LNL-INFN(REP) 88/94

# GLUEBALLS AND HADRONIZATION FROM SEPARATED $J^{PC}$ SOURCES IN $p\bar{p}$ ANNIHILATIONS AT REST

U. Gastaldi
INFN, Laboratori Nazionali di Legnaro
Via Romea 4, I-35020 Legnaro (Padova), Italy

## ABSTRACT

Experiments at LEAR have confirmed or discovered structures produced in $p\bar{p}$ annihilations at rest, which can be interpreted as glueball states or other exotics. Their experimental evidence is out of question, but there are ambiguities in the interpretation and even in the assignement of the quantum numbers of some of these mesons. Removal of the ambiguities requires measurements of the relative contributions of the six $J^{PC}$ types of initial states of annihilations and extracting the final states produced by each individual $J^{PC}$ annihilation source. The values of all observables in $p\bar{p}$ interactions at rest can be changed by variing the target density, which controls the distribution among the six possible $J^{PC}$ quantum numbers of the initial states of annihilation. The fractions of the six $J^{PC}$ annihilation sources vary with the target density. Until recently it was assumed that the ratios between the spin triplet(s) and the spin singlet annihilation fractions were fixed separately for S and P-wave annihilations and independent of the target density. A model independent analysis of the physical processes shows that this assumption is not valid and not supported by the data. A major consequence of this fact is that, by collecting data at different target conditions, it will be possible to separate the contributions from all the different $J^{PC}$ sources to the same annihilation channel. This will permit to study the production of the exotic candidates separately from each $J^{PC}$ allowed set of initial states. Moreover the ensemble of these annihilation data will provide the picture of the hadronization from six sources with $2m_p$ total energy and different discrete quantum numbers $J^{PC}$.

Presented at the 6th Course of the International School of Physics of Exotic Atoms
Erice-Sicily, March 21-30 ,1994

# GLUEBALLS AND HADRONIZATION FROM SEPARATED $J^{PC}$ SOURCES IN $p\bar{p}$ ANNIHILATIONS AT REST

U. Gastaldi
INFN, Laboratori Nazionali di Legnaro
Via Romea 4, I-35020 Legnaro (Padova), Italy

## ABSTRACT

Experiments at LEAR have confirmed or discovered produced in $p\bar{p}$ annihilations at rest, which can be interpreted as glueball states or other exotics. Their experimental evidence is out of question, but there are ambiguities in the interpretation and even in the assignement of the quantum numbers of some of these mesons. Removal of the ambiguities requires measurements of the relative contributions of the six $J^{PC}$ types of initial states of annihilations and extracting the final states produced by each individual $J^{PC}$ annihilation source. The values of all observables in $p\bar{p}$ interactions at rest can be changed by variing the target density, which controls the distribution among the six possible $J^{PC}$ quantum numbers of the initial states of annihilation. The fractions of the six $J^{PC}$ annihilation sources vary with the target density. Until recently it was assumed that the ratios between the spin triplet(s) and the spin singlet annihilation fractions were fixed separately for S and P-wave annihilations and independent of the target density. A model independent analysis of the physical processes shows that this assumption is not valid and not supported by the data. A major consequence of this fact is that, by collecting data at different target conditions, it will be possible to separate the contributions from all the different $J^{PC}$ sources to the same annihilation channel. This will permit to study the production of the exotic candidates separately from each $J^{PC}$ allowed set of initial states. Moreover the ensemble of these annihilation data will provide the picture of the hadronization from six sources with $2m_p$ total energy and different discrete quantum numbers $J^{PC}$.

## 1. INTRODUCTION

The main physics output expected in $p\bar{p}$ annihilations at LEAR is the identification of low mass states of glueballs or of hybrids, which would prove by their existence the direct coupling of gluon to gluon, that is one of the foundations of QCD.

$p\bar{p}$ annihilations at rest feature caracteristics that make them a unique tool to produce and discover glueball states, if their mass is low enough. Apart from the extremely high event rate, the most important advantage of $p\bar{p}$ interactions at rest is that annihilations occur from up to six types of initial states with different $J^{PC}$ quantum numbers and that the distribution of these six types of initial states can be changed by changing the $H_2$ target density. The data analysis is more difficult than in the case of $e^+e^-$ annihilations, which occur only from $1^{--}$ initial states, but offers the opportunity of studiing and comparing spectra produced with same phase space and acceptances from several sets of initial states of different $J^{PC}$ quantum numbers, if the contributions from different sets of initial states can be separated.

Recent years have witnessed progress along the two interconnected lines of finding or confirming states candidated to be exotic and understanding the variation of the distribution of initial states.

The Crystal Barrel and OBELIX collaborations have confirmed with higher statistics previous exotic candidates already seen at LEAR by the ASTERIX experiment (E/i, $0^{++}(1360)$, AX(1565)) and observed new states ($0^{++}(1520)$) [1-10]. The existence of the signals is established without doubt, but their physical interpretation is not assessed and requires i) to establish the $J^{PC}$ initial state(s) from which they are produced, ii) to observe the signals in other decay channels.

Annihilation frequencies (experimental production rates of exclusive channels) have been measured at several target densities and at NTP in coincidence with L X-rays of protonium[1-29]. Dominance of S-wave annihilations in liquid $H_2$ targets [30] and dominance of P-wave annihilations in low pressure targets [31-38] are qualitatively explained by the Day-Snow-Sucher mechanism [39] of combined effect of mixing of atomic levels of protonium (due to collisions with the molecules of the target) and of annihilation widths in S-waves much larger than the annihilation widths in P-waves. A quantitative interpretation of the data in terms of S-wave and P-wave annihilations has been done by the ASTERIX collaboration [11,12] under the tacit assumption that S-wave and P-wave annihilations have separately ratios between the spin triplet(s) and spin singlet components statistical and independent from the target density. We call this assumption SPASSS, from S- and P-wave Annihilations Separately Statistical in Spin, from now on. Under this assumption it was possible to decompose the spectra of a given annihilation channel, collected with two different distributions of initial states, into their S-wave and P-wave components. More than two distributions of initial states appeared redundant since the ratios of the contributions from different spin states were thought to be constant independently for the S and the P-waves. It was therefore also not envisageable to separate the up to two contributions to S-wave annihilations and the up to four contributions to P-wave annihilations by comparison of data collected under different target conditions.

In 1990 it was pointed out that the ASTERIX analysis relied onto the SPASSS assumption, and that spin polarization effects would become observable and usable if SPASSS would not be valid [40]. Two years later a model independent description of the structure of the distribution of the initial states of annihilation has been worked out in Legnaro [41] and has shown that the SPASSS assumption is not correct.

We will see in these lectures that experimental data do not support SPASSS and discuss the consequences concernig the determination of annihilation fractions and branching ratios of annihilation.

Since the intensities of the two S-wave and the four P-wave annihilation sources do not scale proportionally by changing the target density, the possibility opens up of extracting separately all the $J^{PC}$ spectra of a given final state from a linear combination of the spectra collected at different target conditions. We discuss in these lectures a generalization of the treatment suggested for determining $J^{PC}$ branching ratios and annihilation fractions in ref. 41. This generalization should permit to obtain the $J^{PC}$ components of spectra of exclusive annihilation channels.

## 2. EXOTIC CANDIDATES AT LEAR FROM $\bar{p}p$ AT REST

### Scalar Mesons

### $0^{++}(1360)$

A broad structure was seen long ago in $\bar{p}n$ annihilations at rest in the liquid $D_2$ bubble chambers at CERN by the Padova-Pisa and at BNL by the Rome-Syracuse collaborations in the final state $2\pi^+2\pi^-$ recoiling against a $\pi^-$ and a spectator proton. The Padova-Pisa group suggested $0^{++}$ quantum numbers [42]. The Syracuse group interpreted this structure as a $2^{++}$ object [43] and considered it as a baryonium candidate, assuming that it was the dominant decay mode of the AX(1565) observed in the $\pi^+\pi^-$ decay mode by ASTERIX in $\bar{p}p$ annihilations at rest in a NTP $H_2$ target [1]. The reanalysis of the BNL data of Gaspero [44] suggested $0^{++}$ quantum numbers and dominant interfering decay modes $\rho\rho$ and $\sigma\sigma$. The structure has been seen again in $\bar{p}p$ annihilations at rest in liquid $H_2$ by the Crystal Barrel collaboration in the decay mode $\pi^+\pi^-2\pi^0$ [7] and by Obelix in its decay mode $2\pi^+2\pi^-$ in $\bar{n}p$ annihilations in flight with low momentum antineutrons [8]. The $0^{++}$ result and the dominant decay modes $\rho\rho$ and $\sigma\sigma$ have been confirmed and the current tendence is to interpret this structure as a normal isoscalar member of the $0^{++}$ nonet [ 6,7 ]. The decay in the $2\pi^0$ channel of a $0^{++}$ object with similar mass emerges as the dominant amplitude in the recent analysis of the $3\pi^0$ final state in $\bar{p}p$ annihilations at rest in liquid $H_2$ [6]. In this analysis it has been assumed that only the spin singlet S-wave initial states contribute significantly to the $3\pi^0$ channel in $\bar{p}p$ annihilations in liquid $H_2$. Because of interference effects with the other amplitudes present and the large width, the structure does not produce a separate band in the dalitz plot, nor an isolated bump in the mass projection. The decay in the $\eta\eta$ channel of a $0^{++}$ object of similar mass is also observed as a dominant amplitude in the annihilations of $\bar{p}p$ at rest in liquid $H_2$ into $\pi^0\eta\eta$ measured by the Crystal Barrel [5,6].

