# Asian Perspectives

**Jianbei Liu (USTC), Hwidong Yoo (Yonsei U.), and Wataru Ootani (ICEPP, UTokyo)**

CALOR2024, Tsukuba, May 21st, 2024

# Perspectives in China, Korea, and Japan

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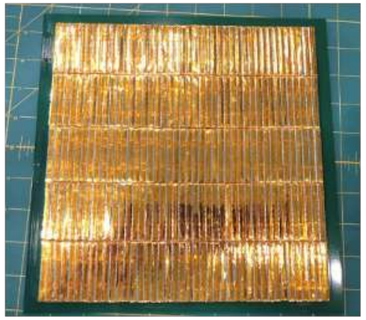
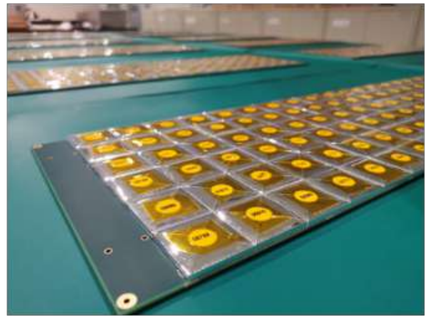
# China

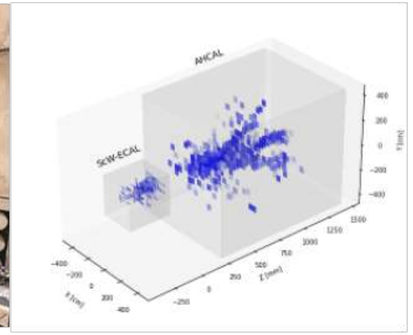
# Calorimeter R&D in China

- Calorimeter R&D for Chinese on-shore program
  - Circular Electron Positron Collider (CEPC)
  - Super Tau Charm Facility (STCF)
  - Electron-ion collider in China (EicC)
  - High Energy cosmic-Radiation Detection (HERD) in the future China's Space Station (CSS)
  - Very Large Area Space Telescope (VLAST)
- Chinese contributions to off-shore programs
  - CMS HGCAL
  - ALICE FoCal
  - LHCb SpaCal

# CEPC Calorimeters R&D

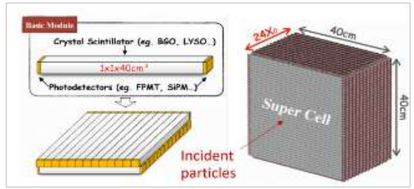
- **High-granularity scintillator calorimeters**
  - Technological prototypes based on scintillator and SiPM of EM and hadron calorimeters
  - Successful beamtest campaigns at CERN in 2022-2023: decent data sets
  - Ongoing data analysis: performance, PID, etc.

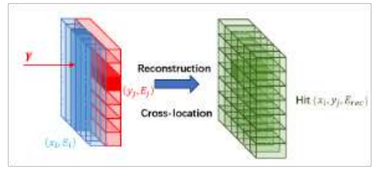



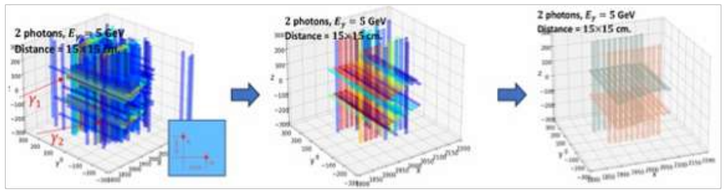


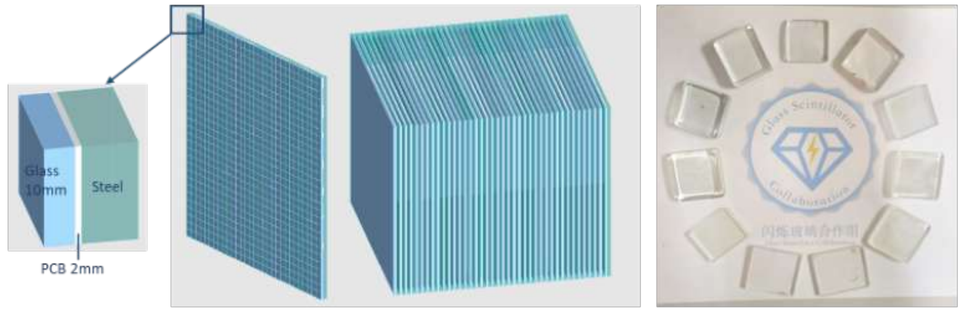

CEPC calorimeter working group
China: IHEP, SJTU, USTC;  Japan: Shinshu U., U. Tokyo

- **Highly granular crystal calorimeter**
  - Aim for $2\sim3\%/\sqrt{E}$ EM energy resolution
- **Hadron calorimeter with scintillating glass tiles**
  - Aim for 2-3% EM energy resolution
- Both optimized for particle-flow paradigm







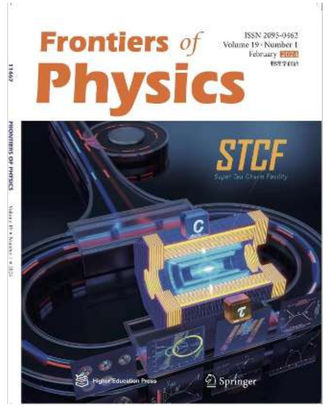


# Super Tau Charm Facility (STCF)


- $E_{cm}$= 2-7 GeV, $\mathcal{L} > 0.5\times10^{35}$ cm $^{-2}$ s $^{-1}$
- Potential for luminosity upgrade and a polarized electron beam
- Site: Suburban "Future Big Science City" in Hefei

STCF Physics and Detector CDR has been released and published

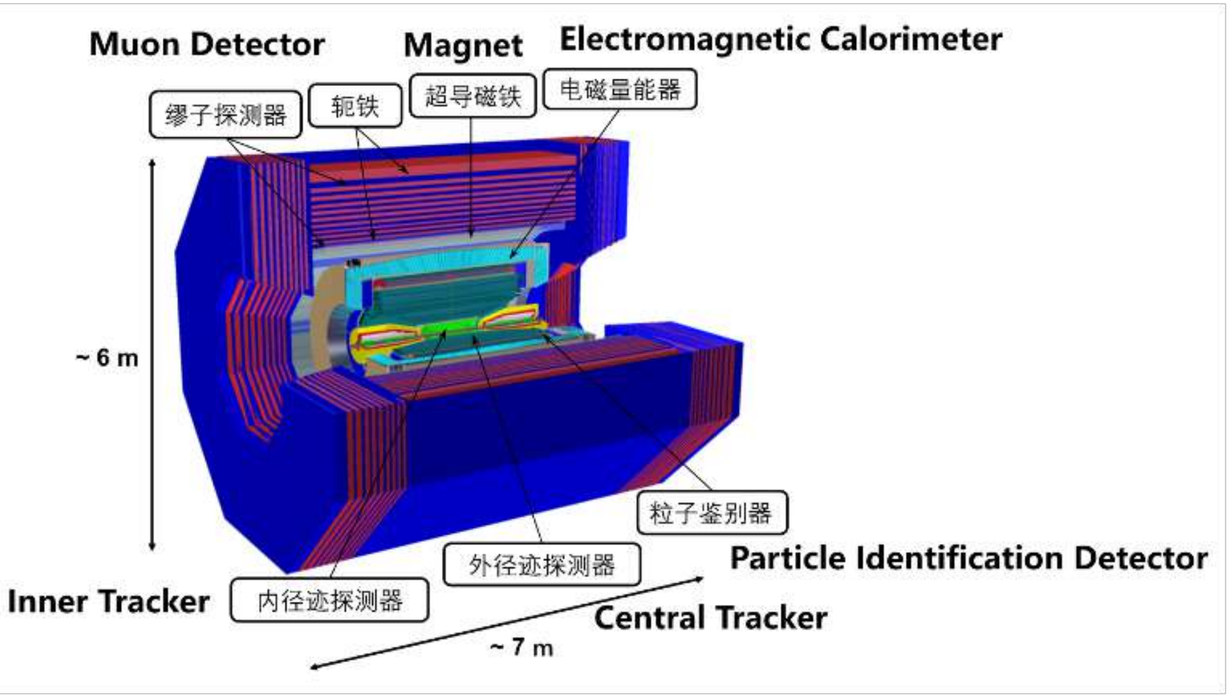
*arXiv:2303.15790*



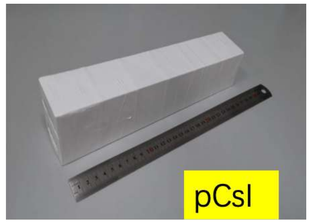

**STCF can produce an enormous amount of "clean" tau leptons and charm hadrons, allowing a full exploration of the unique and great physics potential in the tau-charm energy region: QCD, exotic hadrons, flavor physics and CPV, new physics…**

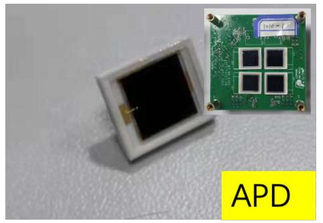
- 14th five-year plan (2021-2025): Design studies and R&D on key technologies, ~0.4 B CNY
- 15th five-year plan (2026-2030): Construction to start during this period, ~6 years, ~4.5 B CNY
- Operating for 15 years to be followed by major upgrades

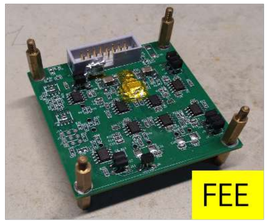
# Super Tau Charm Facility (STCF)

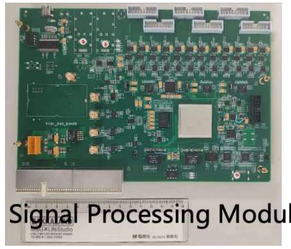



- Homogeneous calorimeter
  - Crystal: pure CsI with size of ~5×5×28 $cm^3$
  - Photon detector: large area APD
  - Electronics: charged sensitive amplifier and waveform sampling
- Intensive R&D on pCsI unit and readout electronics at USTC

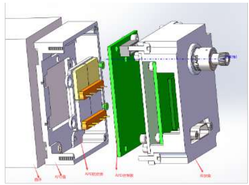


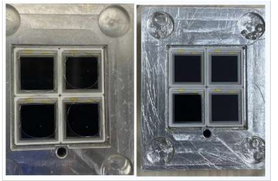



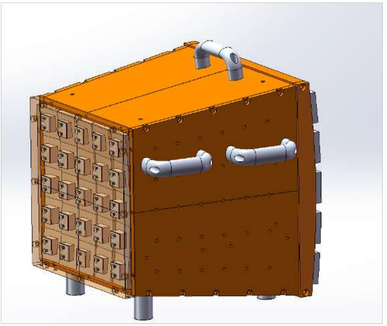




- Building a 5*5 pCsI ECAL prototype with full electronics and plan to test the integrated system with high energy electrons at CERN this summer.



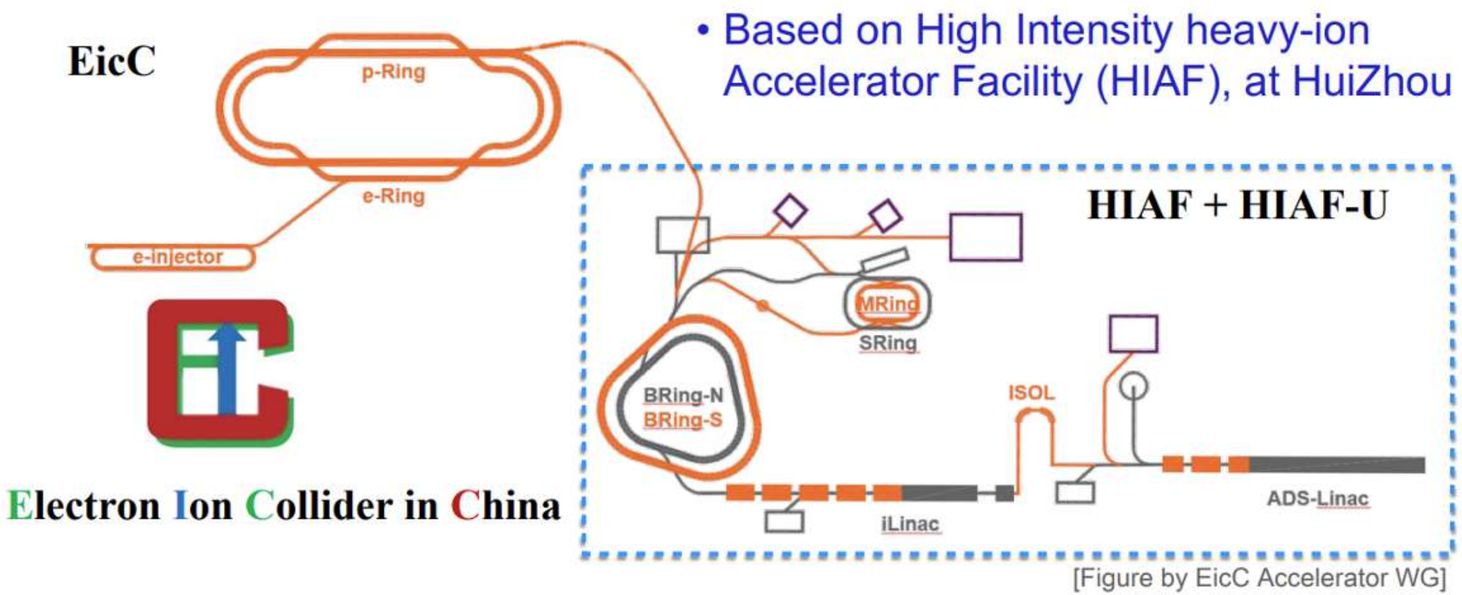




## ➢ STCF ECAL Requirements

- ➢ High Counting Rate
  - ➢ About 1 MHZ background event rate
- ➢ Good Energy Resolution
  - ➢ Better than 2.5% @ 1GeV
- ➢ Good Time Resolution
  - ➢ 300 ps @ 1 GeV

