# Beam tests at HEPS:
# exploring a potential test-beam site

Mengke Cai[1], Qinze Li[1], Kang Liu[1], Yong Liu[1], Yushan Liu[1], Baohua Qi[1], Jibei Shen[2], Jianchun Wang[1], Zijun Xu[1], Haijun Yang[3], Rui Yang[3,4], Lei Zhang[2]

CEPC Physics and Detector Pleneary Meeting

May 13, 2026

1. Institute of High Energy Physics, Chinese Academy of Sciences
2. Nanjing University
3. Shanghai Jiao Tong University and Tsung-Dao Lee Institute
4. Lanzhou University

# Outline

- Motivations: test-beam facilities and why HEPS?
- Recent beam test activities at HEPS
- Summary and prospects

# Motivations

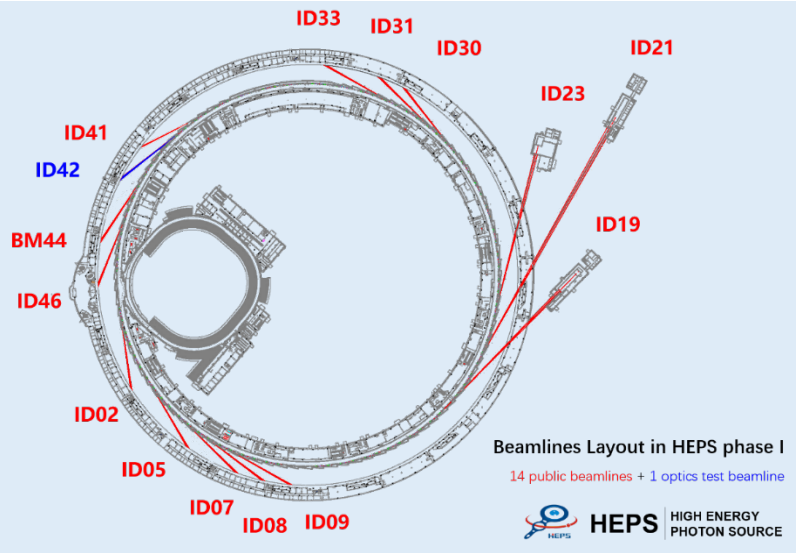
- Consensus: test-beam facilities are critical for detector R&D
  - Guiding detector design and prototyping
    - To evaluate *performance* and to validate *simulation* and *digitisation*
  - In China: convenient for scheduling and shipment (+cost savings)
  - Long-Shutdown 3 (LS3) at CERN due to HL-LHC: beams unavailable in next few years

- Why HEPS?
  - 6 GeV electrons in HEPS storage ring could be used
  - Previous beam tests at BSRF/BEPCII: observed high-energy particles up to ~2.5 GeV

# Preparation of HEPS Testbeam Site

Jianchun Wang

- Joint efforts of EPD, AD and MRD
  - Aug. 29, 2024 Yuhui Li, Jianchun Wang, Zhijun Liang had the first purposeful visit to HEPS. Mengyao Yuan (MRD) served as the local contact. They planned for the 2nd visit after HEPS completing its review by the end of 2025
  - Jan. 14, 2026 Wei Lu, Yi Jiao and Jianchun Wang discussed during the IAS Conference in Hong Kong on possible solutions
  - Jan. 22, 2026 Yuhui Dong and Jianchun Wang discussed the needs and solutions
  - Feb. 6, 2026 Lei Zheng (MRD) and Jianchun Wang discussed on-site tests, per arrangement by Yuhui Dong
  - Feb. 12, 2026 Jianchun Wang, Zhijun Liang and Zijun Xu visited HEPS. Hong Shi (MRD) and Decong Zhu (AD) showed beamlines 39B1A (XBD, X-Ray Beam Diagnostic) and 41I1A (TB, Test Beamline) and a few other beamlines




EPD: Experimental Physics Division
AD: Accelerator Division
MRD: Multi-disciplinary Research Division

# Exploring a potential HEPS Testbeam Site

- Joint efforts of EPD, AD and MRD
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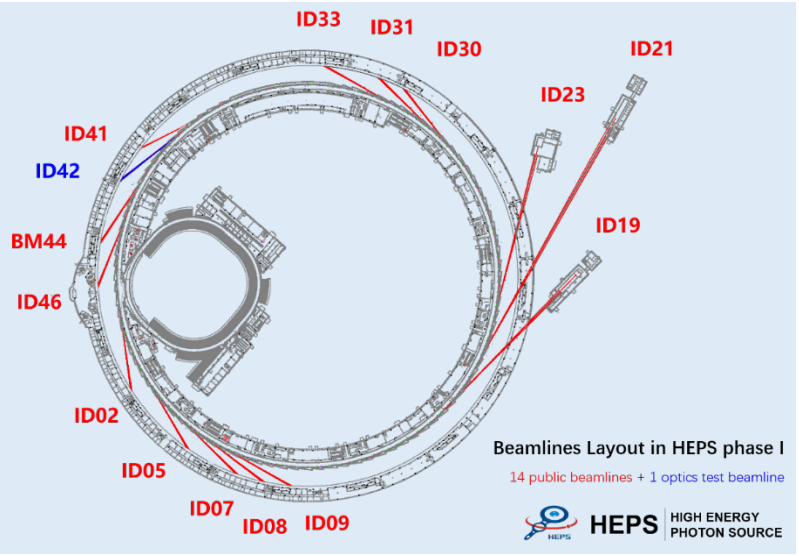
- Beam tests at 39B1A by Zijun Xu, Yong Liu and SiTracker + Calorimeter teams
  - Mar. 7, 2026 A pilot run with plastic scintillator counters for beam rate
  - Apr. 3, 2026 Calorimeter placed upstream of Silicon Tracker due to location constraints, taking data alternatively
  - Apr. 22-23, 2026 SiTrk placed upstream of Calorimeter taking data simultaneously



# HEPS site investigation

Zijun Xu (IHEP)

- Test Beamline 42I1A


- X-Ray Beam Diagnostic Beamline (XBD) 39B1A


- 39B1A was used for follow-up testbeam studies

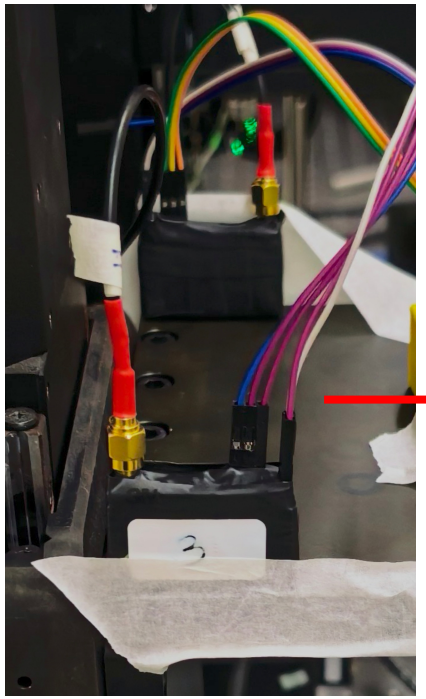
# HEPS site investigation

Zijun Xu (IHEP)

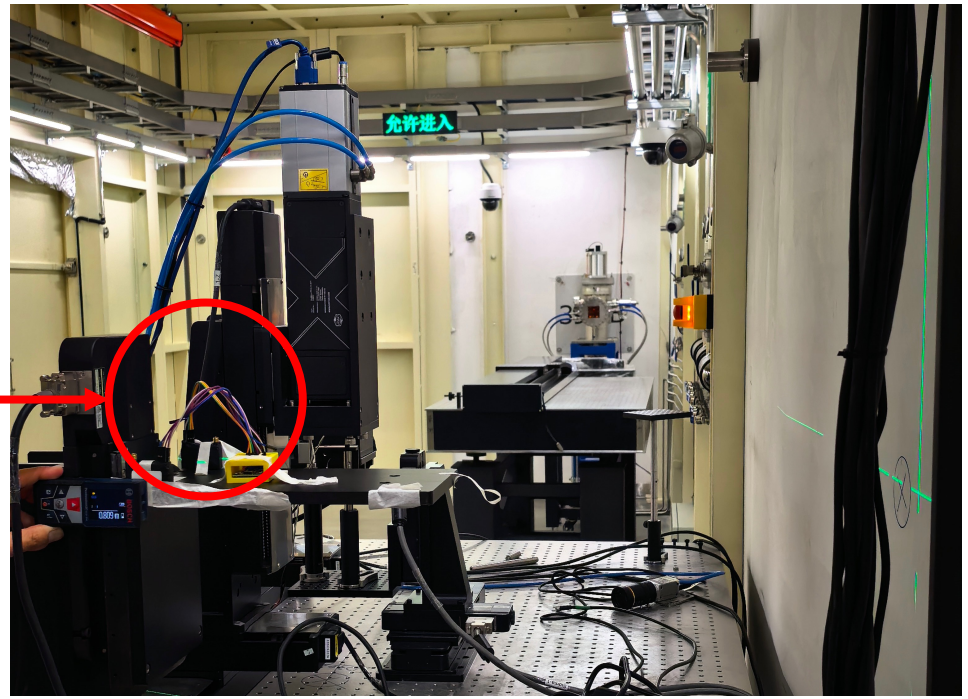
Beamline 39B1A

- First test of beam rate
  - Using two plastic scintillator tiles (coincidence signals)
- Coincidence rate measured at level of ~1Hz

