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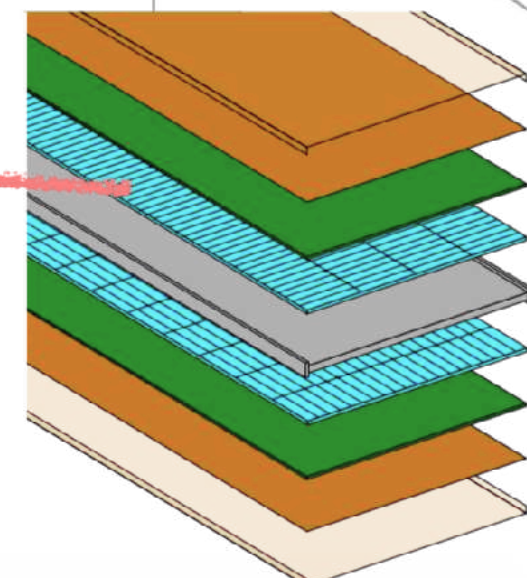
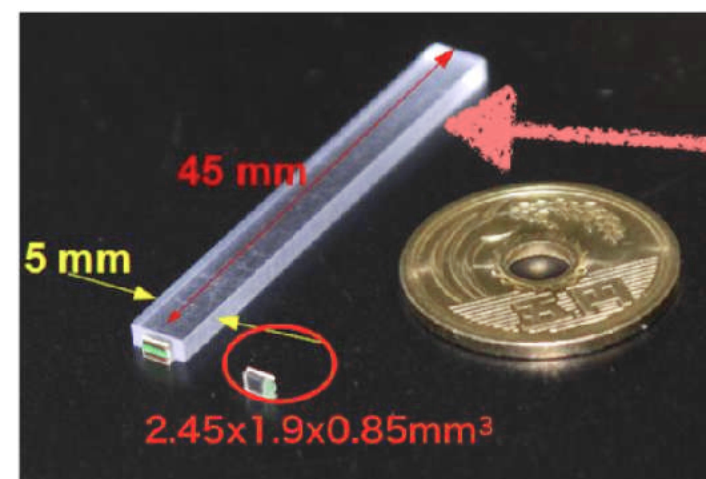
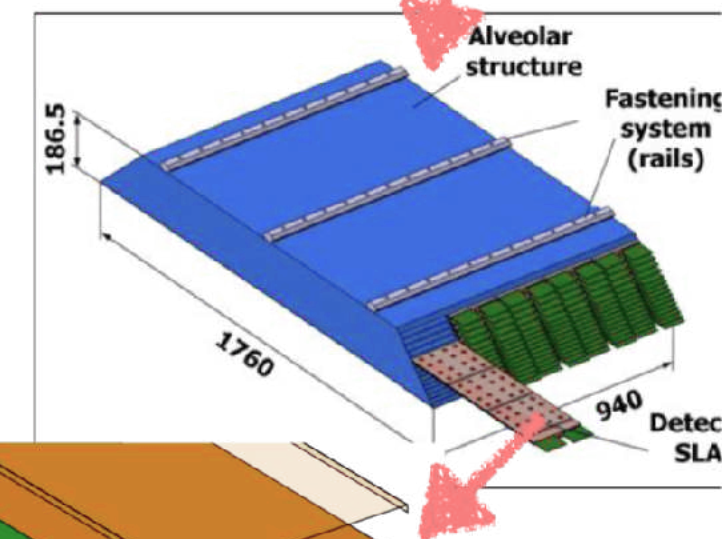
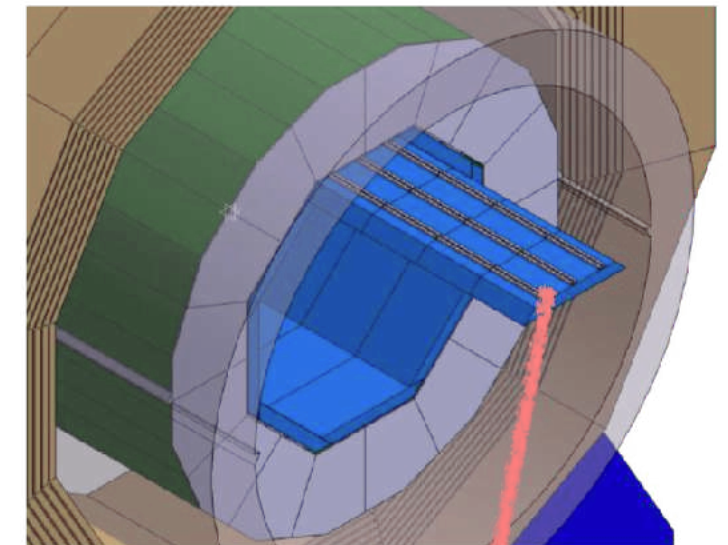
High-granularity scintillator-ECAL for future electron-positron colliders -test beam experiment-

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3. Shinshu University 4. University of Science and Technology in China
5. Institute of High Energy Physics

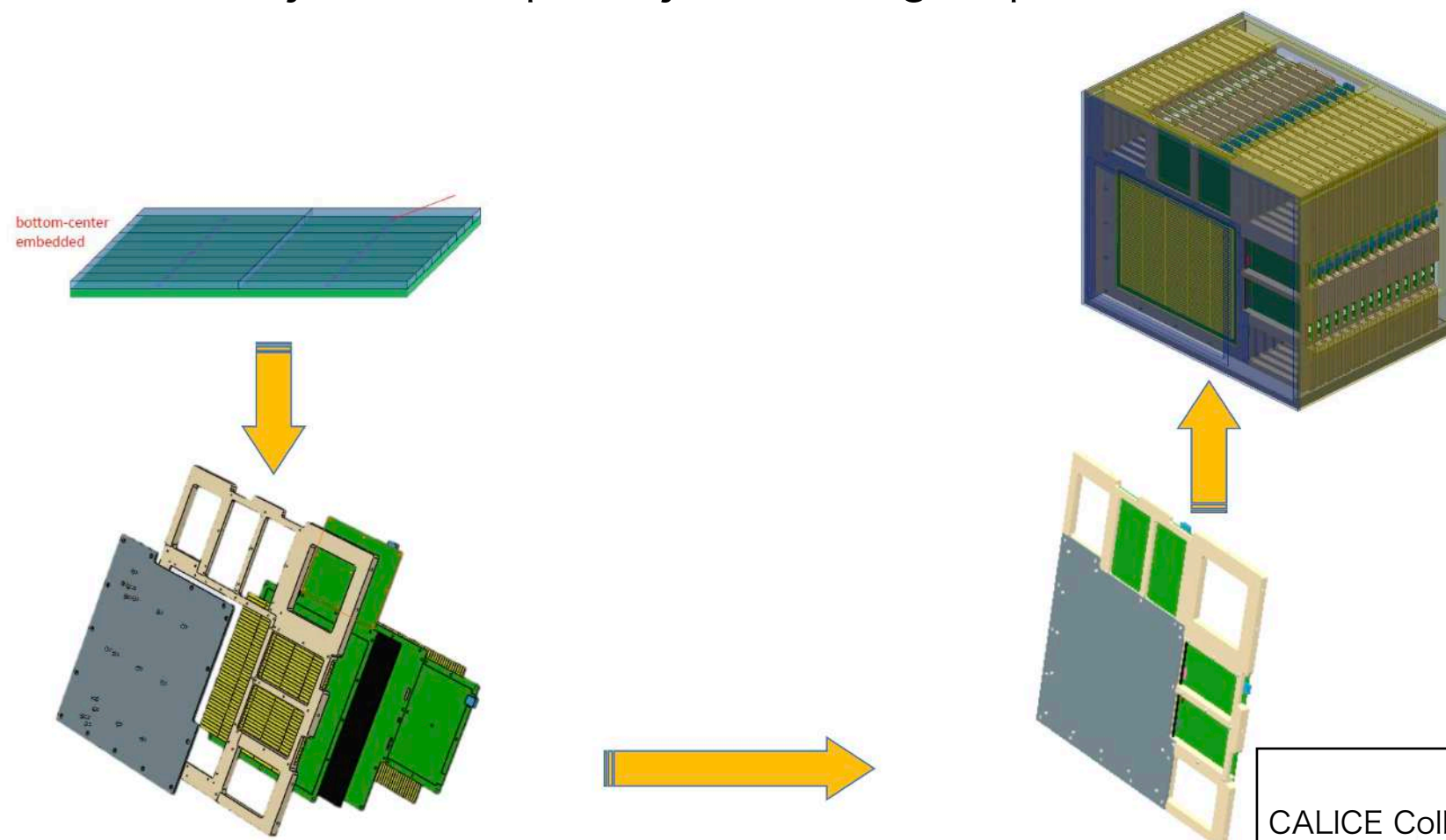
Sc-ECAL

- Scintillator Electromagnetic CALorimeter (Sc-ECAL)
 - Technology option of EM calorimeter for ILC and CEPC
- Based on scintillator strips readout by SiPM
 - $5 \times 45 \times 2$ mm scintillator strip
- Virtual segmentation : 5mm \times 5mm with strips in x-y configuration
- Timing resolution < 1 ns
- Low cost



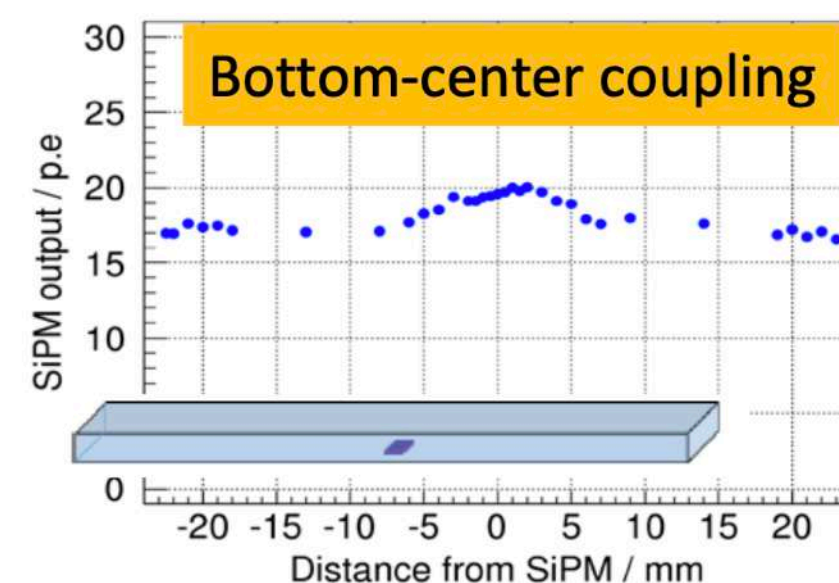
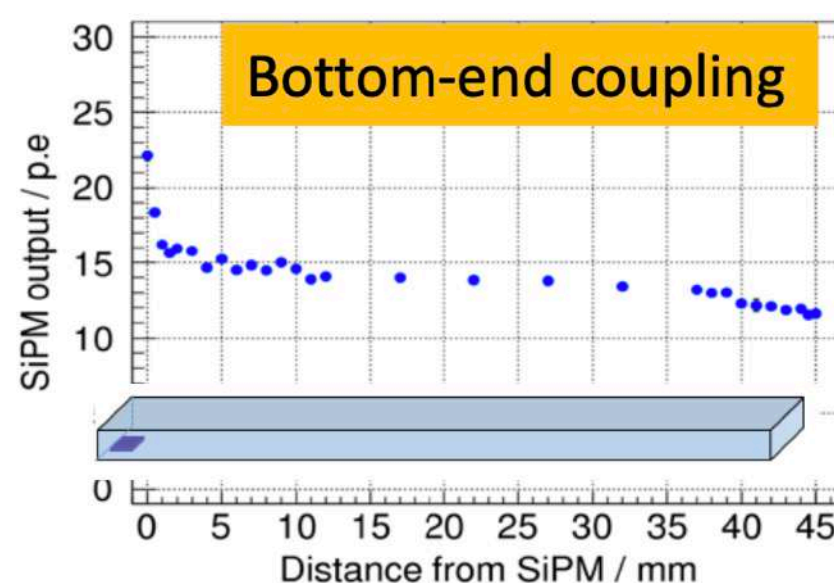
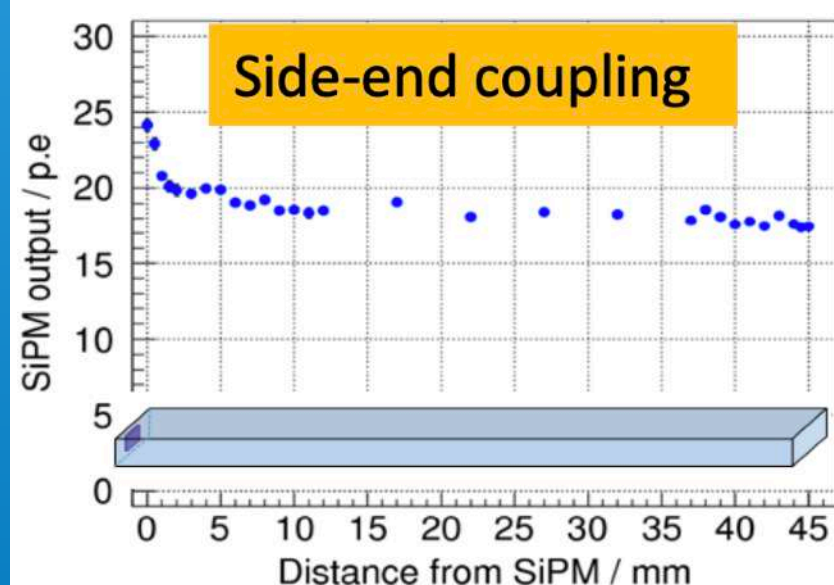
Large technological prototype

- **Large technological prototype for Sc-ECAL has been constructed as a joint effort with Chinese groups working on CEPC**
 - Full 30 layers
 - 210 channels / layer
 - Test beam in DESY at 2021
- **Two detection layers with double SiPM readout developed by UTokyo group will be installed the prototype**
- Two additional layer developed by Shinshu group will also be tested (see next talk)



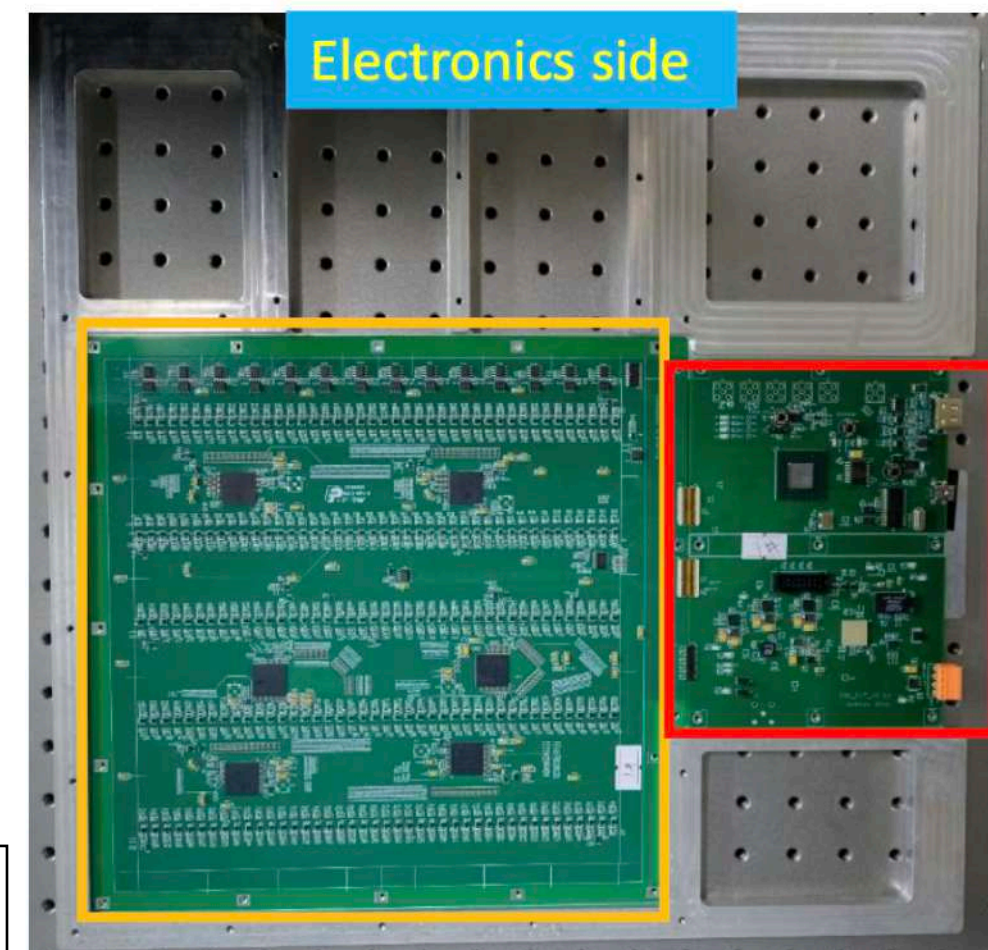
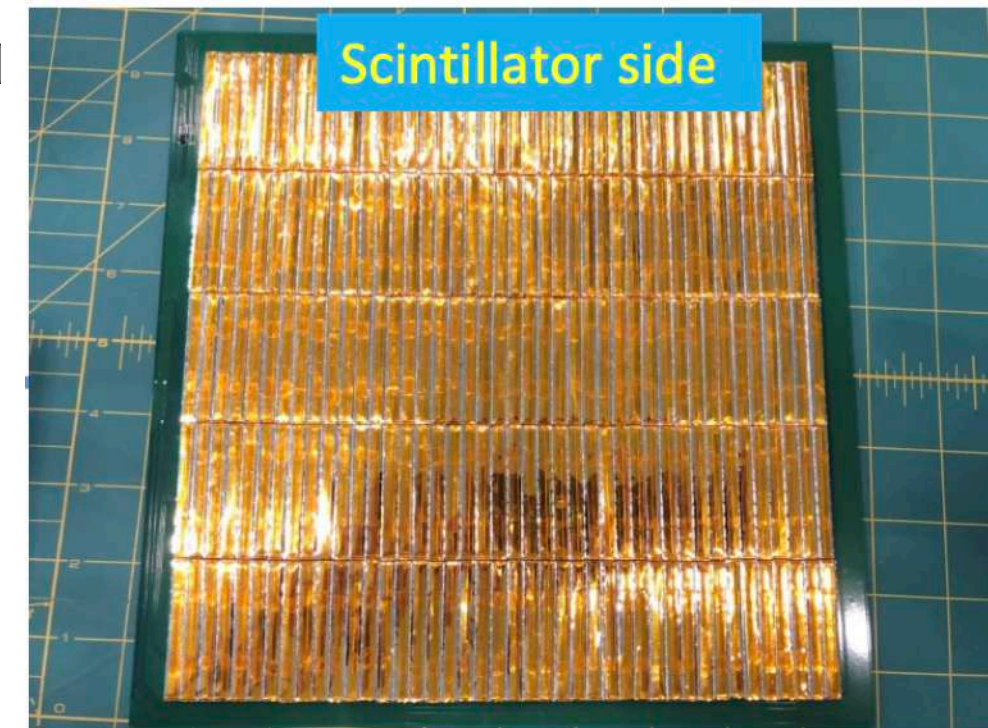
Scintillator strip - SiPM Coupling optimization

