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Sci-Glass Update

Joshua Crafts
The Catholic University of America / Jefferson Lab

A. Asaturyan, M. Battaglieri, J. Bettane, M. Bondi, A. Celentano, J. Crafts, R. DeVita, Y. Ghandilyan, S. Grazzi, T. Horn, G. Hull, M. Josselin, I.L. Pegg, H. Gan, S. Mayilyan, C. Munoz-Camacho, A. Mkrtchyan, H. Mkrtchyan, M. Murray, N. Pilleux, A. Shahinyan, M. Spreafico, A. Somov, V. Tadevosyan, R. Trotta, H. Voskanyan, Y. Zhu

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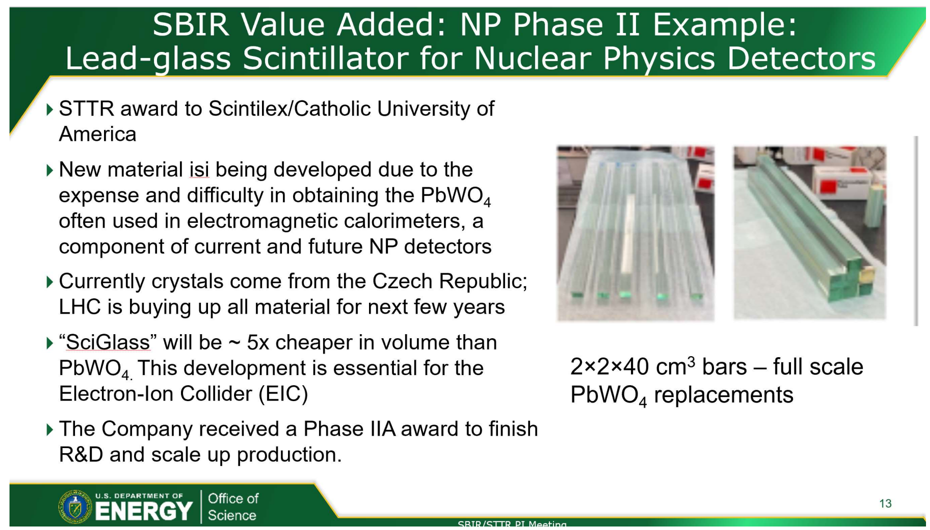
Introduction:

- **Growing Interest in scintillating glass materials**
  - Increasing interest in these glasses in the global nuclear and also high-energy physics community.
    - EIC Detector R&D program - SBIR value added (Phase 2A awarded)
    - A proposal for R&D on scintillator materials for the ECFA DRD& calorimetry was submitted
    - Letters of interest to Snowmass organized by the American Physical Society Division of Particles and Fields

- Much progress made on scintillating glass development and to capitalize on that a generic FY24 R&D proposal on glass scintillator for EIC calorimeters was submitted:
  - Goal: demonstrate scintillating glass with matched areal photosensor coverage and readout electronics over a large dynamic range as a viable cost-effective solution that can be used in the streaming readout DAQ.
  - 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.

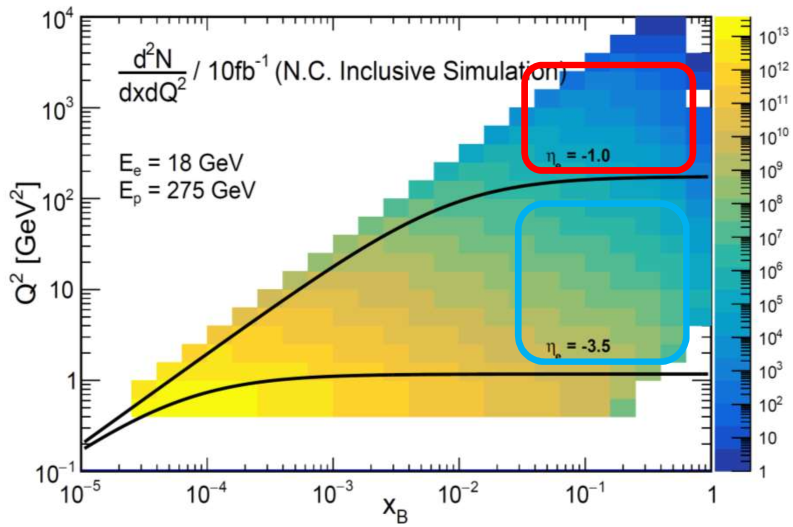


Slide from Dr. Timothy Hallman, Associate Director, Office of Science for Nuclear Physics, presentation at the 2023 Jefferson Lab User Group Meeting.

