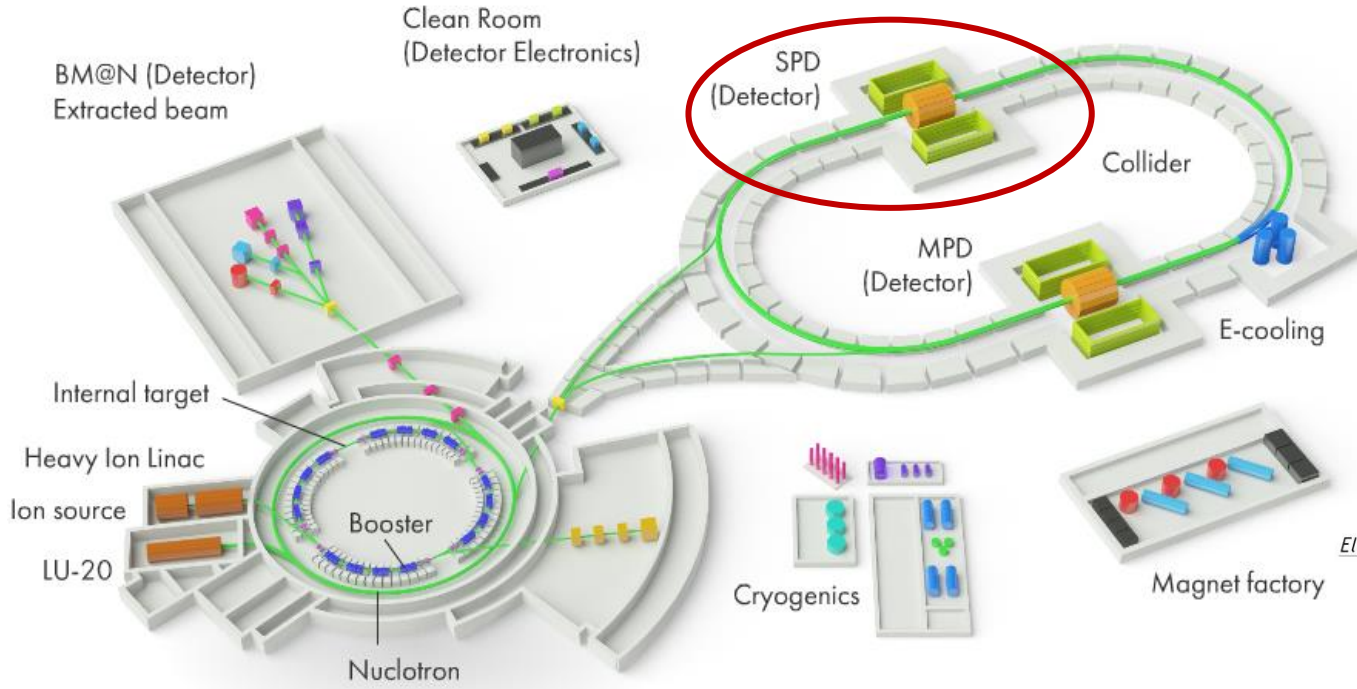


# Optimisation of the FARICH technique for the SPD experiment

*A. Barnyakov* on behalf of BINP aerogel group  
for the SPD collaboration



# SPD@NICA



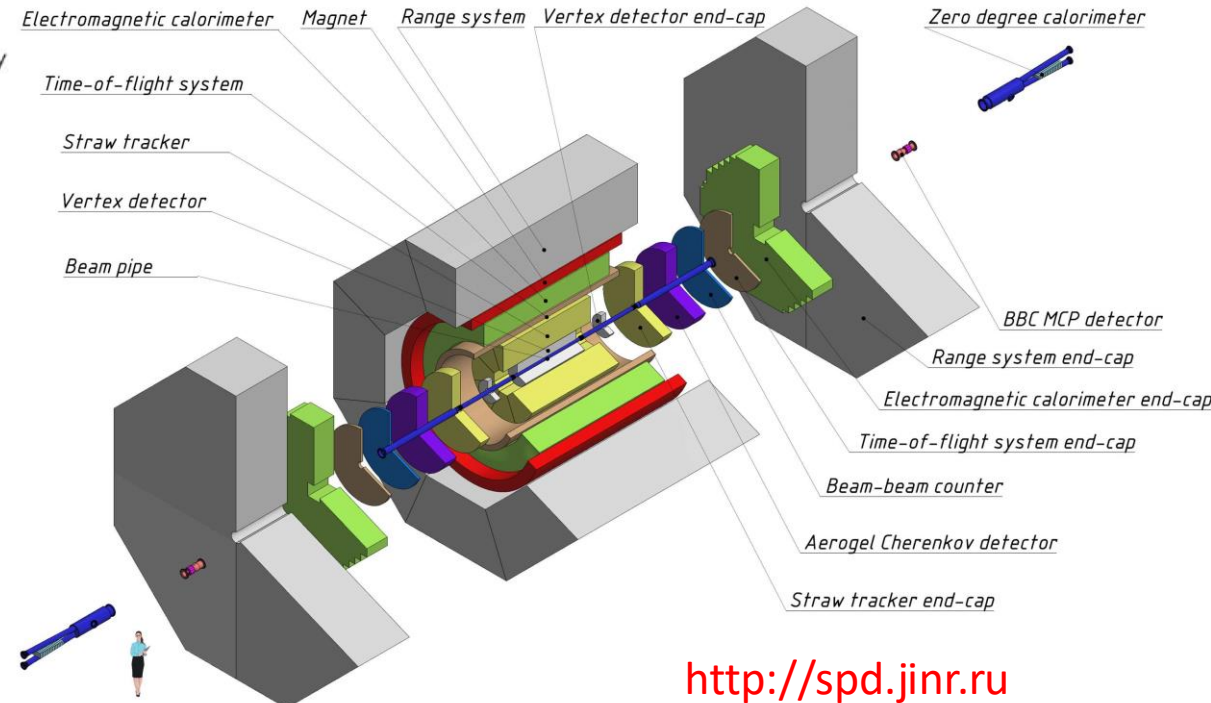
<https://nica.jinr.ru/complex.php>

**Nuclotron based Ion Colliding Facility**  
for fundamental nuclear interaction study

## Spin Physics Detector

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

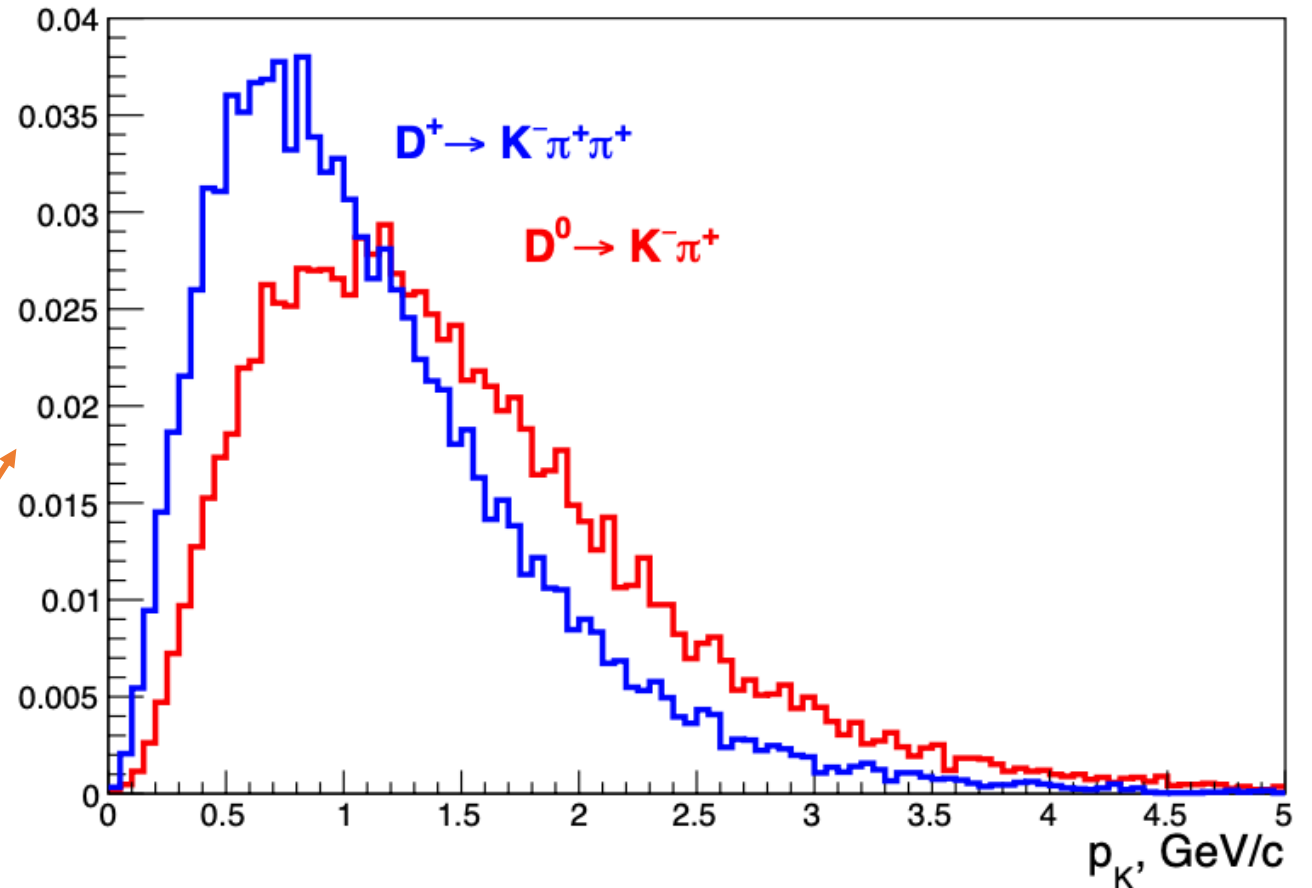
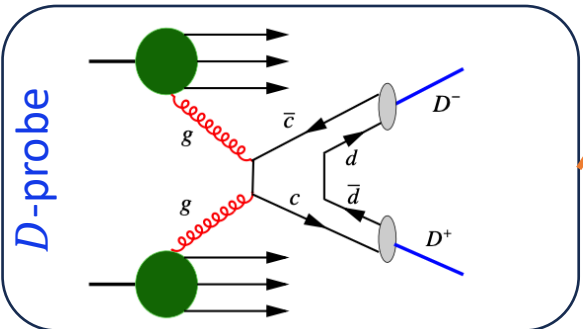
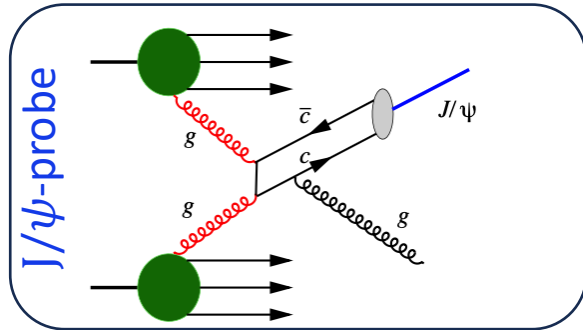
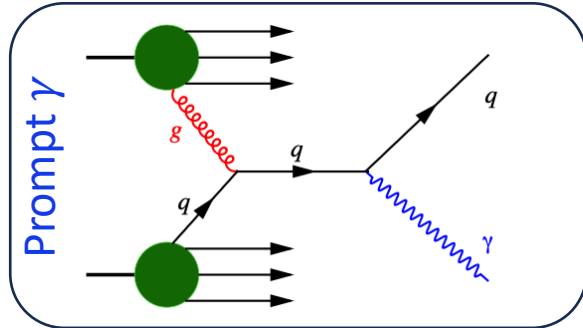
- Polarized  $p$  and  $d$
- $L = 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$



