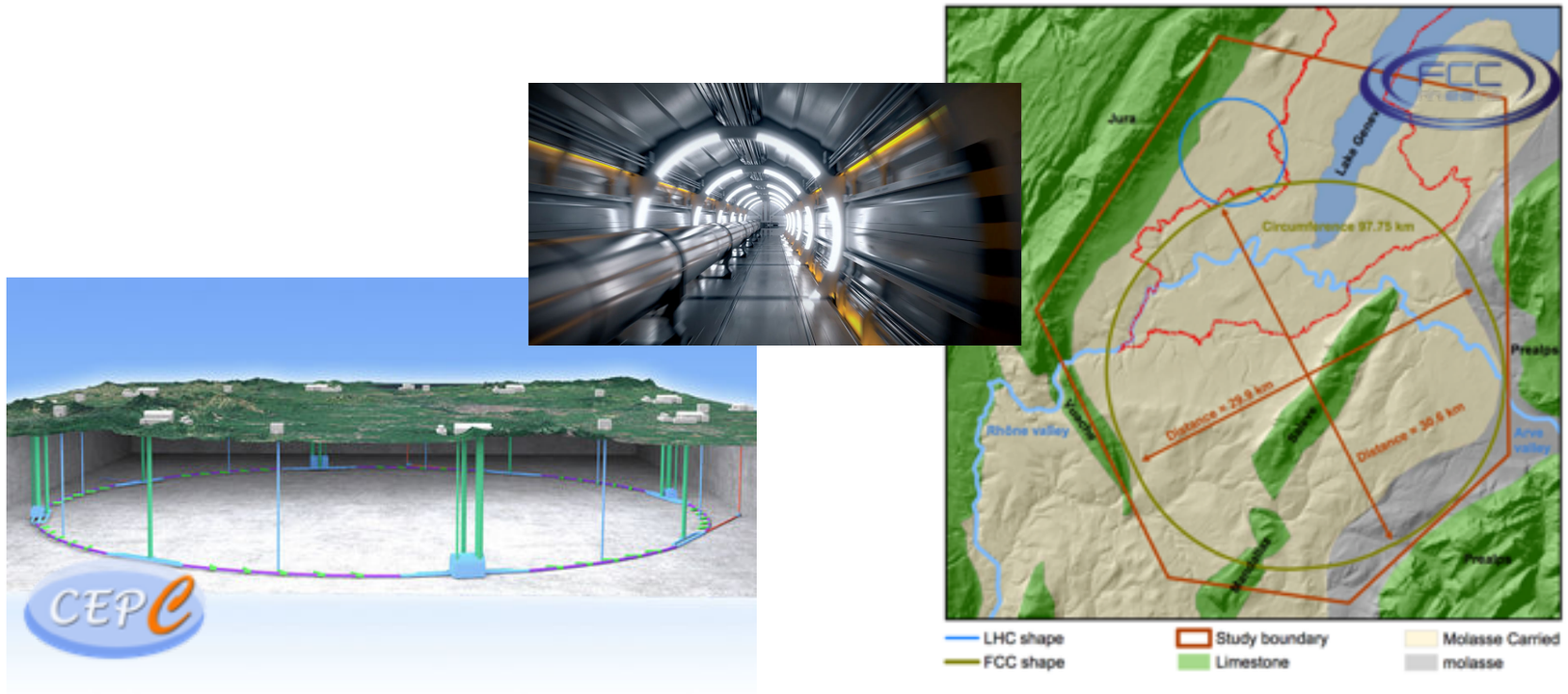
Future Collider Projects

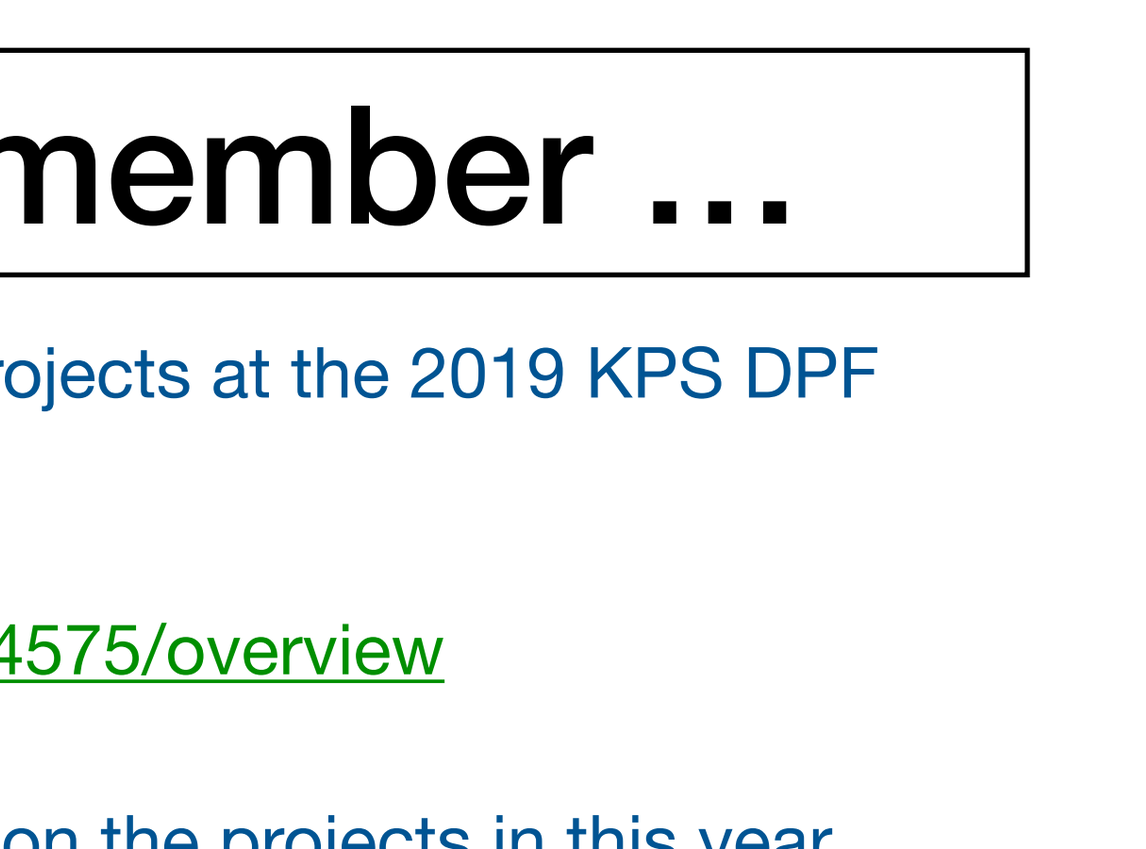
Hwidong Yoo (Yonsei Univ.)



KPS DPF general meeting, Dec. 3, 2020

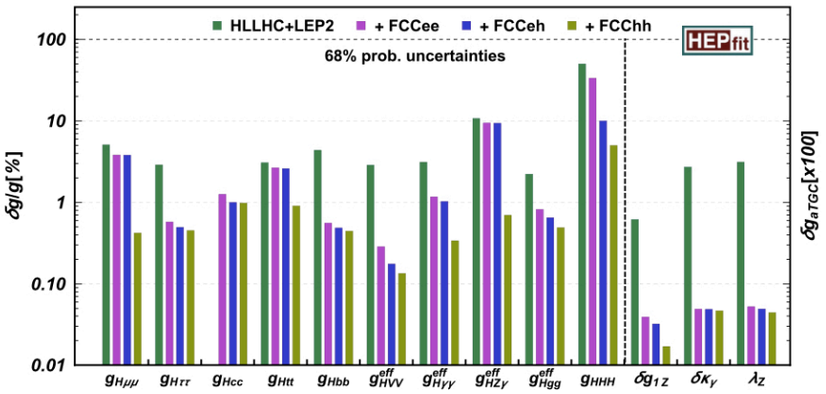
You May Remember …

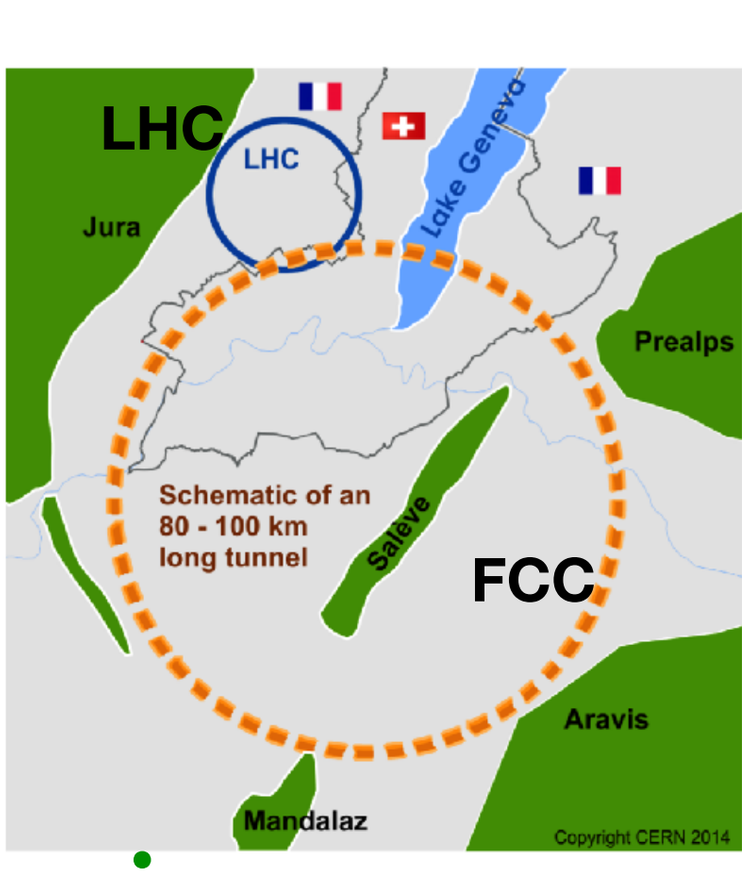
- Reviewed various future collider projects at the 2019 KPS DPF general meeting
  - https://indico.cern.ch/event/844575/overview
- Today, I will focus on the progress on the projects in this year
  - Mostly about the dual-readout calorimeter detector R&D
- We had the dedicated focus session at 2020 KPS fall meeting
  - https://indico.cern.ch/event/966662/

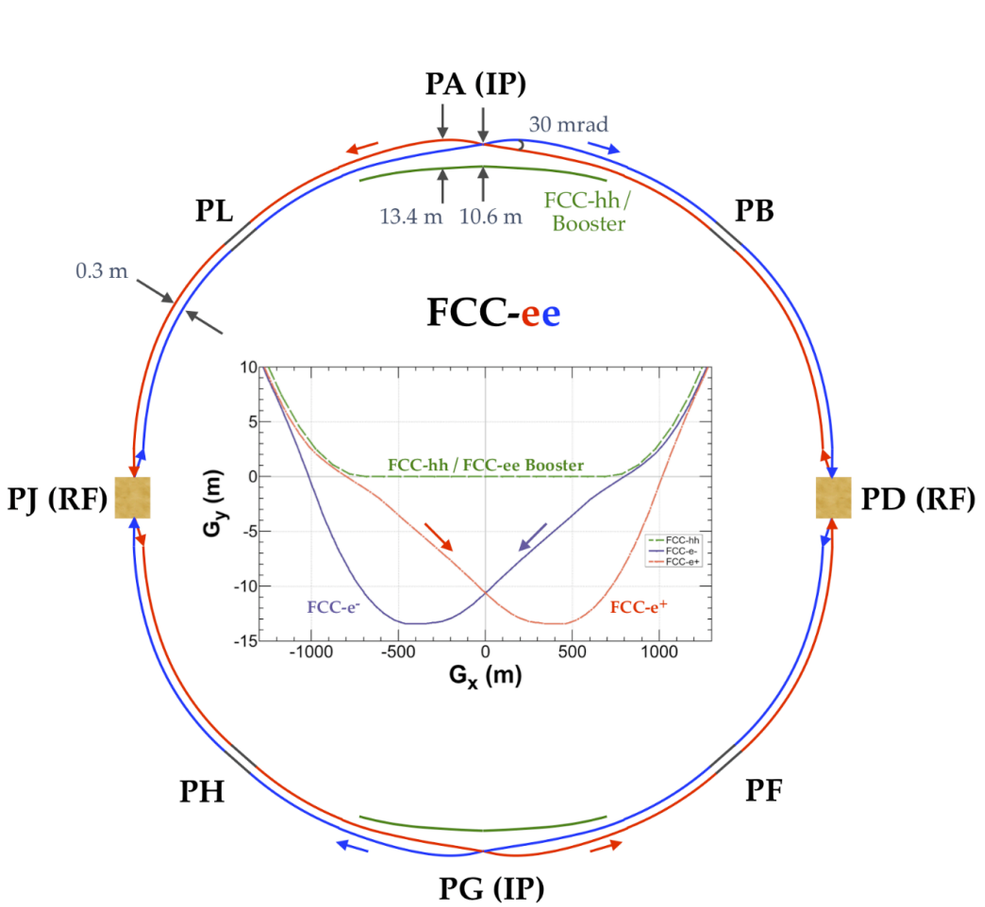


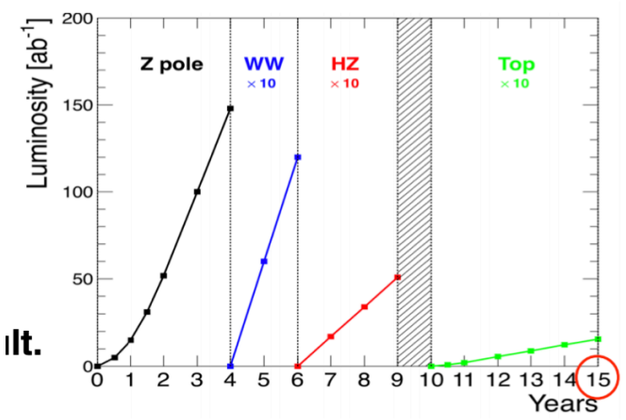
FCC Project

- 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)





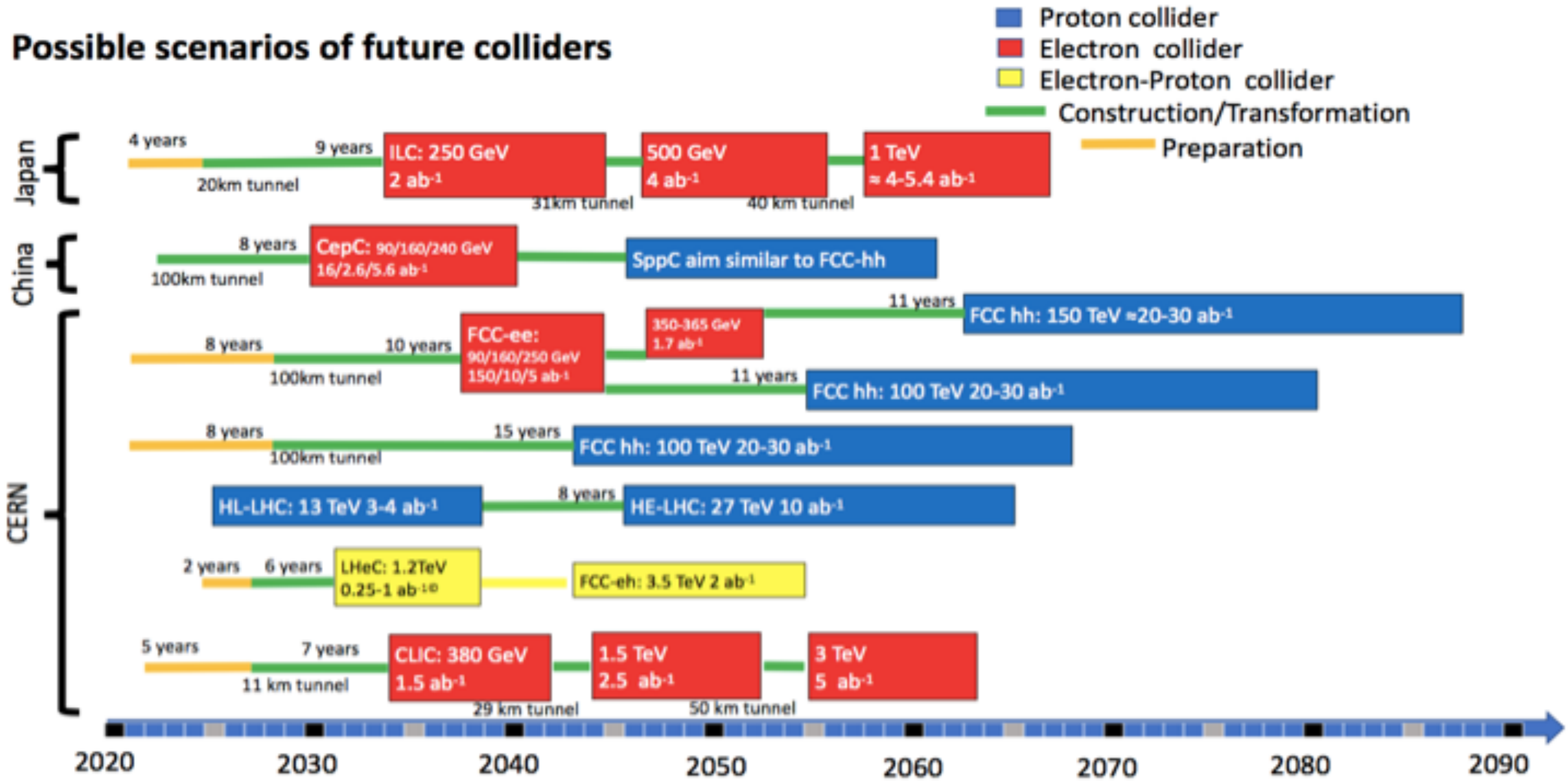




- Precision measurements! => Higgs factory!
  - Higgs factory (HZ): 10^6
  - EW & Top factory
    - $5x10^{12}$ (Z), 10^8 (WW), 10^6 (tt)
  - Flavour factory
    - $5x10^{12}$ (Z->bb, cc, tautau)
  - QED, QCD, BSM, etc.

