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High-granularity crystal calorimeter: the first module development and beam test

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on behalf of CEPC Calorimeter Working Group

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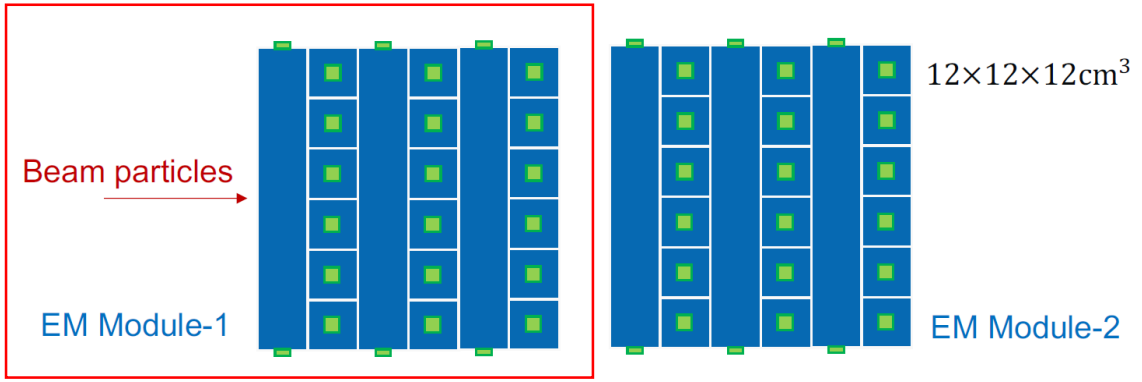
Outline

Crystal module development and beam test:

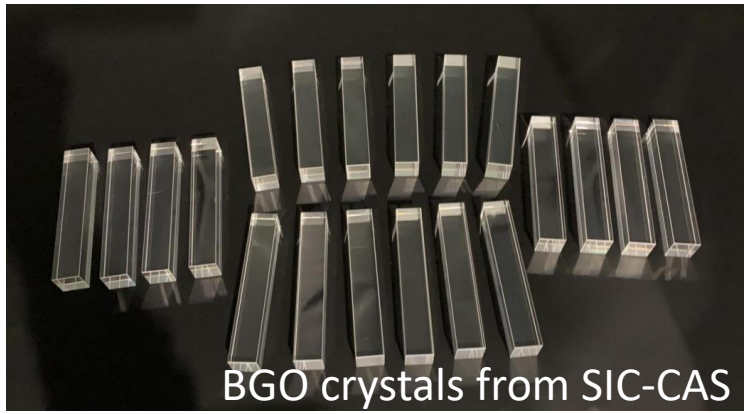
- Recap: crystal module development
  - Uniformity scan of BGO crystal bars
  - Mechanical and PCB design
  - Electronics and trigger scheme
- Crystal module beam tests at CERN T9 beam line

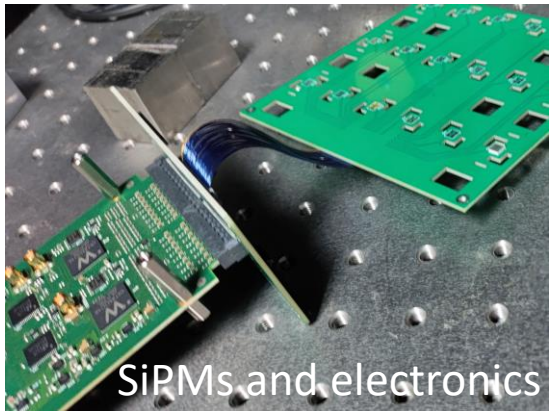
Introduction to the first small-scale crystal module

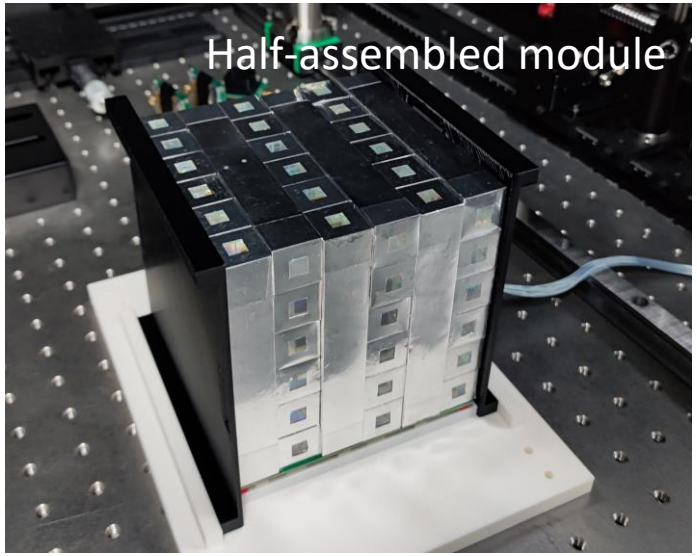
- Motivations: address critical issues at system level
- First 12×12×12 cm^3 BGO modules development
  - Crystal: 36 BGO crystal (12×2×2 cm^3) from SIC-CAS
  - SiPM: HPK 10 μm pixel size, 3×3 mm^2 sensitive area
  - Electronics: Citiroc-1A chips
- Beam test plan
  - Muon, electron and pion data at CERN T9 beam line for the first module (generally < 10 GeV/c)
  - Future plan: 2 modules serial arrangement



Beam test for the first module: 72 channels, double-sided readout







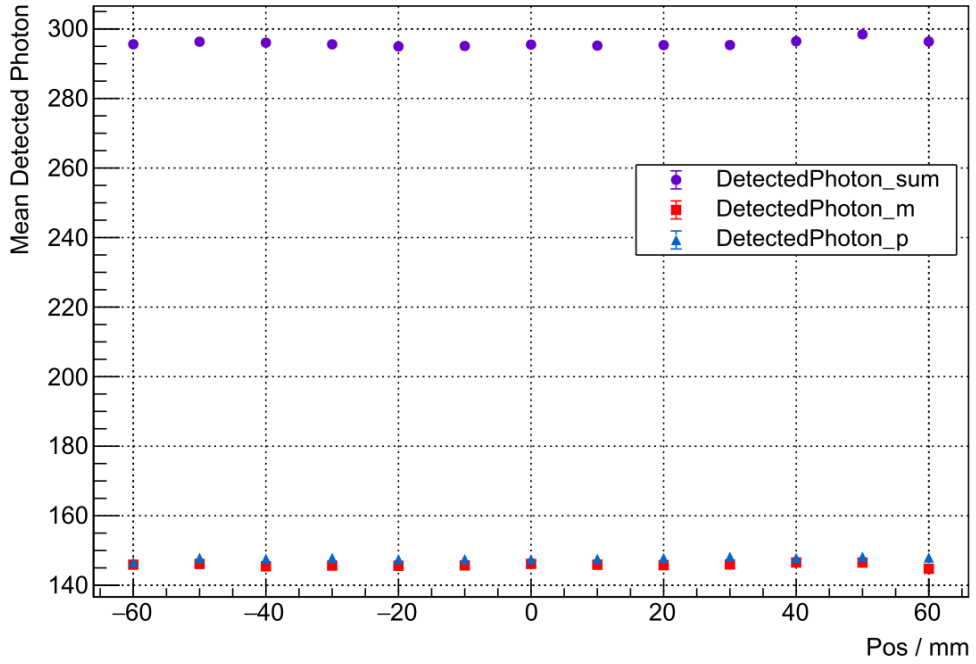
- 36 crystals wrapped with ESR and Al foil
- 3D printed support structure

Uniformity scan of BGO crystal bars

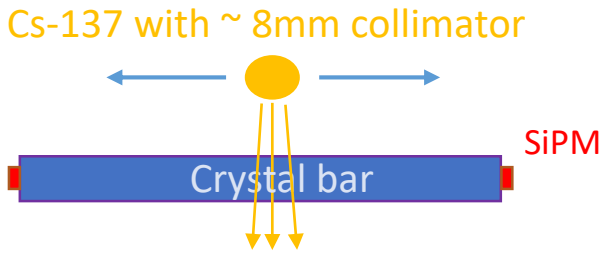
Zhikai Chen (USC)

