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RECENT SEARCHS FOR $S = -1$ STRANGE DIBARYONS

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RECENT SEARCHS FOR S = -1 STRANGE DIBARYONS

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For twenty five years the field of dibaryons has been the subject of extensive work, both theoretical and experimental. Many candidates have been proposed, but very few remain after a larger number of precise experiments, in particular for the proposed non-strange dibaryon resonances. One must first define what is a dibaryon and we would retain the definition of Heddle and Kisslinger [1] "Dibaryons are resonances or bound states in a two baryon system which cannot be explained as baryons interacting via hadronic exchanges". Such states are predicted in particular in quark phenomenology. Bag models [2] which have been generally successful in reproducing the observed meson and baryon spectra predict a spectrum of multi-quark states [3,4,5] such as the Q^6 type.

Concerning narrow dibaryons, it is well known by considerations on colour-magnetic forces of QCD [6] that six-quark states are more likely for strange systems. Among the most extensive calculations the predictions of the Nijmegen group [3,4] are based on the MIT bag model. They have considered all colour-singlet arrangements of six-quarks into two clusters of m and n quarks (m+n = 6) with SU (3) colour representations c and c'. Aerts and Dover [7] have studied the stability of these individual quark clusters against spontaneous dissociation by quark emission as well as the stability of these $Q^n \times Q^m$ states against dissociation into two colour-singlet baryons.

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The maximum of stability is reached when the spin of the clusters is zero and their flavor representations are of lower dimensionality. The optimum case, which is the S = −2 state, flavour singlet called the H, could even be stable with respect to strong decay. A search for this H dibaryon has been made at the Brookhaven National Laboratory by means of the $pp \rightarrow K^+K^+X$ reaction [8]. No narrow structure was observed; upper limits for the production cross section of such a state vary from 30 to 130 nb depending upon mass. Another experiment performed at CERN [9], looking for S = −2, I = 1 states in the reaction $d(K^-, K^+)$ H, did not show evidence for narrow structures ($\Gamma \leqslant 8$ MeV) at the level of 5 to 40 nb/sr. These results do not rule out the existence of the H, since no reliable estimates of the production cross section can be made.

There is no flavour singlet in either the S = −1 or S = 0 six quark systems. However the six quark S = −1 system permits a lower dimensional flavour representation than for S = 0 and is favoured energetically. Two candidates emerge from table 1, where are listed predictions concerning the S = −1 and S = −2 dibaryons, which are of $Q_4 \times Q_2$ structure, coupling to P waves of the baryon–baryon system. The strong decay widths of these states which are respectively spin singlet (D_S) and spin triplet (D_T), have been calculated by Aerts and Dover [7] and found to be less-than 10 MeV. They are predicted to lie 40MeV apart just below (M_{D_S} = 2.11 GeV) and above (M_{D_t} = 2.15 GeV) the ΣN threshold (2.13 GeV). There have been several experiments which indicate structure in the Λp missing mass spectrum in this mass range for the reaction d (K^-, π^-) Λp [10,11,21].

S	Quark structure	$^{2I+1,2S+1}L_J$	Mass (MeV)
− 2	$(qqss)_3 - (qq)_3$	$^{11}P_1$	2295
− 2	$(qqqs)_3 - (qs)_3$	$^{11}P_1$ $^{31}P_1$	2297
− 2	$(qqss)_3 - (qq)_3$	$^{13}P_J$	2330
− 2	$(qqqs)_3 - (qs)_3$	$^{13}P_J$ $^{33}P_J$	2337
− 1	$(qqqs)_3 - (qq)_3$	$^{21}P_1$	2112
− 1	$(qqqs)_3 - (qq)_3$	$^{23}P_J$	2152

TABLE 1 – Strange $q^4 - q^2$ dibaryons lying below the ΛΛπ (for S = −2 states) or the ΛNπ (for S = −1 states) thresholds predicted by Mulders, Aerts and de Swart [ref. 3].

