A LYSO Crystal Calorimeter for DarkSHINE Experiment

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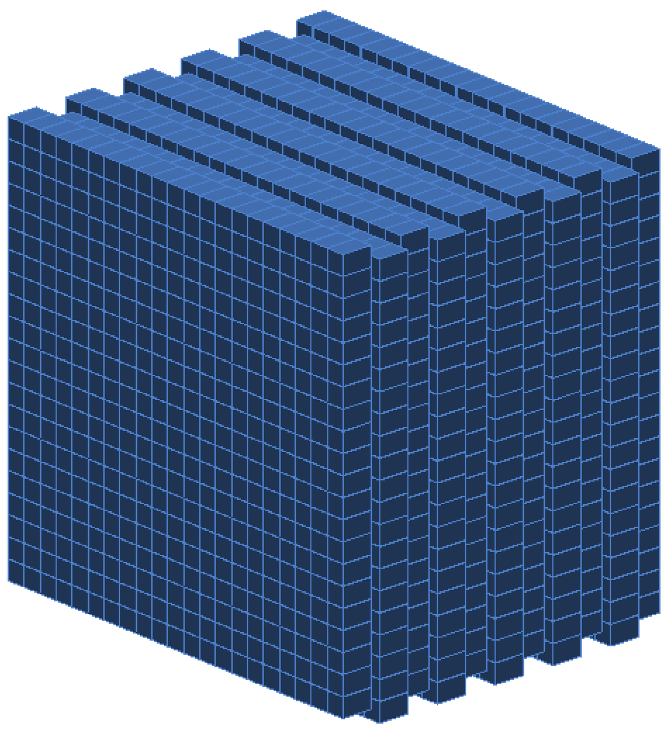
Introduction

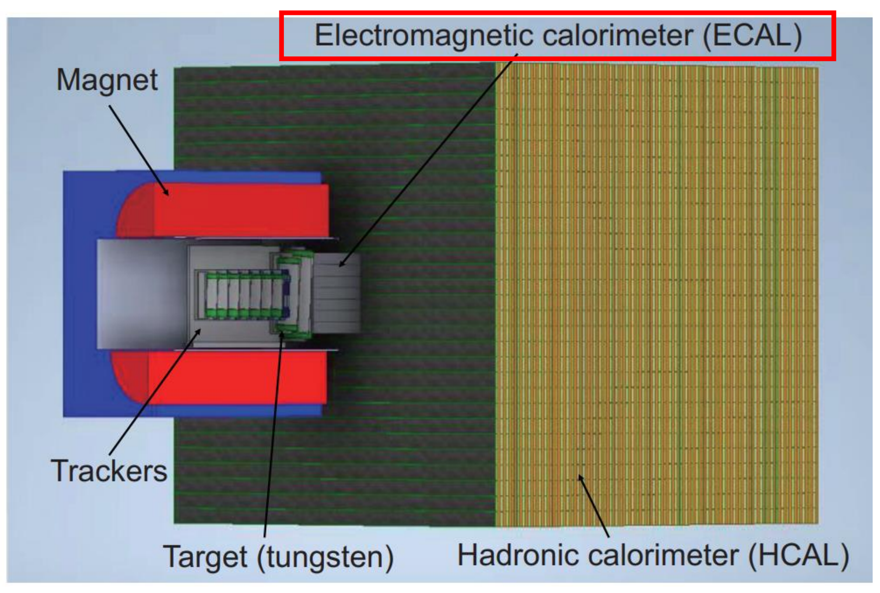
A large amount of astronomical observations has strongly indicated the existence of dark matter. New physics theories beyond the Standard Model predict candidate particles for DM, with the "Dark Photon" being a prominent candidate.

Dark SHINE is an experiment designed to detect the decay of dark photons into invisible light-mass DM particles (LDM). It relies on the Shanghai Hard X-ray Free Electron Laser (SHINE) facility, which is expected to employ an 8 GeV high-frequency single electron beam to collide with a target. By measuring the energy loss of recoiled electrons, DarkSHINE detector has excellent sensitivity for detecting dark photons with mass in MeV range.

