SEARCH FOR S = - 1 STRANGE DIBARYONS

BY MEANS OF THE REACTION $pp \rightarrow K^+X$

R. Frascaria
Institut de Physique Nucléaire
91406 ORSAY FRANCE

Abstract

An experimental search for strange S = - 1 dibaryons, performed at Saturne National Laboratory by means of $pp \rightarrow K^+X$ is described. The experimental status and the theoretical previsions are presented first. A presentation of our preliminary results is then given, with a discussion on further developments.

I. Introduction

The field of dibaryons is still the subject of an extensive work, both theoretical and experimental. We deal here with "*resonances or bound states in a two baryon system which cannot be explained as baryons interacting via hadronic exchanges*" as defined by Heddle and Kisslinger (Ref. 1). This research started twenty years ago as a check of SU3 (Ref. 2) but no positive conclusion was reached at this time on the existence of such objects. A new interest arose with new precise measurements on nucleon-nucleon scattering over a large range of energy made at Argonne National Laboratory (Ref. 3). Unfortunatly the broad structures observed (Γ > 100 MeV) are now widely interpreted as $N\Delta$ threshold effects manifested in different partial waves, rather than non-strange dibaryon resonances. Till recently, there was no experimental evidence for six quark non-strange states, these states being predicted in phenomenological bag models (Ref. 4) with narrow width (Γ < 20 MeV). However, candidates have been proposed recently as a result of an experiment performed at Saturne National Laboratory (Ref. 5). The reaction studied is $p(^3He,d)D$ - D is for dibaryon- and presents evidence for a narrow I = 1 structure with M_0 = 2.24 GeV and a width Γ = 16 MeV. From a theoretical point of view (Ref. 6) it is difficult to understand why this state would be narrow, since it is well above the $NN\pi$ threshold. Another non-strange candidate has been also proposed (Ref. 7) observed in the reaction $^3He(p,d)D$ at Saturne and in the reaction $p(d,p)D$ (Ref. 8) with a mass m_0 = 2120 MeV and a width Γ = 20 MeV, which should be also a I = 1 state. In this case, this structure lies 50 MeV below the $N\Delta$ threshold and this can account for its narrow width ; but no I = 1 states are predicted in six-quark bag models below 2200 MeV (Ref.9). An extensive experimental work is in progress at Saturne to corroborate the existence of these enhancements appearing in missing mass spectra. It is done through many different reactions : $p(^3He,d)D$ and $^3He(p,d)D$ yet mentioned, $pp \rightarrow d\pi$ (Ref. 10), $pp \rightarrow \pi^-X$ (Ref. 11), $pp \rightarrow \pi^+X$ (Ref. 12) and $pp \rightarrow pp\pi^0$ (Ref. 16).

Dealing with narrow dibaryons, it is well known that six quark states are more likely for strange systems, by considerations on colour-magnetic forces of QCD (Ref. 13). Jaffe has shown that the lowest-lying S = - 2 six quark state (named H) could be stable. This H dibaryon has been recently searched at Brookhaven National Laboratory by means of the $pp \rightarrow K^+K^+X$ reaction (Ref. 14). 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. This does not rule out the existence of the H, no reliable estimates of the production cross section being made. Another experiment performed at CERN (Ref. 15), looking for S = - 2, I = 1 states in the reaction $d(K^-, K^+)H$, did not show evidence for narrow structures ($\Gamma \leq$ 8 MeV) at the level of 5 - 40 nb/sr.

The next strange candidate is the S = - 1 six quark system. The study of this strange dibaryon has been recently started at Saturne (Ref. 12) by means of the reaction $pp \rightarrow K^+X$. A preliminary experiment has been done to check the experimental apparatus and determine the best experimental conditions. The feasibility of the experiment has been demonstrated and data will be taken next fall. This paper presents the experiment, emphasizing two interesting aspects : first, it is a good illustration of a fundamental experiment done with an intermediate energy particle accelerator, and second it shows the difficulties encountered in missing mass spectrum experiments to record reliable data. Before presenting the experimental method, we give the present experimental situation-not exhaustive - and stress the fundamental interest to check theoretical six quark bag models. We will conclude showing our very preliminary results and discussing new possible developments.

