A Prototype of Lead Tungstate Electromagnetic Calorimeter Built in AANL for EIC Collider

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Abstract

The Electron-Ion Collider (EIC), which is being built at Brookhaven National Laboratory in the US, will be a unique particle accelerator where electrons will collide with protons or nuclei to scan the internal structure of nucleons. Electromagnetic Calorimeter (EmCal) based on lead tungstate ($PbWO_4$) crystals is proposed to be a key element of particle identification system of EIC.

A quality assurance of crystals produced by CRYTUR, the light yield and transmission of crystals have been measured at A.I. Alikhanyan National Scientific Laboratory (AANL). Measurements showed that the crystals have an average light output of ~16 pe/MeV, and that within the error, the light output of a crystal at two different points located at a distance of ~14 cm from each other is almost the same (within 3 – 5 %). 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 obtained are compared with the results of other groups of the EIC EmCal collaboration. Selection of final design of the EIC calorimeter and requirements to the characteristics of crystals will be based on combined analysis of the results from different groups of collaboration. From this point of view, the results of AANL as an independent data, are very important and interesting. We are planning to continue these studies, as well as radiation hardness and low energy resolution of EmCal using electron beam with energy of 10 - 75 MeV from the linear accelerator LINAC-75 and proton beam with energy of 18 MeV from the C18/18 cyclotron, both at AANL.

Introduction

The physics program of the Electron-Ion Collider (EIC [1]), construction of which is planned at the Brookhaven National Laboratory, includes the most important and key questions that experimental communities of the world need answers to: the origin of spin of nucleon, the gluon structure of nuclei, the origin of hadronic mass, etc. 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.

A detailed description of the particle identification (PID), trajectory reconstruction, electromagnetic and hadron calorimetry systems of the EIC's main detector, called the Electron-Proton/Ion Collider (ePIC), is presented in [2–5]. Options selection, optimization, and design of the Electromagnetic Calorimeter (EmCal) for ePIC are still in the development phase and require additional research. To this end, many groups of the ePIC collaboration create prototypes, conduct independent tests, and compare results.

It is especially important to study the characteristics of EmCal crystals and prototypes, which is the main goal of the work carried out at the A.I. Alikhanyan National Science Laboratory (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 ($PbWO_4$), which is characterized by a small Molière radius (R_M = 2.0 см), high density (ρ ≈ 8.3 g/cm³), fast response (< 2 ns) and radiation resistance.

The EIC EmCal design is based on a series of approximately 3000 $PbWO_4$ crystals, 2.0 × 2.0 × 20 cm³ in size.

The AANL group has extensive experience in the field of calorimetry. It led the design and construction of electromagnetic calorimeters for the HMS and SHMS spectrometers in Experimental Hall C of the Jefferson Laboratory [5–7].

Methods

Prior to the prototype construction, 20 crystals on hand from CRYTUR were tested, and best 16 were used in the prototype assembly.

After the first visual inspection, all crystals were examined with a DeltaPix digital microscope. Dimensions of the crystals were measured with a high-precision caliper (accuracy better than 50 µm) and a Mituito Electric Digital Height Gage sensor (accuracy 3–5 µm).

The transverse light transmission of crystals was measured with a FLAME-S XR1 optical spectrometer from Ocean Insight. The measurements used the OceanART software application. Systematic errors and reproducibility of our measurements is better than 10%.

Light yield (in photoelectrons) was measured using cosmic muons as they passed through a $PbWO_4$ crystal 20.5 mm thick. The single photoelectron calibration was done by means of low intensity LED light shining on the PMT photocathode. The cosmics trigger was formed by two 10×10×50 mm³ scintillation counters placed above and below the crystal at a short distance. The trigger electronics consisted of N840 leading edge discriminator and N455 quad coincidence unit, both from CAEN. The PMT signals were digitized by CAEN V792N QDC.

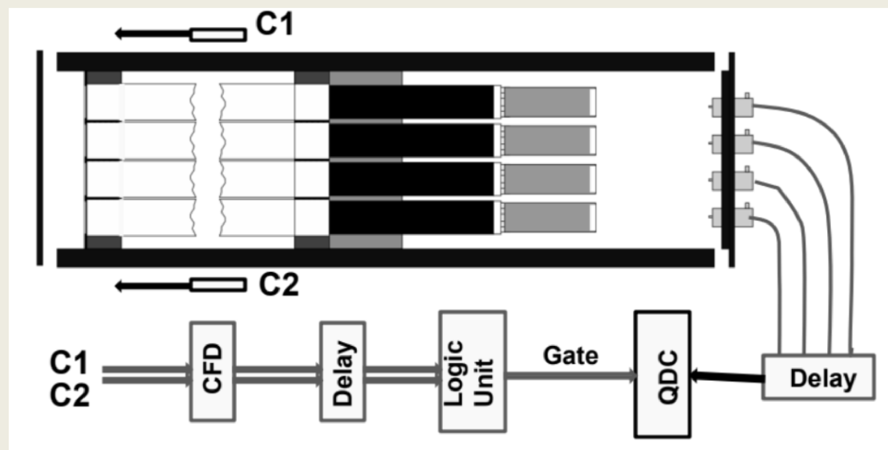
The DeltaPix digital microscope and Mituito Electric Digital Height Gage sensor used in crystall quality studies.

