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OBSERVATION OF THE SCALAR MESON AT 1260 MeV IN THE REACTION $\pi^- p \to \pi^+\pi^- n$ AT 17.2 GeV/c

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Abstract

A 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 well fitted by the Breit-Wigner formula. A fit to low and high $|t|$ S-wave needs a new object which we call G (1260) with a width of (160±10) MeV in addition to a broader ε (1300) resonance. Unusuel production properties of the former are tentatively explained in terms of a hybrid meson trajectory. An importance of the polarized target information is also discussed.

1. Introduction

After ten years of the high statistics studies of the 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 $\varepsilon(1300)$, $S^*(980)$, $\varkappa(1350)$ and $\delta(980)$, can be understood as conventional $q\bar{q}$ states. However, the understanding is rather qualitative than quantitative (cf. Fig. 1a). Moreover, unconventional states gg, $qq\bar{q}\bar{q}$, $q\bar{q}g$ 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 [illegible] $\to \gamma X$. 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 a polarized target information shed a new light.

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 a two-resonance fit to the low and high momentum transfer S wave is described. In Section 4 we discuss the importance of the polarized target data. The paper is closed by conclusions in Section 5.

2. Discussion of S wave at high four momentum transfer

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

$$\pi^- p_{\uparrow} \to \pi^+\pi^- n \qquad (1)$$

at 17.2 GeV/c for the nucleon momentum transfer $0.2 < |t| < 1.0$ GeV^2 have been published [5]. 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 $0.2 < |t| < 1.0$ GeV^2 obtained in Ref. [5]. For comparison the S wave intensity for $0.005 < |t| < 0.2$ 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 $0.005 < |t| < 0.2$ GeV^2 region (as in Fig. 1a) extrapolated to the $0.2 < |t| < 1.0$ GeV^2 region assuming dominance of the π-trajectory. Namely we use the formula

$$\frac{d\sigma_0^L}{dt} \propto -\frac{t}{(t-\mu^2)} e^{A(t-\mu^2)} \qquad (2)$$

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 - 7.5) GeV^2 has been taken from the fits to $\pi^+\pi^-$ data of CERN-Munich group [6]. Two following observations are in order:

i) The resonant structure produced in the higher $|t|$ region is different from $\mathcal{E}$ (1300) known from the studies at the low momentum transfer (cf. Particle Data Group [7]). The structure is much more narrow, shifted to lower masses and, above all, consistent with the Breit-Wigner shape.

ii) The exchange of π-trajectory is not the dominant production mechanism for the new resonance. Around 1450 MeV the S wave intensity falls with t about two times slower than the above formula predicts. This is also seen in Fig. 2 showing relative intensities i.e. fractions of total intensity as a function of $\sqrt{-t}$ for the mass interval (1450 - 1500) 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 idependently of t.

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

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

where A_1 and π denote the appropriate exchange amplitudes. In Fig. 3 the t dependence of the polarization for P_c wave in the mass region is shown to be practically flat implying $A_1 \sim \pi$. The detailed Regge-pole analysis [10] of the polarized target data in the $\mathcal{E}$ mass region (for 1.35 [illegible]) [illegible] the same conclusion.

Thus in order to explain the S wave [illegible] MeV for $|t|>0.2$ GeV^2 we propose to [illegible] unnatural trajectory to the [illegible] of A_1 [illegible] hybrid states [11] [illegible] very high [illegible] with the intercept comparable to that of π [illegible]. The hybrid meson trajectory [illegible] the conventional one due to the stronger [illegible] [12]. If we assume $\alpha'_{q\bar{q}g} = 0.5$ GeV^{-2} [illegible] 0^{-+} and [illegible] 1^{++} hybrid meson ground [illegible] predicted by the theory [11, 13] then [illegible] trajectories will have intercepts comparable [illegible] trajectory. Thus unnatural parity [illegible] competitive with the conventional [illegible] tions of matter be concerned.

