中国科学院高能物理研究所
Institute of High Energy Physics, Chinese Academy of Sciences

# 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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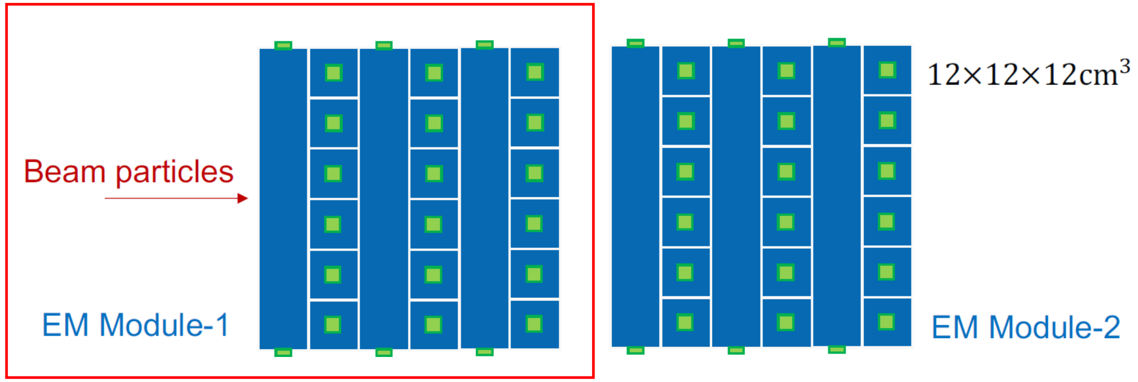
# Outline

Crystal module development and beam test:

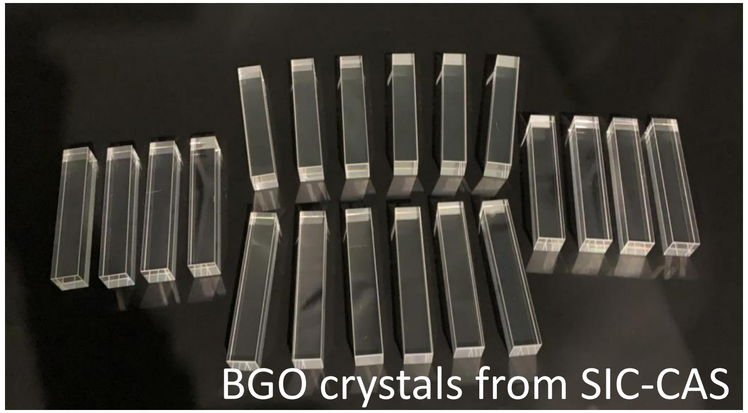
- Recap: crystal module development
  - Uniformity scan of BGO crystal bars
  - Mechanical and PCB design
  - Electronics and trigger scheme
- Crystal module beam tests at CERN T9 beam line

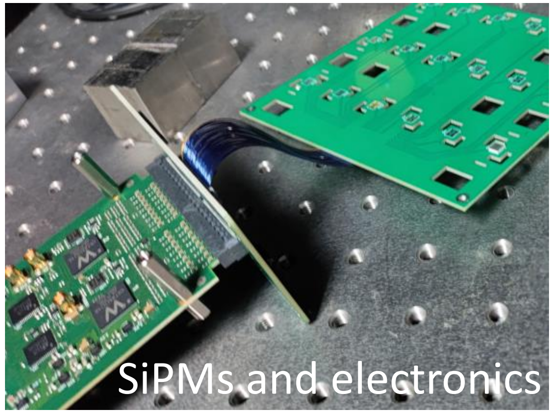
# Introduction to the first small-scale crystal module

- 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


BGO crystals from SIC-CAS


SiPMs and electronics

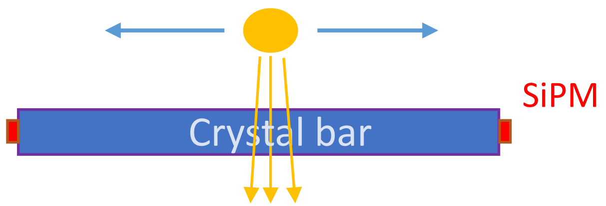

Half-assembled module

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

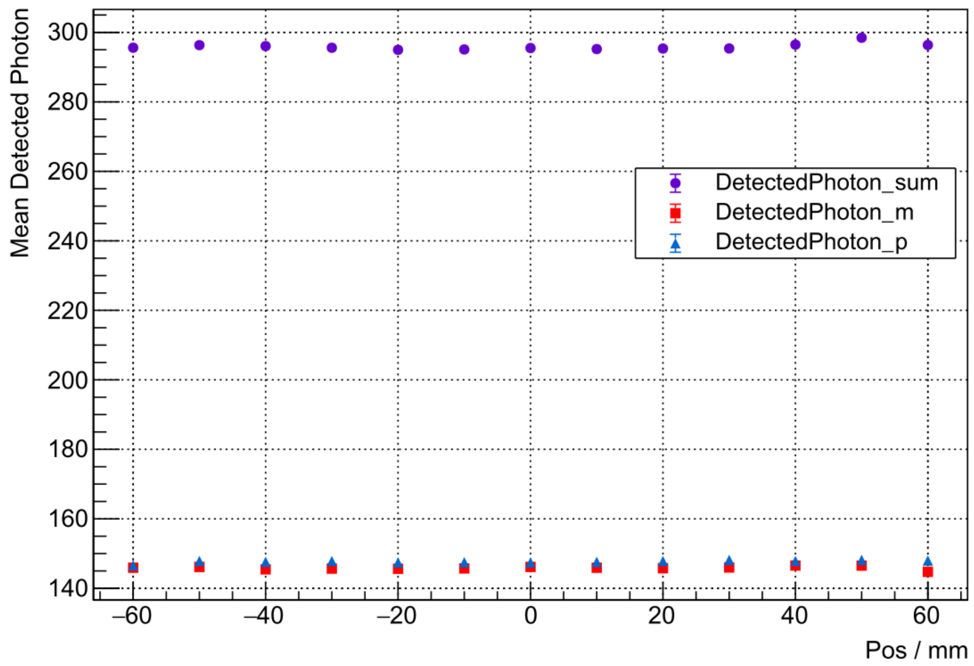
# Uniformity scan of BGO crystal bars

Zhikai Chen (USC)

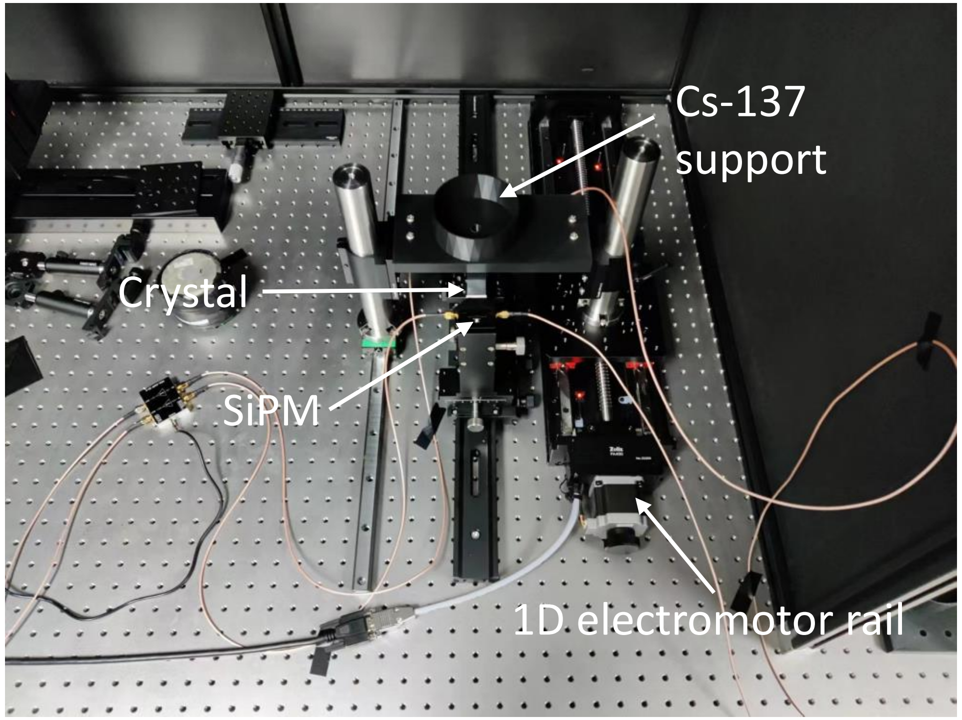
- Batch test of SIC-CAS BGO crystal bars
  - 40 crystals with ESR and Al foil wrapping
  - Scan with Cs-137 radioactive source




