May 2013 Status Report and Proposal for EIC Calorimeter Development

The EIC Calorimeter R&D Consortium

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Overview

Within the EIC calorimeter consortium, there are four major R&D efforts to develop calorimeter technology: 1) the RD1 (2011) effort to develop a W-powder/Scintillating Fiber-based compact SPACal-type electromagnetic calorimeter (UCLA/IU/TAMU/PSU/BNL); 2) the development of a Tungsten plate-based accordion-shaped EMC(BNL); 3) the R&D project on crystal calorimeter development based on BSO and PWO crystals(USTC); and 4) Monte Carlo simulations for both detector design and physics to develop detector requirement specifications and physics capabilities for a comprehensive detector at EIC(BNL).

The UCLA/IU/TAMU/PSU/BNL team focuses on the preparation for prototype construction this summer. We have experienced serious delay in setting up the contract with BNL. A SiPM readout scheme will be tested in this round of prototype testing. Significant progress has been made on the electronics for the SiPM readout and prototype electronics will be tested in the beam test run, expected in the fall of 2013. This project will not request new funding at this committee review meeting.

The BNL (PHENIX) team has been working on an accordion shaped EMC using Tungsten plate. Valuable experiences have been gained regarding quality and mechanical tolerance of Tungsten plates from the commercial vendor. A new prototype EMC design, light collection scheme and SiPM readout will be studied next year. The project requires the allocation of $112.5k this year as in the original three-year proposal submitted last year.

The USTC crystal R&D team has performed quality test on a sample of 9 BSO crystals. The results are promising. The proposed activities in 2013-2014 include a beam test of BSO crystal array and the test of LYSO crystals. Simulation effort on a crystal detector in EIC detector will continue. The requested budget is $75k.

The Monte Carlo simulation project by the BNL team aims at the development of tracking and calorimeter requirements for an EIC detector. A separate report covering both the tracking and calorimeter related simulations will be submitted by the BNL group.

Reports from these R&D project teams are included. We note that a close collaboration between IU and the BNL group on the SiPM readout electronics has been formed and the efforts are complementary to each other. We also note that JLab has done much work in the SiPM readout. We hope to organize a workshop on the calorimeter and its readout development in the near future to summarize progresses in this area. We expect that the final configuration for the SiPM readout electronics will emerge based on a complete study and evaluation of the prototyping results from both groups in the coming a few years.

EIC Detector R&D Project RD1 Progress Report
Reporting Period: From 01/01/2013 to 05/01/2013

Project Name: Development of a New Technology for Fiber Sampling Calorimeters for EIC

Project Leader: Huan Z. Huang

Date: 05/17/2013

Past

What was planned for this reporting period?

The main goals for this period were to prepare for the construction of the prototype modules in the summer 2013. Major tasks include selecting vendors for materials and placing orders for materials, especially those with long lead time. We have also arranged with UCLA machine shops to prepare for our project when materials arrive.

The electronics effort also started with the development of preliminary requirements and design for MPPC readout electronics.

What was achieved?

We experienced some delays in setting up the subcontract between BNL and UCLA. We have been in communication with vendors (Kuraray fibers, Heavy tungsten powder, and Hamamatsu) regarding our requirements. We decided to order multi-clad fibers from Kuraray. That is needed to achieve the desired light yield from the detector with readout based on MPPC. The second long lead item is MPPC from Hamamatsu. We had a face-to-face meeting with Hamamatsu representatives at BNL where we discussed our requirements. After that meeting we decided to proceed with the last year's production model of MPPC without waiting for the newer MPPC model which may become available in summer 2013. The order for 3x3 mm^2 (25 um pixels) MPPC from Hamamatsu has been placed and the anticipated date of delivery is middle of July.

A design for new moulding form for tapered towers is in progress as well as the design of a light collection for barrel calorimeter. A new type of epoxy was tested for infusion. Epotec 301-1 was found to be superior in our application to Bicron BC-600. It is less viscous and injections to depth of 2 inches can be achieved within few minutes.

A sample of several Hamamatsu MPPCs was sent to IUCF to initiate the electronics work by having the first-hand experience with these detectors. Simple tests have been performed at IUCF to confirm earlier results of BNL group.

A request for a test run at FNAL in Nov. 2013 was submitted to FNAL. There are two requests for the last open window in calendar year 2013. It is

still not clear if we will be granted requested time. We are working with FNAL on the test beam schedule.

IU started on the detailed engineering design of a prototype fully integrated MPPC module which will fit in the available area behind the light guide, approximately 21 × 21 mm^2. There are four principal functional blocks: MPPC's (in this case, 4) whose signals will be summed to a single readout channel, preamplifier and cable driver, temperature compensated bias voltage regulator for each independent MPPC device, and slow controls interface. Some months ago we sketched out a preliminary design for each of these. We began now with a detailed design and prototyping of the bias voltage regulator; Fig. 1 shows a photograph of the pre-prototype.

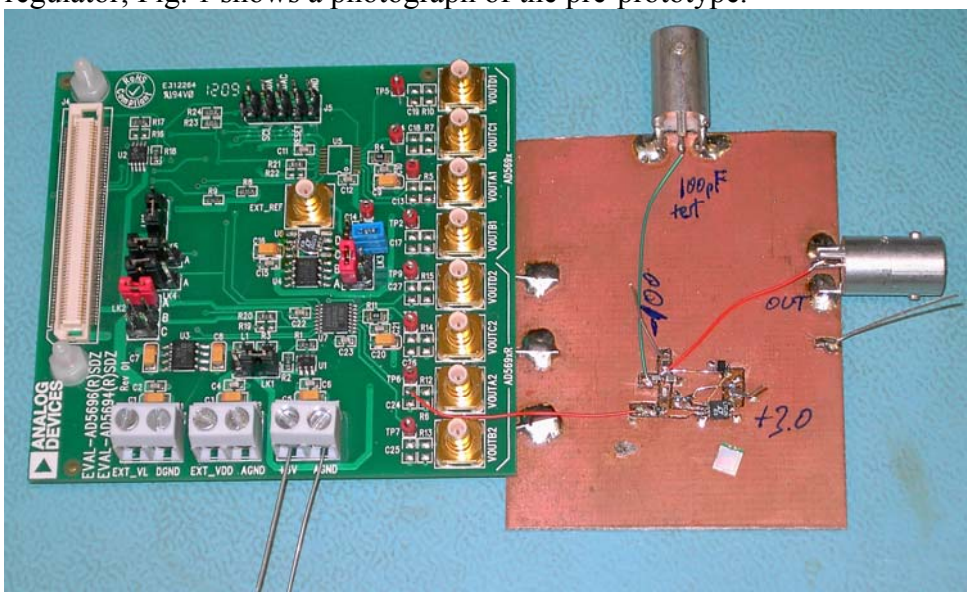


Fig. 1. Single channel bias voltage regulator (right), connected to DAC eval board (left). For scale, a 3x3 mm^2 Hamamatsu MPPC lies on the regulator board near the bottom.

The operating point of the MPPC will typically be at least 1 V over the breakdown (quenching) voltage, so for 1 % gain stability and 1 % gain tuning to match the four MPPC's, we need better than 10 mV stability and 10 mV control resolution of the bias voltage. The latter is easily assured by design with a 12-bit DAC and control range of 60 to 80 V, but the former requires some design effort and ultimate verification on a prototype. Temperature compensation will be provided locally without intervention from the control system by means of an auxiliary DAC with a reference driven by an NTC thermistor mounted closely to the MPPC's. In this way the compensation slope, nominally +56 mV/K, can be optimized in situ and absolute accuracy of the temperature sensor is irrelevant. Once temperature compensation is tuned, the remaining significant instability is due to noise in the voltage reference, DAC, and regulator circuit, and due to load regulation error from large amplitude MPPC signal pulses. These items are the subject of current investigation.

The noise of a quality but affordable and compact voltage reference and DAC may be as low as roughly 8 ppm, or about 0.7 mV. Simple SPICE models of the regulator circuit indicate another roughly 0.1 mV contribution.

Our tests so far are generally consistent with these values (see Fig. 2), however we observe occasional bursts of popcorn noise of about 8 mV amplitude, which threatens to be a problem. It is hoped that this is originating in the resistors, particularly the sense resistor with 80 V bias, and we are investigating other parts.

