Sc-ECAL Status and Perspectives

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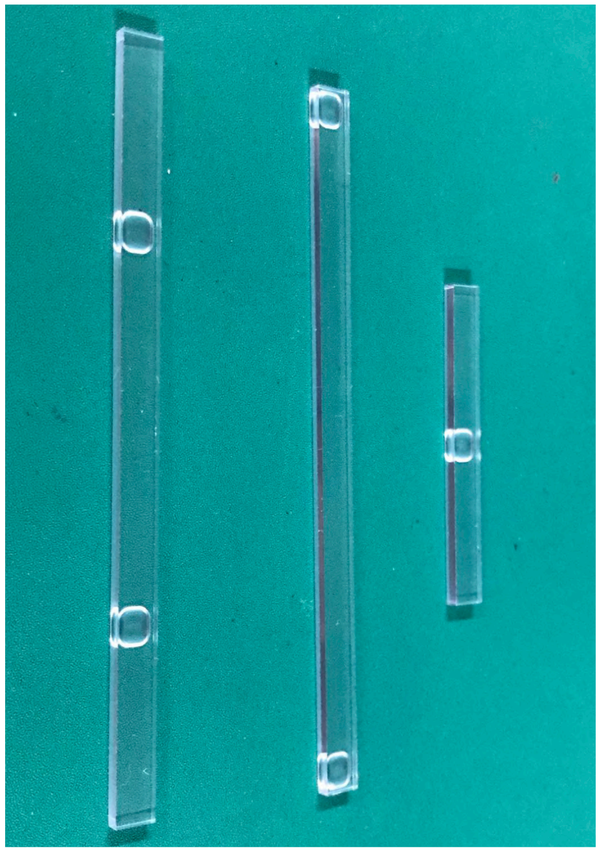
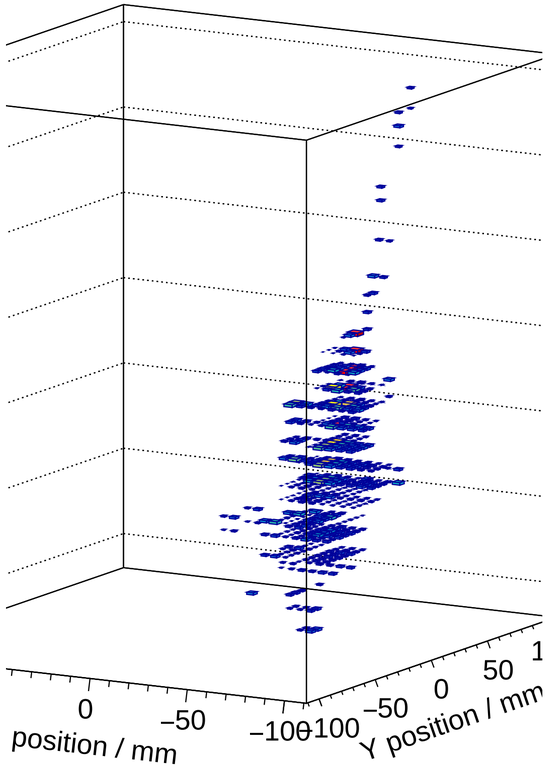
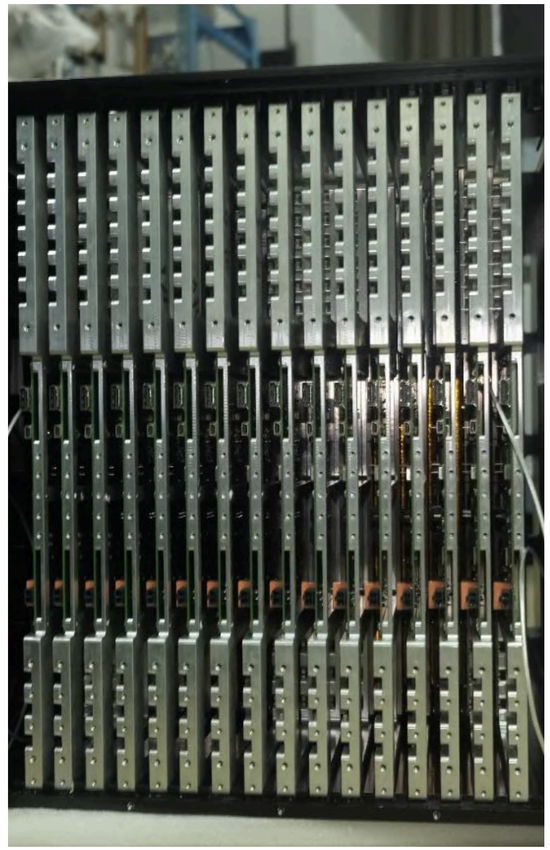
on behalf of Sc-ECAL group

ILC TC meeting, Mar. 24th, 2022







Sc-ECAL Group

ILD R&D group

SHINSHU UNIVERSITY

ICEPP The University of Tokyo

THE NIPPON DENTAL UNIVERSITY

University of Tsukuba

CEPC R&D group

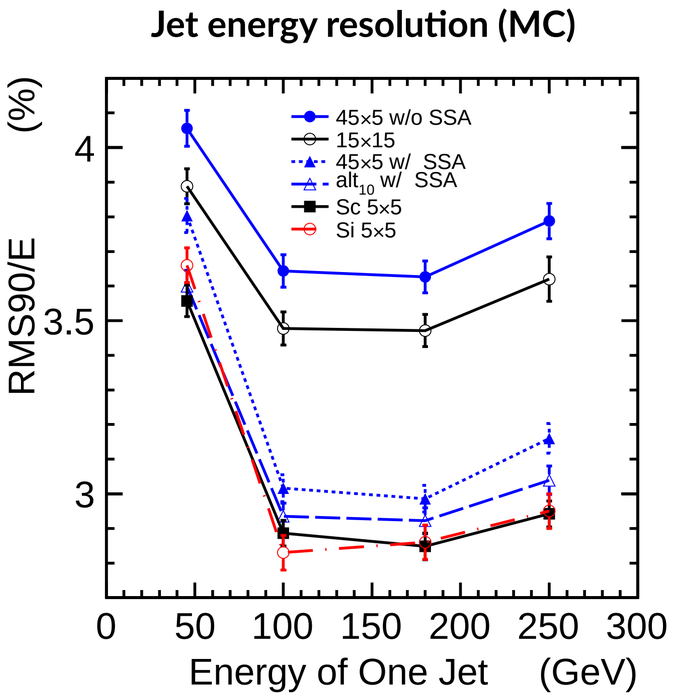
中国科学技术大学 University of Science and Technology of China

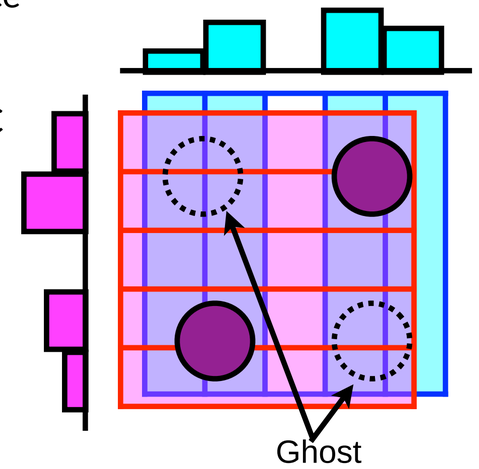
Institute of High Energy Physics
Chinese Academy of Sciences

