Potential of a HEPS testbeam site

Zhijun Liang, Yong Liu, Zijun Xu

On Behalf of many colleagues

CEPC Day

May 27, 2026

*previous talk at CEPC Physics and Detector meeting 2026-May-13
https://indico.ihep.ac.cn/event/29449/#10-potential-of-a-heps-testbea

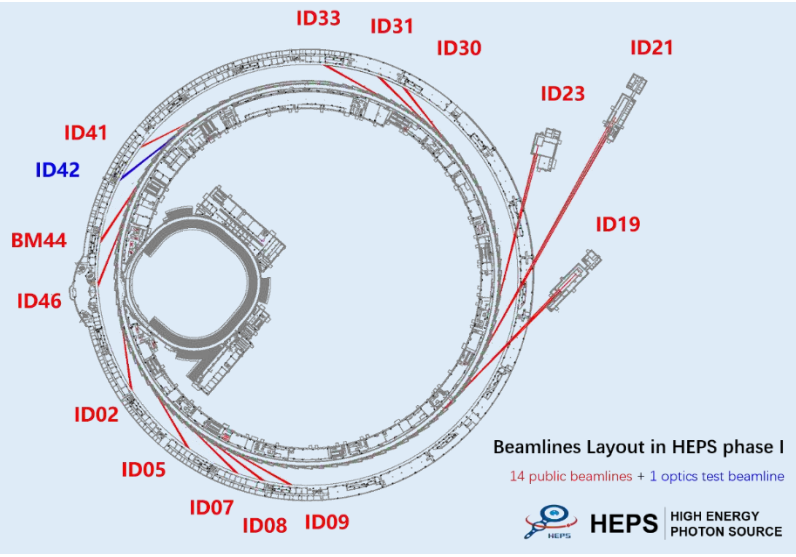
Motivations

- Test-Beam facilities are critical for detector R&D
  - Guiding detector design and prototyping
    - To evaluate performance and to validate simulation and digitisation
  - Long-Shutdown at CERN due to HL-LHC upgrade, beam unavailable in next few years
  - domestic facility: convenient for scheduling, shipment, cost saving, ...

- Why HEPS?
  - 6 GeV electrons in HEPS storage ring could be used
  - test-beam studys at BSRF/BEPCII: observed high-energy particles up to ~2.5 GeV
    - 2020-Dec-28, CEPC day, "Testbeam opportinity at BSRF"
    - 2021-Jul-28, CEPC Phy. and Dec., "Beam tests with a BGO matrix calorimeter at a BSRF station"

Exploring a potential HEPS Testbeam Site

- 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 (苑梦瑶 / 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 (郑雷 / 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 (石泓 / MRD) and Decong Zhu (祝德充 / AD) showed beamlines 39B1A (XBD, X-Ray Beam Diagnostic) and 42I1A (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

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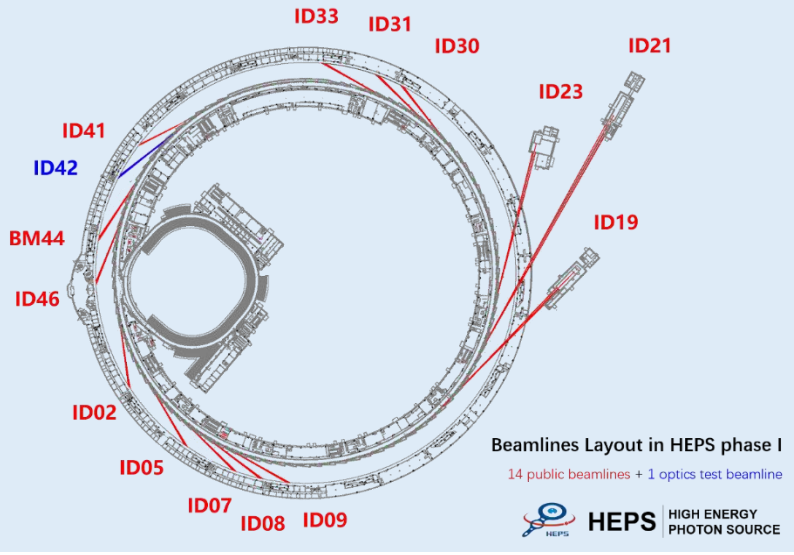
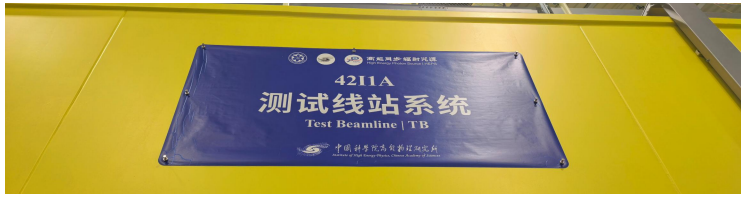
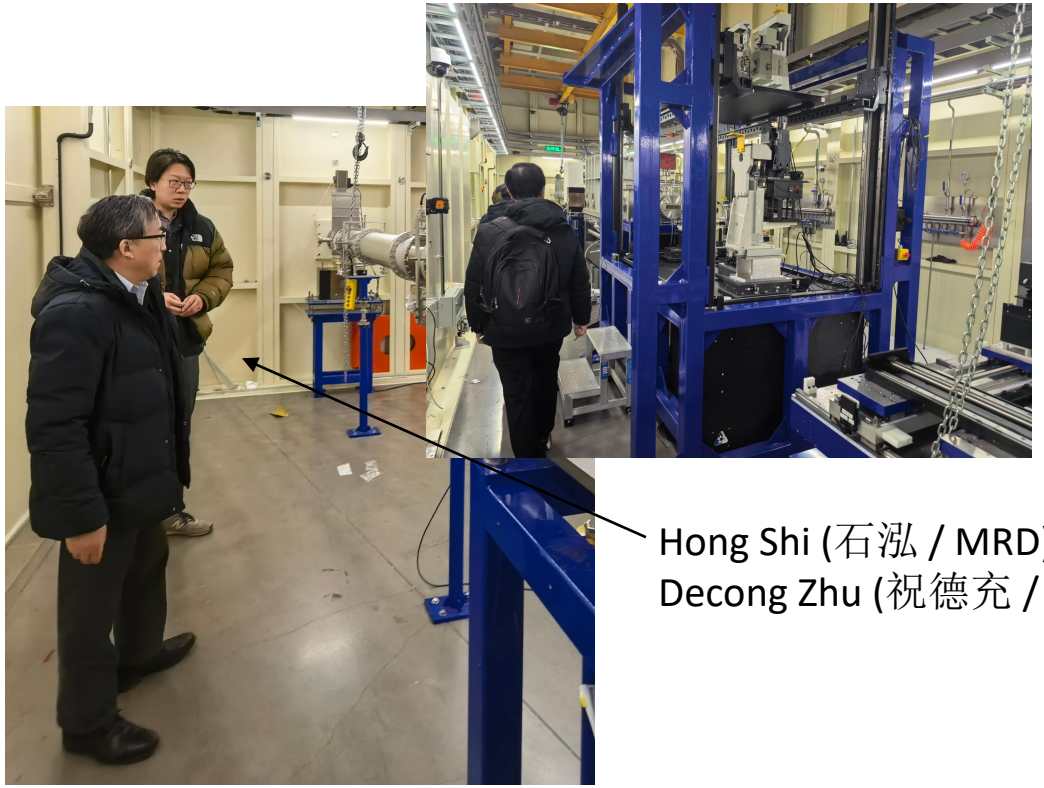
- 3 times testbeam at the 39B1A beamline by the SiTracker + Calorimeter teams, with many supports from **Decong Zhu (祝德充/AD)** and **Hong Shi (石泓/MRD)**
  - Mar. 7, 2026 A pilot run with small plastic scintillators
  - Apr. 3, 2026 SiTrk (Silicon Strip Tracker) and Calorimeter taking data in turns due to installation space constraints
  - Apr. 22-23, 2026 SiTrk + Calorimeter taking data simultaneously



HEPS site investigation, 2026-Feb-12

- Test Beamline 42I1A





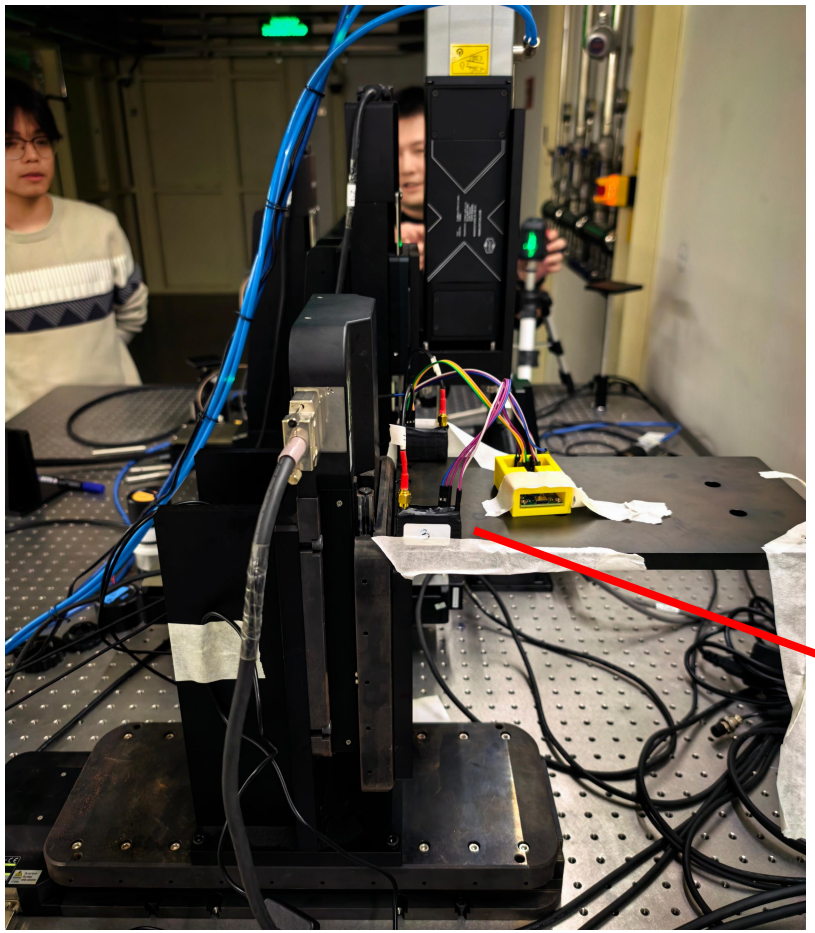
Hong Shi (石泓 / MRD)
Decong Zhu (祝德充 / AD)

