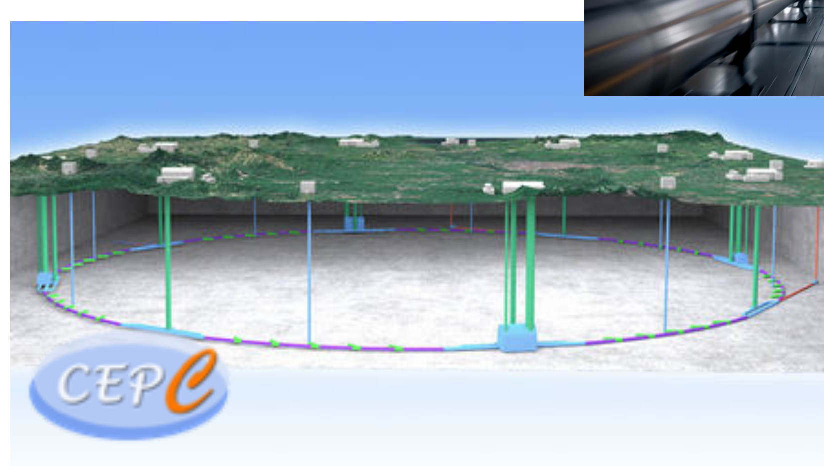
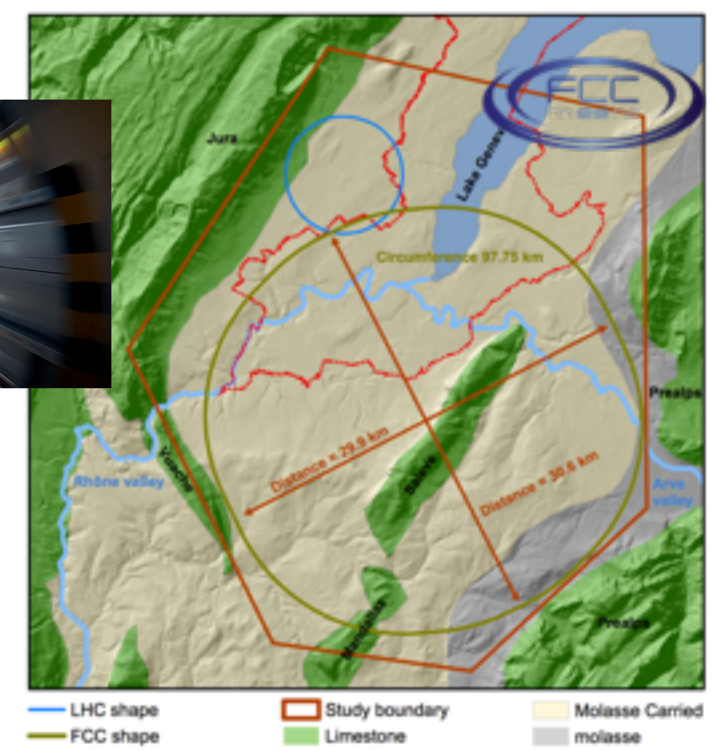
Dual-Readout Calorimeter R&D in Korea

Hwidong Yoo (Yonsei Univ.)

On behalf of
the Dual-Readout Calorimeter Team

Supported by www.kisti.re.kr

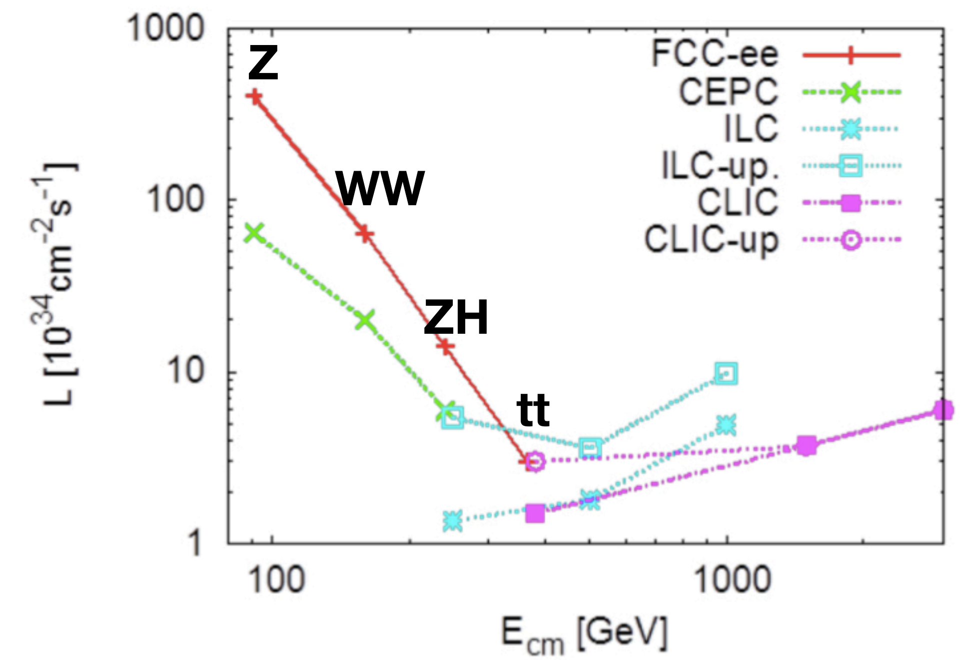


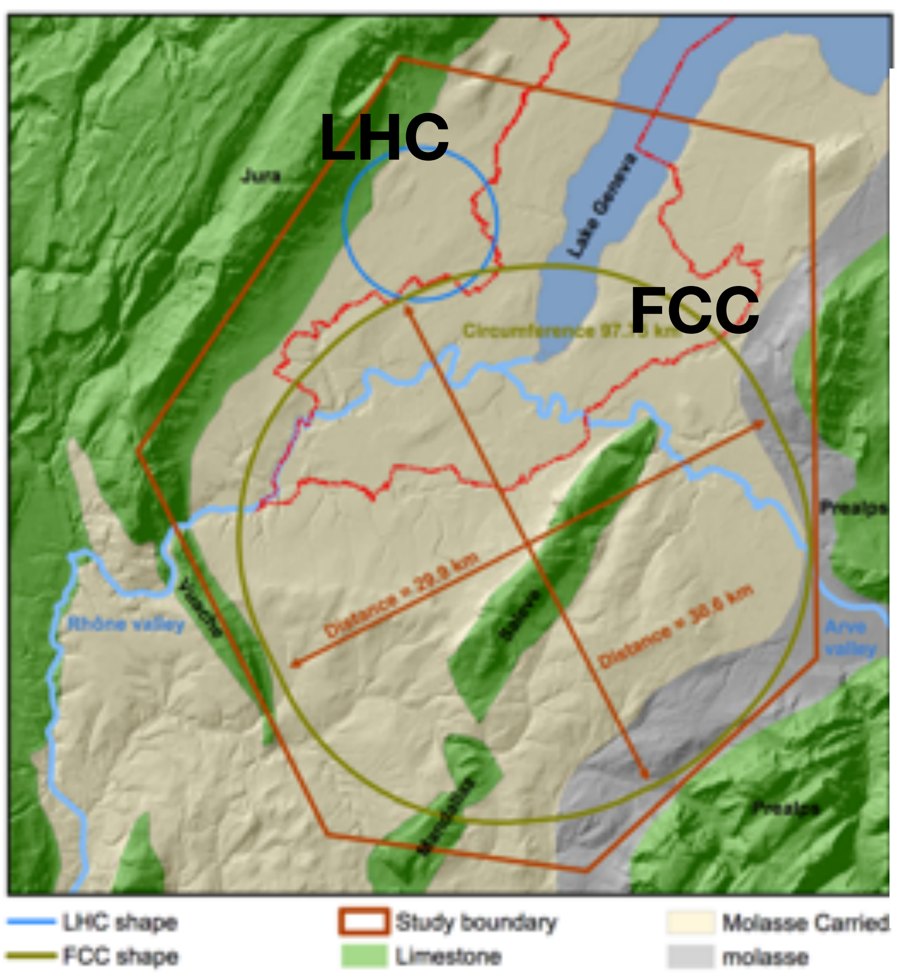


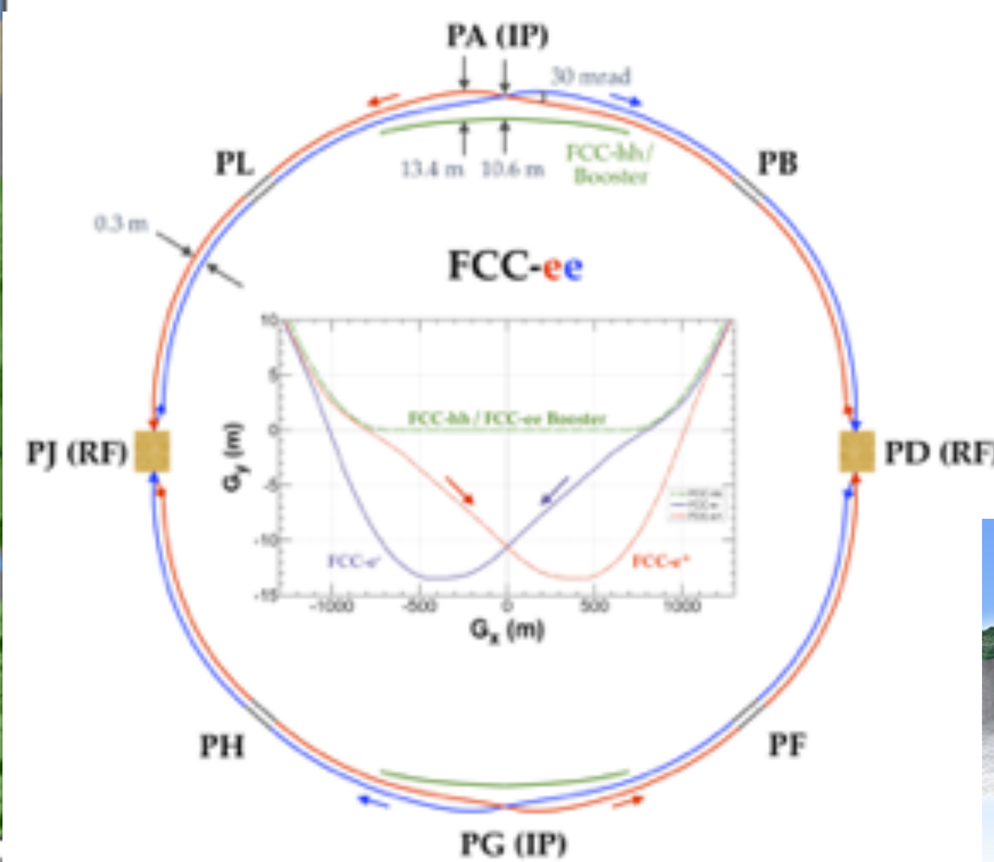
TOP detector seminar,
Mar. 2, 2021

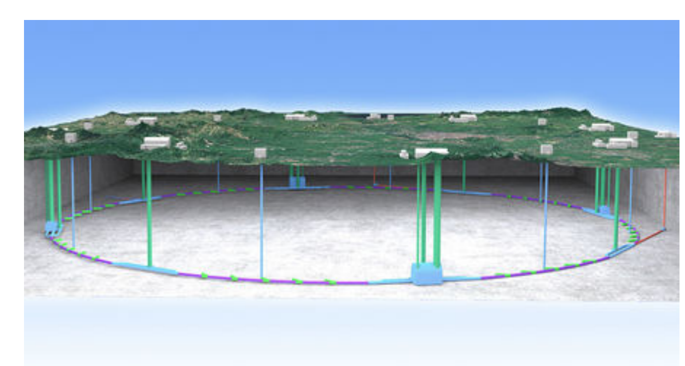
CEPC, FCC-ee Projects

- Programs in two phase
  - Phase 1: FCC-ee (Z, W, H, tt) as Higgs, EW and top factory
  - Phase 2: FCC-hh (~100 TeV) as natural continuation at energy frontier (ion an eh options)



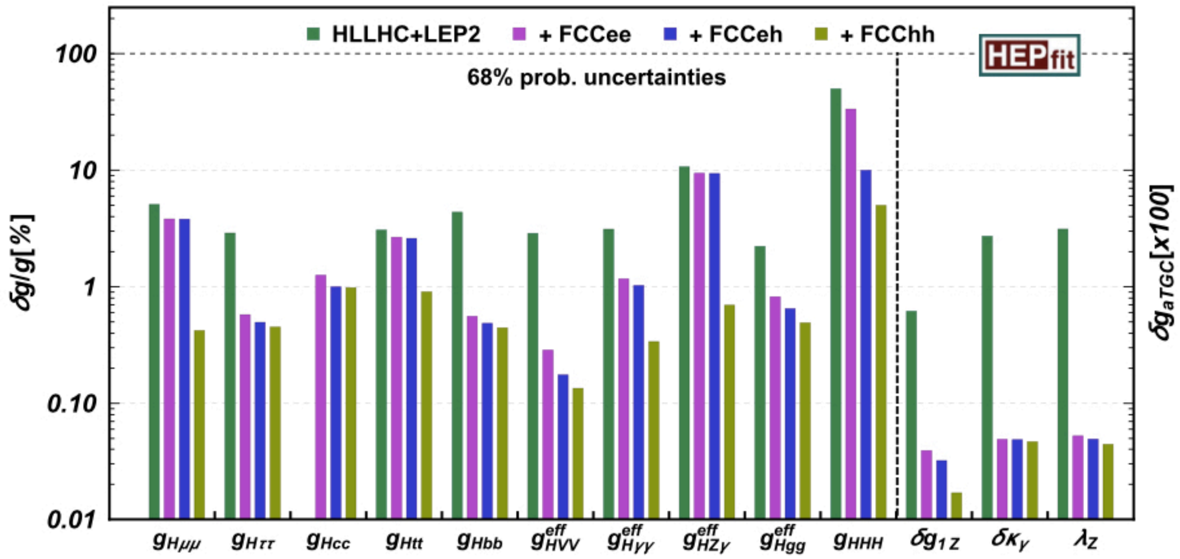


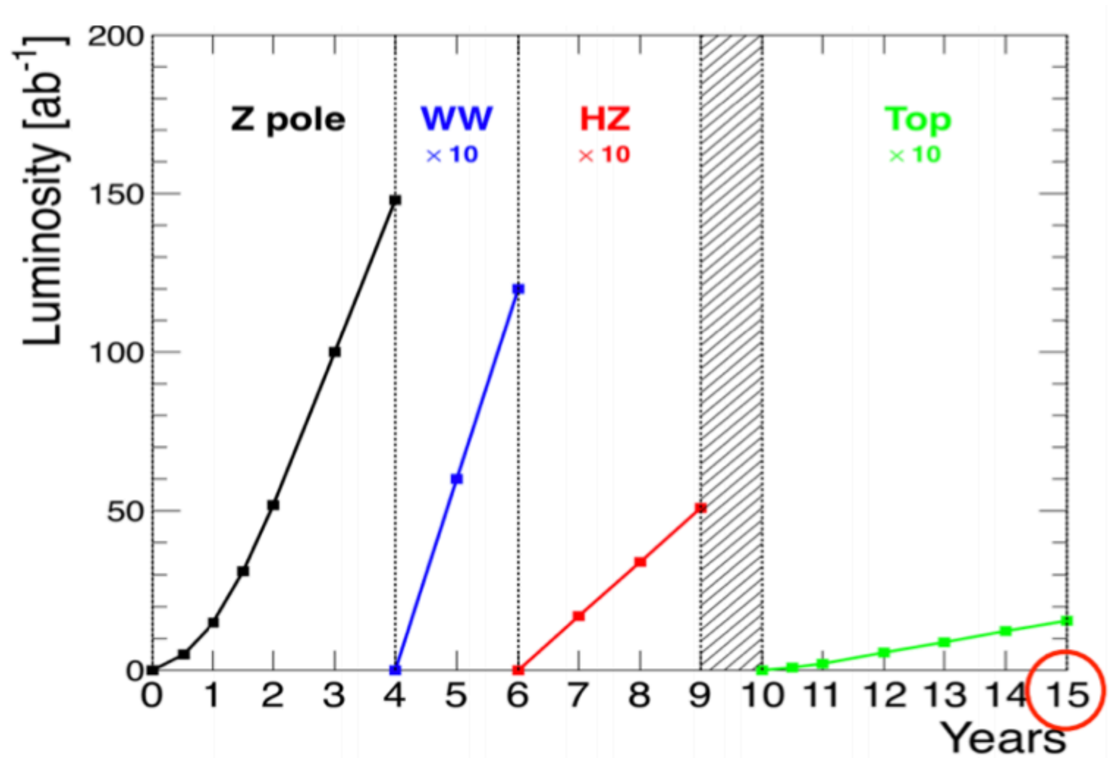




CEPC, FCC-ee Projects

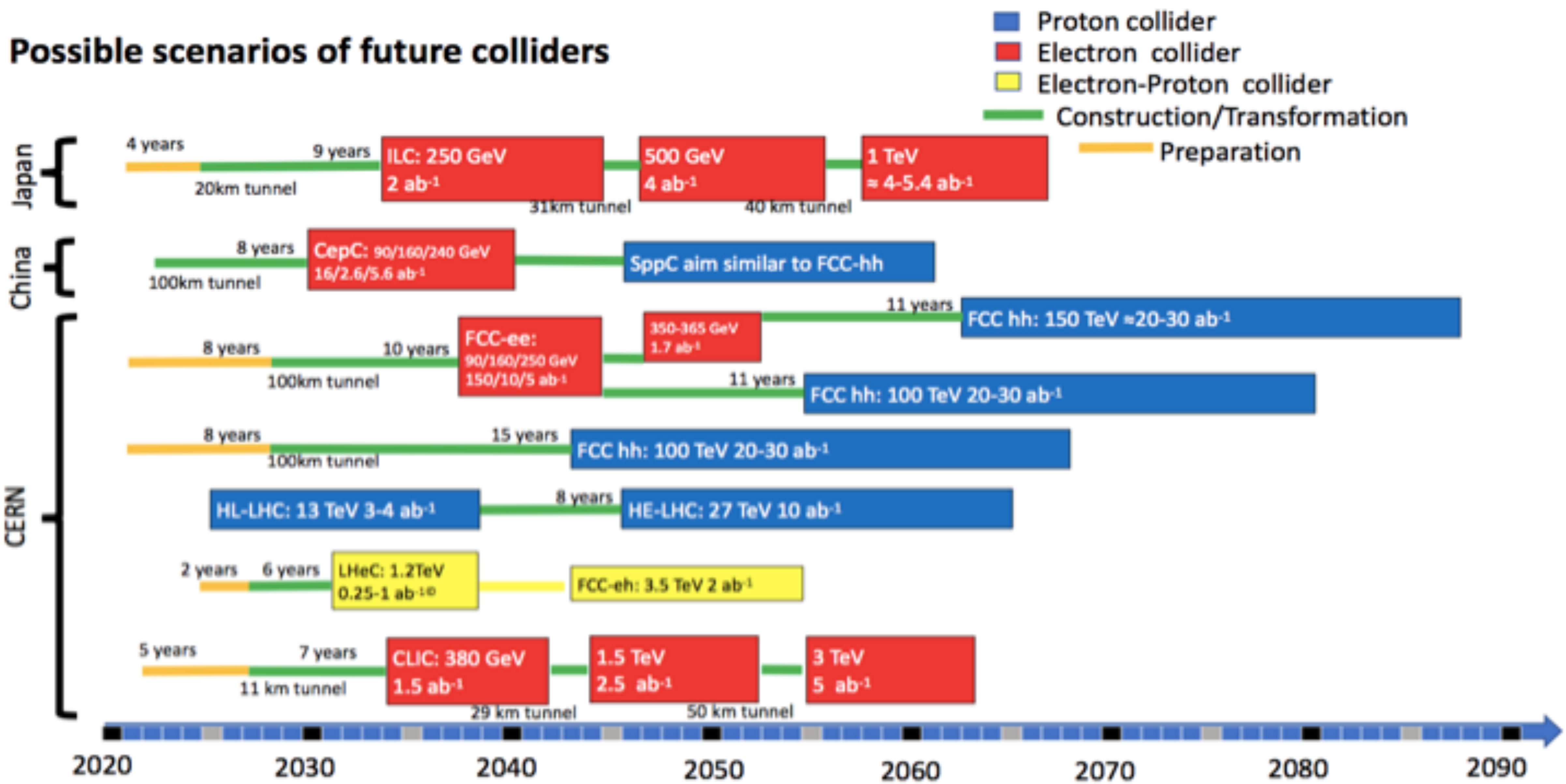
- Higgs factory and others
  - Higgs factory (HZ): 10^6
  - EW & Top factory
    - 5×10^{12} (Z), 10^8 (WW), 10^6 (tt)
  - Flavour factory
    - 5×10^{12} (Z->bb, cc, tautau)
  - QED, QCD, BSM, etc.





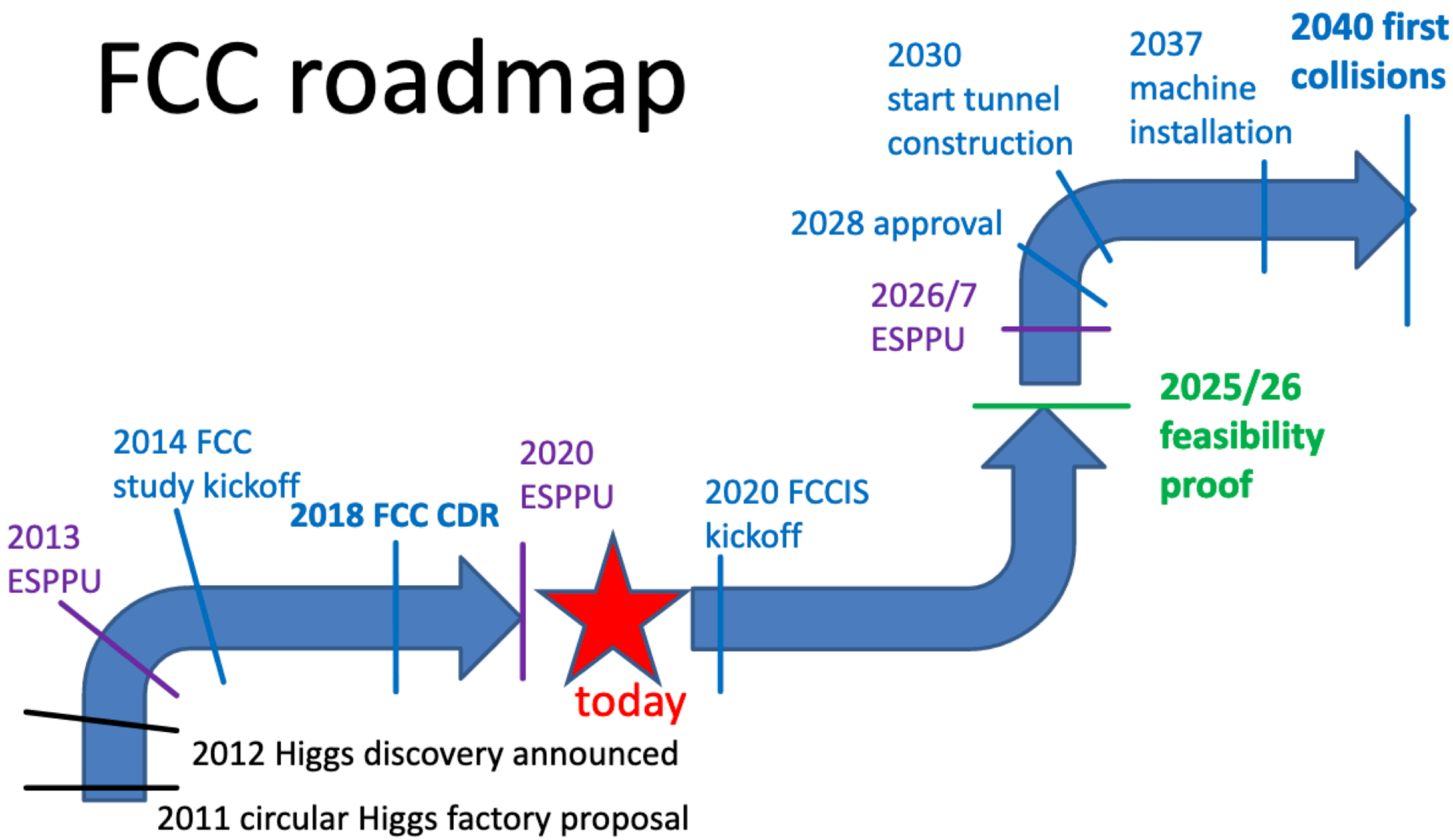
Roadmap of FC Projects

- Time flies very fast!