II. The S = - 1 dibaryons

Since the years 1960-1965 many contradictory experiments have been done suggesting - or not- narrow S = - 1 dibaryon resonances. They are mainly the result of bubble chamber experiments on $K^-d \to \Lambda p\pi^-$. Many of them report enhancements in the Λ p invariant mass distributions in a broad mass region ranging from the Λ N to the ΣN thresholds, one of them being repeatedly seen in the vicinity of the ΣN threshold namely 2130 MeV.

These different enhancements are tabulated in table I, where we only retain the structures having narrow widths ($\Gamma \leq 30$ MeV) whatever can be their interpretation. Generally the bubble chamber experiments present limited statistics except for the experiment of Braun et al (Ref. 31). The mass and the width given for the D (2130) differ slightly from one experiment to the other ; that can be explained as due to the way the underlying Λp_s, $\Sigma^\circ p_s$ and $\Sigma^+ n_s$ contributions have been subtracted . The result obtained by the Rome-Vanderbilt - Saclay collaboration at CERN (Ref. 22) is of particular interest. It is a high precision missing mass spectrometer experiment in coincidence with scintillation counters around the target allowing the rejection of a large part of the quasi free reaction on one nucleon of the deuterium target. The π^- are detected at very forward angles corresponding to low momentum transfer to the dibaryon.

Concerning the enhancement close to the ΛN threshold, only one experimental group (Ref. 26)reports on its existence observed in a missing mass spectrometer experiment of the $pp \to K^+X$ reaction. Another bubble chamber experiment in $K^-d \to \Lambda p\pi^-$ - with low statistics - did not confirm this enhancement (Ref. 27).

The other two structures at 2098 (Ref. 27) and 2220 MeV (Ref. 28) are obtained through more complicated reactions and must be taken with caution.

Different calculations predict the existence of narrow dibaryon resonances either in potential models (Ref. 28 , 29) or in six-quark bag calculations (Ref. 4). Another approach, the dual topoligical unitarization (DTU) relates the dibaryon spectrum to the baryonium spectrum (Ref. 30). The important result of these calculations, is the prediction of existing narrow S = - 1 dibaryons below the $\Lambda N\pi$ threshold. For instance the calculation of Mulders et al (Ref. 4) based on MIT bag model leads to two narrow states with $Q_4 \times Q_2$ configuration. Aerts and Dover (Ref. 13) have shown that these two states couple to P-waves with the baryon-baryon system. Very small widths are predicted ($\Gamma \leq 10$ MeV).

Could the structure observed in $K^-d \to \pi^-\Lambda p$ near ΣN threshold be associated with these predicted six quark states ? It has been pointed out that an enhancement in the Λp mass distribution can be due to cusp behaviour in a two step process $K^-d \to \pi^-\Sigma^+n$ followed by $\Sigma^+n \to \Lambda p$ at threshold which behaves in a v^{-1} law (Ref. 32). The calculation of Toker et al (Ref. 33) suggests that no ΣN bound state exist near ΣN threshold. Aerts and Dover have calculated the production cross section of the predicted $Q_4 \times Q_2$ states in $d(K^-, \pi^-)X$. They found small production cross sections (0.5 to 2 μb/sr). The cross sections peak at θ_L = 15 to 25° for incident momenta $k \cong 0.8$ to 1 GeV/c. As a conclusion of their work, they show that the study of the angular distribution must disentangle a cusp phenomenon (forward peaked) of real dibaryon formation (peak at finite angle). This would mean that the D(2130) observed in ref. 22 has nothing to do with a dibaryon resonance. But the same authors

Table I - Experimental YN mass enhancements

A - *Around ΣN threshold*

Reaction	Mass	Width	References	Observations
$K^- d \to \Lambda p\pi^-$	2130		17	Bubble chamber
	2126	10	18	"
	2130	10	19	"
	2128.7	7	20	"
	2138.8	9	20	At rest
	2127	8	21	Bubble chamber
	2139.8	16.7	22	Missing mass spectrometer
	2129	10	23	Bubble chamber
	2129	5.9	31	"
$K^- d \to \Lambda p\pi^+\pi^-\pi^-$	2130		24	Bubble chamber
$\pi^+ d \to K^+ X$	2139.8	16.7	22	Missing mass spectrometer

