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

Principal Investigator: Tanja Horn

Business Official: Ian L. Pegg

Scintilex Overview

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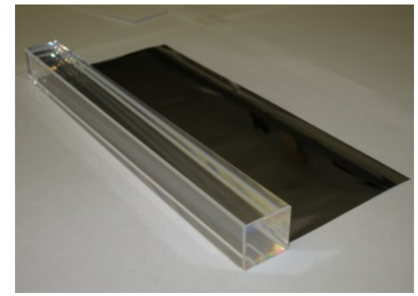
- Main focus: design and construction of instrumentation based on Cherenkov and scintillation light using novel materials
  - Applications: particle detection in nuclear physics experiments and homeland security; also medical



- 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

Cherenkov Detectors

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- 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

Radiators for Cherenkov Light

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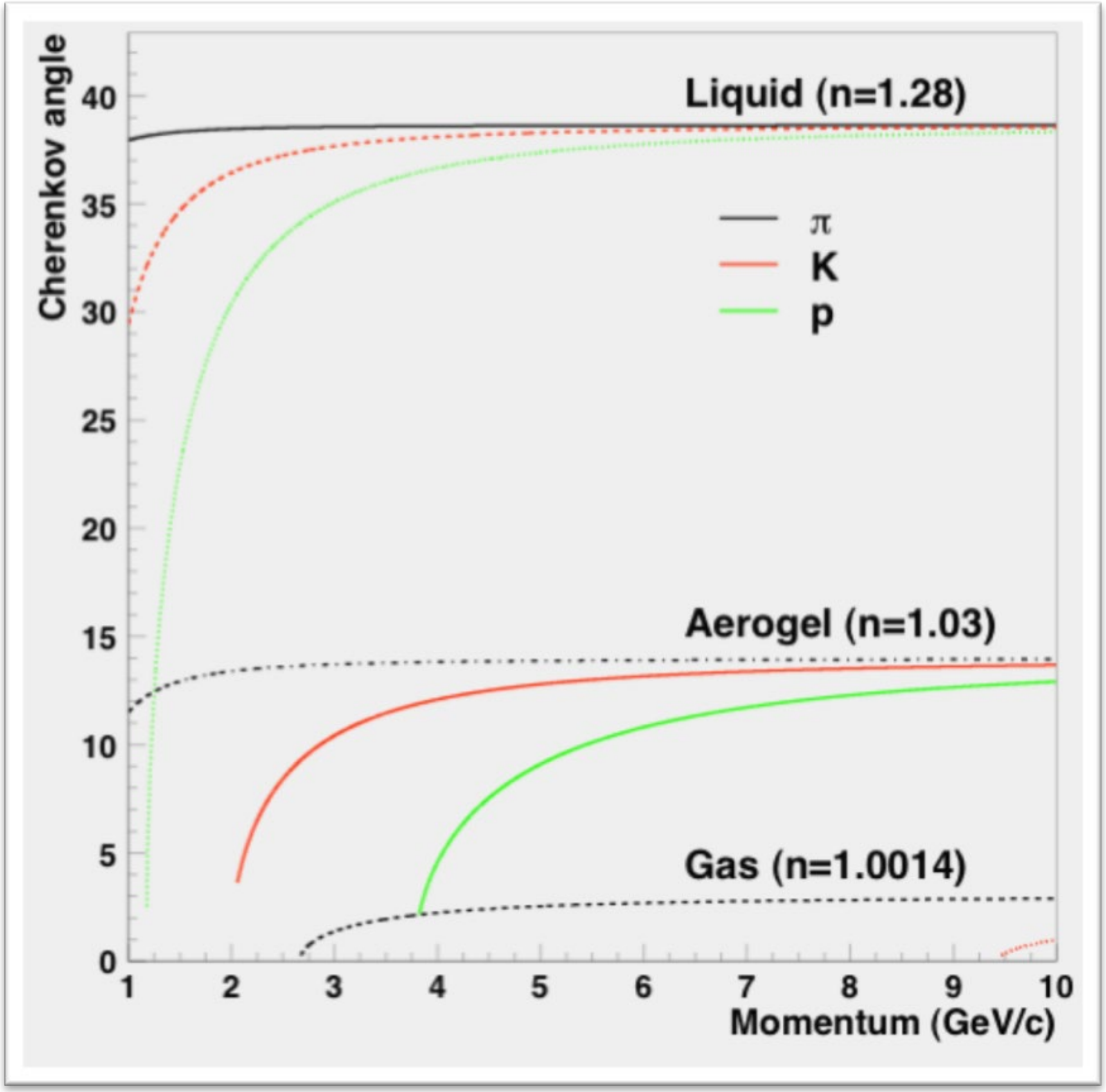
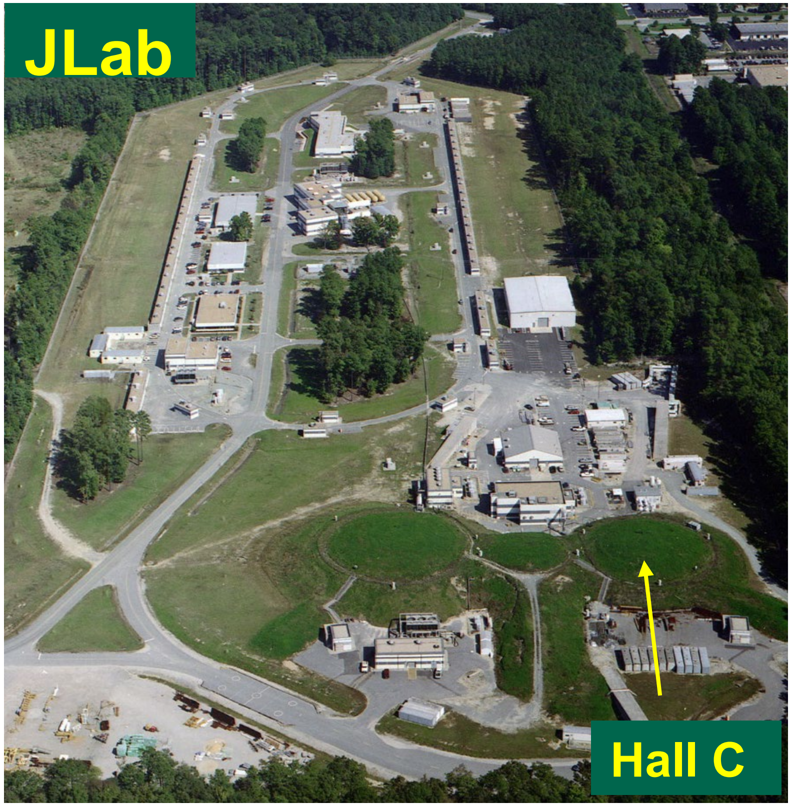


