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NEWS FROM SATURNE IN FEW BODY SYSTEMS

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Abstract:

A brief report on some aspects of mesonic physics in few body experiments performed at LNS (Saclay, France) is presented.

This short contribution cannot be an exhaustive report on the experimental developments at Saturne (Laboratoire National Saturne, LNS) even if it is restricted to few body systems in strong interaction. The Saturne accelerator, associated to the Mimas injector, has delivered about 4200 hours beam time with 93% efficiency for physics in 1990. The new extraction procedure allows two different experiments working simultaneously, at two different energies with a dynamic for the beam intensity of 1 to 10. This has brought forth a large amount of precise data, sometimes very new.

The main characteristics of the beams and the spectrometers of LNS are given in table 1. Other detectors, like ARCOLE, DIOGENE, PINOT and SPES3 are also permanently set up.

As it appears, a rather general tendancy is to investigate the role played by resonances other than the Δ (1236) in different reactions, the excitation of the S_{11} (1535) being the dominant fact in the results presented here. The selection of this N* excitation is obtained by either the choice of energy or momentum transfer, as well as particular channels in the final states. Due to its large branching ratio (BR) to ηN, this hadronic excitation in few body systems is connected to η-meson production, in particular near thresholds in various channels. Another important point of the production of particles near their thresholds is the specific kinematical condition - S-wave production - emphasizing the possible production of resonances or new states of matter. The last part of this short review is concerned with rare events observed in particular reactions, even if these observations lead to surprisingly higher cross sections than expected.

PARTICLE	MAXIMUM ENERGY GeV/NUCLEON	MAXIMUM INTENSITY PARTICLES PER BURST
$p, \vec{p}$	2.9	10^{12}, $\overrightarrow{2 \times 10^{11}}$
$d, \vec{d}$	1.15	10^{12}, $\overrightarrow{2 \times 10^{11}}$
^{3}He	1.69	10^{11}
^{4}He	1.15	10^{11}
$^{6}\vec{Li}$	1.15	$\overrightarrow{7 \times 10^{8}}$
$^{12}C, ^{14}N$	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

To begin, a first chapter reports on the free excitation of the Roper resonance N* (1440) as a way to get information on its internal structure.

EXCITATION OF THE N* (1440) RESONANCE AND THE COMPRESSIBILITY OF THE NUCLEON

The compressibility of the nucleon is related to the excitation of specific N* ($1/2^+$) resonances having large transition matrix element to the ground state. These monopole transitions are directly related to radial oscillations of the nucleon. The Roper resonance N (1440) is a candidate for such an excitation. The E_0 transition matrix element which cannot be measured in photo-excitation is poorly known experimentally. The excitation of radial modes in hadron excitations can be selectively studied in systems which do not lead to strong excitations of other resonances, like Δ resonances or N* spin-flip modes. This is the case in α + p scattering where the direct α-particle transition operator has spin and isospin transfer equal to zero, inducing only radial excitations of the nucleon. This hypothesis is dramatically demonstrated on fig. 1, where the result of an $\alpha + p \rightarrow \alpha'+X$ experiment by a collaboration on SPES4 [1] is shown. The excitation spectrum taken for α particles of 7 GeV/c scattering at angles close to zero shows a strong enhancement,in the tail of the α projectile excitation peaked at the pion threshold, due to the N(1440) excitation.

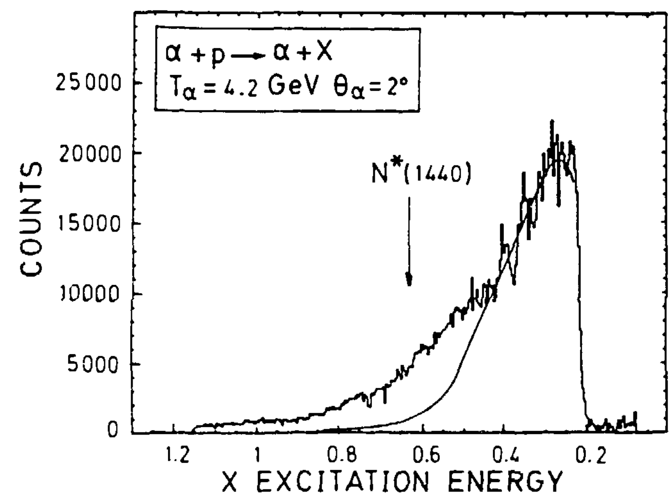


Fig. 1 : Excitation spectrum in $\alpha + p \rightarrow \alpha' + X$

The angular distribution of this excitation falls off rapidly with the angle of the scattered alphas. The cross section for the transition is high, indicating a large exhaustion of the energy weighted monopole sum rule. The extraction of the compressibility depends on the nucleon radius itself and calculations are in progress to obtain constraints on the range of the compressibility modulus.