Recent Update

FCC Roadmap

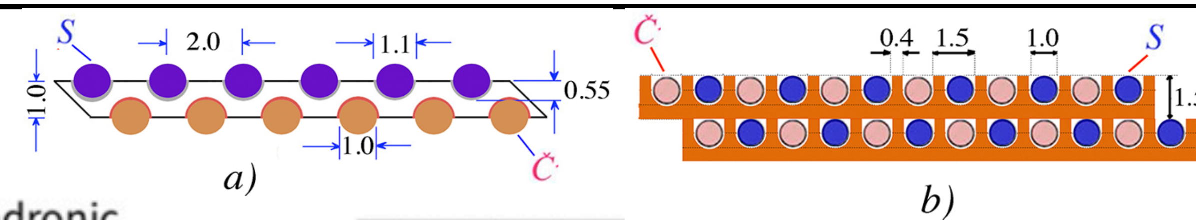


Patrick Janot

FCC Physics and Experiments General meeting
28 Sep 2020

7

Dual-Readout Calorimeter (DRC)



The dual-readout calorimetry

- The major difficulty of measuring energy of hadronic shower comes from the fluctuation of EM fraction of a shower, f_em.
- f_em can be measured by implementing two different channels with different h/e response in a calorimeter.

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

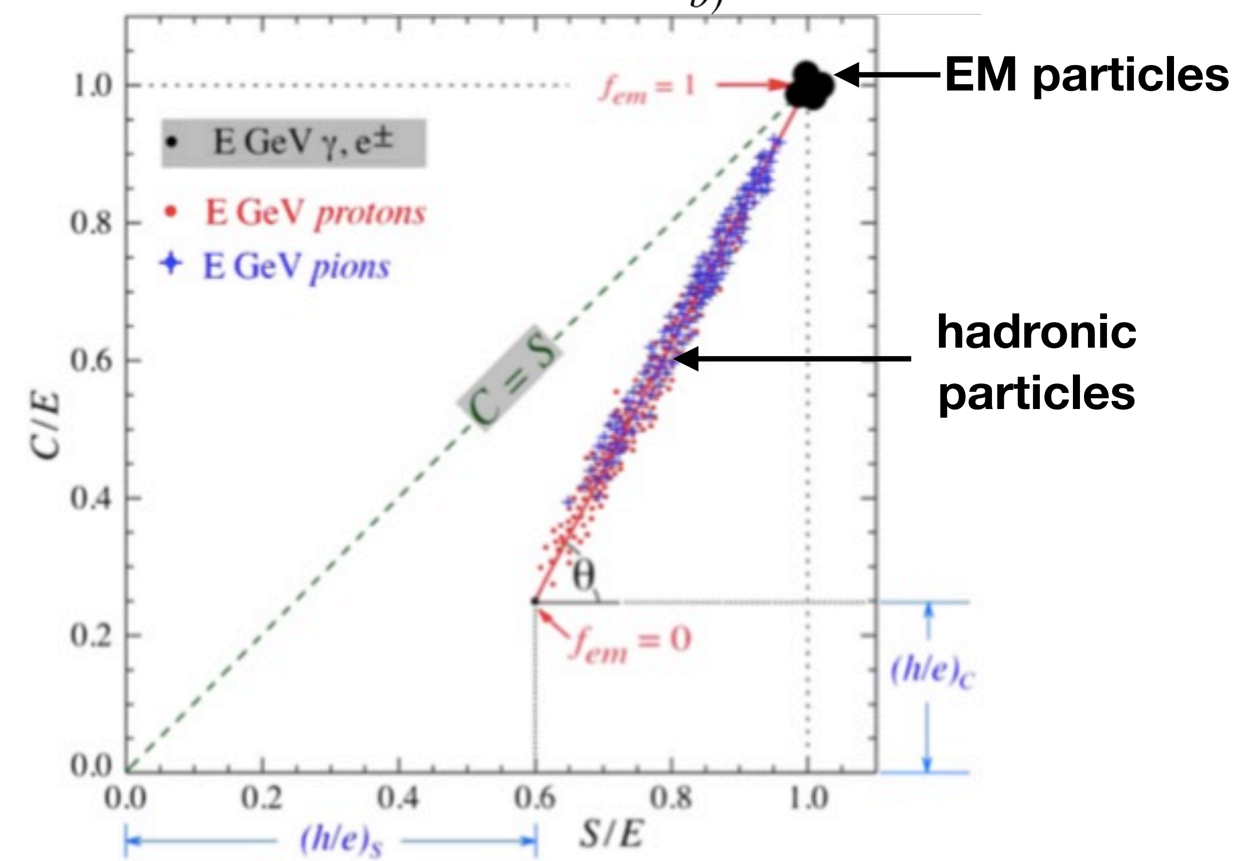
$$C = E\left[f_{em} + \frac{1}{(e/h)_C}(1-f_{em})\right].$$

$$f_{em} = \frac{(h/e)_C - (C/S)(h/e)_S}{(C/S)[1-(h/e)_S] - [1-(h/e)_C]}$$

$$\cot\theta = \frac{1-(h/e)_S}{1-(h/e)_C} \equiv \chi,$$

$$E = \frac{S-\chi C}{1-\chi}.$$

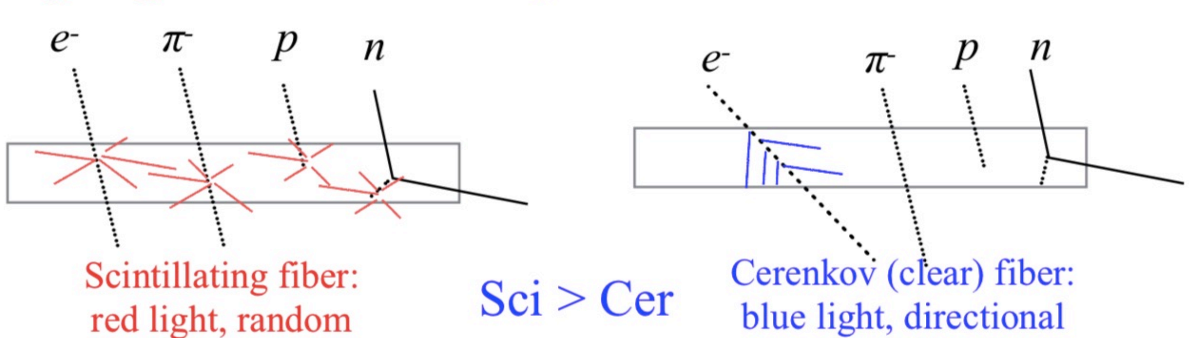
- Dual-readout calorimeter offers high-quality energy measurement for both EM particles and hadrons.
- Excellent energy resolution for hadrons can be achieved by measuring f_em and correcting the energy of hadron event-by-event.

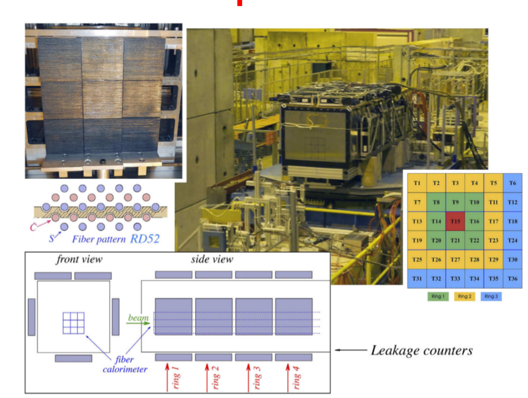


Energy measured from scintillation channel vs Cerenkov channel for EM particle, π & p.

More than 20 years R&D: CERN RD52 experiment

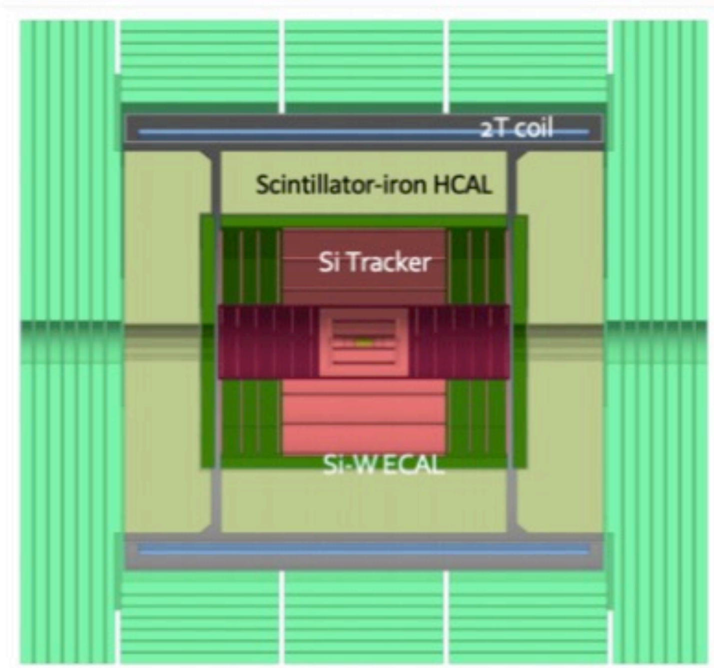
Signal generation: Scintillating & Cerenkov fibers



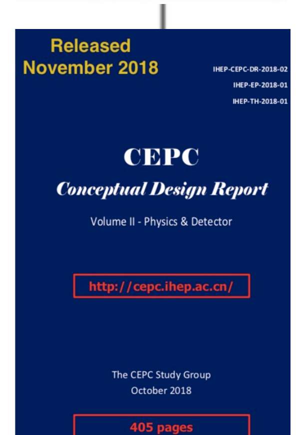


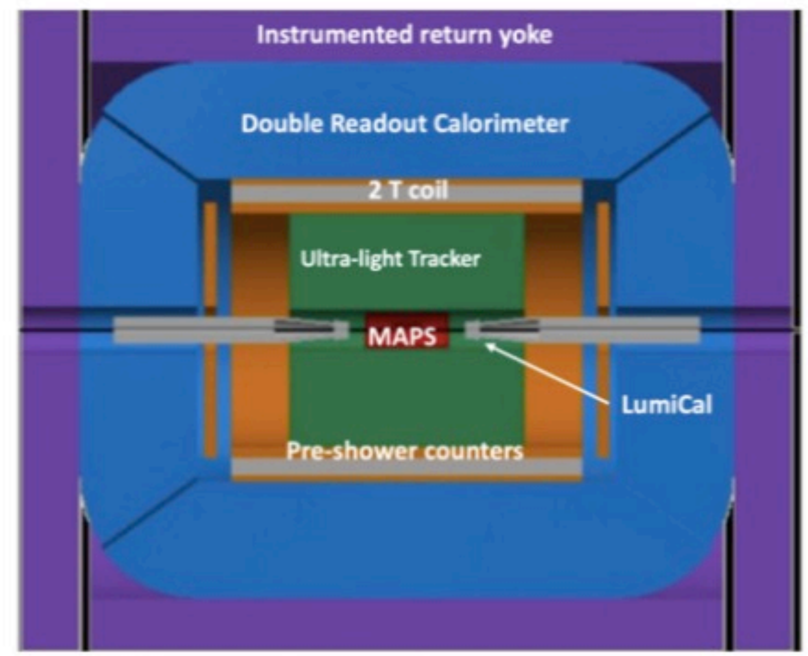
FCC-ee Detector Concept

- 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
- Current efforts from experimental side are concentrated on the DRC R&D



CLD





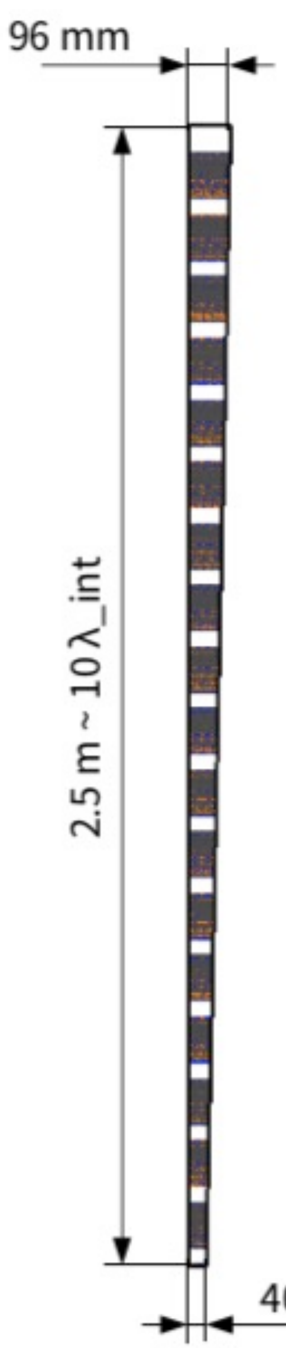
IDEA

- Consolidated option based on the detector design developed for CLIC
    - All silicon vertex detector and tracker
    - 3D-imaging highly-granular calorimeter system
    - Coil outside calorimeter system
- Proven concept, understood performance

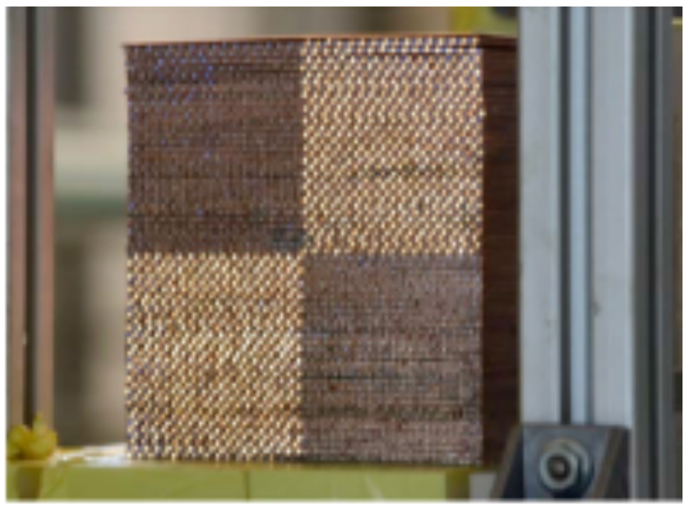
- New, innovative, possibly more cost-effective design
    - Silicon vertex detector
    - Short-drift, ultra-light wire chamber
    - Dual-readout calorimeter
    - Thin and light solenoid coil inside calorimeter system

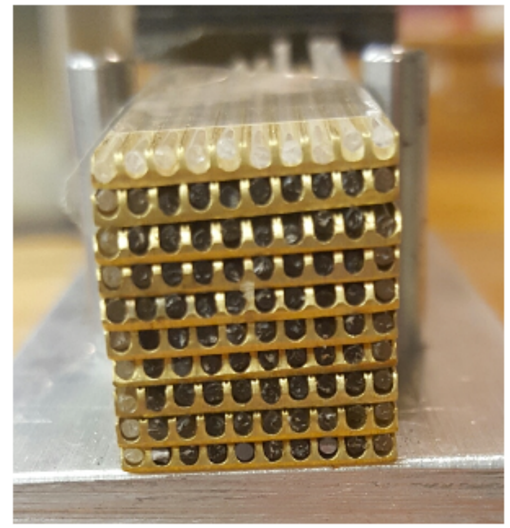
Almost same detector concept for CEPC

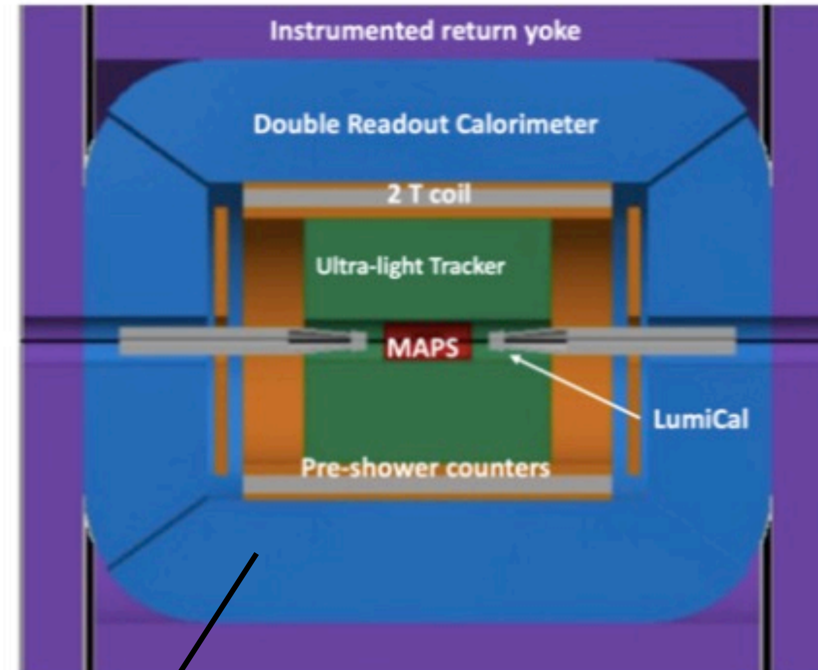
DRC Geometry and Module



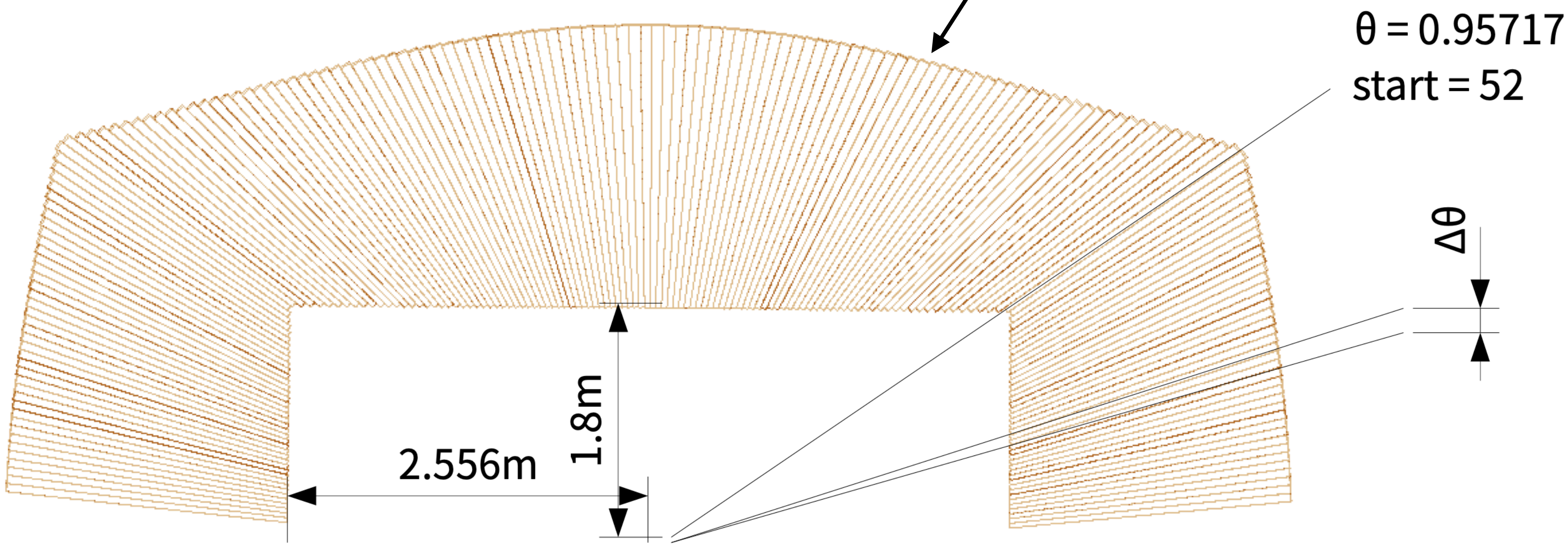
Side view of 0th tower







IDEA



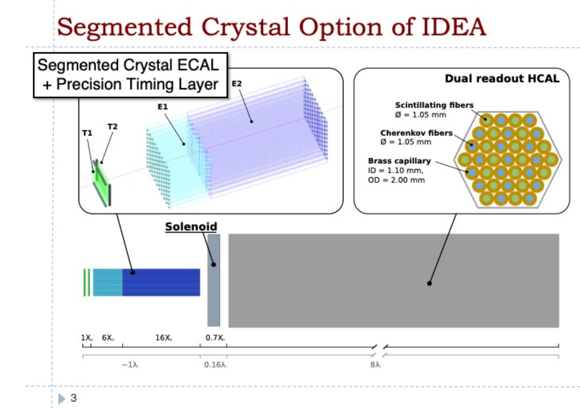
International Collaboration

Prof. Hyonsuk Jo (KNU)
Prof. Yongsun Kim (Sejong U.)
Prof. Jason Lee (UoS)
Prof. Sehwook Lee (KNU)
Prof. Hwidong Yoo (YU)

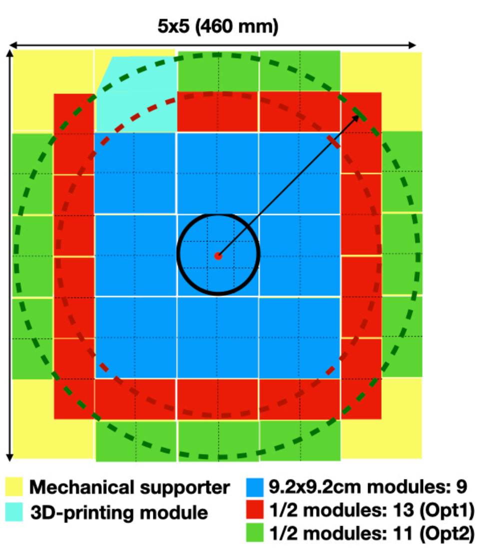
Prof. Rong-Shyang Lu
Prof. Chia Ming Kuo

Taiwan

DRC with crystal



Full-size prototype detector



Korea

Japan

Prof. Yuji Enari
(Active from 2021)

DREAM FOR FUTURE

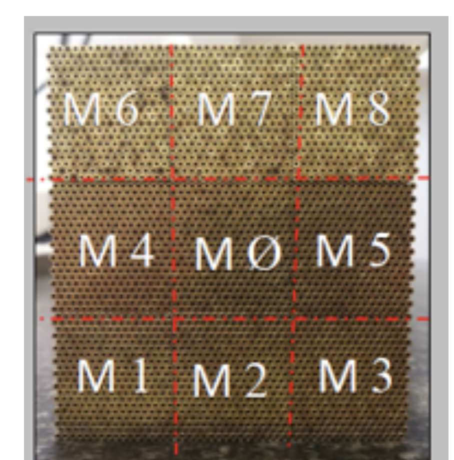
USA

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

Bucatini prototype



International collaboration forms

- Regular meeting
- Compensated R&D options
- Combine efforts

Goal of DRC R&D in Korea

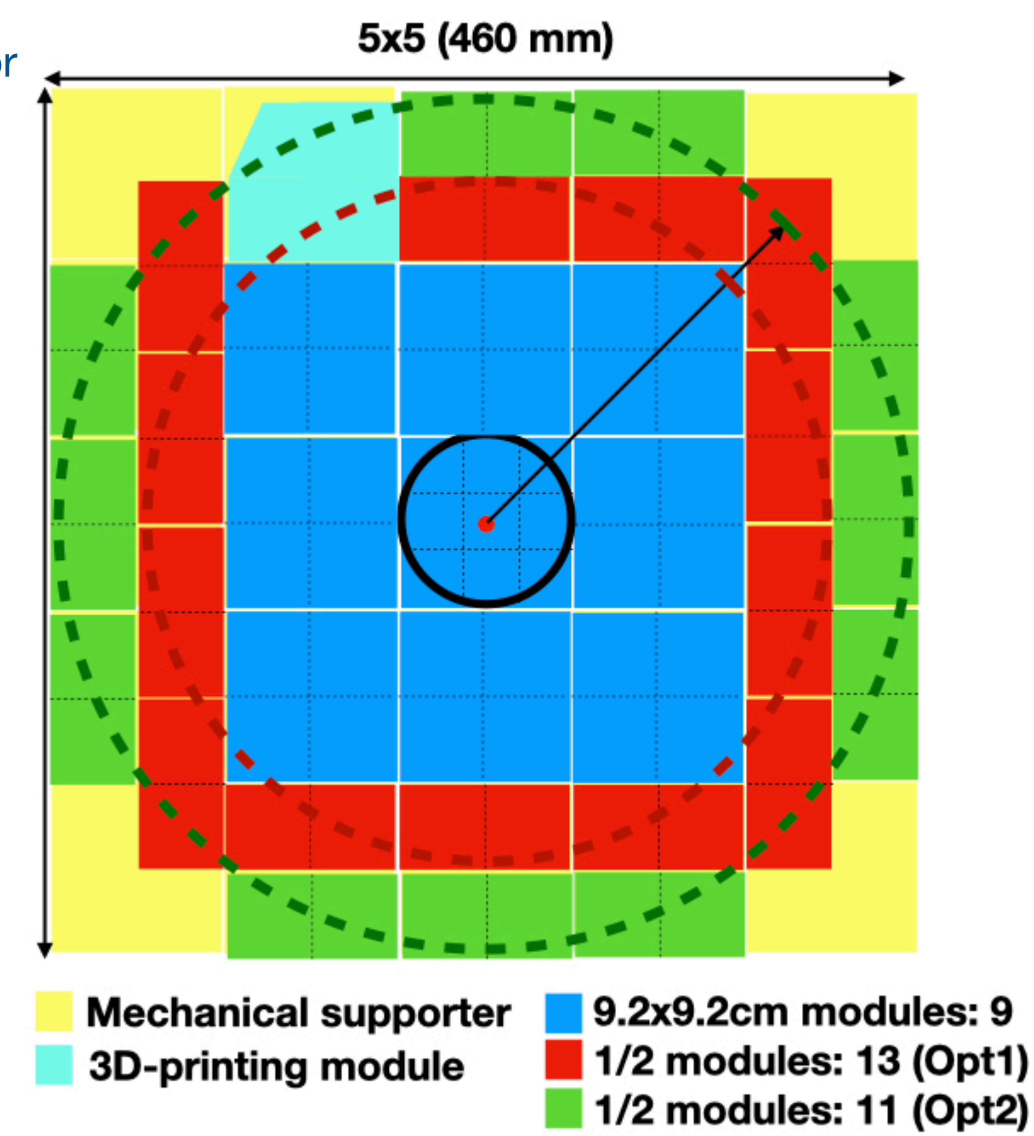
- Primary goal: build a **prototype detector** for the detector design of FCC-ee experiment
  - 5 year R&D funding supported by Korea NRF
  - Contain almost (97.5%) full hadronic shower energy
  - Demonstrate engineering aspects for full geometry detector
  - Optimize the performance of the detector
- Secondary goal: **train next generations** as experts of the (DRC) detector

