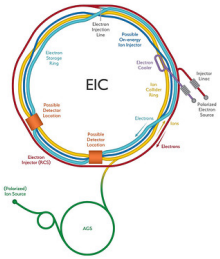


Calorimeter R&D in Korea for future collider projects: Past, Present and Future

Hwidong Yoo (Yonsei Univ.)

Seminar at IFJ PAN,
April 10, 2026

My Profile

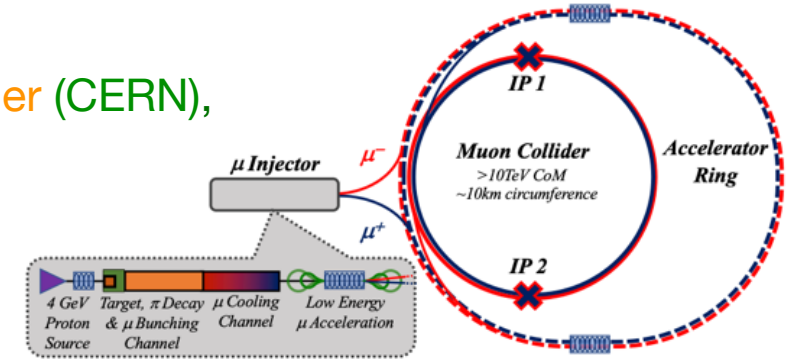
- Professional career
  - Ph.D., Brown University (2002-2008)
  - Postdoc, Purdue University (2008-2014)
  - (Endowed) Assistant/Associate Professor, Seoul National University (2014-2019)
  - Associate/full Professor, Yonsei University (2019-present)
    - University Fellow: Lee Youn Jae Fellow (2023-present)
    - Associate Dean for College of Science in Yonsei University (2024-2026)
    - Physics department chair (2026-presnt)
- Current memberships
  - Member of CMS collaboration, Switzerland (2008-present)
  - Member of DRDCalo collaboration, Switzerland (2024-present)
  - Member of ePIC collaboration, USA (2023-present)

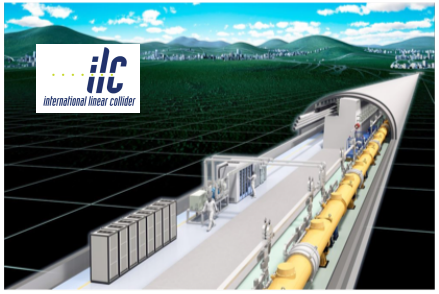
Highlight of Leaderships

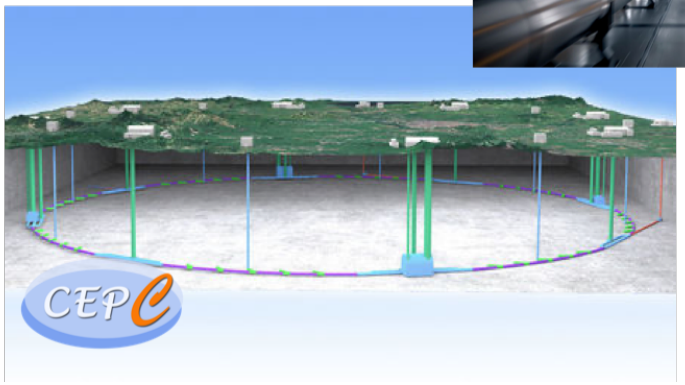
- Team leader of Yonsei University for CMS experiment (2019-present)
- CERN:
  - Delegate of non-member state (Asia-Pacific) in Advisory Committee of CERN Users (2018-present)
  - National Contact (S. Korea) for FCC project (2019-present)
- Proposal team member for DRD6 (2023-2024)
  - WP3 coordinator for DRDCalo (2026-present)
- US: Team leader of Korea-EIC consortium (2023-present)
  - DSL for Barrel Imaging Calorimeter in ePIC collaboration
  - Scientific Observer (S. Korea) for EIC Resource Review Board
- Japan: Belle II Scrutiny Committee member (2024-present)

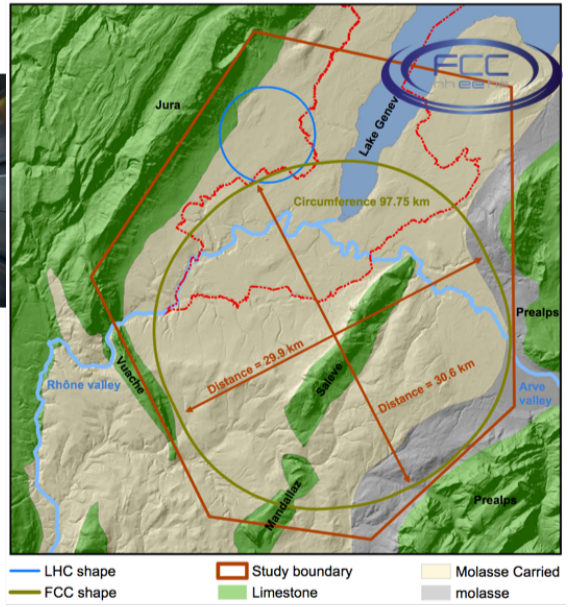
Future Collider Projects in HEP

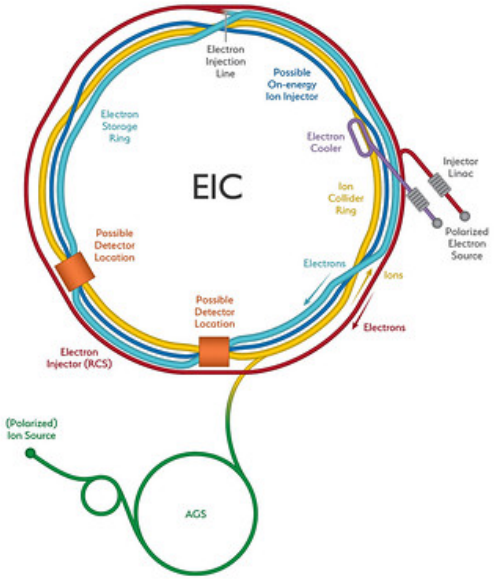
- Many next generation experiments are under discussion
  - Linear colliders: ILC (Japan), CLIC (CERN)
  - Circular colliders: **FCC-ee**/eh/hh, muon collider (CERN), CEPC/SPPC (China)
  - HI colliders: **EIC** (US)





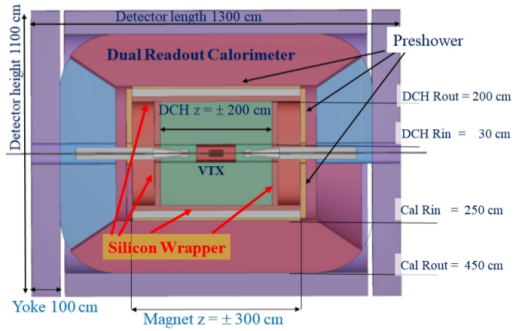


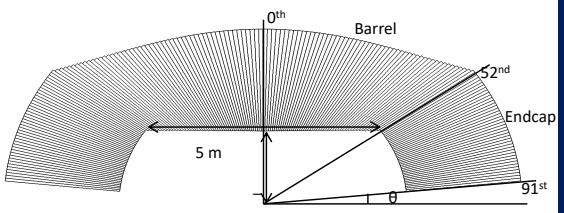




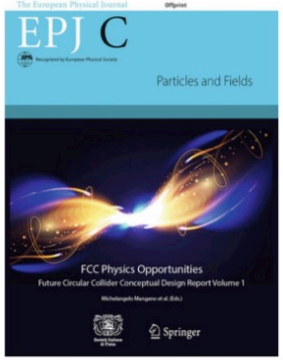
Initial Contributions for CDR

- Dual-readout calorimeter R&D team has contributed major role for CDRs of both CEPC and FCC projects (published in 2018)
  - Prof. Sehwook Lee (KNU), Prof. Jason Lee (UoS=>Yonsei), Prof. Hwidong Yoo (Yonsei U.)

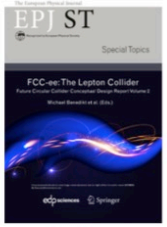




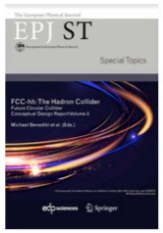
4 CDR volumes submitted to EPJ in December 2018.