### $0^{++}(1520)$

In the high statistics $3\pi^0$ data sample of $\bar{p}p$ annihilations in liquid $H_2$ of the Crystal Barrel a narrow band centrered at 1520 MeV traverses the dalitz plot and intercepts a bump centred at around 1560 MeV [4,6]. The bump is mainly the reflection of the constructive interference between the two bands associated to the broad $\pi^0\pi^0$ enhancement centred at about 800 MeV [6]. The interpretation of the band at 1520 MeV depends critically from assumptions on the relative contributions of the three possible initial states.

In ref.4 the band was interpreted as a $2^{++}$ resonance produced with nearly equal contributions from the three initial states $0^{-+}$, $1^{++}$ and $2^{++}$.

In ref.6 the assumption is made that all $3\pi^0$ events are produced only from the $0^{-+}$ initial states, and the interference effects of all the amplitudes in the $0^{-+}$ channel permit to reproduce the full experimental Dalitz plot without requiring contributions from the $1^{++}$ and $2^{++}$ sources.

One notes also that in the scenario of ref.4 the contibution to the $3\pi^0$ channel from the two P-wave initial states adds up to 60%, and the $f_2(1270)$ is produced dominantly from $1^{++}$ initial states and not appreciably from $2^{++}$ initial states; the tail of a $2^{++}$ resonance with mass higher than 1560 MeV produced by $2^{++}$ initial states and contributing as many events as the $f_2(1270)$ is necessary to fit well the edges of the dalitz plot; the $f_0(1365)$ amplitude was not inserted in the contributions of the $0^{-+}$ initial states. In the scenario of ref.6 there are three $0^{++}$ $2\pi^0$ intermediate states: the $\sigma$, the $f_0(1365)$ and the $f_0(1520)$ plus the $f_2(1270)$ and a $2^{++}$ resonance at about 1560 MeV ; all the amplitudes of these decays interfere since they connect a $0^{-+}$ $\bar{p}p$ initial state to the $3\pi^0$ final state.

The example of the $3\pi^0$ final state illustrates dramatically the interest of measuring separately the spectra from the sources of annihilation of different $J^{PC}$, because even the quantum number assignement of a resonance may depend on it. We shall return to this example later on and insist on the fact that $3\pi^0$ spectra at three target conditions are necessary to separate the contributions of the $0^{-+}$, $1^{++}$ and $2^{++}$ $3\pi^0$ sources.

A $0^{++}$ $\eta\eta$ structure is present at 1560 MeV in the $\pi^0\eta\eta$ final state of $\bar{p}p$ annihilations at rest in liquid $H_2$ [5]. Unlike the $3\pi^0$ channel, the corresponding Dalitz plot does not require the presence of a $2^{++}$ resonance above this mass for a god fit of the data, under the hypothesis that the initial states of annihilation are all $0^{-+}$ [6].

## Pseudoscalars

### E/i

The E/i signal has been observed by Obelix in the $K_oK^{\pm}\pi^{-+}$ decay channel in $\bar{p}p$ annihilations at rest in liquid $H_2$ in the decay channel $K_oK^{\pm}\pi^{-+}\pi^{+}\pi^{-}$ [9]. The statistics exceeds by one order of magnitude the bubble chamber [45,46] and ASTERIX data [2]. The fit requires two $0^{-+}$ contributions. The frequency of the decay channel and of the signal is depressed by a factor of about seven when annihilations occur in a 5 mbar $H_2$ target, confirming the result obtained by ASTERIX [2] that the signal is produced by the $0^{-+}$ S-wave source. This information gives an experimental justification to a drastic simplification of the analysis of data in liquid, where one can assume with a very good approximation that only $0^{-+}$ S-wave initial states contribute to the channel where the E/i is observed. This kind of information is missing in the $3\pi^0$ channel (where we may be spectators in the next future of a completely different scenario, with may be even an increase of the total frequency of the channel at lower densities).

## Tensors

### AX(1560)

The signal of the AX observed by ASTERIX in the decay channel $\pi^+\pi^-\pi^0$ in $H_2$ gas at NTP [1,13,14] has been confirmed by Obelix in $\bar{p}p$ data at rest at NTP and at 5mbar [10] and in $\bar{n}p$ annihilations in flight in the $2\pi^+\pi^-$ final state [8]. If the signal is generated only by a $2^{++}$ resonance mainly produced from P-wave initial states, it must be present in the $\pi^0\pi^0$ decay channel, and it should be very clearly visible in the $3\pi^0$ final state (where the $\rho$ bands are absent) when data will be collected at NTP or lower densities, since the signal is seen in the $\pi^+\pi^-$ decay channel (where interference with the crossing of the $\rho^+$ and $\rho^-$ bands is present and makes the observation difficult). Conversely, if the $0^{++}$ solution for the $\pi^0\pi^0$ signal seen at 1520 MeV in liquid is correct, the signal must be present also in the $\pi^+\pi^-$ channel at NTP, since the fraction of S-waves reduces only by a factor of about two. Both a $0^{++}$ and a $2^{++}$ contribution may be present together with a striking spin polarization effect in S-wave in $\bar{p}p$ data at NTP and 5 mbar [10], but the analysis is still preliminary and rather complex, since five sources, the two S-waves and the $1^{+-}$ $1^{++}$ and $2^{++}$ P-waves can contribute to the $\pi^+\pi^-\pi^0$ final state.

In summary all exotic candidates found at LEAR are confirmed by the recent measurements with high statistics. If the $0^{++}(1360)$ is a normal I=0 meson, the $0^{++}$ isoscalars with lower masses have to be interpreted as exotics. The $0^{++}(1520)$ is a candidate for the ground state of glueballs. The $0^{-+}$ E/i has been for the last decade the prime glueball candidate. The $2^{++}(1560)$ has been a favoured candidate for a $B\bar{B}$ bound state. Several difficulties remain in the interpretation of all these states. In order to remove ambiguites and establish the nature of the states in discussion there is the necessity i) of observing the signals in decay channels, like $K^+K^-$, different from those already studied, ii) of changing in a controlled way the production conditions by variing the $J^{PC}$ distribution of initial states and iii) eventually producing final state spectra from separated sets of initial states of different $J^{PC}$.

# 3. INITIAL STATES IN $p\bar{p}$ ANNIHILATIONS AT REST

## 3.1 General points

Observable quantities in $\bar{p}p$ interactions at rest include the cascade times of the $\bar{p}p$ atom from formation to annihilation [47-49], the intensities of the X-ray radiative transitions of the $\bar{p}p$ atom [31-38], the frequencies ( or production rates) of well identifiable annihilation channels (like annihilations into two narrow mesons recoiling back to back to each other), the shape of the spectra that can be constructed when three or more mesons are produced in the final state ( e.g. Dalitz plots, invariant mass plots, angular distributions, correlations ...). All these observables turn out experimentally to depend from the target density or from the selection of initial states of protonium from which annihilations occur [1-30].

The expectation that this phenomenology might occur, and might be exploited for the study of annihilation dynamics, of meson spectroscopy and the search of exotics, was one of the main motivations of the scientific case of LEAR [50].

## 3.2 Limits of the description of $p\bar{p}$ annihilations at rest in terms of S- and P-wave annihilations

As mentioned in the introduction, until recently it seemed established that $\bar{p}p$ annihilations at rest occur

i) in a liquid $H_2$ target in S-wave with a probability of about 90% and with a contamination of 10% of P-waves;

ii) in a NTP gas target in S-wave in about 50% of the cases and in P-wave in the remaining 50%;

iii) dominantly in P-wave in a NTP gas target when requiring in coincidence a L X-ray of the protonium atom (this requires subtraction of the physical background of events having in coincidence an X-ray not produced by a radiative decay of protonium to its first exited level).

The quantitative elements of the above scenario were based on the measurement of the frequencies of the $\pi^+\pi^-$, $K^+K^-$ and $K_SK_l$ final states in the three target conditions mentioned above [11,12,30], on the first LEAR measurement of the frequency of the $\pi^0\pi^0$ final state in liquid $H_2$[51] and on the assumption that annihilations in P-wave from n=2 levels at NTP contributed with the same proportions of the spin singlet and of the three spin triplets as P-wave annihilations from all atomic n levels in both NTP $H_2$ gas and liquid targets.

