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Invited talk given at the 4th International Conference
on the building blocks of nuclear structure AMALFI (Italy)
MAY 18 - 22, 1992

EXPERIMENTS IN FEW BODY REACTIONS AT LNS IN VIEW OF HADRON STRUCTURE STUDIES

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ABSTRACT : Taking advantage of the selectivity of different few body reactions, several experiments are in progress at the French National Laboratory (LNS) with the aim to bring new insight into Hadron Structure.
Two programs are here developed : the first one concerns the monopole excitation of the proton to the P11 (1440) resonance. The second one studies the meson production near threshold and in particular the $K\bar{K}$ threshold energy domain where $K\bar{K}$ molecules are expected.

The French National Laboratory in Intermediate Energy Physics Saturne (LNS - Saclay, France) is well known and appreciated as a consequence of the huge experimental work performed in the studies of mesonic degrees of freedom, and in particular in few body systems. Many spin variables in proton-proton an neutron-proton interactions have been measured from a few hundred of MeV to 3 GeV, which is the maximum energy available for protons. By elastic or inelastic to one pion, two pions, η, η', ρ, ω, K^+ - meson reactions, elementary mechanisms have been precised in terms of meson exchange and hadronic excitations in intermediate states. Taking advantage of the various kind of light particles that can be continuously accelerated, some of them with high polarisation, the possibility of selective excitations occurs by either quantum number conservation in a reaction or energy-momentum transfer matching. The main characteristics of the beam are given in table 1. Very early, the idea raised for using these opportunities to select hadronic excitations in specific channels that could bring new information on them. For example, in the η-meson field, the large and clean η production in the pd $\rightarrow$ ^{3}He η reaction at threshold, leads to a tagged η-beam [ref. 1] which is now used to look for different branching ratio of the η decay, as $\eta \rightarrow \mu^+\mu^-$. Also a new precise measurement of the η-mass has been done from the crossing of two different reactions, one of them implying the η-meson production [ref. 2].

Another asset of the LNS is the permanent set up of eleven different beam lines, four of them having magnetic spectrometers [table 1]. The high resolution SPES4 spectrometer is 32 meter long and allows the momentum analysis of particles up to 3.8 GeV/c. The two experiments which are here presented are in development with the SPES4 facility :

PARTICLE	MAXIMUM ENERGY GeV/NUCLEON	MAXIMUM INTENSITY PARTICLES PER BURST
$p, \vec{p}$	2.9	10^{12}, $\overline{2 \times 10^{11}}$
$d, \vec{d}$	1.15	10^{12}, $\overline{2 \times 10^{11}}$
^{3}He	1.69	10^{11}
^{4}He	1.15	10^{11}
$^{6}\vec{Li}$	1.15	$\overline{7 \times 10^{8}}$
$^{12}C, ^{14}N$	1.15	10^{9}
$^{16}O, ^{20}Ne$	1.15	1.2×10^{8}
^{40}Ar	0.82	10^{8}
^{84}Kr	0.69	2 to 6×10^{6}
^{127}I	0.62	PLANNED

SATURNE SPECTROMETERS					
	P/Z^{max} [GeV/c]	Angles [deg]	Solid Angle [msr]	Acceptance [%]	Dispersion cm/%
SPES 1	2	0 - 80°	3	± 4	15
SPES 2	0.75	0 - 60°	20	± 17	3
SPES 3	1.4	- 5 - 80°	10	± 40	1.4
SPES4	3.8	- 8 - 30°	0.5	± 3	7

