Search for Low Mass Exotic mesonic structures. Part I: experimental results

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Recently, several papers discussed on the existence of a low mass new structure at a mass close to \( M=214.3 \) MeV. It was suggested that the \( \Sigma^+ \) disintegration: \( \Sigma^+ \rightarrow pP^0 \), \( P^0 \rightarrow \mu^-\mu^+ \) proceeds through an intermediate particle \( P^0 \) having such mass. The present work intends to look at other new or available data, in order to observe the eventual existence of small narrow peaks or shoulders in very low mesonic masses. Indeed narrow structures were already extracted from various data in dibaryons, baryons and mesons (at larger masses that those studied here).

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I. INTRODUCTION

The \( \Sigma^+ \) disintegration: \( \Sigma^+ \rightarrow pP^0 \), \( P^0 \rightarrow \mu^-\mu^+ \) was studied at Fermilab by H. Park et al. [1]. The data were taken by the HyperCP (E871) Collaboration. The authors observed a narrow range of dimuon masses, and supposed that the decay may proceed via a neutral intermediate state \( P_0 \), with a mass \( M=214.3 \text{ MeV} \pm 0.5 \text{ MeV} \).

Several theoretical works were done assuming the existence of this new particle. He, Tandean, and Valencia performed a standard-model interpretation of the data [2]. Later on the same authors demonstrate that the new particle could be a pseudoscalar or axial-vector, but not scalar nor vector [3]. They also suggested that the particle could be a very light pseudoscaler Higgs [4]. Deshpande et al. [5] assume a fundamental spin zero boson, which couple to quarks with flavor changing transition \( s\rightarrow d\mu^+\mu^- \). They estimate the scalar and pseudoscalar coupling constants and evaluate several branching ratios. Geng and Hsiao [6] found that the \( P^0 \) cannot be scalar but pseudoscalar, and determine that the decay width should be as small as \( \approx 10^{-7} \text{ MeV} \). Gorbunov and Rubakov [7] discuss possible sgoldstino interpretation of this possible particle.

The experimental observation was based on three events. We anticipate that this low counting is due to their observation in a weak disintegration channel. In order to eventually strengthen this result by a direct observation, we look at already existing data and try to observe a possible signature of (a) small peak(s), or (a) small shoulder(s), (at a mass not far from the mass of \( P^0 \)). Such mass(es) can be observed, either in the invariant masses of two muons, \( M_{\mu\mu} \), or in missing masses of different reactions, studied with incident leptons as well as with incident hadrons. However the signal, if any, is expected to be small. The spectra are therefore presented in the semi-log scale. The signals will be superposed to a relatively large tail of one pion missing mass. Therefore the signal, if any, can only be observed in precise data, with large statistics, good resolution and small binning. Moreover, the mass range studied must be small. Such data are scarce and concern reactions studied at rather low incident energies, with good resolution. When we found a hint for a small effect, we read out and reanalyzed the data. Several such structures were selected and presented below.

II. SELECTED DATA SHOWING SMALL STRUCTURES IN THE MASS RANGE ABOVE THE PION MASS

A. The missing mass of the \( pp\rightarrow ppX \) reaction

The \( pp\rightarrow ppX \) (X -‘meson type’) reaction was studied at SATURNE (SPES3 beam line), at \( T_p=1520, 1805, \) and \( 2100 \text{ MeV} \) [8]. The missing mass displays a broad structure, in the mass range \( 280\leq M\leq 580 \text{ MeV} \), unstable for different kinematical conditions and slightly oscillating [9], previously called the ABC effect; it was analysed as being due to a superposition of four narrow mesonic states: \( M=310, 350, 430 \text{ MeV}, \) and \( 495 \text{ MeV} \). Above the \( \eta \) mass, narrow mesonic structures were extracted at the following masses: \( M=550, 588, 608, 647, 681, 700, 715, \) and \( 750 \text{ MeV} \) [10].

Since the widths of the missing mass peaks increase for increasing spectrometer angles, we keep only the three lowest angle spectra at \( T_p=1520 \text{ MeV} \), add them, and show the resulting spectra in Fig. 1(a). The high counting rate allows to extract a clear peak at \( M_X=216.5 \text{ MeV} \).
The reaction $pp \rightarrow pp\pi^0\pi^0$ was studied close to threshold at CELSIUS (Uppsala) \[11\]. The missing mass data, after integration over two channels, are shown in Fig. 1(b). The two $\pi^0$ phase space starts at $M_X \approx 240$ MeV. The events in the range $170 \leq M_X \leq 240$ MeV, are mostly physical as the background contribution is estimated to less than 10 events/channel. These data are fitted with a $\pi^0$ peak and two small structures, having the same shape as the $\pi^0$ peak, are extracted at $M_X=182$ and 220 MeV.