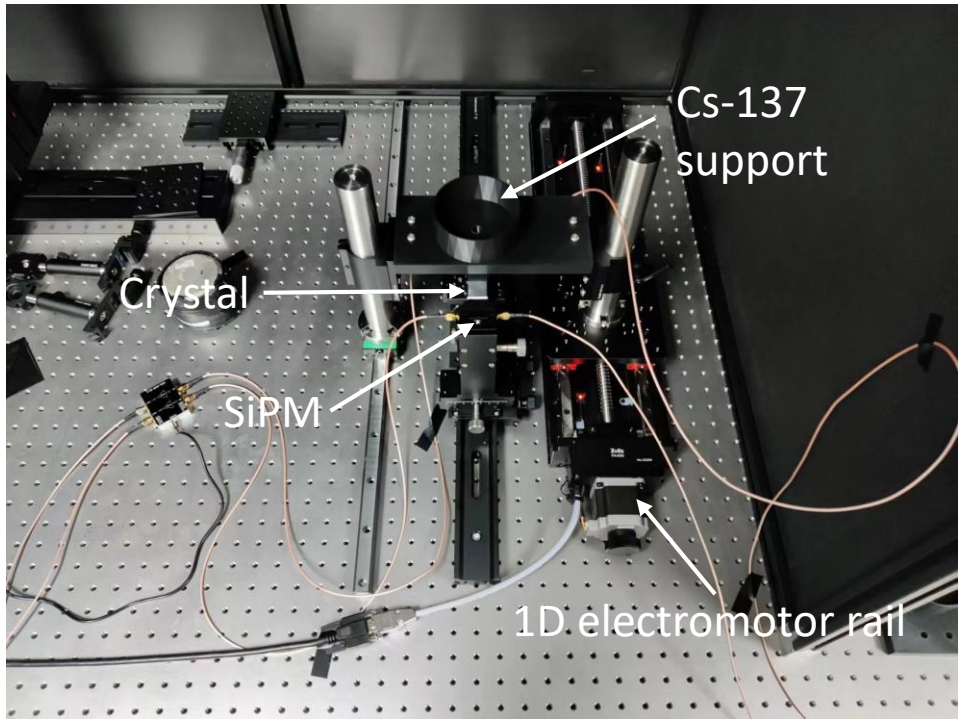
- Batch test of SIC-CAS BGO crystal bars
  - 40 crystals with ESR and Al foil wrapping
  - Scan with Cs-137 radioactive source

Response uniformity along bar



- Generally good uniformity along a single bar





Automatic crystal scan with electromotor stage

Uniformity scan of BGO crystal bars

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  - 40 crystals with ESR and Al foil wrapping
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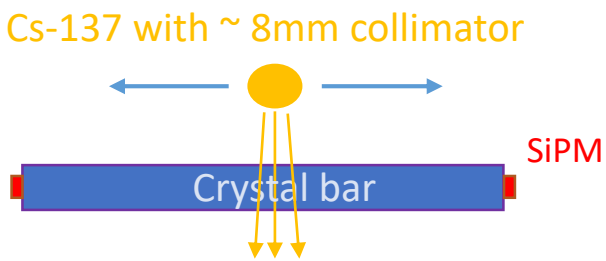
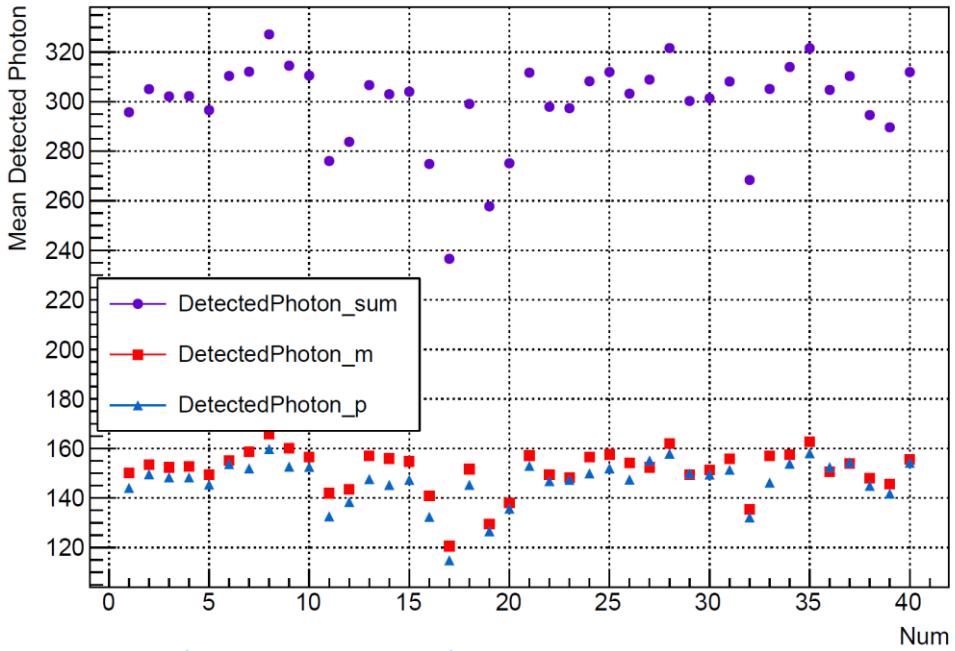
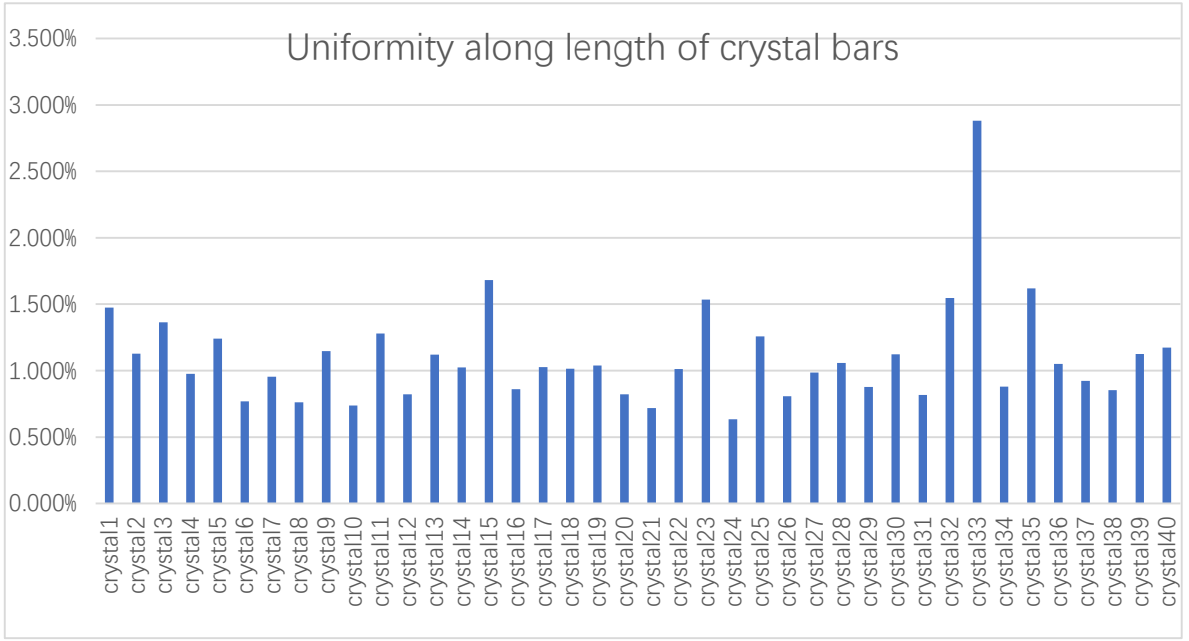


Comparison of 40 crystal bars



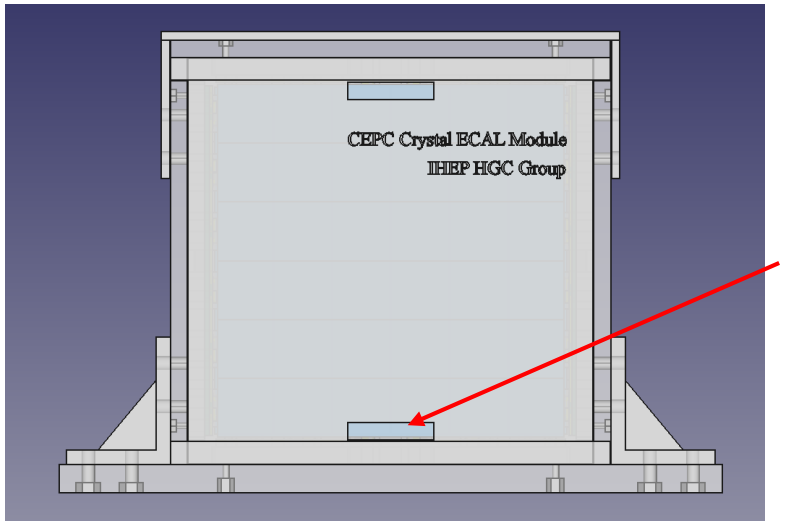
- Tested point: crystal center
- Response varies among bars: coupling, wrapping…