THE ROLE OF THE S_{11} (1535) IN η - MESON PRODUCTION

In a recent past the dominant role played by the S_{11} (1535) has been pointed out in the productions of π and η at backward angles in proton deuteron interactions at energies near and above η threshold [2, 3]. The interpretation of the excitation functions of these productions for very backward angles ($\theta\pi = \theta\eta = 180°$) by LAGET and LECOLLEY [4] singles out the dominance of three body mechanism where the S_{11} (1535) in intermediate states plays the dominant role. Among many others reactions where this important role can be stressed , the pp $\rightarrow$ ppη and pn $\rightarrow$ dη are good candidates. In two different calculations LAGET et al. [5] and GERMOND and WIL¨'IN [6] have pointed out the dominance of the ρ-exchange transition amplitude NN $\rightarrow$ NS_{11} (1535). This occurs due to the large radiative width of the S_{11} resonance which implies through the vector dominance model a large coupling to the virtual ρ. On fig. 2 are plotted the few available data in comparison with the Laget calculation, showing the important role played by the ρ-exchange term.

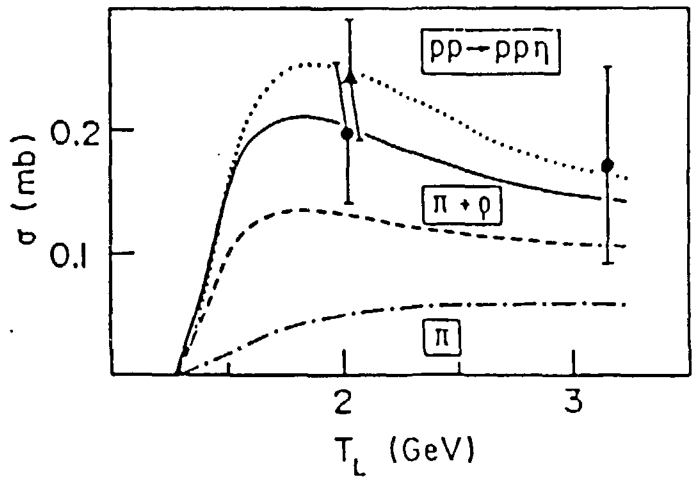


Fig. 2 : The total cross section of the pp $\rightarrow$ ppη reaction cross section is plotted against the laboratory kinetic energy of the incoming proton. The dotted curve corresponds to the π + ρ-exchange PW calculation when Λ_p = 2.15 GeV. The full and dashed curves correspond to the π + ρ-exchange DW calculation when Λ_p = 2.15 GeV and Λp = 2m = 1.88 GeV, respectively. The dash-dotted curve corresponds to the π-exchange DW calculation.

The pp $\rightarrow$ ppη channel is being studied at SPES3 [7] and PINOT [8]. At SPES3 for which the angular and momentum acceptances are large the two protons are detected in coïncidence. The identification of the reaction is clear as shown on fig.3. The experimental program has covered the energy domain from T_p = 1256 up to 1450 MeV ; the analysis of the data is still in progress. At PINOT which is 4π detector for neutral particles (π°, η, high energy gammas) data have been taken recently in the same range of energy with a clear signature of the η. These experiments should be able to test the ρ - dominance in η - meson production.

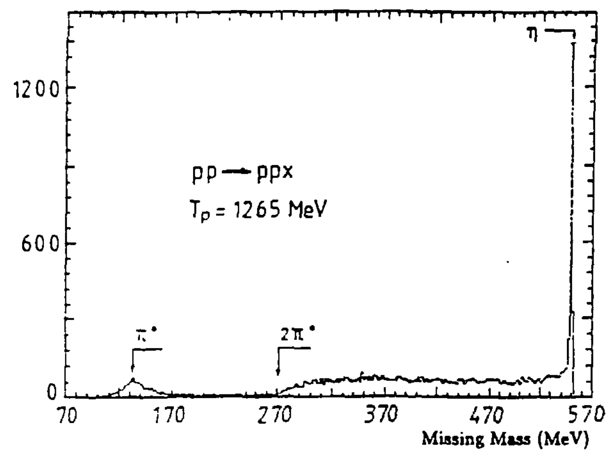


Fig. 3 : Missing mass spectrum measured in p + p → p + p + X at T_p = 1265 MeV

THE N - N* (1535) INTERACTION

Single pion production elementary reactions NN → NNπ are governed by three partial cross sections : σ_{11}, σ_{10} and σ_{01} where the indexes refer to the total isospin of the nucleon pairs in the initial and the final states respectively.

