Hardware development and beam test of crystal ECAL

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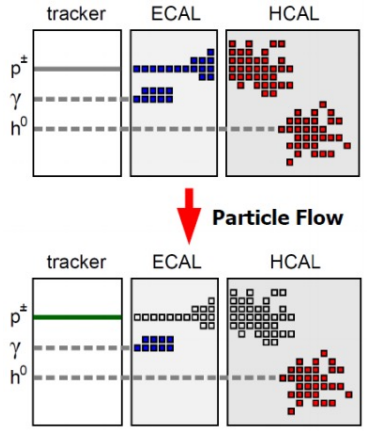
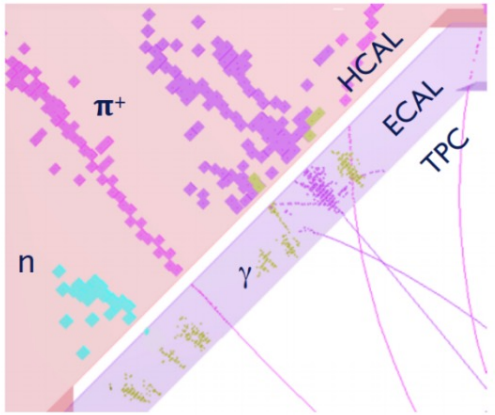
中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Introduction

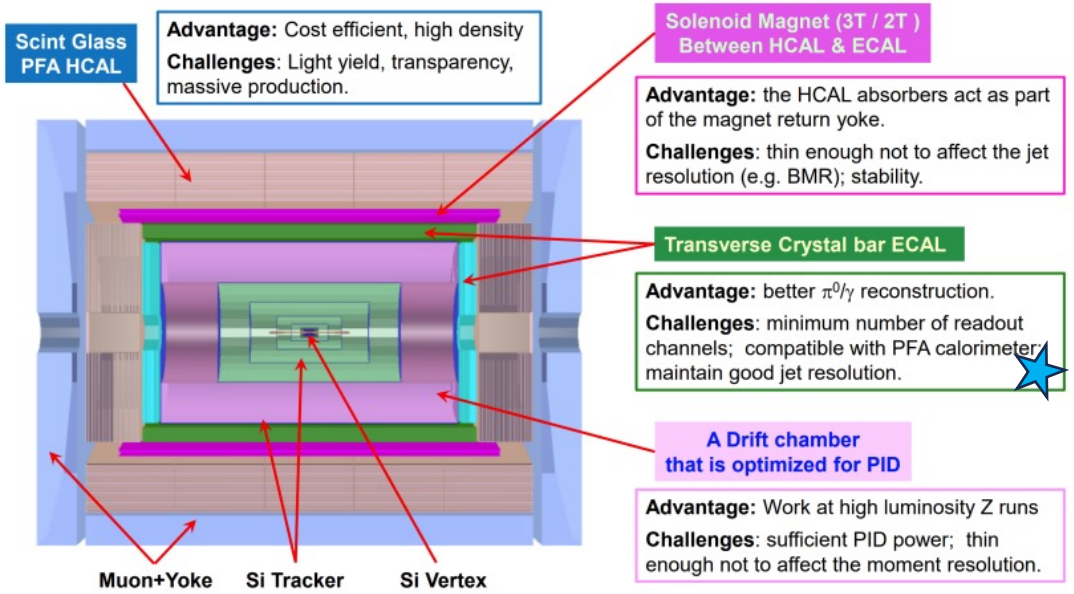
- **CEPC: future lepton collider experiment.**
  - Precise Higgs/EW/QCD measurements.
  - Detector requirement:
    - Jet energy resolution $< 30\%/\sqrt{E}$.
    - $W/Z \to qq$ separation: BMR~4%.

  ➡ Particle flow approach: high granularity calorimeter.

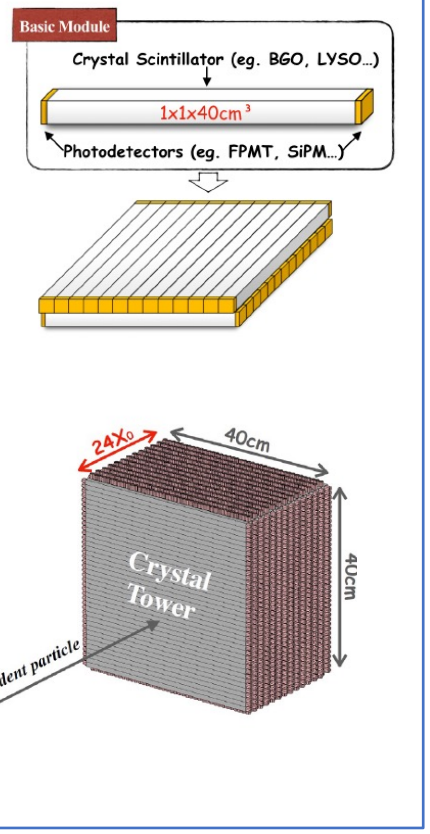


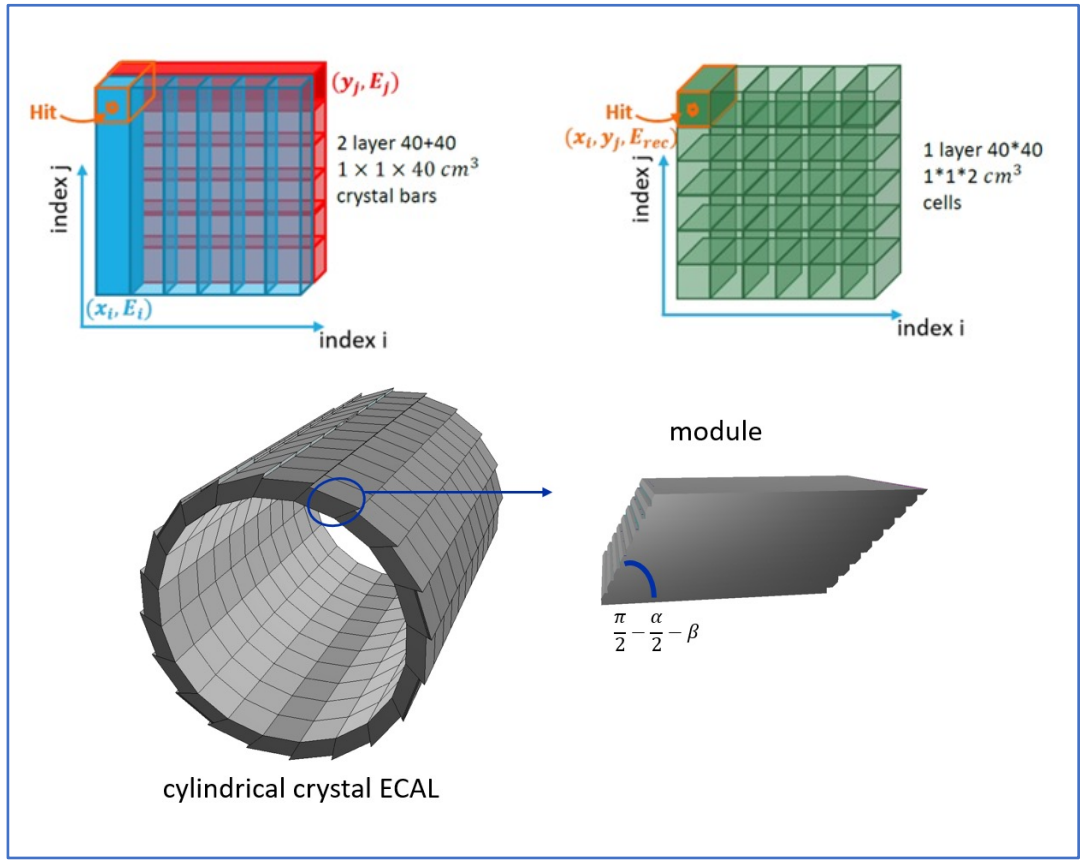


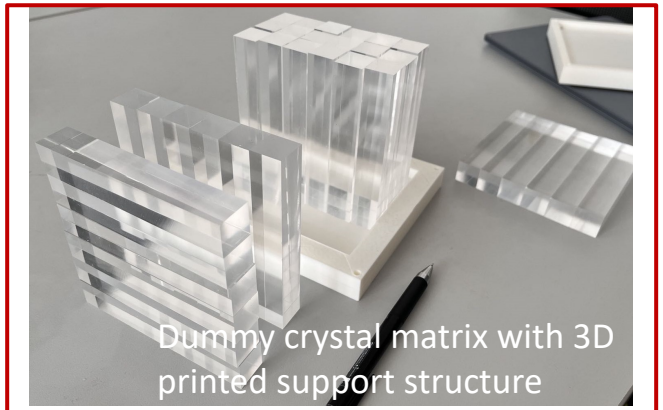
- **CEPC 4th conceptual detector: PFA-oriented.**
  - Homogeneous crystal ECAL:
    - 5D detector: spatial + energy + time.
    - Optimal EM energy resolution: $1\% \oplus 3\%/\sqrt{E}$.
    - High sensitivity to low energy particles.
    - Better γ/π^0 reconstruction.