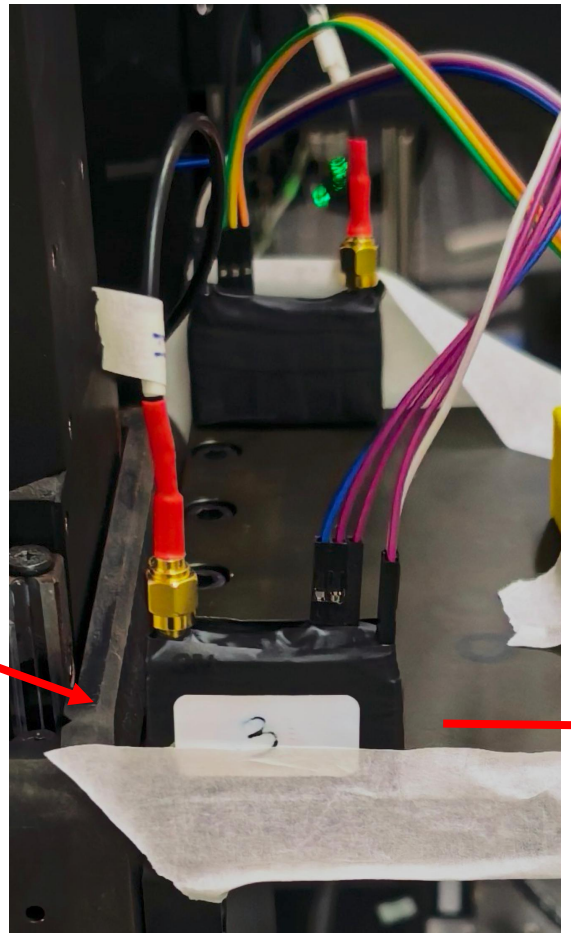
- X-Ray Beam Diagnostic Beamline (XBD) 39B1A

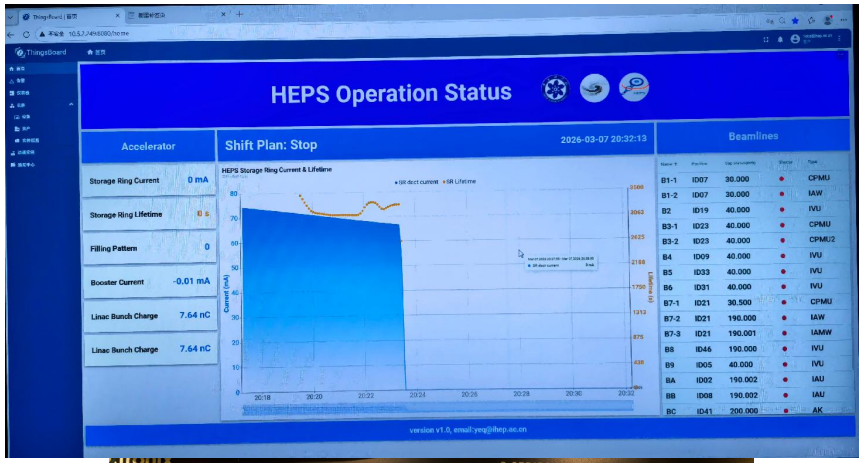
- 39B1A was choosen for follow-up testbeam studies

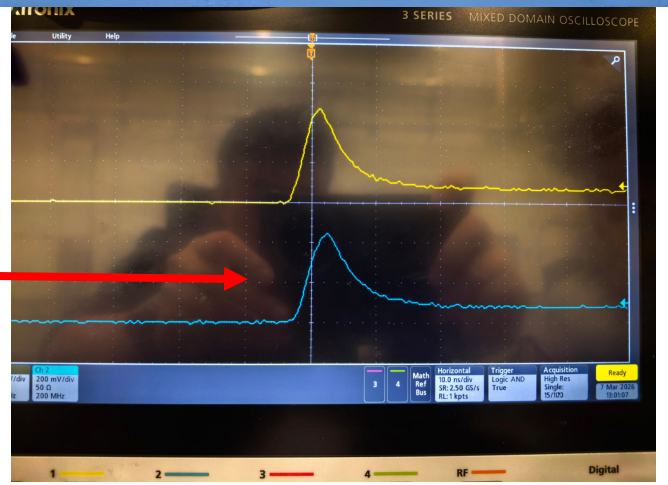
pilot testbeam in 39B1A, 2026-Mar-7

- two plastic scintillator (PS), ~4x2 cm^2, down-stream of a X-ray camera
- Coincidence rate up to ~4 Hz, depends on HEPS operation status





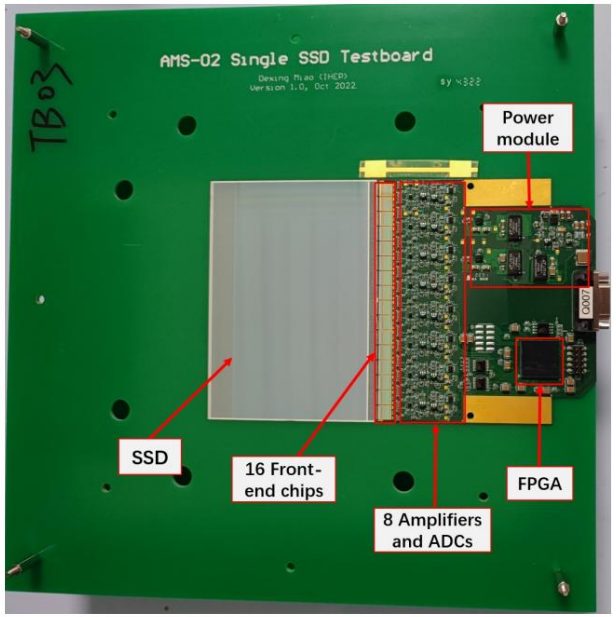


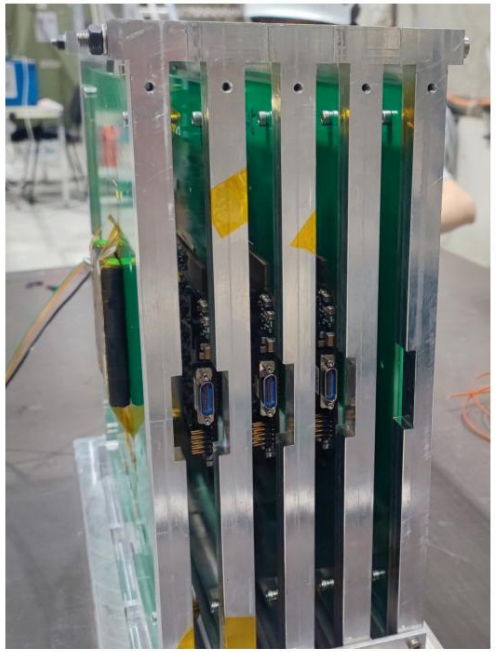


Silicon Tracker and Calorimeter for testbeam

6 layers Silicon-strip tracker + PS trigger

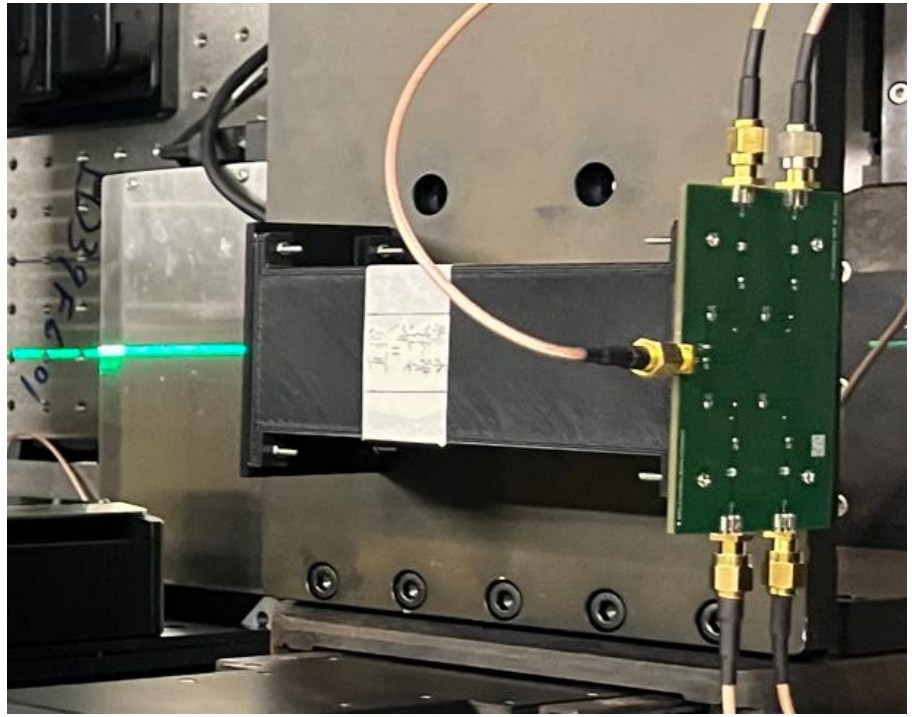
- 3X + 3Y: Si-strip sensor layers
- strip pitch 109um
- 8×8cm^2 coverage