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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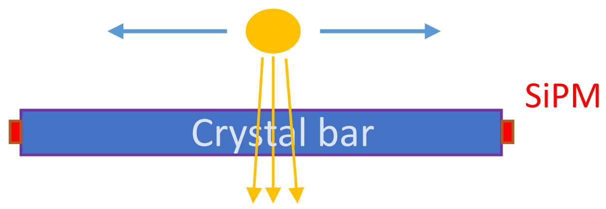
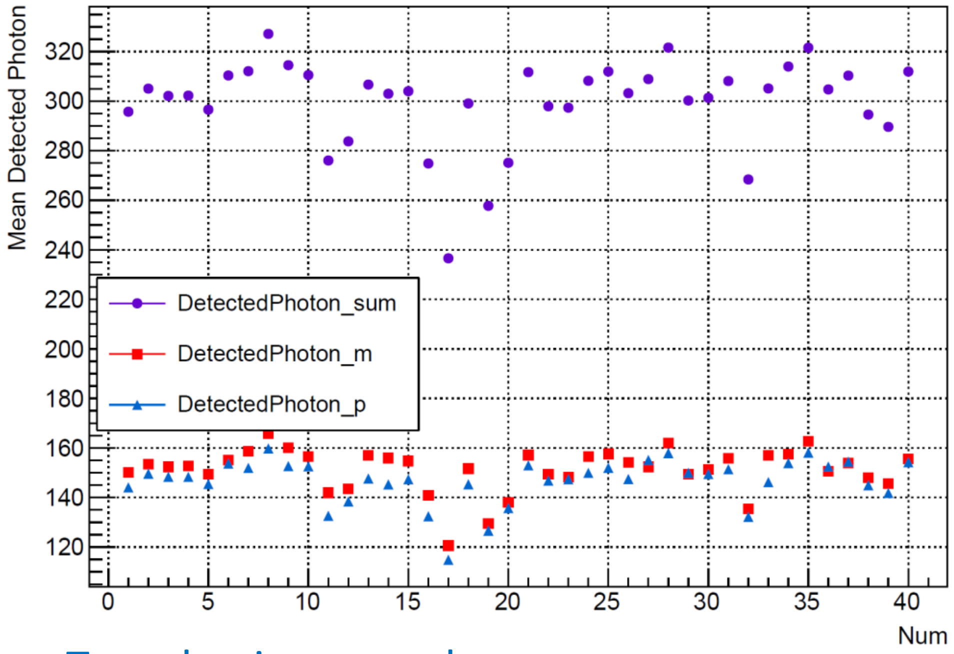
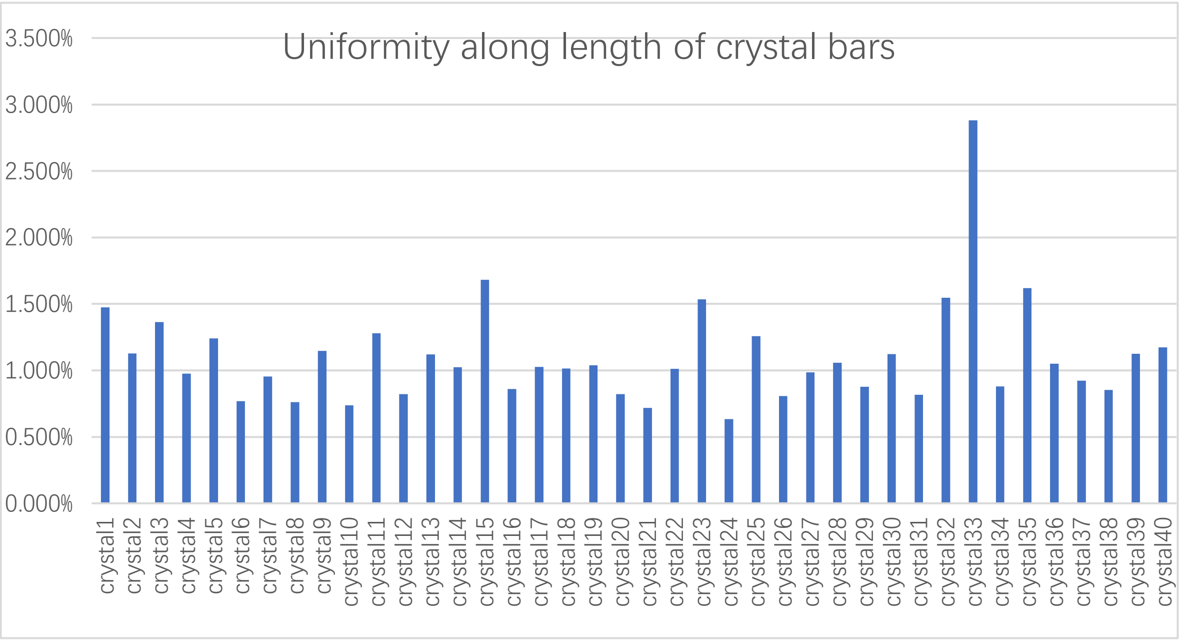



Comparison of 40 crystal bars



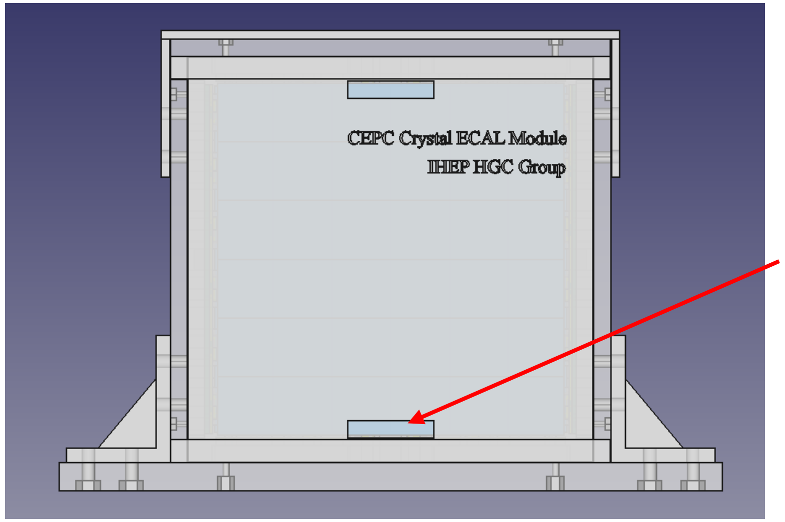




- Tested point: crystal center
- Response varies among bars: coupling? wrapping?

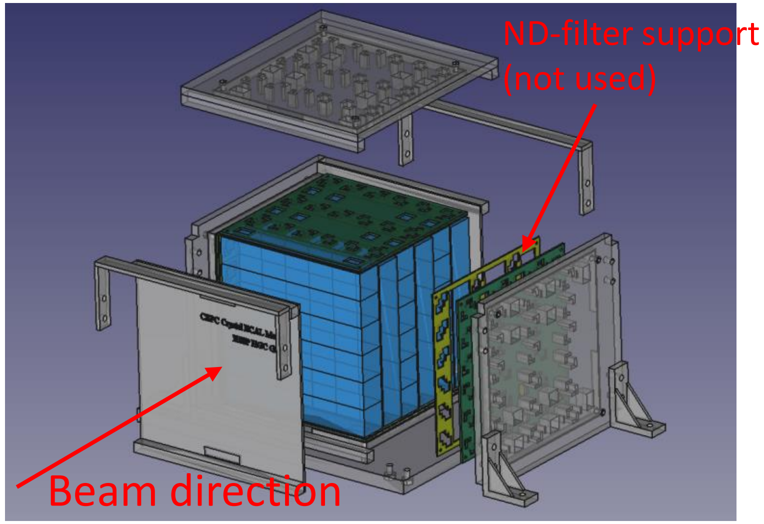
- Uniformity = (Max - Min)/Mean
- Generally uniformity of single bars at 1% level

