Korean Activity of Dual-Readout Calorimeter R&D

Hwidong Yoo (Yonsei Univ.)

On behalf of the Korea
Dual-Readout Calorimeter team

CEPC Day, Aug. 26, 2020

Dual-Readout Calorimeter

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.

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

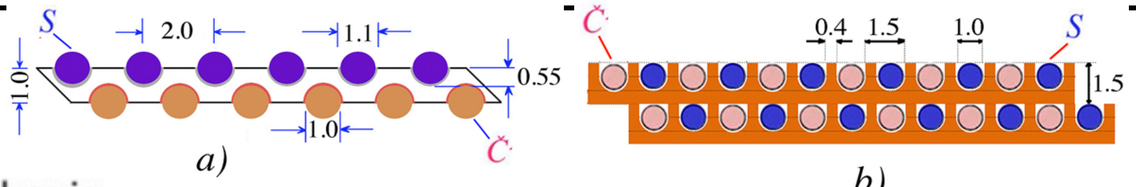
$$C = E[f_{em} + \frac{1}{(e/h)_C}(1-f_{em})].$$

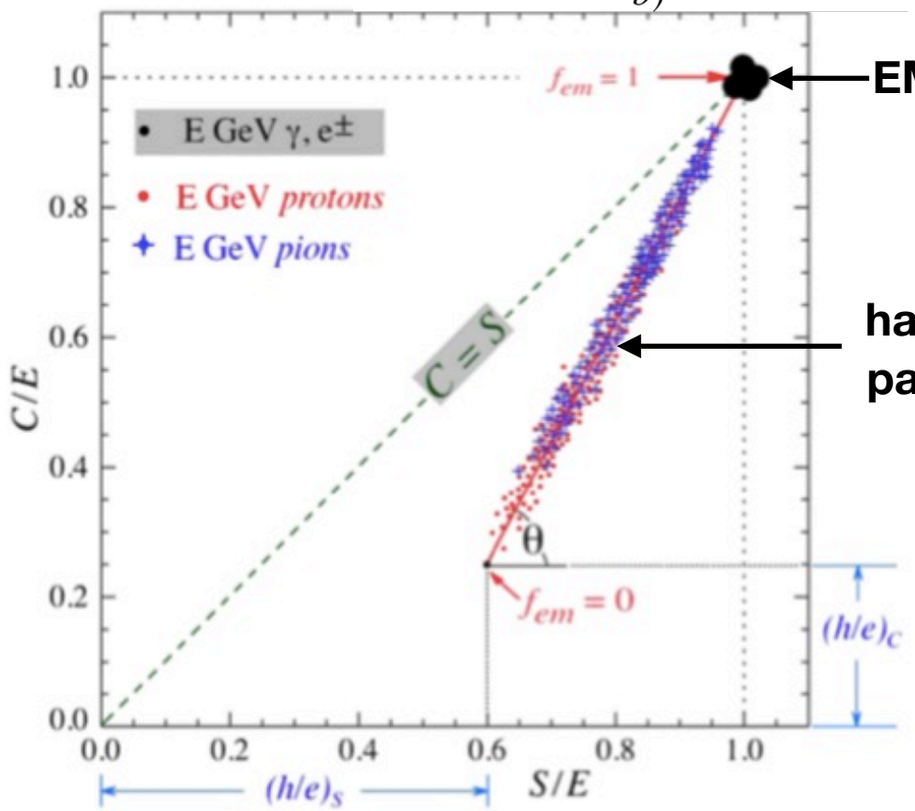
$$\cot\theta = \frac{1-(h/e)_S}{1-(h/e)_C} \equiv \chi,$$

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

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

- 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.

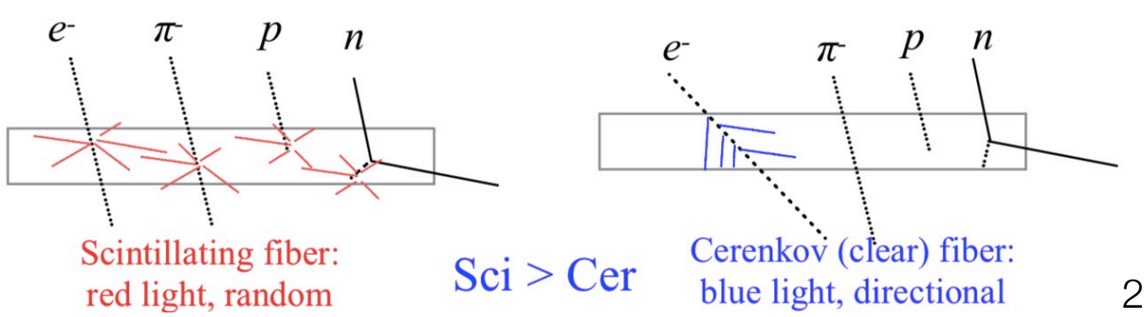


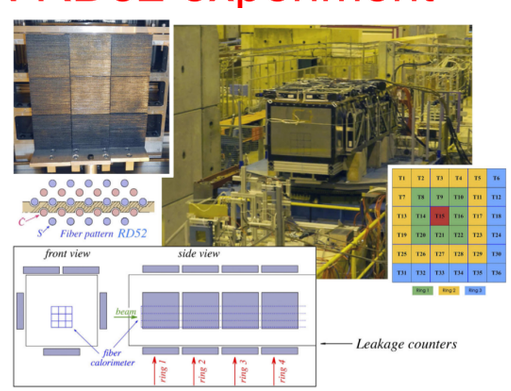


Energy measured from scintillation channel vs Cerenkov channel for EM particle, π & p.

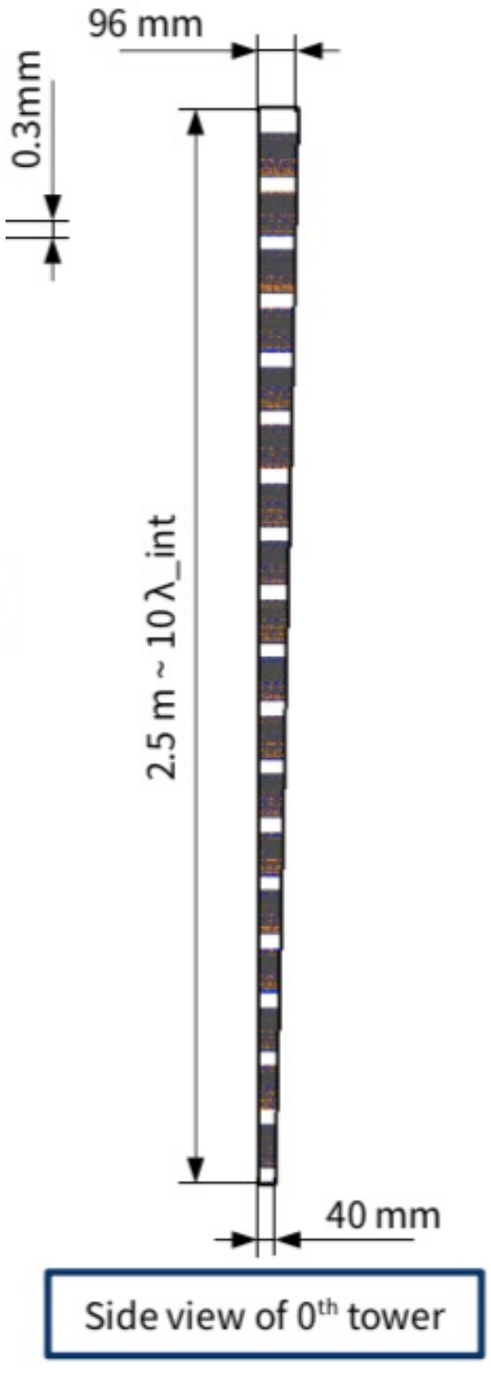
More than 20 years R&D: CERN RD52 experiment