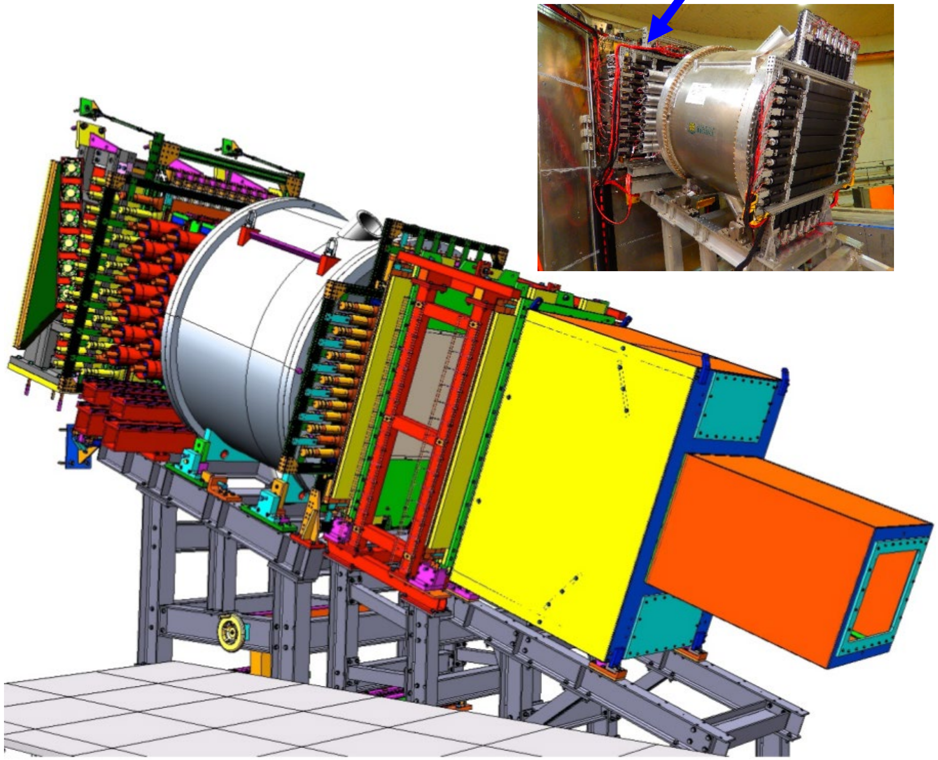
- Aerogel is mandatory to separate hadrons in the 2-8 GeV/c momentum range
- Rayleigh scattering is the dominant cause of aerogel image degradation
- Rayleigh scattering increases as λ^{-4}
  ➔ collection of visible Cherenkov light
- Cherenkov Light is a WEAK source of radiation
  ➔ Medium should be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

1. The Hall C SHMS Aerogel Detector



Jefferson Lab, Newport News, Virginia

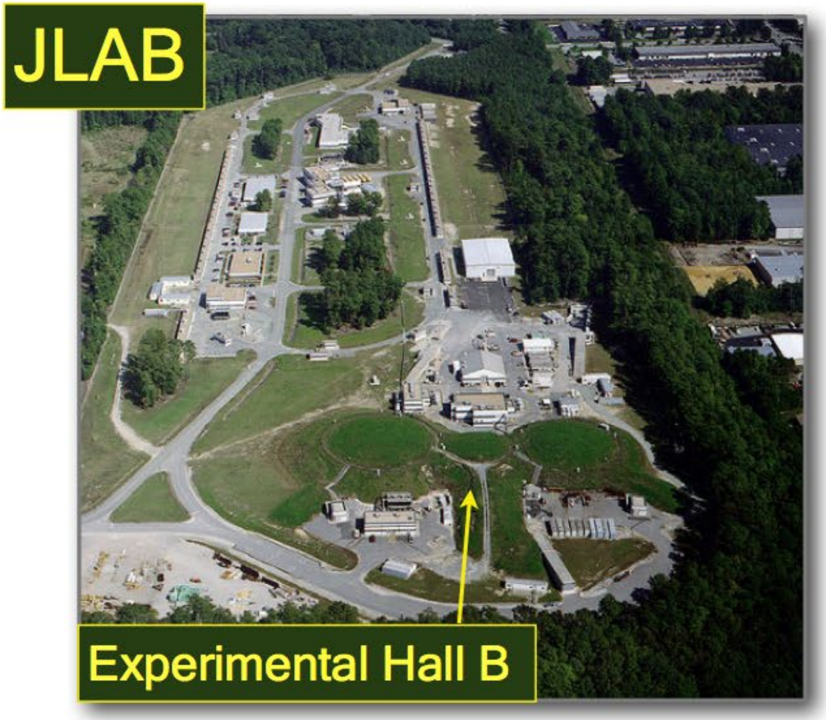
Built by CUA 2011-13, in operation since 2014



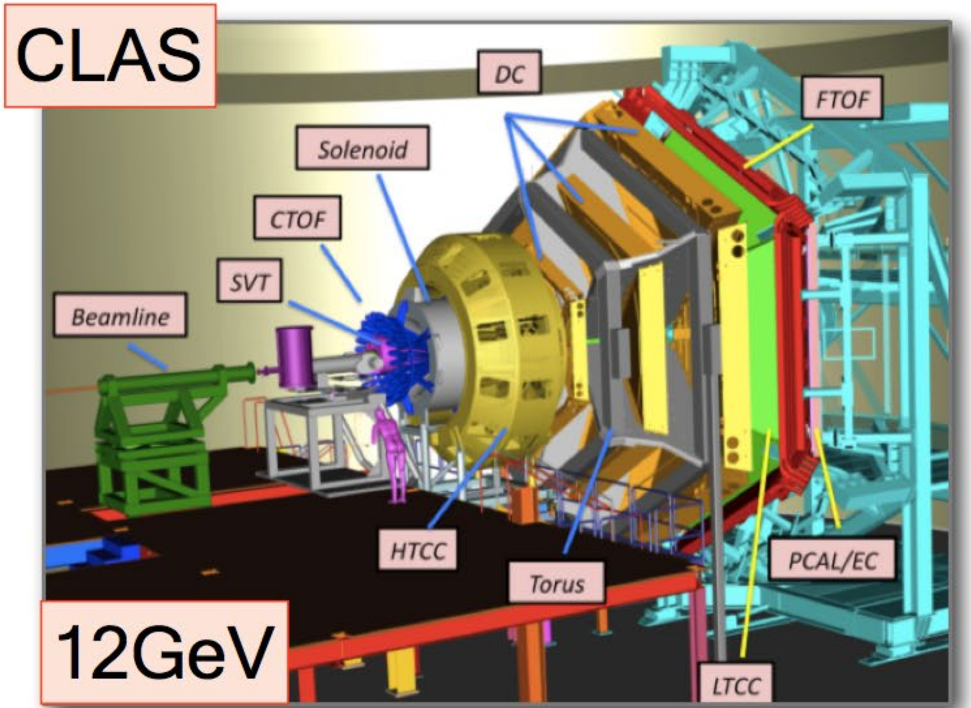
Hall C Super-High Momentum Spectrometer (SHMS)