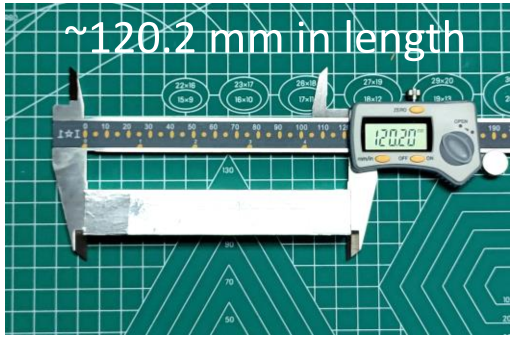
# Mechanical and PCB design

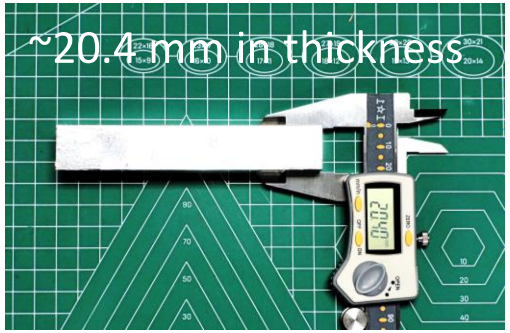
- Mechanical structure and module assembly method



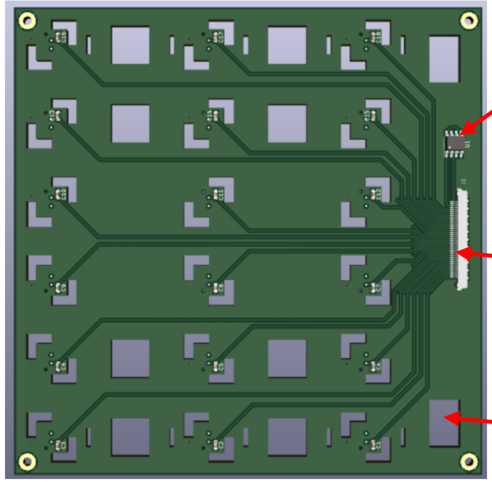

Holes for micro-coaxial cables



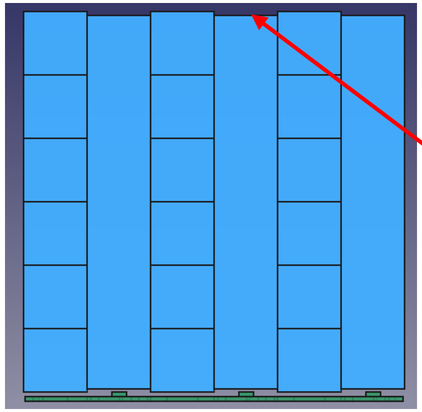

- Difficulties with mechanical design
  - Readout from 4 sides, PCB is non-load-bearing and should be decoupled
  - Module assembly is hard since crystals should be placed orthogonally



Temperature sensor

Micro-coaxial connector

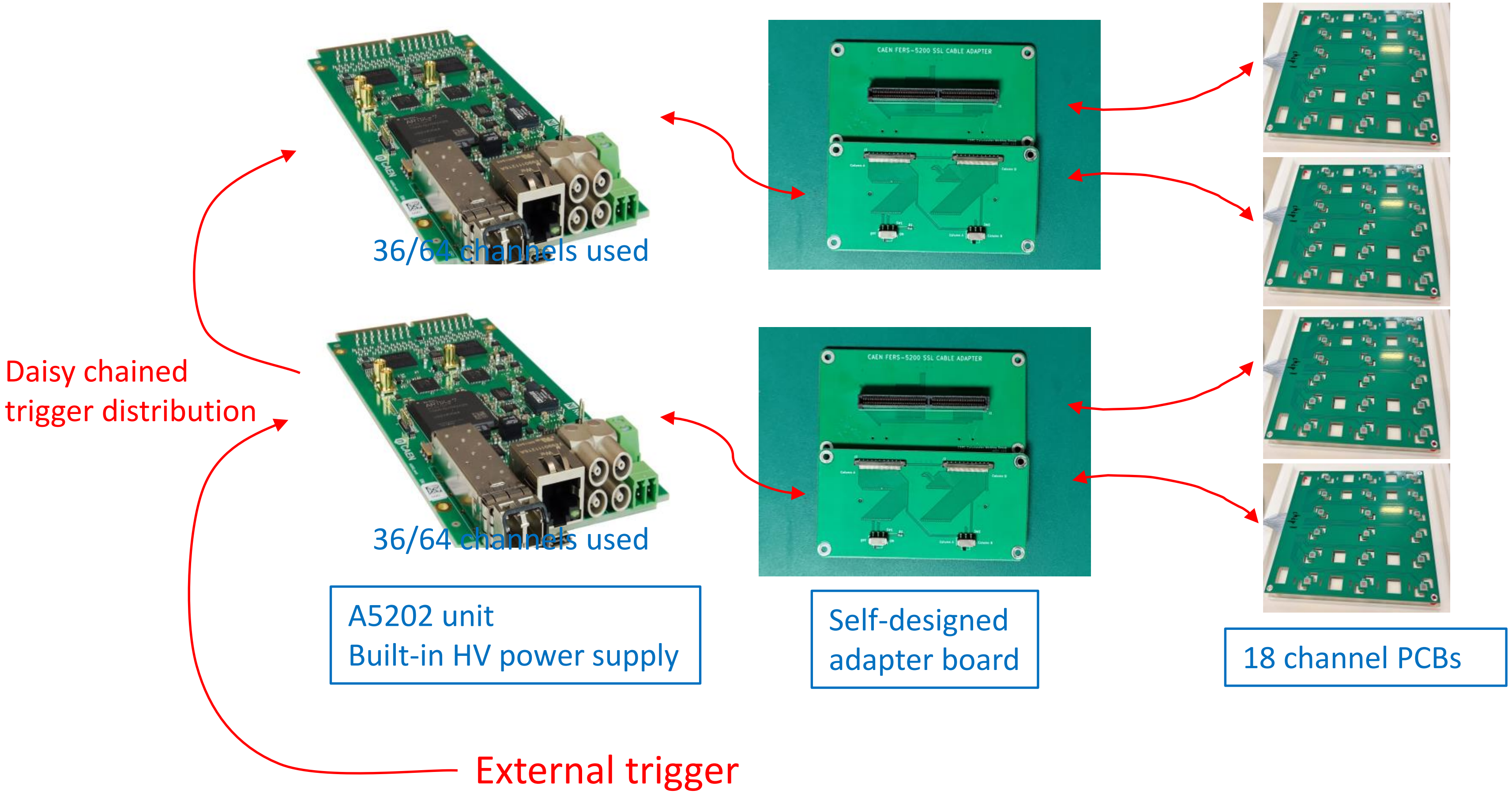
Holes for crystal support



Shorter due to the thickness of wrapping

# Electronics and trigger scheme

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




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

# Outline

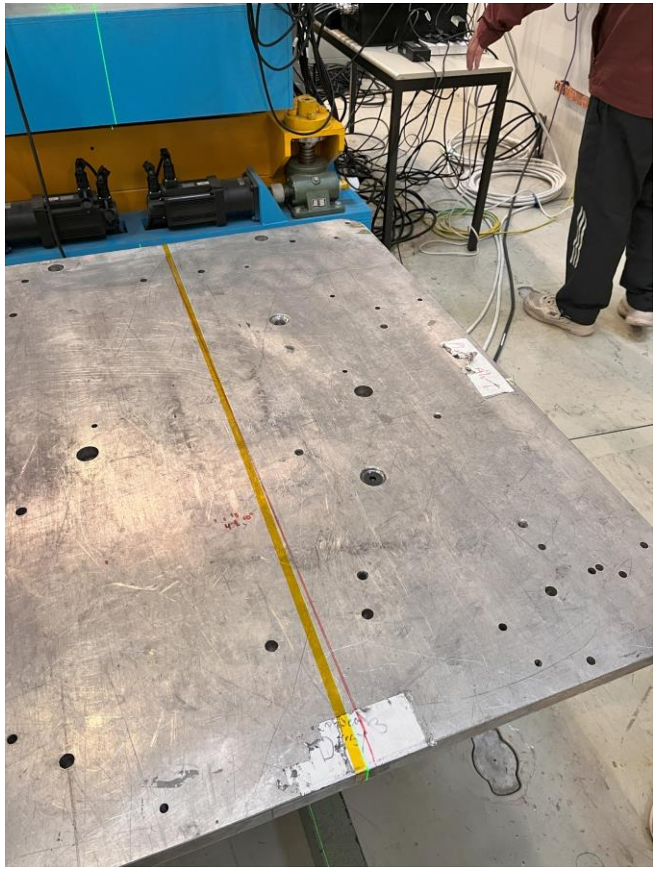
Crystal module development and beam test:

- 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

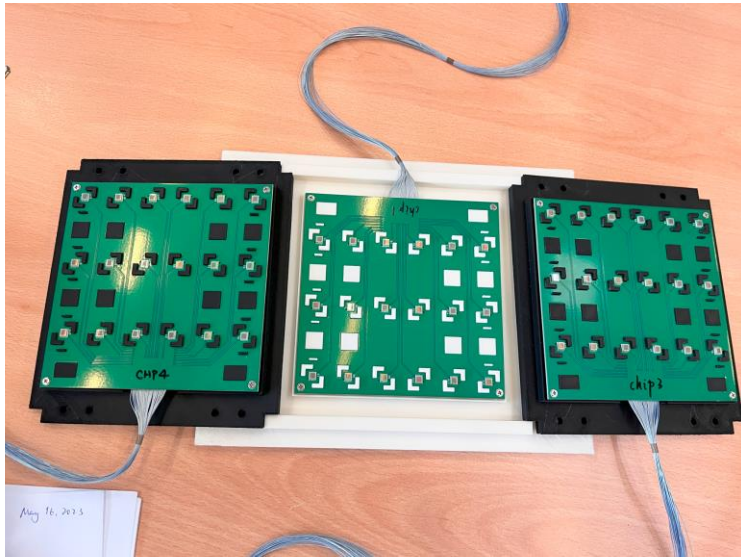
- Transportation: started on May 6th and finished in May 16th

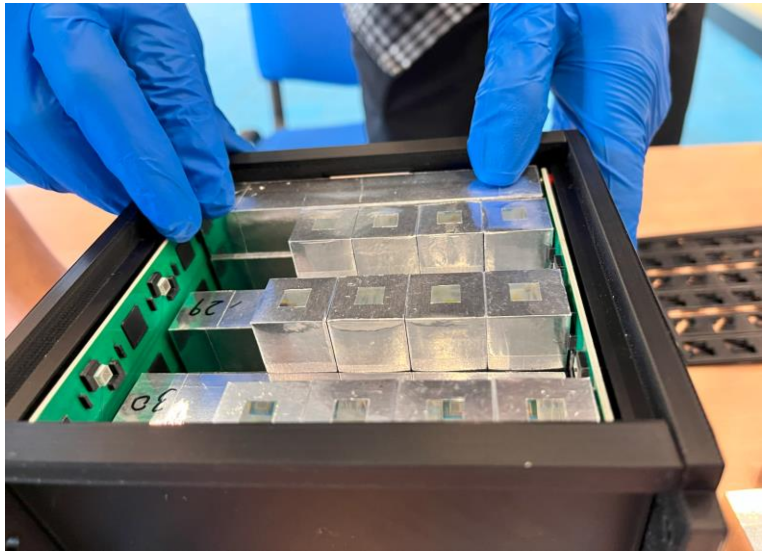
Flight case in total ~75 kg

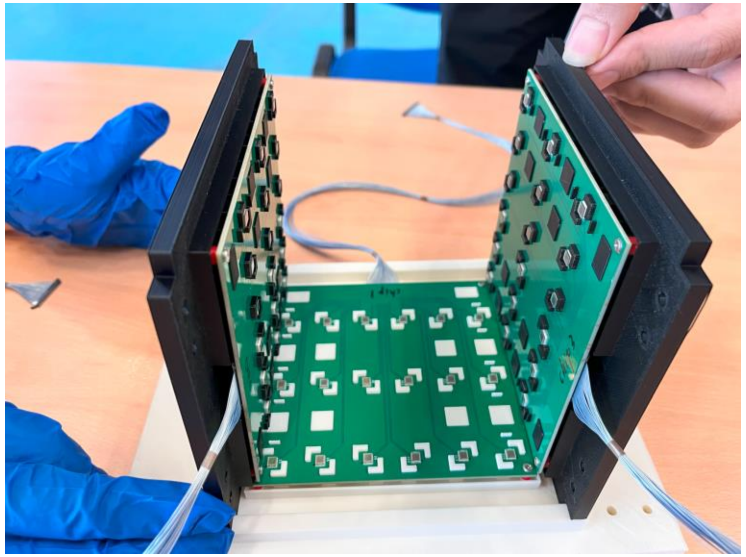


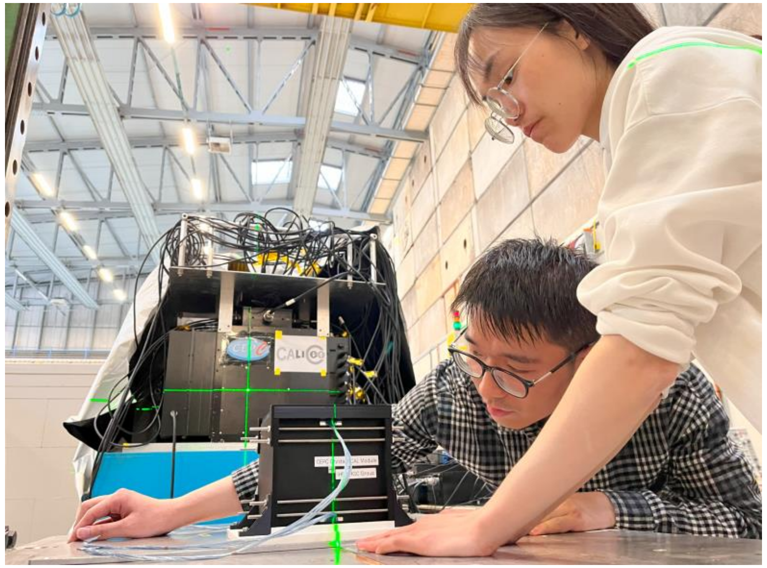
Lifting table for crystal module in front of ScW ECAL and AHCAL