Table 1 : The beams and the spectrometers at LNS

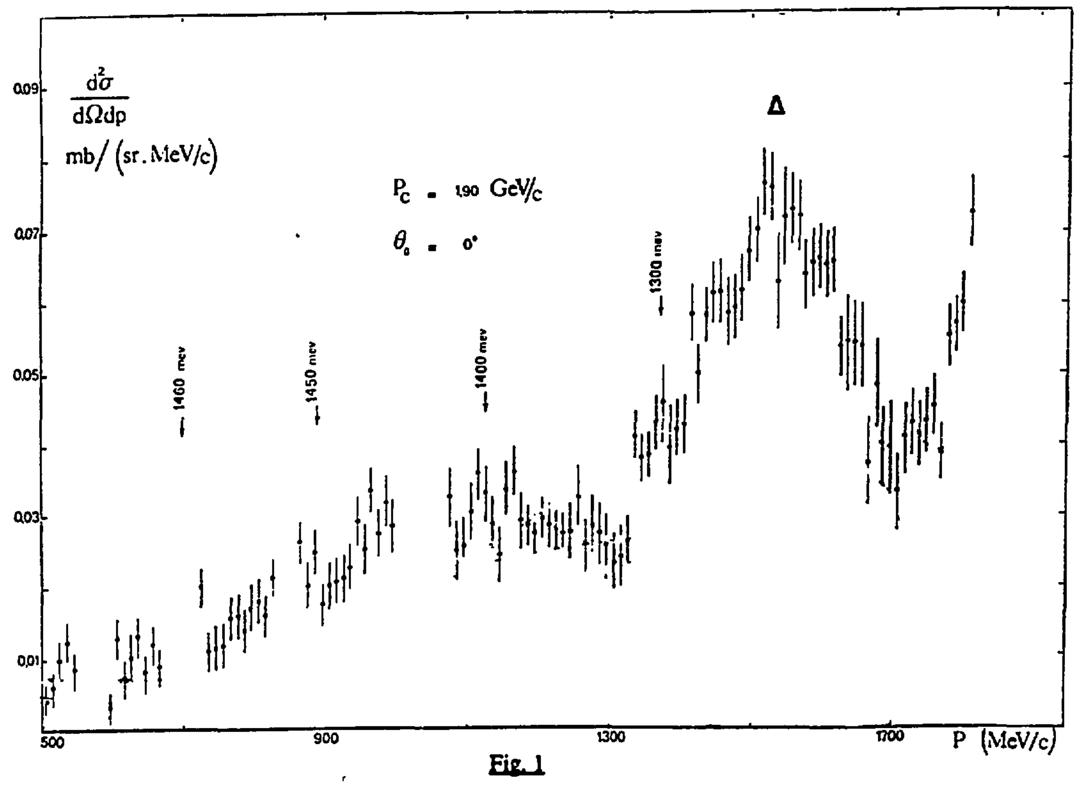


Fig. 1

1 - N → N* (1440) transition

This transition is studied by means of inelastic scattering of α-particles at high energy (7 GeV/c) and forward angles (0 to 4°) onto nucleons [ref. 3].

2 - Meson production near threshold in pd → ^{3}He X [ref. 9]

The mass range for X goes from the η to the ϕ-meson, crossing the $K\bar{K}$ threshold region where exotic mesons are expected to exist ($K\bar{K}$ molecules).

1 - N → N* (1440)

Investigations with pion-photo and electroproduction off the nucleon have contributed substantially to the knowledge of the structure of hadrons. The total cross section for photoabsorption on the proton shows up three main peaks as a function of excitation energy : the magnetic dipole (M_1), electric dipole (E_1) and electric quadrupole (E_2). Systematic analyses of pion photoproduction experiments allows a determination of the various multipoles for the transition to each of these nucleon resonances (see for instance the topical review of Drechsel and Tiator, ref. 4].

Concerning the excitation of the Roper N (1440) with J = 1/2, 1 = 1, the "breathing mode" of the nucleon,only C0 and M_1 radiations corresponding to L_{1-} and M_{1-} (J = l - 1/2) multipoles respectively are induced by electromagnetic interactions. This level has only a small M_1 strength and consequently gives only a small contribution for real photons. The electro-excitation of the nucleon to the P_{11}(1440) has probably been seen at very large Q^2 [ref. 5] but this observation needs to be confirmed. Its study should be investigated in coincidence experiments devoted to resonance studies with either the Mainz Microtron or the CEBAF facilities in the next future. In hadroproduction such as nucleon-nucleon scattering, the study of radial modes of excitations appears to be difficult because the excitation spectrum is dominated by spin-isospin modes as it is shown on fig. 1, where the excitation energy spectra in np → pX at forward angles reveals predominantly the Δ (1232) excitation. A tiny signal is present at $\theta_p = 0°$ that could be associated with the N (1440) excitation.