Roadmap of FC Projects

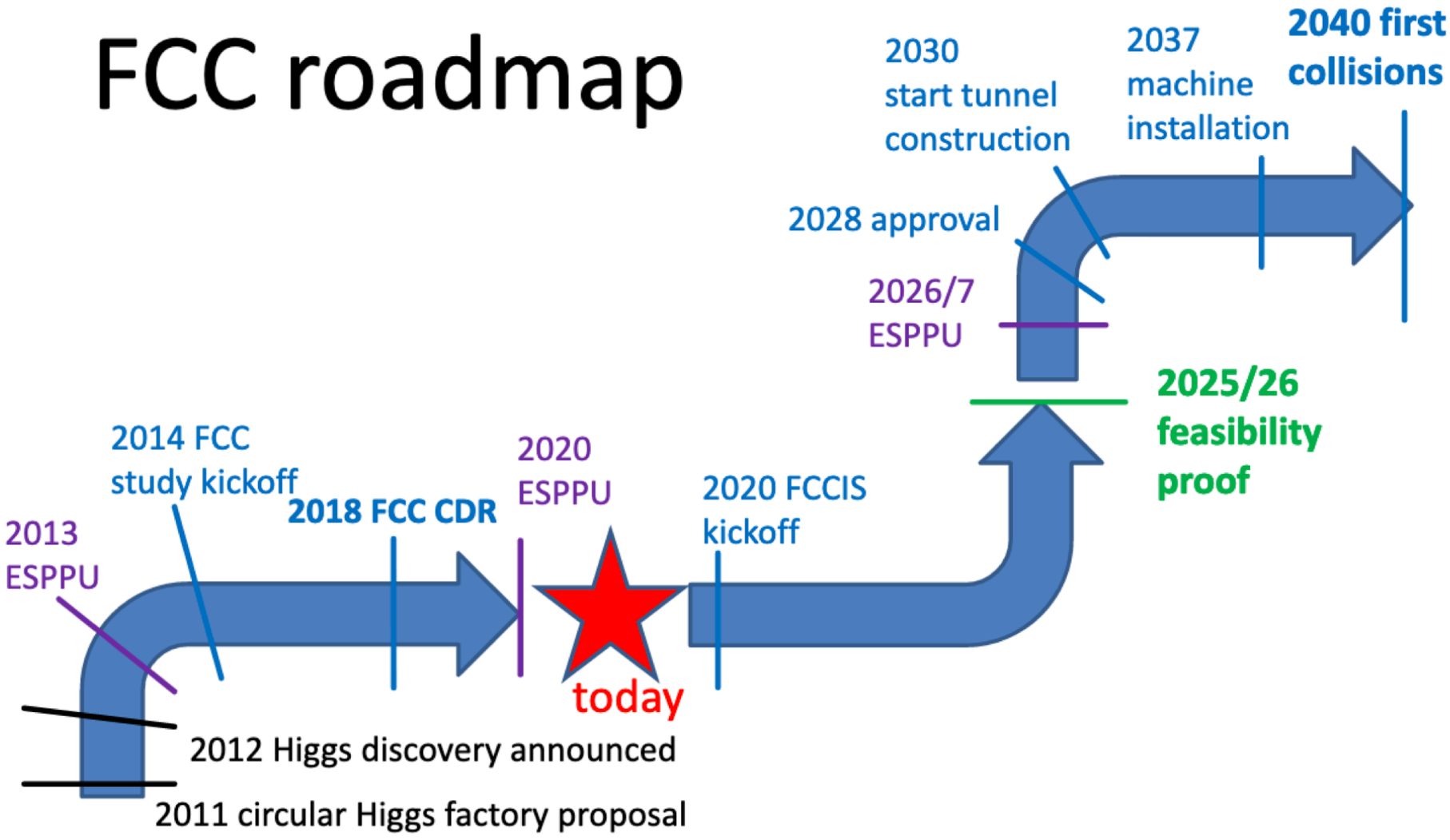
- Time flies very fast!



Recent Update

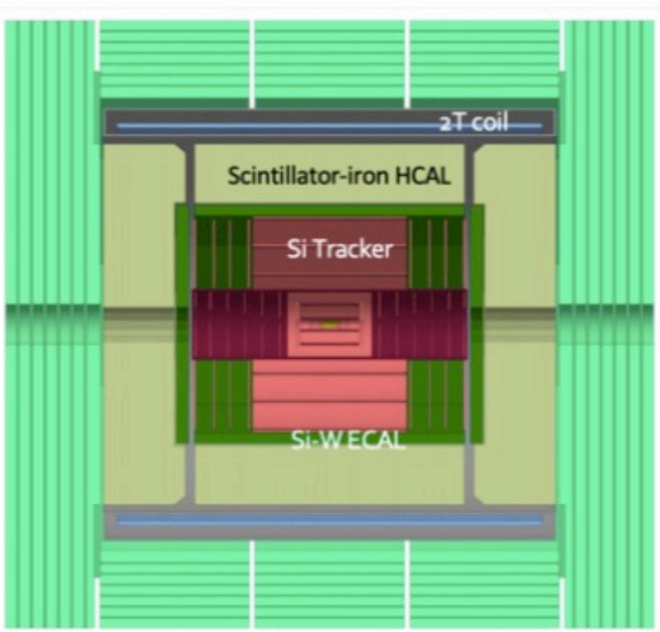
FCC Roadmap

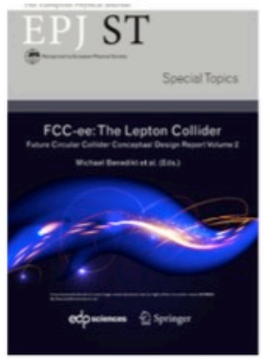
FCC roadmap

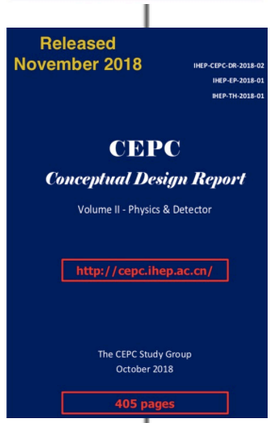


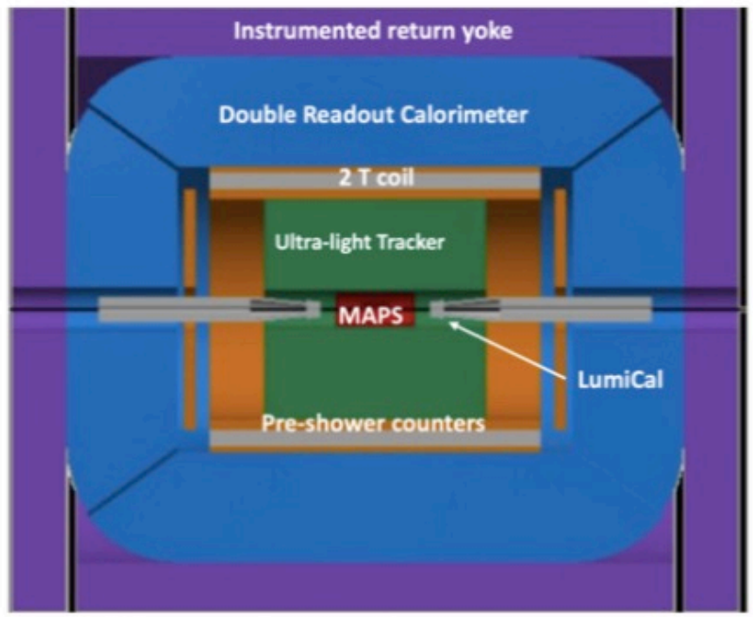
FCC-ee Detector Concept

- 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

- 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

IDEA

- 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

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.

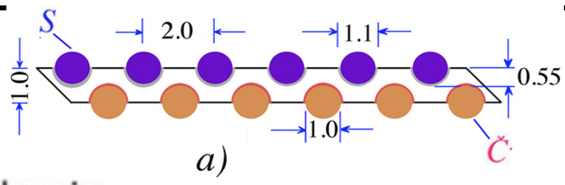
$$S = E[f_{em} + \frac{1}{(e/h)_S}(1-f_{em})],$$

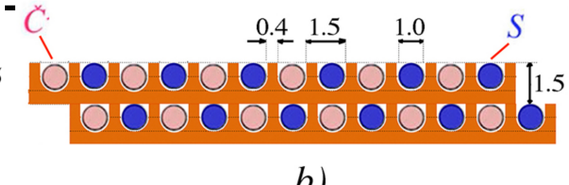
$$C = E[f_{em} + \frac{1}{(e/h)_C}(1-f_{em})].$$

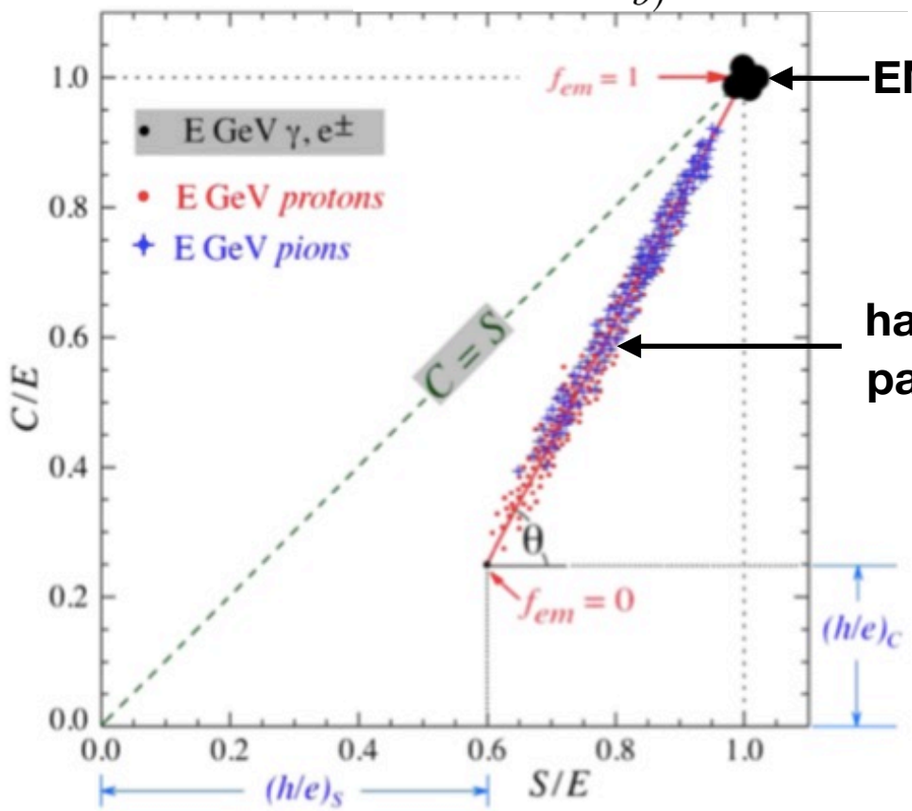
$$\cot\theta = \frac{1-(h/e)_S}{1-(h/e)_C} \equiv \chi,$$

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

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





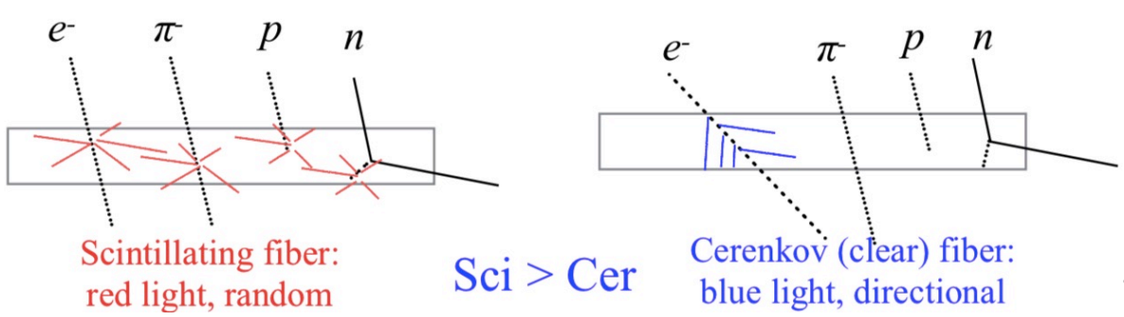


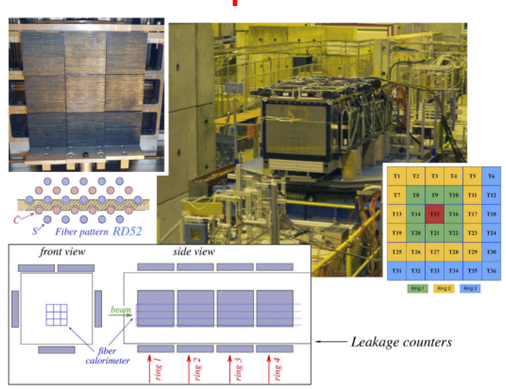
Energy measured from scintillation channel vs Cerenkov channel for EM particle, π & p.

- 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.

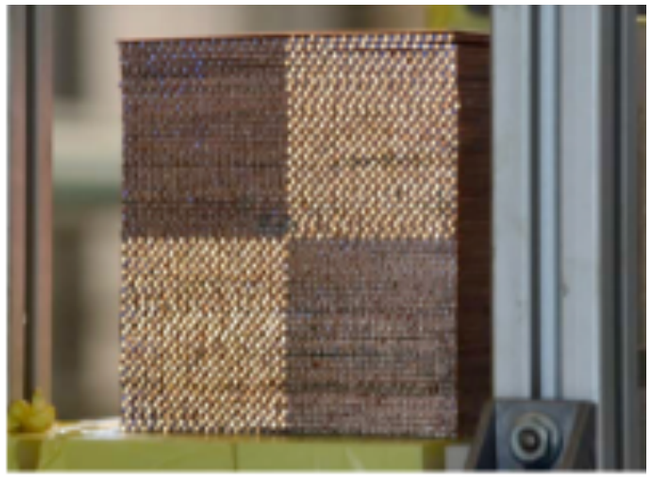
More than 20 years R&D: CERN RD52 experiment

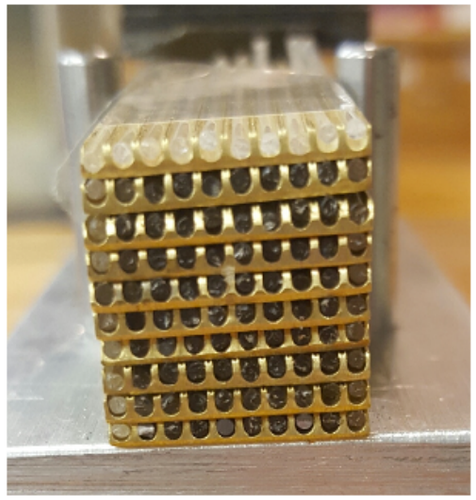
Signal generation: Scintillating & Cerenkov fibers

