RICH DETECTOR AT JEFFERSON LAB, DESIGN, PERFORMANCE AND PHYSICS RESULTS

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Since 2004 the hadron spectrometer of Hall A at Jefferson Lab can be equipped with a proximity focusing RICH. This detector is capable of identify kaon from pion and proton with an angular separation starting from $6\sigma_\theta$ at 2 GeV/c. The RICH design is conceptually similar to the ALICE HMPID RICH; it uses a C$_6$F$_{14}$ liquid radiator and a 300 nm layer of Cs deposited on the cathode pad plane of an asymmetric MWPC. The RICH has been utilized in the Hypernuclear Spectroscopy Experiment E94-107, which took data in the last two years. Design details, performance, and first physics results from the hypernuclear experiment are shortly presented.

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1. Introduction

A proximity focusing RICH has been designed, built and operated in the first hypernuclear spectroscopy experiment (E94-107) performed in Hall A at the Jefferson Laboratory in 2004 and 2005.

The Hall A is dedicated to high resolution and high luminosity electron scattering experiments, served by a continuous electron beam with energy up to 6 GeV. To detect scattered particles, Hall is equipped with two identical, Quadrupole-Quadrupole-Dipole-Quadrupole High Resolution Spectrometers that accept particle momenta up to 4 GeV/c. The two Spectrometers, generally dedicated to the electron and hadron detection separately, can be equipped with timing (Hodoscopes), tracking (Drift Chambers) and PID (Pre/Showers, threshold Čerenkov Counters and RICH), detectors, according to the required experimental needs.

The E94-107 experiment has performed the first systematic study on $^9$Be(e,e'K$^+$$\Lambda$) and $^{12}$C(e,e'K$^+$$\Lambda$) and $^{16}$O(e,e'K$^+$$\Lambda$) hypernuclei. The $\Lambda$ hyperon represents an important probe in the nuclear medium as it is not blocked by the Pauli principle. It has, thus, a relatively weak coupling with the nuclear core, being reasonably well described by the shell model. Moreover, the $\Lambda - N$ interaction may represent an important aspect of the neutron stars behaviour.

The lepton probe used in E94-107, offers, in hypernuclear physics, two relevant advantages at least: presence of strong spin transitions (spin terms are relevant in $\Lambda - N$ potential), and higher energy resolution.

Moreover the electron probe permits the study of complementary (Z-1) hypernuclei. On the other side, the cross sections are quite small respect to the hadronic ones, forcing to investigate phase space with high background, which therefore represents a challenging aspect of such kind of experiment.

In fact, for a clean kaon identification, the required π rejection factor in E94-107 has been estimated to be at least one order of magnitude larger than standard Hall A PID system based, in the hadron arm, on time of flight and two aerogel Čerenkov counters (with $n = 1.015$ and $n = 1.055$).

2. Proximity focusing RICH layout

Figure 1 presents the conceptual layout of the Hall A RICH, which is based on the ALICE HMPID design. The Čerenkov photons are produced by over threshold particles in the liquid freon C$_6$F$_{14}$ with refractive index of 1.28 and thickness of 15 mm. Then they refract on a quartz window of 5 mm and diverges in a 100 mm proximity gap, filled by CH$_4$ at STP.
Eventually they are converted to electrons by a thin layer of CsI (300 nm) deposited on 3 pad planes that represent the cathode of a Multiwire Proportional Chamber (working at 1050 ÷ 1100 HV). The induced charge of the electric avalanche is readout on each pad (11520 in total), by a sample and hold analogically multiplexed front-end electronics. Spatial information is obtained from the segmented pads, whose size is 8 × 8.4 mm².

3. Evaporation system and Quantum Efficiency measurement

One of the most important aspect of the JLab RICH is represented by the deposition of a layer of photoconverted material (CsI) on the pad plane. This is obtained by means of the evaporation of a pure CsI powder in a high vacuum chamber (few 10⁻⁷ mbar).

The Rome group has built, installed and operated at JLab an evaporation chamber for large area pad (up to about 650 × 650 mm²). The target vacuum is obtained in less than 24 hours by three vacuum pumps (scroll, molecular and cryogenic). The CsI powder, heated at 500°C in four crucibles, evaporates toward the pad plane.

A quantum efficiency (QE) online measurement system has been integrated into the evaporation chamber. An UV light generated by a deuterium lamp is directed on the evaporated pad passing through one of three wavelength filters (160, 180 and 220 nm). A small wire chamber at 2 mm from the pad collects the photoemitted electrons, whose current (few nA)
is measured by a picoamperometer. A mirror can divert the UV beam to a reference PMT. The wire chamber over PMT currents ratio times the known reference PMT QE provides a measurement of the deposited CsI QE; a typical measure is reported in figure 2.

![QE SCAN of PAD OLD-SX at $\lambda$=160 nm (date 170505)](attachment:image)

Figure 2. Measured QE distribution the spatial trend in the lower 2D histogram is generally correlated to the amount of CsI powder left in the crucible.

4. RICH performance and physics results

The RICH, operated during the E94-107 experiment, has provided a clean kaon identification. The mean number of photoelectrons measured on a sample of pions is slightly more than 13 with an angular resolution $\sigma_\theta = 5$ mrad which corresponds to a kaon-pion separation of $6\sigma_\theta$ at 2 GeV/c.

Moreover, a pion rejection factor of more than 1:1000 has been estimated from a sample of pion selected by the two aerogel counters requiring the kaon discrimination by the RICH\(^a\).

\(^a\)According to the measured $\sigma_\theta$ and the MonteCarlo simulation, the quoted rejection factor corresponds to an efficiency greater than 95%.
In summary, the RICH has increased the peak detectability in the excitation energy spectra providing a signal to background of more than 7 (instead of 2.5 using time of flight and aerogels only) for the smallest detectable peaks.

In fact, the $^{12}$B$\Lambda$ excitation energy spectrum presents level details not available in the existing measurements; while the $^{16}$N$\Lambda$ spectrum has been never measured before.

Models of the elementary p, K$-\Lambda$ production$^9$ combined to the $\Lambda$ interaction in the nucleus$^{10}$ agree quite well with the lowest energy peaks both in position and in spectroscopy strength, while the disagreements that appear at higher excitation energies (Λ in p shell), especially for the poorly known $^{16}$N$\Lambda$, are of noticeable interest for a fine tuning of the models.

5. Conclusion and perspectives
The RICH build and successfully operated in the E94-107 experiment, is now available in Hall A for an effective PID of hadrons up to 2-2.5 GeV/c. Extension of the momentum range to about 4 GeV/c could be done with relatively small effort, changing the present freon with one with smaller index of refraction (e.g. with C$_5$F$_{12}$) and increasing the proximity gap of few centimeters. Some of the upcoming Hall A experiments and proposals are considering the advantage use of the RICH for $\pi$/K separation.

References
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