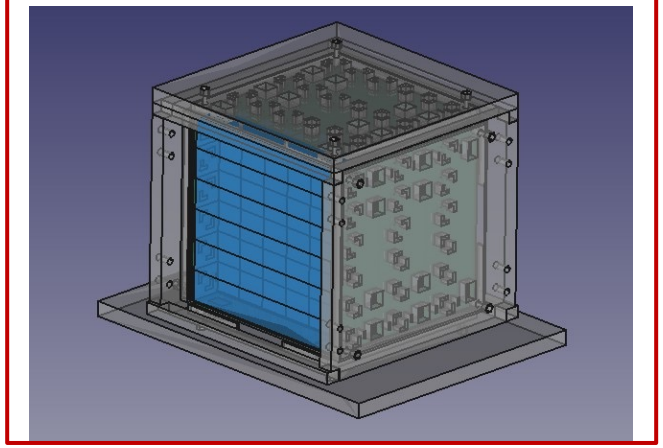


Crystal calorimeter: R&D overview









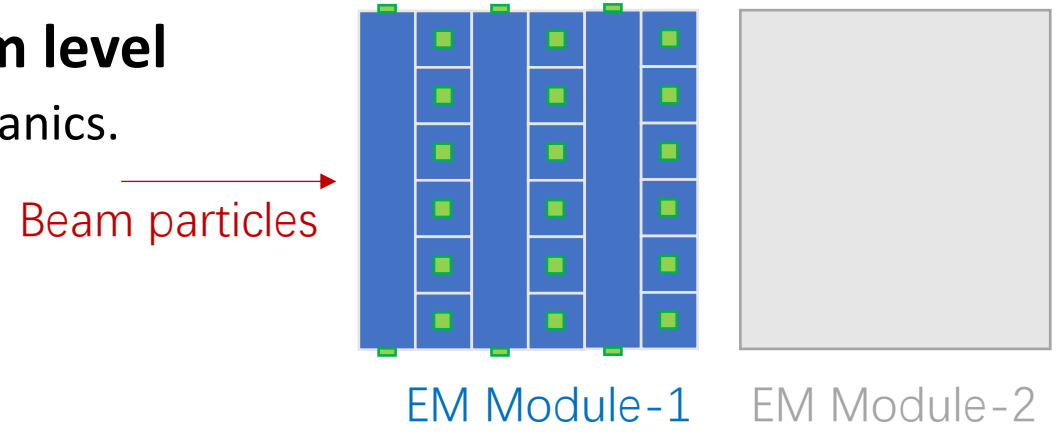
Hardware development: key questions and specs

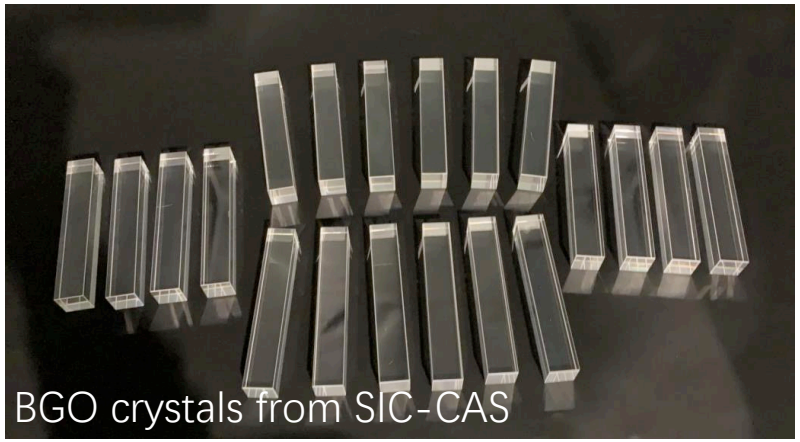
New reconstruction software for long bars
Geometry design and optimization

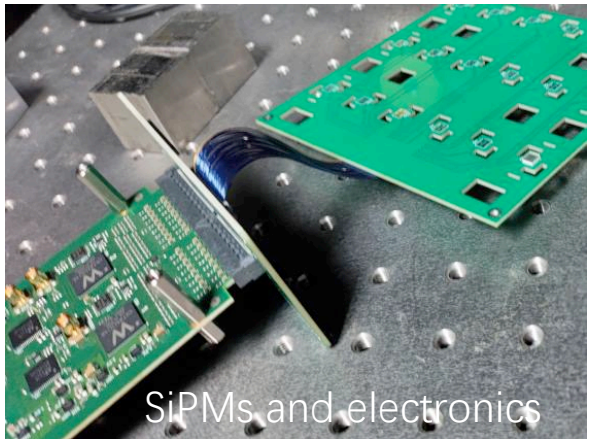
Development of crystal module(s) for beam tests

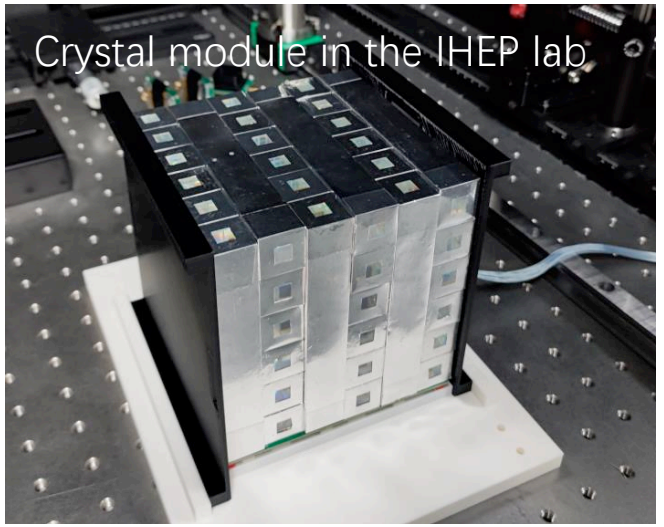
Crystal calorimeter: module development

- **Motivations: to address critical issues at system level**
  - Validation: design of crystal-SiPM, light-weight mechanics.
  - EM shower performance.
- **The first crystal module development**
  - Crystals: 40 BGO bars from SIC-CAS
  - SiPM: 3×3 mm² sensitve area, 10μm pixel pitch
  - Front-end electronics with ASICs (Citiroc-1A)
  - Second module is under consideration




BGO crystals from SIC-CAS


SiPMs and electronics


Crystal module in the IHEP lab

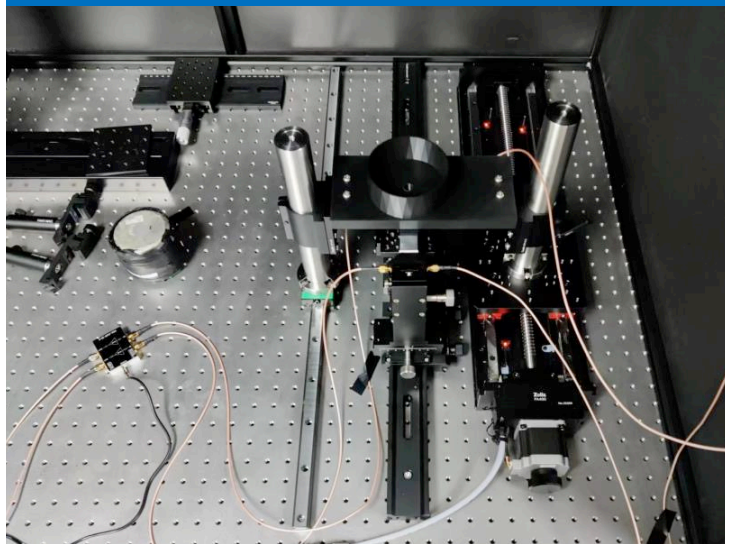
Crystal calorimeter: module development

- **Crystal uniformity**

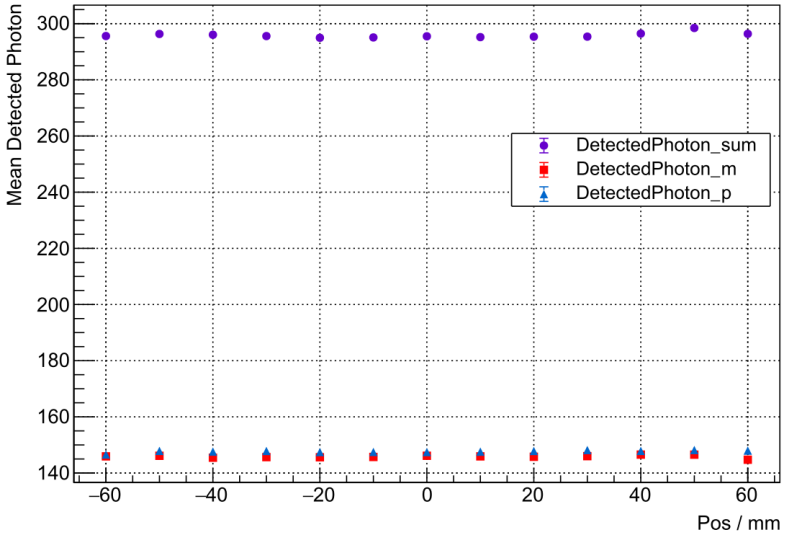
Zhikai Chen (USC)

  - An automated test for uniformity scans.
    - BGO crystals wrapped with ESR and Al foil.
    - Cs-137 source, scanned 40 crystals and 13 points/crystal.
  - Excellent uniformity along the crystal length direction: ~1%.
  - Variation between crystals can be calibrated channel-by-channel.