B - *Around ΛN threshold*

Reaction	Mass	Width	References	Observations
$pp \to K^+ X$	2058	30	25	Missing mass spectrometer

C - *Others*

Reaction	Mass	Width	References	Observations
$\Sigma^-(He^4) \to \Lambda n\, ^3He$	2098	20	26	At rest
$K^-(CF_3Br) \to \Lambda pX$	2220	20	27	

observed the same enhancement in a (π, K) experiment peaked at forward angle. Aerts and Dover show that in this case the D production cross section will be forward peaked. So no conclusions on the nature of the experimental observation can be given at present time. May be a new development on this important question will be given by a group at Brookhaven National Laboratory, who studied recently the $K^- d \to \pi^+ \Lambda N$ reaction over a wide angular range (Ref. 34). The analysis of this experiment is in progress.

It is more difficult to use cusp arguments concerning the enhancement observed with a width of 15 MeV in $pp \to K^+ X$ close to ΛN threshold. The only channel open for ΛN is the three body πNN channel. The structure is found 75 MeV below the first predicted $Q_4 \times Q_2$ state but the theoretical predictions on the dibaryon masses are not so precise. The observation of the structure is peaked at 0° for the K^+. This experiment must to be compared to the (π,K) experiment of Ref. 22 , and should be peaked at 0° for D production. If this enhancement really exists,it could be a good candidate for a dibaryon. Its mass is not well enough defined to say if it is below or above the ΛN threshold.

The decision has been taken last year (Ref. 35) to settle an experiment at Saturne with very high performances to study in a large range of transfer and energy the $pp \to K^+ X$ reaction. The experimental set up is now ready and the next chapter is devoted to describe it.

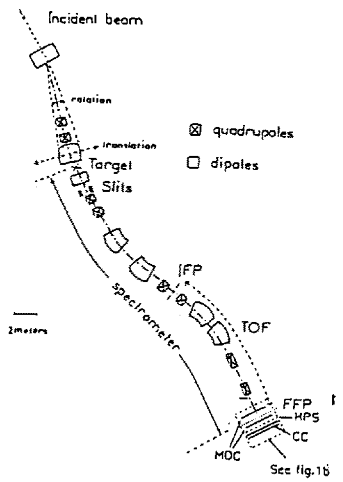
III. The pp → K^+X experiment at Saturne

As a result of the previous chapter, the experimental set up must allow :

- to cover the dibaryon missing mass spectrum from ΛN to ΣN thresholds, at least
- to ensure a good energy resolution (Γ ≦ 1 to 2 MeV)
- to get a precise measurement of the mass of any observed structure
- to study any structure as a function of energy and transfer.

The Saturne synchrotron associated with the SPES 4 beam line presents the required qualities. The synchrotron delivers protons with energies ranging from .2 to 2.9 GeV with an intensity of 10^{12} p/s. The SPES 4 beam line is a Saturne spectrometer (32 meters long !) which allows the momentum analysis to 4 GeV/c.

The SPES 4 is depicted on Fig. 1, with the experimental set up. The (p, K^+) experiment is performed with high proton intensity beam, and the detection of K^+ has to be done in a very high flux of protons and π^+.



1a

1b

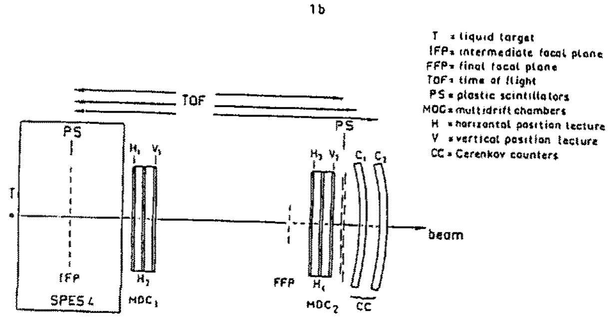


Fig. 1 - Experimental lay out

This K^+ discrimination is achieved by :

- momentum analysis with SPES 4. The solid angle of the spectrometer, defined by a lead collimator, is $\Delta\Omega = 2.5.10^{-4}$ sr. The momentum acceptance is $\frac{\Delta p}{p} = \pm\ 3.5\ \%$

- velocity measurement. A time of flight (TOF) measurement is performed between the intermediate focal plane (IFP) and the final focal plane (FFP), located 16 meters downstream. The "*starts*" are delivered by 12 scintillator counters, each of them viewed by two photomultipliers (Ref. 36). The "*stops*" are given by three parallel planes : one plane of 13 scintillator counters, and two planes of Čerenkov counters.