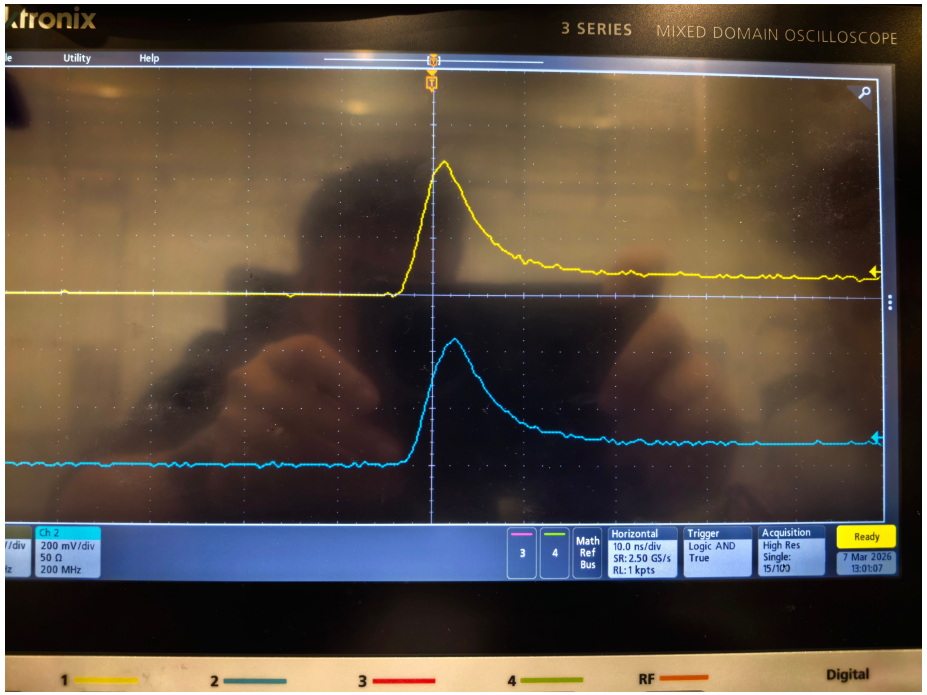
Two scintillator tiles



Setup positioned in downstream of X-ray camera



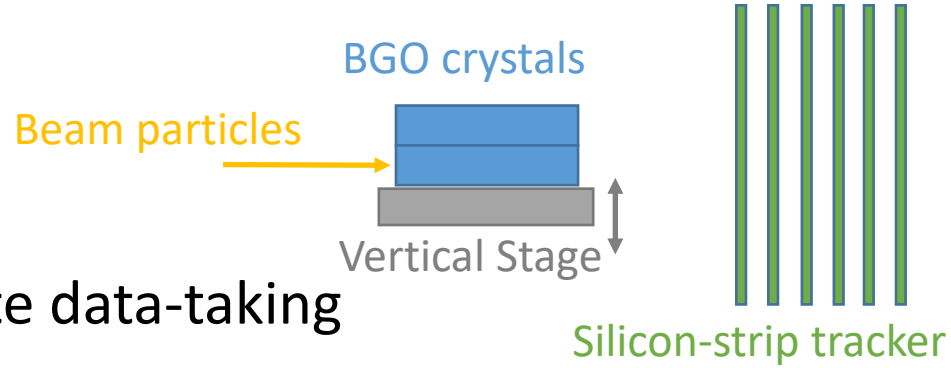

Scintillator-SiPM output signals



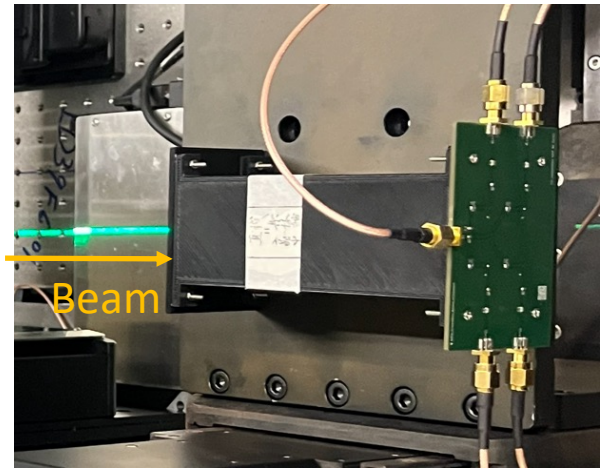
# First beam test at HEPS



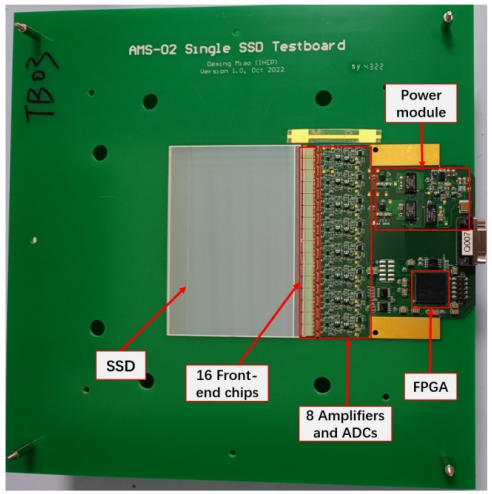
- Beam-test setup
  - Tracker: 6 layers silicon-strip sensors
  - Calorimeter: 4 BGO crystals (10.7$X_0$ depth)
  - Individual DAQ for tracker and calorimeter: separate data-taking

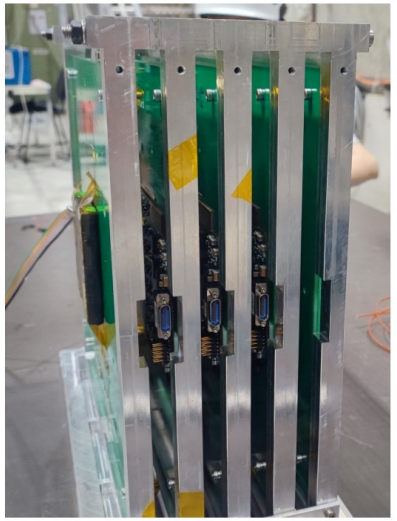


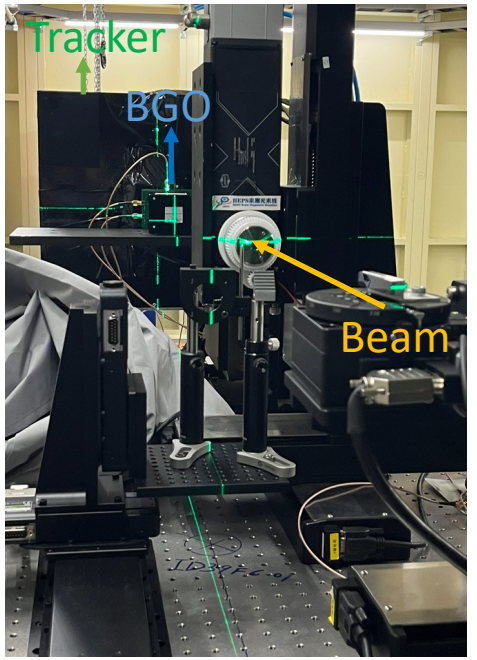

BGO crystal matrix
- BGO: 2×2×12 $cm^3$
- 2×2 BGO bars
- Single-end SiPM readout




Silicon-strip tracker
- 3X + 3Y: Si-strip layers
- 8cm×8cm coverage

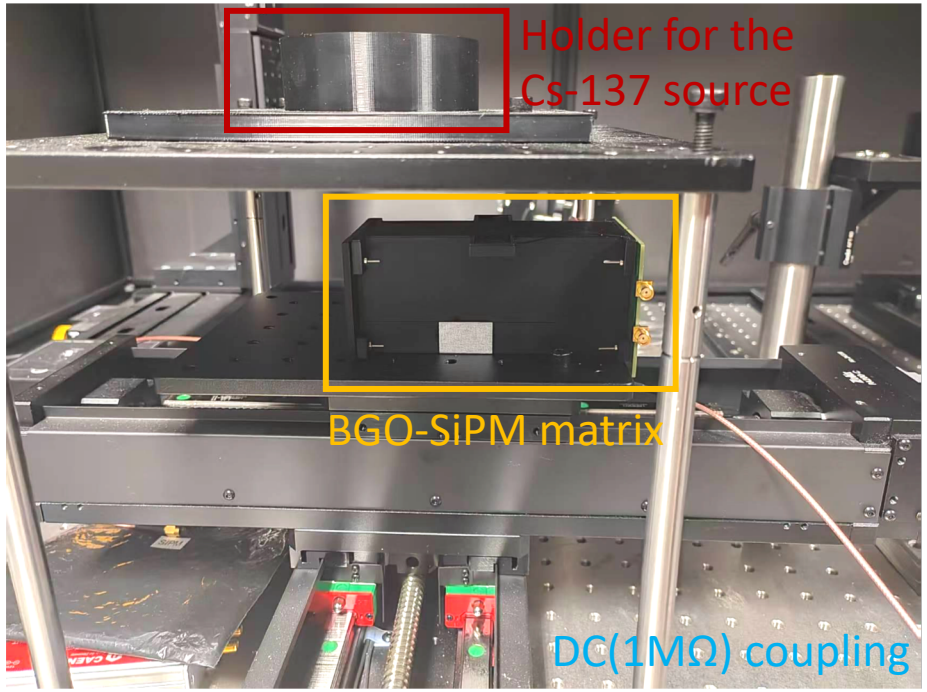


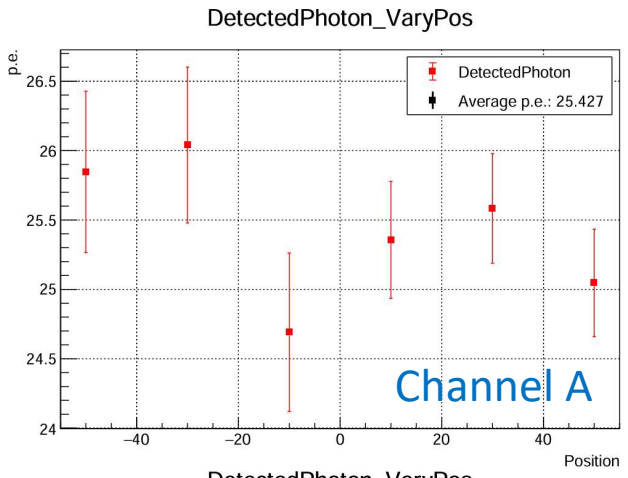


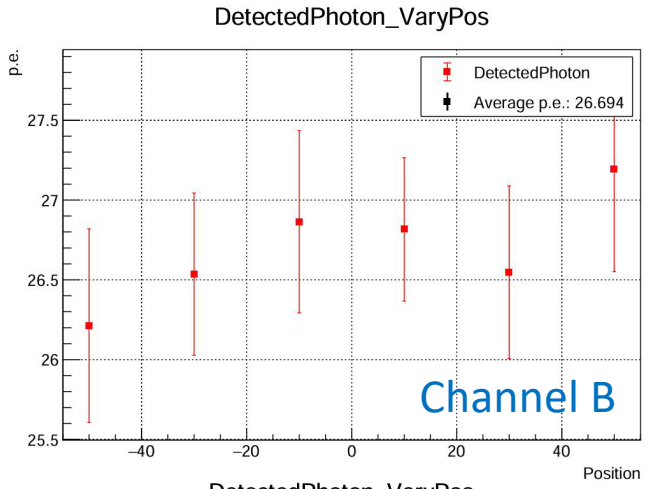
# BGO energy calibration in lab

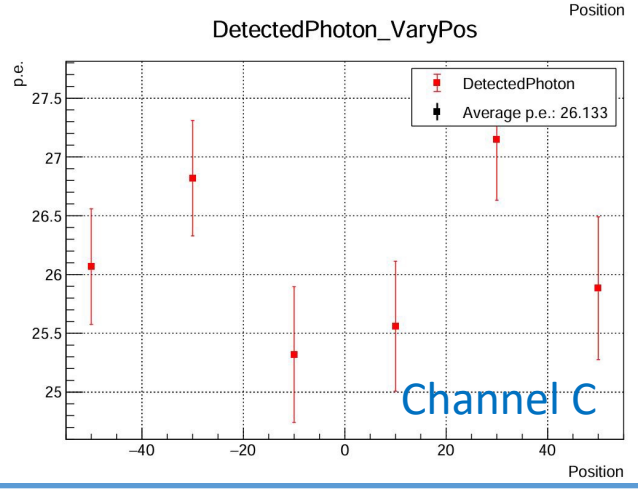
- BGO-SiPM crystals: response measured with Cs-137 and Co-60
  - Good response uniformity along BGO crystal length direction (12cm)