In addition we [illegible] the available data on S wave between 1100 and 1500 [illegible] assuming two resonances with the different production mechanism.

5. Fit to the S wave

The following [illegible] are used in the fit:

i) There are two [illegible] resonances which will be called henceforth [illegible] described by [illegible] Breit-Wigner formula.

ii) There are two different production mechanisms:

a) [illegible] conventional π, A_1 trajectory [illegible] in the relative

$$n = -i r f \qquad (4)$$

for nucleon non-flip (n) and flip (f) amplitudes. The parameter r is set to -0.2 by the typical polarization at $|t| < 0.2\ \text{GeV}^2$.

2) The contribution of the unconventional trajectories. Without a particularly good reason we set

$$n' = -i r' f' \qquad (5)$$

where n' and f' are unconventional non-flip and flip amplitudes. Parameter r' is free. The phase between f and f' amplitudes is also a free parameter of the fit. Thus, our ansatz for nucleon flip (non-flip) amplitude is as follows

$$f = c_1 BW(\varepsilon) + R e^{i\phi} c_2 BW(G)$$

$$n = -i\left(r c_1 BW(\varepsilon) + R r' e^{i\phi} c_2 BW(G)\right)$$

The parameter R has been introduced to account for different t dependence of the conventional and unconventional production mechanisms. By definition it is equal to unity in the higher t region.

In our fitting procedure we take into account the following data in the mass region between 1090 and 1500 MeV:

1) The S wave intensity at low four-momentum transfer, i.e. $|t| < 0.2\ \text{GeV}^2$ from Ref. [2] (see Fig. 1a).
2) The S wave intensity at $0.2 < |t| < 1.0\ \text{GeV}^2$ from Ref. [5] see Fig. 1b).
3) The ratio of the nucleon transversity amplitudes $|g_s / h_s| = |n - if / n + if|$ for $0.005 < |t| < 0.2\ \text{GeV}^2$ (shown in Fig. 1c, taken from Ref. 2). This ratio can be measured in experiments on a polarized target. A deviation of this ratio from unity is the signature of the polarization effect appearing when both flip and non-flip amplitudes contribute to the process. In the higher $|t|$ region $|g_s / h_s|$ is too poorly determined to be used in the fit.

The full line in Figs 1a - 1c shows the fit results. Fitted parameters, their values at χ^2 minimum and parabolic errors are given in Table 1. The following comments are in order:

The Breit-Wigner parameters of G (1260) are well defined by the S wave intensity at $|t| > 0.2\ \text{GeV}^2$ showing clearly the resonant structure with a small background. Judging by these values, G (1260) might be identical to g_s (1240) isoscalar resonance observed in $\bar{K}K$ experiments [14], with the following parameters:

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

It should be also mentioned that in studies of the reaction $\pi^- p \rightarrow K^0_S K^0_S n$ [16, 17] a flatter t dependence of the $K^0_S K^0_S$ S wave was observed around 1300 MeV than near the threshold. 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.

In our two component fit ε (1300) appears as a Breit-Wigner resonance with a resonable hadronic width ~ 200 MeV. Thus apparent large width of the resonant structure at low t would be simply due to $G - \varepsilon$ interference. We are tempted to suggest that $\varepsilon(1300)$ is a "normal" $q\bar{q}$ meson while $G(1260)$ might correspond to a low-lying gluonium or hybrid state. As seen from Table 1, the coupling of $G(1260)$ to a $\pi^+\pi^-$ channel is only twice smaller than that of $\varepsilon(1300)$.

4. Importance of polarization data

In an absence of 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 an 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 far beyond this point.

The ratio $|g_s / h_s|$ is poorly determined and one might wonder whether it is justified to bother at all with such intricacies of the production mechanism. However, as explained below this may reach beyond interpretation of these particular data.

