POSSIBLE OBSERVATION OF THE SCALAR MESON AT ~1280 MeV IN THE REACTION $\pi^- p_\uparrow \to \pi^+\pi^- n$ AT 17.2 GeV/c

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Recent analysis of the reaction $\pi^- p_\uparrow \to \pi^+\pi^- n$ at 17.2 GeV/c for $|t| > 0.2$ GeV^2 yields relatively narrow scalar resonance, with parameters resembling those of $g_s(1240)$. Its unusual production properties are tentatively explained in terms of a hybrid meson trajectory. Importance of the polarized target information is also discussed.

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1. Introduction

After ten years of high statistics studies of the $\pi\pi$ system produced in peripheral process, scalar resonances remain a mystery, although one has to admit that large progress has been made both on experimental and theoretical sides.

The important experimental achievement is the firm resolution of ambiguities in the partial wave analysis due to studies of the $\pi^0\pi^0$ system [1] and polarized target experiment [2].

Main progress in the theory of scalar mesons has been brought by unitarized quark model of Törnqvist [3]. It has been shown that in spite of their unconventional experimental properties the scalar mesons $\varepsilon(1300)$, $S^*(980)$, $\kappa(1350)$ and $\delta(975)$ can be understood as conventional $q\bar{q}$ states. However, the understanding is rather qualitative than quantitative (cf. Fig. 1a). Moreover, unconventional states (gg, $q\bar{q}q\bar{q}$, $q\bar{q}g$) are expected in the same mass range [4]. Their experimental resolution is an important task for experimental meson spectroscopy. It should be noted here that in spite of theoretical expectations there is no evidence for scalar gluonic excitations of matter in $J/\psi \to \gamma X$. Thus it is even more important to reexamine the $\pi p \to \pi\pi N$ data from this point of view. In this study we turn our attention to the region of nucleon momentum transfer $|t| > 0.2$ GeV^2 — a poorly explored terrain, upon which the polarized target information shed a new light.

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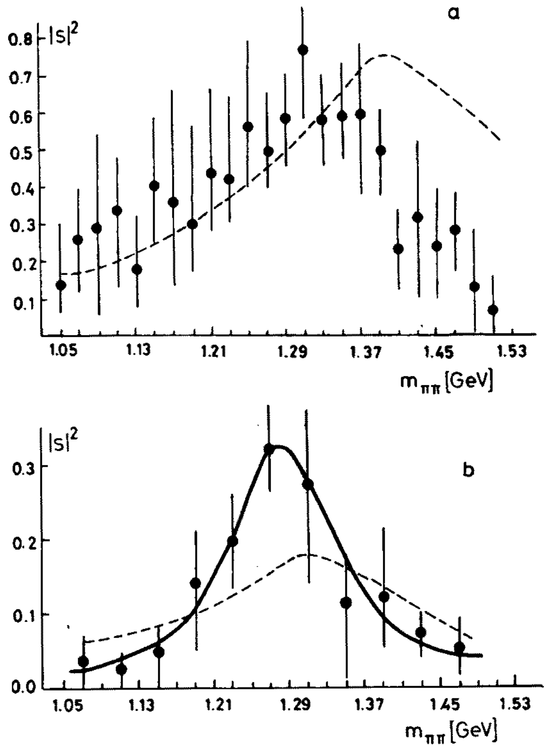

Fig. 1. a) The $\pi\pi$ S wave intensity for the nucleon four-momentum transfer $0.005 < |t| < 0.2$ GeV^2 reproduced from Ref. [2]. Dashed line is the S wave intensity predicted by unitarized $q\bar{q}$ model of Törnqvist [3]. b) The $\pi\pi$ S wave intensity for $0.2 < |t| < 1.0$ GeV^2 reproduced from Ref. [5]. Dashed line is the S wave intensity for $0.005 < |t| < 0.2$ GeV^2 extrapolated to the region $0.2 < |t| < 1.0$ GeV^2 as described in the text. Full line is the Breit-Wigner fit to the distribution

The data we present certainly do not provide strong evidence for the discussed effects. However, we think that they are interesting enough to be published, just to show a potential usefulness of this sort of data for the hadron spectroscopy, if nothing else.