- proton rejection. This is obtained by two Total Reflection Čerenkov Detectors (TRCD). They are made of PERSPEX strips slightly bent to take into account the dependence of the angle of incidence of the particles on momentum, which is the main angle dependence effect in the SPES 4 tuning version here used ; so the particles enter always perpendicular in the CC (± .25°). The indice of the material is such ($\eta = 1.49$) that, in the range of velocities for the particles here considered, the total reflection of the Čerenkov light is always assured for kaons and pions but never for the protons. The CC fast coincidence is entered in the trigger leading to a rejection of $(200)^2$ for the protons, keeping a pion and kaon efficiency higher than 95 % (see for more details, the contribution of J-P Didelez et al. to this conference).

A typical time of flight measurement of pions and kaons is shown on Fig. 2 : a good time separation between pions and kaons is obtained.

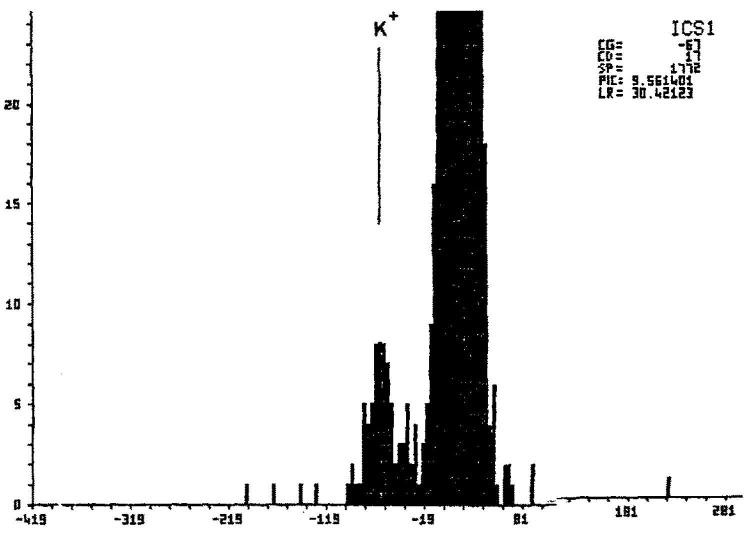


Fig. 2 - Time of flight measurement between IFP and one of the two Cerenkov planes at FFP.

- reconstruction of particle trajectories in FFP and missing mass spectrum at the target position

Two multidrift counters located close to the final image allow the reconstruction of the trajectories in FFP in both horizontal and vertical planes (Ref. 36). Using the inverse matrix of SPES 4, one can display the θ-momentum (or θ-missing mass) and ϕ-momentum planes at the target position (Ref. 37). A reconstructed particle position spectrum in FFP and a missing mass spectrum at the target position are shown on Fig. 3 for the scattering of 2.5 GeV kinetic energy protons on a thick (1 g/cm^2) CH_2 target at θ = 8°. The SPES 4 is tuned at 3.27 GeV/c (this momentum corresponds to protons having the same velocity that the K^+ in the $pp \to K^+X$ experiment. One can see on this figure, the excitation of the ground state

