ASHIPH option for PID on future colliding beam experiments

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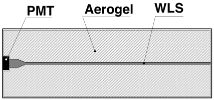
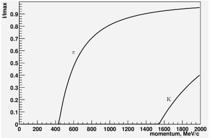
Table of Contents

ASHIPH method for particle identification





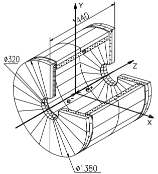
$$P_{thr} = \frac{mc}{\sqrt{n^2-1}}$$

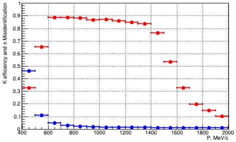
ASHIPH (Aerogel, SHifter, PHotomultiplier) method of light collection was suggested in 1992 (A. Onuchin et al. NIM A315, 1992, 517-520). Cherenkov light from particle in aerogel is collected by the wavelength shifter (WLS) placed in the middle of the counter and transported by WLS like a lightguide to photomultiplier (PMT):

- PMMA based light guide doped with BBQ dye is used as WLS
- This method helps us significantly to decrease the PMT photocathode area and material budget before a calorimeter

ASHIPH systems at the BINP (Novosibirsk):

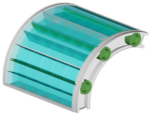
KEDR detector at VEPP-4M
e^+e^- collider (2E=2÷10 GeV)

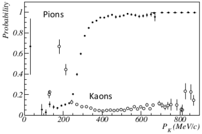




- 160 counters (2 layers), $0.97\times4\pi$
- Thickness ∼70 mm (1 layer)
- n=1.05 (1000 l)
- MCP PMT ⌀PC=18 mm

SND detector at VEPP-2000
e^+e^- collider (2E=0.3÷2 GeV)

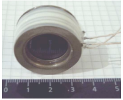


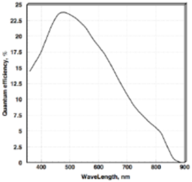


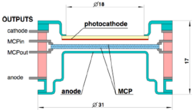
- 9 counters (1 layer, 9 l), $0.6\times4\pi$
- Thickness ∼30 mm
- n=1.13 (π/K-separation, $\sqrt{s}$ >1 GeV)
- n=1.05 (e/π-separation, $\sqrt{s}$ <1 GeV)
- MCP PMT ⌀PC=18 mm

ASHIPH upgrade: MCP PMT → SiPMs as photodetector

MCP PMT

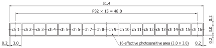


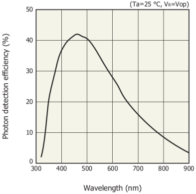




- Manufacturer: "Ekran FEP"(Novosibirsk)
- Borosilikate glass window
- Multialkali (Sb-Na-K-Cs) photocathode
- MCPs with channel diametr of 7 μm
- Maximum QE=23% at λ=500 nm
- Photoelectron collection coefficient ∼0.6
- PDE=QE*CE=23*0.6≃14%
- Axial magnetic field
- Power supply 3÷4 kV

MPPC (Multi-Pixel Photon Counter) S13363-3050NE-16



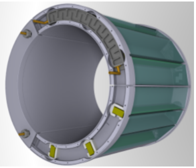


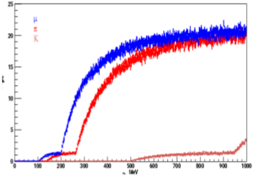
- Manufacturer: "Hamamatsu"
- Effective photosensitive area/channel 3×3 mm
- Number of cells/pixel 3584
- PDE=40% at λ=500 nm
- Any direction magnetic field
- Power supply <100 V (V_{BR}=53 V typ.)
- High level of DCR (0.5 Mcps)

Move to SiPMs must increase detected number of photoelectrons in 2.5 times!

ASHIPH-SiPM proposals for colliding beam experiments

ASHIPH for SND (VEPP-2000, Novosibirsk)



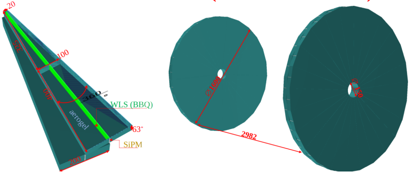


N_{pe} from parametric simulation

- 9 counters 26×10×3 cm^3 in 1 layer
- WLS(BBQ) 260×17×3 mm^3
- 5×9=45 SiPMs 3×3 mm^2
- Two system options: aerogel with n=1.13 and n=1.05 (thickness 3 cm)
- n=1.13 – $N_{pe}(\beta = 1) \approx 20$
  - π/K-separation $\geq 5\sigma$ – 0.3÷1 GeV/c (thr. ∼4ph.e.)
- n=1.05 – $N_{pe}(\beta = 1) \approx 10$
  - e/π-separation $\geq 4\sigma$ – 0.1÷0.4 GeV/c (thr. ∼3ph.e.)