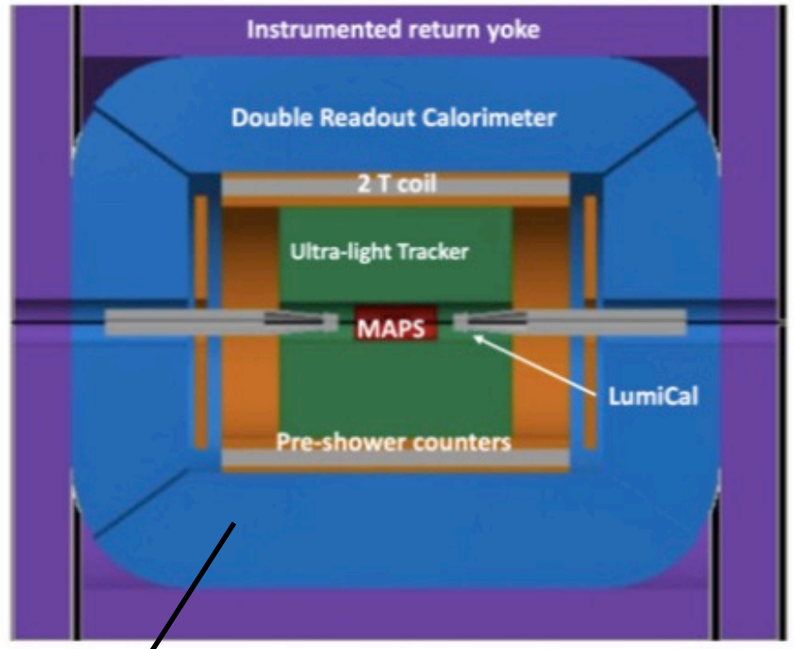


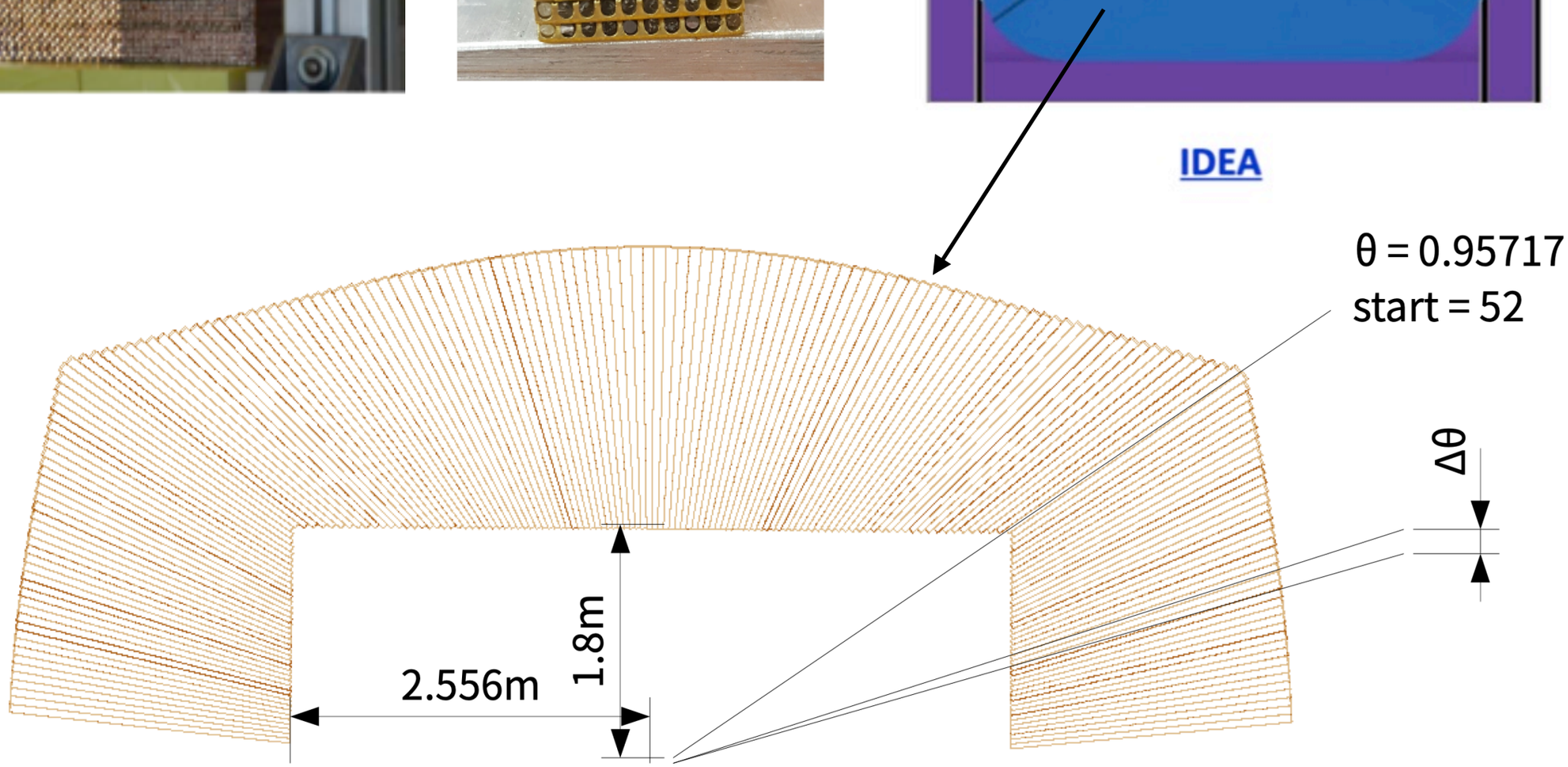


DRC Geometry and Module





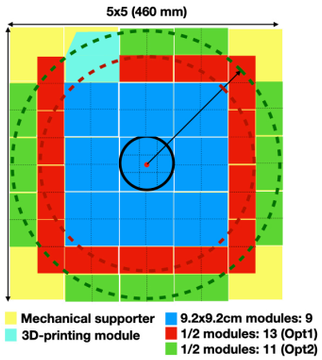




International Collaboration

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

Full-size prototype detector



Taiwan

Prof. Rong-Shyang Lu

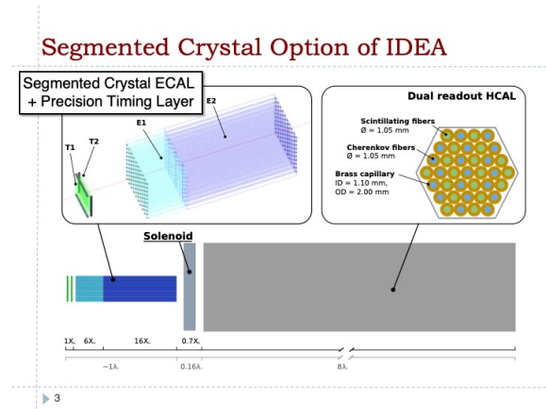
Prof. Chia Ming Kuo

Korea

Japan

Prof. Yuji Enari

USA



Prof. Richard Wigmans

Prof. John Hauptman

Prof. Sarah Eno

Prof. Chris Tully

Europe

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

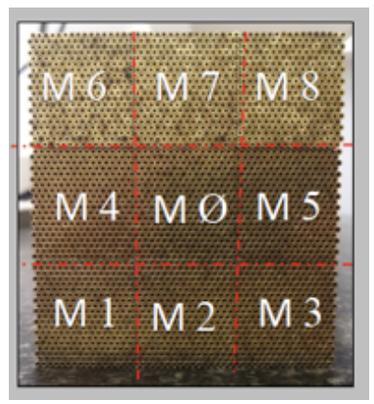
Prof. Iacopo Vivarelli

Prof. Valery Chmill

Big international collaboration for Dual-Readout Calorimeter is forming

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

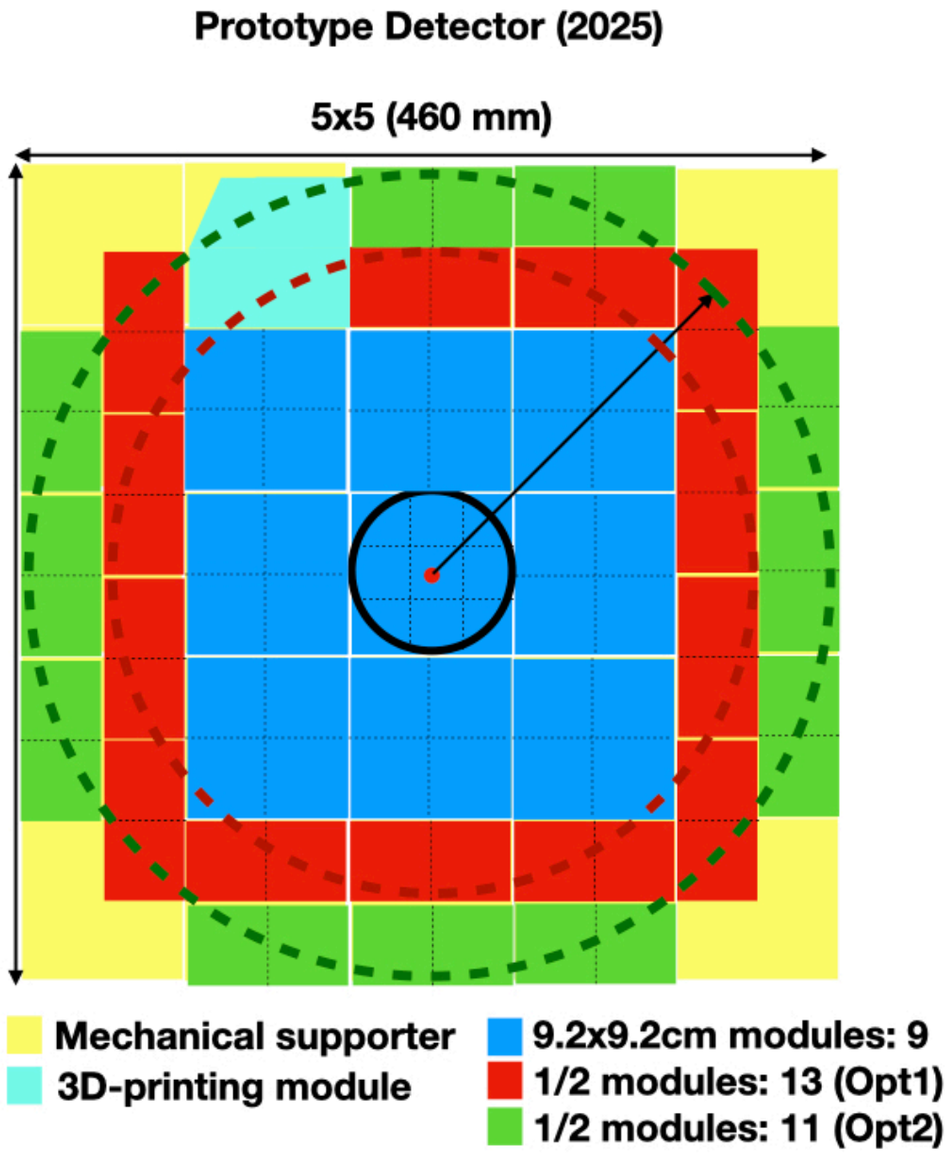
Bucatini Project



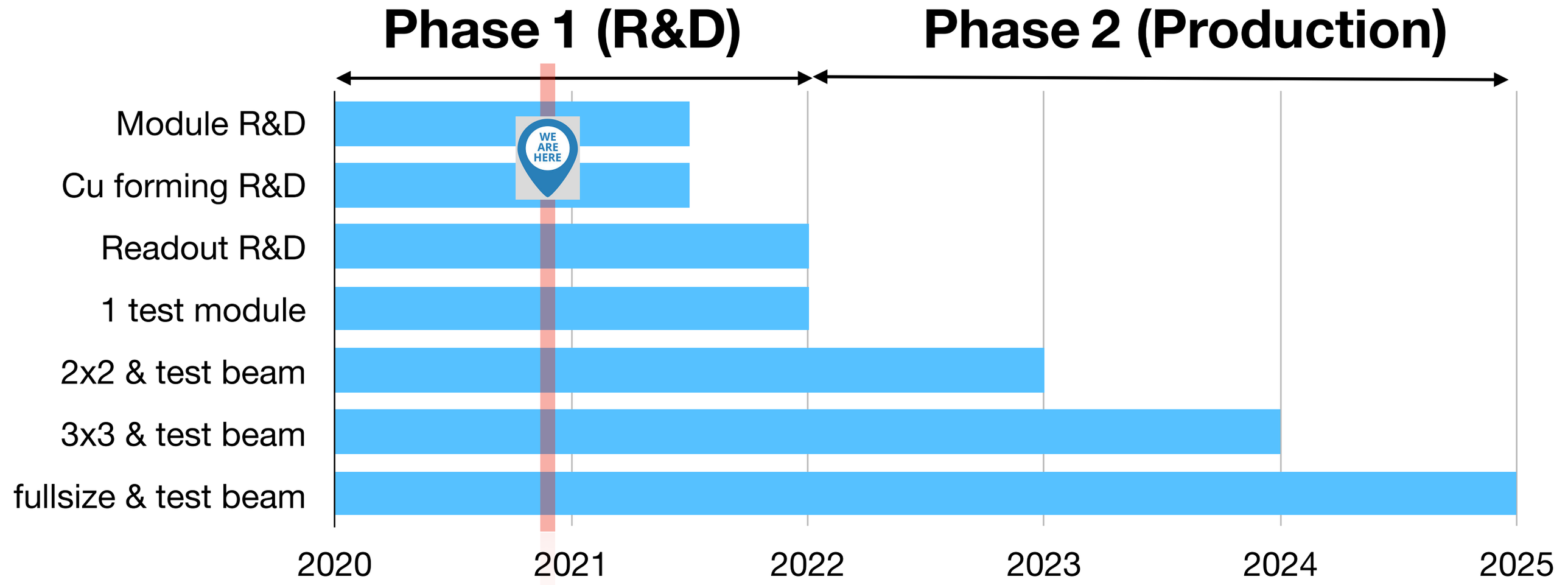
Goal of DRC R&D in Korea

- 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

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



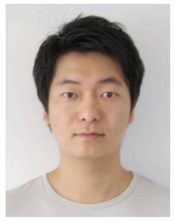
Brief Roadmap in Korea



More details will be defined and decided on the way!

Domestic Collaboration


H.S. Jo


S.H. Lee


S.W. Lee


H.D. Yoo

H.D. Yoo
DR Cal.

J. Hauptman 

R. Wigmans 

Steering Committee

Advisory Committee

S.K. Ha
Hardware

M.S. Ryu
Electronics

S. H. Ko
Software

ML

FPGA expert is welcome!

Cu forming
H.D. Yoo

Module
S.K. Ha

Fiber

Mechanical Support
S.W. Lee

SiPM
B.B. Kim

Readout
M.S. Ryu

Trigger/ DAQ
NOTICE Korea

Reco/pID
I. Watson
Y.J. Lee

GAN
J.S. Park
D.Y Kim

DD4HEP
S. H. Ko

GEANT4
S. H. Ko

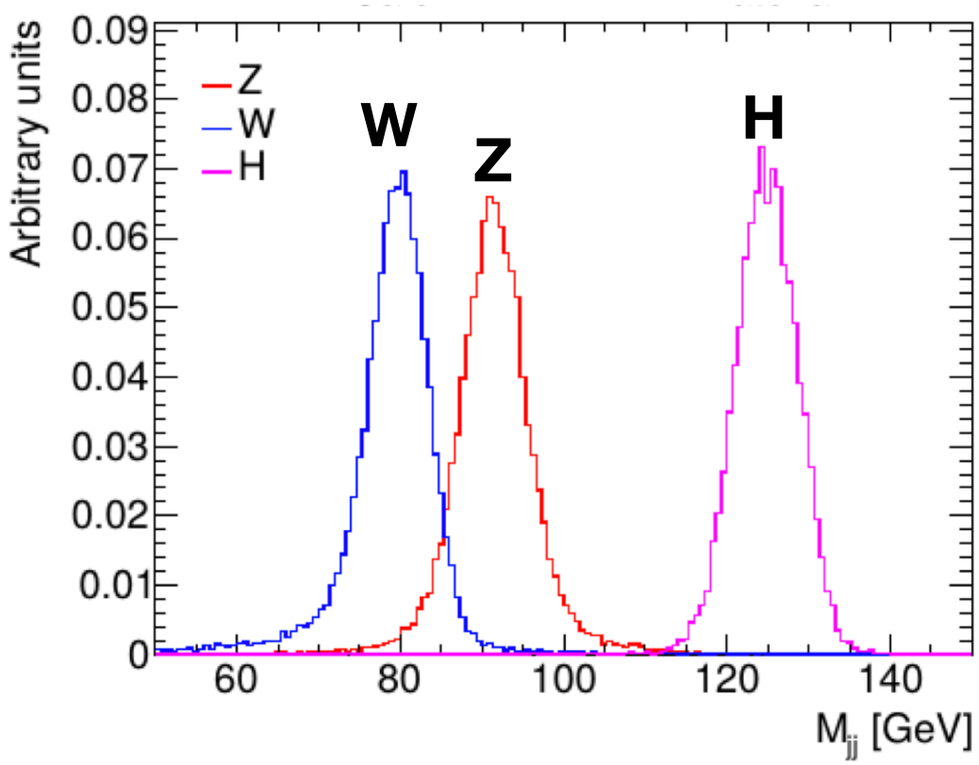
Performance
K.Y. Hwang
M.S. Kim

Magnetic Field
J.H. Lee

We need you!!!

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)



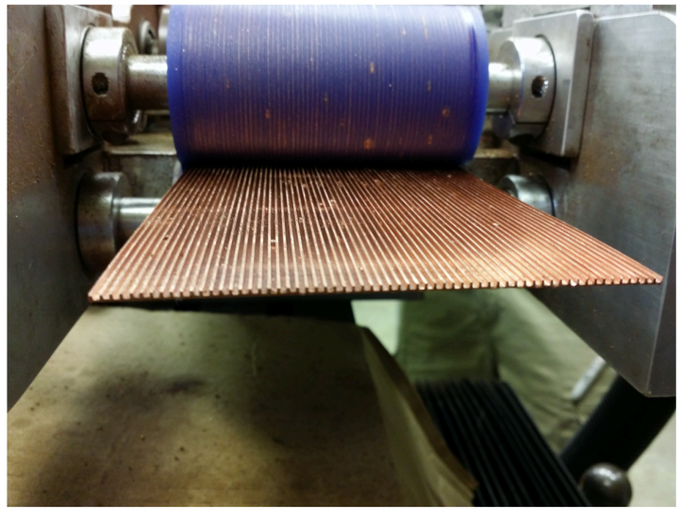
Many more items possible!

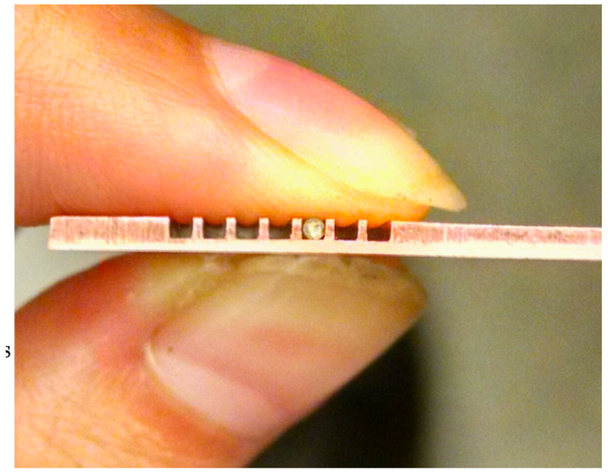
List of Current On-going Effort

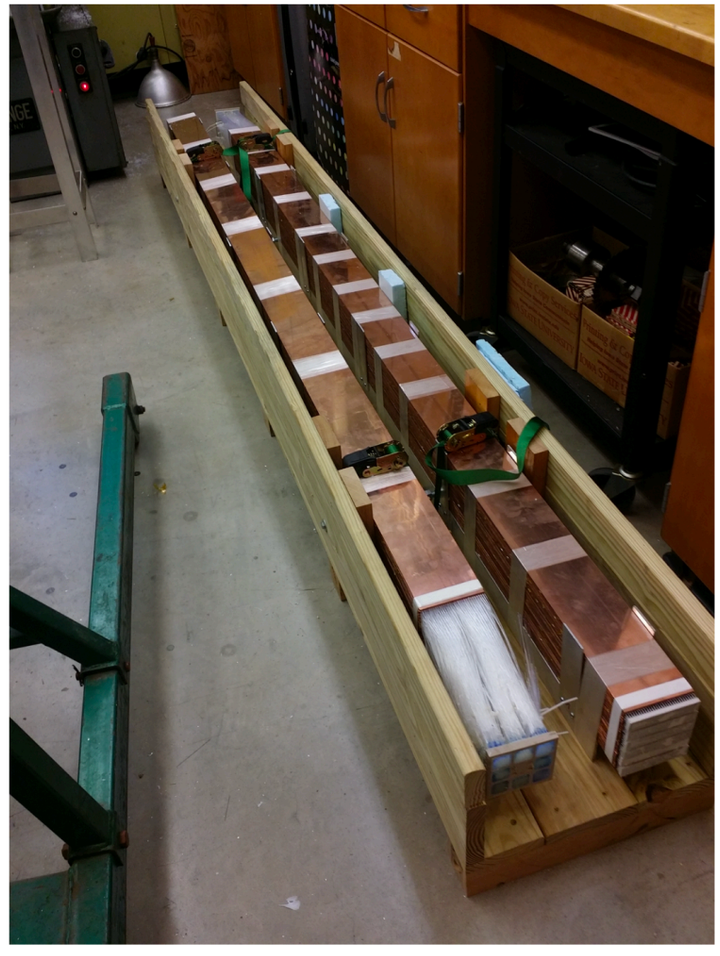
Topic	Name	Status
Module		
Forming: 3D printing, molding, cutting	H.D. Yoo (YU)	Sample produced
Absorber type: Cu, Pb, W, Fe	K.Y. Hwang (YU)	On-going (simulation)
Length: 2.0 m vs. 2.5 m	K.Y. Hwang (YU)	
Electronics		
SiPM design R&D	B.B. Kim (KNU)	On-going
Simulation/Performance		
Calibration	K.Y. Hwang (YU)	On-going
EM energy resolution	S.H. Ko (SNU), K.Y. Hwang (YU)	Preliminary
Pion & jet energy resolution		
Position and angular resolutions	M.S. Kim (YU)	Preliminary
Fast optical photon transport	S.H. Ko (SNU)	Preliminary
Magnetic field	J.H. Lee (KNU)	Started
Physics cases: W, Z, H	K.Y. Hwang (YU)	Started
SW infrastructure		
Migration to Key4Hep	S.H. Ko (SNU)	Preliminary
ML-based application		
Discrimination: electron vs. pion	Y.J. Lee (UoS)	Preliminary
Discrimination: quark vs gluon jets		
GAN: fast simulation	J.S. Park, D.Y. Kim (UoS)	On-going