A selective probe to enhance Nucleon-N (1440) transitions would be of the scalar isoscalar type. In the absence of such a probe, a favorable reaction appears to be the inelastic scattering by α-particles at forward angles, where scalar isoscalar ΔS = ΔT = 0 excitations should be dominant, due to the structure of the α-particle.

Unfortunately due to the composite of the α-particle, excitation of the projectile is also expected. Whereas for α-p scattering the proton → Δ excitation should be small, there is no selection rule inhibiting the Δ excitation inside the α projectile.

eV/c

The α-p scattering has been measured at a beam momentum of 7 GeV/c, close to the maximum momentum delivered by the synchrotron Saturne. The α particles are scattered on a 4 cm length liquid hydrogen target and detected at very forward angles by the SPES4 spectrometer.

A special magnet located at the entrance of the spectrometer allows the separation between the incident α particle and the scattered ones at 0°, provided that their momentum difference is higher than 300 MeV/c. Close to the final focal plane of SPES4, six drift chambers give the positions of the α trajectories. By a reconstruction back to the target position, the rejection of reaction products coming from the entrance collimator of SPES4 is obtained. Time of flight measurements between scintillators at the intermediate focus and the focal plane, associated with four energy loss measurements with thick plastic scintillators yield unambiguous identification of the scattered α-particles. At each angle, a complete excitation spectrum is covered by four to five magnet settings, each of them covering 6% in momentum.

The missing energy spectra $\Omega = E_i - E_f$ have been measured at $\theta_\alpha = 0.8$, 2, 3.2 and 4.1 degrees. Those obtained for the two smallest angles are shown on fig. 2. The spectra indicate a strong rise of the yield above the π threshold and a pronounced structure above 400 MeV, peaked at the smallest angle.

A calculation of the part due to projectile excitation to the Δ has been performed within the impulse approximation using the meson exchange model, in which the spectra observed previously at lower α incident energies (4 GeV/c) were quantitatively described (in this case the energy Region of the Roper resonance is not accessible). The result of this calculation is shown by the solid line in fig. 2. After subtraction of this projectile excitation contribution, one obtains the reduced missing mass spectra in fig. 3 : the excitation of the nucleon to the Roper resonance is clearly seen falling off rapidly by a factor of 2 when going from $\theta = 0.8°$ to 2°. A shift of 30 to 50 MeV in the position of the N* (1440) to lower values of $\Omega = E_i - E_f$ is due to the α-particle form factor.

The differential cross section for the two excitations, the projectile one and the N* (1440) resonance, are given in fig.4. They both show a very steep angular dependance characteristic of a monopole resonance.

In quark models, the Roper occurs as a radial excitation $1s \rightarrow 2s$ of a single quark from the $[56, 0^+]$, to the $[56, 0^+]2$ multiplet with $\Delta S = \Delta L = 0$.

Interpreted as a "breathing mode" of the nucleon this excitation is, in bag models, related to the compressibility of the bag and hence the vaccum pressure. In an harmonic oscillation scheme, this excitation corresponds to 1 $\hbar\omega$. There are also resonances of Roper type which are the ε (1660), Λ (1600), Δ (1600). In the same model the Nucleon to Δ transition is the consequence of the spin flip of a quark and corresponds to $\Delta S = 1$, but as for the Roper, with $\Delta L = 0$. The simularity of the two angular distributions shown on fig4 is a further support for a monopole character of the excitation observed at $\Omega = 410 - 420$ MeV.