Signal generation: Scintillating & Cerenkov fibers

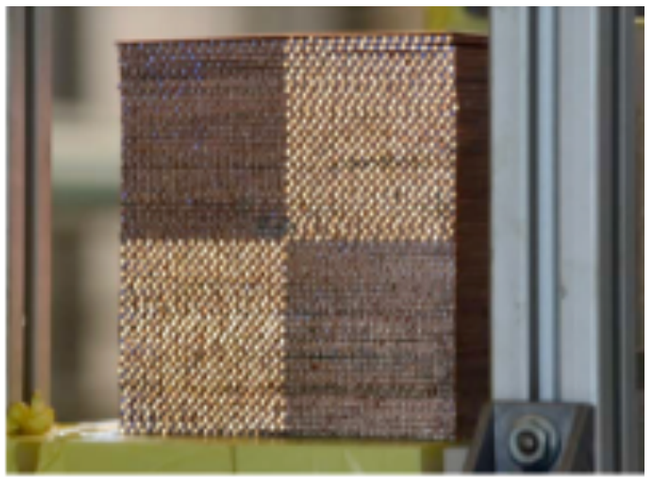


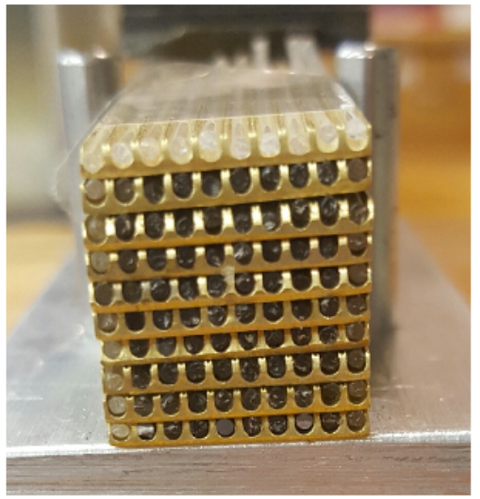


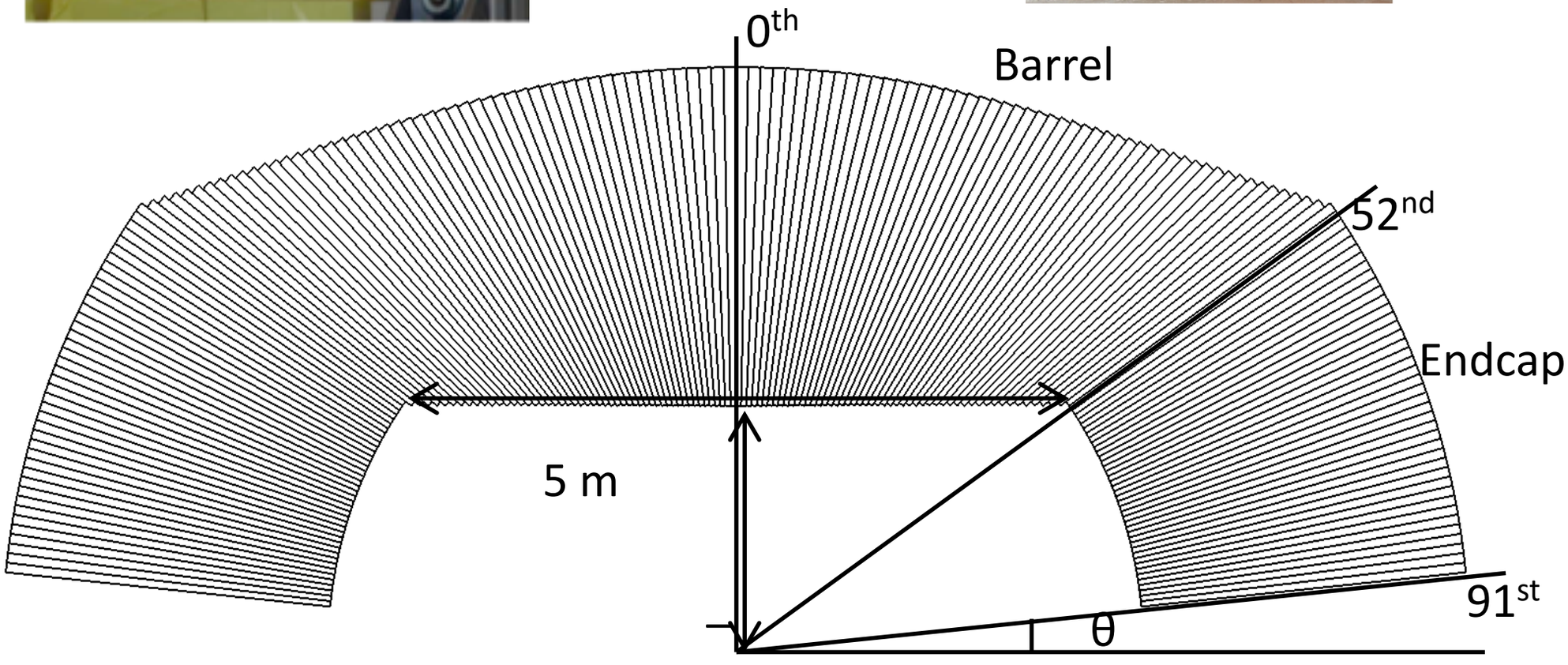
DR Calorimeter Geometry



Side view of 0th tower

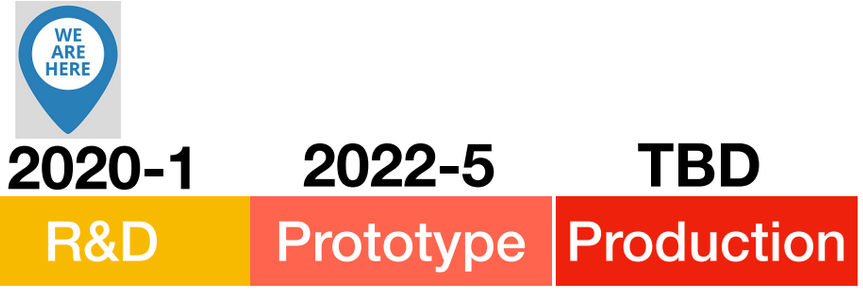






Goal of DR R&D Project

- Primary goal: build a prototype detector for the detector design of CEPC experiment
  - 5 year R&D funding supported by Korea NRF
  - Consists of 16 modules (4 x 4): contain almost (97.5%) full hadronic shower energy
  - Demonstrate engineering aspects for full geometry detector
  - Optimize the performance of the detector

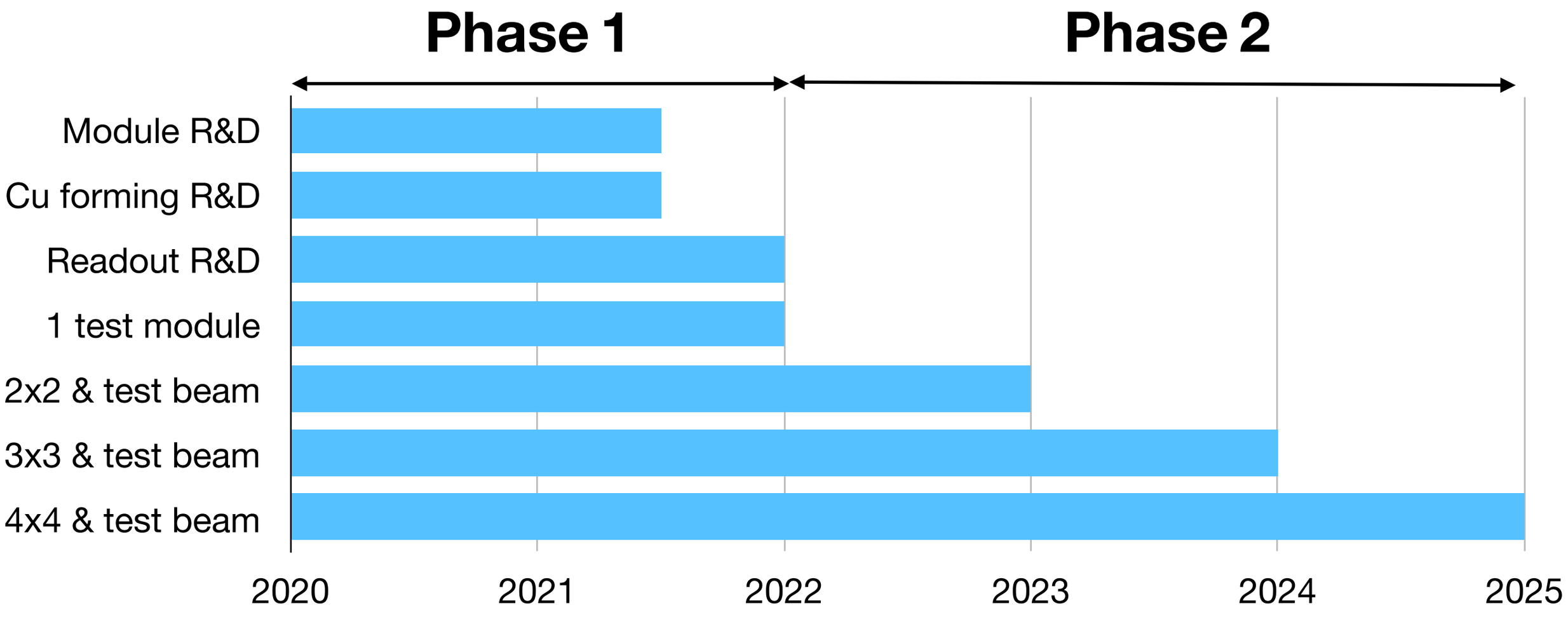


Stage	Topic
Design	Propose a design of Dual-Readout Calorimeter to IDEA detector concept
R&D	Perform R&D (including engineering aspects) based on HW & SW
Prototype	Build 4x4 detector and perform test beams
Production	TBD

Secured Funding in Korea

- ~$0.4M per year from Korea National Research Foundation (NRF)
  - Start from Mar. 2020 to Feb. 2025: full 5 years are guaranteed
  - Total $~2M to build a prototype detector and test beam study
    - Sufficient amount of funding to build full size prototype detector to contain full hadronic shower
    - ~30% overhead included
- Additional small funding is also available
  - Seed research funding from Yonsei University
  - Maximum $100k
- Seeking a full support from wider domestic HEP community in Korea

Brief Roadmap in Korea



More details will be defined and decided on the way!