Context: Precision EM Calorimetry

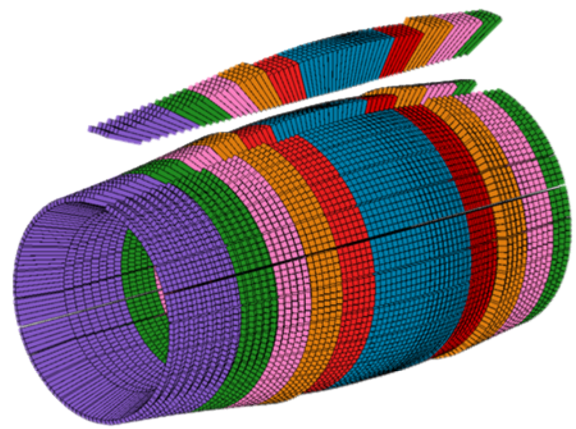
Scattered electron kinematics measurement is essential at the EIC and will remain so for 2nd detector

- ❑ High precision, hermetic detection of the scattered electrons will be necessary over a broad range in η and over energy range from 0.1 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
- ❑ SciGlass (developed with DOE/STTR) supports excellent e/h separation due to its good energy resolution, matched to the backward region requirements while being more cost effective than crystal alternatives.



Requirements

- ❑ Good energy resolution
  - e.g., region -2 < η < -1 requires ~7%/√E
- ❑ e/h separation up to 10^{-4}



eRD105: Summary

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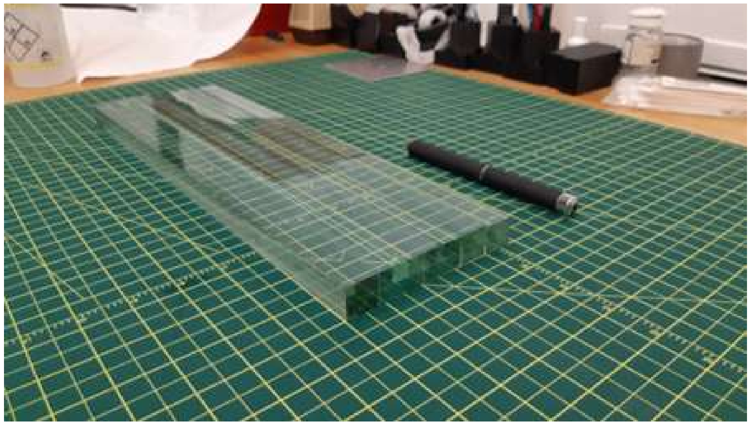
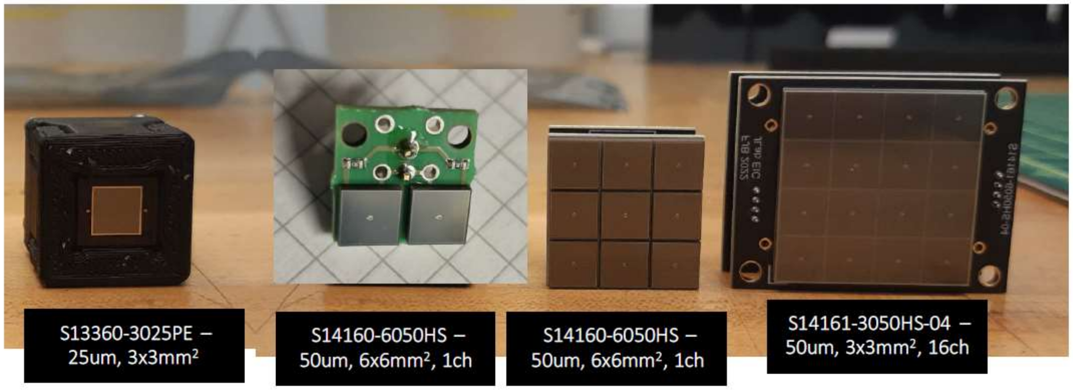
- **FY23: Scale-up to 40 cm complete**
  - ✓ Receive ~25 test samples
  - ✓ Beam test with 3x3 (5x5) prototype with 40+ cm. (CUA, AANL, JLab)
  - ✓ Develop and implement a SiPM-based readout (INFN-GE)
  - ✓ Design and test an optimized streaming RO chain (INFN-GE)
  - Sciglass blocks characterization, including Irradiation (IJCLab-Orsay, Kansas U.)