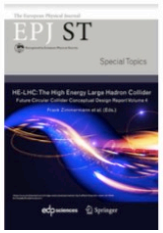
FCC Physics Opportunities



FCC-ee: The Lepton Collider

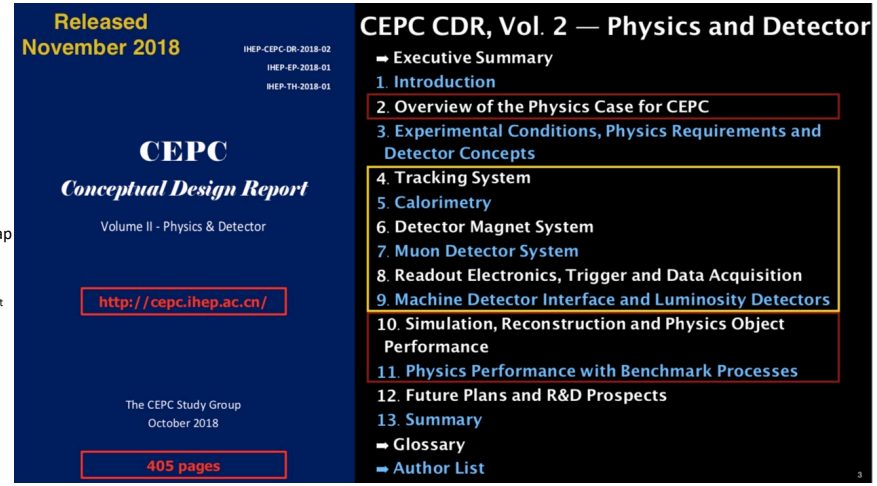


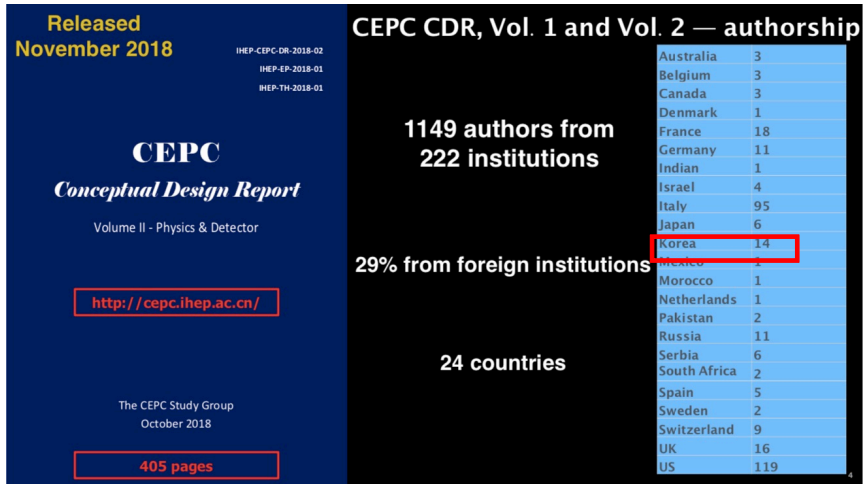
FCC-hh: The Hadron Collider



HE-LHC: The High Energy Large Hadron Collider

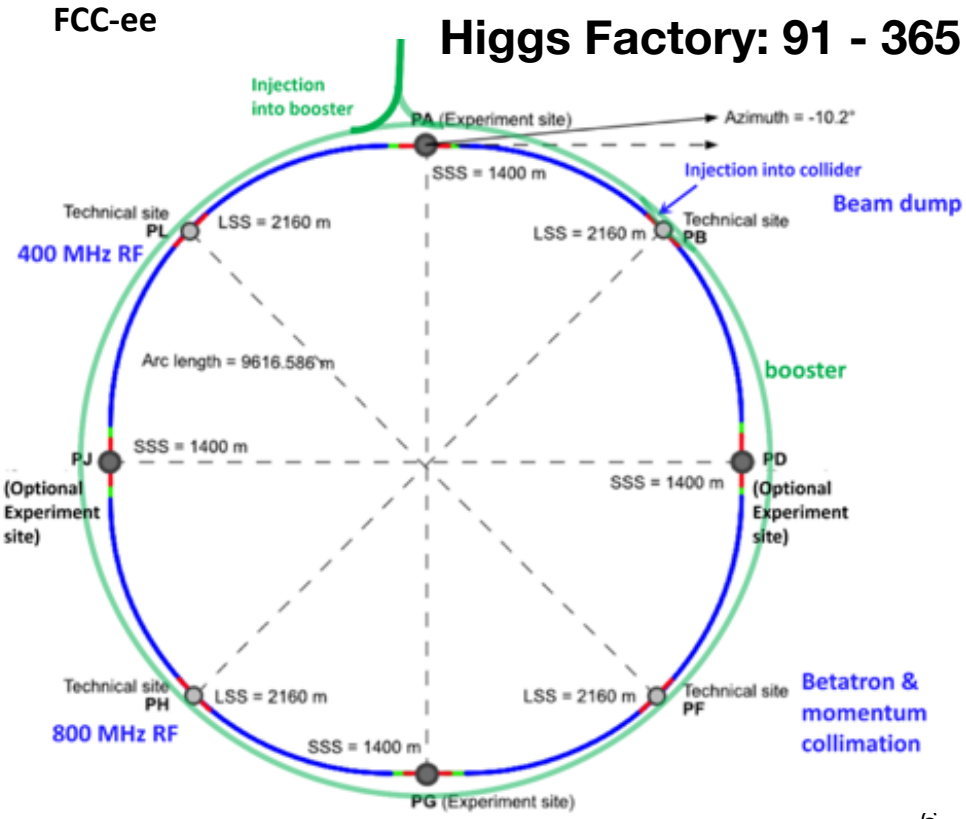
Copies can be requested at http://get-fcc-cdr.web.cern.ch

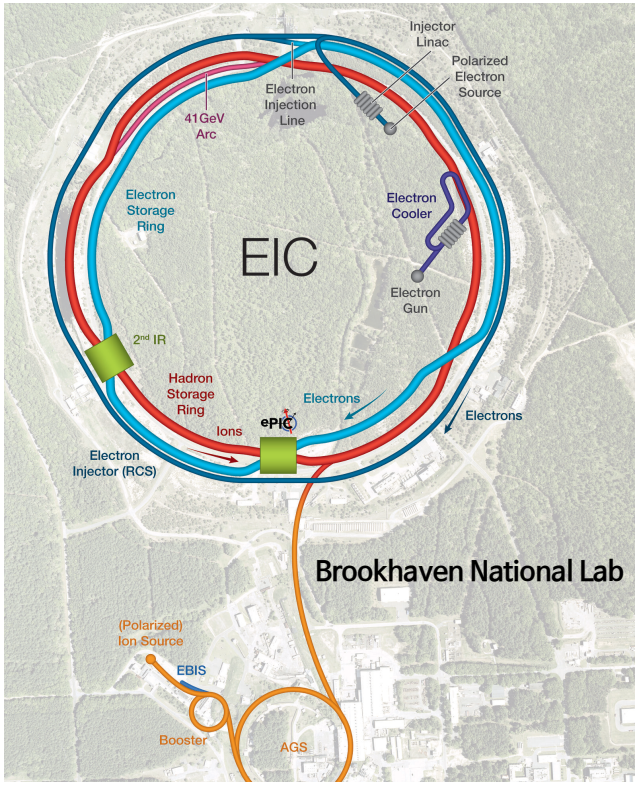


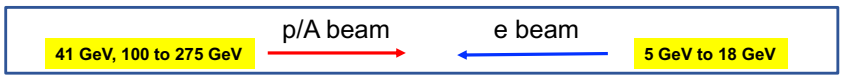


Introduction

- Calorimeter R&D projects in Korea: optical fiber-based calorimeter
  - FCC-ee (+CEPC) IDEA detector: **Dual-Readout Calorimeter**
  - EIC ePIC detector: **Barrel Imaging Calorimeter**