WE ARE HERE

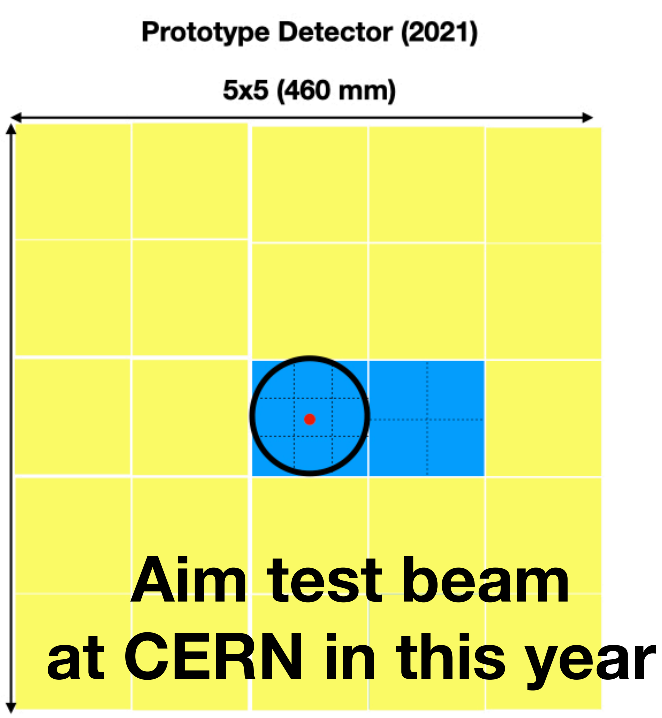
2017-9	2020-1	2022-5	TBD
Design	R&D	Prototype	Production

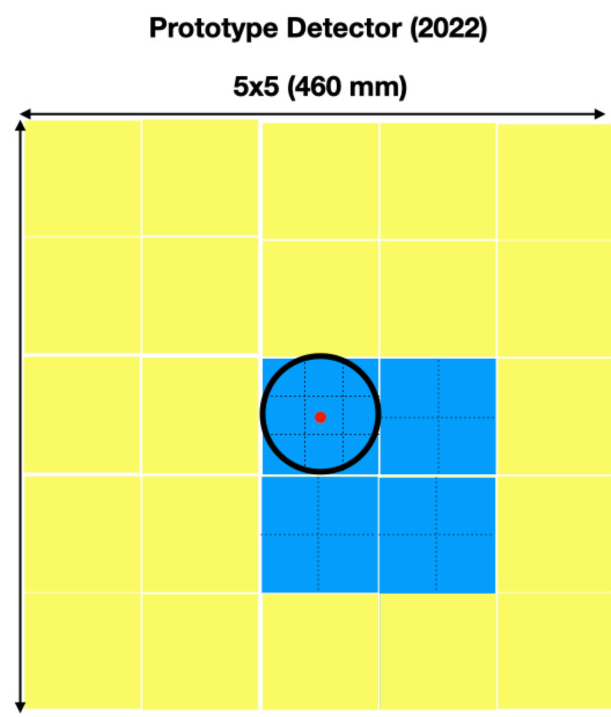
Stage	Topic
Design	Propose a design of Dual-Readout Calorimeter to IDEA detector concept
R&D	Perform R&D (including engineering aspects) based on HW & SW
Prototype	Build 4x4 detector and perform test beams
Production	TBD

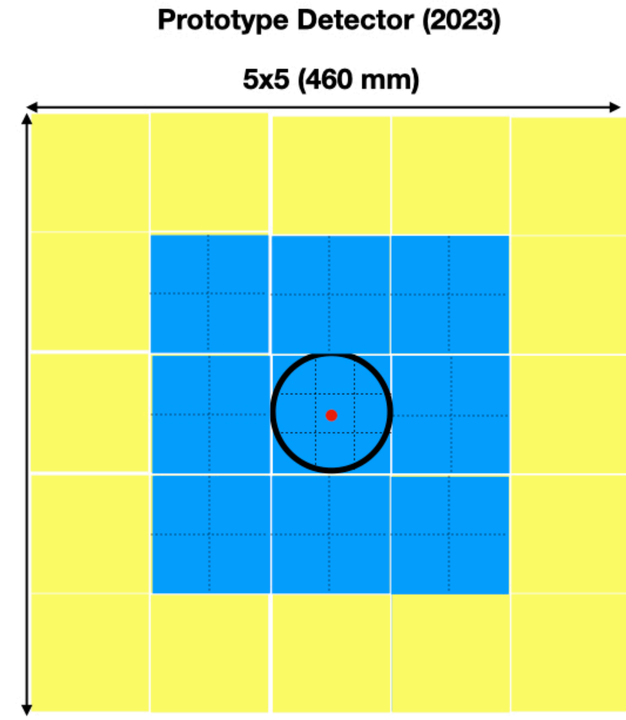
Prototype Detector (2025)

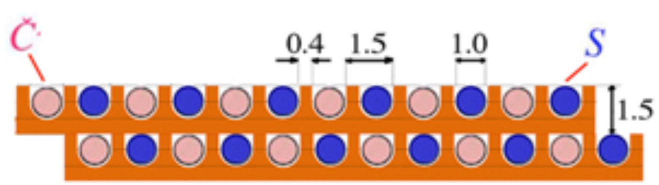


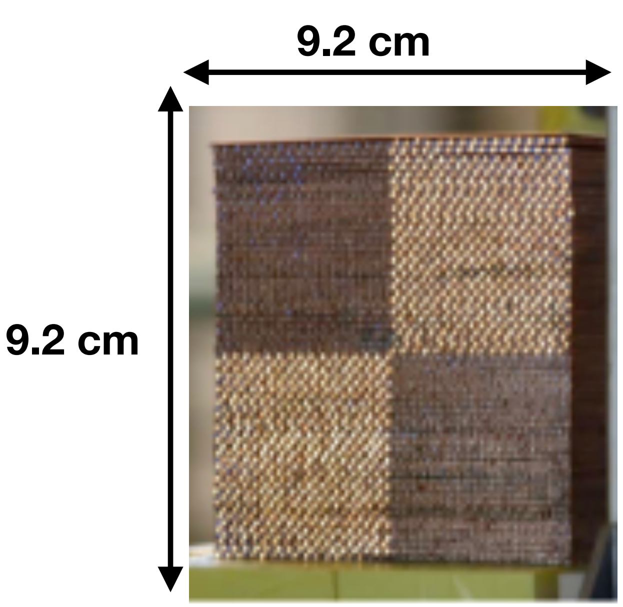
Roadmap of DRC Prototype Detector



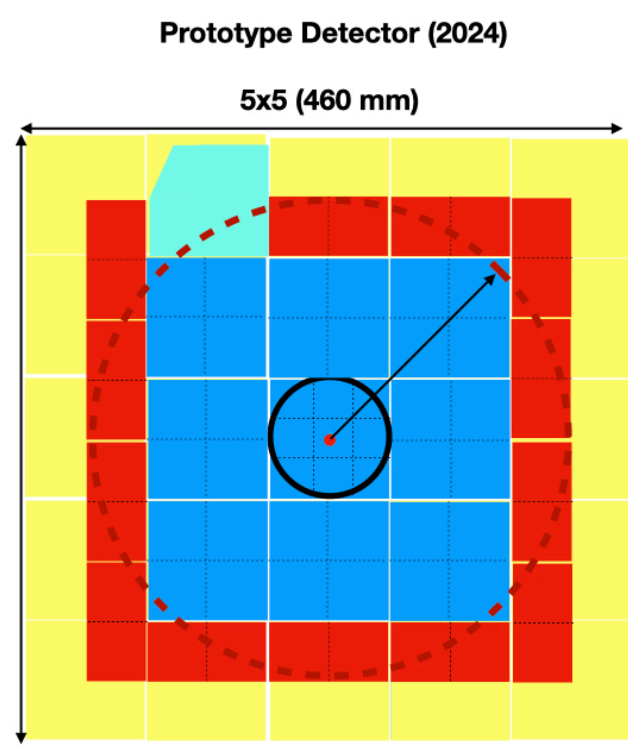


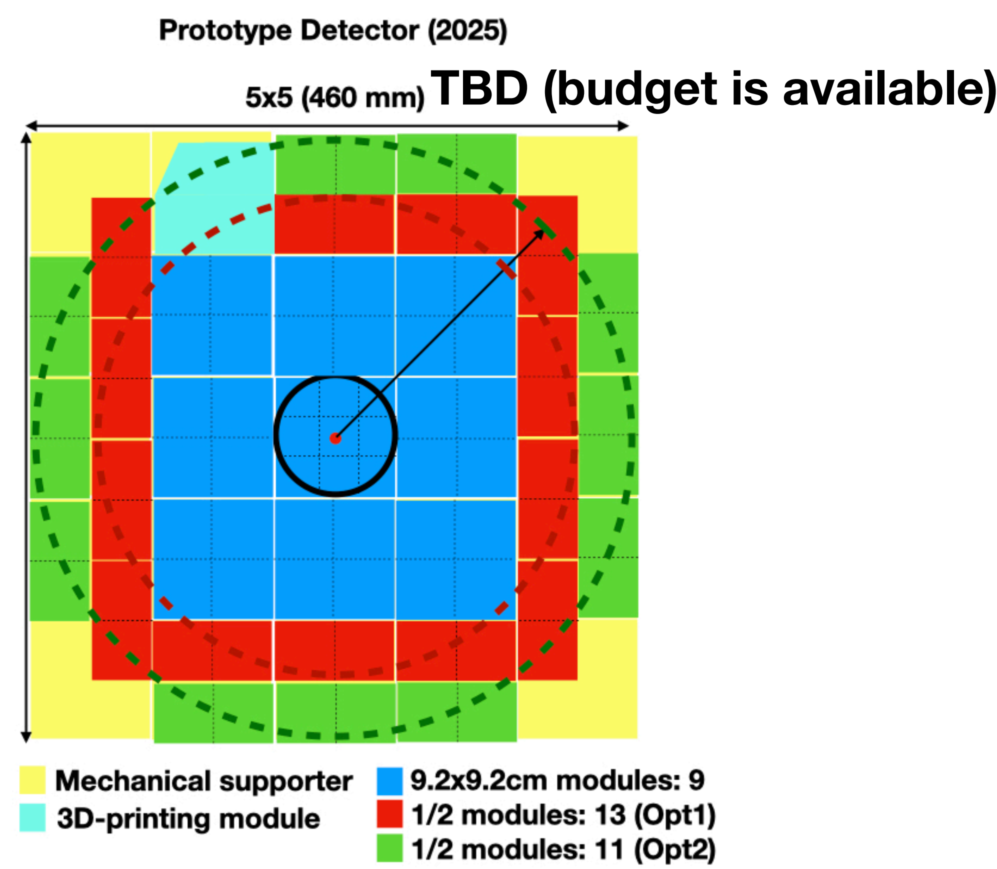




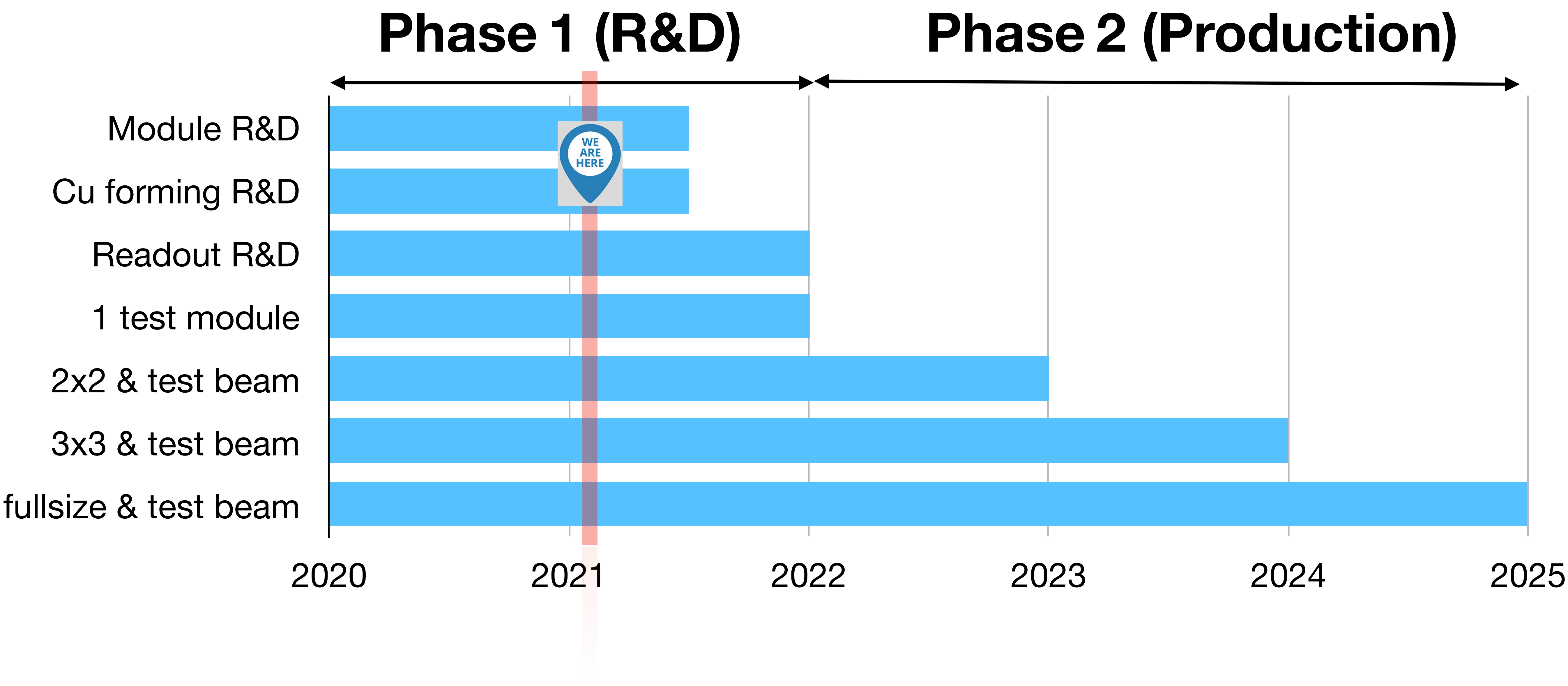


Size of unit module



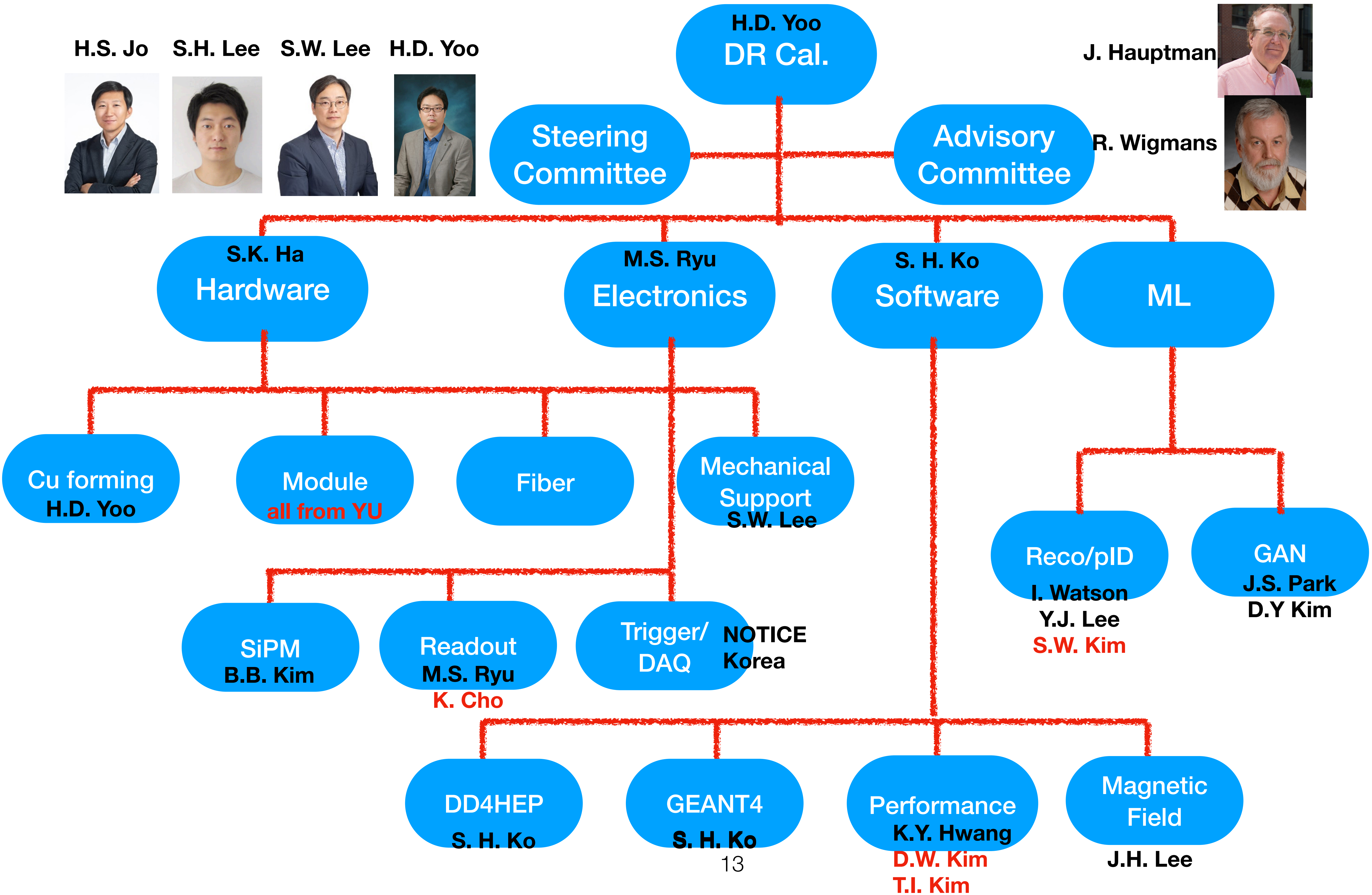


Brief Roadmap in Korea



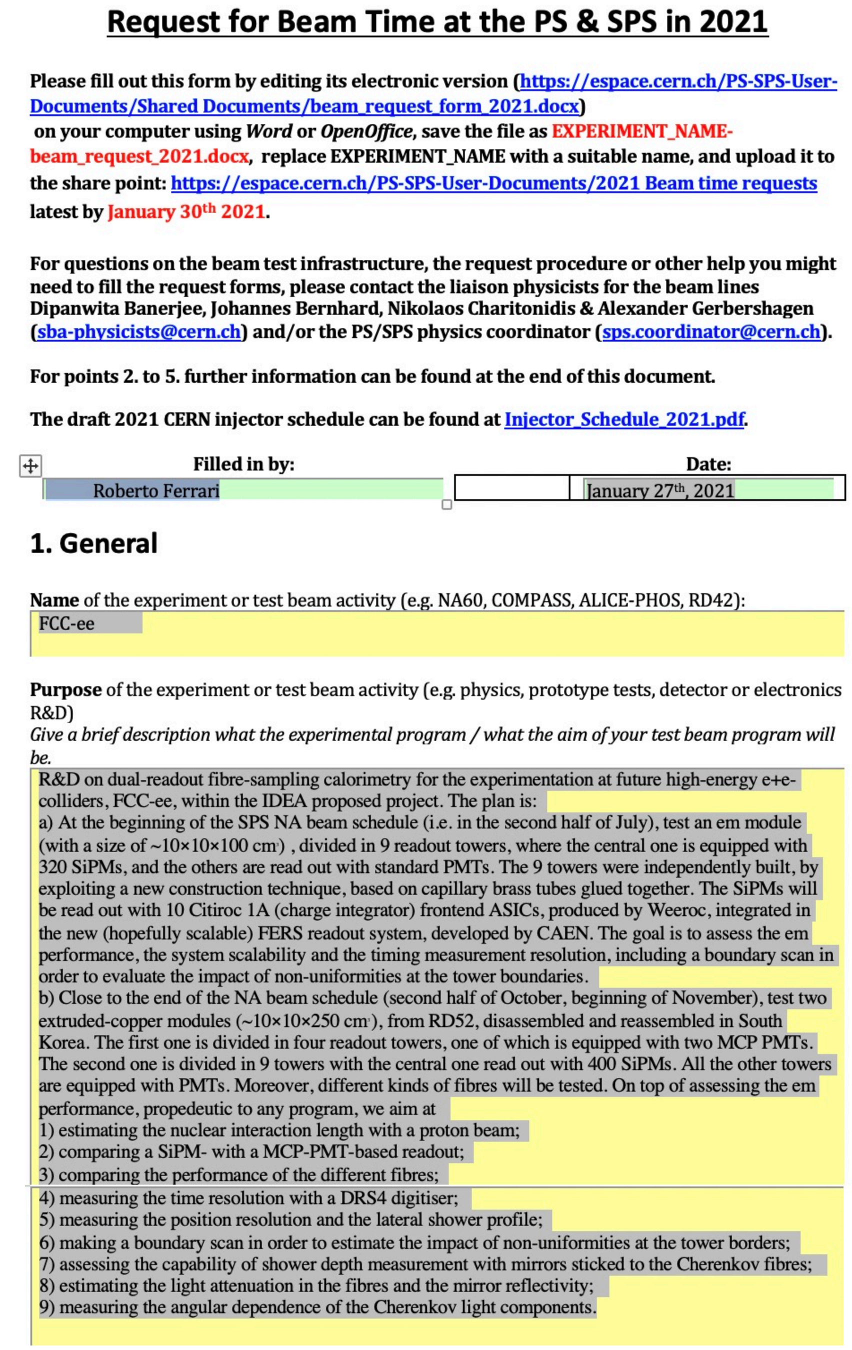
More details will be defined and decided on the way!

Korea DRC Organization



Goal of 2021 R&D in Korea

- Test beam at CERN
  - Plan for two measurements
  - 1st prototype modules are building
- Simulation study
  - Study various performance using GEANT4
  - Optimize detector and module designs
  - Test ML applications
- Snowmass 2021 (postponed by early 2022)
  - Seven LoIs submitted from our team
- Publications plan
  - (At least) three papers based on simulation and ML studies
  - Aim to summarize activities of snowmass 2021 at early next year
- If interested to join, please contact us!
  - **Many undergraduate students are working in our team, easy to start small contribution!**



Request for Beam Time at the PS & SPS in 2021

Please fill out this form by editing its electronic version (https://espace.cern.ch/PS-SPS-User-Documents/Shared Documents/beam_request_form_2021.docx) on your computer using *Word* or *OpenOffice*, save the file as EXPERIMENT_NAME-beam_request_2021.docx, replace EXPERIMENT_NAME with a suitable name, and upload it to the share point: https://espace.cern.ch/PS-SPS-User-Documents/2021 Beam time requests latest by January 30th 2021.

For questions on the beam test infrastructure, the request procedure or other help you might need to fill the request forms, please contact the liaison physicists for the beam lines Dipanwita Banerjee, Johannes Bernhard, Nikolaos Charitonidis & Alexander Gerbershagen (sba-physicists@cern.ch) and/or the PS/SPS physics coordinator (sps.coordinator@cern.ch).

For points 2. to 5. further information can be found at the end of this document.

The draft 2021 CERN injector schedule can be found at Injector_Schedule_2021.pdf.

Filled in by:	Date:
Roberto Ferrari	January 27th, 2021

1. General

Name of the experiment or test beam activity (e.g. NA60, COMPASS, ALICE-PHOS, RD42):

FCC-ee

Purpose of the experiment or test beam activity (e.g. physics, prototype tests, detector or electronics R&D)

Give a brief description what the experimental program / what the aim of your test beam program will be.

