Particle Identification system based on aerogel in BINP

A.Yu.Barnyakov, M.Yu.Barnyakov, V.S.Bobrovnikov, A.R.Buzykaev, V.V.Gulevich, P.V.Kasyanenko, A.A.Katcin, S.A.Kononov, D.V.Korda, E.A.Kravchenko, V.N.Kudryavtsev, I.A.Kuyanov, A.P.Onuchin, I.V.Ovtin, N.A.Podgornov, V.G.Prisekin, L.I.Shekhtman, A.A.Talyshev
Budker Institute of Nuclear Physics, Novosibirsk, Russia

A.F.Danilyuk, V.Kirilov, A.Pridein
Boreskov Institute of Catalysis, Novosibirsk, Russia

D.A.Finogeev, A.B.Kurepin, A.I.Reshetin, E.A.Usenko
Institute of Nuclear Research RAS, Moscow, Russia

C.Degenhardt, R.Dorscheid, T.Frach, O.Muelhens, R.Schulze, B.Zwaans
Philips Digital Photon Counting, Aachen, Germany

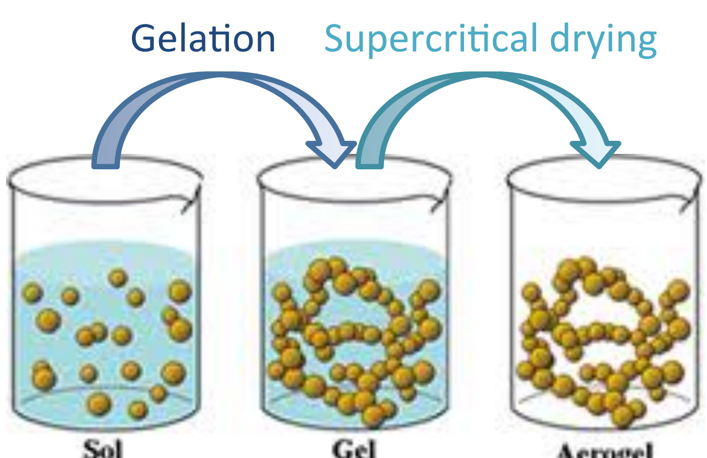
Alexander Barnyakov

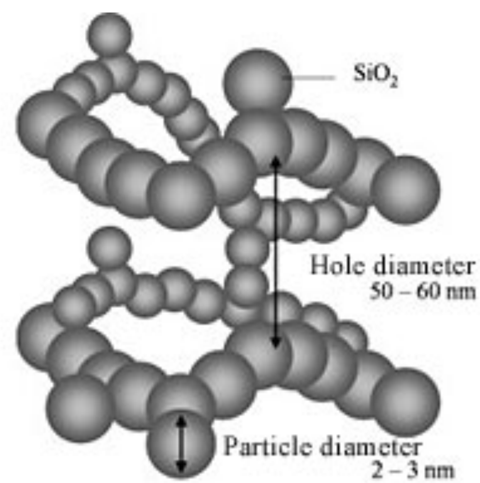
Outline:

- Aerogel
- Threshold counters
  - ASHIPH method
  - The ASHIPH system of the KEDR detector
  - The ASHIPH system of the SND detector
- FARICH
  - Concept
  - Forward RICH for PANDA detector
  - FARICH for Super CTF
- Aerogel production: status and perspectives

Silica aerogel

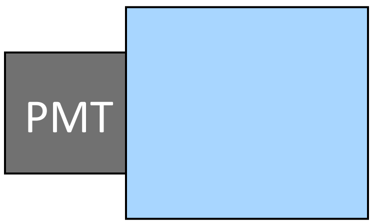
- Silica aerogel was first produced in 1931 by Samuel S. Kistler
- Lightest solids. Close the nature's gap in refractive index between gases ($n-1 \lesssim 10^{-3}$) and liquids/solids ($n \gtrsim 1.3$).
- 3D network of SiO_2 nanometer sized pellets and 50-100 nm pores
- Now produced by sol-gel method out of silicon alkoxide $Si(OR)_4$





Threshold Cherenkov counters

Direct light collection

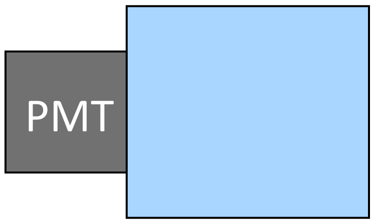


Pros: Simplicity

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

Threshold Cherenkov counters

Direct light collection

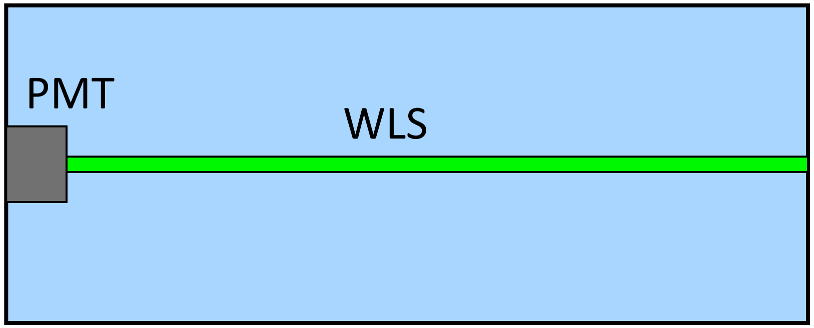


Pros: Simplicity

Cons: 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]



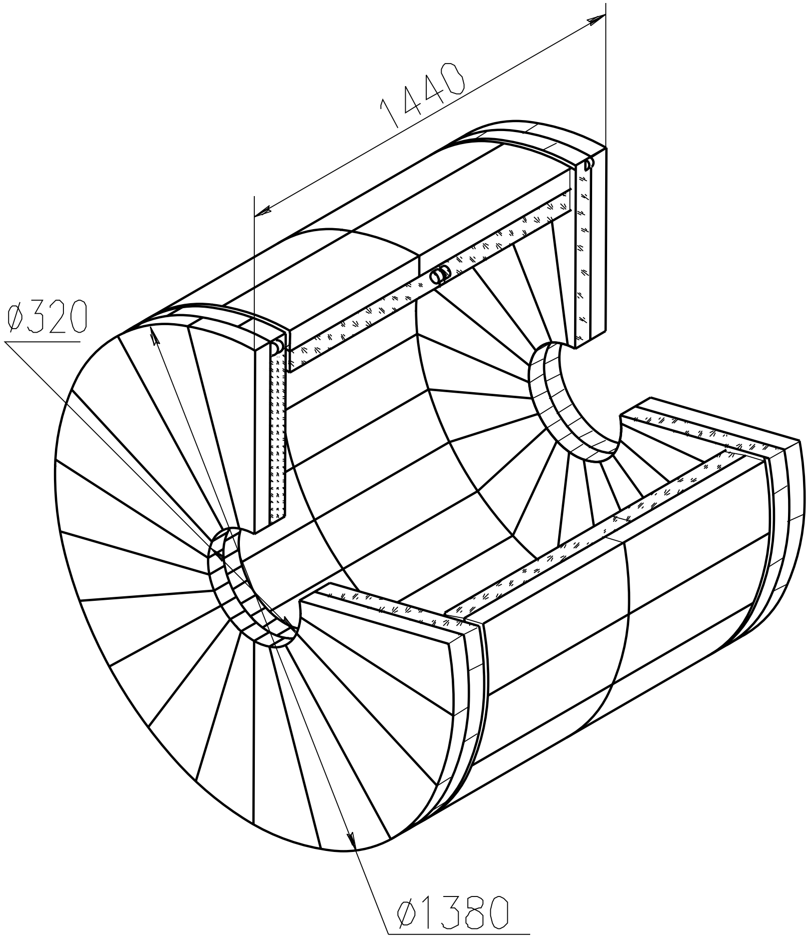
Pros:

- 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

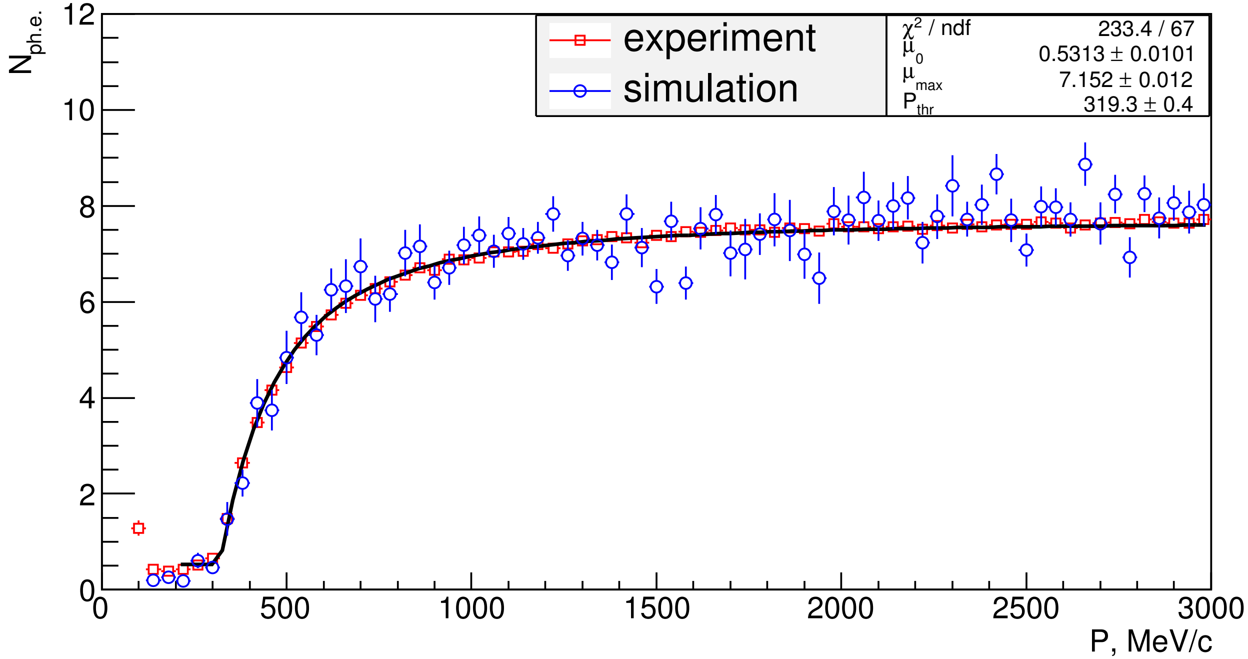
The ASHIPH system of the KEDR detector



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

Since 2014 is under operation in the KEDR experiment at VEPP-4M collider.

The ASHIPH system of the KEDR detector (2)



N_{pe} as a sum of the signal from both barrel layers

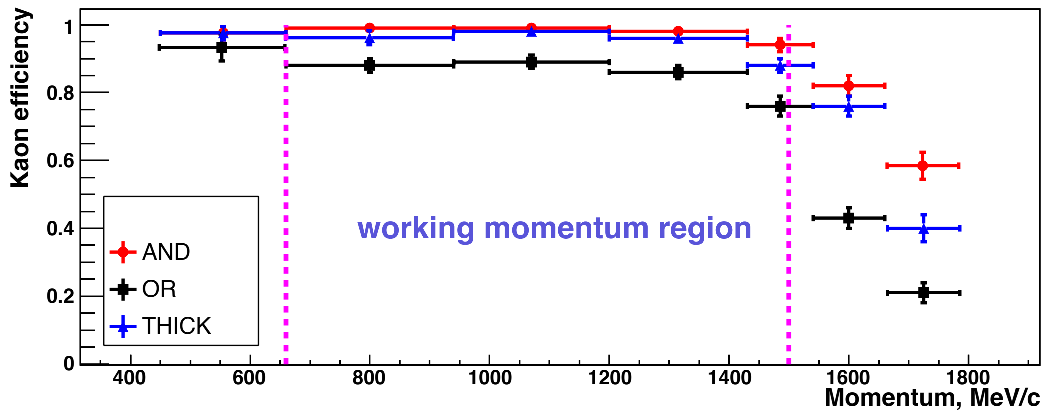
Good agreement MC simulation with experimental data is obtained

Under-threshold efficiency:

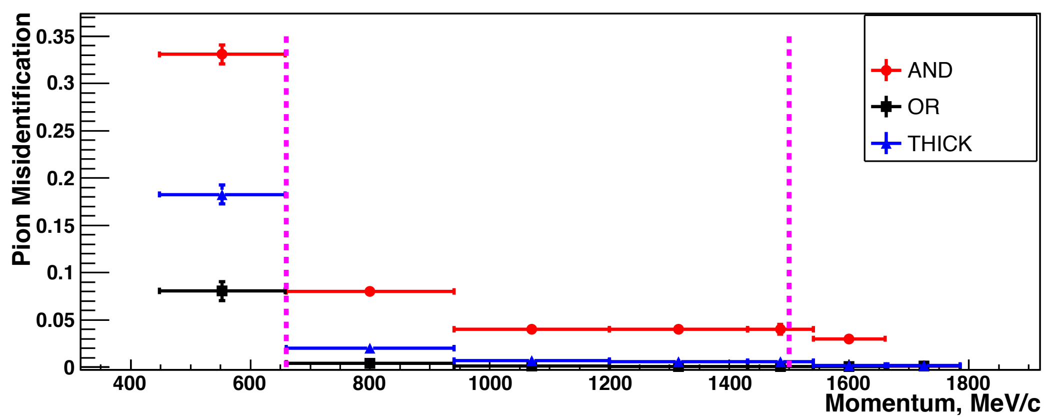
- P_μ < 110 MeV/c – PTFE scintillation
- P_μ > 110 MeV/c – PTFE Cher. light
- P_μ > 130 MeV/c – Cher. light from δ-electrons in aerogel.

*A.Yu. Barnyakov et al 2017 JINST **12** C07041*

The ASHIPH system of the KEDR detector (3)



AND: *relativistic particle have to give a signal in both layers of the system*
OR: *relativistic particle have to give a signal at least in one layer*
THICK: *sum of the amplitudes in both layers have to be more than threshold*



- π/K – 4.3σ at 1.2GeV/*c*
- $e^+e^- \rightarrow e^+e^-$ supp.>600 times

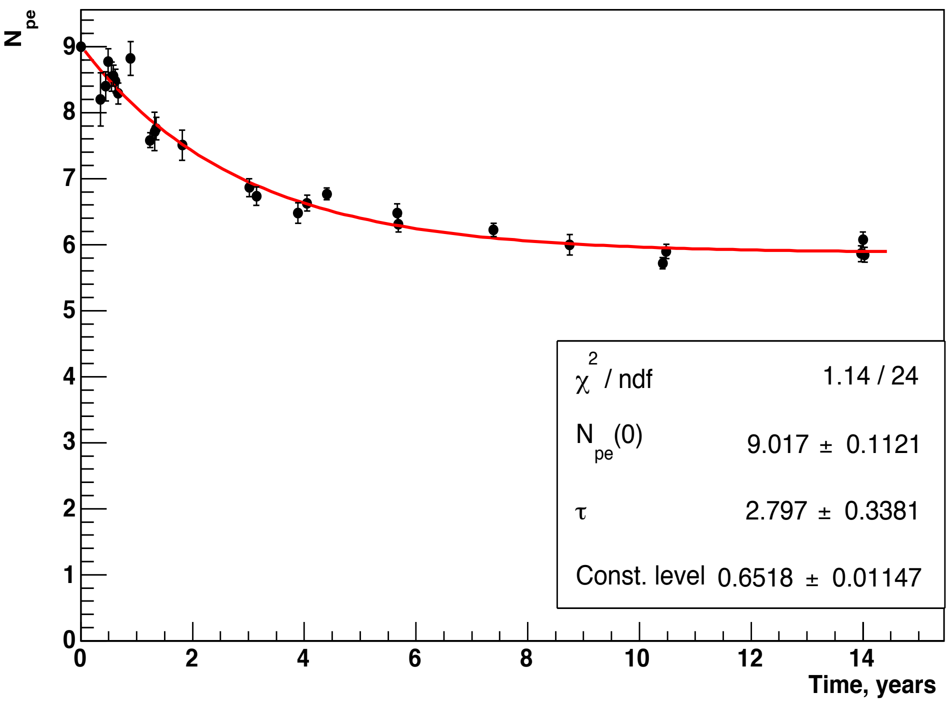
A.Yu.Barnyakov et al, NIM A824 (2016) 79-82

Study in progress (collected data):

- *Br*(J/ψ →pp, ππ, KK, ppγ, ππγ, KKγ, ppπ^0, πππ^0, KKπ^0)
- D-meson masses measurement

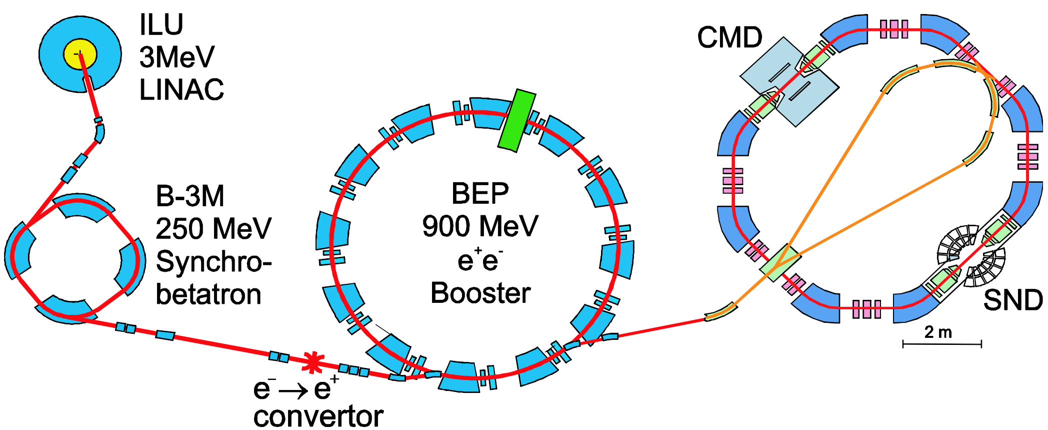
Long term ASHIPH stability

- Since 2000 the stability of ASHIPH counters has been studied.
- 80 counters of the system were under operation in detector from 2003 to 2011.
- The main sources of amplitude decrease were studied:
  - **QE PMT – 18%**
  - **LC(Aerogel) – 22%**



Dynamic of the amplitude dependence on time is explained by slow aerogel degradation which goes to some stable level.