# Electron-ion collider in China (EicC)




[Figure by EicC Accelerator WG]

- Energy in c.m.: 15 ~ 20 GeV
- Electron beam: 3.5 GeV, polarization ~ 80%
- Proton beam: 20 GeV, polarization ~ 70%
- Luminosity: $\gtrsim 2 \times 10^{33}$ cm$^{-2} \cdot$ s$^{-1}$
- Other available polarized ion beams: d, $^{3}He^{++}$
- Available unpolarized ion beams: $^{7}Li^{3+}$, $^{12}C^{6+}$, $^{40}Ca^{20+}$, $^{197}Au^{79+}$, $^{208}Pb^{82+}$, $^{238}U^{92+}$

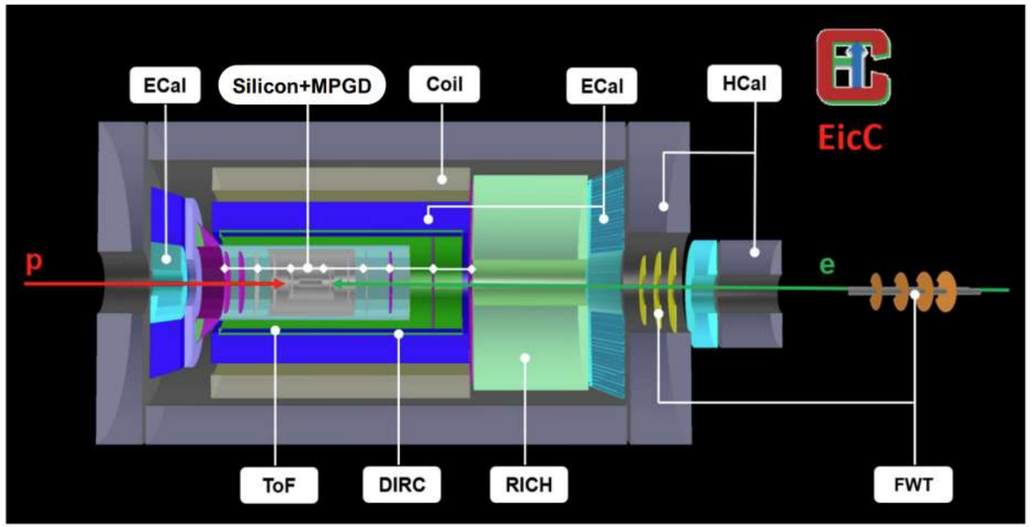

High Intensity heavy-ion Accelerator Facility

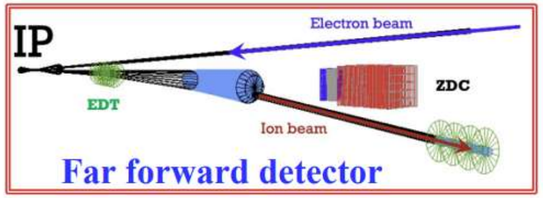
- A national facility on nuclear physics, atomic physics, heavy-ion applications …
- Open to scientists all over the world
- Provide intense beams of primary and radioactive ions
- Beam commissioning is planned in 2025

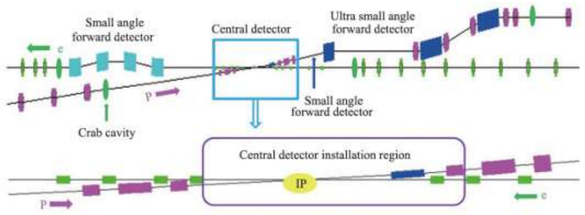
# Electron-ion collider in China (EicC)



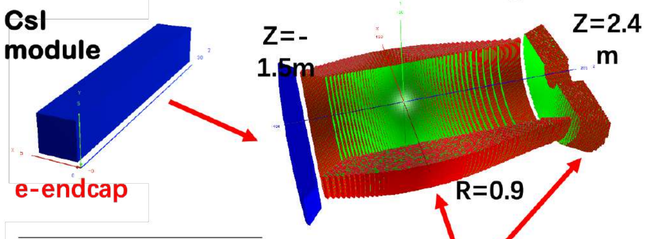
## Conceptual Design of the EicC Detector



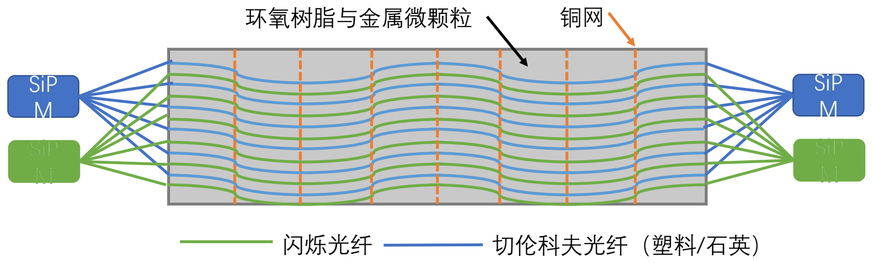

## ECal design

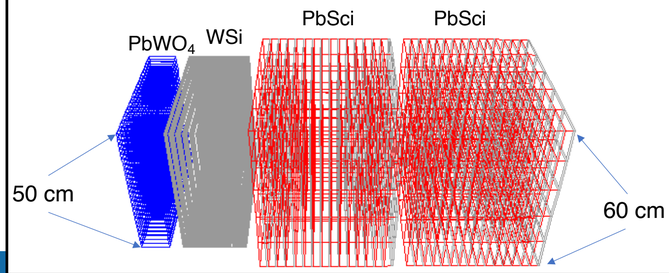



| Parameter | value |
|---|---|
| Distance to IP | 1.5 m |
| $\eta$ acceptance | (-3, -1) |
| Inner radius | 15 cm |
| Outer radius | 128 cm |
| length | 30 cm |
| Radiation length | 16 $X_0$ |
| Front size | 4×4 $cm^2$ |
| Rear size | 4.8×4.8 $cm^2$ |
| Photon detector | APD |
| Total modules | ~2700 |

| Parameter | Barrel | Ion-Endcap |
|---|---|---|
| Distance to IP | | 2.4 m |
| $\eta$ acceptance | (-1, 1.5) | (1.5, 3) |
| length | 60 cm | |
| Radiation length | 16 $X_0$ | |
| Molière radius | 5.02 cm | |
| Front size | 4×4 $cm^2$ | |
| Rear size | 5.7×5.7 $cm^2$ | 4.7×4.7 $cm^2$ |
| N layers | 240 | |
| Scintillator thickness | 1.5 mm | |
| Lead thickness | 0.35 mm | |
| Reflector thickness | 0.065 mm | |
| Sampling ratio | 0.33 | |
| Inner radius | 90 cm | 24 cm |
| Outer radius | 150 cm | 113 cm |
| N fibers(front) | 16 | |
| Photon detector | 6x6 $mm^2$ SiPM | |
| Total modules | ~8000 | ~2300 |

A detector concept for the EicC HCAL



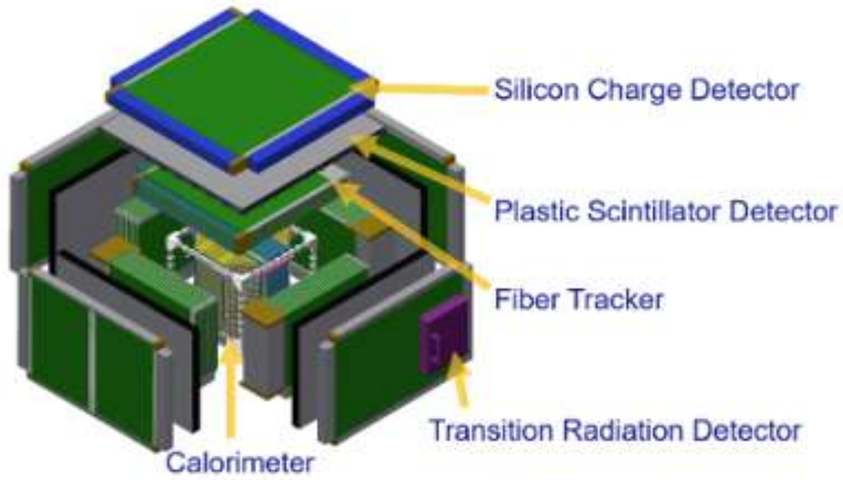




A detector concept for the EicC ZDC (zero degree calorimeter)

# High Energy cosmic-Radiation Detection (HERD) in the future China's Space Station (CSS)

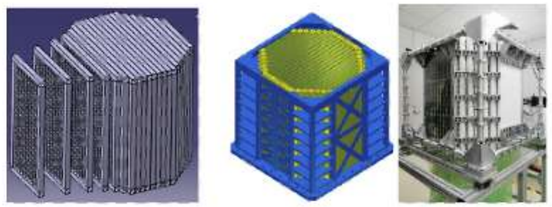


The High Energy cosmic-Radiation Detection (HERD) facility has been proposed as one of several space astronomy payloads onboard the future China's Space Station (CSS), planned for operation starting around 2027 for about 10 years. The primary scientific objectives of HERD are: Indirect dark matter search with unprecedented sensitivity; precise cosmic ray spectrum and composition measurements up to the knee energy; Gamma-ray monitoring and full sky survey.

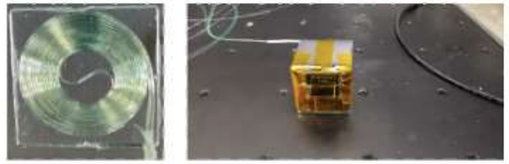



Crystal Array

CALO is made of about 7500 LYSO cubes arranged into an octagonal prism, which corresponds to from all directions 55 radiation lengths and 3 Nuclear Interaction Lengths. Large statistics of cosmic rays up to PeV energy is then feasible, and high energy resolution of high energy particles is also guaranteed. Each crystal has a side length of 3 cm and the space in between crystals is strictly limited for a better energy reconstruction.



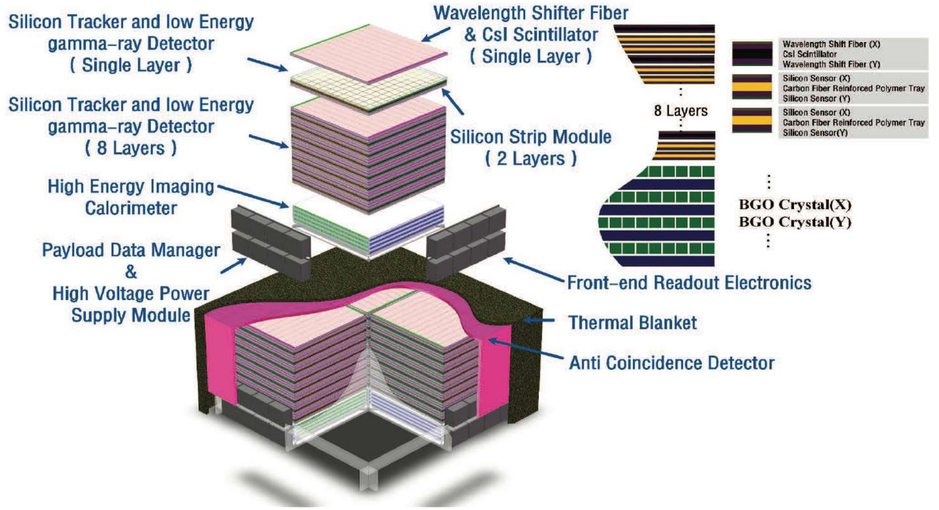
Each crystal is readout by two wavelength shifting fibers on both ends. The four fiber ends, acting as a low range fiber, a high range fiber and two trigger fibers, are routed to a low range intensified sCMOS (IsCMOS) camera, a high range IsCMOS camera, and two trigger systems, respectively.