- Three coupling models investigated: side-end, bottom-end and bottom-center
- Uniformity of light yield along the strip is important to the ECAL energy resolution
- Bottom-center coupling gives the best uniformity with additional advantages:
 - Avoiding the dead area between scintillators introducing by SiPMs
 - Simplifying sensitive layer assembly
 - Allowing for large-size SiPM for a large dynamic range



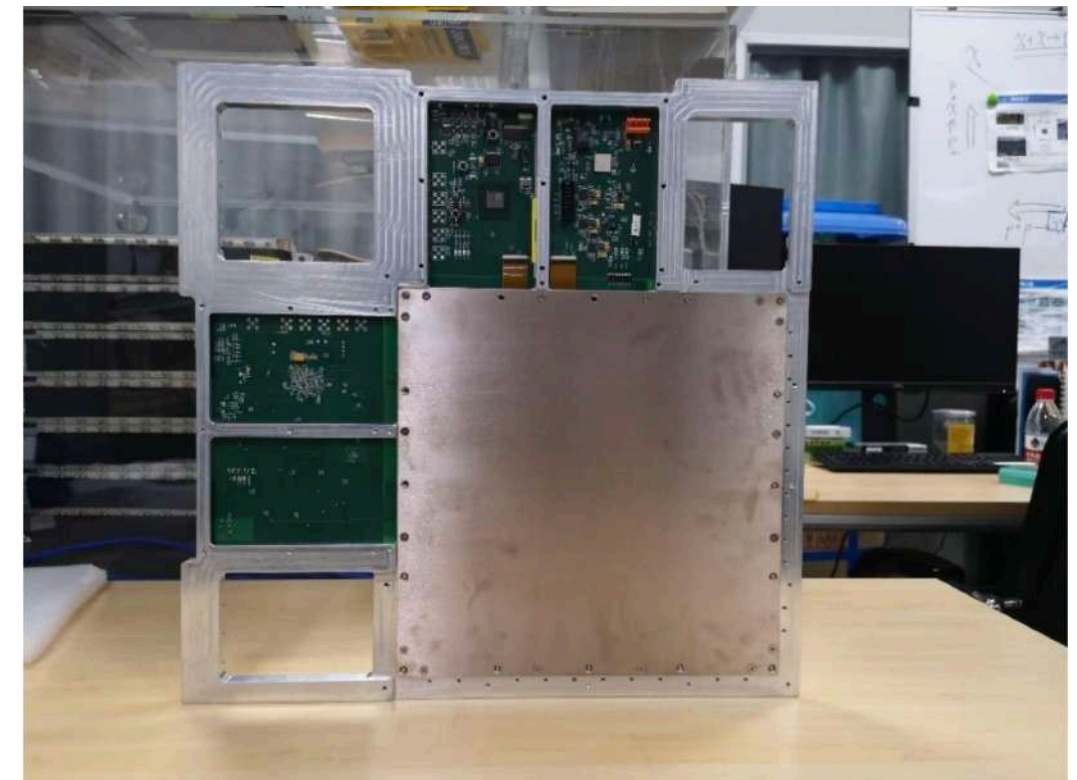
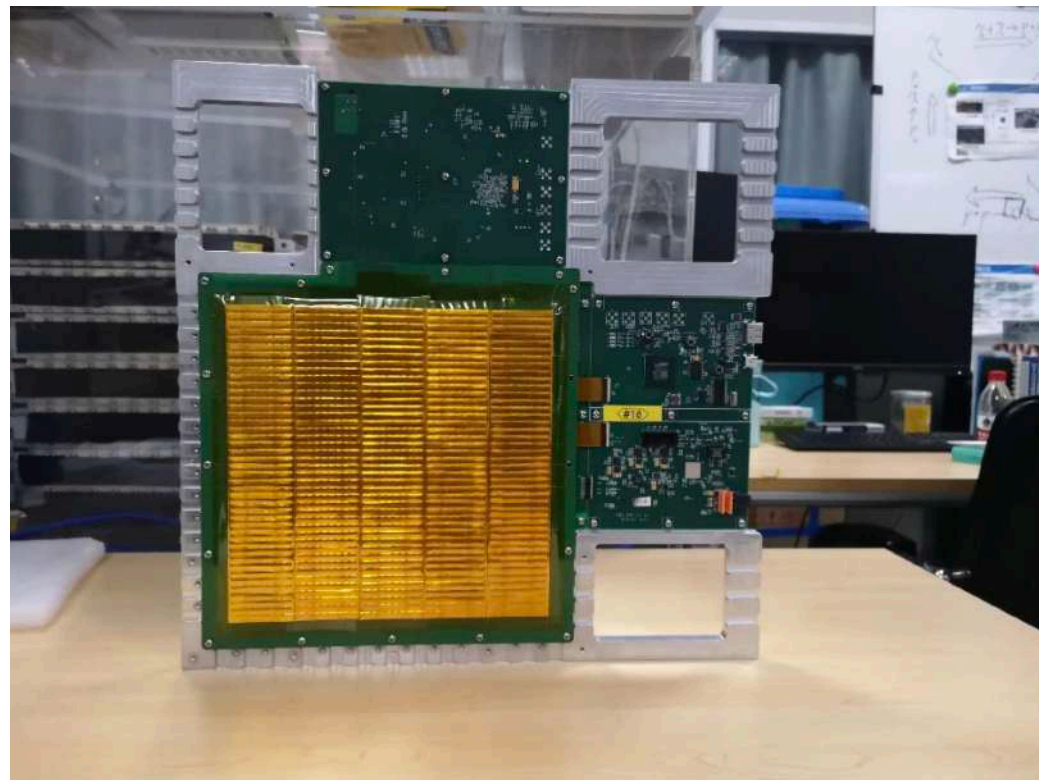
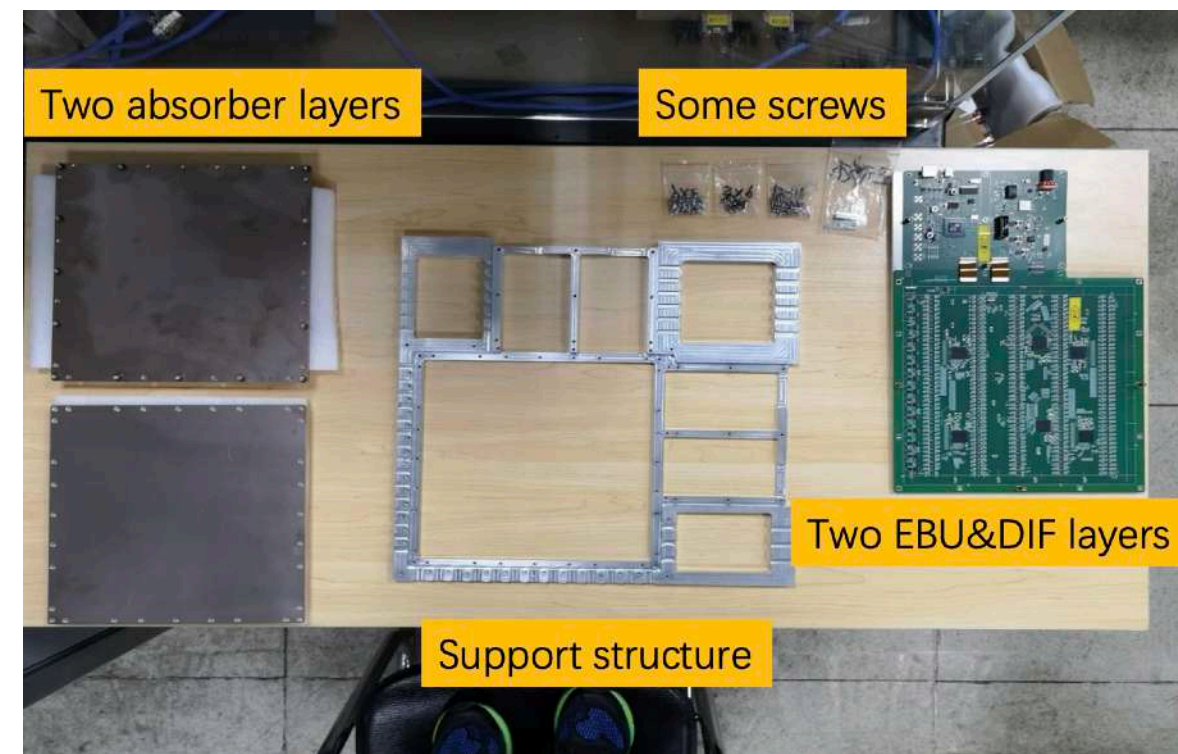
ECAL Base Unit (EBU)

- 210 channels readout with $6 \times$ SPIROC2E chips divided into 5 rows and 42 columns
- Total thickness is controlled under 6mm
- Electronics calibration and SiPM operation voltage adjustment realized
- LED calibration and temperature monitoring circuits under test
- 24 layers of EBU with $10\mu\text{m}$ -pixel SiPMs and 6 layers EBU with $15\mu\text{m}$ SiPMs
- Scintillator strips were wrapped and assembled on EBU boards by Shanghai Institute of Ceramic



Assembly & Mounting

- Single layer support structure produced and mounted
- One super layer consists of two EBU and inserted by two absorber layers
 - Absorber layer : 3.2 mm, 15%-85% Cu-W



Assembly & mounting

- 16 super layers in total

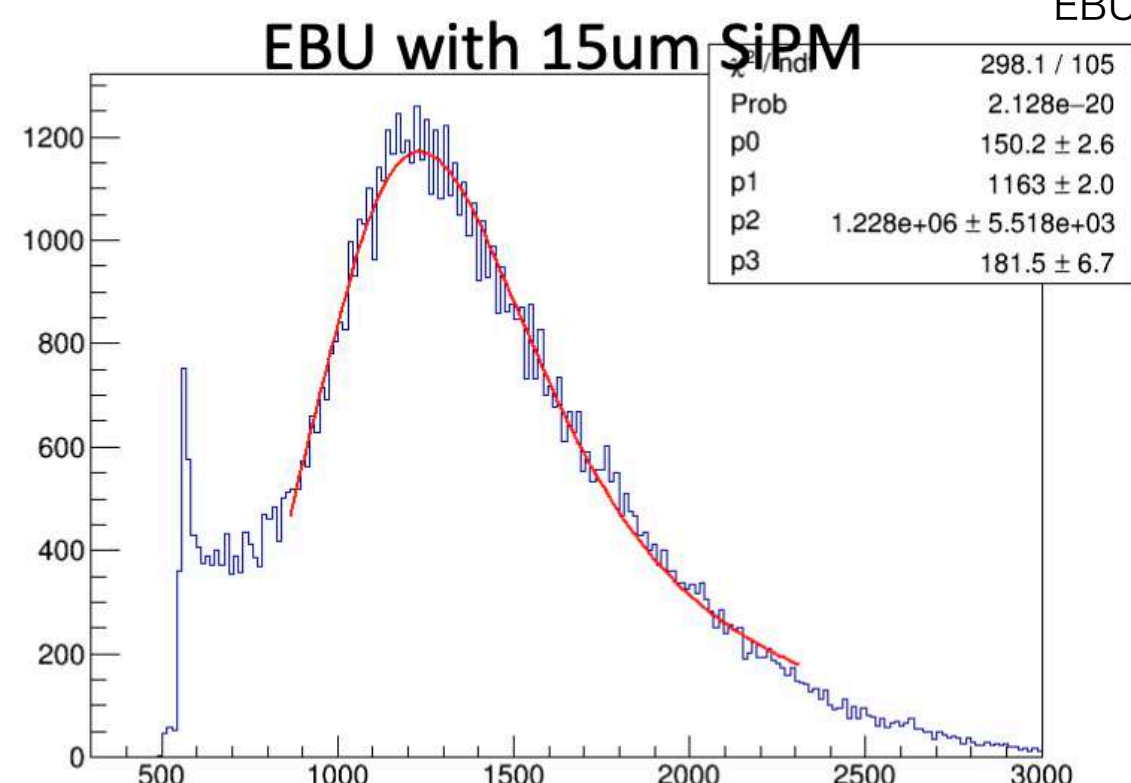
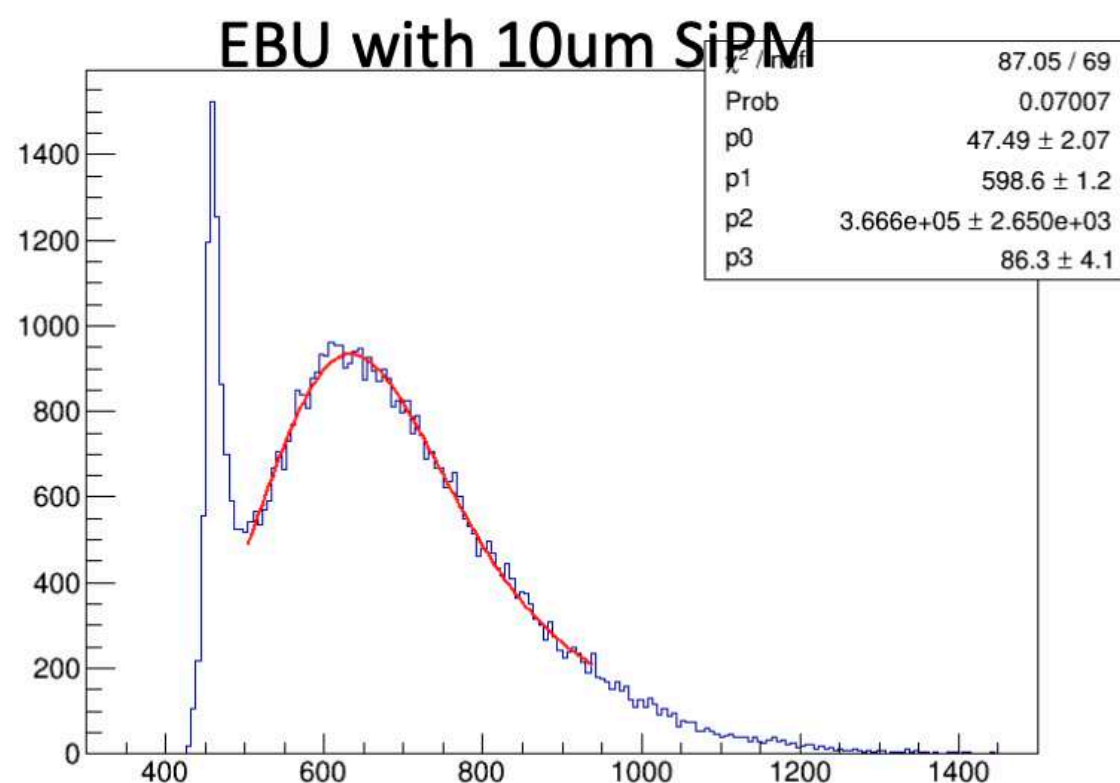
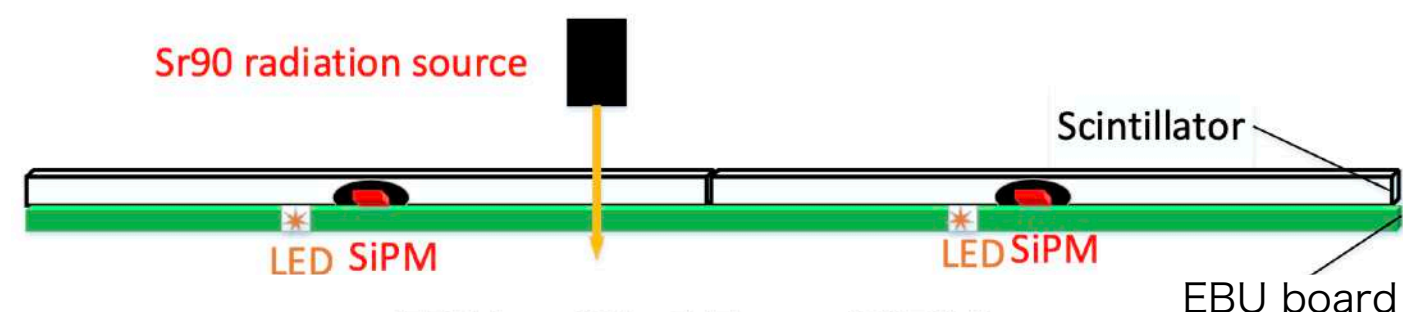