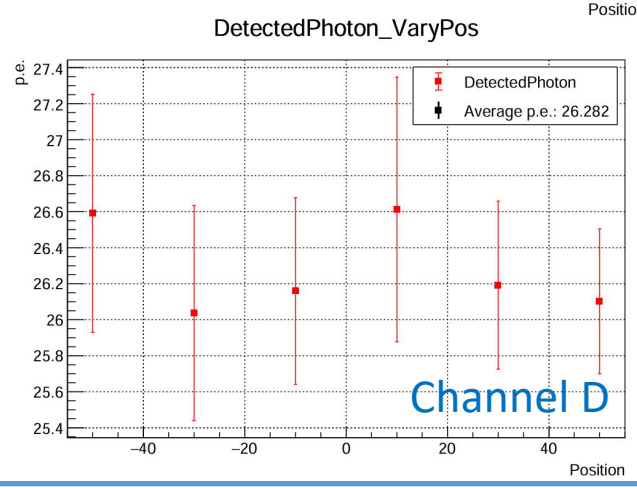



BGO bars: SiPM readout at single end



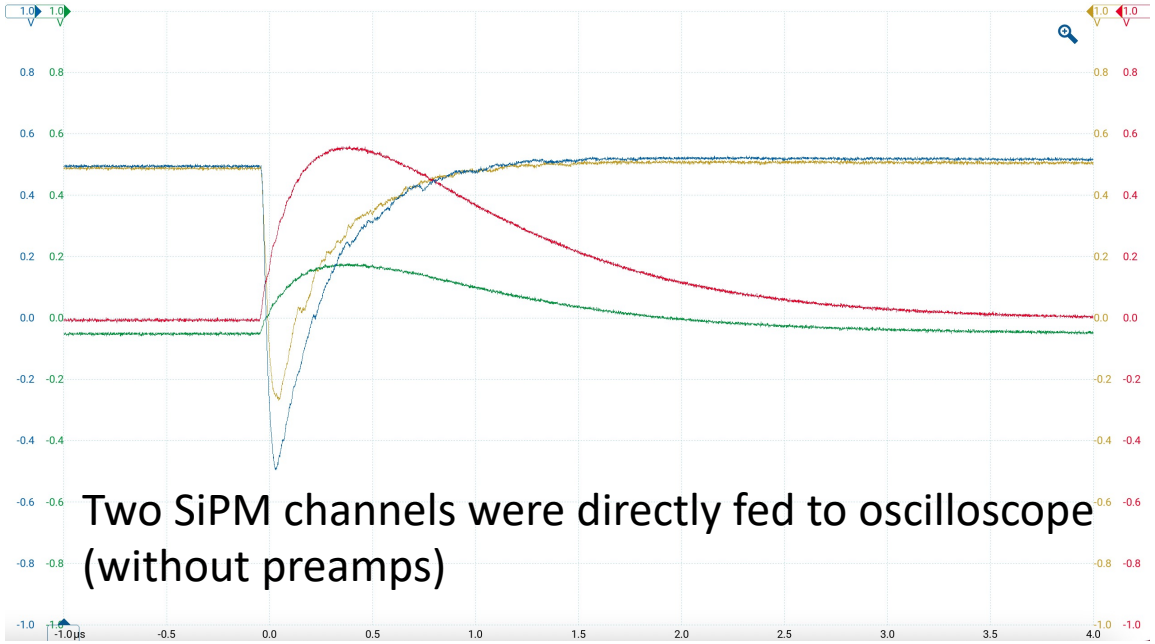



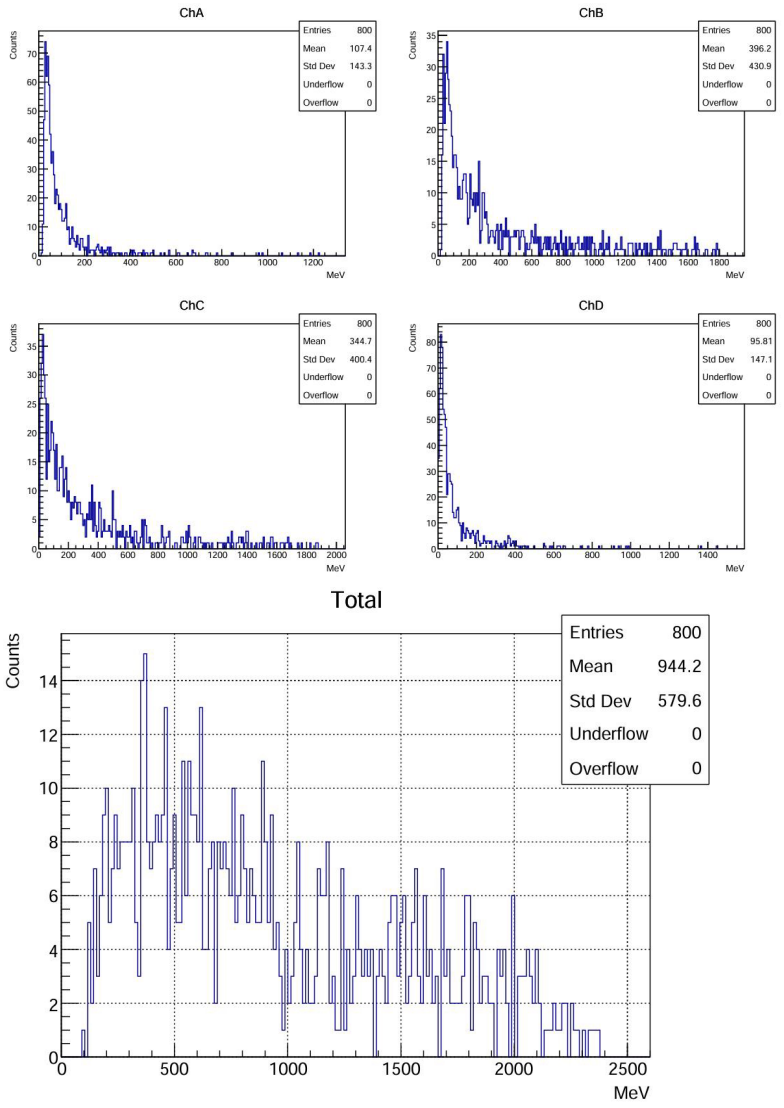
# First beam test at HEPS: energy reconstruction

April 3, 2026

- Observed GeV-equivalent energy signals
  - Reconstructed energy up to 2.5 GeV
- Remaining issue to be addressed
  - BGO could not be positioned in the beam centre, which might lead to underestimate of beam energy



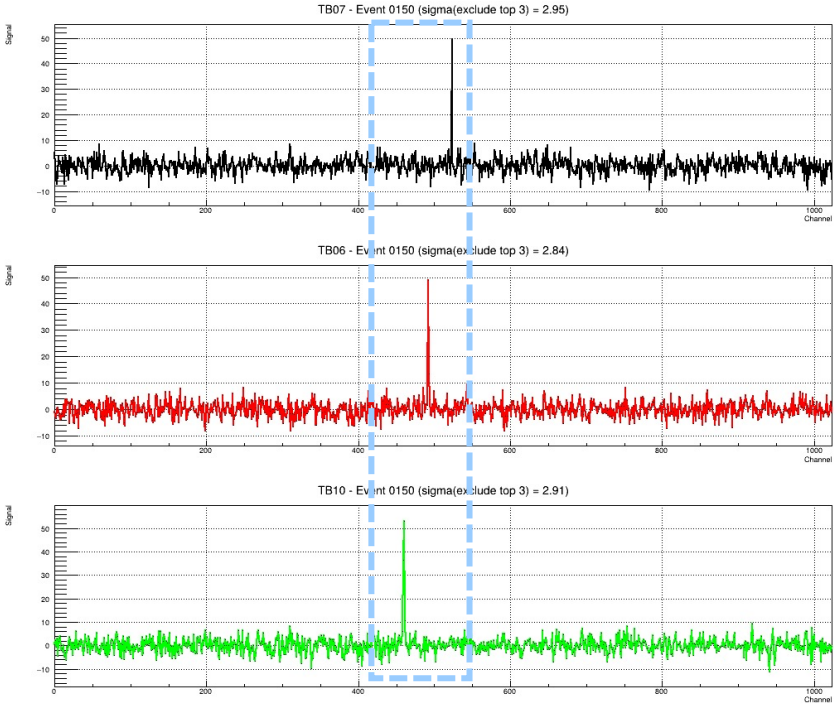
Two SiPM channels were directly fed to oscilloscope (without preamps)

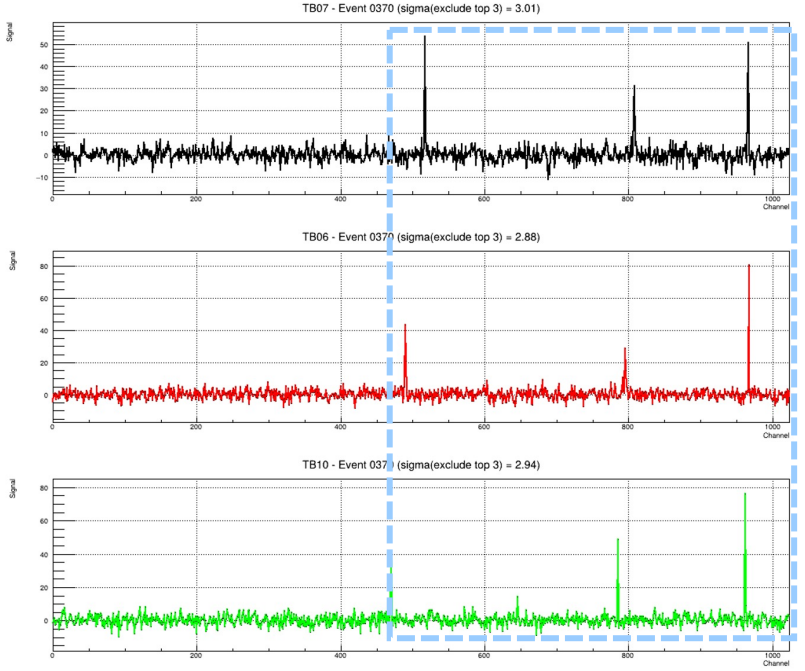


# First beam test at HEPS: tracking



- Silicon microstrip tracker
  - Observed single-track and multi-track events
  - Position resolution O(10) um
  - Single-track events: 5% in the fiducial area




Time windows O(10) µs

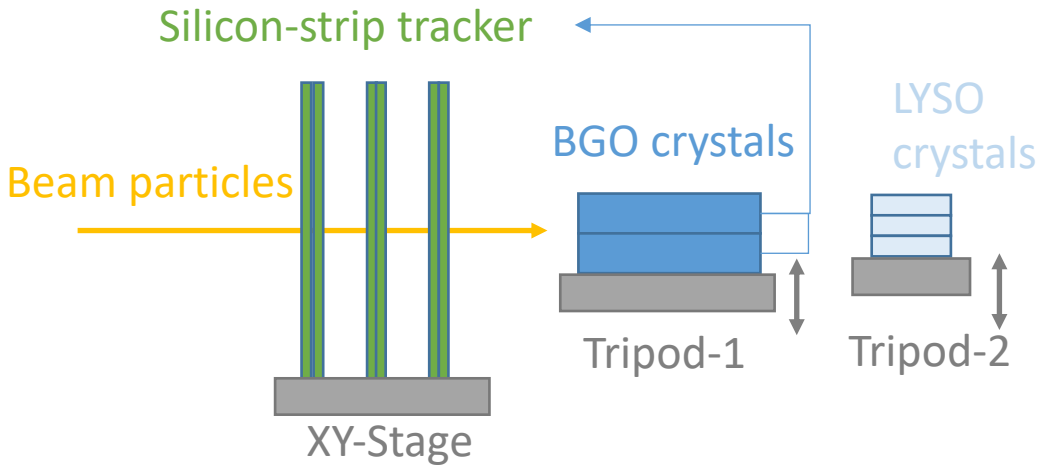
# First HEPS beam test: what we learned

- Major conclusions
  - Observed tracks in all silicon-strip layers: events of single- and multi-tracks
  - Observed large energy signals in BGO-matrix: GeV-equivalent energy
- Remaining issues
  - BGO crystals had to be placed in upstream of silicon tracker
    - Due to limited usable space of the optical table
    - Tracker and BGO could only take physics data **separately**
  - Could not position BGO crystals in the beam center
    - Due to limited travel range of the existing stage
    - Possibly **higher-energy** shower signals
  - Track-calorimeter setup had to be placed in downstream of X-ray camera
    - Camera + frame: ~10 cm thick aluminum (assuming all solid)
    - Could possibly lead to **early EM showers** in upstream