R&D on dual-readout fibre-sampling calorimetry for the experimentation at future high-energy e+e- colliders, FCC-ee, within the IDEA proposed project. The plan is:
a) At the beginning of the SPS NA beam schedule (i.e. in the second half of July), test an em module (with a size of ~10×10×100 cm³) , divided in 9 readout towers, where the central one is equipped with 320 SiPMs, and the others are read out with standard PMTs. The 9 towers were independently built, by exploiting a new construction technique, based on capillary brass tubes glued together. The SiPMs will be read out with 10 Citiroc 1A (charge integrator) frontend ASICs, produced by Weeroc, integrated in the new (hopefully scalable) FERS readout system, developed by CAEN. The goal is to assess the em performance, the system scalability and the timing measurement resolution, including a boundary scan in order to evaluate the impact of non-uniformities at the tower boundaries.
b) Close to the end of the NA beam schedule (second half of October, beginning of November), test two extruded-copper modules (~10×10×250 cm³), from RD52, disassembled and reassembled in South Korea. The first one is divided in four readout towers, one of which is equipped with two MCP PMTs. The second one is divided in 9 towers with the central one read out with 400 SiPMs. All the other towers are equipped with PMTs. Moreover, different kinds of fibres will be tested. On top of assessing the em performance, propedeutic to any program, we aim at
1) estimating the nuclear interaction length with a proton beam;
2) comparing a SiPM- with a MCP-PMT-based readout;
3) comparing the performance of the different fibres;
4) measuring the time resolution with a DRS4 digitiser;
5) measuring the position resolution and the lateral shower profile;
6) making a boundary scan in order to estimate the impact of non-uniformities at the tower borders;
7) assessing the capability of shower depth measurement with mirrors sticked to the Cherenkov fibres;
8) estimating the light attenuation in the fibres and the mirror reflectivity;
9) measuring the angular dependence of the Cherenkov light components.

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

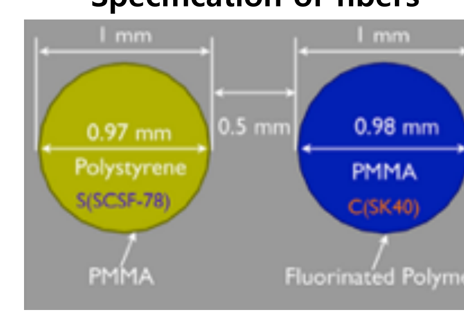
Time resolution: 10 ps —> 5 mm precision

Time resolution: 50 ps —> 25 mm precision

Time resolution: 100 ps —> 50 mm precision

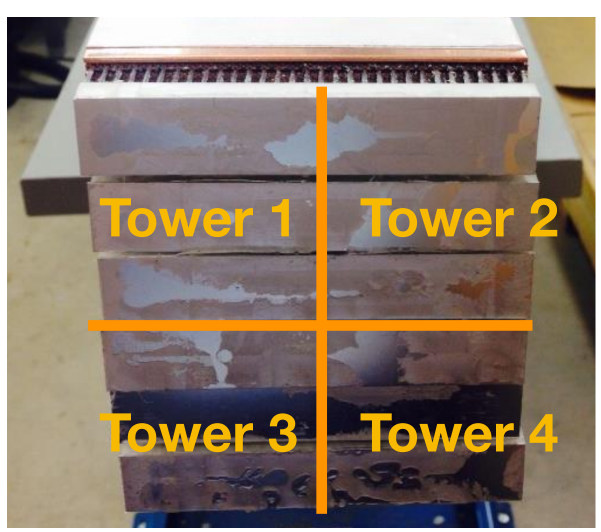
- Plan
  - Dissemble and cleanup all fibers and other components from copper plates
  - Repair plates and assemble new fibers

Specification of fibers

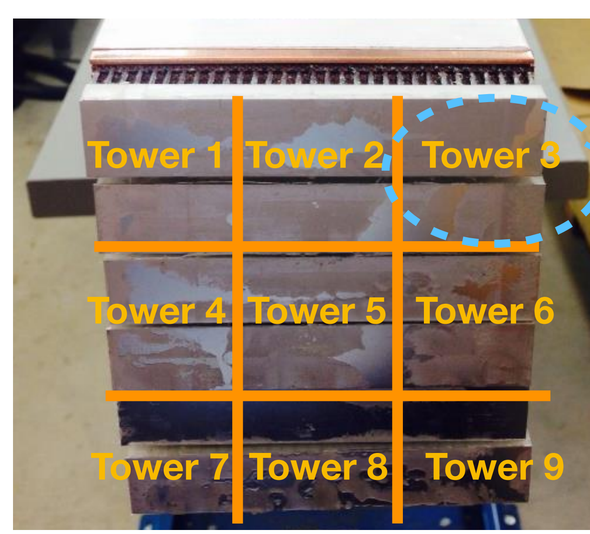


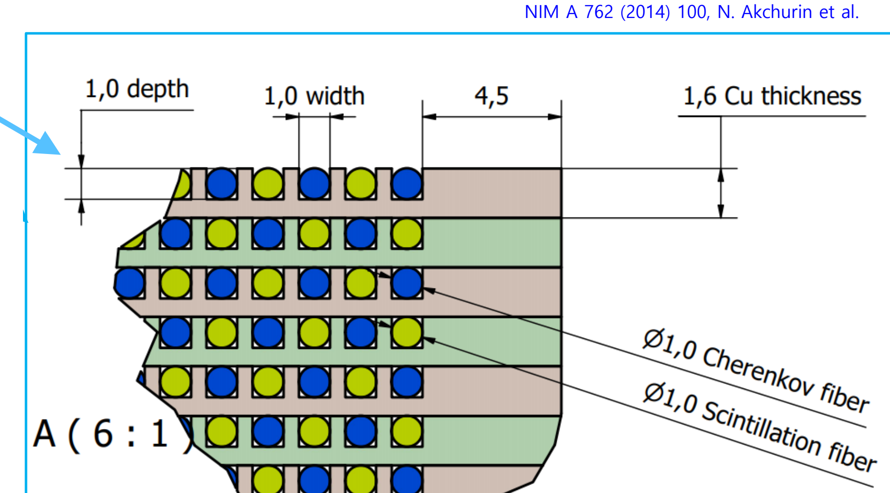
NIM A 762 (2014) 100, N. Akchurin et al.

Module #1 (2x2)



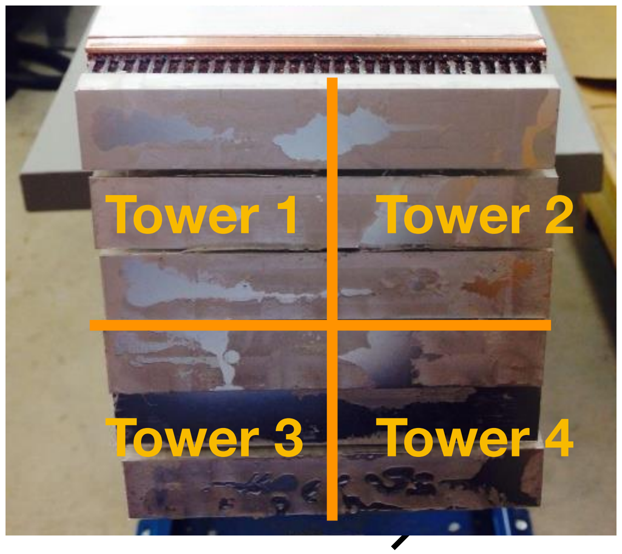
Module #2 (3x3)





Module Configuration

Module #1 (2x2)

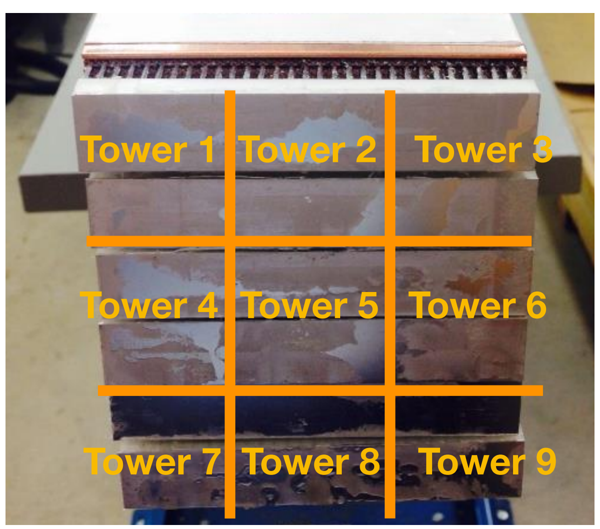


Tower#1	Tower#2
Tower#3	Tower#4

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

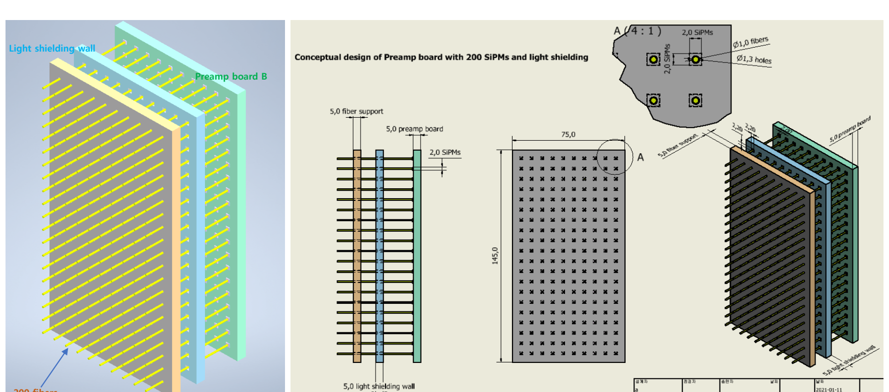
Module #2 (3x3)

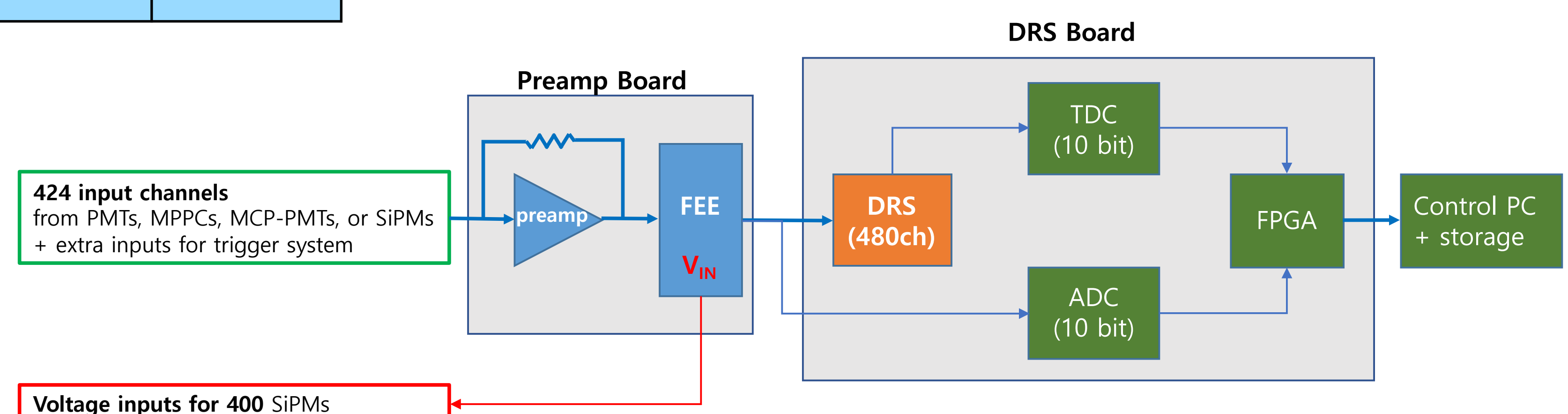


Tower#1	Tower#2	Tower#3
Tower#4	Tower#5	Tower#6
Tower#7	Tower#8	Tower#9

Combination of fibers for Module#2

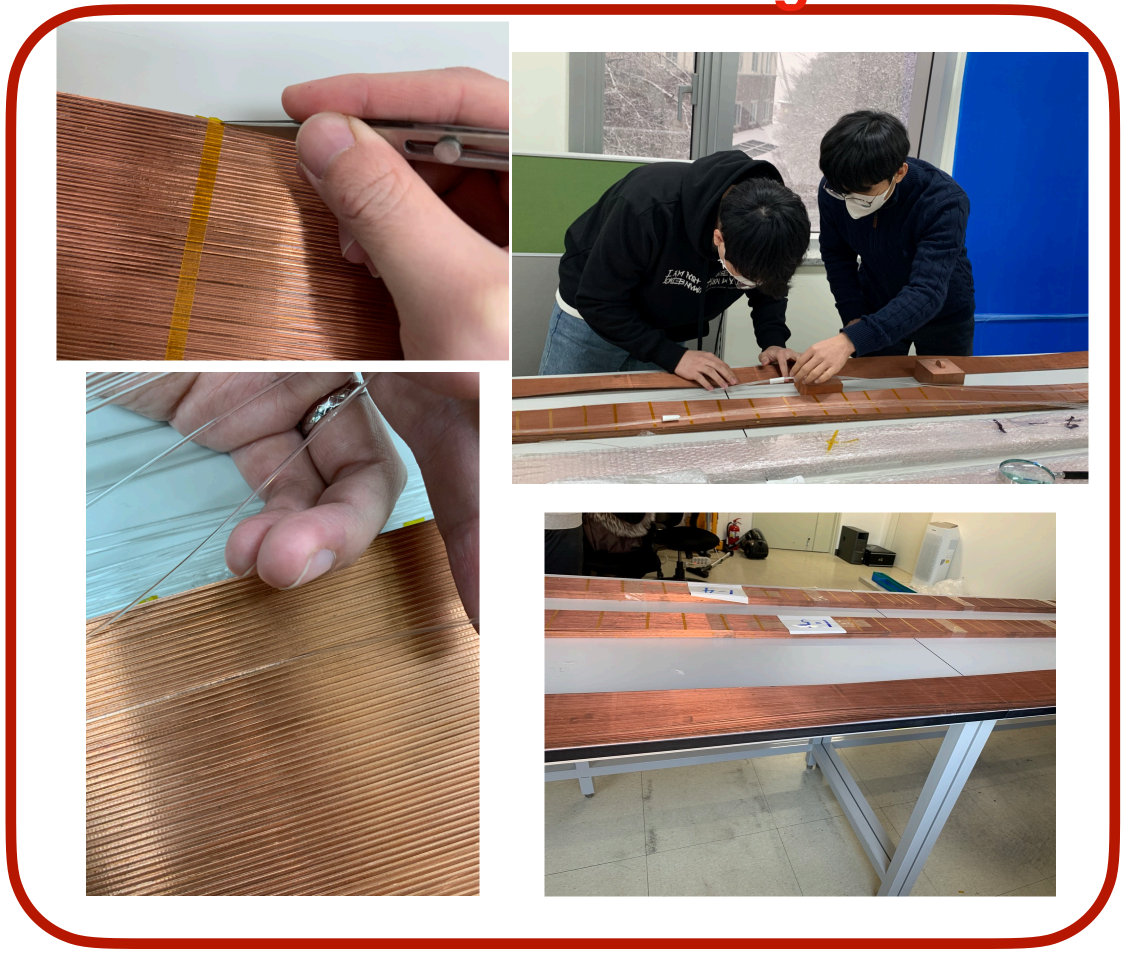
	Tower #1~4 and #6~9	Tower #5
Scintillation fibers	Round / Single cladding	
Cherenkov fibers	Round / Single cladding	
Readout detector (400+16 ch)	16 PMTs	400 SiPMs

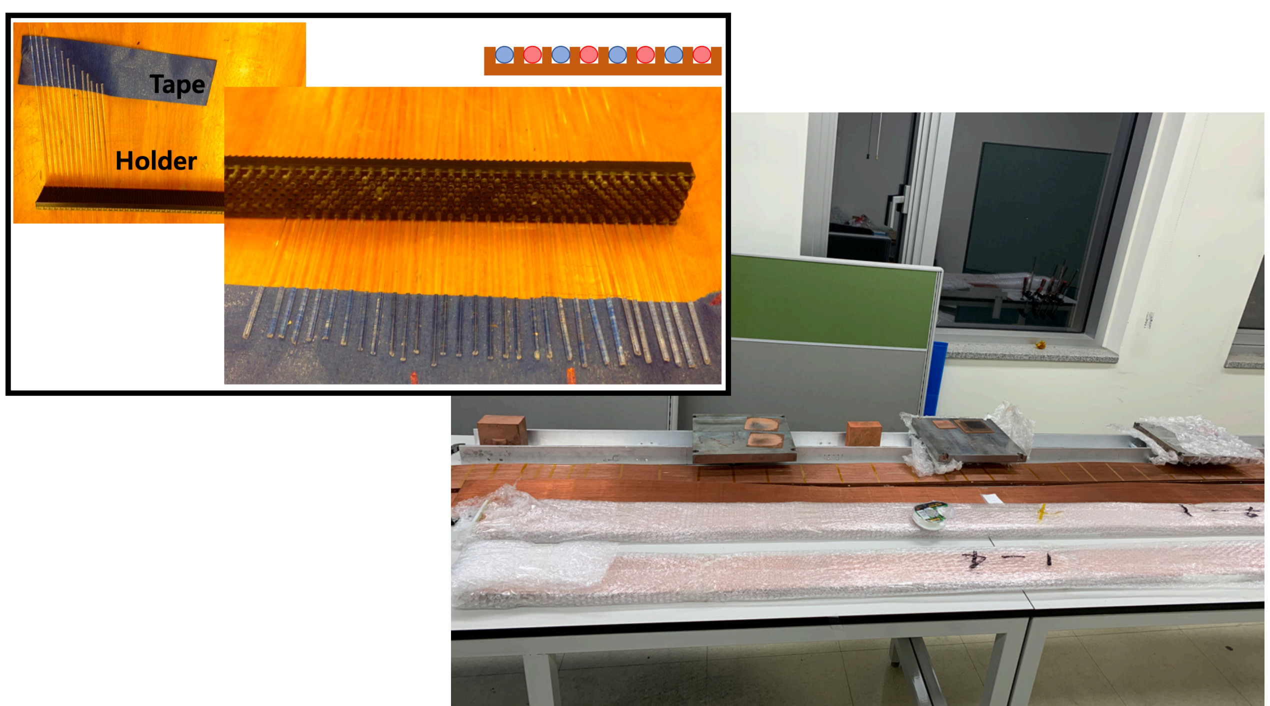




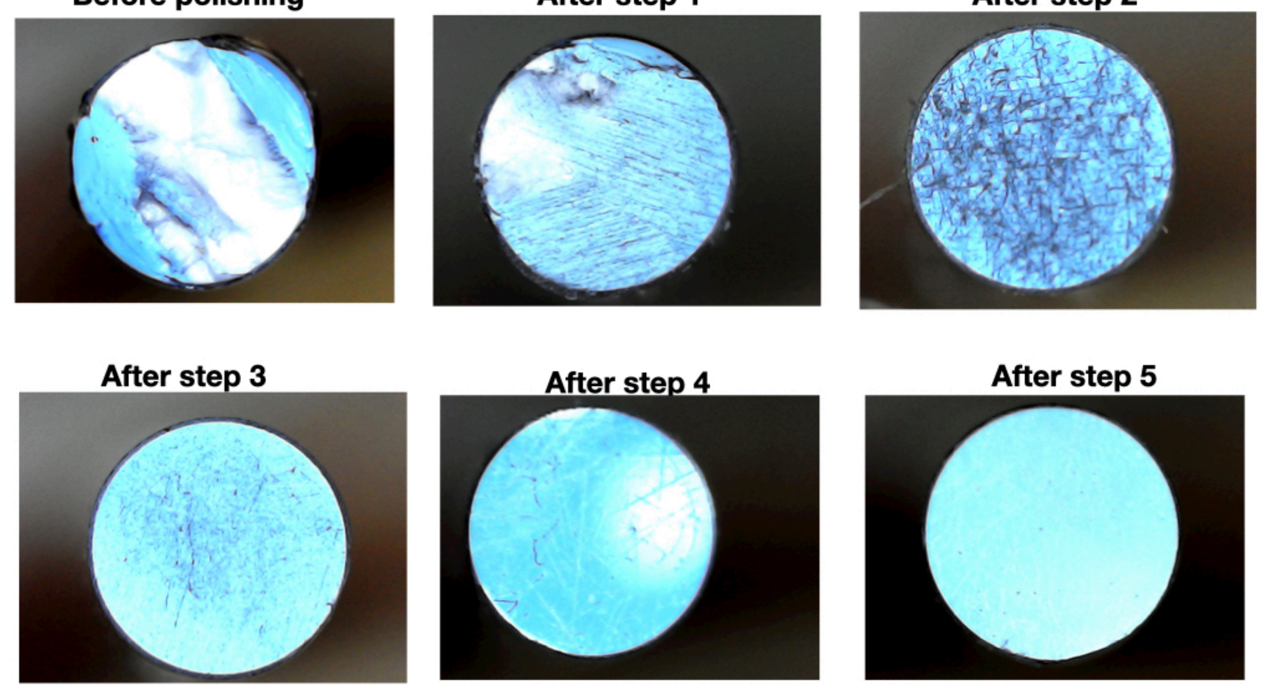
Module Disassembly & Repair

Disassembling



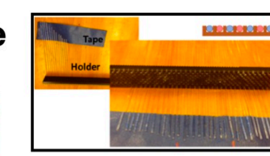


Polishing fibers



Rebuilding procedure

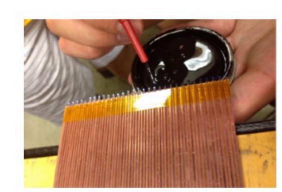
1. Preparation the items (stuffs) for rebuilding module



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

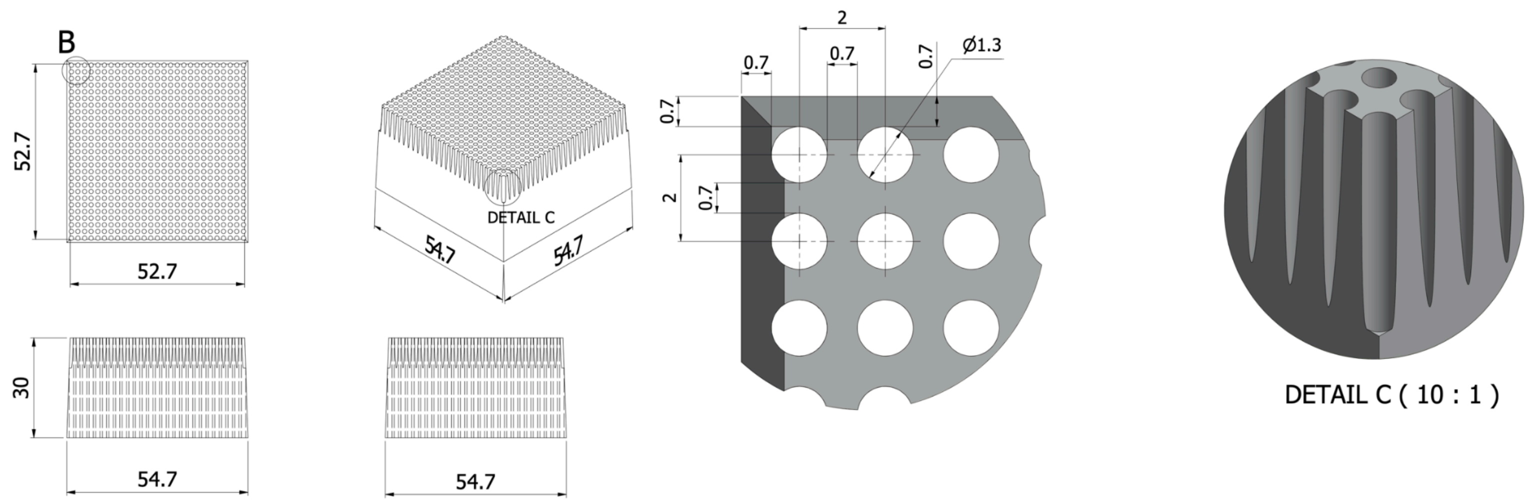
Disassemble was done recently!

