Обработка данных испытаний прототипа FARICH на установке "Выведенные пучки" комплекса ВЭПП-4М

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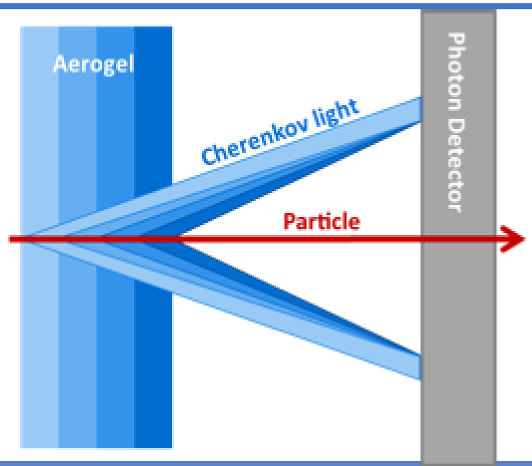
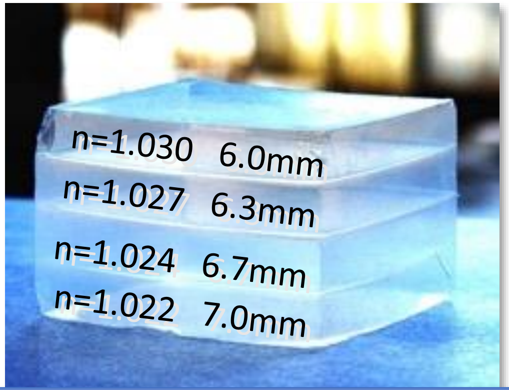
от имени “Аэрогелевой группы” ИЯФ СО РАН

FARICH technique

- The SPD experiment for the NICA collider is currently under development. Expecting momenta of collisions up to *27 GeV/c*
  - *P* of π and *K* mesons ~ *6 GeV/c* in the end-cup section of detector
  - FARICH (Focusing Aerogel CHerenkov Ring Imaging) detector is proposed for "π/K"-separation better than 3σ
- Additionally, FARICH is possible to use with ultra-light aerogel for future experiments with a higher momenta (FCC, CERN; CEPC, China).



The first 4-layer monolithic sample

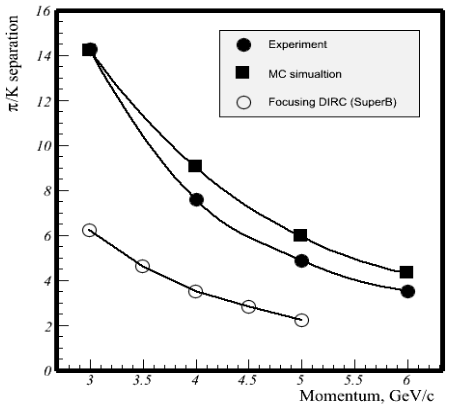


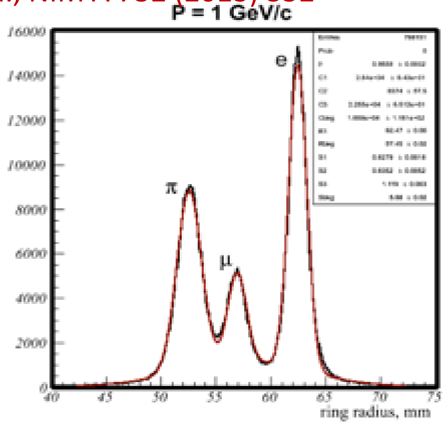
Increase N_{pe} due thickness increase without $\sigma_{\Theta c}$ degradation

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

Excellent PID capability was shown at CERN beam test in 2012

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





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

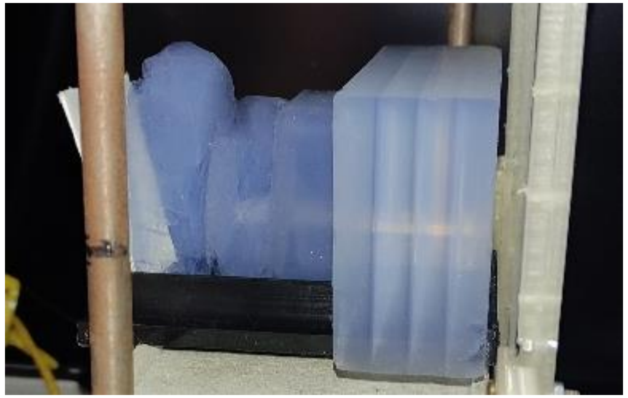
New aerogel samples

In the spring of 2025, the Boreskov Institute of Catalysis synthesized new aerogel (SiO_2) samples for FARICH:

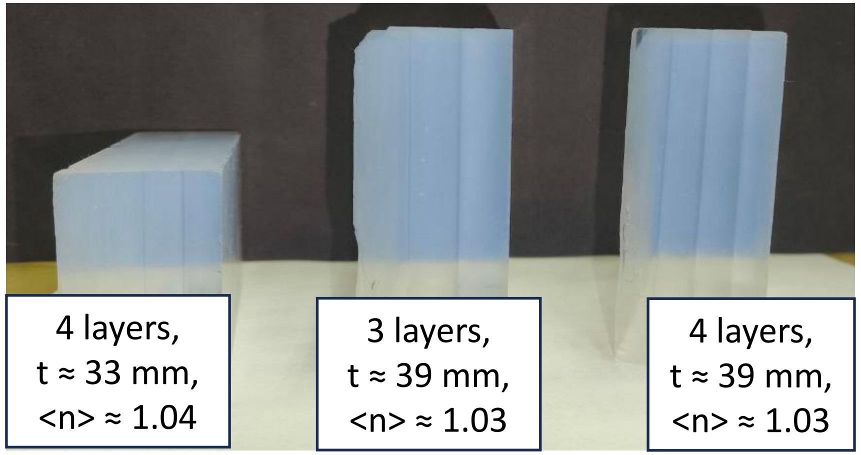
- 3- and 4-layer monoblocks with $n_{max} \approx 1.03$ (for momenta up to 6 GeV/c, for the SPD experiment, Russia).
- Ultra-light blocks with $n_{max} \approx 1.008$ and dimensions of 5x5x15 mm (for experiments with P < 25 GeV/c, for the CEPC, China).

Tests of a FARICH prototype with the new samples were carried out at the "Extracted Beams" facility of the VEPP-4M complex