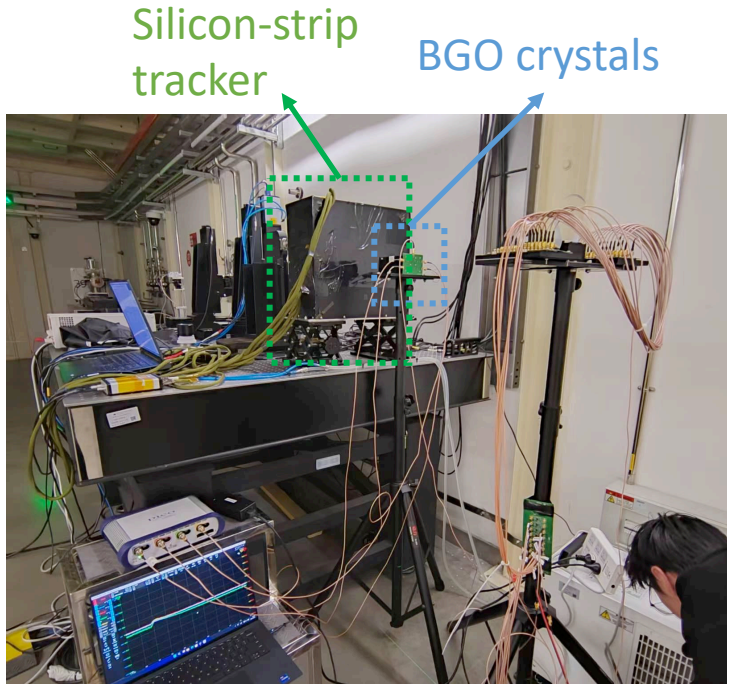
# Second beam test at HEPS: setup

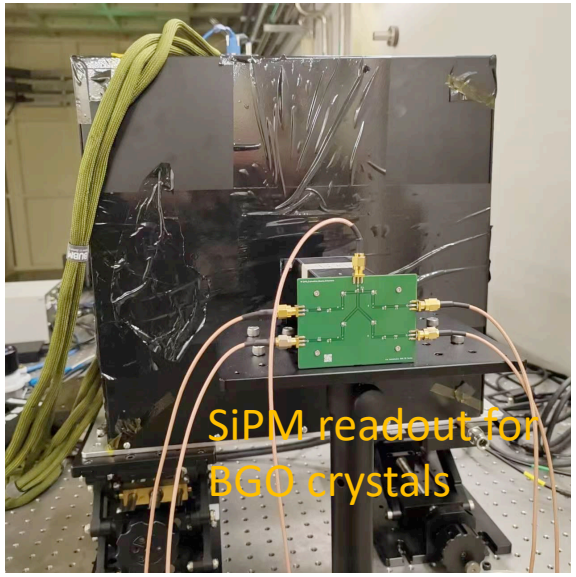


- Beam-test setup
  - Unchanged: 6 layers of silicon-strip sensors and 4 BGO crystals (10.7$X_0$ depth)
  - *Updates* (NEW!)
    - Using BGO-matrix to trigger tracker: **event-level synchronization**
    - Full vertical travel range: capable to position BGO-matrix in the **beam center**




LYSO crystals (one LumiCal module) tested in downstream

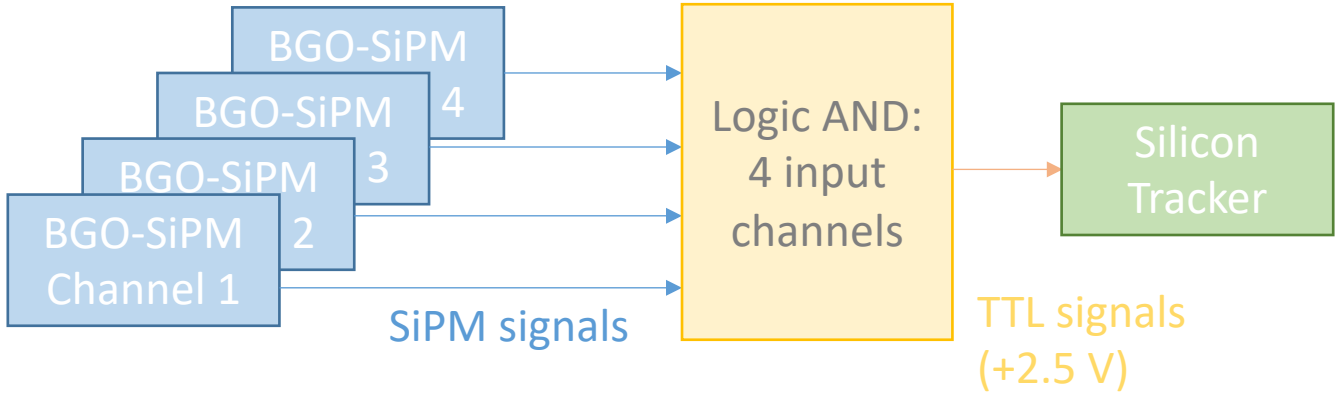


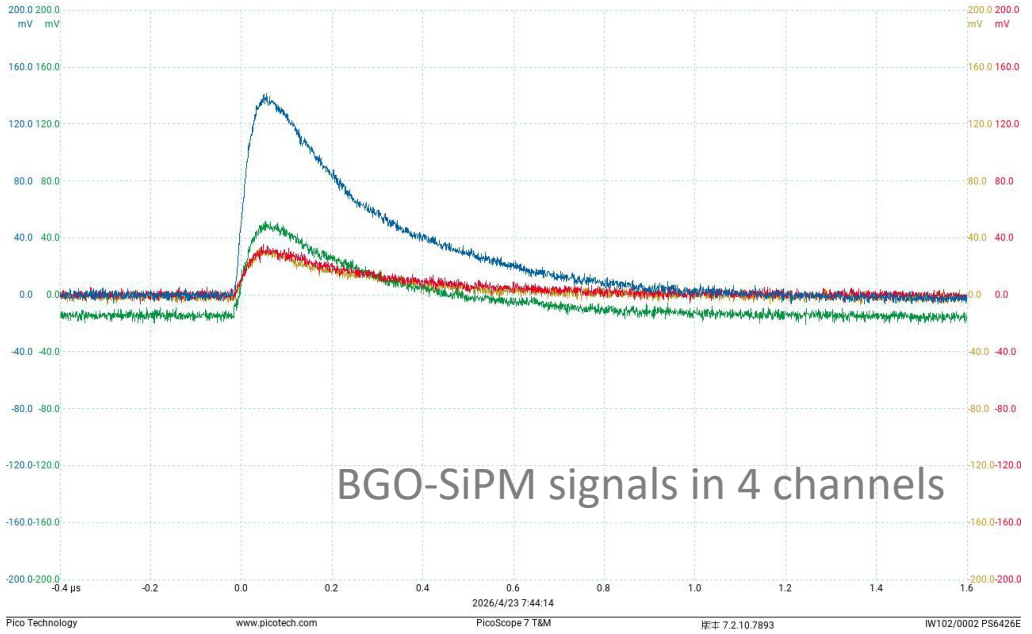
# Second beam test at HEPS: event sync



- Event-level synchronization
  - Coincidence of four BGO-SiPM channels fed to silicon-strip tracker DAQ
    - Feasibility: validated in lab using cosmic muons before moving to HEPS
  - On-site crosscheck at HEPS: successful event-synchronization in mostly all runs




A typical event recorded at HEPS

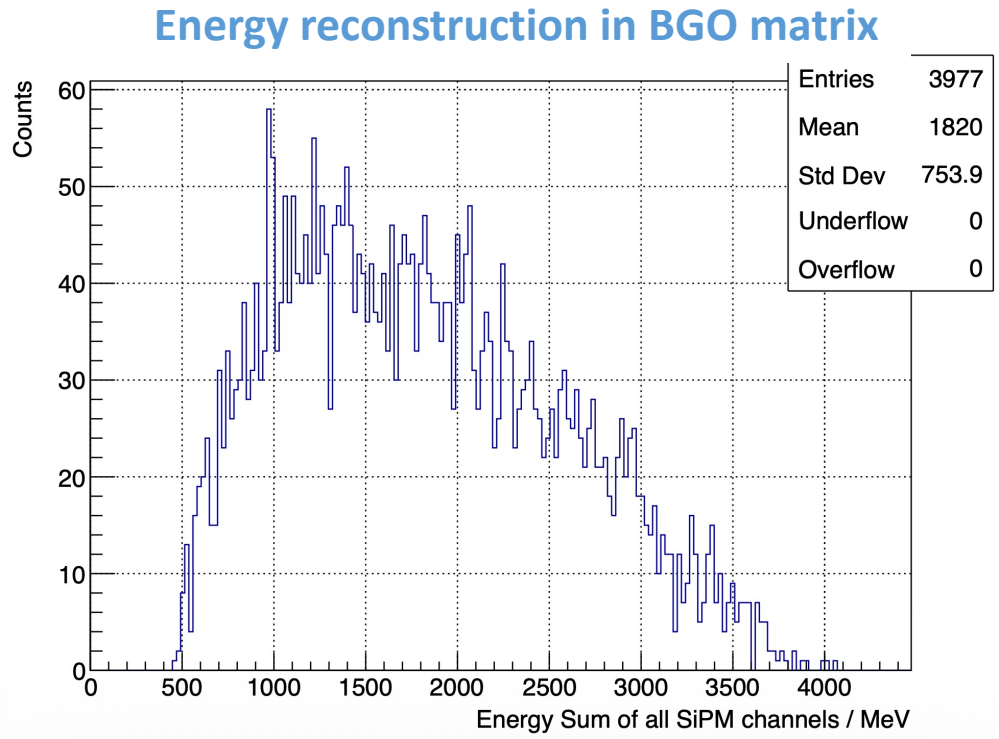



Note: BGO-SiPM signals were directly used for this time, without any preamps, since all preamps would suffer saturation due to large signals.

