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Aerogel Cherenkov counters for experiments at VEPP-2000 e^+e^- collider with SND detector

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The threshold aerogel Cherenkov counters for experiments at VEPP-2000 e^+e^- collider with SND detector are described. For the particle identification in different energy ranges two types of counters with different refractive indexes of aerogel were developed. The counter with n=1.13 is intented for kaon identification up to particle energy of 1 GeV. The counter with n=1.05 is intented for pion identification up to particle energy of 0.45 GeV. Main characteristics of counters measured using electrons, muons, pions, and kaons produced in e^+e^- annihilation are presented.

Technology and Instrumentation in Particle Physics 2014
2-6 June, 2014
Amsterdam, the Netherlands

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PoS(TIPP2014)076

1. Introduction

Experiments at the VEPP-2000 e^+e^- collider [1, 2] with upgraded SND detector [3] have been started in the Budker Institute of Nuclear Physics (Novosibirsk, Russia) in 2010. One of the important items of physics program for the SND at VEPP-2000 is precise measurement of hadronic cross-sections at energies below 2 GeV, which is very relevant for Standard Model tests. For these measurements the effective $e/\mu/\pi/K$ separation is needed. To improve particle identification (PID) in SND in different c.m. energy ranges of VEPP-2000 two systems of threshold aerogel Cherenkov counters (ACC) were developed. The systems have identical design, but different refractive indexes of aerogel.

The ACC system with refractive index of aerogel n=1.13 provides effective kaon identification up to particle energy of 1 GeV. The ACC system with n=1.05 is intended for pion identification in the particle energy range up to 450 MeV. For both systems the results of measurements of main ACC characteristics using particles produced in e^+e^- annihilation in the experiments with SND are presented.

2. ACC layout

The SND ACC system has a cylindrical shape and consists of nine light isolated aerogel counters surrounding the SND tracking system. Solid angle of the ACC system is about $60\% \cdot 4\pi$. The counter design is based on ASHIPH technique (**A**erogel, **SHI**fter, **PH**otomultiplier) [4, 5, 6] (figure 1). Cherenkov light emitted in aerogel is collected by a PMMA (Polymethylmethacrylat) wavelength shifter doped with BBQ (7H-benzimidazo[2,1-a]benz[de]isoquinoline-7-one), where reemitted and transported to the photocathode of photomultiplier. To maximize light collection efficiency, the aerogel radiator is wrapped in a highly reflective PTFE (Teflon) film. A photomultiplier tube with three microchannel plates (MCP PMT) and multialkali photocathode is chosen as a photodetector [7]. Spectral sensitivity of this photocathode is well matched with the BBQ emission spectrum, which has maximum at $\lambda_{max} = 500$ nm. MCP PMTs provide the gain up to 10^8, the typical quantum efficiency at maximum is 23% [8].

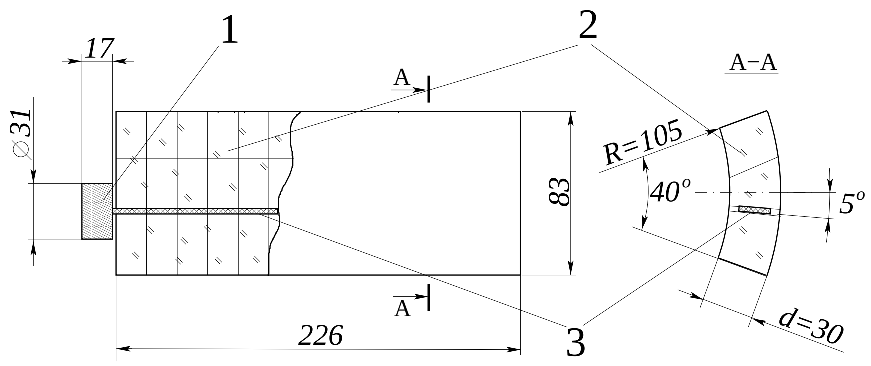

Figure 1: Layout of the SND aerogel Cherenkov counter: 1 — microchannel plate photomultiplier, 2 — aerogel radiator, and 3 — wavelength shifter bar. The dimensions are given in mm.

