Particle detection efficiency of the KEDR detector ASHIPH system

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Outline:

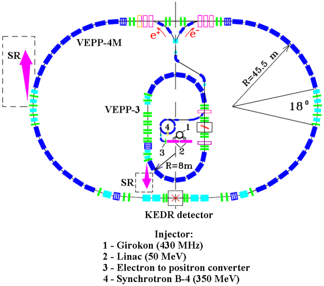
1 August, RICH-2018

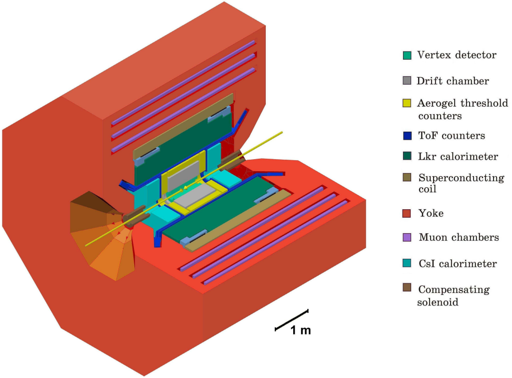
VEPP-4M collider and KEDR detector

- 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 energy measurement:

- Resonant depolarization technique:
  Instant measurement accuracy $\simeq 1 \times 10^{-6}$
  Energy interpolation accuracy $(5\div15)\times10^{-6}$(10÷30 keV)
- Infra-red light Compton backscattering:
  Statistical accuracy $\simeq 5 \times 10^{-5}$ / 30 minutes
  Systematic uncertainty 3×10^{-5}(50÷70 keV)

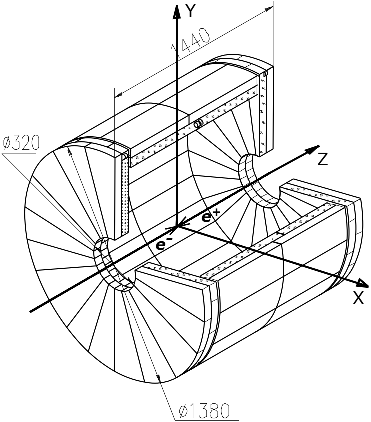


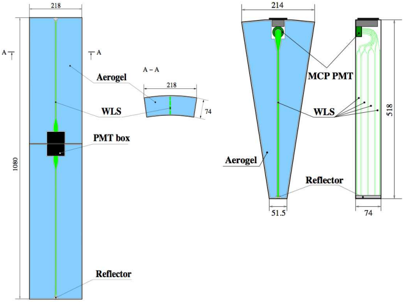


ASHIPH method

- In 1988 the first project of aerogel Cherenkov threshold counters for the KEDR detector with direct light collection was suggested (A. Onuchin et al., World Scientific, 1990, 208-213)
- ASHIPH (Aerogel, SHifter, PHotomultiplier) method of light collection was suggested in 1992. Cherenkov light from 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) (A. Onuchin et al. NIM A315, 1992, 517-520)
  - This method helped us significantly to decrease the PMT photocathode area (cost of the system)
- The fully installed particle identification system of ASHIPH counters began its operation at the KEDR detector in 2014

The ASHIPH system of the KEDR detector

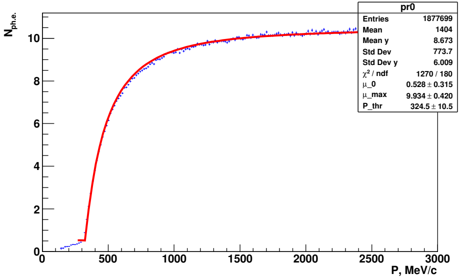




- 160 counters arranged in 2 layers;
- 1000 liters of aerogel with n=1.05;
- π/K-separation in the momentum range 0.6-1.5 GeV/c;
- 160 MCP PMT with multialkali photocathode ⊘18 mm able to work in the magnetic field up to 4.5 T.

Efficiency of cosmic muons detection

The amplitude dependence of barrel counters on momentum of cosmic muons which crossed two layers of aerogel in the KEDR ASHIPH system



$$\mu = \mu_0 + \mu_{max} \cdot \frac{p^2 - p_{thr}^2}{p^2}$$

The sources of under threshold signal:

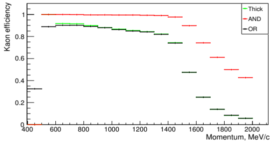
- Cherenkov light from δ-electrons in aerogel;
- Scintillation in PTFE wrapping;
- Cherenkov light in PTFE wrapping.