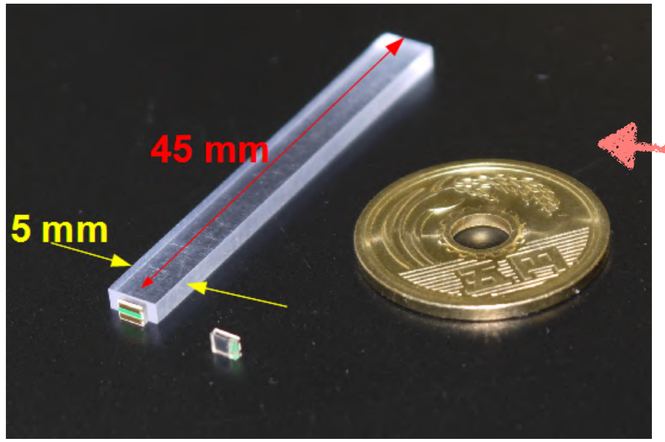
Sc-ECAL in a Nutshell

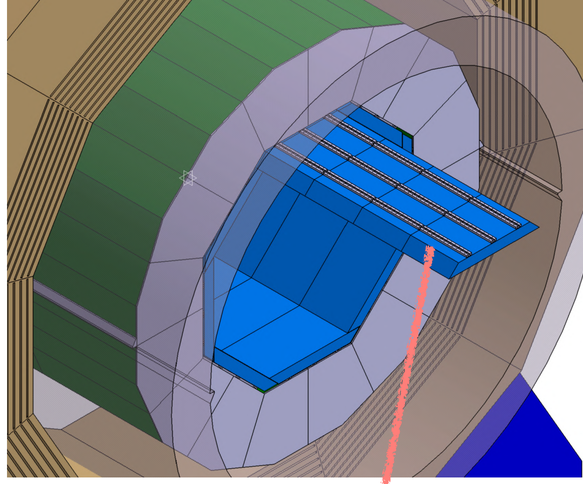
•Scintillator-Tungsten ECAL

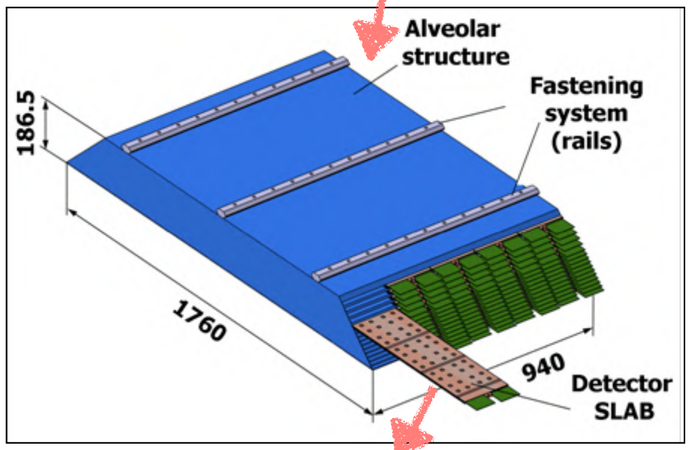
- Scintillator strip (45mm×5mm×^{t}2mm) readout by SiPM
- Virtual segmentation of 5×5mm^2 by strips aligned alternately in horizontal and vertical orientations
- Significant reduction of readout channels($10^8 \rightarrow 10^7$) retaining performance
  - Cost reduction
  - Power consumption reduction→ advantageous especially for CEPC

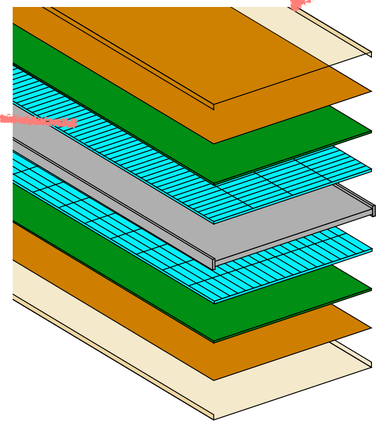










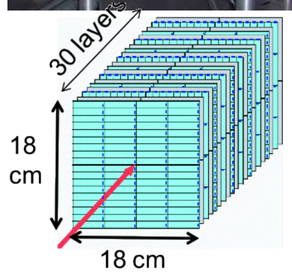


Brief History

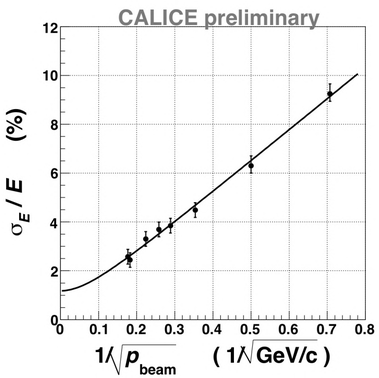
We are here

●Physics prototype

- Scintillator ($45 \times 10 \times 3\ \mathrm{mm}^3$) readout by WLS fibre+SiPM
- Demonstrated good performance (energy resolution and linearity) using 2-32GeV electron at Fermilab



2-32GeV electron @ Fermilab

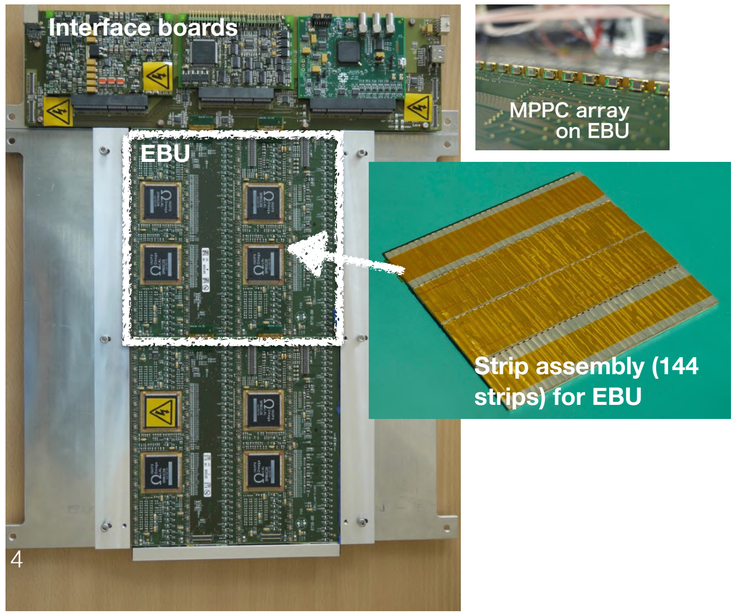


$$\frac{\sigma}{E} = \frac{(12.9 \pm 0.1 \pm 0.4)}{\sqrt{E}} \oplus (1.2 \pm 0.1^{+0.4}_{-1.2})\%$$

Non-linearity < ±2%

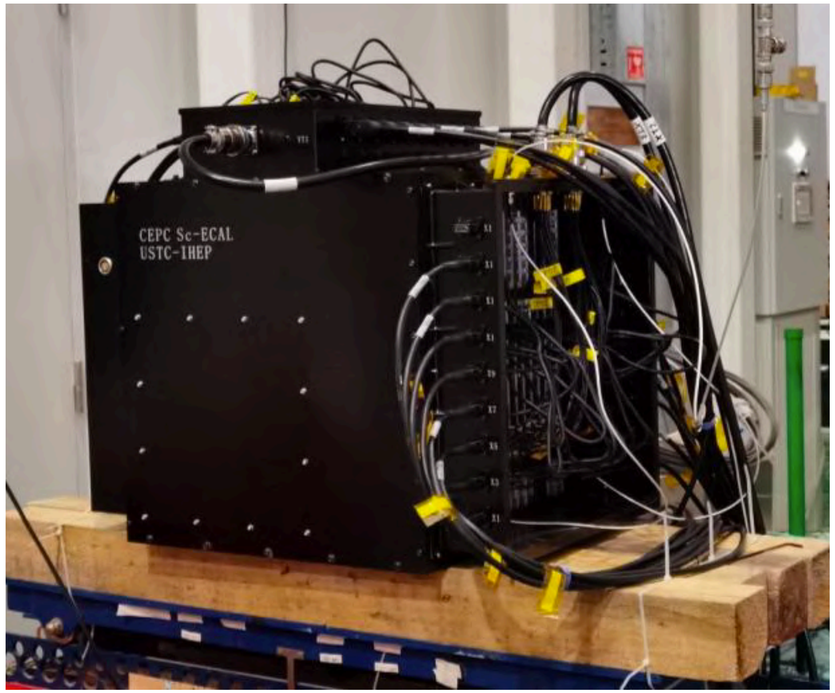
●Technological prototype: single layer

- Scintillator strip ($45 \times 5 \times 2\ \mathrm{mm}^3$) directly coupled to SiPM
- Strips are assembled on PCB with integrated readout electronics (“EBU”)
- 144 strips/EBU readout by 4 ASICs (SPIROC2b)



●Technological prototype: full layer

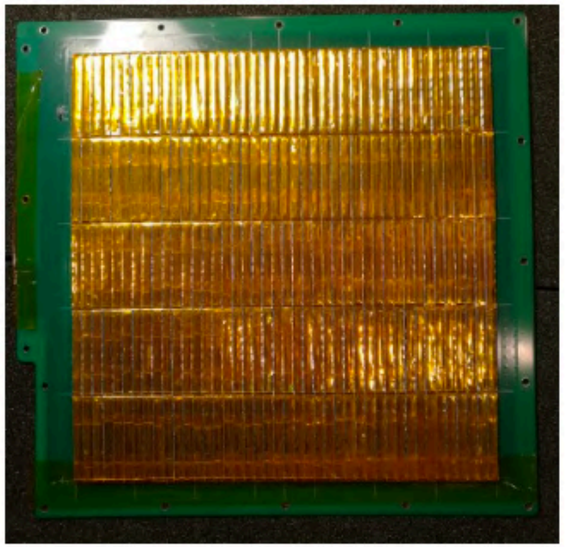
- Joint R&D with CEPC-ECAL group
- Scintillator strip ($45 \times 5 \times 2\ \mathrm{mm}^3$) with SiPM
- 32 layers, $\sim 23.4\, X_0$
- 210ch /EBU



