Highly Transparent Aerogel with Refractive Index < 1.01

- Scintilex
- Aerogel Cherenkov detectors in NP
  - Two examples
- Experiment Requirements and STTR goals
- Project Overview and results
- Outlook

SCINTILEX

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Business Official: Ian L. Pegg

Award: DE-SC0019536

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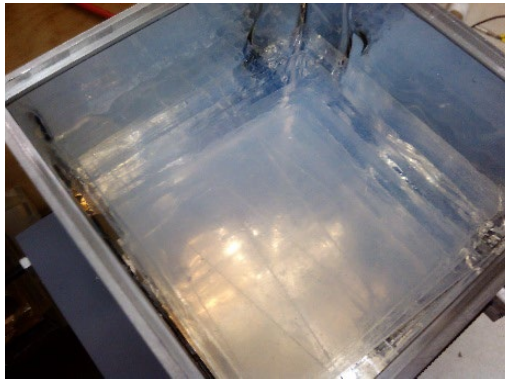
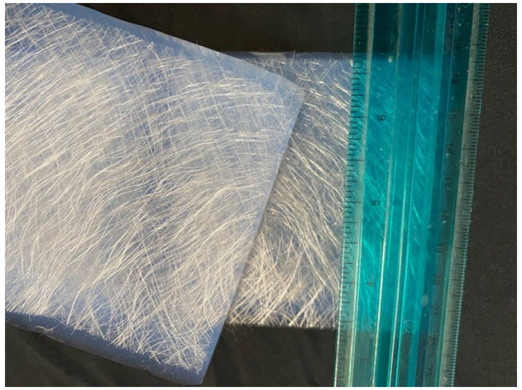
Scintilex Overview

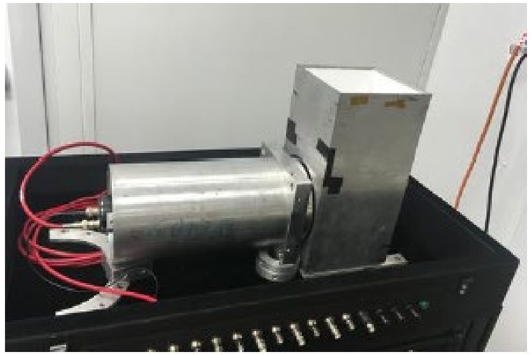
- Main focus: design and construction of instrumentation based on Cherenkov and scintillation light using novel materials
  - Applications: particle detection in nuclear physics experiments and homeland security; also medical



- Activities and expertise
  - R&D new detector materials
  - Pilot testing and scale up; hardware
  - Software development and DAQ systems



- Activities related to aerogel
  - JLab SHMS/HMS detectors; CLAS12 RICH
  - eRD14 EIC Consortium, mRICH
  - PANDA anti-proton test runs



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Cherenkov Detectors

- Goal: Particle Identification for charged subatomic particles, e.g. distinguish protons, pions, and kaons through Cherenkov radiation

- Two main types of Cherenkov detectors:

  - Ring-Imaging Cherenkov (RICH) – determine particle velocity by measuring the Cherenkov angle

$$\mathrm{Cos}\theta > \frac{1}{n\beta} \qquad \beta > \frac{v}{c}$$

  - Threshold detectors – separate two types of particles by determining whether or not each fulfills the threshold condition for Cherenkov radiation

$$v_t > \frac{c}{n}$$

- Material Choice: transparent gases, condensed materials, or Aerogel - depends on velocity range expected and specifics of experiment

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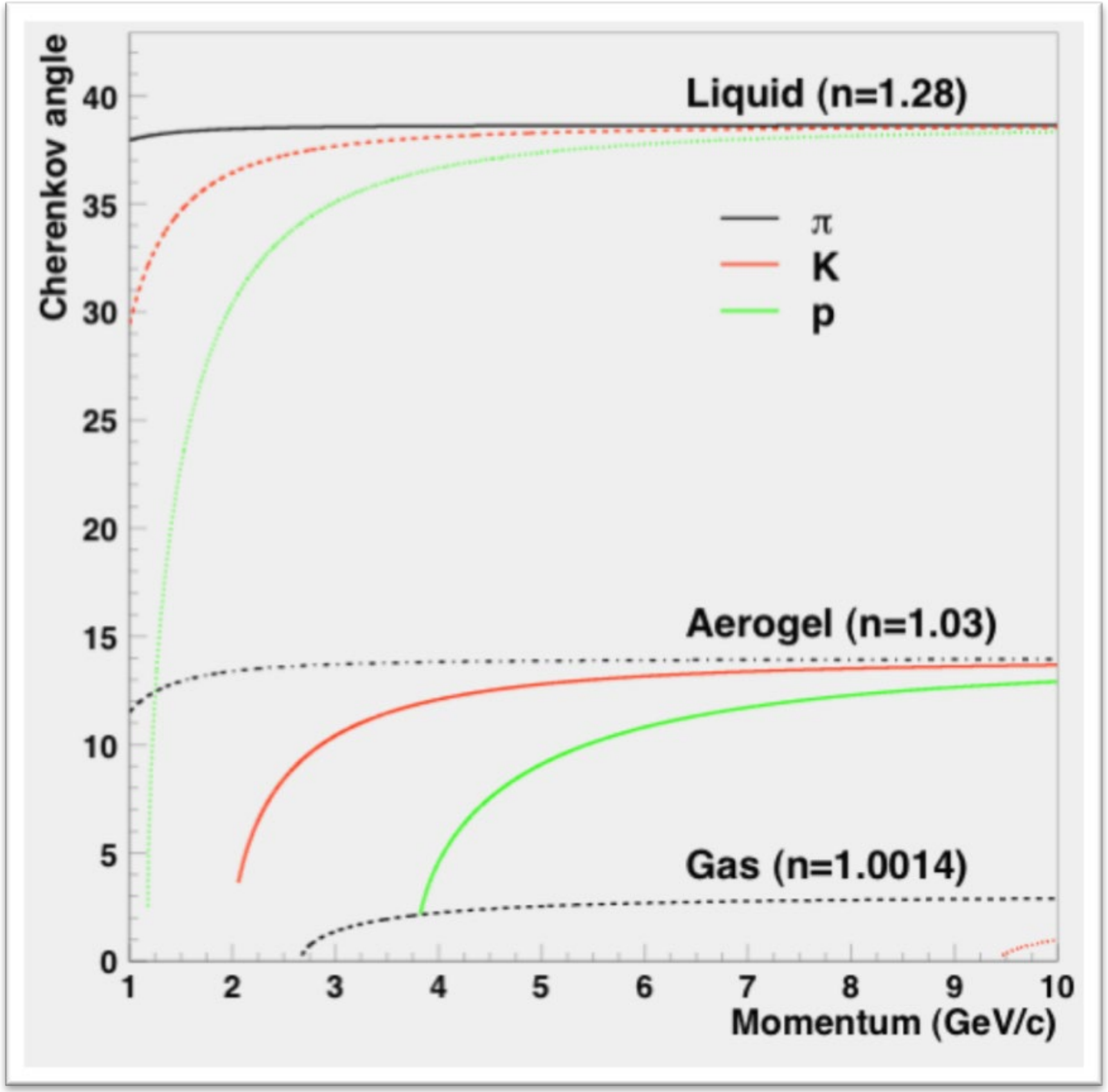
Radiators for Cherenkov Light



