Title of the Project: Generic glass scintillators for EIC Calorimeters (ScintCalEIC) R&D
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Contact Person: Tanja Horn, CUA (hornt@cua.edu)
List of all proponents and institutions:

Marco Battaglieri, INFN-GE
Vladimir Berdnikov, JLab
Julien Bettane, IJCLab-Orsay
Mariangela Bondi, INFN-CT
V. Chaumat, IJCLab-Orsay
A. Fulci, INFN-CT
Josh Crafts, CUA
Stefano Grazzi, INFN-GE
Yeran Ghandilyan, CUA
Tanja Horn, CUA
Giulia Hull, IJCLab-Orsay
M. Josselin, IJCLab-Orsay
G. Mandaglio, INFN-CT
Arthur Mkrtchyan, AANL
Hamlet Mkrtchyan, AANL
Casey Morean, CUA
Carlos Munoz-Camacho, IJCLab-Orsay
Thi Nguyen-Trung, IJCLab-Orsay
Noemie Pilleux, IJCLab-Orsay
A. Riggio, INFN-CT
Alex Somov, JLab
Marco Sprefico, INFN-GE
Albert Shahinyan, AANL
Avnish Singh, CUA
Richard Trotta, CUA
Vardan Tadevosyan, AANL
S. Vallarino, INFN-GE
P.K. Wang, IJCLab-Orsay

Abstract:

Detecting the scattered electron with high precision is essential at the EIC. This requires high-resolution EM Calorimeters, which for any EIC general-purpose detectors, will require good energy resolution and efficiency over a large dynamic range of photon energies. Crystals have been used in many homogeneous precision calorimeters, but they are expensive, their production is slow and complex, and there is only one viable vendor worldwide. The development of scintillating glasses has shown excellent promise to become an alternative to crystals. However, detailed characterizations of the glass properties are needed to demonstrate glass as a viable cost-effective solution as EIC calorimeter technology, particularly in the most demanding conditions. Furthermore, glass and any homogeneous calorimeters consist of relatively large-area modules making light collection with small-size modern silicon-based devices far from trivial. If the high-precision homogeneous EIC EMCals are to achieve the desired resolution performance over the full dynamic range it must be demonstrated that glass (or crystal) can be matched to silicon-based photosensors with adequate areal coverage while also maintaining gain stability, amplification,

form factor, dynamic range, coupling to streaming readout DAQ. ***The proposed generic R&D will address these two focus areas of detailed glass property characterization and performance tests of glass coupled to silicon-based readout over a large dynamic range, also including the streaming readout data acquisition method.*** The results of this R&D could also apply to the EPIC $PbWO_4$ backward electromagnetic calorimeter. Scintillating glasses could be incorporated into the second detector opening new perspectives for homogeneous EM/hadronic calorimetry where large volumes are required.

Introduction

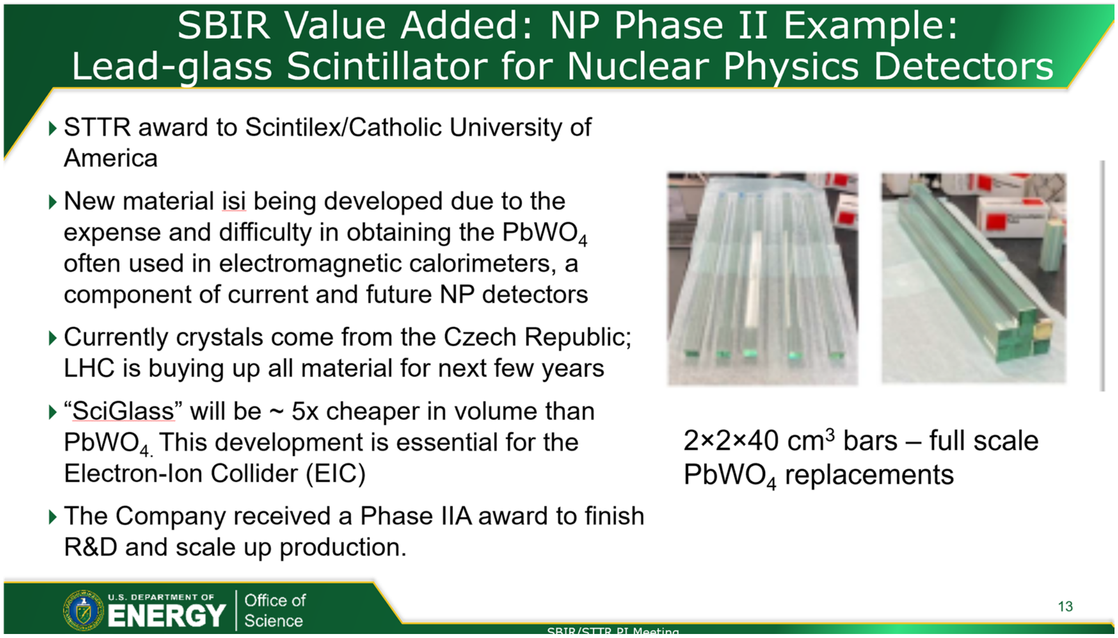
Detecting the scattered electron with high precision is essential at the EIC. This requires high-resolution EM Calorimeters, which for any EIC general purpose detectors, will require reasonably fast scintillation kinetics to handle interaction rates up to 0.5×10^6 Hz, sufficient energy resolution and efficiency over a large dynamic range of photon energies, typically from order 50 MeV to 50 GeV, adapted geometrical dimensions to contain the major part of the EM shower, and moderate radiation hardness up to ~3 krad/year (30 Gy/year) electromagnetic and 10^{10} n/cm^2 hadronic at the top luminosity [1-2].

