Production of doubly-strange systems in the (K^-,K^+) reaction in E885 at BNL

P. Khaustov[2], D. E. Alburger[1], P. D. Barnes[6], B. Bassalleck[14], A. R. Berdoz[2], A. Biglan[2], T. Bürger[11], D. S. Carman[2], R. E. Chrien[1], C. A. Davis[13,8], H. Fischer[11], G. B. Franklin[2], J. Franz[11], L. Gan[13], A. Ichikawa[5], T. Iijima[3], K. Imai[5], Y. Kondo[5], P. Koran[2], M. Landry[13], L. Lee[13], J. Lowe[10,14], R. Magahiz[2], M. May[1], R. McCrady[2], C. A. Meyer[2], F. Merrill[6], T. Motoba[7], S. A. Page[13], K. Paschke[2], P. H. Pile[1], B. Quinn[2], W. D. Ramsay[13], A. Rusek[1], R. Sawafta[1], H. Schmitt[11], R. A. Schumacher[2], R. W. Stotzer[14], R. Sutter[1], F. Takeutchi[4], W. T. H. van Oers[13], K. Yamamoto[5], Y. Yamamoto[9], M. Yosoi[5], V. J. Zeps[12]

(The AGS E885 Collaboration)

[1]Brookhaven National Laboratory, Upton, NY 11973, USA, [2]Carnegie Mellon Univ., Pittsburgh, PA 15213, USA, [3]KEK, High Energy Accelerator Research Organization, Tsukuba, Ibaraki 305, Japan, [4]Kyoto Sangyo Univ., Kyoto 603, Japan, [5]Kyoto Univ., Sakyo-Ku, Kyoto 606, Japan, [6]Los Alamos National Laboratory, Los Alamos, NM 87545, USA, [7]Osaka Electro-Communication Univ., Neyagawa, Osaka 572-8530, Japan, [8]TRIUMF, Vancouver, BC V6T 2A3, Canada, [9]Tsuru Univ., Tsuru 402-8555, Japan, [10]Univ. of Birmingham, Birmingham B15 2TT, UK, [11]Univ. of Freiburg, D-79104 Freiburg, Germany, [12]Univ. of Kentucky, Lexington, KY 40507 USA, [13]Univ. of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada, [14]Univ. of New Mexico, Albuquerque, NM 87131, USA

The E885 collaboration utilized the 1.8 GeV/c K^- beam line at the AGS to accumulate greater than 10 times the world's existing data sample of (K^-,K^+) events on carbon. The data were used to search for signatures of the production of Ξ hypernuclei, double-Λ hypernuclei, and H Dibaryons. Evidence for the creation of $^{12}_{\Xi}$Be is seen. Reasonable agreement between the data and theory is achieved by assuming a Ξ-nucleus Wood-Saxon potential well depth, $V_{0\,\Xi}$, of about 14 MeV. Upper limits for the production of double-Λ hypernuclei are presented. Upper limits for H-Dibaryon production are presented which are a factor of 50 below calculated rates.

1. INTRODUCTION

Our understanding of the baryon-baryon interaction can be tested and expanded by studies of systems with non-zero strangeness. The YN interaction, in the $S = -1$ sector, has been explored by studies of Λ hypernuclei. However, unambiguous data pertaining to $S = -2$ systems are nearly nonexistent.

The E885 experiment at the AGS was performed to study the production of S=-2 systems. The experiment was senstive to the production of double-Λ and Ξ-hypernuclei and also produced the most sensitive search for the H-Dibaryon to date. Kaons from the

AGS 1.8 GeV/c separated beam line were focused on a ^{12}C target manufactured from synthetic diamond wafers. A K^+ spectrometer located downstream of the target was used to detect, identify, and momentum analyze the scattered K^+ mesons. The reconstructed momenta of the incident and outgoing kaons were used to determine the missing mass. A total of 3×10^5 (K^+,K^-) events were collected and analyzed.

2. PRODUCTION OF Ξ HYPERNUCLEI

Figure 1 shows experimental excitation energy histogram for ^{12}C(K^-,K^+)X in the region around zero hyperon binding. This excitation energy spectrum is equivalent to a missing mass spectrum with its zero shifted to correspond to the combined mass of ^{11}B+Ξ^-. Our energy resolution, 6.1 MeV/c^2 rms, was not sufficient to resolve individual hypernuclear states. However, we have made a comparison with theoretical predictions by smearing the theoretical calculations with our experimental resolution. The data clearly show an enhancement around zero excitation energy when compared to a Monte Carlo simulation based on quasi-free Ξ production which has been normalized to the total number of ^{12}C(K^-,K^+)X events (curve QF).

The theoretical double differential cross section for $^{12}\mathrm{C}(K^-, K^+)^{12}_{\Xi}\mathrm{Be}$ has been calculated, for both bound and unbound Ξ^-s, in the Kapur-Peirls framework which was developed originally for an estimate of the (π^+, K^+) strength function [1]. The DWIA calculation was performed for a K^- momentum of 1.8 GeV/c and outgoing K^+ angular range of $0° < \theta_{K^+} < 16°$. A series of Woods-Saxon Ξ^- well depth parameter values were used: $V_{0\Xi}$ = 12, 14, 16, 18, and 20 MeV. Further details of the calculation can be found in the references [2] and [3] in which the (K^-,K^+) cross sections for the ^{12}C and ^{16}O targets have been estimated for $p_{K^-} = 1.6$ GeV/c.