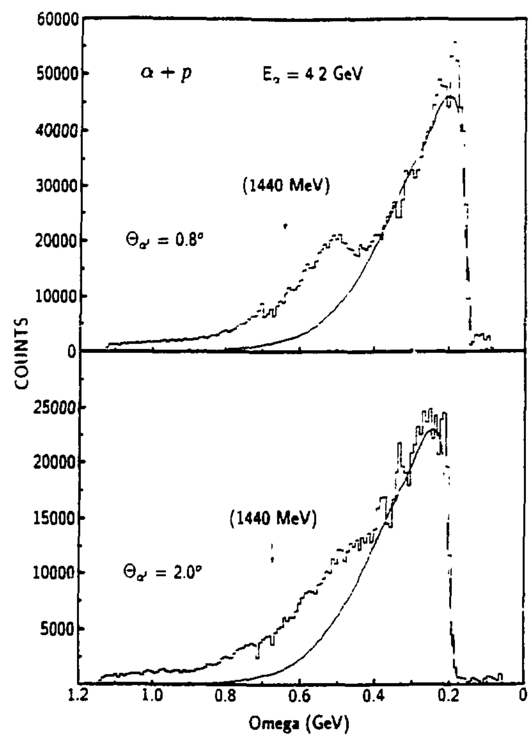


Fig.2

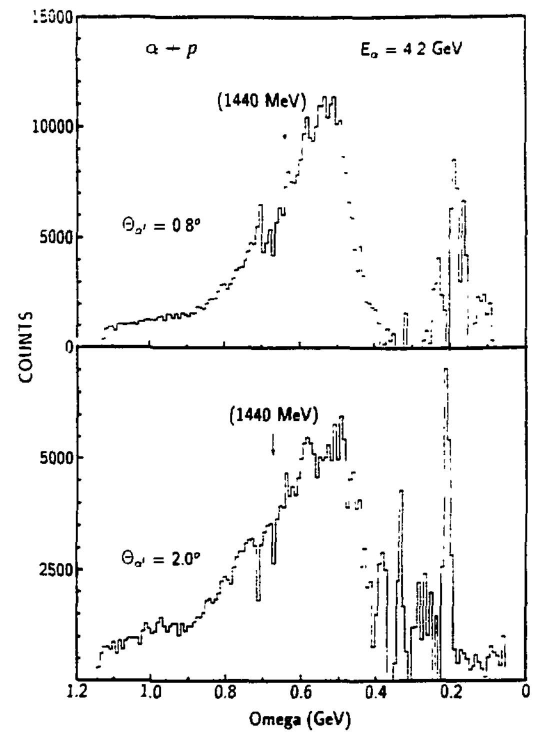


Fig.3

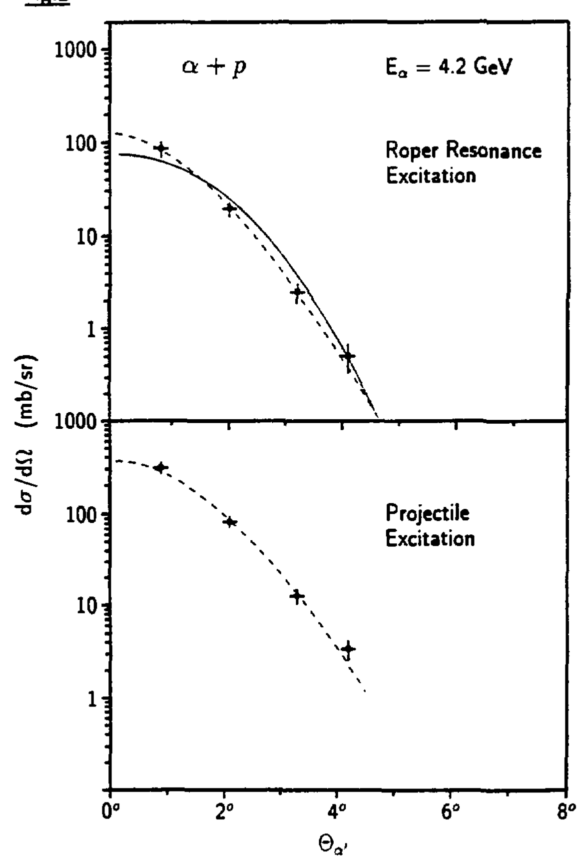


Fig. 4

The monopole excitations give information on the compression modulus, or the incompressibility of a baryon. The excitation energy of the breathing mode is proportional to the square root of the compression modules K_N

$$K_N = (\frac{m_0}{\hbar^2}) E_x^2 < r_N^2 >$$

A range has been given for K_N depending of the model of baryons which is used. For the constituent quark model, K_N = 3GeV, where in a cloudy bag model K_N is of the order of 900 - 1200 MeV, based on the experimental value of the excitation energy of the Roper (see for instance Badhuri et al. [ref. 6], or G.E. Brown et al. [ref. 7]). As we are here discussing the building blocks of nuclear matter, it is interesting to stress the role that the incompressibility of a nucleon may play as nuclear matter is compressed. At the stage where nuclear matter is compressed to the point when the nucleons press against each other, the incompressibility of the nucleon cannot be ignored.

