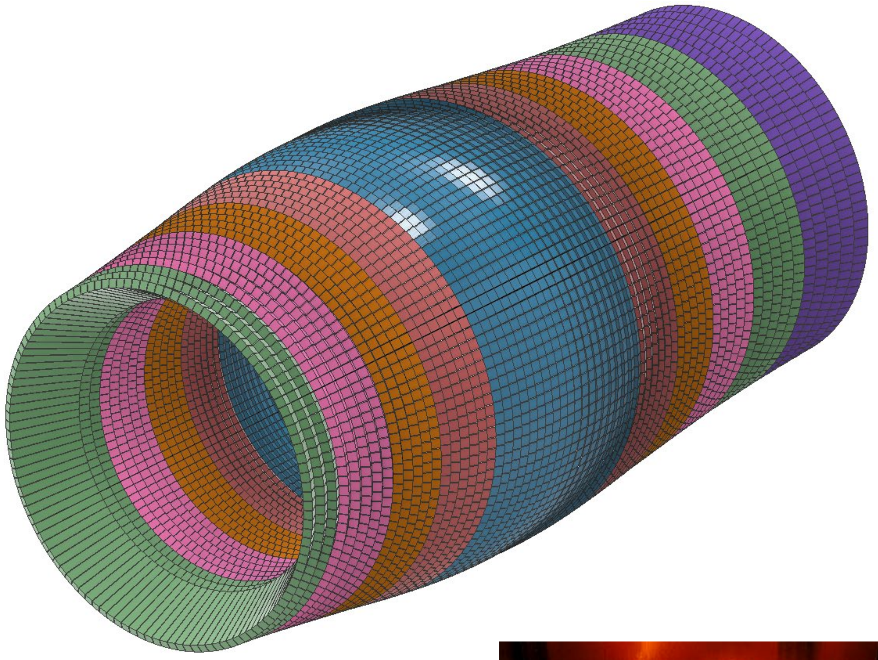
# SciGlass Electromagnetic Barrel Calorimeter

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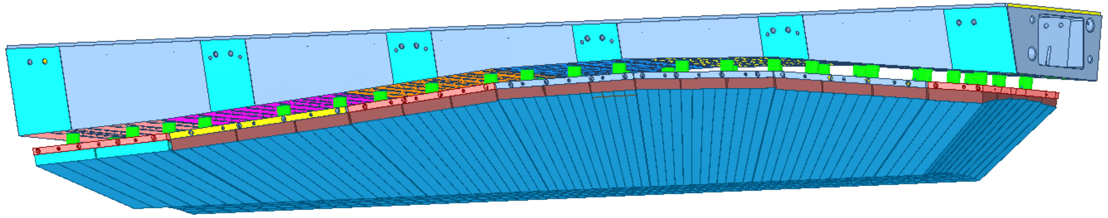


# Charge and focus of this Presentation

**EPIC Barrel ECAL review**

Request for information from the proponents

GD/I conveners, 12/12/2022

It is asked that the proponents address the following questions:

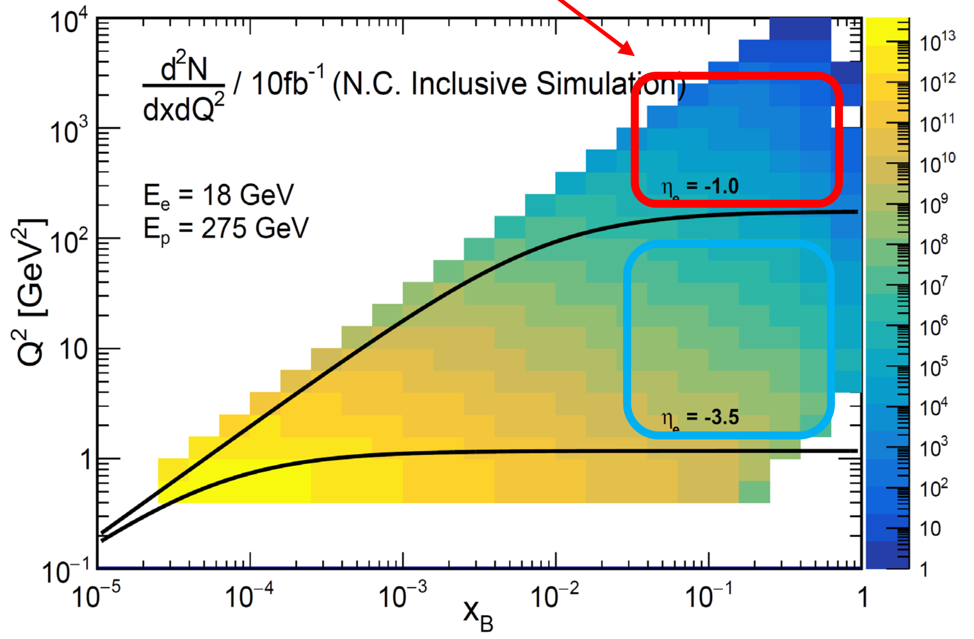
1. Reminder of the proposed **detector configuration** for the use in the ePIC detector.
2. **Input information**:
   a. **R&D, prototypes and their tests**: done so far, ongoing effort, future planning (with timelines); results from prototypes and their tests
   b. Pertinent **information on similar technology/design** that is used by other experiments or R&D efforts (example reference could be literature, and or conference talks).
   c. **Simulation studies**: already performed, ongoing and planned (with timelines); results from the simulations; particular care in (i) showing how realistic the parameters used in simulations are and (ii) reporting what is missing for a fully realistic simulation (backward, specific event categories, …)
   d. Does the simulation take into account the **realistic light collection uniformity, response of the selected photosensors and related FEE**?

# 1. Detector Configuration: Design Considerations

## Scattered electron kinematics measurement is essential at the EIC

- Goal: provide continuous coverage in EM calorimetry in particular in the electron-going direction
- High precision, hermetic detection of the scattered electron is required over a broad range in η and over energy range from 0.3 to tens of GeV
  - In the very backward direction high precision is required for electron kinematics measurement
  - In backward and barrel region it is required for clean electron identification. In the barrel region, driven by high-x and high-$Q^2$ science drivers

Physics kinematic region enabled by the Barrel EMCal




| η | [-4 .. -1.75] | [-1.75 .. 1.3] |
|---|---|---|
| Material | $PbWO_4$ | SciGlass |
| $X_0$ (mm) | 8.9 | 24-28 |
| $R_M$ (mm) | 19.6 | 35 |
| Cell (mm) | 20 | 40 |
| $X/X_0$ | 22.5 | 17.5 |
| Dz (mm) | 60 | 56 |

- Here, we selected **SciGlass** (developed with DOE/STTR) for the barrel as it provides very good e/h separation and energy resolution, matched to the backward region needs

# 1. Detector Configuration: SciGlass Barrel EMCal

- Concept: Homogeneous EM calorimeter – typical materials in lepton induced hadron scattering: crystals and glass, a **well-established detector technology**
- Barrel EMCal readout electronics can be identical with the backward EM calorimeter → **no additional technology required**
- **Moderate number of readout channels**
- Advanced design concept built on PANDA precision homogeneous barrel EMCal design
- Experienced team of institutions (AANL, CUA, FIU, JMU, UKY, MIT..) including **many early-career researchers** working on design, simulation, prototypes


