Current status of R&Ds on aerogel RICH detectors at the BINP

Alexander Barnyakov

Budker Institute of Nuclear Physics

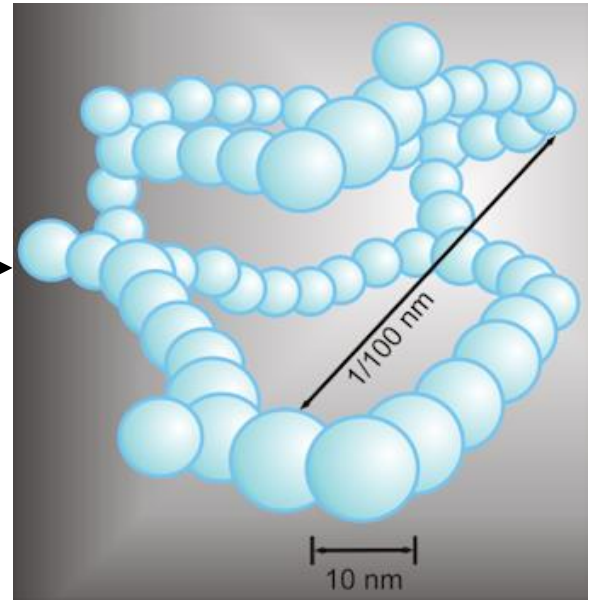
Shanghai, 21-26 October 2026



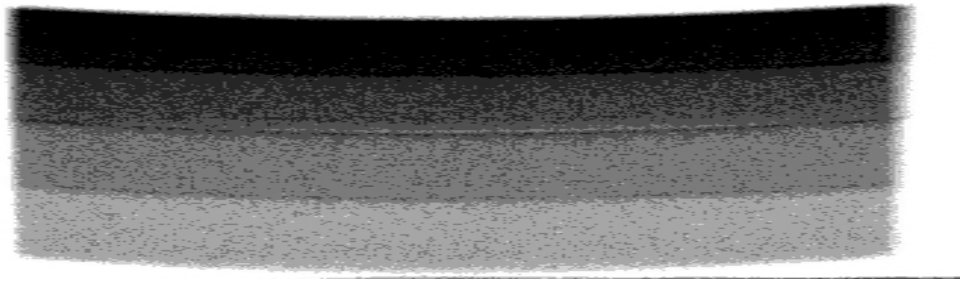
Aerogel

- **A**dvance
- **G**LASS
- **O**PTIMIZED
- **R**esearch
- **A**pparatus

AEROGEL based on SiO_2 (**GLASS**) is nano-structured (**OPTIMIZED**) material with tunable refractive index!



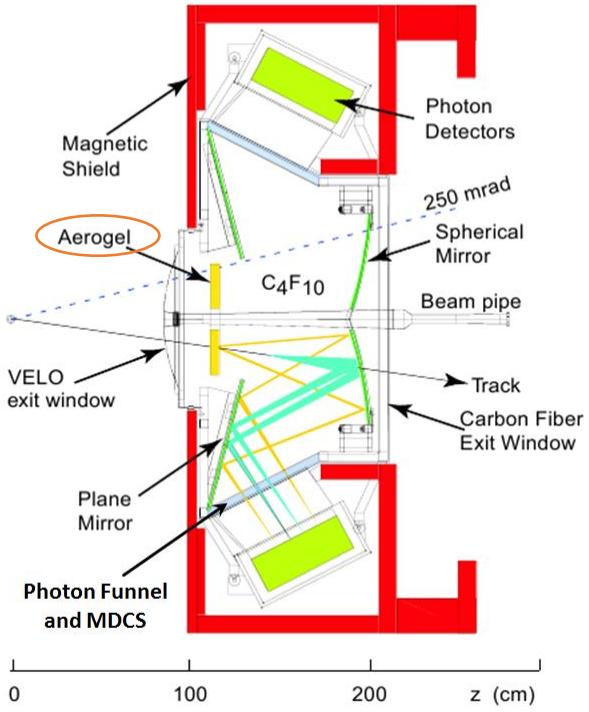
Multi-layer focusing aerogel



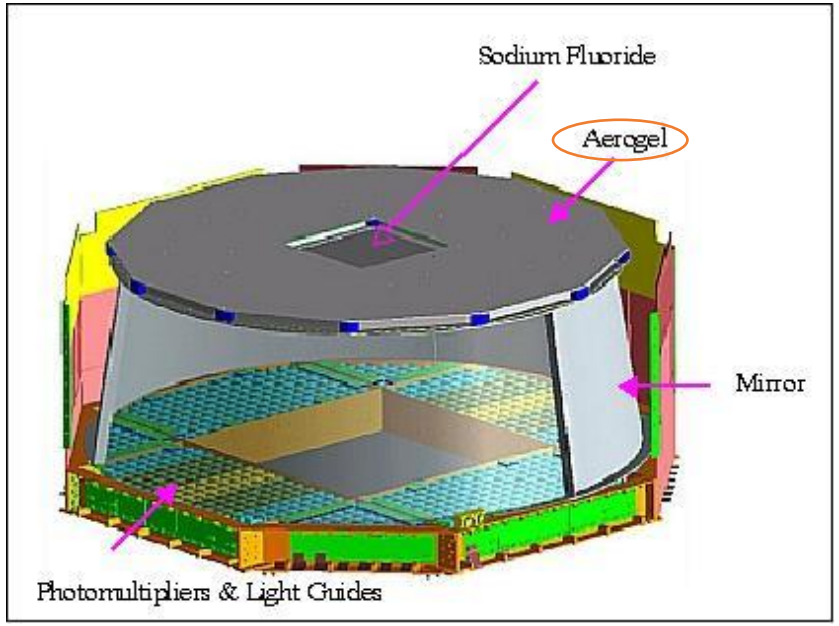
is double **OPTIMIZED GLASS**

RICH detectors based on Novosibirsk aerogel

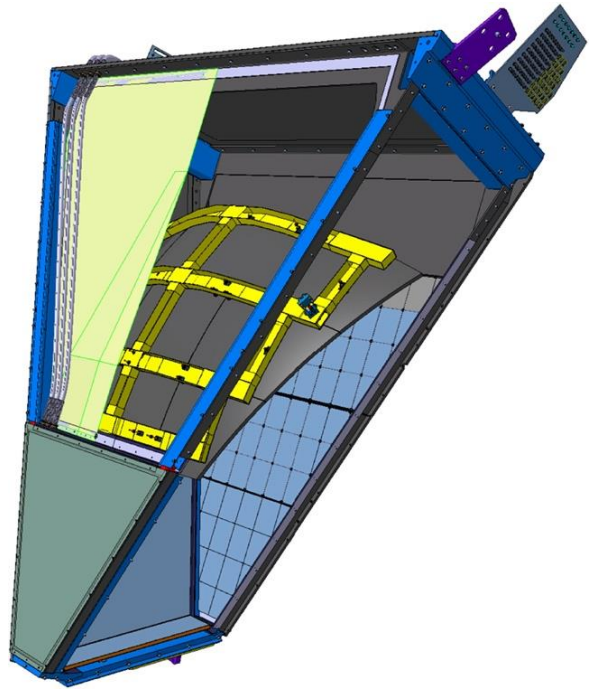
LHCb RICH1 was equiped with the LARGEST aerogel tiles in the world in 2005



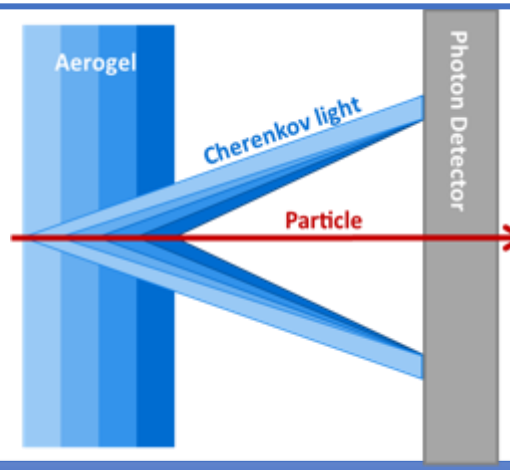
Experimental performances of the RICH based on aerogel exploited at the ISS since 2010 is better than results of simualations



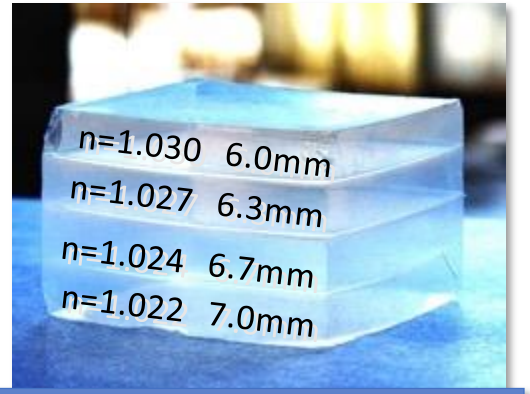
The largest aerogel radiator (6 sq.m.) has been exploited in CLAS-12 experiment since 2020



FARICH technique milestones



The first 4-layer monolithic sample



Increase N_{pe} due thickness increase without $\sigma_{\Theta c}$ degradation

T.Iijima et al., NIM A548 (2005) 383 and A.Yu.Barnyakov et al., NIM A553 (2005) 70

2004÷2005

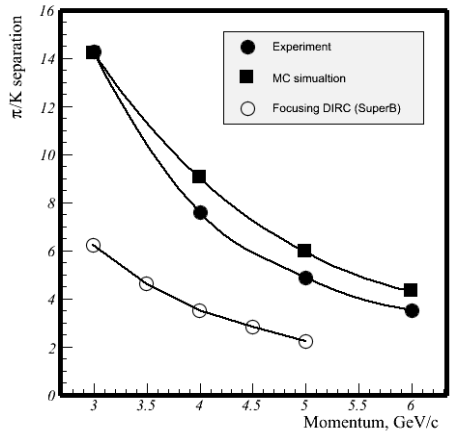
The Belle II (ARICH) is the first application of the method

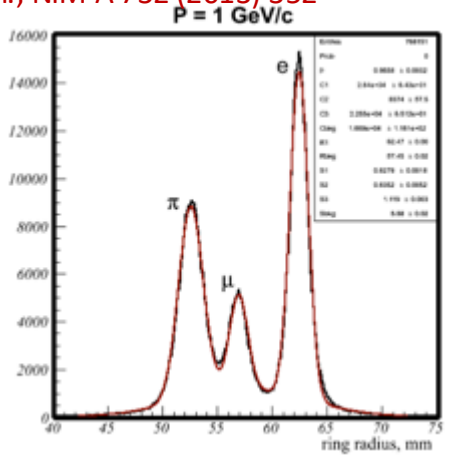


2017

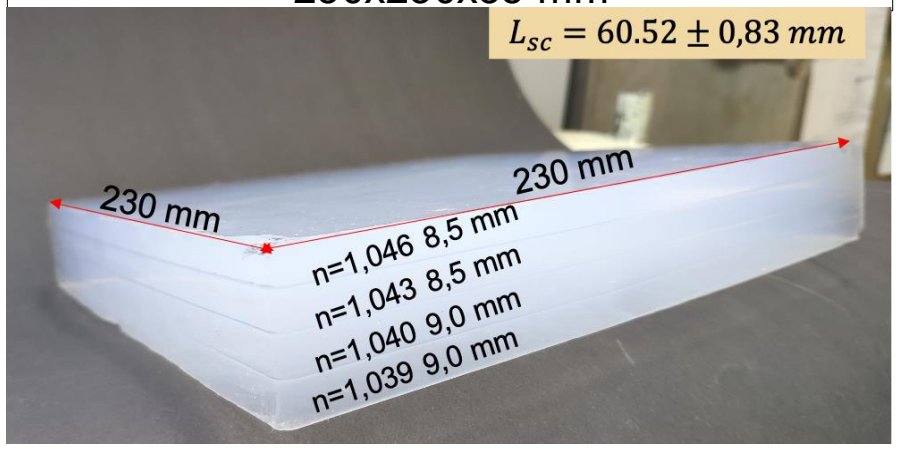
Excellent PID capability were shown at CERN beam test in 2012

A.Yu. Barnyakov, et al., NIM A 732 (2013) 352



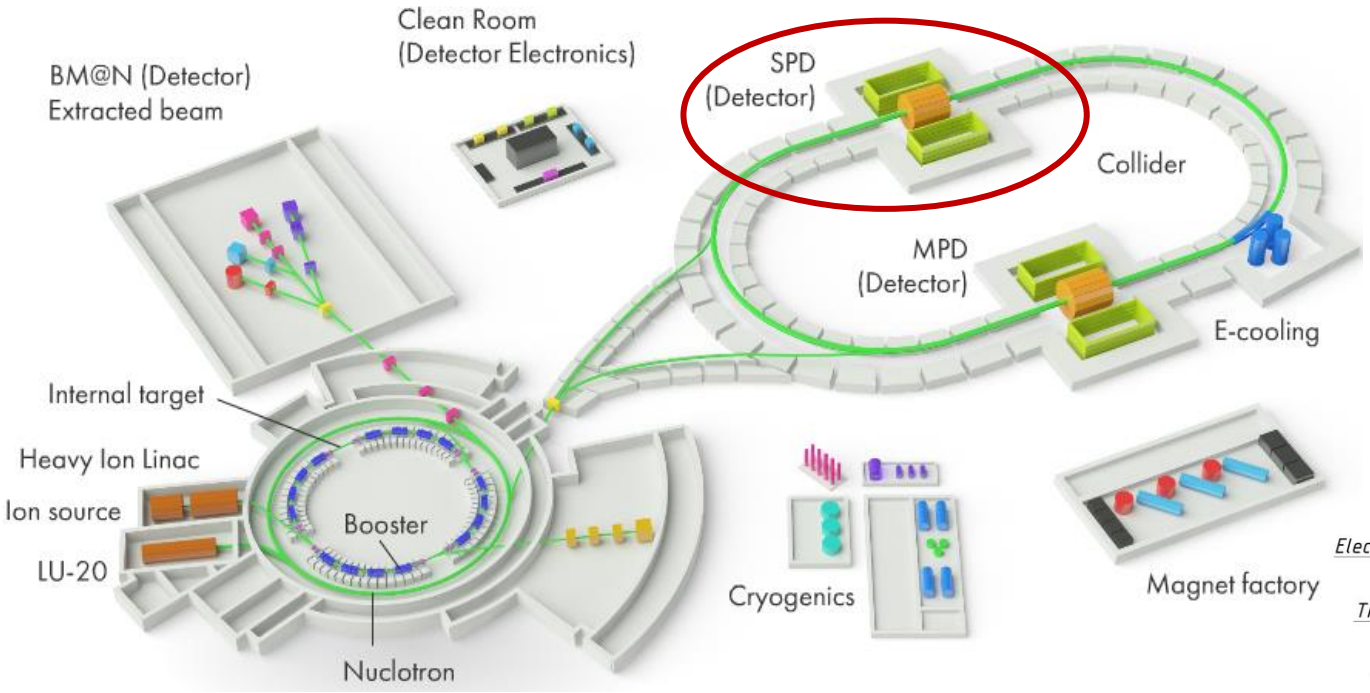


Two 4-layer focusing aerogel blocks 230x230x35 mm



2022÷2023

SPD@NICA



https://nica.jinr.ru/complex.php

Nuclotron based **I**on **C**olliding f**A**cility

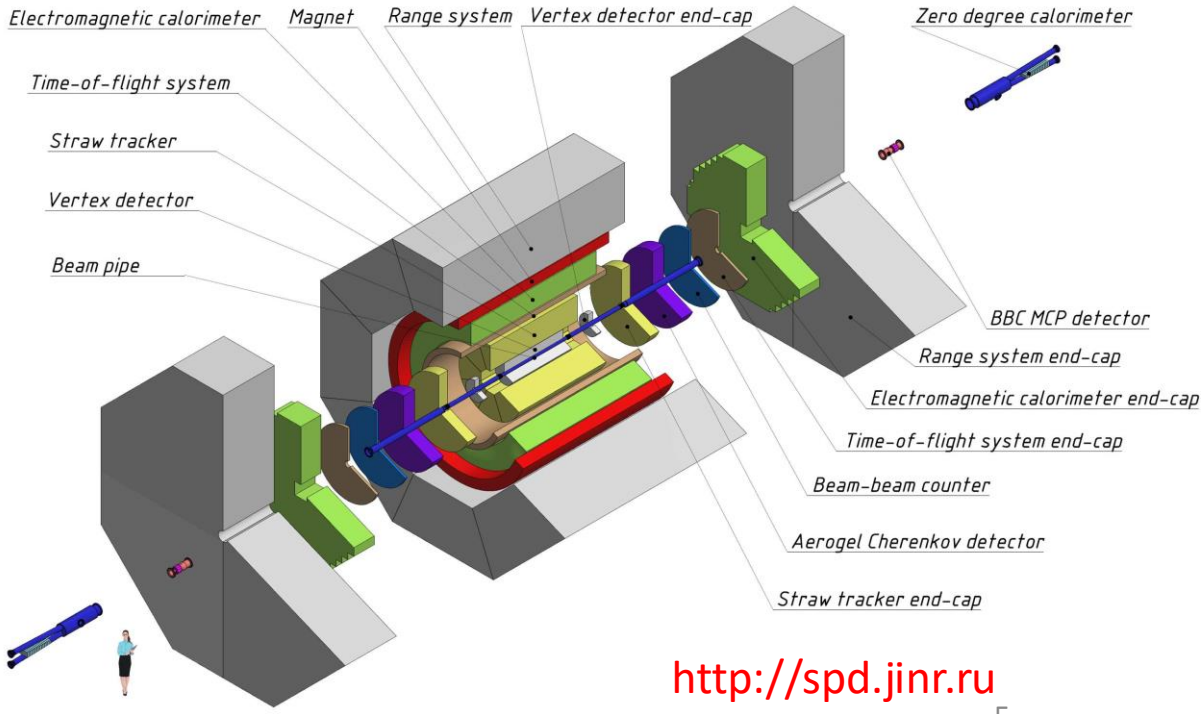
for fundamental nuclear interaction study

Spin **P**hysics **D**etector

to investigate nucleon and light nuclei $(p \,\&\, d)$ spin structure with help of colliding beams at the energies up to 27 GeV.

