Aerogel Cherenkov Detectors in JLab Hall C

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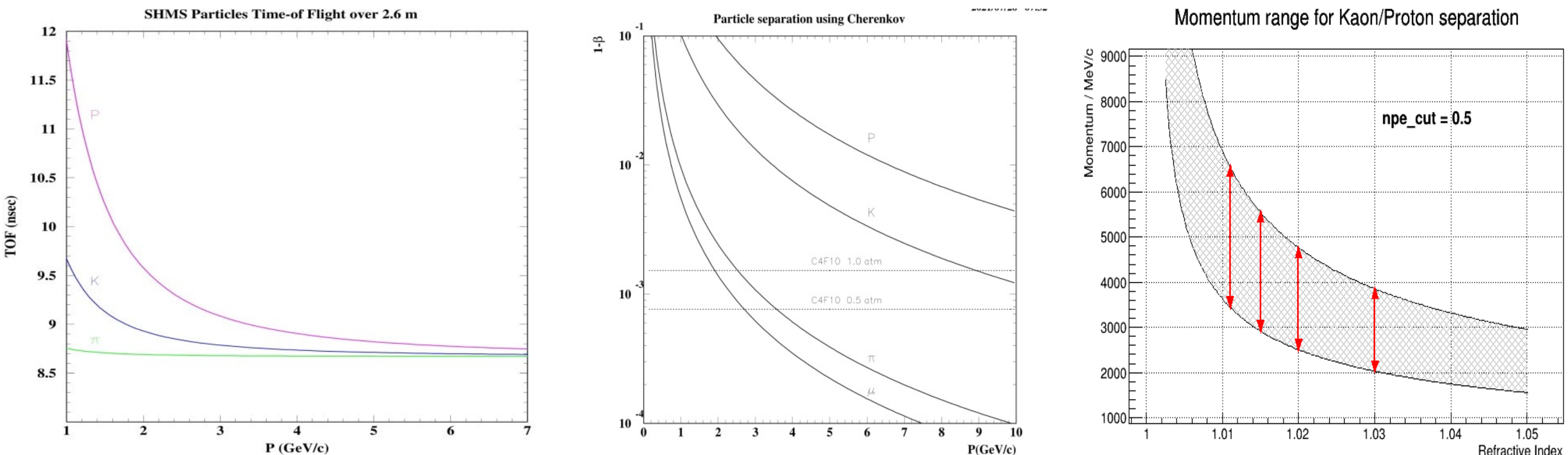
Aerogel Detector for PID

- For particle identification (PID) a combination of Time-of-Flight (TOF), threshold gas Cherenkov counter and segmented lead-glass electromagnetic calorimeter is used.
- In addition, for coincidence measurements, use of the coincidence time difference between scattered electrons and secondary hadrons is very efficient. But even with perfectly calibrated detectors, π/K/p separation deteriorates with momentum $\Delta t \sim 1/P^2$.
- TOF is effective at low momentum, but it becomes useless above P ~ 2.5 GeV/c.
- In addition, in this range hadrons tend to become above the detection threshold in gas Cherenkov detectors, making π/K/p separation more difficult.



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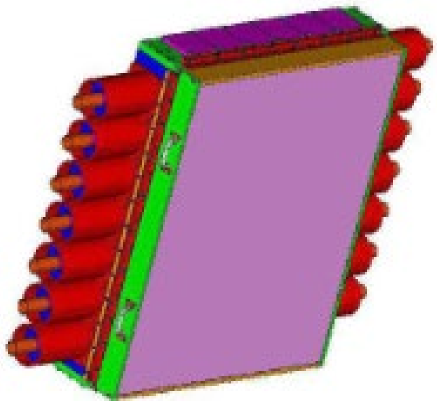
- To complete the PID capability of the spectrometers additional Cherenkov detectors with an index of refraction $1.006 < n < 1.03$ was needed for good hadron identification at $P > 3$ GeV/c.
- In fact traditional gas and liquid radiators have a refractive index smaller than 1.0018 (C_5F_{12}) or larger than 1.27 (liquid C_6F_{14}).
- To avoid the use of gases at high pressure or in unmanageable liquefied form, the possible way to close the gap in refractive indexes is aerogel, that can be produced with n from 1.004 to 1.110.