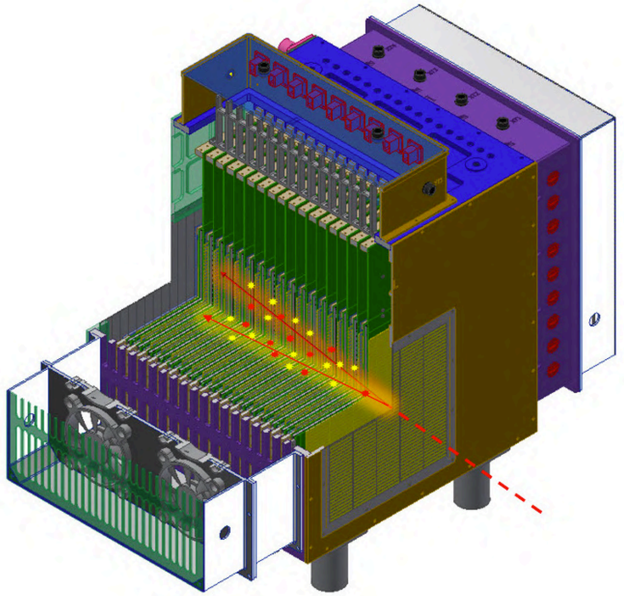
Large Prototype

- **Large technological prototype of Sc-ECAL**
  - Jointly developed by R&D groups for CEPC and ILD
  - Full layers (32 layers)
    - Detection layer of 210×225mm^2 with 210 scintillator-strips
      - 30 layers with single SiPM readout
      - 2 layers with double SiPM readout
    - Absorber plate (3.2mm-thick 15%-85% Cu-W alloy)
    - Total material thickness $23.4\,X_0$

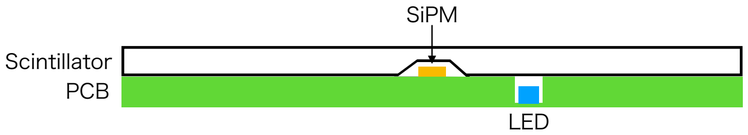
Detection layer on EBU



Large prototype



Strip-SiPM coupling

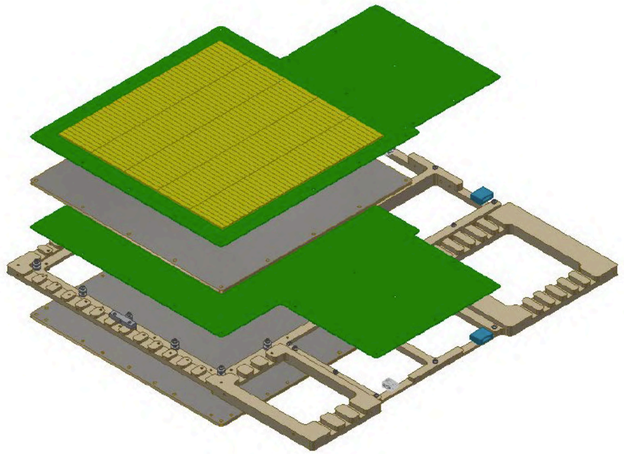


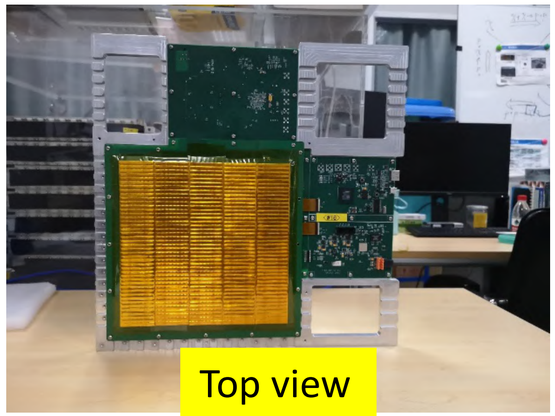
Layout of detection layers

Large Prototype

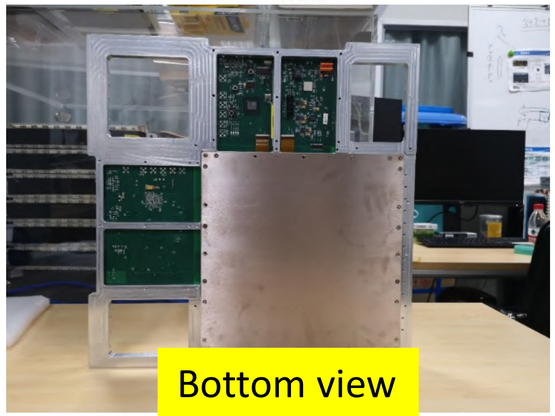
•Super-layer

- Composed of two sets of EBU and absorber plate
- Strips are aligned alternately in horizontal and vertical orientations
- 16 super-layers in total





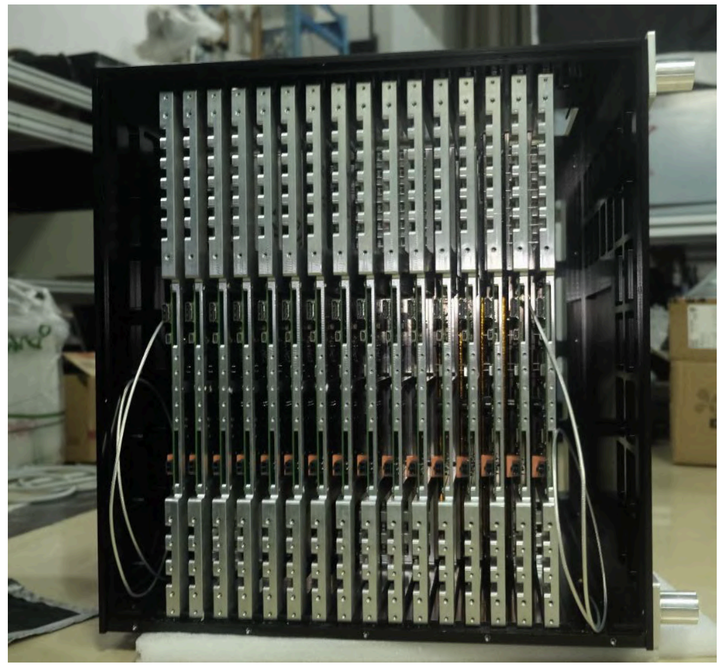
Top view



Bottom view

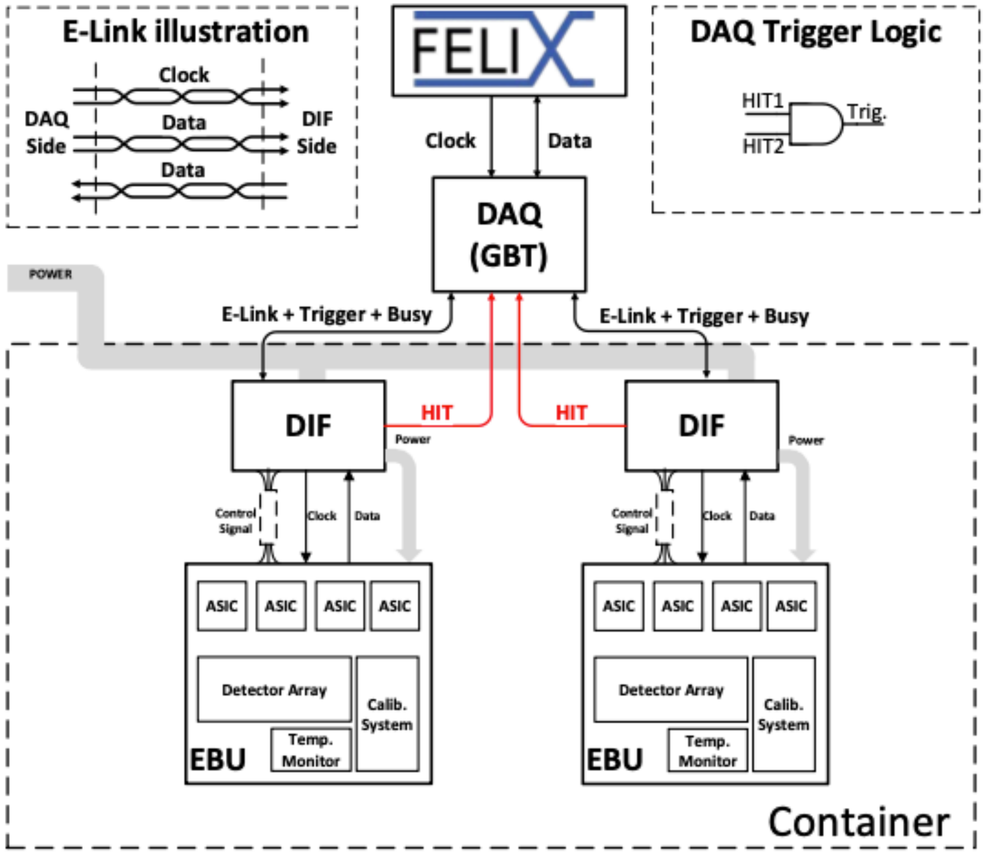
•Mechanical structure

- Mechanical structure with $17\times$ slots for super-layer modules
- Whole setup can be rotated by $90°$ for cosmic ray test
- Air-cooling fans at both sides

