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PERFORMANCE OF SILICA AEROGEL THRESHOLD CERENKOV COUNTERS*

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ABSTRACT

Results from a series of test beam measurements are presented for a two-cell silica aerogel threshold Cerenkov counter system. The main achievement is the detection of 13 ± 1 photoelectrons in a full-size $n=1.008$ silica aerogel cell, which is read out with a fine mesh photomultiplier in different magnetic fields up to 1.35 T.

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Results from a series of test beam measurements are presented for a two-cell silica aerogel Cerenkov counter system. The main achievement is the detection of 13 ± 1 photoelectrons in a full-sized $n=1.008$ silica aerogel cell which is read out with a fine mesh photomultiplier in different magnetic fields up to 1.35 T.

1. Introduction

The study of CP violation at an asymmetric B-factory requires good particle identification (PID), in particular excellent K/π separation over the entire momentum range up to 4.5 GeV. One of the key modes is $B^0 \rightarrow \pi^+\pi^-$ which needs to be separated from the penguin process $B^0 \rightarrow K^+\pi^-$. Due to the boost of the $B\bar{B}$ system, momenta in the forward direction can reach 4.5 GeV in both modes which may be of similar magnitude. K and π momenta from generic B decays, however, typically lie below 2 GeV. Covering the low-momentum range by dE/dx measurements in the drift chamber, an elegant, inexpensive PID system can be designed with two cells of silica aerogel threshold Cerenkov counters having refractive indices of $n=1.008$ and $n=1.06$. [1]

2. Design Considerations

A system design is sketched in Figure 1. [2] The aerogel cells are arranged in a barrel and an angled forward endcap providing an angular coverage of 0.3 r ($\pi - 0.59\text{ r}$) in the forward (backward) direction. The cells are nearly projective. Typical dimensions at the cell center are $10 \times 8\text{ cm}^2$ for $n=1.008$ and $9.1 \times 11.4\text{ cm}^2$ for $n=1.06$; cell lengths are 12 cm and 4 cm, respectively. The refractive indices are varied slightly over the polar angle to compromise photoelectron yield ver-

sus accessible momentum. The aerogel is housed in light containers whose inner walls are covered with a highly diffuse reflector such as PTFE film. Small airgaps are maintained in front and behind each aerogel cell to reduce backgrounds from δ -rays and from leakage out the front of the calorimeter. The aerogel is read out with one compact photon detector operating in a magnetic field, such as a fine mesh tube, a hybrid photodiode or a microchannel plate. The photon detector is located in the neighboring cell to provide proper signal detection even if the charged particle passes through the photon detector. Further details are given in ref. 2 [3] Such a PID system places a minimum of inactive material in front of the CsI(Tl) crystal calorimeter, thus maintaining a good energy resolution and high efficiency for all photons.

The expected performance is displayed in Figure 2, assuming that at least 10 photoelectrons are detected. This will give a nearly 4σ K/π separation over the entire momentum range. Monte Carlo studies have shown that the system still works reasonably for 7.5 photoelectrons, but that a detection of 5 photoelectrons is unacceptable. [3]. High photoelectron yields can be obtained with aerogel produced in a two-process. An additional heat treatment yields further improvements in light transmission.

3. Results from Beam Tests

The performance of a two-cell silica aerogel threshold Cerenkov counter device has been stud-

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Figure 1: Design of a 2-cell PID system using silica aerogel threshold Cerenkov counters.

Figure 2: Probability of detecting particles in a 2-cell silica aerogel threshold Cerenkov detector.

Figure 3: Layout of the test beam setup.

ied in several beam tests at CERN. A schematic view of the setup is shown in Figure 3. Entering from the negative z direction, the beam passed through two CO_2 gas Cerenkov counters, two scintillation counters, two aerogel cells with $n=1.008$ and $n=1.06$, and another two scintillation counters. The gas Cerenkov counters provided $\pi(K)$ thresholds of 2.6 (9.6) GeV. For triggering, the two scintillation counters closest to the aerogel were used. The aerogel was housed in Al boxes whose inner walls were covered with six layers of 50 μm thick PTFE film. The walls of the $n=1.008$ aerogel container were sprayed, in addition, with PMP wavelength shifter.