- ❑ Aerogel is mandatory to separate hadrons in the 2-8 GeV/c momentum range
- ❑ Rayleigh scattering is the dominant cause of aerogel image degradation
- ❑ Rayleigh scattering increases as λ^{-4}
  ➔ collection of visible Cherenkov light
- ❑ Cherenkov Light is a WEAK source of radiation
  ➔ Medium should be as transparent as possible

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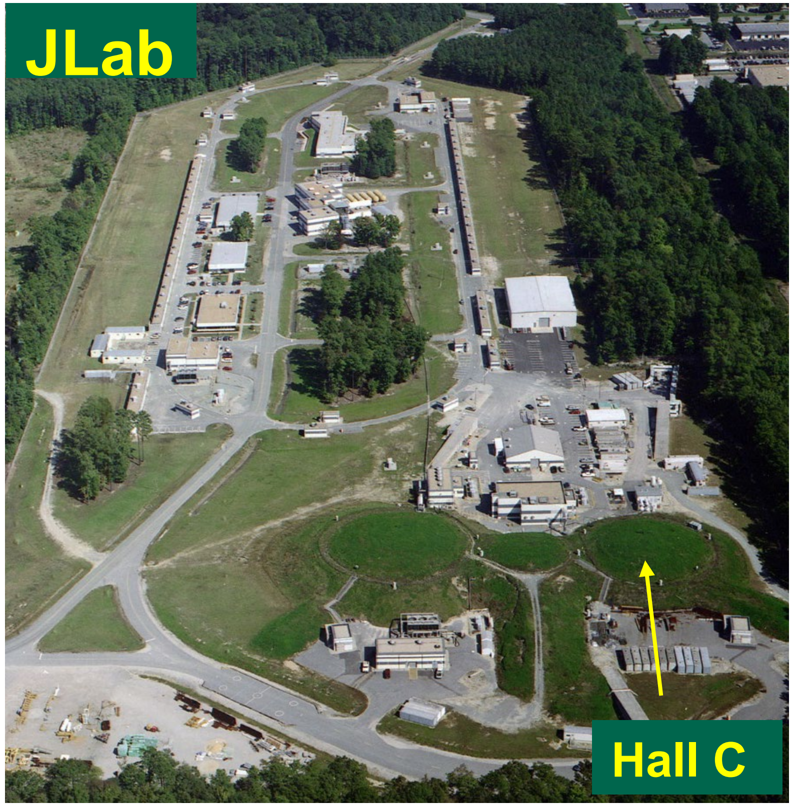
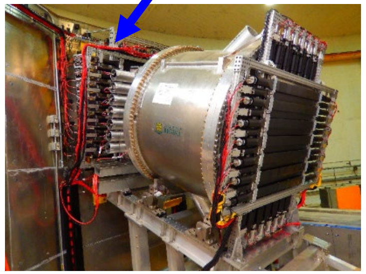
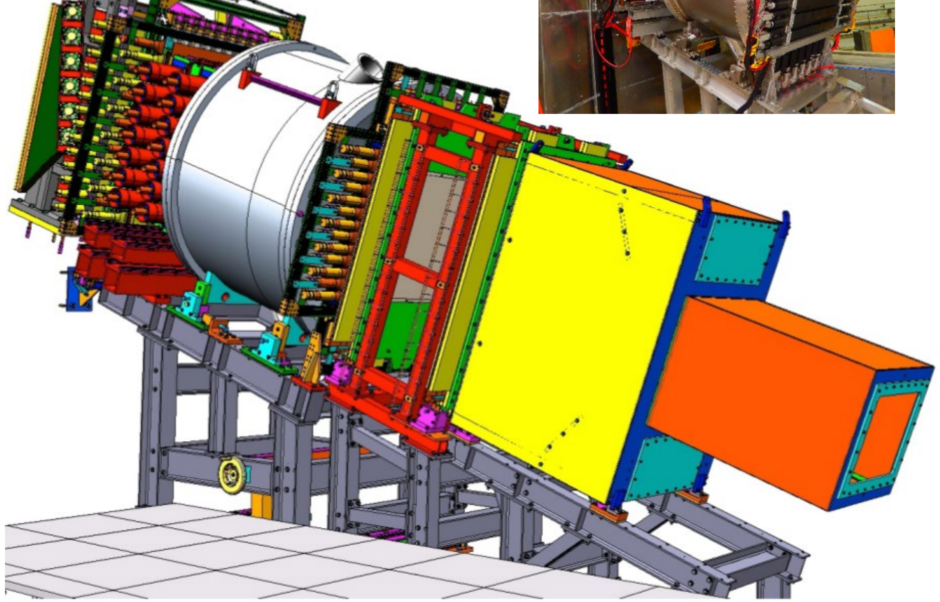
1. The Hall C SHMS Aerogel Detector



Jefferson Lab, Newport News, Virginia

Built by CUA 2011-13, in operation since 2014





Hall C Super-High Momentum Spectrometer (SHMS)

SHMS aerogel detector goal: distinguish protons from kaons from 1 to 10 GeV/c

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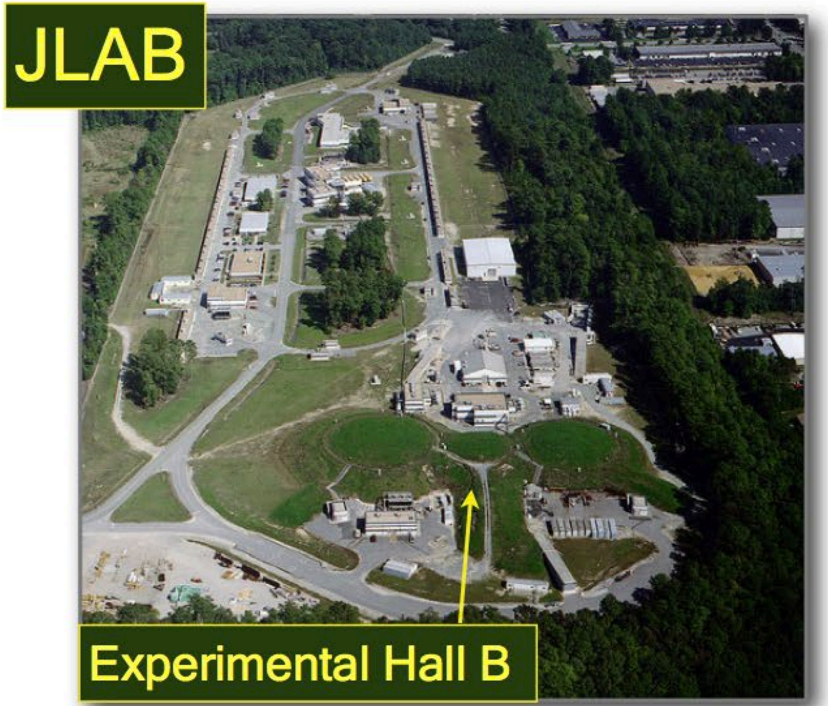
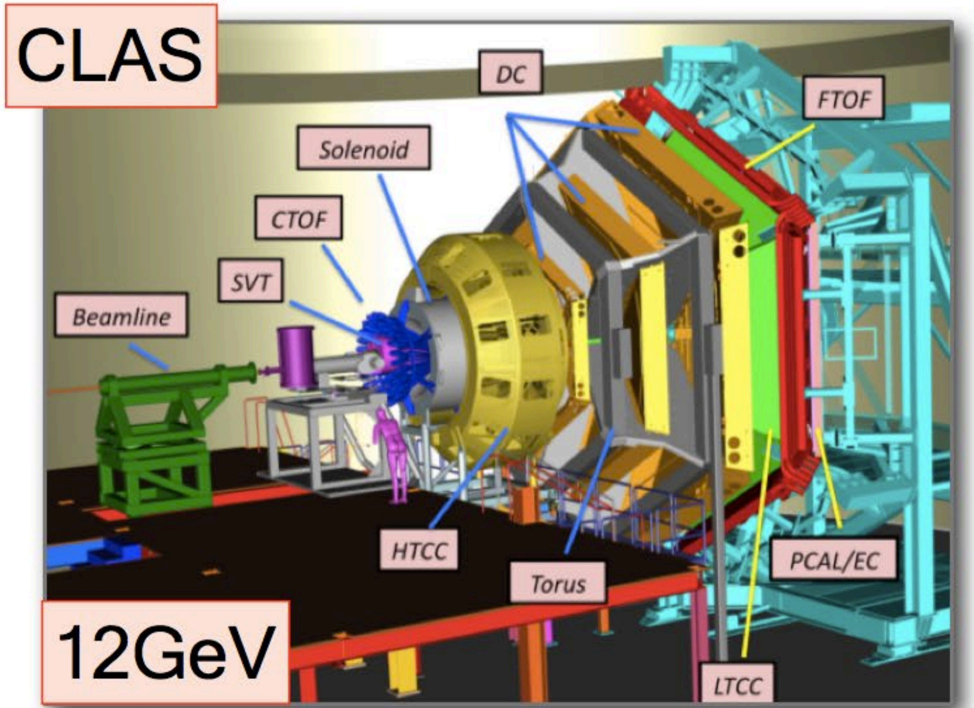
2. The CLAS12 RICH



