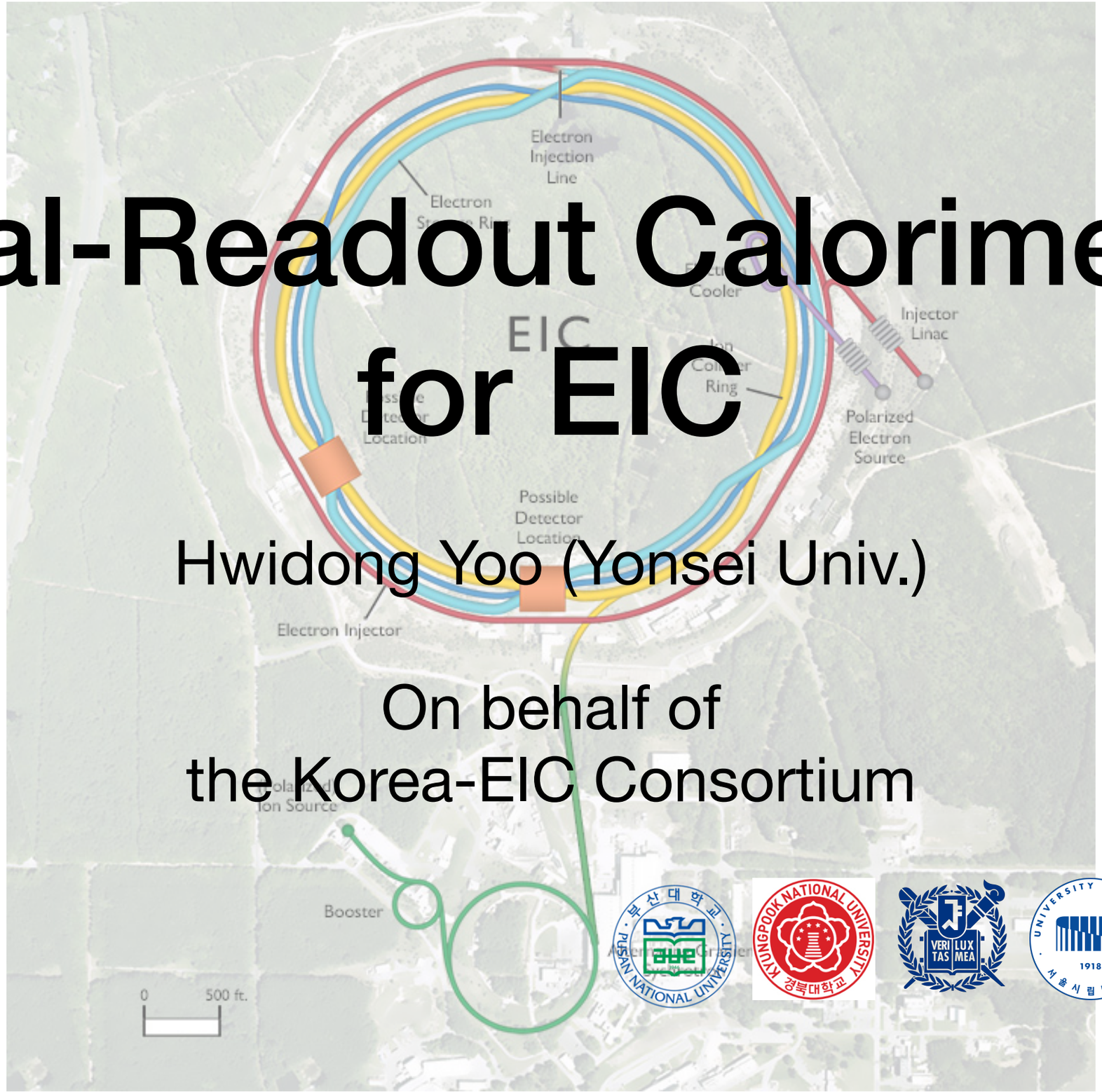
DREAM FOR FUTURE

Dual-Readout Calorimeter for EIC



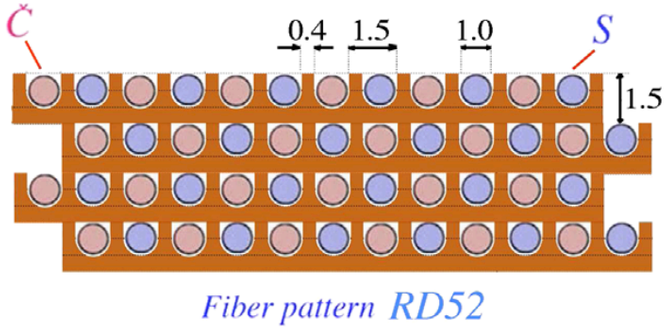
Hwidong Yoo (Yonsei Univ.)

On behalf of
the Korea-EIC Consortium

Supported by KiSTi www.kisti.re.kr

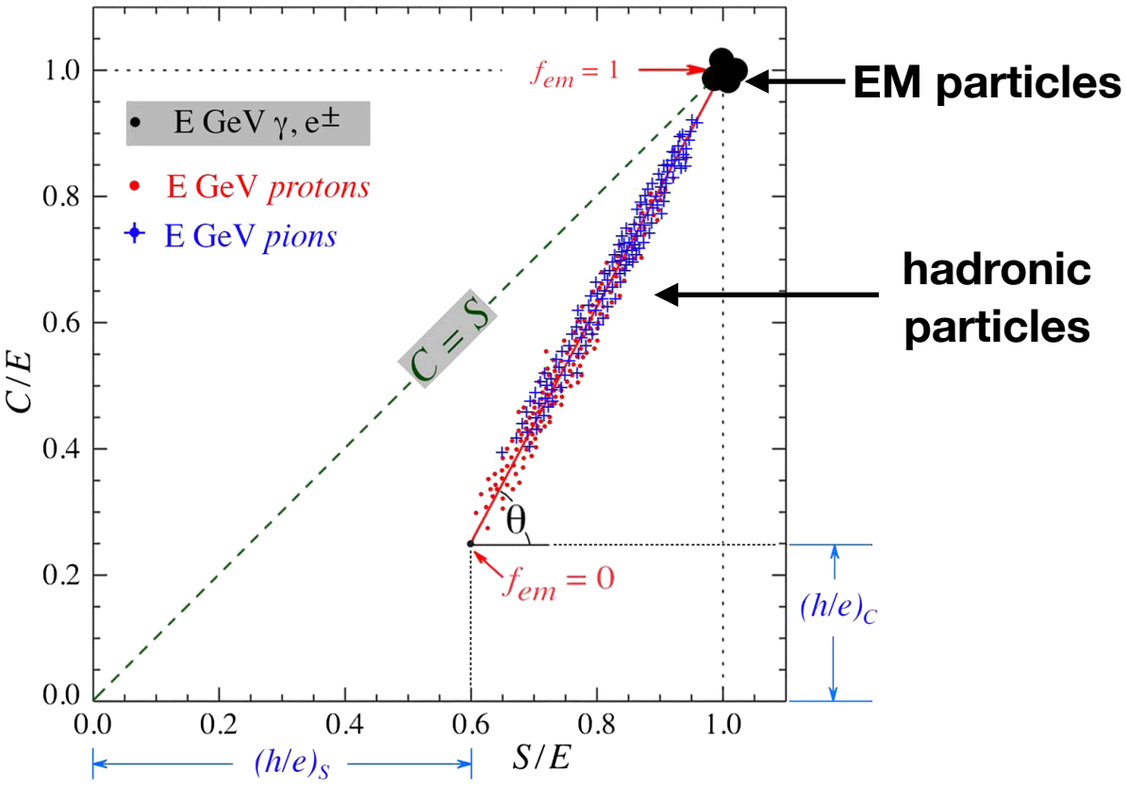
Dual-Readout Calorimeter (DRC)

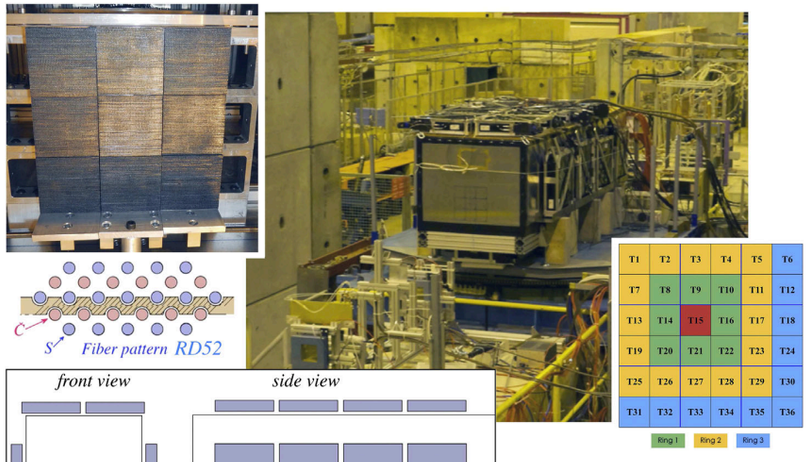
- DRC offers high-quality energy measurement for both EM particles and hadrons
  - DRC consists of two different optical fibers (S, C) in a single component
  - The main culprit of poor hadronic energy resolution is fluctuations of the EM shower components of hadron showers (f_{em})
  - f_{em} can be 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

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

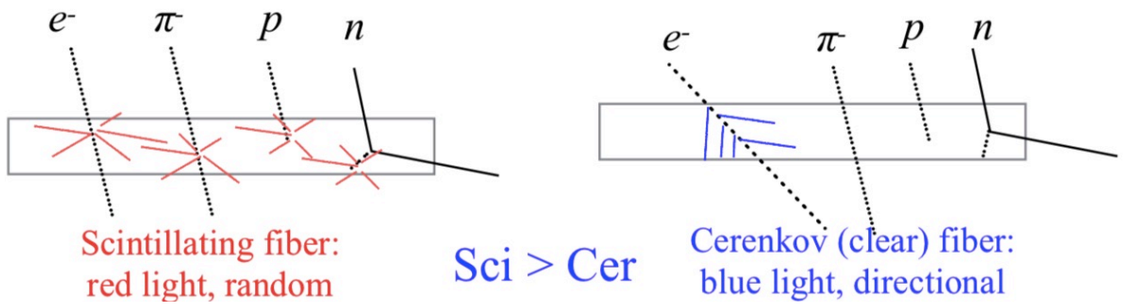




CERN RD52 experiment

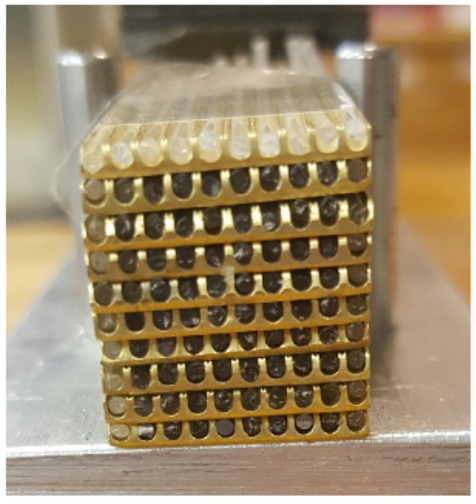
$$E = \frac{S - \chi C}{1 - \chi}.$$
$$\cot\theta = \frac{1 - (h/e)_S}{1 - (h/e)_C} = \chi,$$

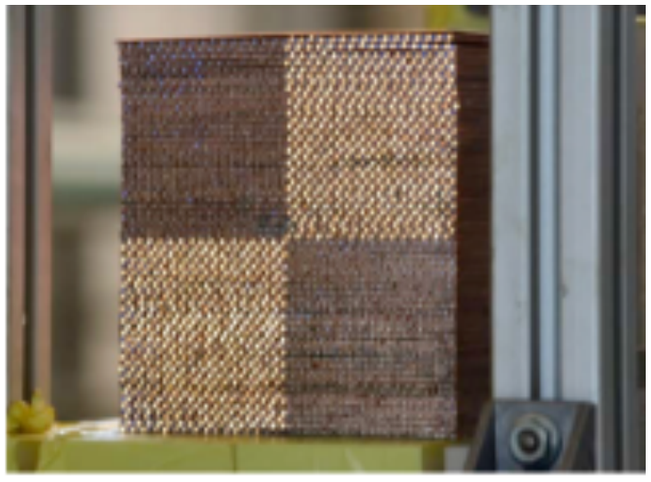
Signal generation: Scintillating & Cerenkov fibers