→ See Rosi Reed talk

→ See Josh Crafts talk

→ See Renee Fatemi talk
→ See Dmitry Kalinkin talk

# 1.Homogeneous Design based on PANDA

**PANDA**

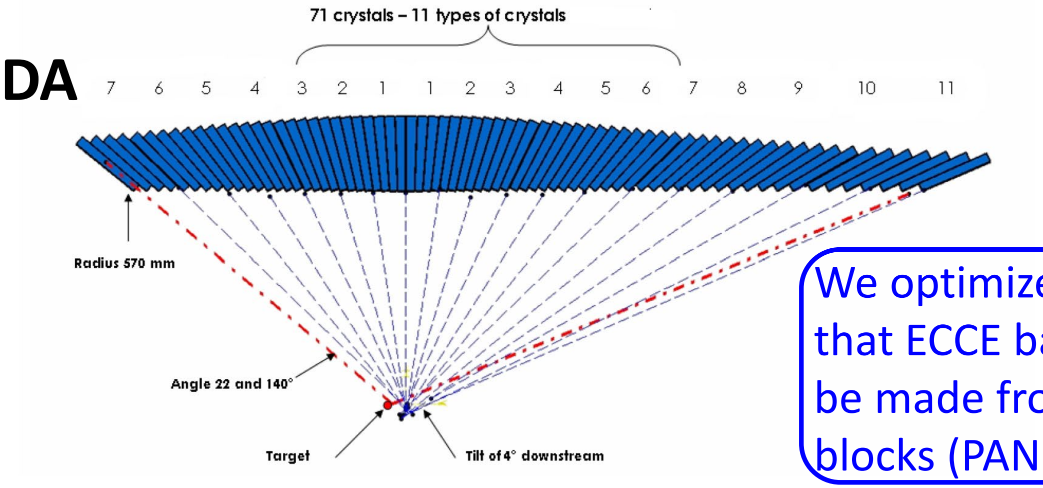



**Figure 5.4:** Crystal arrangement of the barrel along the beam axis. Positions of the different crystal types are indicated. Due to the mirror symmetry, 11 types are sufficient instead of 18.

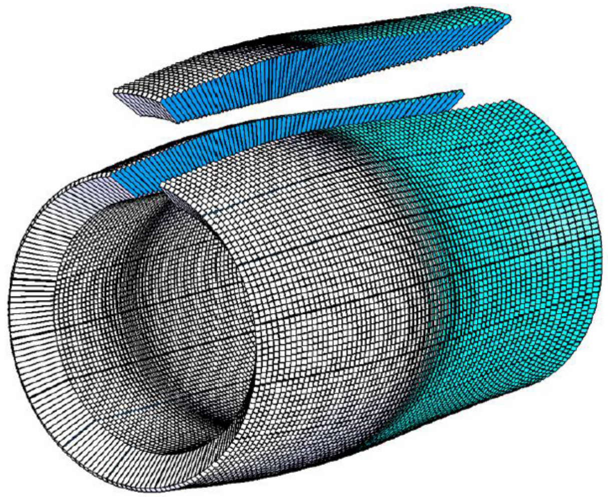
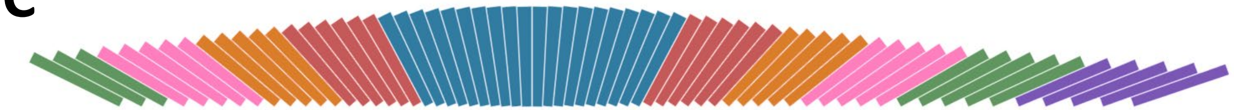


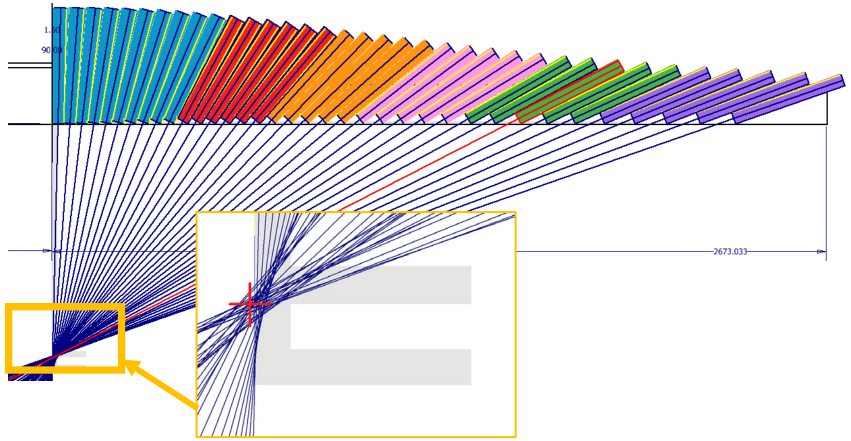
**Figure 5.5:** View of the total barrel volume with a separated single slice of 710 crystals. A slice covering 1/16 of the barrel volume.

**EIC**

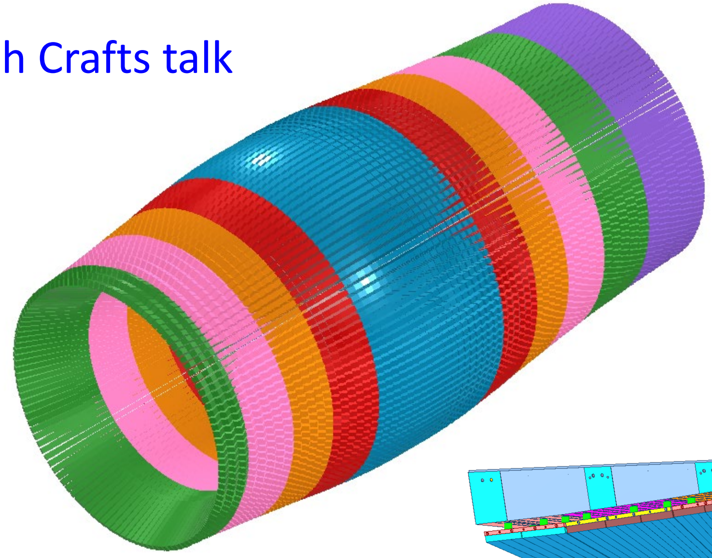
**Based on realistic CAD design (CUA)**

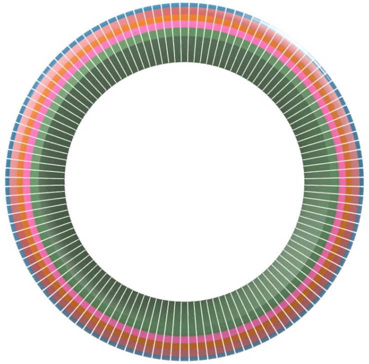


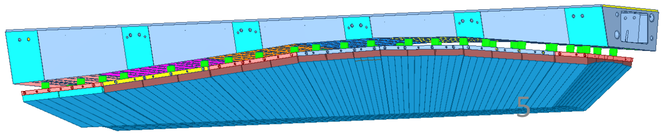
We optimized the geometry so that ECCE barrel calorimeter can be made from 6 families of blocks (PANDA has 11 families)



→ For details see Josh Crafts talk







# 2.A Glass Scintillator (SciGlass) Fabrication

SCINTILEX

**SBIR/STTR DE-SC0020619, DE-SC0021459**

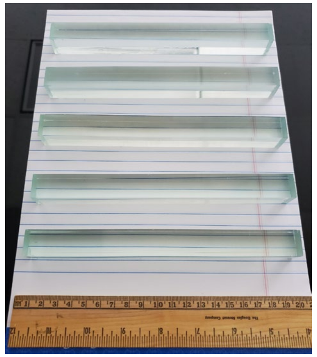
- Scintilex in collaboration with the VSL at CUA has made much progress with the development and fabrication of SciGlass over the last 3 years
- Scintilex has an SBIR phase-II/IIA award to start large-scale production of larger blocks (40+ cm, rectangular and projective shapes) to meet the specific schedule of the EIC
- Sci-Glass of length 20cm can now be produced reliably and 40cm long blocks can now be produced routinely – so far we have received 3 lab size batches (10-20 samples), most recently 25 blocks of 40cm length