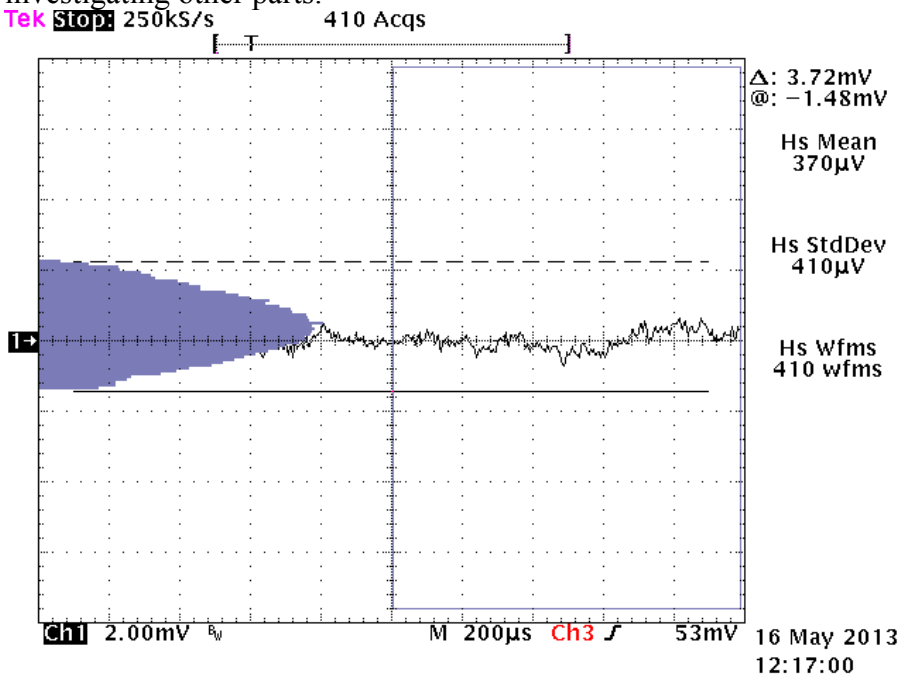


Fig. 2. Noise on MPPC bias voltage regulator output at −80 V. (AC coupled with 56 s time constant.)

A "maximum" amplitude pulse from the MPPC (~10,000 pixels fired) draws a hefty ~440 pC pulse from the bias voltage supply (decoupling capacitor at first, of course). It is important that the voltage deviation that this causes remains within the 10 mV allowance and that it returns to the nominal voltage promptly, in order to avoid baseline shift and pile-up effects from modifying the MPPC gain. Such an issue would be particularly problematic in our scheme where several MPPC sum to a single readout channel, since the full history of pulses on the output is not sufficient information to correct the data. Fig. 3shows the observed transient response; magnitude is 3× the allowed value but recovery is prompt – within ~5 bunch crossing intervals so an occupancy of maximum amplitude pulses of as much as 20% is certainly no problem at all – and stable. It is simple to increase the decoupling capacitance to reduce the peak deviation.

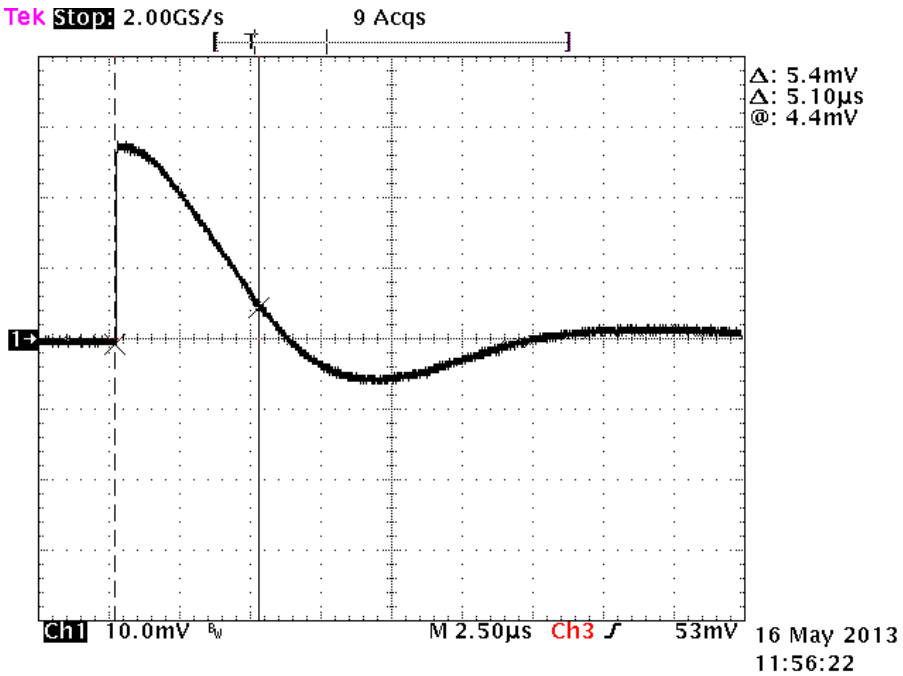


Fig. 3. Transient response of MPPC bias voltage regulator at −72 V with +440 pC load pulse.

After the bias voltage regulator design is completed we will turn to the preamplifier. Several options are under consideration but the baseline design is a simple regulated common-base NPN stage followed by an R-C load to provide some shaping, and then a cable driver to be determined. The bias voltage regulator (4 channels) is expected to dissipate ~48 mW total from +3.3 V and −100 V supplies, and the preamplifier and cable driver another ~30 mW. This should allow instrumenting a large calorimeter with no significant concerns about cooling of the frontend electronics.

What was not achieved, why not, and what will be done to correct?

We are concerned about the delay in the subcontract setup and the delivery of materials for construction. We have been working with the BNL and the UCLA contract and grant office on the issue. It will be a challenge to meet the construction schedule for beam test in Nov. We will work with FNAL for the beam schedule.

Future

What is planned for the coming months and beyond? How, if at all, is this planning different from the original plan?

Once all components will be in hand (mid. summer) testing of the SiPMs and construction of prototype for the test run will take place. The design of new moulding form will be finished and then form will be made at UCLA.

IUCF in cooperation with BNL will continue development of multiple MPPC readout scheme for the test run.

The mass testing of the MPPC will take place at UCLA. By the end of summer we expect to have well developed technique to build tapered towers.

We do not expect any deviation from original planning.

What are critical issues?

The schedule for material delivery and the prototype module construction is very tight for test beam in November.
Uncertainties with the time window for beam test at FNAL will hopefully be resolved soon.

Additional information:

We will continue to investigate neutron fluxes at EIC. At present we are taking data with a He3 counter at STAR experimental hall. This counter will measure the flux of thermal neutrons at different locations at STAR experimental hale. The idea is to use these measurements to normalize calculation from MC calculations for neutron fluxes in future.

EIC Detector R&D Report

Reporting Period: First Half FY 2013

Project Name: EIC Calorimeter R&D at BNL

Project Leader: Craig Woody

Date: May 16, 2013

Past

What was planned for this quarter?

The main goal of our R&D this past quarter was to build a small prototype calorimeter using our accordion tungsten plate and scintillating fiber design. This would allow us to understand the mechanical assembly process for building this type of calorimeter, determine the tolerances required using actual mechanical components, and provide us with a detector that could be used to the study light collection from groups of fibers in order to form towers. In addition, we planned to develop the electronics and readout system for the calorimeter using silicon photomultipliers.

What was achieved?

We succeeded in building a small prototype calorimeter consisting of a stack of ten layers of scintillating fibers and eleven accordion shaped tungsten plates. This absorber stack is shown in Fig. 1.

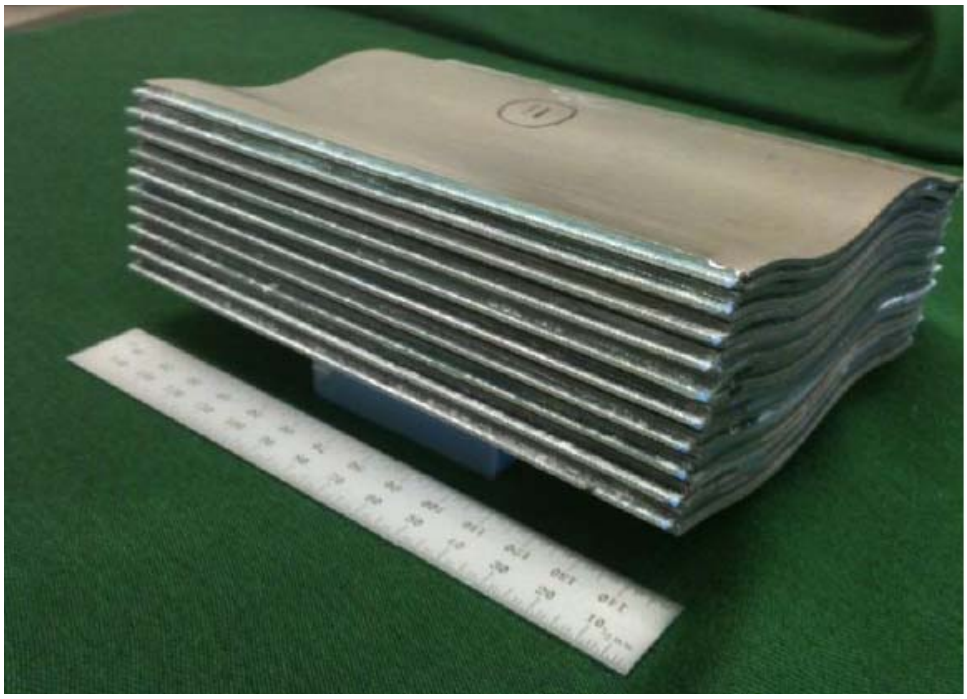


Fig. 1. Absorber stack of the first prototype of an accordion tungsten plate and scintillating fiber calorimeter.