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

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

Experimental Requirements Summary

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Mechanical

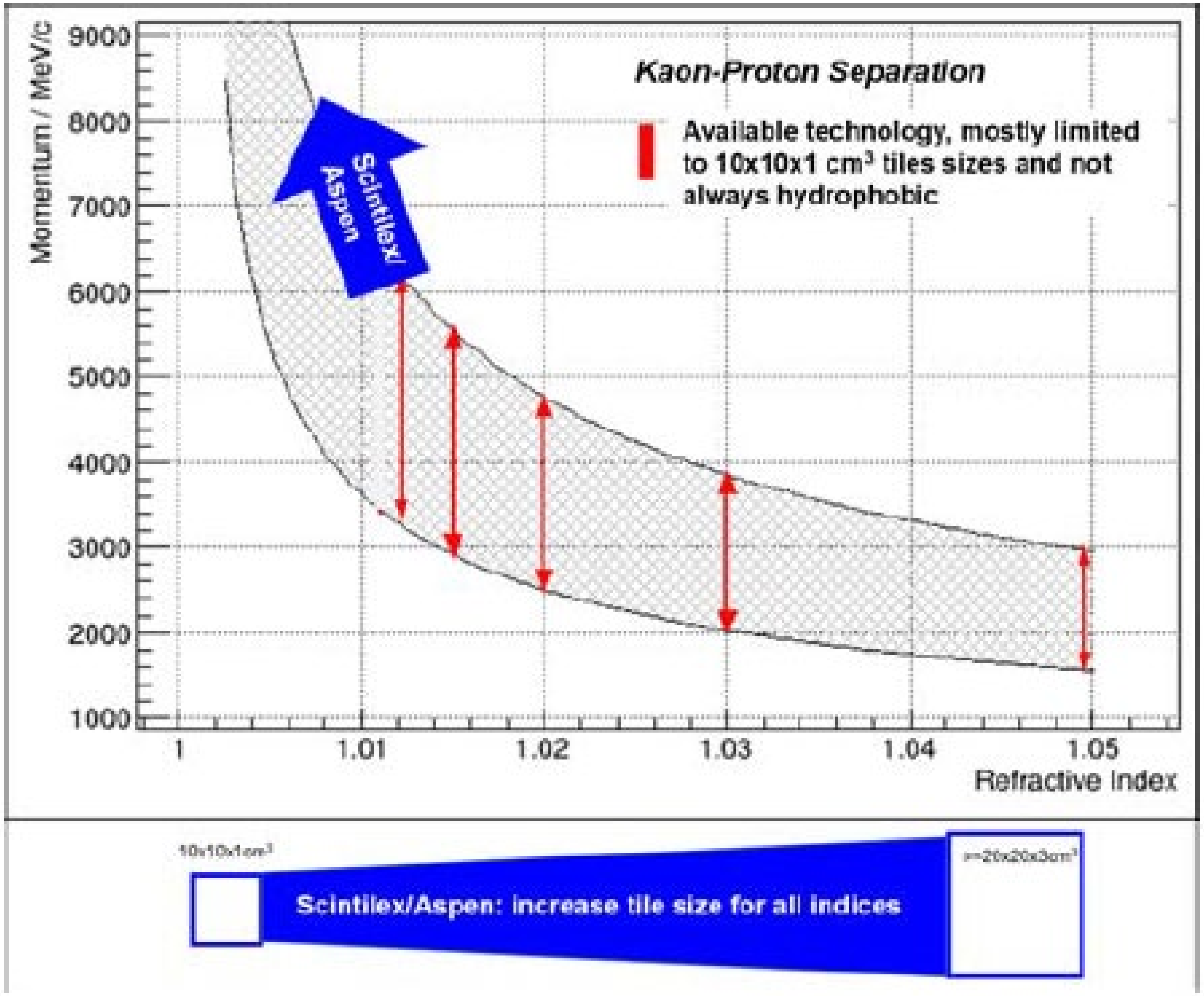
- Dimension tolerance: 0.25% of tile size in transverse dimension and 1-2% in thickness
- Tile integrity: >95% of tiles without bubbles, visible cracks and >95% of tiles without chips on corners; chips limited to <1% area
- Surface planarity: Δ_{surf} < 1% of lateral side

Optical

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

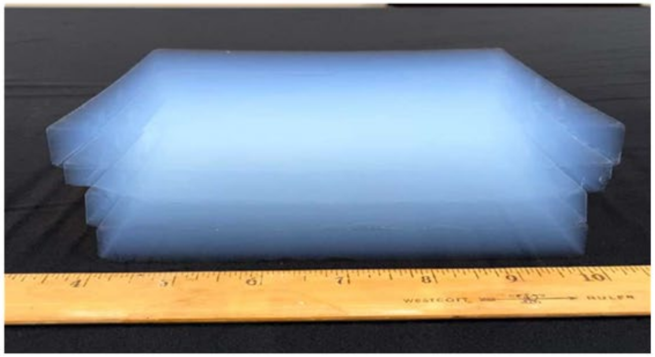
> - Tile sizes as large as possible
> - Index <1.01 for high momenta