In spite of the large errors the $|g_s / h_s|$ ratio is consistent with the following trend. At the low mass ($m \simeq 700$ MeV) this ratio is close to 0.6, then $|g_s / h_s|$ exceeds the value of 1.0 around 1100 MeV and finally comes back to $\simeq 0.7$ around $m_{\pi\pi} = 1500$ MeV (see Fig. 4a). This tendency should be contrasted with the fairly constant $|g / h|$ ratio for the P_0 and D_0 waves in the relevant resonance regions (ρ and f) cf. Fig. 4b and 4c).

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 parity non-flip amplitude n can be ascribed to the A_1 exchange [6]. 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-π and R-π-π 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. In particular, in the whole $S^* - \varepsilon$ region $|g_s / h_s|$ should remain constant unless a third object interferes, as our data seem to suggest.

Let us make a more general remark. 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 ~ 0.5 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. Another example can be found even in the present polarized target data [2]. At $m_{\pi\pi} = 1500$ MeV $|g_D / h_D|$ in Fig. 4c 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 $J^{PC} = 2^{++}$.

5. Conclusions

i) The partial wave analysis of the reaction $\pi^- p_\uparrow \to \pi^+\pi^- n$ for $0.2 < |t| < 1.0$ GeV^2 shows a resonant structure in the S wave which can be parametrized by the Breit-Wigner formula with $m = (1260 \pm 20)$ MeV, $\Gamma = (160 \pm 10)$ MeV. Such an object can be incorporated in the description of the low t S wave in addition to a "normal" but relatively narrow $\varepsilon(1300)$.

ii) G (1260) is 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.

Acknowledgments. The authors are much indebted to the colleagues from the CERN-Munich group for a kind permission to use their data.

REFERENCES

[1] N.M. Cason et al.: Phys. Rev. D28, 1586 1983

[2] H. Becker et al.: CERN-Cracow-Munich Coll. : Nucl. Phys. B151, 46 1979

[3] N.A. Törnqvist: Phys. Rev. Lett. 49, 624 1982

[4] F.E. Close: Rutherford Lab. preprint RL-83-090

[5] H. Becker et al.: CERN-Cracow-Munich Coll. : to be published

[6] B. Hyams et al.: Phys. Lett, 51B, 272 1974

[7] M. Roos et al.: Particle Data Group : Phys. Lett. 111B, 1982

[8] A.C. Irving, R.P. Worden: Phys. Rep. 34C, 117 1977

[9] H. Becker et al.: Nucl. Phys. B150, 301 1979

[10] I.SSakrejda, J, Turnau: Acta Phys. Pol. B12, 305 1981

[11] M. Chanowitz, S. Sharpe: Nucl. Phys. B222,2211 1983

[12] T.M. Cho, W. Weinzierl: preprint PAR LPTHE 81/10 1981

[13] M. Chanowitz, S. Sharpe: LBL preprint LBL-16489 1982

[14] A. Etkin et al.: Phys. Rev. D25, 2446 1982

[15] Gray et al.: Phys. Rev. D27, 307 1983

[16] N.M. Cason et al.: Phys. Rev. Lett. 36, 1485 1976

[17] V.A. Polychronakos et al.: Phys. Rev. D19, 1317 1979

TABLE I

Results of the fit to the S wave

Parameter	Value	Parabolic error
m_{ε} MeV	1258	20
Γ_{ε} MeV	220	18
m_{G} MeV	1260	23
Γ_{G} MeV	156	10
c_1 $ub^{1/2}$	1.12	0.03
c_2 $ub^{1/2}$	0.56	0.02
r'	0.36	0.12
R	0.30	0.01
ϕ [deg]	-154	2

Figure captions

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] . Full line is the result of the fit described in the text. 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] . Full line is the result of the fit described in the text, dotted 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

(c) $|g_s / h_s|$ ratio for $0.005 < |t| < 0.2$ GeV^2 reproduced from Ref. [2] . The full line is the result of the fit desribed in the text

Fig. 2. Relative intensities of main partial waves as a function of four-momentum transfer for 1150 MeV $< m_{\pi\pi} <$ 1400 MeV

