Homogeneous EM Calorimeter R&D for EIC
(part of eRD1)


A.I. Alikhanyan National Science Laboratory/Yerevan, Catholic University of America, The Vitreous State Laboratory, Institut de Physique Nucleaire d’Orsay/France, Jefferson Laboratory, Brookhaven National Laboratory, Caltech
Overview FY20 Plans

- **Continue working with vendors on crystal/glass production** – optimize QA procedures, material characterization to provide feedback; investigate alternative sources of raw material

- **Fabrication method: produce larger glass samples** with adequate surface quality for physical, luminescence, and radiation hardness tests

- **Validation: Prototype beam test program** – quantify performance and response of crystal and glass to different photosensors and streaming readout

- **Design: Extend evaluation of homogeneous calorimetry** – develop MC for resolution studies and matching crystal/glass, increase efforts to other regions

- **Additional radiation hardness studies** – evaluate resistance to hadron radiation (MC40 synchrotron) and higher EM radiation doses (IPNO)

- **Submit SBIR/STTR proposal** – glass scintillator development
What was achieved in FY20 – to date

- Continue working with vendors on crystal/glass
  - Received an additional 116 Crytur crystals
  - Meetings with SICCAS on QA – expect 500 crystals

- Produce larger glass samples – fabrication method
  - Produced five 2x2x2cm3 and two 2x2x20cm3 glass samples
  - Optimization of formulation, scale up, and polishing methods

- Prototype beam test program - validation
  - Documentation submitted and approved
  - Installation for 2020 test run ongoing – in collaboration with Hall B and the EIC SRO Consortium

- Additional radiation hardness studies
  - Hadron irradiation test completed at MC40 Cyclotron/Birmingham

- Submit SBIR/STTR proposal
  - STTR Phase 1 was awarded!
Crystal Activities – characterization and vendors

- **SICCAS**: failure rate ~13% of crystals produced in 2019/20 due to major defects – inspected onsite in Shanghai
  - Meetings with vendor, most recent on January 6th about QA

- **CRYTUR**: Strict quality control procedures – so far 100% of crystals accepted
  - Continuing meetings to improve capacity and discuss raw material availability

Publication on crystal studies in collaboration with NPS project
Glass Scintillator – formulation

- Two main glass formulations for calorimeter application

  - Nominal: optimized LY, timing, radiation hardness, etc.
  - Very high-density compared to nominal, emits at >550nm, good LY

VSL-Scintilex-G4 (nominal)

VSL-Scintilex-SC1

Scintillation light
Glass Scintillator – polishing

- Testing and optimizing different methods (specifications on: flatness, roughness, parallelism, perpendicularity)

Method 1

Method 2

Method 3

<table>
<thead>
<tr>
<th>PMT</th>
<th>Entries</th>
<th>Mean</th>
<th>RMS</th>
<th>$\chi^2 / \text{ndf}$</th>
<th>Constant</th>
<th>Mean</th>
<th>Sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>26727</td>
<td>210.1</td>
<td>352.4</td>
<td>132 / 128</td>
<td>118.2 ± 2.4</td>
<td>364.9 ± 21.5</td>
<td>428.1 ± 10.7</td>
</tr>
</tbody>
</table>

Signal?

Signal
Glass Scintillator – Scale-Up

- Progress with scale-up – 2x2x20cm³ samples produced, issues associated with further scale-up identified, solutions are being implemented and tested

**Example: SC1 glass**

- 1cm x 1cm x 0.5cm (test size)
- 2cm x 2cm x 4cm (medium size)
- 2cm x 2cm x 20cm (large size)
  - Unpolished, Bubbles on surface only – will be removed during cutting and polishing

2019
1cm x 1cm x 0.5cm

Up to 4cm x 4cm x 40cm

2023
Glass Scintillator – Initial Beam Test Program

- Constructed a 3x3 prototype of geometry representative of NPS and EIC EMCal
- All documentation submitted for 2020 Spring beam tests, installation and running now!
  - Beam energy provided by pair spectrometer - select electrons going through the center of the middle crystal

- Tests in collaboration with Hall B and EIC SRO Consortium and will include:
  - Crystal/glass with PMT
  - Crystal/glass with SiPM
  - Crystal/glass with Streaming Readout

PS resolution <0.6%

- FADC amplitude histogram with 4.69 GeV peak
Test Lab for crystal and glass Readout

- Based on BDX-MINI test runs at Jlab in 2019, INFNGE developed V2.0 of Waveboard digitizer to read out SiPMs.

- Work on synchronization MRPC and crystal/glass readout ongoing.

- Instrumenting 9 channels (to begin with) to test and optimize the entire readout chain: SiPM, preamps, fADC, and Streaming DAQ system.
Glass/crystal – Schedule for TDR 2023

- What achievements are required for TDR 2023 readiness
  - Finalize glass formulation and fabrication method
  - Completion of crystal/glass design in simulation
  - Validation of performance with prototype

- How much time do you envision to complete your ongoing project

<table>
<thead>
<tr>
<th>Item</th>
<th>Task</th>
<th>2019 FY20</th>
<th>2020 FY21</th>
<th>2021 FY22</th>
<th>2022 FY23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass fabrication</td>
<td>Composition optimization</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Characterization</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scale up and additional geometries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Show uniformity and reproducibility</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fabrication process optimization</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Performance tests with prototype</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Process design verification to scale up</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large scale production study</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software</td>
<td>Prototype</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design options</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cost/performance optimization</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prototype</td>
<td>Base version</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Initial commissioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upgrade and commissioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam test</td>
<td>Beam test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Data analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Glass Scintillator – Radiation Hardness

- Low dose rate EM and hadron irradiation completed

- VSL-Scintilex-G4 (nominal)
- VSL-Scintilex-G4 (nominal) and SC-1 glass

Before irradiation

After 2min 160KeV Xray at >3k Gy/min

Fluence: 2E15 p/cm²

Fluence: 1E15 p/cm²

Photograph taken immediately after irradiation.
No visual evidence of radiation damage

- G, T, SC, EC series are EM radiation hard
- G, SC series are radiation hard under hadron irradiation
Homogeneous EM Calorimetry

- **EMCal**: central and auxiliary detectors
  - **Hadron-endcap EMCAL**
  - **Barrel-EMCAL**
  - **Electron-endcap EMCAL**

**Example: JLEIC detector**

- **Materials:**
  - **Lead Tungstate (PbWO₄)** – high resolution, $15-25$/cm³, limited vendors
  - **Glass (DSB:Ce)** – alternative active material, easier to manufacture than crystals and more cost effective