Design Specifications of Detectors



- Sensitive area: 120×70 cm² (HMS) and 110x100 cm² (90×60 cm² for the lowest index) (SHMS)
- Radiator thickness: ~9 cm for both detectors
- Detector depth: ≤ 30 cm (to fit in detector stack)

- Diffusion box scheme for collecting Cherenkov light. The photon detection probability is directly proportional to the fraction of detector surface covered by PMTs. An increase in the area covered by PMTs results in an increase of the number of photons detected.

- Taking into account requirements of Hall C experiments and momentum range of spectrometers, we chose aerogels with indexes of refraction of n = 1.030 and 1.015 for HMS, and n=1.030, 1.020, 1.015 and 1.011 for SHMS.
- The n = 1.03 aerogel allows for good pion/proton separation up to 4 GeV/c, while the n = 1.015 aerogel material can be used for pion/kaon separation in the momentum range 1-3 GeV/c, and for pion/proton separation up to 6 GeV/c.

- We used Aerogels commercially available from Japanese Fine Ceramics Center (JFCC) for n=1.011 and 1.015, and Matsushita Electric Works (Japan) for n=1.02 and n=1.03. They are known to be highly transparent, hydrophobic and have ~~a~~ light output which is almost linear with the radiator thickness.

Dimensions of Aerogel tiles

- To estimate possible difference in size between aerogel tiles, first for the randomly selected samples the thickness and the width were measured.
- For the measurement of the thickness each aerogel tile was placed in between two aluminium plates. Using a calliper, we measured the thickness of each tile from the distance between these two aluminium plates.
- Similar, a calliper was used to measure the lateral width of each tile of the selected sample of aerogel. The distance between two opposite sides of the tiles was measured in several points, and an average over these measurements was considered as the tile width.

Index	Width (mm)	Thickness (mm)
1.030	113.10 ± 0.40	11.58 ± 0.07
1.020	110.82 ± 0.59	11.42 ± 0.33
1.015	111.83 ± 0.22	11.10 ± 0.15
1.011	112.28 ± 0.35	10.93 ± 0.10

When the dimensions of all the tiles were measured, the differences in block sizes were determined, the tiles with different sizes were divided into groups. This helped to minimize possible difficulties during stacking.

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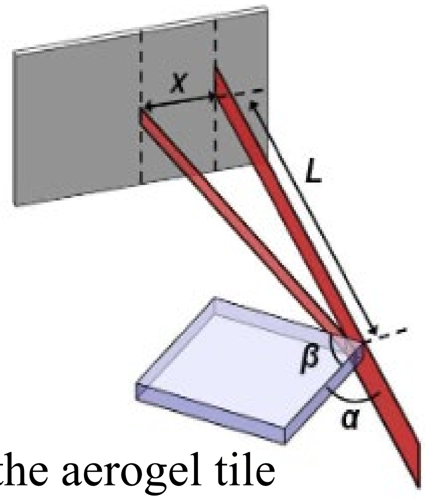
Aerogel Refractive Index

The refractive index of a sample of aerogel tiles was measured with a technique based on Snell's Law. It consists of measuring the refraction of a beam of light (red, λ~670 nm) incident on one corner of an aerogel tile (as shown in picture).

The beam of light is incident on the tile at an angle α with respect to the normal to the surface of its corner. The fraction of light goes through the tile, refracts and hits a screen placed at a distance *L* from the tile. Refraction in the aerogel bends the incident light, so that it is separated from the part of the beam that does not go through the aerogel by a distance *x* on the screen.



