

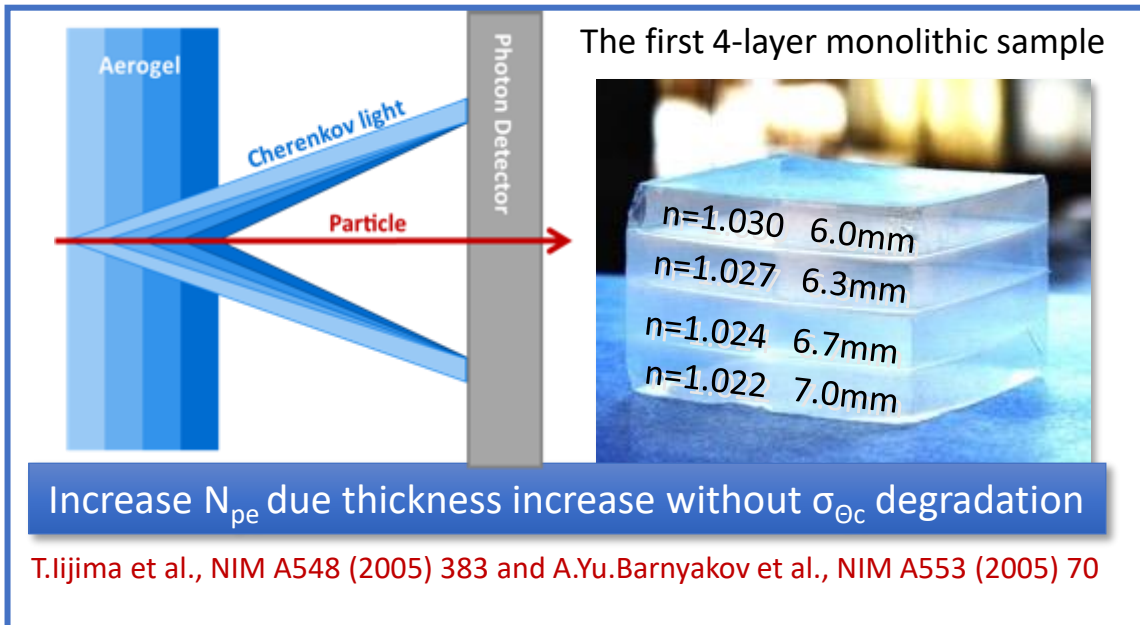
Data processing of aerogel RICH prototype

Ofitserov Artyom

on behalf of “Aerogel team” Budker Institute of Nuclear Physics
(Novosibirsk)

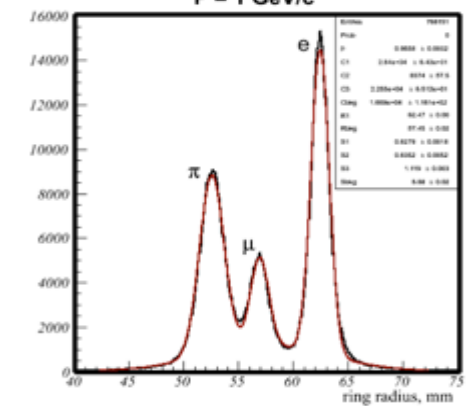
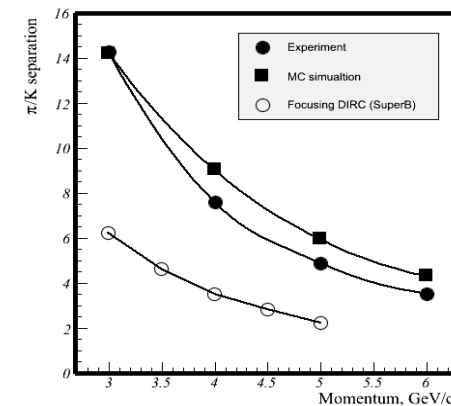
FARICH technique

- The SPD experiment for the NICA collider is currently under development. Expecting momenta of collisions up to $27 \text{ GeV}/c$
 - P of π and K mesons $\sim 6 \text{ GeV}/c$ 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).



Excellent PID capability was shown at CERN beam test in 2012

A.Yu. Barnyakov, et al., NIM A 732 (2013) 352
P = 1 GeV/c



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

$$N_{pe}(\beta = 1) \sim 500 \cdot \frac{n^2 - 1}{n^2} \cdot t \cdot QE$$

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 $n_{\text{max}} \approx 1.03$ (for momenta up to 6 GeV/c, for the SPD experiment, Russia).
- Ultra-light blocks with $n_{\text{max}} \approx 1.008$ 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

$$n_{\text{max}} \approx 1.03$$

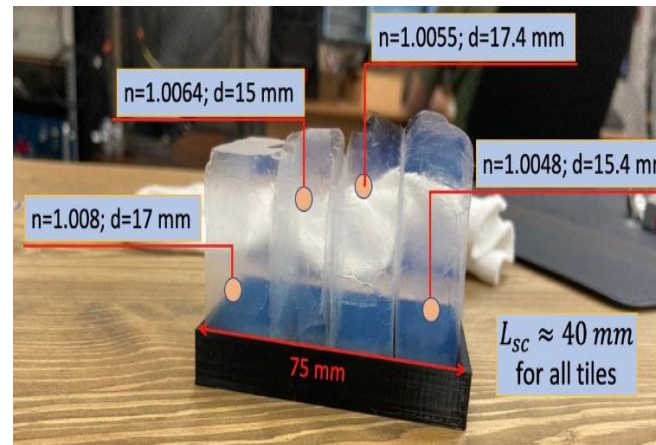
$$n_{\text{max}} \leq 1.008, n_{\text{min}} \approx 1.005$$



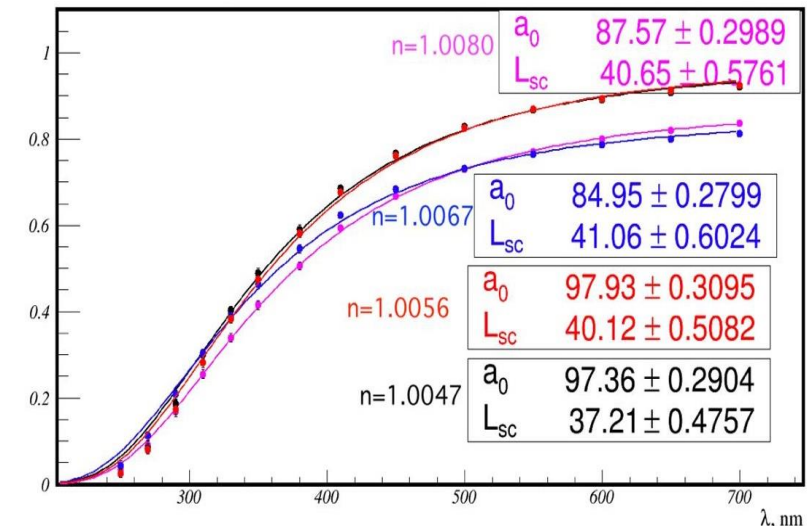
4 layers,
 $t \approx 33$ mm,
 $\langle n \rangle \approx 1.04$