Upgrade is already in progress!

ASHIPH for SPD (NICA, Dubna)

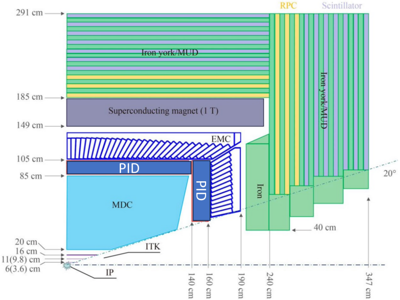


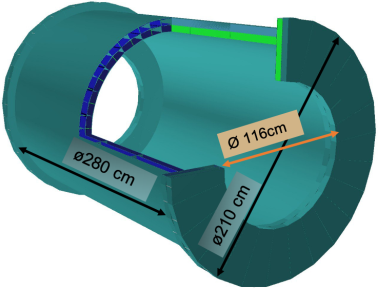
- 2 layers in two endcaps
- The layer consists of 25 identical sectors (trapezoid counters)
- The layers are rotated by φ relative to each other by half a period
- Counter contains two volumes with separate light collection:
  - small – closest to the collider axis
  - large – at a larger radius
- Aerogel: 6cm÷8cm/layer & n=1.02÷1.03
- $N_{pe}^{\Sigma}(\beta = 1) \approx 16 \div 20$
- π/K-separation:
  - $\geq 4\sigma$ – 0.7÷2.5 GeV/c (thr. 3 ph.e.)

Considered as an option!

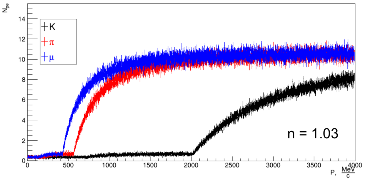
ASHIPH-SiPM proposals for colliding beam experiments

ASHIPH system proposal for STCF (Hefei, China)





- Aerogel in two layers: 6cm+6cm & n=1.03
- 200 counters in barrel, 100 in endcap
- π/K-separation up to 5σ (0.7÷2.5 GeV/c)



For future colliding 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)

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

Considered as an option!

ASHIPH-SiPM prototypes

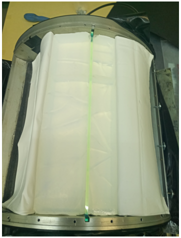
Two types of ASHIPH-SiPM prototypes were created:

- Small ⇒ similar in sizes to the ASHIPH counter for SND and SPD experiments
- Big ⇒ similar in sizes to the ASHIPH counter for SPD and STCF experiments

Main goals:

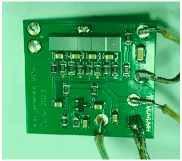
- To test light collection uniformity
- To test and chose WLS dye:
  - BBQ (τ=15 ns)
  - NOL-1 (τ=0.7 ns)
- To test and chose SiPMs
  - Hamamatsu
  - NDL
  - JoinBon and ...
- To test and develop FEE
- To test π/K-separation and chose aerogel

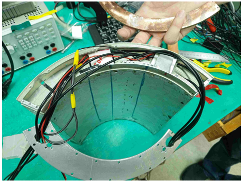
The small ASHIPH-SiPM prototype



- The segment of the SND detector ASHIPH system are used
- The segment consist of three separate counters:
  - Two counters from the segment were used:
    - 1st counter: Aerogel with n=1.05, thickness 30 mm
    - 2nd counter: Aerogel with n=1.12, thickness 25 mm (counter not fully filled up to 30 mm)
- Counter dimensions: R=105÷141 mm, length 260 mm, width 80 mm
- WLS position: displaced by $\sim 5^{\circ}$ from counter center
- Aerogel cover: teflon with a refractivity of R∼98%
- A line of 5 SiPMs allows cover a WLS with sizes 17x3 mm^2
- Series connection of 5 SiPMs with parallel distribution of bias voltage

Status and R&D of ASHIPH-SiPM option for PID, Int.J.Mod.Phys.A 39 (2024)



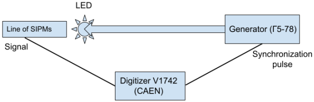


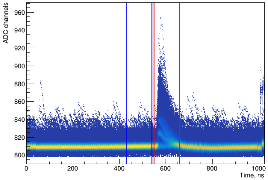
Temperature stabilization system

- Platinum temperature sensor on the electronics board (SMD0805V Pt1000)
- Thermoelectric Peltier Module (30×30 mm)
- Air copper radiator

