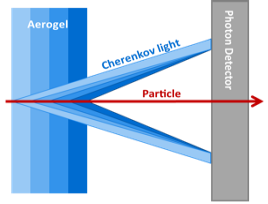
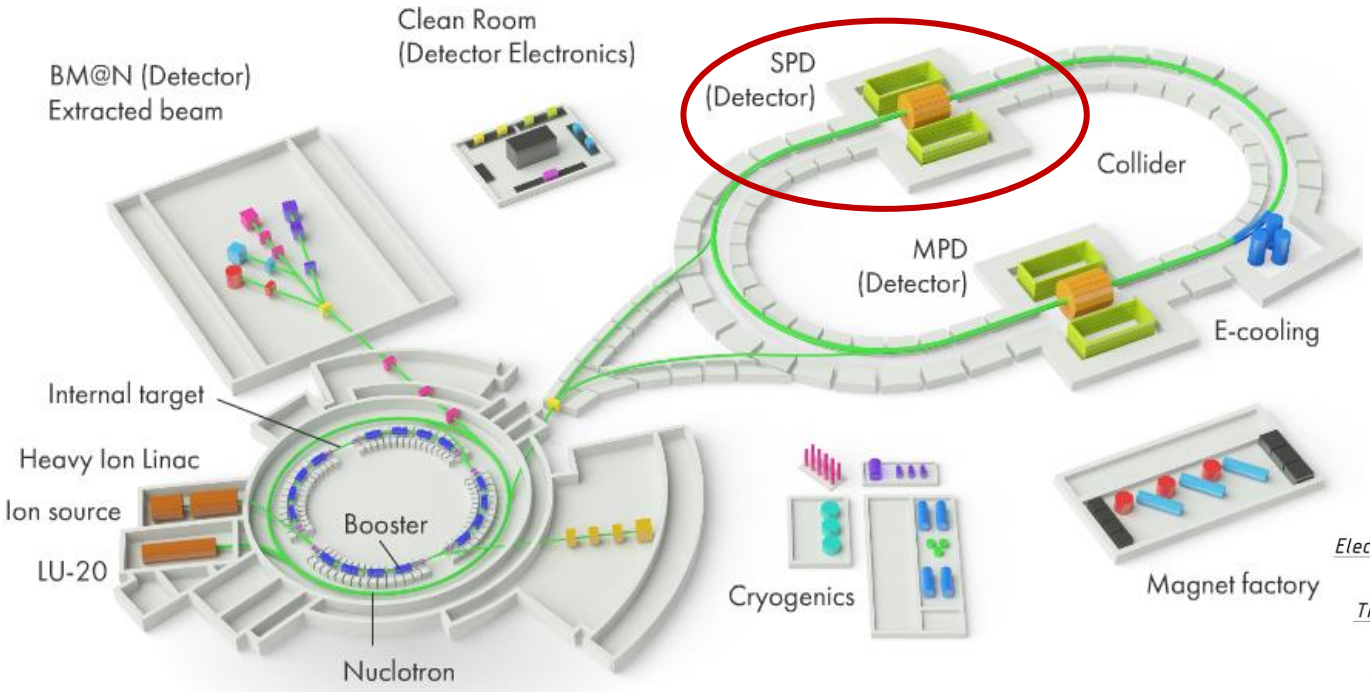


Optimisation of the FARICH technique for the SPD experiment

A. Barnyakov on behalf of BINP aerogel group

for the SPD collaboration

SPD@NICA



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

Spin Physics Detector

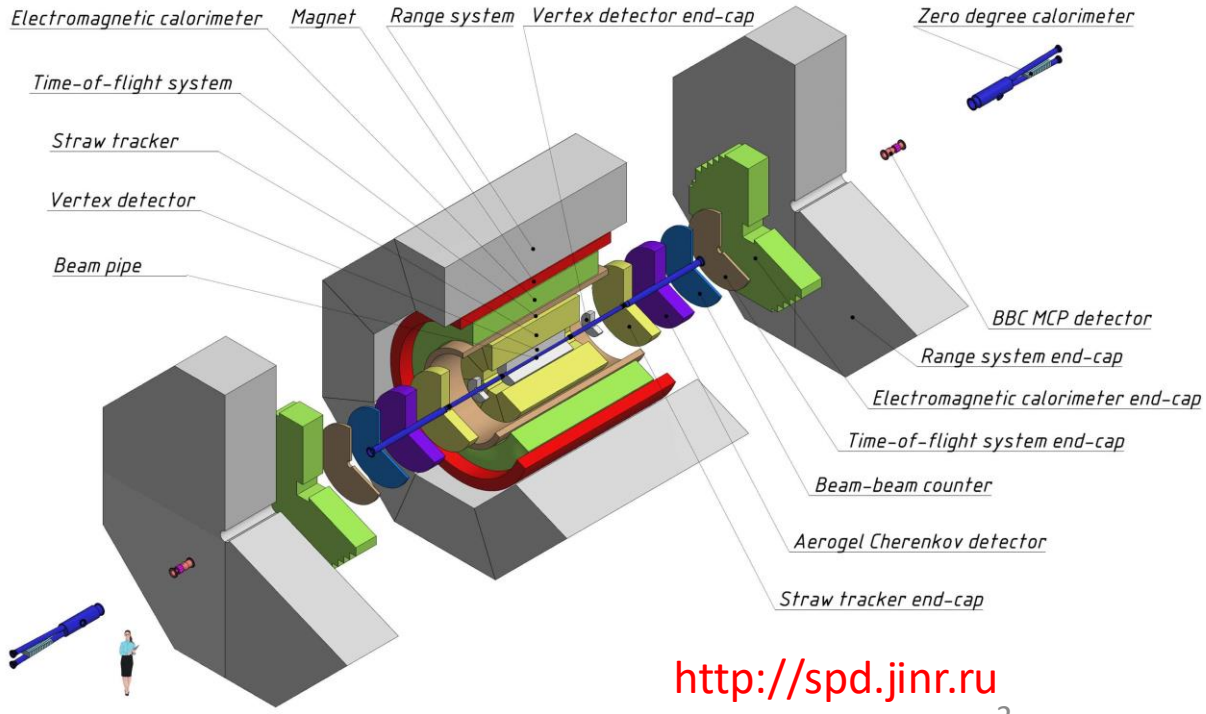
to investigate nucleon and light nuclei (p & d) spin structure with help of colliding beams at the energies up to 27 GeV.

– Polarized p and d

– $L = 10^{32} cm^{-2} s^{-1}$

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

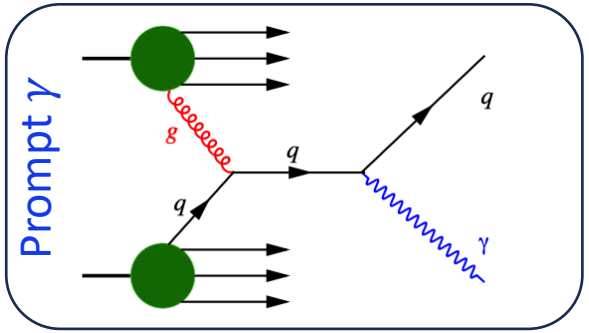
for fundamental nuclear interaction study