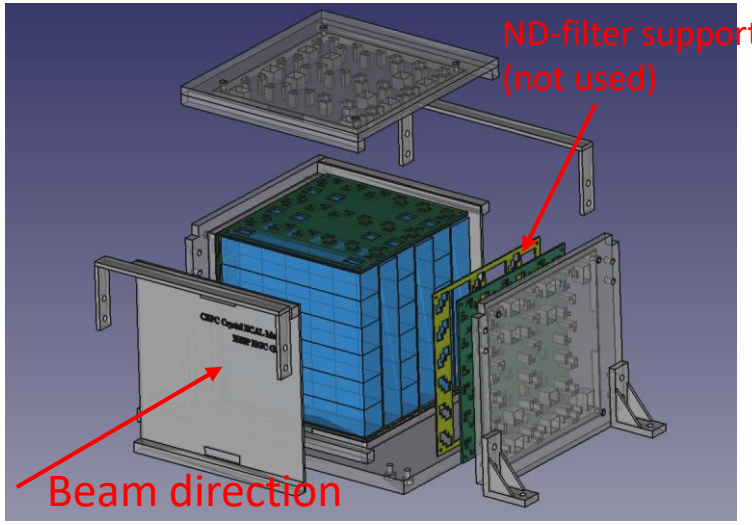
- Uniformity = (Max - Min)/Mean
- Generally uniformity of single bars at 1% level

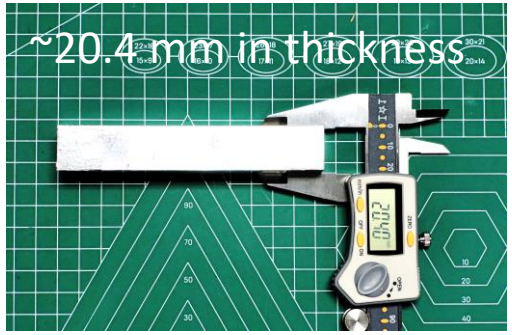
Mechanical and PCB design

- Mechanical structure and module assembly method

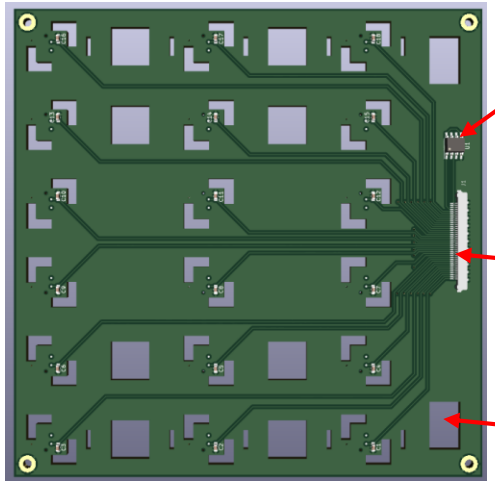


Holes for micro-coaxial cables





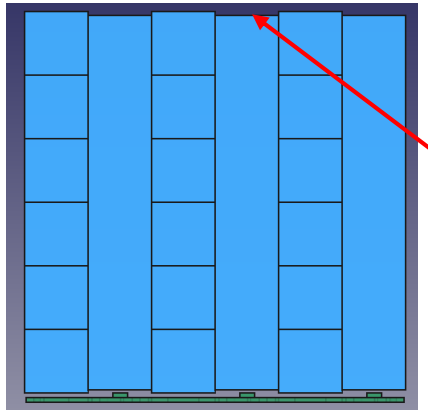
- Difficulties with mechanical design
  - Readout from 4 sides, PCB is non-load-bearing and should be decoupled
  - Module assembly is hard since crystals should be placed orthogonally



Temperature sensor

Micro-coaxial connector

Holes for crystal support



Shorter due to the thickness of wrapping

Electronics and trigger scheme

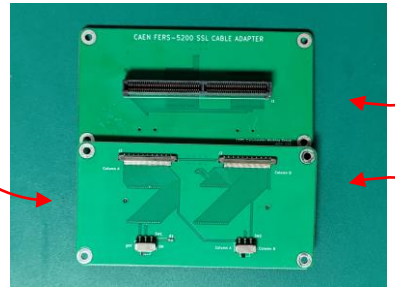
- Electronics: two A5202 units with self-trigger or external trigger

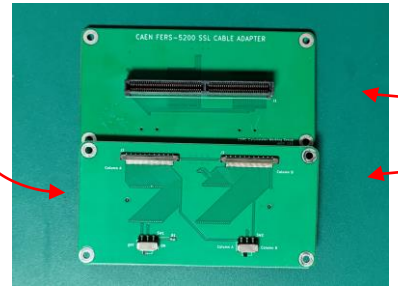
36/64 channels used

36/64 channels used

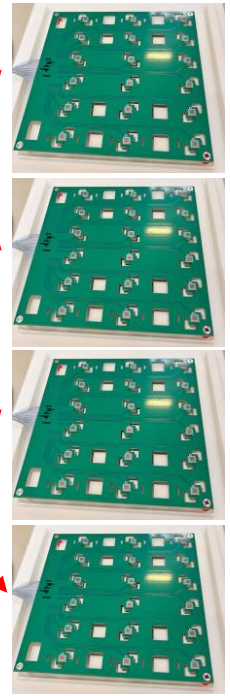
Daisy chained
trigger distribution

A5202 unit
Built-in HV power supply





Self-designed
adapter board



18 channel PCBs

External trigger

- Acquisition mode: High gain & Low gain & Timing
- Event synchronization of 2 units: triggers within 20 ns
- External trigger: daisy chain
- Self-trigger: coincidence of 2 PCBs of one unit

Outline

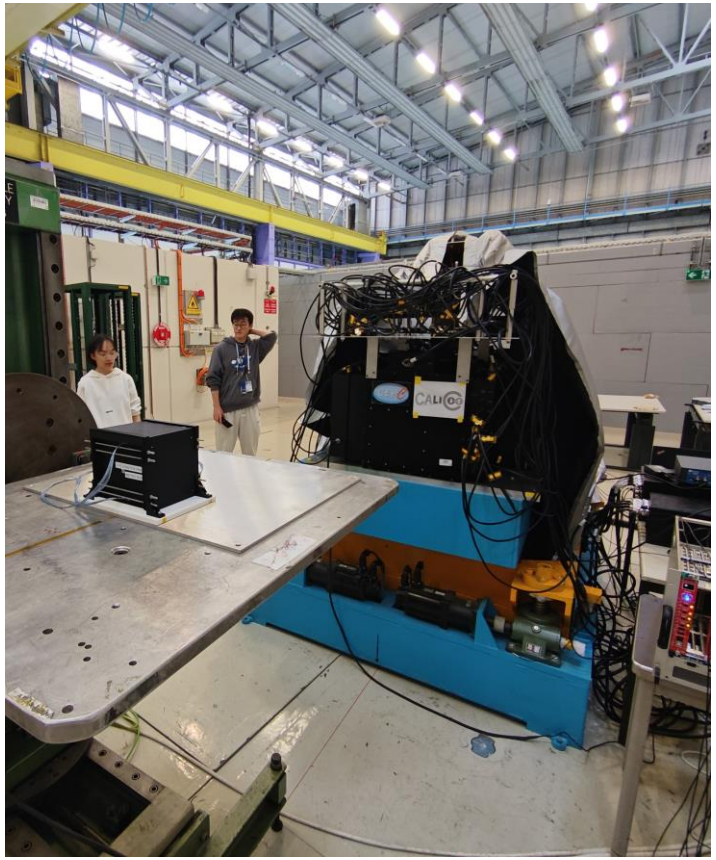
Crystal module development and beam test:

- Recap: crystal module development
- Crystal module beam tests at CERN T9 beam line
  - Transport and preparations
  - Installation of module
  - Beam test with muon, electron and pion
  - Summary and data analysis plan

Transport and preparations

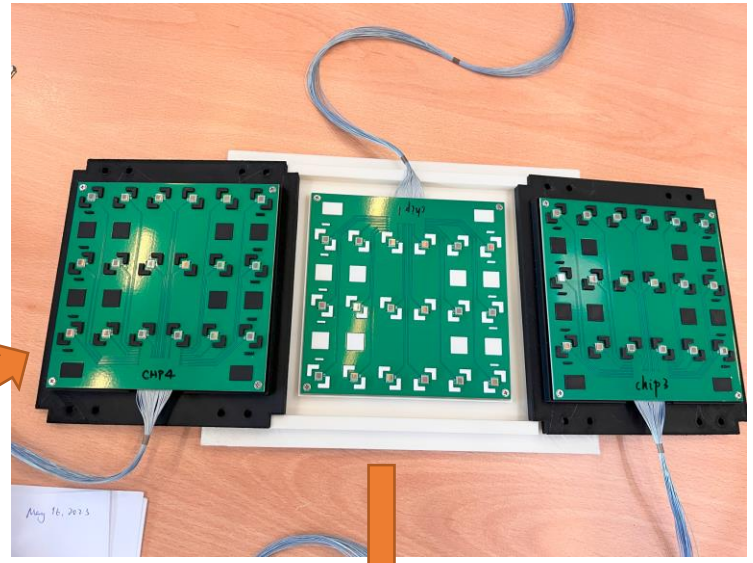
- Transportation: started on May 6th and finished in May 16th