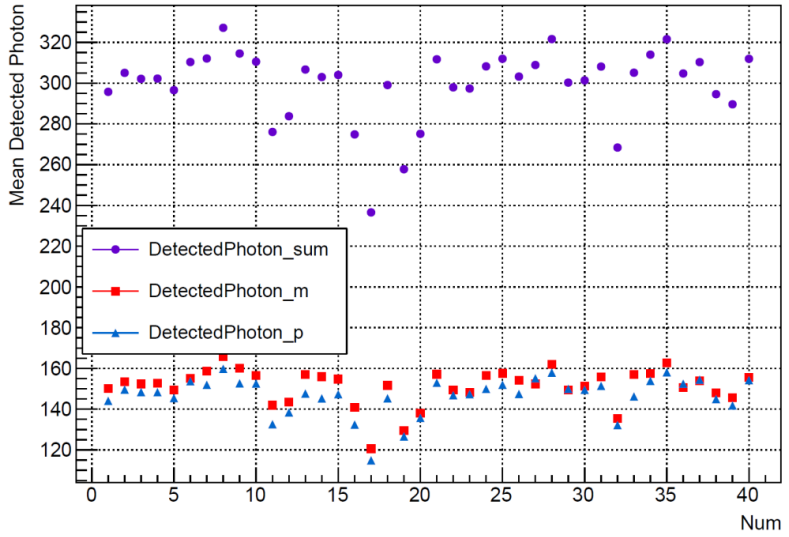
Automated Teststand for uniformity scans



Response uniformity along crystal bar length



Average response to Cs-137 of each BGO bar

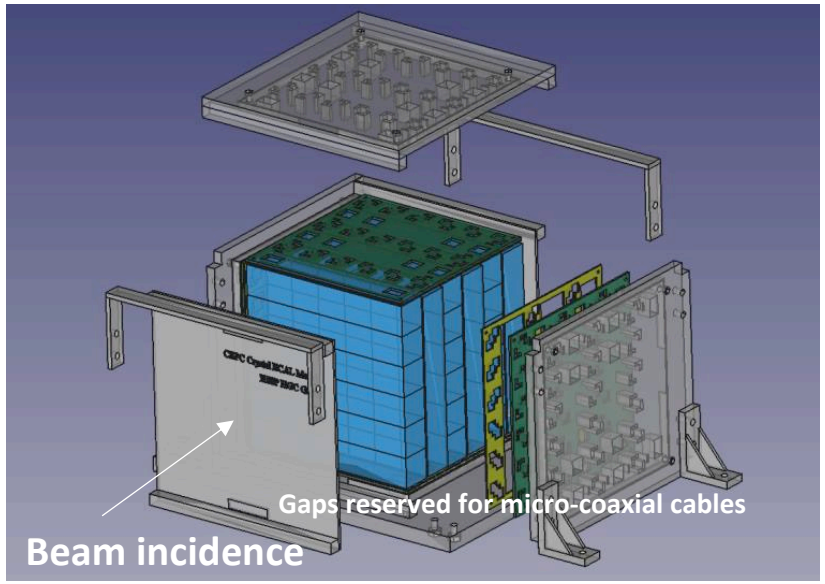


Crystal calorimeter: module development

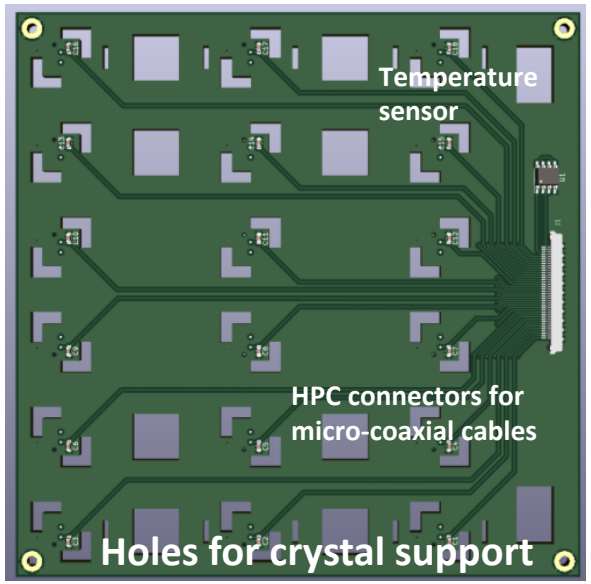
- **Mechanics and readout**

Baohua Qi (IHEP)

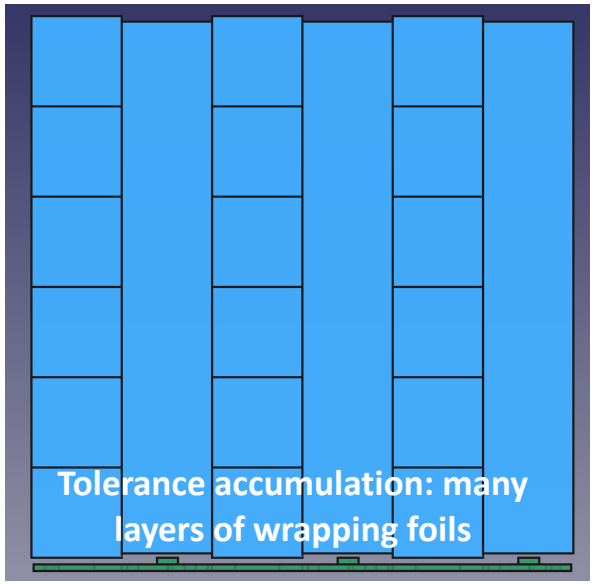
  - Mechanical support: custom-made 3D printer, with light weighted and enough strength.
  - Readout PCB: high pin-count (HPC) connectors for SiPM signals and one temperature sensor.
  - Extra supports for crystals to avoid the stress on PCB/SiPM.
  - Specific assembly procedure for orthogonal arranged of crystals.