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

Fig. 4. $|g / h|$ ratio for $0.005 < |t| < 0.2$ GeV^2 reproduced from Ref. [2] . a) S wave, b) P_o wave, c) D_o wave

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

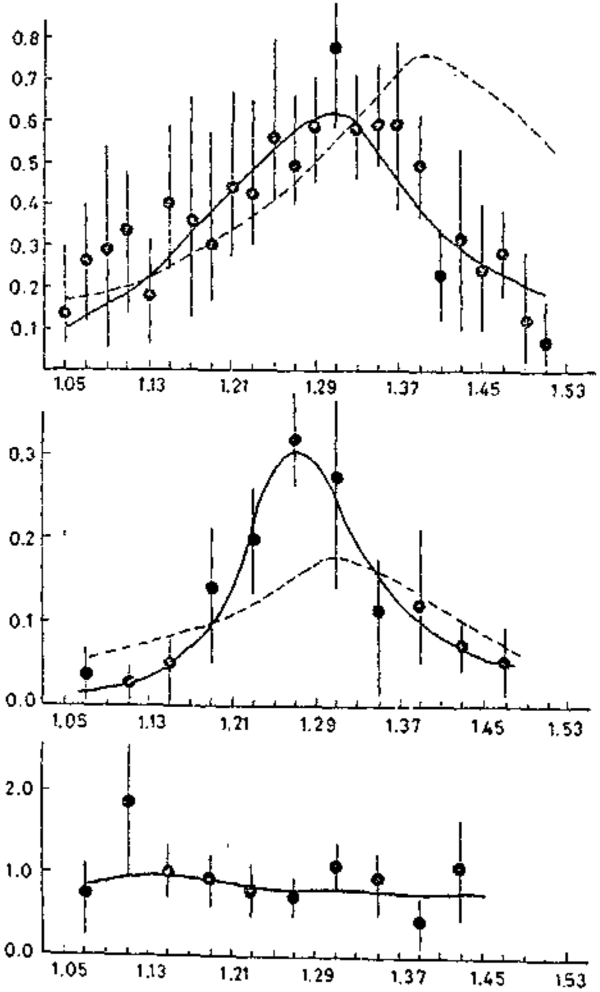


Fig. 1 a,b,c

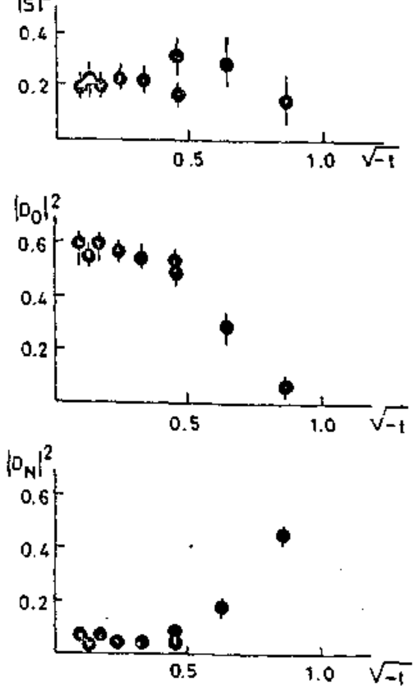


Fig. 2

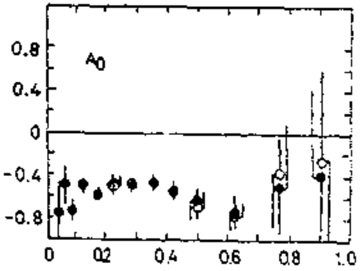


Fig. 3