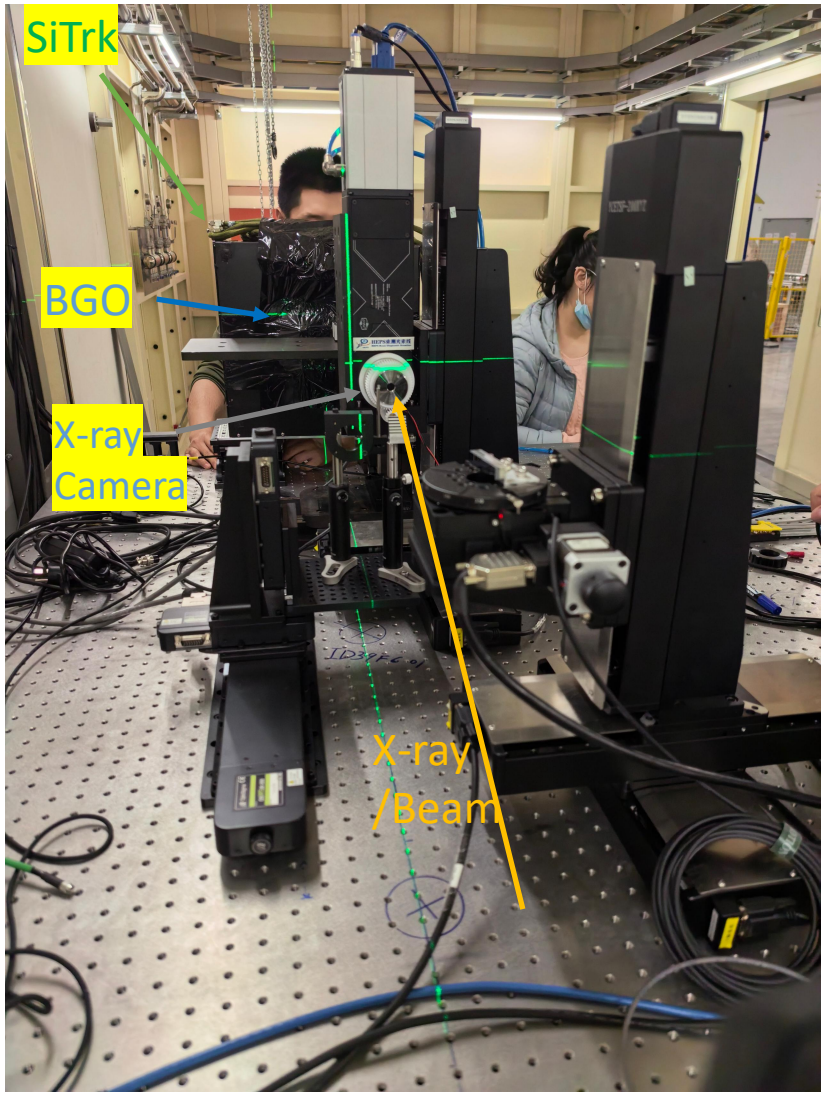


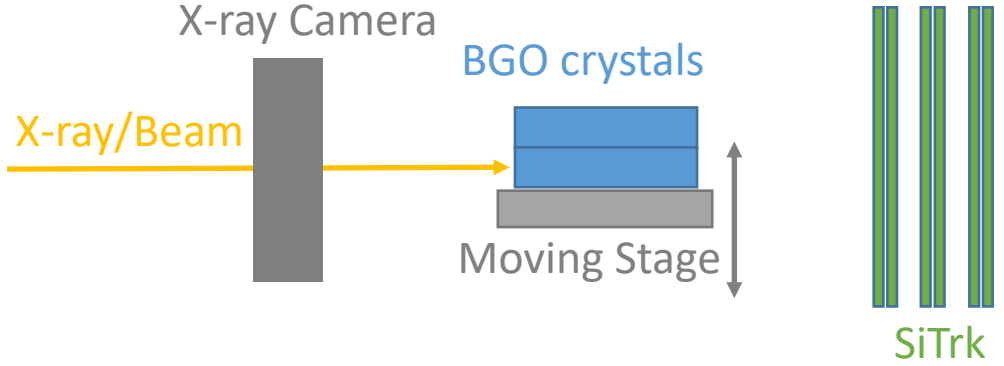
4 BGO crystals Calorimeter:

- 10.7X_0 depth
- BGO: 2×2×12 cm^3
- Single-end SiPM readout



1st testbeam with SiTrk+Calorimeter, 2026-Apr-3

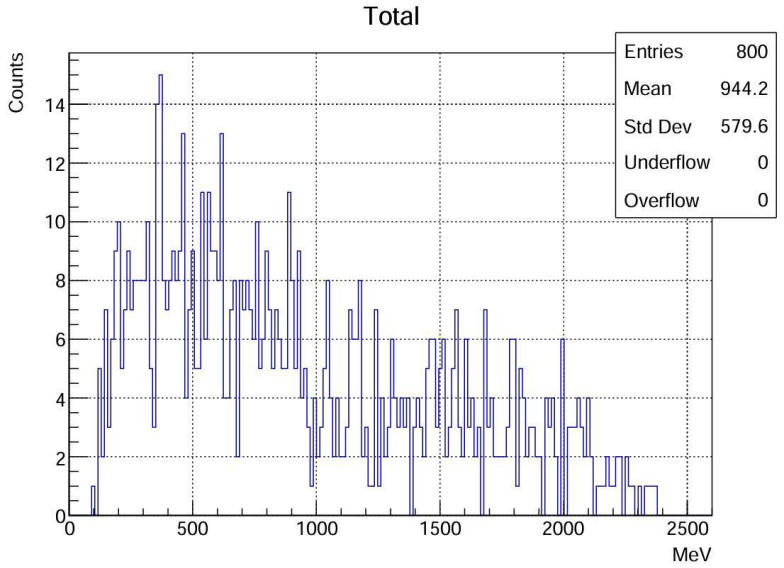




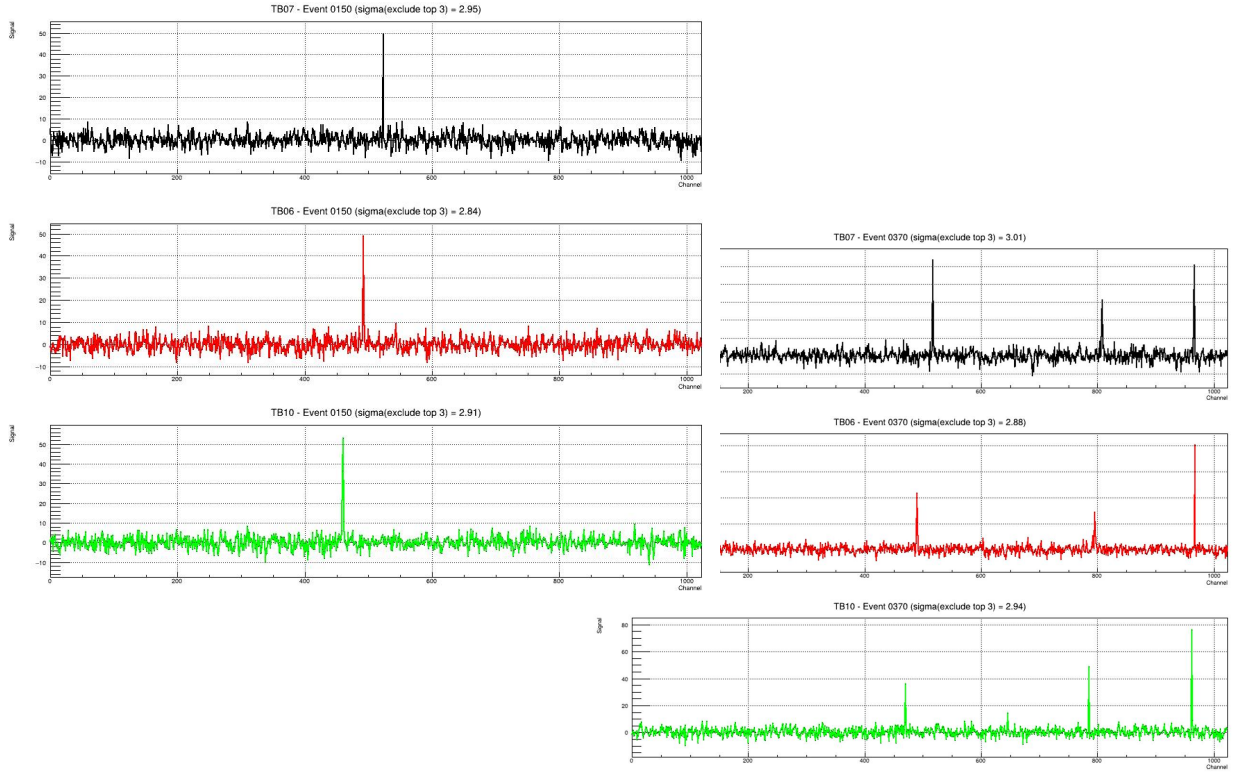
- X-ray camera in front of SiTrk and Calo setup
  - ~10 cm thick aluminum (assuming all solid)
  - constently data-taking for X-ray
  - Could possibly lead to early EM showers
- BGO crystals had to be placed on the existing moving stage, between X-ray Camera and SiTrk
  - Due to limited usable space of the optical table
  - Could not position BGO crystals in the beam center, due to limited travel range of the moving stage
- * SiTrk and BGO taking data alternatively