Things have changed for several reasons:

i) the recent measurement of the $\pi^0\pi^0$ frequency in liquid $H_2$ by the Crystal barrel [17] is three times larger than the previous one [51], while the recent measurements of the frequencies of the $\pi^+\pi^-$ and $K^+K^-$ channels in liquid [18] and NTP [23] confirm the previous values[11,12]. Injecting the new value of the $\pi^0\pi^0$ frequency in liquid $H_2$ in the usual derivation of the P-wave fraction (which makes use of the SPASSS hypothesis) one obtains a P-wave contribution in liquid $H_2$ of nearly 30%.

ii) it has been demonstrated, on the basis of a model independent analysis of the structure of the annihilation fractions that the SPASSS hypothesis of constant proportions of the four P-wave annihilation fractions is wrong and may be used only as a first approximation [41].

iii) the ensemble of the available measurements of the $\pi^+\pi^-$, $K^+K^-$, $K_SK_l$ channels is not consistent with the SPASSS hypothesis.

iiii) more measurements of annihilation frequencies have become available, extending the set of target densities and channels explored [13-30]. The use of the model independent treatment of ref.41 shows that there are inconsistencies among the experimental data, some of which must be affected by systematic errors, and that the ensemble of measurements does not support SPASSS.

Fig 1 shows the nominal values of the annihilation frequency of a number of channels at all the target densities explored, and at NTP in coincidence with protonium X-rays. The data in coincidence with X-rays are arbitrarily indicated as if they would have been collected at $10^{-5}$ atm. The line connecting the data point is just for guiding the eye and visualize the fact that the ratio of increments of the experimental frequencies around the NTP point is not universal for all the cannels.

Fig. 2 shows the ratio between the $K^+K^-$ and the $\pi^+\pi^-$ frequencies versus the target density. Several possible systematic errors common to the two measurements of the frequencies are factorized away by the ratio.

Table 1 lists measurements of annihilation frequencies of some exclusive final states, restricting to the most recent measurements at LEAR, when LEAR measurements are available.

Table 1. Annihilation frequencies * $10^3$

| **Channel** | **Liquid H** | **NTP** | **5 mbar** | **X-ray** |
|---|---|---|---|---|
| $\pi^+\pi^-$ | 3.03 ±0.13<br>[18] | 4.30 ±0.14<br>[11] | 4.26 ±0.11<br>[23] | 4.69 ±0.50<br>[11] |
| $\pi^0\pi^0$ | 0.693±0.043<br>[17] | 1.27 ±0.2<br>[24] | | |
| $K^+K^-$ | 0.99 ±0.05<br>[11] | 0.69 ±0.04<br>[11] | 0.46 ±0.03<br>[23] | 0.34 ±0.05<br>[11] |
| $K_sK_l$ | 0.76 ±0.04<br>[30] | 0.36 ±0.06<br>[12] | | 0.073±0.056<br>[12] |
| $\pi^+\pi^-\pi^0$ | 69.0 ±9<br>[30] | 52.0 ±3.5<br>[13] | | 48.5 ±5<br>[13] |

### 3.3 Description of $p\bar{p}$ annihilations at rest in terms of six $J^{PC}$ annihilation sources

In order to discuss the data we recall the definitions and some of the results obtained with the model independent formalism of ref.41.

i) $^df(ch)$ is the annihilation frequency or production rate of the channel ch at a density d. This is an experimental quantity obtained dividing the number of times the channel ch is produced by the total number of antiprotons which annihilate at rest. This quantity depends from the target density. If the measurement of the angular distributions of the particles present in the channel ch permits it, $^df(ch)$ can be decomposed in its $J^{PC}$ contributions $^df(ch)_{JPC}$.

ii) $B(ch)_{JPC}$ is the annihilation branching ratio for the annihilation channel ch from a state $J^{PC}$. It is density independent and is normalized so that the sum of the branching ratios of all annihilation channels from an initial state with $J^{PC}$ quantum numbers is one.

iii) $^dF_{JPC}$ is the annihilation fraction of the $J^{PC}$ initial states. It gives the contribution to annihilation af all the annihilation channels from all the initial states with quantum number $J^{PC}$.

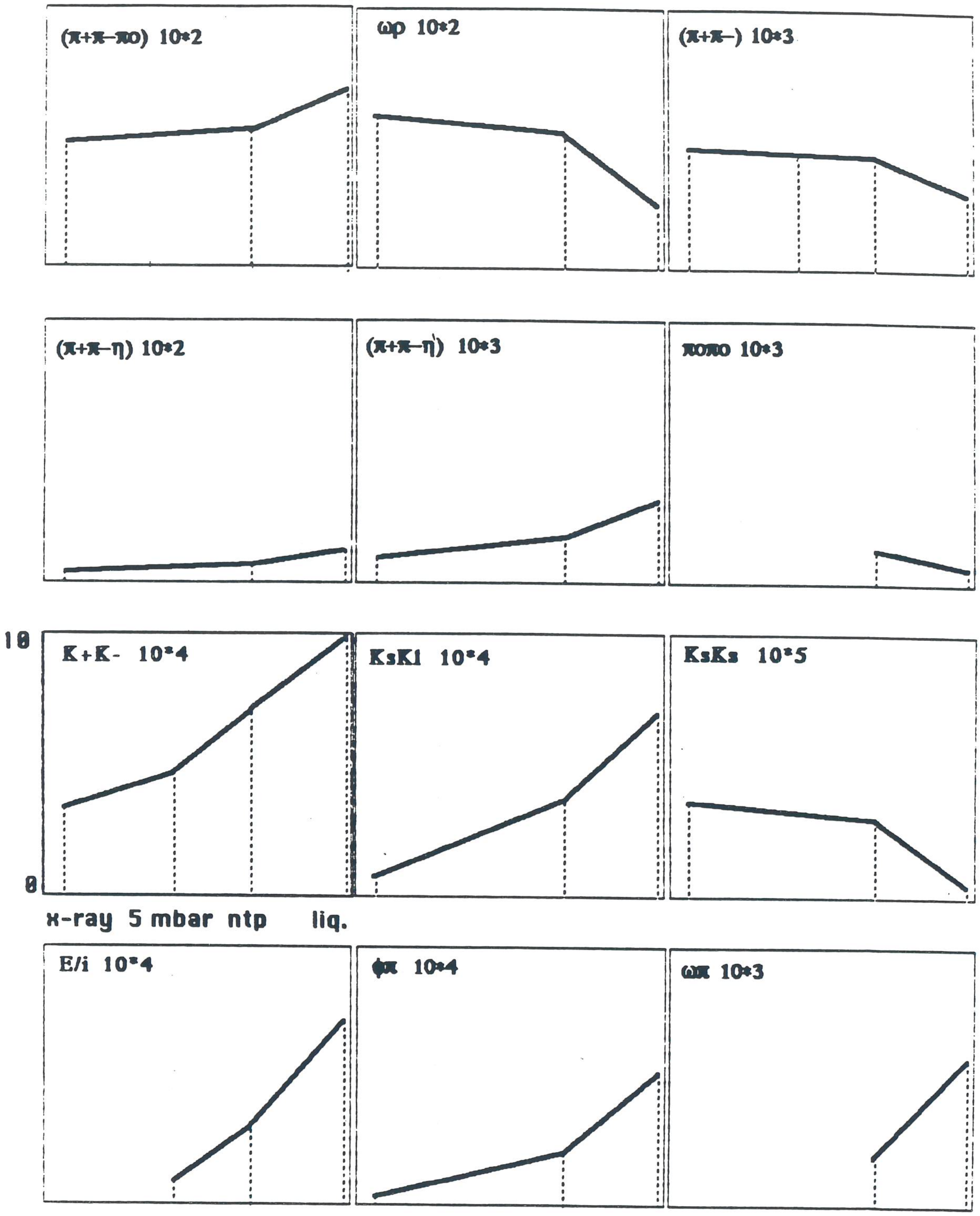

Fig. 1 Frequencies of annihilation of exclusive channels versus target density.