Glass pouring into the mold at Scintilex/VSL

Custom fabrication setup for 40cm SciGlass

SciGlass 40cm before polishing

SciGlass 20cm has been produced reliably and 40cm can now we produced routinely



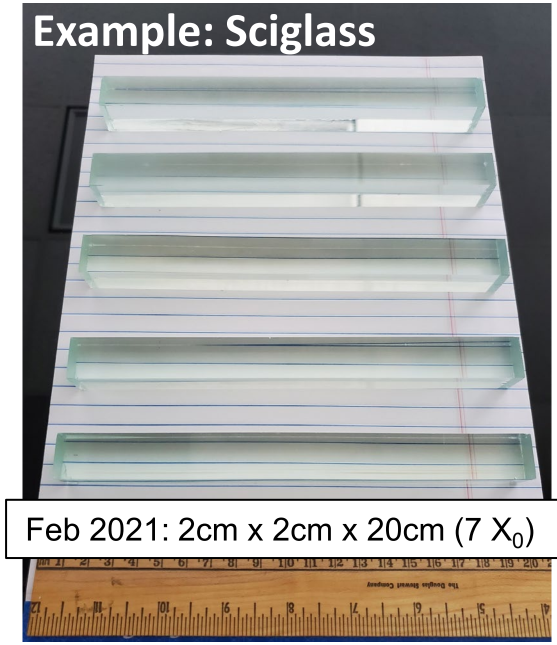
# 2.A Glass Scintillator (SciGlass) Timeline

SCINTILEX

**SBIR/STTR DE-SC0020619, DE-SC0021459**

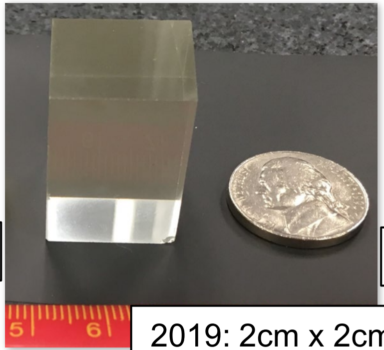
- Pre-STTR Feasibility Studies: 2018 - 2019 (test samples)
- STTR Phase 1: 2020 - 2021 (formulation optimization)
- STTR Phase 2: 2021 – 2023 (scale up to 40cm)
- STTR Phase 2A: 2023 – 2025
- Production: Commercial glass furnaces can produce many tons of glass per day; therefore, production rates of several 1000 glass blocks per day should be achievable, thus greatly expediting the production process and reducing costs.

Main risks of developing high-quality SciGlass were addressed by DOE/SBIR grants and generic detector R&D program




Feb 2021: 2cm x 2cm x 20cm (7 $X_0$)

Dec 2021: 2cm x 2cm x 40cm

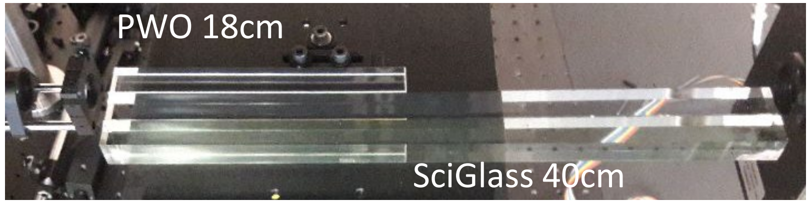


2019: 2cm x 2cm x 4cm

2018: 1cm x 1cm x 1cm

**Spring 2023: SciGlass 40cm can now be produced routinely**

Summer 2022: 2cm x 2cm x 40cm first detector prototypes



# 2.A R&D: eRD105: SciGlass R&D

**The main goal of this R&D project is to demonstrate that SciGlass is a viable cost-effective solution as EIC calorimeter technology**

- ❑ The R&D effort benefits from a separately funded DOE SBIR/STTR Phase 2/2A providing facilities and resources for the glass fabrication and scale-up production
- ❑ eRD105 made good progress in FY22 towards completion – albeit there are delays due to Covid19 and start of R&D funding
- ❑ The remaining R&D in FY23 aims at optimizing the readout (SiPM matrix and services) matched to glass and comparison of different glass geometry shapes with prototypes and beam tests.

SCINTILEX

SBIR/STTR DE-SC0020619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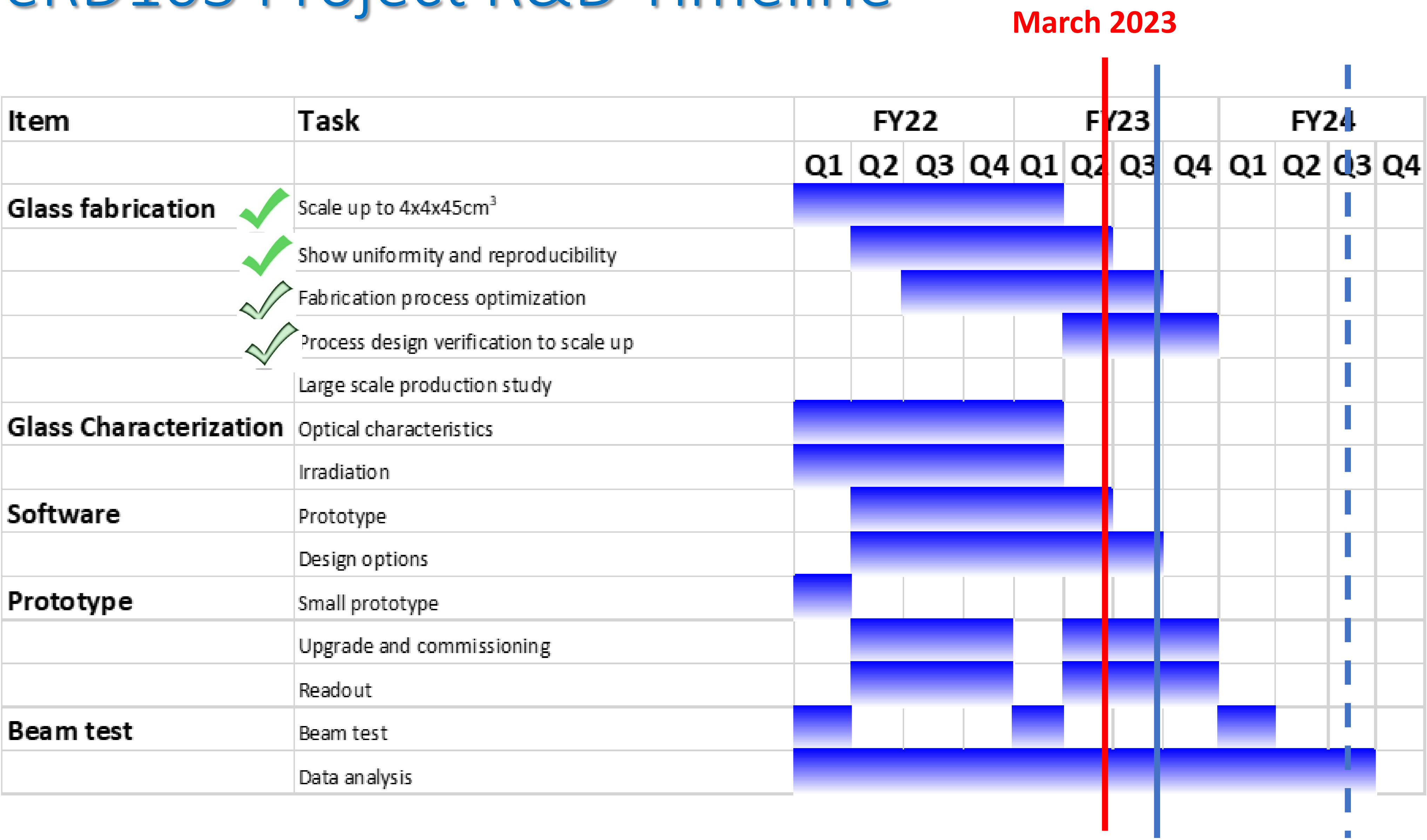
# 2.A R&D: eRD105 Milestones for FY23 and beyond

- **FY23: Scale-up to 40 cm complete**
  - Receive ~25 test samples
  - Beam test with 3x3 (5x5) prototype with 40+ cm. (CUA, AANL, JLab)
    - HallD Jlab beam test logistic: installation, safety, DAQ etc. (JLab)
    - Beam test preparation and data analysis (CUA, AANL)
  - Develop and implement a SiPM-based readout (INFN-GE)
  - Design and test an optimized streaming RO chain (INFN-GE)
  - Sciglass blocks characterization, including Irradiation (IJCLab-Orsay, Kansas U.)
  - Implement process for different geometries (CUA)

