ELSEVIER

Nuclear Physics A639 (1998) 111c–116c

NUCLEAR PHYSICS A

(K^-_{stop}, π^0) with the Neutral Meson Spectrometer

A. Rusek[a] for the E907 Collaboration*

[a]Brookhaven National Laboratory, Upton, NY 11973

During the 1997 proton run at the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory (BNL), we carried out a study of $^{12}C(K^-_{stop}, \pi^0)X$ using a combination of the Neutral Meson Spectrometer (NMS) and an active target as part of E907. Presented here is a brief review of the method and a demonstration of the current performance with calibration data and preliminary results.

1. INTRODUCTION

To date, all counter experiments studying Λ hypernuclei have used reactions in which the Λ is produced on a neutron, namely the (K^-, π^-) and (π^+, K^+) reactions. The "mirrors" of the systems which are studied with these reactions, those in which the Λ is produced on a proton, are accessible through reactions such as (K^-, π^0) and (π^-, K^0). Of these reactions, the first one can be done at rest, avoiding the uncertainties in beam momentum and in energy losses in the target suffered by in-flight reactions. As a result, the potential for very good resolution exists. However, until recently these reactions have not been used due to the relative difficulty in detecting the neutral mesons involved. In 1996 the NMS, a large acceptance, high resolution spectrometer designed and built at Los Alamos, was moved to BNL for the purpose of carrying out a study of several hypernuclear systems using the (K^-, π^0) reaction. Of the studies proposed, only $^{12}C(K^-, \pi^0)^{12}_{\Lambda}B$ has been investigated so far and preliminary results are presented here.

The π^0 decays into two photons with a branching ratio of 98.8%. Its short lifetime, 0.8×10^{-16} s, means that it will decay within the target where it was produced, so that its presence must be inferred from observation of the decay products.

The total energy of the π^0 can be expressed in terms of the decay photon observables as

$$E_{\pi^0} = E_1 + E_2 = m_{\pi^0}\sqrt{\frac{2}{(1-\cos\eta)(1-X^2)}}. \qquad (1)$$

*J. Comfort, C. Gaulard, A. Ramirez, *Arizona State U.*; R. Chrien, R. Gill, P. Pile, A. Rusek, R. Sutter, *Brookhaven National Laboratory*; W. Briscoe, *George Washington U.*; L. Tang, *Hampton U.*; J. Peng, C. Riedel, H. Thiessen, *Los Alamos National Laboratory*; C. Neerman,K. Johnston, *Louisiana Tech U.*; R. Sawafta, *North Carolina A. & T.*; I. Supek, *Ruder Boskovic Institute*; O. Hashimoto, *Tohoku U.*; R. J. Peterson, A. Saunders; *U. of Colorado*; M. Ahmed, X. Cui, A. Empl, E. Hungerford, A. Lan, B. Mayes, M. Youn, *U. of Houston*; V. Zeps, *U. of Kentucky*; J. Bjoraker, D. Dehnhard, J. Gerald, J. O'Donnell, *U. of Minnesota*; D. Androic, D. Bosnar, M. Furic, T. Petkovic, M. Planinic, *U. of Zagreb*; M. Taragin, *Weizmann Institute.*

PII S0375-9474(98)00257-7

Here, m_{π^0} is the π^0 mass, η is the opening angle between the two decay photon paths in the laboratory frame, and X is the "energy-sharing" variable, defined as:

$$X = \frac{E_1 - E_2}{E_1 + E_2} \tag{2}$$

The measurement of η and X for each event thus determines the π^0 energy, and constitutes the principle on which the NMS is based [1].

2. THE NEUTRAL MESON SPECTROMETER

Three space points are needed to measure the angle η, the one at which the π^0 decays and the points at which the two decay γ-rays convert and initiate a shower. The first of these points is taken to be the stopping point of the incoming K^-, since the π^0 is short-lived and does not travel far from the interaction point. This point is determined in experiment E907 by an active target, which is designed to measure the stopping point position with sub-millimeter resolution transverse to the beam, and is described elsewhere in these proceedings [2].

The other two points are determined by the NMS system. To do this, the NMS employs converter layers, two on each arm, made of bismuth germanate (BGO), 0.5 radiation lengths (RL) thick, each followed by a set of tracking chambers which track the conversion products back to the BGO layer. The conversion point can, in principle, be deduced with sub-mm accuracy. The BGO crystals are each attached to a photo-multiplier tube (PMT) so that the energy loss in the BGO can be included in the total energy measurement.

The conversion layers are followd by a cesium iodide (CsI) calorimeter, 16 RL thick. The CsI crystals are each attached to a PMT. The signal from the CsI crystals, along with those from the BGO are used to deduce the total energy deposited in each arm for every trigger event.