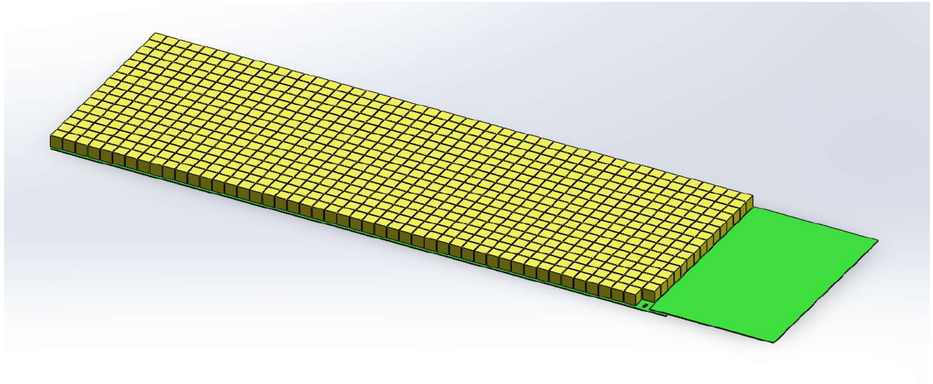


# Very Large Space Telescope (VLAST)



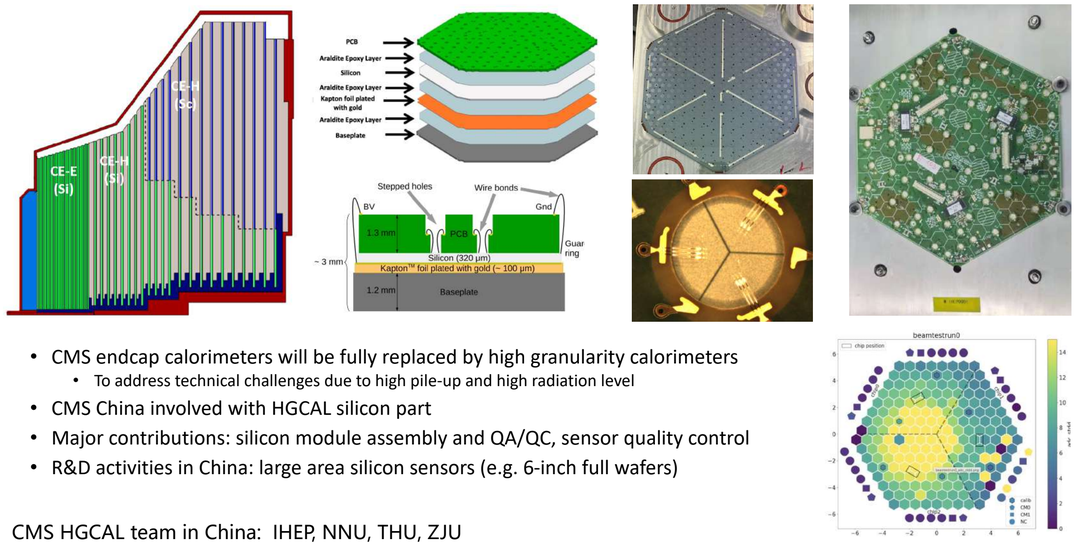
- The Very Large Area Gamma Ray Space Telescope (VLAST) is the new generation of high-energy gamma ray astronomical observations
  - Dark matter indirectly
  - Time-domain Astronomy
  - Study the generation, propagation, and interaction processes of cosmic rays;
- The area of Calorimeter is about 10 $m^2$
- A high-granularity crystal calorimeter was proposed by USTC for VLAST



# Chinese contributions to projects outside China

## CMS High-Granularity Calorimeter Upgrade (HGCAL)




- CMS endcap calorimeters will be fully replaced by high granularity calorimeters
  - To address technical challenges due to high pile-up and high radiation level
- CMS China involved with HGCAL silicon part
- Major contributions: silicon module assembly and QA/QC, sensor quality control
- R&D activities in China: large area silicon sensors (e.g. 6-inch full wafers)

CMS HGCAL team in China: IHEP, NNU, THU, ZJU

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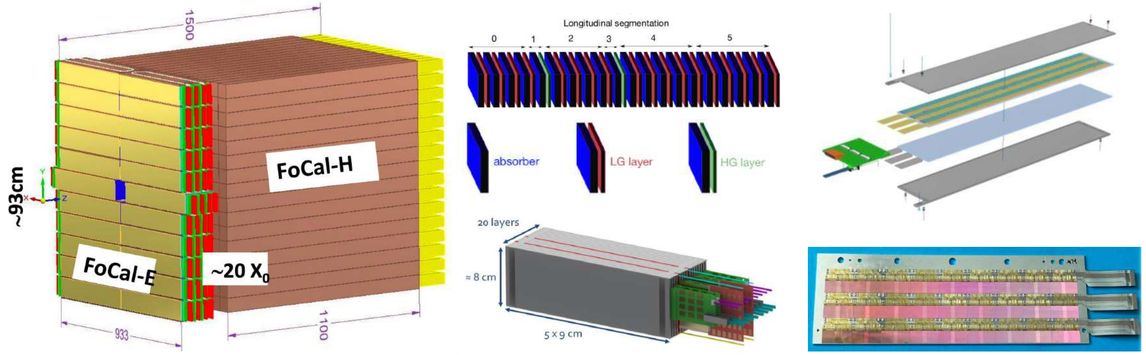
## ALICE Forward Calorimeter (FoCal)




- ALICE FoCal: a new calorimeter 7m from IP, pseudo-rapidity 3.4 – 5.8
- ALICE China involved with FoCAL silicon pixel sensors (ALPIDE), readout electronics and module integration
  - "Digital ECAL" technology with extreme high granularity
  - Great separation power in photons and neutral pions in forward regions

ALICE FoCal team in China: CCNU, CIAE

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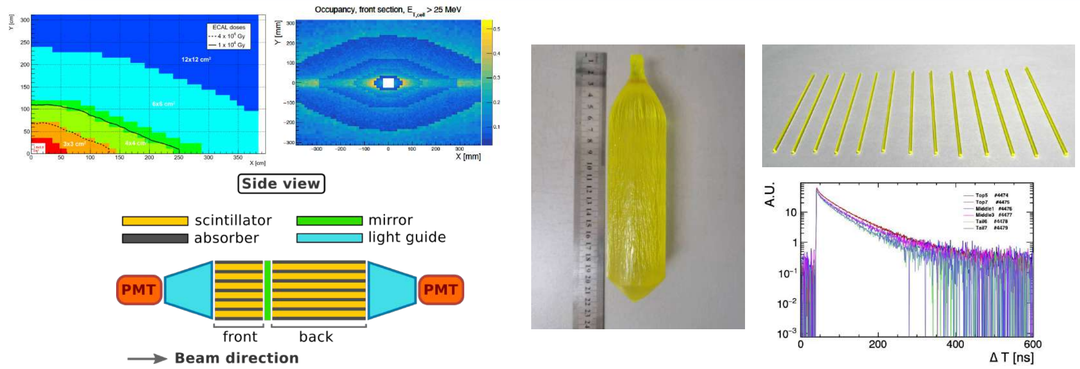
## LHCb Calorimeter Upgrade (SpaCal)









- LHCb ECAL Upgrade-2 R&D: to address high radiation and high pile-up
  - New technologies: radiation hardness, o(10) ps timing resolution, finer transverse granularity, longitudinal segmentation
- LHCb ECAL teams in China: involved with SpaCal R&D activities
  - Characterisations of crystal fibers (e.g. GAGG) on light output and timing performance, ECAL simulation and design optimisations, prototyping and beamtests

LHCb SpaCal team in China: PKU, SCNU, WHU

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# Korea

# Calorimeter R&D in Korea

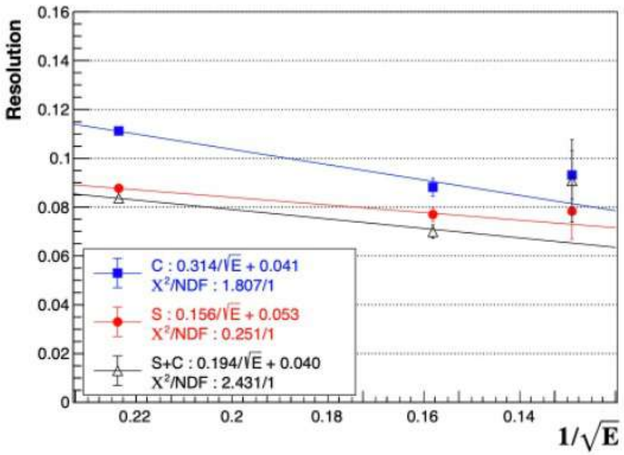
- Significant Korean contributions to calorimeter R&D
  - Dual-Readout Calorimeter R&D for FCC-ee and CEPC
  - Barrel Imaging Calorimeter (BIC) for Electron-Ion Collider (US)

# Dual-Readout Calorimeter R&D for FCC-ee and CEPC



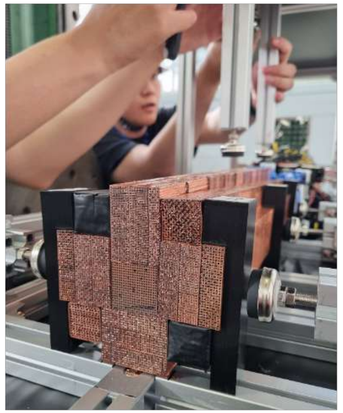
## •Test beam 2022 at CERN (SPS-H8)

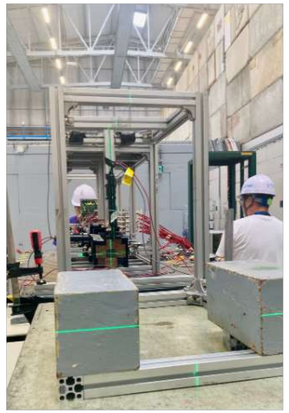
- Two full-size (2.5 m length) modules are newly built by Korean group
  - R&D applications: various optical fibers, high granularity by SiPM, new DAQ system for fast time resolution, etc.
- Test-beam experiment at CERN (August) with 13 institutions, 34 participants (including 23 students)

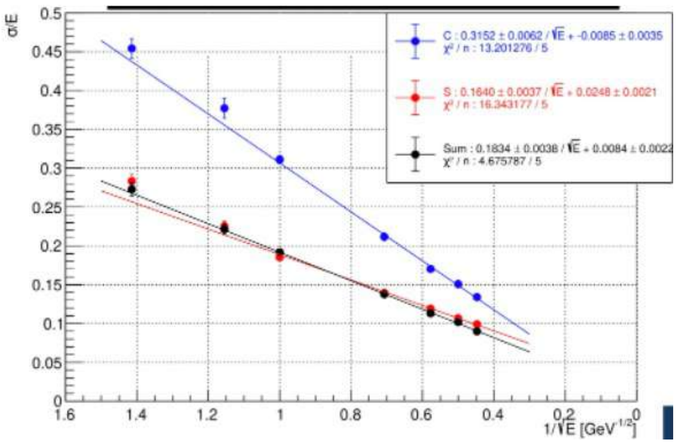




## •Test beam 2023 at CERN (PS-T9)

- Built small prototype calorimeter modules
  - 50 cm long, 30 kg for low energy test
  - A lot of improvements for the experimental setup compared to 2022 test-beam
  - R&D applications: high granularity readout (MCP-PMT), three different Cu forming (lego-like, 3D printing, Skiving fin heatsink)
- Test-beam experiment at CERN (July) with 6 institutions, 20 participants (including 15 students)







# Dual-Readout Calorimeter R&D for FCC-ee and CEPC

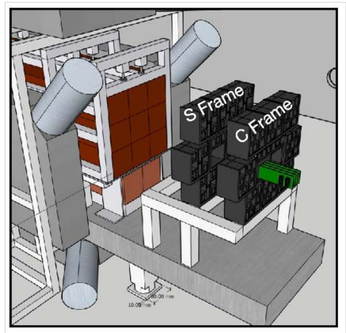


- Preparation for testbam 2024 at CERN (SPS-H8)
  - Bigger protype detector to measure the hadronic energy resolution
    - 3x3 modules (totally 9 modules) based on skiving fin heatsink Cu forming
    - 30cm×30cmx250cm
  - Detector assembly almost done



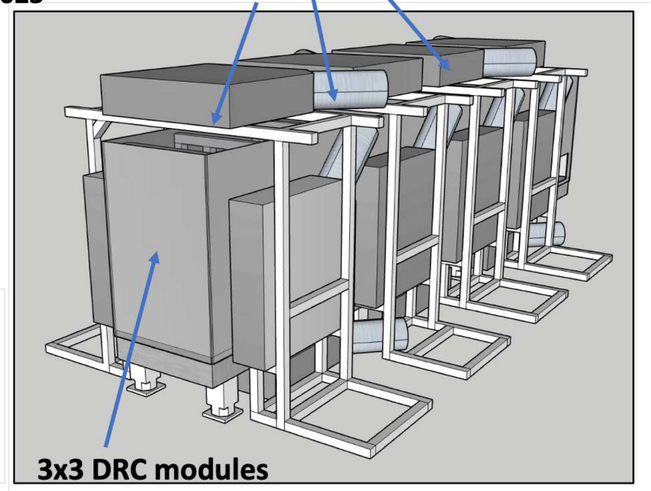
Front view

- Readout frame and mechanical supporter design under discussion




**Same DAQ systems used for TB 2022 and 2023**

**Similar experimental setup as TB 2022**

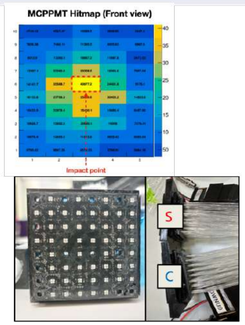



# Dual-Readout Calorimeter R&D for FCC-ee and CEPC

## •High Granularity Readout R&D

• Test two options for high granularity readout: SiPM vs. MCP-PMT

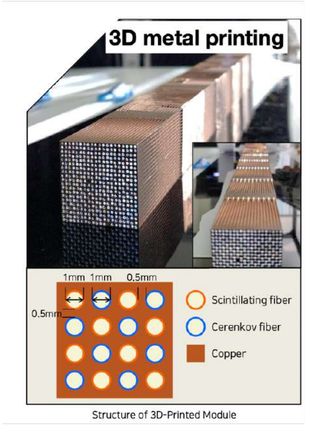
| | 2022 module | | 2023 module | | 2024 module | |
|---|---|---|---|---|---|---|
| | Scintillation | Cerenkov | Scintillation | Cerenkov | Scintillation | Cerenkov |
| channels | 200 | 200 | 50 | 50 | 64 | 64 |
| Type | SiPM | | MCP-PMT | | MCP-PMT | |
| Grouping | 1 fiber per SiPM | | 4 fibers per cell of MCP-PMT | | 4 fibers per cell of MCP-PMT | |