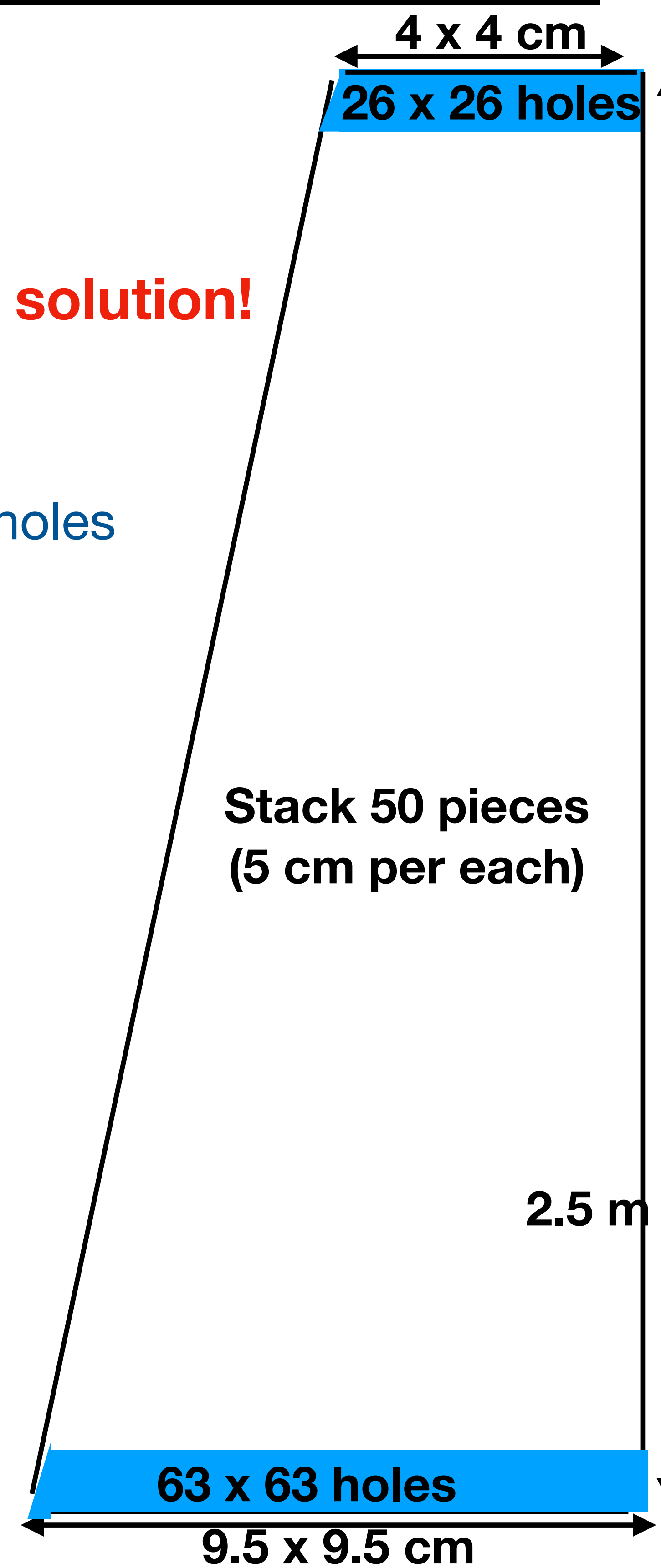
3D Printing Module R&D

- 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



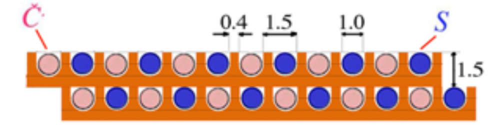


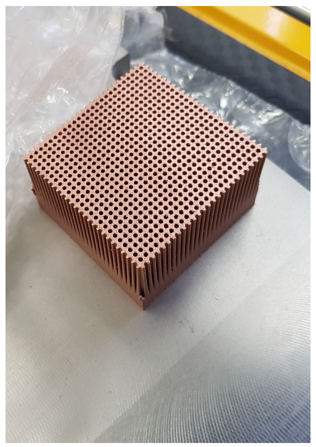
With 3D printing consultant company in Korea

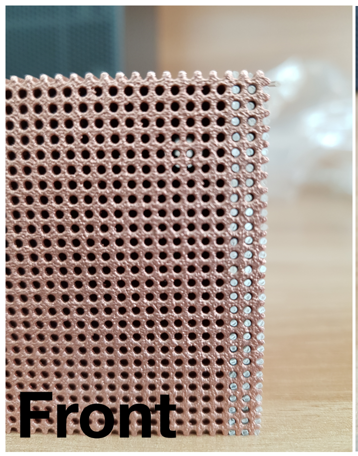
- **have world-wide expert networking**

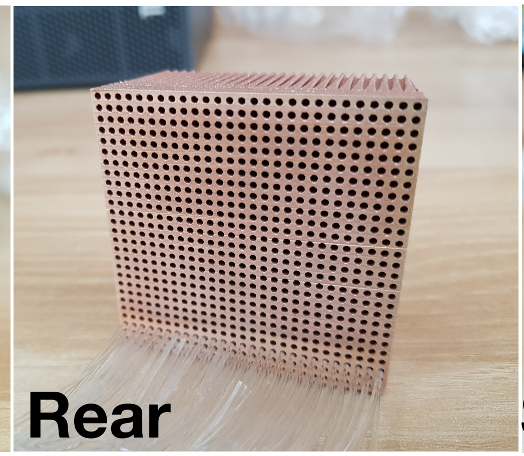
Two Samples Produced

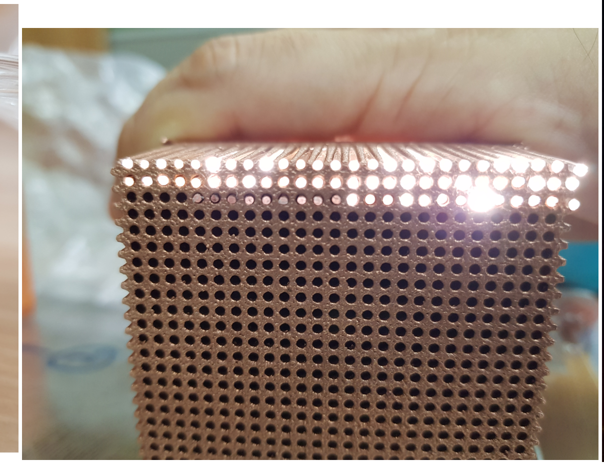
- 1st samples (from Finland, using EOS 3D printer)

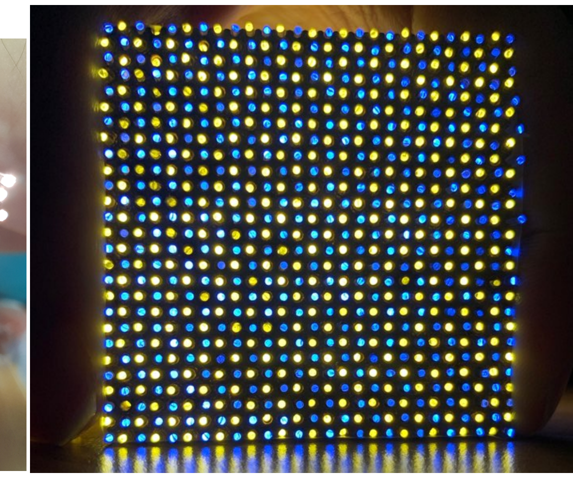




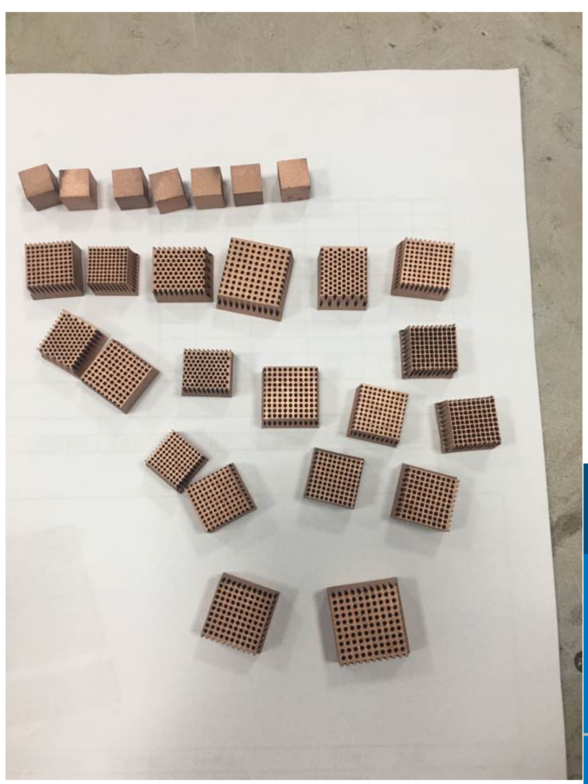


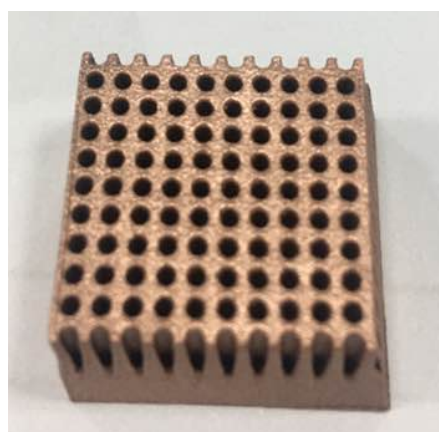


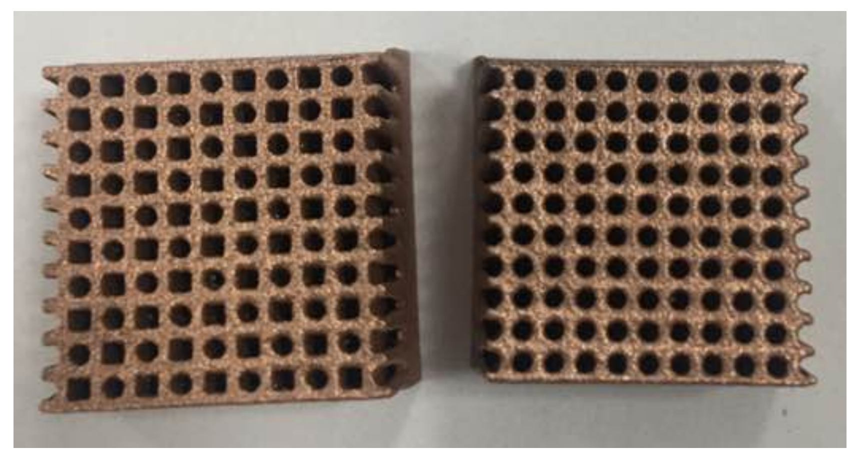




- 2nd samples (from China, using Farsoon)





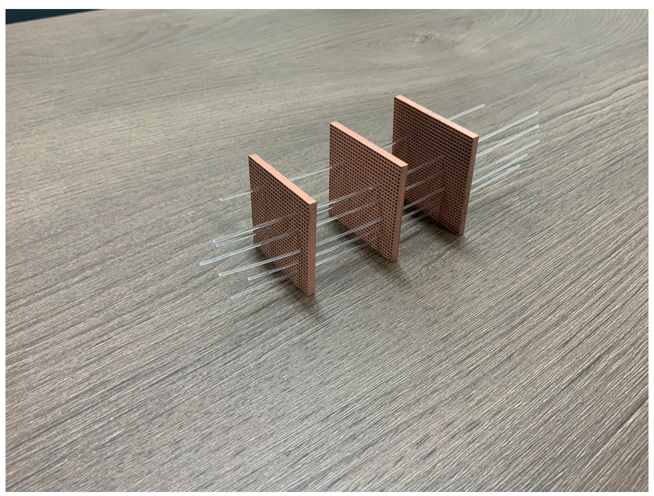


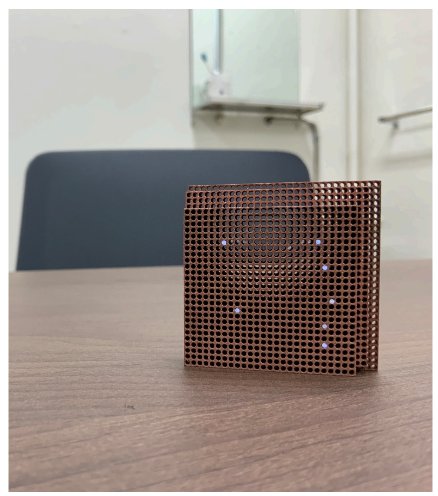
	Samples	1	2	3	4	5	6	7	8	9	10
Hall diameter (mm)	Designed	1.0	1.1	1.2	1.1	1.0	1.3	1.1	1.2	1.2	1.1
	Outcome	0.9-0.95	0.9-0.95	1.0-1.05	0.8-0.85	0.8-0.85	1.1-1.15	0.9-0.95	1.0-1.05	1.0-1.05	0.9-0.95
Wall thickness (mm)	Designed	0.5	0.5	0.5	0.4	0.3	0.7	0.5	0.3	0.5	0.4
	Outcome	0.52	0.6	0.62	0.5	0.45	0.81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

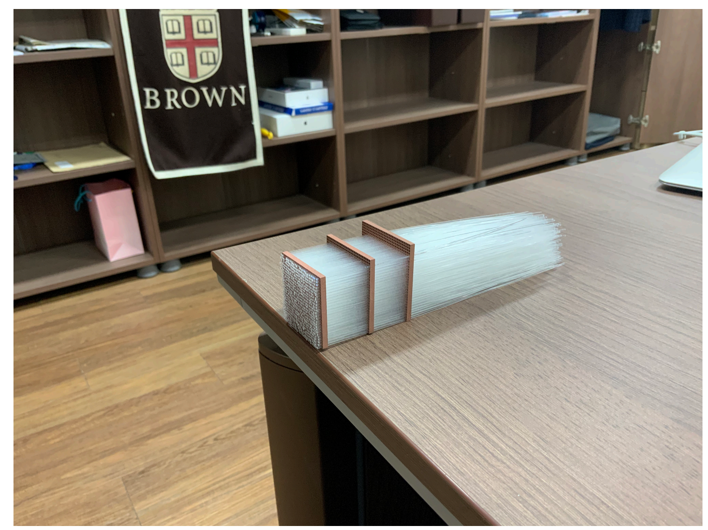
Prototype under discussion!

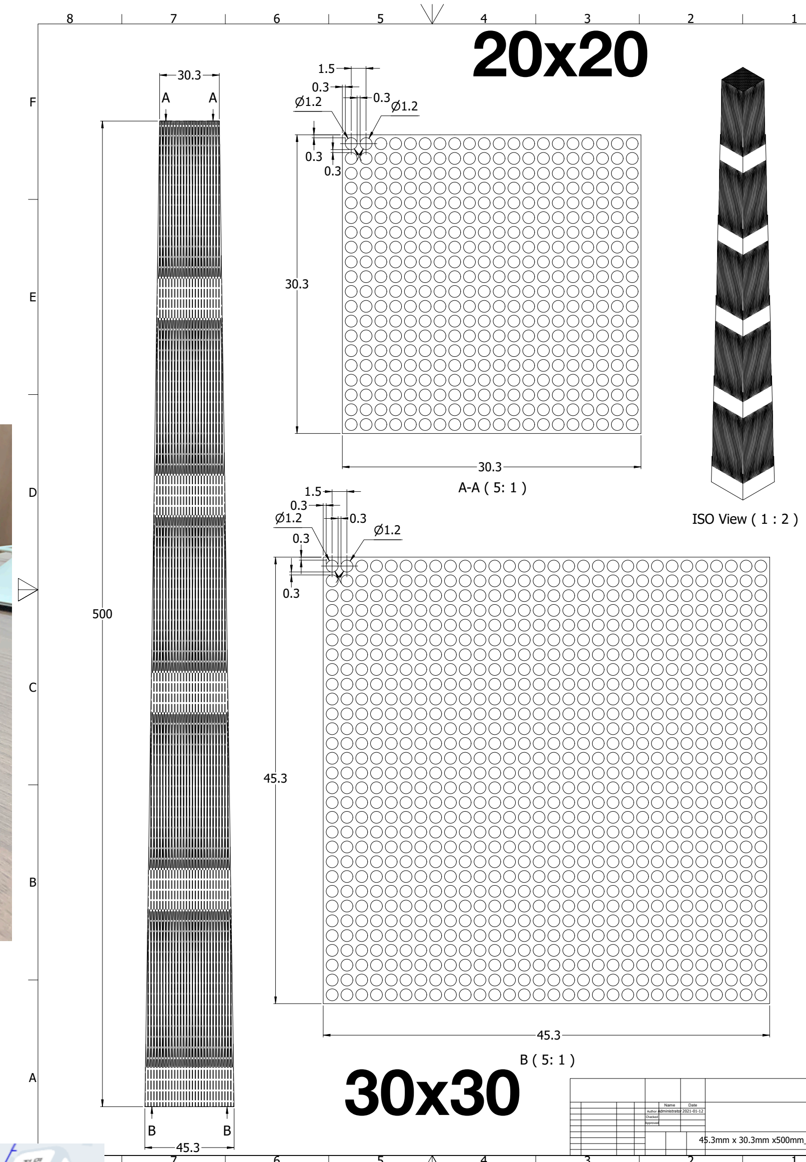
Toward Prototype 3D Module

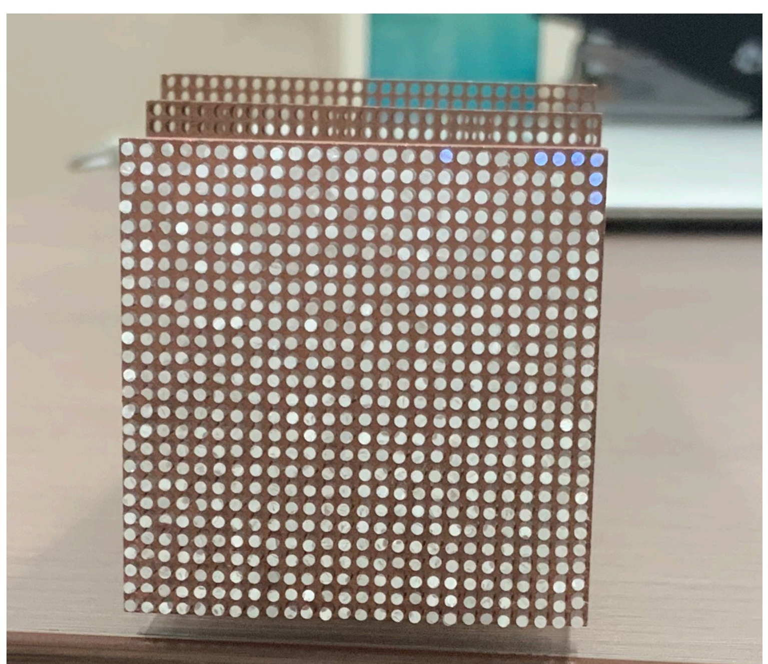
- Under test and design
    - We suppose to have the 3D-printed copper blocks for the prototype module in this spring

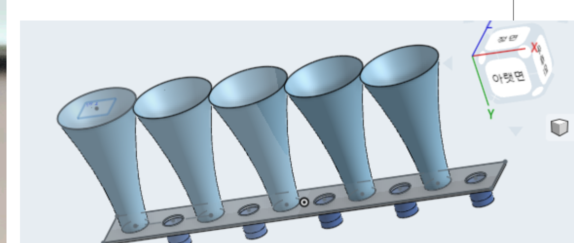








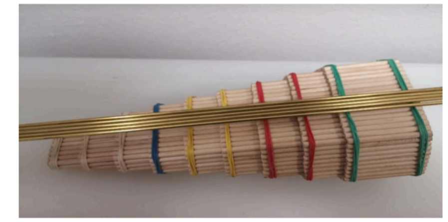


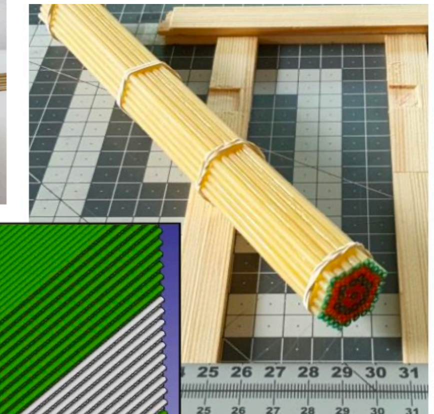


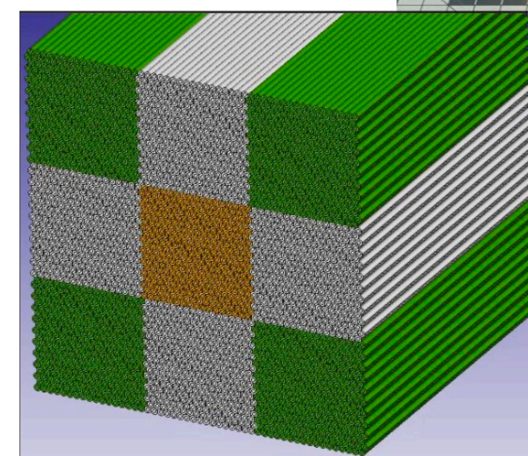
Using gravity, we can insert fibers smoothly (sliding inside)

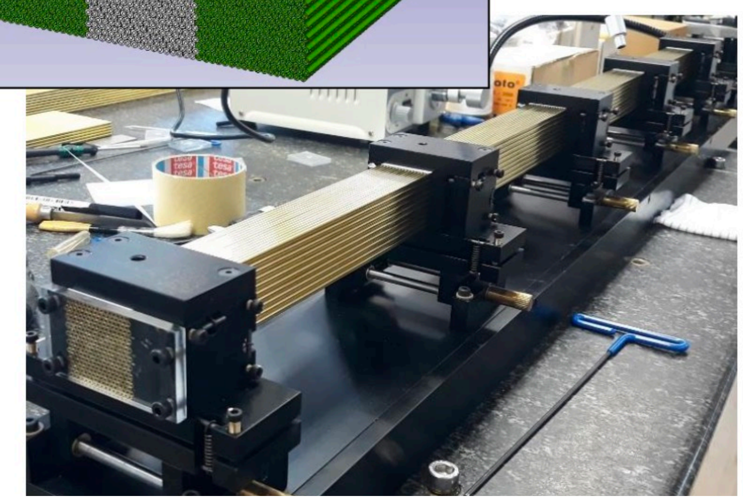
Bucatini Prototype Detector

- Main objectives of the R&D plan for the next years
  - Construction of an EM-size of a DRC and evaluation of its performance
  - Identifying and evaluating solutions at system level- Mechanics, Sensors, Readout scheme, Calibration
  - Proof of concept of the dual-readout technique with respect to hadronic performance
- Execution in two steps
  - Short-term plan: construction and evaluation of a module with EM shower containment (10 x 10 x 100 cm^3) and a high-granularity core (3.5 x 3.2 x 100 cm^3) equipped with SiPMs
  - Mid-term plan: design, construction and evaluation of a scalable system with hadronic shower containment, partially equipped with SiPM for cost/performance optimization
- 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 at DESY is scheduled at February (also consider a beam-time at CERN)