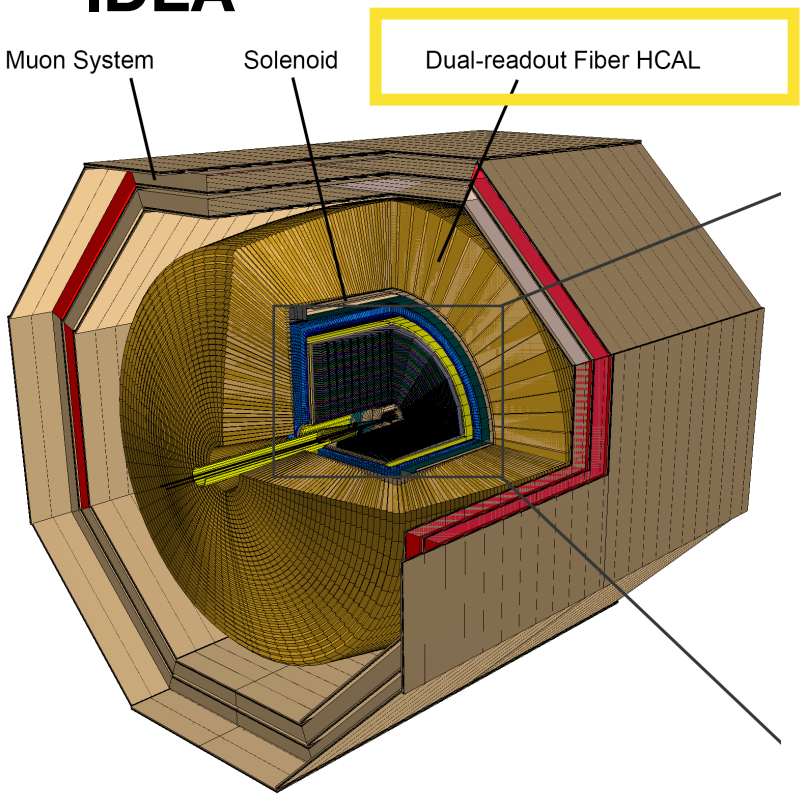




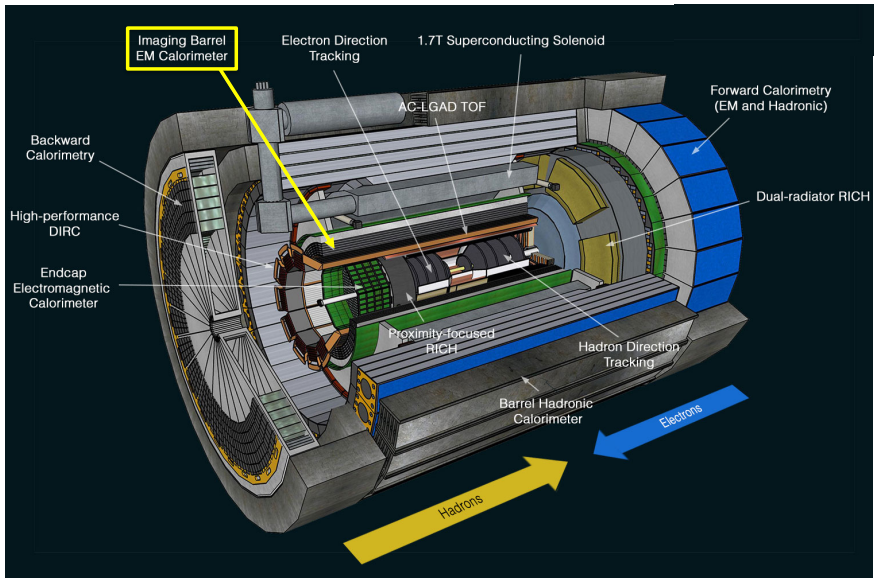
Introduction

- Calorimeter R&D projects in Korea: optical fiber-based calorimeter
  - FCC-ee (+CEPC) IDEA detector: Dual-Readout Calorimeter
  - EIC ePIC detector: Barrel Imaging Calorimeter

IDEA



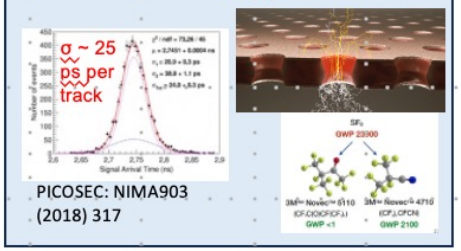
ePIC



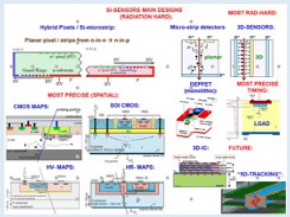
R&D on Detector Technologies

Implemented through Detector R&D (DRD) collaborations hosted at CERN, with review and oversight provided by DRD Committee (DRDC) and ECFA Detector Panel

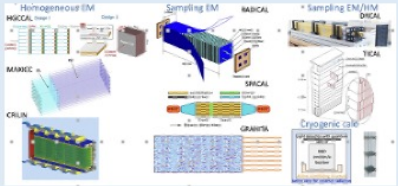
DRD1: Gaseous Detectors
Large · Fast · eco-friendly gases · MPGD, e.g. GEMs



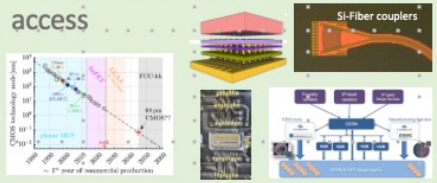
DRD3: Semiconductor Det.
Monolithic CMOS · LGADs · radiation hardness · interconns.



DRD6: Calorimetry
Energy resolution · High granularity · dual readout · particle flow · sandwich · optical

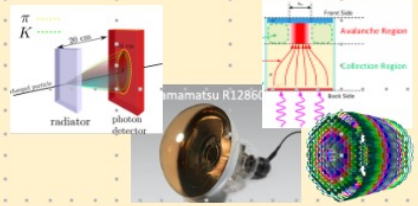


DRD7: Electronics
ADC/TDC IP Blocks · Opto-electronics · packaging · power · extreme environments · COTS · intelligence on detector · foundry access

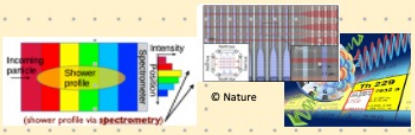


DRD2: Liquid Detectors
for Neutrinos · Dark Matter · 0νββ

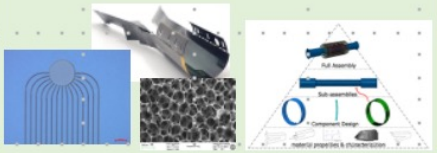
DRD4: Photon detectors
vacuum, solid-state (SiPM), hybrid single-photon and SciFi detectors · applications in PID and RICH



DRD5: Quantum Sensors
Quantum dots · superconduct. nanowires · bolometers · TES · MMC · nuclear clocks
First applications for DM, first projects in HEPP happening



DRD8: Mechanics
Ultra-thin beam pipes · CF foam and new materials · curved, retractable sensors · air & micro-channel cooling · eco-friendly cooling fluids · robots · augmented reality