To follow the N (1440) excitation in nucleon matter as a function of the A dependance of the target, a program of inelastic scattering of α particles on light nuclei (d, C, etc...) is in progress at LNS. Preliminary spectra where obtained a few years ago in $\alpha d \rightarrow \alpha X$.

Finally, to come back to the free N $\rightarrow$ N* (1440) transition, more exclusive experiments are needed to bring new information to characterize this excitation energy region of the Roper resonance. Due to the strong excitation which is observed, yielding high rates for the N* (1440) production, decay products of the N* (1440) in one proton plus one pion or two pion can be detected in coincidence with the scattered α-particles. A new detector is in project around the target position of the SPES4 facility to realize this goal. These coincident measurements should precise the different branching ratio which are still quite imprecise.

Moreover, if the N* (1440) is split in a (56, 0^+)2 NRQM state and an hybrid of Q^3G type as proposed by Golowich and al. [ref. 8], the comparison between photo and hadroproduction of the N* (1440) would shed light on this interesting question.

2 - Meson production near threshold in pd $\rightarrow$ ^{3}He X
The K$\bar{K}$ system

Some interesting features of meson production near threshold in the pd $\rightarrow$ ^{3}He X reaction have been observed (in which the missing mass for X goes from the η to the ϕ mesons) [ref. 9]. A precursor work was done a few years ago [ref. 10] covering the excitation function close to thresholds from π - to ϕ - mesons by large energy steps except in the region of the η - meson where precise data were taken. Near η threshold a very interesting pattern was observed between the two channels (^{3}He + η) and (^{3}He + X), the X-system being either 2 pions in a 1- state or 3 pions in relative S-states forming 0^- systems in the final state [ref. 11].

The experimental conditions in such experiments and the specific assets of the "Excitation function for meson production near threshold" or in *abrege* in French *"courbe des seuils"* are the following :

– The proton beam delivered by the Mimas/Saturne complex, continuously variable in energy from 150 to 2900 MeV by 1 MeV step, is focussed on a liquid deuterium target at a special position relatively to the SPES4 spectrometer allowing the detection of the scattered ^{3}He particles at 0 degree. For each chosen incident proton energy, the SPES4 beam line is tuned at a central magnetic field value corresponding to a null c.m. momentum for the ^{3}He (and consequently the same for X, the missing system). So, at each measurement, the c.m. energy goes into the production of the mass of X. Due to the momentum acceptance of the SPES4 spectrometer, which is about $\pm$ 3% in dp/p for fully transmission, the c.m. relative energy of X with respect to ^{3}He is at most a few MeV. If X is a meson, the available phase space is zero at threshold : if the production of X is observed it is due either to the limited momentum resolution of the apparatus or to the energy width of the meson if this one is larger than the energy resolution. Consequently, the study of this meson production near threshold allows the determination of its variation as a function of the relative c.m. momentum between ^{3}He and X, for very small values of it.

Above two meson production threshold, the excitation of a particular meson generally appears over a multipion background, or at even more higher energy, over a $K\bar{K}$ production.

One of the most important features of the *"courbe des seuils"* is that, as the proton beam energy is varied, a specific bosonic object X is selected in a S-wave with respect to the ^{3}He : this is a very nice kinematical situation in the search for η - or η' - meson nucleus or S - wave resonance effects.

Another interesting feature arises at the crossing of 2 pions, 3 pions..., 2 kaons thresholds : these multi-meson productions are done at rest in their c.m. allowing the search for and the study of S-wave resonances between them. Due to Lorentz boost, the angular acceptance given by SPES4 near thresholds is equal or close to 4π. Among these multi-meson productions at threshold, the 2 kaon case seems very promising in view of the possible existence of $K\bar{K}$ molecules weakly bound as predicted by WEINSTEIN and ISGUR [ref. 12] in their variational calculation of $q^2 - \bar{q}^2$ states.