The reaction pp → ppπ° is related to σ_{11} by :

(1) $\sigma(pp \rightarrow pp\pi^\circ) = \sigma_{11}$ while the reaction np → ppπ^- is the sum of σ_{01} and σ_{11} as
(2) $\sigma(np \rightarrow pp\pi^-) = 1/2\,(\sigma_{01} + \sigma_{11})$.

So, from the simultaneous measurements of (1) and (2), σ_{01} can be extracted. This cross section which is pure I = 0 in the initial channel can only excite N* in intermediates states (Δ forbidden), allowing the study of the NN* interaction. This program is in progress at LNS, the reaction (1) being measured with SPESO [9] and its modified version SPESO 2π, the reaction (2) being measured with ARCOLE [10]. This last one has ended with cross sections and asymmetry measurements from T_p = 572 MeV up to 1134 MeV. The asymetries are shown on fig. 4, the cross sections being not yet available. The SPESO program on reaction (1) is still in progress, but cross sections

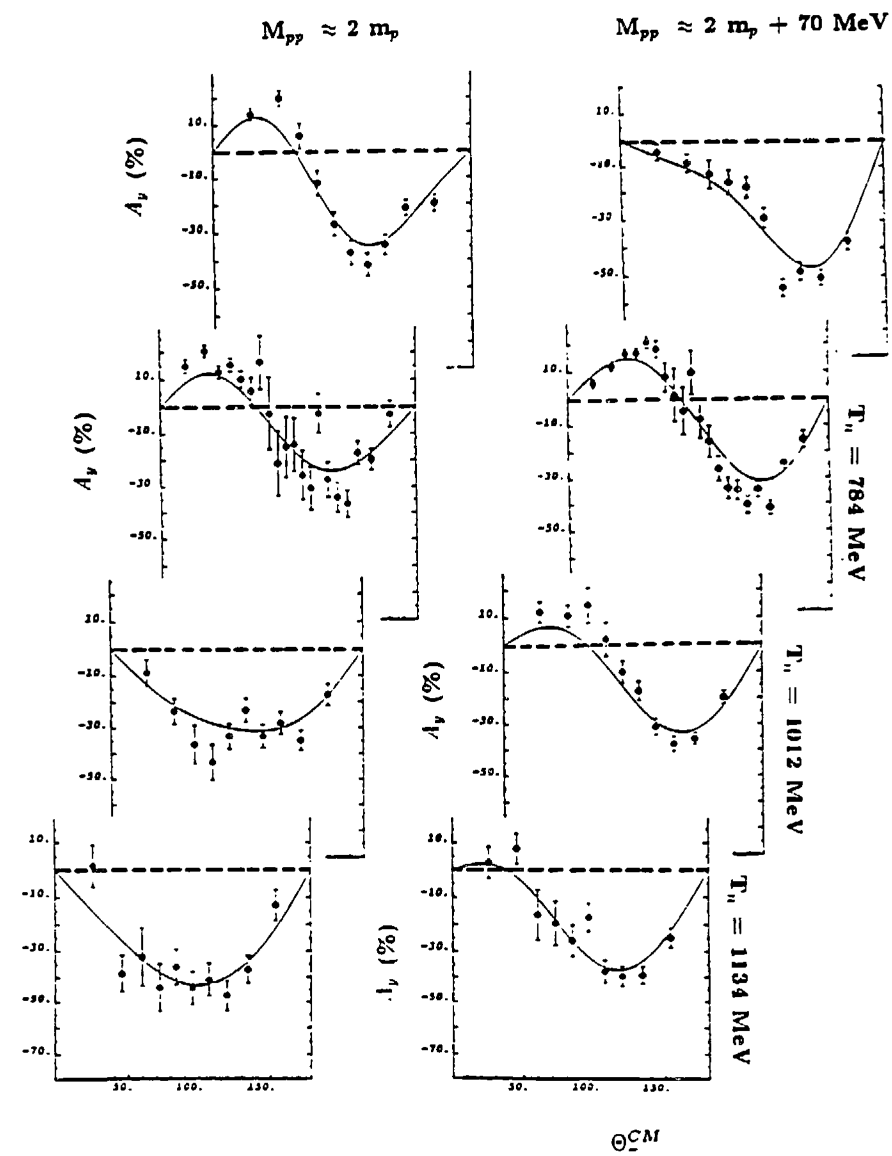


Fig. 4 : Preliminary results of beam asymmetries for four different neutron energies in the reaction np → ppπ⁻. The spectra on the left side correspond to a missing mass $M_{pp} \approx 2m_p$ and on the right side to $M_{pp} \approx 2m_p + 70$ MeV.

between T_p = 485 MeV and 560 MeV have already been analyzed. They are shown on fig.5 in comparison with previous np → nnπ+ measurements. The resulting σ_{01} cross section is also shown in comparison with a LAGET calculation [11] . This experimental program will explore in next october the energy region between 600 MeV and 1100 MeV where the S_{11} is expected to be dominant and should produce an increase of the σ_{01} cross section.

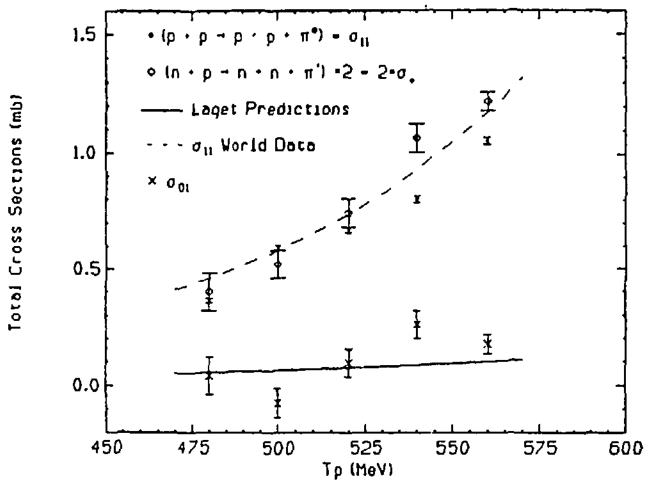


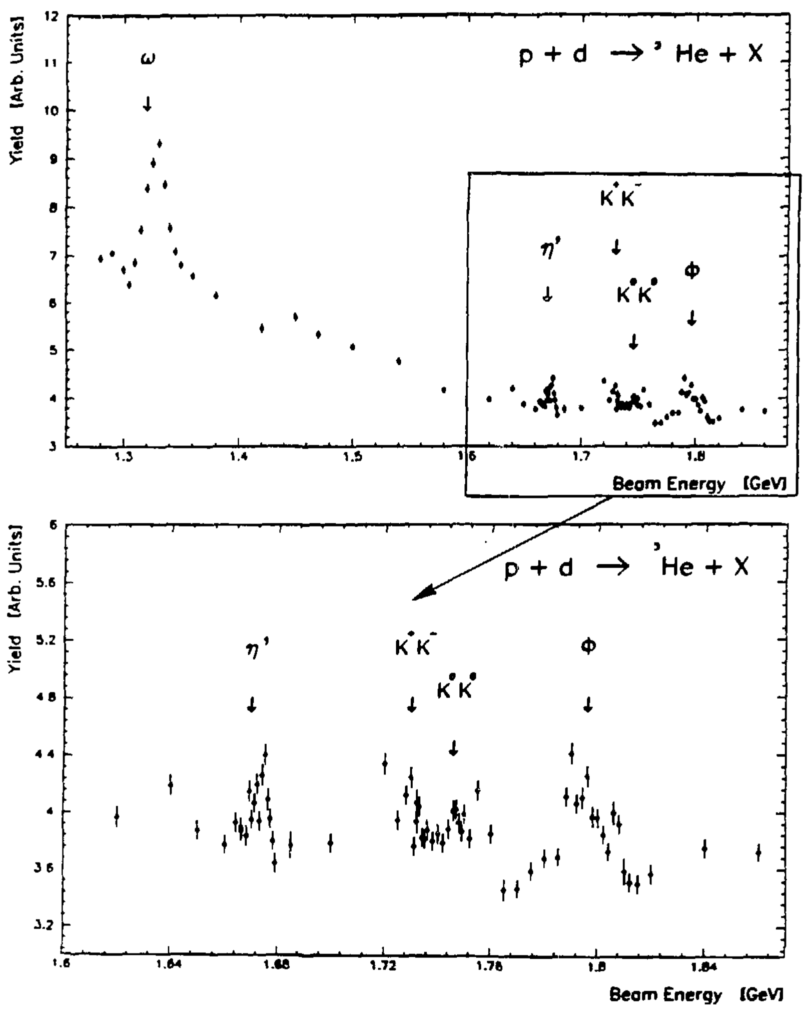
Fig. 5 : The σ_{01} cross section (crosses and fill line)