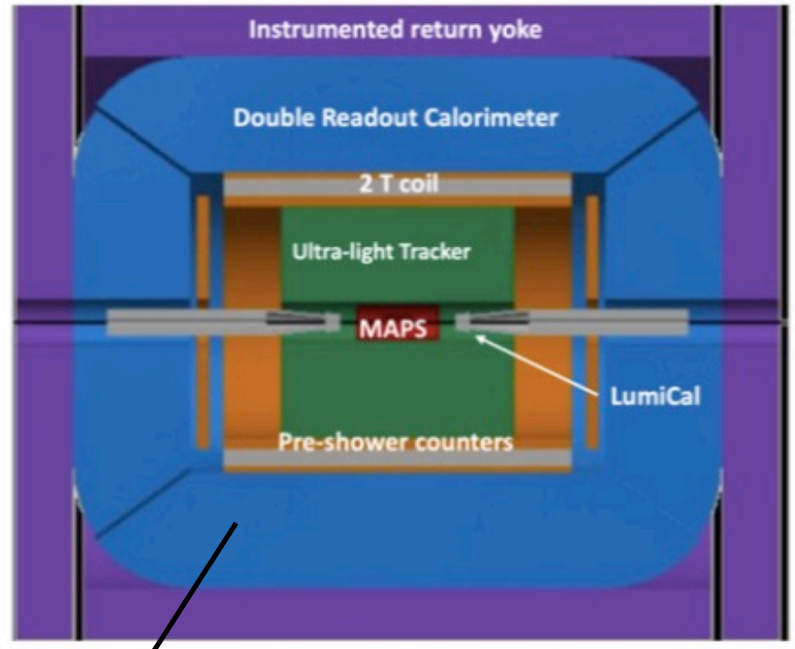


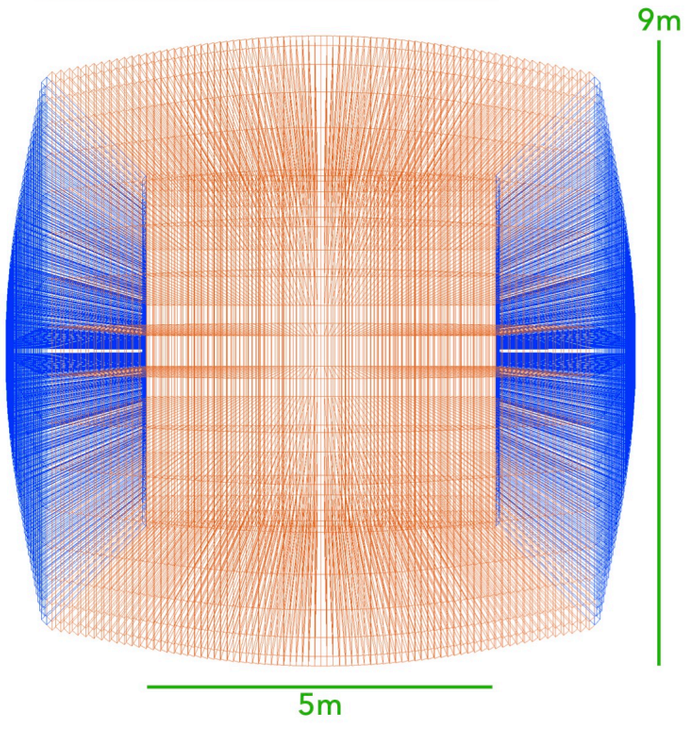
DRC Geometry and Module

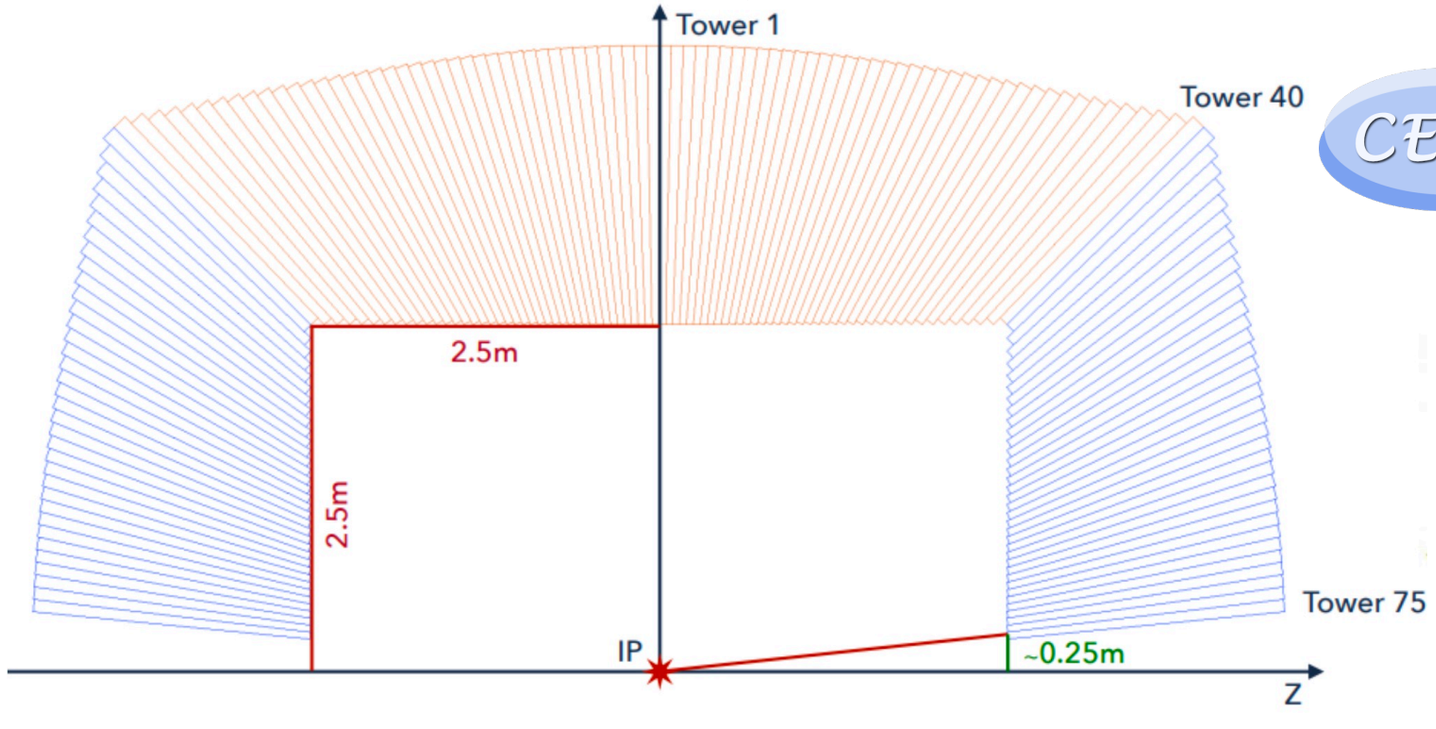
- Korean team led the design of the Dual-Readout Calorimeter (DRC) for IDEA detector
  - Included in the CDRs of both FCC-ee and CEPC, published at the end of 2018
- **Calorimeter design for EIC project** with Korea HI community is also on-going











DRC International Collaboration

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Prof. Yongsun Kim (Sejong U.)
Prof. Jason Lee (UoS)
Prof. Sehwook Lee (KNU)
Prof. Sanghoon Lim (PNU)
Prof. Hwidong Yoo (YU)

Prof. Rong-Shyang Lu

Prof. Chia Ming Kuo

Taiwan

Korea

Japan

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(Active from 2021)

USA

Prof. Sarah Eno

Prof. Chris Tully

Prof. Richard Wigmans

Prof. John Hauptman

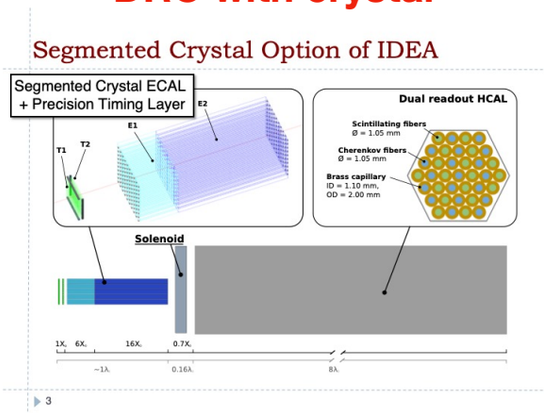
Europe

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

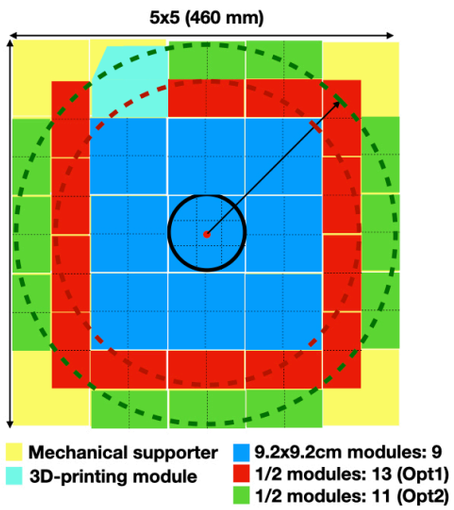
Prof. Iacopo Vivarelli

Prof. Valery Chmill

DRC with crystal

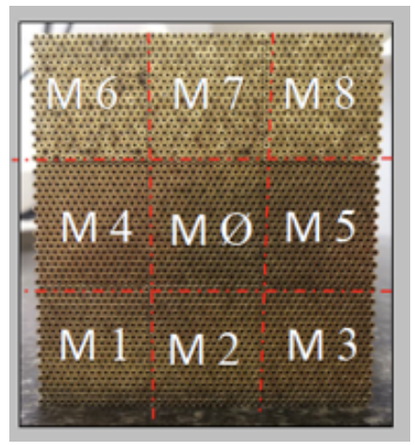


Full-size prototype detector



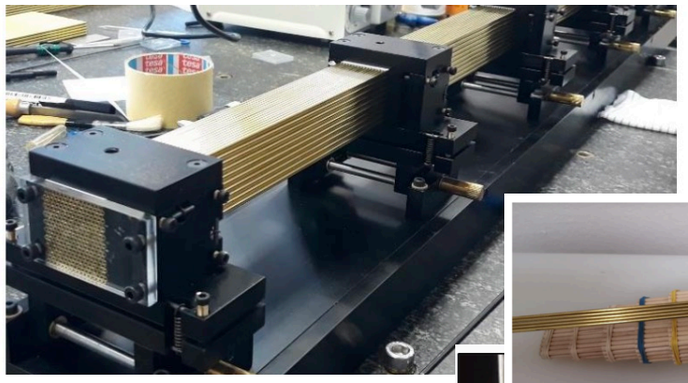
Design for EIC calorimeter

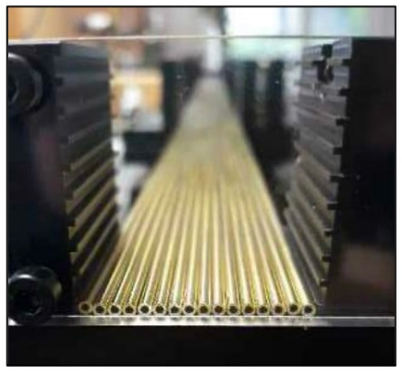
Bucatini prototype

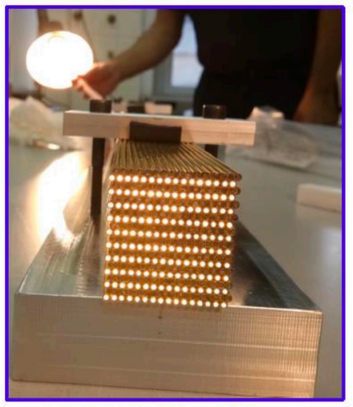


Bucatini Prototype Detector

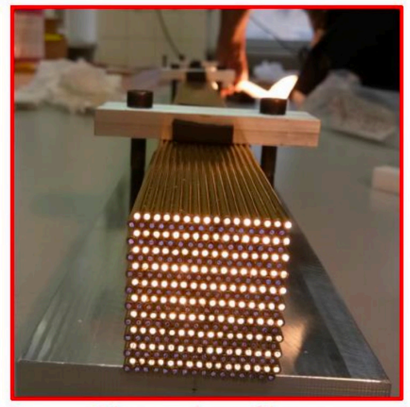
- Design requirement of EM prototype (10 x 10 x 100 cm^3)
  - Brass capillaries with outer diameter 2 mm and inner diameter 1.1 mm
  - 9 individual modules of 16 x 20 capillaries (160 C & 160 S fibers per module)
  - Each capillary of the central module to be equipped with a SiPM (total 320)
  - The rests of the surrounding modules to be equipped with PMTs (2 per module)
- Beam time is scheduled at June (DESY) and August (CERN)



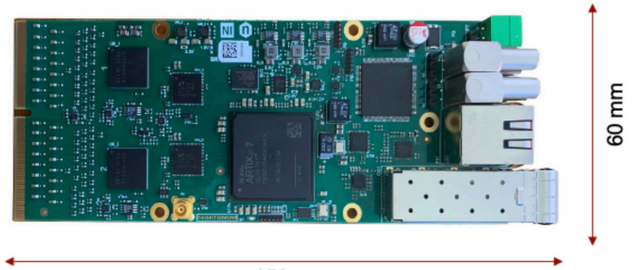




Scintillation fibers



Cherenkov fibers

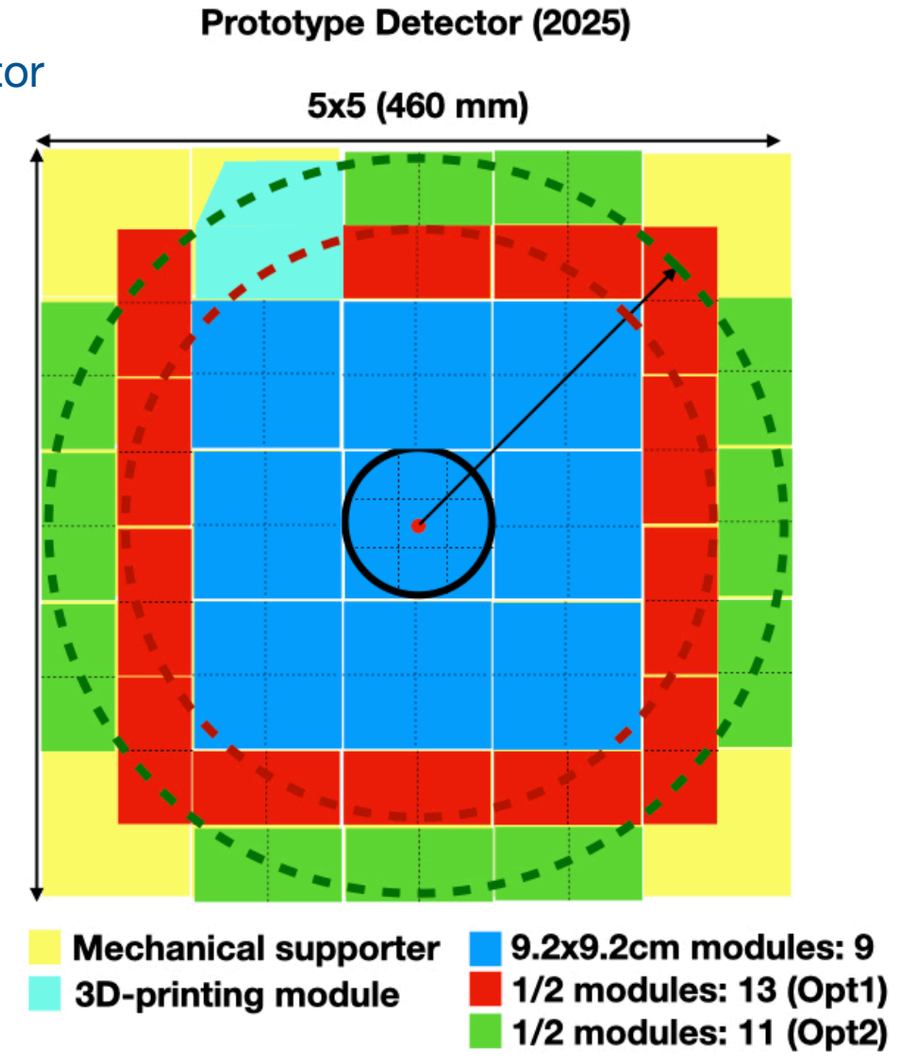


Korea Prototype Detector

- Primary goal: build a prototype detector for the detector design of CEPC experiment
  - **5 year (2020.Mar. - 2025.Feb.) R&D funding** supported by Korea NRF ($~0.4M/year, total **$~2M** for 5 years)
  - 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

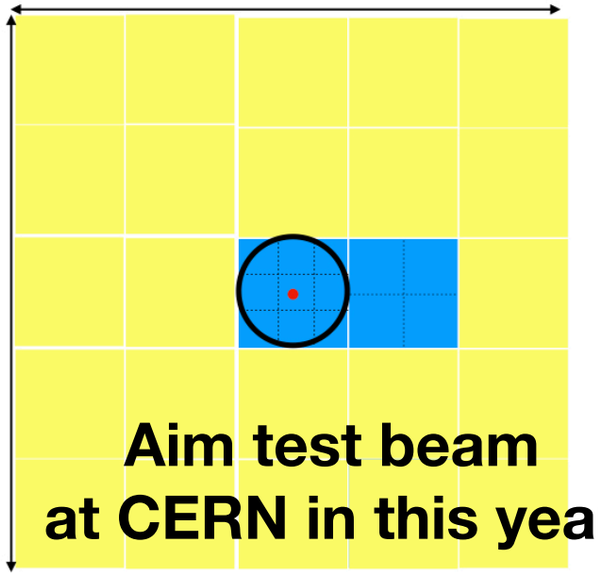
Stage	Topic
Design	Propose a design of Dual-Readout Calorimeter to IDEA detector concept
R&D	Perform R&D (including engineering aspects) based on HW & SW
Prototype	Build 4x4 detector and perform test beams
Production	TBD



Roadmap of DRC Prototype Detector

Prototype Detector (2021)

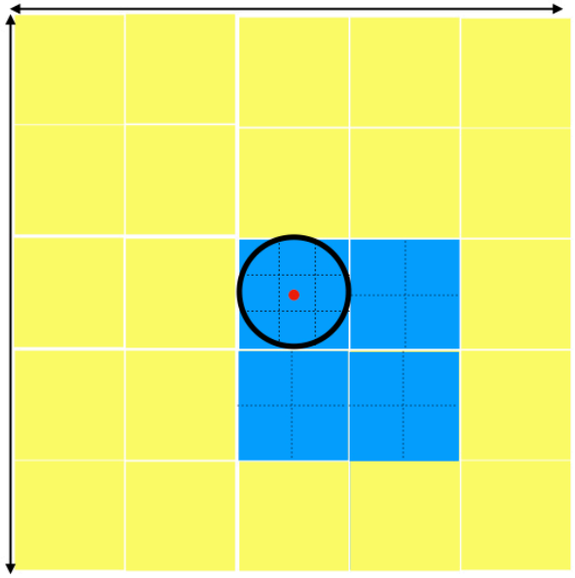
5x5 (460 mm)



Aim test beam at CERN in this year

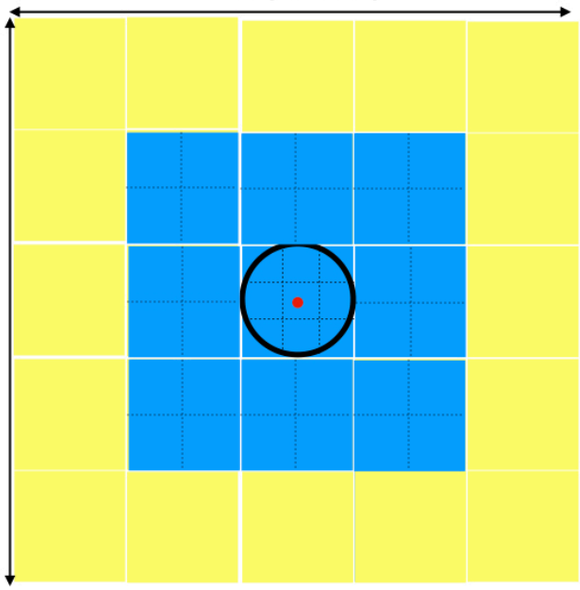
Prototype Detector (2022)

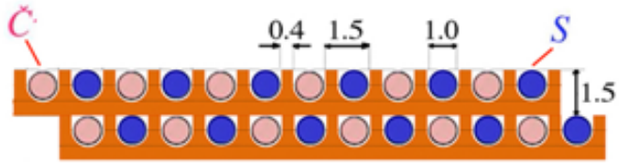
5x5 (460 mm)