Continuos Electron Beam Accelerator Facility (CEBAF)



CEBAF Large Acceptance Spectrometer (CLAS)

RICH goal: **π/K/p identification from 3 up to 8 GeV/c and 25 degrees**

~4σ pion-kaon separation for a pion rejection factor ~ 1:500

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Experimental Requirements Summary

Mechanical

- Dimension tolerance: 0.25% of tile size in transverse dimension and 1-2% in thickness
- Tile integrity: >95% of tiles without bubbles, visible cracks and >95% of tiles without chips on corners; chips limited to <1% area
- Surface planarity: Δ_{surf} < 1% of lateral side

Optical

- Density variation: < 4.7%
- Refractive index variation: <0.2%
- Scattering length better than 43 mm at 400nm
- Absorption coefficient: A >0.95

- Tile sizes as large as possible
- Index <1.01 for high momenta

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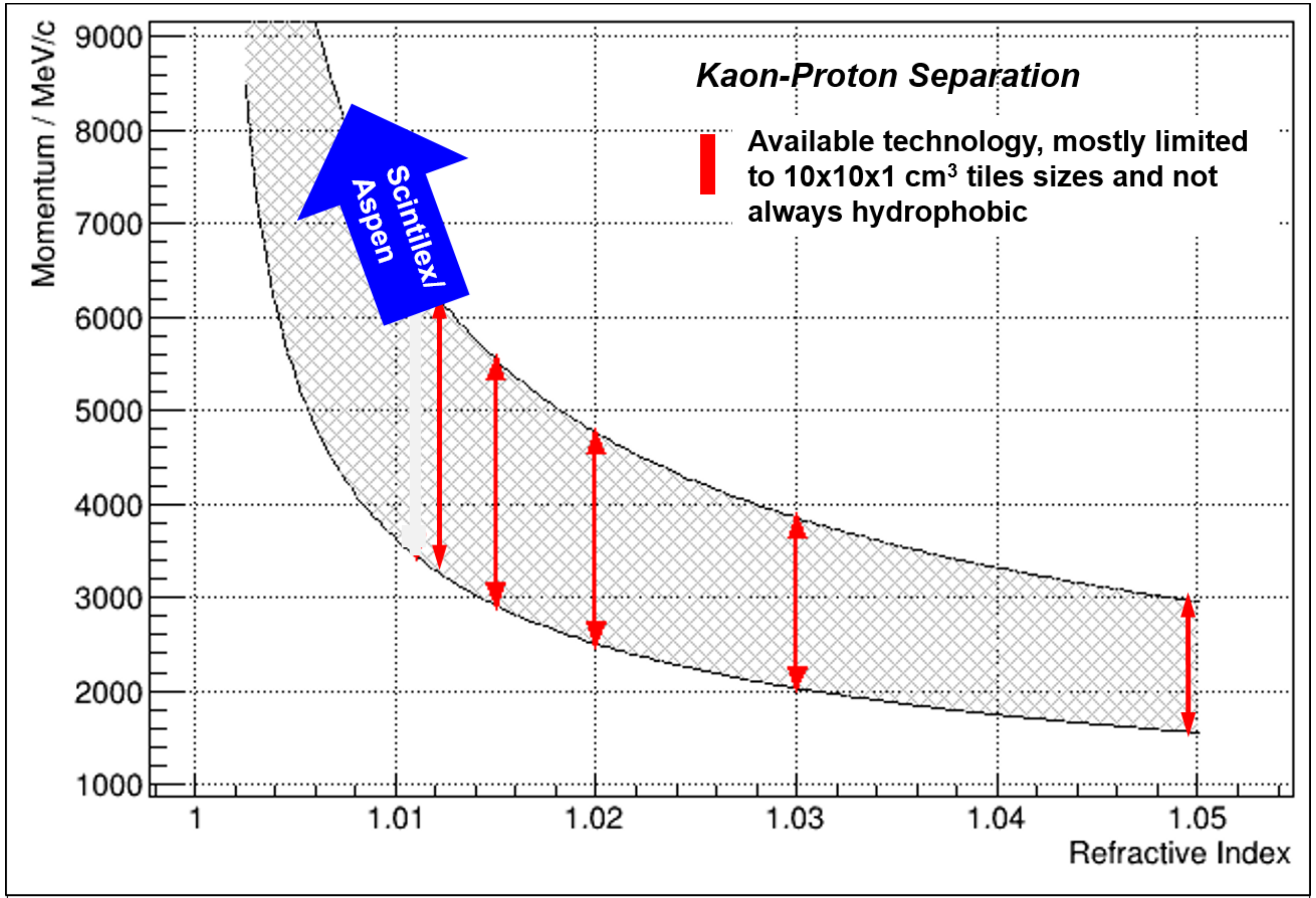
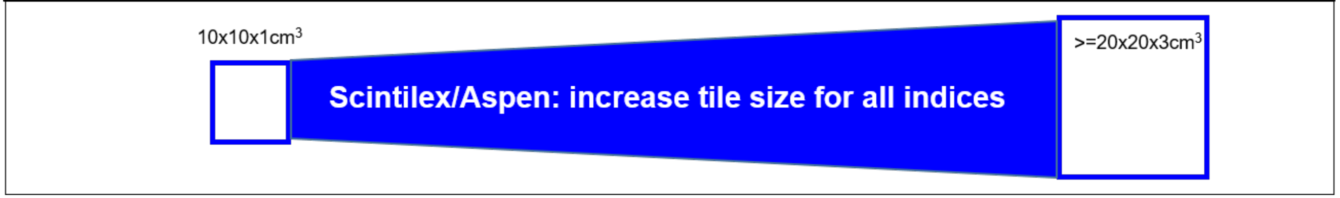
Scintilex - STTR Concept