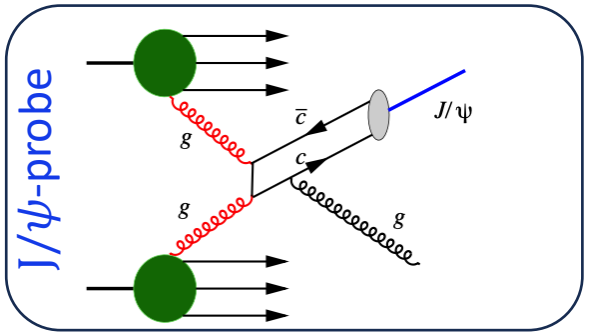


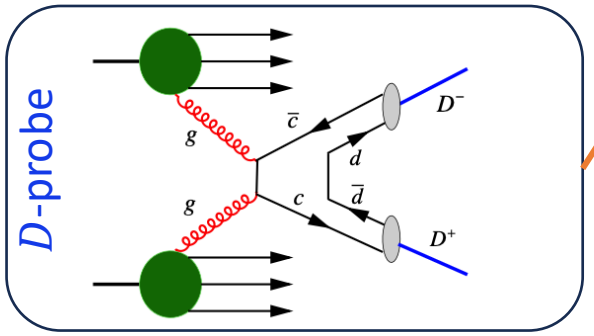
http://spd.jinr.ru

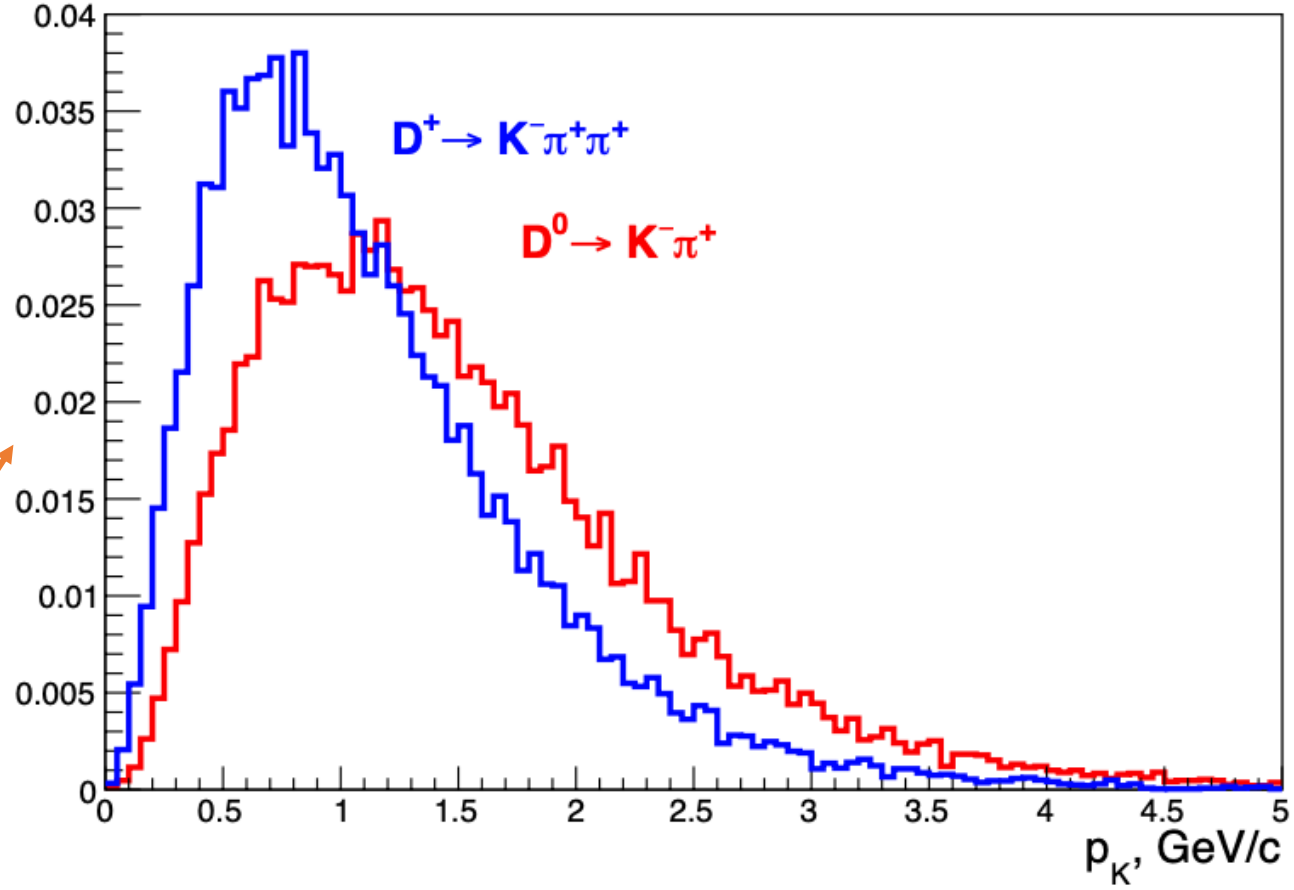
PID system: requirements

Three major probes for Gloun TMD investigations are considered:





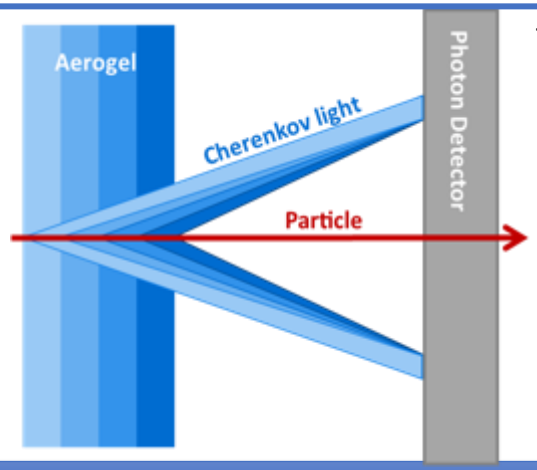




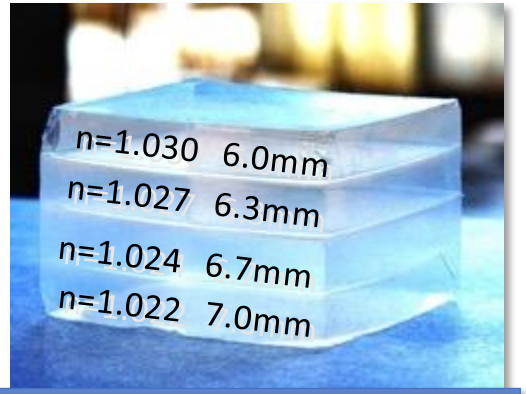
- The reliable π/K-separation up to P=6 GeV/c is required
- RICH based on radiator with n≤1.05 (aerogel) + focusing are needed

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

FARICH technique idea & major MileStones



The first 4-layer monolithic sample

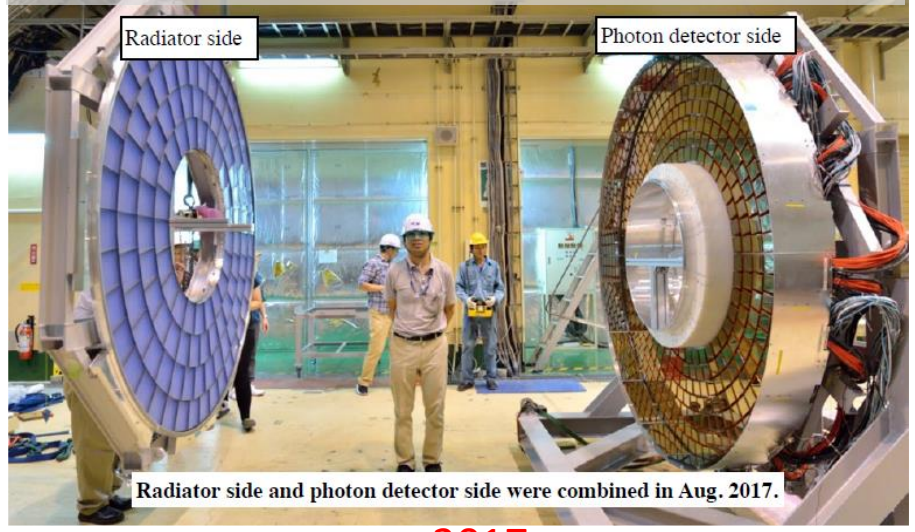


Increase N_{pe} due thickness increase without $\sigma_{\Theta c}$ degradation

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

2004÷2005

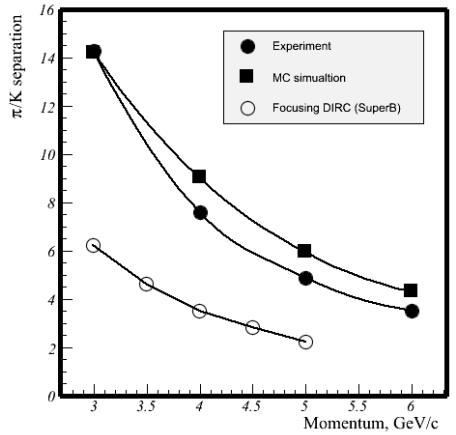
The Belle II (ARICH) is the first application of the method

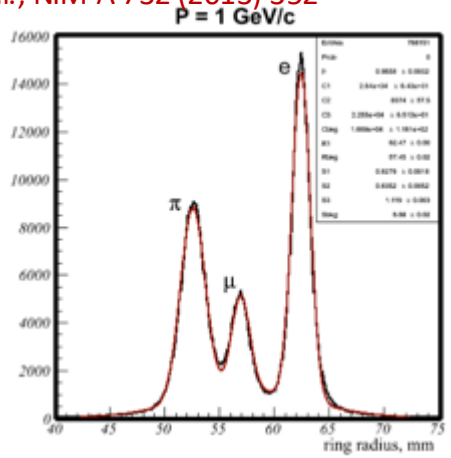


2017

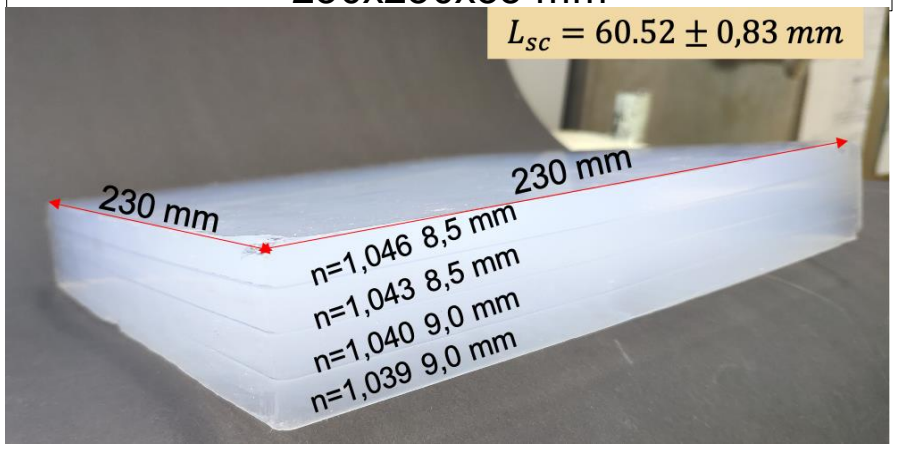
Excellent PID capability were shown at CERN beam test in 2012

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





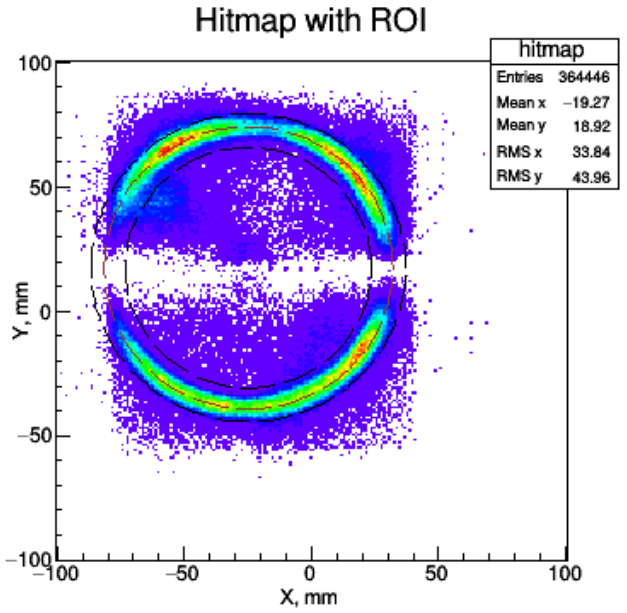
Two 4-layer focusing aerogel blocks
230x230x35 mm