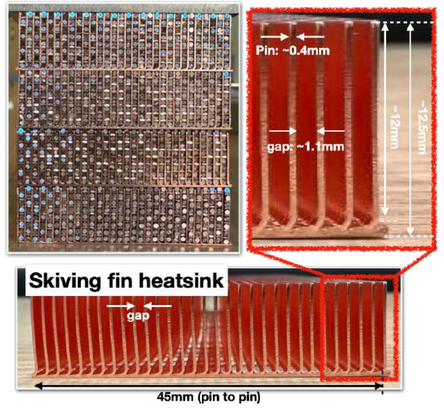





## •Copper Forming R&D

• Test various Cu forming for engineering solution of mass production
  • With experts from local industry and mechanical engineering

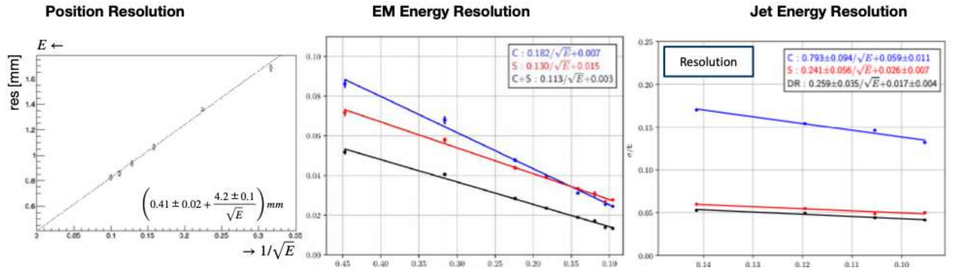


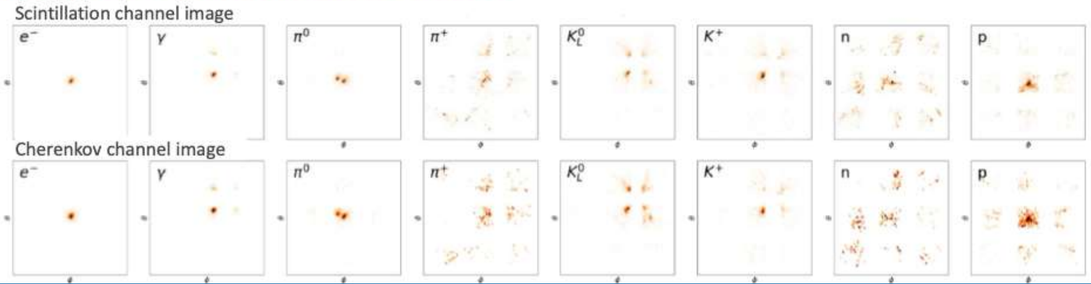


## •Simulation studies

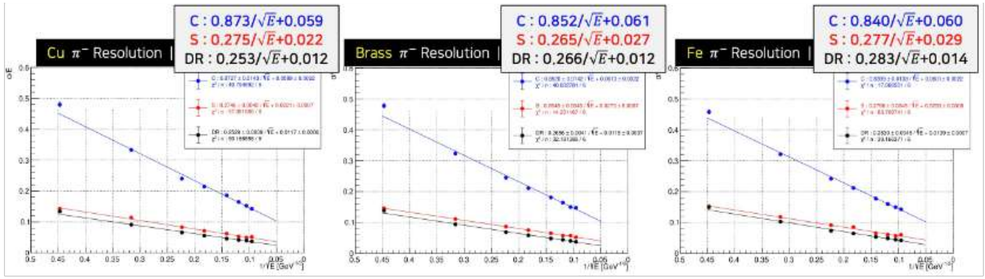
### Energy & position resolution




### Particle ID with Machine Learning

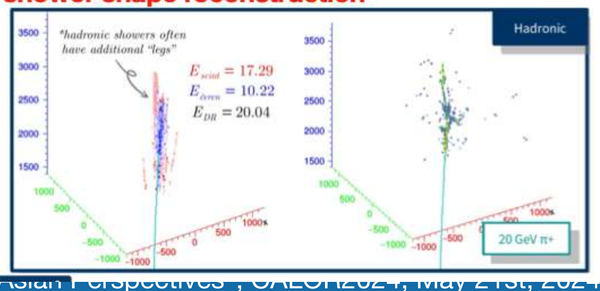



### Comparison of Absorber types




Pion energy resolution

### 3D shower shape reconstruction



# Barrel Imaging Calorimeter for Electron-Ion Collider (US)



- Korean BIC group aims to be responsible for 50% of the barrel ECAL construction and relevant R&D

## Korean institutions for the BIC

**USA**
- Argonne National Laboratory
- NASA Goddard Space Flight Center
- Oklahome State University
- University of Connecticut
- University of California Santa Cruz

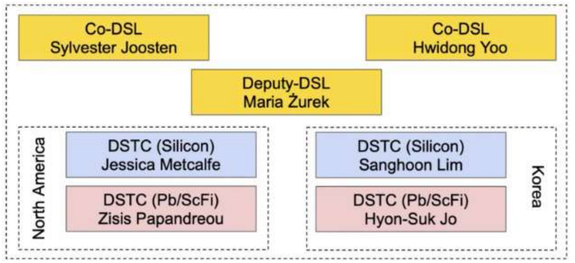
**Canada**
- University of Manitoba
- University of Regina
- Mount Allison University
- NSERC
- Canada Fund for Innovation

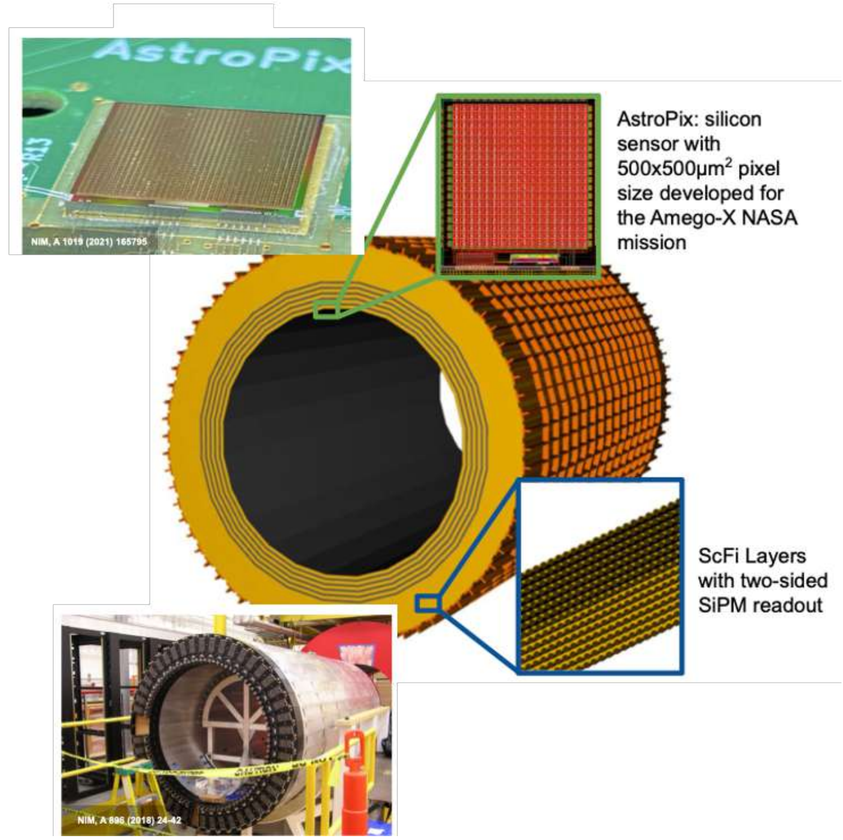
**Korea**
- Kyungpook National University
- Yonsei University
- University of Seoul
- Pusan National University
- Korea University
- Sungkyunkwan University
- Hanyang University
- Gangneung-Wonju National University

**Germany**
- Karlsruhe Institute of Technology
- University of Giessen

**ePIC BIC Detector Subsystem Collaboration**

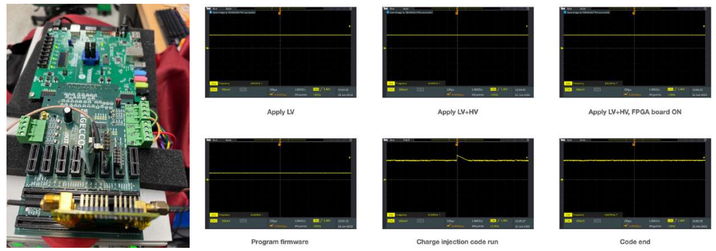
### Managements in bECAL



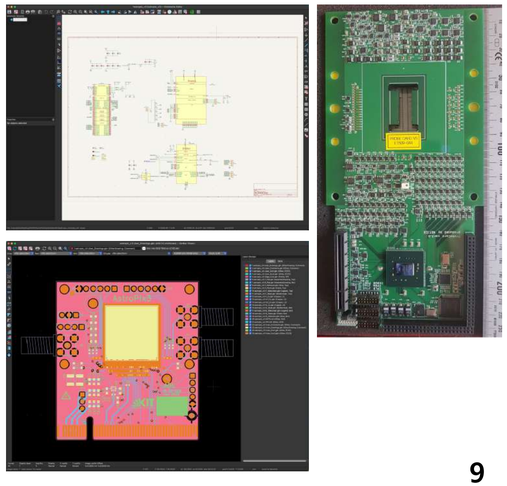



# Barrel Imaging Calorimeter for Electron-Ion Collider (US)

- Silicon Layer Test & Assembly
  - Testbench with AstroPix v2

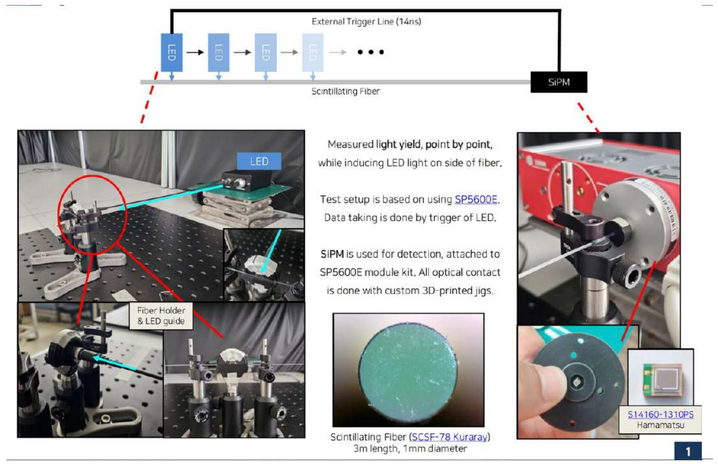


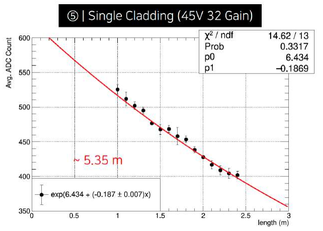

  - Testbeam with ALPIDE telescope
  - Simulation development for TDR
  - Chip test machine

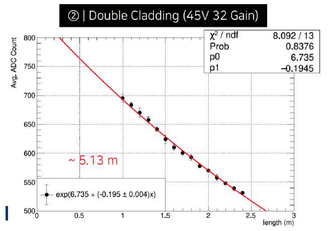


- Pb/SciFi Layer R&D

Fiber attenuation measurement



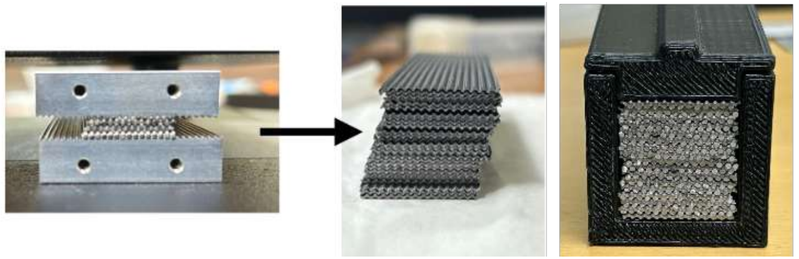



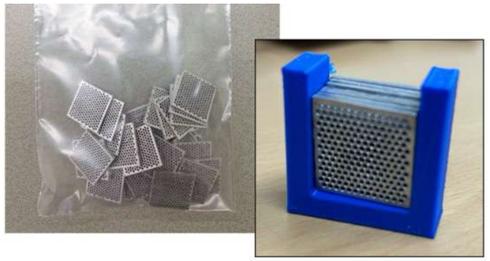




| | SC | DC |
|---|---|---|
| Avg. | 5.19 m | 4.87 m |
| Stdev. | 0.45 m (~9%) | 0.18 m (~4%) |

