1 FCAL upgrade

The JEF experiment requires an upgrade of the inner part of the GlueX lead glass forward calorimeter with high-granularity, high-resolution $PbWO_4$ crystals. The calorimeter will improve the separation of clusters in the forward direction and the energy resolution of reconstructed photons by about a factor of two. The size of the lead tungstate insert is 1 m x 1 m. The insert is an array of 50 x 50 crystal modules with a beam hole of 2 x 2 modules in the middle and consists of 2496 modules. Each crystal has the following dimension: 2 cm x 2 cm x 20 cm. Crystals are purchased from two vendors: SICCAS (China) and CRYTUR (Czech republic). CRYTUR crystals are know to have slightly better radiation properties and will be used for the instrumentation of three inner layers of the calorimeter insert. Properties of recently produced crystals have been studied in detail and can be found in Ref. [1]. SICCAS crystals with the length of 18 cm were used in the hybrid calorimeter (HyCal) in the experimental Hall B [2]. Crystals from these vendors were also chosen for the instrumentation of the Neutral Particle Spectrometer, which is being currently constructed in Hall C.

The size of the FCAL insert may slightly vary depending on availability of funds. The project is funded by the Jefferson Lab. We also applied for the NSF grand (PI is Prof. L. Gan from the University of North Carolina in Wilmington). In the next section, we will describe the design of $PbWO_4$ modules and the status of the project.

1.1 Design of the FCAL insert

1.1.1 Module design

Design of the $PbWO_4$ module is based on the HyCal calorimeter, which was used in several experiments in Hall B. Schematic view of the module is presented in Fig. 1. The lead tungstate crystal is wrapped with the reflective material (ESR) and Tedlar. The crystal is attached to the PMT housing. Two flanges are positioned at the crystal and housing ends and are connected together using brass strips, which are brazed to the flanges. Four screws on the PMT housing flange provide strip tension and hold the assembly together. Hamamatsu PMT 4125 is inserted inside the housing and is coupled to the crystal using an optical grease. The PMT is pushed towards the crystal by using a G10 plate and four screws. The PMT is read out using an active base, which was designed for the Hall C lead tungstate calorimeter (NPS) [3]. The base combines a voltage divider and an amplifier powered by the current flowing through the divider. The base is attached to the PMT socket.

In Summer 2018 we constructed a small calorimeter prototype consisting of 12 x 12 modules. The prototype layout is presented in Fig. 2. The calorimeter was successfully operated during the PrimEx experiment in Spring 2019 and used for the reconstruction of Compton events. The calorimeter was also tested during several GlueX high-luminosity runs.

Some modifications have been recently made in the module design: (1) We performed a detailed study of the PMT magnetic field shielding using magnetic fields produced by Helmholz

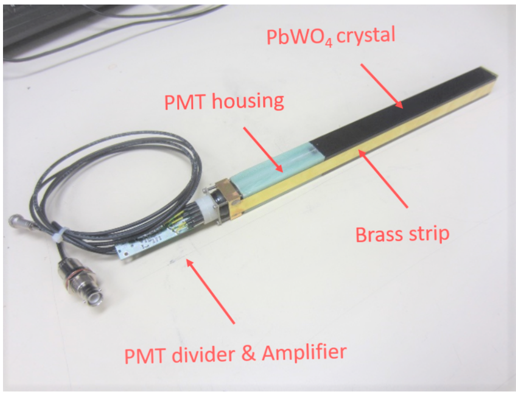

Figure 1: $PbWO_4$ module used in the FCAL 2 calorimeter prototype.

coils [4]. The shielding was also simulated using TOSCA field simulation program [5]. It was demonstrated, that the PMT housing made of the 1020 steel and two layers of mu-metal foils inside it will reduce the fringe filed of the Solenoid magnet (of about 50 Gauss) to the level sufficient for the reliable PMT operation (2) The magnetic field shielding requires to use a 3.5 cm long optical light guide between the crystal and PMT. Light collection was measured for different diameters of light guides and different coupling materials between the crystal and light guide using a test setup positioned downstream of the GlueX Pair Spectrometer [6] (3) Integrated to the GlueX detector, the Compton calorimeter allowed to measure realistic operational conditions (PMT rates and anode current) for the FCAL 2 insert. These measurements were used to tune the design of the PMT active base.

The mechanical design of the $PbWO_4$ module has been finalized. Some details can be found on the FCAL2 construction page [7]. We have already assembled a few modules and are ready for mass production.

1.1.2 Installation of the FCAL 2 in Hall D

Jefferson Lab is responsible for the integration of the FCAL 2 calorimeter to Hall D. The FCAL 2 calorimeter will be installed on the existing FCAL frame, which will be modified to accommodate cooling elements. Schematic view of the FCAL 2 frame is presented in Fig. 3. The initial design of the calorimeter support structure and infrastructure (including cabling) was complete. The FCAL 2 assembly procedure is being currently developed. The final review of the design and technical drawings is expected to be in the Fall of 2020.