# Second beam test at HEPS: energy spectrum

April 22, 2026

- Over-night run with ~4,000 events
  - Successful event synchronisation of track-calorimeter
  - This enables to select sing-track events and to narrow down hit position range
- Energy spectrum measured in BGO matrix
  - Including all events that pass the trigger
    - Coincidence of four BGO-SIPM channels
  - Wide distribution in 0.5 – 3.5 GeV



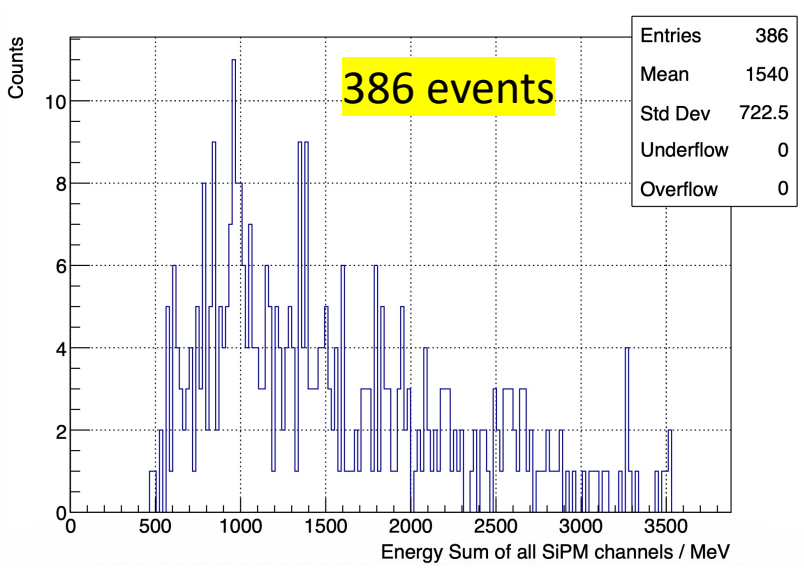

The energy spectrum and mechanism are to be further investigated and understood

# Second beam test at HEPS: energy sum

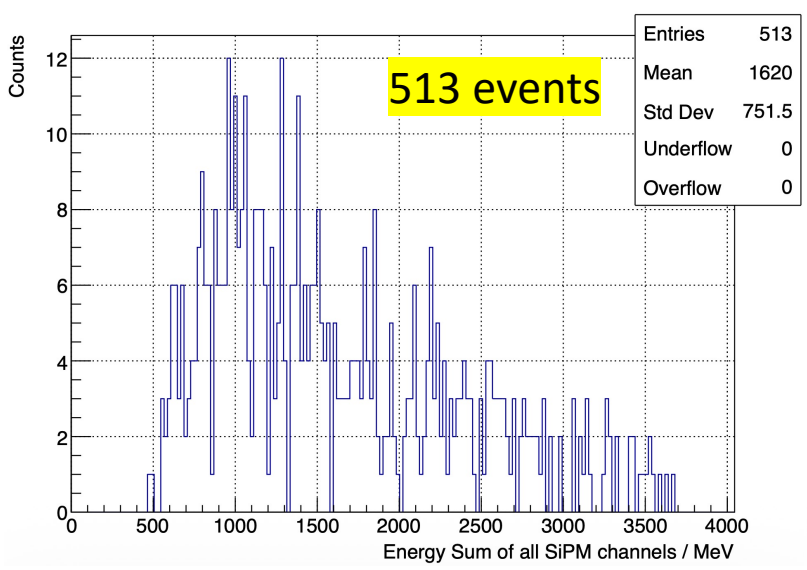


- ***Single-track* events**: selected using the silicon tracker for all scenarios
- Energy spectra in BGO matrix
  - Different ranges of track hitting positions are required w.r.t. the BGO matrix centre
  - Aligned transverse positioning of silicon track and BGO matrix at ~1mm precision

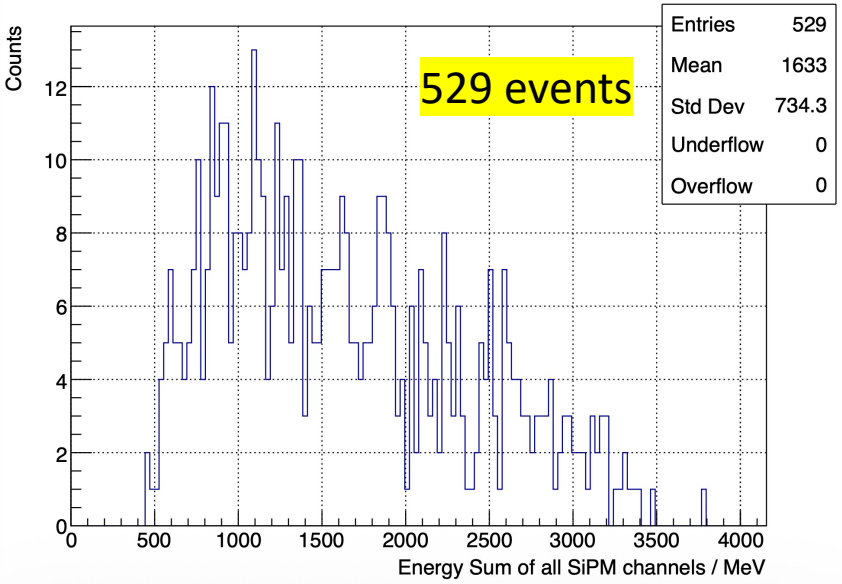
Tracks within $40\times40\ \mathrm{mm}^2$




Tracks within $20\times20\ \mathrm{mm}^2$



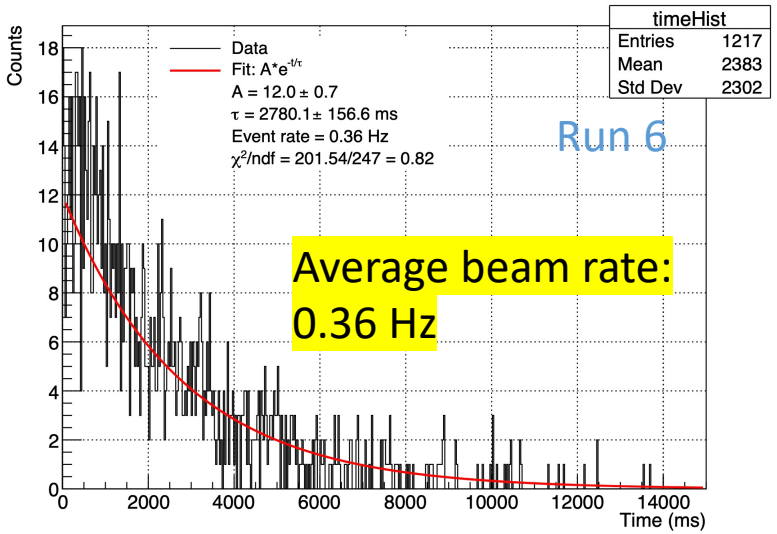

Tracks in $10\times10\ \mathrm{mm}^2$

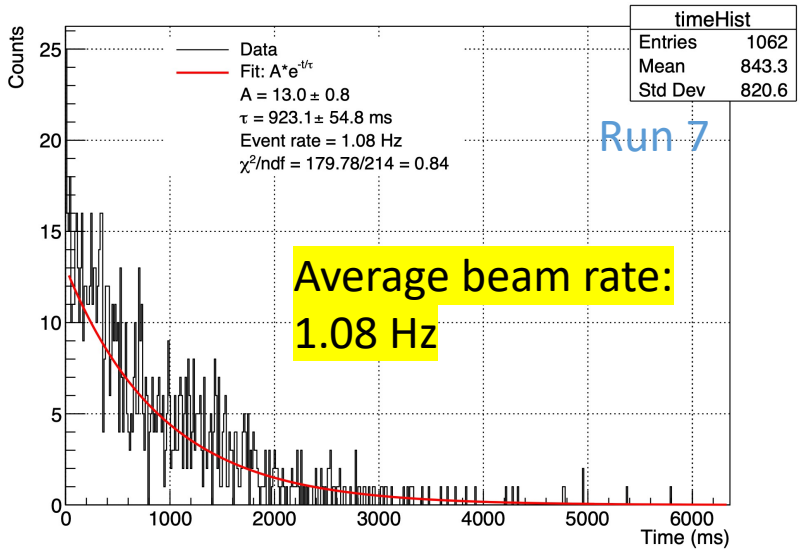


# Beam rates tested at HEPS

- Time interval was measured between every two neighbouring events
  - (Follows an exponential distribution)
  - Average beam rate can be extracted: 0.17 – 1.08 Hz, which seem to depend on HEPS beam operation and testbeam trigger scheme

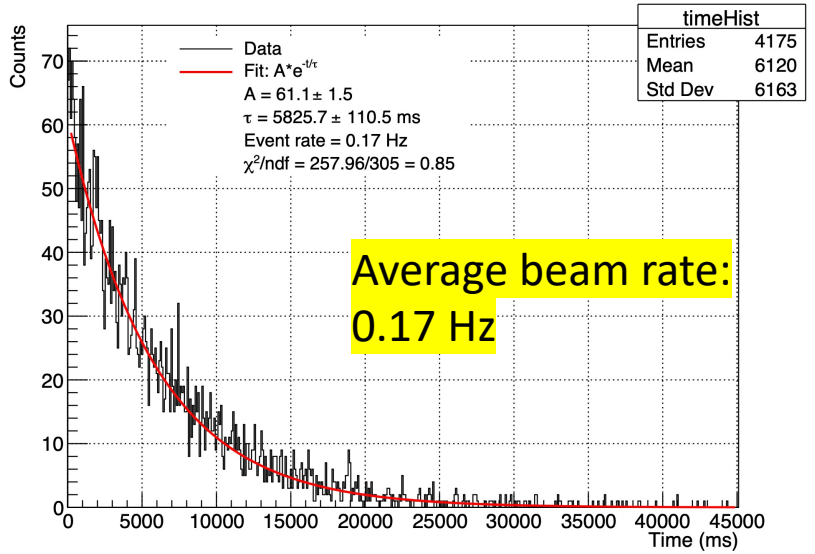
Event Time Interval (Apr. 3, 2026)




Trigger scheme in the first beamtest:
coincidence of two BGO-SiPM channels

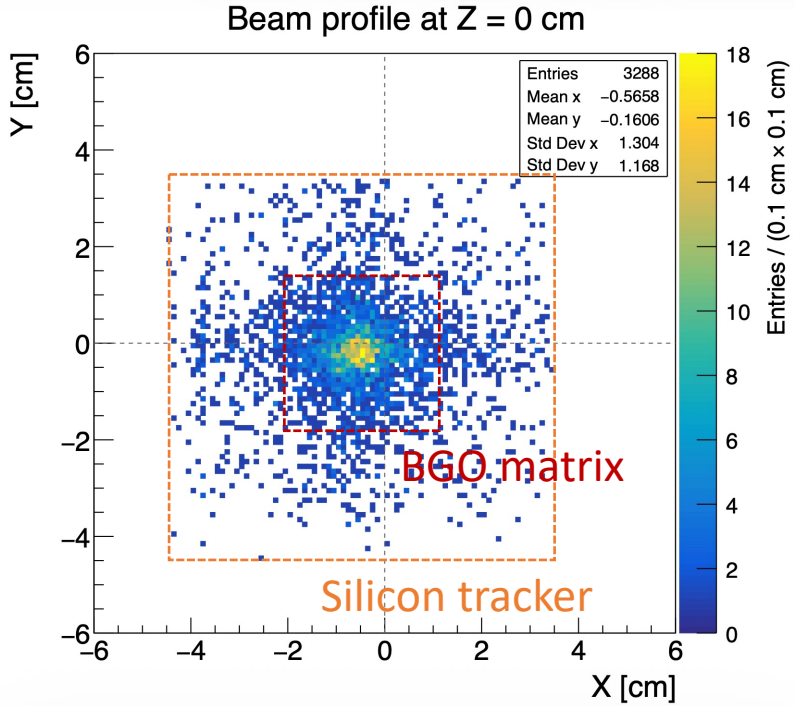
Event Time Interval (Apr. 22, 2026)