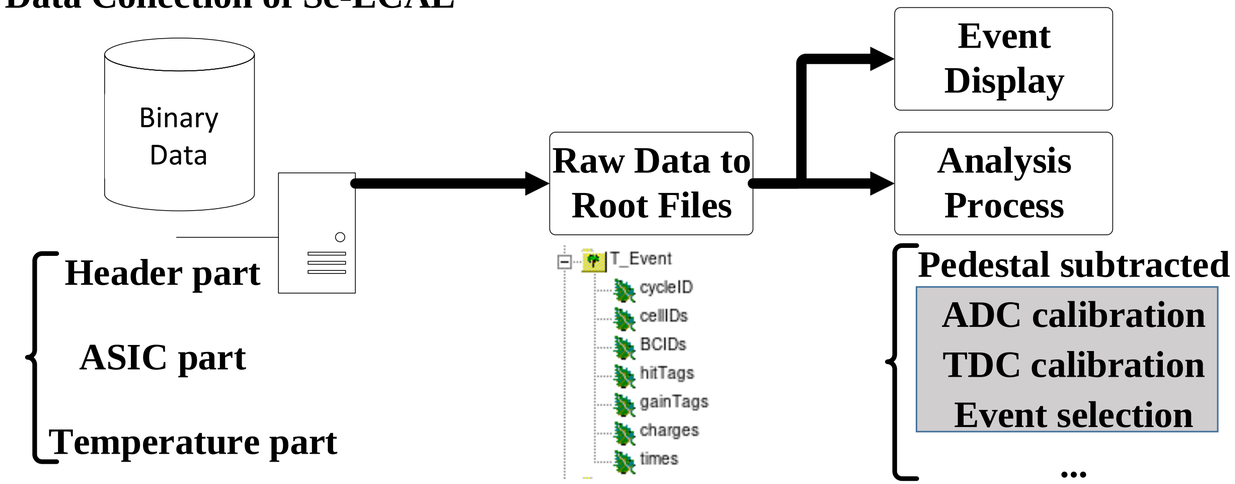


Large Prototype

DAQ



Data Collection of Sc-ECAL

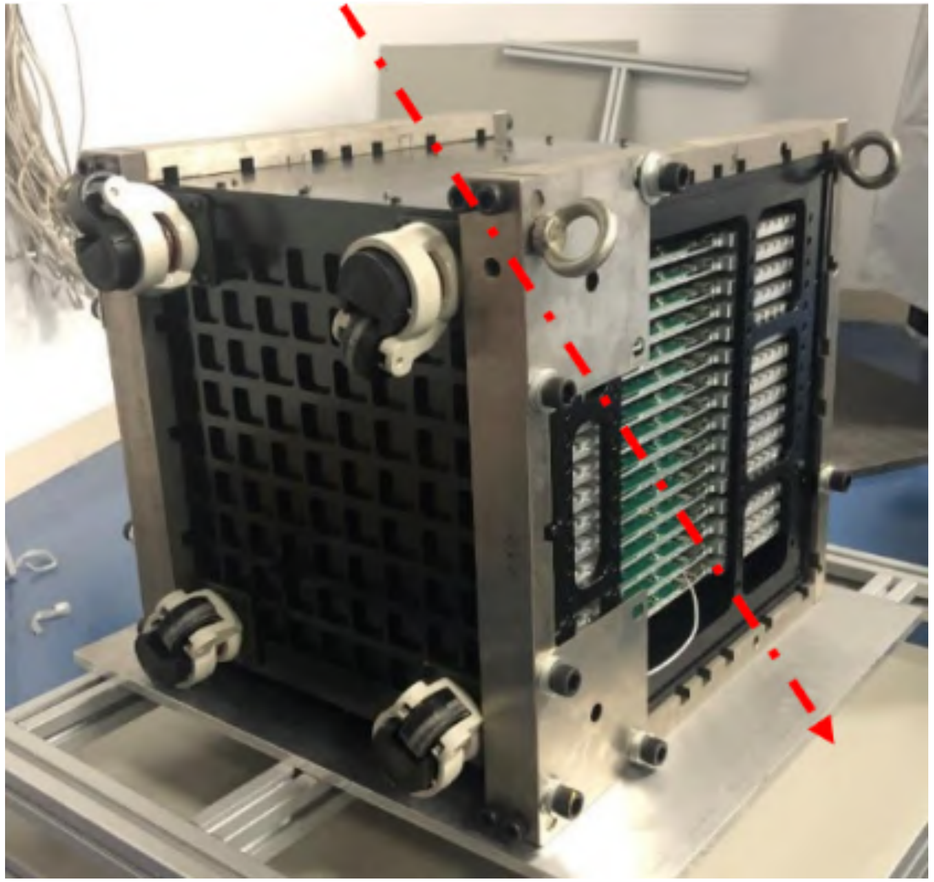


Large Prototype

Commissioning

- **No beam test performed yet due to pandemic**
- **Long LED run (~1 month)**
  - SiPM calibration (gain, cross-talk, after-pulsing)
  - Electronics calibration
  - Stability test
- **Long cosmic ray run (~3 month)**
  - MIP calibration
  - Stability test
  - Performance study
    - Detection efficiency, position resolution
    - Study with cosmic-ray induced shower

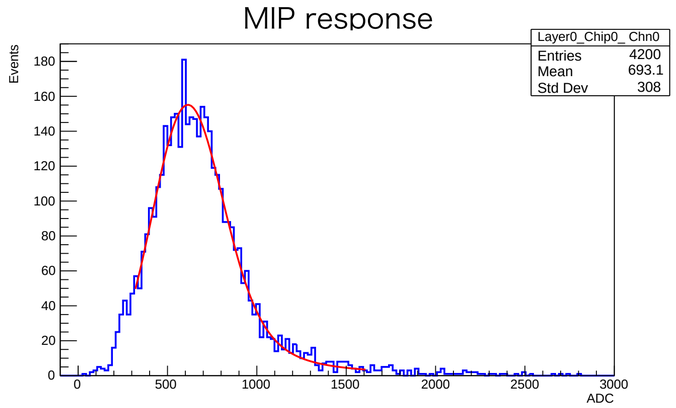
Prototype rotated by 90° for cosmic-ray test