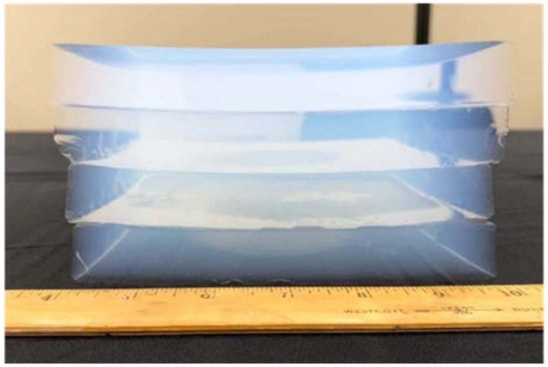
Scintilex - STTR Concept

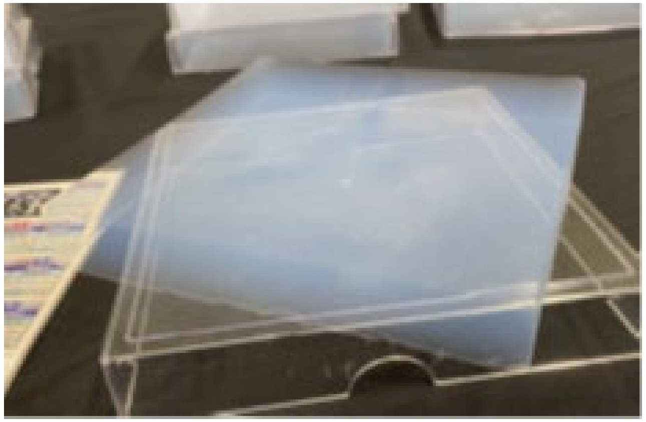


Production 10-20 aerogel tiles - complete

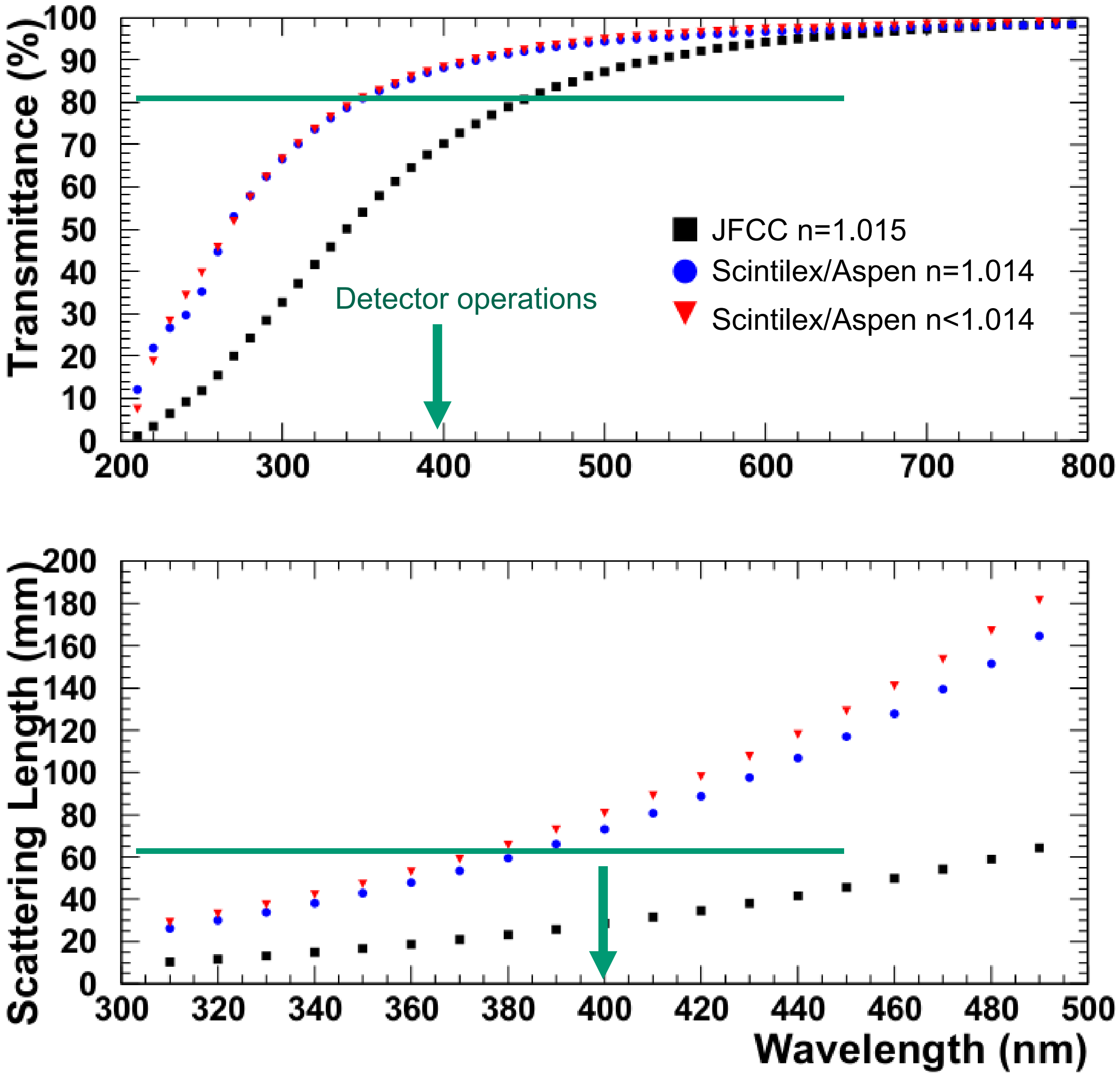
SCINTILEX







Optical Properties



Installation/Commissioning of Single Counter

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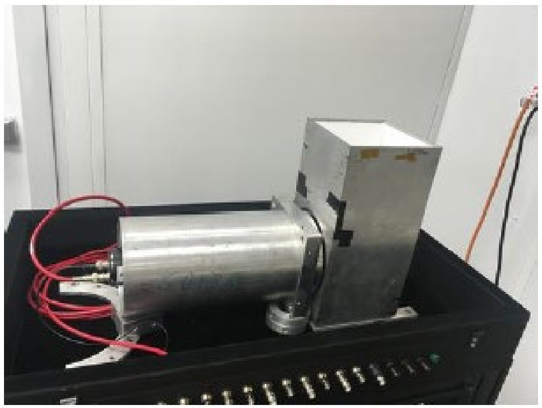
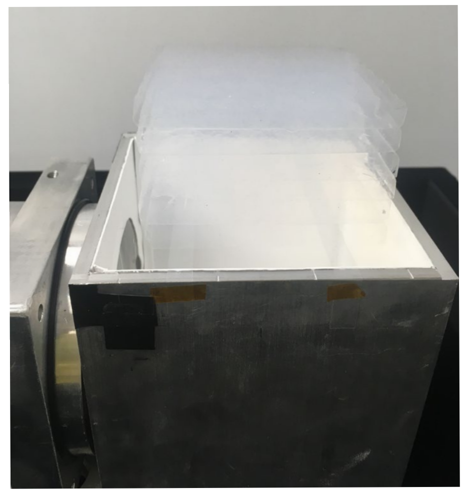
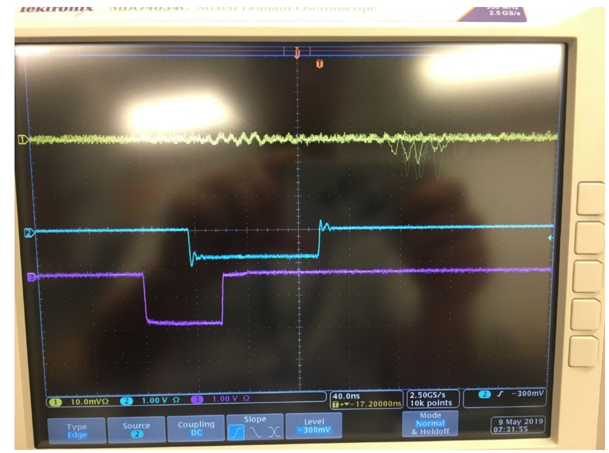
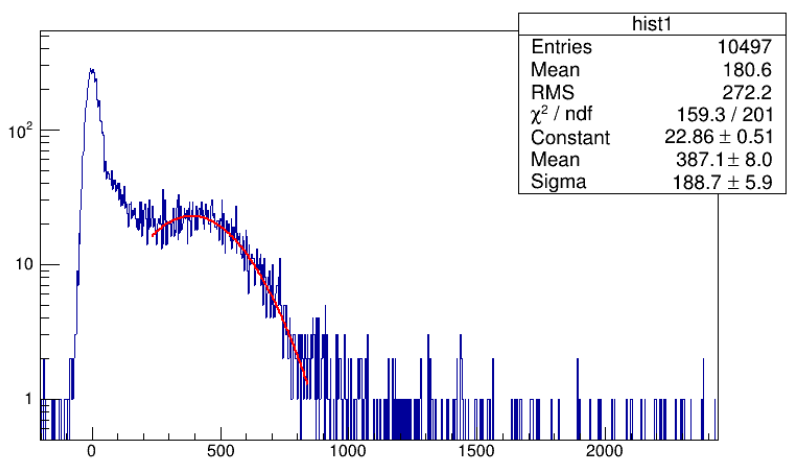