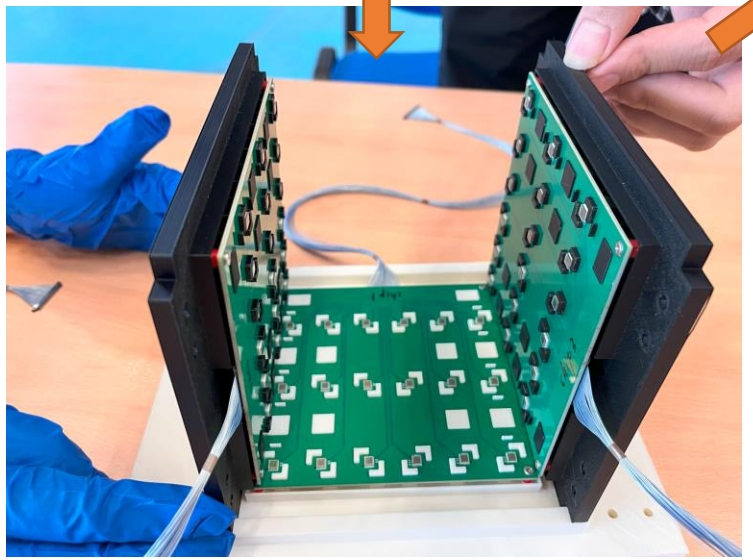
Flight case in total ~75 kg

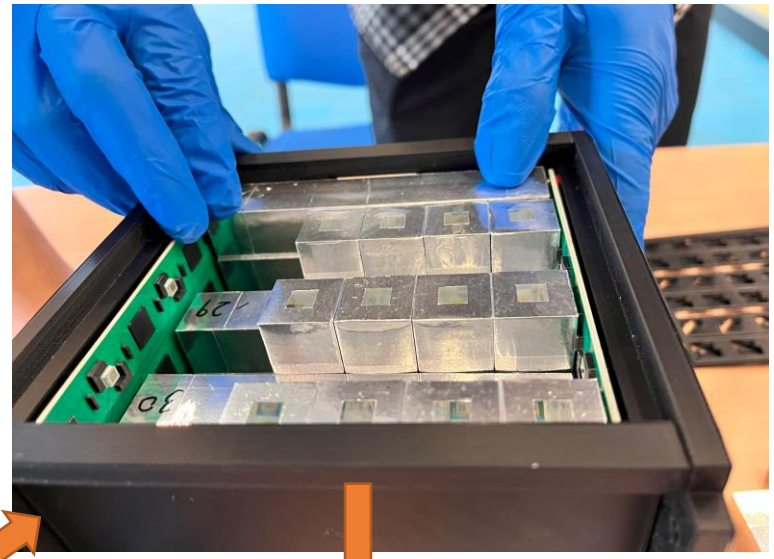


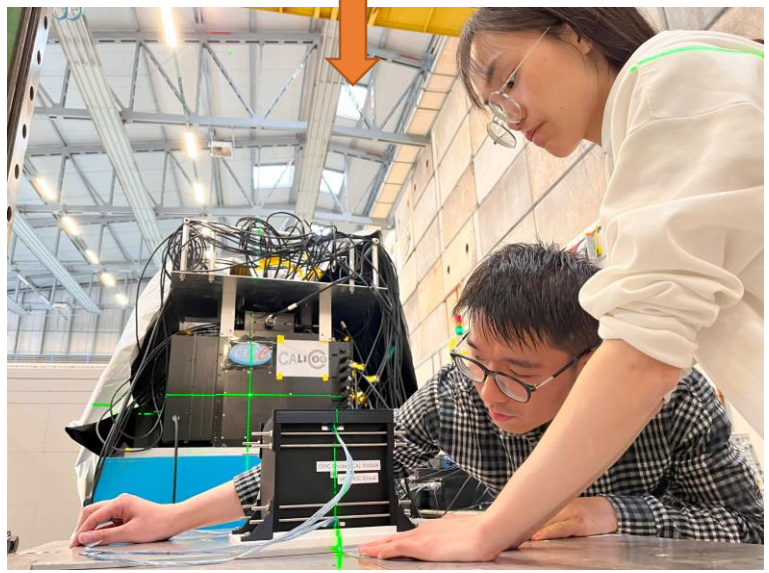
Lifting table for crystal module in front of ScW ECAL and AHCAL