The individual tungsten plates had a tapered thickness that varied from ~ 1.3 mm at the front to ~ 1.7 mm at the back. The scintillating fibers were glued between two such plates to form a "sandwich" and the sandwiches were then glued together to form the stack. Unfortunately, the plates received from the manufacturer were thicker than we had specified and effectively created an absorber thickness of 2.6- 3.4 mm between the scintillating fibers, which was thicker than we desired. Also, the plates did not conform well to the desired accordion shape. However, this first stack does serve as a mechanical prototype that can be used to help specify the dimensions, tolerances and shape of the absorber plates in the future. It will also allow us to do a number of tests to study the light output of the scintillating fiber array at the back of the detector. The fibers would be grouped into towers measuring roughly 2 x 2 cm^2 (corresponding to approximately one Moliere radius). This could be accomplished by making a moulded or 3D printed plastic structure consisting of an array of reflecting cavities as shown in Fig. 2. The individual compartments would be painted or coated with a white reflecting and diffusing material and equipped with one or more SiPMs for the readout.

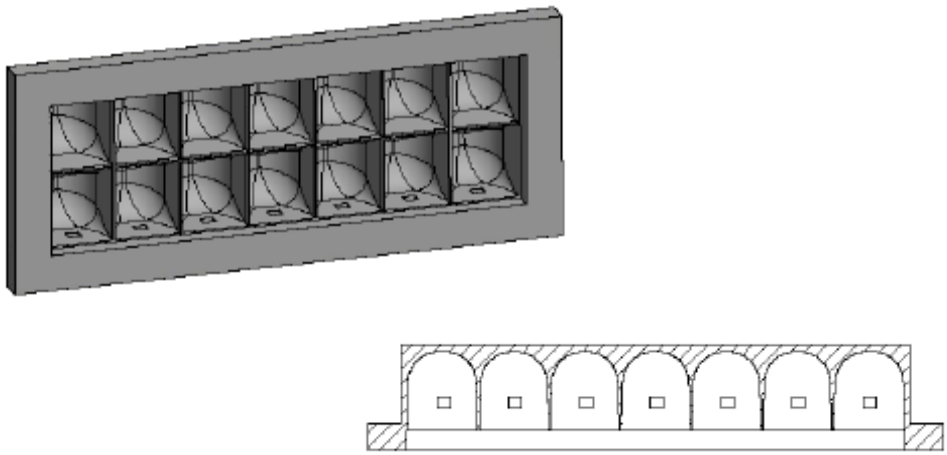


Fig. 2. Array of reflecting cavities that could be fitted onto the back of the prototype calorimeter stack.

We have studied a number of white reflective paints and coatings and have determined that a number of them could be used to provide good reflective properties inside the cavity. Figure 3 shows the reflectivity curves measured for some of these materials. In addition to the walls of the cavity, the ends of the fibers exiting the back of the stack can be surrounded with a white reflecting epoxy to increase the reflectivity of the back surface of the stack. We have also measured the reflectivity of various reflector materials mixed with epoxy as shown in Fig 4. The prototype stack was potted with BC600 epoxy mixed with 40% Al_2O_3, which is shown in Fig. 5. However, some of the reflector and epoxy mixtures were tested after the stack was potted, and it seems that TiO_2 and $BaSO_4$ give a higher reflectivity. We plan to continue to study new types of reflectors and paints to try and improve overall reflectivity of the cavity during the next several months in order to find an optimum combination which would provide the best the light collection efficiency and uniformity for the next calorimeter prototype.

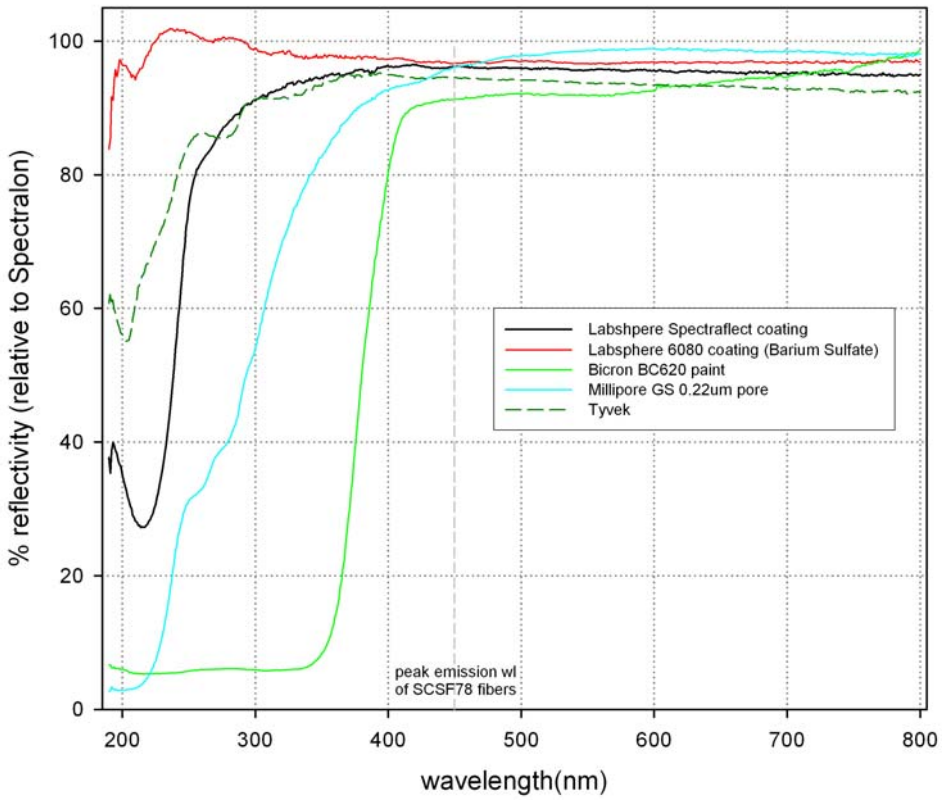


Fig. 3. Reflectivity of various white paints and reflective coatings.

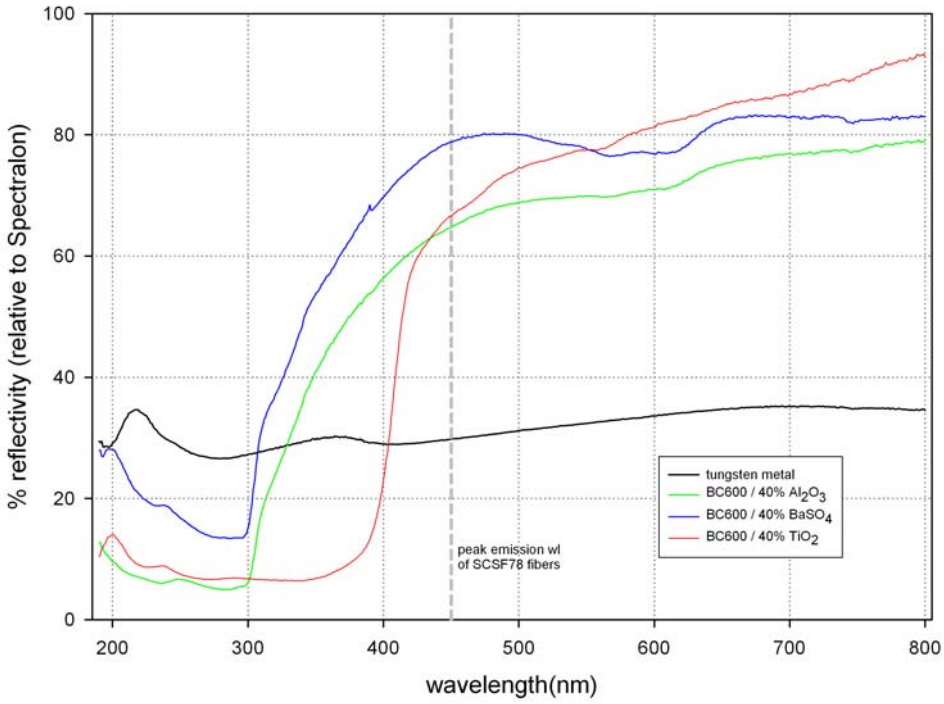


Fig. 4. Reflectivity of various reflective materials mixed with epoxy.

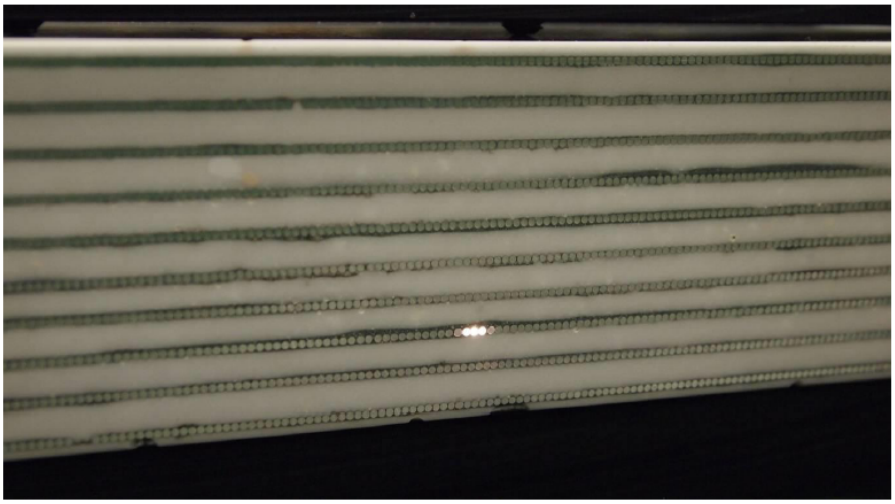


Fig. 5. End of prototype stack showing fiber ends embedded in white reflecting epoxy.