International Collaboration

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

Taiwan

Prof. Rong-Shyang Lu

Prof. Chia Ming Kuo

Korea

CEPC

DREAM FOR FUTURE

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

- **Have a regular working meeting**
- **Try various (compensated) options**
- **Combine R&D efforts**

Many other people (and institutes) are missing!

Domestic Collaboration

H.S. Jo

S.H. Lee

S.W. Lee

H.D. Yoo

H.D. Yoo
DR Cal.

Steering Committee

Advisory Committee

J. Hauptman

R. Wigmans

Hardware

Electronics

Software

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

GEANT4
S. H. Ko

Geometry
S. H. Ko

Performance
K.Y. Hwang
M.S. Kim
J.H. Lee

Reco/ML
Y.J. Lee

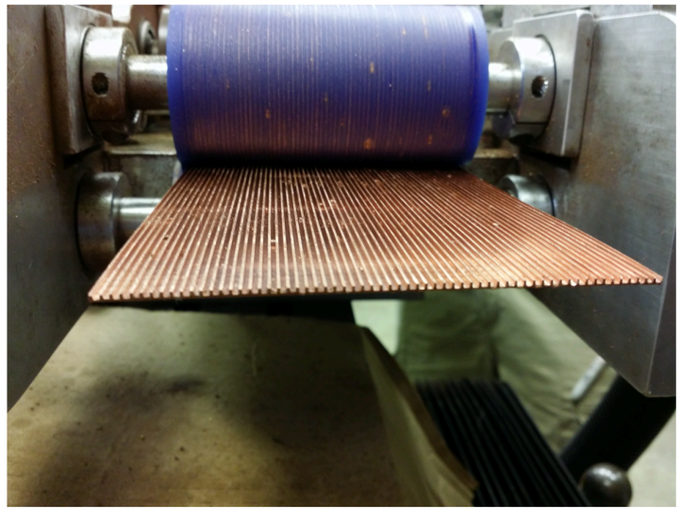
GAN
J.S. Park
D.Y Kim

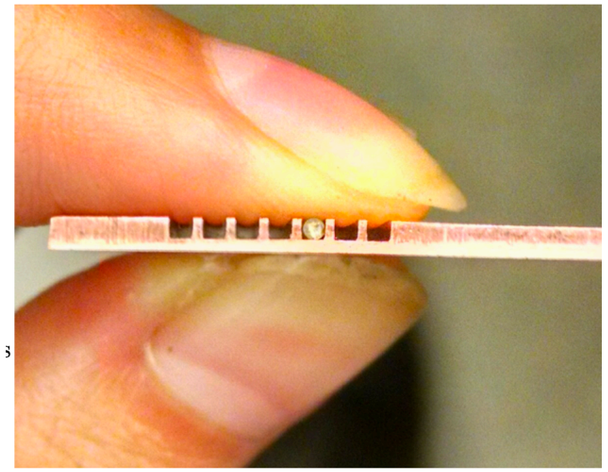
List of Current On-going Effort

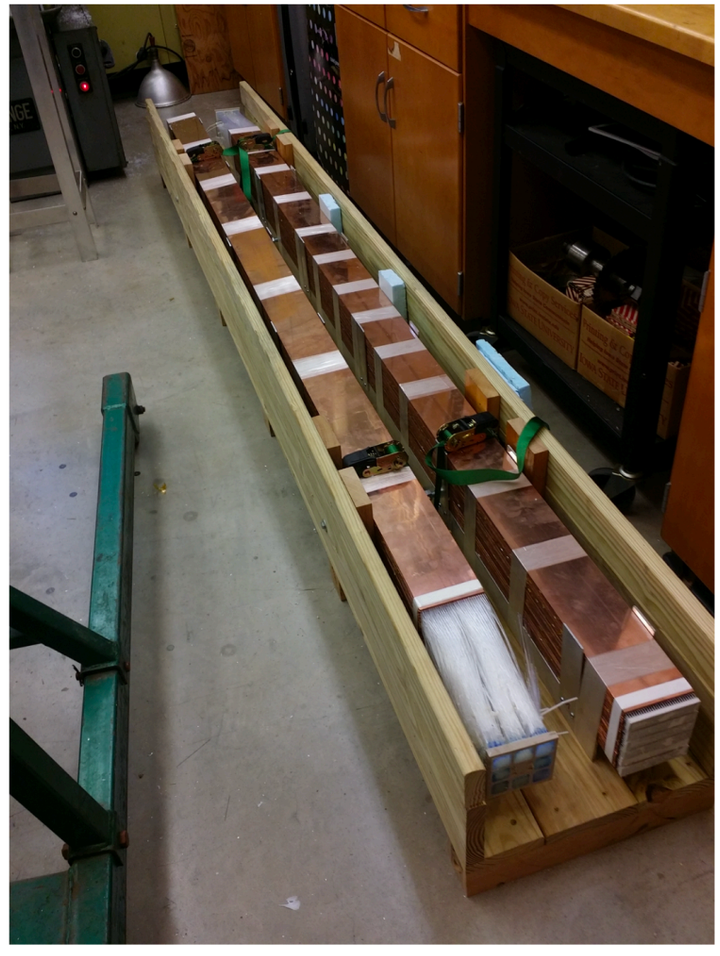
Topic	Name	Status
Module		
Forming: 3D printing, molding, cutting	H.D. Yoo (YU)	Sample ordered
Absorber type: Cu, Pb, W, Fe	K.Y. Hwang (YU)	On-going (simulation)
Length: 2.0 m vs. 2.5 m	K.Y. Hwang (YU)	
Electronics		
SiPM design R&D	B.B. Kim (KNU)	Idea
Simulation/Performance		
Calibration	K.Y. Hwang (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