The theoretical $^{12}_{\Xi}$Be production curves for these Ξ potential well depths, folded with the 6.1 MeV r.m.s. experimental resolution, are shown for comparison with the data in Fig. 1. The expected location of the ground state of $^{12}_{\Lambda\Lambda}$Be (assuming a total binding energy of the Λ's, $B_{\Lambda\Lambda}$, of 25 MeV) and the thresholds for $^{11}_{\Lambda}\mathrm{Be} + \Lambda$ and $^{11}\mathrm{B} + \Xi^-$ production are indicated. Visual inspection shows that the theoretical curve for the value of the Ξ-nucleus potential well depth $V_{0\,\Xi}$ = 14 MeV agrees with the data reasonably well in the region of excitation energy -20 MeV<E<0 MeV and much better than the curve for $V_{0\,\Xi}$ = 20 MeV. If any of the observed signal results from direct two-Λ production without an intermediate $^{12}_{\Xi}$Be state, the discrepancy between the $V_{0\,\Xi}$ = 20 MeV results and the remaining experimental signal becomes even larger. We conclude that the excess of events below zero excitation energy are likely due to Ξ hypernuclear production but the Ξ potential depth is significantly shallower than the value of 21 MeV to 24 MeV extracted from early emulsion data by Dover and Gal[4].

3. PRODUCTION OF $^{12}_{\Lambda\Lambda}$Be HYPERNUCLEI

The $^{12}\mathrm{C}(K^-, K^+)$X excitation spectrum shown in Fig. 1 can be used to search for indications of the production of double-Λ hypernuclei through the reaction $^{12}\mathrm{C}(K^-, K^+)^{12}_{\Lambda\Lambda}\mathrm{Be}$. Since the double-$\Lambda$ hypernuclear states are expected to be much narrower than the our experimental resolution, 6.1 MeV r.m.s., the resultant peaks should be Gaussian with the resolution width. Bound states of $^{12}_{\Lambda\Lambda}$Be will be below the mass threshold of $^{10}\mathrm{Be} + 2\Lambda$

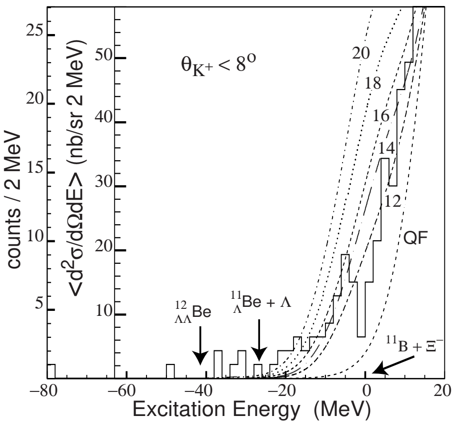

Figure 1. Excitation-energy spectra from E885 for ^{12}C(K$^-$,K$^+$)X for θ_{K^+} <14° (top figure) and θ_{K^+} <8° (bottom figure) along with $^{12}_{\Xi}$Be production theoretical curves for V$_{0\,\Xi}$ equal to 20, 18, 16, 14, and 12 MeV. Curve QF shows the results of a quasi-free Ξ production calculation.

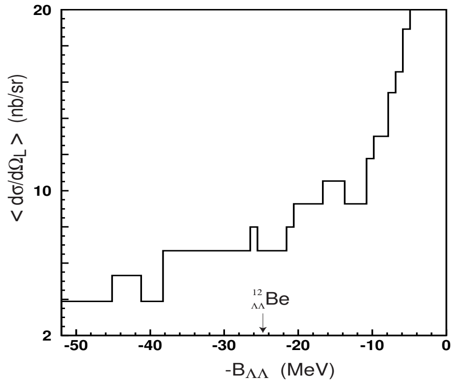

Figure 2. 90% C.L. upper limits on the production cross section of double-Λ hypernuclei, ^{12}C$(K^-,K^+)^{12}_{\Lambda\Lambda}$Be*, as a function of the binding energy of 2Λ's. The origin of the B$_{\Lambda\Lambda}$ axis corresponds to the (^{10}Be + 2Λ) mass.

which lies 17 MeV below that of ^{11}B + Ξ$^-$. Since no distinct peaks were seen in the bound region of $^{12}_{\Lambda\Lambda}$Be, we have set a 90% C.L. upper limit on the direct production cross section of $^{12}_{\Lambda\Lambda}$Be* in Fig. 2 as a function of the binding energy of 2Λ's, B$_{\Lambda\Lambda}$ ($= M_{^{10}\mathrm{Be}} + 2M_\Lambda - M_{^{12}_{\Lambda\Lambda}\mathrm{Be}}$). The K^+ scattering angle was averaged over $\theta_{K^+} < 14°$ in the laboratory frame. If the residual Λ-Λ binding energy is assumed to be 5 MeV as previously reported[5–7], the signal of the ground state would appear at B$_{\Lambda\Lambda}$ = 25MeV. The upper limit determined in this region is 6 ∼ 8 nb/sr, compared to 10 nb/sr for a 10 MeV excitation.

