

Institute of High Energy Physics
Chinese Academy of Sciences

BESIII

Zero Degree Calorimeter for BESIII

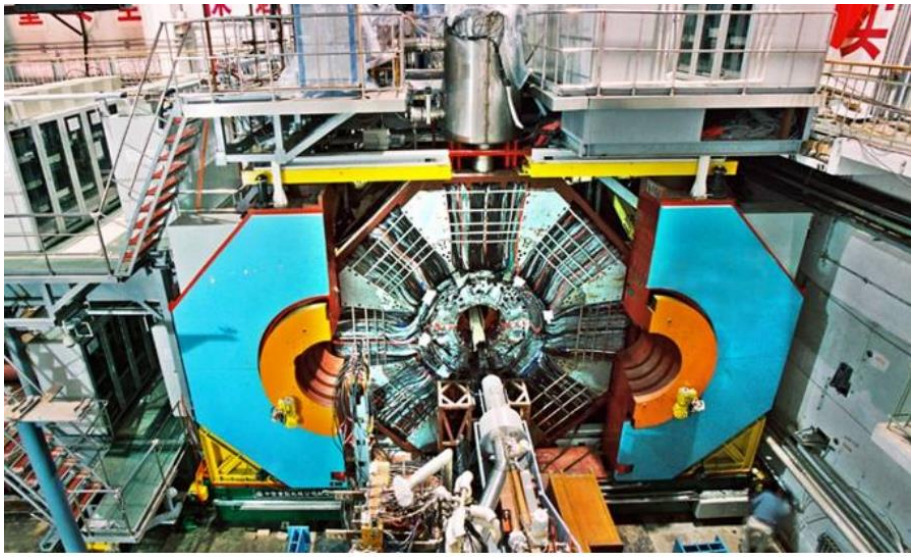
Lei Zhang (张雷), Yuhui Miao (缪语辉), Jiawei Wan (万家威) ,
Yilun Wang (王翊伦),

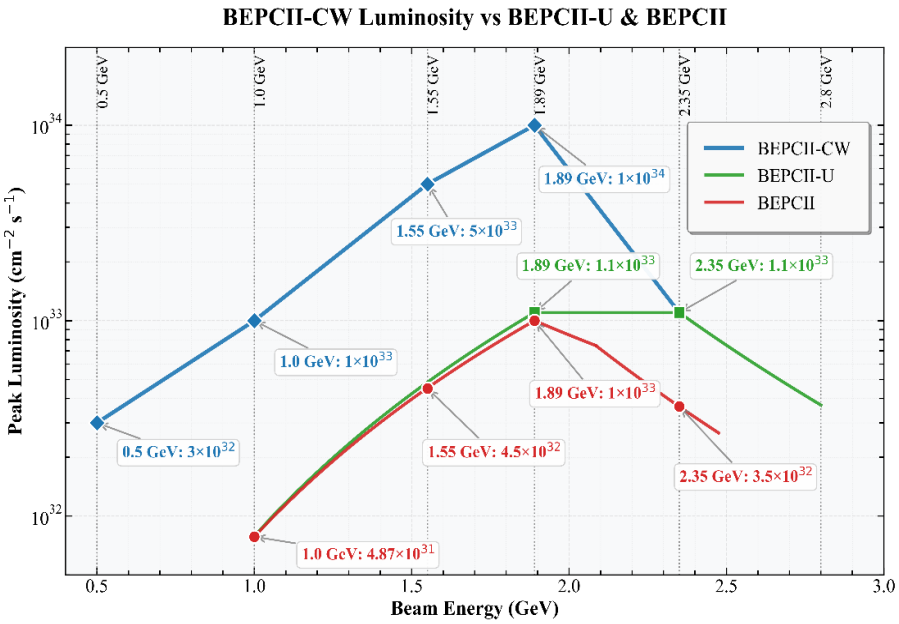
Xiao Cai (蔡啸), Sheng Dong (董胜), Xiaohui Qian (钱小辉)

On behalf of the BESIII-ZDC team

Shanghai, Oct 24, 2026

BESIII



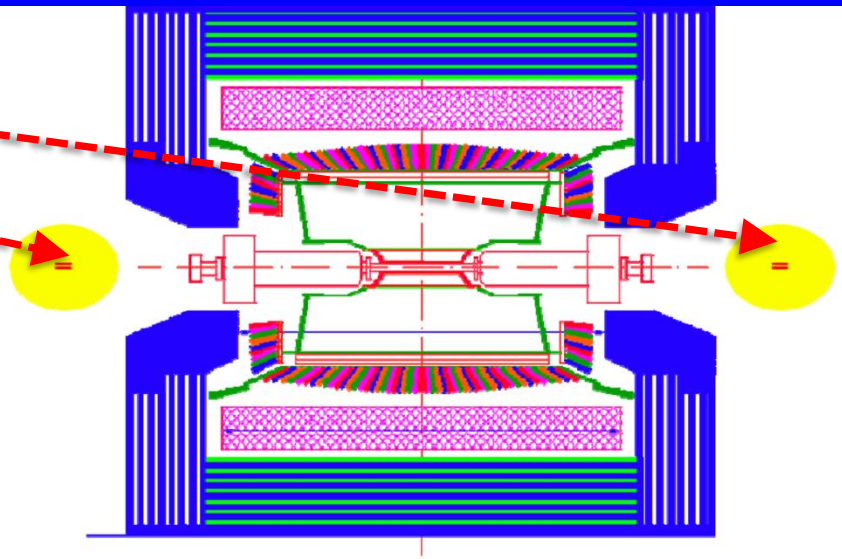


- Beijing Spectrometer(BESIII) is a general purpose detector at Beijing Electron-positron Collider (BEPCII).
- BEPCII-U has achieved a threefold increase in luminosity,
- Subsequent BEPCII-CW will raise the luminosity further, by roughly a factor of 10.

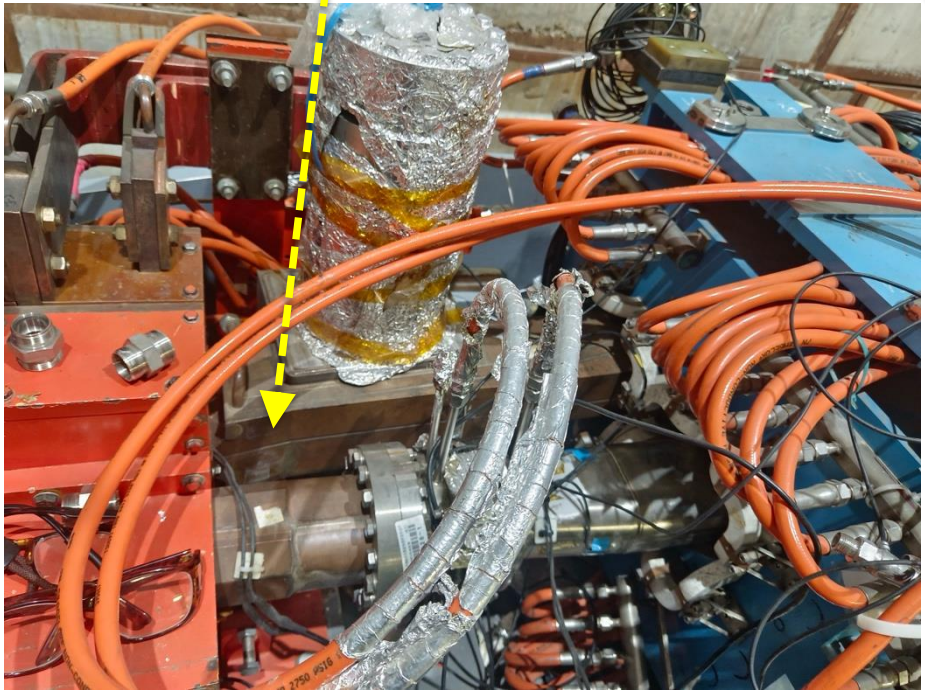
Location of fBLM

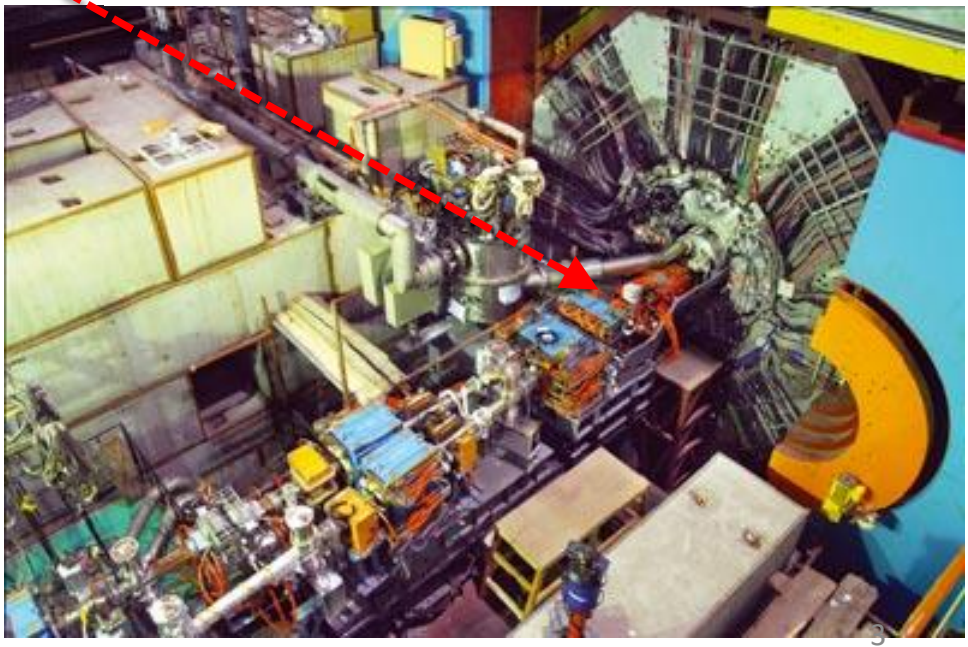
3.3 m < z < 3.5 m

θ = 0 in the CMS frame



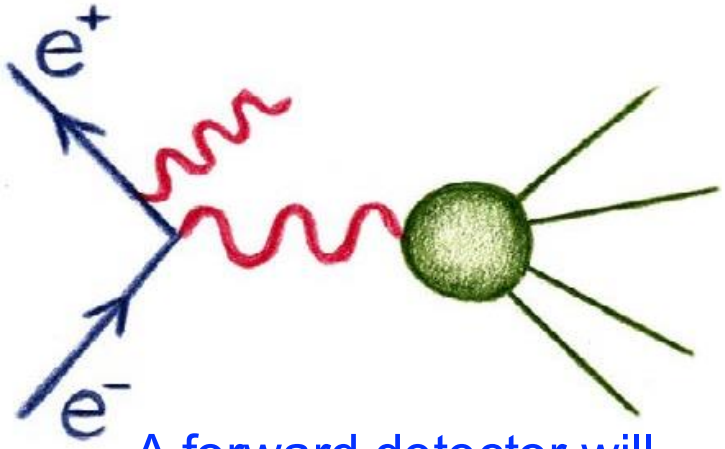
Copper window in the outgoing beam pipe



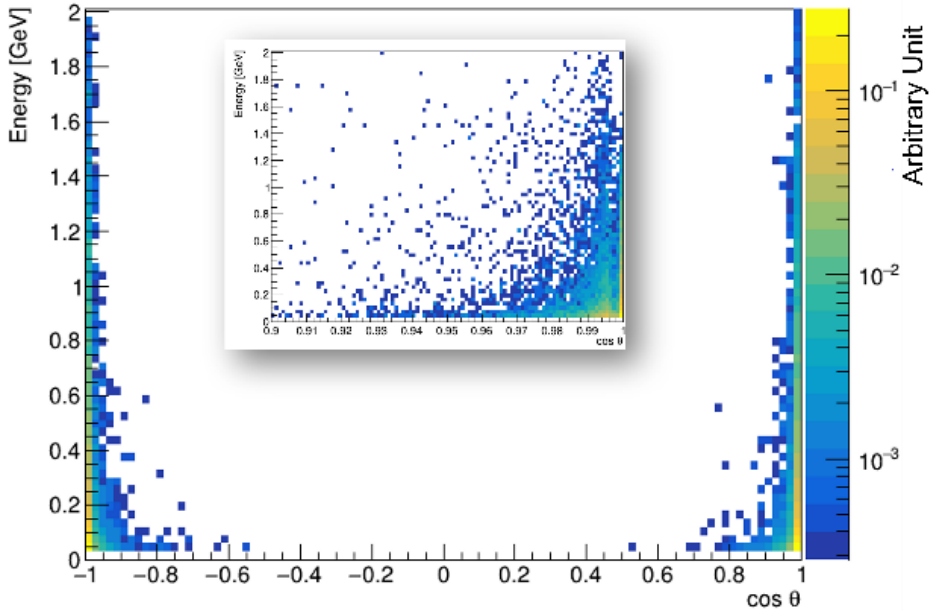


ISR return

- Initial-state radiation (ISR) return
  - $e^+e^- \to \gamma_{ISR} e^+e^- \to \gamma_{ISR}$ X lowers the effective e^+e^- collision energy.
- ISR photons are mostly in the forward region (|cosθ| > 0.99)
  - EMC (|cosθ|<0.93) detects only large-angle ISR photons, resulting in low efficiency.