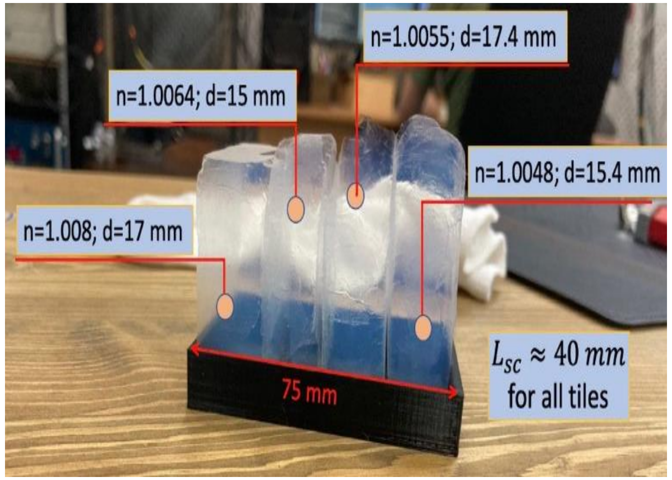
$n_{max} \approx 1.03$



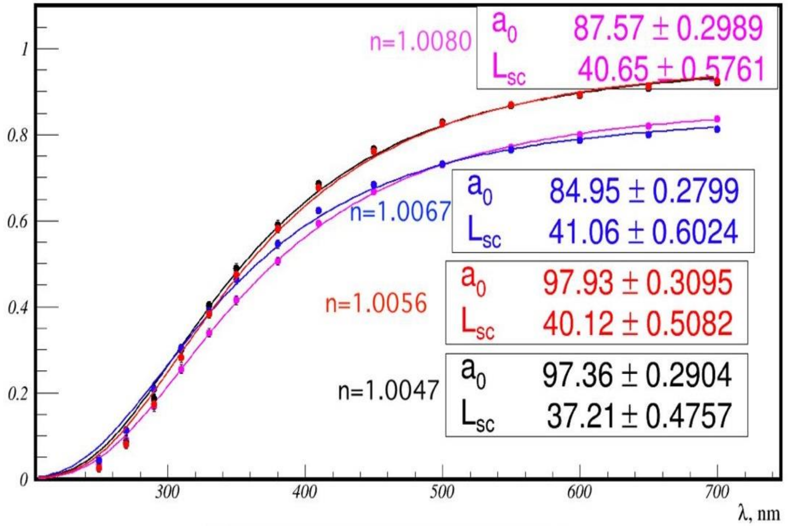
Dual focusing radiator



$n_{max} \lesssim 1.008$, $n_{min} \approx 1.005$



Focusing assembly from ultra-light aerogel



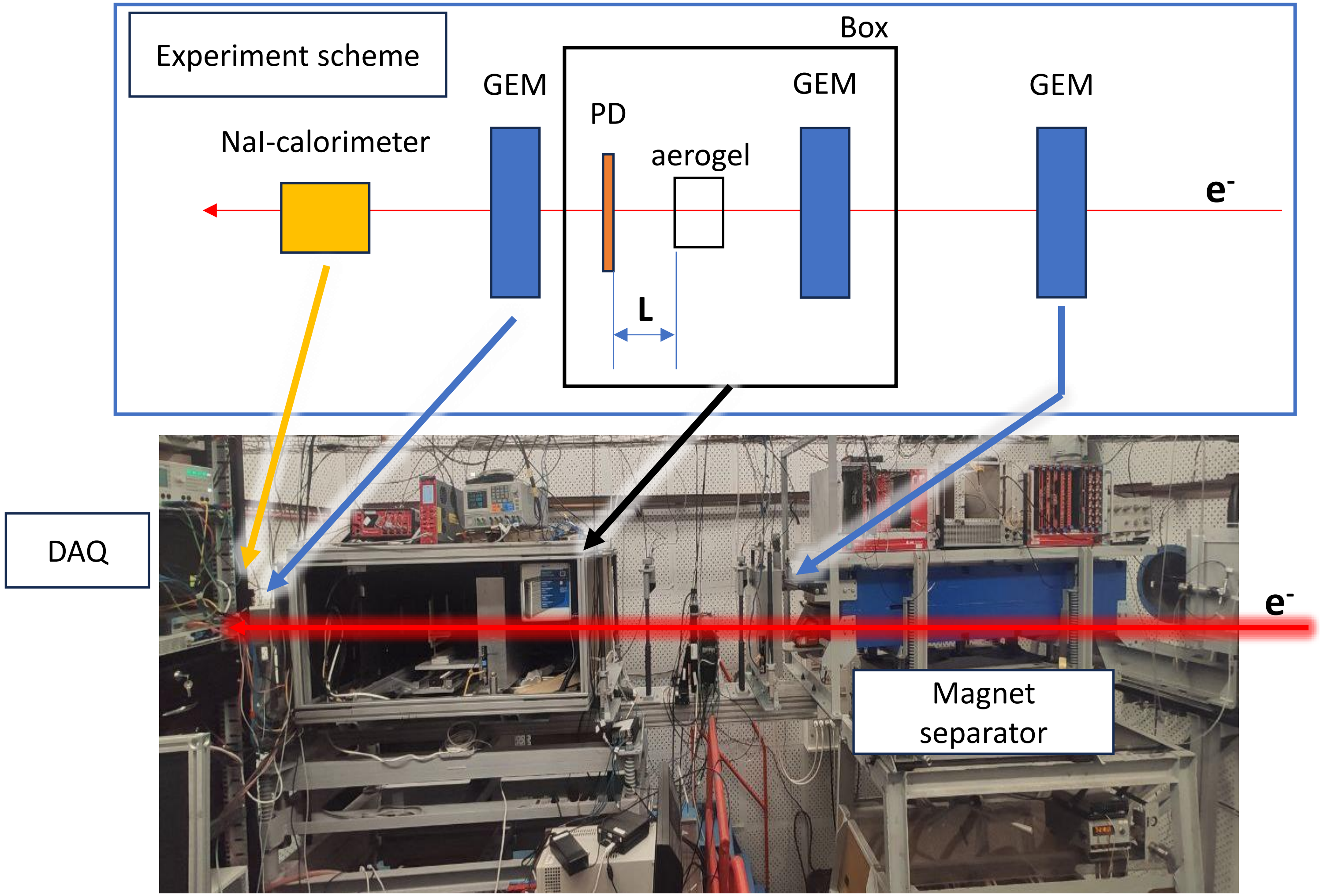
$$T = \frac{I}{I_0} = a_0 \cdot e^{-\frac{d}{L_{sc}\cdot(\lambda/400)^4}} = a_0 \cdot e^{-\frac{C\cdot d}{\lambda^4}}$$

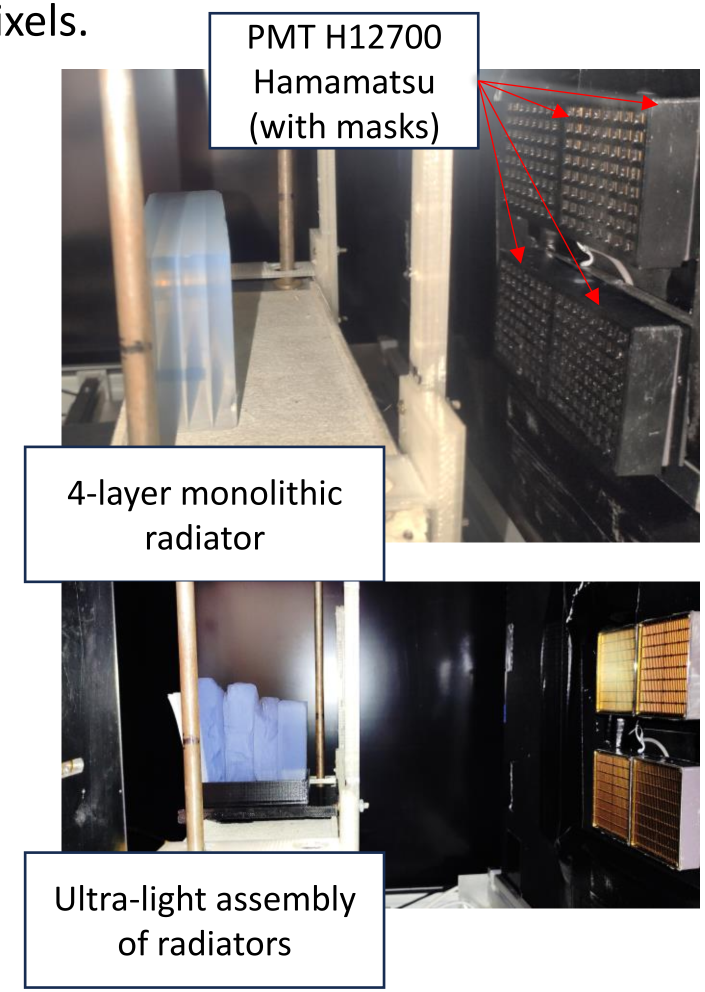
d – thickness of sample,
λ – wave length (nm),
L_{sc} – length of scattering at 400 nm,
a – surface scattering coefficient

e⁻ TBeam experiment

Tests were performed with new aerogel samples at various distances L from the photodetector to the output surface of the radiator, both with and without a mask simulating a 3.4 mm pixel.

- Electron energy E ~2.5 GeV
- Photodetector – 4 H12700 Hamamatsu PMTs, each with an 8x8 array of 6 mm pixels.

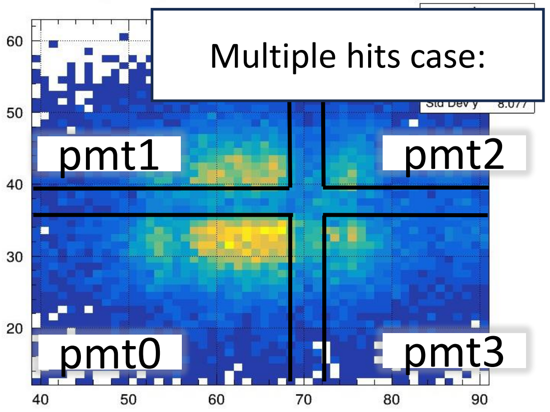


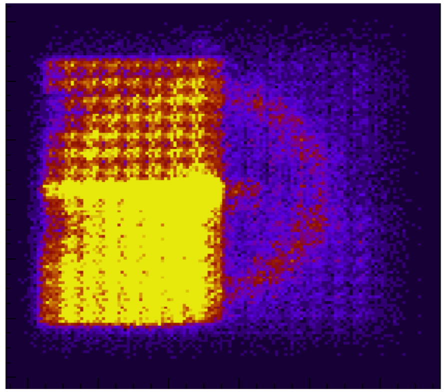


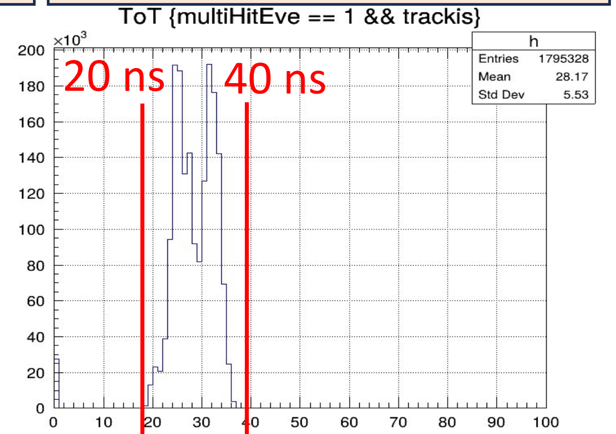
Case of a e^- hitting a PMT

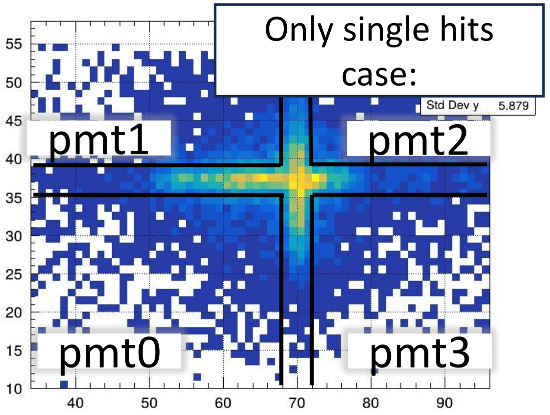
Pixels with more than 1 hit per event were observed from raw data and marked.

