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Measurement of the analyzing power A_{y0} for the reaction H$(\vec{p},d)\pi^+$ between 1000 and 1300 MeV

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The analyzing power A_{y0} of the reaction H$(\vec{p},d)\pi^+$ has been measured at a fixed value of the Mandelstam variable $u_d = -0.17\,\text{GeV}^2$ for nine proton energies between 1000 and 1300 MeV. The experiment was performed at SATURNE with the SPES1 spectrometer. The data exhibit structure around $\sqrt{s} \simeq 2.37\,\text{GeV}$. The origin of this structure could be related to a resonancelike behavior of the ^1S_0P or ^1G_4F partial amplitudes. [S0556-2813(97)00712-7]

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The reaction H$(p,d)\pi^+$ and its inverse have been studied extensively both theoretically and experimentally over the last two decades [1].

On the theoretical side, this process is included in a more general study of the πNN system. The unitary model [2,3] describes the processes $\pi d \rightarrow \pi d$, $pp \rightarrow d\pi^+$, and $NN \rightarrow NN$ in a coupled-channels framework. However, this model does not take into account multipion production and therefore is restricted to energies below about 800 MeV. Other relativistic approaches have been developed for low energies [4] ($T_p \leqslant 800\,\text{MeV}$) or for high energies [5] ($1200 \leqslant T_p \leqslant 2100\,\text{MeV}$), but no theoretical model can reproduce the very precise data which exist over a large energy range.

An alternative procedure for interpreting the data is to reconstruct the helicity amplitudes [6] or to extract the dominant partial amplitudes [7,8]. The most recent partial-wave analysis [8], which included all existing data from threshold up to 1380 MeV, permitted extraction of the first 15 partial-wave amplitudes (corresponding to total angular momentum $J \leqslant 4$). These amplitudes are conveniently available via the interactive code SAID [8].

The data for various observables exhibit apparent structure at different energies which, if confirmed, might be connected with possible dibaryon resonances. Of particular interest to us here is structure previously identified around $\sqrt{s} \simeq 2.4\,\text{GeV}$. A broad structure was found in this region in the ratio $R = \sigma(0°)/\sigma(30°)$ [9]; it is not reproduced by the partial-wave analysis [8]. One can comment that the cross section at 0° had to be extrapolated from data measured at larger angles. Another possible experimental signature of a structure in this energy region is a plot of the energy dependence of it_{11} at $\theta_{\text{c.m.}}(\pi) \simeq 40°$ [10–12]. A very sharp spike in the value of it_{11} is observed. There are large discrepancies between the partial-wave analysis of Ref. [8] and this data set.

Measurements of A_{y0} have also been performed by several groups [13–17]. A broad structure is observed near $\sqrt{s} \simeq 2.4\,\text{GeV}$ when the data are plotted at a value of the Mandelstam variable $u_\pi \simeq 0$. This bump corresponds to a maximum of A_{y0} near $\theta_{\text{c.m.}}(d) \simeq 105°$ (corresponding to $u_\pi \simeq 0$ for $T_p \simeq 1150\,\text{MeV}$). The SAID predictions (version SP96) qualitatively reproduce this structure.

These data were taken in large energy steps; no data exist for A_{y0} between 1050 and 1200 MeV. We report here new measurements of A_{y0} between 1000 and 1300 MeV in steps of 25–50 MeV, at $u_d \simeq -0.17\,\text{GeV}^2$, a region where no structure is predicted by the phase shift analysis. This value of u_d corresponds to $\theta_{\text{c.m.}}(d)$ around 90° where some partial-wave amplitudes vanish [3], so that the analysis and interpretation of the data should be easier.

The experiment was performed using the polarized proton beam ($\simeq 5\times10^{10}$–2×10^{11} protons/burst) delivered by the synchrotron at the Laboratoire National Saturne. The polarization of the incident proton was measured using the high energy polarimeter of SATURNE with an absolute precision of better than 2% [18]. Typical polarizations of 70–80 % were obtained. The cylindrical liquid hydrogen (LH_2) target was 11 cm long, with a 150-μm Mylar window fixed to a ring of aluminum at the entrance.

