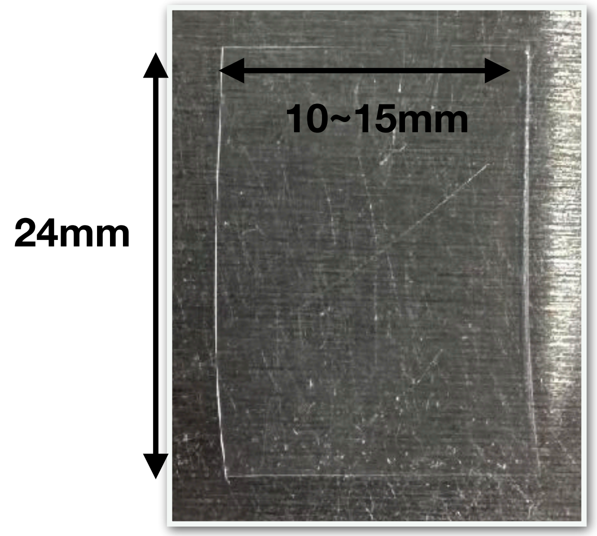
- **Procedure of fiber layer unit assembly**
  - Time cost: **20m/fiber layer units**

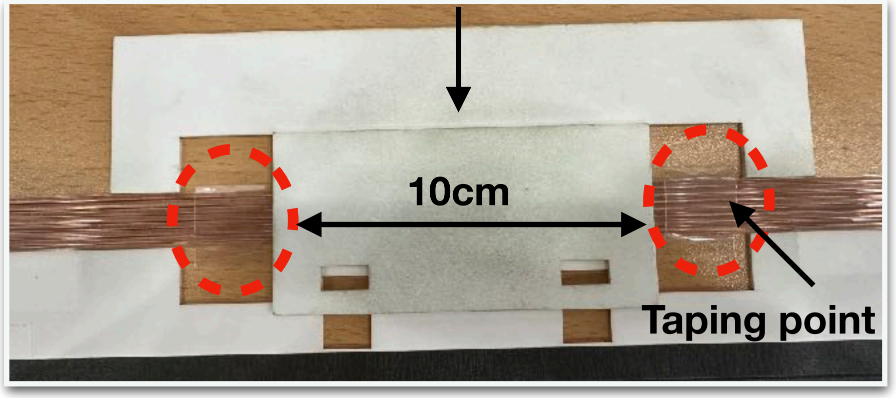
1. Aligning fiber & wire



- align fibers and wires using fiber layer units assembly jig

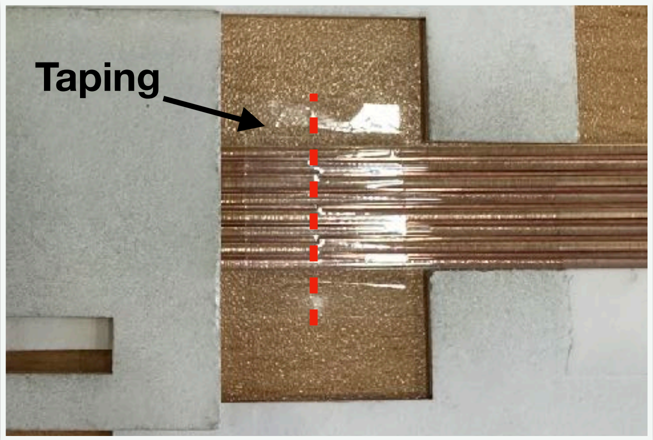
2. Taping





- The height of tape is 24mm
- Taping at 10cm interval

3. Expand copper wire



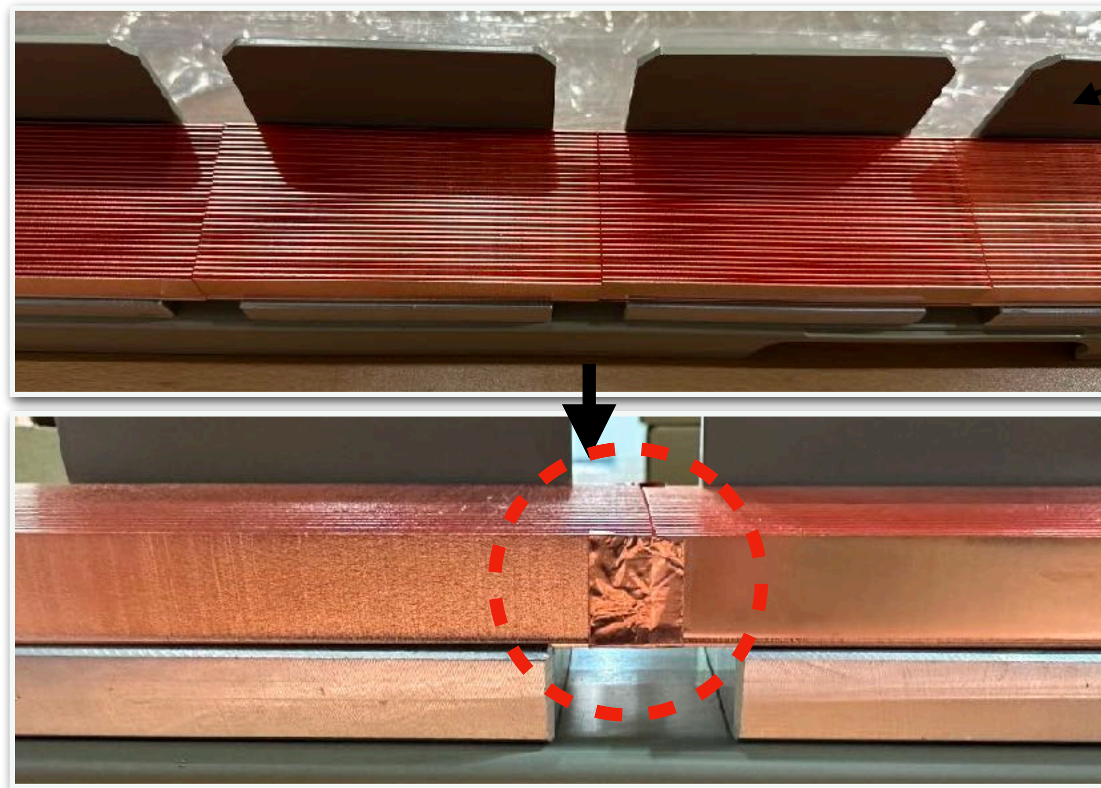
✳ **Length**
  - **Optical fiber: 3m**
  - **Copper wire: 1.25m**

- Expand copper wire at the half point of layer with the tape

Assembly of SFHS Stack

- **Procedure of SFHS stack assembly**
  - Time cost: **2hr/stack**
  - **~8hr/tower**

1. Copper block



Stack assembly jig

- Put 25 copper blocks on the stack assembly jig
- Then, taping btw copper blocks using copper tape