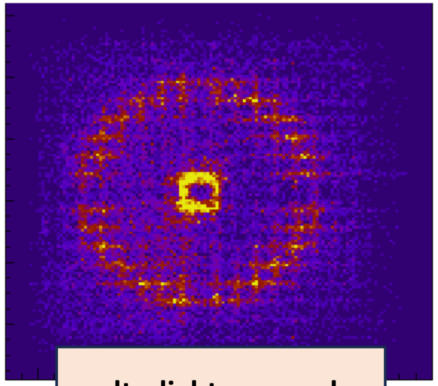
Position of the Electron tracks in the PD plane	Cherenkov rings	Time information



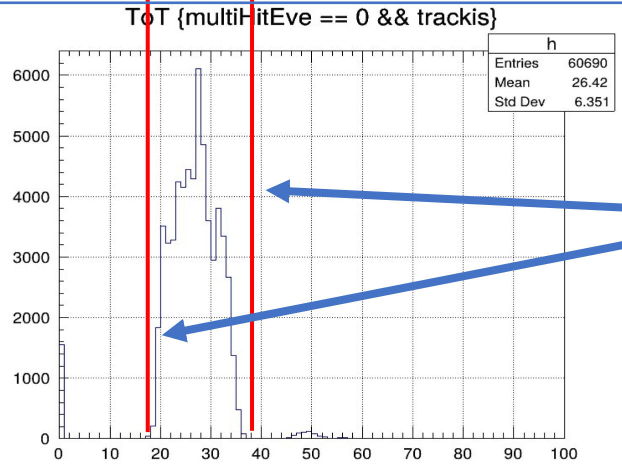








ultralight, no mask



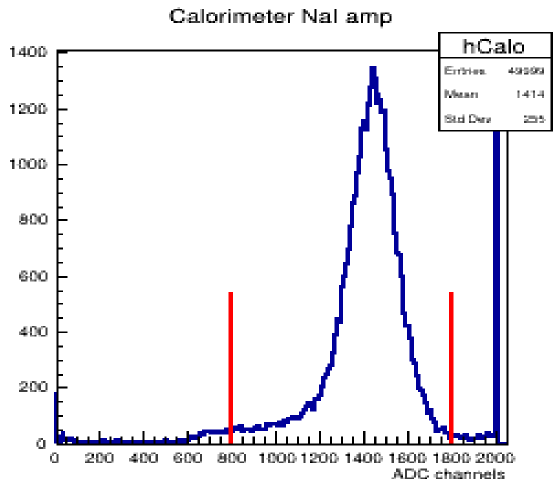
H12700
Hamamatsu

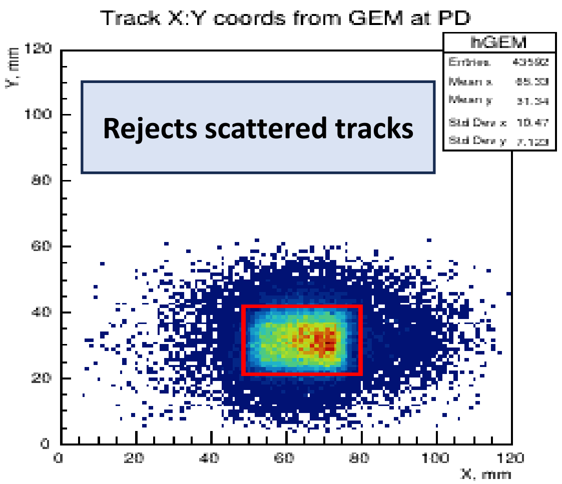
- ***Another PMT must be used instead of flat-panel H12700***
- **Needed an additional investigation to determine what exactly causes such effect.**

