Option of aerogel threshold Cherenkov counters for the Super Tau-Charm facility

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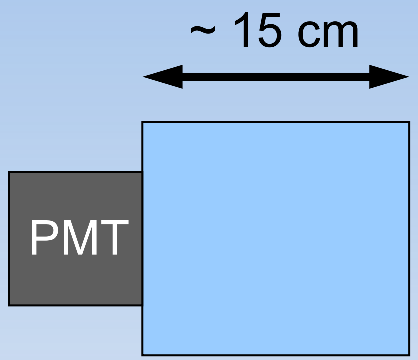
behalf of BINP Aerogel team

Outline

- ASHIPH counters
- Basic option (2 layers, n = 1.03)
- Advanced option (3 layers, n = 1.03 and 1.015)
- Prototype and electronics
- Conclusion

Threshold aerogel Cherenkov counters

Due to absorption and strong light scattering in aerogel photon detector must be close (10-15 cm) to particle trajectory



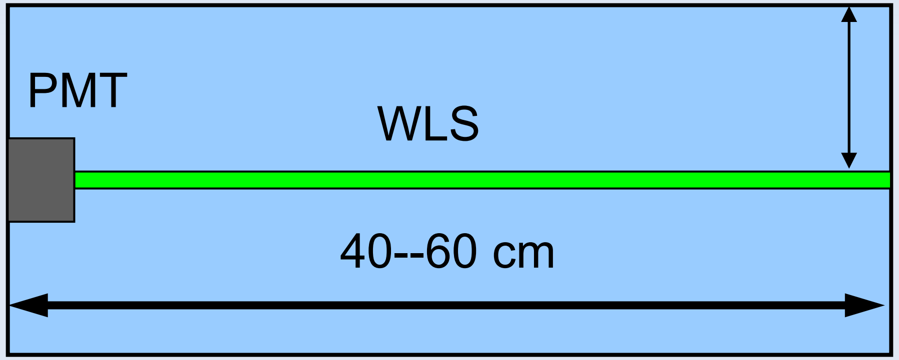
Direct light collection

Pro: Simplicity

Con: Counter size limited → large PMT number&area → high total cost

ASHIPH – Aerogel-SHIfter-PHotomultiplier

Suggested by A.Onuchin et al. for PID of the KEDR detector [NIM A315 (1992) 517]



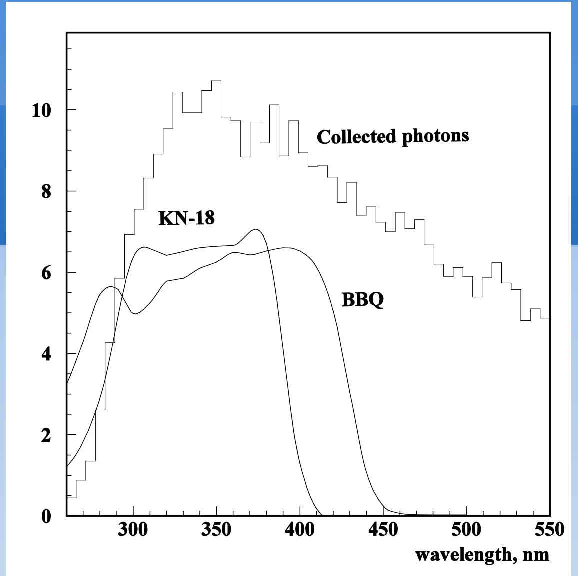
Pros:

- Large light collection area
- Small PMT (up to 10x smaller p.c. area in comparison with direct LC)
- Low cost

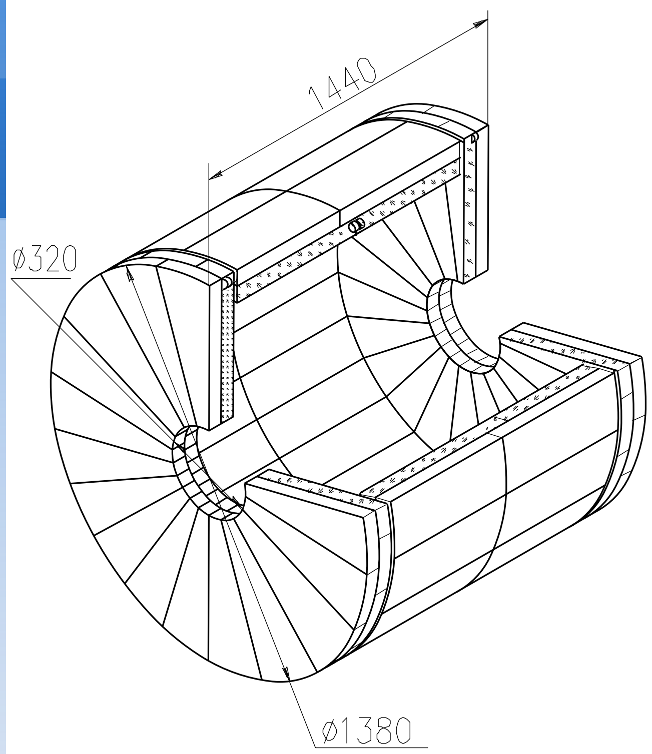
Cons:

- Particle acceptance loss due to WLS

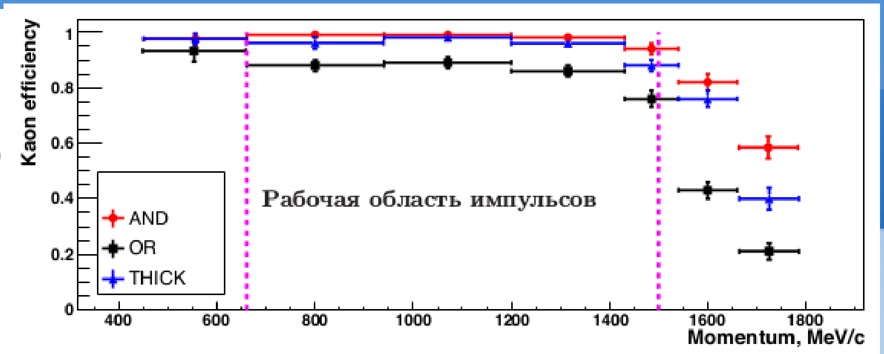
ASHIPH technique at e^+e^- collider experiments

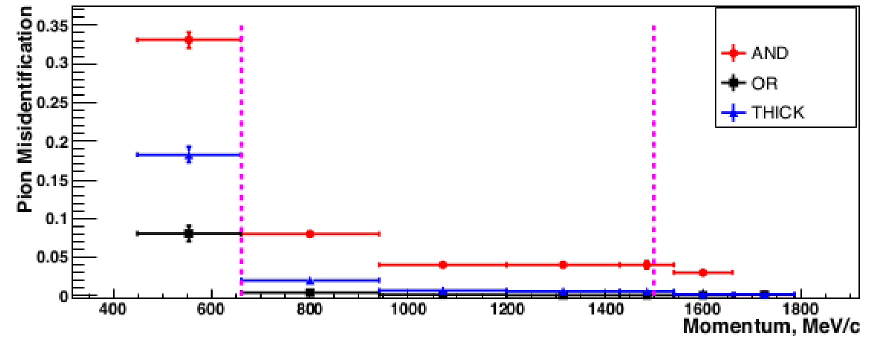


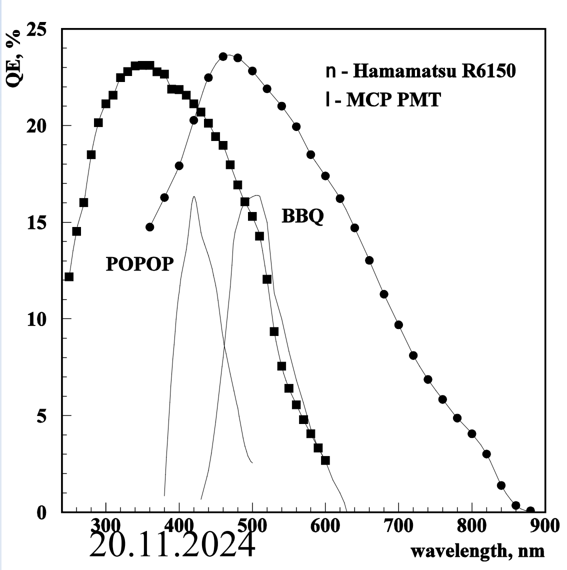
- PMMA light guide doped with BBQ dye is used as wavelength shifter
- MCP PMTs are used as Ph. detectors



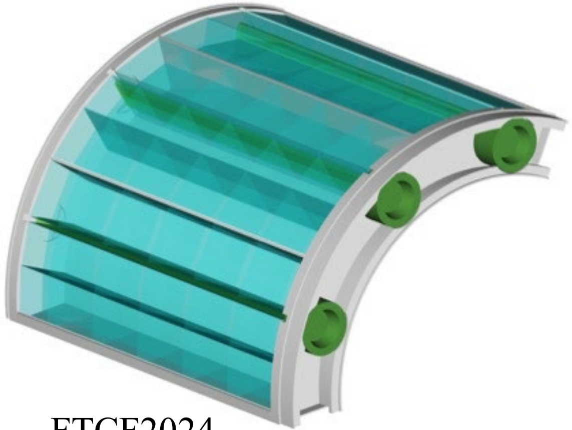
KEDR:
- 160 counters (2 layers)
- n=1.05 (1000l)
- WLS (BBQ)
- MCP PMT øPC=18 mm
- 0.97x4π
- 24% X_0

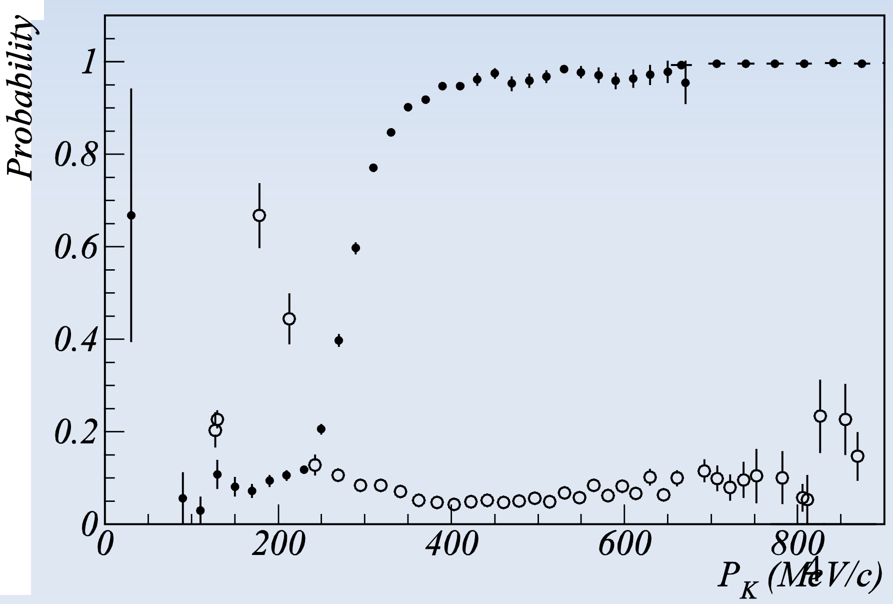




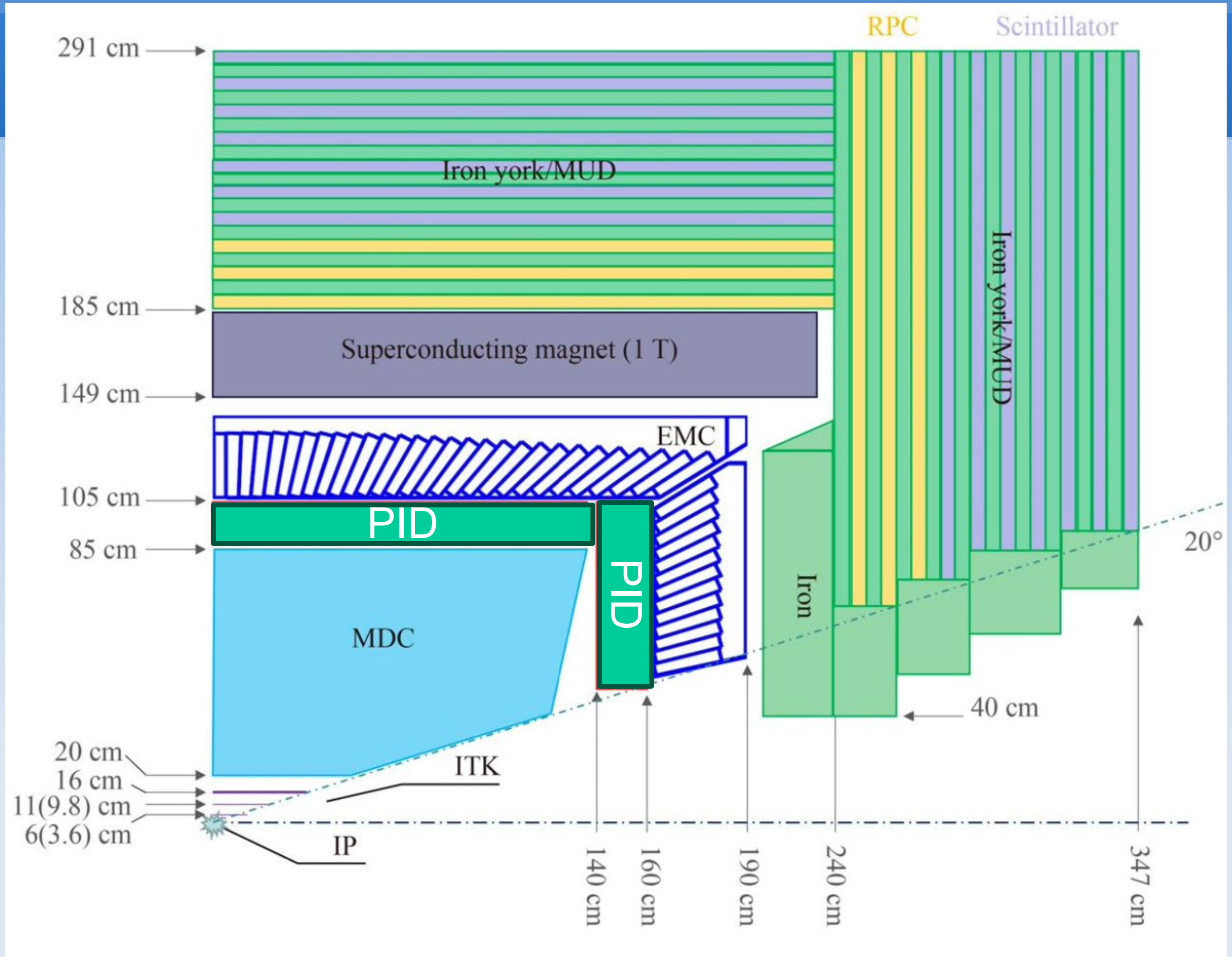


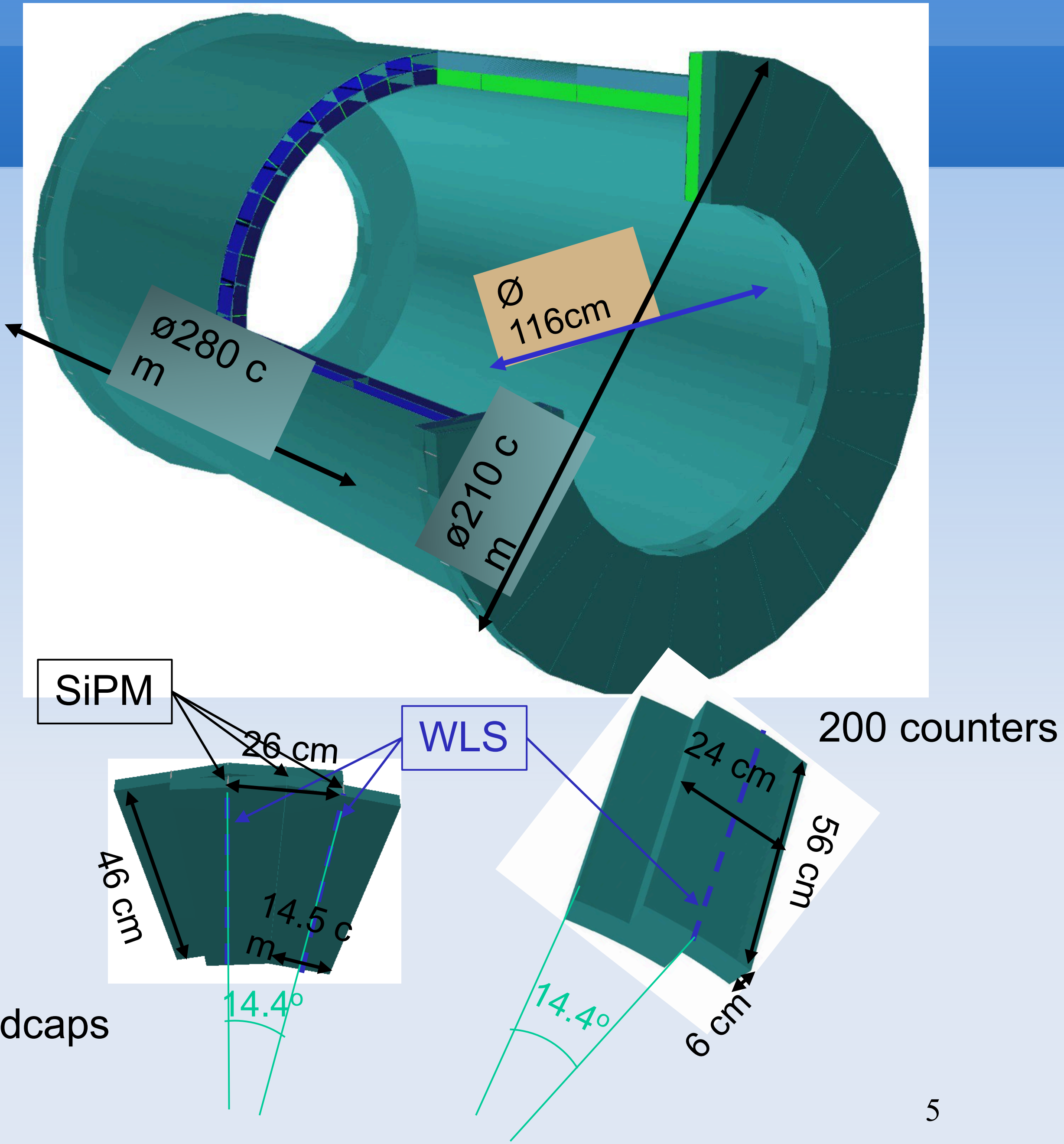
SND:
- 9 counters (1 layer)
- n=1.13 (9l)
- WLS (BBQ)
- Thickness ~ 30 mm
- MCP PMT øPC=18 mm
- 0.6x4π