2. Inserting fiber layer unit

- Insert fiber layer unit from the middle of block

S fiber

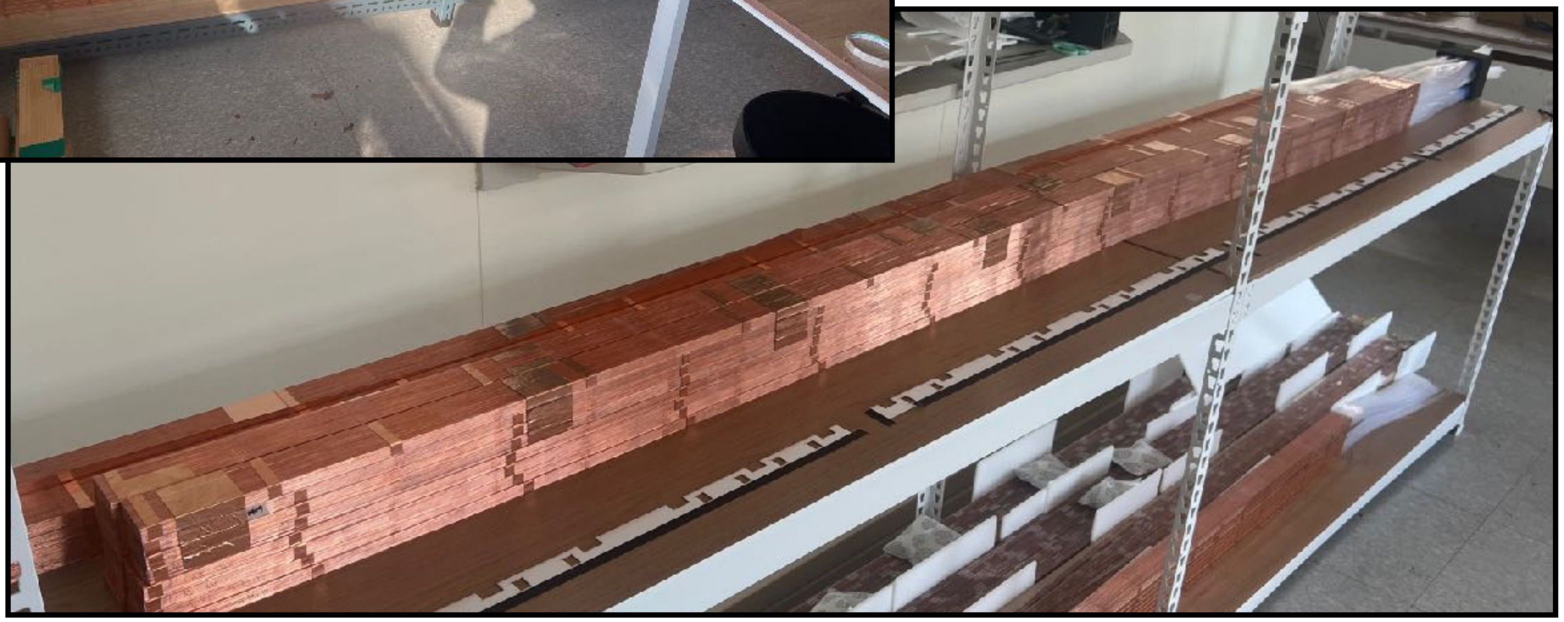
Front view

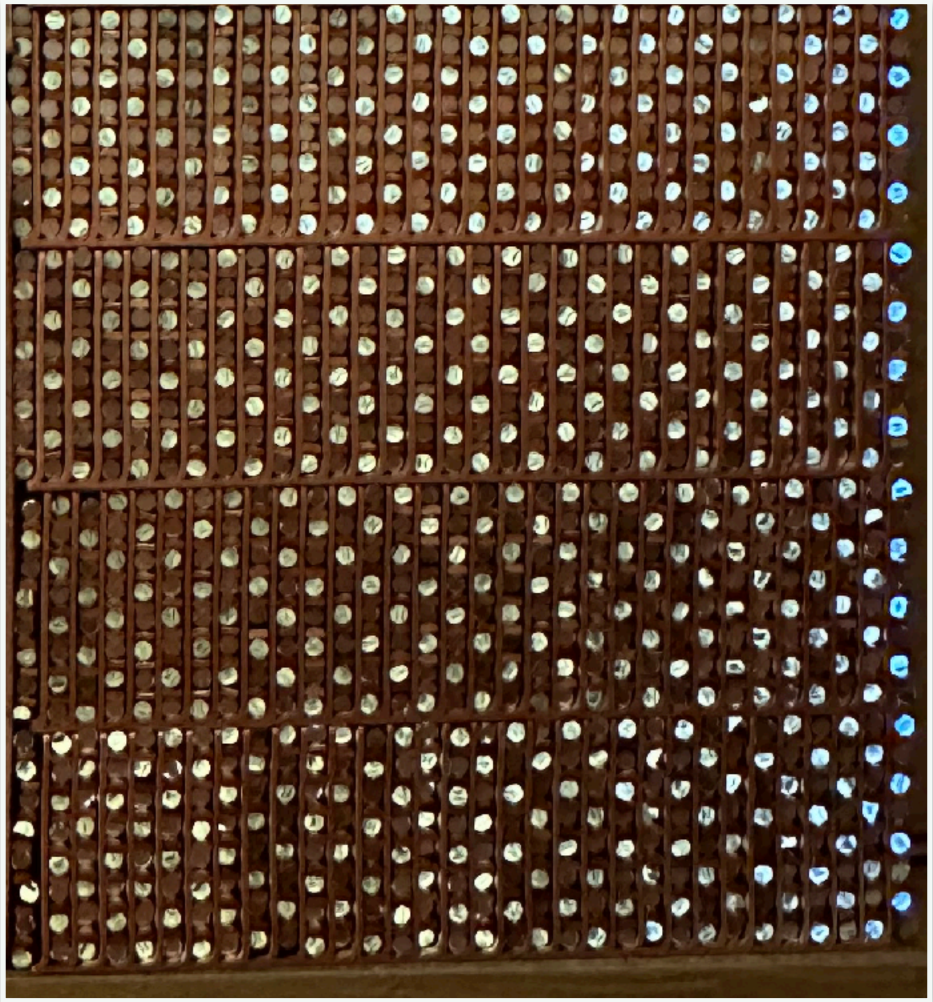
Assembly of SFHS Stack & Module

- Currently, **~80%** layers & **~70%** stacks are built

◀ Stack storage

▼ First module for the module assembly/readout frame test



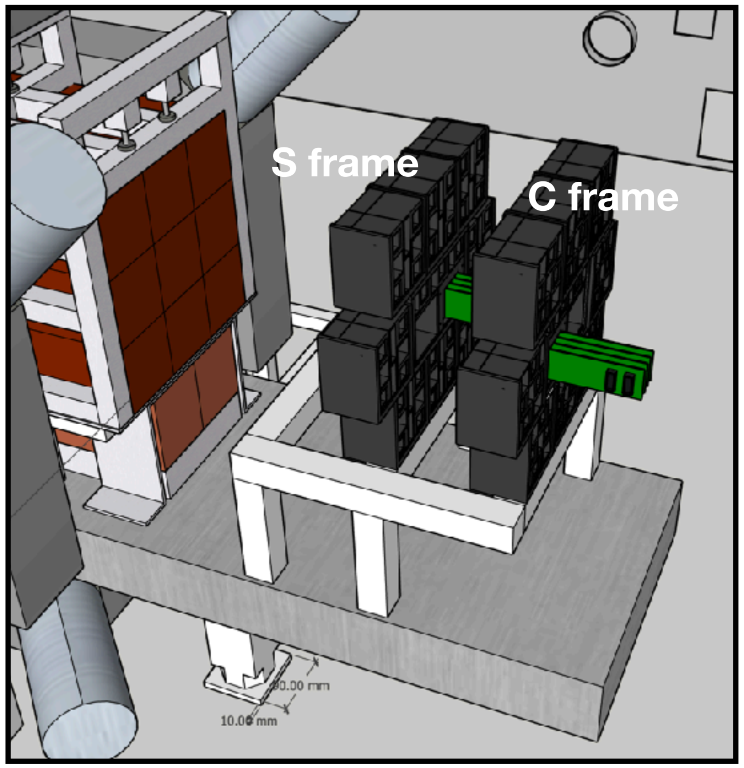


Front view

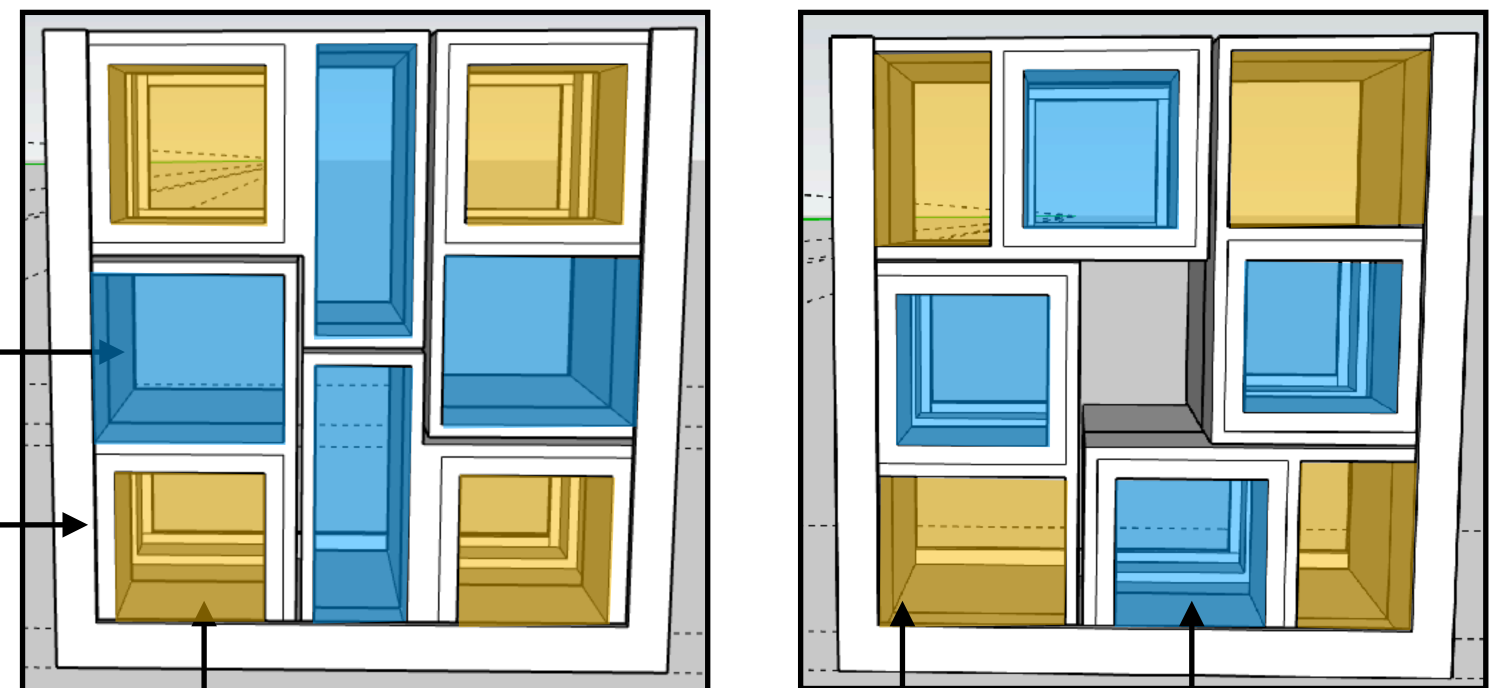
Readout Frame

- **3D printing readout frame**
  - Dimension of readout frame is same as 1 module dimension
  - 2 types of Inner case for fiber bundle & PMT
  - Outer case to hold inner case