3 layers,
 $t \approx 39$ mm,
 $\langle n \rangle \approx 1.03$

4 layers,
 $t \approx 39$ mm,
 $\langle n \rangle \approx 1.03$



Focusing assembly from
ultra-light aerogel



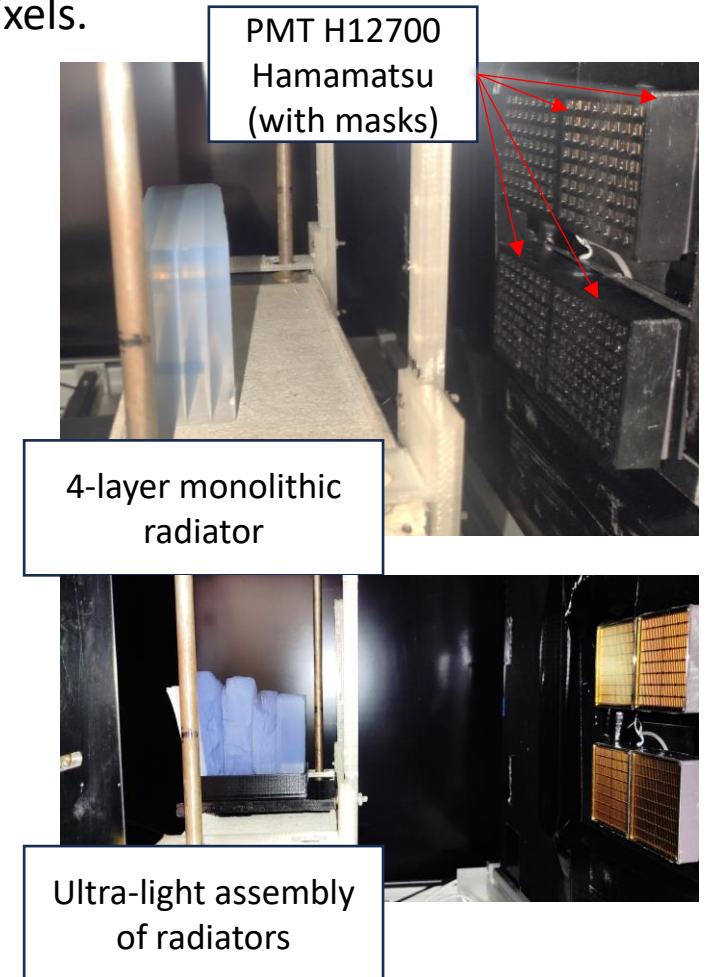
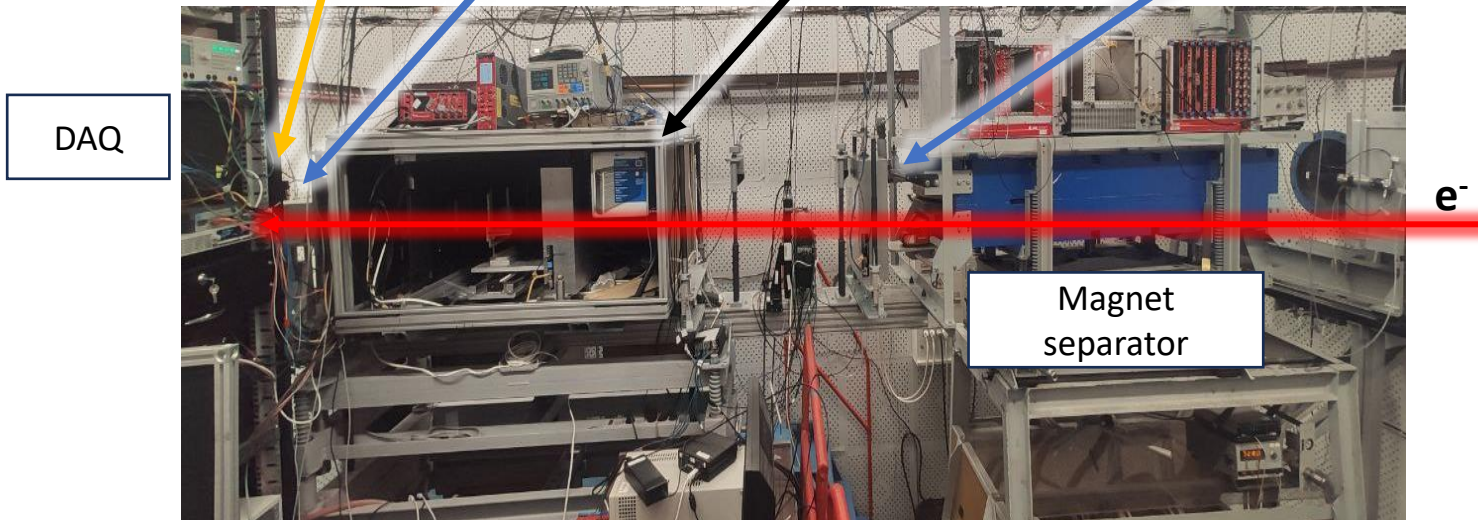
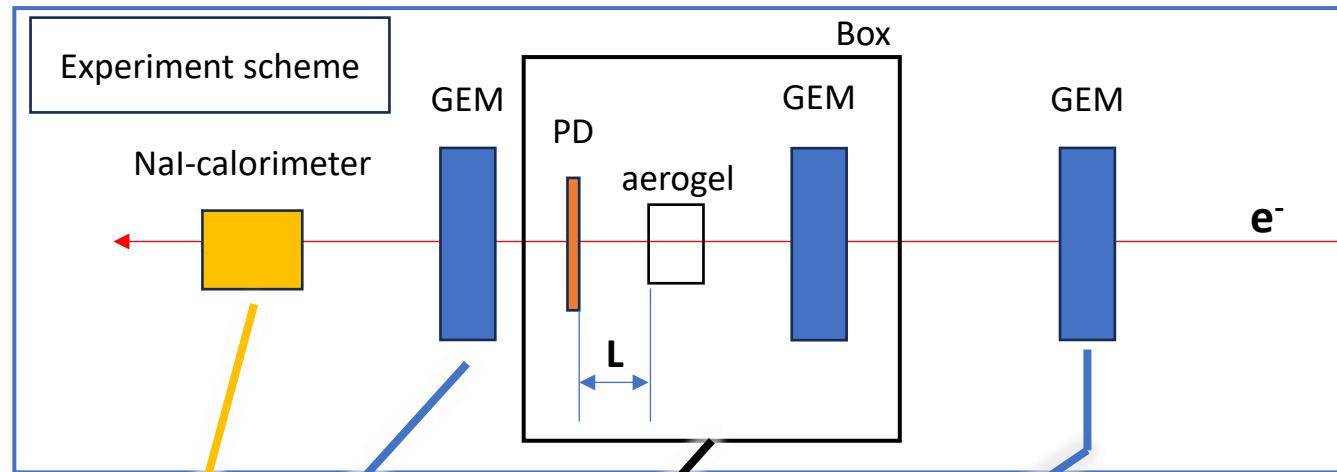
$$T = \frac{I}{I_0} = a_0 \cdot e^{-\frac{a}{L_{sc} \cdot (\lambda/400)^4}} = a_0 \cdot e^{-\frac{C \cdot d}{\lambda^4}}$$

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.

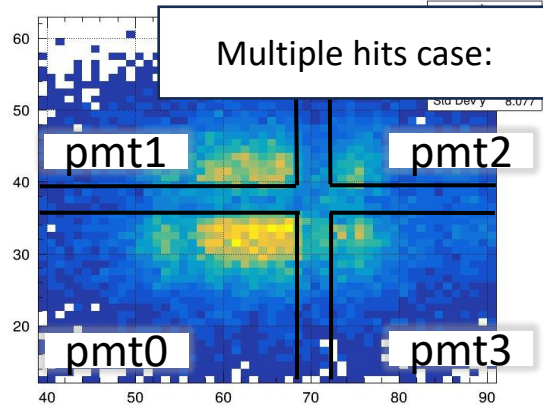
- Electron energy $E \sim 2.5$ GeV
- Photodetector – 4 H12700 Hamamatsu PMTs, each with an 8x8 array of 6 mm pixels.