SND at VEPP-2000



Symmetric e^+e^- collider with round beams

$2E_{max}$=2000 MeV

$L=10^{31} cm^{-2}s^{-1}$ at E=510 MeV

$L=10^{32} cm^{-2}s^{-1}$ at E=1000 MeV

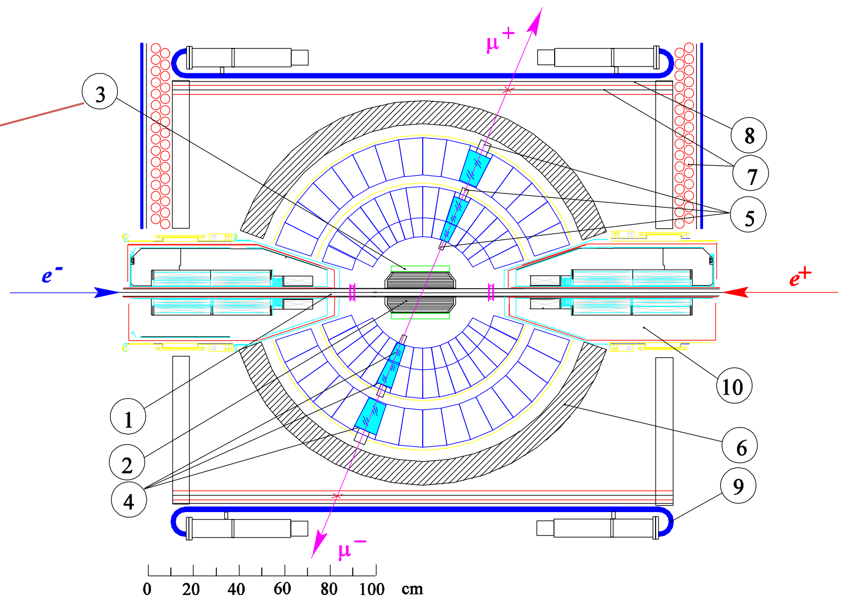
1. VEPP-2000 beam pipe
2. Tracking system
3. Aerogel Cherenkov counters
4. NaI(Tl) crystals
5. Vacuum phototriodes

}EMC

6. Fe absorber
7.
8.
9.

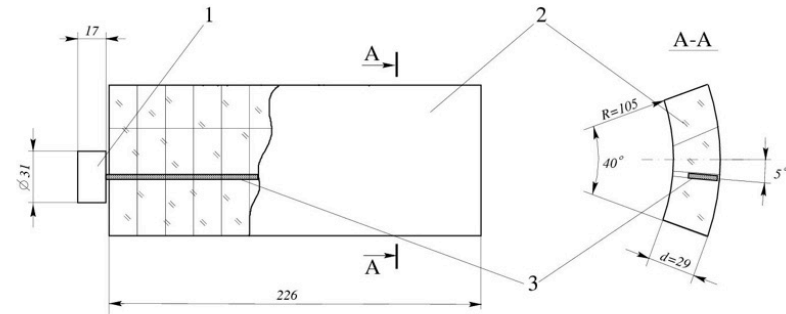
}Muon system

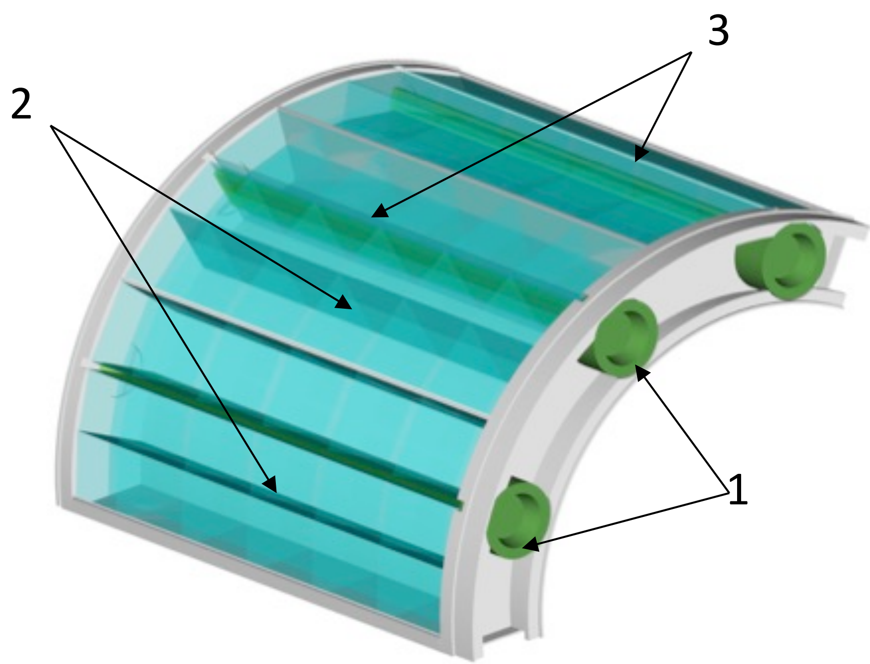
10. VEPP-2000 s.c. focusing solenoids



The ASHIPH system of the SND detector

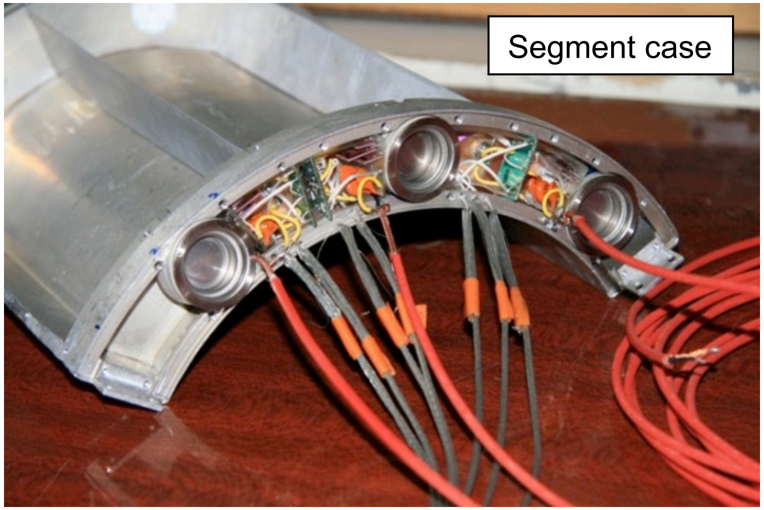
- 9 counters (1 layer)
- 9 liters of aerogel:
    - n=1.13 for π/K (300÷870MeV/c)
    - n=1.05 for e/π (up to 450 MeV/c)
- WLS (BBQ)
- MCP PMT øPC=18 mm
- Diffusive LC (PTFE)
- Thickness ~ 30 mm
- 0.6x4π

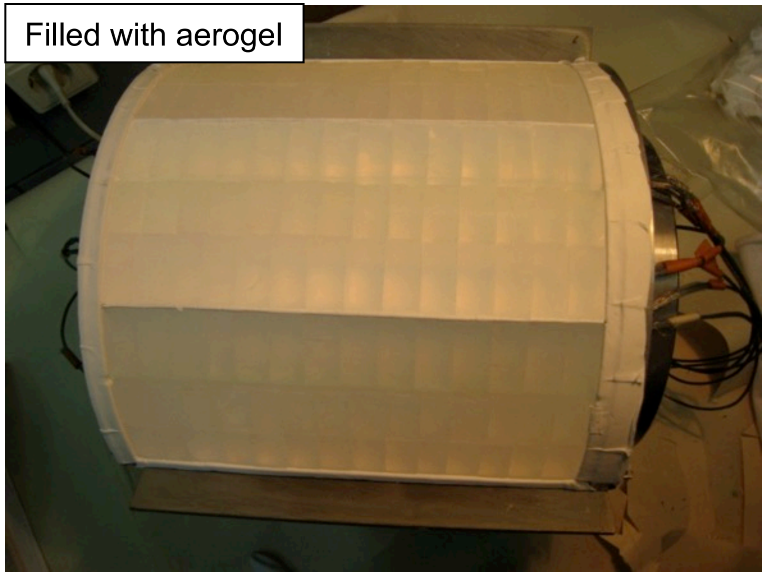


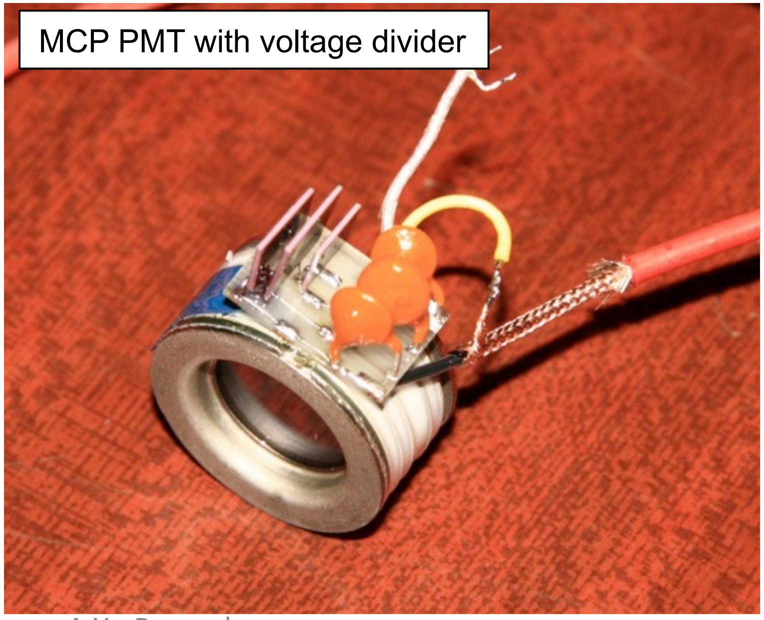


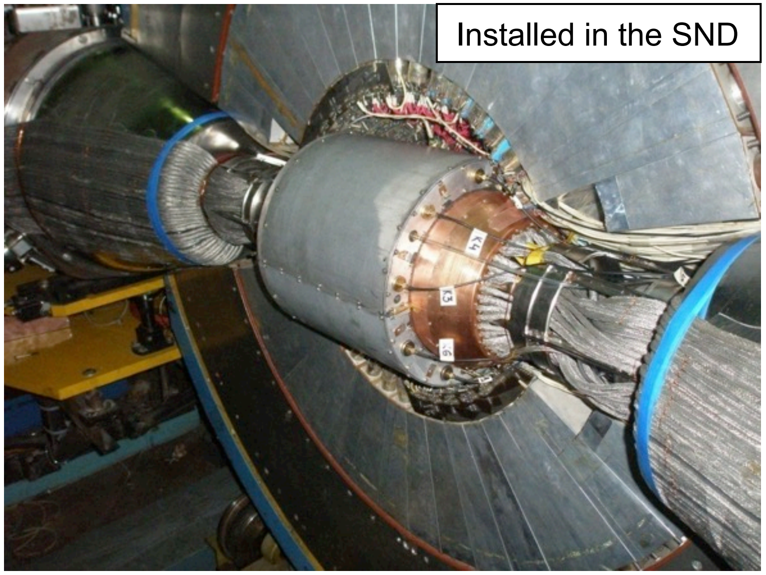
1 - PMT, 2 – aerogel, 3 - WLS

SND counters assembling & installation



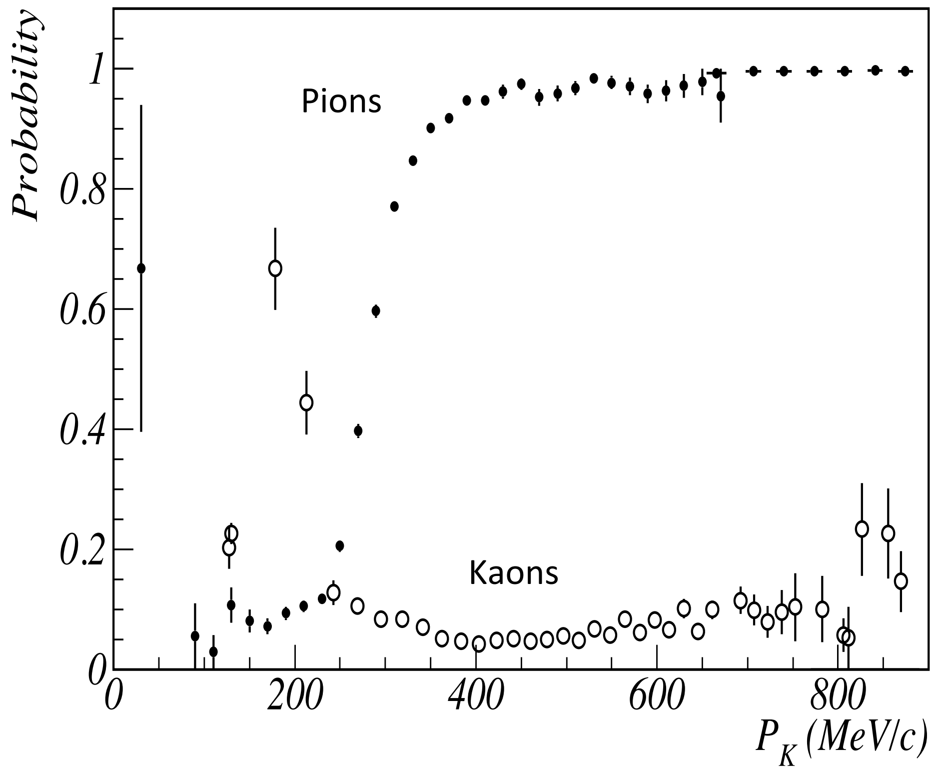




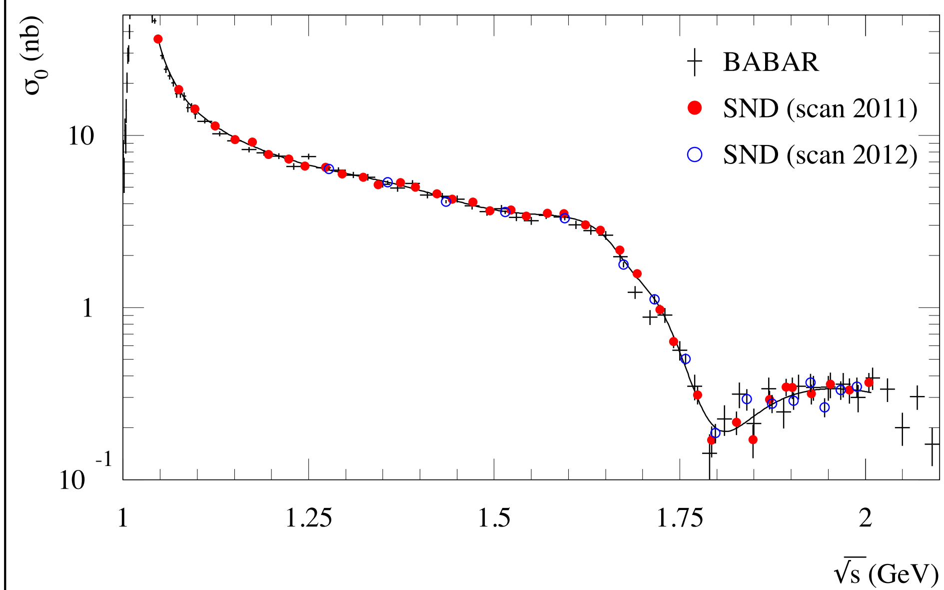


The staus of SND detector ASHIPH system

The Born cross section for $e^+e^- \to K^+K^-$ process



A. Y. Barnyakov et al., JINST 9 C09023 (2014)



The most accurate measurement is performed with SND detector

M.N.Achasov et al, Phys. Rev. D94 (2016) 112006

ASHIPH upgrade

MCP PMT → SiPM

Pros:

	MCP PMT	SiPM
PDE=QE*CE	25*0.6≈15%	30-45%
Magnetic field imm.	Axial	Any direction
Power supply	2÷4 kV	<100V

Cons:

- High level of noise → New specific FEE → Cooling system
- Radiation tolerance is still low.

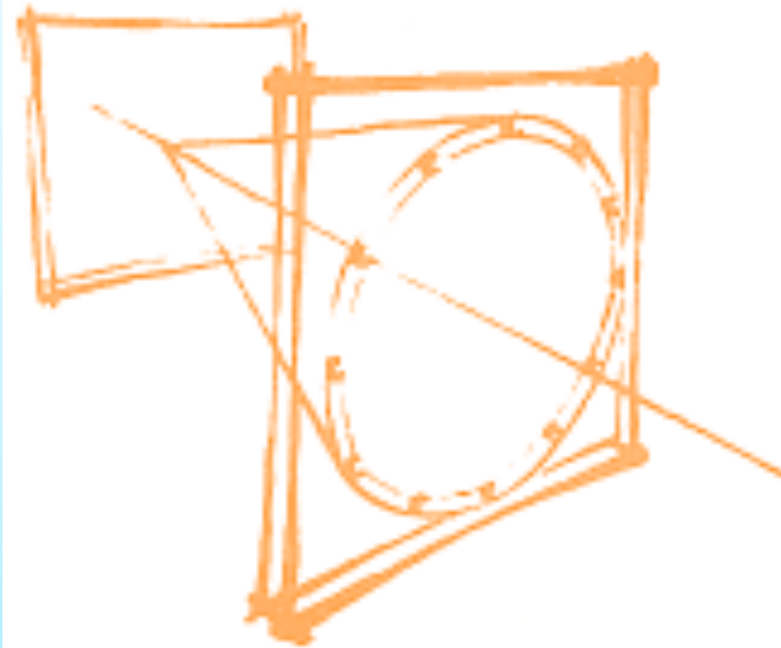
In case of existing experiments such upgrade are possible right now.

For Super Cτ (B)- Factories SiPM R&D is needed.