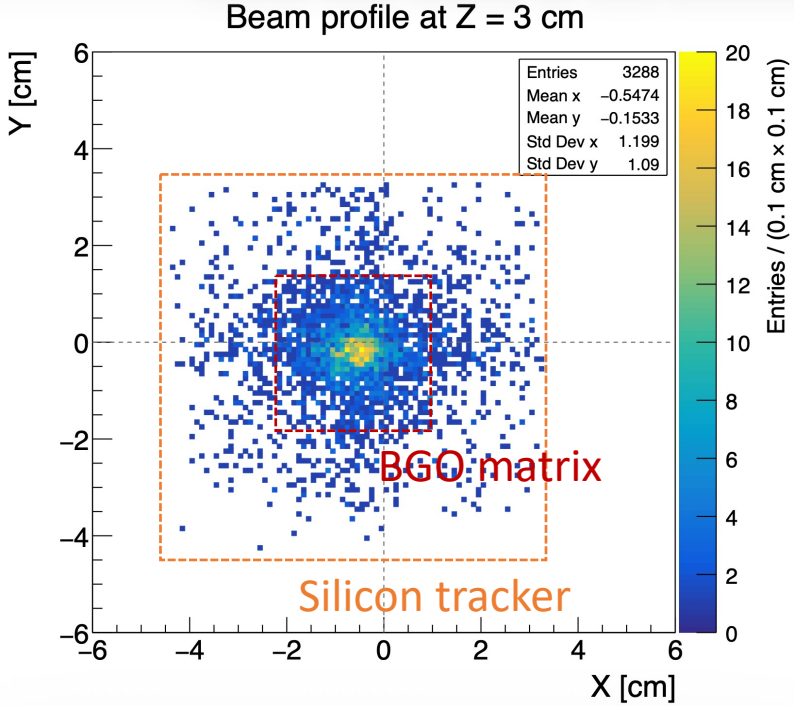


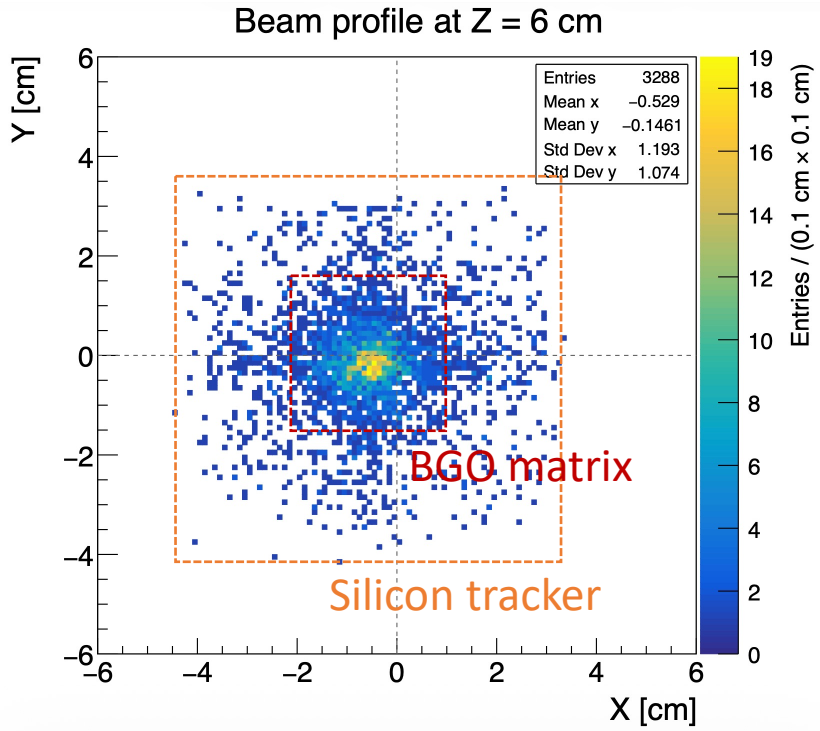

Trigger scheme in the second beamtest:
coincidence of four BGO-SiPM channels

# Beam profiles in 2D

- Silicon-strip tracker: transverse beam profiles in 2D
  - 6 layers: along beam direction: Z=0, 3 cm and 6 cm (Upstream → Downstream)
  - Silicon tracker (fiducial area of $8\times8\ \mathrm{cm}^2$): aligned with BGO matrix centre



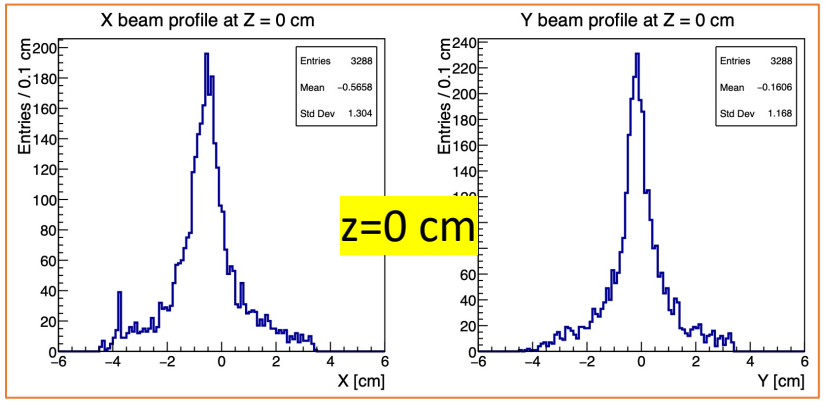



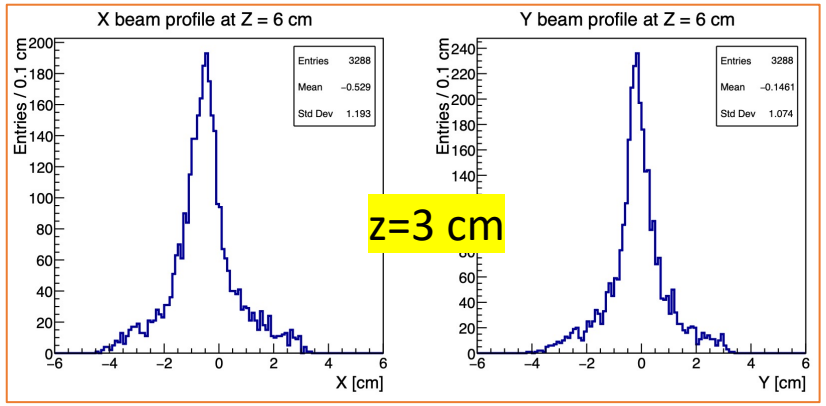



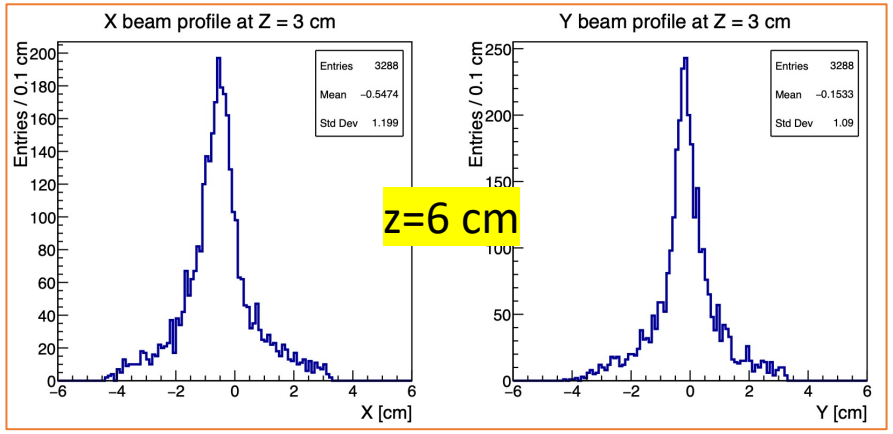

Reminder: silicon tracker was triggered by BGO matrix → multi-track events in area of $8\times8\ \mathrm{cm}^2$

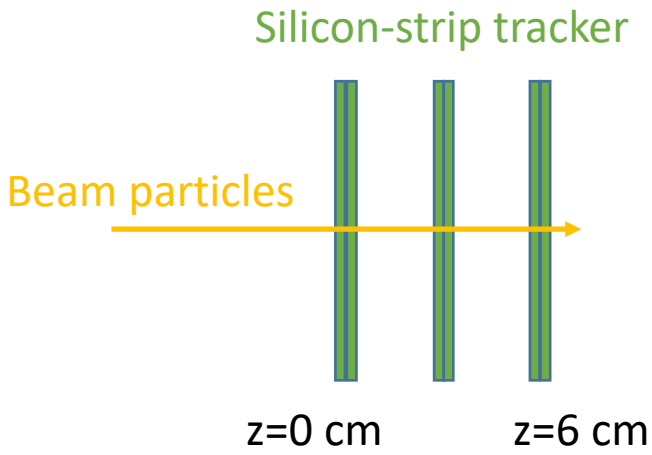
# Beam profiles: projection to 1D

- Silicon-strip tracker: beam profile projection
  - Beam is highly collimated within $\pm 1$ cm, surrounded with a halo-like structure
  - Asymmetric pattern: ~10% wider positioning spread in horizontal than vertical



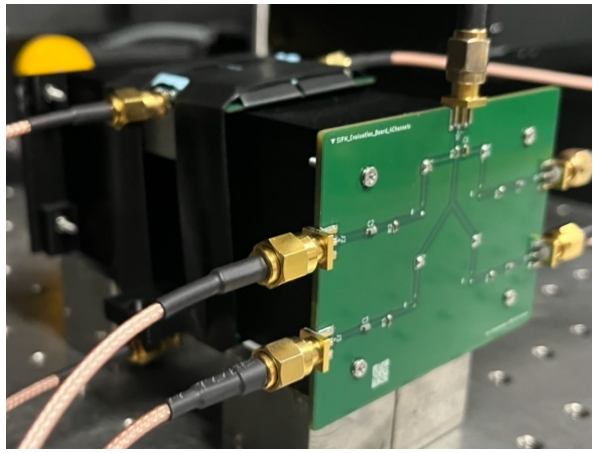



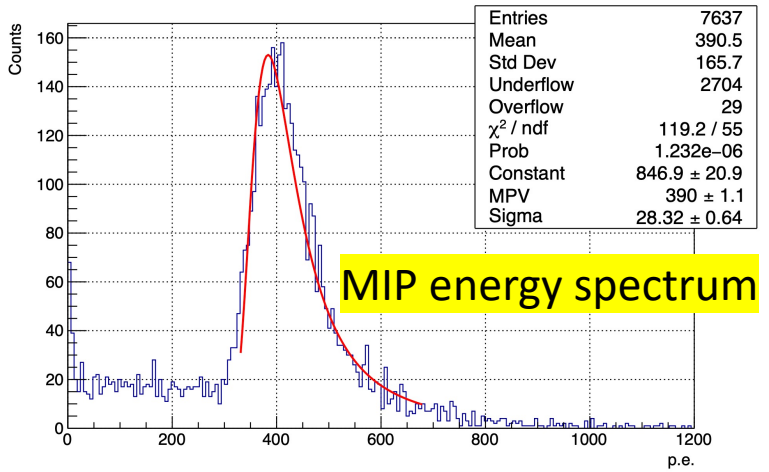



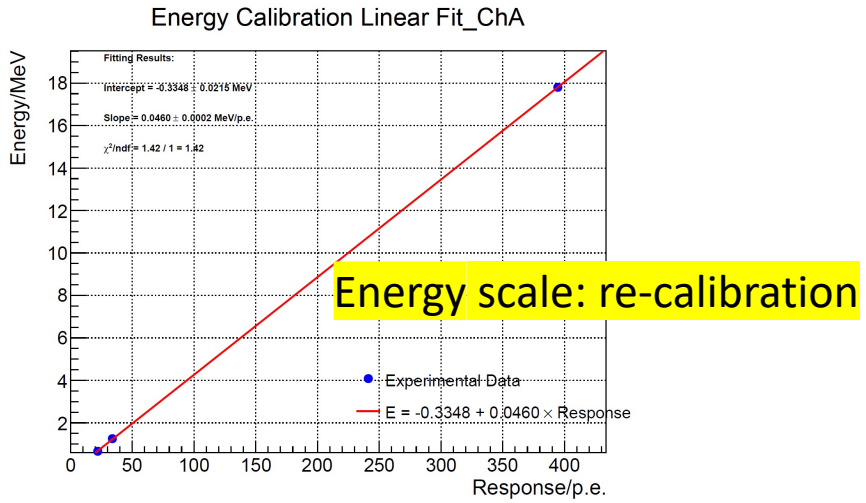



# BGO energy calibration: further studies (1)

- Cs-137 and Co-60 were used for energy calibration in lab
  - Two energy points: 0.662 MeV and 1.17/1.33 MeV
    - This BGO setup can not separate two gammas from Co-60 (to cover the wide dynamic range)
  - But still concerned about the energy-scale uncertainty in extrapolation to 3 orders of magnitude  higher energy at HEPS (GeV-level)
- Cosmic-ray tests for BGO matrix: in past two weeks in May
  - To add a third MIP-energy calibration (~17.8 MeV)