– Polarized p and d

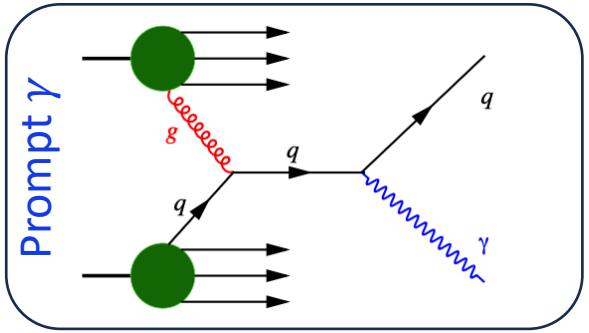
– $L = 10^{32} cm^{-2} s^{-1}$

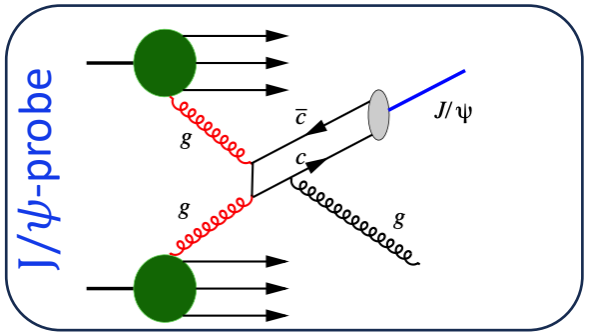


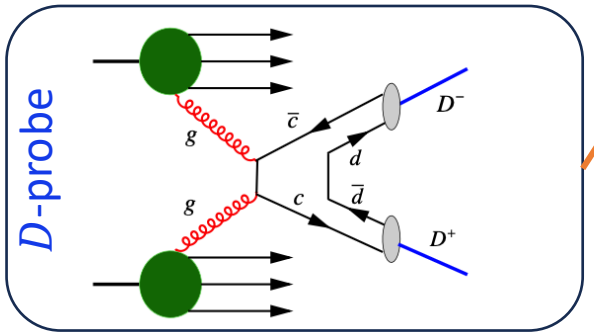
http://spd.jinr.ru

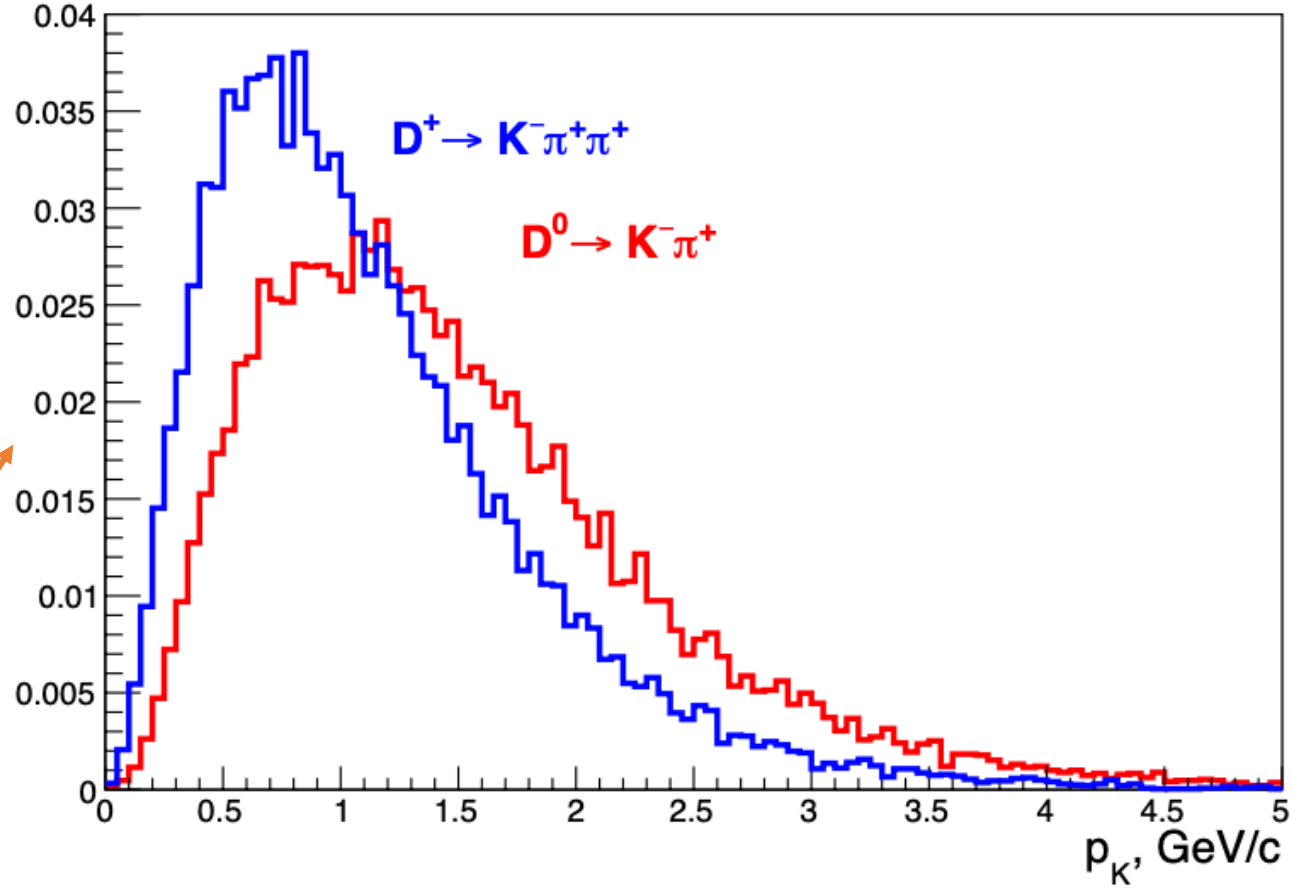
PID system: requirements

Three major probes for Gloun TMD investigations are considered:









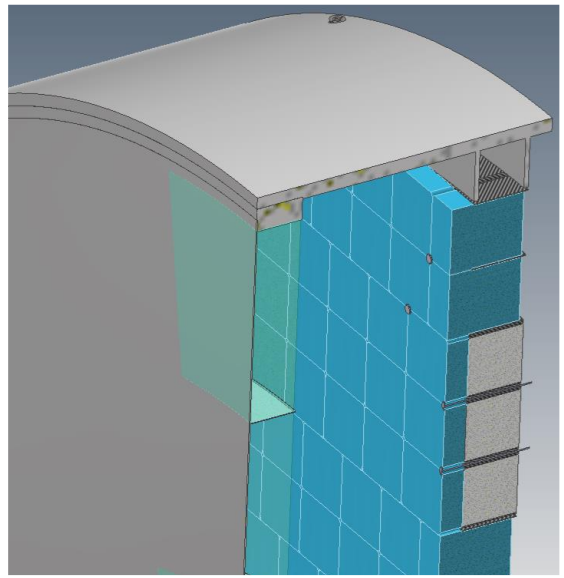
- The reliable π/K-separation up to P=6 GeV/c is required
- RICH based on radiator with n≤1.05 (aerogel) + focusing are needed

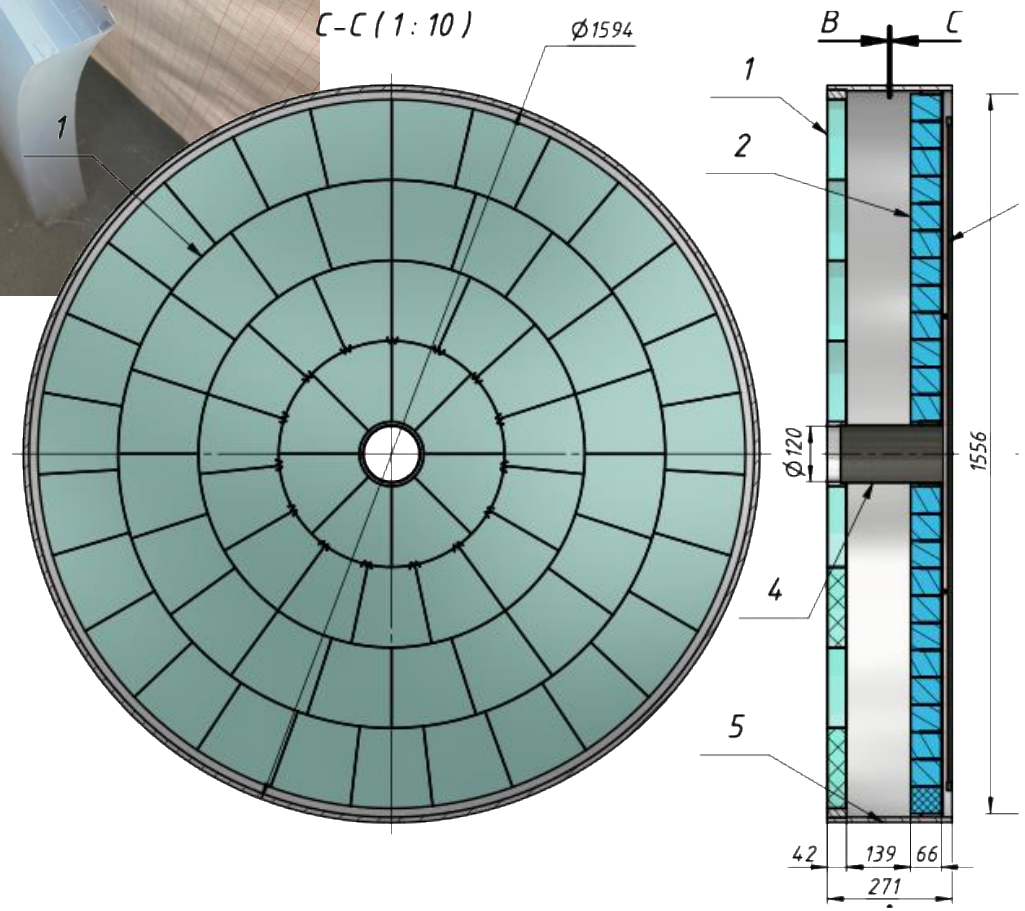
to provide $\sigma_C \sim 2.5\ mrad/track$ and π/K-separation ≥ 3 σ @ 6 GeV/c

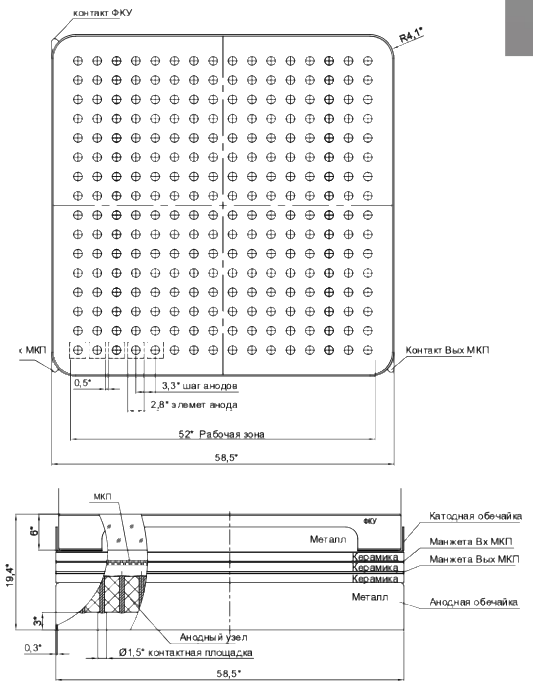
Technical design of the SPD-FARICH system

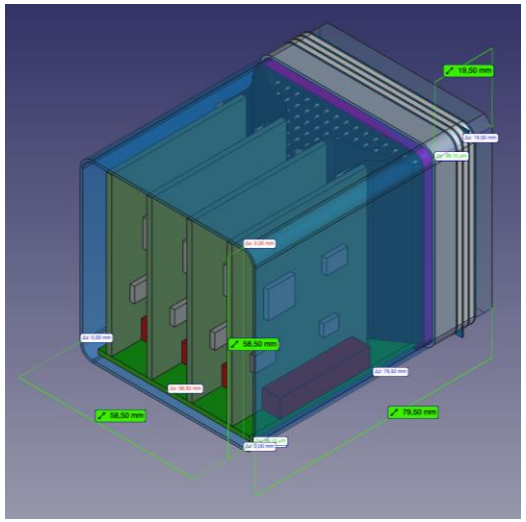


- 70 aerogel tiles per end-cap round shaped with lateral size ≤200 mm
- 550 position-sensitive square MCP PMTs with 59x59 mm per end-cap
- FEE based on DMXG64 ASIC chips developed at the BINP proposed