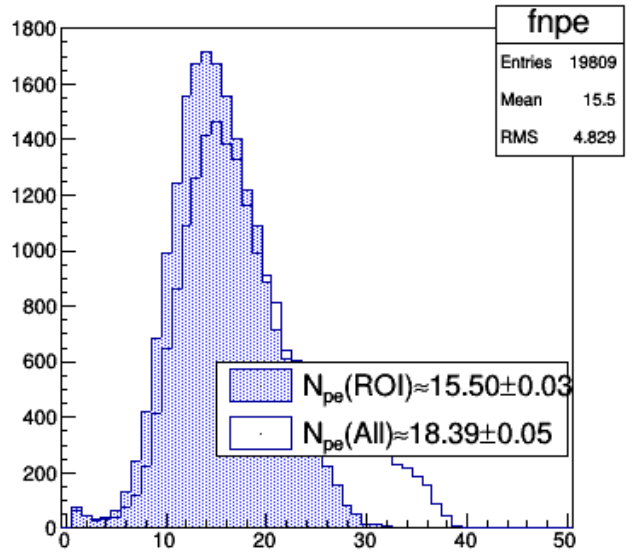


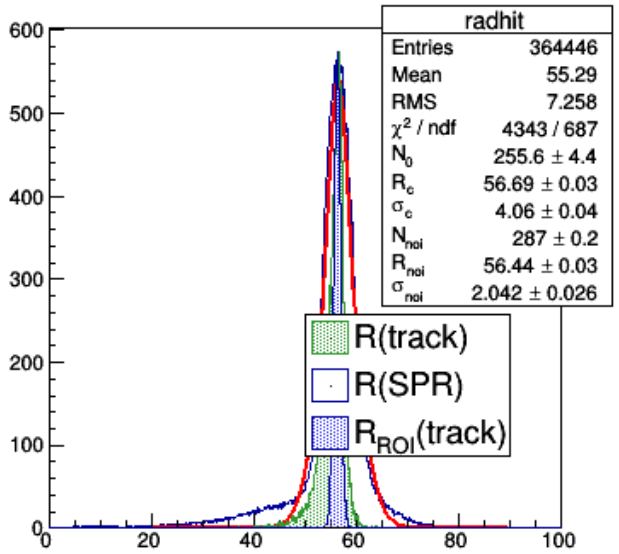
2022÷2023

Beam test results with the largest 4-layer focusing aerogel

Pixel 6x6 mm
Geom.Eff. ~ 80%

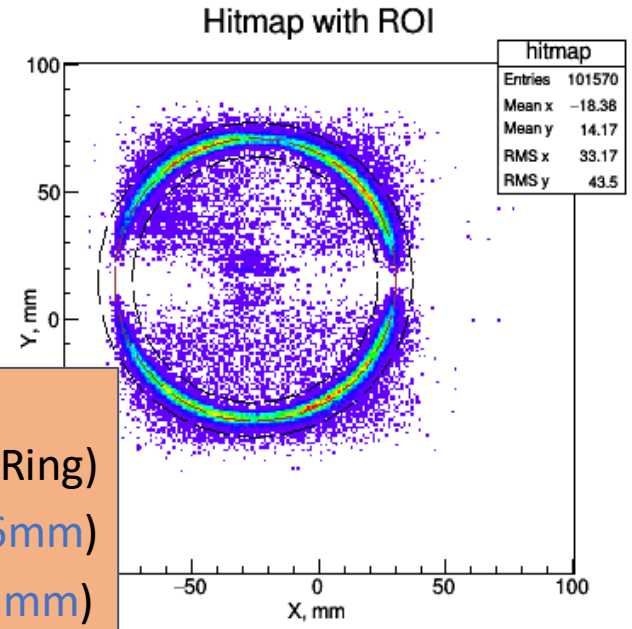


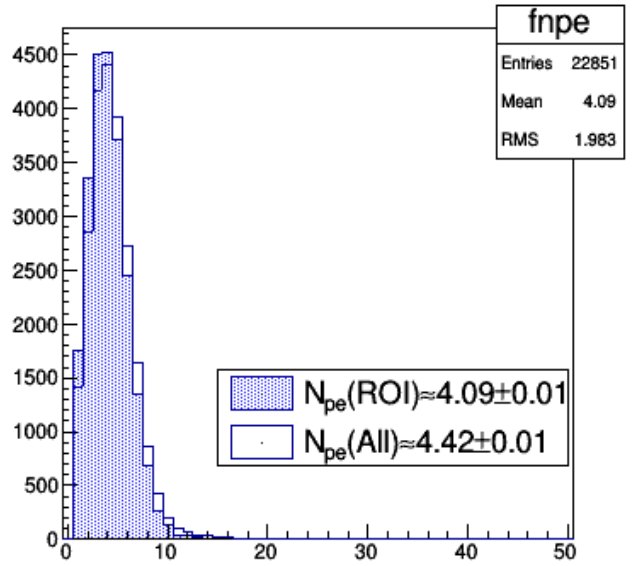


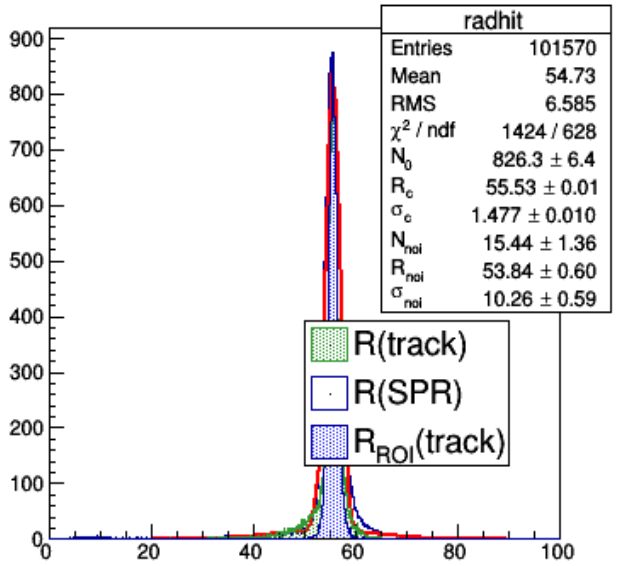


Made with help of shadow mask

Pixel 3x3 mm
Geom.Eff. ~ 20%



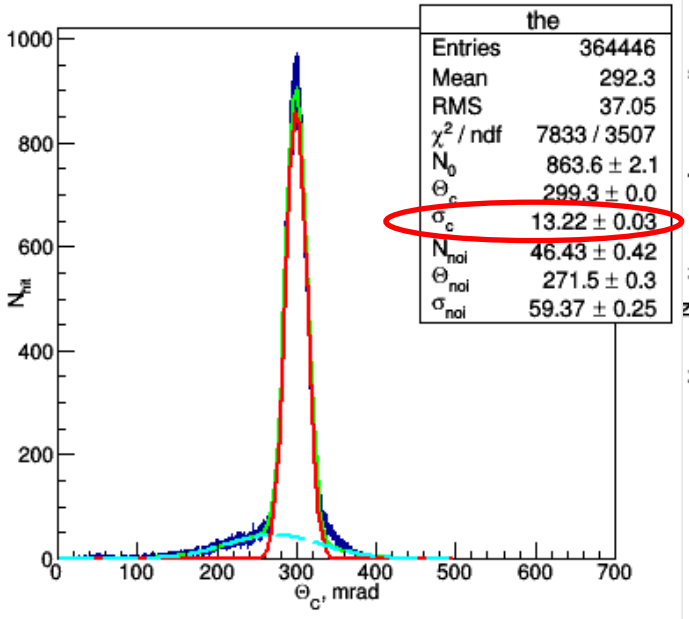




Main results:

- N_{pe} ≈ 16 (~ 0.8 of Ring)
- σ_θ^{1pe} ≈ 13.5 $mrad$ (■ 6mm)
- σ_θ^{1pe} ≈ 7.0 $mrad$ (■ 3mm)

Cherenkov angle Single Photo-Electron (*SPE*) resolution



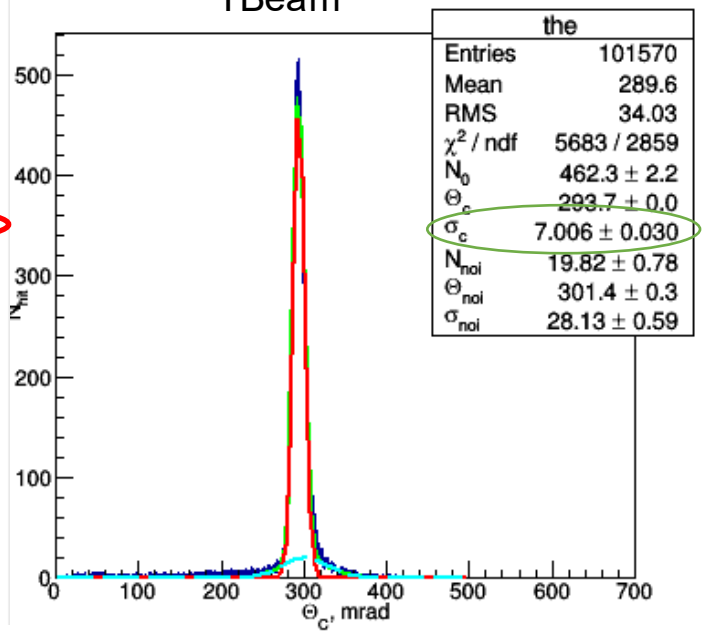
4-layers: 1.039 ÷ 1.046

6x6 mm

Geom.Eff. ~ 80%

$N_{pe} \approx 16$

TBeam



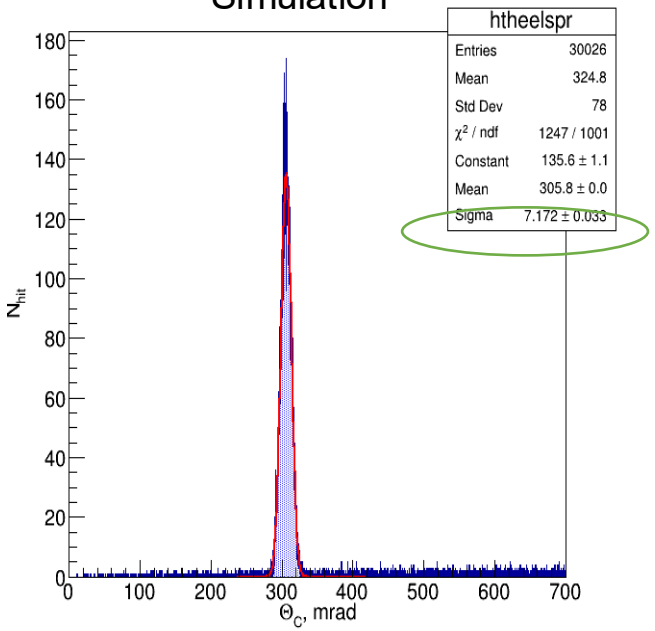
–

3x3 mm

Geom.Eff. ~ 20%

$N_{pe} \approx 4$

Simulation



4-layers: (ideal profile)

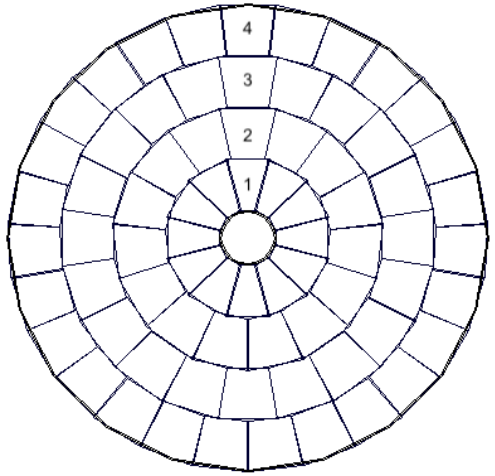
3x3 mm

Dimensions of the tiles 23x23x3.5 cm allow us to design the full-scale FARICH systems for the future experiments.