Double-side readout
layer



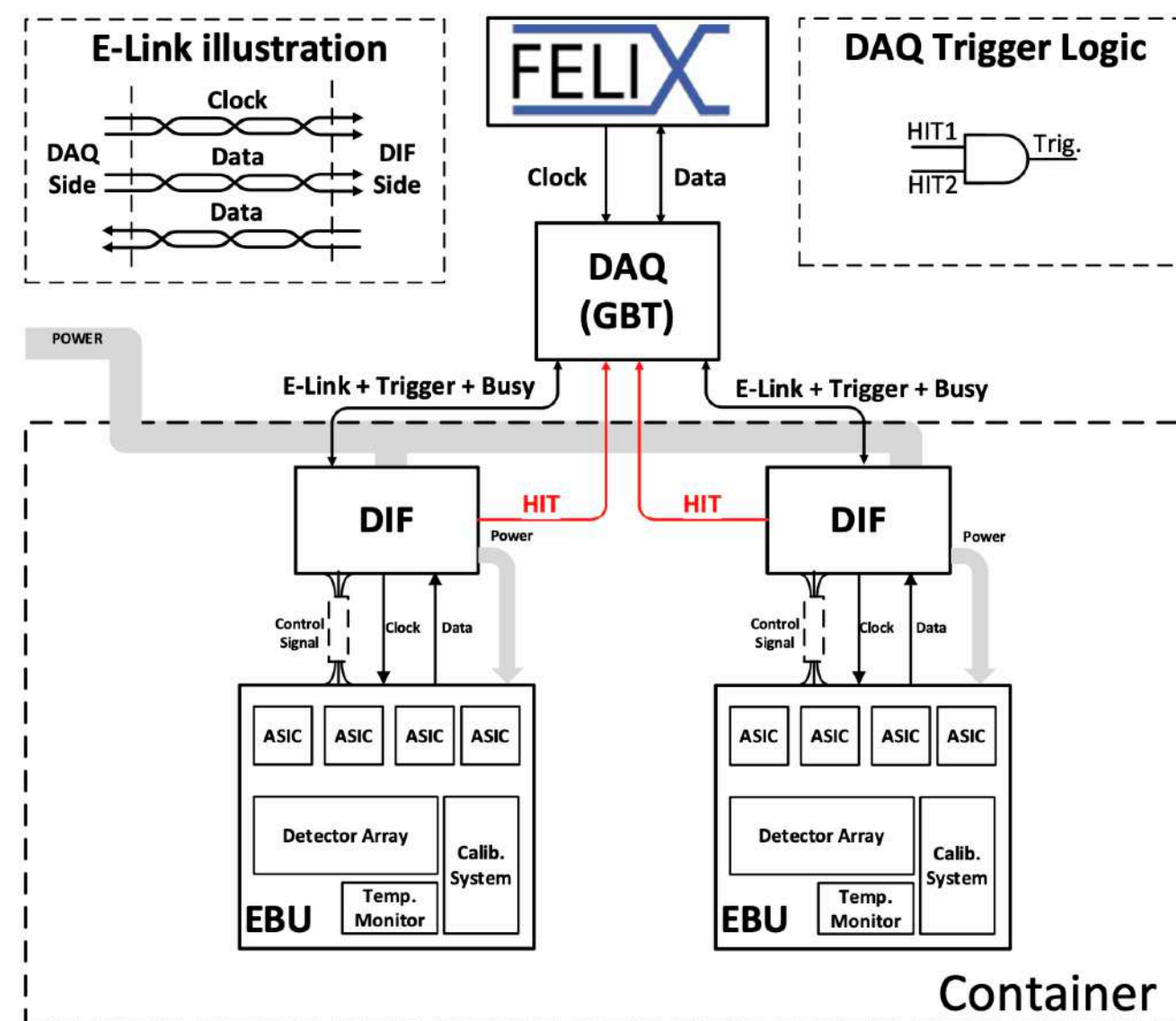
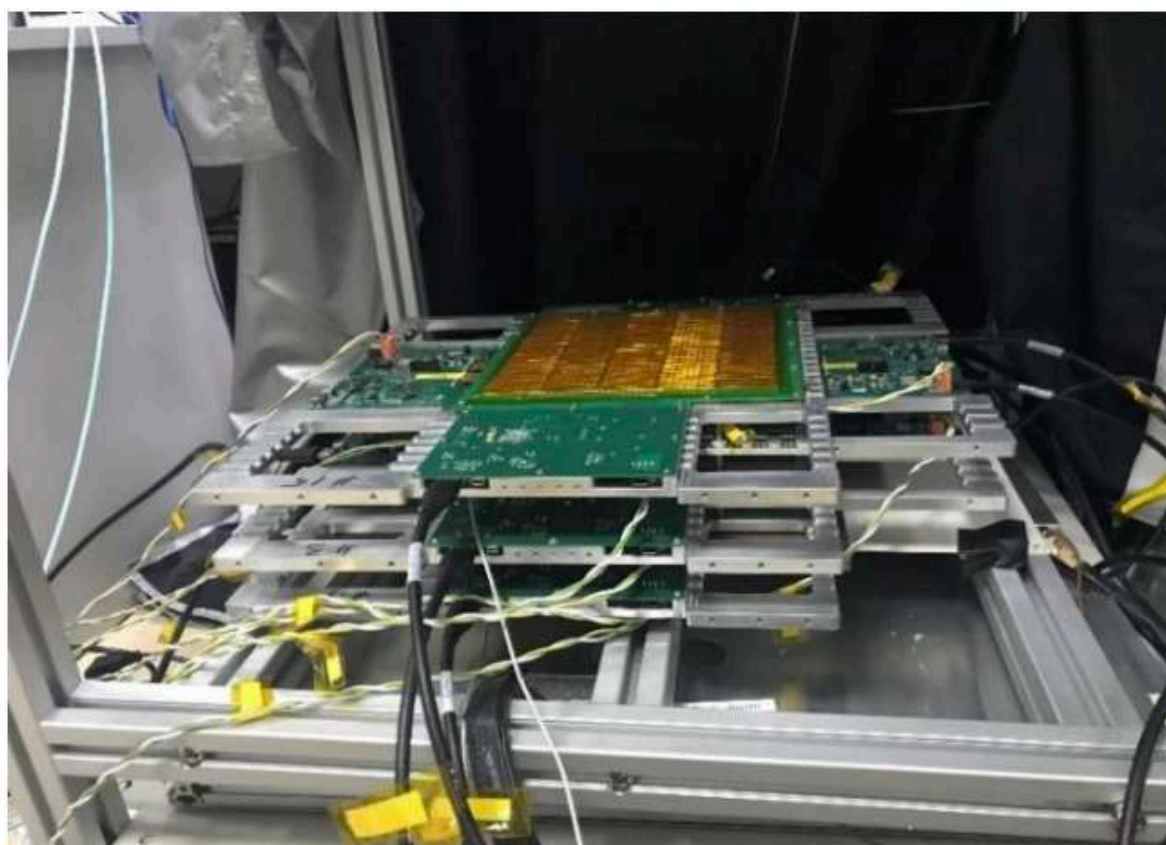
MIP test with Sr90

- Tested two layers of EBUs with $10\mu\text{m}$ SiPM and $15\mu\text{m}$ SiPM respectively
 - Self-trigger (auto-trigger)
 - SiPM on recommended voltage
 - Spectrum fit : langaus (landau \times gaus)
- **Distinct MIP signals can be detected both the SiPMs**



EBU combined test with DAQ

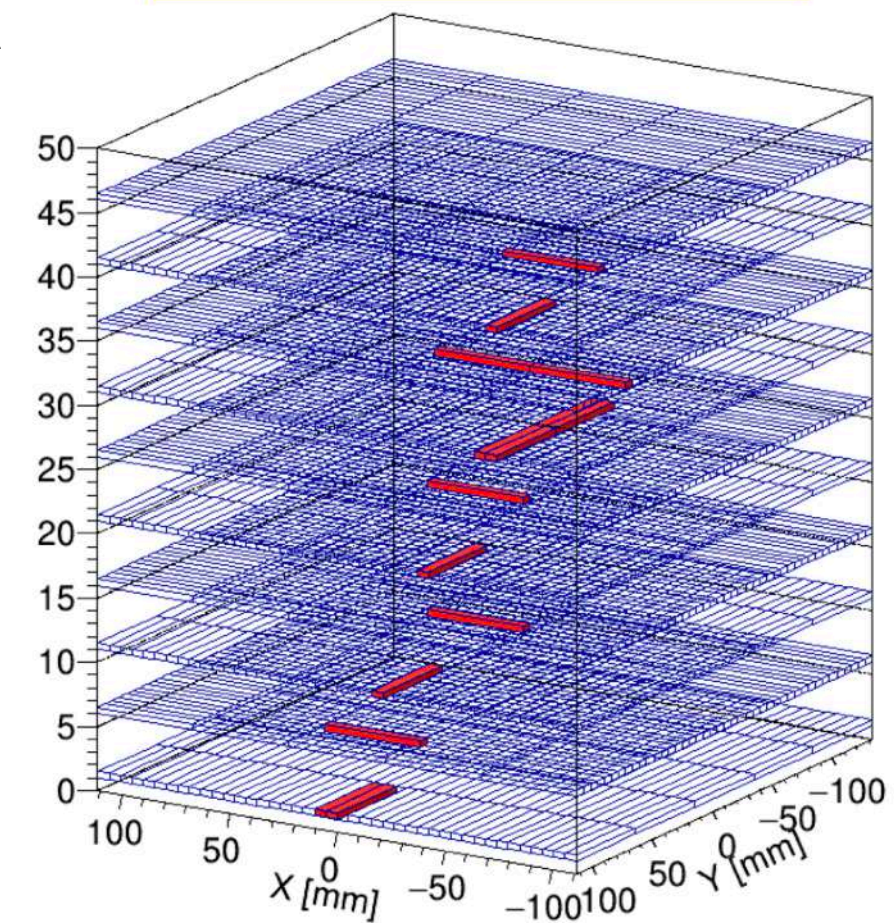
- 5 super layers (10 EBUs) are combined with FELIX
- Trigger as the coincidence of 2 EBUs
- Synchronize some EBUs using the same trigger



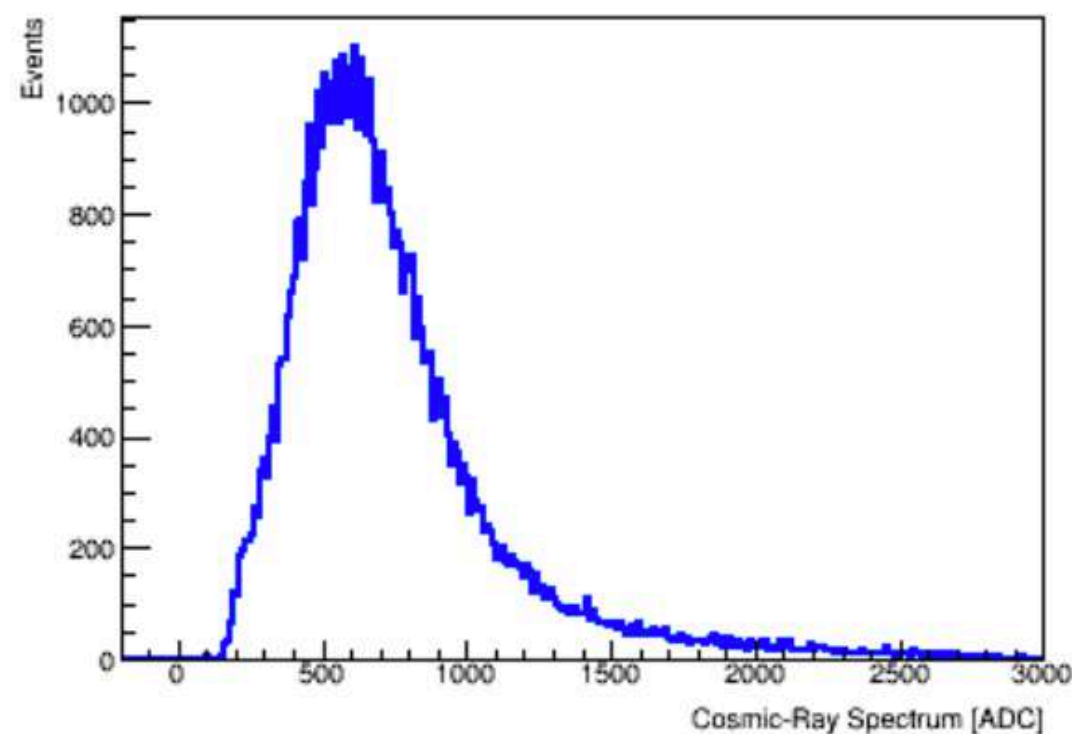
Cosmic-ray test result

- **The combined system worked properly and yielded correct data**
 - All EBUs functioned well
 - DAQ took data from each EBUs successfully
 - EBUs were properly synchronized
- Distinct MIP signals can be detected at each EBUs.