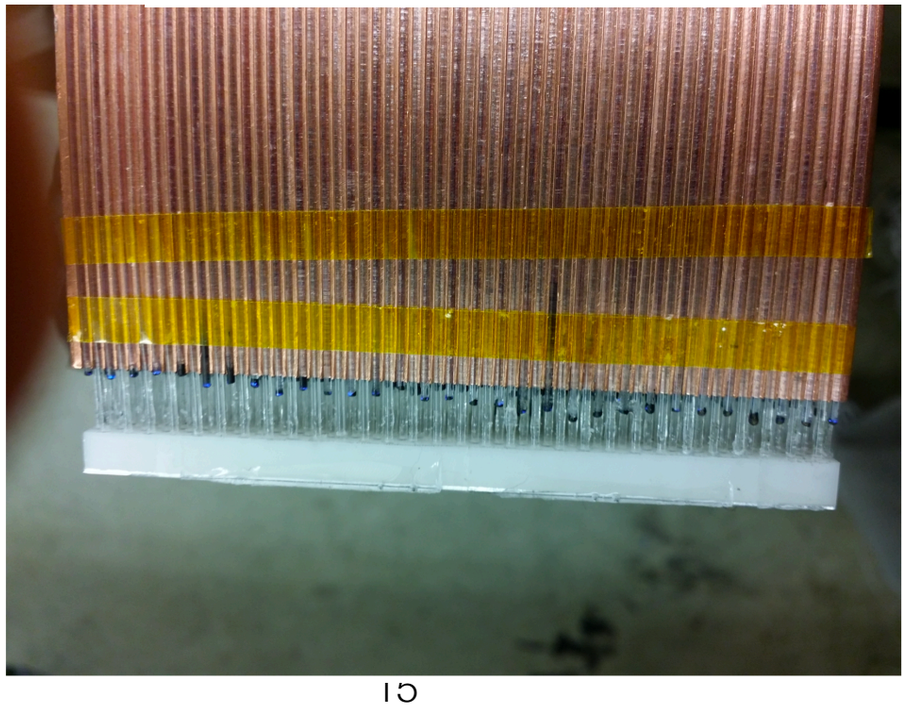
Module Building (2016)

- 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 printing for alternative possibility at 2020





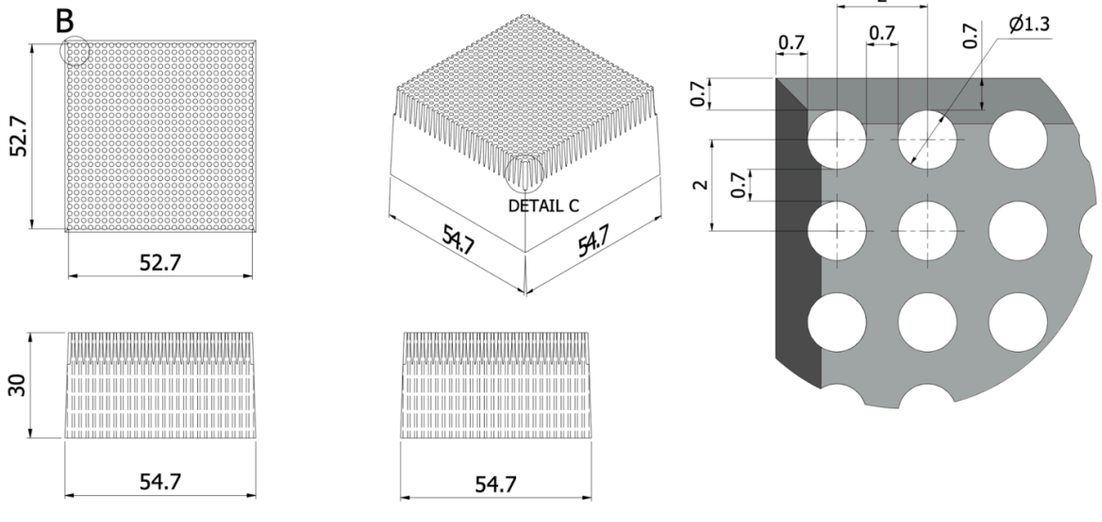


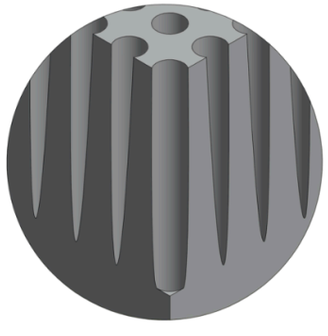


New Module Design (2020)

- Produced samples using 3D metal printer
  - Pure Cu density: > 99 (95)%
  - Projective, rectangular
  - ~1.0 (1.3) mm diameter hole for fibers
  - ~0.5 (0.7) mm separation between two holes

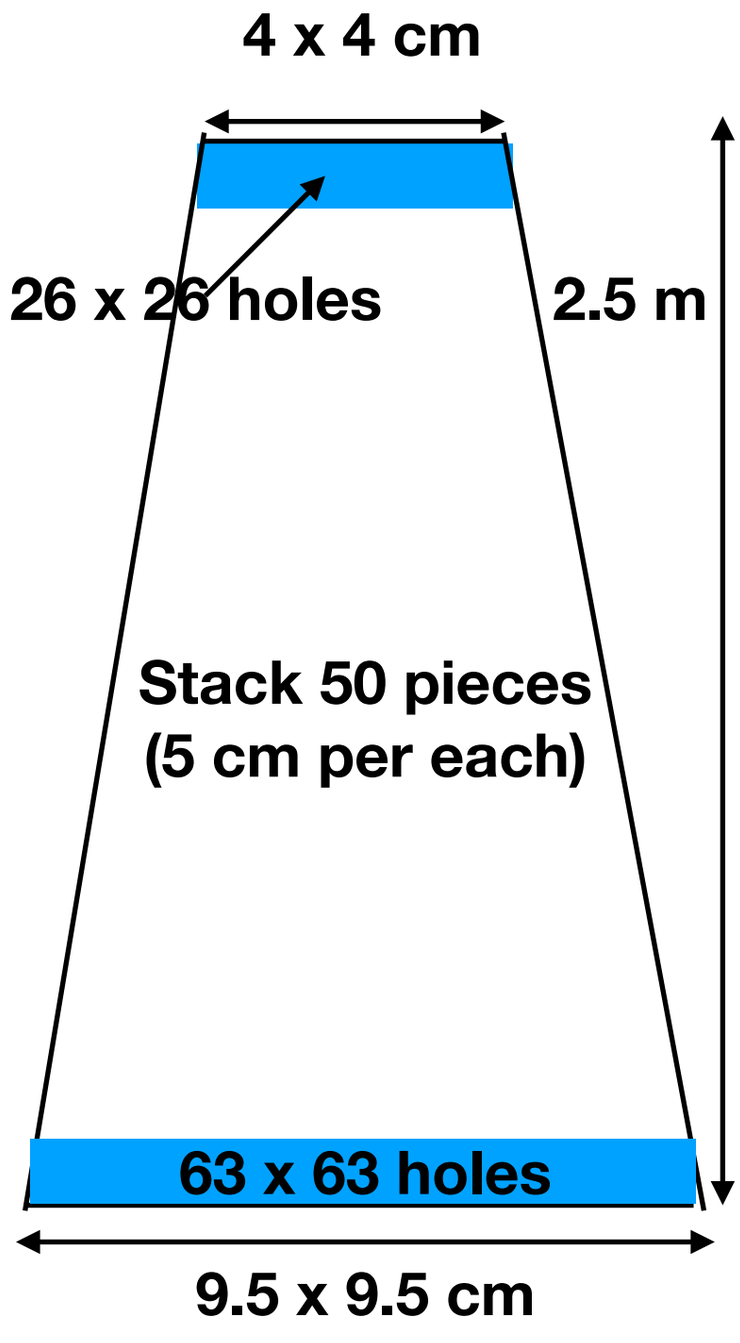
- Different size between front and end (projective shape)





DETAIL C (10 : 1)

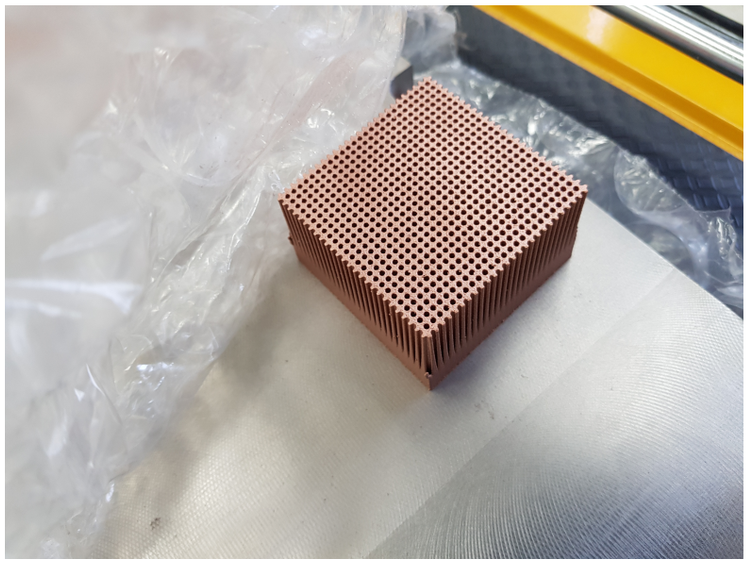
With 3D printing consultant company in Korea
- **have world-wide expert networking**

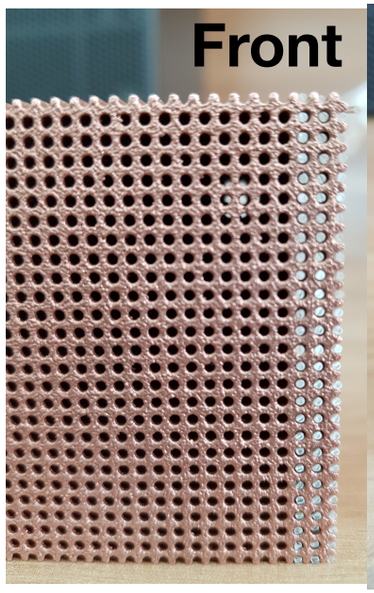


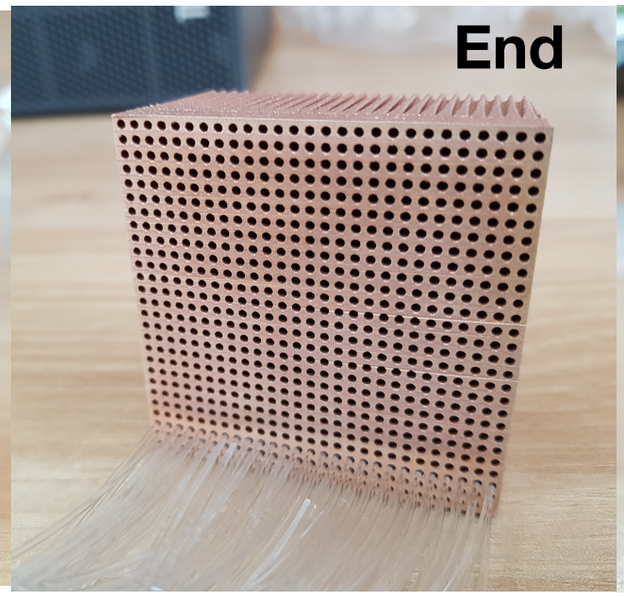
Typical structure of wedge tower module

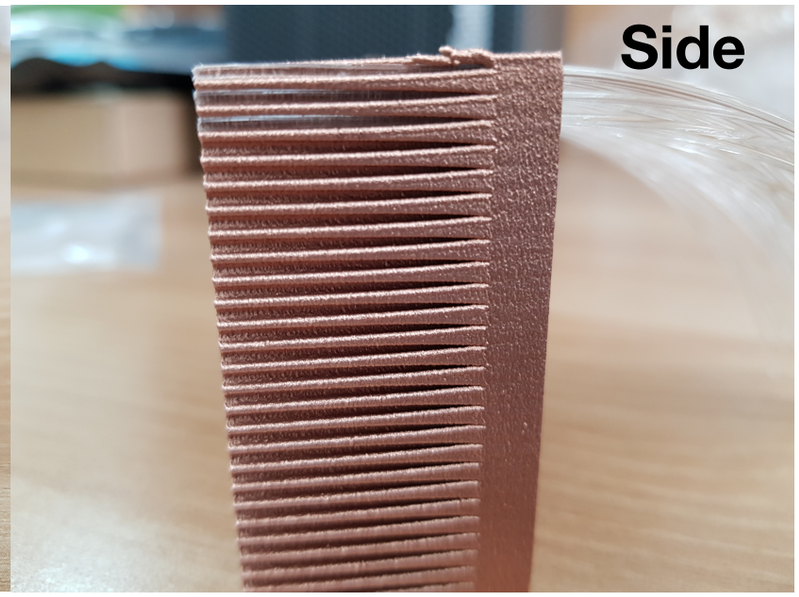
Status of 3D Printing

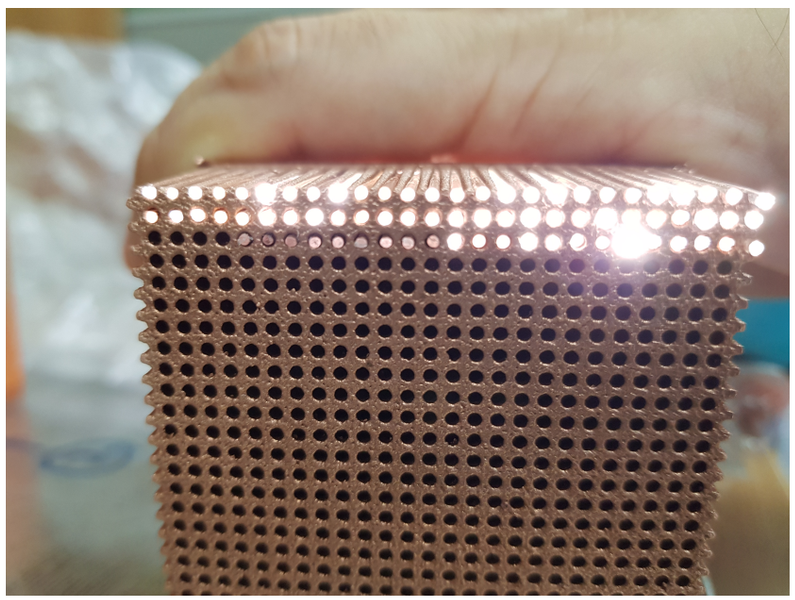
- Successful outcome for the test samples
- Prototype projective module using 3D printing under discussion

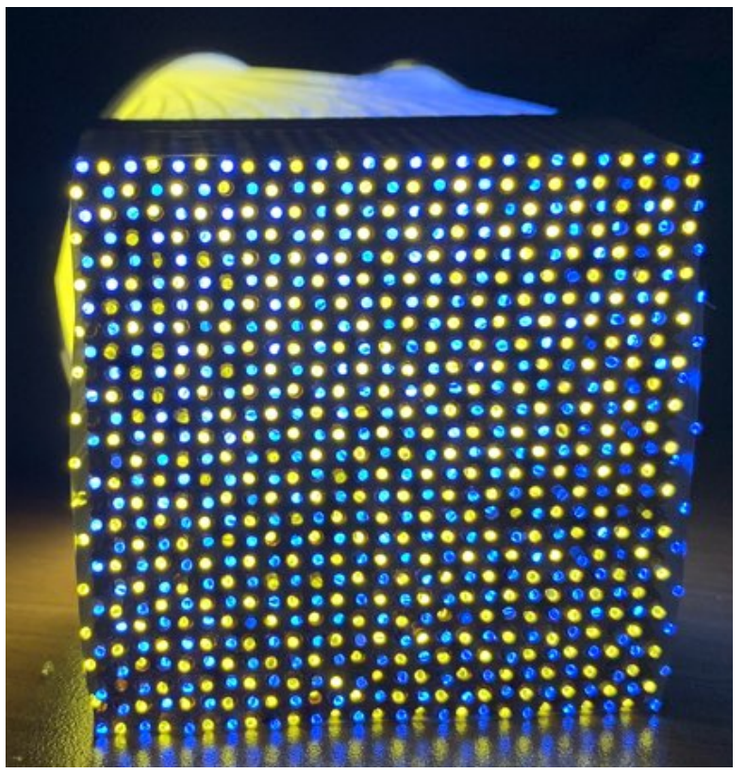


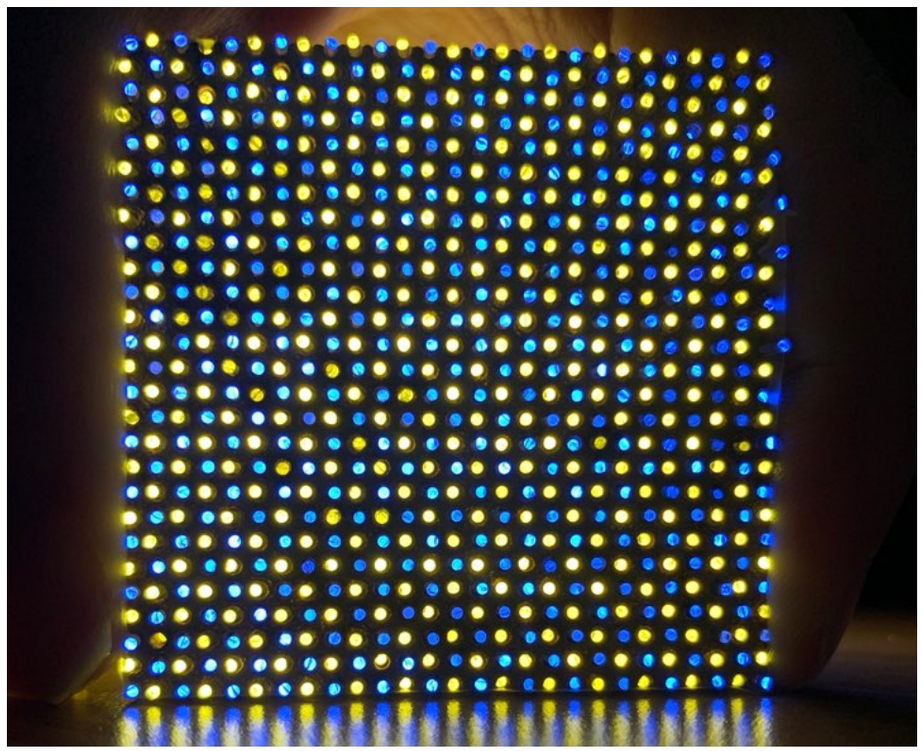












DD4hep Migration

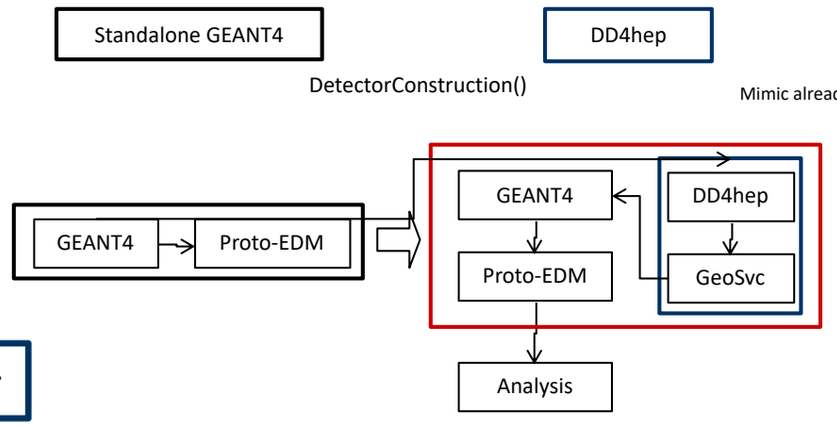
- Migrate dual-readout simulation framework to dd4hep

