The latest results from OBELIX

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The most recent achievements of the analysis of the data collected by the OBELIX experiment at LEAR are presented. The most interesting results concern the apparent OZI-rule violation in some annihilation channels and the consequent explanation in terms of a polarized $(s\bar{s})$ strangeness content of the nucleon, a further convincing evidence for the presence of two pseudoscalar states in the E/ι region and finally the observation of a tantalizing anomaly in the total antineutron-proton cross section at very low momenta.

1. INTRODUCTION

I shall not summarize the physics results obtained so far by the OBELIX experiment, contained in more than 50 research papers from 1991 up to now, but perhaps report on the most recent results achieved in the last year, just or not yet published.

OBELIX was a magnetic spectrometer installed at the M1 branch of the LEAR machine at CERN, and a detailed description can be found in Ref. [1]. It was designed to detect and recognize with a large angular acceptance ($\sim 3\pi$ sr) all the charged and the neutral particles emitted from the interaction of low momentum (< 400 MeV/c) antinucleons with nucleons and nuclei. Its main experimental features are: charged particles momentum resolution $< 3\%$; π^0 reconstructed mass resolution $\sim 8\%$; particle identification (π/K) up to 600 MeV/c by time-of-flight and specific energy loss measurements; vertex reconstruction precision in the target ~ 1 mm. The detector was equipped with a first level trigger system capable of selecting the multiplicity of the charged particles, some simple topologies and low energy kaons.

Thanks to the modular conception of the spectrometer and to the quite large unobstructed space allowed in the target region, data could be collected with targets of liquid H_2, H_2 at NTP and also at low pressure (5 mbar), D_2, He and other solid materials. The use of H_2 at different densities with $\bar{p}$ at rest was of paramount importance to disentangle the different contributions arising from the initial states of the $(\bar{p}p)$ atom. With LH_2 the annihilation proceeds predominantly ($\sim 90\%$) from S-states, with NTP H_2 in nearly equal proportions from S- and P-states and at low pressure H_2 predominantly from P-states ($\sim 90\%$).

A unique feature of OBELIX was the capability of using an Isospin filter in the study of the $(\overline{\mathcal{N}}\mathcal{N})$ interaction. It was provided by the $\bar{n}$ beam, that allowed to select the **I=1** component of the $(\overline{\mathcal{N}}\mathcal{N})$ interaction in a much cleaner and more reliable way than with the use of a deuterium target, as previously done. Futhermore, the $\bar{n}$ beam had a quite wide momentum band ($50 \div 400$ MeV/c), and it was possible to select also different percentages of the initial angular momentum states by looking at the events collected at low momenta ($\sim 70\%$ S-state, $\sim 30\%$ P-state) or at high momenta ($\sim 30\%$ S-state, $\sim 70\%$ P-state). A detailed description of the $\bar{n}$ beam can be found in [2].

OBELIX collected more than 4×10^8 events on tape. About 75% of them were up to now analyzed, sometimes only in a preliminary way.

2. OZI RULE VIOLATIONS AND STRANGENESS IN THE NUCLEON

Recent results on $(\overline{\mathcal{N}}\mathcal{N})$ annihilations from LEAR, in particular from OBELIX, showed unambiguous evidence for the failure of the application of the Okubo-Zweig-Iizuka (OZI) rule [3] for some annihilation channels with a naïve nucleon wave function. Two explanations were put forward to explain such an anomaly. Locher *et al.* [4] proposed rescattering diagrams with OZI-allowed transitions in the intermediate state, *e.g.* $\overline{\mathcal{N}}\mathcal{N} \to \overline{K^*}K \to \phi\pi$. Ellis *et al.* [5] assumed that the nucleon wave function contains polarized $(s\bar{s})$ pairs. Then the observed OZI violation is only apparent since there are additional classes of connected quark-line diagrams.