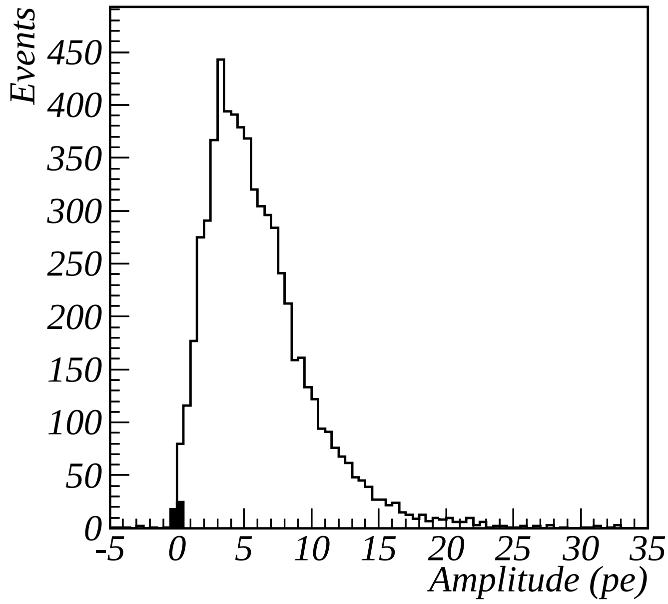

Figure 2: The amplitude spectrum of the ACC (n=1.13) for electrons from the $e^+e^- \to e^+e^-$ reaction in photoelectrons (pe). Black histogram shows inefficiency of counter.

3. ACC with n=1.13

The ACC system with n=1.13 was used in experiments from 2010 to 2012. The c.m. energy range of VEPP-2000 was from 1 to 2 GeV. The refractive index of aerogel was chosen based on the requirement of π/K separation in the momentum range up to 870 MeV/c. The upper limit is the maximum K-meson momentum at highest e^+e^- collision energy at VEPP-2000.

The study of ACC performance has been done using events of e^+e^- annihilation collected in experiments at VEPP-2000 collider with the SND detector [10]. The events with final particles hit in the effective region of Cherenkov counters have been selected. The regions of shifters and edges of counters have been excluded. These criteria reject 25% of total area of ACC system.

The amplitude spectrum for electrons from the $e^+e^- \to e^+e^-$ reaction is shown in figure 2. Black histogram shows events, when a particle (e^+ or e^-) hit the counter, but this did not lead to the counter response, i.e. inefficiency of counter. The detection efficiency is determined with a threshold of 0.2 photoelectrons, which provides 90% efficiency for the single-photoelectron signal.

The experiments with this system have been carried out during more than one and half year and the time dependences of main counter characteristics were obtained (figures 3, 4). The average signal from electrons obtained just after installation of ACC system into the detector was about 8 photoelectrons, the detection efficiency was 99.6%. At the end of the measurement period the average signal was about 6 photoelectrons, the detection efficiency was 99%. Observed decrease of the ACC performance is explained by changing of the light absorption length due to oxidation of metal impurities in the aerogel [9].

The ACC characteristics for pions were measured using $e^+e^- \to \pi^+\pi^-\pi^0$ events. The mo-

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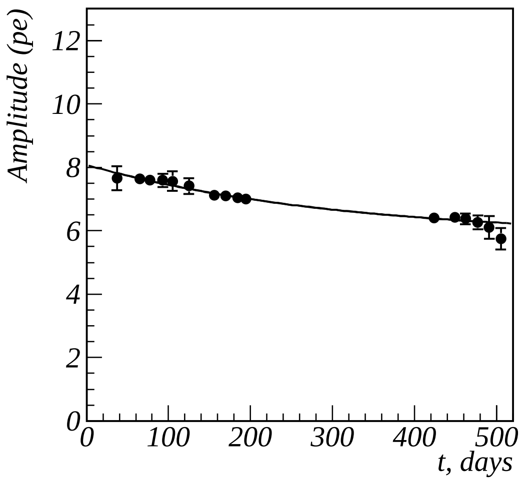

Figure 3: The time dependence of the ACC (n=1.13) amplitude for electrons.

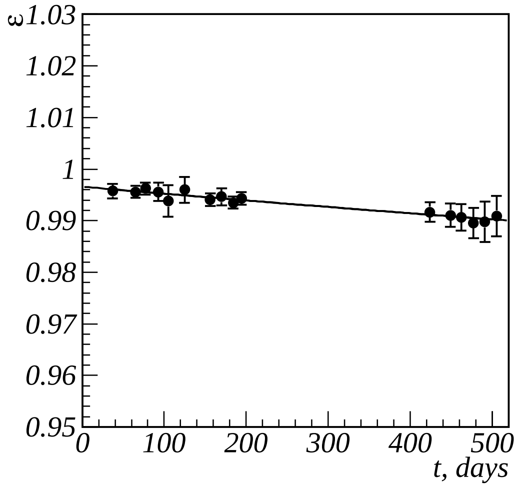

Figure 4: The time dependence of the ACC (n=1.13) detection efficiency for electrons.

mentum dependences of ACC amplitude and detection efficiency are shown in figures 5 and 6. The charged pion momenta were determined using a kinematic fit. For momenta larger than 650 MeV/c, the efficiency and amplitude were measured using $e^+e^- \to \mu^+\mu^-$ events. For the muons, momentum was recalculated using the formula $p_\pi = p_\mu(m_\pi/m_\mu)$, where p_μ is the muon momentum, m_π and m_μ are the pion and muon masses. Amplitude data were approximated by the function

$$\mu = \mu_0 + \mu_{max} \cdot \frac{p^2 - p_{thr}^2}{p^2}, \tag{3.1}$$

where $p_{thr} = 265$ MeV/c — threshold of Cherenkov radiation for pions in the aerogel. The average ACC amplitude for electrons for the same period of experiment (horizontal line) is shown in figure 5 too. It is seen that maximal counter signals for pions and electrons are very close. The results for detection efficiency are similar.

