The exclusive reaction $\bar{p}p \rightarrow \pi^+\pi^-\eta$

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Abstract

We consider the possibility to perform a spin parity study of the $\pi^+\pi^-\eta$ final state. We show the importance of this analysis in particular regarding the understanding of the scalar nonet. We evaluate the trigger performances, the apparatus acceptances and we show the results of the analysis of a limited data sample. Finally we describe a very preliminary spin-parity analysis and we evaluate the necessary statistics to be taken.

1 Introduction

In this draft we study the possibility to perform a spin-parity analysis on the $\bar{p}p \rightarrow \pi^+\pi^-\eta$ annihilation reaction at rest. This final state is of primary importance to study the properties and the decay modes of some poorly known resonances and to investigate the presence of exotic states. In particular we point our attention on the study of the scalar mesons $a_o(980)$ and $a_o(1450)$. The first one has been observed long time ago by Bubble Chamber experiments[7, 8] and it is a non $\bar{q}q$ meson candidate[1]. The second one has been very recently observed by the Crystal Barrel experiment[6] (CB) and needs confirmation.

Up to now the $\pi^+\pi^-\eta$ final state was studied exploiting very low statistic data samples obtained by inclusive experiments, with no discovery of new resonances. On the contrary a very detailed analysis has been performed on the neutral channel $\pi^0\pi^0\eta$ by the Crystal Barrel experiment. The spin-parity analysis of this high statistics data sample requires the presence of a new $I^G, J^{PC} = 1^-, 0^{++}$ resonance called $a_o(1450)$.

In order to obtain a great improvement in this field, we propose to perform an high statistic study of the exclusive reaction:

$$\bar{p}p \rightarrow \pi^+\pi^-\eta \tag{1}$$

exploiting the $\eta \rightarrow \gamma\gamma$ decay mode. This will allow to study the charged components of the $a_o(980)$ and $a_o(1450)$ isospin triplets verifying and completing the Crystal Barrel results on this topic.

Advantages of this measurement are the low background level and the possibility to improve the analysis performances by changing the protonium initial state distribution with the well known technique of varying the target density.

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Finally we would like to outline the possibility to perform a coupled analysis with the channel:

$$\bar{p}p \ \rightarrow \ K^{\pm}\pi^{\mp}K_S \tag{2}$$

detected in an exclusive way exploiting the $K_S \rightarrow \pi^+\pi^-$ decay mode. This would allow to improve the fit sensitivity and to measure directly for the first time the a_o decay branching ratio into $\pi\eta$ and $\bar{K}K$ states.

In this draft we discuss the physical motivations of the measurement of reaction (1) (in sect. 2) and the present experimental situation (in sect. 3). Moreover sect. 4 describes the measurement feasibility, the trigger performances and the apparatus acceptance. Finally in sect.5 we evaluate the necessary statistics and we discuss the features of the spin-parity analysis.

2 Physics motivations

In the search of exotic particles, particular attention has been paid to the study of the 0^{++} mesons, where the glueball ground state is expected.

In the old classical definition (see fig. 1a)) the 0^{++} nonet was composed by five wide members $({K_o}^*(1430), f_o(1370))$ and four rather narrow members $(a_o(980), f_o(975))$. But large problems lied with this multiplet, in particular due to the following points:

- the presence of one extra state, the $f_o(1525)$, that was indicated as a glueball candidate;
- the low mass and width values of the $a_o(980)$ and $f_o(975)$ members with respect to the one of the other nonet members;
- the fact that these two masses are too much close one each other and to the $\bar{K}K$ threshold.

Very recently (see fig. 1b)) a new composition of the scalar nonet has been proposed [2]. In this case the four narrow member $(a_o(980), f_o(975))$ have been replaced by the $f_o(1525)$ and by a new resonance, the isospin triplet $a_o(1450)$ discovered by Crystal Barrel. In this approach the old narrow members of the nonet cannot be classified as conventional mesons, but become exotic candidates.

As a consequence it is of great interest to verify both these schemes, to study the properties of the $a_o(980)$ resonance and to confirm the existence of the $a_o(1450)$.

As we have already said, due to the low mass value and to the strong coupling with the kaonic channels, models have some difficulties to place the $a_o(980)$ in the scalar nonet. For these reasons this state has been also interpreted as a $\bar{K}K$ (i.e. a kaon-antikaon bound state), as an a hybrid meson $(\bar{q}qg)$ or as a multiquark structure $(2\bar{q}2q)$. One of the most effective methods to investigate the nature of this resonance is to study its decay modes $a_o(980) \rightarrow \pi\eta$ and $a_o(980) \rightarrow \bar{K}K$ through the measurement of the ratio:

$$R \ = \ \frac{BR(a_o(980) \ \rightarrow \ \bar{K}K)}{BR(a_o(980) \ \rightarrow \ \pi\eta)} \tag{3}$$

The present experimental situation on R is poor and not clear. In fact only three results, in disagreement between them, are available: $R = 0.7 \pm 0.3$ [3], $R = 0.25 \pm 0.08$ [4] and $R = 1.16 \pm 0.18$ [5].

The Obelix experiment has the capability to measure directly this quantity through the coupled analysis of reactions (1) and (2), exploiting respectively the a_o decay modes:

$$a_o{}^{\pm}(980) \ \rightarrow \ \pi^{\pm}\eta \tag{4}$$

$$a_o{}^{\pm}(980) \ \rightarrow \ K^{\pm}K_S \tag{5}$$

In the same data sample it is also possible to verify the existence of the $a_o(1450)$ resonance, in the up-to-now unobserved decay mode $\pi^{\pm}\eta$. This resonance has been observed for the first time by the Crystal Barrel experiment [6] studying the reaction $\bar{p}p \rightarrow \pi^0\pi^0\eta$. This state has not been observed directly as an invariant mass peak (see fig. 2), but it is requested by the spin-parity analysis. It should be noted that also the GAMS experiment has studied this final state with a lower statistic observing the reaction $\pi^-p \rightarrow \eta\pi^0\pi^0 n$ at 100 GeV/c (see fig. 3). However they did not find any clear evidence for structures in the $a_o(1450)$ region.

By the way the CB experiment has found for this state a mass and a width respectively $M = 1450 \pm 40\ MeV/c^2$ and $\Gamma = 270 \pm 40\ MeV/c^2$. These results have been obtained assuming that annihilations in liquid hydrogen proceed only from S-wave. Finally only the neutral component of this new state has been observed, while the corresponding charged partners have never been observed.

For these reasons we propose to study the reaction (1) at rest. As a matter of fact in such a final state it is possible to study the charged states of the $a_o(980)$ and $a_o(1450)$ resonances. Moreover a coupled analysis of this channel with reaction (2) is possible, leading to the evaluation of the a_o decay branching ratios through the evaluation of the R parameter (see eq.3). Finally the possibility to vary the protonium initial state distribution, taking data in different target conditions, allows us to do a more performing analysis.