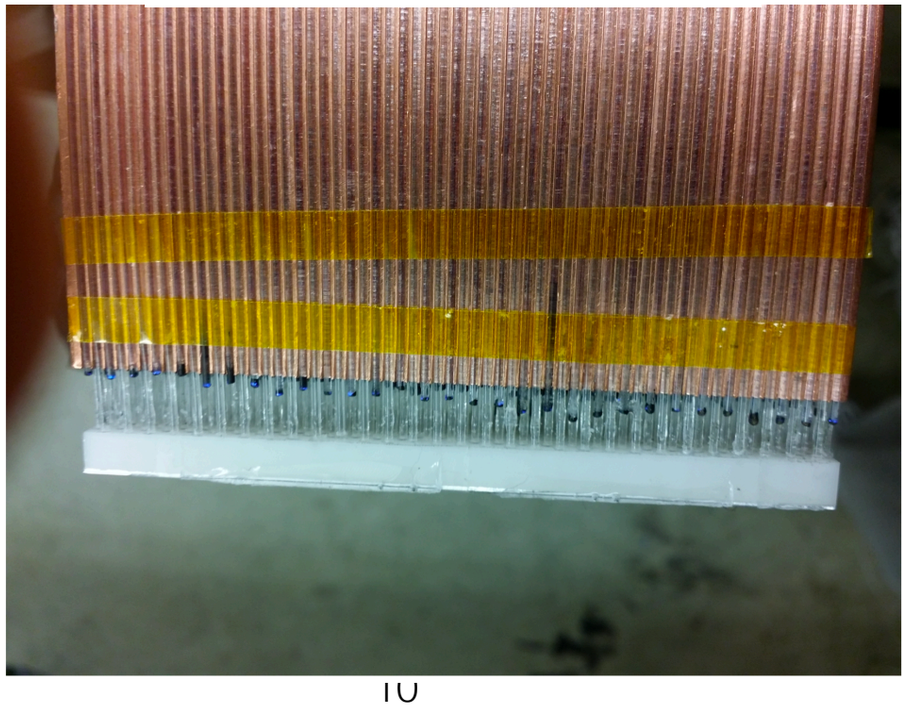
Previous Module Building

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



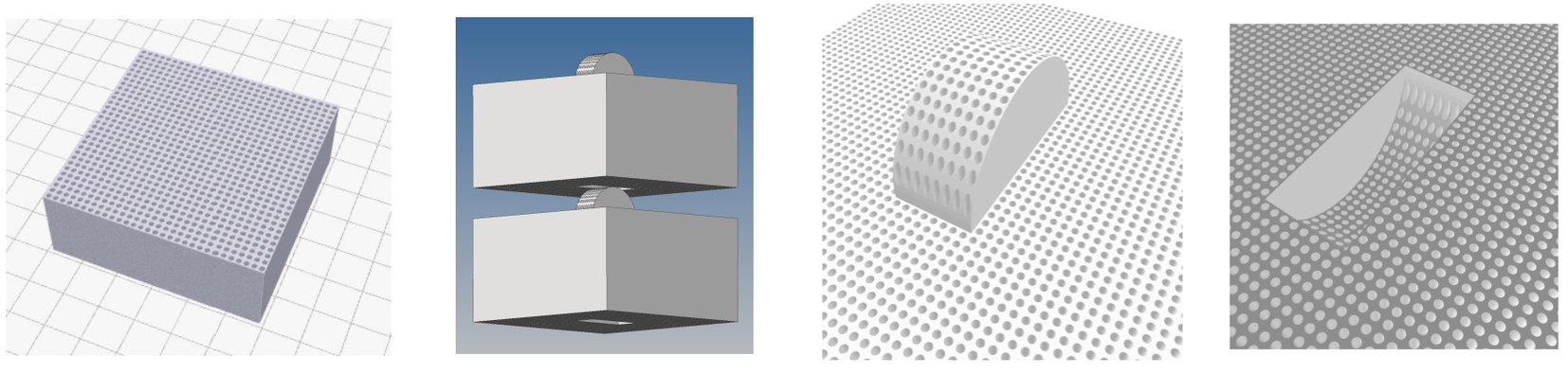




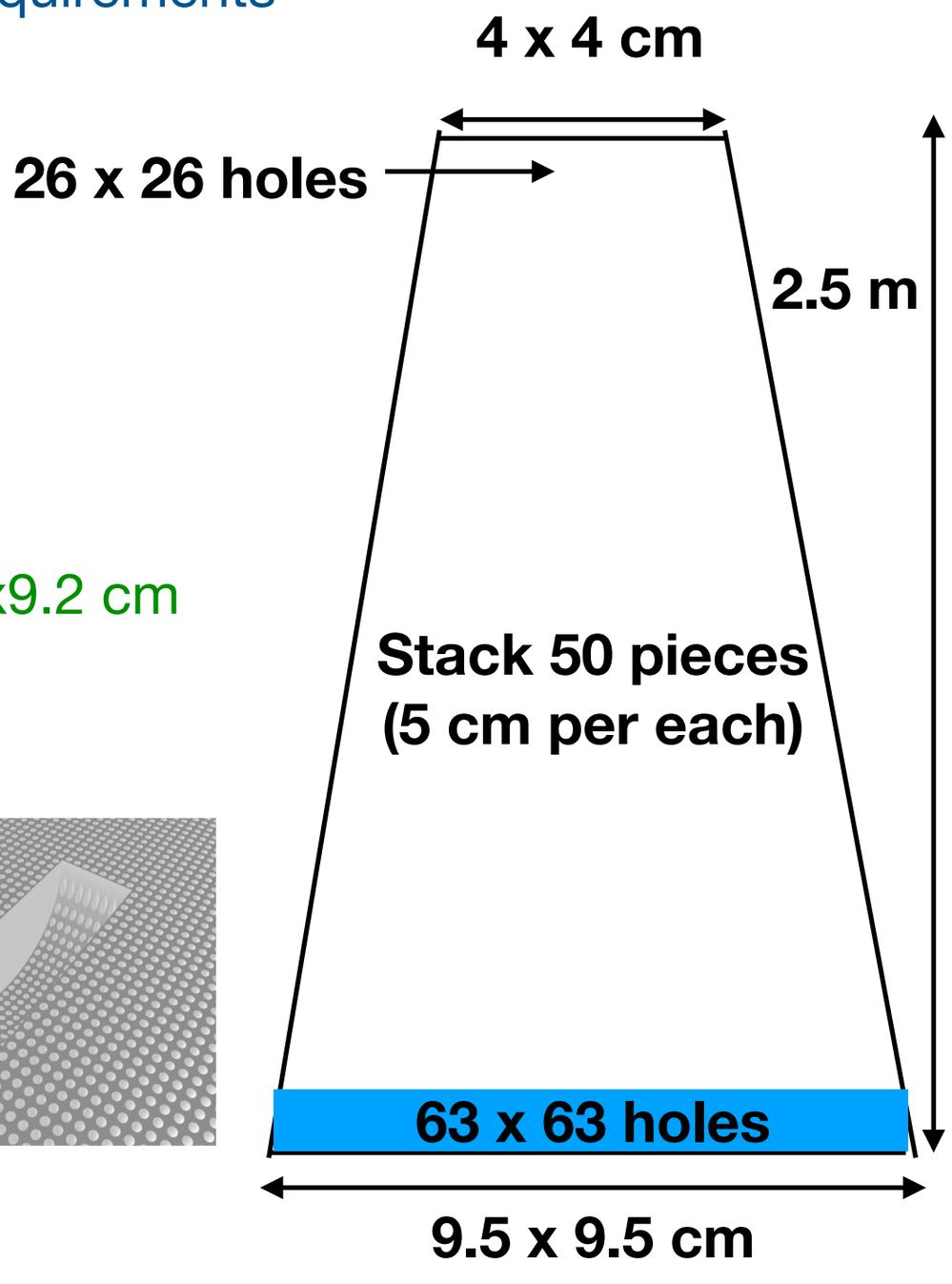


Status of 3D Printing

- Ordered two pieces of samples with specific requirements
  - Cu density: > 99.5%
  - 1 mm diameter for a hole for fibers
  - 0.5 mm distance between two holes
  - 60 x 60 holes with precise alignment in 9.2x9.2 cm (height 5 cm)



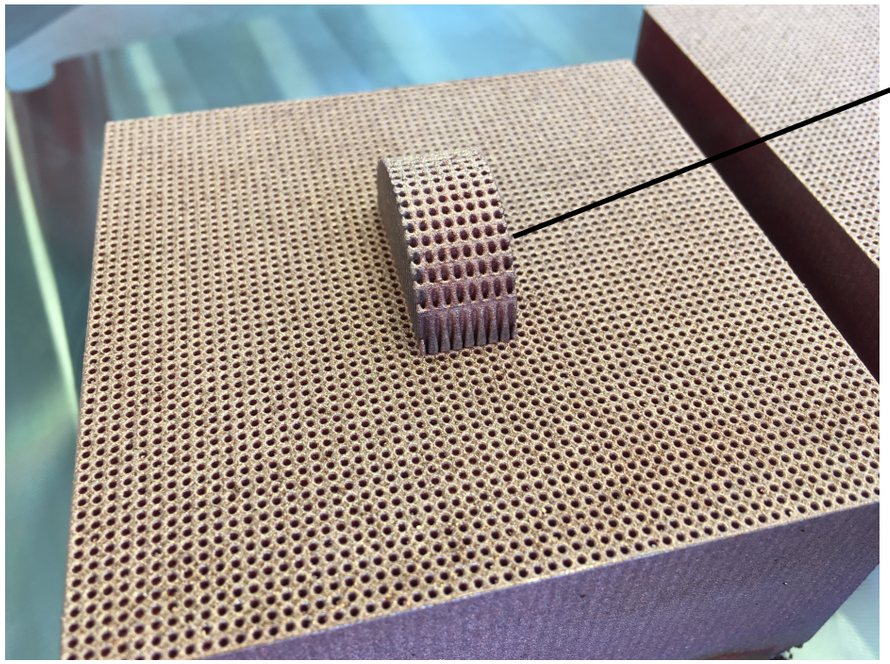
With 3D printing consultant company in Korea
- **have world-wide expert networking**

