STUDY OF THE MISSING-MASS SPECTRA IN THE REACTIONS

$\pi^- d \rightarrow K^+ + \text{MM}$ AND $K^- d \rightarrow \pi^+ + \text{MM}$ AT 1.4 GeV/c

TO SEARCH FOR STRANGE DIBARYON STATES

[Rome-Saclay-Vanderbilt*) Collaboration]

G. D'Agostini¹⁾, G. Auriemma¹⁾, J.P. de Brion²⁾, A. Caillet²⁾, J.B. Cheze²⁾,
J. Derré²⁾, G. Marel²⁾, G. Marini¹⁾, G. Martellotti¹⁾, F. Massa¹⁾, A. Nigro¹⁾,
E. Pauli^{2,3)}, C. Pigot²⁾, A. Rambaldi¹⁾, S. Reucroft⁴⁾, C.E. Roos⁴⁾, A. Sciubba¹⁾,
G. Vrana^{2,5)}, J. Waters⁴⁾, M. Webster^{3,4)}

ABSTRACT

The reactions $\pi^- d \rightarrow K^+ + \text{MM}$ and $K^- d \rightarrow \pi^+ + \text{MM}$ have been studied at 1.4 GeV/c to search for strange dibaryon states with quantum numbers $Q = -1$, and $S = -1$. No structures are found which could indicate the production of such states and upper limits for the cross-sections are established.

(Submitted to Physics Letters B)

*) Research supported by NSF grant PHY80-01621.

1) INFN and Ist. di Fisica, Univ. di Roma, Rome, Italy.

2) DPhPE, CEN, Saclay, Gif-sur-Yvette, France.

3) CERN, Geneva, Switzerland.

4) Dept. of Physics, Vanderbilt University, Nashville, USA.

5) College de France, Paris, France.

1. INTRODUCTION

In recent years an increasing interest has been taken in dibaryon systems in the more general framework of multiquark states. The interest in dibaryons is twofold. On the one hand, dibaryons may be regarded as two nucleons bound by conventional nuclear forces. The deuteron, for example, is usually interpreted as such a state, although some recent work has raised the question of whether it should be considered as partially composed of a six-quark state [1]. On the other hand, since the advent of QCD, many theoretical models predict states with more than three quarks bound by "colour" forces rather than by "mesonic" forces [2].

In the field of strange dibaryons, there is only one clear candidate for such states. It is the so-called H_1^+ , which has quantum numbers $Q = +1$, $S = -1$, $I = 1/2$, and a mass of $2.13 \text{ GeV}/c^2$. It has been seen in several bubble-chamber experiments [3] as an enhancement in the invariant mass of the (Λp) system, just below the (ΣN) threshold, in the reaction $K^- d \rightarrow \pi^- \Lambda p$. The production cross-section seems to have a strong momentum-transfer dependence ($\sim e^{-30t}$). Recently, in an experiment performed by our Collaboration, the existence of such a state has been confirmed in the reaction $K^- d \rightarrow \pi^- + MM$ and it has been observed for the first time in the line-reversed reaction $\pi^+ d \rightarrow K^+ + MM$ [4].

Our Collaboration at the CERN PS (experiment PS159) has been using a missing-mass spectrometer to search in several reactions for different dibaryon systems. In this paper we present the results obtained on the reaction

$$\pi^- d \rightarrow K^+ + MM \quad (1)$$

and on the line-reversed reaction

$$K^- d \rightarrow \pi^+ + MM \quad (2)$$

at $1.4 \text{ GeV}/c$ incident momentum. The observed missing-mass spectrum ($Q = -1$, $S = -1$) ranges from ~ 2.0 to $\sim 2.4 \text{ GeV}/c^2$. A dibaryon state would appear as an enhancement above the background due to the interaction of the beam particle with a single nucleon of the deuteron.

A possible signal near the (Σ^-n) threshold could be interpreted as a hyper-nuclear $I = 3/2$ bound state. In the past, many experiments have searched, with negative results, for such a state; among them two counter experiments [5,6] have looked for the existence of a spin singlet (Σ^-n) state by detecting particles produced at large angles. Recent indications [7] of the existence of a (Σ^-n) bound state near threshold have not been confirmed. Our apparatus, whose acceptance is strongly peaked in the forward direction, is appropriate to search for the existence of a possible spin triplet state.