Deuterons were detected in the front part of the POLDER polarimeter [19] placed in the focal plane of the SPES1 spectrometer. The primary goal of this experiment was to obtain tensor polarizations and spin transfer coefficients by measuring the polarization of the recoil deuteron from the H$(\vec{p},\vec{d})\pi^+$ reaction [20]. The analysis of the polarization data will be reported elsewhere [21]. The detection system consisted of two scintillators (S_1 and S_2), 10 and 8 cm in diameter, respectively, placed near the focal plane of the spectrometer and used to trigger the acquisition system. Two multiwire chambers were placed close to S_1 and S_2 to reconstruct the trajectory of the detected deuteron.

A monitor near the target in the horizontal plane was used to measure the relative intensity of the beam for each state of

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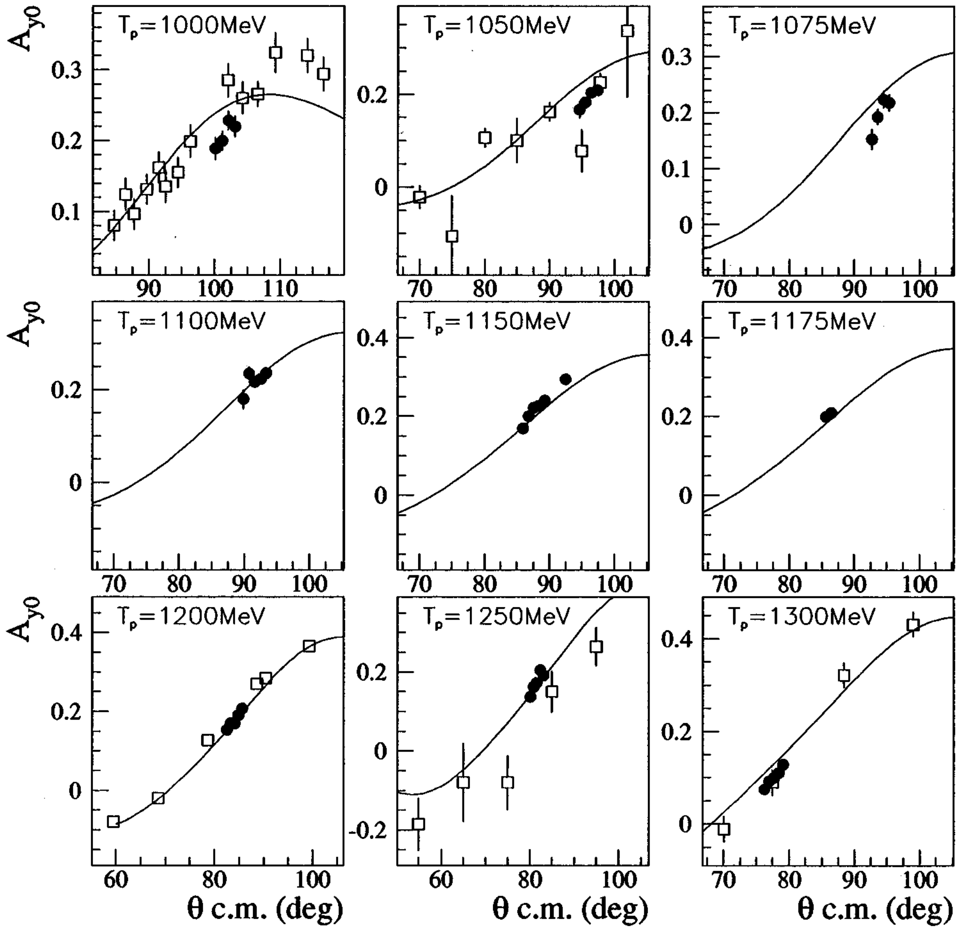

FIG. 1. Our results (circles) for all the energies are compared to previous data (squares [13–17] and triangles [15]). The solid line corresponds to the predictions given by the SAID program (SP96 solution).

polarization. A small asymmetry (average about 2%) was observed between the counting rates in the monitor for the two beam states, arising from the integrated analyzing power for all detected particles. For data points measured at the same energy, the relative systematic error in A_{y0} is estimated at less than 1%, based on the dispersion of the measured asymmetries of the monitor around the average value. The systematic error in the measured energy dependence of A_{y0}, is primarily determined by the uncertainty in the polarization of the beam, which, as mentioned above, is less than 2%.