This dilemma, quite typical of low energy hadronic physics (do we need quarks or simply hadrons to describe the phenomena?) convinced the OBELIX Collaboration to undertake a study of the following two-body reactions, with $\bar{n}$ momentum from 50 to 400 MeV/c: (1) $\bar{n}p \to \phi\pi^+$ $[^3S_1,\ ^1P_1]$; (2) $\bar{n}p \to \omega\pi^+$ $[^3S_1,\ ^1P_1]$; (3) $\bar{n}p \to \overline{K^{*0}}K^+$ $[^3S_1,\ ^1P_1]$; (4) $\bar{n}p \to \eta\pi^+$ $[^3P_0,\ ^3P_2]$; (5) $\bar{n}p \to \eta'\pi^+$ $[^3P_0,\ ^3P_2]$.

In the brackets I have indicated the initial states from which the reactions may proceed, at low energies. The results on $(1) \div (3)$ have just been published [6], those for (4) and (5) are under publication [7]. For reaction (1) the new data confirm the previous observation [8] of a dynamical selection rule for which the annihilation proceeds only from S-wave. This is clearly demonstrated both by the angular distribution of ϕ decay products and of ϕ production angle and by the momentum dependence of the cross-section, shown in Fig. 1a). From this complete set of data I may conclude that ϕ production in $\overline{\mathcal{N}}\mathcal{N} \to \phi\pi$ annihilation occurs at 100% from $^3S_1$ state, with a $\sim 2\%$ incertitude.

The results for reaction (2) are quite interesting. From a very careful analysis of the ω-decay Dalitz plots it appears that there is a sizable P-wave contribution ($\sim 20\%$ at low $p_{\bar{n}}$, $\sim 40\%$ at high $p_{\bar{n}}$). The P-wave contribution manifests itself also in the momentum dependence, shown by Fig. 1b). A departure from the S-component behaviour represented by the Dover-Richard fit [9] is quite clear. I notice that in previous experiments on ω production with $(\bar{p}p)$ at rest, and in particular on the ratio R between ϕ and ω production, it was always implicitly assumed that both mesons were produced from the same percentages of initial states. Incidentally, taking into account only the production of ϕ and ω from $^3S_1$ initial state, there is an excellent agreement between this result from OBELIX ($R_S = 0.112 \pm 0.014$) and the previous one from Crystal Barrel ($R_S = 0.111 \pm 0.016$) [10].

Reaction (3) is important in this discussion since it is the intermediate state in the rescattering process suggested in Ref. [4]. The cross section as a function of $p_{\bar{n}}$ exhibits a flat behaviour, shown in Fig. 1c). This is in contrast with the S-wave scaling trend required by the rescattering model, by hypothesis.

Given the success of the mechanism based on the polarized intrinsic strangeness in the

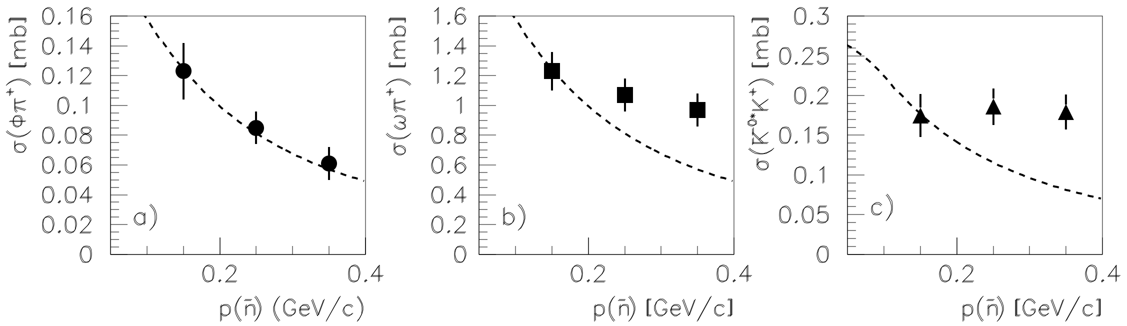

Figure 1. Trend of cross sections as a function of $p_{\bar{n}}$ for the reactions a) $\bar{n}p \rightarrow \phi\pi^+$, b) $\bar{n}p \rightarrow \omega\pi^+$ and c) $\bar{n}p \rightarrow \overline{K^{0*}}K^+$. The dashed curve represent the trend of S-wave annihilations as delivered by Dover-Richard's model.