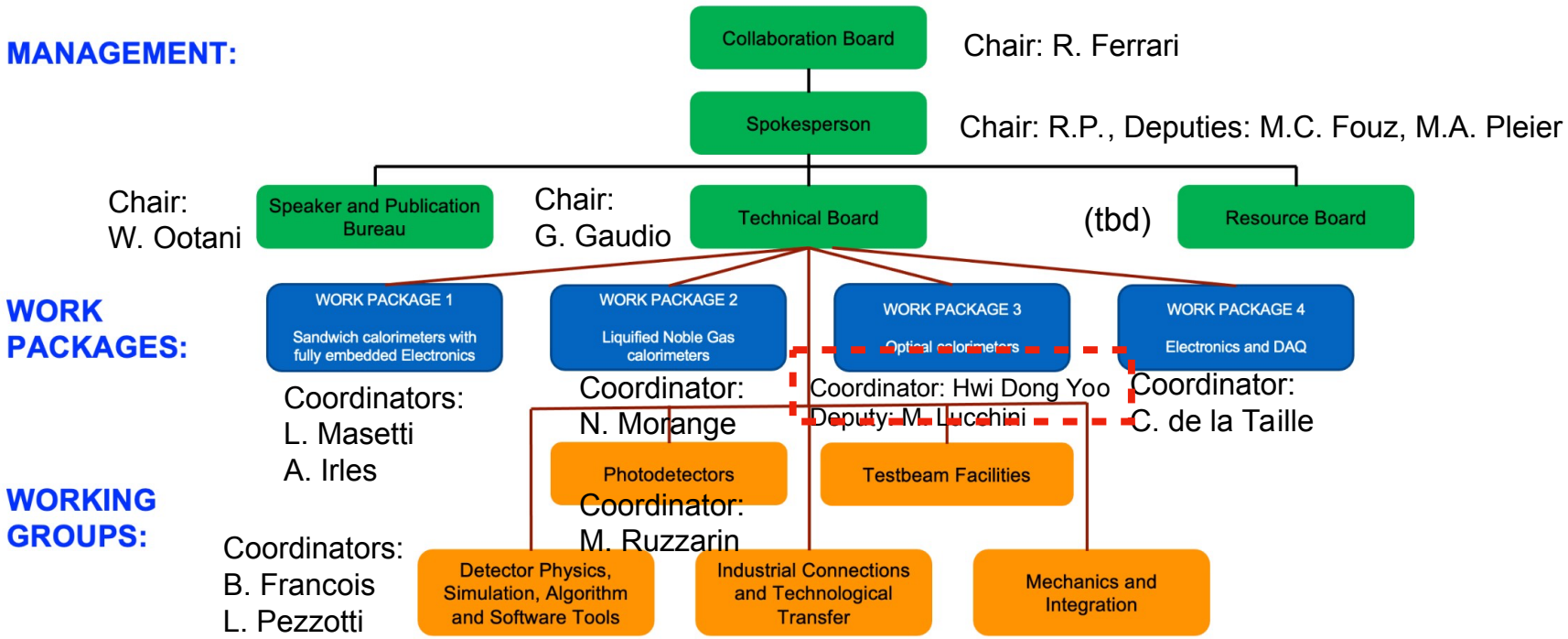
Courtesy T. Bergauer

DRDCalo Activities in Korea

- Hwidong Yoo
  - current WP3 coordinator
  - Calorimetry group co-coordinators in FCC Detector Concept Group

Project	Scintillator/WLS	Photodetector	DRDTs	Target
Task 3.1: Homogeneous and quasi-homogeneous EM calorimeters				
HGCCAL	BGO, LYSO	SiPMs	6.1, 6.2	e^+e^-
MAXICC	PWO, BGO, BSO	SiPMs	6.1, 6.2	e^+e^-
Crilin	PbF_2, PWO-UF	SiPMs	6.2, 6.3	$\mu^+\mu^-$
OREO	oriented PWO-UF	SiPMs	6.2, 6.3	$e^+e^-/\mu^+\mu^-$
Task 3.2: Innovative Sampling EM calorimeters				
GRAiNITA	$ZnWO_4$, BGO	SiPMs	6.1, 6.2	e^+e^-
SpaCal	GAGG, organic	MCD-PMTs,SiPMs	6.1, 6.3	e^+e^-/hh
RADiCAL	LYSO, LuAG	SiPMs	6.1, 6.2, 6.3	e^+e^-/hh
Task 3.3: (EM+)Hadronic sampling calorimeters				
DRCal	PMMA, plastic	SiPMs, MCP	6.2	e^+e^-
TileCal	PEN, PET	SiPMs	6.2, 6.3	e^+e^-/hh
Task 3.4: Materials				
ScintCal	-	-	6.1, 6.2, 6.3	$e^+e^-/\mu^+\mu^-$/hh
CryoDBD Cal	TeO, ZnSe, LiMoO NaMoO, ZnMoO	n.a.	-	DBD experiments

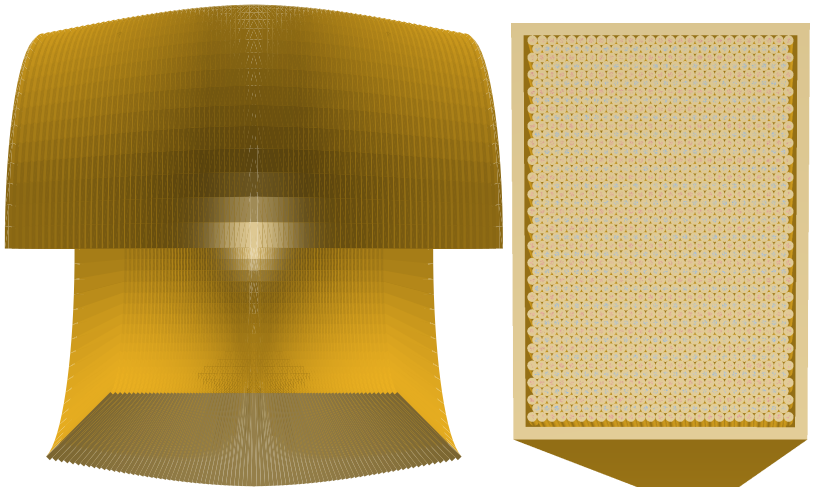
Table 2: Overview of R&D activities on optical calorimeter concepts.



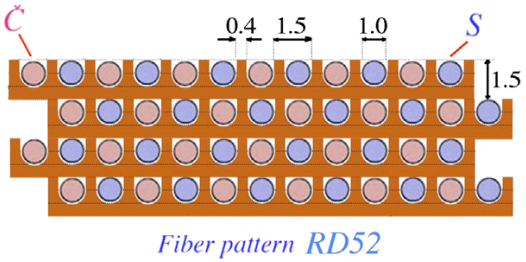
Part I: Dual-Readout Calorimeter for FCC-ee

Dual-Readout Calorimeter (DRC)

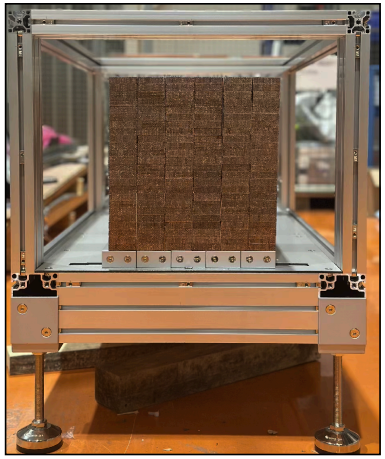
- FCC-ee (+CEPC) IDEA detector: Dual-Readout Calorimeter

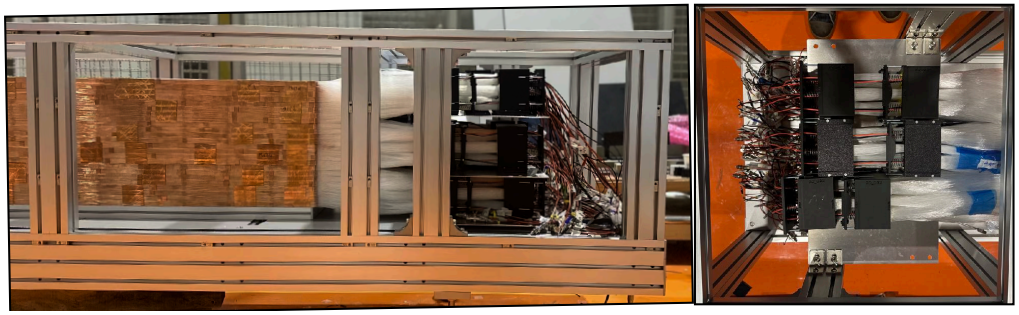


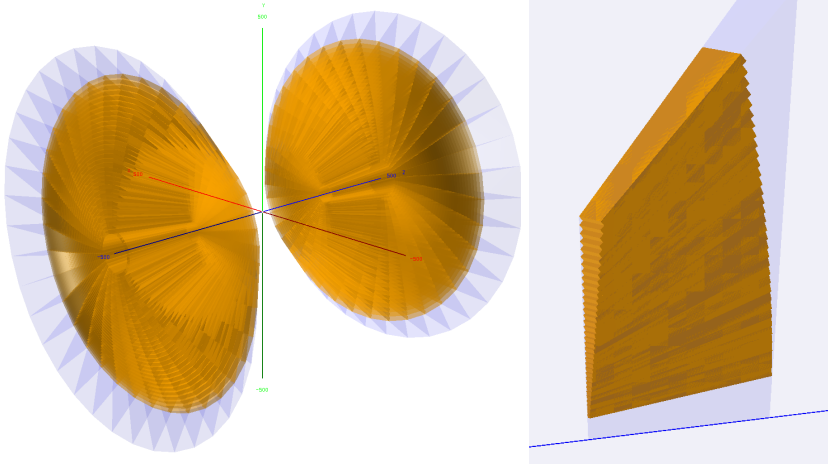
gure 29: Barrel region of the dual-readout calorimeter, with a few towers tal
t for visualization purposes (left). Backside of one tower with the assembly of tul
d the support structure around them, forming one tower (right).



