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FESR ANALYSIS OF BARYON REGGE EXCHANGES IN $K^-p \rightarrow \Lambda\pi^0$ SCATTERING

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FESR and a fit to 5 GeV/c data are used to determine residue functions and trajectory parameters of baryon poles governing $K^-p \rightarrow \Lambda\pi^0$ backward scattering. The N_α pole is found to make only a small contribution. In the dip region, all the residues are slowly varying with u and none is vanishing. Nevertheless, the dip is reproduced at the right position, resulting from destructive interference between various pole contributions. Extrapolating the obtained residues, it results that the unwanted parity partners are suppressed by the vanishing of the residues at the appropriate positive values of u.

1. *Introduction*

Much effort has been devoted in the past to the study of baryon Regge exchange in various meson-baryon scattering processes. However, progress in the field was practically brought to a halt because many uncertainties continue to persist. Some of them are generally affecting the Regge model; there is no a priori possibility to determine the number of contributing poles, the precise form of the residue functions is unknown and so is the shape and size of cuts. Baryon exchange brings along the additional problem of McDowell pairs.

Various models, differing in approach, sophistication and number of parameters, have been constructed. However, the best they can yield is a good fit to a limited amount of data, but they can hardly lead to more general conclusions.

It seems, therefore, to be more appropriate to try to extract from the data as much as possible model independent information rather than perform best fits using an ever increasing set of parameters, pertinent to a very particular model.

The present paper is concerned with a FESR analysis of baryon Regge exchanges in backward $K^-p \rightarrow \Lambda\pi^0$ scattering. The advantage of using this particular process is twofold. Firstly, its u-channel is nonstrange and of pure 1/2 isospin, allowing one to study the exchange of trajectories carrying nucleon quantum numbers, while avoiding the diffi-

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culties related to Δ exchange. Secondly, good partial wave analyses exist for this reaction [1, 2].

In Section 2, a set of FESR, nonrequiting knowledge of the annihilation amplitude in the t-channel, is written down and their further use is explained. In Section 3 the input and the results are discussed, the conclusions are summarized in Section 4.

2. *The FESR*

The parity conserving amplitudes, appropriate for reggeization, are [3]:

$$\tilde{F}^{\pm} = \pm A - \left[\sqrt{u} \pm \frac{M+M'}{2}\right] B, \tag{1}$$

$\pm$ being the naturality, A and B the usual invariant amplitudes for $0^-\frac{1}{2}^+ \to 0^-\frac{1}{2}^+$ scattering and M, M' are respectively the nucleon and Λ mass. Apart from the Regge poles (and cuts), the only singularity of these amplitudes is the branch point at $u = 0$.

Despite the apparent nonexistence of McDowell doublets, (in the particle spectrum) little is known about the relative importance of trajectories forming a McDowell pair in the scattering region. In the following, the choice is made to treat the parity partners on an equal basis. This is a useful assumption as far as the analytic properties of the resulting amplitudes are concerned.

Disregarding cuts, the parametrization of the Regge amplitudes is:

$$\tilde{F}^{\pm} = \sum_{i=1}^{r} \gamma_i^{\pm}(\sqrt{u})\, \frac{1+\tau_i e^{-i\pi(\alpha_i^{\pm}-\frac{1}{2})}}{\sin \pi(\alpha_i^{\pm}-\frac{1}{2})} \left(\frac{s}{s_0}\right)^{\alpha_i^{\pm}-\frac{1}{2}}, \tag{2}$$

where $\gamma_i(\sqrt{u})$, τ_i, $\alpha_i(\sqrt{u})$ are the residue function, signature factor and trajectory function of the i-th pole, respectively. γ_i and α_i automatically incorporate McDowell symmetry if they are taken as:

$$\alpha_i^{\pm} = \alpha_{si}(u) \pm \sqrt{u}\, \alpha_{ai}(u), \tag{3a}$$

$$\gamma_i^{\pm} = \pm\gamma_{si}(u) + \sqrt{u}\, \gamma_{ai}(u). \tag{3b}$$

In the following it will be assumed, for simplicity, that $\alpha_{ai} = 0$ and $\alpha_{si} = a_i + b_i u$ (linear trajectories).

Because the process $K^-p \to \Lambda\pi^0$ displays no symmetry when interchanging the s and t channels, there is no point in using an energy variable with given crossing symmetry like $(s-t)/2$. Therefore, the energy variable in Eq. (2) is simply s. From the same point of view, there is no loss of information when nonsymmetric integration contours are used for the FESR (Fig. 1) and this fact will be fully exploited.

Adding up and subtracting $\tilde{F}^{\pm}$ and then dividing the result by $\sqrt{u}$ as in Ref. [4], we get two functions suitable for the fixed u FESR. If these functions are multiplied by s^n, the corresponding FESR are subtracted and Eqs. (2), (3) are also used, it yields

$$\int_{N'}^{N''} ds \cdot s^n \operatorname{Im} B = \sum_{i=1}^{r} \gamma_{ai}\tau_i \frac{N''^{\alpha_i+n+\frac{1}{2}} - N'^{\alpha_i+n+\frac{1}{2}}}{\alpha_i+n+\frac{1}{2}}, \tag{4a}$$

$$\int_{N'}^{N''} ds \cdot s^n \operatorname{Im} \left[-A + \frac{M+M'}{2} B \right] = \sum_{i=1}^{r} \gamma_{si}\tau_i \frac{N''^{\alpha_i+n+\frac{1}{2}} - N'^{\alpha_i+n+\frac{1}{2}}}{\alpha_i+n+\frac{1}{2}}, \tag{4b}$$

where s_0 was set equal to 1.