To measure the subthreshold ACC response for kaons, the process $e^+e^- \to K^+K^-$ was used. The momentum dependences of ACC amplitude and detection efficiency are shown in figures 7 and 8. The measured subthreshold efficiency is about 10%. The effects that lead to nonzero efficiency are following:

- Cherenkov radiation of δ-electrons;
- Cherenkov radiation and scintillations in the teflon film;
- nuclear interactions and decays of K mesons, in particular at low momenta $P_K < 200$ MeV/c.

From comparison of figures 6 and 8 π/K separation power was obtained (see table 1). At momentum of 350 MeV/c separation power is 2.8 σ, that corresponds to the pion suppression by more than two orders of magnitude. This is sufficient for effective π/K separation in many reactions studied at VEPP-2000. At momenta below 350 MeV/c, the additional information from other detector systems (in particular, from the drift chamber) should be used.

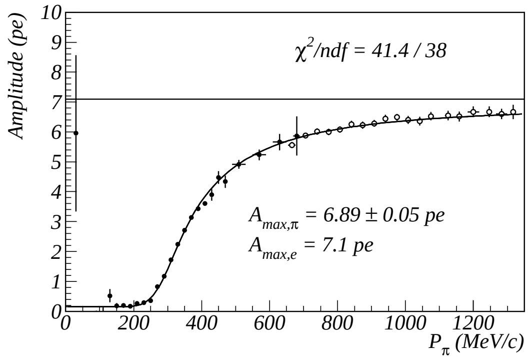

Figure 5: The dependence of the ACC (n=1.13) amplitude on charged pion momentum. Filled circles — pion data. Open circles — muon data. Solid curve — an approximation function of experimental data. Horizontal line — average ACC signal for electrons.

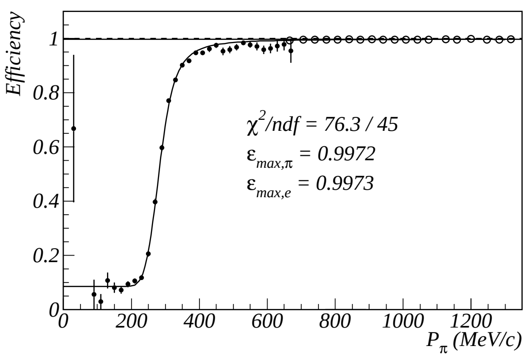

Figure 6: The dependence of the ACC (n=1.13) detection efficiency on charged pion momentum. Filled circles — pion data. Open circles — muon data. Solid curve — an approximation function of experimental data. Horizontal line — average ACC efficiency for electrons.

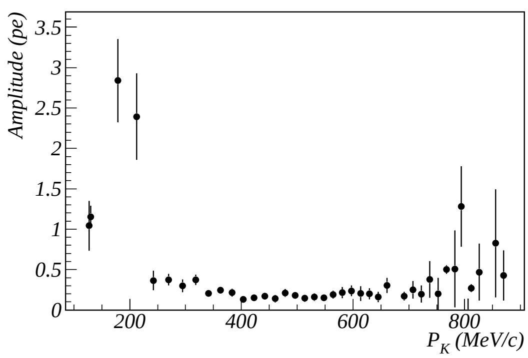

Figure 7: The dependence of the ACC (n=1.13) amplitude on charged kaon momentum.

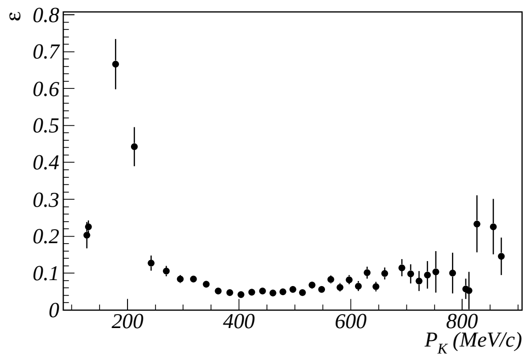

Figure 8: The dependence of the ACC (n=1.13) detection efficiency on charged kaon momentum.

p, MeV/c	ε_K	ε_π	σ
300	0.10	0.68	1.7
350	0.07	0.90	2.8
400	0.05	0.96	3.4

Table 1: π/K separation

4. ACC with n=1.05

In the end of 2012 the VEPP-2000 started work in the energy range below 1 GeV. In this energy region $e/\mu/\pi$ separation in $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \pi^+\pi^-$ processes is needed. For effective e/π-separation in the particle energy range up to 450 MeV the ACC system with n=1.05 was developed. The upper limit is determined by threshold of Cherenkov radiation for π meson.