# Installation of module

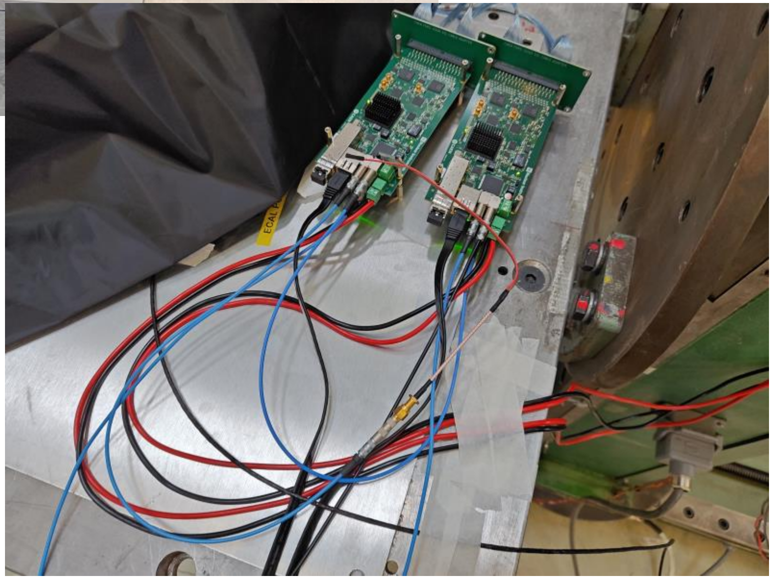




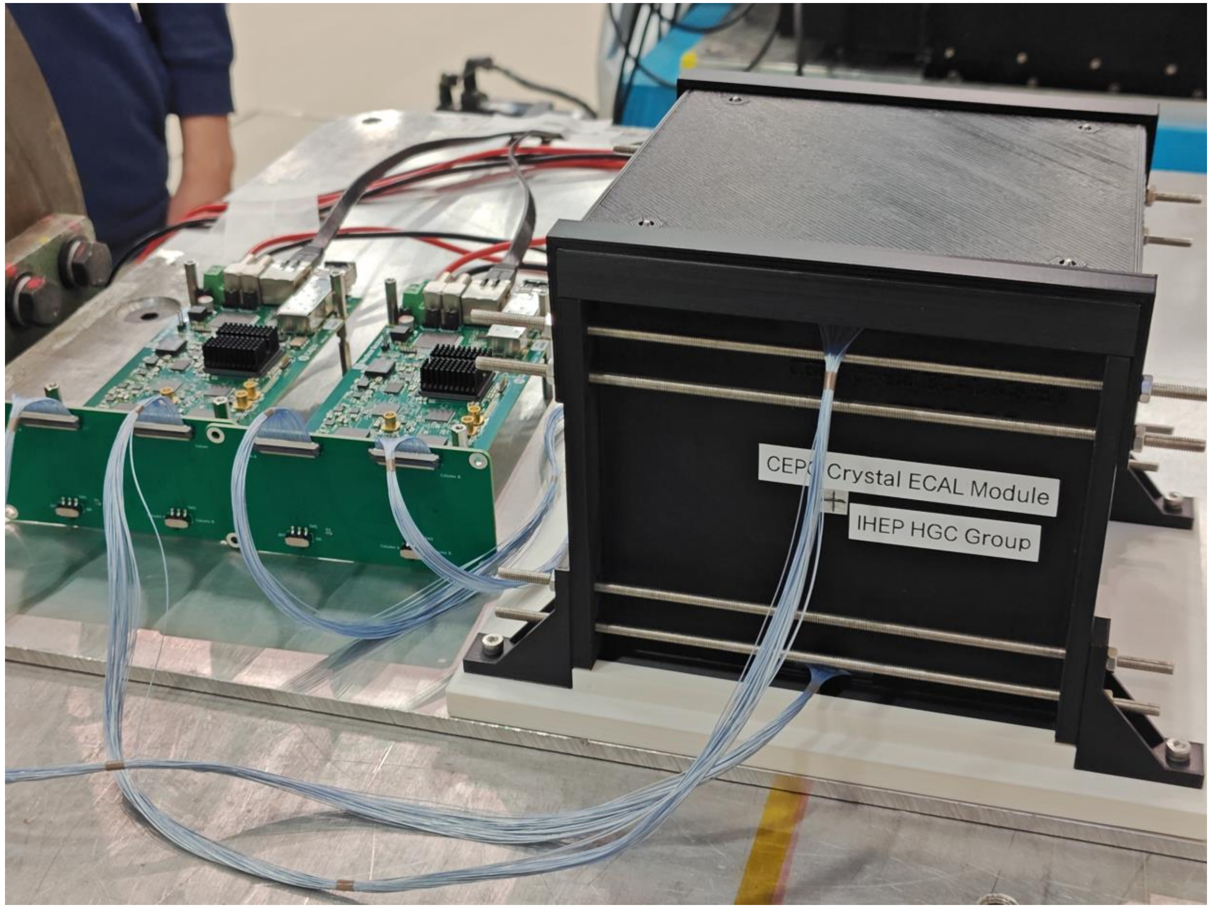




# Installation of module



Connection scheme for the chained run starting and external trigger



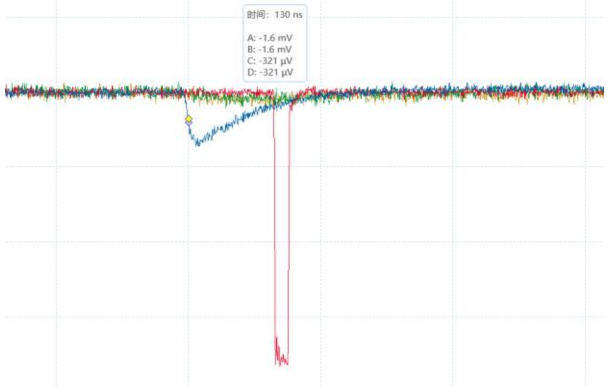

Thanks to the efforts of Yong, Dejing, Baohua, Zhiyu and Lijun!

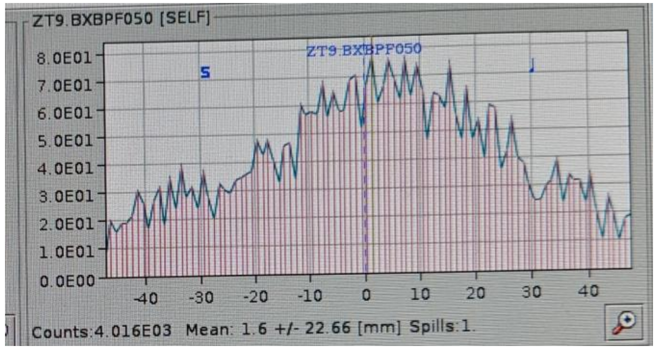
# Beam test with muon: parameter scans

- 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

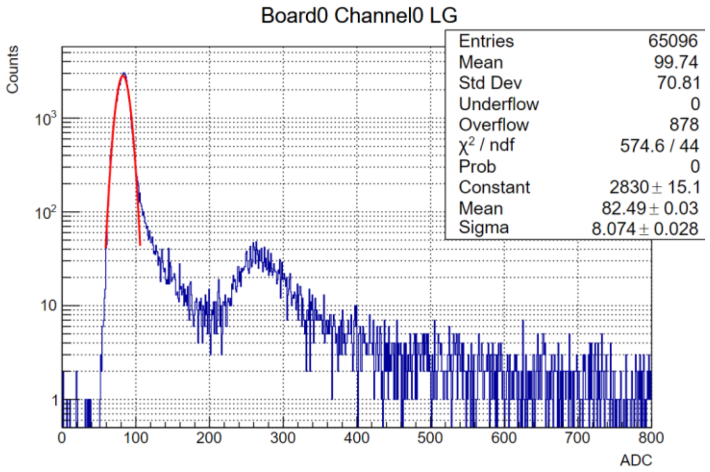
| HG | LG | Hold-Delay Time | Shaping Time |
|---|---|---|---|
| 34 | 4 | 5 ns | 12.5 ns |
| 44 | 24 | 10 ns | 25 ns |
| 49 | 34 | 50 ns | 37.5 ns |
| 54 | 44 | 100 ns | 50 ns |
| 59 | 52 | 150 ns | 62.5 ns |
| | 56 | 200 ns | 75 ns |
| | 58 | 300 ns | 87.5 ns |
| | 61 | | |
| | 62 | | |
| | 63 | | |