3 Experimental situation

In the field of protonium annihilation into $\pi\pi\eta$, there are only 4 previous measurements: two of them are Bubble Chamber results while the others are done by second generation experiments. They differ significatively in statistics, analysis techniques and initial state selection.

3.1 The early experiments: bubble chambers

The first experiment that collected data on the $\pi\pi\eta$ final state was performed at the Columbia BNL Bubble chamber[7] with a liquid hydrogen target. They analysed the final state $\bar{p}p \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^o$ (with the π^o missing) and identified the η particle through its decay mode into $\pi^+\pi^-\pi^o$. Due to the low statistic collected (about 254 $\pi^+\pi^-\eta$ events), *no spin parity analysis* was made.

At the CERN Bubble Chamber the $\pi^+\pi^-\eta$ final state was studied analyzing about 20000 annihilations into $\pi^+\pi^-\pi^+\pi^-\pi^o$ (π^o missing) [8]. The $\pi^+\pi^-\pi^o$ invariant mass distribution was dominated by the phase space and the ω resonance. In this sample the η signal lied on a 40 % background. In order to reduce this background a rejection cut on the ω resonance was applied. In this way a sample of 459 $\pi^+\pi^-\eta$ events was selected with a cut in the $\pi^+\pi^-\pi^o$ invariant mass around the η particle with an estimated background of about 30 %. The spin parity analysis, mostly limited by the statistics, did not include the $a_o(980)$. *No new resonance* was needed to describe the data.

3.2 Second generation experiments

The more recent data on the $\pi\pi\eta$ come from two LEAR experiments: ASTERIX and Crystal Barrel.

The ASTERIX collaboration analysed two samples of 4 prong data (with and without L-X ray request) taken with a gaseous target at STP[9]. They selected events according to the hypothesis $\bar{p}p \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^o$ with the π^o missing. They identified the $\pi^+\pi^-\eta$ events with the same technique of the CERN Bubble Chamber collaboration: a cut in the $\pi^+\pi^-\pi^o$ invariant mass (see fig. 4) and a rejection cut on the ω. They obtained 5434 $\pi^+\pi^-\eta$ events over a 30% background. For the spin parity analysis, a background subtracted Dalitz Plot was used. The background Dalitz Plot was obtained by using events with a $\pi^+\pi^-\pi^o$ invariant mass in two regions around the η selection window. Due to statistics limitations, some oversimplifying assumptions were made to describe the protonium P-wave states. *No new resonance* was required by the data.

The Crystal Barrel collaboration for the first time studied the $\pi\pi\eta$ channel in an exclusive final state and with high statistics[6]. They collected events on the annihilation reaction $\bar{p}p \rightarrow \pi^o\pi^o\eta$ $(\rightarrow 6\gamma)$ in a liquid hydrogen target. They used for the spin-parity analysis 280000 fully reconstructed events with a background contamination lower than 1%. In order to fit the data *a new* $I^G J^{PC} = 1^- 0^{++}$ *resonance is needed* in the $\pi\eta$ S-wave with a mass around 1450 MeV/c^2 and a full width about $\Gamma = 270\ MeV$. The resonance is requested in every fit performed, independently from the used parameterization. *This resonance was not seen in any other experiment.* It must be noted that even in the Crystal Barrel data the resonance cannot be seen as a peak in the $\pi^0\eta$ invariant mass distribution (see fig.2). However the resonance has been observed through the Dalitz Plot analysis without any doubt even in the first collected sample whose size was 108000 events[5].

4 Measurement feasibility

The OBELIX experiment can study the $\pi^+\pi^-\eta$ final state *in an exclusive way* exploiting the decay $\eta \rightarrow \gamma\gamma$ and using all the subdetectors of the apparatus. $\pi^+\pi^-\eta$ events have been already observed with OBELIX in the first two prong data sample taken at STP with all the OBELIX subdetectors installed[10]. From that test it was clear that the $\pi^+\pi^-\gamma\gamma$ reconstructed final state is dominated by the $\pi^+\pi^-\pi^o$ reaction and by the background while the $\pi^+\pi^-\eta$ reaction contribution is around 5-7 %. In spite of this, the $\pi^+\pi^-\gamma\gamma$ final state is more convenient with respect to the competing one, namely the $\pi^+\pi^-\pi^+\pi^-\pi^o$, for studying the $\pi^+\pi^-\eta$ reaction, since in this case η events are a fraction of the order of 0.1 % and the background in the η region is never lower than 28 %. However, since the branching ratio for the reaction $\bar{p}p \rightarrow \pi^+\pi^-\eta$ with $\eta \rightarrow \gamma\gamma$ is of the order of 0.5% in LH_2 [8] and 0.35% at STP [9], selective triggers must be used to enhance this reaction over the background. In June 95, a dedicated acquisition to test this measurement with the HARGD trigger was made. In the following subsections, we give the details of the tests and some results of the data analysis.

4.1 Trigger rate tests

In the trigger tests, the set-up was the following:

- A $\bar{p}$ beam with 300 MeV/c momentum and with and intensity of 5×10^4 $\bar{p}/s$.
- The target was LH_2 inserted in a cylindrical vessel ($L = 25$ $cm, \phi = 15$ cm); the beam pipe and target set up was a modification of the configuration used in the $\bar{n}$ measurements.
- Active detectors were: TOF, AFS, HARGD and a Si beam monitor.

For the measurements 5 basic trigger signals were available:

MB Minimum Bias OR toffino

2P Two prong trigger, requiring multiplicity 2-2 on toffino and 2-2 on toffone;

HA HARGD trigger type A (in BAD event logic): requiring $20 < NDIGOR < 80$ (energy demand) and more than 4 hit towers in the calorimeter (multiplicity demand); an hit tower is defined by having more than 3 hit pads;

HB HARGD trigger type B (in BAD event logic): requiring $20 < NDIGOR < 80$ (energy demand) and from 3 to 7 hit towers in the calorimeter (multiplicity demand); an hit tower is defined as before;

BTB Standard Back to back trigger

In the acquisition these trigger signals were combined to get 5 different acquisition triggers:

2PA (2P trigger and HA signal) plus a MB trigger prescaled with a factor 1/3200

2PB (2P trigger and HB signal) plus a MB trigger prescaled with a factor 1/768

MBA Minimum Bias OR toffino with flags for 2 prong trigger and HARGD trigger A

MBB Minimum Bias OR toffino with flags for 2 prong trigger and HARGD trigger B

BTB Standard Back to back trigger

The acquisition time was about 40 hours, mostly spent with triggers 2PA and 2PB. The rate of trigger 2PA was 50 Hz at 5×10^4 $\bar{p}/s$; the rate of rejected events (mostly by the HARGD trigger and the pile-up logic) was about 93 %. The rate of trigger 2PB, at the same beam intensity was 65 Hz with a clear rate of 70 %.