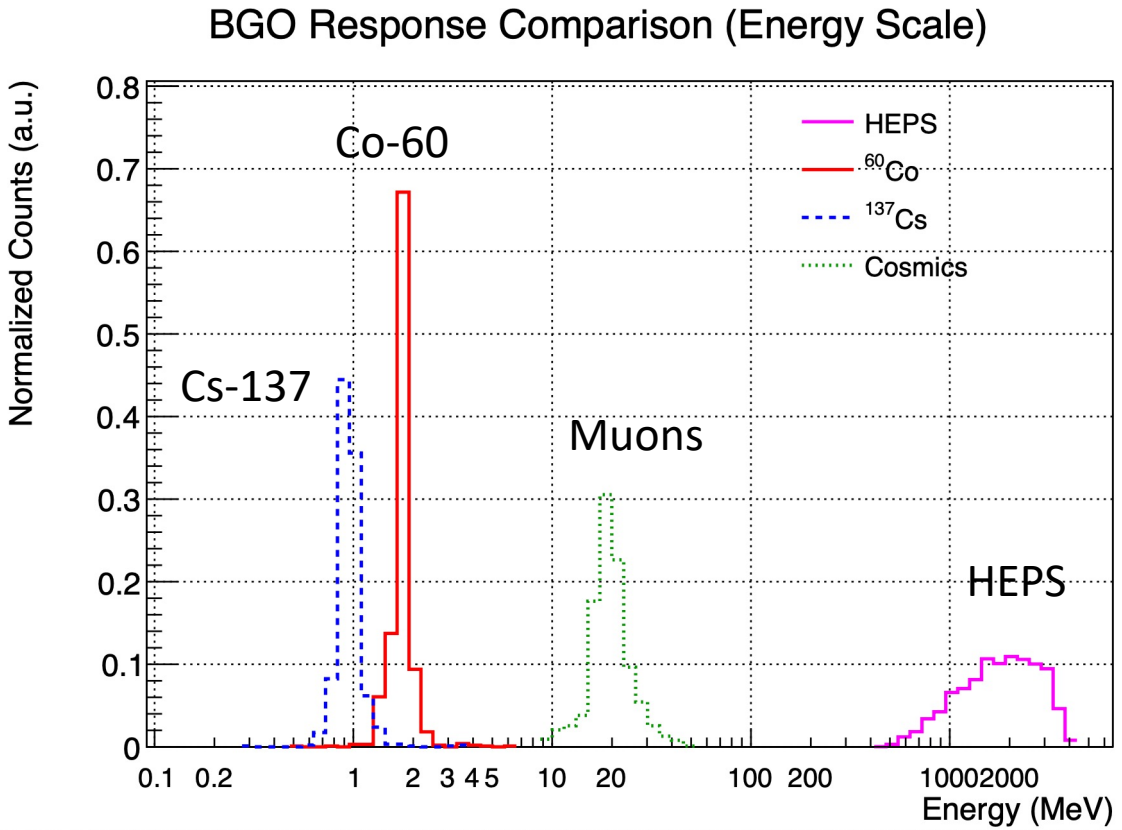


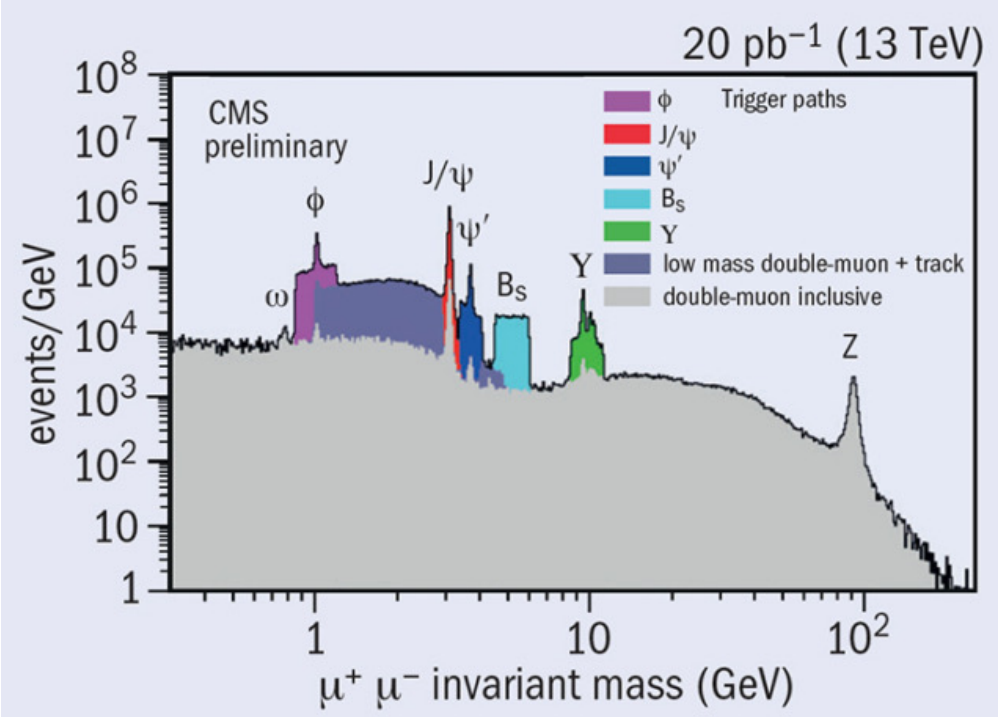
# BGO energy calibration: further studies (2)

- Conclusion: beam energy spectrum mostly remains the same
  - Results shown are based on the energy recalibration

Three orders of magnitude

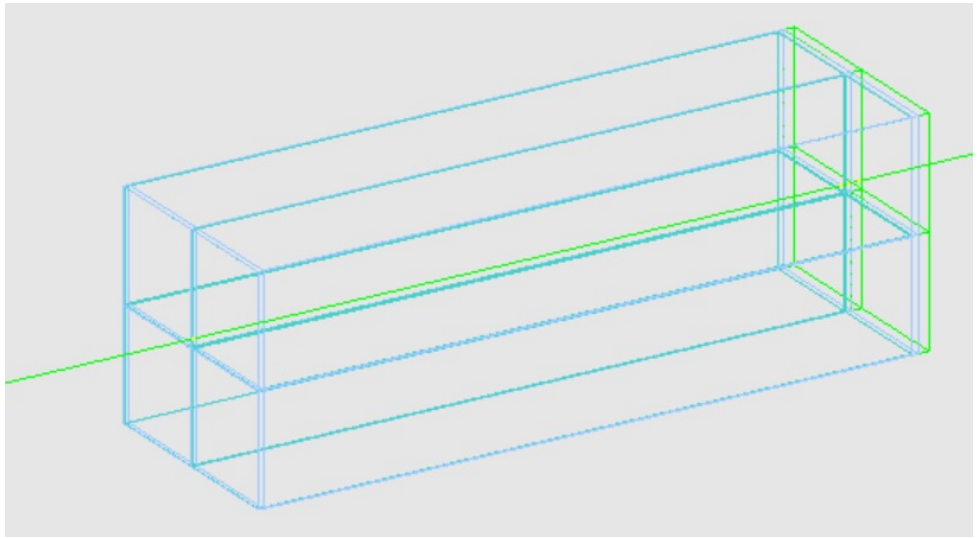



Two orders of magnitude

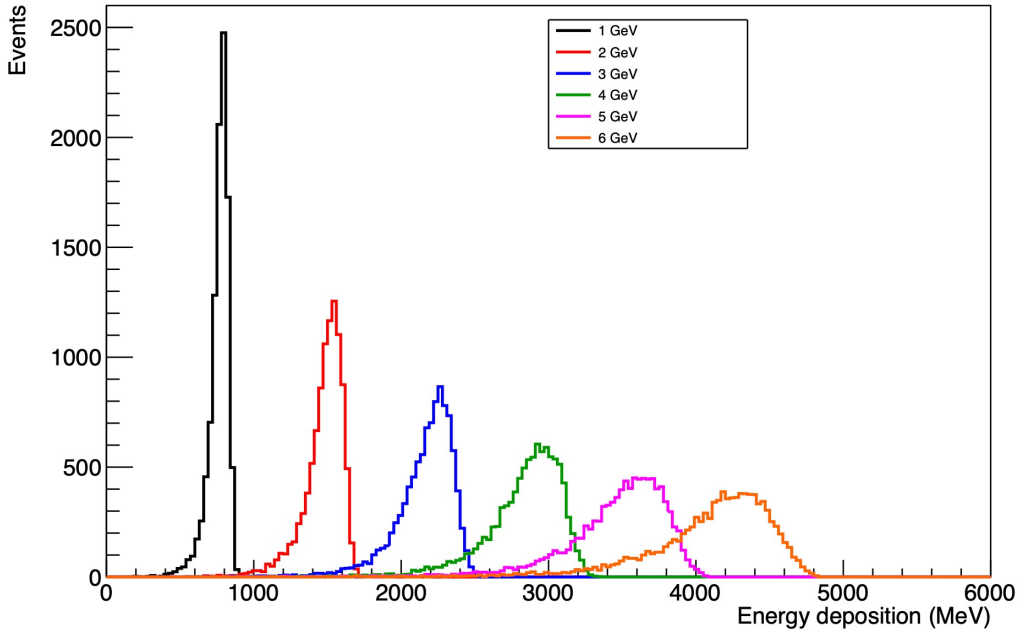


# BGO matrix: Geant4 simulation studies

- **EM shower response** of BGO-crystal matrix: Geant4 simualtion
  - Incident in the BGO matrix centre along crystal length
  - Energy scans with electrons in the range of 1– 6 GeV (with a step of 1 GeV)
  - Energy peaks of single-energy electrons can be well separated



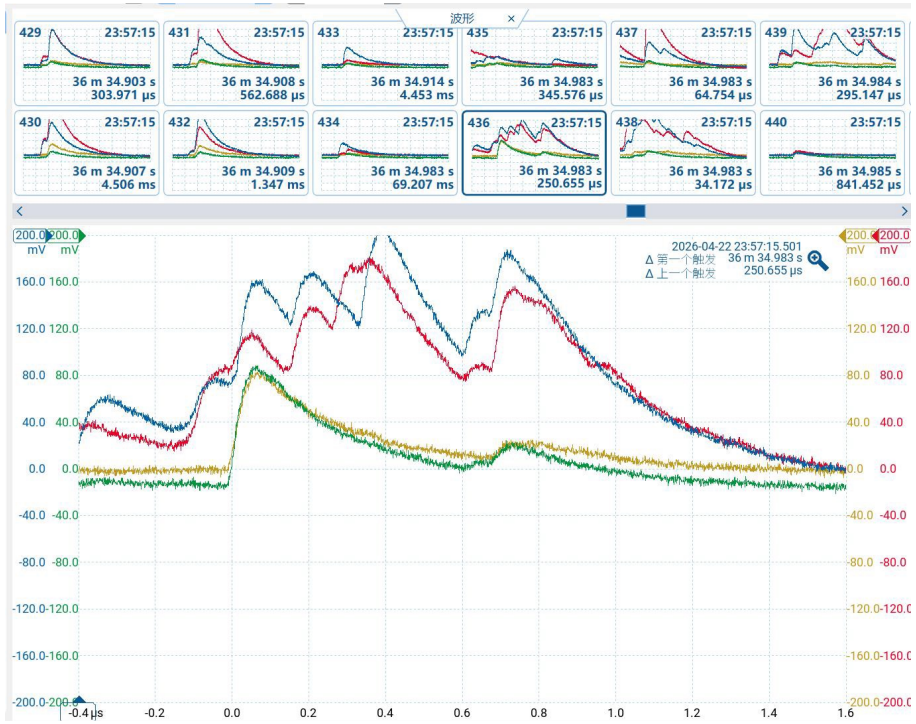
BGO-matrix energy reconstruction (in stack)