From these variables and the angle β between two sides of the aerogel tile (90º in our case), one can determine the refractive index *n* of the tile using,

Index	Refractive Index
1.030	1.0303 ± 0.0007
1.020	1.0198 ± 0.0009
1.015	1.0152 ± 0.0004
1.011	1.0111 ± 0.0003

$$\frac{n}{n_{air}} = \sqrt{\frac{sin^2(\alpha)+sin^2(\gamma)}{sin^2(\beta)} + 2\,\frac{\sin(\alpha)\sin(\gamma)}{\tan(\beta)\sin(\beta)}},$$

$$\gamma = tan^{-1}\left(\frac{x}{L}\right) - \alpha + \beta, and$$

$$n_{air} = 1.000265$$

The dominant source of systematic uncertainties ($\pm 0.7 \times 10^{-3}$) is the measurement of the angles α and β.

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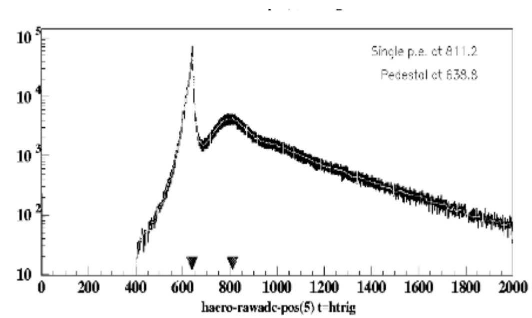
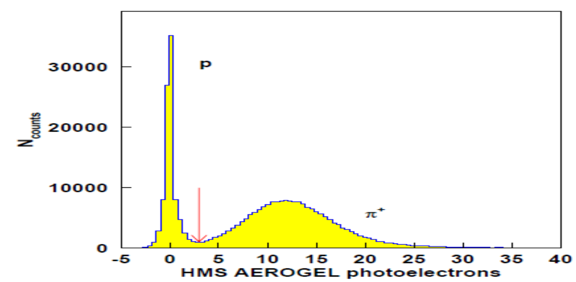
HMS Aerogel Detector Performance

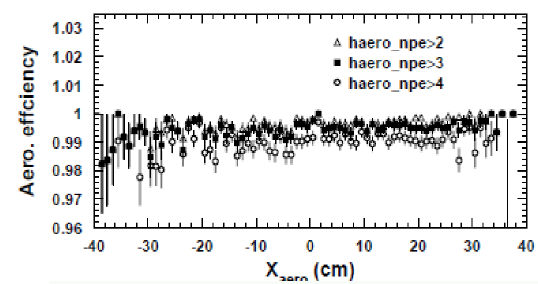
Calibration of each PMT was performed at different applied high voltages, by measuring the Single Photo-Electron peak position. This allowed us to roughly equalize the response functions for PMTs, and to determine their gains at a given high voltage.



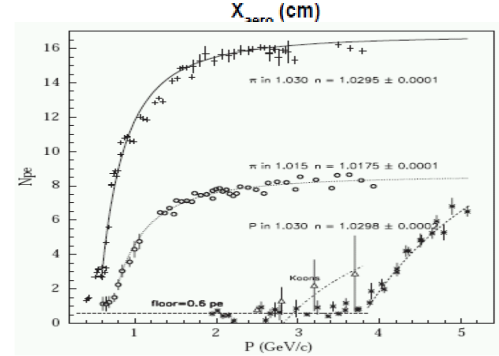
The total number of photo-electrons for protons and pions at HMS spectrometer momentum P = 3.1 GeV/c in aerogel with ndex of refraction n = 1.030. One can see very clean separation of protons and pions.



Pion detection efficiency of the HMS Aerogel detector with tray n = 1.030 along x-coordinate (vertical axis) for different cuts on number of photoelectrons (N>2, 3 or 4).