2. THE MISSING-MASS SPECTROMETER

The experimental set-up (see fig. 1), together with the characteristics of the separated beam and the procedure of analysis, has been fully described elsewhere [8]. We recall briefly that it consists of a single-arm forward magnetic spectrometer in which the identification of the trigger particle produced in the 40 cm target is achieved with aerogel ($\check{C}_1$) and water ($\check{C}_2$) Čerenkov counters and high-resolution time-of-flight measurements between counters S_2 and H_j . The fraction of the solid angle $\Delta\Omega^*/4\pi$ covered in the centre-of-mass system (c.m.s.) by the spectrometer is of the order of $\approx 1\%$. The trigger particle momentum is measured with a resolution of $\Delta p/p^2 \approx 6 \times 10^{-3} \text{ (GeV/c)}^{-1}$.

The beam momentum is measured by an upstream magnetic spectrometer, with a resolution of $\Delta p/p \approx 2 \times 10^{-3}$; the rejection of the residual beam contamination is obtained through an aerogel Čerenkov counter ($\check{C}_0$) and time-of-flight measurements between two counters, S_1 and S_2 .

In studying the reaction (2) a set of twelve scintillation counters (T) was added around the target, to reduce the large number of triggers due to the 3π decay mode of the K^- beam particles. The signals from counters T were used in the trigger logic to select events with at least one additional large-angle particle (T counter multiplicity $m_T \geq 1$), thus rejecting a substantial fraction of beam decays. Therefore the trigger was $(S_1 \cdot \check{C}_0 \cdot S_2 \cdot P_2) \cdot \check{C}_1 \cdot (m_H = 1) \cdot (H_C \cdot \check{C}_2)$ for reaction (1) and $(S_1 \cdot \check{C}_0 \cdot S_2 \cdot P_2) \cdot (m_T \geq 1) \cdot \check{C}_1 \cdot (m_H = 1) \cdot (H_C \cdot \check{C}_2)$ for the reaction (2), in the

notation of ref. [8]. Furthermore, for the reaction (2), an on-line cut on the momentum of the forward particle was used, such that momenta less than 0.9 GeV/c were rejected. This cut drastically reduced $K_{\pi 3}$ beam decays, but limited the accepted missing-mass range to less than $\sim 2.35 \text{ GeV}/c^2$.

The acceptance of the apparatus has been evaluated by Monte Carlo calculations in the reactions $\pi^- d \rightarrow K^+ + H_1^-$ and $K^- d \rightarrow \pi^+ + H_1^-$ for a ($Q = -1, S = -1$) H_1^- dibaryon isotropically produced in the centre of mass. The acceptance is almost independent of the dibaryon mass, in the range 2.0-2.4 GeV/c^2 , and is $\sim 0.5\%$ for reaction (1) and $\sim 0.3\%$ for reaction (2). The difference is mainly due to the presence in the trigger of the additional target counters T. The acceptance is considerably larger if the dibaryon production is strongly peaked at low momentum transfer to the deuteron.

The missing-mass resolution was investigated in several reactions on a hydrogen target. In the reaction $\pi^+ p \rightarrow K^+ + \Sigma^+$ at 1.4 GeV/c the Σ^+ mass was measured with a resolution of $\sigma \sim 3.5 \text{ MeV}/c^2$ [8]. The kinematics on a deuterium target results in an expected resolution of $\sigma \sim 5 \text{ MeV}/c^2$ for the reaction (1), and $\sigma \sim 7 \text{ MeV}/c^2$ for the reaction (2).

The pion reactions on hydrogen were also used to evaluate the overall experimental detection efficiency by comparing the forward cross-sections measured in our apparatus with previously published data [9]. The systematic error, mainly due to the large uncertainty in the published differential cross-sections, is $\sim \pm 25\%$.

3. RESULTS ON THE REACTION $\pi^- d \rightarrow K^+ + \text{MM}$

The missing-mass spectrum for reaction (1) is shown in fig. 2a. The sample of 25773 events corresponds to an incident flux of $2.71 \times 10^{10} \pi^-$, i.e. a total sensitivity of 53.2 events/nb.

The dashed line gives the Monte Carlo simulation of the reaction $\pi^- p(n) \rightarrow K^+ \Sigma^-(n)$, where (n) is a neutron spectator, while the solid line also takes into account the contribution due to the process $\pi^- p(n) \rightarrow K^+ \Lambda \pi^-(n)$. These

Monte Carlo calculations use a momentum distribution of the neutron spectator taken from Ref. [10]. The well-known uncertainties of this distribution particularly affect the tail of the evaluated distributions. Nevertheless, as can be seen, the sum of these two channels fits very well the experimental data and there is no evidence for structures either below or above the $(\Sigma^- n)$ threshold.