1. Concept



2. Sketch

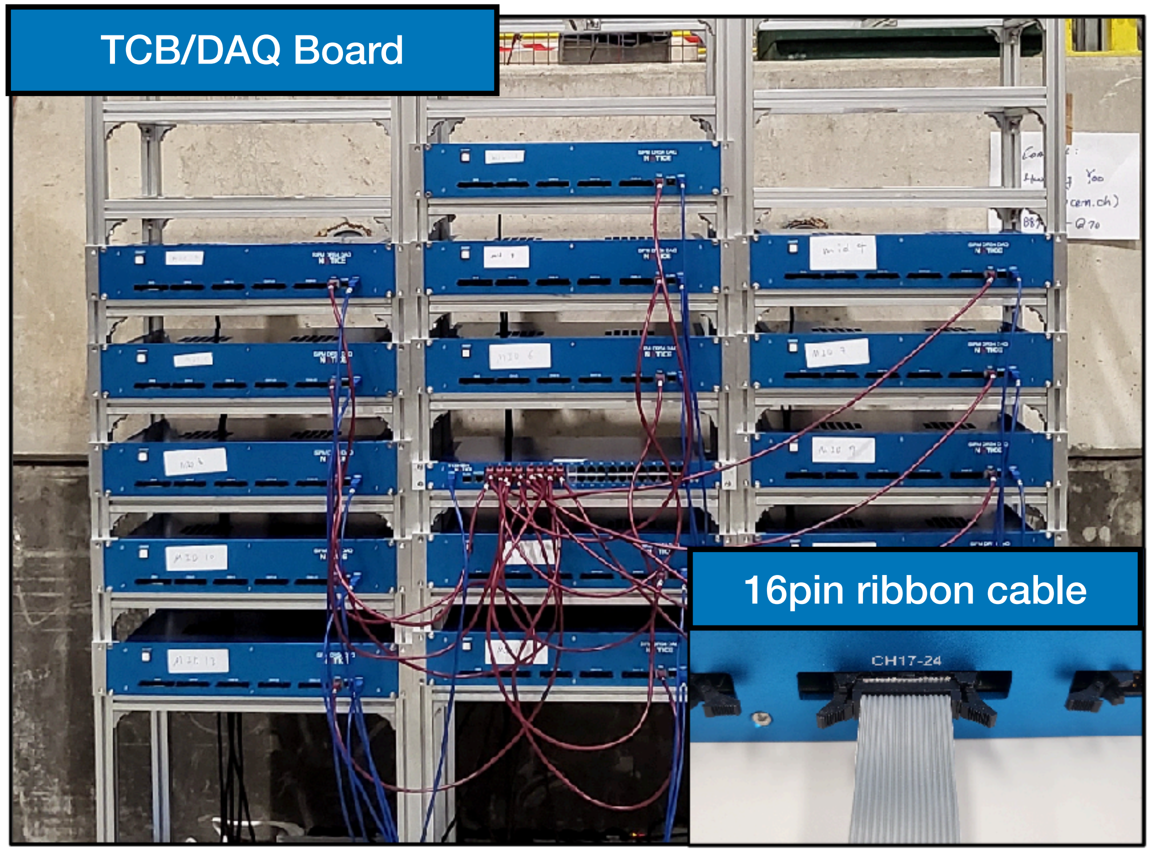


3. Printing

4. S/C frame assembled

Readout System

- **DAQ system**
  - Same DAQ system for TB2022 & 2023 will be used
    - TCB: external trigger and clock generator
    - DAQ: 32ch / board
  - Use 21 DAQ boards & 1 TCB board (including ancillary detectors)



DAQ Board	Channels
DAQ #1	2022 module(24ch) + trig.(7ch (T1 & T2 & Veto & coin. & NIM))
DAQ #2	2024 module S 32ch (except M5)
DAQ #3	2024 module C 32ch (except M5)
DAQ #4	SC SiPM 16 ch(2022module) + 2024 M5 6ch + 2ch(inverse)
DAQ #5 ~ #16	SiPM S1~6, C1~6
DAQ #17 ~ #20	MCP-PMT (2025 M5 module)
DAQ #21	Ancillary

