Join research and development AANL, BUDKER, NICA-SPD for Aerogel Cherenkov detector

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For the AANL- SPD Collaboration

JINR NICA-SPD DUBNA
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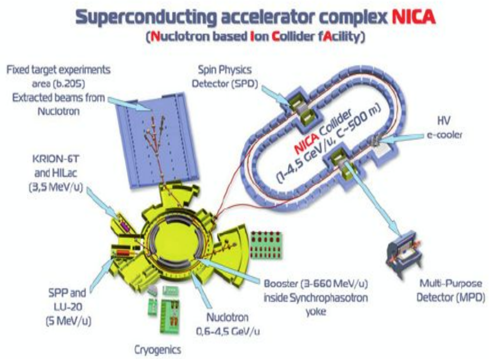
Budker Institute of Nuclear Physics

A. ALIKHANYAN National Laboratory

SPD NICA

NICA: Nuclotron-Based Ion Collider

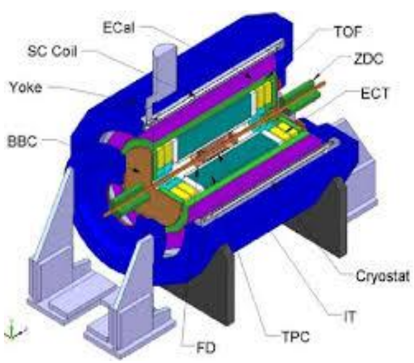


Key Parameters of The NICA Collider

Ring circumference, m	503,04		
Number of bunches	22		
R.m.s. bunch length, m	0.6		
Ring acceptance, π mm·mrad	40.0		
Long. Acceptance, Δp/p	±0.01		
γtransition (Etransition, GeV/u)	7.091 (5.72)		
β*, m	0.35		
Ion Energy, GeV/u	1.0	3.0	4.5
Ion number/bunch, 1e9	0.275	2.4	2.2
R.m.s. emittance, h/v π·mm·mrad	1.1/1.0	1.1/0.9	1.1/0 .76
R.m.s. Δp/p, 1e-3	0.62	1.25	1.65
IBS growth time, s	190	700	2500
Peak luminosity, $cm^{-2} \cdot s^{-1}$	1.1e25	1e27	1e27

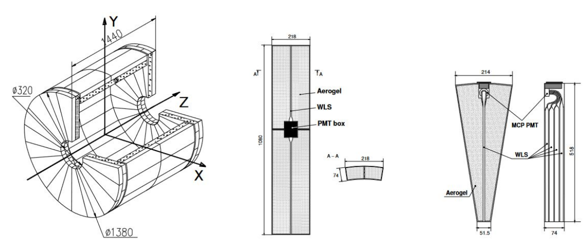
Heavy ion colliding beams up to $^{197}Au^{79+}$ + $^{197}Au^{79+}$
at $\sqrt{s_{NN}} = 4 \div 11$ GeV, $L_{average} = 1x10^{27}$ $cm^{-2} \cdot s^{-1}$
Light-Heavy ion colliding beams of the same energy range and L
Polarized beams of protons and deuterons in collider mode:
$p\uparrow p\uparrow \sqrt{s_{pp}} = 12 \div 26$ GeV $L_{max} \approx 1x10^{32}$ $cm^{-2} \cdot s^{-1}$
$d\uparrow d\uparrow \sqrt{s_{NN}} = 4 \div 13.8$ GeV
Extracted beams of light ions and polarized protons and deuterons for fixed target experiments:
$Li \div Au = 1 \div 4.5$ GeV/u ion kinetic energy
$p, p\uparrow = 5 \div 12.6$ GeV kinetic energy
$d, d\uparrow = 2 \div 5.9$ GeV/u ion kinetic energy
Applied research in ion beams at kinetic energy starting with 3 MeV/u

Aerogel Detector for SPD (Spin Physics Detector)



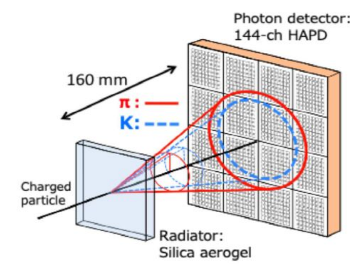
Spin Physics Detector (SPD)

Option (I)



It is based on the ASHIPH technology developed at the KEDR experiment

Option (II)

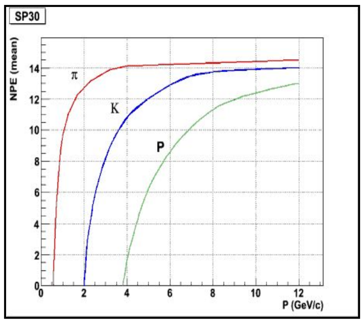


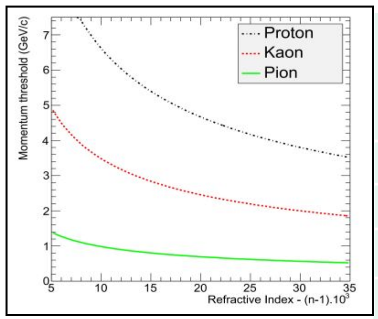
Ring Imaging Aerogel Cherenkov (ARICH) or Focusing RICH (FARICH).

Aerogel Cherenkov Detector Properties

According to the physics program of the SPD experiment, the major task of the particle identification (PID) system is to separate pions and kaons in final states at momentum range above 1.5 GeV/c, where it is not possible with other systems (TOF and dE/dx).

Cherenkov counters are the best option for solving such a problem. Aerogels are most useful materials as the Cherenkov radiator due to their transparency and adjustable refractive indices that can fill the gap between the gases and liquids .