<http://spd.jinr.ru>

# PID system: requirements

Three major probes for Gloun TMD investigations are considered:



- The reliable  $\pi/K$ -separation up to  $P=6 \text{ GeV}/c$  is required
- RICH based on radiator with  $n \leq 1.05$  (aerogel) + focusing are needed to provide  $\sigma_c \sim 2.5 \text{ mrad}/\text{track}$  and  $\pi/K$ -separation  $\geq 3 \sigma @ 6 \text{ GeV}/c$

# FARICH technique idea & major MileStones

The first 4-layer monolithic sample

$n=1.030$	6.0mm
$n=1.027$	6.3mm
$n=1.024$	6.7mm
$n=1.022$	7.0mm

Increase  $N_{pe}$  due thickness increase without  $\sigma_{ec}$  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

Radiator side

Photon detector side

Radiator side and photon detector side were combined in Aug. 2017.

2017

Excellent PID capability were shown at CERN beam test in 2012

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

$\pi/K$  separation

Momentum, GeV/c

$P = 1 \text{ GeV}/c$

ring radius, mm

Two 4-layer focusing aerogel blocks  
230x230x35 mm

$L_{SC} = 60.52 \pm 0,83 \text{ mm}$

230 mm

230 mm

$n=1,046$	8,5 mm
$n=1,043$	8,5 mm
$n=1,040$	9,0 mm
$n=1,039$	9,0 mm

2022÷2023

# Beam test results with the largest 4-layer focusing aerogel

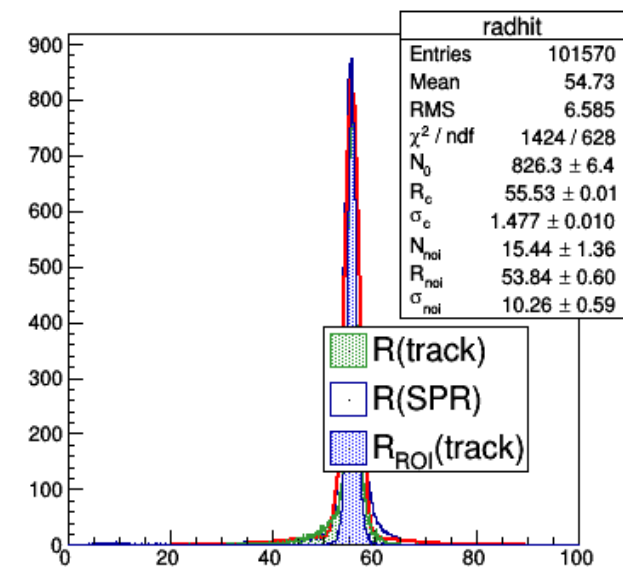
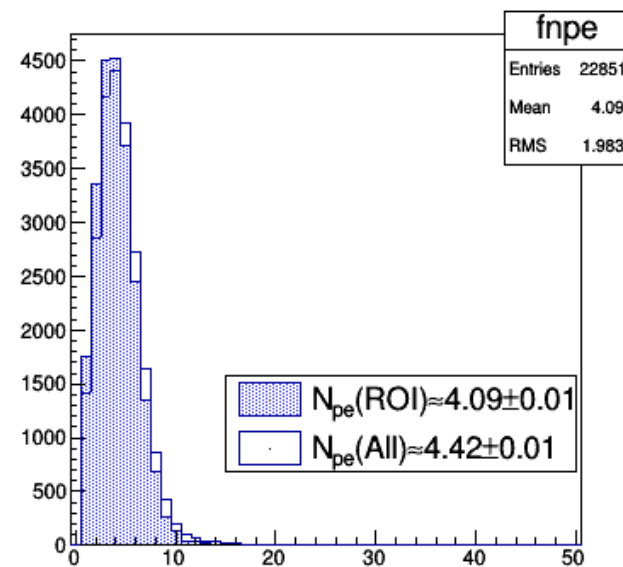
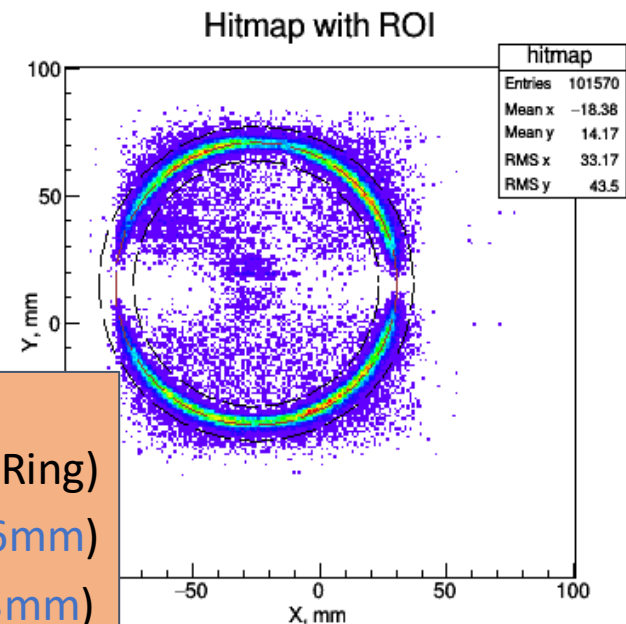
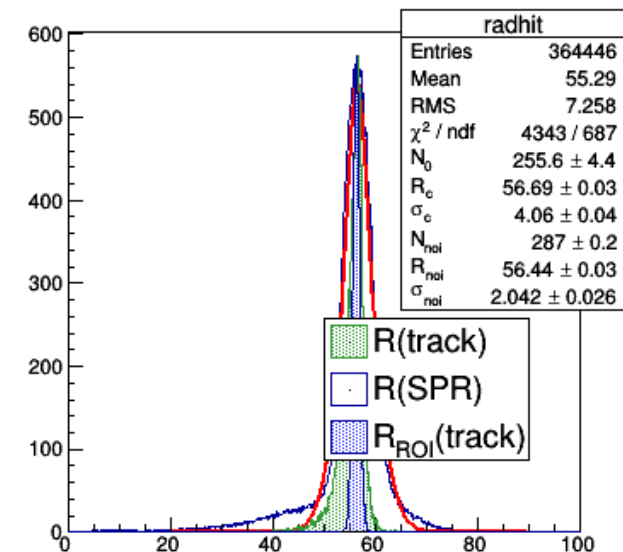
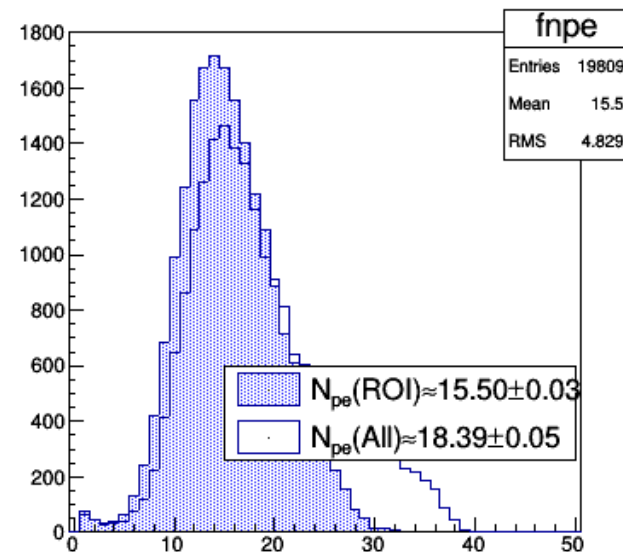
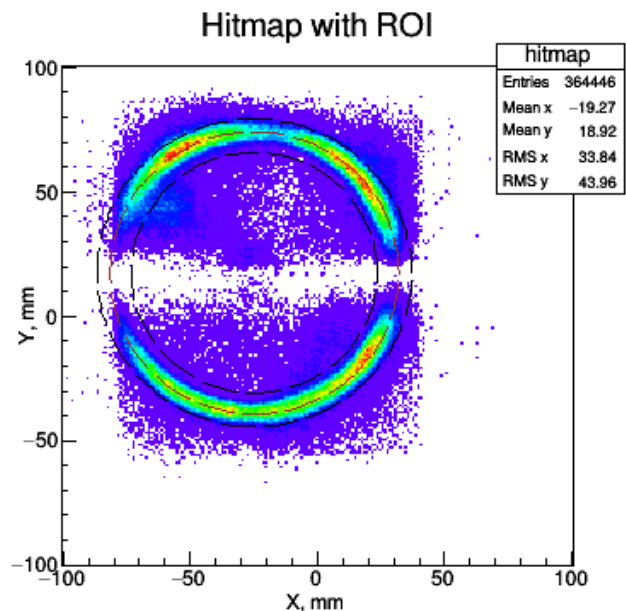
Pixel 6x6 mm  
Geom.Eff. ~ 80%