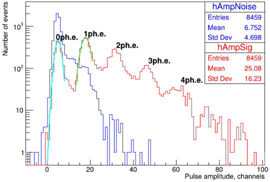
Temperature stabilisation at 15°C on SiPMs in case of external temperature 45°C is achieved

SiPM calibration





Distribution of maximum pulse amplitude



$A_{1ph.e.}$ – from the distance between the peaks

$$N_{ph.e.} = (A_{sig} - Aped)/A_{1ph.e.}$$

The number of photoelectrons is described by the Poisson distribution for small LED level:

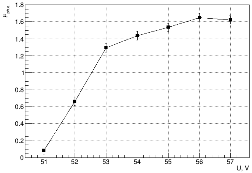
$$P(n,\mu) = \frac{e^{-\mu}}{n!}\mu^n, \quad \mu = -lnP(0,\mu),$$

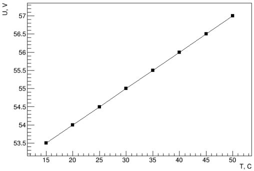
where n – number of photoelectrons, μ – average number of photoelectrons.
Probability of missing photoelectron:

$$P(0,\mu) = \frac{N^{sig}_{ped}}{N^{sig}} \cdot \frac{N^{noise}}{N^{noise}_{ped}},$$

where N^{sig} – total number of events in the signal spectrum,
N^{noise} – total number of events in the noise spectrum,
N^{sig}_{ped} – number of events in the pedestal of the signal spectrum,
N^{noise}_{ped} – number of events in the pedestal of the noise spectrum.

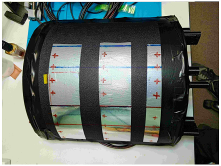
T=15°C

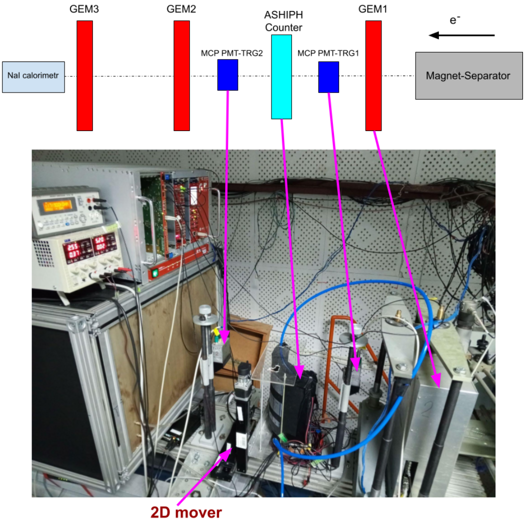




Testing the small ASHIPH-SiPM prototype at electron beam

- Beam test facilities at the BINP, electron energy – 2.5 GeV;
- Tracking based on 3 coordinate GEM detectors (σ_x=50 μm, σ_y=50 μm) and NaI calorimeter;
- The trigger is formed from the coincidence of two counters based on a MCP-PMT;
- The signals from the counters and the prototype are digitized by V1742 CAEN;
- ~50000 events were collected in each of 12 different geometric areas of the counter at temperatures 15°C and 45°C, and at different bias voltages on the SiPMs.

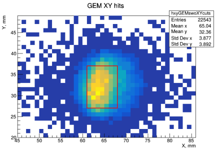




Testing the small ASHIPH-SiPM prototype at electron beam (T=15°C)

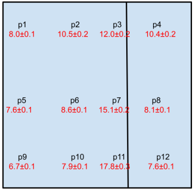
Prototype of the ASHIPH counter with n=1.05 aerogel

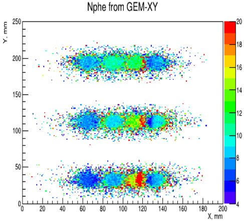
The number of photoelectrons at different geometric points of the counter

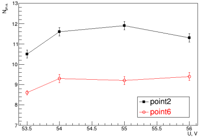


61<x<68; 27<y<37

U=53.5 B





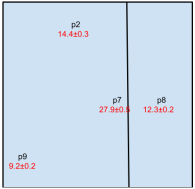


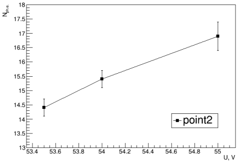
- Average number of photoelectrons per counter $N_{ph.e.} \simeq 8.6$ ((p2+p9)/2)
- Inhomogeneity of light collection is $\sim \pm 22\%$