Before going further in the pd $\rightarrow$ ^{3}He X *"courbe des seuils"*, let me take as a reference work the nice experiment performed in the 70's at the Nimrod accelerator by a group from Imperial College [ref. 13], studying the reaction $\pi^- p \rightarrow n$ X near the thresholds for the production of η, ω, η', f_0 and ϕ. The experiment used pion beams between 0.7 and 4 GeV/c and was settled to detect the neutrons at 0 degree. On figure 5-a is shown their results around the phi production. The peak corresponding to the phi is appearing with some difficulty over a multipion background. It is only when a $K\bar{K}$ selection by charged particle detectors placed around the target is operated than a clear phi signal emerges from the background (fig. 5-b) ; this allows the determination of the ratio of the ϕ production to multipions, to be a few percents.

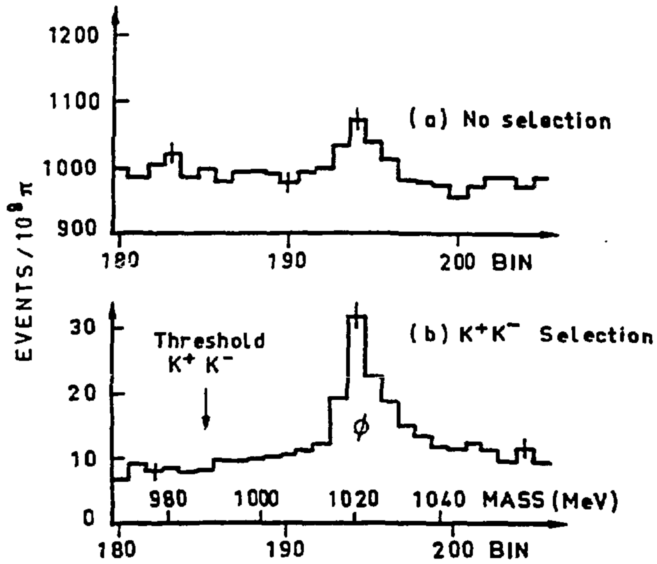


Fig.5 : The $\pi^- p \rightarrow nX$ excitation function near the ϕ-meson production

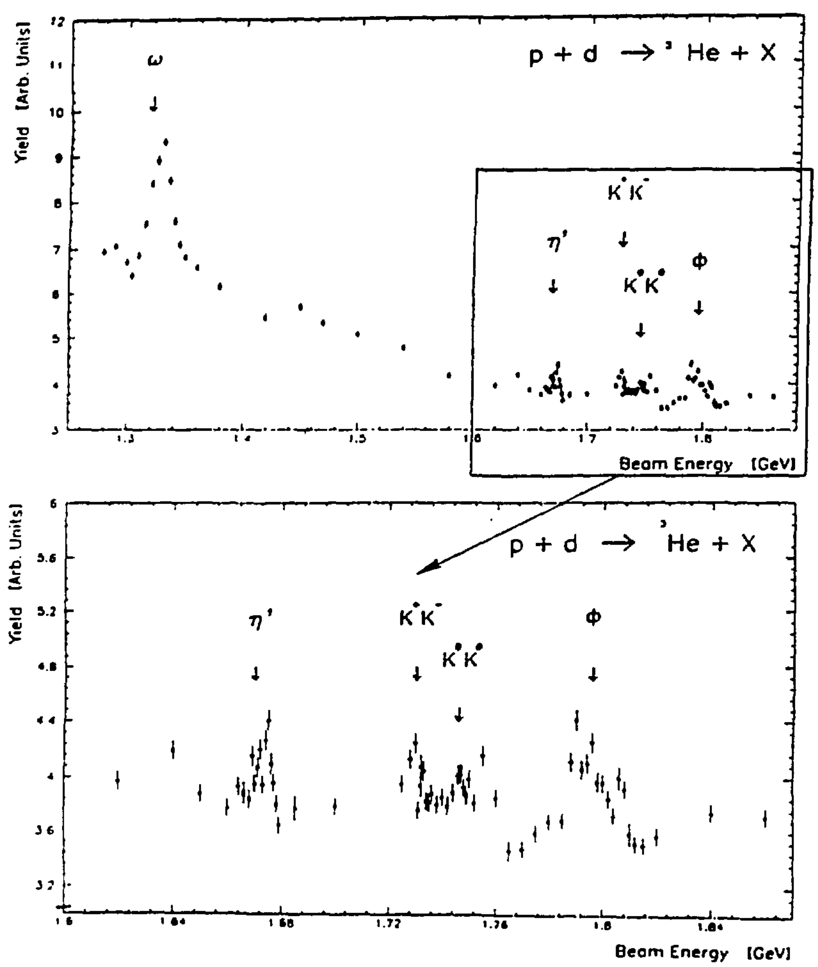


Fig.6 : The LNS pd $\rightarrow$ ^{3}HeX "courbe des seuils"