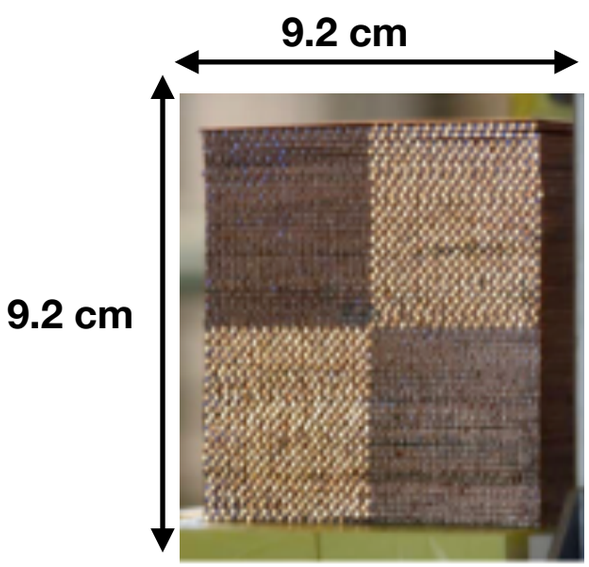


Prototype Detector (2023)

5x5 (460 mm)



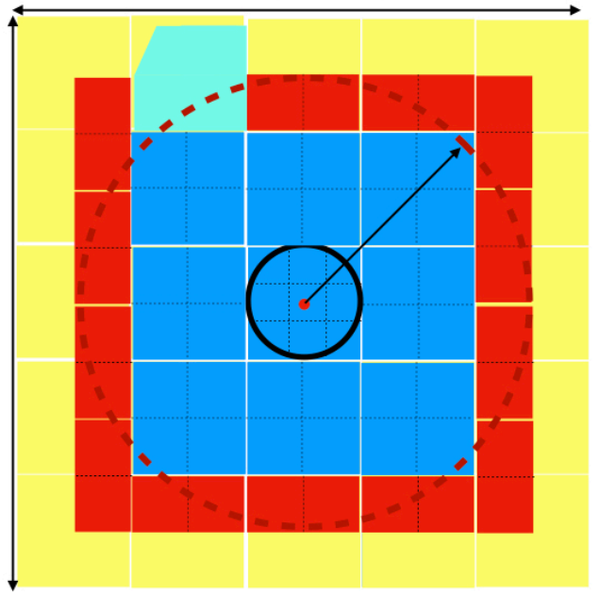




Size of unit module

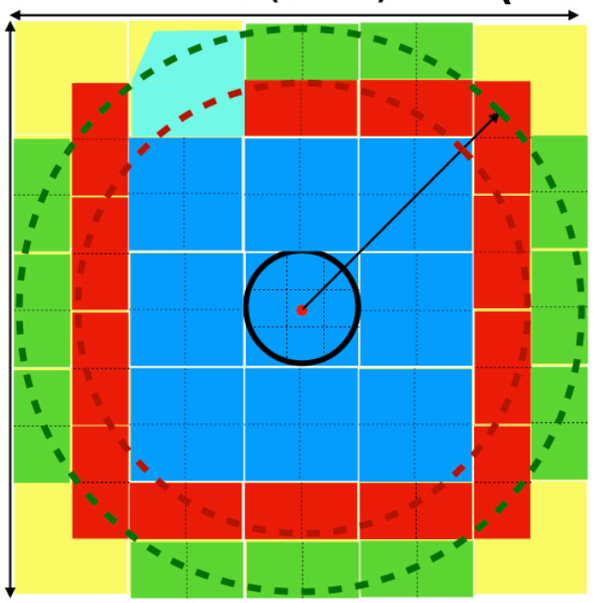
Prototype Detector (2024)

5x5 (460 mm)



Prototype Detector (2025)

5x5 (460 mm) **TBD (budget is available)**



Mechanical supporter
3D-printing module
9.2x9.2cm modules: 9
1/2 modules: 13 (Opt1)
1/2 modules: 11 (Opt2)

Test-beam at 2021

Goal	Details
Physics	Measurement of nuclear interaction length using proton beam
	Measurement of energy and position resolution using electron beam
R&D	Readout test (MCP vs. SiPM)
	Time resolution (< 50 ps)
	Optical fibers (various types)
Training	Next generation experts for DRC HW

Signal starting time difference: 2 ns/m

Time resolution: 10 ps —> 5 mm precision

Time resolution: 50 ps —> 25 mm precision

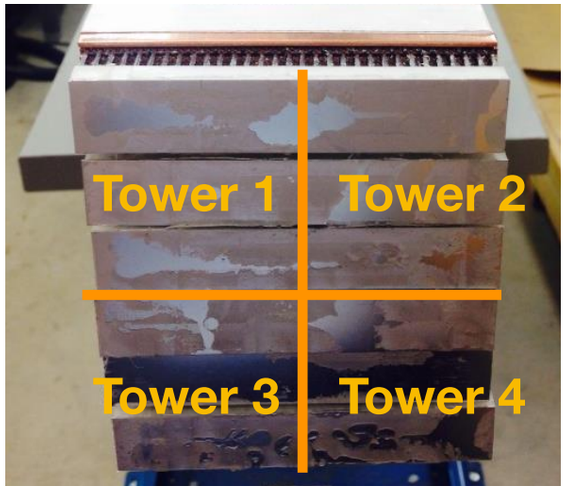
Time resolution: 100 ps —> 50 mm precision

- Plan

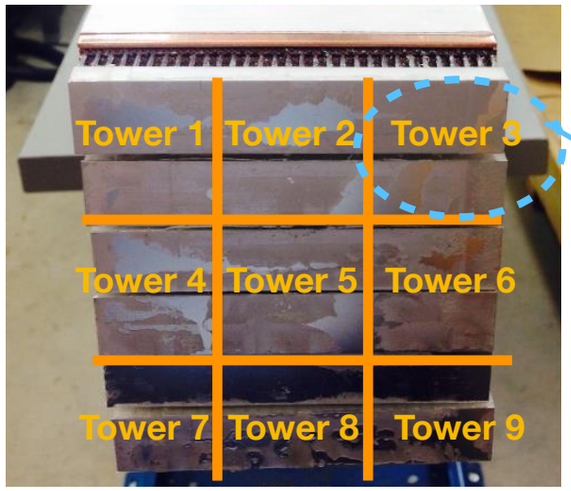
- Dissemble and cleanup all fibers and other components from copper plates

- Repair plates and assemble new fibers

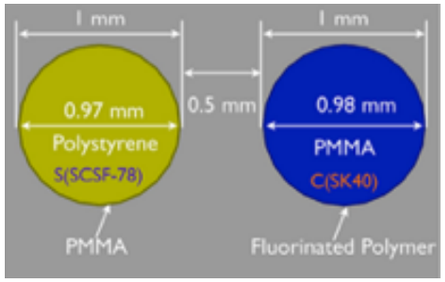
Module #1 (2x2)



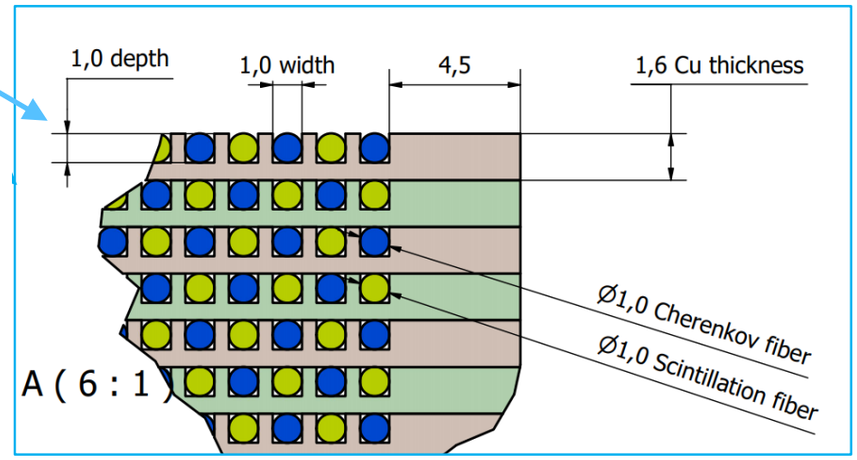
Module #2 (3x3)



Specification of fibers

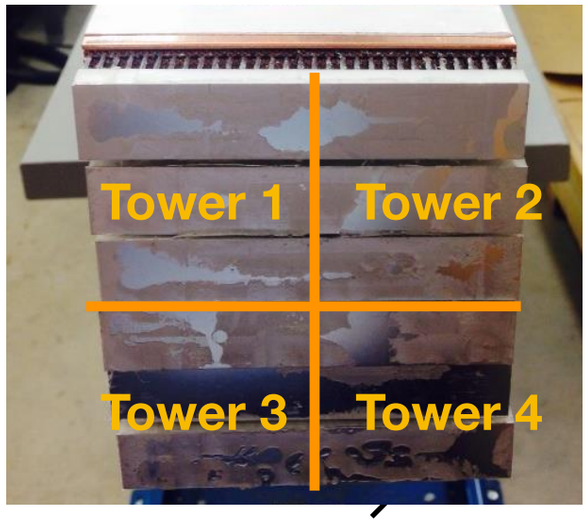


NIM A 762 (2014) 100, N. Akchurin et al.



Module Configuration

Module #1 (2x2)



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

Combination of fibers for Module#1

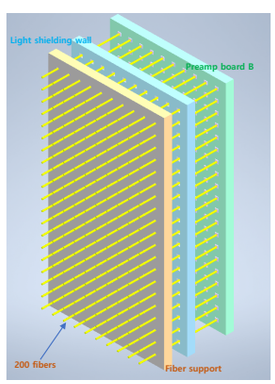
	Tower #1	Tower #2	Tower #3	Tower #4
Scintillation fibers	Round / Single cladding	Round / Single cladding	Round / Double cladding	Square / Single cladding
Cherenkov fibers	Round / Single cladding			
Readout detector (2*4 ch)	2 PMTs	2 MCP-PMTs	2 PMTs	2 PMTs

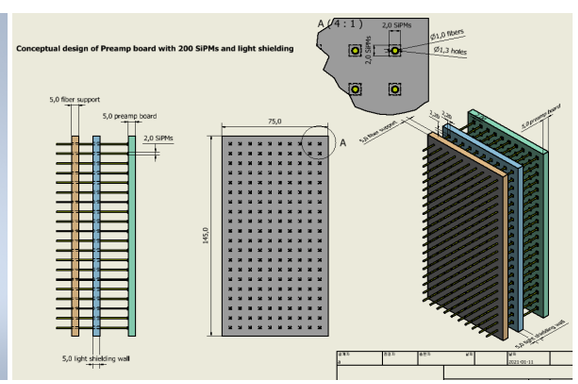
Module #2 (3x3)

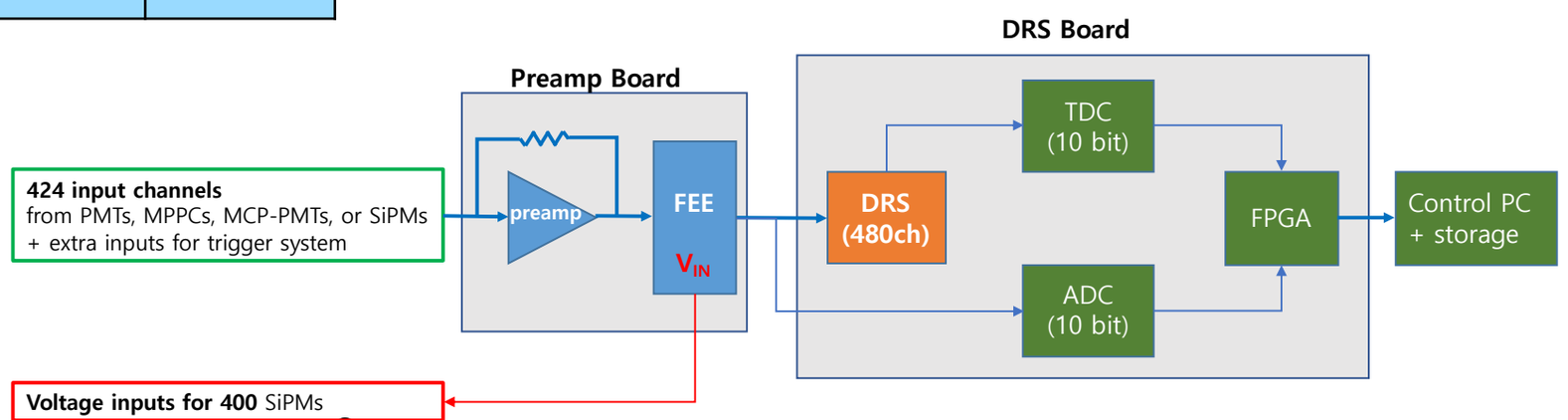
Tower#1	Tower#2	Tower#3
Tower#4	Tower#5	Tower#6
Tower#7	Tower#8	Tower#9