Measured Attenuation length

Pb layer prototype test and R&D





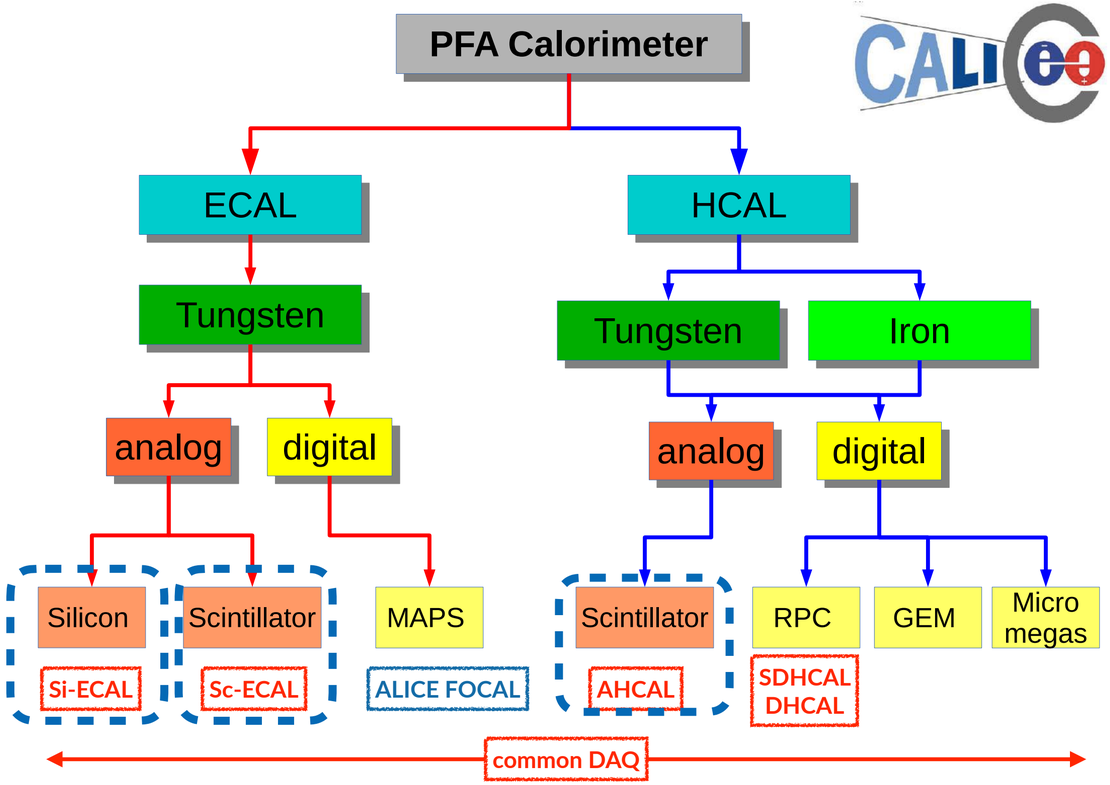
# Japan

# Calorimeter R&D in Japan

- HEP
  - High-granularity calorimeters for future Higgs factories (ScW-ECAL, SiW-ECAL, AHCAL)
  - Flavor experiments (Belle II, KOTO, COMET, MEG II)
  - R&D for calorimeter with new technologies
- NP
  - ALICE FoCal
  - ePIC ZDC at EIC

# Calorimeter R&D for Higgs Factories

## High-granularity calorimeter for particle flow

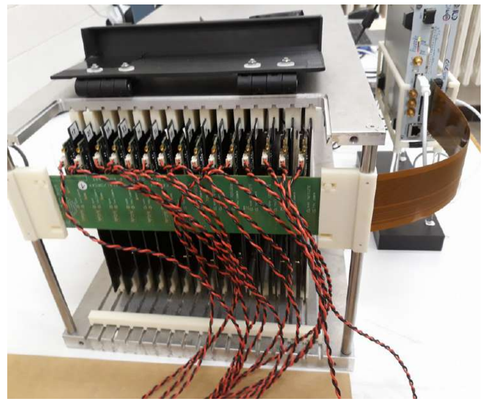



Japanese contributions

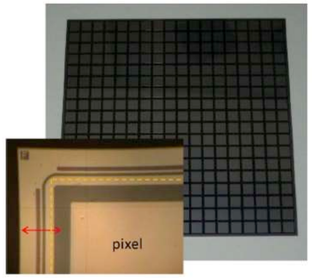
Tokyo, KEK, Shinshu

## SiW-ECAL prototype

- **Si-sensor** (cell size 5×5mm² )
- **Analogue readout**
- Tungsten absorber
- 15 layers



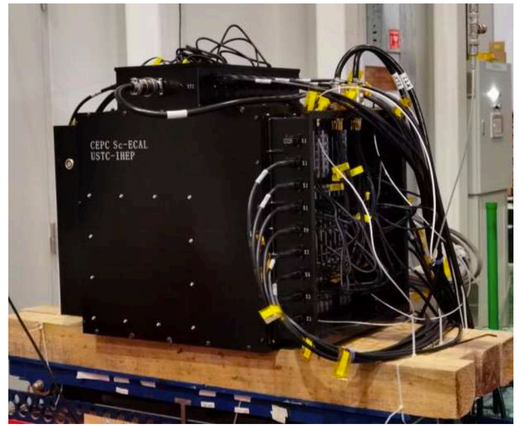
Si-sensor



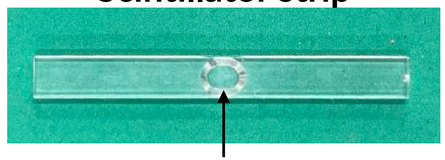

## ScW-ECAL prototype

- **Scintillator strips**

  $(45 \times 5 \times 2\ \mathrm{mm}^3$ each))
- **Analogue readout**
- Tungsten absorber
- 32 layers (24$X_0$, 1λ)




Scintillator strip



SiPM in dimple

CALICE ➡ DRD-Calo

Talk by T. Murata

# Flavor Experiments

## MEG II ($\mu \rightarrow e\gamma$)

Talk by K. Yamamoto

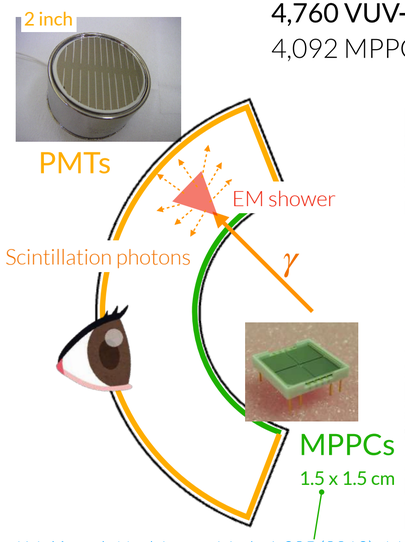
4

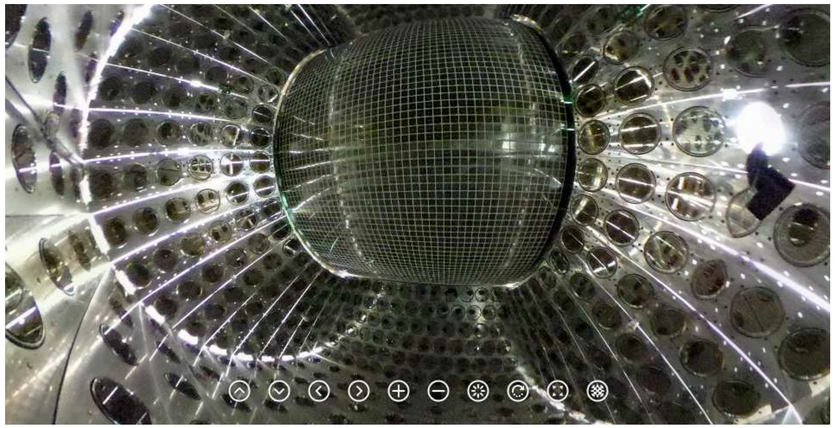
### Liquid xenon (LXe) calorimeter

4,760 VUV-sensitive photosensors
4,092 MPPCs + 668 PMTs

×

900 L liquid xenon
- High stopping power ($X_0$ = 2.8 cm)
- High light yield (46,000 photons/MeV)
- Fast response (45 ns decay time)



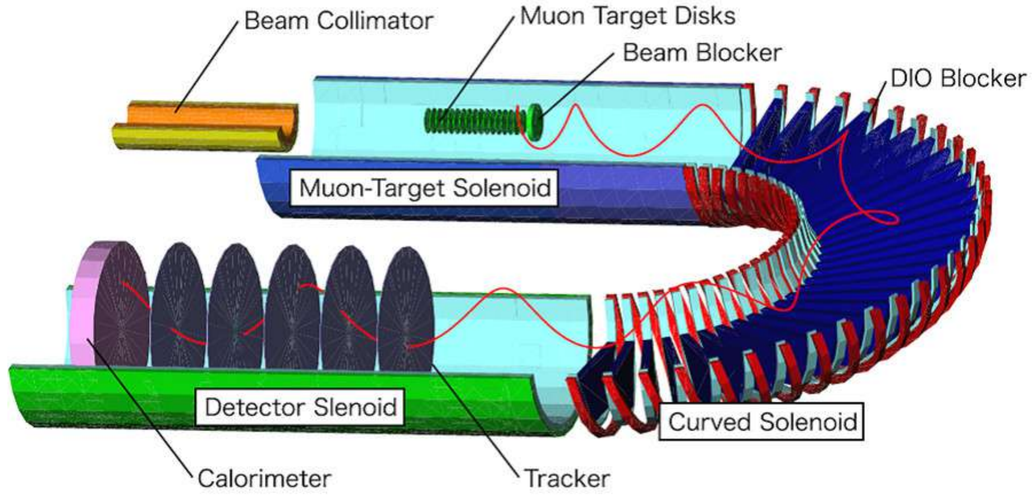
K. Ieki, et al., Nucl. Instru. Meth. A 925 (2019), 148-155



➡ MEG III?

## COMET ($\mu N \rightarrow eN$)

### StrECal



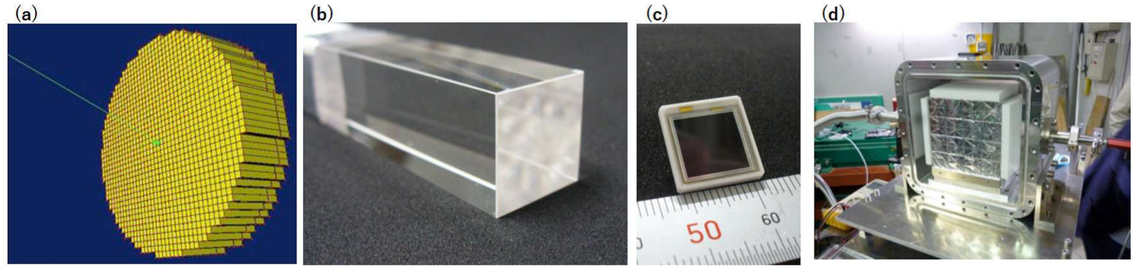



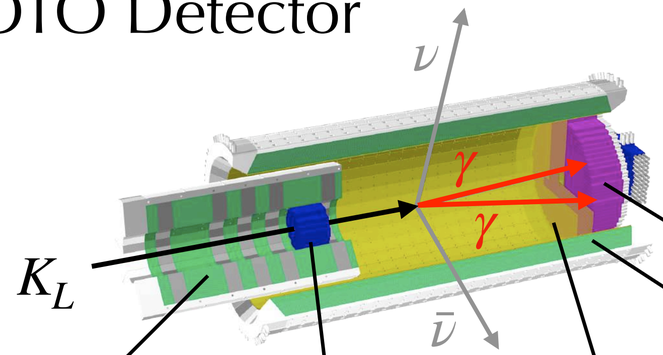

**Fig. 6.** (a) Schematic view of the electromagnetic calorimeter (ECal), (b) photograph of 2 cm × 2 cm LYSO crystal, (c) photograph of the APD, and (d) photograph of the prototype with 7×7 crystals of LYSO.