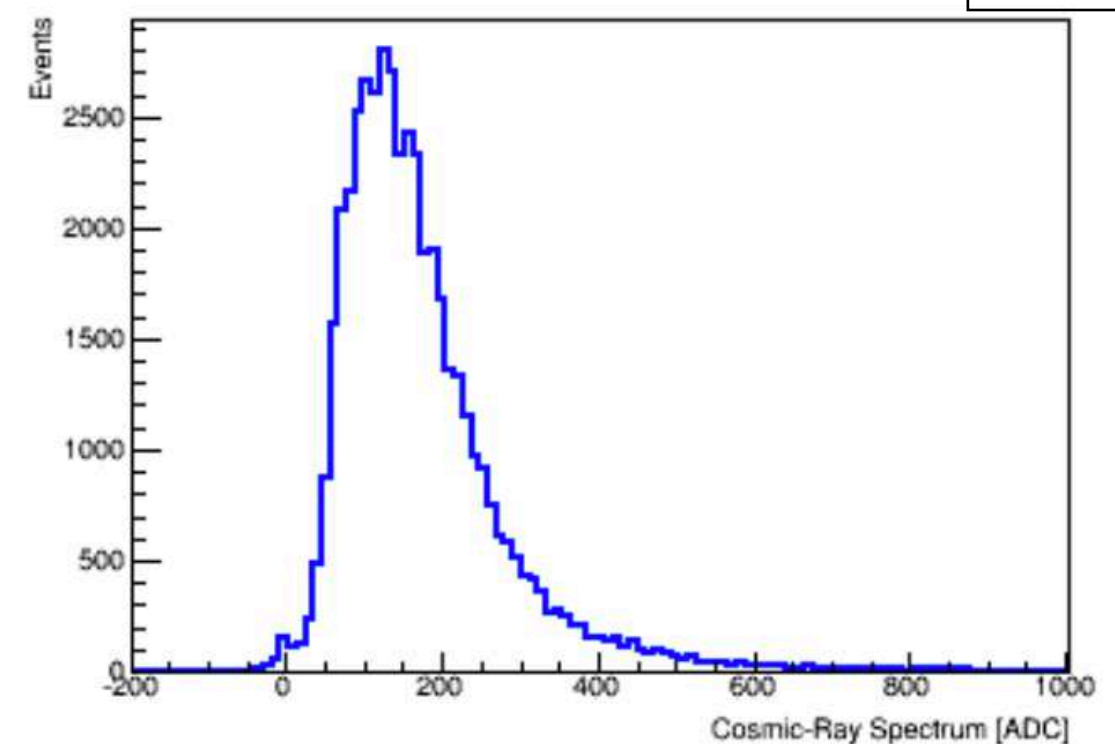
Tracking reconstruction



EBU with $15\mu\text{m}$ SiPM



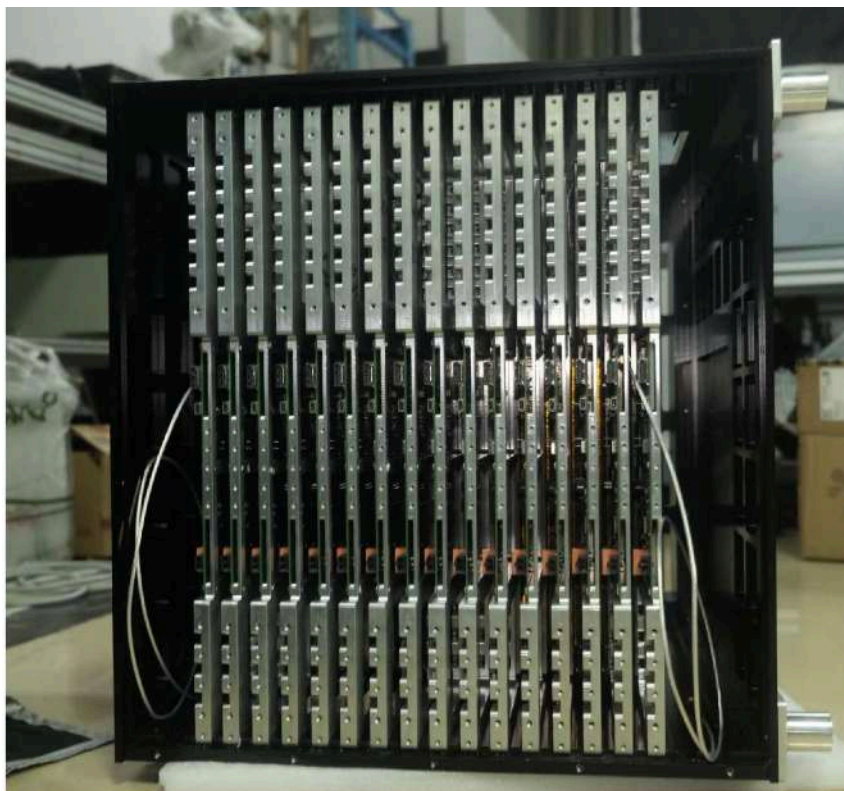
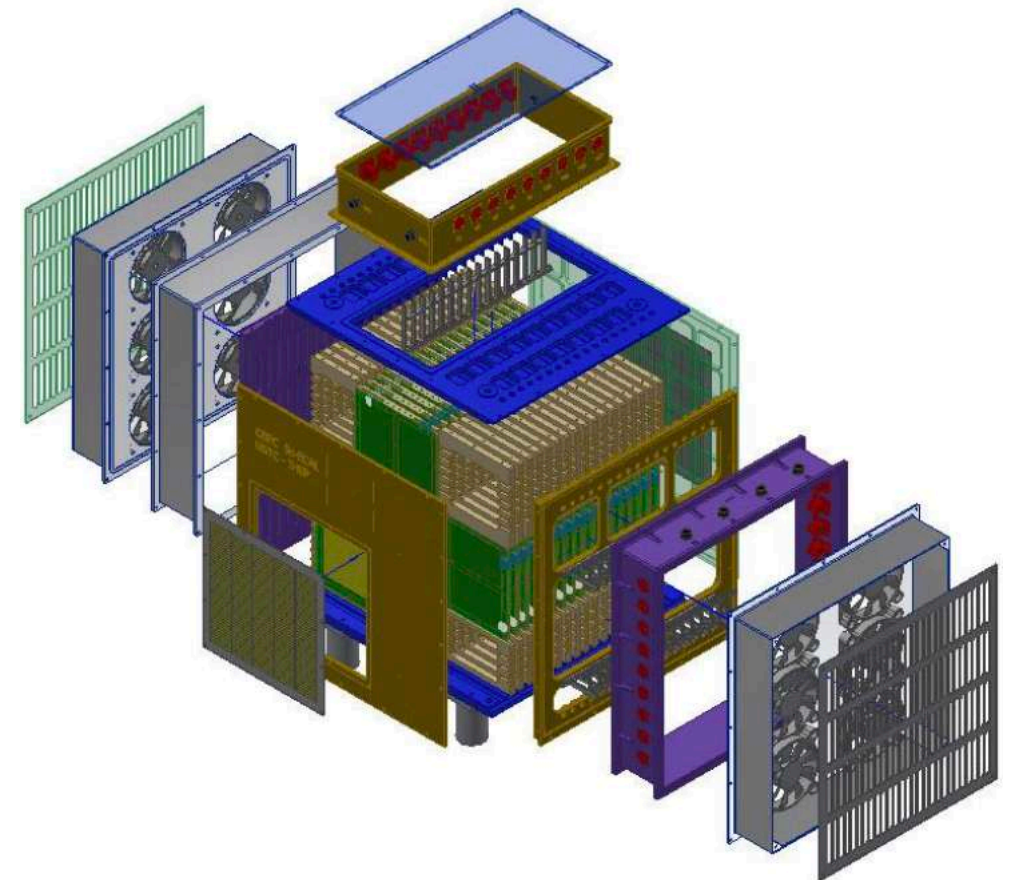
EBU with $10\mu\text{m}$ SiPM



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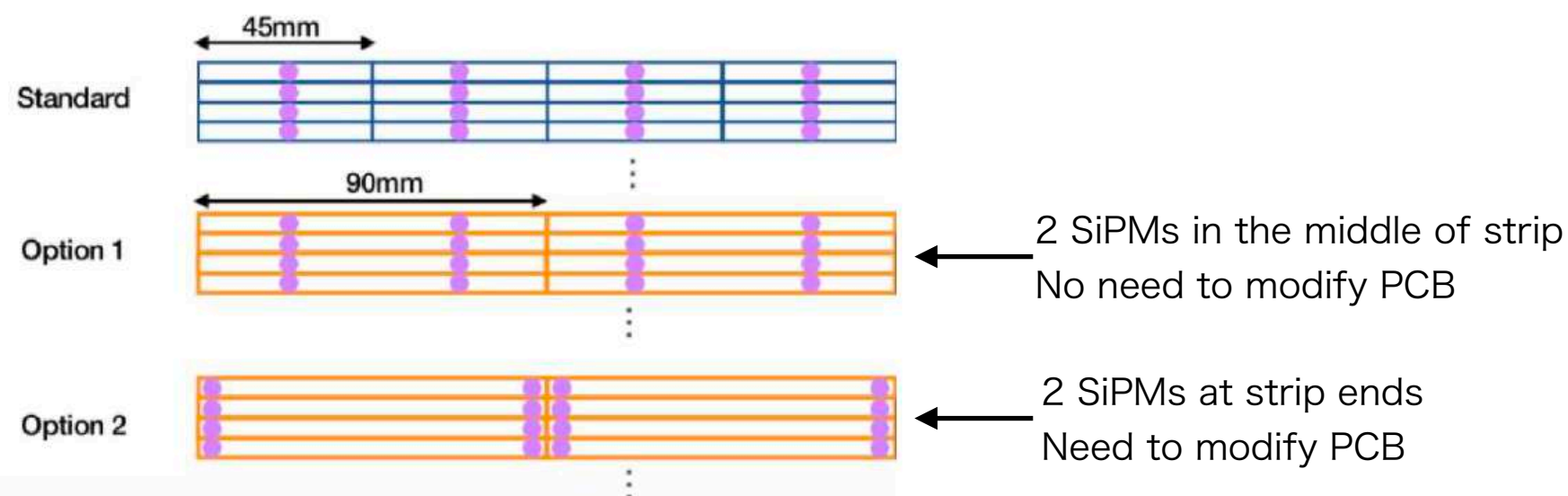
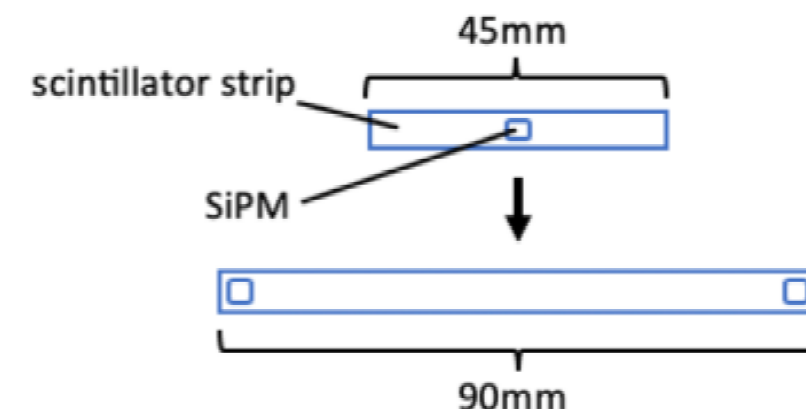
Mechanical structure

- The mechanical structure was manufactured
 - hold at most 17 super layers
- **Assembly of full Sc-ECAL prototype finished**



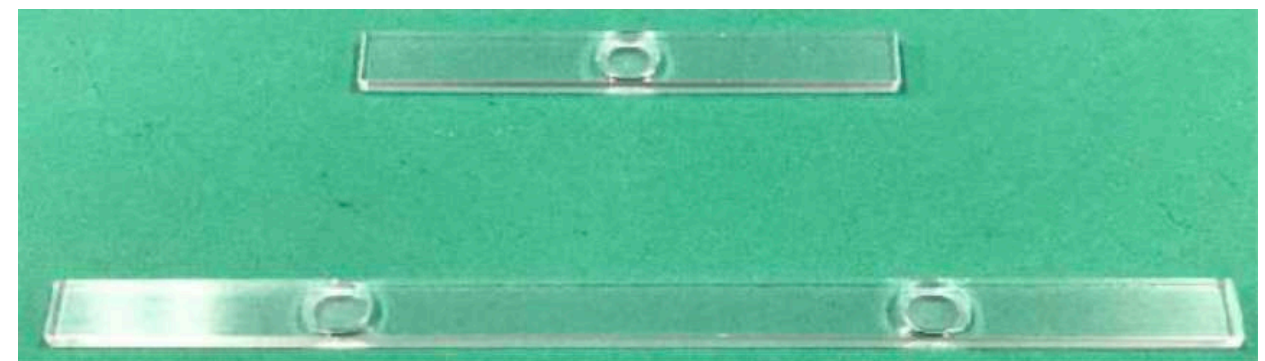
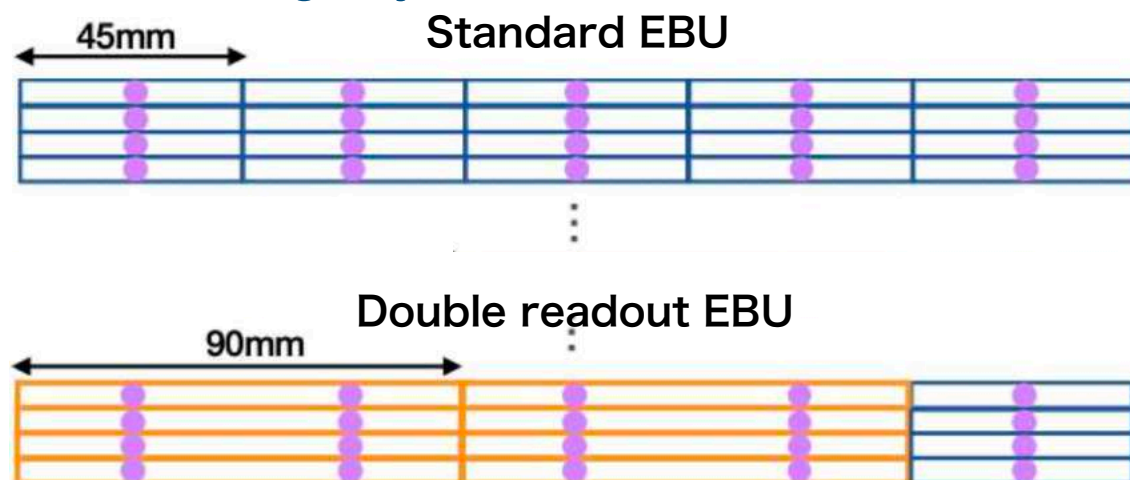
Double SiPM readout

- **Readout by 2 SiPMs at strip ends**
- Twice longer strip ($L=90\text{mm}$) to keep the number of SiPMs
- Possible advantages
 - Eliminating noise by taking coincidence
 - Higher light yield by summing 2 SiPM readouts
 - Even lower light yield for each SiPMs (\rightarrow less saturation)
 - Position reconstruction by charge and/or timing difference between two readouts (\rightarrow reduce ghost hits)
- **Two detection layers with double SiPM readout have been added to Sc-ECAL prototype**
 - Two possible implementations \rightarrow option 1 adopted



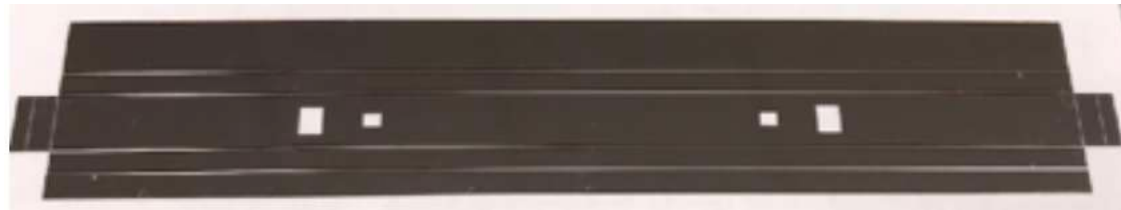
Production of scintillator strips for double readout layer

- **SiPM cavities in the middle of the strip (option1)**
 - Implementation with minimal modifications using standard EBU
 - Designs of strips and reflectors are the same as the standard EBU configuration
- **200 × 90mm strips** and **100 × 45mm strips** were produced
 - 5 rows of 45mm strips at 1 line for the standard configuration
 - 90mm + 90mm + 45mm at 1 line for the double-readout layer
- Scintillator strips produced by injection moulding
 - Injection moulding would be the only possibility for the large scale production
 - Production of large 2mm-thick plate by injection moulding → machining (strip shape + cavity)
 - Foreseen lower light yield compared to commercial PVT scintillator
 - Light yield test done



Reflector wrapping (90mm strip)

- Wrapping by hand with a help of jig



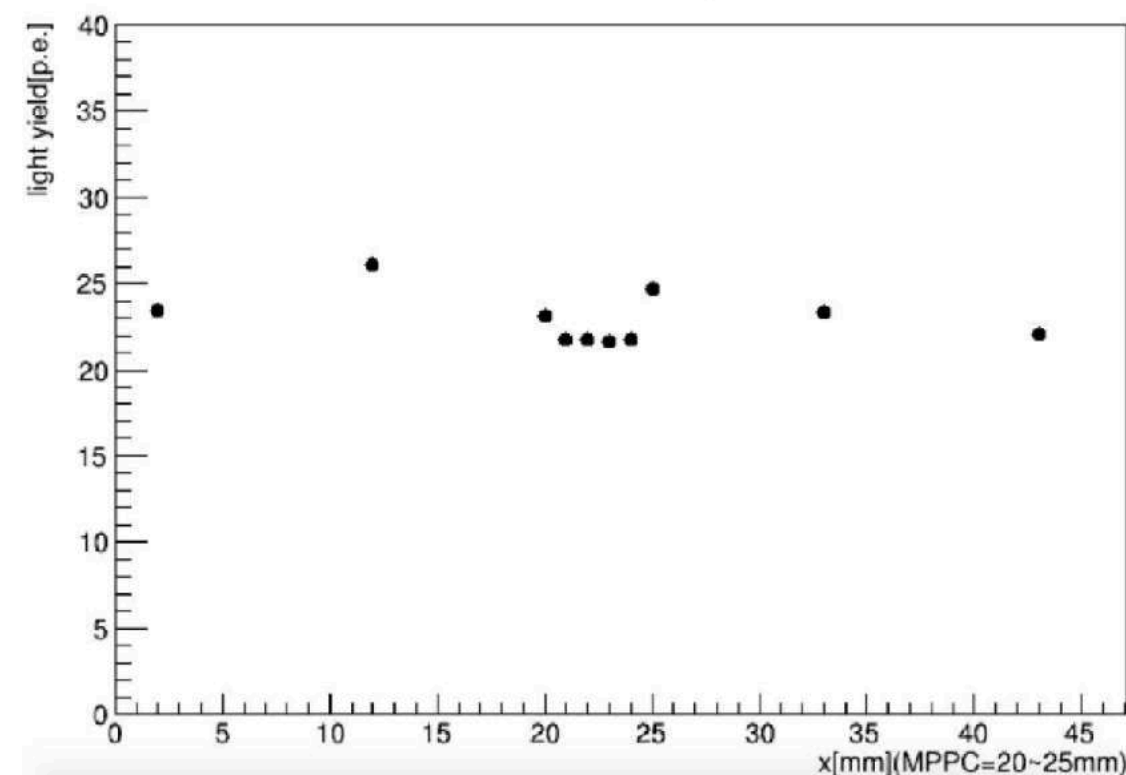
Light yield test & Cosmic-ray test

- LY of strip produced by injection moulding is lower by ~20% compared to the standard 45mm strip produced by China