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

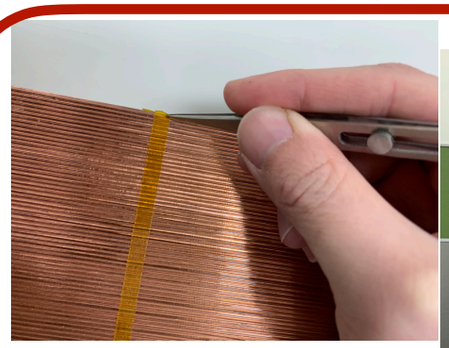


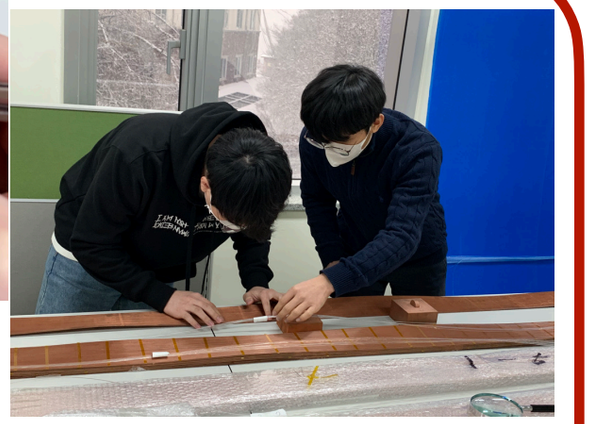


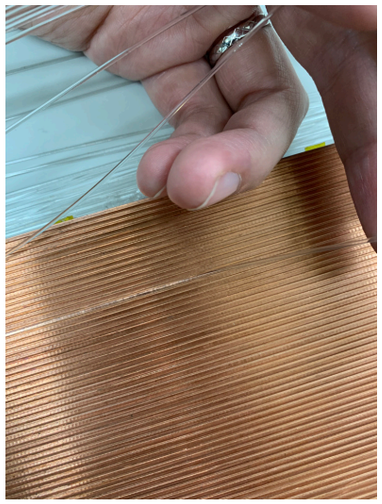


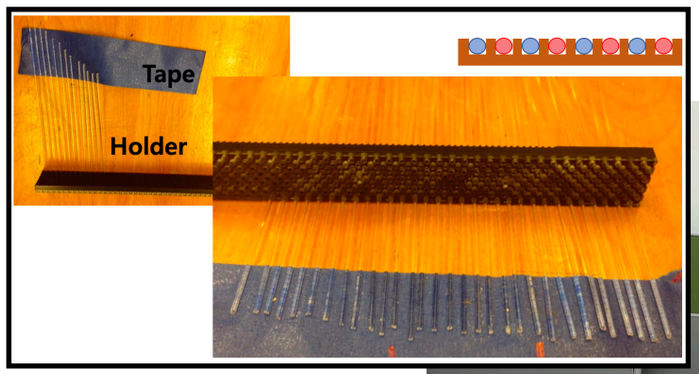
Module Disassembly & Repair

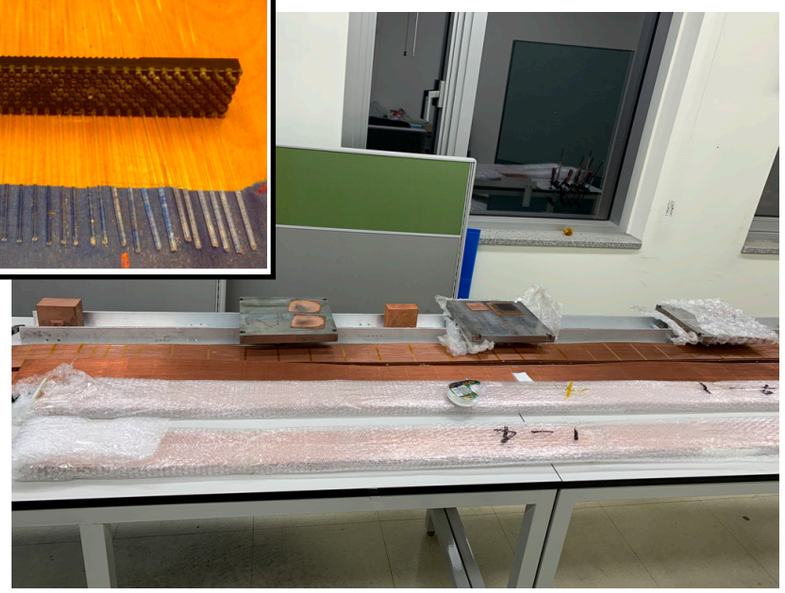
Disassembling



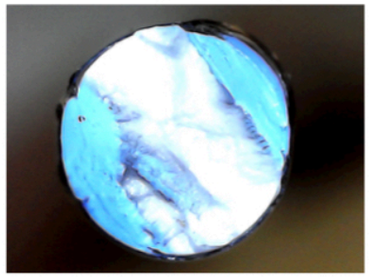


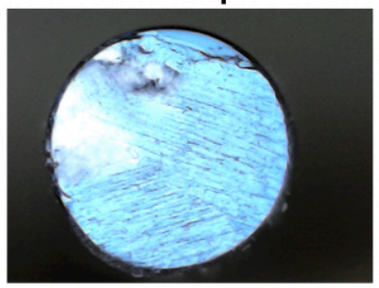


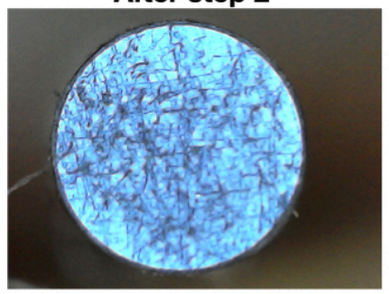


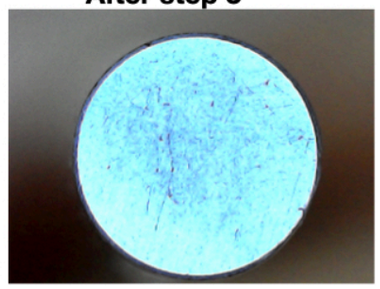


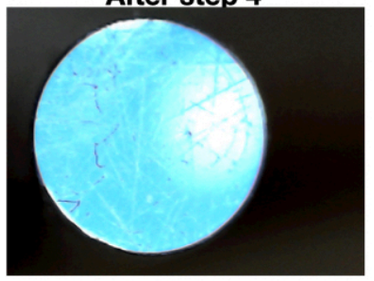
Polishing fibers

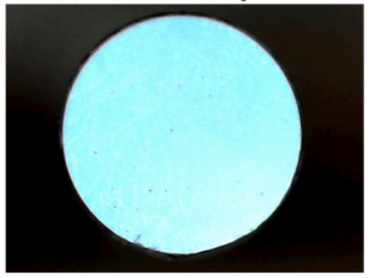






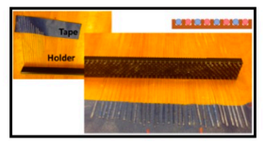






Rebuilding procedure

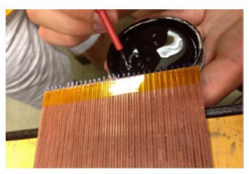
1. Preparation the items (stuffs) for rebuilding module



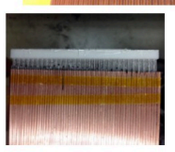
2. Putting the fiber on the copper plates

3. Checking out the condition of fiber after putting it on plate (measurement of luminosity)

4. Painting the end of scintillation fibers

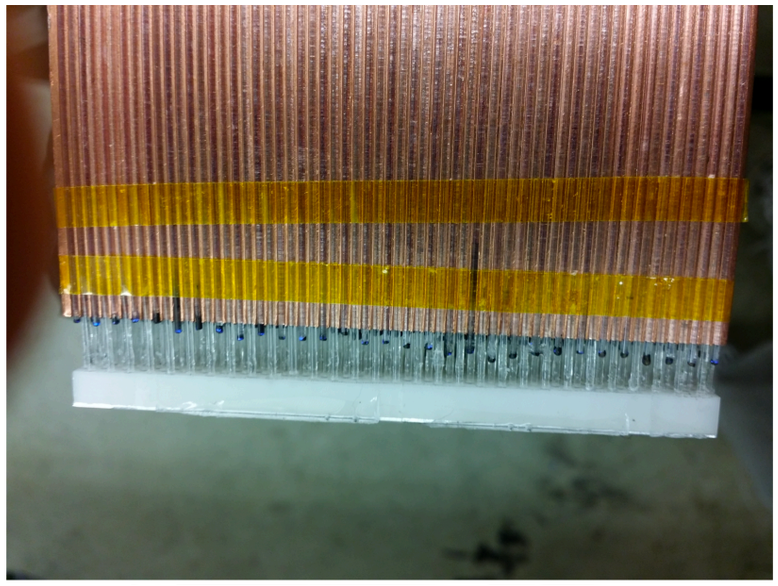


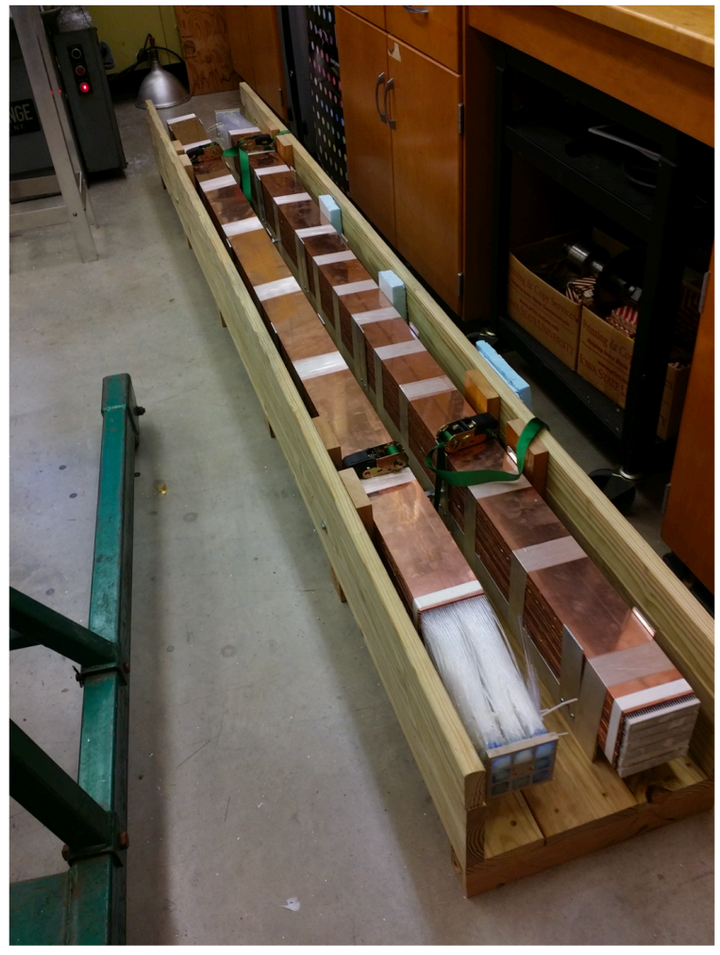
5. Epoxy on the Fibers to Attach Holder



Module Building in 2016

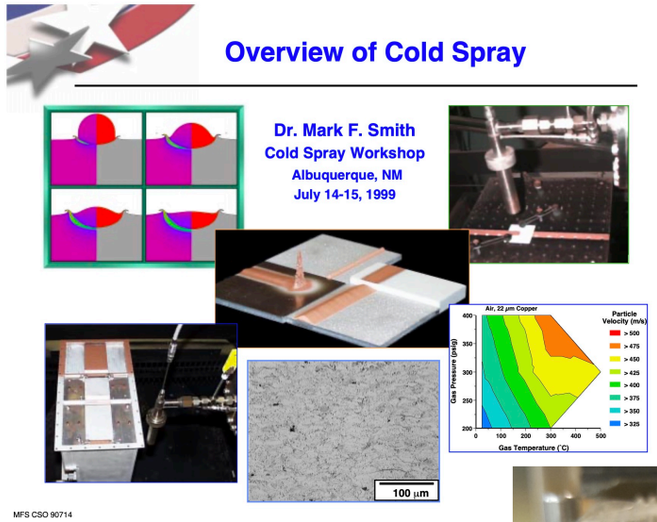
- For 2016 test beam, two Cu modules were produced by cutting
- This technical approach has already been proved well by previous module building
- Testing innovative 3D metal printing for alternative possibility at 2020

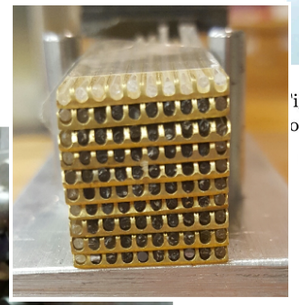


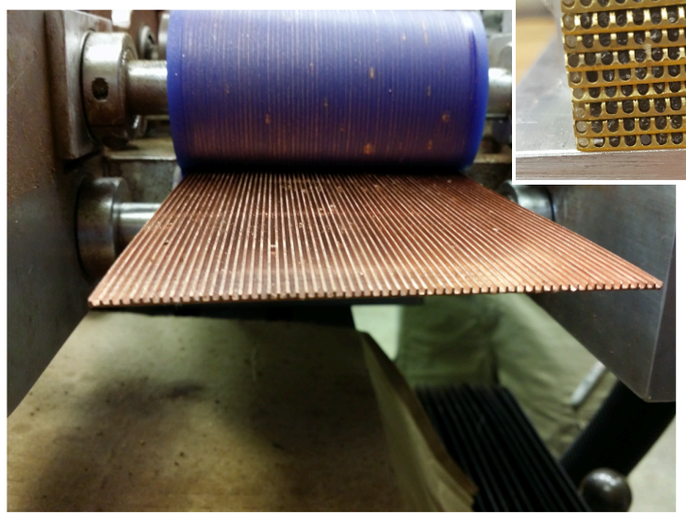


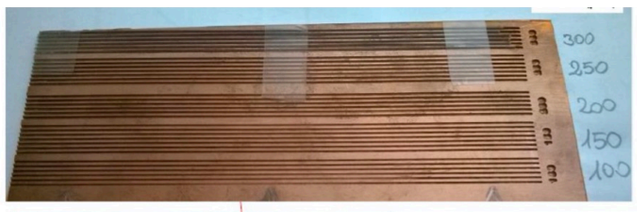
Previous Copper Forming R&D

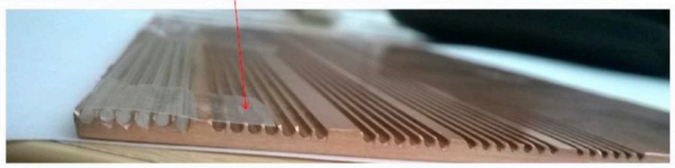
- We tried many options (by John Hauptman et al in CERN RD52)

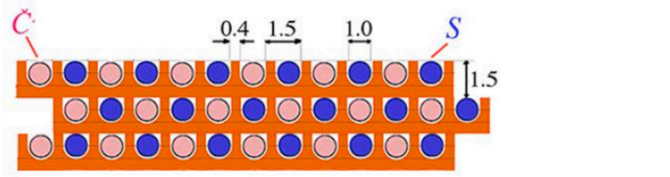


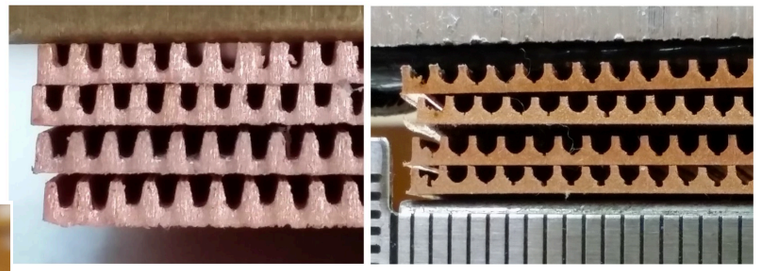




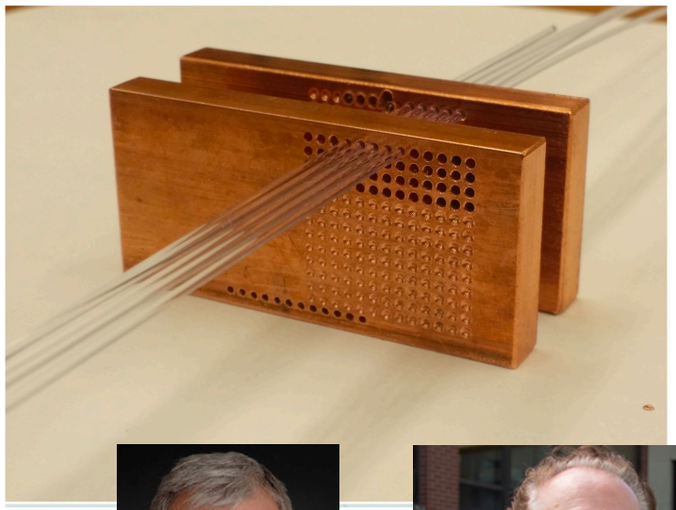


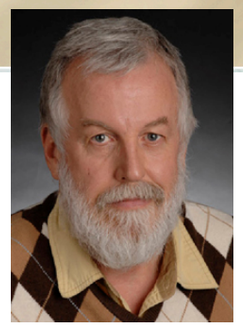






igure 25: Water-jet grooved plates on the left (2.5 meters long) and the precision rolled orresponding grooves on the right.





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

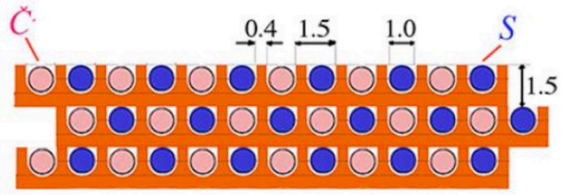
Contents

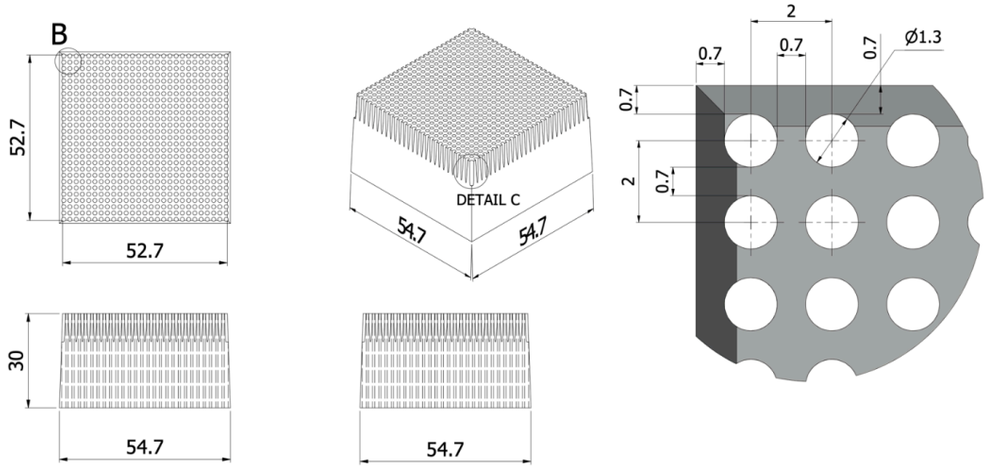
3D Printing Module R&D

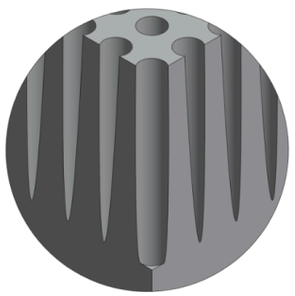
- Two major questions on the DRC for engineering aspects
  - Complex design
  - Projective shape

→ **3D printing can be a solution!**

- Use 3D metal printer to produce Cu blocks with fine structure holes
  - ~1 mm diameter for a hole
  - ~0.5 mm wall thickness between holes