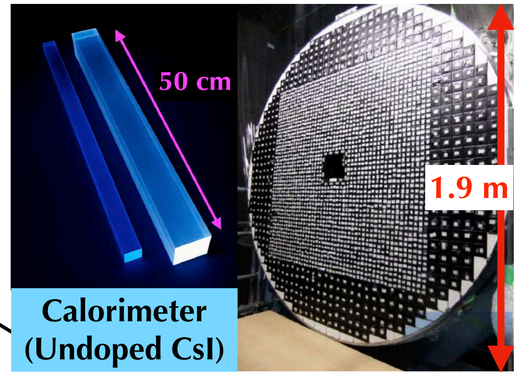
Phase I ➡ Phase II

# Flavor Experiments

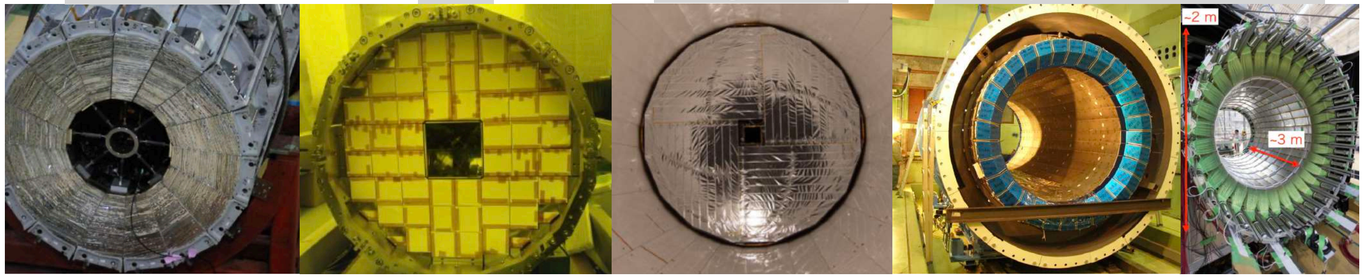
## KOTO ($K_L^0 \to \pi^0 \nu\bar{\nu}$)

KOTO Detector



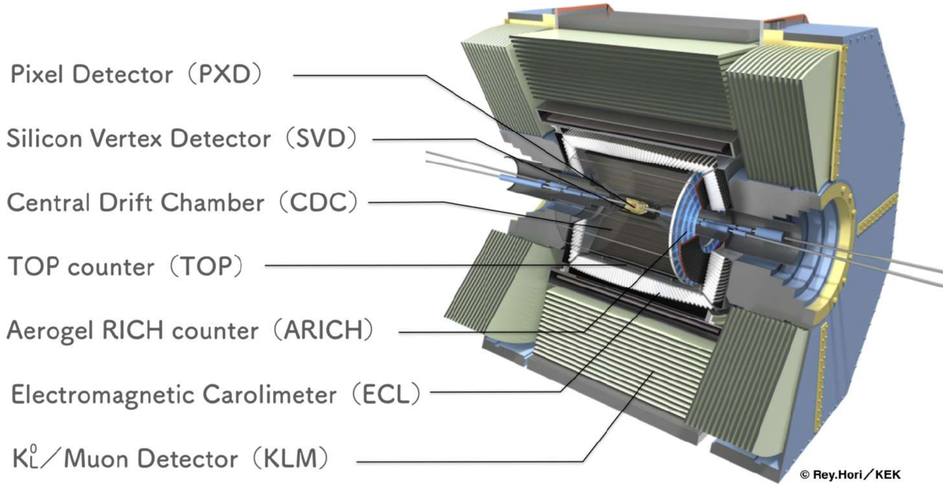



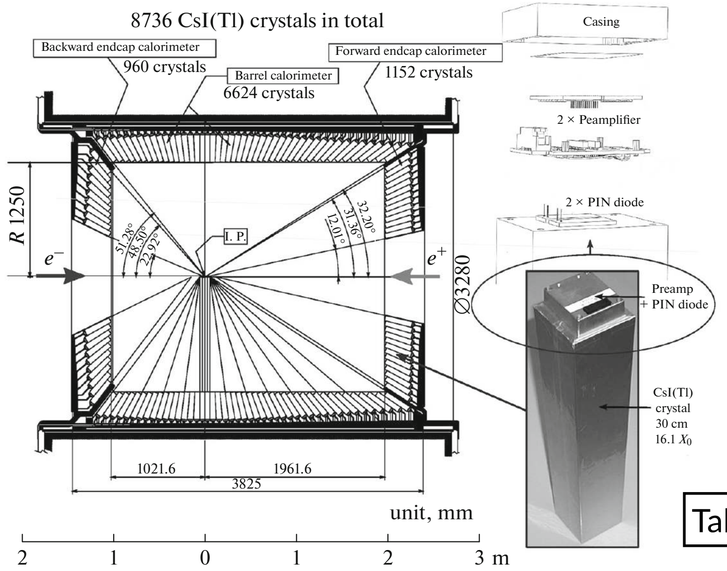

Front Barrel | NCC | Charged Veto | Main Barrel / Inner Barrel (Lead/plastic sci. sandwich)




→ **KOTO II**

## Belle II




Talk by K. Miyabayashi

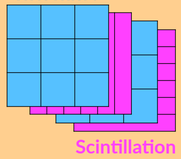
# Calorimeter with New Technologies

## High-granularity dual-readout calorimeter with psec timing

UTokyo

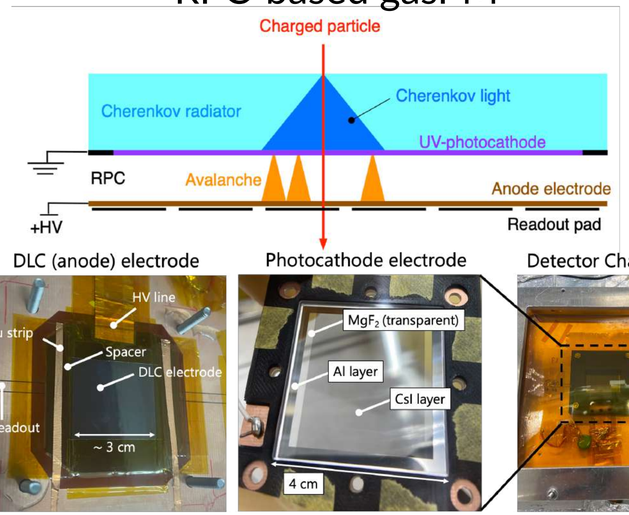
**Dual-readout**

**Cherenkov detector**
Cherenkov radiator + UV-GasPM
- High-granularity readout
- psec timing
- Low-cost

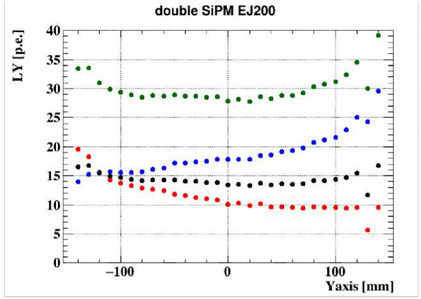



**Scintillation detector**
SiPM-on-strip technology
- High-granularity
- low-cost

### Cherenkov detector with RPC-based gasPM

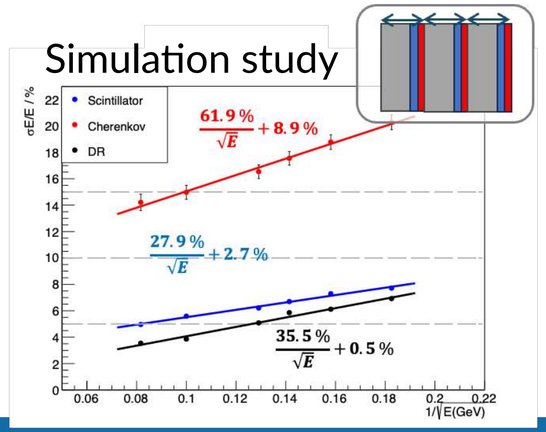



### Scintillator strip detector




Enough light yield near SiPM
Good uniformity apart from dimple

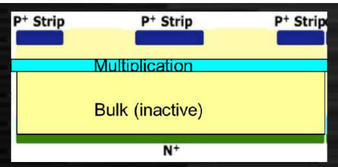
### Simulation study




Talks by T. Kamiyama
Posters by W. Li, H. Ogawa

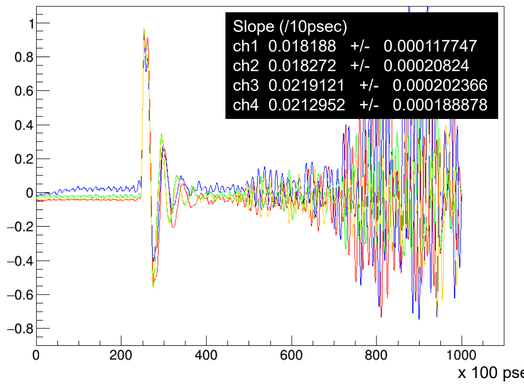
## LGAD for Calorimeter

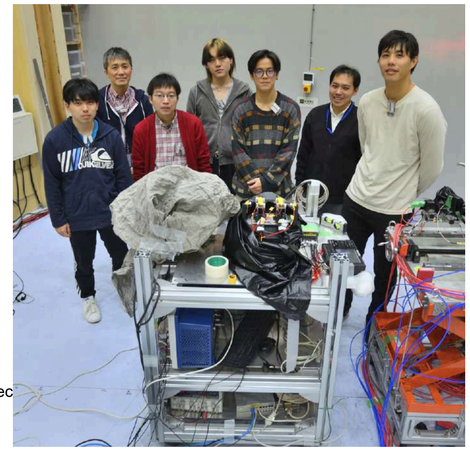
UTokyo



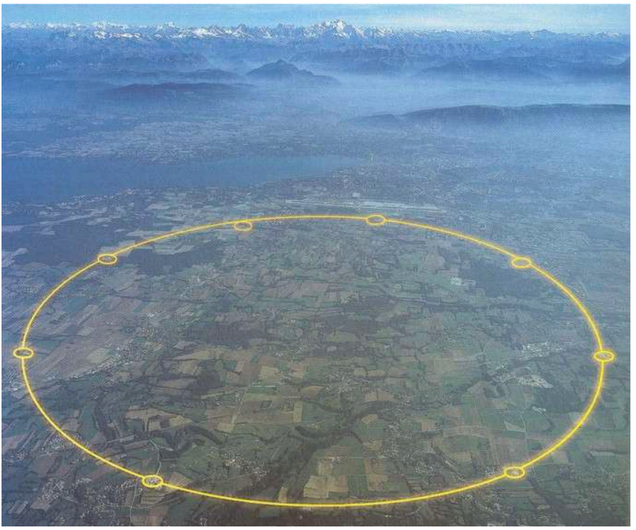

Inverse LGAD (single sided)
- The same structure as reverse APD
- Current structure has 5-10 μm active thickness (confirmed with ion injection)
  → too thin (limited by the production process)
- Intrinsically low Landau Fluctuation
- Relatively flat multiplication expected (tbc)
- Lower cross talk than AC-LGAD expected (tbc)

### Beam test at KEK ARTBL



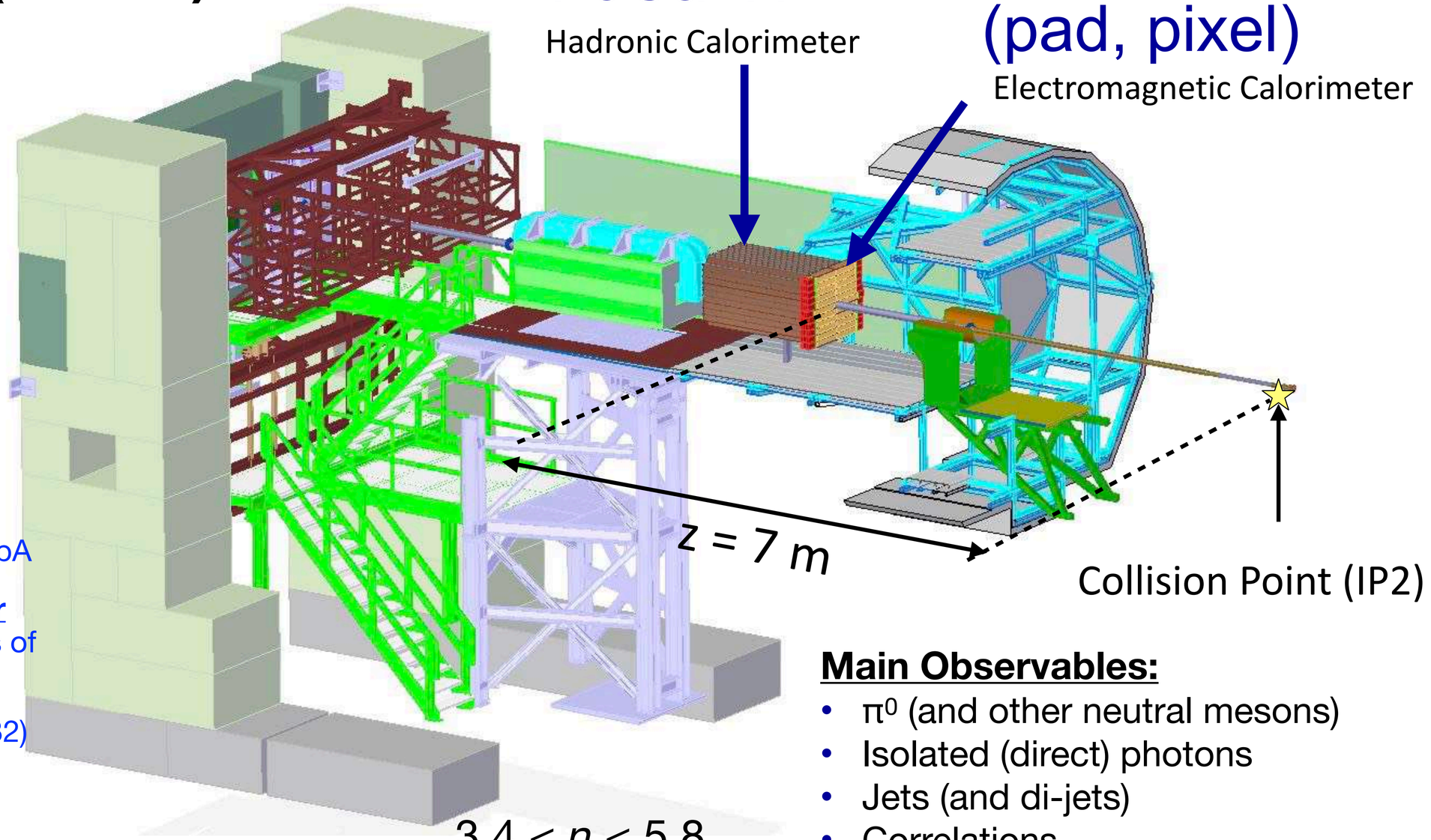
# Forward LHC (FoCal)



- **Fo**rward **Cal**orimeter
- LHC ALICE, $\sqrt{s_{NN}}$ = 8.8 TeV, pp, pA
- Non-linear QCD evolution, **Color glass condensate**, initial stages of Quark Gluon Plasma (QGP)
- Physics in LHC Run 4 (2029-2032)
- **TDR approved by LHCC on March 2024**

FoCal (LoI) : CERN-LHCC-2020-009

* T. Chujo (FoCal co-project leader, E-pad rep.)




