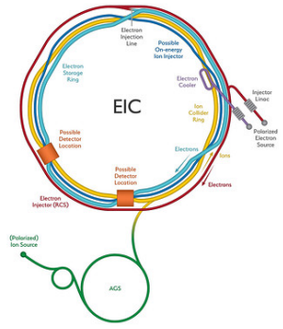


DREAM FOR FUTURE

Status of Dual-Readout Calorimeter R&D in Korea

Hwidong Yoo (Yonsei Univ.)

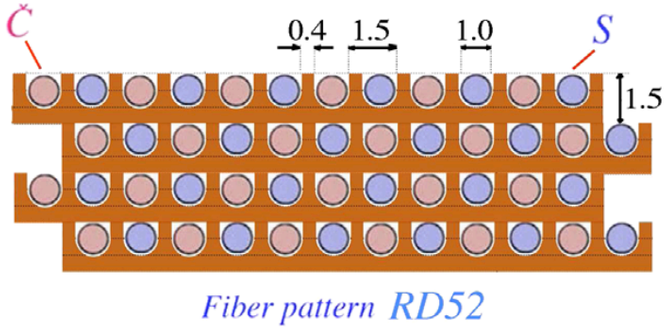
On behalf of
the Korea Dual-Readout Calorimeter Team

RD_FCC collaboration meeting,
December 15, 2021

Supported by KiSTi www.kisti.re.kr

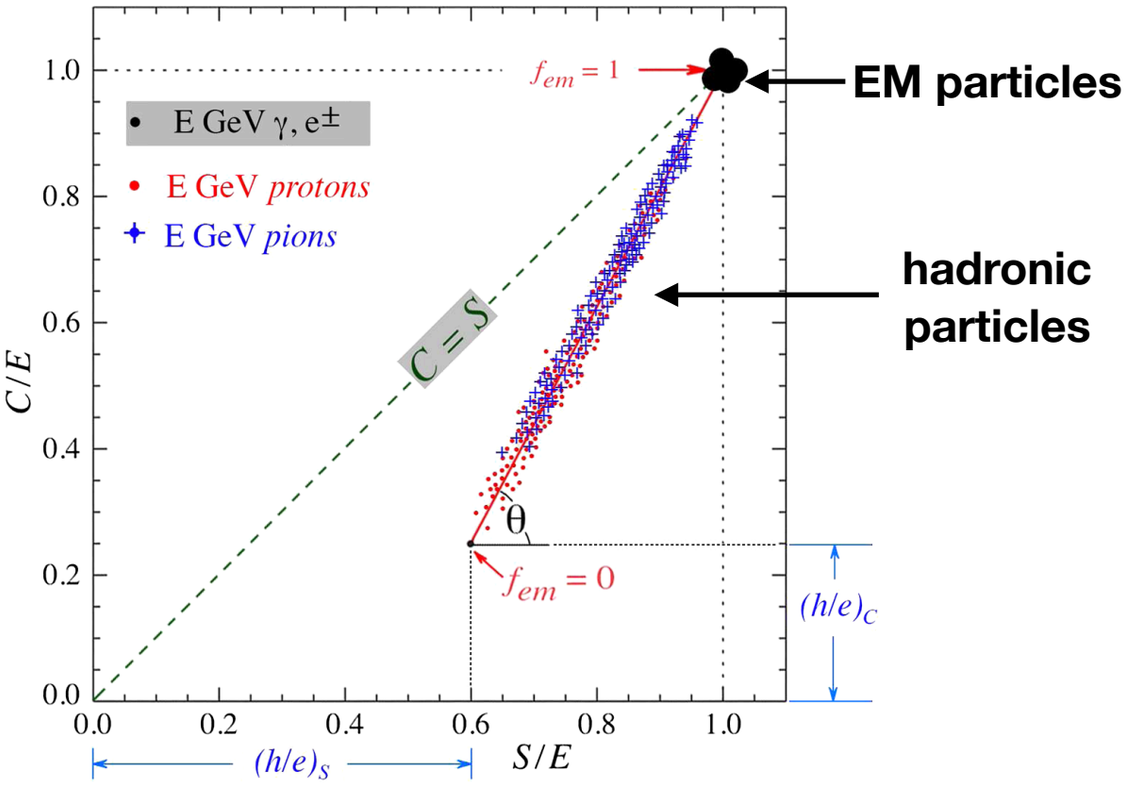
Intro: Dual-Readout Calorimeter (DRC)

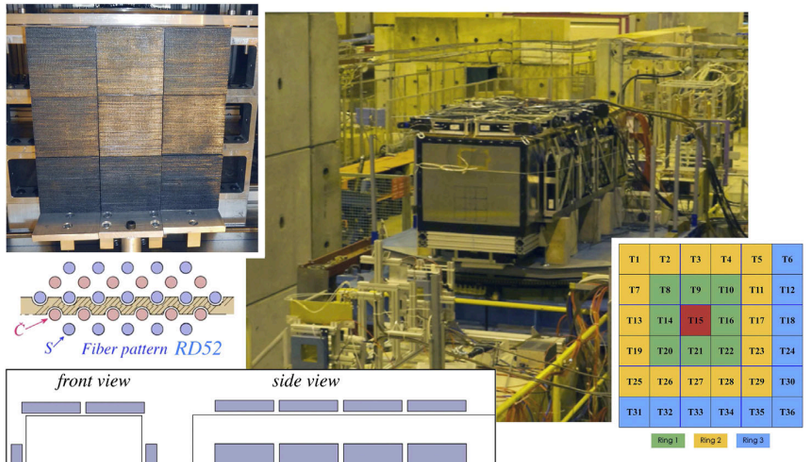
- DRC offers high-quality energy measurement for both EM particles and hadrons
  - DRC consists of two different optical fibers (S, C) in a single component
  - The main culprit of poor hadronic energy resolution is fluctuations of the EM shower components of hadron showers (f_{em})
  - f_{em} can be determined using the measured values of scintillation and Cerenkov signals
- Excellent hadron energy resolution can be achieved by correcting the energy of hadron event-by event



Fiber pattern RD52

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

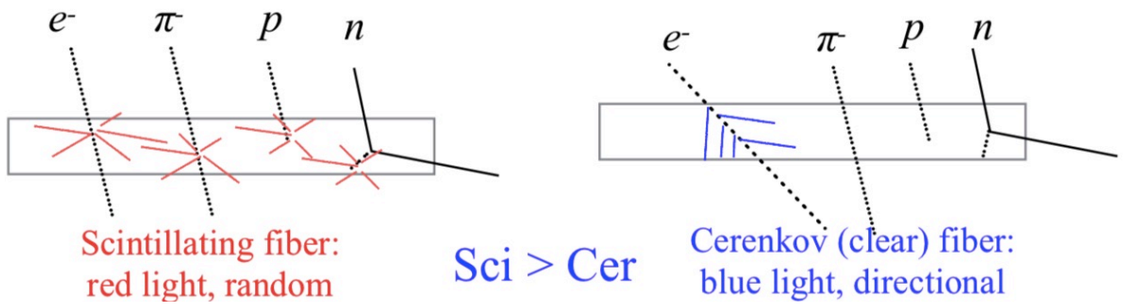




CERN RD52 experiment

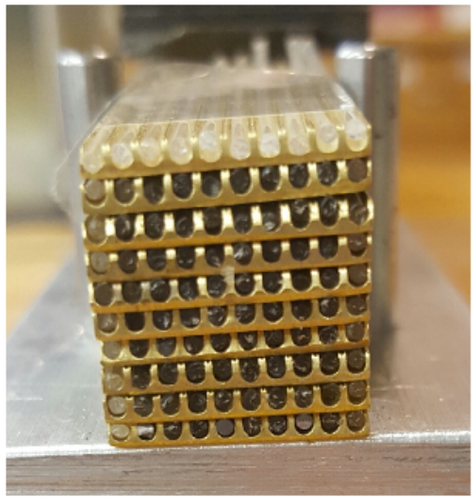
$$E = \frac{S - \chi C}{1 - \chi}.$$
$$\cot\theta = \frac{1 - (h/e)_S}{1 - (h/e)_C} = \chi,$$

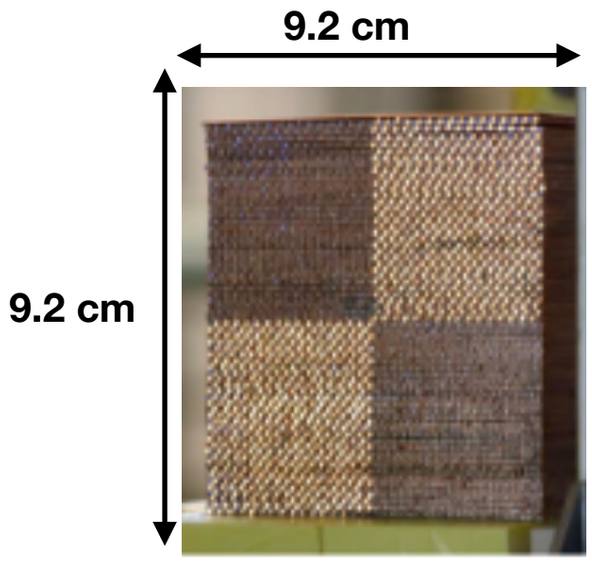
Signal generation: Scintillating & Cerenkov fibers



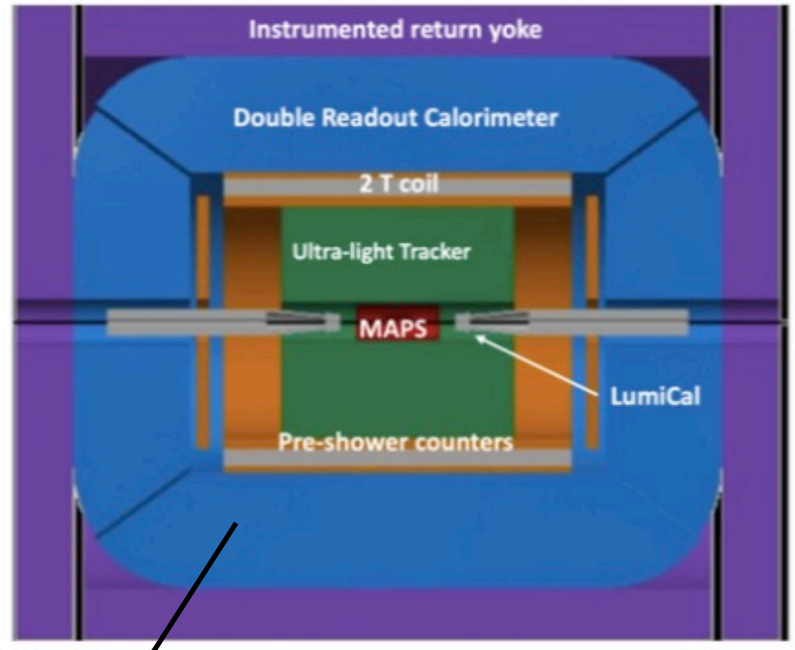
Intro: DRC Geometry and Module

- Korean team led the design of the Dual-Readout Calorimeter (DRC) for IDEA detector
  - Included in the CDRs of both FCC-ee and CEPC, published at the end of 2018

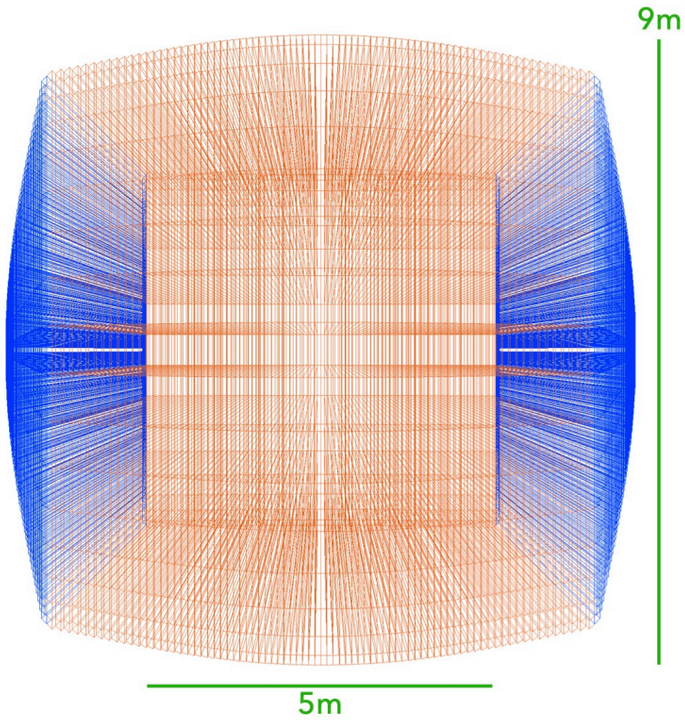


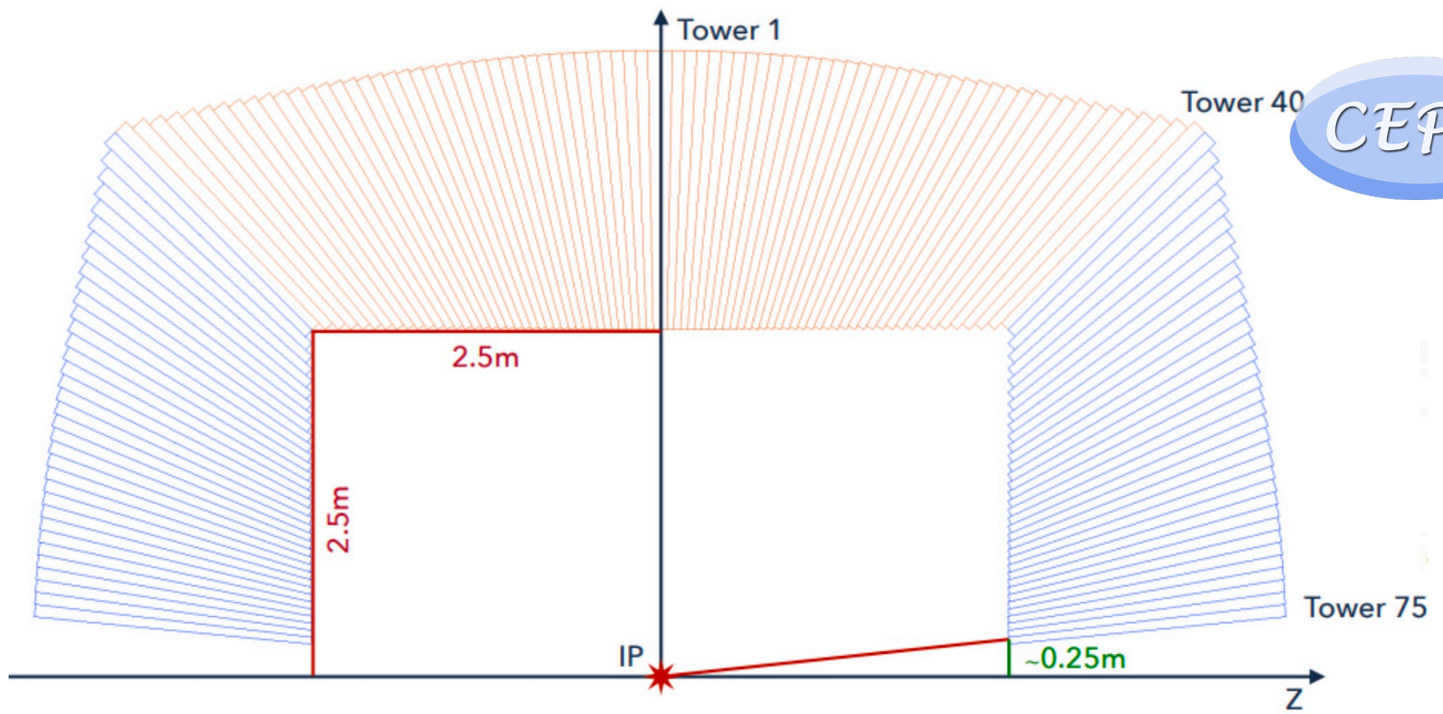


Size of unit module



IDEA





Intro: DRC International Collaboration

Prof. Hyonsuk Jo (KNU)
Prof. Yongsun Kim (Sejong U.)
Prof. Sanghoon Lim (PNU)

Prof. Jason Lee (UoS)
Prof. Sehwook Lee (KNU)
Prof. Hwidong Yoo (YU)

KiSTi www.kisti.re.kr

Prof. Rong-Shyang Lu

Prof. Chia Ming Kuo

Taiwan

Korea

Japan

東京大学 THE UNIVERSITY OF TOKYO

Prof. Yuji Enari

FCC hh ee he

DREAM FOR FUTURE

CEPC

USA

Prof. Sarah Eno

Prof. Chris Tully

TEXAS TECH UNIVERSITY

Prof. Richard Wigmans

STATE

Prof. John Hauptman

Europe

INFN

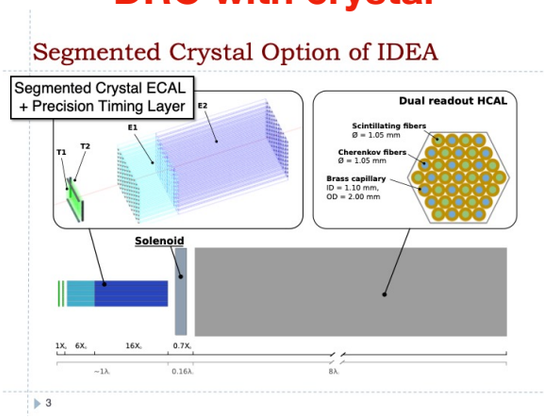
Prof. Paolo Giacomelli (Bologna)
Prof. Romualdo Santoro (Insubria)
Prof. Roberto Ferrari (Pavia)
Prof. Franco Bedeschi (Pisa)