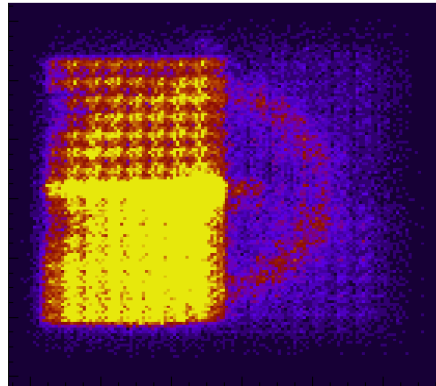
Case of a e^- hitting a PMT

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

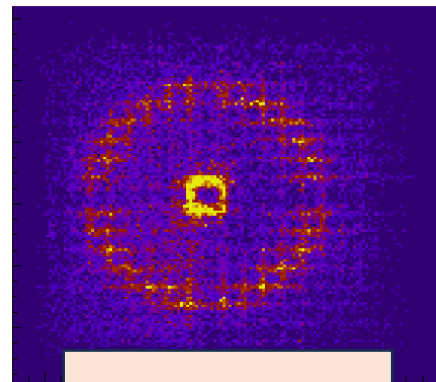
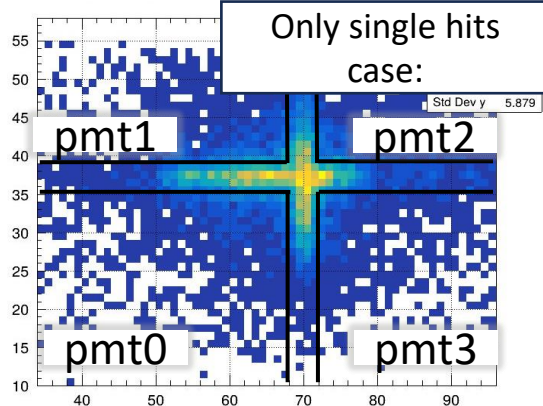
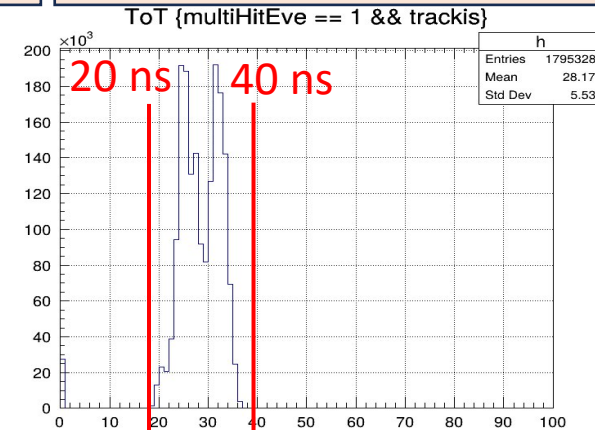
Position of the Electron tracks in the PD plane



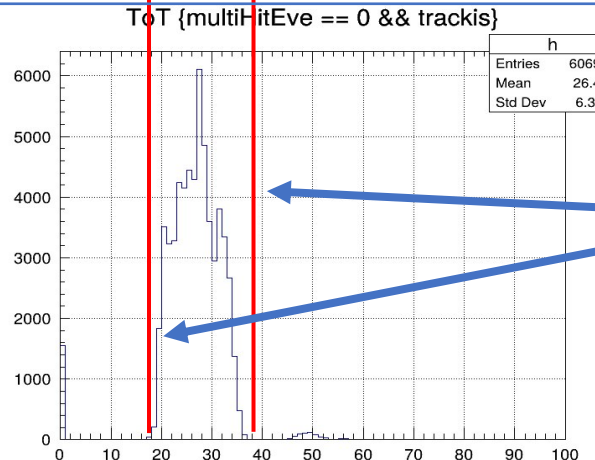
Cherenkov rings



Time information



ultralight, no mask

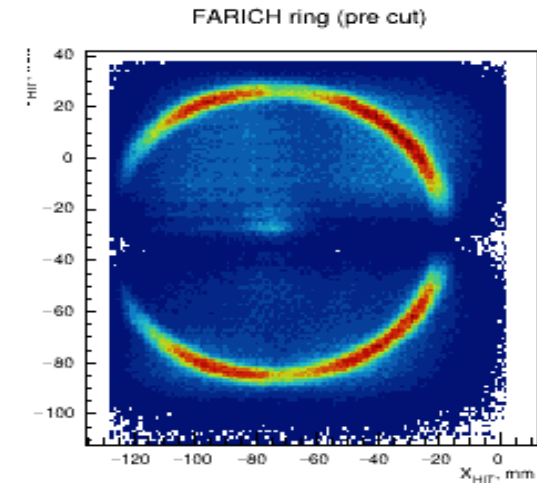
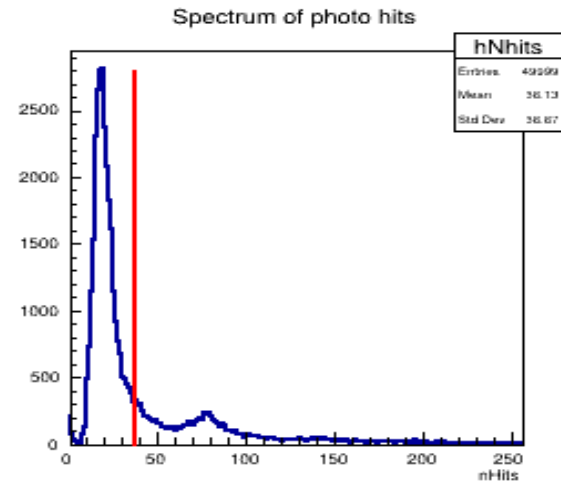
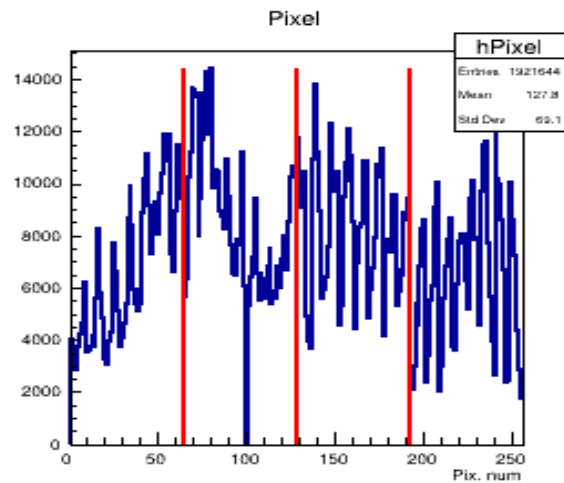
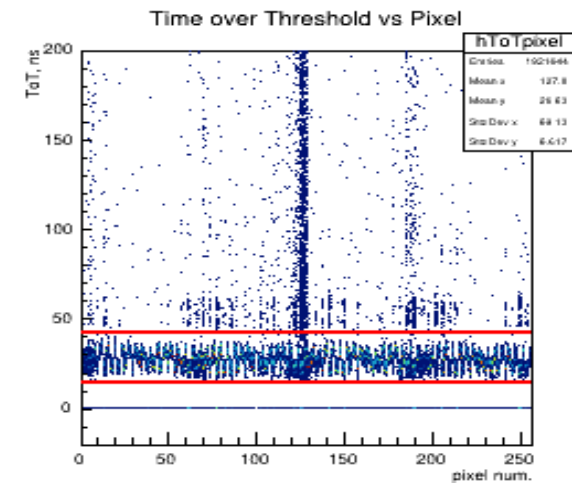
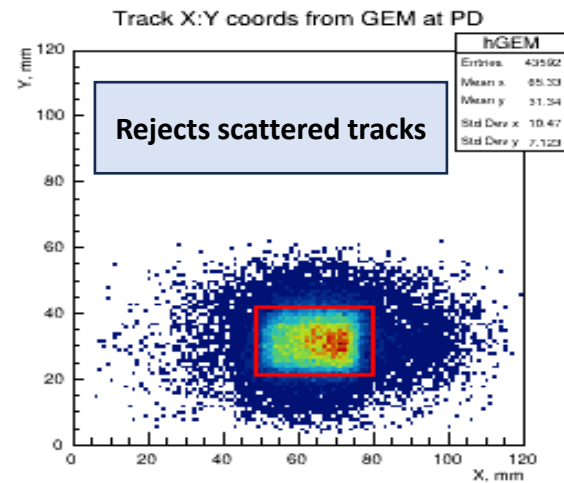
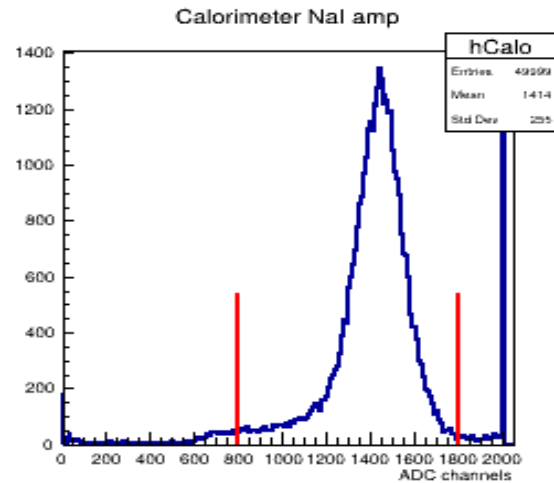


