

Методика ФАРИЧ: статус разработок и перспективы

А.Ю. Барняков

от имени ``Аэрогелевой группы ИЯФ СО РАН``

- Аэрогель
- ФАРИЧ для СЦТФ
- ФАРИЧ для эксперимента SPD@NICA
- ФАРИЧ для π/K разделения выше 20 ГэВ/с



Физика частиц при средних и высоких энергиях
НИЦ Курчатовский институт – ИФВЭ (г. Протвино)
2-5.06.2026г.



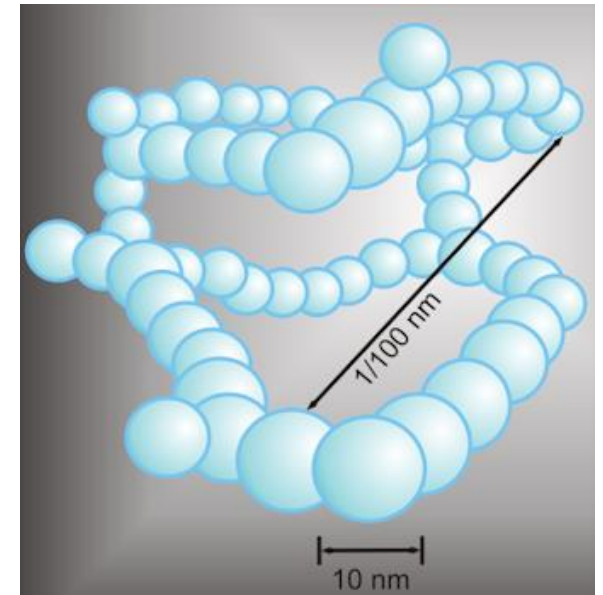
Aerogel is a classical nanomaterial



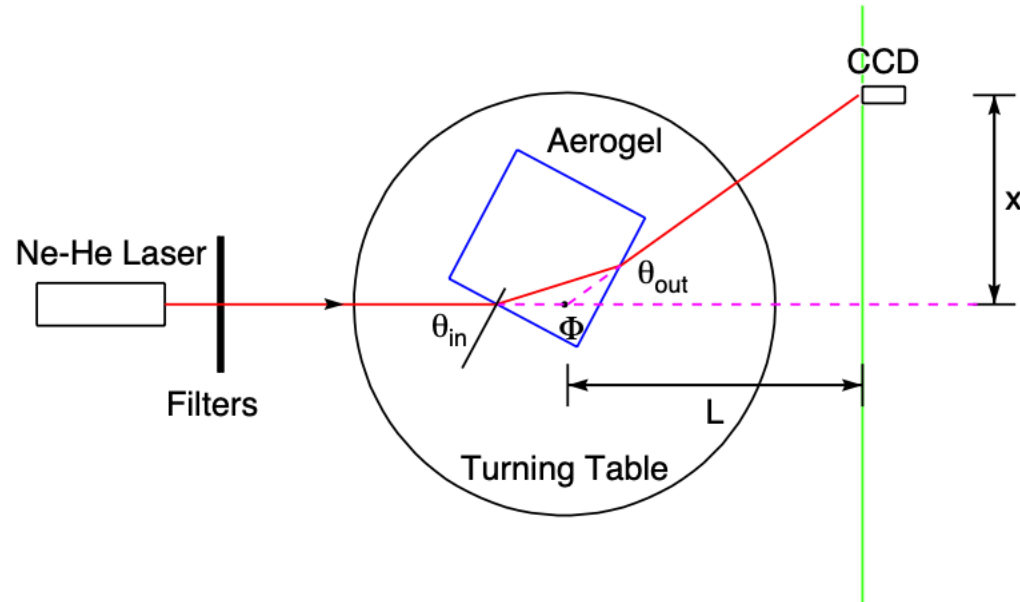
- Aerogel was first synthesized by Samuel Stephens Kistler in 1931
- S.S.Kistler, "*Coherent Expanded Aerogels and Jellies*", Nature, 1931, vol. 127, p. 741

Aerogel – is a porous material with pore dimension less than visible light wavelength.

It is a classical **nanomaterial**. The most interesting for physics experiments are silicon dioxide based aerogels, although aerogels based on metal oxides, carbon, gelatin and other substances are widely used in various other applications.



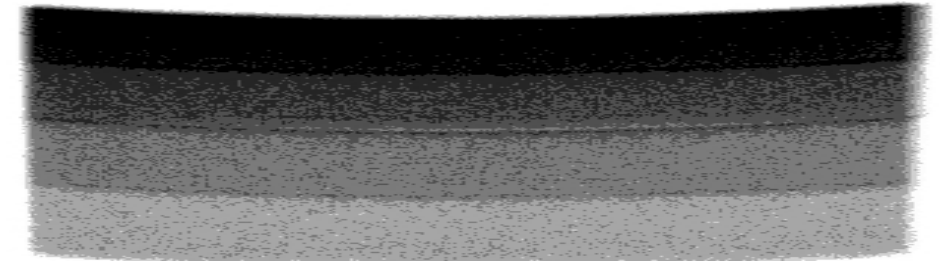
Main aerogel params for FARICH: Refractive index



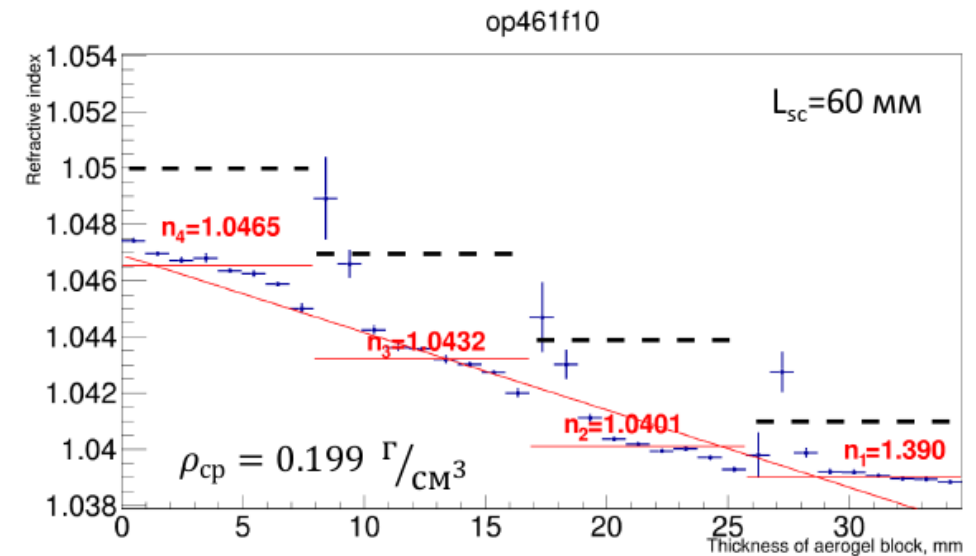
Empirical relation is used for fast determination of n :

$$n^2 = 1 + 0.438 \cdot \rho \left[\frac{g}{cm^3} \right]$$

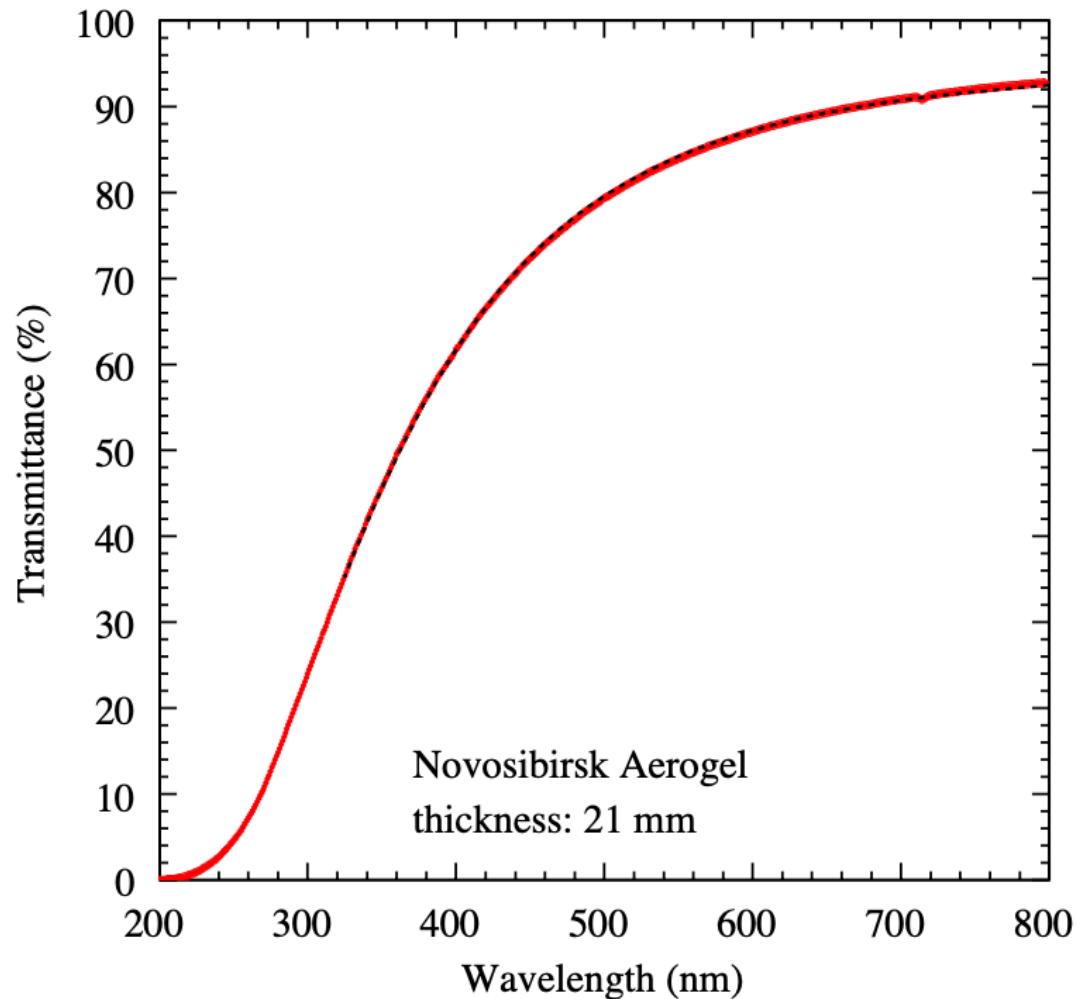
Empirical equation is in good agreement with theoretical dependence Lorentz-Lorentz formula evaluated for gas mixtures.



- Refractive index profile is measured with help of digital X-ray setup at the BINP.
- Normalized on averaged refractive index calculated through bulk density



Main aerogel params for FARICH: transparency and Rayleigh light scattering



- Hunt formula to fit the transmittance (T) usually are used in two variations:

- $$T(\lambda) = \frac{I}{I_0} = A_0 e^{-\left(\frac{d}{L_{sc}^{400} \times \left[\frac{\lambda}{400}\right]^4}\right)}$$

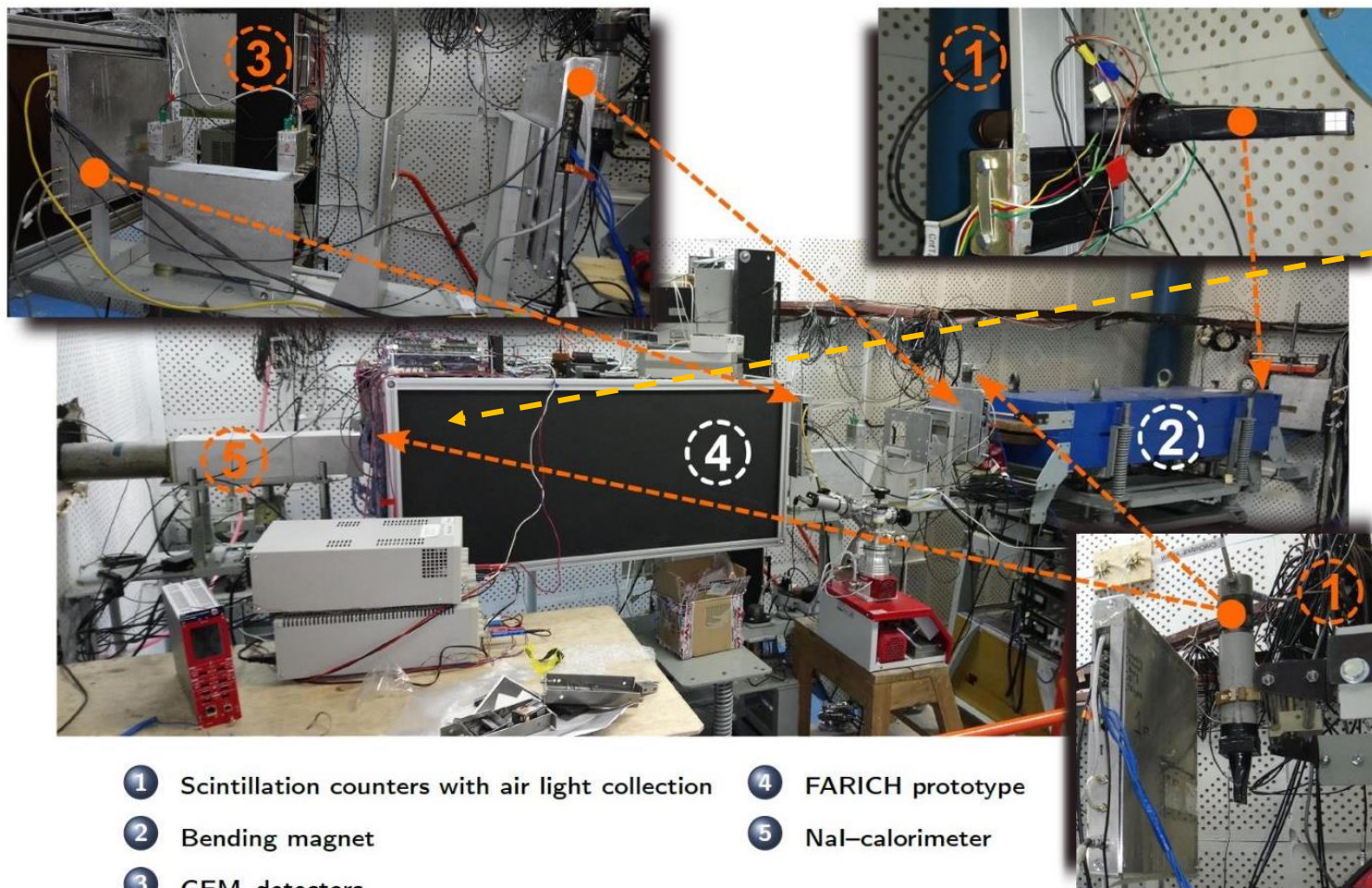
- or

- $$T(\lambda) = \frac{I}{I_0} = A_0 e^{-(C \cdot d / \lambda^4)}$$

- where d – aerogel thickness, L_{sc}^{400} – light scattering length at 400 nm and C – so called clarity, A_0 – coefficient responsible for light absorption and scattering at the surface of aerogel samples.

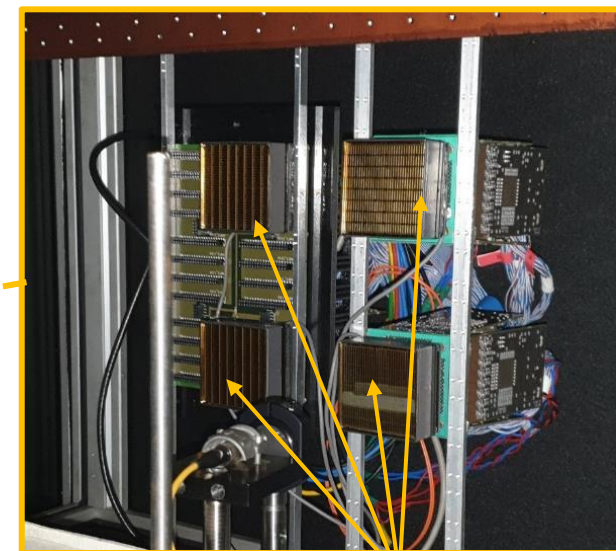
BINP beam test facility

Example disposition of equipment in experimental hall (15/03/2018)

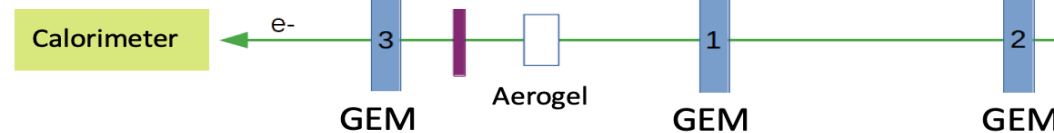


- | | |
|--|--------------------|
| ① Scintillation counters with air light collection | ④ FARICH prototype |
| ② Bending magnet | ⑤ NaI-calorimeter |
| ③ GEM-detectors | |

G N Abramov et al 2014 JINST 9 C08022

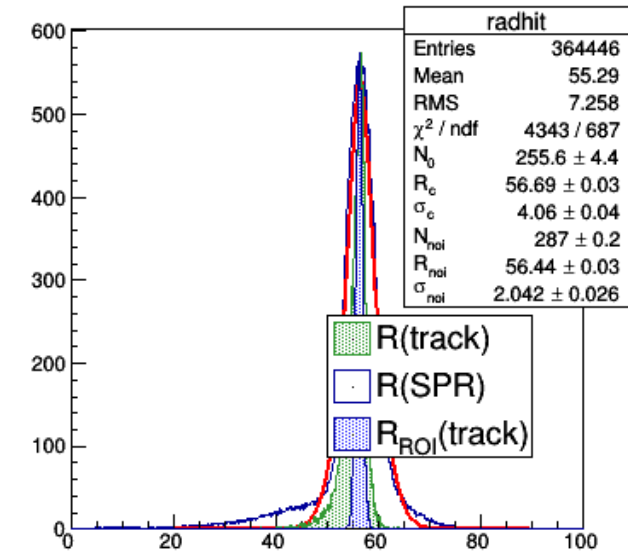
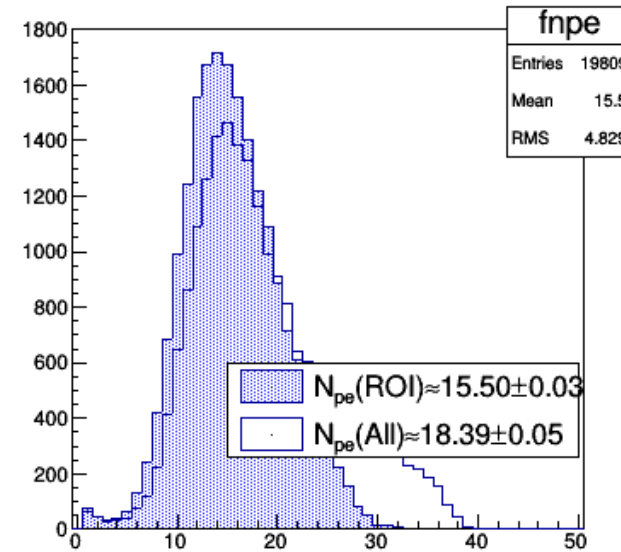
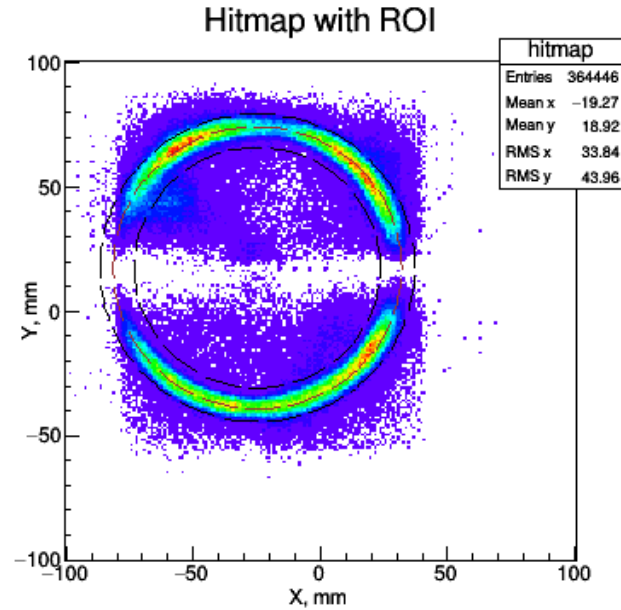


4 MaPMT H12700

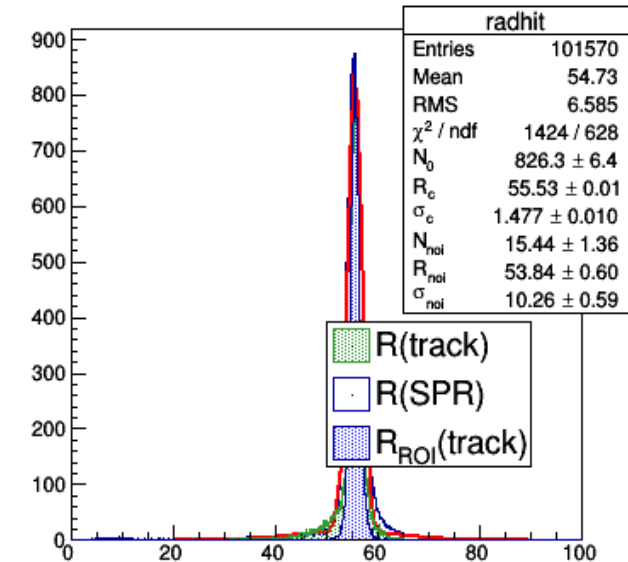
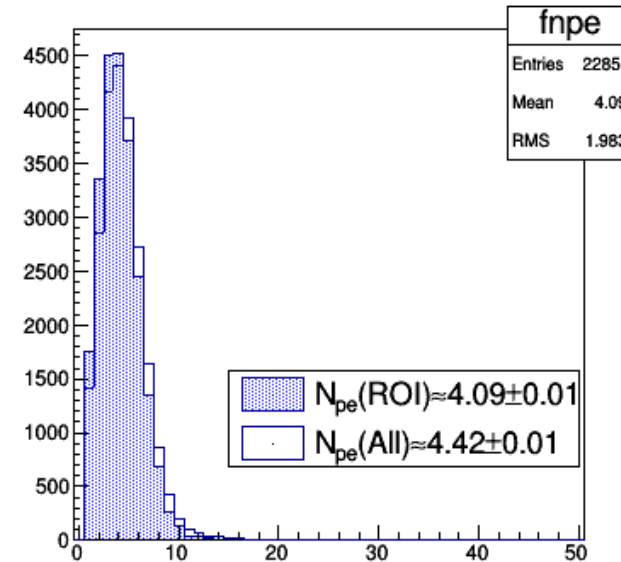
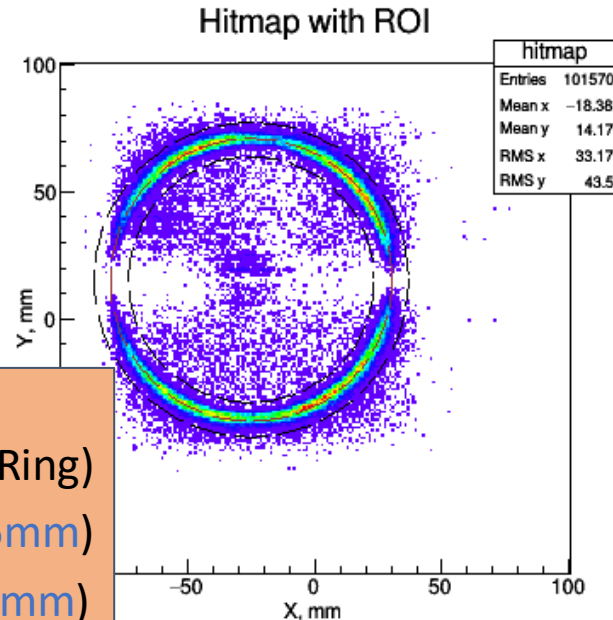


Beam test results with 4-layer aerogel $n_{\max}=1.046$

Pixel 6x6 mm
Geom.Eff. $\sim 80\%$



Pixel 3x3 mm
Geom.Eff. $\sim 20\%$

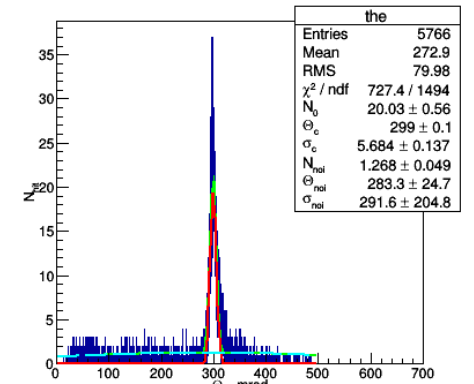
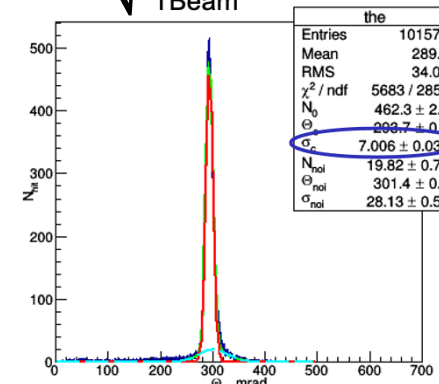
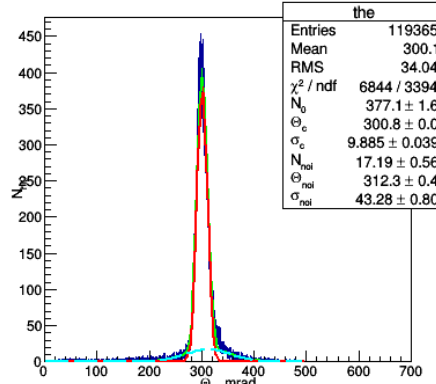
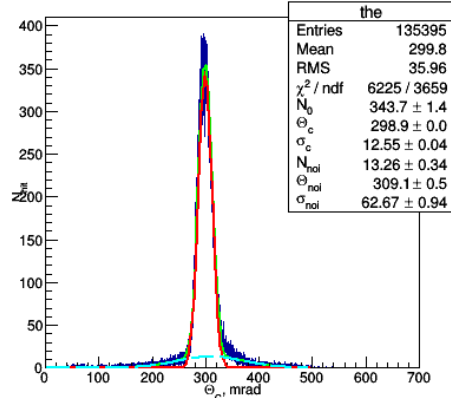
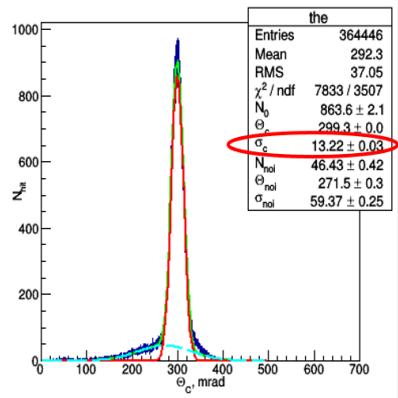