The $pp \rightarrow ppX$ reaction was also studied at Jülich COSY-TOF \[12\]. Both protons in the final state were detected in order to study the $\eta$ production. The data were read and shown in Fig. 1(c). Since they are given in the original work as a function of the missing mass squared with constant binning ($\Delta M_X=0.002$ GeV$^2$), they are plotted versus $M_X$ as given, up to 210 MeV (empty circles), and for larger missing mass they are integrated over two channels (full circles). The peak corresponding to $\pi^0$ missing mass is fitted by a gaussian, at $M_X=135$ MeV ($\sigma=67$ MeV), and the data at larger missing mass are fitted with a polynomial. Two structures can be extracted, the first one at $M=197$ MeV, not valid statistically, and the second at $M=224$ MeV. They are very narrow, therefore, if fitted by only one structure, which includes both narrow structures, they result in a broad gaussian centered at $M=214$ MeV (dashed curve in Fig 1(c)).

**B. The missing mass of the ep→e'pX reaction**

The $\pi^0$ electroproduction at threshold for $Q^2=0.05$ GeV$^2$ was measured at MAMI \[13\]. The missing mass spectra is integrated over 4 channels. Insert (b): missing mass of the $p(\vec{e},e'\vec{p})\pi^0$ reaction studied at JLAB Hall A at $\theta_{cm}=90^0$ \[14\]. Insert (c): missing mass of the $p(e,e'p)X$ reaction measured at JLAB Hall C \[15\].
be attributed to the Bethe-Heitler process (ep→e′p′γ reaction).

![Figure 3](image1.png)

**FIG. 3**: The missing mass of the p(e,e′p)X reaction [16] studied at JLAB Hall C at Q^2=4.0 GeV^2. The empty circles correspond to Monte-Carlo simulations; the full circles correspond to data. Inserts (a), (b), (c), and (d) correspond respectively to p_0^0=2 GeV and θ_p^0=23^0, p_0^0=2 GeV and θ_p^0=20^0, p_0^0=2.2 GeV and θ_p^0=17^0, and p_0^0=2.45 GeV and θ_p^0=17^0.

![Figure 4](image2.png)

**FIG. 4**: The missing mass of the p(e,e′p)X reaction [16] studied at JLAB Hall C at Q^2=2.8 GeV^2. The empty circles correspond to Monte-Carlo simulations; the full circles correspond to data. Inserts (a), (b), (c), and (d) correspond respectively to p_0^0=1.9 GeV and θ_p^0=33^0, p_0^0=1.55 GeV and θ_p^0=23^0, p_0^0=1.7 GeV and θ_p^0=19^0, and p_0^0=1.7 GeV and θ_p^0=23^0.

C. Discussion

We have looked at some existing data, in order to find evidence for the existence of a new boson. All spectra shown here, display a structure, but at slightly different masses. However, there is an indication of a possible regrouping around several mass values. The statistics is too low for giving an evidence if the results privilege one unstable mass or a few better defined masses. We increase therefore the number of spectra studied, as those shown in Figs 3 and 4. These spectra are not shown here. The corresponding quantitative informations are summarized in Table I. They favor a regrouping into several values; the same conclusion is favored by the existence of more than one peak in the same spectrum, as in Fig. 1(b). In summary these narrow structures masses (see Fig. 5), are tentatively observed at:

M=181±2 MeV (5 events),
M=198±2 MeV (5 events),
M=215±5 MeV (12 events),
M=227.5±2.5 MeV (5 events),
M=235±1 MeV (3 events).