  → **progress, cross-checks are planned for early October at Giessen U.**
  - Implement process for different geometries (CUA)

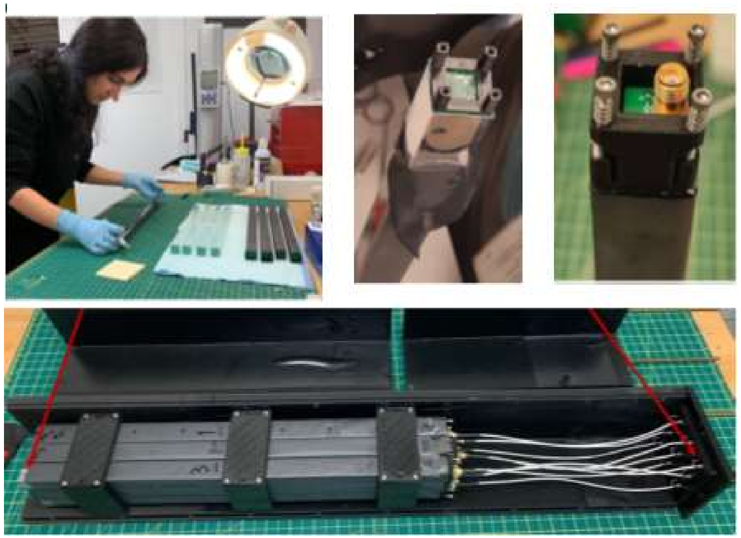
  → **progress, to be completed with Phase 2A**



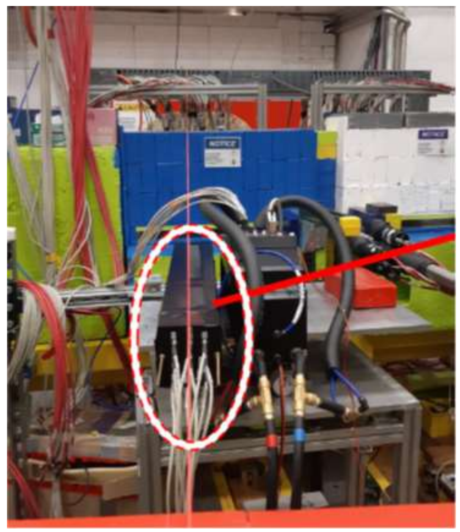


Prototype Beam Tests - 3x3 with 40cm blocks

Prototype construction



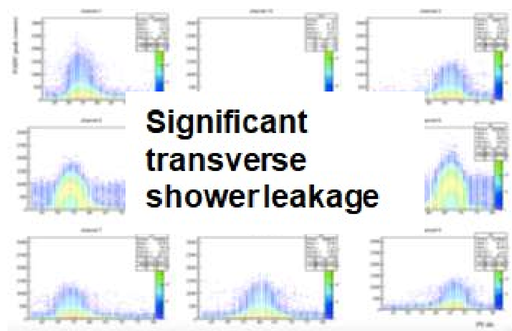
Prototype in Hall D at JLab

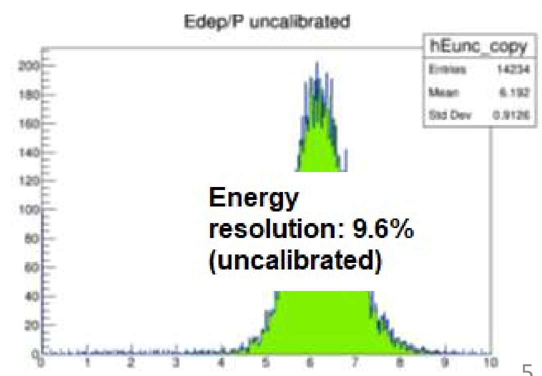


SciGlass development is supported by SBIR/STTR DE-SC0020619

- 3x3 array prototype with SiPM readout, envisioned for EIC and other NP experiments
- Custom matrix of 50micron pixel pitch, devices –> compact readout size: longitudinal dimensions ~2cm without cables and services

The longitudinal shower is now largely contained in the 40cm block in comparison with our earlier tests with 20cm long blocks, but there is significant transverse shower leakage that increases the energy resolution → need larger array of 40cm long blocks