UNIVERSITY OF SUSSEX

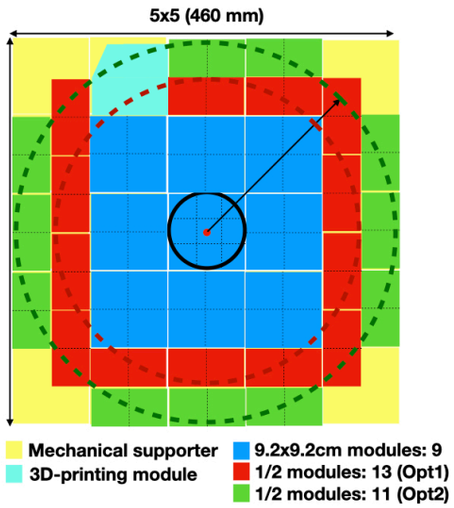
Prof. Iacopo Vivarelli

Prof. Valery Chmill

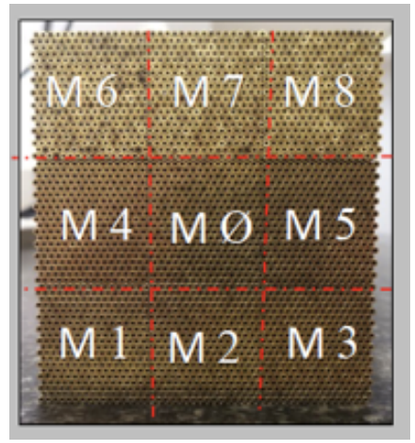
DRC with crystal



Full-size prototype detector



Bucatini prototype

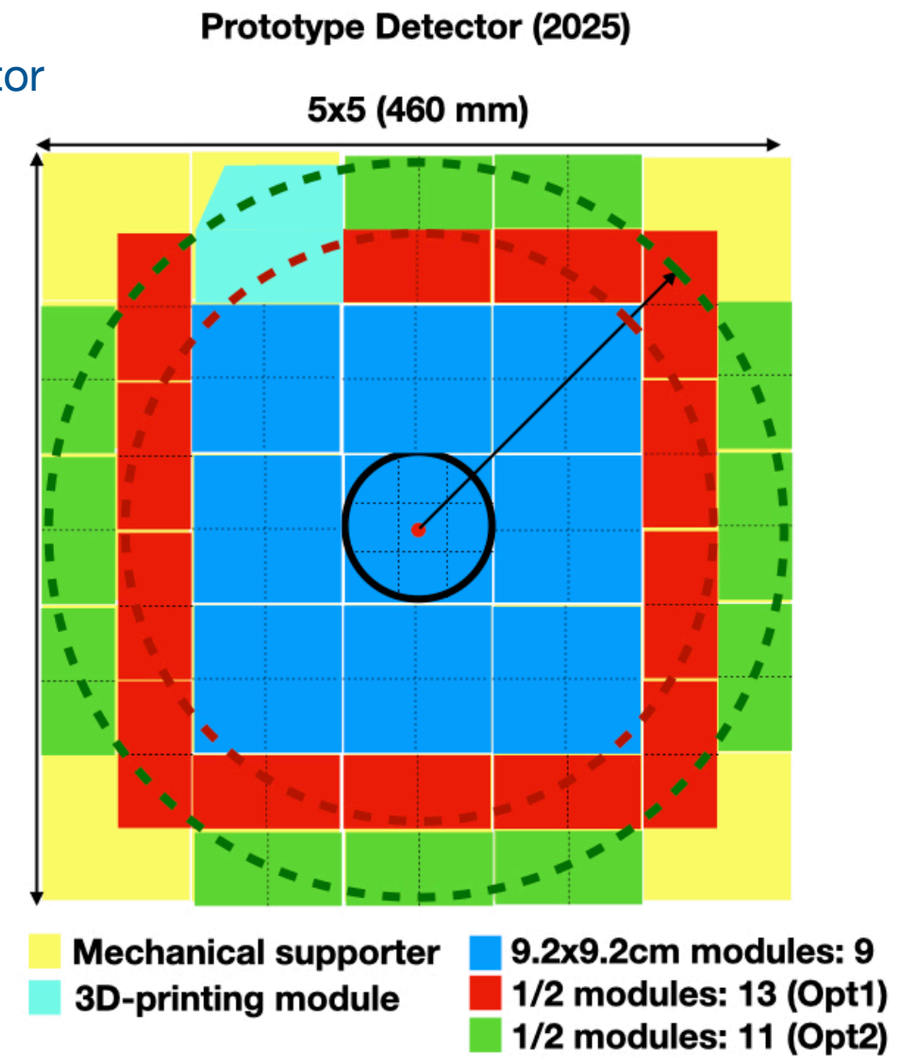


Intro: Korea Prototype Detector

- Primary goal: build a prototype detector for the detector design of future collider projects
  - **5 year (2020.Mar. - 2025.Feb.) R&D funding** supported by Korea NRF ($~0.4M/year, total **$~2M** for 5 years) => 2nd year in this program
  - Contain almost (97.5%) full hadronic shower energy
  - Demonstrate engineering aspects for full geometry detector
- Secondary goal: train next generations as experts of the (DRC) detector

2017-9	2020-1	2022-5	TBD
Design	R&D	Prototype	Production

Stage	Topic
Design	Propose a design of Dual-Readout Calorimeter to IDEA detector concept
R&D	Perform R&D (including engineering aspects) based on HW & SW
Prototype	Build 4x4 detector and perform test beams
Production	TBD



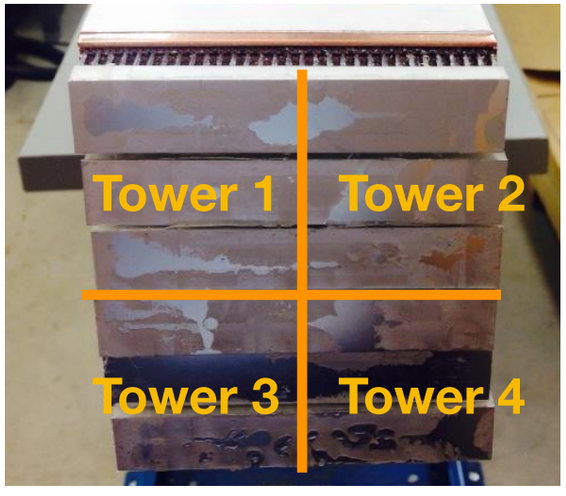
1. Two Module Production

- Two module buildings for initial R&D and upcoming test-beam experiment are on-going
- Various assembly steps are precisely being visited
  - Optical fiber treatments
  - PMT and electronics R&D
  - Housing and assembly kit design

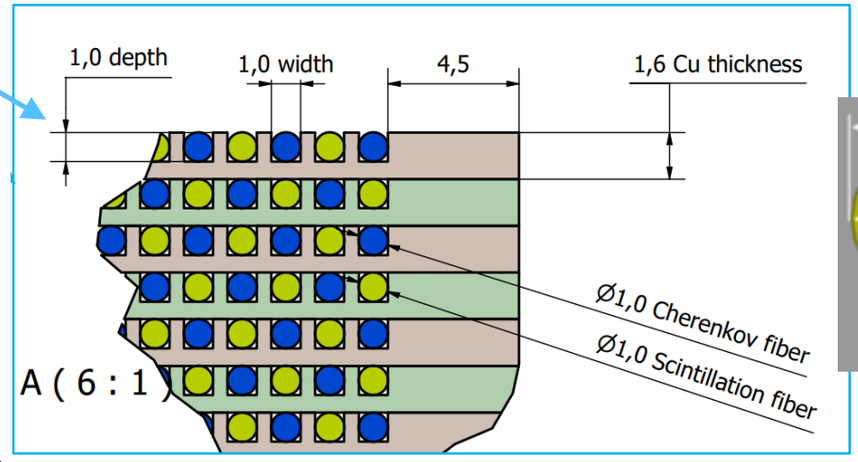
Test-beam plan

Goal	Details
Measurements	Time resolution, shower depth, longitudinal shower profile, light attenuation length etc.
	Position resolution, EM energy resolution, lateral shower profile, uniformity etc.
R&D	Readout test (MCP vs. SiPM)
	Time resolution (< 50 ps)
	Optical fibers (various types)
Training	Next generation experts for DRC HW

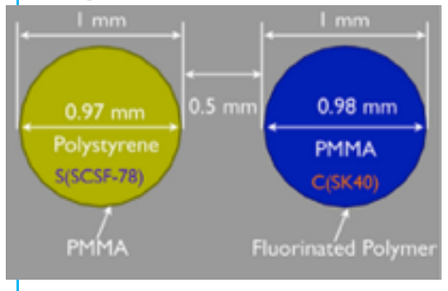
Module #1 (2x2)



Module #2 (3x3)



Specification of fibers



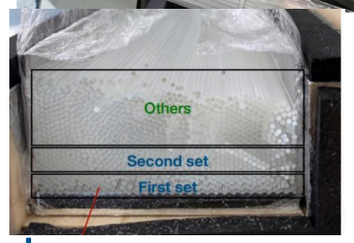
NIM A 762 (2014) 100, N. Akchurin et al.

Optical Fiber Treatment

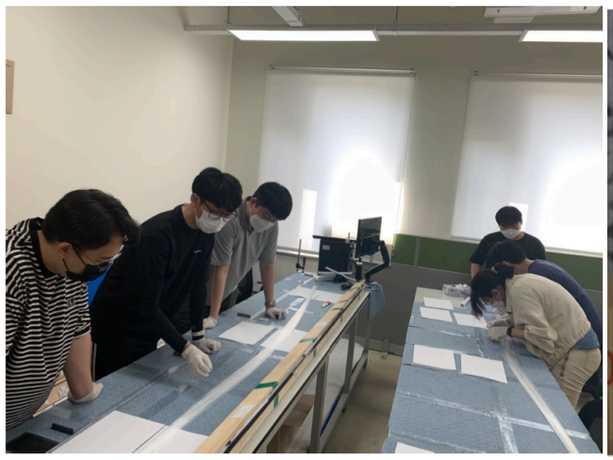
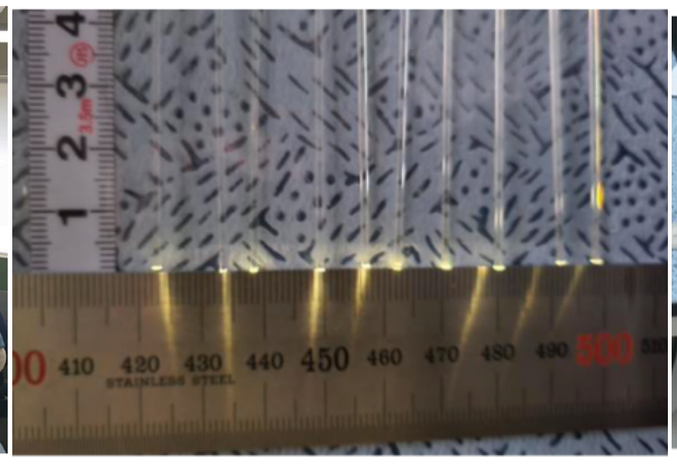
- Fibers delivered at early spring
  - From Kuraray (S) and Mitshbishi (C)



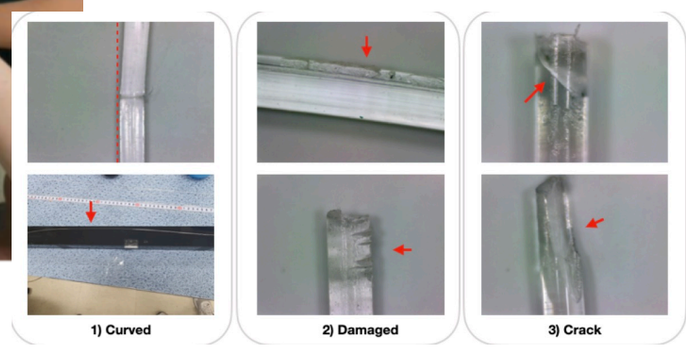




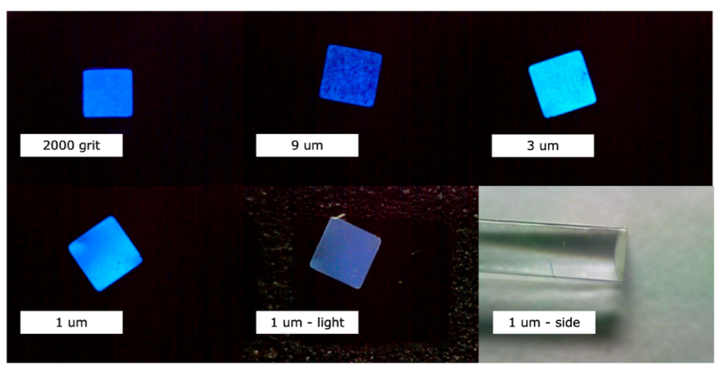
- Check the quality of fibers in details: check 1-by-1 and make a database

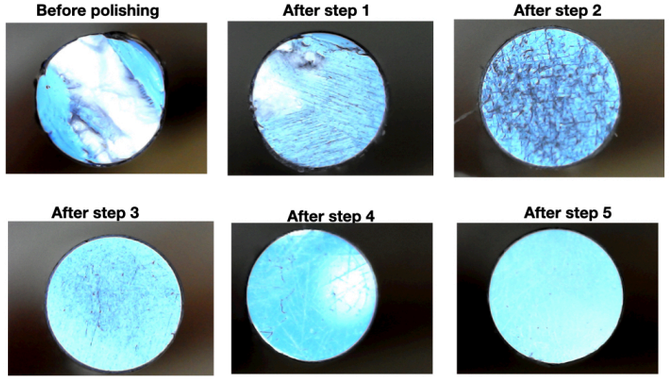



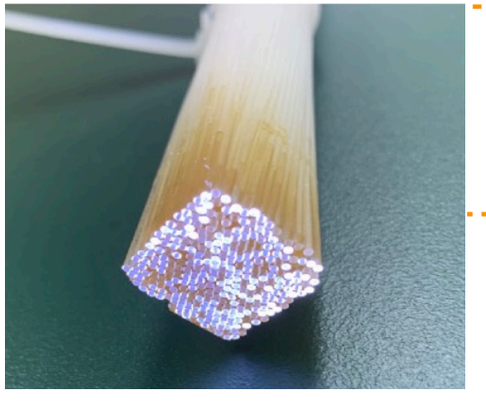
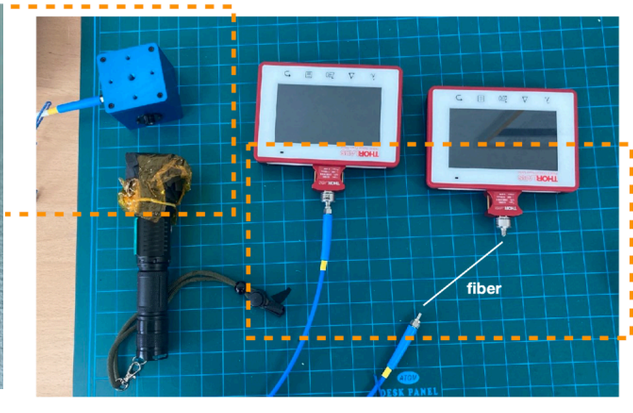




- Straightening, polishing, bundling, Inserting, light yield test etc.