We notice that the range exhibiting the largest num-

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Fig. 1 of Ref. [15] an example of missing mass distribution for the reaction p(e,e′p)X. These data are read and reported in Fig. 2(c). The widths of all π^0 and η peaks are related to their masses (proportional to 1/M). These widths define the width of the small peak extracted at M=220 MeV. Several other peaks are introduced, following the results of the pp→ppX reaction studied at SPES3 (SATURNE, Saclay) [8]. After introduction of an arbitrary two-pion phase space, a contribution of the p(e,e′p)γ reaction is observed around M_X=0. More de-

tailed data from the same experiment [16], are reported in several spectra where structures can be extracted in the same missing mass range. The measurements were performed for two values of the four momentum transfer squared between the initial and the final electron, namely at Q^2=2.8 GeV^2 and Q^2=4 GeV^2. The measurements were performed for a few values of P_0^0 and a few values of θ_p^0. Four spectra are shown in Fig. 3 for Q^2=4 GeV^2. Fig. 4 shows another selection of spectra corresponding to Q^2=2.8 GeV^2. In both figures empty circles correspond to Monte-Carlo simulations [16] and full circles correspond to data. In the missing mass range studied here an excess of counts can be seen between data and the simulation which were fitted by a polynomial. The quantitative informations are given in Table I. The discrepancy between data and simulation for M_X ≤ 60 MeV has
number of experimental mass structures, namely around M=215 MeV, agrees with the value extracted at Fermilab: M=214.3 MeV [1]. There is also an additional but qualitative evidence in favour of a structure at M=214.3 MeV [1]. There is also an additional but qualitative evidence in favour of a structure at M=215 MeV, agrees with the value extracted at Fermilab: M=214.3 MeV [1]. There is also an additional but qualitative evidence in favour of a structure at M=215 MeV, agrees with the value extracted at Fermilab: M=214.3 MeV [1].

![FIG. 5: Masses of the weakly excited structures extracted from several experiments (see text and table I).](image)

TABLE I: Masses (in MeV) and number of standard deviations (S.D.) of the narrow peaks extracted around M~215 MeV, from the (p,e,e'p)X reaction studied at JLAB Hall C [16] for Q^2=4 GeV^2 (Fig. 3) and Q^2=2.8 GeV^2 (Fig. 4). The width of the peak is given by σ (in MeV). p_0 is in GeV, and θ is in degrees.

| Fig. insert set in [16] | Q^2 | p_0 | θ° | M | σ | S.D. |
|-------------------------|-----|-----|----|---|---|------|
| Fig. 3 (a)              | 10  | 4.0 | 2  | 23 250 22 9.5 |
| (b)                     | 11  | 4.0 | 2  | 20 225 22 4.9 |
| (c)                     | 21  | 4.0 | 2.2| 17 230 17 5.2 |
| (d)                     | 5   | 4.0 | 2.5| 17 210 17 6.3 |
| Fig. 4 (a)              | 14  | 2.8 | 1.9| 33 200 17 1.9 |
| (b)                     | 19  | 2.8 | 1.55| 23 175 17 4.0 |
| (c)                     | 34  | 2.8 | 1.7| 19 215 17 3.0 |
| (d)                     | 36  | 2.8 | 1.7| 23 210 17 2.9 |

**III. SELECTED DATA SHOWING SMALL STRUCTURES IN THE MASS RANGE BELOW THE PION MASS**

**A. The missing mass of the pp→ppX reaction**

The natural question, following the previous result, is to look, in already published data, at (a) possible structure(s) below the mass of the pion (M=135 MeV). All the data reanalyzed below, are read and their mass recalibrated, when necessary, to adjust the pion peak at M=135 MeV. The pion missing mass peak is described by a gaussian and the structure(s) at lower mass(es) is (are) described by a gaussian with the same width as the one given for π^0. The observed structures are small, therefore a semi-log scale is used. Also the mass(es) extracted is (are) not always stable since the corresponding statistics is not reach. A small background is arbitrarily drawn. If it will be modified, the results will not change much, since we are in the xesemi-log scale.

Fig. 6 shows the missing mass spectra studied at SATURNE (SPES3 beam line) in the useful range, at T_p=1520 MeV, and at four different spectrometer angles. A small peak is easily extracted at forward angles. When the spectrometer angle increases, the excitation of this exotic structure increases also relatively to the π^0 excitation, but the resolution gets spoiled and the peak although still extracted, is no more clearly separated from the π^0 peak. Fig. 7 shows another selection of four missing mass spectra. Here again the experimental results are well fitted with introduction of a second peak at a mass close to M~65 MeV. Table II gives the quantitative informations. σ describes the width of the peaks and R is the ratio of the exotic structure excitation relative to the π^0 excitation.