It's also impossible to separate such parasitic signals via time information

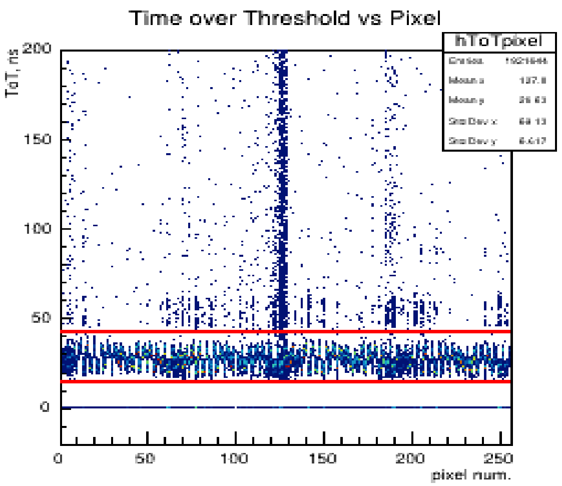
Data processing

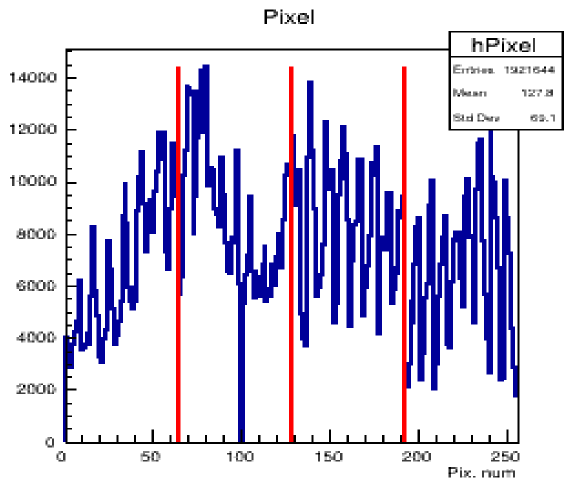
Applying Cuts at raw data

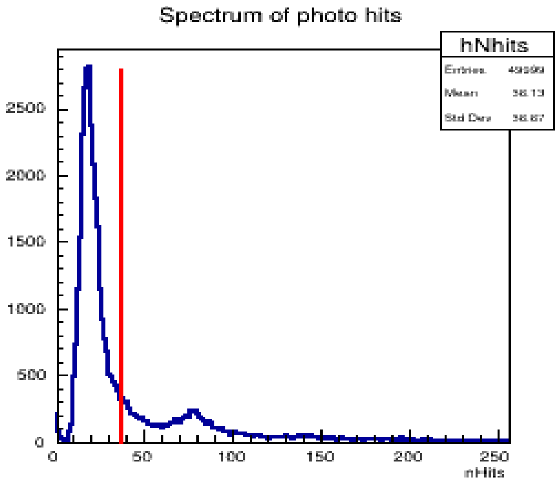


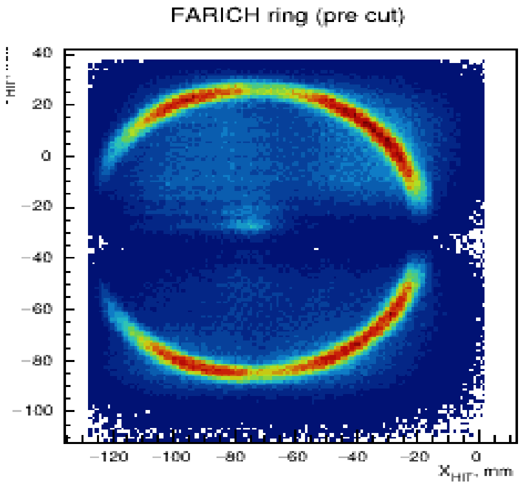


Rejects scattered tracks





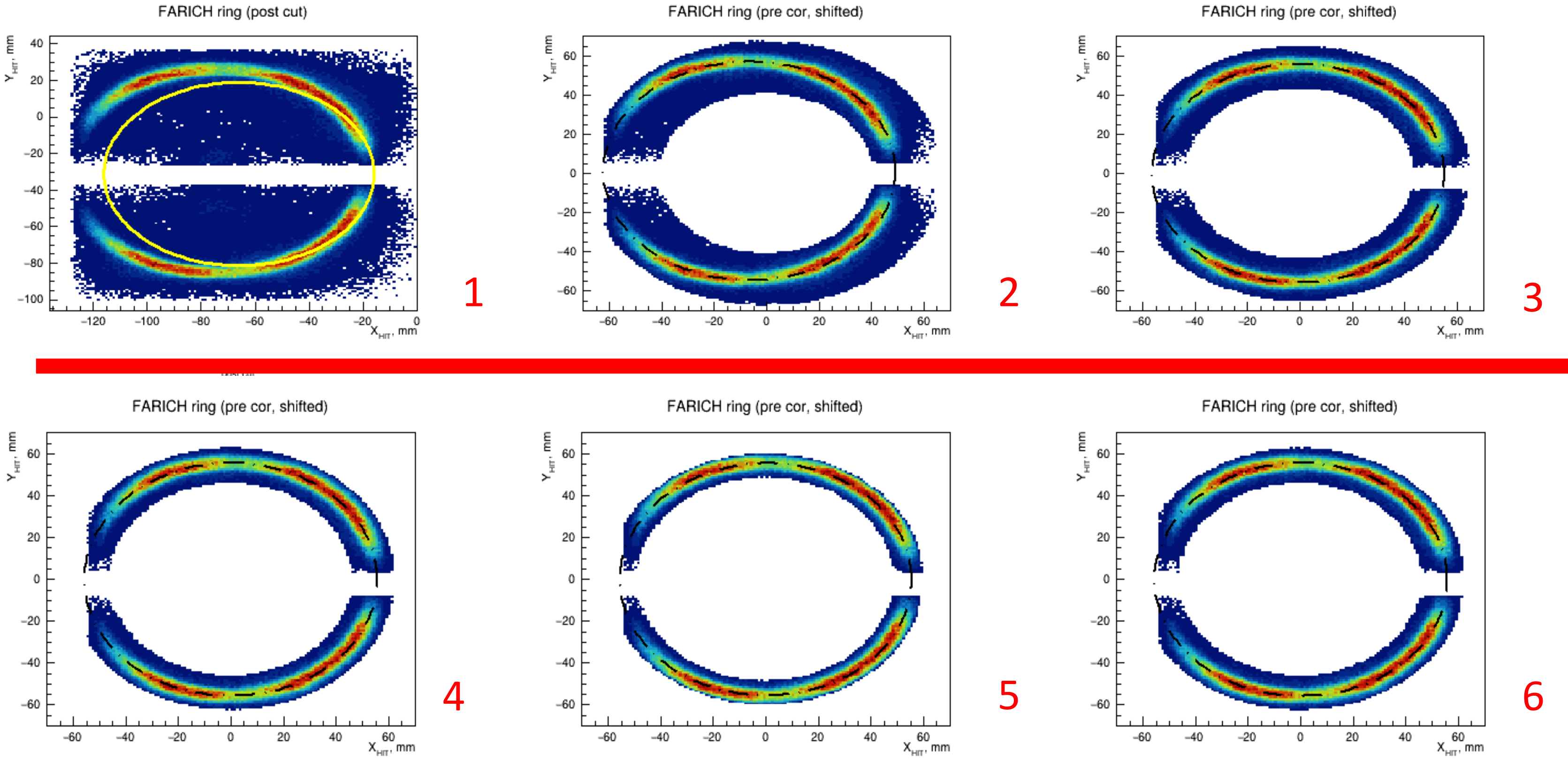


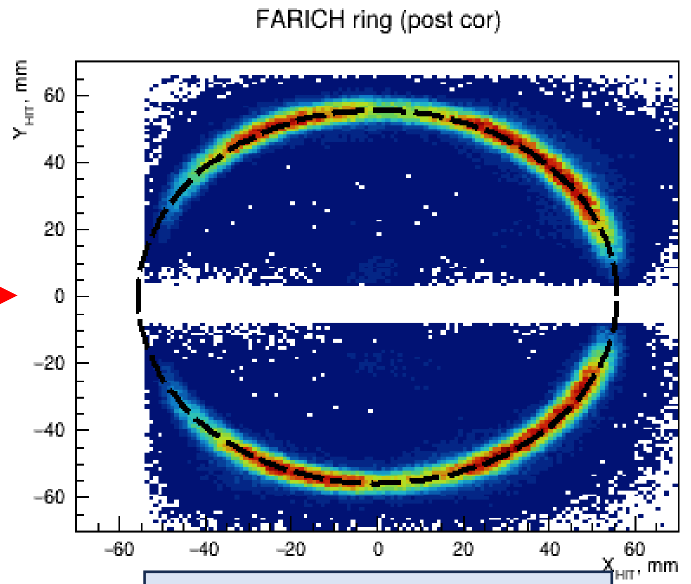


There are plenty of scattered or parasitic hits, it is necessary to cut them off for better approximations

Data processing

Chain fit to determine <x0>, <y0>

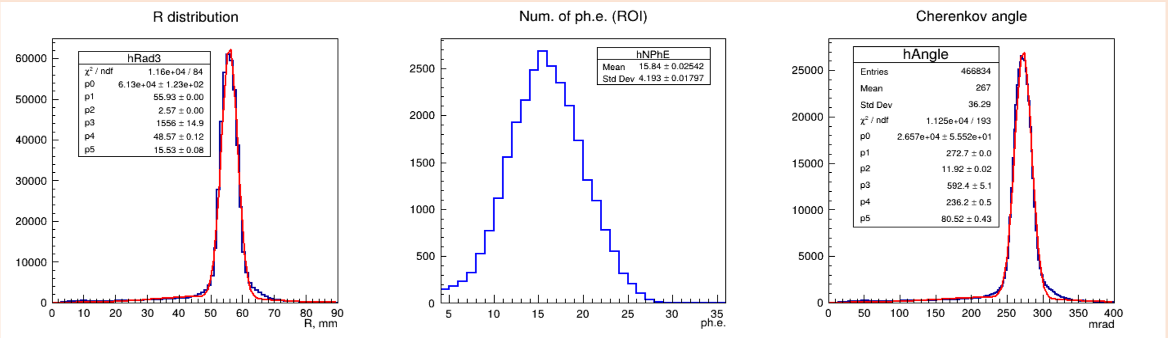




<X0>, <Y0>, <R> of rings are obtained

At this point the distributions of *R*, $N_{ph.e.}$, reconstructed Cherenkov angle are obtained.

PID capability may be estimated



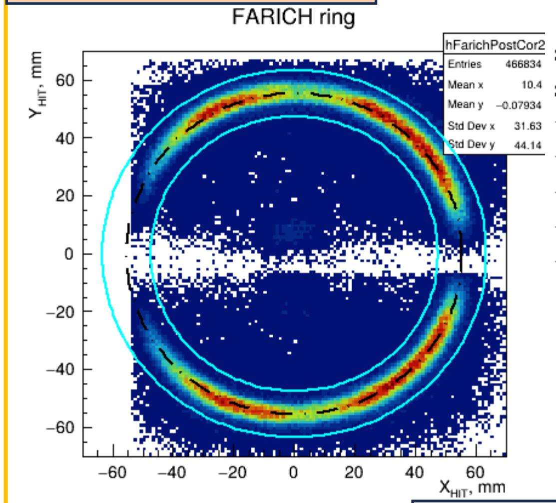
Focusing aerogel ($n_{max} \approx 1.03$)

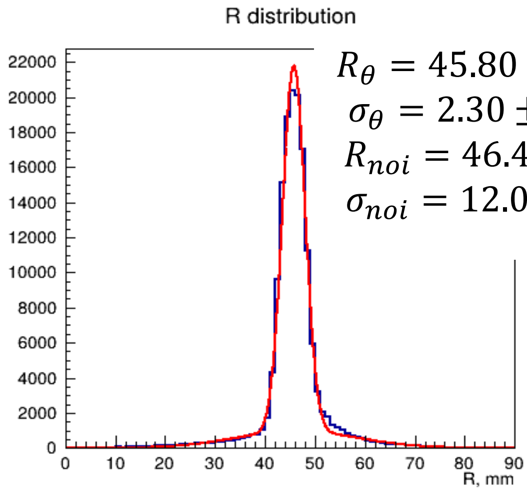
Goals:

- Testing new samples
- Comparison between 3 and 4-layers samples

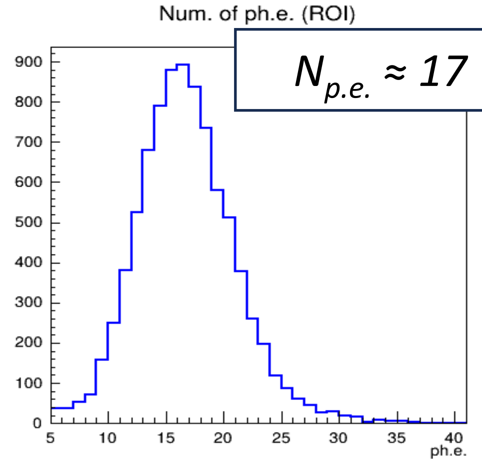
Focusing aerogel ($n_{max} \approx 1.03$)

No mask: 6x6 mm





$R_\theta = 45.80 \pm 0.01$
$\sigma_\theta = 2.30 \pm 0.01$
$R_{noi} = 46.4 \pm 0.1$
$\sigma_{noi} = 12.0 \pm 0.1$
[mm]