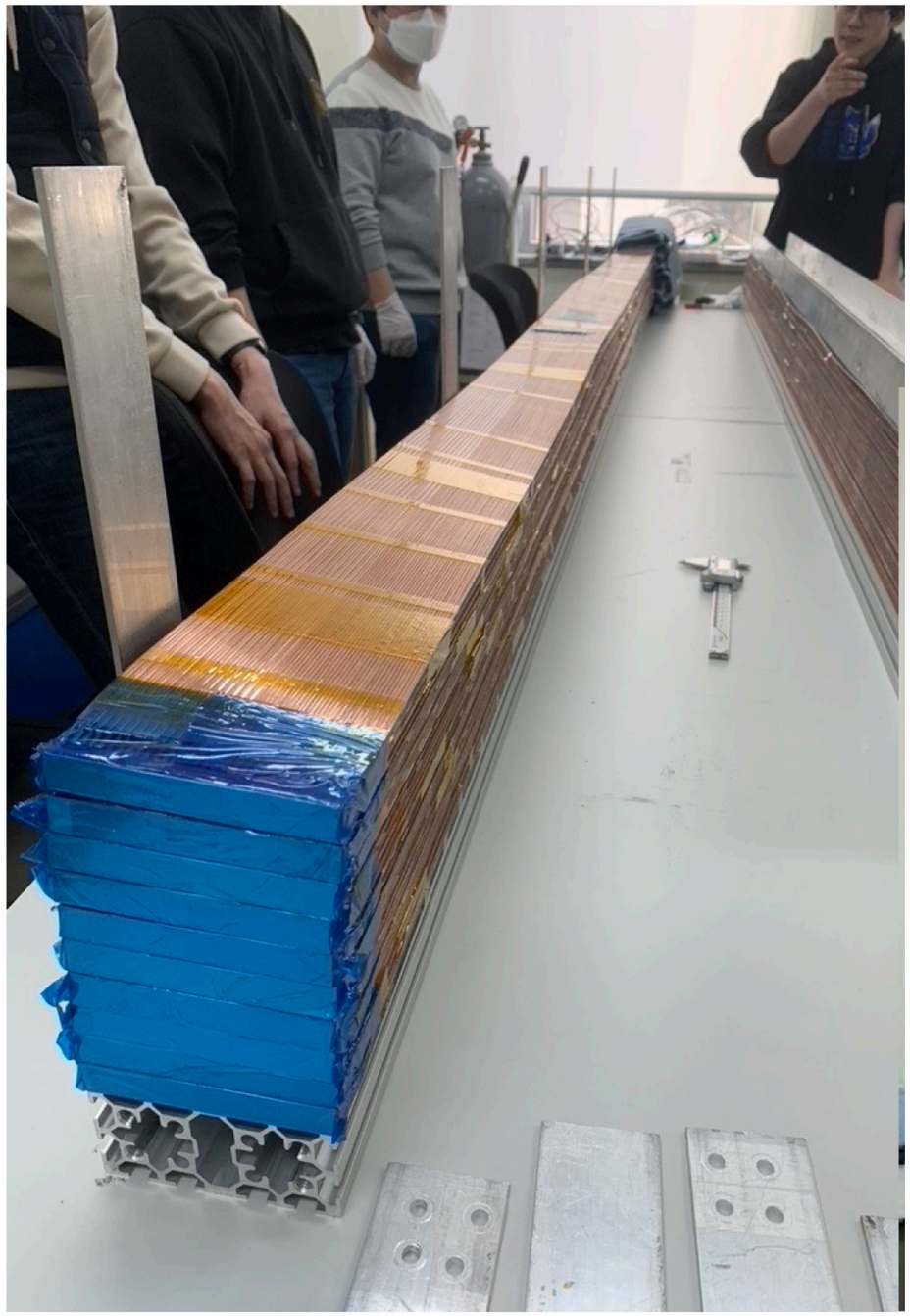


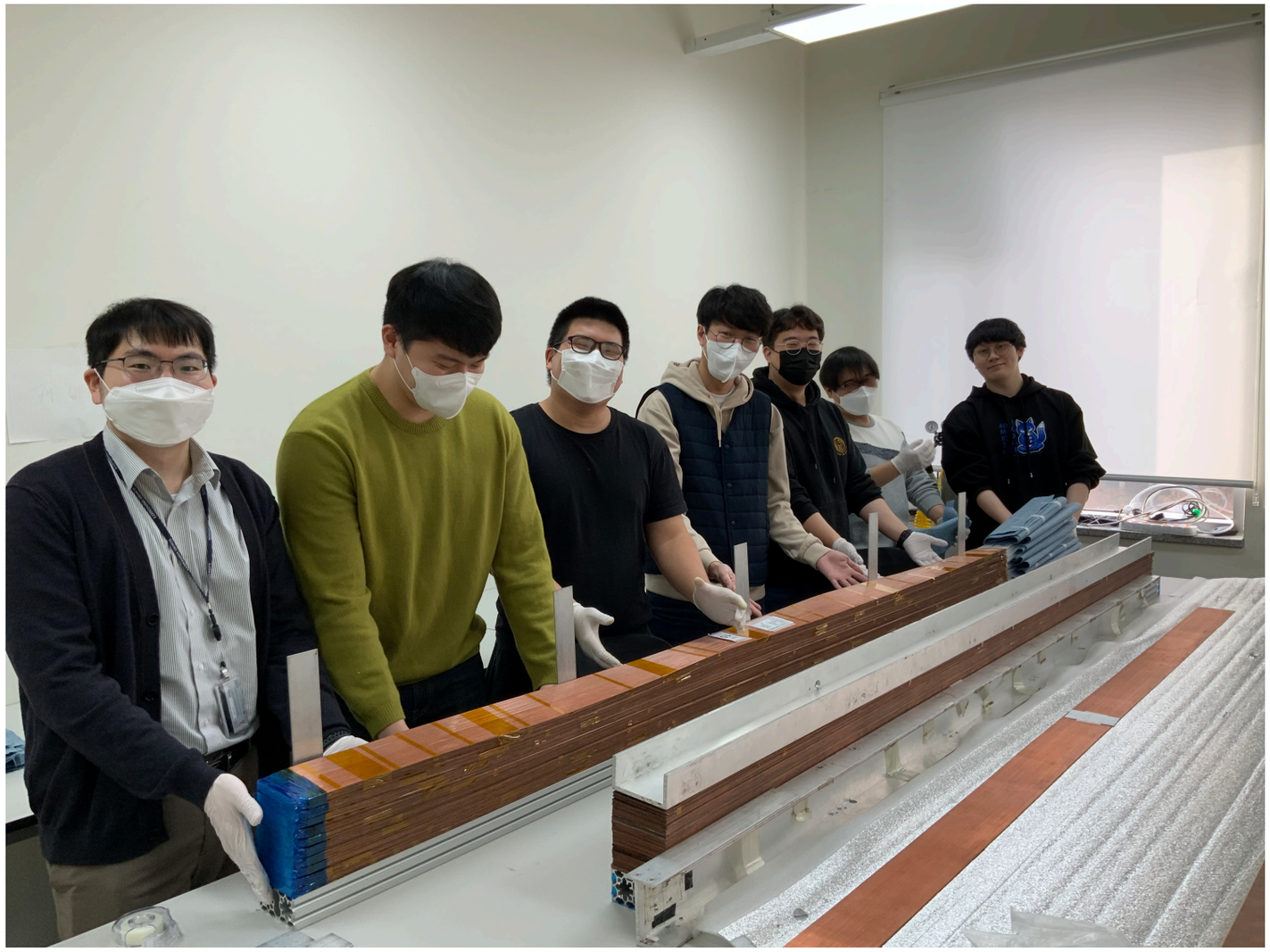


1st Module Assembly

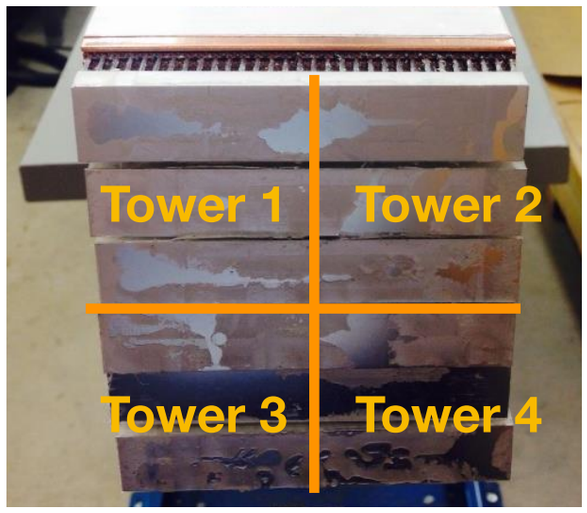
- We stacked copper plates which optical fibers were inserted for 1st module





Electronics R&D: Configuration

Module #1 (2x2)

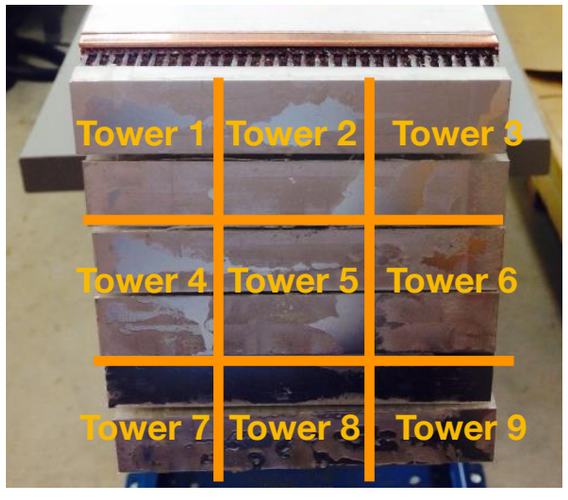


Tower#1	Tower#2
Tower#3	Tower#4

Combination of fibers for Module#1

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

Module #2 (3x3)



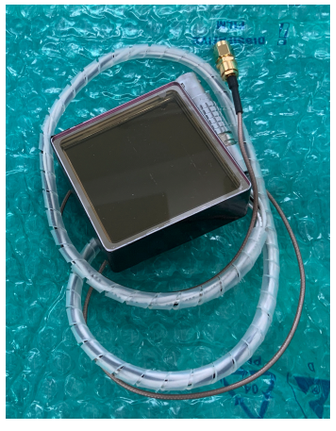
Tower#1	Tower#2	Tower#3
Tower#4	Tower#5	Tower#6
Tower#7	Tower#8	Tower#9

Combination of fibers for Module#2

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

Electronics R&D: Status

- 3 types of PMTs will be tested



The biggest number of pixels (16675) have been chosen
to avoid the saturation effect of photon counting for the scintillation lights.

SiPM	Photo-sensitive area	pixel size	Photo detection eff. (Silicone resin)		number of pixels	photo
S14160-1310PS	1.3x1.3 (1.69 mm²)	10 μm	~15% at 400 nm	~17% at 550 nm	16675	

MCP-PMT: excellent timing performance

MCP-PMT	Window size	Light / pour size	Q.E. (Bialkali)	max. HV (V)	Rise time (ns)	photo
PLANACON XP85012	53x53 mm²	scintillation / 25 um	~7% at 550 nm	2400	0.6	
PLANACON XP85112		Cerenkov / 10 um	~21% at 400 nm	2800	0.5	

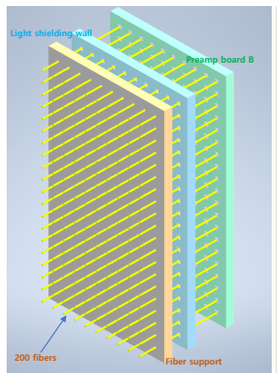
https://www.photonis.com/products/planacon

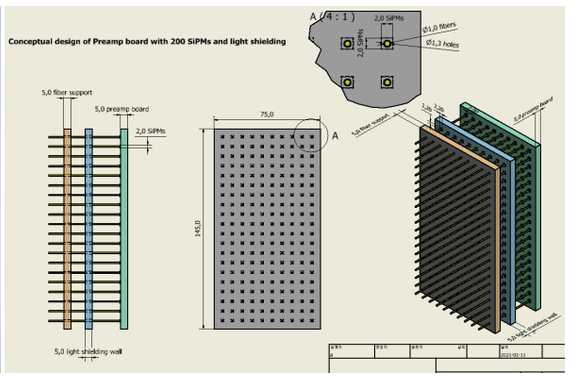
PMT: window size and timing performance

PMT	Window size	Q.E. (Super bialkali, SBA)		max. HV (V)	rise time (ns)	photo
		Ck.	Sc.			
R11265-100	23x23 mm²	~35% at 400 nm	~7% at 550 nm	1000	1.3	

https://www.hamamatsu.com

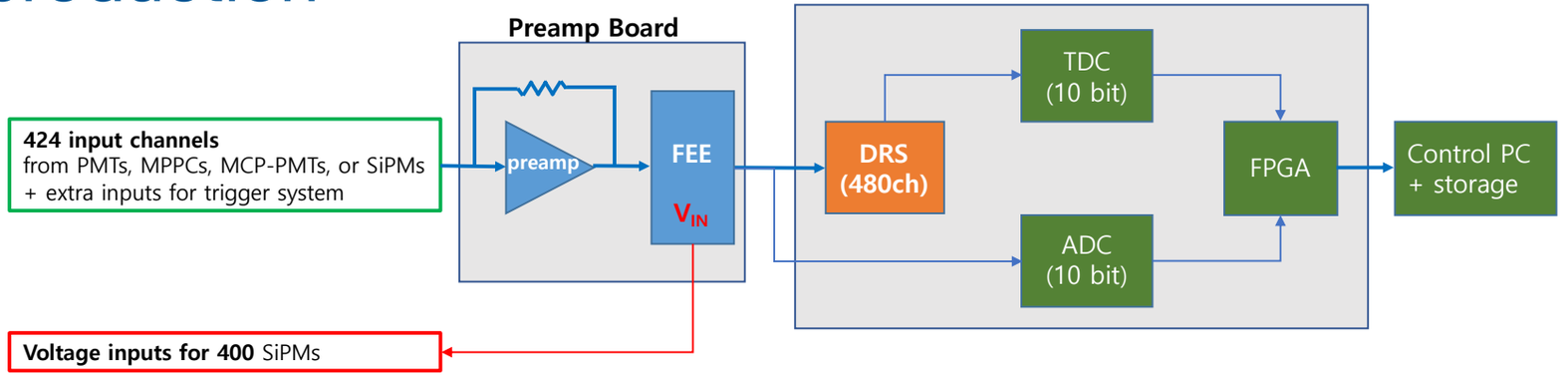
- Electronics are under production

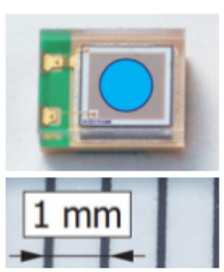


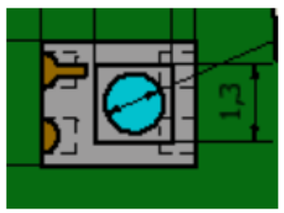


424 input channels
from PMTs, MPPCs, MCP-PMTs, or SiPMs
+ extra inputs for trigger system

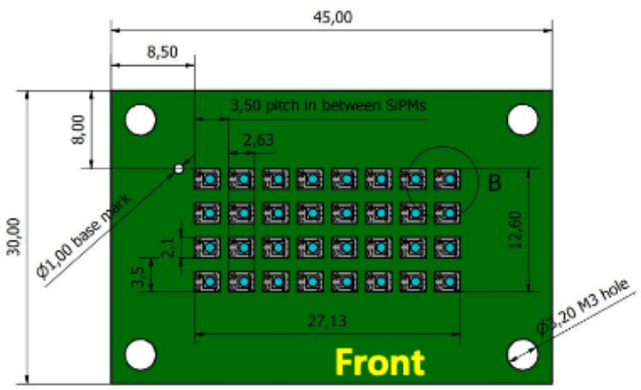
Voltage inputs for 400 SiPMs

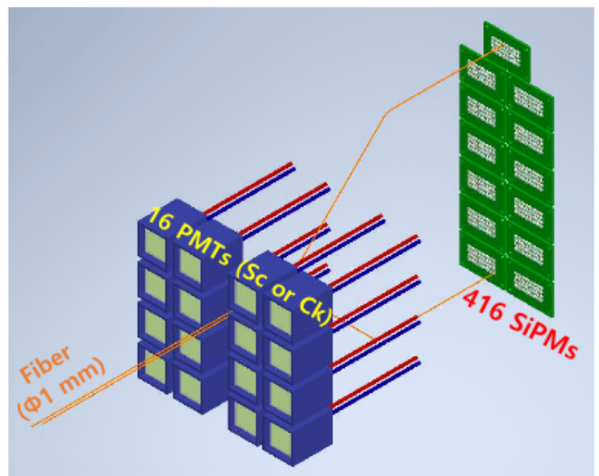




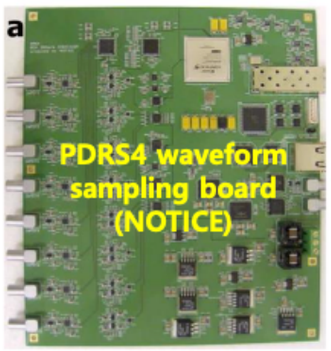


Single SiPM





Preamp board based on DRS4



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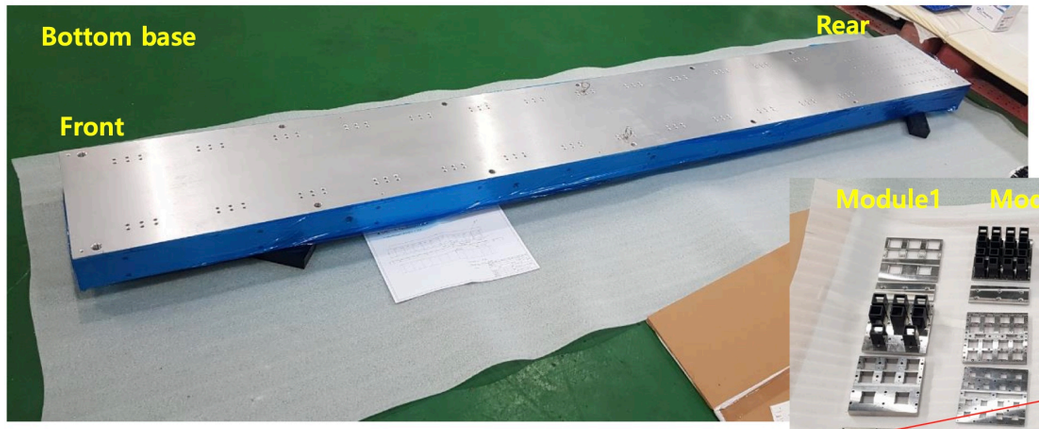
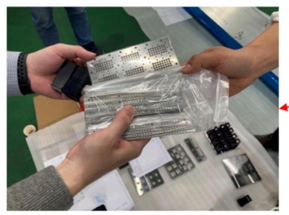
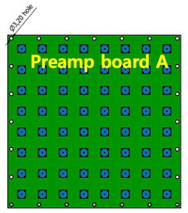
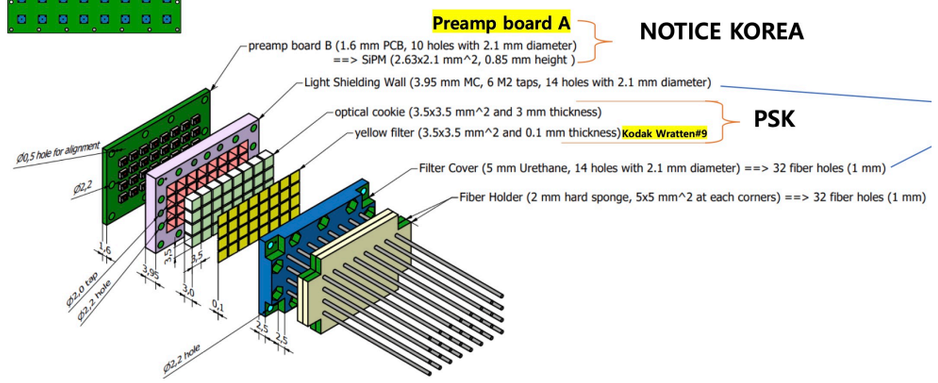
Supporter & Assembly Kit Design