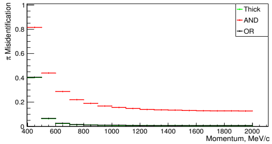
- $P_{thr}(\mu)$=324.5±10.5 MeV/c → n=1.051±0.004
- $N_{ph.e.}$ from relativistic muons (P>1.2 GeV/c):
  - 1^{st} layer 5.80 ph.e.
  - 2^{st} layer 4.08 ph.e.
  - 2 layers 9.73 ph.e.
- Efficiency of relativistic particles detection at the threshold 0.3 ph.e. (P>1.2 GeV/c):
  - 1^{st} layer 97.04±0.10%
  - 2^{st} layer 90.74±0.10%
  - 2 layers 99.38±0.10%

Investigation the efficiency

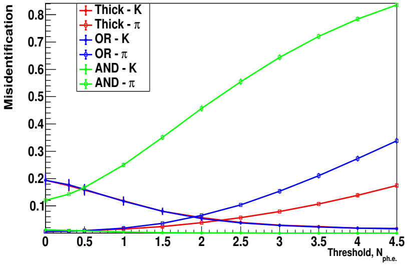
- To evaluate registration efficiency for kaons and pions with some momenta muons with corresponding momentum were chosen ($P_\mu = P_{K,\pi} * [m_\mu / m_{K,\pi}]$)
  - $950 < P_K < 1450\ MeV/c :\to 200 < P_\mu < 300\ MeV/c \to 0.885 < \beta < 0.944$
  - $950 < P_\pi < 1450\ MeV/c :\to 700 < P_\mu < 1100\ MeV/c \to 0.989 < \beta < 0.995$
- The several approaches of efficiency measurement of double layer system were studied:
  - AND $\to$ a relativistic particle gives a signal in both layers of the system
  - OR $\to$ a relativistic particle gives a signal at least in one layer of the system
  - THICK $\to$ sum of the amplitudes in both layers exceeds threshold

Two layer system efficiency (all system, threshold 0.3 ph.e.)





$950 < P_{K,\pi} < 1450$



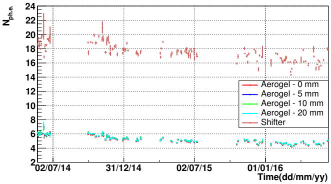
π/K–separation better than 4σ in the momentum range from 0.95 to 1.45 GeV/c.

Long term stability ASHIPH system in the KEDR detector from cosmic muons

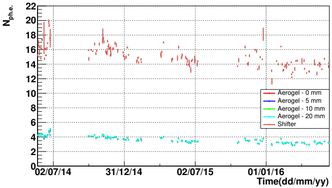
We can separate the signal from aerogel and shifter – separate causes degradation (QE of PMT or Aerogel). The signal in shifter should be stable.

Data from cosmic muons with P>1.2 GeV/c

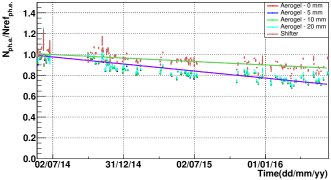
1st layer (0-80 cnt)



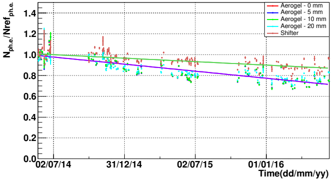
2nd layer (80-160 cnt)



1st layer (0-80 cnt)



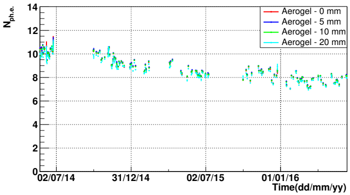
2nd layer (80-160 cnt)



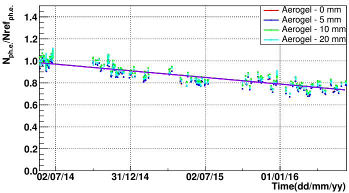
«Aerogel» – area of the aerogel with electronics and shifter cut and indented from the walls.

Long term stability ASHIPH system in the KEDR detector from cosmic muons

Thick counter



Thick counter (normalized $N_{ph.e.}$)



The main reasons of the lightout degradation:

- QE of PMT – in average 13%
- Aerogel – in average 16%

Geometric efficiency: $e^+e^- \to e^+e^-$ events

Data from May 2014 – $e^+e^- \to e^+e^-$ events ($\sim$40 mln. events)

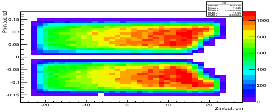
$$\varepsilon = \frac{N_{\text{atc\_tracks}}}{N_{\text{tracks}}},$$

N_{tracks} - number of charged particle tracks, $N_{\text{atc\_tracks}}$ - number of charged particle tracks hits in the system ASHIPH.