Threshold momentum of particles for aerogel with different n

Type of Particle	P_{th} in n=1.030	P_{th} in n=1.015	P_{th} in n=1.010	P_{th} in n=1.006
μ	0.428	0.608	0.746	0.963
π	0.565	0.803	0.984	1.272
K	2.000	2.840	3.482	4.500
P	3.802	5.397	6.618	8.552

Several options of aerogel Cherenkov detectors used in collider experiments were considered.
Two options for SPD Cherenkov are selected for detailed studies:

- Aerogel counter based on wavelength Shifters and Phototubes (ASHIPH)
- Aerogel, Ring Imaging Cherenkov (ARICH) or Focusing ARICH (FARICH)

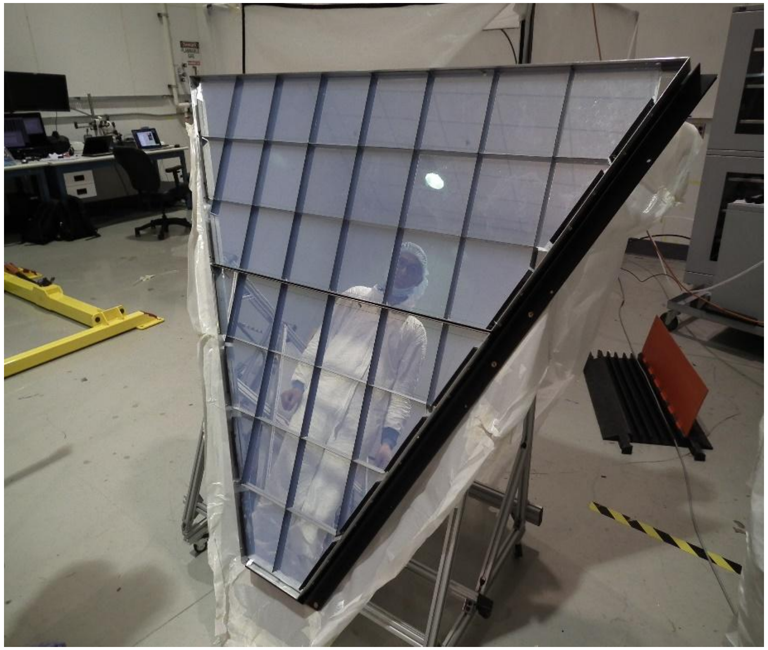
Relatively simple ASHIPH type Aerogel Detector, positioned at the end-caps of the SPD will extend π/K separation range from 1.2 GeV/c to 2.5 GeV/c.
More complicated RICH type aerogel detector is the best option to provide reliable π/K-separation in a wide momentum range (from 0.6 to 5.0 GeV/c).

SPD need Aerogel detector to improve π/K/p separation above 1.5 GeV/c momentum

History of aerogel radiators in Novosibirsk

slide from Alexander Barnyakov

- **KEDR ASHIPH** system (VEPP-4M – BINP):
  - π/K-separation in the momentum range 0,6÷1,5 GeV/c.
  - Aerogel n = 1,05 (V~1000 L).
- **SND ASHIPH** system (VEPP-2000 – BINP):
  - π/K-separation in the momentum range 300÷870 MeV/c.
  - Aerogel n = 1,13 (V~9 L).
- **DIRAC-II** (PS – CERN):
  - π/K-separation in the momentum range 5,5÷8,0 GeV/c.
  - Aerogel n = 1,008 (V~9 L).
- **AMS-02** aerogel RICH (ISS):
  - Search for antimatter, study of cosmic rays.
  - Aerogel n = 1,05 (S~1 m^2).
- **LHCb** aerogel RICH (LHC – CERN):
  - π/K-separation in the momentum range 5,5÷8,0 GeV/c.
  - Aerogel n = 1,03 (S~0,5 m^2), aerogel tile 20x20x5 см^3.
- **CLAS-12** aerogel RICH (J-Lab):
  - π/K- & K/p-separation at level 4σ with several momentum GeV/c.
  - Aerogel n = 1,05 (S~6 m^2), aerogel tile 20x20x2-3 см^3.



Novosibirsk aerogels are hydrophilic!

- Aerogel with bulk density 0.24 g/cm^3 has internal surface area by 10^6 times larger than external.

- There are a lot of OH−groups at the aerogel's SiO_2 surface. These groups are primary adsorption centres which are able to attract hundreds of the H_2O molecules per each.

- In the hydrophobic aerogels OH−groups are exchanged by hydrophobic radicals such like $Si(CH_3)_3$.

- Influence of adsorbed water on optical parameters of hydrophilic aerogels produced in Novosibirsk are very well studied already.

- Heating of hydrophobic aerogel up to above 175℃ makes it hydrophilic. Also more active radicals are able to replace $Si(CH_3)_3$ – groups and change aerogel optical parameters.

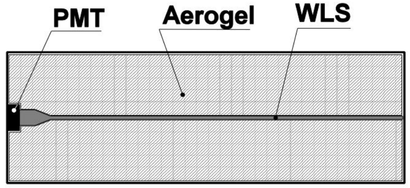
- Before the finalization of any aerogel based counters' design it is necessary to investigate influence of materials (such like WLS, hermetics or second gas/liquid Cherenkov radiators) which are going to be used in the construction on the aerogel transparency.

- For (FA)RICH counters the major optical parameter is **Rayleigh Light scattering length**, while for threshold aerogel counters with diffusive light collection (like ASHIPH) it is **light absorption length** .