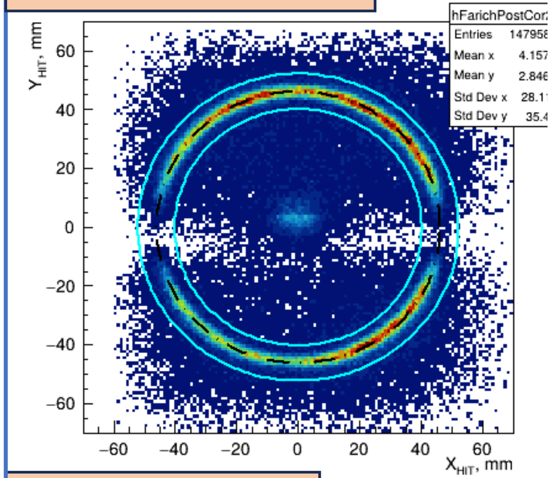


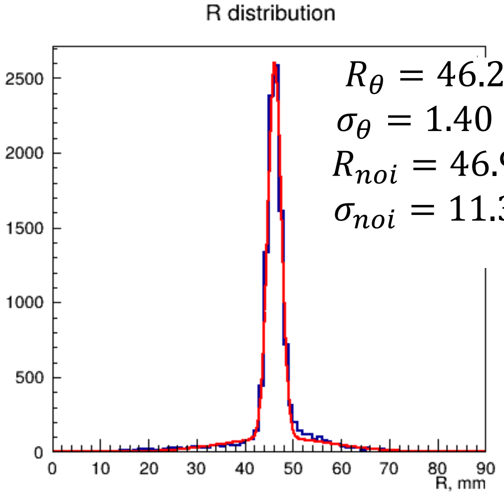
$N_{p.e.} \approx 17$

Geom. Eff. ~80%

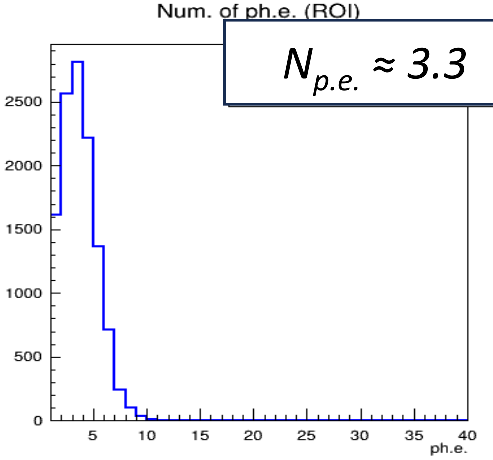
Estimated as
P = 6 GeV/c : "π/K" = 2.8 σ

Mask: ~ 3.4x3.4 mm





$R_\theta = 46.2 \pm 0.1$
$\sigma_\theta = 1.40 \pm 0.02$
$R_{noi} = 46.9 \pm 0.3$
$\sigma_{noi} = 11.3 \pm 0.3$
[mm]



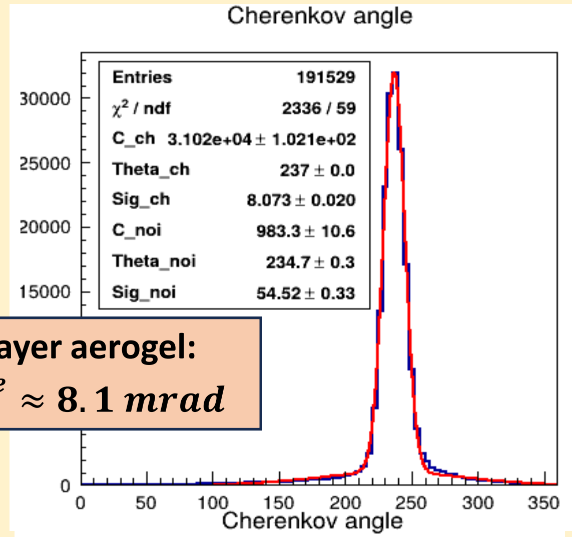
$N_{p.e.} \approx 3.3$

L_f = 200 mm,
4 layers aerogel

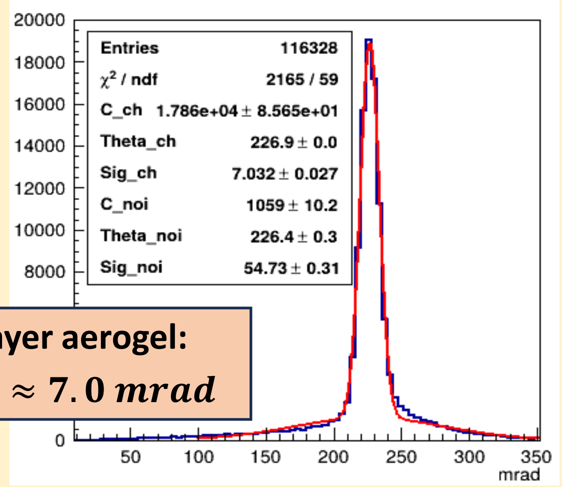
Geom. Eff. ~20%

Estimated as
P = 6 GeV/c : "π/K" = 4.5 σ

Comparison between 3- and 4-layers radiators for SPD:



3-layer aerogel:
$\sigma_\theta^{1\,p.e} \approx 8.1\,mrad$



4-layer aerogel:
$\sigma_\theta^{1\,p.e} \approx 7.0\,mrad$

- 3-layer and 4-layer aerogel's single photon resolution is almost equal.
- 3-layer is better option because of its stability and easier synthesis

Focusing aerogel ($n_{max} \approx 1.008$)

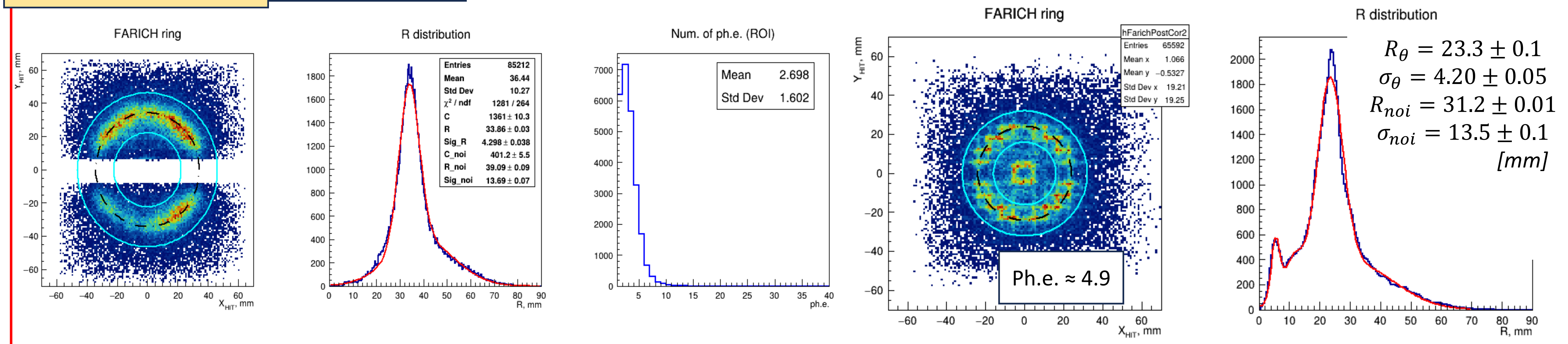
Goals:

- Testing new samples

Ultra-light aerogel (n = 1.008)

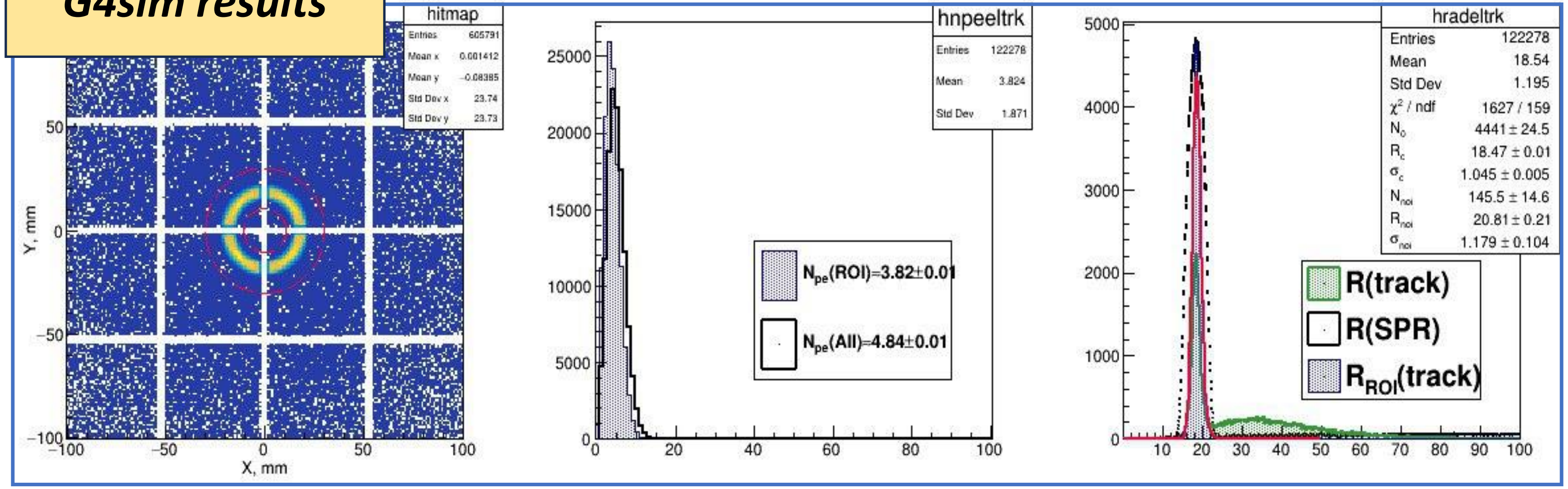
e^-TBeam results

No mask: 6x6 mm



$R_\theta = 23.3 \pm 0.1$
$\sigma_\theta = 4.20 \pm 0.05$
$R_{noi} = 31.2 \pm 0.01$
$\sigma_{noi} = 13.5 \pm 0.1$
[mm]