The center-of-mass angle of the scattering was reconstructed using the measured momentum of the deuteron; this determination does not require knowledge of the spectrometer angle setting. Effects of energy loss in the target were included. Good precision on the angle determination was obtained thanks to the small total acceptance in momentum (0.8%) and to the kinematics of the reaction $[75° \leqslant \theta_{\mathrm{c.m.}}(d) \leqslant 105°]$.

Time-of-flight and energy loss measurements were used to eliminate background. The remaining background was always much less than 0.5% of the peak. Uncertainties in the background subtraction make a negligible contribution to the uncertainty in the energy or angle dependence of A_{y0}.

The analyzing power A_{y0} is deduced from the equation

$$A_{y0}=\frac{1}{p_y}\frac{N_2-N_3}{N_2+N_3}, \tag{1}$$

where p_y is the polarization of the incident proton beam. N_2 and N_3 are the dead-time-corrected total numbers of deuterons detected for spin-up (2) and spin-down (3) states of the incident protons.

Data have been measured at nine different energies and several angles which cover the kinematical domain around $u_d = t_\pi \simeq -0.17\ \mathrm{GeV}^2$. In Fig. 1 our data are plotted as a function of $\theta_{\mathrm{c.m.}}(\pi)$ and compared with other experiments [13–17]. The solid lines represent the result of the partial-wave analysis (version SP96) from SAID [8].

As can be seen, our data have lower values than those of Ref. [13] for 1000 MeV, but are in fair agreement at 1050 MeV with the more precise data of Ref. [14]. No previous data are available between 1050 and 1200 MeV. Good agreement is obtained with data of Refs. [16] and [17] for 1200 and 1300 MeV. Data from Ref. [15] disagree with our data at 1050 and 1250 MeV and also with those from Ref. [14] at 1050 MeV. The SAID predictions [8] overestimate our data between 1000 and 1075 MeV.

Figure 2 shows the energy dependence of A_{y0} for $u_d = -0.17\ \mathrm{GeV}^2$ between 800 and 1300 MeV. The experimental values shown were interpolated from the data of Fig. 1. Separate (linear) interpolations were made from the different data sets. The linear dependence agrees with the SAID prediction for such a small range of center-of-mass angles (or u_d variable). The solid curve represents the result of the partial-wave analysis from SAID.