nucleon (PISN) in explaining the data on ϕ/ω production by $\bar{n}$, it seemed useful to analyze other reactions that could test other predictions. One of them was that the formation of an $(\bar{s}s)$ system with $J^{PC} = 0^{-+}$ should be enhanced from spin-singlet states. η and η' have a strong $(\bar{s}s)$ component but the annihilation channels (4) and (5) proceed from spin triplet states only, namely $^3P_0$ and $^3P_2$. It was shown [7] that the cross-section as a function of $p_{\bar{n}}$ for (4) exhibits a P-wave scaling, as expected. Due to the reduced sample of reconstructed η' it was not possible to obtain also for (5) a $p_{\bar{n}}$ dependent cross-section. However it was possible to extract the ratio K_0 of the production yields of η' and η, and a value of $(0.63 \pm 0.16_{st.} \pm 0.04_{syst.})$ was found, in fair agreement with the value found by the Crystal Barrel Collaboration with $\bar{p}$ at rest $(0.548 \pm 0.046 \pm 0.014)$ [11].

From this measurement it was concluded that no strong violations of the predictions of the Quark Line Rule were observed, in agreement with the PISN picture. This result strengthens also the statement by Dover and Fishbane [12] that the 0^{-+} quantum numbers for the $(\bar{s}s)$ admixture in the nucleon may be discarded.

Finally I wish to recall a recent measurement by OBELIX [13] in which, by a careful spin-parity analysis of the $\bar{p}p \rightarrow K^+K^-\pi^0$ channel with $\bar{p}$ at rest at three Hydrogen densities, it was possible to compare the production yields of the $f_2'(1525)$ meson, which is mainly an $(\bar{s}s)$ system, with that of the $f_2(1270)$, which is mainly a $(\bar{n}n)$ system, in both S- and P-wave. A production ratio $R[f_2'(1525)/f_2(1270)]$ of $(47 \pm 14) \times 10^{-3}$ was found for S-wave, of $(149 \pm 20) \times 10^{-3}$ for P-wave. The naïve OZI-rule prediction for $R(f_2'/f_2)$ is 16×10^{-3}, and the PISN model predicts a strong apparent violation of the rule for the annihilation from the P-wave, as observed. The rescattering mechanism predicts very low production rates of f_2' from S- and P-states [14] of the order of 10^{-6}.

Let me add two personal remarks to this series of measurement by OBELIX.

a) It is the first time that I see, in a low-energy hadronic process, that a model based on quark diagrams is the only one able to explain the experimental findings.

b) It is conceptually very appealing the idea that quite different experimental phenomena, like deep-inelastic muon and electron-nucleon scattering, pion-nucleon σ-term extracted from $\pi\mathcal{N}$ scattering and estimated from baryon mass splitting, and apparent OZI-rule violation could be linked by the "strangeness in the nucleon".

3. E/ι REGION: CONFIRMATION OF TWO PSEUDOSCALARS

A previous analysis [15] of the four prong data in the channel $(K^{\pm}K^0_{miss}\pi^{\mp}\pi^+\pi^-)$ provided evidence for two pseudoscalar states in the E/ι region: $\eta(1415)$ decaying dominantly to $K\overline{K}\pi$ and $\eta(1460)$ decaying dominantly to K^*K. However, these data were affected by a non-negligible background ($\sim 20\%$) and the analysis model neglected the energy dependence of the E/ι partial widths to different decay modes.