Current Status

- Status sheet [LINK]

Layer Status

Name	Total	01/25 ~ 01/31	02/01 ~ 02/07	02/08 ~ 02/14	02/15 ~ 02/21	02/22 ~ 02/29
	3818					
	Quantities	SKKU+PNU		설날	TB2023 workshop?	
		10개	20개	20개		20개
SK	9			9		
Guk	413	10	20	15		
KY	386	10	24			
SW	248	10	20			
DW	273	10	20	13		
Yun	264	10	20	10		
HE	273	10	20			
SY	291	10	20	5		
HS	261	10	20			
IK	387	40	40	8		
HI	413	60	20			
MW	500	40	40	41		
JR(GWNU)	50					
SG(GWNU)	50					
HJ(SKKU)	49	49				
JS(SKKU)	50	50				
JH(PNU)	49	49				
Total(week)	3818	220	264	101		0
Target						
Completed	82.86%					

Stack Status

Name	Total	01/25 ~ 01/31	02/01 ~ 02/08	02/09 ~ 02/14	02/15 ~ 02/21
	Quantities	SKKU+PNU		설날	TB2023 workshop
		0개	1개	1개	
	Stack Type	S	S		
Guk	13		1		
KY	10.5		(레이어로 대체)		
SW	11.5		1		
DW	13		1		
Yun	10.5		1	1	
HE	10		1		
SY	11.5		1		
HS	10		1		
Total(week)	100	0	7	1	
Target (Total)	144				
Completed %	69.44%				
S Total	92				
Completed %	67.65%				

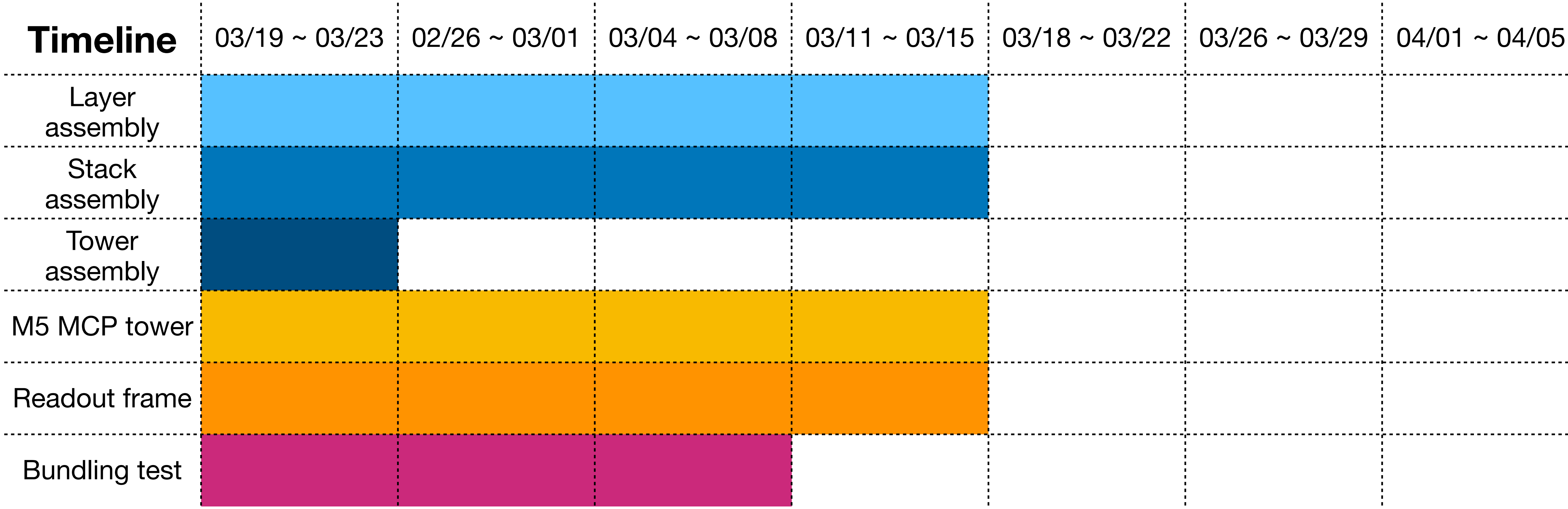
Yonsei Log

KNU Log

Name	Total	01/22 ~ 01/26	01/29 ~ 02/02	02/05 ~ 02/09	02/12 ~ 02/16	02/19 ~ 02/23
	137					
	Quantities					
Prof. SW	15				15	
JH	22	2	3	7	10	
HS	45	6	5	11	23	
KM	55	9	3	15	28	
Total(week)	137	17	11	33	76	0

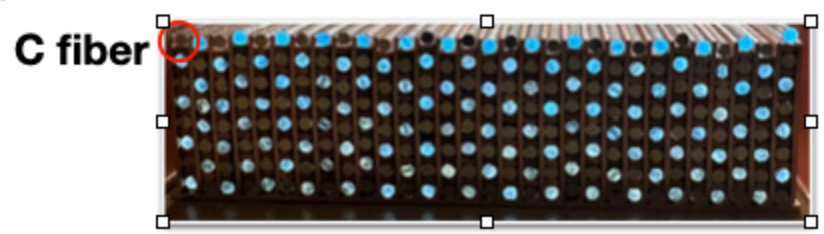
- Layer assembly is **~82%+137 layers(KNU)** done
- Stack assembly is **~69%** done
- Also, thanks to GWNU, PNU, and SKKU for their contribution

Plan

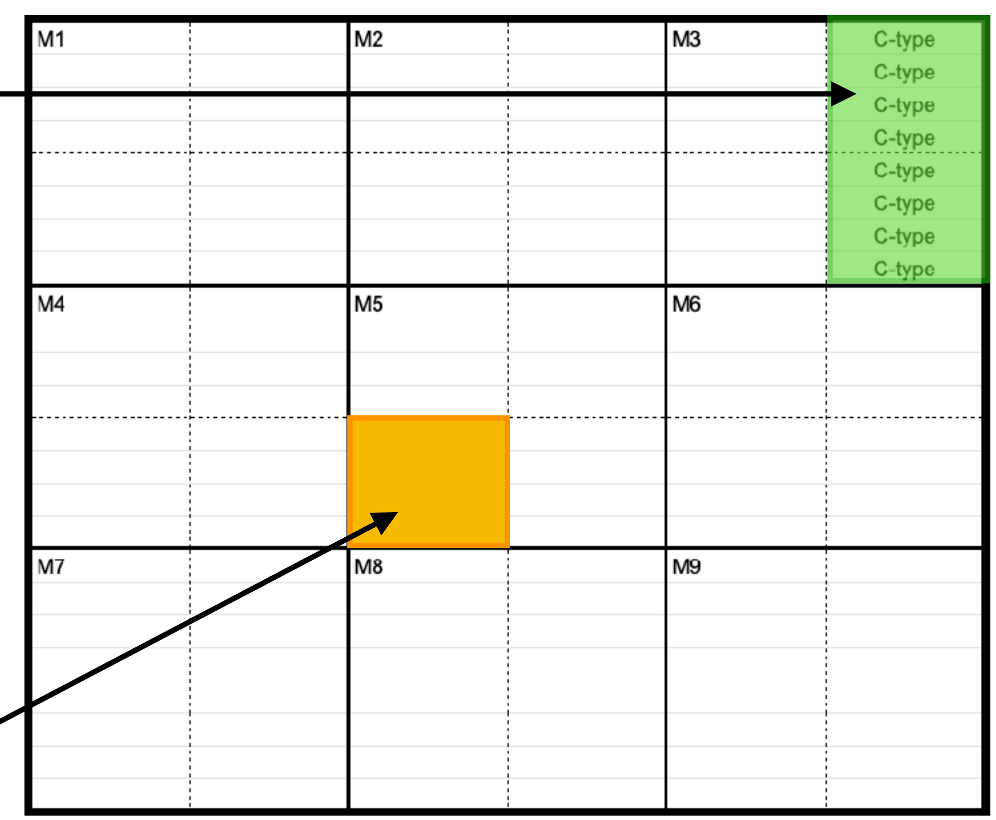


- Bundling(epoxy) test
  - Will use C-type stacks corresponding to 2 towers

- Stack type
  - Have 8 c-type stacks



C type (front view)