$3.4 < \eta < 5.8$

$\eta = -\ln(\tan(\theta/2))$

**Main Observables:**

- $\pi^0$ (and other neutral mesons)
- Isolated (direct) photons
- Jets (and di-jets)
- Correlations
- J/Ψ, UPC

Courtesy of T. Chujo

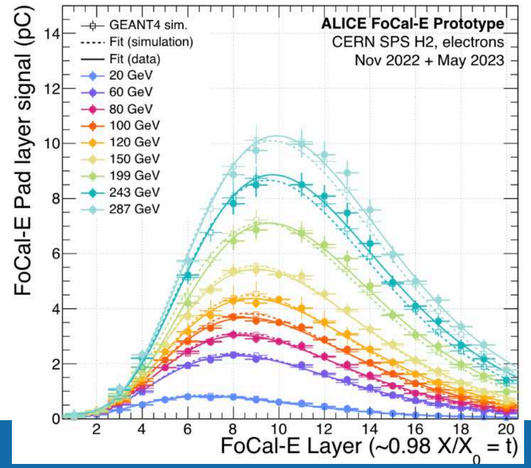
# ALICE FoCal Japan

**Responsibilities:**

**(1) FoCal-E pad, (2)readout and trigger**

- Univ. of Tsukuba
- Tsukuba Univ. of Tech
- RIKEN
- Hiroshima Univ.
- Nara Women's Univ.
- Saga Univ.
- Nagasaki Inst. of App. Sciences
- Kumamoto Univ.

**8 institute, 25 members**

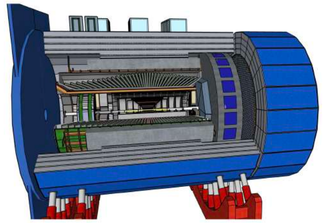



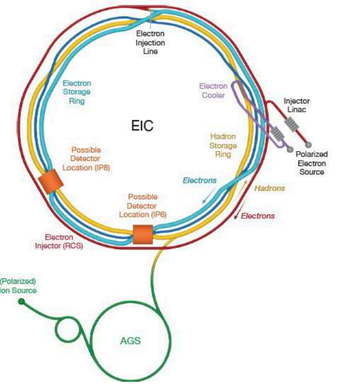

Longitudinal shower profiles

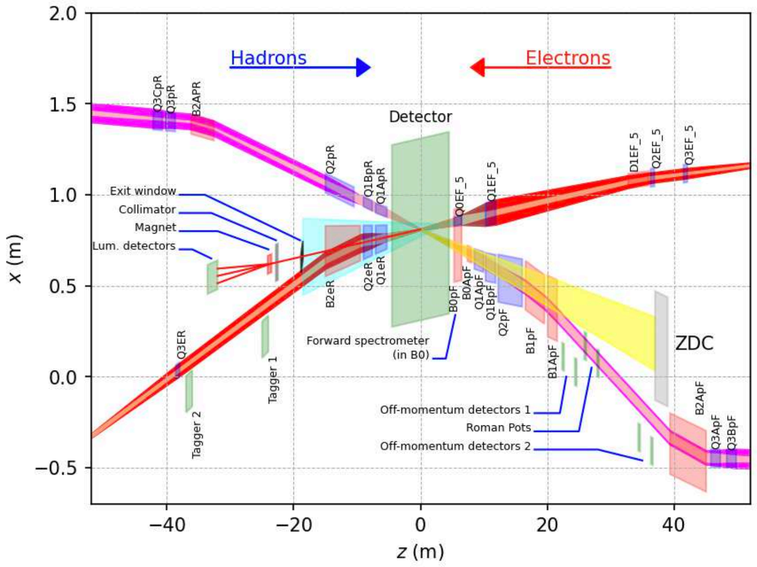
arXiv:2311.07413

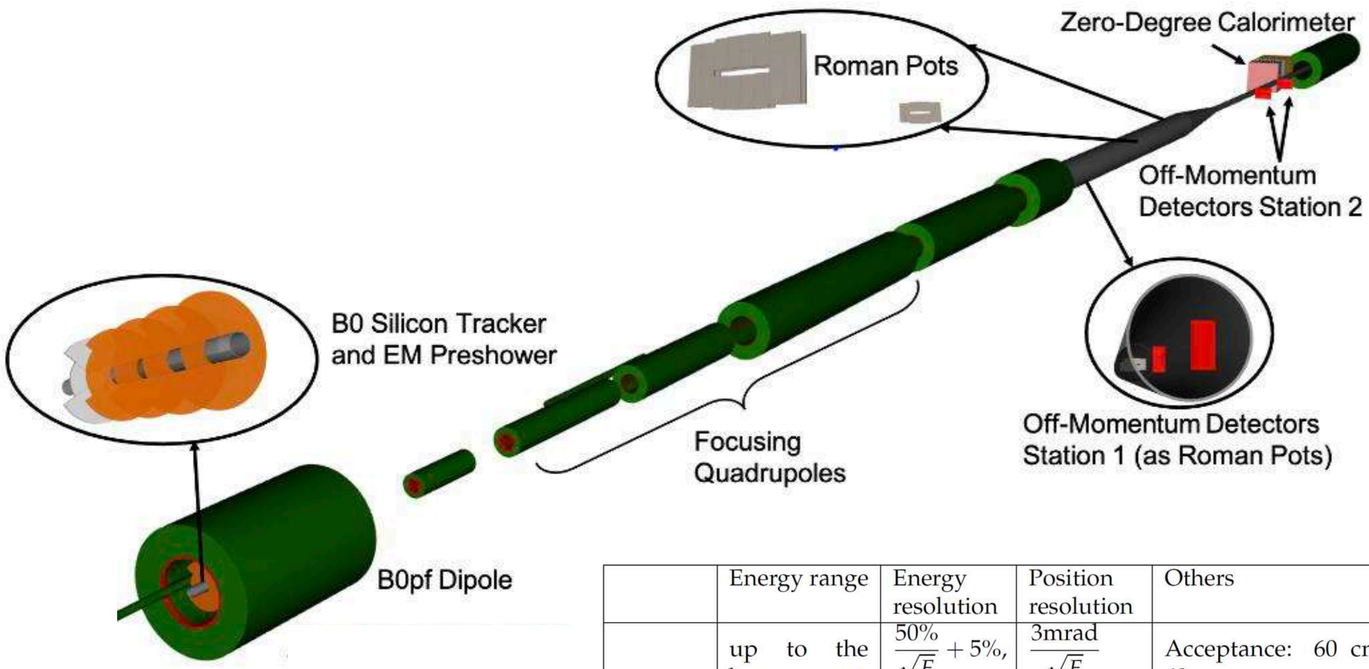
Courtesy of T. Chujo

# ePIC ZDC at EIC





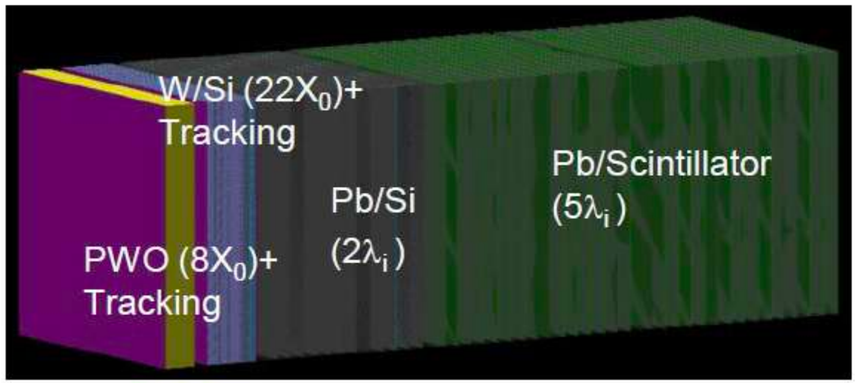

ZDC at around z = +35 m

Aperture: ~ 4 mrad

Available space: 60 x 60 x 200 cm

ePIC-ZDC collaboration in Japan

- RIKEN, Tsukuba, Tsukuba Tech, Shinshu, Kobe
- First test beam with Taiwan group at ELPH, Tohoku Univ. on March 2024.



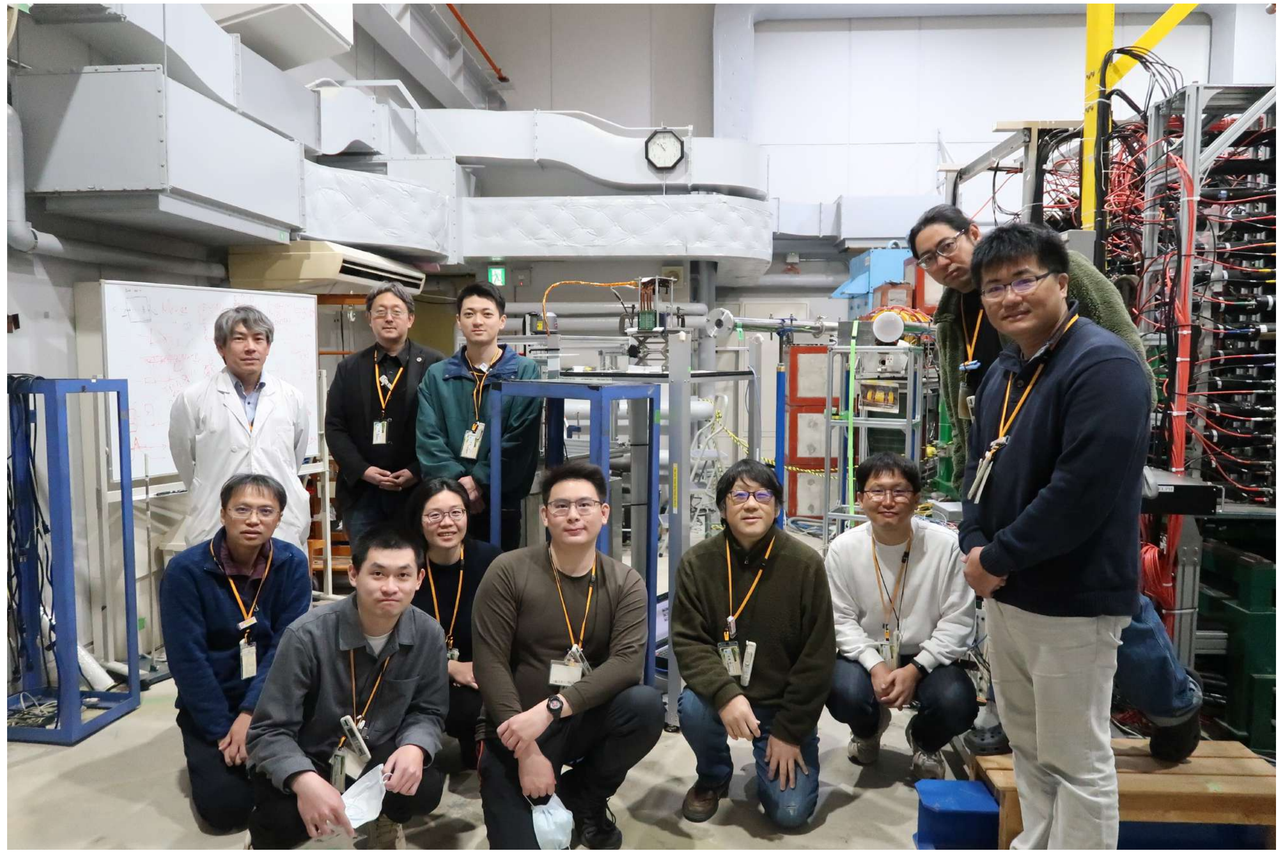

Courtesy of T. Chujo

| | Energy range | Energy resolution | Position resolution | Others |
|---|---|---|---|---|
| Neutron | up to the beam energy | $\frac{50\%}{\sqrt{E}} + 5\%$, ideally $\frac{35\%}{\sqrt{E}} + 2\%$ | $\frac{3\text{mrad}}{\sqrt{E}}$ | Acceptance: 60 cm × 60 cm |
| | | Note: The acceptance is required from meson structure measurement. Pion structure measurement may require a position resoultion of 1 mm. | | |
| Photon | $0.1 - 1$ GeV | $20 - 30\%$ | | Efficiency: $90 - 99\%$ |
| | | Note: Used as a veto in e+Pb exclusive J/$\psi$ production | | |
| | $20 - 40$ GeV | $\frac{35\%}{\sqrt{E}}$ | 0.5–1 mm | |
| | | Note: u-channel exclusive electromagnetic $\pi^0$ production has a milder requirement of $\frac{45\%}{\sqrt{E}} + 7\%$ and 2 cm, respectively. Events will have two photons, but a single-photon tagging is also useful. Kaon structure measurement requires to tag a neutron and 2 or 3 photons, as decay products of $\Lambda$ or $\Sigma$. | | |