MESON PRODUCTION NEAR THRESHOLD

This program which uses the pd → ^{3}HeX reaction has mainly two different purposes.

1 - Study of meson production mechanisms.

The pd → ^{3}HeX reaction in the vicinity of η production (X = η) as a function of incident proton energy studied at SPES4 [ref. 12], has shown a very interesting interference pattern with the 2π or 3π channels [see fig. 6]. The interpretation of this strong cusp has been given by Wilkin [13] as due to a strong coupling between the ^{3}He η and ^{3}HeX channels, where X can be a J = 1^- 2π state or J = 0^- 3π state, both states having isospin 1. The results suggest that the η - ^{3}He interaction is strongly attractive. In a new recent experiment [14], this excitation function of meson production near threshold has been pursued covering the region of ω, η' and ϕ - mesons. These results are shown on fig. 7. A similar behaviour to the η production is observed for the η' production. The ω-meson is also strongly produced and its $\bar{q}$ dependance - where $\bar{q}$ is the c.m. momentum of the ω - has been studied.



Threshold excitation function obtained at SPES 4 between 1.28 and 1.86 MeV incident proton energy in the reaction pd → ^{3}He X. Beam energy and spectrometer momentum were adapted such a way, that the mesons are produced at rest in the c.m. system. The lower spectrum is a blow up of the upper curve.

Fig. 7 : The pd → ^{3}HeX threshold excitation function from X = ω to X = φ

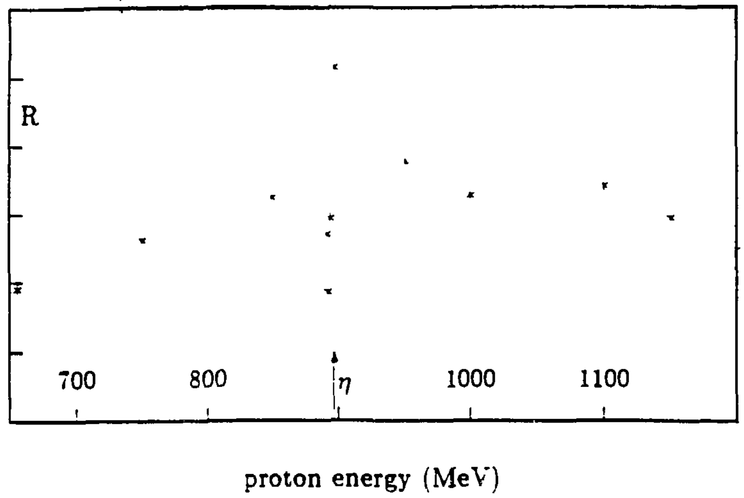


Fig. 6 : The pd → ^{3}HeX threshold excitation function of the η-meson for X

2 - Isoscalar meson structure

As far as the ϕ-meson is concerned a high rate production is observed as compared to its production in $\pi^- p \rightarrow nX$ reaction [15]. This observation as well as the ω, η, η' strong excitations lead to the conclusion than I = 0 meson are strongly produced near threshold in pd interactions and than the reaction pd → ^{3}HeX is a good tool to explore the isoscalar meson spectrum. Interesting structures are observed in the vicinity of the $K\bar{K}$ threshold, where the f_0 (975) should appear. Some new information should be extracted from this experiment and its extension to more exclusive measurement (K^+K^- in coïncidence) about the f_0 (975)-a_0 (980) dilemna [16], and in particular on the nature of the f_0 as a possible $K\bar{K}$ molecule.