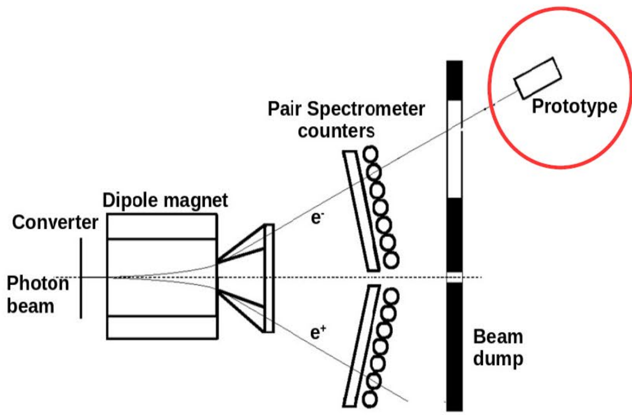


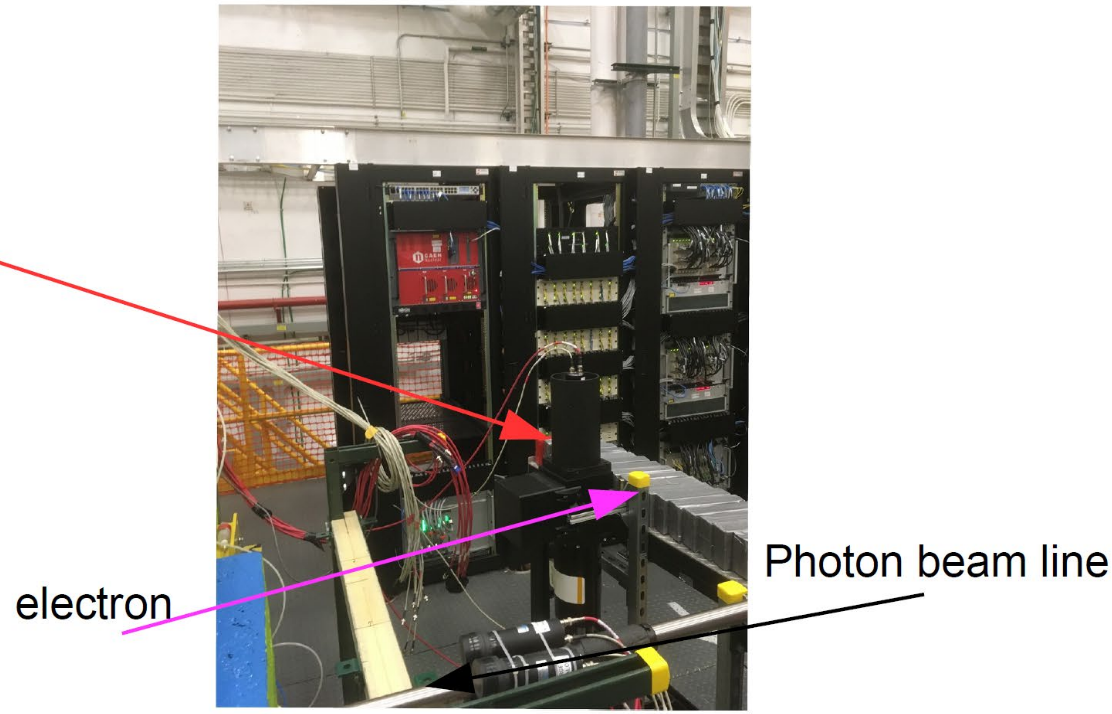




Preliminary result for Scintilex/Aspen aerogel n=1.014: Number of photoelectrons produced ~ 10.5