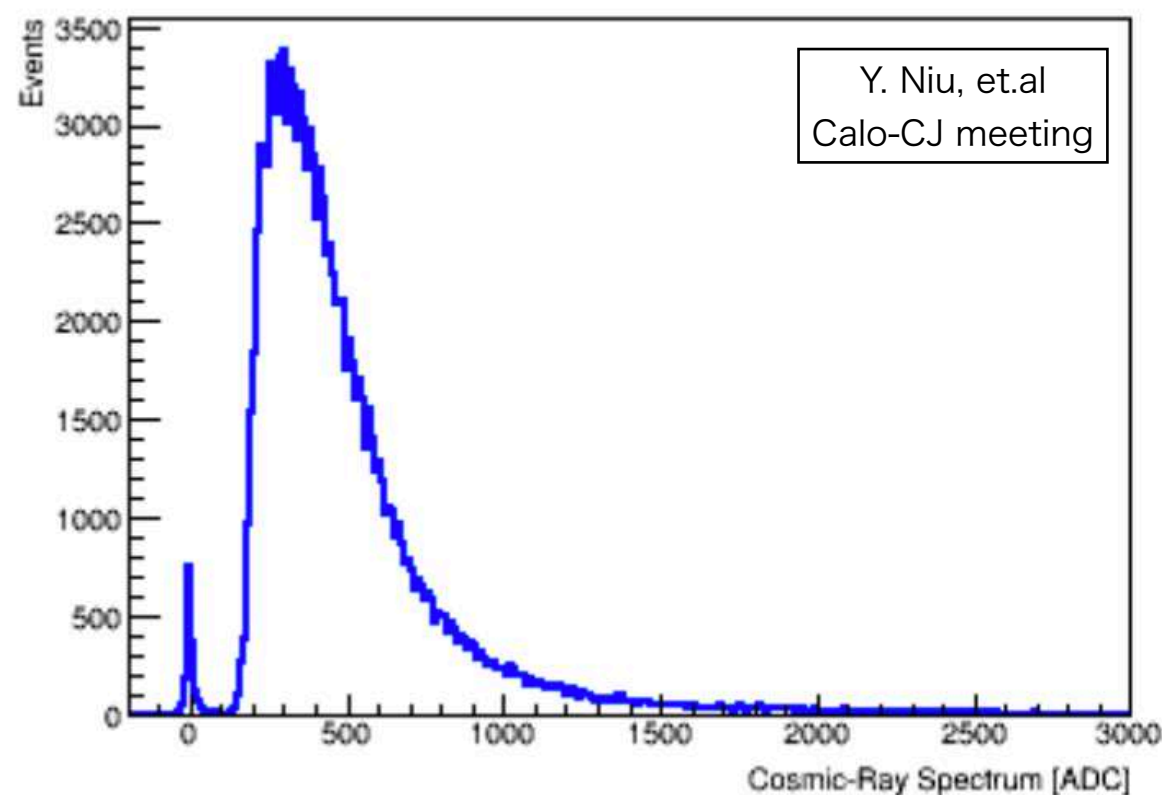
→ **Still sufficient light yield**

- Double-readout layer can also detect MIP signal at combined test

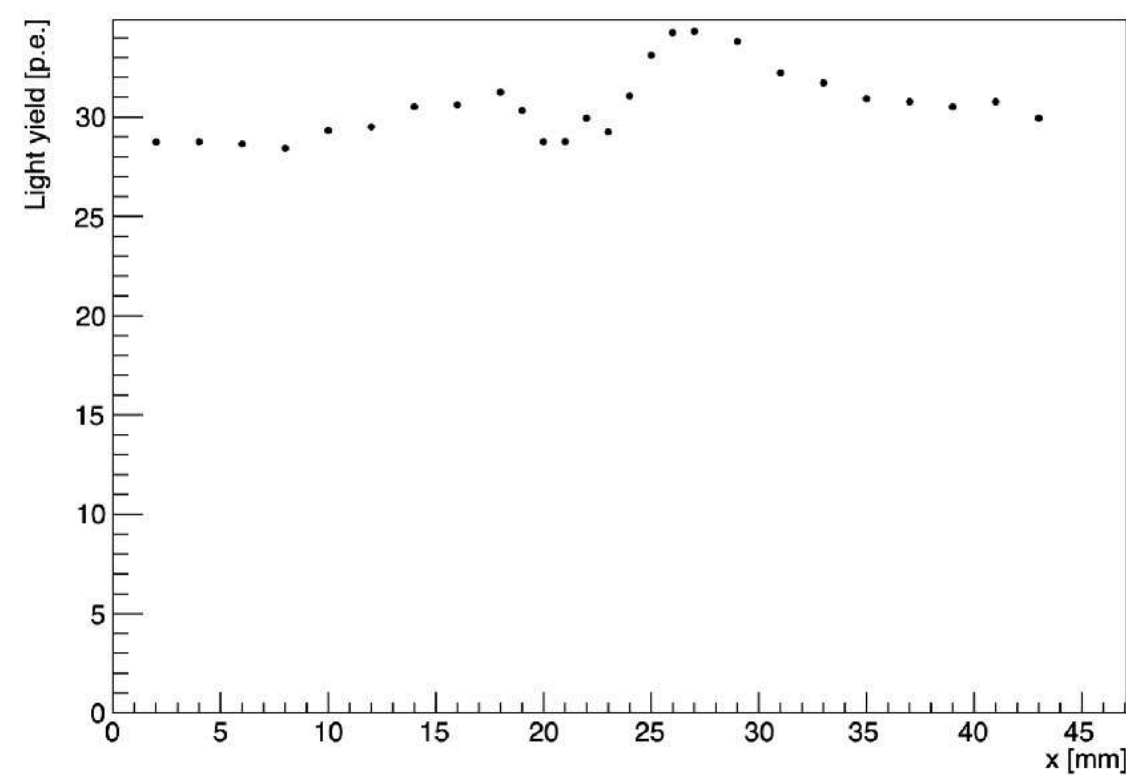
45mm strip produced by injection moulding



Combined cosmic-ray test for double-readout layer

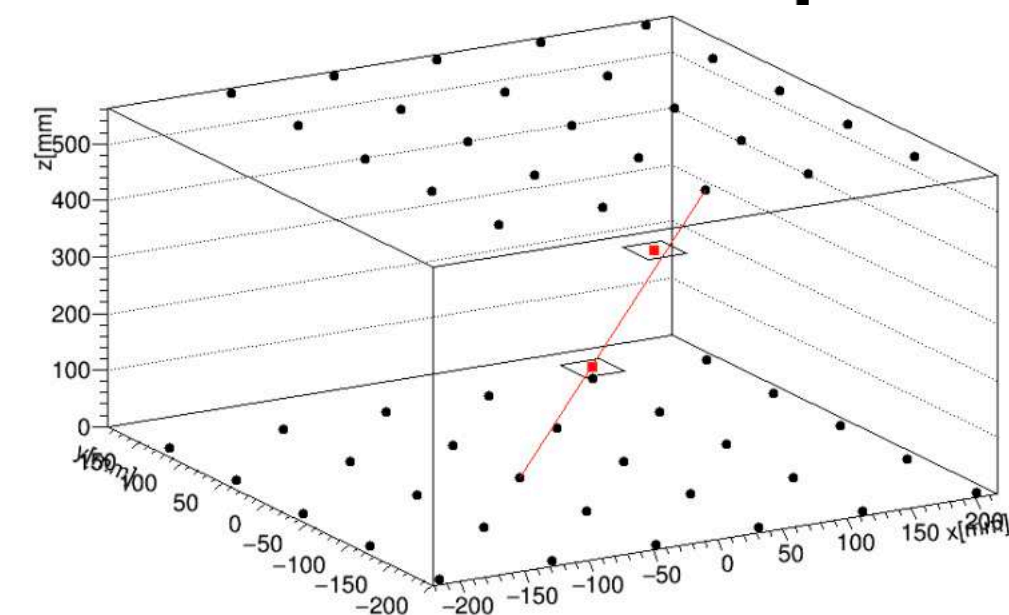
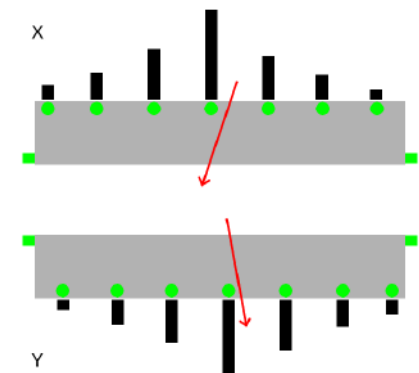
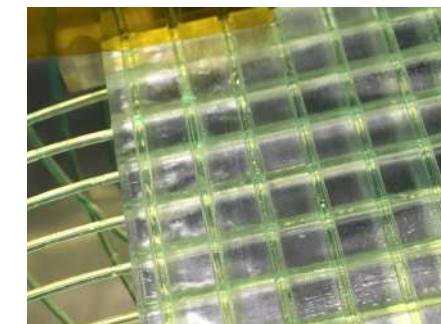
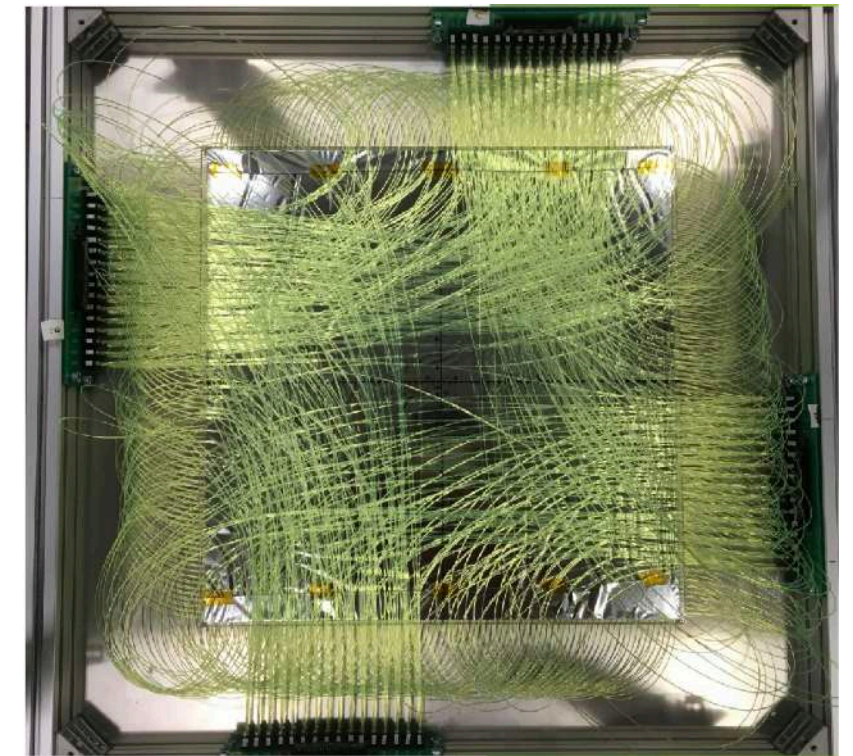


Standard 45mm strip for Sc-ECAL prototype



Cosmic-ray hodoscopes

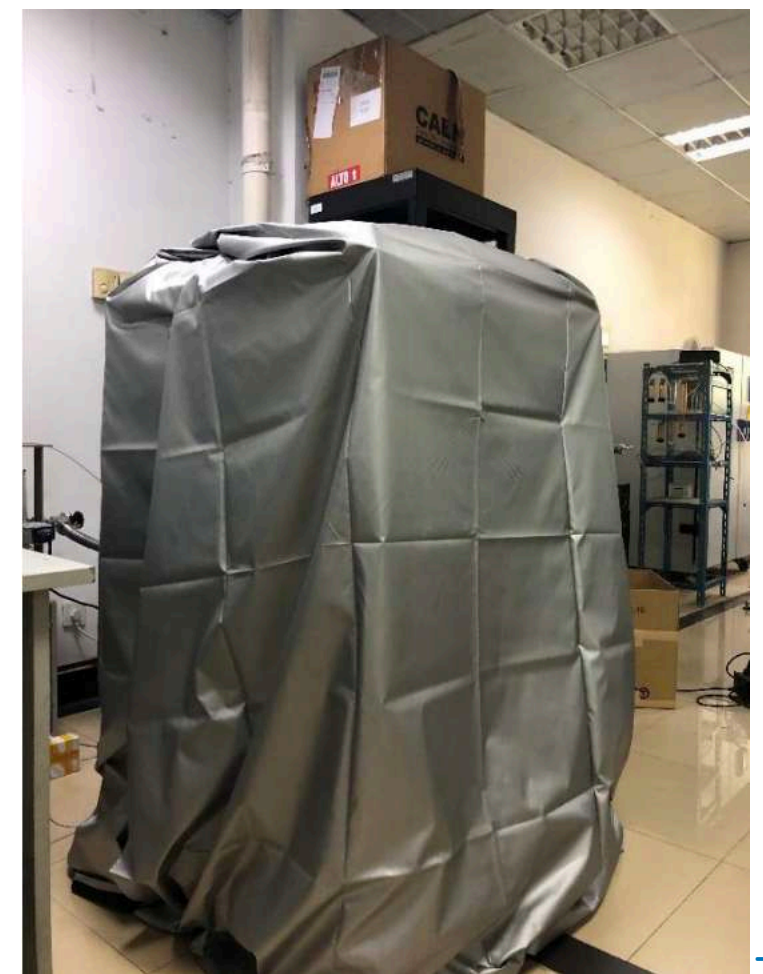
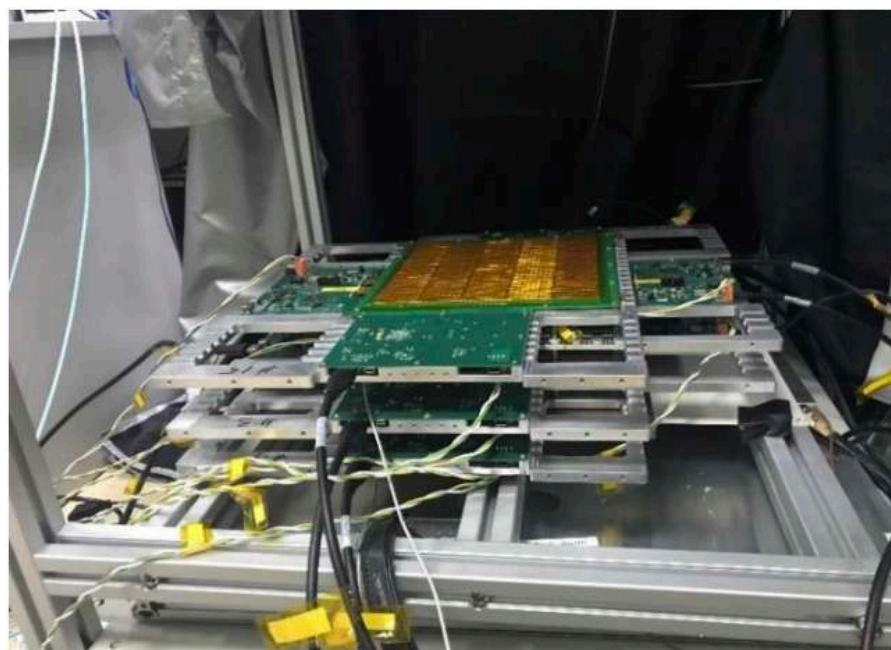
- CR hodoscopes were developed and commissioned at DESY in 2017
 - Use CR test for AHCAL larger prototype
 - See the proceedings at PD18 for details : <https://doi.org/10.7566/JPSCP.27.012009>
- To be used at CR test of the detection layers for Sc-ECAL prototype
- DAQ system for EBU is based on FELIX, while hodoscope DAQ is based on EASIROC module
 - The synchronization between 2 system is needed
 - EUDAQ framework can be used to operate 2 system simultaneously
 - EUDAQ producers under development