3x3 size module configuration

- Build MCP-PMT of M5
  - Will use good quality of layer and alignment of front side

Summary

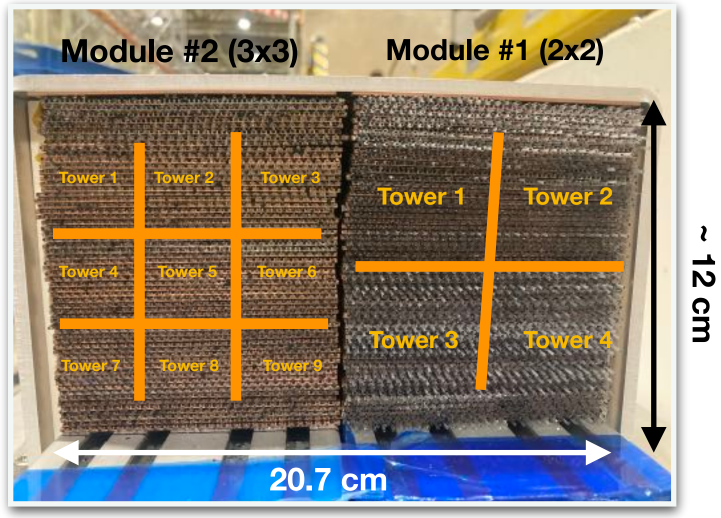
- Korea DRC team plans to build 3x3 size module for TB 2024
  - Use Skiving Fin Heatsink (SFHS) copper forming
  - High granularity readout with MCP-PMT
  - Aim to finish by end of March and ship to CERN during April in 2024

Back up

Introduction

- **History of prototype dual-readout calorimeter in Korea**
- We have built various prototype of the dual-readout calorimeter since 2022

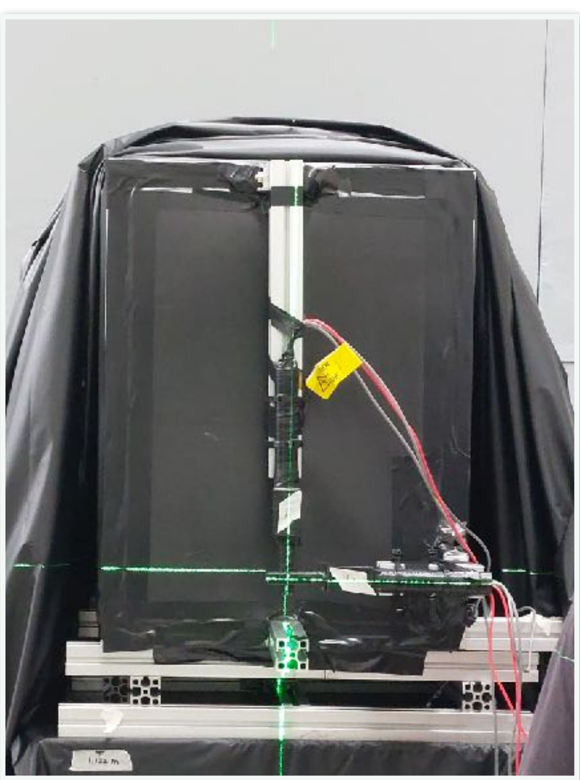
Prototype in TB2022

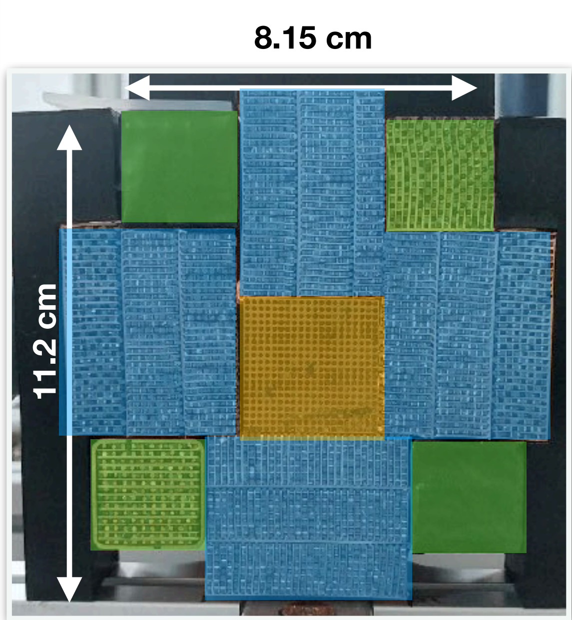


- The first prototype modules
- Repair and reassemble copper modules built in 2016 in US
- Various new systems and R&D applied
  - Single/double/square scintillating fibers used
  - New electronics readout & DAQ systems
  - High granularity readout with SiPM

Prototype in TB2023

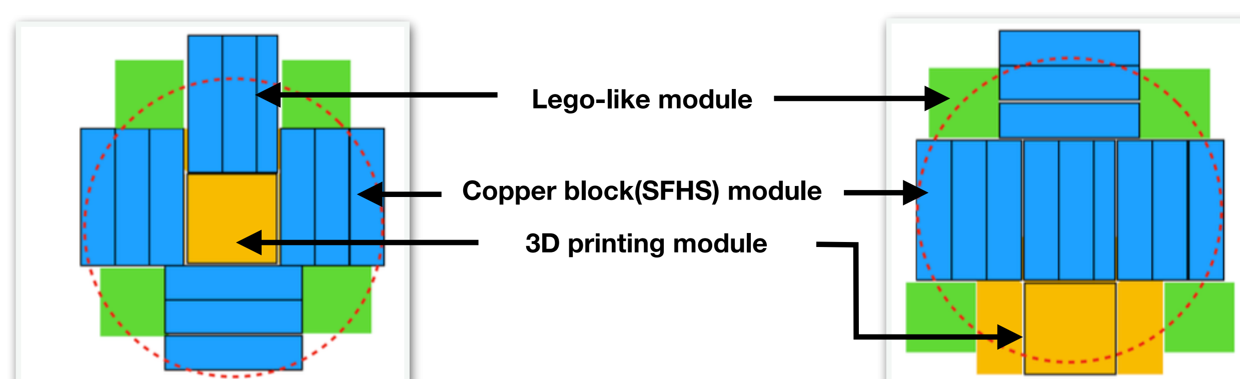
More details in SW's talk(H2.05)