ASHIPH system proposal for STCF (basic)



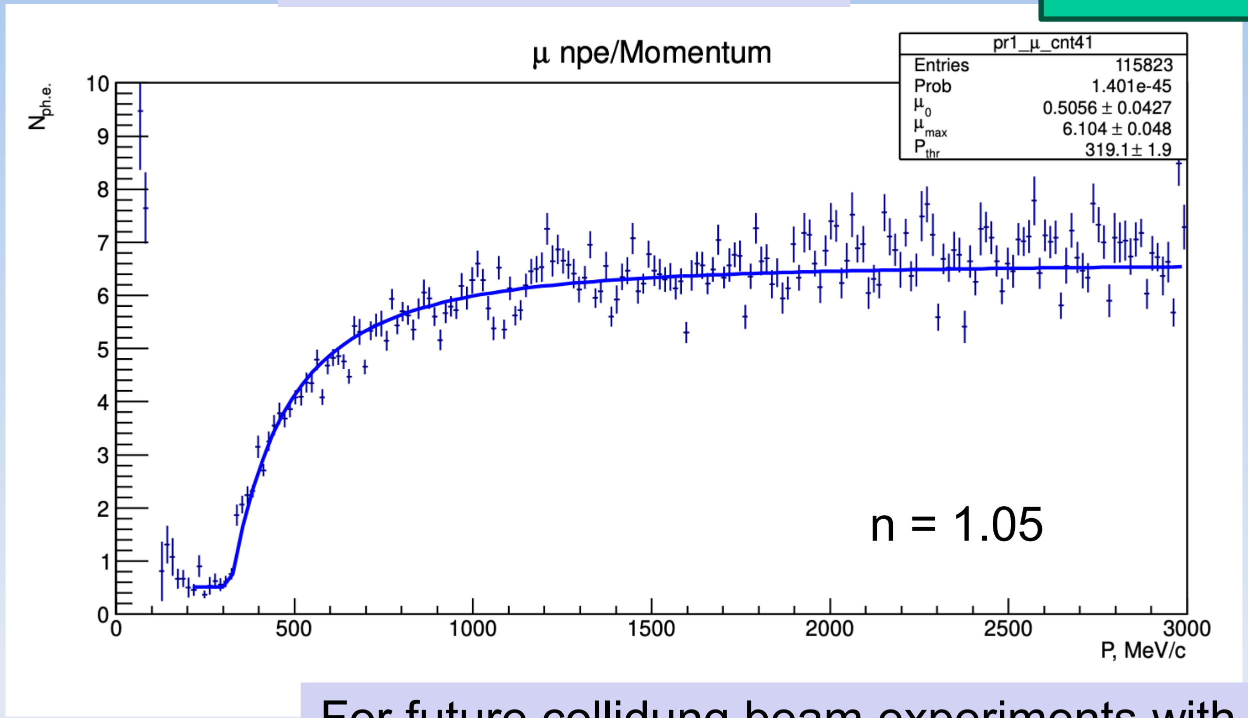


100 counters in 2 endcaps

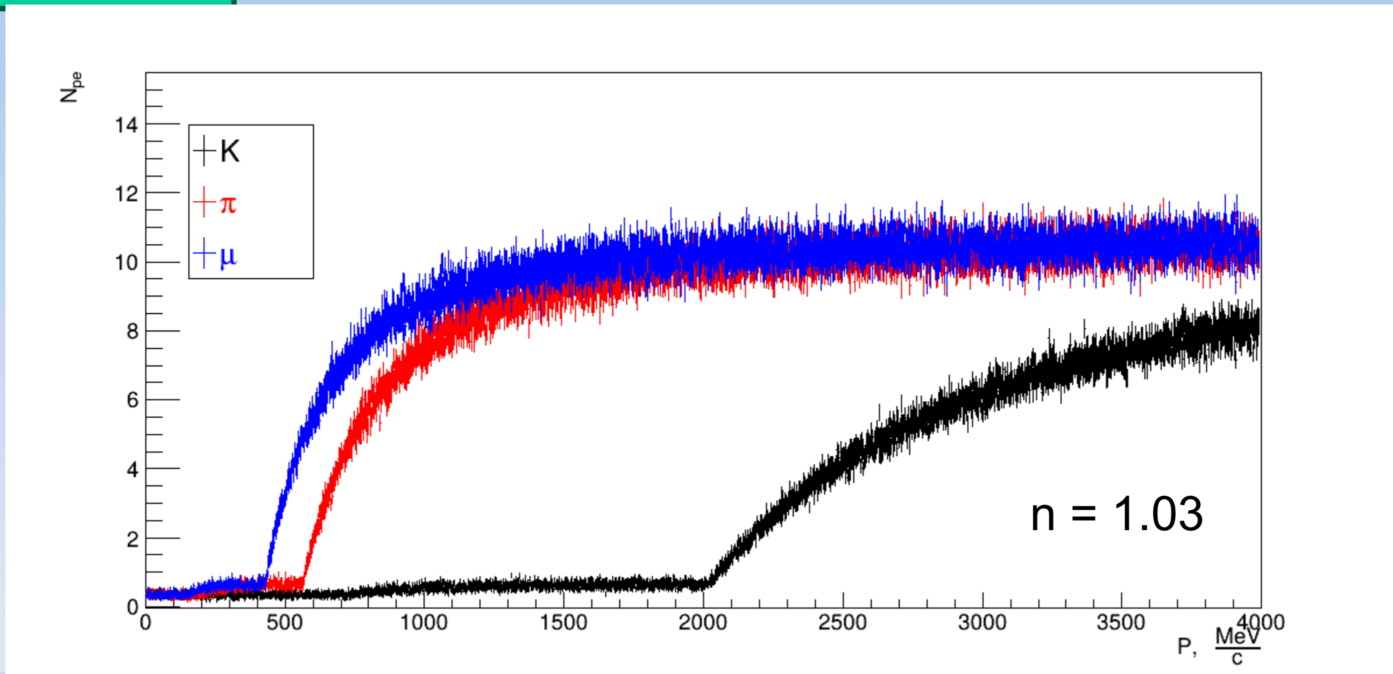
ASHIPH basic optin, expectations

MCP PMT → SiPM
Gives increase of
amp. by 2÷2.5 times

KEDR experimental data



STCF proj. param. sim.



For future collidung beam experiments with high intesity interaction
high operational rate of the detector subsystems is required:
for future Super Charm-Tau factory time between two bunch-crossing about 6 ns is expected!!!

WLS(BBQ)→ WLS(NOL-1…13)

$\sigma_t(old) \approx 17ns \rightarrow \sigma_t(new) \approx 0.5 \div 1ns$ is expected!!!

Advanced option (1)

Objectives:

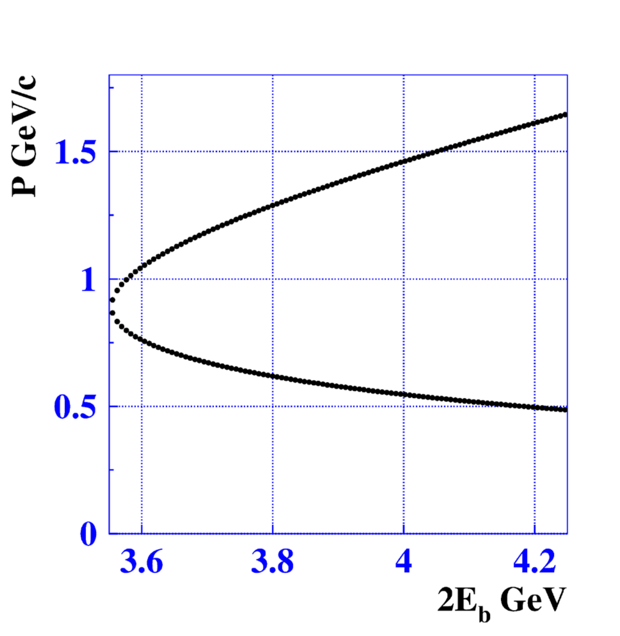
μ/π identification is needed in the momentum range below 900 MeV/*c* (muon system provides μ/π identification at higher momentum)

Premises from physical program:

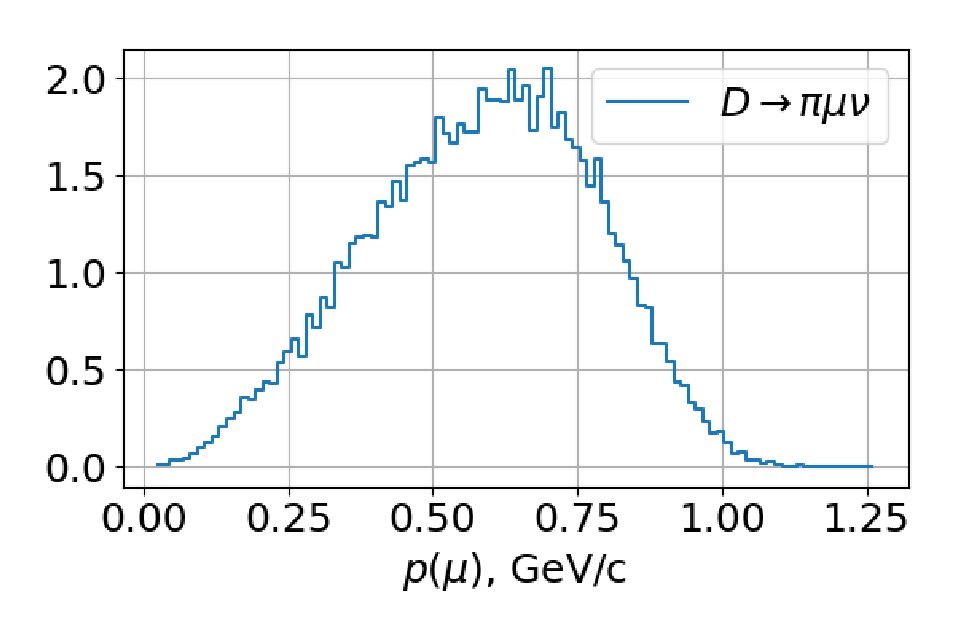
$\tau\to\mu\gamma$: Minimum and maximum of muon momentum depends on E_{cm} and spreads from 500 to 1600 MeV/*c*

Muons from D-meson and τ decays have momentum from ~250 to ~1000 MeV/*c*

Pmin(μ) and Pmax(μ) for $\tau\to\mu\gamma$

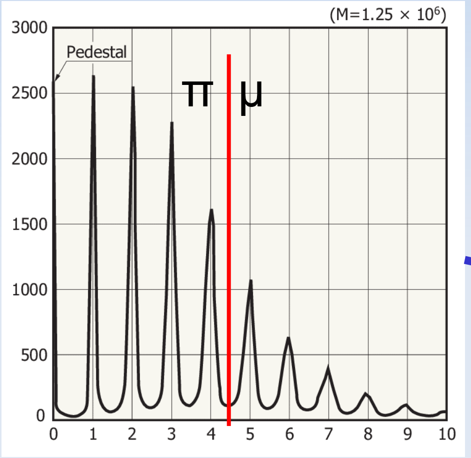


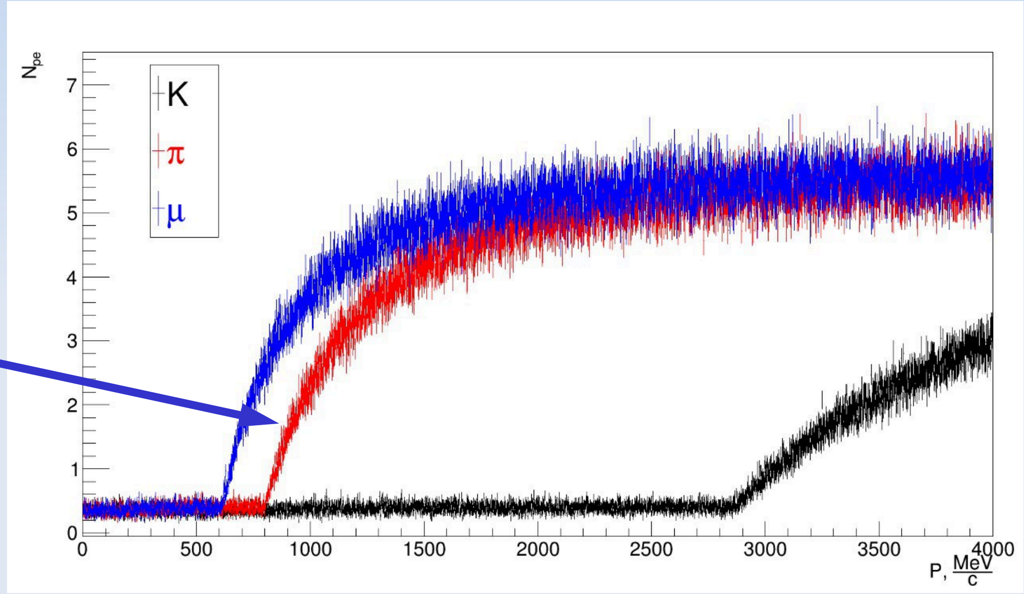
P(μ) for $D\to\pi\mu\nu$

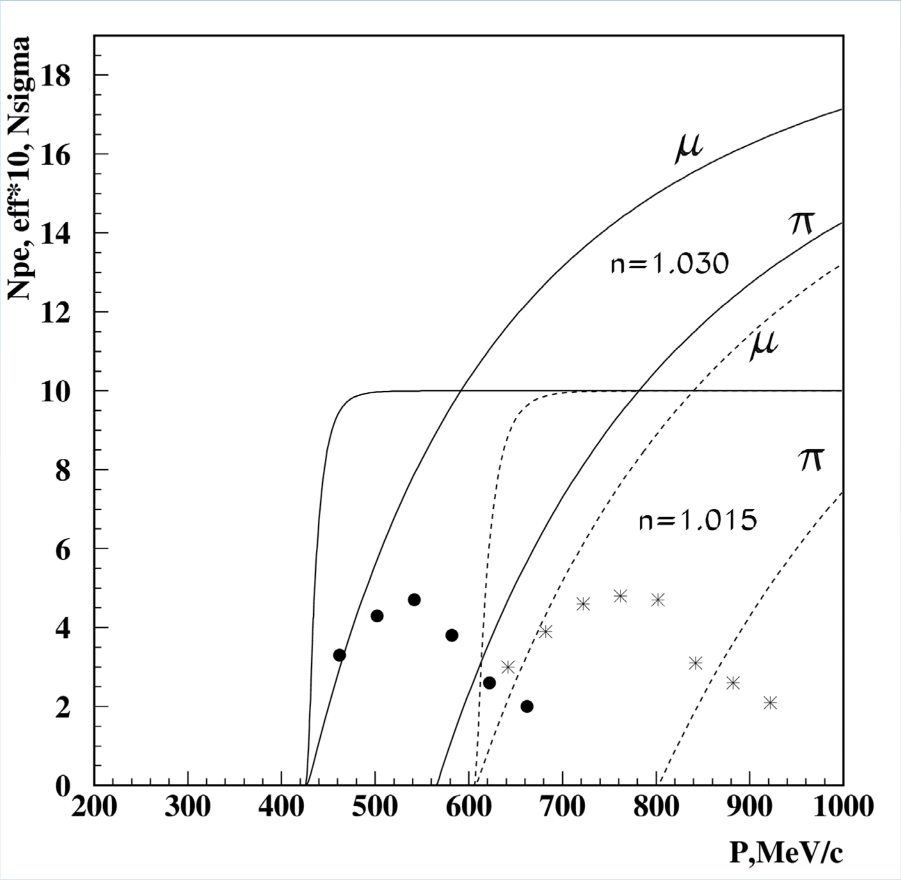


Advanced option (for the discussion)