Hodoscope commissioning

- Hodoscope setup completed
- EASIROC module cannot work properly
 - Something wrong with power supply or FPGA
 - Now working on this matter

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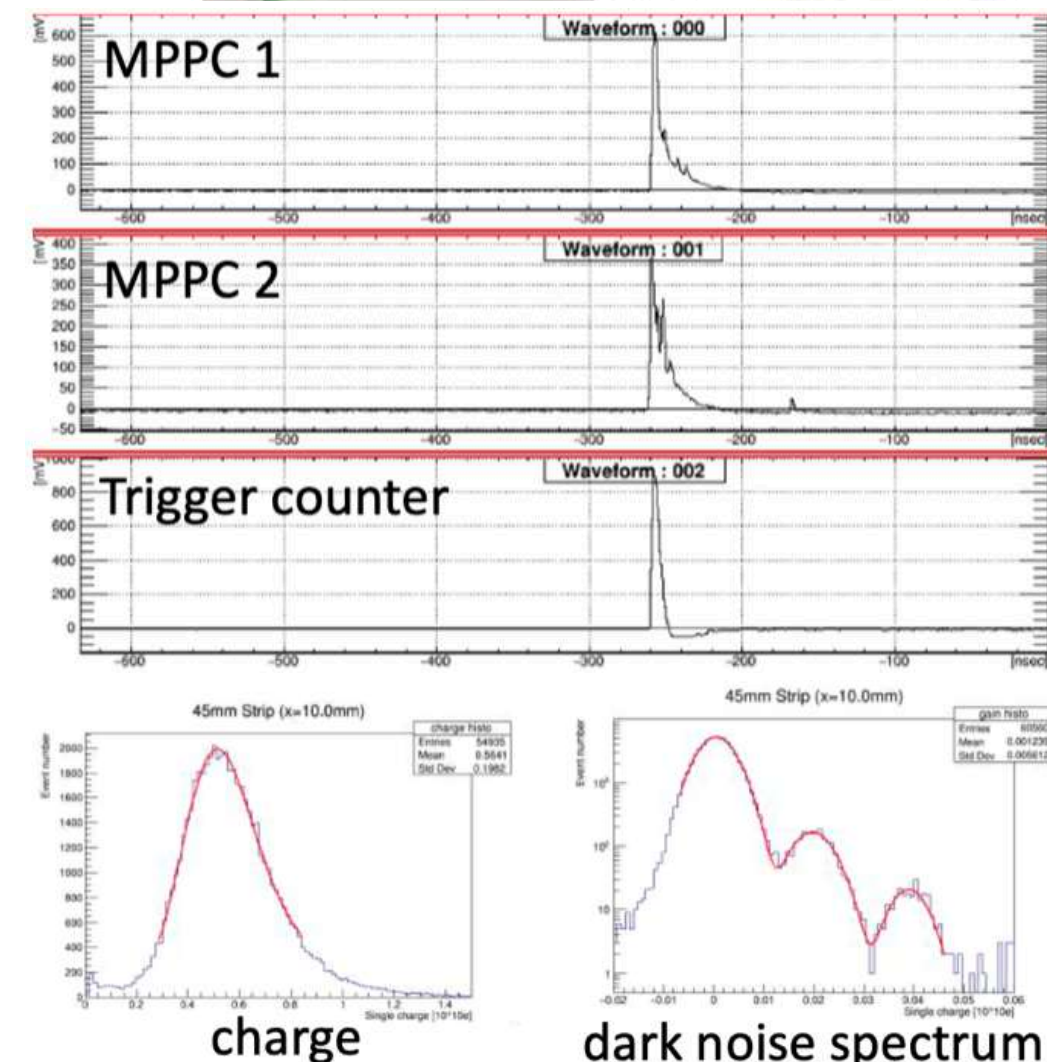
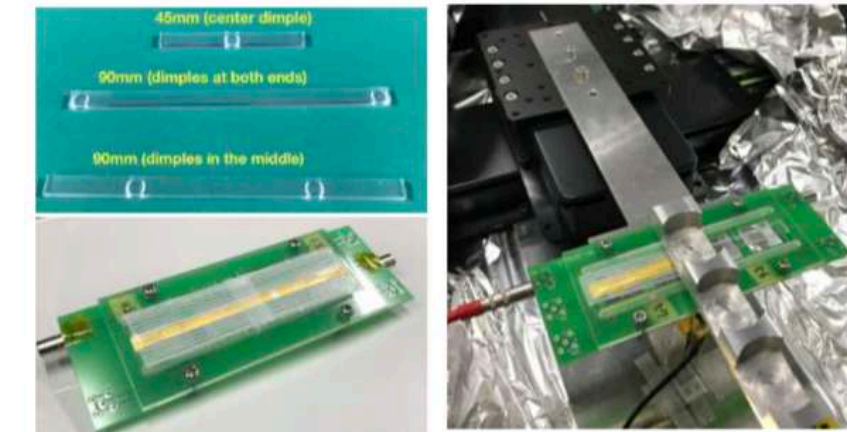
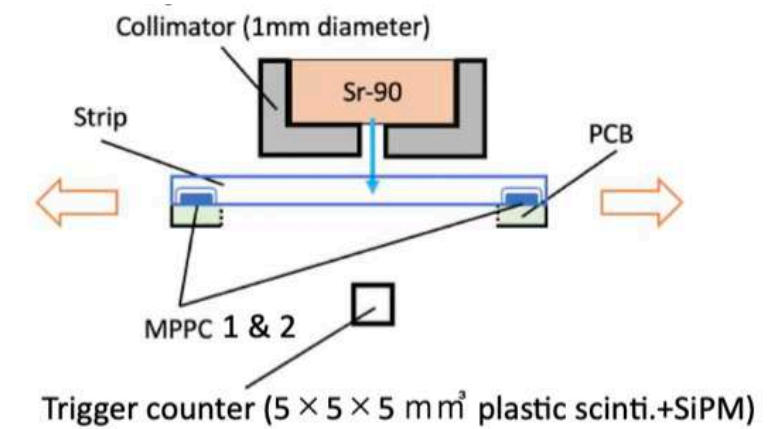
Summary and Prospects

- Large technological prototype for Sc-ECAL to be constructed
 - In preparation for test beam at DESY in 2021
 - Strip assembly on EBU and mounting on mechanical structure completed
 - EBU combined test with DAQ using cosmic ray successfully done
- Two detection layers with double SiPM readout have been installed to Sc-ECAL prototype
 - New readout method with double SiPM proposed to improve the performance of scintillator strip for Sc-ECAL
 - 2 detection layers using double-readout constructed
 - Combined test with the prototype successfully done
- Hodoscope commissioning
 - Mechanical setup finished
 - Dealing with some problems of EASIROC module

Backup

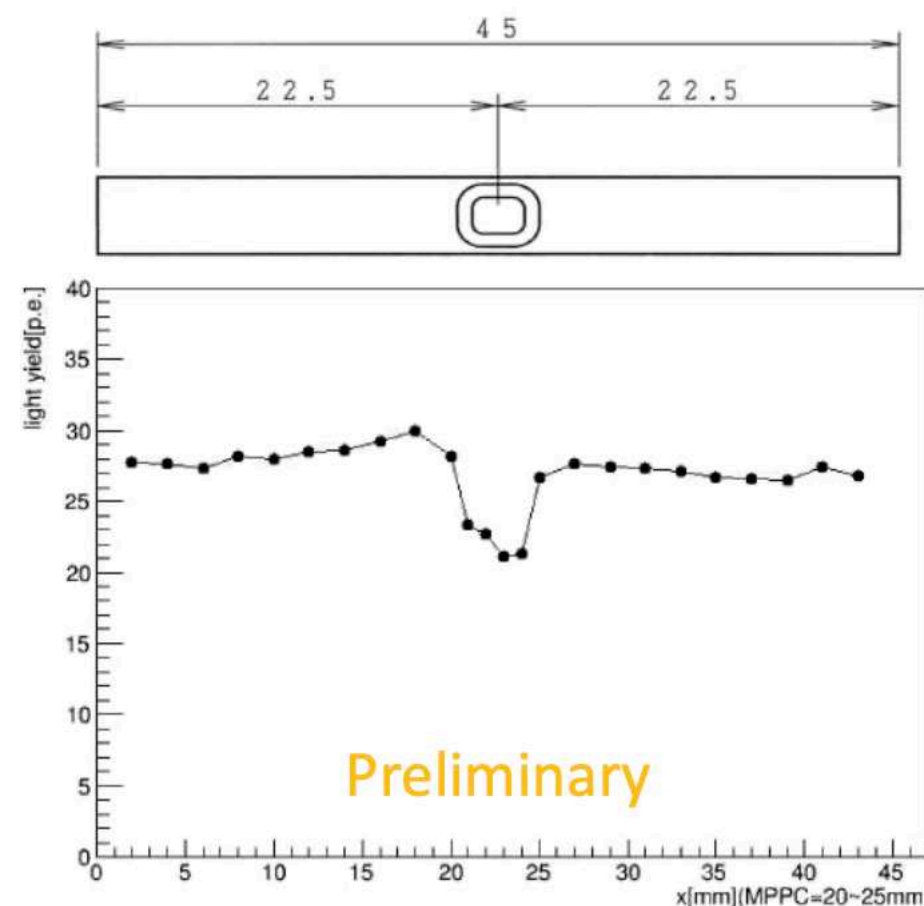
Setup

- Plastic scintillator : EJ-212 Reflector : ESR2
- MPPC : S12571-015P (1×1 mm², 15 μm-pixel)
 - V_{op} : ~68 V
- Measurement
 - Position dependence of N for 2 types of 90mm strips
 - 45mm strip with center dimple is also tested for comparison
- Waveform from MPPC is digitized by waveform digitizer
 - Digitized waveform is integrated to estimate charge
- The charge is then converted into number of photoelectrons being divided by single photoelectron charge



Performance test

- Just to check consistency with previous study
- $N_{pe} \sim 27$ (average)
- Larger than observed by Chinese group
 - Higher PDE for $15\mu m$ than $10\mu m$ MPPC used for Chinese setup
 - Lower V_{over} ($\sim 5V$) compared to $7V$ for Chinese setup
- Larger reduction of light yield around dimple
 - Misalignment (shift of sensor from center of dimple) can be considered

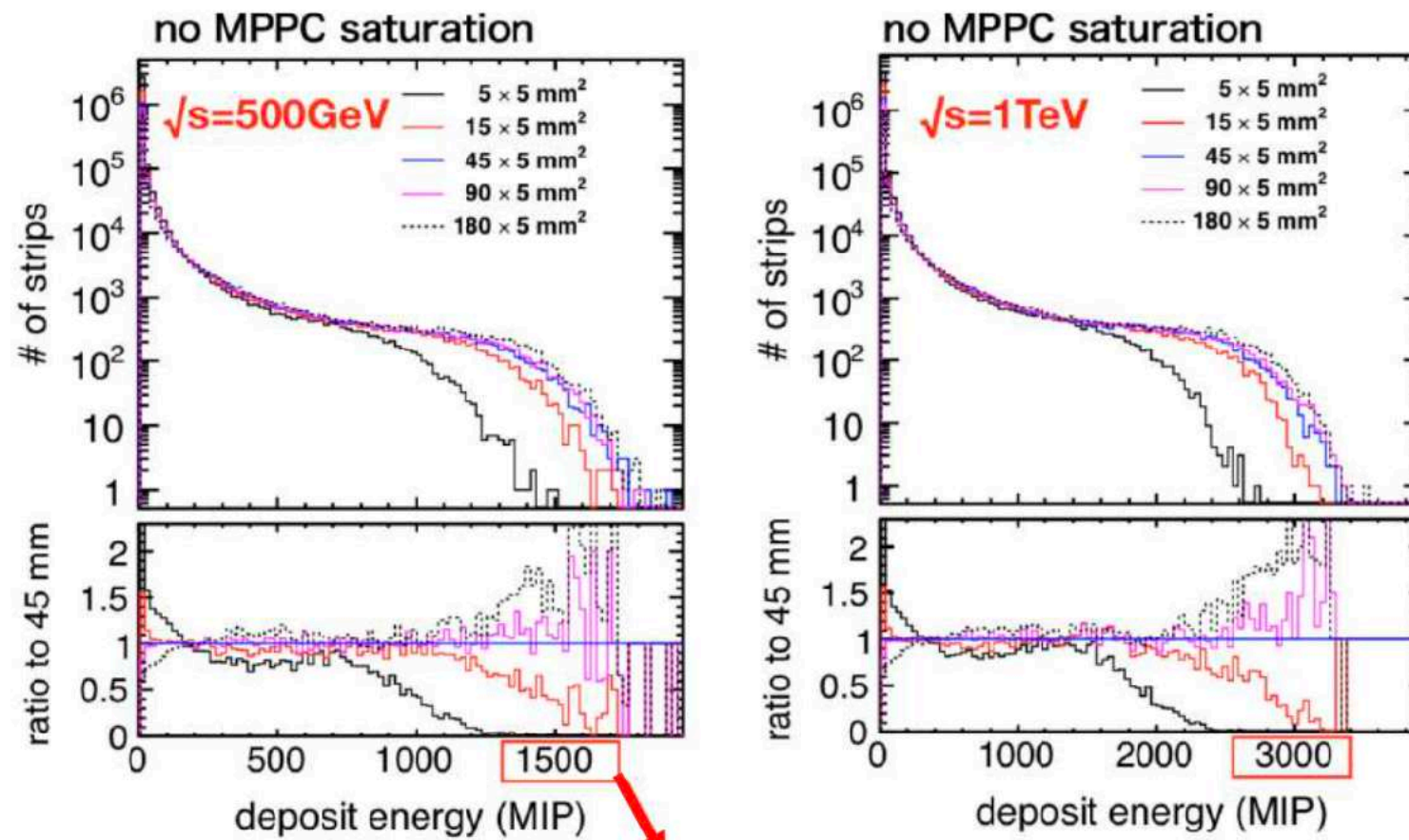


Measured by Chinese group
MPPC with $10\mu m$ pixel was used

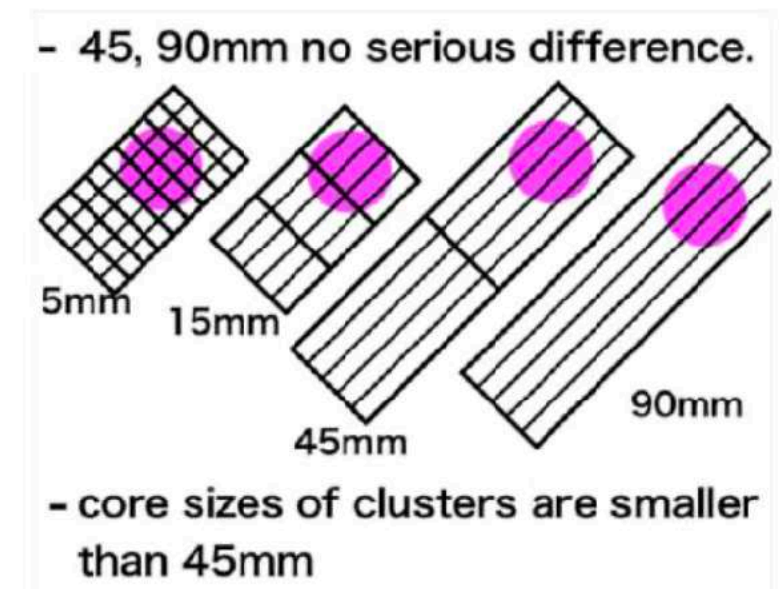


SiPM saturation with Longer Strip

- Previous MC study done by Shinshu University
 - Considering Bhabha events at $\sqrt{s}=500$ GeV & 1 TeV