Motivated by these consideration, the OBELIX Collaboration decided to collect a new high statistics sample in the channel $\bar{p}p \to (K^{\pm}K^0_S\pi^{\mp})\pi^+\pi^-(K^0_S \to \pi^+\pi^-)$ which is not affected by background. Meanwhile also the analysis tools were improved; a quite complete description of the procedure can be found in Ref. [16].

The conclusion of the analysis is that two pseudoscalar states are needed for describing the data. The first one has $M = 1405 \pm 5$, $\Gamma = 50 \pm 5$ MeV/c^2 and decays dominantly to $K\overline{K}\pi$, the second $M = 1500 \pm 10$, $\Gamma = 100 \pm 20$ MeV/c^2 and decays dominantly to $K^*\overline{K}$. This result is fully compatible with the previous one [15], apart from a slight shift in the masses, probably due to the different analysis programs that have been used.

4. SEARCH FOR ISOTENSOR $\pi\pi$ STATES

A complete spin-parity analysis of the $\bar{n}p \to \pi^+\pi^+\pi^-$ channel was recently published [17]. The analysis showed the necessity of introducing in the amplitude, besides the conventional contributions of S-wave $\pi\pi$ non resonant interaction and of $\rho^0(770)$ and $f_2(1270)$ mesons, four new states, namely the $f_0(1500)$, the $f_2(1565)$, the $f_0(1370)$ as a broad background contribution and finally the $\rho'(1450)$. With these ingredients the description of the overall Dalitz plot was good, with some little defects of the fit especially in the $(\pi^-\pi^+)$ invariant mass spectrum from 1.2 to 1.5 GeV/c^2.

Bearing in mind the interest in detecting signals of the I=2 $\pi\pi$ interaction, the insertion of a new contribution in the amplitude, as an I=2 $(\pi^+\pi^+)$ interaction, was attempted to check if it could have any positive effect on the fits' results [18].

The I=2 $(\pi^+\pi^+)$ amplitude was added coherently to each partial wave amplitude, weighting it by proper isospin Clebsh-Gordan coefficients. Two hypotheses have been tested, namely an s-wave amplitude and a d-wave one, both in the simplified form of an effective range expansion amplitude or of a Breit-Wigner function to resemble a possible resonant contribution, whose mass and width were to be optimized by the fit. A grid procedure was adopted in the analysis. The best solution was achieved, for both the scalar and tensorial hypothesis, with the insertion of an I=2 Breit-Wigner contribution, with $M = 1400 \div 1500$, $\Gamma = 150 \div 400$ MeV/c^2. Unfortunately neither the likelihood values nor the χ^2 for the two cases help in understanding which of the two spin hypothesis is better verified. However, the contribution of such an amplitude seems to be meaningful to get better fits, even if its contribution does not exceed $(7 \pm 1) \times 10^{-3}$ over the full Dalitz plot, corresponding to a total production rate of less than 10^{-5}.

5. LOW ENERGY $\bar{\mathcal{N}}\mathcal{N}$ CROSS SECTIONS

The possibility of measuring very low momentum cross sections both for the $(\bar{p}p)$ system (I=0, I=1) and the $(\bar{n}p)$ system (I=1) is a unique capability of OBELIX. Since in some previous measurements [19] the annihilation cross section $\sigma_{ann}(\bar{p}p)$ at the lowest $\bar{p}$ incident momentum (44 MeV/c) showed an anomalous trend, an effort was done in order to push down the lower limit. $\sigma_{ann}(\bar{p}p)$ was measured down to 37 MeV/c, but the aforesaid departure from a smooth trend was not confirmed. The data agree with a theoretical model based on the expansion of the scattering amplitude in terms of S–wave and P–wave scattering lengths [20]. Also the annihilation cross section $\sigma_{ann}(\bar{n}p)$ down to 60 MeV/c previously reported [21], did not show departures from a smooth behaviour well represented by an effective range expansion approximation, as shown by Fig. 2. However, the recently analyzed [22,23] total cross section $\sigma_T(\bar{n}p)$, shown in the same figure, shows an interesting anomaly below 100 MeV/c. With the same set of parameters, which fit well $\sigma_{ann}(\bar{n}p)$, it is impossible to reproduce $\sigma_T(\bar{n}p)$.