- ***Another PMT must be used instead of flat-panel H12700***
- ***Needed an additional investigation to determine what exactly causes such effect.***

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

Data processing

Applying Cuts at raw data

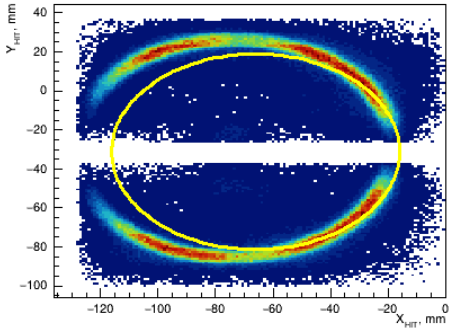


There are plenty of scattered or parasitic hits, it is necessary to cut them off for better approximations

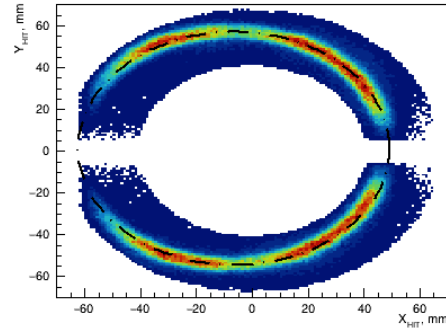
Data processing

Chain fit to determine
 $\langle x0 \rangle, \langle y0 \rangle$

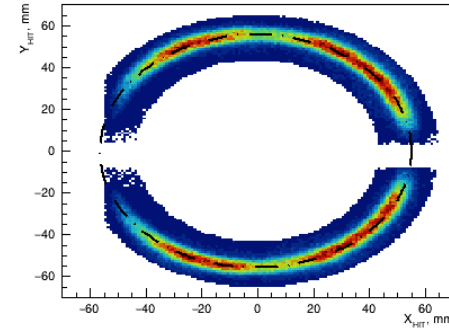
FARICH ring (post cut)



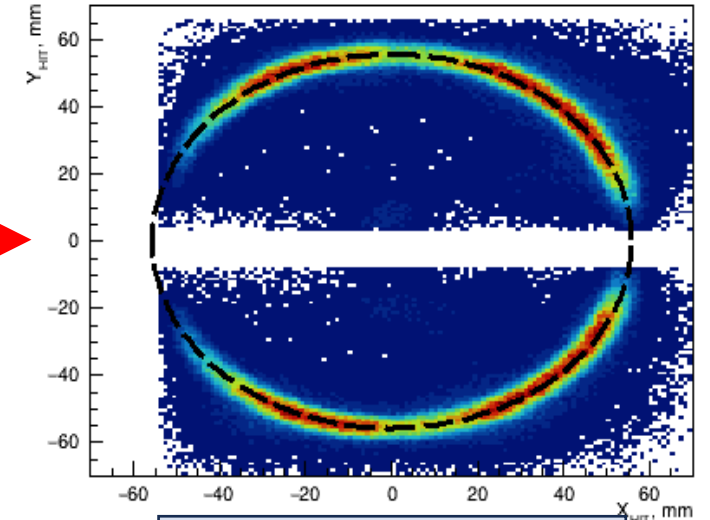
FARICH ring (pre cor, shifted)



FARICH ring (pre cor, shifted)

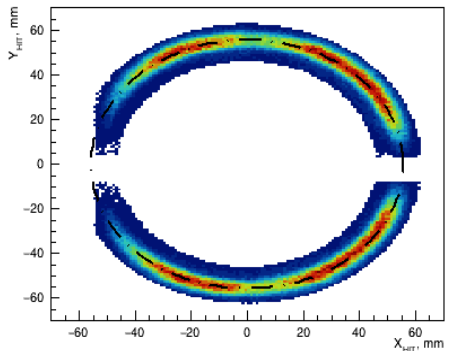


FARICH ring (post cor)

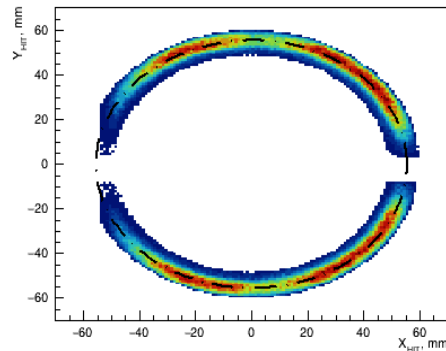


$\langle X0 \rangle, \langle Y0 \rangle, \langle R \rangle$ of rings
are obtained

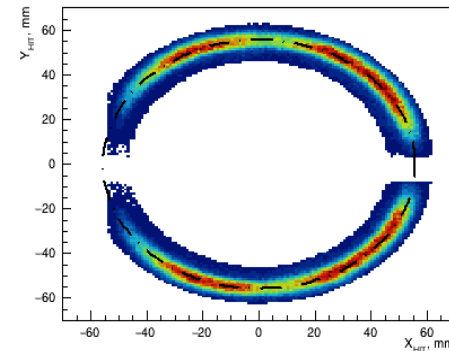
FARICH ring (pre cor, shifted)



FARICH ring (pre cor, shifted)



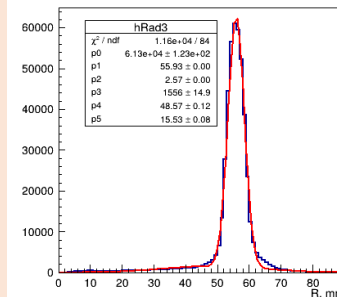
FARICH ring (pre cor, shifted)



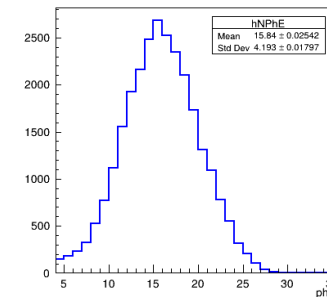
At this point the distributions of R , $N_{ph.e.}$,
reconstructed Cherenkov angle are obtained.