Main results:

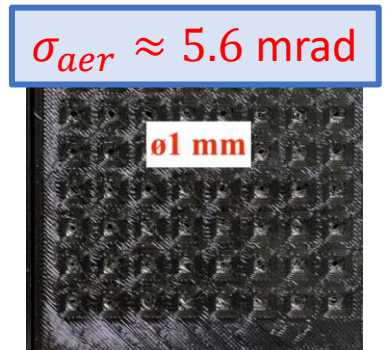
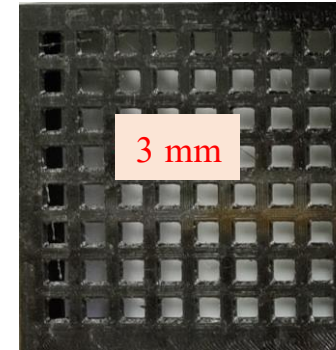
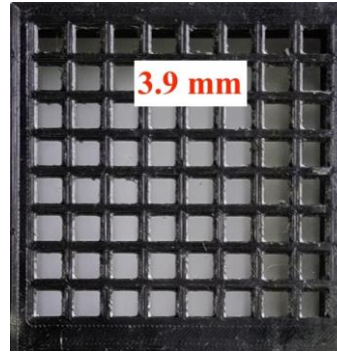
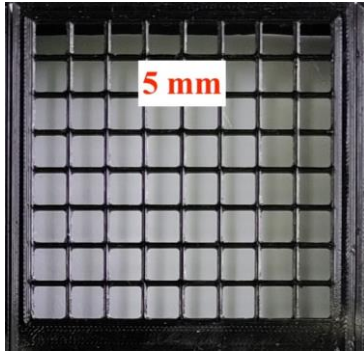
- $N_{pe} \approx 16$ (~ 0.8 of Ring)
- $\sigma_{\theta}^{1pe} \approx 13.5 \text{ mrad}$ (■ 6mm)
- $\sigma_{\theta}^{1pe} \approx 7.0 \text{ mrad}$ (■ 3mm)

Approach with masks: $\sigma_{\theta_c}^{1pe}$

$$= \sqrt{\frac{\Delta_{pix}^2}{(\sqrt{12} \cdot L \cdot n)^2} + \sigma_{aer}^2 + \sigma_{trk}^2}$$



No mask:
 $6 \times 6 \text{ mm}$



$\sigma_{aer} \approx 5.6 \text{ mrad}$

04/23: $L \approx 200 \text{ mm}$
Geom.Eff. $\sim 80\%$
 $N_{pe} \approx 16$

12/23: $L \approx 180 \text{ mm}$
Geom.Eff. $\sim 56\%$
 $N_{pe} \approx 12$

12/23: $L \approx 180 \text{ mm}$
Geom.Eff. $\sim 36\%$
 $N_{pe} \approx 8$

04/23: $L \approx 200 \text{ mm}$
Geom.Eff. $\sim 20\%$
 $N_{pe} \approx 4$

12/23: $L \approx 180 \text{ mm}$
Geom.Eff. $\sim 2\%$
 $N_{pe} \approx 1$

π/K : -5.5 GeV/c
 μ/π : -1.2 GeV/c

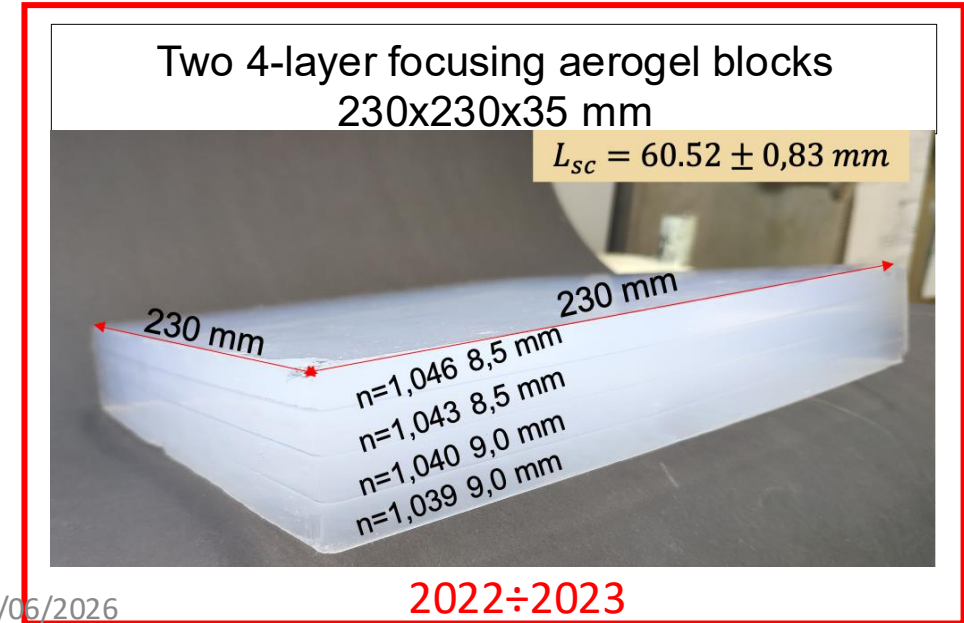
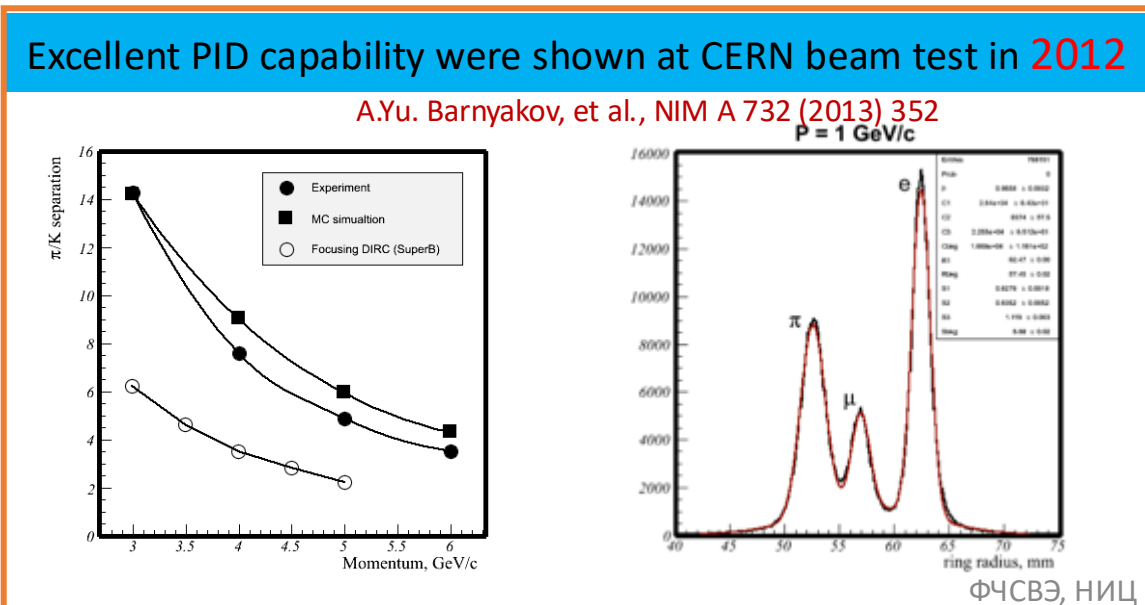
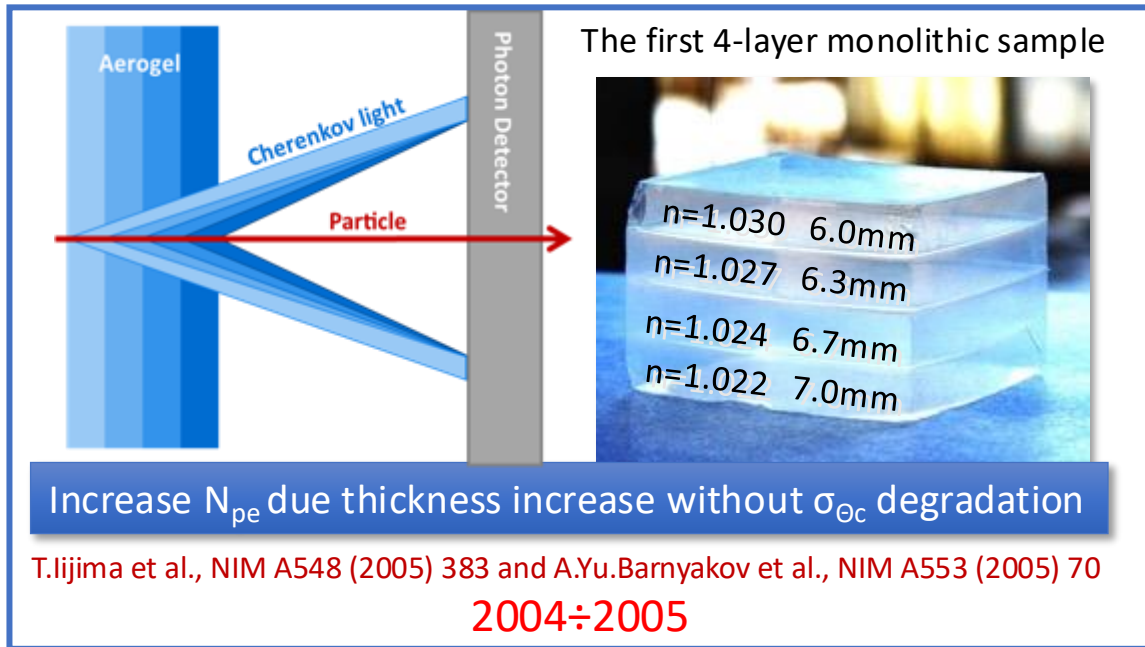
6 GeV/c
 1.4 GeV/c

6.5 GeV/c
 1.5 GeV/c

8.0 GeV/c
 1.6 GeV/c

8.5 GeV/c
 1.7 GeV/c

FARICH technique milestones



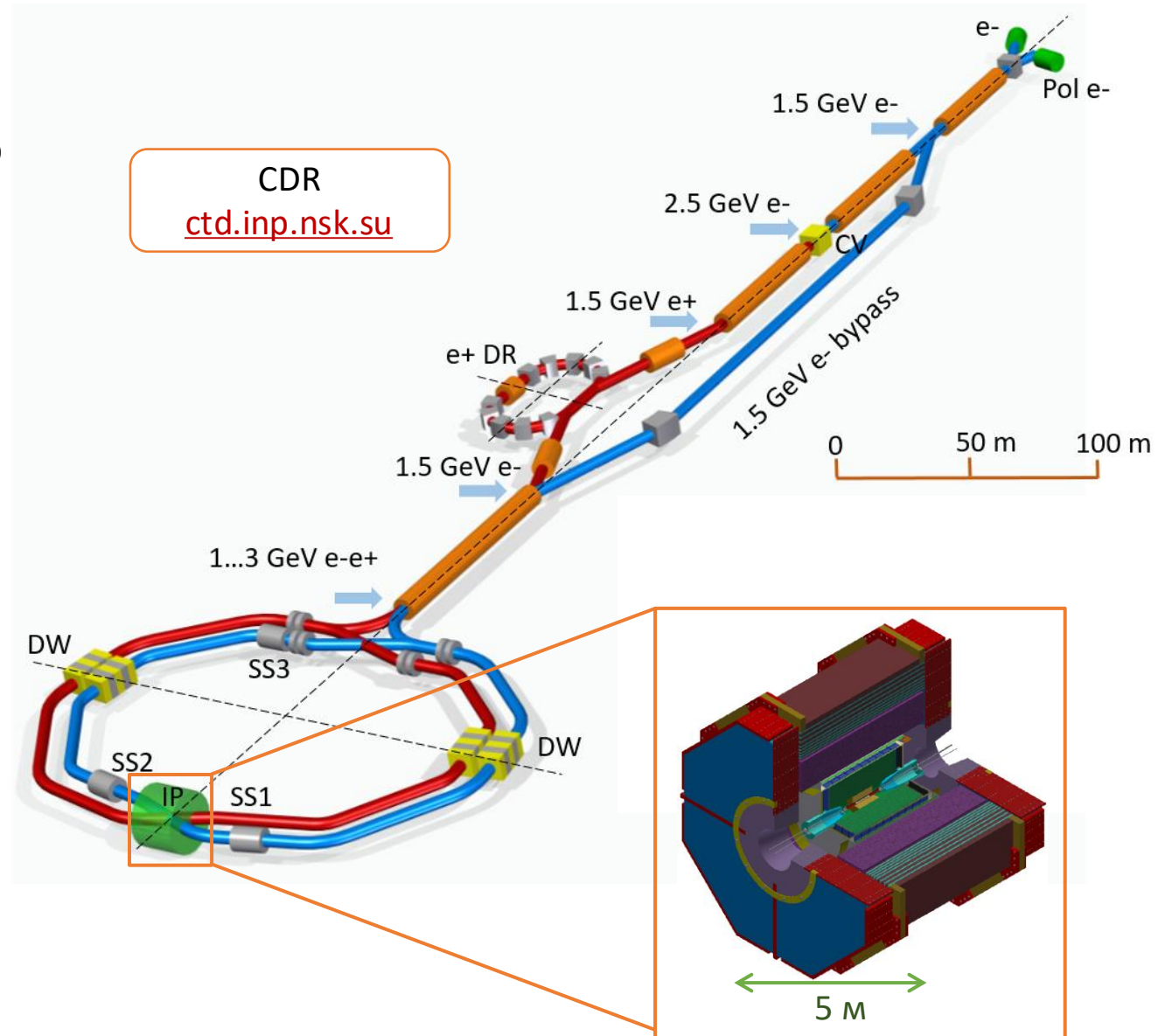
The SCT experiment

- Super charm-tau factory is e^+e^- collider, dedicated to precision study of properties of charm-quark, τ -lepton, study of strong interactions, search of BSM physics

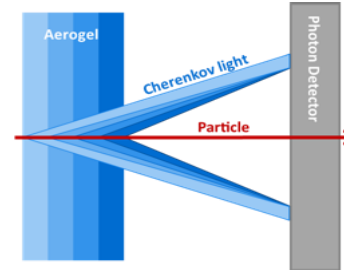
- Beam energy from 1.5 (1.0) to 3.5 GeV
- Luminosity $\mathcal{L} = 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ @ 2 GeV
- Longitudinal polarization of the e^- beams

- Experiments will be conducted using state-of-the-art general purpose detector

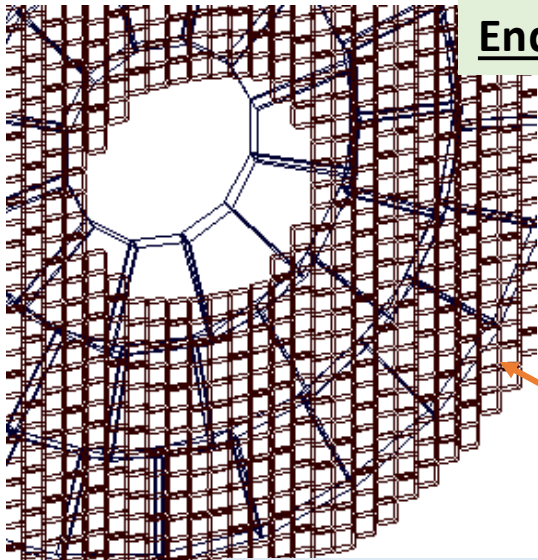
- Tracking (including low p_t)
- Calorimetry (high resolution, fast, π^0/γ sep.)
- **PID system:**
 - π/K – separation up to 3.5 GeV/c
 - μ/π – separation up to 1.5 GeV/c



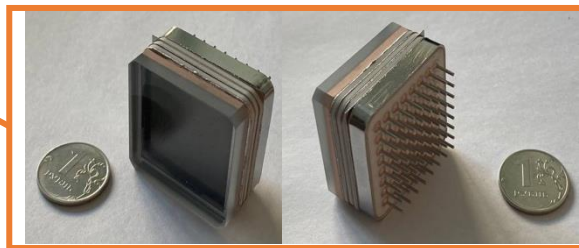
FARICH system for the SCTF project



Endcap part Sketchs & key elements

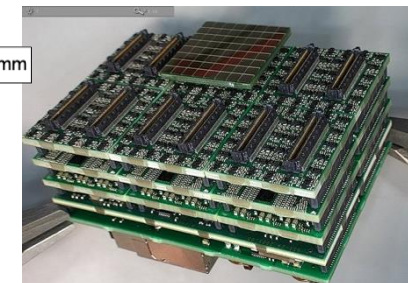
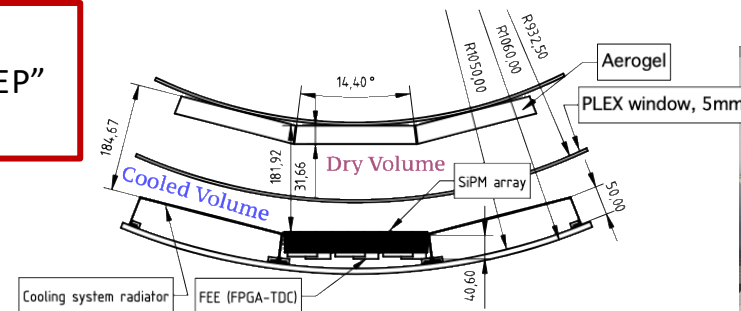


- 2x55 trapezoidal aerogel tiles in end caps:
- 2x1000 MCP PMTs 34x34mm² from "Ekran FEP"
- MCP PMTs can operate without cooling



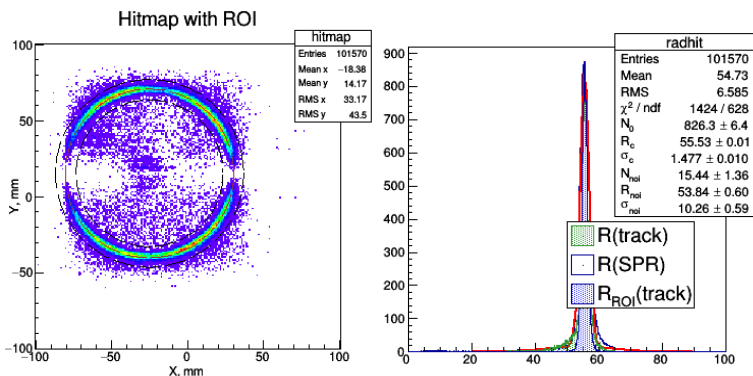
The first square MCP PMT produced in Russia

All details and components are produced in Russia



Measured angle resolution

- 33×33 mm² total area
- 27×27 mm² sensitive area
- 8×8 pixels with 3×3 mm size



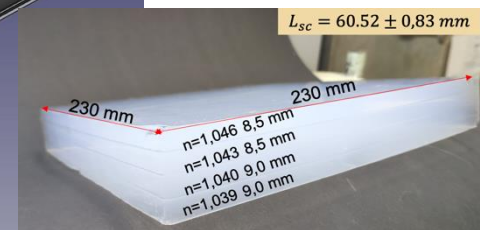
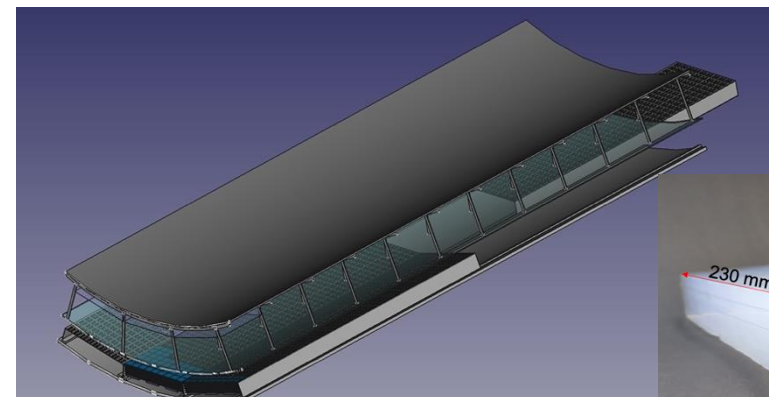
Single PE resolution 7.5 mrad was measured

It corresponds to:

- Excellent π/K -separation in whole operation momentum range
- Reliable μ/π -separation up to 1.5 GeV/c

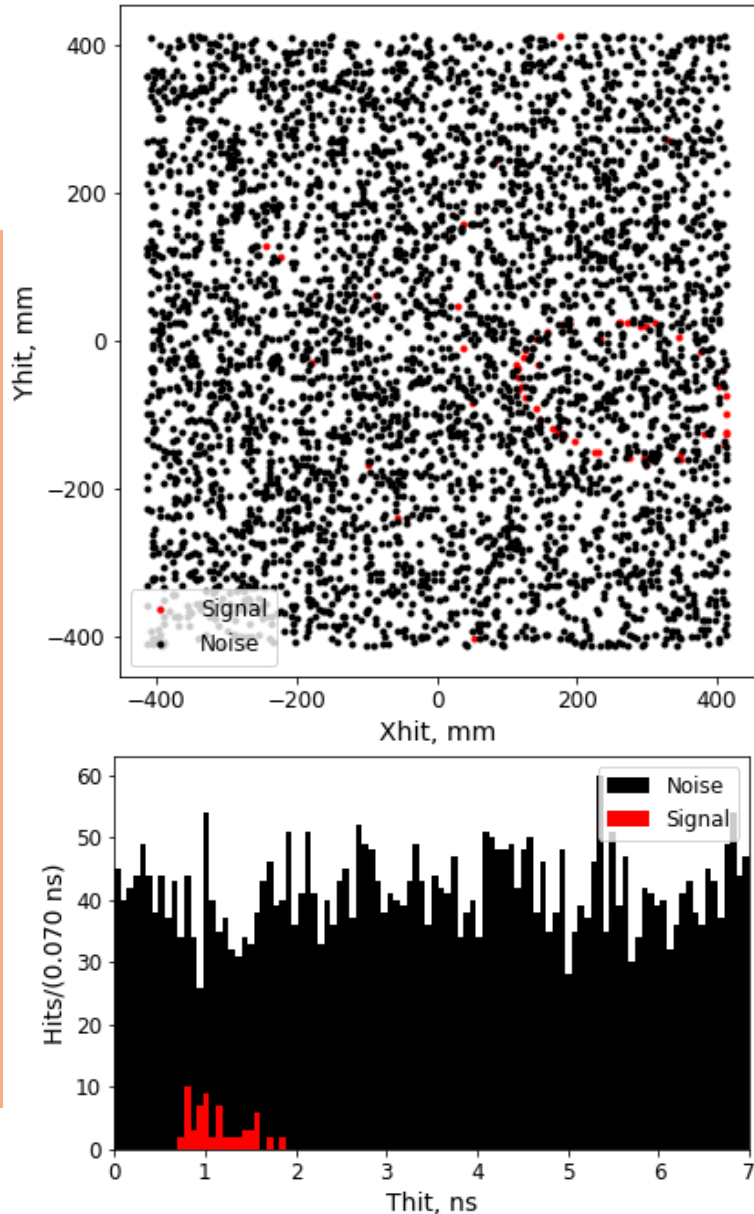
Barrel part Sketchs & key elements

- 275 aerogel tiles 200x202x35 in barrel part
- only SiPM will operate in magnetic field
- effective cooling system is required



Several R&Ds on reconstruction of events in the FARICH

Single FARICH event in with DCR $\sim 10^6$ cps/mm².



- **LPI group** developed classical approach so called “slider box”
 - X,Y-scan of the PD area is performed with fixed geometry box to search its position when the maximal number of hits are inside the box
 - The scan on time axis is also performed to find the time gate with maximal number of hits
 - It was shown that such method works very well until the $\text{DCR} \sim 10^5 \text{cps/mm}^2$

Bulletin of the Lebedev Physics Institute, 2023, Vol. 50, No. 12, pp. 534–539.

- **HSE group** developed reconstructions algorithms based on ML approaches
 - It was shown that CNN could help to suppress noise pile-up sufficiently without degradation of events reconstruction efficiency up to $\text{DCR} \sim 10^5 \text{cps/mm}^2$.
 - ML based algorithms are working in case of $\text{DCR} \sim 10^6 \text{cps/mm}^2$, however with some less reconstruction efficiency.

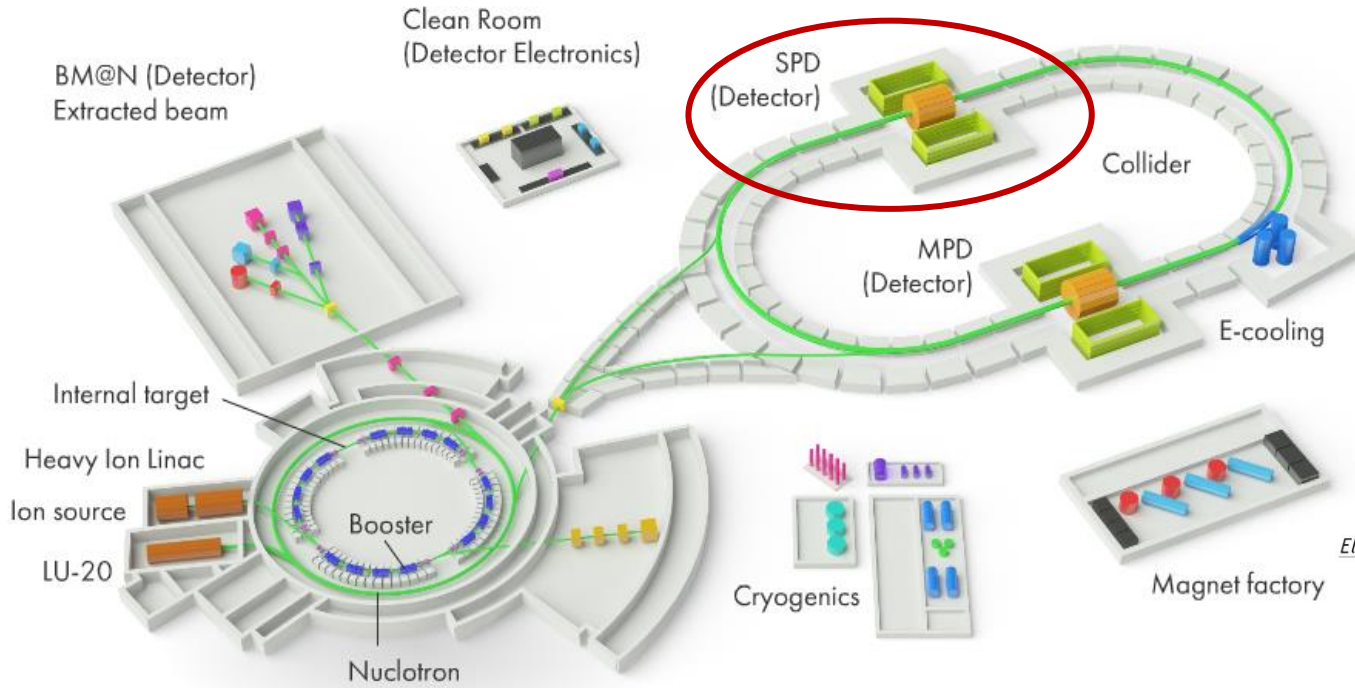
Physics of Atomic Nuclei, 2023, Vol. 86, No. 5, pp. 864–868.