We have also studied how we would read out the reflecting cavity with more than one SiPM. We are investigating two options. One would be to passively add the signals from multiple SiPMs into the input of a single preamplifier, and the second would be to use multiple preamplifiers and then sum their outputs. The passive summation would be the most convenient and cost effective, and we have done some preliminary tests to study this configuration. Figure 6 shows the passive addition of the outputs from four SiPMs as a function of the input signal generated with a light pulser and shows that the signals add essentially linearly, indicating that there is no problem in coupling the inputs together. We now need to study how these signals behave through the preamplifier and readout chain.

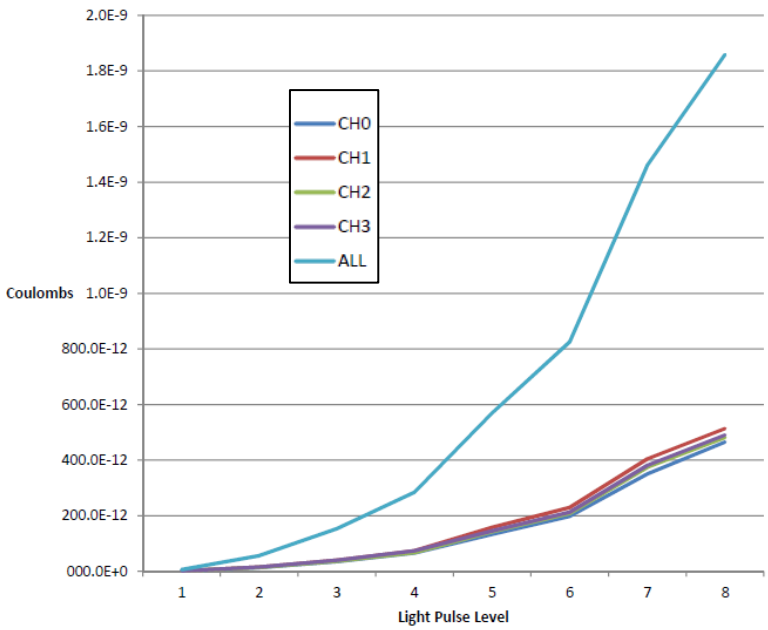


Fig. 6. Passive addition of multiple SiPM outputs connected together.

Due to their steep gain dependence with temperature, one also needs to stabilize the gain of the individual SiPMs whether they are summed passively or after going through individual preamplifiers. We have developed a feedback circuit that uses a thermistor temperature sensor to apply a correction to the bias voltage of the SiPM in order to stabilize its gain. This circuit seems to provide very good gain stabilization as shown in Fig. 7.

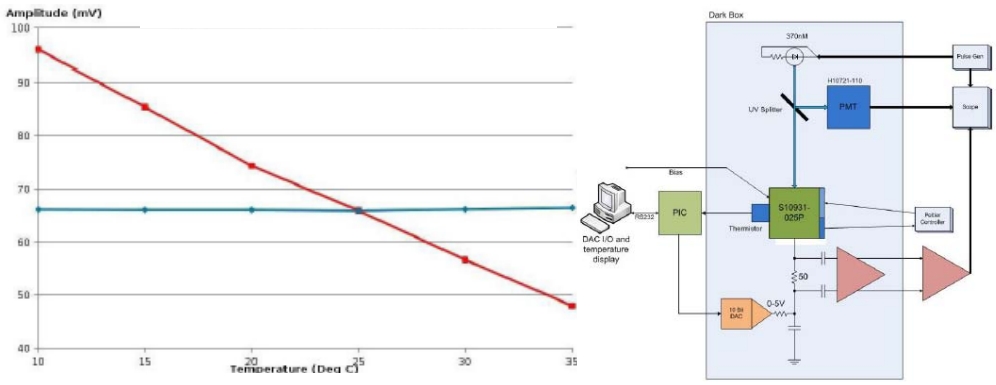


Fig. 7. Plot on the left show the stabilization of the SiPM gain using the feedback circuit shown on the right.

What was not achieved, why not, and what will be done to correct?

The plates we received from our supplier (Tungsten Heavy Powder) were not of the correct thickness and did not conform well to the desired accordion shape. We plan to order ~ 100 new thinner tungsten plates with tighter specifications on the thickness tolerance. We have also learned from building this first prototype that it may not be possible to maintain such tight tolerances on larger plates. We will therefore explore the possibility of using flat tapered plates, or possibly completely flat plates with a tapered thickness layer of tungsten powder epoxy surrounding the fibers. This would require tilting the plates in the final calorimeter in order to achieve a projective geometry, which we will study using Monte Carlo simulations.

Future

What is planned for the next quarter and beyond? How, if at all, is this planning different from the original plan?

We plan to build a new prototype calorimeter with 7x7 towers using the new plates and test it in a test beam at Fermilab later this year. We will also complete our studies on the light collection with the reflecting cavities and equip this prototype with a cavity array that has optimal light collection properties. At least some portion of the cavities will have provisions for multiple SiPM readout. We will also continue to investigate how to add multiple SiPM outputs together to form a single readout channel for each tower and how to stabilize the gain of multiple SiPMs with temperature. We

will also investigate a calorimeter geometry with tilted flat plates using Monte Carlo simulations.

What are critical issues?

Obtaining a set of new tungsten plates that have the proper thickness and tolerances that will allow us to build the next prototype calorimeter.

Optimizing the light collection efficiency and uniformity from the reflecting cavities.

Developing the readout and gain stabilization of multiple SiPMs for reading out a single tower.

Studying the flat tilted plate geometry using Monte Carlo simulations

Additional information:

We are requesting continued funding for Year 2 at the level requested in the original proposal. The original budget request is listed below.

Item	Year 1	Year 2
Materials and supplies for testing fine sampling modules	10	
Materials and supplies light output studies	10	
Development of readout electronics and DAQ	5	10
Technical support and designer	5	10
Construction of full scale high resolution prototype module		40
Test beam activities		15
Total Direct	**30**	**75**
Overhead (50%)	15	37.5
Total (including overhead)	**45**	**112.5**

EIC Detector R&D Progress Report
Reporting Period: From 11/2012 To 05/2013

Project Name: Crystal R&D for a Forward Calorimeter at EIC

Project Leader: Yifei Zhang

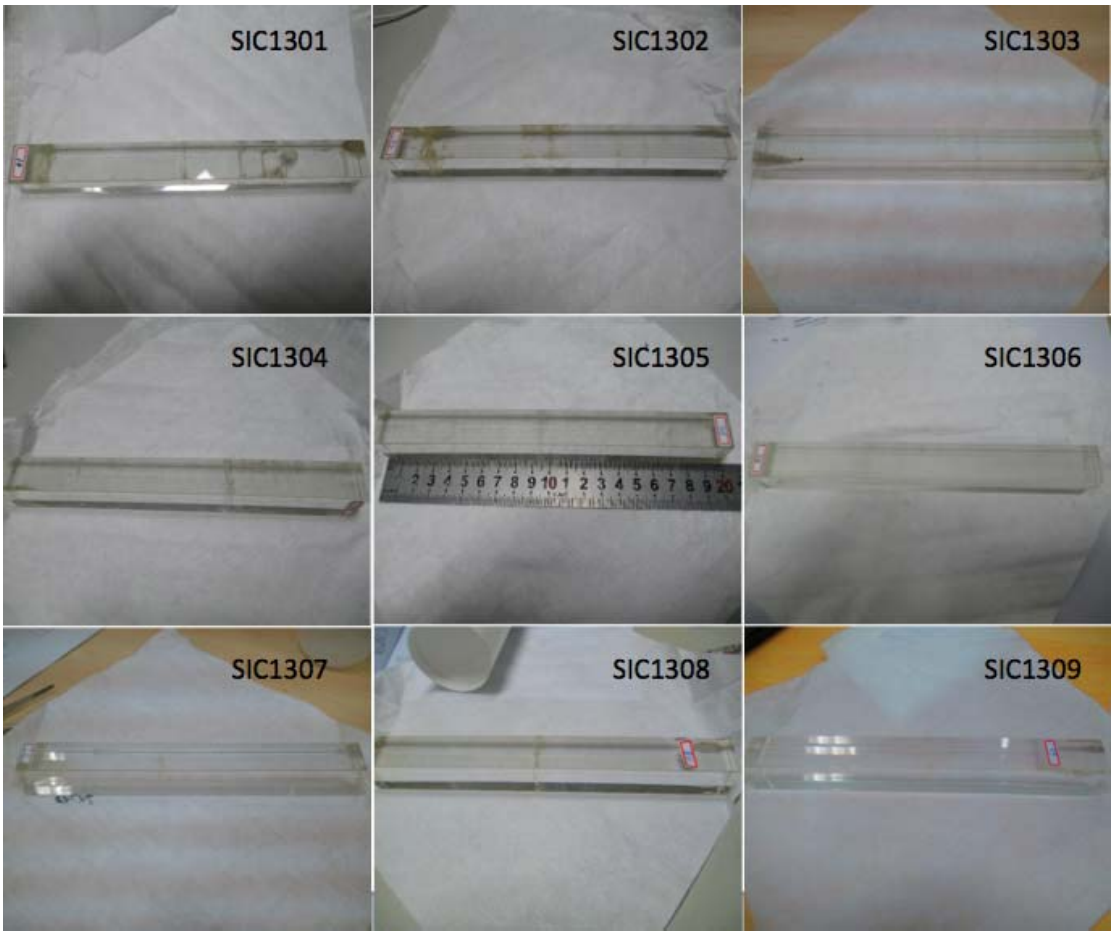
Date: 05/11/2013

The planned work and the progress for the report period:

1) Test improved BSO crystals

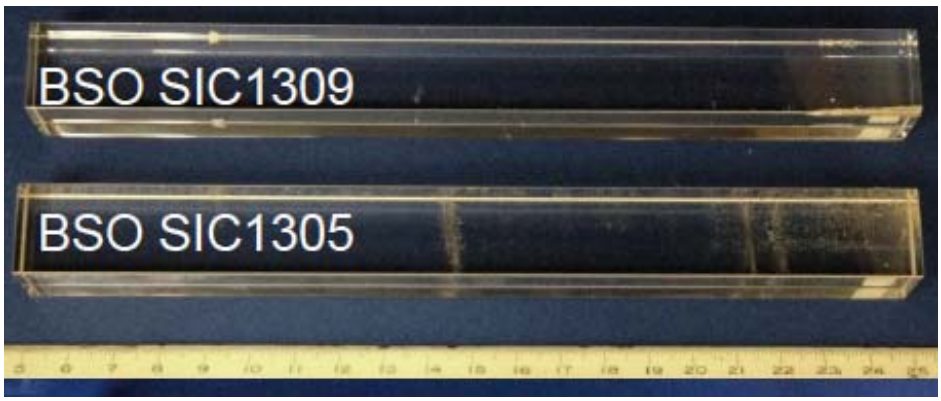
Up to now we have received a total of 12 long BSO crystals. Nine of them with relatively better quality and uniform geometric size (20×20×200 mm^3) were selected to make a prototype of 3×3 crystal array. They were labelled as SIC130X, where the X from 1 to 9 is used to identify each crystal. We tested the emission spectra, light yield output, decay time and uniformity of these crystals. Two of them were delivered to CALTECH for irradiation damage test. We summarize the testing results in this progress report.

The figure below shows the general appearance of the 9 BSO crystals:

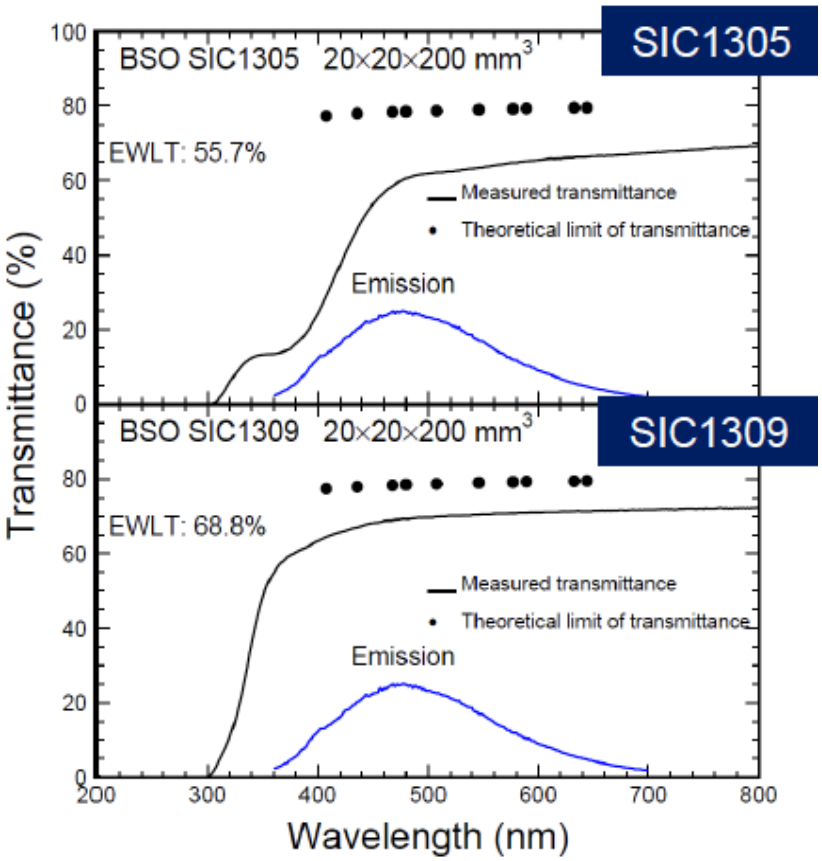


The purity and the transparency quality improve from SIC1301 to SIC1309. The better SIC1308 and SIC1309 are with less disfigurement in the production and present better performance either in transmission or in light yield (LY) output. The general appearance of SIC1301 – 1306 showed a little bit canary yellow and with some layered impurity. The SIC1308 – 1309 are more transparent and with much better apparent purity. Especially the SIC1309 looked flawless.

Detailed picture below shows SIC1305 with some layered impurity in the center and the end of the crystal, while the 1309 has no apparent fault.

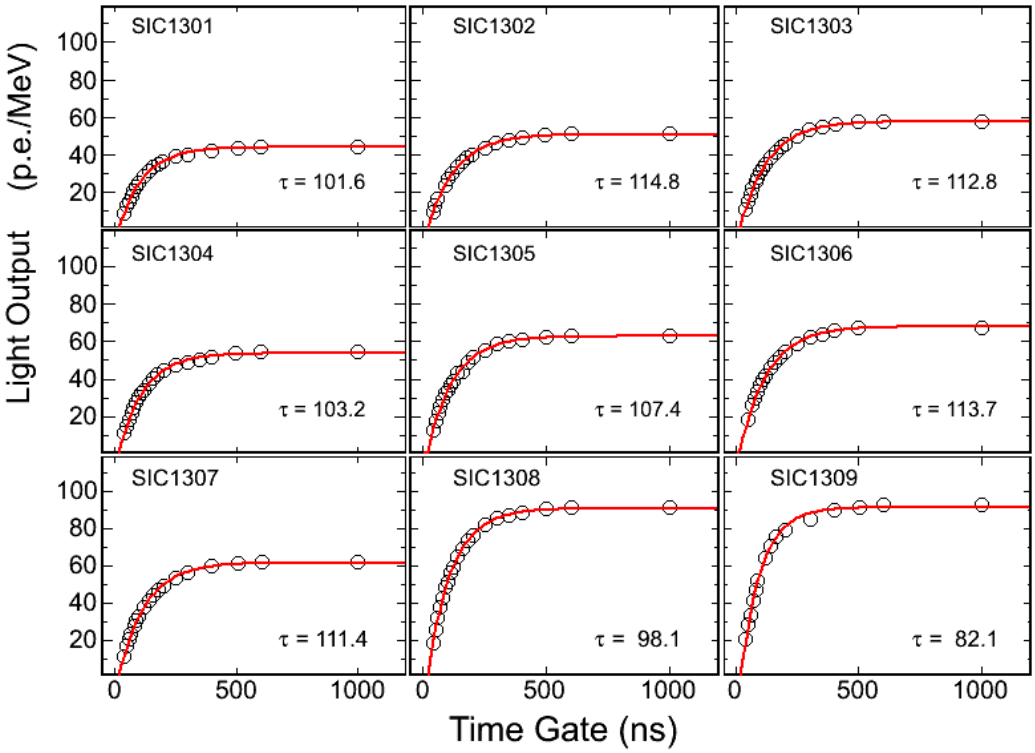


1-1) Longitudinal Transmittance (LT)
The figure below shows the longitudinal transmittance for SIC1305 and SIC1309.



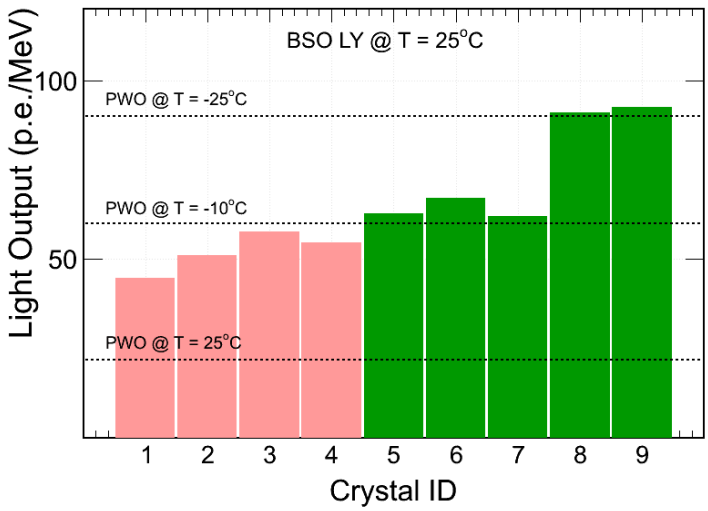
The LT of SIC1309 with high wavelength is approaching to the theoretical limit and there is no obvious absorption observed. The quality BSO crystals can be improved if we can maintain the production quality of crystals close to that of SIC1309.