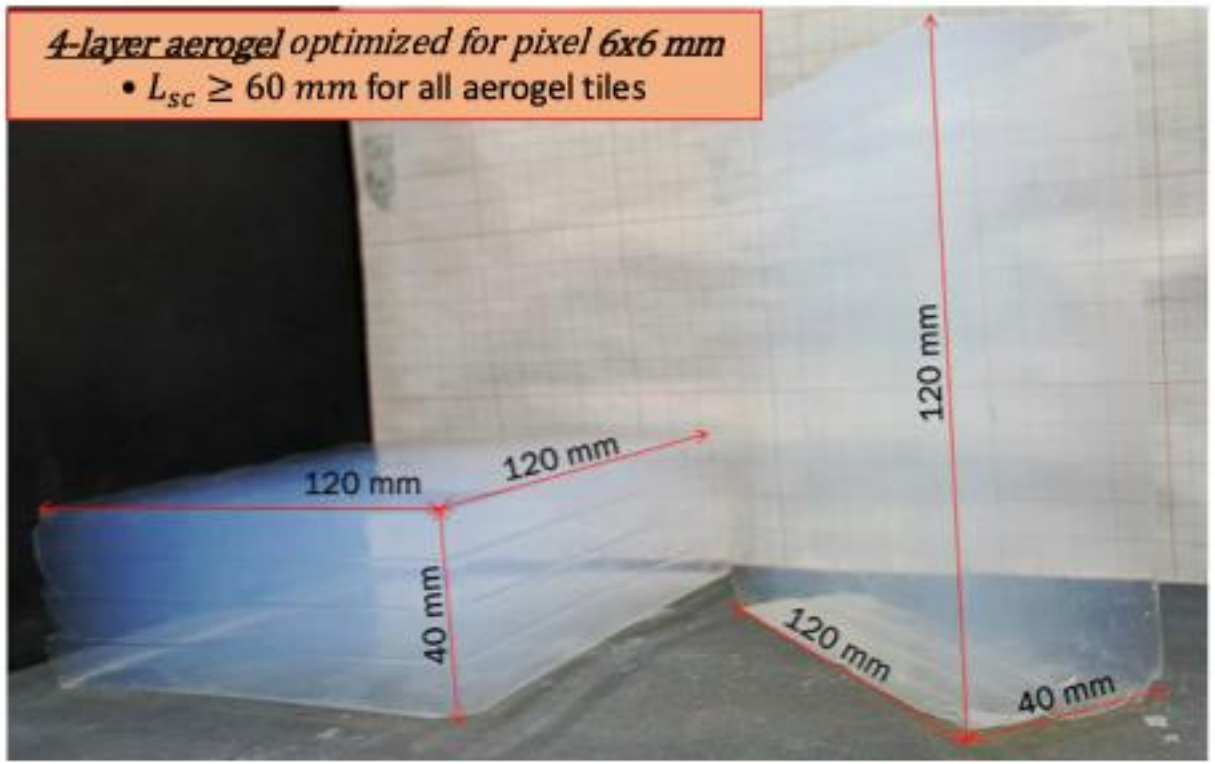


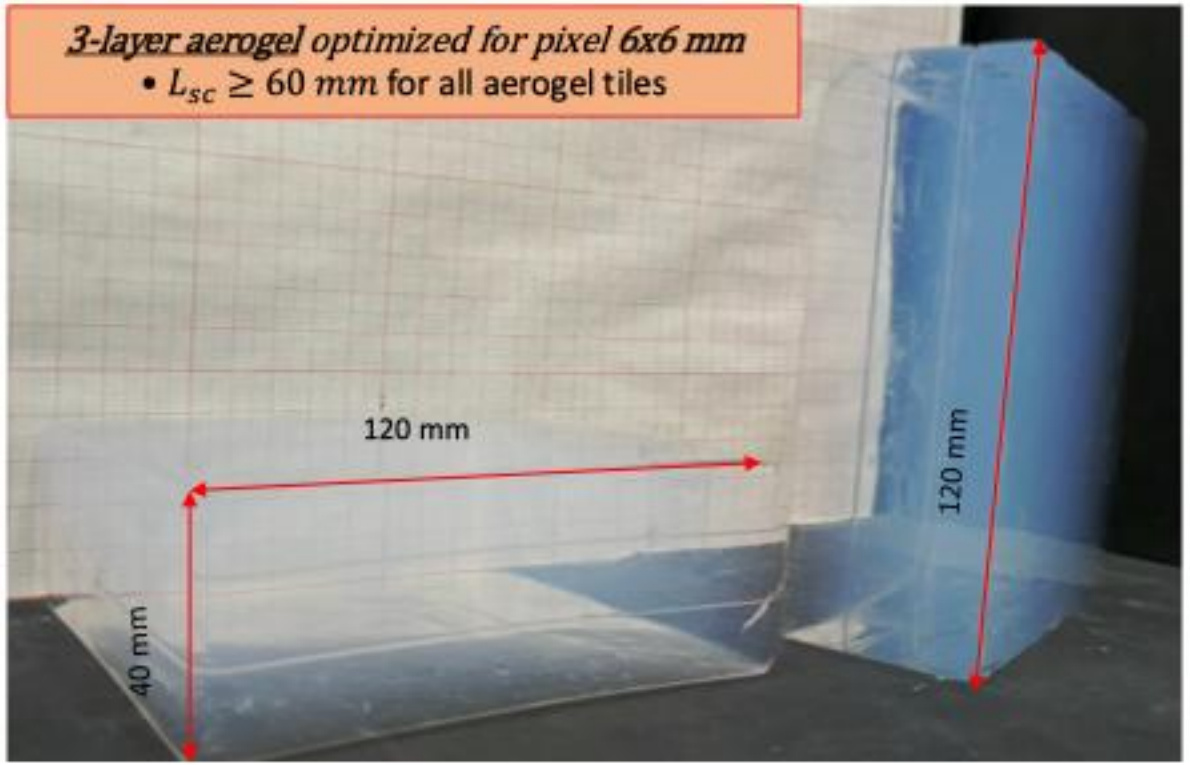




Multi-layer focusing aerogel radiator optimisation

n_{max}=1.05–>	n_{max}=1.04 – to increase Cherenkov angle difference at the high momentum range;
t_{tot}=35 mm –>	t_{tot}=40 mm – to compensate the Npe decrease connected with decrease of refractive index
Δ_{pix}= 3 mm –>	Δ_{pix}= 6 mm – to decrease the number of electronics readout channels;
N_{layer}=4 –>	N_{layer}=3 – to improve stability and reliability of production technology

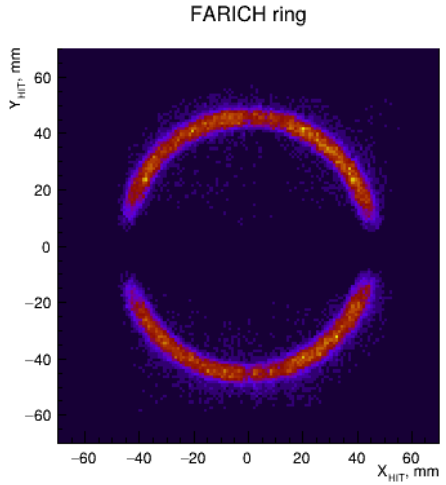


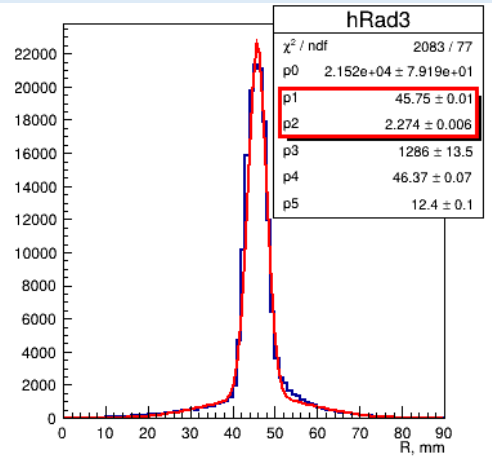


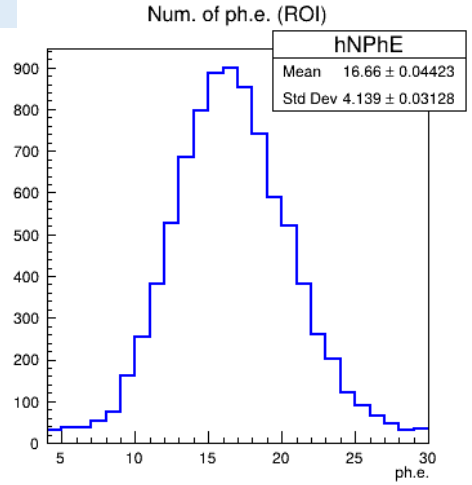
These new aerogels were tested in June 2025 with relativistic electrons at the BINP

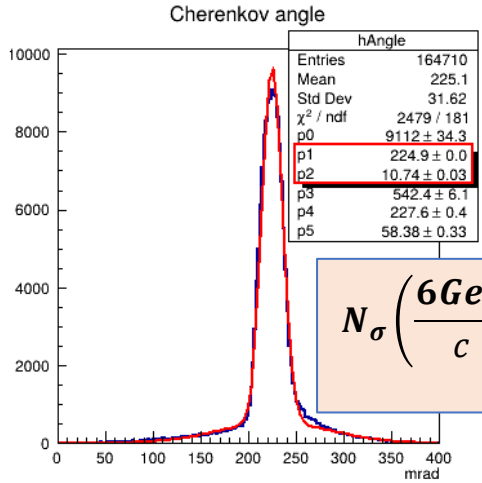
Beam tests at BINP results: June 2025

4-layer, n_{max}=1.04, t=40 mm





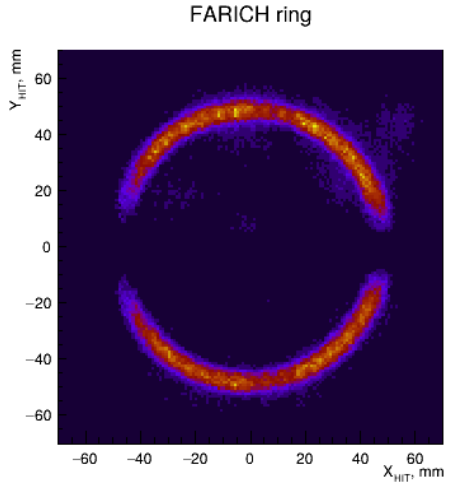


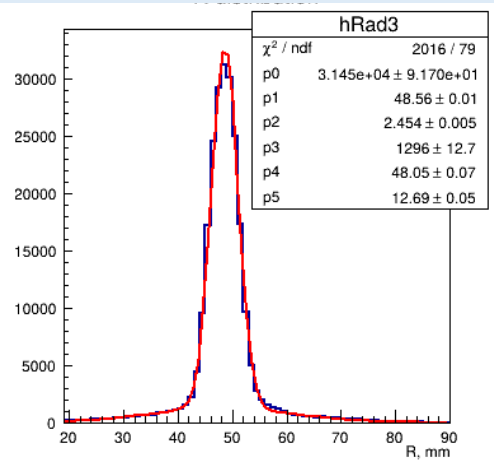


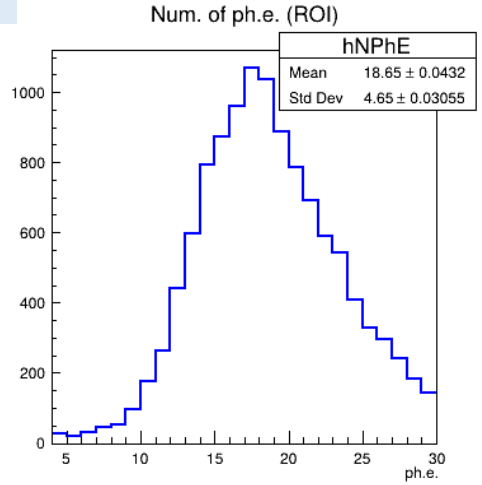
$$\sigma_{1pe} \approx 10.7\ mrad$$

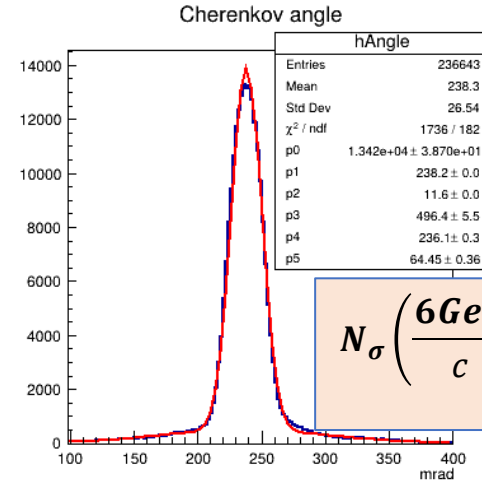
$$N_\sigma\left(\frac{6GeV}{c}\right) \approx \frac{11\ mrad}{10.7 mrad/\sqrt{N_{pe}}} \approx 4.2$$

3-layer, n_{max}=1.04, t=40 mm







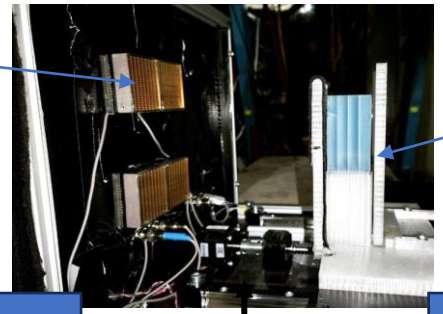


$$\sigma_{1pe} \approx 11.6\ mrad$$

$$N_\sigma\left(\frac{6GeV}{c}\right) \approx \frac{11\ mrad}{11.6 mrad/\sqrt{N_{pe}}} \approx 4.1$$

The first test of the FARICH at the hadron beam of the SPASCHARM beamline of accelerator complex U-70 (IHEP-Protvino, Russia)

PMT H12700 Hamamatsu



Aerogel

- Primary particles are protons with P up to 45 GeV/c
- Secondry particles produced with help of Al-target
- Magnet-separator selects momenta 1.5≤P≤10 GeV/c (for this run)

CALO

TRACKER №4

FARICH

TRACKER №5

TRACKER №3

TRACKER №2

MAGNET
B=0÷0.7 T

TRACKER №1

TRG-Scint 2
3x3cm

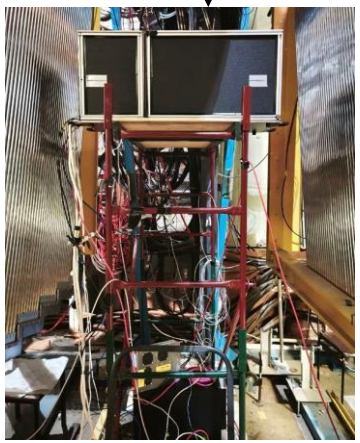
TRG-Scint 1
3x3cm

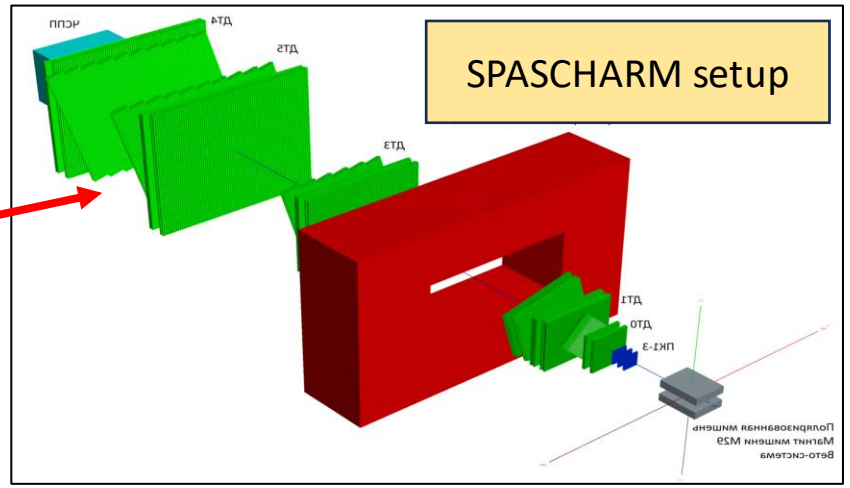
TRG1&&TRG2 placed before target make the trigger signal for DAQ