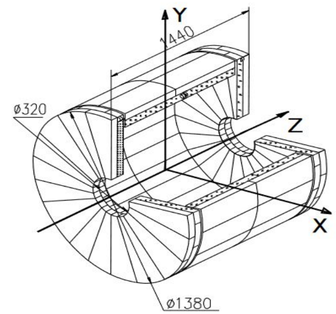
Option (I): ASHIPH
(Aerogel, wavelength Shifters & Phototubes)

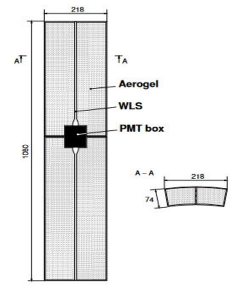
We assume the Aerogel Detector, positioned at the end-caps of SPD to extend π/K separation range from 1.2 GeV/c (with TOF) to 2.5 GeV/c.
It is based on the ASHIPH technology developed at the KEDR experiment

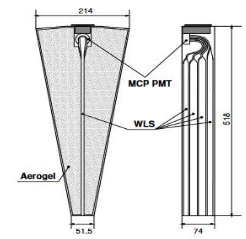
Aerogel SHIfter and PHotomultiplier



PMMA light guide doped with BBQ dye
is used as wavelength shifter



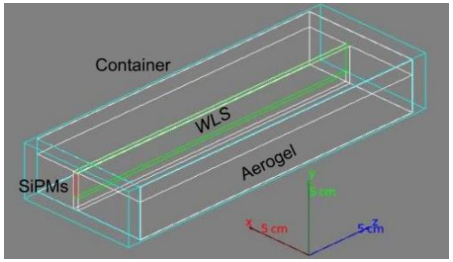


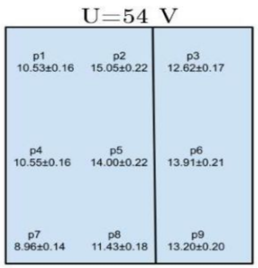


We are working on this project in collaboration with SPD and BIHEP (Novosibirsk).
Prototypes of counter are constructed and tested at BIHEP, MC simulation at AANL.

Vardan's Geant4 simulation results (work in progress)

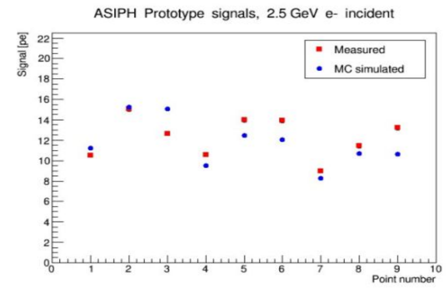
ASHIPH Prototype





Data from 2.5 GeV e- beam measurements, courtesy of I.Ovtin.

Results



Comparison of real and simulated data

slide from Alexander Barnyakov

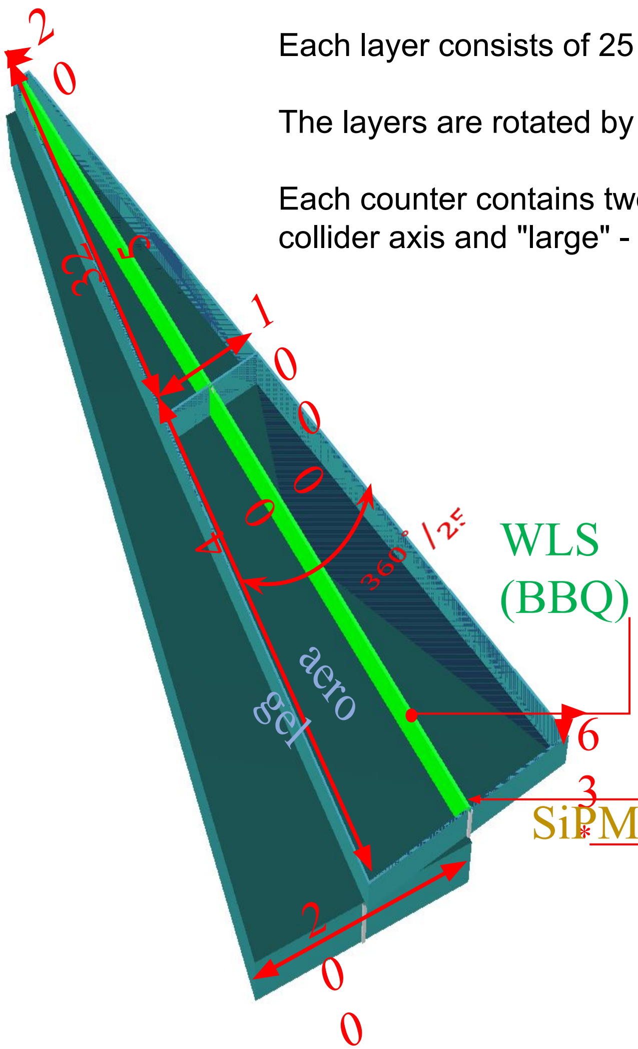
ASHIPH (Aerogel, wavelength Shifters & Phototubes) for SPD-NICA

