Status of Cherenkov counters prototyping for the SPD experiment

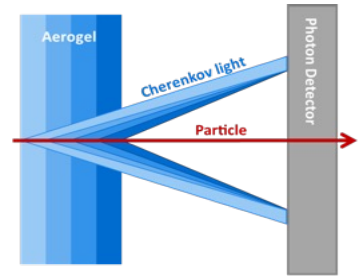
A.Yu.Barnyakov on behalf of PID group

- FARICH prototype status and progress:
  - Aerogel optimization and production
  - Status of MCP PMT development in Russia
  - Status of preparation of the prototype for mixed hadron beam tests
- ASHIPH prototype status and plans for beam tests
- Summary and other R&D activities supported by MSHE

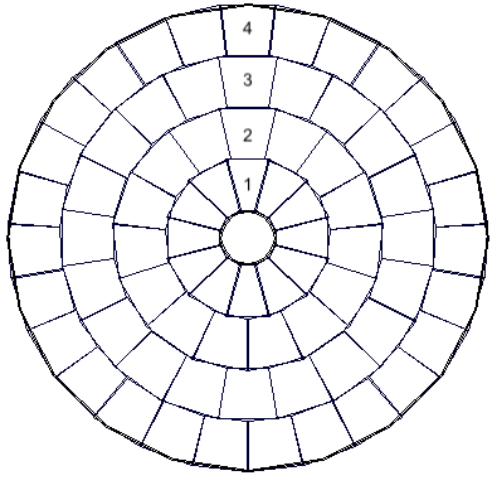
SPD Collaboration Meeting

5-8 November2024, JINR, Dubna, Russia

FARICH system conceptual design

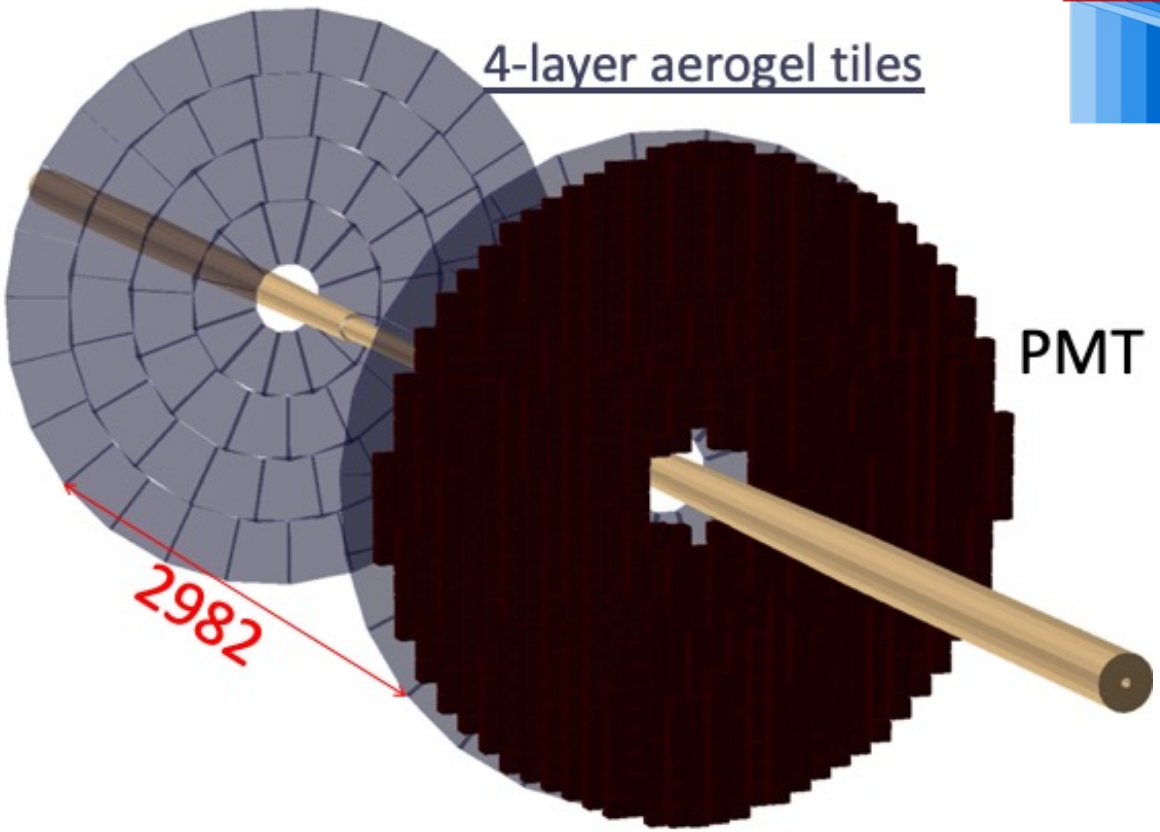


Aerogel:
74 tiles

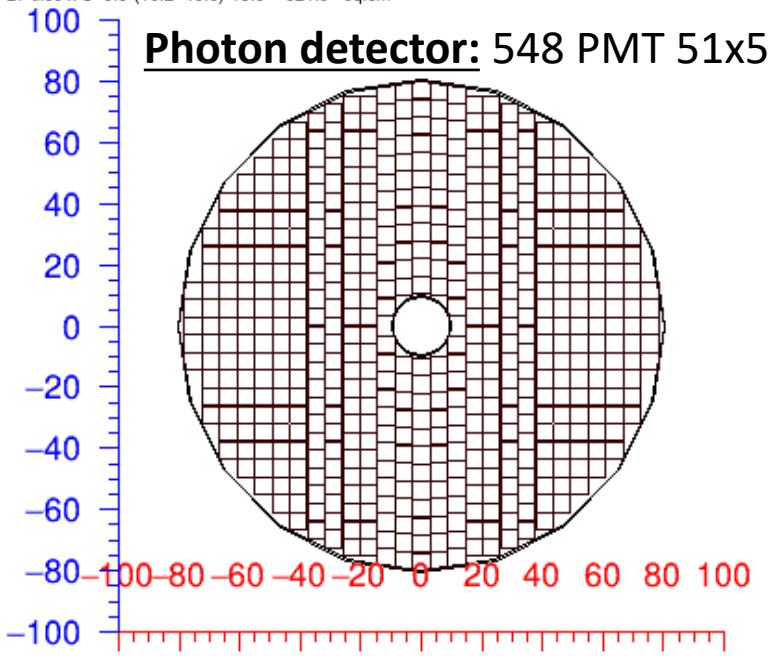


1 – 12 tiles x S=0.5•(5.6 + 15.6)•18.5 = 159.0 sq.cm
2 – 15 tiles x S=0.5•(12.2+20.2)•18.5 = 299.7 sq.cm
3 – 20 tiles x S=0.5•(15.0+20.8)•18.5 = 331.15 sq.cm
4 – 27 tiles x S=0.5•(15.2+19.6)•18.5 = 321.9 sq.cm

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



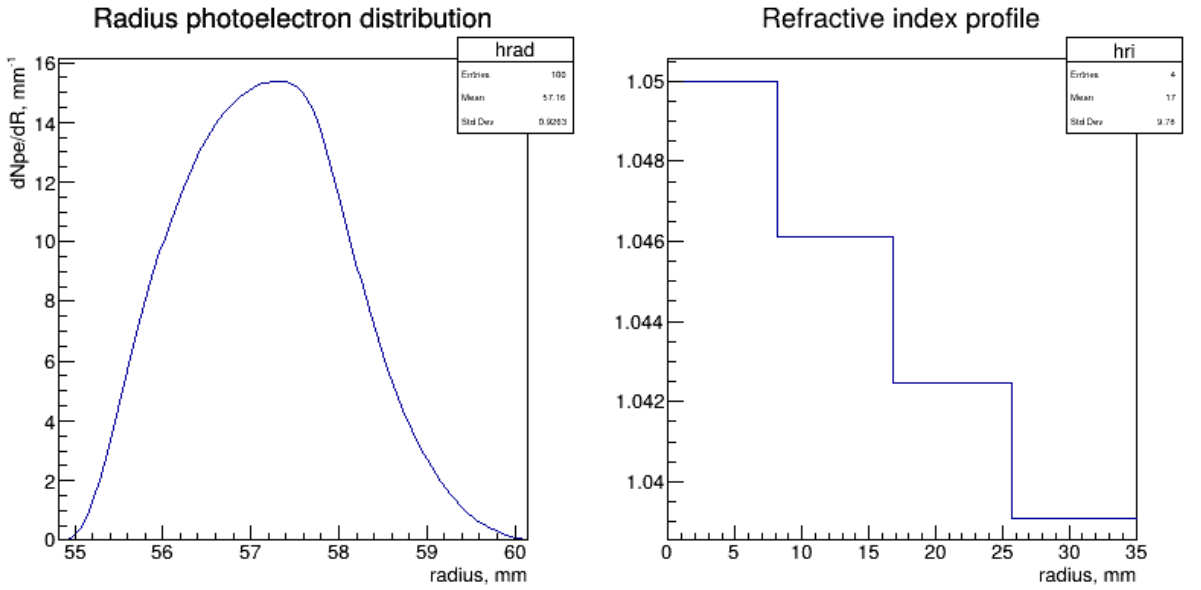
Photon detector: 548 PMT 51x51 mm

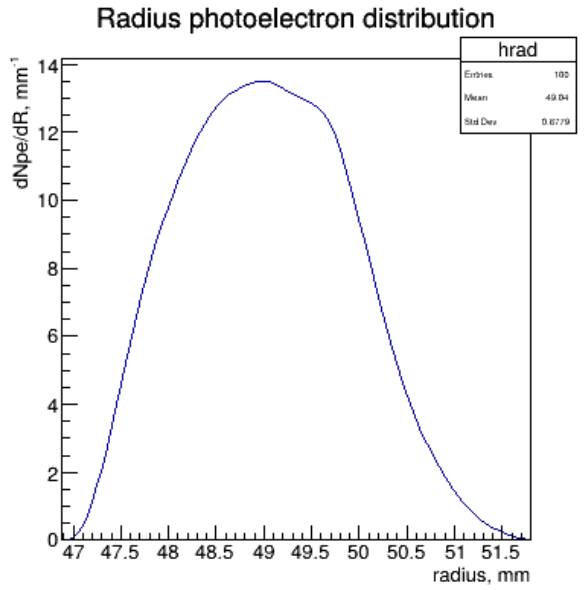


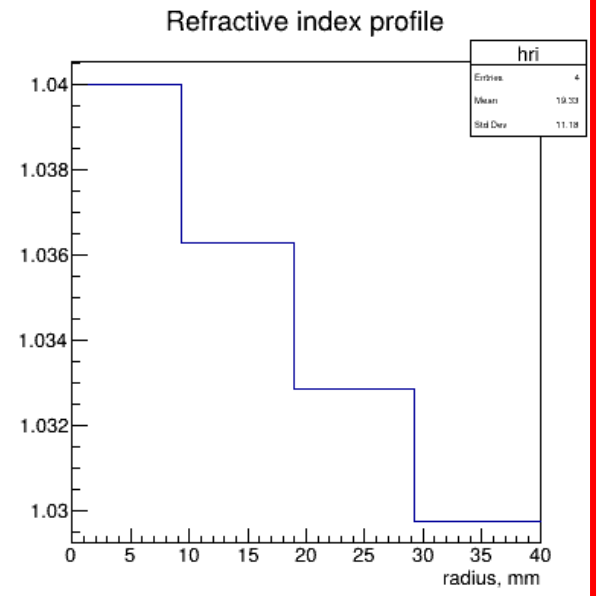
FARICH system:

- 4-layer aerogel with n_{max}=1.05 (or less)
- Focus distance – 20 cm
- PS PD – MCP-PMT or SiPM arrays with pixel 3÷6 mm
  550 PMTs per endcap if lateral sizes ~51x51 mm
  2200 PMTs per endcap if lateral sizes ~27x27 mm

Aerogel optimization and status of production

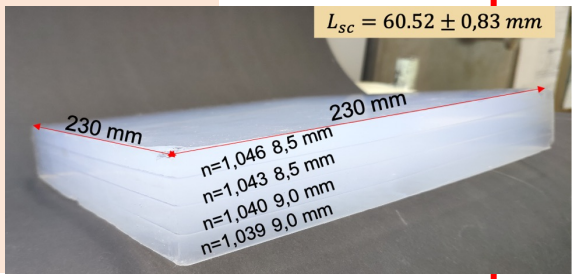






4-layer aerogel with n_{max}=1.05 and t_{tot}=35 mm

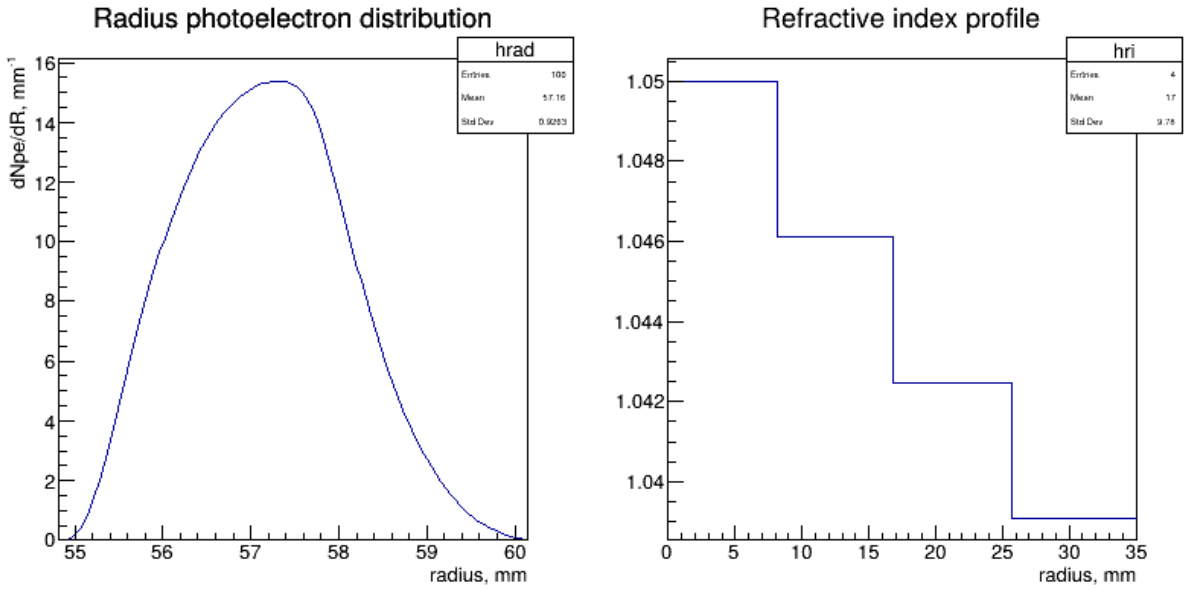
- PDE for H12700 and pixel 6×6 mm
- N_{pe}≈40
- $\sigma_{tr}^{\theta_c} \approx 1.6$ mrad
- π/K–separation at 6 GeV/c – 6.0 σ
- Already exist
- Material budget ~ 3%X_0

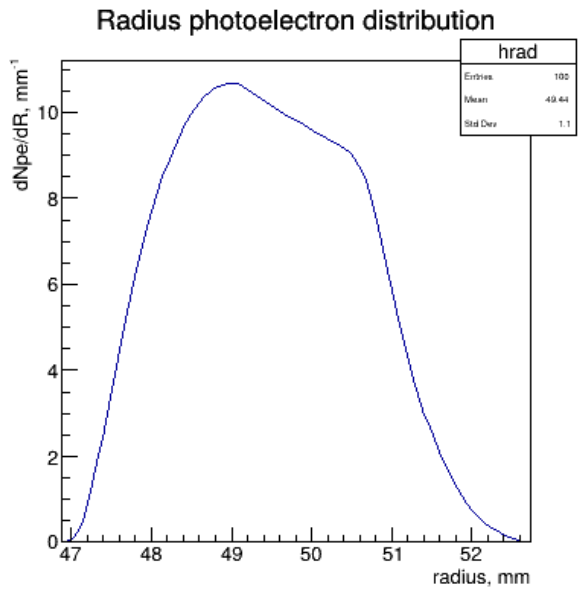


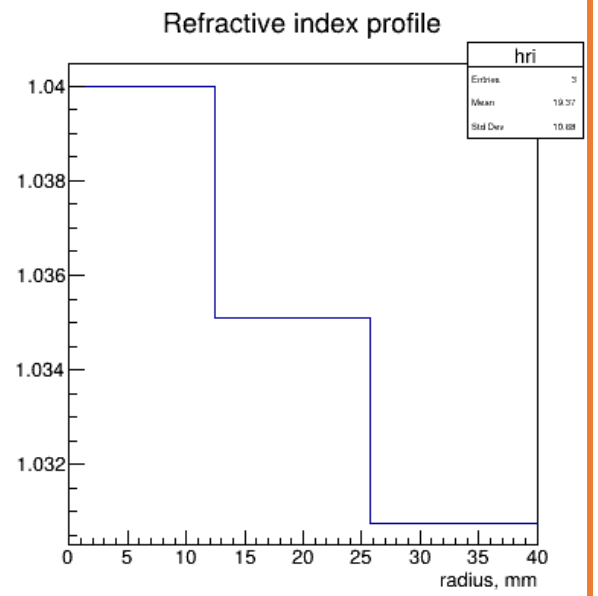
4-layer aerogel with n_{max}=1.04 and t_{tot}=40 mm

- PDE for H12700 and pixel 6×6 mm
- N_{pe}≈34
- $\sigma_{tr}^{\theta_c} \approx 1.7$ mrad
- π/K–separation at 6 GeV/c – 6.5 σ
- “New4”
- Material budget ~ 2.7%X_0

Aerogel optimization and status of production

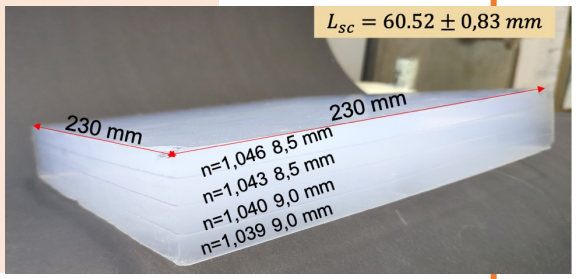






4-layer aerogel with n_{max}=1.05 and t_{tot}=35 mm

- PDE for H12700 and pixel 6×6 mm
- N_{pe}≈40
- $\sigma_{tr}^{\theta_c} \approx 1.6$ mrad
- π/K–separation at 6 GeV/c – 6.0 σ
- Already exist
- Material budget ~ 3%X_0



3-layer aerogel with n_{max}=1.04 and t_{tot}=40 mm

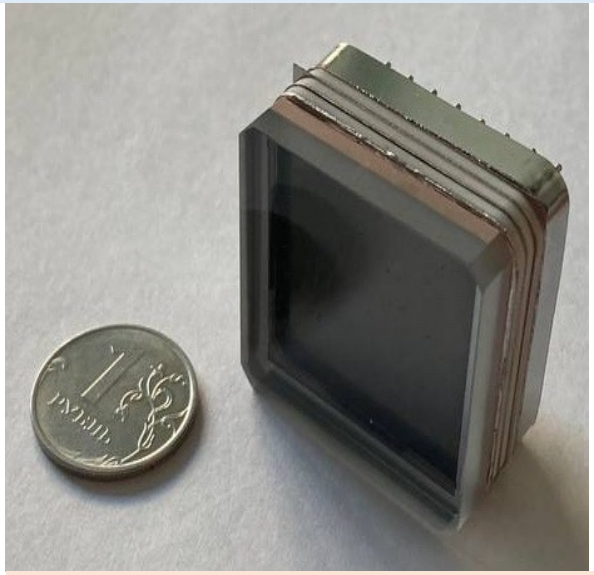
- PDE for H12700 and pixel 6×6 mm
- N_{pe}≈35
- $\sigma_{tr}^{\theta_c} \approx 1.8$ mrad
- π/K–separation at 6 GeV/c – 6.1 σ
- “New3”
- Material budget ~ 2.7%X_0

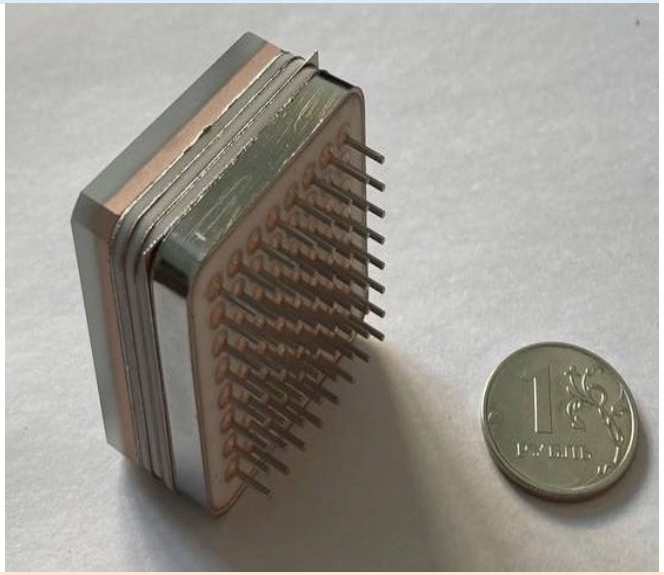
Production of “new” focusing aerogel with latteral sizes above 10×10 cm is planed for 2024-2025!