The main characteristic of these results is the observation of a peak at 2.129 GeV at the ΣN threshold, with a narrow width (< 10 MeV). This effect is strongly favoured when a cut is done on the momentum of correlated spectator protons, keeping those having a momentum higher than 100 MeV/c^2. The angular distribution is peaked at 0°. The more recent, complete experiment studying this effect has been performed at CERN by a Rome-Saclay-Vanderbilt collaboration [12] comparing the two reactions :

$$(1)\ K^-d \rightarrow \pi^- + X \quad \text{and}$$
$$(2)\ \pi^+d \rightarrow K^+ + X$$

Results from the reaction (2) are given in fig. 1. One observes the influence of the multiplicity cut M_T on the emergence of the threshold effect at 2.13 GeV : for $M_T \geq 3$, which corresponds at least to 1 proton and two charged particles coming from the Λ decay, the two bumps at 2.07 and 2.17 GeV corresponding to the quasi free production of Λ and Σ disappear and the ΣN threshold effect shows up strongly. This effect is now commonly associated with a cusp effect due to the opening of the ΣN threshold and the strong coupling of this channel to the Λp channel. However, a detailed analysis of the data does not rule out completely the presence of a small resonant contribution in the matrix elements of reactions (1) and (2) at ΣN threshold [12].

Since kaons and pions are spin zero, and since the elementary $KN \rightarrow \pi Y$ spin-flip amplitude is an order of magnitude lower than the non-spin-flip amplitude, the dibaryon that would preferentially be produced in the (K^-,π) and (π,K^+) reactions is the D_t. In the case of the (K^-,π) reaction, to observe the D_t, which is coupled to P-waves of the B-B channel, it is necessary to look at specific angles for the emitted pions, indicative of the $\Delta L = 1$ transition. This experiment with kinematical conditions such as $\theta_\pi \neq 0°$ has been recently performed at Brookhaven (experiment AGS 773) [13]. The incident kaon momentum was 870 MeV/c . Their results are presented on fig. 2 for pion angles ranging from 9 to 27° : the large bump observed would correspond to the sum of two peaks : the first one would be the cusp effect at 2129 MeV, the second one is a peak centered at 2139 MeV ± 2 MeV with a width $\Gamma = 8 \pm 2$ MeV; the differential cross section follows the expected slope for the D_T state production (maximum at 21°) [6]. The same group has acquired new data at $\theta_\pi = 22°$

and confirm the previous results. One can note that a bubble chamber experiment performed by Tan et al. [11] for $K^-d \to \pi^-$ (Λp) using stopped K^- showed the same kind of result with two peaks in the missing mass spectrum shown on fig. 3 : the second peak at 2138.8 ± 0.7 MeV with $\Gamma = 9.1 \pm 2.4$ MeV was already presented by Aerts as a good candidate for the D_T dibaryon.

The $pp \to K^+ X$ reaction is a simple system in which the hyperon-nucleon interaction can be studied through final state interaction (FSI) between the two baryons in the output channel, and thus effects of both D_S and D_t dibaryons may be observed. A $pp \to K^+X$ experiment was performed at BNL in 1968 [14] which was statistically accurate but suffered from a poor K^+ momentum resolution and bad absolute momentum determination. This experiment showed a strong FSI just above the Λp (2054 MeV) threshold in the Λp missing mass spectra taken at $\theta_K = 0$ for two different incident proton energies (T_p = 2.85 and 2.4 GeV) (see fig. 4). The analysis of this experiment in terms of a simple S-wave formalism yields scattering lenghts compatible with the scattering lenghts determined in ref. [15] by the analysis of the available $\Lambda p \to \Lambda p$ data. These data are very few for kinetic energies in the range $6 < T_\Lambda < 45$ MeV and show some discrepancies at one energy (Berkeley 71 and 77).