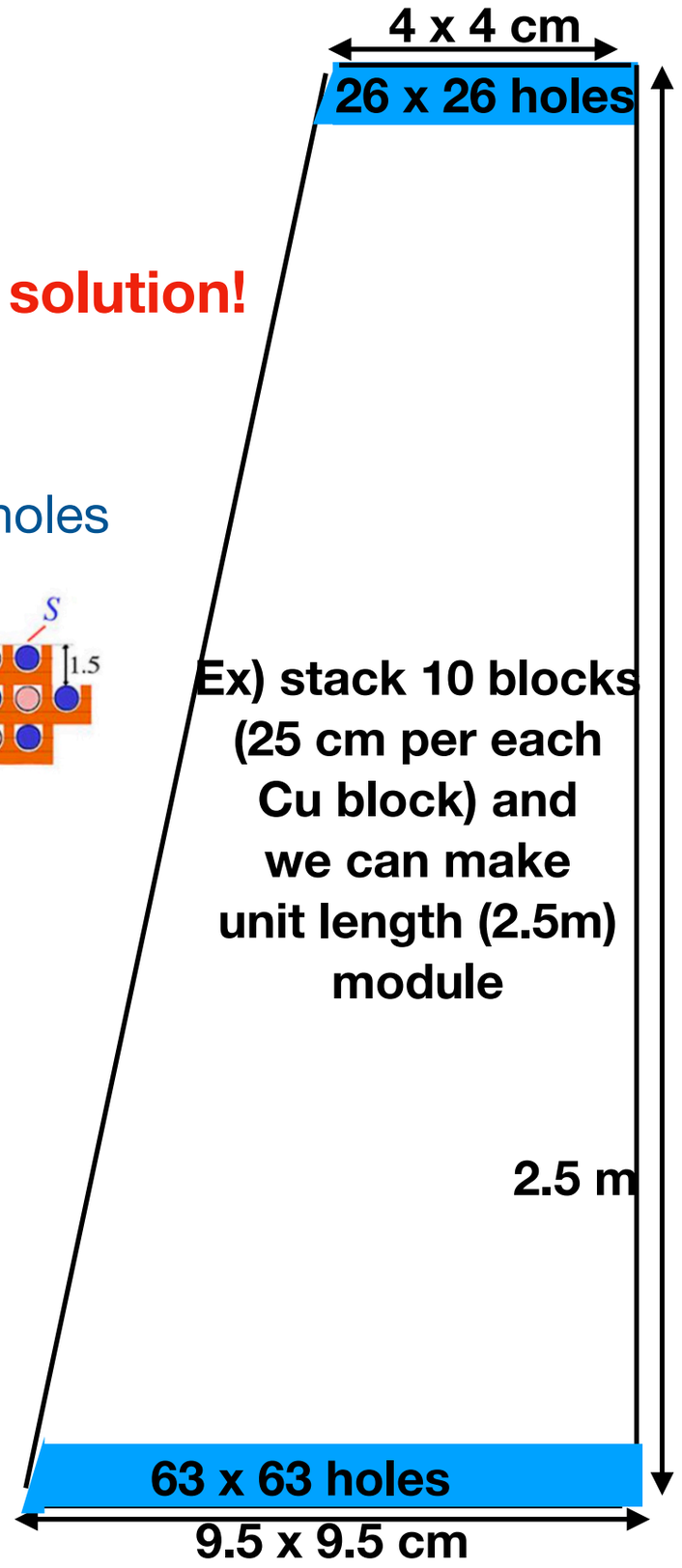






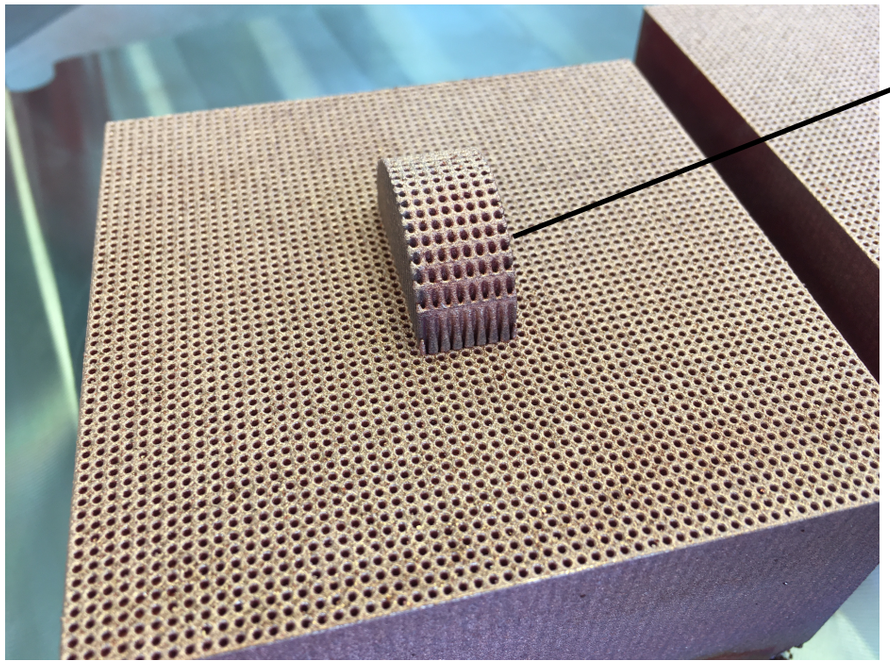
DETAIL C (10 : 1)

With 3D printing consultant company in Korea
- **have world-wide expert networking**



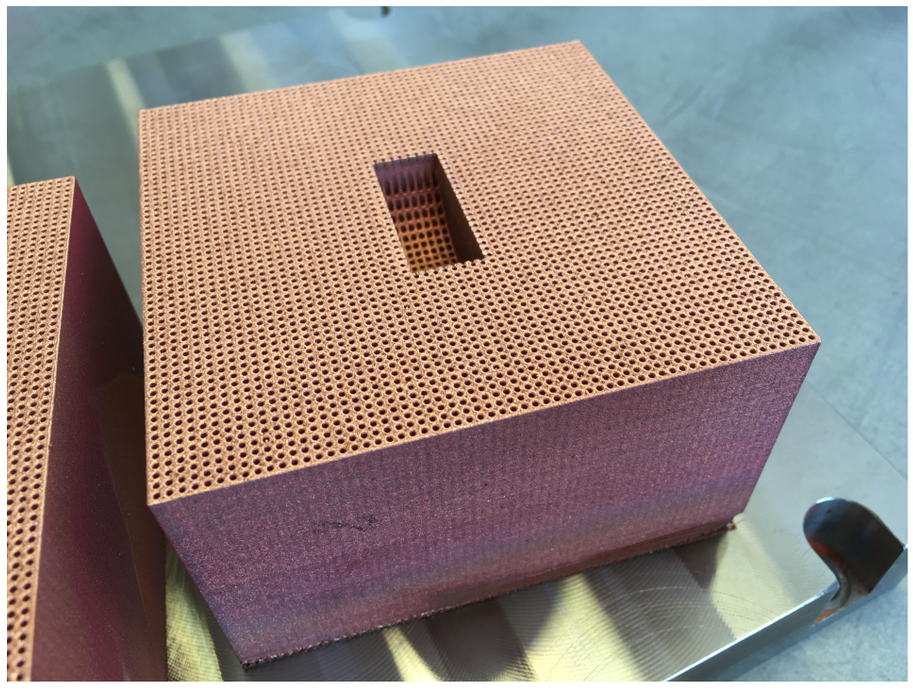
1st Trial: Finland Company

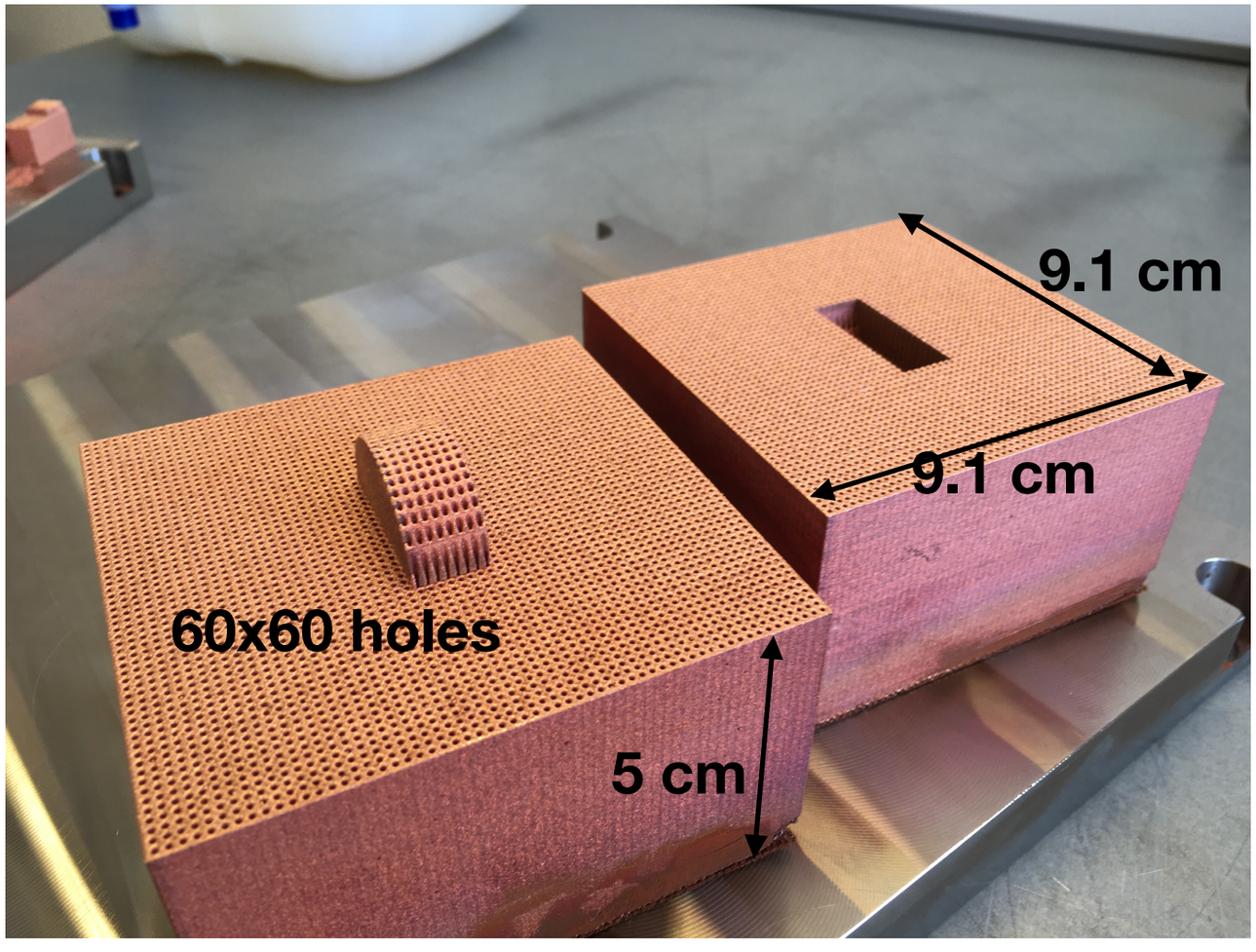
- The 1st trial is not hopeless, but the hole size is < 0.7 mm, therefore can not assemble the optical fibers



Nose (not sufficient quality)

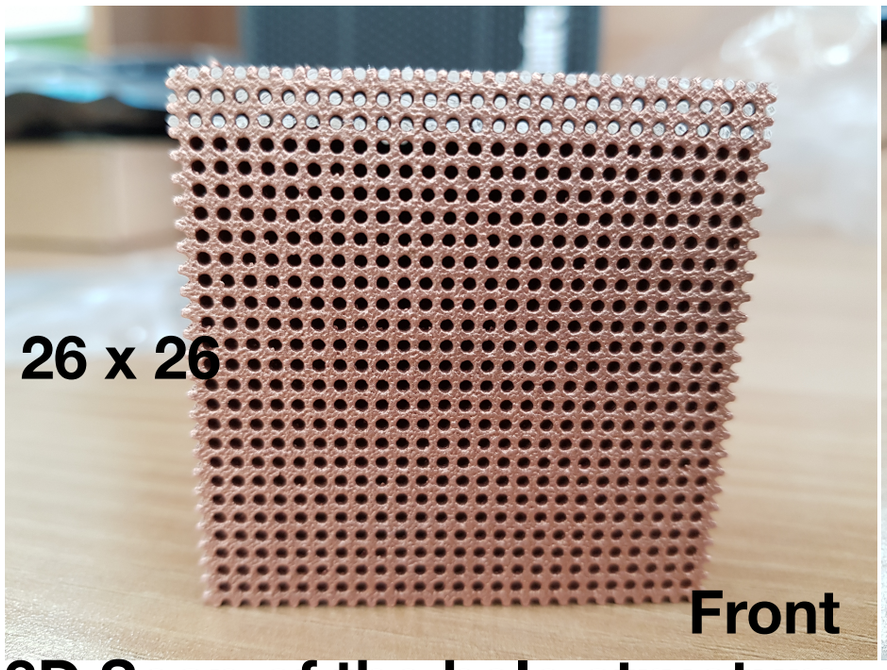
EOS (Germany)

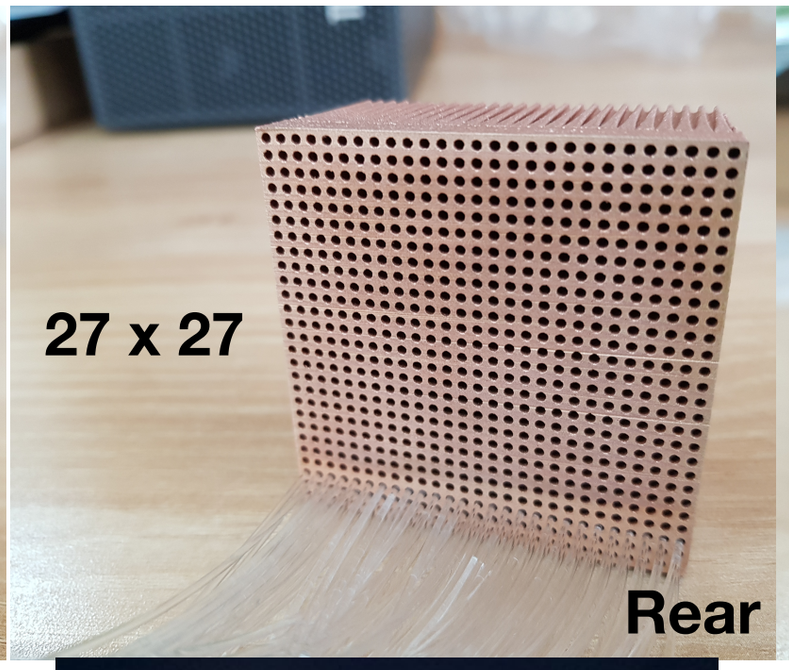




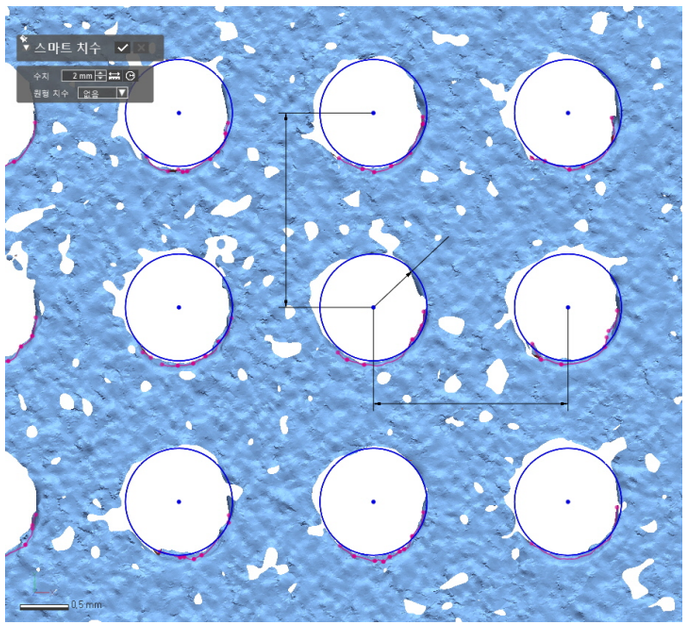
2nd Trial: Finland Company

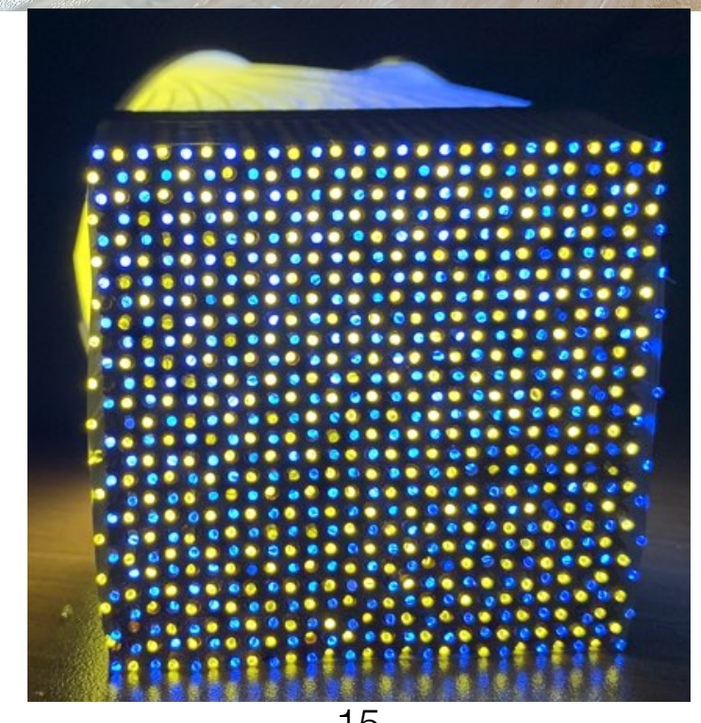
- Very successful projective shape and ~1.1mm diameter of the hole, but failed for < 0.5 mm wall thickness