Installation of module

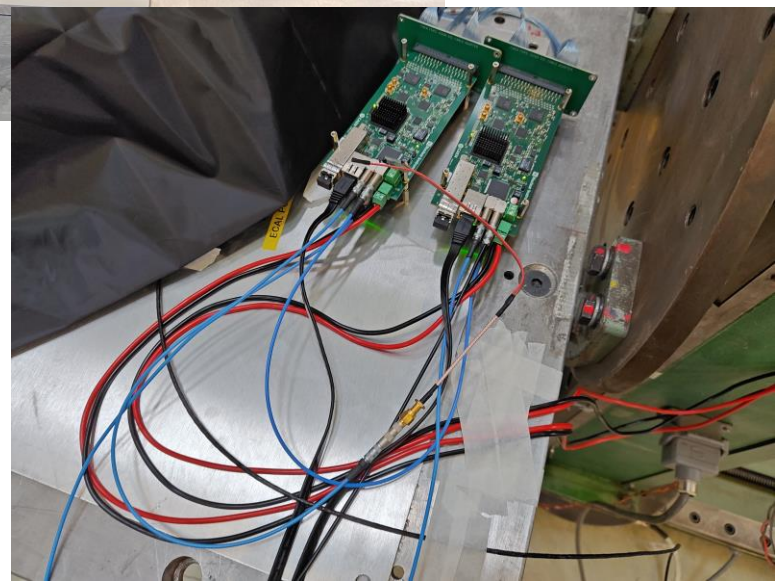




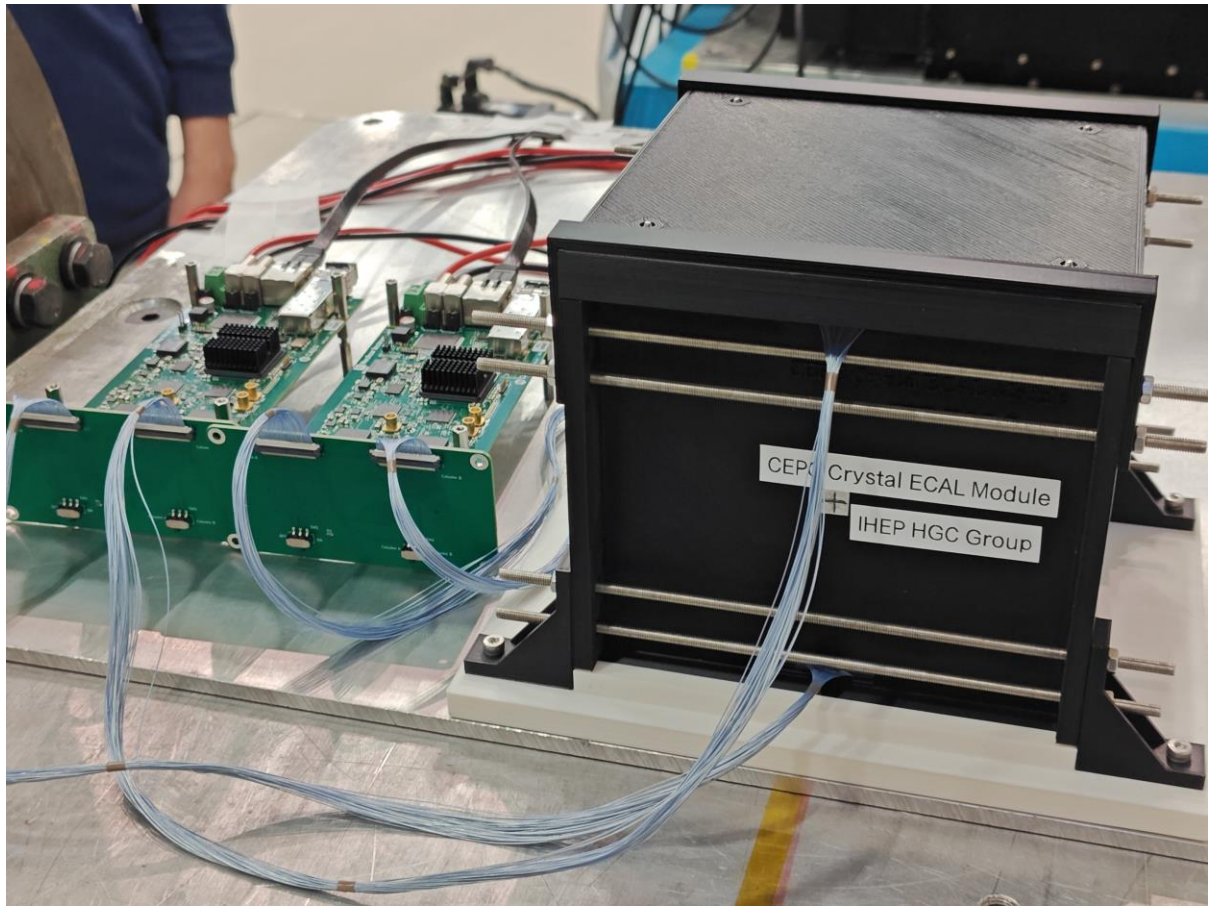




Installation of module



Connection scheme for the chained run starting and external trigger



Thanks to the efforts of Yong, Dejing, Baohua, Zhiyu and Lijun!

Beam test with muon: parameter scans

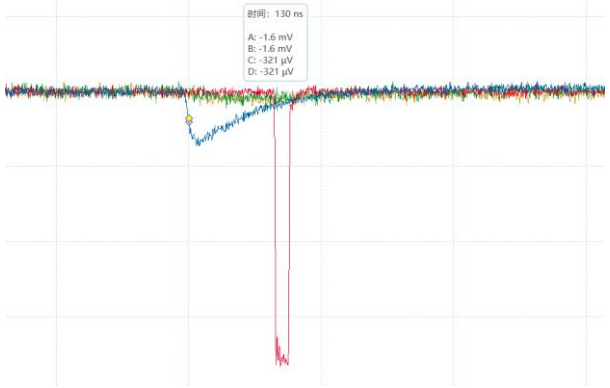
- External trigger from beam telescopes in front of beam pipe: ~2k per spill
- 10 GeV/c muon- beam: MIP response
  - High-gain and Low-gain scans
  - Hold-Delay time scans
  - Shaping time scans
  - Position, HG discriminator scans…

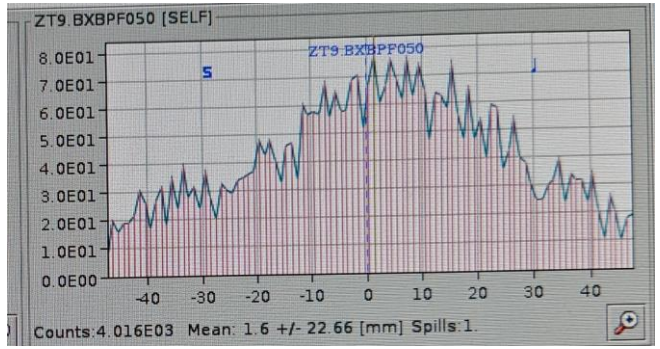
Muon-: ~5.5M events

HG	LG	Hold-Delay Time	Shaping Time
34	4	5 ns	12.5 ns
44	24	10 ns	25 ns
49	34	50 ns	37.5 ns
54	44	100 ns	50 ns
59	52	150 ns	62.5 ns
	56	200 ns	75 ns
	58	300 ns	87.5 ns
	61		
	62		
	63		

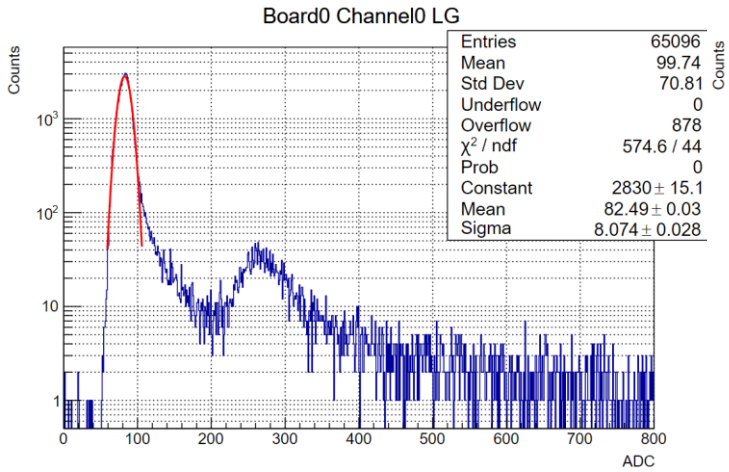
Parameters for electron tests in red

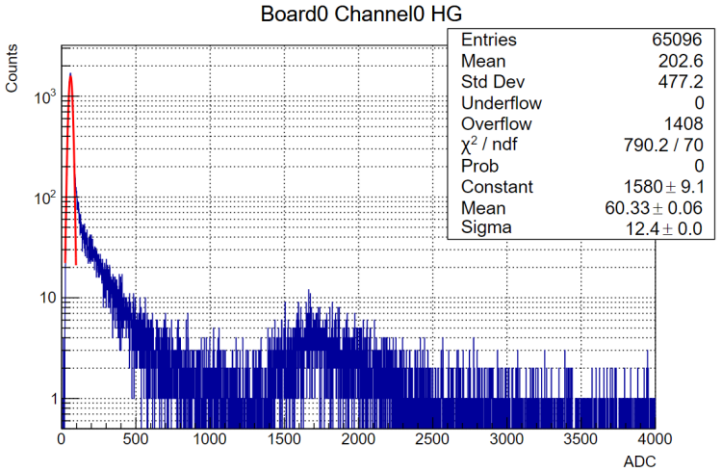
Delay of external trigger: ~130 ns





Beam profile of muon





- General MIP signal at H/L gain (log scale)

Beam test with electron: energy scans

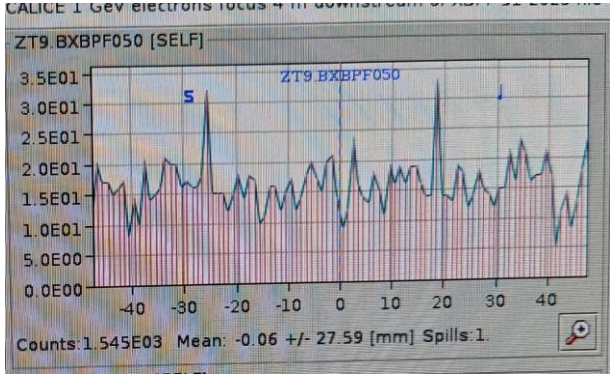
- Energy scans: 0.5~5 GeV/c e- beam
  - Hold-Delay set to 200 ns
  - Shaping time set to 87.5 ns (maximum)
  - HG 49, LG 34/44/56, larger value for low energy particles

Momentum	HG	LG	#Run (10k per run)
0.5	49	56	2
1	49	44/56	16
2	49	34/44	20
3	49	34/44	20
4	49	34/44	20
5	49	34/44	20

Much lower event rate

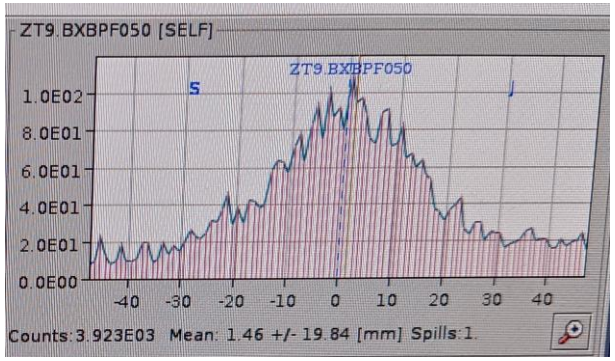
- Some data with different setups will be included later