Construction of the prototype

The prototype consists of 16 $PbWO_4$ crystals 2.05 × 2.05 × 20 cm³ in size, arranged in a 4 × 4 matrix. The modules are held in support frames printed using 3D printing technology.

The crystals are wrapped in 65 µm ESR reflector and 30 µm Tedlar foil for light tightness. Each crystal is coupled to a Hamamatsu R4125-01 PMT using optical grease. The matrix of crystals with PMT-s and HV dividers is placed in a metal dark box. HV and signal connectors are on the rear wall of the box.

The high voltage to PMT-s is provided from CAEN SY5527LC power supply. The PMT signals are digitized by CAEN V792N QDC. The trigger for studies with cosmic rays was organized similar to the tests of individual crystals.



The light tight box holding the prototype assembly, and schematics of its construction and electronics for studies with cosmic rays.

Results

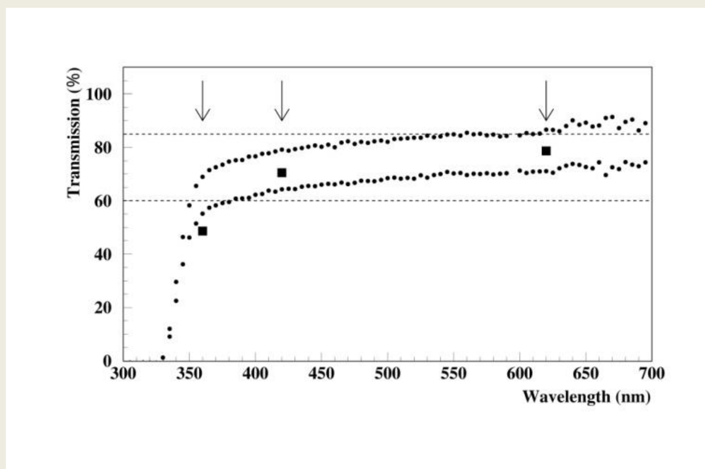
Visual inspection showed that despite some scratches, all crystals were suitable for further research and testing.

The average crystal dimensions are 20.47 × 20.48 × 200.13 mm³, which corresponds to the nominal requirements, and the divergences do not exceed ±50 µm.

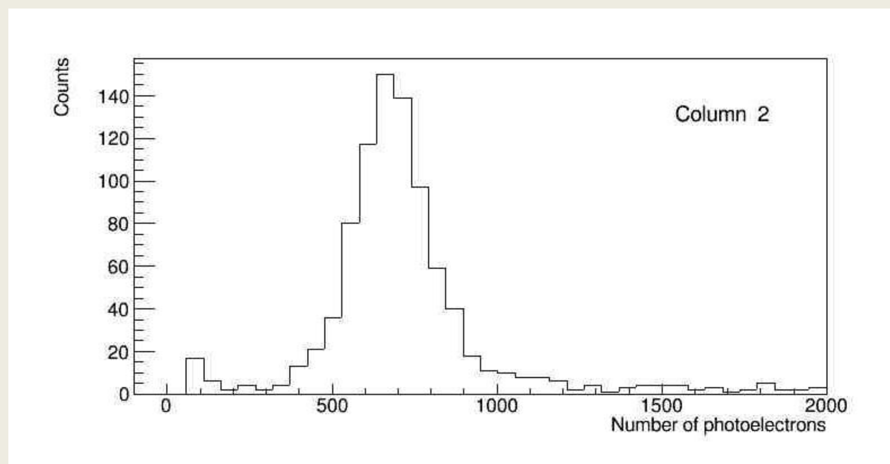
The average transverse light transmittance of the crystals was 62.82, 68.38, and 75.68% at wavelengths λ = 360, 420, and 620 nm. For most of the crystals transmission passes the EIC calorimeter specifications.

The average light output from crystals is ~16 pe/MeV with a standard deviation of 0.9 pe/MeV, which is within the measurement error. This result is in agreemwnt with the previous measurements [6].

The light output of crystal at two different points ~14 cm apart is same (within 3–5%), which indicates good optical homogeneity.



Transverse light transmittance for the best and worst CRYTUR crystals (shown as dots). Arrows and squares indicate wavelengths and transmittance values provided by CRYTUR. The dotted lines indicate the acceptable transmittance range for EIC.



Distribution of the total number of photoelectrons produced by cosmic muons in a column of the prototype.

Conclusions

The quality of $PbWO_4$ crystals from CRYTUR was investigated at AANL. The crystals were visually checked, and their sizes were measured. Light transmission through crystals was measured. The size variations, and light transmissions as well are within the EIC specifications.

An EmCal prototype was created, consisting of 16 $PbWO_4$ crystals arranged in a 4 × 4 matrix. The prototype was tested by cosmic muons. The measured light yield from straight through muons is in agreement with previous measurements.

Our results confirm conclusions of other EIC collaboration groups that the quality of crystals produced by CRYTUR meets all the requirements for the EIC electromagnetic calorimeter EmCal [5].

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