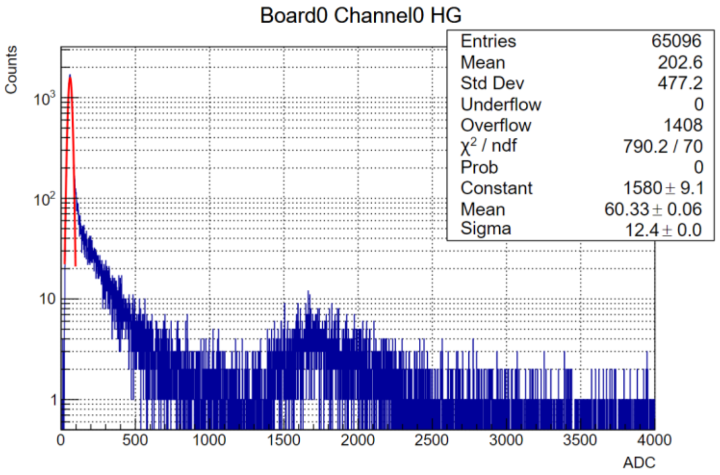
Delay of external trigger: ~130 ns






Beam profile



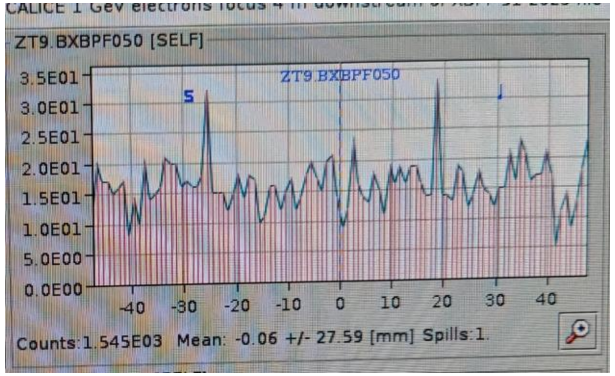
# Beam test with electron: energy scans

- 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

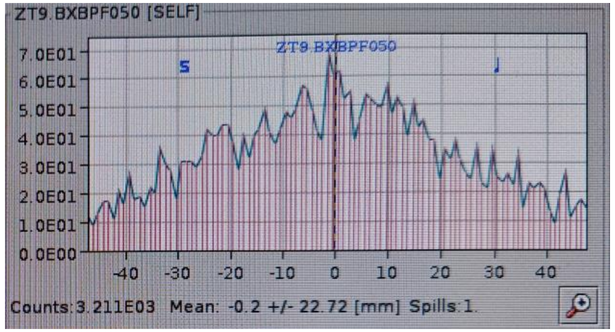
| Momentum | HG | LG | #Run (10k per run) |
|---|---|---|---|
| 0.5 | 49 | 56 | 2 |
| 1 | 49 | 44/56 | 16 |
| 2 | 49 | 34/44 | 20 |
| 3 | 49 | 34/44 | 20 |
| 4 | 49 | 34/44 | 20 |
| 5 | 49 | 34 | 10 |

Much lower trigger rate

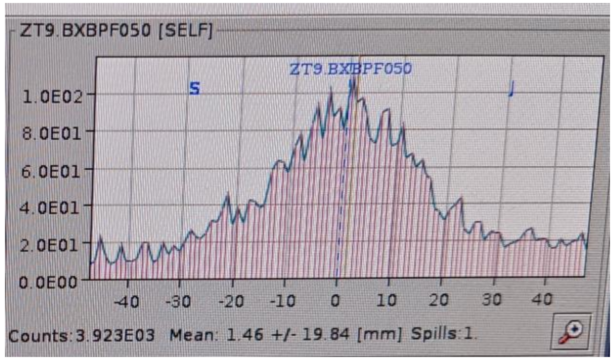
- Some data with different HG parameter will be included later