The conclusion is that there must be an anomaly in $\sigma_{el}(\bar{n}p)$, possibly linked to the existence of quasi–nuclear $\bar{\mathcal{N}}\mathcal{N}$ states near threshold [24]. However, some cautions arise from the errors in the measurements; the "anomaly" has a statistical significance corresponding to 3σ. Another effect that emerges from the data, without doubts about the statistical significance, is the dominance of the **I=0** component in the $(\bar{\mathcal{N}}\mathcal{N})$ interaction over the **I=1** one at low momenta. Whereas at 200 MeV/c $\sigma_T(\bar{p}p)$ is only $\sim$ 10% larger than $\sigma_T(\bar{n}p)$, at 70 MeV/c $\sigma_{ann}(\bar{p}p)$, exceeds by $\sim$ 50 $\sigma_T(\bar{n}p)$ and by $\sim$ 70% $\sigma_{ann}(\bar{n}p)$.

It means a dominance of the **I=0** component over the **I=1** one by about a factor $\sim$ 2.5. The effect may be explained, following Dover et al. [9], by the coherence of the ρ, ω, δ and σ meson exchange in the central and tensor terms of the $(\bar{\mathcal{N}}\mathcal{N})$ medium range interaction in the **I=0** channel.

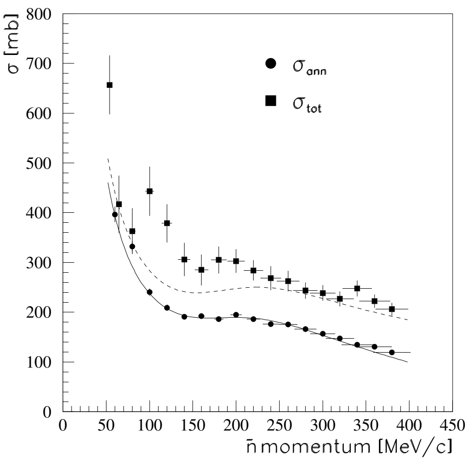

Figure 2: Total $(\bar{n}p)$ cross section $\sigma_T(\bar{n}p)$ and $\sigma_{ann}(\bar{n}p)$ annihilation cross section as measured by OBELIX. The solid curve is a prediction of $\sigma_{ann}(\bar{n}p)$ obtained by means of an effective range expansion approximation. The dashed curve is the prediction for $\sigma_T(\bar{n}p)$.

6. COUPLED CHANNEL ANALYSIS OF THE $(\bar{p}p)$ ANNIHILATION AT THREE DENSITIES

This item constitutes the more ambitious long–range program for the analysis of the data collected by OBELIX. The aim is to fit simultaneously the data collected on the channels $\bar{p}p \to \pi^+\pi^-\pi^0$, $\bar{p}p \to K^+K^-\pi^0$, $\bar{p}p \to K^{\pm}K^0\pi^{\mp}$ and $\bar{p}p \to \pi^+\pi^-\eta$ at three different densities of the Hydrogen target. The spin–parity formalism used to fit the Dalitz plot is the K–matrix and P–vector one. The analysis program, very ambitious, is nearly completed and quite interesting preliminary results have already been presented [25]; in particular for the ratio of the $f_0(1500)$ coupling constants to KK and $\pi\pi$ the value 0.75 has been found.

7. CONCLUSIONS

In the last year OBELIX has produced a wealth of new and interesting results, in particular concerning the annihilation dynamics. I may expect that the final analysis of the full bulk of data, scheduled within the next two years, will provide a real breakthrough in the comprehension of the annihilation dynamics involved in $(\bar{\mathcal{N}}\mathcal{N})$ interaction and in the light quark meson spectroscopy.

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