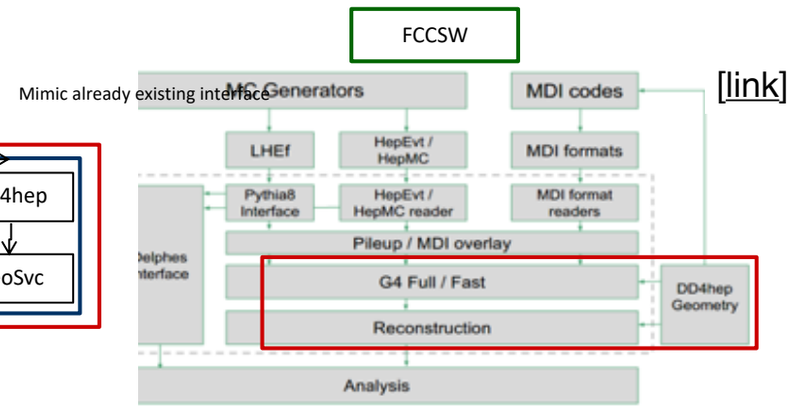
More details: S.H. Ko's talk in FCC workshop (link)

  - 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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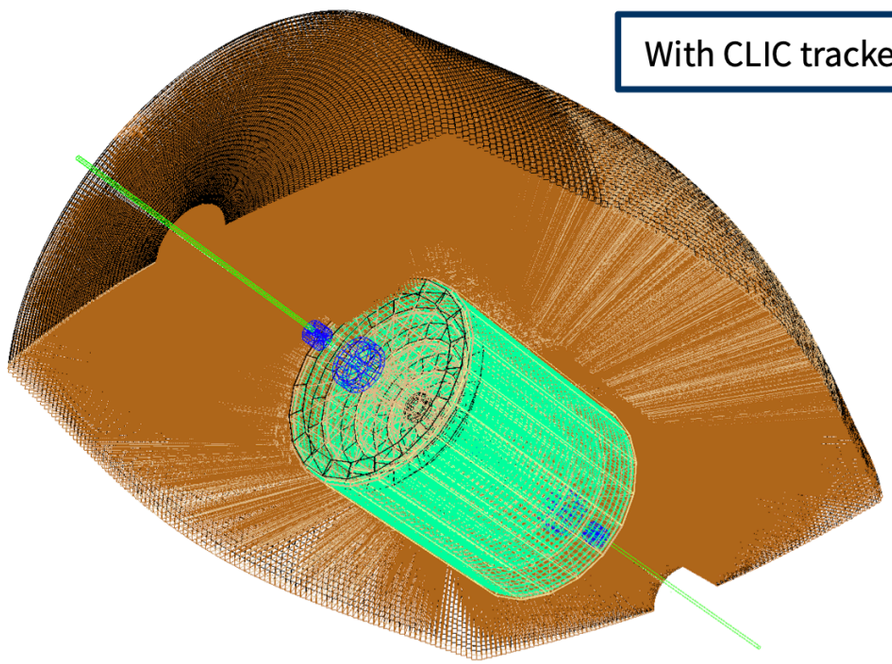
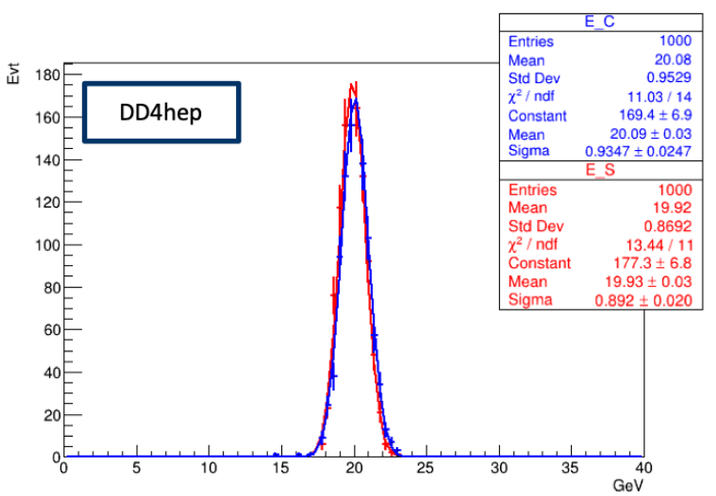
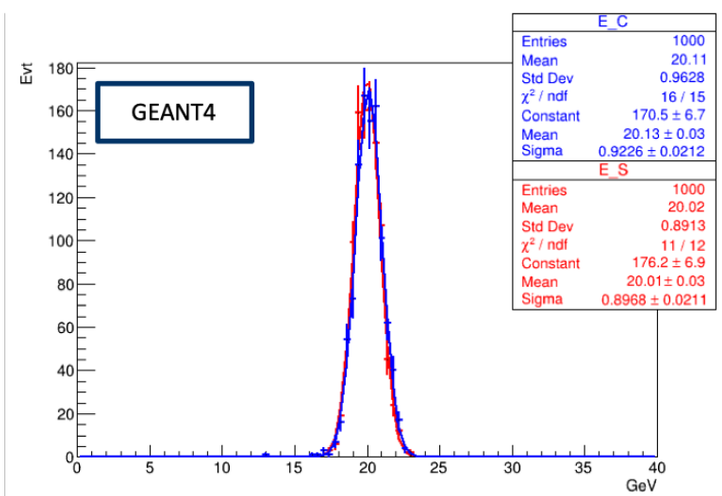
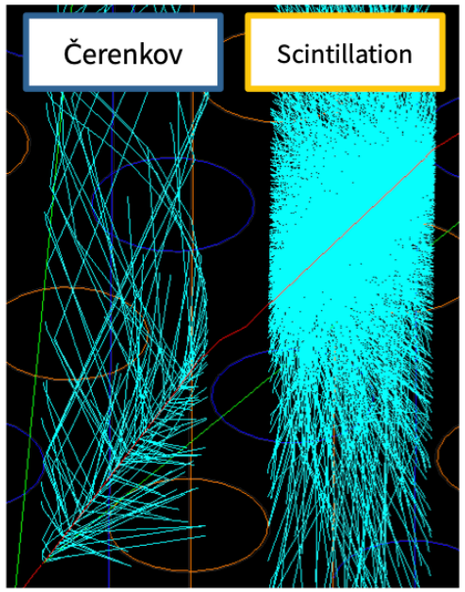


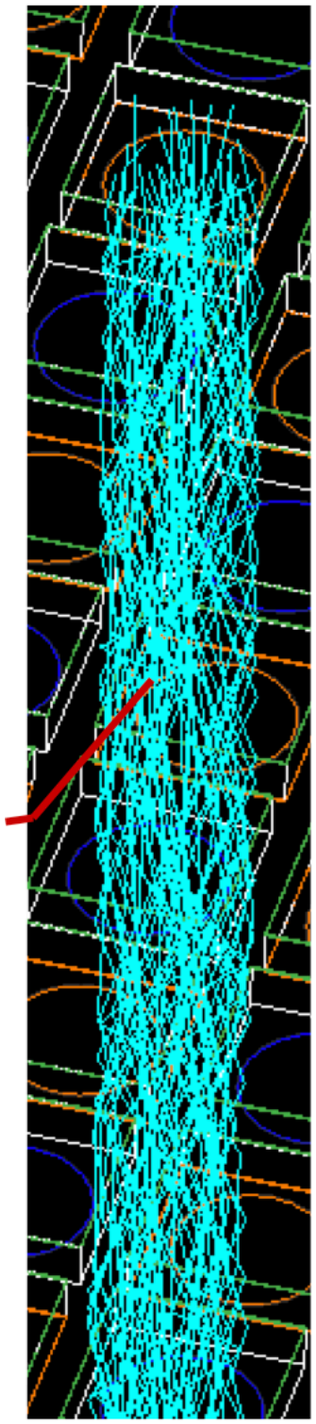




(Semi-)Fast Simulation

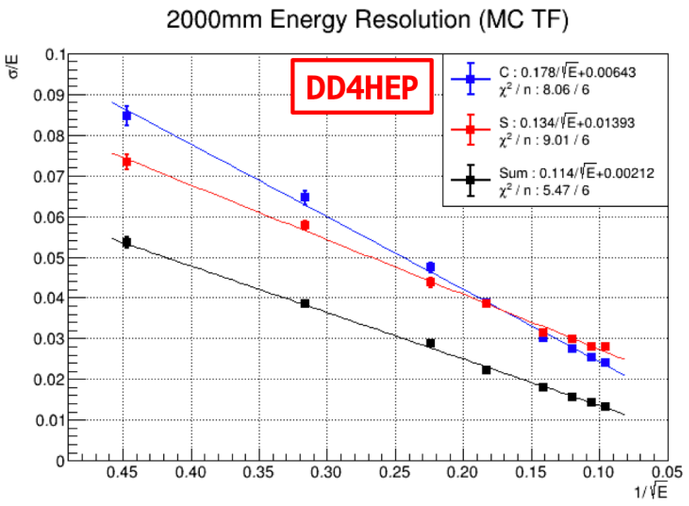
- Full GEANT4 simulation of optical photon tracking explodes CPU cost: O(h)/evt
  - Developing fast simulation for optical photon tracking: O(few mins)/evt
- Excellent consistency of the detector performance with DD4HEP and Semi-Fullsim

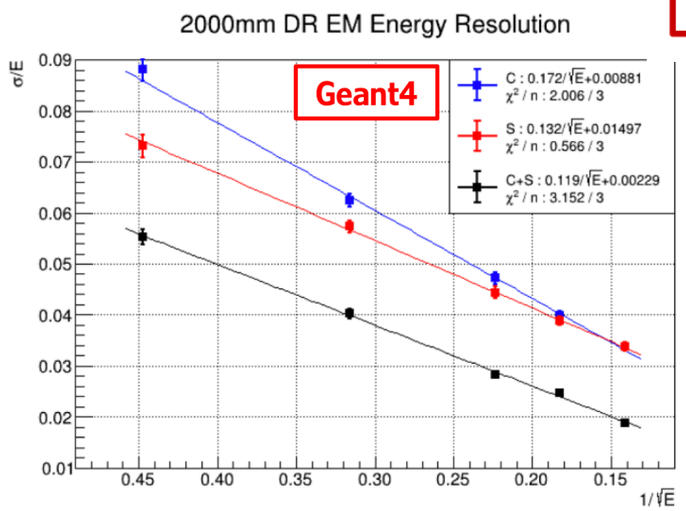




Important for a longitudinally unsegmented calorimeter

EM validation



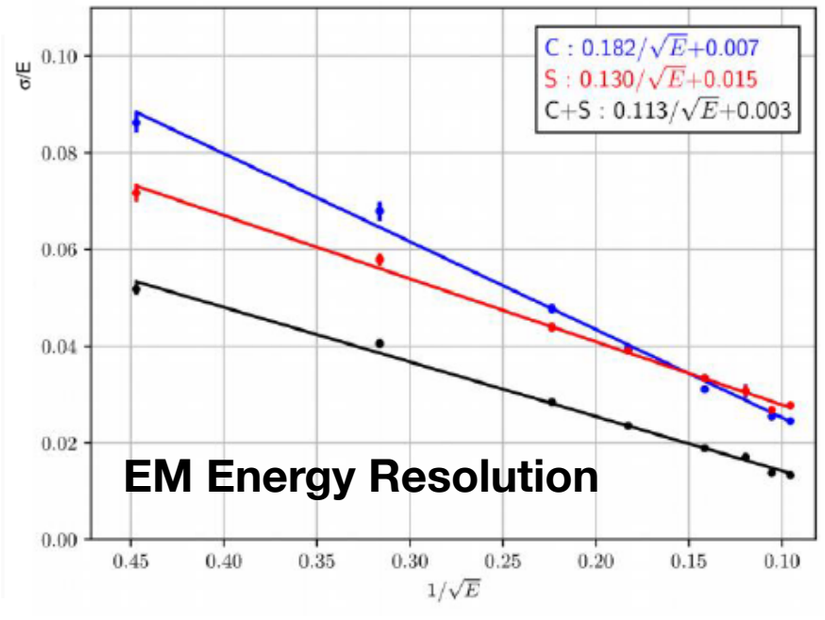


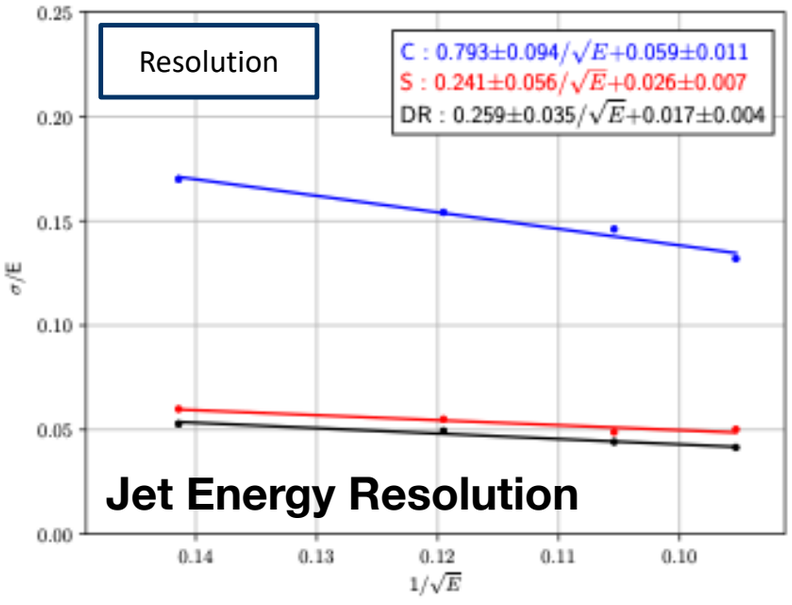
- 2000mm Wedge geometry EM energy resolution is measured with 5 different energy electron beams.
- Stochastic terms of energy resolutions are similar.

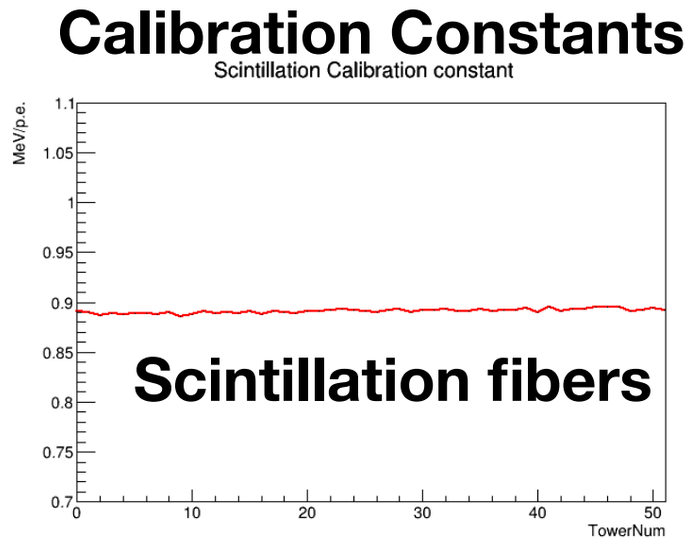
More details: S.H. Ko's talk in FCC workshop (link)

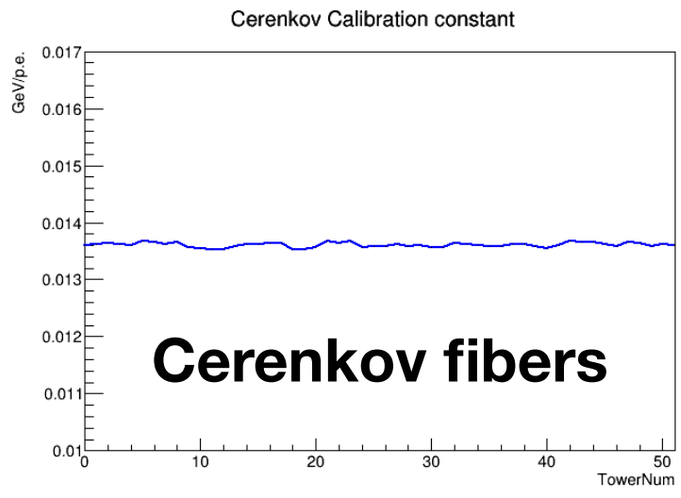
Energy Resolution

- 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)