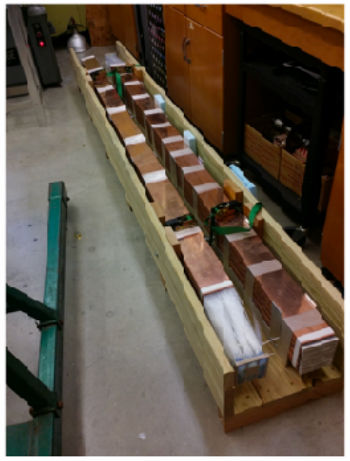
- Tested 3 copper forming technologies
  - Lego-like, Skiving Fin HeatSink (SFHS), 3D metal printing
- 2 module configuration has been used
- High granularity readout with MCP-PMT

3D printing module center | **SF heatsink module center**

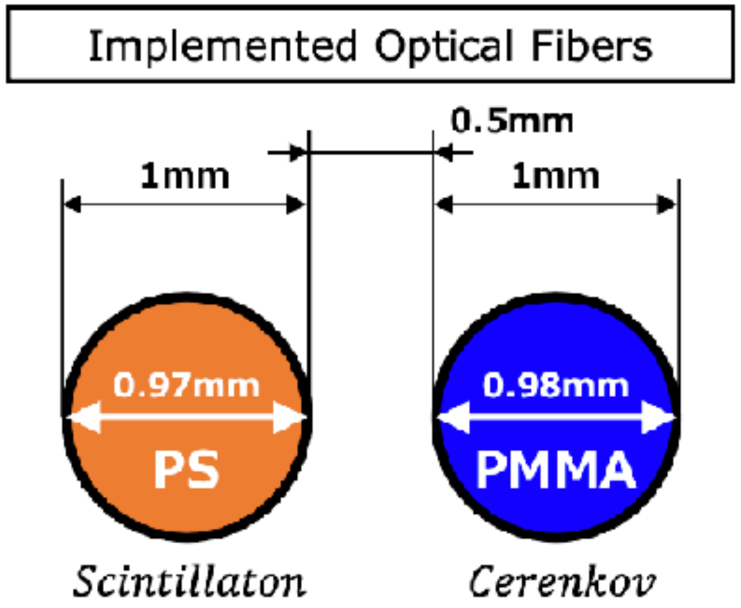


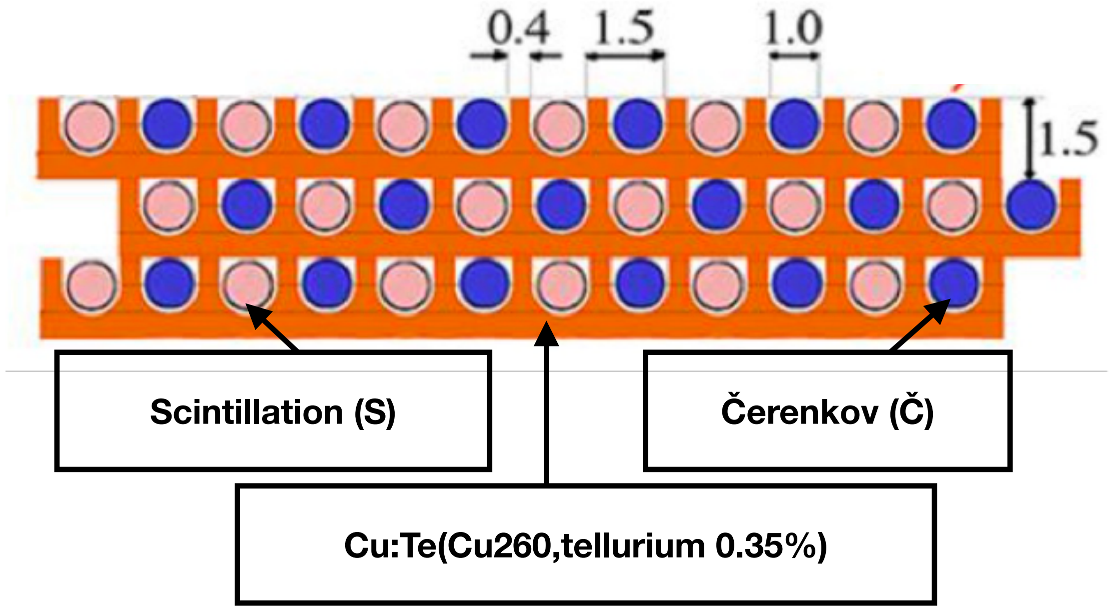
- The dual-readout calorimeter can be divided by 2 parts in building process
  i) Copper plate
    - To build calorimeter, we have to disassemble and clean up all plates because they were used in 2016
    - **61 plates** are used to build a module
  ii) Optical fibers
    - Čerenkov fibers: round shape 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





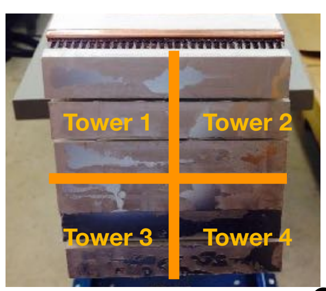
TB2022 (ii)

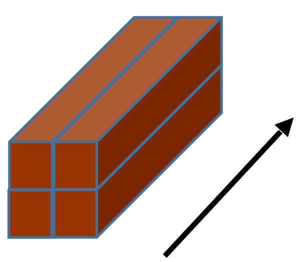
- The dual-readout calorimeter can be divided by 2 parts in building process

- **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**

Module #1 (2x2)