4.2 Data analysis

For the analysis, we summed the 2PA and 2PB sample and we selected only the events with two long tracks (¿30 cm) of opposite charge in the JDC detector, with a vertex inside the target and with two neutral clusters detected in the electromagnetic calorimeter. These events were submitted to a two constraints (2C) kinematical fit to the hypothesis $\bar{p}p \rightarrow \pi^+\pi^-\gamma\gamma$. In order to select the $\pi^+\pi^-\eta$ final state we considered only events with a χ^2 probability greater than 10% and with a $\gamma\gamma$ decay angular cumulative distribution greater than 10%. In this way, we rejected most of the background.

In fig. 5a) the $\gamma\gamma$ invariant mass distribution is shown. The peaks due to π^0 and η are evident. In the inset is shown the region of the η mass ($M_\eta = 547.45$ MeV/c^2), where a

$\sigma_\eta \simeq 15\ MeV/c^2$ peak lies over a flat background. For the analysis we accepted events in a 2σ mass interval centered around the η mass, namely in the interval $M_{\gamma\gamma} \in [515-575]\ MeV/c^2$. There we estimated a background contribution less than 20%, that could be reduced by optimizing the fit errors. In order to build $\pi^+\pi^-\eta$ Dalitz Plot and to obtain the $\pi^\pm\eta$ and $\pi^+\pi^-$ invariant mass distributions, we submitted these events also to a three constraints (3C) kinematical fit to the hypothesis $\bar{p}p \rightarrow \pi^+\pi^-\eta$. In fig. 5b) the $\pi^\pm\eta$ invariant mass distribution is shown for the about 10000 events selected after the background subtraction. A structure around $1\ GeV/c^2$ corresponding to the $a_o(980)$ resonance and the peak of the $a_2(1320)$ state are evident. On the contrary no structures appear in the $a_o(1450)$ region. In fig. 5c) the $\pi^+\pi^-$ invariant mass distribution is shown. The contributions of the $\rho^o(770)$ and $f_o(980)$ are evident after the background subtraction. Furthermore an high invariant mass peak maybe due to the $f_2(1270)$ resonance or to a kinematical reflection appears.

We evaluated the background shape in the Dalitz plot and in the projections by using the well known side bins method. In fact we choose the events with a $\gamma\gamma$ invariant mass belonging to the intervals $bg1$ and $bg2$ placed side by side the η peak (see hatched areas in fig. 6a)). As previously described the events falling in these regions were submitted to the 3C fit. The obtained invariant mass distributions are shown in fig. 6b) and c).

In fig. 7 we show the $\pi^+\pi^-\eta$ obtained Dalitz Plot. The arrows indicate the position and the contribution of the different resonances.

In table 1 the performances of the two triggers 2PA and 2PB are summarized. As one can see they have a different behaviour and the number of $\pi^+\pi^-\eta$ events corresponding to 1 million of events on tape is varying from 2250 up to 3000. Considering all the items of the table, the trigger 2PB seems to be more suitable even if the enrichment factor is lower. In fact on one hand it can saturate very easily the data acquisition system, on the other it gives less distortion to the invariant mass distributions.

4.3 Acceptance and efficiency

In order to check the apparatus acceptance and the trigger distortion for reaction (1) and to correct the experimental dalitz plot for the spin parity analysis, extensive Monte simulations have been made. The used code is based on the GEANT3 package [11] which takes into account the geometry and the efficiencies of all the detectors of the apparatus.

The simulated events corresponding to reaction (1) have then been submitted to the whole analysis chain used for real data. In this way we have estimated an average reconstruction efficiency of about 5%.

The acceptance plot is shown in fig. 8; as one can see the whole allowed phase space region is covered with a fairly constant efficiency. Moreover we want to underline that the gamma detection in the electromagnetic calorimeter does not affect the acceptance uniformity.

5 Spin-parity analysis

In order to perform the first raw spin parity analysis of the $\pi^+\pi^-\eta$ Dalitz Plot and the sensibility tests, a fit program has been implemented. Most of it has been taken fromthe one used in the $\pi^+\pi^-\pi^o$ final state analysis that is a well known, long developed and accurately tested program[12]. Obvious changes have been made in the descriptions of some amplitudes. The program allows the simultaneous fit of one to four different Dalitz Plots with different initial state compositions and the $\pi\pi$-S wave scattering data of the CERN-Munich group[13].

To fit the experimental Dalitz Plot and to test the resonance sensibility, we used the following partial waves composition:

$\pi^+\pi^-$ S wave: described by a K-matrix parameterization with 2 0^{++} poles;

$\pi^+\pi^-$ P wave: $\rho^o(770)$ described with a Breit-Wigner; there is the possibility to include $\rho-\omega$ mixing, switched off in these tests;

$\pi^+\pi^-$ D wave: $f(1270)$ is included with a K-matrix formalism;

$\pi^\pm\eta$ S wave: two resonances: $a_o^\pm(980)$ in a Flatté parameterization [14] and $a_o^\pm(1450)$ with a Breit-Wigner;

$\pi^\pm\eta$ D wave: $a_2^\pm(1320)$ is included with a K-matrix formalism.

The protonium initial states which can contribute to the $\pi^+\pi^-\eta$ final state are: ${}^1S_0$, ${}^3S_1$, ${}^1P_1$, ${}^3P_1$ and ${}^3P_2$. Although in the program all 5 initial states have been fully described, in the fits of the LH_2 data and in the tests, we made the ansatz that only the protonium S-wave is needed. This can be regarded as a good approximation at the present level of sensibility, since in LH_2 the S-wave is dominant, in the $\pi^o\pi^o\eta$ analysis [6] there is no need of P-wave and even at STP the $\pi^+\pi^-\eta$ final state is dominated by the S-wave contribution[9].

