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Lead Tungstate Electromagnetic Calorimeter Prototype Built in AANL for EIC

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Abstract. We present design and characteristics of prototype of electromagnetic calorimeter (EmCal) for the Electron-Ion Collider (EIC) which was designed and built in A.I. Alikhanyan National Science Laboratory (AANL). Electromagnetic Calorimeter (EmCal) based on lead tungstate ($PbWO_4$) crystals is proposed to be a key element of particle identification system of EIC. A prototype of EmCal was designed, constructed and tested with cosmic muons. It consists of 16 $PbWO_4$ crystals arranged in a 4×4 matrix. The results confirm conclusions of other groups in the EIC collaboration that the quality of crystals produced by CRYTUR meets requirements for EmCal of EIC.

1 Introduction

The Electron-Ion Collider (EIC) is a particle accelerator designed to study the quark-gluon structure of protons and nuclei, to clarify the origin of nucleon spin and mass, as well as to investigate physical phenomena related to dense gluon systems [1]. Through collisions of polarized electrons with protons, deutrons and ions at EIC, scientists aim to uncover the structure of proton spin, origin of nucleon mass, and many unsolved problems of physics beyond the Standard Model.

To implement such a physics program, the EIC will provide an intense beam of 18 GeV electrons colliding with protons (41–275 GeV) and nuclei (up to 166 GeV/nucleon) at luminosities of the order of 10^{34} $cm^{-2}sec^{-1}$. The EIC detector system must provide (e/π) and (K/π) separation up to a momentum value of 60 GeV/c.

The Electron-Ion Collider (EIC) is a unique collider with diverse physics topics that impose special requirements on the detector design. A detailed description of the particle detection and identification systems of the EIC's main detector ePIC is presented in Ref. [2–5].

Selection of constructive elements, design and optimization of the Electromagnetic Calorimeter (EmCal) for ePIC require additional research. To this end, many members of the ePIC collaboration create EmCal prototypes, conduct independent tests, and compare results.

It is especially important to study characteristics of EmCal crystals with prototypes, which is the main goal of the work carried out at the AANL. A typical electromagnetic calorimeter is a transparent, homogeneous radiator of crystals large enough to completely contain a shower of secondary particles. In experiments over the past ten years, the preferred material has been the inorganic scintillator lead tungstate, which is characterized by a small Moliere radius (R_M = 2.0 cm), high density ($\rho \simeq 8.3\ g/cm^3$), fast response (< 2 ns) and radiation resistance.

The highest resolution in electromagnetic calorimeters can be provided by homogeneous materials, e.g., lead tungstate (PWO) crystals. The EmCal design is based on a series of approximately 3000 $PbWO_4$ crystals 2.0×2.0×20 cm^3 in size.

2 Construction and test of the prototype

Several electromagnetic calorimeter prototypes for EIC have been constructed and tested by the ePIC collaboration. We designed and built our prototype to conduct independent research into key aspects of the EIC calorimetry.

Currently, the only two companies in the world with mass-production capabilities for $PbWO_4$ crystals are SICCAS in China and CRYTUR in the Czech Republic. CRYTUR and SICCAS produced about 1000 crystals each for Jefferson Laboratory. The characteristics of these crystals are given in [6].

A small batch of crystals, with nominal dimensions of 20.5×20.5×200 mm^3, produced by CRYTUR was provided to AANL for research on their quality and the construction and testing of a prototype of electromagnetic calorimeter.

Longitudinal (Z) and transverse (X, Y) dimensions, the transverse transmittance of the light in the range of wavelength λ=200-1000 nm, and Light yield (LY) of crystals were measured [7]. Based on the results of these studies, we selected the best 16 $PbWO_4$ crystals to build the EmCal prototype.

The crystals in the prototype are arranged in a 4×4 matrix. The modules are held in support frames made of plastic by means of 3D printing technology. Thus, a compact, small calorimeter was obtained, with minimal gaps between the crystals (< 250 μm).

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The side surfaces of the crystals are wrapped with one layer of high quality ESR reflective film and one layer of black light-isolating Tedlar paper. The back face of each crystal is optically coupled with R4125 photomultiplier tube (PMT) using optical grease, while the front face is to be used for the LED light monitoring system.