A new $pp \to K^+X$ experiment has been performed at the Saturn National laboratory with high resolution to study Λp and ΣN FSI in a large range of momentum transfer and missing mass. The experiment utilizes the SPES 4 beam line. The experimental set up has been given elsewhere [16]. The SPES 4 beam line is a 32 meter long spectrometer which allows the momentum analysis of particles up to 4 GeV/c: the solid angle of the spectrometer is $\Delta\Omega = 2.5\ 10^{-4}$ with momentum acceptance $\Delta p/p = \pm 3.5$ % and momentum resolution 10^{-4}. The protons and pions are partly rejected by means of total reflection Cerenkov detectors. The discrimination between particles (protons, pions and kaons) is obtained by velocity measurements over a 16 meter flight path. A typical spectrum is shown in fig. 5 applying more restrictive Cerenkov amplitude windows off line.

Using multidrift chambers, reconstruction of particle trajectories are done at the focal plane and a missing mass spectrum is obtained. The results of a this investigation include cross sections for K^+ at $\theta_K = 0°$, 6, 8, 10 and 12°. K^+ for protons of 2.3 GeV. The Θ_K = 10° missing mass spectrum is shown on fig. 6. The error bars are only statistical. The total number of events is 7500 over the full mass spectrum. The spatial resolution in the dispersive plane is of the order of 0.5 mm, leading to a momentum resolution for the retracing of about .250 MeV/c at 1200 MeV/c. The energy losses in the target and in the scintillators at the intermediate focal plane and the multiple scattering yields an energy straggling of 2.3 MeV (FWHM). This has been checked on ^{12}C (p,p') low level excitations. The missing mass spectrum, which is shown, is the result of a convolution of the data by 3 MeV bins. The general trend of this new spectrum is compatible with a previous one having less statistics [16] : the small deviations at 2065 and 2085 MeV which were observed with low confidence level are not confirmed here. The thresholds for the Λ and Σ^+ production are shown. The full lines correspond to the phase space calculations of the reactions pp → K^+ Λp and → $K^+\Sigma^+n$ or $K^+\Sigma^\circ p$. The missing mass spectrum shows two strong deformations in comparison to the phase space calculation.

In order to understand the basic meson production process, which does not require a dibaryon resonance, one traditionally has employed a meson exchange model. Fair agreement with experiments has been achieved in the case of pion production where extensive data are available. In the case of kaon production early calculations done in the 1960's [17] showed that the kaon exchange mechanism dominates the pp → $K^+\Lambda p$ reaction. Due to a lack of data the predictions were restricted to total cross sections where FSI play a minor role. This is not the case for the forward differential cross section since the Λ produced can undergo a strong low energy interaction with the spectator proton. This effect is clearly seen in the SATURNE experiment which exhibits strong enhancement in the Λ-p missing mass close to threshold.

We present here preliminary calculations of the pp → $K^+\Lambda p$ differential cross section done within the one kaon exchange mechanism with Λ-p final state interaction by J.F. Germond. The model is best illustrated by the graph of fig. 7. Technical details of the calculations are based upon work [18] on pion production off nuclei. One finds a linear relation between the pp → $K^+\Lambda p$ and the K^+p → K^+p amplitudes. Due to antisymmetry the K^+p elastic scattering amplitude is required both in the forward and backward direction. It is taken here to be the same which is consistent with recent K^+p phase shift analysis [19]. The Λ-p final state interaction was parameterized in the s-wave by a separable potential with parameters adjusted to a scattering length a and effective range r_0 identical for the singlet and triplet s-state ($a = -1.80$ fm, $r_0 = 3.42$ fm). No attempt to get an absolute normalization was done although this is quite possible in this model. In order to simplify the calculations non-relativistic kinematics for the Λ-p pair have been used which is consistent with the treatment of the final interaction. The predictions for the missing mass spectra below the Σ threshold are compared in fig. 6 with the data on pp → K^+X reaction at 2.3 GeV. An overall energy resolution of 10 MeV was convoluted with the theoretical calculations. The region of the FSI in the missing mass spectrum close to the Λp threshold is rather well reproduced. A discrepancy between this calculation and the data appears at higher missing mass ; a p-wave contribution to the Λp scattering cross section, which is not taken into account in this calculation, could explain this discrepancy. Nevertheless a small structure seems to appear around 2095 MeV in missing mass, with a low confidence level. The analysis of the other missing mass spectra at θ = 6, 8, 12°; which is in progress, has to confirm or not this structure.