- Beam test results are in good agreement with MC simulation
- The tiles were optimised for 3x3 mm pixels and 200 mm focusing distance to provide reliable μ/π–separation up to P=1.5 GeV/c

FARICH system conceptual design (base option)

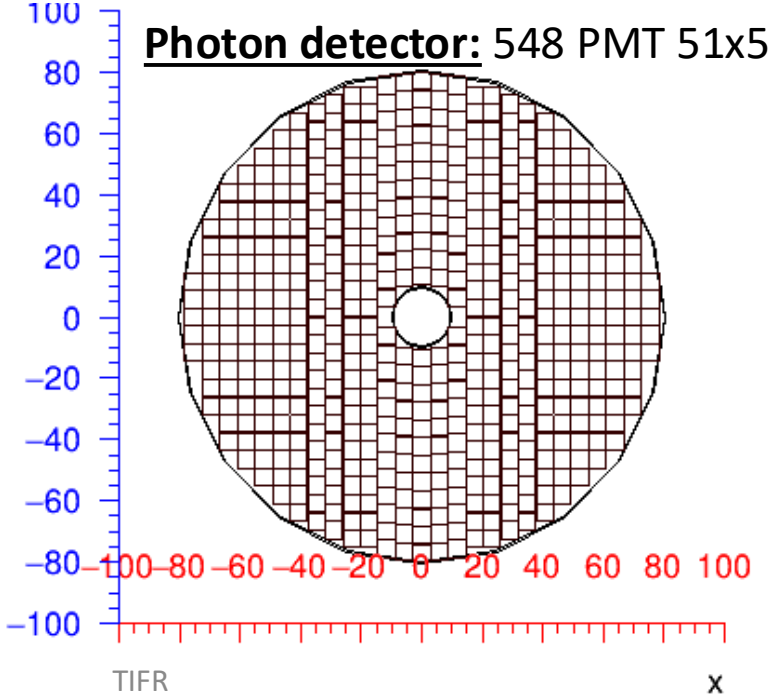
Aerogel:
74 tiles

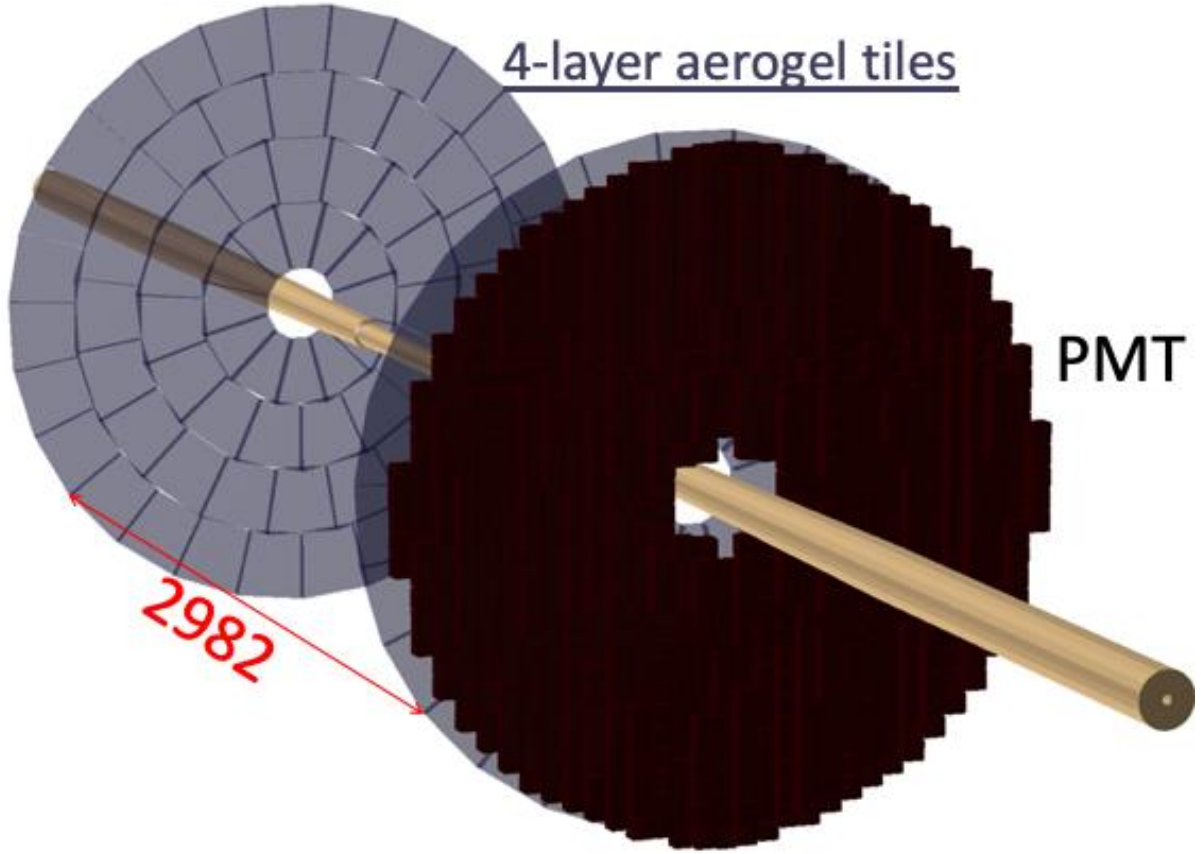


1 – 12 tiles x S=0.5•(5.6 + 15.6)•18.5 = 159.0 sq.cm
2 – 15 tiles x S=0.5•(12.2+20.2)•18.5 = 299.7 sq.cm
3 – 20 tiles x S=0.5•(15.0+20.8)•18.5 = 331.15 sq.cm
4 – 27 tiles x S=0.5•(15.2+19.6)•18.5 = 321.9 sq.cm

S(aer)/S(total)=21717.8/22383.8=0.97

Photon detector: 548 PMT 51x51 mm





FARICH system:

- 4-layer aerogel with n_{max}=1.05
- Focus distance – 20 см
- PS PD – MCP-PMT or SiPM arrays with pixel 3÷5 mm
  550 PMTs per endcap if lateral sizes ~51x51 mm
  2200 PMTs per endcap if lateral sizes ~27x27 mm

On possibilities for optimizations

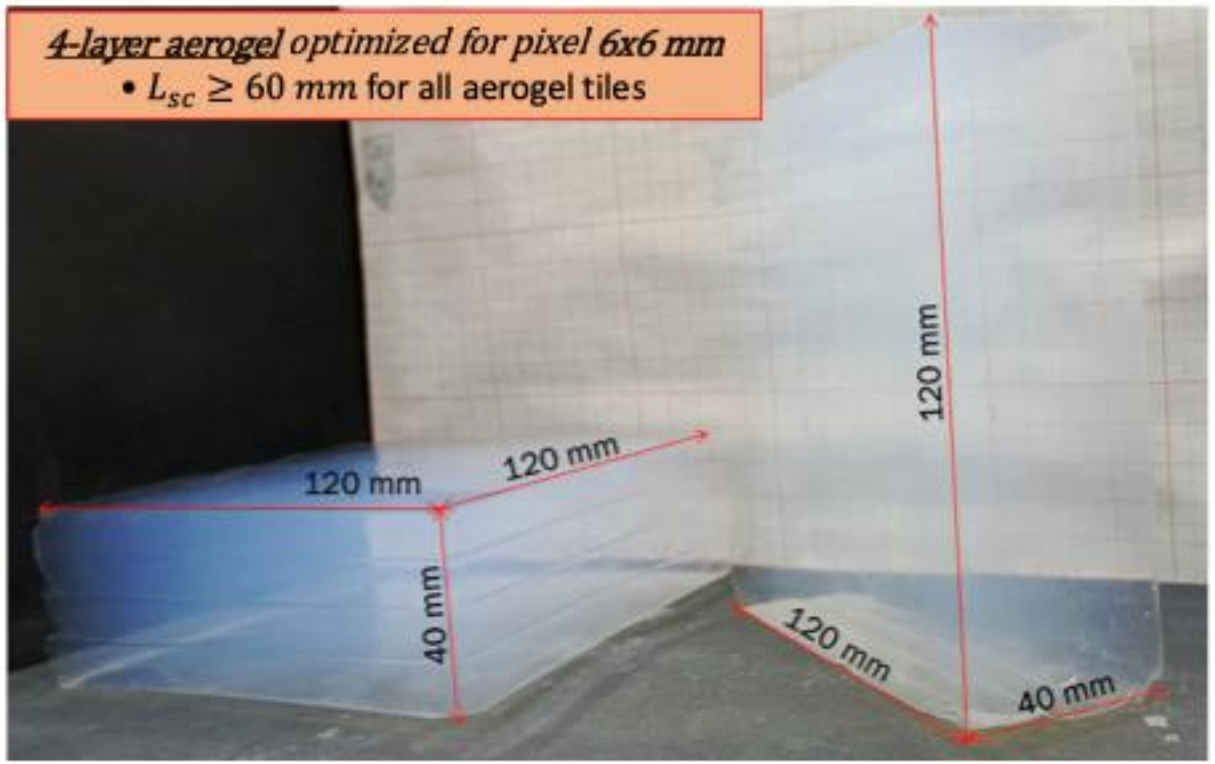
- $cos(\theta_C) = \frac{1}{n \cdot \beta}$. $n_{\downarrow} \rightarrow \Delta\theta_C^{\pi/K\uparrow}$
- $\sigma_C^{tr} = {}^{1}/_{\sqrt{N_{pe}}} \cdot \frac{}{\sqrt{\left(\frac{\Delta_{pix} \cdot \cos\theta_C}{L \cdot \sqrt{12}}\right)^2 + \left(\frac{\sigma_n}{n \cdot \tan\theta_C}\right)^2 + \left(\frac{t \cdot \sin\theta_C}{L \cdot \sqrt{12}}\right)^2}} \sim \sqrt{t}$
- $N_{pe}(\beta = 1) \sim 500 \cdot \frac{n^2 - 1}{n^2} \cdot t \cdot PDE$