Scintillator-based calorimeters have been known to provide excellent performance for many decades. Homogeneous calorimeters provide generally the best performance for high-resolution measurements but require high volumes of dense scintillating materials. For hadron physics measurements with electromagnetic reactions, such as at multiple setups at Jefferson Lab and PANDA/GSI, the most common precision calorimeter of choice has been lead-tungstate, $PbWO_4$ (PWO). However, crystals are expensive, production is slow and complex, and only one viable vendor worldwide exists. Furthermore, homogeneous calorimeters consist of relatively large-area modules making light collection with small-size modern silicon-based devices far from trivial.

To address the first of these challenges, efforts to develop scintillating glasses have been ongoing over the last decades within the EIC R&D and the DOE SBIR/STTR (see Fig. 1) programs, and beyond [2-4]. The most promising efforts for the requirements of EIC are the recent development of Sciglass and CSGlass. SciGlass is a radiation hard material optimized to provide characteristics like or better than $PbWO_4$. CSGlass is based on SciGlass, but has a higher density and has an optimized Cherenkov vs. Scintillation light output, which could be of interest for hadron calorimetry using the dual readout method [3]. There has been increasing interest in these glasses in the global high-energy physics community, e.g., a proposal for R&D on scintillator materials for the ECFA DRD& calorimetry was submitted, as well as letters of interest to Snowmass organized by the American Physical Society Division of Particles and Fields to advance calorimetry with novel materials. Requirements and specifications for these glasses are application specific and those for these two applications are different than those for EIC. In this proposed R&D we focus solely on the EIC application. Here, scintillating glass fabrication is expected to be cheaper, faster, and more flexible than PWO crystals while providing the required calorimeter performance. SciGlass and CSGlass are being developed by Scintilex, LLC in collaboration with the Vitreous State Laboratory at CUA. Scintilex has demonstrated a successful scaleup method and can now reliably produce glass samples of sizes up to ~15 radiation lengths.

To address the challenges of combining multiple silicon devices to have sufficient areal coverage of the homogeneous scintillator module while at the same time keeping the response of these multiple channels linear and within specs, initial tests have been carried out over the last year within the EIC Project R&D program eRD105 [3]. These tests confirmed that a silicon-based readout of homogeneous calorimeters (PWO and scintillating glass) is possible, but also revealed challenges (scaling of SiPMs in a matrix, gain stability, amplification, form factor, dynamic range, coupling to streaming readout DAQ). If the high-precision EIC EMCals are to achieve the desired resolution performance over the full dynamic range then these challenges must be addressed.

The proposed generic glass scintillator for EIC Calorimeters (ScintCalEIC, SCE) R&D project will build on the successful EIC glass scintillator research carried out over the last four years to demonstrate scintillating glass with matched areal photosensor coverage and readout electronics over a large dynamic range as a viable cost-effective solution as EIC calorimeter technology that can be used in the streaming readout data acquisition method. The results from areal photosensor coverage and readout electronics, as well as those for streaming readout, could also apply to the EPIC PWO backward electromagnetic calorimeter. Scintillating glasses could be incorporated into the second detector opening new perspectives for homogeneous EM/hadronic calorimetry where large volumes are required.



SBIR Value Added: NP Phase II Example:
Lead-glass Scintillator for Nuclear Physics Detectors

- STTR award to Scintilex/Catholic University of America
- New material isi being developed due to the expense and difficulty in obtaining the PbWO$_4$ often used in electromagnetic calorimeters, a component of current and future NP detectors
- Currently crystals come from the Czech Republic; LHC is buying up all material for next few years
- "SciGlass" will be ~ 5x cheaper in volume than PbWO$_{4.}$ This development is essential for the Electron-Ion Collider (EIC)
- The Company received a Phase IIA award to finish R&D and scale up production.