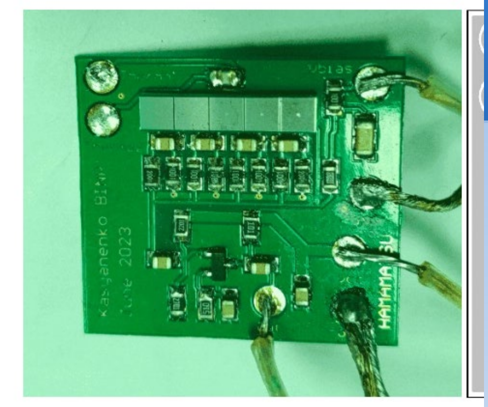
- The suggestion is to have 3-layer system: 1 layer, thickness 6 cm n = 1.05 + 2 layers, 6 cm thickness (1 thick with 12 cm possible) with n = 1.015
- Use of SiPM open the possibility to have ID above π threshold
- This will provide μ/π identification from 450 to 800(900?) MeV/c

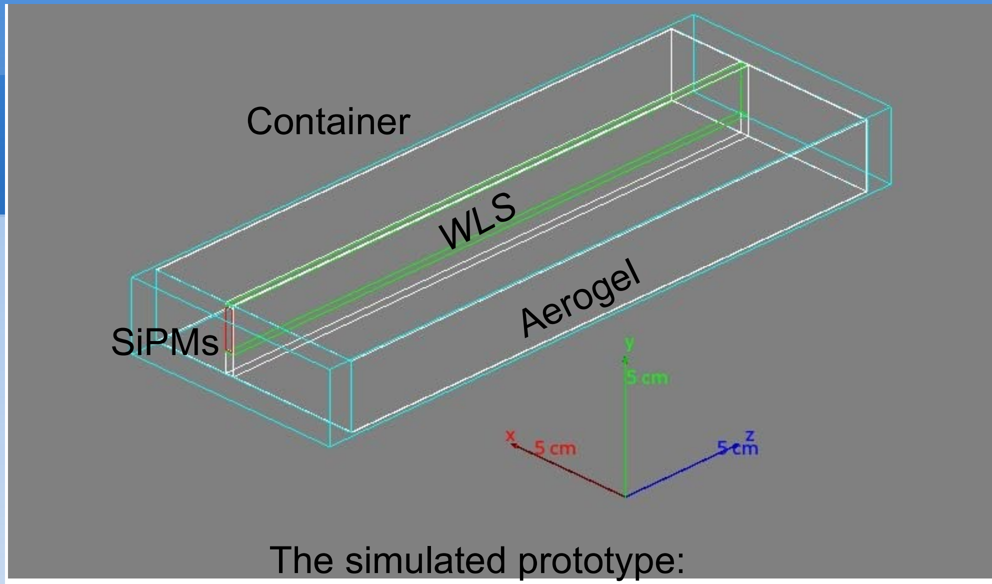




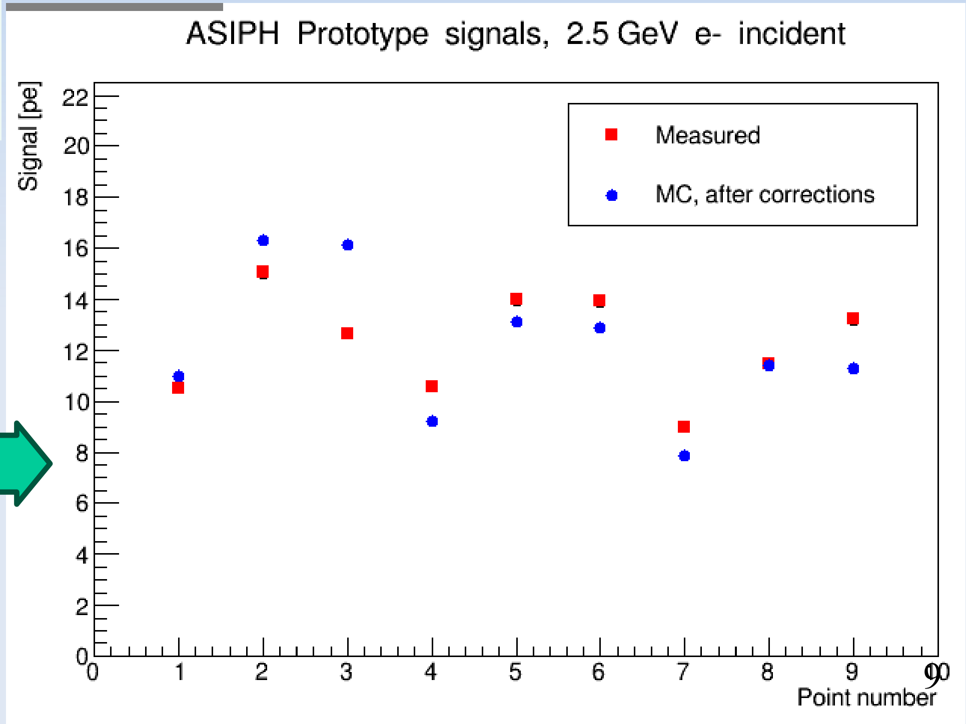


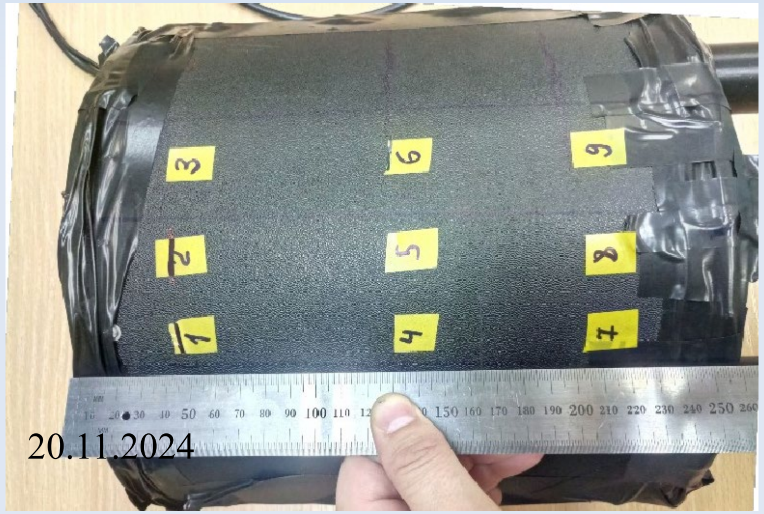
Some prototyping and beam test results





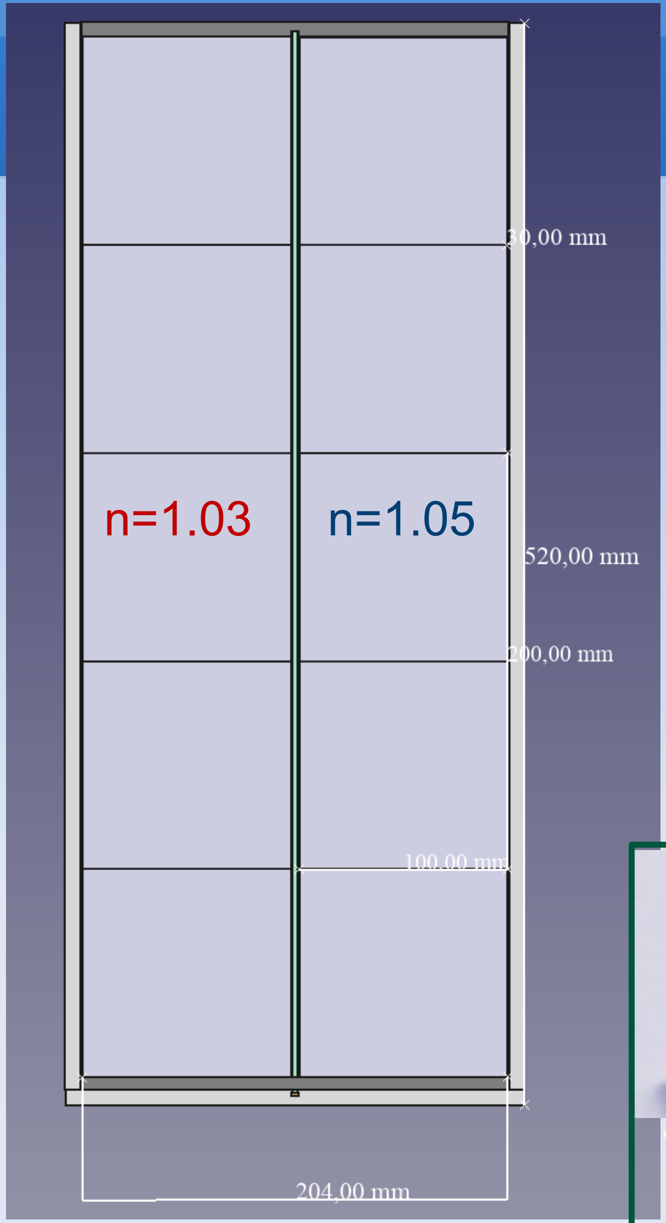
SND ASHIPH counter was upgraded and tested with relativistic electrons (2.5 GeV) at the BINP beam test facilities.

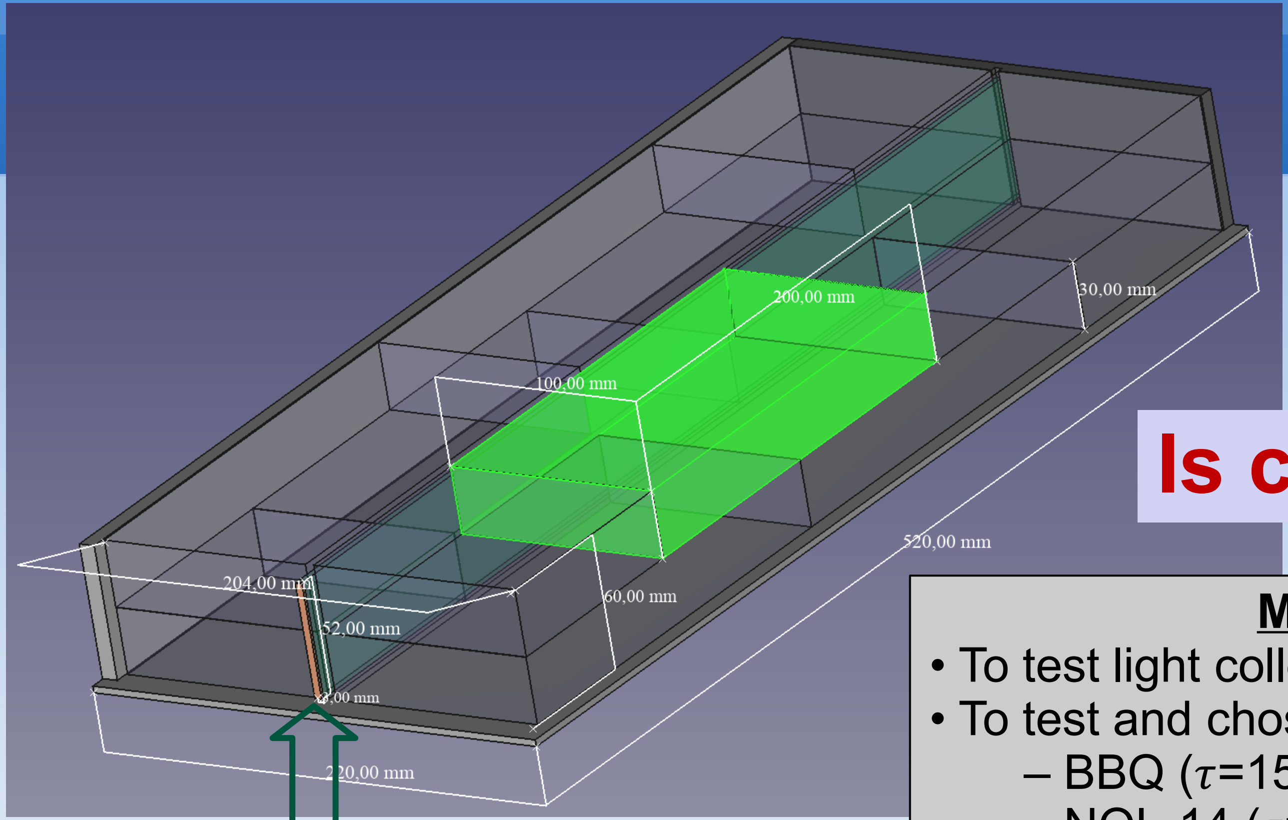


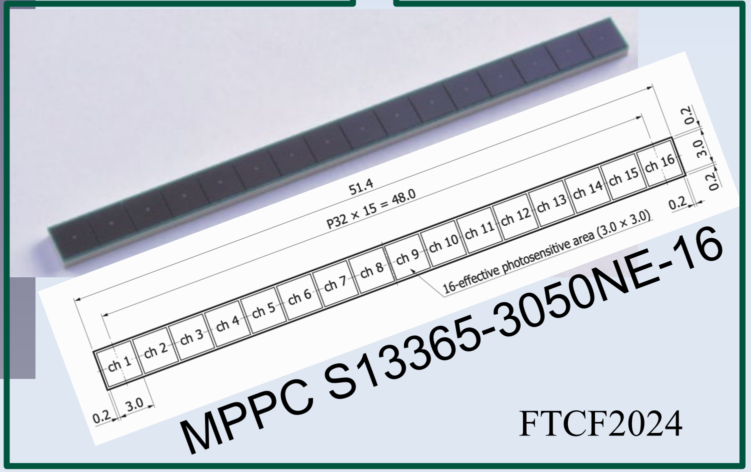


- Beam test results and GEANT4 simulation are in good agreement
- Expected effect of Amp. increas is demonstrated!!!

Design of ASHIPH prototype for STCF (Hefei)(1)





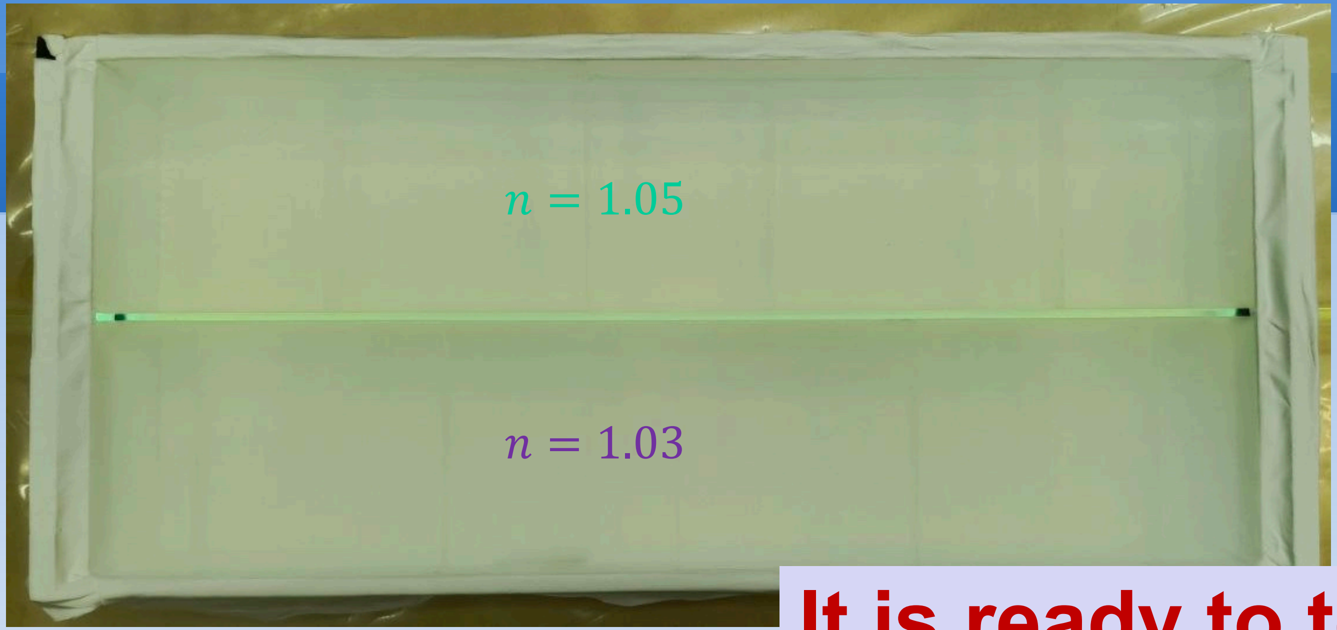


Is coming soon!!!