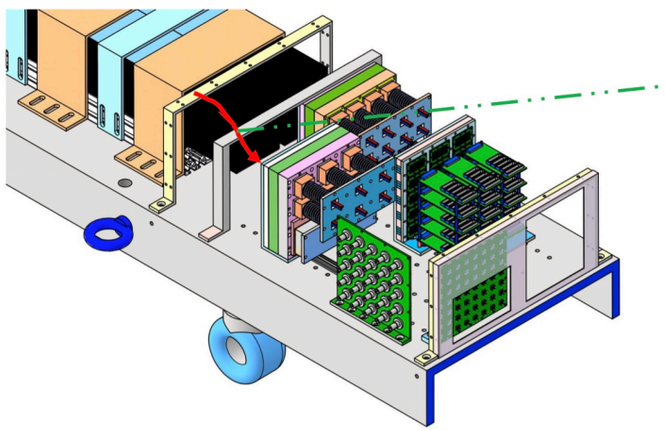


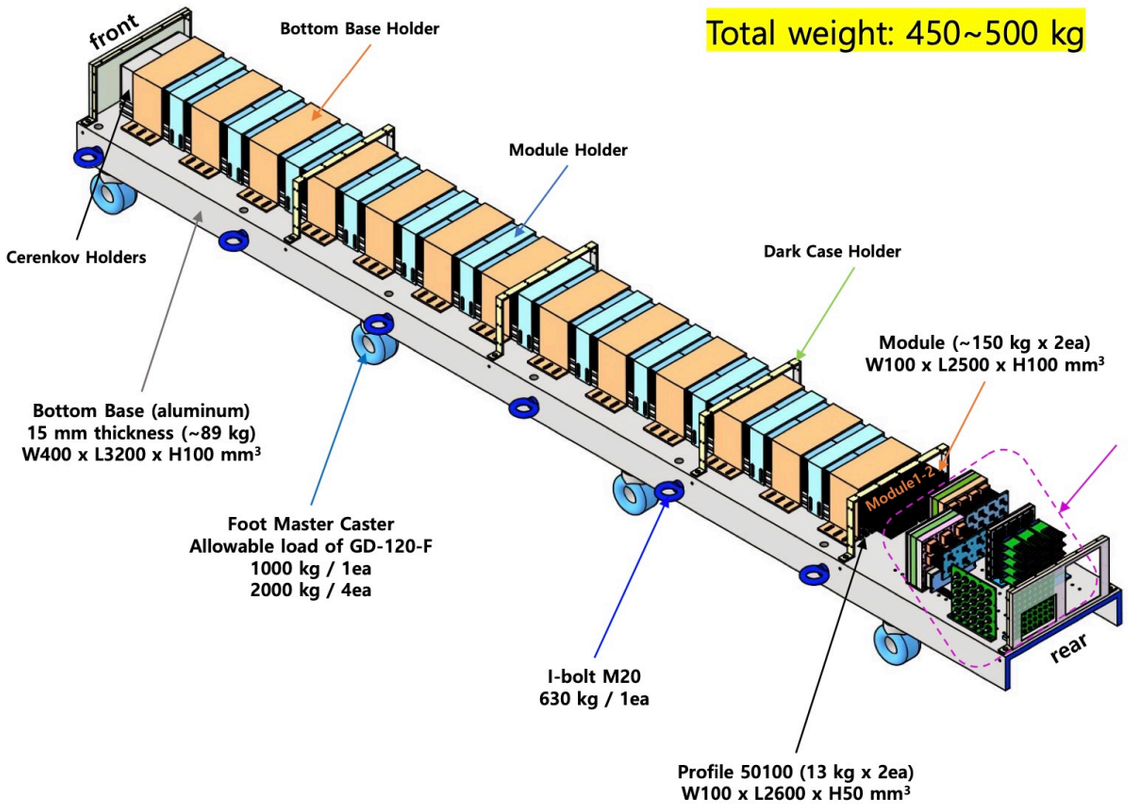


Dr. Ha brought some pieces. (11/19)
- Fiber Frames for SiPM
- Two Fiber Bundle Cases for each modules

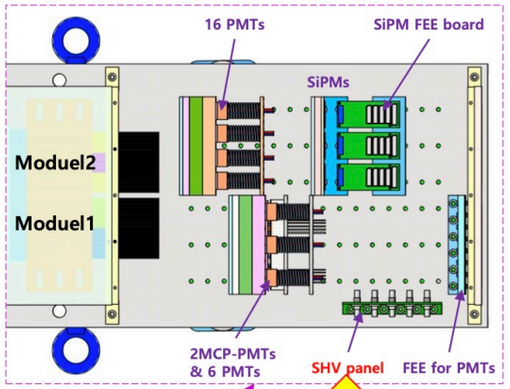








Total weight: 450~500 kg

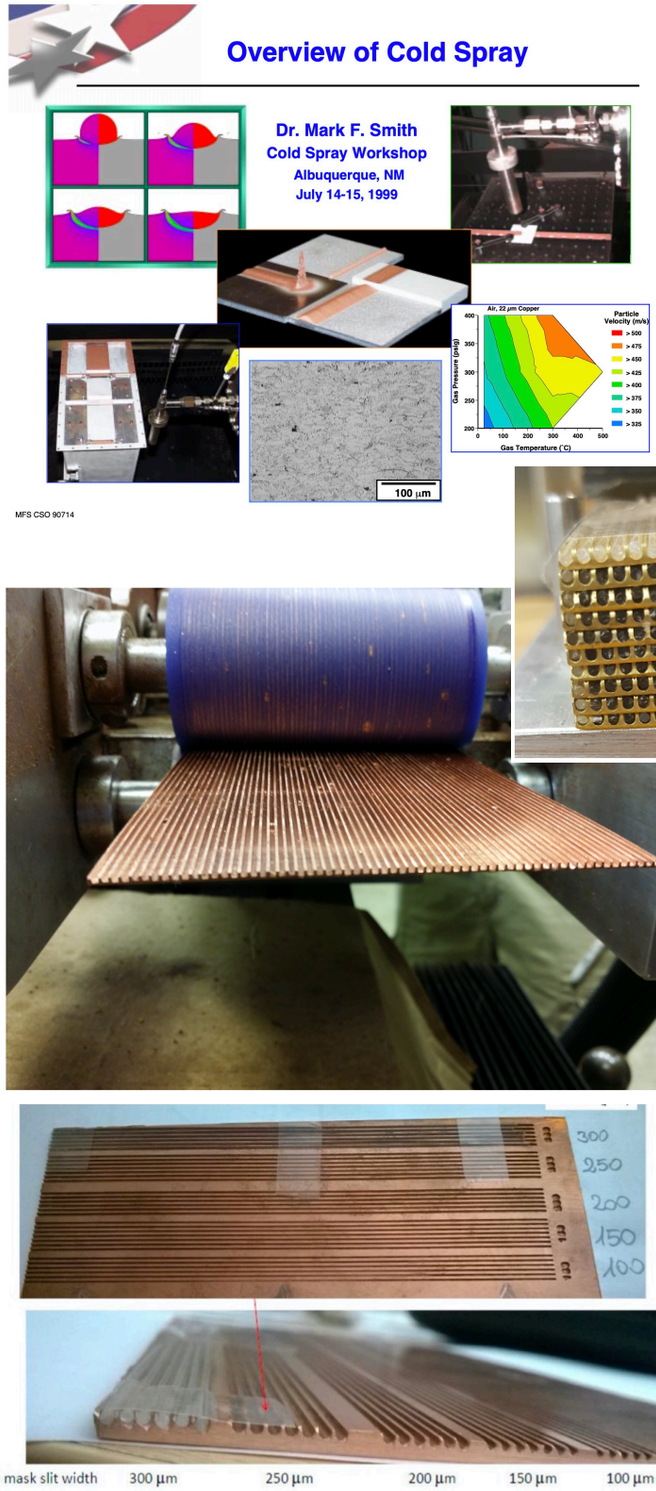


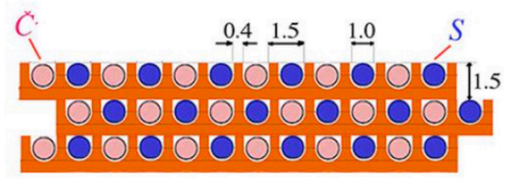
Frames of Readout System

Universal Multichannel Power Supply System
SY4527Full (600W) 8U, 16 slots
AG7435SN (300 W) 24ch, 3.5 kV, 3.5 mA (9W/ch)

2. Copper Forming

- We tried many options (by John Hauptman et al in CERN RD52)





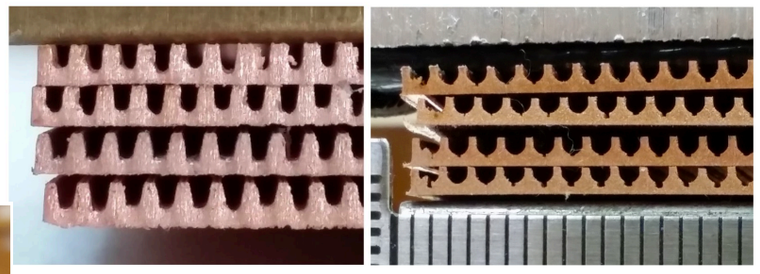
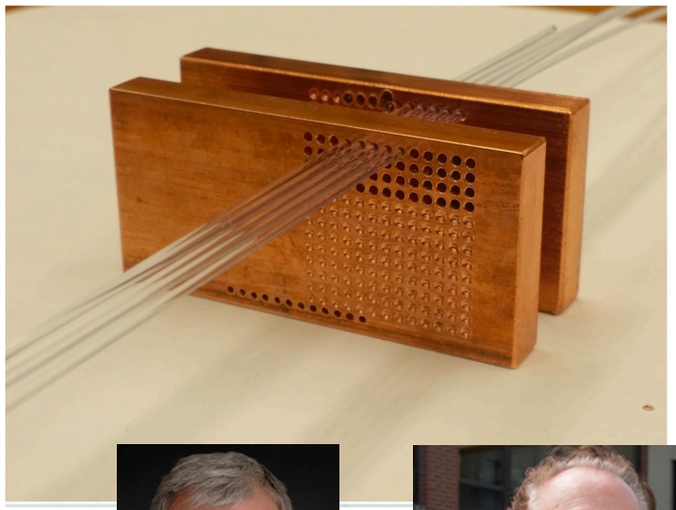
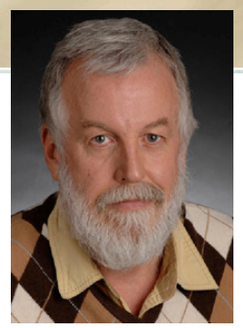


Figure 25: Water-jet grooved plates on the left (2.5 meters long) and the precision rolled corresponding grooves on the right.





R. Wigmans

J. Hauptman

RD52 Copper Forming (draft)

distribution

John Hauptman, Sehwook Lee, Fabrizio Scuri, Silvia Franchino,
Bobae Kim, Ryonghae Ye, Hyunsuk Jo, Richard Wigmans

15 March 2018

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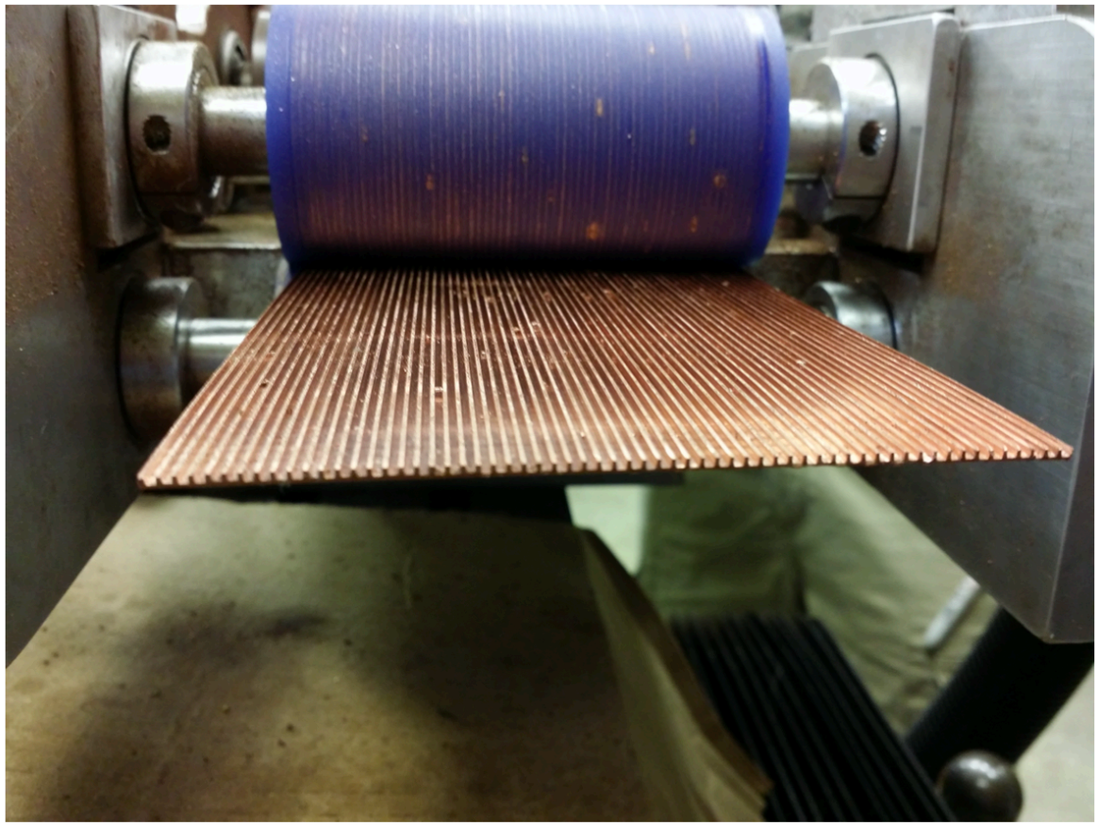
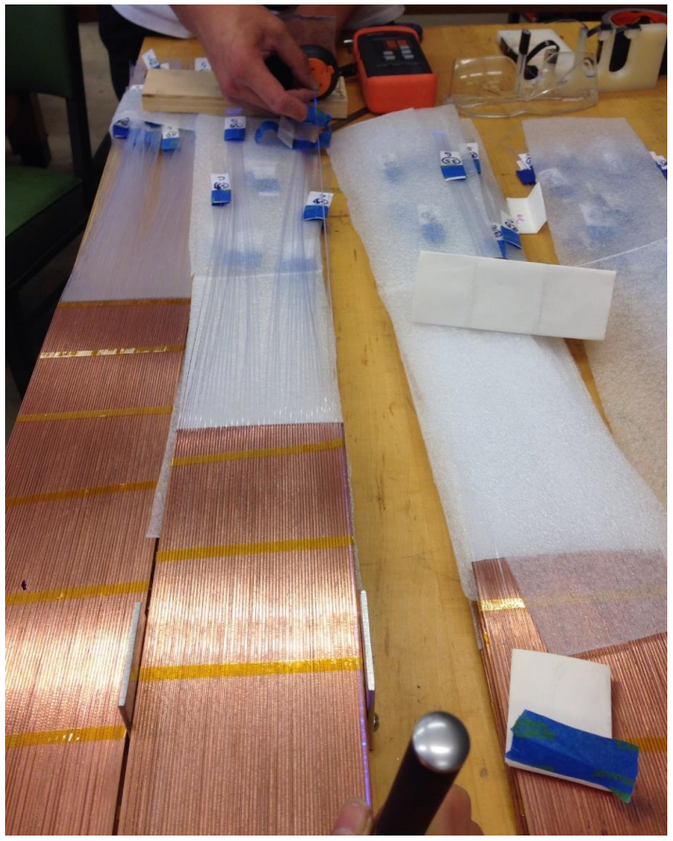
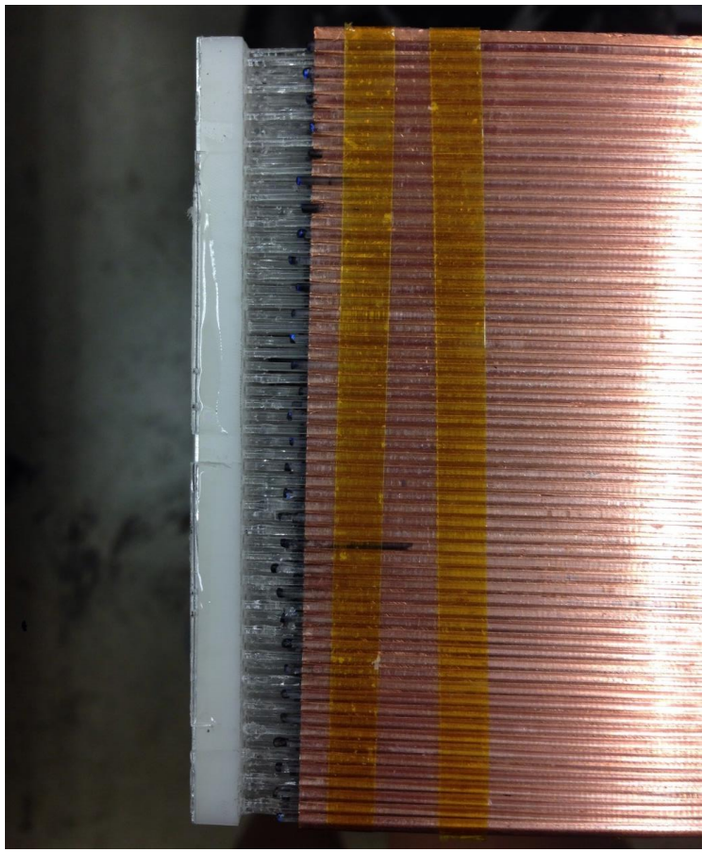
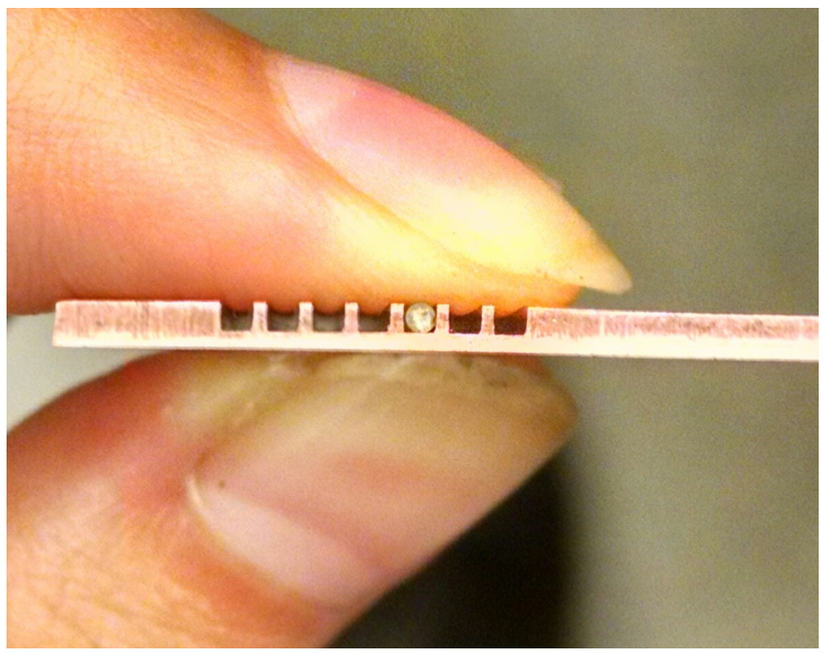
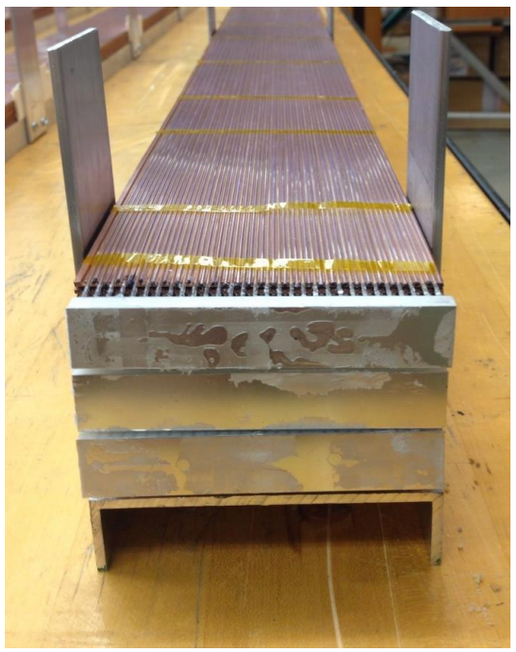
Cutting