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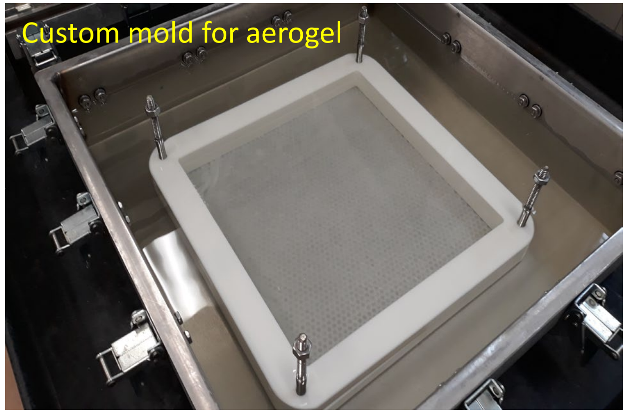
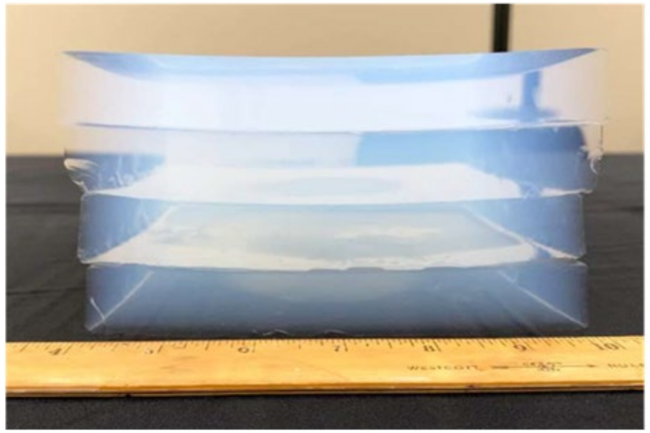
Production of Aerogel Monoliths (Tiles)

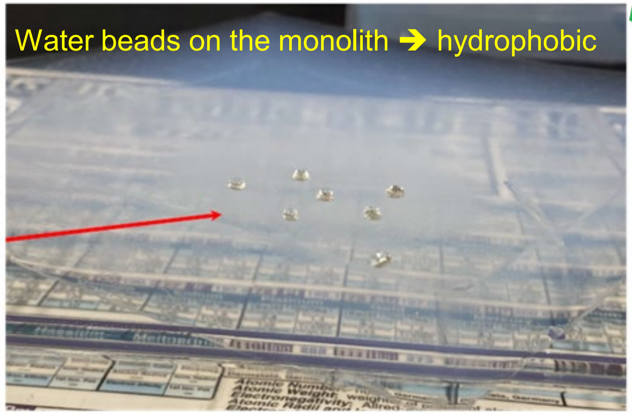




Monoliths are ~15cmx15cm in area

Monoliths thickness >2cm

- ❑ Developed a process to address the previously observed surface curvature of gels with thickness > 2cm - physics requires the gels to be as flat as possible



- ✔ Successfully fabricated thick (> 2cm) aerogel monoliths with refractive index <1.01
  - Sol-Gel formulation was developed during Phase-1 and further optimized during Phase-2
- ✔ The monoliths fulfill the mechanical specs
- ✔ The monoliths are hydrophobic

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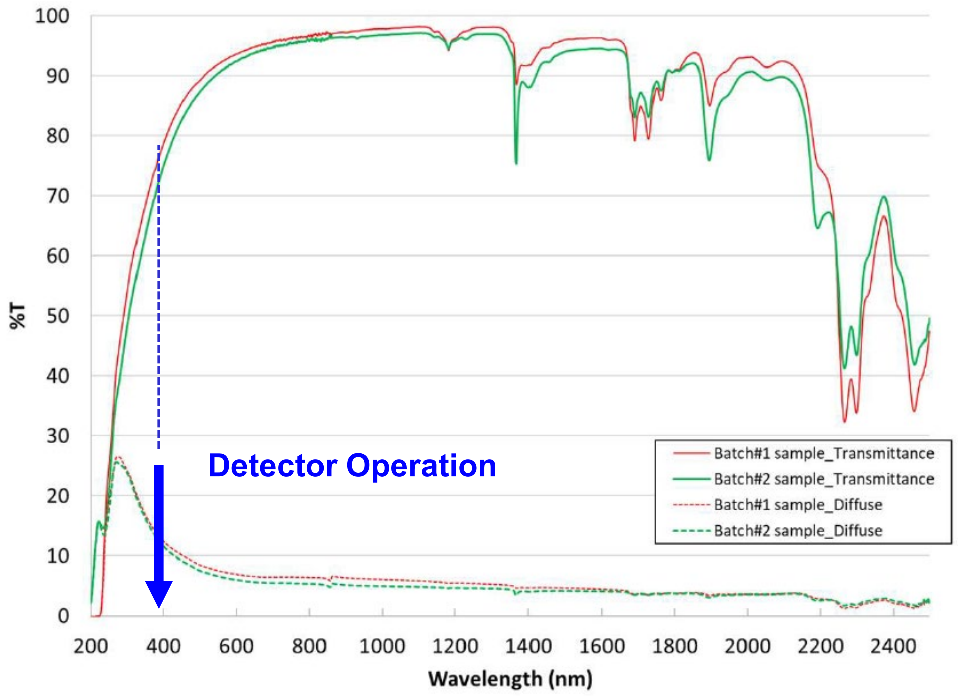
Aerogel Optical Properties

Sample #	Thickness (cm)	Density (g/cc)	Clarity (mm^4/cm)	Absorption Coefficient	Scattering Length (mm)	Transmittance (% at 400nm)
Batch 1	2	0.052	0.00568	0.995	45	78.83
Batch 2	2	0.049	0.00660	0.973	39	75.00



- The Absorption Coefficient is higher than 95%
- The Scattering Length is better than 43mm for Batch 2 and 45mm for Batch 1 at 400nm