Status of MCP PMT development in Russia

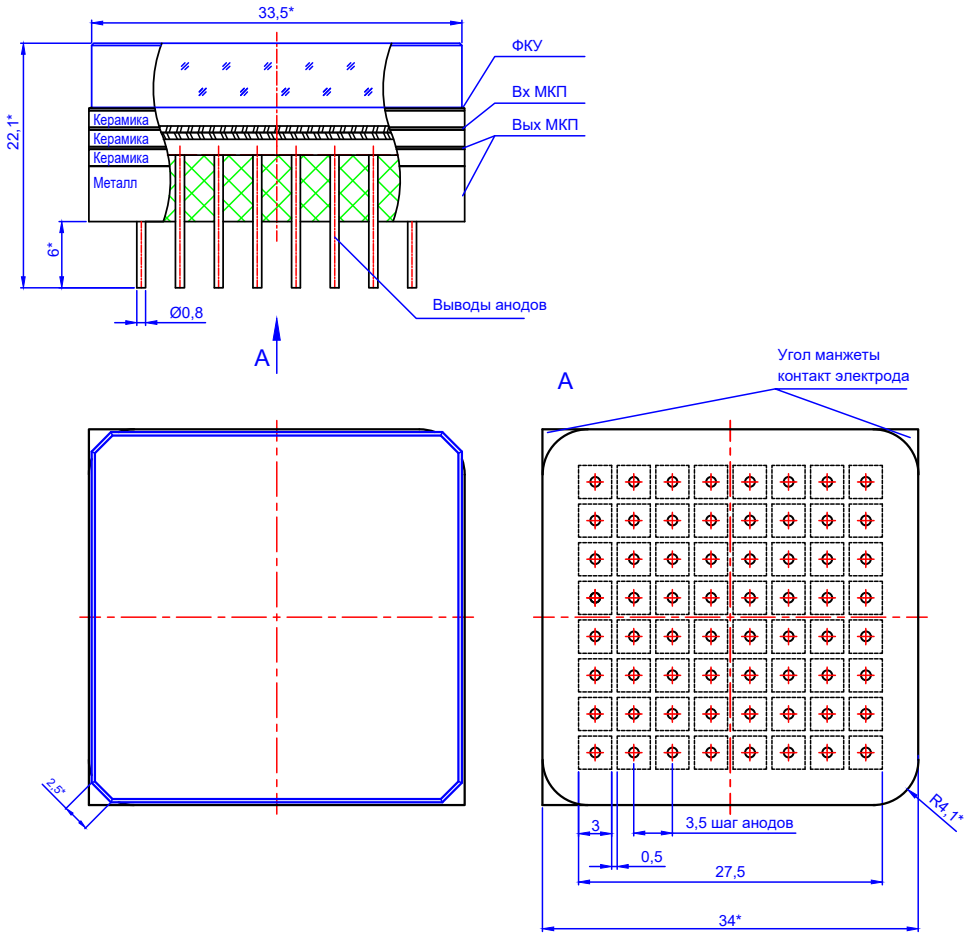
Square MCP PMT from “Ekran FEP”:

- 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 until the end of 2024





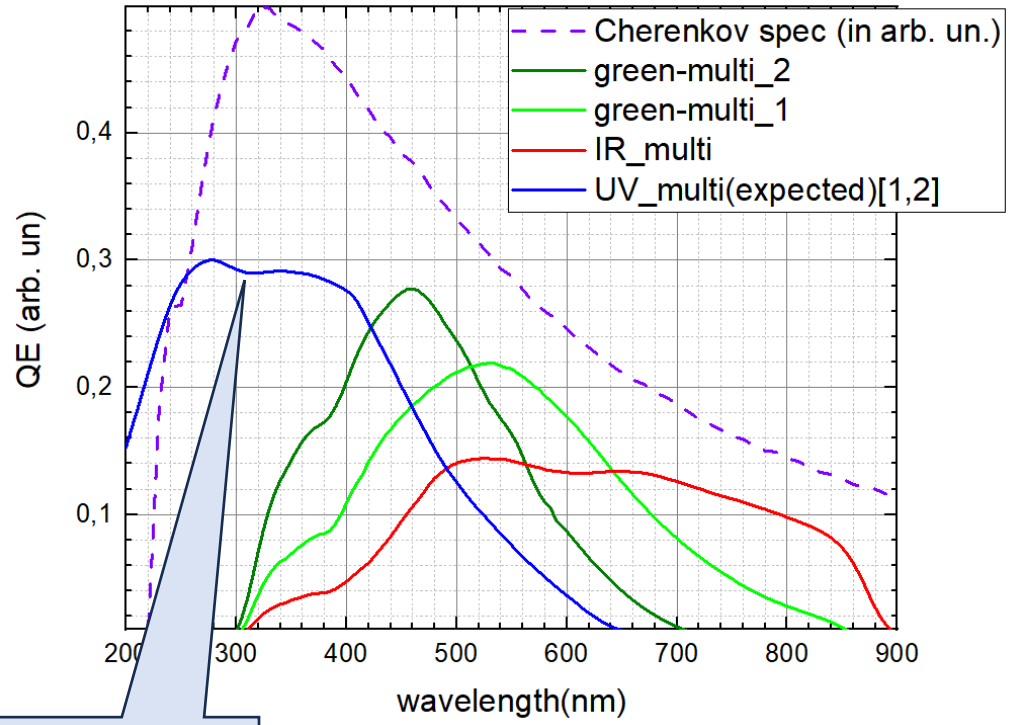
The first prototype fully asembled and vacume sealed prototype



* Размер для справок. Возможны незначительные изменения.

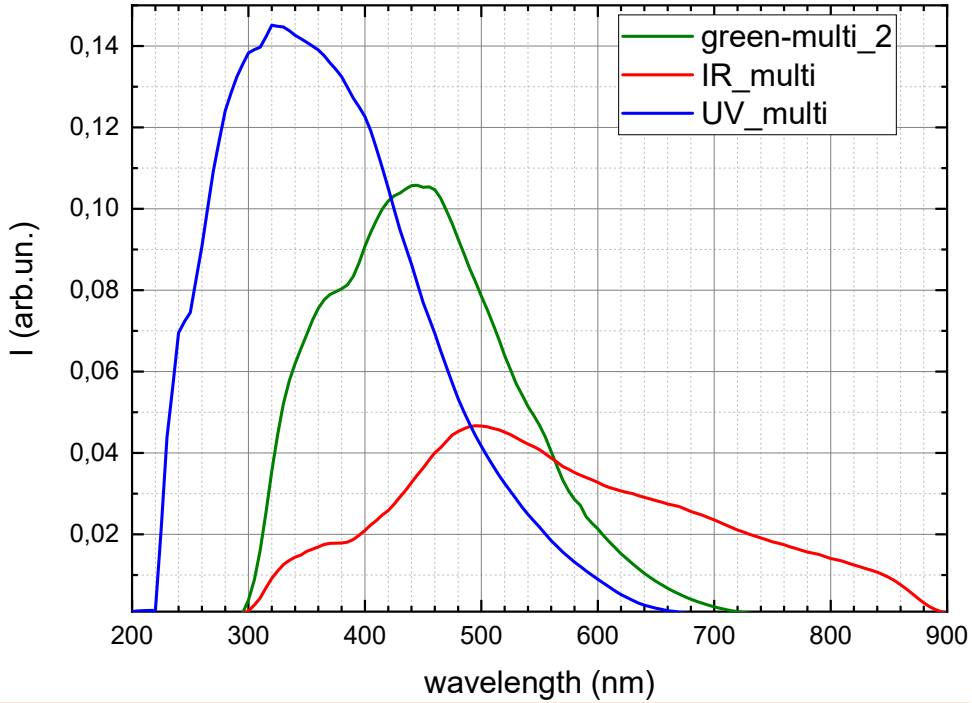
Photocathode options for “Ekran FEP” MCP PMTs

Multi-alkali PCs options and Cherenkov spectrum



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

Convolutions of Ch. Sp. with QE of Multi-alkali PCs



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

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

– **factor of 2** in comparison with standard “IR_multi” PC

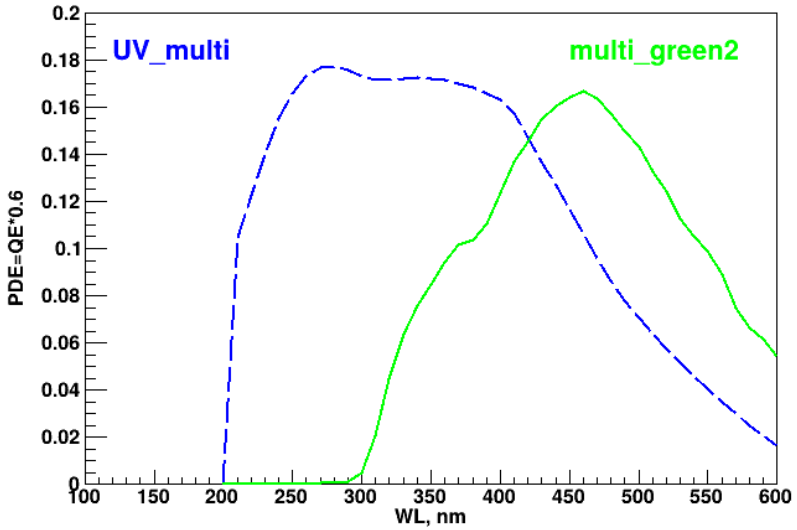
“UV_multi” QE based on data from papers:

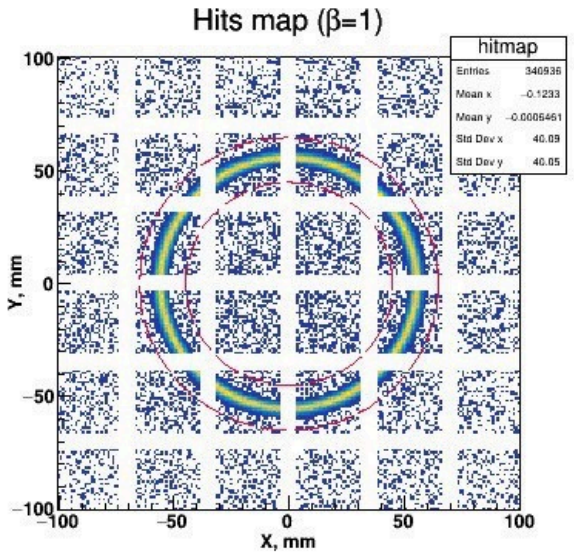
1. Orlov, D. A., et al., High quantum efficiency S-20 photocathodes in photon counting detectors. Journal of Instrumentation, 2016 11(04), C04015–C04015

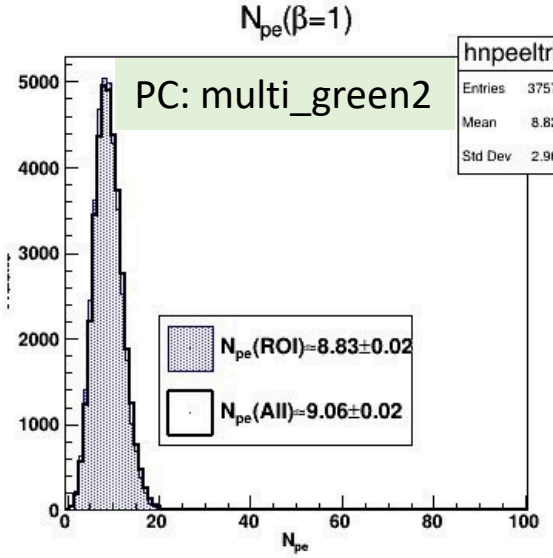
2. Milnes, J., et al., UV photocathodes for space detectors. Proceedings Volume 12181, Space Telescopes and Instrumentation 2022: Ultraviolet to Gamma Ray, 121813B (2022).

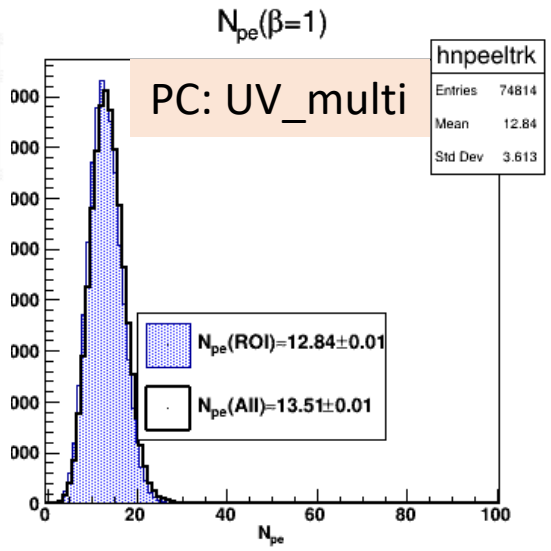
FARICH prototype based on MCP-PMT (Ekran FEP)

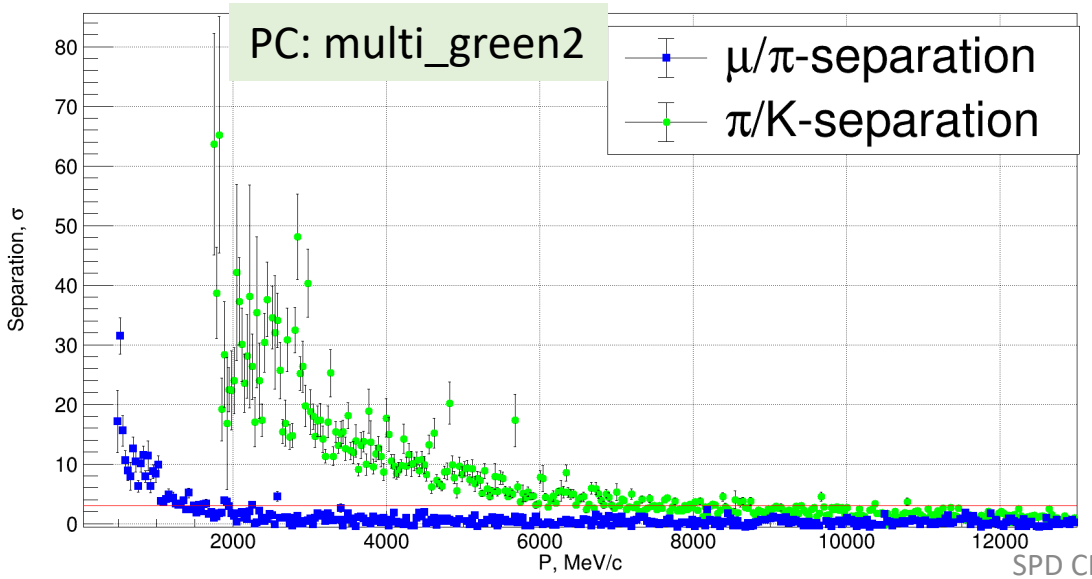
(expected performances: Geant4 simulation results)