Beam profile 1 GeV/c

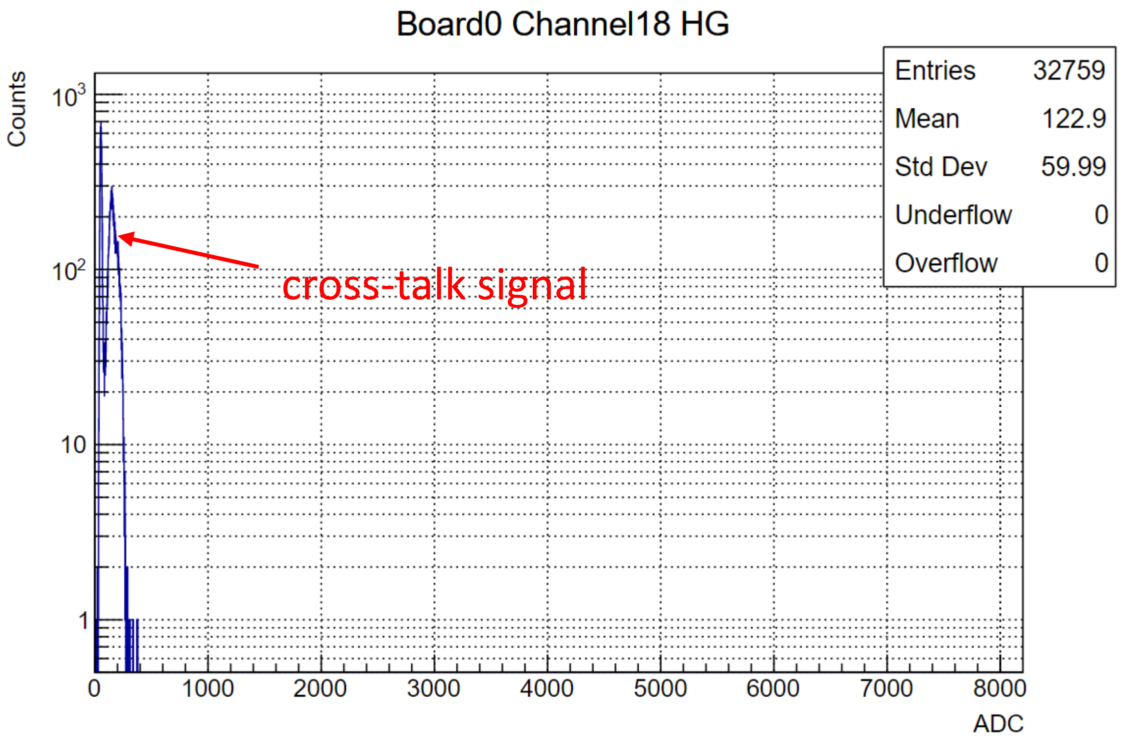



Beam profile 2 GeV/c



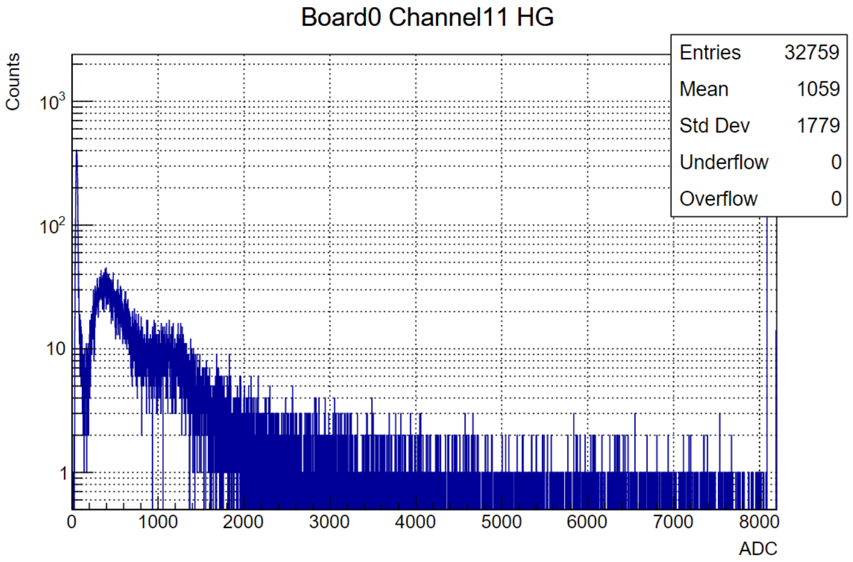

Beam profile 4 GeV/c

# Beam test with electron: issues

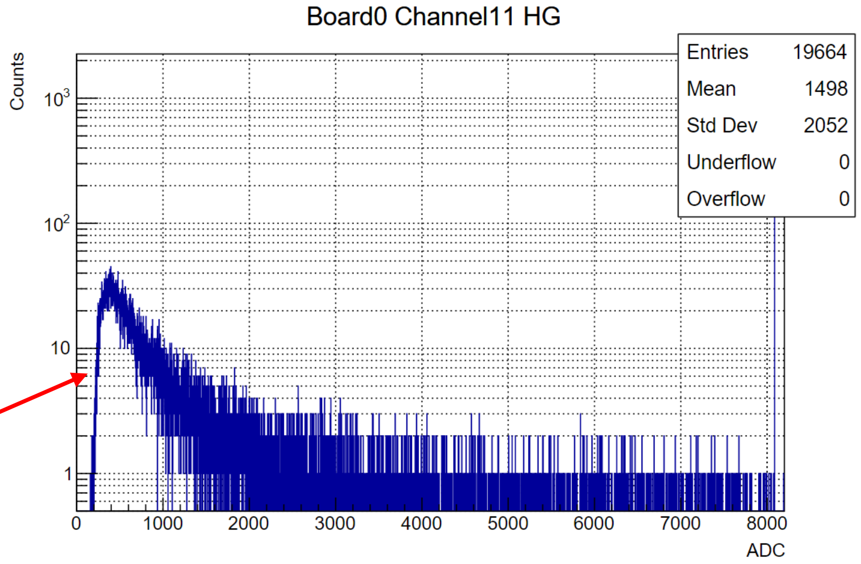



- Channels without SiPM connection: cross-talk signal

Seems MIP signal and pedestal have been removed
Still need to be investigated

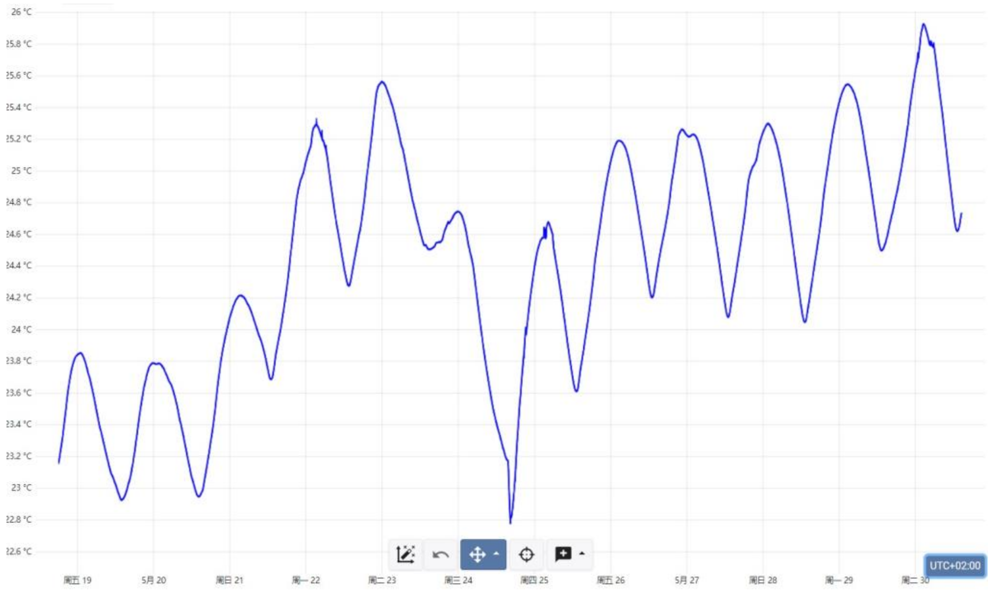



Select events with cross-talk



# 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 high fluence
  - > 80% trigger lost
- Temperature monitoring




Recorded temperature curve

# Summary and data analysis plan

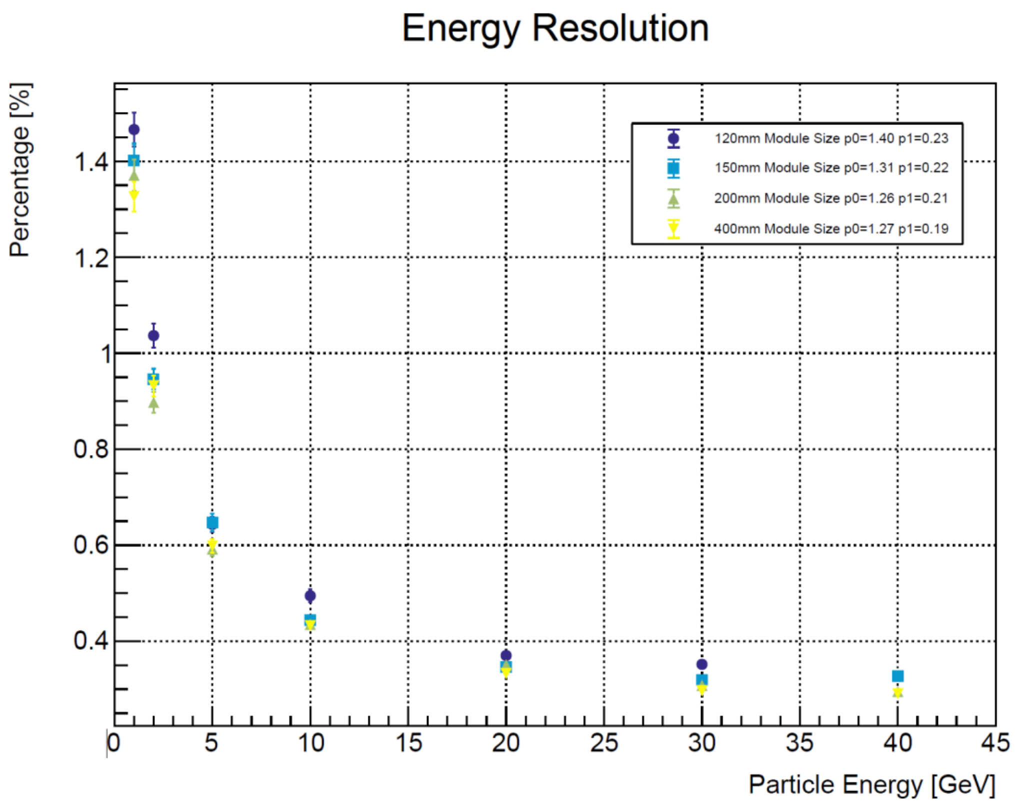
- The beam test for the first crystal module has been successfully completed!

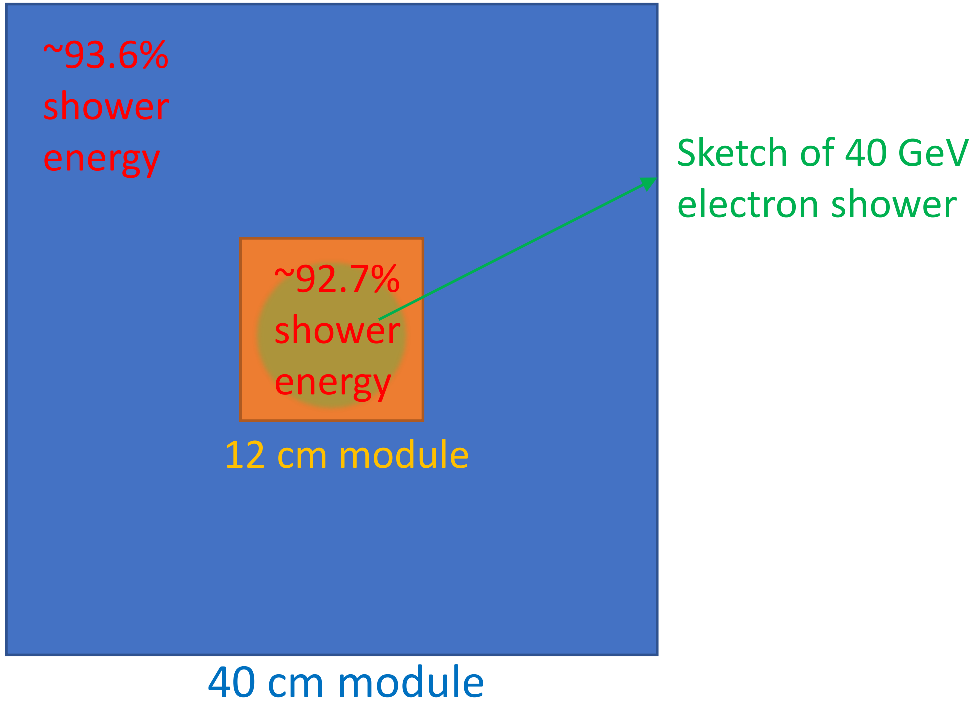
- Data conversion and selection: synchronized event
- Geant4 simulation of one module: EM energy resolution
- Event display tool
- MIP calibration channel by channel
- Energy reconstruction of electron data
- Correction of cross-talk
- Analysis of timing information
- Influence of background radiation from lifting table
- …