Main goals:

- To test light collection uniformity
- To test and chose WLS dye:
  - BBQ (τ=15 ns)
  - NOL-14 (τ=0.74 ns)
- To test and chose SiPMs
  - Hamamatsu
  - NDL
  - JoinBon and …
- To test and develop FEE
- To test π/K-separation and chose aerogel

Design of ASHIPH prototype for STCF (Hefei)(3)



Main goals:
- To test light collection uniformity
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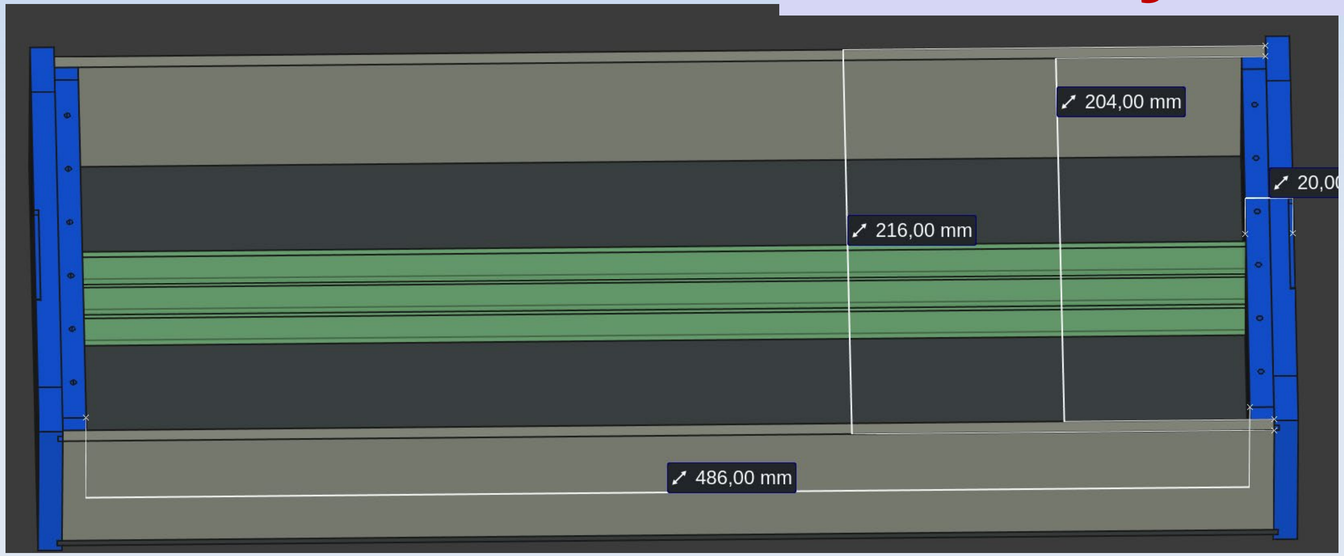
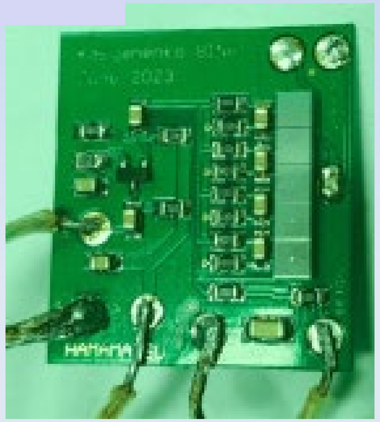
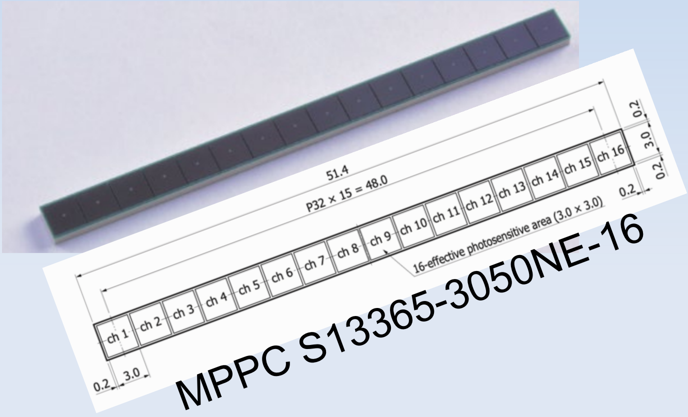
- To test and chose SiPMs
  - Hamamatsu
  - NDL
  - JoinBon and …
- To test and develop FEE
- To test π/K-separation and chose aerogel

It is ready to test!!!



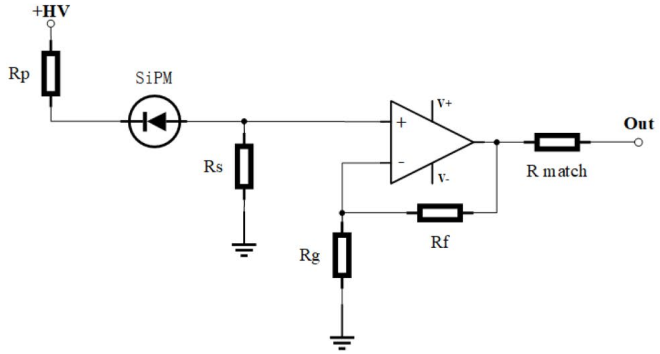




- 3 arrays 5 SiPMs each were made from MPPC S13365-3050NE-16 (Hamamtsu)
- 3 channels of V1742 (CAEN) degitizer will be used to readout

Electronics

PreAMP



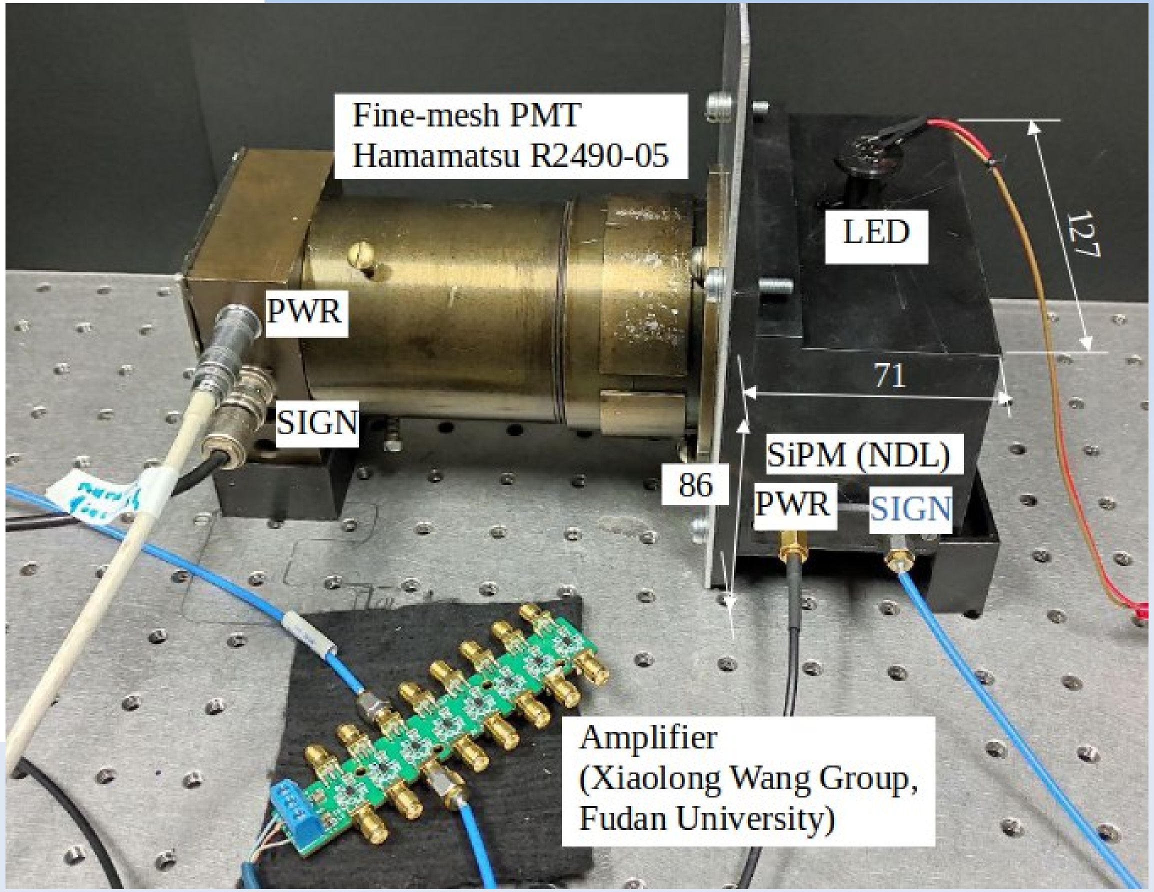
Gain: +20 V/V

1000V/A

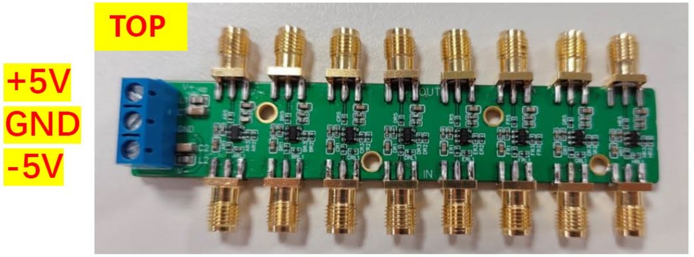
Bandwidth(-3dB): 400 MHz

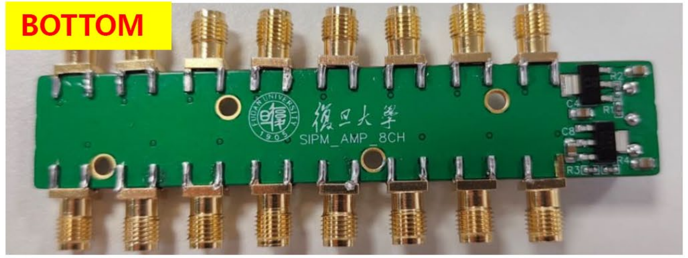
Baseline noise(RMS): 300uV

Output impedance: 50Ω



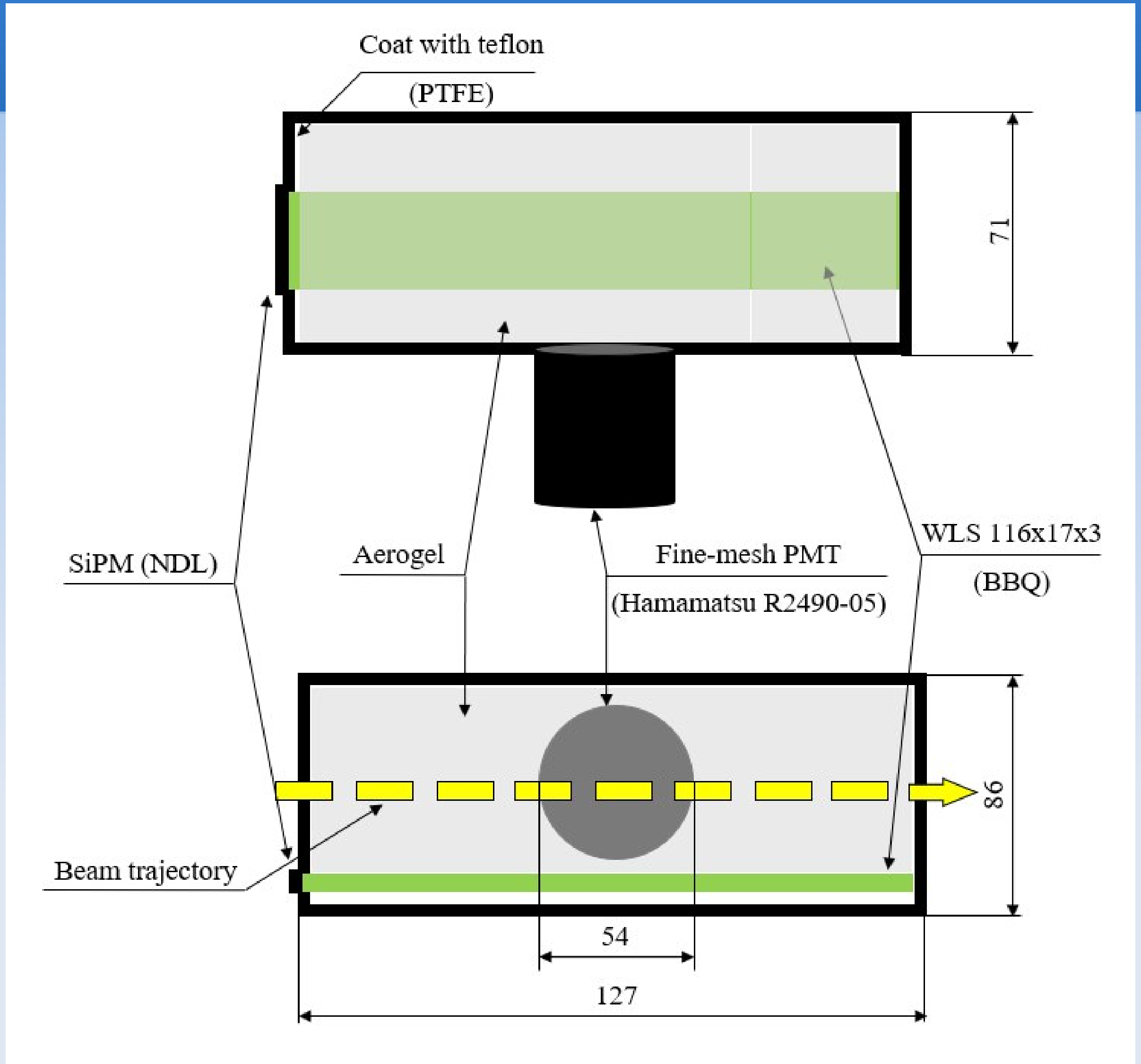
SiPM preamplifier(8-channel)





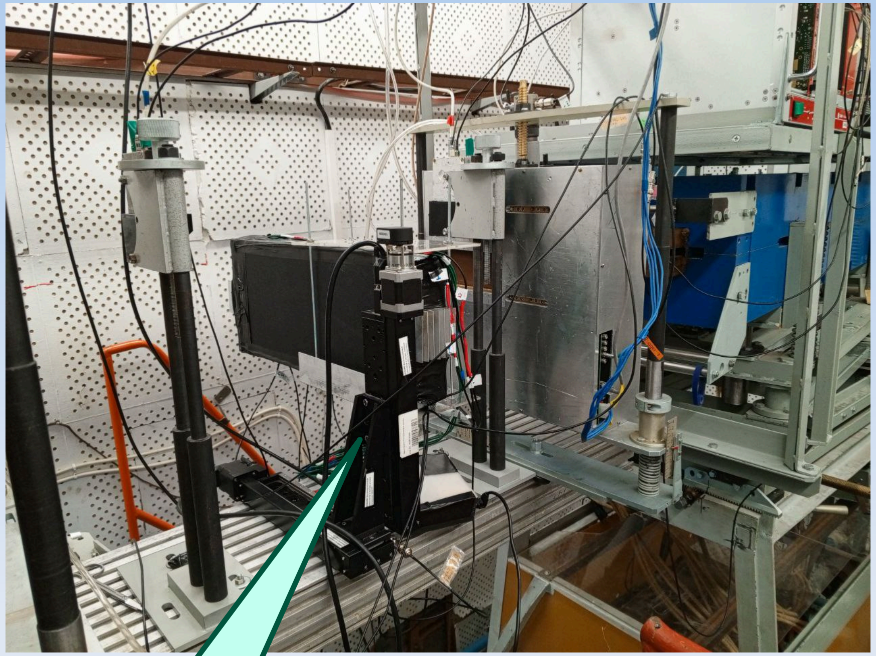
For more information see : https://link.springer.com/article/10.1007/s41365-023-01328-7