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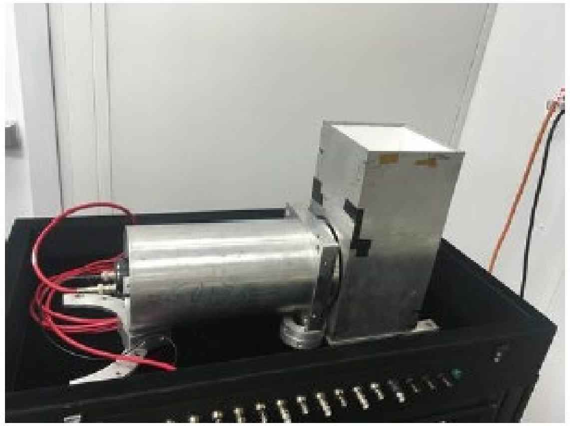
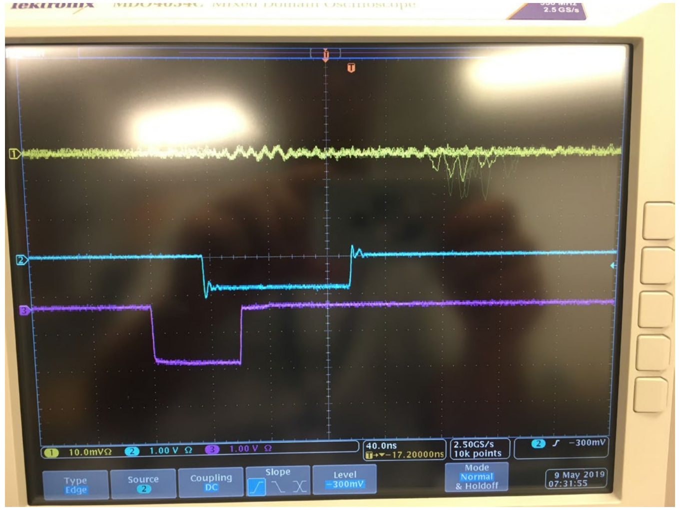
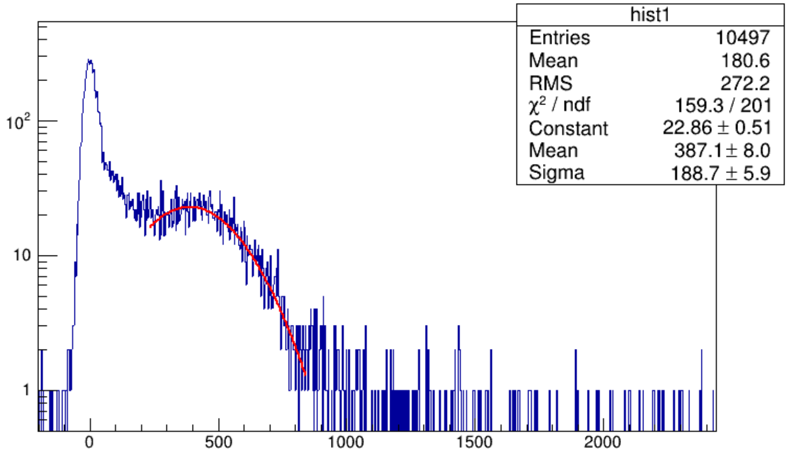
Installation/Commissioning of Single Counter

To test the actual performance of the aerogel for particle detection a prototype of the detector is needed – the light yield is an essential parameter.







- ✔ A prototype was designed, constructed, and commissioned with cosmic muons
- ✔ Average light yield measured on the test bench for Scintilex/Aspen aerogel n=1.009: **8 photoelectrons** (33% higher than currently available low refractive index aerogels)

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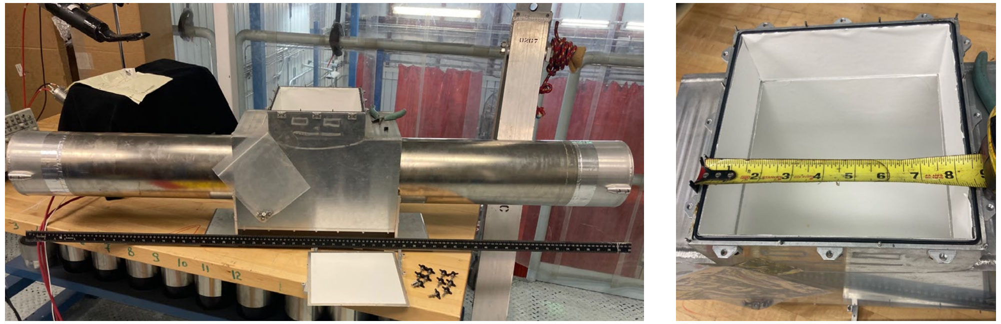
Beam Test Campaign

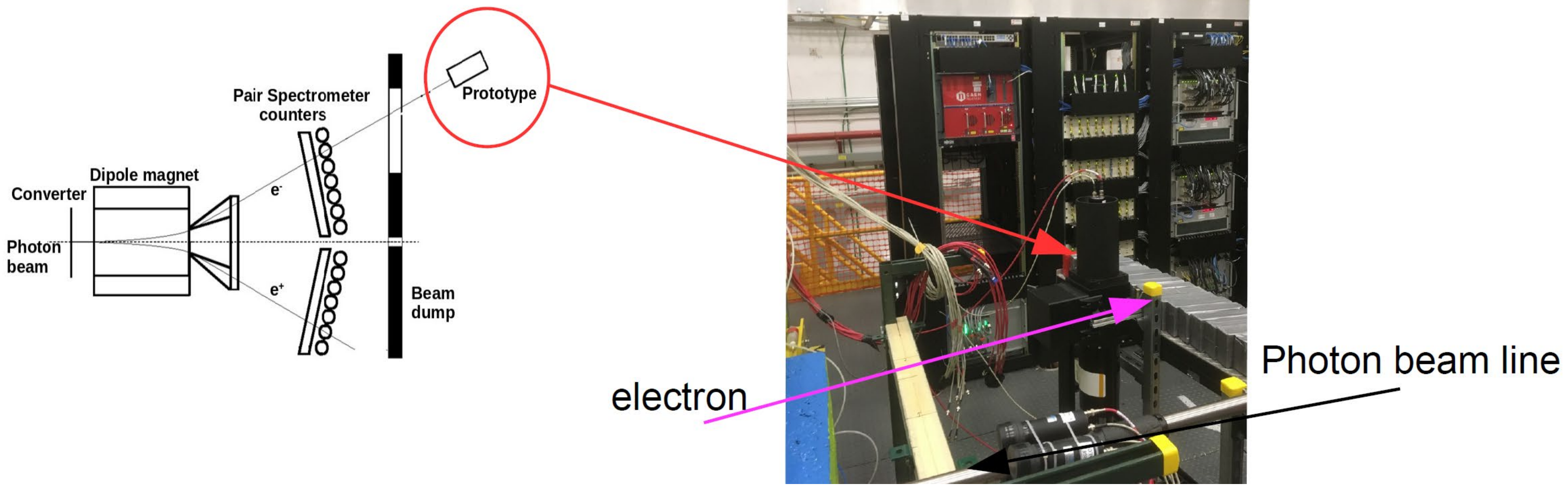
Goal: Test the efficiency of the aerogel for particle detection with particle beam



Large aerogel compartment prototype fitting up to 20cmx20cm tiles

- ✔ Established method for prototype beam tests
- ✔ Collected data with 10cmx10cm aerogel – results confirm those obtained from the test bench
- ✔ Large compartment prototype designed and constructed
- ❑ Commission and take data – will be done in collaboration with EIC RICH detector team