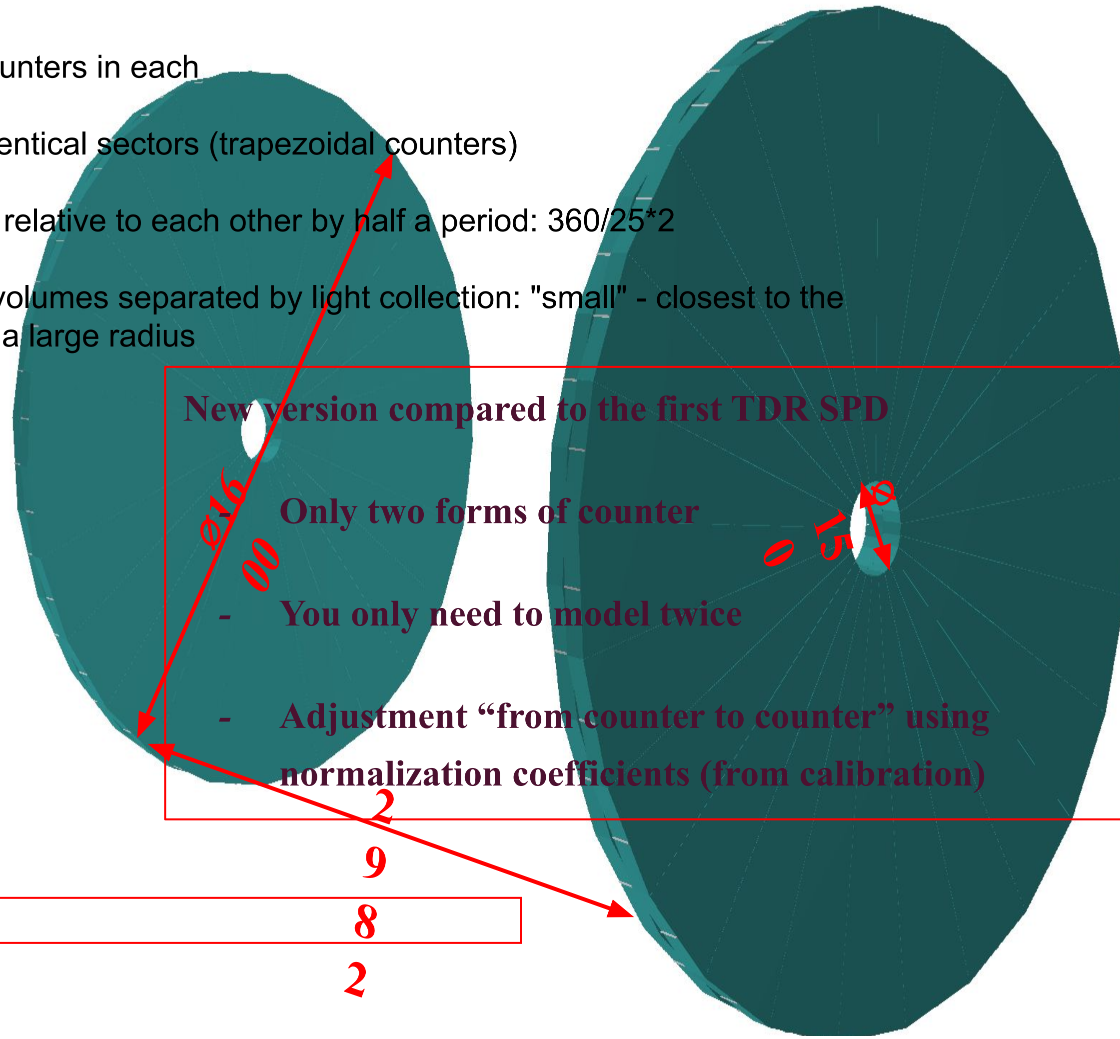
2 ends with two layers of counters in each

Each layer consists of 25 identical sectors (trapezoidal counters)

The layers are rotated by Φ relative to each other by half a period: 360/25*2

Each counter contains two volumes separated by light collection: "small" - closest to the collider axis and "large" - at a large radius





New version compared to the first TDR SPD

- **Only two forms of counter**
- **You only need to model twice**
- **Adjustment "from counter to counter" using normalization coefficients (from calibration)**

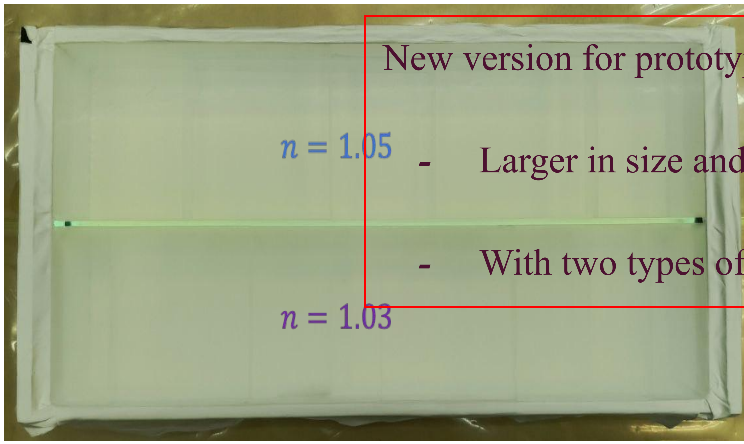
Prototype of ASHIPH Detector for SPD-NICA project

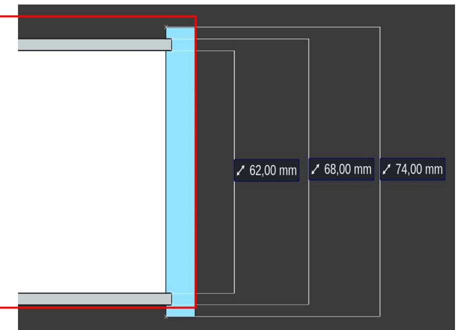
Work is complimentary with other projects:
СНД (ВЭПП-2000, ИЯФ) и STCF (USTC, Hefei)