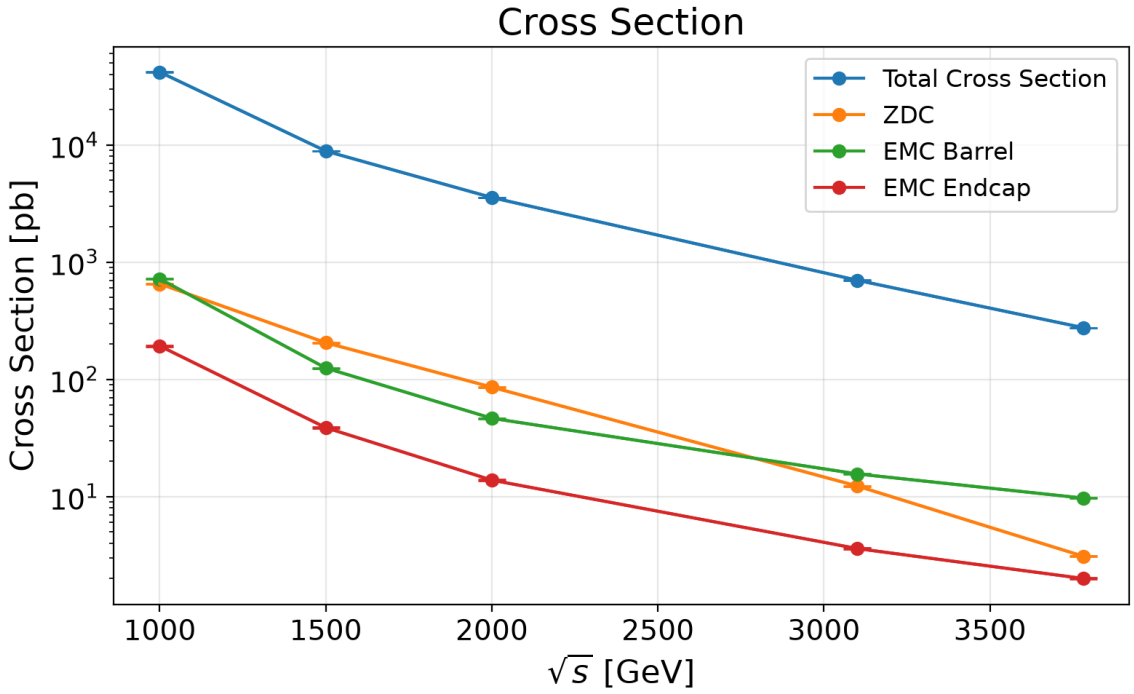


A forward detector will significantly boost ISR physics



ISR acceptance

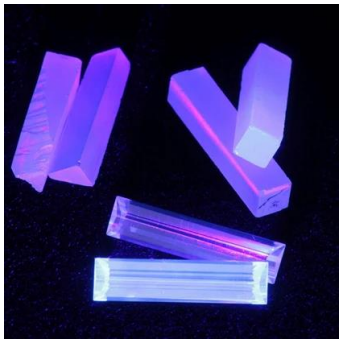
- Benchmark process: $e^+e^- \to \gamma_{ISR}\pi^+\pi^-$ at five COM energies
  - Energy-deposit requirementy: $E_{dep} > 50$ MeV and $E_{dep} / E_{\gamma}^{truth} > 40\%$
- ZDC has large acceptance comparing to BESIII main detector EMC
  - Endcap at all energies, barrel at 1.5 and 2.0 GeV

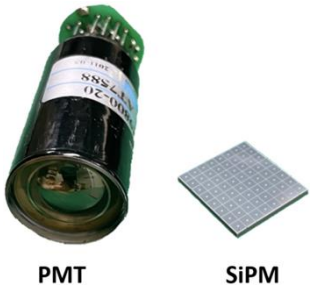


Machine learning may further improve ISR photon tagging

Technology Choice for ZDC

- Challenges
  - High radiation level in the forward region
  - High event rate, difficult for Trigger&DAQ system
- LYSO crystal for calorimetry
  - High light yield and high radiation hardness
- SiPM sensor: Compact, low working voltage, large dynamic range, cost-effective



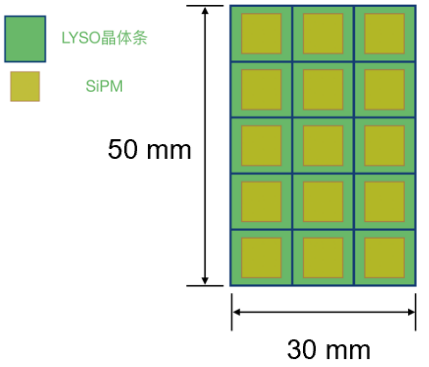


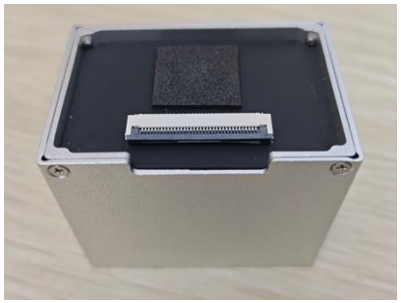
- Candidates for CEPC
  - SiPM selected by CEPC ref. detector, both calorimeter and Muon
  - LYSO+SiPM: the baseline for CEPC luminometer

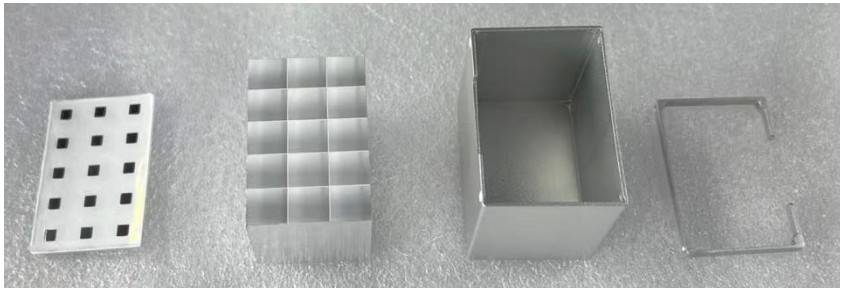
Detector Module

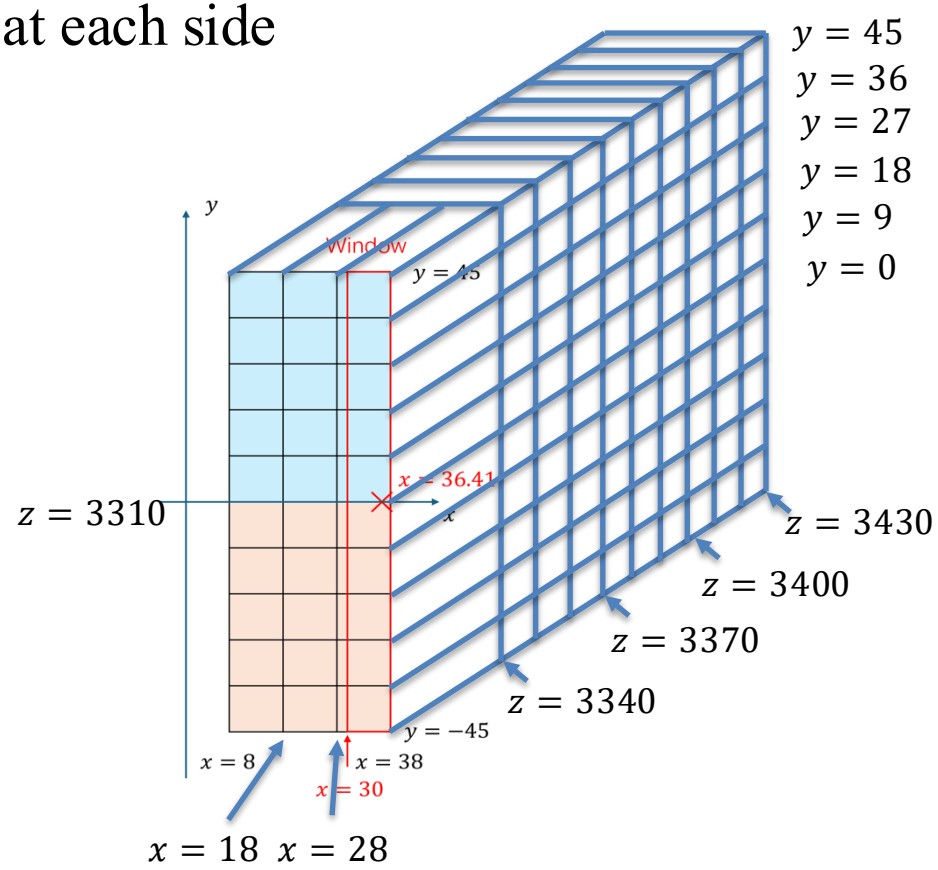
- Module design
  - 3×5 LYSO bar array (bar dimension: 1cm×1cm × 3cm)
  - SiPM board mounted with the same 3x5 SiPM array
  - 8 module in one sub-detector at each side

15-channel module

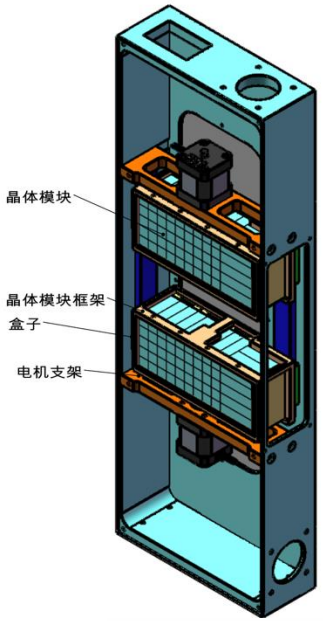




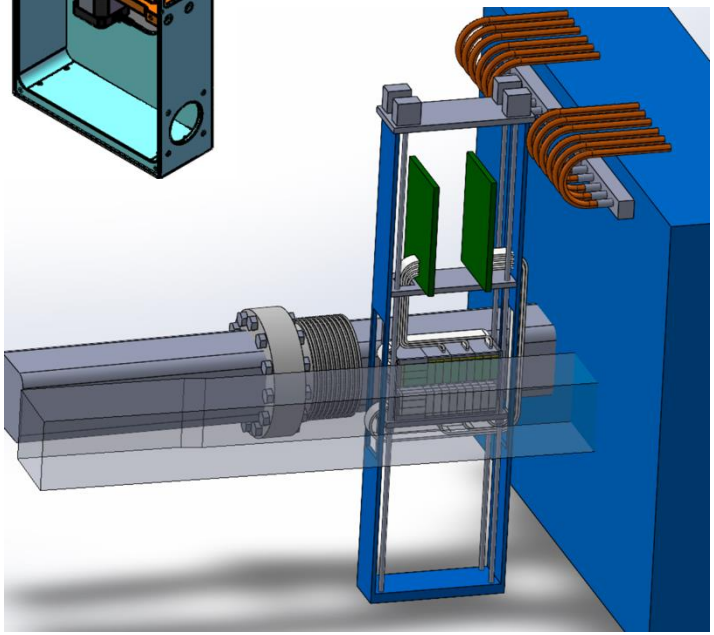


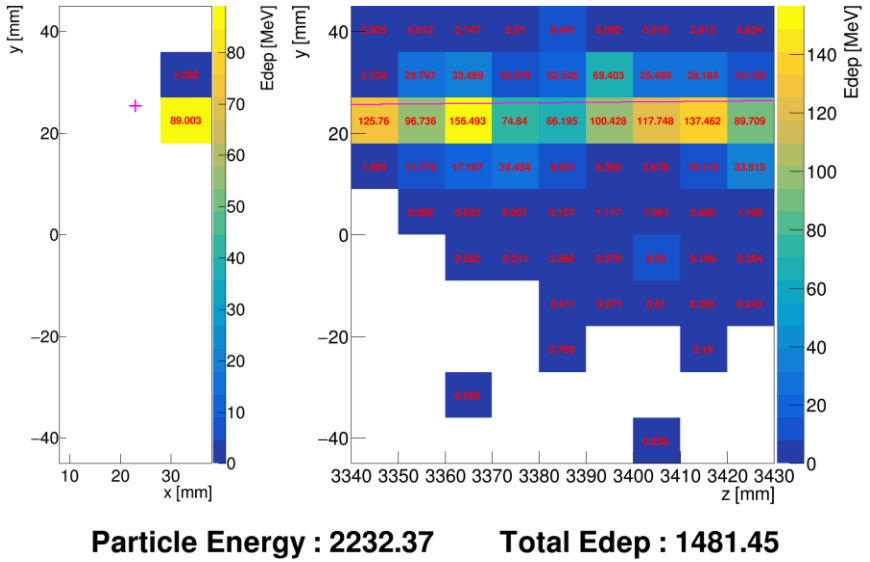


Detector of Zero Degree Calorimeter (ZDC)



- Two sub-detectors with 240 channels in total
  - Fully modalized design, optimal for energy and position