Made with help of  
shadow mask

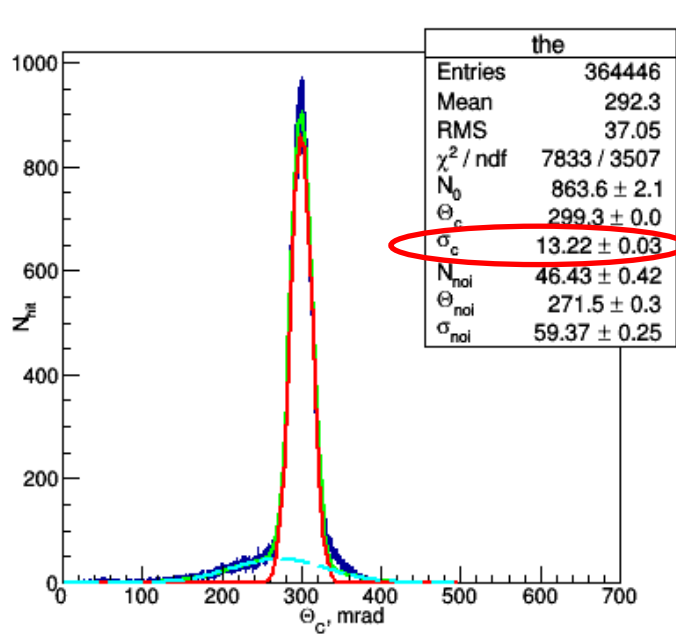
Pixel 3x3 mm  
Geom.Eff. ~ 20%

## Main results:

- $N_{pe} \approx 16$  (~ 0.8 of Ring)
- $\sigma_{\theta}^{1pe} \approx 13.5 \text{ mrad}$  (■ 6mm)
- $\sigma_{\theta}^{1pe} \approx 7.0 \text{ mrad}$  (■ 3mm)

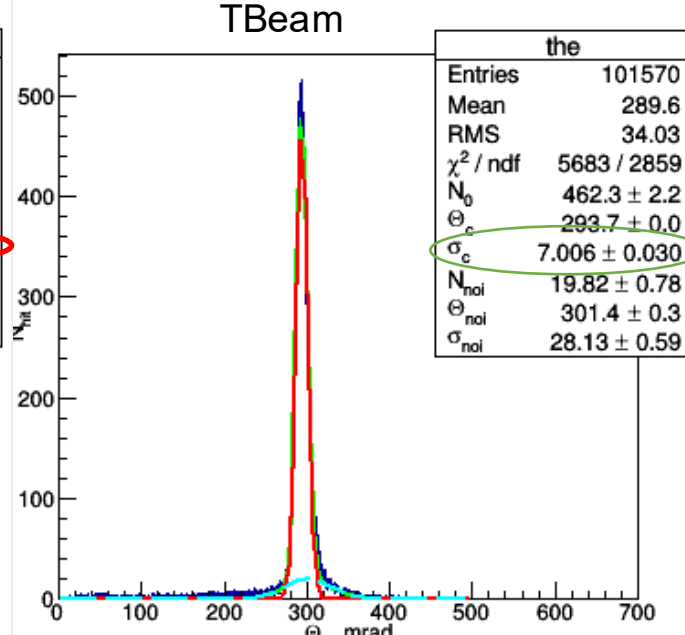


# Cherenkov angle Single Photo-Electron (*SPE*) resolution



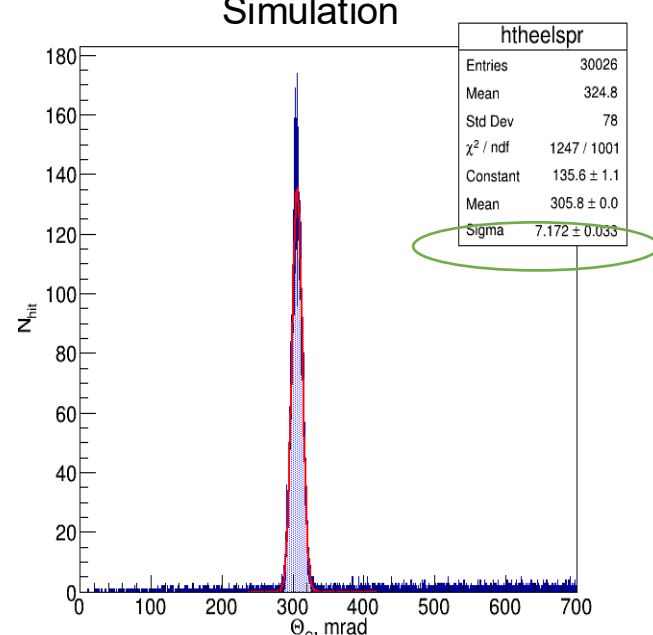
4-layers:  $1.039 \div 1.046$   
**6x6 mm**

Geom.Eff.  $\sim 80\%$   
 $N_{pe} \approx 16$



—  
**3x3 mm**

Geom.Eff.  $\sim 20\%$   
 $N_{pe} \approx 4$



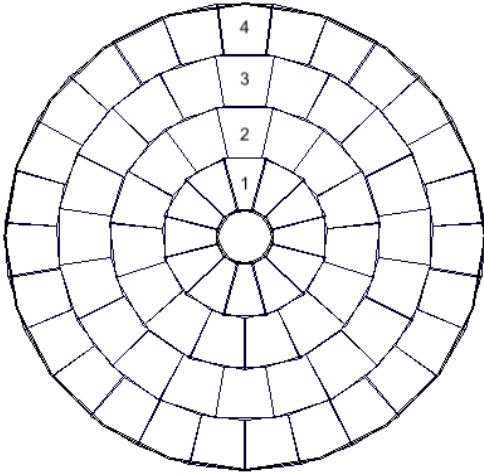
4-layers: (ideal profile)  
**3x3 mm**

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  $\mu/\pi$ -separation up to  $P=1.5 \text{ GeV}/c$