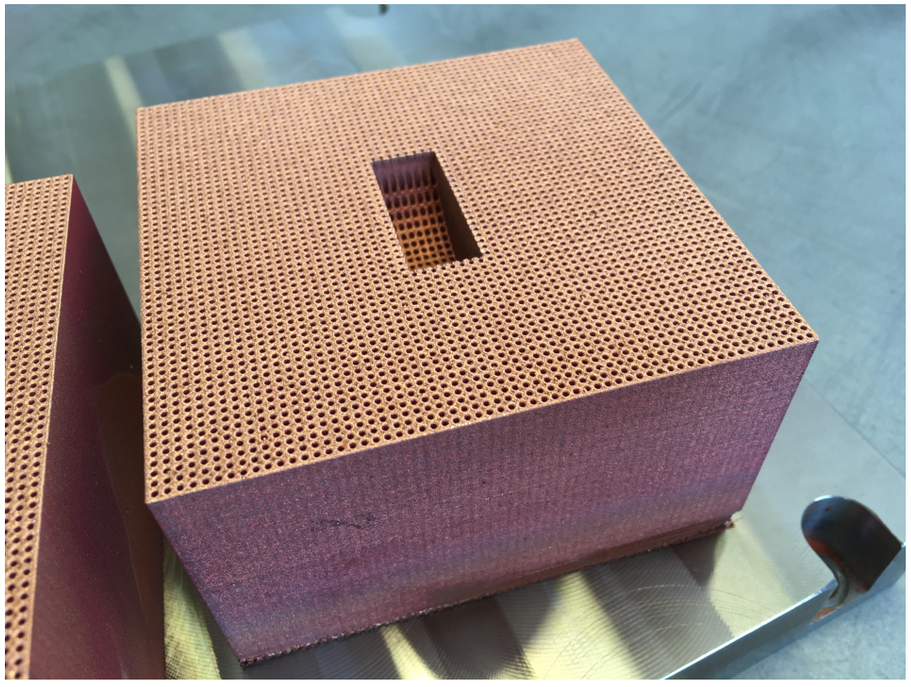


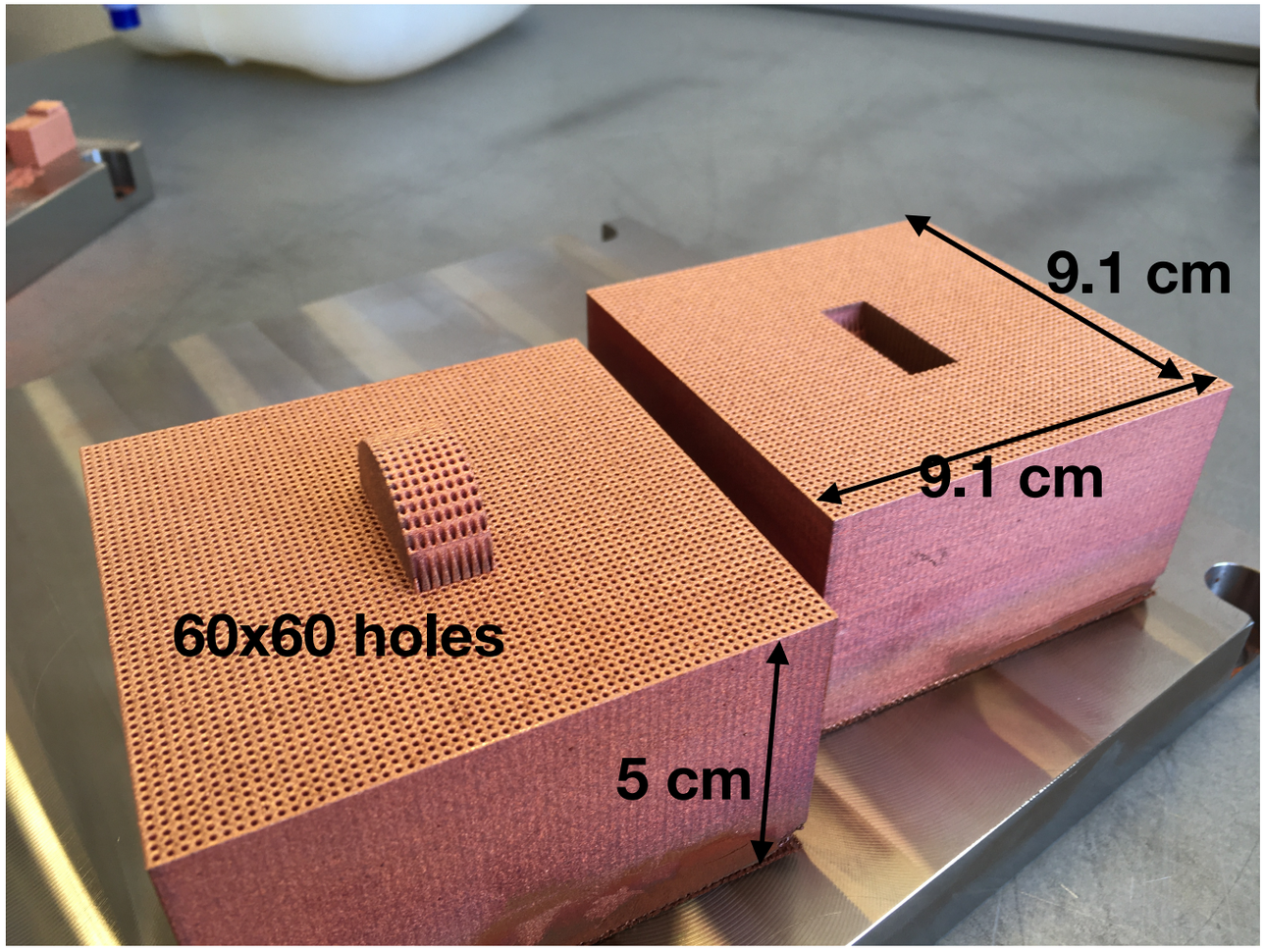
Typical structure of wedge tower module

Status of 3D Printing

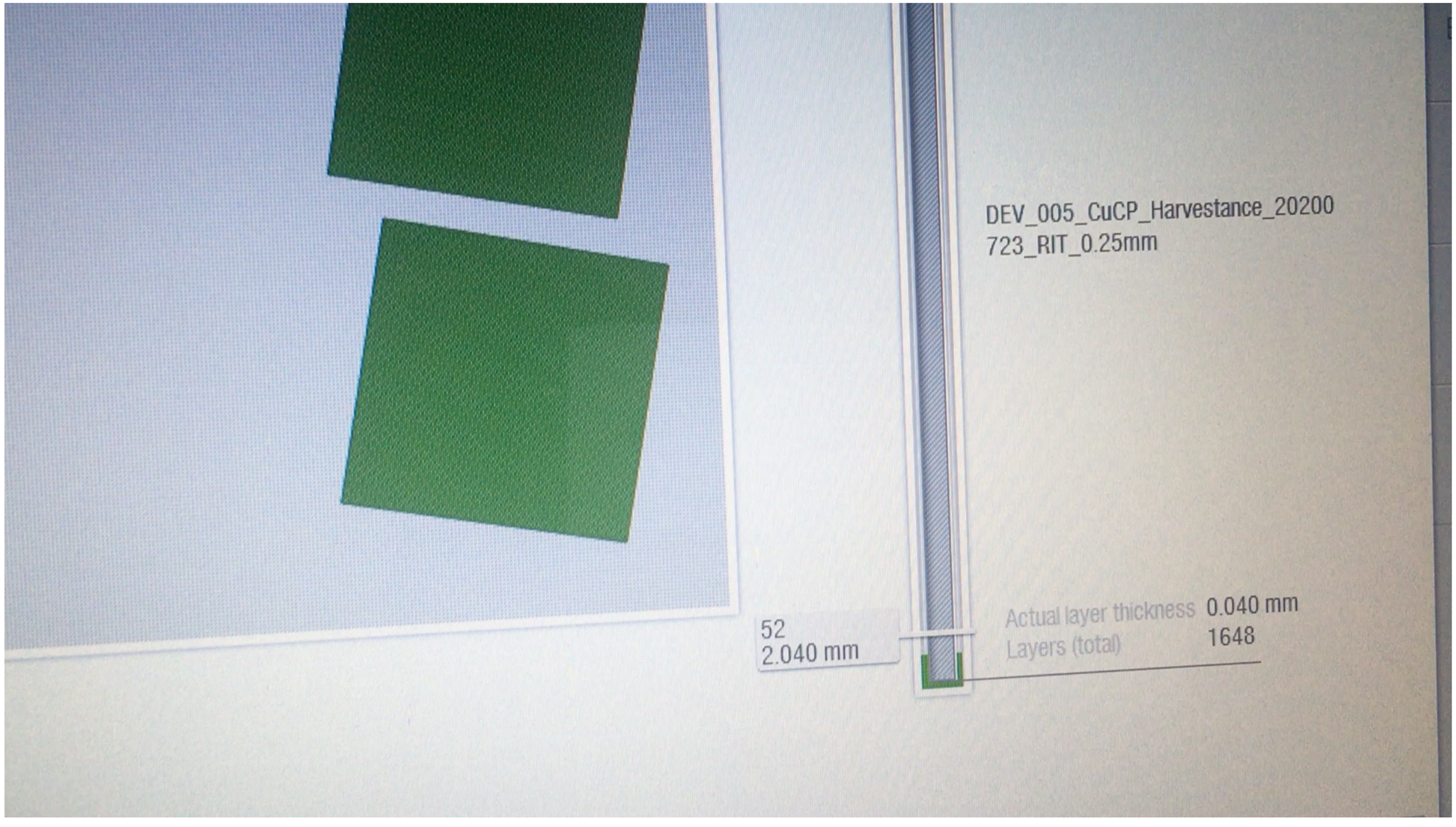
- The 1st trial is not hopeless, but we should investigate more details and will try several other options to improve