Beam Test Campaign

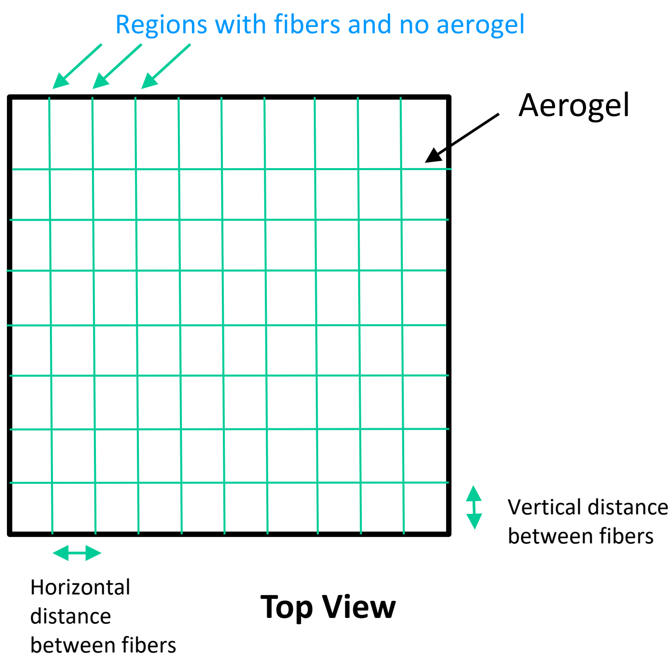


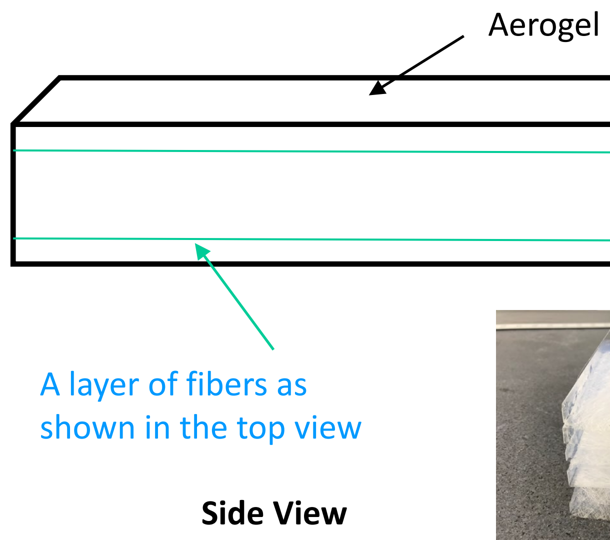


Use AI to Optimize Large-Size Composite Aerogels

- 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.

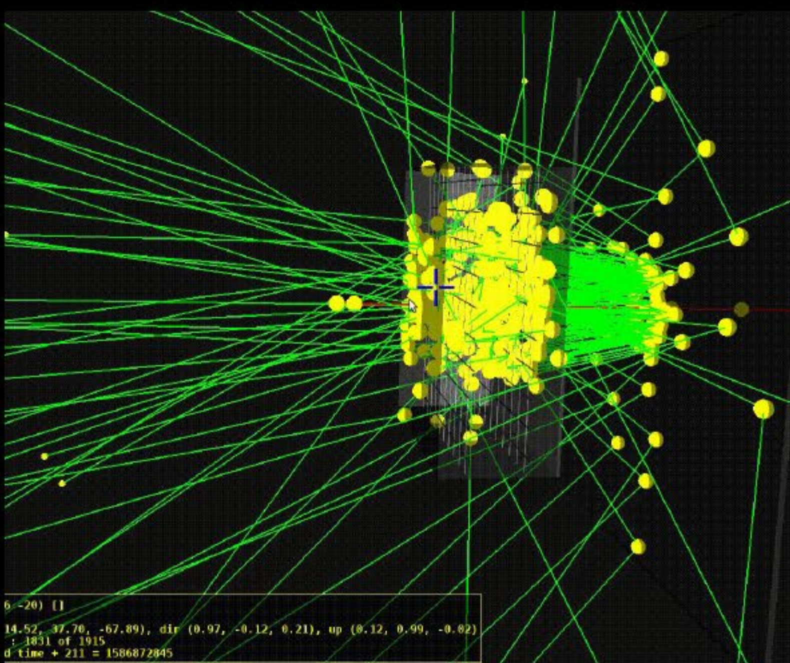




AI approach: Bayesian Optimization

…to optimize aerogel+fiber

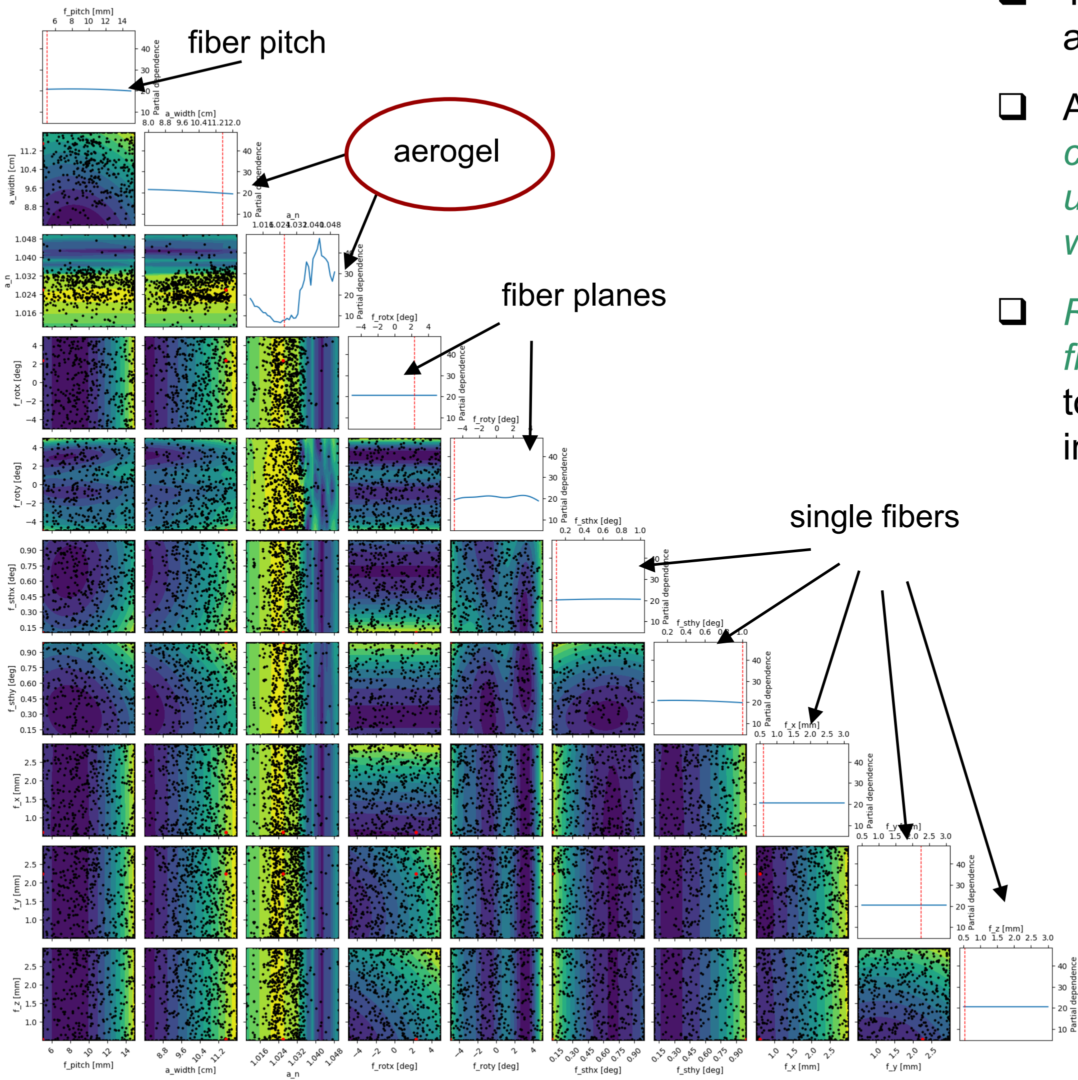
Simulation of Aerogel with block of Fibers