Electron: ~980k events within ~4h beam time



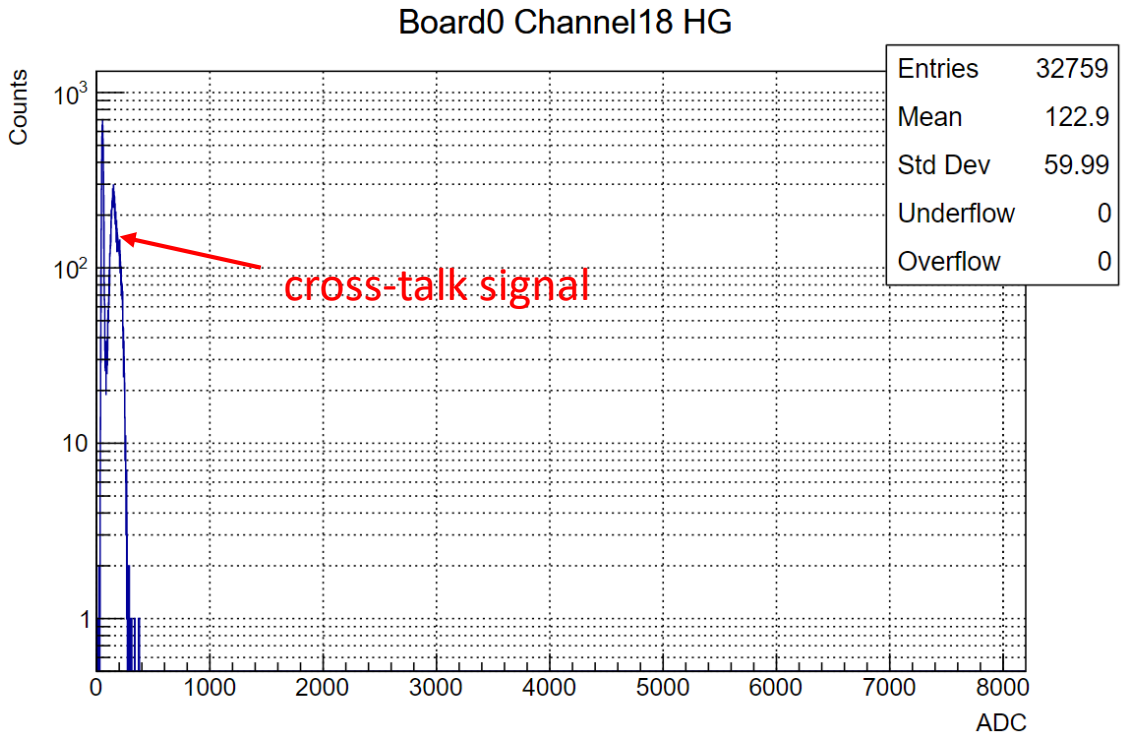
Beam profile 1 GeV/c

Beam profile 2 GeV/c

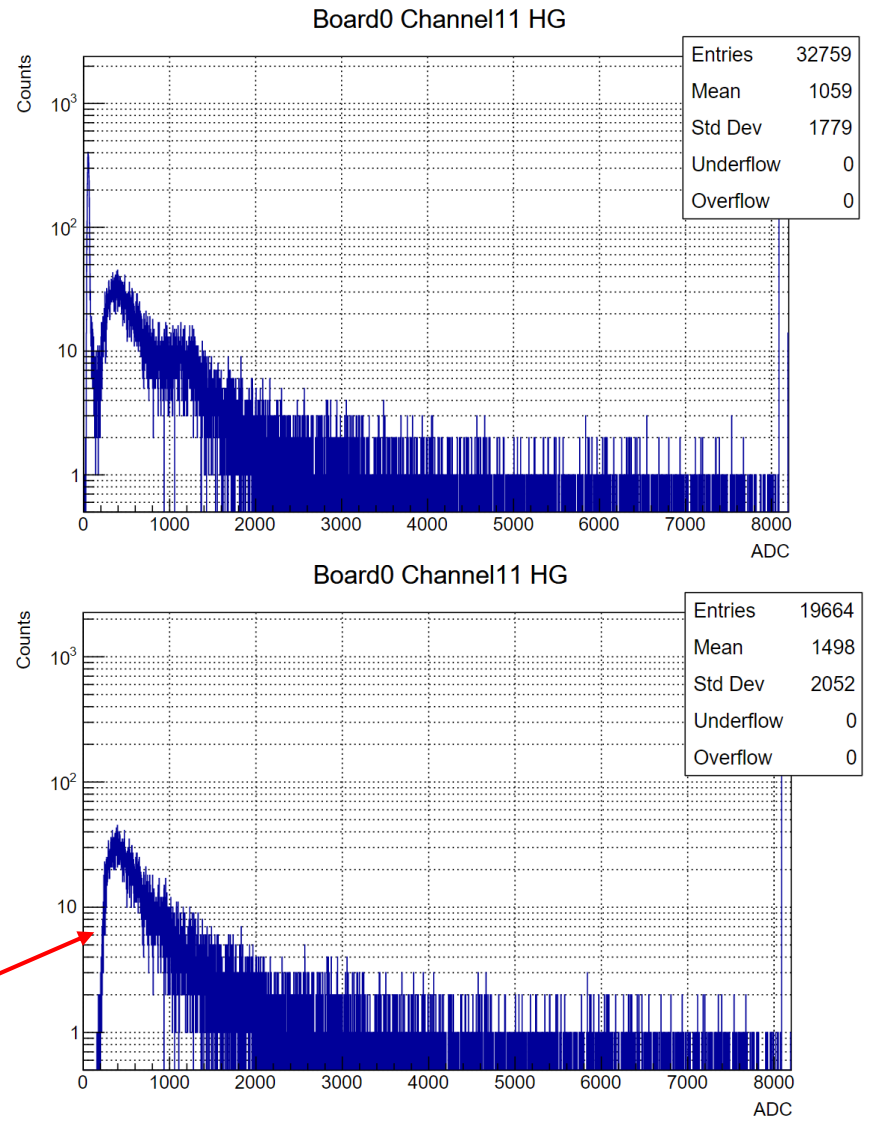


Beam profile 4 GeV/c

Beam test with electron: issues



- Channels without SiPM connection: cross-talk signal
- Cross-talk from adapter boards/PCBs…



Select events with cross-talk

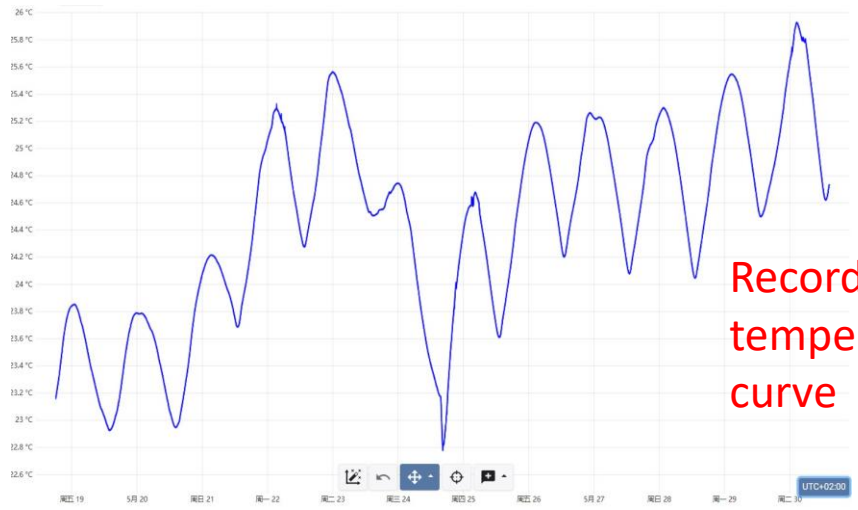
- Seems MIP events and pedestals do not contribute much to cross-talk
- Still need to be investigated

Other data acquired

- Parasitic test: self-trigger of “leaked particles” form upstream
  - Almost MIP-like particles
  - Hold-Delay scan result is different: delay of the external trigger is longer
  - Validation of long-term data-taking capability
- Pion- beam test: capability under ~20k events per spill
  - > 80% trigger loss at such high fluence
- Temperature monitoring
  - ~2℃ temperature change during the beam test

Parasitic: ~3.3M events

Pion-: ~140k events



Recorded temperature curve

Summary and data analysis plan

- The beam test for the first crystal module has been successfully completed!