Prototype of the ASHIPH counter with n=1.12 aerogel

- The prototype is not completely filled with aerogel (up to 30 mm), the thickness is 25 mm
- ASHIPH with MCP PMT the SND detector contains aerogel with n=1.13

U=53.5 B





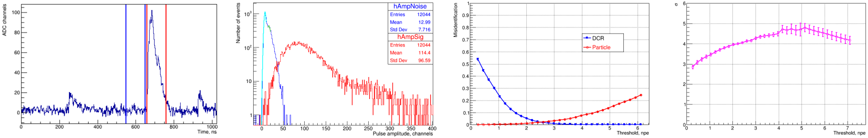
- Average number of photoelectrons per counter $N_{ph.e.} \simeq 11.8$
  - For aerogel with n=1.13, 30 mm $N_{ph.e.} \simeq 11.8 \times 1.3 = 15.3$ is expected
- Inhomogeneity of light collection is $\sim \pm 22\%$

Testing the small ASHIPH-SiPM prototype at electron beam

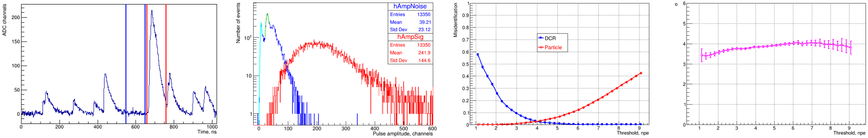
- **Subthreshold efficiency is mainly determined by own DCR of the SiPMs**
  - Other sources:
    - Cherenkov light from δ-electrons in aerogel
    - Scintillations in teflon
    - Cherenkov light in teflon

Prototype of the ASHIPH counter with n=1.05 aerogel

T=15°C, U=53.5 V, point p2



T=45°C, U=57 V, point p2

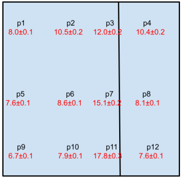


$$K[\sigma] = \sqrt{2} * (\mathrm{erf}^{-1}(1 - 2\varepsilon_K) + \mathrm{erf}^{-1}(1 - 2 * (1 - \varepsilon_\pi)))$$

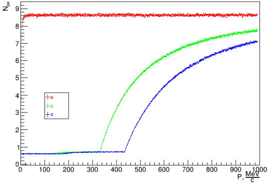
Comparison of the quality of separation of ASHIPH-MCP and ASHIPH-SiPM

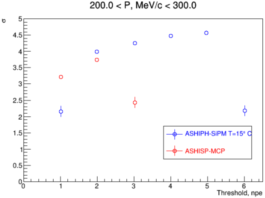
Prototype of the ASHIPH counter with n=1.05 aerogel

Maps with inhomogeneity of light collection



Average in points p2 и p9



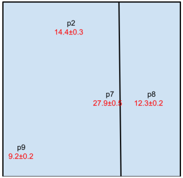


e/π separation

Test results of the threshold aerogel Cherenkov counter system with n=1.05 using electrons and muons at p<500 MeV/c, JINST 9 C08010, 2014

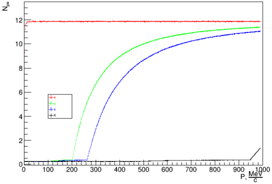
Prototype of the ASHIPH counter with n=1.13 aerogel

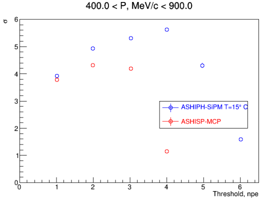
Maps with inhomogeneity of light collection



n=1.12

Average in points p2 и p9

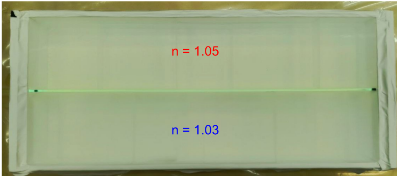


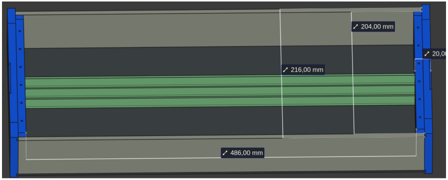


π/K separation

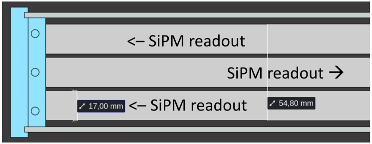
Particle identification system based on dense aerogel, NIMA 732 (2013) 330–332