A. ALIKHANYAN National Laboratory
The Catholic University of America
Jefferson Lab
Thomas Jefferson National Accelerator Facility
INFN Genova
IJCLab
Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis
THE UNIVERSITY OF KANSAS
SCINTILEX

- FY24: Final test of different geometries
  - projective SciGlass as required for barrel EMCal application
  - optimization of reflector and impact of a carbon fibre inner support structure for the glass blocks on calorimeter performance

# 2.A eRD105 Project R&D Timeline




Not yet taking into account delayed start in Project R&D contracts

**Good progress towards completing the R&D – some items complete ahead of schedule**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# Example of SciGlass Characterization: Radiation Hardness

## EM irradiation:

- ~1 MeV Co-60
- 160 keV Xray

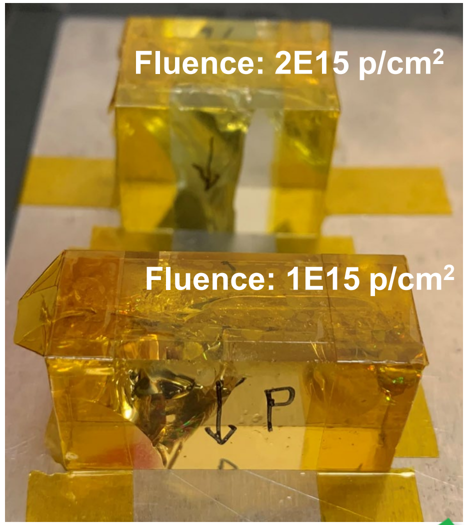
**Before irradiation**

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

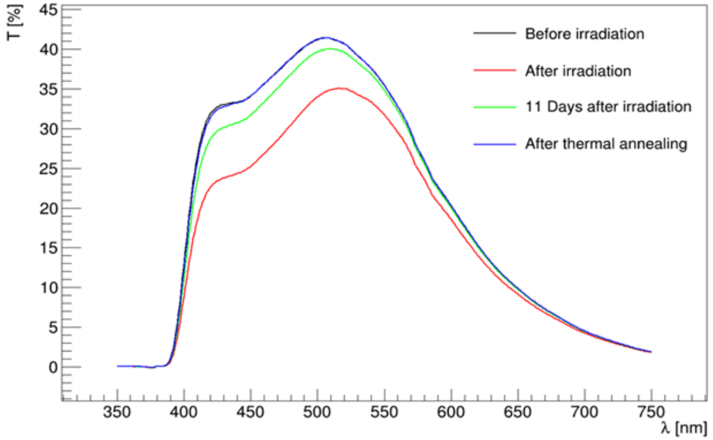
## Hadron irradiation:

- 40 MeV protons

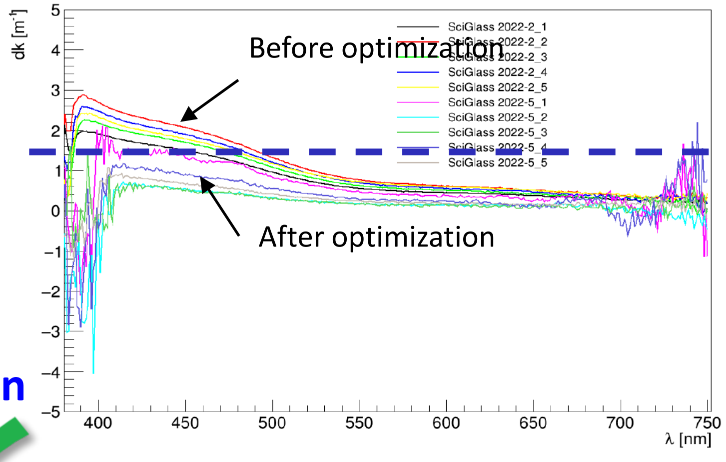
Photograph taken immediately after irradiation. No visual evidence of radiation damage (don't get fooled by the yellow Kapton tape)