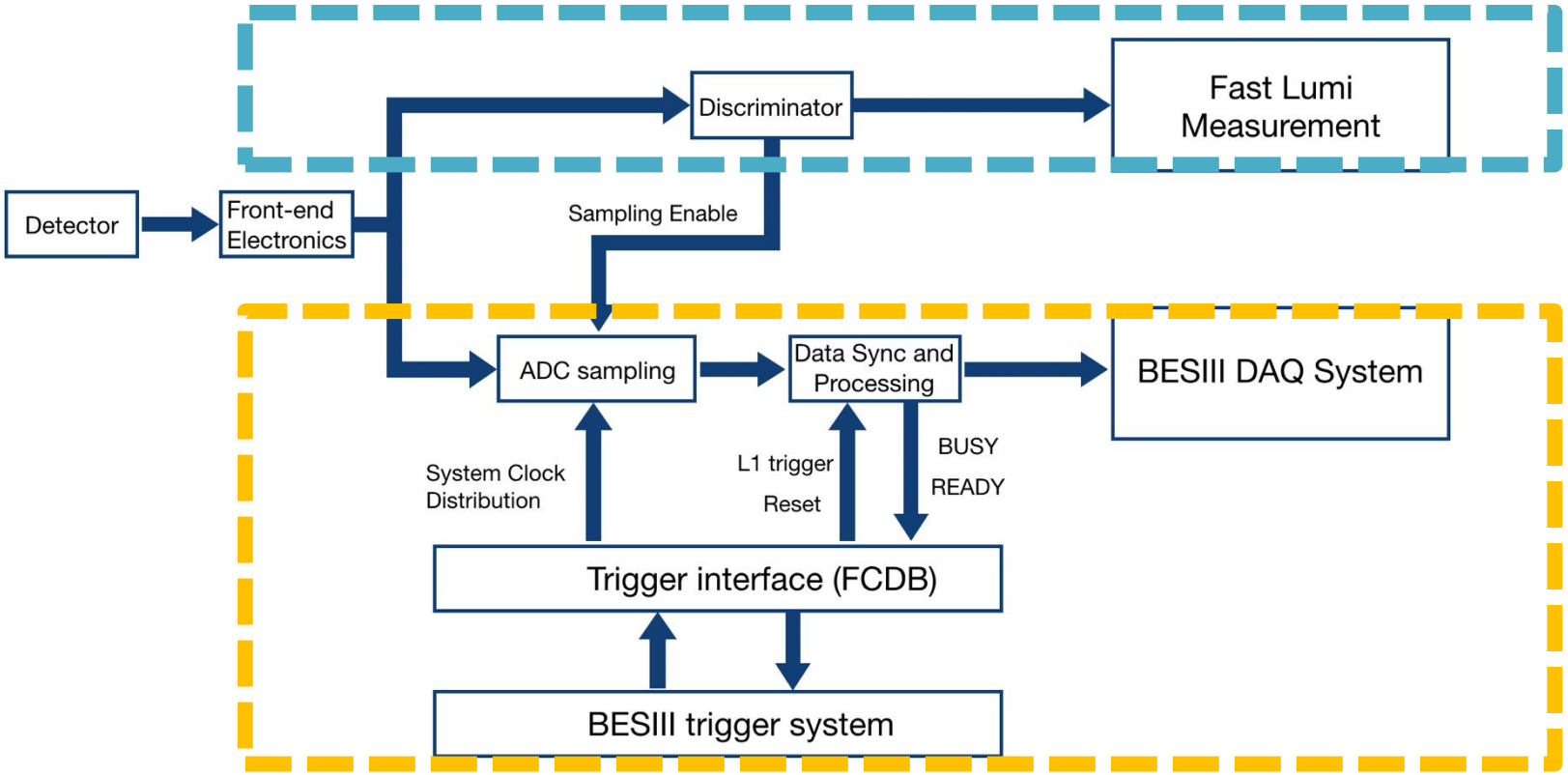




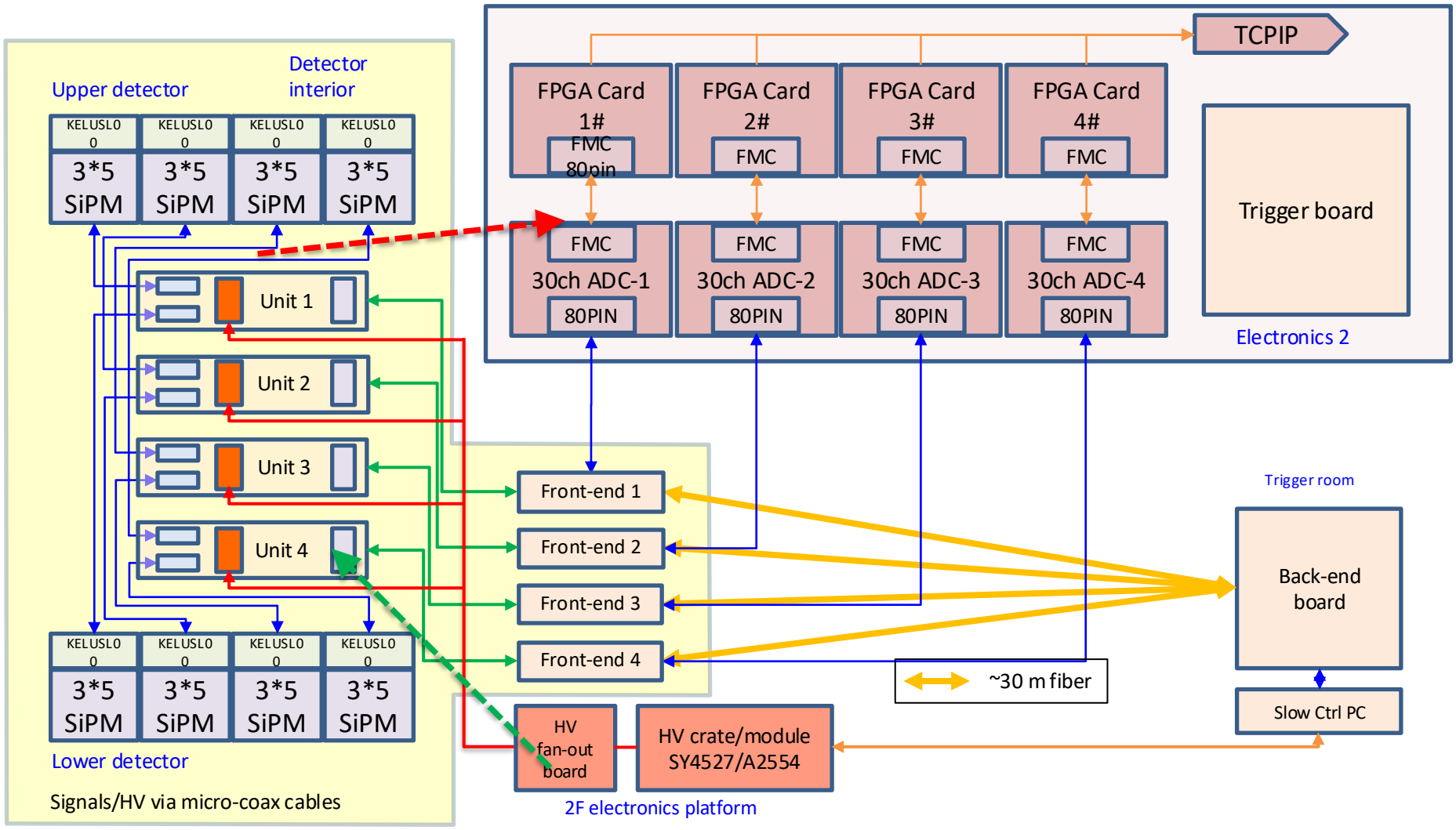
Particle Energy : 2232.37 **Total Edep : 1481.45**

Readout Electronics Architecture

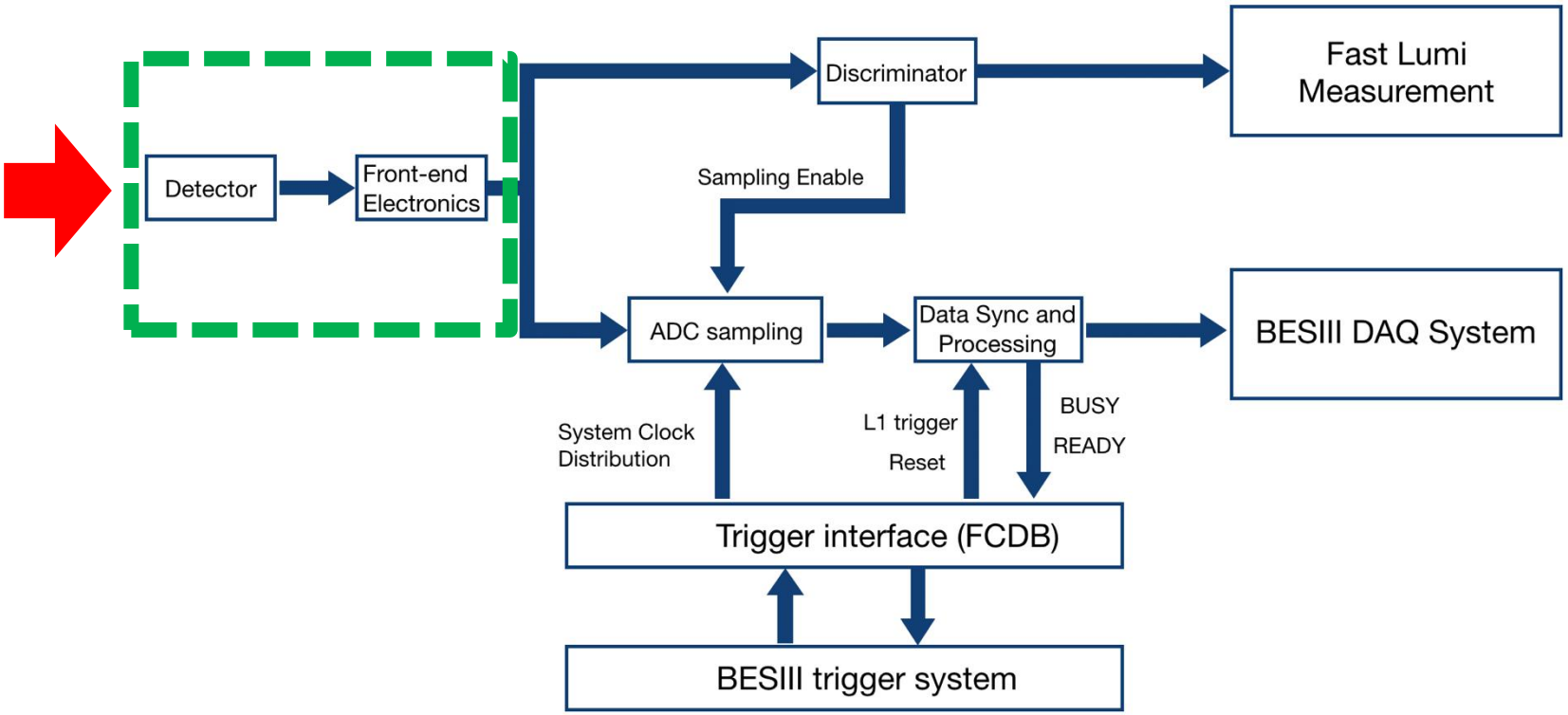
- Three blocks:
  - Front-end, Lumi. monitoring, ISR photon tagging & DAQ



Readout Electronics Topology



Electronics for Lumi. monitoring



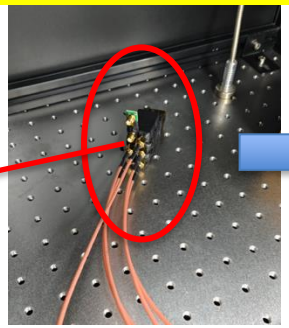
Long and careful R&D processes

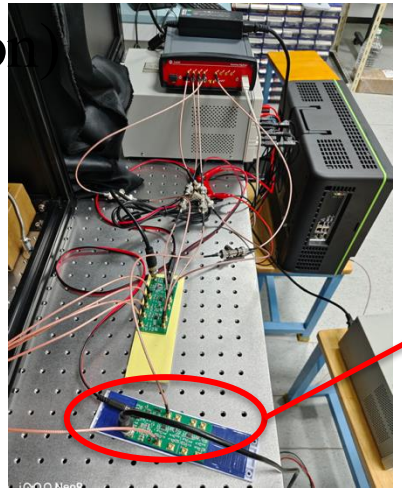
- LYSO+SiPM module and readout integration
  - Front-end electronics (first version)