SPD@NICA

Spin Physics Detector

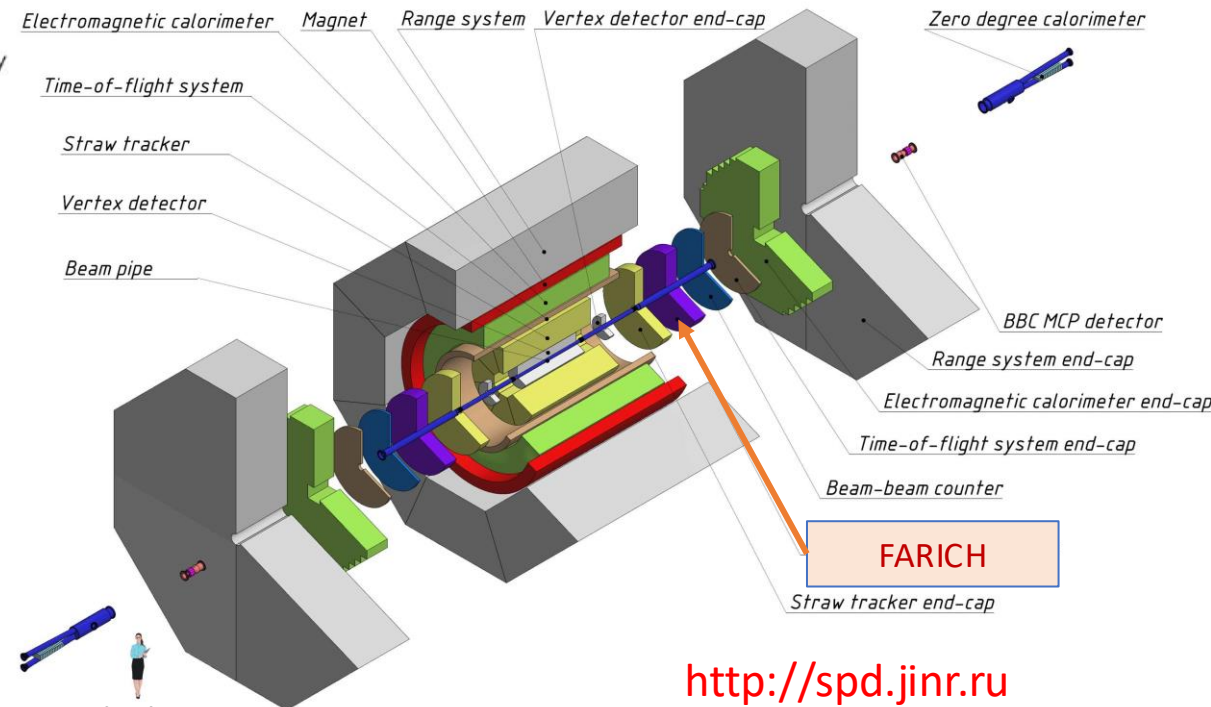
to investigate nucleon and light nuclei (p & d) spin structure with help of colliding beams at the energies up to **27 GeV**.

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



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

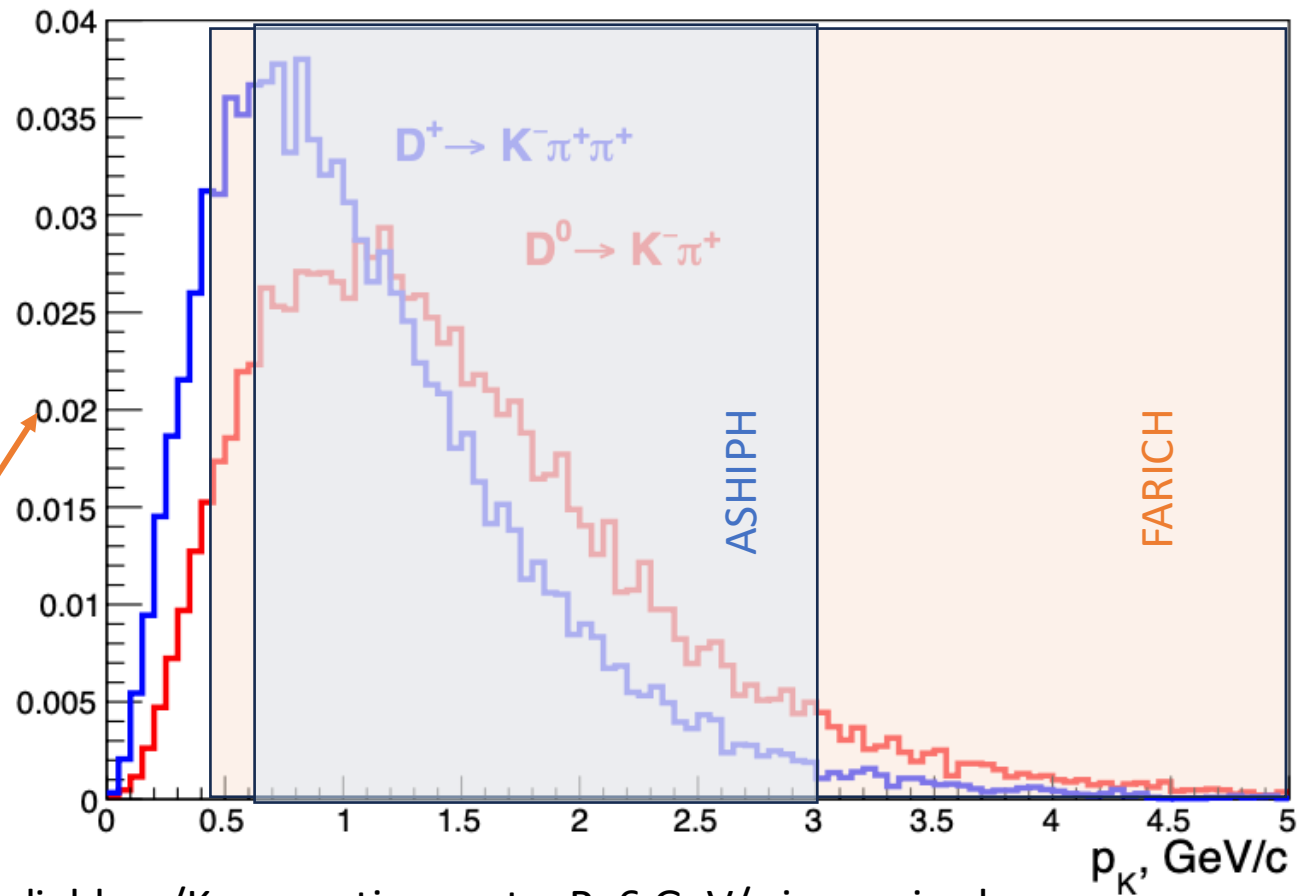
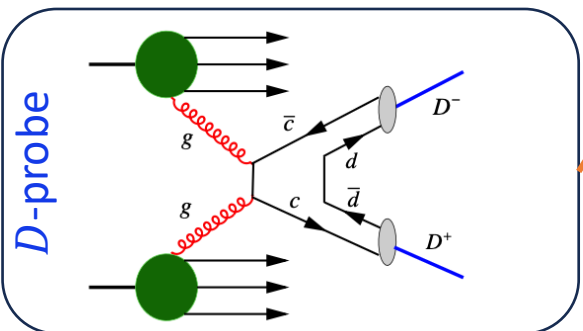
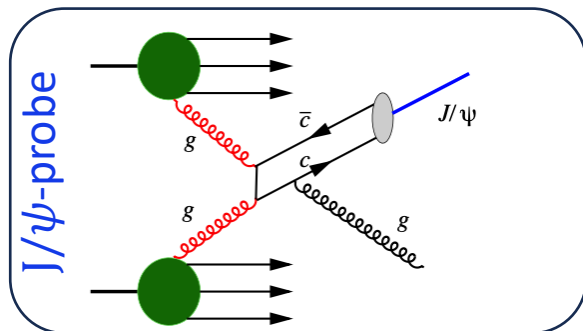
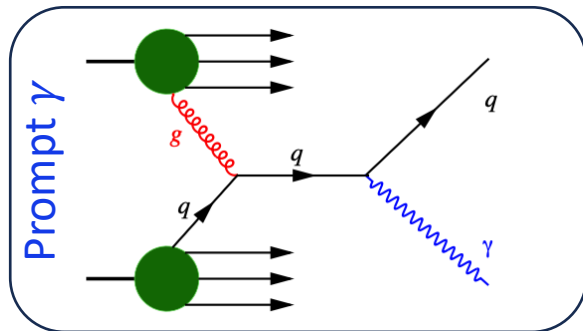
Nuclotron based **I**on **C**olliding **f**acility
for fundamental nuclear interaction study



<http://spd.jinr.ru>

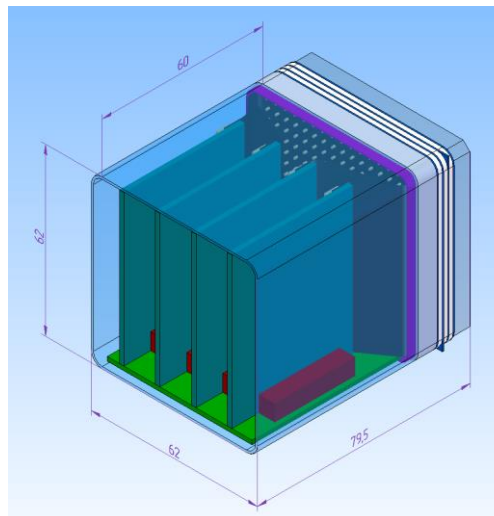
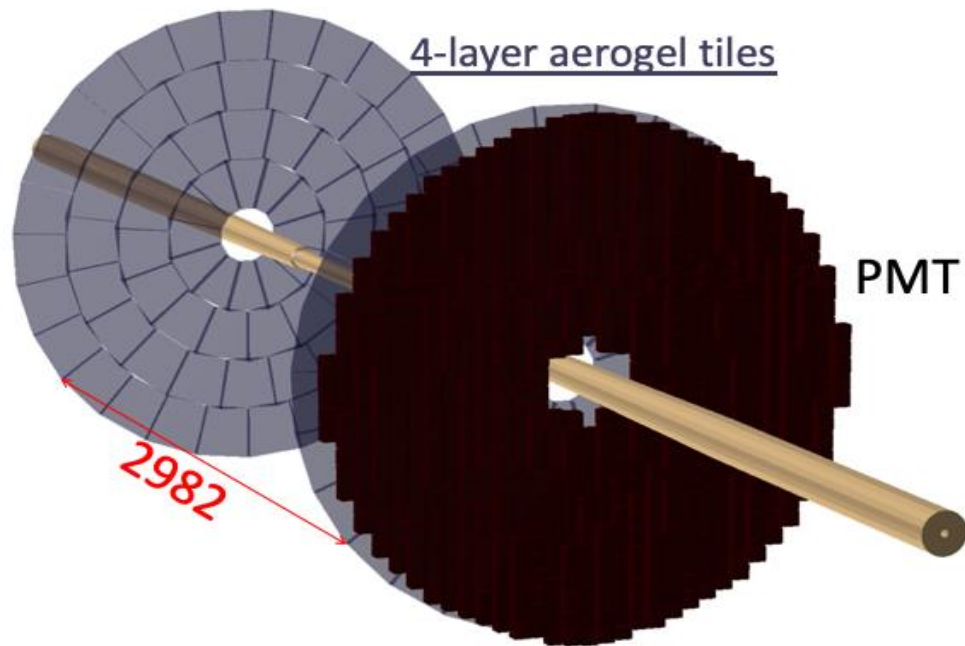
PID system: requirements

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 $n \leq 1.05$ (aerogel) + focusing are needed to provide $\sigma_c \sim 2.5$ mrad/track and π/K -separation $\geq 3 \sigma$ @ 6 GeV/c

FARICH system for the SPD-NICA



Rectangular MCP PMT with active area 50x50 mm

- Construction and design are under development in Novosibirsk by BINP and Ekran FEP in close cooperation
- All details and components will be produced in Russia

Goal parameters:

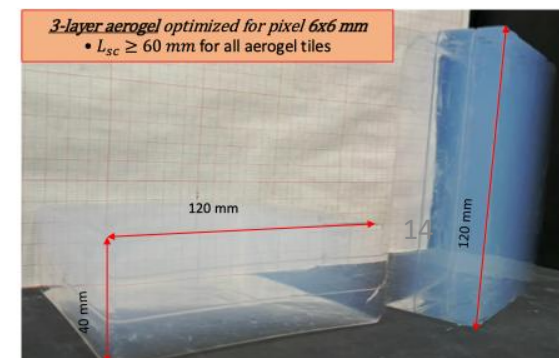
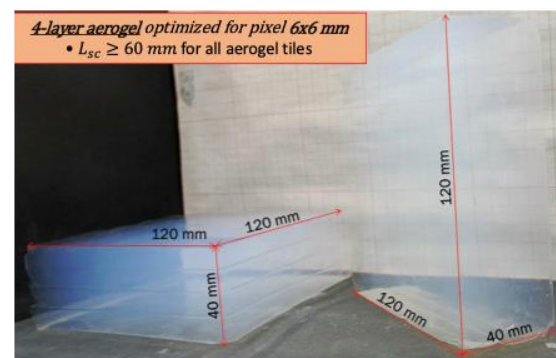
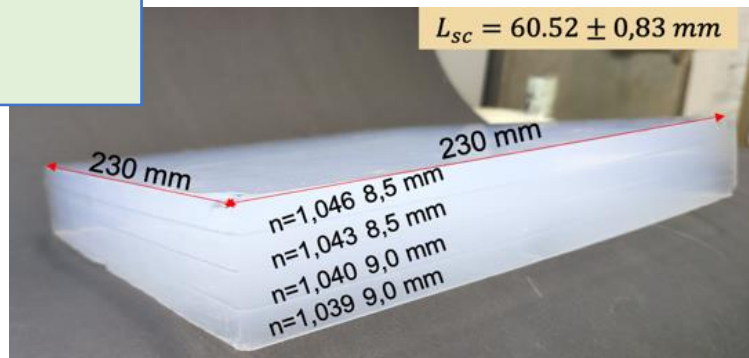
- $62 \times 62 \text{ mm}^2$ total area
- $50 \times 50 \text{ mm}^2$ sensitive area
- 16×16 pixels with $3 \times 3 \text{ mm}$ size
- Multi-alkali PCs extended in blue region
- Fused silica input window
- Gain $\geq 5 \cdot 10^5$

Aerogel:

- 2 end-caps $\times$ 74 tiles (4 form-factors)
- 4 or 3-layer focusing aerogel ($n_{\max} \leq 1.05$)
- Focal distance $\sim 20 \text{ cm}$

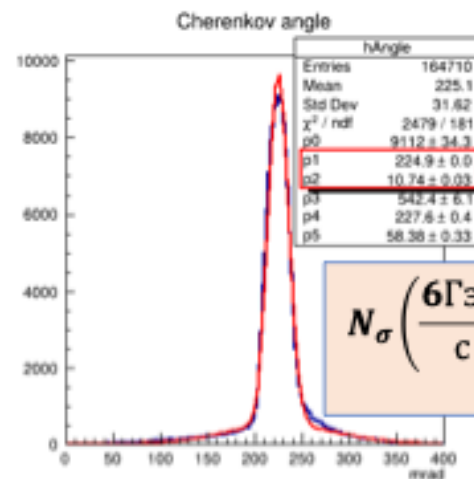
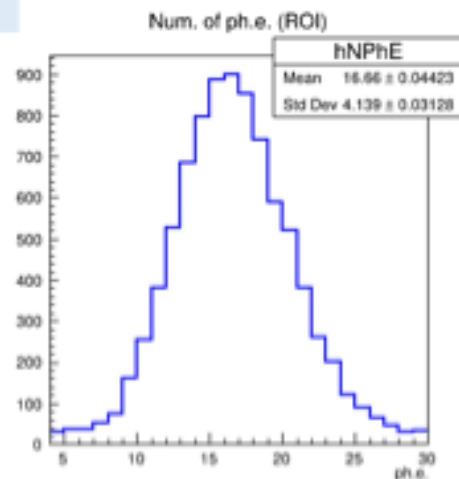
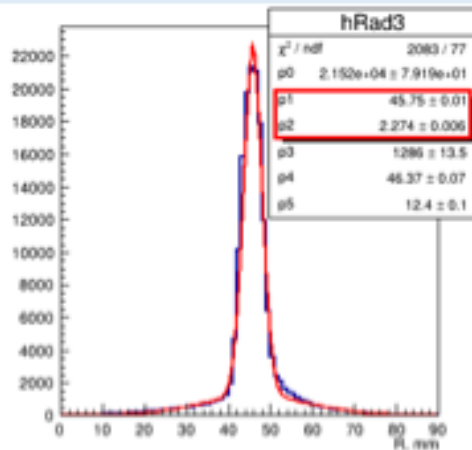
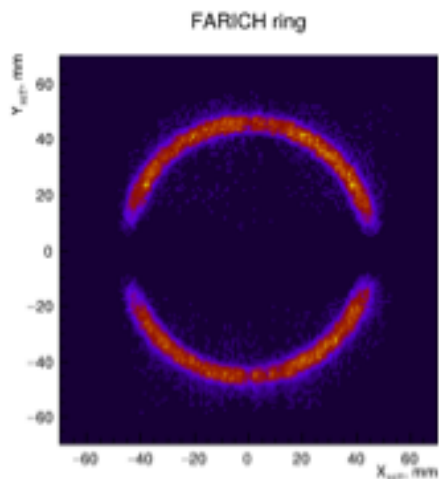
Position-sensitive MCP-PMT:

- $2 \times 508 \text{ PMTs} \sim 60 \times 60 \text{ mm}^2$



Beam test results with relativistic electrons: June 2025

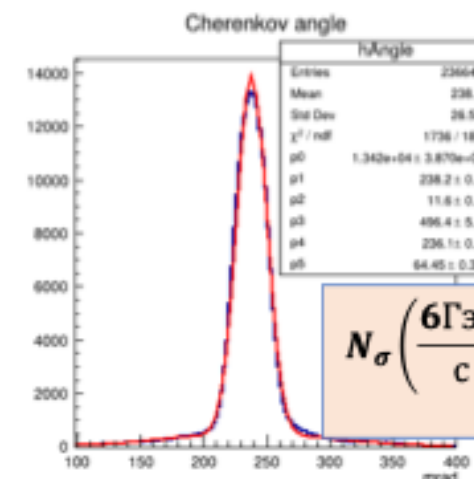
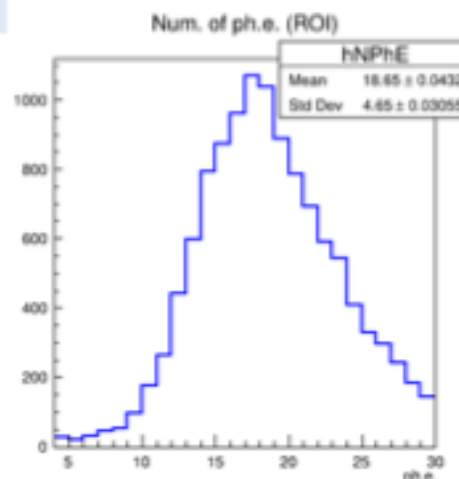
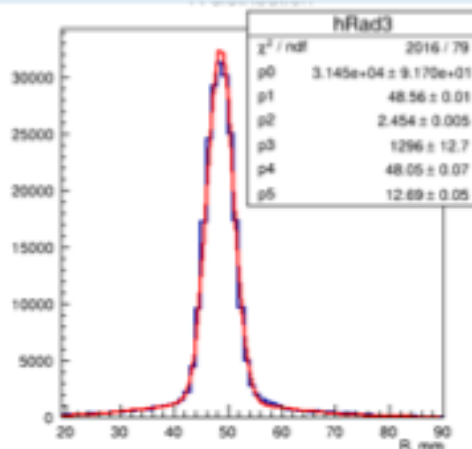
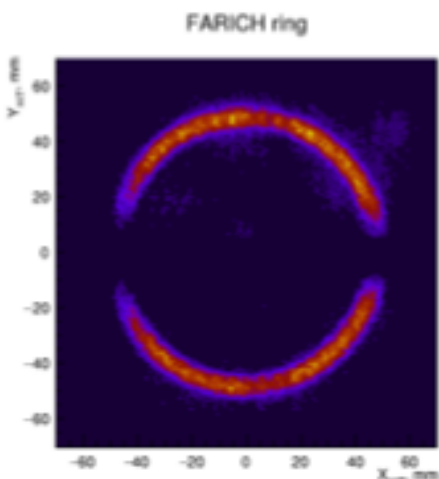
4-layer, $n_{\max}=1.04$, $t=40$ mm



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

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

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

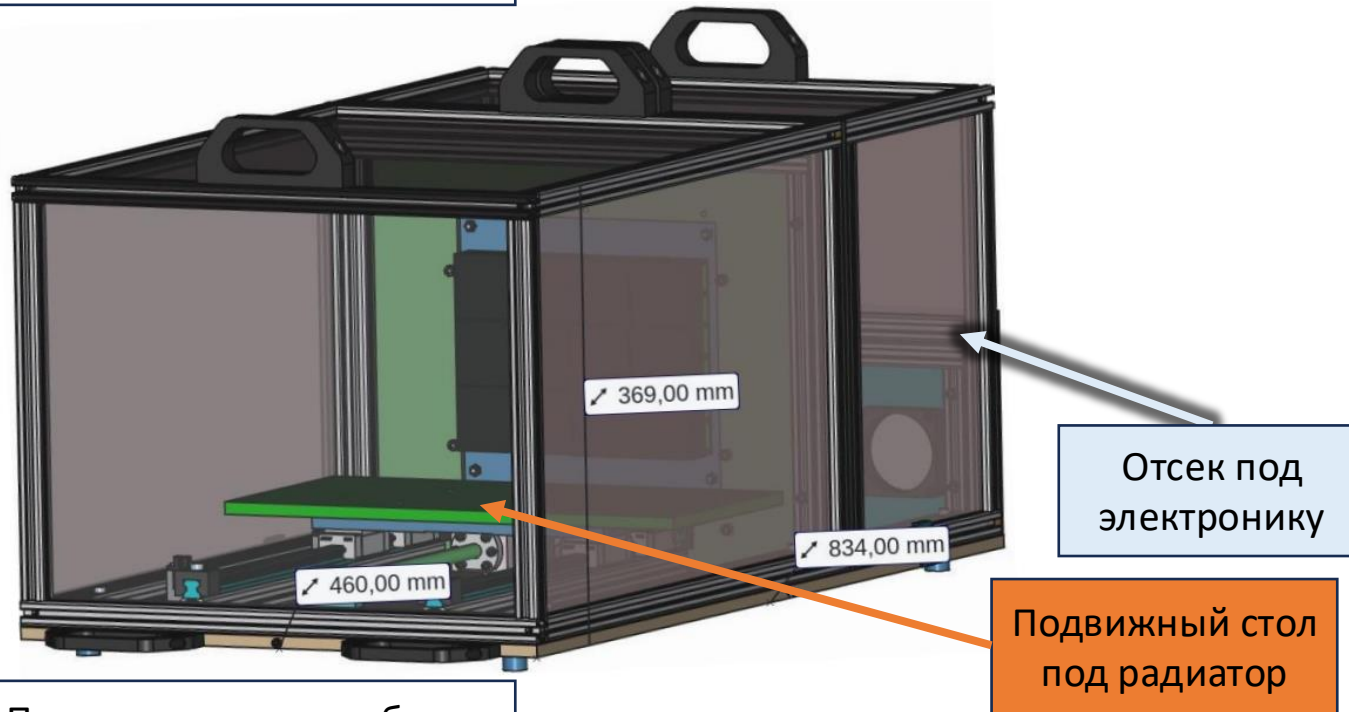


$$\sigma_{1pe} \approx 11.6 \text{ mrad}$$

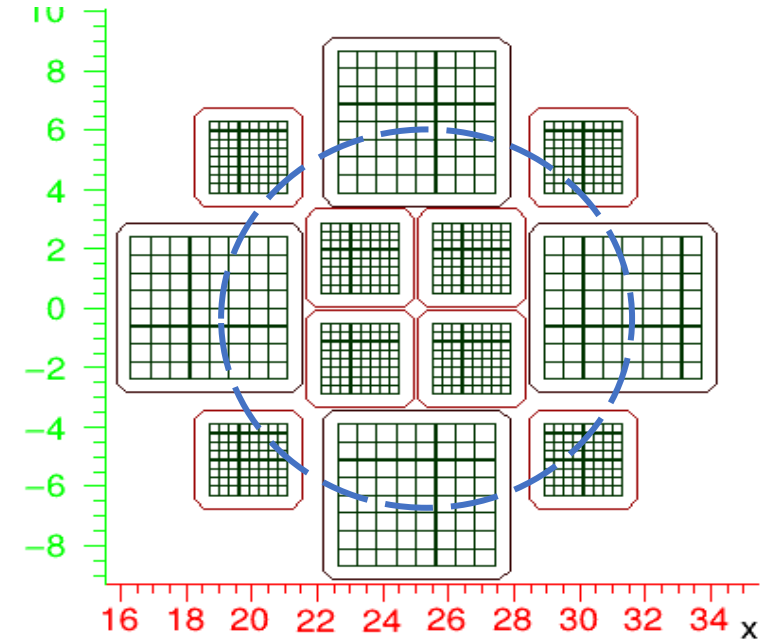
$$N_{\sigma} \left(\frac{6\Gamma_{\text{ЭВ}}}{c} \right) \approx \frac{11 \text{ mrad}}{11.6 \text{ mrad} / \sqrt{N_{pe}}} \approx 4.1$$