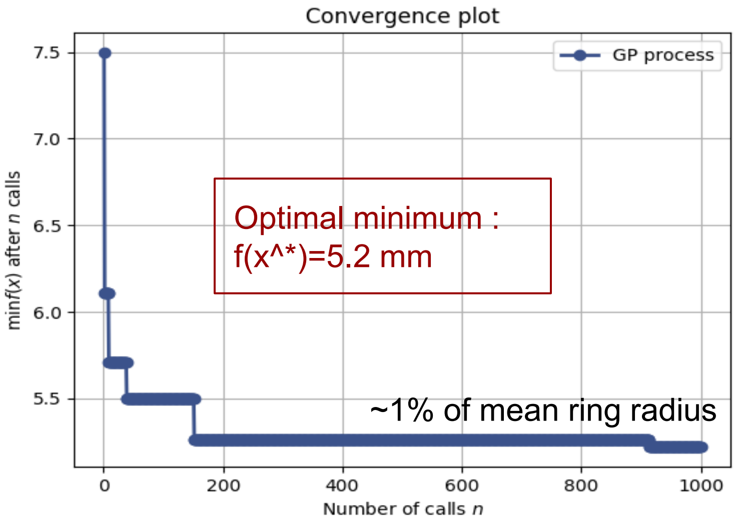
Variable	Description	# pars	Range
Rigid rotation of tiles f_rotx, f_roty	all fibers rotating by same angle along x, y (z along aerogel thickness)	2	(-5,5), (-5,5) deg
Single fibers rotation f_sthx, f_sthy	used to estimate tolerances on single fiber angles x, y	2	(0.1,1.0) deg
Single fibers shifts f_x, 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)

Table of Sensitive Parameters
(fiber and aerogel)

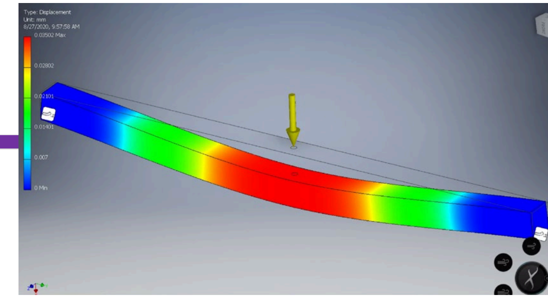
Aer-Fi Preliminary Results



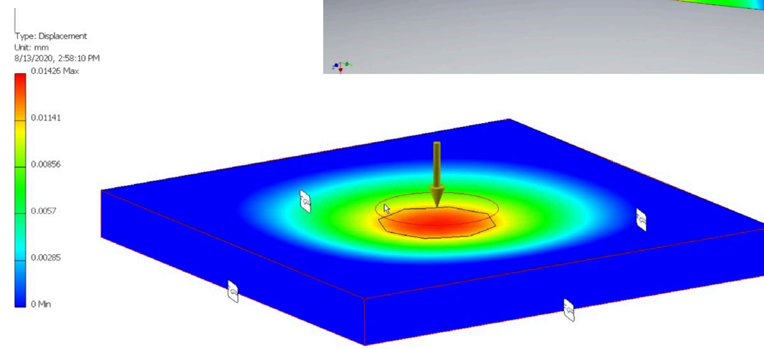
- The dominant contribution comes from the aerogel refractive index
- Another optimization suggests a *thickness of 6 cm, a fiber gap of 25 mm and diameter of 50 um*; with these values the optimal *index and width of the aerogel tile is 1.026 and 11.5 cm*
- *Resolution does not depend critically on the fibers* - single fibers parameters indicate tolerances of up to 1 deg in (θ_x, θ_y) and 3 mm in (x,y,z) from the flat partial dependence



Consider more Objective Functions

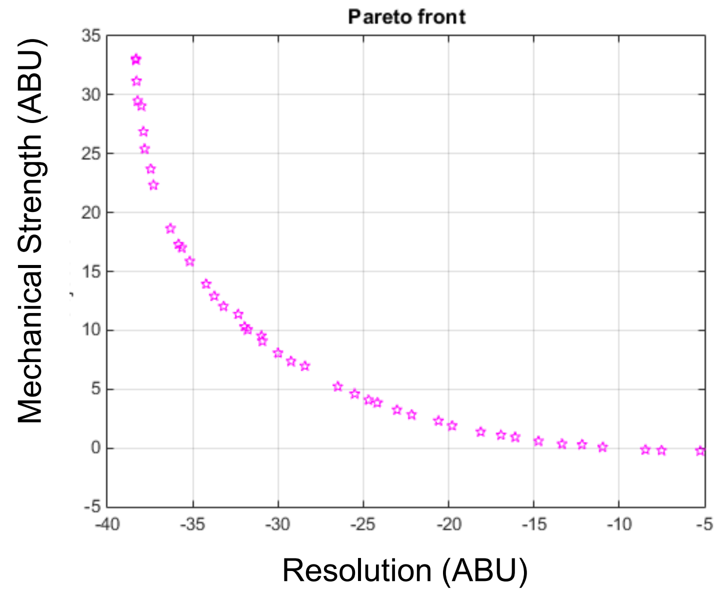


- ❑ Objective functions: mechanical strength and resolution
  - Perhaps add cost later as well



- ❑ To develop the mechanical strength function stress simulations in Autodesk Inventor are being developed