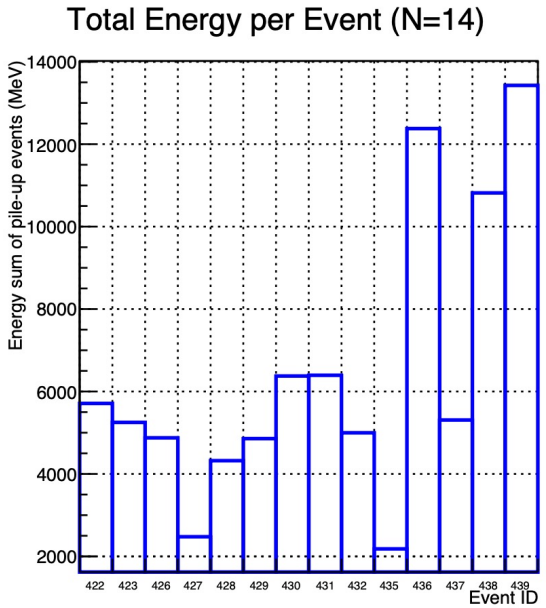


# Second beam test at HEPS: unexpected



- Events most probably due to multiple high-energy electrons
  - “Pile-up” events, separated by ~100 ns in time
  - Observed only in a single run in mid-night: neither before nor afterwards
  - Likely more hints in the HEPS log → HEPS experts for better understanding




Reconstructed energy of 14 pile-up events: up to 14 GeV

These “pile-up” events also led to the failure of BGO-tracker event synchronization (more events recorded in BGO-crystals)

# Summary and prospects

- Successful beam tests at one HEPS beamline
  - Using silicon-strip tracker and BGO-crystal calorimeter
  - Observed single and multiple tracks in silicon tracker
  - Observed GeV-energy equivalent signals in BGO calorimeter
  - Average beam rate in the range of 0.1-1Hz
- Prospects
  - Better understanding on the beam energy structure and production mechanism
  - To explore possibilities at other beamlines at HEPS
- Acknowledgement
  - Coordinating efforts of several divisions (AD, EPD and MRD)
  - Local technical assistance and support from HEPS colleagues

# Spare slides

For discussion

# Discussion: beamline requirements for CEPC sub-detectors

- General requirements
  - Beam repetition rate: 1-10 kHz
    - Feasible for typical DAQ systems
    - Data taking time can be acceptable
  - ≥ 100kHz would be desirable for DAQ stress tests
- Trackers
  - Favour high-momentum collimated beams: low multiple scattering effects
  - Either electrons or hadrons can be accepted
- Calorimeters and PID detectors
  - (Quasi-) Single-particle beams
  - Wide beam energy range: typically 0.1 – 100 GeV for CEPC calorimeters
  - Diverse beam types
    - Muons (calibration), electrons/positrons, pions/protons

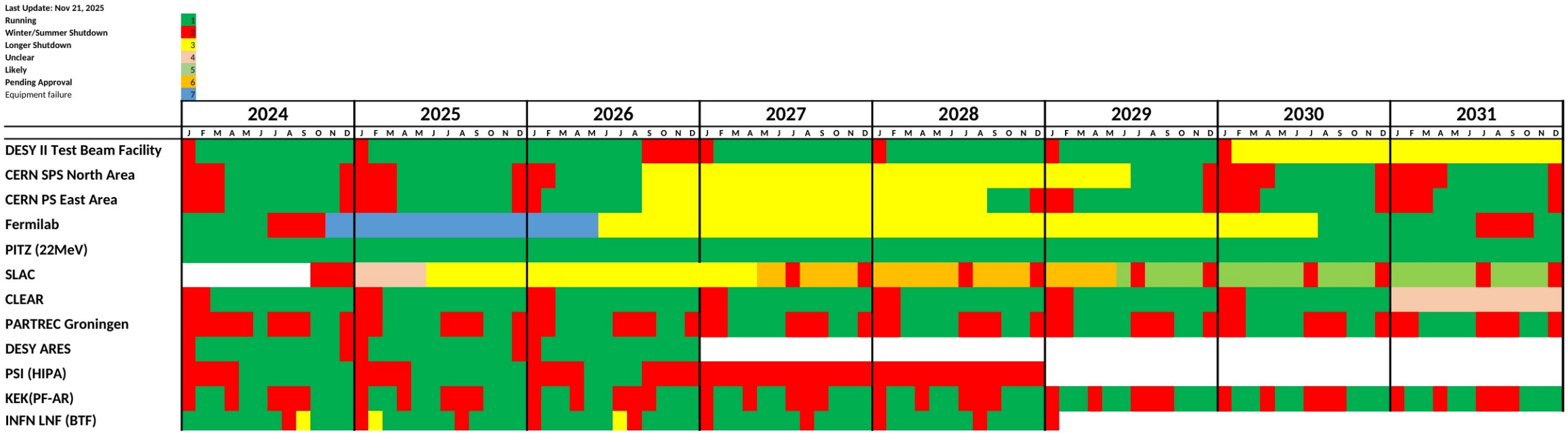
# Discussion: a list of (possible) test-beam sites in China

- HEPS in Huairou, Beijing
  - Other beamlines ?
  - Details remain to be discussed
- CSNS in Dongguan, Guangdong
  - Hadron test-beam: part of CSNS Phase-2 Upgrade
  - Sub-GeV hadrons, as secondaries of primary 1.6 GeV protons hitting target
- PWA at the BEPC-II site
  - Details remain to be discussed

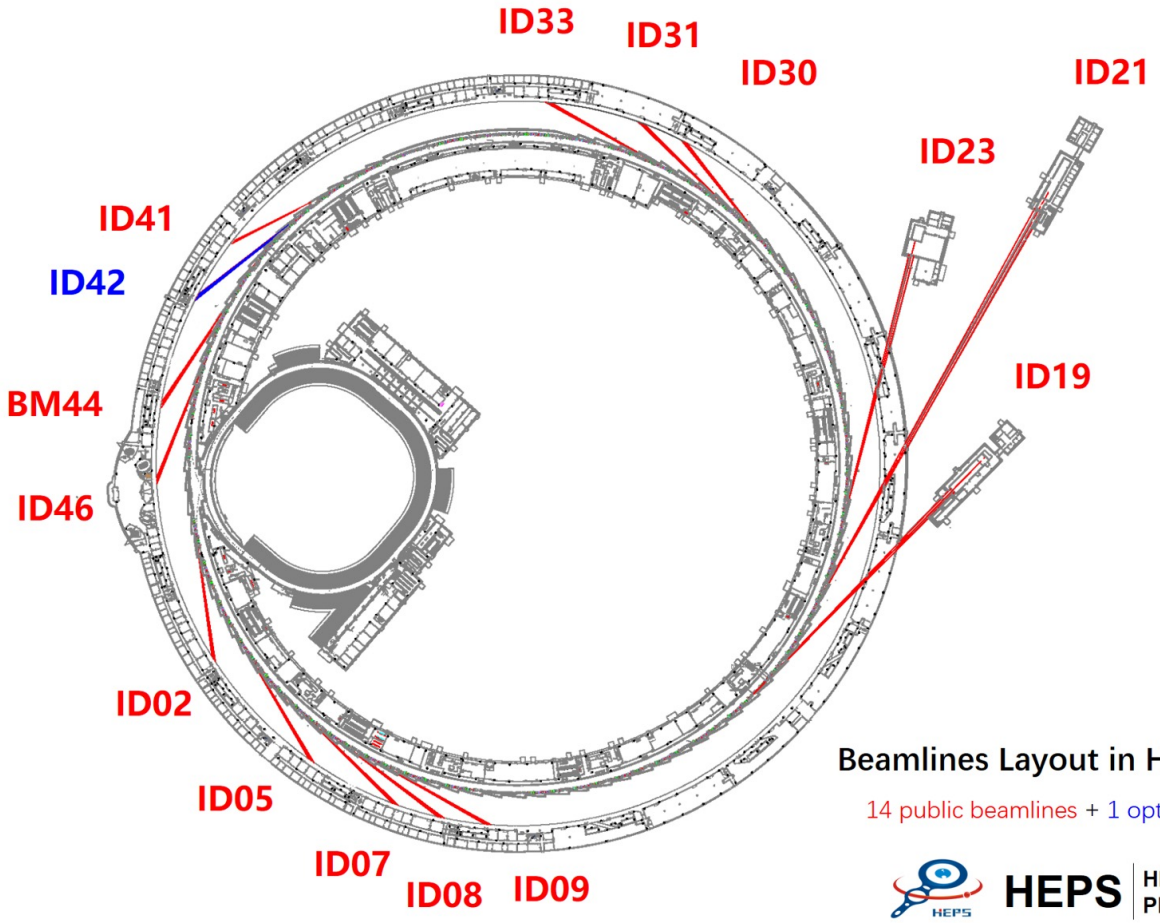
# Test-beam facilities: planning

- A global picture (link)

Last Update: Nov 21, 2025



# HEPS information




Beamlines Layout in HEPS phase I

14 public beamlines + 1 optics test beamline

HEPS HIGH ENERGY PHOTON SOURCE

Beamlines layout in HEPS Phase-1: link

| | |
|---|---|
| Microfocusing X-ray protein-ID02 Crystallography Beamline | ID30-Transmission X-ray Microscopy Beamline |
| Low Dimension Structure Probe-ID05 Beamline | ID31-High-Pressure Beamline |
| Engineering Materials Beamline-ID07 | ID33-Hard X-ray High Energy Resolution Spectroscopy Beamline |
| Pink Beam SAXS Beamline-ID08 | BM44-Tender X-ray Beamline |
| Hard X-ray coherent scattering-ID09 Beamline | ID41-High Resolution Nanoscale Electronic Structure Spectroscopy Beamline |
| Hard X-ray Nanoprobe Multimodal-ID19 Imaging Beamline | ID42-Optics Test Beamline |
| Hard X-ray Imaging Beamline-ID21 | ID46-X-ray Absorption Spectroscopy Beamline |
| Structural Dynamic Beamline-ID23 | |

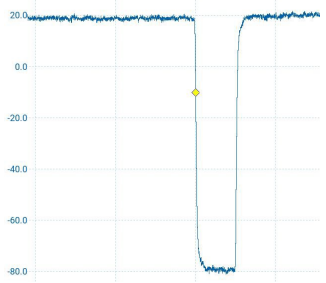
# Preamplifiers: gain calibration

- Preamp gain calibration: an important step for energy reconstruction
  - Lab tests: with preamps for Cs-137 and Co-60
  - HEPS beam tests: without preamps for large signals
  - Gain values are ~9.6 (design nominal value is 10.0)

Waveform generator


Input: 10mV


Output: 100mV




Waveform signal integration