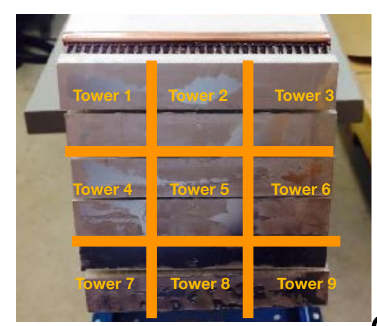
Module#1

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

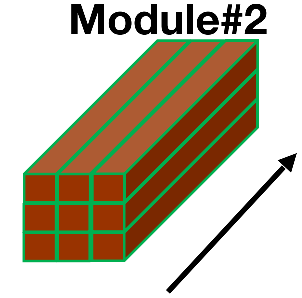
Combination of fibers for Module#1

	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

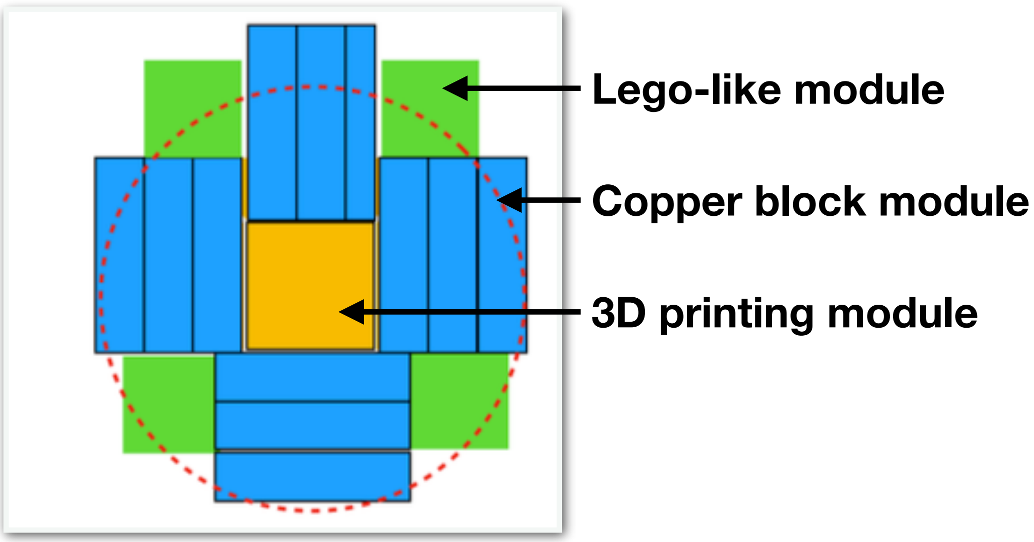
Combination of fibers for Module#2

	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

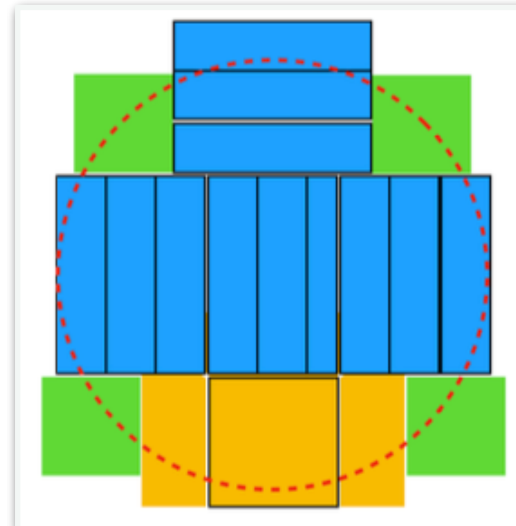
TB 2023

- **Module Structure**

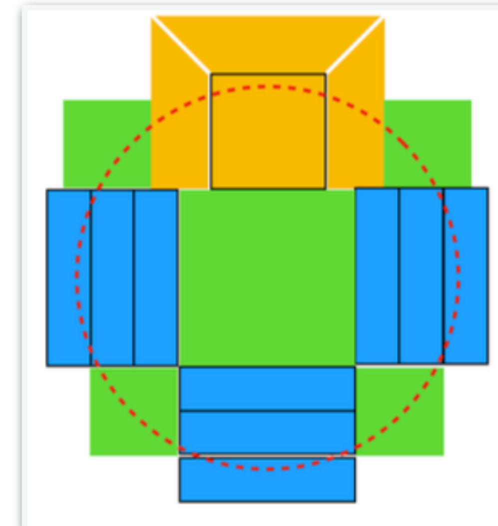
3D printing module center



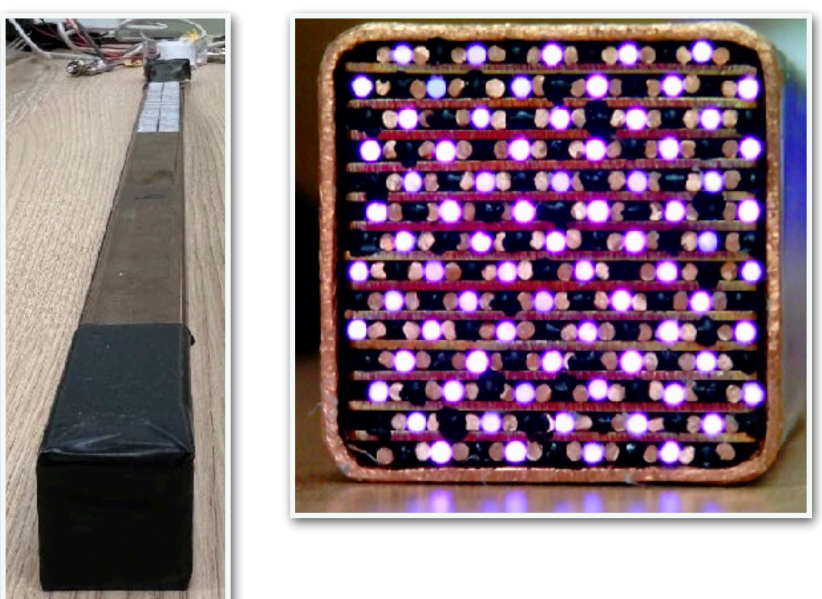
SF heatsink module center



Lego-like module center

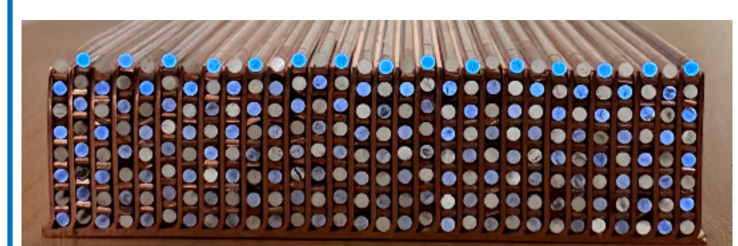


Lego-like module



3D printing module

SFHS module



Fiber Specification

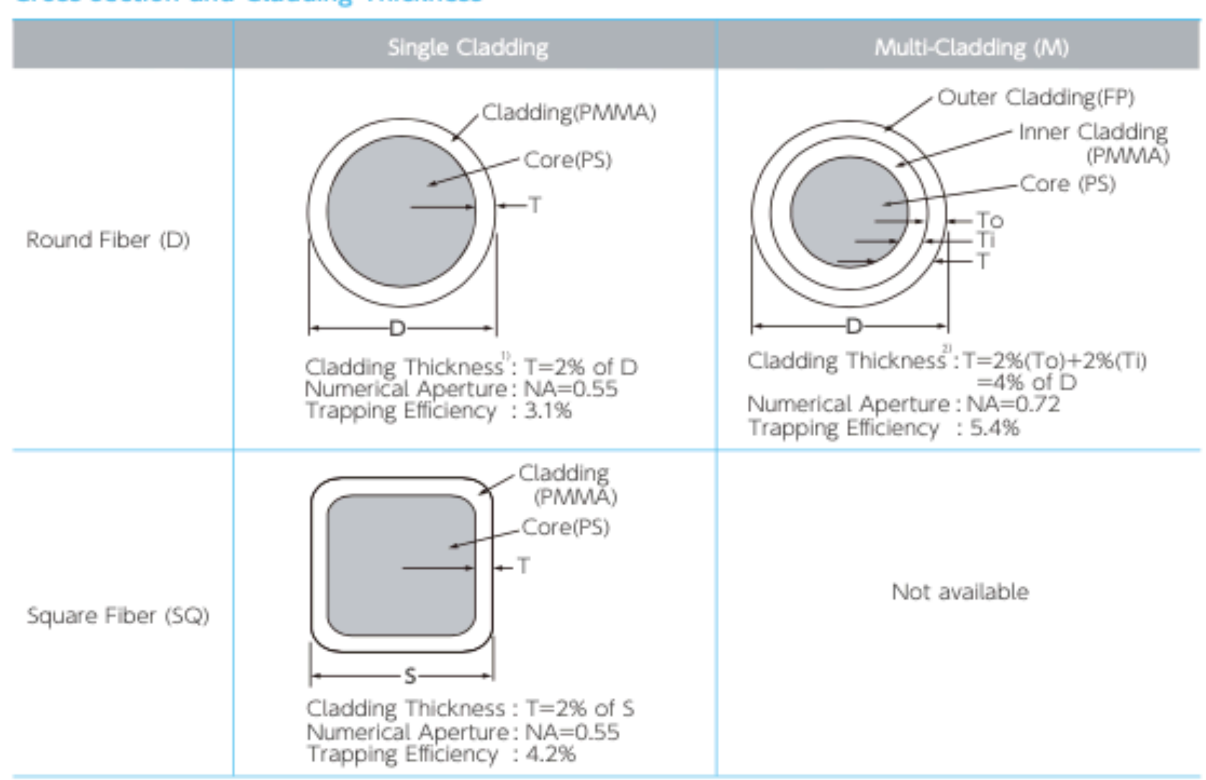
- **Čerenkov fiber**

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**

Cross-section and Cladding Thickness



1) In some cases, cladding thickness T is 3% of D. 2) In some cases, cladding thickness T is 6% of D, To and Ti are both 3% of D.