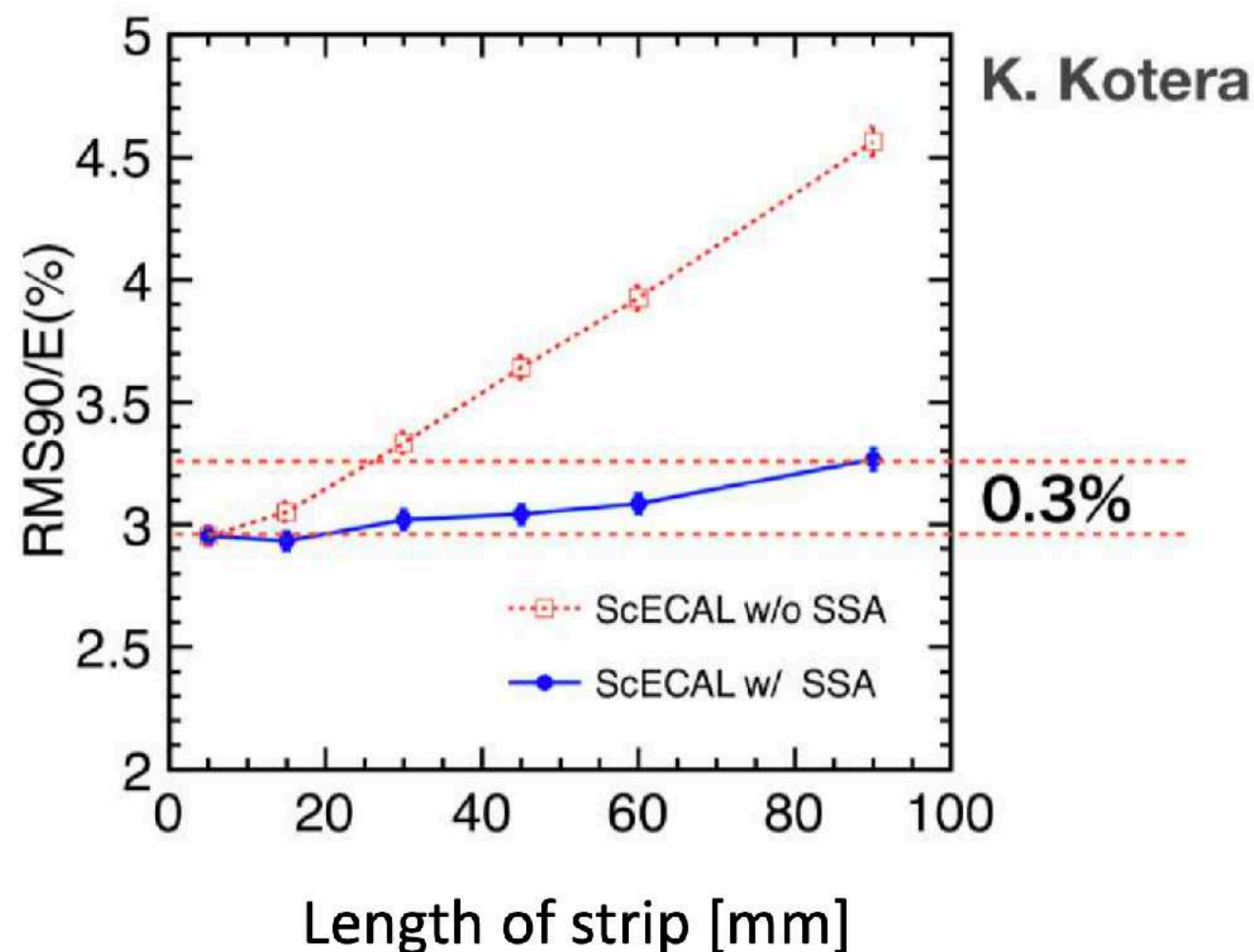
K.Kotera



- No significant difference at longer strip
 - Cluster size is smaller than strip length
- Saturation not worsened with longer strip

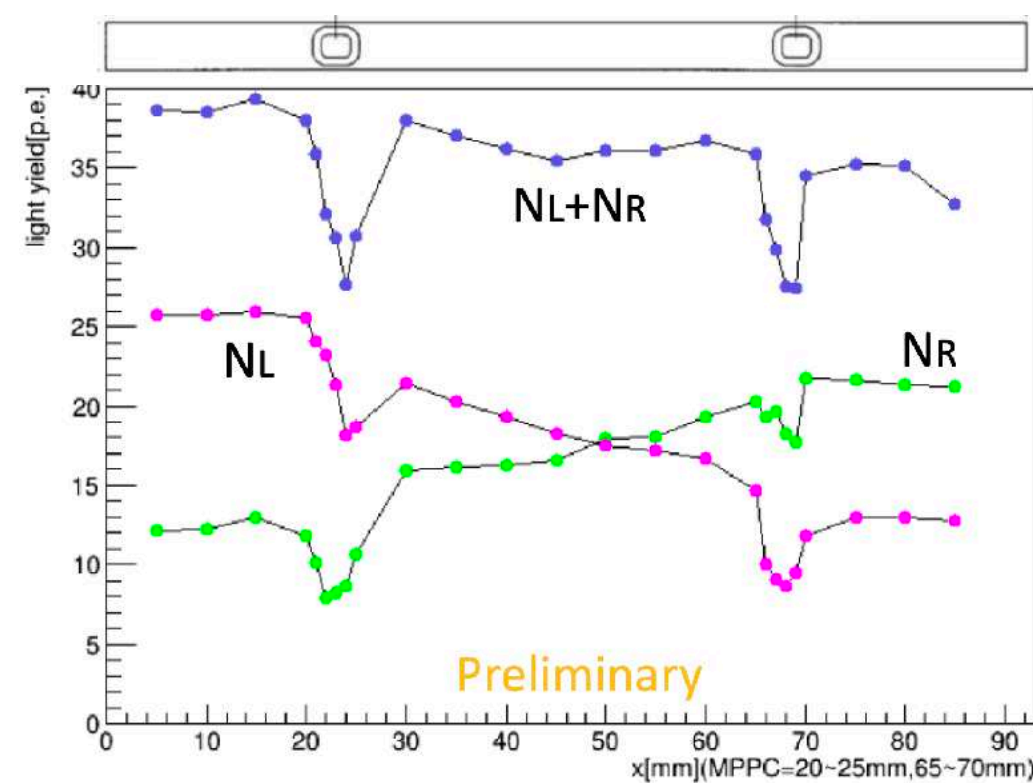
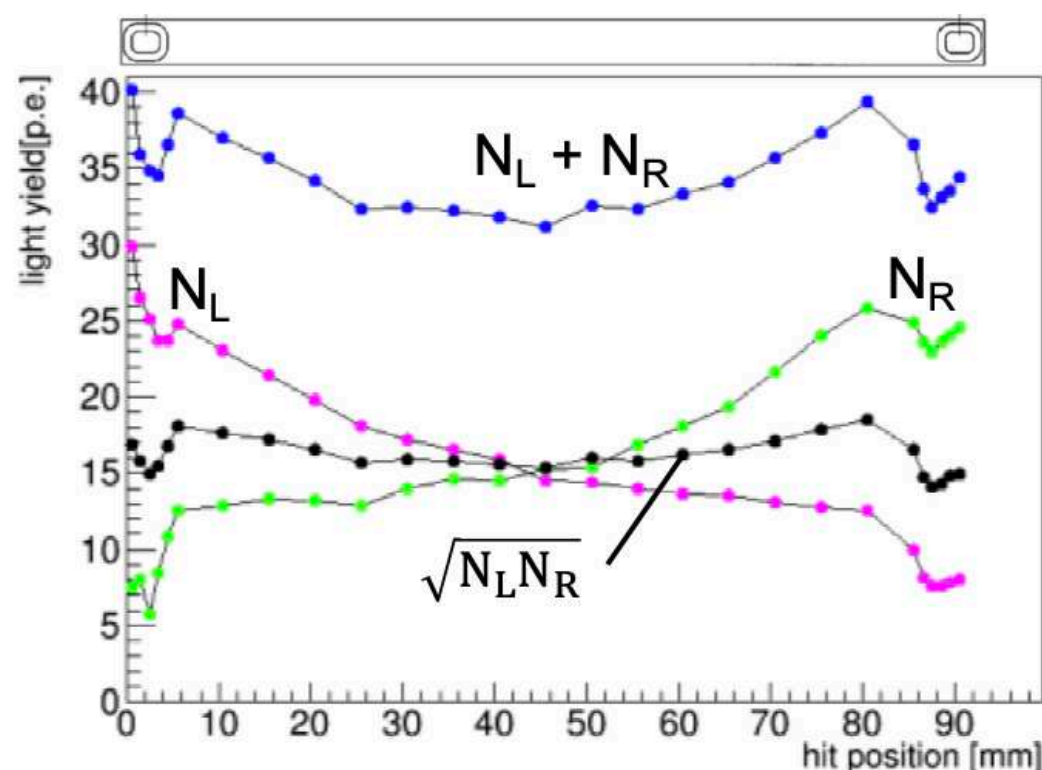
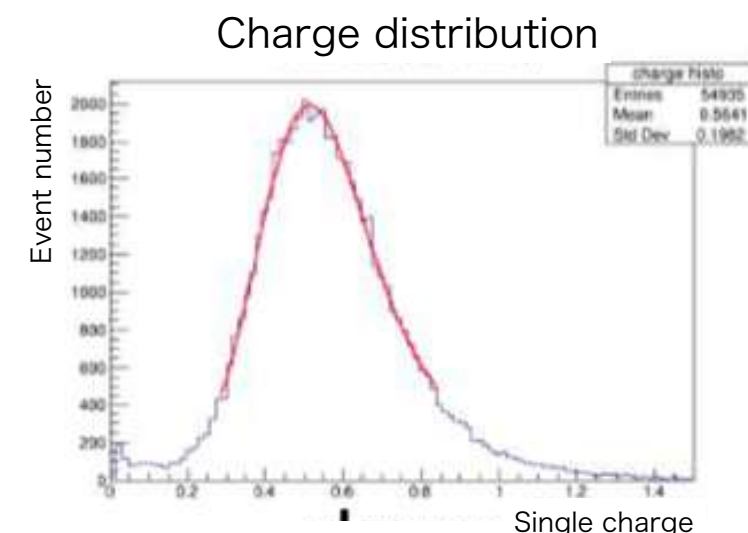
Jet energy resolution with longer strip

- Previous MC study done by Shinshu group
- JER slightly worsened for longer strip due to ghost hits and pile-up
- N.B. not taken into account possible improvements with double readout
 - Noise reduction by coincidence
 - Position reconstruction
- Planned simulation study to see the effect of double readout



Performance test

- Two SiPMs strip end
 - More or less flat response with sum of two readouts
 - Larger light yield (~35 p.e.) than 45mm strip (~27 p.e.)
 - Position-dependent N_{pe} for each MPPC readout
 - Possibility of position reconstruction using charge and timing
- Two SiPMs in middle of strip
 - More or less flat response with sum of two readouts
 - Larger light yield (~35 p.e.) than 45mm strip (~27 p.e.)
 - No position dependence outside dimples
 - No chance of position reconstruction outside dimples

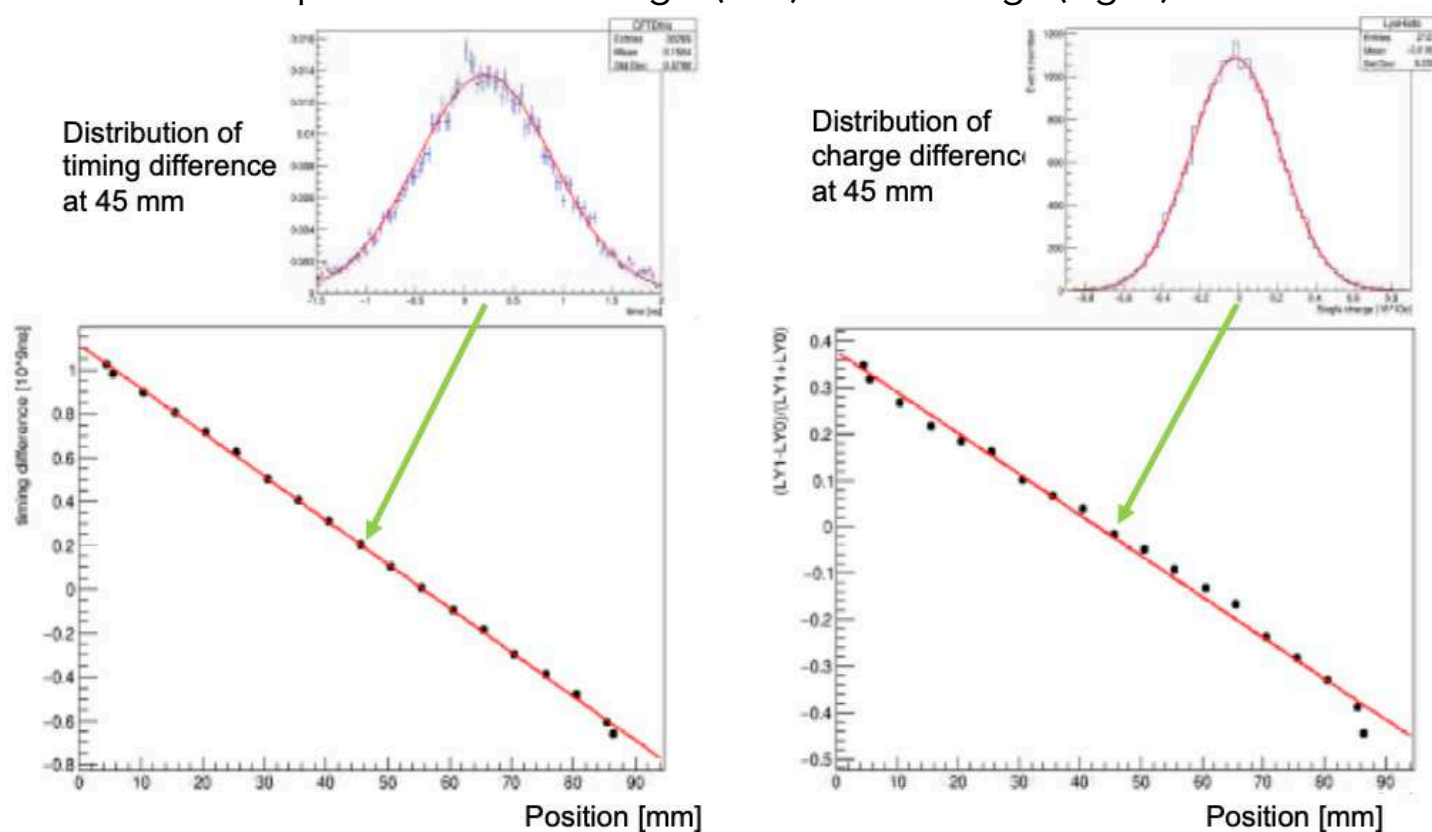


Position reconstruction

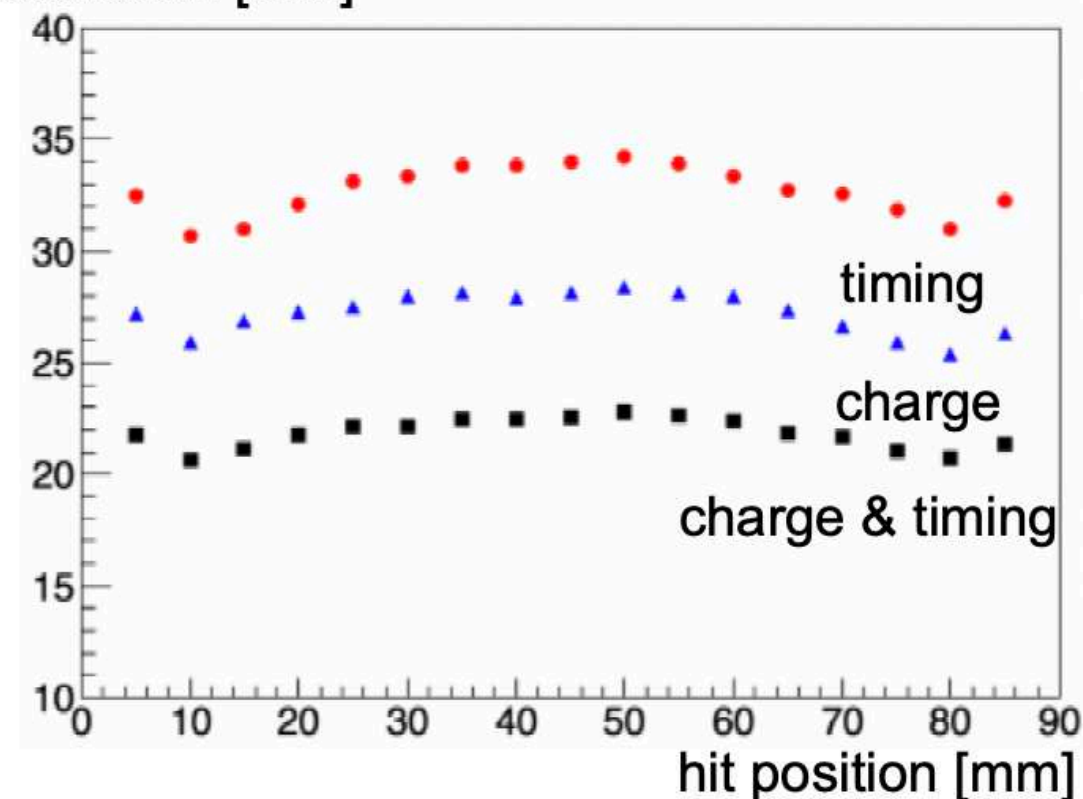
- Position reconstruction from weighted mean for charge and timing difference
- **$\sigma \sim 20\text{mm}$ was obtained with combined reconstruction**
 - The achieved resolution is not too bad
 - The effect in calorimeter performance to be studied by MC simulation

$$X = \frac{\frac{x_{\text{charge}}}{\sigma_{\text{charge}}^2} + \frac{x_{\text{time}}}{\sigma_{\text{time}}^2}}{\frac{1}{\sigma_{\text{charge}}^2} + \frac{1}{\sigma_{\text{time}}^2}}$$