2×2×40 cm^3 bars – full scale PbWO$_4$ replacements

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SBIR/STTR PI Meeting

Figure 1: *Slide from Dr. Timothy Hallman, Associate Director, Office of Science for Nuclear Physics, presentation at the 2023 Jefferson Lab User Group Meeting.*

Background on scintillating glass R&D for EIC

Previous years have characterized scintillating glasses from small to large radiation lengths and different compositions on the test bench [4]. The glasses have excellent radiation resistance (no damage up to 100 Gy electromagnetic and 10^{15} n/cm^2 hadron irradiation, the highest doses tested to date) and good transmittance in the near UV domain. Measured light yields were reasonable for detector tests, but more detailed studies by our team revealed losses along the length of long compared to short samples. In the proposed program this attenuation will be quantified, which would provide the foundation for optimizations in the glass fabrication.

Beam tests with glass detector prototypes of different array sizes and readout options have been carried out and have provided important feedback on parameters that impact performance as a calorimeter detector [4]. For example, it was found that the wrapping of the glass modules and the choice of the reflector have a large impact on the attenuation of light along the samples. Furthermore, tests with SiPMs, the photosensors envisioned for EIC, showed that the areal coverage of the scintillator as well as the design of the electronics to the dynamic range of interest is extremely important, and thus far unresolved for glass as well as EIC PWO crystal calorimeters. As an example, our 2023 5x5 glass array beam test with 2 SiPM matrix readouts (Fig. 3) showed an energy resolution worse than expected from a 3x3 prototype equipped with PMT and from GEANT-based simulations. This was traced back to the readout electronics not being optimized for the rapid fluctuation of signal rate that, in turn, affected the SiPMs gain stability. The proposed R&D will focus on optimizing the photosensor areal coverage with matched readout electronics (also applicable to PWO) and validating the solution with cosmic rays and further beam tests, also including different detector geometries. Testing of different geometries is necessary to show that the full glass module (glass scintillator plus readout chain) would also work in complex scenarios like a barrel calorimeter or cylindrical or hexagonal inserts.

We estimate that the proposed generic R&D can be accomplished within three years, where the first year would focus on test bench measurements of the glass and SiPM photosensors to optimize the configuration and initial beam tests, the second year would focus on the commissioning of a detector prototype with optimized parameters and the last year on prototype tests with different detector geometries.

Recent Accomplishments

Beam tests with 5x5 array and SiPM and SRO

A first prototype ECAL was assembled using 25 glass blocks of nominal dimensions 2x2x20 cm^3 and instrumented with two 6x6mm^2 Hamamatsu S13360-6075 SiPMs per block and tested at INFN-Genova and CUA and JLab with cosmic rays. Preliminary on-beam tests were performed in spring 2023 using the JLab PS tagged-gamma facility that provided a tagged electron/positron beam of ~4 GeV (Fig. 3). Photo sensors were powered using a custom biasing circuitry based on the CLAS12-FT-Hodo. The SiPM signal was processed with a custom-made trans-impedance amplifier developed for the same CLAS12 detector. Signals were acquired using two different branches: streaming and triggered DAQ. The triggered DAQ used FADCs routinely used in Hall-D standard DAQ, triggered by a PS signal to precisely identify the electron/positron energy. The streaming DAQ system used the chain developed by CUA, JLab-EPSCI, and INFN Groups that includes: FADC250 and VTP boards + CODA (CEBAF On-line Data Acquisition) + TriDAS (Triggerless Data Acquisition System) + JANA2. The comparison between the two branches was essential for assessing the performance of the system. Tests proved that both the triggered and streaming readout provided similar results in terms of data collection and recording. On-beam tests were useful to access the limitations of the whole DAQ system (FEE+DAQ). The electromagnetic shower developed and partially contained in the 5x5 glass matrix was reconstructed in both DAQ chains but a rate-dependent gain variation worsened the calorimeter energy resolution. The issue was traced back to the biasing circuitry that for large SiPM current (high rate and a large number of photoelectrons, Npe) resulted in a variation of the biasing voltage. A second issue, related to a too-narrow pre-set signal integration window on FADCs (both branches) also resulted in a worse-than-expected energy resolution. This was fixed, increasing the time window from 80ns to 200ns, during the data tacking. In summary, on-beam tests were extremely useful to understand the whole system demonstrating that to reach the calorimeter design performance in term of time and energy resolution all parameters in the chain (scintillating material characteristics, FEE performance, and DAQ settings) needs to be individually studied and optimized. This is the subject of the proposed R&D program.