LYSO Crystal ECAL for DarkSHINE

- Non-uniform magnetic field
- Tungsten target (0.1 X_0)
- Silicon tracker: tag and recoil
- LYSO Crystal ECAL
- Scintillator-steel HCAL





$52.5 \times 52.5 \times 44 cm^3$ volume with 4851 LYSO crystals ($2.5 \times 2.5 \times 4 cm^3$)

- Homogenous ECAL, 3D segmentation
- Staggered structure to prevent leakage
- 3×10^{14} events/year at 10MHz

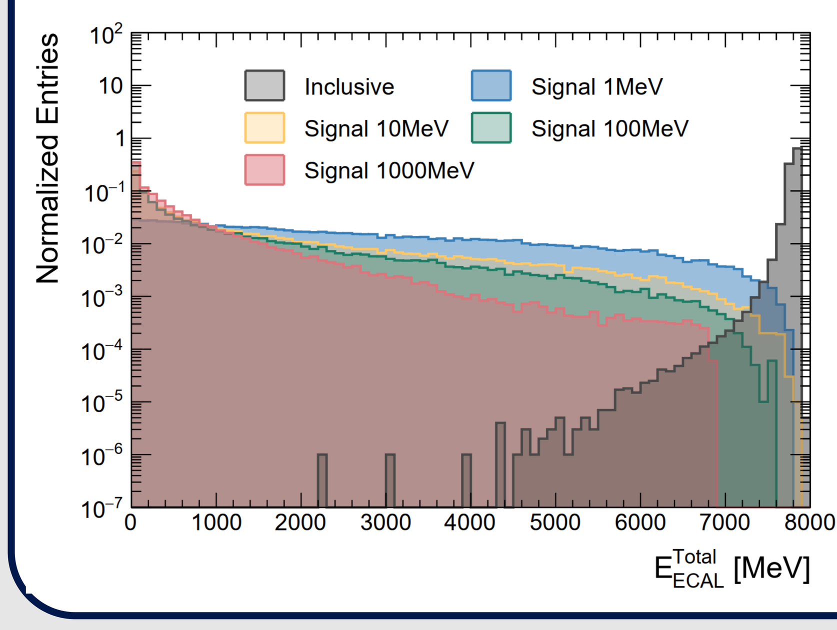
Key requirements

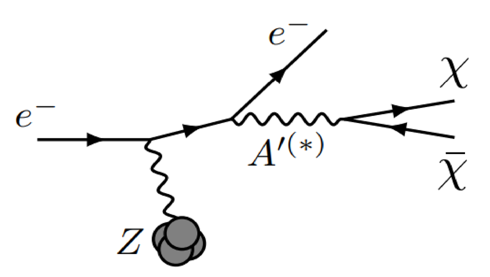
- ☐ Radiation hardness
- ☐ Large volume
- ☐ Fast response

Signal and Background

Inclusive	Bremsstrahlung	Electron-Nuclear	Photon-nuclear	Photon-to-muons
1.0	6.7×10^{-2}	3.76×10^{-6}	2.32×10^{-4}	1.64×10^{-6}

(ECAL rejection: Bremsstrahlung; Tracker and HCAL rejection: Electron-Nuclear, Photon-nuclear, Photon-to-muons)





Dark photon invisible decay

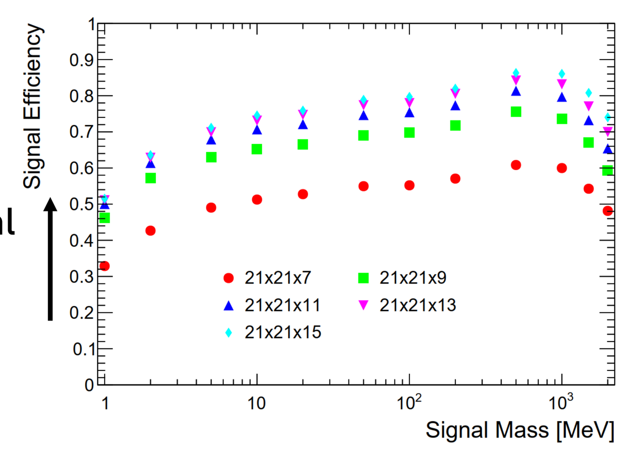
Dark photons have significant energy loss in ECAL, compared with inclusive process