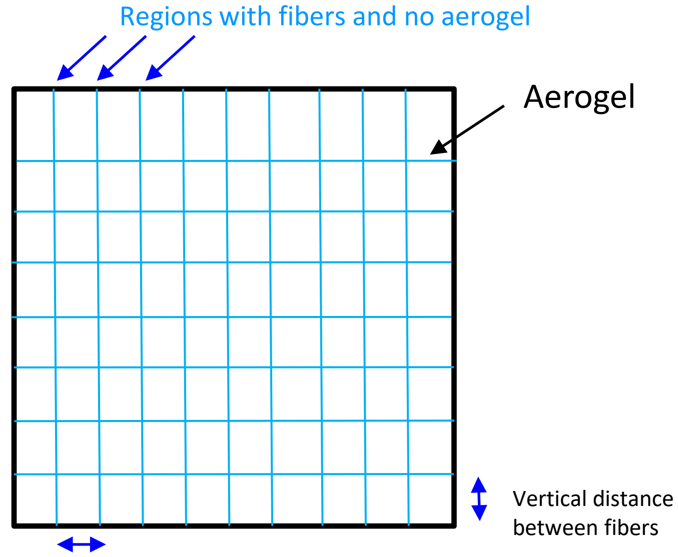
Setup of the aerogel beam test:



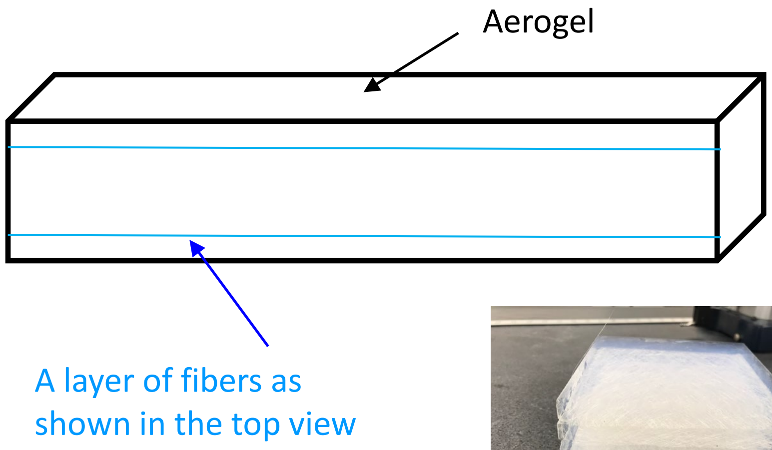
Reinforcement of Large-Size Composite Aerogels

- Aerogels with low refractive indices are very fragile - tiles break during production and handling, and their installation in detectors.

- To improve the mechanical strength of aerogels, Scintilex developed a reinforcement strategy. The general concept consists of introducing fibers into the aerogel that increase mechanical strength, but do not affect the optical properties of the aerogel.



Top View



Side View

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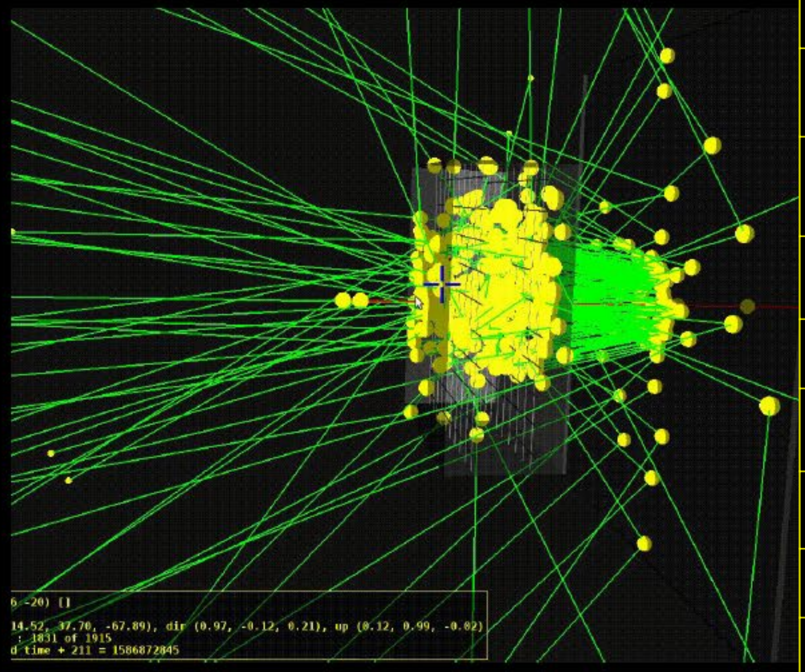
Use an AI approach: Bayesian Optimization

…to optimize aerogel+fiber

Simulation of Aerogel with block of Fibers



Variable	Description	# pars	Range
Rigid rotation of tiles f_rotx, f_roty	all fibers rotating by same angle along x, y (z along aerogel thickness)	2	(-5,5), (-5,5) deg
Single fibers rotation f_sthx, f_sthy	used to estimate tolerances on single fiber angles x, y	2	(0.1,1.0) deg
Single fibers shifts f_x, f_y, f_z	to estimate tolerances on single fiber positioning x, y, z	3	(0.5, 3.0) mm
Fiber diameter	Fixed to 50um	0	
Fiber pitch f_pitch	distance between fibers	1	(5,15) mm
Fiber gap	distance between planes of fibers fixed to 25 mm	0	
Aerogel thickness	Fixed to 6 cm	0	
Aerogel width a_width	Side of a square, orthogonal to thickness	1	(8,12) cm
Aerogel refractive index a_n	Allowed to vary	1	(1.01,1.05)

Developed a GEANT4 simulation of the aerogel in an NP detector geometry

Table of Sensitive Parameters (fiber and aerogel)

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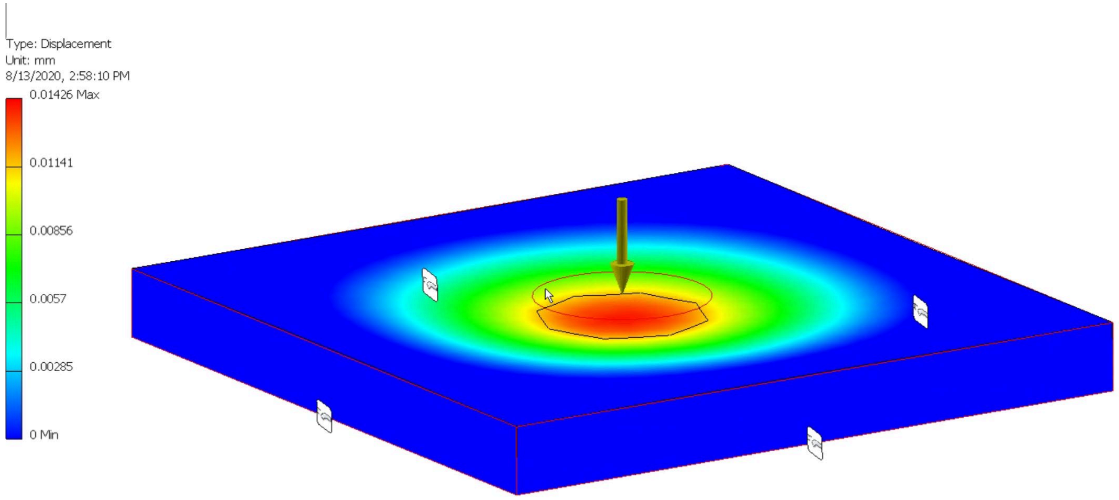
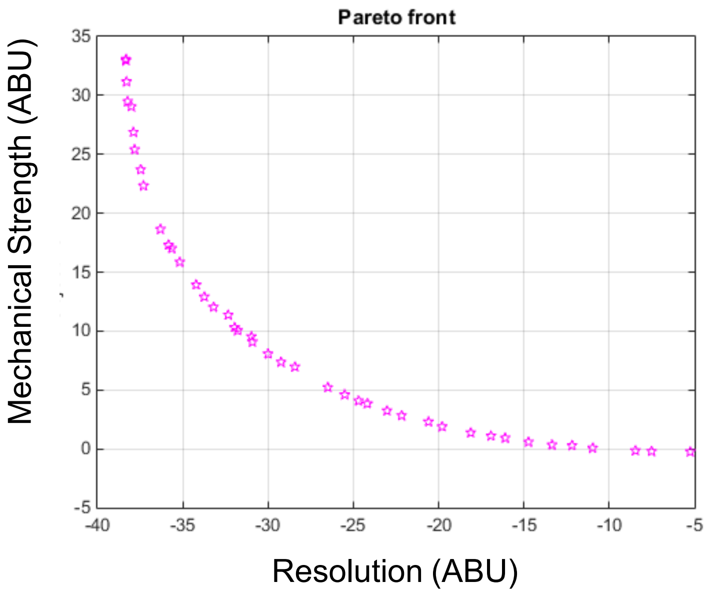
Consider more Objective Functions