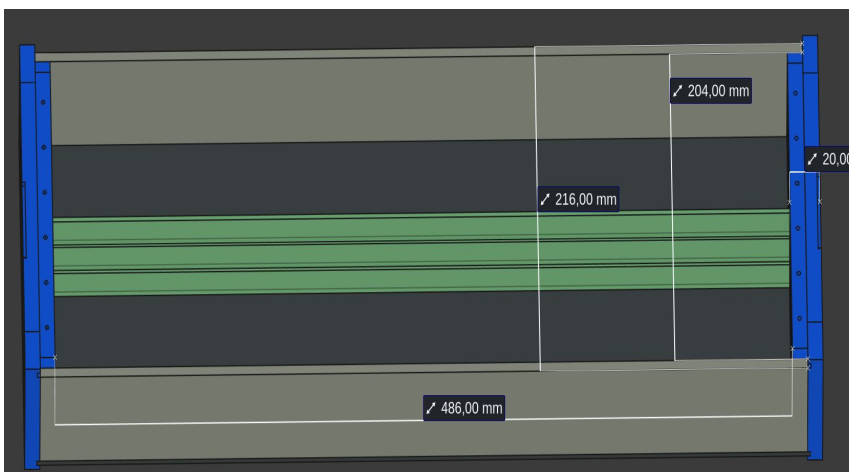
slide from Alexander Barnyakov

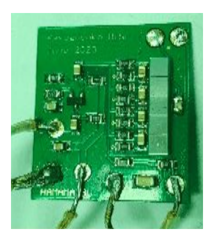
New version for prototype

- Larger in size and thicker than before
- With two types of aerogel n=1.03 and n=1.05





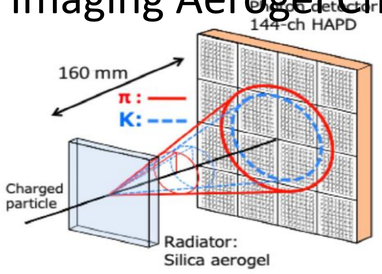


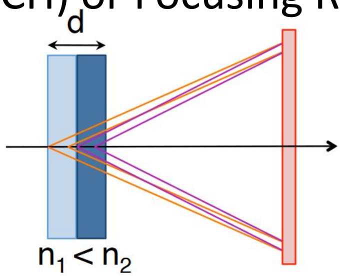


- 3 channel digital readout CAEN V1742 (DRS4)
- 3 linear arrays 5 SiPM / MPPC S13365-3050NE-16 Hamamtsu

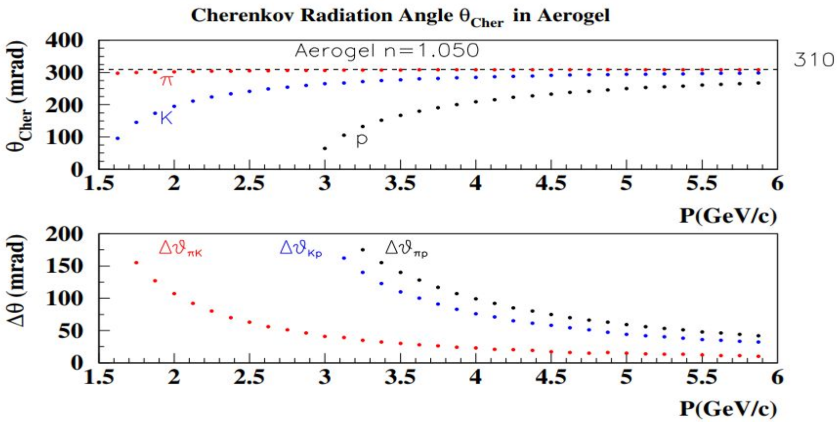
Option (II): ARICH
Aerogel Ring Imaging Cherenkov

Due to increase of dimensions of the SPD setup (from 160 mm to 300 mm), the space in the end-cup region can be used to install more sophisticated Cherenkov detector: Ring Imaging Aerogel Cherenkov (ARICH) or Focusing RICH (FARICH).





Cherenkov photons are emitted at an angle ϑ, depending on the refractive index n and particle velocity v. If we measure p and ϑ, we can separate different particles through the relation $\cos\vartheta = c/(n \times v) = 1/(n \times \beta)$



RICH type aerogel could provide π/K separation up to momentum ~ 5 GeV/c. The main problem in constructing such a counter is a photon detector which should cover all the ring area (~ 2 m²) and high cost (>$1 M) of the detector.

More detailed studies, MC simulations, design and tests of prototypes are needed before we can propose best option of Aerogel detector for SPD. (work in progress)

AANL-SPD Collaboration

- Collaboration started in 2020

  MOU AANL/NICA-SPD signed in 2021

  AANL group's proposed contribution:

  1. assembling of EmCal modules for SPD, will conduct detailed tests ;
  2. take part in the installations and commissioning of the SPD EmCal,;
  3. Perform necessary Monte-Carlo simulations.

AANL- SPD Collaboration Current Team

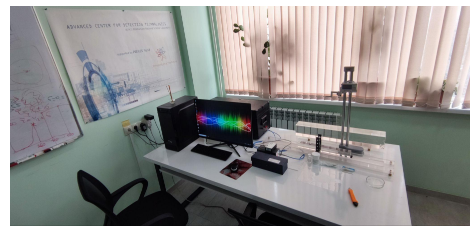
Nikolay Ivanov (doctor)
Hamlet Mkrtchyan (doctor, professor)
Albert Shahinyan (PhD in engineering)
Arthur Mkrtchyan (PhD)
Vardan Tadevosyan (scientist)
Alvard Malkhasyan (student)
Argine Hakobyan (student)

- Since 2022 by request from the SPD Collaboration the AANL group is doing studies on Aerogel detector.
- In 2022 at SPD Collaboration meeting we presented report "Design, Construction and Performance of Aerogel detectors for HMS and SHMS Spectrometers at Jlab Hall C".
- In 2023 our group, as a winner of NICA support program, conducted project "Development of aerogel based Cherenkov counter (prototype) for SPD".
- In 2023 A. Malkhasyan and A. Hakobyan visited JINR as a summer student.