Ring Imaging Cherenkov detectors with aerogel radiators

- If the Cherenkov radiation angle is measured, the identification quality will be higher than in threshold counters.
- In the 1980s and 1990s, a whole series of RICH detectors were constructed:
  - CRID, SLD detector, SLAC(C_6F_{14} n=1.277, C_5F_{12}/N_2 n=1.0017)
  - RICH, Delphi detector, CERN, (C_5F_{12}|C6F14, C4F10)
  - RICH, CLEOIII detector, Cornell, (LiF, n=1.50)
  - DIRC, detector BaBar, SLAC, США (SiO_2, n=1.47)
- Main problem – they do not provide π and K identification with 4÷10 GeV/*c* momenta
- **Material with n=1.03÷1.05 is needed. Aerogel!**

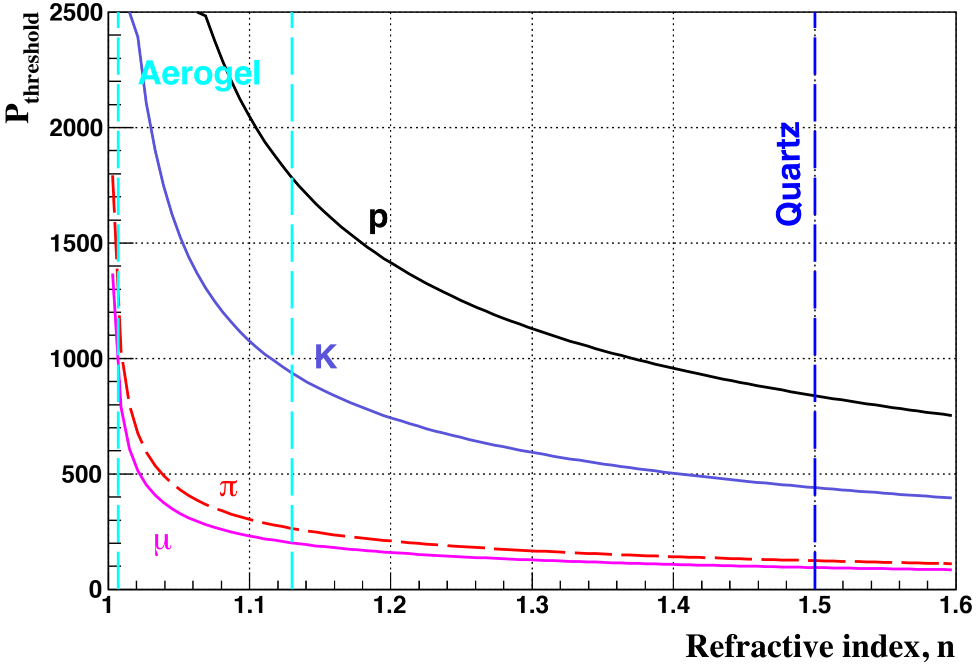
$\cos\theta = 1/n\beta$



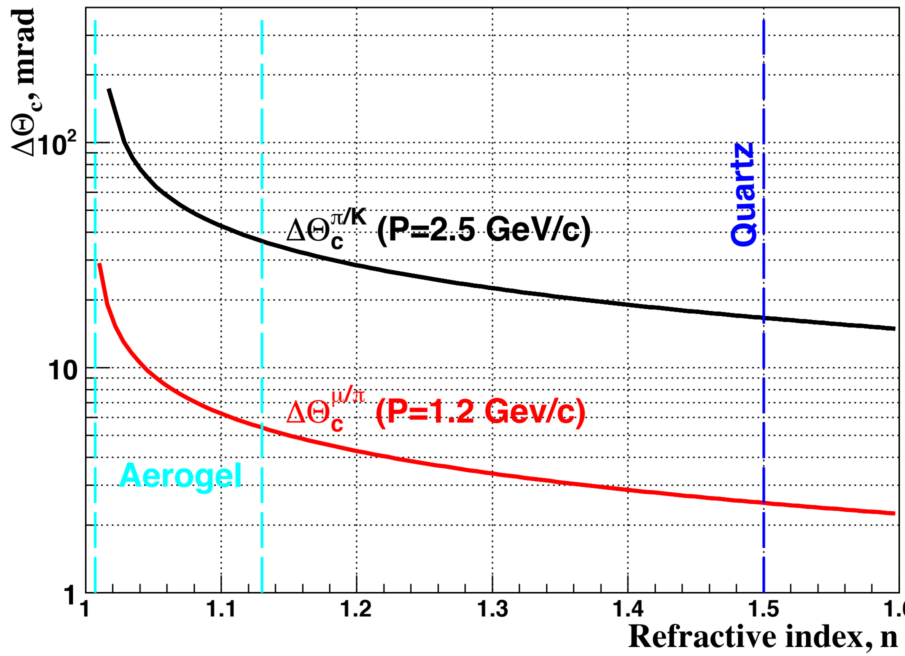
Focusing Aerogel RICH for PID system

(Motivation)

Dependence of Cherenkov threshold momentum on refractive index



Dependence of $\Delta\Theta_c$ on refractive index



Aerogel threshold counters for reliable K/π separation up to 2GeV/c could be used.

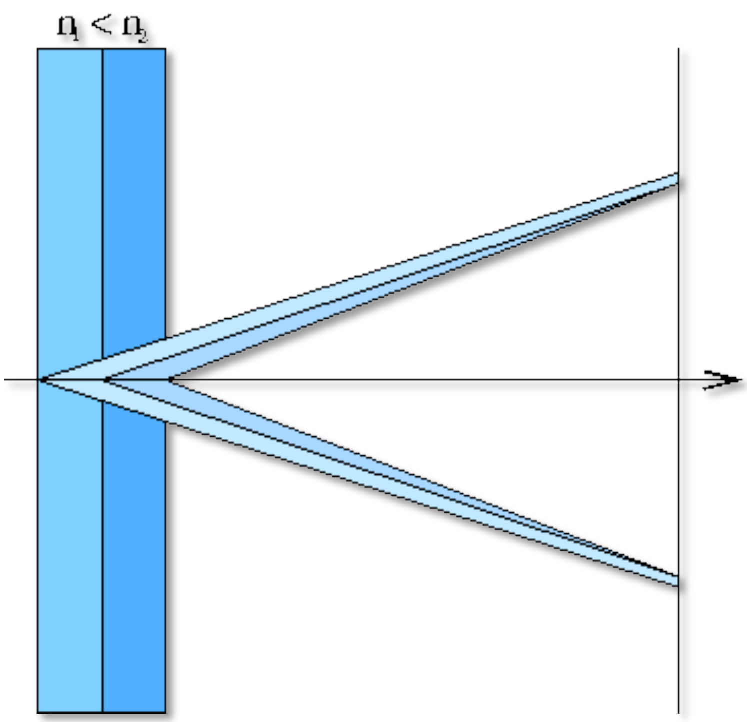
For reliable μ/π separation we need aerogel RICH with $\sigma_{track}(\Theta_c) < 2.5$ mrad

Focusing Aerogel RICH – FARICH

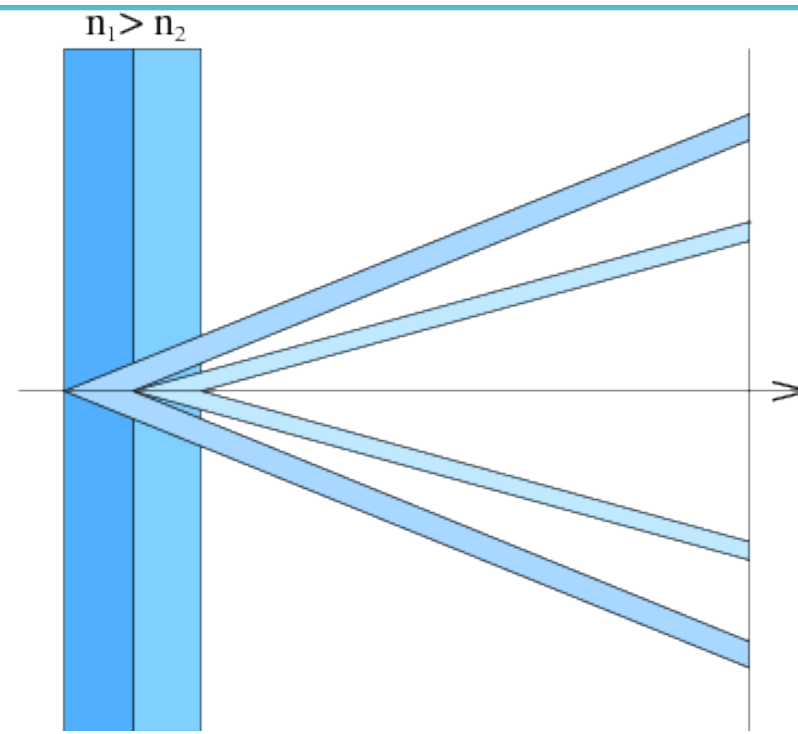
(Concept)

Focusing aerogel improves proximity focusing design by reducing the contribution of radiator thickness into the Cherenkov angle resolution

Single ring option



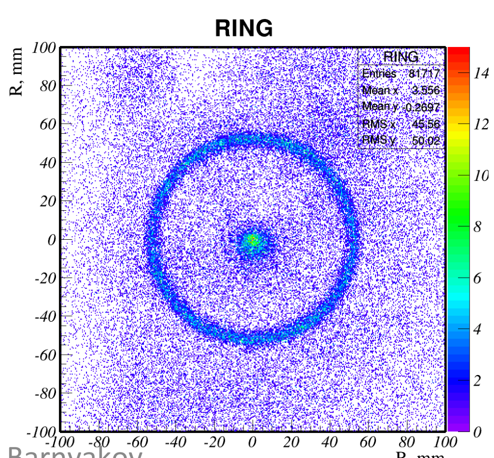
Multi-ring option

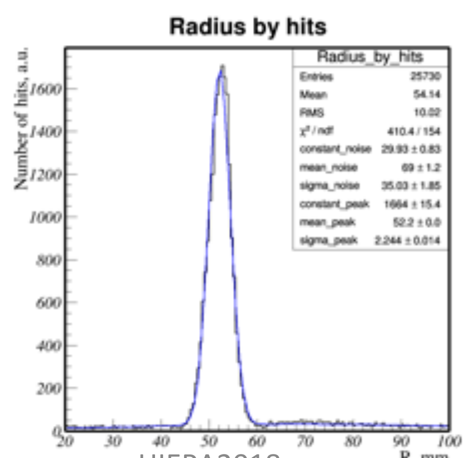


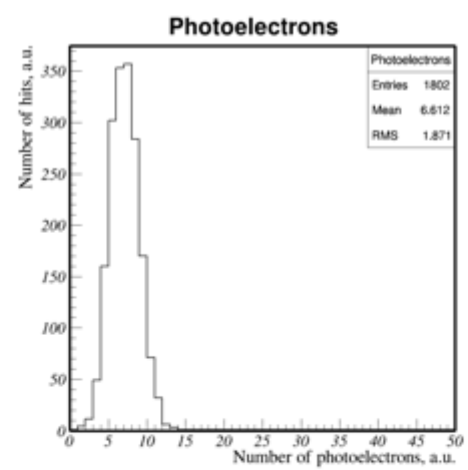
T.Iijima et al., NIM A548 (2005) 383
A.Yu.Barnyakov et al., NIM A553 (2005) 70

Single ring option: two approaches

Two blocks	**Two layer block**
• Aerogel RICH for Belle-II: – n_1=1.045, n_2=1.055 – Thickness – 20 + 20 mm – Distance – 200 mm • HAPD with 5x5 mm pixel • σ_Θ=15.8 mrad and N_{pe}=8.6 $\sigma_\Theta(\text{track})= \sigma_\Theta/\sqrt{N_{pe}} \approx 5.4$ mrad *S.Nishida et al., NIM A 766 (2014) 28*	• Aerogel from BINP&BIC: – n_1=1.045, n_2=1.053 – Thickness – 15 + 15 mm – Distance – 200 mm • Philips DPC3200 – 4x4 mm pixel • σ_Θ=11.2 mrad and N_{pe}=6.6 $\sigma_\Theta(\text{track})= \sigma_\Theta/\sqrt{N_{pe}} \approx 4.4$ mrad *Preliminary results of BINP testbeam 2016*



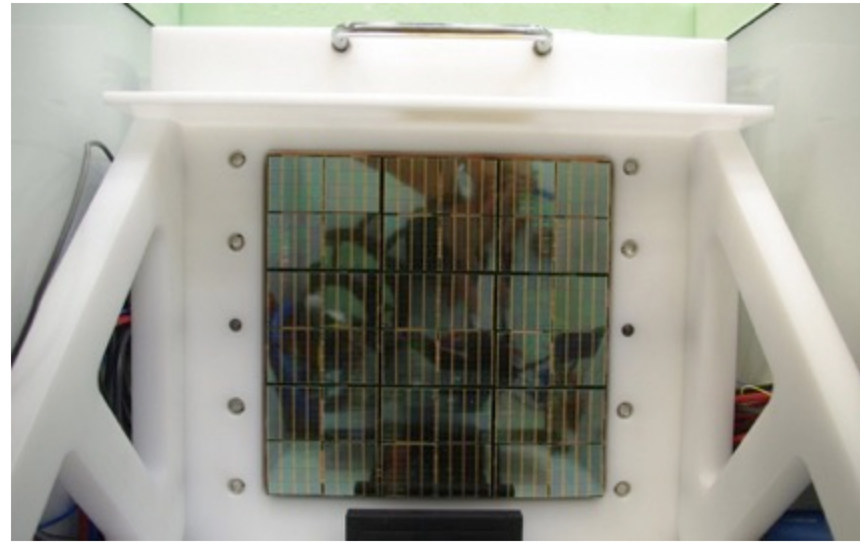




Beam test of FARICH at CERN PS T10, June 2012

4-layer aerogel

- n_{max} = 1.046
- Thickness 37.5 mm
- Focal distance 200 mm



Test conditions

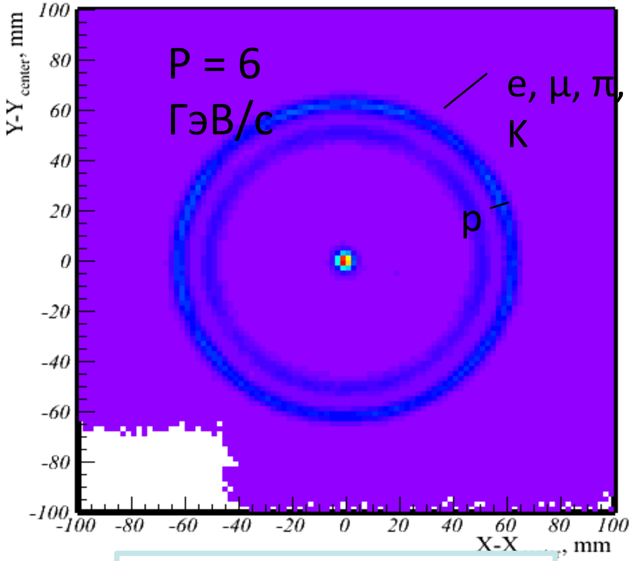
- Positive polarity: e^+, μ^+, π^+, K^+, p
- Momentum: 1–6 GeV/c
- Trigger: a pair of sc. counters 1.5x1.5 cm^2 in coincidence separated by ~3 m
- No external tracking, particle ID, precise timing

DPC matrix 20x20 cm^2

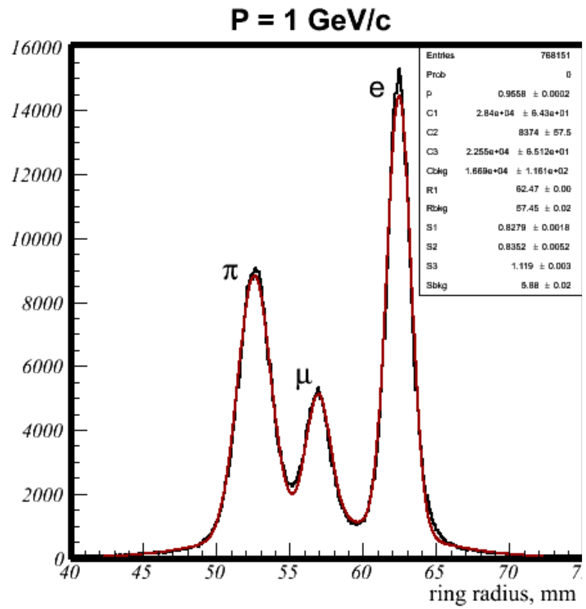
- Sensors: DPC3200-22-44
- 3x3 modules = 6x6 tiles = 24x24 dies = 48x48 pixels
- 576 time channels
- 2304 amplitude (position) channels
- Operation at –40°C to reduce dark counts

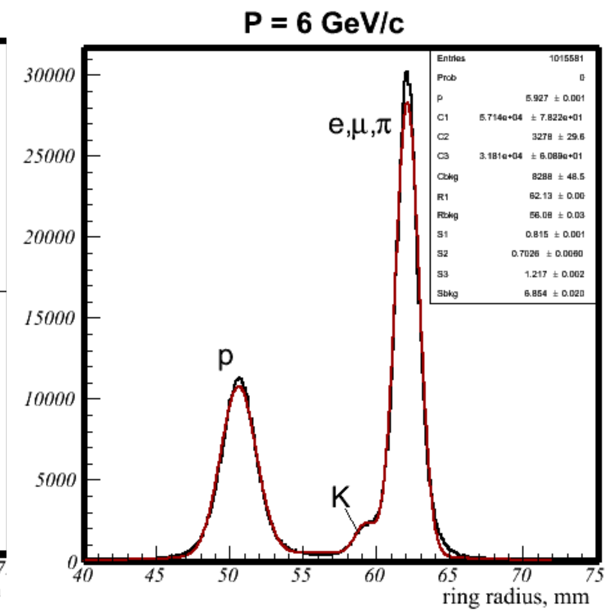
Beam test results at CERN PS T10, June 2012