The theoretical Dalitz Plot is an incoherent sum of the partial waves on the two considered initial states:

$$DP_{th}(\rho) = \sum_{J^{PC}} f^{\rho}_{J^{PC}} PW_{J^{PC}} \tag{6}$$

where $f^{\rho}_{J^{PC}}$ is the weight of the J^{PC} initial state which is a function of the density ρ; $PW_{J^{PC}}$ is the theoretical Dalitz Plot for the J^{PC} state. Each term $PW_{J^{PC}}$ can be written in the following way:

$$PW_{J^{PC}} = |\sum_{\alpha} A_{J^{PC}}(\alpha)|^2 \tag{7}$$

with α resonance in the intermediate state and $A_{J^{PC}}(\alpha)$ the elementary amplitude for the process $(\bar{p}p)_{J^{PC}} \rightarrow \alpha + spectator$. In the most general case where α is a resonance of spin l and the angular momentum between α and the spectator meson is L, the amplitude can be written as:

$$A_{J^{PC}}(\alpha) = Z_{J^{PC},L,l} F_l(\alpha) Bc(L) \tag{8}$$

where $Z_{J^{PC},L,l}$ is the normalized Zemach tensor[15], $Bc(L)$ is a centrifugal barrier factor and $F_l(\alpha)$ is the production amplitude of the resonance α. The barrier factor used is a Blatt-Weisskopf one[16]. The explicit formulations for $F_l(\alpha)$ as a function of s (dimeson invariant mass squared) are:

- Breit-Wigner:

$$F_l(\alpha) = \frac{\Lambda(\alpha) Bc(l)}{s - m(\alpha)^2 + im(\alpha)\Gamma_\alpha} \tag{9}$$

- K-matrix:

$$
\begin{aligned}
F_l(\alpha) &= (1 - i\rho\hat{K})^{-1}\hat{P} && (10)\\
\hat{K}_{ij} &= \sum_h \frac{g_i(\alpha_h) g_j(\alpha_h) Bc(l)_i Bc(l)_j}{s - m(\alpha_h)^2} + C_{ij} && (11)\\
\hat{P}_i &= \sum_h \frac{\Lambda(\alpha_h) g_i(\alpha_h) Bc(l)_i}{s - m(\alpha_h)^2} && (12)
\end{aligned}
$$

- Flatté:

$$F_l(\alpha) = \frac{\Lambda(\alpha) Bc(l)}{s - m(\alpha)^2 + i(\rho_1 g_1 + \rho_2 g_2)} \qquad (13)$$

See [5, 12, 17] for details.

The partial waves have been written as:

0^{-+} $({}^1S_0)$

$$
\begin{aligned}
PW_{0^{-+}} = \ & |A_{0^{-+}}(\eta(\pi^+\pi^-)_{S-wave}) + A_{0^{-+}}(\eta f_2(1270)) + \\
& A_{0^{-+}}(\pi^-(\pi^+\eta)_{S-wave}) + A_{0^{-+}}(\pi^+(\pi^-\eta)_{S-wave}) + \\
& A_{0^{-+}}(\pi^- a_2^+(1320)) + A_{0^{-+}}(\pi^+ a_2^-(1320))|^2 \qquad (14)
\end{aligned}
$$

1^{--} $({}^3S_1)$

$$PW_{1^{--}} = |A_{1^{--}}(\eta\rho^o(770)) + A_{1^{--}}(\pi^- a_2^+(1320)) - A_{1^{--}}(\pi^+ a_2^-(1320))|^2 \qquad (15)$$

5.1 Results of Spin-Parity Analysis

The $\pi^+\pi^-\eta$ experimental Dalitz Plot corrected for background and acceptance has been fitted with an amplitude containing only protonium S-wave, $(\pi\pi)_S$, $f_2(1270)$, $a_o(980)$, $a_2(1320)$ and $\rho^o(770)$ as described before. The CERN Munich scattering data has been included in the fit. A solution is found at a minimum of χ^2 of 687 for 446 d.o.f. In view of the fact that: acceptance corrections need refinements, the Poisson fluctuations on efficiency are not negligible with respect to errors on real data and that no account is made for the experimental resolution on the theoretical Dalitz Plot, the solution found can be regarded as a satisfactory description of data at the present level of approximation. The singlet and triplet S-wave percentages are in agreement with the previous known values (see table 2). Even the resonance intensities are not too far from previous results (see table 3).

5.2 Results of the sensibility tests

For the sensibility tests, we simulated experimental Dalitz Plots with known theoretical amplitudes with different percentage of $a_o(1450)$ in the singlet S-wave and we fitted these Dalitz Plots twice, including and excluding the $a_o(1450)$ amplitude. The generating amplitude is taken from the solution of the real data except for the $a_o(1450)$ part. The $a_o(1450)$ component has been inserted with the same phase relative to the $a_o(980)$ as the solution A of ref. [5]. The intensity of $a_o(1450)$ in the singlet S-wave has been changed in the tests from 0% to 6% in step of 2% covering the spectrum of the intensity found in the Crystal Barrel data with different parameterizations (see table 3). For each $a_o(1450)$ intensity 6 Monte Carlo Dalitz Plots with different statistics have been generated starting from 20000 events to 120000 in steps of 20000. Errors in the binned Dalitz Plot cells are enlarged to simulate a 20% background subtraction uniformly distributed. Since our goal is to check the effect of an increase in statistics only, we use the same random sequence for all the Dalitz plots to alter the mean values. This means that the results of different tests are strongly correlated and the main effect of the different statistics is to change the errors on the fitted parameters. A total of $6 \times 4 = 24$ Monte Carlo Dalitz plots have been generated and submitted to the Spin-Parity fit with the two competitive hypothesis. The initial values for the amplitudes and phases are the same for all the fits and are different from the generating amplitudes. The initial intensity for $a_o(1450)$ is always zero. All fits find a solution for the minimum of χ^2. As can be seen in fig. 10 the program gives a good χ^2/ndf around 1.0 for all fits made with the right hypothesis ($a_o(1450)$ included) independenty from the initial statistics in the Monte Carlo Dalitz plots. Also all fits made on the Dalitz plot with 0% of $a_o(1450)$, not shown in fig. 10, give $\chi^2/ndf = 1.0$ for both hypotheses. For the fits made with the wrong hypothesis (no $a_o(1450)$ in the fitting amplitude) we observe a worse χ^2/ndf, whichi increases roughly linear with the statistics. A more quantitative estimator of the sensibility to $a_o(1450)$ than the χ^2/ndf of the fit is the error on the $a_o(1450)$ reconstructed intensity. In the tests with 2% of $a_o(1450)$ intensity, fitted with the right hypothesis, we found that the error on the intensity decreases clearly with the increase of statistics. In these conditions, we found that the minimum of statistics needed to observe a 2% signal of $a_o(1450)$ with a 3 σ confidence level is around 60000 events (see fig.11).

6 Conclusions

In this draft we have studied the possibility to perform detailed studies and analyses on the $\bar{p}p \to \pi^+\pi^-\eta$ reaction. We have emphasized the importance to study the properties of the resonances produced in this final state, that is connected to the detection of exotic states in the scalar nonet. Furthermore this would allow the first confirmation (or refutation) of the new resonance $a_o(1450)$ observed recently by Crystal Barrel.

This would be the first exclusive measurement of reaction (1). We would like to underline that this is the first case in which it is possible to exploit all the features of the apparatus and, in particular, to use a combined trigger on charged and neutral particles. Moreover the number of events on the Dalitz plot would be one or two orders of magnitude greater than the ones up to now available.