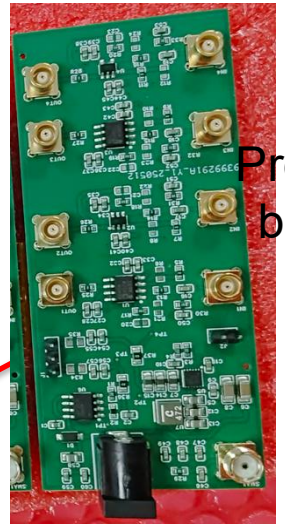
SiPM board

LYSO+SiPM module



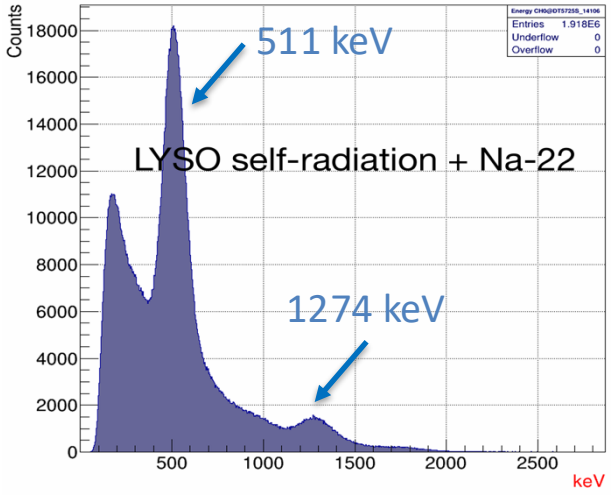


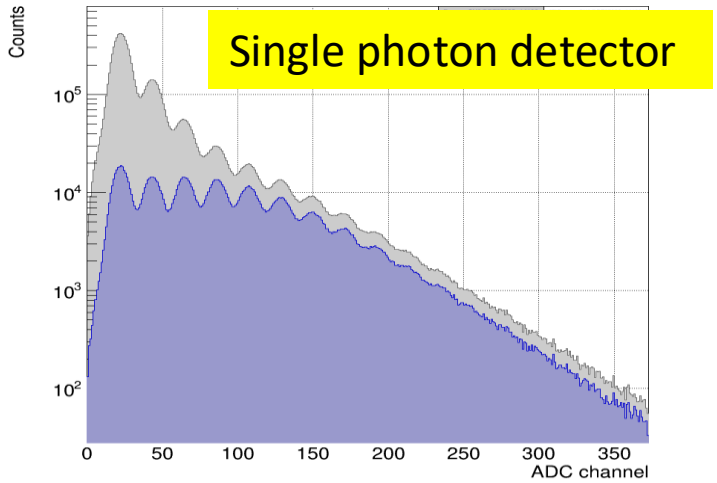




Preamp board

- Lab tests with radioactive sources and a laser system

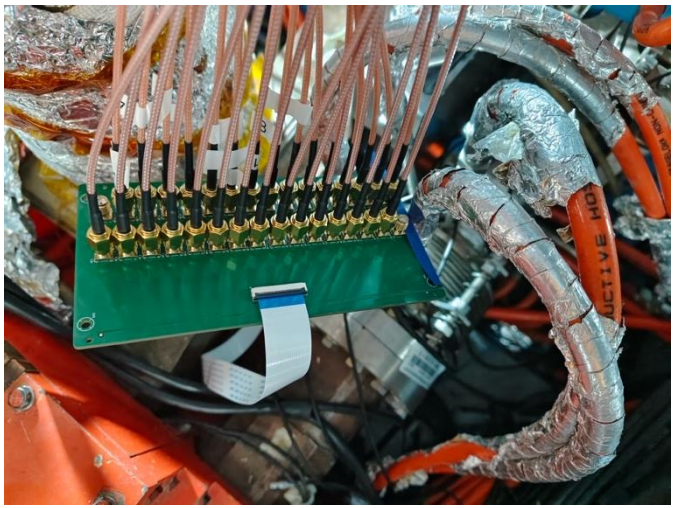


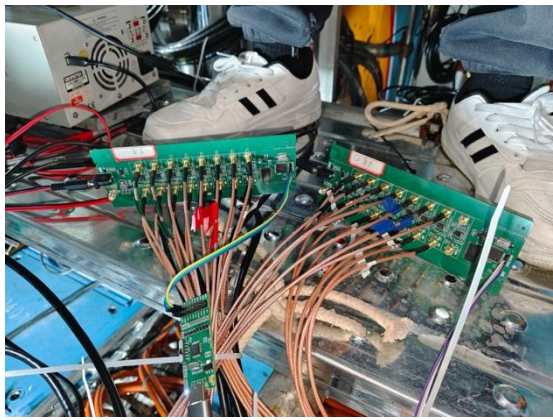


Long and careful R&D processes

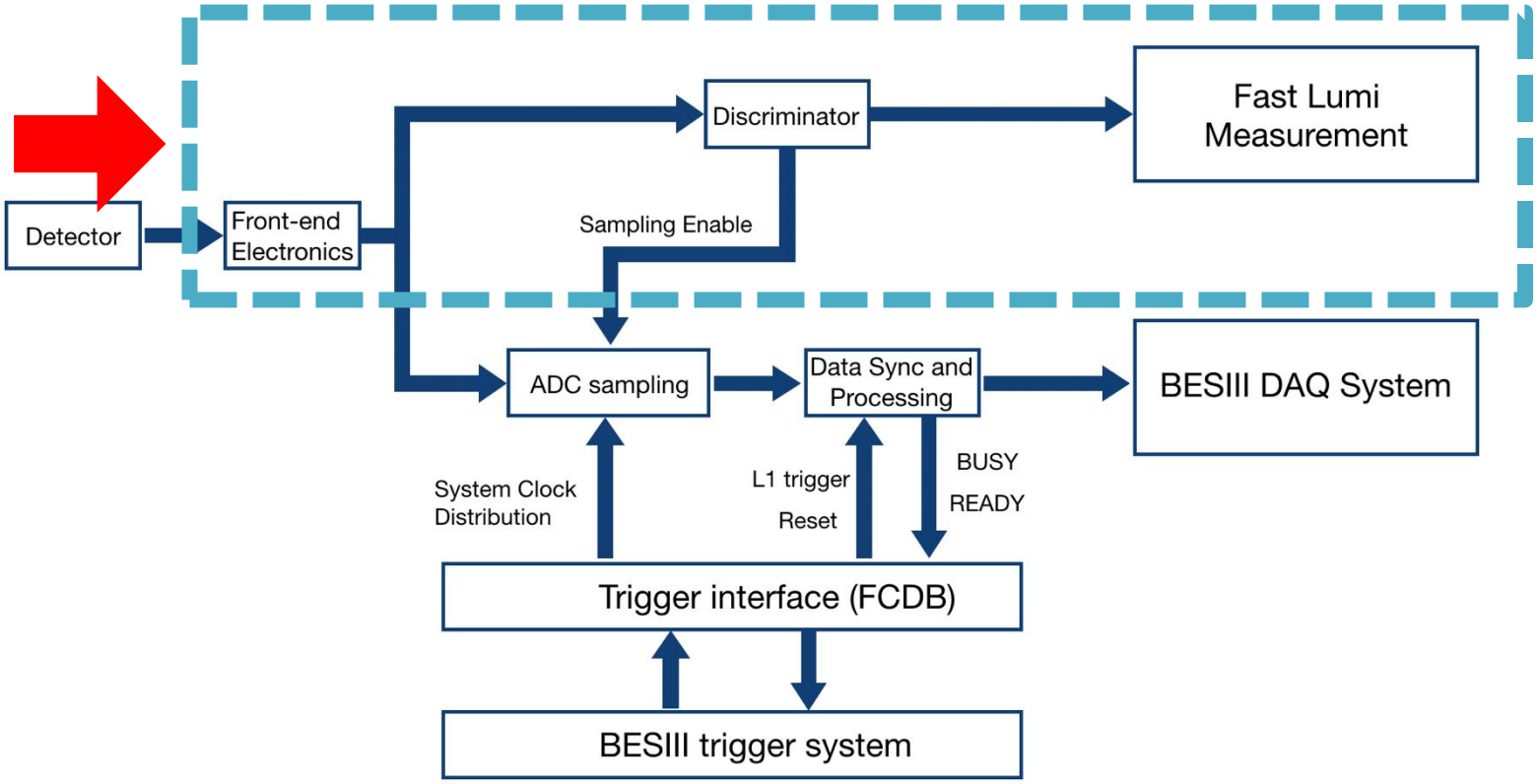
- Insitu test at BEPCII: test the reliability of LYSO and SiPM







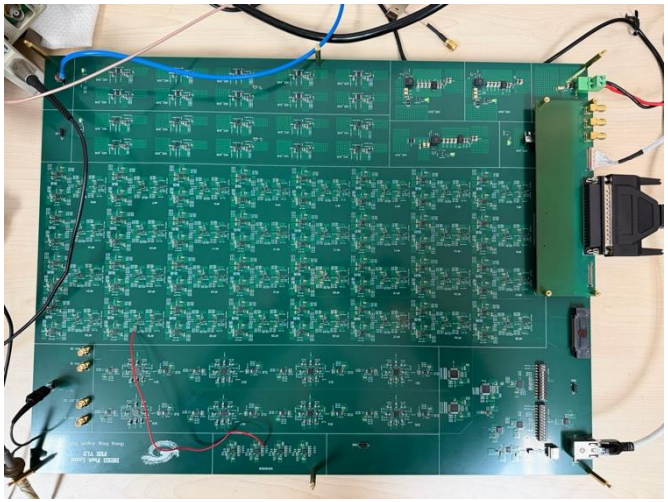
Electronics for Lumi. monitoring



Fast luminosity electronics

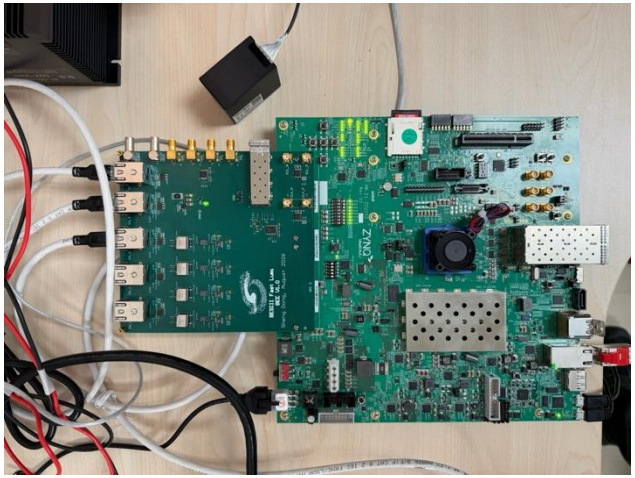
- Front-end electronics (FEE)
  - Amplification, fan-out, discrimination and pulse shaping

FEE V0.1



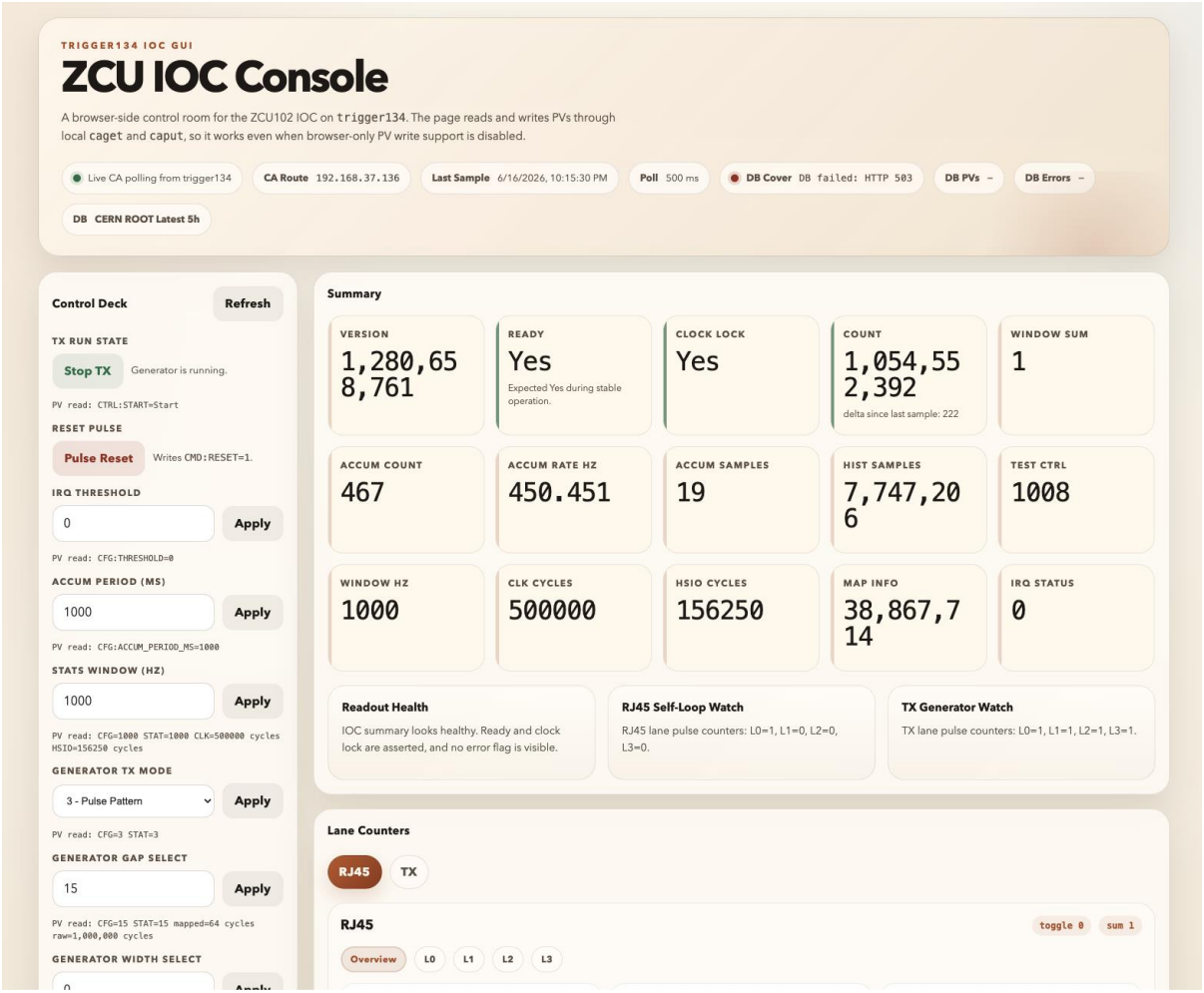
- Back-end electronics (BEE)
  - Data aggregation, SPI communication and Ethernet data output