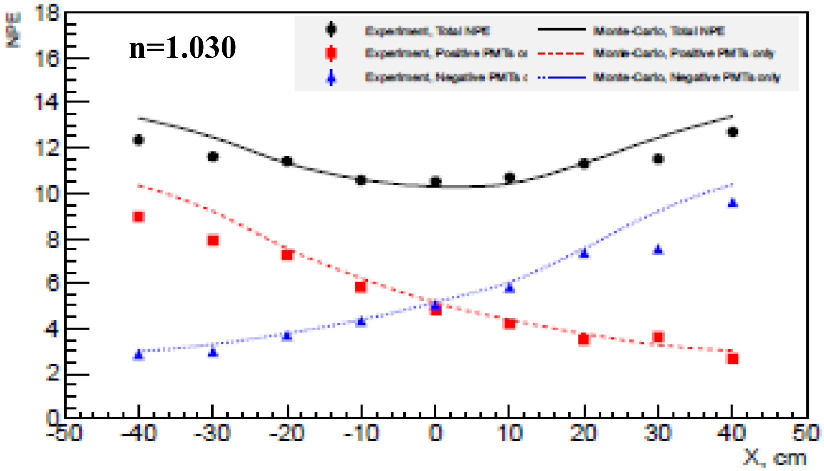


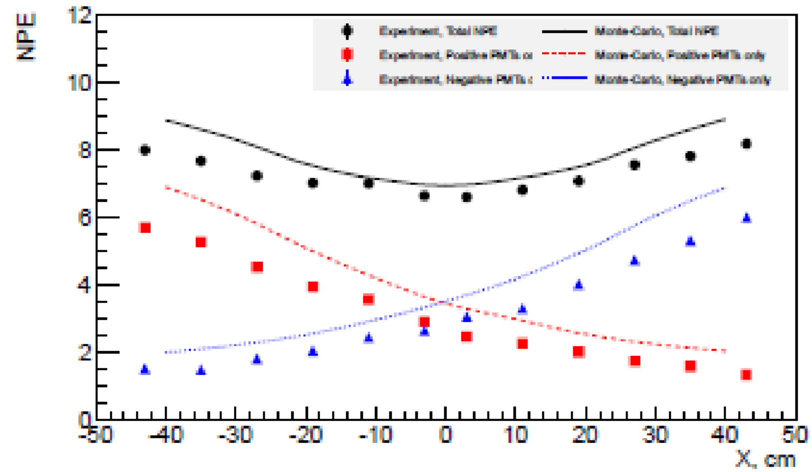
The momentum dependence of number of photoelectrons (Npe) for 2 types of aerogel material and for different particles (experimental data and fits to them are shown).



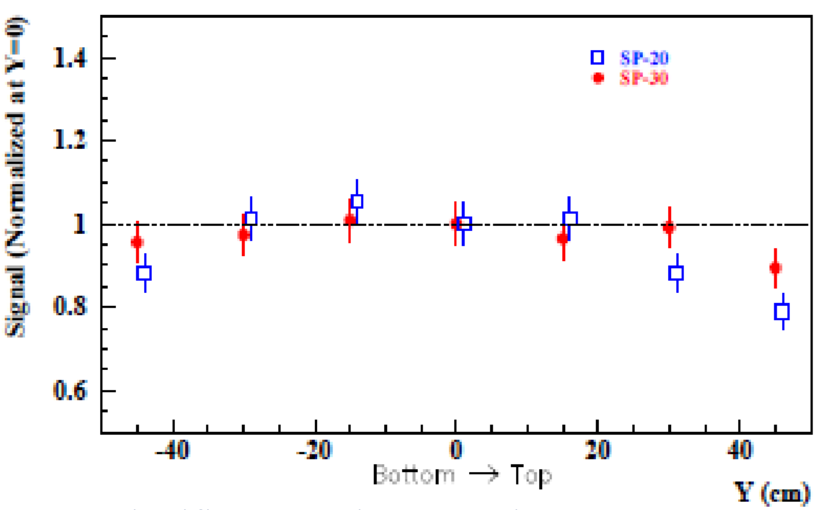
SHMS Aerogel Detector Performance

Data show a signal increase at either edges of the detector (close to PMTs).
The slight asymmetry is caused by an imbalance of the QE of the left & the right side PMTs.