The aerogel cells consisted of a stack of different sized pieces adding up to total volumes (x - y - z) of $10 \times 8 \times 12.5 \text{ cm}^3$ for $n=1.008$ and $10 \times 8 \times 4 \text{ cm}^3$ $n=1.06$. Small air gaps were maintained behind each aerogel cell. For readout fine mesh photomultipliers were used whose photocathodes were reduced to 2 inches and 1.5 inches via PTFE film masks. For optimized light collection the fine mesh tubes were also offset into the airgap.

The fine mesh tubes, operated at 2300 V, have a gain of a *few* $\times 10^7$ at $B = 0 \text{ T}$. Since the gain drops sharply in high magnetic fields, additional adjustable linear amplifiers became necessary. For the readout of $n=1.008$ aerogel, further a current preamplifier with a gain of 50 was added right after the tube. For proper electric shielding, the two aerogel cells and the trigger counters were mounted inside a light-tight metal box, which was pushed inside a magnet. The magnetic field was adjustable from 0 T to 1.35 T.

Data were taken in two different test beam areas providing momentum ranges of 1-5 GeV and 1-10 GeV for both positively and negatively charged particles with pions dominating. For absolute calibration a pulsed LED was used. Calibration points were taken with a single photoelectron spectrum and with several multi photoelectron spectra. Cross-checks were made with beam particles below threshold as well as calibrations with a Quantacon tube. This calibration procedure has an accuracy of 5-10%.

Figure 4 shows the pulse height distributions of $n=1.008$ aerogel measured in a 5 GeV π^- beam at $B=0 \text{ T}$ and $B=1.35 \text{ T}$, respectively.

In both distributions a prominent peak is well-separated from the pedestal. At $B=0 \text{ T}$, a yield of $N_{pe} = 13.0 \pm 1.0$ is observed, corresponding to an excess noise factor of $\text{ENF} = 2.0 \pm 0.1$. At $B=1.35 \text{ T}$, a yield of $N_{pe} = 15 \pm 2$ is measured; the errors are dominated by systematic effects. Similar yields are found at other B-field strengths. For the $n=1.06$ aerogel the photoelectron yield is $N_{pe} = 11 \pm 1$ for magnetic fields up to $B=1 \text{ T}$. Because of lacking another high-gain current sensitive preamplifier measurements at higher fields were not achievable. All results are preliminary.

Figure 5 shows the average photoelectron yield versus magnetic field strength. Within errors all data are consistent with a yield of 13 photoelectrons. The B-field dependence of the gain is plotted in Figure 6a for a 16-inch fine mesh tubes. At $B=1 \text{ T}$, the gain has dropped by nearly 2 orders of magnitude while the resolution has not changed significantly. Figures 6b display the relative resolutions of the pulse height distributions for $n=1.008$ versus the B-field. The resolutions remain constant except at very high fields where they decrease slightly.

The uniformity of light collection in the $n=1.008$ aerogel cell was also studied by varying the beam position with respect to the photomultiplier. Figure 7 shows the results. The yield decreases slightly with distance leading to a $\pm 12\%$ uniformity.

To demonstrate that silica aerogel is a Cerenkov detector the momentum dependence of the response to π 's, K 's, and p 's has been measured. The results for the $n=1.008$ aerogel are plotted in Figure 8. The pion data have been fitted with the expected threshold function leaving the refractive index as a free parameter. The fit yields $n_{\text{fit}} = 1.0091 \pm 0.0004$ which is in good agreement with the value $n=1.0087$ specified by the manufacturer. Using this fit function we can make predictions for the K and p threshold curves which provide an excellent parametrization of the data (see Figure 8). For the $n=1.06$ aerogel cell the same technique yields $n_{\text{fit}} = 1.061 \pm 0.004$ which agrees well with $n=1.063$ quoted by the manufacturer. Figure 9 summarizes all measured yields from Figure 8 versus $\beta\gamma$. Within errors all data are well described by the expected thresh-

Figure 4: Pulse height distribution of $n=1.008$ aerogel at a) $B = 0$ T and b) at $B = 1.35$ T.