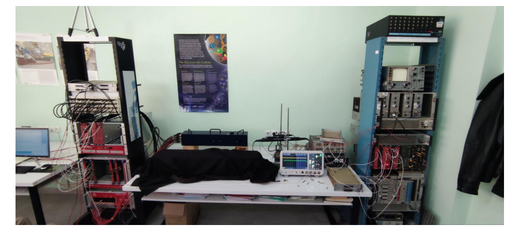
Students and young scientists

Lab room

Clean room



Spectro-photometer

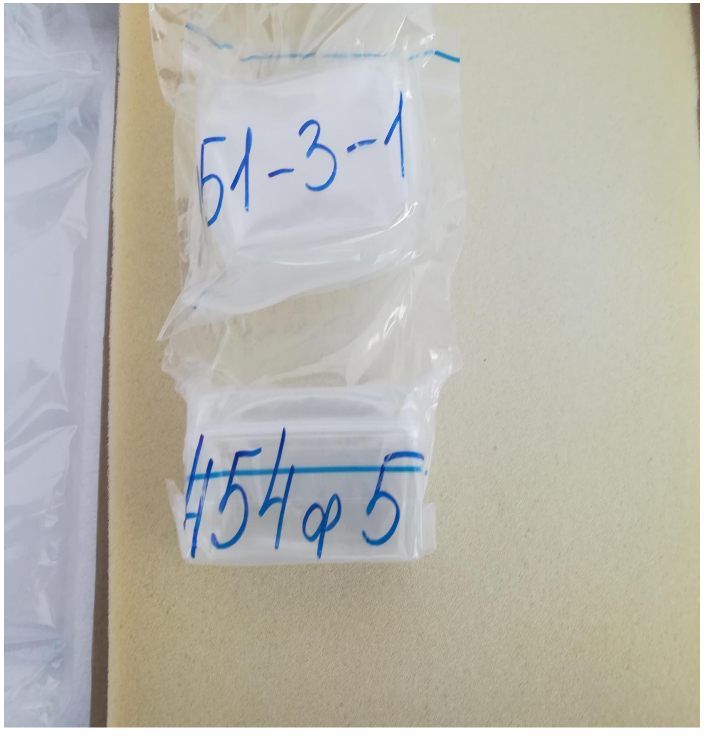


DAQs

3D printers

Microscope

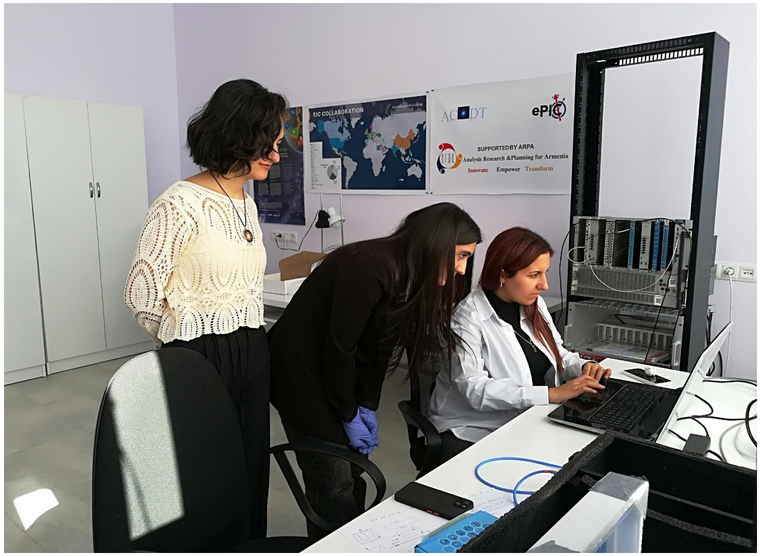
BINP Aerogel transmittance measurements at AANL

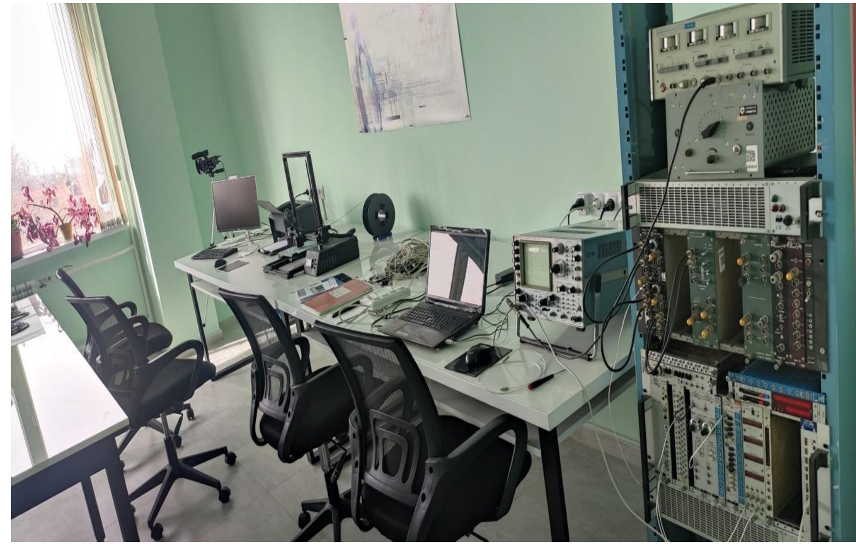


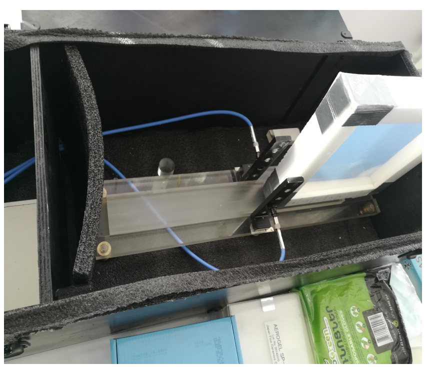
- In April 26 of 2024 delegation from BINP/JINR visited AANL, and provided samples of aerogel manufactured at BINP (Alexander Barnyakov):
- Single-layer, with transverse dimensions 20cm × 20cm and thickness 3cm
- Double-layer (# 454-5), with transverse dimensions 7cm × 4cm and thickness 3cm
- Double-layer (# 451-3-1), with transverse dimensions 6cm × 4cm and thickness 4 cm