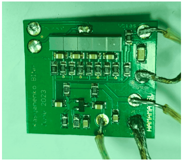
The big ASHIPH prototype



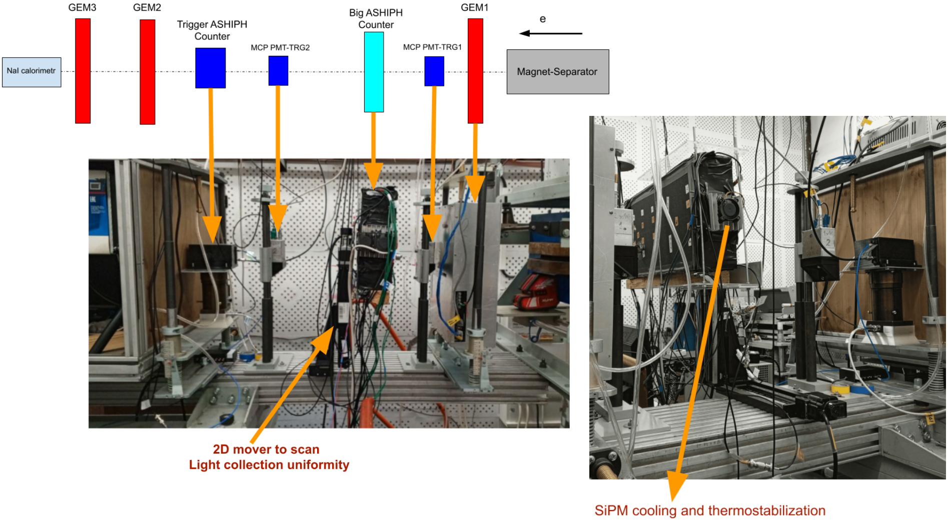


- Rectangular shape 50×22×64 cm
- Two types of aerogels – with n=1.03 and n=1.05 for different halfs the volume
- Aerogel blocks have a size 100×100×60 mm
- 3 WLS plates based on Plex with BBQ dope, endcap size is 17×3 mm
- 3 arrays of 5 SiPMs each were made from MPPC S13365-3050NE-16 (Hamamatsu) – same as for small ASHIPH prototype





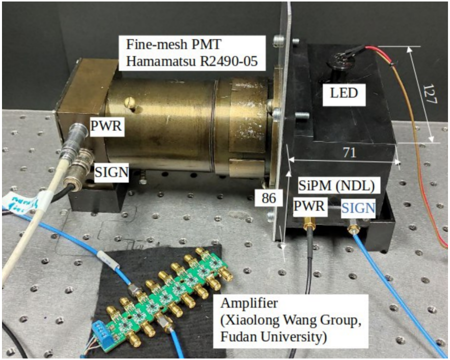
Testing the big ASHIPH prototype at electron beam



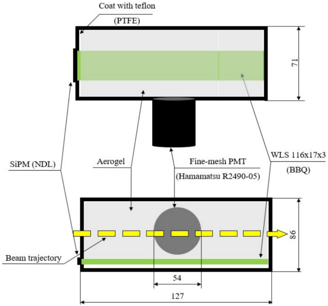
- 3 channels of V1742 (CAEN) degitizer are used to readout SiPMs
- T=15°C on SiPMs during data acquisition
- ∼50000 events were collected in each of 11 different geometric areas of the counter

Trigger ASHIPH counter

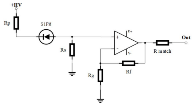
Several functions – Trigger counter, WLS and SIPMs test stand



Aerogel with n=1.008

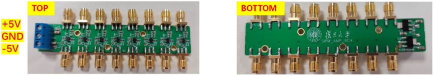


PreAMP



Gain: +20 V/V
1000V/A
Bandwidth(-3dB): 400 MHz
Baseline noise(RMS): 300uV
Output impedance: 50Ω

SiPM preamplifier(8-channel)



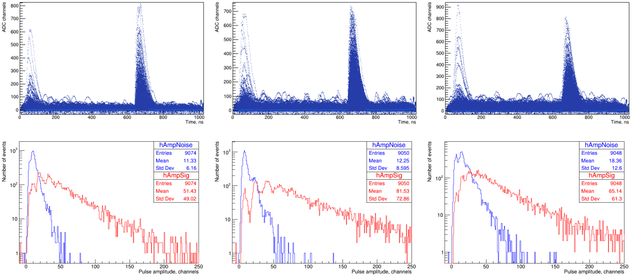
For more information see : https://link.springer.com/article/10.1007/s41365-023-01328-7

Testing the big ASHIPH prototype at electron beam

Bias voltages on the SiPMs: $U_1 = 56\ V$, $U_2 = 56\ V$, $U_3 = 57\ V$ (for p11, p15: $U_1 = 57\ V$, $U_2 = 57\ V$, $U_3 = 57\ V$)