1st testbeam with SiTrk+Calorimeter, 2026-Apr-3

- Confirmed the O(1) Hz level event rate
- Observed large energy signals in BGO-matrix: GeV-equivalent energy
- Observed tracks in all SiTrk layers: events of single- and multi-tracks

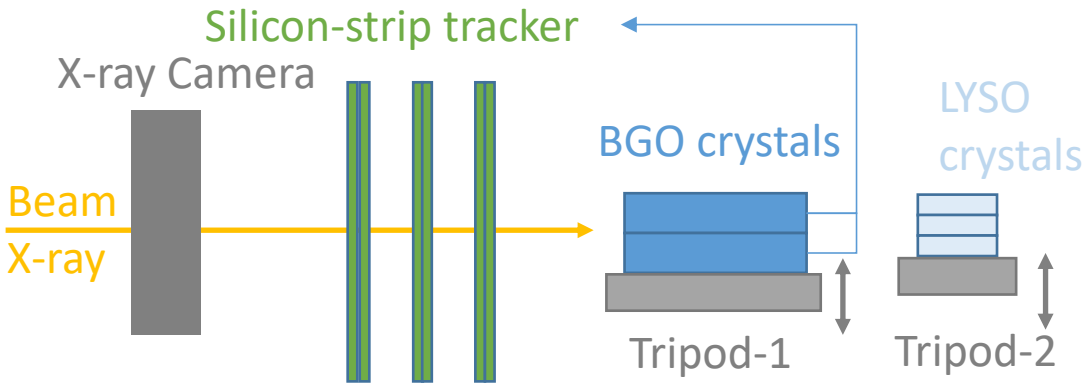


*BGO could not be positioned in the beam center, which might lead to underestimate of beam energy

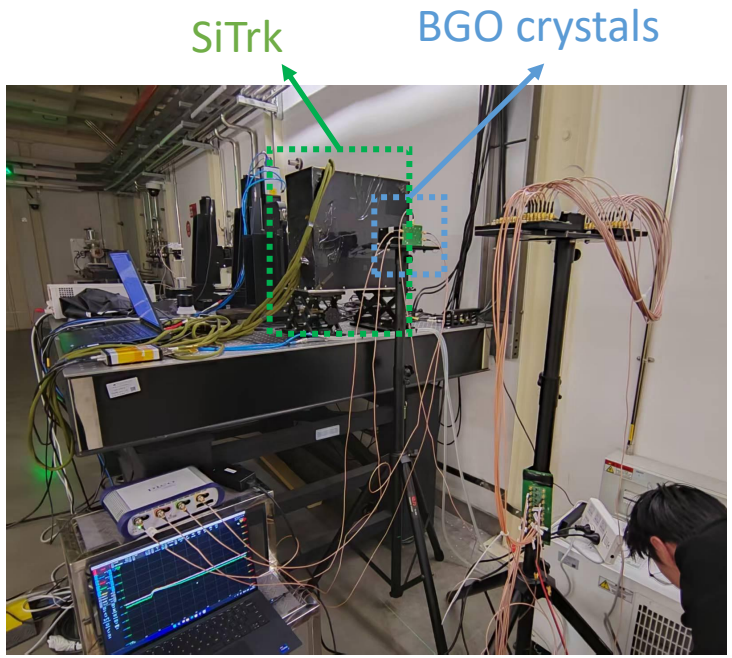


2nd testbeam with SiTrk+Calorimeter, 2026-Apr-22/23

- Beam-test setup improved
  - X-ray Camera + SiTrk + 4 BGO crystals (10.7X_0 depth)
  - limitation: *Camera still need constently data-taking for X-ray
- Using BGO signal to trigger SiTrk readout
  - beam-profile measured by SiTrk to guide the position of BGO
  - veto tracks NOT from beam direction
  - distinguish single/multi-track events

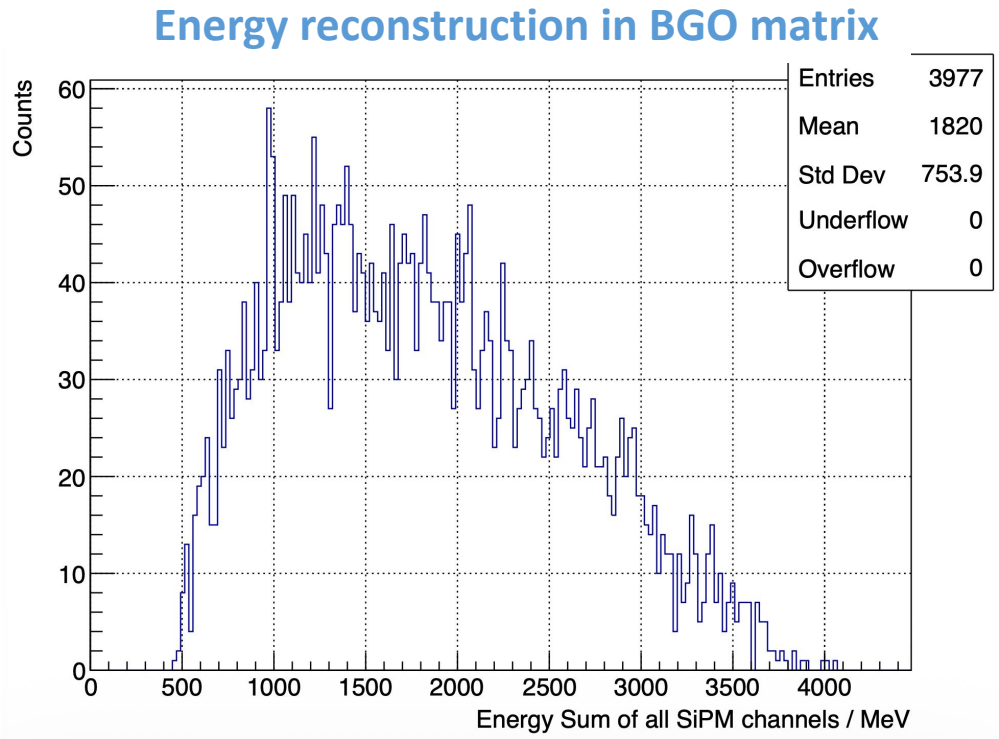


LYSO crystals (LumiCal module)
tested in downstream



2nd testbeam with SiTrk+Calorimeter, 2026-Apr-22/23

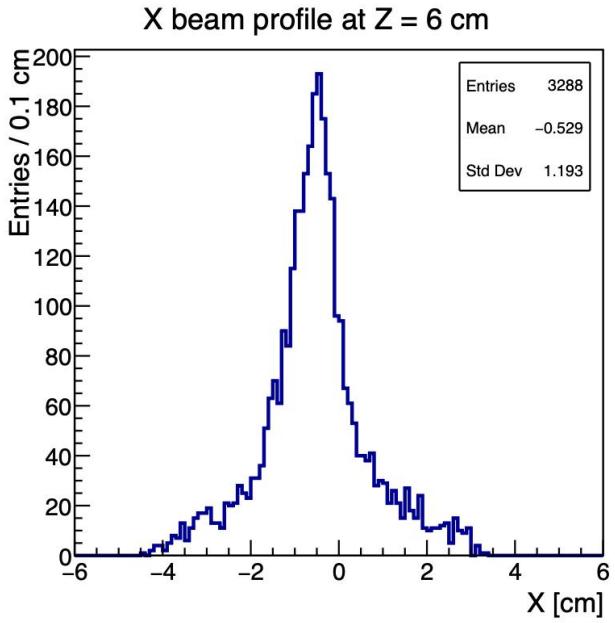
- Over-night run with ~4,000 events
  - Successful event synchronisation of track-calorimeter
  - This enables to select sing-track events and to narrow down hit position range
- Energy spectrum measured in BGO matrix
  - Including all events that pass the trigger
    - Coincidence of four BGO-SIPM channels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