Concerning the mass region starting at (ΣN) - threshold, two structures are clearly seen : the first one at 2129 MeV corresponds to the well-known cusp effect [20] : the second one which shows up at 2140 MeV could be associated to the structure observed in previous experiments, either bubble chamber events with inflight K^- [21] or from rest [11] or in a (K^-,π^-) recent experiment performed at BNL [13]. The width of the observed effect is a few MeV. Calculations of the cross section around the ΣN thresholds in terms of the meson (π or K) exchange model are in progress.

The pp → K^+X experiment at LNS is a collaboration between the following physicists :

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FIGURES

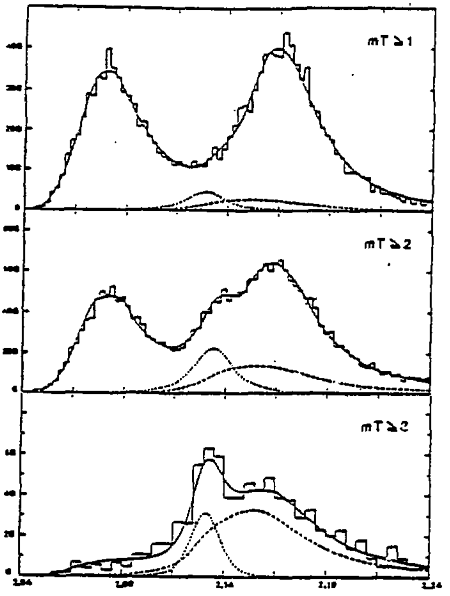

Fig. 1 : The $\pi^+d \to K^+X$ missing mass spectrum for 1.4 GeV/c pion momentum, (Ref. 12)

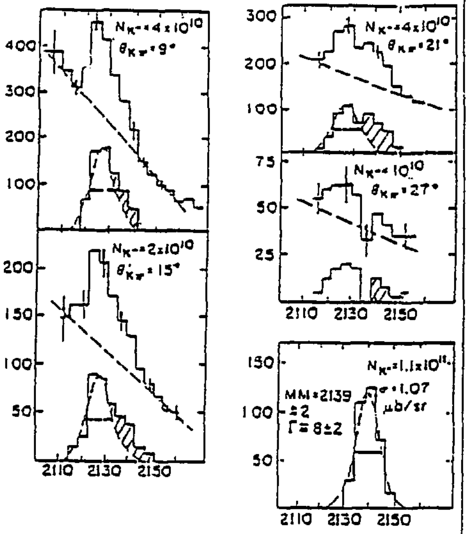

Fig. 2 : The $K^+d \to \pi^-X$ missing mass spectrum for .87 GeV/c Kaon momentum, (Ref. 13)

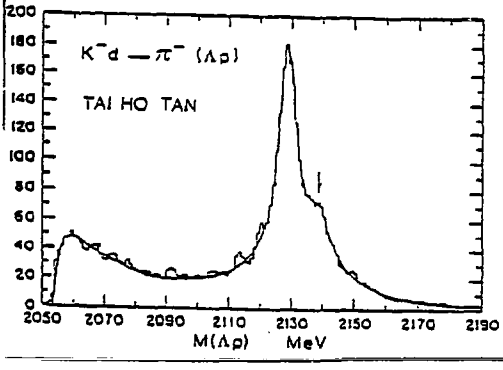

Fig. 3 : The $K^-d \to \pi^-\Lambda p$ missing mass spectrum for stopped K^- (Ref. 11)