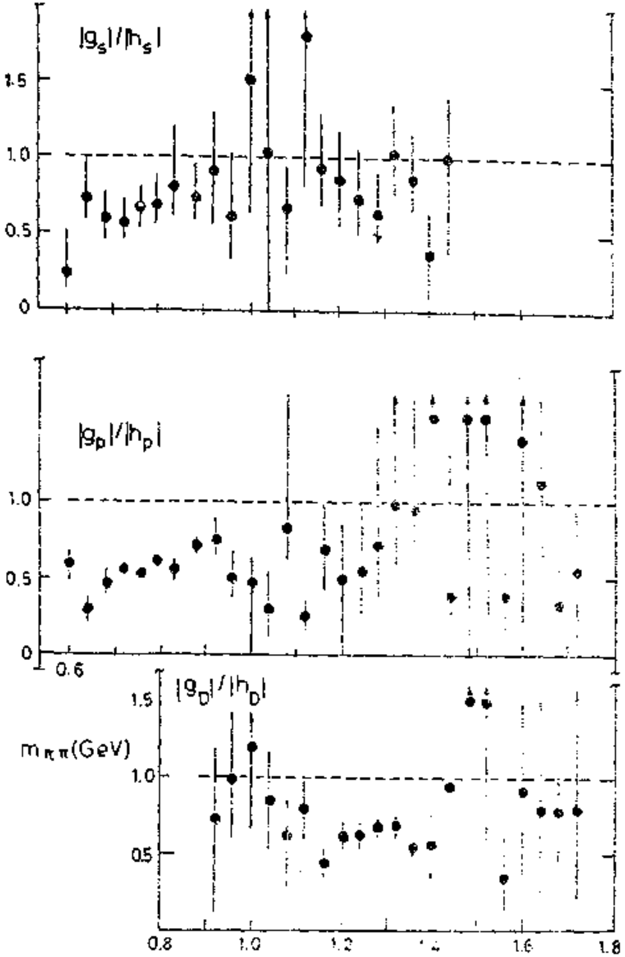
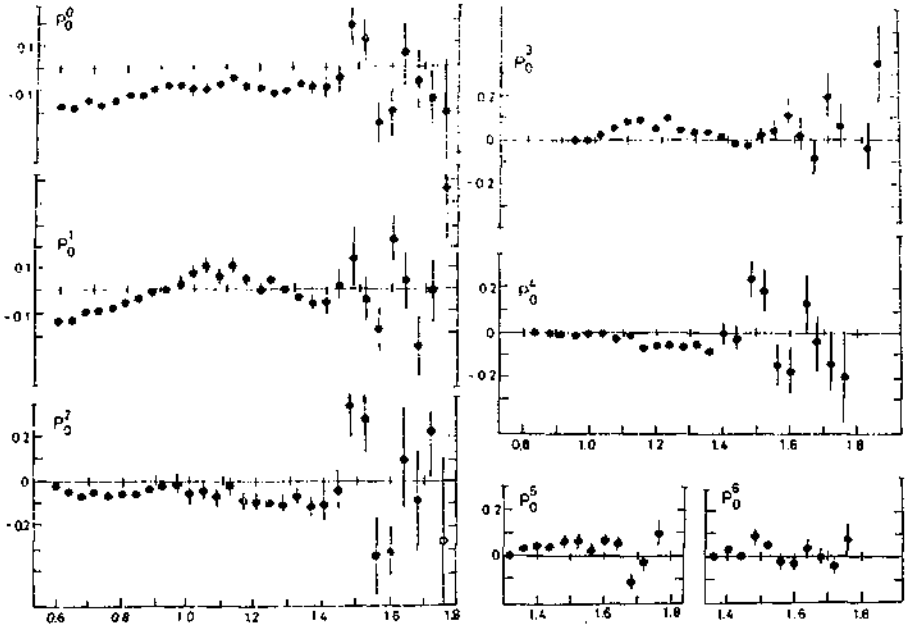


Fig. 4 a, b, c

P_0^0
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-0.1
P_0^1
0.1
-0.1
P_0^7
0.2
0
-0.2
0.6
0.8
1.0
1.2
1.4
1.6
1.8
P_0^3
0.2
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-0.2
P_0^4
0.2
0
-0.2
0.8
1.0
1.2
1.4
1.6
1.8
P_0^5
0.2
0
1.4
1.6
1.8
P_0^6
1.4
1.6
1.8

Fig. 5.