1-2) Light yield output and decay time.
Below are the light yield output testing results for the nine crystals:



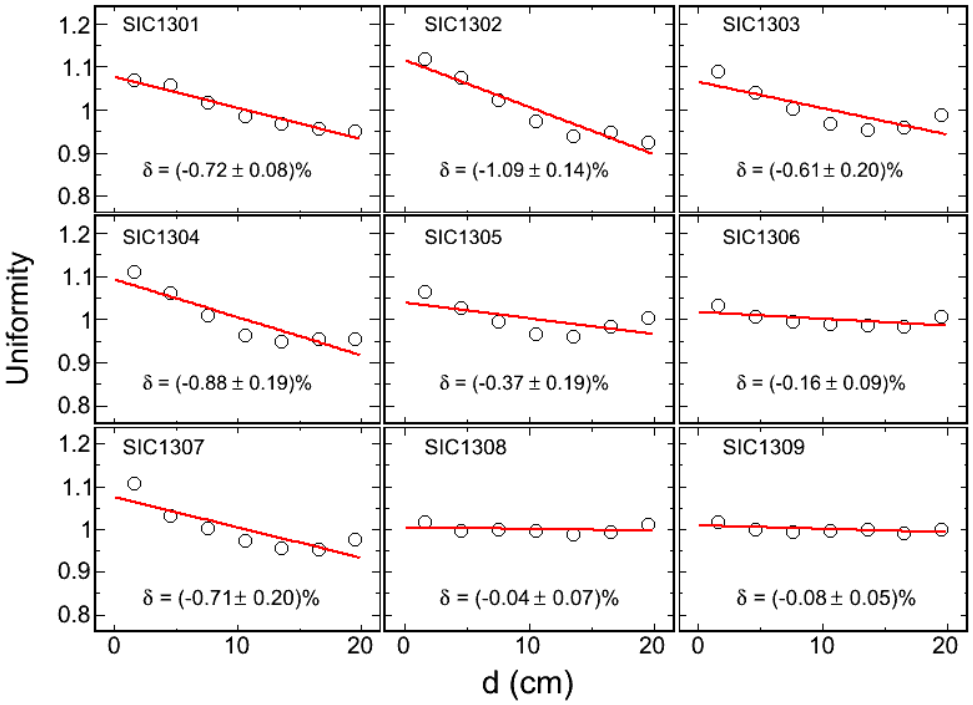
The significant increase in the LY output from SIC1301 to SIC1309 is clearly observed. SIC1301 gives a minimum LY output ~ 44 p.e./MeV. SIC1308 and 1309 has achieved ~90 p.e./MeV. From the scanning of the LY output in different gate width, we extract the decay time of the BSO crystal, which is typically around 100 ns. SIC1308 and 1309 seem to be a little bit faster.

The plot below shows the LY output of the 9 BSO crystals at room temperature ~ 25°C. 5 out of 9 BSO crystals have LY above the PWO LY line at T = -10°C. SIC1308 and 1309 achieved highest LY output and comparable with PWO at T = -25°C.



1-3) Uniformity testing

To study the light response uniformity, we attached the PMT in one side (the distance to the end coupled to PMT d=0) and move the radiation source to scan the different position of the 9 BSO crystals along the longitudinal side. The results are shown in the following figures.

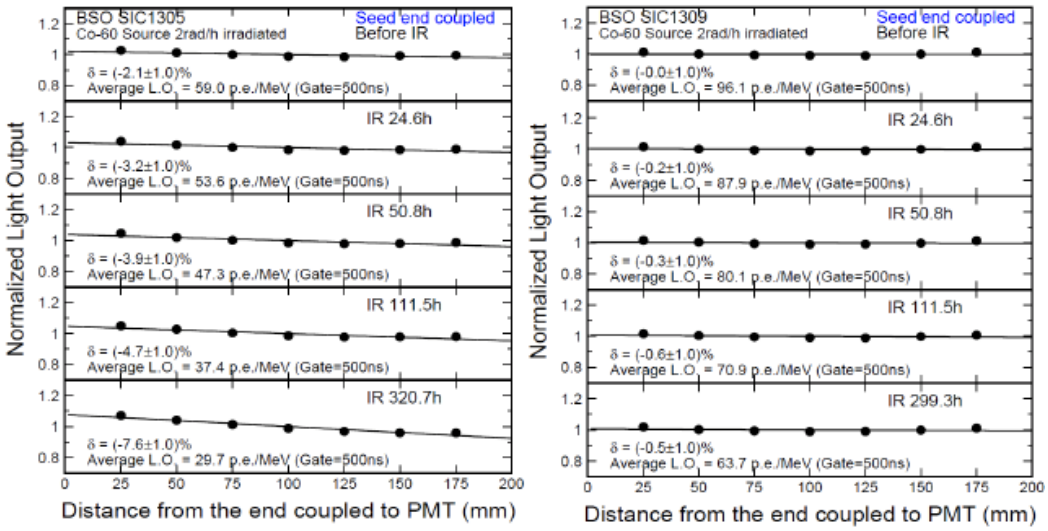


Again, the two crystals SIC1308 and 1309 shows quite uniform performance along the longitudinal side.

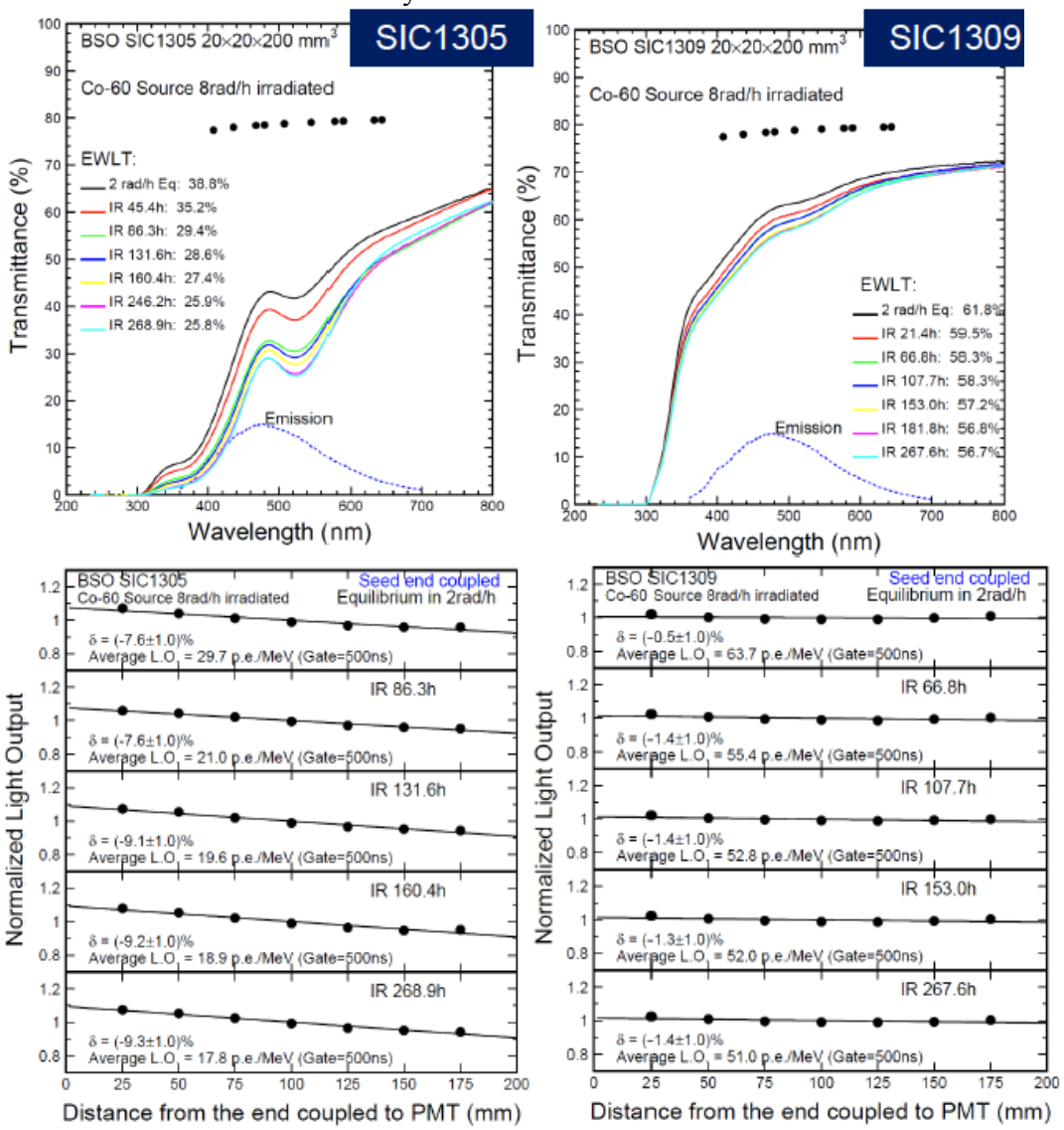
1-4) Irradiation damage test at CALTECH

We delivered two crystals SIC1305 and SIC1309 to Cal Tech for the irradiation damage test this February. The following figure shows that the longitudinal transmittance varies as a function of wavelength with different irradiate time. The best crystal SIC1309 consistently keeps the best performance and with the lowest degradation of EWLT.