Fig. 8 shows a selection of missing mass peaks from CELSIUS in inserts (a), (b), and (c). Insert (a) shows the data from the pp→ppπ^+π^- reaction studied at CELSIUS [18] at T_p=775 MeV. The σ of the peaks equals 20 MeV, and R=17 10^{-2}. Insert (b) shows the data from the pp→ppγγ reaction studied at CELSIUS [19] at T_p=1360 MeV. Here σ=16 MeV and R=6.6 10^{-2}. Insert (c) shows the data of the pp→ppX reaction studied at CELSIUS [11] at T_p=650 MeV. Here σ=17 MeV and R=8.3 10^{-2} for the ratio of the "60"/'135" peaks and R=20 10^{-2} for the ratio of the "100"/'135" peaks. In all these spectra a peak at M~65 MeV is observed, and also another one is extracted at M=100 MeV. Ta-
FIG. 6: Missing mass spectra for \( \mathrm{pp} \to \mathrm{ppX} \) measured at SATURNE (SPES3 beam line) at \( T_p = 1520 \) MeV. Inserts (a), (b), (c), and (d) correspond respectively to the following spectrometer angles: \( \theta_{\text{spec.}} = 0^\circ, 2^\circ, 5^\circ, \) and \( 9^\circ \).

TABLE II: Quantitative information on the small structure extracted from the missing mass spectra studied with \( \mathrm{pp} \to \mathrm{ppX} \) reaction at SATURNE (SPES3 beam line) \[8\]. The incident proton energies \( T_p \) and the mass \( M \approx 65 \) are in MeV. \( R \) is the ratio of the \( M \approx 65 \) MeV structure excitation over the \( \pi^0 \) excitation.

| Fig. | \( T_p \) | \( \theta_{\text{pp}} \) | \( \sigma \) | \( M \approx 65 \) | \( R \) |
|------|---------|---------|---------|----------------|------|
| 6(a) | 1520    | 10.3    | 65      | 7.2 \( \times \) 10^{-3} |
| 6(b) | 1520    | 11.5    | 82      | 9.6 \( \times \) 10^{-3} |
| 6(c) | 1520    | 17      | 74      | 27 \( \times \) 10^{-3} |
| 6(d) | 1520    | 9       | 28      | 77 \( \times \) 10^{-3} |
| 7(a) | 1520    | 13      | 38      | 9.4 \( \times \) 10^{-2} |
| 7(b) | 1520    | 17      | 38      | 18.7 \( \times \) 10^{-2} |
| 7(c) | 1805    | 9       | 27      | 13.8 \( \times \) 10^{-2} |
| 7(d) | 1805    | 13      | 40      | 10.0 \( \times \) 10^{-2} |

Fig. 7 gives the quantitative informations. Several spectra from COSY-Julich are reported in Fig. 9. They are all integrated by two channels in order to increase the precision. The effect in the spoiling of the resolution is observed, going from insert (a) to insert (c). Table III gives the quantitative informations. Insert (a) shows the data from the \( \mathrm{pd} \to \mathrm{3He} \pi^0 \) reaction measured by the GEM detector at COSY \[20\] at \( T_p = 328 \) MeV. Here \( \sigma = 13 \) MeV and \( R = 1.7 \times \) 10^{-2} for the ratio of the "60°/135°" peaks and \( R = 10.9 \times \) 10^{-2} for the ratio of the "100°/135°" peaks. A large statistics missing mass spectra was obtained with the \( \mathrm{pd} \to ^3 \mathrm{T} \pi^+ \) reaction studied at COSY \[21\] at \( T_p = 328 \) MeV also. The authors said that "small background was subtracted for each angular bin". The data are read, integrated by two channels, and shown in Fig. 9(b). A small peak at \( M = 73.6 \) MeV is extracted. Insert (c) shows the missing mass spectra of the \( \mathrm{dp} \to ^3 \mathrm{He} \eta \) reaction at \( T_d = 1780 \) MeV \[22\]. Here \( \sigma = 29 \) MeV and \( R = 25.2 \times \) 10^{-2} for the ratio of the "61°/135°" peaks and \( R = 2.8 \times \) 10^{-2} for the ratio of the "100°/135°" peaks.