Новый прототип ДЧК

3D модель прототипа



Прототип во время сборки

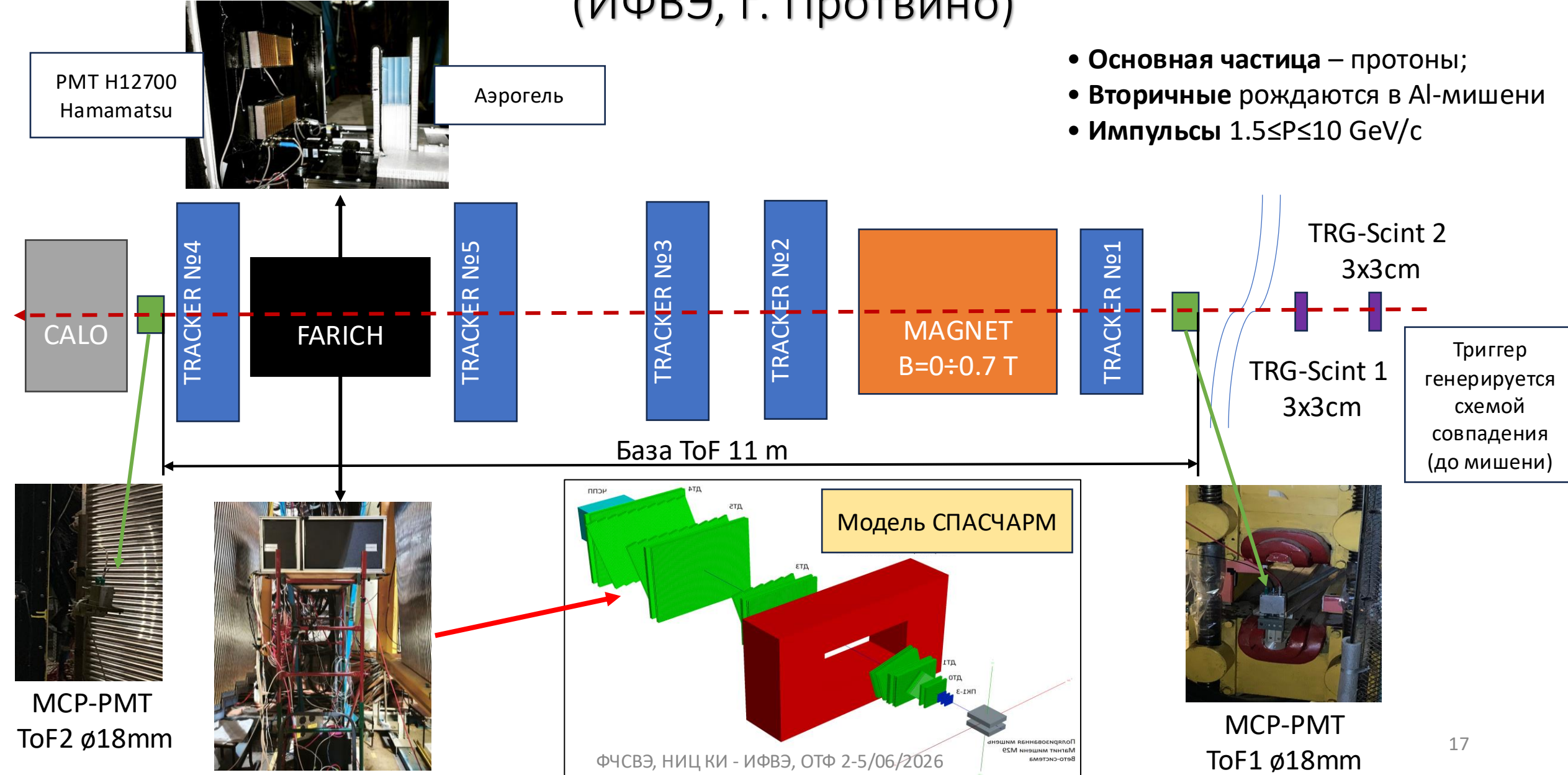


Модернизация ФД прототипа 2026

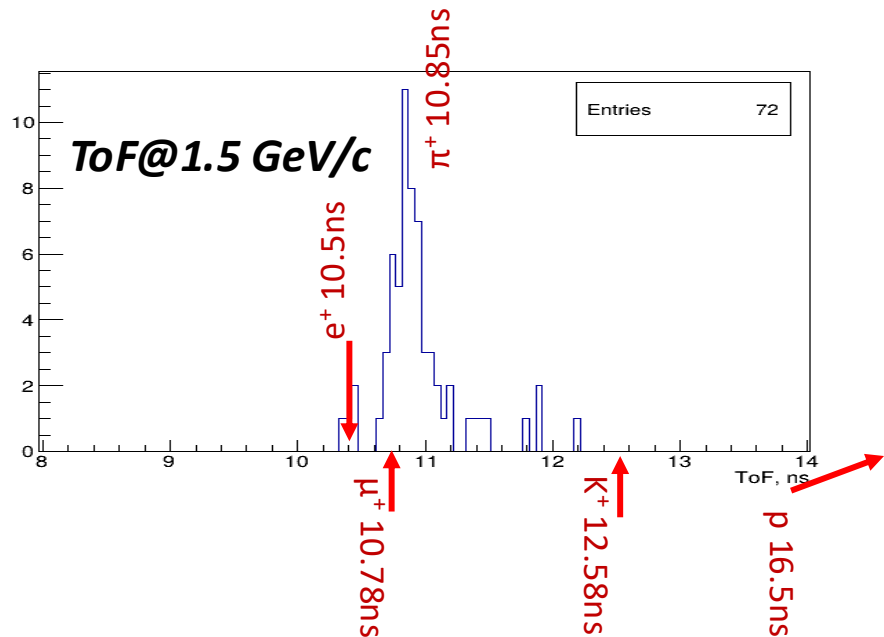
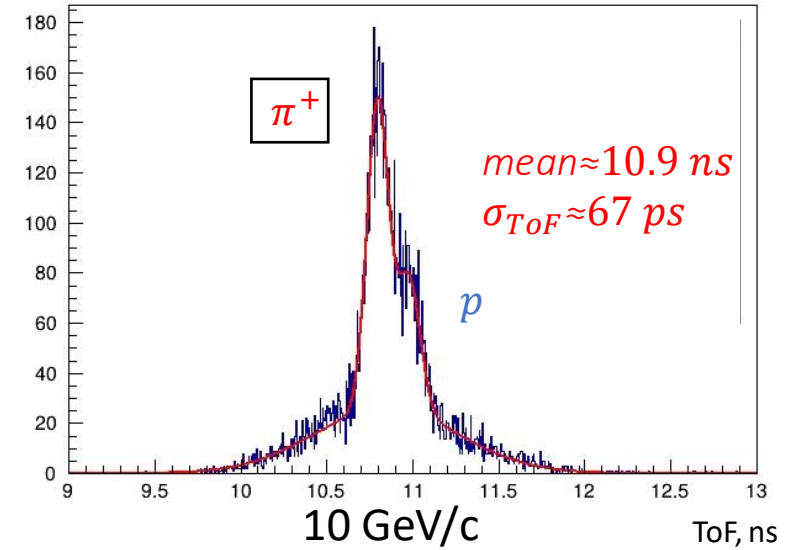
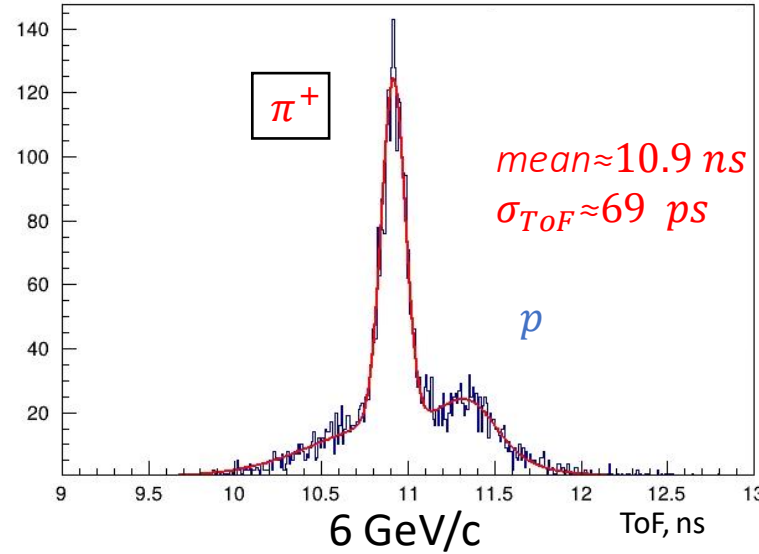
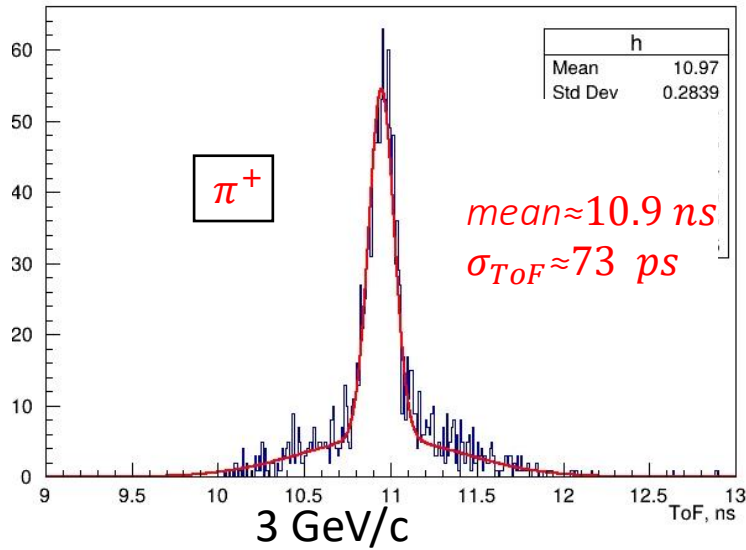
- Текущая версия прототипа может считывать до 12 ФЭУ H12700 (Hamamatsu) при помощи FEE DiRICH (GSI)
- В 2026 году планируем добавить к 4-ем ФЭУ H12700 8 ФЭУ с МКП от «Экран ФЭП»
- В 2027 году оснастить 9-ю фоторегистрирующими модулями на основ КЧФЭУ с МКП и DMXG64

Испытания прототипа на адронном пучке на базе СПАСЧАРМ@У-70 (ИФВЭ, г. Протвино)

- Основная частица – протоны;
- Вторичные рождаются в Al-мишени
- Импульсы $1.5 \leq P \leq 10$ GeV/c



Предварительные результаты: TOF



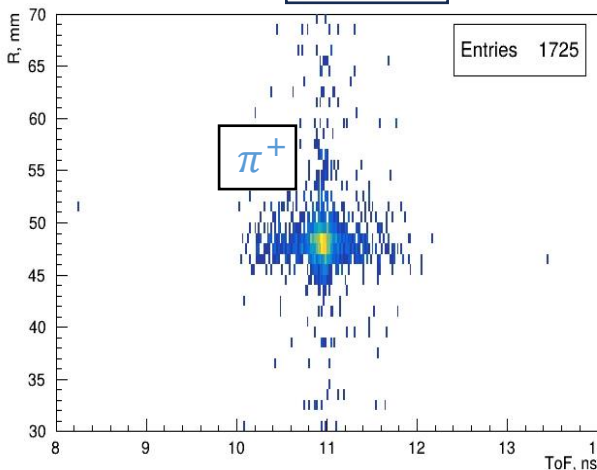
- σ_{TOF} по экспериментальным данным $\sim 70 \text{ ps}$
- Состав пучка π^+ ($\sim 75\%$), p ($\sim 20\%$), K^+ ?, e^+ ?
- Ниже $P=3 \text{ ГэВ/с}$ протонов нет

Предварительные результаты: R_c и N_{pe}

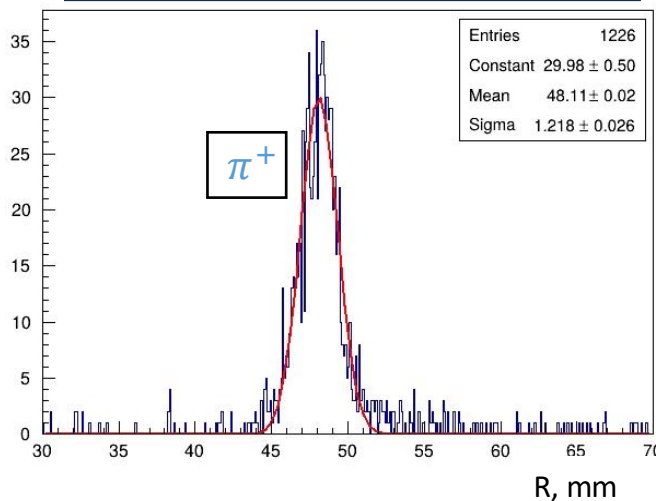
Без привлечения трековой системы (пока!)

3 GeV/c:

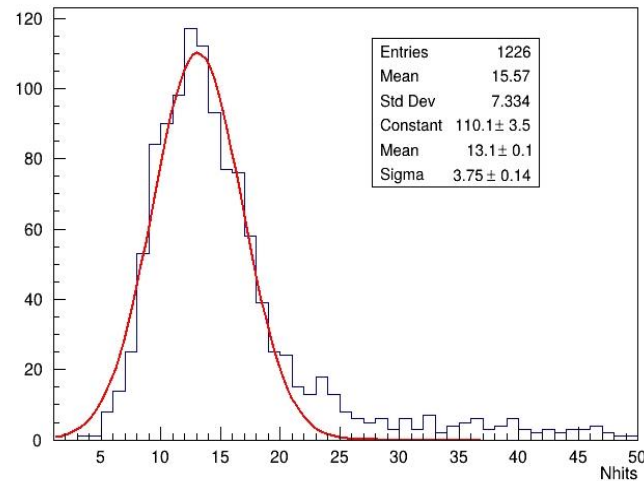
R vs ToF



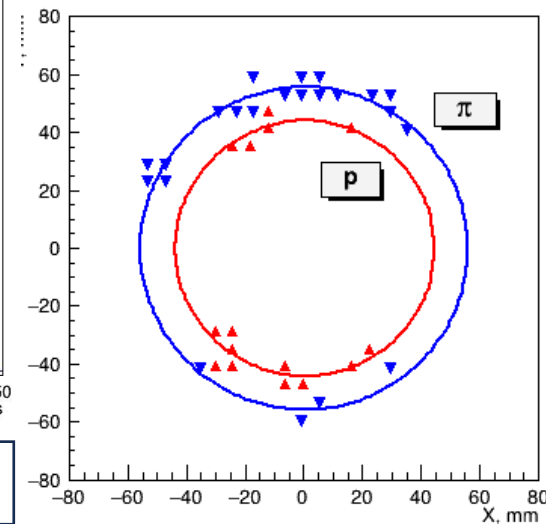
Распределение радиусов.
Time cut & ToF cut



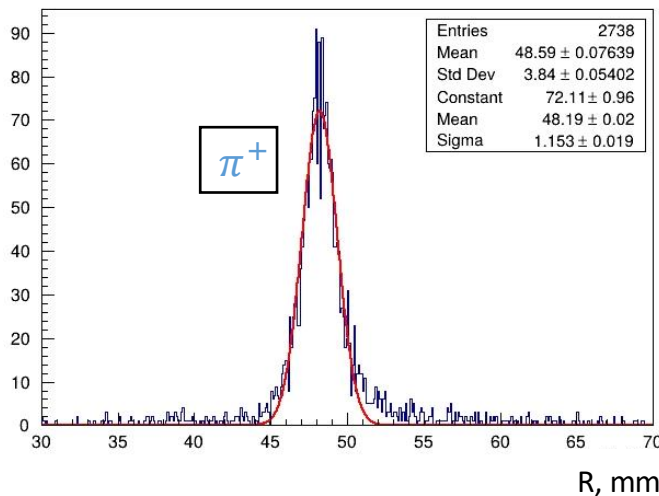
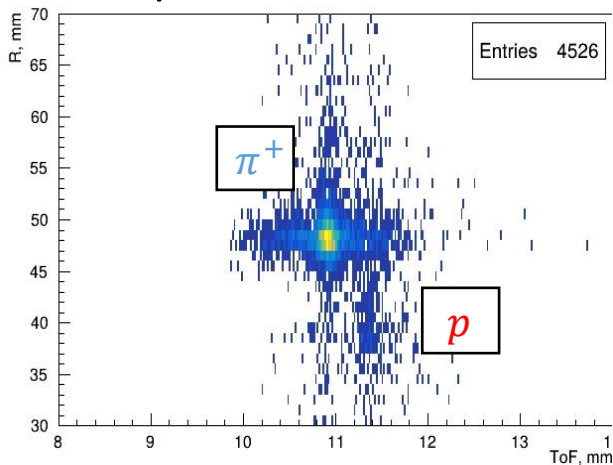
Распределение фотоэлектронов



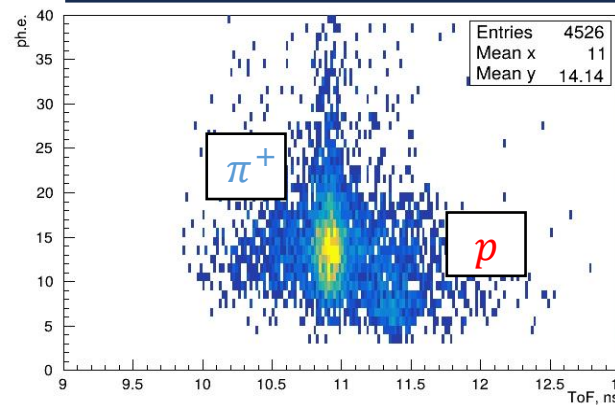
Сравнение кольца пиона и
протона@6 GeV/c



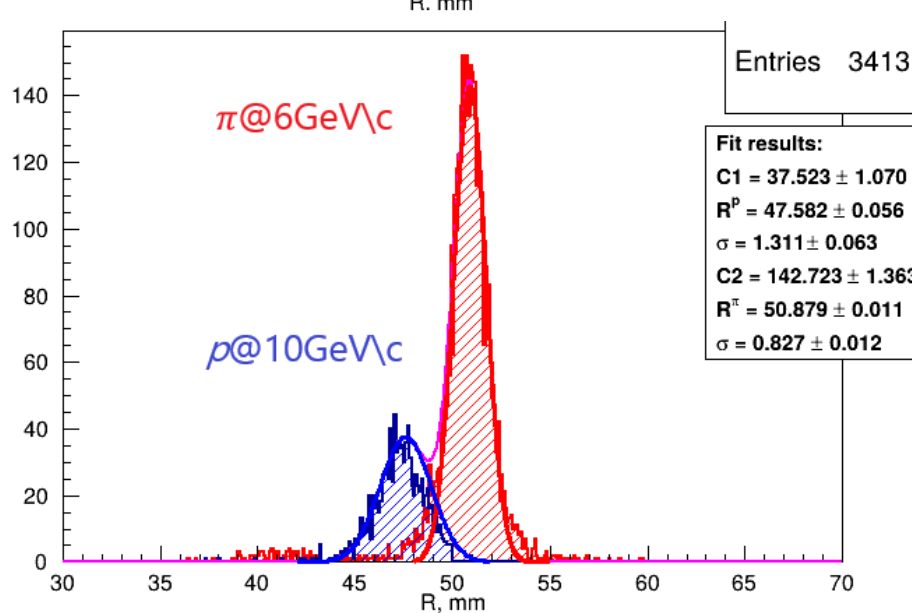
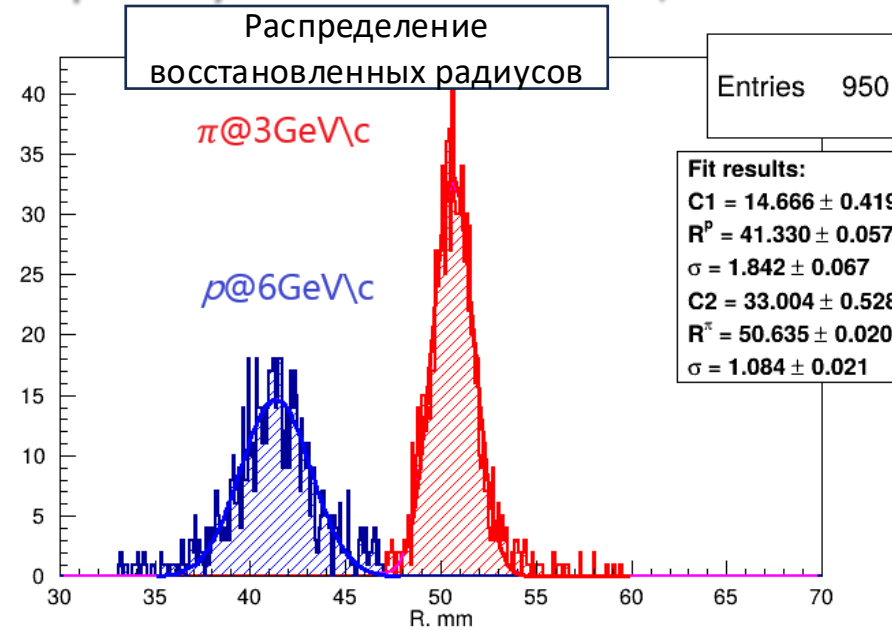
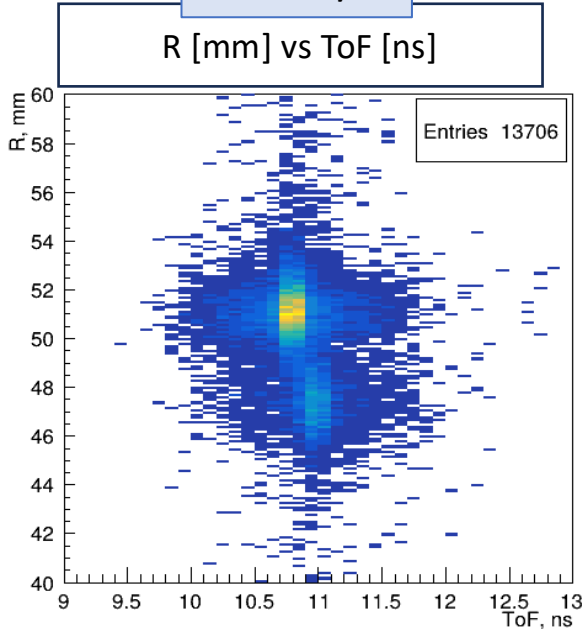
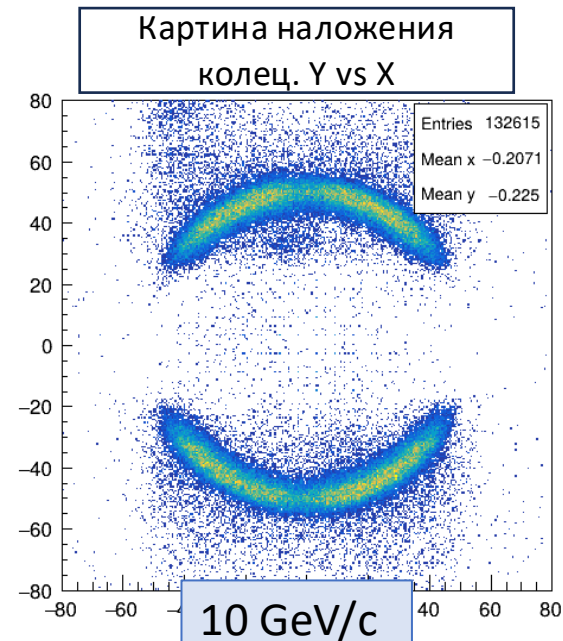
6 GeV/c:



Распределение фотоэлектронов
vs ToF



Предварительные результаты: оценка π/K разделения



$$N_\sigma = \frac{(R^\pi - R^p)}{0.5(\sigma_{R_{\text{track}}}^\pi + \sigma_{R_{\text{track}}}^p)}$$

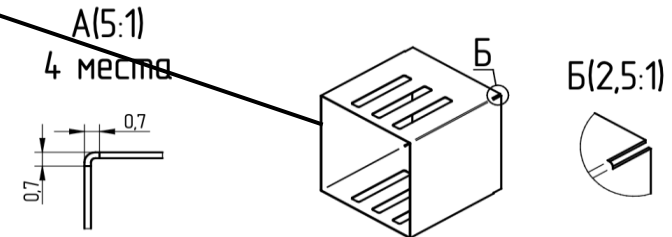
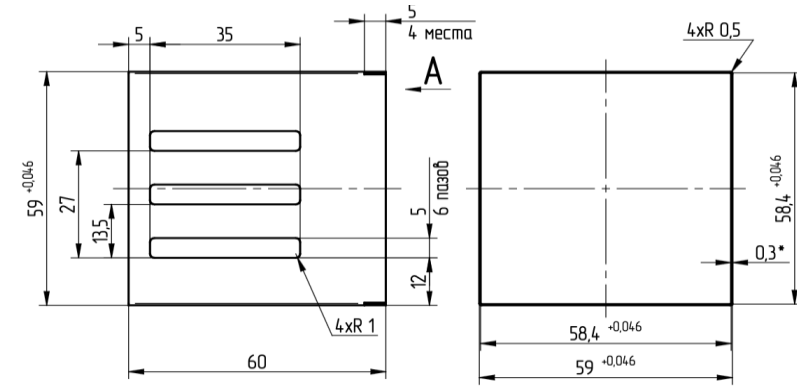
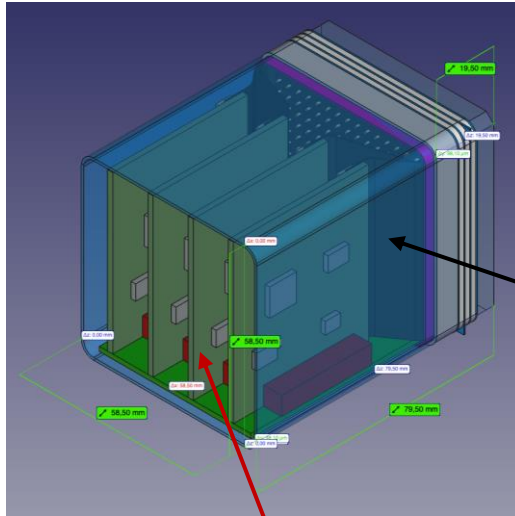
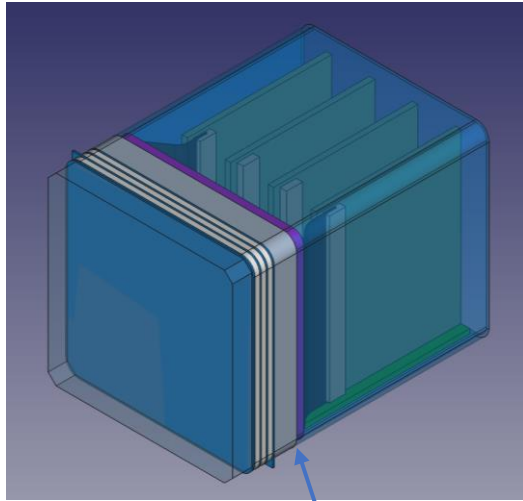
$\pi/K \sim 6.4\sigma @ 3 \text{ GeV}/c$

$\pi/K \sim 3.1\sigma @ 5.4 \text{ GeV}/c$

- Аэрогель: 3-слоя; $t_{\text{tot}}=40 \text{ мм}$; $n_{\text{max}}=1.04$
- пиксель $6 \times 6 \text{ мм}$; 60% кольца
- нет трековой информации

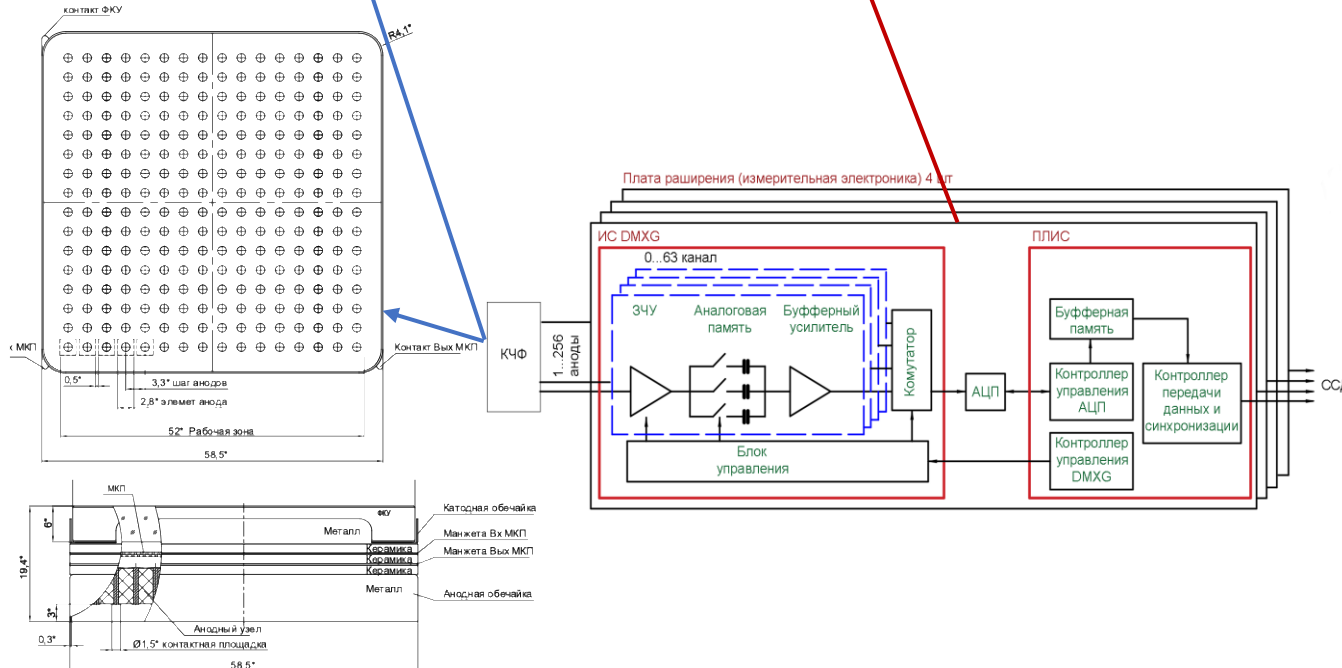
Результат может быть лучше!!!