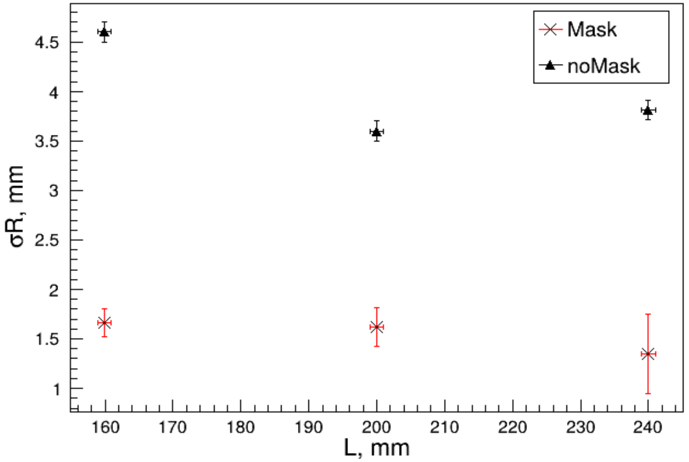
G4sim results

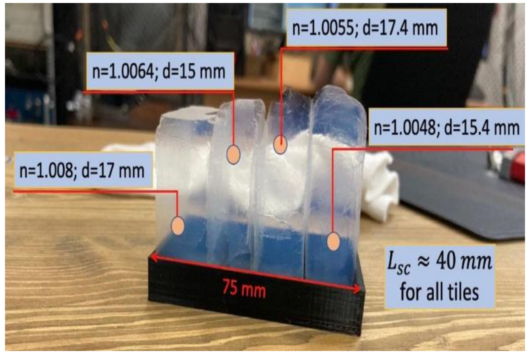


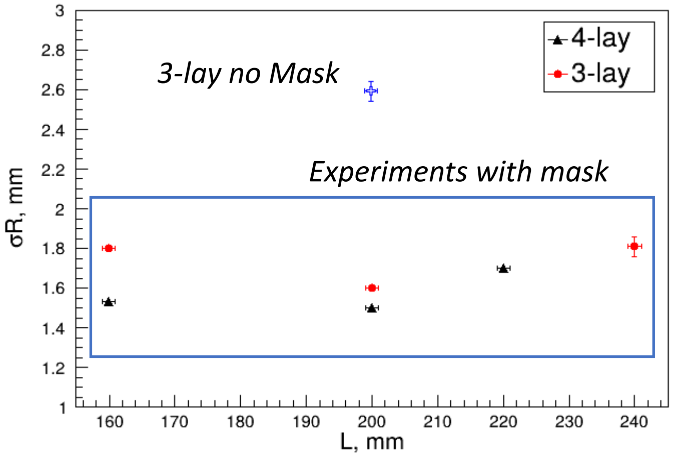
To improve the result a monolithic radiator and better PD must be used

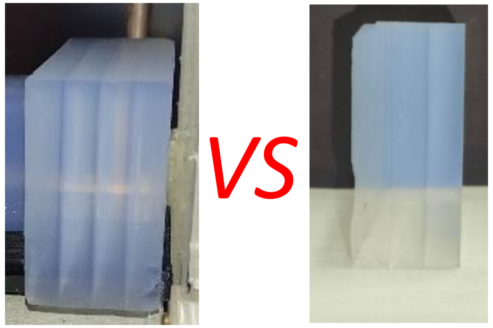
Additionally…

The focal length of the samples was studied.
However, due to the instability of the accelerator it was not possible to carry out the experiment to the end for each sample.
During the experiment the prototype was set with different L = 160, 200, 220 (240) mm.

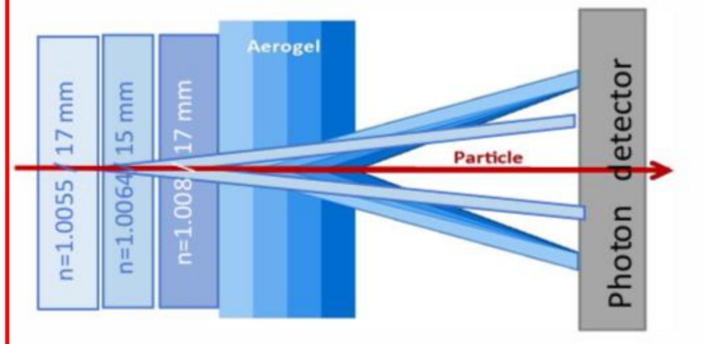




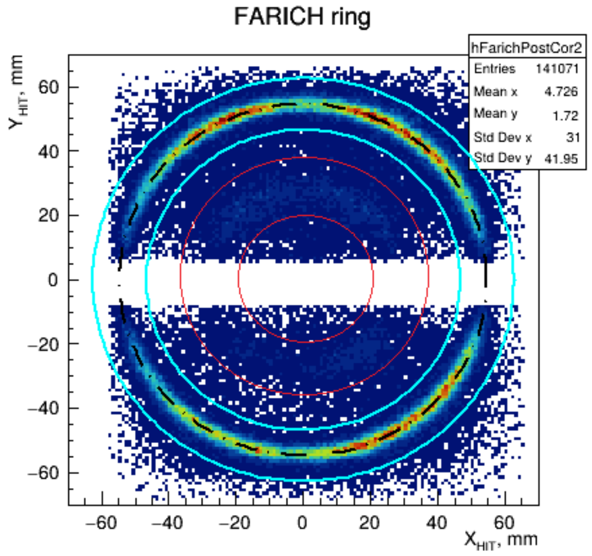


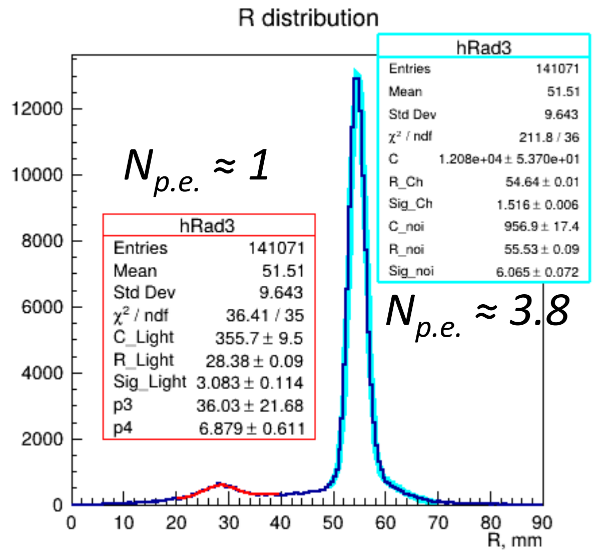


FARICH with dual aerogel radiator



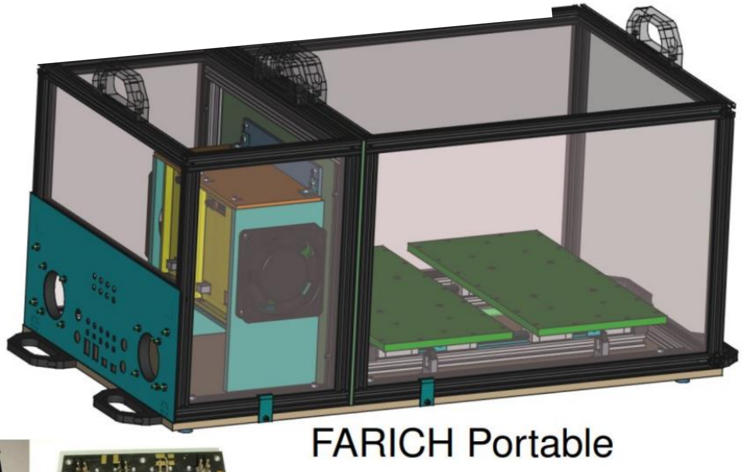
Mask: ~ 3.4x3.4 mm



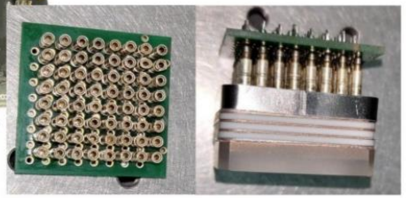


Main idea of concept:
μ/π–separation:
– from 0.8 to 2.5 GeV/c (pixel 3x3 mm).
π/K–separation:
– from 1.1 to 13 GeV/c (pixel 3x3 mm).