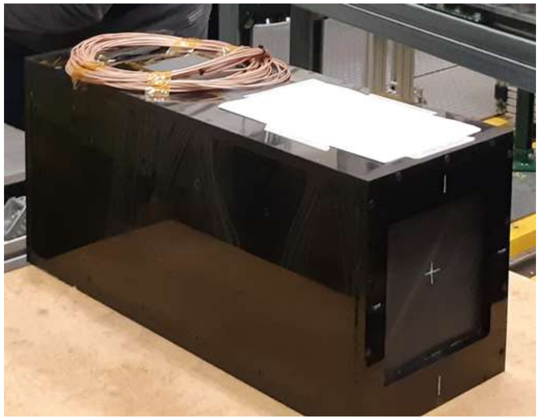
Prototype Beam Tests – 5x5 with 40cm blocks

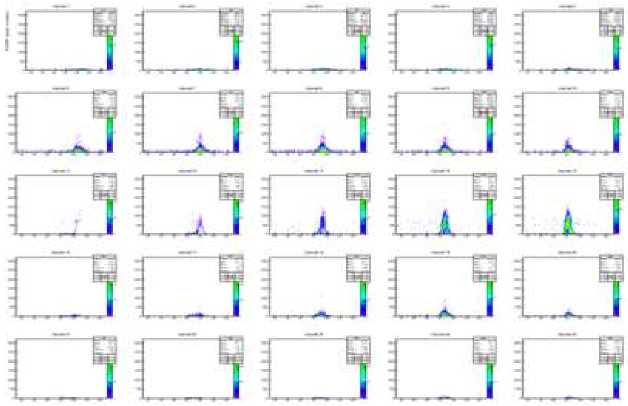
Initial test with a 5x5 prototype

- 25 glass blocks of dimensions 2x2x40cm^3 and Hamamatsu SiPMs (S14160-6050HS) - two per block
- Sensors were powered with custom biasisng circuitry based on Jlab detectors. The SiPM signal was processed with a custom trans-impedance amplifier
- Signals were acquired using two branches: streaming (SRO) and triggered DAQ (standard hall method), both using FADCs
- Placed downstream form the high granularity pair spectrometer in the test beam station

Preliminary results

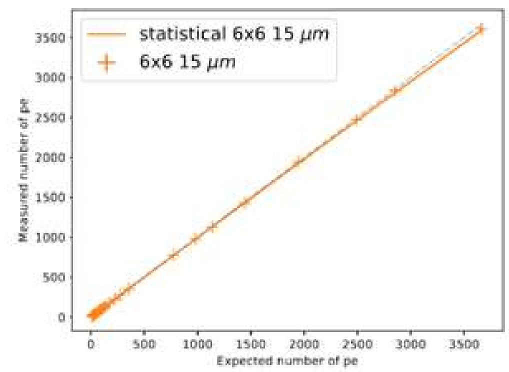
- Demonstrated SiPMs and SRO (envisioned for EIC) for SciGlass – both streaming and triggered DAQ provided similar results
- The EM shower was reconstructed correctly, but a rate-dependent gain variation – traced back to the biasing circuitry – plus a too narrow pre-set signal integration window increased the energy resolution

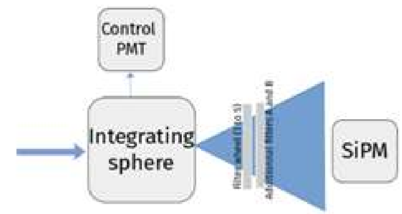


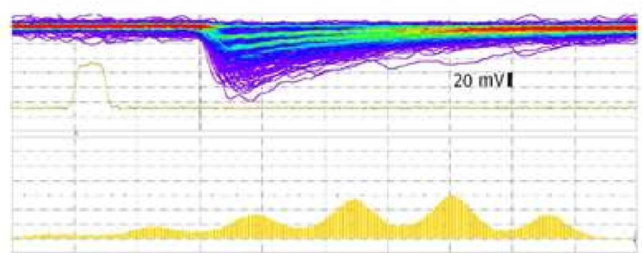


SiPM Test Bench Characterization

- **Calorimeters at EIC require photo-sensors with a very large dynamic range expanding more than 3 orders of magnitude.**
  - Both the Hamamatsu S14160-6015 and S14160-6010, high density, large array SiPMs were tested at IJCLab-Orsay and were shown to have linearity within 2% over 3 orders of magnitude and were within statistical expectations (figure on right).
    - Promising Candidates.
- **The SiPM must also detect at low energies**
  - Requires low dark current in order to trigger signals close to the single p.e. amplitude
  - These SiPM waveforms (figure on right) were measured using a low intensity LED and show a clear separation between the individual p.e. signals allowing for valid small signal identification







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

Program of the Generic R&D

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.