Concept of the photon detection module

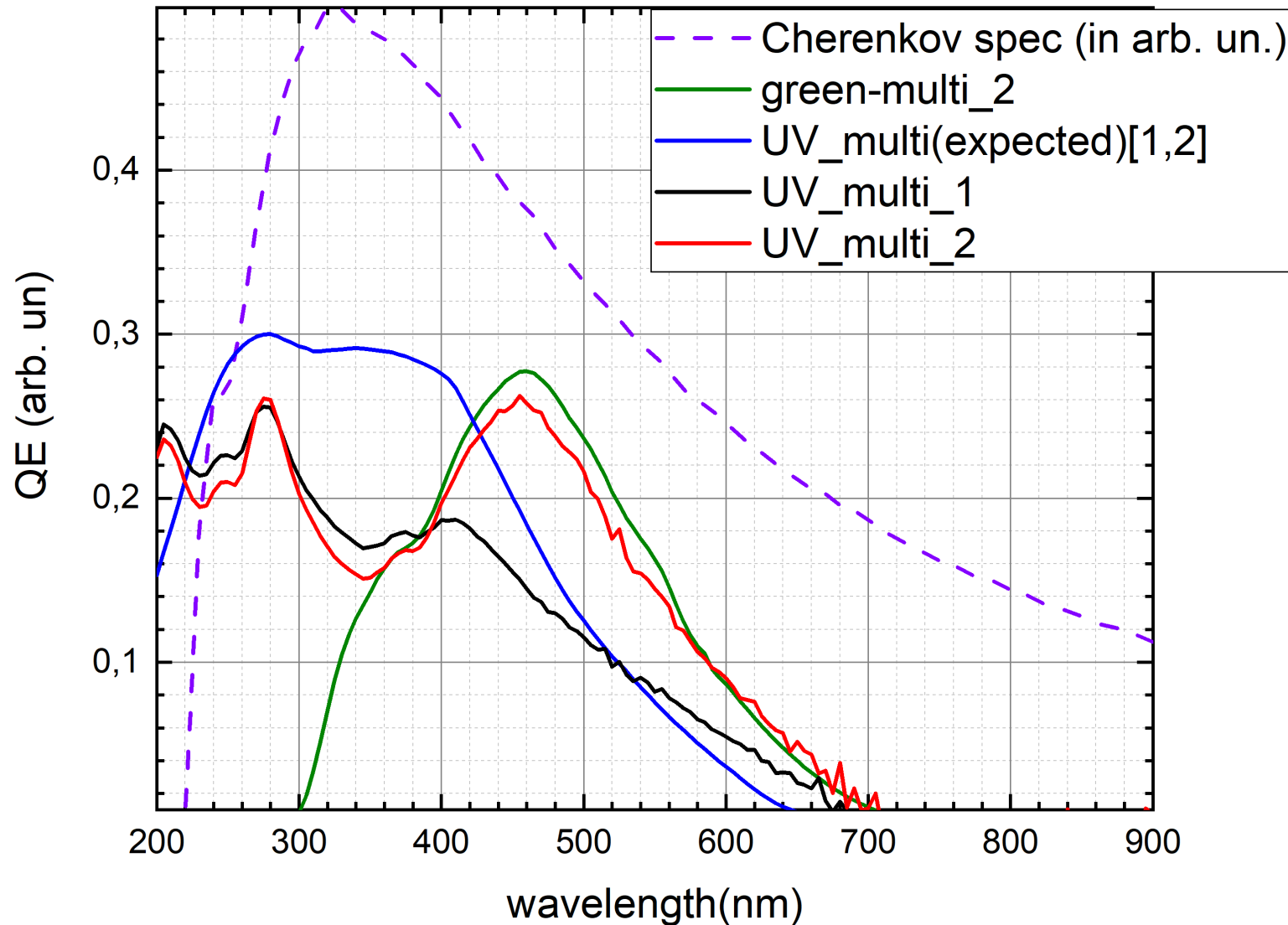


Current design concept:

- Square position-sensitive MCP PMT with 256 anode pads 2.8x2.8 mm each
- 4 readout PCB with 1 ASIC DMXG64 each are reading out through C-Link protocol (USB-3.0 or Eth. plugs)
- Flexible PCBs are used to connect MCP PMT and FEE
- Backend board placed HV-divider and HV-plugins
- CFRP shield has ventilation holes and could be a construction element of the large system
- The estimated mass of the module is 200g (MCP PMT)+ 200g (FEE)



Photocathode optimisation

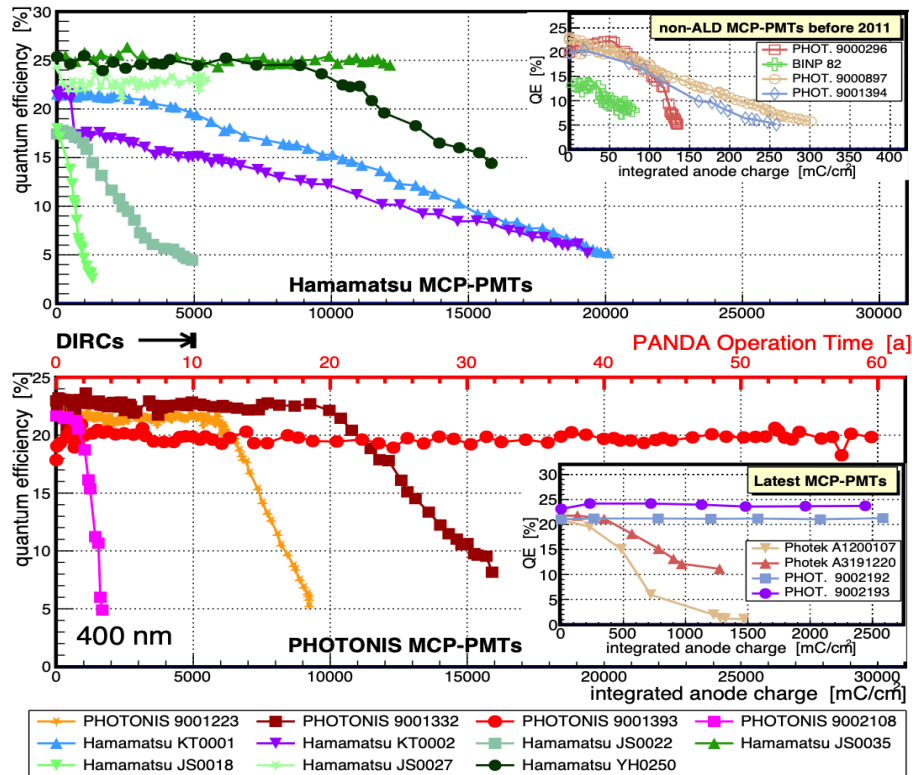


- Use of the multi-alkali PCs deposited on fused quartz input window with extended sensitivity in UV-region allows us to increase light collection by of 1.5 times
- UV-multi-alkali PC deposited on fused quartz is a base option for the MCP PMT based photon detection modules
- Bi-alkali PCs are also considered as an alternative option

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

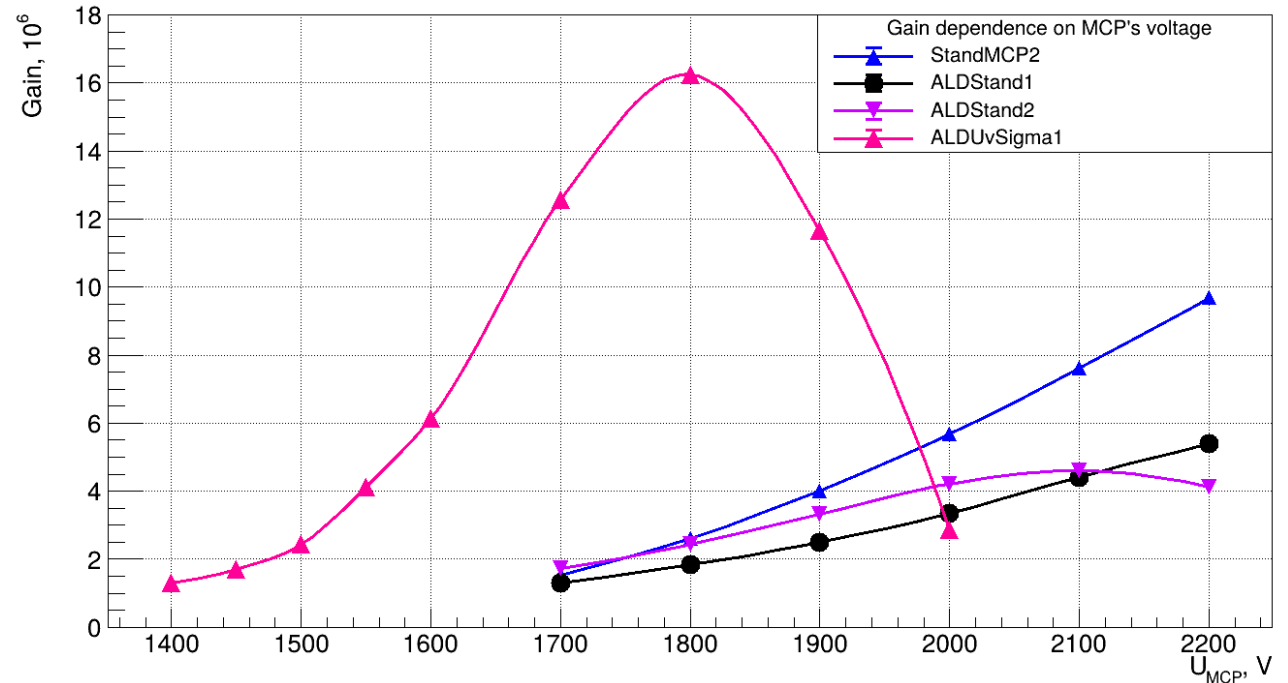
2. Milnes, J., et al., UV photocathodes for space detectors. *Proceedings Volume 12181, Space Telescopes and Instrumentation 2022: Ultraviolet to Gamma Ray*, 121813B (2022).

MCP with ALD: PC lifetime, Gain and CE



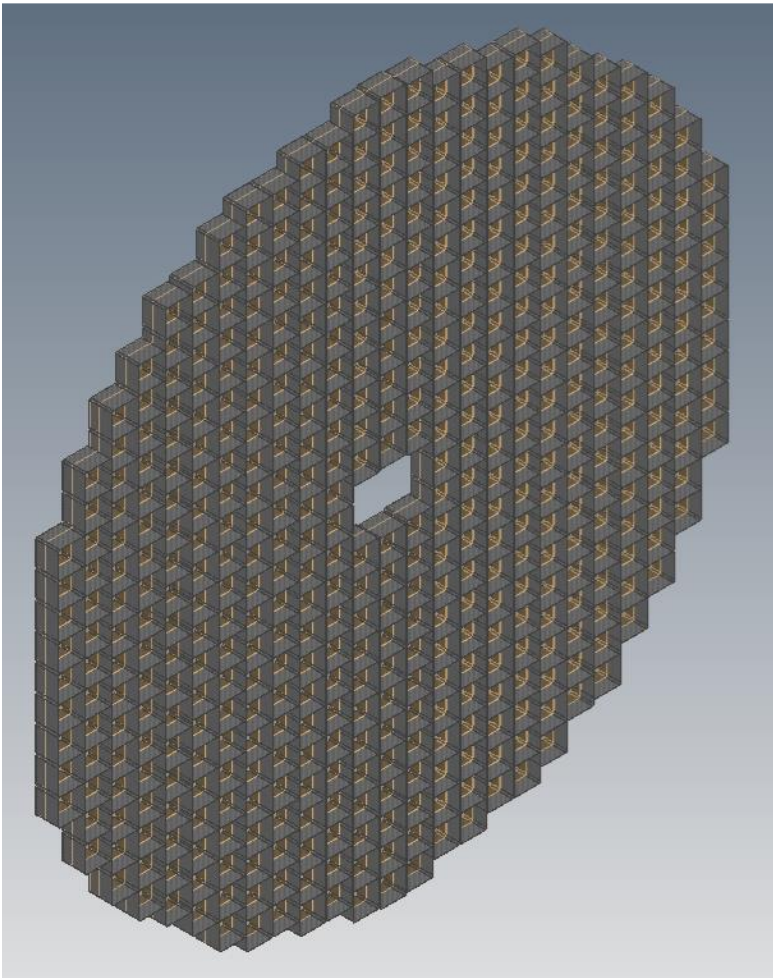
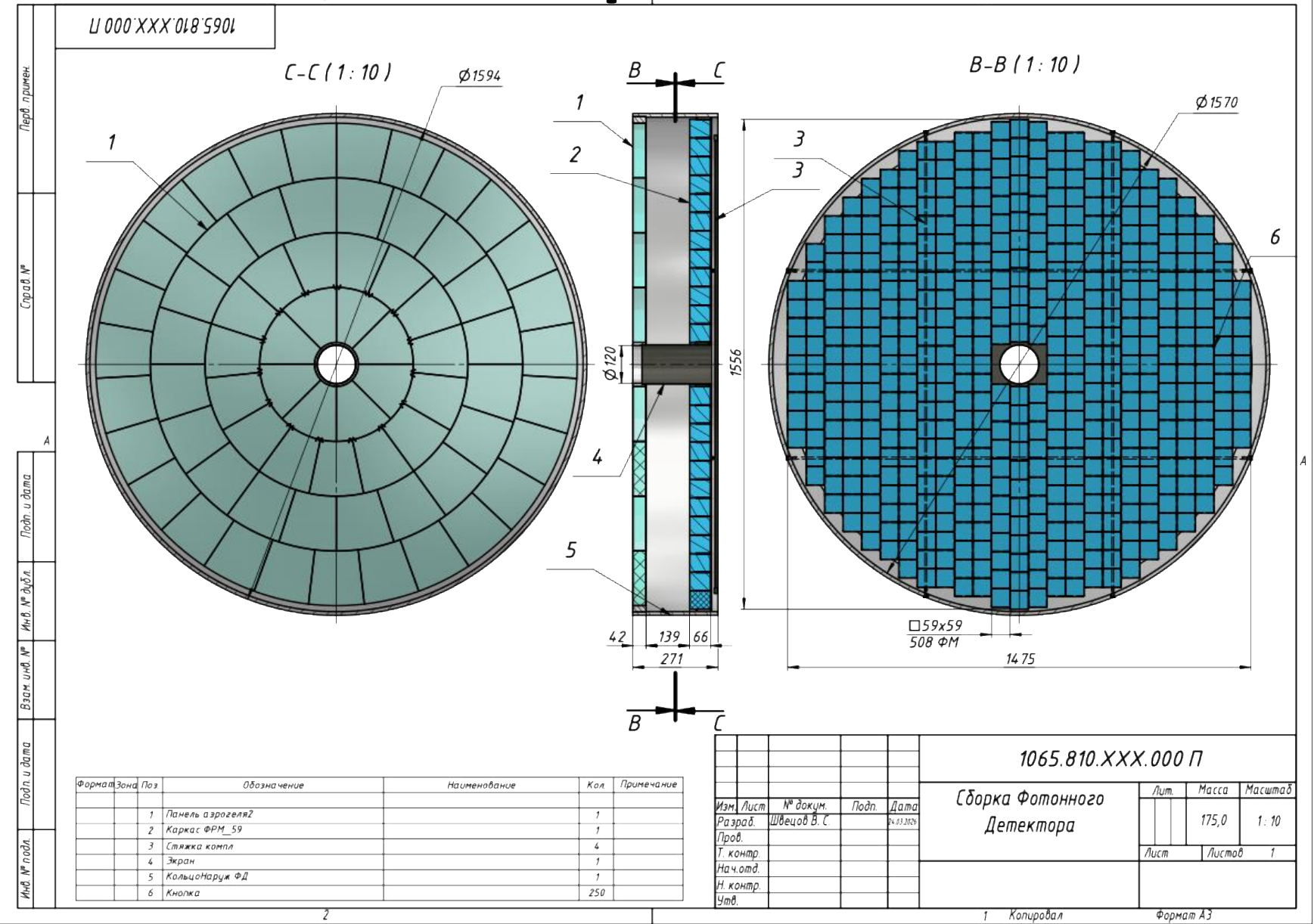
- It is known, that ALD coating is able significantly improve the PC's lifetime in colliding beam experimental conditions
- Also it is increase the gain and allows us to operate at lower voltges
- We expect to get PE collection efficiency >60% by use ALD coating at the entrance of the first MCP

For $U_{PC-MCP}=300V$ Gain dependence on MCP's voltage



- According to our very preliminary results of relative measurements, the PE collection efficiency increased by 25% for MCPs with ALD coating at the entrance plane in comparison with standard one
- Further optimisations of the ALD coating and MCP bulk resistivity are foreseen

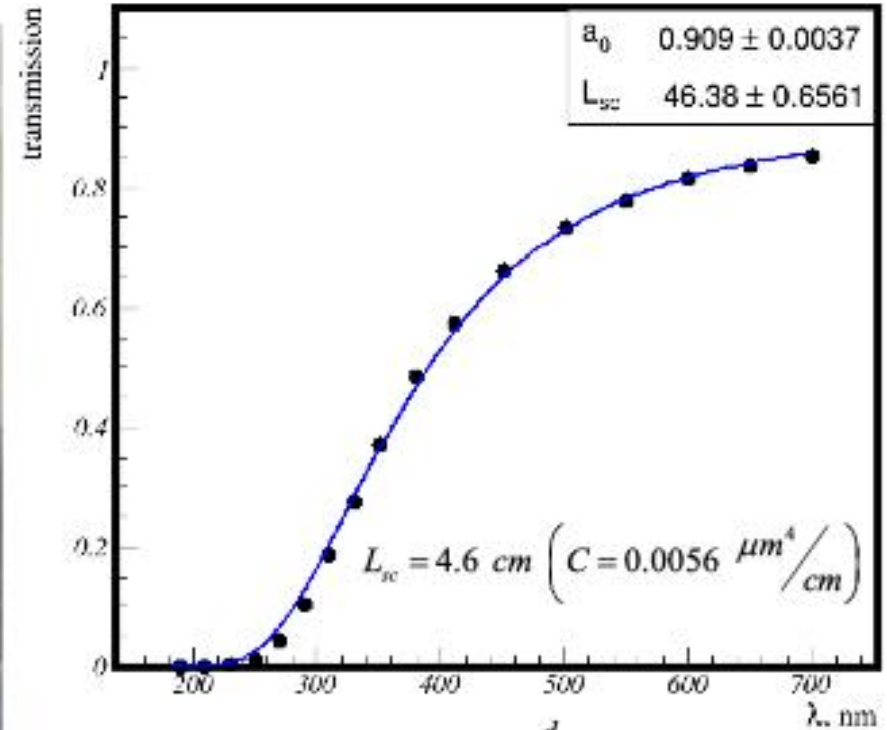
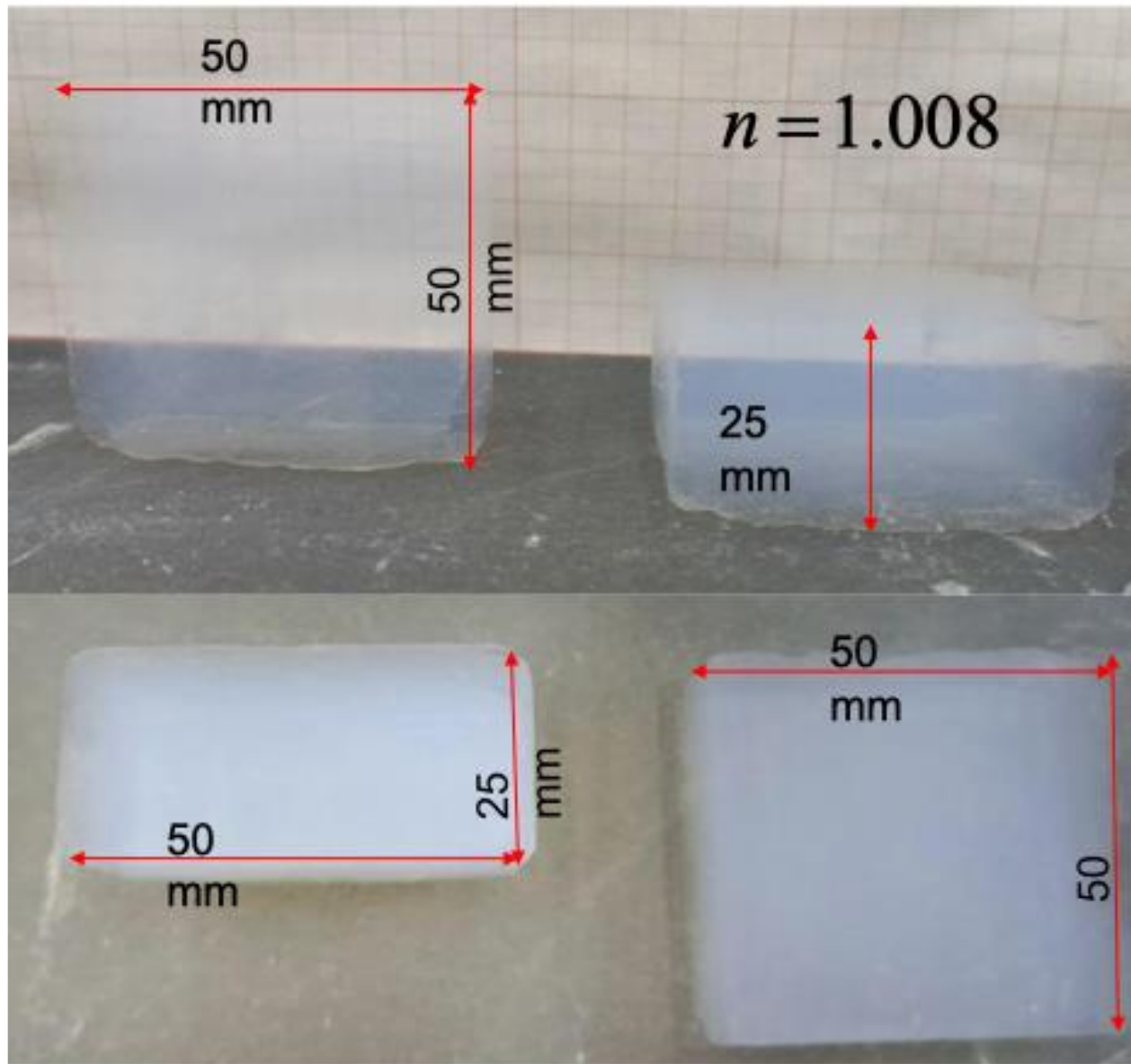
Технический проект системы ФАРИЧ-SPD: ver.1.0



Motivations for π/K -separation above 20 GeV/c

- Future e^+e^- H-factories such like FCCee (CERN) and CEPC (China) have extensive physics programme at Z-pole ($\sqrt{s} = 91.2 \text{ GeV}$).
- Expected 4×10^{12} Z-bozons ($\int L dt \approx 100 \text{ ab}^{-1}$) will provide extensive statistic of $b\bar{b}$, $c\bar{c}$ and $\tau^+\tau^-$ for precise flavor physics investigations.
[arXiv:2412.19743v2 [hep-ex] 31 Dec 2024]
- π/K - separation is needed not only to suppress combinatorial background and to separate similar topology of final states like:
 $B_{(s)}^0 \rightarrow \pi^+\pi^-$, $B_{(s)}^0 \rightarrow K^+K^-$, $B_{(s)}^0 \rightarrow K^\pm\pi^\mp$ and so on.
- Baseline option of the CEPC detector is able to provide π/K - separation at the level of 2σ up to 20 GeV/c by combining dE/dx and ToF techniques.
[Y.Zhu et al., NIM A 1047 (2023) 167835]
- π/K -separation at the level $\geq 3\sigma$ in wider momentum range is highly desirable for such experiments.