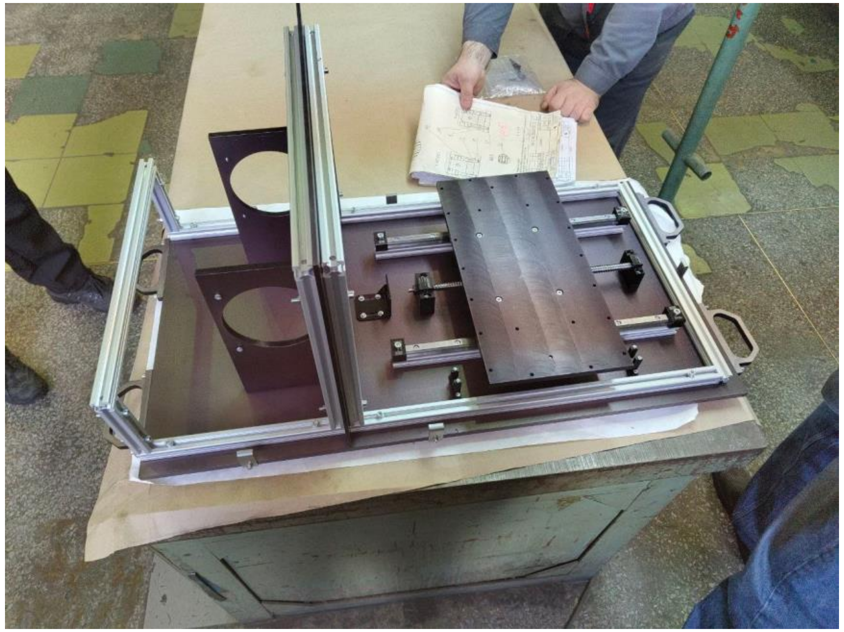
New FARICH prototype



Connectors for PMT



A prototype of PMT with MCP by Ekran FEP (Novosibirsk)



The frame of future prototype is already made

Summary

- FARICH prototype was assembled based on new synthesized this year samples of aerogel by Boreskov Institute of Catalysis with $n_{max}< 1.03$ (for SPD) and $n_{max}< 1.008$ (potentially for the future experiments with higher momenta).

- According to processing the PID capability of *"π/K"*-separation of FARICH for SPD is about 4.5 σ at 6 GeV/c with a pixel 3.4x3.4 mm^2.

- A comparison between 3 and 4-layers monolithic samples (for SPD) was performed. It seems that 3 layer is better option because of the $\sigma_{\theta}^{1\,p.e}$ (~$7.0_{[4\text{-lay}]}$ against ~$8.0_{[3\text{-lay}]}$ mrad). It's easier to produce and it has better stability.

- The results of FARICH (n ≤ 1.008) prototype may be improved by using monolithic focusing sample and better PD.

- Agreement between expectations of focusing length and experimental results is observed.

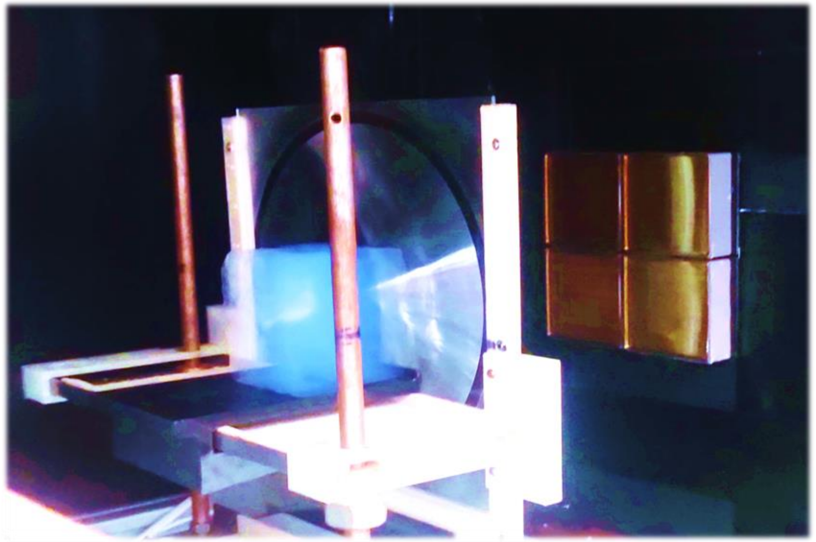
- FARICH with dual focusing radiator was also tested.

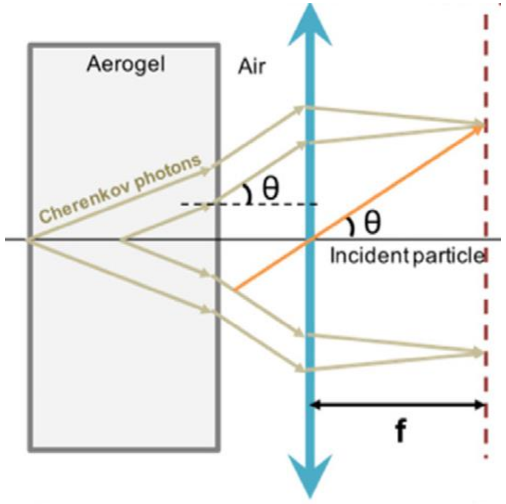
- Work continues…

BACKUP

RICH based on Fresnel lens

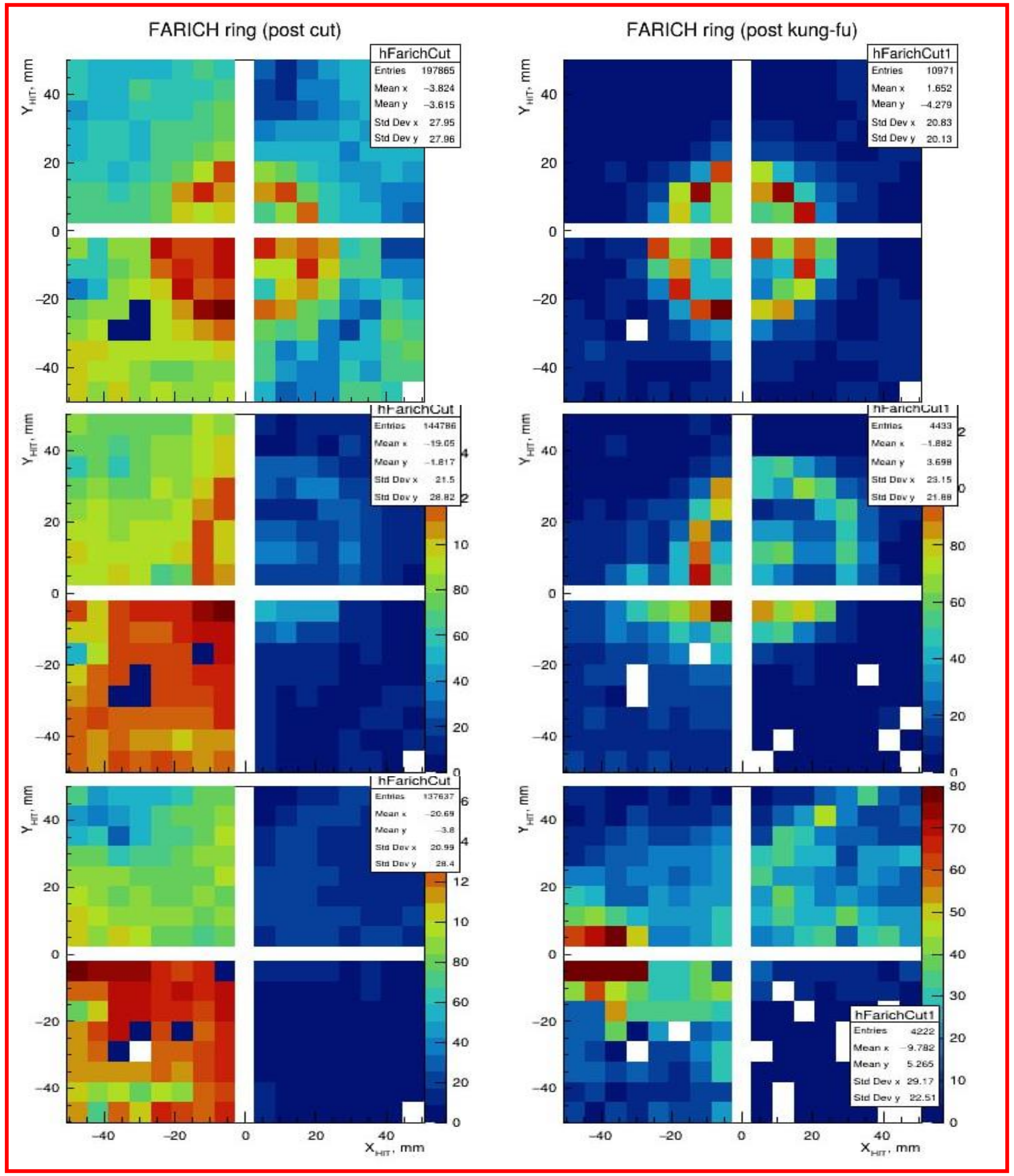
RICH with FL was also tested with aerogel n ~ 1.008





- ***We need to use another lens with a better transmission***
- ***There were scattered photons in the middle of the ring***
- ***There is a limitation on radius after which there are strong scattering is observed***