The above introduction is followed by four Sections. In Section 2 we discuss the S wave in $\pi^+\pi^-$ system produced in the reaction $\pi^- p_\uparrow \to \pi^+\pi^- n$ at high four-momentum transfer. In Section 3 we discuss the importance of the polarized target data. The paper is closed by conclusions in Section 4.

2. *Discussion of S wave at high four-momentum transfer*

Recently the results of the model independent partial wave analysis of the polarized target data

$$\pi^- p_\uparrow \to \pi^+\pi^- n \tag{1}$$

at 17.2 GeV/c for the nucleon momentum transfer $0.2 < |t| < 1.0$ GeV^2 have been published [5]. In most cases (in particular for all mass bins above 900 MeV) unique solution has been found after extensive search for ambiguities. In the present paper an interpretation of some results of the above mentioned analysis is attempted. In Fig. 1b we present the S wave intensity for $0.2 < |t| < 1.0\ \text{GeV}^2$ obtained in Ref. [5]. For comparison the S wave intensity for $0.005 < |t| < 0.2\ \text{GeV}^2$ as given by the polarized target data analysis [2] is presented in Fig. 1a. The dotted line in Fig. 1b represents the S wave intensity in the $0.005 < |t| < 0.2\ \text{GeV}^2$ region (as in Fig. 1a) extrapolated to the $0.2 < |t| < 1.0\ \text{GeV}^2$ region assuming dominance of the π-trajectory. Namely we use the foımula

$$\frac{d\sigma_0^L}{dt} \alpha - \frac{t}{(t-\mu^2)} e^{A(t-\mu^2)}, \tag{2}$$

where σ_0^L is a partial cross section for the $\pi\pi$ wave with spin L and helicity $m = 0$, μ is the pion mass, and $A = (7\text{–}7.5)\ \text{GeV}^2$ has been taken from the fits to $\pi^+\pi^-$ data of CERN--Munich group [6]. It should be underlined that the above mentioned procedure of the extrapolation should be considered as unambiguous. The slope parameter A in the formula (2) does not show any significant change as a function of the $\pi\pi$ mass and seems to be universal for all partial waves. The above statement is based on high statistics data from CERN-Munich spectrometer [6]. Two following observations are in order:

(*i*) The resonant structure produced in the higher $|t|$ region seems to be different from ε(1300) known from the studies at the low momentum transfer (cf. Particle Data Group [7]). The structure looks much more narrow, shifted to lower masses and, above all, consistent with the Breit-Wigner shape of typical hadronic width ~200 MeV.

The statistical significance of this effect, e.g. in terms of χ^2, is not overwhelming. In fact it is possible to reproduce the shape of both curves with a single polynomial of 3-rd degree with $\chi^2/\text{n.d.f.} = 33/29$. However, such fit reproduces poorly the S-wave intensity at $t > 0.2\ \text{GeV}^2$ ($\chi^2 = 20$ for 10 data points) and, what is more important, χ^2 is not a good measure of the effect because the errors seem to be very much overestimated. We can see in Fig. 1a that the points fluctuate much less than the error bars indicate. The polynomial fit to the low t data gives absurdly small $\chi^2/\text{n.d.f.} = 10/20$. If we use the Breit-Wigner formula instead of the polynomial the situation is reversed. The fit to both distributions gives $\chi^2/\text{n.d.f.} = 23/29$. Low t data contribute with $\chi^2 = 19$ for 24 data points whereas high t data contribute with absurdly small $\chi^2 = 3$ for 10 data points. The Breit-Wigner fit to high t data alone gives $m = 1280$ MeV, $\Gamma = 130$ MeV and $\chi^2/\text{n.d.f.} = 1.1/8$.