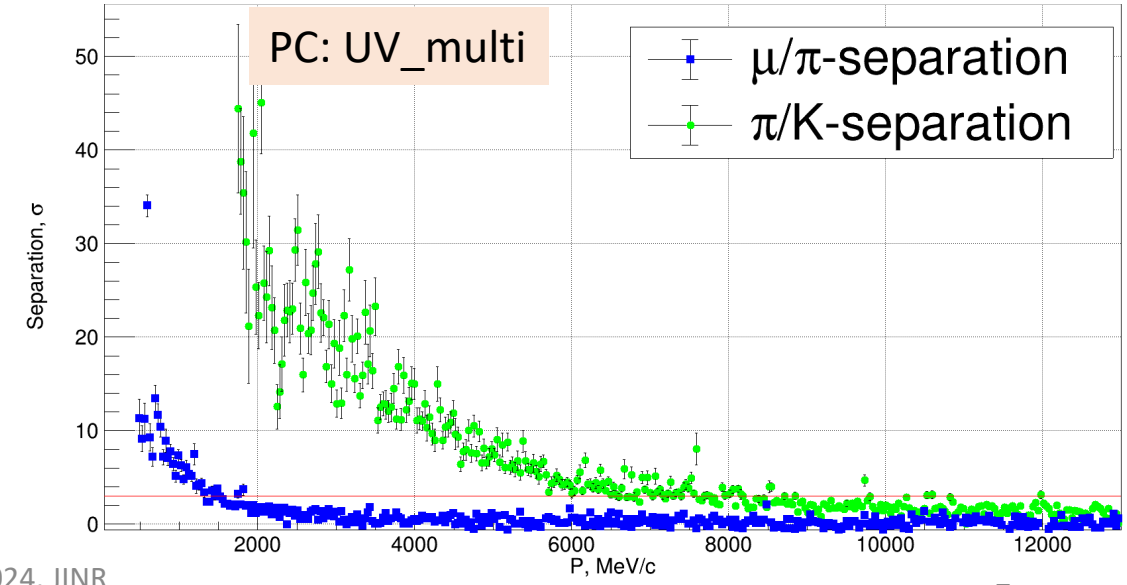




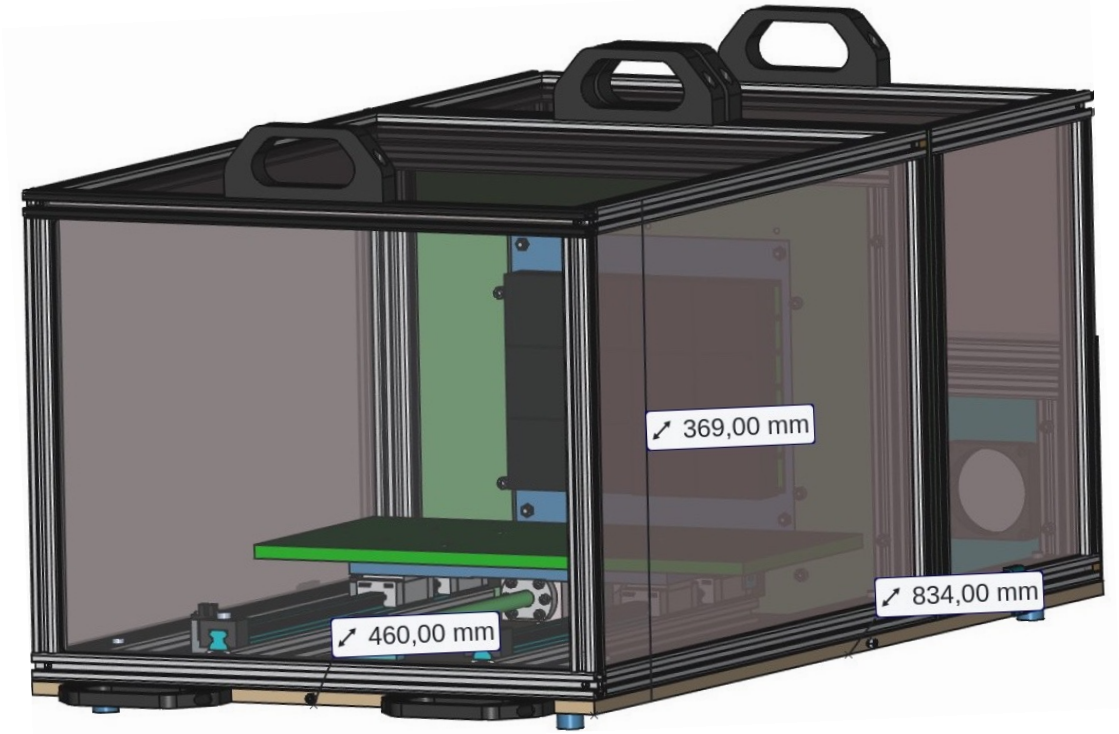


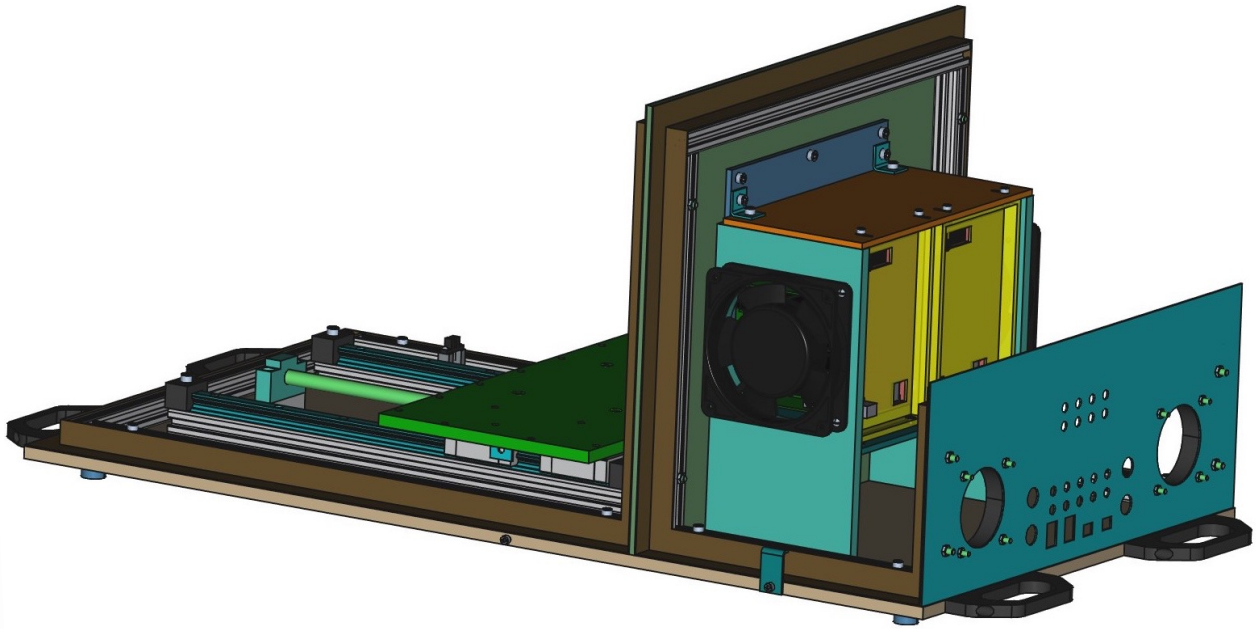






FARICH prototype with full ring detection



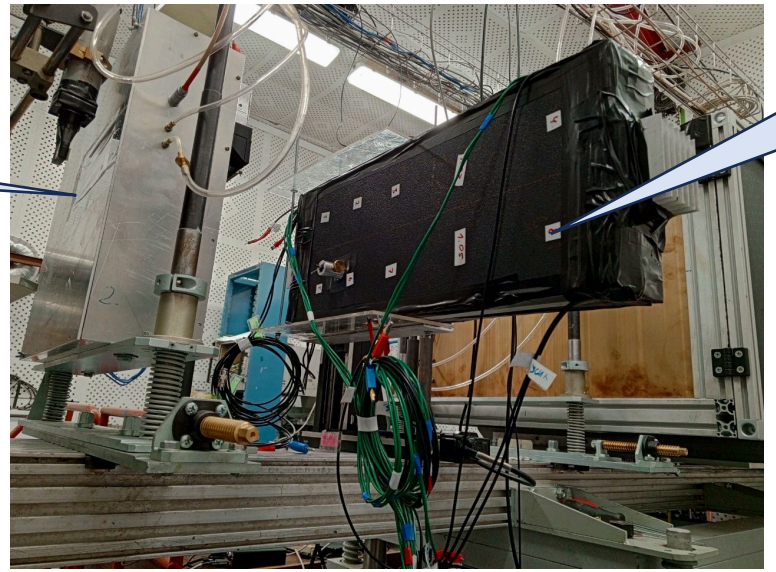


FARICH compact prototype based on MCP PMT:

- Tech. draws are ready
- Materials, components and equipment are purchased
- Production was started at the BINP
- Readout system (based on DiRICH+TRB3 boards from GSI) is ready
- 4-layer focusing aerogel is ready
- The prototype will be able operate with N6021 (NNVT) and “Ekran FEP” MCP PMTs

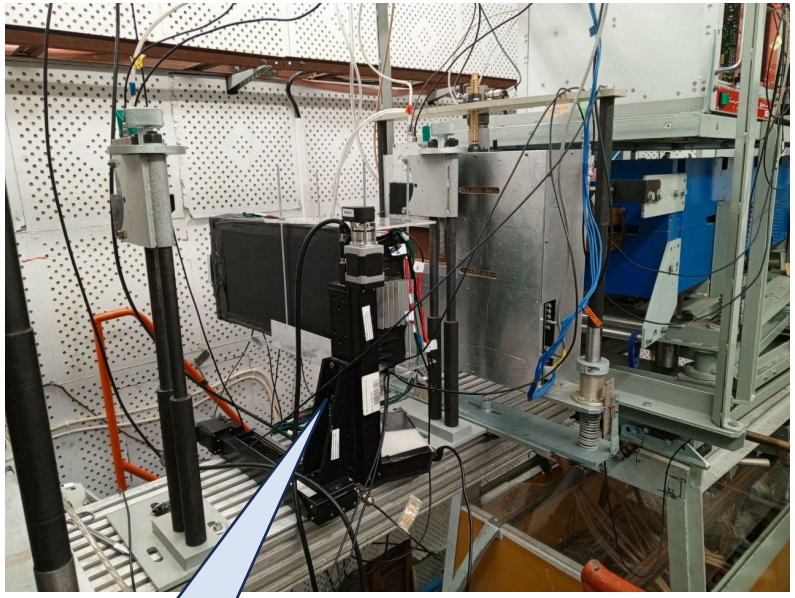
ASHIPH prototype at the BINP beamline

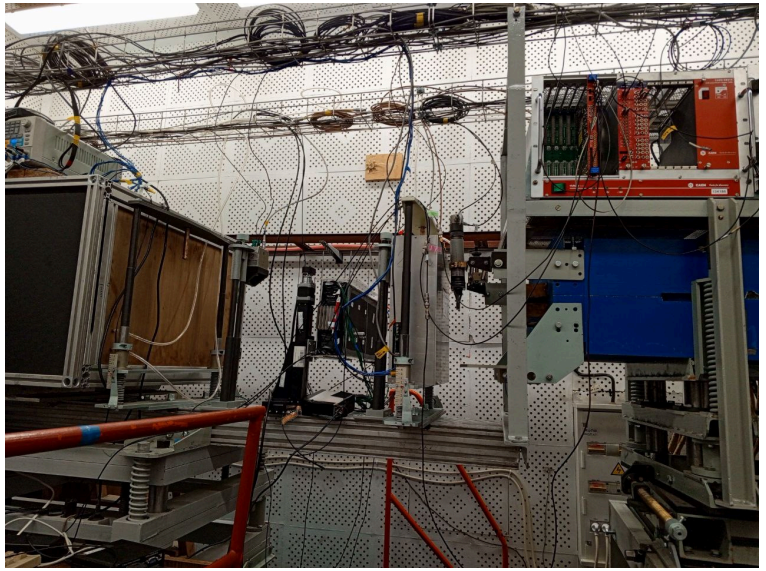
Tracker based on GEM
$\sigma_{x,y} = 50\mu m$