PID capability may be estimated

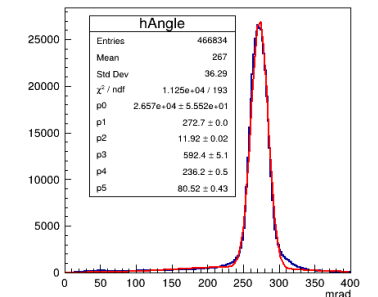
R distribution



Num. of ph.e. (ROI)



Cherenkov angle



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

Goals:

- Testing new samples
- Checking the focusing length
- Comparison between 3 and 4-layers samples

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

No mask: 6x6 mm

FARICH ring

hFarichPostCor2
Entries 466834
Mean x 10.4
Mean y -0.07934
Std Dev x 31.63
Std Dev y 44.14

R distribution

$$\begin{aligned} R_{\theta} &= 45.80 \pm 0.01 \\ \sigma_{\theta} &= 2.30 \pm 0.01 \\ R_{noi} &= 46.4 \pm 0.1 \\ \sigma_{noi} &= 12.0 \pm 0.1 \end{aligned} \quad [\text{mm}]$$

Num. of ph.e. (ROI)

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

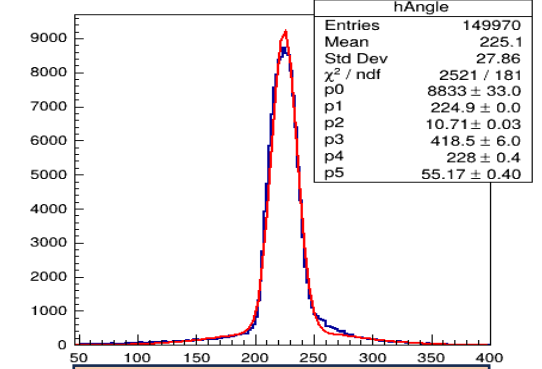
Geom. Eff. ~80%

Estimated as

$$P = 6 \text{ GeV/c} : \pi/K = 2.8 \sigma$$

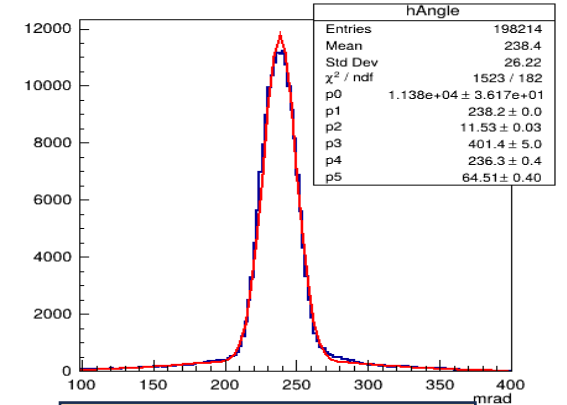
Comparison between 3- and 4-layers radiators for SPD:

Cherenkov angle



4-layer aerogel:

$$\sigma_{\theta}^{1p.e.} \approx 10.7 \text{ mrad}$$



3-layer aerogel:

$$\sigma_{\theta}^{1p.e.} \approx 11.5 \text{ mrad}$$

- 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

Mask: ~ 3.4x3.4 mm

hFarichPostCor2
Entries 147958
Mean x 4.157
Mean y 2.846
Std Dev x 28.1
Std Dev y 35.4

R distribution

$$\begin{aligned} R_{\theta} &= 46.2 \pm 0.1 \\ \sigma_{\theta} &= 1.40 \pm 0.02 \\ R_{noi} &= 46.9 \pm 0.3 \\ \sigma_{noi} &= 11.3 \pm 0.3 \end{aligned} \quad [\text{mm}]$$

Num. of ph.e. (ROI)

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

Geom. Eff. ~20%

Estimated as

$$P = 6 \text{ GeV/c} : \pi/K = 4.5 \sigma$$

$L_f = 200 \text{ mm}$,
4 layers aerogel

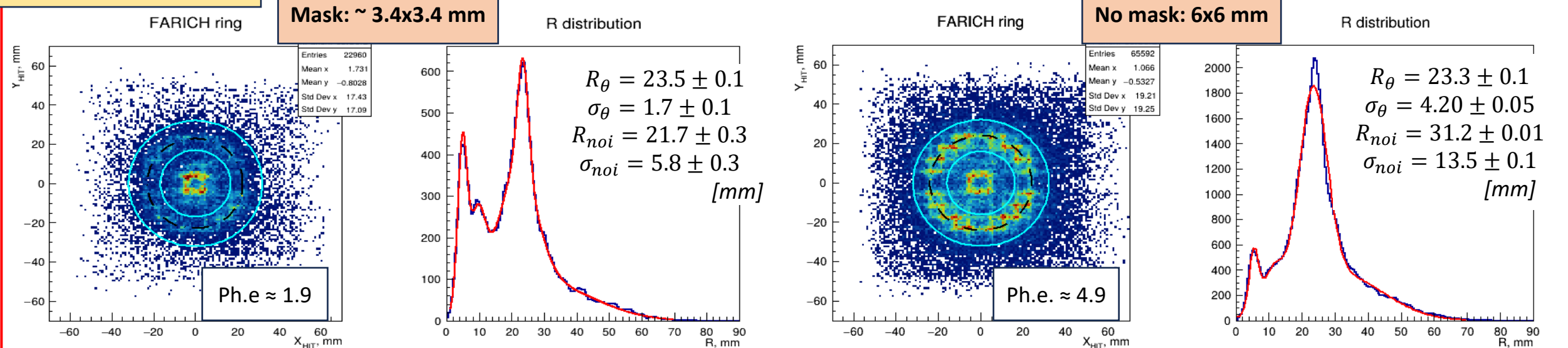
Focusing aerogel ($n_{\text{max}} \approx 1.008$)

Goals:

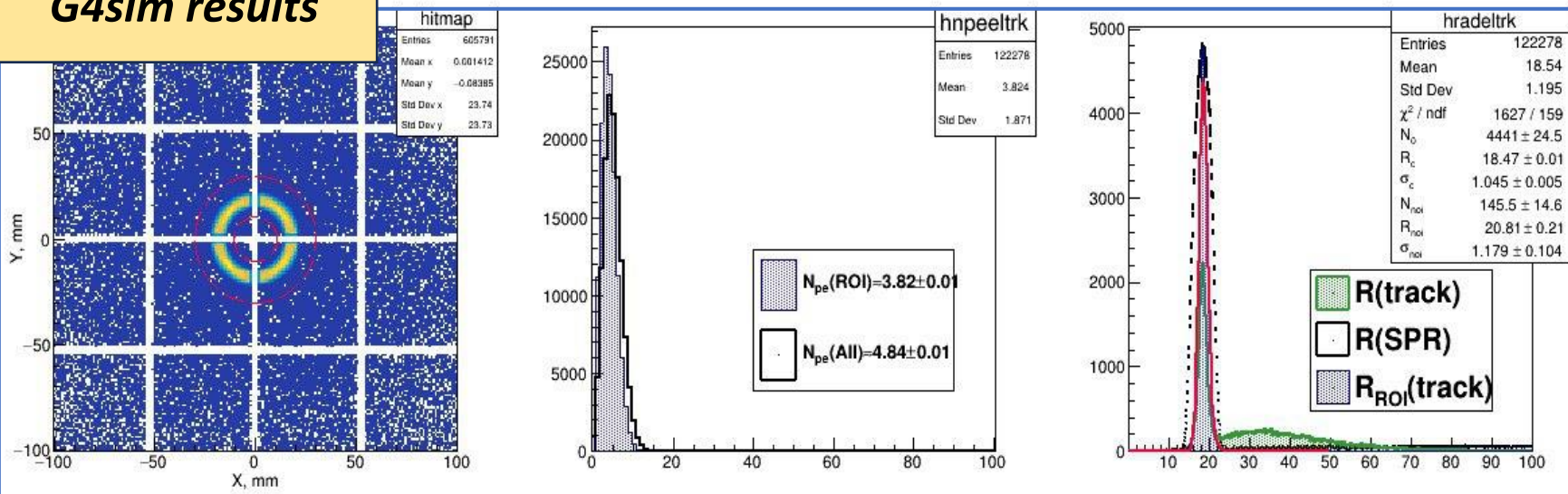
- Testing new samples
- Checking the focusing length

Ultra-light aerogel ($n = 1.008$)

e^- TBeam results



G4sim results



P = 7 GeV/c : “ π/K ” $\approx 3\sigma$ with 3.4 mm pixel

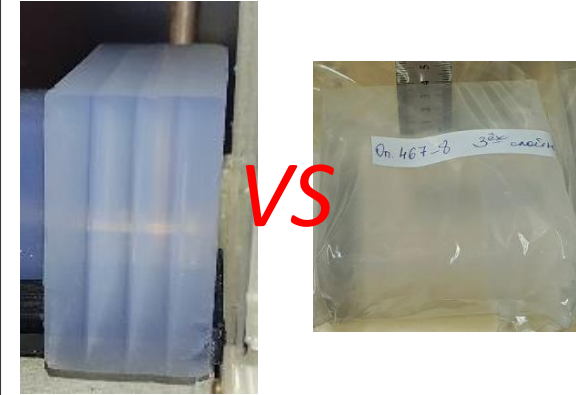
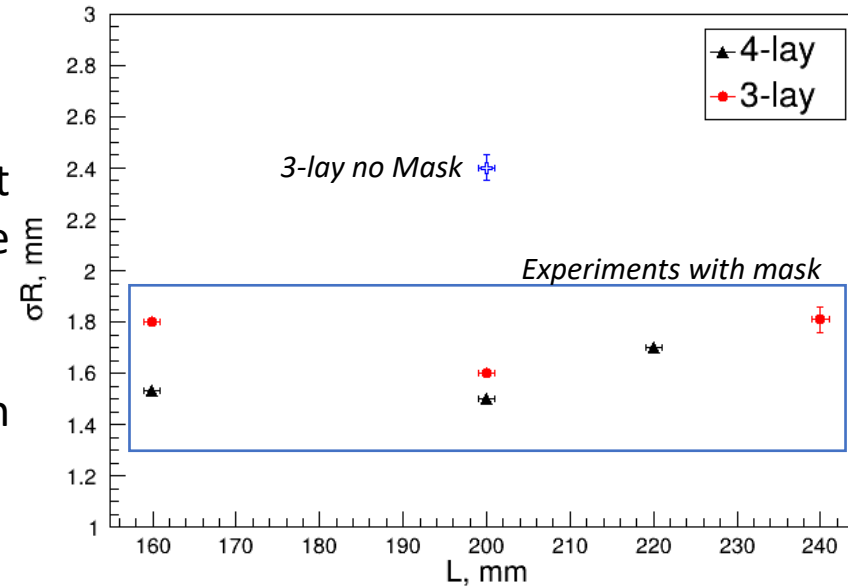
- *More or less good agreement between G4sim and TBeam is observed*
- *To improve the PID capability a monolithic radiator and better PD must be used*

Checking the focusing distance

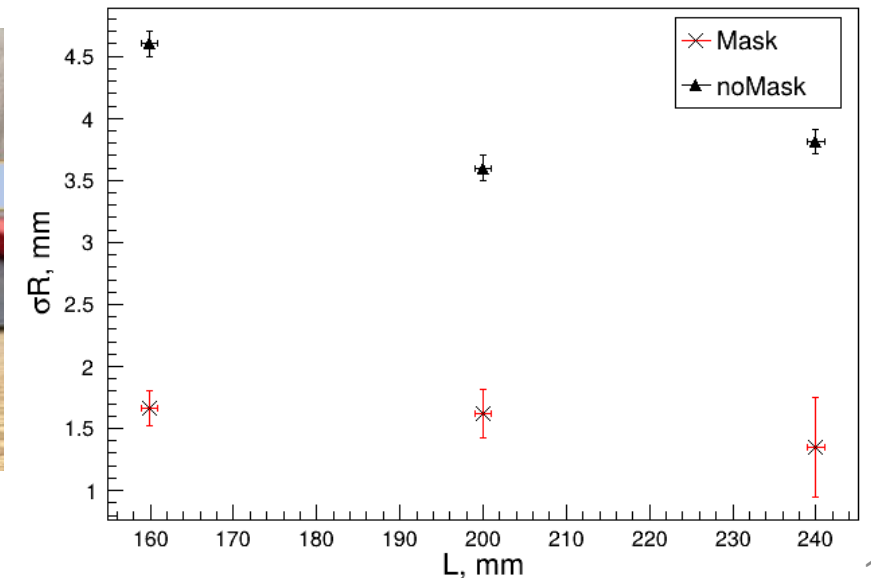
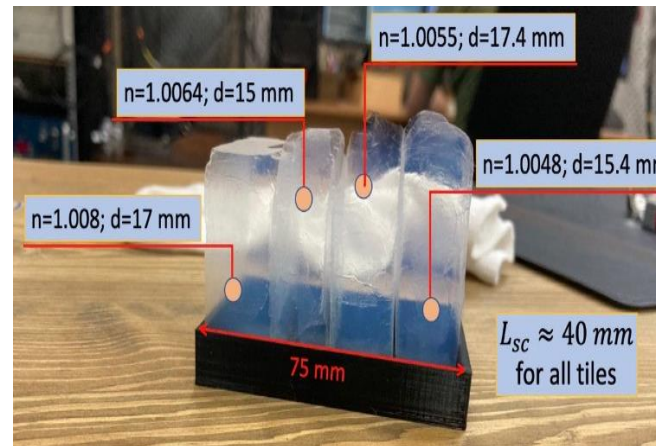
The focal length of the samples was studied.

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.