S: Kurary SCSF-78
C: Mitsubishi SK-40

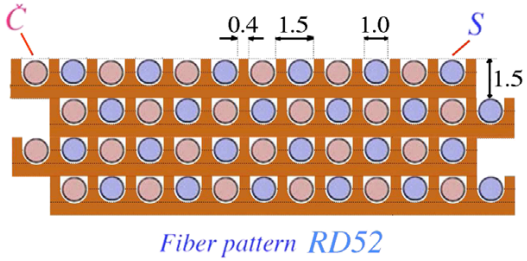






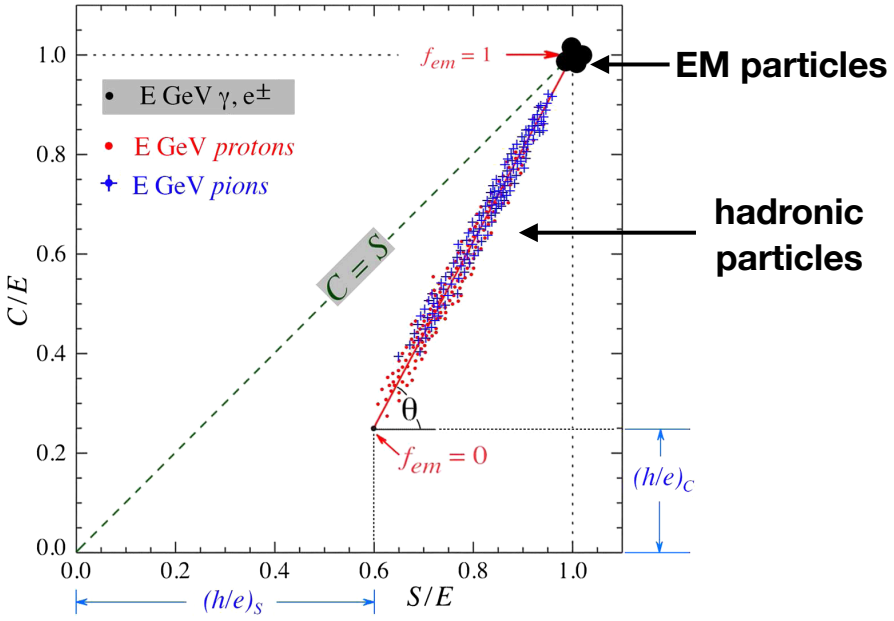
Dual-Readout Calorimeter (DRC)

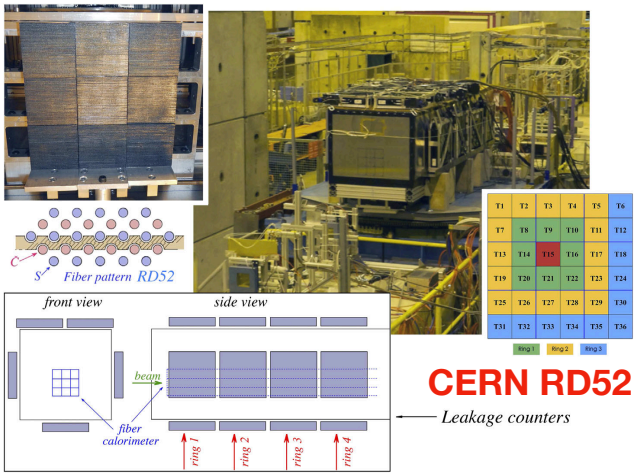
- DRC offers high-quality energy measurement for both EM particles and hadrons
  - DRC consists of two different optical fibers (S, C) in a single component
  - The main culprit of poor hadronic energy resolution is fluctuations of the EM shower components of hadron showers (f_{em})
  - f_{em} can be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

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

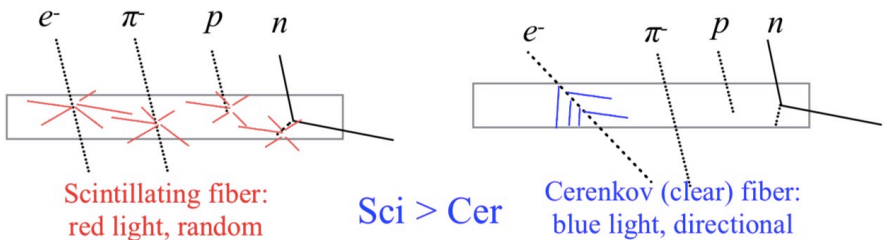




CERN RD52 experiment

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

Signal generation: Scintillating & Cerenkov fibers



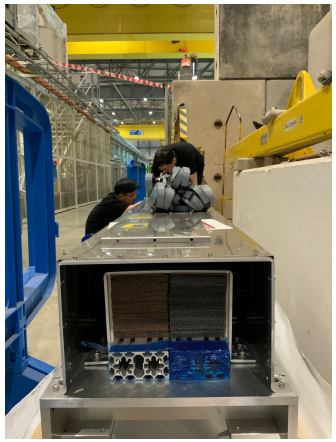
Scintillating fiber: red light, random

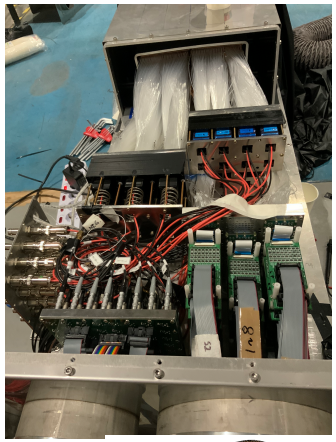
Sci > Cer

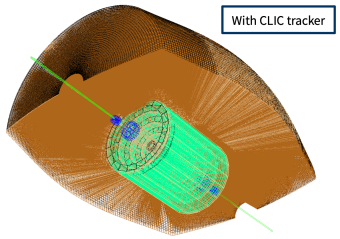
Cerenkov (clear) fiber: blue light, directional

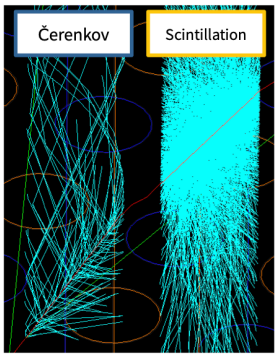
Status of DRC R&D in Korea

- We are doing all aspects of the DRC R&D
  - Module building
  - Electronics system
  - DAQ system
  - Data analysis framework
  - Test-beam experiments at CERN
  - Full/fast GEANT4 simulation framework (standalone, key4hep)
  - Performance studies using simulation







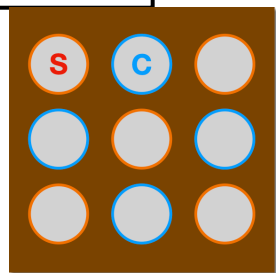


Important for a longitudinally unsegmented calorimeter

9 institutes participates DRC projects in Korea

Module Building in Korea

- Dual-readout calorimeter (DRC) from Korea DRC group:
  Two optical fibers (S and C) with **Cu absorber**
  - Various Cu forming was studied and tested for the last few years
  - Test beam experiment has been performed at CERN SPS or PS **since 2022**