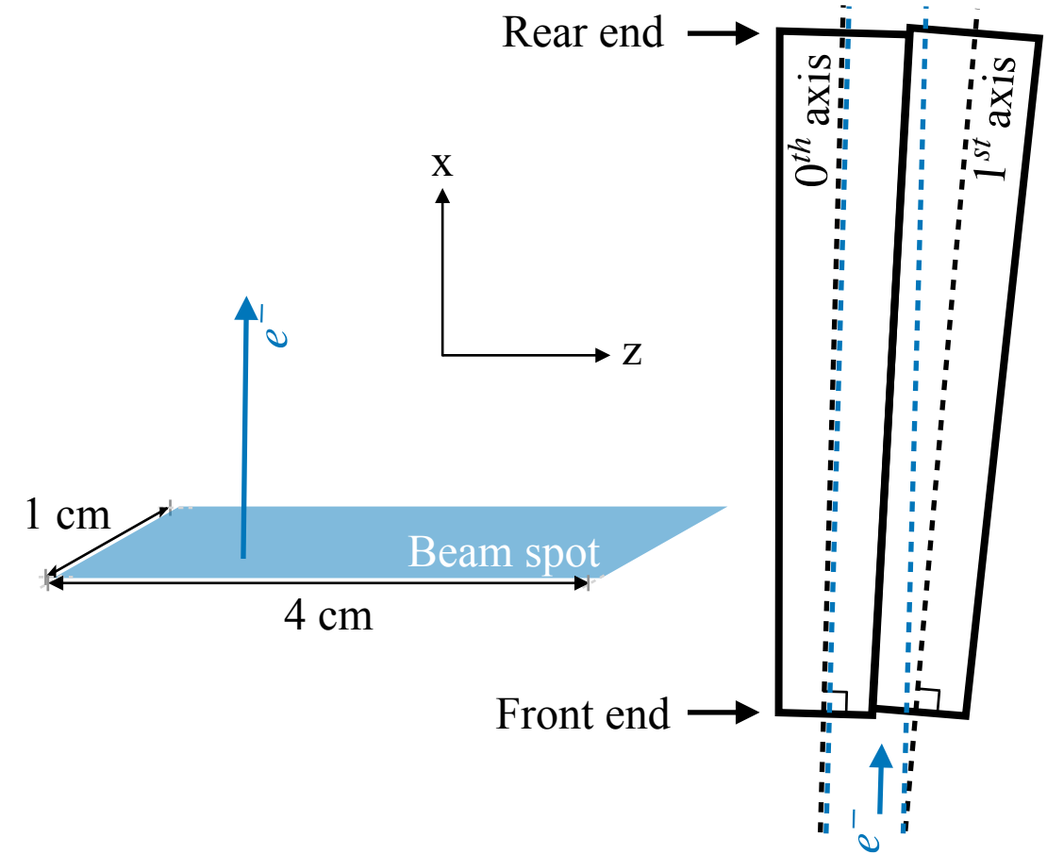


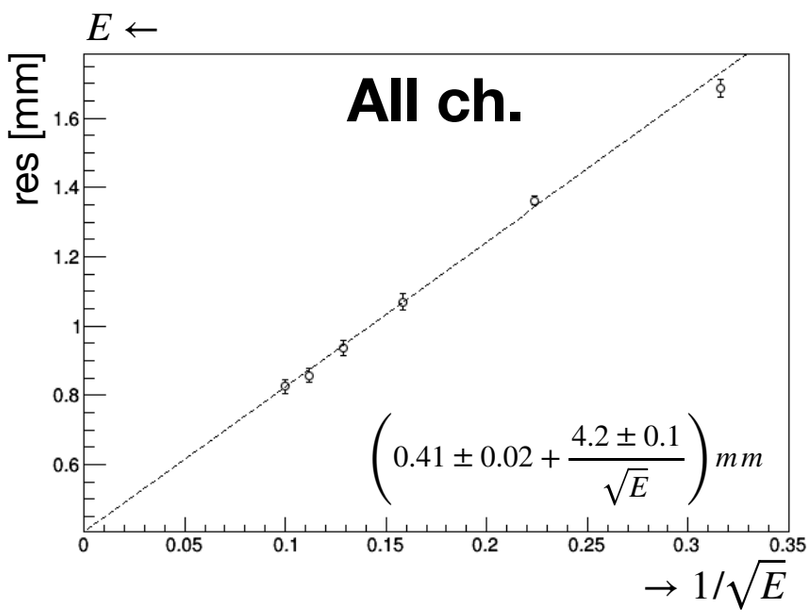


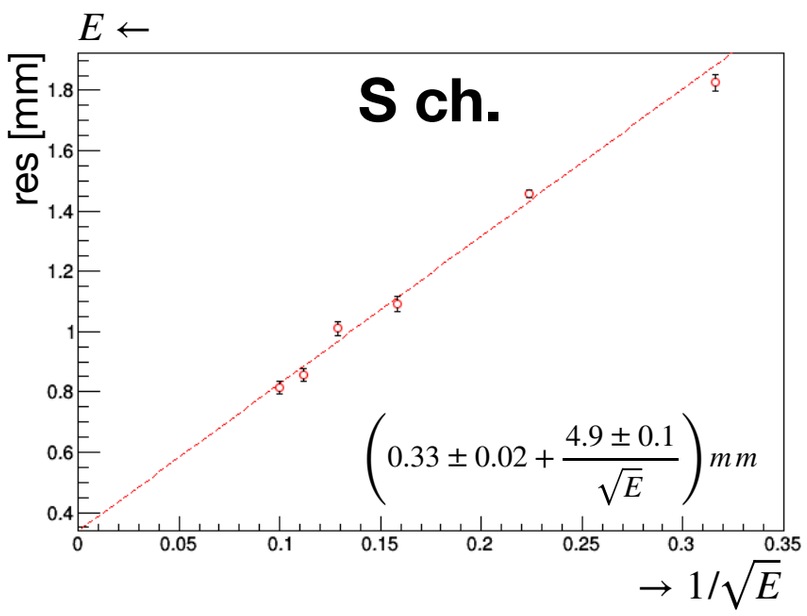
Tower #

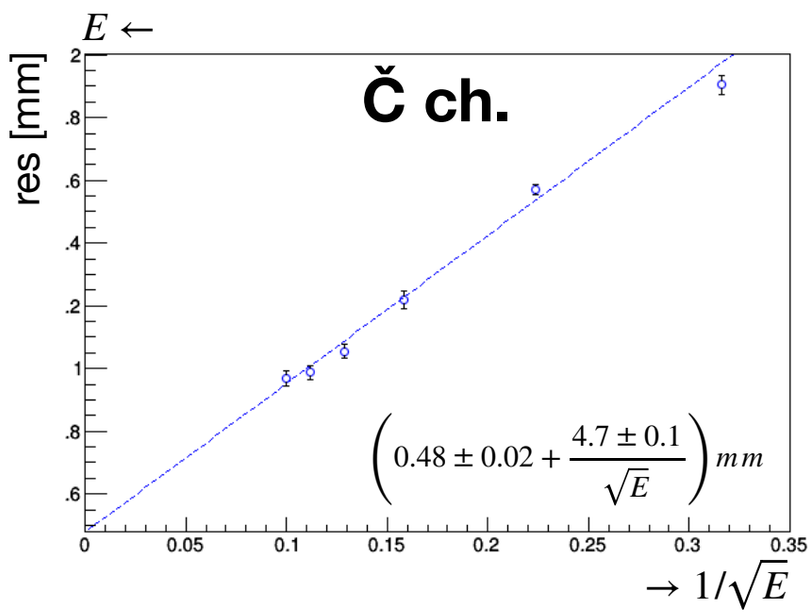
Position Resolution

- 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
  - $\vec{x}_{reco} = \frac{\sum_i E_i \times \vec{x}_i}{\sum_i E_i}, i : \#\text{SiPM}$
- Preliminary position resolution:
  - $4.2\ \text{mm}/\sqrt{E} + 0.4\ \text{mm}$





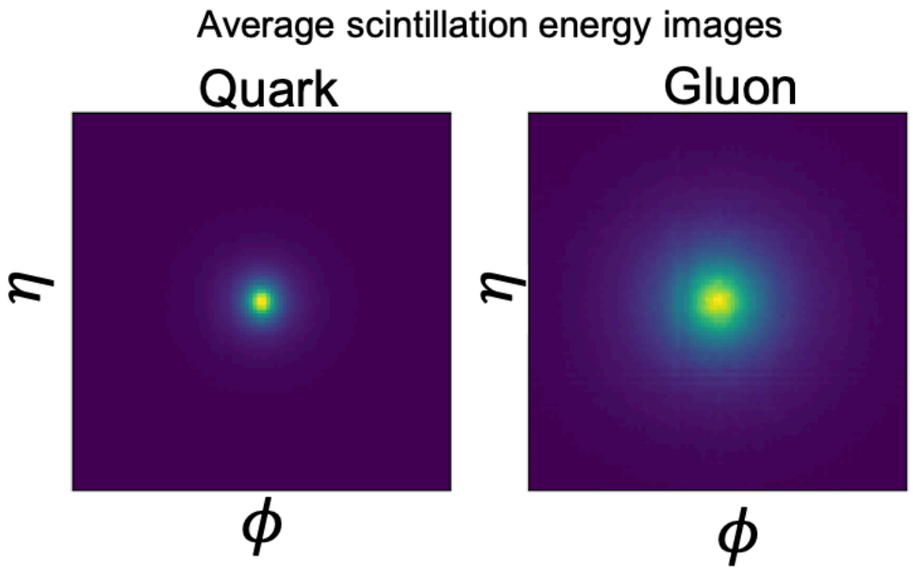




ML-based Application

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

More details:
Y.J. Lee's talk
in CEPC workshop
(link)



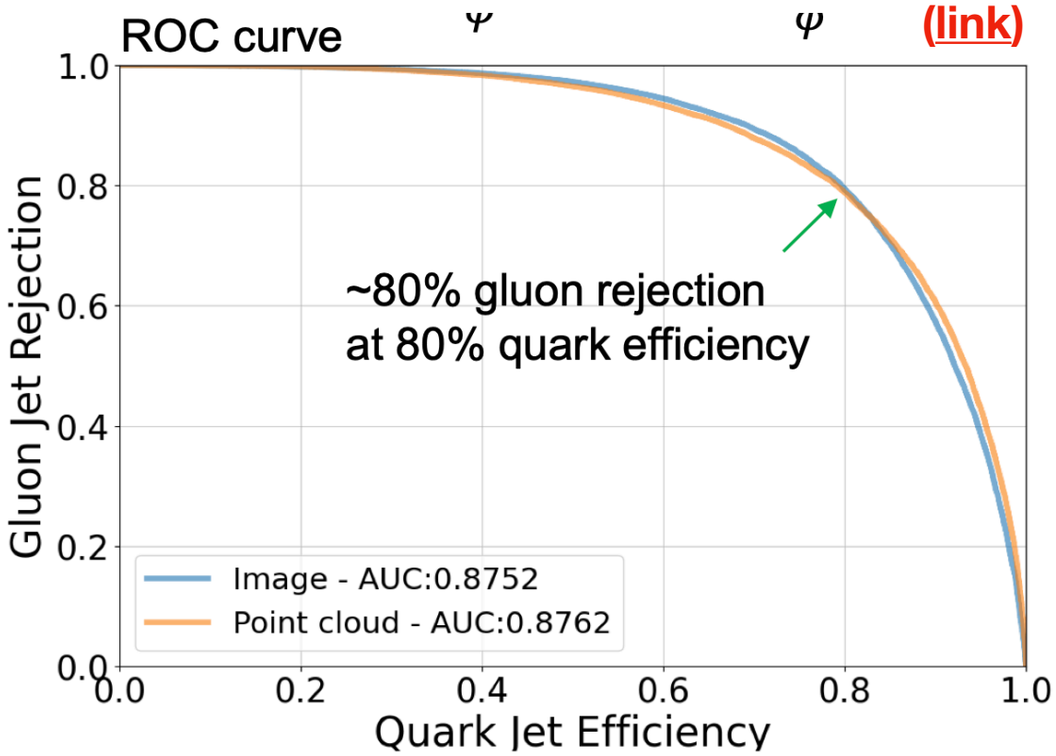
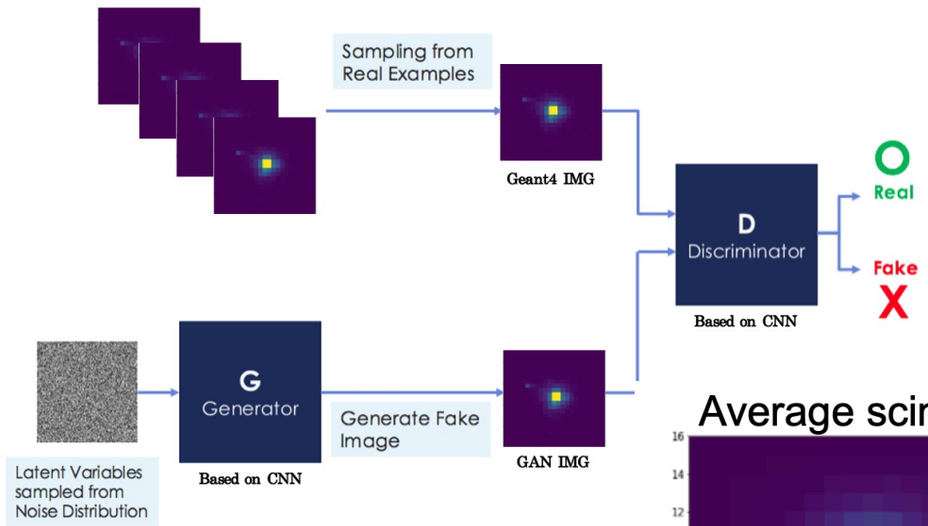
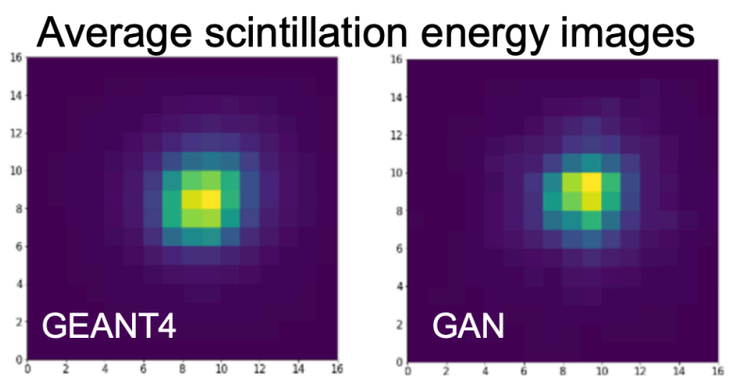
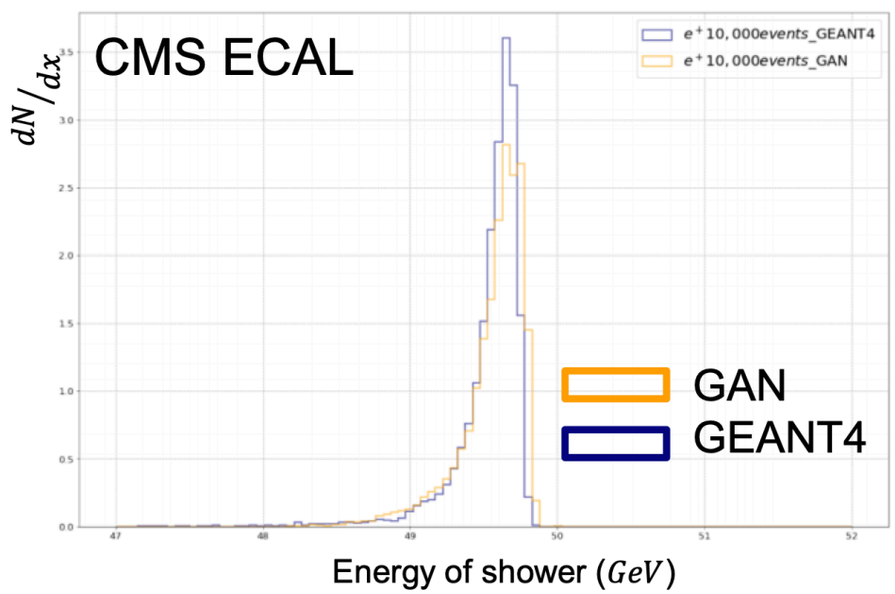


Image data format under development

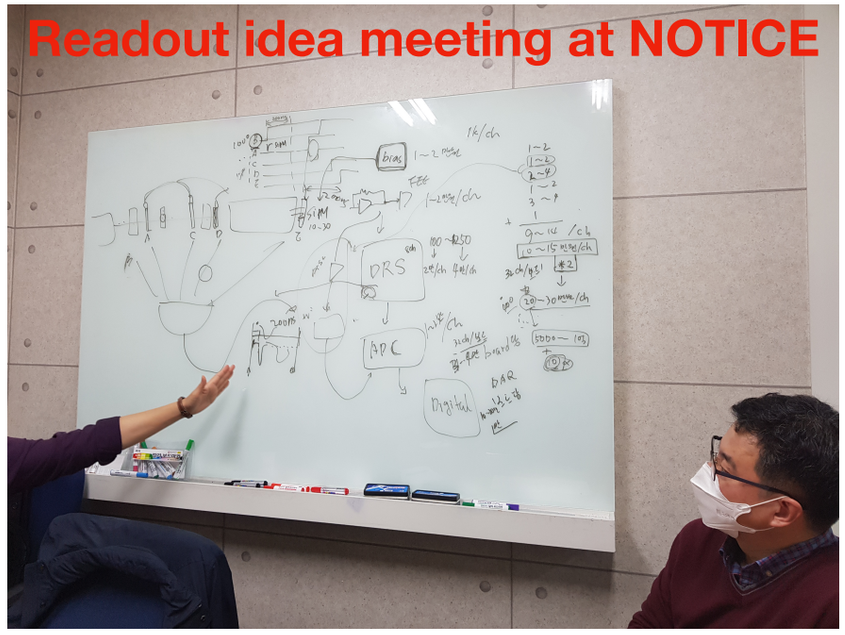




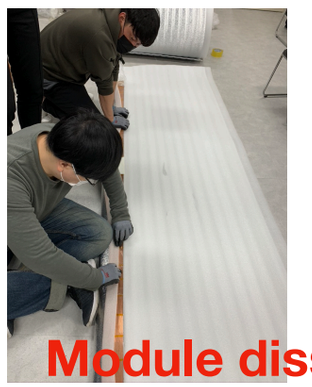


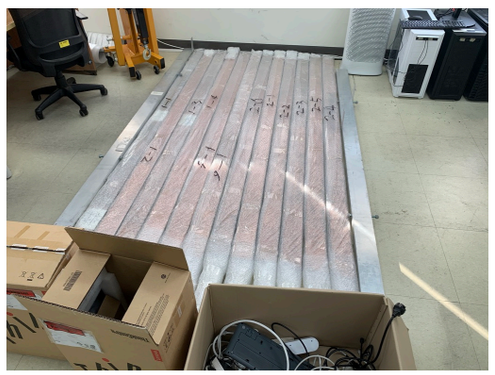
Test Beam 2021

- Target to Nov. of 2021 (TBD), using SPS (CERN)
  - Physics goal: 1) measurement of nuclear interaction length using proton, 2) measurement of energy and position resolution
  - R&D goal: 1) readout test (MCP vs. SiPM), 2) optical fibers (various types), 3) time resolution (< 50 ps processing)
  - Training goal: next generation experts for DRC HW
- Start rebuilding & upgrading two modules (under preparation)

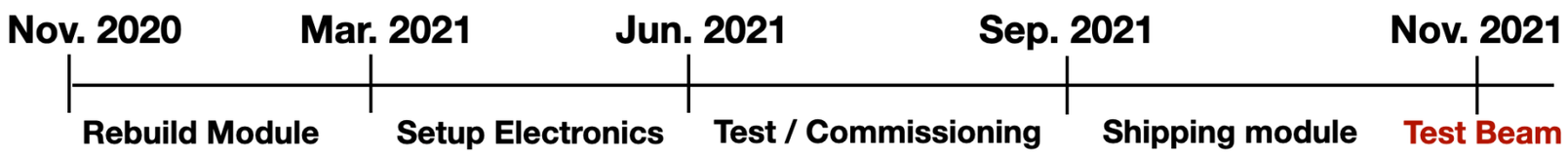


- We will have a training program for beginners! (TBA)
- Brainstorming idea discussions just started!!