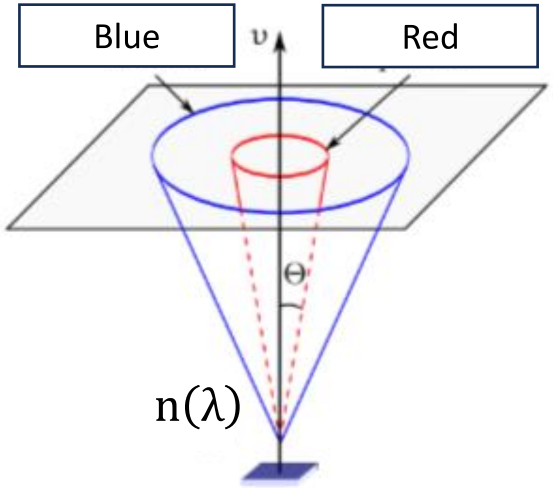
Demonstration of ring shift



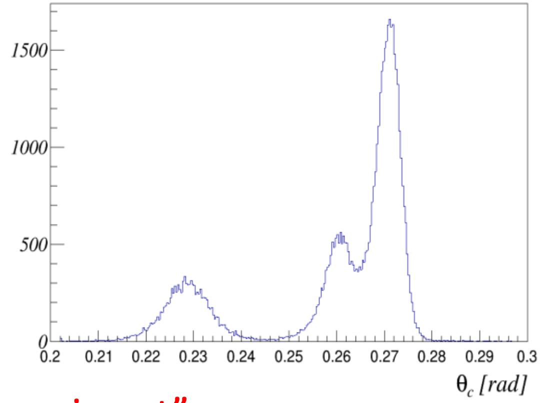
About PID

$\cos(\theta_{Ch}) = \frac{1}{n\beta}$ - famous expression of Cherenkov angle

$n = \mathrm{n}(\lambda)$ - in general. It's ignored during data process



particles momentum 6 GeV/c



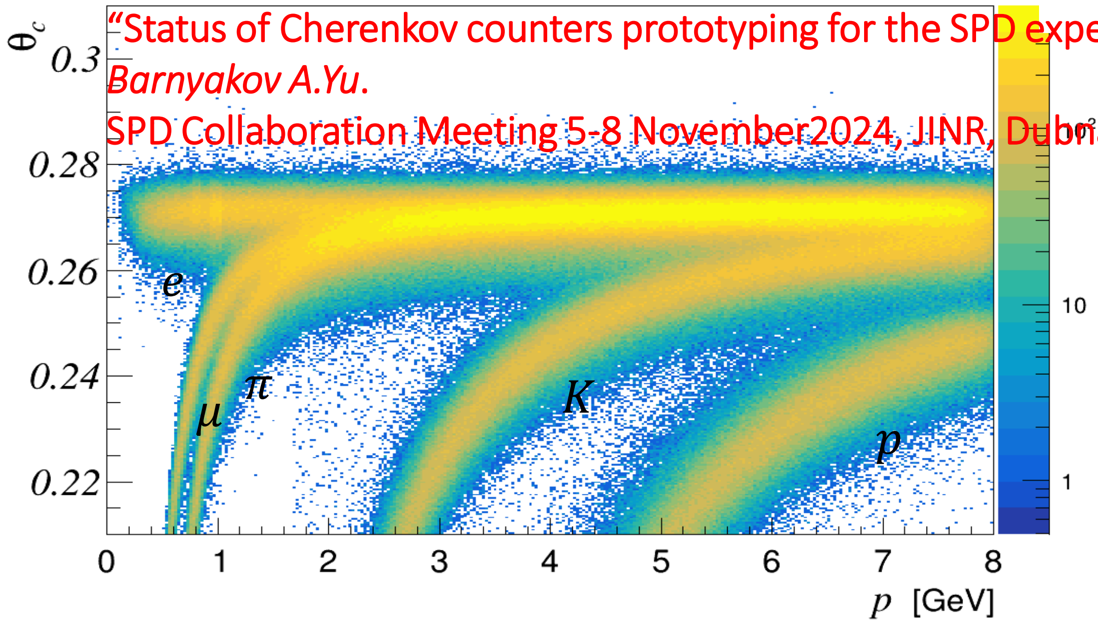
$$N_\sigma^{i/j} = \frac{(\theta^i - \theta^j)}{\sigma_\theta^{track}}, m^i < m^j$$

$$\sigma_\theta^{track} = \frac{\sigma_\theta^{1ph.e.}}{\sqrt{N_{ph.e.}}}$$

$N_{ph.e.} = N_{ph.e.}(\beta)$ or $N_{ph.e.} = N_{ph.e.}(P)$

since $N_{ph.e.} \sim sin^2(\theta_{Ch})$

Simulation of FARICH for SPD

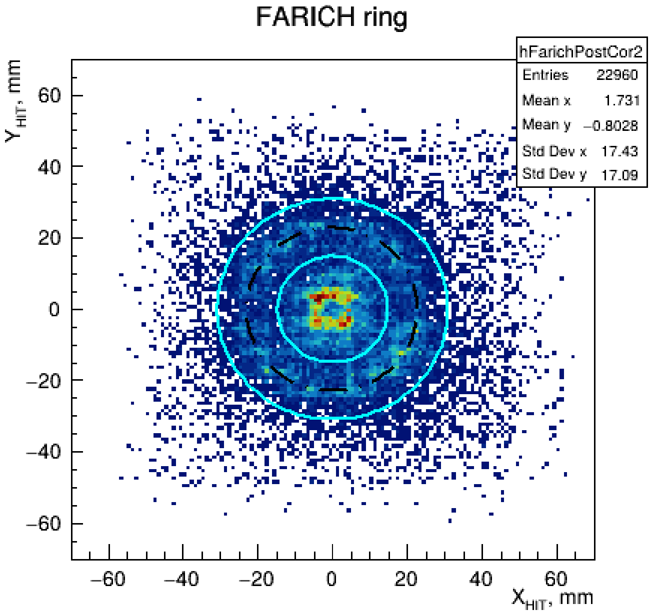


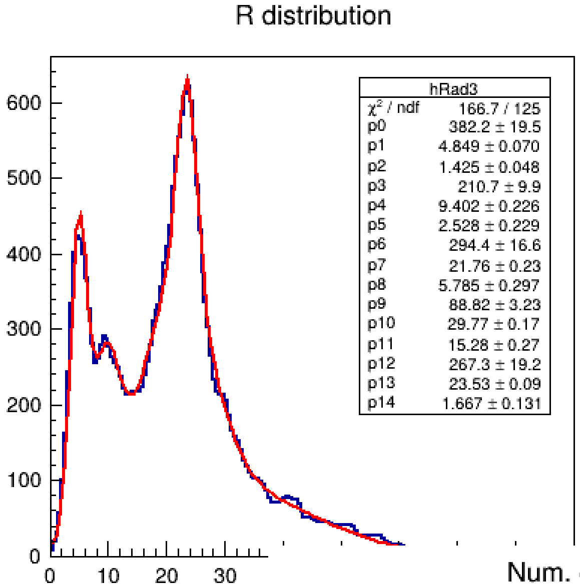
"Status of Cherenkov counters prototyping for the SPD experiment"

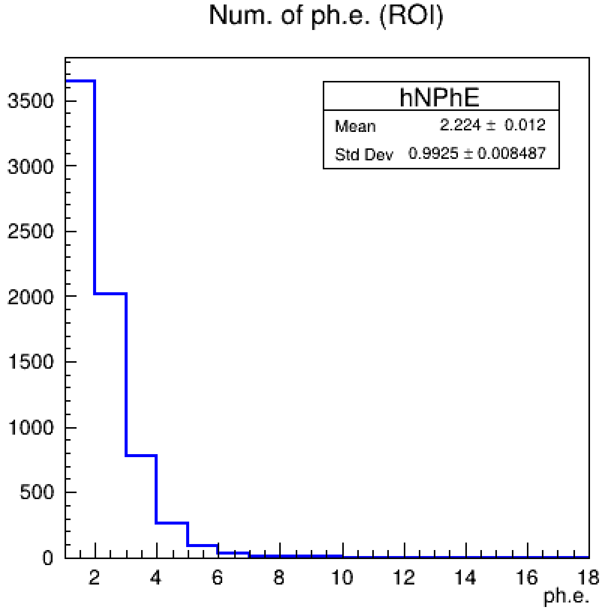
Barnyakov A.Yu.

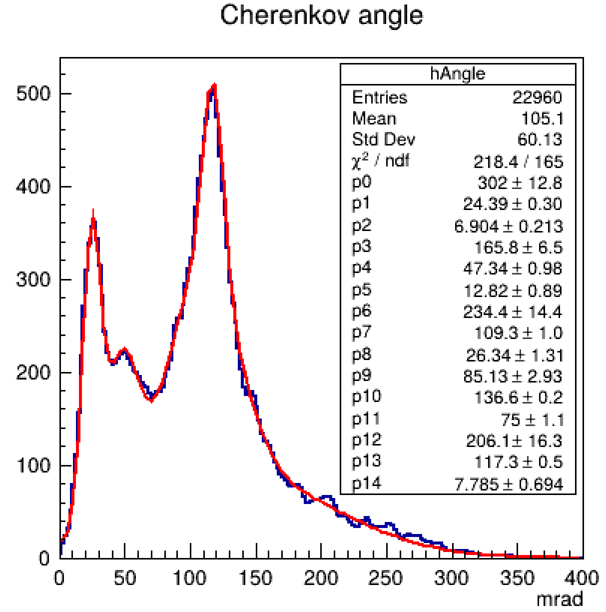
SPD Collaboration Meeting 5-8 November2024, JINR, Dubna, Russia

About ultra-light…









Lord of the ring on behalf Novosibirsk brotherhood of the ring