Geometry Optimization

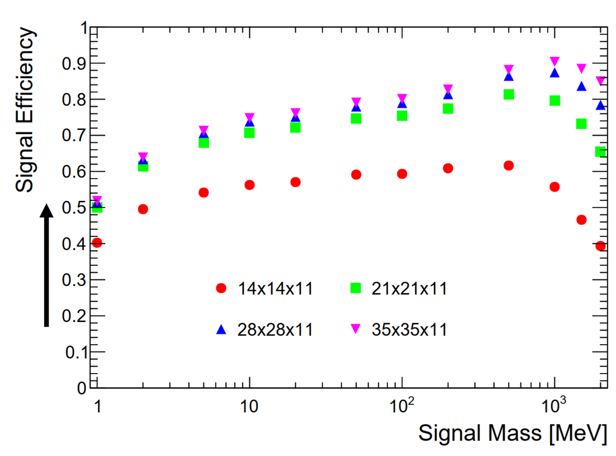
Volume optimization

The ECAL's overall dimensions of $52.5 \times 52.5 \times 44 cm^3$ were selected to provide a substantial signal efficiency while considering constructed costs.

Longitudinal size increases

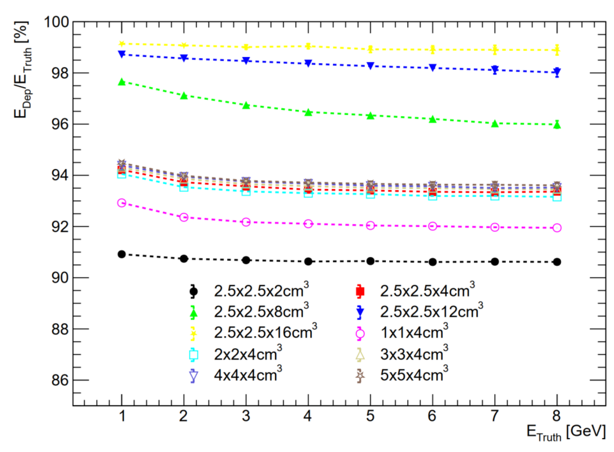


Transverse size increases

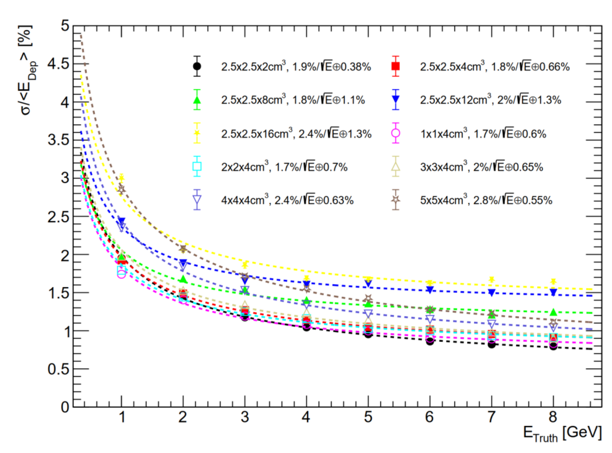


Segmentation optimization

The chosen crystal size of $2.5 \times 2.5 \times 4 cm^3$ emerged from the analysis of energy containment and resolution for 1~8GeV electrons.