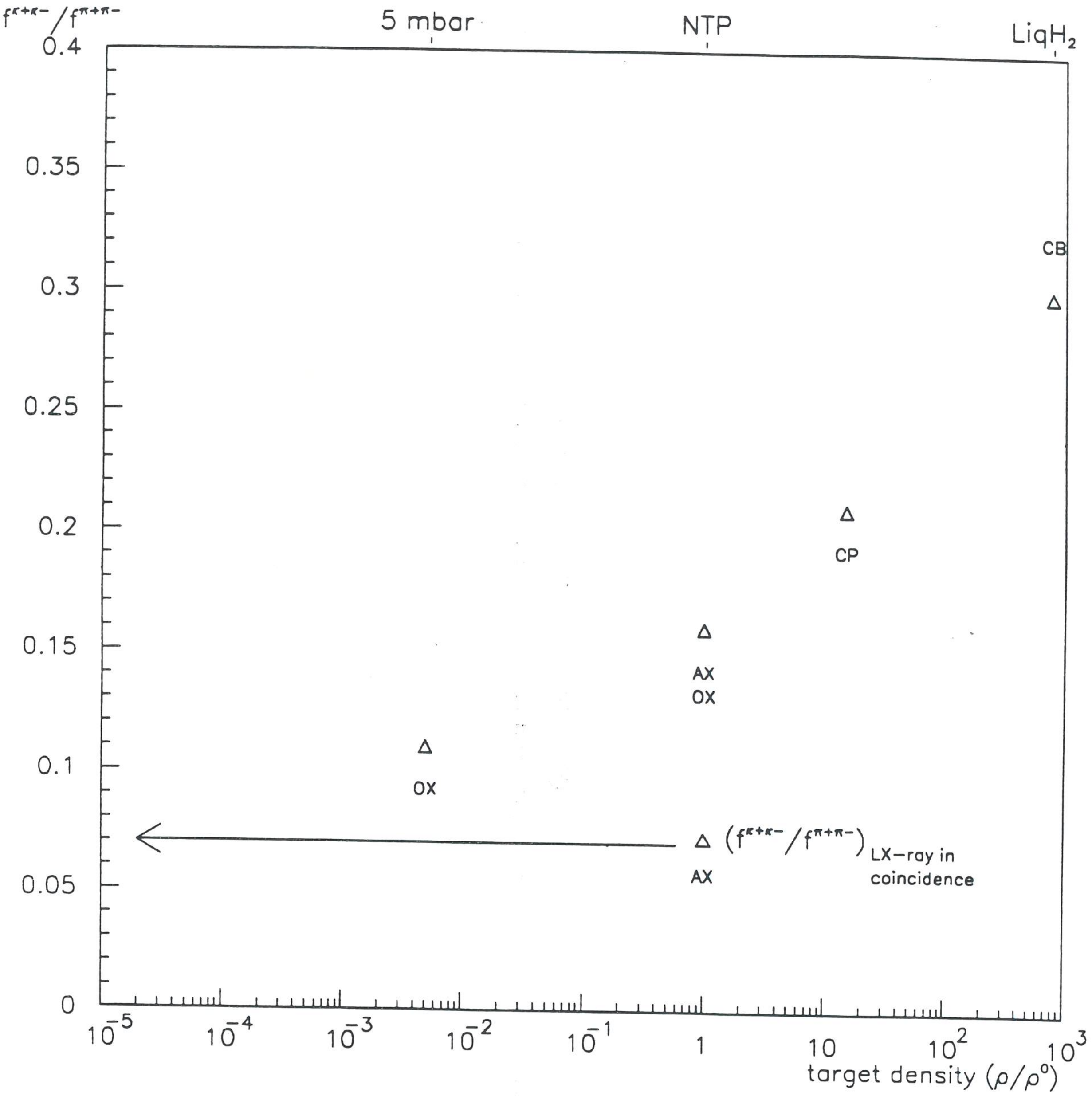

Fig. 2 Ratio between the $K^+K^-$ and $\pi^+\pi^-$ annihilation frequencies versus target density.

It depends from the density d of the target. The ${}^{d}F_{JPCs}$ fractions are normalized so that their sum over all the six $J^{PC}$s is one.
In this framework one can express the annihilation frequency of an annihilation channel in terms of the branching ratios and of the annihilation fractions with the linear equation

$$\Sigma \quad {}^{d}F_{JPC} \quad B^{ch}{}_{JPC} = \Sigma \, {}^{d}f^{ch}{}_{JPC} = {}^{d}f^{ch} \tag{1}$$

The analysis of the structure of the ${}^{d}F_{JPC}$ annihilation fractions in terms of the physical parameters that control the atomic cascade of $p\bar{p}$ atoms shows that the ratios between the triplet(s) and singlet S-wave and P-wave annihilation fractions are not independent from the target density . Therefore annihilations at each target density d are caracterized by six ${}^{d}F_{JPC}$ parameters which cannot be derived from only one of them and at each density annihilations in S-wave and annihilations in P-wave correspond to different blends of singlet and triplet(s). One cannot speak then of S-wave and P-wave annihilations in absolute. The ${}^{d}F_{JPC}$ parameters cannot be computed via atomic cascade calculations, since experiments have not yet measured separately the annihilation widths and the strong interaction shifts of the two S-wave and four P-wave sublevels of protonium [37,52].

The annihilation fractions can be extracted from the measurements of the $J^{PC}$ annihilation frequencies of annihilation channels into two narrow mesons. Under the assumption that $p\bar{p}$ atoms are formed with a statistical distribution of intial states and that collisions do not mix singlet and triplet spin states [53], one has the two separate sum rules

$$\begin{aligned} {}^{d}F_{1}{}^{--} + {}^{d}F_{0}{}^{++} + {}^{d}F_{1}{}^{++} + {}^{d}F_{2}{}^{++} &= 3/4 \qquad (2) \\ {}^{d}F_{0}{}^{-+} + {}^{d}F_{1}{}^{+-} &= 1/4 \qquad (3) \end{aligned}$$

Measurements at four different target densities are necessary to determine the spin triplet annihilation fractions at each of the target densities exploited, while two different target densities are sufficient to determine the spin singlet annihilation fractions at the corresponding two densities.
The set of measurements currently available is not yet sufficient to carry out this program. However the use of the model independent formalism permits to check the consistency of the data. We shall come back later on to this point.

### 3.4 Data are not compatible with the SPASSS hypothesis

The SPASSS hypothesis that the relative contributions of the four P-wave annihilations scale proportionally when the target conditions are changed, corresponds to assume that the ratios between the three triplet annihilation fractions and the singlet are three constants independent from the density d

$${}^{d}F_{0}{}^{++}/{}^{d}F_{1}{}^{+-} = p_0 \qquad {}^{d}F_{1}{}^{++}/{}^{d}F_{1}{}^{+-} = p_1 \qquad {}^{d}F_{2}{}^{++}/{}^{d}F_{1}{}^{+-} = p_2 \tag{4}$$

This hypothesis plus the hypothesis that singlet and triplet states do not mix during the cascade implies that also the ratio of singlet to triplet S-wave annihilations must be a constant

$${}^{d}F_{1}{}^{--}/{}^{d}F_{0}{}^{-+} = s \tag{5}$$

The independence from the density of the three p values implies that $p_0+p_1+p_2 = 3$ since the annihilations have to be distributed statistically in spin at zero target density, were collisions are absent. From (2) and (3) it follows also that s=3. Assuming SPASSS it follows that the fraction of annihilations in S-wave increases or decreases proportionally to one of the two S-wave annihilation fractions, e.g. to ${}^{d}F_{0}{}^{-+}$

$$ {}^{d}F_{S\text{-wave}} = {}^{d}F_{0^{-+}} + {}^{d}F_{1^{--}} = (1+s)\,{}^{d}F_{0^{-+}} = 4\,{}^{d}F_{0^{-+}} \qquad (6) $$

and that also the fraction of P-wave annihilations decreases or increases following the variation of ${}^{d}F_{0^{-+}}$

$$ \begin{aligned} {}^{d}F_{P\text{-wave}} &= {}^{d}F_{1^{+-}} + {}^{d}F_{0^{++}} + {}^{d}F_{1^{++}} + {}^{d}F_{2^{++}} = \\ &= (1+p_0+p_1+p_2)\,{}^{d}F_{1^{+-}} = \\ &= (1+p_0+p_1+p_2)\,(1/4 - {}^{d}F_{0^{-+}}) \qquad = 1 - 4\,{}^{d}F_{0^{-+}} \end{aligned} \qquad (7) $$

More generally, under the SPASSS hypothesis, once fixed the dependence of one $J^{PC}$ annihilation fraction from the target density one knows the way all the other 5 fractions vary with the target density. Obviously under SPASSS it makes quite sense to describe $p\bar{p}$ annihlations at rest in terms of S- and P-wave annihilations, since the blend of singlet and triplet(s) is constant in each wave, and the parameter that expresses the ratio between annihilations in S- and P-wave caracterizes uniquely the distribution of initial states. Under the SPASSS hypothesis, it follows also that the relation between the ratio of increment of annihilation fractions and the ratio of increment of the measured annihilation frequencies at three different densities a, b and c must be satisfied for all $J^{PC}$s and all channels:

$$ ({}^{a}F_{JPC} - {}^{b}F_{JPC})/({}^{b}F_{JPC} - {}^{c}F_{JPC}) = ({}^{a}f^{ch} - {}^{b}f^{ch})/({}^{b}f^{ch} - {}^{c}f^{ch}) \qquad (8) $$

This relation implies the very binding relation between the frequency of annihilations of all channels measured at three different target densities or conditions: for any pair of channels chi and chj

$$ ({}^{a}f^{chi} - {}^{b}f^{chi})/({}^{b}f^{chi} - {}^{c}f^{chi}) = ({}^{a}f^{chj} - {}^{b}f^{chj})/({}^{b}f^{chj} - {}^{c}f^{chj}) \qquad (9) $$

If we compute the ratio of incremental ratios for the $\pi^+\pi^-$, $K^+K^-$, $K_SK_l$ channels with a=LX-ray in coincidence at NTP, b=NTP and c=liquid we get different values, that range from 1.34 for the $K^+K^-$ channel to 0.44 for the $\pi^+\pi^-$ channel. This indicates that the SPASSS assumption is not supported by the very data used in the derivation of the S and P wave ratios in liquid and at NTP.