We can therefore set an upper limit for the production cross-section of a possible dibaryon resonance. Figure 2b shows this limit, at the 95% confidence level, as a function of missing mass. Estimated systematic errors are included, and for the resonance we have assumed a width negligible with respect to the experimental resolution, $\sigma \sim 5 \text{ MeV}/c^2$. At $(\Sigma^- n)$ threshold the upper limit of the c.m.s. differential cross-section for the production of a dibaryon state in the backward direction turns out to be $\sim 23 \text{ nb/sr}$.

One can also extract from the data the c.m.s. differential cross-section of the process $\pi^- p(n) \rightarrow K^+ \Sigma^-(n)$, for the K^+ at 0° . From the fit shown in fig. 2a one obtains $14.0 \pm 3.5 \text{ } \mu\text{b/sr}$. This result is consistent with the Σ^- production cross-section on hydrogen [9].

4. RESULTS ON THE REACTION $K^- d \rightarrow \pi^+ + \text{MM}$

The experimental missing-mass spectrum of 64 295 events obtained in reaction (2) is shown in fig. 3a. The incident flux was $6.84 \times 10^9 K^-$, corresponding to a total sensitivity of 13.4 events/nb.

The analysis of this process is complicated by the presence of several different contaminations. Although the largest contamination, due to the already mentioned $K_{\pi 3}$ beam decays, is out of the mass range explored, a small contribution comes from other sources. All the possibilities have been studied by Monte Carlo calculations and found to be rather small in the accepted mass range. We will mention here only the most important, i.e. the smooth background due to the channel

which starts at $\sim 2.05 \text{ GeV}/c^2$ and correctly accounts for the small contamination below the $(\Sigma^- n)$ threshold.

The dashed line in fig. 3a shows the contribution coming from the process $K^- p(n) \rightarrow \pi^+ \Sigma^-(n)$. The shape has been evaluated by Monte Carlo calculations as before. The solid line takes into account also the contributions due to $K^- p(n) \rightarrow \pi^+ \Lambda \pi^-(n)$ and to the contaminations mentioned above. The sum of these effects gives a curve which fits well the experimental data.

Again, as for the previous reaction, we can set an upper limit at the 95% confidence level for the backward production of a narrow dibaryon state of a width negligible with respect to the experimental resolution, $\sigma \sim 7 \text{ MeV}/c^2$. This limit, including the estimated systematic error, is shown in fig. 3b as a function of missing mass. At $(\Sigma^- n)$ threshold the upper limit of the c.m.s. differential cross-section for the backward production of a dibaryon state is $\sim 1.7 \text{ } \mu\text{b}/\text{sr}$.

The c.m.s. differential cross-section for a forward π^+ in the reaction $K^- p(n) \rightarrow \pi^+ \Sigma^-(n)$, extracted from the fit shown in fig. 3a, is $250 \pm 60 \text{ } \mu\text{b}/\text{sr}$. Again the result is consistent with the existing data of the Σ^- production on hydrogen [11].

5. CONCLUSIONS

We have set experimental upper limits for the production cross-section on deuterium of dibaryon states with quantum numbers $Q = -1$ and $S = -1$. In particular, for a bound state at $(\Sigma^- n)$ threshold, the experiment gives, at 95% confidence level, the following upper limits for the c.m.s. backward-production differential cross-section at $1.4 \text{ GeV}/c$:

$$\frac{d\sigma}{d\Omega^*} \leq 23 \text{ nb}/\text{sr} \text{ in reaction (1) ,}$$

$$\frac{d\sigma}{d\Omega^*} \leq 1.7 \text{ } \mu\text{b}/\text{sr} \text{ in reaction (2) .}$$

The relative significance of these two limits can be appreciated in the framework of a triangular diagram production mechanism (see fig. 4). In this

scheme the ratio (R) of the two expected c.m.s. differential cross-sections should be given approximately by the ratio of the corresponding two "feeding" cross-sections and of the squared deuteron form factor, $F^2(q)$, evaluated in the two different kinematical situations. Thus,

$$R = \frac{\left[\frac{d\sigma(K^- d \rightarrow \pi^+ H_1^-)}{d\Omega^*} \right]_{\theta_{\pi^+}^* = 0^\circ}}{\left[\frac{d\sigma(\pi^- d \rightarrow K^+ H_1^-)}{d\Omega^*} \right]_{\theta_{K^+}^* = 0^\circ}} \sim \frac{\left[\frac{d\sigma(K^- p \rightarrow \pi^+ \Sigma^-)}{d\Omega^*} \right]_{\theta_{\pi^+}^* = 0^\circ}}{\left[\frac{d\sigma(\pi^- p \rightarrow K^+ \Sigma^-)}{d\Omega^*} \right]_{\theta_{K^+}^* = 0^\circ}} \cdot \frac{F^2(q'')}{F^2(q')},$$

where q' and q'' are the laboratory neutron momenta.