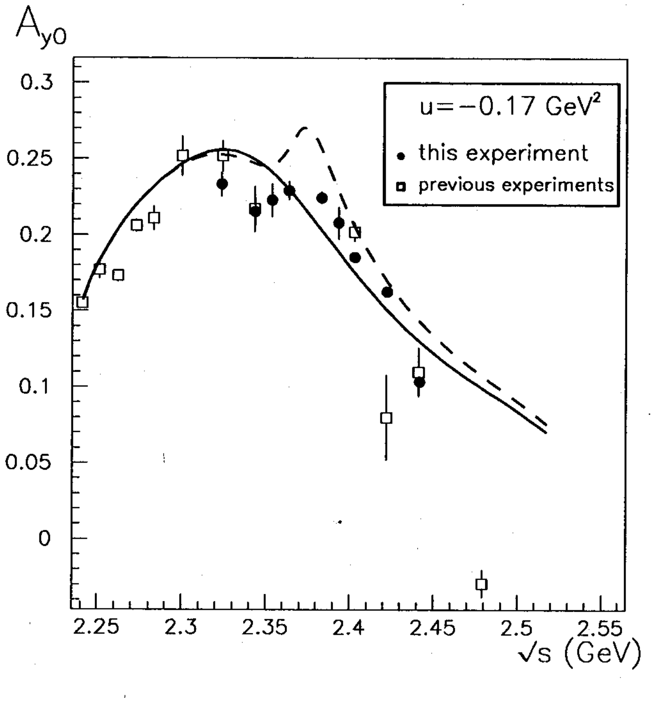

FIG. 2. Energy dependence of A_{y0} at $u=-0.17\,\mathrm{GeV}^2$ from all existing data [13–17]. The solid line corresponds to predictions from SAID program (SP96 solution). Our data (solid circle) exhibit a bump centered around 2.37 GeV. The dashed line is obtained by adding a resonant part in the partial amplitude ${}^1S_0P$.

Our results exhibit possible structure near 1100 MeV (corresponding to $\sqrt{s}\simeq 2.37\,\mathrm{GeV}$) with a relatively small width not explained by the partial-wave analysis. If the first two and the last of the present data points define the ‘‘background’’ values of A_{y0}, the structure is a bump, nicely fitted with a Gaussian shape of width [full width at half maximum (FWHM)] $\simeq 70\,\mathrm{MeV}$. In the absence of definitive knowledge of the ‘‘background’’ values of A_{y0}, it is difficult to estimate the statistical significance of the structure. It might be related to that discussed above in the ratio R and in it_{11}. One can stress that the apparent bump is centered at $\theta_{\mathrm{c.m.}}\simeq 90°$ ($T_p\simeq 1130\,\mathrm{MeV}$ for $u_d=-0.17\,\mathrm{GeV}^2$).

We consider here the hypothesis that the structure is due to an energy dependence of the partial-wave amplitude corresponding to a resonancelike behavior (counterclockwise rotation in the Argand diagram) produced by a pole in the complex energy plane. We used the formalism described in Ref. [22] where the S matrix is composed of a background term S_B and a resonance term S_R which are parametrized as follows:

$$T=e^{2i\delta_B}\frac{\eta_B x}{\epsilon-i}+T_B,$$

$$T_B=\frac{\eta_B e^{2i\delta_B}-1}{2i}, \tag{2}$$

where $x=\Gamma_i/\Gamma$ (Γ_i is the partial width of the channel to be considered and Γ the total width) and $\epsilon=2(M_R-\sqrt{s})/\Gamma$ (M_R is the resonance mass). The background amplitude is taken from SAID (solution SP96). The parameters M_R, Γ, and x are adjusted in order to produce a structure in the A_{y0} experimental data near 2.37 GeV. In a second step we compared the resulting calculations of the cross-section ratio $\sigma(0°)/\sigma(30°)$ and the vector polarization it_{11} with the existing data, as shown in Fig. 3.