If one insists in assuming SPASSS (with the justification that the errors of the ratios of increments are large and SPASSS is not definitively ruled out), then one should modify whithin the errors the nominal values of the frequencies of the $\pi^+\pi^-$, $K^+K^-$ and $K_SK_l$ channels in order to get equal values for the ratios of increments of expression 8 (since the nominal values are not consistent with the SPASSS hypothesis),and one could then use the corrected values for the derivation of the S- and P-wave fractions in liquid $H_2$. It results that the combined use of the existing nominal values of the fraquencies of the $\pi^+\pi^-$, $K^+K^-$, $K_SK_l$ channels, of the SPASSS assumption and of the wright value for the $\pi^0\pi^0$ frequency in liquid would give a result for the S-wave fraction in liquid affected by a systematic error. The use of the recent data at 5 mbar of Obelix as condition c confirms with a smaller error lack of consistency of the ensamble of data with the SPASSS hypothesis [54].

## 3.5 Spin polarization effects are expected if SPASSS is not valid

Inconsistency of data with SPASSS means that the effects that render the ratios of spin triplet(s) to spin singlet annihilations not constant and not independent from the target conditions have become observable.

One very noticeable effect that we are therefore lead to expect is for instance a variation of the ratio and possibly an inversion of relative importance of the S-wave spin triplet to spin singlet annihilation fractions under large variations of the target density. This could be evidentiated by a large change of the ratio of the contributions of the $\rho^0\pi^0$ and of the $\rho^+\pi^-$ and $\rho^-\pi^+$ channels produced from S-wave. The fisical reason for such an effect would be an enhancement with diminishing target density of singlet P-wave annihilations faster (or slower) than the enhancement of annihilations in the P-wave spin triplets, reflecting (because of the relations 2 and 3) in a reduction of singlet S-wave annihilations faster (or slower) than the reduction of triplet S-wave annihilations.

## 3.6 Inconsistencies of available data on two body annihilation fractions

The use of the model independent formalism permits to check the internal consistency of the data set available, and to indicate problems.
The $K_SK_l$ channel is produced only from $1^{--}$ initial states.
The variation vith target density of the $K_SK_l$ frequency is therefore a direct indicator of the variation of the $1^{--}$ annihilation fraction, since the ratio between the $K_SK_l$ fraquency and the $1^{--}$ annihilation fraction is the $K_SK_l$ branching ratio, which is density independent.
From the numerical values of table 1 we deduce that the $F_{1--}$ fraction reduces going from liquid to NTP gas target by a factor of about 2. This is actually the main experimental support of the scenario of S-wave annihilation that reduces going from liquid to gas, and is confirmed by preliminary measurements in other channels, like $\phi\pi^0$.
Inspecting the variation of the $\pi^0\pi^0$ channel we see that the frequency of this channel doubles in going from liquid to gas at NTP. Both $0^{++}$ and $2^{++}$ initial states can contribute to the $2\pi^0$ channel. We do not know the two corresponding branching ratios and we know that a priori we cannot assume that the two annihilation fractions $F_{0++}$ and $F_{2++}$ change proportionally to each other with a change of target density. From these $2\pi^0$ data alone we can only conclude that the reduction of target density is accompanied by an increase of the $2\pi^0$ frequency, which may be due to either or both effects of an increase of ${}^dF_{0++}$ and ${}^dF_{2++}$, or an increase of the one of the two annihilation fractions associated to the larger of the $2\pi^0$branching ratios. We are not authorized from these data to say that the total fraction of P-wave has grown by a factor of 2.

If we consider equation (1) jointly for the case of the $\pi^+\pi^-$ and $2\pi^0$ channels, we remember that the $\pi^+\pi^-$ channel can have a contribution by the $1^{--}$ source in addition to the contribution from the $0^{++}$ and $2^{++}$ sources, and exploit the relations

$$B_{0++}(\pi^+\pi^-)=2B_{0++}(2\pi^0) \quad \text{and} \quad B_{2++}(\pi^+\pi^-)=2B_{2++}(2\pi^0) \qquad (10)$$

we get in a model independent way the result that the fraction of $1^{--}$ annihilations is proportional to the difference ${}^df(\pi^+\pi^-) - 2{}^df(2\pi^0)$.

Available data indicate that this difference is constant [25]. This would mean, if systematic errors are not present in one or more of the data, that the $1^{--}$ annihilation fraction remains constant going from a liquid to a NTP gas target. This result is clearly at variance to the one derived from the $K_lK_s$ channel . Cross checks of the results in liquid and in gas at NTP of Obelix and Crystal Barrel and simultaneous collection of $\pi^+\pi^-$ and $2\pi^0$ data with the same trigger for the data in gas are necessary to remove systematic errors that must be hidden somewhere.

## 3.6 No $J^{PC}$ Branching Ratio is available, no Annihilation Fraction is available

Under the present circumstances, since we do not know the value of any annihilation fraction and only experimental frequencies are determined directly, no branching ratio is available for annihilations from $J^{PC}$ initial states for any channel.

The S-wave and P-wave fractions, ratios and branching ratios that one finds in previous publications have been obtained under the SPASSS assumption (which is not valid and may be used only as a first approximation), and computed using data which are not consistent with SPASSS. Their derivation is therefore not consistent. Moreover the very definition of S-wave and P-wave branching ratios is misleading, since these branching ratios are not density independent.

### 3.7 Perspectives

In ref. 41 a strategy of measurements at four target densities of frequencies of convenient annihilation channels into two narrow meson final states has been indicated as necessary to extract the annihilation fractions at those four target densities and the $J^{PC}$ branching ratios for the channels investigated. Two narrow mesons in the final state have the advantage that the kinematics is known in advance and simple, so that the computation of acceptances and the measurement of the efficiencies of the apparata are relatively straightforward. Using narrow mesons has the advantage that the background subtraction is simple and clean. Channels whith a vector meson offer the possibility of separating the $J^{PC}$ components of the annihilation frequencies by measuring the angular distributions of the decay products of the vector meson. Existing data of annihilation frequencies in $H_2$ at various densities, and at NTP with LX-rays in coincidence, indicate that one should find for each $J^{PC}$ one channel at least with $Bch_{J^{PC}}$ different from zero among the channels $\omega\omega$, $\omega\phi$, $K_sK_l$, $K^+K^-$, $\pi^+\pi^-$,$\pi^0\pi^0$, $\phi\eta$. The measurements of the annihilation frequencies and their $J^{PC}$ decomposition for these channels at four target conditions should permit to extract all the annihilation fractions and the branching ratios

The first annihilation fractions and $J^{PC}$ branching ratios that are possible to derive are those of the $0^{-+}$ and $1^{+-}$ spin singlet states, since measurements at two target densities are sufficient to the task, under the hypothesis that collisions do not mix atomic states with different spin. Quite amusingly it looks like the E/i glueball candidate can be instrumental to this task. Since the E/i seems to be produced only from $0^{-+}$ initial states its production rate (or channel frequency) is proportional to the $0^{-+}$ annihilation fraction, and the E/i can then act as a direct monitor of the $0^{-+}$ fraction just as well as the $K_sK_l$ channel is a direct monitor of the $1^{--}$ fraction. High statistics data on the E/i have been collected by Obelix in liquid $H_2$ , at NTP and at 5 mbar. As mentioned previously the signal is depressed at 5 mbar [9] , according to expectation since it was depressed in the ASTERIX data at NTP when requiring a L X-ray in coincidence[2]. The channel $\phi\eta$ can be produced from $1^{--}$ and $1^{+-}$ initial states, like the channel $\phi\pi^0$. While the channel $\phi\pi^0$ seems to have a negligible $1^{+-}$ branching ratio, since the signal seen at NTP disappears when the request of L X-rays in coincidence is made, the same request does not kill the the $\phi\eta$ signal [16]. The separation of the $0^{-+}$ and of the $1^{--}$ contributions to the $\phi\eta$ signal can be made on the basis of the $\sin^2\theta$ and flat angular distributions of the $\phi$ decay angle in the rest system of the $\phi$, and with the cross check that the contribution from the $1^{--}$ states must scale as the $K_sK_l$ contribution. Obelix has collected a sizeable data sample of $K^+K^-\pi^0$ annihilations in liquid $H_2$ and is going to collect a large sample at NTP. From these data the dependence of the $\phi\eta$ production rate can be studied in parallel to the E/i dependence, and it should then be possible to extract the values of the $F_{0^{-+}}$ anf $F_{1^{++}}$ annihilation fractions in liquid and at NTP, the E/i production branching ratio from $0^{-+}$ states and the $\phi\eta$ production branching ratio from $1^{+-}$ states.