The NMS resolution is determined by both the angular and the calorimetry resolutions. Our goal is to achieve a resolution of at least 1.0 MeV. With a reasonable position resolution in the NMS chambers and the active target chambers, on the order of 1.0 mm, the energy resolution can be kept within the goal by restricting X to values between -0.2 and 0.2.

3. CALIBRATION

The initial calibration of the NMS is done with cosmic ray data taken during dedicated cosmic-ray runs, and between beam spills during normal running. These data are used to gain-match the CsI and BGO crystals, and to sort out systematics in the tracking chambers. The temperature dependence of the response is also tracked and corrected for by using the cosmic ray data.

After the initial calibration, two reactions are used to further calibrate and test the performance of the NMS. The first is $\pi^-_{stop} + p \rightarrow n + \gamma$, in which a π^- beam is brought to a stop in a high-pressure hydrogen target, and the NMS is triggered on any sum pulse-height above a given threshold in either one of the arms. The monoenergetic γ provides a clean absolute calibration as well as relative gain matching for all CsI and BGO crystals.

To test the system with π^0's, the reaction $K^+_{stop} \rightarrow \pi^+ + (\pi^0 \rightarrow 2\gamma)$ is used. The K^+'s are brought to a stop in the active target, where their interaction probability is small, allowing them to undergo decays. They decay into $\pi^+ + \pi^0$ with a branching ratio of 21%. The π^0 is monoenergetic, providing a good additional absolute energy calibration for the calorimeter, while the two-γ final state provides a test of the angle measurement.

The result of the stopped K^+ measurement is presented in Fig. 1, where the π^0 measured energy distribution is shown. The data represented in the figure were subjected to the requirements that the measured π^0 mass lie between 128.0 and 140.0 MeV/c^2, and that the absolute value of X be less than or equal to 0.2.

The calorimetry resolution for this mode was found to be 7.8% at 100 MeV (fwhm) in each arm, while the angular resolution is about 14 mr (fwhm). This angular uncertainty is not adequate to achieve the goal of 1.0 MeV resolution in excitation energy, and is most likely the dominant source of the 3.0 MeV spread in Fig. 1. The problems with the angle measurements are understood to be systematic errors in chamber alignment, and active target analysis errors, that is, difficulties with identifying the correct K stopping point. By restricting the data to come from a specific set of converter layers, one in each arm, a resolution slightly larger than 1.0 MeV is possible, but the count rate is very low in this case. The alignment problems are currently being corrected. Apart from the systematics and target errors, the angular uncertainties are expected to be dominated by the intrinsic chamber resolution, both in the NMS and in the target, and should amount to no more than 2.0 mr.

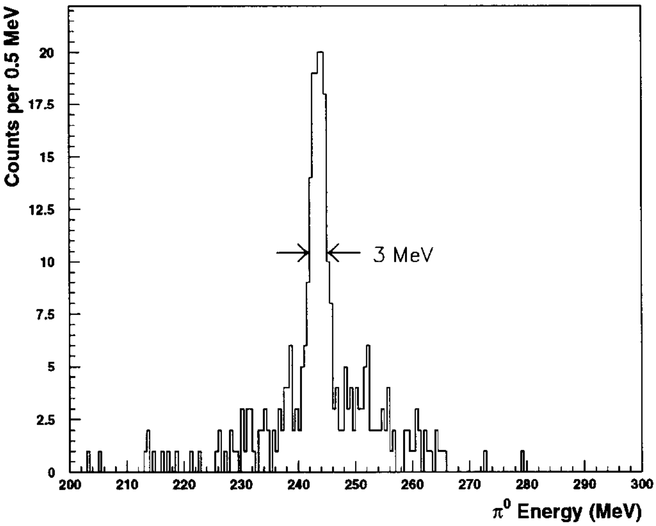

Figure 1. The energy distribution for π^0's produced in the reaction $K^+_{stop} \rightarrow \pi^+ + \pi^0$. At the time of this presentation, we have achieved a resolution of 3 MeV.

4. PRELIMINARY RESULTS

During the data-taking mode of the run about 1.45×10^8 K^- were stopped in the active target. The geometric acceptance of the NMS for the particular configuration in which this data was taken was 8 msr. The probablity for converting two γ rays in the BGO layers, one in each arm, is 0.36.

The 1997 run encountered many problems with the tracking chambers, which lead to low detection efficiency. Taking these into account, as well as detection and analysis efficiencies in the active target, we expect about 15 counts for the ground-state region of ${}^{12}_{\Lambda}B$ and about 30 counts for p_Λ excited states around 11 MeV in excitation energy. With the resolution achieved for the K^+ data, we do not expect to be able to resolve finer structure of ${}^{12}_{\Lambda}B$ as yet.