Hit positions

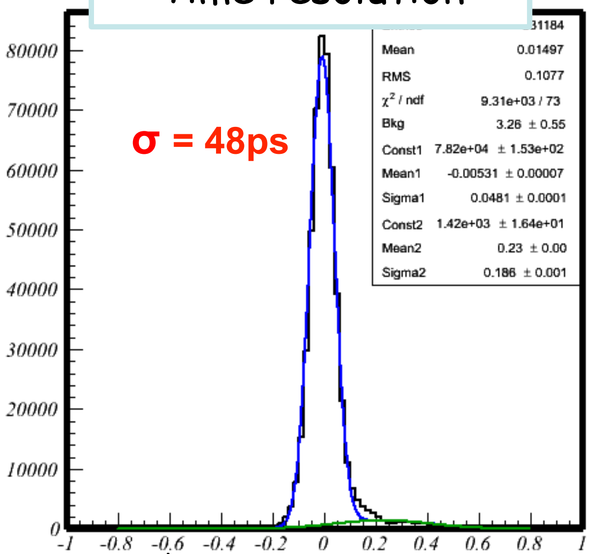


Ring radius distributions



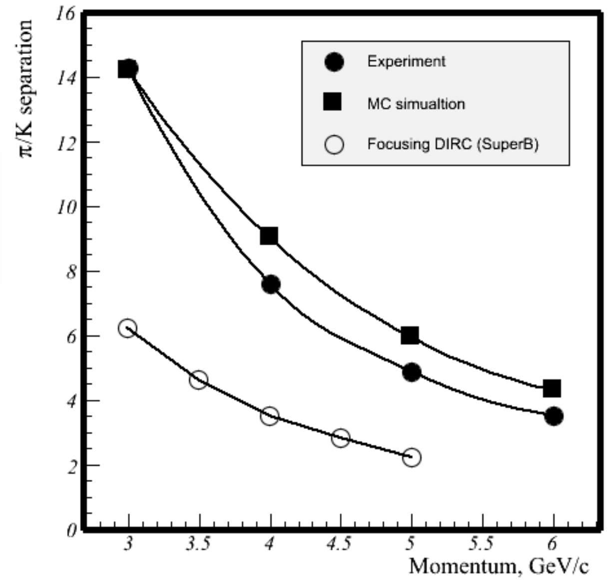


Time resolution



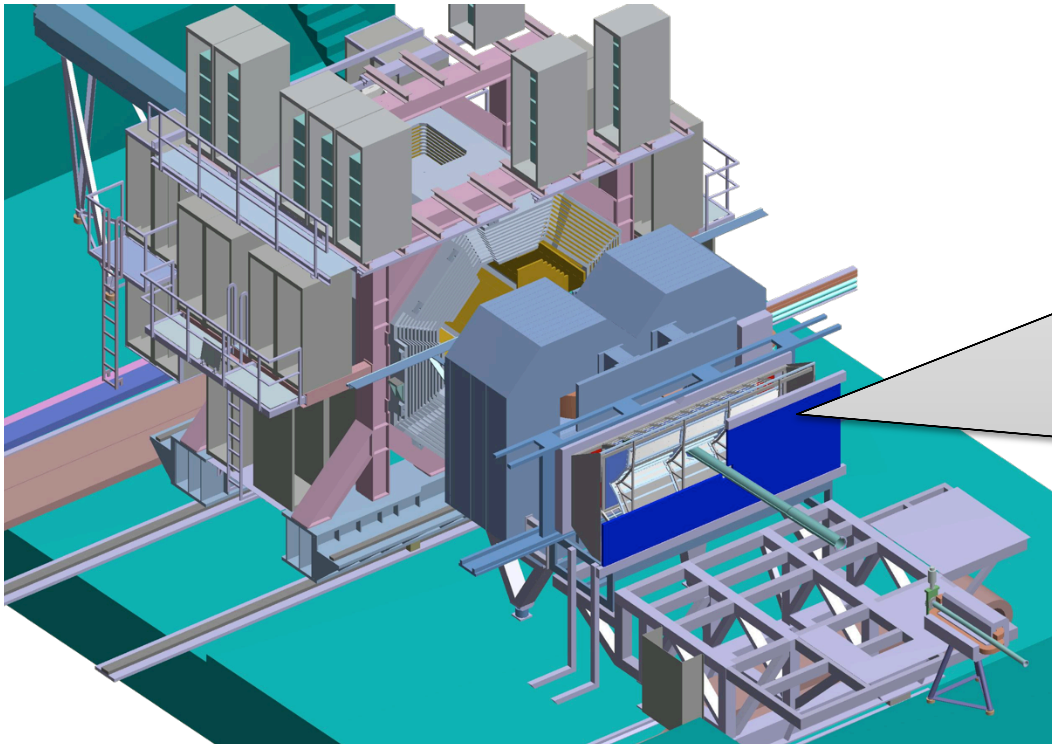
$$S(\pi/K) = \frac{R_\pi - R_K}{\sigma_\pi}$$

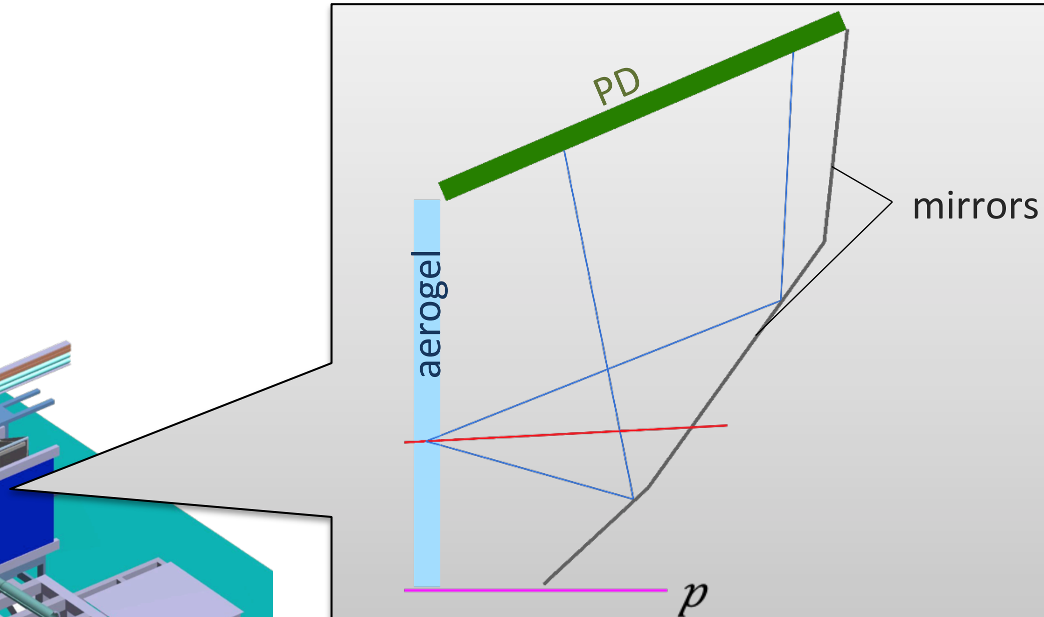
π /K : 7.6σ @ 4 GeV/c
μ /π : 5.3σ @ 1 GeV/c



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

Forward RICH for PANDA





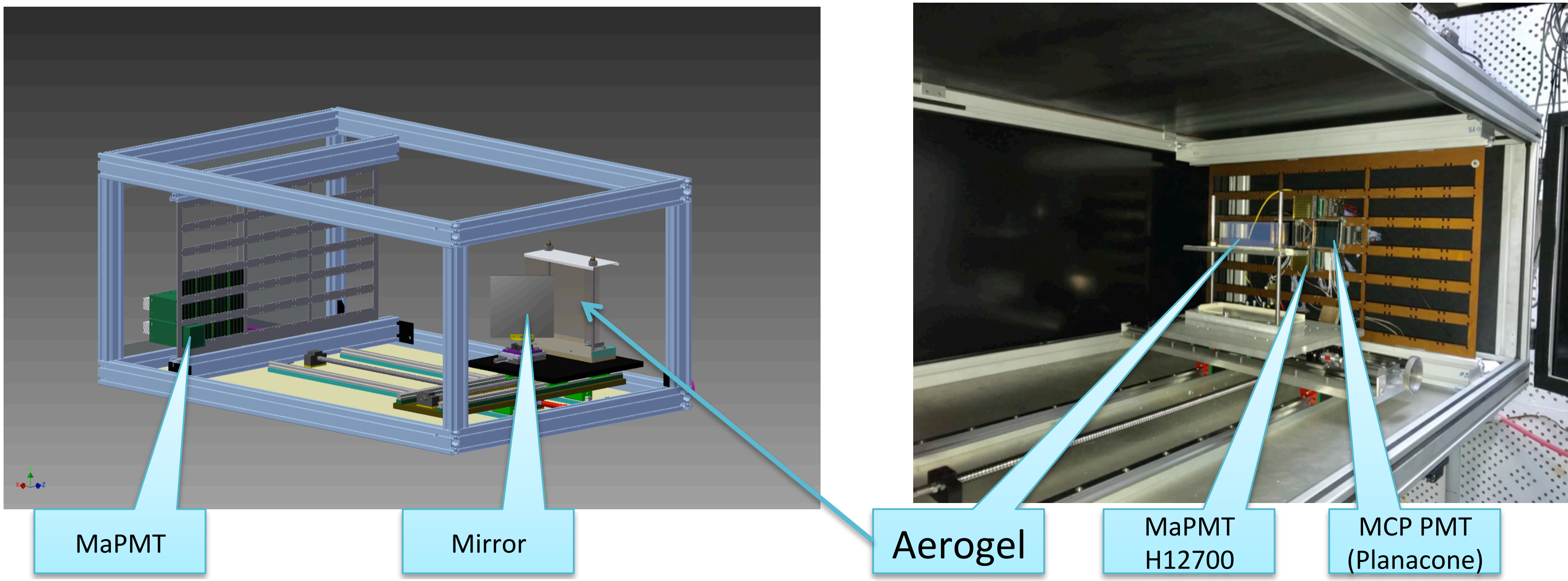
Particle ID: π/K/p up to 10 GeV/c
$3m^2$ detector area (MaPMTs)

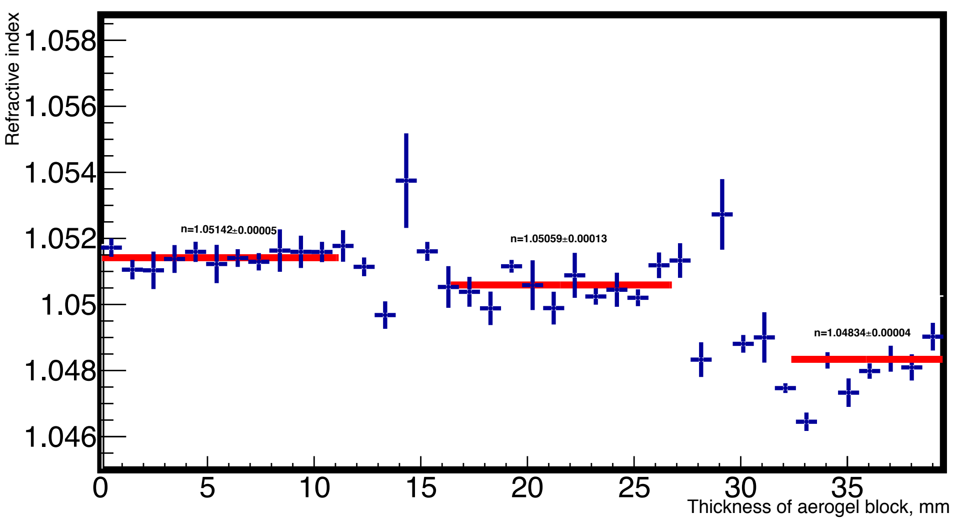
Radiator
- Focusing 2- or 3-layer aerogel
- 40 mm thick

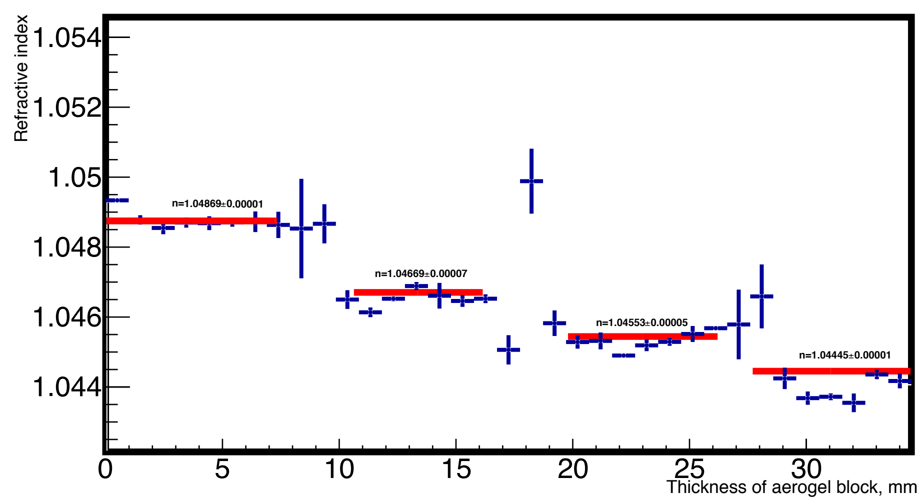
Mirrors
- Flat segments
- Float glass substrate 2 mm thick
- Al+SiO_2 coating, R≥90%

Photon Detector
Hamamatsu H12700 MaPMT
- flat panel,
- 8x8 anode pixels of 6mm size
- 87% active area ratio
- Bialkali photocathode
- Gain: $1.5\cdot10^6$

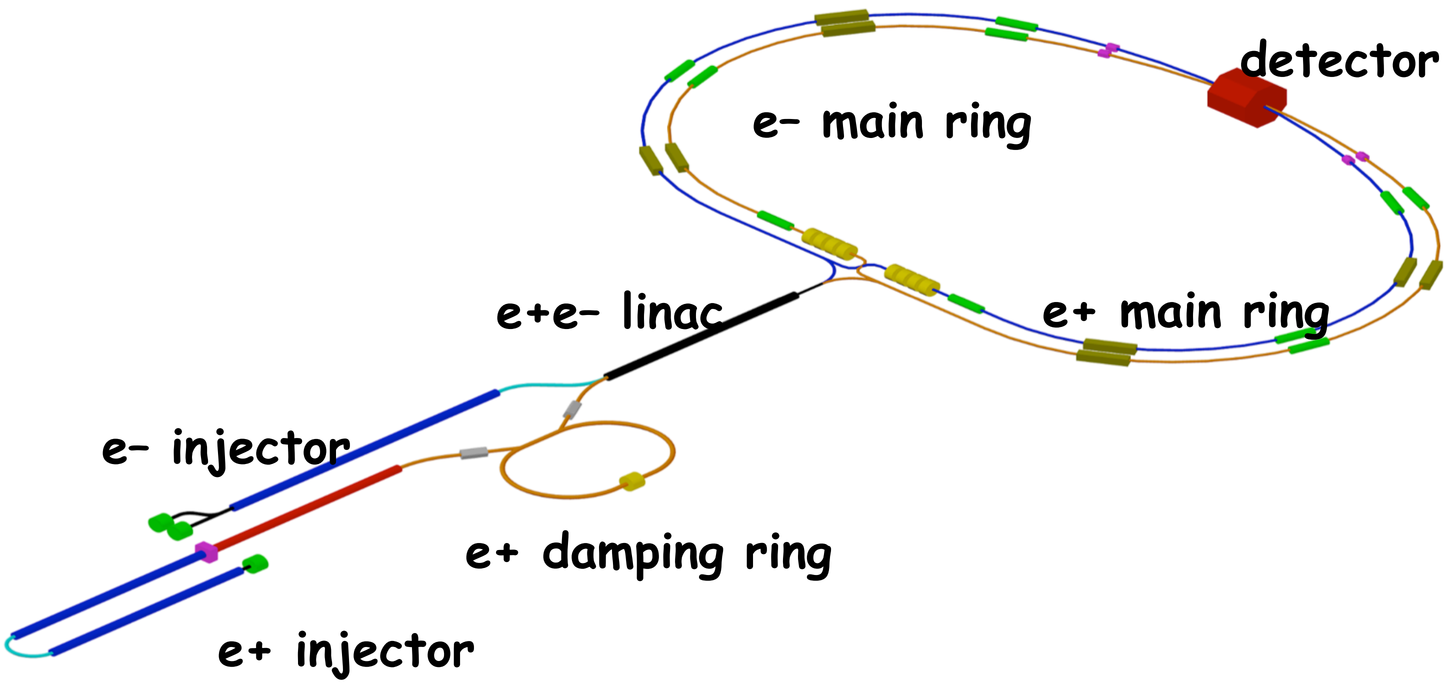
Forward RICH for PANDA (prototype)







Super Charm-Tau Factory project



Factory outline:

- Double ring symmetric e^+e^- collider with Crab Waist scheme
- $E_{c.m.} = 2\div5$ GeV
- $L = 10^{35}$ $cm^{-2}s^{-1}$ (100 times more than existing c-τ factories)
- Longitudinal polarization of e^- - beams in IP

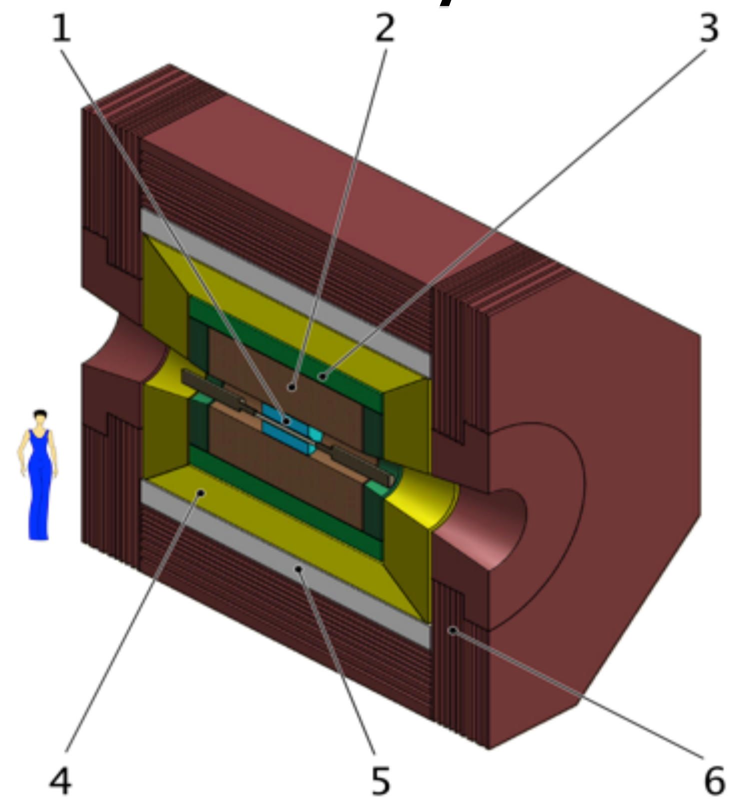
Detector for Super cτ-factory

Physical program:

- Rare decays of D-mesons, τ-lepton;
- D-meson oscillations;
- Searches for lepton-flavor-violating decays of τ (for instance τ → μγ);
- …

Detector requirements

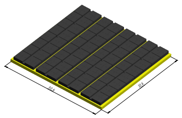
- An excellent momentum resolution for charged particles and a good energy resolution for photons;
- K/π separation higher than 3σ; μ/π separation up to 1.5 GeV/c;
- DAQ system, which is able to read events at a rate of 300÷400kHz with 30kB event length;
- …