We conclude that for the distributions in Fig. 1 the errors seem to be overestimated by ~50%. The S-wave intensity at low t is better described by the 3-rd degree polynomial whereas the analogic distribution at high t is better described by the Breit-Wigner formula. The source of the error overestimation is hard to trace. Let us remind that partial wave analysis is a procedure in which the nonlinear relations between the moments of the angular distributions and the partial wave amplitudes are solved by minimization of the appropriately defined χ^2 function. The error definition for the fitted parameters (i.e. partial wave intensities and relative phases) is to some extent arbitrary, i.e. its statistical meaning is not obvious as the χ^2 function is not parabolic at the minimum in our case. It should be noted that this sort of problem is quite frequently met in the partial wave analysis.

All said above certainly does not prove that the S-wave intensity distributions at low and high t do differ significantly; however, we hope it explains why we believe it is so.

(*ii*) The exchange of π-trajectory does not seem to be the dominant production mechanism for the new resonance. Around 1250 MeV the S-wave intensity falls with t about two times slower than formula (2) predicts. This is also seen in Fig. 2a showing relative intensities (i.e. fractions of total intensity) as a function of $\sqrt{-t}$ for the mass interval 1150–1400 MeV. While the D_0 fraction falls down rapidly above $\sqrt{-t} = 0.2$ GeV and D_N takes over, the S wave represents about 20% of intensity independently of t.

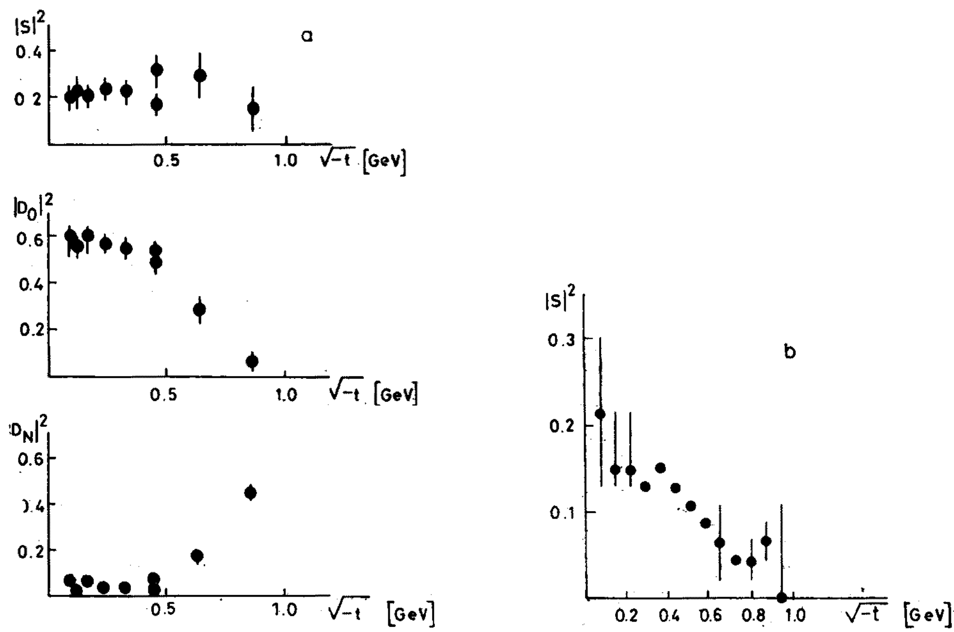

Fig. 2. a) Relative intensities of main partial waves as a function of four-momentum transfer for $1150 < m_{\pi\pi} < 1400$ MeV. b) Relative intensity of S wave as a function of four-momentum transfer for 690 MeV $< m < 890$ MeV

In Fig. 2b we reproduce from Ref. [2] the t dependence of the S-wave intensity in the $\varrho(770)$ mass region. It is consistent with the π-exchange mechanism like D_0 in Fig. 2a. Thus we conclude that the abnormal behaviour of the S-wave t-dependence in Fig. 2a has to be attached to the f(1270)-mass region rather than S-wave in general. Again we have to admit that we have here indication of the effect rather than statistically significant observation. However, it seems to be a reasonable consistency check for the previously discussed t dependence of the S-wave mass spectrum.