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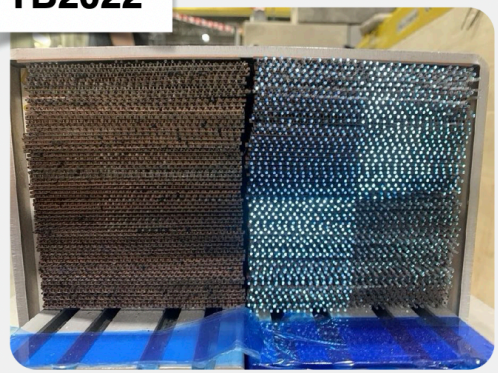
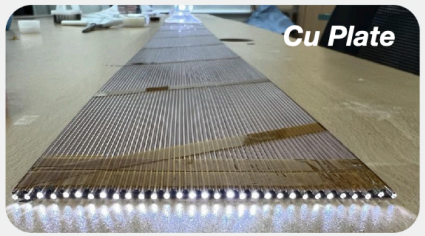
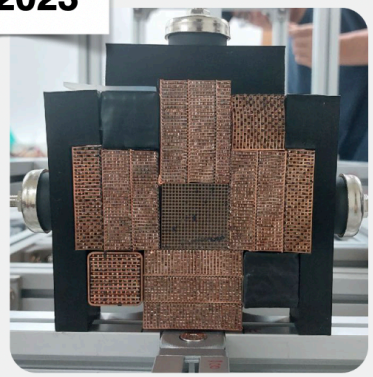
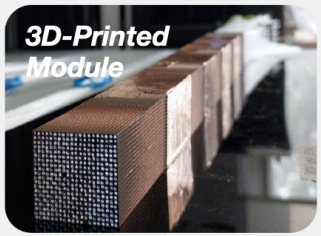




EM Performance Study
Cu Plate
~3.5 ρ_M, > 30 X_0
PMT, SiPM
10 ~ 120 GeV e^+
@SPS H8

TB2023





Low Energy EM Performance Study
3D-Printed Module, SFHS, Lego-Like
~3 ρ_M, ~17 X_0
PMT, MCP-PMT
0.5 ~ 5 GeV e^+
@PS T9

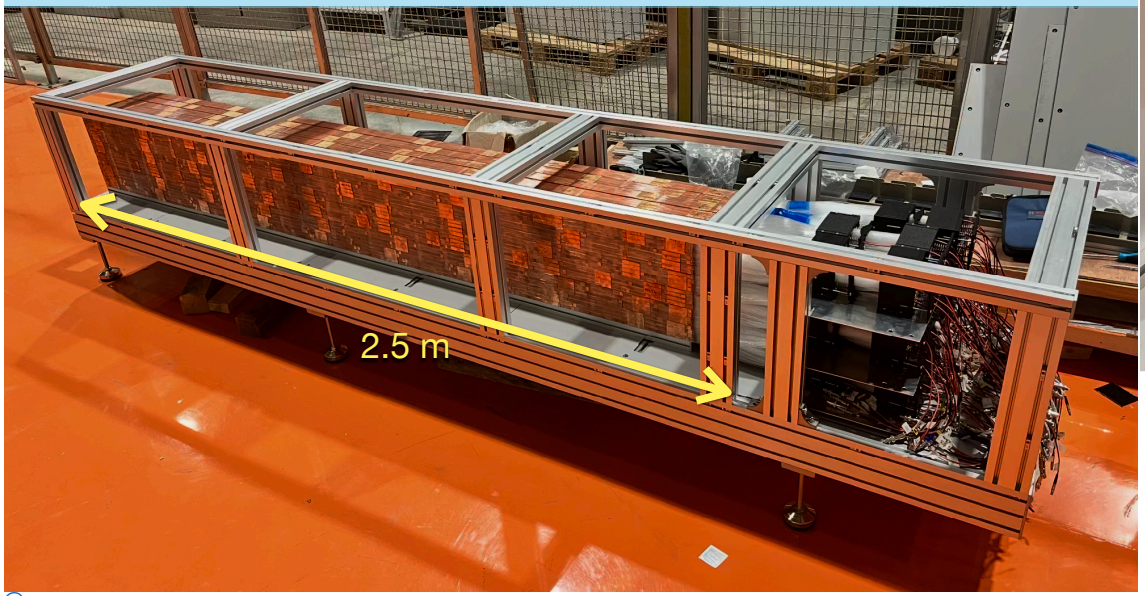
TB2024 & TB2025

EM&Hadron Performance Study
SFHS, Cu Plate
~90% lateral hadron deposit, ~10 λ_{int}
PMT, MCP-PMT, SiPM
10~120 GeV e^+, **20~120 GeV π^+**
@SPS H8

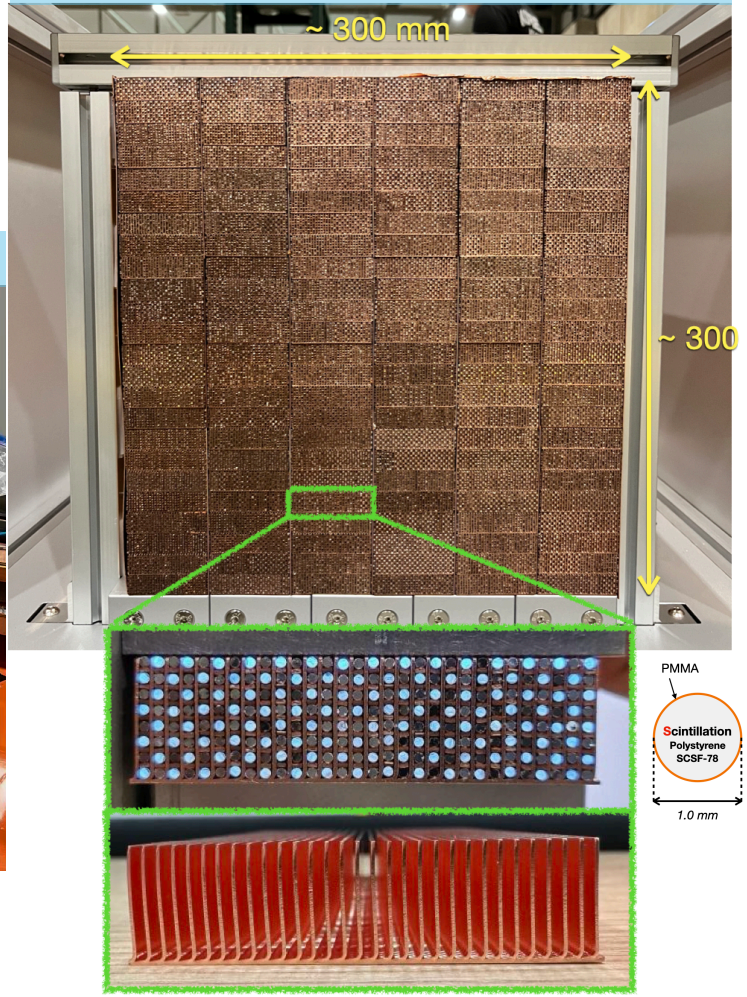
Module Building in Korea

- **Module** for 2026 test beam experiment
  - Baseline: the module used in TB2025
    - Constructed with skived fin heat sink (SFHS) shape **Cu** + alternatively accumulated **optical fibers**
  - Dimension: 30 cm × 30 cm × 2.5m
    - Longitudinally unsegmented
    - Depth: **~10** λ_{int}
    - a lateral hadronic shower containment: 93.6% (π, E=60 GeV)