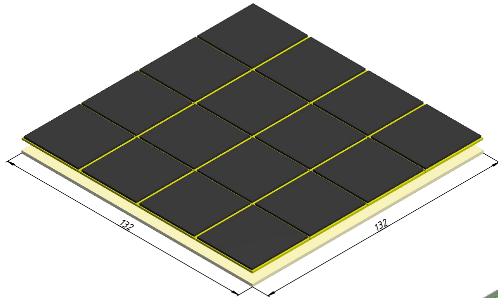
- 1 – Vertex Detector
- 2 – Drift Chamber
- 3 – PID => FARICH
- 4 – EMC
- 5 – Superconducting Solenoid
- 6 – Yoke + MU system

See CTF CDR (https://ctd.inp.nsk.su/docs/ScTau_CDR_en/CDR_en_ScTau.pdf)

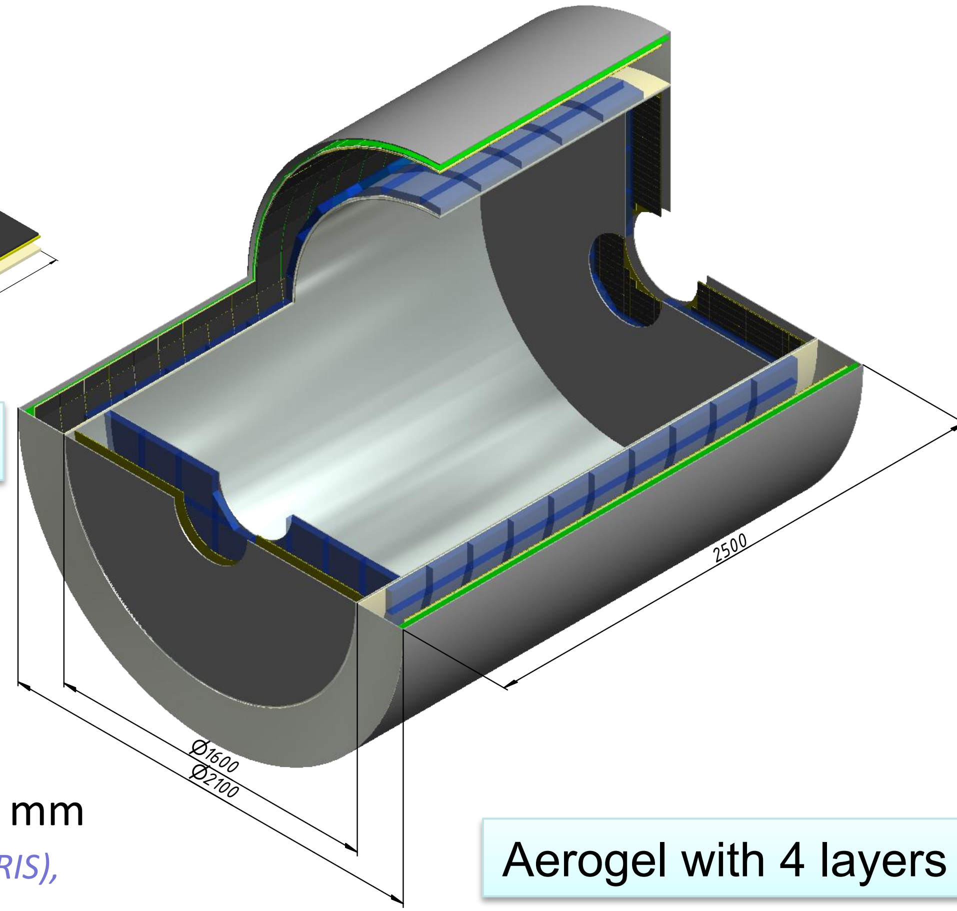
FARICH system



Tile with 64 pixels



Module with 16 tiles



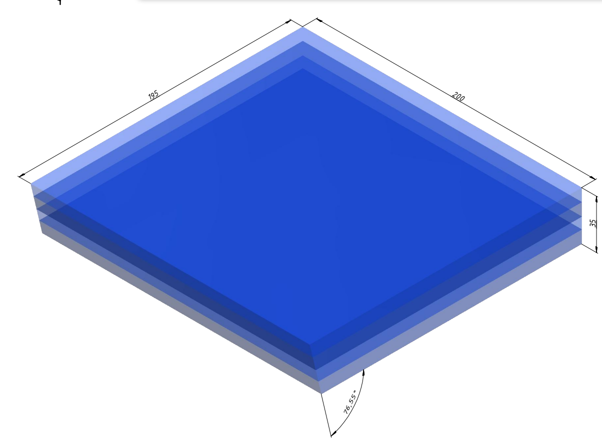
Main parameters

- Focusing aerogel radiator, n_{max}=1.07, 4 layers
- Proximity focusing at distance 200 mm
- Photon detector:~3x3mm^2, pitch 3.5÷4 mm

  DPC (Philips), MPPC (Hamamatsu), NUV-HD (FBK-IRIS), ArrayJ (SensL), MA MCCP PMT (Planacon)
- Area of the photon detector: 20 m^2
- Area of the aerogel radiator: 14 m^2
- ~1÷2•10^6 channels
- Readout electronics based on ASIC

  TOFPET-2 or similar

Aerogel with 4 layers



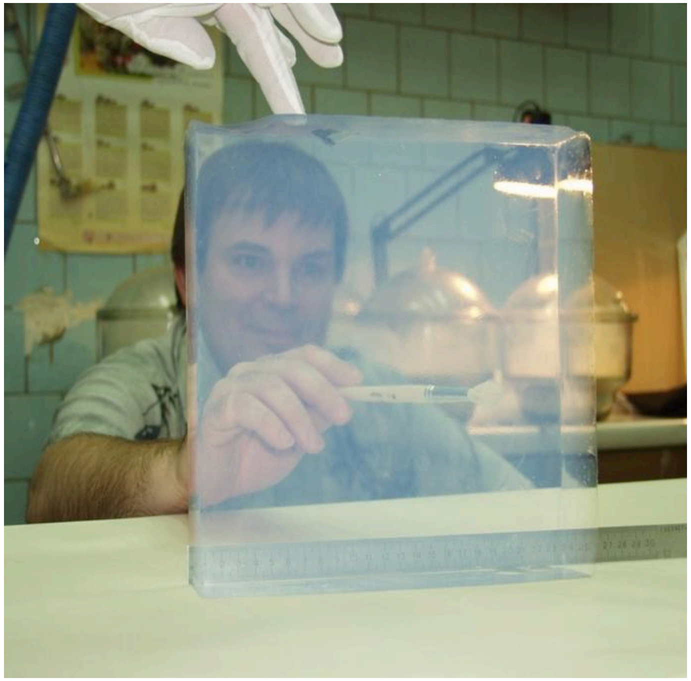
Production of aerogel in Novosibirsk

- Started in 1986 by the Boreskov Institute of Catalysis SB RAS in cooperation with the Budker Institute of Nuclear Physics SB RAS
- Hydrophilic
- Refraction indices 1.006 – 1.08 (1.08-1.13 produced by sintering)
- Block dimensions up to 200x200x50 mm^3 (n=1.03) & 200x200x30 mm (n=1.05)
- Inner surface 800 m^2/g
- Remarkable optical quality has been achieved:

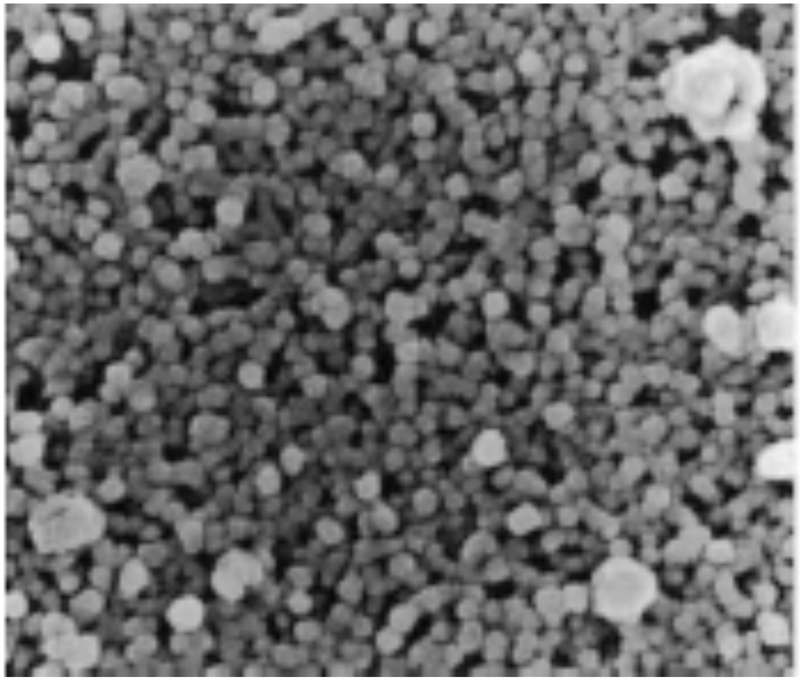
  L_{abs} (400nm) = 5 – 7 m

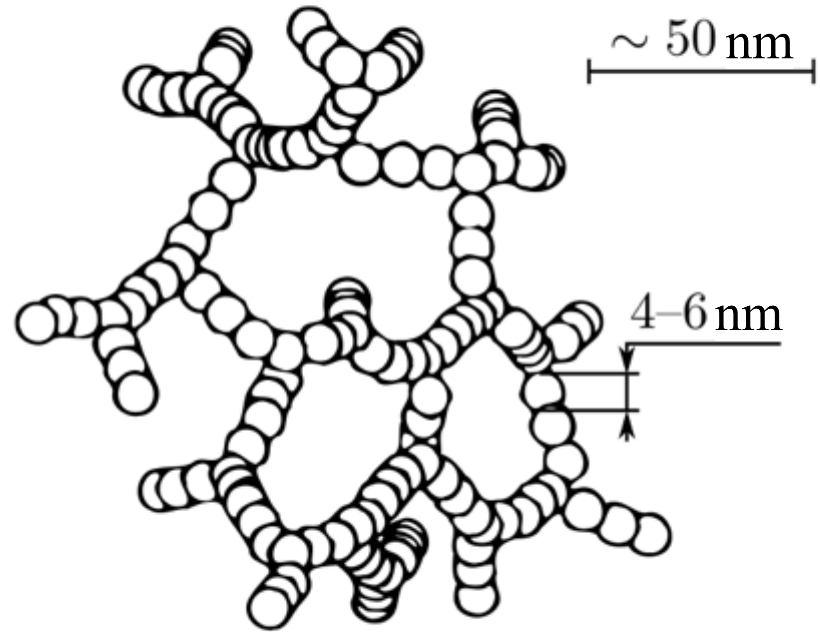
  L_{sc} (400nm) = 4 – 6 cm

  (Clarity = 0.0043 – 0.0064 $\mu m^4/cm$)



Refractive index





$SiO_2 + H_2O(1 \div 5\%)$

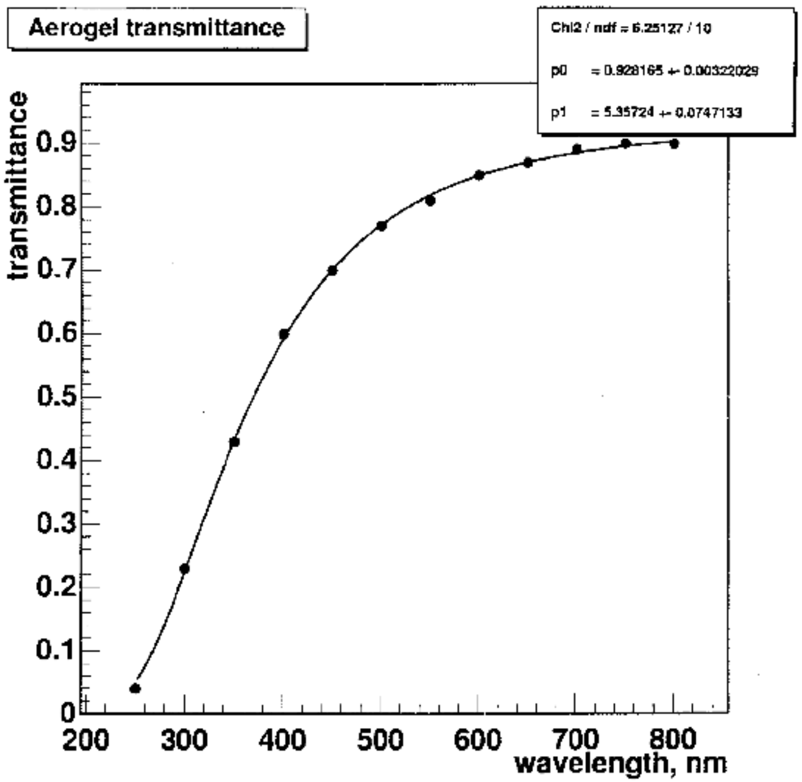
$$\boxed{n^2 = 1 + 0.438 \cdot \rho}$$

n=1.006…1.070 – synthesis
n=1.070…1.130 – sintering

Light scattering

Rayleigh scattering on aerogel structure elements

Transmittance:
$$T = \frac{I}{I_0} = A \cdot \exp \frac{-d}{L_{sc} \cdot (\lambda/400)^4} = A \cdot \exp \frac{-C \cdot d}{\lambda^4}$$

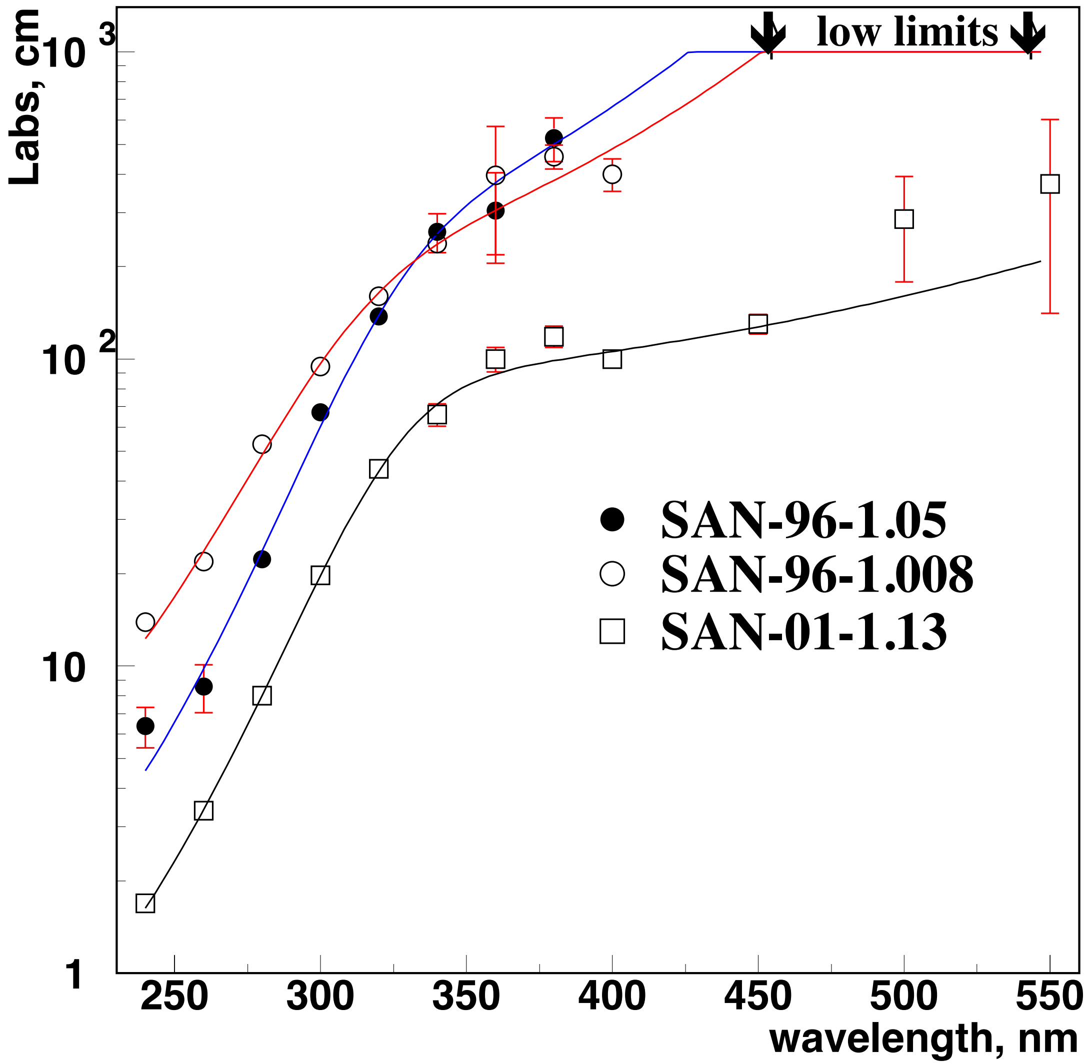


A – surface scattering coefficient
~0.95 for intrinsic surface
~0.70 for polished surface