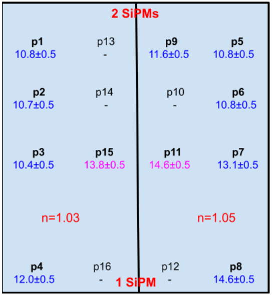
Distributions for Point 1

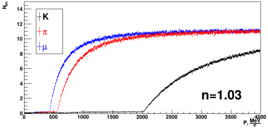
SiPM1 SiPM2 SiPM3

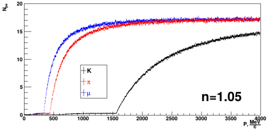


$N1_{ph.e.}$=2.4 $N2_{ph.e.}$=4.8 $N3_{ph.e.}$=3.6

Total $N_{ph.e.} = N1_{ph.e.} + N2_{ph.e.} + N3_{ph.e.} = 10.8$

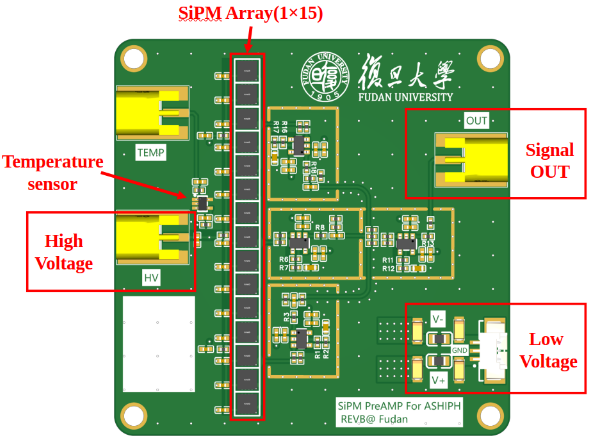


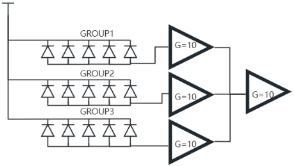


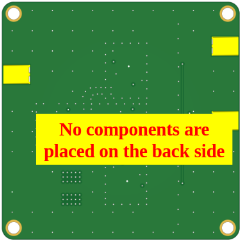


- Good agreement between measurements and estimations for relativistic particles is demonstrated with aerogel n=1.03
- Some disagreement with aerogel n=1.05 could be explained by worse aerogel optical parameters
  - the procedure for annealing the aerogel was not followed!

Next step: 3 lines of 5 SiPMs (three WLS are readout) $\Rightarrow$ 1 line of 15 SiPMs (one WLS bar is readout)







Xiyang Wang for Fudan University group

Summary

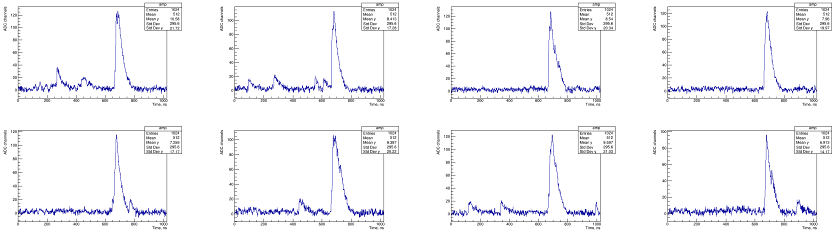
- The ASHIPH technique of Cherenkov light collection was developed in BINP
- Upgrade ASHIPH method is suggested $\Rightarrow$ SiPMs as photodetector
- ASHIPH-SiPM proposals for colliding beam experiments are presented
  - Upgrade of ASHIPH system for the SND experiment is on going now
  - PID systems based on ASHIPH counters with SiPM were proposed for STCF (USTC, Hefei) and SPD-NICA (JINR, Dubna) projects to provide reliable π/K-separation up to 3 GeV/c.
- The small and big the ASHIPH-SiPM counter prototypes were constructed for tests
- Good agreement of estimated and measured light collection in prototypes was demonstrated at the beam test at the BINP

Thank you for your attention!