The PMTs are wrapped with electrical insulation paper and a sheet of μ-metal magnetic shielding. The 16 PMT assemblies are positioned in 19.5 mm diameter holes in a single piece iron holder, such that they can be easily slid and pressed against crystal.

Signal and high-voltage cables, as well as electronics and DAQ system for prototype tests were prepared. The whole assembly of crystals with photomultipliers and high-voltage dividers is placed in a dark, light-insulated metal box. On the rear end wall of the box, there are connectors for high-voltage power supply and output signals. A picture of the assembled EmCal prototype and circuit diagram of the electronics and data acquisition system used in cosmic ray studies are shown in Fig. 2.

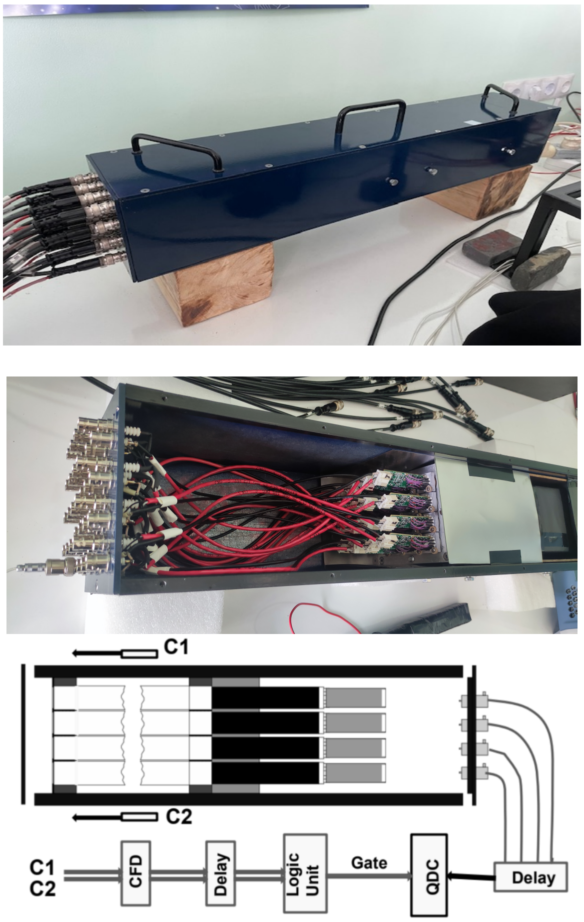

Figure 1. (Top and middle) Picture of assembled EmCal prototype. (Bottom) Circuit diagram of the electronics and data acquisition system used in cosmic ray research. C1 and C2 – trigger scintillation counters, CFD – discriminator, Logic Unit – coincidence module, Gate – Gate signal, QDC –charge-to-digital converter, Delay – delay line.

Prior assembly of the prototype, the PMTs were calibrated by shining low intensity blue LED light on the surface of photocathodes and identifying single photoelectron peak positions in the ADC signal spectra.

The prototype was tested with cosmic muons. Muons, passing through all four layers of the calorimeter, lose a total energy of ∼100 MeV (∼25 MeV in each block). As a result, they generate ∼700-800 photoelectrons, which is ∼7-8 pe/MeV. Taken into account partial coverage of the end surface of the crystal with the PMT R4125 photocathode of ∼50%, this number is in good agreement with 16 pe/MeV light output of $PbWO_4$ reported in [6].

In Fig. 2 is shown the distribution of summed signal from four modules of a prototype column generated by cosmic muons. In these measurements the trigger scintillators, 2.5 cm wide, were located in the middle of the crystals. However, due to high transparency of the crystals, no strong coordinate dependence of signals was expected. This was confirmed by MC simulations for one module, presented in Fig. 3. The expected signal variation with coordinate is ±2.5% at most.

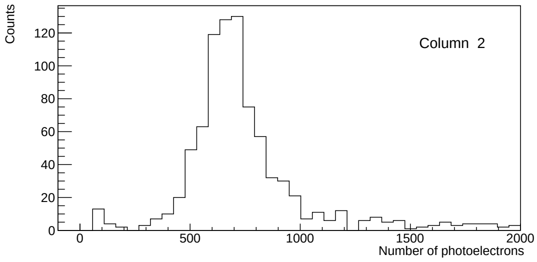

Figure 2. Distributions of the total number of photoelectrons produced by cosmic muons in column 2 of the prototype.