## Irradiation of 20cm long blocks (30-100 Gy)

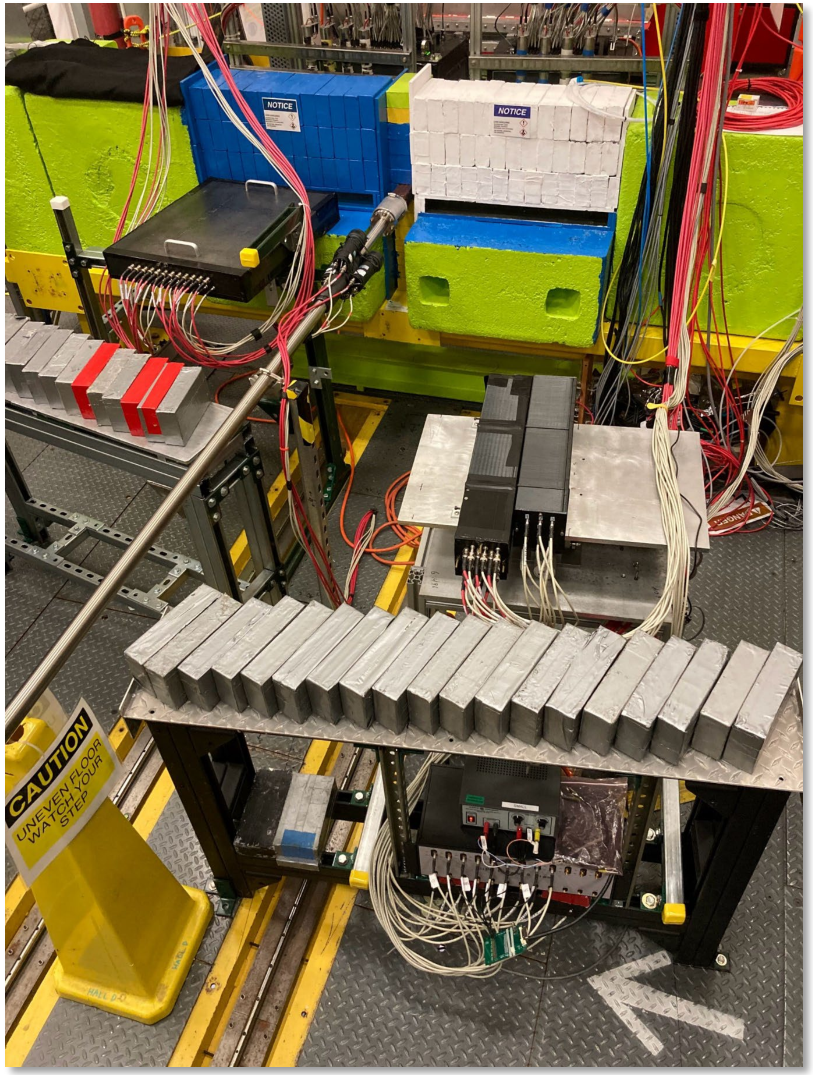



**SciGlass overall consistent with NP specification**

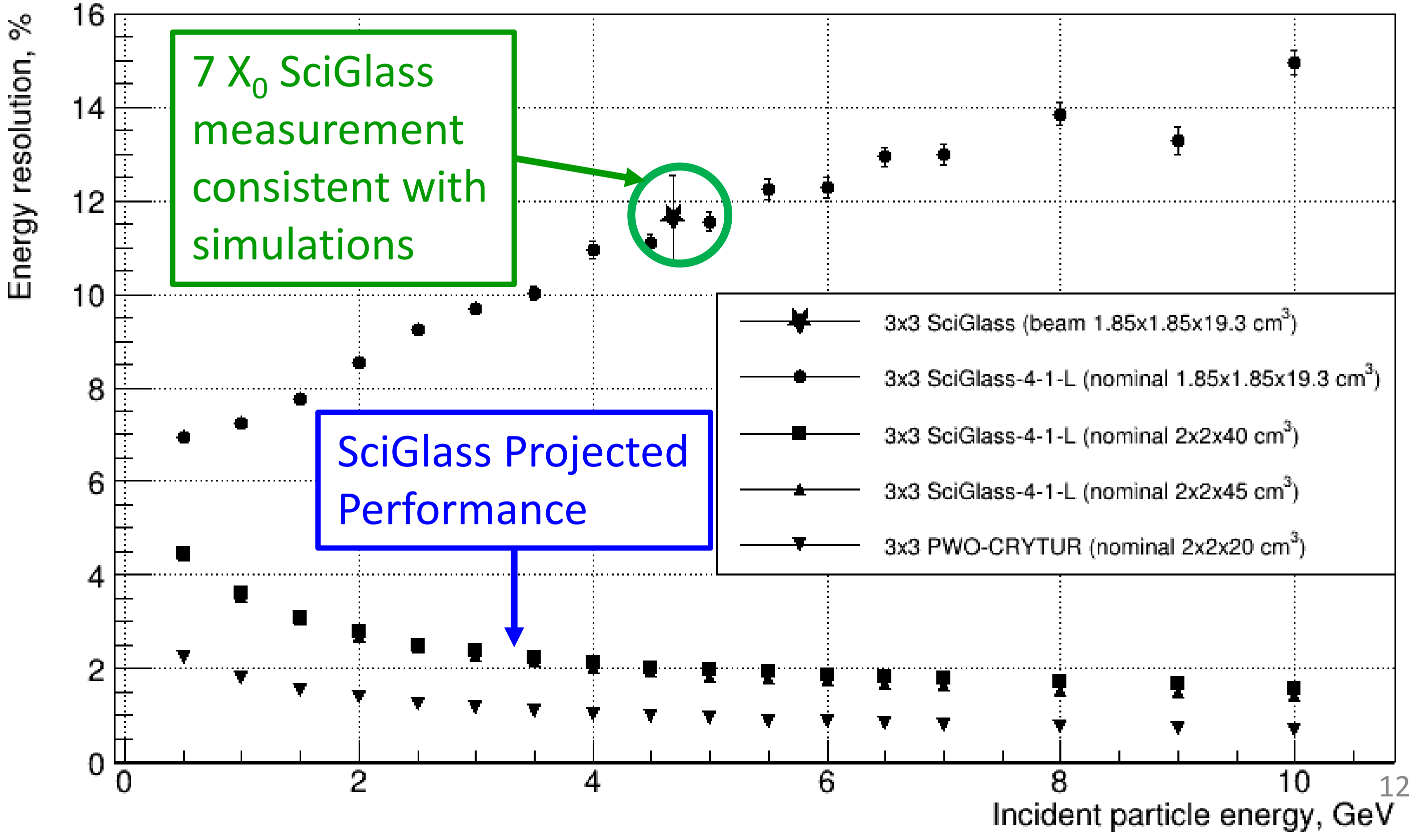


# 2.A 3x3 Prototype tests (20cm) - Complete

SciGlass development is supported by SBIR/STTR DE-SC0020619

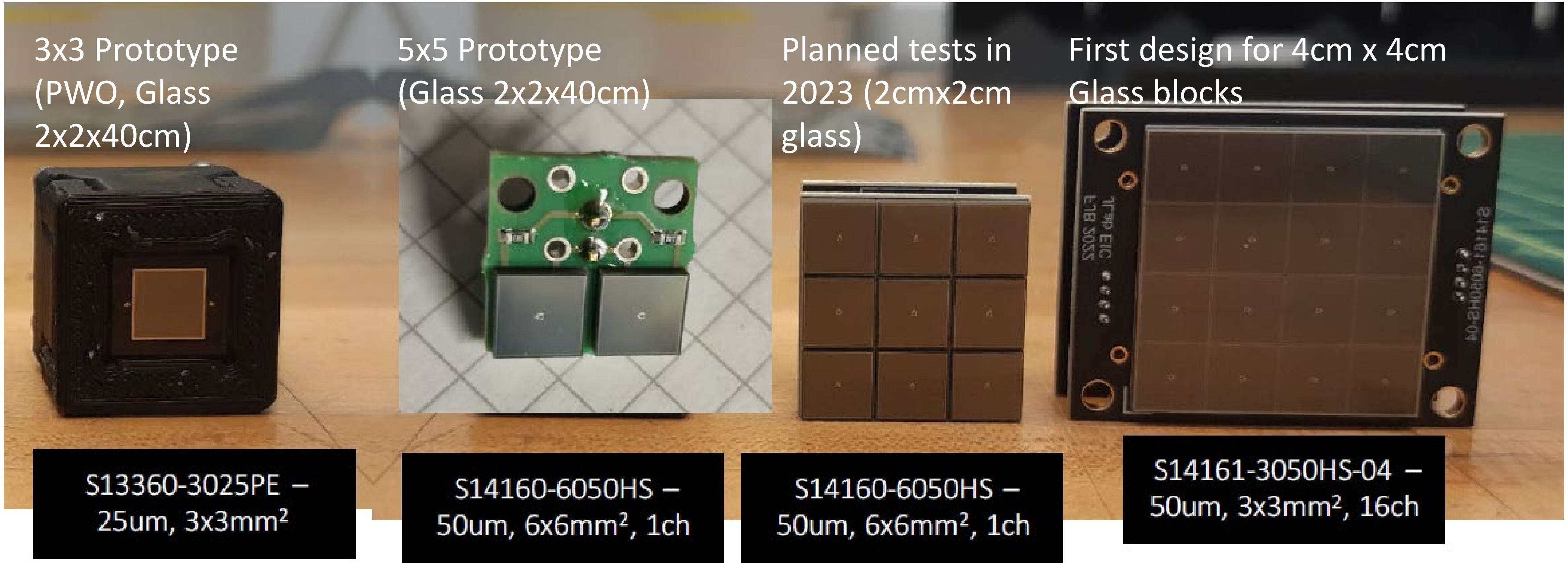


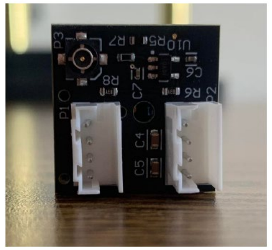

- Prototype 3x3 array installed and tested – energy resolution measured for three different beam energies
- **Results for ~7 $X_0$ blocks – matches with Geant4**
- **Plans for 2022/2023: Test with ~15$X_0$ (40cm) long blocks**

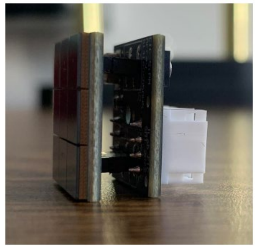


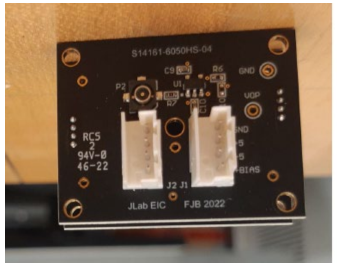
# 2.A Prototype tests 40cm with SiPM Readout

**Goal:** evaluate suitable SiPM device and configurations (matrix and services) for homogeneous calorimeters (also of interest for PWO)



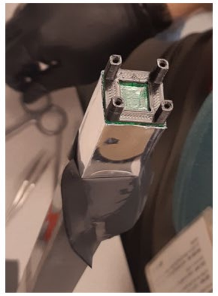




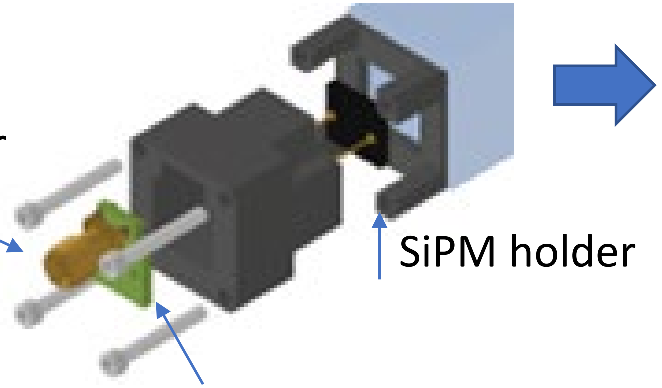
# 2.A 3x3 Prototype 40cm - Complete

**SciGlass development is supported by SBIR/STTR DE-SC0020619**

## Readout Configuration



- ❑ Each glass block read by 1 SiPM (Hamamatsu S13360-3025PE)
- ❑ Bias voltage and signal amplification provided by custom designed board
- ❑ 2 piece holder concept developed to attach SiPM to glass