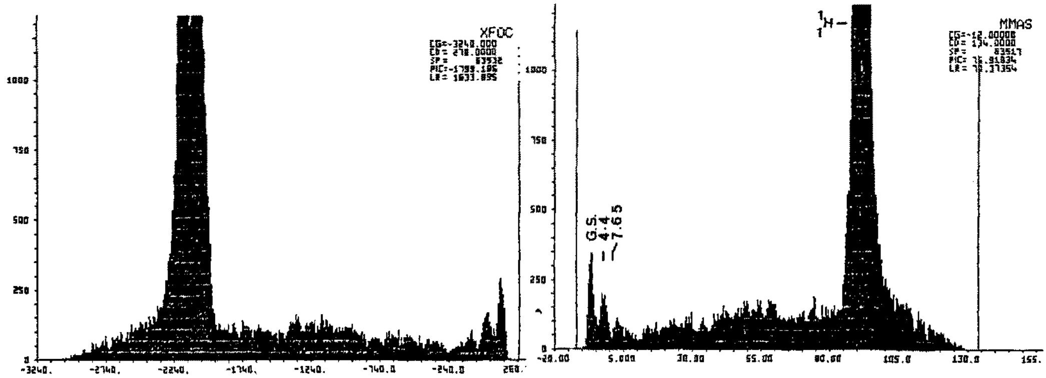


Fig. 3 - Horizontal position of the scattered protons in the focal plane (XFOC, 0.1 mm scale) and missing mass spectrum (MMAS, MeV scale).

and the two first levels (4.4 and 7.65MeV) of ^{12}C and the elastic scattering of the protons on the hydrogen of the target. An energy resolution of 1.5 MeV is obtained. A better energy resolution can be achieved with a thinner target. Irregularities appear in the spectra : they are the consequence of differential linearity defects of the MDC. That show the inherent difficulties encountered in high energy resolution missing mass spectrometer experiments. These defects can be partially corrected, smoothing a physical continuum spectrum.

Nevertheless, it implies that any part of a missing mass spectrum must be covered at least by two different tunings of the spectrometer. On Fig. 4 the $pp \to \pi^+X$ rough continuum obtained in the preliminary run is shown at the target position for two different momentum tunings, namely p_o and p_o - 2 %. The mean of the measurements are less dispersed that each of it, leading to a ± 5 % uncertainty compared to a linear regression of the spectrum (full curve).

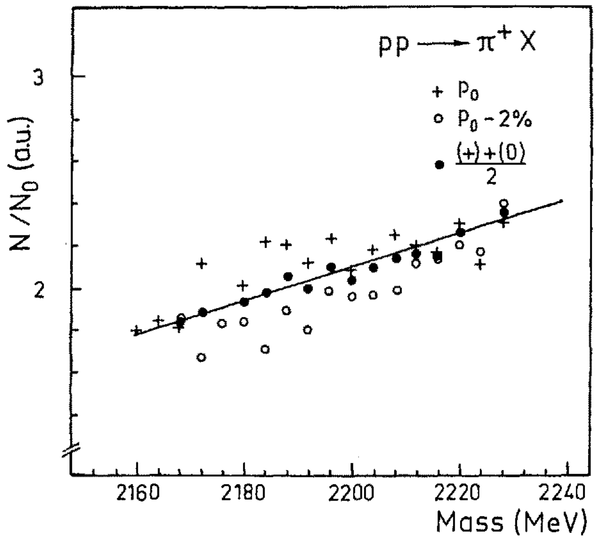


Fig. 4 : Missing mass spectrum obtained by adding two different measurements with two different SPES 4 field tunings.

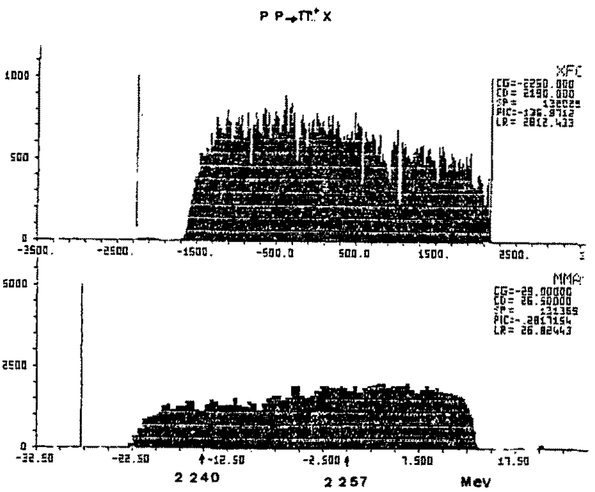
To end with this chapter, we say a few words about the trigger of the experiment. For one event, it is defined by a fast coincidence between one scintillator of the IFP with two associated ones in the FFP. The flashing of the two Čerenkov planes is required. The pion flux is about 500 to 1000 times higher than the K flux. To reduce the dead time of the data taking system, a fast (less than 1 ns) analogic time converter defines a time window between IFP and FFP open on the time range of the kaons and acting on the fast reset of the data taking system for any particle outside of the time window. This reduces the dead time to a few per cent at maximum proton intensity.