BEE test setup

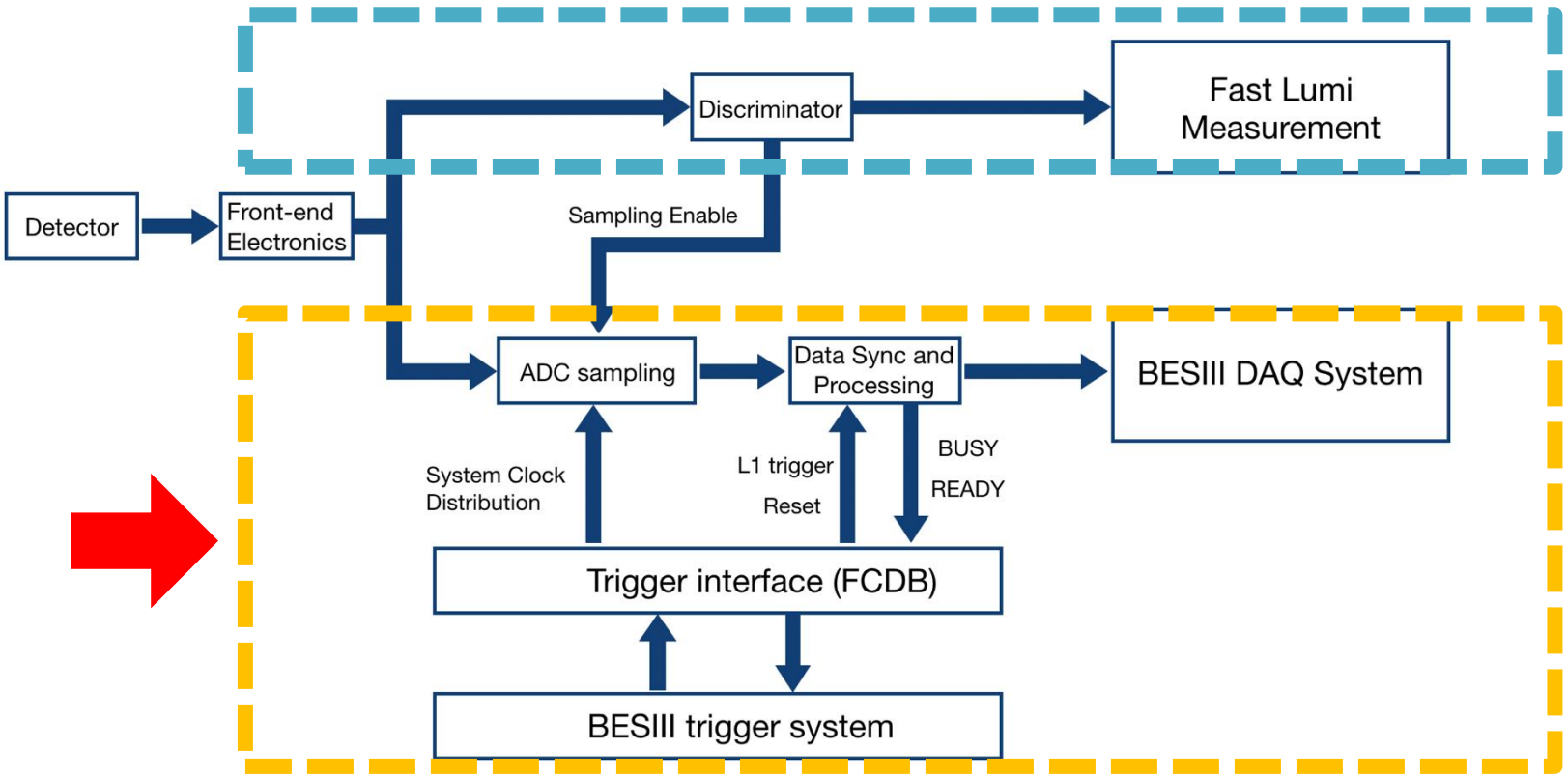


Fast luminosity control software

- Control software
  - Count readout, count-rate monitoring, slow control of detector by SPI

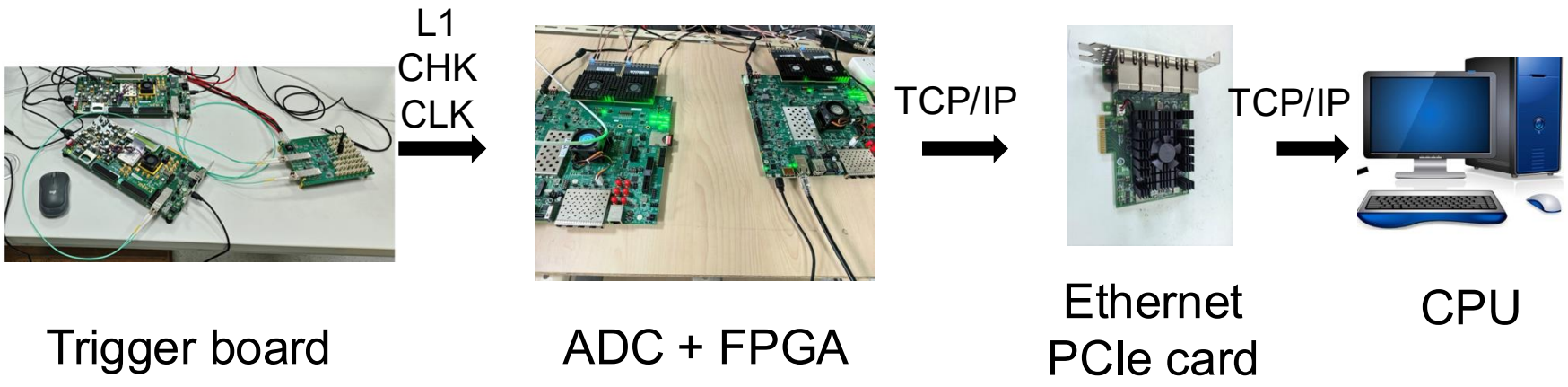


Electronics for ISR photon tagging



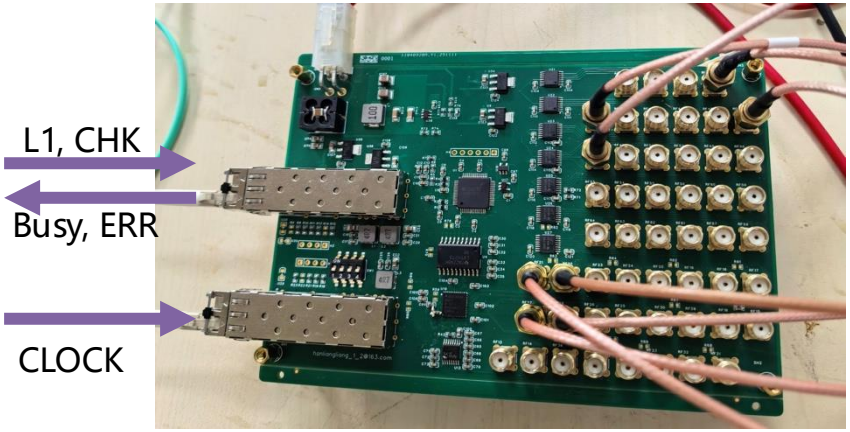
Readout integration and synchronization

- Full readout chain passed all tests
  - Sampling, event building, buffering and network transfer
  - LYSO/SiPM→preamplifier→ADC→ FPGA → CPU → Ethernet
  - Events matched across boards using trigger IDs and CHK signals
  - Multiple FPGAs synchronized with stable latency
  - Stable laboratory operation with a packet loss rate $< 10^{-8}$

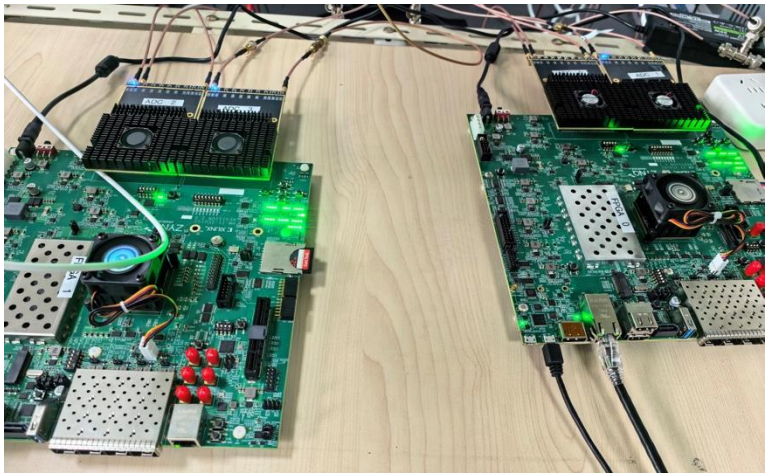


Hardware: Trigger board

- Timing Synchronization
  - Distribute BESIII CLK/L1/CHK signals to different boards
  - Enable system-wide timing synchronization of 120 channel

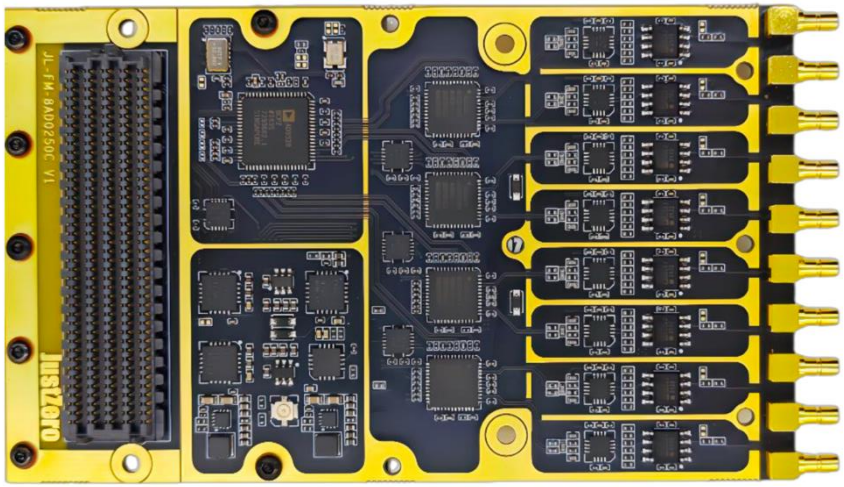


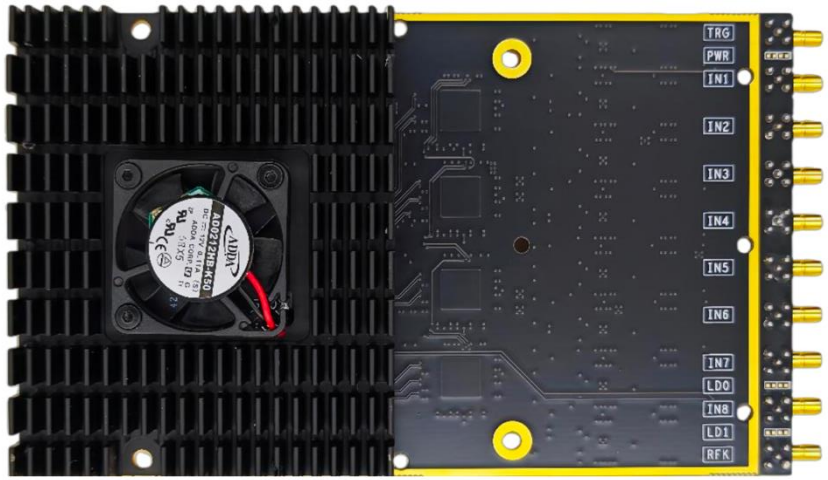
CLK/L1/CHK



ADC board status

- Front-end ADC board: 8 ch per board
  - Sampling rate: 250 MSPS, 14-bit ADC resolution;
  - Effective number of bits (ENOB): approximately 9–10
- Testing completed
  - Energy resolution: 12% FWHM/E at 1274 keV





FPGA board and cpu processor

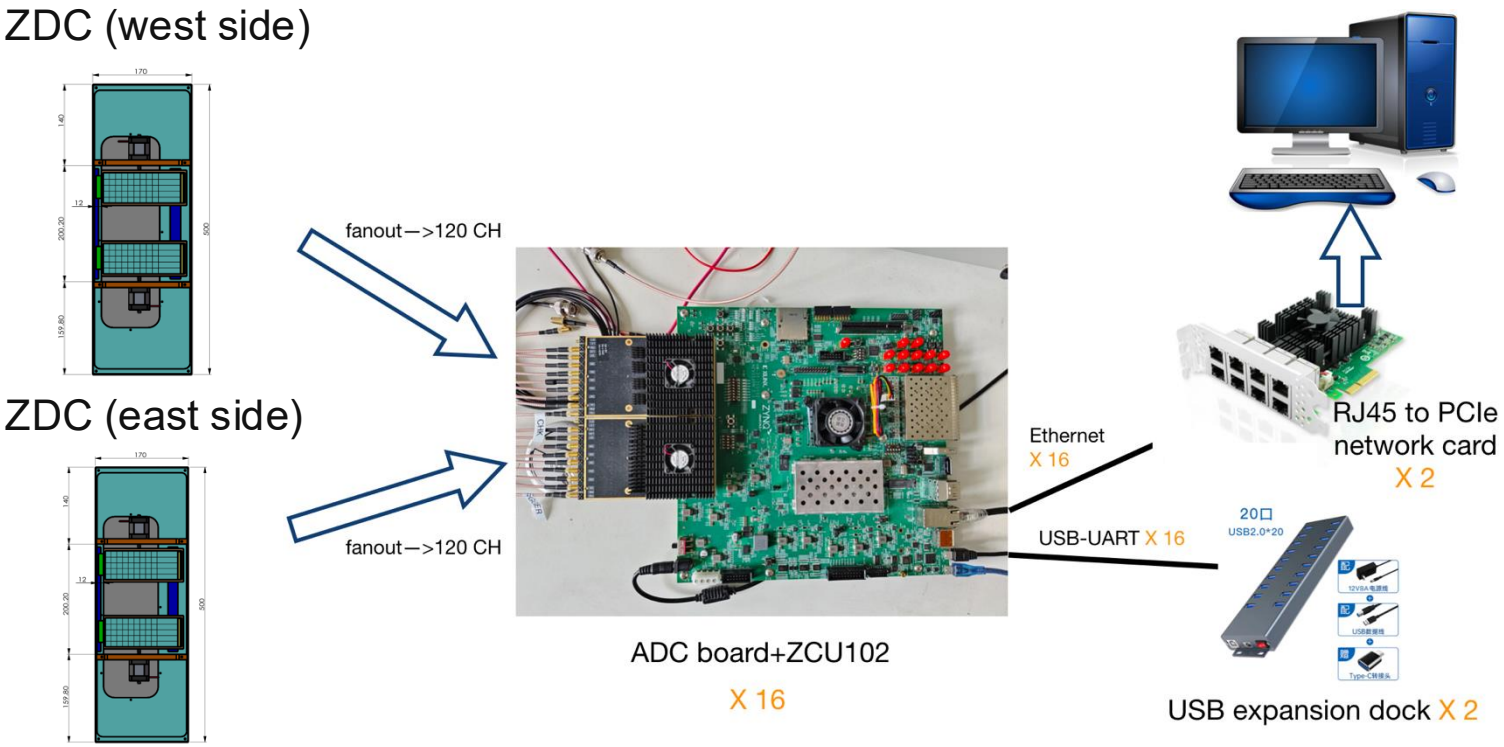
- Data Acquisition board
  - ZCU102 with AMD Zynq UltraScale+ XCZU9EG
  - Connection to 2 ADC boards of 16 ch