HYPERON-NUCLEON INTERACTION

The hyperon nucleon scattering data obtained from buble chamber experiments are scarce mainly due to the difficulty which exists in producing and making interact the short-living hyperons in the same detector volume. The associated production of an hyperon-nucleon pair (YN) in few body interactions is a simple way to study the baryon baryon interaction at low relative energies. A high resolution pp → K^+X experiment has been developed at SPES4 with a performant kaon detection [17]. A first data taking done at T = 2.3 GeV incident kinetic energy and θ = 8, 10, 12° kaon emission angles showed two remarkable features in the missing mass spectra (MM) respectively close to Λ - p and Σ - N thresholds. A theoretical analysis in terms of π and K exchange diagrams with hyperon-nucleon final state interaction (Y - N FSI) [18] was able to reproduce correctly the data. In particular a peak observed at 2131 MeV with a width of 9 MeV (FWHM) was explained as a cusp effect enhanced by a pole close to the Σ - N thresholds.

To follow the momentum and energy dependence of these structures, new data have been taken at T = 2.7 GeV and θ = 13, 16, 20 and 23° with an improved set-up and higher statistics. These results are shown in fig. 8 in comparison with the calculation in the model of ref. 18.

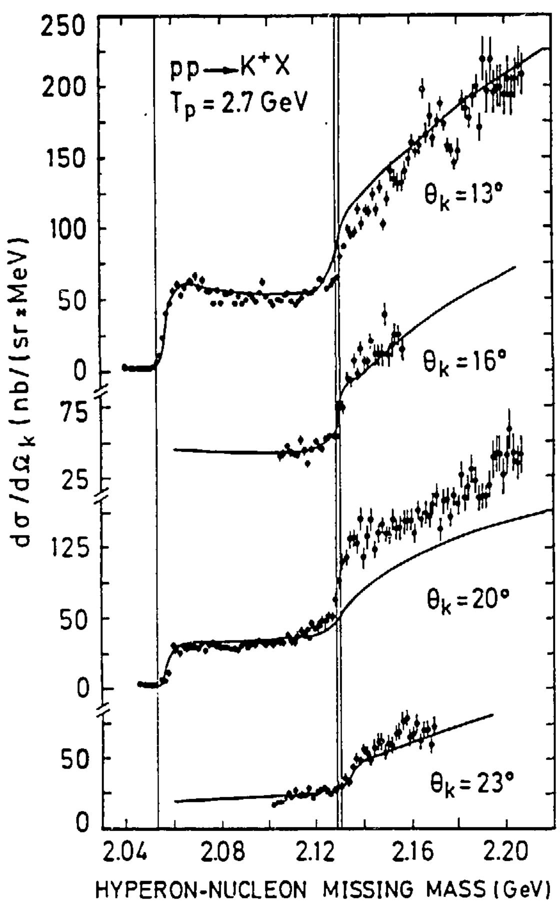


FIGURE 8

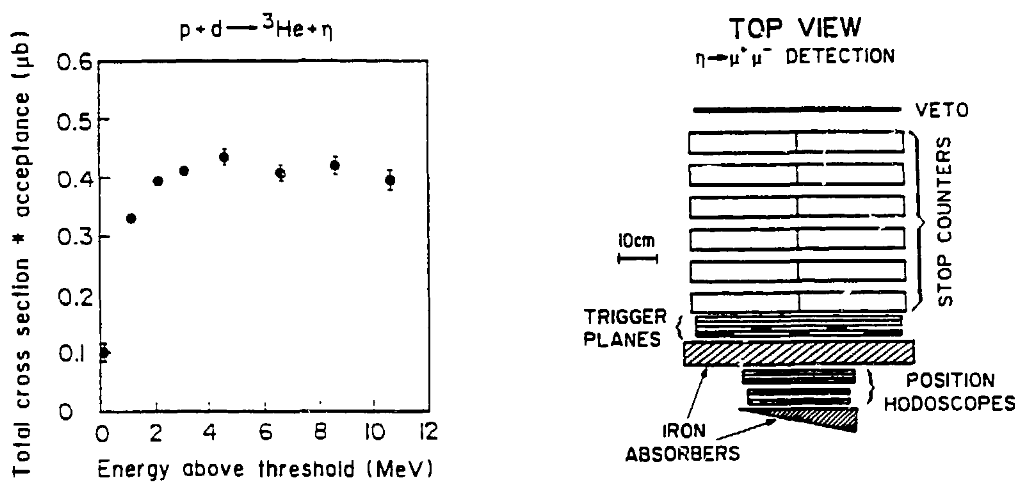
Differences appear with the first results which are mainly :

- The previous structure at 2131 MeV seems to be not observed in these new conditions but one is seen at 2136 ± 2 MeV in the θ = 20° MM spectrum with a width of 16 MeV (FWHM).