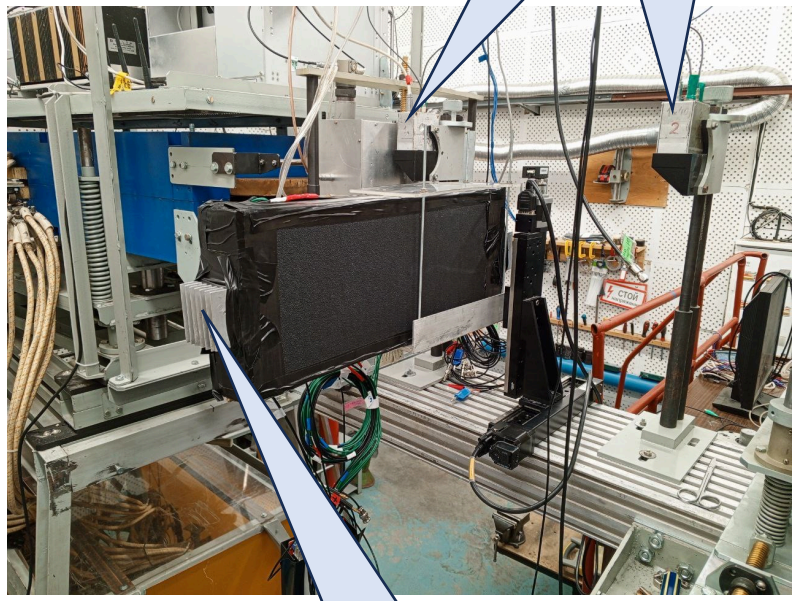


ASHIPH prototype and points for beam crossing

Trigger counters based on MCP PMT







2D mover to scan Light collection uniformity

Radiator for SiPM cooling and thermostabilization

Summary *or* status of R&Ds supported by MSHE

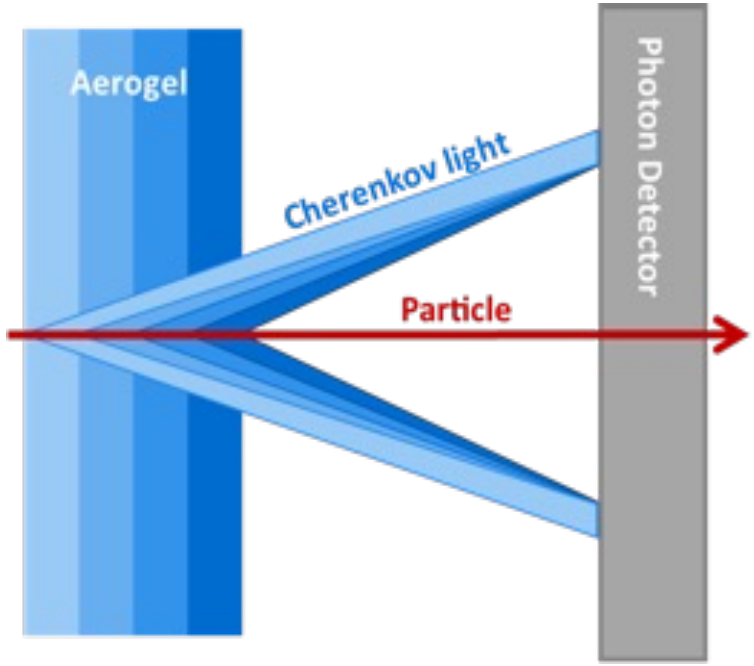
- Optimisation of main parameters of multilayer focusing aerogel Cherenkov radiators according to the SPD experiment needs and conditions was done. Process of production has started in Novosibirsk by the BINP and BIC in close cooperation.
- Investigation of the main parameters of square multi-anode MCP PMT produced by “Ekran FEP” (Novosibirsk) and further its optimisation in close cooperation with producer are expected in 2024-2025.
- FARICH prototype based on MCP PMT as a position-sensitive photon detectors is designed and it is under production process. Main parameters of the FARICH prototype based on MCP PMTs from “Ekran FEP” were obtained with help of GEANT4 simulation. It was shown that reliable π/K–separation up to P=6GeV/c is possible.
- New conceptual design of end cap PID system based on aerogel Cherenkov threshold counters was suggested. This design has more axial symmetry. It is necessary to implement this new geometry in SPD simulation framework for further optimisation. Pile-up of physics events and backgrounds in the counter will determine its overall sizes.
- Prototype of aerogel Cherenkov threshold counters (ASHIPH with SiPM) for the SPD experiment is developed and ready to test with beams. The first beam tests are expected in 2024-2025.
- Several batches of new stable and radiation hard precise Hall sensors based on InSb layer were produced in close cooperation of the BINP and the LU (Lobachevsky University). The first tests were performed and sensitivity 9uV/oersted while thermal drift is 0.03%/K were demonstrated. Radiation hardness tests are planed for 2025.

BACK UP SLIDES

FARICH motivation

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

To get $\langle N_{pe} \rangle \gg 5$ from aerogel with n=1.05 & thickness 1 cm is too hard practice task!!!

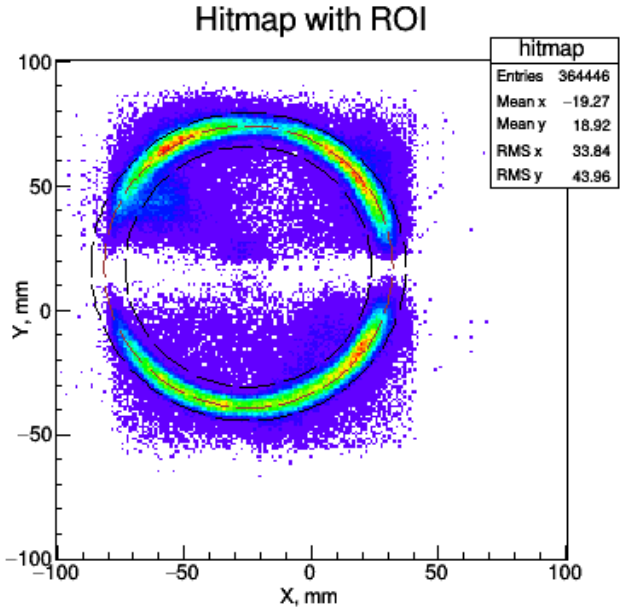


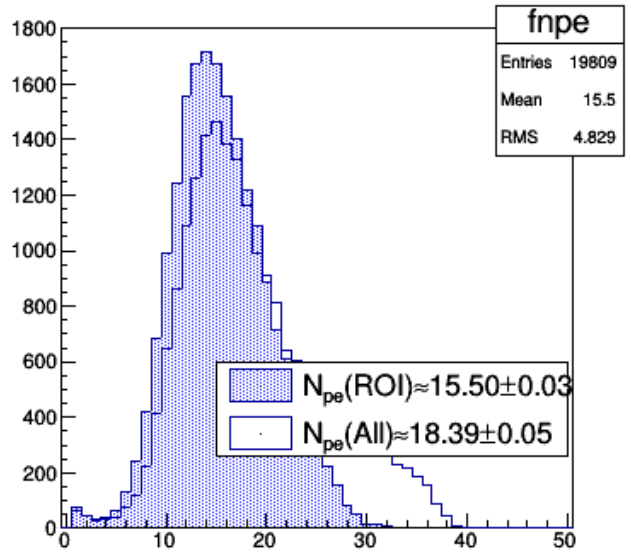
- Thicknesses and refractive indexes in each layer are adjusted in such way that Cherenkov rings from each layer overlap in the same region of the position-sensitive photon detector.
- The number of detected Cherenkov photons increases due to increase of the thickness without degradation of Cherenkov angle resolution due to uncertainties of photon emission point.

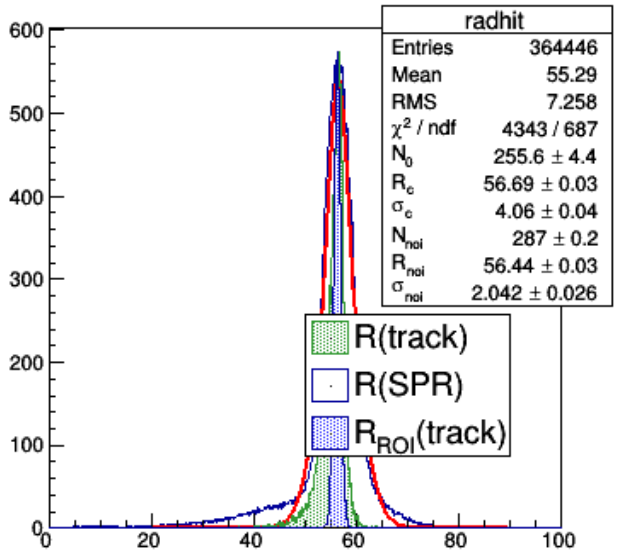
T.Iijima et al., NIM A548 (2005) 383 and A.Yu.Barnyakov et al., NIM A553 (2005) 70