Passive material increases

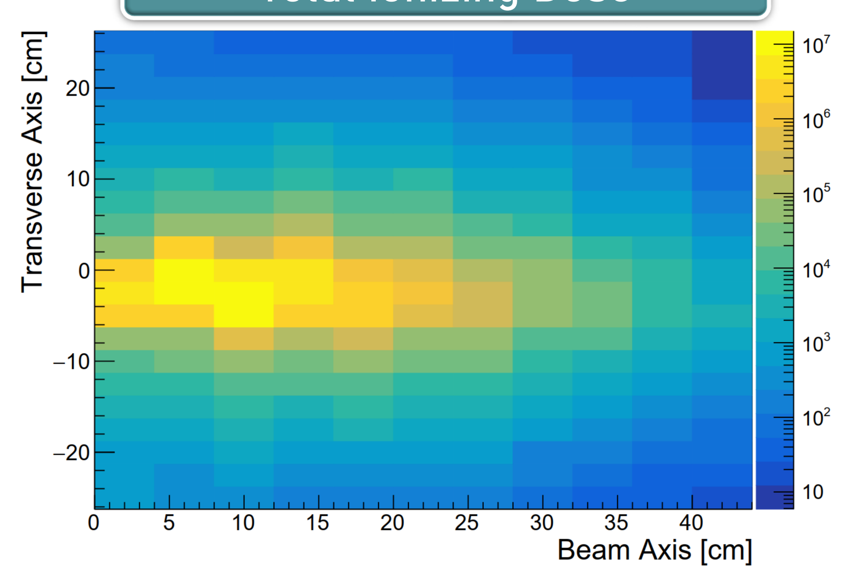


$< 2\%/\sqrt{E}$ EM resolution is possible

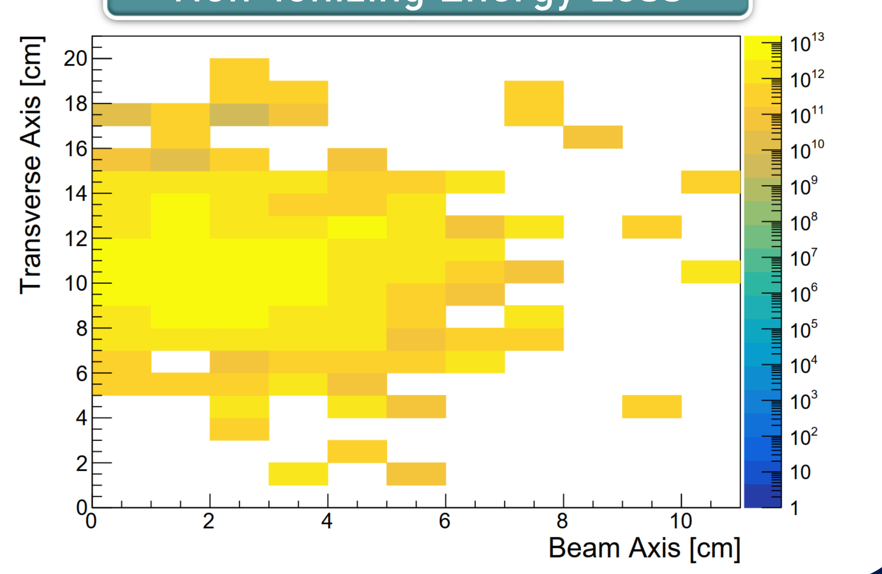
Radiation Damage

- Radiation damage from 3×10^{14} electron-on target events was estimated
- Ionizing energy loss in the most irradiated crystal: ~10^7 **rad**
- Non-ionizing energy lose in the most irradiated silicon : ~10^{13} n_{eq}