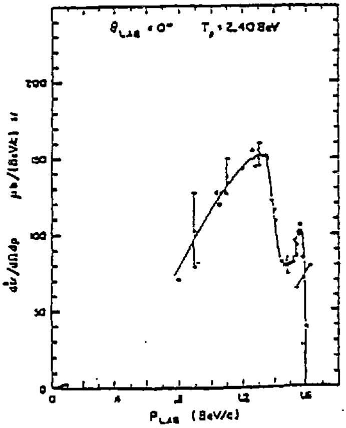

Fig. 4 : The $pp \to K^+X$ missing mass spectrum for 2.4 GeV proton kinetic energy. (Ref. 14)

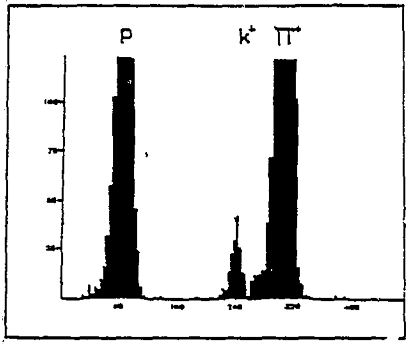

Fig. 5 : Typical time spectrum from this experiment

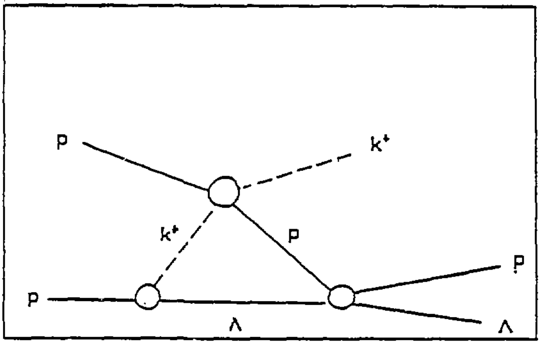

Fig. 7 : Graph calculated by Germond.

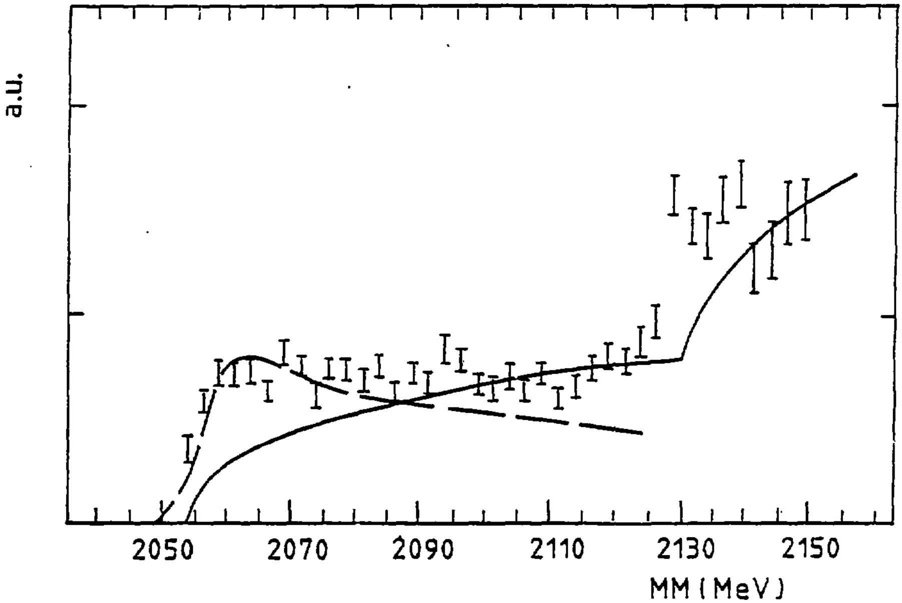

Fig. 6 : Missing mass spectrum for $pp \to K^+X$ at $\vartheta_K = 10°$. The solid line is the 3-body phase space for $pp \to K^+\Lambda p$ and $pp \to K^+(\Sigma N)^+$. The dashed curve is the impulse approximation of GERMOND in a K-meson exchange model with Λp final state interaction ; this one is a S-wave calculation with a separable potential fitted to give the scattering length parameters ($a = -1.8$ fm $r_0 = 3.42$ fm).