IV. Preliminary results and developments

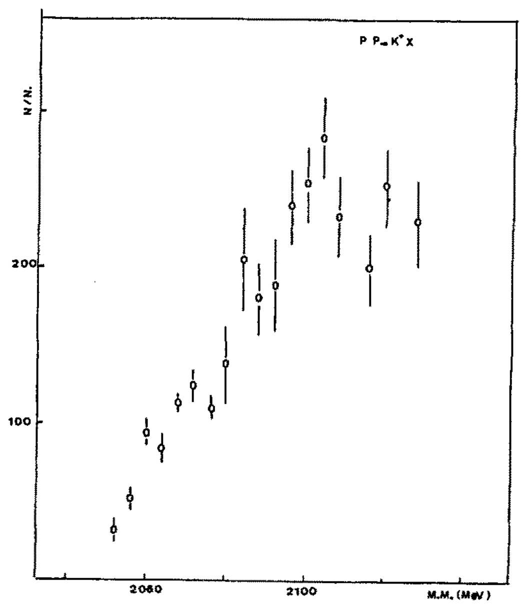
The goal of the first run of April 85, which was to demonstrate the feasibility of the experiment, detecting K^+ even at 0°, has been reached. The momentum range of the detected K^+ covered 1.2 GeV/c to 1.7 GeV/c. Only a few per cent (3 to 9 %) of the K^+ produced at the target position does not decay in the SPES 4. The momentum selection and the position and angle reconstructions of the particle trajectories eliminate the decay products of the pions and kaons. The statistics for the kaon production is too low to bring any conclusion at this time. Nevertheless we are able to present two preliminary results taken at $\theta = 8°$ for scattered particles for $T_p = 2.5$ GeV kinetic energy incident protons.

1. The $pp \to \pi^+X$ reaction comes out easily in the same experiment. Data have been registred from 2100 to 2300 MeV for the missing mass. As an example Fig. 5 shows the spectra obtained in the mass region of 2240 MeV, which corresponds to the mass of the structure seen in the reaction $p(^3He, d)D$ of Ref. 5. No particular enhancement seems to appear with a 10 MeV width corresponding to this non-strange dibaryon.

2. A missing mass spectrum of the reaction pp → K^+X is shown, on Fig. 6, in the mass region of the D (2058). This strange dibaryon resonance has been seen in Ref. 25 well peaked at 0° for Tp = 2.4 and 2.8 GeV. The spectrum displayed on Fig. 6 for θ = 8° shows a right increase of the cross section starting from Λp threshold, but nothing can be said about the observation or not of a structure in the vicinity of this threshold (too low statistics at present time). The investigation of this mass region will be pursued in the next experiment even at θ = 0°.



<u>Fig. 5</u> : *Position spectrum in the focal plane and missing mass spectrum of the reaction pp → K^+X at θ = 8° and Tp = 2.5 GeV.*



<u>Fig. 6</u> : *Preliminary pp → K^+X missing mass spectrum obtained at θ = 8° and Tp = 2.5 GeV.*

The experimental development will consist to add two other total reflection Čerenkov detectors (TRCD) tilted by a few degrees : the game is to eliminate an important part of the pion flux, playing on the different opening angle of the light produced by pions and kaons ($\Delta\theta = 4°$) in the TRCD (see J-P Didelez et al. contribution to this conference, Fig. 4). This attempt will be made in the next experiment, and a pion rejection higher than 95 % is expected. This experimental set up can also be used for other experiments. That could be for instance the reaction $p + d \rightarrow K^{+}+nD$ for dibaryon research, or $p + d \rightarrow K^{+} + {}^{3}_{\Lambda}H$ for strange three baryonic states study.