Figure 3 *Postdocs and students install the 5x5 glass prototype in Hall D.*

SiPM Test bench characterizations

Calorimeters at EIC require photo-sensors with a very large dynamic range expanding more than 3 orders of magnitude. In that regard, we have tested different models of SiPM on the test bench[1]. Recently, large-area high-density SiPMs by Hamamatsu (S14160-6015 and S14160-6010) have been tested at IJCLab-Orsay. Figure 4 shows linearity within 2% over 3 orders of magnitude and is compatible with the statistical expectation based on the number of pixels in the SiPM. This makes these models very promising candidates for high-resolution calorimetry for both crystals and glass homogeneous calorimeters.

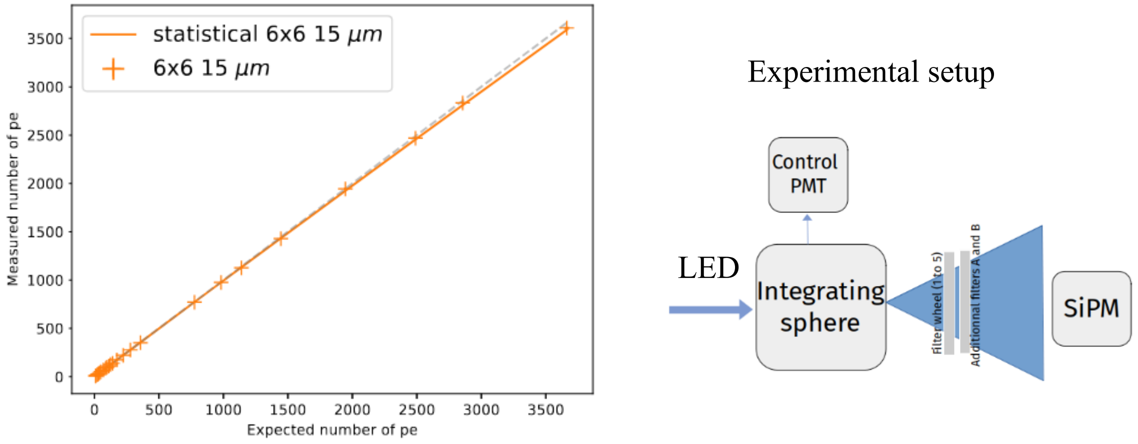

Figure 4: Linearity measurement for 6x6mm^2 SiPM with 15μm pixel size (S14160-6015). The number of photo-electrons measured is linear within 2% up to 3500 as a function of the input signal. This deviation is compatible with the statistical expectation based on the number of pixels.

Another crucial requirement for EIC EM calorimetry is the ability to detect very low energies, which requires SIPM to have a low dark current rate to be able to trigger signals close to the single p.e. amplitude. Figure 5 shows the waveforms measured in these SiPMs using a low-intensity LED. They show a clear separation between the individual p.e. signals, which will enable to measure very small signals from electromagnetic showers.

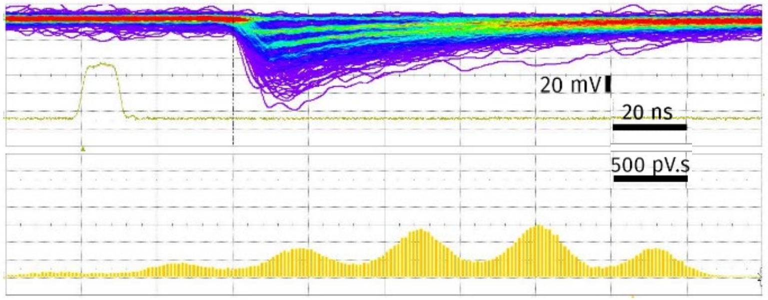

Figure 5: Waveform (top) and integrated signal (bottom) showing single p.e. signals in Hamamatsu S14160-6015, produced with a low-intensity LED.

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[1] Hamamatsu 14160-6050HS: 4x4 matrix: https://userweb.jlab.org/~yeran/SciGlass/5x5_prototype/EIC_SiPM-4x4-S14161-6050HS-04.pdf; 3x3 matrix: https://userweb.jlab.org/~yeran/SciGlass/5x5_prototype/S14160-6050HS_Report_Rev2.pdf

Proposed Research Program

Measurements on the test bench are needed to quantify the properties of glass scintillator properties (attenuation, timing, scintillation vs. Cherenkov) and the readout electronics (areal coverage, selection, and tuning of electronics components), as well as the reflector choice. To demonstrate the optimized glass module over a suitable dynamic range prototype detector test with beam will be carried out. This will require the design and construction of the prototype (a 5x5 array as needed) instrumented with 40+cm scintillating glass and SiPM readout. A control measurement with a PMT-instrumented prototype may be carried out as well. Up to 4-5 GeV these tests can be done at Jefferson Lab with a clean tagged electron beam. The prototype will be installed behind the Pair Spectrometer in Hall D. This method for calorimetry tests has been established with a series of successful measurements during the eRD1 program since 2018. Test facilities for higher energy ranges (10 GeV – 30GeV) are available at Fermilab and CERN, but there the impact of mixed beams must be considered.