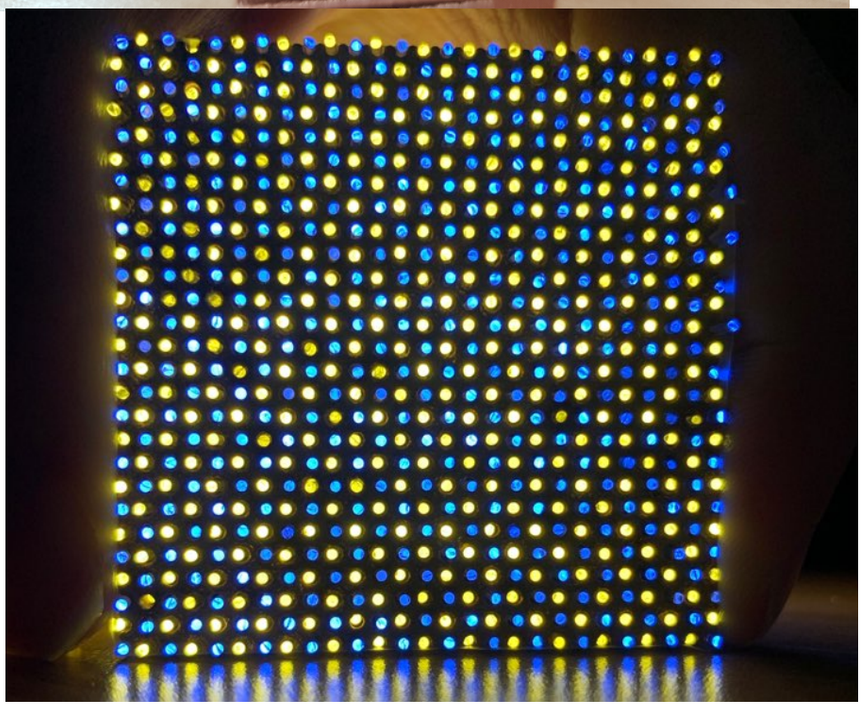




3D Scan of the hole structure





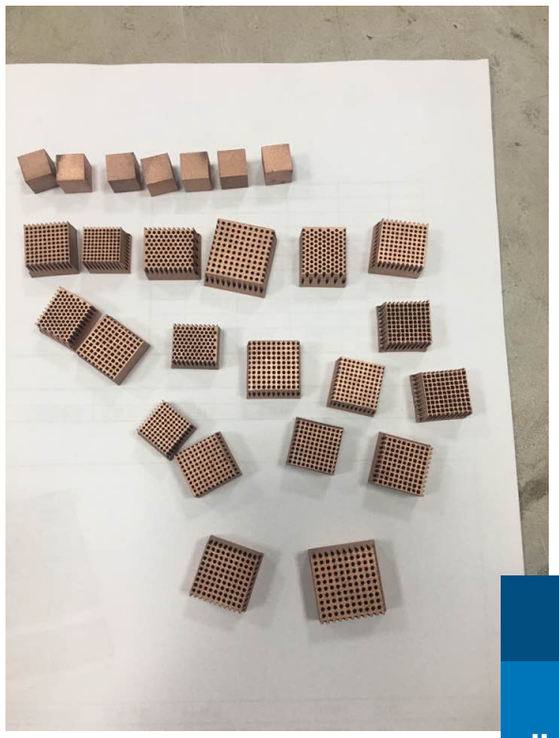


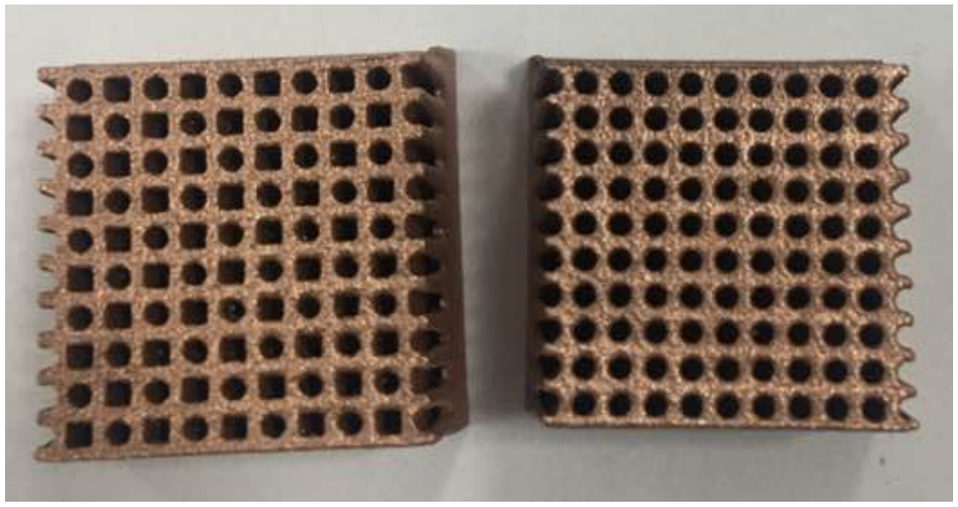
3rd Trial: China Company

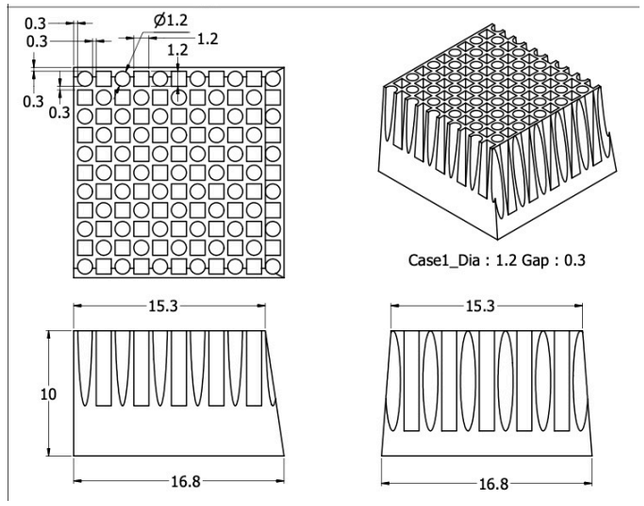
- Scan various values and designs for the diameter and wall thickness

- Achieve < 0.5 mm wall thickness with ~1.0mm diameter of the hole!!

Farsoon



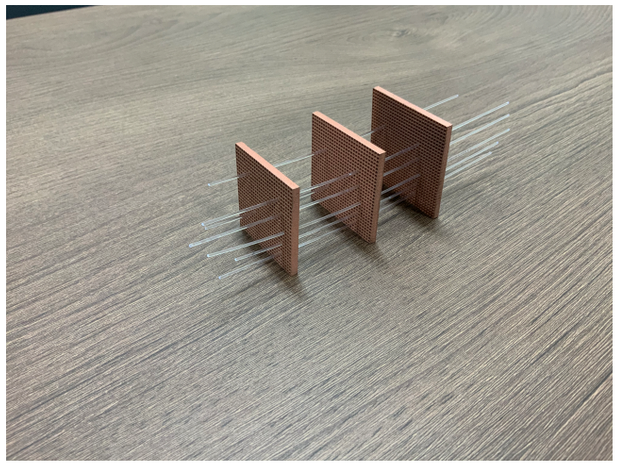


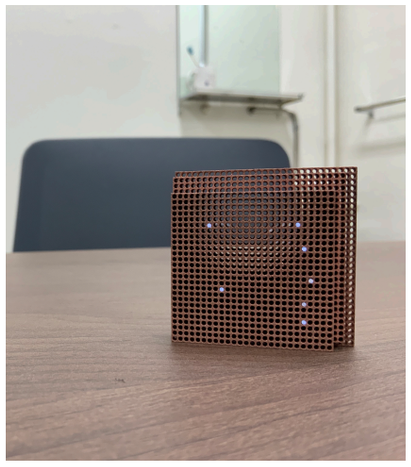


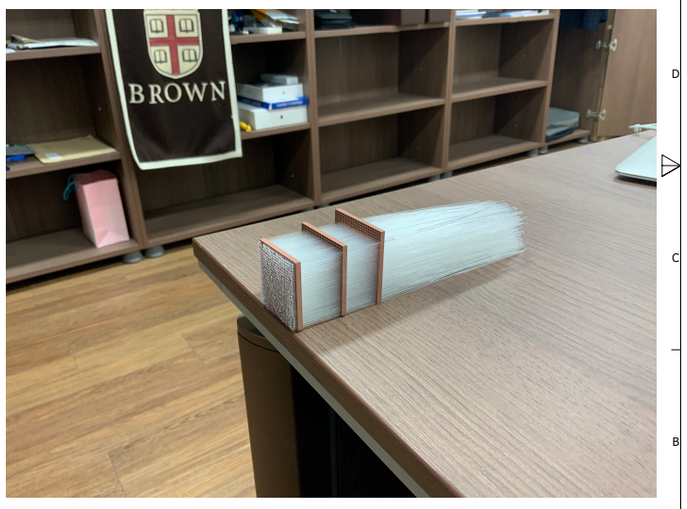
	Samples	1	2	3	4	5	6	7	8	9	10
Hall diameter (mm)	Designed	1.0	1.1	1.2	1.1	1.0	1.3	1.1	1.2	1.2	1.1
	Outcome	0.9-0.95	0.9-0.95	1.0-1.05	0.8-0.85	0.8-0.85	1.1-1.15	0.9-0.95	1.0-1.05	1.0-1.05	0.9-0.95
Wall thickness (mm)	Designed	0.5	0.5	0.5	0.4	0.3	0.7	0.5	0.3	0.5	0.4
	Outcome	0.52	0.6	0.62	0.5	0.45	0.81	0.6	0.4	0.65	0.52

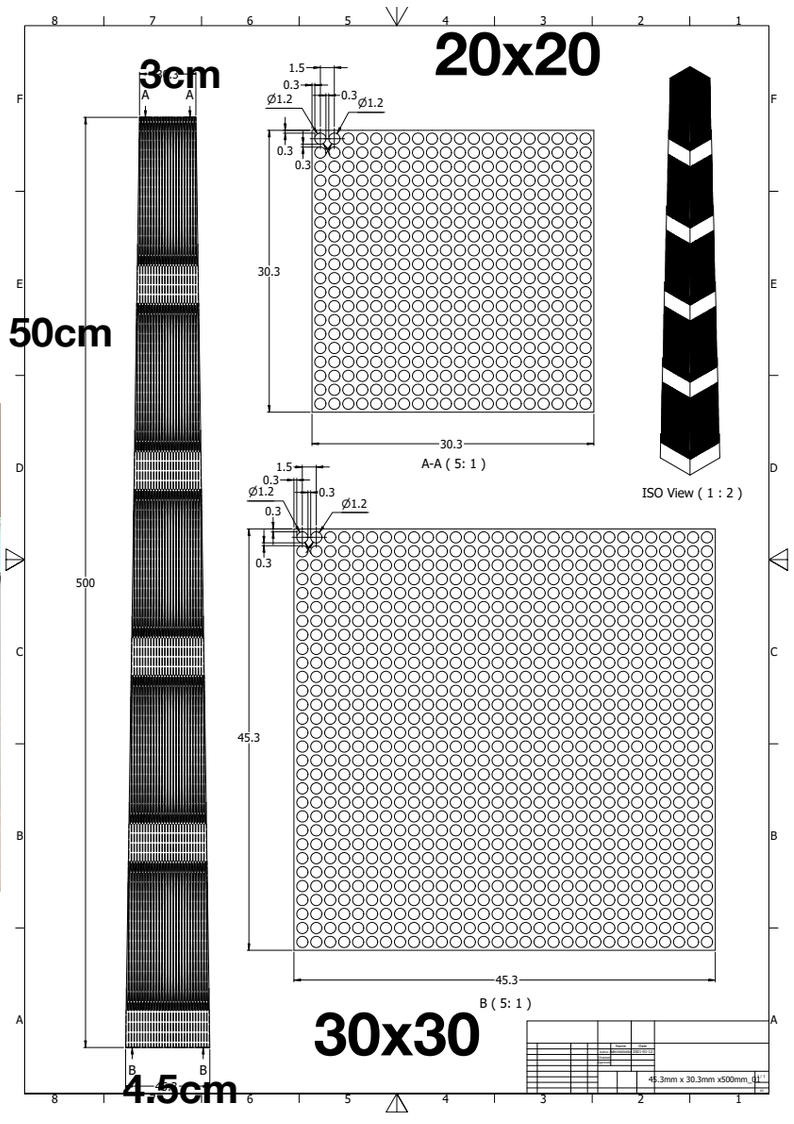
Toward Prototype 3D Module

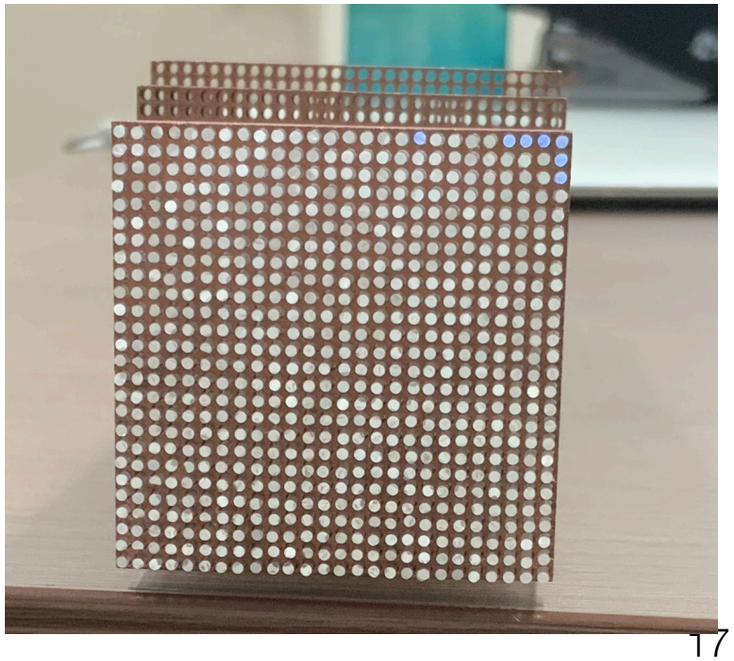
- Under test and design: check alignment of holes and very successful!
- Ordered five 3D-printed copper blocks (10 cm length each) for the prototype module