Status of 3D Printing



Computing Facilities

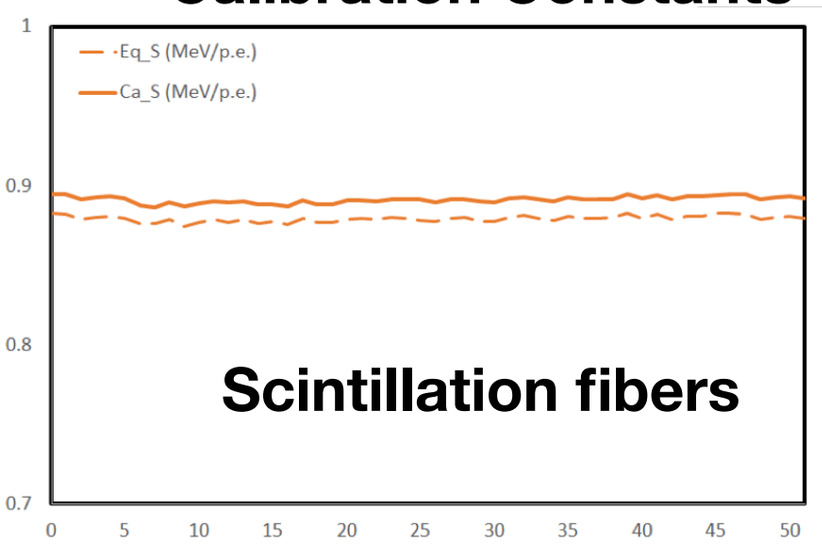
- Need huge resources for CPU and storage to perform full GEANT4 simulation
  - Due to full optical photon simulation for scintillation and Cerenkov fibers
  - Ex) take about 8 weeks for calibrations of all modules (92) using 300 threads
- Current available resources: maximum 700 CPUs are available for our study!
  - KISTI: 150 cores under condor configuration
    - Additional 150 cores will be provided at Fall
  - KNU: 100-200 cores supported by supercomputing center
  - UoS: 100-200 cores supported by supercomputing center
  - SNU: ~150 cores available

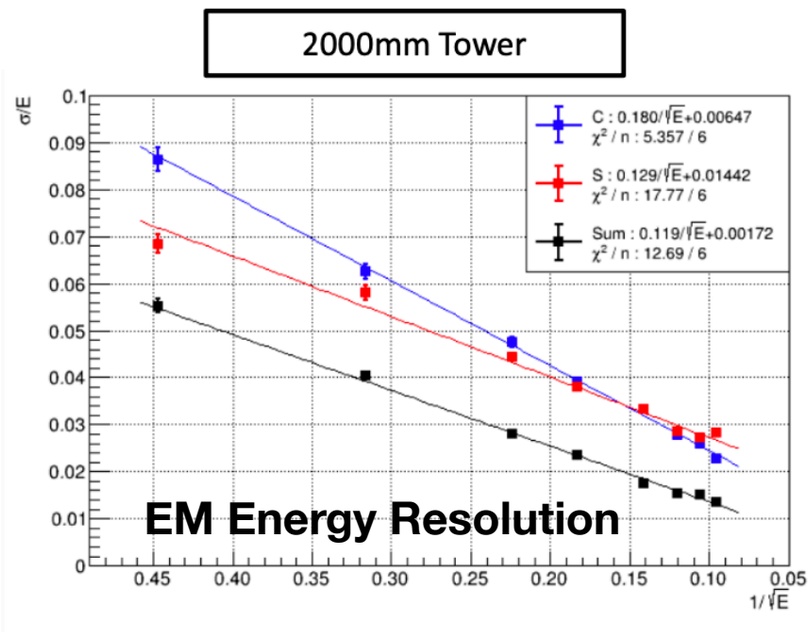
Status of Simulation

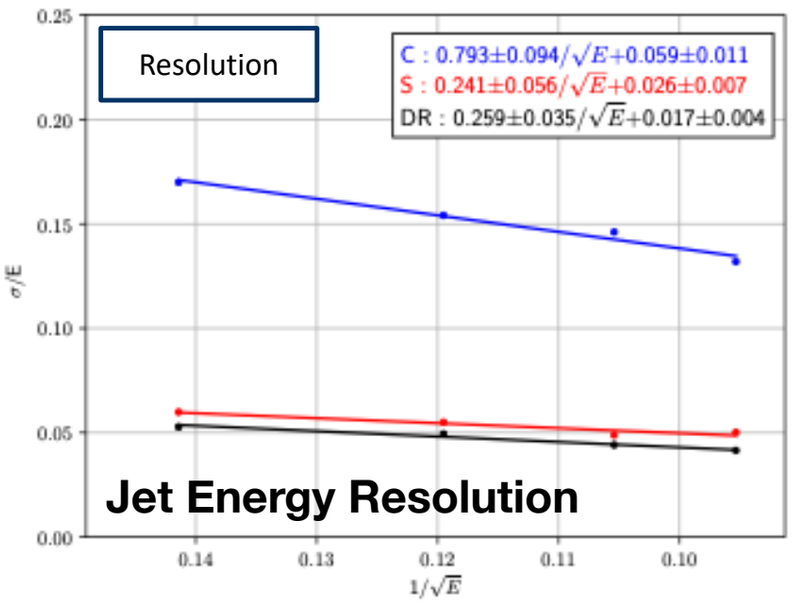
- Production of calibration constant with full GEANT4 simulation is on-going
  - Barrel (up to 52nd towers) has been done

More details presented by S.H. Ko at July ECAL workshop: link

- Excellent EM and hadronic energy resolutions obtained by GEANT4 simulation
  - EM energy resolution: ~11%/sqrt(E)
  - Pion energy resolution: ~21%/sqrt(E)
  - Jet energy resolution: ~26%/sqrt(E)







Status of SW Infrastructure

Migration to Key4HEP elements

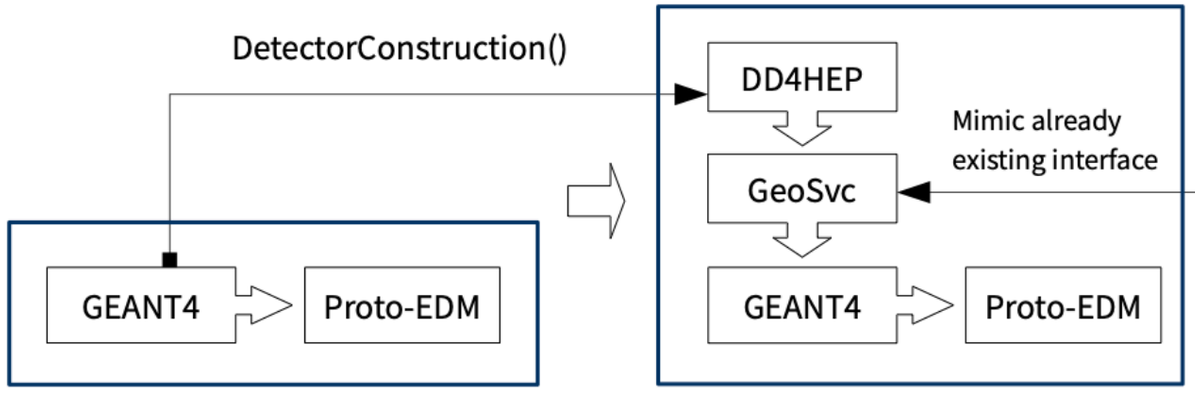
More details presented by S.H. Ko at July ECAL workshop: link

Migration to Key4HEP elements

- Migration to centralized SW is a good opportunity to take a look into combined detector performances, e.g. tracker+calorimeter, ECAL+HCAL, .etc.
- However, migrating in a one big leap is not an ideal choice.
  - Core software is still rapidly evolving, may introduce extra efforts for integration & maintenance.
  - May need to test several options internally, usage of standalone SW is still too convenient to abandon.

→ Start by migrating to necessary subset of Key4HEP elements (e.g. DD4HEP, EDM4HEP) based on the current standalone SW is a natural choice.

- DD4HEP & GeoSvc interface will provide great convenience already for plugging-in other detector components compared to G4 standalone.