# FARICH system conceptual design (base option)

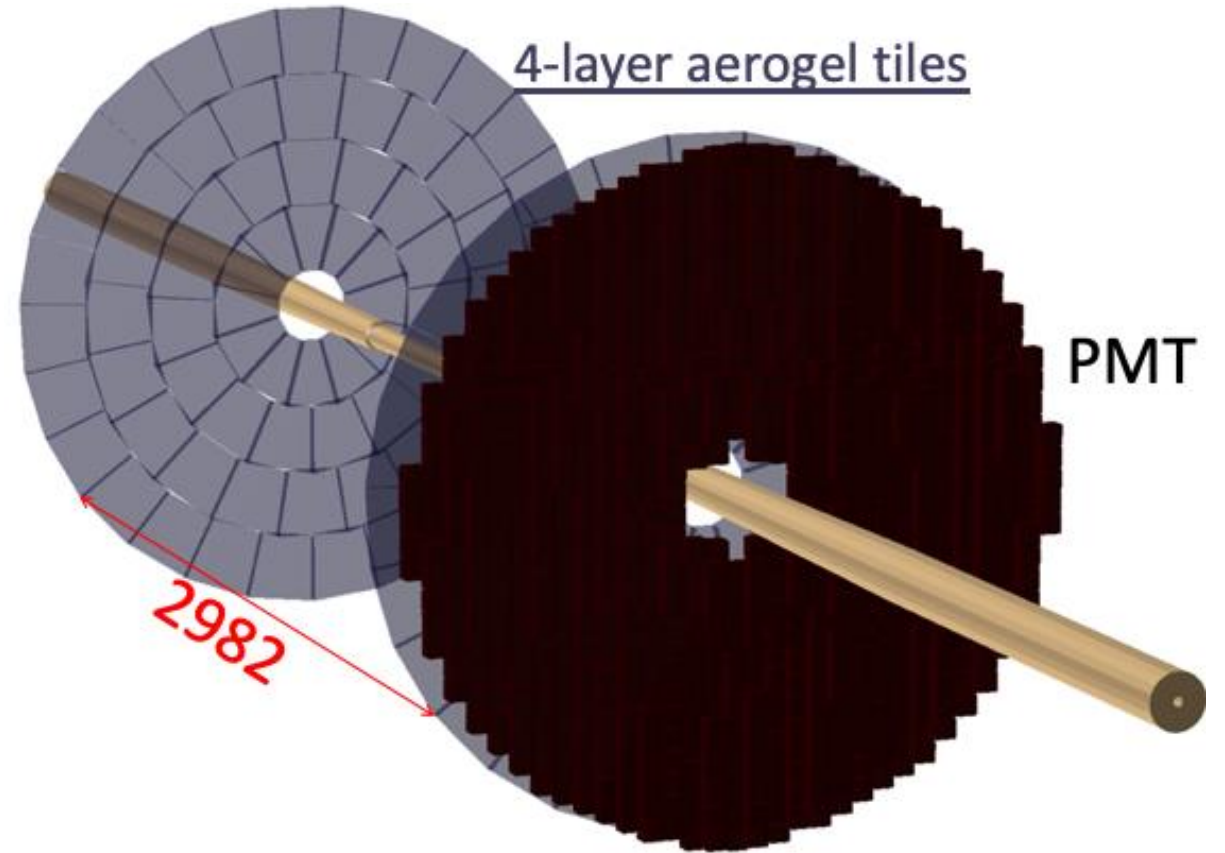
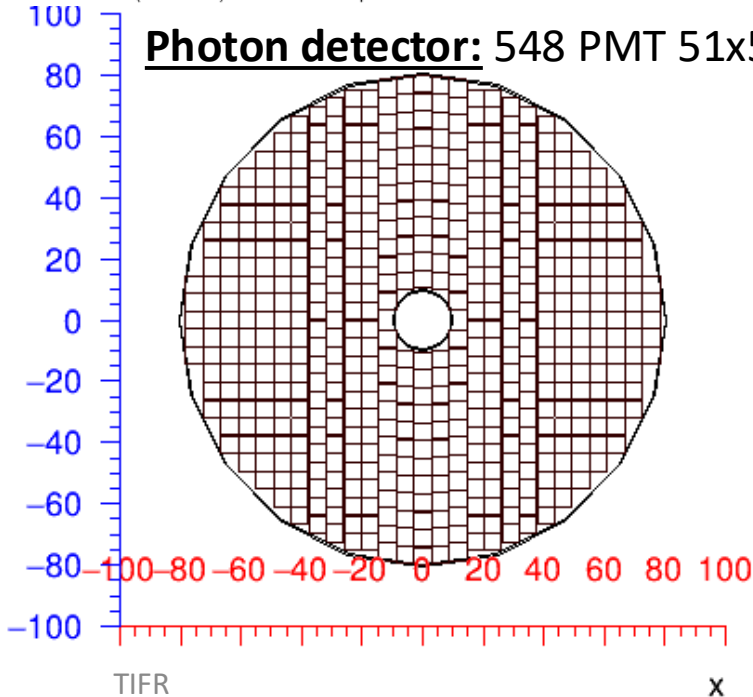
**Aerogel:**  
74 tiles



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

$$S(\text{aer})/S(\text{total})=21717.8/22383.8=0.97$$

**Photon detector:** 548 PMT 51x51 mm



## FARICH system:

- 4-layer aerogel with  $n_{\text{max}}=1.05$
- Focus distance – 20 cm
- PS PD – MCP-PMT or SiPM arrays with pixel  $3 \div 5$  mm
- 550 PMTs per endcap if lateral sizes  $\sim 51 \times 51$  mm
- 2200 PMTs per endcap if lateral sizes  $\sim 27 \times 27$  mm

# On possibilities for optimizations

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

$n$ ,  $t$ ,  $N_{layers}$ ,  $L$ ,  $PDE$  and  $\Delta_{pix}$  are parameters for optimization

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

# Multi-layer focusing aerogel radiator optimisation

$n_{\max}=1.05 \rightarrow$

$t_{\text{tot}}=35 \text{ mm} \rightarrow$

$\Delta_{\text{pix}}=3 \text{ mm} \rightarrow$

$N_{\text{layer}}=4 \rightarrow$

$n_{\max}=1.04$  – to increase Cherenkov angle difference at the high momentum range;

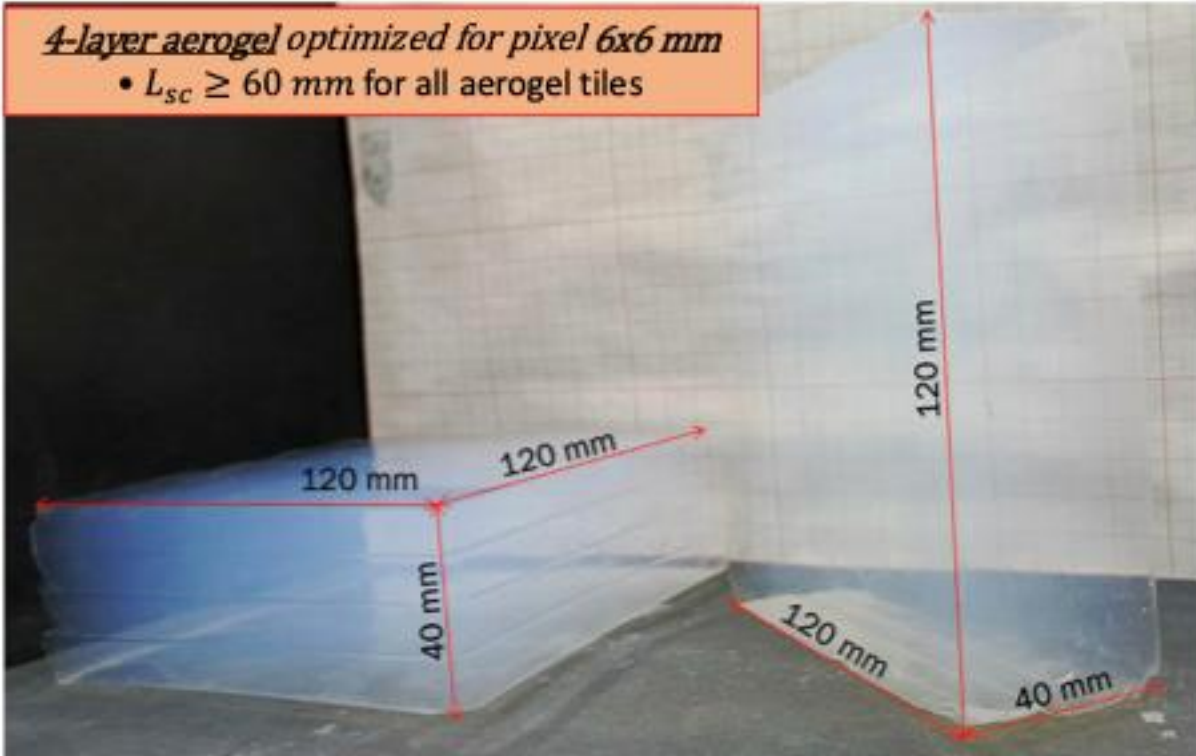
$t_{\text{tot}}=40 \text{ mm}$  – to compensate the  $N_{\text{pe}}$  decrease connected with decrease of refractive index

$\Delta_{\text{pix}}=6 \text{ mm}$  – to decrease the number of electronics readout channels;

$N_{\text{layer}}=3$  – to improve stability and reliability of production technology

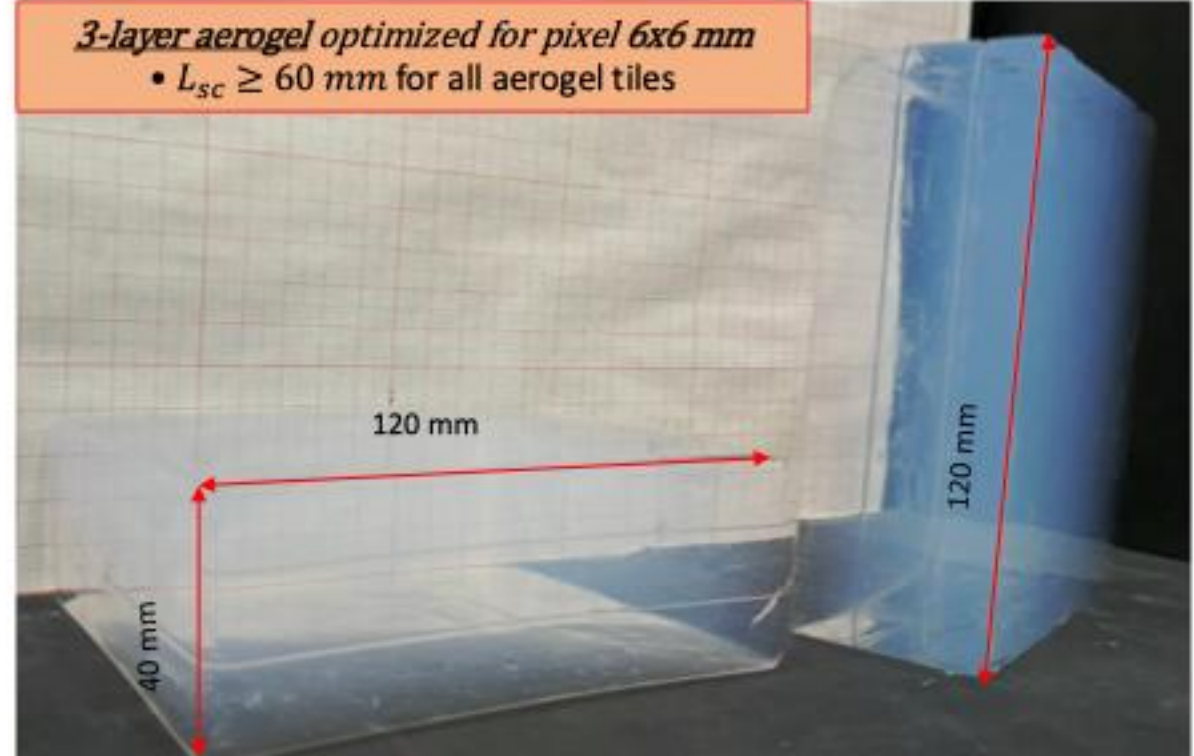
*4-layer aerogel optimized for pixel 6x6 mm*