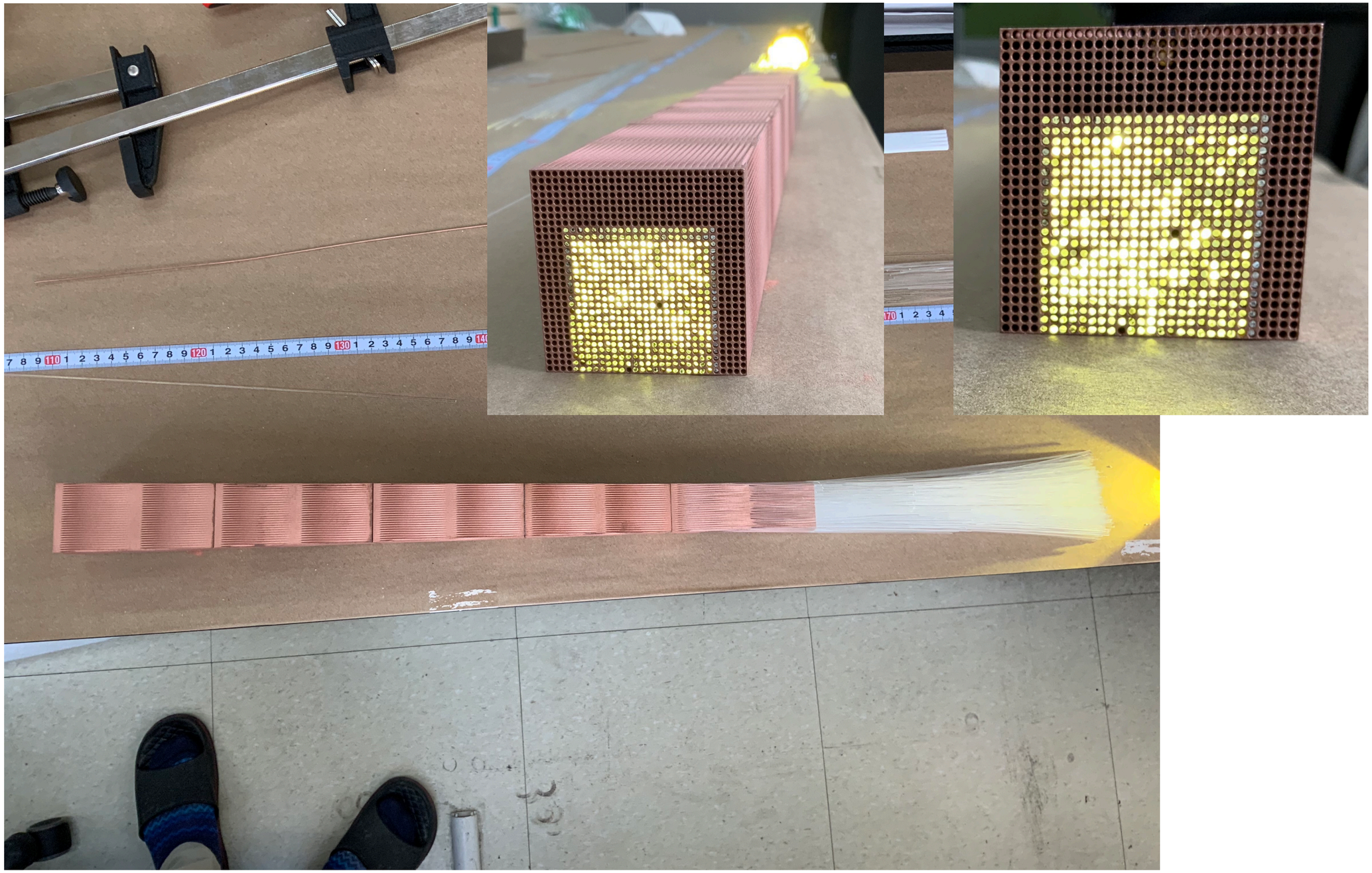


Prototype 3DP Module

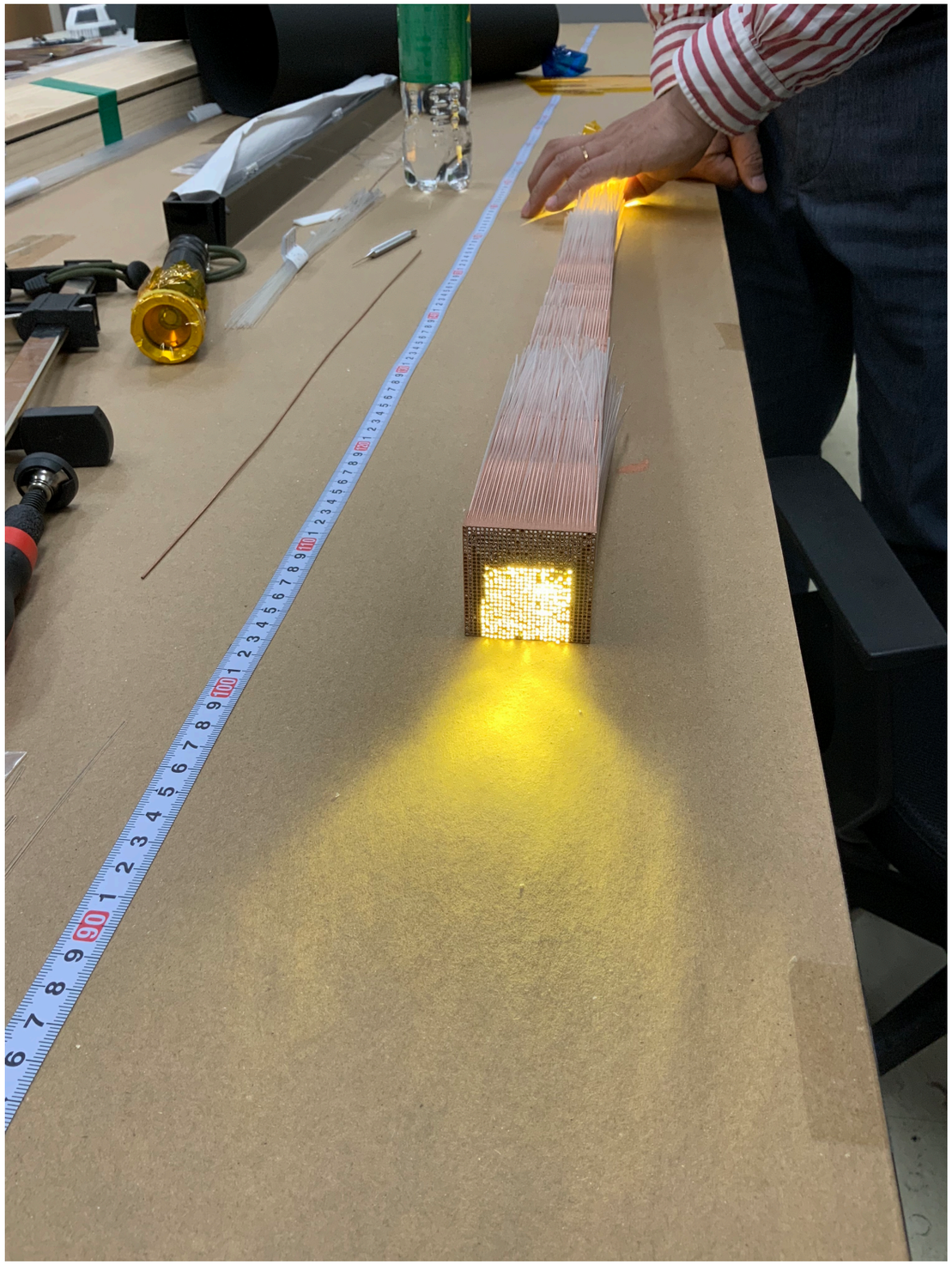
- 1st projective DRC module!

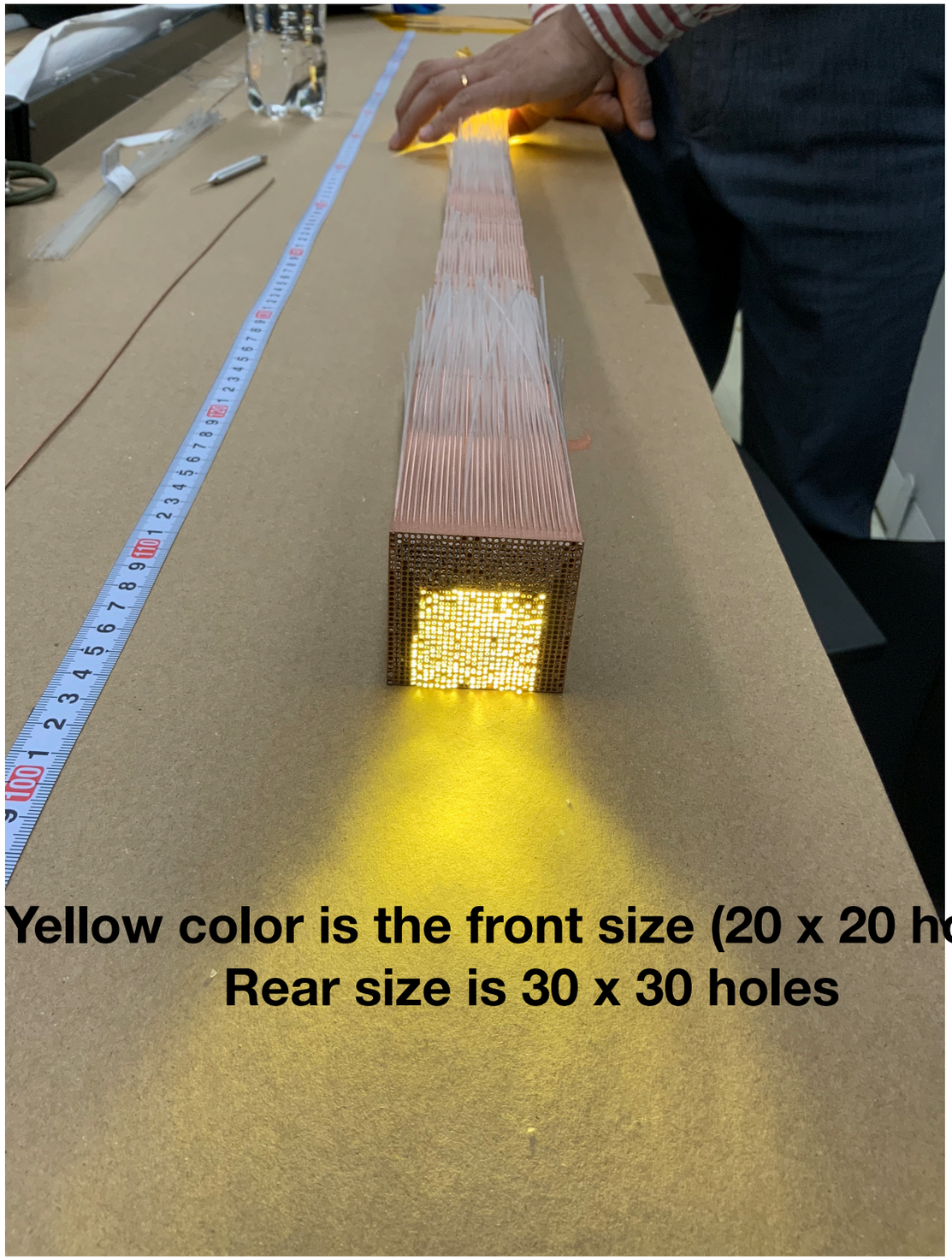
Prototype 3DP Module

- Insert fibers into entire holes: well aligned!



Prototype 3DP Module



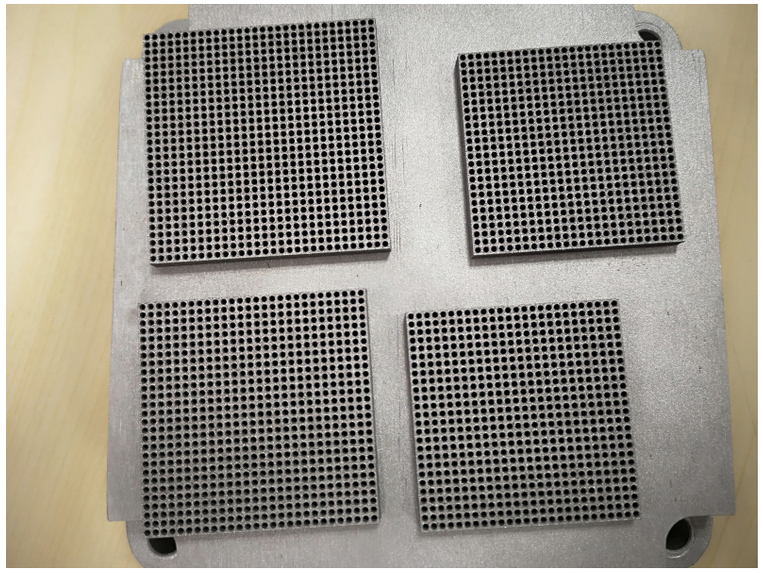


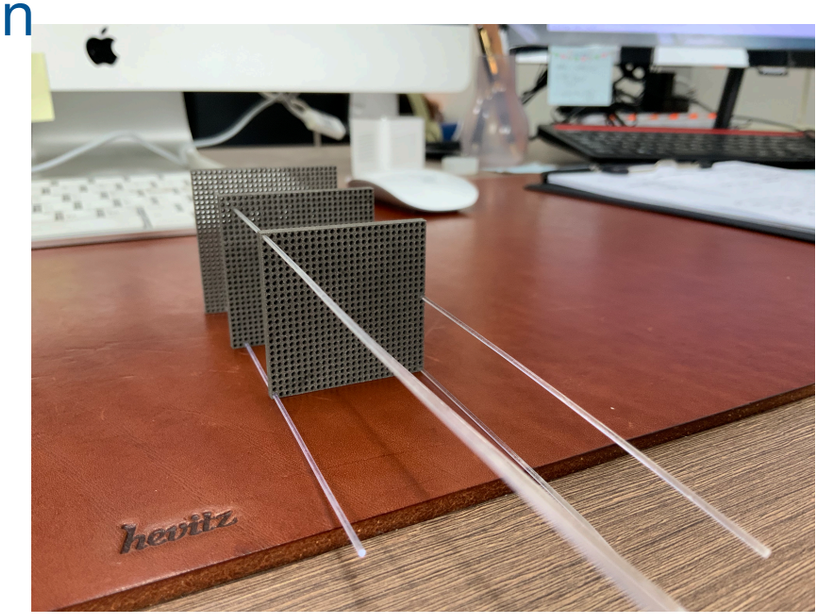
Yellow color is the front size (20 x 20 holes)
Rear size is 30 x 30 holes

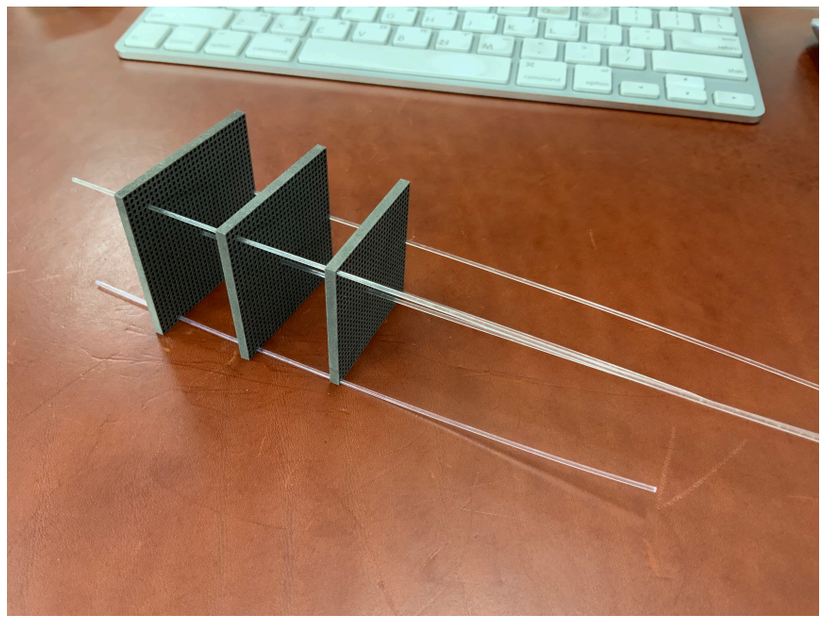
3DP DRC with W?