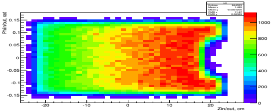
Selection Bhabha events:

- 2 collinear tracks of opposite charge from IP;
- $\geq$2 clusters in the EMC;
- energy of clusters in the calorimeter $\geq$450 MeV;
- momentum track P>1300 MeV/c;
- polar angle $20^{\circ} < \theta^{\circ} < 160^{\circ}$ (94% from 4π).

«Aerogel» – area of the aerogel with electronics and shifter cut and indented from the walls.



«All counter» – aerogel+shifter with electronics cut and indented from the walls.



Two layers by «OR»

Area counter indented	Geometric efficiency
1)«Aerogel»–0 mm	95.7±0.6%
2)«Aerogel»–5 mm	86.1±0.6%
3)«Aerogel»–10 mm	76.2±0.6%
4)«All counter»–0 mm	99.5±0.5%
5)«All counter»–5 mm	99.1±0.6%
6)«All counter»–10 mm	98.4±0.6%

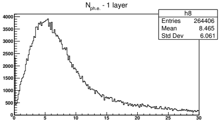
Two layers by «AND»

Area counter indented	Geometric efficiency
1)«Aerogel»–0 mm	84.6±0.6%
2)«Aerogel»–5 mm	74.4±0.6%
3)«Aerogel»–10 mm	64.5±0.5%
4)«All counter»–0 mm	86.4±0.6%
5)«All counter»–5 mm	76.5±0.6%
6)«All counter»–10 mm	66.5±0.5%

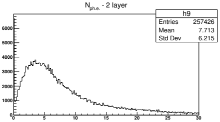
Registration efficiency: $e^+e^- \to e^+e^-$ events

Data from J/ψ peak – runs 21740÷23114 (28/04/2015÷22/02/2016), L_{int}=1.533 nb^{-1}

Endcaps

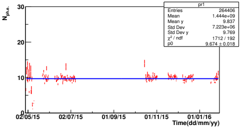


Ineff=2214/264406=0.008

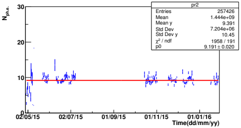


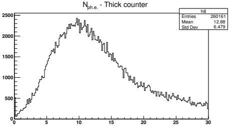
Ineff=6496/257426=0.025

1st layer (1-20, 61-80 cnt)



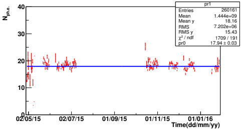
2nd layer (81-100, 141-160 cnt)





Ineff=518/260161=0.0020

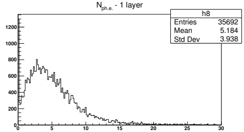
Thick counter (endcap)



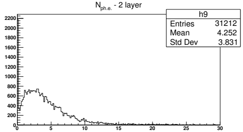
$e^+e^- \to e^+e^-$ suppression factor: for one layer – 80, for double layer – 500

Registration efficiency: $e^+e^- \to e^+e^-$ events

Barrel

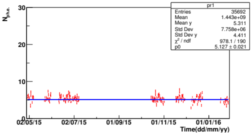


Ineff=1216/35692=0.034

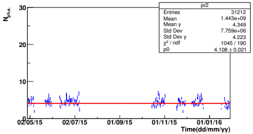


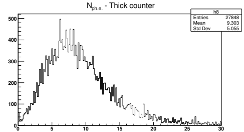
Ineff=2096/31212=0.067

1st layer (21-60 cnt)



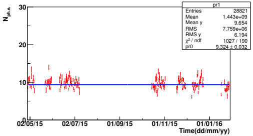
2nd layer (101-140 cnt)





Ineff=60/27848=0.0021

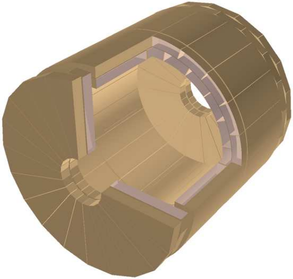
Thick counter (barrel)



$e^+e^- \to e^+e^-$ suppression factor: for one layer – 20, for double layer – 460

Simulation of ASHIPH counters

KedrSim – KEDR detector simulation package based on GEANT 3.21 (choice of Geant3.21 is historical).



Simulation includes:

1. Realistic geometry description of all 160 counters:
   - three active media – aerogel, shifter, PTFE
   - electronics boxes and HV outputs.
2. For all counters individual aerogel refractive index was used and measured inhomogeneities of the light collection were taken into account.
3. The digitized amplitudes from calibrated single-photon spectra and pulse shapes are generated.