The proposed generic R&D plan for glass scintillators for EIC calorimeters builds on the results from the previous EIC glass scintillator research and focuses on the following topics:

- **Quantification of light attenuation**: in glass characterization, over the last years a change in the shape of transmittance curves was observed when going from small to large radiation lengths. The focus has been on improving the transmittance in the region of interest, but a more complete understanding of the impact of glass bulk on transmittance properties would allow a precise determination of light attenuation with a measurement. Depending on the results optimize glass fabrication as needed
- **Quantification of timing properties**: in previous measurements, a range of timing response was determined, but the contribution of slower components was not investigated in detail. Detailed measurements will be performed to determine the impact of slow components on energy resolution.
- **Quantify Cherenkov vs. Scintillation light**: to further investigate the timing properties of scintillating glass, measure separately Cherenkov and Scintillation light from the same volume.
- **Quantify the impact of the reflector**: The present choice of the reflector is based on PWO, but the best reflector for glass may be different from what is used for PWO. For example, in previous tests, it was observed that the choice of the reflector plays a large role in glass performance, e.g., it results in light yield variations along the length of the sample. We will perform studies for reflector selection
- **The choice of electronics** plays a large role in calorimeter performance. The Sciglass block's large cross-section (tens of cm^2) requires a large photosensor area. Considering the small SiPM individual size (less than 1 cm^2) a matrix of 9 or 16 units would be necessary to collect enough scintillation light. The corresponding increase in capacitance, when all SiPMs in the matrix are connected, requires special care in designing the front-end preamplifier and the biasing circuitry to maintain the optimal performance obtained with a single SiPM readout. Moreover, the FEE output needs to be matched to the streaming readout framework expected for EIC. Considering the large number of individual channels to be read out, a dedicated ASIC will be necessary to digitize the signal in a wide dynamic range. A final solution to measure precisely charge and time has not yet been found and further studies are necessary with existing chips to verify the whole acquisition pipeline. These studies will be highly beneficial for the EIC PWO-based calorimeters too.
- **Impact of SRO for homogeneous EM calorimeters**; as mentioned above, the DAQ scheme expected for EIC will be in streaming mode. Despite the significant flexibility offered by the SRO, the absence of a trigger that defines a readout window imposes a careful definition of sparsification thresholds in conjunction with the acceptable rates of the back end. Any implementations need to be tested in a realistic on-beam configuration

with the real noise expected in an experimental hall. The full SRO pipeline needs to be tested to demonstrate that results are superior to conventional triggered solutions.

- **Demonstrate that the full glass module will work in different geometries**: One of the big advantages of SciGlass concerning PWO is the possibility of shaping the blocks in a custom way (e.g., tapered for barrel calorimeter or cylindrical or hexagonal). On-beam tests are necessary to verify and optimize the light collections of different geometries.