Recent beam test results

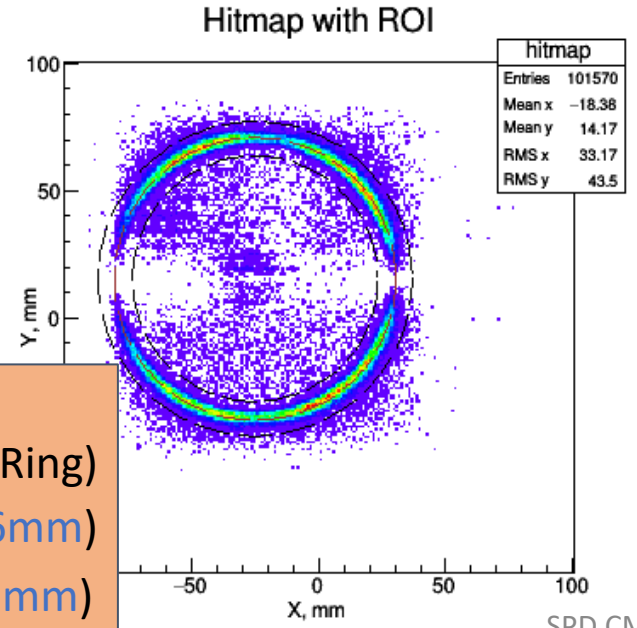
Pixel 6x6 mm
Geom.Eff. ~ 80%

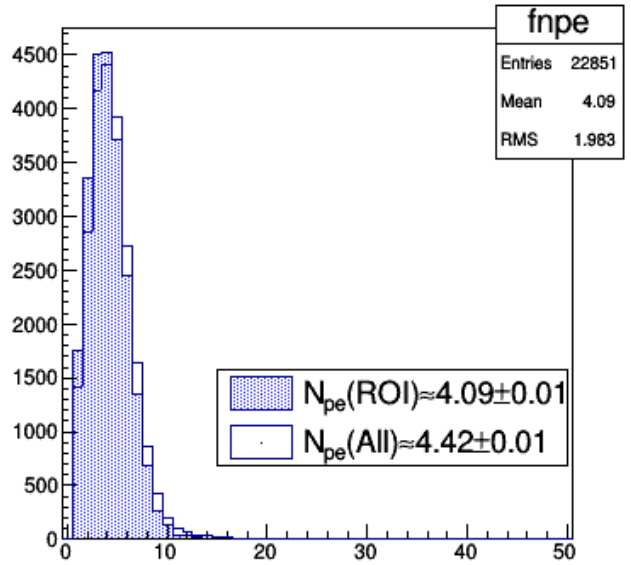


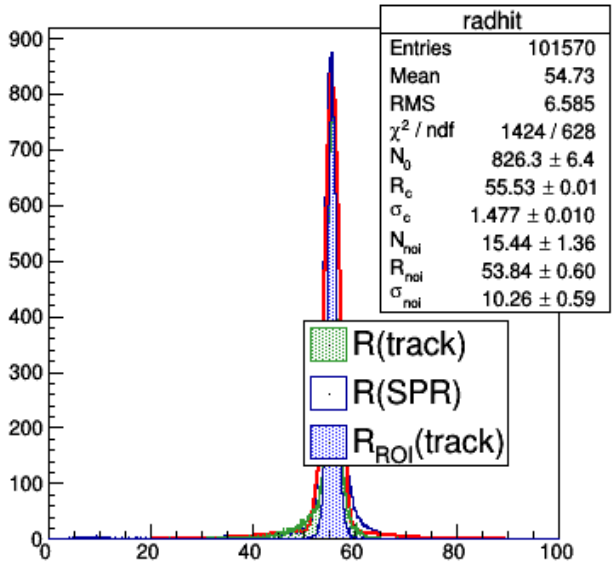




Pixel 3x3 mm
Geom.Eff. ~ 20%



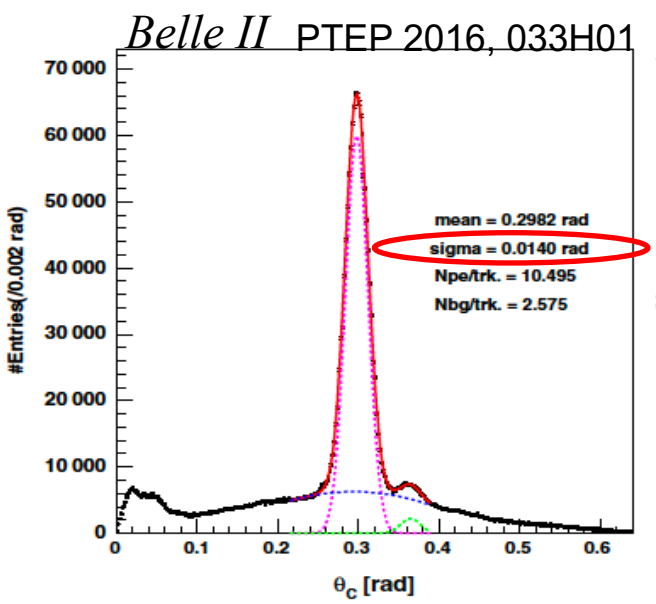


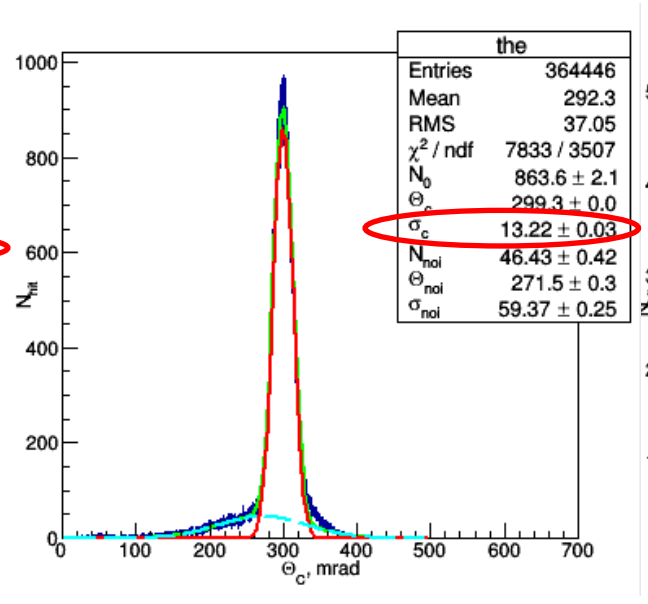


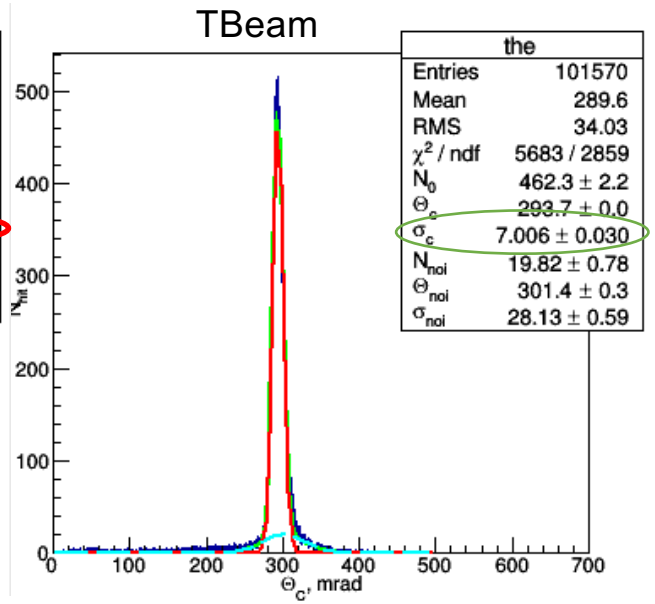
Main results:

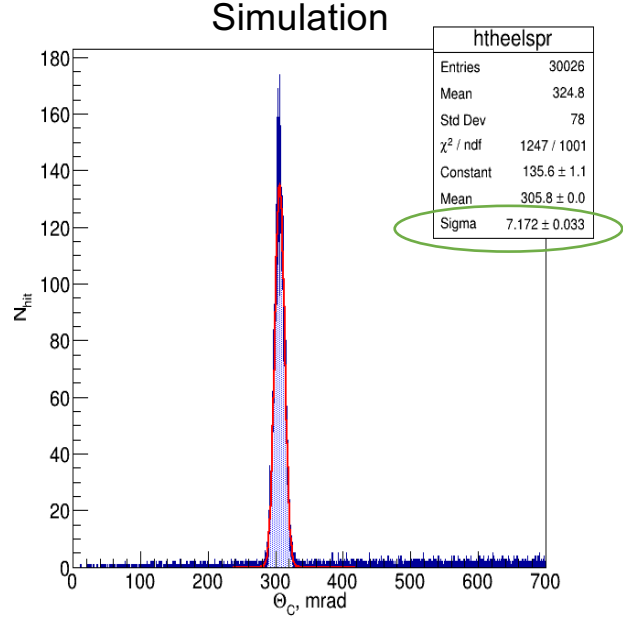
- N_{pe} ≈ 16 (~ 0.8 of Ring)
- σ_θ^{1pe} ≈ 13.5 $mrad$ (■ 6mm)
- σ_θ^{1pe} ≈ 7.5 $mrad$ (■ 3mm)

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









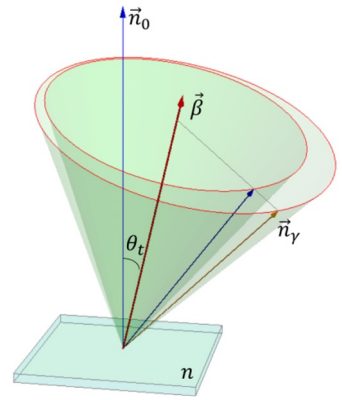
Aerogel: 20+20 mm (Chiba Univ.)	4-layers (Novosibirsk) –>	–	4-layers (ideal profile)
n(400nm): 1.045 +1.055	1.039 ÷ 1.046	–	1.041 ÷ 1.050
Pixel: 5x5 mm	6x6 mm	3x3 mm	3x3 mm
Geom.Eff. ~ 90% $N_{pe} \approx 10.5$	Geom.Eff. ~ 80% $N_{pe} \approx 16$	Geom.Eff. ~ 20% $N_{pe} \approx 4$	

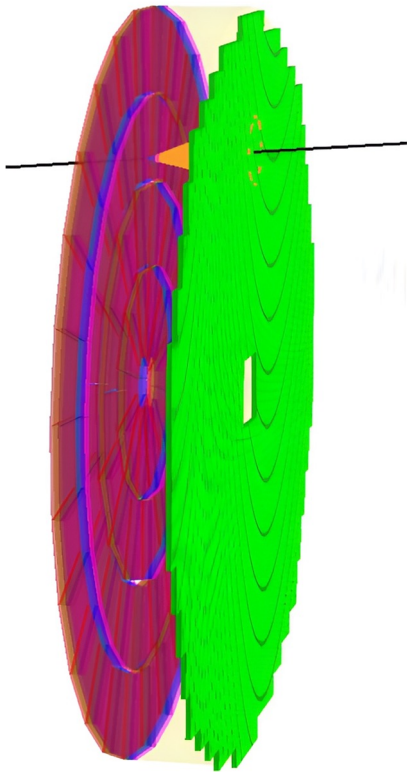
Beam test results are in good agreement with MC simulation and corresponds to:
π/K–separation at level of 3σ up to P=4.5 GeV/c for 6x6 mm pixel
π/K–separation at level of 3σ up to P=8.5 GeV/c for 3x3 mm pixel

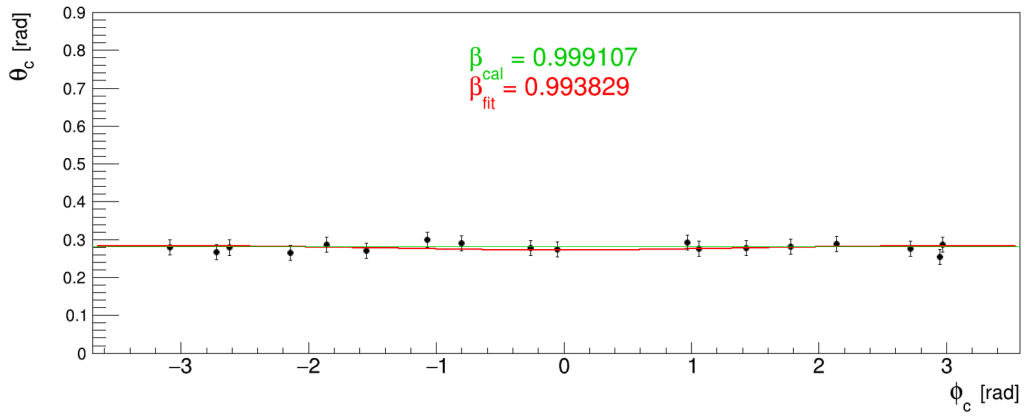
Dimensions of focusing aerogels 23x23x3.5 cm allow us to design the full-scale FARICH systems for the future particle physics experiments.