Module dissembling



Building virtual Lab under discussion

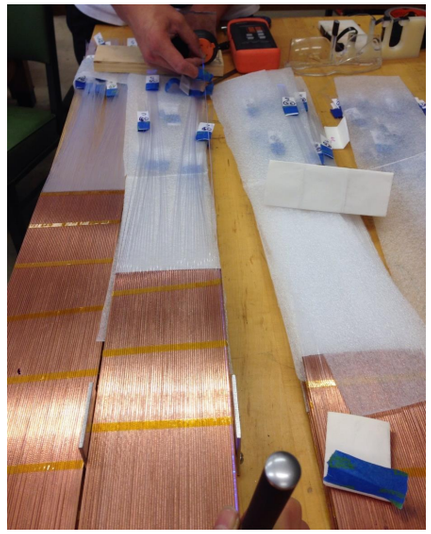
Preparation for Rebuilding

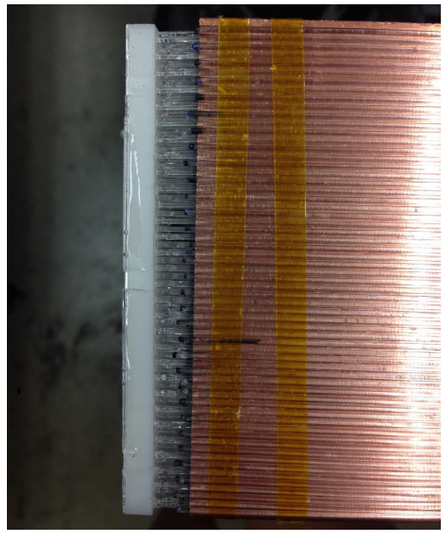
Aug. 2020

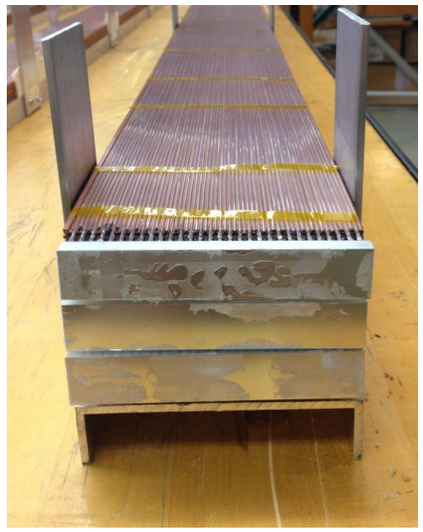
Dec. 2020

Ready for rebuilding

Feb. 2021

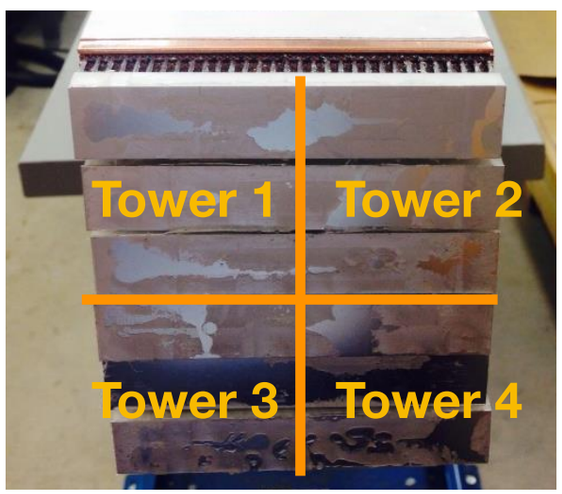






Completion of rebuilding (3600 fibers/module)

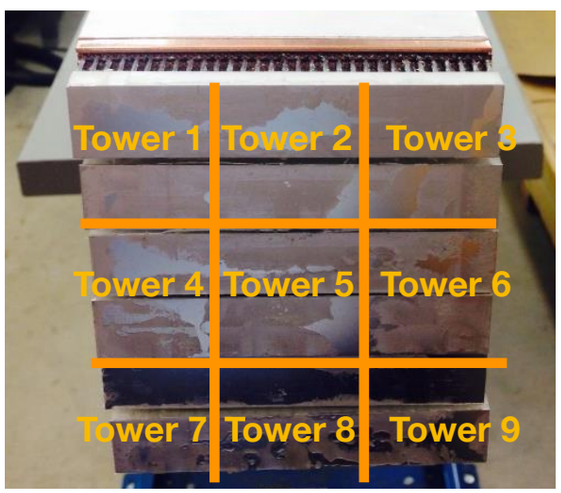
Module #1 (2x2)



450 S/ tower
450 Č/ tower

200 S/ tower
200 Č/ tower

Module #2 (3x3)



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 of interest (LoI): overview of dual-readout activities
  - https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF6-008.pdf
- 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
  - Aim to deliver 1st set of MC samples during Nov.
  - If interest using our MC samples, please contact us! (hdyoo@cern.ch)

Dual-Readout Calorimetry

Letter of Intent

Authors:
Jinky Agarwala[1,2], Nural Akchurin[3], Sebastiano Albergo[4,5], Massimiliano Antonello[6,7], Sunanda Banerjee[8], Franco Bedeschi[9], Mihaela Bezak[10], Massimo Caccia[6,7], Valery Chmill[10], Christopher Cowden[3], Jordan Damgov[3], Sarah C. Eno[11], Roberto Ferrari[2], Gerardo Ganis[12], Gabriella Gaudio[2], Paolo Giacomelli[13], Stefano Giagu[14,15], John Hauptman[16], Clement Helsens[12], Bob Hirosky[17], Aneliya Karadzhinova-Ferrer[10], Sanghyun Ko[18], Shuichi Kunori[3], Jason Lee[19], Sehwook Lee[20], Yong Liu[21], Marco Lucchini[22], Harvey Newman[23], Toyoko Orimoto[24], Lorenzo Pezzotti[1,2], Giacomo Polesello[2], Edoardo Proserpio[6,7], Jianming Qian[25], Manqi Ruan[21], Željko Samec[10] Romualdo Santoro[6,7], Alan Sill[3], Christopher G. Tully[22], Iacopo Vivarelli[26], Valentin Volkl[12], Hwidong Yoo[27], Ren-Yuan Zhu[23]

[1]Università degli Studi di Pavia; [2]INFN, Pavia; [3]Texas Tech University; [4]Università degli Studi di Catania; [5]INFN, Catania; [6]Università degli Studi dell'Insubria; [7]INFN, Milano; [8]Fermi National Laboratory; [9]INFN, Pisa; [10]Ruđer Bošković Institute; [11]University of Maryland; [12]CERN; [13]INFN, Bologna; [14]Università La Sapienza, Roma; [15]INFN, Roma I; [16]Iowa State University; [17]University of Virginia; [18]Seoul National University; [19]University of Seoul; [20]Kyungpook National University; [21]IHEP, Beijing; [22]Princeton University; [23]California Institute of Technology; [24]Northeastern University; [25]University of Michigan; [26]University of Sussex; [27]Yonsei University.

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

J.H. Yoo[1], S.W. Lee, C.S. Moon[2], S.H. Ko[3], D. Stuart[4], S.H. Lee[5], and J.W. Park, H.D. Yoo *[6]

[1]Korea University, Republic of Korea
[2]Kyungpook National University, Republic of Korea
[3]Seoul National University, Republic of Korea
[4]University of California, Santa Barbara, USA
[5]University of Seoul, Republic of Korea
[6]Yonsei University, Republic of Korea

August 30, 2020

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

J. Huang[1], Q. Hu[2], S.H. Lim[3], S.H. Lee, Y.J. Lee[4], and S.W. Kim, H.D. Yoo *[5]

[1]Brookhaven National Laboratory, USA
[2]Lawrence Livermore National Laboratory, USA
[3]Pusan National University, Republic of Korea
[4]University of Seoul, Republic of Korea
[5]Yonsei University, Republic of Korea

August 31, 2020

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

Y.S. Kim[1], M. Murray[2], and K.H. Kim, Y.J. Kwon, H.D. Yoo *[3]

[1]Sejong University, Republic of Korea
[2]University of Kansas, USA
[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

K.W. Nam, Y. Maravin[1] and H.D. Yoo *[2]

[1]Kansas State University, USA
[2]Yonsei University, Republic of Korea

August 30, 2020

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

P. Chang[a], S. K. Ha[b], K. Y. Hwang[b], H. D. Yoo[b]

[a]*University of California San Diego, USA*
[b]*Yonsei University, Republic of Korea*

MC Taskforce for SM2021

- Technical goal in our team: develop a proper MC sample infrastructure with the DRC R&D project

  - Practical goal for SM2021: provide physics MC samples with full GEANT4 simulation of the DRC detector (for the IDEA detector) to user groups

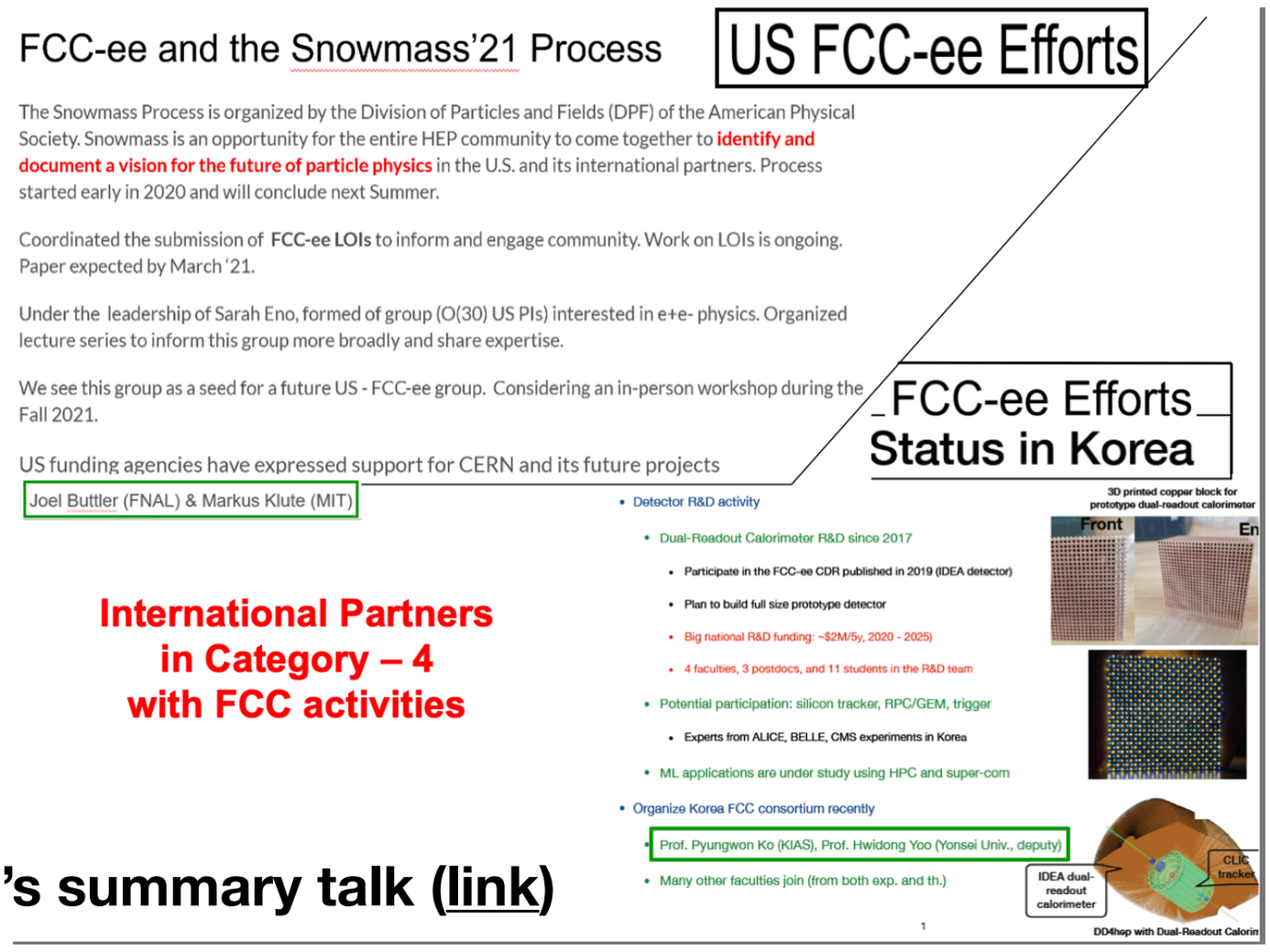
- We will help users can study the physics sensitivity under much more realistic experimental environment

MC production checklist

	Mendatory	Multi-jet	H→Zγ	τ
GEN-lv	Matrix-element (H, Z, W, τ) kinematics (Pt, η, φ)	Parton kinematics	Fermion(Z→ff) & γ kinematics	τ decay particle kinematics
	Matrix-element particle mass	Mono-boson invariant mass, Pt	Z boson invariant mass, Pt	τ invariant mass, Pt
	MET kinematics	Di-boson invariant mass, Pt	H invariant mass, Pt	τ branching fraction
				Final state lepton kinematics (leptonic channel)
				Kinematics with Fastjet clustering (hadronic channel)
SIM-lv	Total energy deposit			Energy deposit with Fastjet clustering
	MET kinematics			
RECO-lv	S, C, DR energy			S, C energy with Fastjet clustering

Korea National Contact for FCC

- FCC national contact: Prof. Pyungwon Ko (KIAS)
  - Deputy: Prof. Hwidong Yoo (Yonsei Univ.)
- First kick-off meeting for FCC national contact held during FCC workshop (link)
  - General introduction of each country's current effort
- Initial organization: EU countries, US, Korea

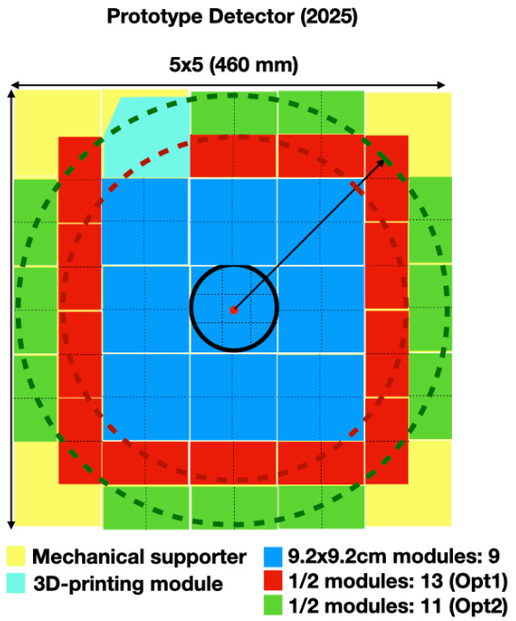


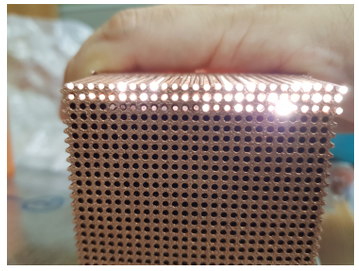
International Partners in Category – 4 with FCC activities

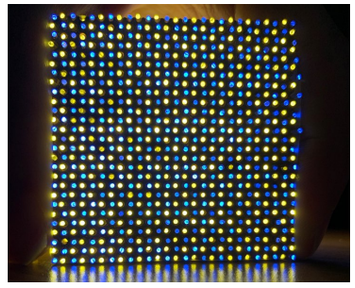
G. Bernardi's summary talk (link)

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
- Test beam 2021 is under discussion and preparation
  - Rebuild two modules for the 1st test-beam experiment
  - Various Snowmass21 plans are in pipeline
  - We welcome to join us: more opportunities waiting for you!