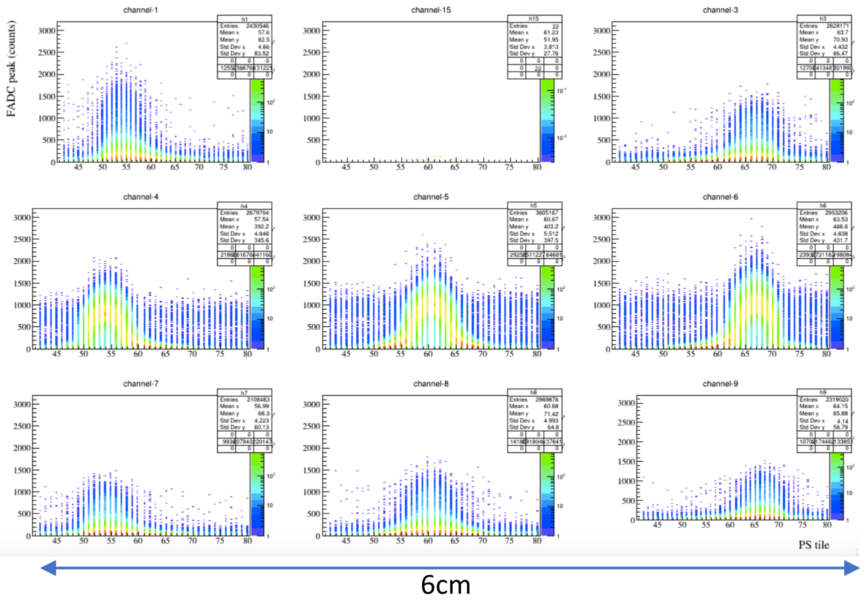


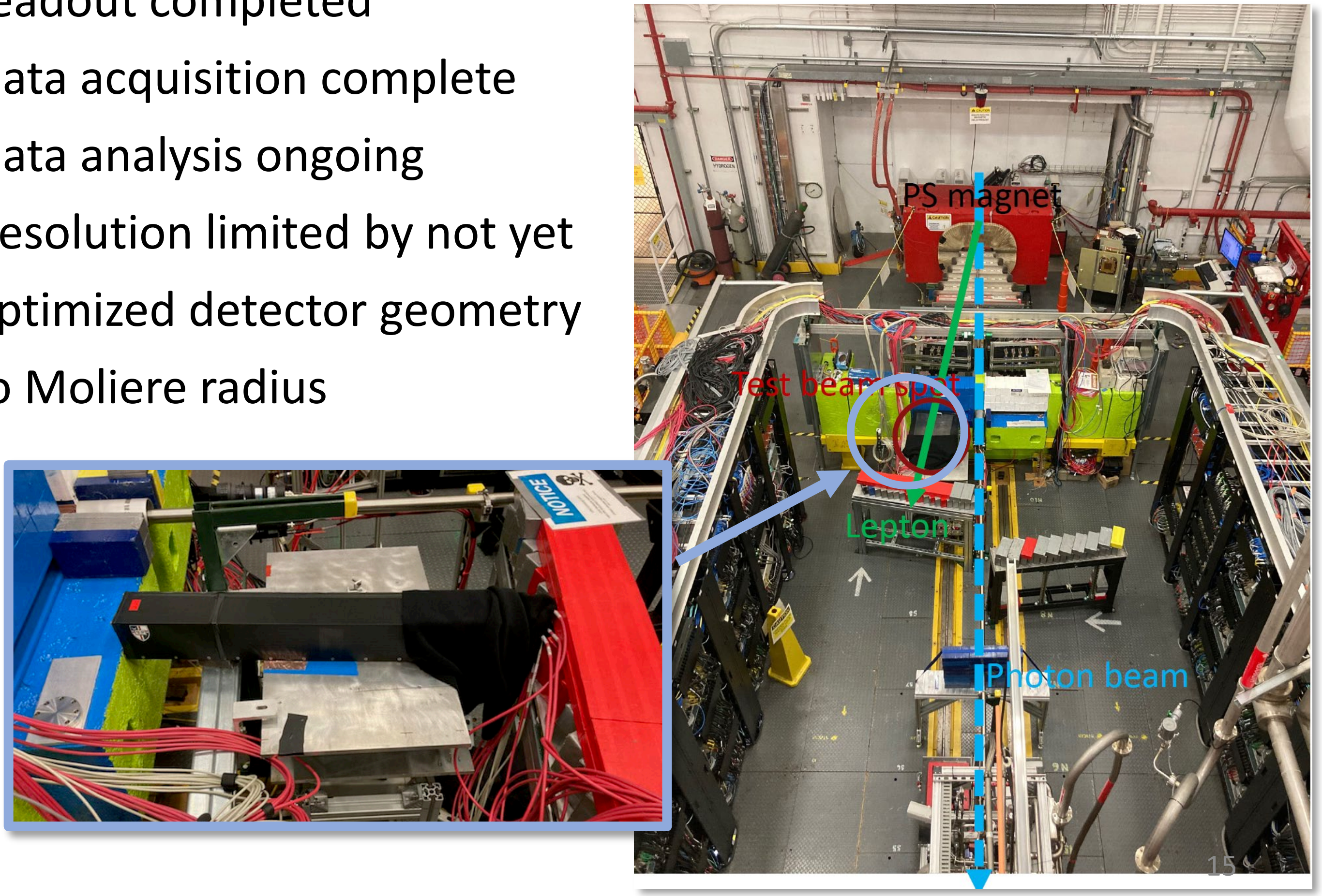

# 2.A 3x3 Prototype 40cm - Complete


## Installation and first data

**SciGlass development is supported by SBIR/STTR DE-SC0020619**


- December 2022: First test with ~15$X_0$ (40cm) long blocks and SiPM readout completed
- Data acquisition complete
- Data analysis ongoing
- Resolution limited by not yet optimized detector geometry to Moliere radius