Custom SiPM readout PCB



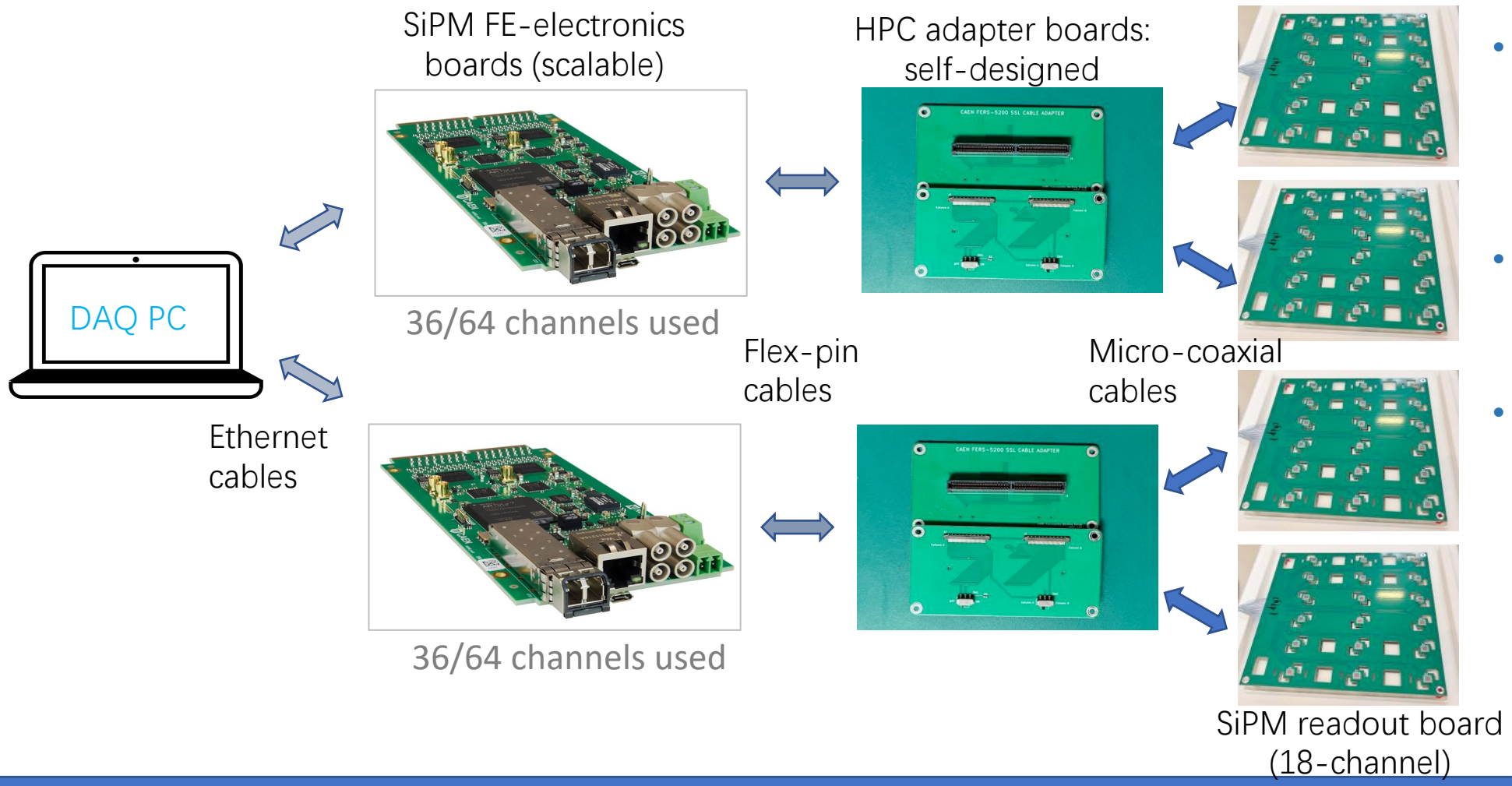
Module dimensions



Crystal calorimeter: module development

- **Front-end electronics and DAQ**

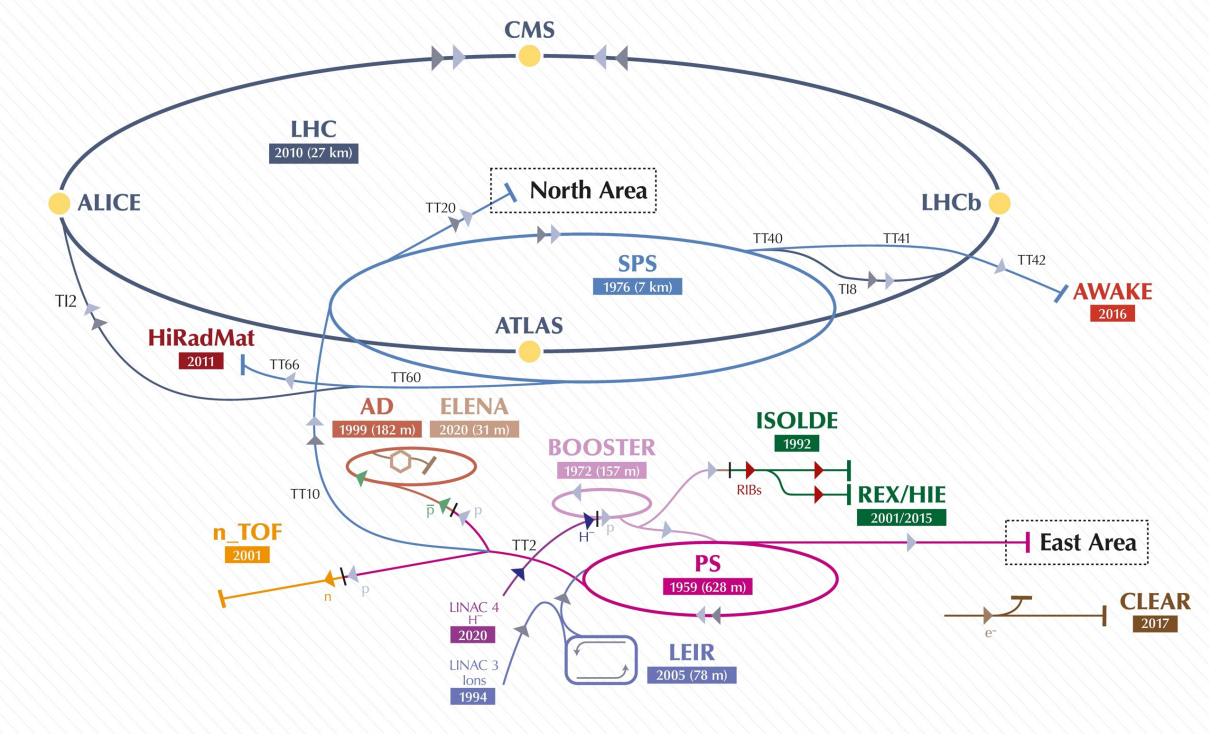
Baohua Qi (IHEP)



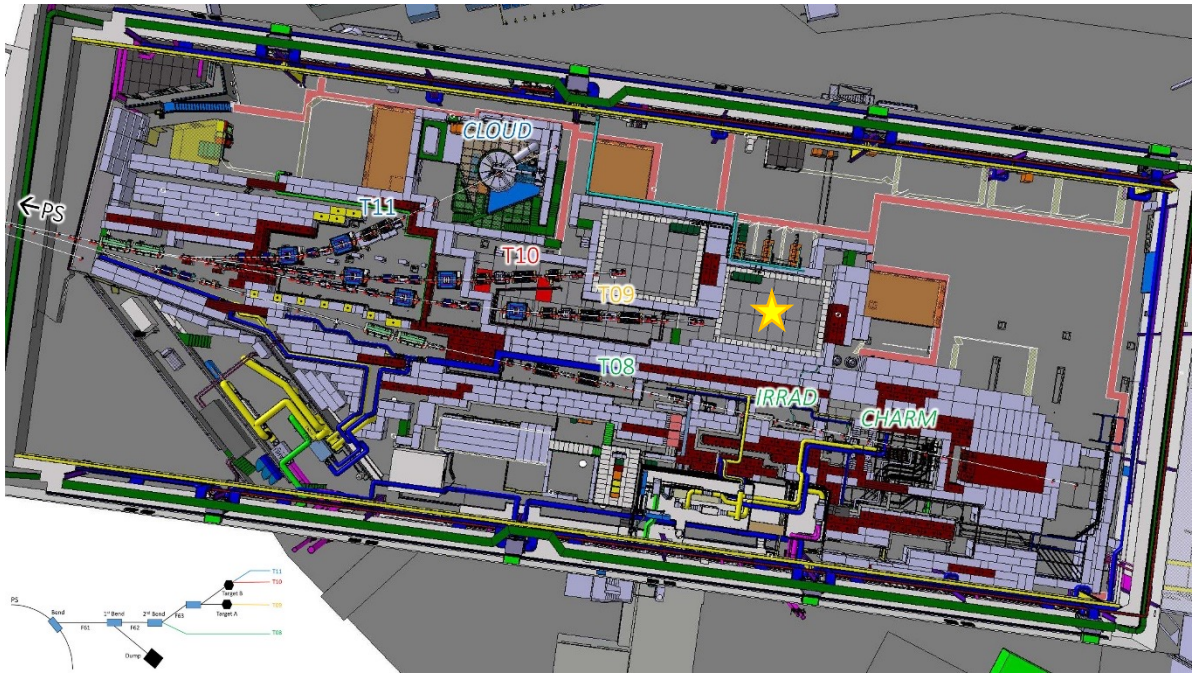
- **Data acquisition**
  - ADC in high gain
  - ADC in low gain
  - Timing: ToA, ToT
- **Event synchronization**
  - Trigger within 20 ns of two boards
- **Trigger modes**
  - External trigger: support daisy chain
  - Auto trigger: support coincidence of 2 channels

Crystal calorimeter: BT @ CERN

- **CERN Proton Synchrotron: primary 24GeV protons**
- **Secondary particles at PS-T09**
  - Muons, electrons (up to 5 GeV/c), charged hadrons (up to 15 GeV/c)
  - Typical beam structure: 0.4s/spill, 1-2 spills/SC, 10-30s for a super cycle