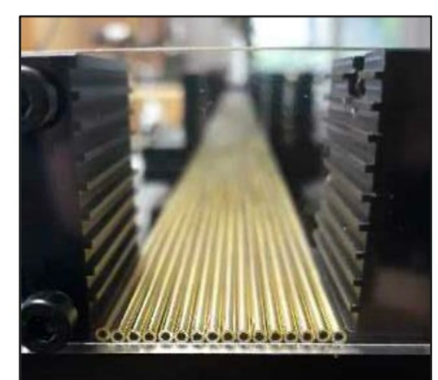




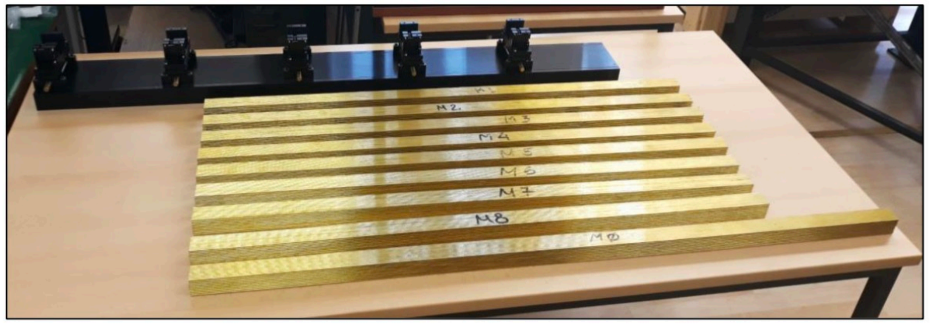


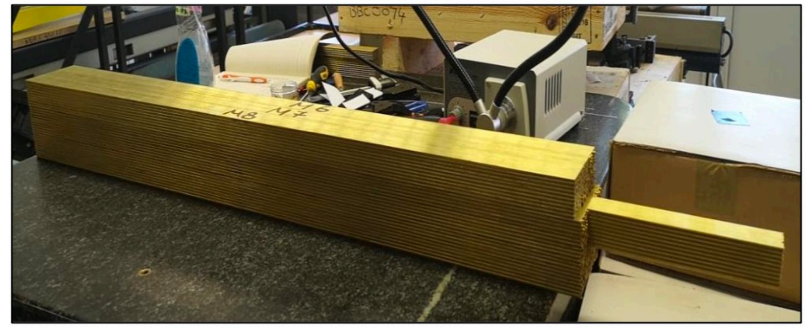


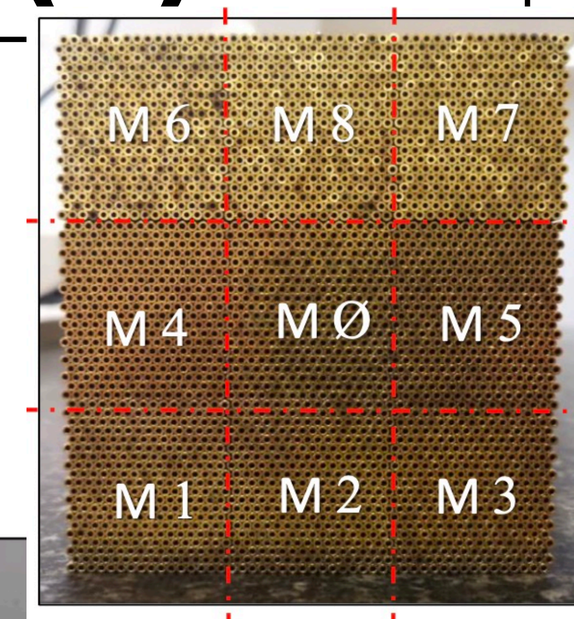
Assembly system

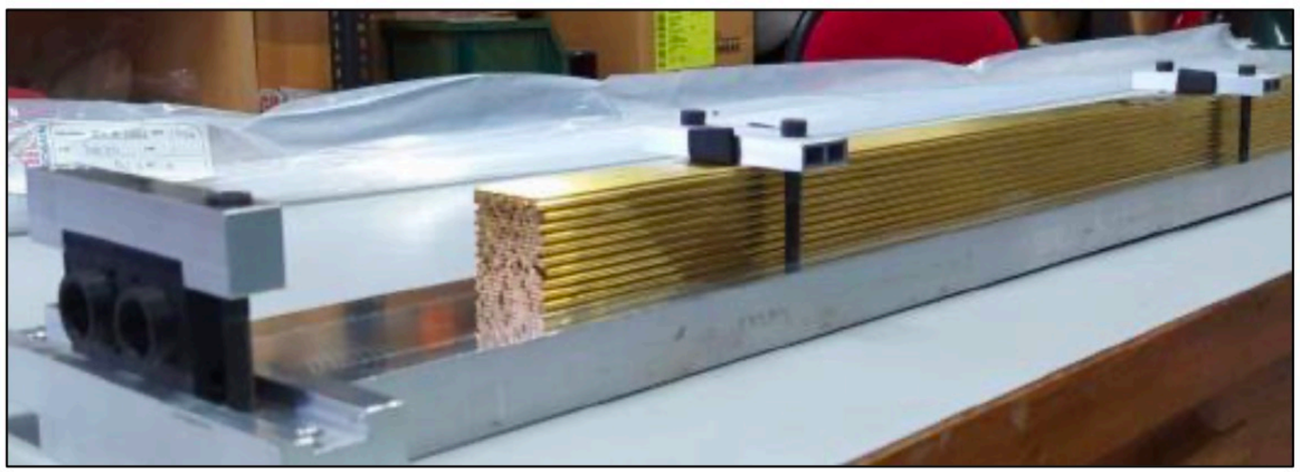


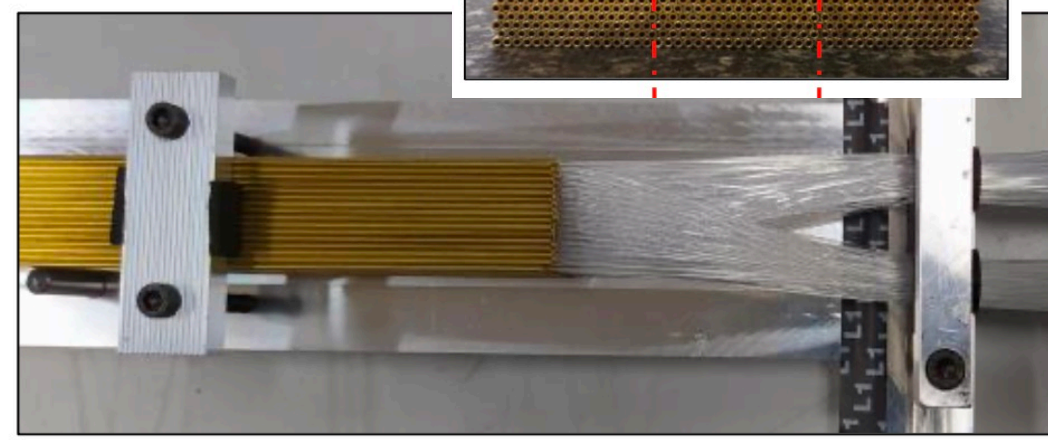
Module Assembly (1)

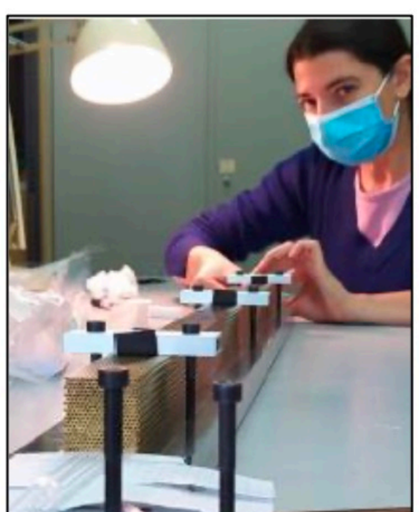


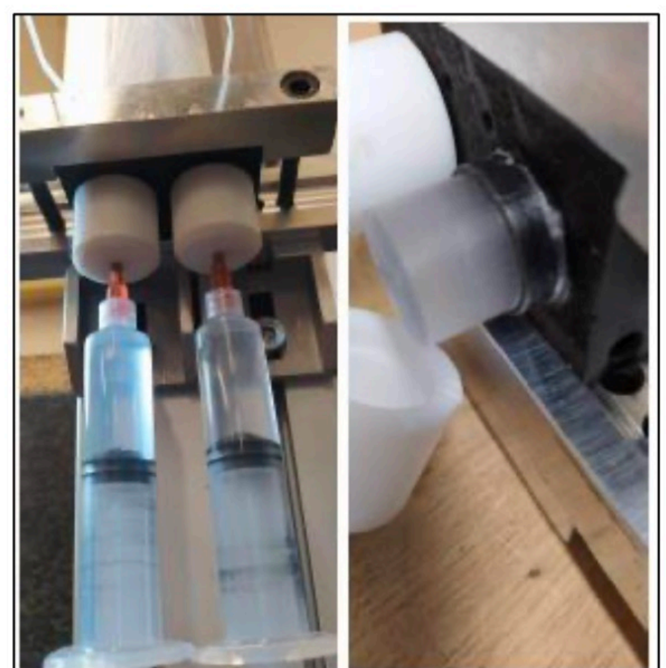






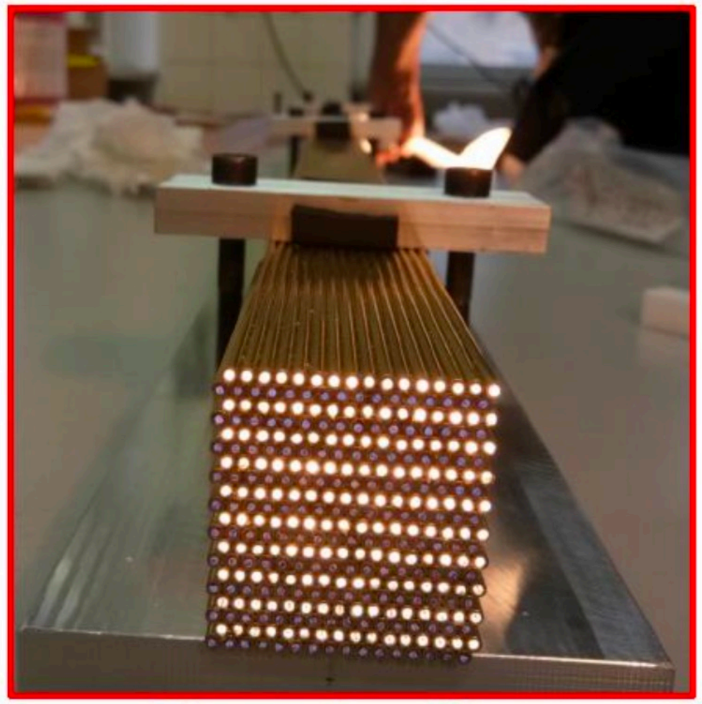




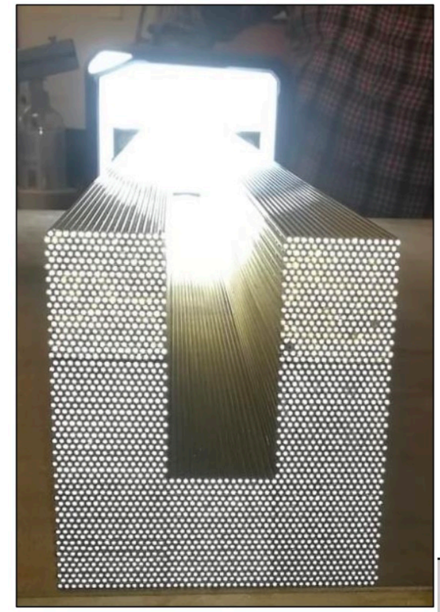


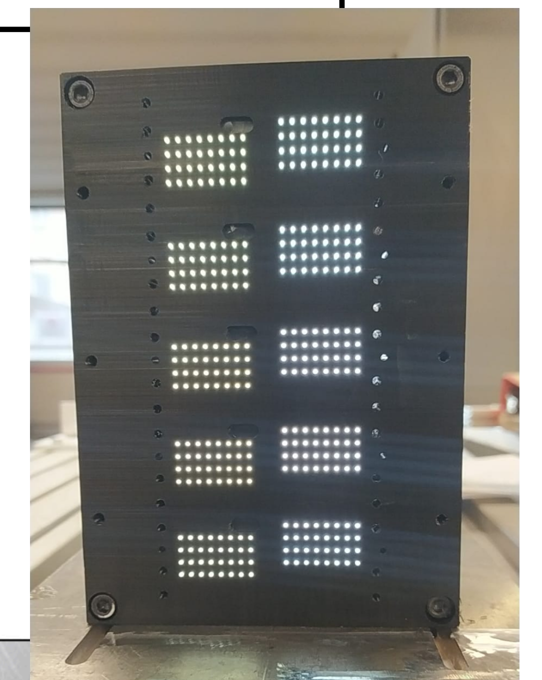
Module Assembly (2)

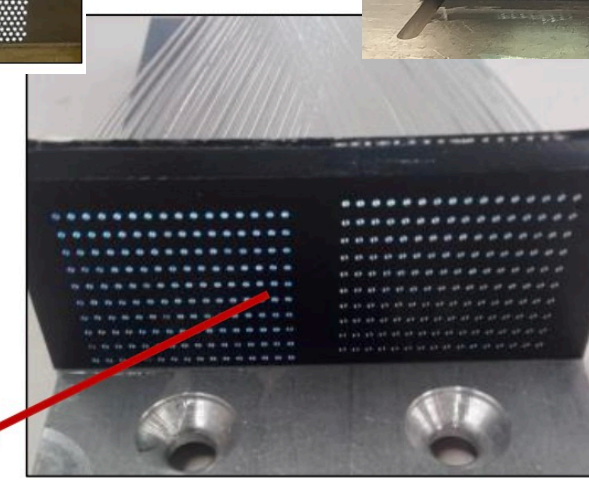
Scintillation fibers



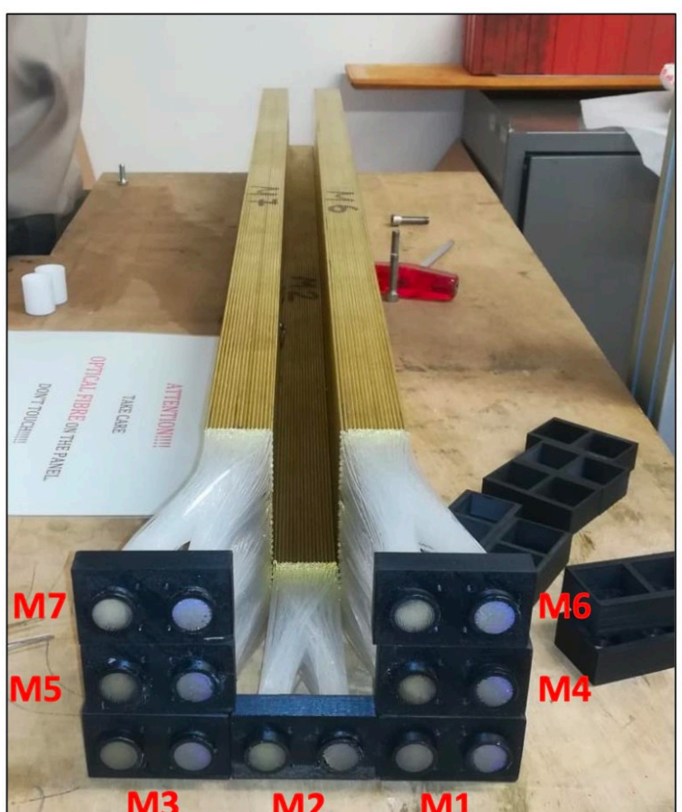
Cherenkov fibers

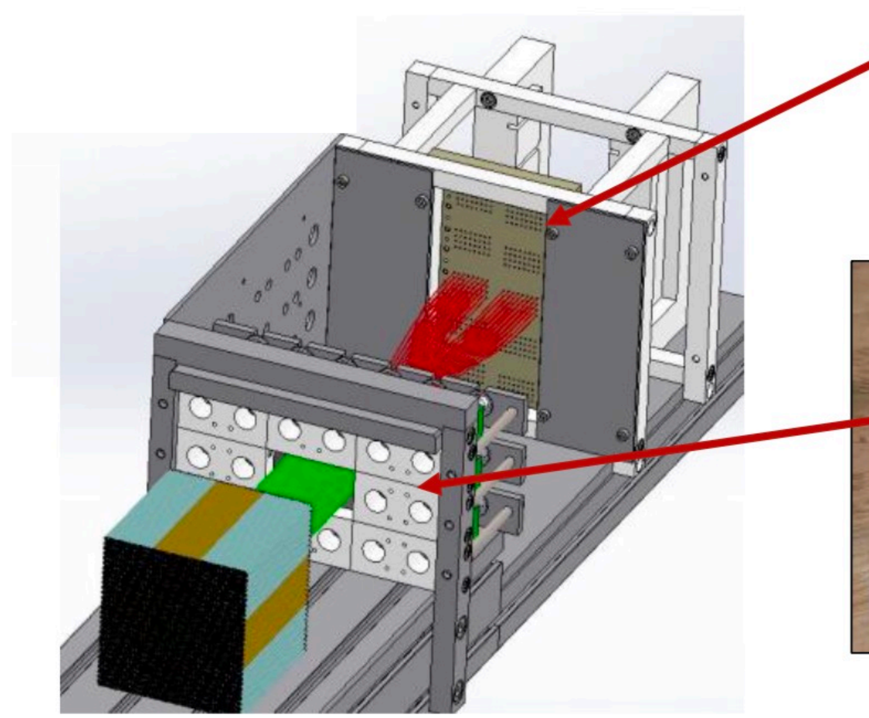






Fiber grouping for SiPMs

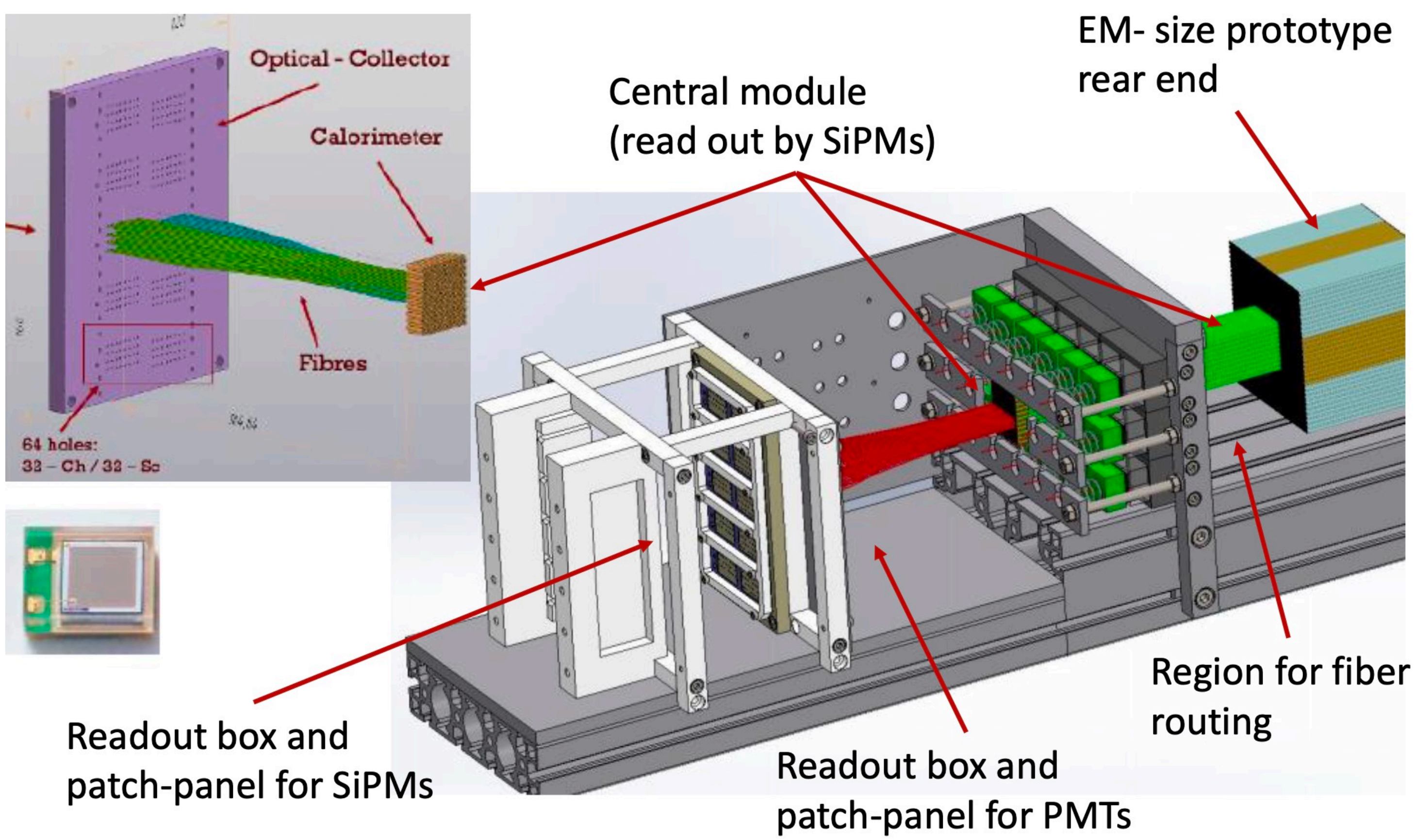


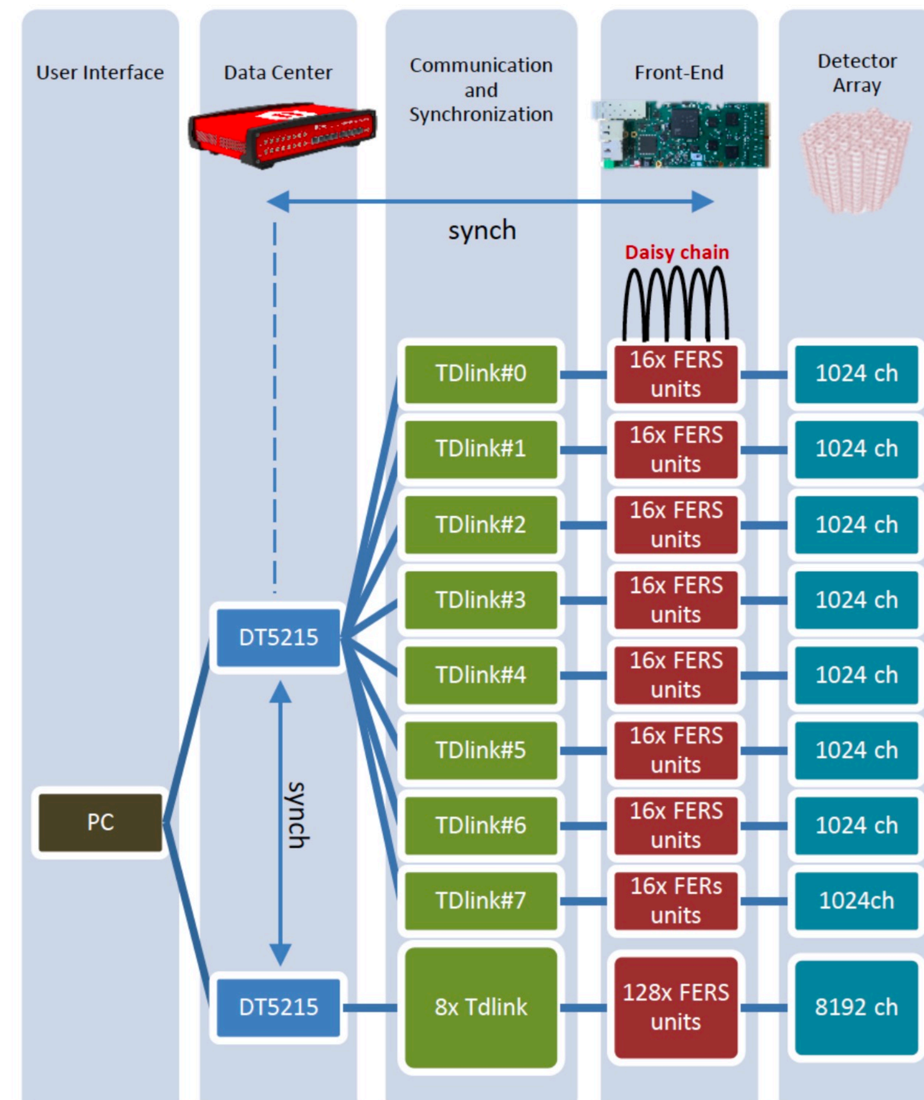


Fiber grouping for PMTs

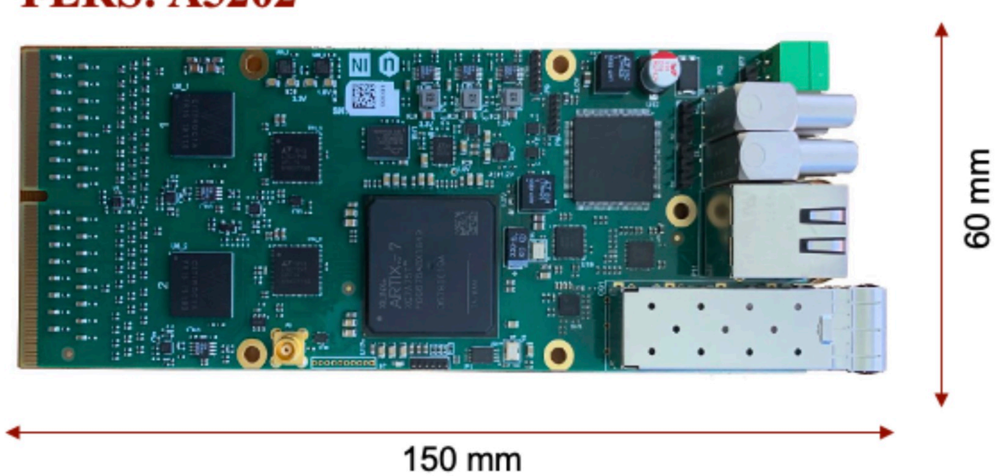
Readout Electronics

- The readout of the PMTs will be based on Caen QDC (V862AC) and TDC (V775N) modules
- The readout of the highly granular module (320 SiPMs) will be based on the Caen FERS system (5200) using 5 readout boards (A5202)





FERS: A5202

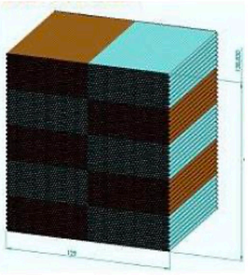


- **Two Citiroc1A for reading out up to 64 SiPMs**
- **Timing measured with 64 TDCs implemented on FPGA (time resolution ~ 200 ps)**

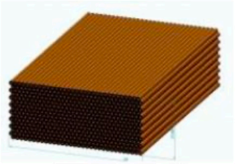
Toward Hadronic Prototype

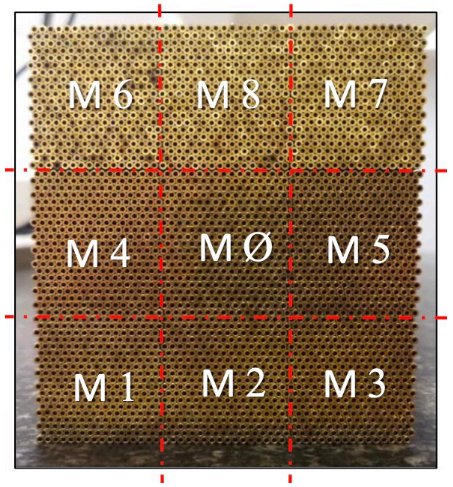
- From EM- to hadronic-size DR prototype: 2021 - 2025
  - Alternative and scalable solution for the DR mechanical structure
  - Alternative approach for the readout scheme