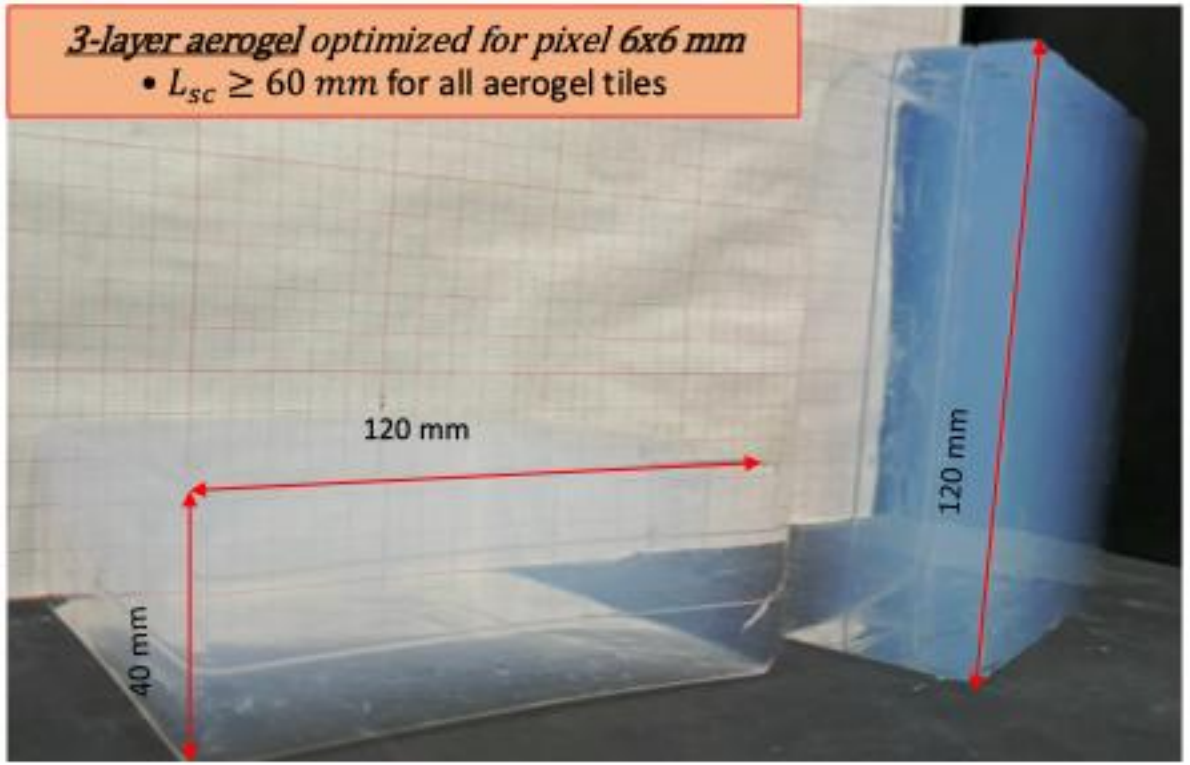
n, t, N_{layers}, L, PDE and Δ_{pix} are parameters for optimization

It is necessary to find optimal compromise for each project!!!

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

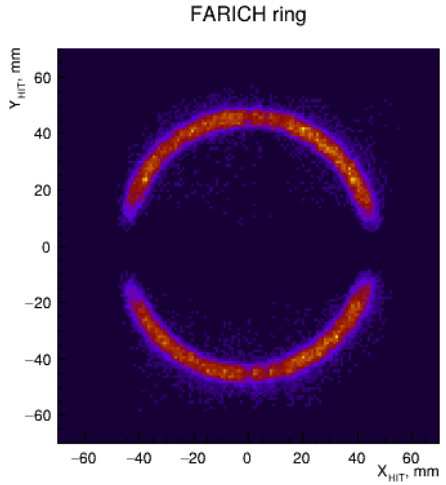


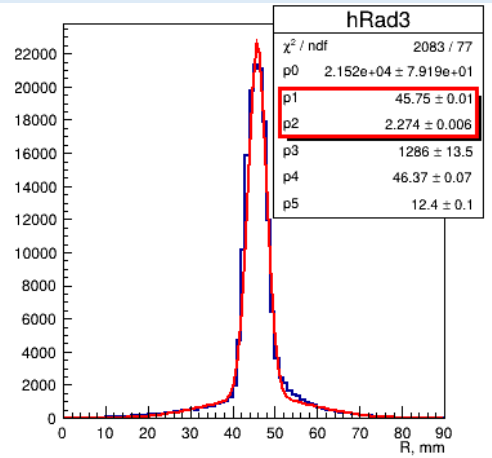


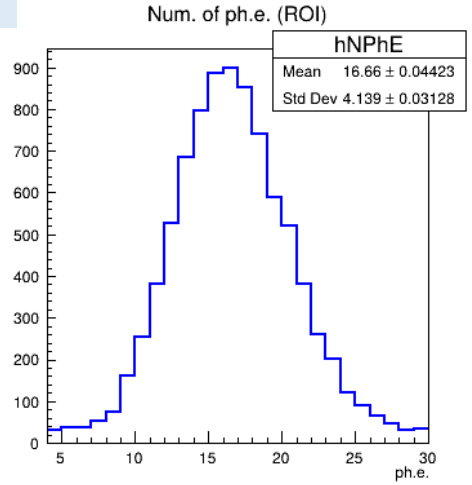
These new aerogels were tested in June 2025 with relativistic electrons at the BINP

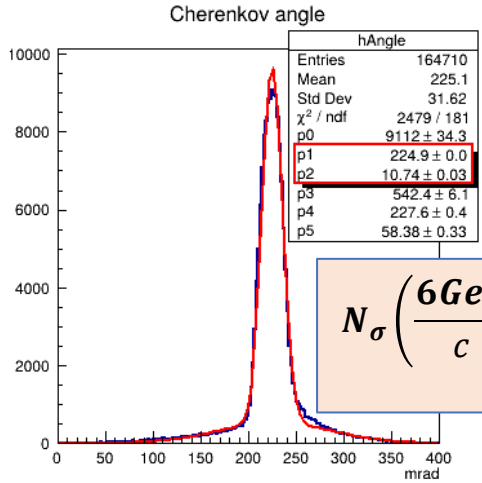
Beam tests at BINP results: June 2025

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





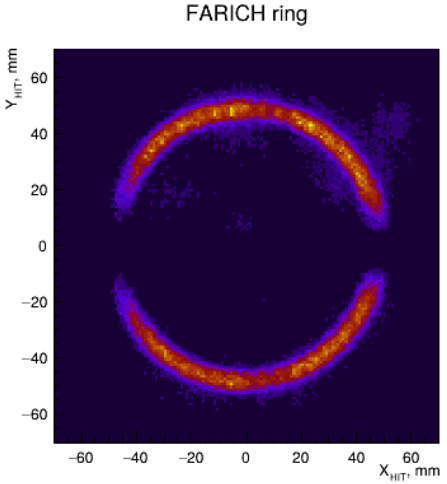


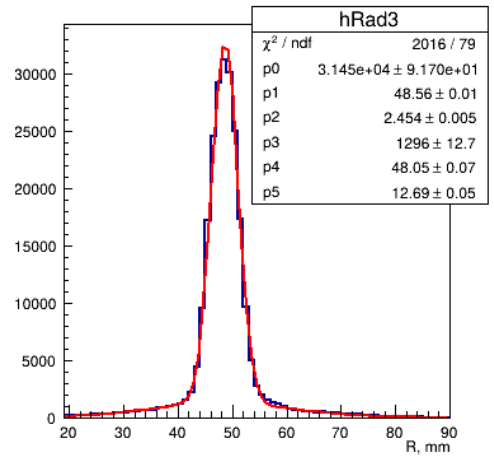


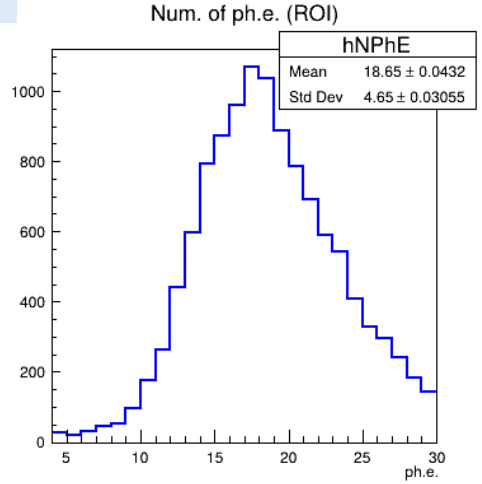
$$\sigma_{1pe} \approx 10.7\ mrad$$

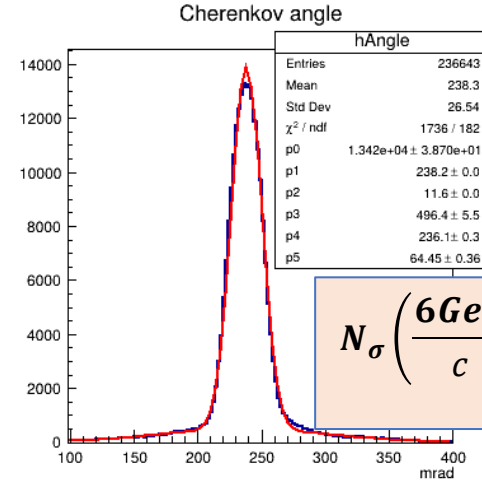
$$N_\sigma\left(\frac{6GeV}{c}\right) \approx \frac{11\ mrad}{10.7 mrad/\sqrt{N_{pe}}} \approx 4.2$$

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









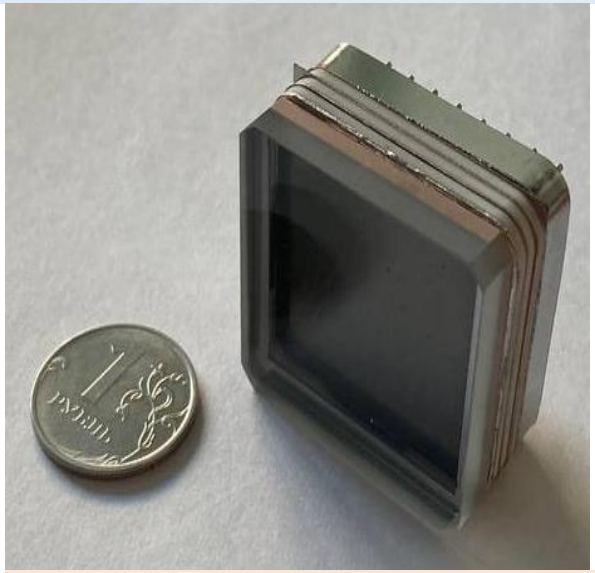
$$\sigma_{1pe} \approx 11.6\ mrad$$

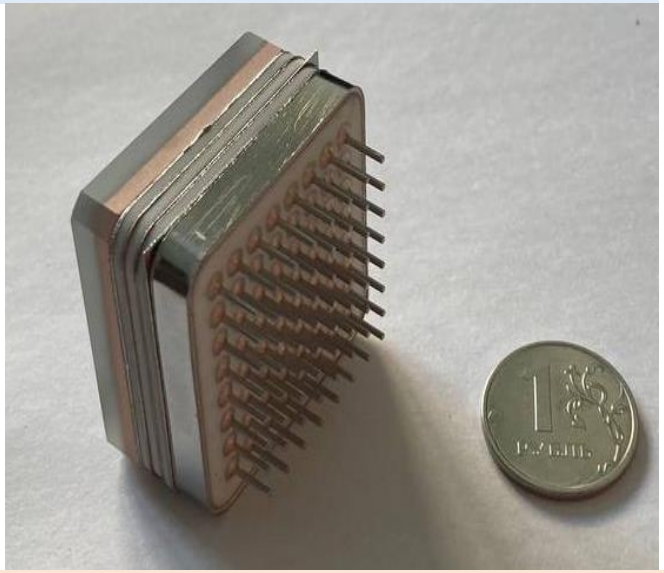
$$N_\sigma\left(\frac{6GeV}{c}\right) \approx \frac{11\ mrad}{11.6 mrad/\sqrt{N_{pe}}} \approx 4.1$$