- $L_{\text{SC}} \geq 60 \text{ mm}$  for all aerogel tiles



*3-layer aerogel optimized for pixel 6x6 mm*

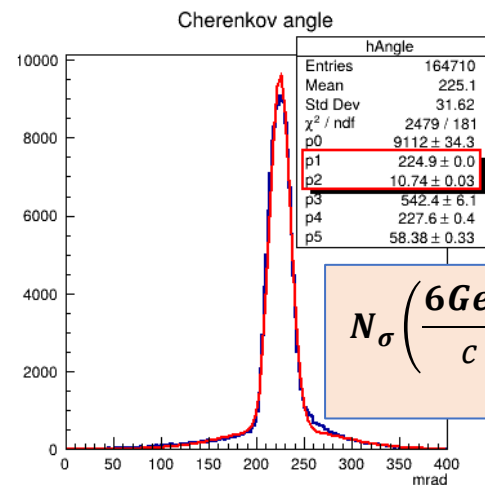
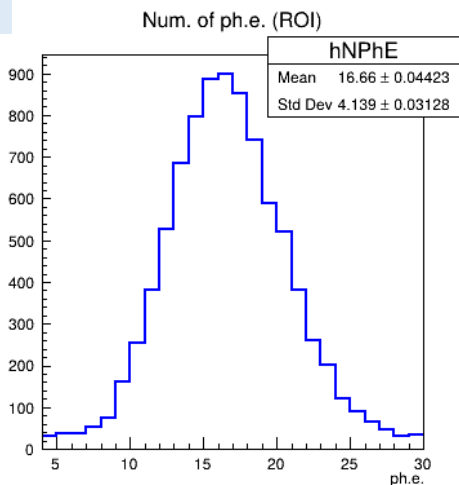
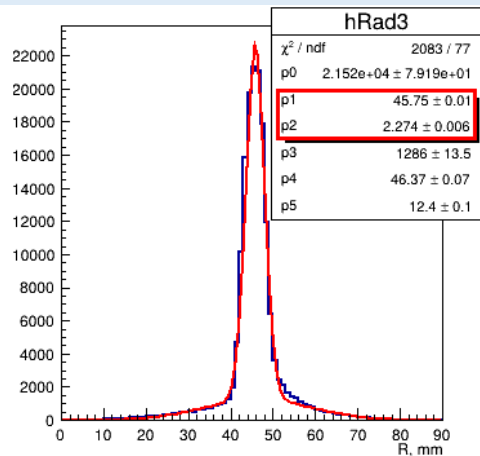
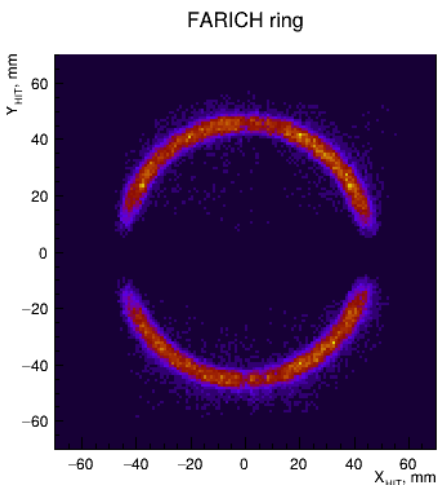
- $L_{\text{SC}} \geq 60 \text{ mm}$  for all aerogel tiles



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

# Beam tests at BINP results: June 2025

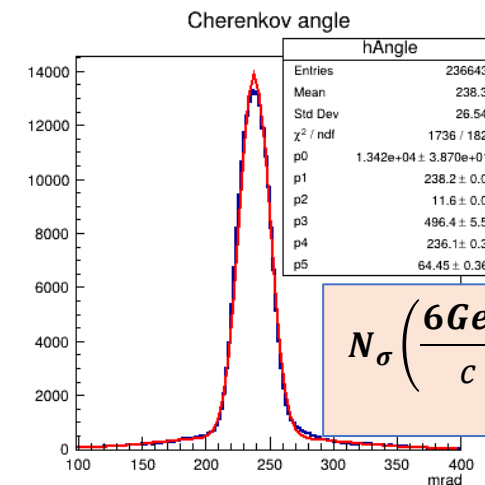
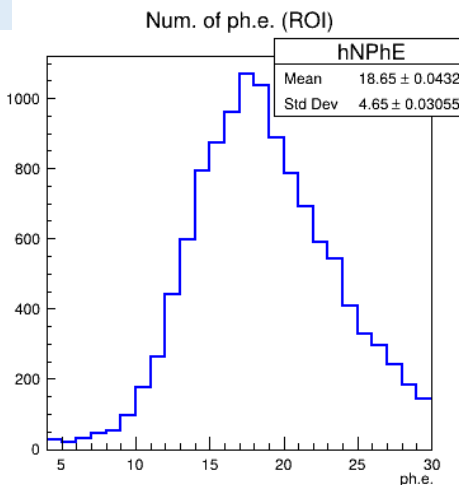
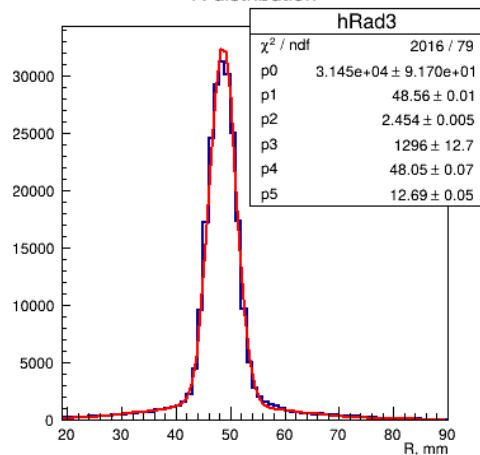
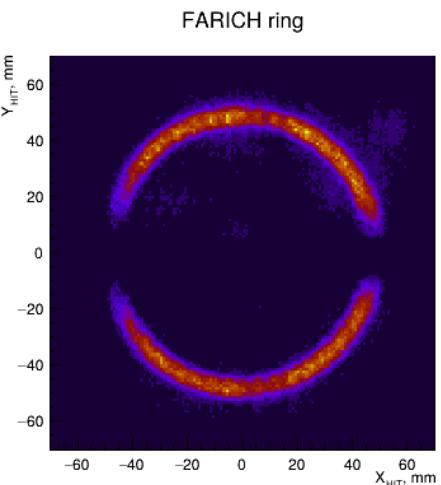
4-layer,  $n_{\max}=1.04$ ,  $t=40$  mm



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

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

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



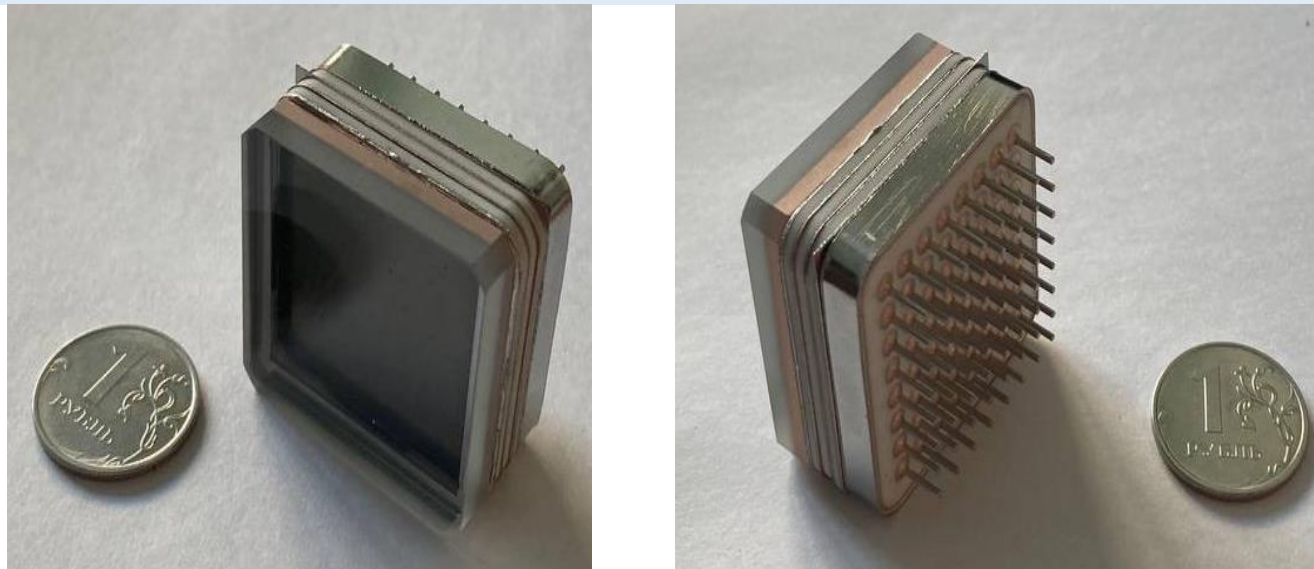
$$\sigma_{1pe} \approx 11.6 \text{ mrad}$$