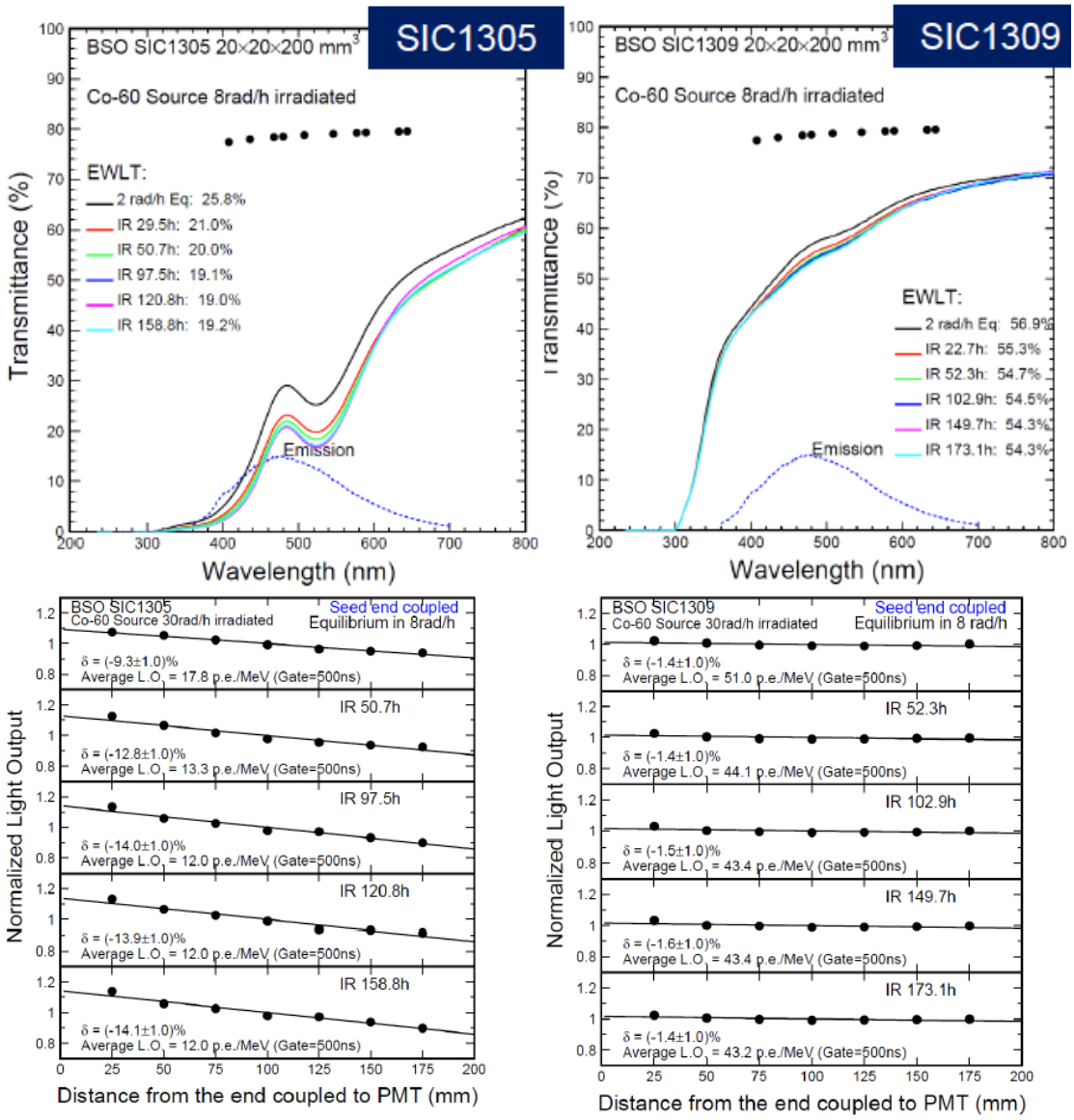
The plot below shows the uniformity of SIC1305 is slightly downgraded after long time irradiated at 2rad/h continuously while the SIC1309 uniformity remains excellent.



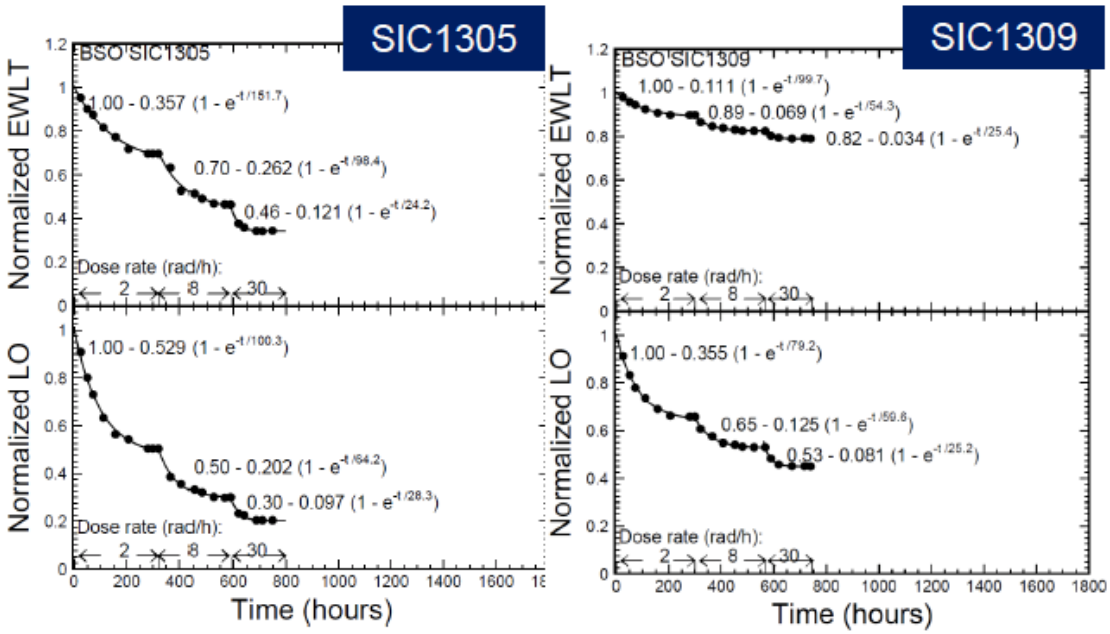
The same EWLT and uniformity test under 8rad/h:



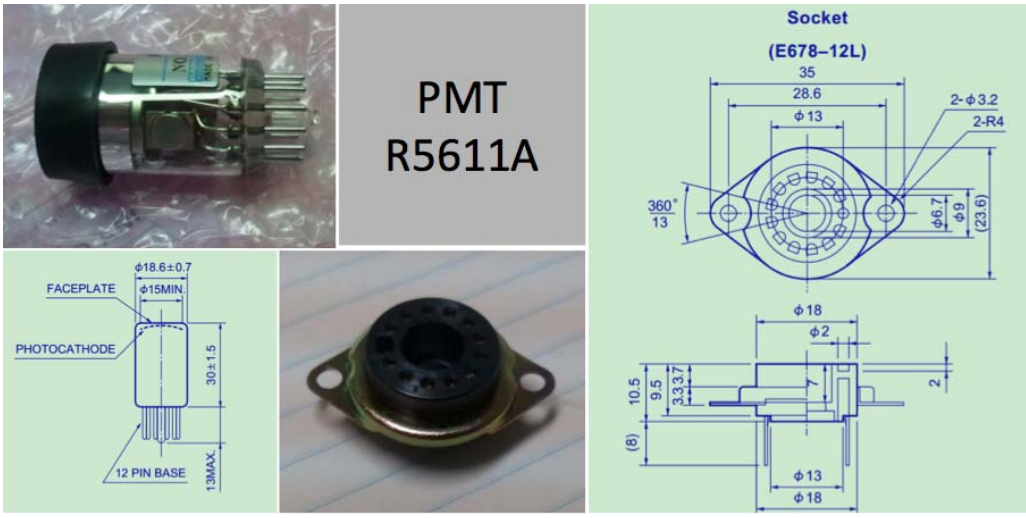
We also performed the EWLT and uniformity test under 30rad/h:



Below shows the normalized EWLT as a function of irradiation time. Damages in SIC1305 and 1309 are dose rate dependent. SIC1309 showed the lowest degradation of transmittance and light yield output.

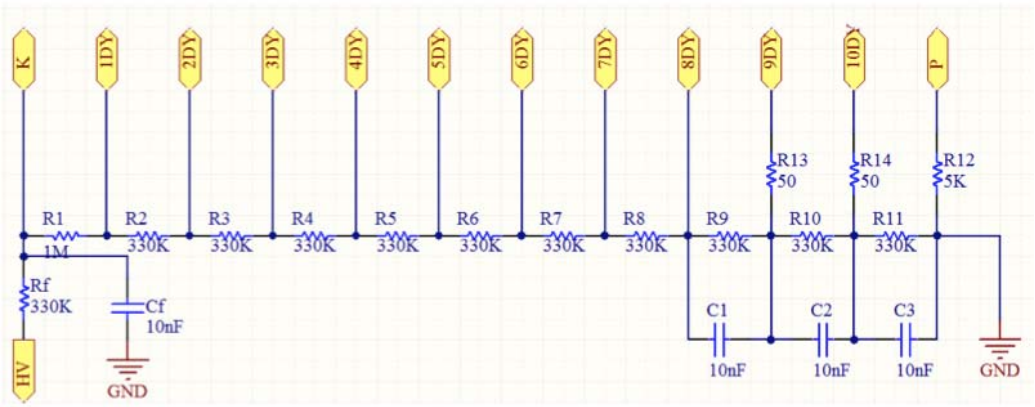


2) Design PMT based read-out for a BSO crystal array prototype.