Summary and data analysis plan

Ongoing

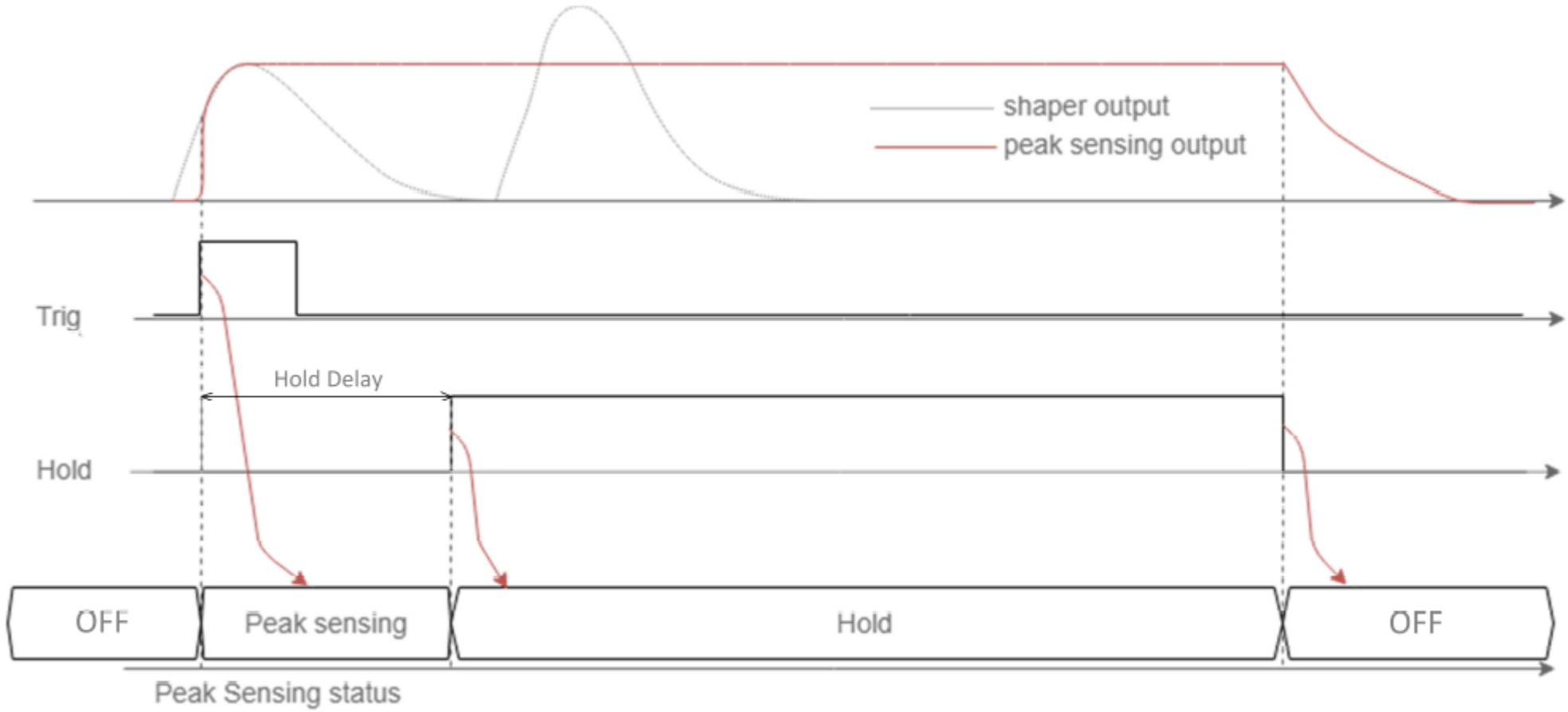
- Data conversion and selection: synchronized event
- Geant4 simulation of one module: EM energy resolution
- Event display tool
- MIP calibration channel by channel

Plan

- Energy reconstruction of electron data
- Analysis of timing information
- Temperature calibration
- Influence of cross-talk and background radiation from lifting table
- …