Funding Request, Budget, and Milestones

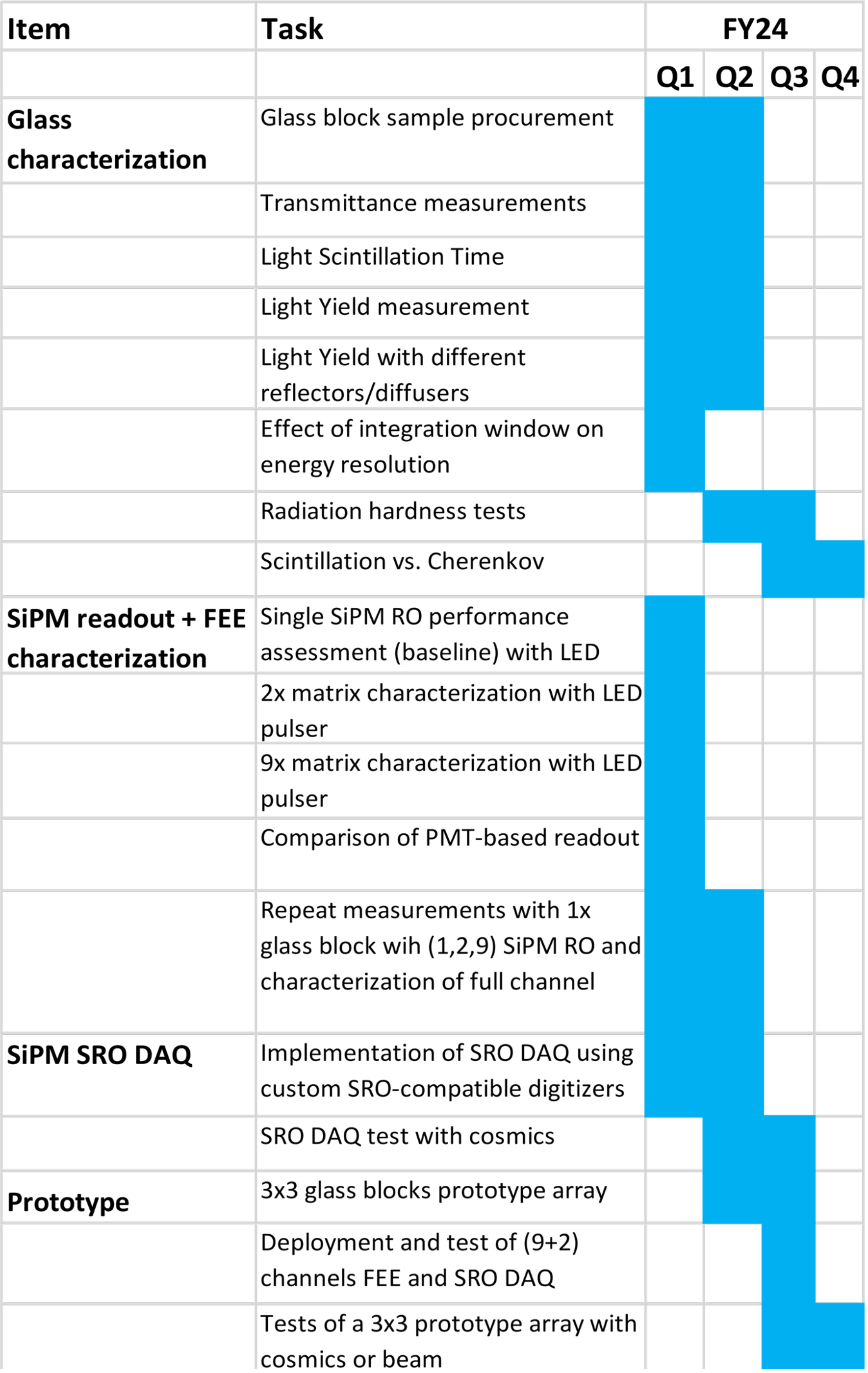
- **FY24:** Test bench measurements and initial validation with beam complete.
    - Receive ~25 test samples.
    - Measure transverse transmittance at selected points along the sample. (CUA, IJCLab)
    - Measure of scintillation time constant(s) and achievable time measurement. (AANL)
    - Measure light yield at selected points along the 40+cm sample. In addition, measure the light yield for different length samples, e.g., 1cm, 5cm, 20cm (CUA, INFN-GE, IJCLab).
    - Repeat the same measurement with different light reflectors/diffusers (CUA, IJCLab).
    - Measure light yield for different integration gates to investigate the impact of slow components on energy resolution. (AANL, CUA)
    - Measure separately Cherenkov and Scintillation light from the same glass sample using the signal waveforms. (CUA)
    - Measure radiation hardness of 40+cm samples (IJCLab)
    - Develop and implement a SiPM-based readout (INFN-CT)
    - Design and test an optimized streaming RO chain (INFN-GE)
    - Perform initial tests with cosmics (and beam if possible) to validate electronics and DAQ solutions for homogeneous calorimeters. (AANL, CUA)
- **FY25:** Prototype tests of full glass module (block+readout chain) complete
    - Beam test at JLab (and FNAL/CERN if high purity beams are available) with 3x3 (5x5) prototype with 40+ cm full glass module (optimized block+readout chain). (CUA, AANL, JLab, INFN-GE, INFN-CT)
        - HallD Jlab beam test logistics: installation, safety, DAQ, etc. (JLab)
        - Beam test preparation and data analysis (CUA, AANL, INFN-GE, INFN-CT)
        - Beam test preparation and SRO data analysis (INFN-GE, INFN-CT)
- **FY26:** Final test of different geometries
    - Receive a scintillating glass of different geometries for different EIC applications, e.g., tapered for barrel or tapered/hexagonal for cylindrical/hexagonal inserts
    - Validate optimized glass module parameters for different detector geometries

The funding request for "*FY24: Test bench measurements and initial validation with beam complete*" is shown in Table 1 separated by the institution. The areas of responsibility for each

FY24 Request	**CUA**	**IJCLab-Orsay**	**INFN-GE**	**AANL**	**TOTAL**
Student Support	14,000	8,000	8,000	5,000	35,000
Fringe	1,071	0	0	0	1,071
Materials	3,000	3,000	11000	3,000	20,000
Optimization of FEE boards (preamp/biasing: custom and commercial + LED or LASER system for SiPM tests) Mechanical supports, reflectors, optical components					
Travel	0	2,000	8,000	8,000	18,000
Indirect Cost	10,662	2,600	5,000	3,000	21,262
TOTAL	28,733	15,600	32,000	19,000	**95,333**