Side-view



Front-view

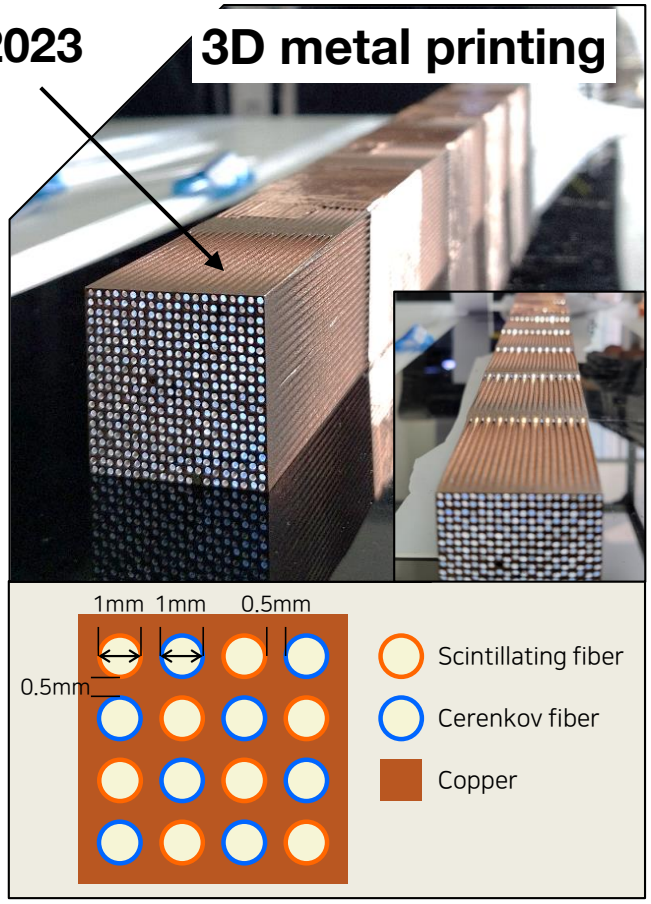


Cu Forming R&D

- Try to find a solution for mass production with local mechanical engineering experts and manufacturers
  - Skiving fin heatsink, 3D metal printing, drilling, etc.

TB2023

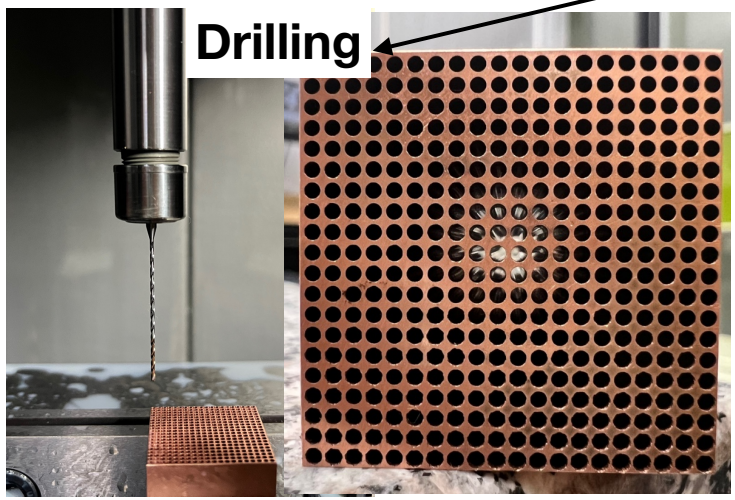
3D metal printing

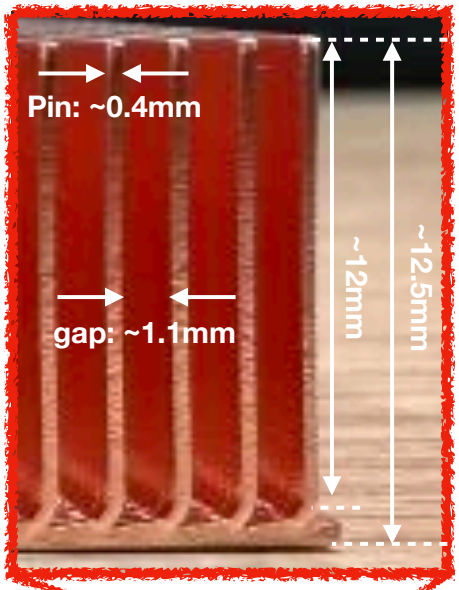


Structure of 3D-Printed Module

Current R&D

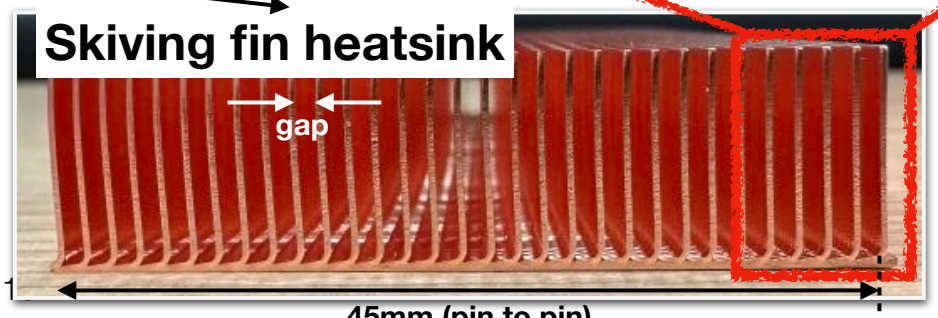
Drilling



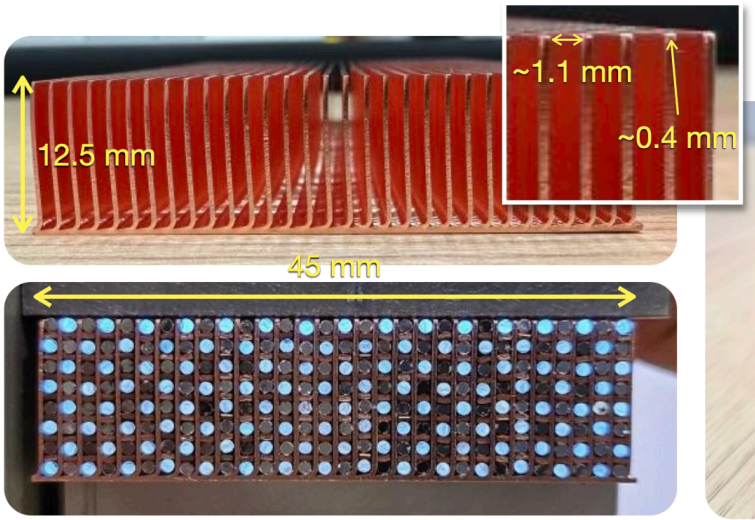


TB2024/2025

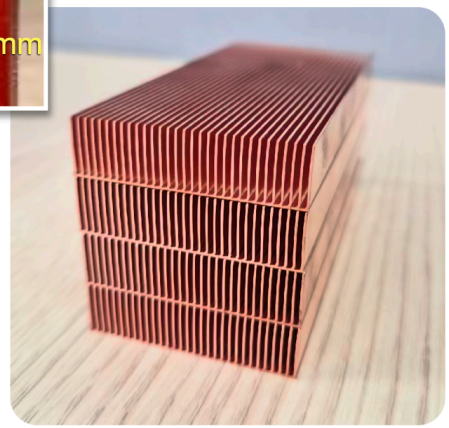
Skiving fin heatsink



Skiving Fin Heatsink Module

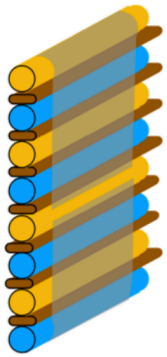


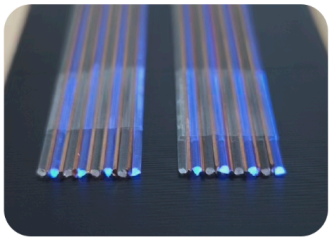
Tower Unit (x 36)



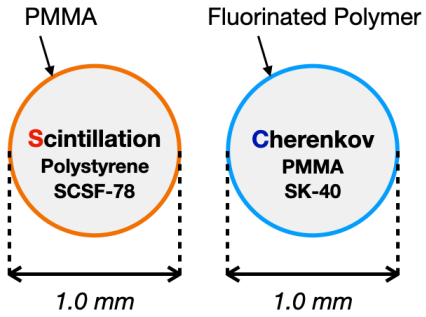
S C

- ***Cu* + *Optical Fiber*** (SCSF-78, SK-40) geometry.
  total ~28 km
- 30 cm × 30 cm × 250 cm (**~*10* λ_{int}**)
- Longitudinally ***unsegmented***