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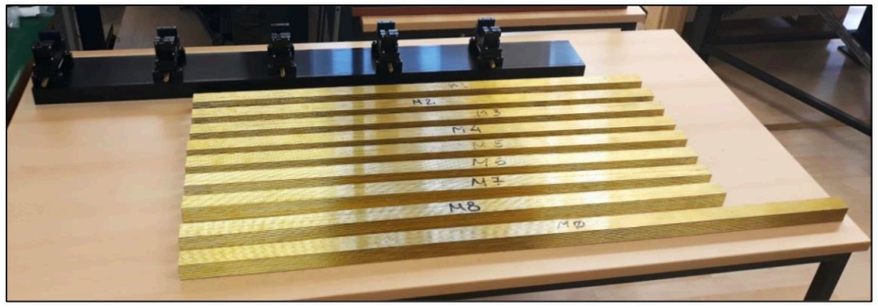
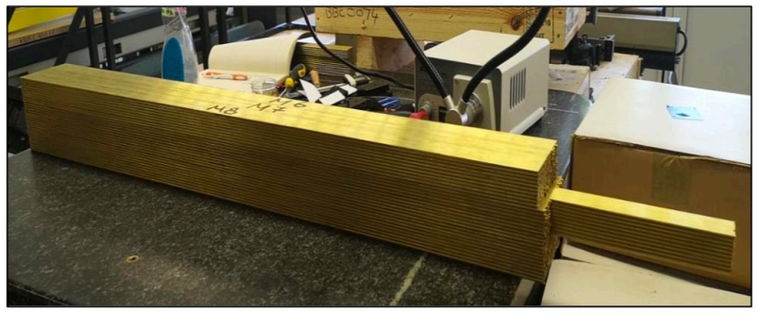
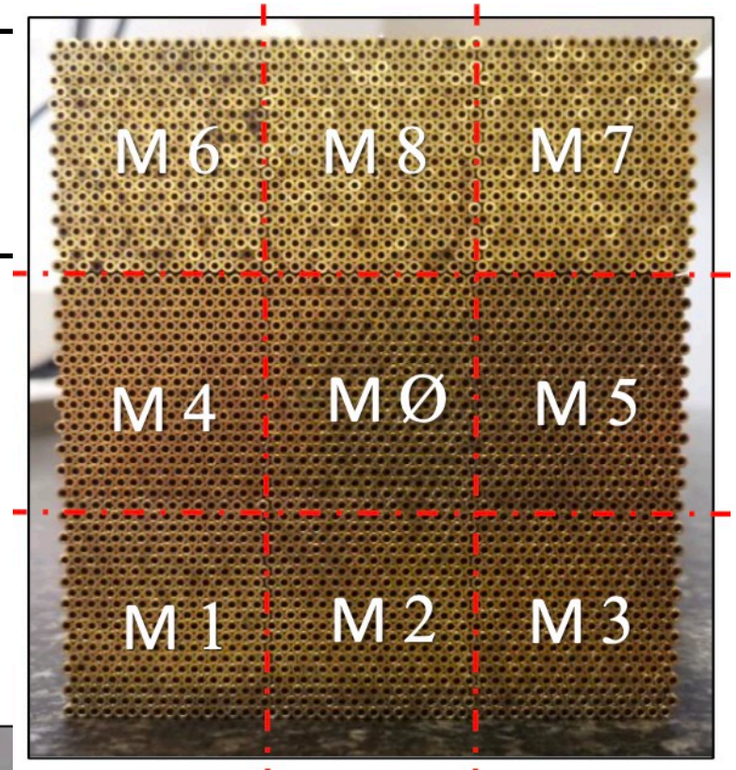
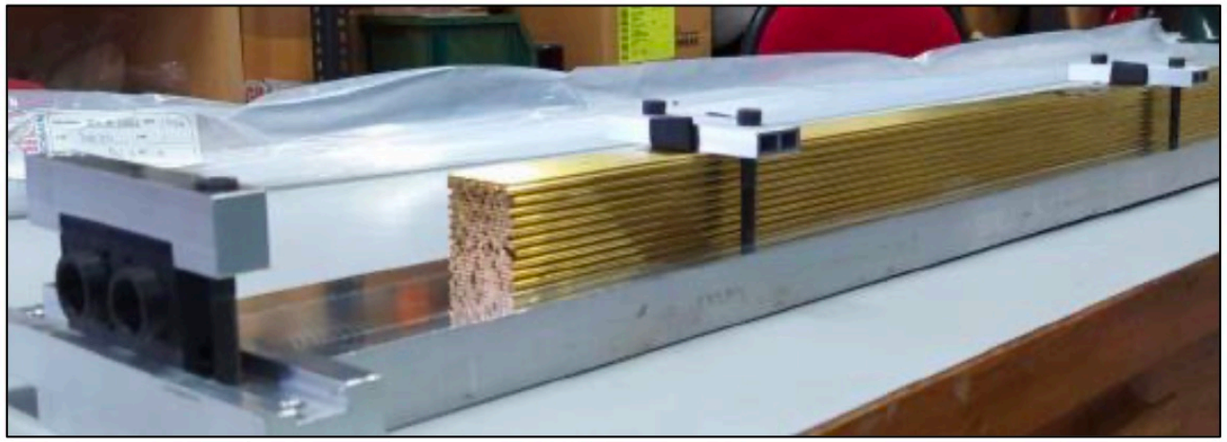
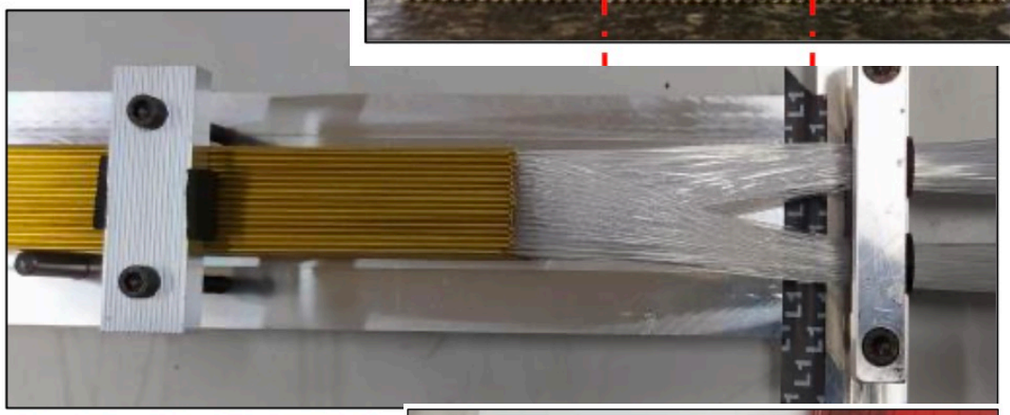
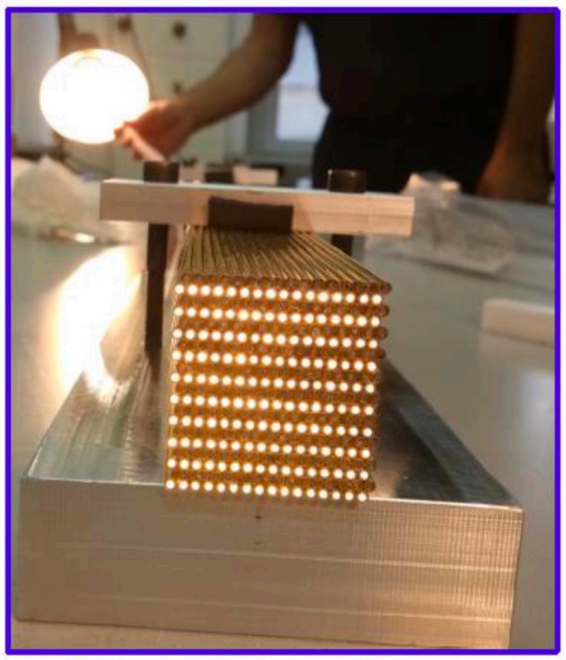




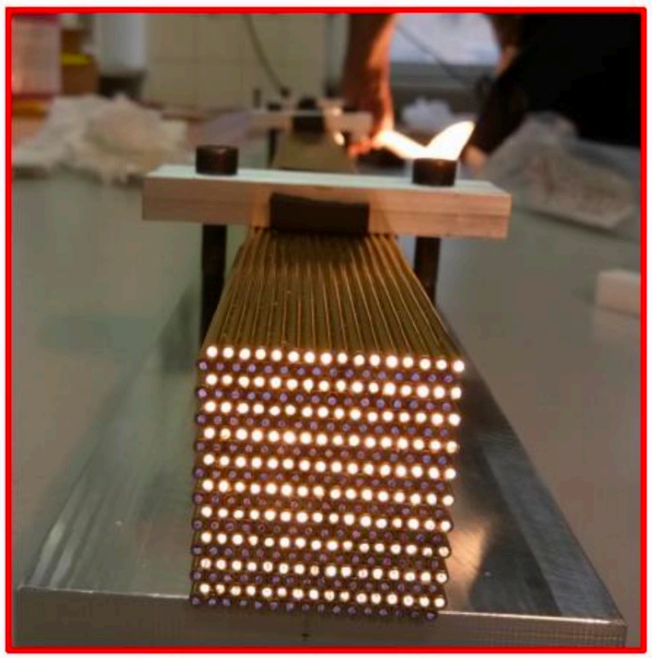




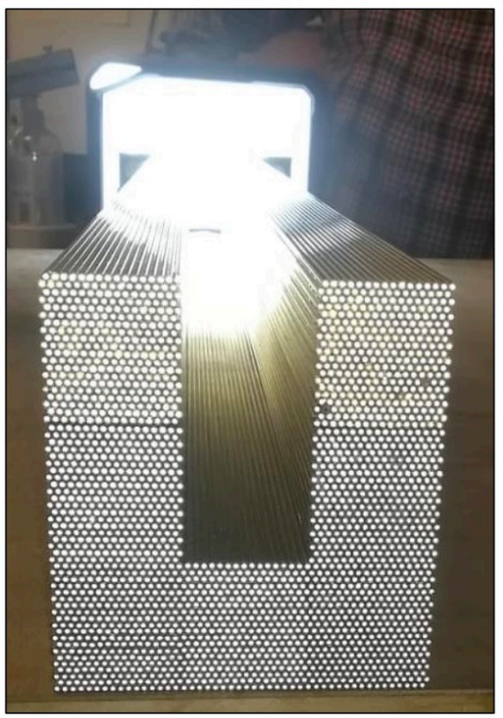


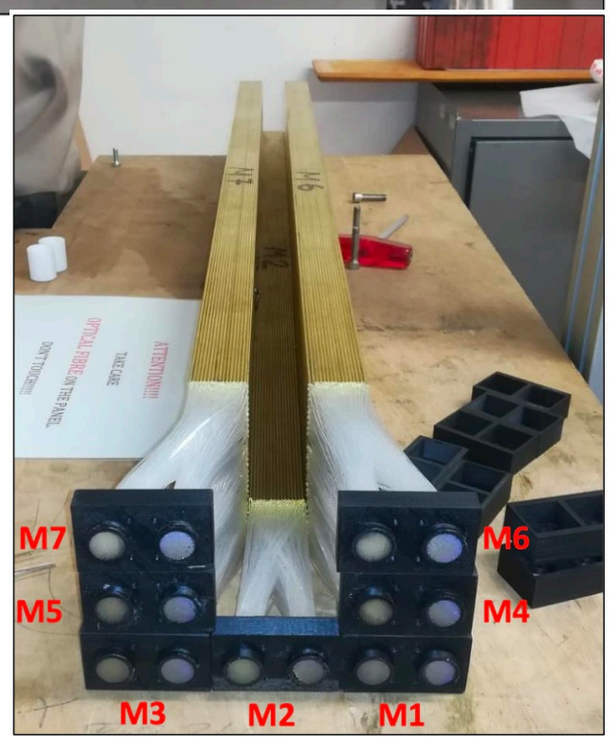


Scintillation fibers



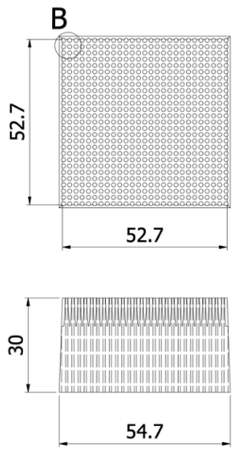
Cherenkov fibers

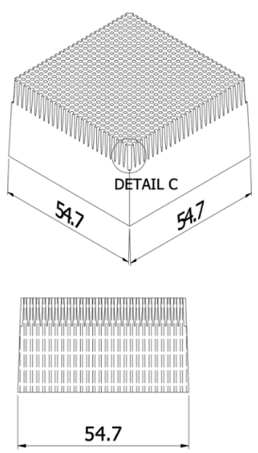


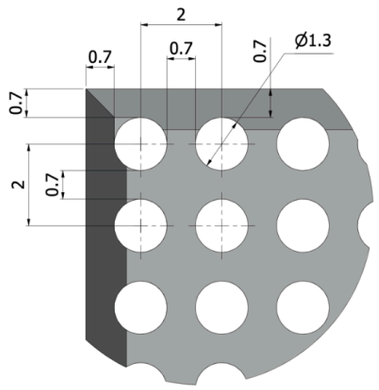


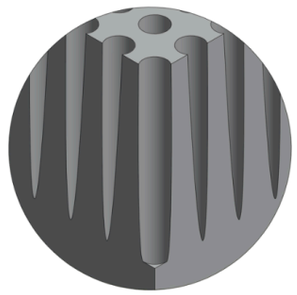
Cu Forming R&D in Korea

- Precise forming with innovative technology: 3D metal printer

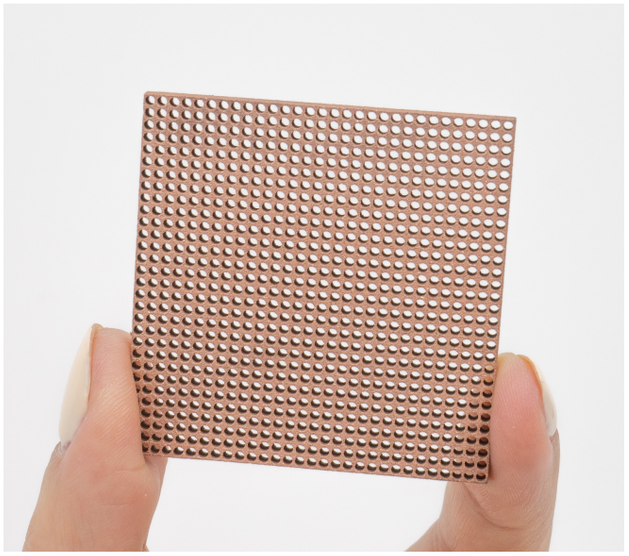








DETAIL C (10 : 1)