Figure 6: a) Gain of 16 stage fine mesh tube and b) Relative resolution of $n=1.008$ aerogel vs B-field.

Figure 5: Observed number of pe yield vs B-field.

Figure 7: Uniformity measurement

Figure 8: Measured threshold curves vs momentum for π 's, K's and p's in $n=1.008$ aerogel.

Figure 9: Measured threshold curves vs $\beta\gamma$ in $n=1.008$ aerogel.

Figure 10: a) observed π/p separation and b) observed π/K separation; efficiencies (open circles) and p (K) misidentification probabilities (open circles).

old curve demonstrating that the aerogel is a Cerenkov detector. These threshold curves can also be well reproduced in GEANT Monte Carlo simulations. [5]

In Figure 9 a response from particles below threshold is observed indicating a small background contribution from δ -rays and backplash. To estimate this background in more detail low momentum (3.5 GeV) p and K data have been studied which have been well extracted by the gas Cerenkov counters. Figures 10 display the π efficiencies and $p(K)$ rejection probabilities after background subtraction as a function of minimum observed photoelectron yield. In the p data, only the photomultiplier noise needs to be subtracted. In the K data, on the other hand, one needs to correct for additional backgrounds from K decays and wrong-tagged kaons. From Figure 10a we determine a 3.7σ π/p separation for an efficiency of $\epsilon_\pi = 97\%$ and a p rejection of 3%. Similarly using Figure 10 b, we estimate a 3.8σ K/π separation for $\epsilon_\pi = 98.5\%$ (97%) and a K rejection of 5% (2.5%). This is slightly higher than our Monte Carlo studies indicate where a 3% K/π rejection for a 98.5% π efficiency had been obtained. [5]

4. Conclusion

A PID system based on silica aerogel threshold Cerenkov counters is a simple, robust, and powerful device providing excellent particle identification over the entire solid angle and momentum range. Of all proposed PID systems it has the least impact on the other subsystems in a B-factory detector. Reliable production of high-quality $n=1.008$ silica aerogel has been demonstrated using a two-step process plus an additional heat treatment. [6] A proof of principle for such a PID system has been established by measuring $N_{pe} = 13 \pm 1$ ($N_{pe} = 11 \pm 1$) for $n=1.008$ ($n=1.06$) silica aerogel cells in magnetic fields up to 1.35 T (0.8 T). Furthermore, a uniform light collection within $\pm 12\%$ has been observed. The aerogel shows the expected threshold behavior of a Cerenkov detector. The refractive indices obtained from a fit agree well with the values quoted by the manufacturer. The study of particles below threshold indicate that back-

ground levels from δ -rays and backplash are 3-5% yielding K/π (π/p) separations of nearly 4σ .

The test beam measurements indicate that fine mesh photomultipliers must be operated parallel to the B field. If fine mesh tubes are used for readout, the design in Figure 1 needs to be modified slightly. It is, however, expected that a less bulky photon detector like a hybrid photodiode or a microchannel plate is used in the end. At the moment, the noise performance of such large-area detectors is not adequate.

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REFERENCES

1. D. Hitlin *et al.*, Workshop on Physics and Detector Issues for a High-luminosity Asymmetric B -Factory at SLAC, **SLAC-373**, ed. D. Hitlin (1991).
2. D. Boutigny *et al.*, Letter of Intent, **SLAC-443** (1994), p. 147.
3. G. Eigen, **Calt-68-1975**, December 1994.
4. J.Y. Oyang, *BaBAR* note #137, April 1994.
5. X. Shi, *BaBAR* note #142, May 1994.
6. P. Tsou, private communication.