Total Ionizing Dose

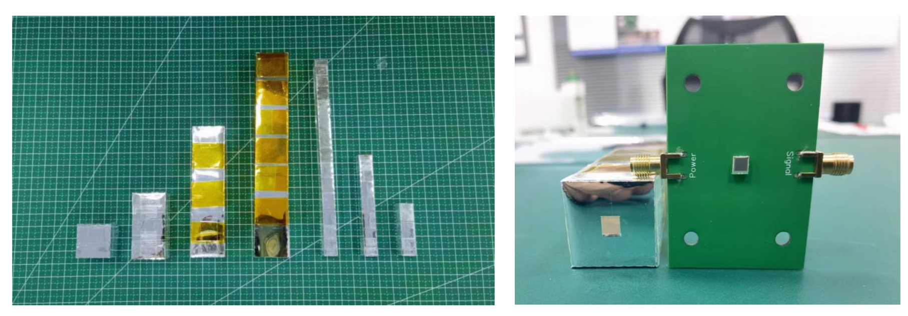


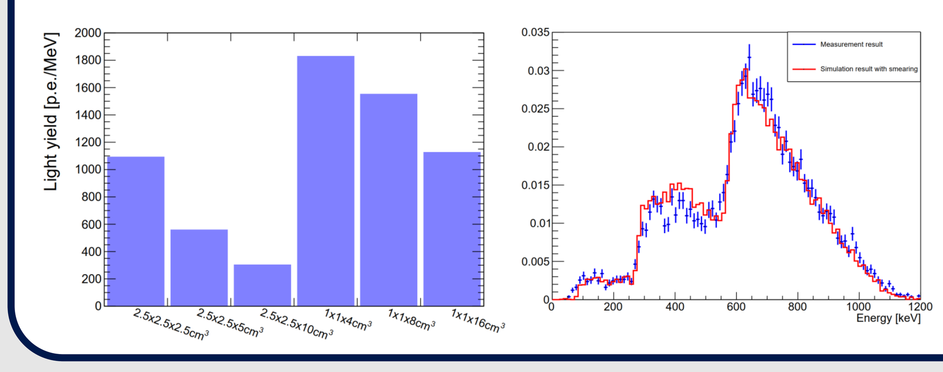
Non-Ionizing Energy Loss



Unit test

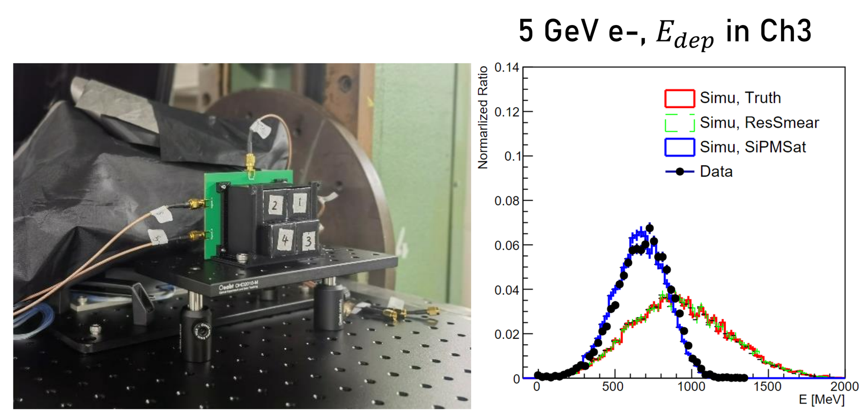
- LYSO covered by ESR, coupled with SiPM





- DESY beam test, Oct. 2023
- 1-5 GeV single electrons
- SiPMs show obvious saturation especially at 5GeV

5 GeV e-, E_{dep} in Ch3



Prototype R&D

LYSO module

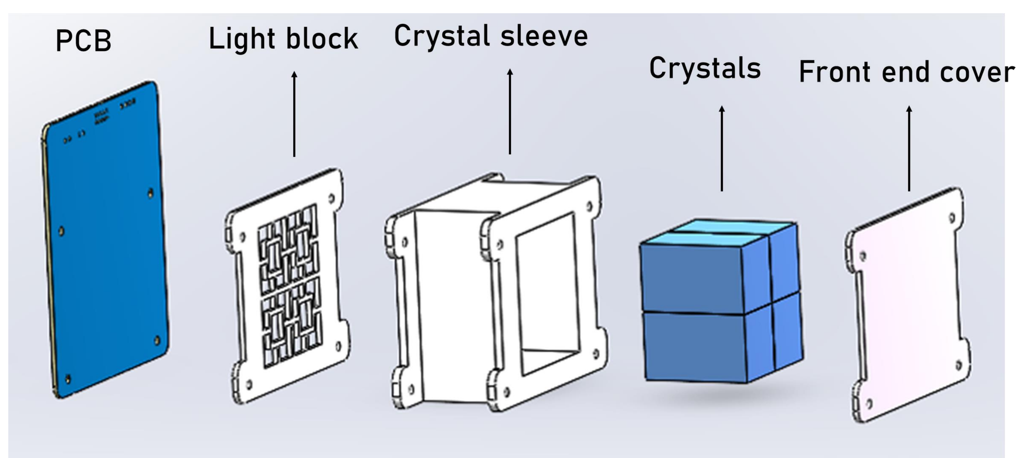
- ☐ $2.5 \times 2.5 \times 4 cm^3$
- ☐ 4-9 ch per layer