- Easy and cost-effective forming: Lego-like

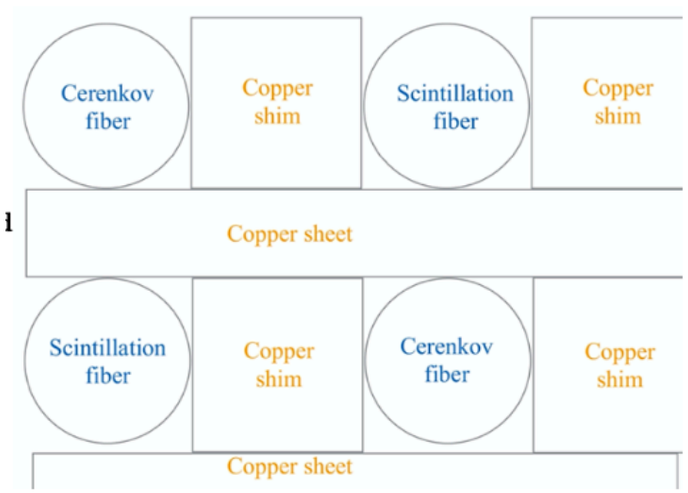


Figure 27: Direct stacking of copper shims and fibers. The shims bear the load.

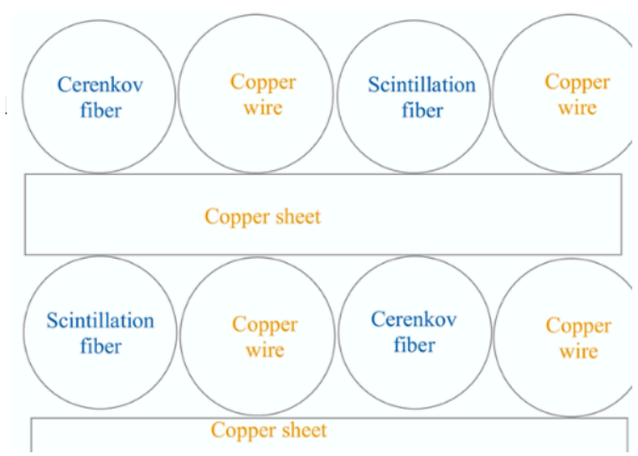
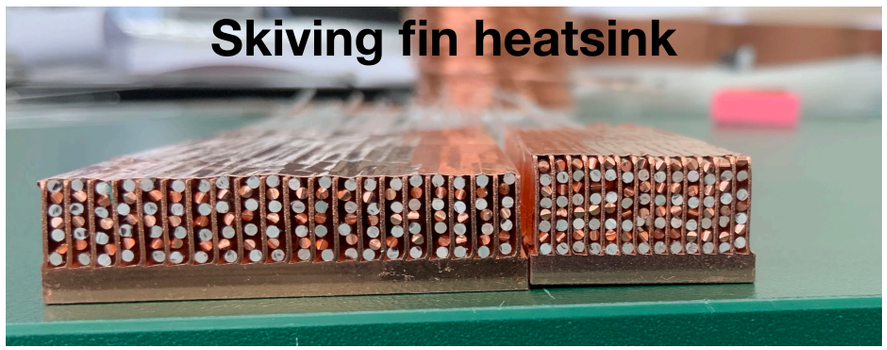
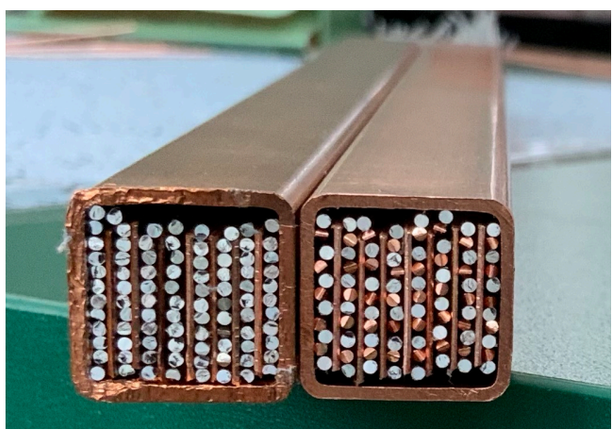


Figure 28: Direct stacking of copper wires (1.05mm diameter) and fibers on 0.5mm copper sheets. The slightly oversized copper wires carry the load.

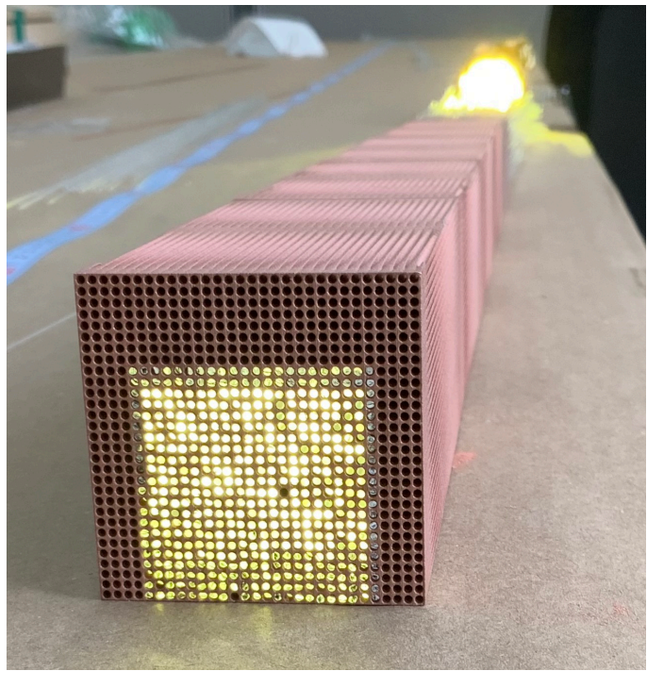


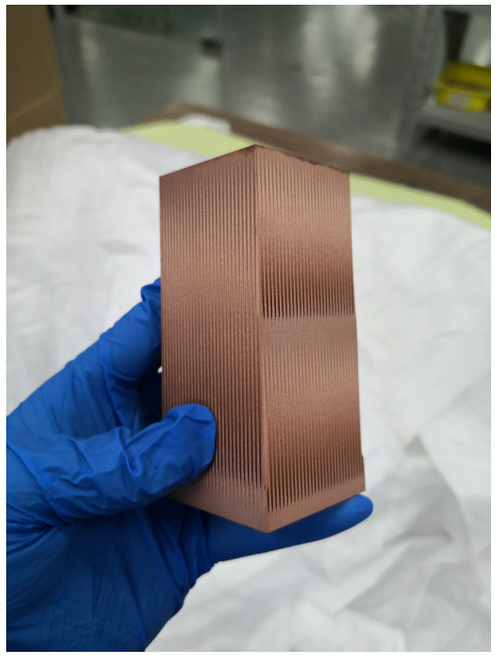


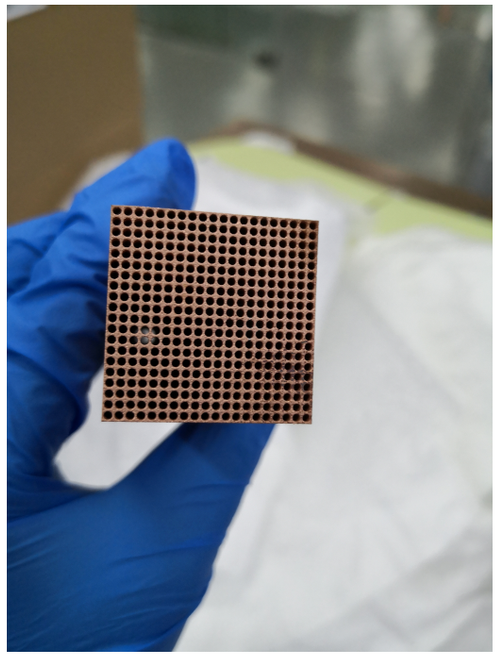
3D Metal Printing

with Harvestance
We will be your left hand

- 1st projective DRC module!