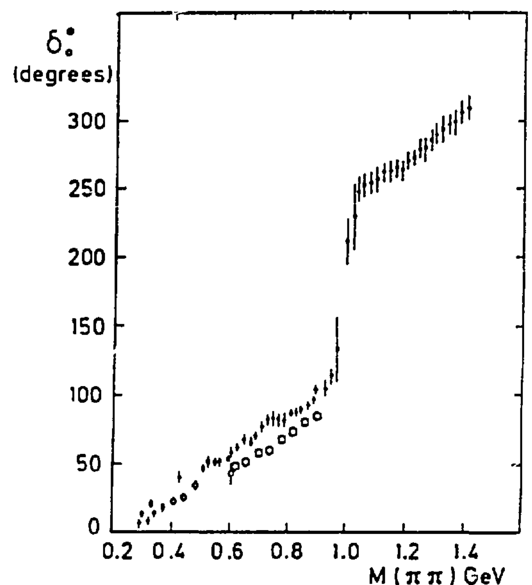
On figure 6 is shown the *"courbe des seuils"* for pd $\rightarrow$ ^{3}He X obtained at LNS in the experiment LI # 183/219 [ref. 9] as a function of the incident kinetic proton energy. The lower spectrum is a blow up of the upper curve. The excitations of the ω, η' and ϕ-mesons are clearly seen ; in particular the ratio peak over background for the ϕ is better than the same ratio measured in the Nimrod experiment with the two kaons in coincidence : this demonstrates the high selectivity of the pd $\rightarrow$ ^{3}He X reaction to produce isospin 0 heavy mesons. This remark can be the starting point for a discussion about the f_0 (975) whose assigment and $q\bar{q}$ composition is controversial [ref. 5].

As a matter of fact, the 0^{++} multiplet $^3P_0$ is not yet well understood. In particular in the non-strange partners of this multiplet, the a_0 (983) and f_0 (975) are too close in mass while the a_0 (983) and the f_0 (1400) are too far : it is difficult to understand why the f_0 (975) which has a 20% branching ratio to $K\bar{K}$ and so a significant $s\bar{s}$ component, can be degenerated in mass as much to be below the a_0 (983) which is known to have no strange component ($K\bar{K}$ B.R. only seen). This fact lead to the idea that the a_0 (983) and the f_0 (975) are not $q\bar{q}$ states. Different theoretical predictions exist ; some of them are mentionned here :

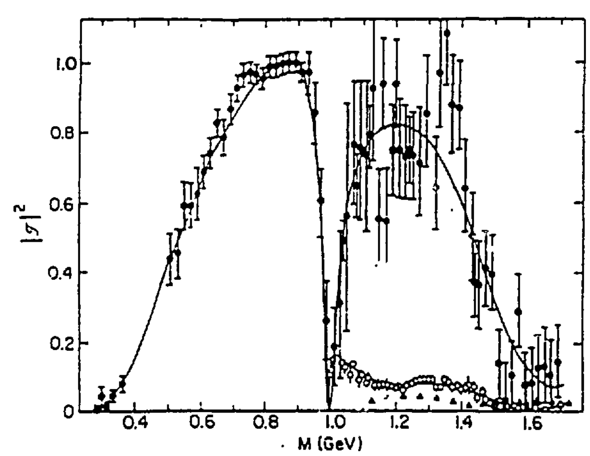
- based on experimental results of the study of pp $\rightarrow$ pp(MM) at CERN ISR, Au et al. [ref. 14] have proposed the existence of a glueball S(991) with a width of $\Gamma = \pm 21$ MeV.
- in a M.I.T. bag model, JAFFE [ref. 15] found $q^2\bar{q}^2$ states with hidden $s\bar{s}$ component with large $K\bar{K}$ coupling.
- as already mentioned, WEINSTEIN and ISGUR [ref. 16] in a variational calculation in a non relativistic potential model found q^2q^2 states weakly bound in $K\bar{K}$ S-wave molecular shape, coming with J = 0 and I = 0 or 1.
- very recently, CANNATA et al. [ref. 17], in the study of $K\bar{K}$ threshold effects by means of a separable potential formalism have added to the usual π - π and K - $\bar{K}$ channels an exotic channel with heavy constituents and found a strong coupling between this new channel and the $K\bar{K}$ one. As a consequence the f_0 (975) appears to behave like a $K\bar{K}$ molecule bound by this exotic channel.