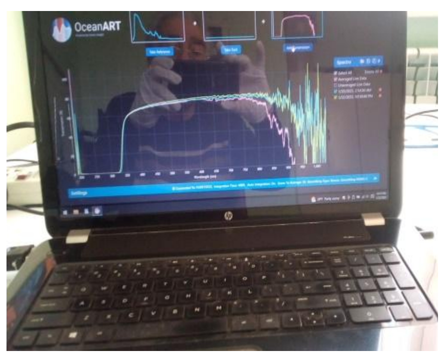
- Aerogels unpacked and transmittance measurements at AANL started in October 2024.

BINP Aerogel transmittance measurements at AANL



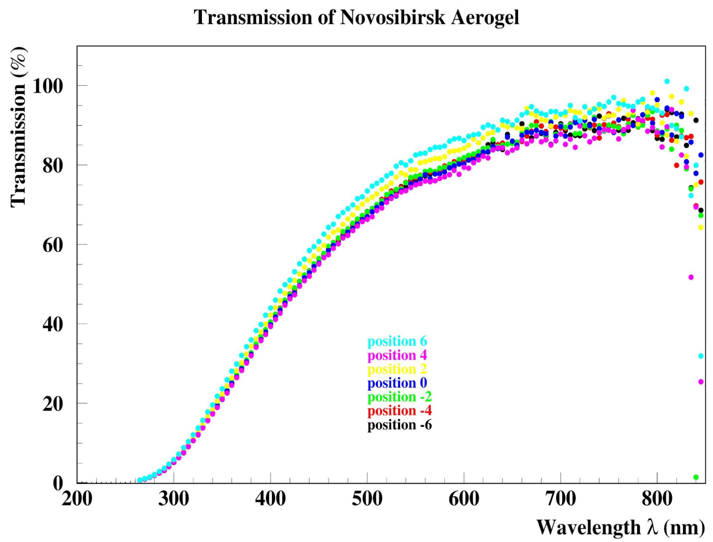


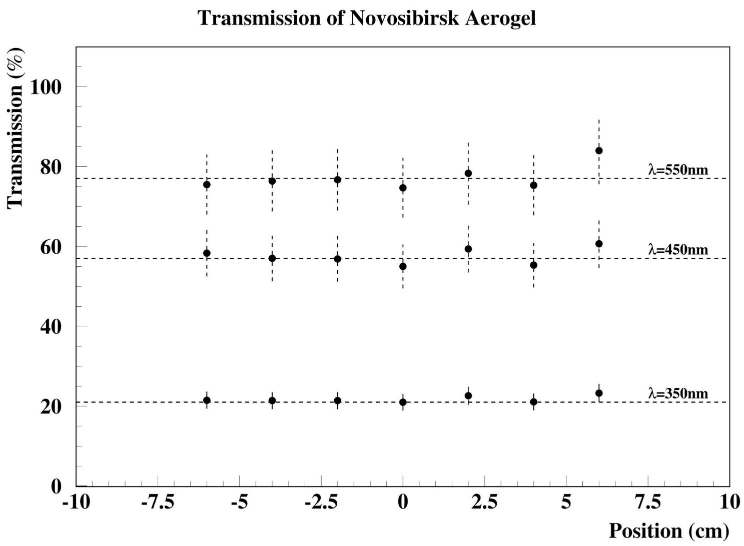




- The transmittance of the aerogel was measured using a 402 OCEAN-ART (FLAME-S-XR1) optical spectrometer.
- This compact and light weight device is very easy to use. Its working range covers from ultraviolet to visible (UV-Visible, 200-1025 nm).
- We used OceanArt Software, which allows us to measure absorbance, transmittance, and reflectance.
- The measurement process includes three steps:
- a. Initial measurement (performed with the light on without the sample),
- b. Dark current measurement with light on but Shatter closed)
- c. Transmittance measurement (shatter open, sample in place, between input and output fibers).