Focusing distance of prototype based on aerogel samples used in this experiment agreed with expectations

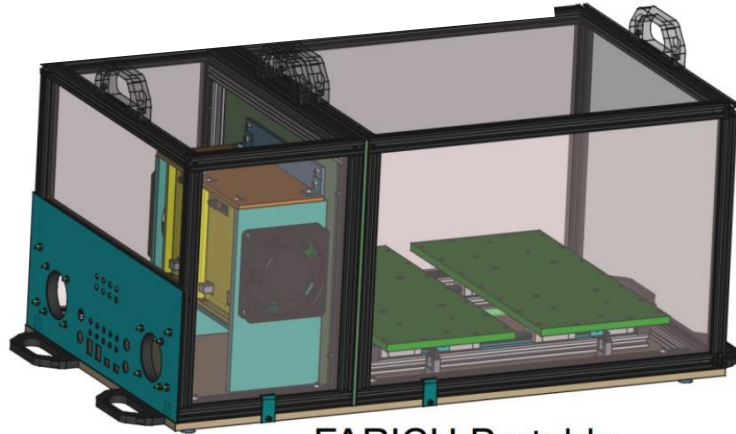


Summary

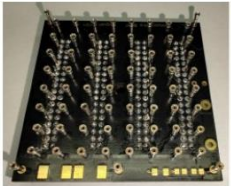
- FARICH prototype was assembled based on new synthesized this year samples of aerogel by Boreskov Institute of Catalysis with $n_{\max} < 1.03$ (for SPD) and $n_{\max} < 1.008$ (potentially for the future experiments with higher momenta).
- According to processing the PID capability of “ π/K ”-separation of FARICH for SPD is about 4.5σ at 6 GeV/c with a pixel $3.4 \times 3.4 \text{ mm}^2$.
- A comparison between 3 and 4-layers monolithic samples (for SPD) was performed. It seems that 3 layer is better option because of the $\sigma_{\theta}^{1 p.e}$ ($10.7_{[4\text{-lay}]}$ against $11.5_{[3\text{-lay}]}$ mrad). It's easier to produce and it has better stability.
- PID capability of “ π/K ”-separation of the current FARICH ($n \leq 1.008$) prototype estimated as 3.0σ at 7 GeV/c. More or less good agreement between G4sim and TBeam is observed. It's possible to improve the PID (better PD and monolithic sample are necessary).
- Agreement between expectations of focusing length and experimental results is observed.
- Work continues...

BACKUP

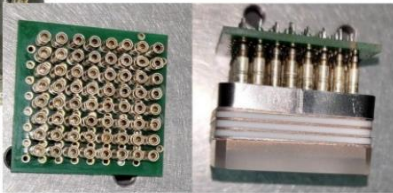
New FARICH prototype



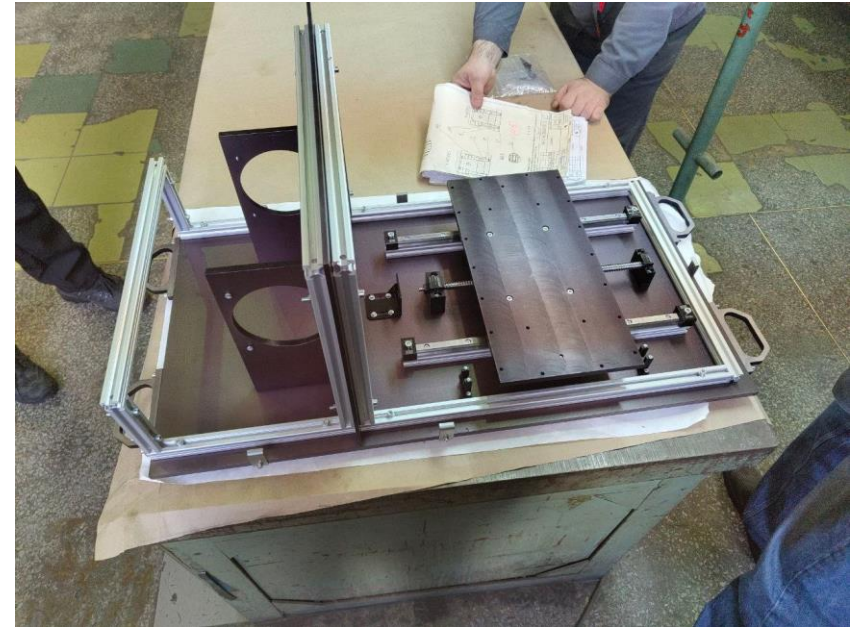
FARICH Portable



Connectors for PMT



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

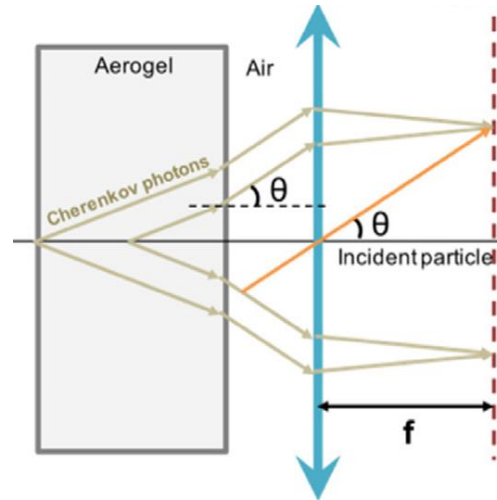
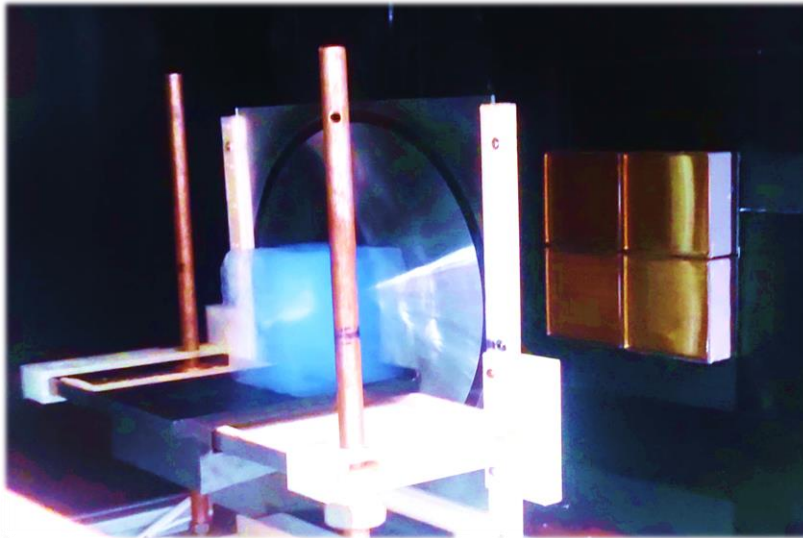