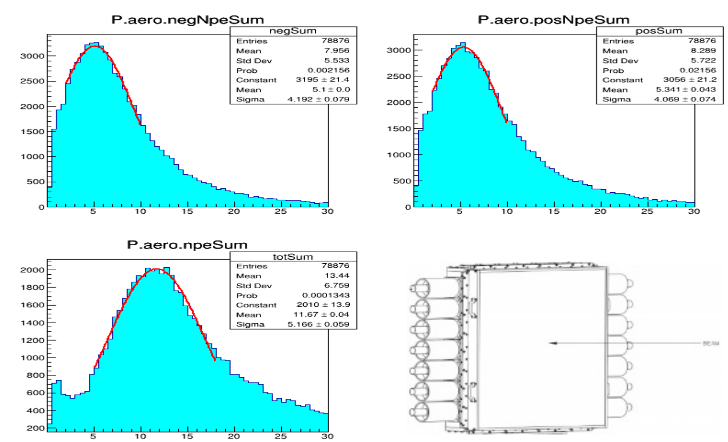


SP30,SP20 , Vertical coordinate dependence



No significant vertical coordinate dependence.

Number of photoelectrons



Top: Nneg (left), Npos (right) & N tot (bottom)

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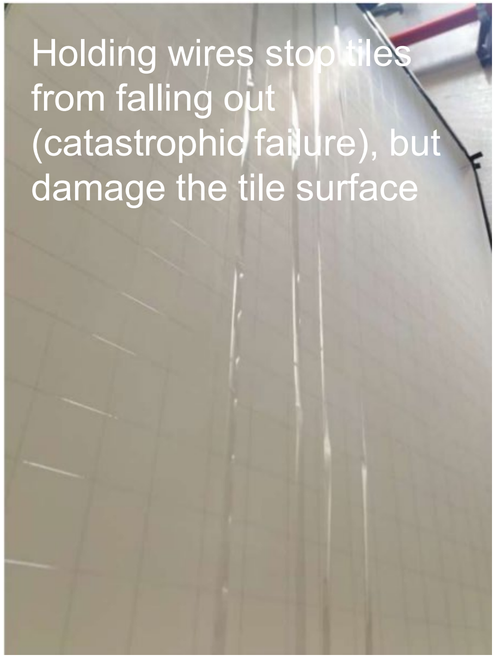
Problem with SHMS Aerogel Detector

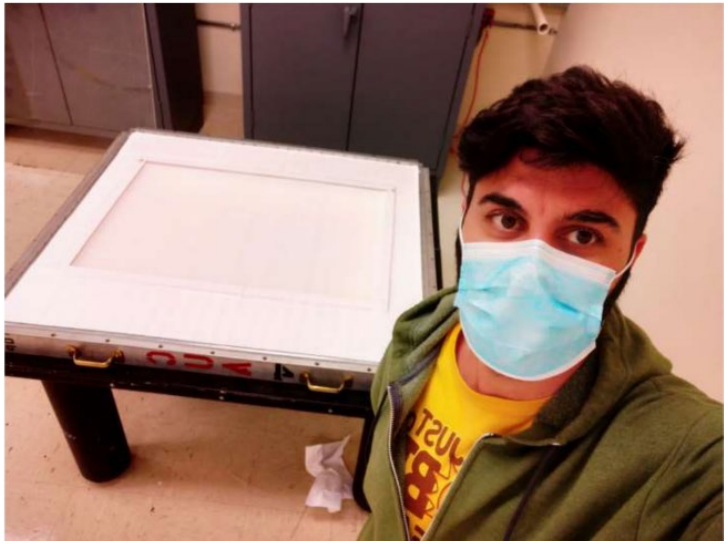
- Depending on kinematics experiments need to exchange aerogel tray from one index to another. This is done in the detector hut.
  - We slide out aerogel from detector stack, disconnect mounted tray from diffusion box, and put other tray in place.
  - For moving of tray in and out of the detector hut, an overhead crane is needed.
  - Done this many times for HMS and SHMS aerogel detectors, without any problem.