ToF distance ~ 11 m



MCP-PMT
ToF2 ø18mm

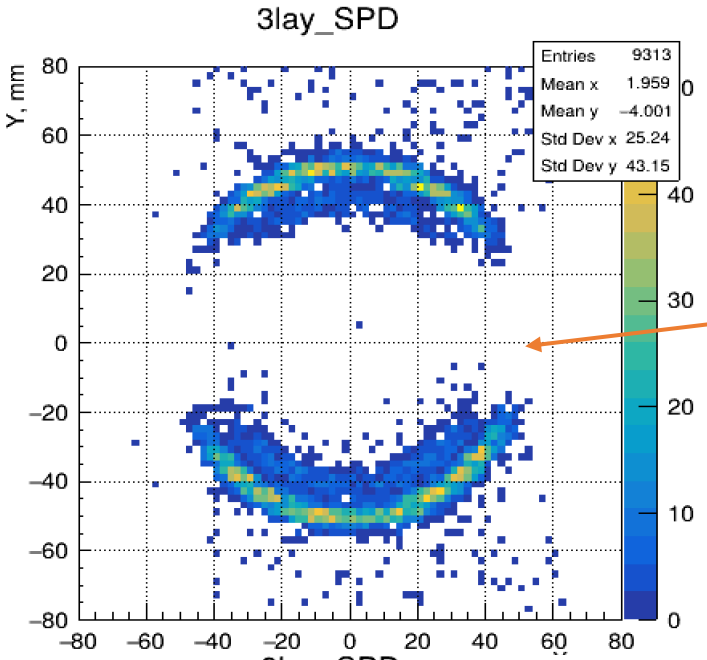




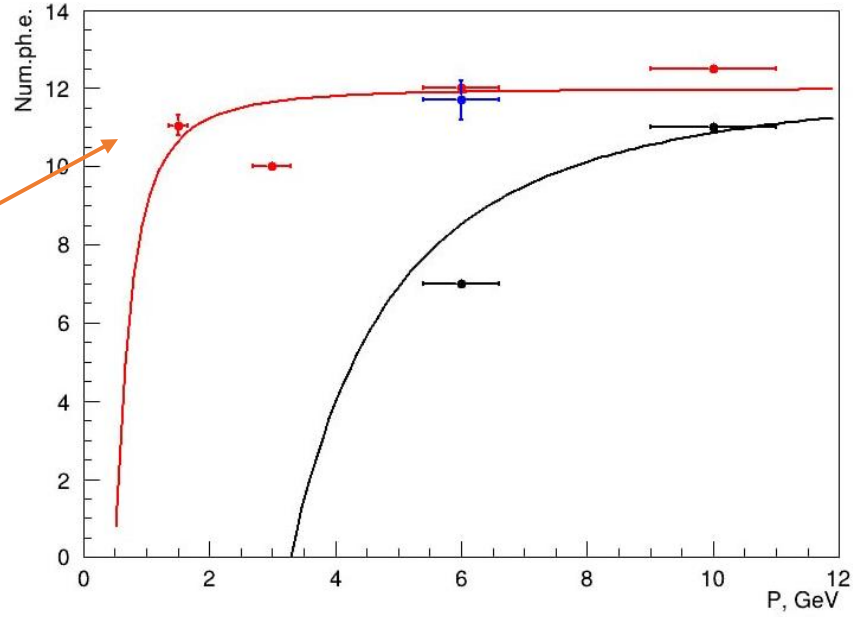


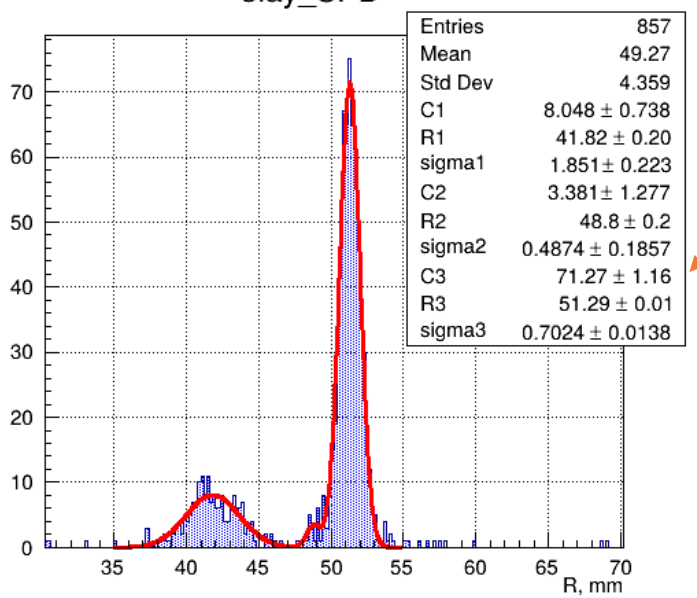
MCP-PMT
ToF1 ø18mm

Hadron beam test result 2026



Gemetrical eff.~60%



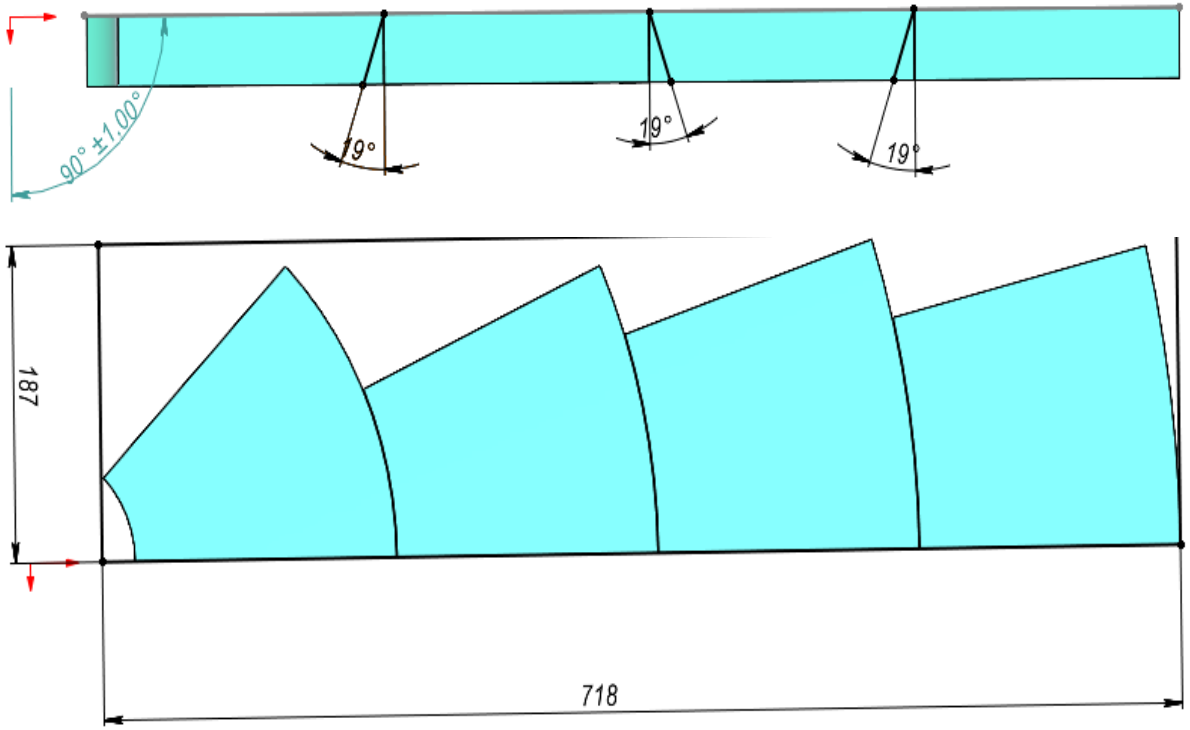


P=6 GeV/c ± 10%

π/K-separation @ 6 GeV/c:

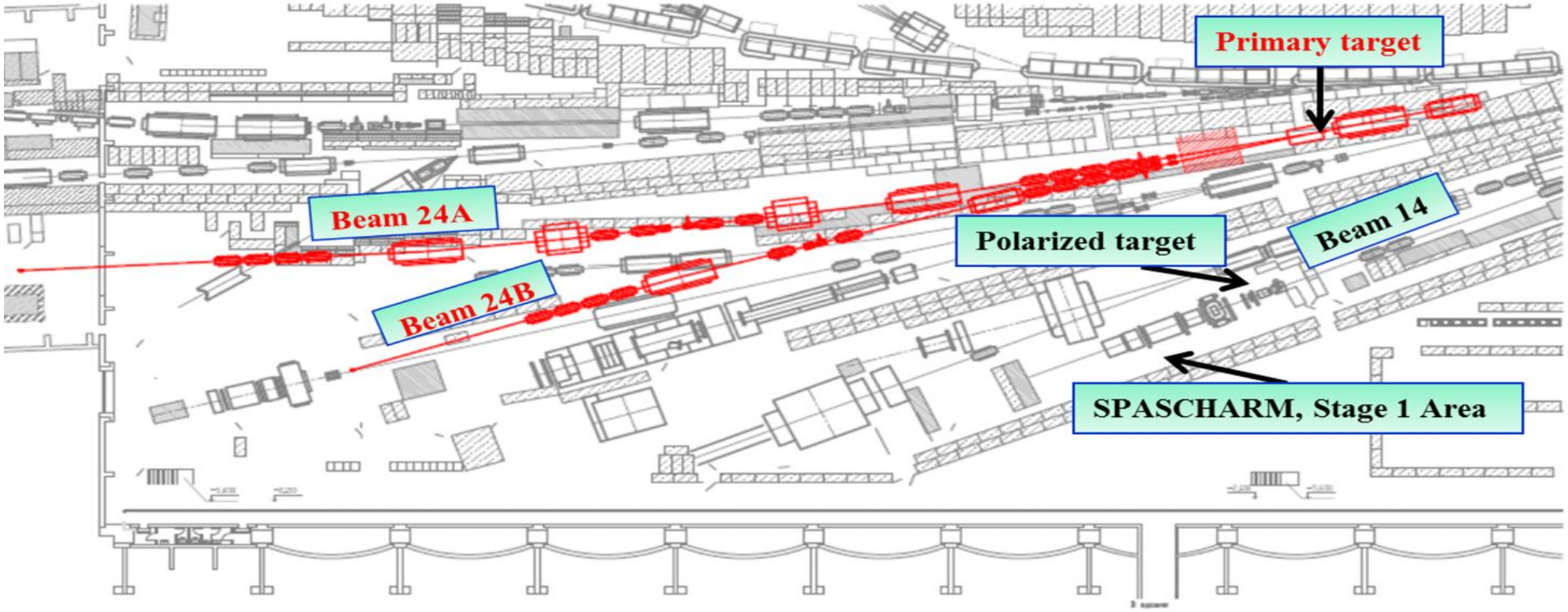
- 3-layer; n_{max}=1.04; t=40 mm – 4.5σ
- 4-layer; n_{max}=1.04; t=40 mm – 4.5σ
- 4-layer; n_{max}=1.05; t=35 mm – 4.3σ

Further prototyping: proto based on round shaped aerogel tiles

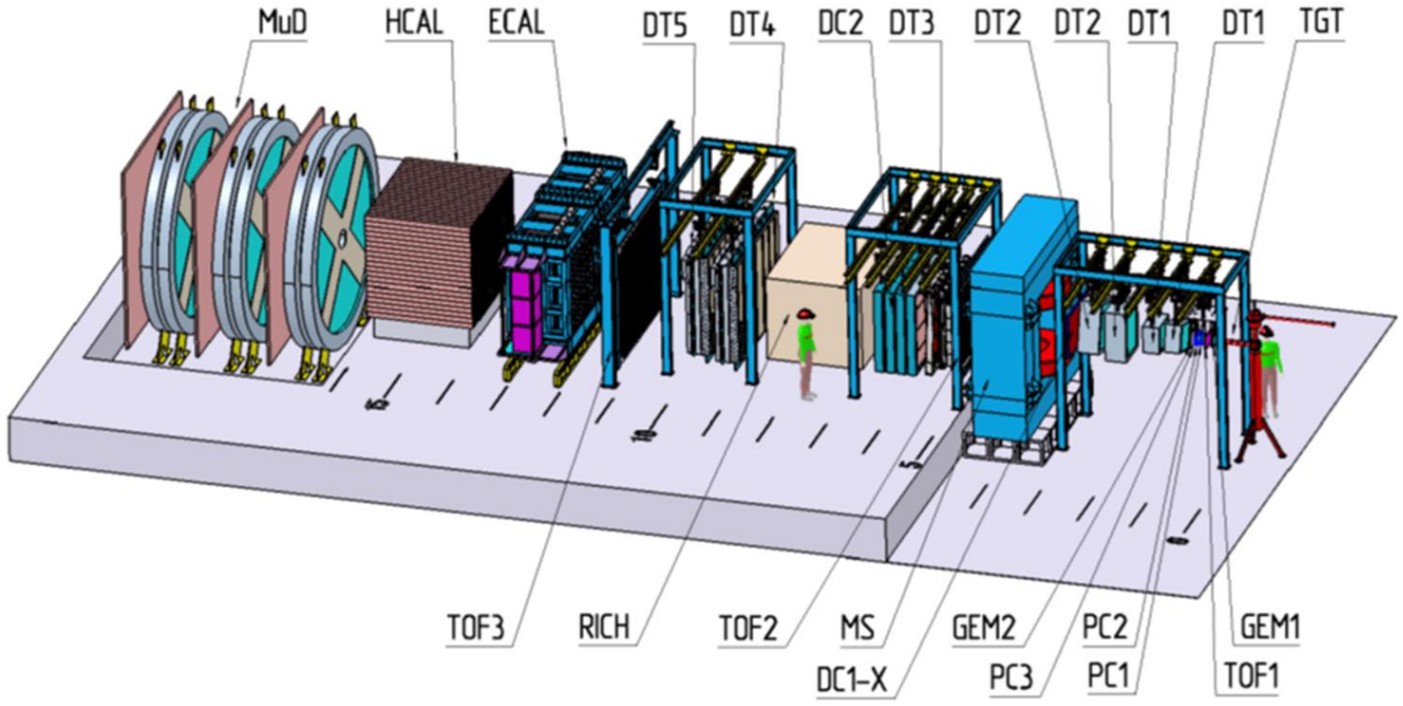


- In 2027-2028 we are going to produce segment of the FARICH system for the SPD@NICA experiment based on:
  - 4 round shaped aerogel tiles with facets
  - 36-48 position-sensitive MCP PMTs with 5x5 cm active area
- **MAIN goals are:**
  - to investigate edge effects and select shape of borders between aerogel tiles and material and properties of the walls between them
  - to investigate dependence of FARICH PID capability on track angle

Upgrade of the SPASCHARM experiment at the U-70 accelerator complex in IHEP-Protvino



SPASCHARM: SETUP & TASKs for PID

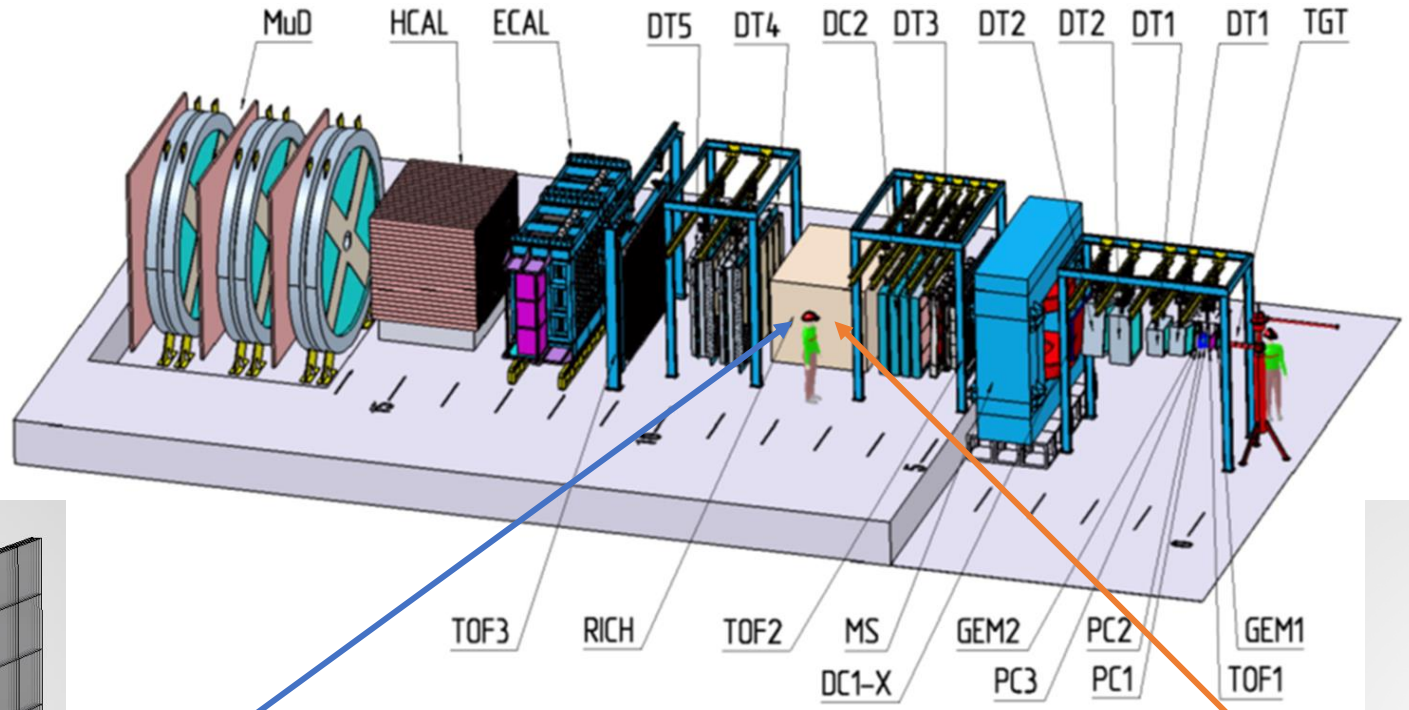


Expected data for 1 month operation with polarized protons

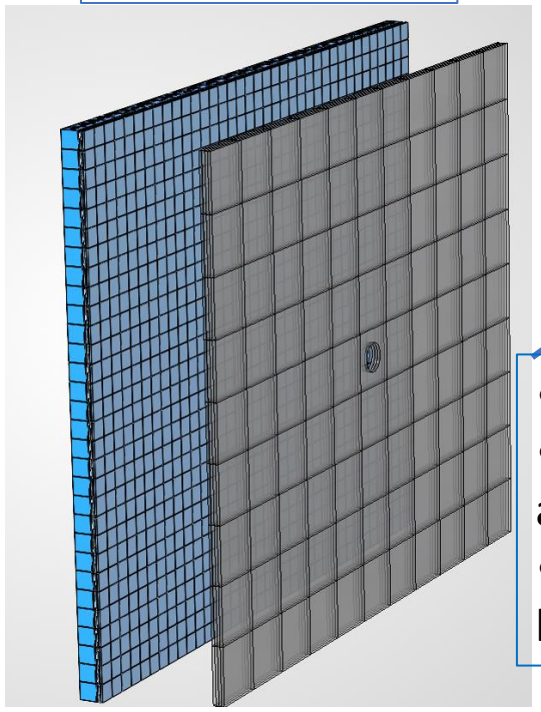
№	частица	N_{EV}	S/B	№	частица	N_{EV}	S/B
1	π^+	$6.1 \cdot 10^9$		17	$\rho^+(770) \rightarrow \pi^+\pi^0$	$3.0 \cdot 10^8$	0.4
2	π^-	$3.6 \cdot 10^9$		18	$\rho^-(770) \rightarrow \pi^-\pi^0$	$1.5 \cdot 10^8$	0.31
3	K^+	$5.5 \cdot 10^8$		19	$a_0(980) \rightarrow \eta\,\pi^0$	$5.7 \cdot 10^6$	0.8
4	K^-	$2.5 \cdot 10^8$		20	$\eta \rightarrow \pi^+\pi^-\pi^0$	$7.8 \cdot 10^6$	4.0
5	p	$4.7 \cdot 10^9$		21	$\omega(782) \rightarrow \pi^+\pi^-\pi^0$	$3.0 \cdot 10^7$	1.4
6	$\bar{p}$	$2.3 \cdot 10^6$		22	$K^{*}(892) \rightarrow K^+\pi^0$	$3.4 \cdot 10^7$	0.29
7	n	$3.5 \cdot 10^9$		23	$\bar{K}^{*}(892) \rightarrow K^-\pi^0$	$9.7 \cdot 10^6$	0.71
8	$\bar{n}$	$2.5 \cdot 10^6$		24	$\omega(782) \rightarrow \gamma\,\pi^0$	$7.8 \cdot 10^6$	2.5
9	$\pi^0 \rightarrow \gamma\gamma$	$2.5 \cdot 10^9$	9.1	25	$\Lambda \rightarrow p\,\pi^-$	$2.3 \cdot 10^7$	10.0
10	$\eta \rightarrow \gamma\gamma$	$1.3 \cdot 10^8$	2.5	26	$\Lambda \rightarrow n\,\pi^0$	$2.1 \cdot 10^7$	0.67
11	$\varphi(1020) \rightarrow K^+K^-$	$3.7 \cdot 10^6$	25	27	$\Delta^{++} \rightarrow p\,\pi^+$	$1.0 \cdot 10^9$	0.59
12	$\Xi^- \rightarrow \Lambda\,\pi^-$	$3.5 \cdot 10^7$	10	28	$\bar{\Xi}^+ \rightarrow \bar{\Lambda}\,\pi^+$	$1.0 \cdot 10^6$	17
13	$K^0_S \rightarrow \pi^+\pi^-$	$6.7 \cdot 10^7$	0.9	29	$\Sigma^0 \rightarrow \Lambda\,\gamma$	$3.5 \cdot 10^7$	0.25
14	$\rho^0(770) \rightarrow \pi^+\pi^-$	$3.6 \cdot 10^8$	0.37	30	$\Sigma^0(1385) \rightarrow \Lambda\,\pi^0$	$9.8 \cdot 10^7$	0.77
15	$K^{0}(892) \rightarrow K^+\pi^-$	$5.8 \cdot 10^7$	0.77	31	$\omega(782) \rightarrow e^+e^-$	$2.0 \cdot 10^5$	4.0
16	$\bar{K}^{0}(892) \rightarrow K^-\pi^+$	$3.1 \cdot 10^7$	1.25	32	$\rho^0(770) \rightarrow \mu^+\mu^-$	$1.0 \cdot 10^5$	4.0