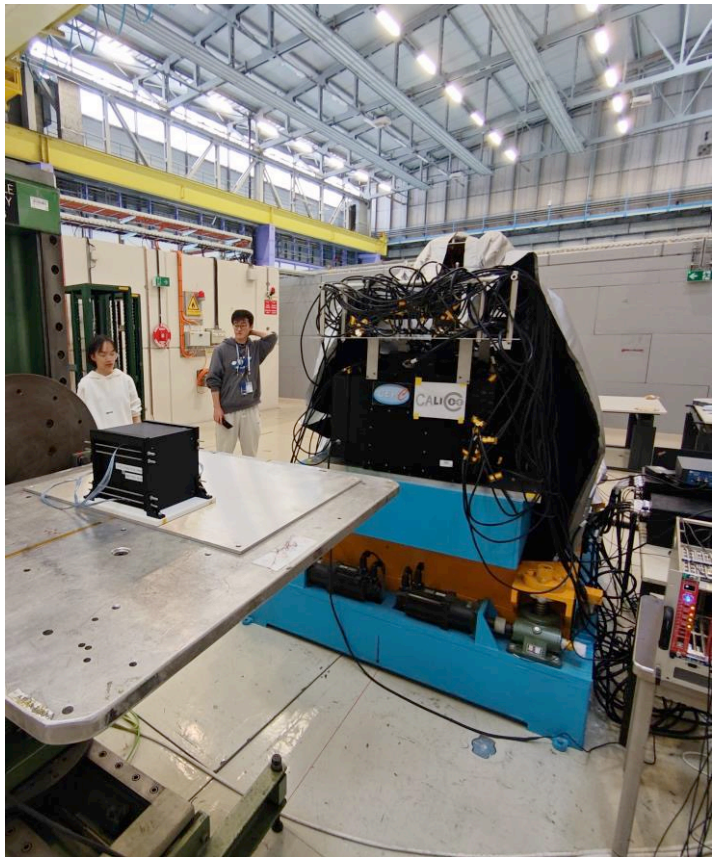
East Area (B.157) PS-T9

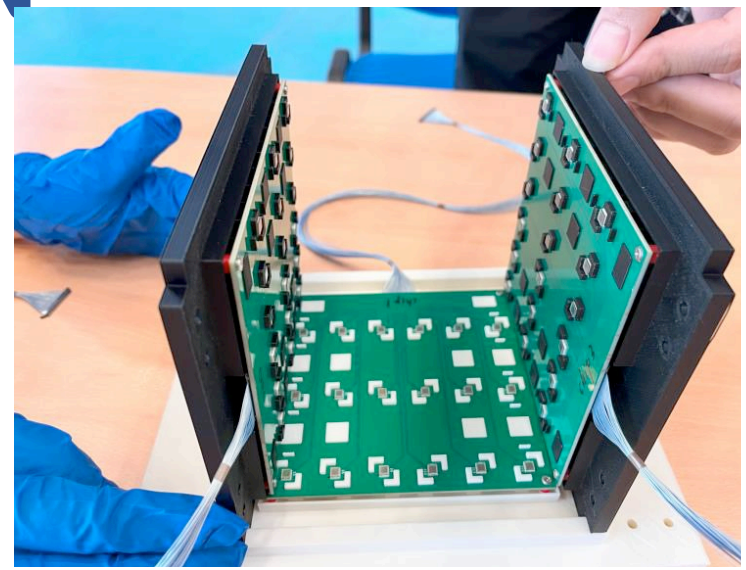


Crystal calorimeter: BT @ CERN

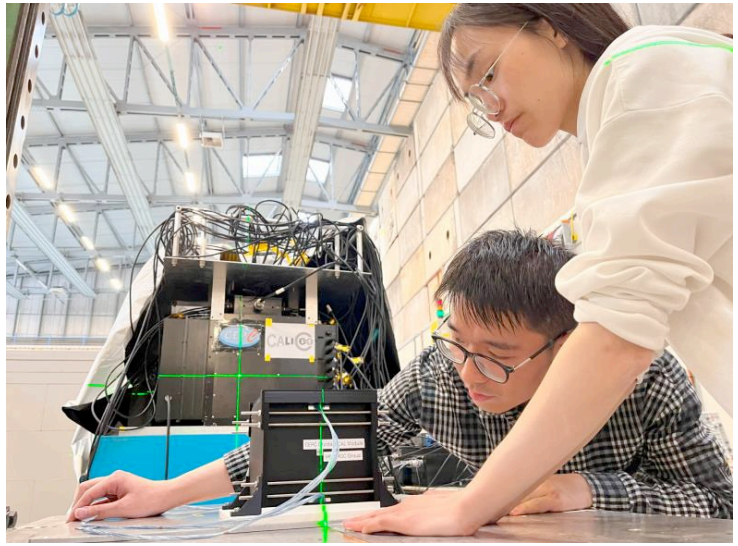
Shipping crystals to CERN

Crystal module placed on a motorized table, in upstream of ScECAL and AHCAL prototypes

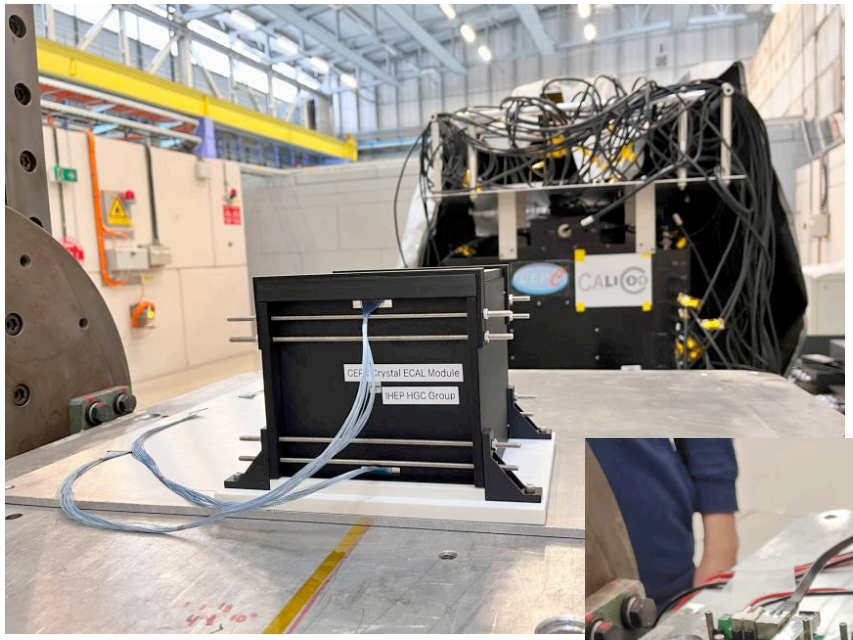


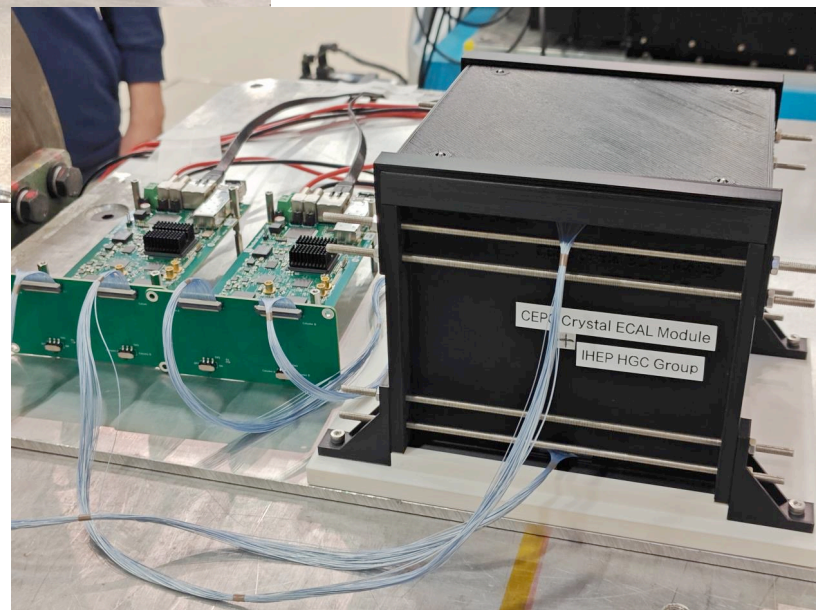


Crystal module assembly at CERN

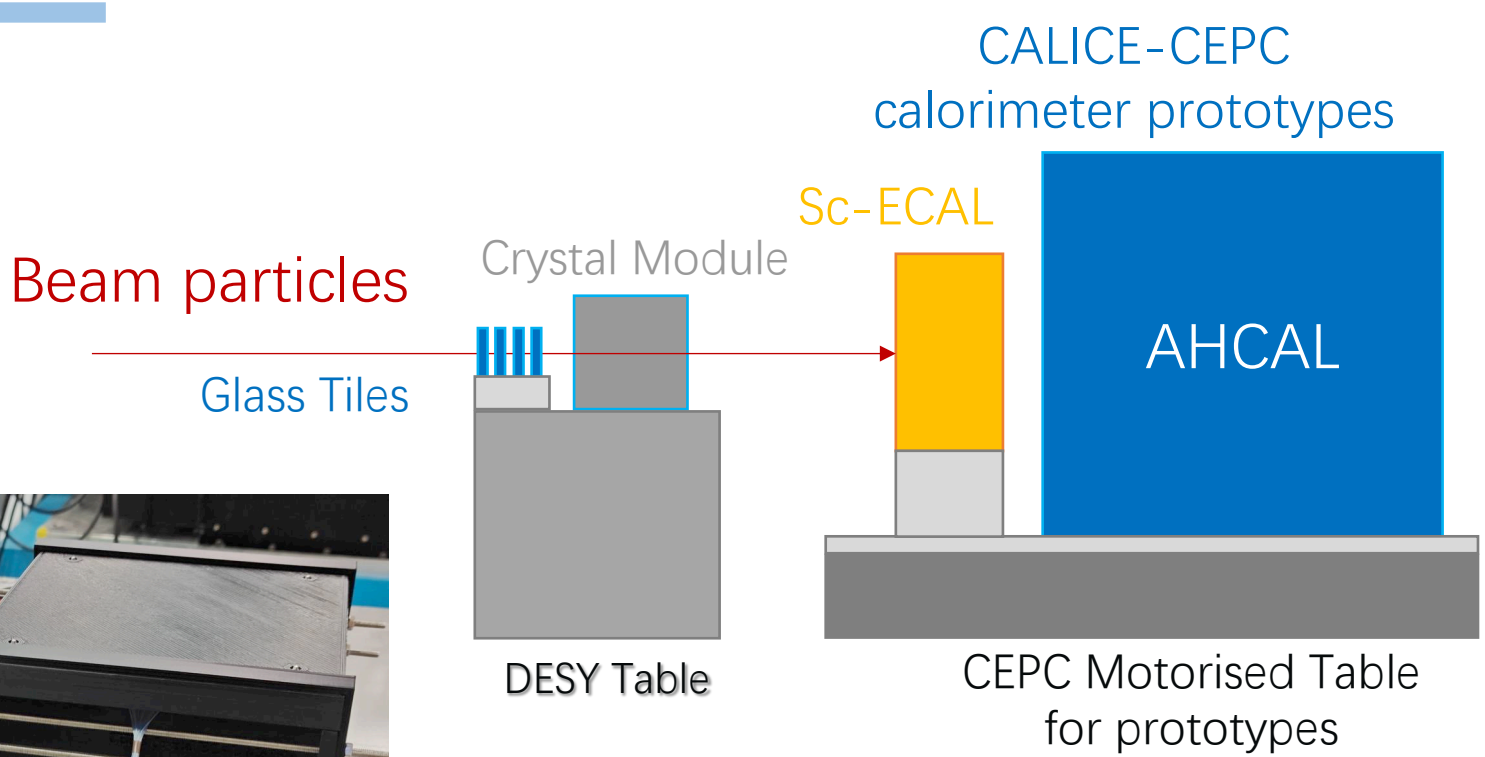


Crystal calorimeter: BT @ CERN





Parasitic runs with CEPC calorimeter prototypes

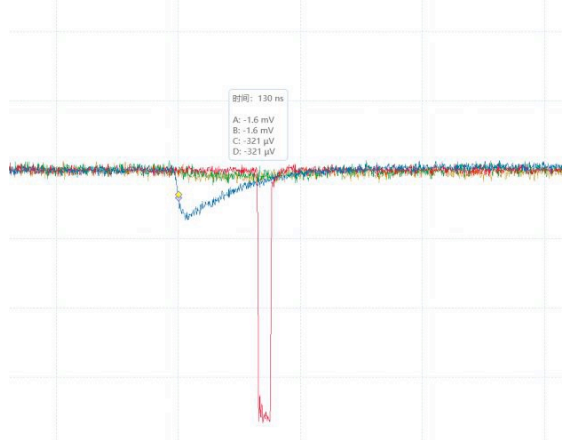


DESY Table: remote control for vertical/horizontal movements of crystal module and glass tiles