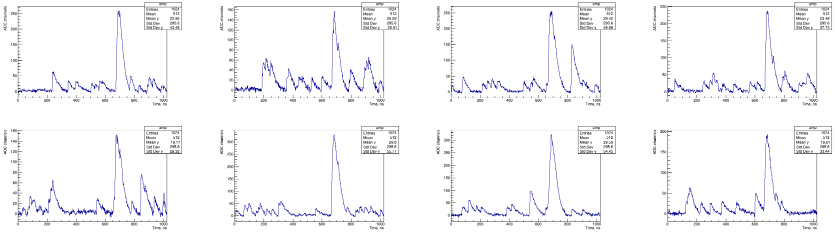
BACKUP

Testing the small ASHIPH-SiPM prototype on electron beam

Typical waveforms at T=15°C



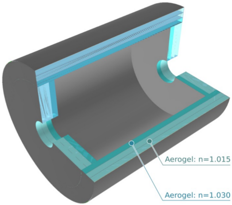
Typical waveforms at T=45°C

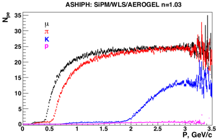


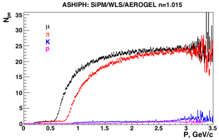
ASHIPH-SiPM proposals for colliding beam experiments

Under consideration!

ASHIPH for Super Charm-Tau Factory (Sarov, Russia)	**ASHIPH for VEPP-6 (Novosibirsk, Russia)**

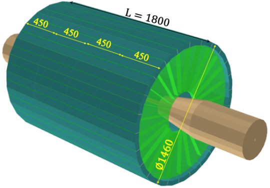


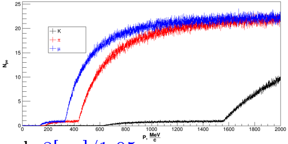




- Aerogel in three layers (6000 l): n=1.03 (8 cm) and n=1.015 (8+8 cm)
- 1400 counter with sizes ~18×30×8 cm^3
- Amount of material ~15%X_0
- Light collection – WLS(BBQ) and 28000 SiPMs 3×3 mm^2
- π/K-separation: 0.5÷2 GeV/c
- μ/π-separation: 0.4÷0.9 GeV/c

EPJ Web of Conferences 212, 01012 (2019), A.Yu. Barnyakov et al 2020 JINST 15 C04032



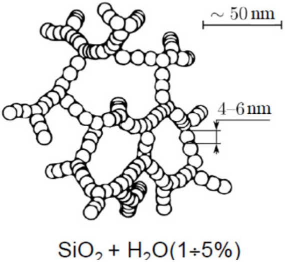


- Aerogel: 8[см]/1.05
- $N_{pe}^{\sum}(\beta = 1) \approx 20$
- 300 counters 45×17×4 cm^3 in two layers
- WLS – BBQ 45×20×3 mm^3
- (6÷12)×300=1800÷3600 SiPMs 3×3 mm^2
- π/K-separation:
  - $\geq 4\sigma$ – 0.5÷1.5 GeV/c (thr. 5 ph.e.)
  - $\geq 2.5\sigma$ – 1.5÷2.0 GeV/c (thr 10 ph.e.)

Aerogel

S.S.Kistler, "Coherent Expanded Aerogels and Jellies", Nature, 1931,vol. 127, p. 741.

- Aerogel – porous silicon dioxide (SiO_2) with a refractive index in the range between gases on the one hand and solids and liquids on the other
- Main manufacturers for HEP: Institute of Catalysis SB RAS (Novosibirsk) и Matsushita (Japan)
- Refractive index $n^2 = 1 + 0.438 \cdot \rho$
  - n=1.006...1.070 – synthesis
  - n=1.070...1.130 – sintering + synthesis
- An important parameter is the scattering length of light
  - $L_{sc} \approx 5$ sm at 400 nm, $L_{sc} \sim \lambda^4$
- Aerogel block size up to 200×200×50 mm (IC SB RAS)



Aerogel – number of photons

$$n\uparrow\Big|_{470°C}^{600\,°C} \qquad \frac{d^2N}{dxd\lambda} = 2\pi z^2 \sin^2\Theta(\lambda)\frac{1}{\lambda^2}$$

$$L_{sc}\downarrow\Big|_{470°C}^{600\,°C} \qquad N_{pe} = a_0\frac{L_{sc}(\lambda)}{d}\left(1 - e^{-\frac{d}{L_{sc}(\lambda)}}\right)$$

$$\frac{N_{pe}^{n=1.029}}{N_{pe}^{n=1.028}}\Bigg|^{d=40\ mm} = 1.04; \qquad \frac{N_{pe}^{L_{sc}=42}}{N_{pe}^{L_{sc}=48}}\Bigg|^{d=40\ mm} = 0.95;$$

$$\frac{N_{pe}^{600\,°C}}{N_{pe}^{470°C}}\Bigg|_{exp}^{40\ mm} = \frac{8.22}{7.11} \approx 1.15;$$

$$\frac{\frac{N_{pe}^{600\,°C}}{N_{pe}^{470°C}}\Big|_{exp}^{40\ mm}}{\frac{N_{pe}^{n=1.029}}{N_{pe}^{n=1.028}}\Big|^{d=40\ mm} \times \frac{N_{pe}^{L_{sc}=42}}{N_{pe}^{L_{sc}=48}}\Big|^{d=40\ mm}} = 1.16$$