- RED – tasks for HCAL and ECAL
- GRAY – tasks for MUD
- YELLOW – tasks for PID:
  - π/K up to 8.5 GeV/c
  - π/p up to 17 GeV/c

SPASCHARM: 2 RICH options

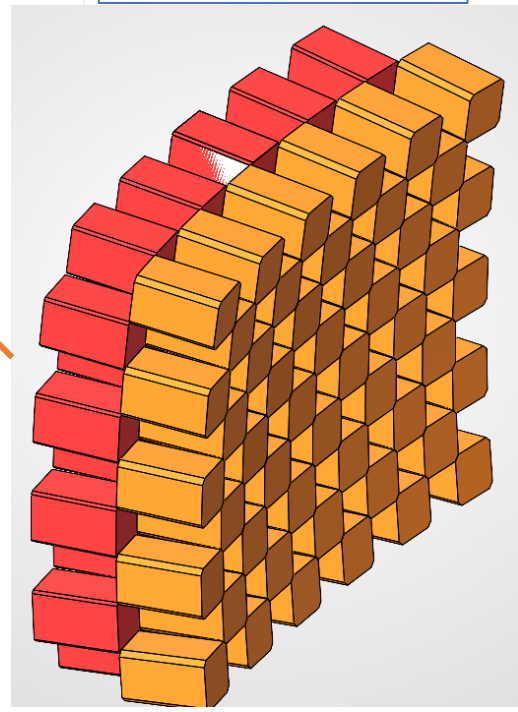


FARICH approach



- 1100 PS PMTs 6x6 cm
- 99 multilayer focusing aerogel tiles
- focusing preserved for large track angles

mRICH approach

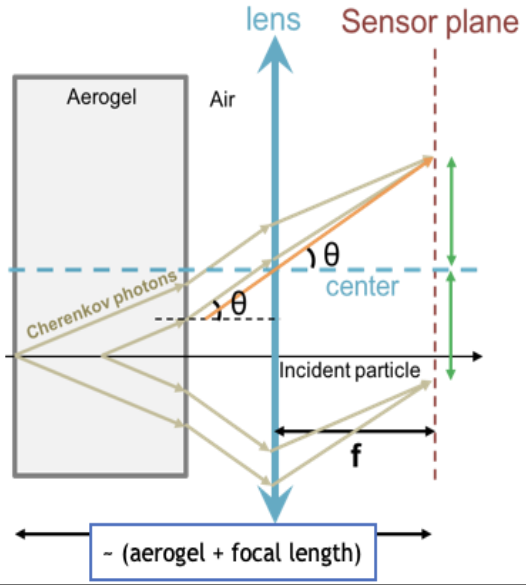


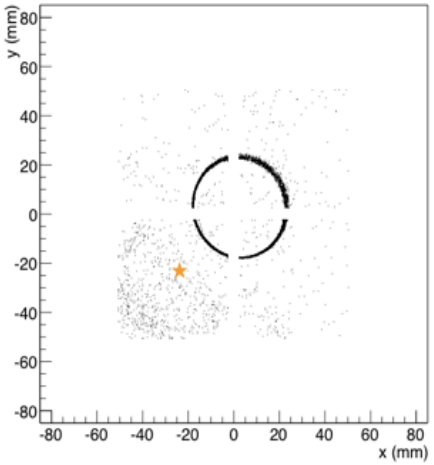
- 360 PS PMTs 6x6 cm
- Fresnel Lenses
- Single layer thick aerogel tiles
- Small track angles range is accepted

Modular aerogel RICH: sketch & concept

This option is inspired by GSU group R&D activities [D. Sharma et al., NIM A1061 (2024) 169080]

Lens-Based mRICH Design



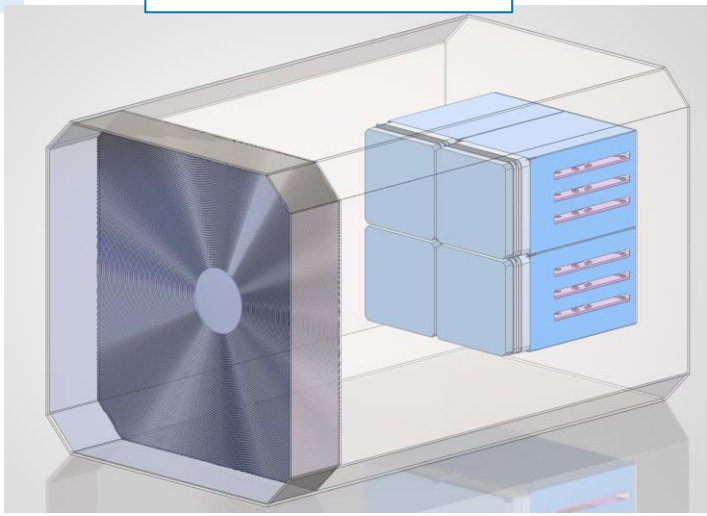


- 9 GeV/c pion beam incident at third quadrant (star) in simulation
- Ring image is **shifted toward the central region** on the sensor plane

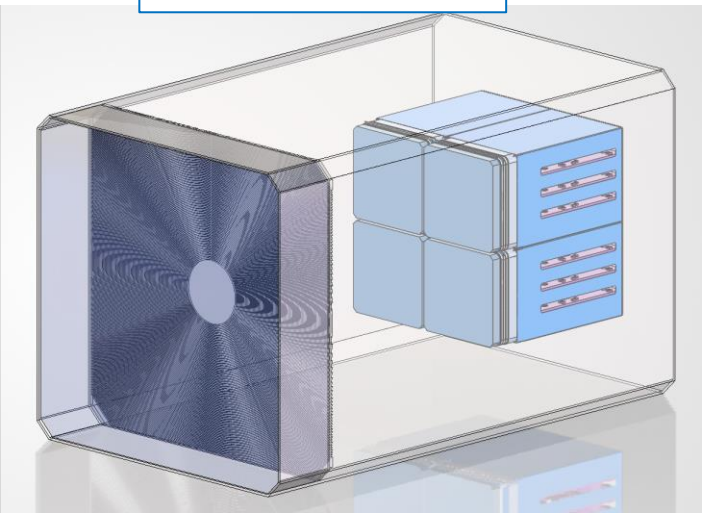
Aerogel RICH with Fresnel lens = modular RICH

- Focusing is good enough while track tilt ≤ 6°:
  - each module looks on IP;
  - lateral size of module is limited.
- There is serious degradation of performance at the edge of the module:
  - two layer system with overlapping regions (~15 mm) improve the system performance.

1st layer module

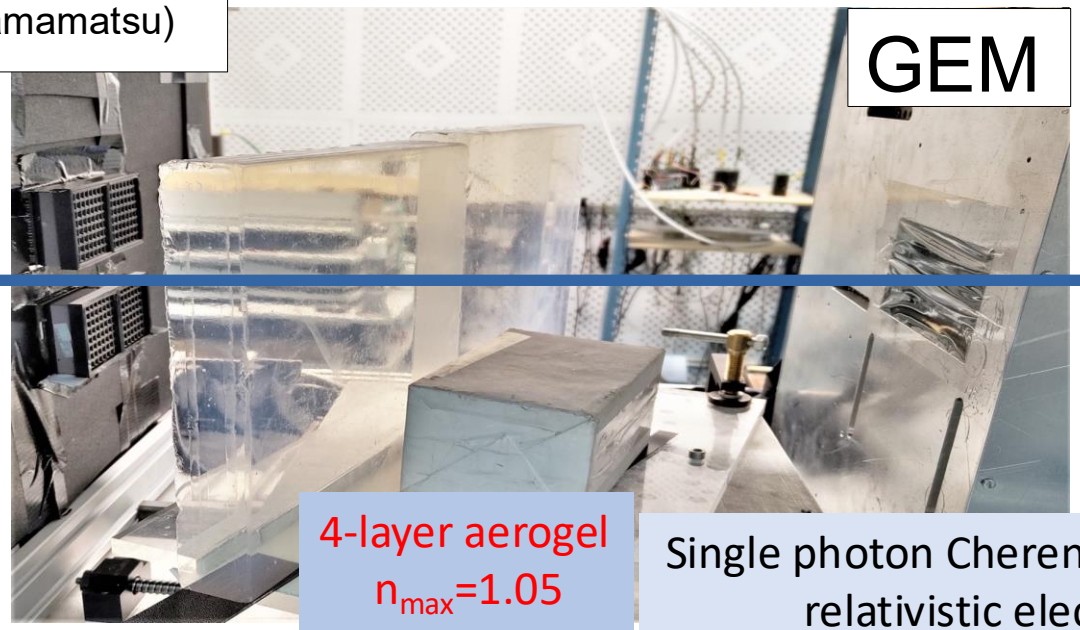


2nd layer module



mRICH vs FARICH: very first beam test results

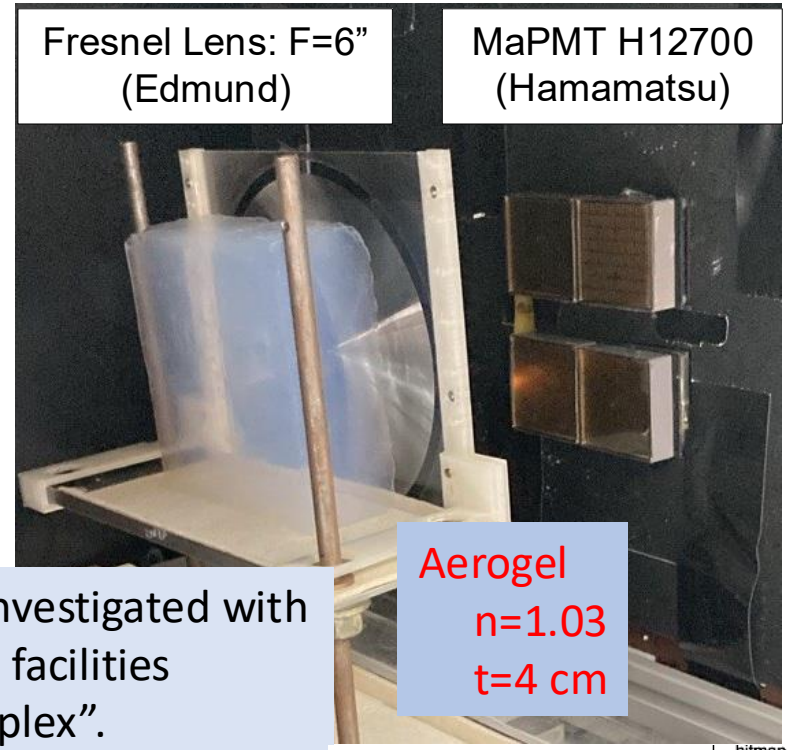
MaPMT H12700 (Hamamatsu)



4-layer aerogel
n_{max}=1.05
t=3.5 cm

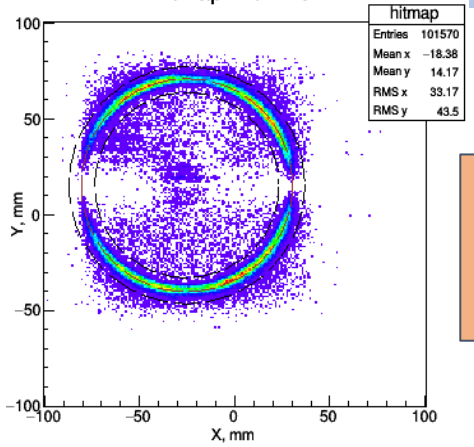
Fresnel Lens: F=6" (Edmund)

MaPMT H12700 (Hamamatsu)



Aerogel
n=1.03
t=4 cm

Single photon Cherenkov angle resolution is investigated with relativistic electrons at BINP beam test facilities "Extracted beams of VEPP-4M complex".

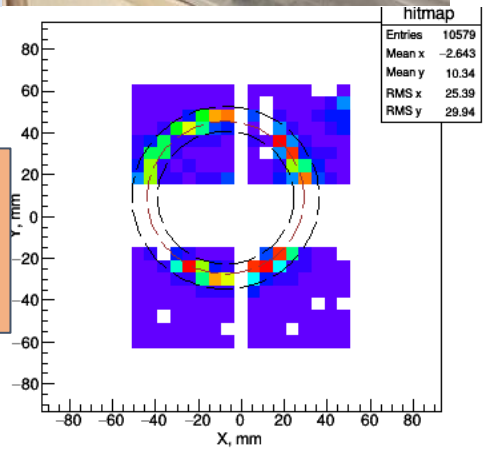


Main results:

- N_{pe} ≈ 16 (~ 0.8 of Ring)
- σ_θ^{1pe} ≈ 10 $mrad$ (■ 6mm)

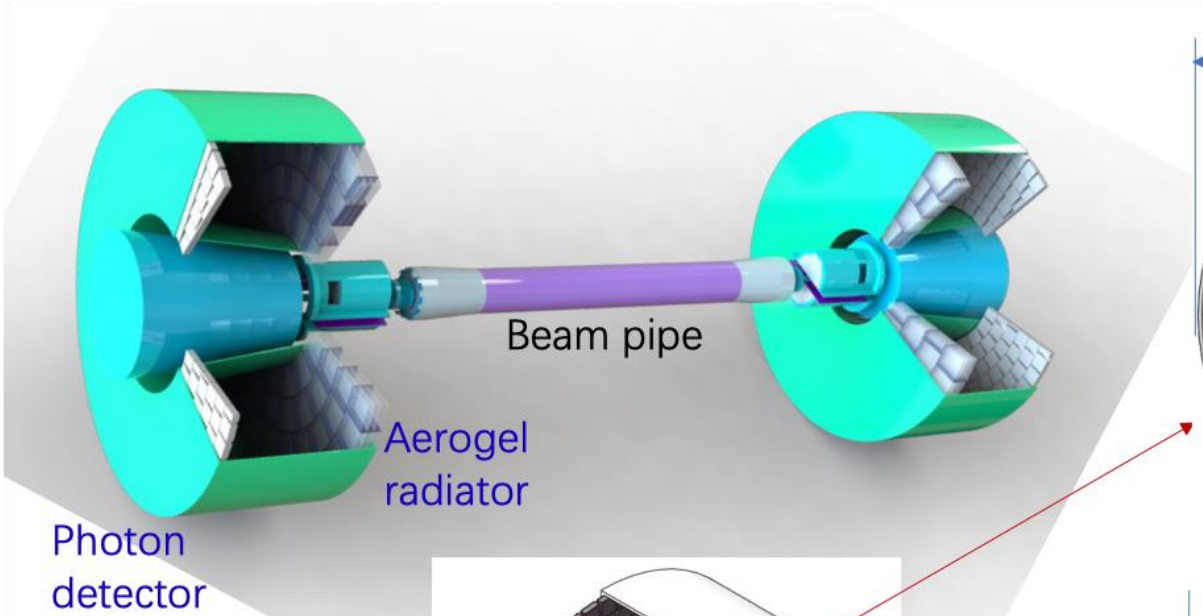
Main results:

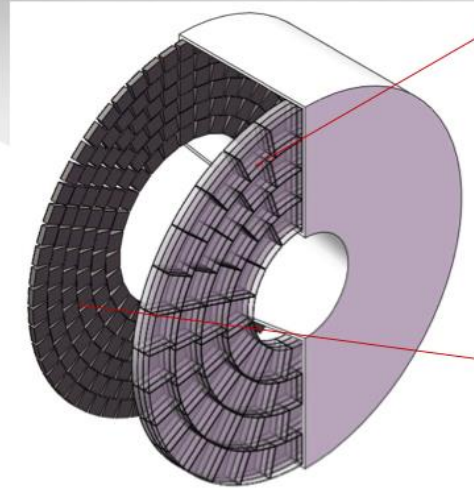
- N_{pe} ≈ 5.3 (~ 0.6 of Ring)
- σ_θ^{1pe} ≈ 10 $mrad$ (■ 6mm)