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

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Program of the Generic R&D (cont.)

- **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.

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Summary and Path Forward

- Much progress made with scintillating glass development for EIC and increasing global interest in scintillating glass technology
  - Scale up to 40cm complete and demonstrated reliable production
  - Recently completed beam tests demonstrate SiPM+SRO for SciGlass
  - STTR Phase 2A awarded
- To keep up the momentum, submitted a FY24 Generic Detector R&D proposal that will build on the successful research of the last years
  - Goal: demonstrate scintillating glass with matched areal photosensor coverage and readout electronics over a large dynamic range as a viable cost-effective solution that can be used in the streaming readout DAQ.
  - 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.

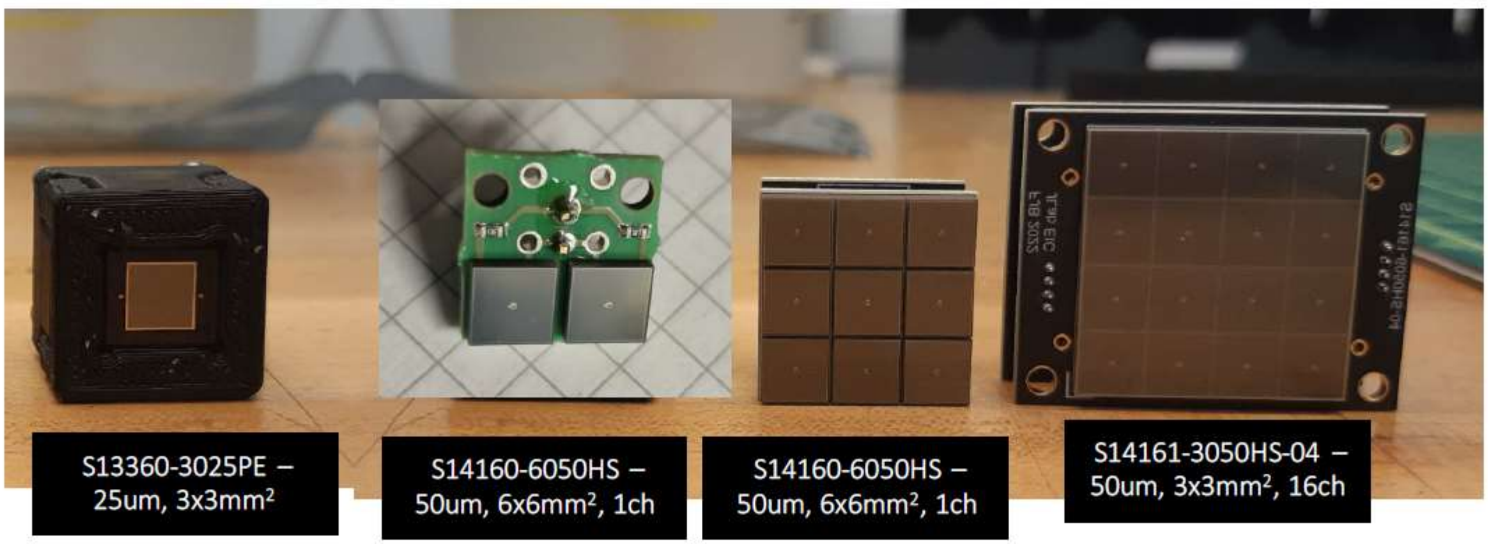
Thank you for your time.
Questions?

[redacted]

Backup Slides

Ongoing SiPM integration:

- Research is ongoing in collaboration with INFN and CRYTUR to develop SiPM integration for application onto Sci-Glass for full detector implementation.
    - Initial 3x3 prototypes instrumented with single SiPM channel readouts
    - 5x5 prototype instrumented with 2x Hamamatsu S1416-6050HS SiPMs per channel
    - Next step test bench examination of the 3x3 matrix of individually packaged SiPMs
    - Large array multi SiPM packages in testing for larger geometry glass blocks



Cherenkov Glass Update:

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- Cherenkov or CSGlass is the other project ongoing in collaboration with VSL Scintilex to produce another detector glass.
  - This glass has a base formula derived from the Sci-Glass but will have a higher density due to it being hadronically compensated
  - Ongoing tests to separate the Cherenkov component of the light signal from the scintillating light
  - Multiple avenues being pursued.
    - Wavelength filtering
    - Timing seperation
    - AI/ML Studies
- Further test bench studies and in beam tests will follow

SCINTILEX