Assuming the values of refs. [9] and [11] for the "feeding" cross-sections, the ratio R turns out to be of the order of 5×10^2 . According to this rough model, the upper limit obtained in reaction (2) would be more stringent than the one obtained in reaction (1).

We conclude that, within the limits shown in figs. 2b and 3b, we observe no $S = -1$, $I = \frac{3}{2}$ dibaryonic triplet state.

Acknowledgements

We have very much appreciated the CERN hospitality and we thank the PS Division for the very efficient operation of the Proton Synchrotron over the last two and a half years.

REFERENCES

- [1] V.A. Matveev and P. Sorba, Lett. Nuovo Cimento 20, 435 (1977).
- [2] See, for example
R.L. Jaffe, Phys. Rev. Lett. 38, 195 (1977);
Chan Hong-Mo, M. Fukugita, T.H. Hansson, H.J. Hoffman, K. Konishi,
H. Høgaasen and Tsou Sheung Tsun, Phys. Lett. 76B, 634 (1978);
P.J. Muldert, A.T. Aerts and J.J. De Swart, Institute for Theoretical
Physics, Nijmegen, Report THEF-NYM-79.19 (1979).
- [3] Tai Ho Tan, Phys. Rev. Lett. 23, 395 (1969);
D. Eastwood, J.R. Fry, F.R. Heathcote, G.S. Islam, D.J. Candlin, G. Gopley,
G.R. Evans, J.R. Campbell, W.T. Morton, P.J. Negus, M.J. Counihan,
D.P. Goyal, D.B. Miller and B. Schwarzschild, Phys. Rev. D 3, 2603 (1971);
O. Braun, H.J. Grimm, V. Hepp, H. Stroebele, C. Thoel, T.J. Thouw,
F. Gandini, C. Kiesling, D.E. Plane and W. Wittek, Nucl. Phys. B124, 45
(1977).
- [4] G. D'Agostini et al., Evidence for the production of a 2130 MeV/c² dibaryon
state ($Q = +1$, $S = -1$) in the reaction $\pi^+d \rightarrow K^+ + MM$ at 1.4 GeV/c, to
be published.
- [5] H.F. Davis and H.R. Gustafson, Phys. Rev. D 1, 2989 (1970).
- [6] M. May, Proc. 2nd Int. Conf. on Meson-Nuclear Physics, Houston, 1979 AIP
Conf. Proc. No. 54 (Ed. E.V. Hungerford III, 1979), p. 658.
- [7] H. Stroebele, H.G. Dosh, O. Braun and V. Hepp, preprint CERN HD-TH-80-5
(1980);
H. Stroebele, H.G. Dosh, O. Braun and V. Hepp, Baryon 1980, Proc. 4th Int.
Conf. on Baryon Resonances, University of Toronto, Toronto, 1980 (ed.
Nathan Isgur) (University of Toronto, Toronto, 1980), p. 357.

- [8] G. D'Agostini, M. Arrignon, G. Auriemma, A. Bezaguet, J.P. de Brion,
A. Caillet, J.B. Cheze, J. Derré, G. Ducastaing, G. Durand, E. Gennari,
M. Lemoine, R. Llosa, G. Marel, G. Marini, G. Martellotti, F. Massa,
A. Nigro, E. Pauli, C. Pigot, A. Rambaldi, S. Reucroft, C.E. Roos,
B. Rothan, K. Schultze, A. Sciubba, S. Tentindo, J. Vrana, M. Webster
and E.G.H. Williams (Rome-Saclay-Vanderbilt Collaboration), A missing
mass spectrometer for momenta below 1.5 GeV/c, preprint CERN EP/81-17
(1981). To be published in Nucl. Instrum. Methods.

