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The aerogel threshold Cherenkov detector for the High Momentum Spectrometer in Hall C at Jefferson Lab

R. Asaturyan[a,*], R. Ent[b], H. Fenker[b], D. Gaskell[b], G.M. Huber[c], M. Jones[b], D. Mack[b], H. Mkrtchyan[a], B. Metzger[b], N. Novikoff[d], V. Tadevosyan[a], W. Vulcan[b], S. Wood[b]

[a] *Yerevan Physics Institute, Yerevan 375036, Armenia*
[b] *Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA*
[c] *Department of Physics, University of Regina, Regina, SK, Canada S4S 0A2*
[d] *Houston Baptist University, Houston, TX 77074, USA*

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Abstract

We describe a new aerogel threshold Cherenkov detector installed in the HMS spectrometer in Hall C at Jefferson Lab. The Hall C experimental program in 2003 required an improved particle identification system for better identification of $\pi/K/p$, which was achieved by installing an additional threshold Cherenkov counter. Two types of aerogel with $n = 1.030$ and $n = 1.015$ allow one to reach $\sim 10^{-3}$ proton and 10^{-2} kaon rejection in the 1–5 GeV/c momentum range with pion detection efficiency better than 99% (97%). The detector response shows no significant position dependence due to a diffuse light collection technique. The diffusion box was equipped with 16 Photonis XP4572 photo multiplier tubes (PMTs). The mean number of photo-electrons in saturation was $\sim$16 and $\sim$8, respectively. This allows even for separation of slower particles slightly above threshold.

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1. Introduction

The aerogel detector described in this paper was designed and built for experiments carried out in Hall C at Jefferson Laboratory.

A number of (e, e′h) experiments, where a scattered electron is measured in coincidence with

*Corresponding author.
E-mail address: asatur@jlab.org (R. Asaturyan).

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a hadron, have been performed in Hall C since 1995. The Hall C base experimental equipment consists of two magnetic spectrometers, the High Momentum Spectrometer (HMS) and the Short Orbit Spectrometer (SOS) [1]. Depending on the specific requirements of the experiments, one can detect either negatively charged (mostly electrons) or positively charged particles by choosing the proper polarity of the magnetic field and the trigger configuration.

The HMS is designed to detect secondary products of reactions in the momentum range from 0.5 to 7.3 GeV/c, while the SOS momentum extends only up to $\sim$1.7 GeV/c. Both spectrometers are equipped with a pair of drift chambers and X–Y timing scintillator hodoscope planes for trigger formation.

For particle identification (PID), a combination of Time-of-Flight (TOF), threshold gas Cherenkov counter and segmented lead–glass electromagnetic calorimeter (EC) is used. In addition, for coincidence measurements, use of the coincidence time difference between scattered electrons and different types of secondary hadrons is very efficient. But even with perfectly tuned hodoscope arrays and calibrated detectors, in such a configuration $\pi/\mathrm{K}/\mathrm{p}$ separation dramatically deteriorates with momentum as $\Delta t{\sim}1/P^2$. While TOF is very effective at low momentum, it becomes in practice useless above $P{\sim}3$ GeV/c. In addition, up to the highest momentum setting of the Hall C HMS neither kaons nor protons will trigger on an atmospheric gas Cherenkov detector. Although pions will trigger on a gas Cherenkov from roughly 3 GeV/c momentum (for C_4F_{10} gas), initial light output will be too low for meaningful π/K separation. Thus, the HMS PID system needs to be augmented for good hadron identification above 3 GeV/c.

A series of Hall C experiments ran in the summer of 2003 that required such an improvement of the HMS PID system. The purpose of the "Baryon Resonance Electroproduction at High Momentum Transfer" [2] experiment was to measure inelastic nucleon transition amplitudes to the $\Delta(1232)$ and $S_{11}(1536)$ baryon resonances via the $\mathrm{p(e,e'p)}\pi^\circ$ and $\mathrm{p(e,e'p)}\eta$ reactions, respectively, at the momentum transfer of $Q^2 = 7.5\,(\mathrm{GeV}/c)^2$. The scattered electrons were detected in the SOS in coincidence with recoil protons of up to $\sim$5 GeV/c momentum in the HMS. In this experiment, it was important to suppress high-momentum pions with respect to protons.

A second experiment, termed "The Charged Pion Form Factor", measured the pion form factor at $Q^2 = 1.6$ and $2.5\,(\mathrm{GeV}/c)^2$ [3]. In this experiment, one detected pions and electrons in coincidence from the reactions $\mathrm{e + p \to e' + \pi^+ + n}$ and $\mathrm{e + d \to e' + \pi^- + p + p}$ or $\mathrm{e + d \to e' + \pi^+ + p + n}$ (in order to estimate contributions from background physics processes). Here, the HMS was set up for pion detection. At the highest momentum setting of this experiment, $P_{\mathrm{HMS}}{\sim}3.4$ GeV/c, the ratio of π^+ to protons was expected to be $\sim$1 and good proton rejection became important.

Finally, the experiment "Duality in Meson Electroproduction" checked the low-energy cross-section factorization and the quark–hadron duality phenomenon in semi-inclusive electroproduction of pions (kaons) [4]. Here, it was important to identify kaons and pions at a momentum $P_{\mathrm{HMS}} \geqslant 3$ GeV/c.

The general requirement for these three experiments was a high detection efficiency for pions in the HMS and the capability to separate protons from pions in the first two cases, and pions from kaons in the third case.

The experiments were planned to run at an electron beam intensity up to 90 μA, hitting a liquid hydrogen (or deuterium) target with a length of 4 cm, yielding rates as high as 1 MHz.

To keep the HMS standard detector configuration intact and not to compromise on HMS performance, the new PID detector should be designed with the following restrictions:

- have a large sensitive area to match HMS spectrometer acceptance, with an effective area of $\sim 1\,\mathrm{m}^2$;
- be slim to fit in an $\sim$25 cm slot in-between the second drift chamber and first hodoscope, the only readily available space in the HMS detector stack;