The study of ACC performance has been done using events of e^+e^- annihilation collected

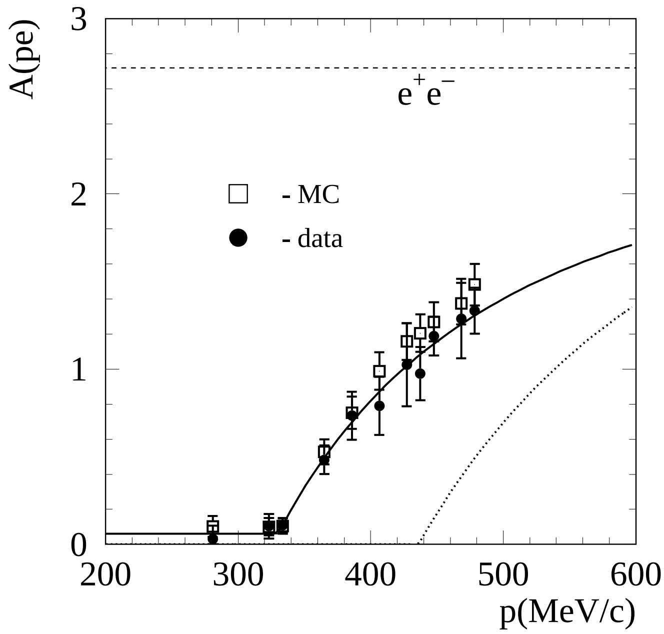

Figure 9: The momentum dependence of the ACC (n=1.05) amplitude for the muons from $e^+e^- \to \mu^+\mu^-$ reaction. Filled circles — experimental signal for one muon. Open boxes — MC simulation of ACC signal for muons. Solid curve — an approximation function of experimental data. Horizontal line — average ACC signal for electrons. Dotted curve — expected ACC signal for charged pions.

in experiments at VEPP-2000 collider with the SND detector in the energy range from 500 to 1000 MeV.

The average signal for electrons from the $e^+e^- \to e^+e^-$ reaction obtained just after installation of ACC system into the detector was about 4.5 photoelectrons for the whole system, the detection efficiency was 97.5%. By the end of the measurements period (about half a year after installation) the average signal was 3.5 photoelectrons, the detection efficiency was 95.5%.

The momentum dependence of the ACC amplitude for the muons from $e^+e^- \to \mu^+\mu^-$ reaction is shown in figure 9. The experimental data (filled circles) are approximated by the function 3.1 (solid curve), where $p_{thr} = 330$ MeV/c — threshold of Cherenkov radiation for muons in the aerogel. It is seen that data are well described by the theoretical dependency. The level of subthreshold signal is about 3%. MC simulation of ACC signal for muons (open boxes), average ACC amplitude for electrons for the same period of experiment (horizontal line) and expected ACC signal for charged pions (without subthreshold efficiency) are shown in figure 9 too. The MC simulation satisfactorily describes experimental data for muons. At the momenta above 400 MeV/c the suppression of the background from $e^+e^- \to \pi^+\pi^-$ reaction is not efficient enough. This results in some systematic difference between MC and experimental data.

5. Conclusions

For PID in the SND detector two systems of threshold aerogel Cherenkov counters were designed and produced:

1. ACC system with refractive index of aerogel n=1.13;
2. ACC system with refractive index of aerogel n=1.05.

The ACC system with n=1.13 has been used in experiments at the VEPP-2000 collider with the SND detector from 2010 to 2012. The system was calibrated with particles (e, μ, π, K) produced in e^+e^- collisions. The average signal from electrons is 6-8 photoelectrons. This system provides pion suppression by more than two orders of magnitude at momenta above 0.35 GeV/c.

The ACC system with n=1.05 has been used in experiments from the end of 2012. The system was tested using electrons and muons from $e^+e^- \to e^+e^-$ and $e^+e^- \to \mu^+\mu^-$ reactions at momenta less than 500 MeV/c. The average signal from electrons is 3.5 photoelectrons. The detection efficiency is 95.5%. The momentum dependence of the ACC amplitude for the muons was obtained.

Acknowledgments

The work is supported by the Ministry of Education and Science of the Russian Federation, the grants Sci. School-2479.2014.2, RFBR 12-02-01250-a, 12-02-00065-a,14-02-00129-a, 14-02-31401 mol-a, MK-4285.2014.2.

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