L_{sc} – scattering length at λ=400nm
> 4.5 cm

C – clarity ($0.4^4 / L_{sc}$)
< 0.0057 μm^4/cm

Light absorption

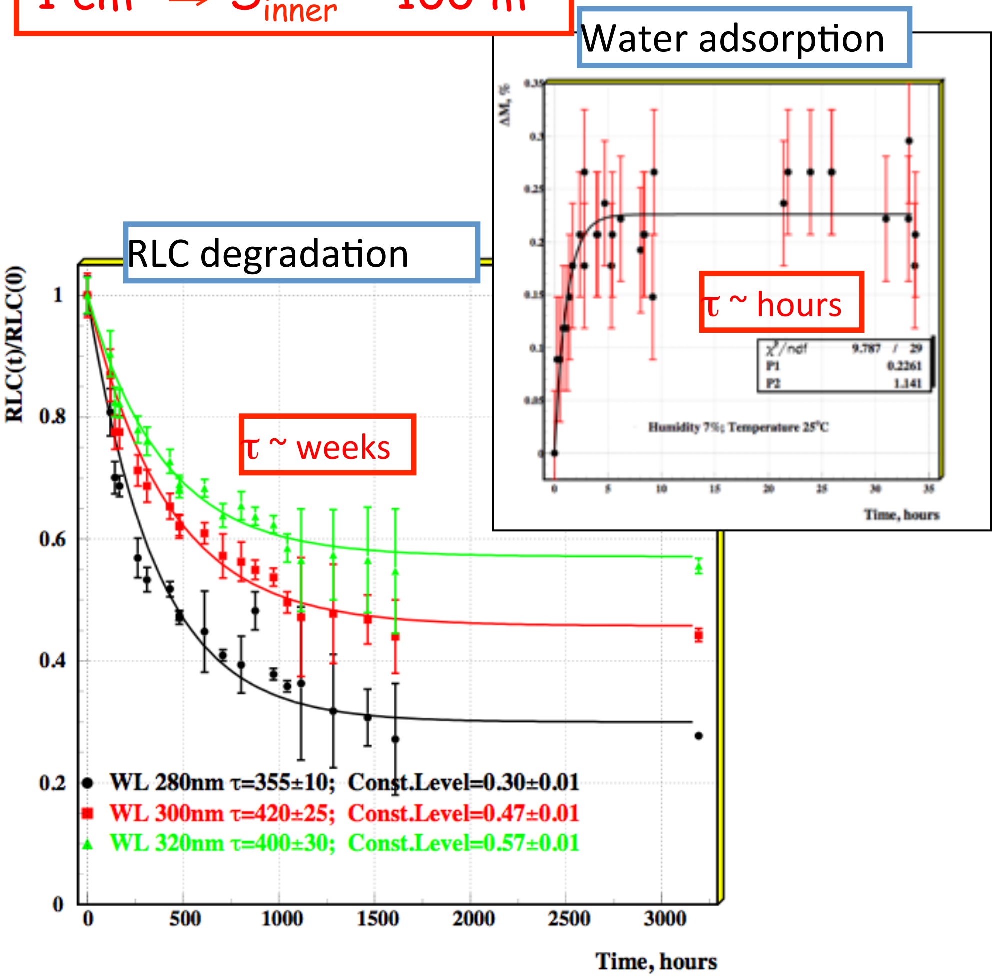


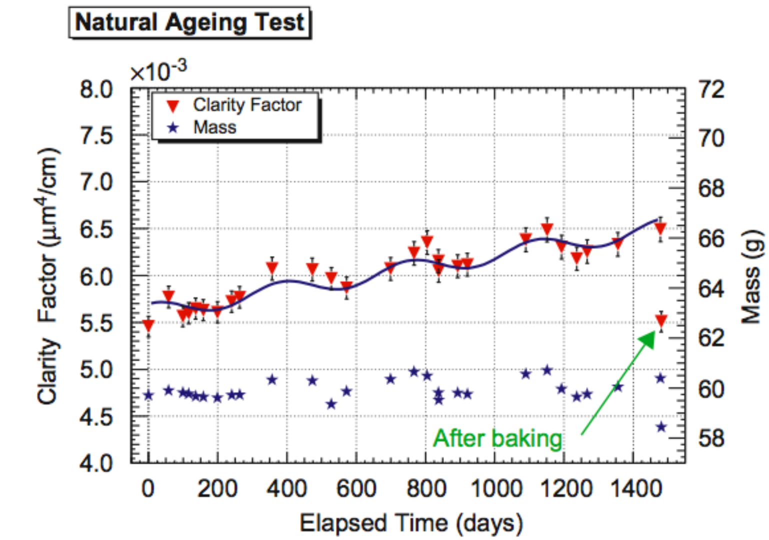
Light is absorbed by impurities.

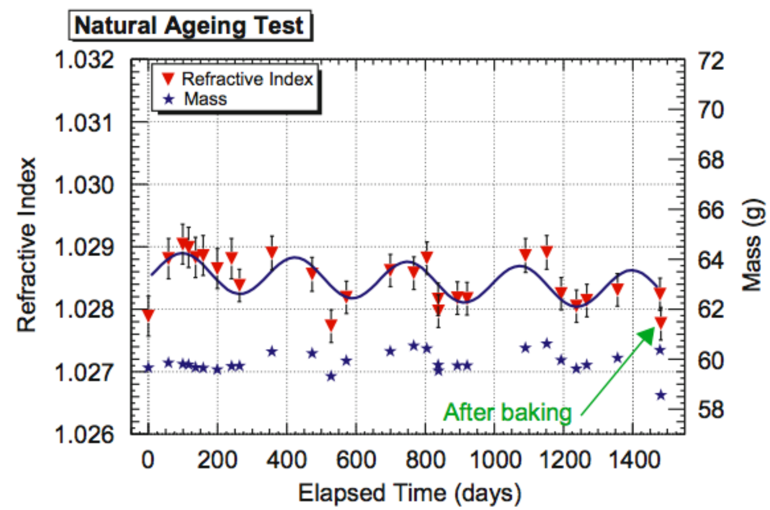
Contamination of metals (Fe, Co, Cu, Mn, etc.) is determined by raw material quality and synthesis technology.

Water adsorption

$1\ cm^3 \Rightarrow S_{inner} \sim 100\ m^2$



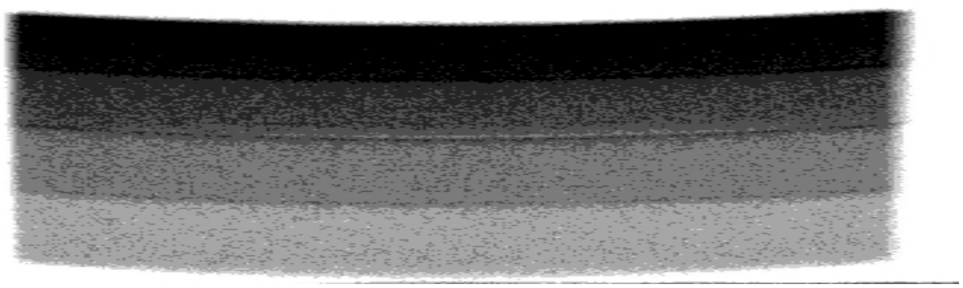




A.Yu.Barnyakov et al., NIM A598 (2009) 166

D.L.Perego, NIM A595 (2008) 224

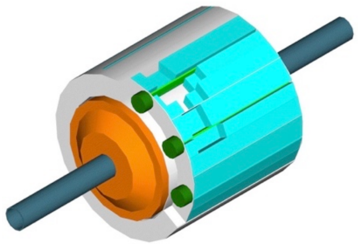
Aerogel study with digital X-ray setup



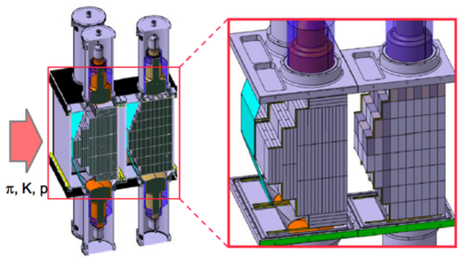
	n	h, mm
Layer 1	1.050	6.2
Layer 2	1.041	7.0
Layer 3	1.035	7.7
Layer 4	1.030	9.7

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

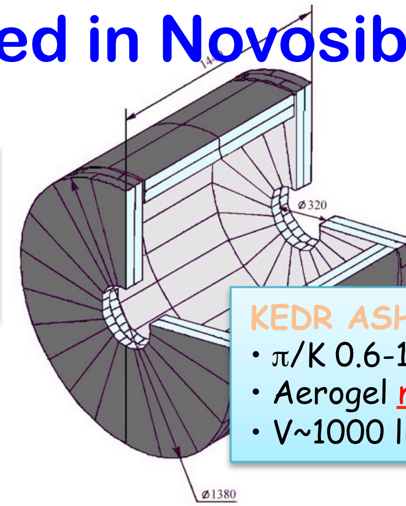
Application of aerogel produced in Novosibirsk



SND ASHIPH system
- π/K at 300-870 MeV/c
- Aerogel n=1.13
- V~9 liters



DIRAC-II (PS-CERN)
- Aerogel n=1.008
- π/K 5.5-8 GeV/c
- V~ 12 liters

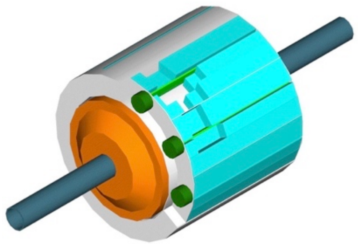


KEDR ASHIPH system
- π/K 0.6-1.5 GeV/c
- Aerogel n=1.05
- V~1000 liters

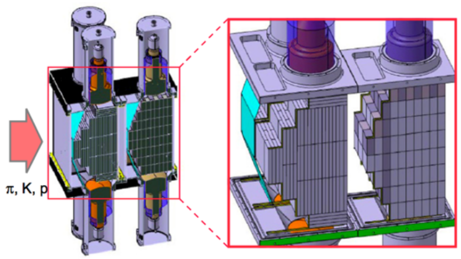
<u>Produced in Novosibirsk:</u>

- \>1000 l of aerogel for threshold ACC

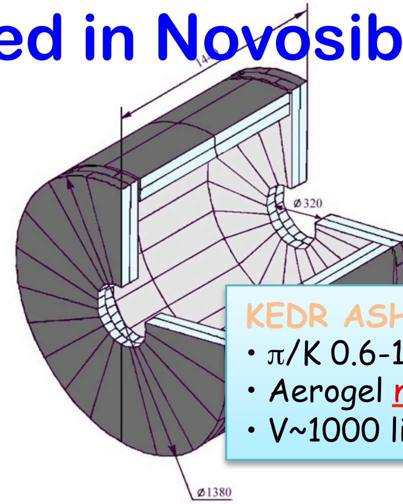
Application of aerogel produced in Novosibirsk



SND ASHIPH system
- π/K at 300-870 MeV/c
- Aerogel n=1.13
- V~9 liters



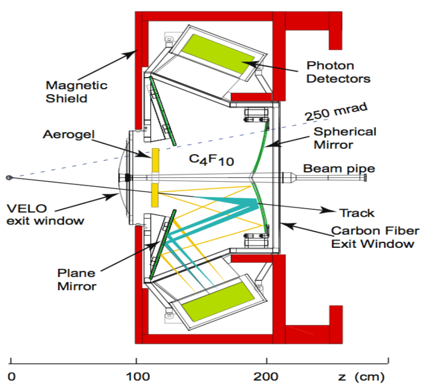
DIRAC-II (PS-CERN)
- Aerogel n=1.008
- π/K 5.5-8 GeV/c
- V~ 12 liters



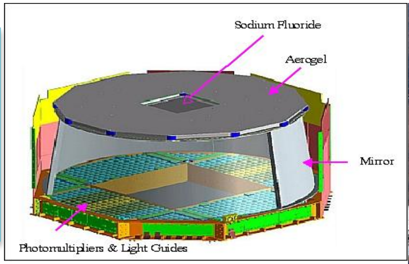
KEDR ASHIPH system
- π/K 0.6-1.5 GeV/c
- Aerogel n=1.05
- V~1000 liters

Produced in Novosibirsk:

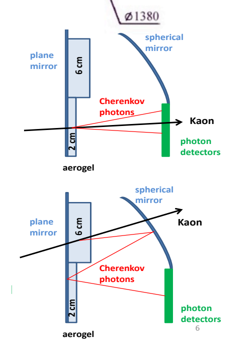
- >1000 l of aerogel for threshold ACC
- >6 m^2 of aerogel radiators for RICH counters

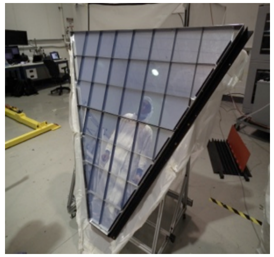


RICH1 LHCb (LHC-CERN)
- π/K 5.5-8.0 GeV/c
- Aerogel n=1.03; size 20x20x5 cm^3
- S ~ 0.5 m^2

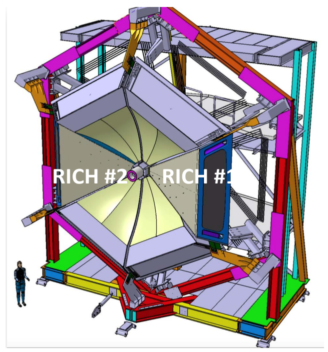


RICH of AMS-02 (ISS)
- Antimatter search & Cosmic rays study
- Aerogel n=1.05; S ~ 1 m^2

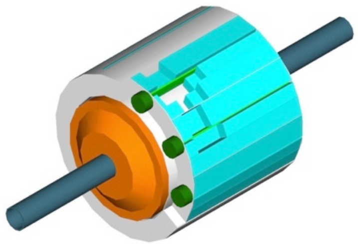


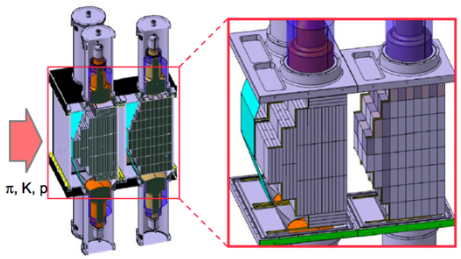


RICH CLAS-12 (J-Lab)
- $\pi/K/p$ at 4σ level up to few GeV/c
- Aerogel n=1.05
- S ~ 6 m^2

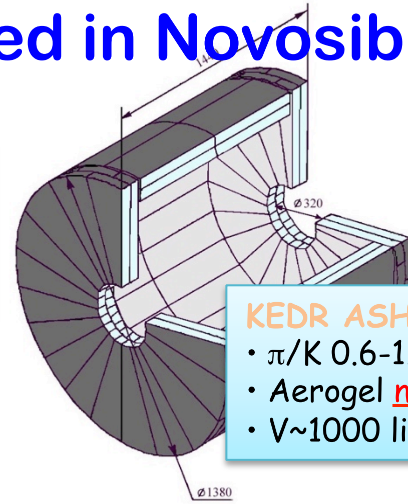


Application of aerogel produced in Novosibirsk



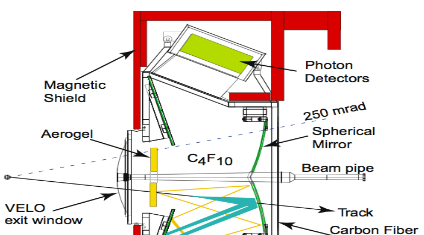


DIRAC-II (PS-CERN)
- Aerogel n=1.008
- π/K 5.5-8 GeV/c
- V~ 12 liters



KEDR ASHIPH system
- π/K 0.6-1.5 GeV/c
- Aerogel n=1.05
- V~1000 liters

SND ASHIPH system
- π/K at 300-870 MeV/c
- Aerogel n=1.13
- V~9 liters

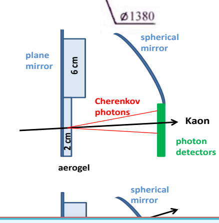


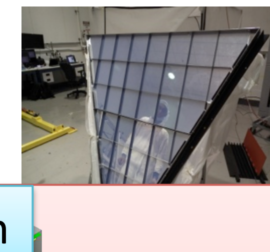
Produced in Novosibirsk:

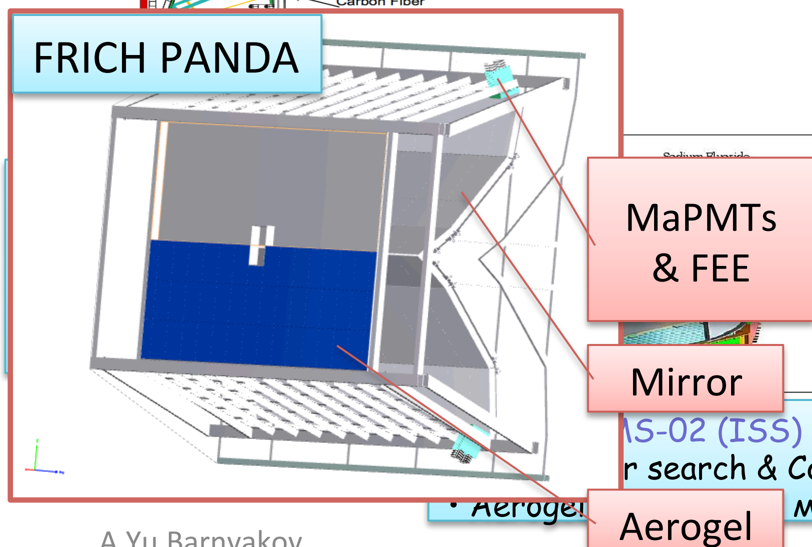
- >1000 l of aerogel for threshold ACC
- >6 m^2 of aerogel radiators for RICH counters

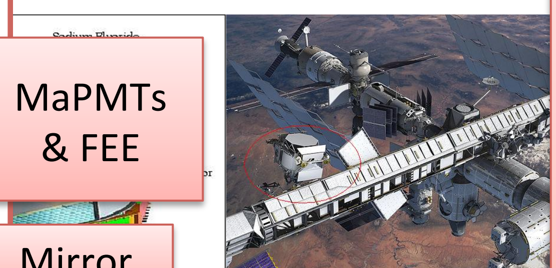
Future projects:

- ~20 m^2 for FARICH are needed

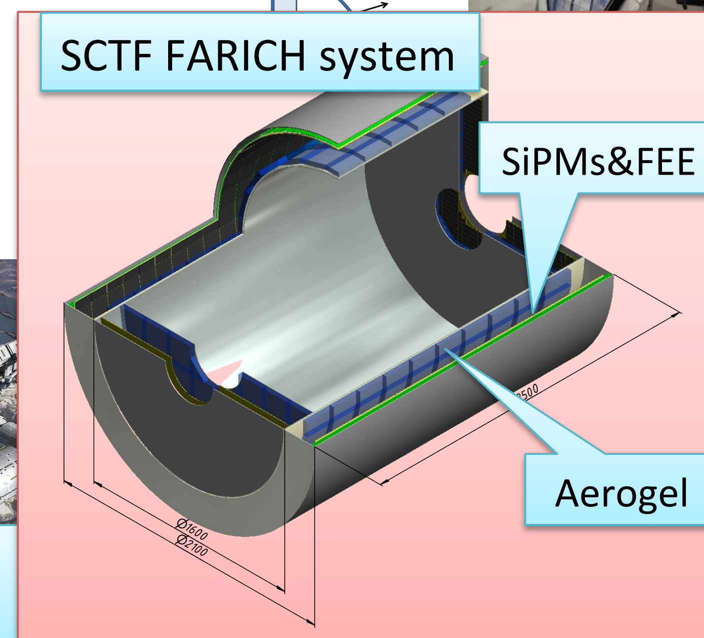






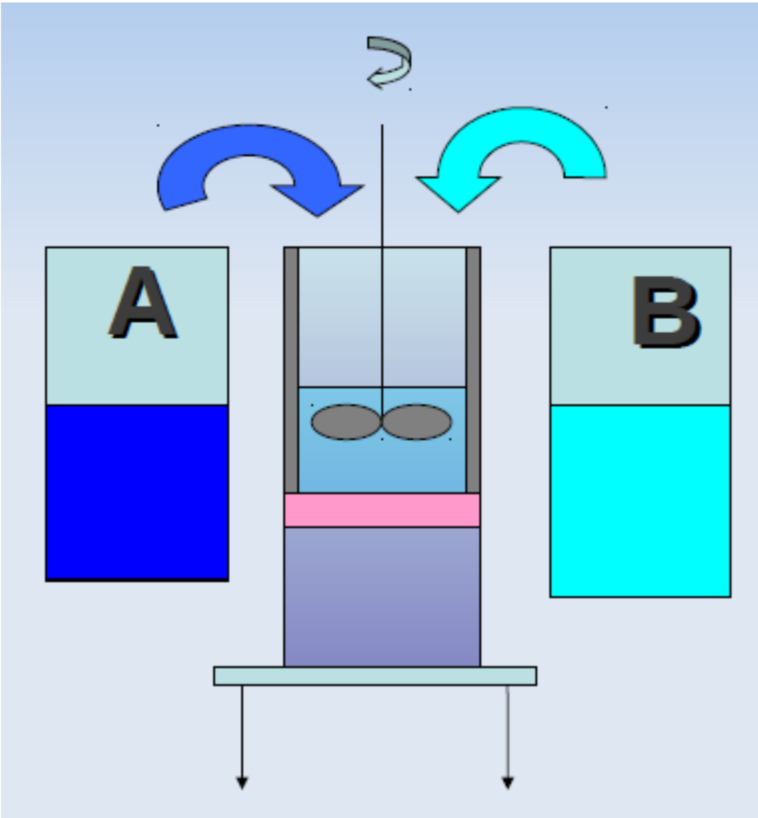


...S-02 (ISS)
...r search & Cosmic rays study
- Aerogel ... m^2



Addendum

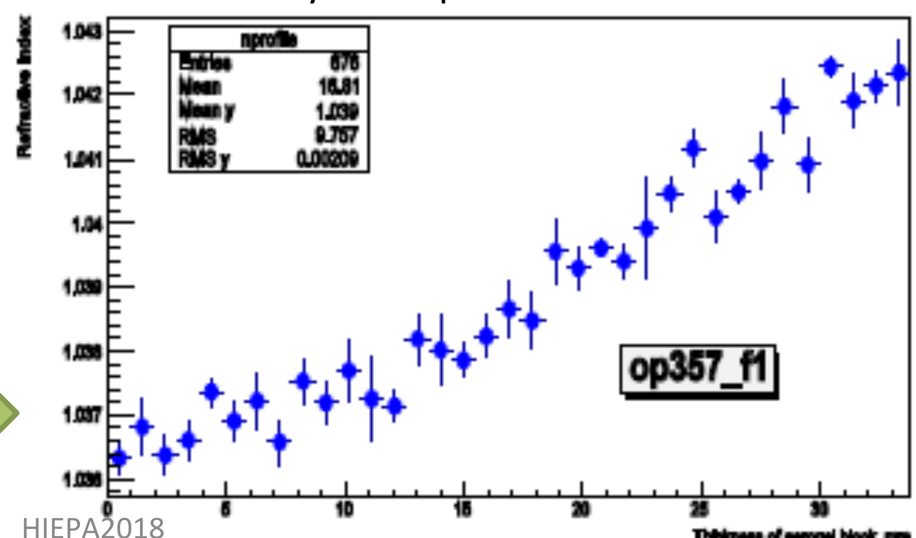
Continuous density gradient aerogel



To produce aerogel tiles with designed profile of gradient we modernized the method suggested by [S.M. Jones "A method for producing gradient density aerogel", J Sol-Gel Sci Technol. 44 (2007) 255]

- We mix two pre-prepared mixtures with different content of TEOS fed by peristaltic pumps from vessels A and B.
- The mixture with designed concentration of TEOS seeps through the filter to the mould where gelation takes place.
- The mould is positioned on the vertically moving table. The peristaltic pumps and moving table are controlled by a computer.

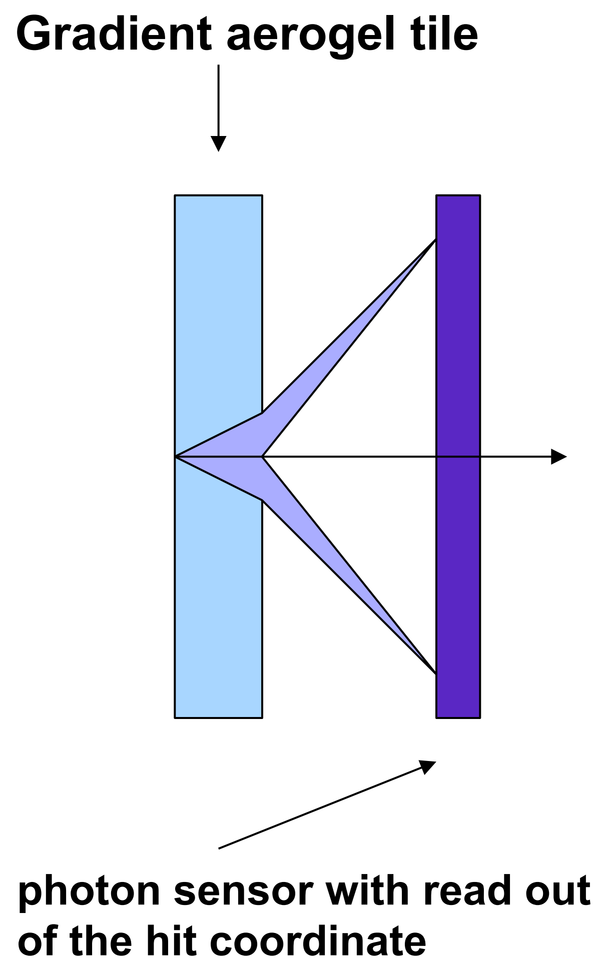
Refractive index profile along thickness



FARICH perspectives

For the proximity focusing RICH detectors there are 3 main contributions to the resolution: $\sigma_\Theta^2 = \sigma_{chr}^2 + \sigma_{geom}^2 + \sigma_{phot}^2$

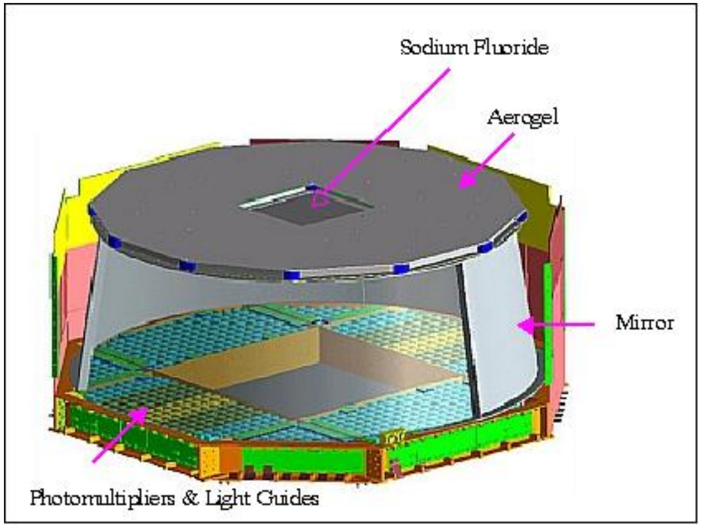
- Suggested technilogy of gradient aerogel tile production could give us radiators with $\sigma_{geom} << \sigma_{chr}$
- Philips Digital Photon Counting are working on the next version of the sensor which could read out the time and micro-cell number(instead of the number of fired cells)of the hit, $\sigma_{phot} \approx 20\ \mu m << \sigma_{chr}$
- **Could we build RICH with $\sigma_\Theta^2 \approx \sigma_{chr}^2$?**

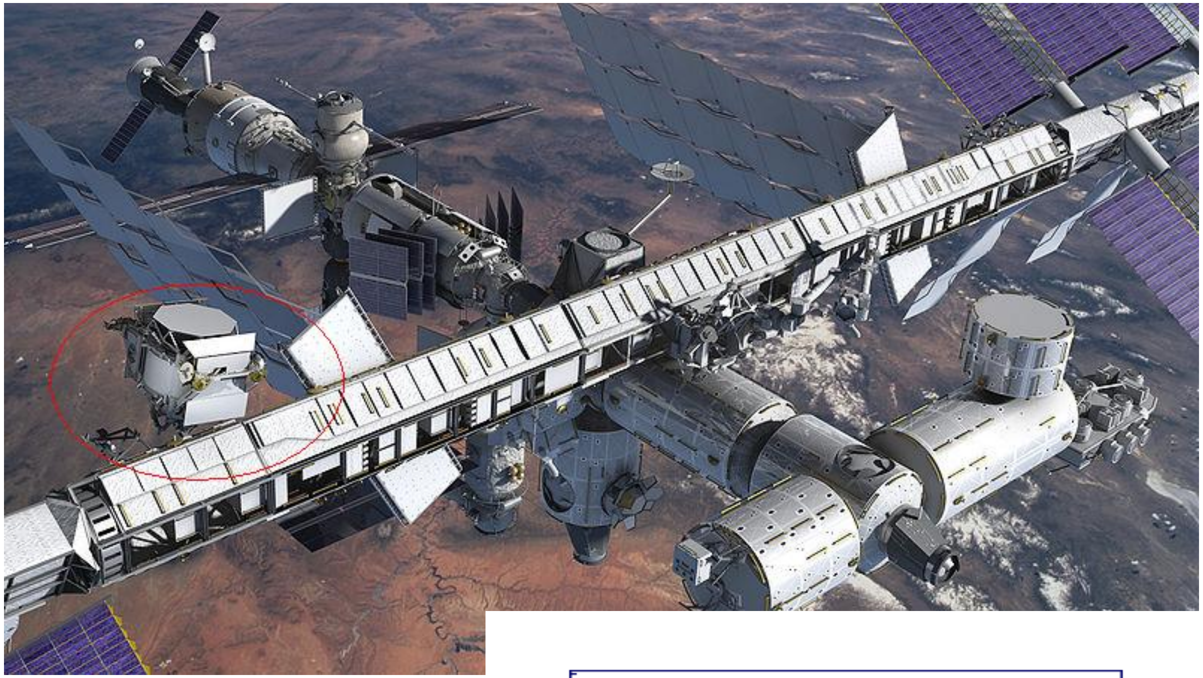


Summary

- Development of aerogel Cherenkov counters for HEP experiments have been carrying out in Novosibirsk since 1986 by BINP and BIC in close cooperation.
- The ASHIPH method for threshold Cherenkov counters was developed. Good π/K-separation was achieved in ASHIPH system of the KEDR detector and the SND dtector.
- Aerogel radiators for RICH detector of the AMS02 experiment were produced in Novosibirsk. Experimental number of photoelectrons and Cherenkov angle resolution are in good agreement with MC simulation. The AMS02 experiment has been operating since 2010 at ISS.
- Production of aerogel radiators with 200x200 transvers dimensions and high transparency for RICH of CLAS12 project is organized in Novosibirsk.
- Two projects of FARICH detectors for PANDA experiment and SCTF experiment are under development now.

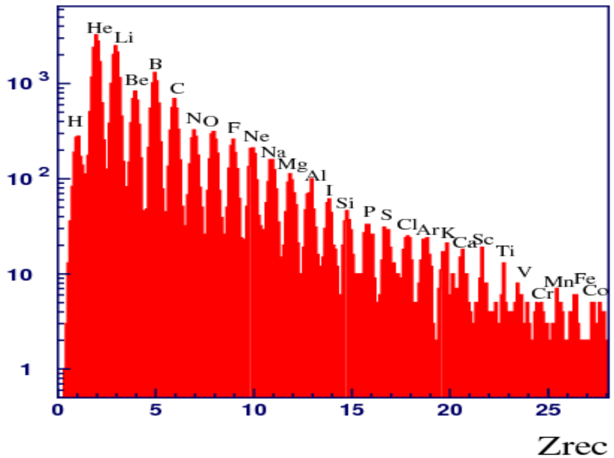
Aerogel RICH of AMS-02 at ISS





- Antimatter search
- Dark matter
- Cosmic rays
- Strangelets search
- …

M=8.5T, V=54m³, S=1m², B=1.26kGs
TOF, TRD, RICH, Si Tracker, eCal

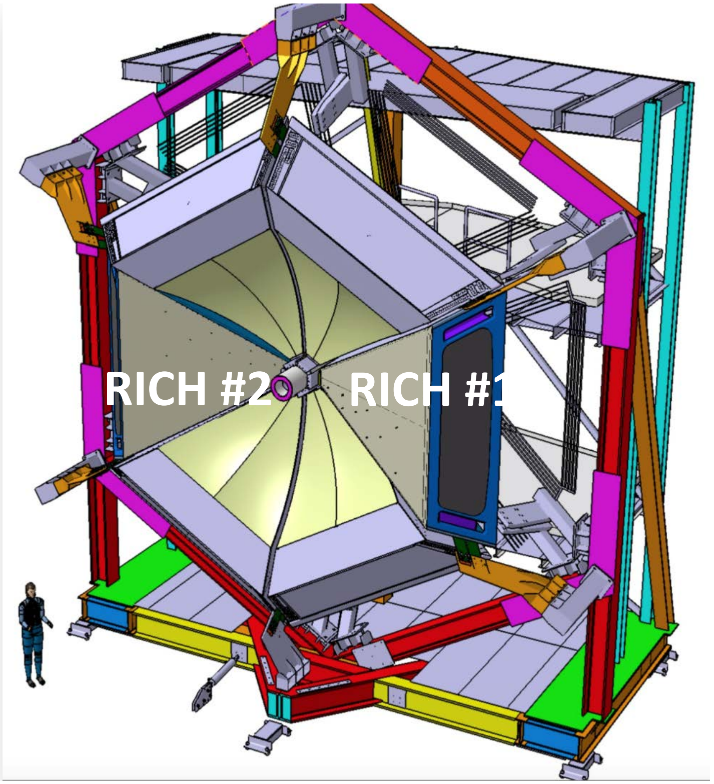


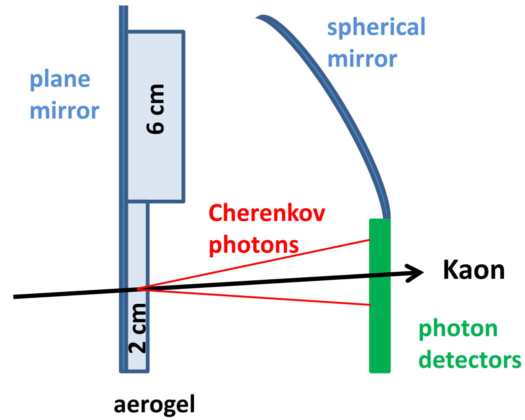
Measurement of Z of the nucleon, $N_{pe} \sim Z^2$

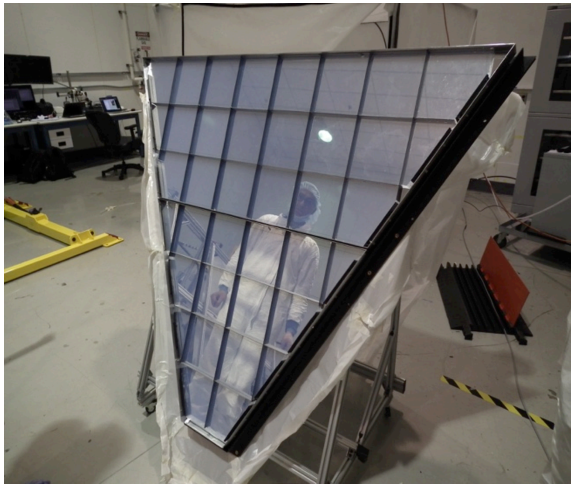
BIC/BINP production, n=1.05

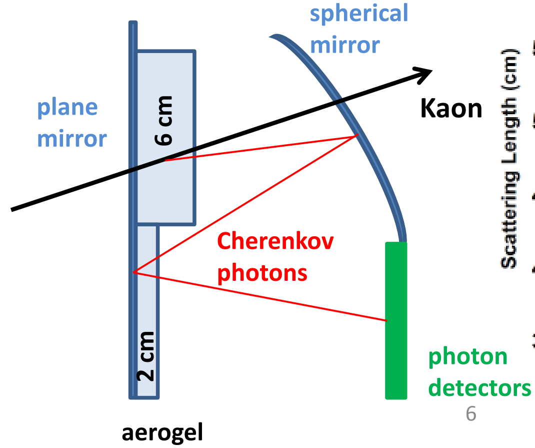
It has working at ISS since 2011

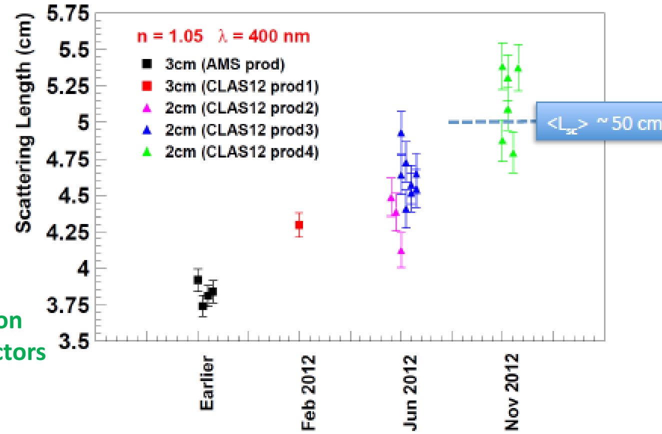
RICH detector for the CLAS12







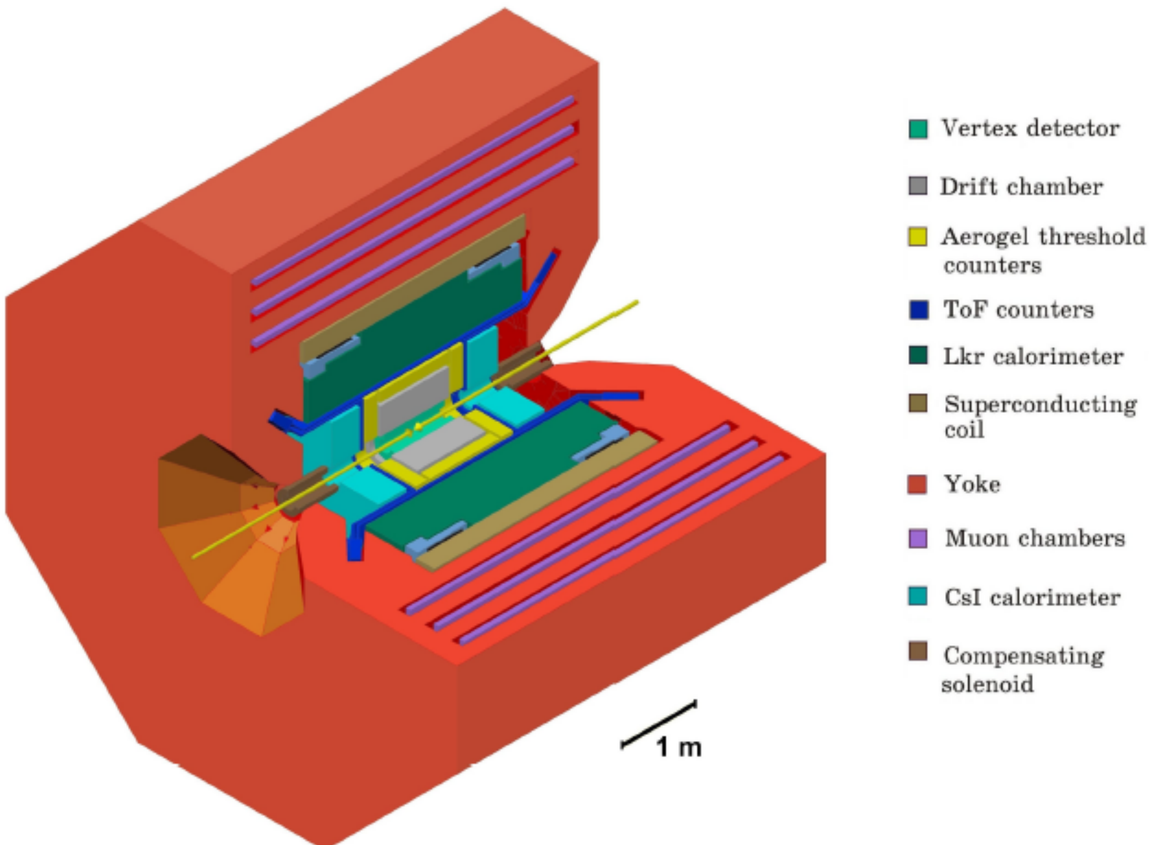




- **K/π** and **K/p** separation at **>4σ** level in **few GeV/c** region;
- The RICH will replace the existing LTC detectors;
- Installation in CLAS12 by **September 2017**;