Move IN/OUT of beamline: coordination with testing of CEPC calorimeter prototypes

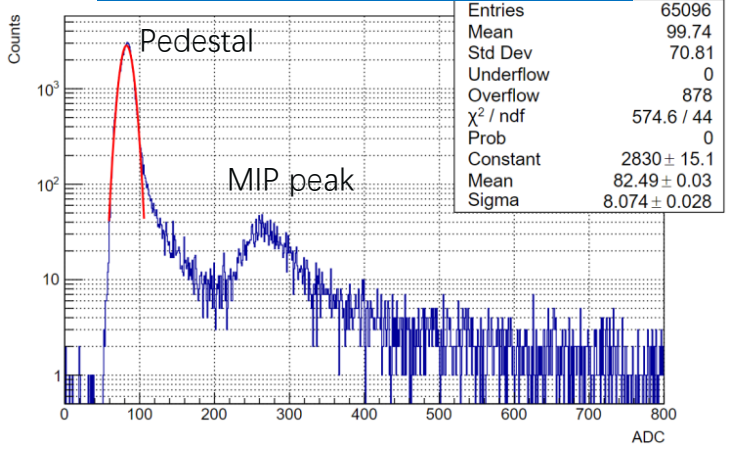
Crystal calorimeter: BT @ CERN

- **Muon beam: parameter scan & calibration**
  - Triggered by the beam telescope: ~2k per spill.
  - ASIC parameter scan with 10 GeV muon:
    - High gain and low gain, hold delay time, shaping time, HG discriminator.
  - Muon position scan for calibration.
  - Observed delay from external trigger: ~130 ns.
  - ~5.5M muon events collected.

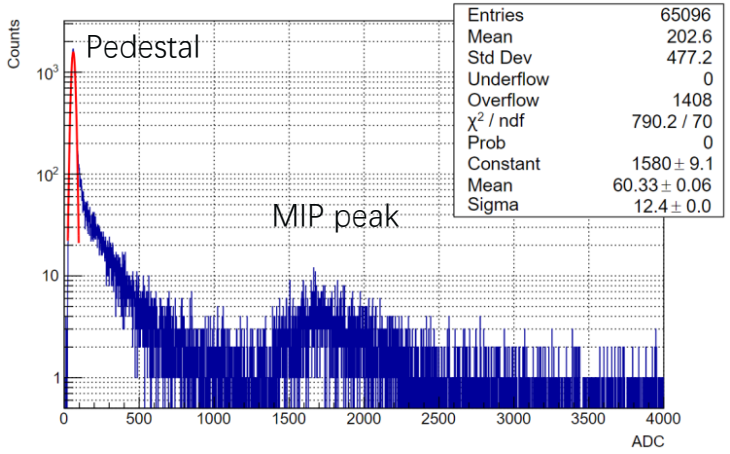


HG	LG	Hold-Delay Time	Shaping Time
34	4	5 ns	12.5 ns
44	24	10 ns	25 ns
49	34	50 ns	37.5 ns
54	44	100 ns	50 ns
59	52	150 ns	62.5 ns
	56	200 ns	75 ns
	58	300 ns	87.5 ns
	61		
	62		
	63	Parameters for electron tests in red	

Energy (ADC) in Low Gain



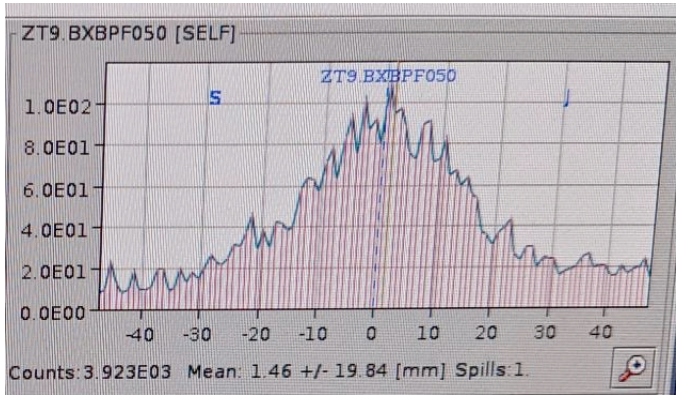
Energy (ADC) in High Gain



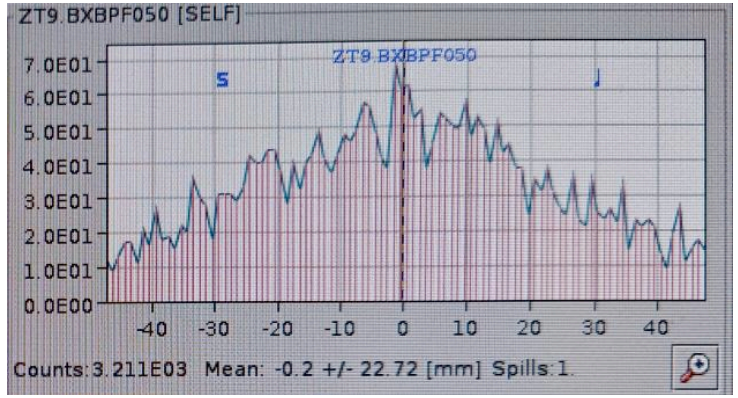
Crystal calorimeter: BT @ CERN

- **Electron beam**
  - Energy scan: 0.5, 1, 2, 3, 4, 5 GeV.
  - Further optimize ASIC settings: HG 49, LG tuned with beam energy.
  - Considerable impacts from upstream materials
    - Beam instrumentation: Cherenkov detector, SciFi hodoscope, …
    - Would lead to significant momentum spread
  - Larger beam spread with lower beam energy.
  - ~1M events collected.

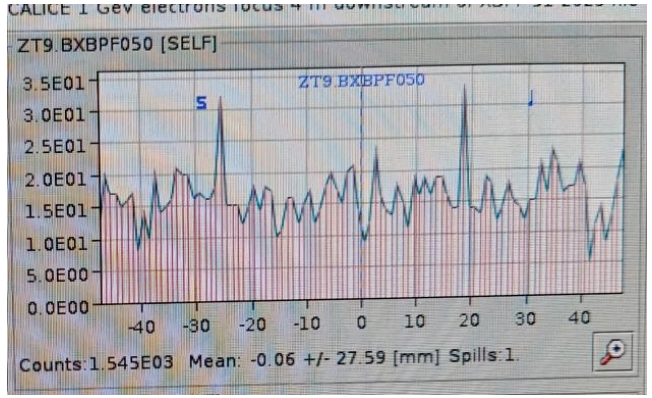
Electron beam profiles from SciFi hodoscope