Table 1: *FY24 request by institution*

institution are indicated above and the overall timeline is shown in Figure 4. Some of the tasks will be carried out at two or more sites, which provides systematic cross-checks and therefore increased confidence in our results. Furthermore, this distribution of measurements contributes to enhanced student training opportunities as students will have the opportunity to report on their results to the entire multi-institution team at bi-weekly meetings or monthly meetings. This model has worked



Item	**Task**	**FY24**			
		Q1	**Q2**	**Q3**	**Q4**
Glass characterization	Glass block sample procurement	🟦	🟦		
	Transmittance measurements	🟦	🟦		
	Light Scintillation Time	🟦	🟦		
	Light Yield measurement	🟦	🟦		
	Light Yield with different reflectors/diffusers	🟦	🟦		
	Effect of integration window on energy resolution	🟦			
	Radiation hardness tests		🟦	🟦	
	Scintillation vs. Cherenkov			🟦	🟦
SiPM readout + FEE characterization	Single SiPM RO performance assessment (baseline) with LED	🟦			
	2x matrix characterization with LED pulser	🟦			
	9x matrix characterization with LED pulser	🟦			
	Comparison of PMT-based readout	🟦			
	Repeat measurements with 1x glass block wih (1,2,9) SiPM RO and characterization of full channel	🟦	🟦		
SiPM SRO DAQ	Implementation of SRO DAQ using custom SRO-compatible digitizers	🟦	🟦		
	SRO DAQ test with cosmics		🟦	🟦	
Prototype	3x3 glass blocks prototype array		🟦	🟦	
	Deployment and test of (9+2) channels FEE and SRO DAQ			🟦	
	Tests of a 3x3 prototype array with cosmics or beam			🟦	🟦

Figure 4: *Estimated timeline for the proposed glass R&D project.*

very well for three of us (AANL, CUA, and IJCLab-Orsay) during the construction of the Neutral Particle Spectrometer where ~1100 PWO crystals had to be characterized [6-7].

CUA: We request support for a laboratory technician or student to carry out the glass and readout characterization and development tasks listed above. The laboratory technician or student will be stationed at CUA or JLab where some of the test bench setups are already available. Materials and supplies are requested for standard operation, upgrades, and maintenance of these test bench setups or new developments of setups (mechanical components, reflectors, optical components). A fraction of time will be dedicated to prototype tests with cosmics (or beams as possible) towards the end of the funding period. This entails the design and construction of a prototype detector in collaboration with AANL and INFN-GE and its commissioning and initial data taking. This builds on and benefits from previously constructed prototypes and beam tests carried out by this group of institutions. JLab will contribute to organizing and maintaining the beam test program. The laboratory technician or student will be supervised by Dr. Tanja Horn as part of her group.

IJCLab-Orsay: will perform characterization of the produced large (40+cm) SciGlass blocks, and evaluate the radiation hardness from low to high doses, produce analysis software, and contribute to mechanical designs, prototype construction, and beam tests as possible. Support for a student is requested. Materials for mechanical supports, reflectors, and optical components are requested as well. Travel is requested for a visit to JLab for additional characterization and/or participation in prototype tests.

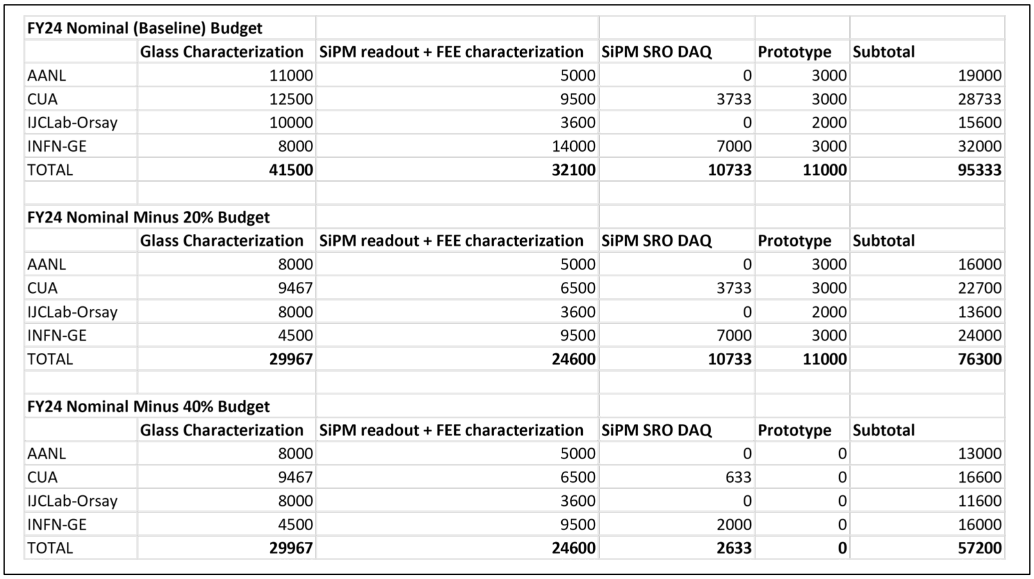
INFN-GE will be responsible for optimizing the readout framework and developing matched SiPM matrices and services for the beam tests including boards and communication/analysis software, and for streaming readout tests. A detailed timeline for FY 24 (INFN-GE and IN FN-CT) is shown below.