ASHIPH prototype II – wls test stand



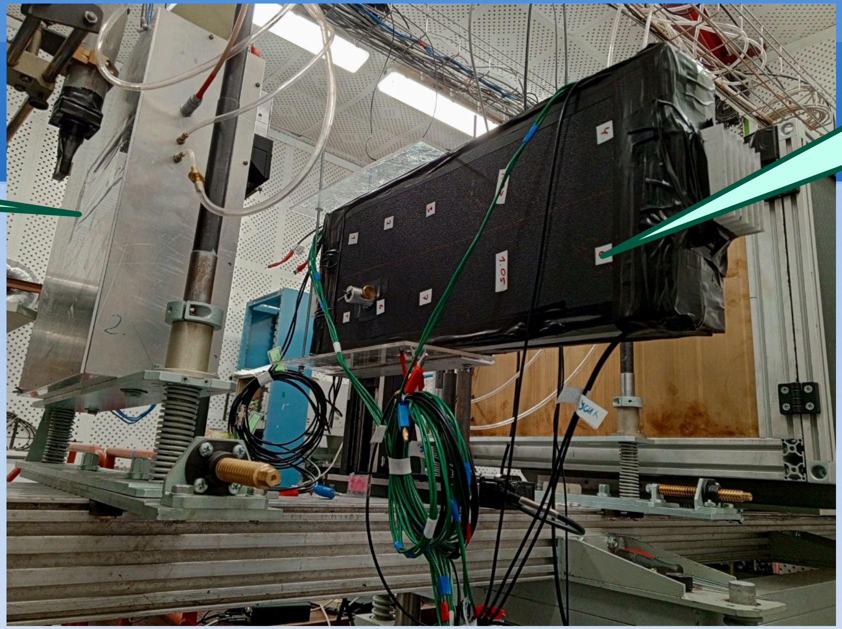
ASHIPH prototype at the BINP beamline

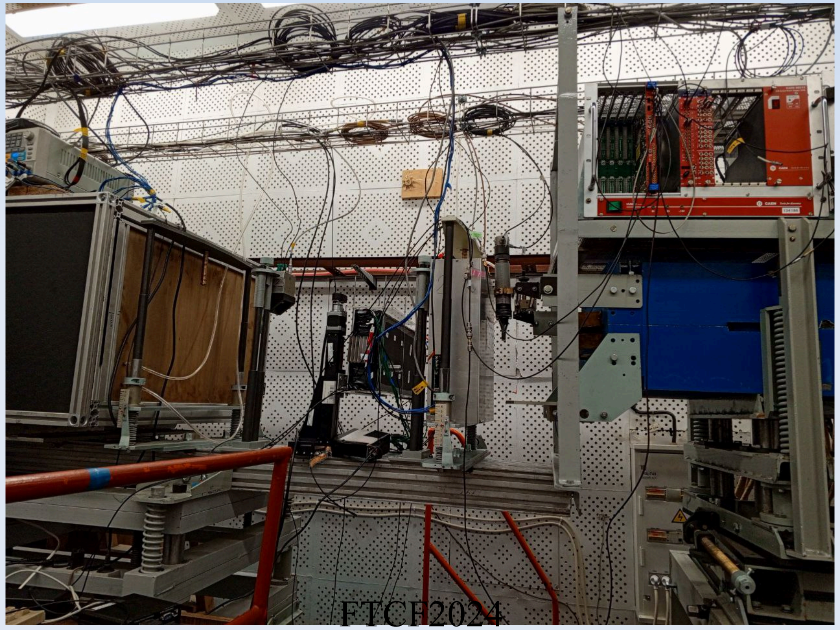
Tracker based on GEM $\sigma_{x,y} = 50\mu m$

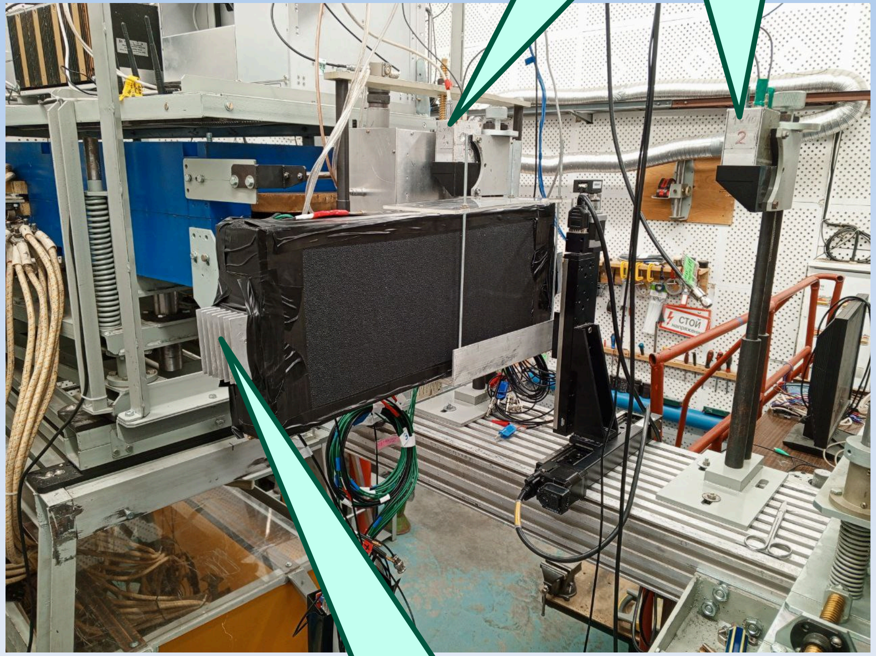


ASHIPH prototype and points for beam crossing

Trigger counters based on MCP PMT







2D mover to scan Light collection uniformity

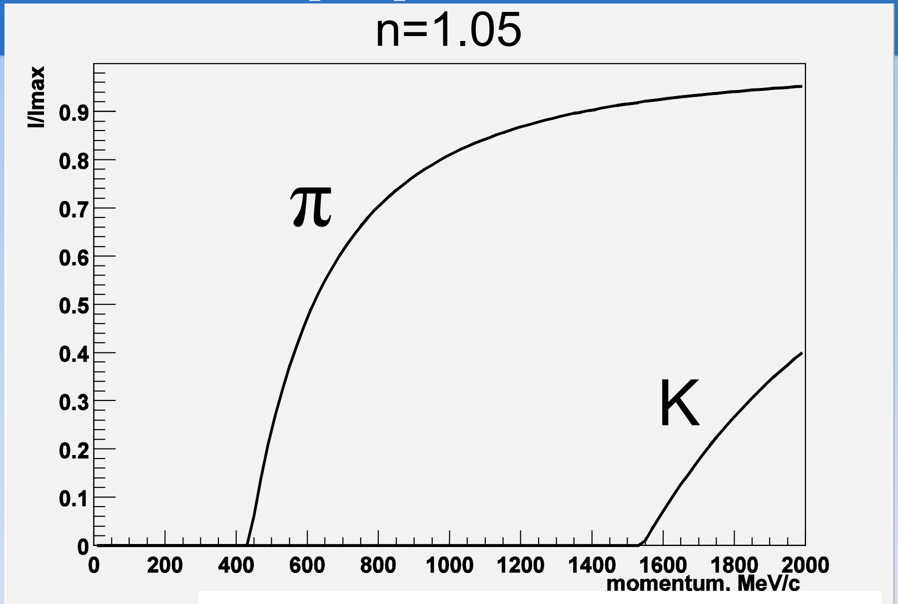
Radiator for SiPM cooling and thermostabilization

Summary

- Two options of ASHIPH system are considered for STCF:
  - single index n= 1.03, total thickness 12 cm
  - two indices n=1.03 + 1.015, total thickness 18 cm
- The first ASHIPH prototype for STCF at BINP is produced and prepared for the beam test:
  - WLS plate based on Plex with BBQ dope Aerogel of n=1.03 for half volume of the prototype and with n=1.05
- The special stand for WLS testing is designed and produced

Additional slides

Requirements on aerogel tiles for use in threshold Cherenkov counters (1)



Index of refraction of aerogel is selected considering physics tasks and working regions of other PID methods: KEDR – 1.05, SND – 1.13, DIRAC – 1.008

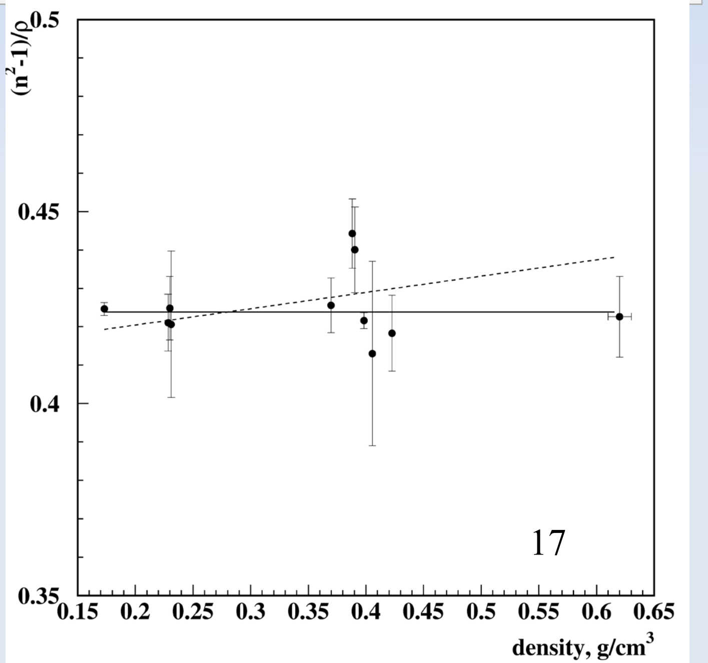
$$I_{Ch} \sim z^2 \left(1 - \frac{1}{n^2\beta^2}\right)$$ if β→1, (n-1) << 1 ⇨ $$I_{Ch} \sim \rho$$

Variation of index of refraction from tile to tile:

- in one counter n=1.050±0.002 ⇨ ρ=0.234±4% ⇨ 4% variation of Cherenkov light intensity from different tiles -- much less than light collection variation within the counter.
- The momentum of the Cherenkov threshold is also vary – this does not matter because it is out of working region

The density of all tiles is measured to determine index of refraction.

$$n^2 = 1 + 0.438 * \rho[g/cm^3]$$



Requirements on aerogel tiles for use in threshold Cherenkov counters (2)

At λ=400 nm

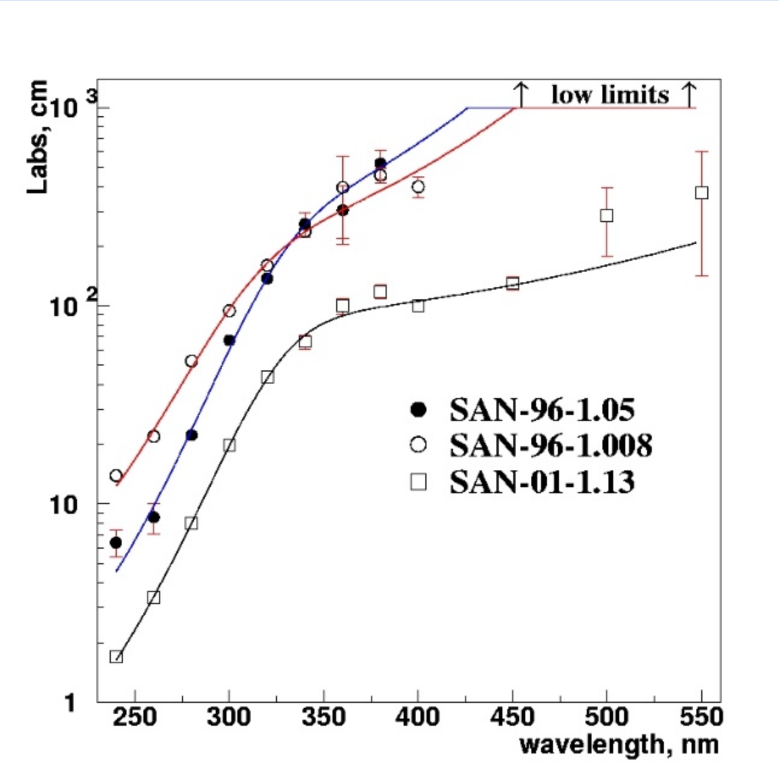
- L_{sc}~ 40 mm, L_{abs}~ 4-5 m

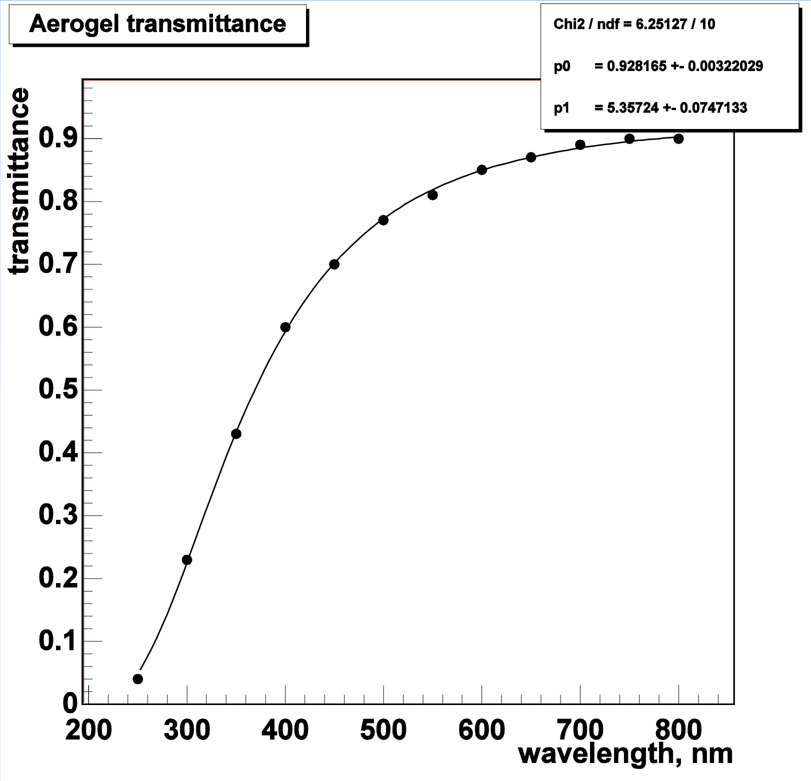
At λ=300 nm

- L_{sc}~12 mm, L_{abs}~ 0.5-1 m

$dN/d\lambda \sim 1/\lambda^2$

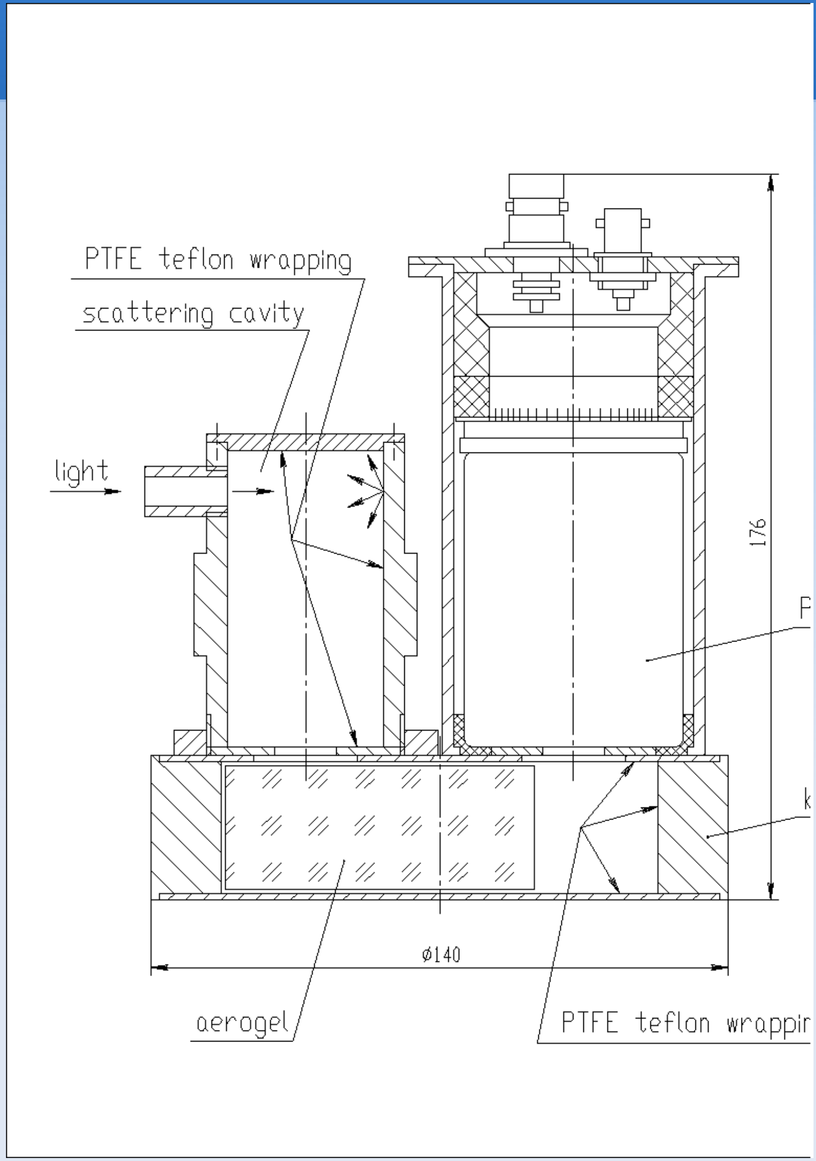
In aerogel counters with the diffusive light collection the light absorption in aerogel is the main effect defining the number of detected Cherenkov photons.