4 GeV/c electrons



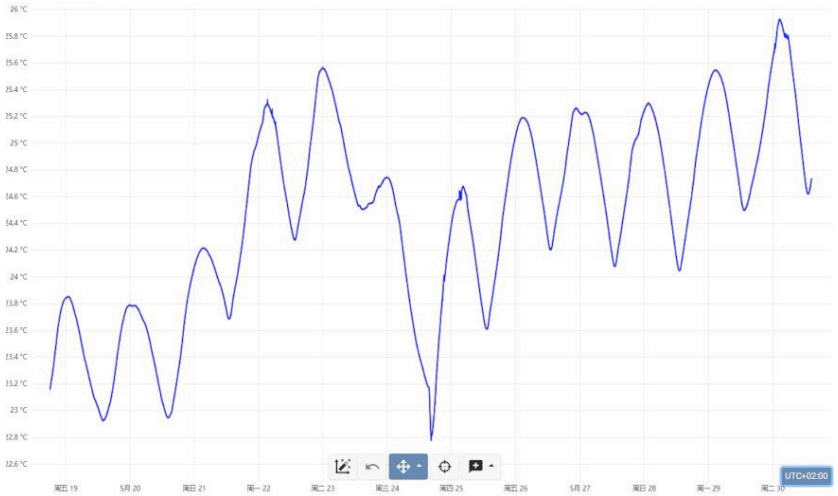
2 GeV/c electrons



1 GeV/c electrons

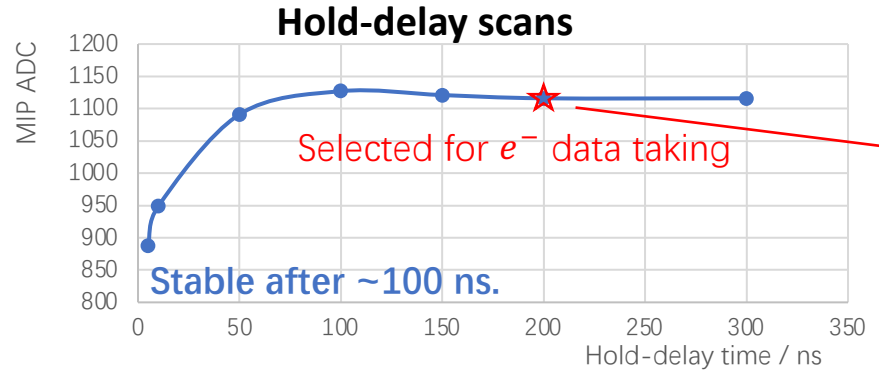
Crystal calorimeter: BT @ CERN

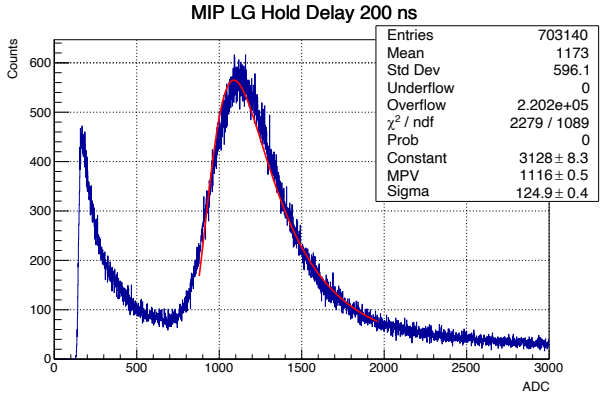
- **Other data acquired:**
  - Parasitic test: self-trigger of “leaked particles” form upstream
    - Almost MIP-like particles
    - Validation of long-term data-taking capability
  - Pion- beam test: capability under ~20k events per spill (0.4s)
    - > 80% trigger loss at such high fluence
  - Temperature monitoring:
    - PS-T9 experimental area: ~2℃ temperature change during the full period.



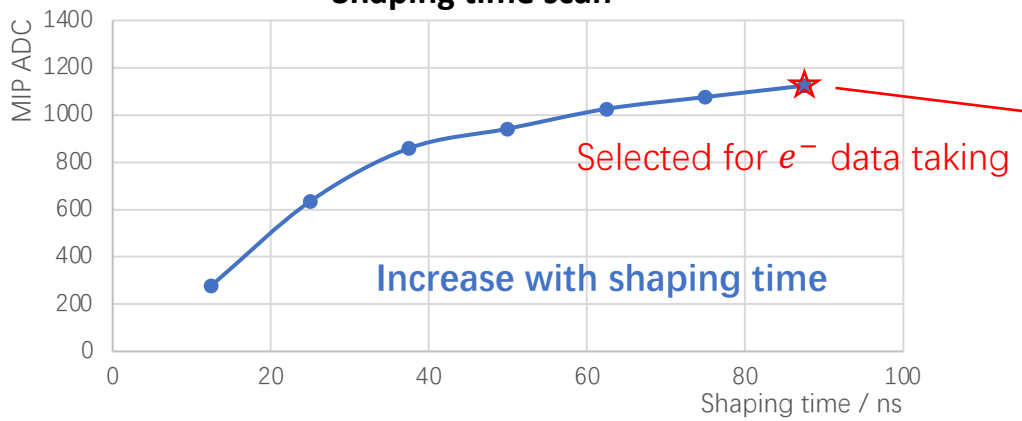
Beam data analysis

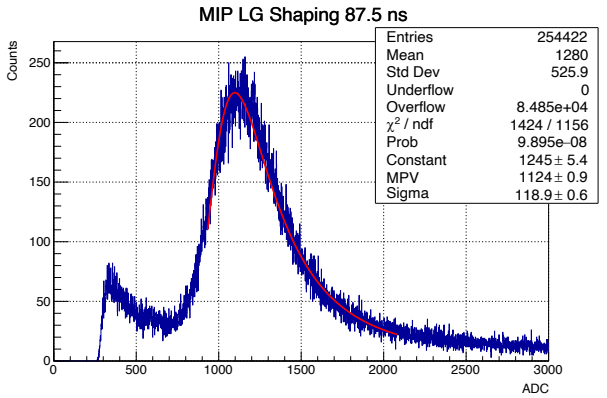
- **Parameter scan and optimization for ASIC**
  - Hold-delay time scan:
    - 10 GeV muon, HG 59, LG 63, scan from 5 ns to 300 ns.





  - Shaping time scan:

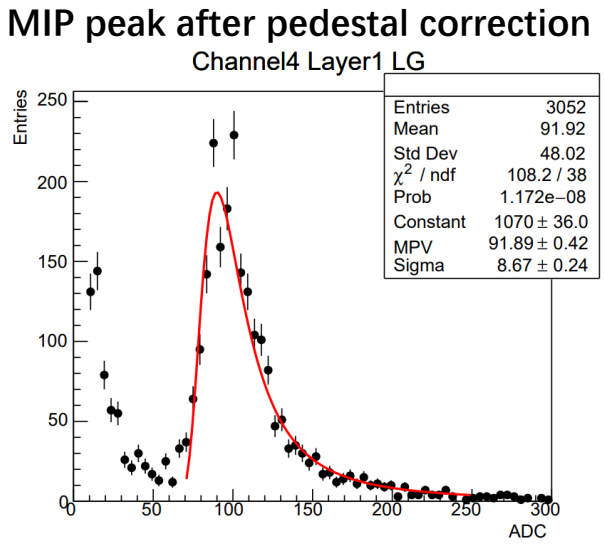


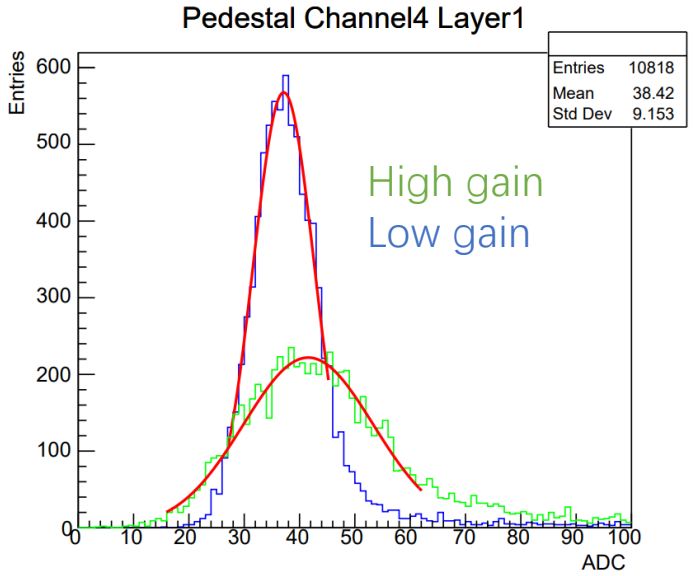


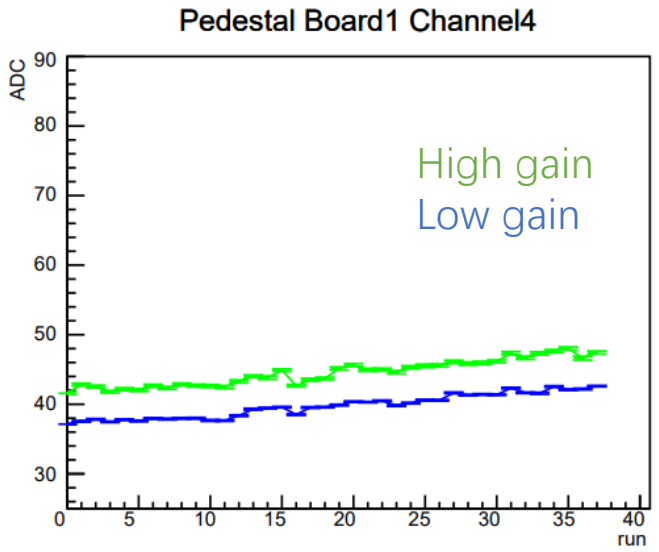
Beam data analysis

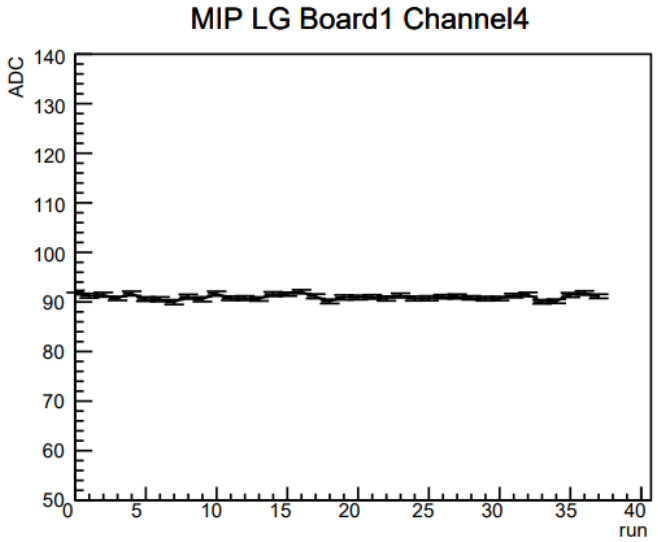
Zhiyu Zhao (SJTU)
Baohua Qi (IHEP)

- **Pedestal fit and MIP calibration**
  - Fit the pedestal peak channel-by-channel, and shift to 0.
    - Fluctuate over time, board and gain mode.
  - Calibrate the data with MIP response: stable over the run.
  - Observed 2 damaged channels with pedestal only.
    - Used the signal of adjacent channel.