- The theoretical model is unable to reproduce this θ = 20° spectrum above the Σ - N thresholds. The T = 2.3 GeV measurements have t values close to zero and yield very similar MM spectra. This is not the case for the new data at T = 2.7 GeV where the t values are very different and far from zero and the behaviour of the MM spectra could be strongly dependent on the 4-momentum t. A separation of the different channels is needed in further experiments. This will be realized with a new experimental area in development at LNS [19].

1 - $\eta \to \mu^+ \mu^-$ decay

The large η production observed in proton deuteron interactions near threshold has lead to the development of a tagged "η-beam". This facility is now working to determine more precisely the η branching ratio in two muons $\eta \to \mu^+ \mu^-$. The η-mesons are tagged by the detection of the ^{3}H at 0° in pd $\to$ ^{3}He η at 0° ; a $10^5\eta$/s beam intensity is obtained. The fig. 9 shows the total cross section pd $\to$ ^{3}He η measured near threshold with SPES2 [20]. A first run with a two-arms muon detector as shown on fig. 9 has already accumulate a statistics ten times higher than the original work done by DZHELYADIN et al. [21]. The analysis of the data is in progress.



a) FIGURE 9 b)

2 - Charge symmetry breaking in d + d $\to \alpha + \pi_0$ reactions

The search for the observation of the d + d $\to \alpha + \pi^0$ reaction which is forbidden by isospin conservation in strong interaction has started a long time ago at LNS . The characterization of this reaction by the detection of the α particles with SPES4 lead to the determination of an upper limit of 19 pb . A new experiment where the α particles scattered at θ = 110°c.m. and coming from the interaction of deuterons of 1.1 GeV kinetic energy are detected in SPES4 in coïncidence with either one gamma or two gammas from the π^o decay by 36 lead glass detectors has succeeded in the measurement of this reaction [22]. The center of mass cross section is found to be $0.97 \pm 0.20 \pm 0.15$ pb/sn from the analysis of two different group of events [one gamma against two gammas]. In the same experiment as a check of the good operation of the set up, the dd $\rightarrow \alpha\gamma$ reaction has been also measured ; the cross section is $0.82 \pm 0.18 \pm 0.10$ pb/sr. The rather high value found for the π^o production could be explained as due to the proximity of the η threshold : again the S_{11} resonance could enlarge the production rate of η-meson which by η-π mixing transforms to π_o. This important result should encourage the physics community to pursue such measurements in particular in this energy domain with an improved detector.

3 - Possible observation of ${}^{5}_{\Lambda}$He by means of ^{4}He(p,k^{+})${}^{5}_{\Lambda}$He

In an experiment dedicated to the observation of hypernuclei by means of (p,k^{+}) reactions on deuterium, ^{3}He and ^{4}He targets a significant signal of ${}^{5}_{\Lambda}$He production has been observed at SPES4 [23]. After time of flight cuts, trajectory trackings, subtraction of empty target events, a signal appears in the missing mass near the expected value corresponding to the ${}^{5}_{\Lambda}$He mass (only 2 MeV difference). The kinetic energy of the incident protons was 2 GeV and the angle for the detected kaons was 7°. The measured cross section is 0.4 nb/sr which is high for such large momentum transfer reaction (q = 3.6 fm^{-1}). Shimmura et al. [24] was expecting a 0.2 to 0.3 nb/sr value in a calculation with H - J potentiel including short range correlations. This experimental result has to be confirmed : if so, this (p,K^{+}) experiment would allow the investigation of high momentum components of Λ in hypernuclei, and correlatively Λ - nucleon interaction at short distance in nuclear medium. Another explanation could also imply three-body mechanisms with N* having large branching ratio into NK, in a similar way to the *mechanism observed in pd $\rightarrow$ ^{3}He η reaction* .

There are now convergent ways at LNS to establish reliably the validity of the meson-exchange picture in its medium range. This is achieved by studying the dynamics of light and heavy meson production in complementary few body systems. This is a good way to isolate discrepancies which could occur between precise experimental data and the meson theoretic scheme. If such deviations appear one could have the chance at the end to pull out new phenomenon due to the underlying quark structure of hadrons.

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