Aerogel with $n=1.008$ (Novosibirsk)



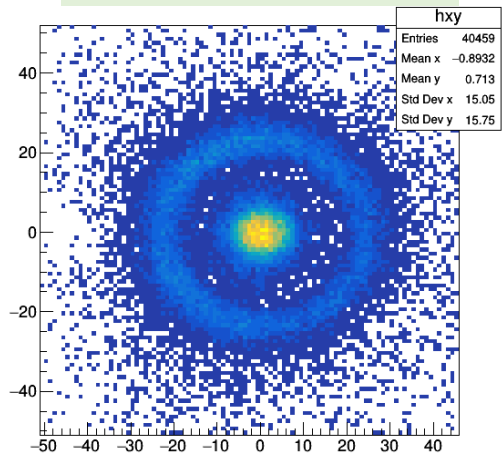
$$T = \frac{I}{I_0} = a_0 \cdot e^{-\frac{d}{L_{sc} \cdot \left(\frac{\lambda}{400}\right)^4}} = a_0 \cdot e^{-\frac{C \cdot d}{\lambda^4}}$$

d – thickness of a sample,
 λ – wavelength in nanometers,
 L_{sc} – scattering length at 400 nm,
 a_0 – surface scattering coefficient,
 C – clarity coefficient

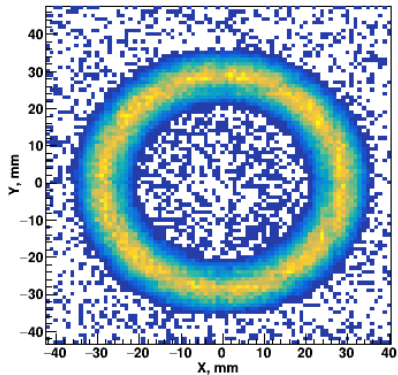
RICH based on aerogel n=1.008: some beam test results

Tbeam e⁻@2.5GeV

- $t_{\text{aer}}=25+25=50$ mm
- $L_F=200$ mm



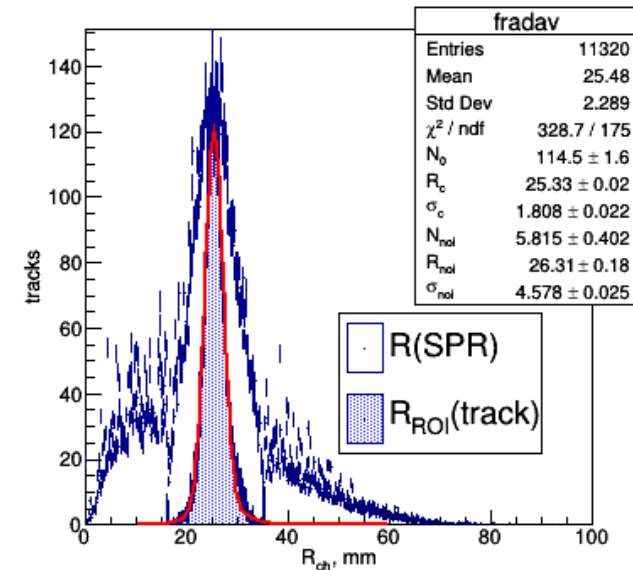
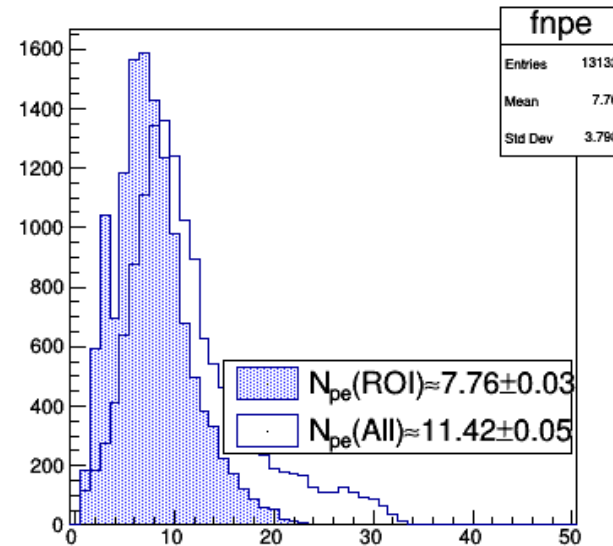
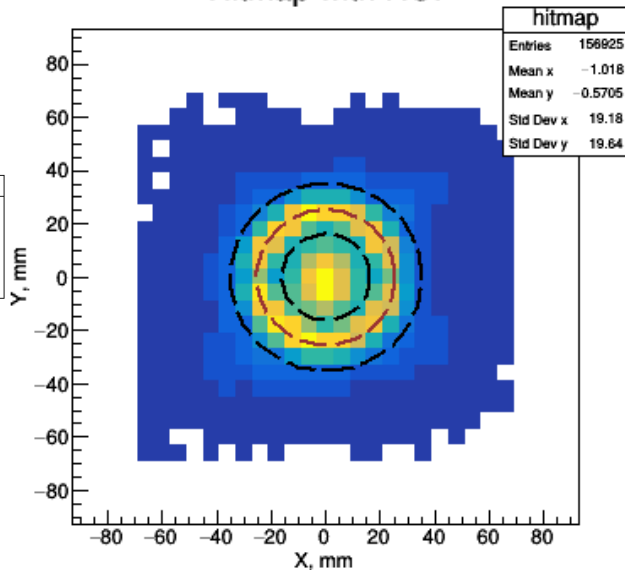
Hits map ($\beta=1$)



Geant4 sim.:

- $t_{\text{aer}}=60$ mm
- $L_F=250$ mm

Hitmap with ROI



TBeam results reconstructed w/o track information:

- MaPMT H12700 with QE(400nm) $\approx 20\%$
- Pixel 6x6 mm
- Aerogel:
 - stack of 3 tiles $25+25+25=75$ mm
 - refractive index $n \approx 1.008$
- $L_F=235$ mm

OUTPUT:

- SiPM based photon detector with PDE(400nm)=45÷50% will allow us to detect **10÷20 ph.e.** for relativistic tracks
- RICH based on aerogel with $n=1.008$ and pixel 3x3mm is able to provide π/K -separation at $P=10$ GeV/c
- *Proximity focusing system and PD with $\sigma_x \leq 1$ mm is required to reach π/K -separation above 20 GeV/c*

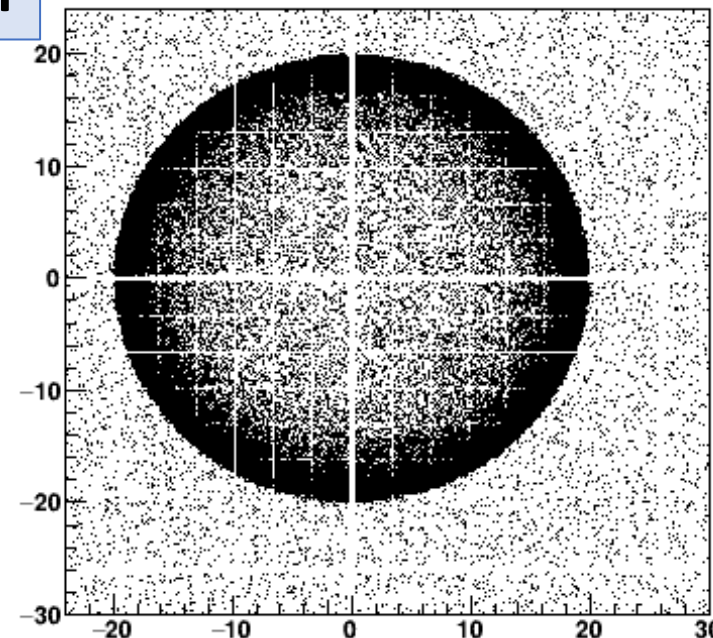
G4sim conditions

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

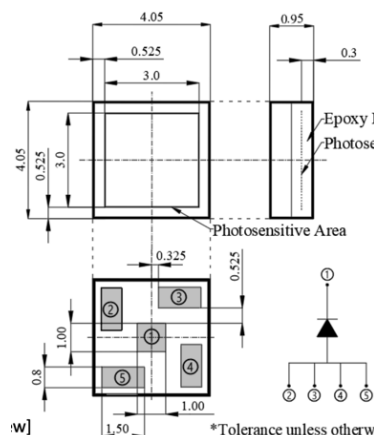
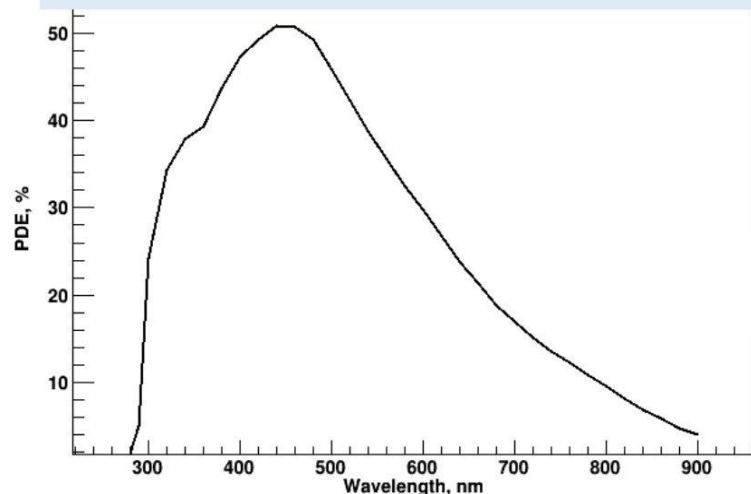
Focal distance is 300 mm

- 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*
- $L_{\text{sc}}(\lambda) = L_{\text{sc}}(400\text{nm}) \cdot \left(\frac{\lambda}{400}\right)^4$
- $n(\lambda) = \sqrt{1 + a_0 \cdot \frac{\lambda^2}{\lambda^2 - \lambda_0^2} \cdot \frac{(n(400)^2 - 1)}{a_0 \cdot \frac{400^2}{400^2 - \lambda_0^2}}}$, where
 $\lambda_0 = 83.22$ nm and $a_0 = 0.05639$ is taken
from *Eur. Phys. J. C 52, 759–764 (2007)*



PDE for MPPC-S14160 (Hamamatsu)



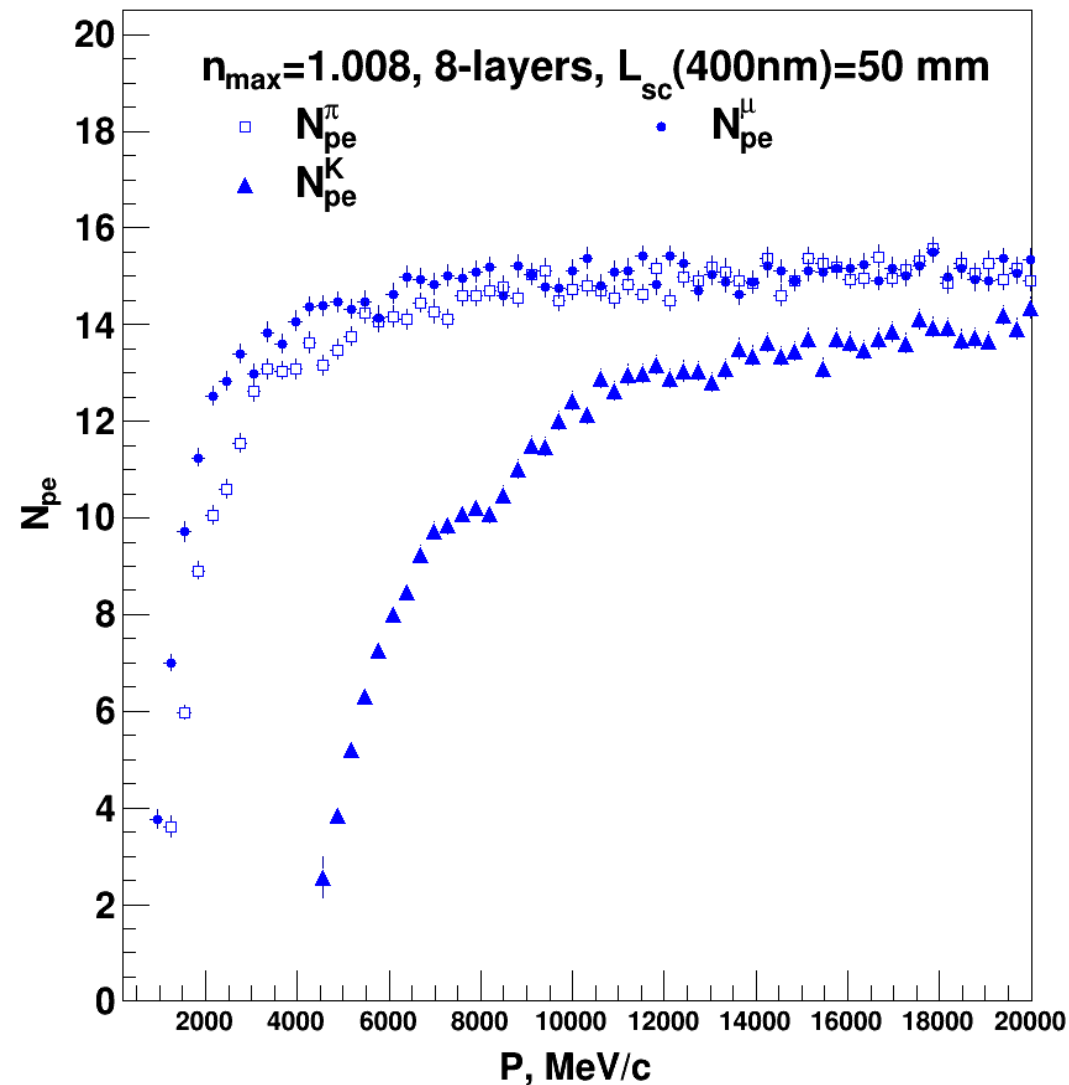
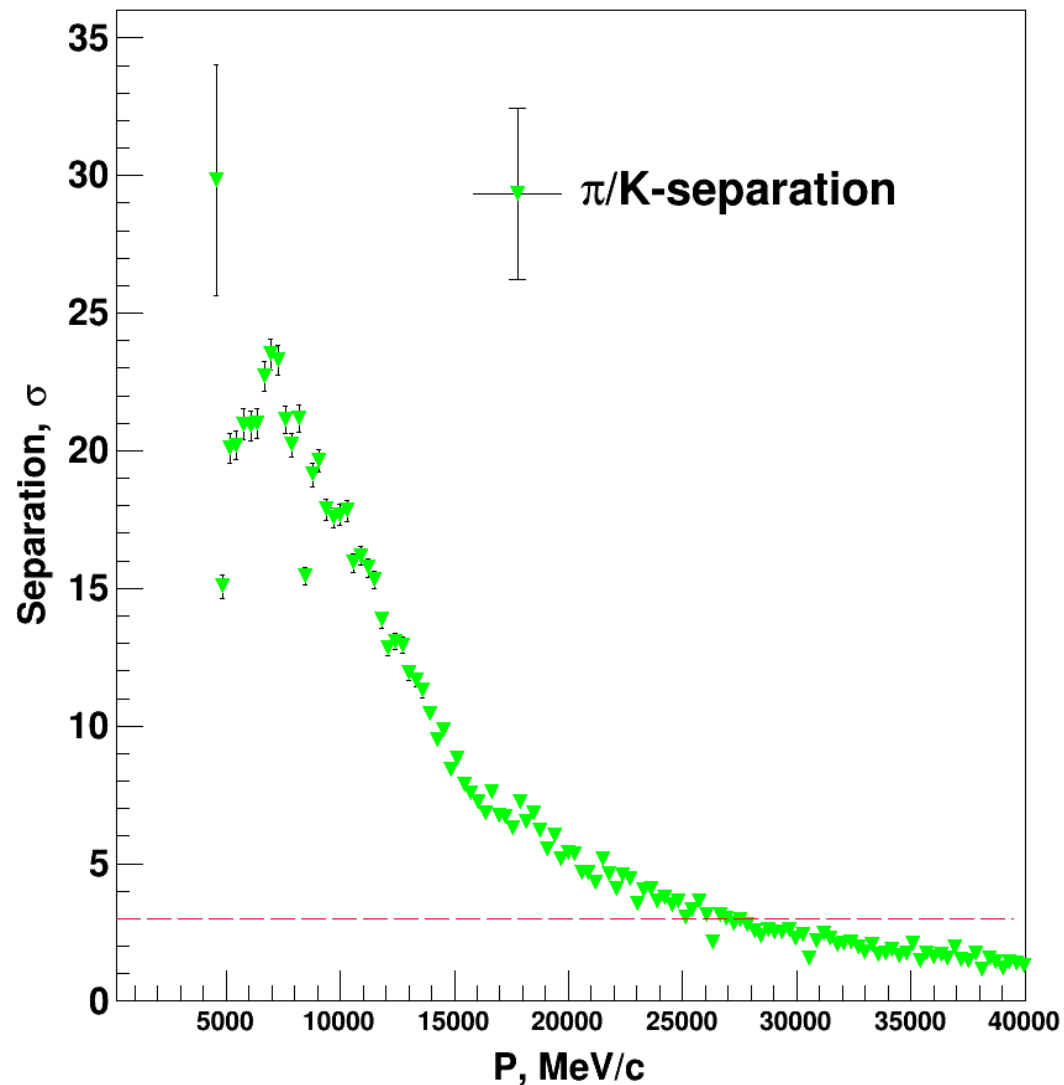
SiPM PSS15 11-3030 from NDL (China)

$$x_c = \frac{L}{2} \cdot k \cdot \frac{(Q_2 + Q_3) - (Q_1 + Q_4)}{(Q_1 + Q_2 + Q_3 + Q_4)}$$

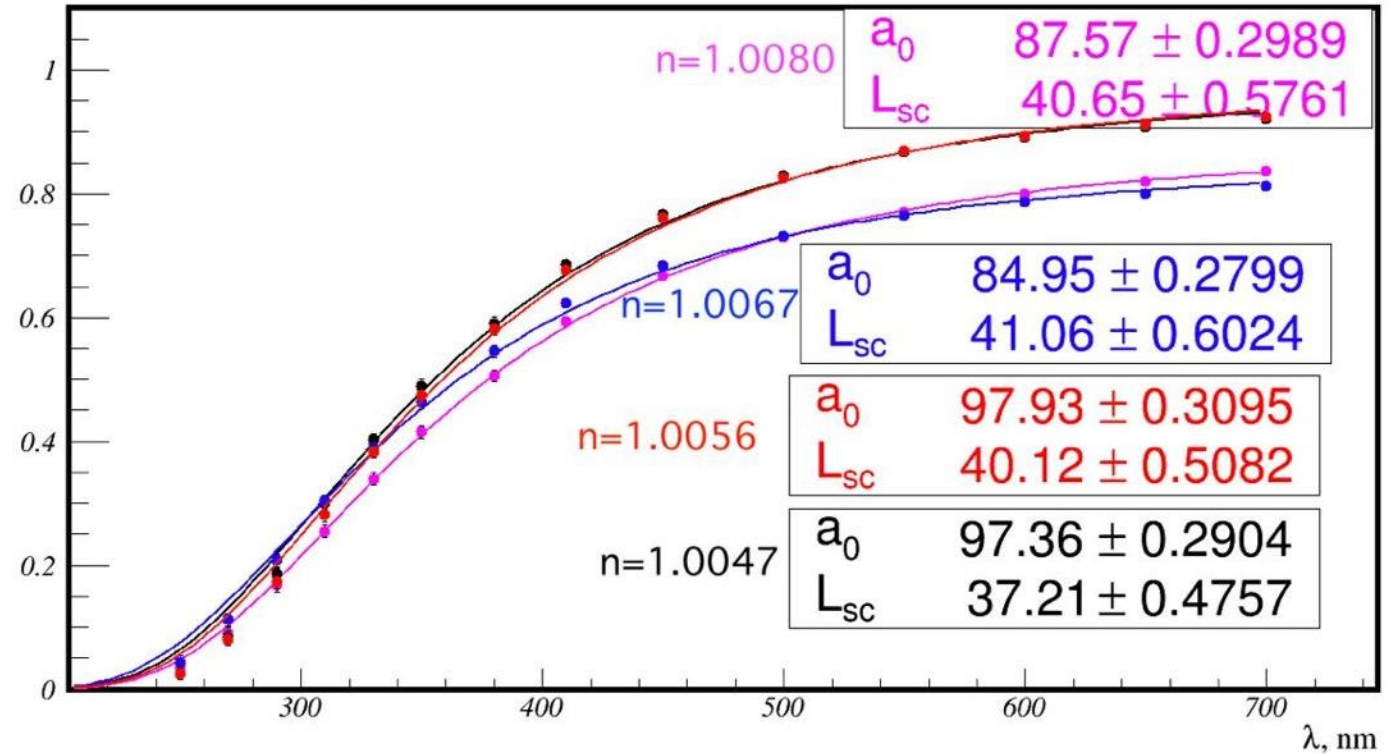
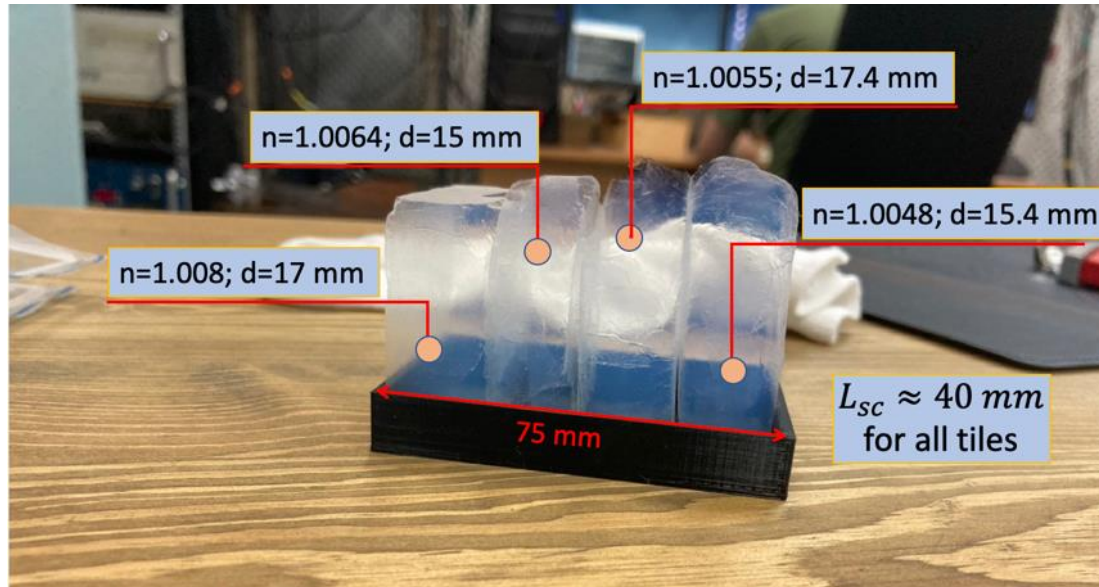
$$y_c = \frac{L}{2} \cdot k \cdot \frac{(Q_3 + Q_4) - (Q_1 + Q_2)}{(Q_1 + Q_2 + Q_3 + Q_4)}$$

Exact hit positions from G4sim are smeared by Gaussian with $\sigma_x = 200\mu\text{m}$

π/K -separation in 20÷30 GeV/c region: G4sim results

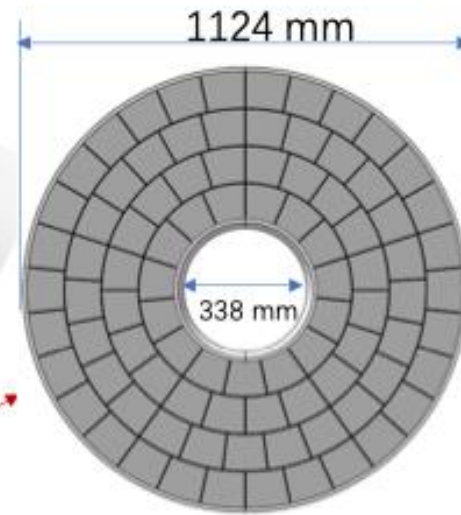
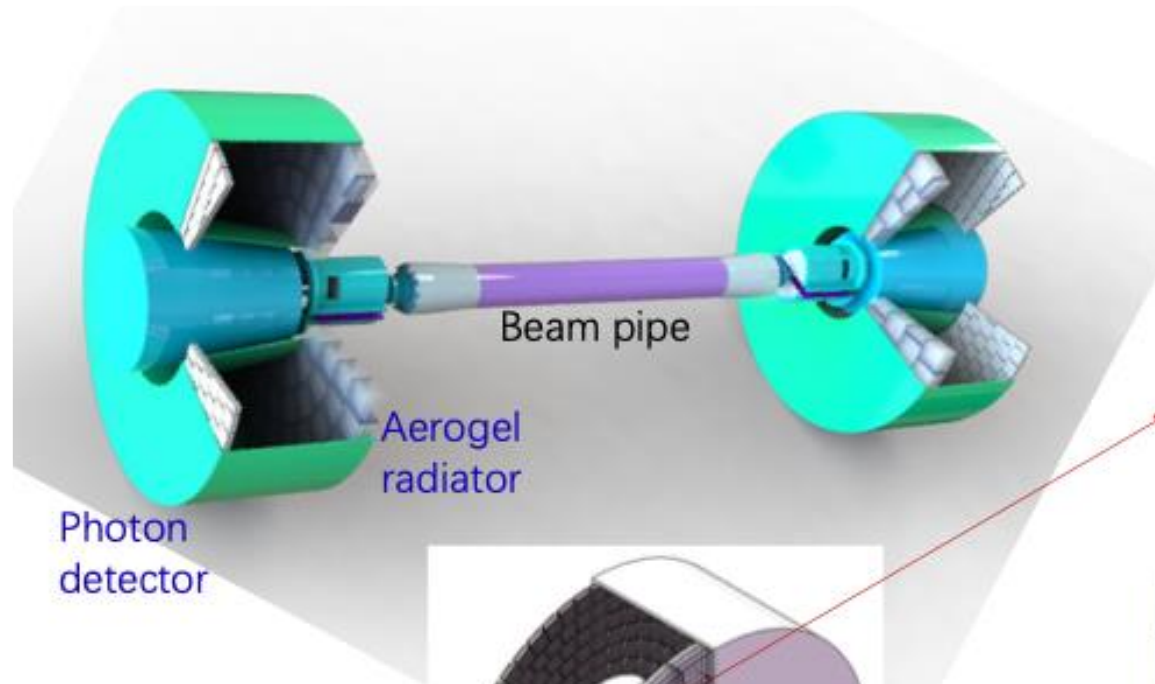


Some practical results of 2025



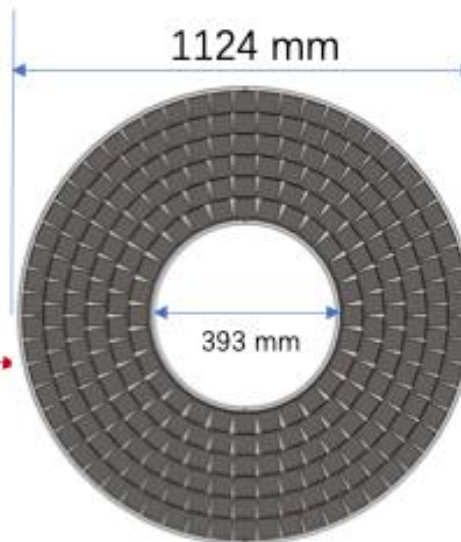
In 2025 for the first time ultra-light SiO_2 aerogels with high transparency were produced in Novosibirsk!
 Next step is produce multilayer aerogel samples with $n \leq 1.008$ and total thickness $30 \div 40$ mm