Whatever could be the extra $q\bar{q}$ nature of these mesons, a search for the 0^{++} missing $q\bar{q}$ states would consequently be needed.

Coming back to the pd $\rightarrow$ ^{3}HeX excitation function shown on fig. 6, it is remarkable that not only the vector meson like the ω or ϕ are well excited but also the scalar ones like the η'. It may be possible to get complementary or even new information on the nature of the f_0 and a_0 mesons. What is known of the f_0 (975) comes out from phase shift analysis of π - π elastic scattering as shown on figure 7 - a, where the I = J = 0 π - π phase shifts are plotted as a function of the π - π mass. The passage by 180 degres at 975 MeV (the $K\bar{K}$ threshold is at 987.3 MeV) corresponds to the classified f_0 (975), yielding a hole in the I = 0 S-wave cross-section (see figure 7-b).



(fig. 7a)



(fig. 7b)

Fig.7 : I = I = 0 π - π phase shifts [ref. 9] (fig.7 a) ; The resultant S wave cross section scaled by M^2 : the solid dots are for the $\pi\pi$ elastic cross section, the open circles are for $\pi\pi \rightarrow K\bar{K}$ and the triangles for $\pi\pi \rightarrow \eta\eta$ (fig. 7b) [14]

The LNS *"courbe des seuils"* presents interesting structures around the K^+K^- and $K^\circ K^\circ$ thresholds with a small increase of the averaged cross-section in between the η' and ϕ mesons (see fig. 6, lower part). Are those structures signature of cusp effects at thresholds superimposed on the f_0 and a_0 mesons ? It is clear that this mass region must be more precisely studied and this has been recently done in July 1992. An investigation of a coincident experiment between the ^{3}He particles and two coplanar forward charged particles has also been done in a set up which scheme is shown on figure 8. This configuration of the detector selects the ^{3}He $K\bar{K}$ outgoing channel and so well suited to study the $K\bar{K}$ B.R. of the f_0 (975).

A very coarse analysis of this new experiment confirms the observation of the ω and η productions. A structure seems to be present at the K^+K^- threshold but these data need careful analysis.

A similar coincident experiment with a more elaborated charged particles detector is in development in Bonn (RFA) to be installed at the new Cosy facility for 1993 - 94 [ref. 18].

As a perspective, other reactions can also be promising : the pd $\rightarrow$ t X selects the I = 1 channel and can usefully compared to the pd $\rightarrow$ ^{3}He X *"courbe des seuils"*. The α-α $\rightarrow$ α-α X reaction at and above the $K\bar{K}$ thresholds, where the two outgoing α could be detected for instance with the SPES3 spectrometer, should select pure I = 0 channels. A similar role can be played by the dd $\rightarrow$ αX reaction already studied in the past at Saturne [ref. 19].

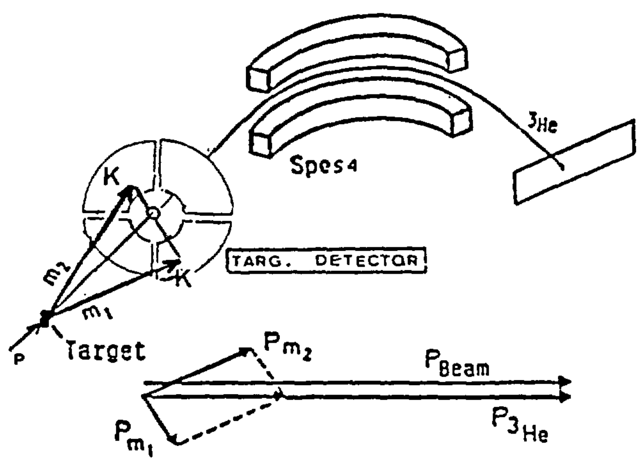


Fig 8

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