We selected R5611A PMTs for the prototype read-out. It's size, peak-wave length, energy resolution, gain, etc are considered to be suitable for our crystal prototype design.

The base from Hamamatsu is too large to be used in our prototype. We designed a base at USTC. Below shows the schematic diagram and the base:

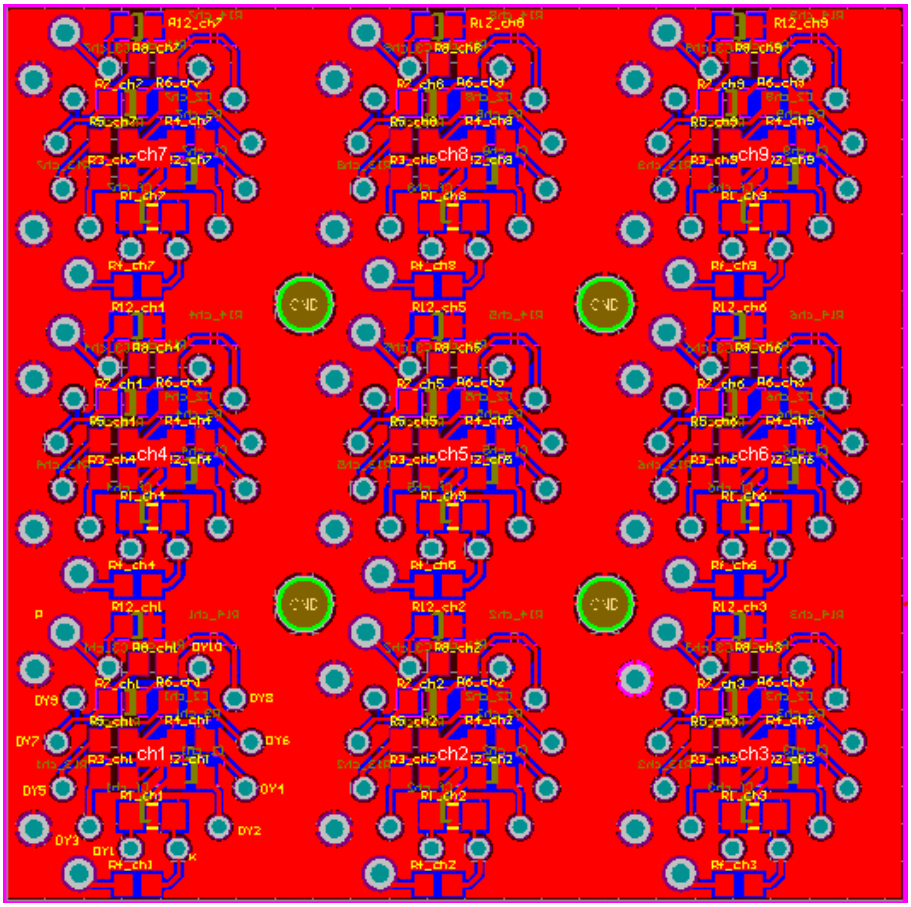


VOLTAGE DISTRIBUTION RATIO AND SUPPLY VOLTAGE

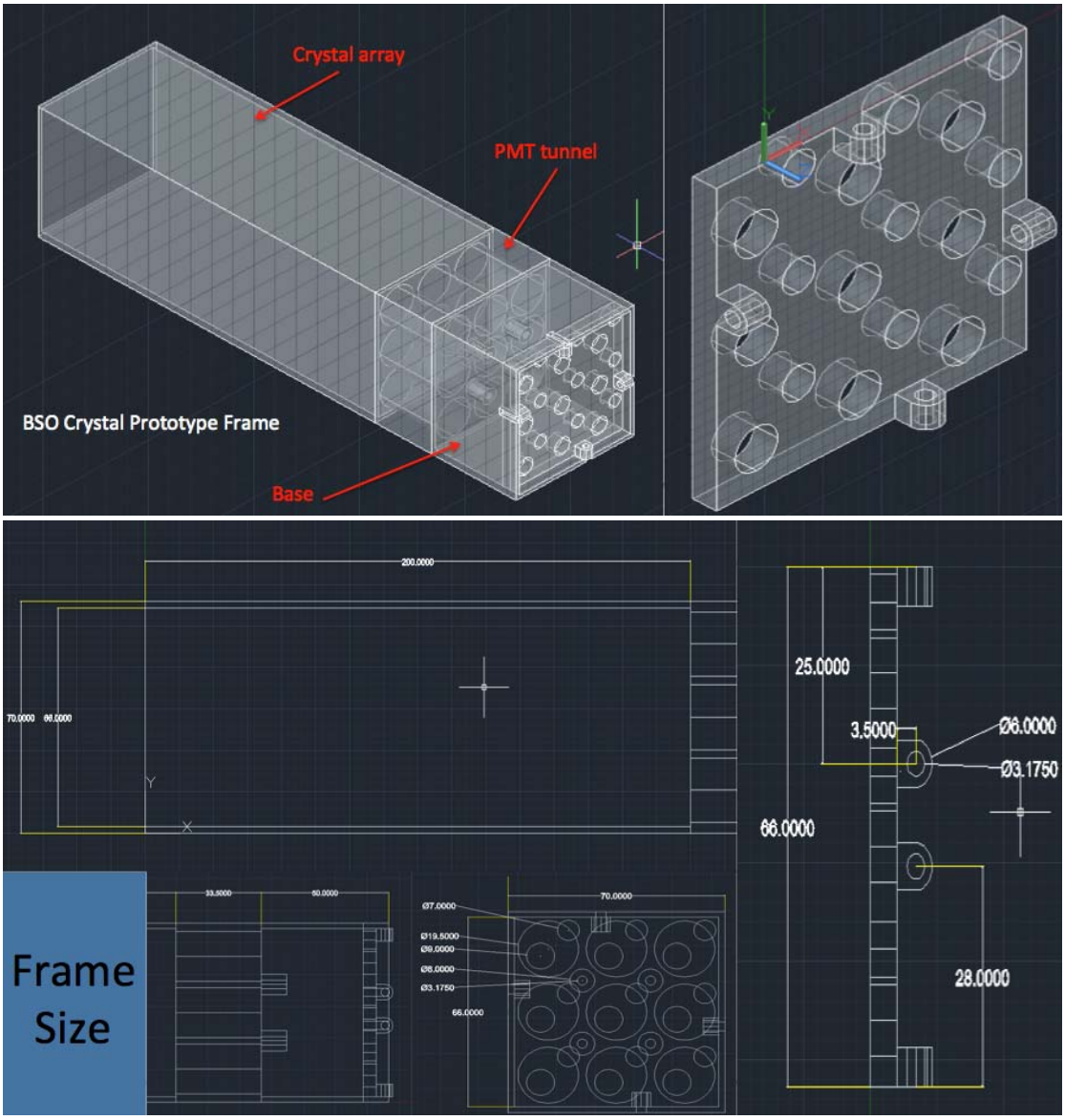
Electrodes	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	P
Ratio	3	1	1	1	1	1	1	1	1	1	1	1

Supply Voltage : 1000Vdc, K : Cathode, Dy : Dynode, P : Anode

The base:



The designed 3×3 BSO crystal array prototype frame is below:



3) Possible beam test for the prototype.

   We are still evaluating options for beam testing of the crystals. Possible options are to join the Calorimeter Consortium beam test run at Fermi Lab in Nov. 2013 or to use an electron beam at BES, Beijing late this year. Two crystals SIC1305 and SIC1309 are still under testing at Cal Tech. The assembly of the prototype array will be delayed.

4) Continue simulations for design optimization of a crystal calorimeter in an EIC detector.
   The Geant4 simulation is on progress. Results are coming soon.

Future

1) Continue simulations for design optimization of a crystal calorimeter in an EIC detector.

2) Beam test for the BSO prototype.

3) Possible R&D of LYSO crystal samples with much higher LY output.

LYSO is a unique crystal with high light yield output (a factor of 5 higher than BGO and a factor of 20 higher than BSO) and fast decay time (similar as PWO ~ 40ns).
The only disadvantage of LYSO is the price. The melting point temperature is quite high > 2000^oC, a factor of 2 higher than BSO, which requires high condition in production, better equipment, high electricity cost. The raw material of Lu2O3 is only mined in Guangxi China and quite expensive. The demands of the medical PET also increase the price. Now the cost is above 40USD/cc.

SICCAS can also provide us LYSO crystal samples for testing. If we use some LYSO crystals for acceptance coverage in the low electron energy region at large angle, we can improve the energy resolution using LYSO crystals. We plan to do some simulation on this.

We propose to purchase some LYSO crystals for further testing. We include the LYSO crystal sample purchase in our budget request.

Usage	Cost (kUSD)	
LYSO samples purchase aim for a 3x3 prototype 20x20x200mm each	40	Samples for R&D and testing, prototype design
Electronics, frame	15	PMT based read-out
0.5 postdoc + 1 student	20	Labor for simulation and testing
Total	75	