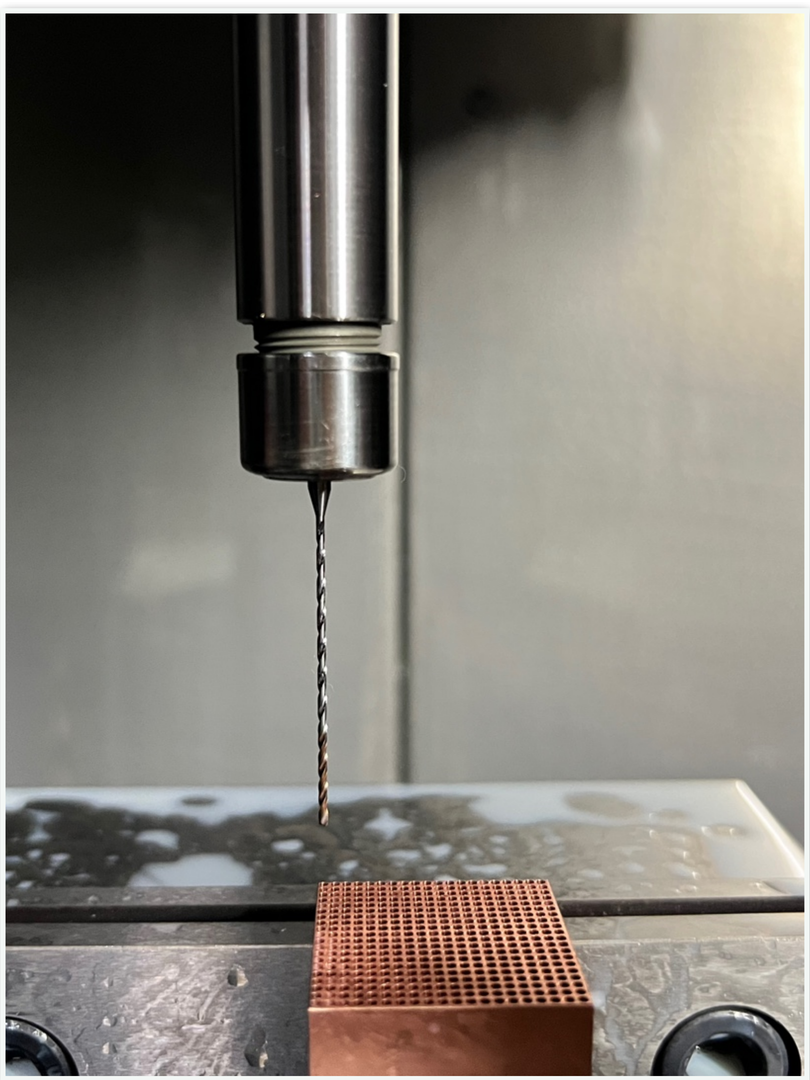
Plan for Assembly Automation

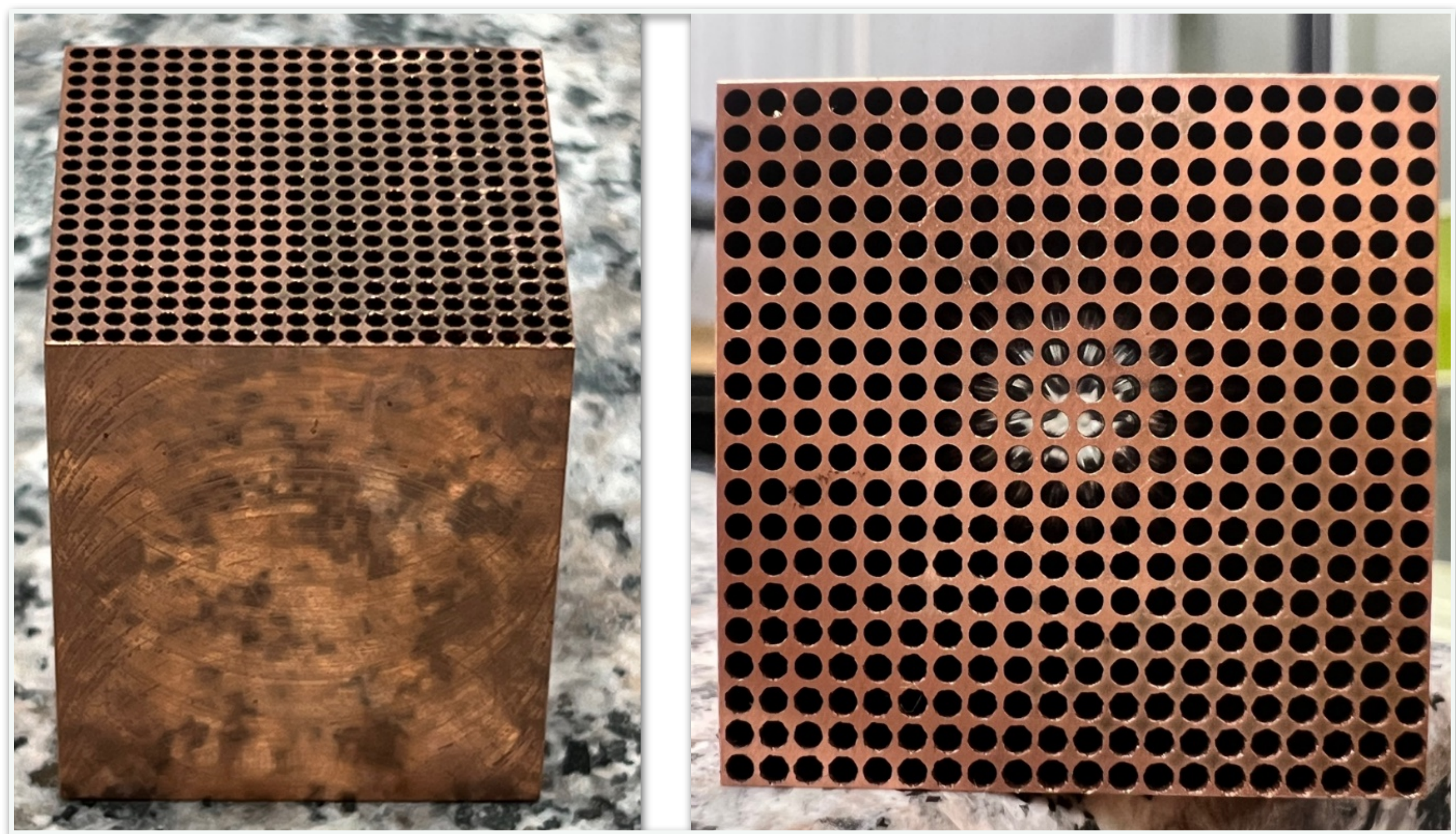
- Take very long time to assemble one tower with current procedure manually
- Consider to make assembly automation machine to reduce assembly time consumption dramatically
- Under discussion with local manufacturer

Alternative Approach

- “Drilling” might be another good option for copper forming to build full 4pi detector

- R&D on-going with mechanical engineering experts in Korea institutes





Summary

- Korea DRC team plans to build 3x3 size module for TB 2024
  - Use Skiving Fin Heatsink (SFHS) copper forming
  - High granularity readout with MCP-PMT
  - Aim to finish by end of March and ship to CERN during April in 2024
- Engineering solutions to build 4pi detector are under discussion
  - Automation machine for module assembly with SFHS copper blocks
  - Drilling is being tested with mechanical experts for alternative approach