- [9] Ph. Livanos, Thesis, Université de Paris-Sud (1980), to be published;
Ph. Livanos, J.P. Baton, C. Coutures, C. Kochowski and M. Neveu, Baryon
1980, Proc. 4th Int. Conf. on Baryon Resonances, University of Toronto,
Toronto, 1980 (ed. Natham Isgur) (University of Toronto, Toronto, 1980),
p. 35;
G.E. Kalmus, G. Borreani and J. Louie, Phys. Rev. D 2, 1824 (1970);
E. Arik, D.R.S. Boyd, C. Brankin, D.J. Candlin, I.F. Corbett, S.M. Fisher,
M.G. Green, G.D. Hallewell, G.S. Ioannidis, P.J. Litchfield, D.C. Lowe,
L.P. Mapelli, K.J. Peach, B. Pollock, L.R. Scotland and A. Shirani,
Baryon 1980, Proc. 4th Int. Conf. on Baryon Resonances, University of
Toronto, Toronto, 1980 (ed. Natham Isgur) (University of Toronto, Toronto,
1980), p. 27.

- [10] G. Alberi, L.P. Rosa and Z.D. Thomé, Phys. Rev. Lett. 34, 503 (1975).

- [11] R. Armenteros, M. Ferro-Luzzi, D.W.G.S. Leith, R. Levi-Setti, A. Minten,
R.D. Tripp, H. Filthuth, V. Hepp, E. Kluge, H. Schneider, R. Barloutaud,
P. Granet, J. Meyer and J.P. Porte, Nucl. Phys. B8, 233 (1968);
A. Berthon, J. Vrana, I. Butterworth, P.J. Litchfield, J.R. Smith, J. Meyer,
E. Pauli and B. Tallini, Nucl. Phys. B24, 417 (1970);
D.F. Kane, Phys. Rev. D 5, 1583 (1972);
A. Caillet, Thesis, Université de Paris-Sud (1981).

Figure captions

Fig. 1 : The experimental set-up.

Fig. 2 : a) Missing-mass spectrum for the reaction $\pi^- d \rightarrow K^+ + MM$ at 1.4 GeV/c.

The dashed curve gives the Monte Carlo prediction for the contribution $\pi^- p(n) \rightarrow K^+ \Sigma^-(n)$, while the solid line takes into account also $\pi^- p(n) \rightarrow K^+ \Lambda \pi^-(n)$. The thresholds for the possible non-resonant channels are shown. The experimental missing-mass resolution is $\sigma \approx 5 \text{ MeV}/c^2$.

b) Upper limit, at 95% confidence level, of the c.m.s. differential cross-section for the production of a narrow dibaryon state in the backward direction. Estimated systematic errors are included.

Fig. 3 : a) Missing-mass spectrum for the reaction $K^- d \rightarrow \pi^+ + MM$ at 1.4 GeV/c.

The dashed curve gives the Monte Carlo prediction for the contribution $K^- p(n) \rightarrow \pi^+ \Sigma^-(n)$. The solid line also takes into account the channel $K^- p(n) \rightarrow \pi^+ \Lambda \pi^-(n)$ as well as the background discussed in the text. The thresholds for the possible non-resonant channels are shown. The experimental missing-mass resolution is $\sigma \approx 7 \text{ MeV}/c^2$.

b) Upper limit, at 95% confidence level, of the c.m.s. differential cross-section for the production of a narrow dibaryon state in the backward direction. Estimated systematic errors are included.

Fig. 4 : Triangular diagrams for the production of an H_1^- state (see text).

In order to evaluate the ratio R described in the text, the following simplified assumptions were made: the "spectator" neutron momentum was evaluated assuming the proton being off-mass shell; the Σ^- and neutron were assumed to have the same velocity; phase-space effects were ignored.

Čerenkov Counters

- χ_0 : Aerogel ($n=1.05$)
 χ_1 : Aerogel ($n=1.094$)
 χ_2 : Water with wave-length shifter

Multi Wire-Proportional-Chambers

- $Ch_{11,12,13,14,15}$: 1mm spacing MWPC
 $Ch_{1,2,3,4}$: 2mm spacing MWPC

Scintillation Counters

- S_1 : PILOT-U Scintillator 5x10x0.5 cm³
 S_2 : PILOT-U Scintillator 5x10x1 cm³
 P : NE 110 Scintillator 4x3x0.3cm³
 H_j ($j=1,,9$): PILOT-U Scint. 25x75x2.5cm³
 H_c : NE 110 Scintillator 225x55x1 cm³

Fig. 1

Fig. 2

Fig. 3

Fig. 4