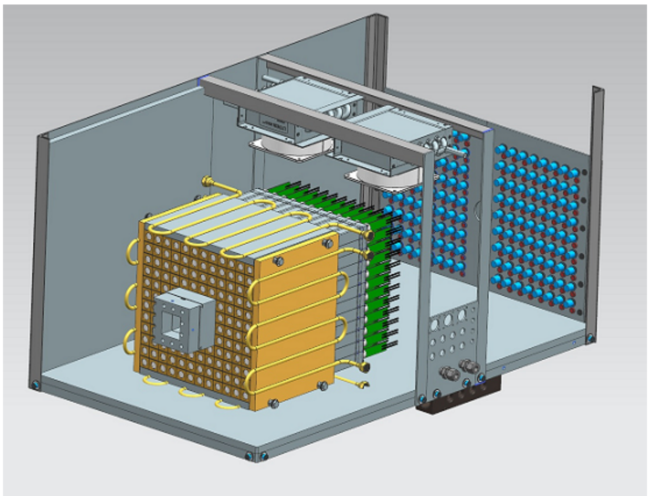

Figure 2: Schematic view of the Compton calorimeter used in the Hall D PrimEx experiment.

1.2 Status of the project

1.2.1 Procurement of components for the FCAL insert

We have already purchased and checked 64 crystals from CRYTUR, which are needed for the instrumentation of 3 inner layers of the calorimeter insert. Procurement of SICCAS crystals is organized in several steps. 500 crystals were ordered in 2019. We have already received the first batch of 132 crystals. Delivery of other crystals is scheduled on the end of summer of this year (2020). Preparation of the new contract to order about 500 more crystals is in progress. These crystals are expected to be delivered to the lab by the end of Spring 2021. We plan to continue ordering crystals, depending on the availability of funds, and have all crystals ready by the end of Spring 2023. The production rate of crystals by SICCAS is about 100 crystals a month.

Jefferson Lab has already purchased 500 PMTs from Hamamatsu, which is enough to start fabricating calorimeter modules. The lead time of PMTs is relatively fast, 100 - 150 tubes a months. JLab has ordered read out and trigger electronics for about 1600 new calorimeter channels. This includes VXS crates (already delivered to the Lab), Flash ADCs, crate readout controllers and trigger modules. Procurement of components needed for fabrication, such as light guides, soft iron PMT housings, mu-metal, flanges, etc. is in progress.

1.2.2 Fabrication and installation schedule

Fabrication of modules will be performed at Jefferson Lab in the special area in the TEDF building designated to the FCAL 2 project. All fabrication tools, procedures, and setups needed to perform QA checks of crystals are in place. We plan to assemble a few hundred

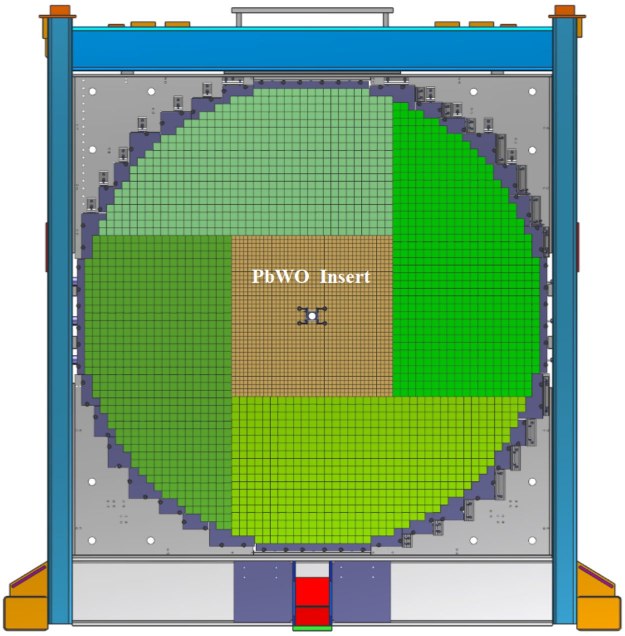

Figure 3: FCAL 2 frame with calorimeter modules installed: $PbWO_4$ crystals (brown area), lead glass blocks (green).

modules by the end of this year. Based on our experience with the Compton Calorimeter, we can fabricate about 10 modules per day, assuming two people working on it. It will take 12 - 14 months for the whole project to complete. The fabrication can be sped up by getting summer students involved.

Refurbishing of the FCAL calorimeter can be done by a few groups of people performing different tasks in parallel. We expect that the most time consuming procedure would be to repair original lead glass modules of the FCAL after disassembling, re-wrapping of the module with an Aluminized Mylar foil may be required. Some time estimates of the FCAL 2 installation in Hall D are listed in Table 1. We expect that the FCAL 2 can be integrated to the Hall D detector in about 6 months; we expect to start the detector installation after the Spring run in 2023.

References

[1] T. Horn *et al.*, Nucl. Instrum. Meth. A **956** (2020).

[2] M. Kubantsev *et al.*, AIP Conference Proceedings (2006).

[3] V. Popov and H. Mkrtchyan *et al.*, Proceedings of the IEEE conference, California, 2012.

Activity	Time (month)
Disassemble FCAL modules	1.5
Modify FCAL frame	1
Install lead glass and $PbWO_4$ modules	2.5
Connect cables	1
Total	6

Table 1: Main installation steps of the FCAL 2 detector. Reparation of the original FCAL lead glass modules can be performed in parallel to these activities.

[4] A. Somov *et al.*, "Study of the FCAL 2 magnetic field shielding using Helmholz coils", GlueX-doc-4166, 2019.

[5] S. Glamazdin "Magnetic shielding simulation using TOSCA", https://halldweb.jlab.org/talks/2018/Hybrid_FCal_shield.pdf

[6] A. Somov, A. Asaturyan, J. Crafts, "Light collection studies of the $PbWO_4$ module with light guide", https://halldweb.jlab.org/wiki/index.php/Light_Guide.

[7] FCAL construction page https://halldweb.jlab.org/wiki/index.php/FCAL_Insert.