Single module constructed from 10 mini-modules ~ 13 x 30 x 200 cm³



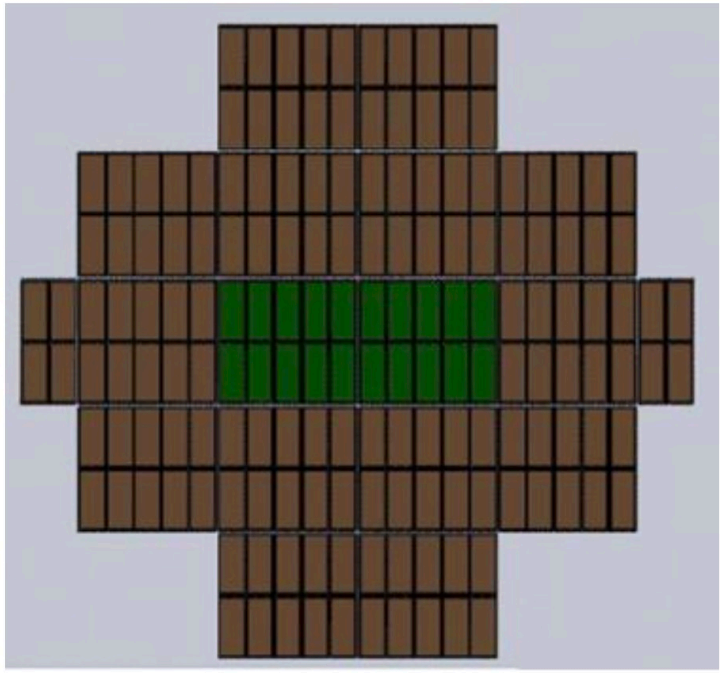
Mini-module constructed from 32 x 16 capillaries



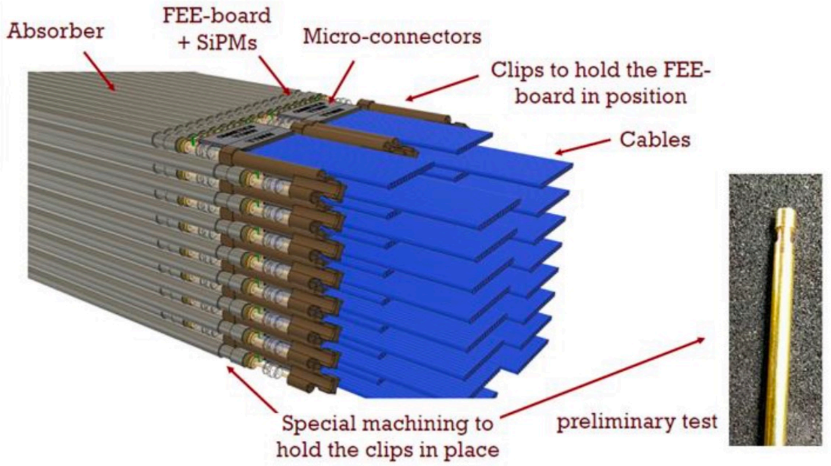


(10 x 10 x 100 cm³) → (65 x 65 x 200 cm³)

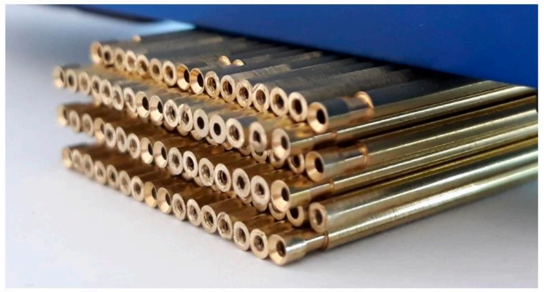
- **17 modules in total**
- **2 central modules readout with SiPMs**
- **15 modules readout with PMTs**



* One possible design

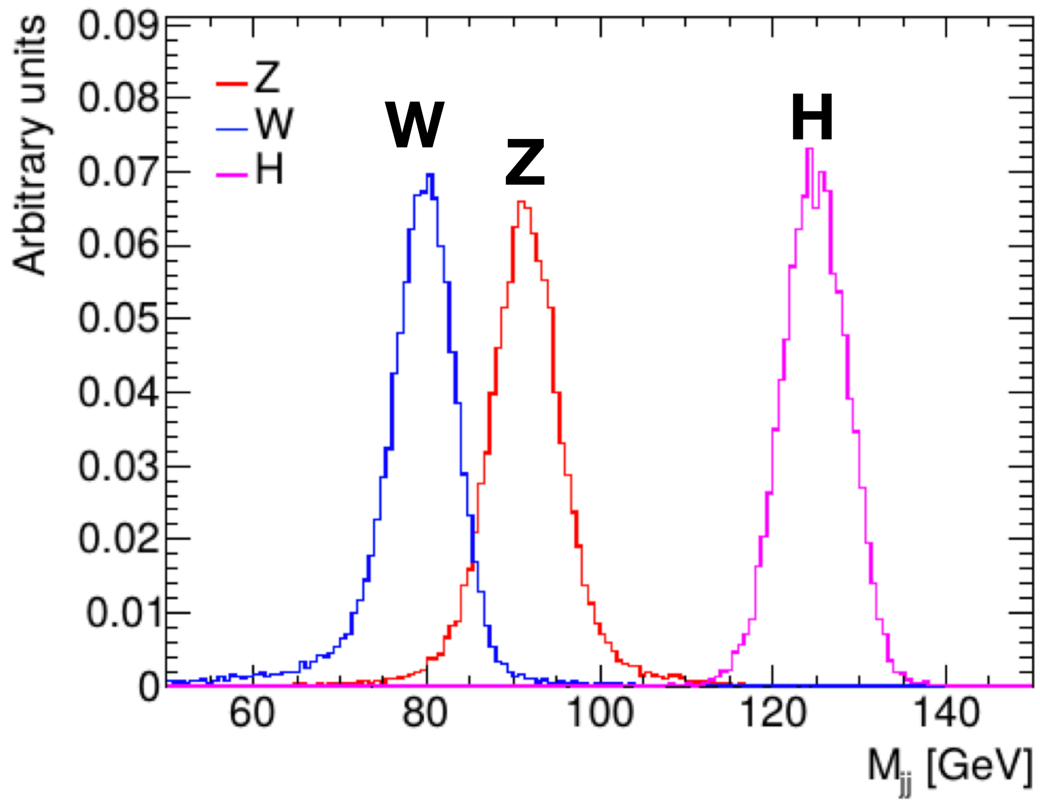


Mockup with PCB and capillaries



Physics Topics with DRC

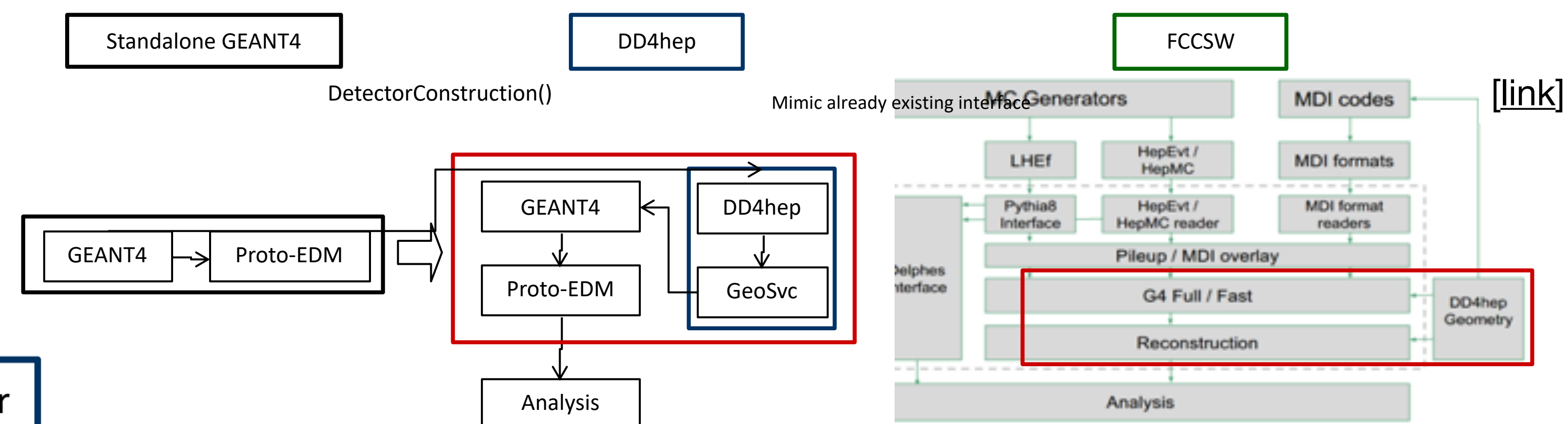
- Considerable physics objects with DR Cal: (for example) Higgs->gg, bb, cc, ττ, γγ, Zγ, ZZ, WW, invisible
- Physics object goals
  - Hadronic channel
    - W/Z/H mass separation: energy resolution 3-4% level
    - 5D information: energy + hit (3D) + timing
  - Excellent jet flavour tagging
    - Need a co-work with VTX (tracking) detector R&D group
    - Discriminate quark (u, b, c) and gluon jets with ML
  - Tau channel
    - Clear separation gamma and pi^0 reconstruction
    - Collimated topologies: separate gamma from close to hadronic showers
  - Related PID is quite important
- Need to check all necessary detector requirement for each physics topics (objects)



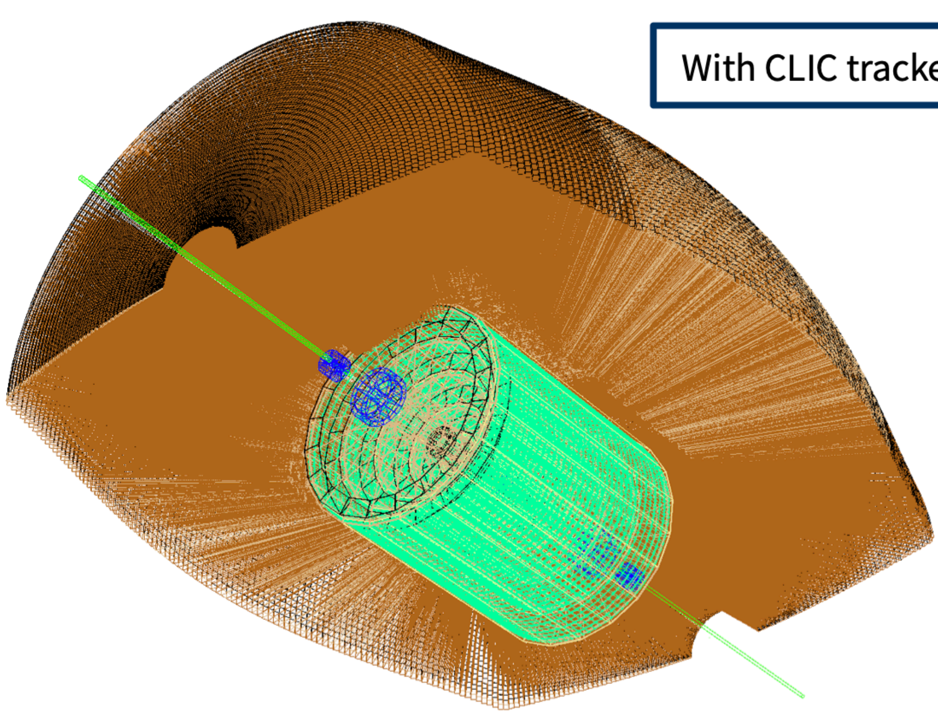
Many more items possible!

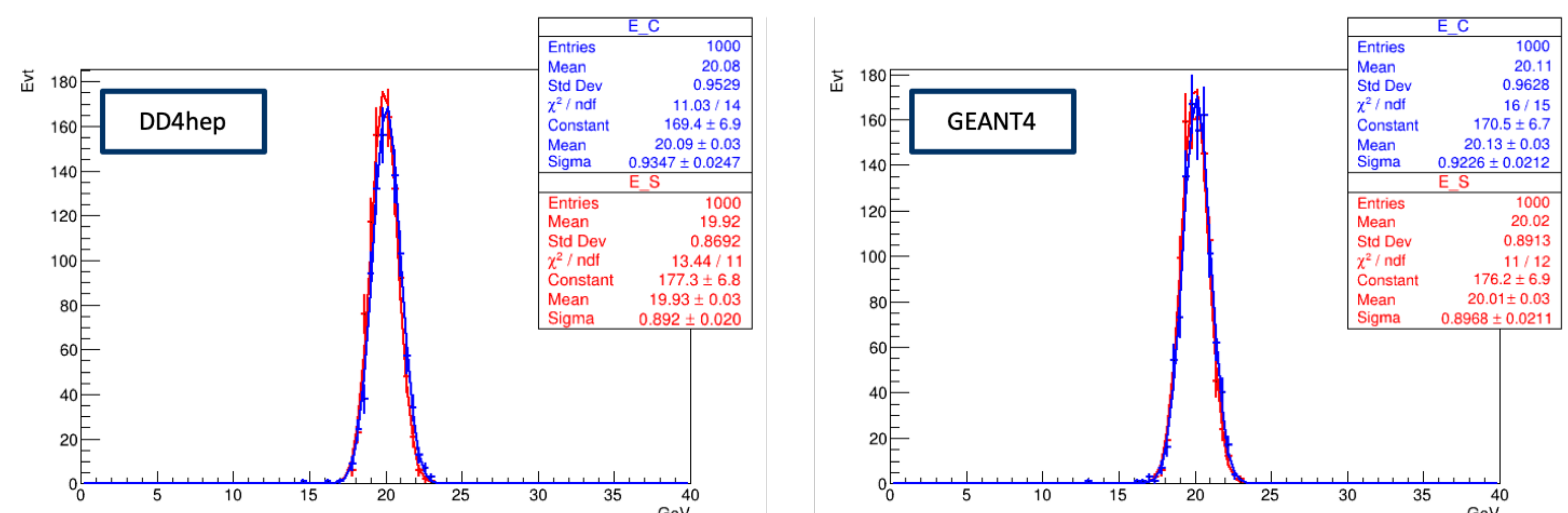
DD4hep Migration

- 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



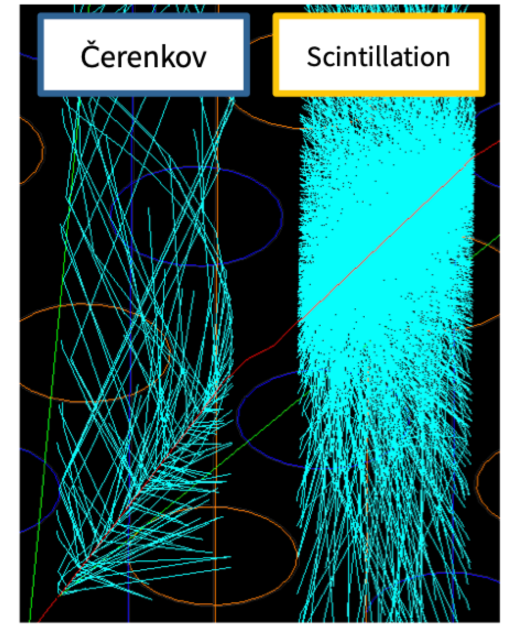
With CLIC tracker



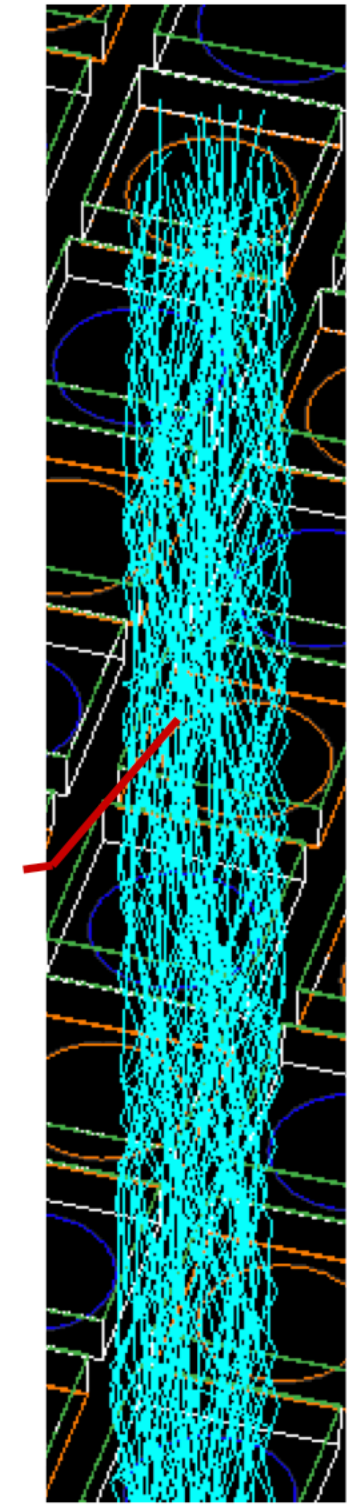


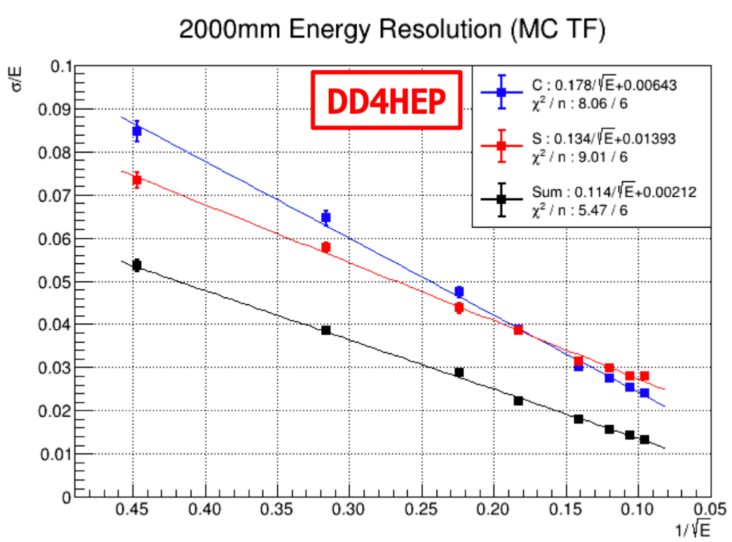
(Semi-)Fast Simulation

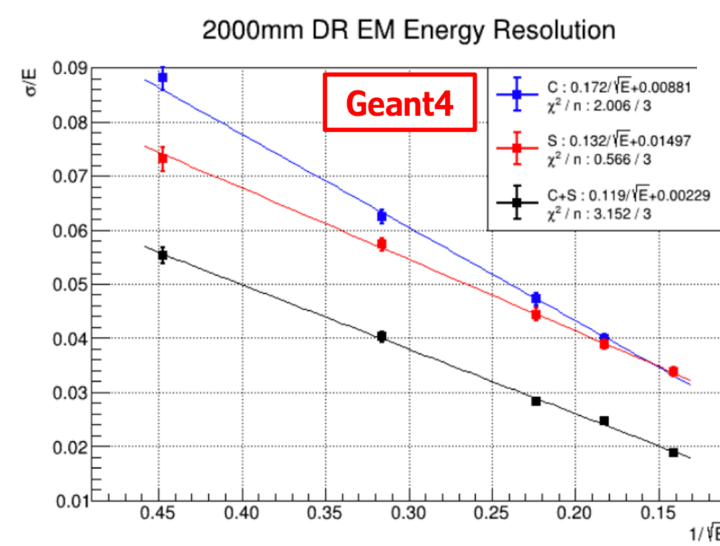
- Full GEANT4 simulation of optical photon tracking explodes CPU cost: O(h)/evt
    - Developing fast simulation for optical photon tracking: O(few mins)/evt
- Excellent consistency of the detector performance with DD4HEP and Semi-Fullsim



Important for a longitudinally unsegmented calorimeter





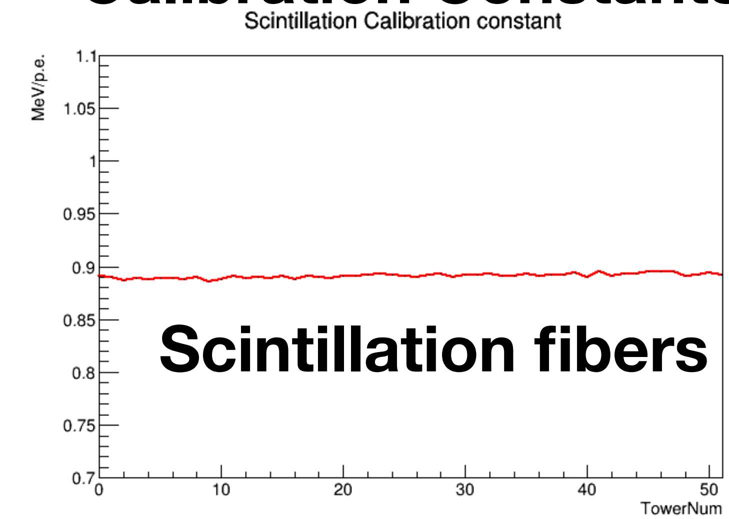


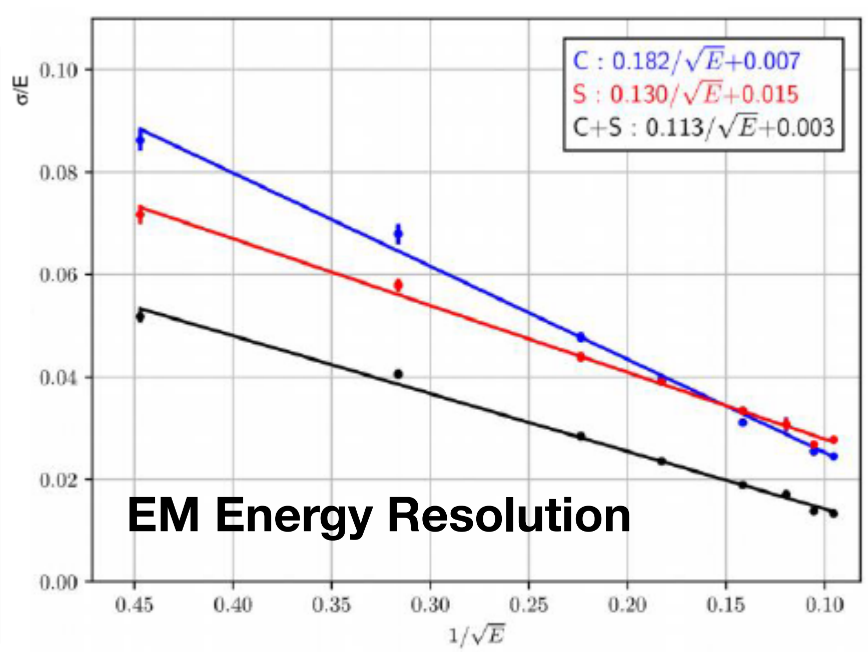
- 2000mm Wedge geometry EM energy resolution is measured with 5 different energy electron beams.
- Stochastic terms of energy resolutions are similar.