The π^0 total energy spectrum from the (K^-_{stop}, π^0) data is shown in Fig. 2. The cuts applied to the data to produce this plot are the same as those for the K^+ data. The focus of this experiment is in the region around $E_{\pi^0} = 300$ MeV. The ground state should appear around 307 MeV while the p-shell states should appear about 10 MeV lower. At the present resolution and statistics we cannot expect to resolve the doublet splittings, but we do see a hint of the s-shell and p-shell in both the full-scale figure and the expanded-scale spectrum shown in the insert. The structure around $E_{\pi^0} = 287$ MeV can be interpreted as resulting from production of Λ's on hydrogen.

The spectrum from the insert of Fig. 2 is shown in Fig. 3 as a function of the excitation

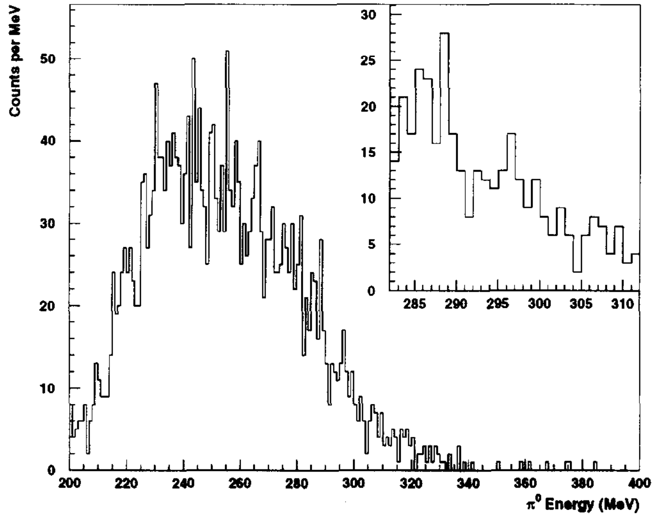

Figure 2. The energy distribution for π^0's produced in the reaction ${}^{12}C(K^-_{stop}, \pi^0)X$. The inserted histogram is the portion of the spectrum where we expect π^0's from ${}^{12}C(K^-_{stop}, \pi^0){}^{12}_{\Lambda}B$.

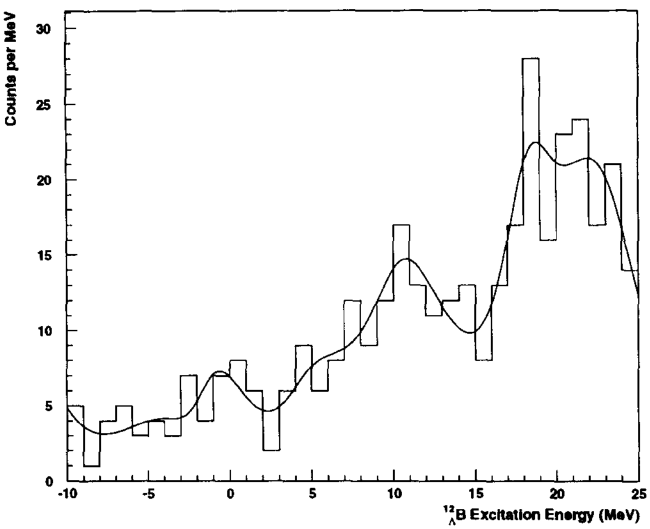

Figure 3. The ^{12}C(K^-_{stop}, π^0)X data plotted as a function of excitation energy in $^{12}_{\Lambda}$B. The curve superposed on the histogram is the result of a smoothing procedure.

energy of $^{12}_{\Lambda}$B. The solid curve is the result of smoothing of the histogram. The smoothing procedure enhances the evidence for s-shell and p-shell peaks near the expected zero and 10 MeV in excitation energy.

5. SUMMARY

We have seen evidence for what might be the first observation of states of $^{12}_{\Lambda}$B produced in the reaction (K^-, π^0). The analysis of the 1997 data is not yet complete, and we expect the current energy resolution of 3.0 MeV to improve and to approach our goal of 1.0 MeV in the near future. This would demonstrate the usefulness of the NMS for this type of spectroscopy. We are currently repairing the NMS tracking chambers, and are looking forward to a productive, high-statistics run in 1998.

ACKNOWLEDGEMENTS

We wish to acknowledge the assistance of Los Alamos National Laboratory and Cy Hoffman in making the Neutral Meson Spectrometer available for these measurements. We also appreciate the technical advice provided by Chris Morris, Dick Boudrie, and Jim Amann in the installation of the NMS at Brookhaven. The AGS staff, especially Joe Scaduto, was instrumental in setting up this device.

REFERENCES

1. R.L. Boudrie, C.L. Morris and J.L. Matthews, "Proposal for a High Resolution Spectrometer for Neutral Mesons" Los Alamos report LA-UR 91-1847 (1991).
2. M. Ahmed "E907 Live Target", in these proceedings.