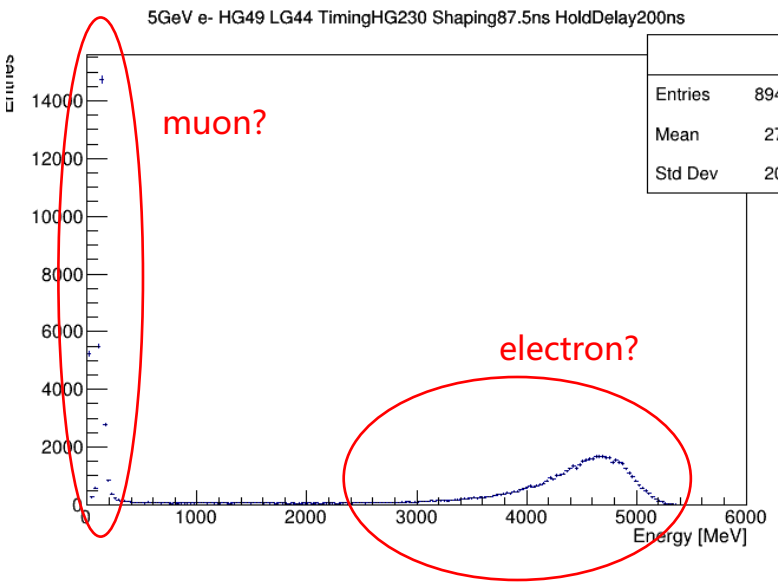


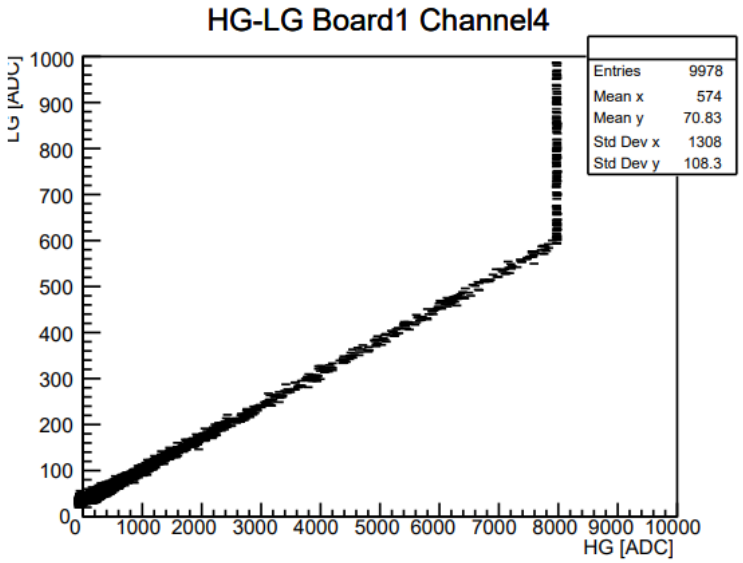


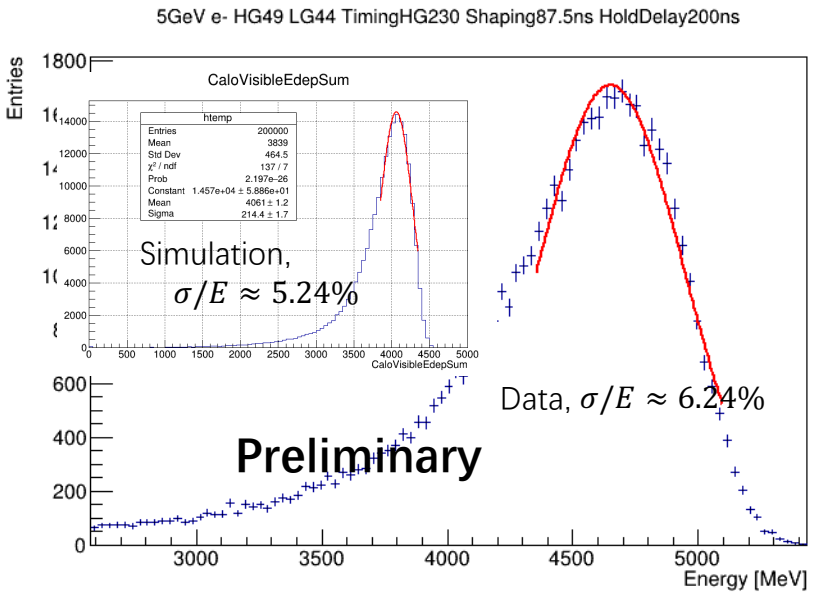
Beam data analysis

- **Preliminary electron energy: 5 GeV data**
  - Calibrated with 10 GeV muon data.
  - Event synchronization: two board trigger time $\delta T < 20ns$.
  - HG/LG conversion threshold: 7800 ADC.
  - Threshold: 0.5MIP
  - Comparison with simulation is undergoing.

Zhiyu Zhao (SJTU)
Baohua Qi (IHEP)

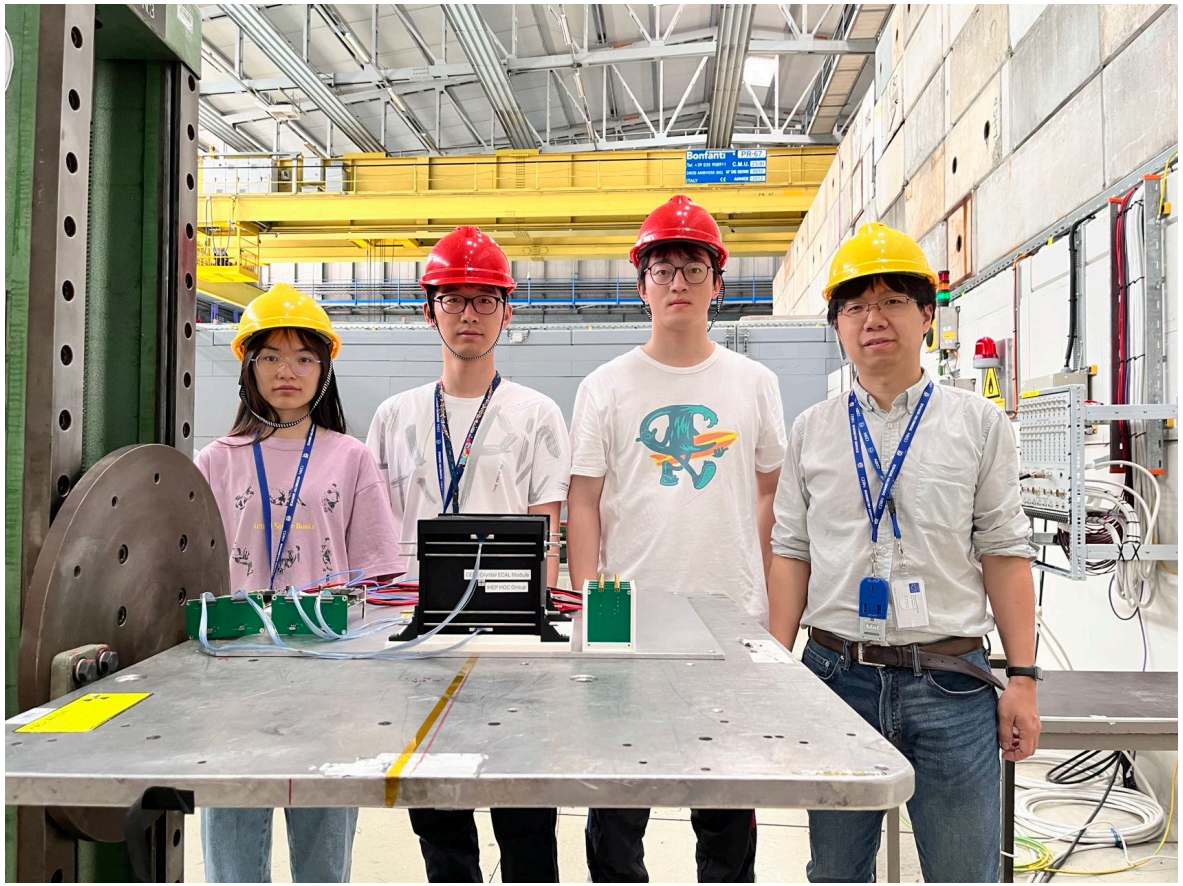






Acknowledgements

- **Strong teamwork and team's hardworking spirit in day and night**
- **Enormous and substantial support from CERN and CALICE**



Very successful beam test campaigns.

A big Thank You to the whole CALICE and CEPC calorimeter teams!

Summary and plans

- **Ongoing activities**
  - Data conversion and selection: event synchronization and crosscheck.
  - Geant4 simulation and realistic digitization: EM energy resolution.
  - MIP calibration channel by channel.
  - Event display tool.

- **Plan**
  - Modelling of upstream beam instrumentation in G4: beam momentum spread.
  - Energy reconstruction of electron data.
  - Timing data analysis: ToA timestamps.
  - Temperature corrections for crystals and SiPMs.
  - Influences of crosstalk and background of DESY table.
  - Development of the 2nd crystal module.