Position dependence of charge (left) and timing (right) difference

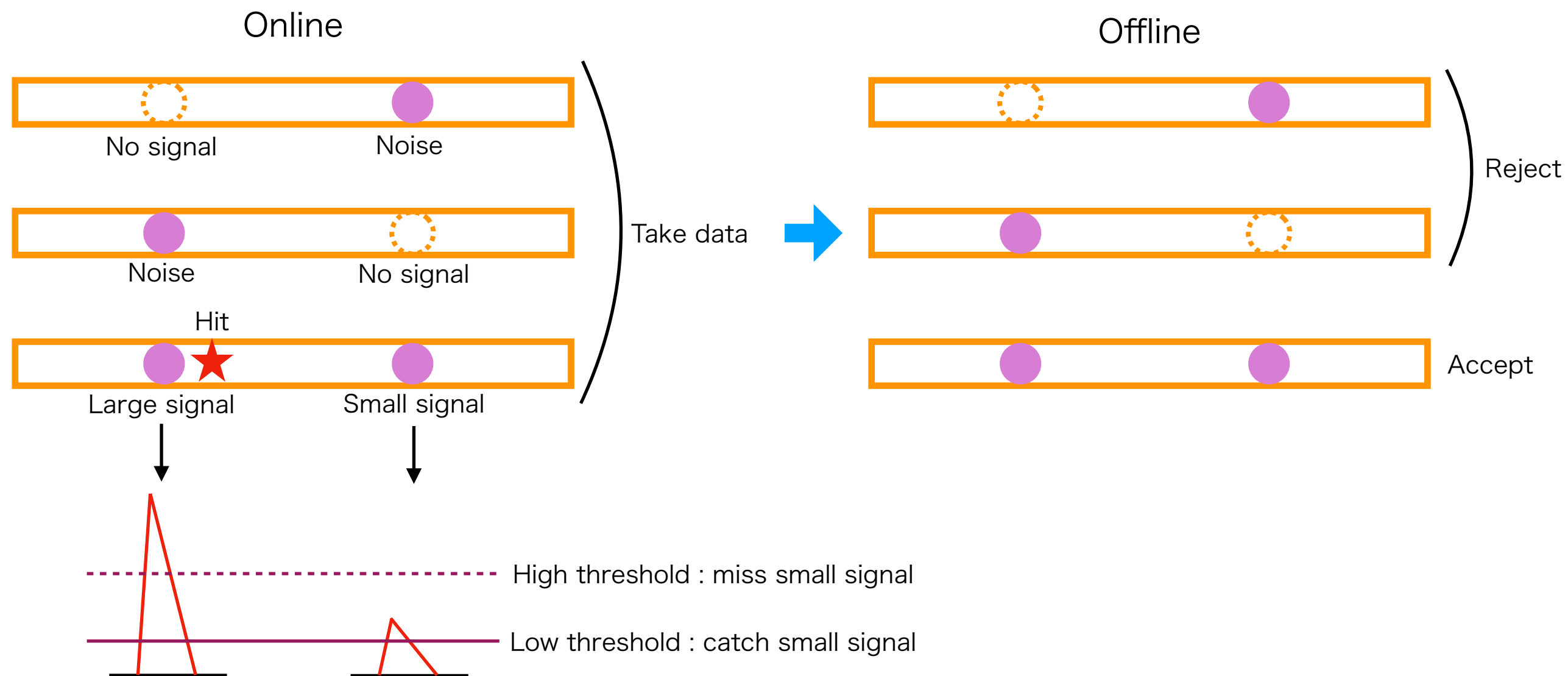


Position dependence of light yield for 90mm strip resolution [mm]



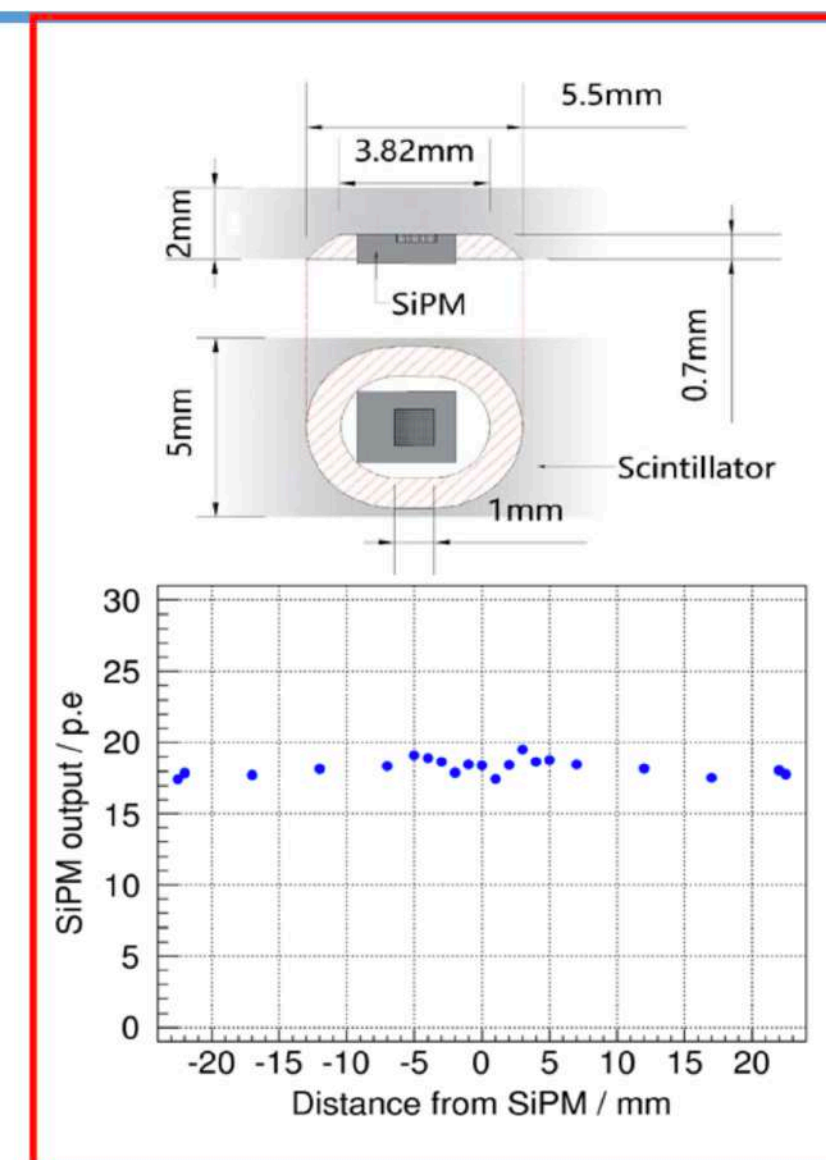
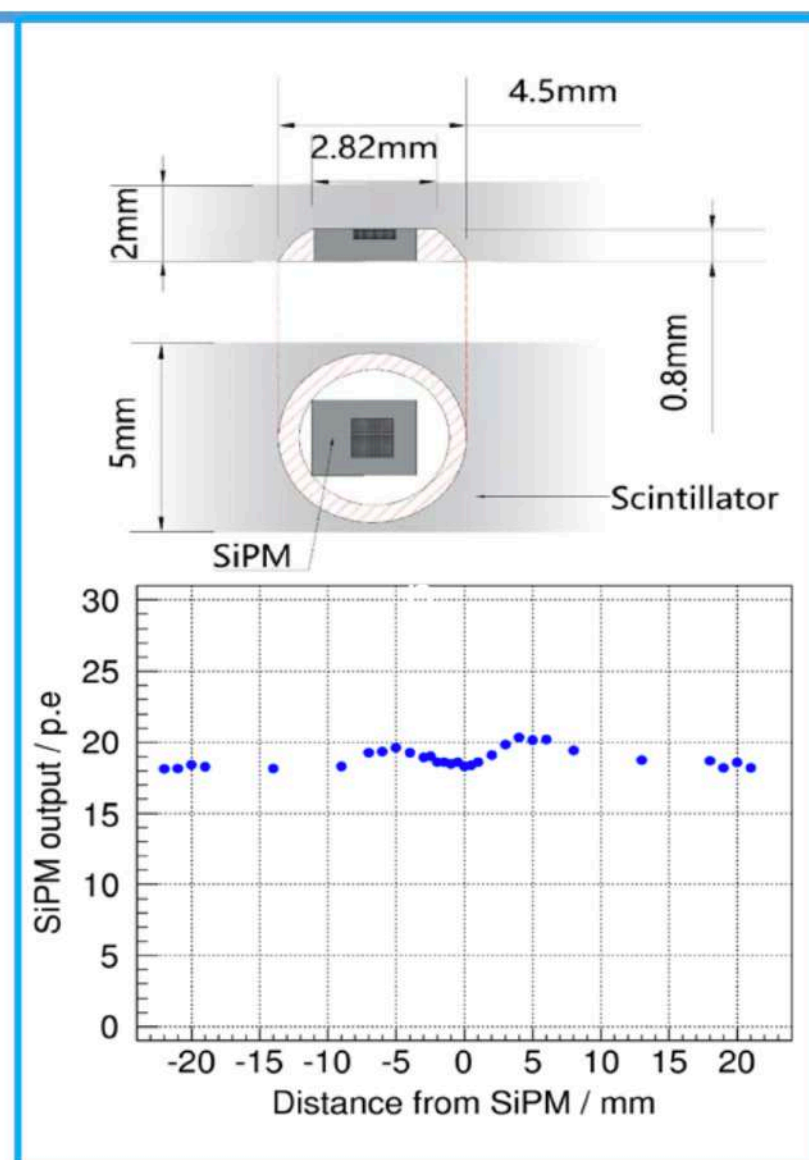
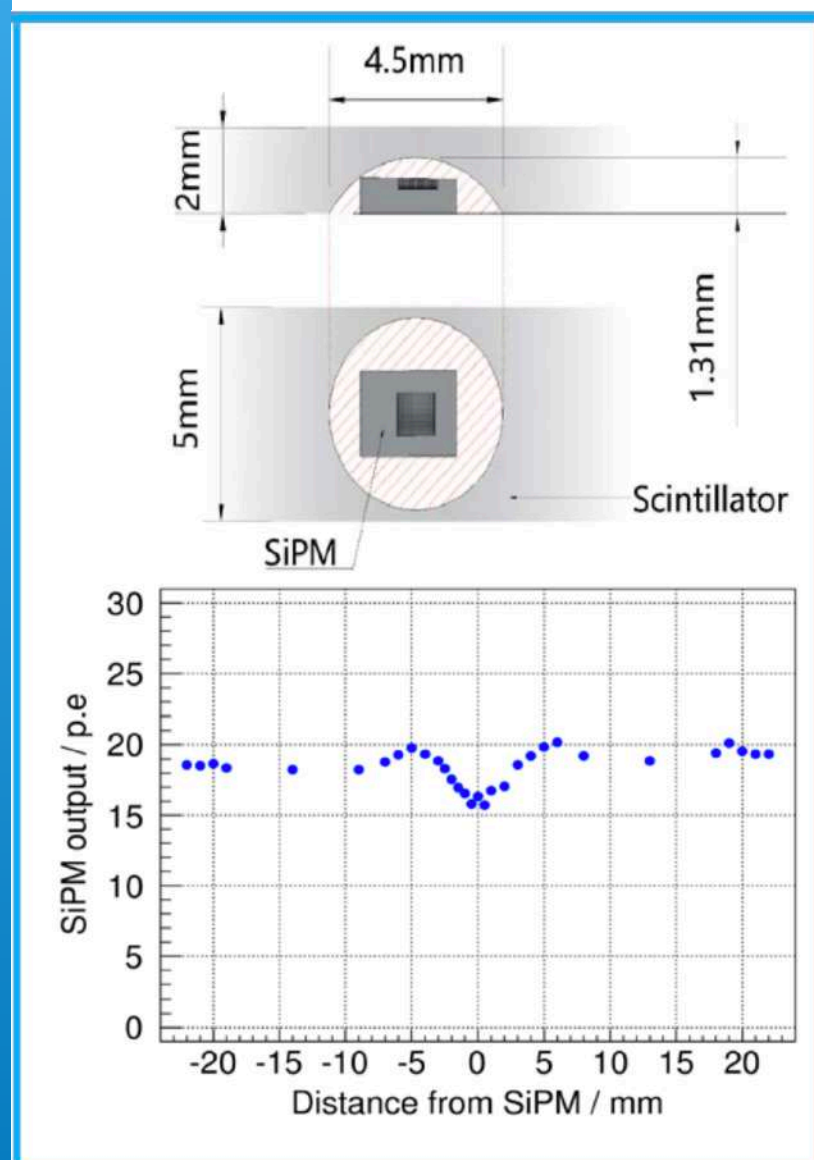
DAQ

- Double-readout layer uses the same DAQ system as the standard layer
 - Online coincidence between two SiPMs is not possible in the current DAQ system
- Noise reduction by taking coincidence in offline analysis
 - Need dedicated low threshold run



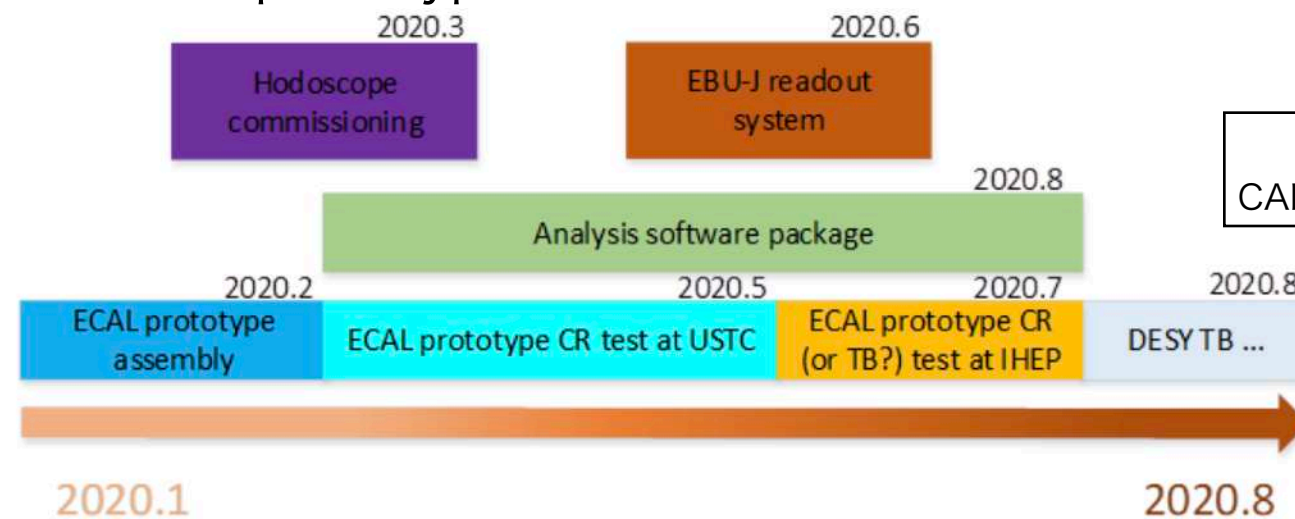
Design of the bottom-center coupling

- The uniformity of the sensitive cell with a racetrack-shaped dimple can reach 4%



Status & Schedule

- Status of Double-readout layer
 - Soldering of SiPMs on EBU was completed
 - Double-readout strips wrapped with ESR have shipped to China
 - Strip assembly on EBU will be done at a Chinese company in March
 - The commissioning will be done in China in March and April
 - Calibration using position-sensitive cosmic-ray hodoscopes
- Schedule of the Sc-ECAL prototype:



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6-Jul-20	28		Target Aug.2020: perform test beam in DESY for full ECAL prototype						
13-Jul-20	29								
20-Jul-20	30								
27-Jul-20	31		BL4S	X	Belle-II PXD	X		AFP-TOF	
3-Aug-20	32		CMS OT 2S	X	Belle-II PXD	X	LCTPC-Pix	X	
10-Aug-20	33		MBI	X	Summer Students	X	LCTPC-Pix	X	
17-Aug-20	34		ATLAS-ITk-TJCMOS	X	CEPC-ECAL	X		CALICE AHCAL	X
24-Aug-20	35		CMS-Pixel-Phase2	X	CEPC-ECAL	X		CEPC-STCF	X
31-Aug-20	36		CMS-Pixel-Phase2	X	MUonE	X		CEPC-STCF	X
7-Sep-20	37		CLIC Pixel	X	ELAD	X		BCGS	X