For somebody knowing a long and confused story of the $\pi\pi$ S-wave solutions it might be unjustified to draw conclusions from only few data points based on low statistics experiment. However, it should be underlined that in the polarized target experiment the partial wave analysis is model independent and that there are no ambiguities, at least in the mass region in question.

The production mechanism deserves special attention. In reaction (1) the S wave is produced by the unnatural parity exchange. In the conventional Regge-pole phenomenology [8] only π and A_1 trajectories were considered. Excluding π-exchange as the dominant production mechanism of the new object we are left with the A_1 trajectory. However, polarized target data [9] show that A_1-exchange falls with t as fast as the π-exchange. This can be seen directly from the t dependence of the polarization A_0 defined as

$$A_0 = \frac{\mathrm{Im}\,(A_1\pi^*)}{|A_1|+|\pi|^2}\,, \tag{3}$$

where A_1 and π denote the appropriate exchange amplitudes. In Fig. 3 the t dependence of the polarization for P_0 wave in the mass region is shown to be practically flat implying that $A_1 \sim \pi$. The detailed Regge-pole analysis [10] of the polarized target data in the ϱ mass region for $0.005 < |t| < 1.0\ \mathrm{GeV}^2$ leads to the same conclusion.

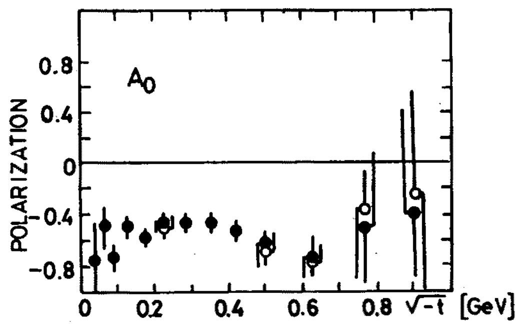

Fig. 3. The P_0 wave polarization $A_0 = \mathrm{Im}\,(A_1\pi^*)/(|A_1|+|\pi|^2)$ in the ρ mass region as a function of the nucleon four-momentum transfer. The figure is reproduced from Ref. [9]

Thus in order to explain the S wave intensity around 1250 MeV for $|t| > 0.2\ \mathrm{GeV}^2$ we propose to introduce an unconventional trajectory of the $q\bar{q}g$ analogue of A_3 and A_1. The theory of the hybrid states [11] indicates that such trajectory might exist with the intercept comparable to that of π and A_1. Indeed, the hybrid meson trajectory should be flatter than the conventional one due to the stronger colour forces [12]. If we assume $\alpha'_{q\bar{q}g} \approx 0.5\ \mathrm{GeV}^{-2}$ [12] as well as the A_3-like 2^{-+} and A_1-like 1^{++} hybrid meson ground states in the mass range predicted by the theory [11, 13] then the appropriate hybrid trajectories will have intercepts comparable to that of the π-trajectory. Thus unnatural parity unconventional trajectories may be competitive with the conventional ones when coupling to the gluonic excitations of matter is concerned.

Thus we suggest that $\varepsilon(1300)$ is a two-component structure containing the conventional $q\bar{q}$ meson and the gluonic excitation of matter, probably a glueball. As two different production mechanisms are involved we feel that we have insufficient information to extract precise parameters of these objects. However, assuming that at large t the nonconventional G(1280) dominates the mass spectrum, we estimate its mass and width to be $m \sim 1280$ MeV and $\Gamma \sim 130$ MeV. Judging by these values, G(1280) might be identical to $g_s(1240)$ isoscalar resonance observed in $K\bar{K}$ experiments [14], with the following parameters:

$$M_{g_s} = (1240 \pm 10)\ \text{MeV}, \qquad \Gamma_{g_s} = (140 \pm 10)\ \text{MeV}.$$

It should be also mentioned that in studies of the reaction $\pi^- p \to K_s^0 K_s^0 n$ [16, 17] t dependence of the $K_s^0 K_s^0$ S wave was observed to be flatter around 1300 MeV than near the thres hold.In these papers, however, the effect was tentatively ascribed to $I = 1$ produced by B-exchange mechanism. The data of Ref. [14] allow a model independent separation of the isospin components.