Simulation of ASHIPH counters

The signal from particle in counter:

$$\boxed{I = I_{\text{ch\_aer}} + I_{\text{ch\_sh}} + I_{\text{ch\_tef}} + I_{\text{sc\_aer}} + I_{\text{sc\_sh}} + I_{\text{sc\_tef}}.}$$

The magnitude of scintillation signal is proportional to the energy loss in a matter:

$$I_{\text{sc}_\text{i}} = \alpha_\text{i} \Delta E_\text{i},$$

where α_i – coefficient of proportionality.

The number of the Cherenkov photo-electrons from relativistic particles above threshold:

$$I_{\text{ch}_\text{i}} = \frac{dN_\text{i}}{dx_\text{i}} = K_\text{i} \cdot z^2 (1 - \frac{1}{(n_\text{i}\beta)^2}),$$

where n_i – refraction index, K_i – proportionality factor taking into account inhomogeneity of light collection, $\beta = v/c$.

The proportionality factor is determined from experimental data as:

$$\boxed{K_\text{i} = \frac{\frac{N_{\text{ph.e.}}}{L_{\text{track}}}}{z^2 (1 - \frac{1}{(n_\text{i}\beta)^2})},}$$

where $N_{\text{ph.e.}}$ – number of photoelectrons, L_{track} – track length in counter.

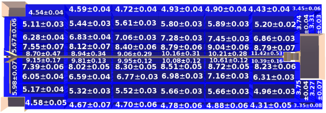
Distribution of K_i

Data from cosmic muons

Long counter of the first layer

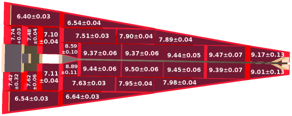
Short counter of the first layer

Long counter of the second layer.



Short counter of the second layer.

Endcap counter



Type of counter	Inhomogeneity of light collection ($\delta = (x_{max} - x_{min})/x_{mean}$)
Short counter of the first layer	±26%
Long counter of the first layer	±25%
Short counter of the second layer	±32%
Long counter of the second layer	±36%
Endcap counter	±19%

Simulation of ASHIPH counters

The number of photoelectrons is described by the Poisson distribution:

$$P_n = \frac{\mu^n e^{-\mu}}{n!},$$

where n – number of photoelectrons, μ – average number of photoelectrons in the counter.

The amplitude distribution is a convolution of single-electron spectrum with a Poisson distribution with mean μ:

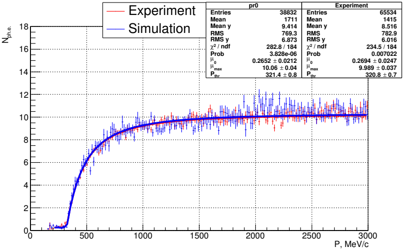
$$F(x) = \sum_{n=0}^{n=25} P_n f_n(x).$$

$$f_n(x) = \int f_1(y) f_{n-1}(x-y) dy,$$

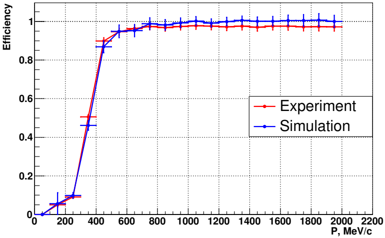
here $f_1(x)$ - single-photoelectron spectrum.

Data from cosmic muons – «Thick counter» (barrel counters)

Amplitude



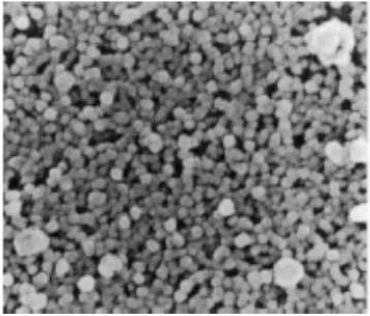
Efficiency (threshold 1.0 ph.e.)