- One CPU processor connected to 8 FPGA (128 channel)
  - Two CPU in total to readout the whole ZDC detector

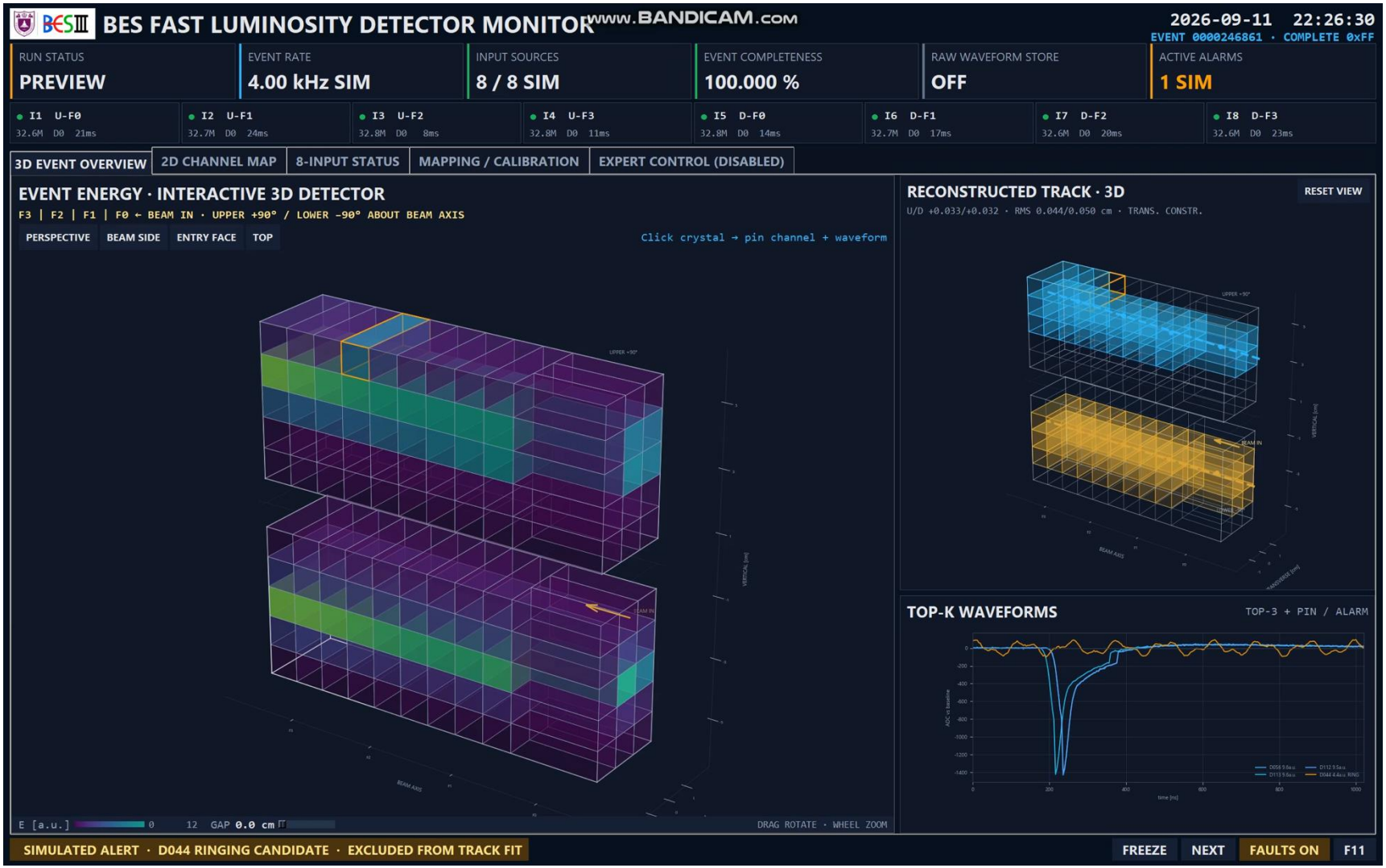
Towards full system 240 CH readout

- From 32 channels to 120 channels each side (240 in total)



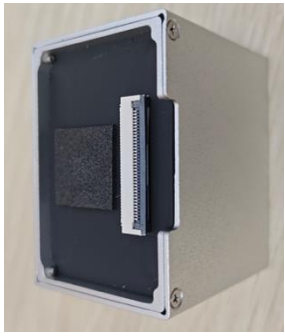
Monitoring interface and event display

- Interactive event visualization and waveform monitoring.



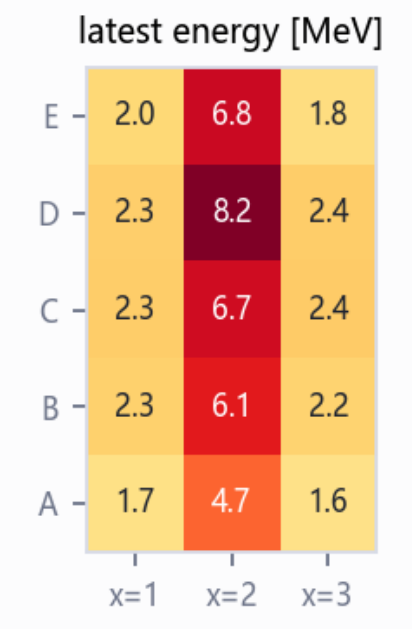
120-channel GUI demonstration using simulated data.

Cosmic-ray test of the integrated prototype

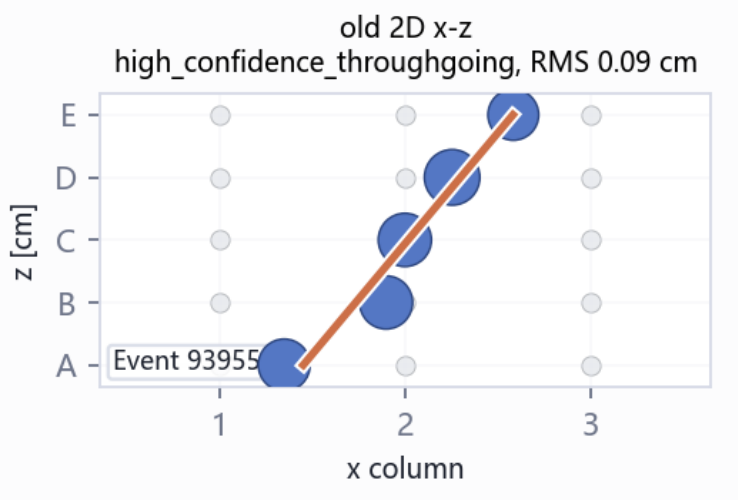


- Two FPGA boards read out 15-channel
  - LYSO+SiPM module (7 + 8 channels)
- Cosmic-ray tests the full chain
  - Online: detector module, front-end, ADC/FPGA and DAQ
  - Offline: energy rec. and track-let rec.

Energy deposits (MeV)

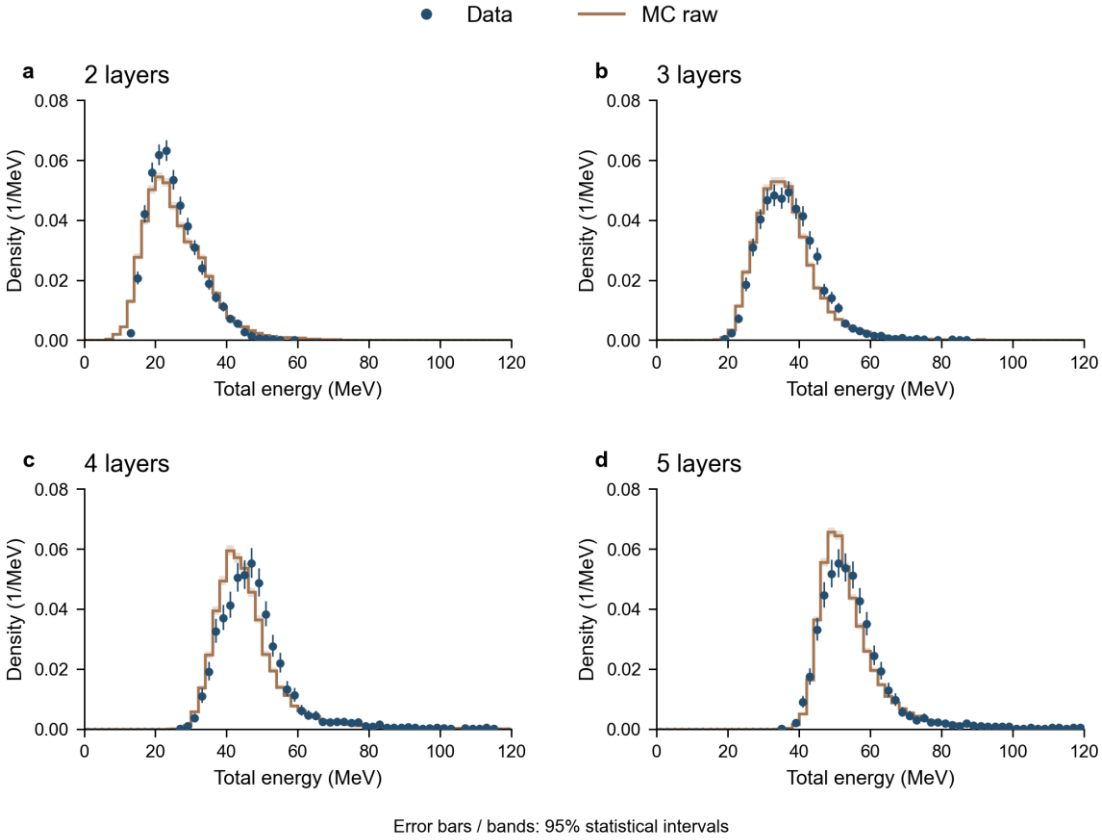


Reconstruct track-let



Data-MC comparison on MIP

- Measured cosmic-ray spectra show a good agreement with the MC simulation from GEANT4



Concrete plan

- Current status: LYSO + SiPM front-end modules delivered and under test; 32-channel ADC tests completed.
- Near-term : luminosity readout board assembled, with on-site tests at BEPC scheduled for next week.
- Next milestone: complete single-side 120-channel joint tests and integrate the readout and online processing chain.
- Full-system: expand to 240 ch., validate syn. and DAQ integration with BESIII, and full system commission

Summary

- The BESIII Zero Degree Calorimeter presented
  - R&D stage completed and installation planed in this year
- Main target: ISR photon tag and luminosity monitor
  - R&D for energy and timing measurement system
  - Fast ADC, high performance FPGA for data processing
  - Synchronization among channels, and with BESIII detector
- Expected to boost BESIII physics potential significantly
- Good platform
  - High radiation hardness detectors R&D
  - Forward physics studies

The end

BEPCII Upgrade and ZDC Motivation

Higher luminosity and shorter bunch spacing expose the limits of the aging ZDD/BLM monitors.

~3×

Luminosity at √s > 3 GeV after the 2024 BEPCII upgrade

6 ns

Bunch-collision period after the upgrade

Existing ZDD / BLM

Aging hardware and limited timing resolution cause frequent data loss and larger monitoring errors.

The current monitors support beam tuning only and cannot join the BESIII physics DAQ.

A new ZDC combines fast relative-luminosity monitoring with synchronized forward photon and electron measurements.

BESIII-ZDC team

- Nanjing University
  - Lei Zhang, Shenjian Chen, Yuhui Miao, Jiawei Wan, Yilun Wang, Guangyan Xiao, Shuxian Liu
  - Detector design, sim.&rec. software, detector unit R&D, Backend & Readout electronics, Energy measurement system, …
- IHEP
  - Xiao Cai, Fei Li, Jingzhou Zhao, Sheng Dong, Xiaohui Qian
  - Frontend electronics, Luminosity system, Trigger&DAQ global system
- Close collaborators
  - Tianjun Li (HNU), Xiaoshuai Qin (SDU), Xiaolin Kang (CUG), ……
- More collaboration are welcome!