In the next section we will see that it is possible to define density independent annihilation branching ratios for channels with several mesons in the final state. The main motivation for studying those channels is the study of known exotic candidates and the search of new ones as intermediate resonances. However the measurements of the frequencies and of the spectra of exclusive channels which can be produced only by a subset of the six $J^{PC}$ that can be present in $p\bar{p}$ at rest (e.g. the $3\pi^0$ channel ) may be also very useful for the determination of the spin triplet annihilation fractions, and will permit severe cross-checks of the results obtained with the two body channels. To the purpose of measuring annihilation fractions it may be useful to mask some spectra by appliing the same acceptance filter to all $J^{PC}$ spectra oof a channel and measuring filtered annihilation frequencies. The masks may be chosen so to exlude or to evidentiate some $J^{PC}$ contributions in the tentative of extracting a signal proportional to only one $J^{PC}$ source.

## 4. SEPARATION OF THE SIX DIFFERENT $J^{PC}$ ANNIHILATION SOURCES

### 4.1 SPECTRA from initial states of selected $J^{PC}$

In this chapter we extend the discussion of ref.41 to the case of final states with more than two narrow mesons. The discussion is finalized to the extraction of the physics of a given channel by inspecting, separately for each $J^{PC}$ from which selection rules do not forbid the production of the channel, the spectra of the channel produced from initial states of only one given $J^{PC}$ .

Ideally we would like to separate the events of a given annihilation channel into different samples each produced from initial states with the same $J^{PC}$, and then produce for each $J^{PC}$ sample the relevant physics spectra, like invariant masses of combinations of particles, angular distributions, dalitz plots etc..

In reality we can only obtain data of annihilation into a given channel at different target densities and produce the relevant spectra. Linear combinations of these experimental spectra will permit to derive the spectra associated to each single $J^{PC}$ source.

Let us call ${}^{d}\mathrm{Spectrum}^{ch}$ a spectrum reguarding the channel ch obtained at a density d and normalized to the number of all the annihilations that have been necessary to produce it. We use the same normalization adopted for the channel annihilation frequencies in ref.41, namely the ratio between the number of all events with annihilations in the channel under consideration and the total number of antiprotons.

Let us call $\mathrm{SPECTRUM}^{ch}{}_{JPC}$ the spectrum that would be obtained for the selected channel by $p\bar{p}$ atoms all annihilating from atomic levels with the same $J^{PC}$. For the annihilation channel considered, since there are more than two narrow mesons present in the final state, there will be in general several different interfering amplitudes associated or not to production of intermediate resonances. The interplay of these amplitudes connecting the same $J^{PC}$ initial state to the same final state annihilation channel gives the imprint to the channel and causes the shape of all the spectra of the channel associated to that $J^{PC}$ source . Each $\mathrm{SPECTRUM}^{ch}{}_{JPC}$ is normalized like the $J^{PC}$ branching ratios: the spectrum contains all the events produced in the channel considered for a given number of annihilations all from the same $J^{PC}$ source. For each $\mathrm{SPECTRUM}^{ch}{}_{JPC}$ of the channel the ratio between the number of entries and the number of annihilations from the initial states of the $J^{PC}$ source gives the same value, which is the branching ratio of the channel $B^{ch}{}_{JPC}$ (like in the case of the two body annihilations).

With these definitions, it results then that we can extend formula (1) to all the spectra of a given channel, which are a linear combination of their $J^{PC}$ components with coefficients that are indeed the $J^{PC}$ annihilation fractions, which specify (at each target density d) for each $J^{PC}$ what is the fraction of all annihilations occuring with that $J^{PC}$. When we write expression (1)

$$\Sigma \quad {}^{d}F_{JPC} \quad B^{ch}{}_{JPC} = \Sigma \, {}^{d}f^{ch}{}_{JPC} = {}^{d}f^{ch} \qquad (1)$$

${}^{d}f^{ch}$ expresses more generally the frequency of a channel ch with several mesons in the final state, and we can write the more general relation

$$\Sigma_{JPC}\ {}^{d}F_{JPC}\quad \mathrm{SPECTRUM}^{ch}{}_{JPC} = {}^{d}\mathrm{Spectrum}^{ch} \qquad (11)$$

From the above expression we get that, if ${}^{d}\mathrm{Spectrum}^{ch}$ has been measured at a sufficient number N of different target densities (or conditions) d, we can derive each of the N $\mathrm{SPECTRUM}^{ch}{}_{JPC}$ due to the N active $J^{PC}$ sources as a linear combination of the spectra ${}^{d}\mathrm{Spectrum}^{ch}$ measured at the N target conditions . To this purpose we must independently know (from other measurements) the N sets of ${}^{d}F_{JPC}$ parameters. We will have

$$\mathrm{SPECTRUM}^{ch}{}_{JPC} = \Sigma_{d}\ G_{JPC}{}^{d}\ {}^{d}\mathrm{Spectrum}^{ch} \qquad (12)$$

where the coefficients $G_{JPC}{}^{d}$ are obtained inverting the set of N linear equations (11) and depend then from the N sets of ${}^{d}F_{JPC}$ values.

When this work will have been carried through, individual spectra of the type $\mathrm{SPECTRUM}^{ch}{}_{JPC}$ will be available and ready to be interpreted by introducing the amplitudes and relative phases for all direct and intermediate resonant channels. The fit will be satisfactorily when, for a given channel ch and source $J^{PC}$, it will simultaneously fit all types of $\mathrm{SPECTRUM}^{ch}{}_{JPC}$ (like angular distributions, invariant masses, dalitz plots, ...)

At present one is confronted to a situation where there is much less information and more freedom. When data are available only at one target density, for each type of spectrum exists only one ${}^{d}\mathrm{Spectrum}^{ch}$ at one density d. The fit procedure is to construct tentatively for each contributing source $J^{PC}$ which is allowed to contribute by selection rules, a ${}^{d}\mathrm{Spectrum}^{ch}{}_{JPC}$ that is not normalized in absolute, has amplitudes and phases as free parameters and has as a free parameter its contributions to the measured ${}^{d}\mathrm{Spectrum}^{ch}$. When data are available at more than one target conditions, the best procedure in our present state of ignorance of the values of the ${}^{d}F_{JPC}$ values, is to fit the data with free parameters for the amplitudes and phases tried for each $J^{PC}$ contribution and with free relative contributions of the different allowed $J^{PC}$ spectra, but with the constraint that the amplitudes and phases tried for each $J^{PC}$ contribution are the same for all target conditions.

Once obtained the individual $\mathrm{SPECTRUM}^{ch}{}_{JPC}$ each of them will display its physical caracteristics and will be different from the other ones of different $J^{PC}$ because of selection rules imposing additional restrictions to intermediate states not permitted from all the $J^{PC}$ sources of the channel. This will help intuition and understanding, and it will be the first case in hadronic physics of separation of identical final states produced from initial states of different $J^{PC}$ in the same kinematical conditions and with the same available phase space .
Having obtained for the spectra of a channel their $J^{PC}$ decomposition into $\mathrm{SPECTRUM}^{ch}{}_{JPC}$ we will have immediately available from any spectrum the channel branching ratios $B^{ch}{}_{JPC}$. Links with coupled channels will be directly exploitable by restricting to the common $J^{PC}$ sources and comparing spectra of coupled channels produced from the same $J^{PC}$ source ( one may think for instance to the relations that link the amplitudes present in the $3\pi^0$ and in the $\pi^+\pi^-\pi^0$ channels that have in common the three sources of the $3\pi^0$ channel). When one considers channels that can be produced by the same set of different $J^{PC}$ initial states (like for example the $3\pi^0$ , $2\pi^0\eta$ , $\pi^0 2\eta$ , $3\eta$ , $\pi^0\eta\eta'$ which can be produced by initial states with the three $J^{PC}$ values $0^{-+}$, $1^{++}$ and $2^{++}$ ) the procedure of decomposition of the experimental

spectra and extraction for each channel and type of spectrum of the $\mathrm{SPECTRUM}^{ch}{}_{JPC}$ will use the same set of ${}^{d}F_{JPC}$ coefficients. This will enable internal cross-checks of the consistency of the data, of the procedure of reconstruction of spectra from the different $J^{PC}$ sources, and direct coupled channel analyses.