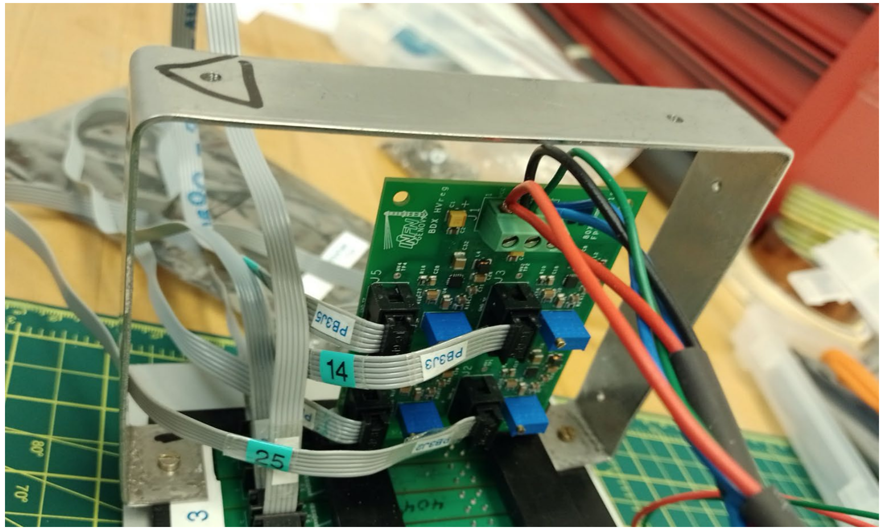
# 2.A 5x5 Prototype 40cm - Ongoing

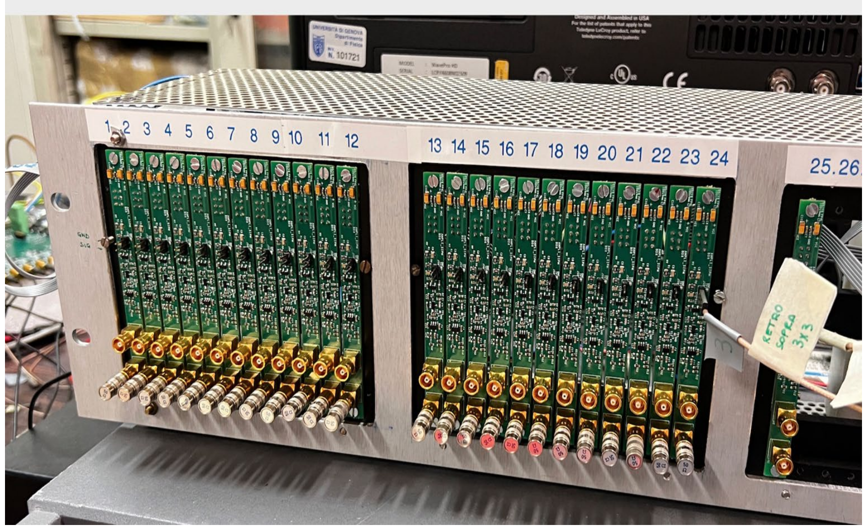
## Readout Configuration

- Each glass block read by 2 SiPMs (Hamamatsu S14160-6050HS)
- Bias voltage provided by custom designed board
- Signal amplification by custom transimpedance amplifier
- Commissioning for beam test at ~4 GeV:
  - Single PE test – 5-6 mV amplitude, 600pW area
  - Cosmics to check for saturation
  - Amplifier test
  - Energy deposition projections

Two readout configurations are tested in parallel in this beam test campaign:

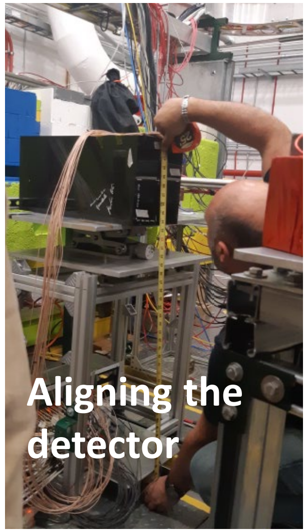
1) Nominal trigger
2) Streaming Readout (details not discussed here)



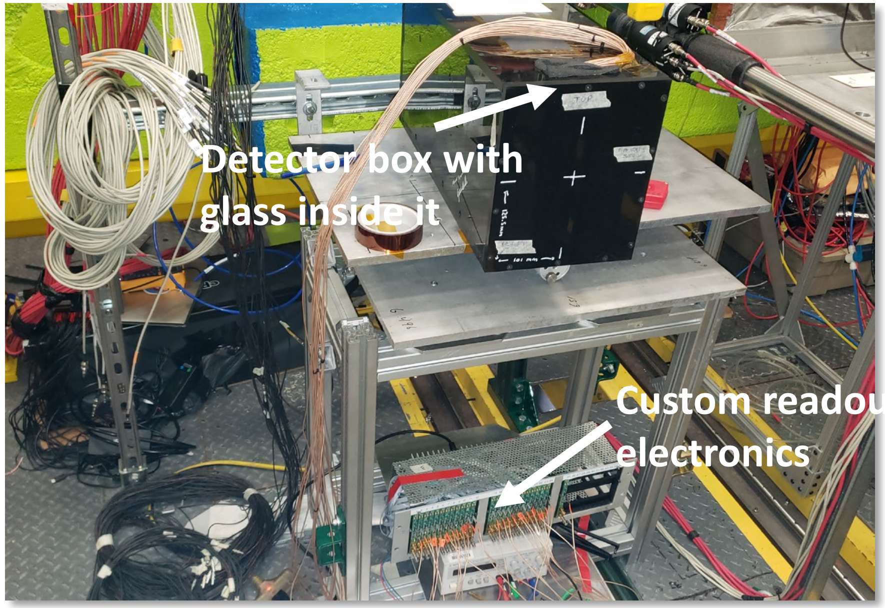
# 2.A 5x5 Prototype 40cm - Ongoing

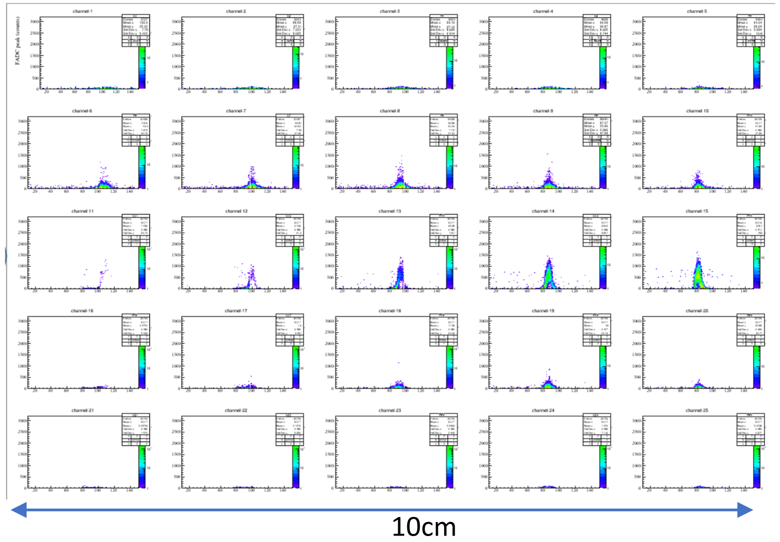
## Installation and first data


- ❑ Installation and alignment completed
- ❑ Initial commissioning allowed to isolate and address issues (e.g., bad connection at fADC)
- ❑ Next (March 2023): complete any remaining fixes and start production data (triggered and SRO), make calibrations, extract resolutions, test different SiPM matrix
- ❑ Future test planned at CERN summer 2023

**5x5 Prototype in the beamline**



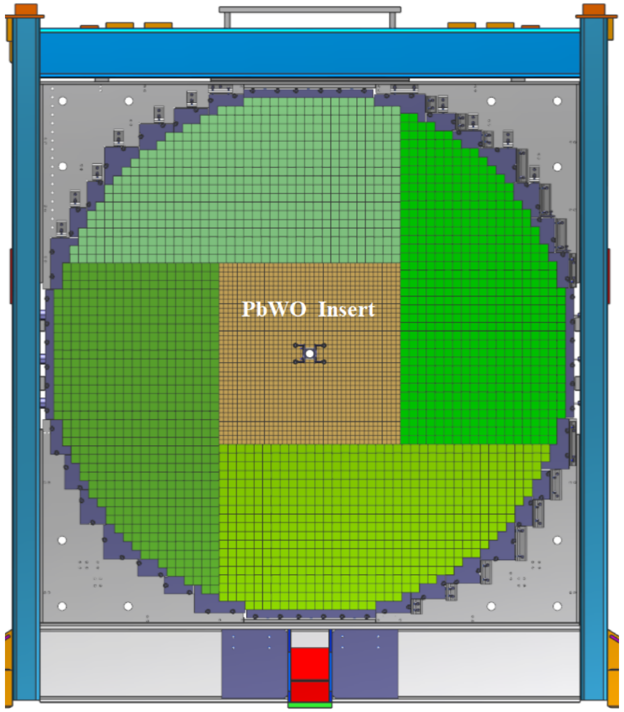

**First amplitude data**

# 2.B Homogeneous EM Calorimeters at JLab

**Based on PWO crystals and glass**


**Neutral Particle Spectrometer (Hall A/C)**

Nucl.Instrum.Meth.A 956 (2020) 163375




**Forward CAL Insert (Hall D)**



**HMS and SHMS EMCal (Hall A/C)**

# 2.B Homogeneous Scintillating Glass Calorimeters in Experiments

Scintillating Glass of different formulation has been used for beam tests and as EMCal in the 1980s

https://inspirehep.net/literature/261664

**Performance of a scintillating glass calorimeter for electromagnetic showers, 1988**

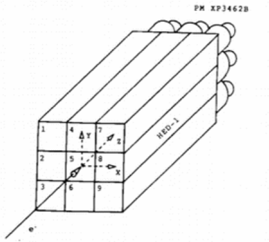


Fig. 3. Layout of the calorimeter setup in the test beam.