4. PRODUCTION OF THE H DIBARYON

Production of the H-dibaryon could occur via the (K^-,K^+) reaction on two protons in a nucleus: $K^- + (pp) \rightarrow K^+ + H$. A relatively narrow peak structure should be seen in the missing mass spectrum as A.T.M. Aerts and C.B. Dover have sgiwb in their calculation for a ^{3}He target: ^{3}He$(K^-,K^+)Hn$[8]. Although the peak position depends on the H mass, the peak will be well-separated from that of the quasi-free Ξ$^-$ production if the H is sufficiently light. We have calculated the expected peaks due to the direct H production in ^{12}C$(K^-,K^+)H + ^{10}$Be* using the method adopted by J.K. Ahn *et al.* [9]. It was assumed that the (K^-,K^+) reaction would take place with two protons in a carbon nucleus as mentioned above and that the residual ^{10}Be* would behave as a spectator in this model. Fig. 3 represents the excitation energy spectrum with several expected peak shapes corresponding to several assumed values for the H mass. No clear peak due to the H production was found in the spectrum. Some events in the deeply bound region may result from misidentification of pions and protons as kaons. From this experimental result, an upper limit on the cross section for direct H production was calculated with

90% C.L. as a function of the H mass, which is shown in Fig. 4. The structure seen in the upper limits is due to statistical fluctuations in the remaining background events. Again, the cross section was averaged over the scattering angle $\theta_{K^+} < 14°$. The resulting upper limit is in the range of a few nb/sr to 10 nb/sr for an assumed H mass below 2100 MeV/c^2.

The dashed line represents a theoretical calculation based on the scenario of A.T.M. Aerts and C.B. Dover[8]. The original calculation was performed for H production of a ^{3}He target and is shown as the dotted line in Fig. 4. We have obtained an upper limit which is fifty times lower than the theoretical calculation in the deeply bound region.

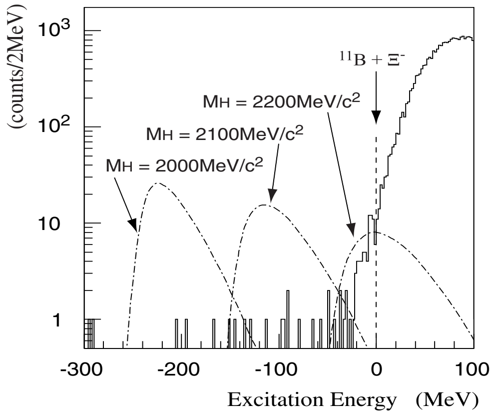

Figure 3. Expanded view of excitation energy spectrum. The dashed lines represent expected peak shapes of the H production with the H mass of 2000 MeV/c^2, 2100 MeV/c^2 and 2200 MeV/c^2 respectively.

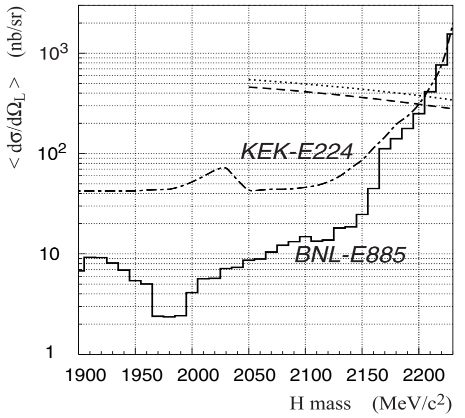

Figure 4. 90% C.L. upper limits for H production on ^{12}C. Theoretical calculation based on the model of Aerts and Dover (dashed line) and original calculation for ^{3}He target (dash-dot line). The KEK-E224 result is shown as dash-dotted line.

REFERENCES

1. T. Motoba, H. Bandō, R. Wünsch, and J. Žofka, Phys. Rev. C **38**, 1322 (1988).
2. Y. Yamamoto, T. Motoba, T. Fukuda, M. Takahashi and E. Ikeda, Prog. Theor. Phys. Suppl. **117**, 281 (1994).
3. K Ikeda, T. Fukuda, T. Motoba, M. Takahashi and Y. Yamamoto, Prog. Theor. Phys. **91**, 747 (1994).
4. C. B. Dover and A. Gal, Annals of Phys. **146**, 309 (1983).
5. M. Danysz et al., Phys. Rev. Lett. **11**(1963)29.
6. D. Prowse, Phys. Rev. Lett. **17**(1963)782.
7. S. Aoki et al., Prog. Theor. Phys. **85**(1991)1287.
8. A.T.M. Aerts and C.B. Dover, Phys. Rev. D **28**, 450 (1983).
9. J.K. Ahn *et al.*, Phys. Lett. B **378**, 53 (1996).