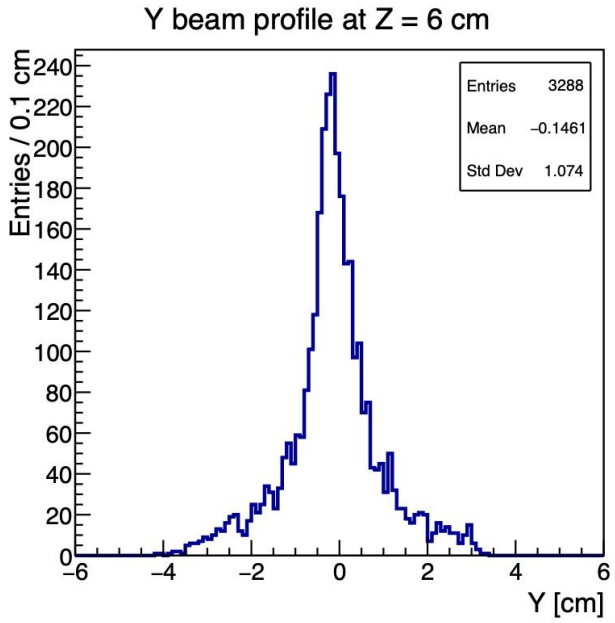


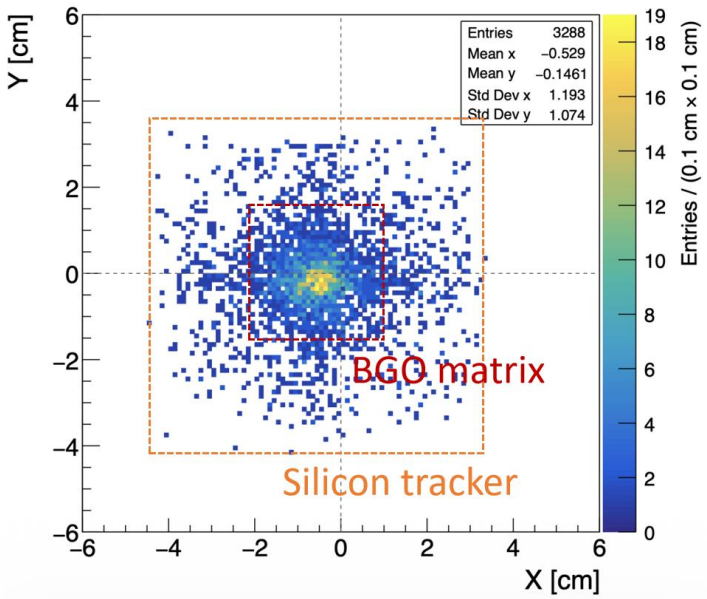
The energy spectrum and mechanism are to be further investigated and understood

Beam profile by SiTrk

- SiTrk fiducial area of 8x8cm^2 , aligned with BGO matrix center
- SiTrk was triggered by BGO matrix → multi-track events dominant
- Beam is collimated within ± 1 cm, surrounded with a halo-like structure
- ~10% wider spread in horizontal (X) than vertical (Y)

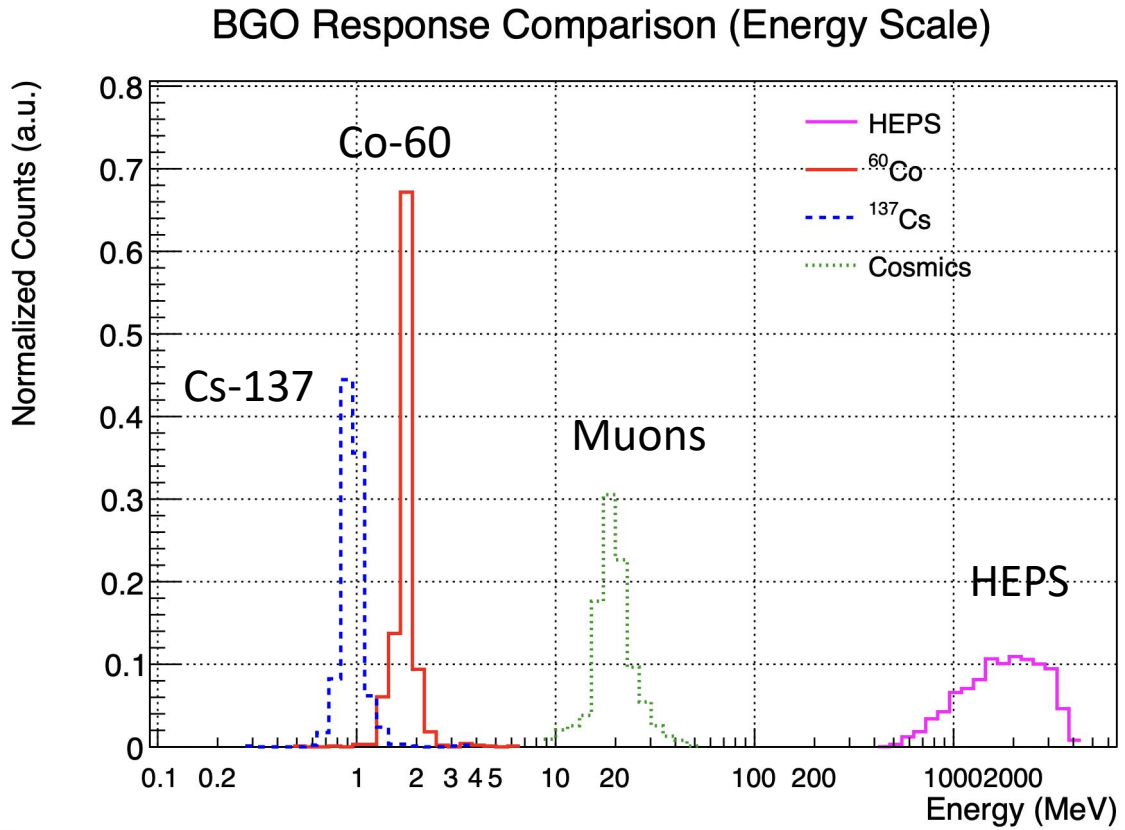


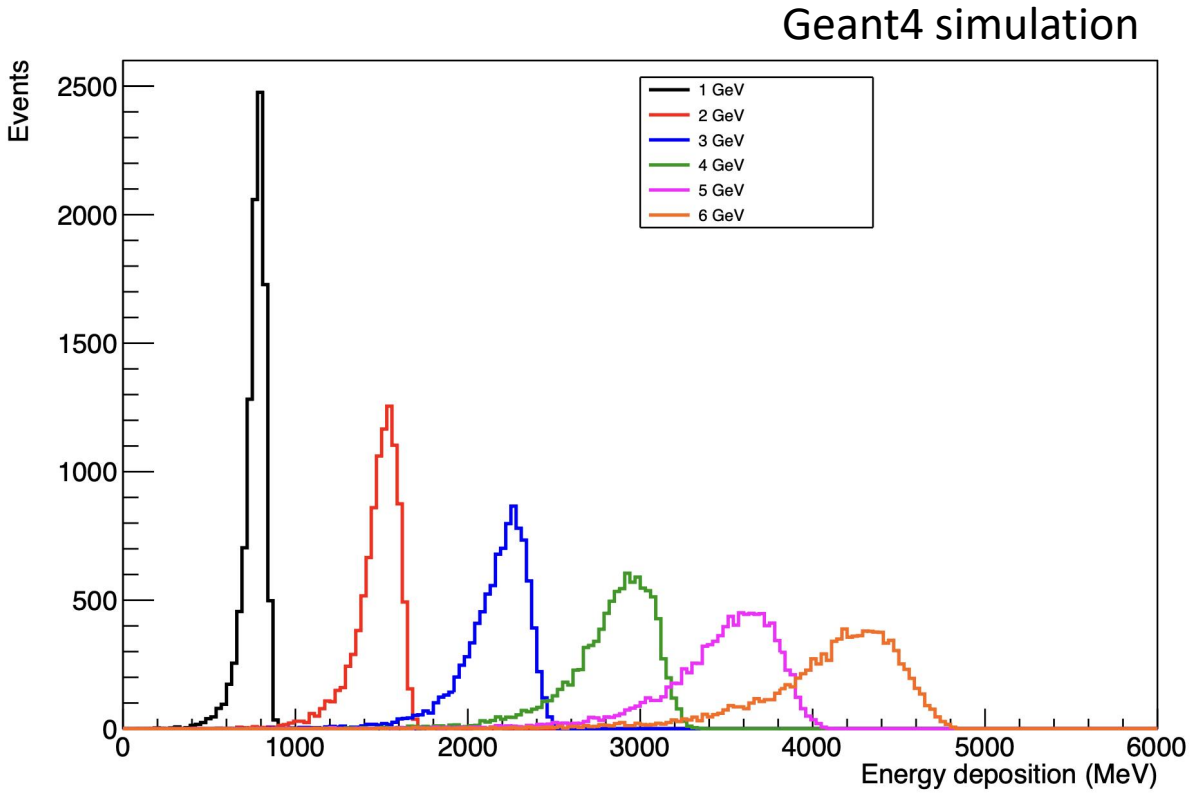




BGO energy calibration and Geant4 simulation

- Cs-137, Co-60, and cosmic-ray were used for energy calibration
- EM shower response of BGO-crystal matrix from Geant4 simualtion