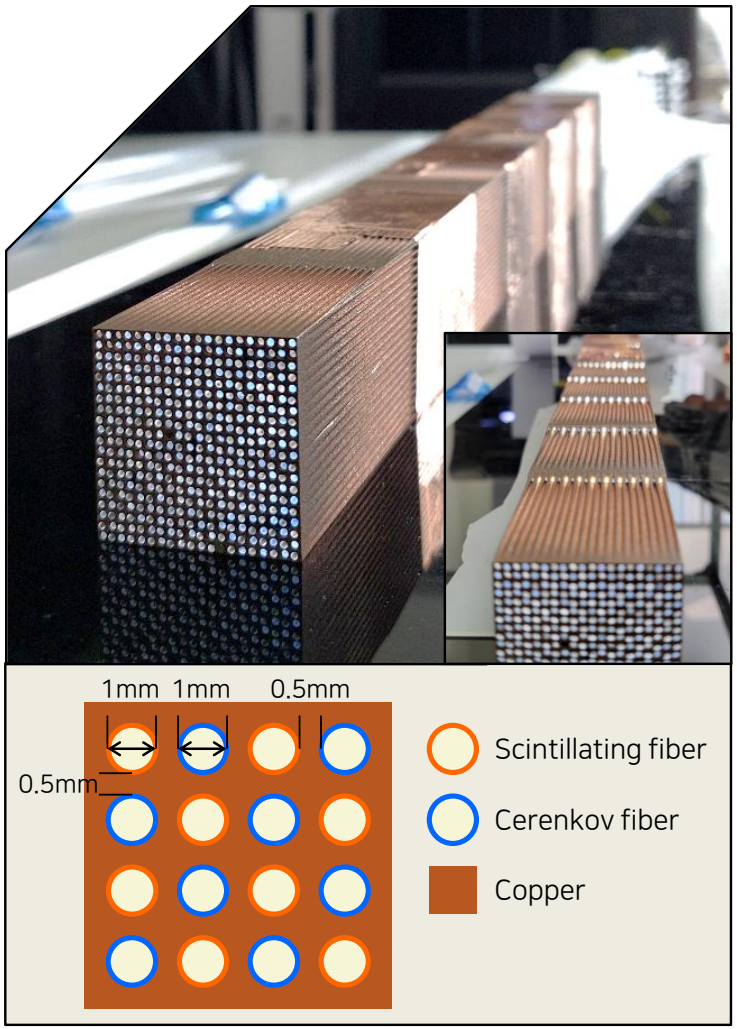




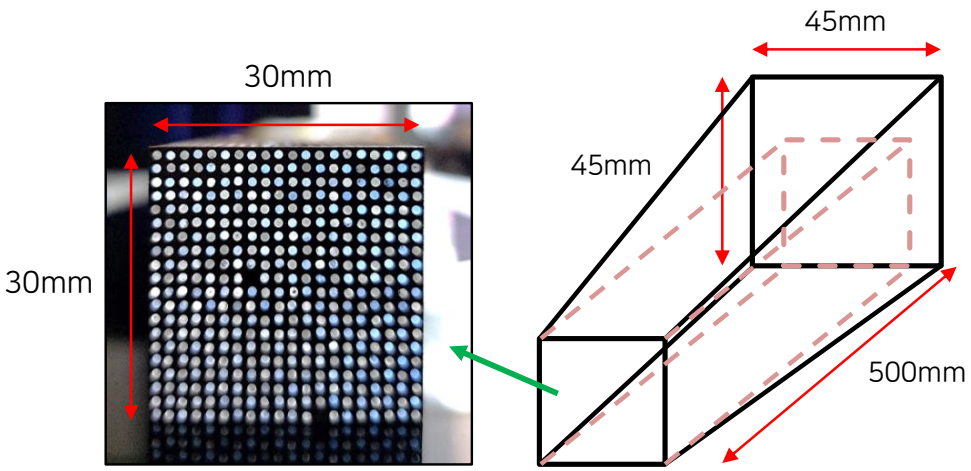
Layer Unit (x 1152)



Cu Forming: 3D Metal Printing



Structure of 3D-Printed Module



Front Side

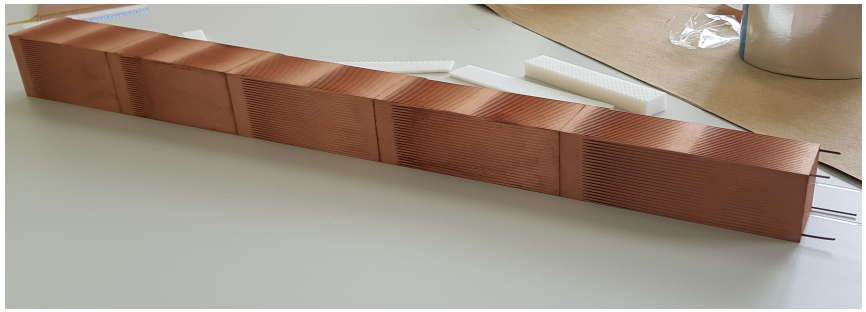
Projective geometry

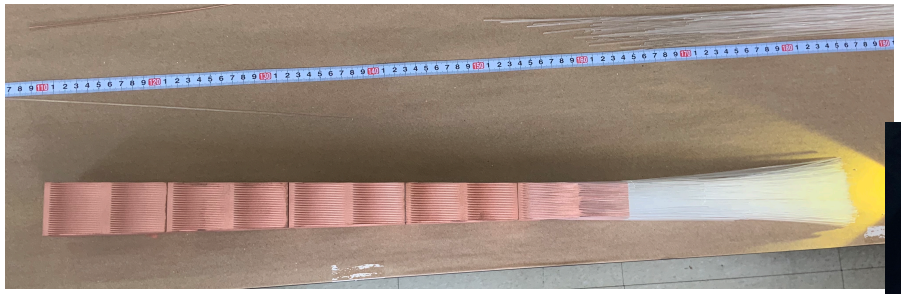
- 3D-Printed module is made using 3D metal printing technology.
- It has projective geometry as a prototype of 4π geometry aiming on FCC IDEA detector.
- Total 812 (S 406, C 406) fibers are implemented in copper.
- Fibers are implemented on side of the module, following the projective slope by varying length.

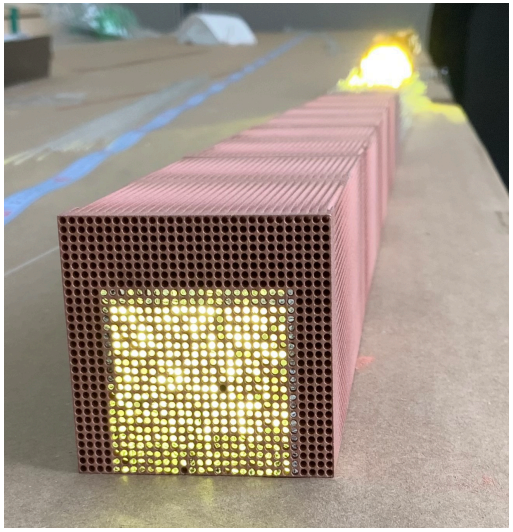
3D Metal Printing

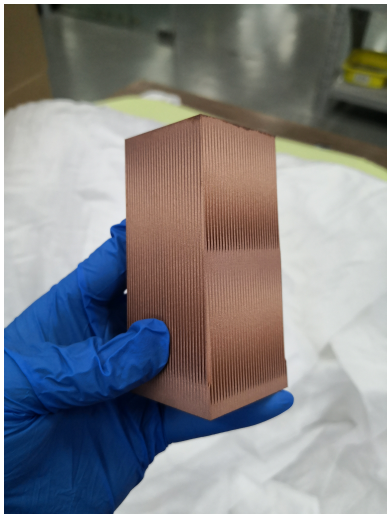
with Harvestance

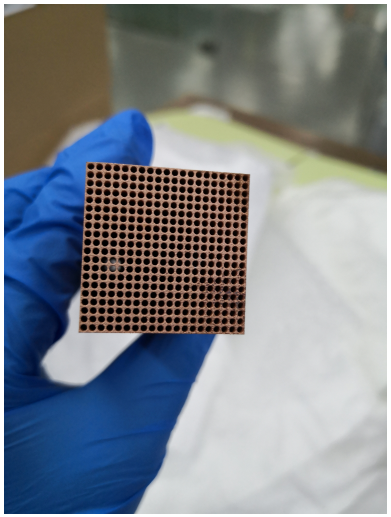
- 1st projective DRC module!











INSIDE 3D PRINTING SEOUL CONFERENCE & EXPO

Drilling Module

- “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