## 4.2 The $\pi^+\pi^-\pi^0$ channel

Let us consider more in detail the spectra of the $\pi^+\pi^-\pi^0$ and $3\pi^0$ channels. For these channels all the physical information is contained in the Dalitz plot spectrum.
The $\pi^+\pi^-\pi^0$ final state can be produced from 5 sources, since only the $0^{++}$ states cannot contribute to the channel. At a given density d the experimental dalitz plot corrected by acceptance ${}^{d}(\pi^+\pi^-\pi^0)$ is the sum of five $(\pi^+\pi^-\pi^0)_{JPC}$ contributions and is given by

$$
\begin{aligned}
{}^{d}(\pi^+\pi^-\pi^0) = {} & {}^{d}F_{0-+}\,(\pi^+\pi^-\pi^0)_{0-+} + {}^{d}F_{1--}\,(\pi^+\pi^-\pi^0)_{1--} + \\
& {}^{d}F_{1+-}\,(\pi^+\pi^-\pi^0)_{1+-} + {}^{d}F_{1++}\,(\pi^+\pi^-\pi^0)_{1++} + {}^{d}F_{2++}\,(\pi^+\pi^-\pi^0)_{2++}
\end{aligned}
$$

Five densities are necessary to extract all the $(\pi^+\pi^-\pi^0)_{JPC}$ dalitz plots. We are still far from that goal, because measurements of the channel in liquid, 3atm, NTP , 5 mbar and NTP with L x-rays in coincidence at NTP exist, but the annihilation fractions for all these five target conditions are missing

ASTERIX analyzed the ${}^{d}(\pi^+\pi^-\pi^0)$ data at NTP and with L X-rays in coincidence at NTP under the SPASSS assumption [1,11,12]. According to that assumption the data have under all target conditions constant ratios between the two annihilation fractions of the S-wave and the three annihilation fractions of the P-wave. The spin singlet and triplet S-wave contributions scale both according a same factor s when changing target condition, and the three P-wave contributions scale all according a same (1-s )factor. ASTERIX defined a S-wave dalitz plot and a P-wave dalitz plot, since the shape of the Dalitz plots of the S-wave and P-wave contributions do not change, because the ratio of their internal components remain unchanged. Linear combinations of the NTP and L X-ray dalitz plots permitted to derive the S-wave dalits plot and the P-wave one and they were subsequently analyzed separately [11,12]. Since we know at present that the SPASSS assumption cannot be correct, there is no fixed shape S-wave dalitz plot, since the ratio of the two contributions may change with target conditions. There is as well no fixed shape P-wave dalitz plot, since the ratios between its three components may change by varying the target conditions.

## 4.3 The $3\pi^0$ channel

The $3\pi^0$ final state can be produced from 3 sources. At a given density d the ${}^{d}(3\pi^0)$ dalitz plot is the sum of three $(3\pi^0)_{JPC}$ contributions given by

$$
{}^{d}(3\pi^0) = {}^{d}F_{0-+}\,(3\pi^0)_{0-+} + {}^{d}F_{1++}\,(3\pi^0)_{1++} + {}^{d}F_{2++}\,(3\pi^0)_{2++}
$$

Fig.3 illustrates the above relation in the case of liquid $H_2$, using the data of ref.4.

When $3\pi^0$ data will be available at three of the densities exploited to study the $\pi^+\pi^-\pi^0$ spectra, the relevant ${}^{d}F_{JPC}$ parameters will be the same. The $(3\pi^0)_{0-+}$ , $(3\pi^0)_{1++}$ and $(3\pi^0)_{2++}$ spectra are coupled respectively to the $(\pi^+\pi^-\pi^0)_{0-+}$ , $(\pi^+\pi^-\pi^0)_{1++}$ and $(\pi^+\pi^-\pi^0)_{2++}$ spectra.

Let us consider the three $J^{PC}$ dalitz plots and speculate how their sum can change with reduction of the target density.

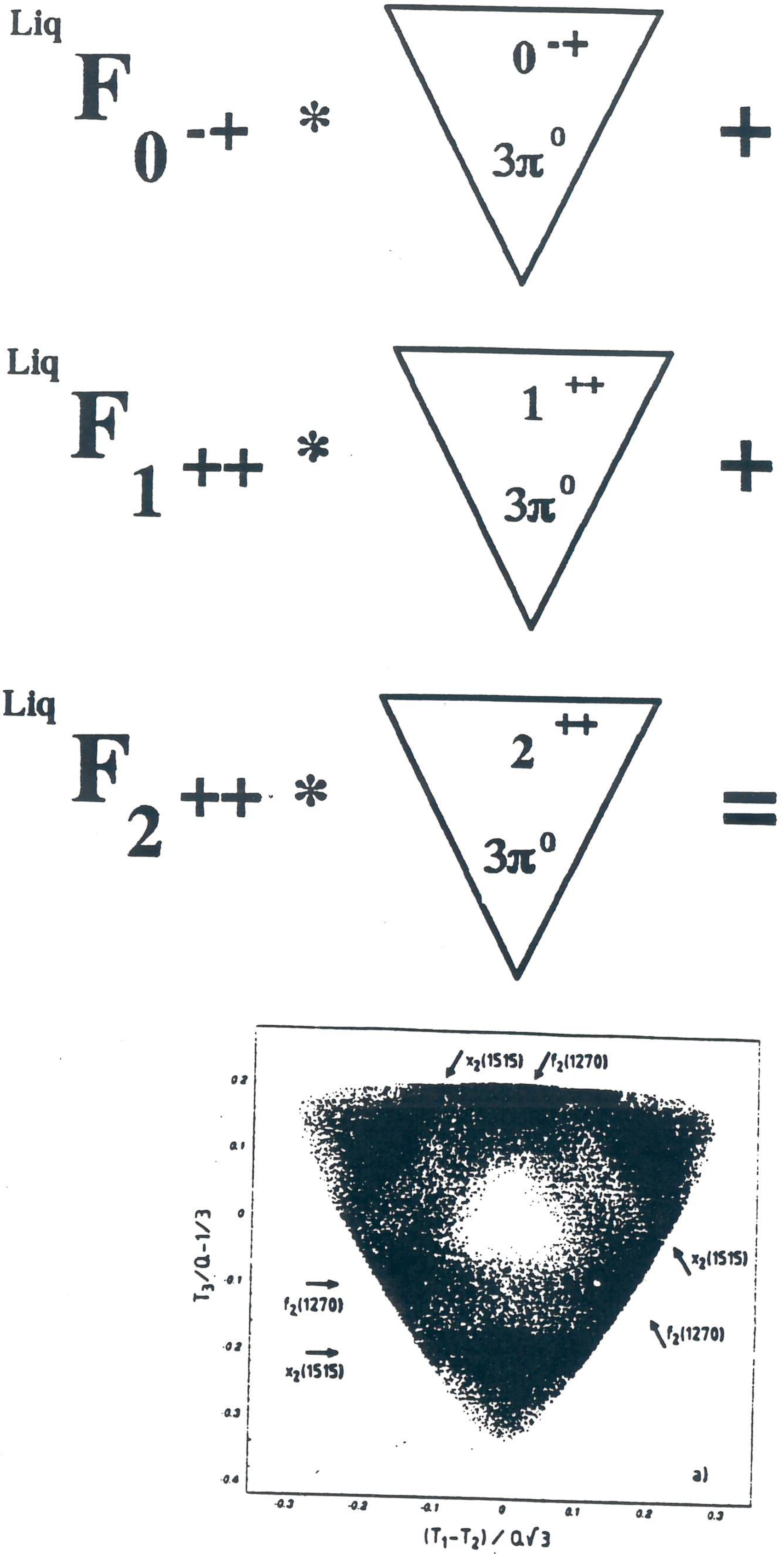

Fig.3 $J^{PC}$ decomposition of the $3\pi^0$ Dalitz plot of $p\bar{p}$ at rest in liquid $H_2$

If a scalar resonance is present in the the $(3\pi^0)_{0-+}$ plot it features a flat band associated to a flat decay angular distribution in the region of the dalitz plot where it does not interfere whit other amplitudes. By reducing the target density $^{d}F_{0-+}$ lowers, so a flat band due to a scalar produced from $0^{-+}$ states must reduce accordingly.

If a tensor resonance is produced by $2^{++}$ initial states, a band must be present in the $(3\pi^0)_{2++}$ dalitz plot with a $\sin^2\theta$ distribution in the regions where it does not suffer interferences. By reducing the target density $^{d}F_{2++}$ increases, so a $\sin^2\theta$ band due to a tensor resonance from the $2^{++}$ states must increase accordingly.

A tensor resonance produced from $1^{++}$ initial states features a $1/3+\cos^2\theta$ distribution in the regions of the dalitz plot where it is not affected by interferences. By a reduction of target density $^{d}F_{1++}$ increases. If $^{d}F_{1++}$ and $^{d}F_{2++}$ increase with reduction of target density but not proportionally to each other, and the corresponding Dalitz plots feature each a different dominant tensor resonance, the variation of the contributions of these two resonances can permit to visualize a J polarization effect. If the $1++$ and $2^{++}$ dalitz plots contain the same tensor resonance the sum of their $\sin^2\theta$ and $1/3+\cos^2\theta$ contributions ccould mimic a scalar produced from $0^{-+}$ states at one density. By reducing the density of the target this artificial flat band would increase in intensity instead of decreasing. These consideration illustrate how crucial is the change of target density in removing in a simple and direct way the existing ambiguity wether the narrow band at 1520 MeV is due to a tensor or a scalar meson or if there are two structures with different quantum numbers at very similar masses.

## 5. CONCLUSIONS and OUTLOOK

The exploratory work done so far has by ASTERIX and Obelix permitted to ascertain that the variations of the annihilation frequencies are large and well visible when the distributions of initial states are modified by changing the selection of initial states or the target density.