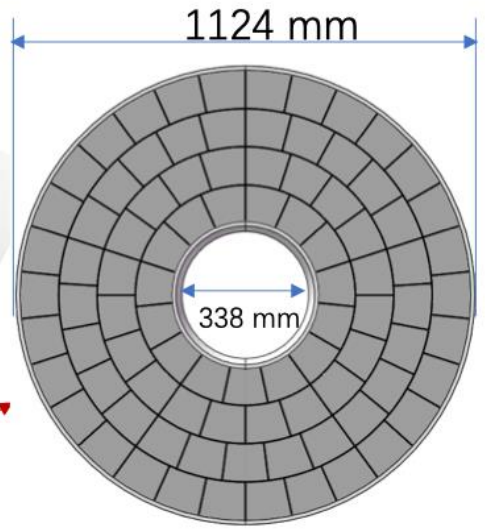


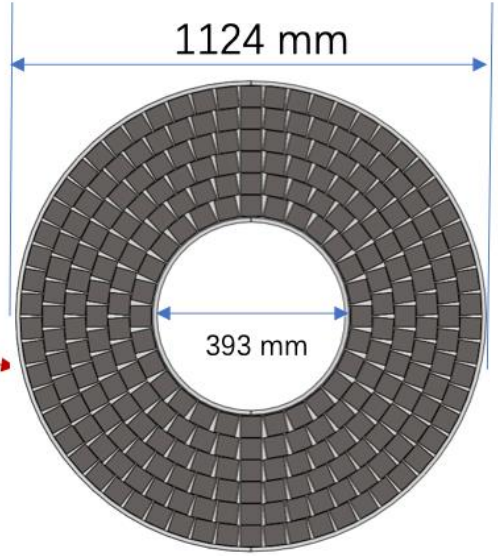
In both cases TB results are in good agreement with simulation

FARICH option for CEPC end-cap region









From Jian Wang,
mechanical group

Aerogel radiator :
-90 aerogel tiles in 4 layers
-each tile of ~10 cm x 10 cm

Photon detector:
-258 PMTs(sensor module) in 6 layers
-each PMT(sensor module) of ~5 cm x 5 cm

CEPC FARICH option G4sim data

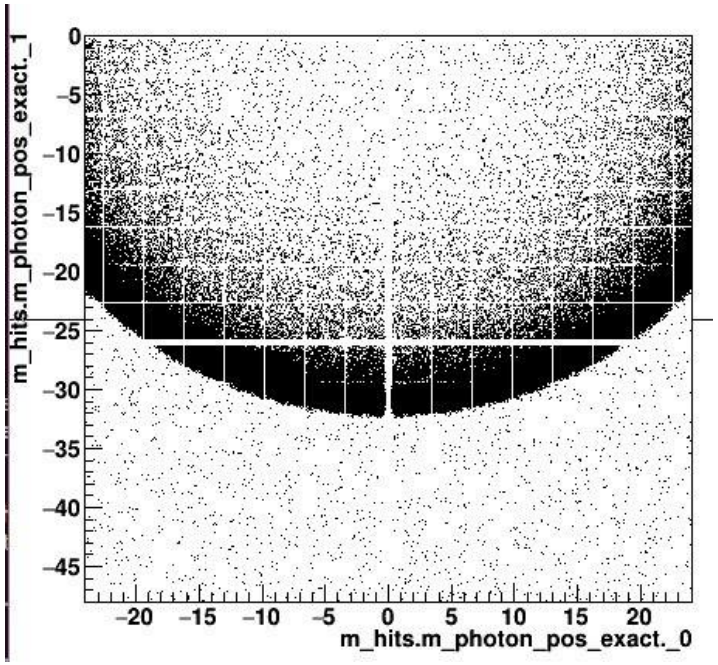
8-layers aerogel n_{max}=1.008 (2 tiles)

1) 1.0055, t = 8.24
2) 1.0058, t = 8.02
3) 1.0061, t = 7.80
4) 1.0064, t = 7.59

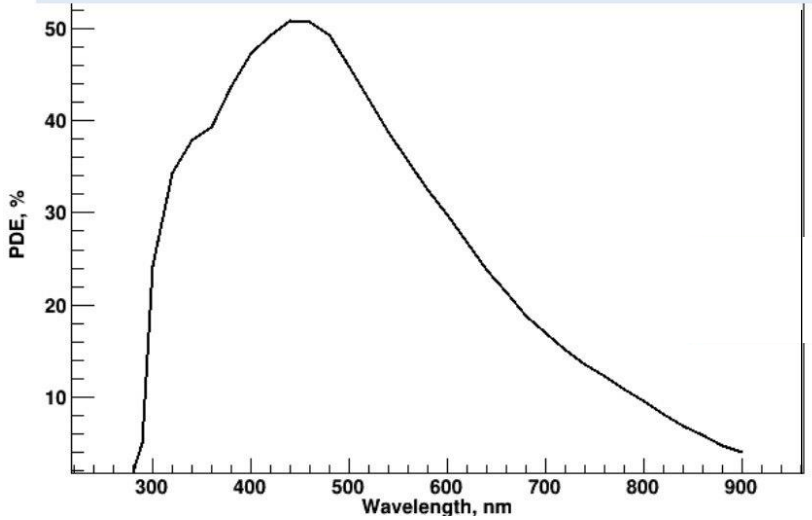
5) 1.0068, t = 7.38
6) 1.0072, t = 7.18
7) 1.0076, t = 6.99
8) 1.0080, t = 6.80

- L_{abs} is taken from *NIMA494 (2002) 491–494*
- $L_{sc}(\lambda)=L_{sc}(400nm)\cdot\left(\frac{\lambda}{400}\right)^4$
- $n(\lambda)=\sqrt{1+a_0\cdot\frac{\lambda^2}{\lambda^2-{\lambda_0}^2}\cdot\frac{(n(400)^2-1)}{a_0\cdot\frac{400^2}{400^2-{\lambda_0}^2}}}$, where

λ_0=83.22 nm and a_0=0.05639 is taken from *Eur. Phys. J. C 52, 759–764 (2007))*



PDE for MPPC-S14160 (Hamamatsu)



pixel = 3 mm & $\sigma_x \approx 0.2mm$ like PSS-SiPM

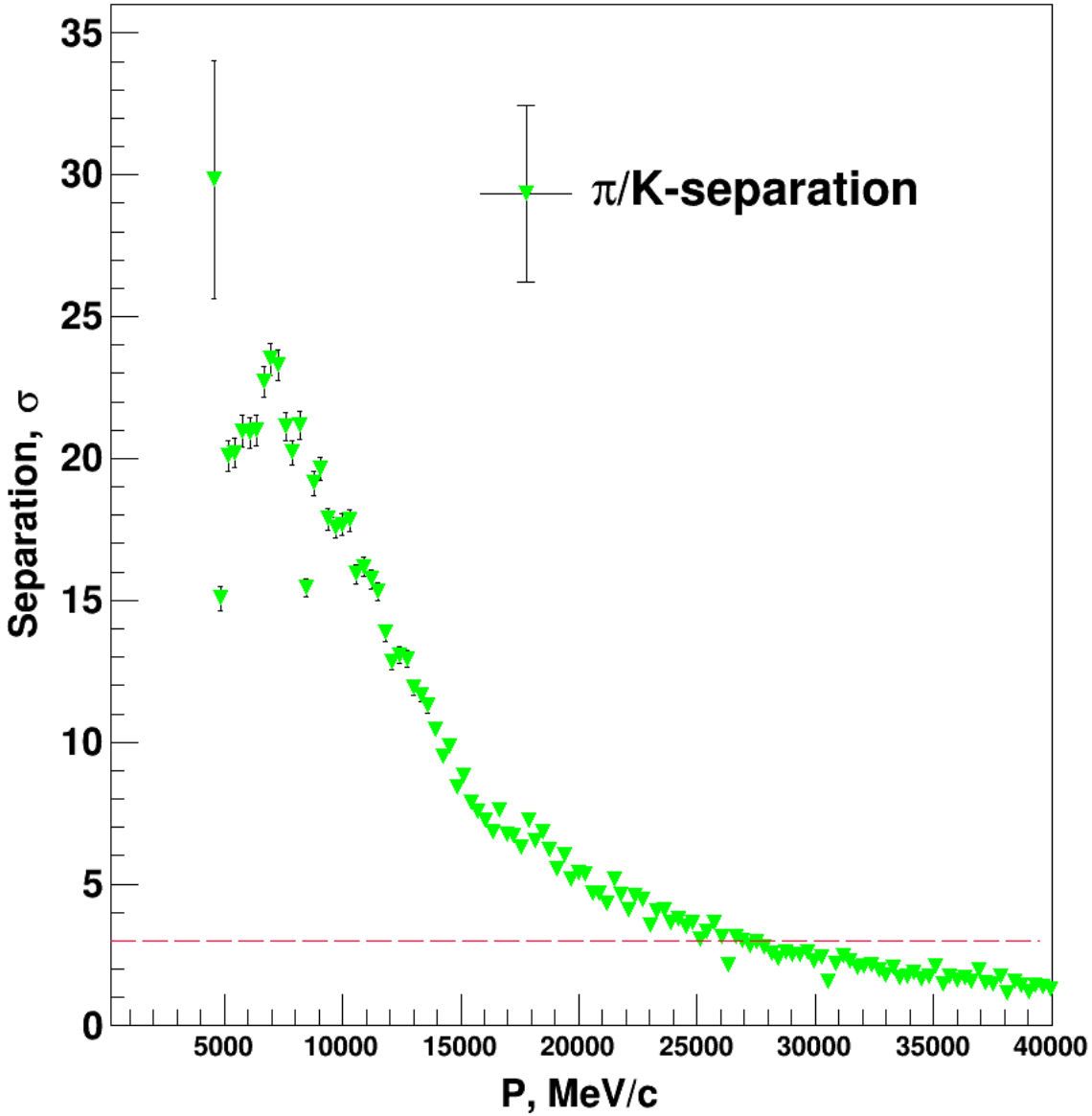
Focal distance is 300 mm

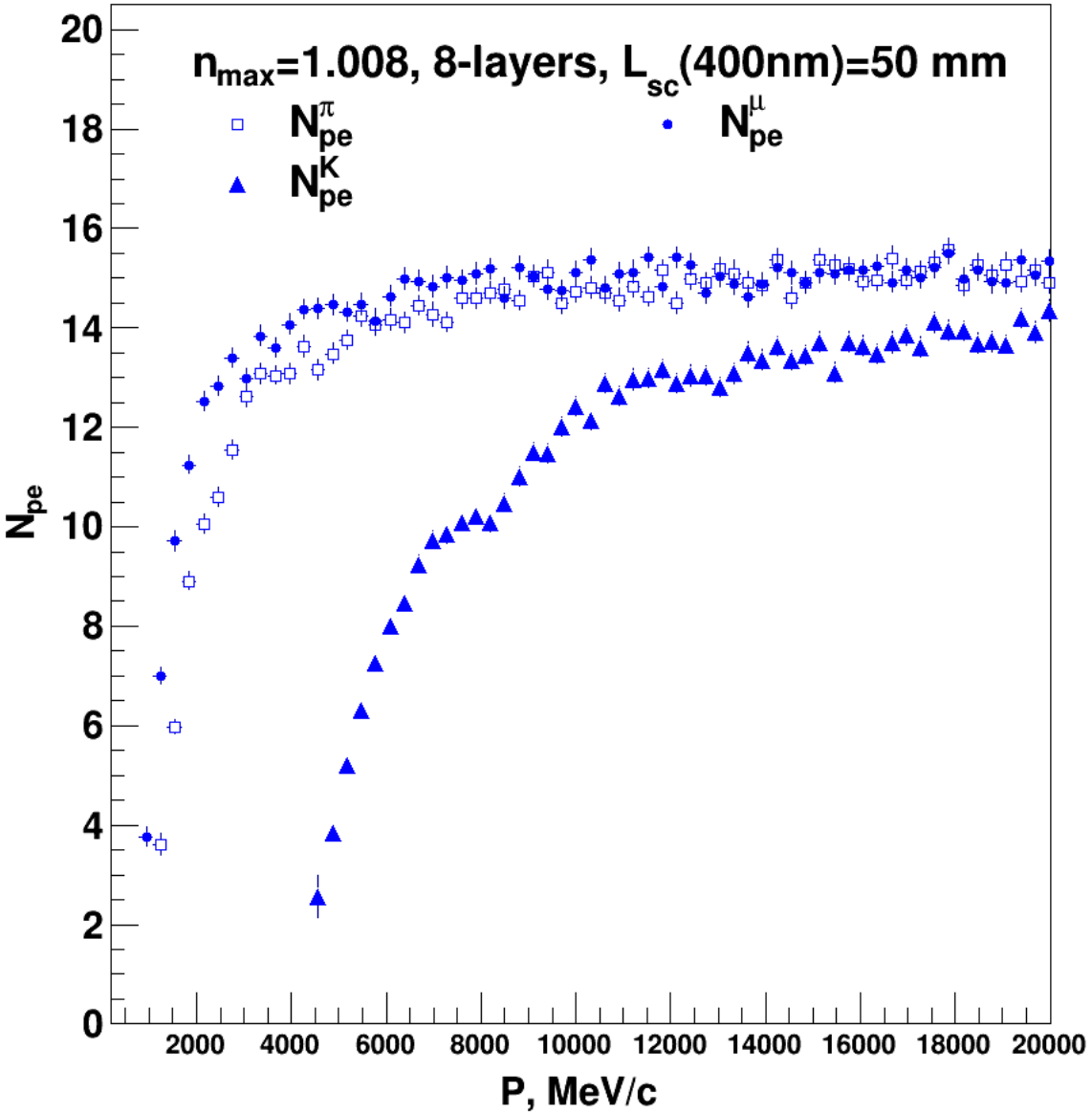
Main impacts to resolution:

- Emmision point uncertainty σ_{thick}~0.8 $mrad$;
- Refr.indx dispersion σ_n ~1.0 $mrad$;
- Spatial resolution σ_x ~0.7 $mrad$;

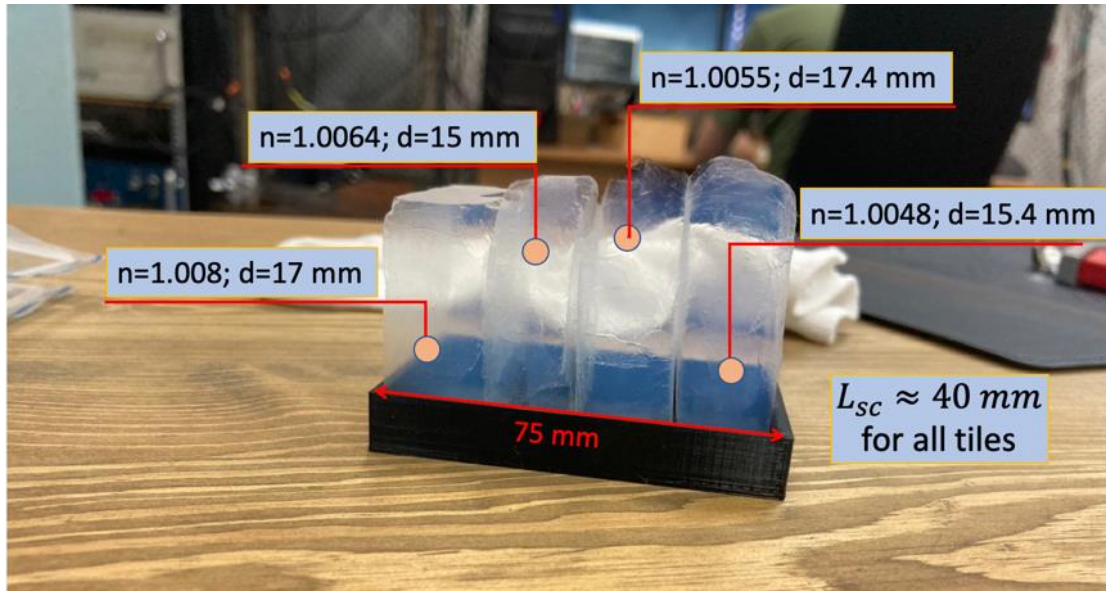
TOTAL: $\sqrt{\sigma_x^2+\sigma_n^2+\sigma_{thick}^2}\Big/\sqrt{N_{pe}}$. $\approx 0.4\ mrad$