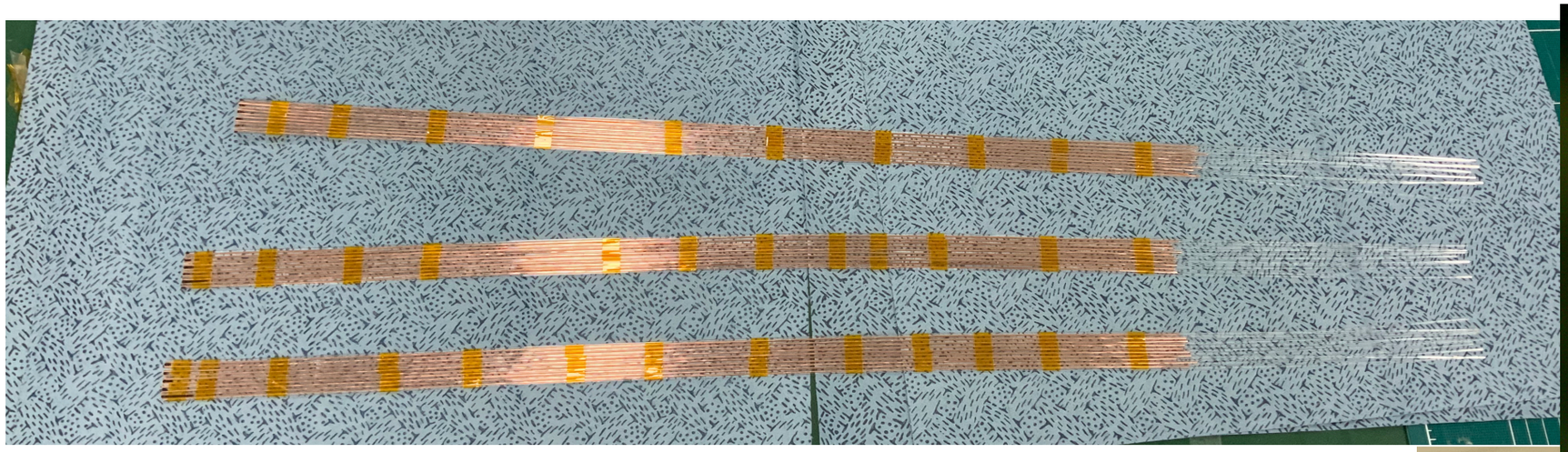


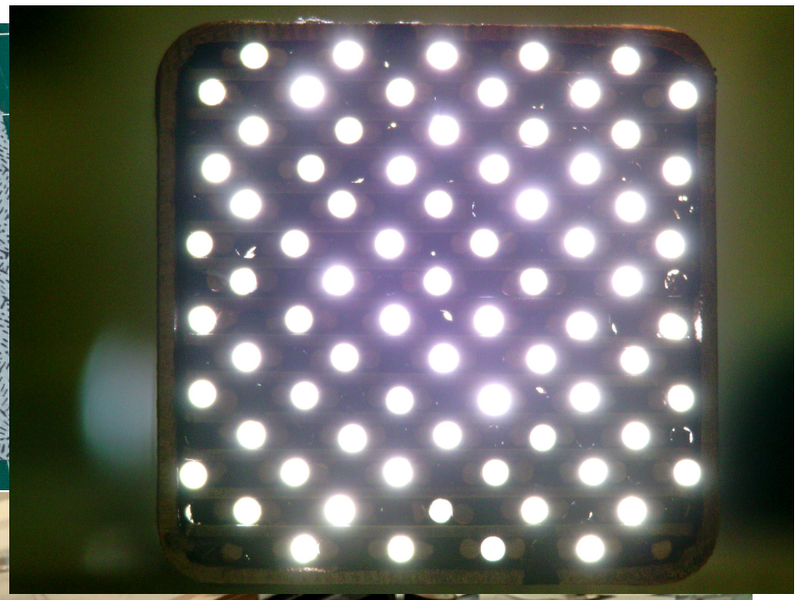


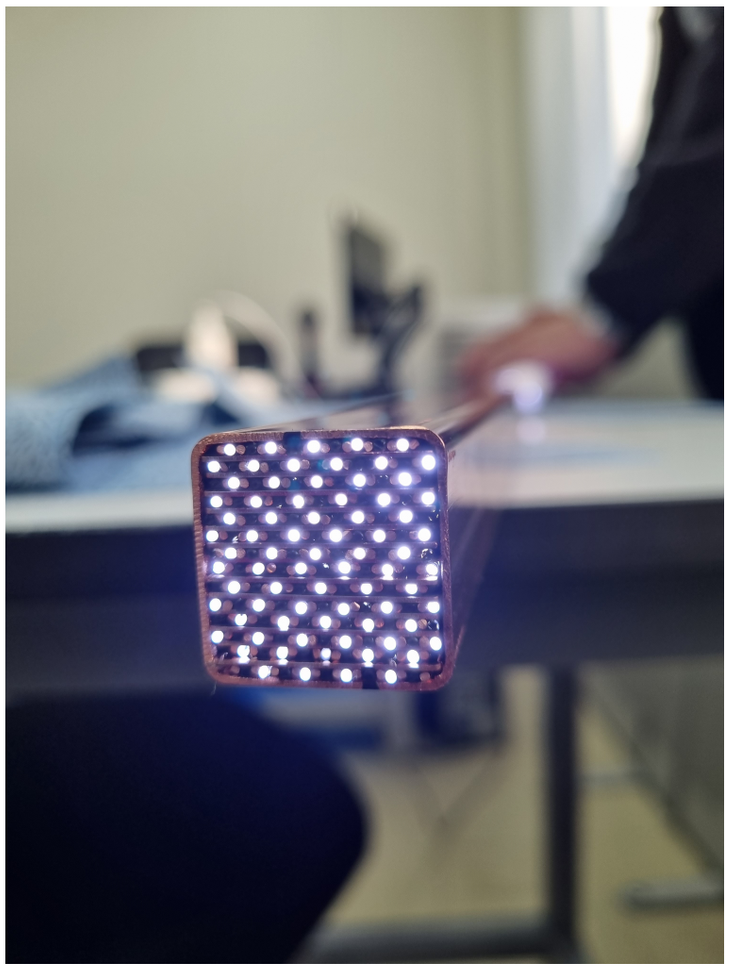


INSIDE 3D PRINTING SEOUL
CONFERENCE & EXPO

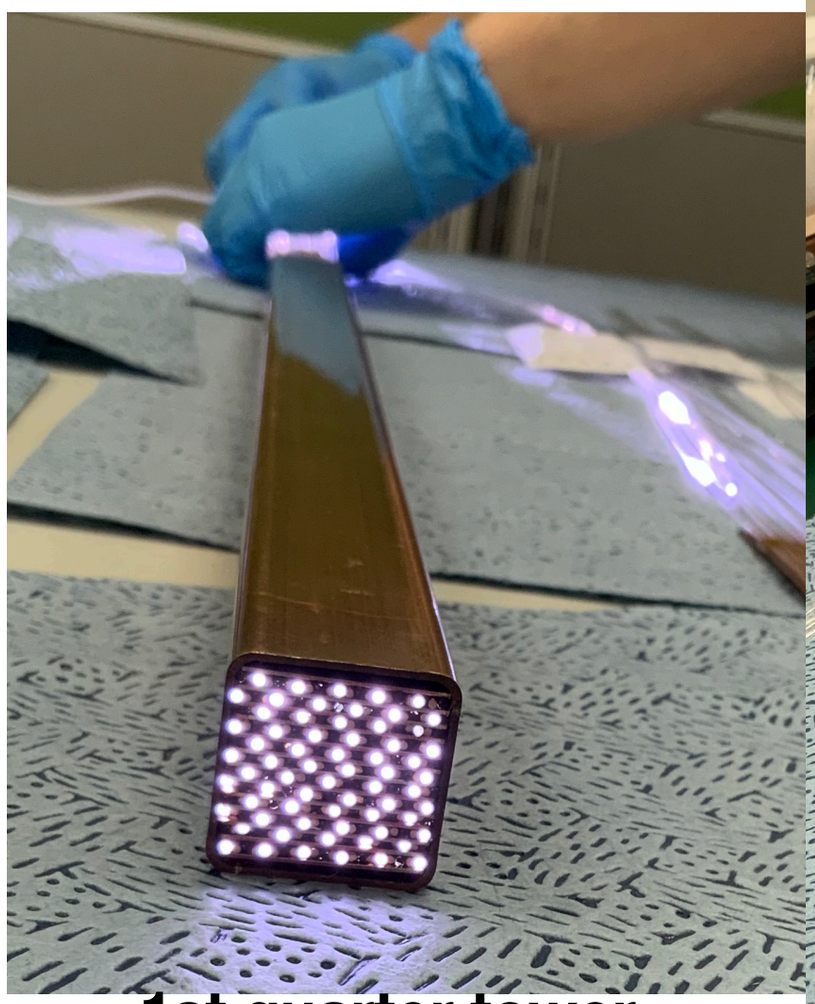
LEGO-like: Quarter Tower



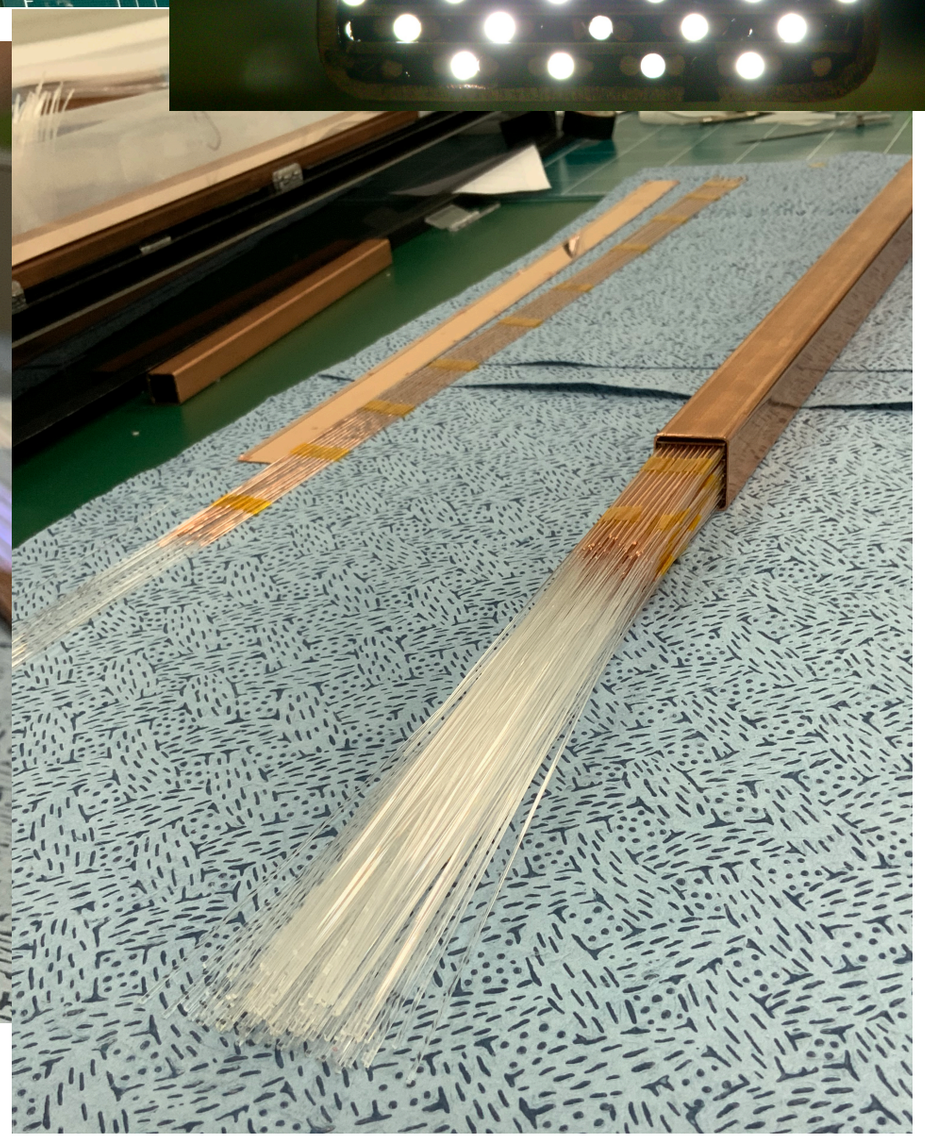




2nd quarter tower



1st quarter tower



Toward Detector Construction

- For TDR, need to demonstrate feasibility of detector construction in engineering aspects

	Cost	Forming	Assembly	Accuracy
		Production rate		**Performance**
Cutting	Moderate	Difficult	Difficult	Fair
Bucatini	Low	Moderate	Easy	Excellent
3D printing	Ultra high	Easiest	Easiest	Perfect
LEGO-like	Very low	Easy	Easy	Good

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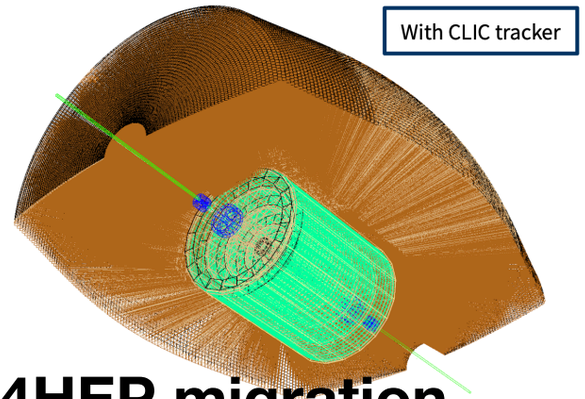
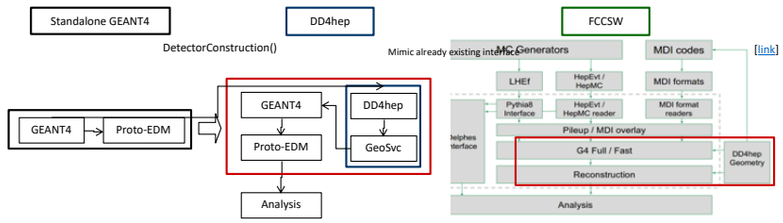
3. Software Development

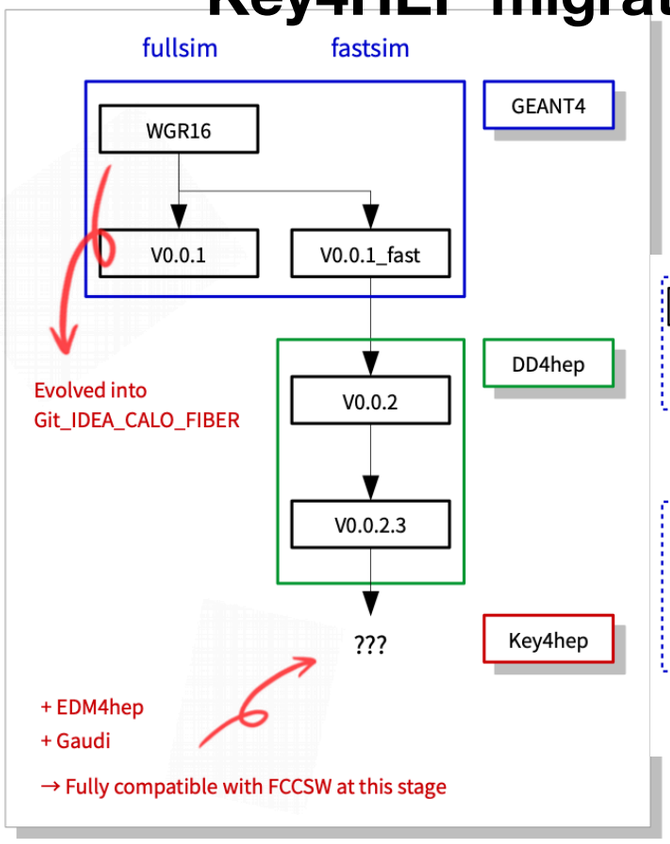
- Many SW development are on-going!
  - Migration to DD4HEP framework
  - Faster simulation: developing optical photon transport in GEANT4 => O(100) times faster
  - Migration to Key4HEP framework
    - Add digitization, reconstruction, calibration, etc.



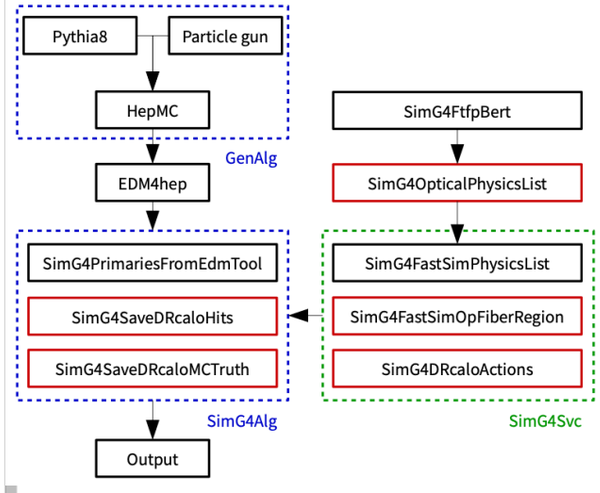
DD4HEP migration



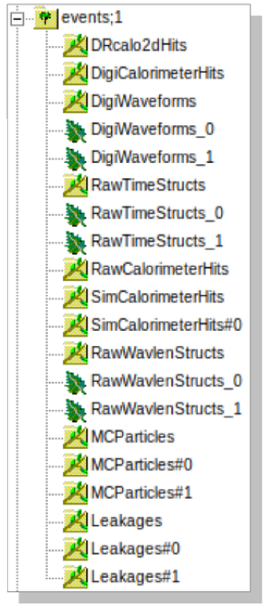
Key4HEP migration



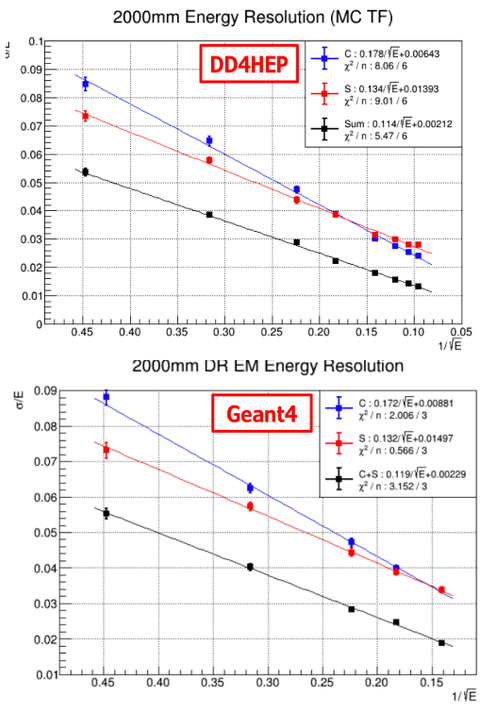
Simulation flow

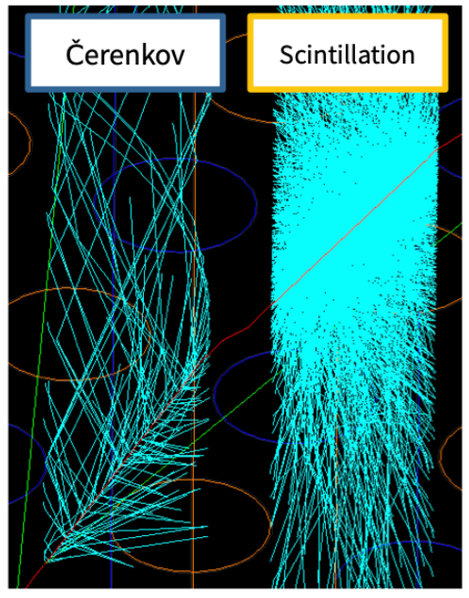


EDM4hep



Faster simulation





Important for a longitudinally unsegmented calorimeter

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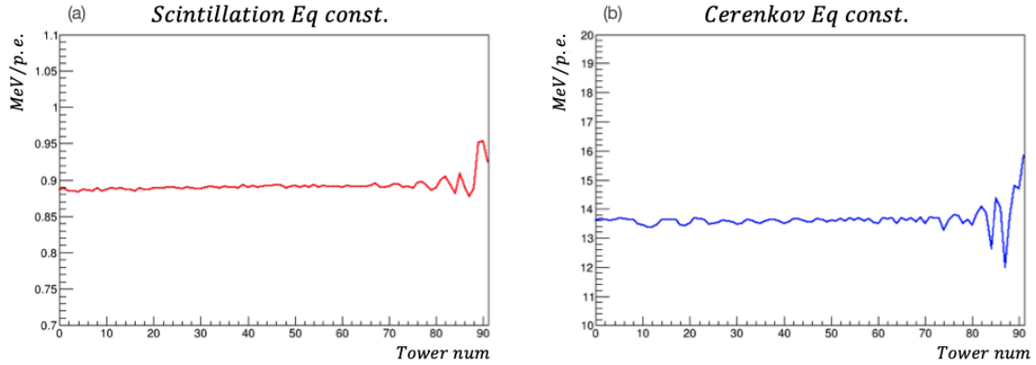
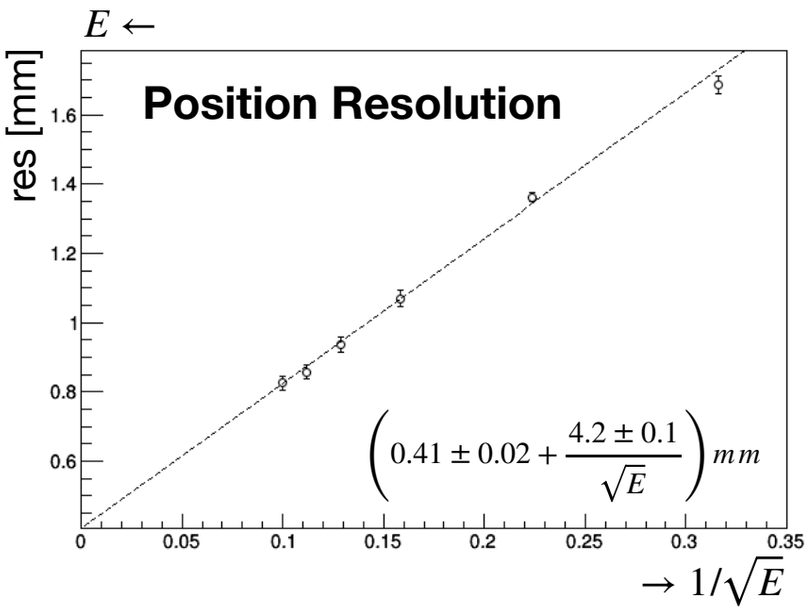
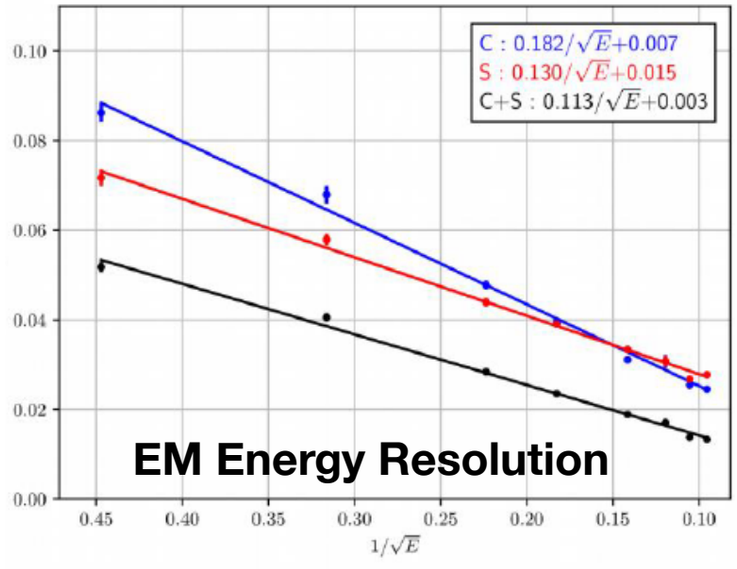
Simulation Studies

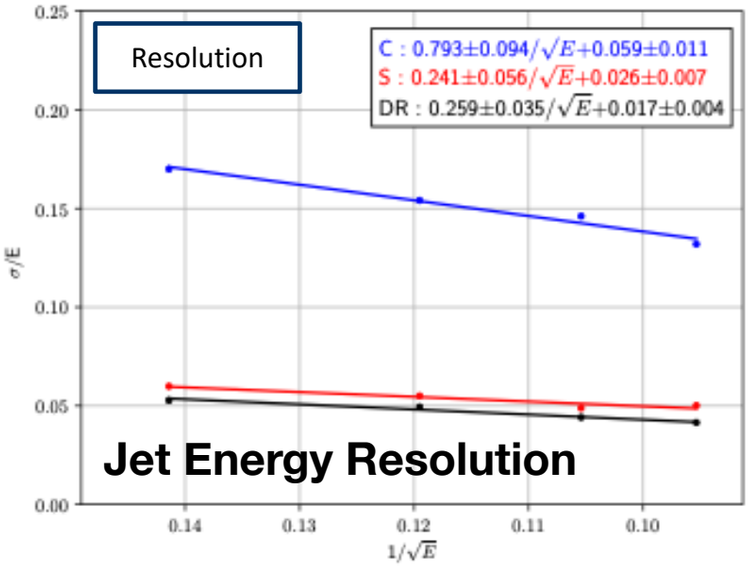
- Many simulation studies are on-going
  - First full GEANT4 based simulation performance
  - Using various benchmark physics process (W, Z, Higgs)