3. Importance of polarization data

In absence of the polarized target data one always assumes the one-pion-exchange model, possibly including absorption. This seems reasonable, however, only in the low t region. Thus the analysis of high t region performed in Ref. [5] was possible only thanks to the polarized target data. However, usefulness of the polarization information goes beyond this point.

The data in Fig. 4a and 4b represent the ratio $|g/h|$ of the nucleon transversity amplitudes for P_0 and D_0 partial waves of $\pi^+\pi^-$ system in the reaction $\pi^- p \to \pi^+\pi^- n$ on polarized target at 17.2 GeV/c. We can see that $|g/h|$ is fairly constant in the P_0 and D_0 resonance regions (i.e. ϱ and f).

The simplest solution to the equation $|g/h| = \text{const}$ is $n = Cf$ with a mass independent complex constant C. It is clear that other solutions involve complicated interdependence of phases and moduli of f and n amplitudes which is unlikely to happen accidentally. The solution $n = Cf$ has also a virtue of being phenomenologically interpretable. Unnatural

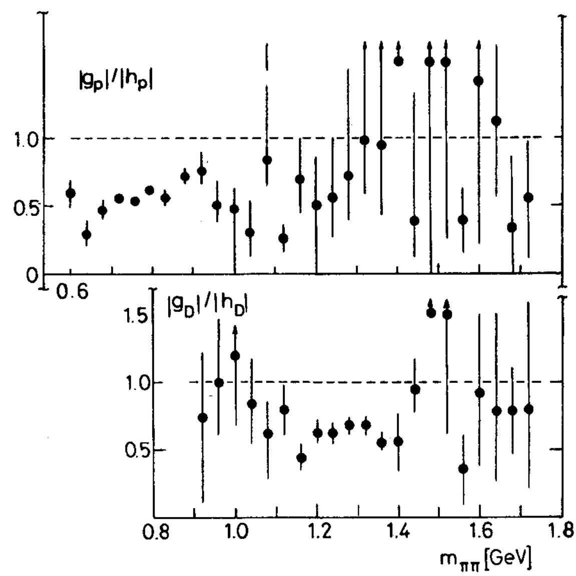

Fig. 4. $|g/h|$ ratio for $0.005 < |t| < 0.2\ \text{GeV}^2$ reproduced from Ref. [2]. a) P_0 wave, b) D_0 wave

parity non-flip amplitude n can be ascribed to the A_1 exchange [8]. The processes $\pi\pi \to \pi\pi$ and $\pi A_1 \to \pi A_1$ dominated by the same resonance R should have proportional amplitudes (when integrated over the momentum transfer). The proportionality factor C in general will depend on $R - A_1 - \pi$ and $R - \pi - \pi$ coupling constants $g_{RA_1\pi}$, $g_{R\pi\pi}$ as well as on a phase induced by the production mechanism. The Regge pole model [8] predicts C to be almost purely imaginary. The P_0 and D_0 waves in their resonance regions exhibit indeed such a simple behaviour.

This simple picture extends to the case when two isoscalars belonging to the same $SU(3)_f$ multiplet mix in some mass region. The $|g/h|$ ratio should remain constant as the ratio $g_{RA_1\pi}/g_{R\pi\pi}$ is independent of the $SU(3)_f$ mixing angle.