# Backup

# 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

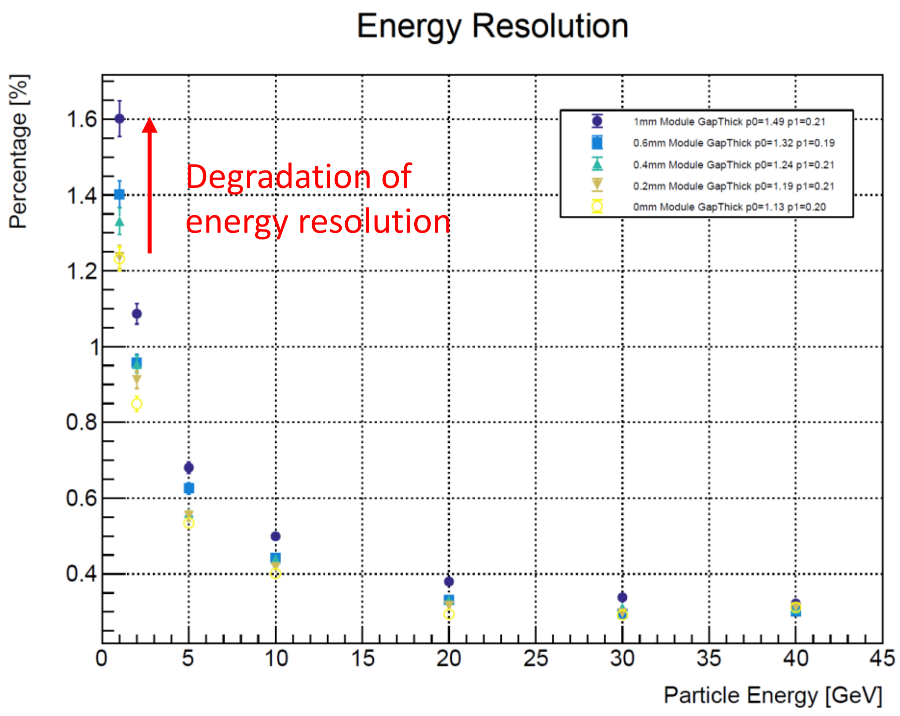


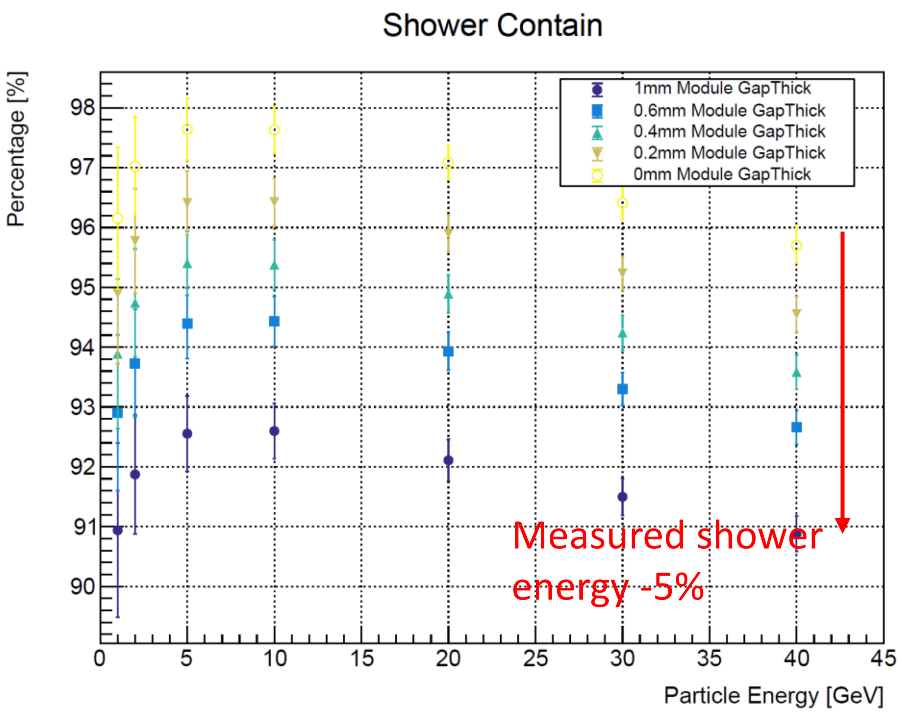



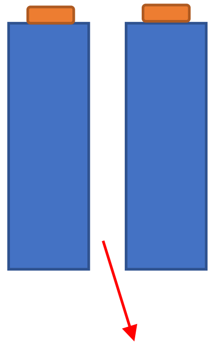

- For EM showers, 12 cm size is enough to contain most of the energy when particles hit on the center of the module
- Degradation of energy resolution: ~0.1% level

# 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 $g/cm^3$



Simulated gap: 0~1 mm

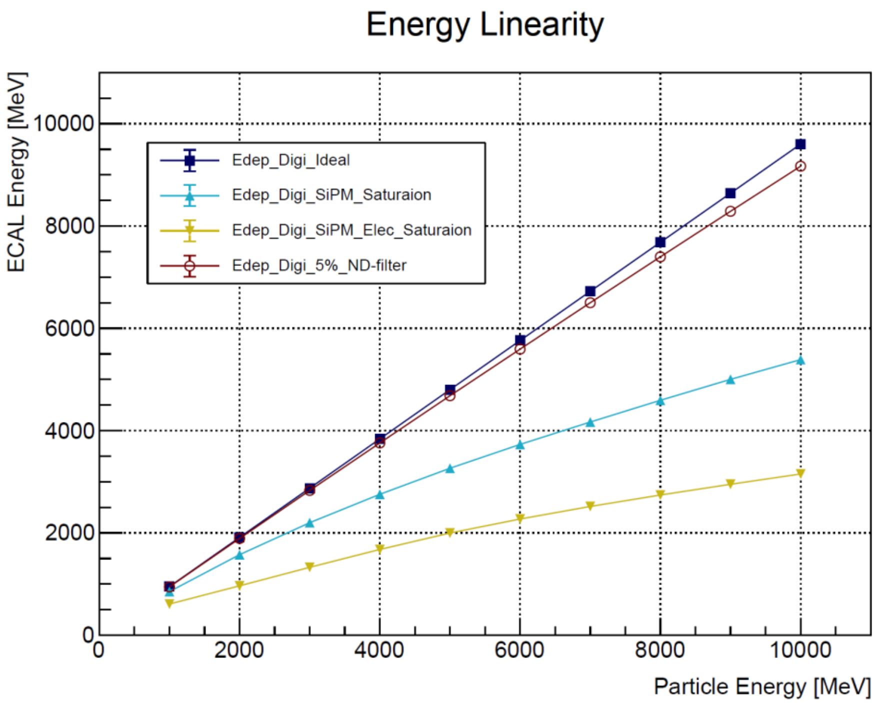

- Impact of gaps is more significant than module size
- Gaps for 12×2×2 $cm^3$ cm crystal: ~0.4 mm
- Control of gaps will be harder with longer crystals: key issue

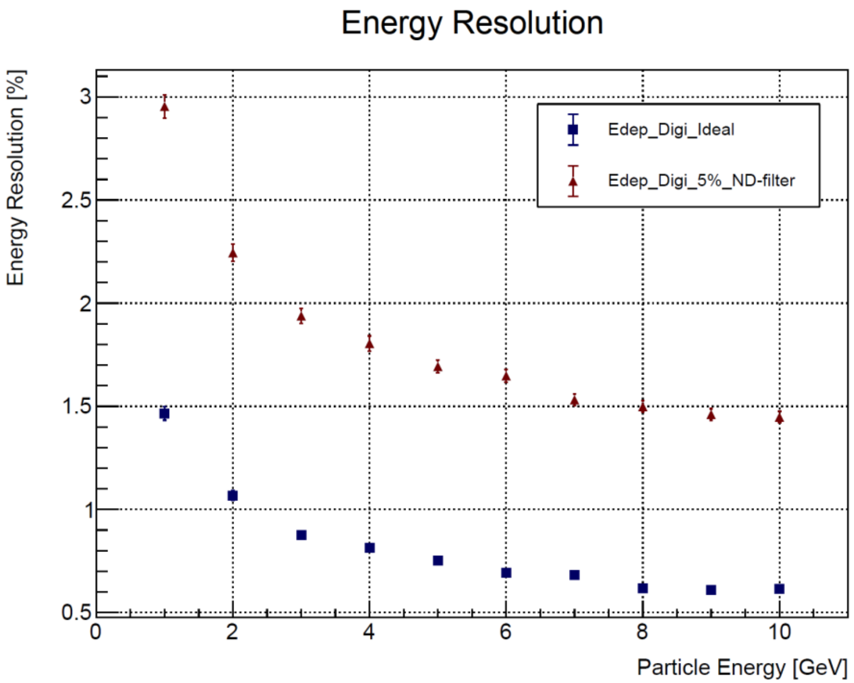
# Activities on small-scale crystal module design

Geant4 Simulation (v11.0)

- 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