RICH 2016, September 9th 2016, Bled: talks by M.Marazita, M.Contralbrigo, E.Kravchenko

KEDR experiment at VEPP-4M

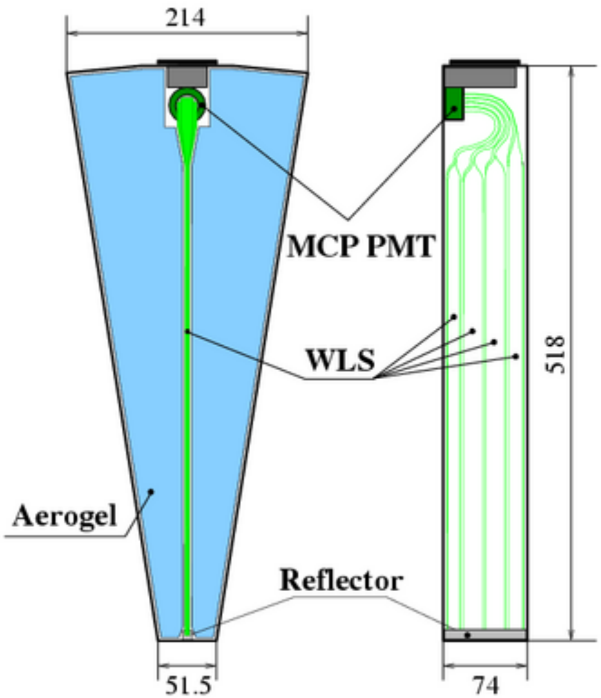


VEPP-4M
- Symmetric e^+e^- collider
- $E_{c.m.}$ = 2–10 GeV
- L = (1÷80) x 10^{30} $cm^{-2}s^{-1}$
- Precise energy calibration:
  RD: (5÷15)x10^{-6}
  CBS: 3x10^{-5}

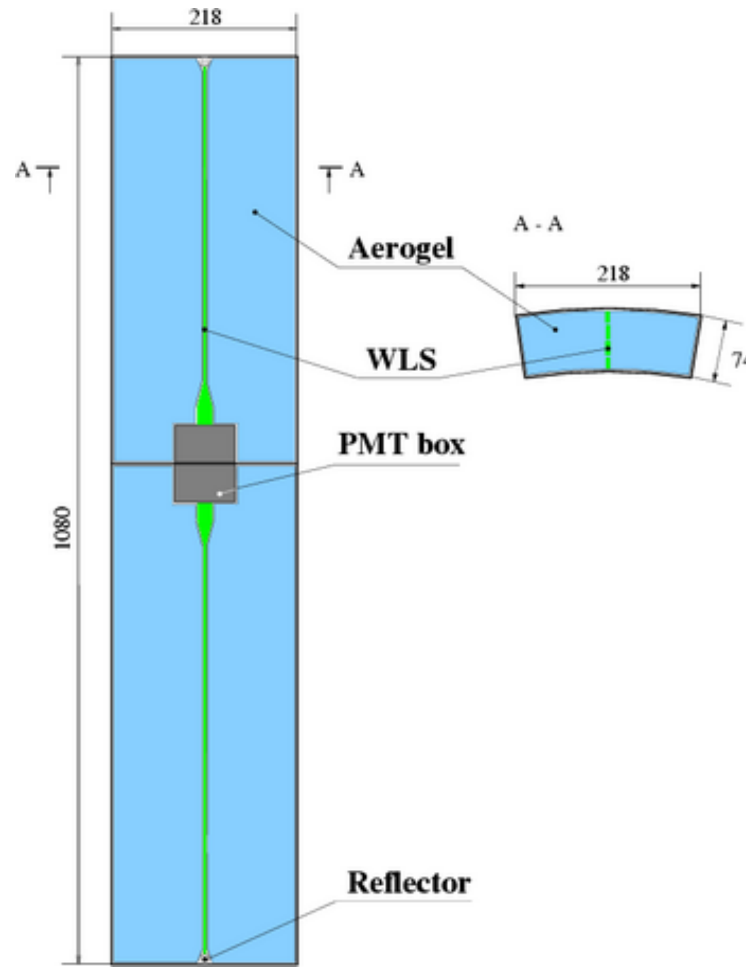
Physics program
- Precise particle mass measurements: *J/ψ, ψ*(2S), *ψ*(3770), *τ* lepton, *D* mesons, *Y* mesons
- Measurements of *ψ* and *Y* mesons lepton width
- R measurement in 2-10 GeV c.m. energy range
- γγ→*hadrons* and other 2γ processes
- Branching fractions measurements in charm and bottom quark systems (above 10^{-4})

KEDR ASHIPH counters

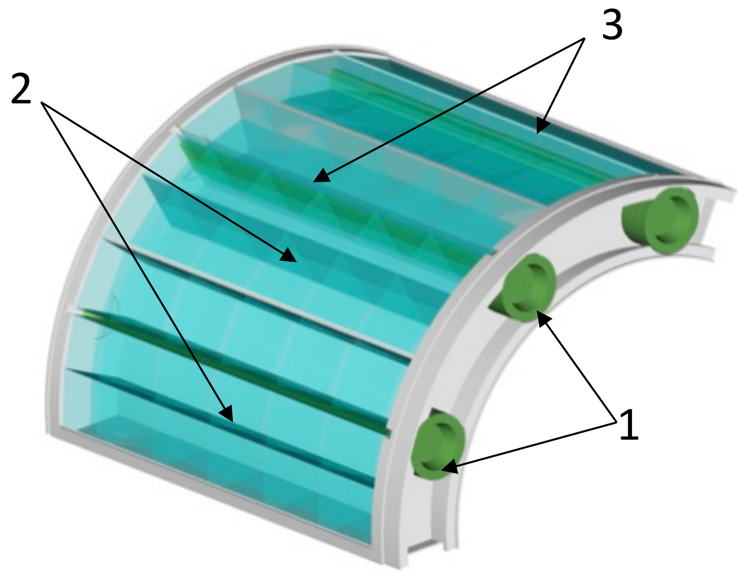
End-cap counter



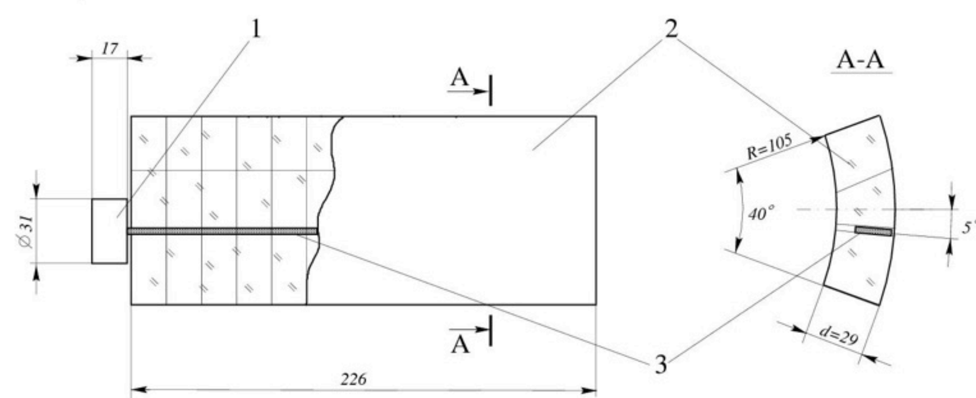
Barrel counter



Aerogel Cherenkov counters for SND



1 - PMT, 2 – aerogel, 3 - WLS



Outline

- π/K separation from 300 to 870 MeV/c
- Cylindrical shape: R=105÷141 mm
- Case material: 1mm of Al
- 3 segments of 3 counters in each
- Solid angle: ~60% of 4π
- Thickness: 0.09 X_o

Counter Design

- Scheme: ASHIPH
- WLS position: displaced by ~5° from counter center
- Aerogel thickness: ~30 mm

Aerogel parameters

- Refraction index: **n=1.13±0.01**
- Density: ρ=0.65 g/cm^3
- L_{sc}=19 mm at λ=400 nm
- L_{abs}=100 cm at λ=400 nm

What it is -- Aerogel?(2)

- Production method:
- Synthesis of the alcogel:
- $Si(OR)_4 + 2H_2O \Rightarrow SiO_2 + 4HOR$
- alkoxide water silica alcohol
- Supercritical drying in the autoclave to remove alcohol P_{max}=100 atm, T_{max}= 260°C
  - methanol -- P_{cr}=81 atm, T_{cr}=230°C
  - isopropanol -- P_{cr}=53 atm, T_{cr}=235°C
  - carbon dioxide -- P_{cr}=73 atm, T_{cr}=31°C

- Aerogel parameters:
- Density 0.003÷1.0 g/cm^3 *(fused silica ρ=2.2* g/cm^3 *)*
- Refractive index
- $n \approx 1 + 0.2 \cdot \rho[g/cm^3] \Rightarrow$
- (n = 1.0006 ÷ 1.2)
- Porosity 99.8%
- Inner surface 800 m^2/g

Era of high transparency aerogel

L.W.Hrubesh, T.M. Tillotson, J.F. Poco "*Characterization of ultralow-density silica aerogels made from a condensed silica precursor*", MRS Proc. 180(1990)315

- One-step technology
- Direct alcogel synthesis
- $Si(OR)_4 + 2H_2O \Rightarrow SiO_2 + 4HOR$
- alkoxide water silica alcohol
- $L_{sc}(400) \sim 20$ mm

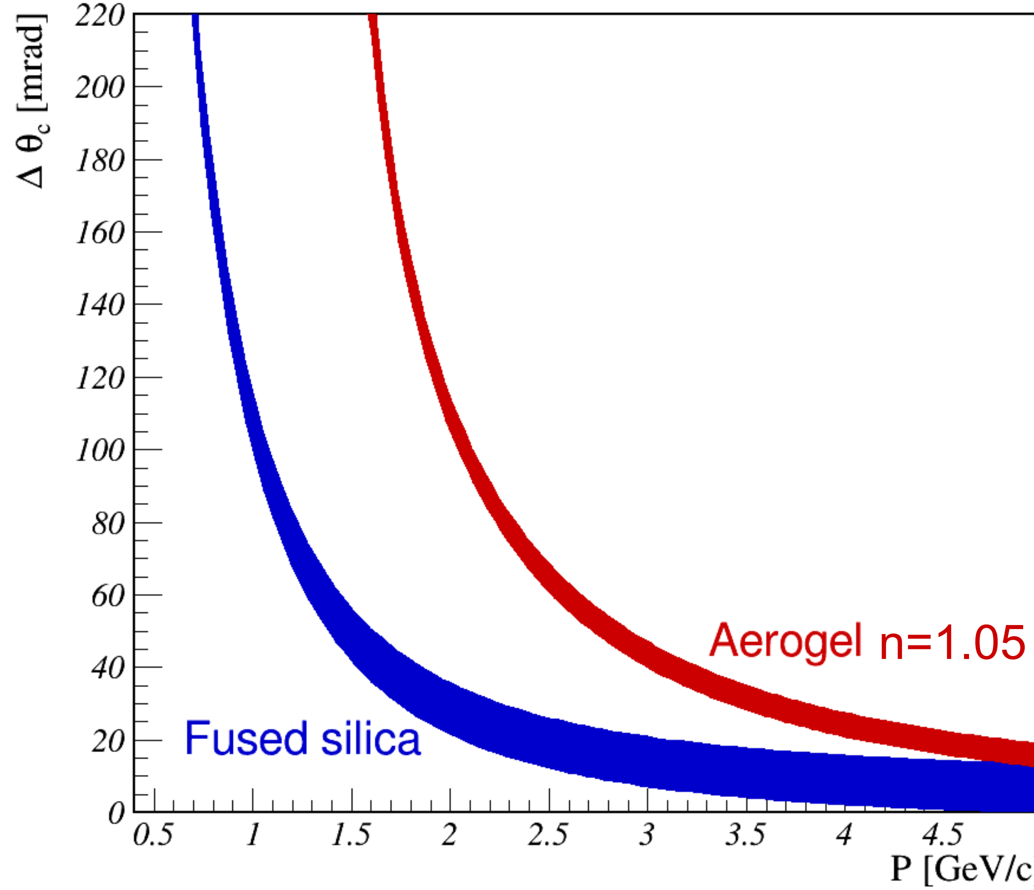
- Two-step technology
- A mixture of oligomers preparation
- $Si_kO_l(OR)_m(OH)_n \Rightarrow SiO_2$+alcohol
- $L_{sc}(400) > 35$ mm

Two-step technology was implemented at BIC in 1992

Quartz vs Aerogel radiators

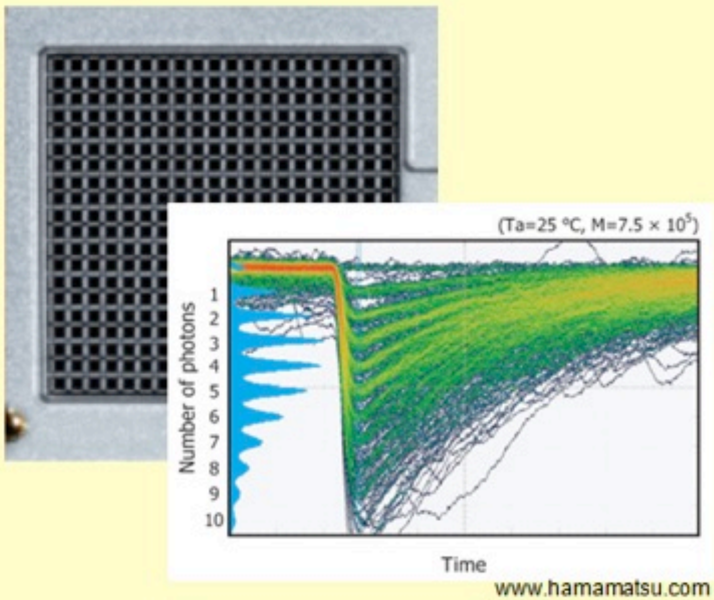
Difference in Cherenkov angle θ_c for π and K

Bands – chromatic dispersion in 350-700 nm



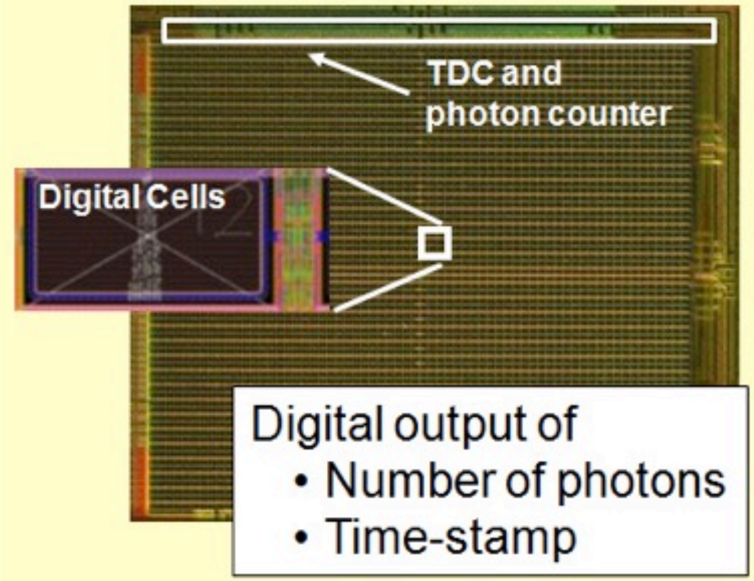
DPC: Front-end Digitization
by Integration of SPAD & CMOS Electronics
Philips Digital Photon Counting (PDPC)

analog SiPM



Summing all cell outputs leads to an analog output signal and limited performance

Digital Photon Counter (DPC)



Integrated readout electronics is the key element to superior detector performance

T. Frach, G. Prescher, C. Degenhardt, B. Zwaans, IEEE NSS/MIC (2010) pp.1722-1727
C. Degenhardt, T. Frach, B. Zwaans, R. de Gruyter, IEEE NSS/MIC (2010) pp.1954-1956