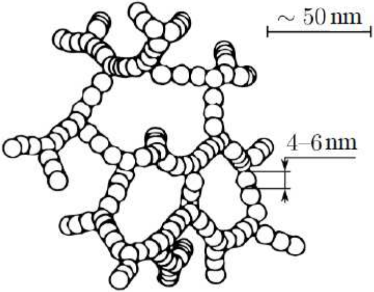


Summary

- The ASHIPH technique of Cherenkov light collection was developed at BINP. It allowed us to decrease significantly the sum of all photocathodes area and production cost.
- The results on the full system efficiency for particles of different momenta has been obtaine:
  - Average number of photoelectrons for relativistic cosmic muons ($>$1.2 GeV/c) that cross both counter layers 9.7±0.4 and bhabha electrons – for endcap 17.9±0.1, for barrel 9.3±0.1.
  - Detection efficiency for muons with $(700 < P_\mu < 1100\ MeV/c)$ is $(1-(3\pm1)\cdot10^{-2})$ for threshold on the amplitude sum equal to 2.0 ph.e..
  - Detection efficiency for under-threshold muons $(200 < P_\mu < 300\ MeV/c)$ in the same approach is 0.05±0.01.
  - These data correspond to π/K–separation better than 4σ in the momentum range from 0.95 to 1.45 GeV/c.
- The amplitude in $N_{ph.e.}$ decreased in three year on 29%. The main reasons of the lightout degradation:
  - QE of PMT $\sim$ 13%
  - Aerogel $\sim$ 16%
- The geometric efficiency on $e^+e^- \to e^+e^-$ events measured. In case «OR» geometric efficiency is 96% and in case «AND» is 89%.
- Inhomogeneity of light collection the ASHIPH counters was measured with cosmic muons – for barrel ±30%, for endcap is ±19%.
- Simulation program of the ASHIPH counters has been being developed.

BACKUP

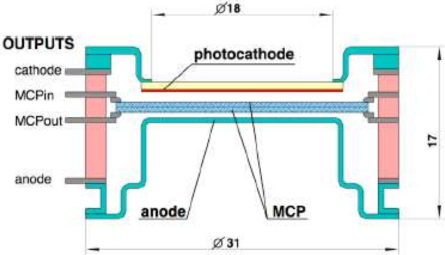


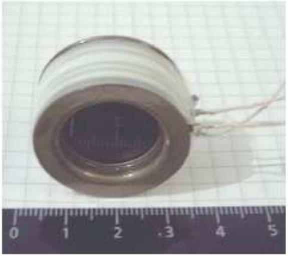


$SiO_2 + H_2O(1\div5\%)$

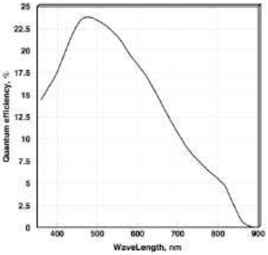
$$n^2 = 1 + 0.438\cdot\rho$$

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





- Manufacturer: "Ekran FEP" (Novosibirsk)
- Borosilicate glass window
- Multialkali (Sb-Na-K-Cs) photocathode
- Maximum QE at λ=500nm
- Two MCPs with channel diameter of 7 μm
- Channel bias angle 13°
- Single anode



Operation in the KEDR detector

HV system:

- High voltage source (HVS) – 6 HV converters H40N (EMCO: 4000 V, 3.75 mA, 15 W) in one standard CAMAC 4M module was developed at BINP.
- High voltage module (HVM, PNPI, St. Petersburg) – 10 modules of 16-ch active HV dividers provide tuning of voltage for each counter from 2500 to 4000 V.
- Maximum current per channel ∼100 mkA.

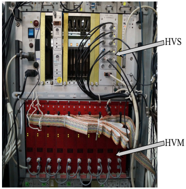
DAQ system:

- The counters are read out by 28 A6 boards.
- A6 board supported in special the KLUKVA standard developed at the BINP.
- A6 has 6 channels with 10-bits flash ADC which makes measurements each 55 ns and save them in a pipe-line register.
- The register is blocked when the detector trigger system generate positive decision.
- Five amplitude values are read out for each channel.

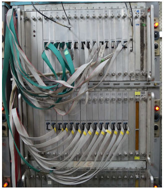
Slow control system:

- The system monitors the dark count rates of the PMTs and provides HV power control.
- In case of emergency each counter is switched off by active HV divider individually.
- Monitoring of the gain stability and the counters efficiency is performed twice per week during calibration runs with LED and cosmic particles.

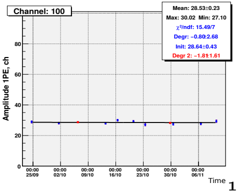
HV system



KLUKVA standard



1 ph.e. amplitude from DB



Some perspective to use in the KEDR experiment

- $Br(J/\Psi \to p\overline{p}, K^+K^-, \pi^+\pi^-, \gamma p\overline{p}, \gamma K^+K^-, \gamma\pi^+\pi^-)$
- $Br(\Psi^{`} \to p\overline{p}, K^+K^-, \pi^+\pi^-, \gamma p\overline{p}, \gamma K^+K^-, \gamma\pi^+\pi^-)$
- $\Psi(3770)$ – D-meson mass measurement.