The published values of S- and P-wave branching ratios of channels of $p\bar{p}$ annihilations at rest are affected by errors not under control since they have been derived using the SPASSS assumption, that is neither correct nor in agreement with the measured frequencies of the channels used to derive the branching ratios. The frequencies of the simplest back to back annihilation channels $\pi^+\pi^-$, $\pi^0\pi^0$ and $K_sK_l$ measured in liquid an at NTP are not consistent when analyzed in a model independent framework. Better control of systematics, crosschecks between experiments and measurements at up to four different target densities or conditions of two body channels are necessary to correct systematic errors and complete the minimum set of data necessary to determine the annihilation fractions .

A systematic and finalized work can permit to extract from data collected under four different distributions of initial states the values of the annihilation fractions (six values per target condition) that caracterize annihilations at each target density. Simultaneously one will derive the $J^{PC}$ branching ratios of the narrow annihilation channels and/or of the more complex final states whose annihilation frequencies will have been measured to derive the annihilation fractions.

Having measured at N different target densities the annihilation spectra of a channels that can be produced by N different $J^{PC}$ initial states, it will be possible to derive the individual $J^{PC}$ spectra by linear combinations of the spectra measured at the N target conditions. The coefficients of the linear combination are determined by the values of the annihilation fractions. For instance, using data at three densities and the annihilation fractions of those three densities, it will be possible to extract the three independent $0^{-+}$, $1^{++}$ and $2^{++}$ dalitz plots for the annihilations into $3\pi^0$ , $2\pi^0\eta$ , $\pi^0 2\eta$ , $3\eta$ , $\pi^0\eta\eta'$. Extracting the $J^{PC}$ dalitz plots of the $\pi^+\pi^-\pi^0$ channel will require five target densities to be used, since the independent spectra are five.

The Crystal Barrel is going to collect $p\bar{p}$ data at rest at about 10 atmosferes in november of 1994. It will be extremely interesting to see how and how much the $3\pi^0$ , $2\pi^0\eta$ , $\pi^0 2\eta$ dalitz plots will change with respect to the spectra obtained in liquid. The contribution of the $0^{-+}$ source will be reduced and the contribution of the $1^{++}$ and $2^{++}$ sources will increase substantially. These contributions will vary according to the variation of the $F_0^{-+}$, $F_1^{++}$ and $F_2^{++}$ sources. It is not known which of the $F_1^{++}$ or the $F_2^{++}$ fraction will grow faster. If the 1520 MeV flat band in the $3\pi^0$ dalitz plot in liquid is dominantly due to a tensor object, its contribution in the 10 atm. dalitz plot will be enhanced. So probably this forthcoming measurement at 10 atm. will be sufficient to give a qualitative answer to the ambiguity between the solutions $0^{++}$alone or $2^{++}$ alone or both a $0^{++}$ and $2^{++}$ at nearby masses . A third measurement at a different density will however be necessary to extract separately the three dalitz plots and give comlplete quantitative measurements about the production rates of the exotic candidates.

The scientific program of measuring annihilation fractions, spectra and branching ratios of all the six annihilation sources besides permitting to identify and measure unambiguously the ground state of glueballs, will provide, at the fixed energy of twice the proton mass, a unique data set on hadronization as a function of the discrete quantum numbers $J^{PC}$ of the initial state, for the six $J^{PC}$ initial states of $p\bar{p}$ anihilations at rest.

## REFERENCES

[1] ASTERIX Collab., B. May et al, Phys. Lett. B225 (1989) 450
[2] ASTERIX Collab., K.D. Duch et al., Z. Phys. C45 (1989) 223
[3] ASTERIX Collab., P. Weidenauer et al., Z. Phys C 59 (1993) 378
[4] Crystal Barrel Collab., E. Aker et al., Phys. Lett.B260 (1991) 249
[5] Crystal Barrel Collab., C. Amsler et al., Phys. Lett.B291(1992) 347
[6] Crystal Barrel Collab., V.V. Anisovich et al., Phys. Lett.B323 (1994) 233
[7] Crystal Barrel Collab., C. Amsler et al., Phys. Lett.B322 (1994) 431
[8] OBELIX Collab., A. Lanaro et al., Nucl. Phys. A 558 (1993) 13c
[9] OBELIX Collab., presented by A. Masoni at the LEAP '94 Conference (Bled,1994)
[10] OBELIX Collab., presented by N. Semprini at the LEAP '94 Conference (Bled,1994)
[11] ASTERIX Collab., M. Doser et al, Nucl.Phys.A486 (1988) 493
[12] ASTERIX Collab., M. Doser et al, Phys. Lett. B215 (1988) 792
[13] ASTERIX Collab., B. May et al., Z. Phys C 46 (1990) 191
[14] ASTERIX Collab., B. May et al., Z. Phys C 46 (1990) 203
[15] ASTERIX Collab., P. Weidenauer et al., Z. Phys C 47 (1990) 353
[16] ASTERIX Collab., J. Reifenrother et al., Phys. Lett.B 267 (1991) 299
[17] Crystal Barrel Collab., C. Amsler et al., Phys. Lett.B297 (1992) 214
[18] Crystal Barrel Collab., C. Amsler et al., Zeit. Phys. C58 (1993) 175
[19] Crystal Barrel Collab., C. Amsler et al., Phys. Lett.B311(1993) 362
[20] Crystal Barrel Collab., C. Amsler et al., Phys. Lett.B327 (1994) 425
[21] M.A. Faessler, Invited talk at NAN '93 and refs. therein
[22] Crystal Barrel Collab., presented by U. Wiedner at the LEAP '94 Conference (Bled,1994)
[23] OBELIX Collab., A. Adamo et al., Phys Lett.B284 (1992) 448
[24] OBELIX Collab., V. Ableev et al, Phys Lett.B329 (1994) 407
[25] OBELIX Collab., M. Agnello et al., Phys Lett.B337 (1994) 226

[26] M. Sapozhnikov, Invited talk at the LEAP '94 Conference (Bled,1994) and refs. therein
[27] OBELIX Collab., presented by A. Zoccoli at the LEAP '94 Conference (Bled,1994)
[28] CPLEAR Collab., R.Adler et al., Phys. Lett.B267 (1991) 154
[29] CPLEAR Collab., R.Adler et al., preprint CERN-PPE/94-85
[30] see the review of R. Armenteros and B. French, in High energy physics, ed E.H.S. Burhop, Vol.4 (Academic Press, New York, 1969) pp237-417
[31] ASTERIX Collab., S. Ahmad et al., Phys. Lett. B157 (1985) 333
[32] ASTERIX Collab., M. Ziegler et al., Phys. Lett. B206 (1988) 448
[33] C.A. Baker et al., Nucl. Phys. A483(1988) 631
[34] C.W.E von Eijk et al., Nucl. Phys. A486 (1988) 604
[35] ASTERIX Collab., U. Schaefer et al., Nucl. Phys. A495 (1989) 451
[36] R. Bacher et al., Z. Phys. A334 (1989) 93
[37] K. Heitlinger et al., Z. Phys. A342 (1992) 368
[38] for a review see C. Batty, Rep. Prog. Phys. 52 (1989) 1165, and Nucl. Phys. A508 (1990) 894
[39] T.B.Day, G.A. Snow and J. Sucher, Phys. Rev. Lett.3 (1959) 61, and Phys. Rev. 118 (1960) 864
[40] U. Gastaldi, Nucl. Phys.23B (1991) 224
[41] U. Gastaldi et al., Phys. Lett.B 320 (1994) 193
[42] A. Bettini et al., Nuovo Cimento 42 (1966) 659
[43] D. Bridges et al., Phys. Rev. Lett. 56 (1986) 215 and 221, and 57 (1986) 1534
[44] M. Gaspero, Sov. J. Nucl. Phys. 55 (1992) 795 and Nucl. Phys. A 562 (1993) 409
[45] R. Armenteros et al., Proc. Int. Conf. on Elementary Particles, Siena, 1963, eds. G. Bernardini and G. Puppi (Societa Italiana di Fisica, Bologna, 1963) Vol. 1, p.287
[46] P. Baillon et al., Nuovo cimento 50 A(1967) 393
[47] ASTERIX Collab., J. Reifenrother et al., Phys. Lett.B 214 (1988) 325
[48] C. Cavion, Padova Univ. Thesis 1991, (unpublished)
[49] OBELIX Collab., A. Adamo et al., Phys Lett.B285 (1992) 15
[50] U. Gastaldi, K. Kilian and G. Plass, "A low energy antiproton facility at CERN: physics possibilities and technical aspects", CERN-PSCC 79-17 (1979) and refs. therein
[51] L. Adiels et al., Z. Phys. C35 (1987) 15
[52] U. Gastaldi, " Low and high resolution protonium spectroscopy at LEAR in ACOL time", in Fundamental symmetries, eds. P. Bloch et al. (Plenum, New York, 1987) 307
[53] R. Bizzarri, Nuovo Cimento 53A (1968) 956
[54] OBELIX Collab., Evidence for spin polarization in $p\bar{p}$ annihilations at rest, in preparation