The data taken with the 2PB trigger would contain at the same time also other final states of interest like $\pi^+\pi^-\pi^0$, $K^+K^-\pi^0$ and $\pi^+\pi^-\pi^0\pi^0$. In particular from the last one it is possible to evaluate the annihilation branching ratios for the reactions:

$$\bar{p}p \to \pi^0\omega \qquad with \qquad \omega \to \pi^+\pi^-\pi^0 \tag{16}$$

$$\bar{p}p \to K_S K_S \qquad with \qquad K_S^1 \to \pi^+\pi^- \quad and \quad K_S^2 \to \pi^0\pi^0 \tag{17}$$

The spin parity analysis of the $\bar{p}p \to \pi^+\pi^-\eta$ reaction can be coupled to that one of the $\bar{p}p \to K^\pm\pi^\mp K_S$ channel. Exclusive data on this reaction have been already taken by the Obelix experiment.

Furthermore as the data taken from OBELIX have shown, there are indications that the $a_o(980)$ production is strongly dependent on the target density, both in channel (1) and (2). At a first look, it seems that the behaviour as a function of the density is different in the $\bar{K}K$ and $\eta\pi$ final state. As a consequence, it is very important to perform the analysis by varying the protonium initial state distribution, taking high statistics data sample in different target conditions, namely Liquid hydrogen(LH), gaseous Hydrogen at STP and Low Pressure (LP).

Finally a very preliminary spin parity analysis, based on the K-matrix formalism, has been performed. Moreover extensive simulations have been made to understand the results sensitivity as a function of the statistics taken. Considering the results obtained we propose to take three data samples at LH, STP and LP conditions. In order to have at least 60000 events on each Dalitz Plot it is necessary to take about 30×10^6 events with the trigger 2PB at each density.

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TRIGGER	2PA	2PB
Beam intensity ($\bar{p}/sec$)	50000	50000
Clear Percentage (%)	93	70
Events taken on Tape	$\sim$ 1500000	$\sim$ 2700000
Trigger enrichment factor	11.3	8.5
$\pi^+\pi^-\eta$ / 10^6 events on tape	$\sim$ 3000	$\sim$ 2250

Table 1: Trigger performances for the two data samples taken in Liquid Hydrogen

	CERN BC [8] fit A	CERN BC [8] fit B	Asterix [9]	CB[6] all fits	Our fit
$^1S_0$ (%)	55	69	66	100	67
$^3S_1$ (%)	45	31	34	0	33
Comments	flat background	elaborated background	P-wave oversimplified	distributions assumed	very preliminary

Table 2: Percentage of the singlet and the triplet of S-wave normalized to 100 % S wave contributing to the $\pi\pi\eta$ final state.

Initial state	Asterix	CB [6] Fit A	CB [6] Fit B	CB[5] Fit A	CB[5] Fit B	CB[5] Fit C	Our fit
$(\pi\pi)_S$	69	50	55	36	45.3	37.8	39
$(\pi\pi)_D$	1	0	0	0.2	0.1	0.0	0.6
$a_o(980)$	2	13	15.5	17	13.4	18.9	15
$a_o(1450)$		5	5	5.5	4.2	3.2	
$(\pi\eta)_P$		1.5	4.5	9.0	5.2	5.5	
$a_2(1320)$ ($^1S_0$)	28	28.5	18	29.6	29.6	34.4	45
$a_2'(1620)$		2	2	2.6	2.2	0.2	
$\rho(770)$	71						82
$a_2(1320)$ ($^3S_1$)	29						18

Table 3: Branching fraction in percent, normalized to 100 % separately for the singlet (upper part) and the triplet (lower part) S-wave for the different fits made on $\pi\pi\eta$ data. The results of our fit, in the last column, shows also the composition of the Dalitz Plot used for the sensibility tests except for the $a_o(1450)$ intensity which was varied.

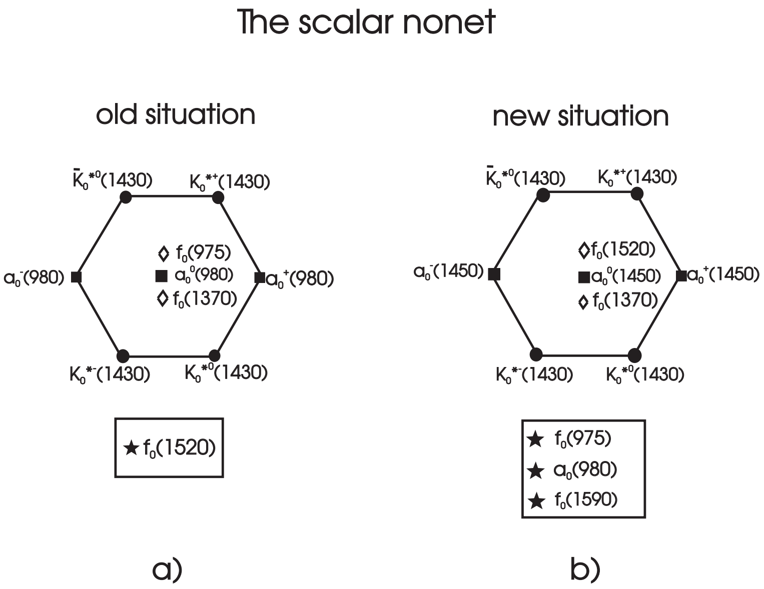

Figure 1: The 0^{++} nonet: old (a) and new (b) situation according to ref. [18] (see also [2]).

Figure 2: Crystal Barrel: $\pi^o\eta$ invariant mass for $\pi^o\pi^o\eta$ events. The vertical line is at the $a_o(1450)$ mass.

Figure 3: GAMS: $\pi^o\eta$ invariant mass for events of the reaction $\pi^-p \to \eta\pi^o\pi^o n$ at 100 GeV/c. No structure is present in the $a_o(1450)$ region; there is no need for $a_o(1450)$ in the data analysis.

Figure 4: Asterix $\pi^+\pi^-\pi^o$ invariant mass around the η meson. The full histogram (with 4 entries/event) contains 2.8 10^6 entries and the η peak about 7000 entries.