- After modification of the Hall C crane, tray SP15 of the SHMS aerogel was damaged during the tray swap procedure due to shaking while start or stop.
  - Many tiles in the tray slid from top to bottom, making aerogel thickness in the tray not uniform, and some tiles were crashed.
  - There is a risk that the whole tray could be damaged due to that shaking.
  - This is very dangerous for aerogel tray and can happen again if we don't find good technical solution.



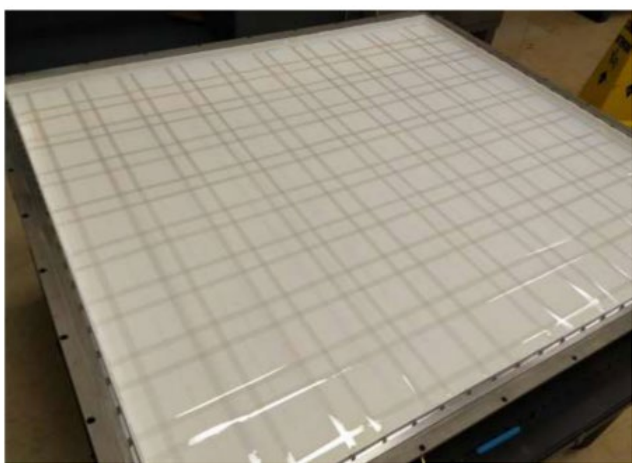
Repair Approach

- For repair works, first we have organized special clean area, making work much safe.
- During refurbishing we noticed that the tray was very dirty.
- This is due to conditions where the detector was originally assembled



- We have modified 2 main trays, SP11 and SP15. Now each tile has 4 fixing points.

SP15

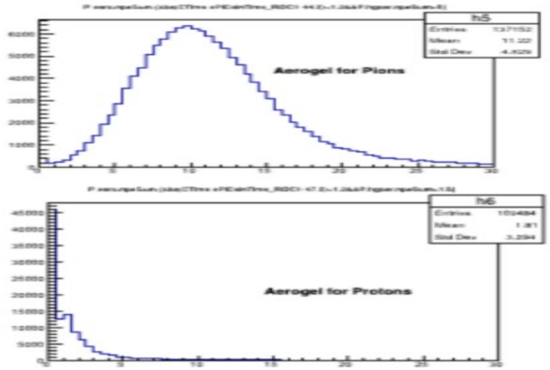


SP11

Performance of Repaired Detector

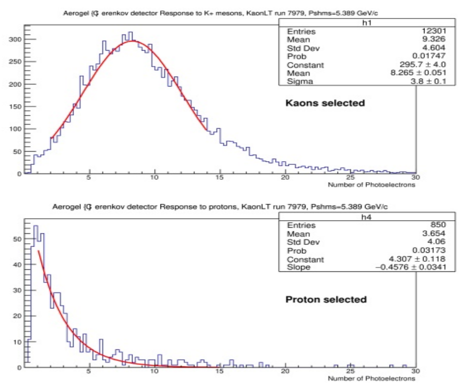
Repaired (SP15) and modified (SP11) trays have been used in Hall C pt-SIDIS, Kaon-LT and CSV experiments and demonstrated good performance.