**Table 2:** Physics requirement for ZDC

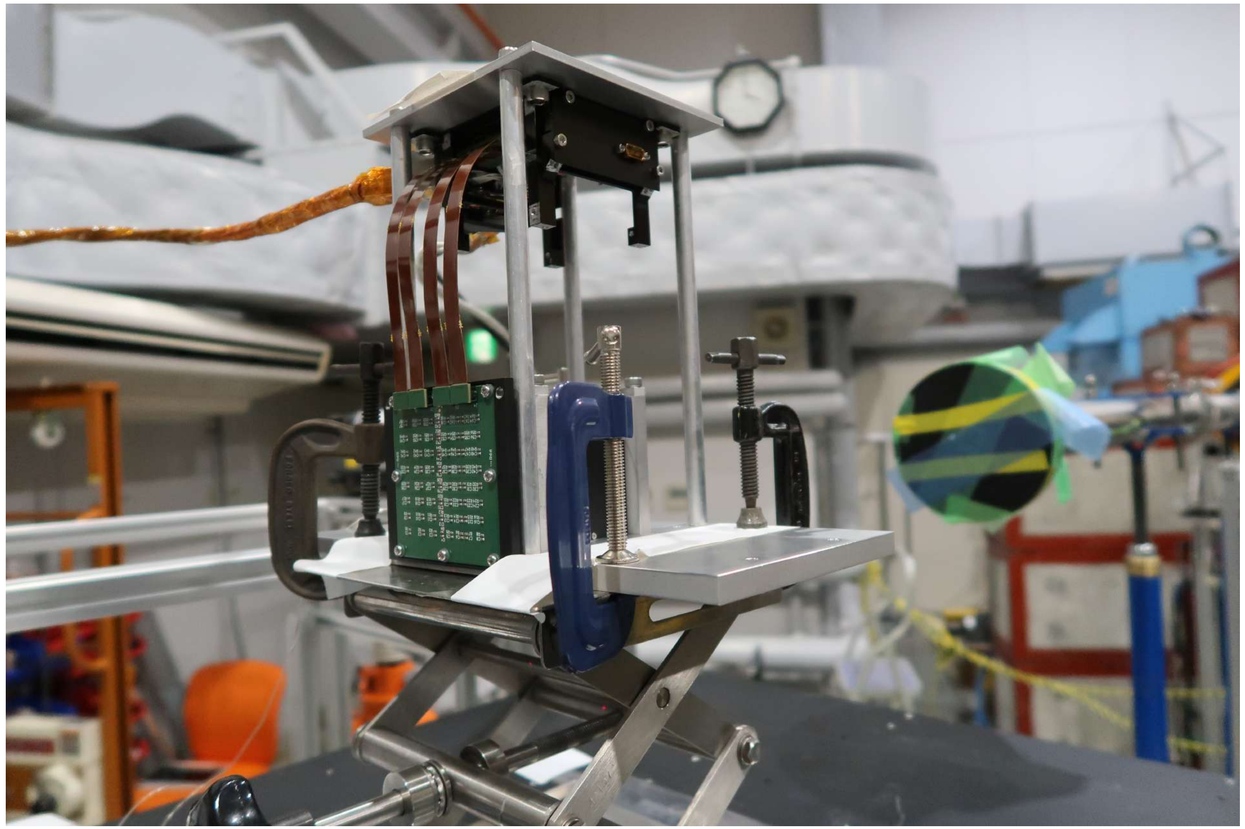
# ePIC ZDC prototype test @ ELPH (2024.03)



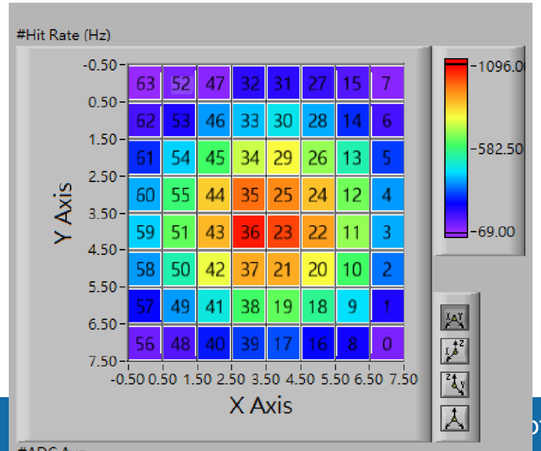


* Collaboration with Taiwan and Korea groups

Courtesy of T. Chujo



LYSO crystal with SiPM readout

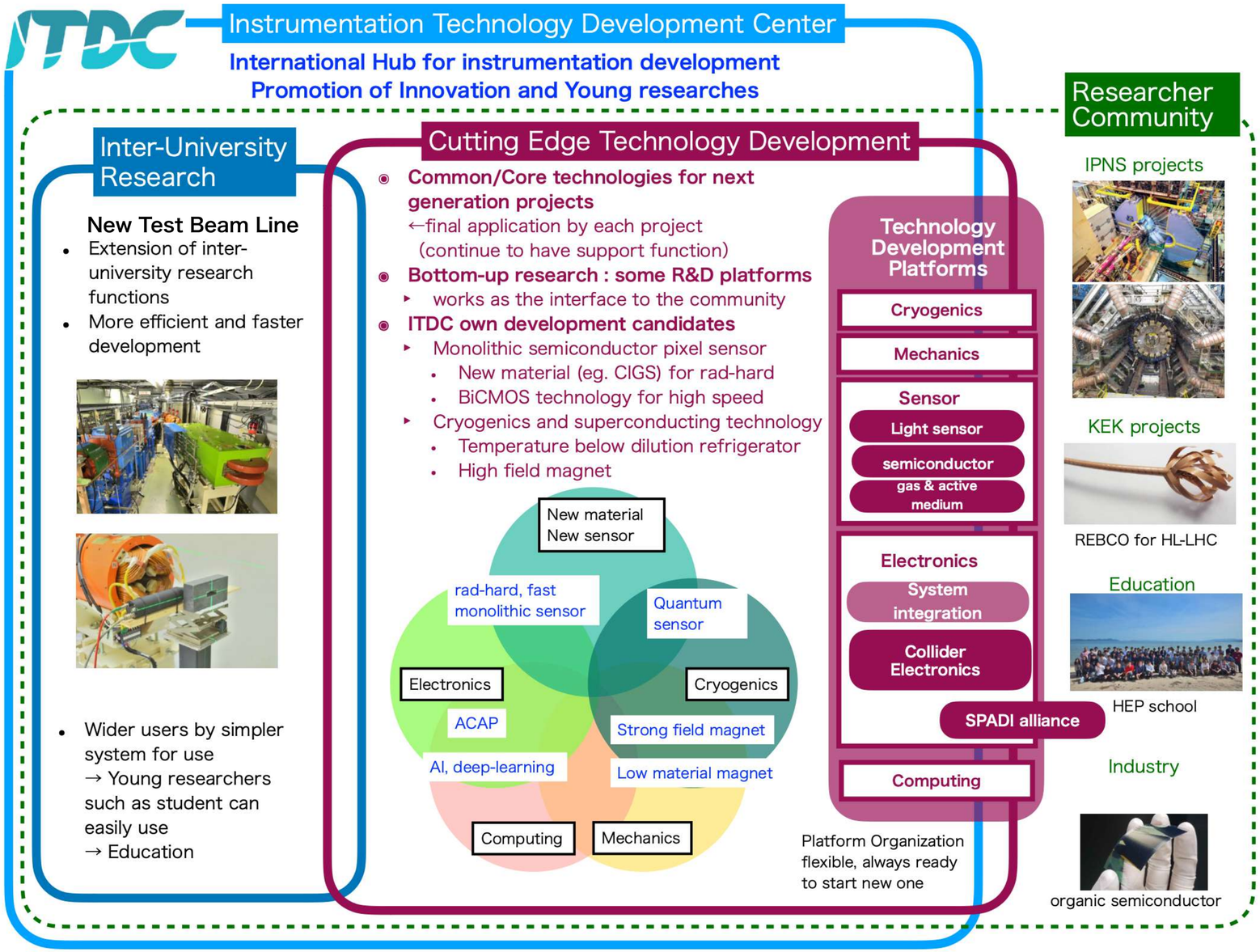



Hit map of LYSO crystal calorimeter from online monitoring

# New KEK initiative for detector R&D



- New detector R&D center (ITDC) has been established
- Technology development platforms (sensor, electronics, cryogenics, mechanics)

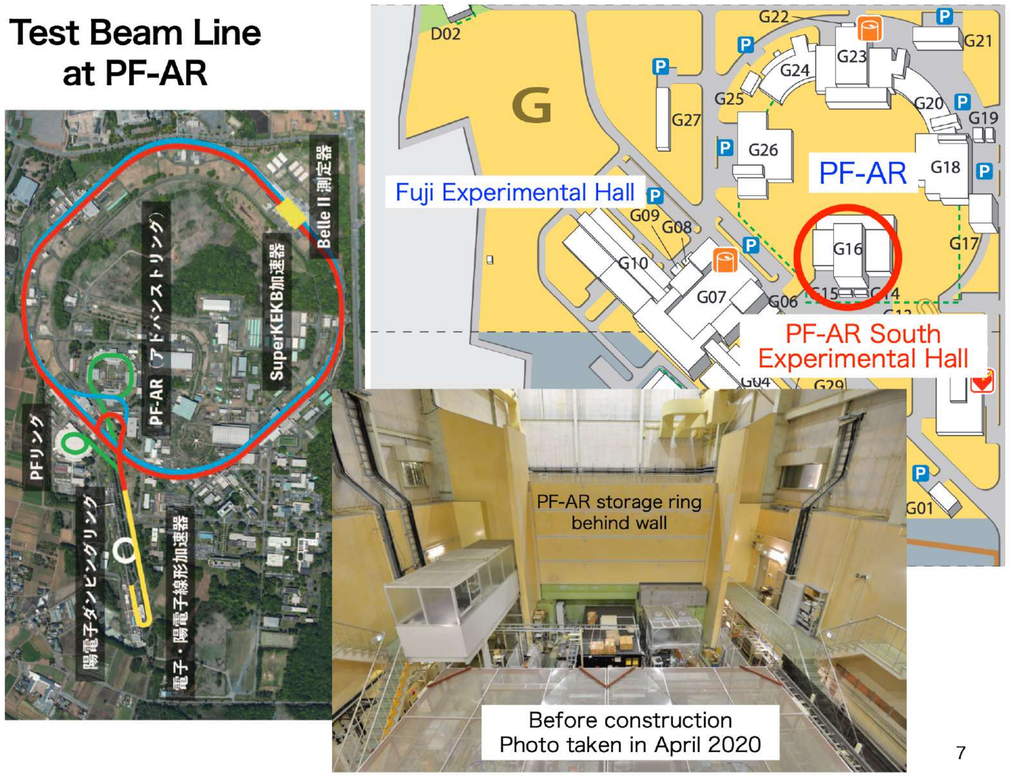



Courtesy of K. Hanagaki (KEK)

# New Test Beam Line

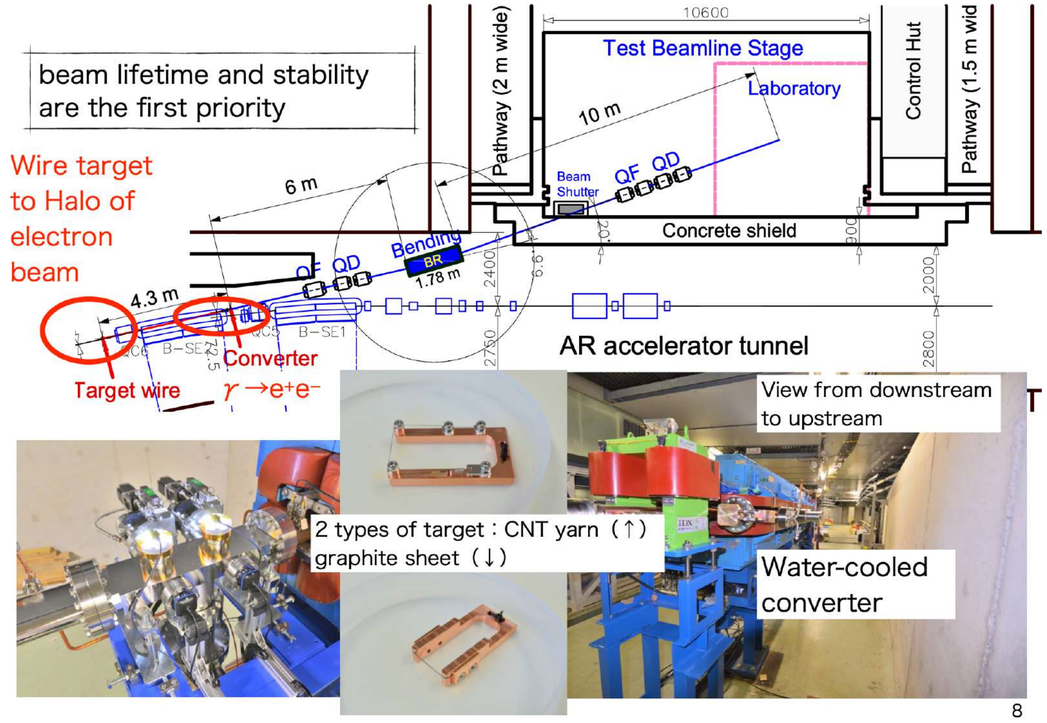
- Electron beam with its energy from roughly 1 to 5 GeV
  - Peak rate is O(kHz) at around 2 or 3 GeV
  - Higher rate will be possible after more experience of running

## Test Beam Line at PF-AR






## Overview of test beam line






Courtesy of K. Hanagaki (KEK)

# Summary

- No summary. Too heterogeneous to summarise.
- There are many calorimeter R&Ds in both on-shore and off-shore programs, including collaborative efforts in Asia, also with Europe and the US.