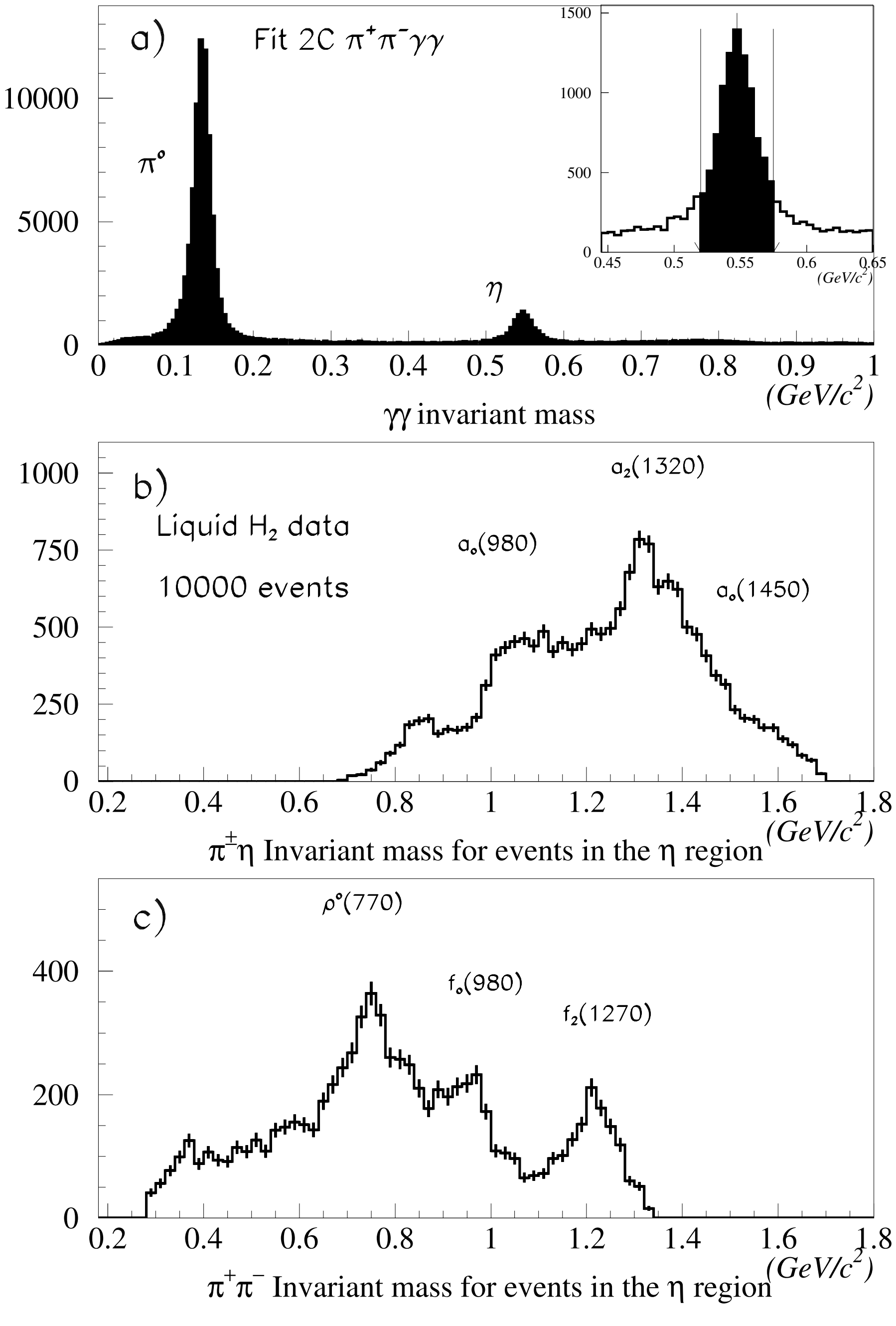

Figure 5: Trigger test data (JUN95, sample 2PA+2PB): the $\gamma\gamma$ invariant mass distribution for events with 2 tracks and 2 gammas passing the 2C fit with a 10% probability is shown in part a). Clear peaks due to π^o and η appear. In the inset is shown the η selection window. For events in the η window, the $\pi^\pm\eta$ and $\pi^+\pi^-$ invariant mass distributions after a 3C fit are shown in parts b) and c).

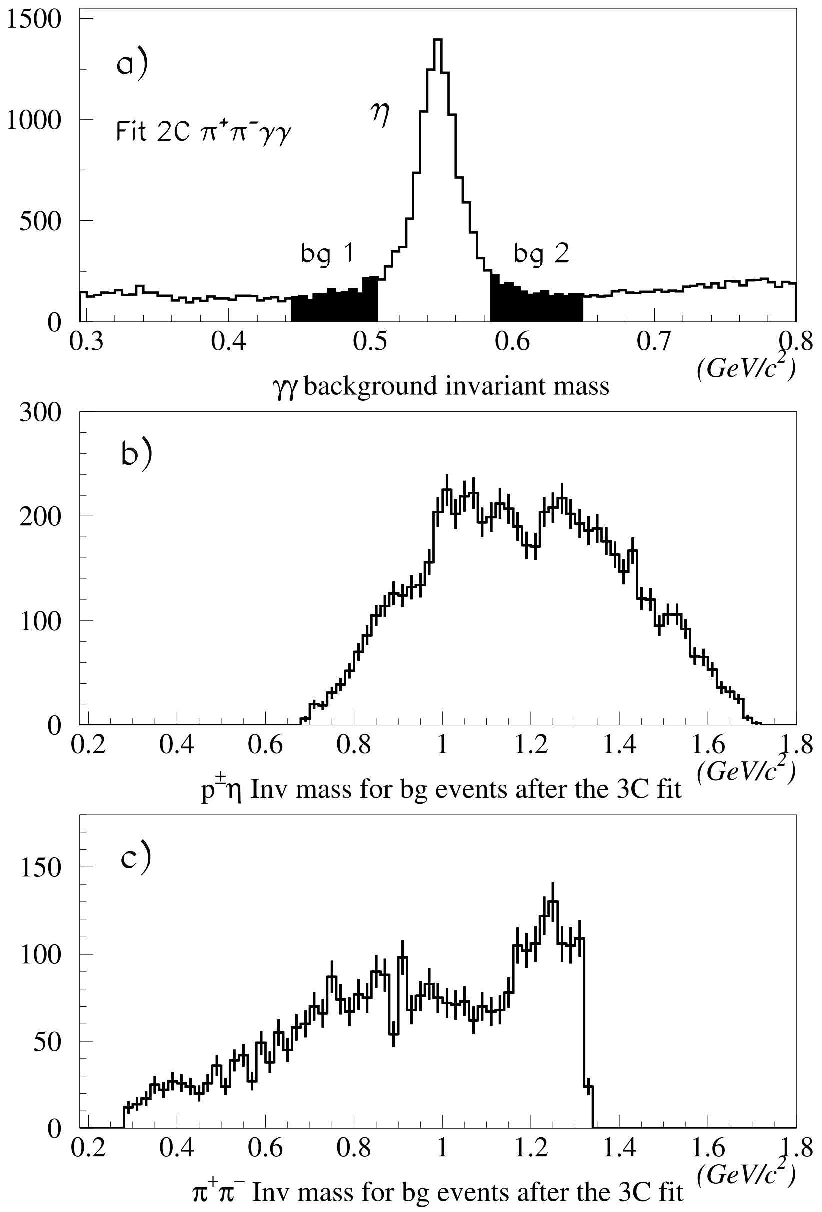

Figure 6: Trigger test data: background selection and invariant mass distributions. In part a) the hatched areas show the background windows selections (bg1 and bg2). Events falling in these regions are submitted to a 3C fit and the invariant mass distributions are shown in b) and c).