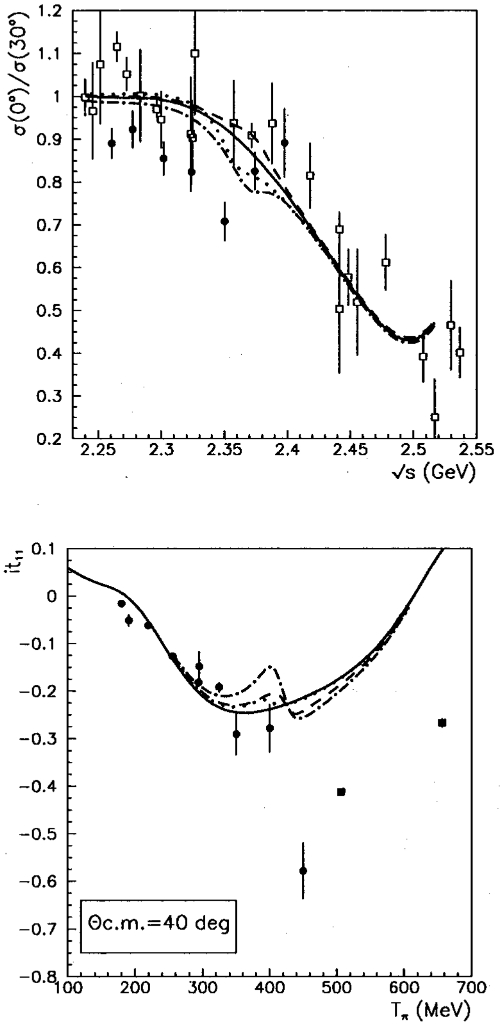

FIG. 3. Results obtained by adding a resonant part in the partial amplitudes ${}^3P_1S$ (dashed line), ${}^1G_4F$ (dotted line), and ${}^3P_1D$ (dash-dotted line) and comparison with the SP96 solution given by SAID (solid line) and with experimental data for it_{11} [10–12] and $\sigma(0°)/\sigma(30°)$ ([9] and references therein).

The main conclusions derived from this analysis are the following.

(i) The partial amplitude ${}^1S_0P$, which is well known to be very sensitive to A_{y0} near 90°, can reproduce a structure in A_{y0} with a small value of x ($\simeq 0.07$) (see Fig. 2). But no significant effects were observed for the two other observables.

(ii) The amplitudes ${}^3P_1S$ and ${}^1G_4F$ can also approximately reproduce the structure in A_{y0} with relatively low $x(\simeq 0.12)$. Λ small effect can also be seen in Fig. 3 for $\sigma(0°)/\sigma(30°)$ and it_{11}. However, these changes certainly do not reproduce the structure apparent in the solid data points there.

(iii) The ${}^3P_1D$ wave can simultaneously both qualitatively reproduce $A_{y0}(90°)$ and significantly affect $\sigma(0°)/\sigma(30°)$ and it_{11}. But this requires a very large partial width ($x \simeq 1$) and strong discrepancies with the well-known cross sections. Strong oscillations would also be expected in the t_{21} deuteron tensor polarization, for example, but no structure is seen in our t_{21} data taken at the same time with POLDER [21].

In conclusion, we have reported in this paper new measurements on the analyzing power A_{y0} near 90°. When plotted as a function of the proton energy at a fixed Mandelstam variable $u = -0.17\ \mathrm{GeV}^2$, these new data provide some evidence of a structure around $\sqrt{s} \simeq 2.37$ GeV with a relatively small width. This apparent structure could have the same origin as the signals already observed in $\sigma(0°)/\sigma(30°)$ and it_{11}. However, an attempt to extract the partial-wave amplitudes which might be responsible for such a structure was not very conclusive.

We have considered a possible resonance in the ${}^1S_0P$ partial-wave amplitude. In the future it would be interesting to study the effect of an intermediate state nucleon+Roper resonance. Indeed, the opening of this channel (for $L=0$) at 2.38 GeV should be dominant in the ${}^1S_0P$ channel.

The ${}^1G_4F$ amplitude also deserves further study. Reference [23] predicted a possible threshold effect of the $N\Delta$ (for $L=2$) at 2.39 GeV and, possibly, in this amplitude. This channel is also interesting if we connect our observation with other signals observed in the coupled NN and πd elastic channels. In the NN channel a structure has been observed in the quantity $k^2 C_{LL} d\sigma/d\Omega$ [24] which may be explained as a resonance in the ${}^1G_4$ partial wave at $\sqrt{s} \simeq 2.43$ GeV. For the elastic πd channel, Ref. [10] reports results for it_{11} which could not be reproduced by conventional models, but could be explained by adding two resonances, a ${}^1D_2$ at 2.2 GeV and a ${}^1G_4$ at 2.48 GeV.

Finally we mention Ref. [25] which proposed several resonant states of πNN or $\pi\pi NN$ in the energy range considered there. At this stage an effect due to the existence of a dibaryon resonance with a unusual quark structure (hidden color, etc.) cannot be rejected, especially if we consider the apparently small width of the experimental signal compared to the widths of the Δ or the Roper. The structure around $\sqrt{s} \simeq 2.4$ GeV continues to be tantalizing and elusive.

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