Status of square MCP PMT development in Russia

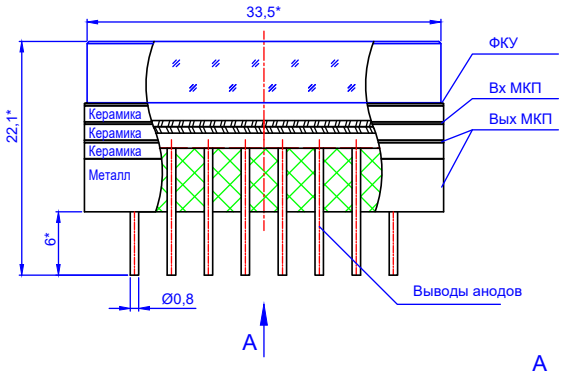
Square MCP PMT from “Ekran FEP”:

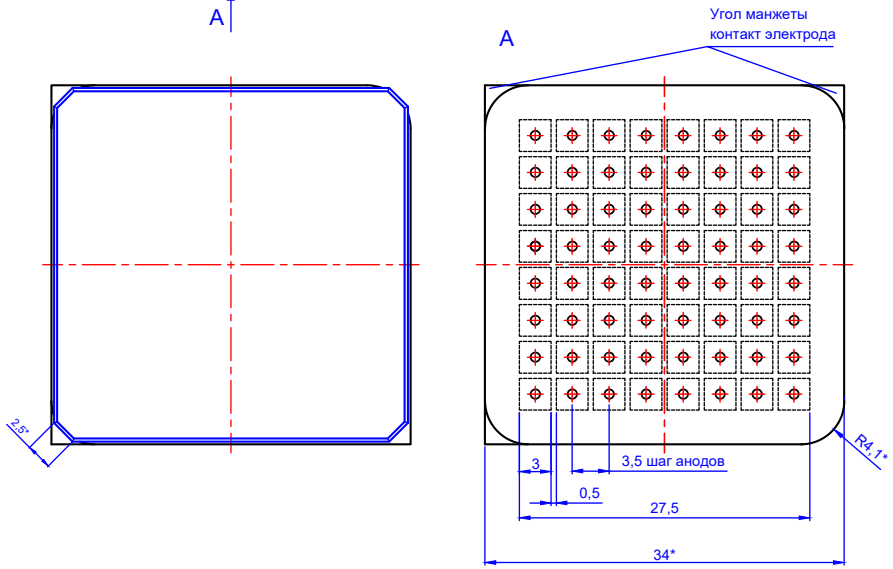
- Construction and design is developed
- All details and components are produced in Russia
- All technological processes are developed and realized
- First samples for test will be available soon in 2025



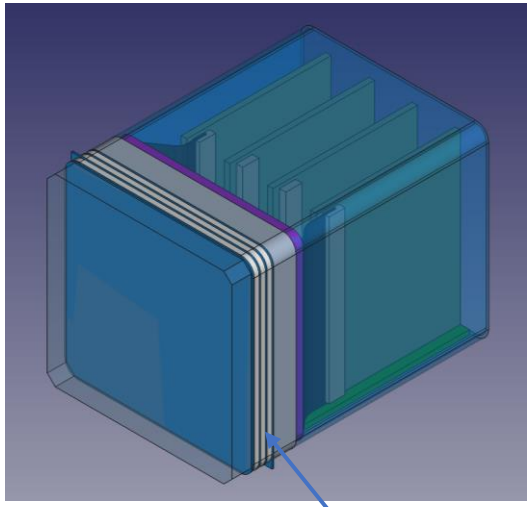


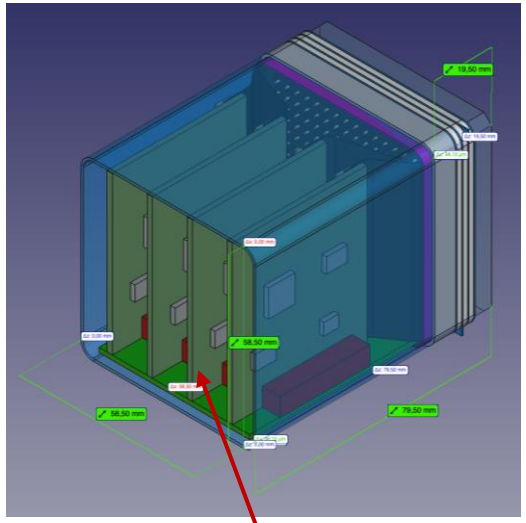
The first prototype fully asembled and vacume sealed prototype

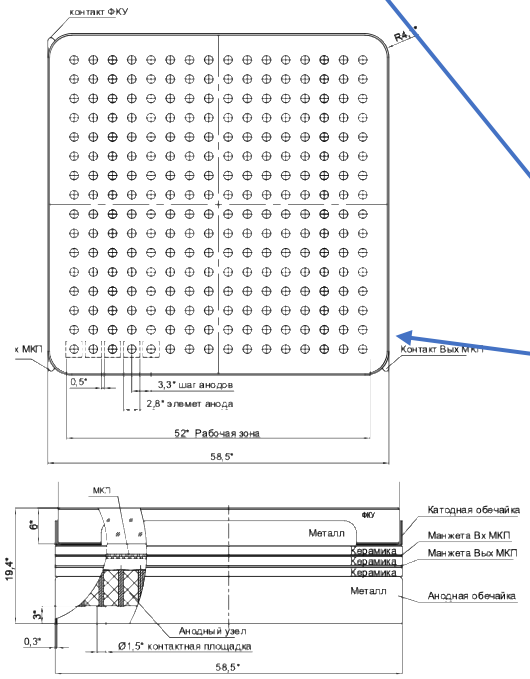


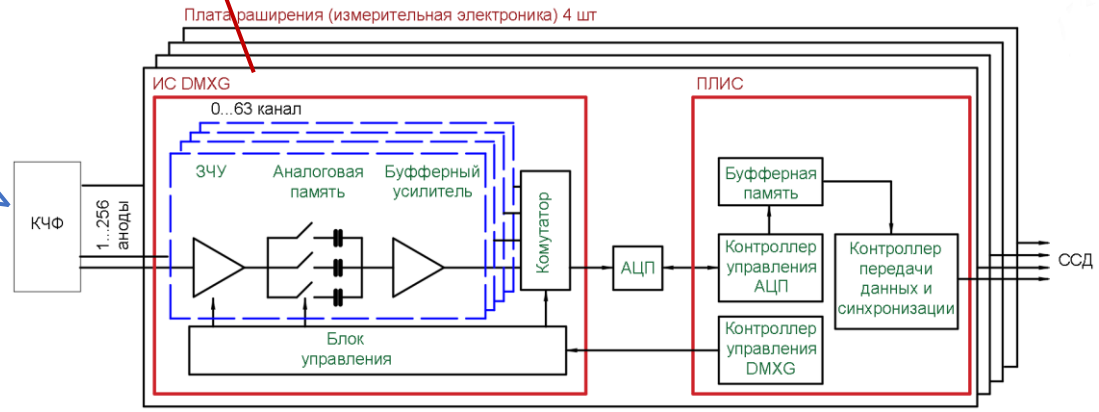


3D-design of the square MCP PMT + FEE module







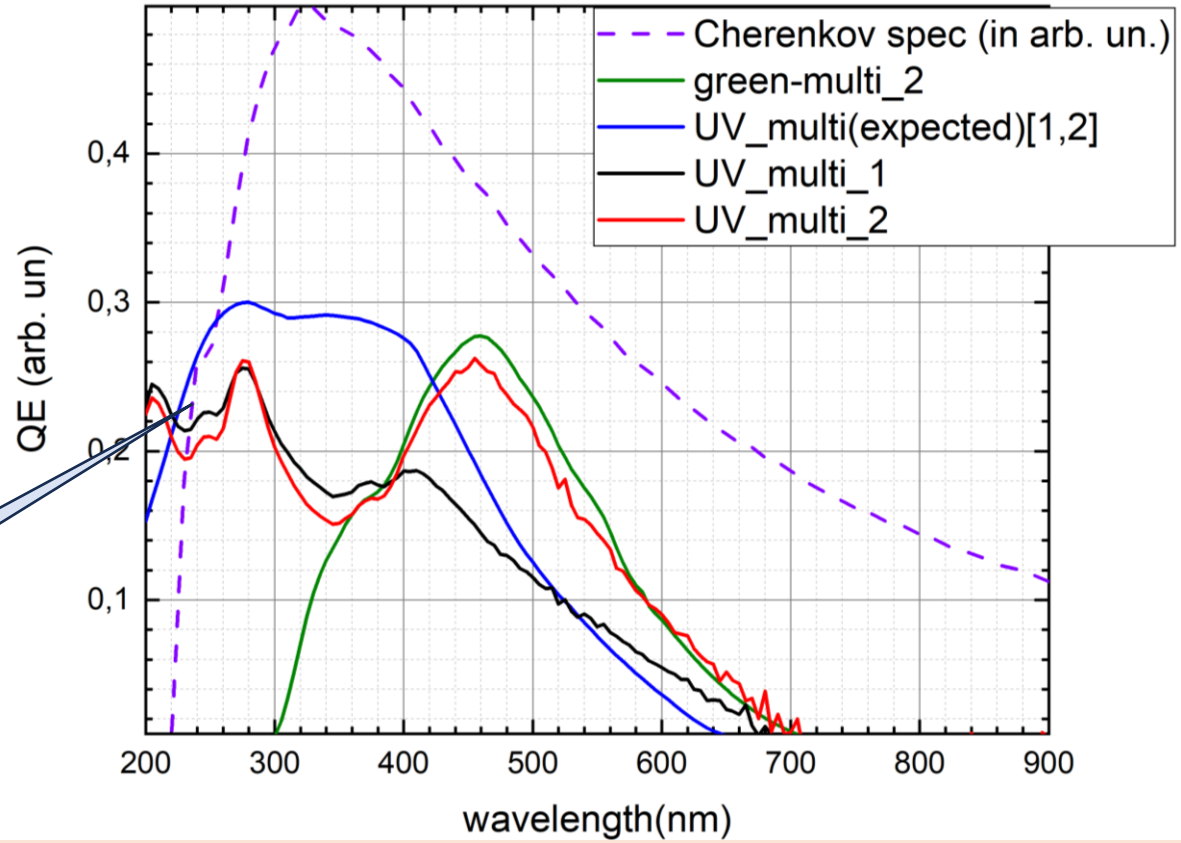


Design and development of PS MCP PMT and corresponding FEE have been started in 2025:

- Square MCP PMT 58x58x19 mm size with 16x16=256 anode pads 2.8x2.8 mm size.
- 4 readout boards based on ASIC chip DMXG64 coupled with anodes by Flexible PCBs will provide signals digitization and transfer them to PC.
- Box made of carbon-fiber reenforced (CFR) plastic is used as a holder for HV divider and readout boards as well.
- The module design is good enough for beam and cosmic ray tests, while for collider experiments more appropriate FEE should be designed.

PC optimization for Cherenkov light detection

Multi-alkali PCs options and Cherenkov spectrum



It is planed to use Quartz to enhence PDE in UV region

The advantages of use **"UV_multi" PC (Quartz)** are expected as following:
– **factor of 1.5** more detcted Cherenkov photons in in comparison with standard "green-multi2" PC

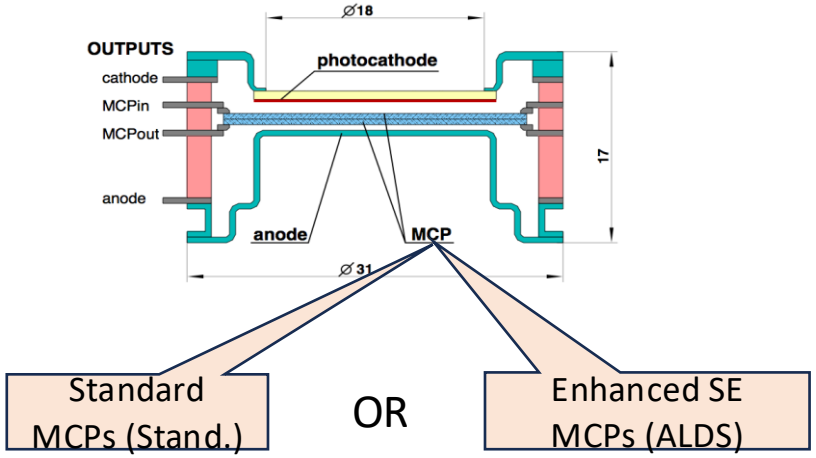
"UV_multi" QE based on data from papers:

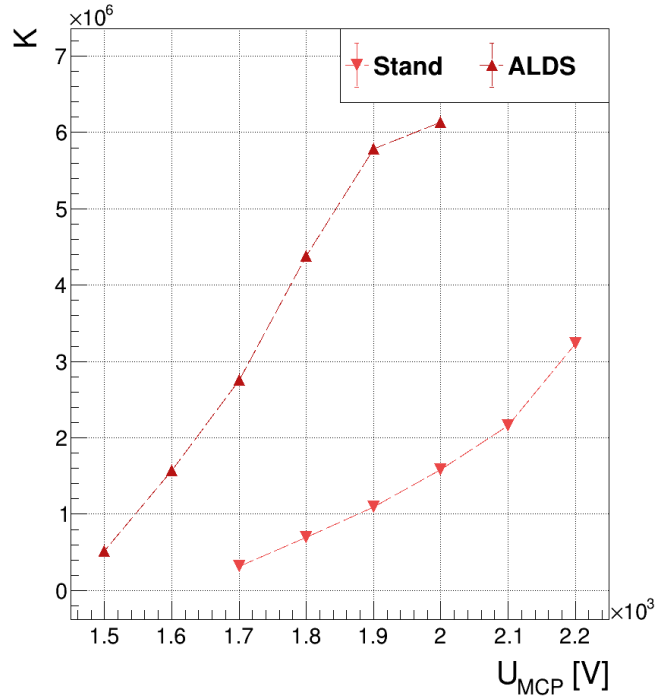
1. Orlov, D. A., et al., High quantum efficiency S-20 photocathodes in photon counting detectors. Journal of Instrumentation, 2016 11(04), C04015–C04015

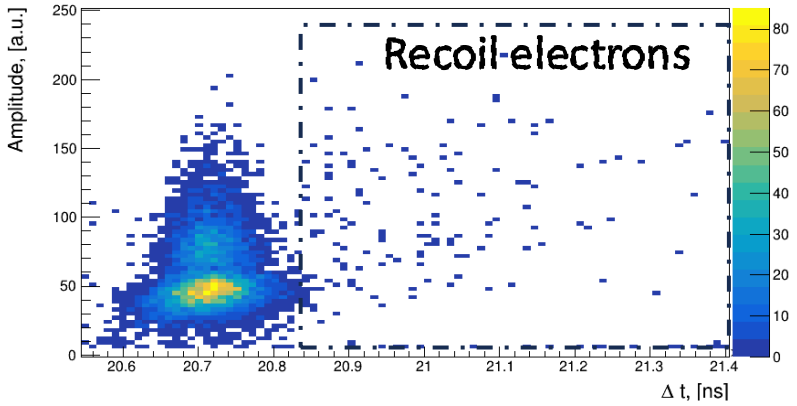
2. Milnes, J., et al., UV photocathodes for space detectors. Proceedings Volume 12181, Space Telescopes and Instrumentation 2022: Ultraviolet to Gamma Ray, 121813B (2022).

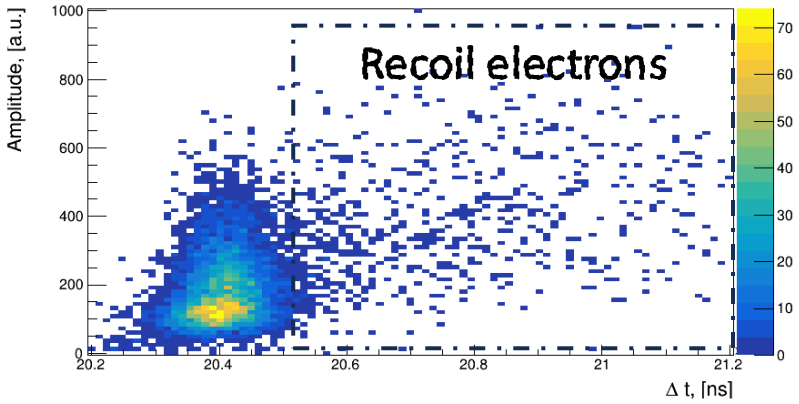
MCP optimization with help of ALD coating

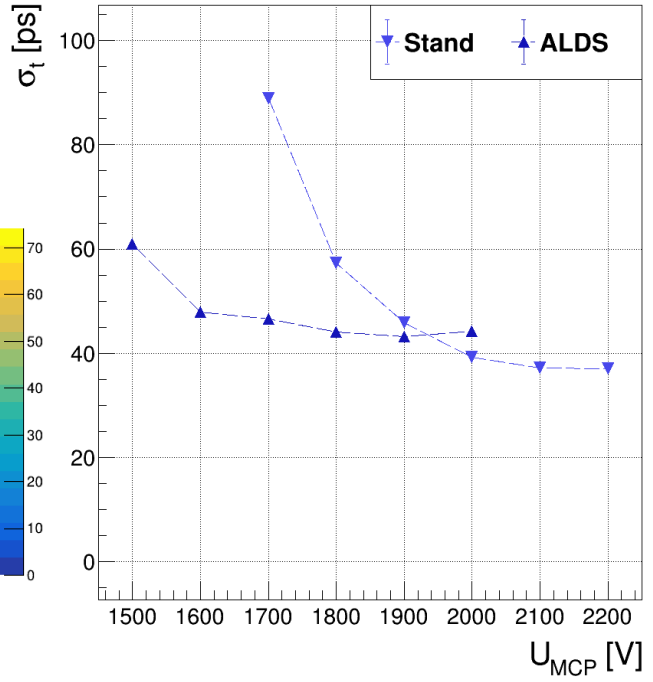
The first ALD tests were performed with standard round-shape MCP PMTs produced by “Ekran FEP” Ltd.