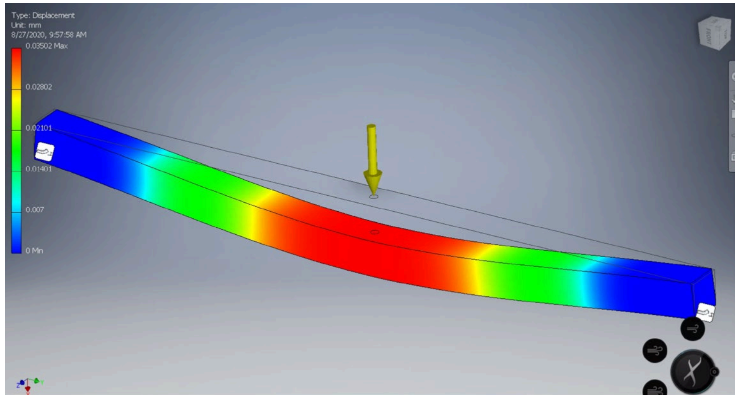
- ❑ Objective functions: mechanical strength and resolution (detector performance)
  - Perhaps add cost later as well

- ✔ To develop the mechanical strength function, stress simulations in Autodesk Inventor (Gmsh+Elmer) have been developed

- ✔ AI approach: At the moment we have a genetic algorithm combined to some metric to define the Pareto front of the functions.







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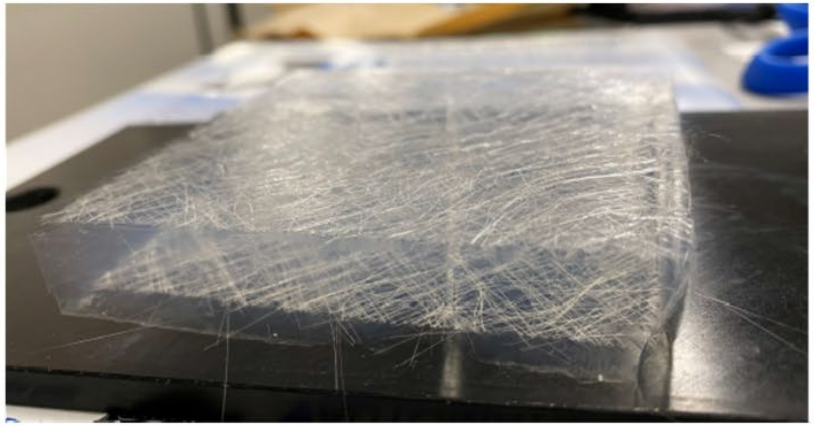
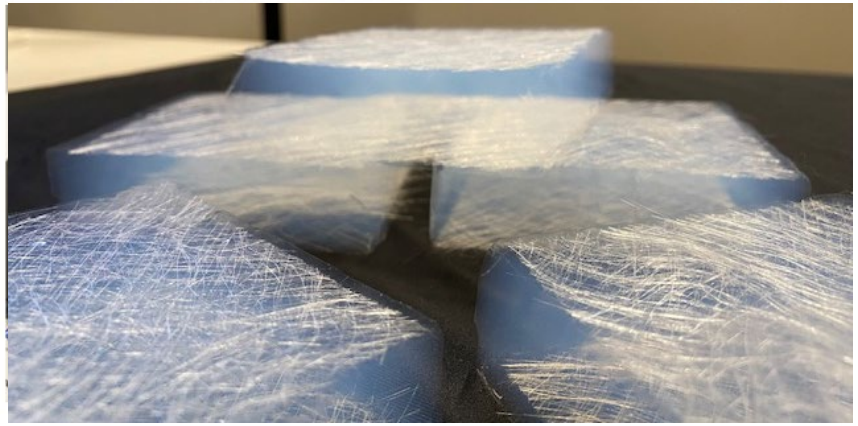
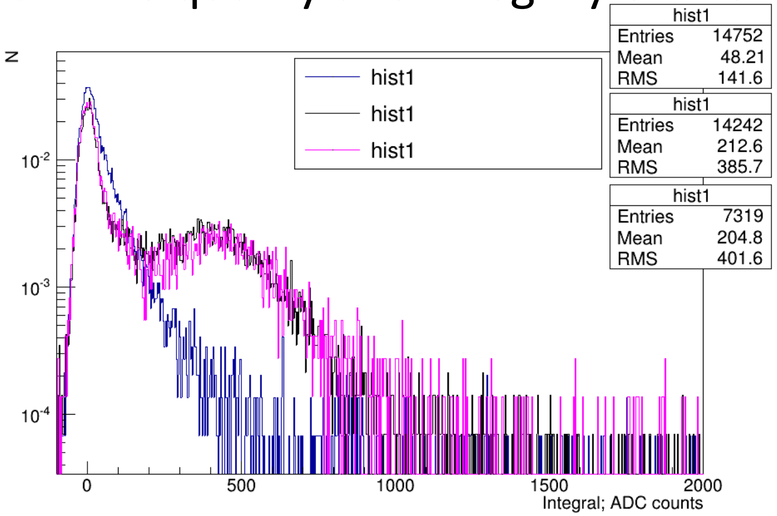
Fabrication of Mechanically Reinforced Tiles





- The first aerogel tiles with fiber embedded in the material were fabricated. The fiber mesh is located near the surface on top and bottom of the aerogel tile
- The quality and integrity of the monoliths is very good.