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

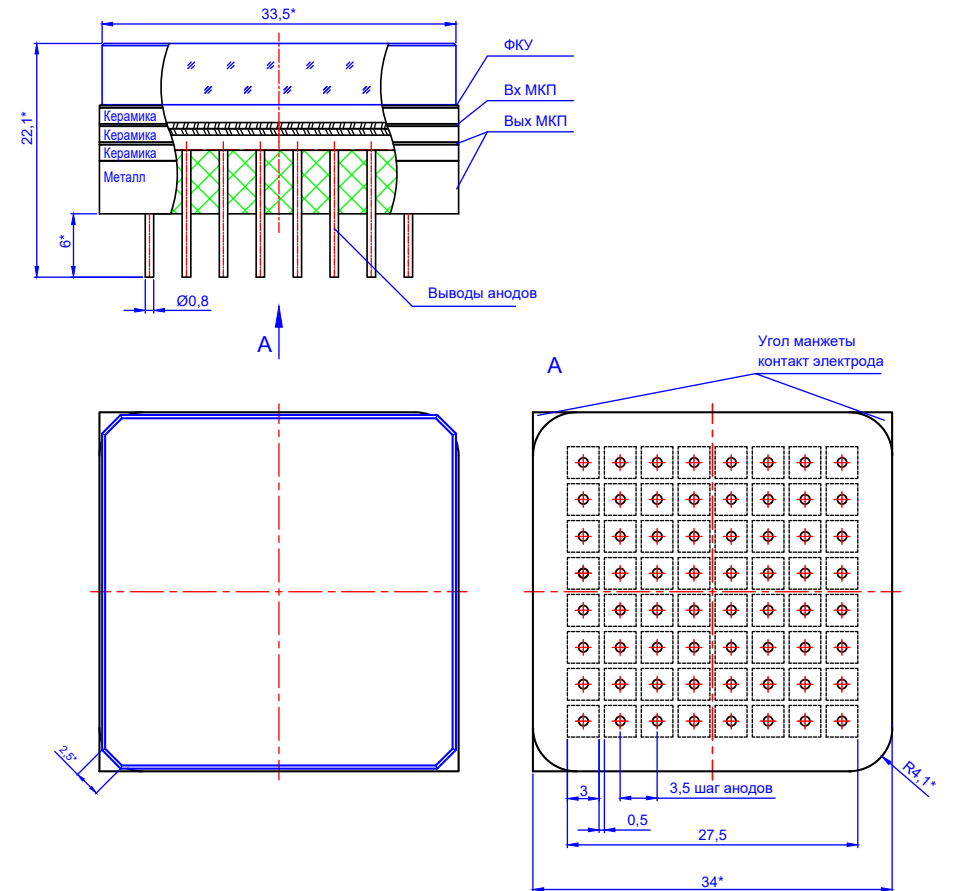
# Status of square MCP PMT development in Russia

## Square MCP PMT from “Ekran FEP”:

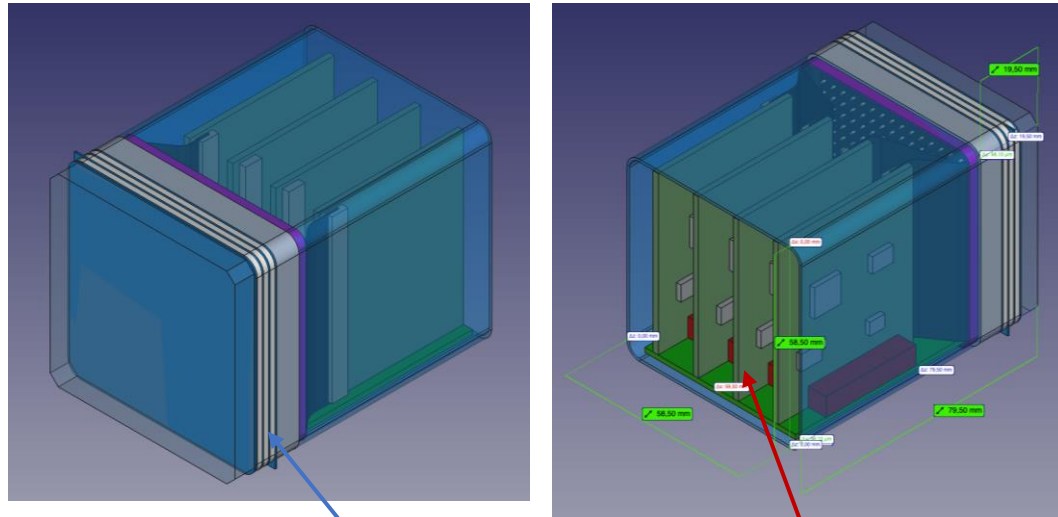
- Construction and design is developed
- All details and components are produced in Russia
- All technological processes are developed and realized
- First samples for test will be available soon in 2025



The first prototype fully assembled and vacume sealed prototype

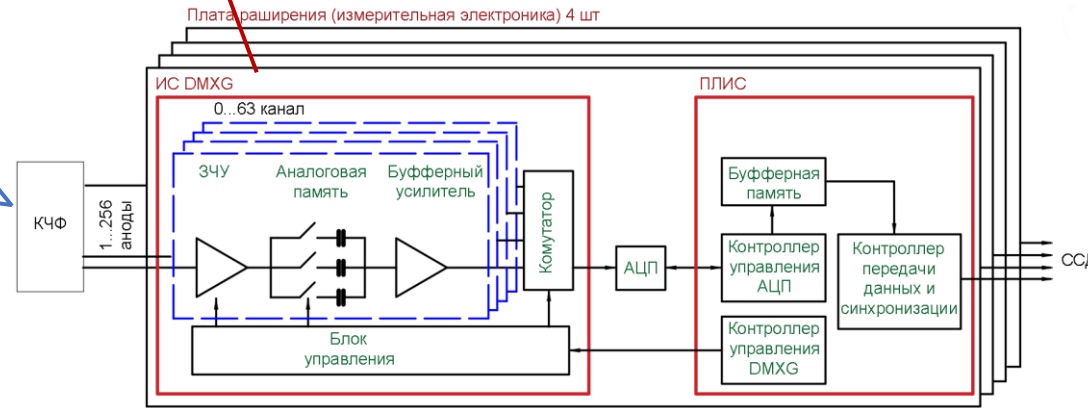
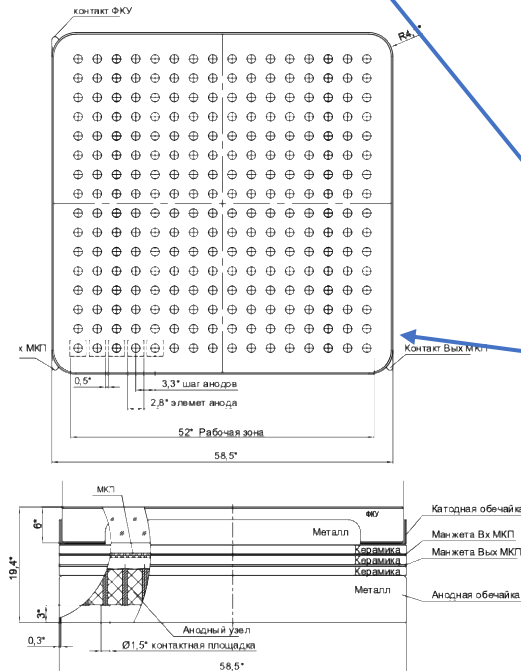


# 3D-design of the square MCP PMT + FEE module



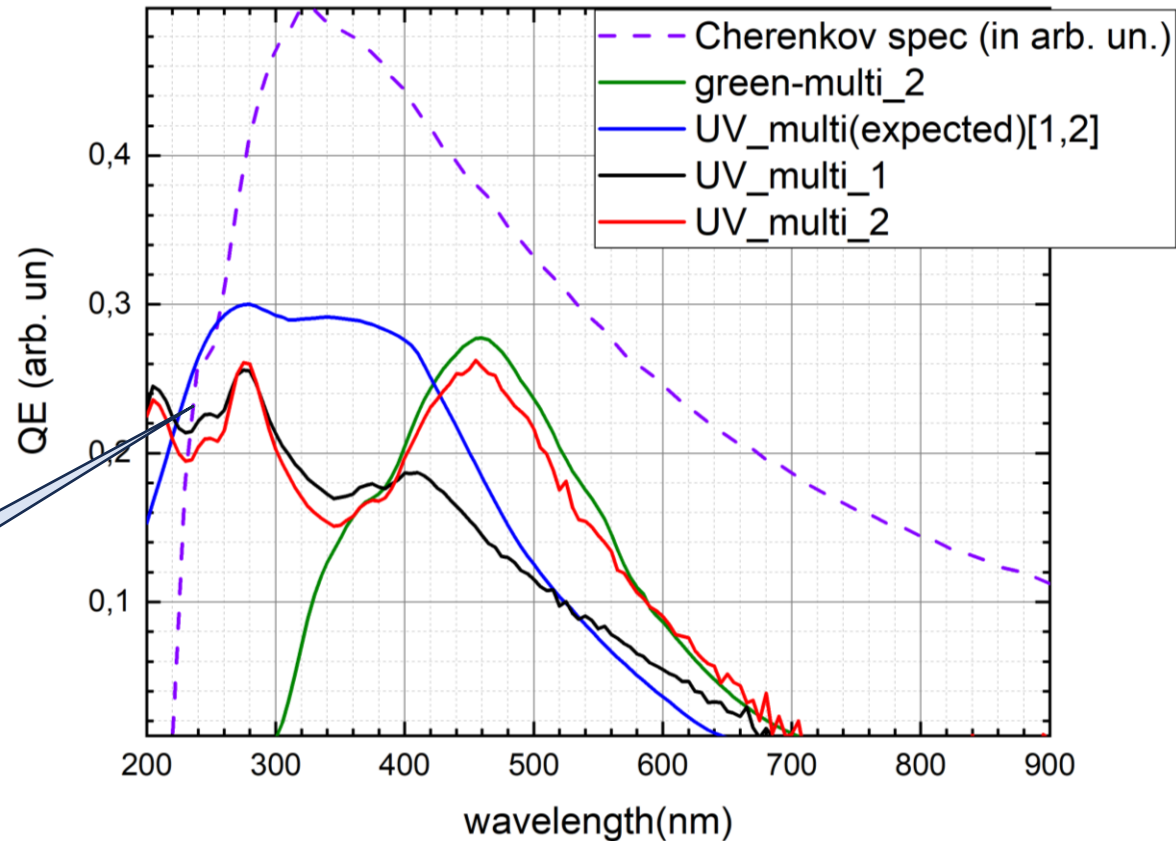
## Design and development of PS MCP PMT and corresponding FEE have been started in 2025:

- 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 reinforced (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 planned to use Quartz to enhance PDE in UV region

The advantages of use **“UV multi” PC (Quartz)** are expected as following:

– **factor of 1.5** more detected Cherenkov photons in comparison with standard “green-multi2” PC

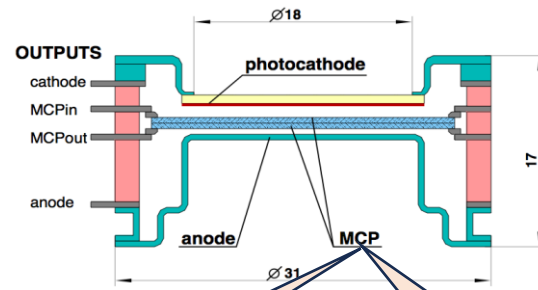
### “UV multi” OE based on data from papers:

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

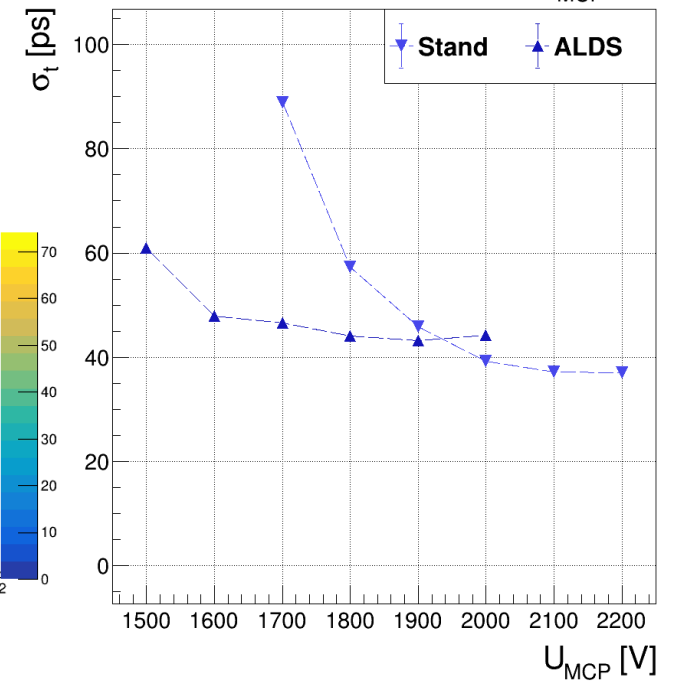
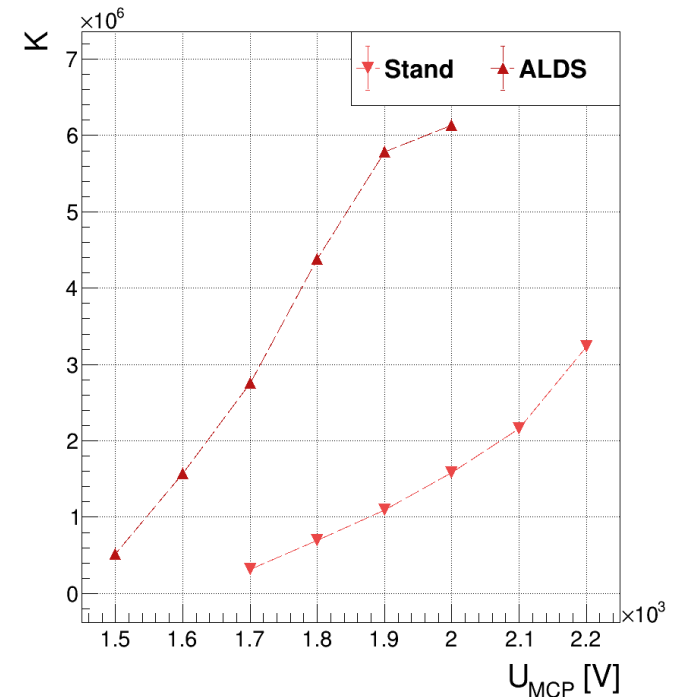
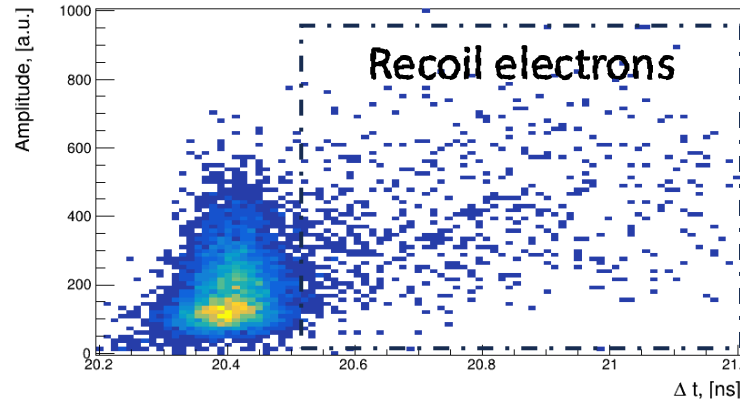
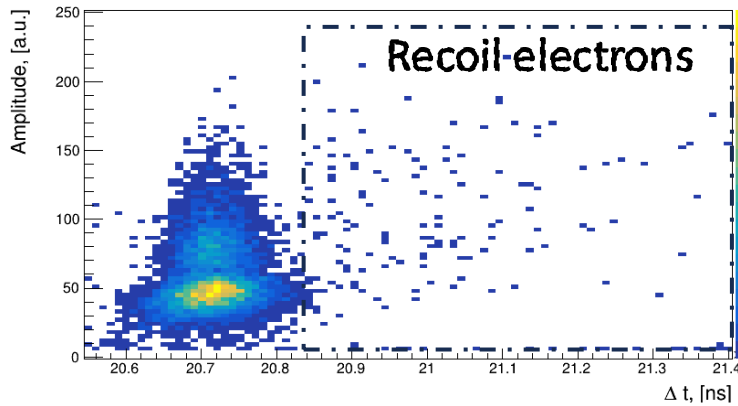
The first ALD tests were performed with standard round-shape MCP PMTs produced by "Ekran FEP" Ltd.



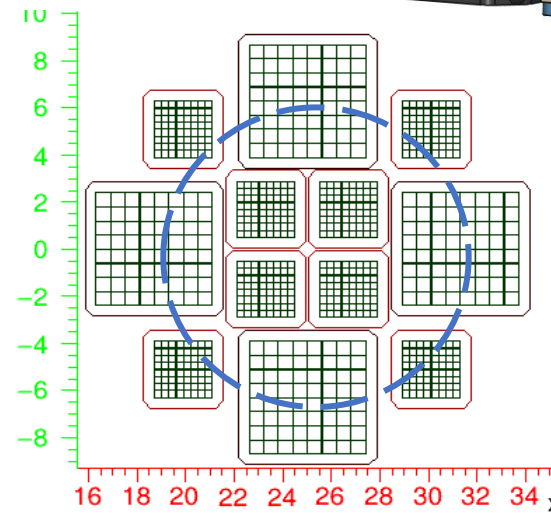
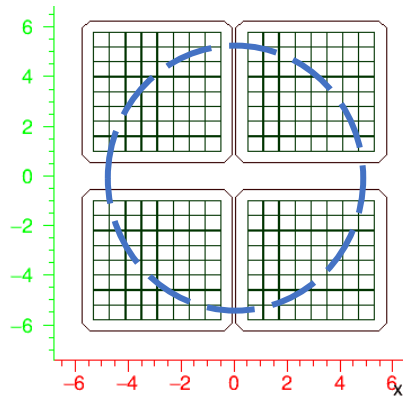
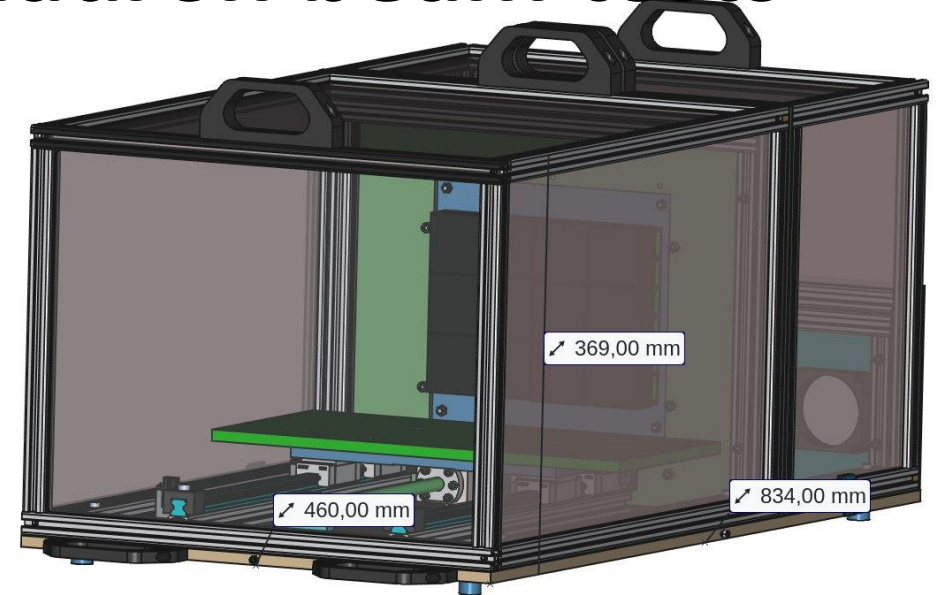
Standard MCPs (Stand.)