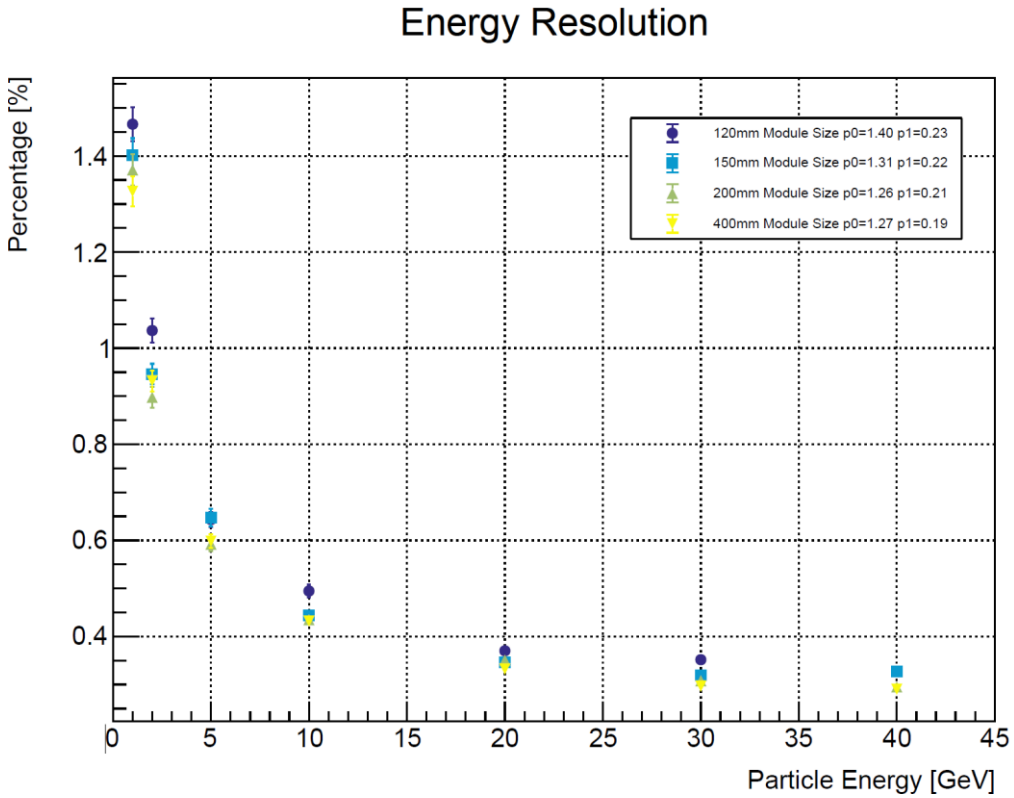
Backup

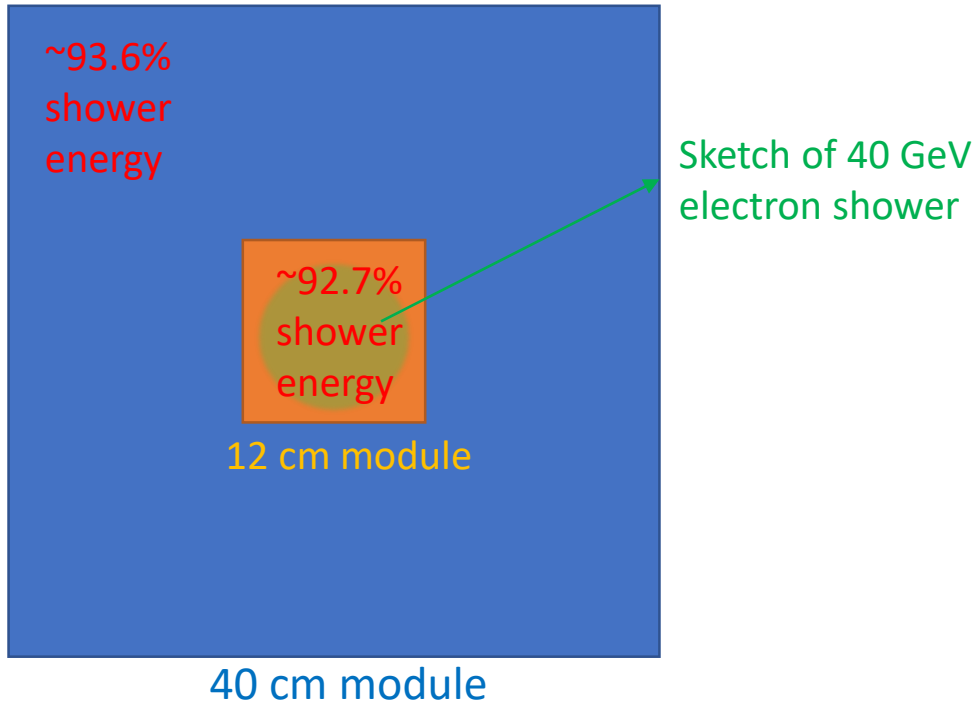
Hold-Delay time



Crystal-SiPM module design: impact of module size

- 40×40×28 supercell: change the length of the crystal bar from 400 mm to 120 mm

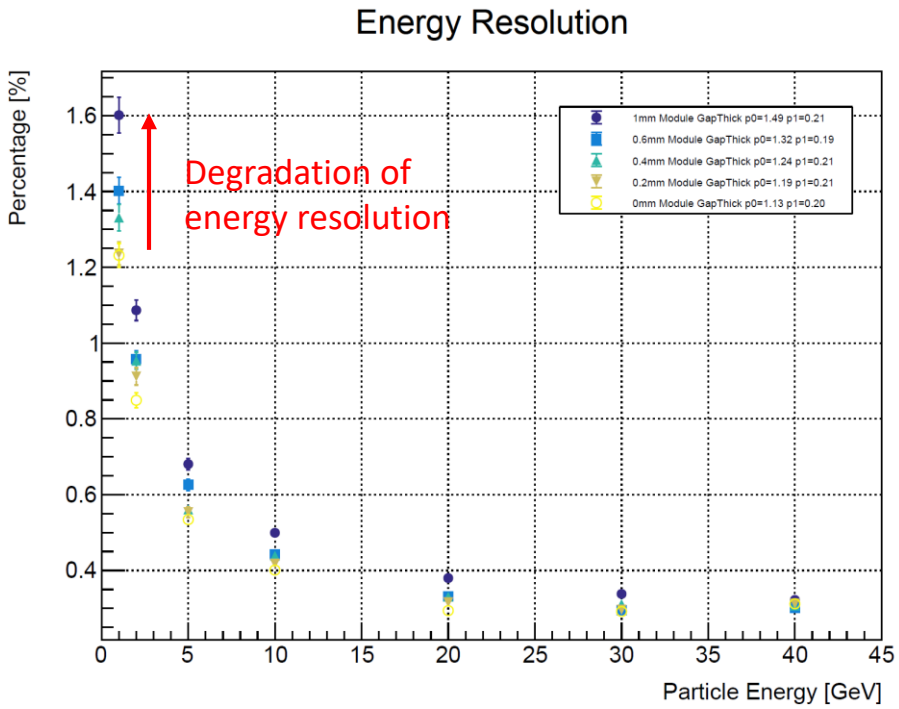


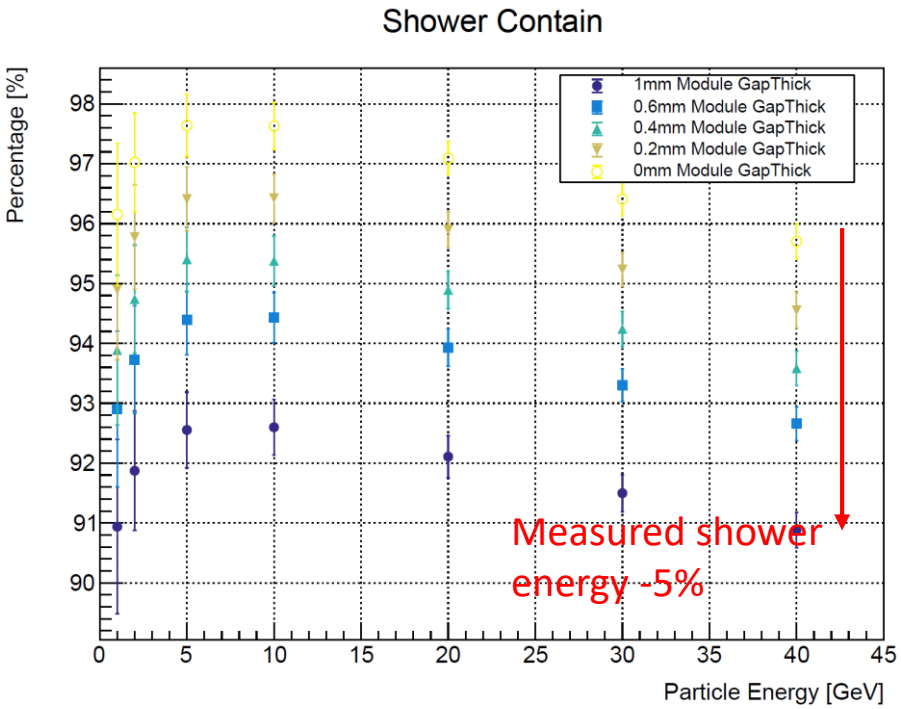


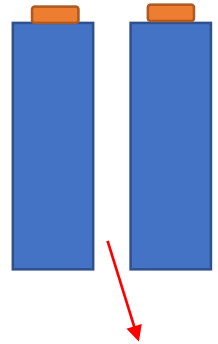
- For EM showers, 12 cm size is enough to contain most of the energy when particles hit on the center of the module
- Degradation of energy resolution: ~0.1% level

Crystal-SiPM module design: impact of gaps

- Gap material in 40×40×28 supercell: ESR film, Al foil, Air
- Density has been set to 2 g/cm^3





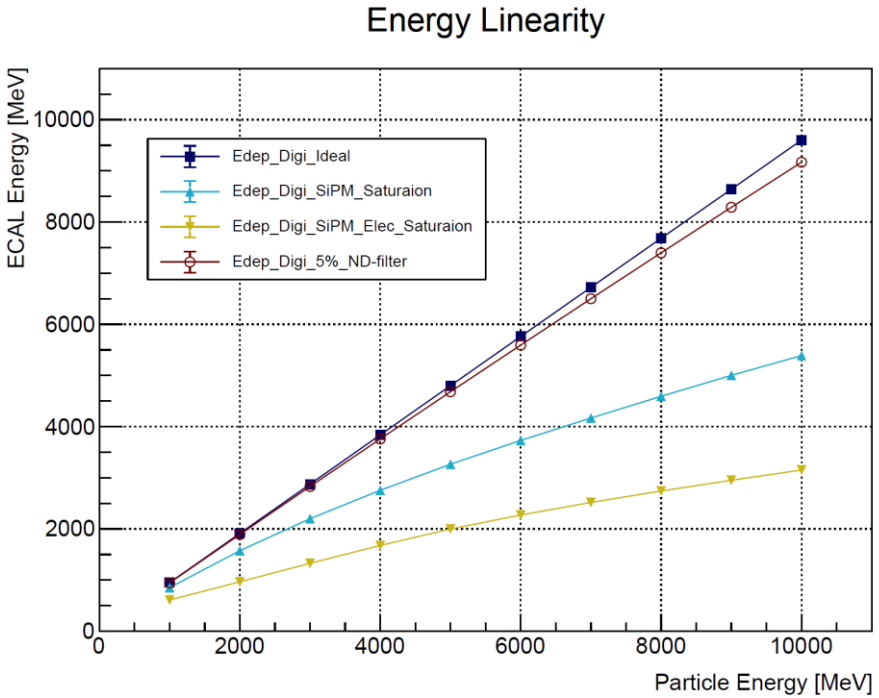


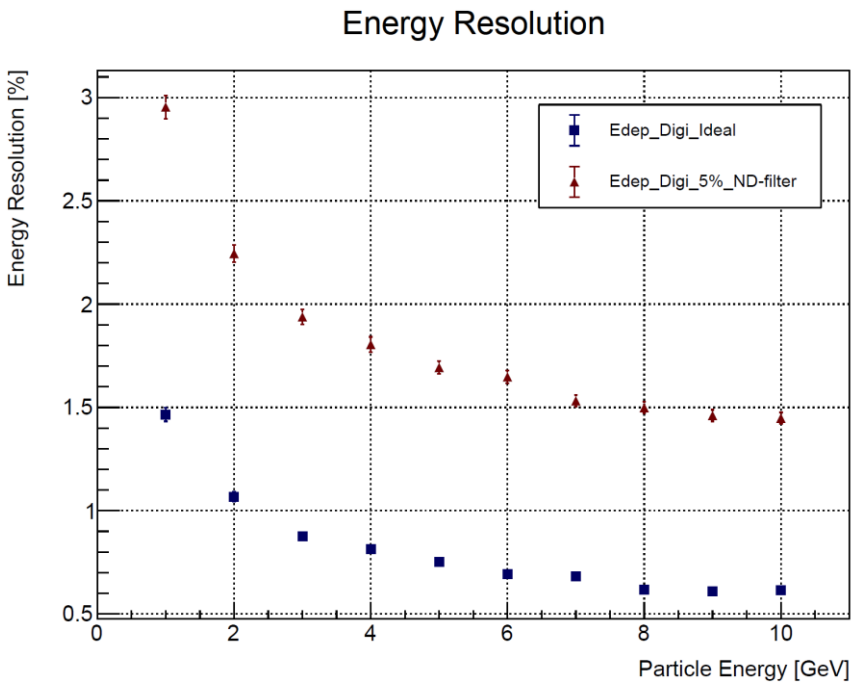
- Impact of gaps is more significant than module size
- Gaps for 12×2×2 cm^3 cm crystal: ~0.4 mm
- Control of gaps will be harder with longer crystals: key issue

Activities on small-scale crystal module design

- Performance check: Geant4 simulation with 1~10 GeV electron
- Saturation considering S14160-3010PS SiPM and Citiroc-1A chip
- 5% (σ = 0.1%) transmittance neutral density filter is used for light attenuation

Digitization: photon statistics, SiPM gain error, ADC error, MIP threshold





- SiPM non-linearity should be further calibrated
- Saturation of electronics can be avoided via high dynamic range ASIC
- 5% neutral density filter can mitigate the saturation effect but will introduce additional uncertainty