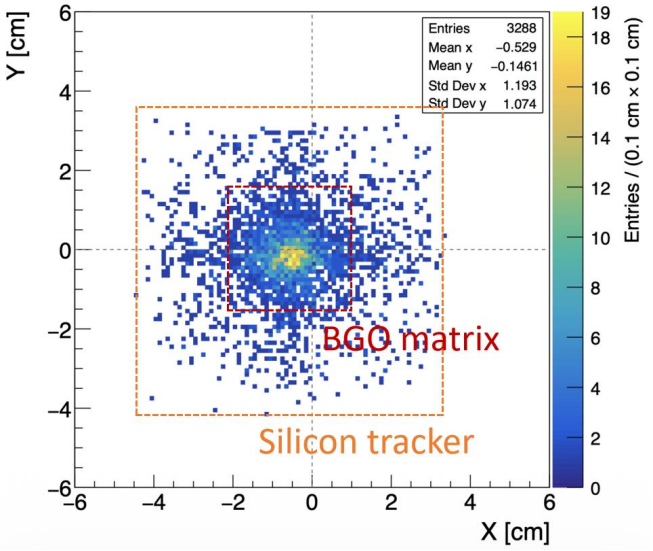


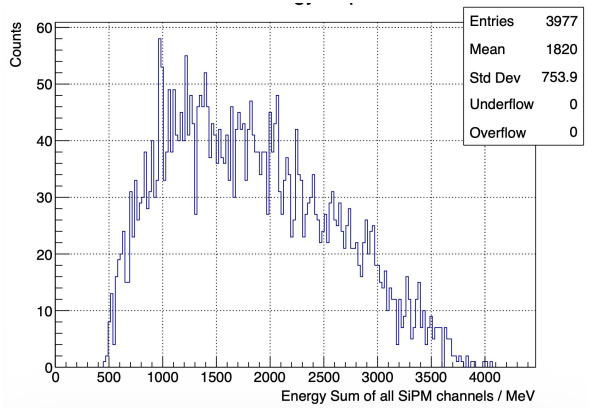


Summary and Prospects

- encuraging preliminary results
  - observed upto 4 GeV tracks by SiTrk+ Calorimeter
  - event rate O(1)Hz, related with HEPS operation status
  - *some limitations from beamline (39B1A) requirements

- prospects
  - investigate the beam profile/energy structure and production mechanism
  - possibilities of other beamlines at HEPS
  - bending magnet + collimator to improve energy spreading





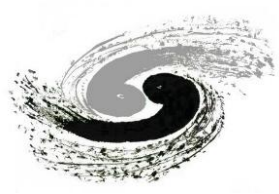
Acknowledgement

- Coordinating efforts of several divisions (AD, EPD, and MRD)

- Local technical assistance and support from HEPS colleagues
  - especially thank Decong Zhu (祝德充/AD) and Hong Shi (石泓/MRD)

- Many young studens/posdocs/colleagues directly contributes to the testbeam activities
  - Mengke Cai[1], Liangchenglong Jin[1], Lankun Li[1], Qinze Li[1], Kang Liu[1], Yushan Liu[1], Baohua Qi[1], Jibei Shen[2], Congcong Wang[1], Rui Yang[3,4], Hui Zhang[1] ...

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



Spare slides

For discussion

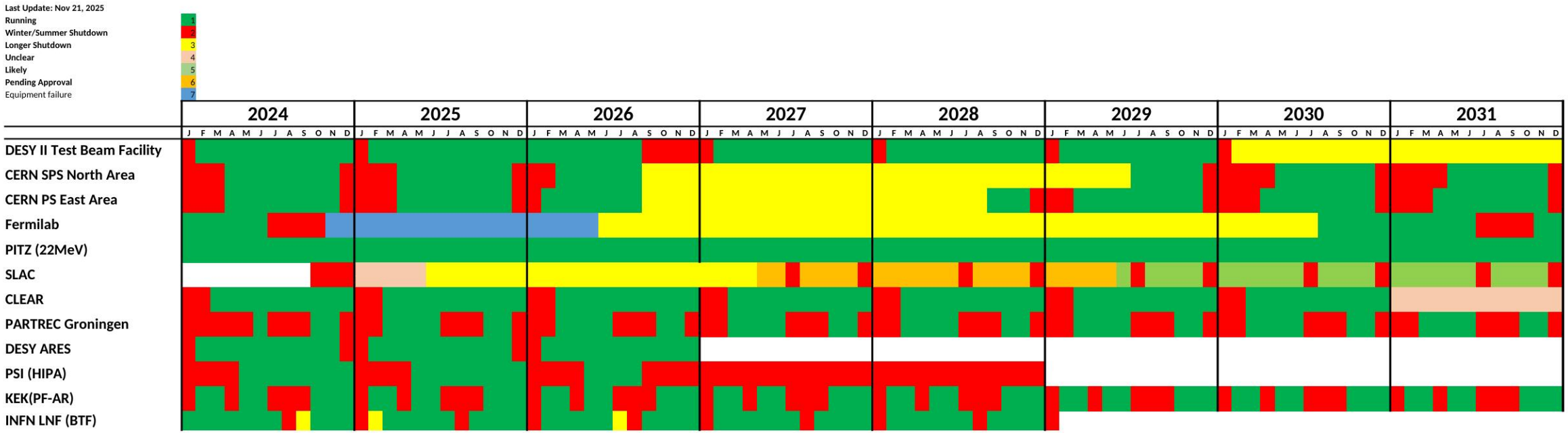
Discussion: beamline requirements for CEPC sub-detectors

- 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

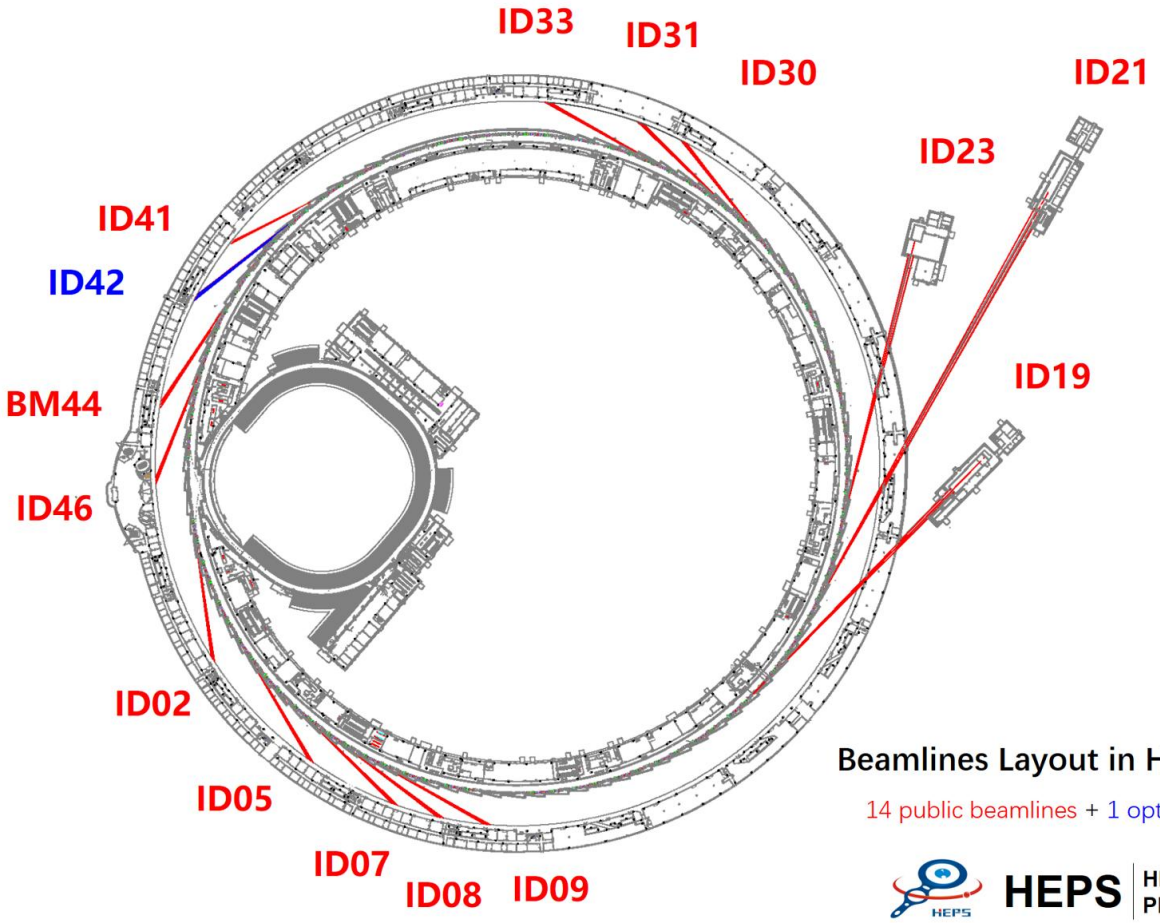
Test-beam facilities: planning

- A global picture (link)