OR

Enhanced SE MCPs (ALDS)



# FARICH prototype for hadron beam tests



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

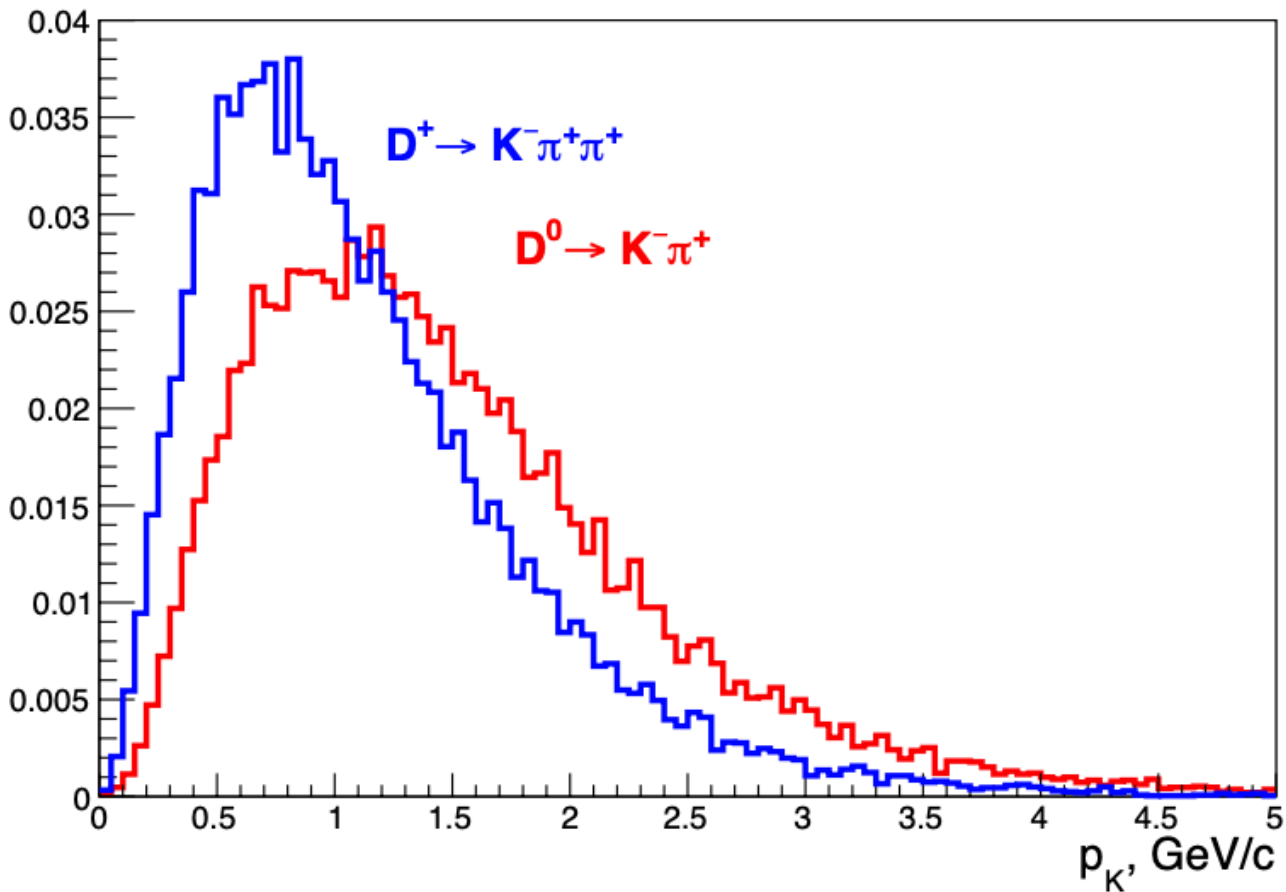
FARICH prototype based on 12 PMTs H12700 + MCP PMTs is expected in Feb. 2026!

# Summary

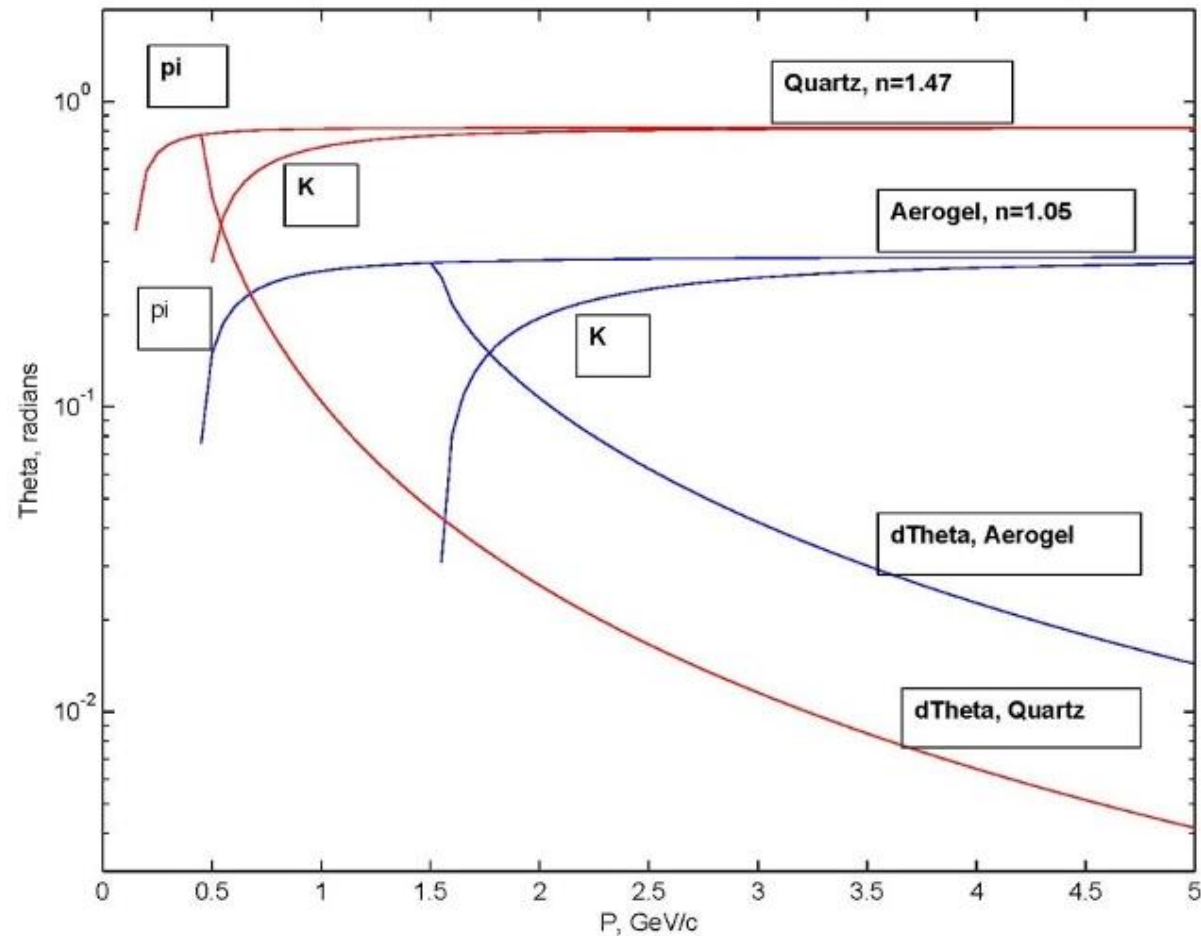
- The FARICH technique is proposed as an base option for PID system of the SPD experiment at the NICA collider
- Several ways for optimization of the focusing multilayer aerogel Cherenkov radiators were proposed and realised in 2025
- Production of the first square position-sensitive MCP based photomultipliers has been started in Novosibirsk
- Optimisation of the multi-alkali PCs to increase their sensitivity to Cherenkov spectra from aerogel by factor of  $1.5 \div 2$  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  
 $\pi/K$ -separation up to  $P=5 \div 6 \text{ GeV}/c$



For reliable  $\pi/K$ -separation at  $P=6 \text{ GeV}/c$  the RICH detector is required:

- $n = 1.05$  (aerogel),
- $\sigma_c \sim 2.5 \text{ mrad}/\text{track}$

# MCP's parameters processing issues

$\langle N_{\text{ph.e.}} \rangle = 0.945022 \pm 0.007957$