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



Fabrication Mechanically Reinforced Tiles

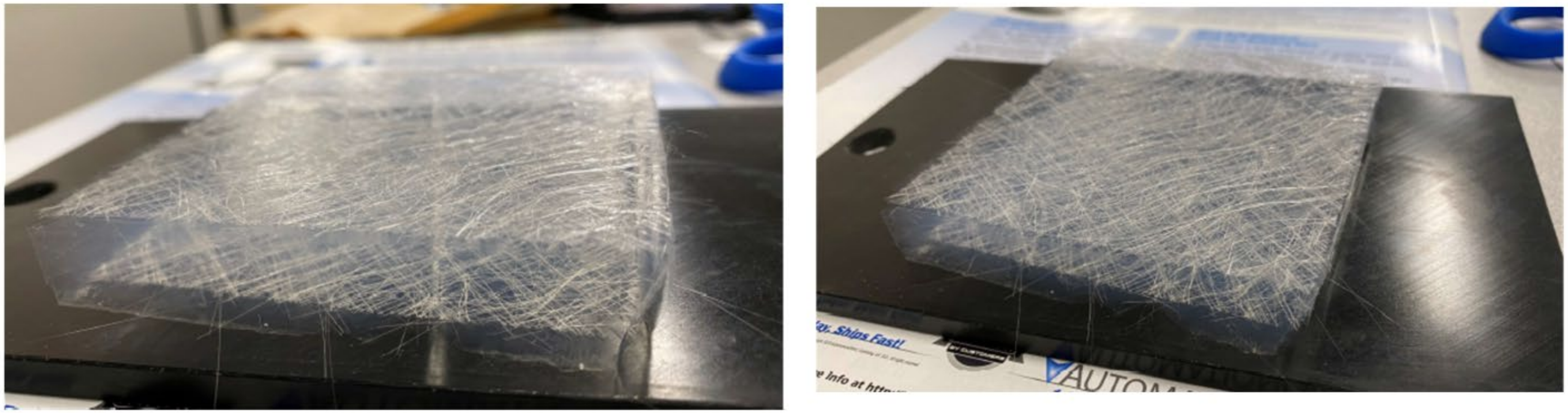
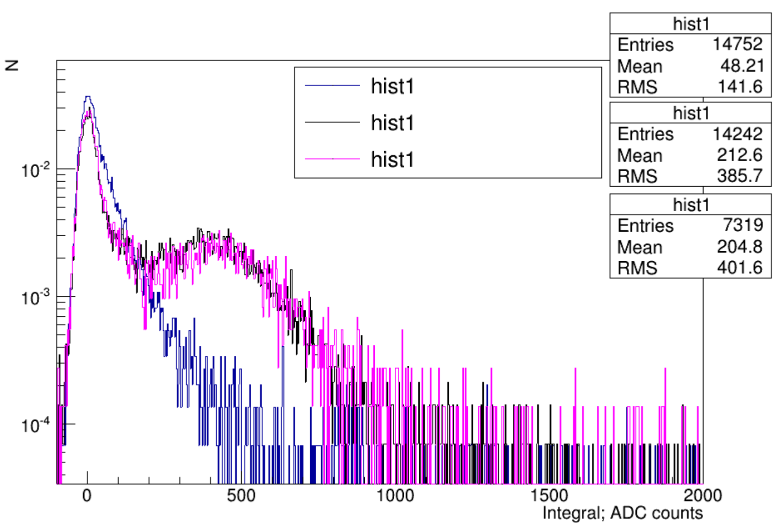


Figure 6: *Mechanically reinforced aerogel tiles*



Preliminary result for Scintilex fiber reinforced aerogel: no significant impact on detector performance

Consistent with MC simulations

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 performance. Preliminary results:
  - Optical properties of tiles are superior to Japanese aerogel
  - Light output suitable for nuclear physics threshold detectors

- Ongoing work to establish uniformity of large tiles and further scale up, as well as beam test campaign

- Investigating novel method to reinforce optical aerogels to facilitate manufacturing and use in nuclear physics detectors

Error on particle velocity

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Error on the particle velocity β measured with a RICH

$$\frac{\sigma_\beta}{\beta} = \frac{\tan\theta_{\mathbf{Ch}}}{\sqrt{\mathbf{N}_\gamma^{\mathbf{det}}}}\sigma_{\theta_{\mathbf{Ch}}}$$

$$\sigma_{\theta_{\mathbf{Ch}}} = \sqrt{\sum_{\mathbf{i}}(\sigma^{\mathbf{i}}_{\theta_{\mathbf{Ch}}})^{\mathbf{2}}}$$

Depends on:

- Number of detected photons
- Error on the Cherenkov angle of the emitted photons $\sigma_{\theta Ch}$

Resolution	Direct (mrad)	Reflected (mrad)
Emission Point	1.7	1.7
Readout Accuracy	2.1	1.0
Chromatic Aberration	3.0	2.5
Aerogel Optical Prop.	≤ 1	≤ 2
Mirror System		≤ 1
σ_θ (1 p.e.)	4.2	3.9

Requirements	Direct	Reflected
Max. momentum	8 GeV/c	6 GeV/c
σ_θ (4σ separation)	1.4 mrad	2.5 mrad
Np.e. Yield	≥ 10	≥ 3

Aerogel General Requirements

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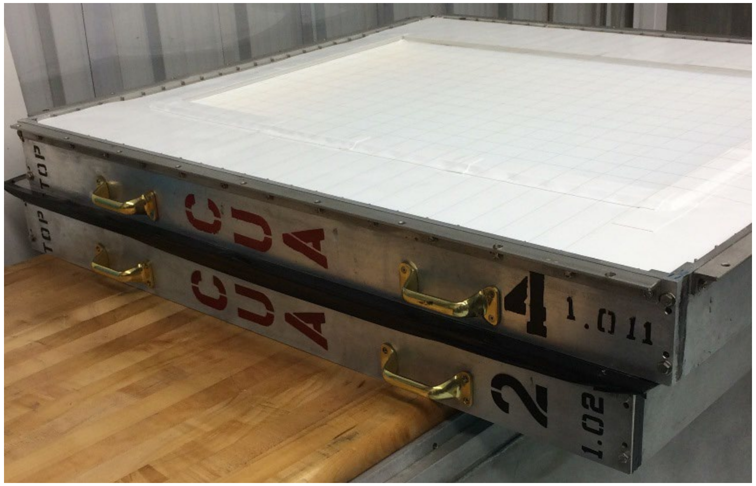

- ❑ Evenly cover a large detector surface (~6000-11000 cm^2)
  - ➢ to reduce gaps between the tiles, transverse tile sizes as large as possible
- ❑ Tiles are stacked in layers up to 10cm
  - ➢ for high and uniform efficiency need uniform thickness and small variations over the tile surface

p_{SHMS}	n	K_{pe}	p_{pe}	Discrimination (5 σ)
3.5	1.030 (1.015)	34 (9)	<0.5 (<0.5)	>1000:1 (lower)
4.5	1.030 1.015	40 15	13 <0.5	1000:1 >1000:1
5.5	(1.030) 1.015	(43) 19	(26) 1	(20:1) >1000:1
6.1	(1.030) 1.015	(44) 20	(31) 6	(10:1) 200:1

- ❑ Multiple refractive indices required to cover for particle momenta between 1-10 GeV/c
  - ➢ need very low index to reach the highest momenta
  - ➢ need tile-to-tile variation to be small

RICH Design and aerogel

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72 (3 cm thick) and 22 (2 cm thick) full squared tile + 30 shaped ones
High transparency and large refractive index (n=1.05) to ensure photon yield
Large area 20 x 20 cm^2 to reduce losses at the edges, variable thickness (2 and 3 cm)