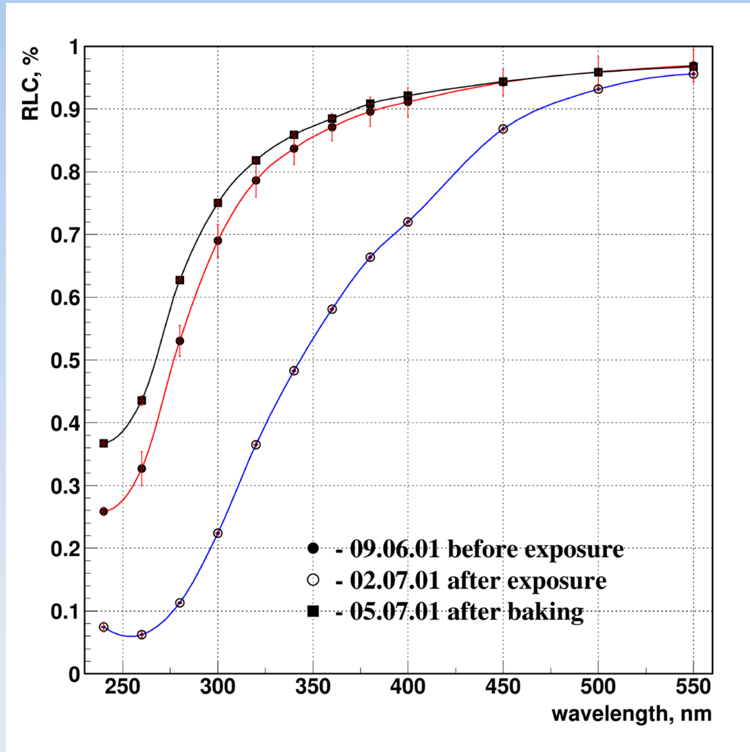




Requirements on aerogel tiles for use in threshold Cherenkov counters (3)

- The method was developed for the measurement of the light absorption length in aerogel.
- The simplified stand for relative control of the light absorption in each tile was used for entrance quality control. More than 15000 tiles were tested for KEDR ATC system.



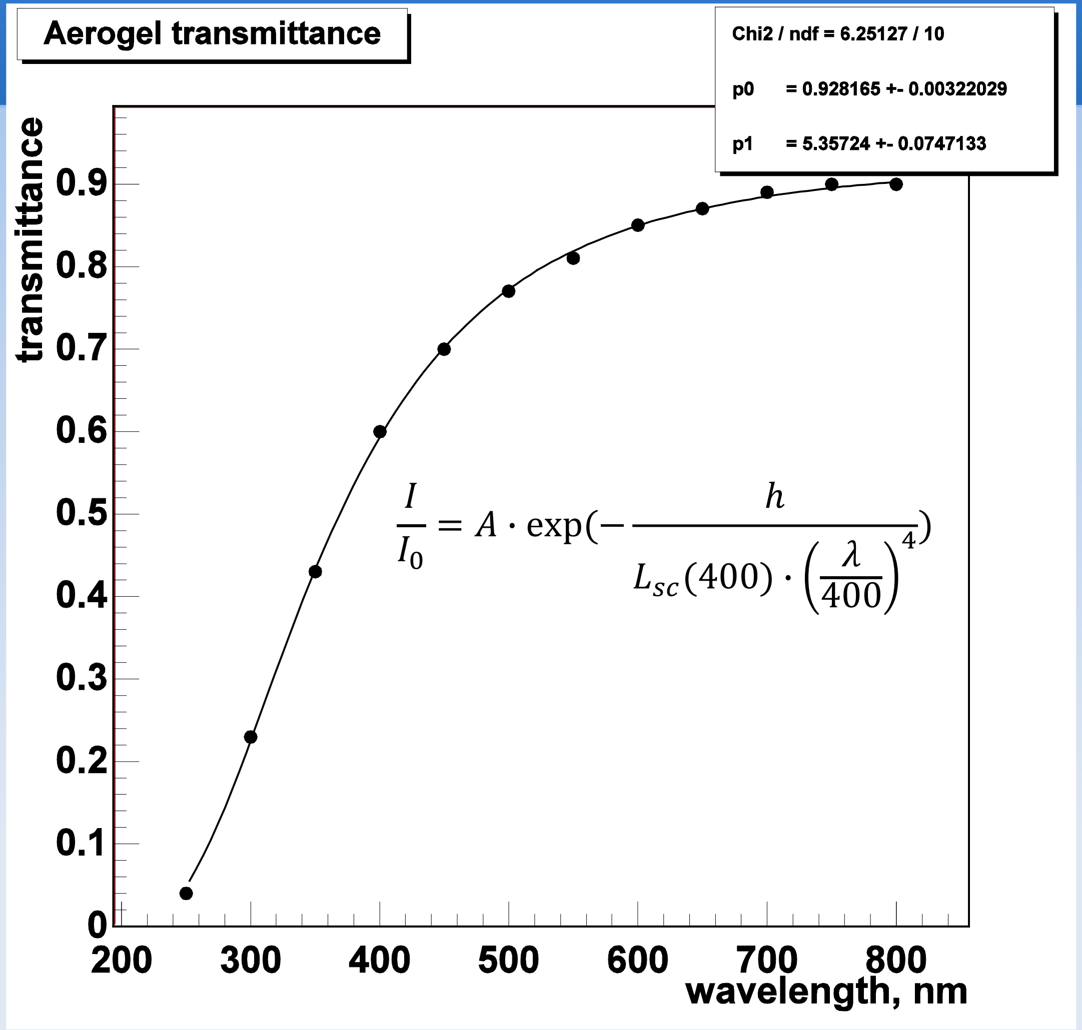


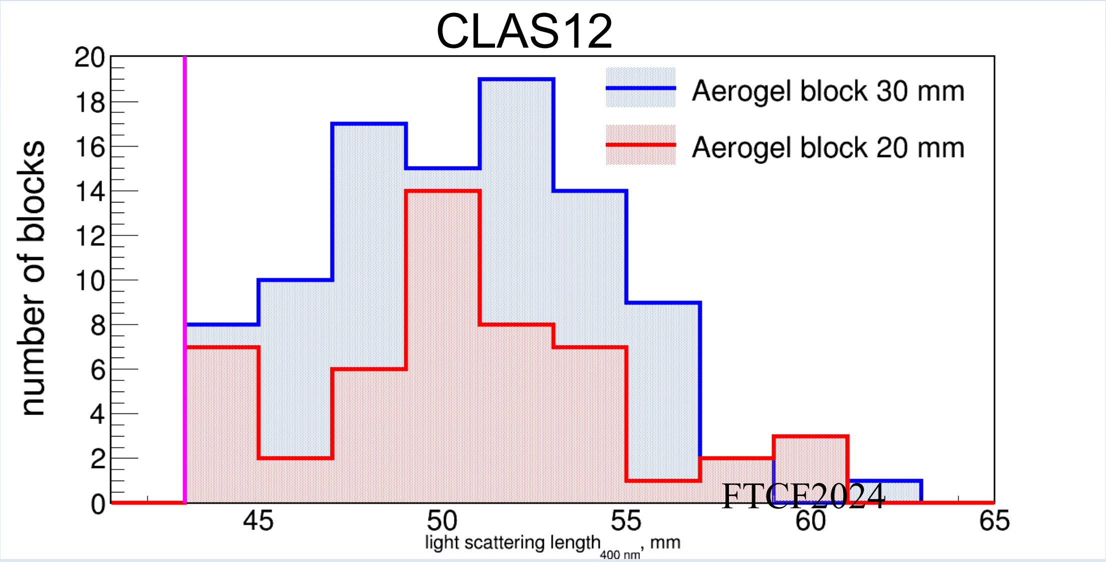
Requirements on aerogel tiles for use in Ring Imaging Cherenkov counters(0)

Transparency requirements:

$$N_{out} = N_0 \frac{L_{sc}}{h}\left(1 - e^{-\frac{h}{L_{sc}}}\right)$$

- L_{sc} at 400 nm (maximum of QE) for h ~ 4 cm must be about 3-4 cm.
- There are no requirements on L_{abs} for RICH detectors

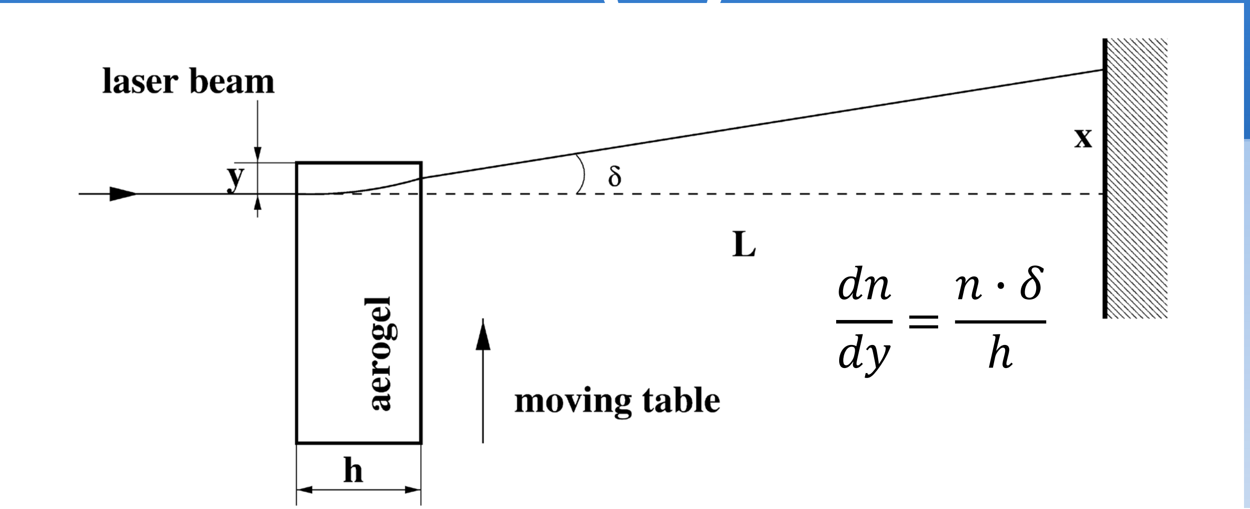


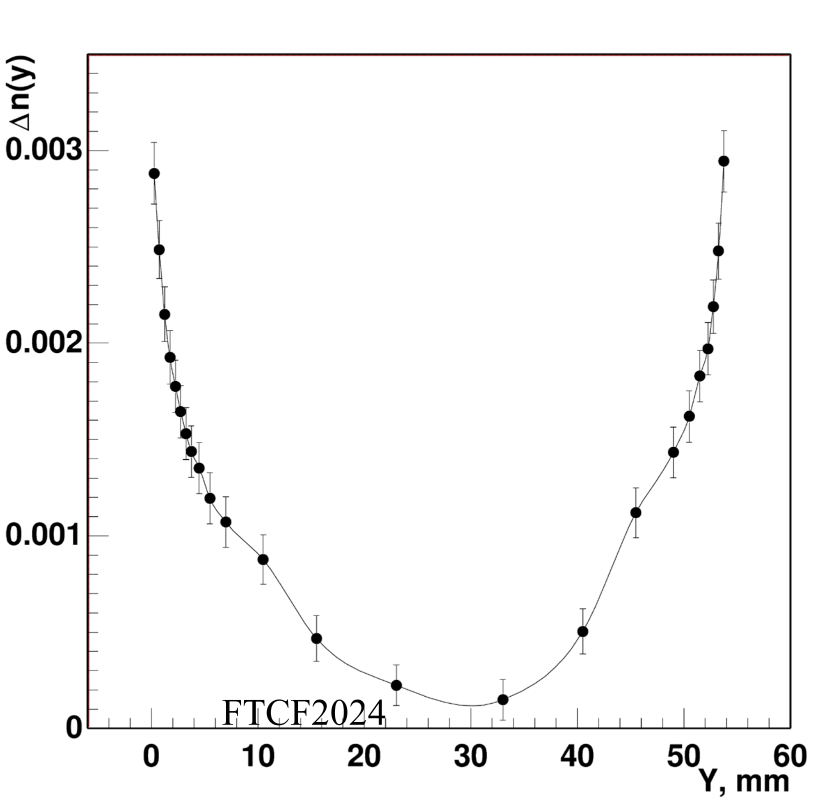


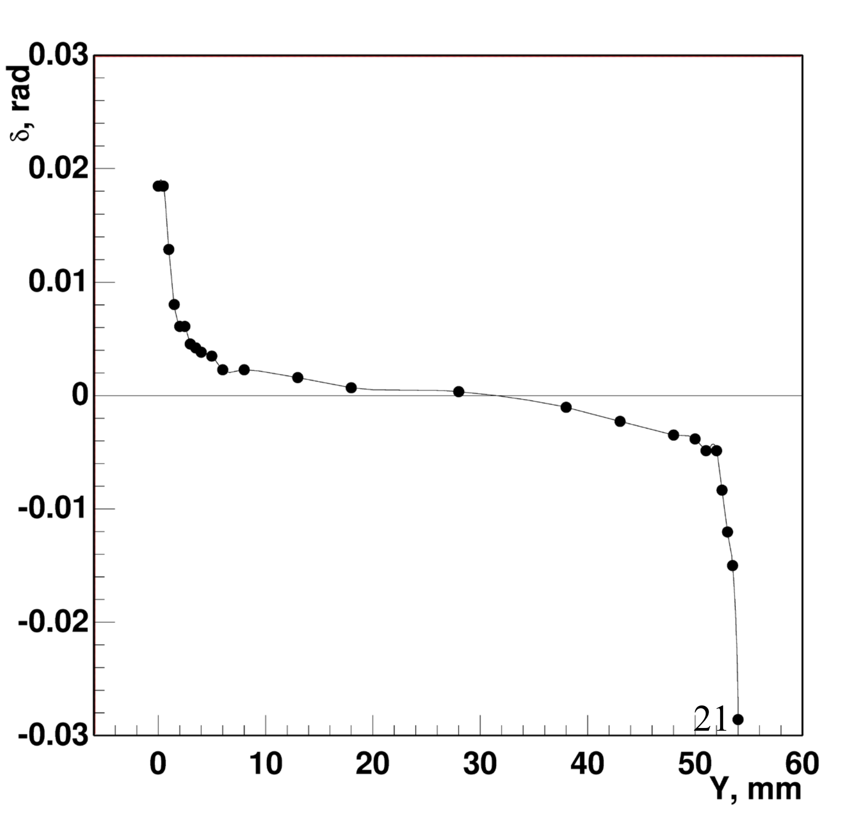
Requirements on aerogel tiles for use in Ring Imaging Cherenkov counters(1)

The are refractive index (density) variations within aerogel block:

- they could be measured using optical methods,
- main variations are close to aerogel tile surfaces

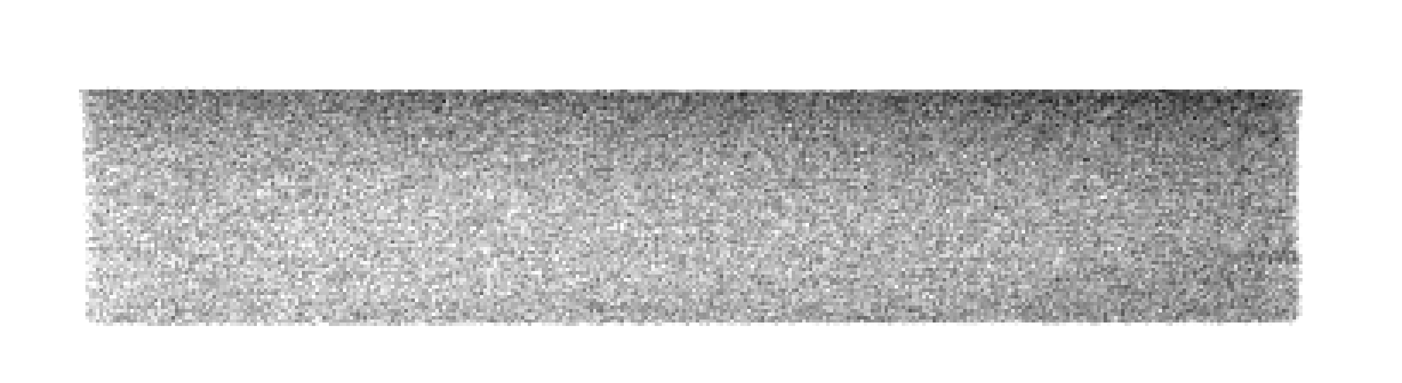






Requirements on aerogel tiles for use in Ring Imaging Cherenkov counters(2)