π /p separation in SP15



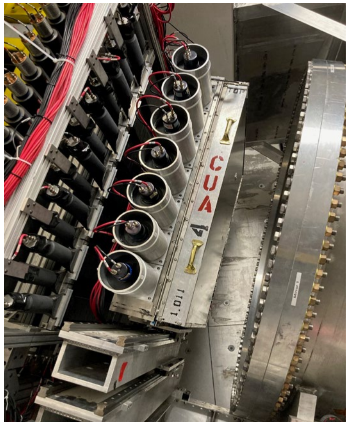
P=3.319 GeV/c

K/p separation in SP11



P=5.389 GeV/c

Trays often were swapped during 2019-2022 experiments. So far no problem.



All trays of SHMS areogel will be used in upcoming experiments and beyond. We need to keep them very safe and detector in operational condition.

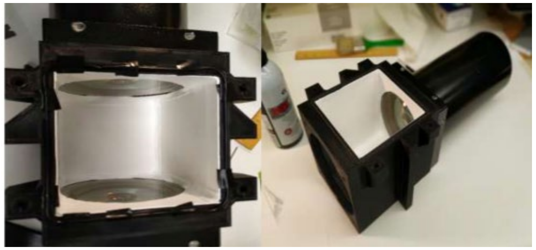
Lesson Learned and future plans

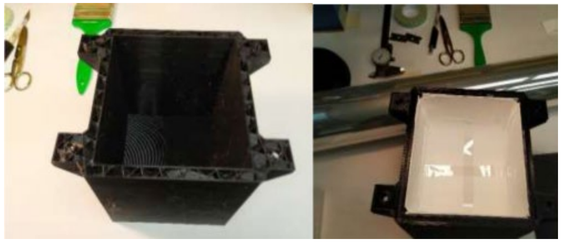
Lesson Learned

- Any work with aerogel detector, including assembling or repairing of the tray must be done in very clean area.
- Unused trays, and whenever detector is not needed for a long time (years) must be stored also in a safe and clean area and covered with plastic.
- The area must be with very low He contamination, to avoid possible poisoning of the PMTs.
- Transportation from the storage area to detector hut, and installation or swapping of aerogel tray must be conducted according to special procedure.

Future plans

- Refurbish next 2 trays of the SHMS Aerogel detector: SP20 and SP30.
- Work on development of better design and modification of aerogel detector.
- Design prototypes with different geometry, and test different optically transparent types of aerogel which can be used for fixing tiles, and study their impact on detector performance. Such work has been started and we plan to continue.





Experiments with use of HMS and SHMS Aerogel Detectors

- **HMS Aerogel Detector has been used at CEBAF 6 GeV energies:**
  - E-01-004 (Fpi-2), "The Charged Pion Form Factor"
  - E-00-108 (Duality), "Duality in Meson Electroproduction"
  - E-01-107 (CT), "Measurement of Pion Transparency in Nuclei"

It was not used since 2006, was damaged while being in the HMS hut in 2006-2011 (probably due to accumulation of He. Needs refurbishing & new PMTs)

- The **SHMS Aerogel Detector has been used after CEBAF 12 GeV upgrade:**
  - E12-06-101, "Measurement of the Charged Pion Form Factor to High Q2"
  - E12-06-104, "Measurement of the Ratio R=σL/σT in Semi-Inclusive Deep-Inelastic Scattering"
  - E12-09-002, "Precise Measurement of pi+/pi- Ratios in Semi-inclusive Deep Inelastic Scattering PartI: Charge Symmetry violating Quark Distributions"
  - E12-09-011, "Studies of the L-T Separated Kaon Electroproduction Cross Section from 5-11 GeV"
  - E12-09-017, "Transverse Momentum Dependence of Semi-Inclusive Pion Production"

It is still in good working condition. But it would be good to buy an extra amount of n = 1.011 aerogels to fill the full effective area of the tray.

Thank You

Publications

1. R. Asaturyan et al.**,** Nucl. Instr. Methods A 548 (2005) pp. 364-374
2. T. Horn et al., Nucl. Instr. Methods A 842 (2017) pp. 28-47