In line with future projects in China

CEPC

- EM calorimeter: BGO+SiPM
- Hadronic calorimeter: Glass+SiPM
- LumiCal: LYSO+SiPM



STCF

- EM calorimeter: pCsI+APD
- Muon: Scint.+WLS+SiPM (one of two options)



LYSO crystal and SiPM

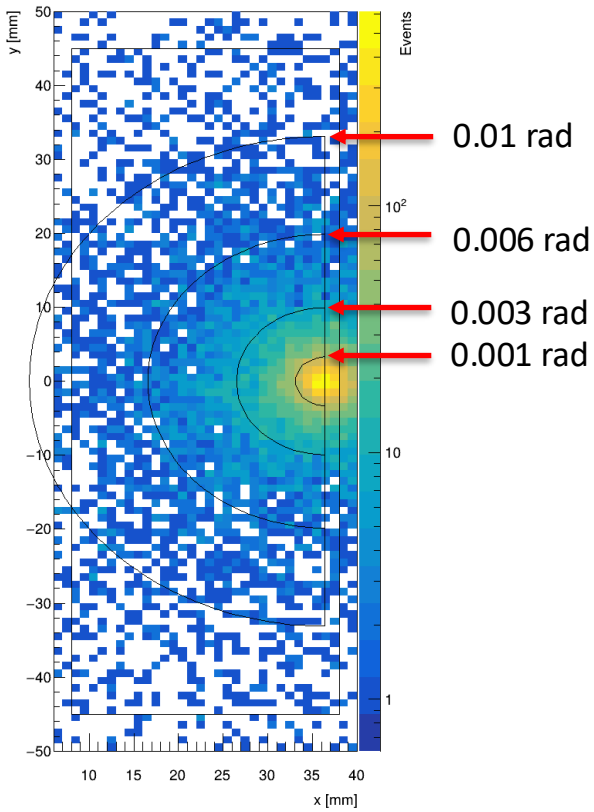
- Quality & Yield improved significantly over recent years

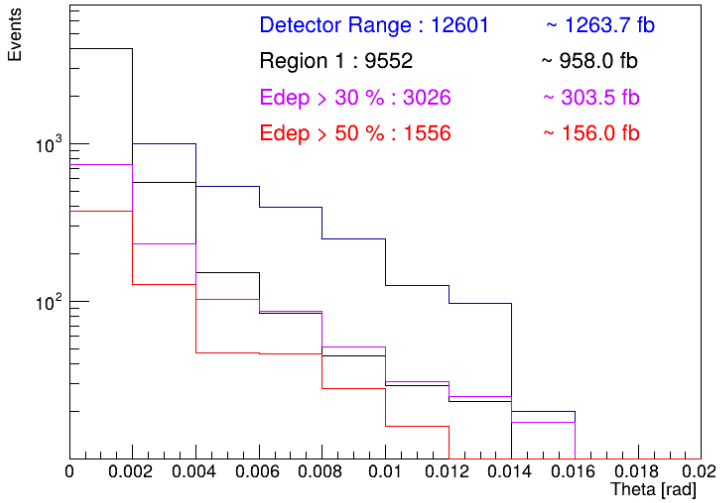
BESIII Zero Degree Calorimeter

- A great platform for the future projects R&D

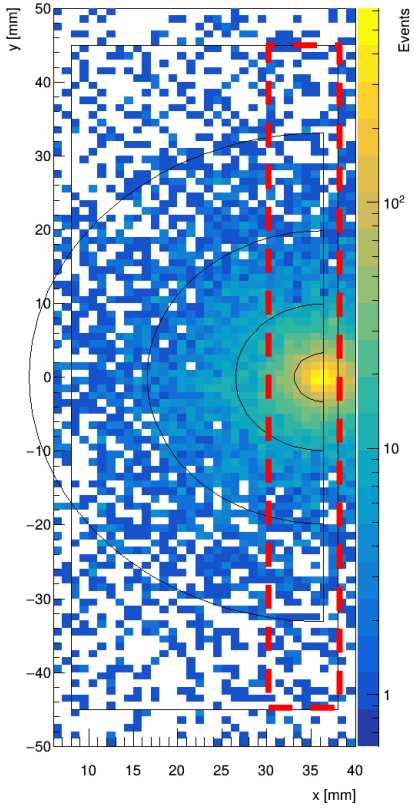
Phokhara, $e^+e^- \to \gamma_{ISR} + n\bar{n},\ \sqrt{s} = 4.68\ GeV$

$22° < \theta_n < 158°\ \ (|\cos\theta_n| > 0.93)$





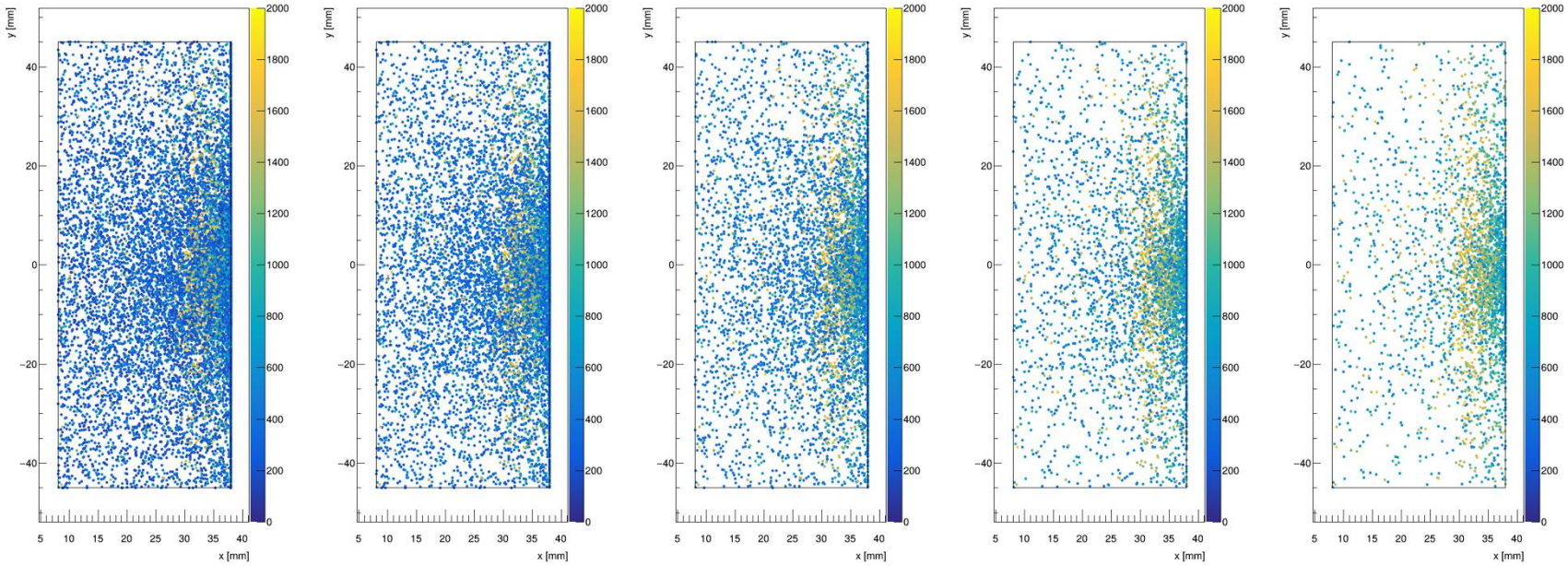
Region 1



(MC Particle Truth, not Simulation)

Phokhara, $e^+e^- \to \gamma_{ISR} + \pi^+\pi^-, \sqrt{s} = 4.68\ GeV$

Simulation

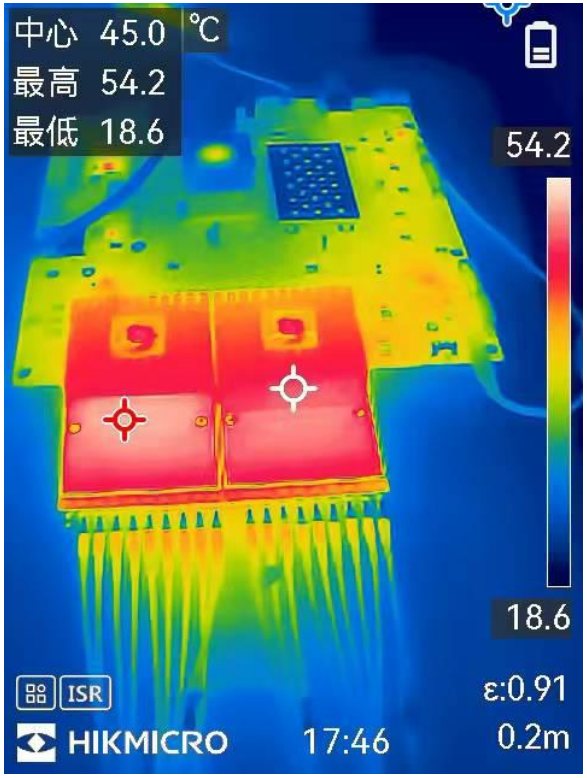


$> 100\ MeV$ $> 200\ MeV$ $> 300\ MeV$ $> 400\ MeV$ $> 500\ MeV$

Thermal performance



Hardware setup



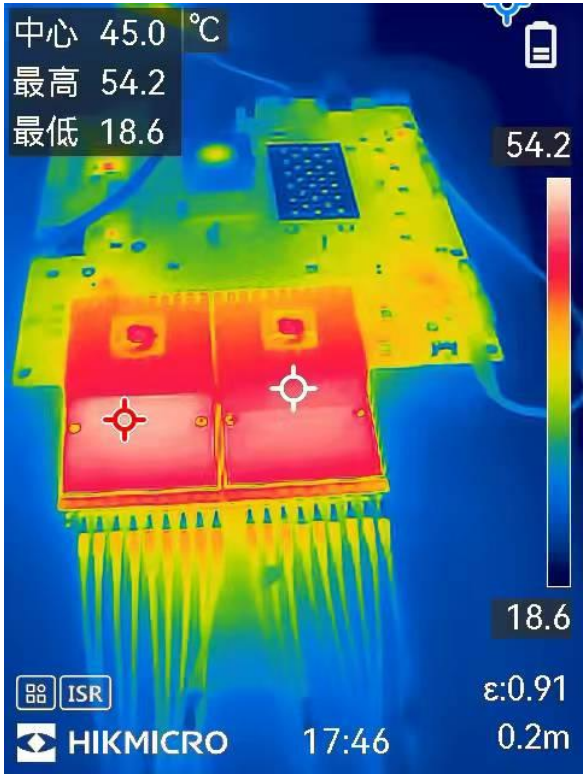
Surface temperature map

- The system remained stable during one week of continuous operation at full load, with the maximum measured surface temperature remaining below 55 °C.

Thermal performance



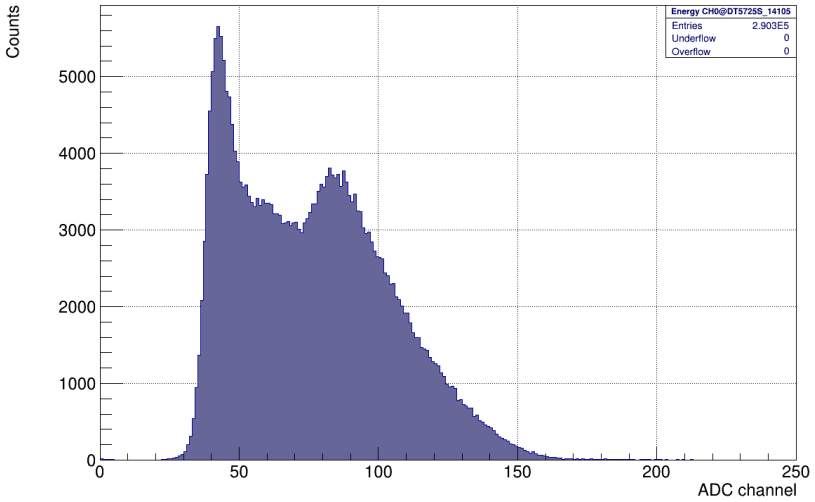
Hardware setup



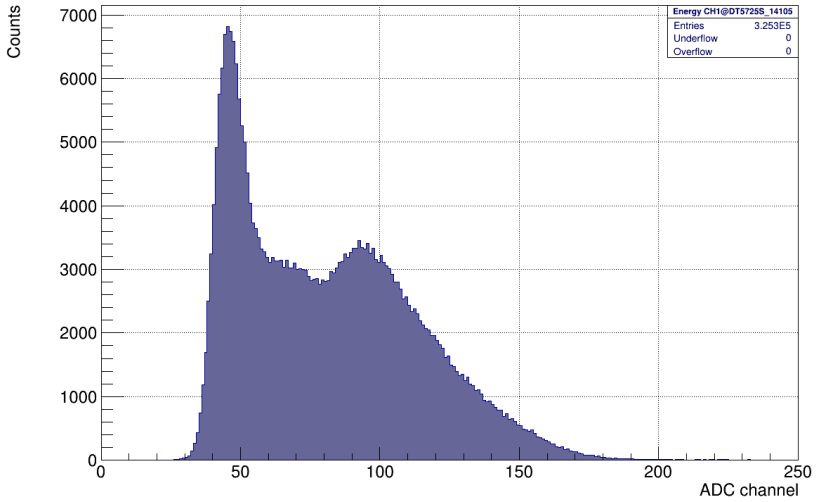
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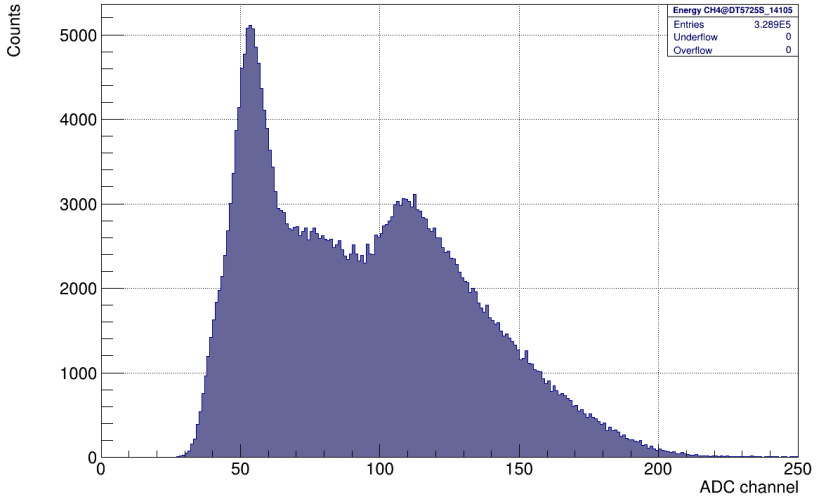
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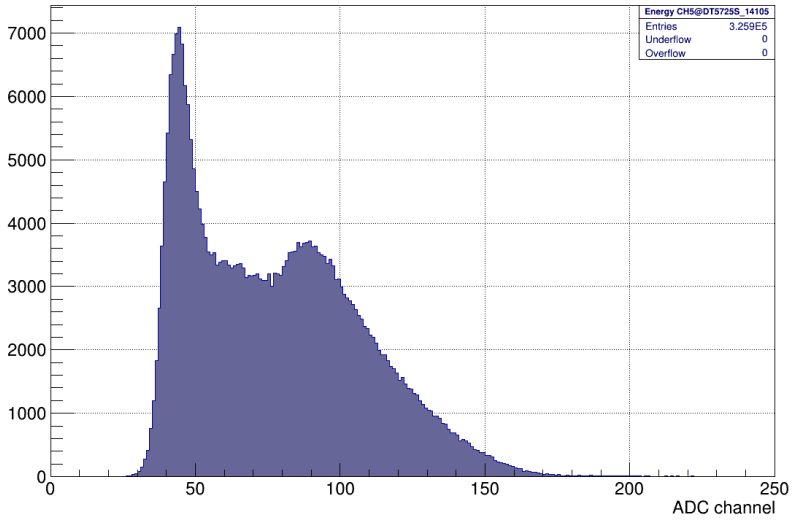
CH1