Calibration Constant

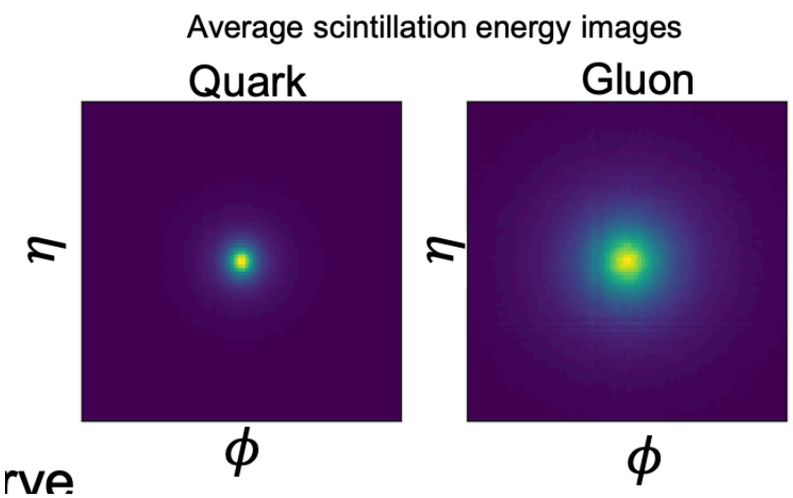


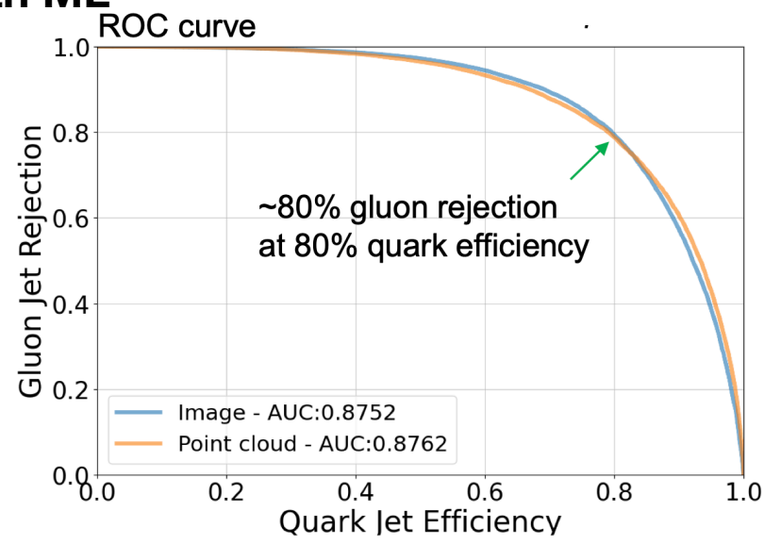




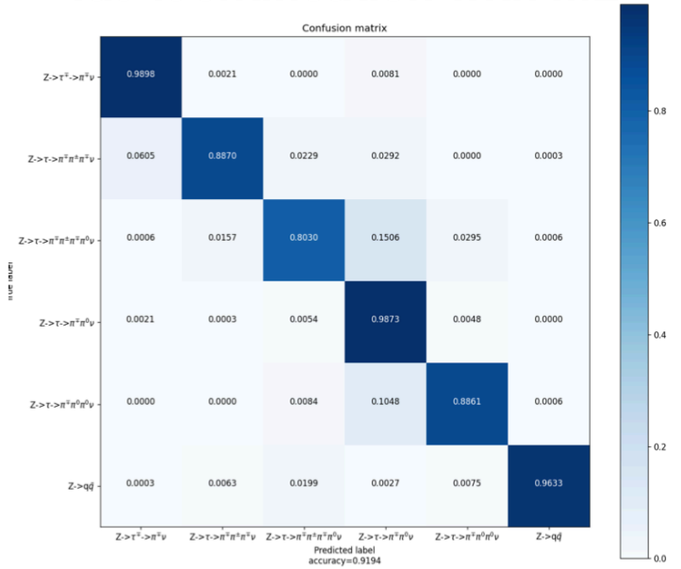


Jet identification with ML





Tau identification with ML



3D Shower Profile

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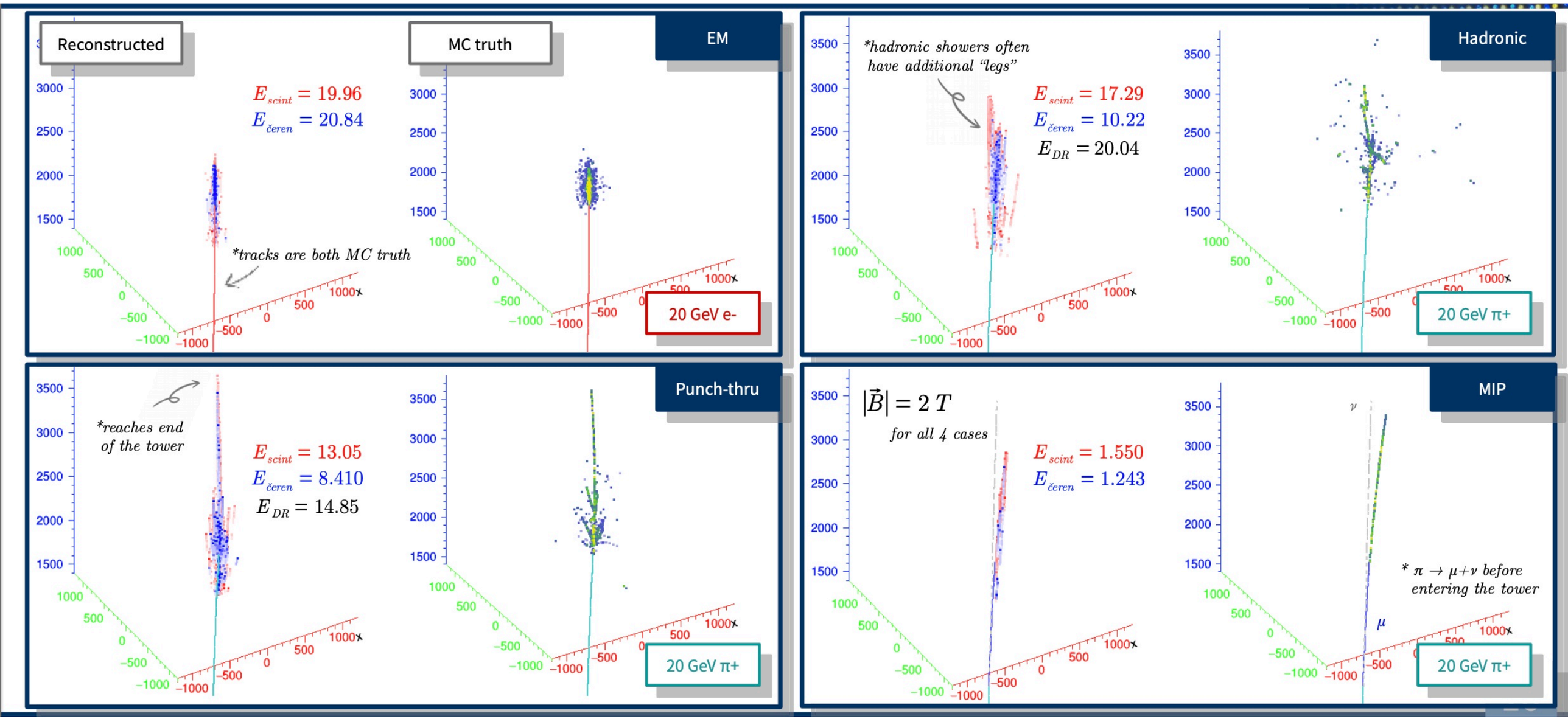
- Develop novel ideas to exploit timing for longitudinal & 3D reconstruction



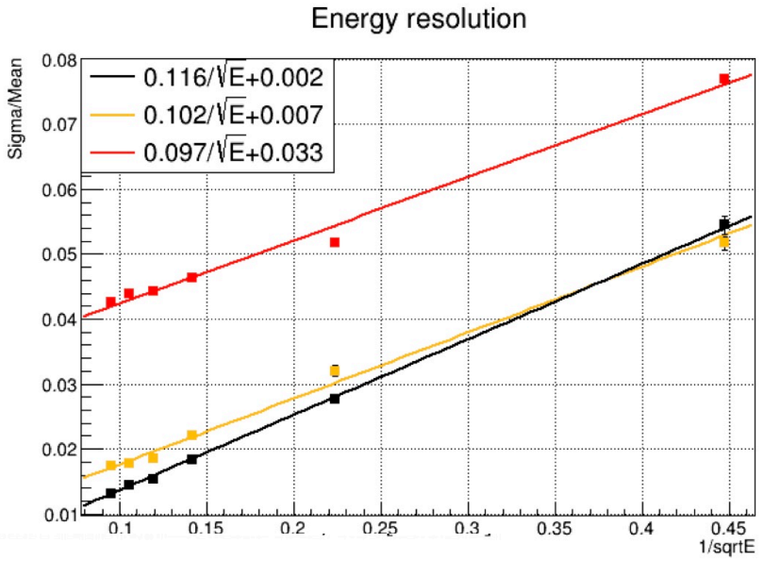
Bonus: Forward Detector for EIC

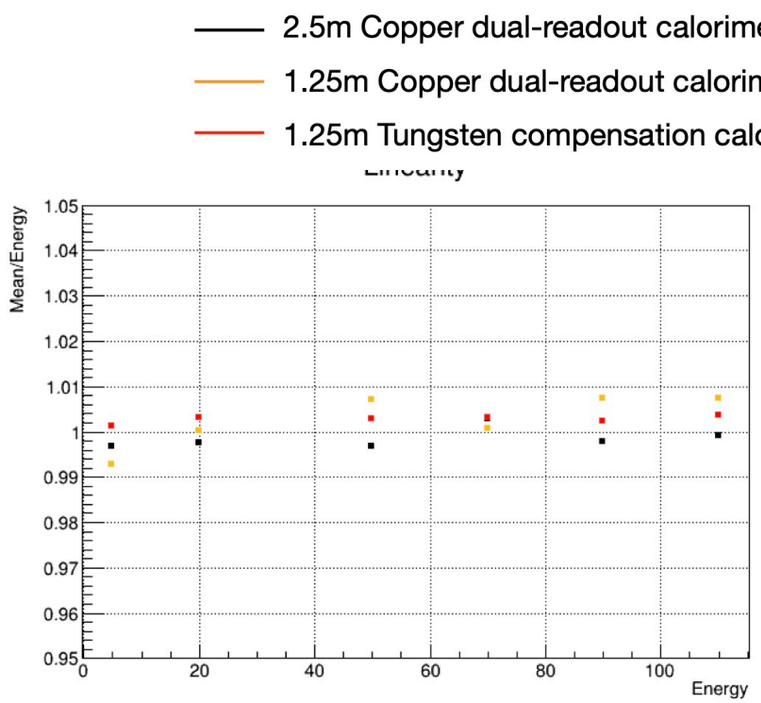
- Initial design and feasibility study for ECCE is on-going

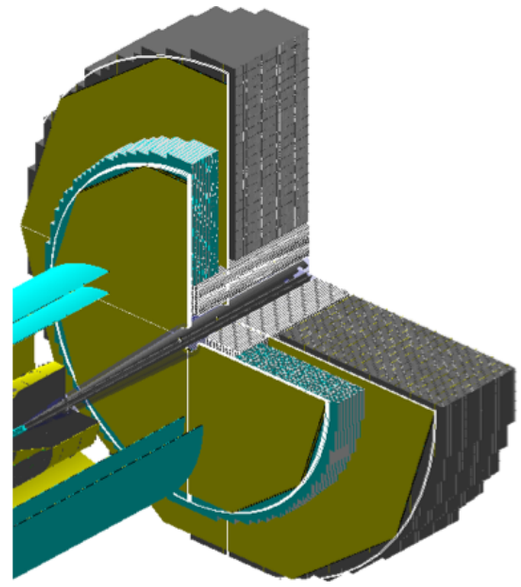
Collaboration with nuclear physicists in Korea

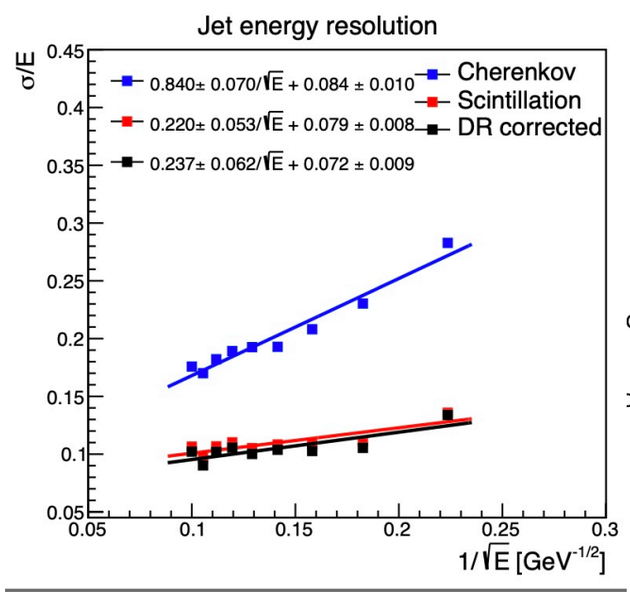
  - DRC pre-design is implemented in Fun4All framework

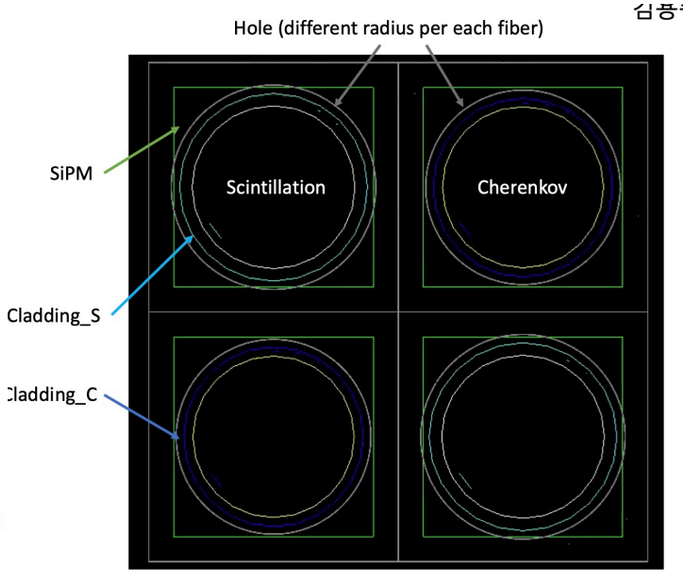
  - Absorber type: Cu vs. W

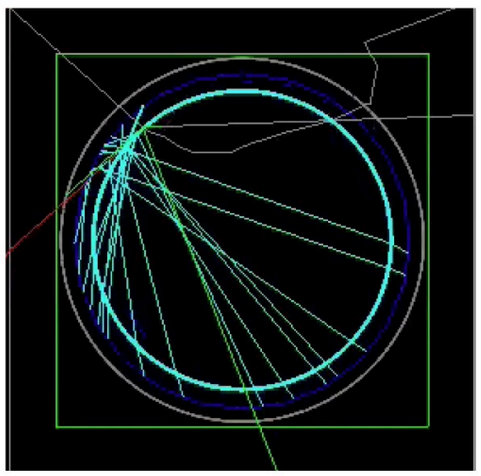


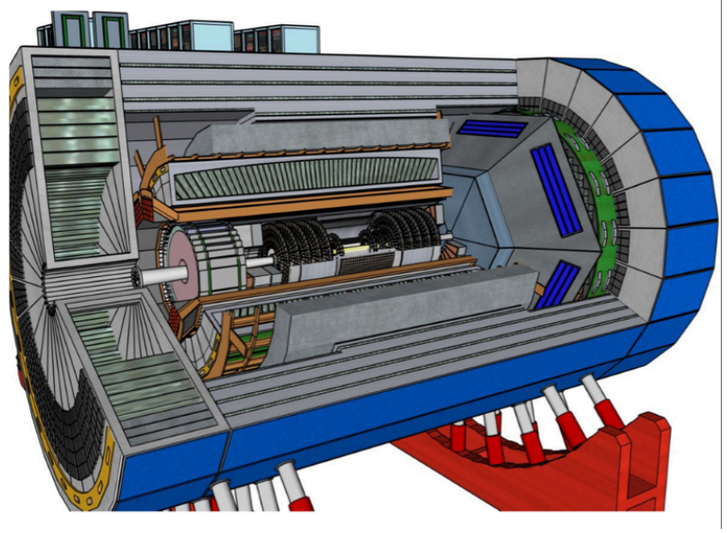












Summary

- Dual-Readout Calorimeter R&D project for future colliders in Korea is very active
  - Build and test full size prototype DRC detector by 2025
  - Collaborate with EU and US teams
- Both HW and SW R&D with all aspects are going well
  - Build two modules with various R&D goals
  - Design new electronics readout system and assembly kit
  - Perform copper forming R&D with 3D metal printing and mechanical stacking methods
  - Develop new SW framework to migrate DD4HEP and Key4HEP with fast GEANT4 simulation
  - Study GEANT4 simulation and wide particle identification with ML technique