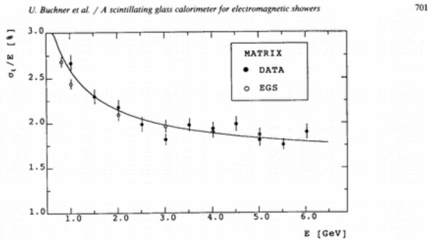



Fig. 12. Energy resolution as a function of the electron energy (black circles) and the EGS prediction (open circles). The line shows the parametrization (4) described in the text.

8x8x66 cm^3

**1.46%/E+2.4%/sqrt(E)+1.63%**

https://inspirehep.net/files/1299a6aa1e200e01f9d7f208800a81f6

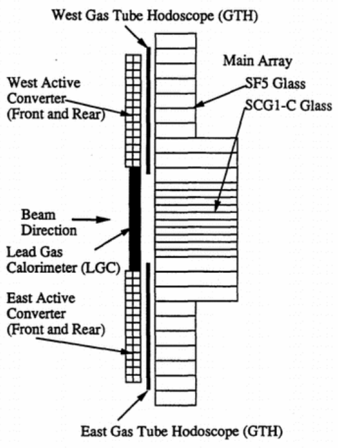



Figure 1. Plan view of the major components of the Experiment 705 calorimeter

| | SCG1-C | SF5 |
|---|---|---|
| Composition (by weight) | BaO 43.4%<br>SiO2 42.5%<br>Li2O 4.0%<br>MgO 3.3%<br>K2O 3.3%<br>Al2O3 2.0%<br>Ce2O3 1.5% | PbO 55%<br>SiO2 38%<br>K2O 5%<br>Na2O 1% |
| Density | 3.36 g/cm3 | 4.08 g/cm3 |
| Radiation Length | 4.25 cm | 2.47 cm |
| Absorption Length (30-200GeV/c2 pions) | 45.6 cm | 42.0 cm |

Table 1. Properties of SCG1-C Scintillating and SF5 Lead Glass

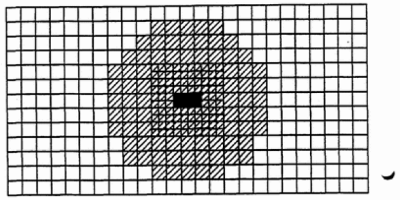


Figure 2. Beam view of the Main Array (SCG1-C scintillating glass is cross-hatched)

**The Experiment 705 Electromagnetic Shower Calorimeter, 1993**

15.x15.x89 cm^3
7.5x7.5x89 cm^3

Rad. Length 20.9 X0

**0.99%+4.58%/sqrt(E)**

***Resolution for mixed calorimeter (lead glass and SCG1-Glass)***

**Results from 1980s scintillating glass calorimeters encouraging → Need to establish performance for SciGlass (different formulation)**

# Summary

- Concept: Homogeneous EM calorimeter – typical materials in lepton induced hadron scattering: crystals and glass, a **well-established detector technology**
- Barrel EMCal readout electronics can be identical with the backward EM calorimeter → **no additional technology required**
- **Moderate number of readout channels**
- Advanced design concept built on PANDA precision homogeneous barrel EMCal design
- Experienced team of institutions (AANL, CUA, FIU, JMU, UKY, MIT..) including **many early-career researchers** working on design, simulation, Prototypes
- Main risks of developing high-quality SciGlass were addressed by DOE/SBIR grants and generic detector R&D program


→ See Rosi Reed talk

→ See Josh Crafts talk

→ See Renee Fatemi talk

→ See Dmitry Kalinkin talk

# 2.B Scintillating Glass considered for future HEP experiments

**Table 3.** Optical and scintillation properties of candidate inorganic scintillators for CalVision and the HHCAL concept

| | BGO | BSO | PWO | $PbF_2$ | PbFCl | Sapphire:Ti | AFO Glass | DSB:Ce Glass[1] | DSB:Ce,Gd Glass[2,3] | HFG Glass[4] |
|---|---|---|---|---|---|---|---|---|---|---|
| Density ($g/cm^3$) | 7.13 | 6.8 | 8.3 | 7.77 | 7.11 | 3.98 | 4.6 | 3.8 | 4.7 - 5.4 | 5.95 |
| Melting point (°C) | 1050 | 1030 | 1123 | 824 | 608 | 2040 | 980[5] | 1420[6] | 1420[6] | 570 |
| $X_0$ (cm) | 1.12 | 1.15 | 0.89 | 0.94 | 1.05 | 7.02 | 2.96 | 3.36 | 2.14 | 1.74 |
| $R_M$ (cm) | 2.23 | 2.33 | 2.00 | 2.18 | 2.33 | 2.88 | 2.89 | 3.52 | 2.56 | 2.45 |
| $\lambda_I$ (cm) | 22.7 | 23.4 | 20.7 | 22.4 | 24.3 | 24.2 | 26.4 | 32.8 | 24.2 | 23.2 |
| $Z_{eff}$ value | 72.9 | 75.3 | 74.5 | 77.4 | 75.8 | 11.2 | 42.8 | 44.4 | 48.7 | 56.9 |
| dE/dX (MeV/cm) | 8.99 | 8.59 | 10.1 | 9.42 | 8.68 | 6.75 | 6.84 | 5.56 | 7.68 | 8.24 |
| Emission Peak[a] (nm) | 480 | 470 | 425<br>420 | \ | 420 | 300<br>750 | 365 | 440<br>460 | 440<br>460 | 325 |
| Refractive Index[b] | 2.15 | 2.68 | 2.20 | 1.82 | 2.15 | 1.76 | \ | \ | \ | 1.50 |
| LY (ph/MeV)[c] | 7,500 | 1,500 | 130 | \ | 150 | 7,900 | 450 | 3,150 | 2,500 | 150 |
| Decay Time[a] (ns) | 300 | 100 | 30<br>10 | \ | 3 | 300<br>3200 | 40 | 180<br>30 | 120, 400<br>50 | 25<br>8 |
| d(LY)/dT (%/°C)[c] | -0.9 | ? | -2.5 | \ | ? | ? | ? | -0.04 | -0.04 | -0.37 |
| Cost ($/cc) | 6.0 | 7.0 | 7.5 | 6.0 | ? | 0.6? | ? | 2.0 | 2.0? | ? |

a. Top line: slow component, bottom line: fast component.
b. At the wavelength of the emission maximum.
c. At room temperature (20°C).


1. E. Auffray, et al., J. Phys. Conf. Ser. 587, 2015
2. R. W. Novotny, et al., J. Phys. Conf. Ser. 928, 2017
3. V. Dormenev , et al., the ATTRACT Final Conference
4. E. Auffray, et al., NIMA 380 (1996), 524-536
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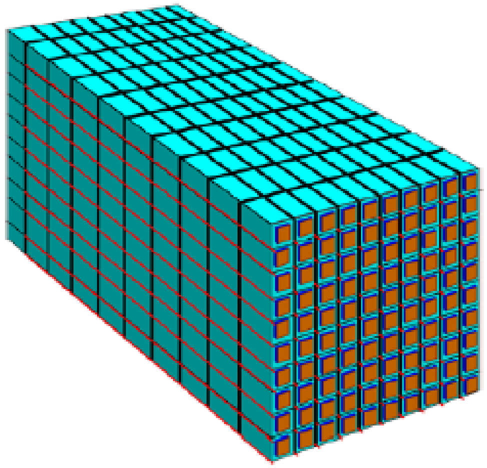
6. I. G. Oehlschlegel, Glastech. Ber. 44, 1971


Low density crystals/glasses



https://arxiv.org/ftp/arxiv/papers/2203/2203.07154.pdf

https://detectors.fnal.gov/projects/calvision/