- Glass characterization: Milestones at Q1 end
    - M1-M1: Glass block samples procurement (different sizes)
    - M2-M3: LY measurement with different light reflectors/diffusers
    - M2-M3: Light scintillation time
    - M3-M3: Effect of the integration window on energy resolution (using 22Na rad source)
- SiPM readout + FEE characterization (light collection, time response, thermal emission background, gain stability, integration time window size): Milestone at Q2 end
    - M1-M1: Single SiPM RO performance assessment (baseline) with LED pulser
    - M2-M2: 2x matrix characterization with LED pulser
    - M2-M2: 9x matrix characterization with LED pulser
    - M3-M3: Comparison with PMT-based readout
    - M3-M6: Repeat measurements with 1x Glass block with (1, 2, 9) SiPM RO and characterization of the full channel
- SiPM SRO DAQ implementation Milestone end Q3
    - M1-M6: Implementation of an SRO DAQ using custom SRO-compatible digitizers (custom-made WB and CAEN)
    - M6-M9: SRO DAQ test with cosmic rays (3x Glass blocks with SiPM RO + 2x plastic scintillators)
- Calorimeter prototype Milestone end Q4
    - M6-M8: Deployment and test of a 3x3 glass blocks (3x3 proto-calo)
    - M8-M9: Deployment and tests of (9+2) channels FEE and SRO DAQ
    - M9-M12Tests of a 3x3 proto-cal with cosmic rays

AANL will contribute their expertise in scintillator characterization, prototyping, simulation development, etc., as continuing our successful collaboration on crystal/glass projects, e.g., the NPS at JLab. We request student support for test bench measurements of the glass blocks. The student would be stationed at AANL or JLab. Travel support is requested for members of the AANL team to travel to JLab to carry out additional test bench measurements to separate Cherenkov and Scintillation light and to design and construct a detector prototype including suitable readout. A plan for a beam test campaign in FY24 would also be prepared. The travel support cost is estimated based on the recent travel costs of two AANL members to Jefferson Lab for the assembly of the Hall C Neutral Particle Spectrometer as well as to carry out their experiments.

In the case of a 20% cut, all four Tasks could still proceed. Cross-checks of the characterizations would be limited or not possible. Student and travel support would be reduced and the time frame for prototype tests would be delayed accordingly.

In the case of a 40% cut, priority would be given to Glass characterization and SiPM readout + FEE characterization. We would not be able to support the SiPM SRO DAQ or the design/construction the detector prototypes. A prototype test campaign would be deferred.



FY24 Nominal (Baseline) Budget

	Glass Characterization	SiPM readout + FEE characterization	SiPM SRO DAQ	Prototype	Subtotal
AANL	11000	5000	0	3000	19000
CUA	12500	9500	3733	3000	28733
IJCLab-Orsay	10000	3600	0	2000	15600
INFN-GE	8000	14000	7000	3000	32000
TOTAL	**41500**	**32100**	**10733**	**11000**	**95333**

FY24 Nominal Minus 20% Budget

	Glass Characterization	SiPM readout + FEE characterization	SiPM SRO DAQ	Prototype	Subtotal
AANL	8000	5000	0	3000	16000
CUA	9467	6500	3733	3000	22700
IJCLab-Orsay	8000	3600	0	2000	13600
INFN-GE	4500	9500	7000	3000	24000
TOTAL	**29967**	**24600**	**10733**	**11000**	**76300**

FY24 Nominal Minus 40% Budget

	Glass Characterization	SiPM readout + FEE characterization	SiPM SRO DAQ	Prototype	Subtotal
AANL	8000	5000	0	0	13000
CUA	9467	6500	633	0	16600
IJCLab-Orsay	8000	3600	0	0	11600
INFN-GE	4500	9500	2000	0	16000
TOTAL	**29967**	**24600**	**2633**	**0**	**57200**

Table 2: *Budget Scenarios*

External Funding

The expertise and use of specialized instruments required for production, characterization, and chemical analysis are made possible through collaboration with the Vitreous State Laboratory (VSL). Additional funds and facilities for glass characterization are provided by the Vitreous State Laboratory at CUA.

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