CH2

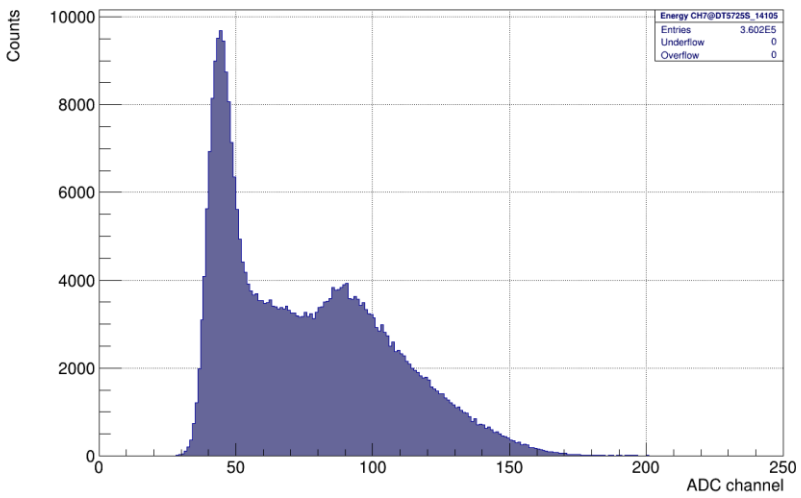


CH5

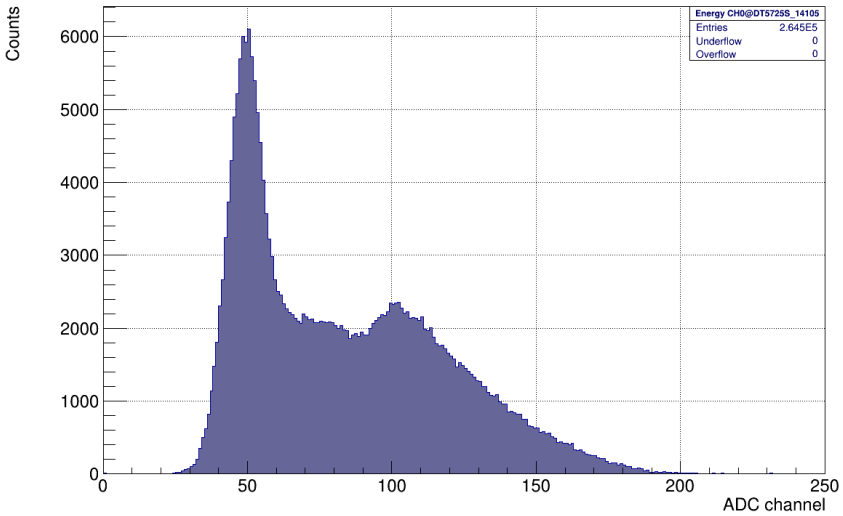


CH6

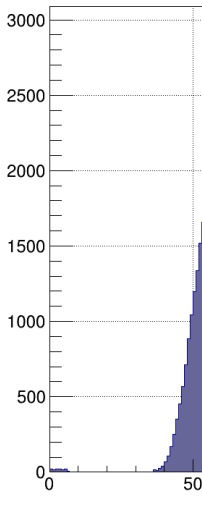
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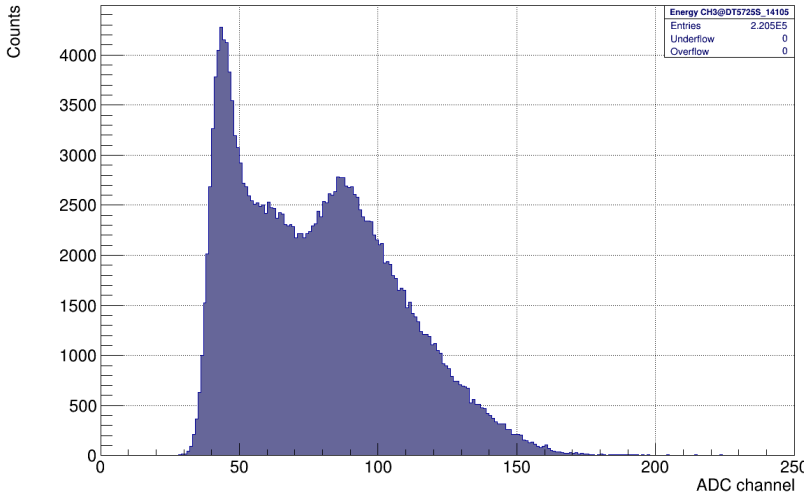


CH8

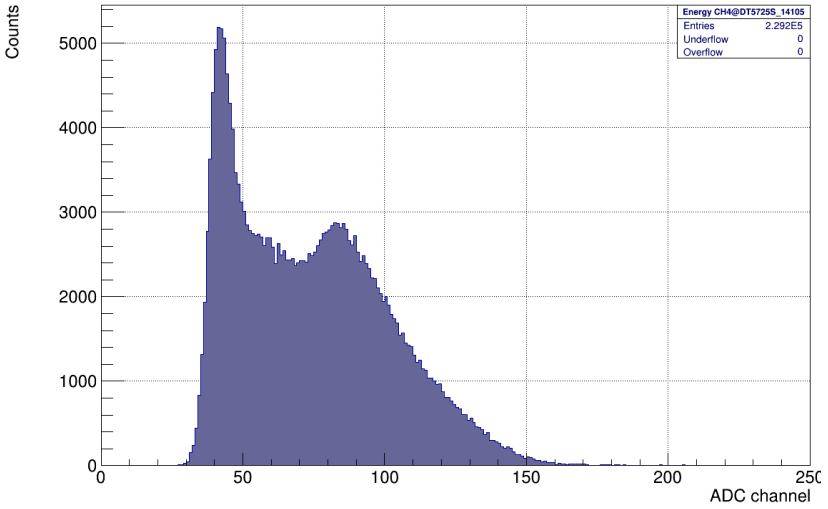


CH9

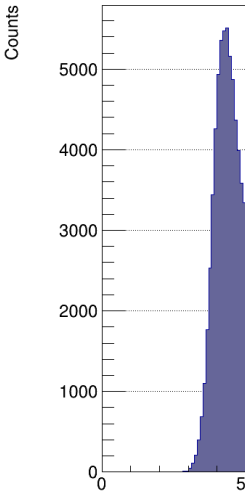




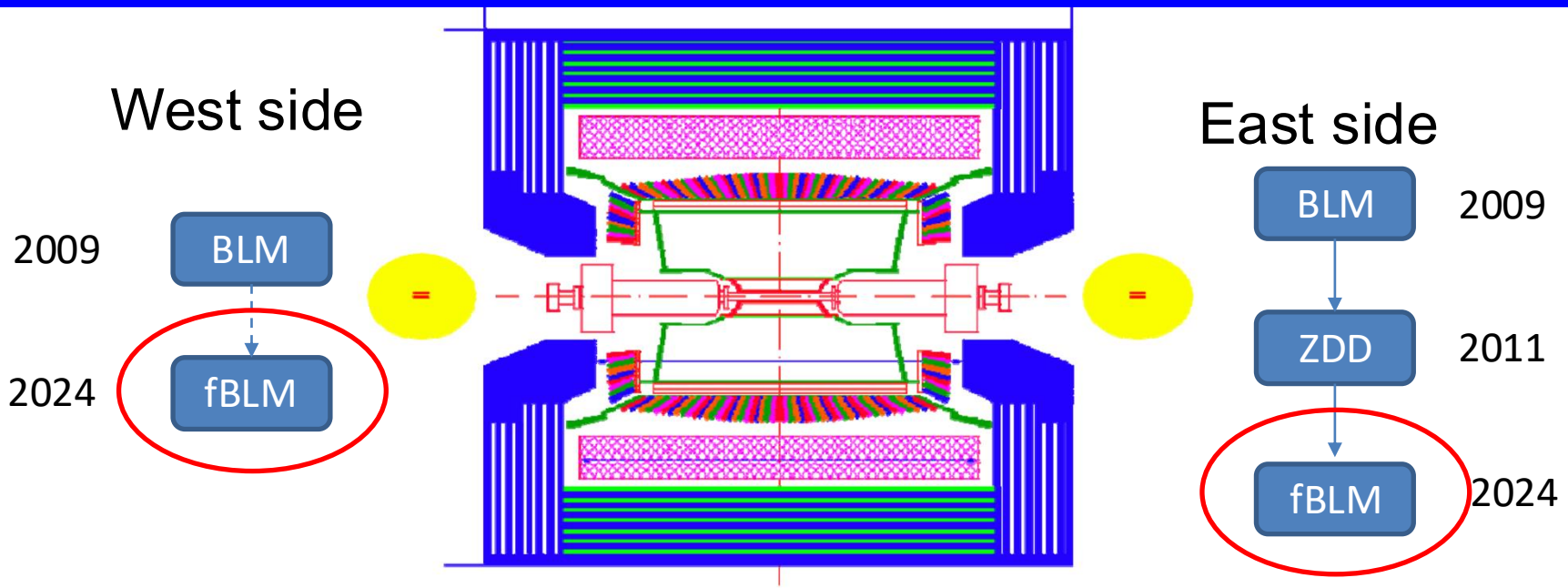
CH11



CH12

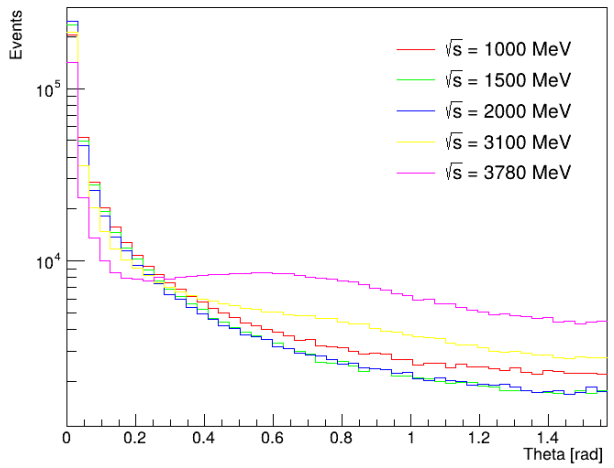


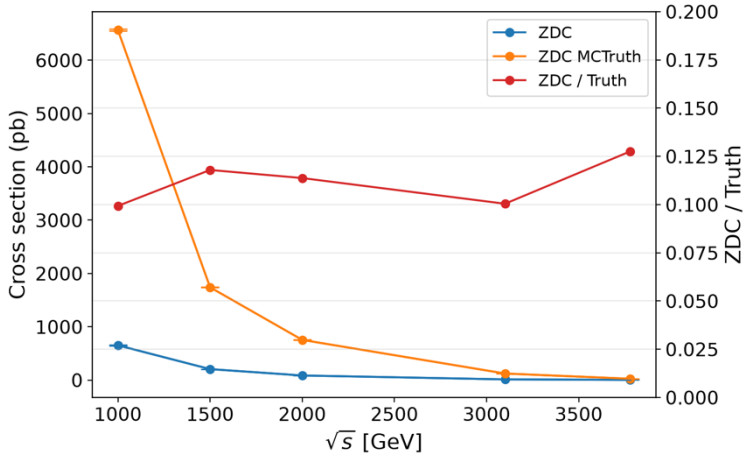
Fast Luminosity Monitor



- BLM: BEPC2 Luminosity Monitor, USTC
  - also called small angle luminosity detector
- ZDD: Zero Degree Detector, INFN
- fBLM: fast BLM, IHEP & Nanjing University
  - Upgrade to handle higher luminosity of BEPCII upgrade
  - also called ZDC, zero degree calorimeter

$\sqrt{s}$ [MeV]	σ_{ZDC}	$\sigma_{ZDC,MCTruth}$
1000	651.9 ± 5.3	6565.6 ± 17.5
1500	205.2 ± 1.44	1740.2 ± 4.2
2000	85.7 ± 0.6	753.6 ± 1.9
3100	12.3 ± 0.1	122.5 ± 0.3
3780	3.1 ± 0.1	24.3 ± 0.1





Higher CM energy makes photons more focused at zero degree, but reduces the number of photons after pions are required to be detected in the main detector