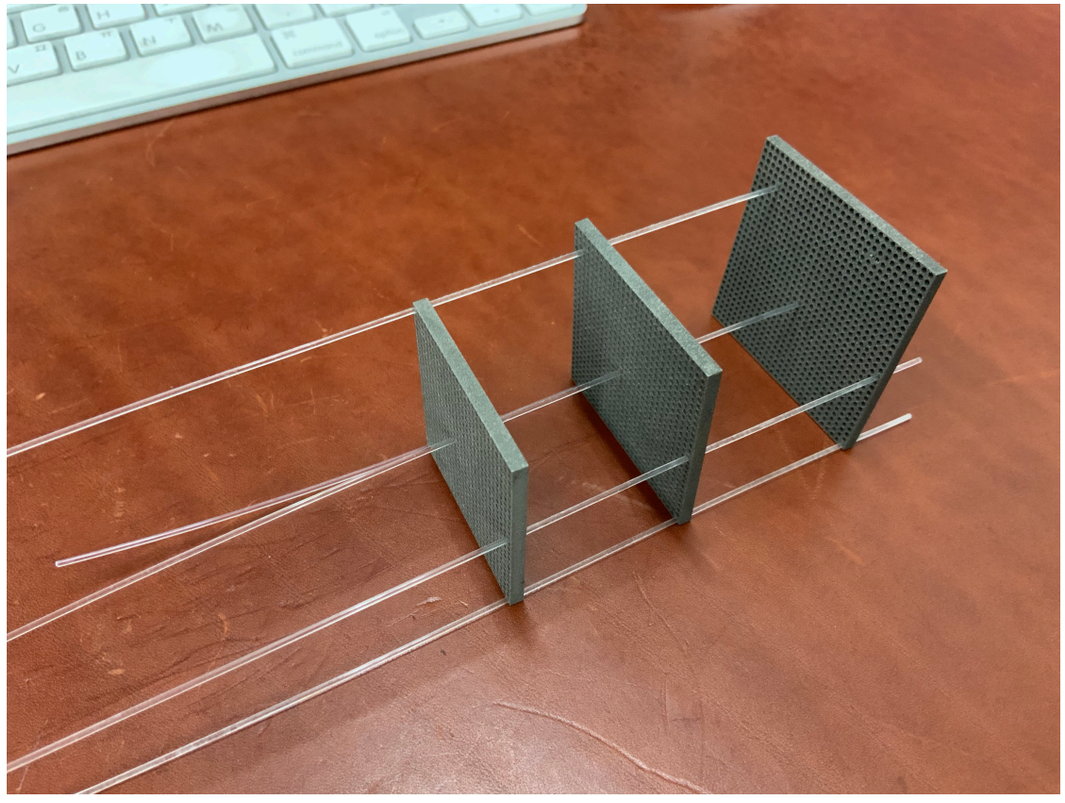
- W can have longer nuclear interaction length than Cu in same dimension => better jet energy resolution

- Test 3DP pieces produced with W (delivered today!)



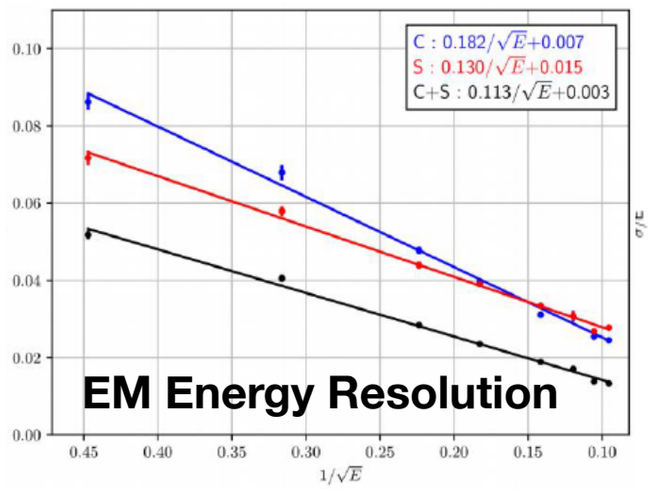


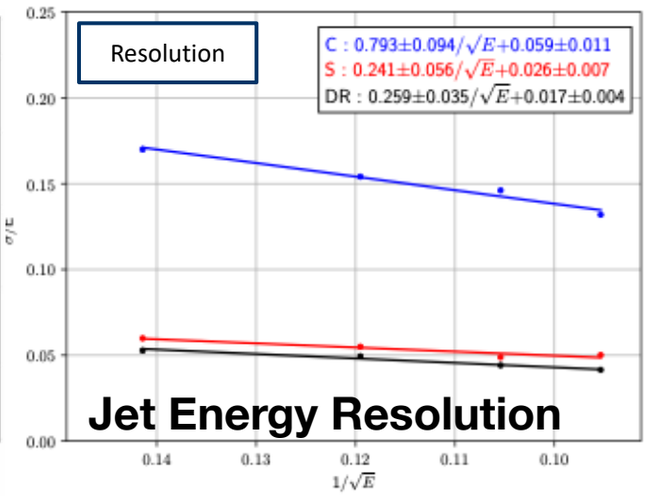


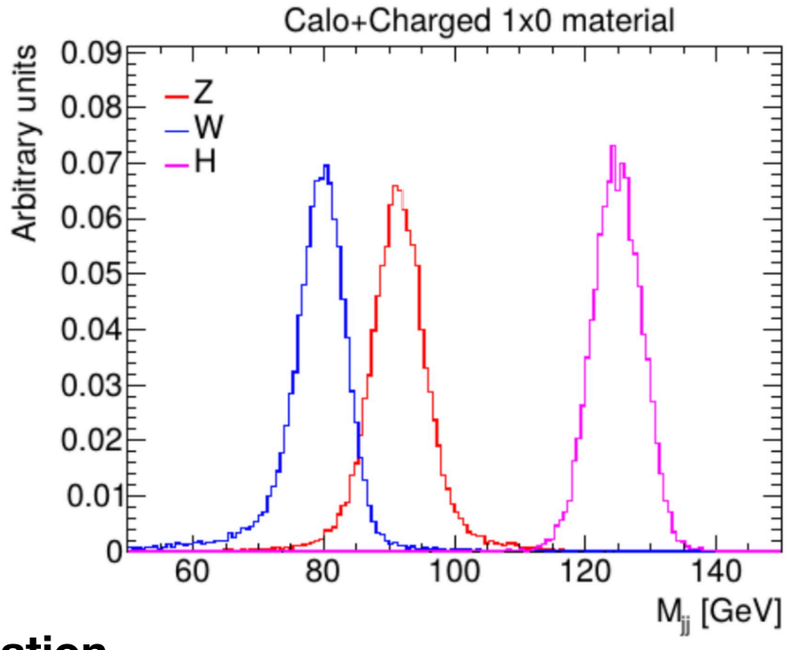


Simulation Studies

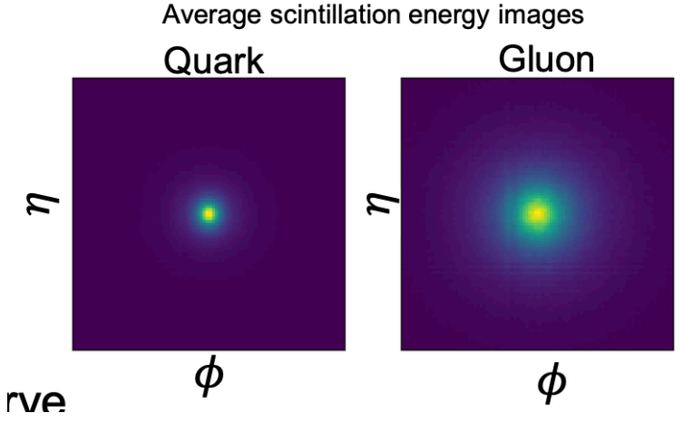
- Various simulation studies are performed
  - Using full GEANT4 simulation
- Excellent EM (~$11\,\%/\sqrt{E}$)and hadronic (~$26\,\%/\sqrt{E}$) energy resolutions
- Excellent separation among W, Z and H bosons in hadronic channel
- Jet and τ identification using ML

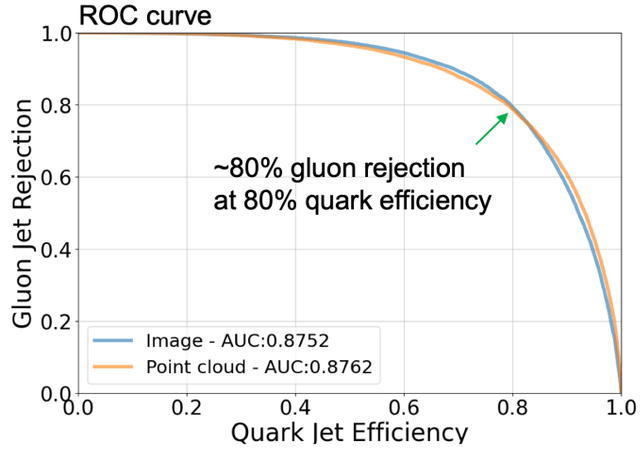




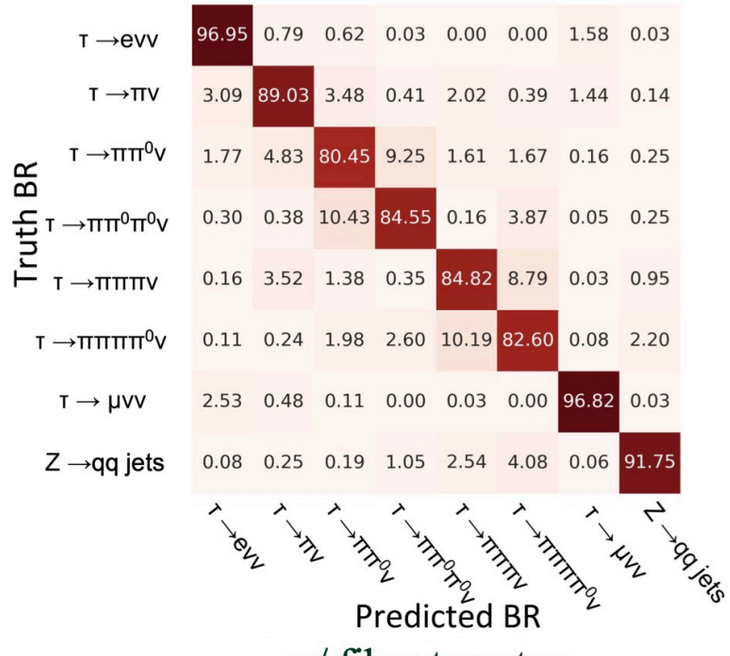


Jet identification





τ identification

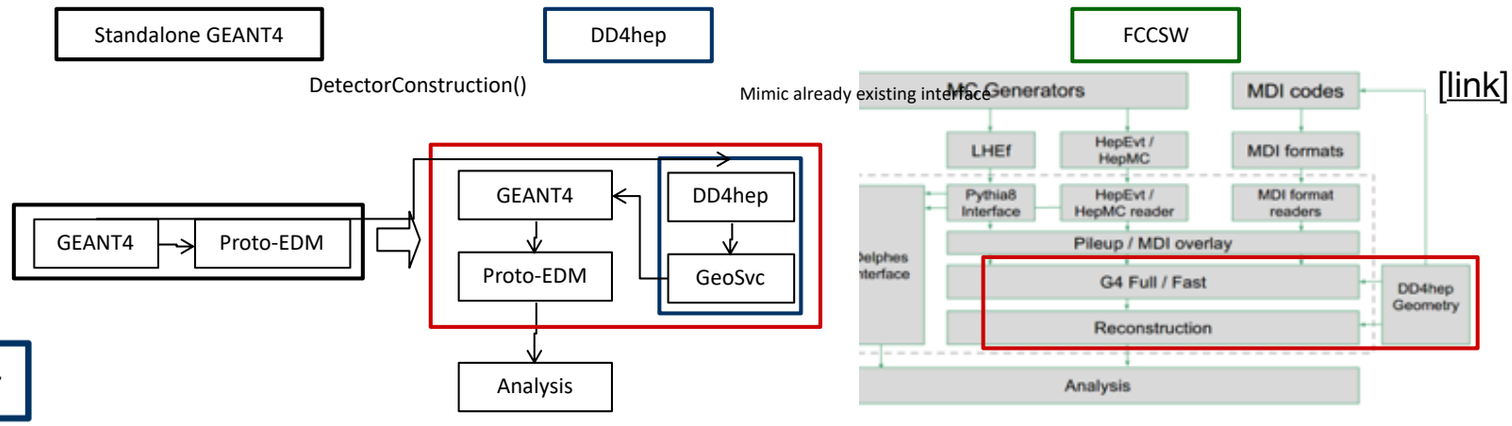


w/ fibre type tag

avg accuracy: 88.3% (w/#p.e. 90.8%)

DD4hep Migration

- Migrate dual-readout simulation framework to dd4hep
  - DD4hep is the next-generation standard of detector description
- Preliminary version is already provided to FCCSW team
  - Good agreement with GEANT4



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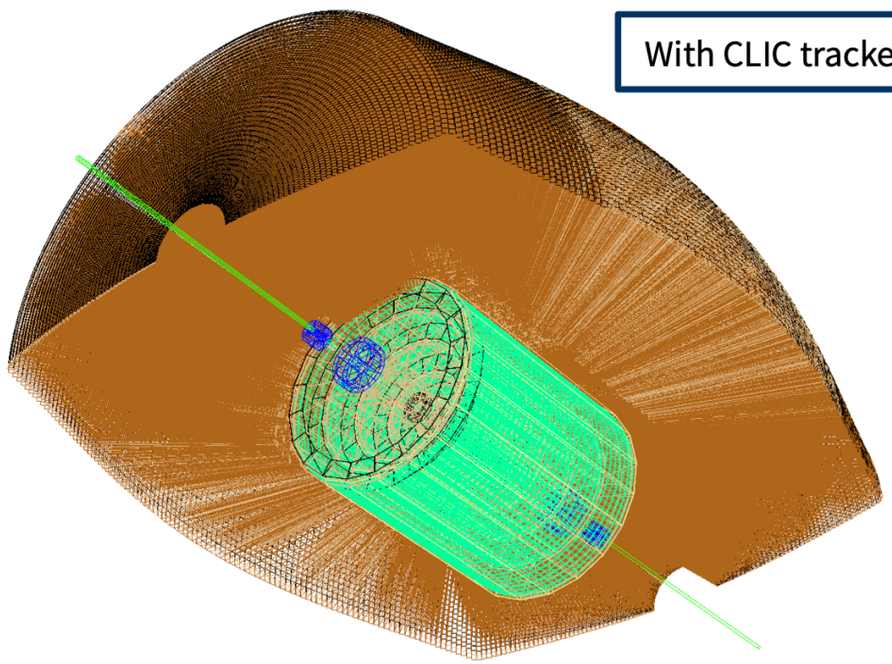

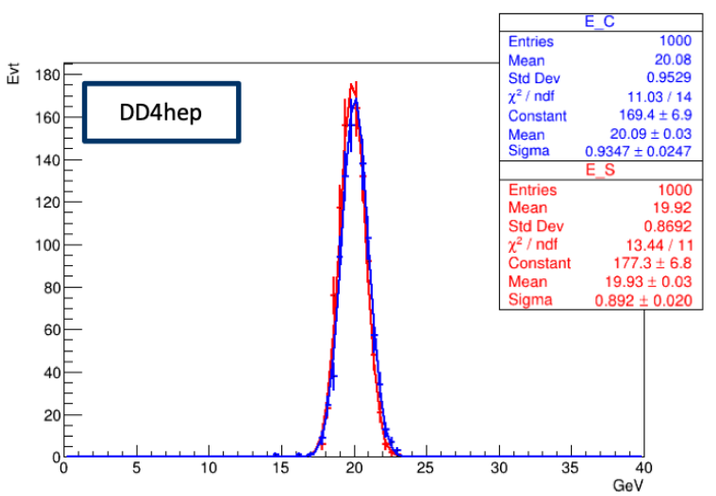

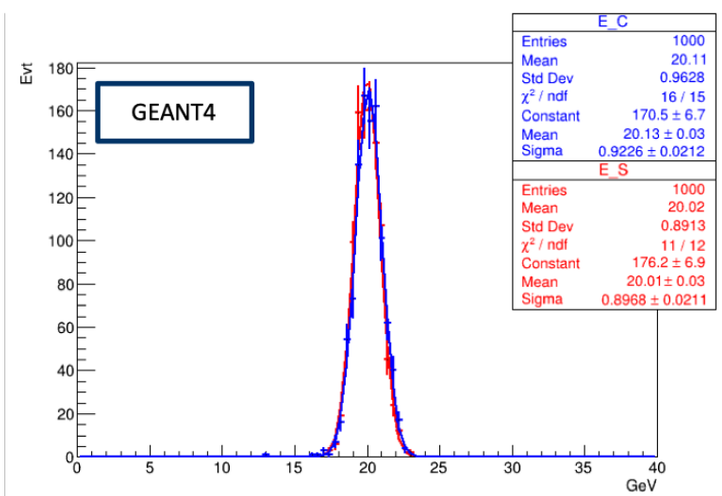

Summary

- Dual-Readout Calorimeter R&D project for future e^+e^- collider in Korea is very active
  - Calorimeter design for EIC project with Korea HI community is on-going
- Innovative 3D-printing module is on-going
  - Collaborating with world-leading 3D metal printing frontier companies
  - Prototype module design and production are underway, stay tune!