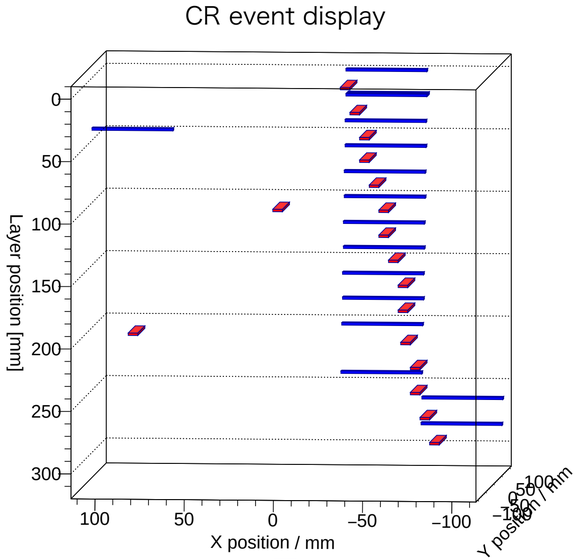


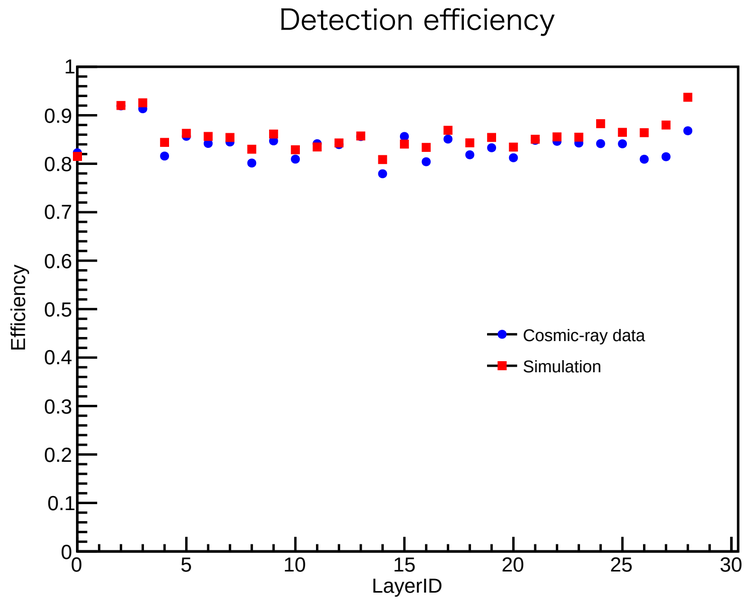
Large Prototype

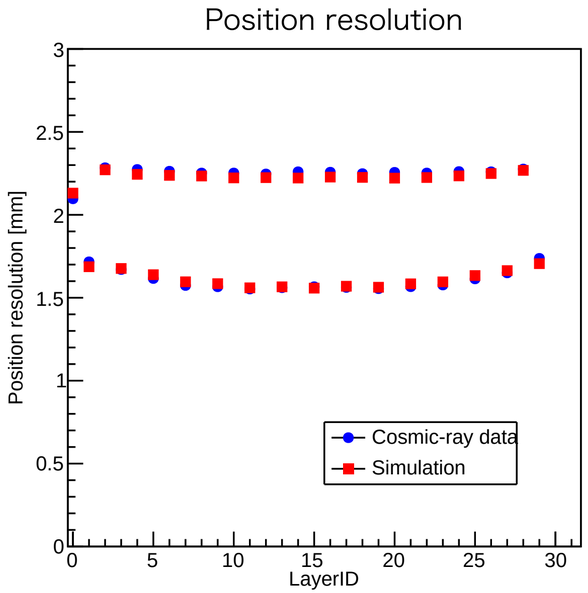
Performance

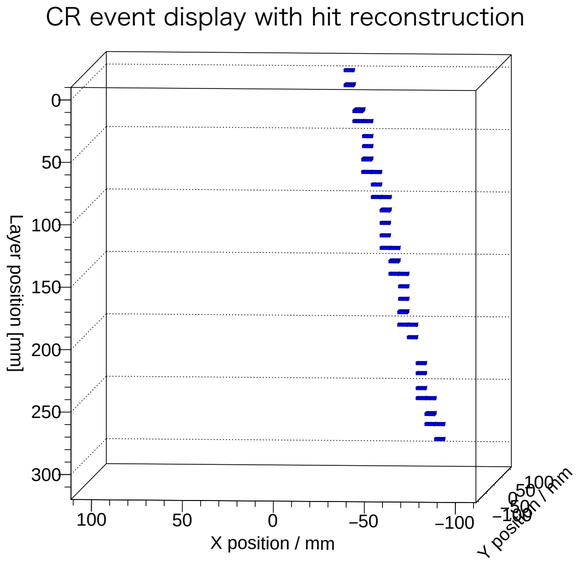
- **Performance measurement with cosmic ray track**
- **Detection efficiency**
  - 80-90%
  - Inefficiency due to threshold and gap between strips
- **Position resolution**
  - 1.5-2.3mm









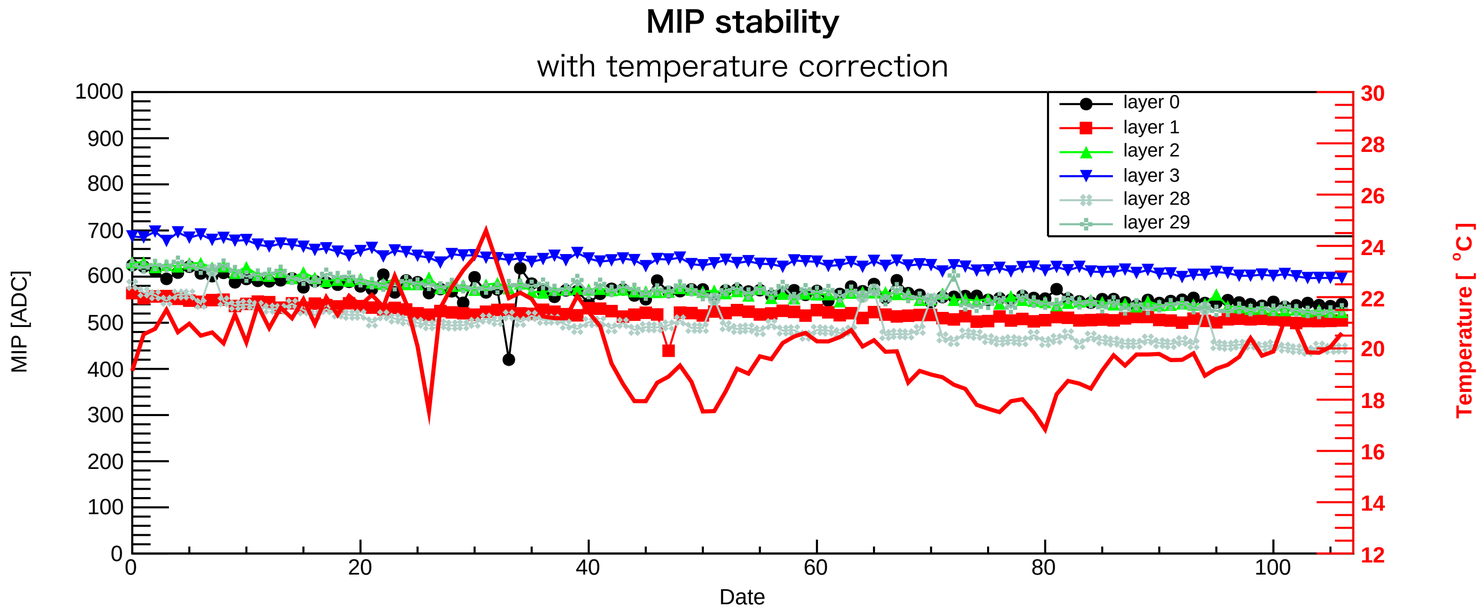


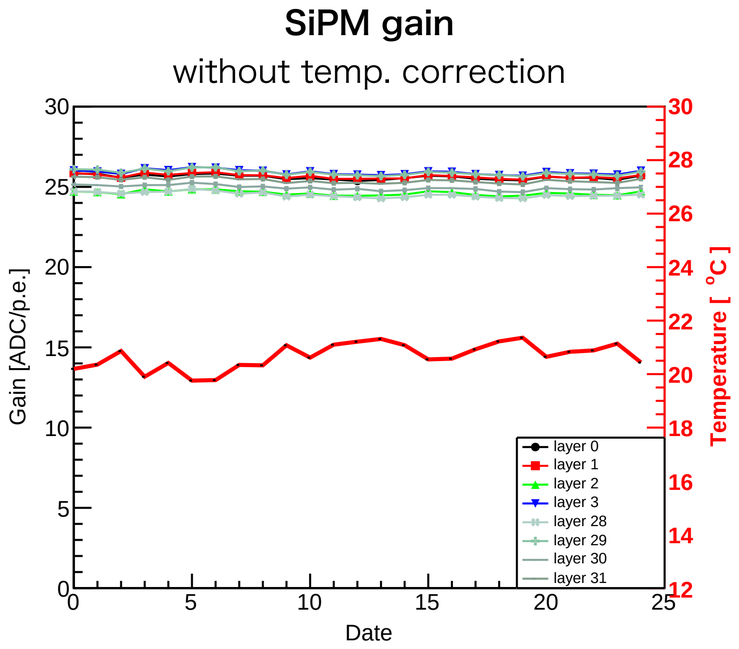
Large Prototype

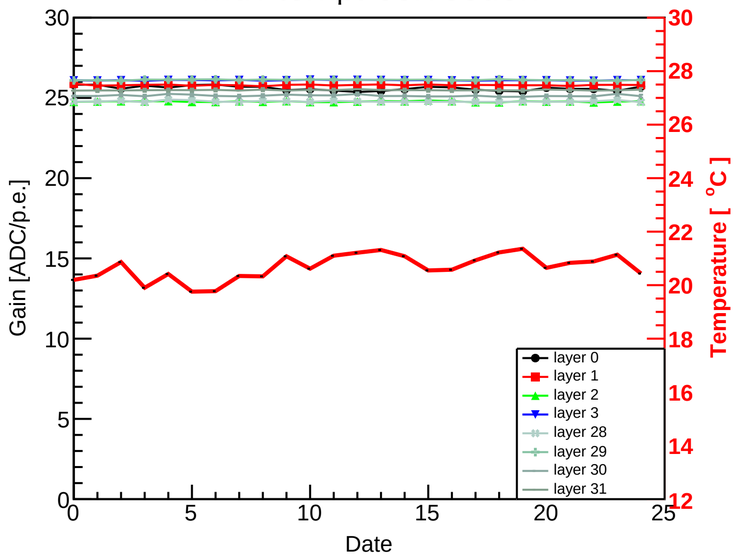
Performance

- **Long-term stability**
  - SiPM gain
    - Very stable over one month
  - MIP gain
    - Constant decrease of 5-10%/3months

      ↔ 1-2%/year @T2K ND280/INGRID
    - Under investigation. Electronics or scintillator?