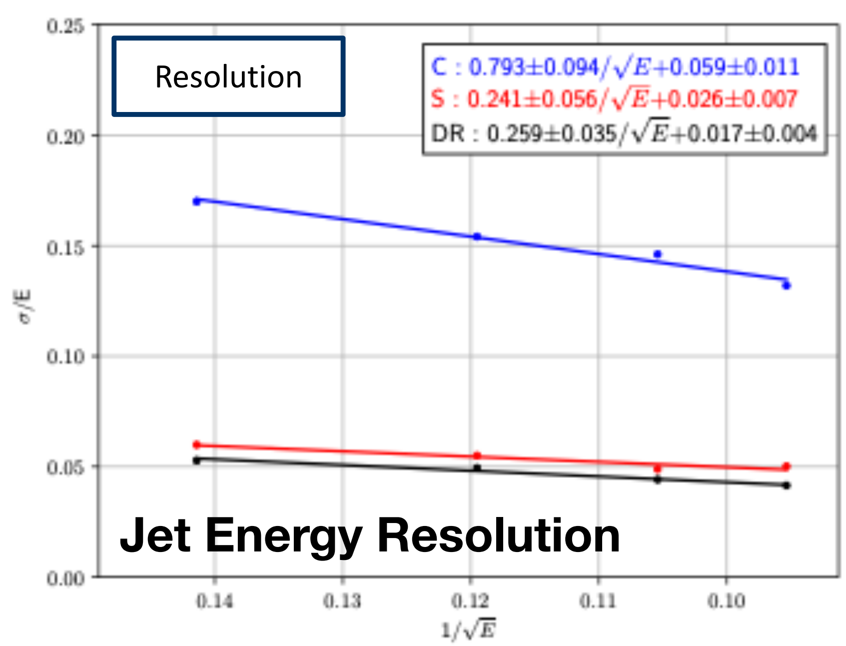
Energy Resolution

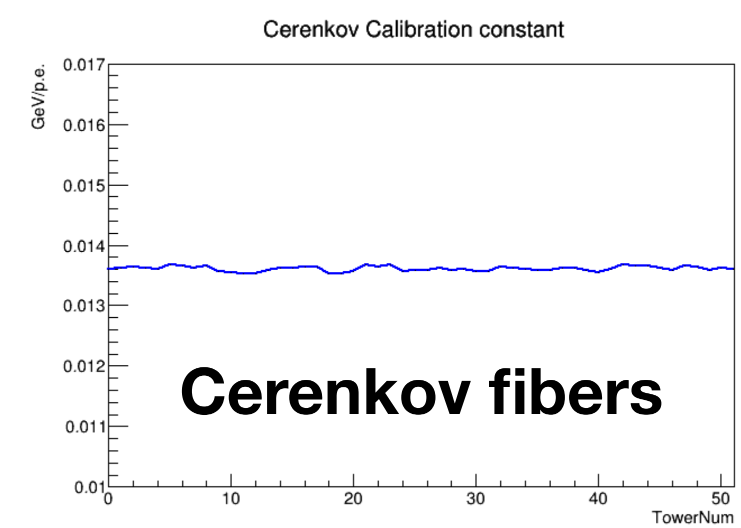
- Production of calibration constant with full GEANT4 simulation is on-going
    - Both barrel and endcap have been done
- Excellent EM and hadronic energy resolutions obtained by GEANT4 simulation
    - EM energy resolution: ~11%/sqrt(E)
    - Jet energy resolution: ~26%/sqrt(E)

Calibration Constants





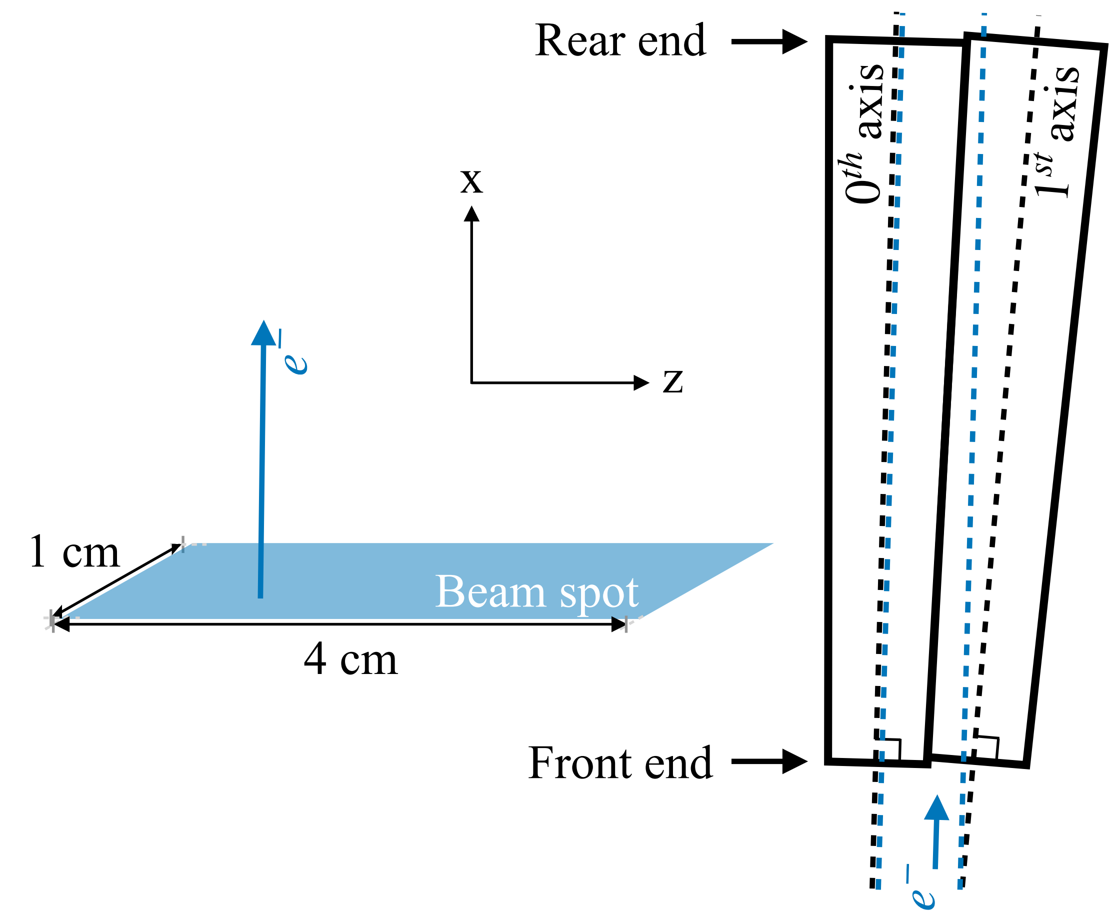


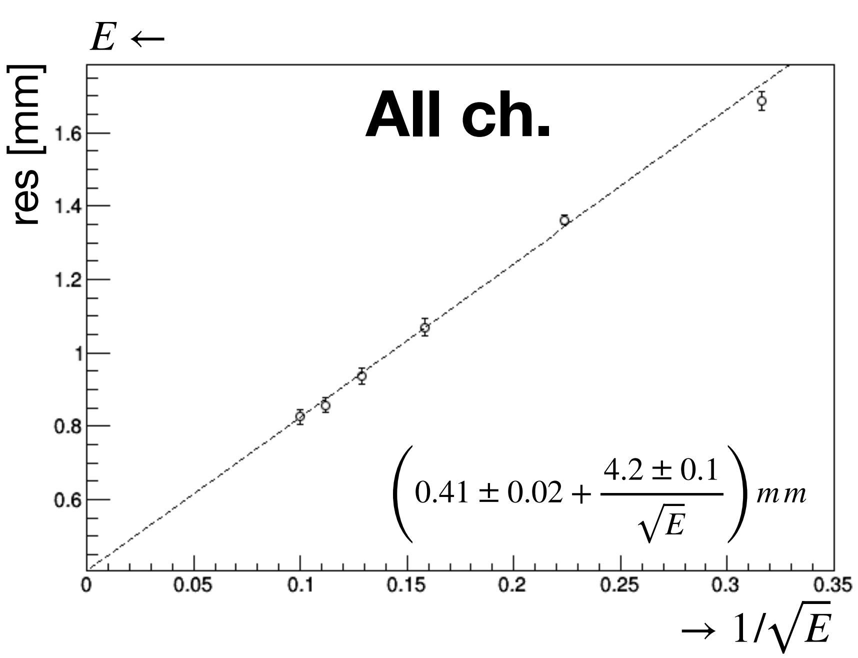


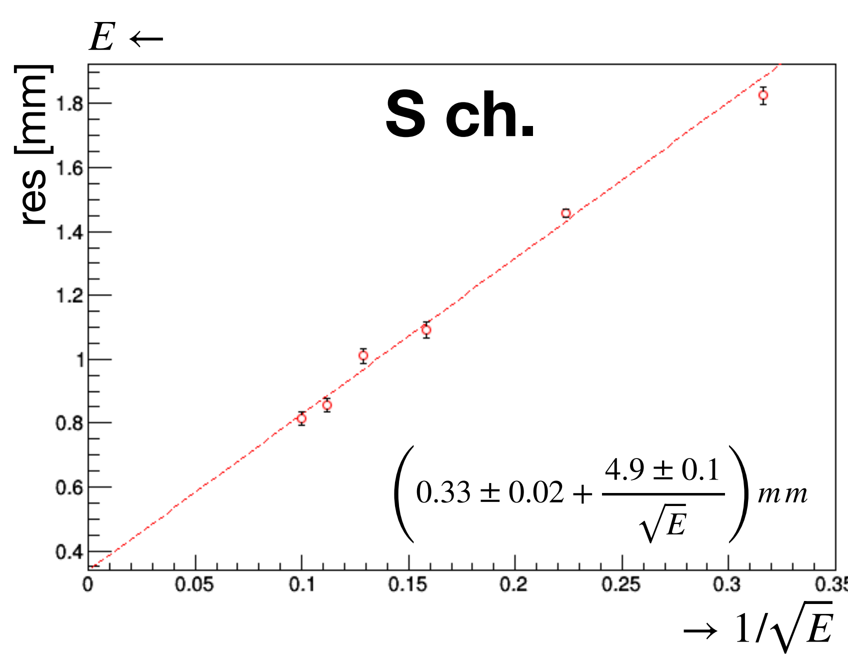
Tower #

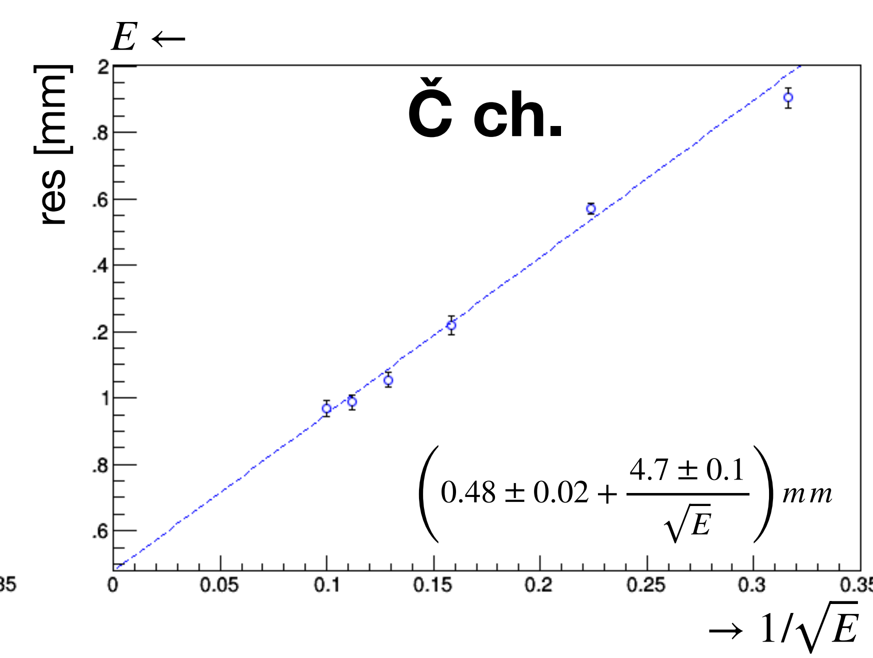
Position Resolution

- Tested by e^- beams of 6 different energies
  - 10, 20, 40, 60, 80 and100 GeV
- Position reconstructed by center of gravity of energies and compared with generated position
  - $\vec{x}_{reco} = \frac{\sum_i E_i \times \vec{x}_i}{\sum_i E_i}$, i : #SiPM
- Preliminary position resolution:
  - $4.2\ \mathrm{mm}/\sqrt{E} + 0.4\ \mathrm{mm}$





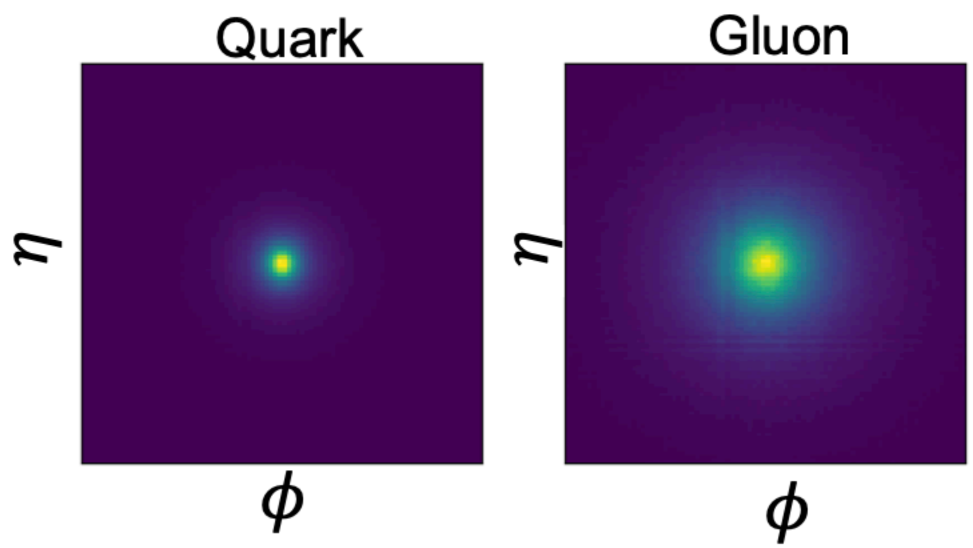




ML-based Application

- ML will be used widely in dual-readout calorimeter R&D

Average scintillation energy images



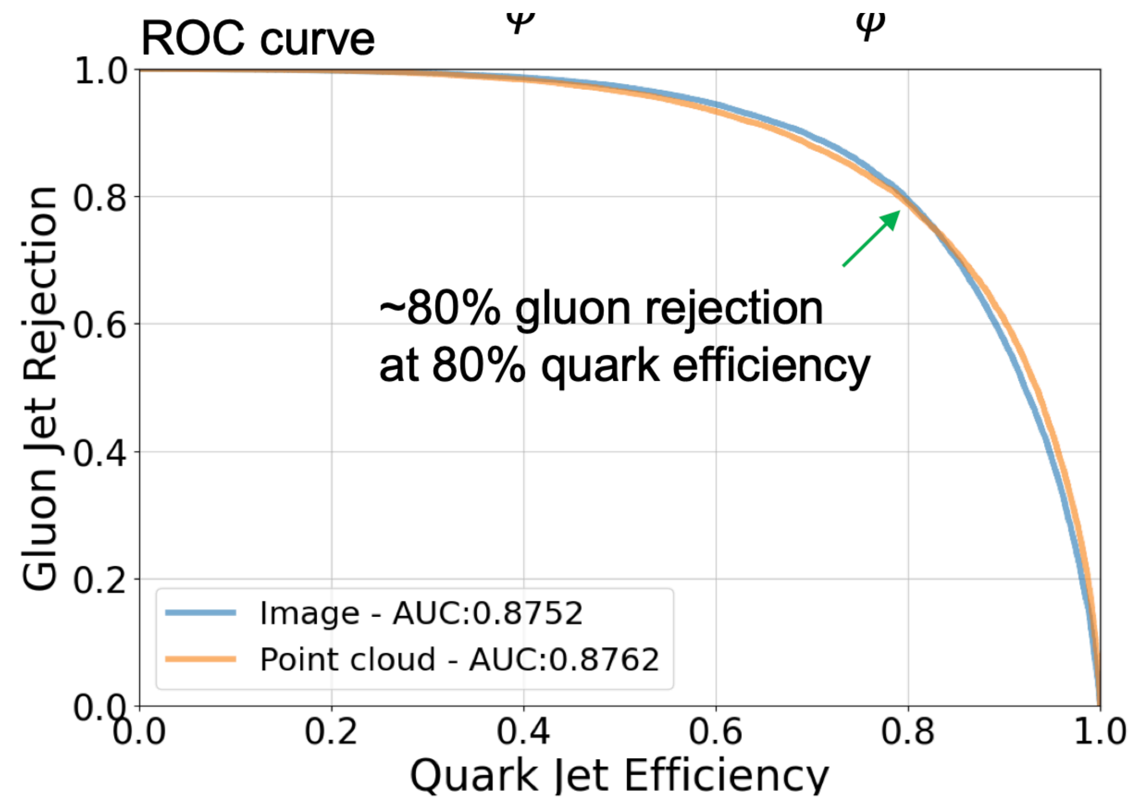
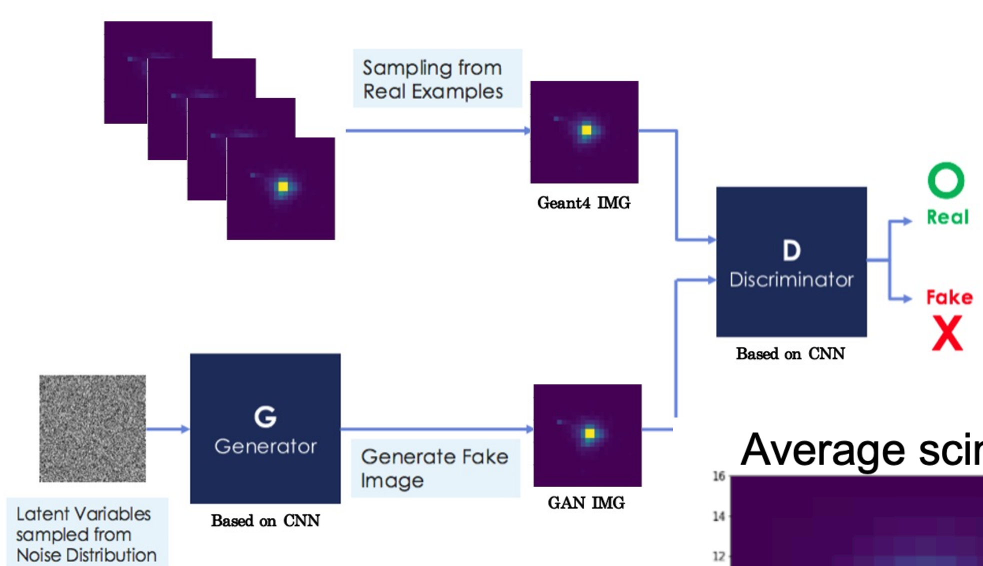
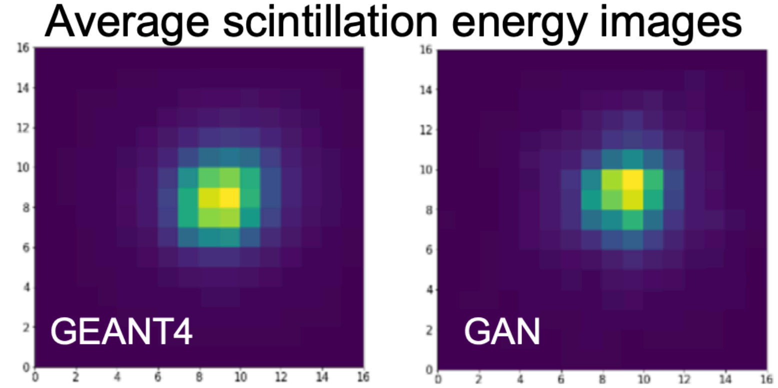
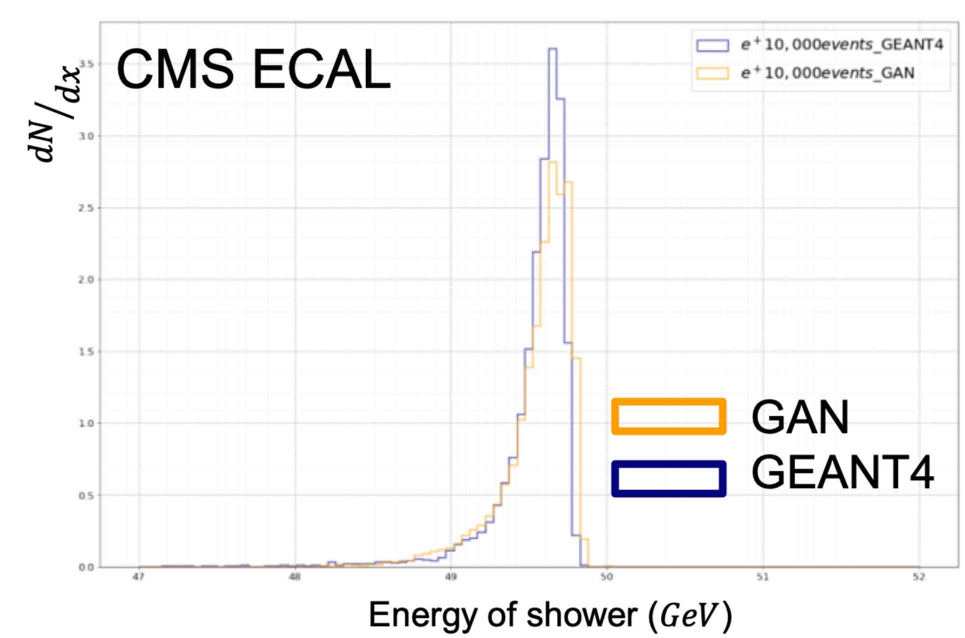


Image data format under development



Average scintillation energy images





Snowmass21 (SM2021)

- Excellent opportunity to
    - Integrate US and world-wide research campaign
    - Increase visibility our local activity to international colleagues
- International dual-readout team prepared a single letter interest (LoI): overview of dual-readout activities
    - https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF6-008.pdf

Dual-Readout Calorimetry

Letter of Intent

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- Additional 7 LoIs related to the dual-readout calorimeter R&D project have been submitted too!
- Various MC production such as multi-jets, Higgs and tau events are underway with GEANT4 + DD4hep infrastructure
    - If interest, please contact us! (hdyoo@cern.ch)

SM2021 with DRC in Korea

- Topic 1: Feasibility study of combining a MIP Timing Detector with the Dual-readout Calorimeter at future e+e- colliders (link)
    - Collaborators: D. Stuart (UCSB), C.S. Moon (KNU), J.H. Yoo (Korea Univ.)
- Topic 2: Heavy flavor tagging using machine learning technique with silicon vertex detector and Dual-Readout Calorimeter at future e+e- colliders (link)
    - Collaborators: J. Huang (BNL), Q. Hu (LLNL), S.H. Lim (PNU)
- Topic 3: tau reconstruction and identification using machine learning technique with Dual-Readout Calorimeter at future e+e- colliders (link)
    - Collaborators: M. Murray (U. of Kansas), Y.S. Kim (Sejong Univ.), Y.J. Kwon (Yonsei Univ.)
- Topic 4: Sensitivity study of H->Zgamma with Dual-Readout Calorimeter at future e+e- colliders (link)
    - Collaborators: Y. Maravin (Kansas State Univ.), K.W. Nam (Kansas State Univ.)
- Topic 5: Multi-object identification with Dual-Readout Calorimeter at future e+e- colliders (link)
    - Collaborators: P. Chang (UCSD)
- Topic 6: Dual-Readout Calorimeter for the future Electron-Ion Collider (link)
    - Collaborators: S.H. Lim (PNU), H.S. Jo (KNU), Y.S. Kim (Sejong Univ.)
- Topic 7: Fast optical photon transport at GEANT4 with Dual-Readout Calorimeter at future e+e- colliders (link)

Feasibility study of combining a MIP Timing Detector with the Dual-Readout Calorimeter at future e^+e^- colliders

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August 30, 2020

Heavy flavour tagging using machine learning technique with silicon vertex detector and Dual-Readout Calorimeter at future e^+e^- colliders

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August 31, 2020

τ reconstruction and identification using machine learning technique with Dual-Readout Calorimeter at future e^+e^- colliders

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[3]Yonsei University, Republic of Korea

August 30, 2020

Sensitivity study of $H \to Z\gamma$ with Dual-Readout Calorimeter at future e^+e^- colliders

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[2]Yonsei University, Republic of Korea

August 30, 2020

Multi-object identification with Dual-Readout Calorimeter at future e^+e^- colliders

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[b]*Yonsei University, Republic of Korea*

Recent Presentations

- Online mini-workshop on a detector concept with a crystal ECAL (July 22 - 23, link)
    - Gabriella Gaudio (INFN, Pavia), "Review of past DREAM work on dual-readout crystals" (link)
    - Marco Lucchini (Princeton U.), "Segmented crystal electromagnetic precision calorimeter (SCEPCAL)" (link)
    - Iacopo Vivarelli (U. of Sussex), "Stand-alone pion resolution with the IDEA concept" (link)
    - Sanghyun Ko (Seoul Nat. U.), "Development efforts of software framework to simulate DR calorimeter" (link)
- CEPC days (Aug. 26th, link)
    - Hwidong Yoo (Yonsei U.), "Korean Activities of Dual-Readout Calorimeter R&D" (link)
- CEPC workshop (Oct. 26 - 28, link)
    - Sarah Eno (U. of Maryland), "Studies on combined calorimeters with crystals and dual-readout" (link)
    - Chris Tully (Princeton U.), "Physics Performance of the New Concept with Crystal ECAL and Dual-Readout HCAL" (link)
    - Iacopo Vivarelli (U. of Sussex), "Performance and analysis results of Dual-Readout simulated data" (link)
    - Yunjae Lee (U. of Seoul), "Simulation and machine learning for the Dual-Readout Calorimeter" (link)
    - Romualdo Santoro (INFN, Insubria), "Status and plans for Dual-Readout Calorimetry R&D" (link)
- IAS mini-workshop, conference (Jan. 14 - 21, link)
    - Roberto Ferrari (INFN, Pavia), "PID with Dual-Readout Calorimeter" (link)
    - Hwidong Yoo (Yonsei U.), "Status of Dual-Readout Calorimeter R&D" (link)

Summary

- Dual-Readout Calorimeter R&D project for future e^+e^- collider in Korea is very active
    - Build and test full size prototype DRC detector by 2025
    - HW R&D and simulation studies for performance and ML applications on-going
- Three major R&D goals in 2021
    - Test beam 2021
        - Rebuild two modules for the 1st test-beam experiment
    - Performance studies using GEANT4 and wide applications with ML technique
    - Various Snowmass 2021 studies are on-going
- Many publications and conference talks are planned
- Innovative 3D-printing module is under study