FARICH for CEPC project sketch

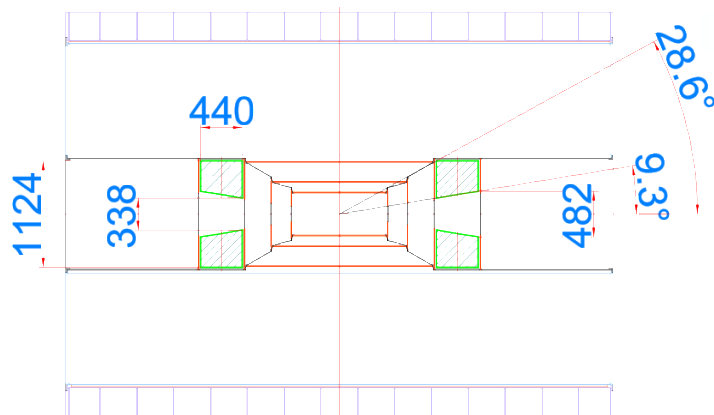
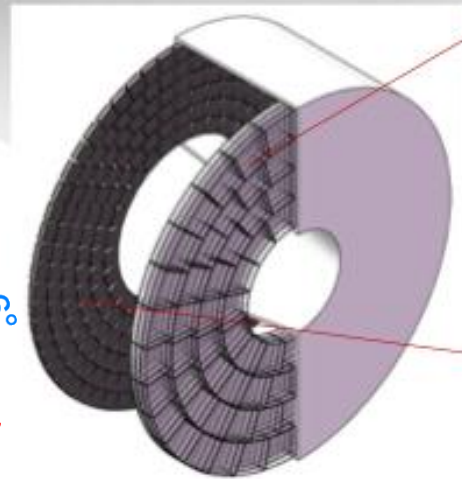


From Jian Wang,
mechanical group

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



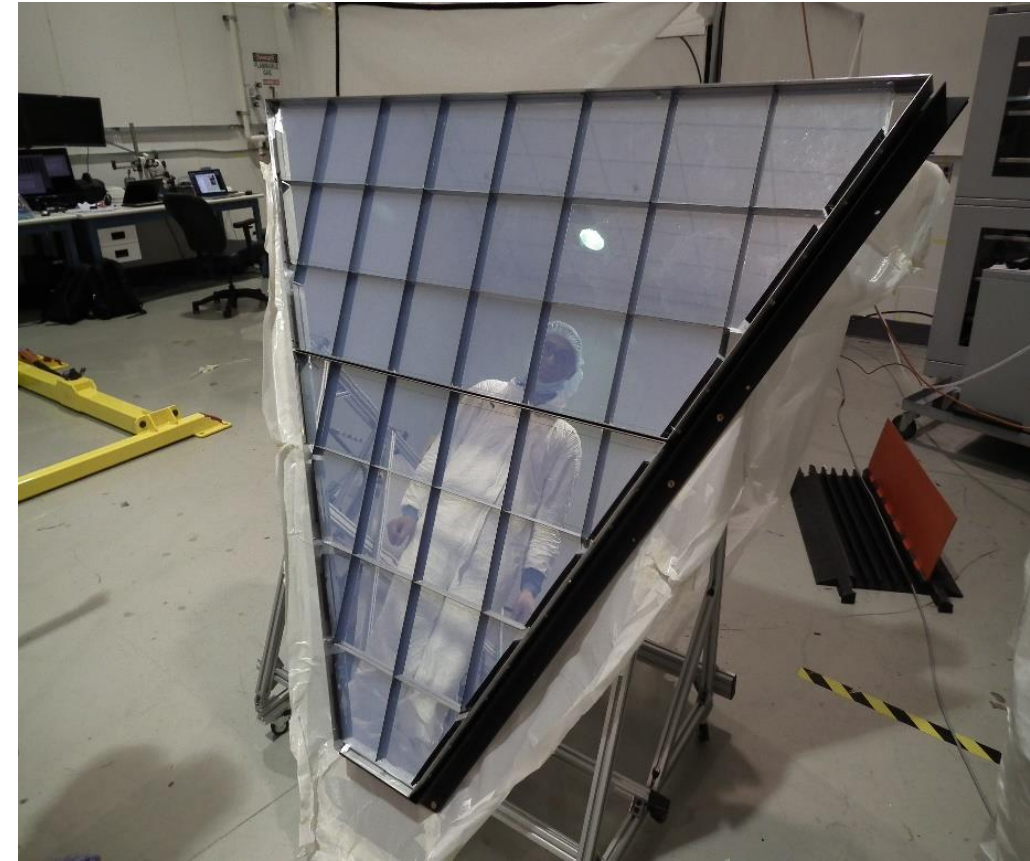
Заключение

- Разработка системы идентификации для Российского проекта Супер С-Тау фабрики сыграла определяющую роль в развитии методики ФАРИЧ
- Сегодня активно ведется разработка системы ФАРИЧ для эксперимента SPD@NICA:
 - Разрабатывается координатно-чувствительный фотоприемник
 - Идет оптимизация аэрогелевого радиатора и технологии его производства
 - Прорабатывается конструкция системы, ПО для моделирования и реконструкции, концепция FEE и DAQ
- Показано, что на основе методики ФАРИЧ с аэрогелями $n \leq 1.008$ можно разрабатывать системы идентификации для π/K разделения в области импульсов $20 \div 30$ ГэВ/с

BACK UP SLIDES

History of aerogel radiators in Novosibirsk

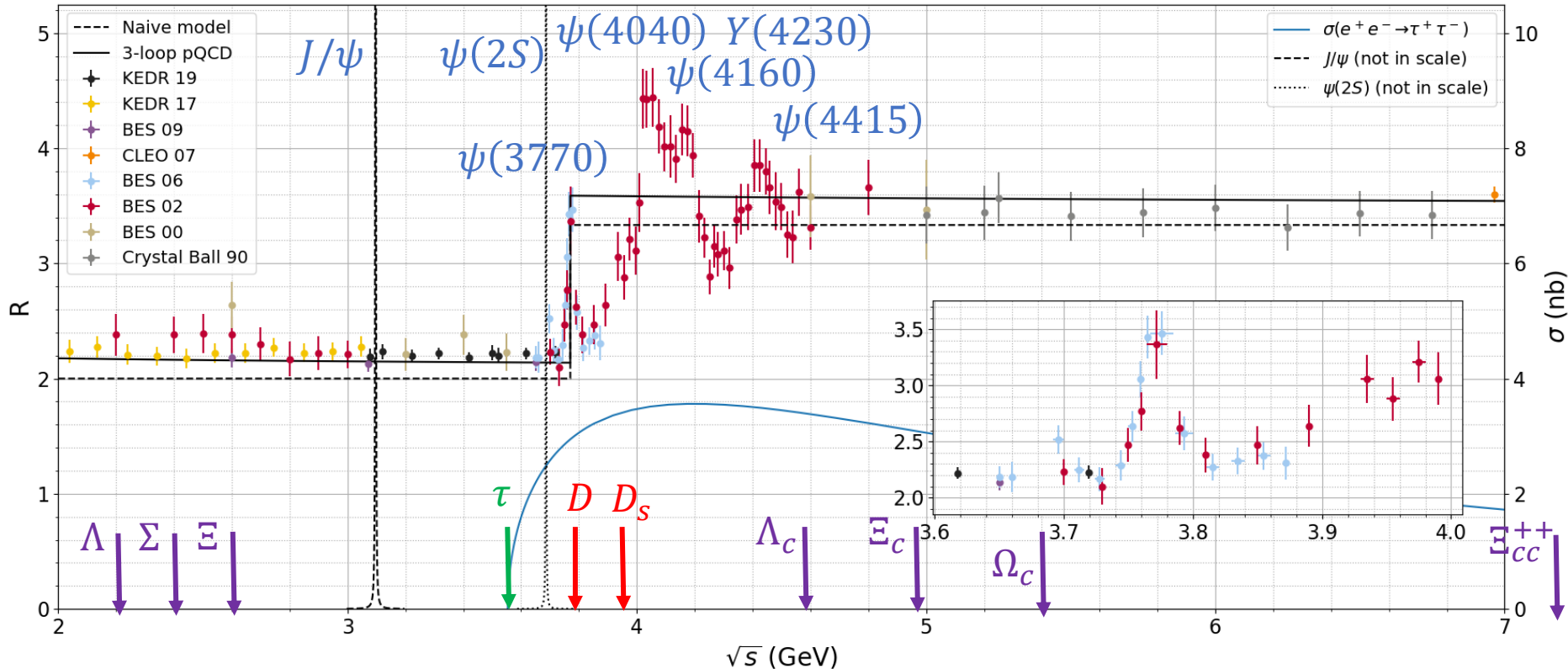
- **KEDR ASHIPH** system (VEPP-4M – BINP):
 - π/K -separation in the momentum range $0,6 \div 1,5$ GeV/c.
 - Aerogel $n = 1,05$ ($V \sim 1000$ L).
- **SND ASHIPH** system (VEPP-2000 – BINP):
 - π/K -separation in the momentum range $300 \div 870$ MeV/c.
 - Aerogel $n = 1,13$ ($V \sim 9$ L).
- **DIRAC-II** (PS – CERN):
 - π/K -separation in the momentum range $5,5 \div 8,0$ GeV/c.
 - Aerogel $n = 1,008$ ($V \sim 9$ L).
- **AMS-02** aerogel RICH (ISS):
 - Search for antimatter, study of cosmic rays.
 - Aerogel $n = 1,05$ ($S \sim 1$ m²).
- **LHCb** aerogel RICH (LHC – CERN):
 - π/K -separation in the momentum range $5,5 \div 8,0$ GeV/c.
 - Aerogel $n = 1,03$ ($S \sim 0,5$ m²), aerogel tile $20 \times 20 \times 5$ cm³.
- **CLAS-12** aerogel RICH (J-Lab):
 - π/K - & K/p -separation at level 4σ with several momentum GeV/c.
 - Aerogel $n = 1,05$ ($S \sim 6$ m²), aerogel tile $20 \times 20 \times 2-3$ cm³.



The SCT energy range

$$R \equiv \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma_0(e^+e^- \rightarrow \mu^+\mu^-)}$$

Threshold production of nonrelativistic particles provides best conditions for their comprehensive study



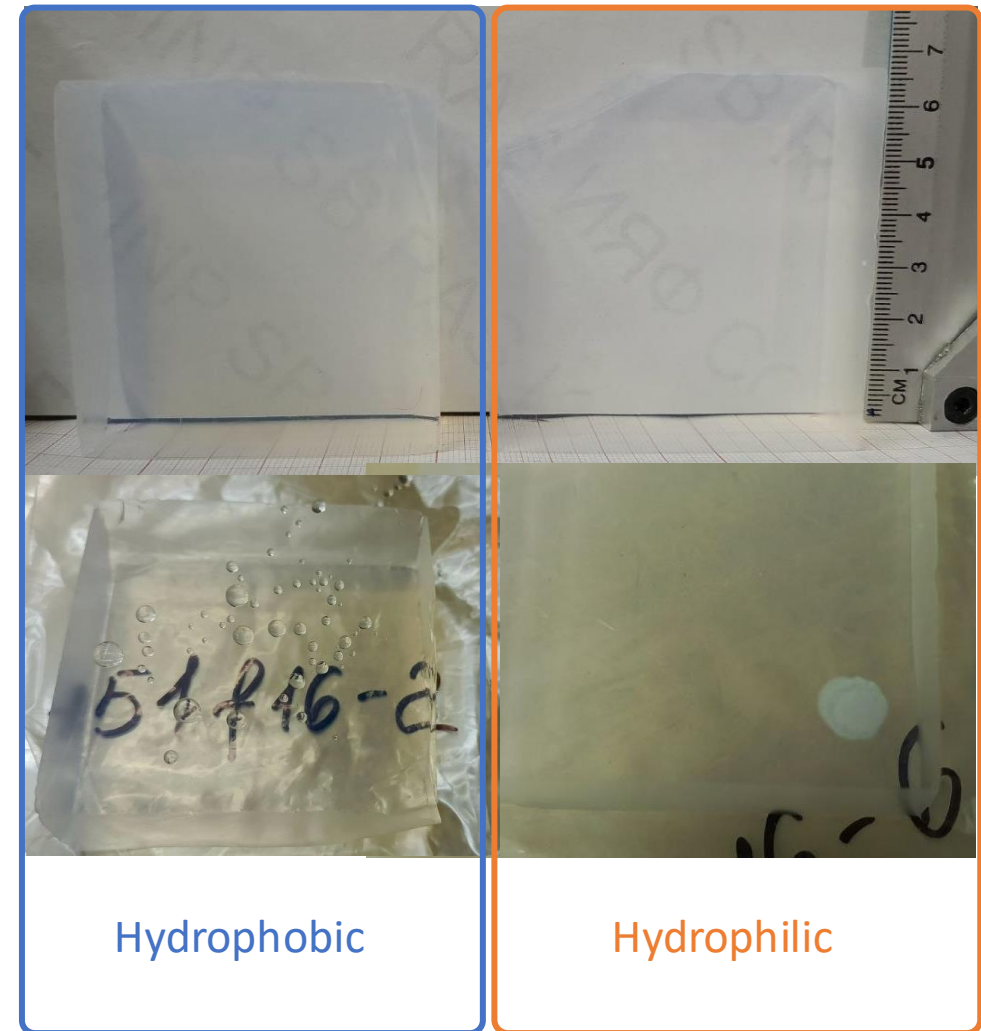
$$\mathcal{L} = 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$$

A one-year dataset

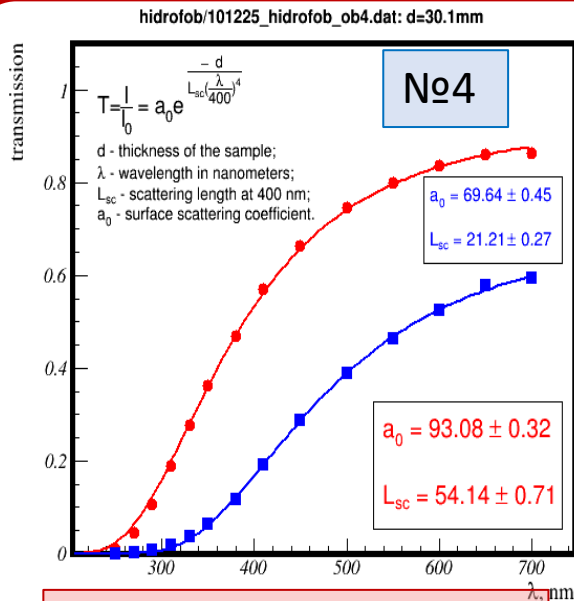
$2E, \text{ GeV}$	Events recorded
3.1	$10^{12} J/\psi$
3.69	$10^{11} \psi(2S)$
3.77	$10^9 D\bar{D}$
4.17	$10^8 D_s\bar{D}_s$
$3.55 \div 4.3$	$10^{10} \tau\tau$
4.65	$10^8 \Lambda_c^+ \Lambda_c^-$

The first experience with hydrophobization #1

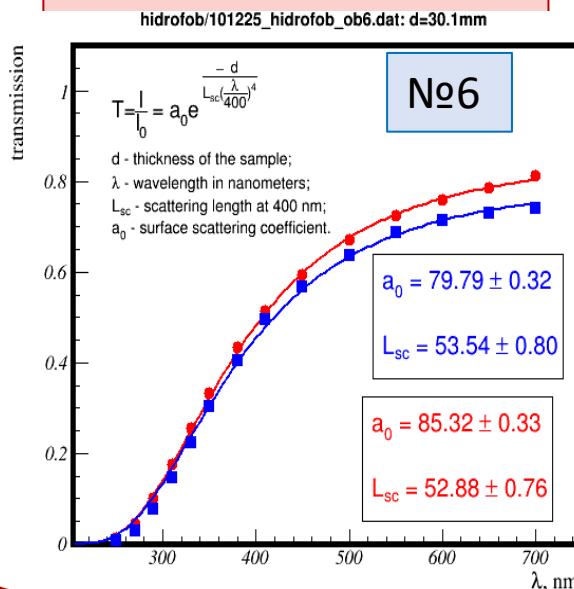
- Production of thick hydrophobic tiles is limited by large time of fabrication because the clarification processes have to be done at low temperatures (below 175°C)
- The main idea is to produce thick multilayer aerogels with standard Novosibirsk's procedure when optical clarification is obtained due to burning of the most organic additions in aerogel and after that make hydrophobization in the vapors of the **HexaMethylDiSilasane** ($[(CH_3)_3Si]_2NH$)



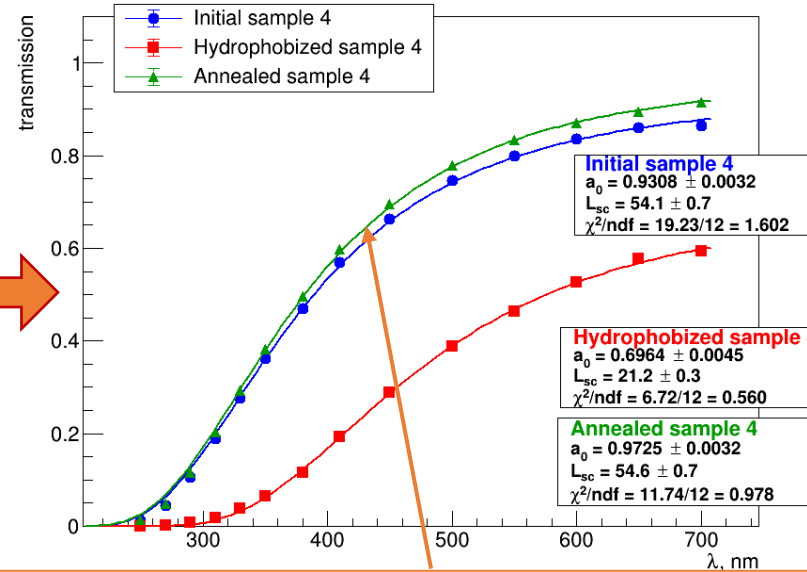
The first hydrophobization experience #2



HMDS – 5% (3 samples)



Sample 4



- 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 destroyed 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

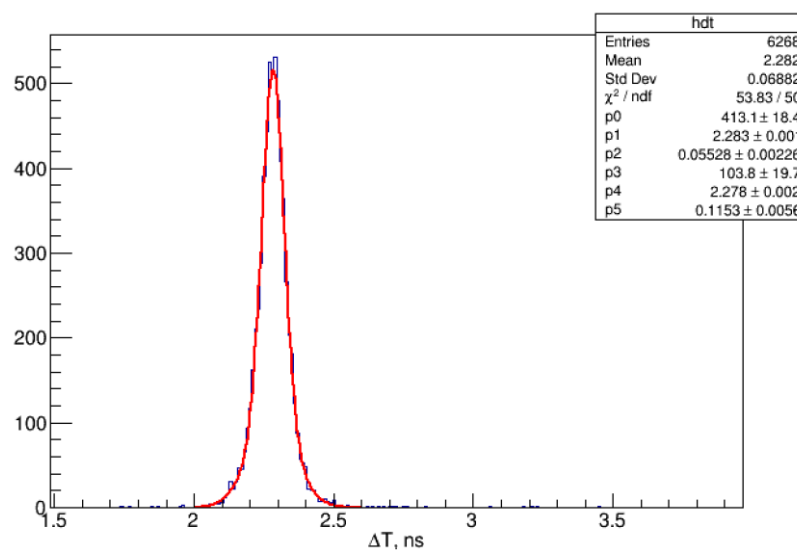
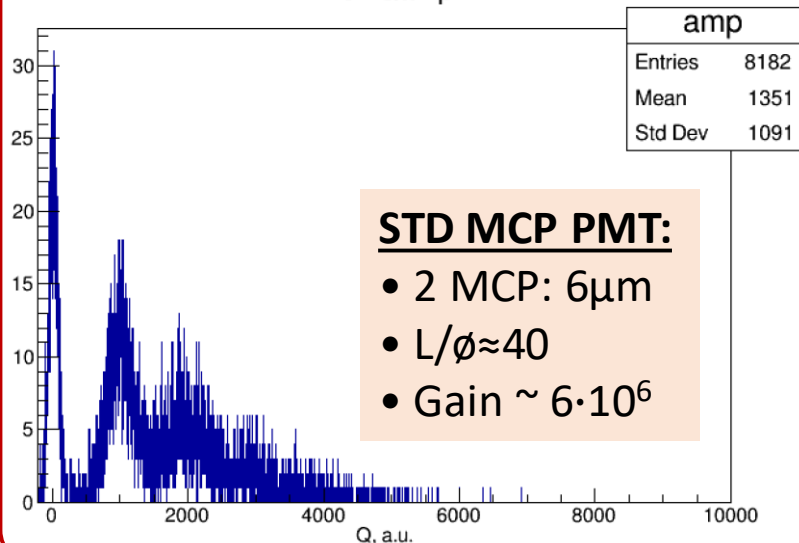


The first practical output:

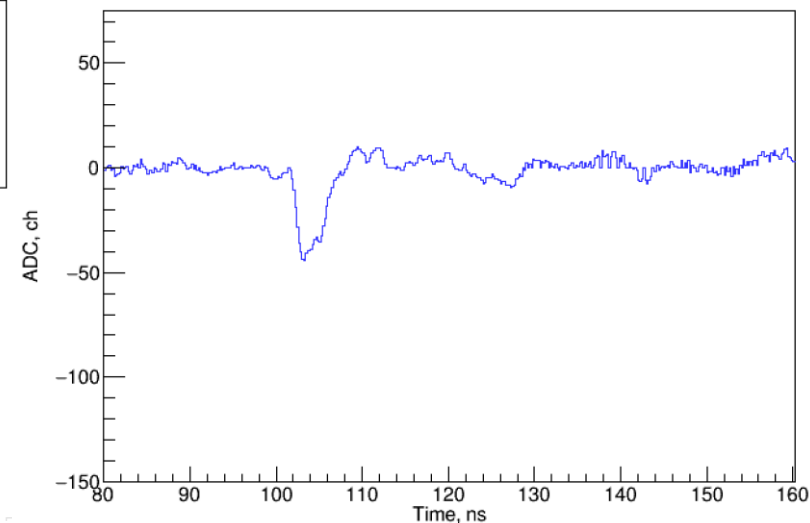
We can produce aerogels as we need (highly transparent, thick and so on), then make tooling after hydrophobization and restore its transparency before the assembling the detector.

MCP optimisation with ALD #2: SPE & TTS

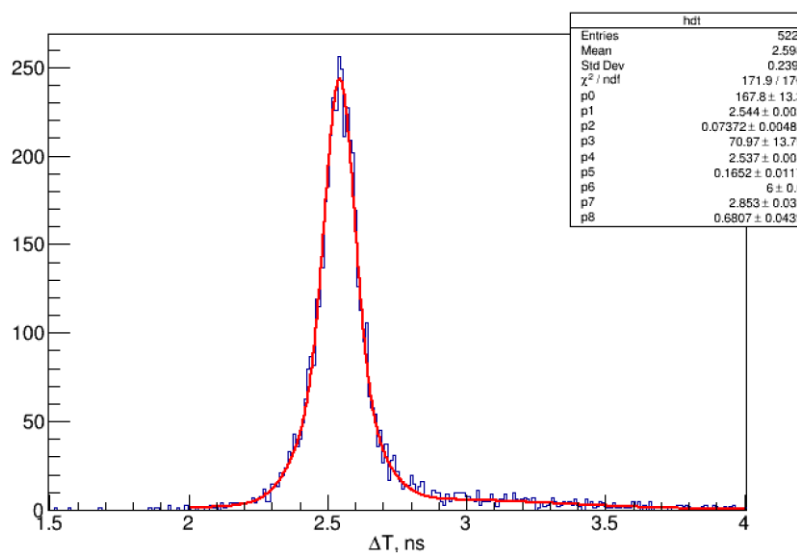
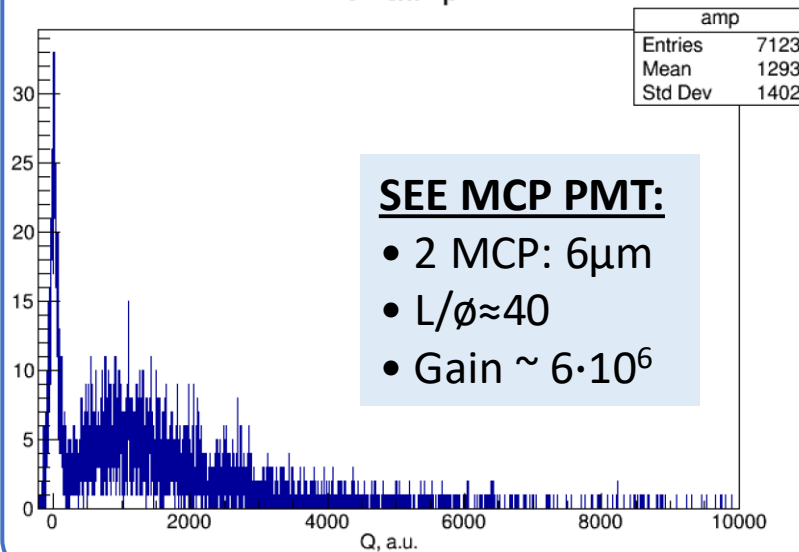
MCPQamp