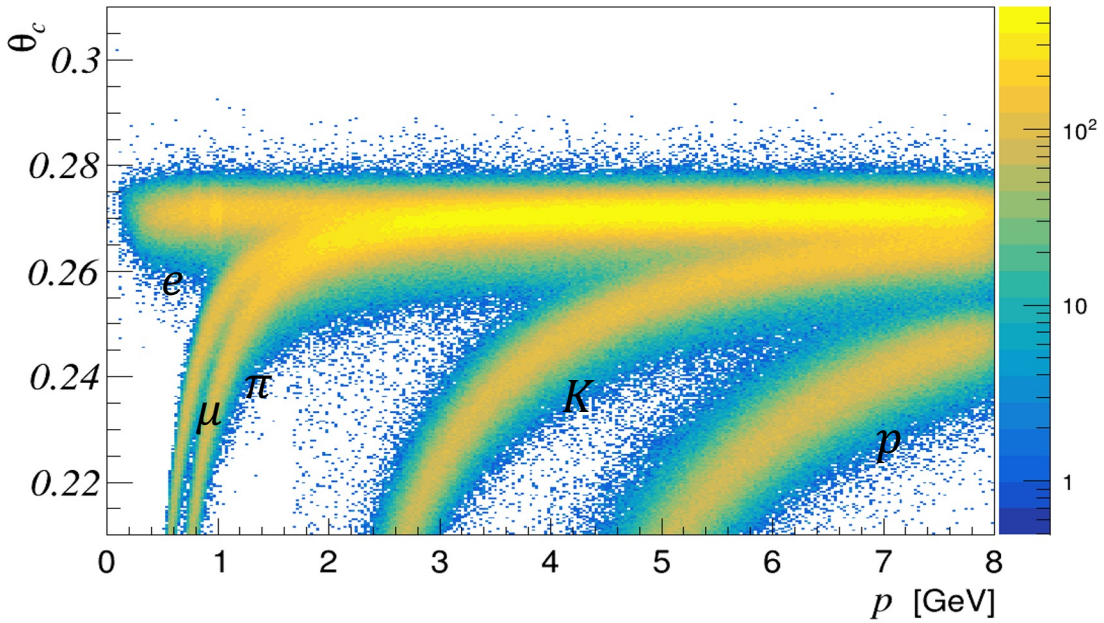
Simulation FARICH in SPD

Reconstruction: fit analytical formula to (θ_c, φ_c) distribution to obtain β









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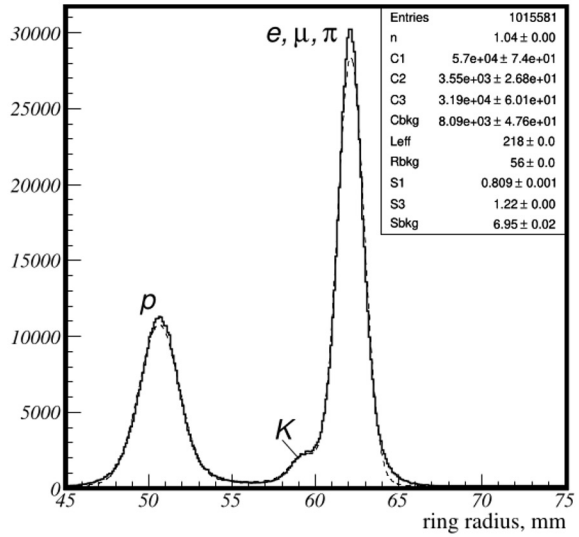
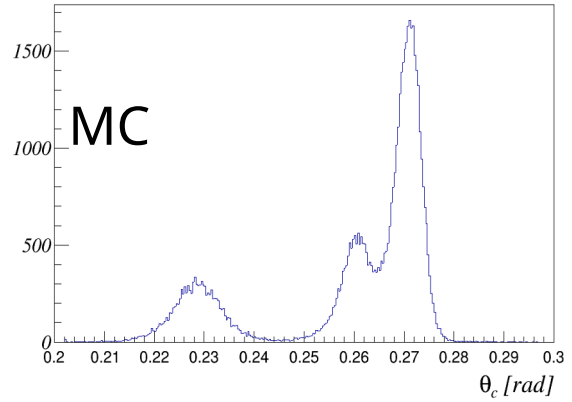
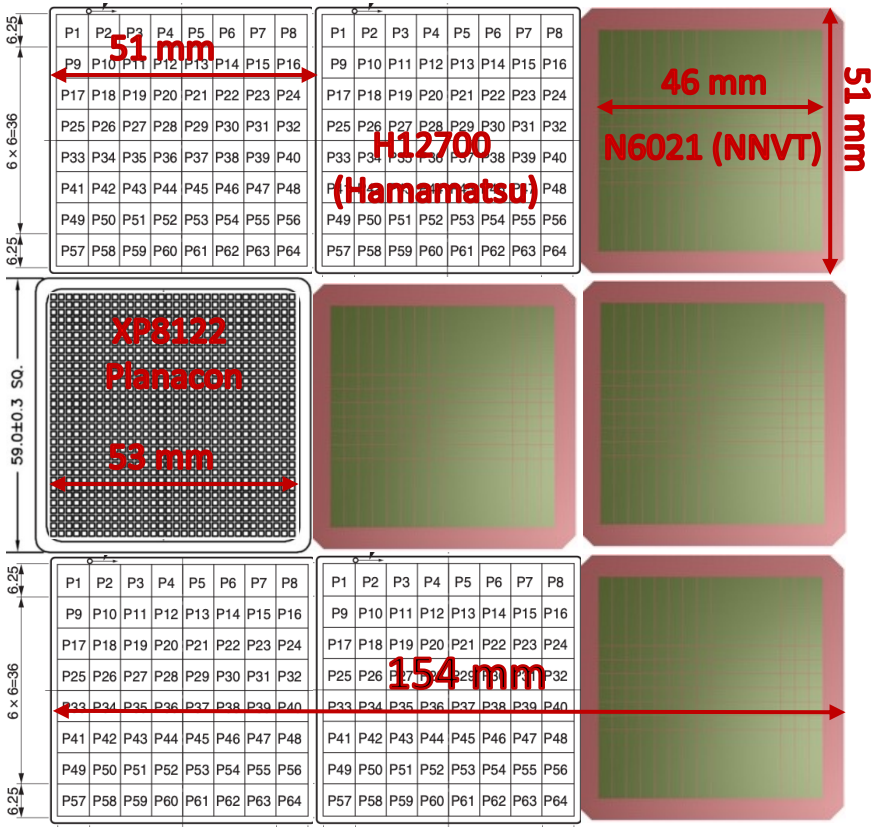


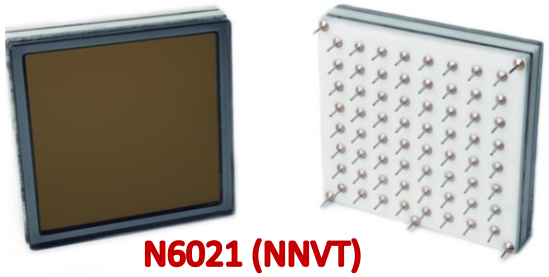
particles momentum 6 GeV/c

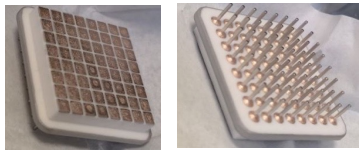


FARICH prototypes

Step #1 (2024/25): 6x6mm

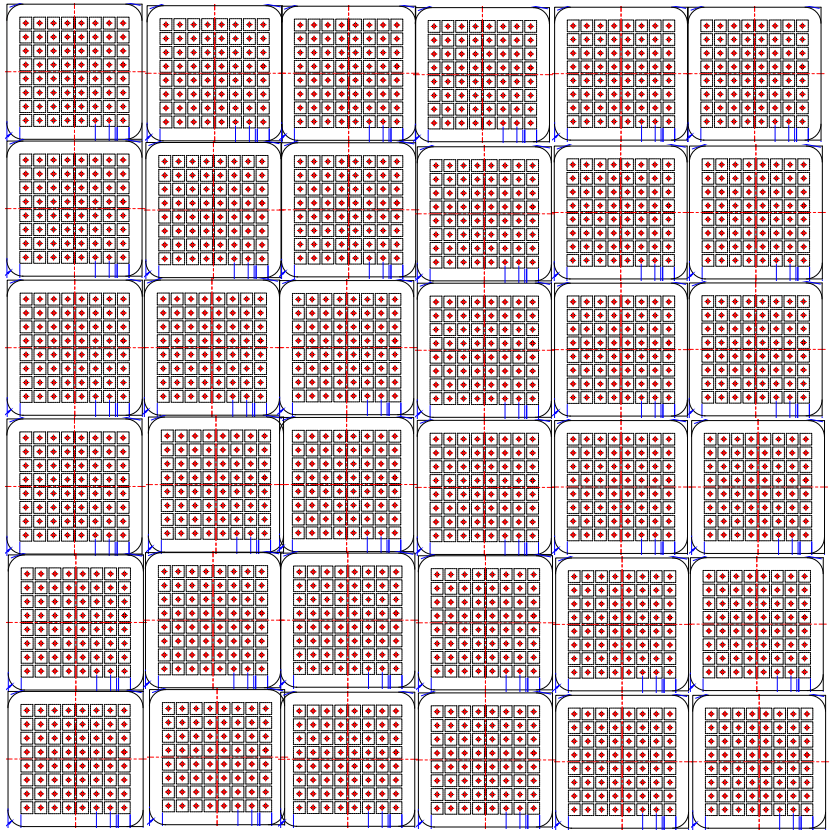






$6\times6\ mm$
- 4 MCP PMTs N6021 from NNVT
- 4 MaPMTs H12700 from Hamamtsu
- 1 XP85122 Planacon MCP PMT from from Photonis
- $S_{sens}/S_{tot} \approx 0.8$
- 2 DiRICH boards (GSI) to readout chan.

Step #2 (2025/26): 3x3mm



- 6x6=36 MCP PMTs from Ekran FEP
- 3x3mm pixel
- $S_{sens}/S_{tot} \approx 0.5$
- 6 DiRICH boards (GSI) to readout 2304 chan.