$$\frac{N_{pe}^{n=1.029}}{N_{pe}^{n=1.027}}\Bigg|^{d=50\ mm} = 1.07; \qquad \frac{N_{pe}^{L_{sc}=41}}{N_{pe}^{L_{sc}=44}}\Bigg|^{d=50\ mm} = 0.97;$$

$$\frac{N_{pe}^{600\,°C}}{N_{pe}^{470°C}}\Bigg|_{exp}^{50\ mm} = \frac{8.05}{7.12} \approx 1.13;$$

$$\frac{\frac{N_{pe}^{600\,°C}}{N_{pe}^{470°C}}\Big|_{exp}^{50\ mm}}{\frac{N_{pe}^{n=1.029}}{N_{pe}^{n=1.027}}\Big|^{d=50\ mm} \times \frac{N_{pe}^{L_{sc}=41}}{N_{pe}^{L_{sc}=44}}\Big|^{d=50\ mm}} = 1.09$$

Some systematical increase of N_{pe} (~10÷15%) are observed in new thick aerogels after increase of backing temperature (470˚C -> 600˚C). This effect could not be quantitively explained by increase of refractive indexes (1.027 -> 1.029) and it is contra to N_{pe} decrease (~5÷6%) expected due to Rayleigh light scattering decrease ($L_{sc}(400nm, 1.027) \approx 47mm \rightarrow Lsc(400nm, 1.029) \approx 41mm$).

Higher temperature baking causes the length of light absorption (L_{abs}) to increase?

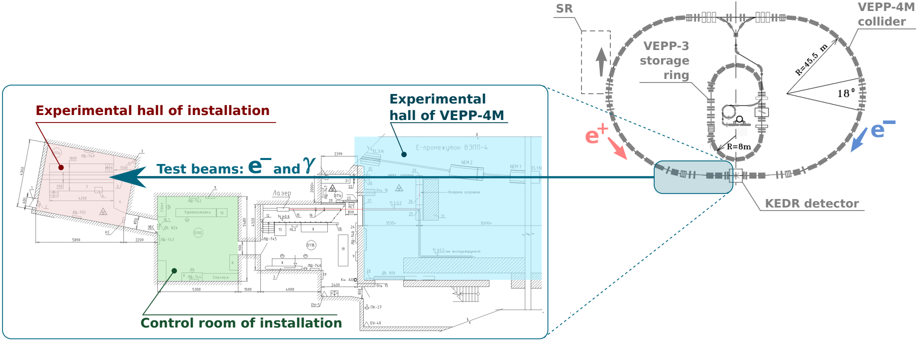
Various options are discussed on how to “remove” light-absorbing impurities without raising the temperature, that is, without sintering the aerogel, and thus without losing transparency due to Rayleigh scattering. 1

Beam test facilities at BINP

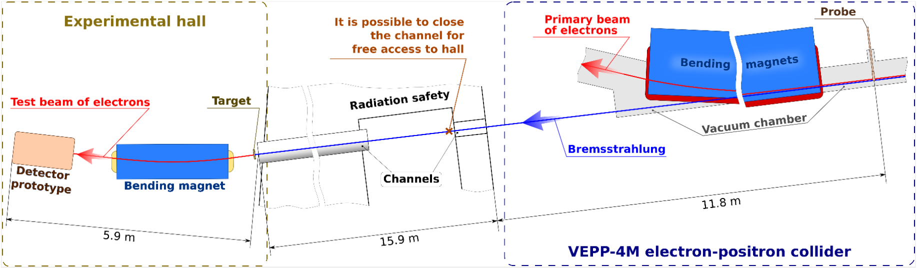
VEPP–4M electron–positron collider is used to provide γ- and electron- beams.

VEPP–4M main parameters:

- Perimeter 366 m;
- Beam energy 1÷5.5 GeV;
- Number of bunches 2×2;
- Luminosity 10^{30} $cm^{-2} \cdot s^{-1}$ for E_{beam}=1.5 GeV.



Beam test facilities at BINP



- A special probe is moved into the halo of a primary electron beam of the VEPP–4M collider for generation of Bremsstrahlung gammas.
- These gammas are converted to electron – positron pairs on a lead target at the entrance to the experimental hall.
- Electrons with a certain momentum are selected using a bending magnet.

The beam parameters:

- Energy range 0.1÷3.5 GeV;
- Intensity 50÷100 Hz;
- Energy spread 7.8% for 0.1 GeV and 2.6% for 3.0 GeV.