- Preliminary result for Scintilex fiber reinforced aerogel: no significant impact on detector performance
  - Consistent with projections from Monte Carlo simulations

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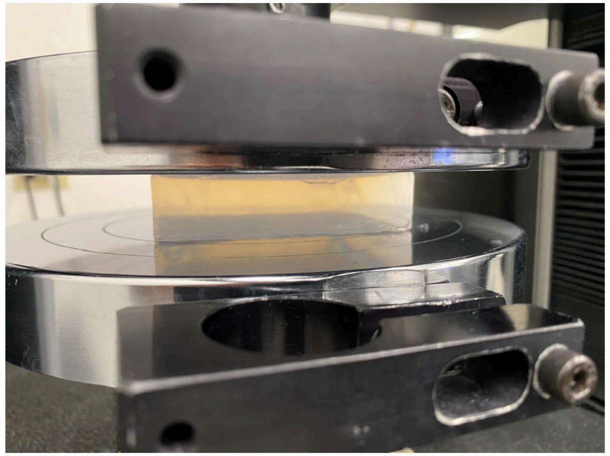
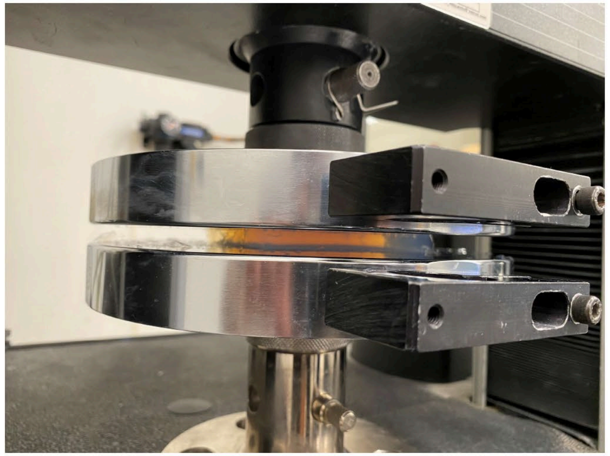
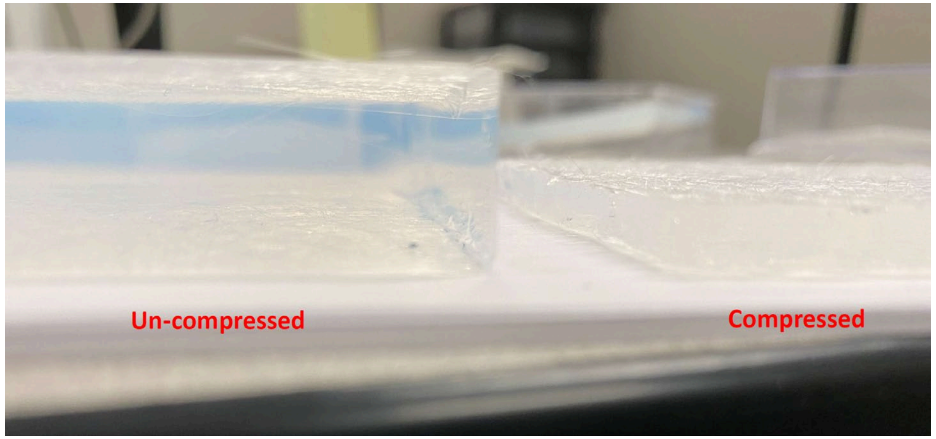
Compression Tests of Mechanically Reinforced Tiles

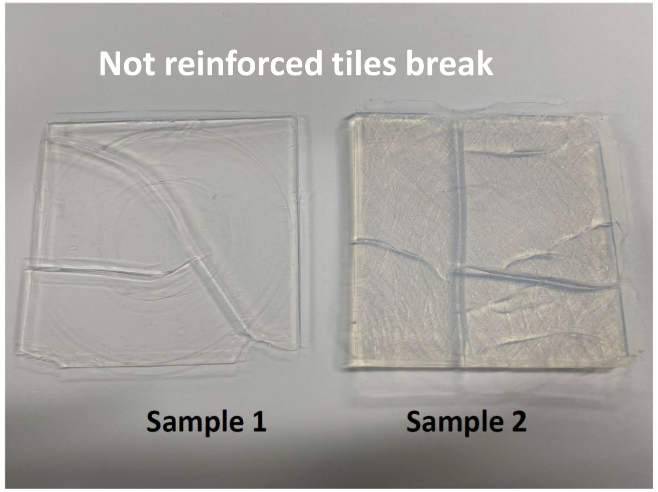


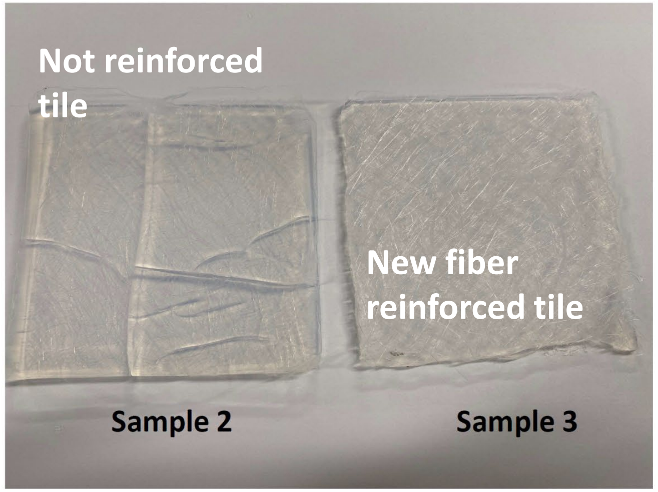
Strain = 0%



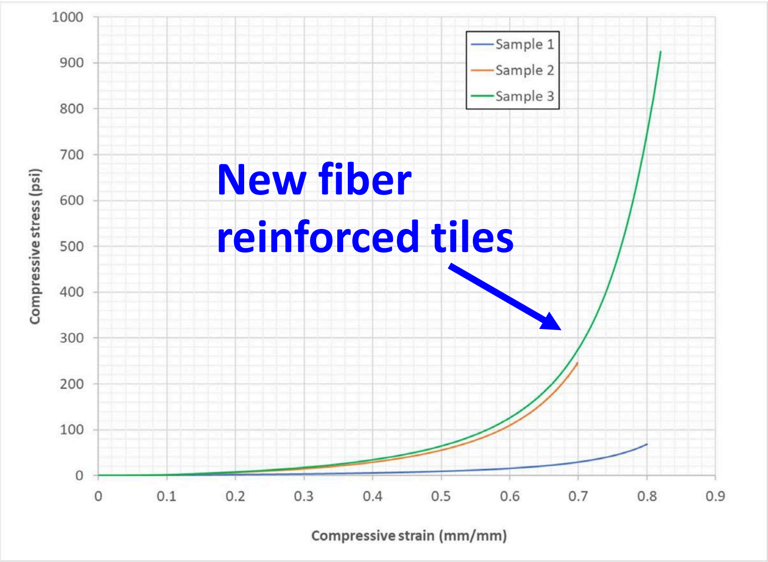
Strain = 82%







Comparison of the stress-strain curves of the three samples



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✓ The produced fiber-reinforced aerogel tiles outperform not reinforced tiles

Summary and Outlook

- Demonstrated capability to produce n<1.014 aerogel (15x15x(2-3)cm^3)
- Constructed and commissioned methods to characterize aerogel tiles optical properties and detector performance.
  - Optical properties of tiles are superior to currently available low refractive index aerogel
  - Light output suitable for nuclear physics threshold detectors
- Established uniformity of large tiles and further scale up
- Demonstrated a novel method to reinforce optical aerogels to facilitate manufacturing and use in nuclear physics detectors

Acknowledgement:
Award: DE-SC0019536

Ongoing discussions about possible production of aerogel tiles for EIC RICH detectors and beam test campaign

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