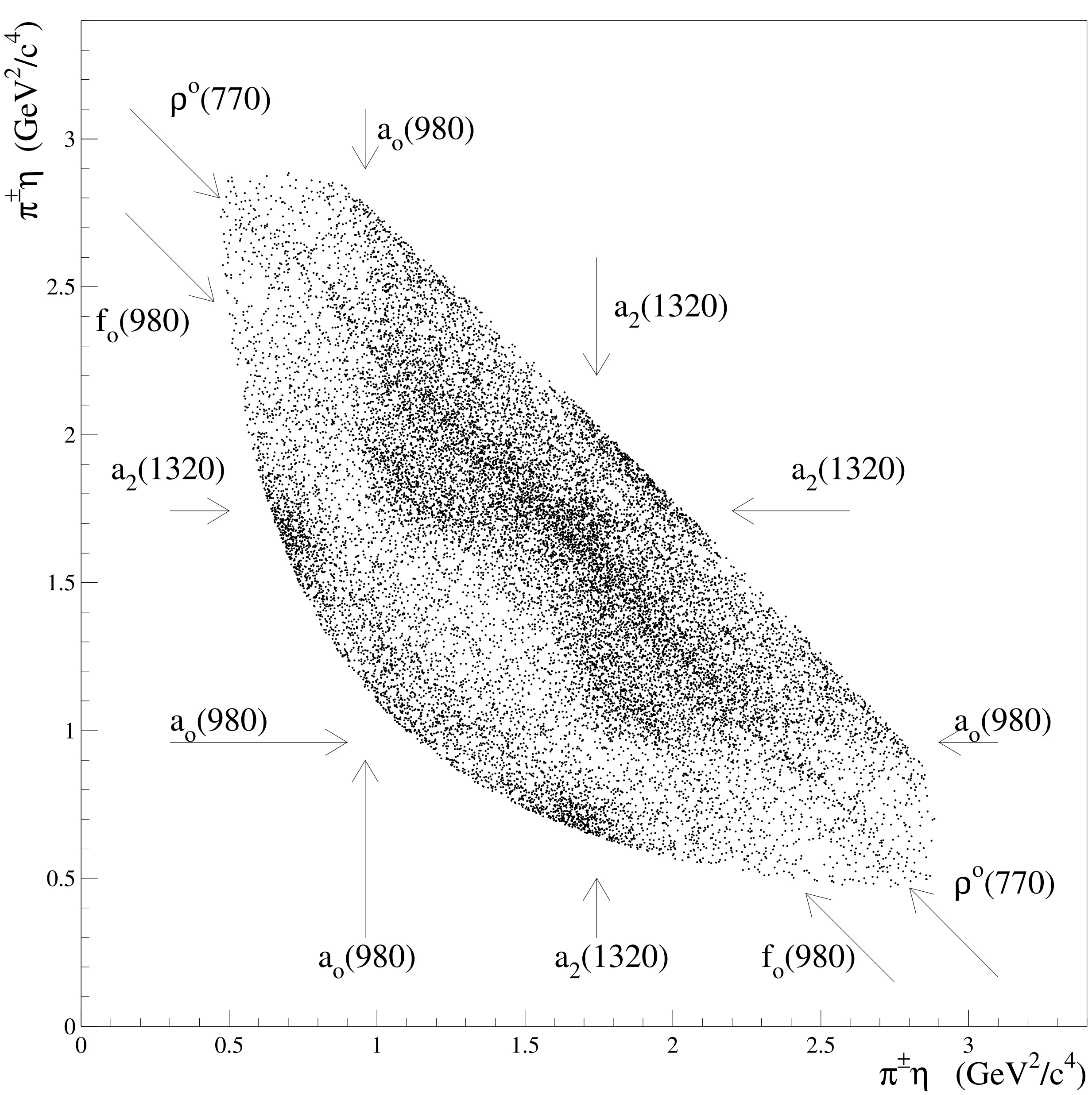

Figure 7: Dalitz Plot for the events passing the 2C fit with $P(\chi^2) > 10\%$, $Q_{\gamma\gamma} > 10\%$ and in the η selection window. Arrows shows the resonances that can be seen in the Dalitz plot.