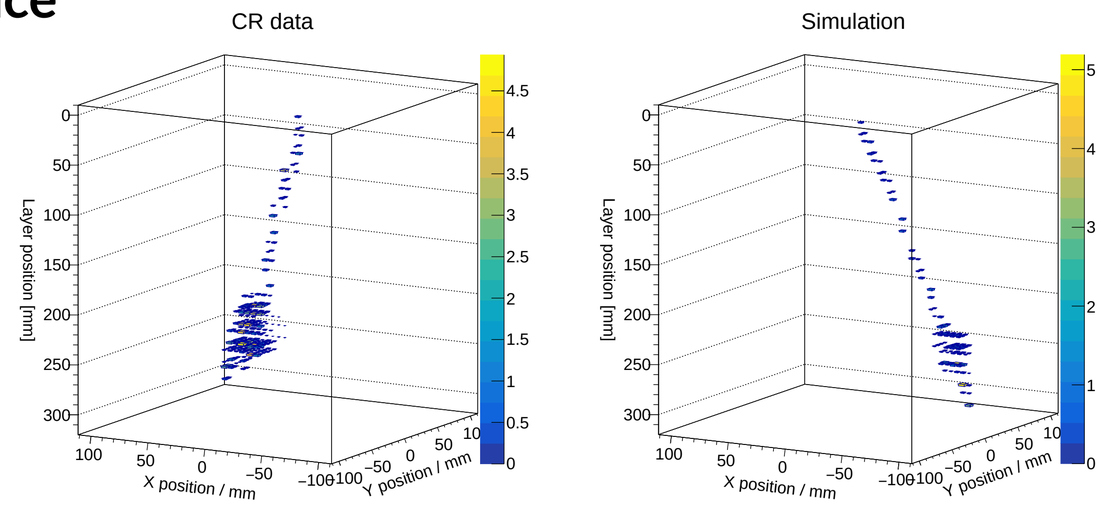


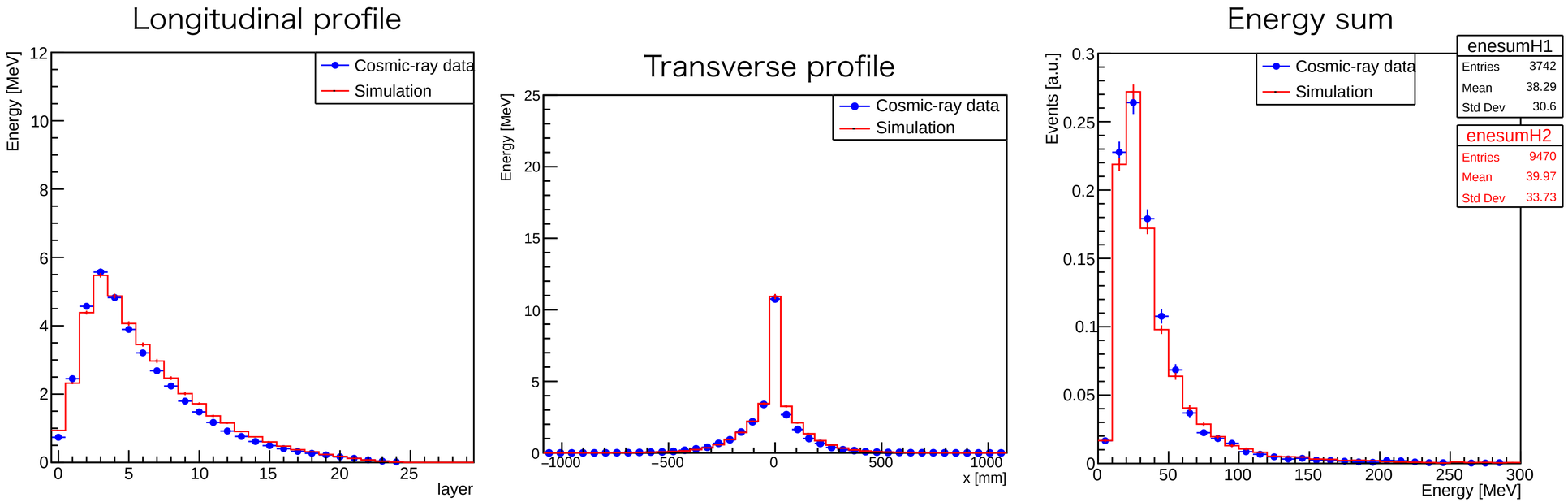


Large Prototype

Performance

- **Study with cosmic-ray induced shower**
  - Good agreement between data and MC
  - Small deviation for higher energy event
    - Likely due to problem of CR energy distribution in MC

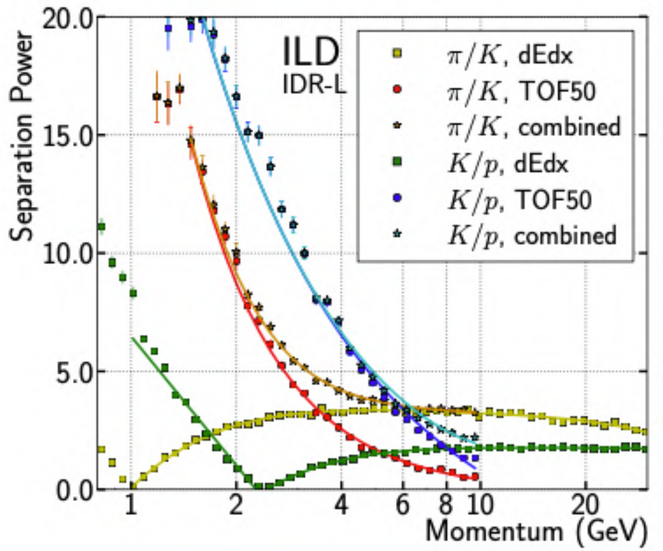




Timing

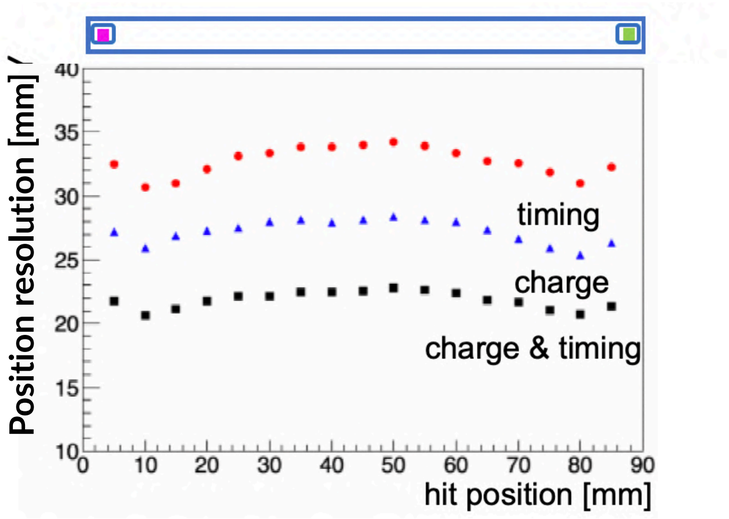
- **Timing capability recognised as additional value by Sc-ECAL group**
  - Particle ID for charged hadron to cover inaccessible momentum region by dE/dx
  - Rejection of pileup/off-timing BG
  - Rejection of slow neutron events
  - Improve PFA performance
  - Hit position reconstruction in double SiPM readout
  - …