It seems to us that the precision measurement of the $|g/h|$ ratio might be a tool for detection of unconventional states. An abrupt departure of $|g/h|$ from the typical value equal to ~ 0.6 in the ϱ-region and to ~ 0.7 in the f-region is a signature of an object with nontypical production mechanism, possibly unconventional one. An example can be found even in the present polarized target data [2]. At $m_{\pi\pi} = 1500$ MeV $|g_D/h_D|$ in Fig. 4b shows a strong variation in four 40 MeV bins. It cannot be ascribed to a faulty partial wave analysis as we can trace it directly from the polarized moments of the angular distribution shown in Fig. 5. The above observation corroborates with the evidence for a isoscalar resonance ($m = 1527 \pm 5$ MeV, $\Gamma = 101 \pm 13$ MeV) produced in $\bar{p}n$ annihilation at rest (Gray et al., [15]). The authors of Ref. [15] cautiously suggest $J^{PC} = 0^{++}$ assignment not excluding however $J^{PC} = 2^{-+}$.

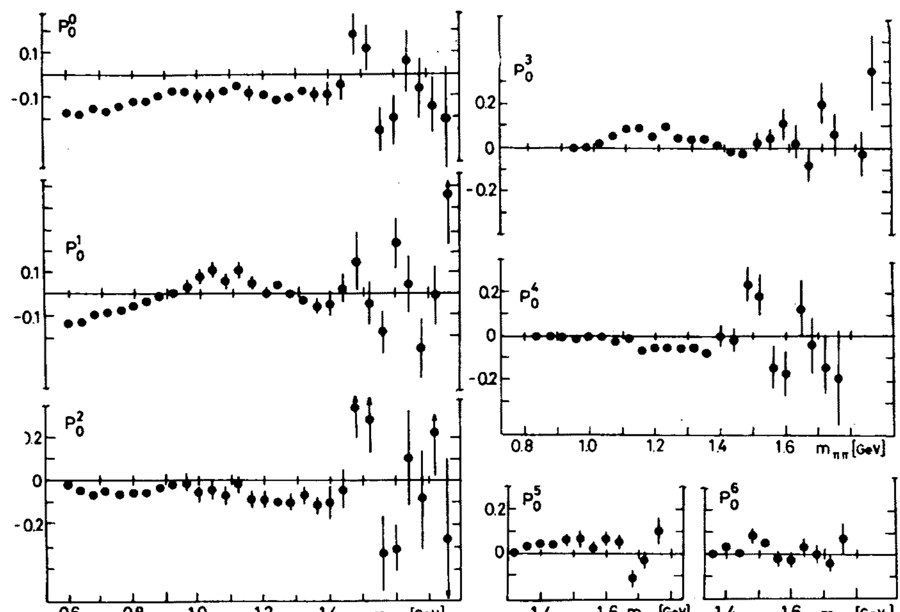

Fig. 5. Polarized moments p_0^l of the angular distribution for a system produced in $\pi^- p_\uparrow \to \pi^+\pi^- n$ reaction at 17.2 GeV [2] for $0.005 < |t| < 0.2$ GeV^2. The moments are defined as $p_0^l = \langle \mathrm{Re}\, Y_0^l(\cos\theta, \varphi) \cos\psi \rangle$ where ψ is polarization angle

4. Conclusions

(*i*) The partial wave analysis of the reaction $\pi^- p_\uparrow \to \pi^+\pi^- n$ for $0.2 < t < 1.0\ \mathrm{GeV}^2$ indicates a resonant structure in the S wave which is different from that observed in the low momentum transfer region i.e. $\varepsilon(1300)$. It can be parametrized by the Bieit-Wigner formula with $m \sim 1280$ MeV and typical hadronic width $\Gamma \sim 130$ MeV.

(*ii*) G(1280) does not seem to be produced neither by π nor by A_1-exchange. We tentatively propose the hybrid meson trajectory and unconventional interpretation for the new resonance (scalar gluonium, scalar hybrid meson).

(*iii*) Precision measurement of the $|g/h|$ ratio might be a tool for detecting unconventional mesons in the exclusive processes.

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