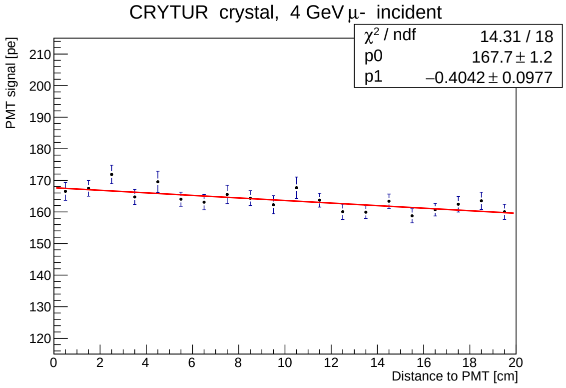

Figure 3. Geant 4 simulation of single module of the prototype. Shown is PMT signal (dots) versus distance from incident 4 GeV muon to the PMT. The line is linear fit to simulated data.

3 Conclusion

An EmCal prototype was created from 16 $PbWO_4$ crystals arranged in a 4×4 matrix. The prototype was tested by cosmic muons. Muons, passing through all four layers of the calorimeter, lose a total energy of ∼100 MeV (∼25

MeV in each block). As a result, they generate ~700-800 photoelectrons, which is ~7-8 pe/MeV. This value is is in good agreement with light output of $PbWO_4$ of 16 pe/MeV from [6], when partial coverage of the end surface of the crystal with the PMT R4125 photocathode ~50% is taken into account.

For the final selection of the calorimeter design, it is important to compare and jointly review the research results of various EmCal groups of the ePIC collaboration and develop common requirements for the characteristics of crystals and the calorimeter design. From this point of view, the data obtained by AANL are an integral part of the basic data and are of general interest.

Our results confirm the conclusions of other ePIC collaboration groups that the quality of crystals produced by CRYTUR meets all the requirements for an electromagnetic calorimeter and can be the basis for the creation of EmCal [5].

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References

[1] R. Abdul Khalek, A. Accardi, J. Adam, D. Adamiak, W. Akers, M. Albaladejo et al., Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report, Nucl. Phys. **A 1026**, 122447 (2022), https://doi.org/10.1016/j.nuclphysa.2022.122447.

[2] Adam, J., Adamczyk, L., Agrawal, N., Aidala, C., Akers, W., et al., ATHENA detector proposal — a totally hermetic electron nucleus apparatus proposed for IP6 at the Electron-Ion Collider, JINST **17**, P10019 (2022), https://doi.org/10.1088/1748-0221/17/10/p10019.

[3] Adkins, J.K., Akiba, Y., Albataineh, A., Amaryan, M., Arsene, I.C., et al., Design of the ECCE Detector for the Electron Ion Collider, e-Print: 2209.02580 [physics.ins-det].

[4] Alarcon, R., Baker, M., Baturin, V., Brindza, P., Bueltmann, S., et al. , CORE – a COmpact detectoR for the EIC, e-Print: 2209.00496 [physics.ins-det].

[5] Bock, F., Schmidt, N., Wang, P.K., Santiesteban, N., Horn, T., et al., Design and simulated performance of calorimetry systems for the ECCE detector at the electron ion collider, Nucl. Instrum. and Methods **A 1013**, 165683 (2021), https://doi.org/10.1016/j.nima.2023.168464.

[6] Horn, T., Berdnikov, V.V., Ali, S., Asaturyan, A., Carmignotto, M., et al., Scintillating crystals for the Neutral Particle Spectrometer in Hall C at JLab, Nucl. Instrum. and Methods **A** 956, 163375 (2020), vol. 956, https://doi.org/10.1016/j.nima.2019.163375.

[7] Mkrtchyan, H., Marukyan, H., Mkrtchyan, A. et al. A Prototype of Electromagnetic Calorimeter Constructed of Lead Tungstate. J. Contemp. Phys. 59, 11–16 (2024). https://doi.org/10.1134/S1068337224700026