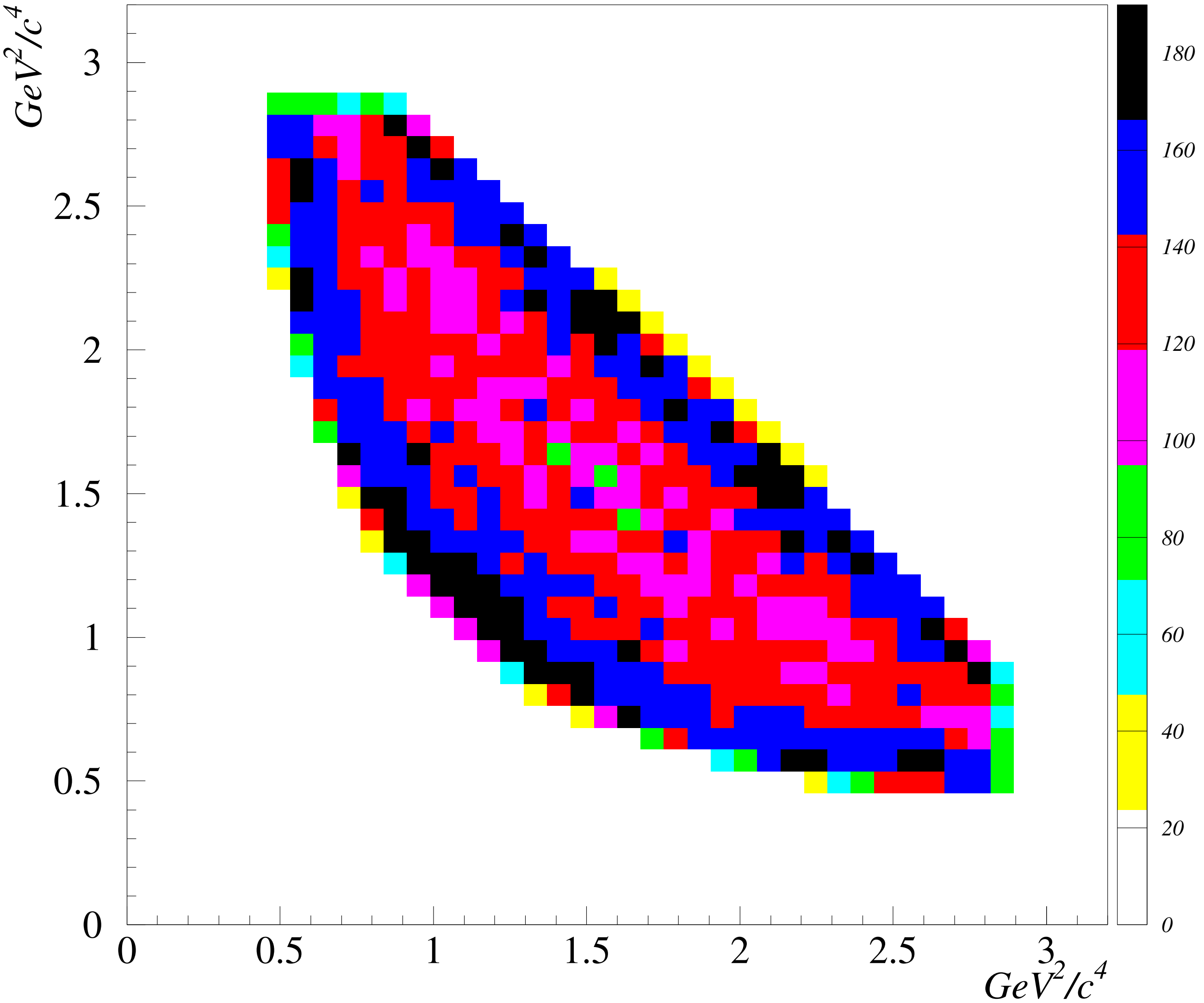

Figure 8: Acceptance Dalitz plot of the Obelix apparatus for the reaction $\bar{p}p \rightarrow \pi^+\pi^-\eta$ at rest.

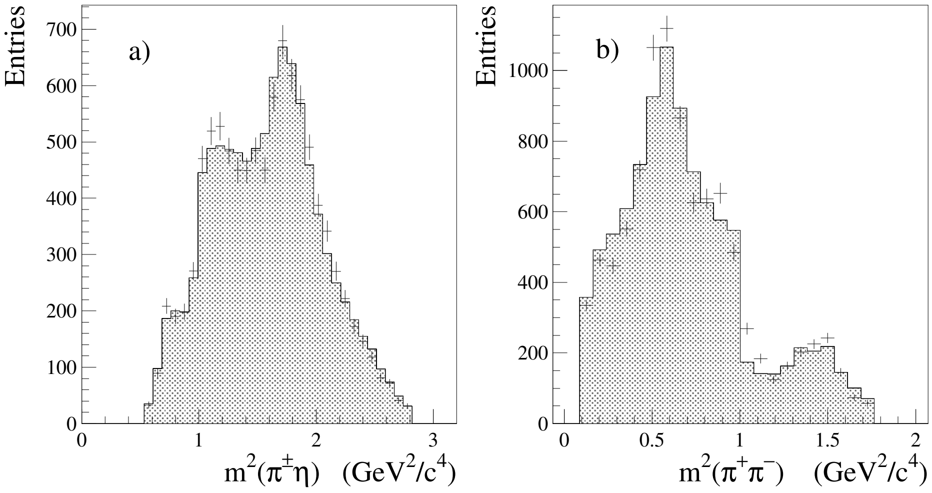

Figure 9: Spin-Parity results: projections for the experimental Dalitz plot (points with error) and the fitting one (continuous line) are shown. Part a) refers to $\pi^\pm\eta$ invariant mass squared while part b) to the $\pi^+\pi^-$ invariant mass.

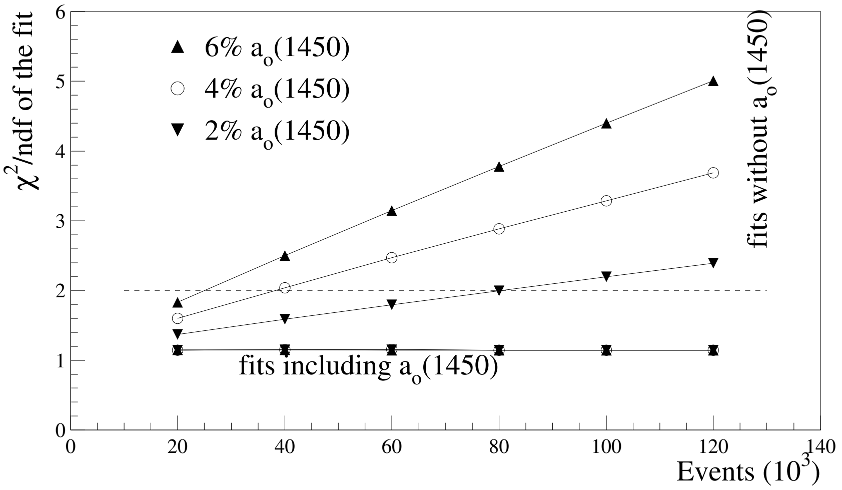

Figure 10: Sensibility tests: the χ^2/ndf of the Dalitz Plot fit is shown as a function of the sample size. We tested 3 conditions of $a_o(1450)$ intensity in the $^1S_0$ wave (2%, 4%, 6%) with two alternative hypothesis in the fits: including or excluding the $a_o(1450)$. The three upper lines refers to fits without the $a_o(1450)$; while all the fits with the $a_o(1450)$ included in the amplitude coincide in the lower line.

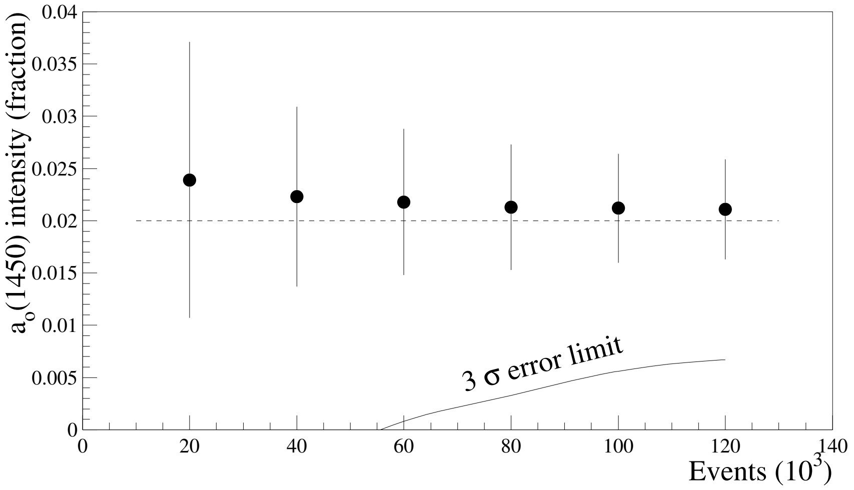

Figure 11: Sensibility tests: for the Dalitz Plot simulated including a 2% of $a_o(1450)$ in the $^1S_0$, we plot the $a_o(1450)$ intensity measured by the fit program with its error as a function of the sample size. Errors clearly decrease with the increasing of the statistics. A smooth curve is drawn at the 3 σ lower error limit. From these tests a 2% of $a_o(1450)$ can be seen as a 3 σ signal only with statistics greater than 60000 events.