Doyoung Kim

Yun Eo

Kyuyoung Hwang

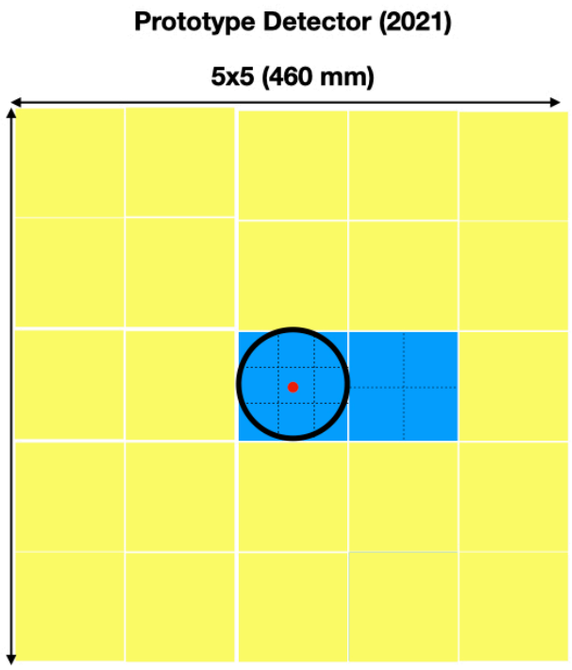
Sanghyun Ko

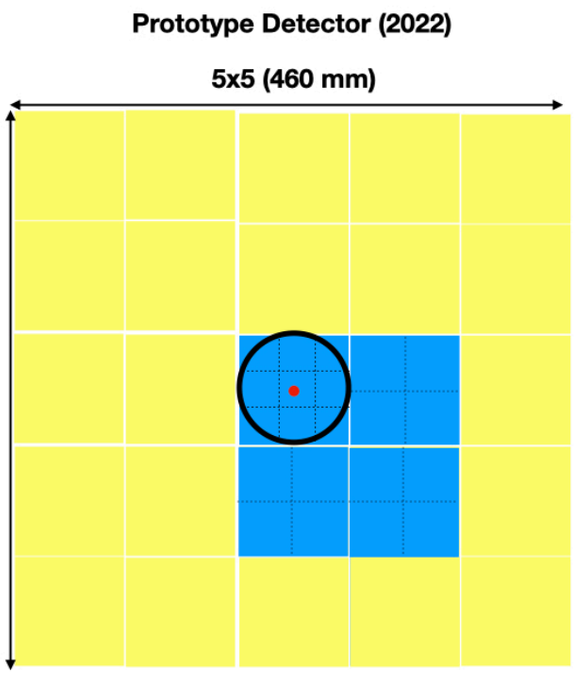
Yunjae Lee

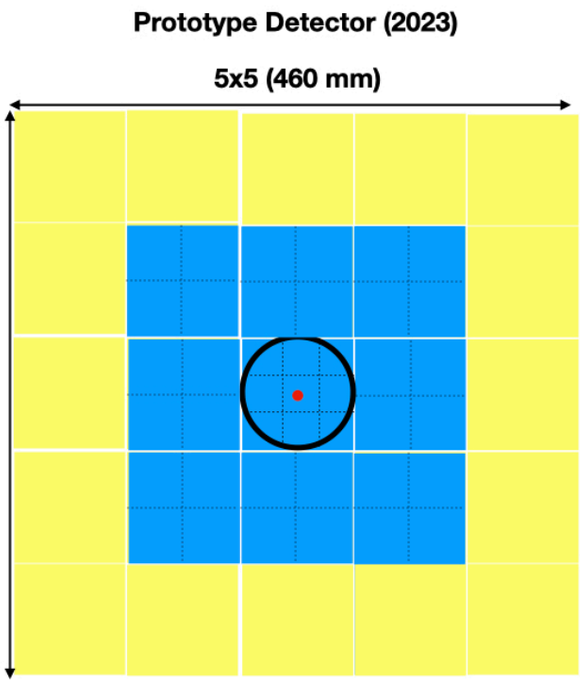
Minsoo Kim

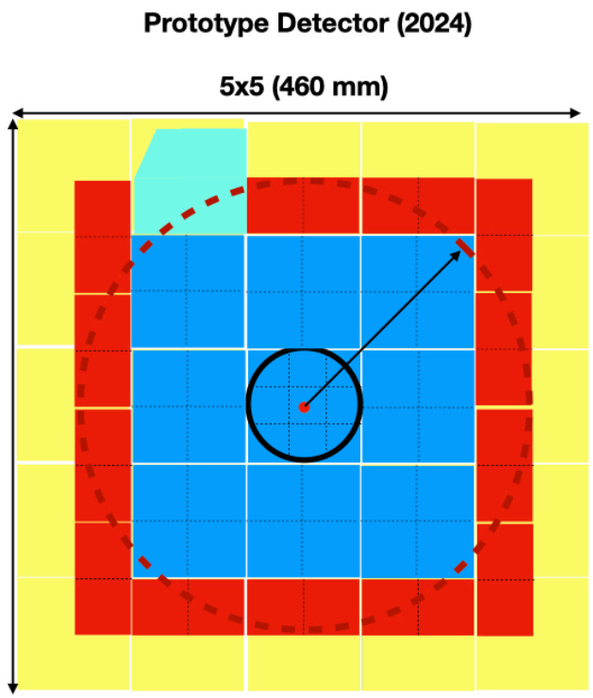
Back Up

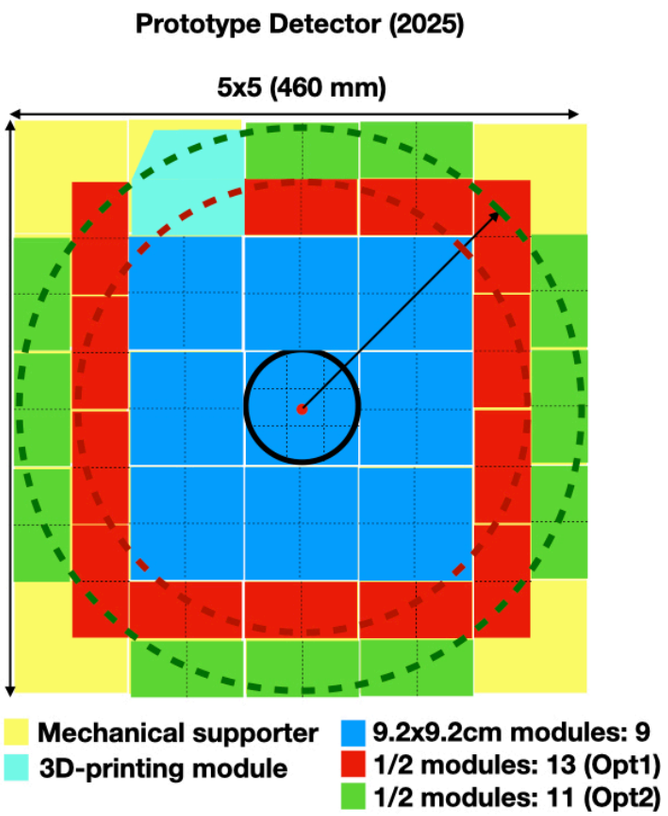
Roadmap of DRC Prototype Detector





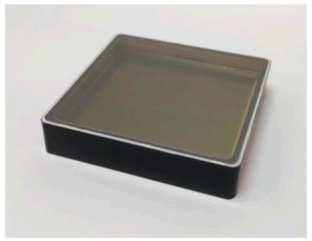


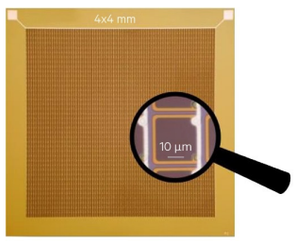


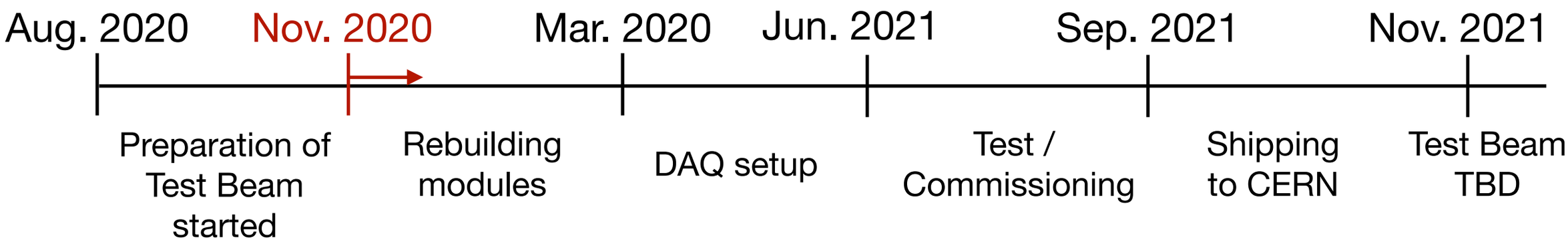


Goal of Test Beam

- Physics goal
  - Measurement of nuclear interaction length using proton/pion
  - Measurement of energy and position resolutions
- R&D goal
  - Readout system test (MCP-PMT & SiPM)
  - Study of various type of optical fibers (scintillation)
  - Time resolution (< 50 ps processing)
- Training goal
  - Training next generation experts for DRC HW
- Time line of test beam at SPS (CERN)

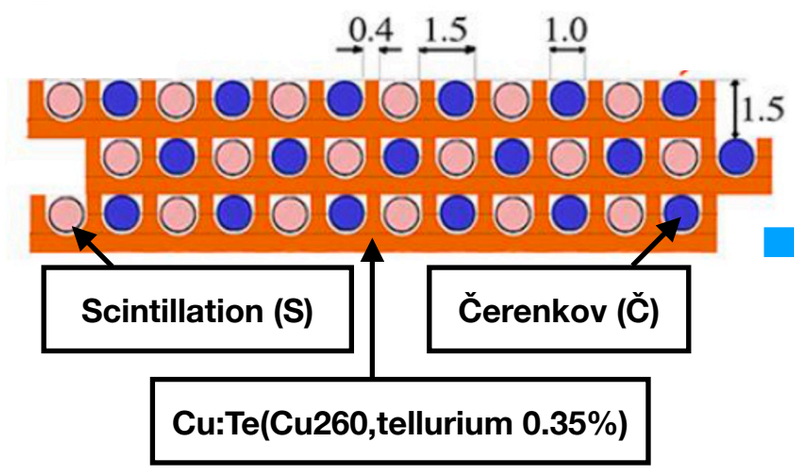




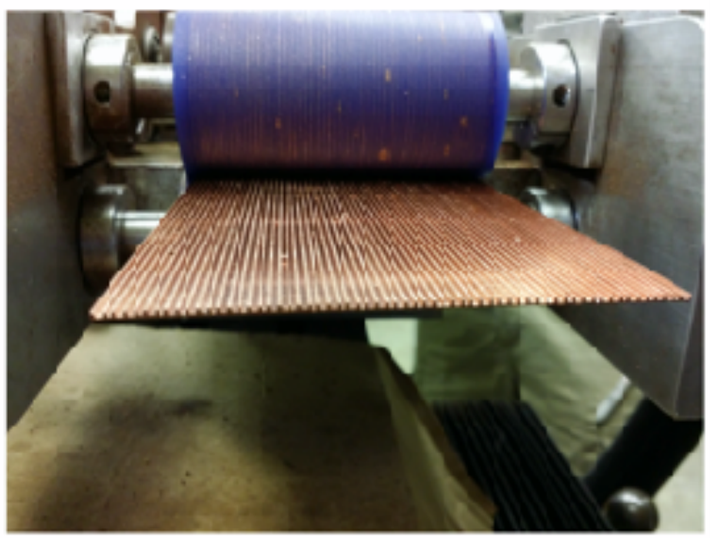


Two Modules for Test Beam

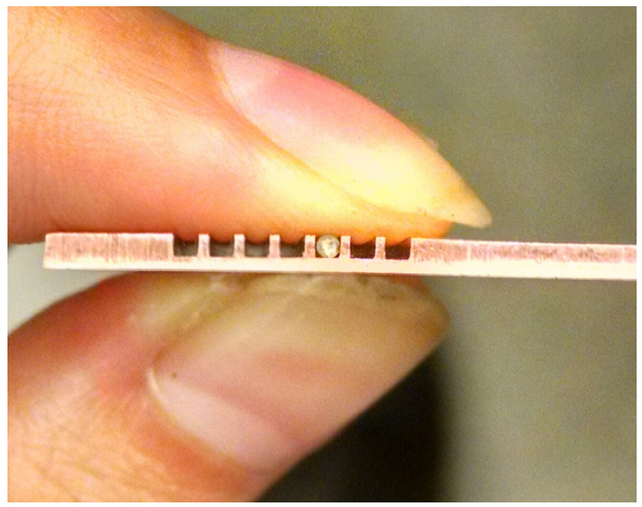
Cross sectional view of module



Making grooves by cutting

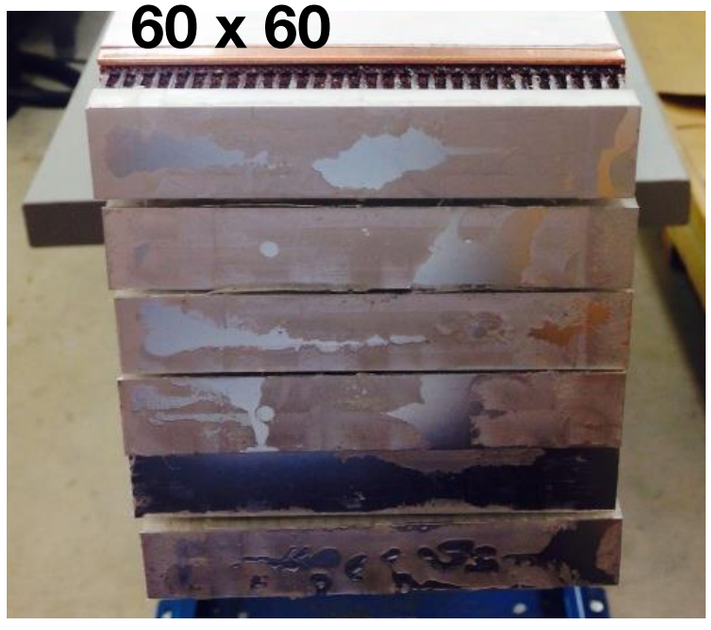


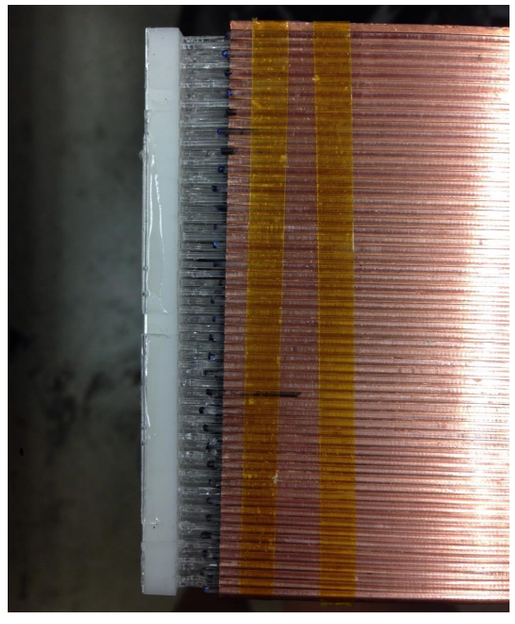
Single fiber on the plate



Two modules (Full version)

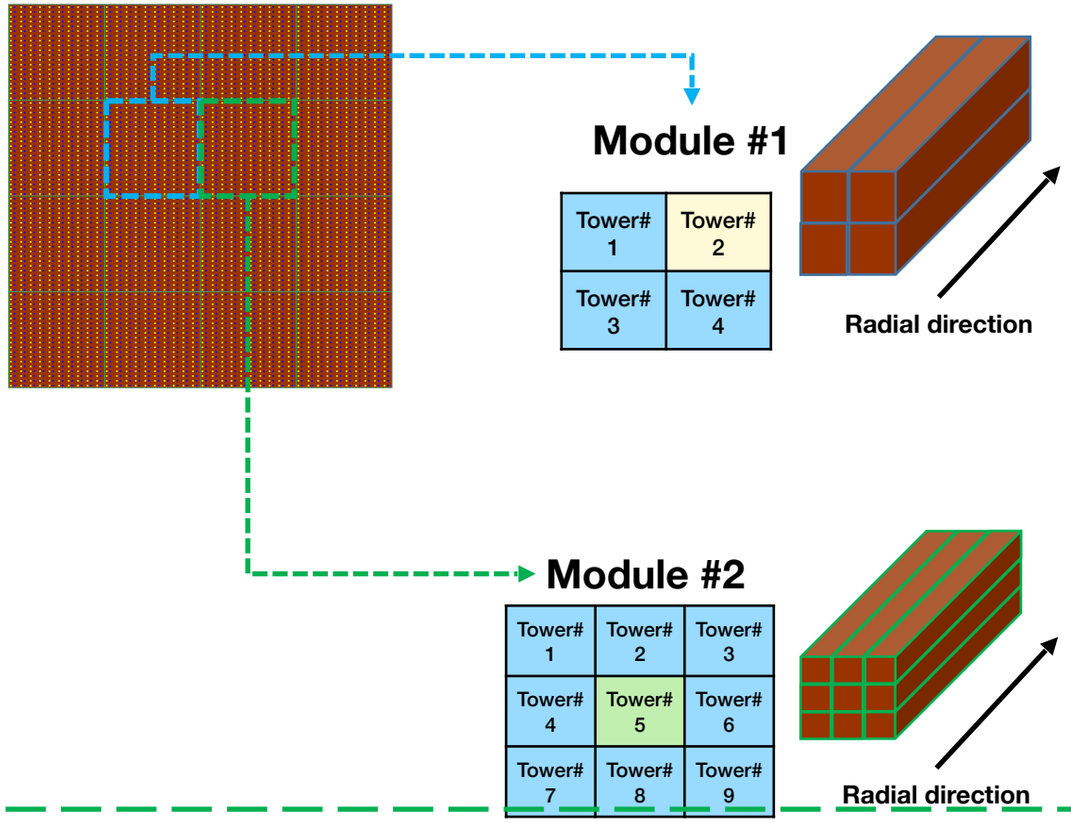
Fibers with Čerenkov reflector





Configuration of Fibers for Test Beam

Front view of prototype detector (4X4 modules)



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	Round / Single cladding	Round / Single cladding	Round / Single cladding
Readout detector (2*4 ch)	2 PMTs or 2 MPPCs	2 MCP-PMTs	2 PMTs	2 PMTs

Combination of fibers for Module#2

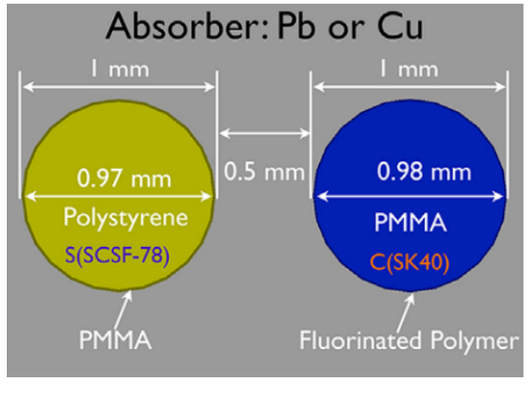
	Tower #1~4 and #6~9	Tower #5
Scintillation fibers	Round / Single cladding	Round / Single cladding
Cherenkov fibers	Round / Single cladding	Round / Single cladding
Readout detector (400+16 ch)	16 PMTs	400 SiPMs

Characteristics of scintillation and Cherenkov fibers

Kuraray product catalog

Light types \ Fiber types		materials	Refractive index	Density (g/cm³)	Cladding type		
					Single		Double
					Square fiber	Round fiber	
Scintillation (Kuraray)	Core (D=0.97 mm)	Polystylene (PS)	1.59	1.05	O	O	O
	Single cladding (2% of D)	Polymethylmethacrylate (PMMA)	1.49	1.19	O	O	O
	Extra cladding (2% of D)	Fluorinated polymer (FP)	1.42	1.43	X	X	O
Cherenkov (Mitsubishi)	Core	Polymethylmethacrylate (PMMA)	1.49	1.19	X	O	X
	Single cladding	Fluorinated polymer (FP)	1.42	1.43	X	O	X

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



Virtual Lab

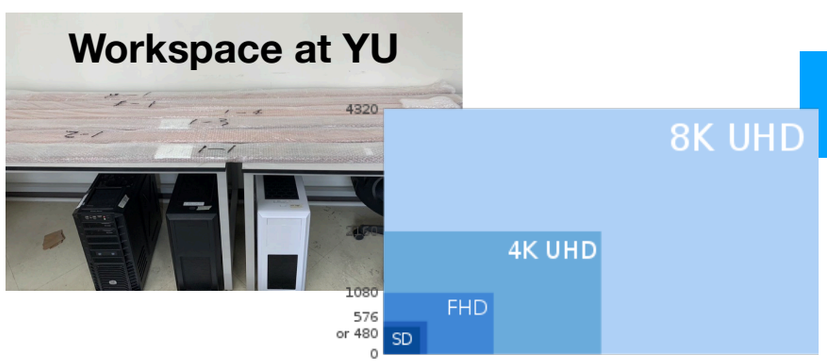
- For future remote-collaboration circumstance
- Build up a solution for remote hardware work
  - For both domestic and international teams
- Two different approach
  - Professional activity
  - Training beginners
- Prototype version can be tested for the module rebuilding
  - Experienced experts are located remotely
  - May need to train new comers remotely (or school via virtual lab)

Current Idea: AR Training

- **Show demonstration**
- **Explain details of hardware building with live-streaming**
  - **Via Zoom or Skype**
- **Record rebuilding => database**

Current Idea: Professional

- Need ultra high-quality live-streaming system
  - To see and recognize “subtle” details
  - Current “fancy” VR/AR (ex: HoloLenz2) can not provide suitable solution
- Key technology for the solution: NDI (network device interface), PTZ camera (pan-tilt-zoom camera), and 4k UHD live-streaming



Remote lab