To conclude, the study of strange exotic states in light systems at Saturne has been demonstrated. It is the result of an experimental effort motivated by theoretical predictions on the existence of exotic multiquark states. It shows clearly the potentiality of the Intermediate Energy Physic to study strange particle behavior in nuclear systems.

References

1) - D.P. Heddle and L.S. Kisslinger, Phys. Rev. C, Vol. 30 n°3 (1984) 965

2) - R.J. Oakes, Phys. Rev., Vol. 131 n° 5, (1963) 2239

3) - A. Yokosawa, Phys. Reports 64(1980) 47

4) - A.T.M. Aerts et al., Phys. Rev. D17 (1978) 260 ; D21 (1980) 1370
P-J. G. Mulders et al., Phys. Rev. D19 (1979) 2635 ; D21 (1980) 2653
R.L. Jaffe, Phys. Rev. D15 (1977) 267 and 281 ; Phys. Rev. Lett. 38 (1977)195, 617 (E)

5) - B. Tatischeff et al., Phys. Rev. Lett. 52 (1984) 2022

6) - A.T.M. Aerts and C.B. Dover, Nucl. Phys. B 253 (1985) 116

7) - B. Tatischeff et al. , submitted to Nuclear Physics

8) - T. Siemiarczuk et al., Phys. Lett. 128 B (1983) 367

9) - P.J.G. Mulders et al., Phys. Rev. D 19 (1979) 2635 ; D21 (1980) 2653

10) - Experiment n° 124, LNS, Saclay-Spokemen : B. Mayer, F. Lehar

11) - Experiment n° 113, LNS (Saclay)-Spokemen : N. Willis, P. Fassnacht

12) - Experiment n° 121, LNS (Saclay)-Spokemen : J-P Didelez, R. Frascaria, B. Preedom

13) - A.T.M. Aerts and C.B. Dover, Phys. Lett., Vol. 46B, 2 (1984) 95

14) - A.S. Carrol et al., Phys. Rev. Lett., Vol. 41, 12 (1978) 777

15) - G. d'Agostini et al., Nucl. Phys. B 209 (1982),1

16) - Experiment n° 129, LNS (Saclay) -Spokemen : J-P Didelez, J-P Egger, G. Pignault, B. Saghai

17) - O.I. Dahl et al., Phys. Rev. Lett. 6 (1961) 142

18) - D. Cline et al., Phys. Rev. Lett. 20 (1968) 1452

19) - G. Alexander et al., Phys. Rev. Lett. 22 (1969) 483

20) - Tai Ho Tan, Phys. Rev. Lett. 23 (1969) 395

21) - W.H. Sims et al., Phys. Rev. D, 3 (1971) 1162

22) - G. Pigot et al., Saclay preprint DPhPE 84-03 (1984)

23) - D. Eastwood et al., Phys. Rev. D3 (1971) 2603

24) - D.P. Goyal and A.V. Sodhi, Phys. Rev. D18, 3 (1978)948

25) - A.C. Melissinos et al., Phys. Rev. Lett. 14, 15 (1965) 604

26) - H.O. Cohn et al., Phys. Rev. Lett, (1964) 668

27) - T. Buran et al., Phys. Lett. 20 (1966) 318

28) - M. Bozoian et al., Phys. Lett. 122B (1983) 138

29) - M.M. Nagels et al., Phys. Rev. D(1979) 1633

30) - L.A.P. Balacs and B. Nicolescu, Z. Phys. C6 (1980) 269, appendix A

31) - O. Braun et al., Nucl. Phys. B124 (1977) 45

32) - R.M. Dalitz, in Meson nuclear physics, HOUSTON (1979) 261

33) - G. Toker et al., Nucl. Phys. A362 (1981) 405

34) - B. Chrien et al., private communication

35) - G. Adams, E. Bovet , G. Blanpied, M. Boivin, J-P Egger, J-P Didelez, R. Frascaria, J-Y Grossiord, C. Perrin, G. Pignault, B. Preedom, B. Saghaï, E. Warde and J. Yonnet, Experiment n° 121 LNS/Saclay)

36) - D. Contardo, thesis, Lyon (France) (1984) : LYON-ORSAY collaboration

37) - J.M. Durand and M. Boivin, rapport interne LNS (1985)