Last Update: Nov 21, 2025



HEPS information



Beamlines Layout in HEPS phase I

14 public beamlines + 1 optics test beamline

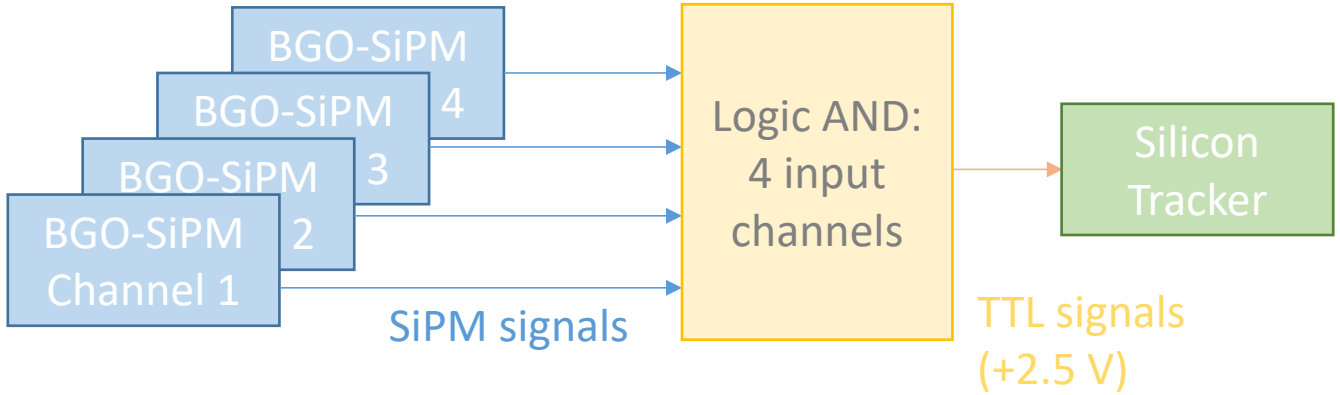
HEPS HIGH ENERGY PHOTON SOURCE

Beamlines layout in HEPS Phase-1: link

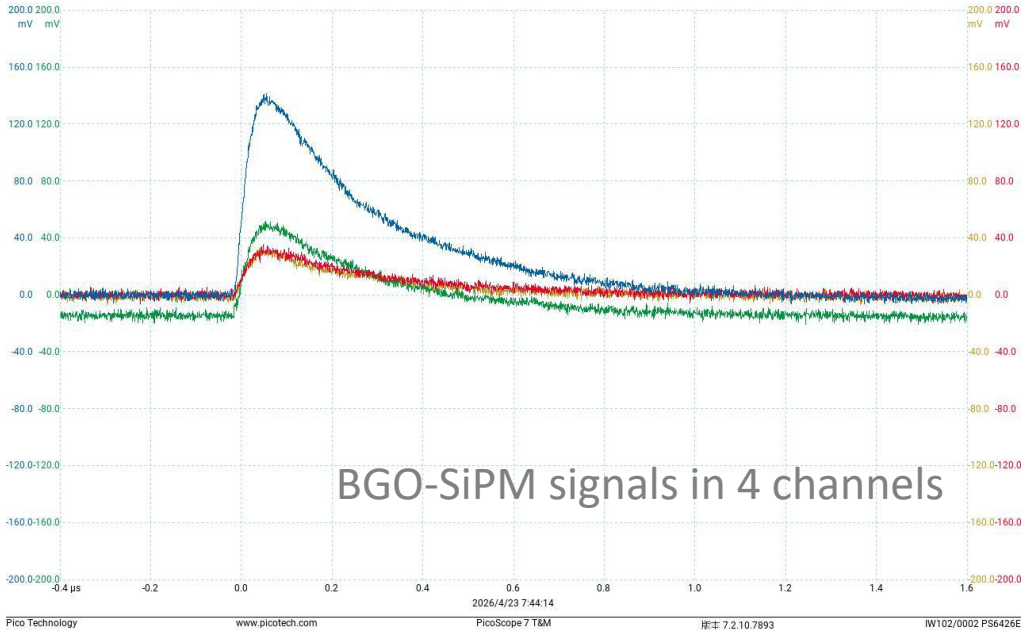
Microfocusing X-ray protein-ID02 Crystallography Beamline	ID30-Transmission X-ray Microscopy Beamline
Low Dimension Structure Probe-ID05 Beamline	ID31-High-Pressure Beamline
Engineering Materials Beamline-ID07	ID33-Hard X-ray High Energy Resolution Spectroscopy Beamline
Pink Beam SAXS Beamline-ID08	BM44-Tender 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	

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

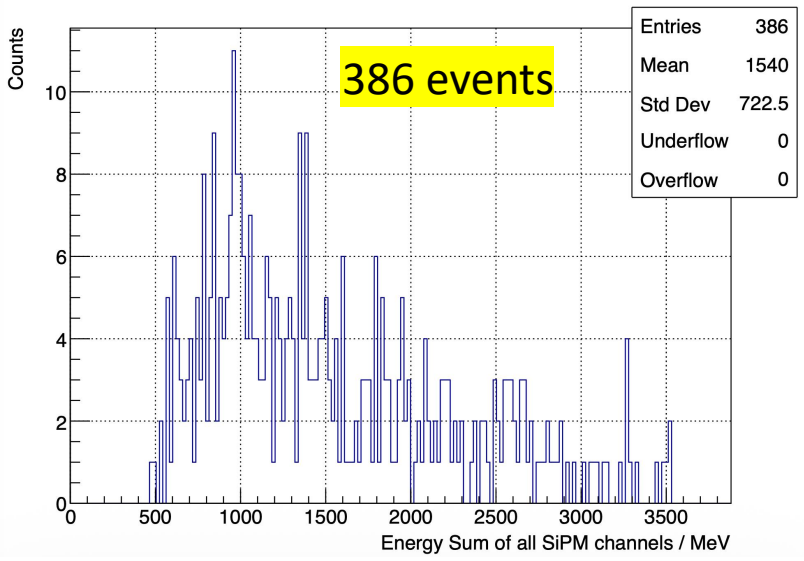


Note: BGO-SiPM signals were directly used for this time, without any preamps, since all preamps would suffer saturation due to large signals.

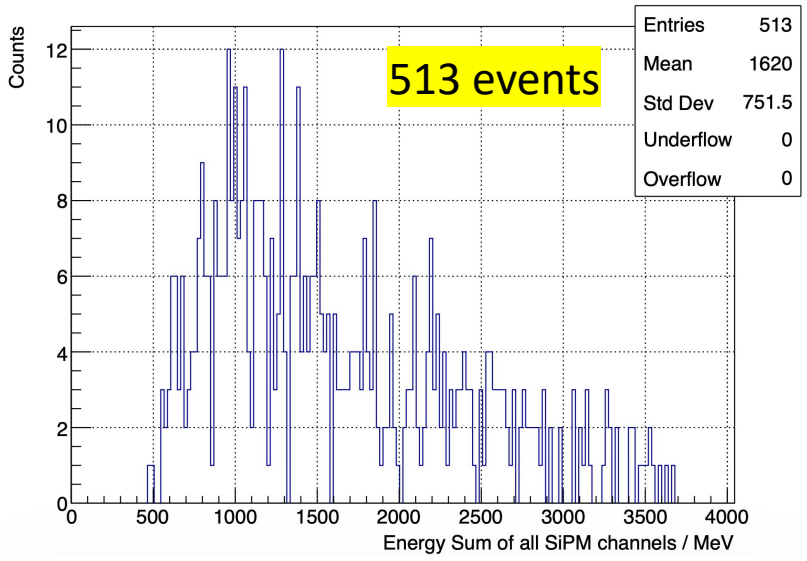
2nd testbeam with SiTrk+Calorimeter, 2026-Apr-22/23