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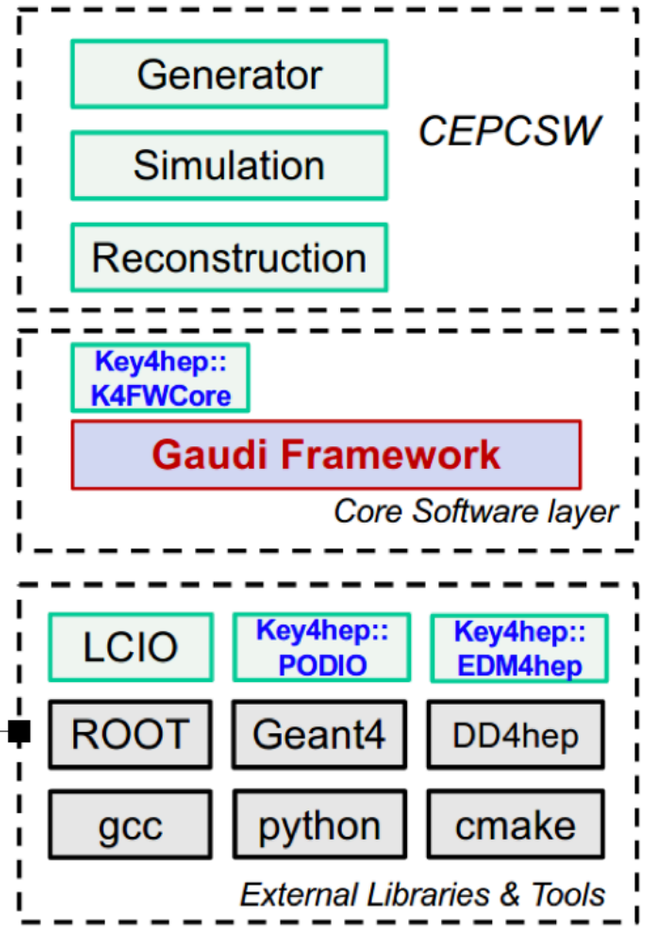
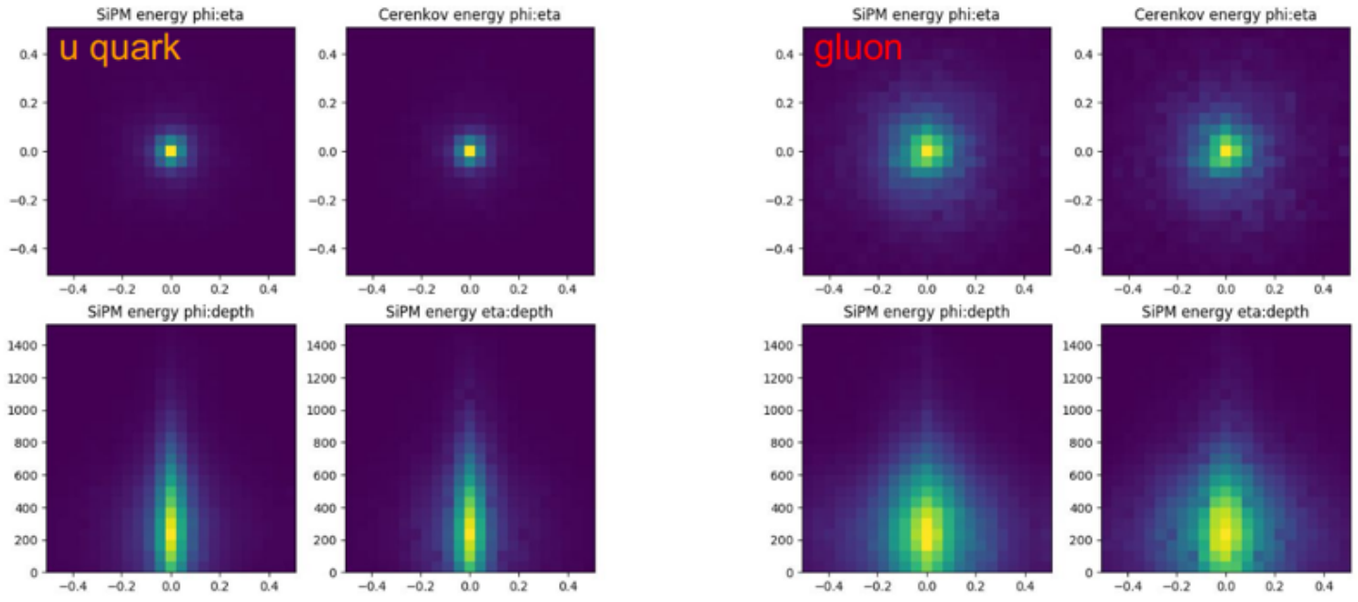
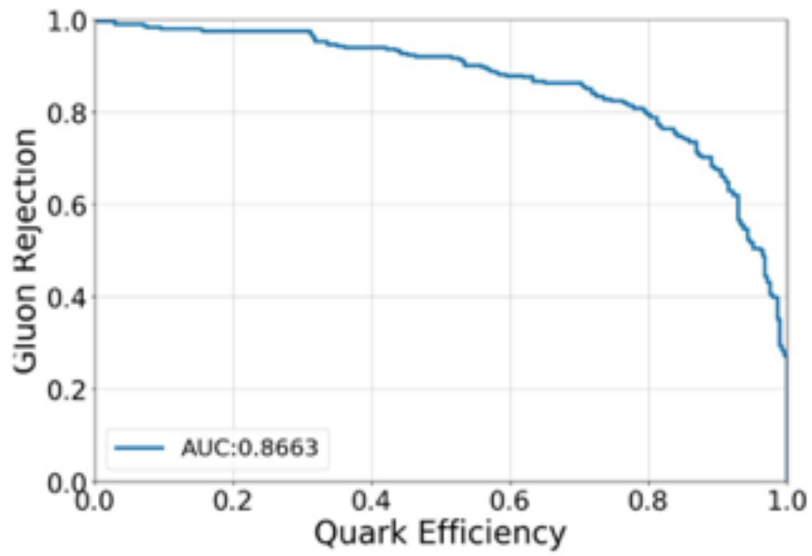


ML-based Application



Quark- vs gluon jets



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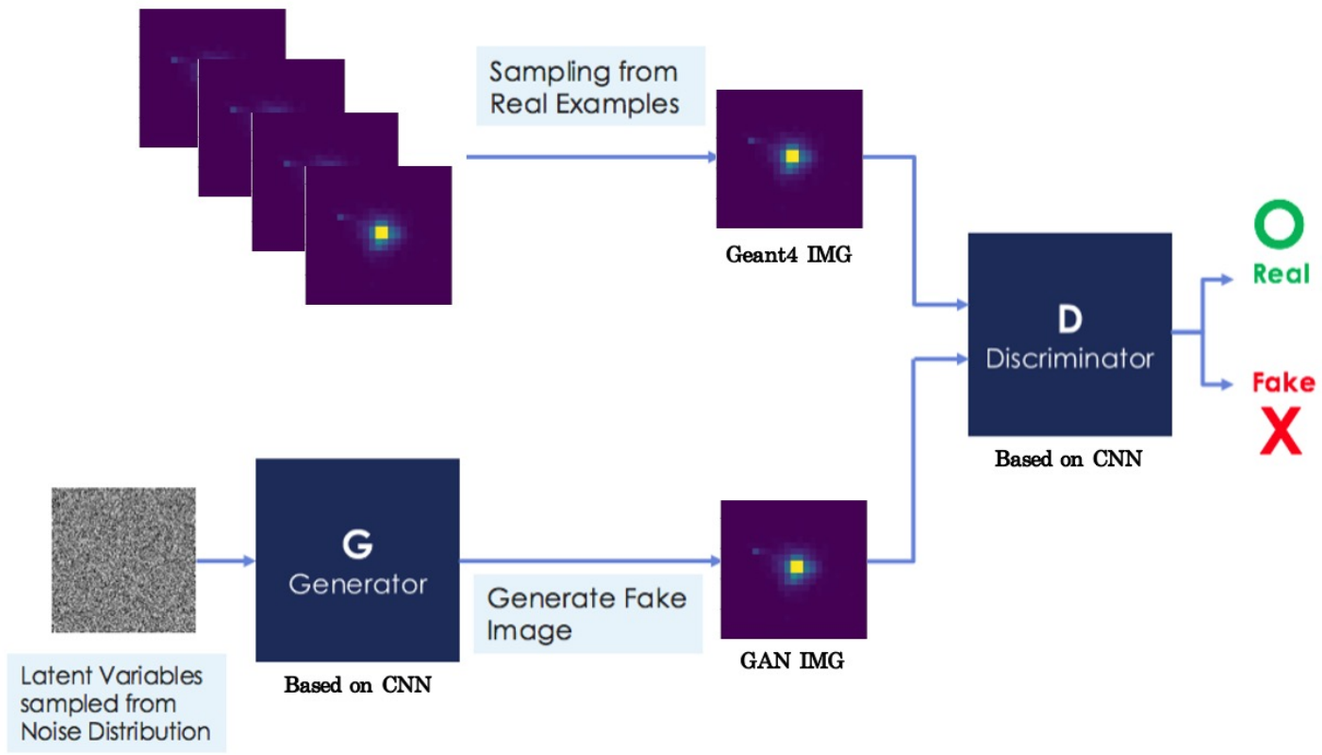
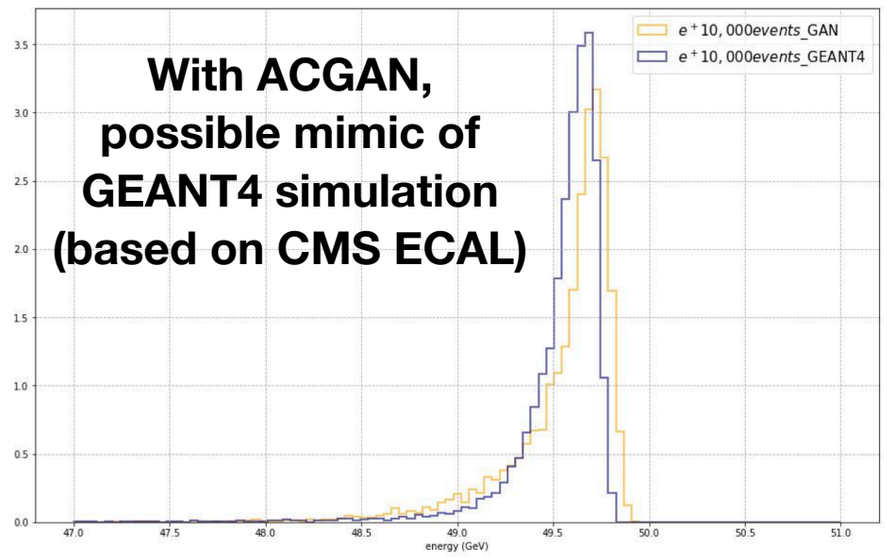