Effect of TOF (res. 50ps) on particle ID performance

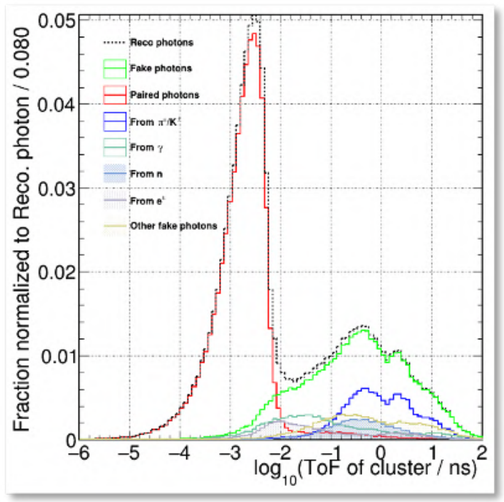


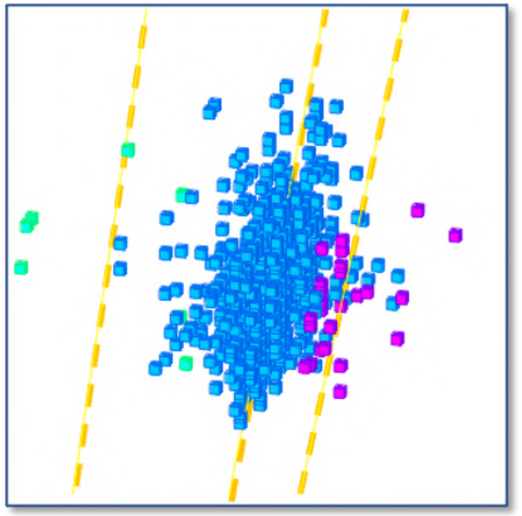
U. Einhaus, arXiv:2110.15115

Hit position resolution with double SiPM readout



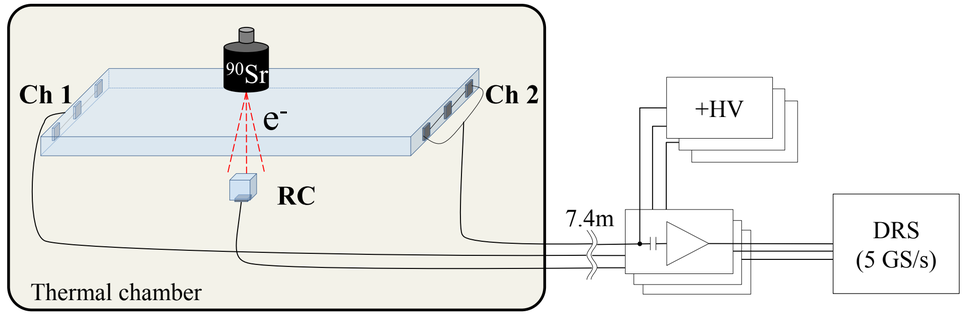
Truth cluster TOF distribution of real photon and fake photon clusters (CEPC)



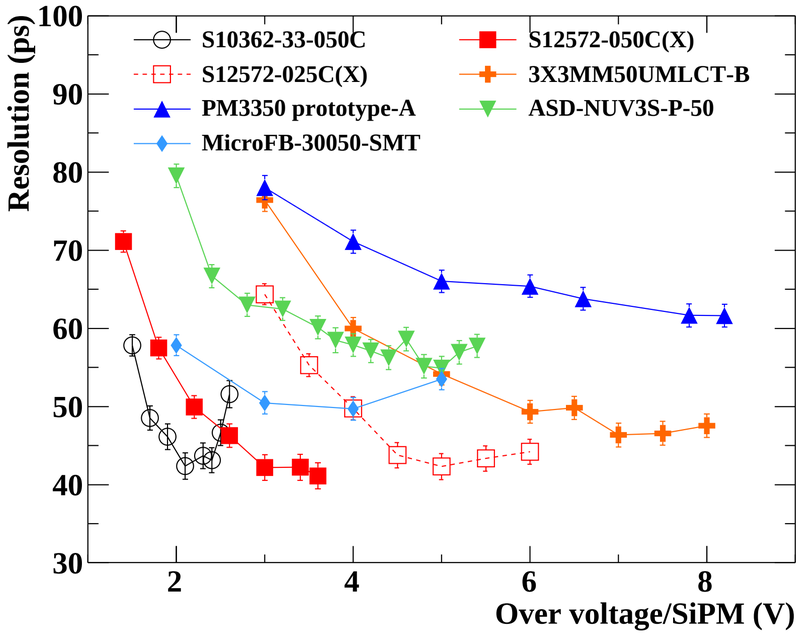


Timing

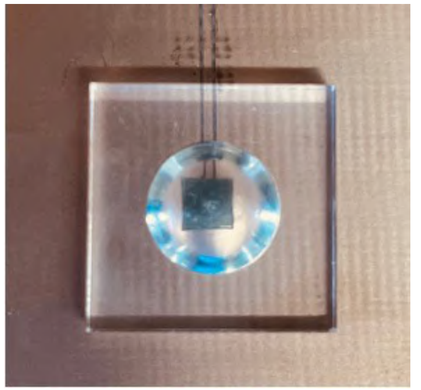
- **What we could do with scintillator+SiPM system?**
- **Our experience on similar detector in MEG II experiment**
  - Scintillator plate read out by multiple SiPMs connected in series
  - Time pickup by waveform analysis (constant fraction)
  - Excellent timing resolution down to $40\,\mathrm{ps}$ with the best configuration
    - Fast scintillator (BC-422): $60 \times 30 \times 5\,\mathrm{mm}^3$
    - 6x SiPM ($3 \times 3\,\mathrm{mm}^2$, pixel pitch: $50\,\mu\mathrm{m}$)
  - Expected $70 - 80\,\mathrm{ps}$ with ~100 photoelectrons



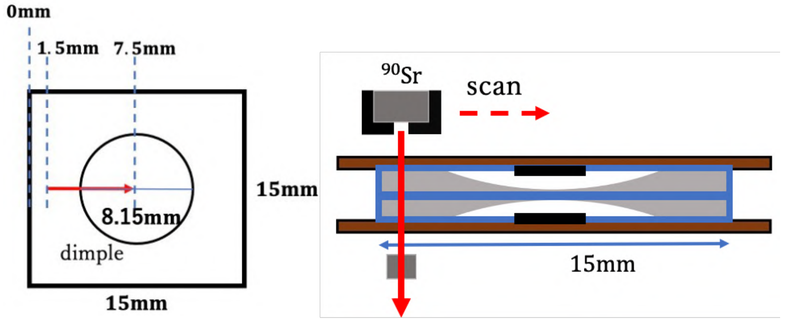
Properties	BC-418	BC-420	BC-422	BC-422Q	BC-404
Light Output[a] (% Anthracene)	67	64	55	19	68
Rise Time[a] [b] (ns)	0.5	0.5	0.35	0.11	0.7
Decay Time[a] (ns)	1.4	1.5	1.6	0.7	1.8
Peak Wavelength[a] (nm)	391	391	370	370	408
Attenuation Length[a] (cm)	100	110	8	8	140
Time Resolution[c] (ps)	48 ± 2	51 ± 2	43 ± 2	66 ± 3	–



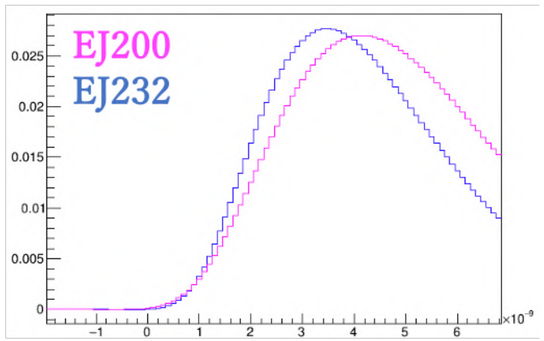
Timing

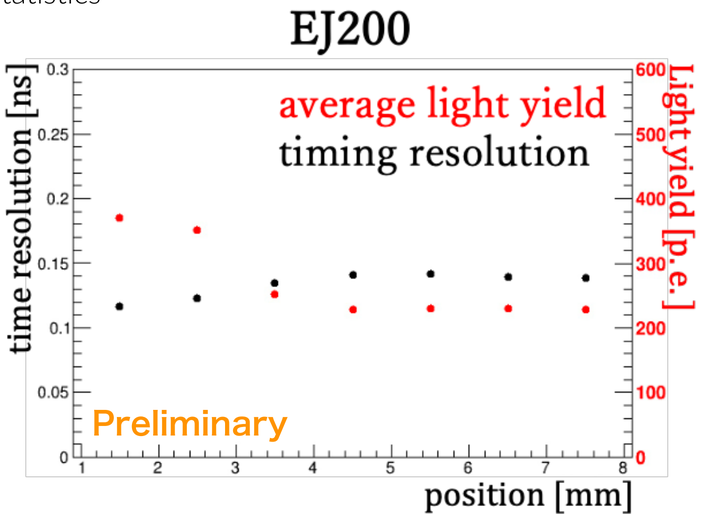


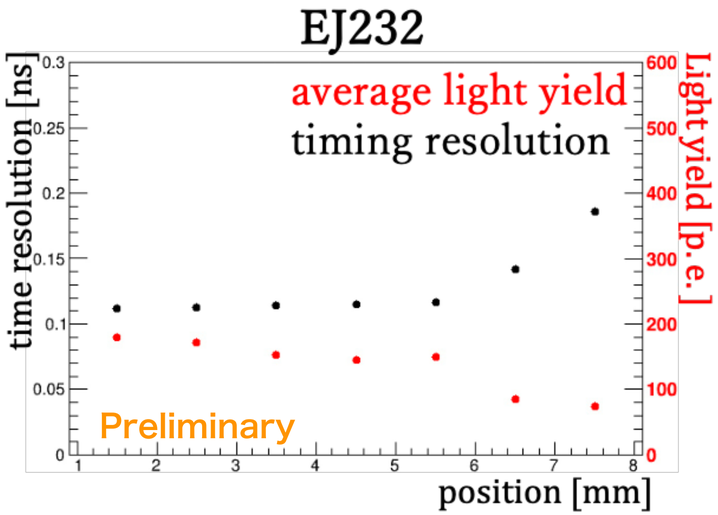
- **Dedicated study in progress**
  - Time resolution with standard strip-SiPM configuration: $300 - 400\,\mathrm{ps}$
  - Dedicated timing layer with scintillator tile + larger SiPM under consideration
    - Target resolution $\sim 50\,\mathrm{ps}$
    - Tile layer would also help solving ghost hit in strip layers