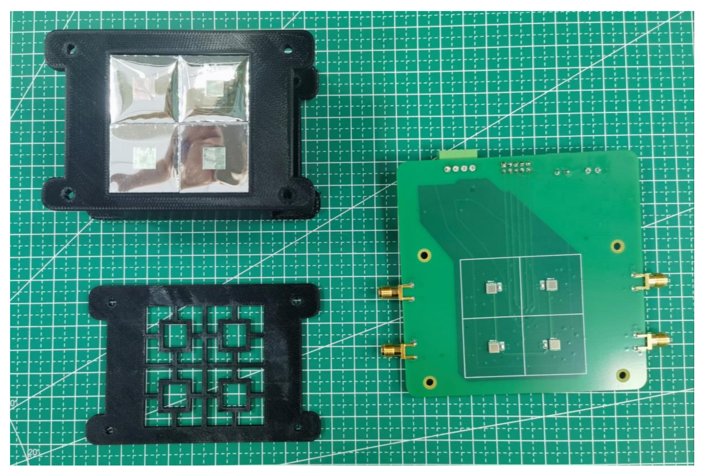
FEE board

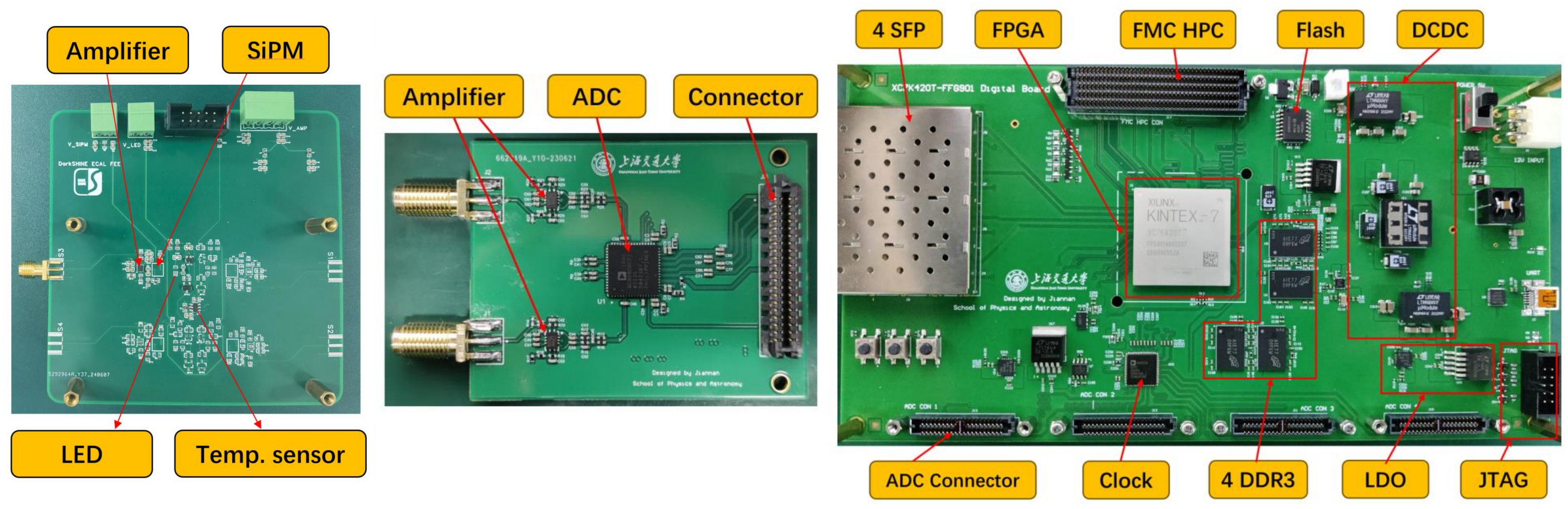
- ☐ SiPM signal amplifying
- ☐ LED calibration
- ☐ Temp. monitoring

DAQ

- ☐ 14bit ADC, 1GS/s
- ☐ FPGA: Kintex-7
- ☐ Amplifier







Summary

- The LYSO crystal ECAL is designed for detecting dark photons. The study involved comprehensive simulations and evaluations to identify an optimal ECAL configuration. The energy distribution and radiation damage was also investigated. Extensive work has been conducted on the detector prototype, with the performance of individual crystal units and multi-channel readout electronics being studied.

The 10th China LHC Physics Conference (CLHCP2024)