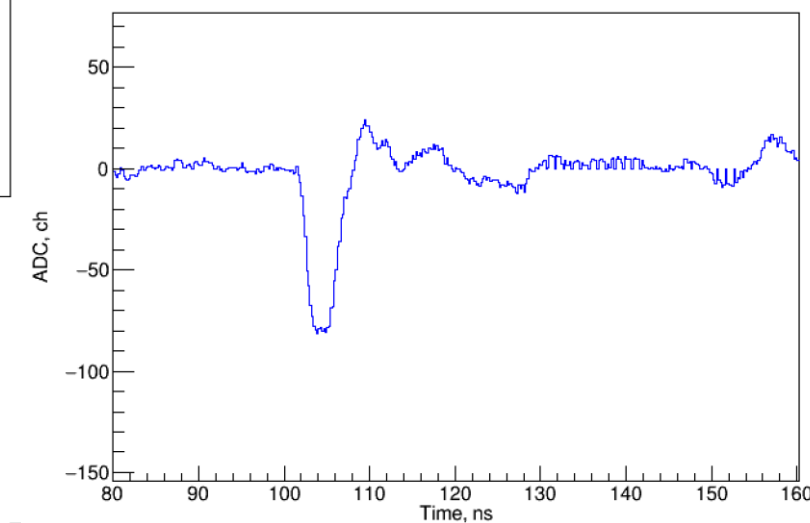
Signal shape



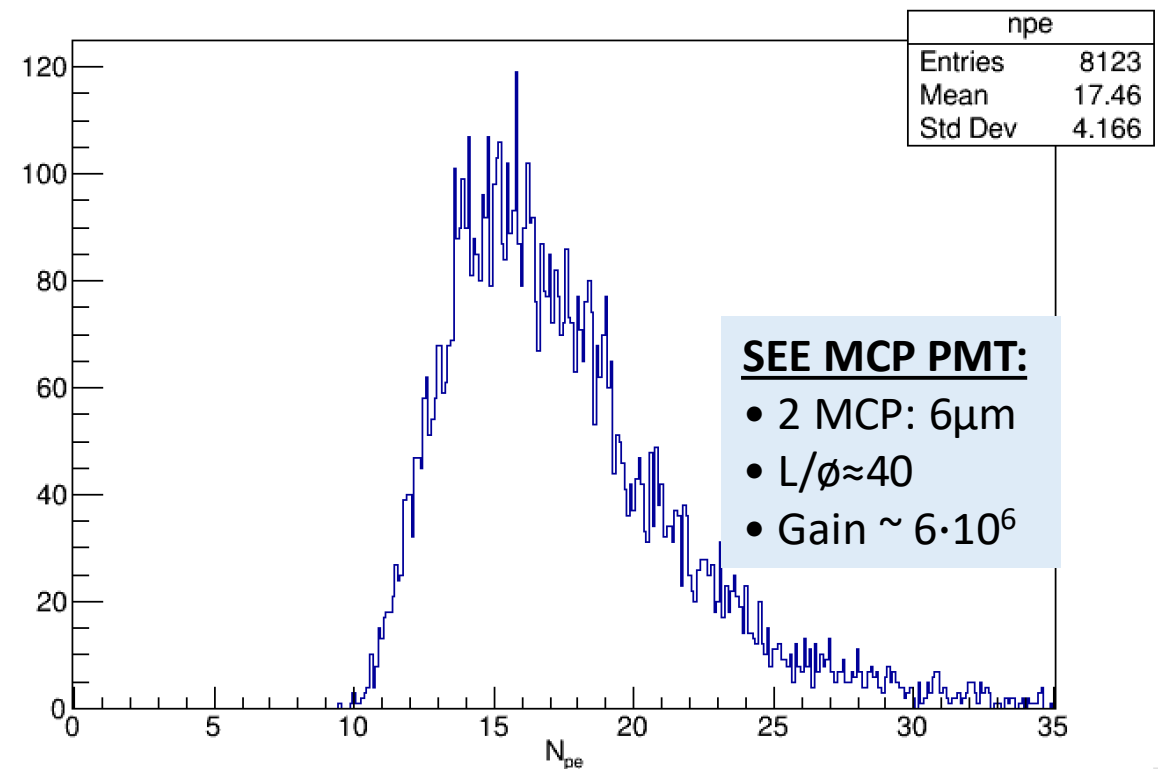
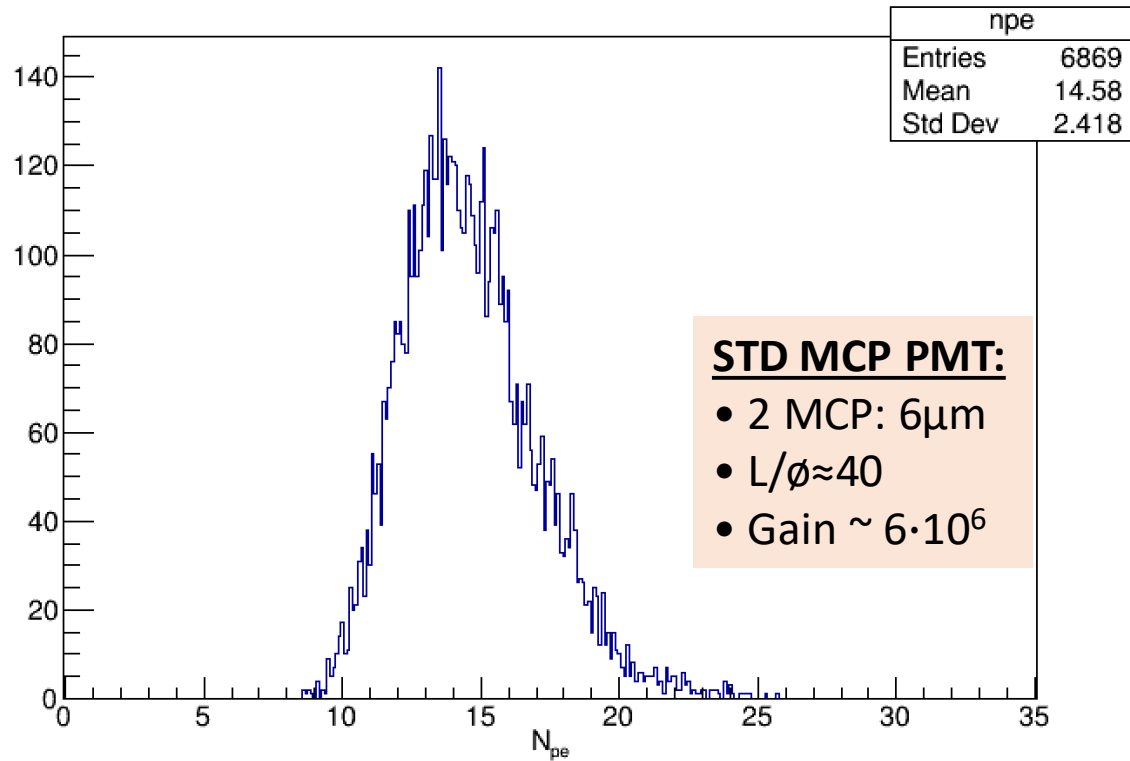
MCPQamp



Signal shape



MCP optimisation with ALD #3: PE Collection Eff.



$$\frac{CE(SEE)}{CE(STD)} = \frac{N_{pe}(SEE) / QE(SEE)}{N_{pe}(STD) / QE(STD)} = \frac{17.46 / 19.65}{14.58 / 20.49} \approx 1.25$$

Practical output:

- SEE MCP Gain $\sim 1 \div 15 \cdot 10^6$
 - $CE(SEE) \approx 1.25 \cdot CE(STD)$
 - TTS(SEE) worse than TTS(STD)
- Further R&D and optimization is needed.

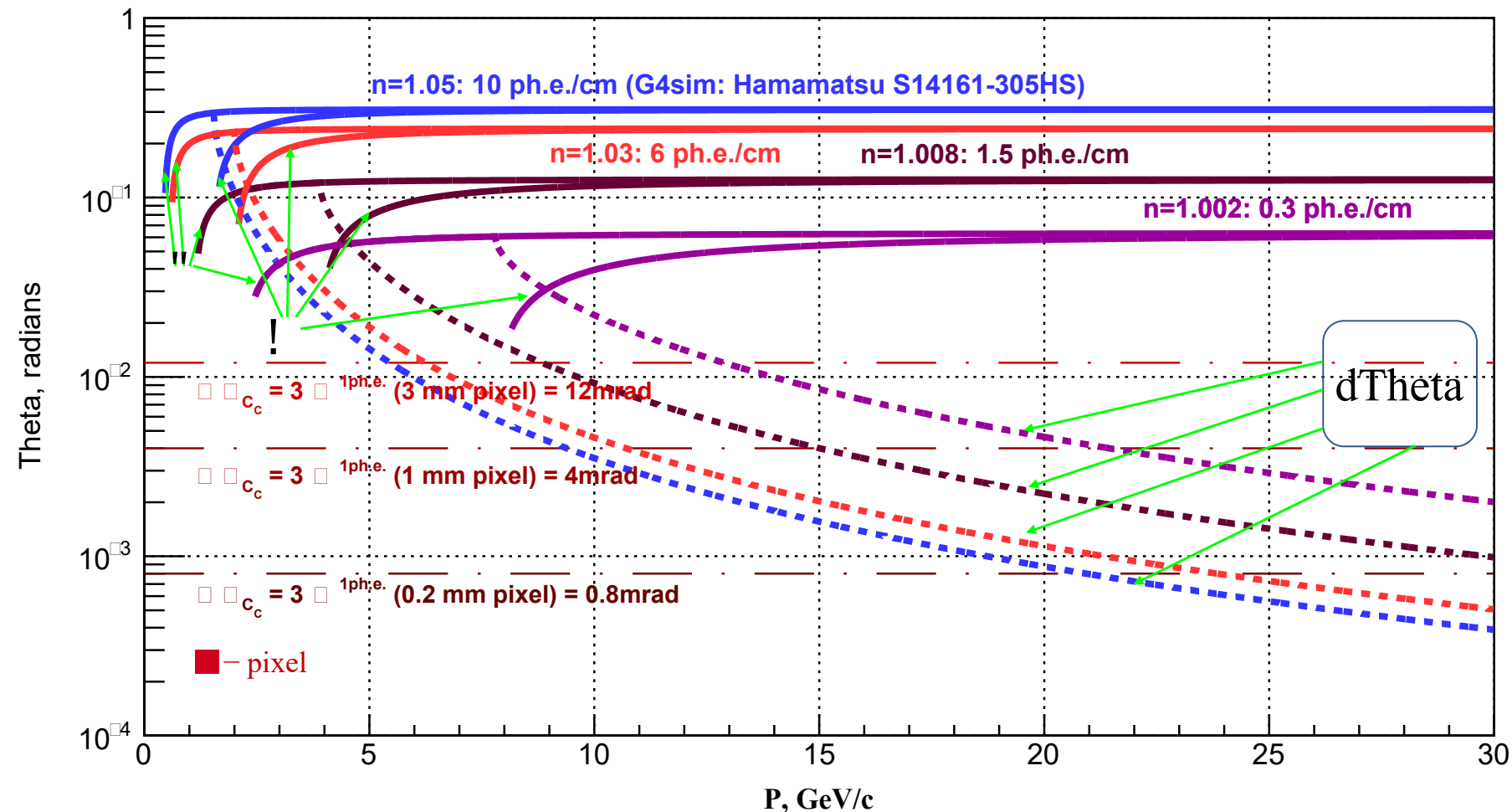
Набранные данные:

Date	aerogels	P, GeV/c	Number, events	Comments
12.03.2026	460f5 4-layer SCTF	5	425k	$n_{\max}=1.046$, $t=35$ mm, 230×230 mm ²
13.03.2026	467 8 3-layer SPD	5	400k	$n_{\max}=1.040$, $t=40$ mm, 100×100 mm ²
	467 1 4-layer SPD	5	340k	$n_{\max}=1.040$, $t=40$ mm, 100×100 mm ²
	467f10 1 4-layer SCTF	5	230k	$n_{\max}=1.046$, $t=35$ mm, 200×60 mm ²
	467f10 1 4-layer SCTF	3	600k	$n_{\max}=1.046$, $t=35$ mm, 200×60 mm ²
14.03.2026	467 1 4-layer SPD	3	600k	$n_{\max}=1.040$, $t=40$ mm, 100×100 mm ²
	467 8 3-layer SPD	3	600k	$n_{\max}=1.040$, $t=40$ mm, 100×100 mm ²
	460f5 4-layer SCTF	3	200k	$n_{\max}=1.046$, $t=35$ mm, 230×230 mm ²
	460f5 4-layer SCTF	1,5	50k	$n_{\max}=1.046$, $t=35$ mm, 230×230 mm ²
15.03.2026	460f5 4-layer SCTF	6	1M	$n_{\max}=1.046$, $t=35$ mm, 230×230 mm ²
	467 8 3-layer SPD	6	600k	$n_{\max}=1.040$, $t=40$ mm, 100×100 mm ²
	467 1 4-layer SPD	6	600k	$n_{\max}=1.040$, $t=40$ mm, 100×100 mm ²
	467 1 4-layer SPD	10	600k	$n_{\max}=1.040$, $t=40$ mm, 100×100 mm ²
	460f5 4-layer SCTF	10	600k	$n_{\max}=1.046$, $t=35$ mm, 230×230 mm ²
	467 8 3-layer SPD	10	600k	$n_{\max}=1.040$, $t=40$ mm, 100×100 mm ²

Тестировались 3- и 4-
слойные радиаторы для SPD,
а также радиатор для C-Тау.

RICH detectors capability for π/K -separation

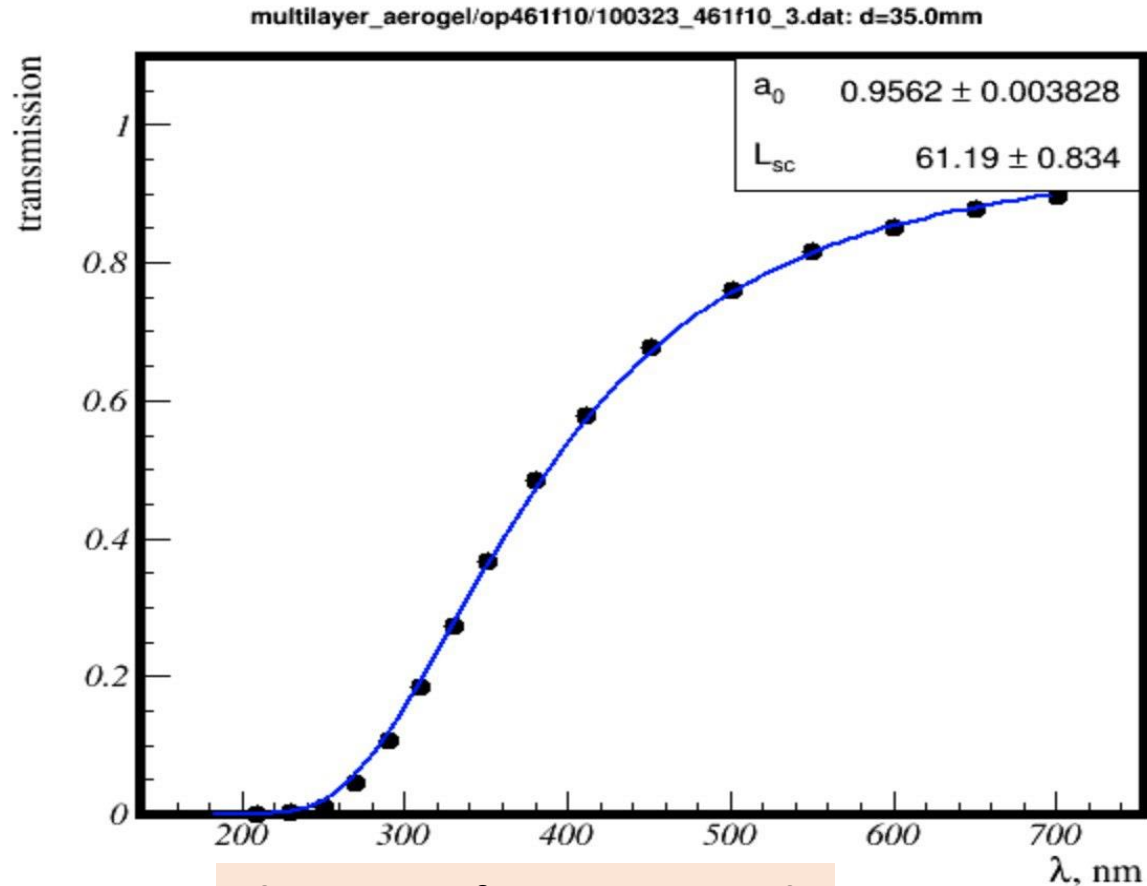
□ / □ separation



- At least 5 hits have to be detected to reconstruct Cherenkov ring.
- Thickness of Cherenkov radiator should be:
 - ≥ 1 cm for $n=1.05$ (aerogel)
 - ≥ 4 cm for $n=1.008$ (aerogel)
 - ≥ 15 cm for $n=1.002$ (C_5F_{12})
- Some focusing system is needed to provide impact from thickness at the level of few mrad for base 200÷300 mm!!!

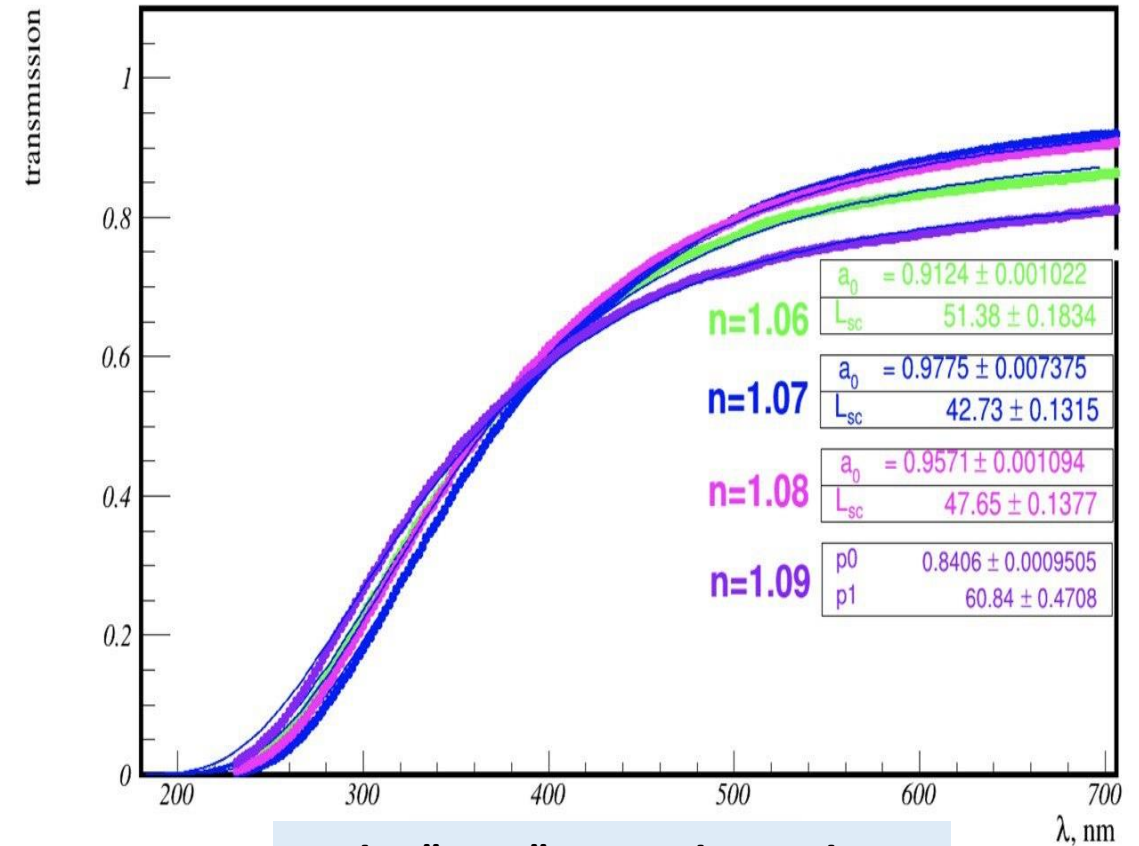
- $\sigma_C^{tr} = 1/\sqrt{N_{pe}} \cdot \sqrt{\left(\frac{\Delta_{pix} \cdot \cos \theta_C}{L \cdot \sqrt{12}}\right)^2 + \left(\frac{\sigma_n}{n \cdot \tan \theta_C}\right)^2 + \left(\frac{t \cdot \sin \theta_C}{L \cdot \sqrt{12}}\right)^2} + \sigma_{tr}^2 \sim \sqrt{t}$
- $N_{pe}(\beta = 1) \sim 500 \cdot \frac{n^2 - 1}{n^2} \cdot t \cdot QE$

Highly transparent aerogels with $n > 1.05$



The Largest focusing aerogel:

- $n_{\max} = 1.05$
- 4 layers
- 230x230x35 mm

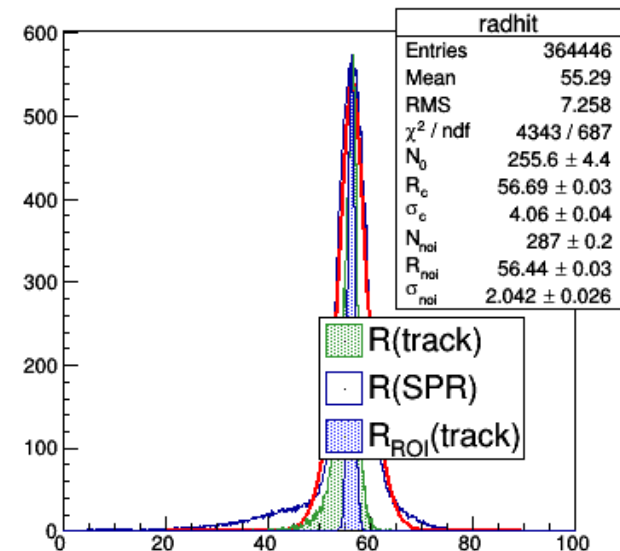
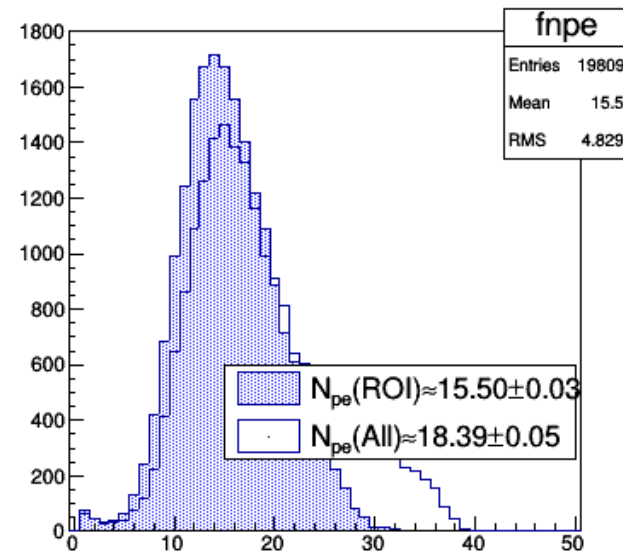
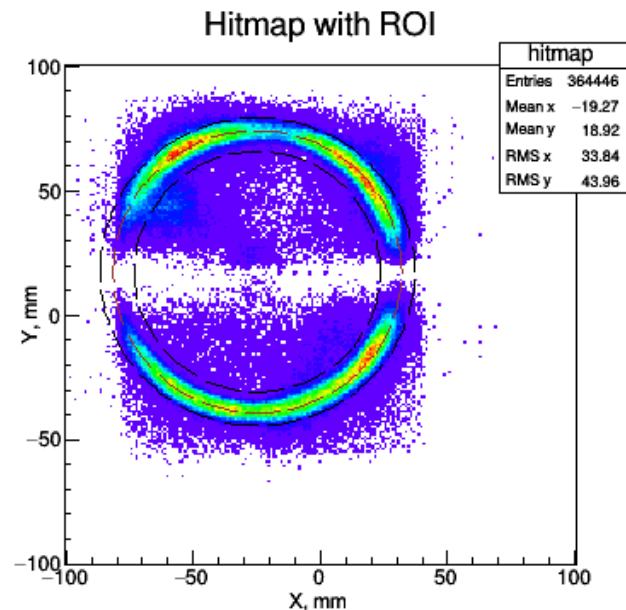


The "new" aerogel samples
with different refractive indexes:
from $n=1.06$ to 1.09
(thickness ~ 22 mm)

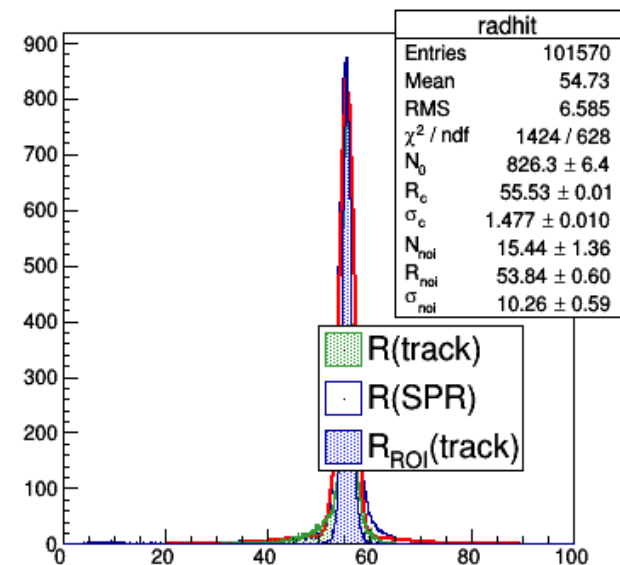
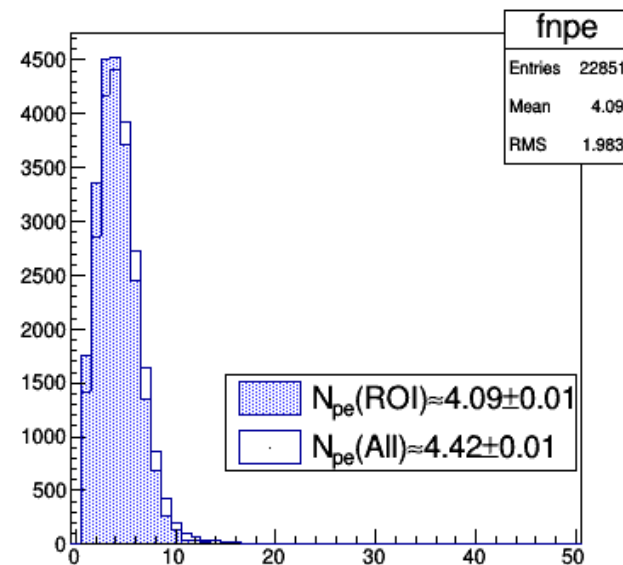
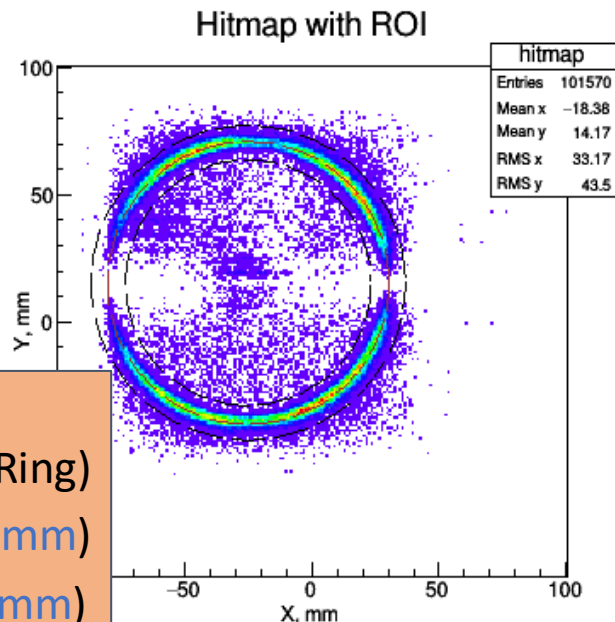
FARICH based on 4-layer aerogel with $n_{\max} = 1.08$ will provide μ/π -separation from **250 MeV/c!!!**

Recent beam test results

Pixel 6x6 mm
Geom.Eff. ~ 80%



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)
- $\sigma_{\theta}^{1pe} \approx 7.5 \text{ mrad}$ (■ 3mm)