BINP Aerogel transmittance measurements at AANL

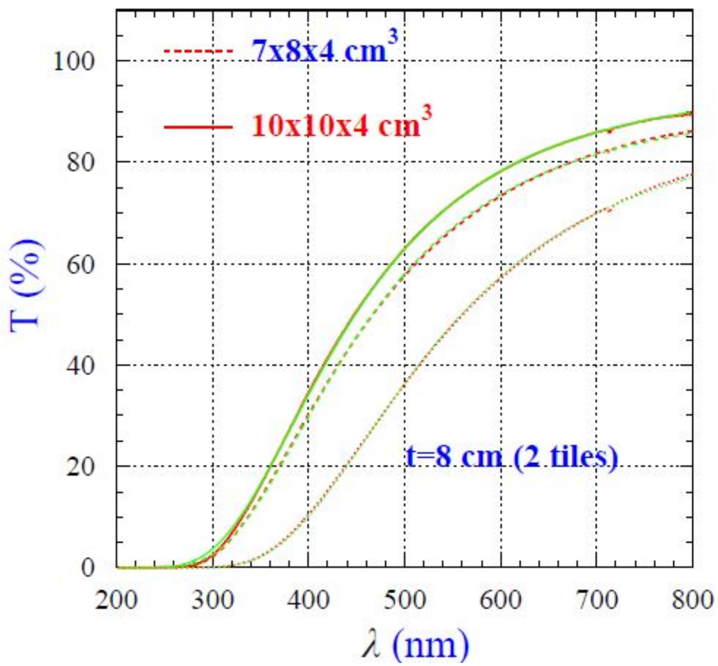


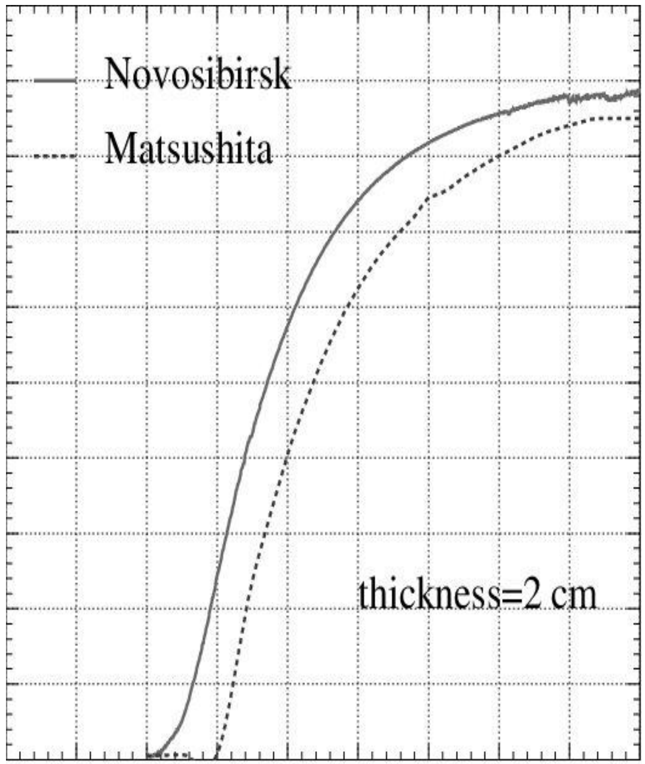


Transmittance as a function of wavelength for 3 cm thick aerogel, produced in BINP Novosibirsk (measured at AANL)

Transmittance of Novosibirsk aerogel as a function of position for different wavelengths (measured at AANL)

Novosibirsk Aerogel transmittance





- Transmittance as a function of wavelength for two samples of 4 cm thick aerogels, produced in Novosibirsk (solid and dashed lines), and for the two samples together (dotted line). NIM, A 519 (2004) 493

- Transmittance as a function of wavelength for Novosibirsk and Matsushita aerogel samples, 2 cm thick. NIM, A 478(2002)348

Works on SPD Aerogel cherenkov

(possibilities at AANL and needed requisites for future works)

1. Aerogel synthesis IR SB RAS, Novosibirsk
not possible

2. Incoming quality control and selection by optical and mechanical parameters

The complexity of the work depends on the type and refractive index of the aerogel. If it is $n > 1.05$ and a water-resistant aerogel, then the mechanical parameters (dimensions), light transmission can be measured and controlled at AANL. Instruments for precise measurements of dimensions and a photospectrometer for measuring light transmission are available. It will be necessary to prepare a stand for measuring the refractive index.

3. Long-term stability studies: the effect of water and other structural materials on optical parameters critical for Cherenkov ring detectors.

Such studies can be organized at AANL. The quality of the aerogel can be monitored by periodic measurements of transparency and refractive index. An appropriate measurement setup must be assembled.

4. Study of the hydrophobization option for highly transparent aerogels and its influence on both the optical parameters themselves and on long-term stability.

Possibly at AANL, if hydrophobized samples are presented.

5. Measuring the refractive index

We will measure the refractive index from the ultraviolet to visible range (UV-VIS, 200-1000 nm) using the generally accepted and accurate "Prism" method.

6. Mechanical processing - manufacturing of radiators

Its possible at AANL, our specialists have such experience. The complexity of the work depends on the sensitivity of the aerogel to moisture and the refractive index. Need to buy a diamond saw, equip a clean room and a fume hood.

Works on SPD Aerogel cherenkov

(possibilities at AANL and needed requisites for future works)

7. Selection of an option, measurement and comparison of characteristics: PMT with MCP, SiPM, or HAPD, etc.

AANL can conduct such studies with PMT and SiPM, but we do not have a ready-made stand and electronics for this. It is necessary to equip a measurement stand with the necessary electronics. The main difficulty is to purchase the photomultipliers and SiPM needed for the detector.

8. Study of temperature dependences of photon detector parameters and development of a system of thermal stabilization and cooling.

At AANL we can conduct such studies with PMT and SiPM. We have a cooling system. It is necessary to create an appropriate temperature-controlled stand and electronics system.

9. Development and assembly of the prototype. It is possible in AANL

if Novosibirsk/Dubna provide the necessary mechanical components, materials and parts. If the prototype is assembled in Dubna or Novosibirsk, then AANL is ready to participate.

10. Prototype testing

It is possible if the prototype is assembled at AANL , and a stand with the corresponding electronics is setup. If this is in Dubna or Novosibirsk, then our group is ready to participate.

11. SImulations and Modeling

AANL can participate in the creation of software and calculations.

SUMMARY

Taking into count complexity and importance of work as well as limited possibilities, best option is to create join Lab with AANL-SPD

In 1-2 years with join effort we will fill the lab with necessary electronics and equipment and create stable base for joint research and development of Aerogel Cherenkov for SPD

Thank You

Спасибо за внимание

Շնորհակալություն