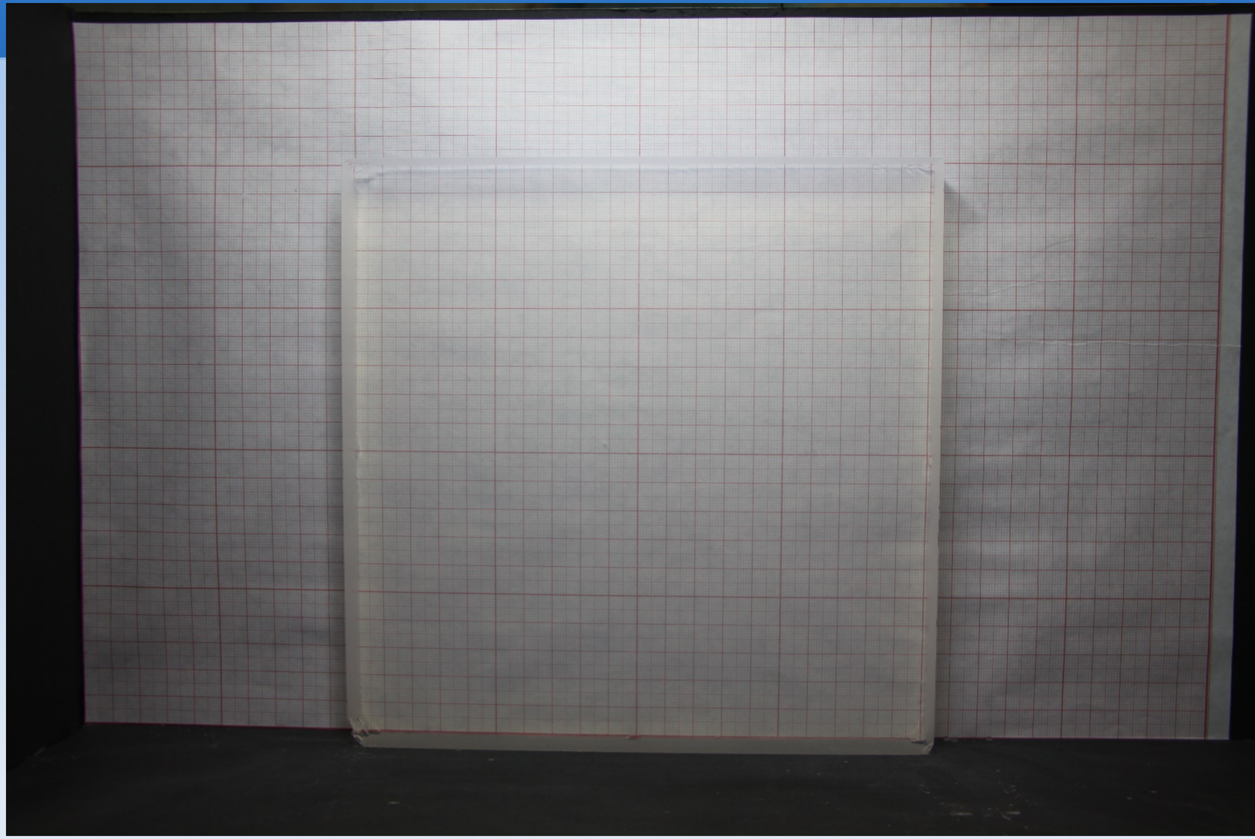
- Refractive index (density) variations can be measured with X-rays also.
- Density variations [$d\rho/\rho = dn/(n-1)$] can reach ~5%. This is comparable with refractive index dispersion over wavelength
- Variations could have constructive or destructive effect on RICH performance
- Regions with large variations close to aerogel tile edges can be cut away



Requirements on aerogel tiles for use in Ring Imaging Cherenkov counters(3)

Requirements on tile dimensions and form:

- The size of aerogel tile ought to be as large as possible. This minimizes edge regions where only part of Cherenkov light is coming out. Maximum size for Novosibirsk aerogel is 20x20 cm.
- Accuracy on tile dimensions are about 0.1-0.2 mm. This is required to fit the support frame

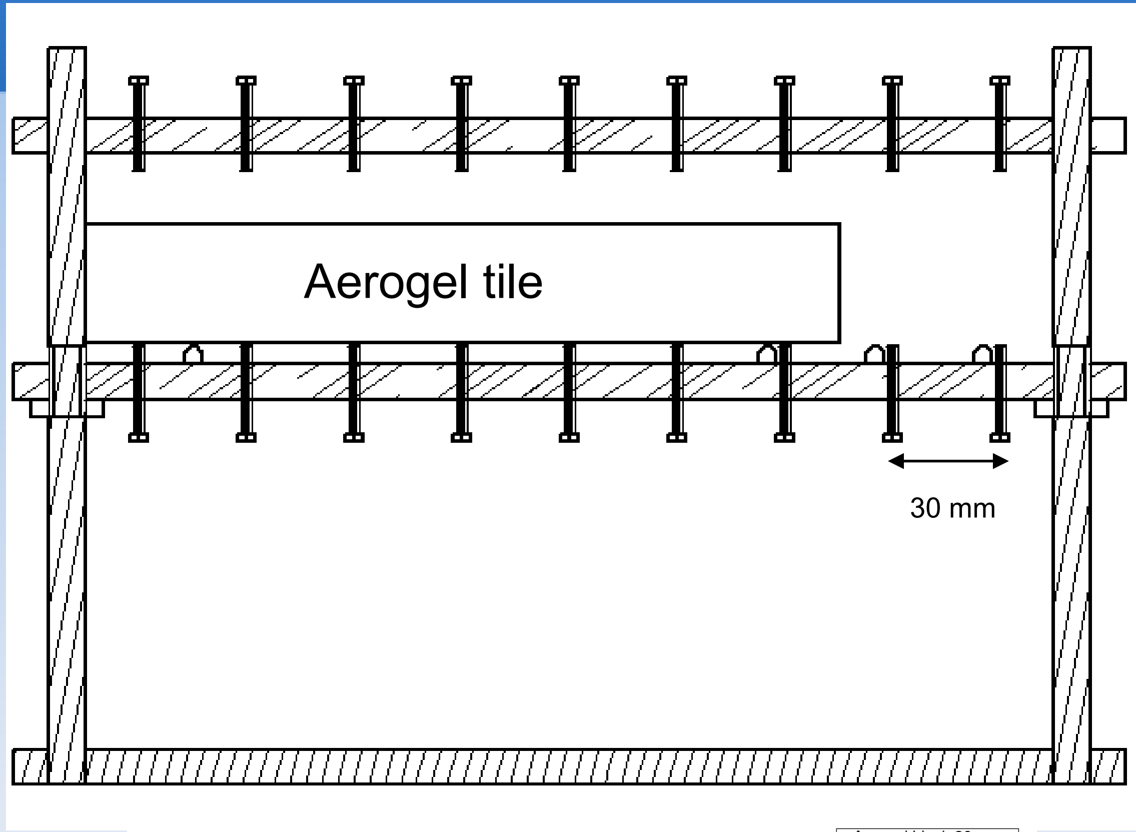


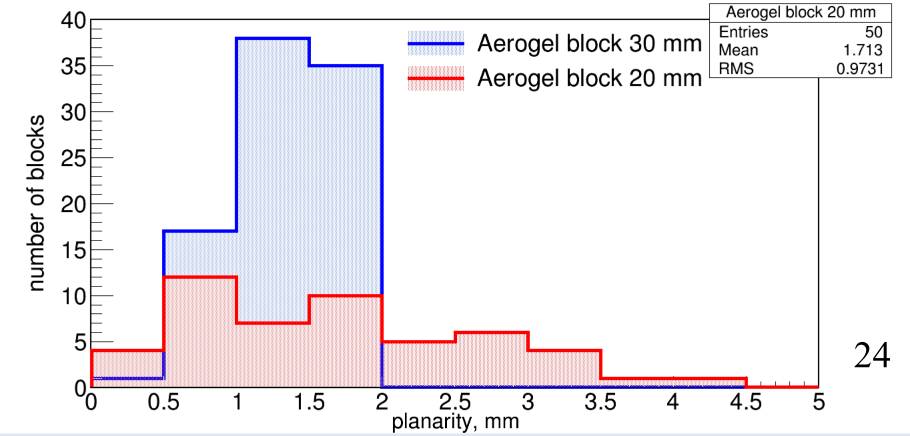
Requirements on aerogel tiles for use in Ring Imaging Cherenkov counters(4)

- RICH can also measure charge of the particle (AMS02). The variations of the thickness of the tile must be as law as possible (<0.2 mm for AMS02).

$$I_{Ch} \sim z^2 \cdot h$$

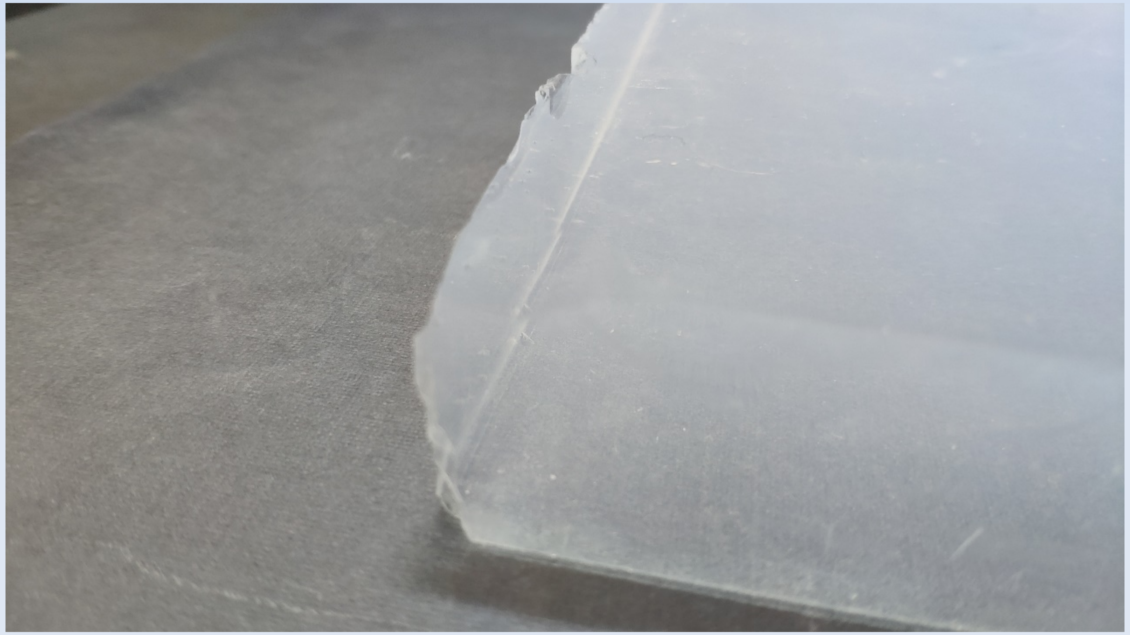
- The bottom surface of the tile can be cut with dimond wire to satisfy this requirement
- The unflatness (planarity) of aerogel surface can affect accuracy of Cherenkov angle measurement.
- Special touch stand was developed to measure thickness and planarity of the tile. For 30 mm thickness CLAS12 tiles height difference does not exceed 2 mm.





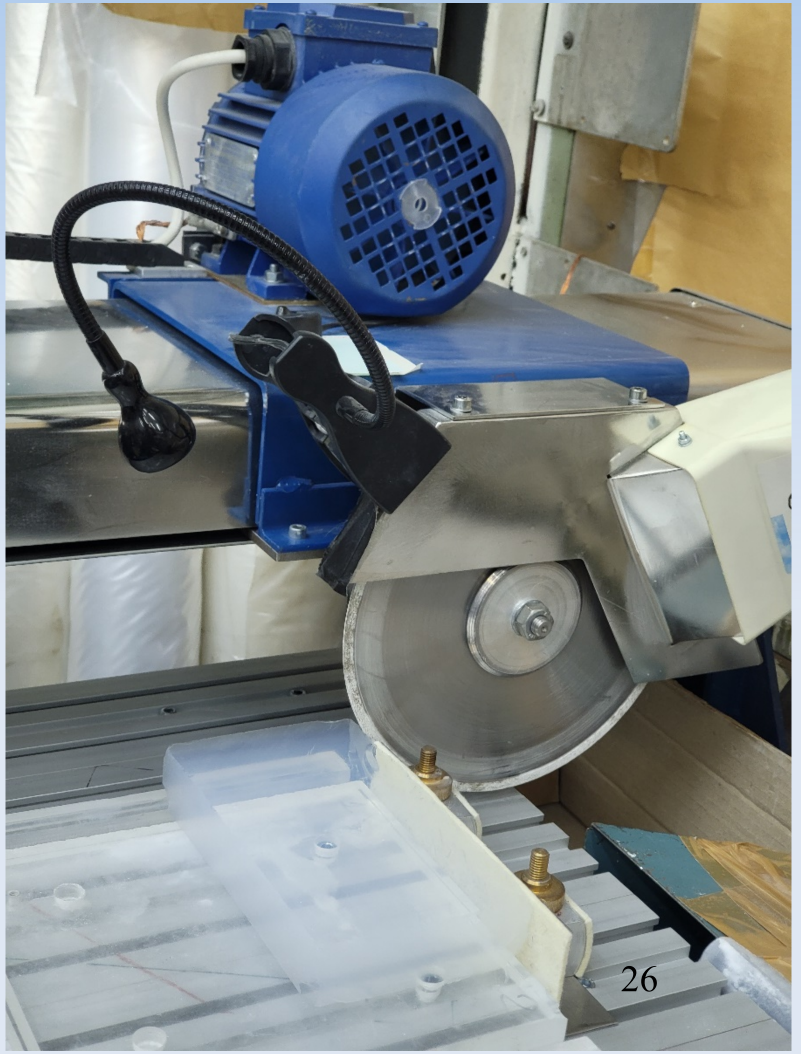
Methods of mechanical processing of the aerogel(1)

- Polishing is used mainly for production of tiles for threshold aerogel counters. Abrasive paper or abrasive wheel can be used.
- After polishing aerogel surface is cloudy. This does not play significant role for threshold counters.