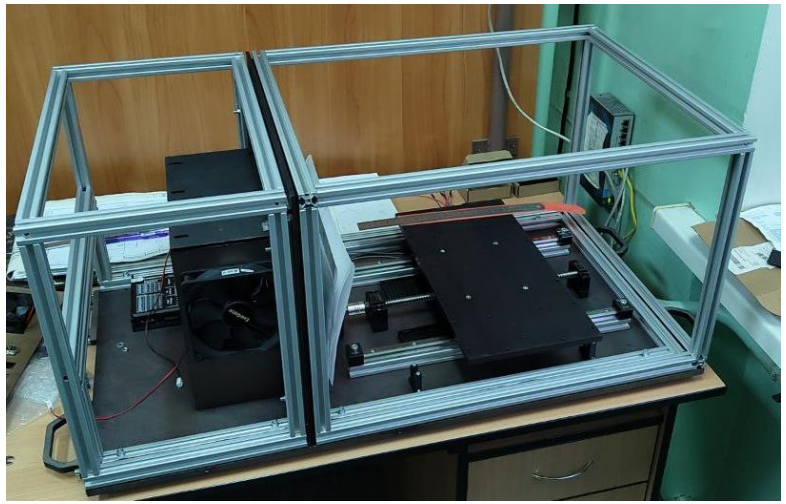


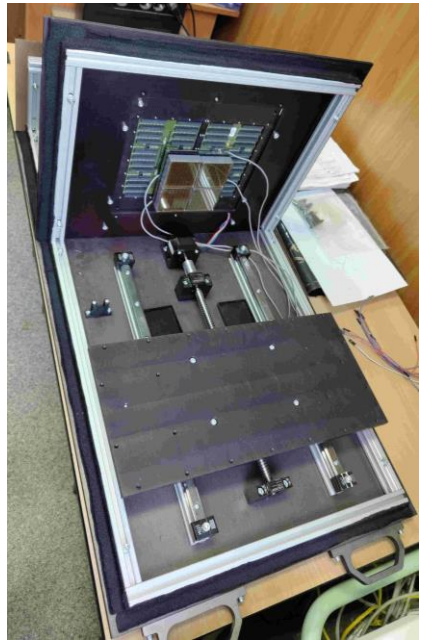


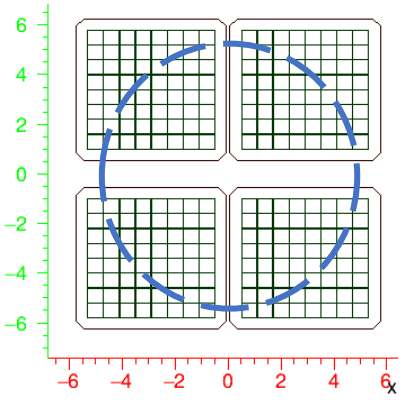


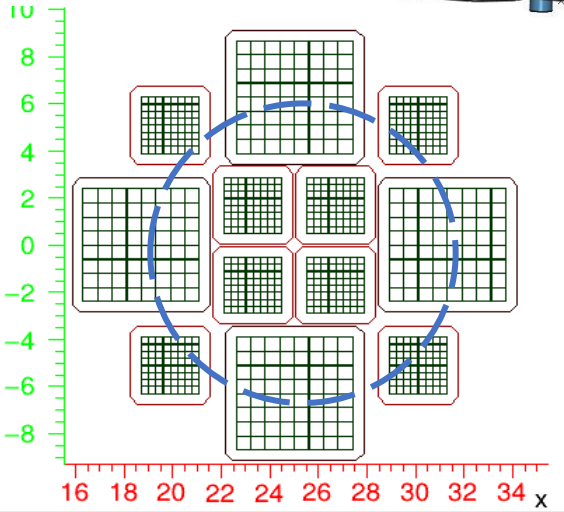


FARICH prototype for hadron beam tests









FARICH prototype based on 4 PMTs H12700 is ready to be tested now

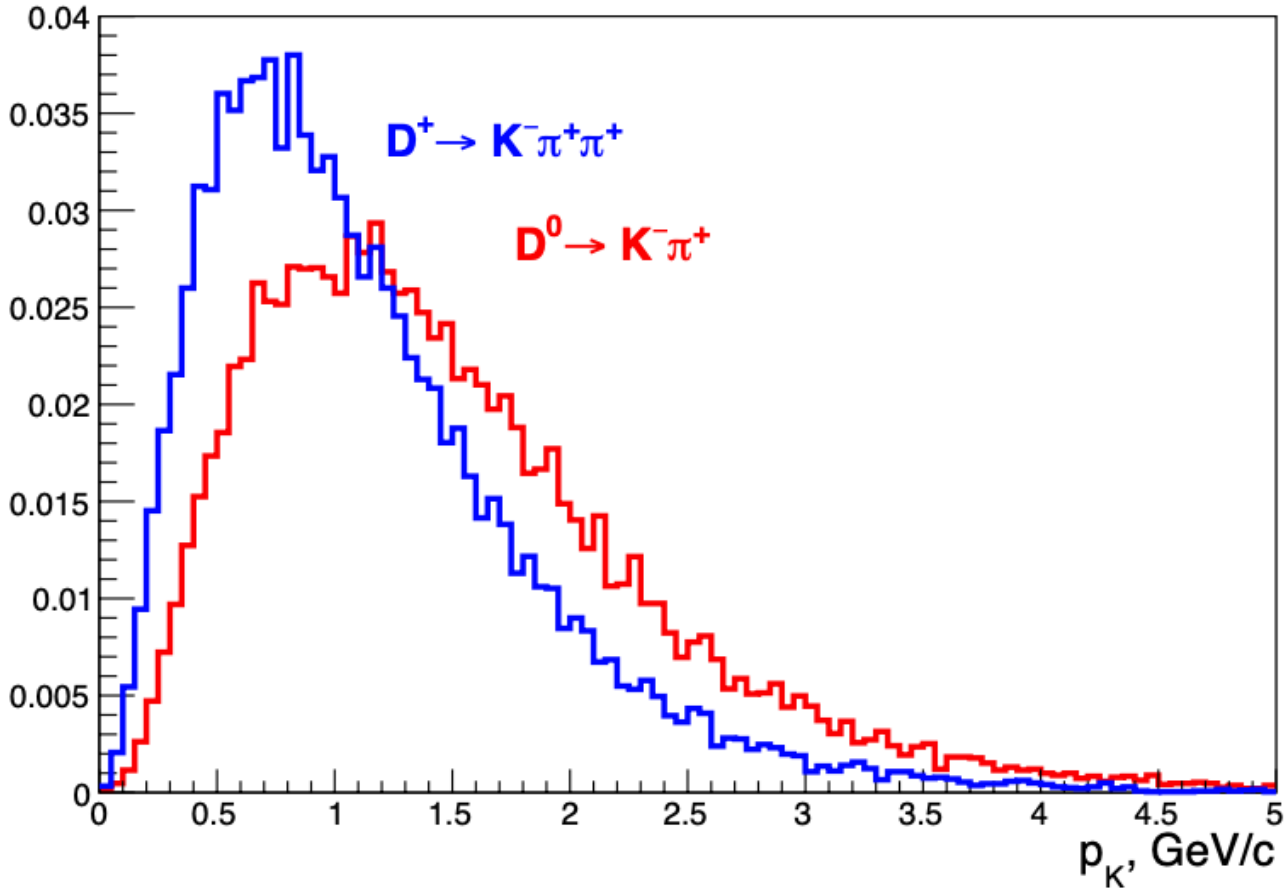
FARICH prototype based on 12 PMTs H12700 + MCP PMTs is expected in Feb. 2026!

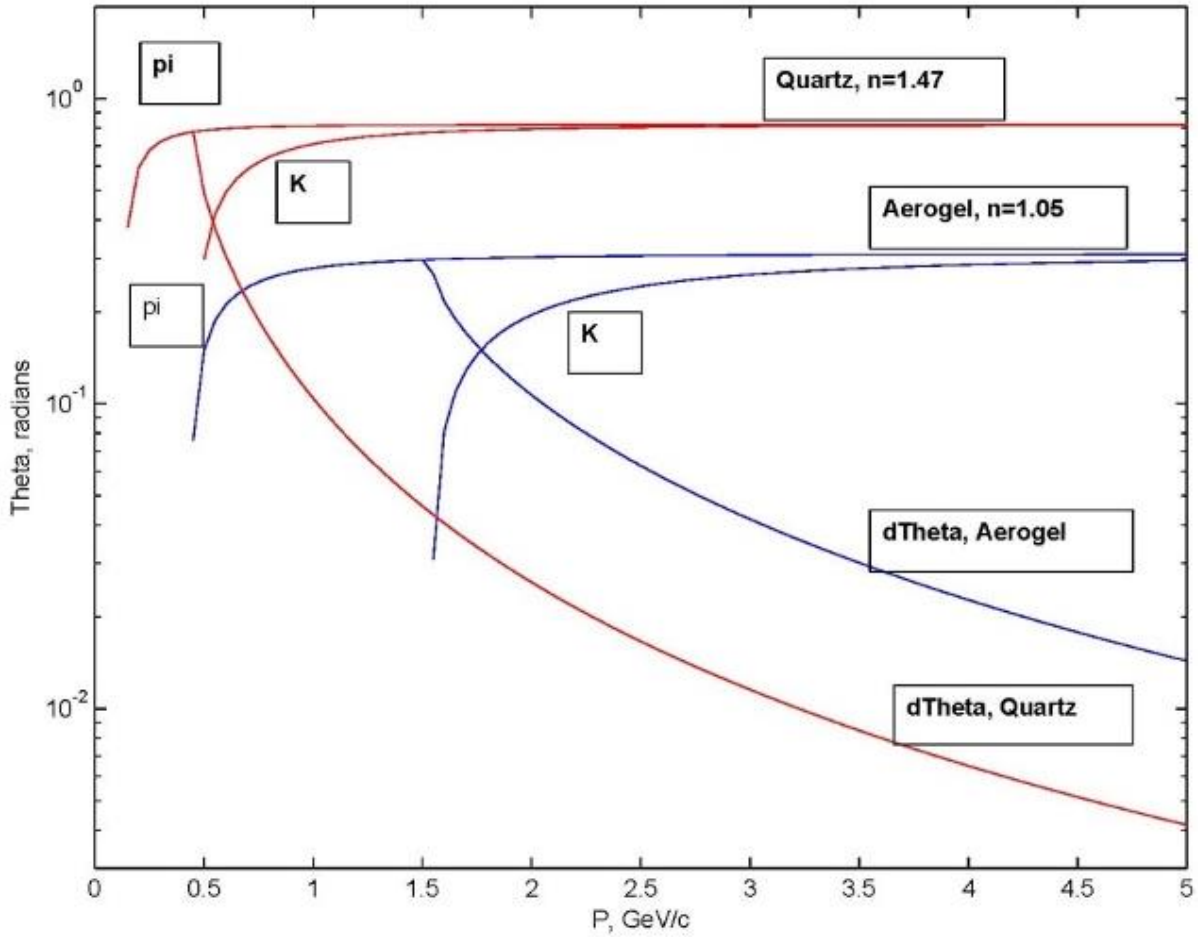
Summary

- The FARICH technique is proposed as an base option for PID system of the SPD experiment at the NICA collider
- Several ways for optimization of the focusing multilayer aerogel Cherenkov radiators were proposed and realised in 2025
- Production of the first square position-sensetive MCP based photomultipliers has been started in Novosibirsk
- Optimisation of the multi-alkali PCs to increase their sensetivity to Cherenkov spectra from aerogel by factor of 1.5÷2 was proposed and tested
- To improve the features and reliability of the MCP based PMTs in the upcoming particle experiments the ALD approach was implemented to coat MCPs produced by standard technology, the first test results are in good agreement with expectations
- The FARICH prototype based on MCP PMTs prepared to be tested with hadron beams at IHEP (Protvino) and JINR (Dubna) beam test facilities in 2026

Back UP slides

PID system: requirements





The main task of SPD PID system is
π/K-separation up to P=5÷6 GeV/c

For reliable π/K-separation at P=6 GeV/c the RICH detector is required:
– $n = 1.05$ (aerogel),
– $\sigma_C \sim 2.5\ mrad/track$

MCP's parameters processing issues