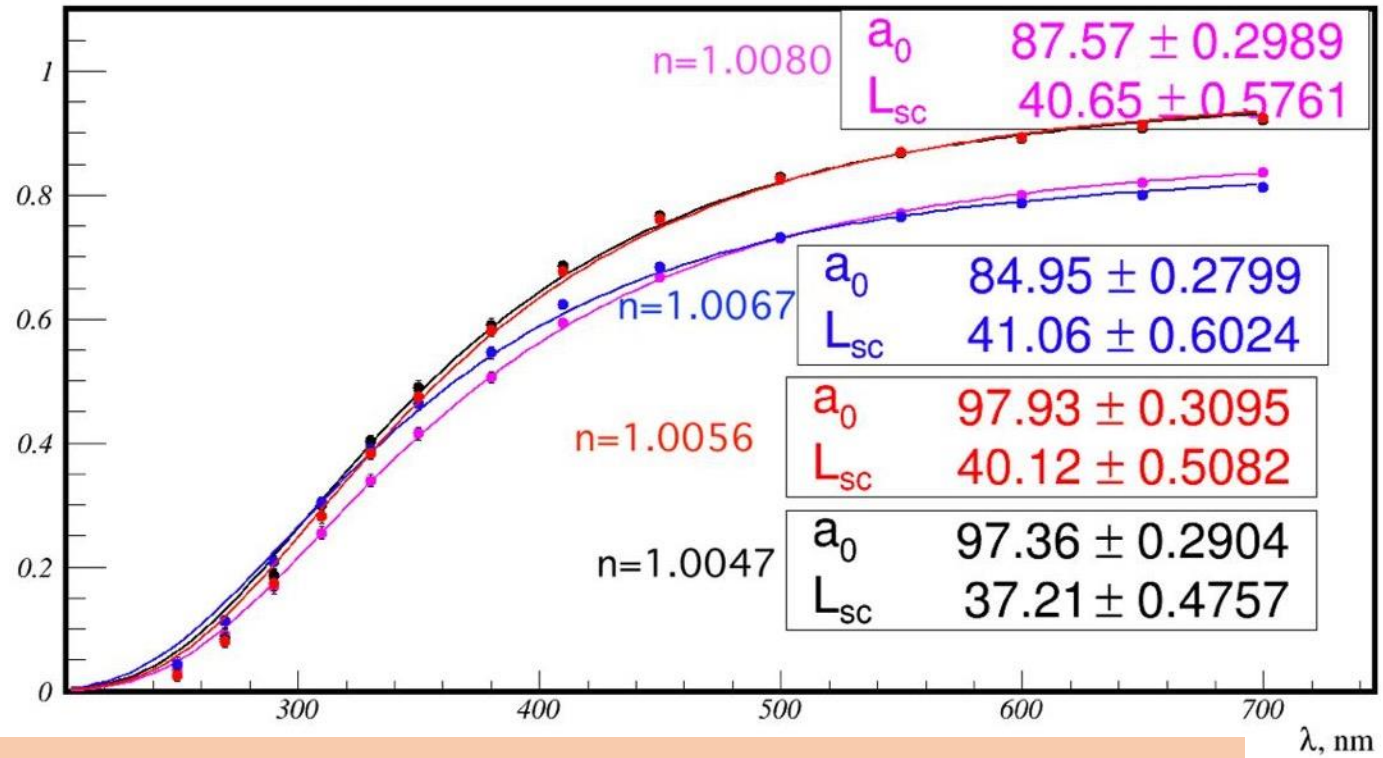
FARICH option for π/K–separation at 30 GeV/c: G4sim results





Some practical results of 2025

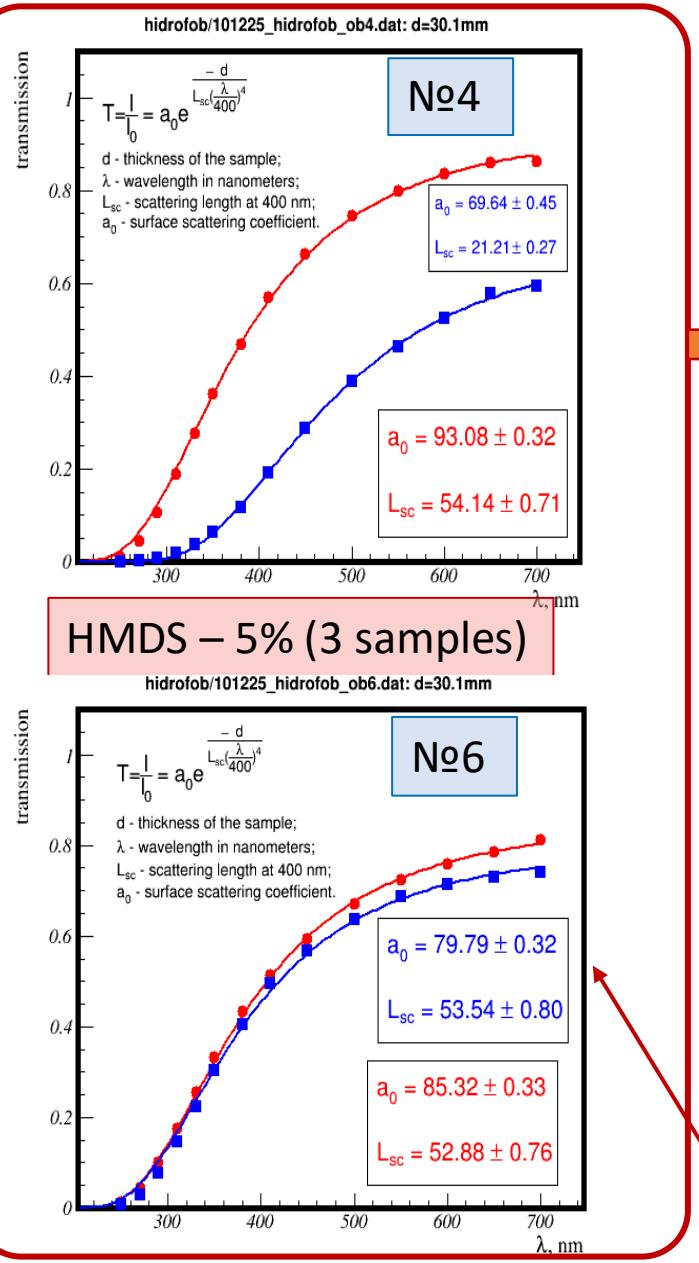


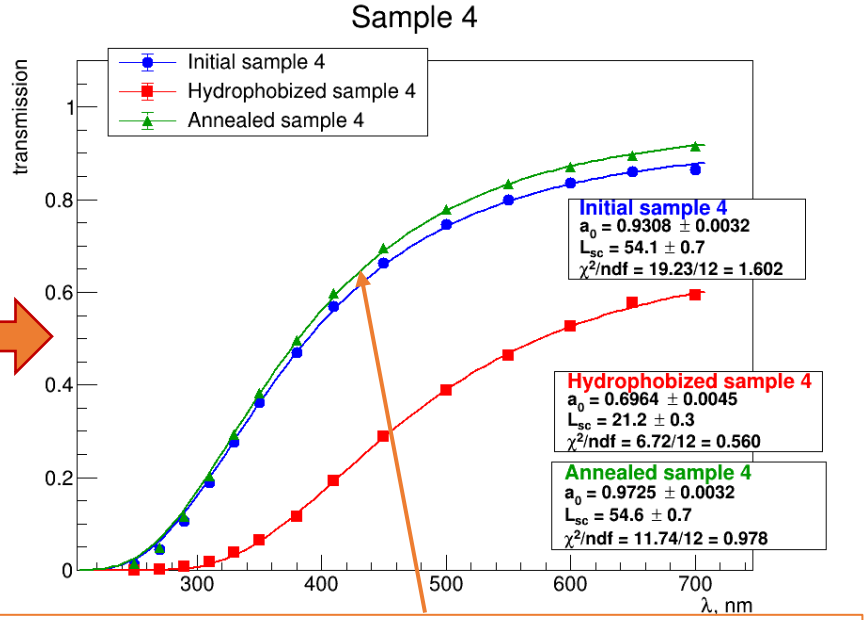


In 2025 for the first time ultra-light SiO_2 aerogels with high transperancy were produced in Novosibirsk!

- The main goal of further R&D on aerogel for the CEPC project is to produce several samples of multilayer aerogels with n_{max} = 1.008 in order to demonstrate the focusing effect in the FARICH detector based on ultra-light multilayer aerogels
- 3 and 4-layer aerogels with latteral size about 10x10 cm are expected until the end of 2026:
  - 3-layer n/t: 1.0080/12.7 mm; 1.0073/13.3 mm; 1.0066/14.0 mm;
  - 4-layer n/t: 1.0080/9.50 mm; 1.0075/10.0 mm; 1.0070/10.0 mm; 1.0065/10.5 mm.

The first hydrophobization experience





- It was shown, it is possible totally restore optical transparency of hydrophobic aerogels with help of annealing (5 hours at 500˚C)
- Hydrophilic aerogel (left) totally destroid in contact with water, while after hydrophobization it can be tooled by water-jet cutting machine
- Influence of hydrophobisation on aerogel transparency has not been studied well yet

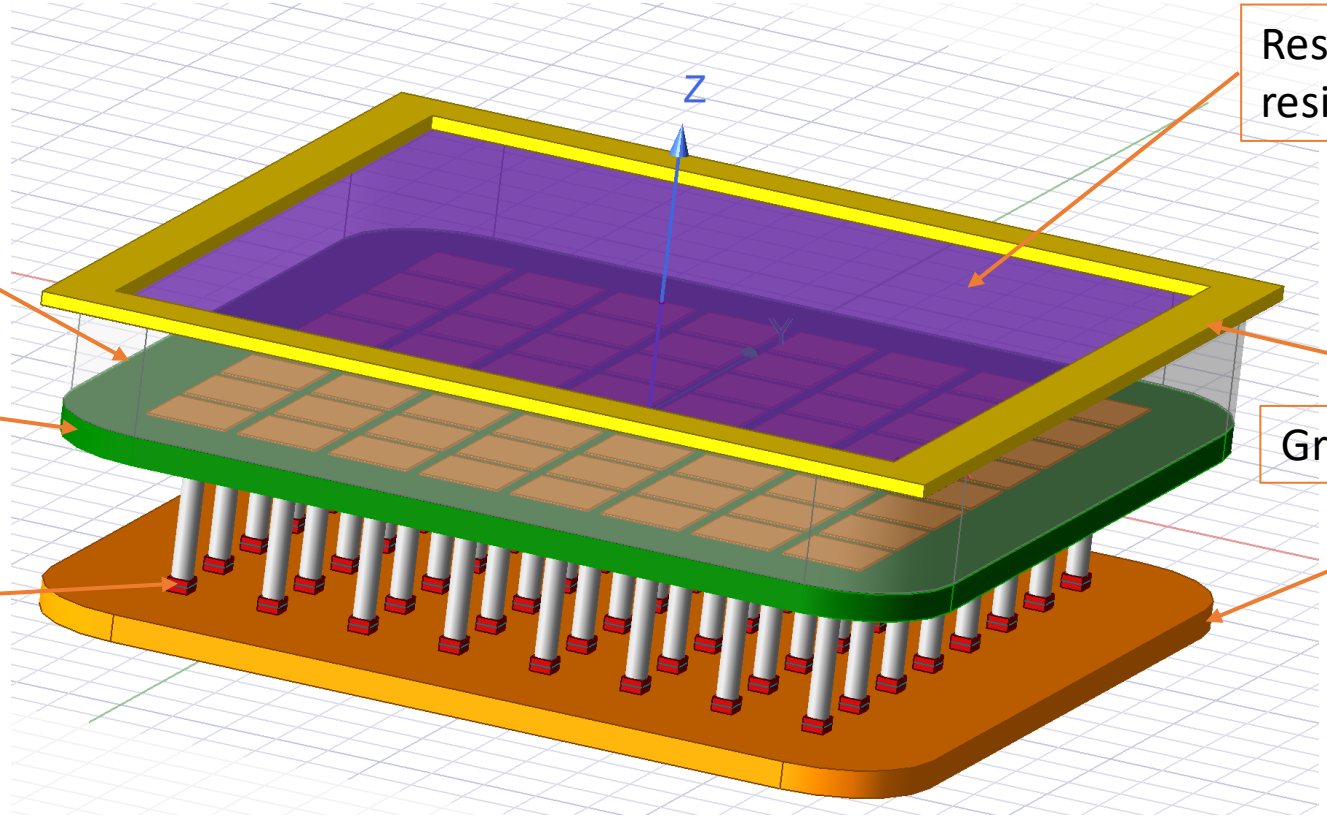


The first practical output:

We can produce aerogels as we need (highly transperant, thick and so on), then make tooling after hydrophobization and restore its tranparency before the assembling the detector.

MCP PMT with excellent spatial resolution

- Tests of LAPPD equiped with capacitvely coupled pixels (1.2x1.2 cm each) demonstrate spatial resolution 0.5÷0.8 mm [NIM A846 (2017) 75].
- Therfore we started simulation of the signal distribution in MCP PMTs based on capacitvely coupled pixels with help of ANSYS-Maxwell framework to determin achievable spatial resolution.



Resistive surface with sheet resistance $\sim 100 kOhm/\blacksquare$

Ceramic (Al_2O_3)

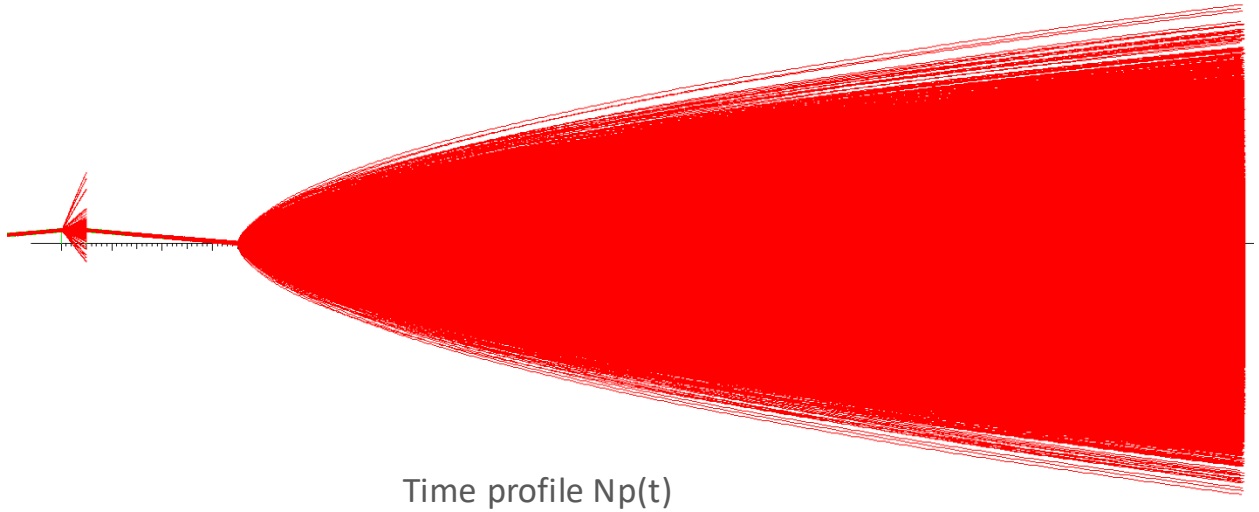
PCB with 64 pads 3x3 mm

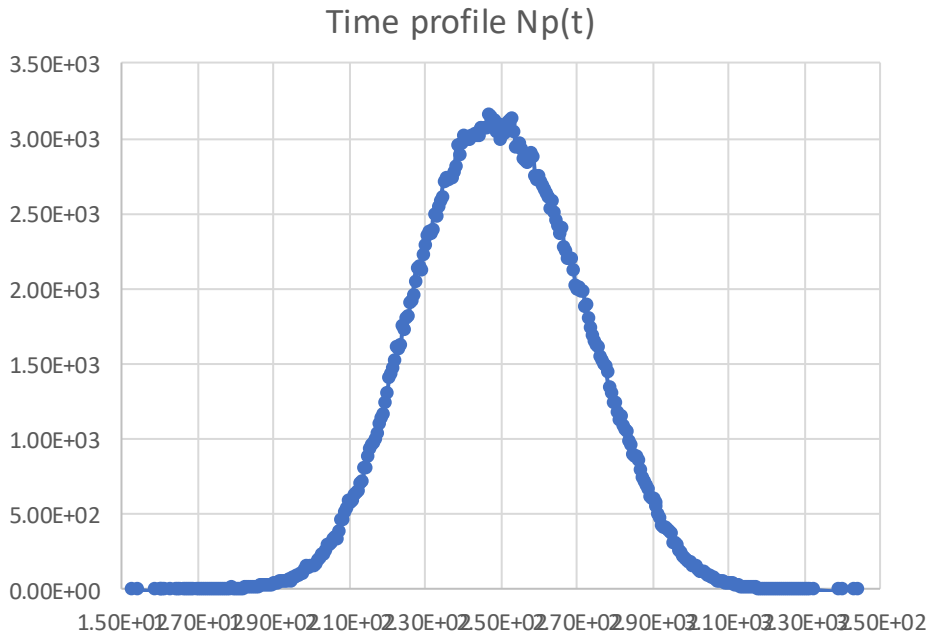
64 50 Ohms terminators & Sensetive probes