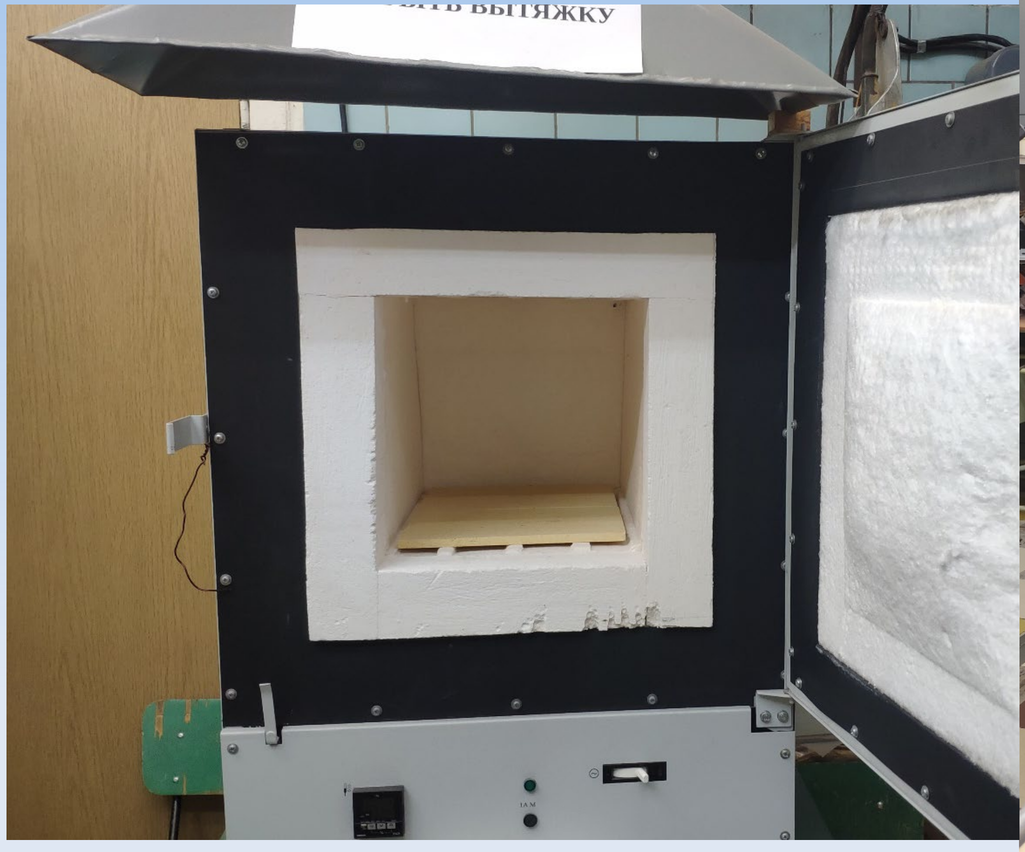
Methods of mechanical processing of the aerogel(2)

- Cutting of aerogel:
  - to give the required size,
  - To remove meniscus, chips and areas with large density variations,
- 2 dimond wheel mashines
  - bottom wheel position and moving table (by hand)
  - top wheel position and fixed table, 2d moving wheel with stepper motor



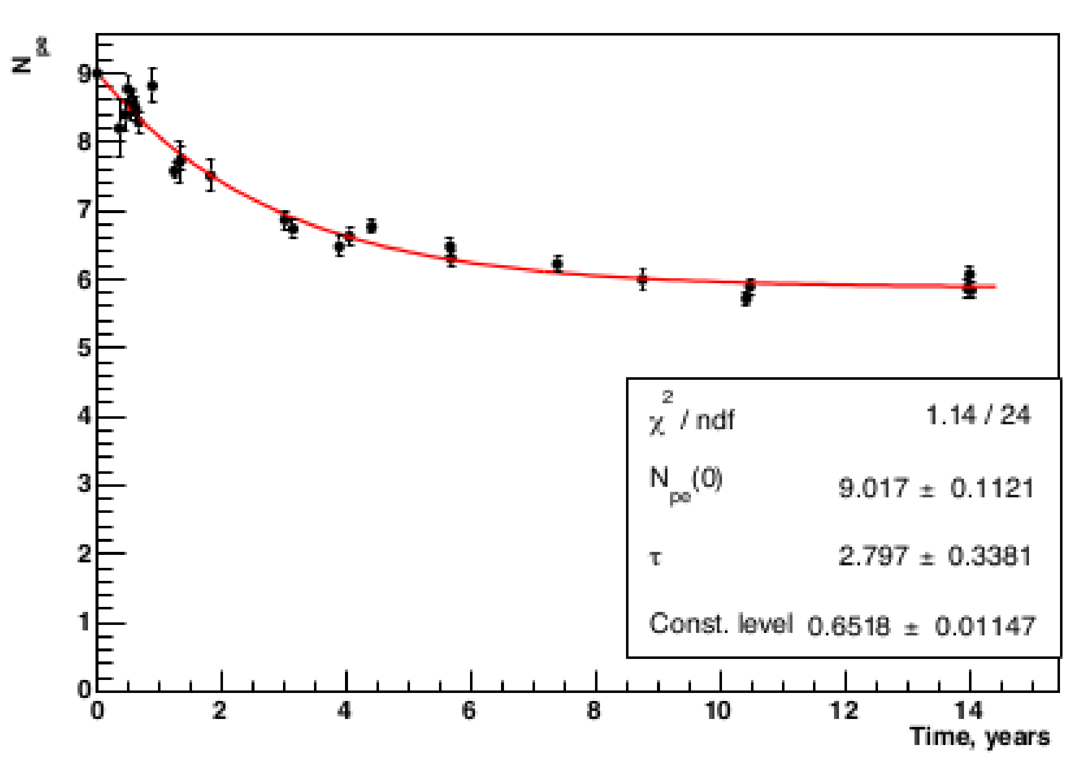
Aerogel storage

- Aerogel produced in Novosibirsk is hygroscopic:
  - To remove absorbed water baking can be used (several hours at 400-500 C). Optical transparency is to 100%.
  - Aerogel need to be stored in dry conditions. We use dry cabinet (0-2% humidity level)

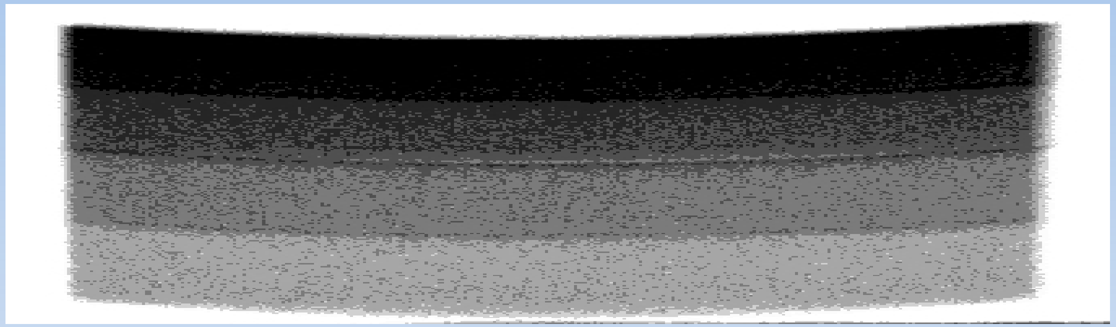


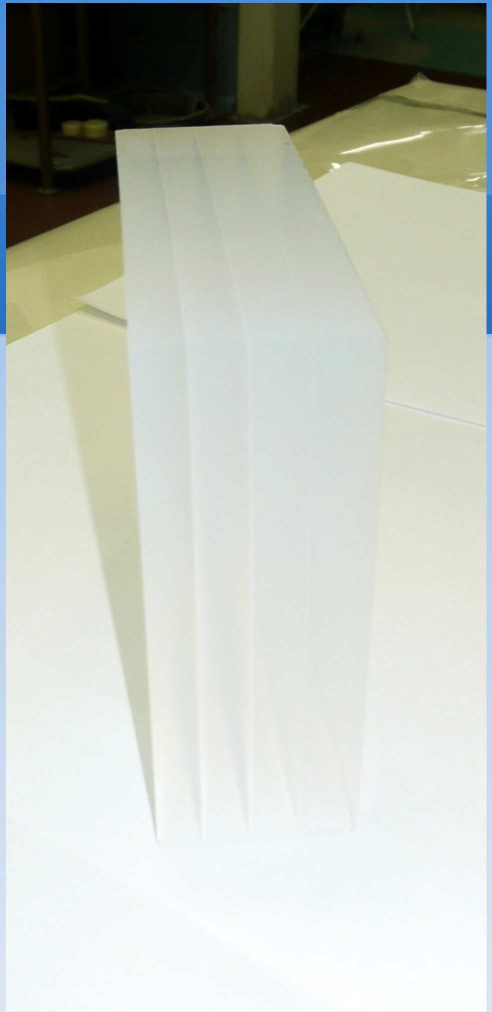
ASHIPH long term stability

A prototype of the endcap ASHIPH counter are under operation since 2000. From time to time it is tested in Cosmic Ray Telescope (CRT). Its signal degradation now has stabilized at the level of 60% from initial value.



Aerogel sample

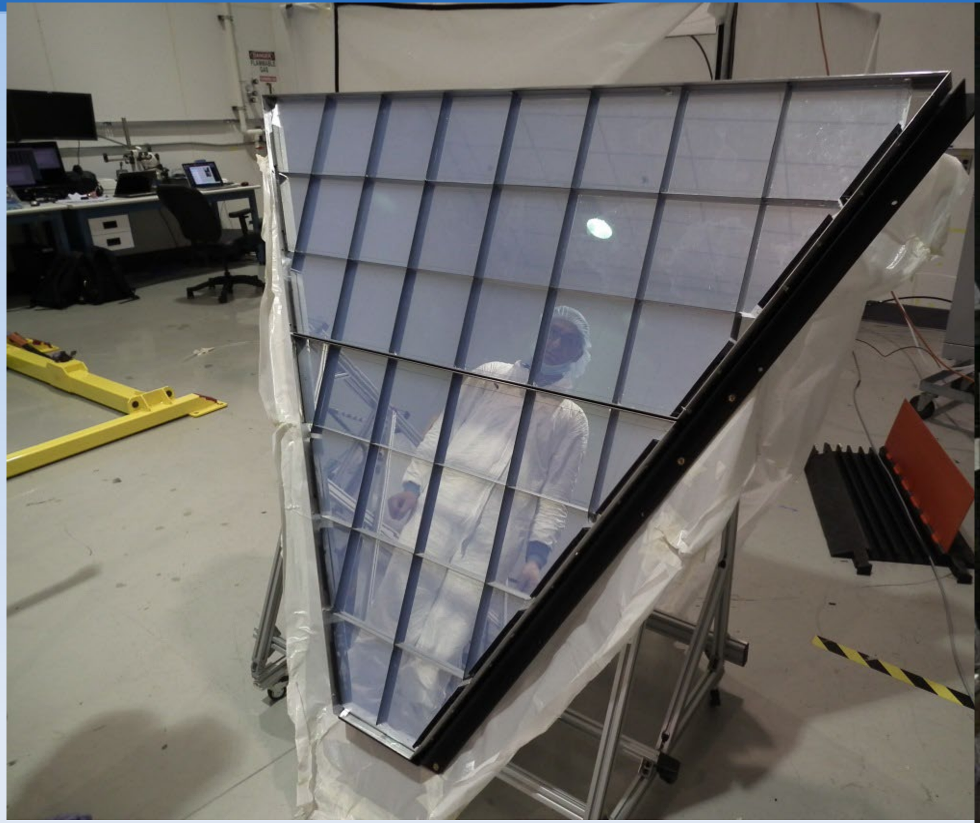


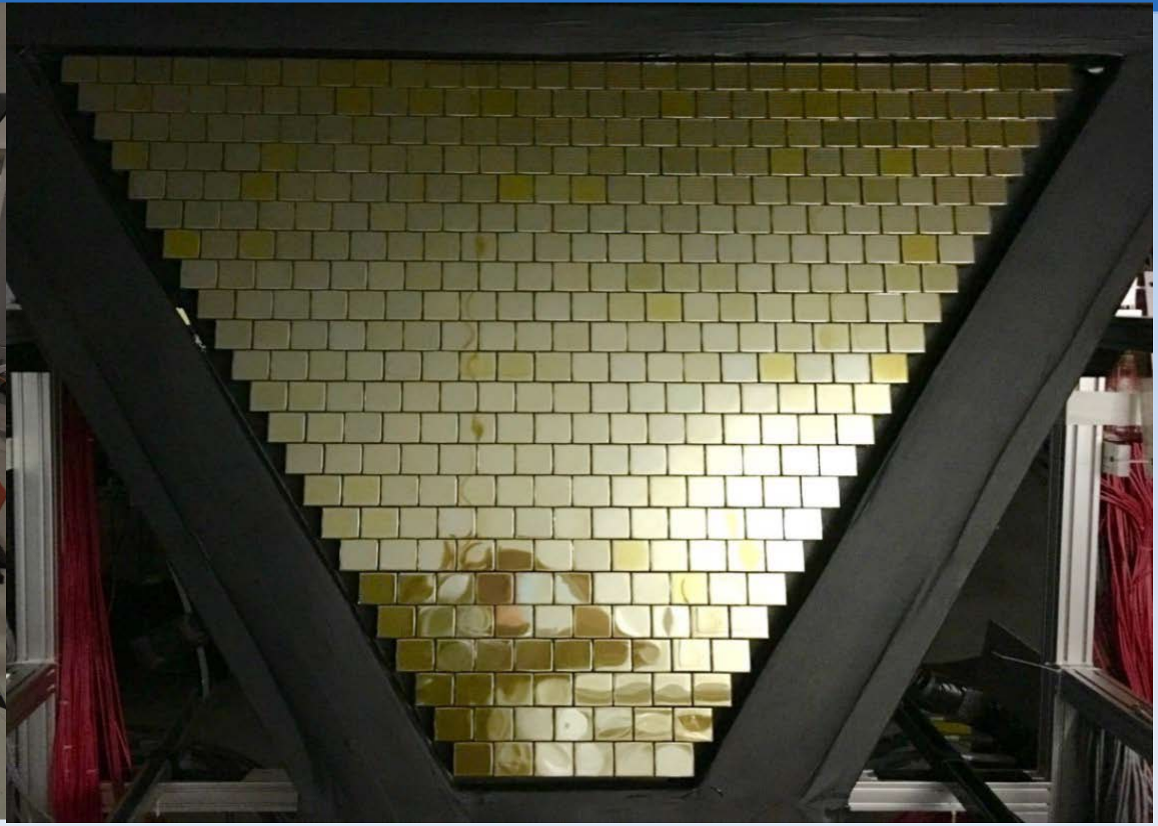


	n	h, mm
Layer 1	1.050	6.2
Layer 2	1.041	7.0
Layer 3	1.035	7.7
Layer 4	1.030	9.7

- $100 \times 100 \times 31\ mm^3$
- Lsc(400nm)=43 mm
- $n^2=1+0.438*\rho$

Aerogel RICH for CLAS12

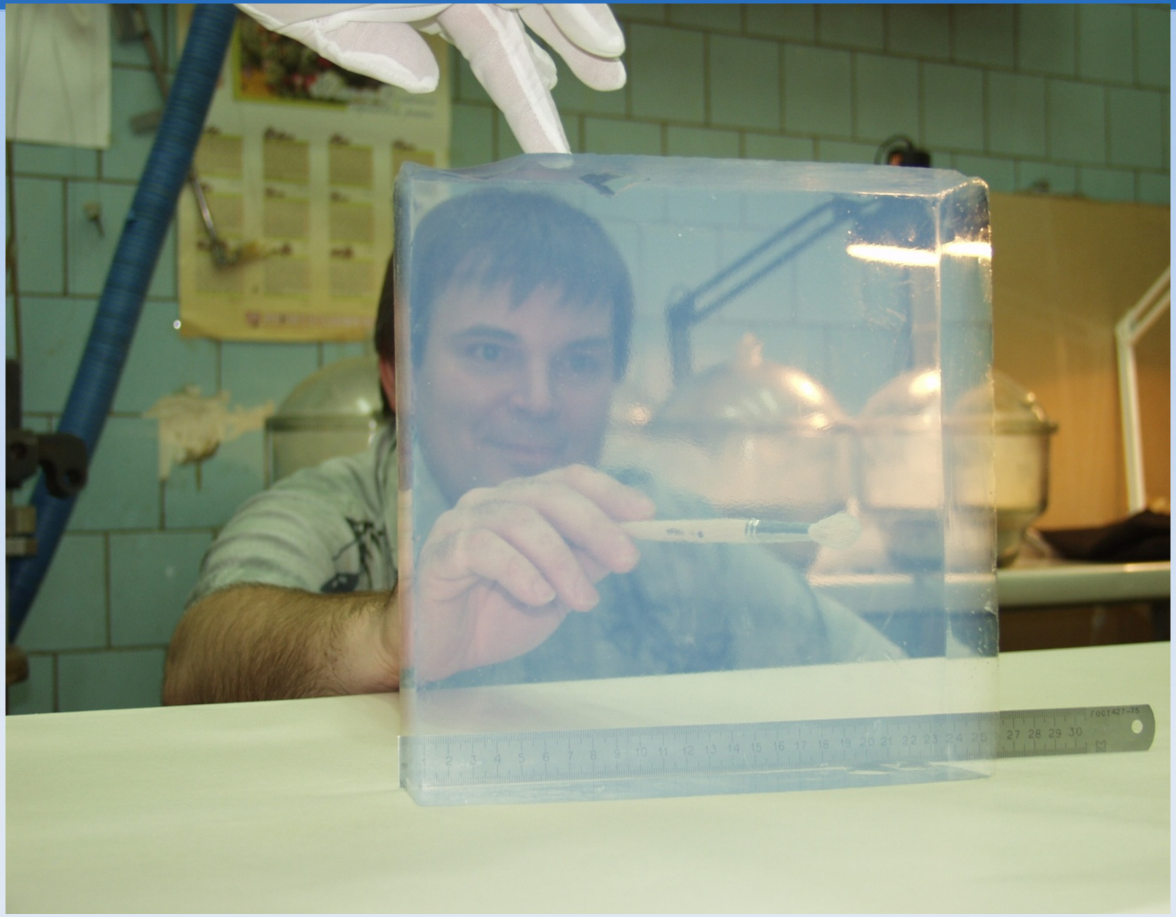




Aerogel development has started in 1986 (KEDR detector project)

More than 3000 liters have been produced:

- 2000 liters – KEDR and SND ASHIPH counters
- ~ 1 м^2 LHCb RICH,
- ~ 2 м^2 AMS02 RICH
- ~ 5 м^2 CLAS12 RICH



n = 1.006 – 1.06 (1.13)

Aerogel degradation due to water adsorption(2)

- The refractive index (n-1) and light scattering length depends on amount of adsorbed water and are changed less than 10% after water adsorption of 2-4% of aerogel mass.
- The light absorption length (L_{abs}) in different aerogel samples after baking is the same, but after water impregnation could be very different
- It is possible to make aerogel selection after water impregnation
- One atom Fe is able to attract 6 molecules of water
- To achieve maximum degradation of L_{abs} it is enough to adsorb 1ppm of water.

(NIM A598 (2009) 166-168)