Snowmass21 (SM21)

- Excellent opportunity to
  - Integrate US and world-wide research campaign
  - Collect new domestic members for DR Cal activity
  - Increase visibility our local activity to international colleagues

- International dual-readout team prepared a single letter of interest (LoI): overview of dual-readout activities
  - We certainly participate in this common activity to integrate

Plan for SM21 in Korea

- Totally seven topics are in pipeline
- Topic1: “Feasibility study of merging the MIP Timing Detector and Dual-Readout Calorimeter at future e^+e^- colliders”
  - Domestic collaborators: C.S. Moon (KNU), J.H. Yoo (Korea Univ.)
  - US collaborators: David Stuart (UCSB)
- Topic2: “Fast optical photon transport at GEANT4 with Dual-Readout Calorimeter at future e^+e^- colliders”
  - US collaborators: S.Y. Jun (Fermilab) & GEANT4 collaboration under discussion
- Topic3: “Heavy flavour tagging using machine learning technique with silicon vertex detector and Dual-Readout Calorimeter at future e^+e^- colliders”
  - Domestic collaborators: S.H. Lim (PNU)
  - US collaborators: Jin Huang (BNL), Qipeng Hu (LLNL)

Plan for SM21 in Korea

- Topic4: “Sensitivity study of H->Zγ with Dual-Readout Calorimeter at future e^+e^- colliders”
    - Domestic collaborators: K.W. Nam (SNU)
    - US collaborators: under discussion
- Topic5: “τ reconstruction and identification using machine learning technique with Dual-Readout Calorimeter at future e^+e^- colliders”
    - Domestic collaborators: K.H. Kim (Yonsei Univ.), Y.S. Kim (Sejong Univ.), Y.J. Kwon (Yonsei Univ.)
    - US collaborators: M. Murray (University of Kansas)
- Topic6: “Various physics cases with Dual-Readout Calorimeter at future electron-ion collider”
    - Domestic collaborators: S.H. Lim (PNU), H.S. Jo (KNU), Y.S. Kim (Sejong Univ.)
    - US collaborators: under discussion
- Topic7: “Multi-object identification in the final state with Dual-Readout Calorimeter at future e^+e^- colliders”
    - US collaborators: P. Chang, F. Wuerthwein, A. Yagil (UCSD)

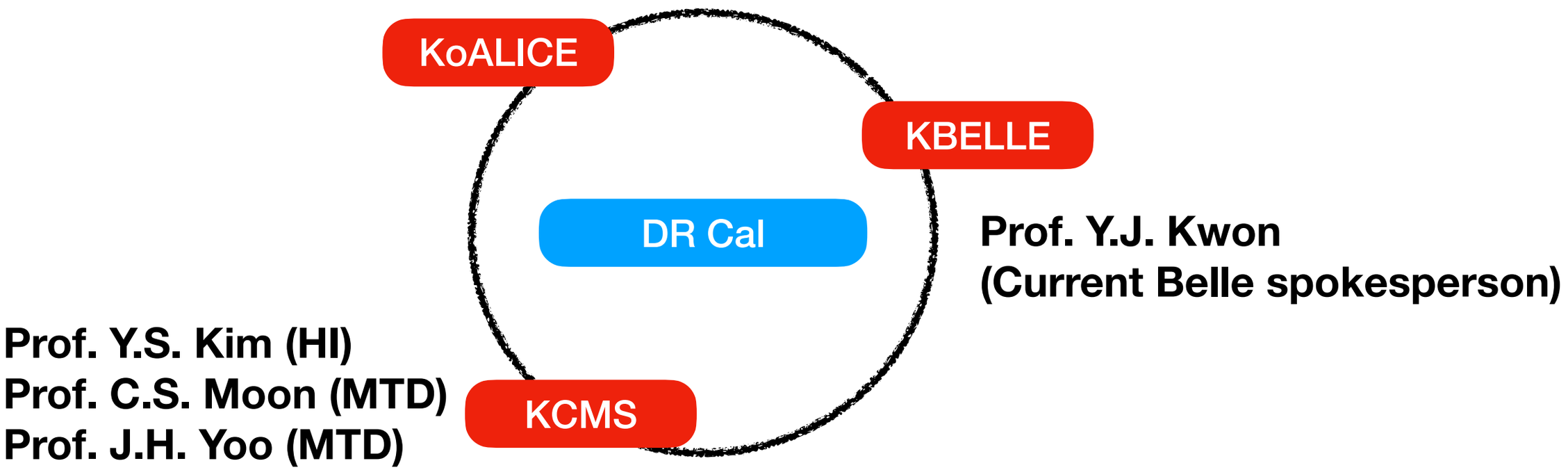
Clustering in Korea

- Combine efforts of current on-going experiments: ALICE, BELLE (II), and CMS in Korea

  - Many experienced experts for various research topics can be provided from the experiments

  - Huge synergies are expected by orthogonal expertise

Prof. S.H. Lim (ITS)



Prof. Y.J. Kwon
(Current Belle spokesperson)

Prof. Y.S. Kim (HI)
Prof. C.S. Moon (MTD)
Prof. J.H. Yoo (MTD)

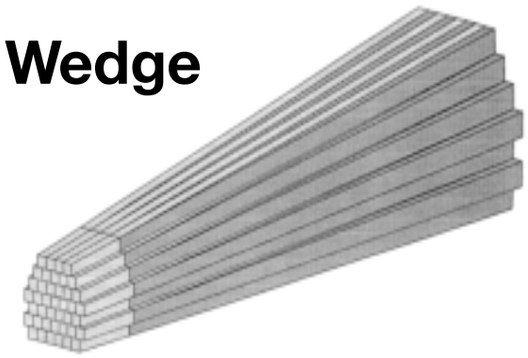
Summary

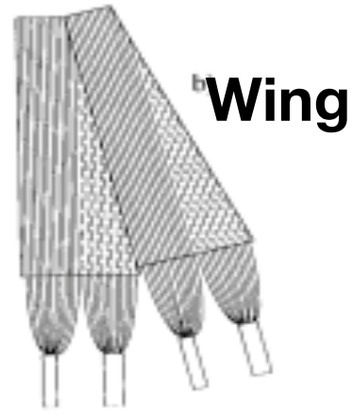
- Dual-Readout Calorimeter R&D project for future e^+e^- collider in Korea is very active
  - 4x4 prototype detectors for next 5 years
  - 3D printing to form Cu module is under study
  - Huge computing facilities are supported by several institutes in Korea
  - Various studies for performance and ML applications are on-going
  - Excellent resolution for both EM and hadronic particles is expected
- Various Snowmass21 plans are in pipeline
  - Totally seven LoIs under discussion
  - Groups are being formed with new domestic collaborators from on-going experiments: ALICE, BELLE(II), and CMS members in Korea
- All members and colleagues are **very young group** (students, young postdocs, faculties within 7 years)!
  - Very promising future of Korea HEP group

Back Up

Geometry R&D

- Two geometry candidates are under consideration
  - Wedge vs. Wing





"Calorimetry", Oxford University Press, R. Wigmans (TTU)

  - Wedge candidate has been used in CDR
  - Under discussion with simulation R&D

Geometry	Configuration	Pros	Cons
Wedge	Single trapezoidal type	Efficient to mass production	Require a mature technique for forming one big tower
Wing	Rectangular + triangle types	Rectangular shape: relatively easier for engineering	More number of towers including triangle shape