The frame of future prototype is already
made

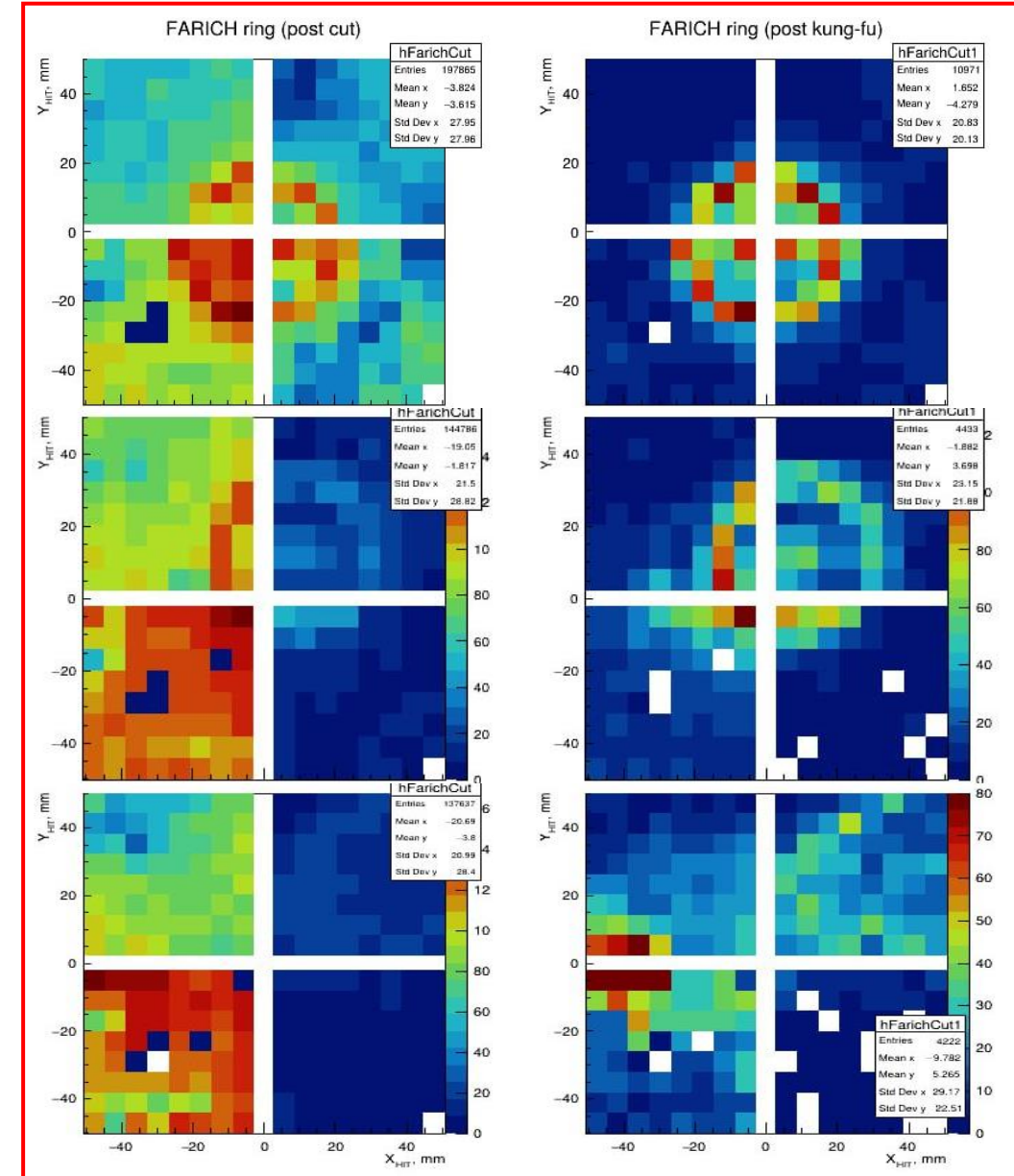
RICH based on Fresnel lens

Demonstration of ring shift

RICH with FL was also tested
with aerogel $n \sim 1.008$



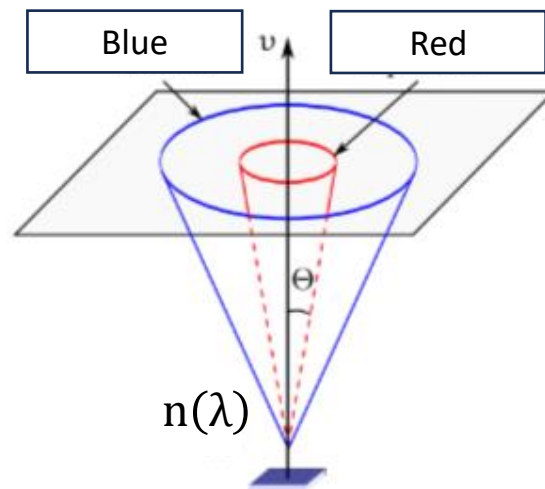
- *We need to use another lens with a better transmission*
- *There were scattered photons in the middle of the ring*
- *There is a limitation on radius after which there are strong scattering is observed*



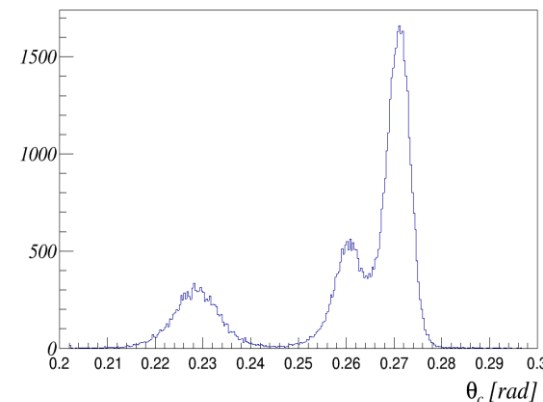
About PID

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

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



particles momentum 6 GeV/c

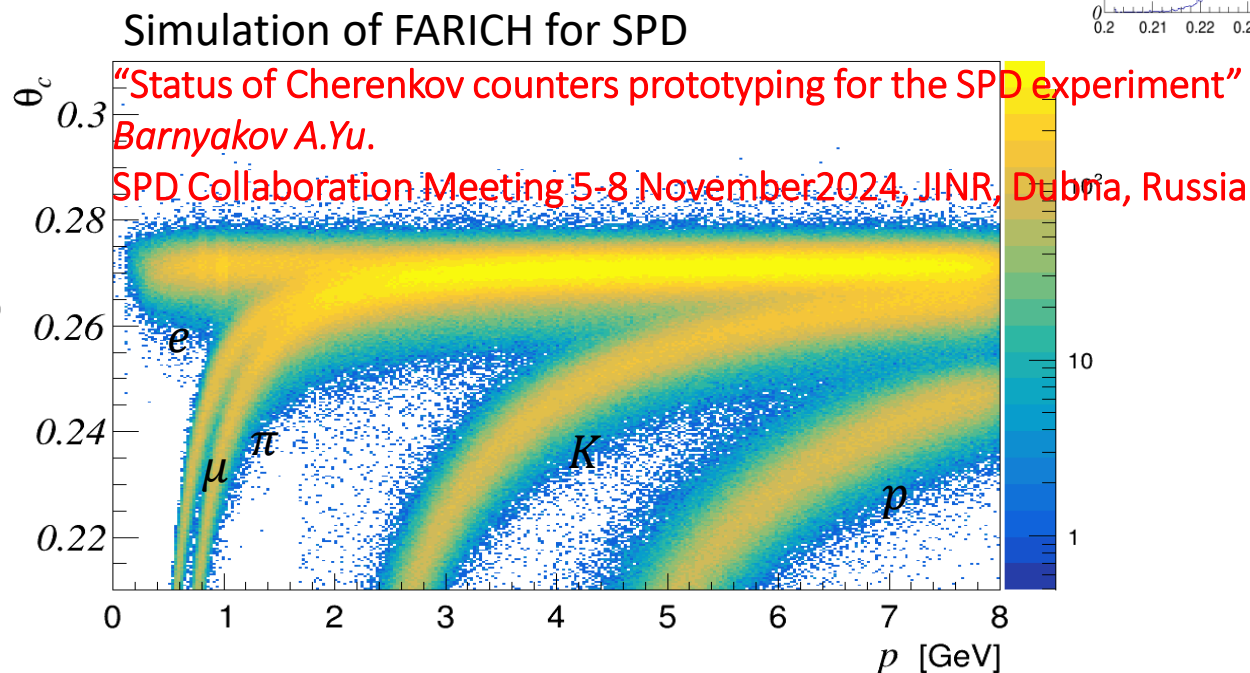


$$N_{\sigma}^{i/j} = \frac{(\theta^i - \theta^j)}{\sigma_{\theta}^{track}}, m^i < m^j$$

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

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

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



Lord of the ring on behalf Novosibirsk brotherhood of the ring