TABLE III: Quantitative informations concerning figs. 8, 9, and 10.

| Fig. | reaction | ref. | lab. | \( M \) (R) | \( M \) (R) |
|------|----------|------|------|-------------|-------------|
| 8(a) | \( \mathrm{pp} \to \mathrm{pp} \pi^- \pi^- \) | \[18\] CELSIUS | 65 (0.17) |
| 8(b) | \( \mathrm{pp} \to \mathrm{pp} \gamma \gamma \) | \[19\] CELSIUS | 65 (0.07) |
| 8(c) | \( \mathrm{pp} \to \mathrm{pp} \pi^0 \pi^0 \) | \[11\] CELSIUS | 60 (0.08) |
| 8(d) | \( \mathrm{p(e, e'} \pi^0 \pi^0 \) | \[14\] JLAB A | 60 (0.01) |
| 9(a) | \( \mathrm{pd} \to ^3 \mathrm{He} \pi^0 \) | \[20\] COSY | 60 (0.02) |
| 9(b) | \( \mathrm{pd} \to ^3 \mathrm{T} \pi^+ \) | \[21\] COSY | 73 |
| 9(c) | \( \mathrm{dp} \to ^3 \mathrm{He} \eta \) | \[22\] COSY | 61 (0.25) |
| 10(a) | \( \gamma \mathrm{p} \to \mathrm{pX} \) | \[23\] JLAB B | 55 (0.06) |
| 10(b) | \( \gamma \mathrm{p} \to \mathrm{pX} \) | \[23\] JLAB B | 65 (0.04) |
| 10(c) | \( \gamma \mathrm{p} \to \mathrm{pX} \) | \[23\] JLAB B | 65 (0.09) |
| 10(d) | \( \gamma \mathrm{p} \to \mathrm{pX} \) | \[23\] JLAB B | 65 (0.10) |
FIG. 8: Missing mass spectra for several different reactions measured at CELSIUS. (a) pp→ppπ⁺π⁻ [18], (b) pp→ppγγ [19], (c) pp→ppX [11]. Insert (d) shows the missing mass of the p(\vec{e}, e'\vec{p})π⁰ reaction [14] studied at JLAB Hall A at θ_{cm}=90⁰.

"97"/"135" peaks.

The missing mass of the p(\vec{e}, e'\vec{p})π⁰ reaction [14] studied at JLAB Hall A at θ_{cm}=90⁰ is read and reported in Fig. 8(d). Two structures, at M=100 MeV and 60 MeV are extracted.

B. The missing mass of the γp→pX reaction

The missing mass of the γp→pX reaction was studied at JLAB in Hall B, in an experiment devoted to study the inclusive η photoproduction in nuclei [23] by the CLAS Collaboration. The data at low missing mass range are read and reported in Fig. 10. We observe the good fit obtained with introduction of a structure at M=100 MeV in inserts (a) and (b) and a structure at M=65 MeV (M=55 MeV in insert (a)) in all inserts.

The mean values of the two low mass structures extracted from the various spectra shown, are M=62 MeV and M=100 MeV.

IV. CONCLUSION

Fig. 11 shows the various exotic masses shown in previous figs.. These masses are M=62 MeV, 80 MeV, 100 MeV, 181 MeV, 198 MeV, 215 MeV, 227.5 MeV, and 235 MeV, although the last one may be uncertain, since determined by only three data, and being located at the limit of the spectra. A few points, located around M=75 MeV, may be thought as being not resolved structures. Indeed when they are extracted none of the structures at M=100 or M=62 MeV is observed. However the symmetry of the masses reported in Fig. 11, may be considered as an indication of their genuine existence.

We have selected some spectra showing these structures. In many other spectra, such extraction is not possible, either since their experimental resolution is worse, either since the dynamics of the experiment (reaction, incident energy ...) is less favourable. In figs. 6 and 7, and table II, six spectra obtained at the same incident energy and same reaction, show that R increases with the spectrometer angle (but the resolution get spoiled, as already indicated). Figs. 6 and 7 show that R increases with the incident energy (but again the resolution spoils in that case).

We suggest that the reason for which these narrow, weakly excited structures were not observed till now is due to the lack of experimental precision (resolution and statistics) of previous experiments.
FIG. 10: Missing mass spectra for $\gamma p \rightarrow pX$ measured at JLAB Hall B \cite{24} CLAS Collaboration. Inserts (a), (b), (c), and (d) correspond respectively to the following kinematical conditions: $0.8 \leq E \leq 0.9$ GeV and $-0.75 \leq \cos(T) \leq -0.50$, $0.8 \leq E \leq 0.9$ GeV and $-0.25 \leq \cos(T) \leq -0.00$, $1.2 \leq E \leq 1.3$ GeV and $-0.50 \leq \cos(T) \leq -0.25$, and $1.2 \leq E \leq 1.3$ GeV and $0.50 \leq \cos(T) \leq 0.75$. E is the beam energy and T is the proton center-of-mass angle.

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FIG. 11: Masses of the weakly excited structures extracted from several experiments.