- ***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

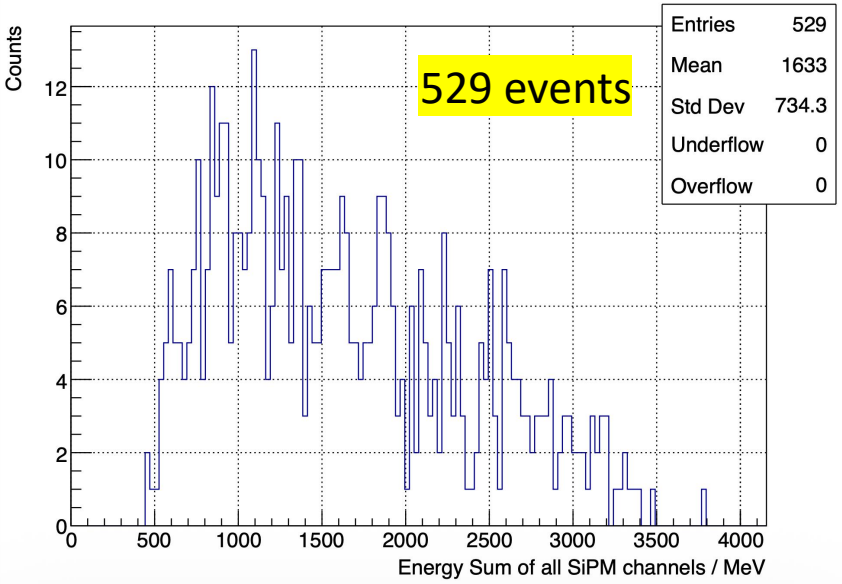
Tracks within 40×40 mm^2



Tracks within 20×20 mm^2



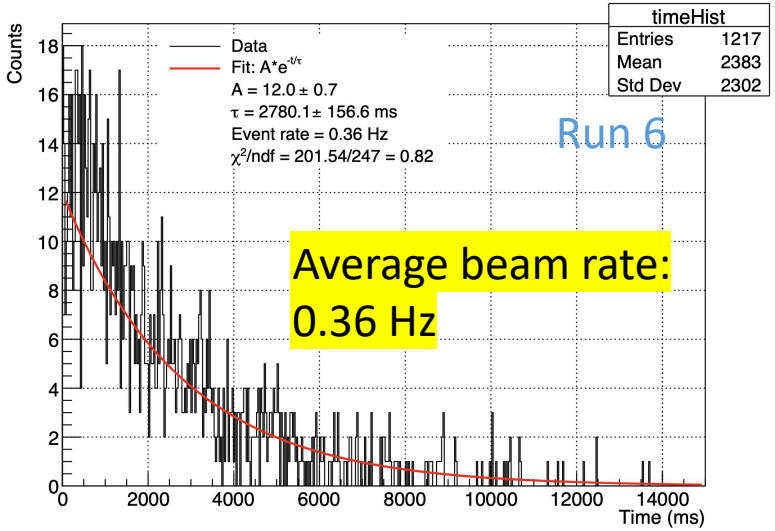
Tracks in 10×10 mm^2

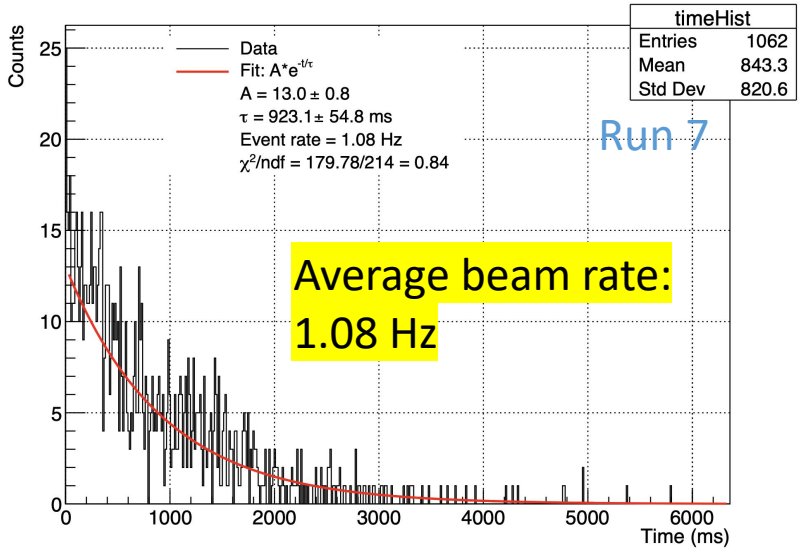


Beam rates tested at HEPS

- 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

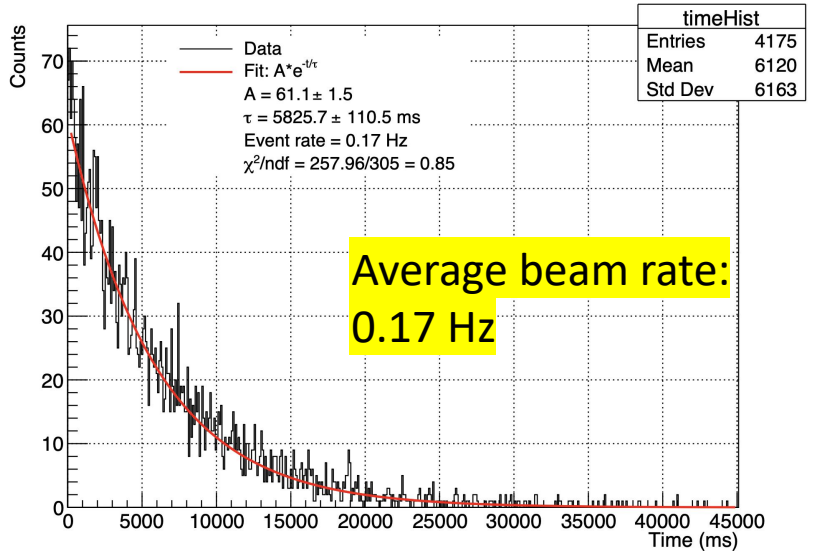
Event Time Interval (Apr. 3, 2026)





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

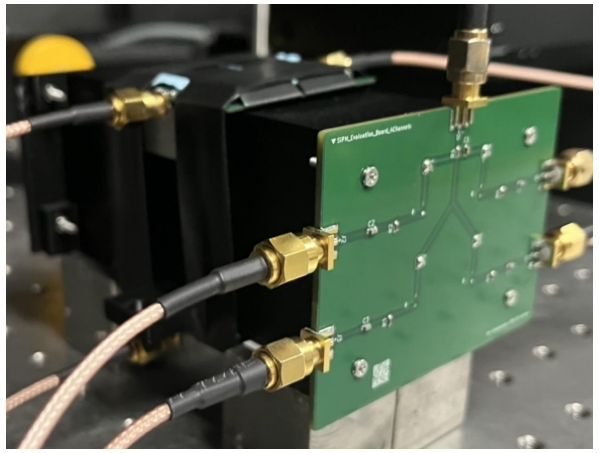
Event Time Interval (Apr. 22, 2026)

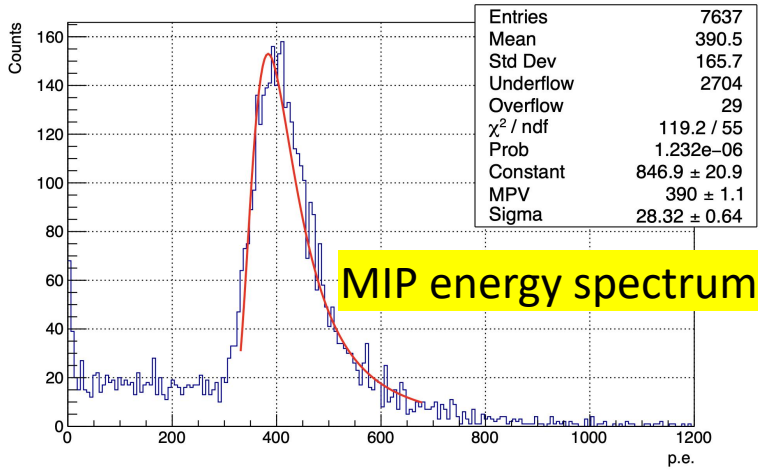


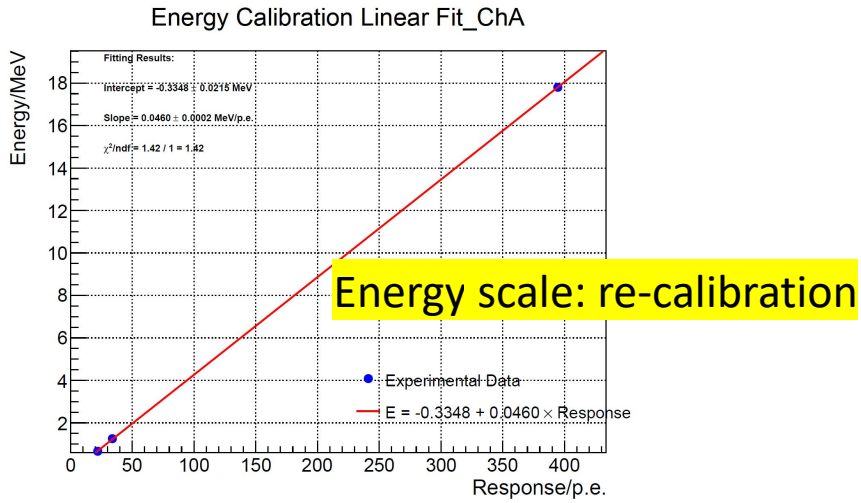
Trigger scheme in the second beamtest:
coincidence of four BGO-SiPM channels

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)

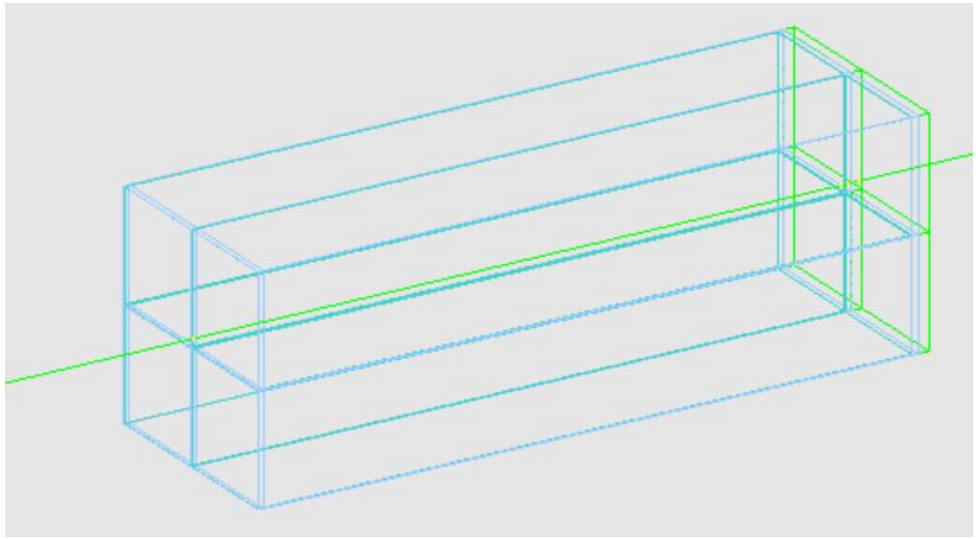






BGO matrix: Geant4 simulation studies

- **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)