- **Preliminary results**
  - Scintillator tile
    - $15 \times 15 \times 3\,\mathrm{mm}^3$
    - standard (EJ200 (=BC408)), fast (EJ232 (=BC422))
  - SiPM: MPPC S14160-3050HS ($3 \times 3\,\mathrm{mm}^2$, pixel pitch: $50\,\mu\mathrm{m}$)...
  - Resolution down to $\sim 110\,\mathrm{ps}$
    - Worse than that for MEG II detector even with higher p.e. statistics
    - Difference is not understood yet



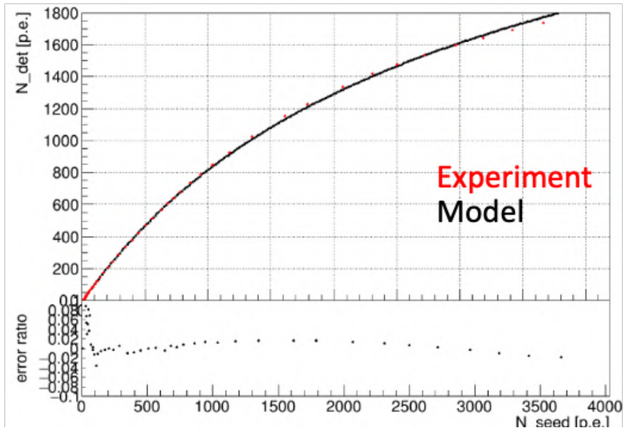


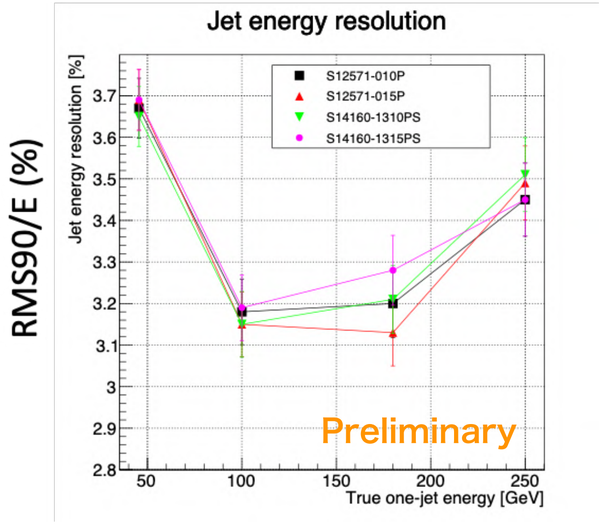


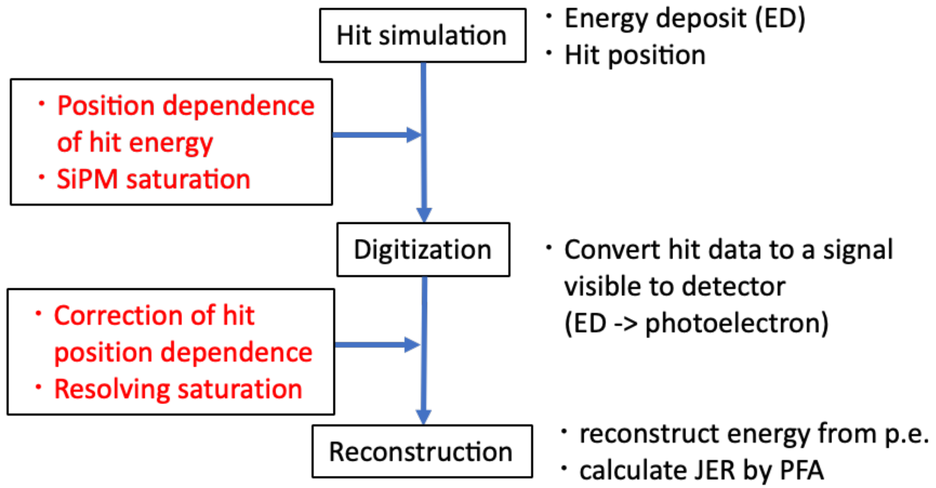
More Realism in Simulation

- **Realistic conditions to implement in simulation**
  - ✓ • SiPM saturation
  - ✓ • Hit position dependence of light yield
  - ✓ • Misalignment between strip and SiPM
  - • Gap between strips (deal area)
  - • …

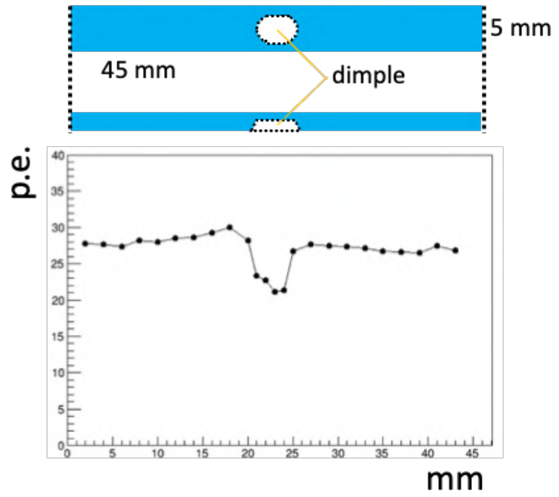
SiPM saturation
(measured with UV laser)

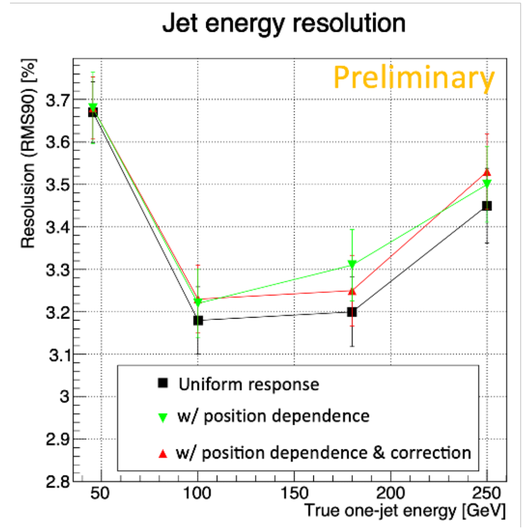






Position dependence of light yield

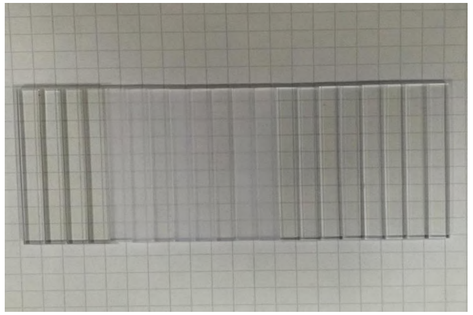
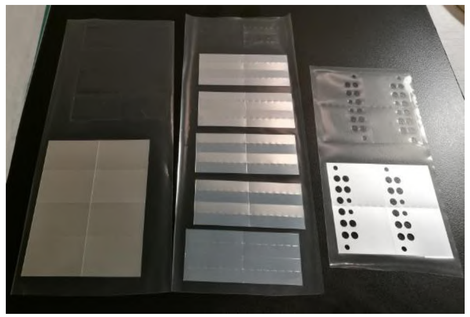
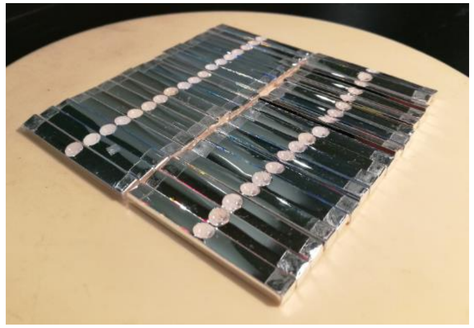




Remaining Challenges

- **Performance evaluation in beam test**
  - Standalone beam test at IHEP BSRF (leakage electron from synchrotron radiation beam line)
  - Combined beam test at CERN with Sc-ECAL and CEPC-AHCAL
- **Engineering R&D for large scale production**
  - Scintillator production (injection moulding)
  - Automated assembly system
  - System for QC/QA

    →More reliable cost estimate
- **Readout electronics**
  - Power pulsing operation
  - Long slab
  - Electronics dedicated for timing
- **Design of infrastructure in ILD**
- **Most urgent R&D items from CEPC viewpoint**
  - Low-power and high-performance SiPM readout ASIC
  - Active cooling


Strip wrapping and assembly on EBU was done by hand (Shanghai Institute of Ceramic)

- **No substantial activity has been started for any other items than preparation for the beam tests**
  - No sufficient manpower and funding for both Chinese and Japanese sides
  - Newcomers would be welcome in these area