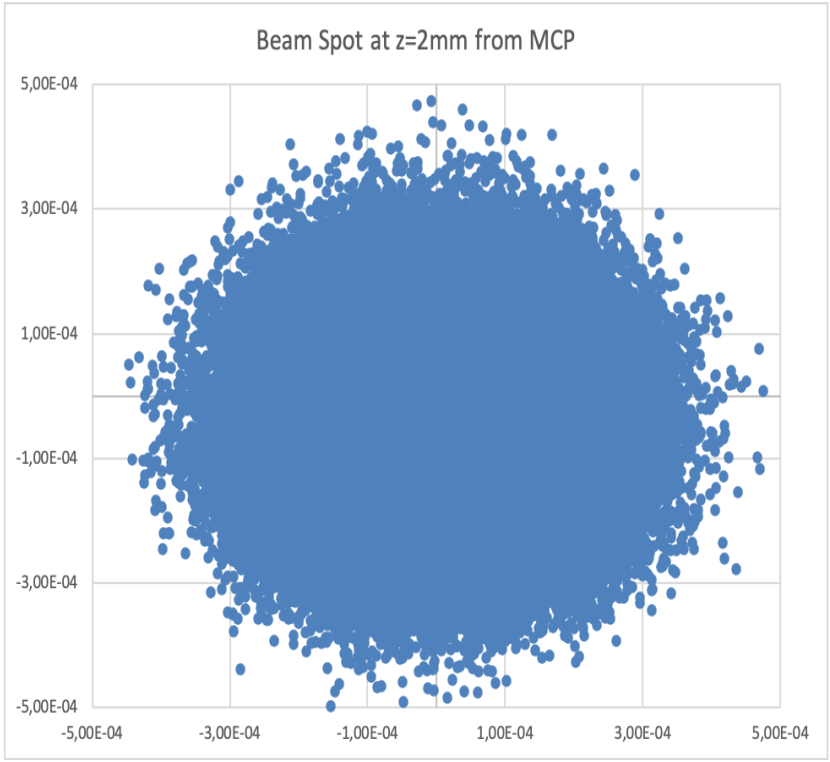
Ground potential

MCP PMT with excellent spatial resolution:

initial simulation data





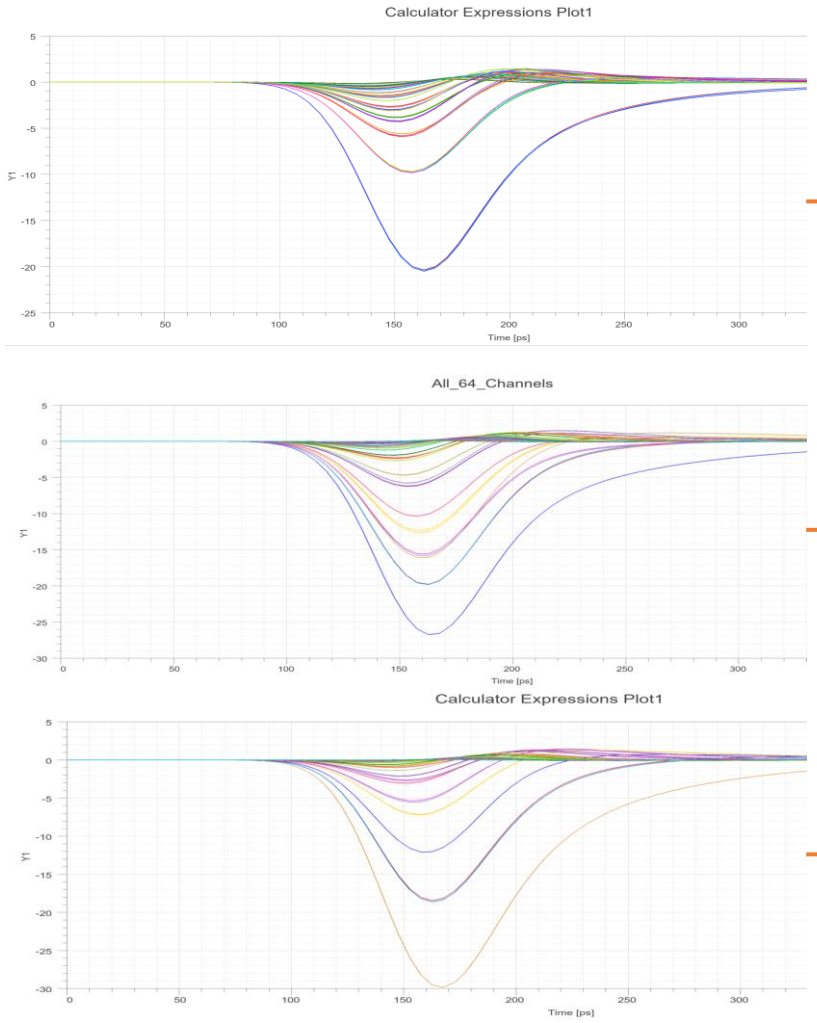


Performed by *Valentin Ivanov* with help of *MCSD3* software

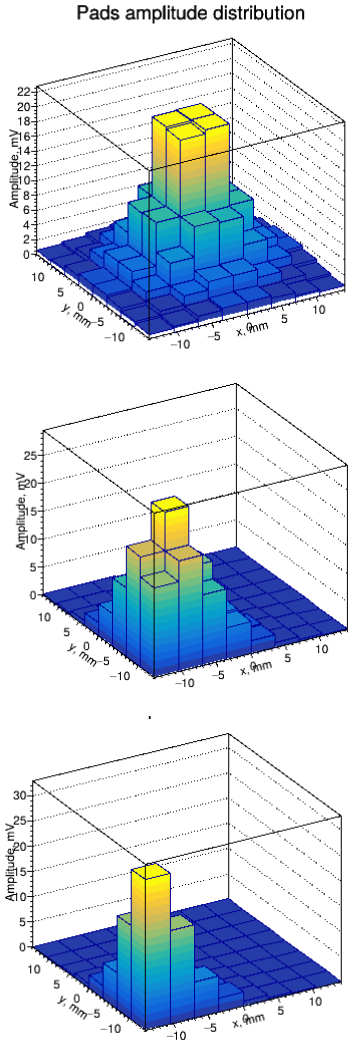
MCP PMT with excellent spatial resolution:

very first results

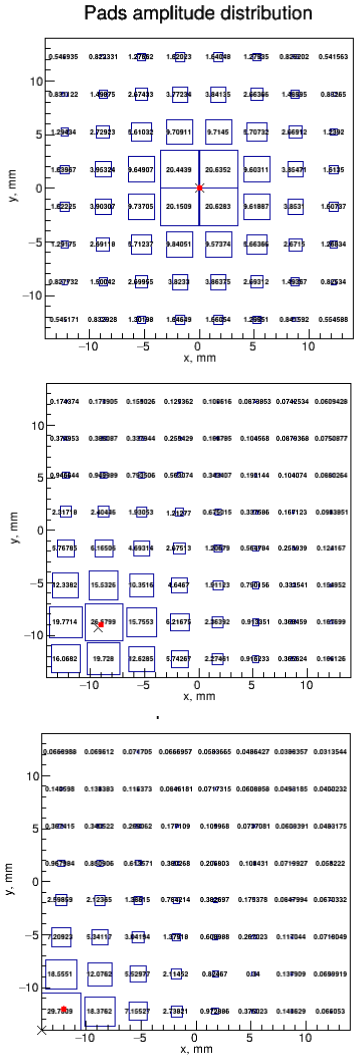
Calculations



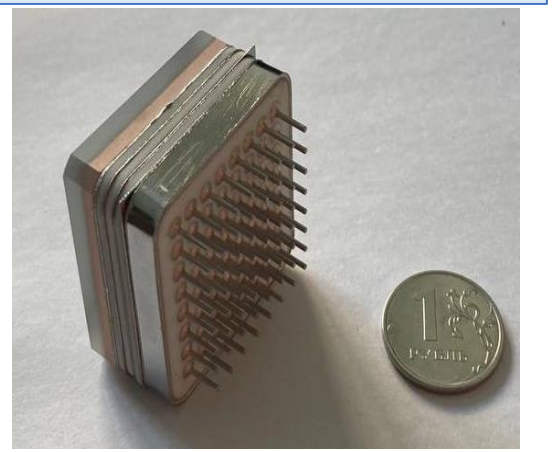
Digitzation



Reconstruction



At the Center accuracy of reconstruction is about 20µm, while close to the conner it degrades up to ~1 mm.



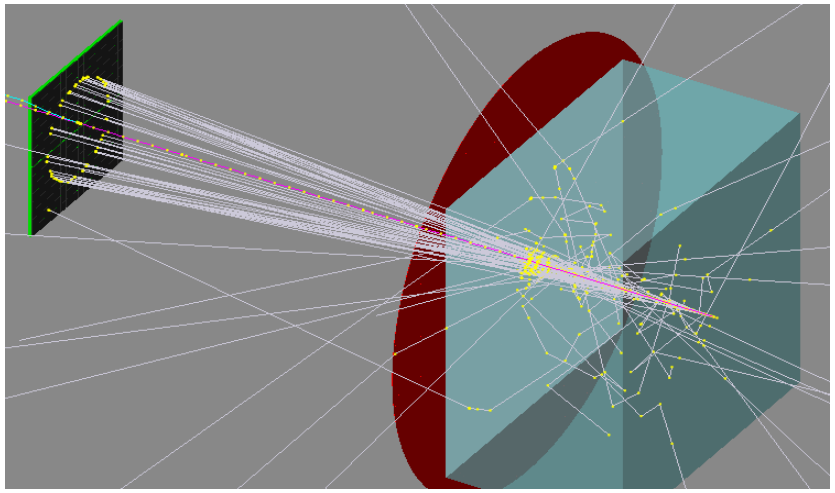
- Production of the first MCP PMTs with 64 directly readout anodes expected until the end of 2026
- Production of the first prototype with capcitively coupled anodes is planed in 2027

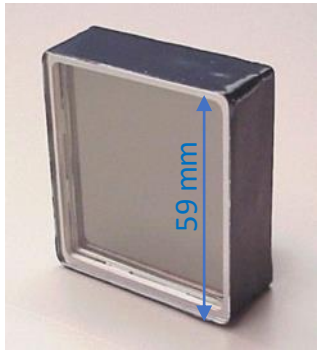
Summary

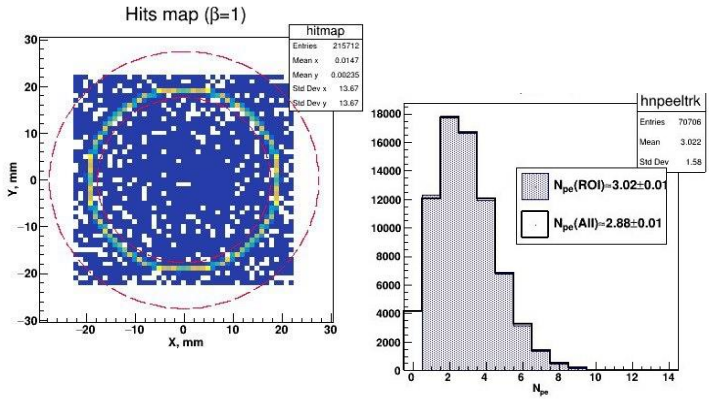
- Several projects of RICH detectors based on aerogel are under development in Novosibirsk:
  - FARICH for the SPD-NICA experiment in Dubna (JINR).
  - mRICH for the SPASCHARM-U70 experiment in Prtvino (IHEP)
  - FARICH based on ultra-light aerogels for the CEPC end-cap region in China.
- Beam test results with new focusing aerogel tiles confirmed the capabilities of FARICH technique to provide reliable π/K-separation at 6 GeV/c and they are in good agreement with calculations and estimations.
- Development and production of the MCP based position-sensetive PMTs was started in Novosibirsk in 2025:
  - Such devices with proper readout structures can be a reliable candidates for position sensetive photon detectors with spatial resolution of several tens microns.

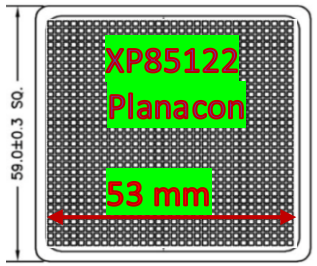
BACK UP

Simulation of mRICH in GEANT4

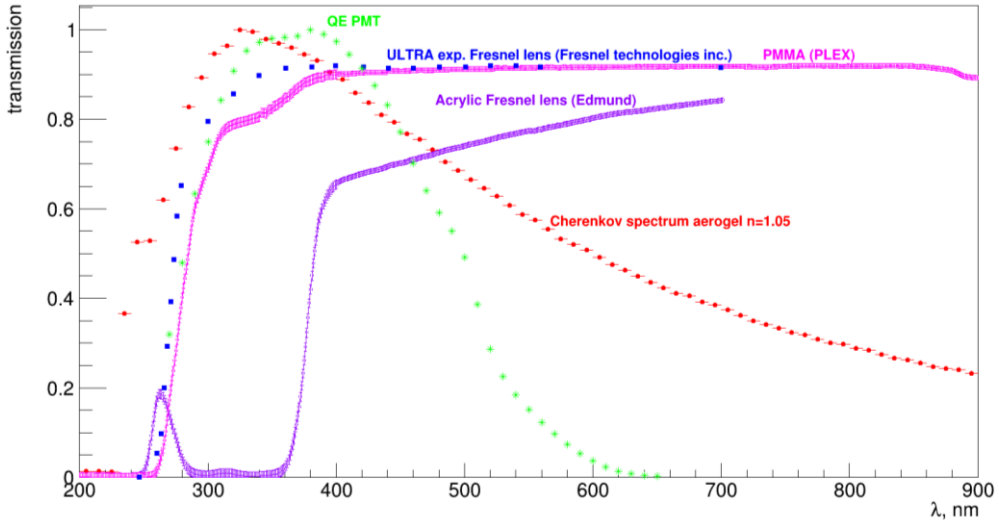








Моделирование выполнено для аэрогеля с n=1.008 и ФЭУ на основе МКП с миллиметровым шагом анодной структуры



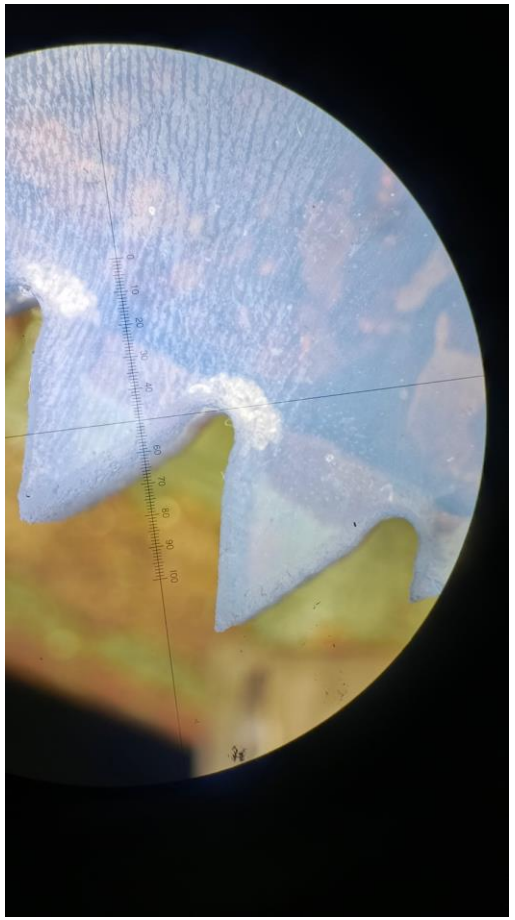
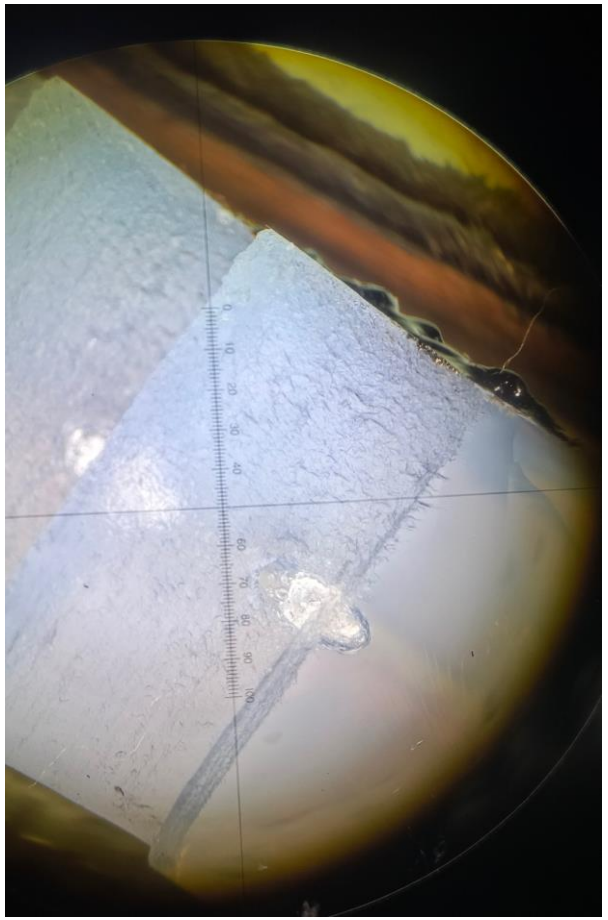
- Разницу в $N_{фэ}$ для FARICH и mRICH в пучковых испытаниях: 16 и 5.3, соответственно, можно объяснить прозрачностью акриловой линзы от Edmund (от 380 нм).
- Известно, что акрил и акриловые линзы бывают с прозрачностью от 250-270 нм.
- Необходимо провести дополнительный НИР по линзам Френеля.

Hydrophilic Novosibirsk aerogels

- 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 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 which are going to be used in the construction on aerogel transparency.
- **Hydrophobization of the hydrophilic aerogel radiators will preserve their parameters or not?!**

The first experience with waterjet cutting of aerogel produced in Novosibirsk



Systematical study of hydrophobization approaches is under going now.

Diamond millinf of the aerogel