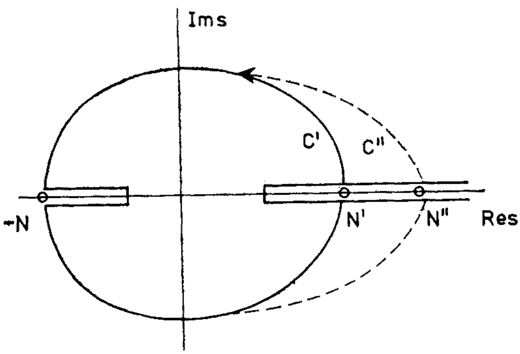

Fig. 1. Integration contour used for the FESR

If N' and N'' are both above the K^-p threshold, phase shifts can be used on the left hand side of Eqs. (4) without any convergence problem. Moreover, the Σ^0 pole does not have to be included.

The sum rules Eqs. (4) require knowledge of the amplitudes on the right hand cut (direct channel) only.

In principle, if there are r contributing poles, taking r different values for n in Eqs. (4) would provide two systems of equations yielding γ_{ai}, γ_{si}. This approach has the short--coming that it increasingly enhances the relative contribution of points close to N'' with greater n. Moreover, because the phase shifts are strongly oscillating at the energies where they are available, the results will be unstable for slight changes of the integration limits N', N''.

Both problems can be circumvented by means of a "statistical" method. For fixed u, e.g. Eq. (4a) may be written as:

$$L(N', N'') = \sum_{i=1}^{r} \gamma_{ai} C_i(N', N''), \tag{5}$$

where, given N', N'', α_i, and τ_i, the coefficients C_i and L are known numbers. Consider now l pairs $(N', N'')_j$ for a single value of n, which we choose to be zero. Then, r numbers γ_{ai} have to be found, allowing the right hand side of Eq. (5), calculated with the j-th set of C_i ($j = 1, \ldots, l$), to become as close as possible to L_j. This can be achieved by performing a least squares linear regression in C_i. Repeated use of these steps for various values of u yields the u dependence of the Regge residues γ_{ai}, γ_{si}.

At the same time it can be found out how well L_j, $\{C_i\}_j$ are correlated by the linear relation Eq. (5). A bad correlation means that additional trajectories have to be added to the right hand side of Eqs. (4).

The method outlined above will be combined with a fit to a differential cross section and polarization at a higher energy. This will yield the residues and the trajectory parameters.

3. *Discussion and results*

The use of low energy phase shifts drastically limits the u range that can be explored. For instance, at c. m. energy of 1.75 GeV u varies from $u_0 = 0.283$ GeV^2 ($\theta = 180°$) to -0.699 GeV^2 ($\theta = 0°$). The use of Eqs. (4) over this whole range means, however, that one has to include the strange meson trajectories expected to dominate the amplitudes in the forward direction. Therefore as we work with baryon trajectories only, in order to keep the number of parameters at a reasonably low value, we expect to obtain reliable values for the residues and a good fit to the data only for $u \geqslant u_{\min} \approx -0.35$ GeV^2.

From the two quoted partial wave analyses that of Ref. [1] was used because it is smoother and therefore better suited for numerical integration.

In the conventional dual framework [5], Regge poles and resonances are considered to give two equivalent descriptions of the imaginary parts of the amplitudes. In practice however, as it is well known, it is difficult to make a clear distinction between resonances and background which is often a superposition of wide, closely spaced resonances. Therefore, in this analysis the full partial wave amplitudes were used. An exception was made for the p waves which are relatively large but contain no resonance in the $\Lambda\pi$ channel [1]. Accordingly, the p waves were set equal to zero in the FESR integrands.

Admiting the poles to be peripheral and neglecting cuts care must be taken in choosing N', N'', in order to avoid regions where the amplitudes are nonperipheral. The analysis [1] finds a nonperipheral s wave resonance $\Sigma(1955)$ having width 170 MeV and coupling 0.08. It follows that N'' must be taken below 1955 MeV. Another s wave resonance is found [1] at 1770 MeV. This state has little influence on the amplitudes since it is very narrow ($\Gamma = 60$ MeV) and has the weakest coupling (0.04) of the whole list. The full s wave is vanishing accordingly between 1770 and 1860 MeV. Between 1860 and 1900 MeV it is much smaller than the d wave. As a consequence, the integration range was taken within the interval 1600–1930 MeV. As expected, the results proved to be stable against displacements of N', N'' to within a few per cent of the full interval.

The free parameters to be determined by fitting the cross sections and polarization at 5 GeV/c [6] and requiring consistency with the partial waves at low energy are the intercepts, slopes and signatures of the Regge trajectories and also the number of trajectories. Because the polarization at 5 GeV/c is nonvanishing [6], as well as at 4.2 GeV/c [7] and because a single pair of parity partners yields no polarization [8], at least two pairs are required.

The quite good fit obtained with two trajectories is shown in Figs. 2, 3. The resulting residue functions are plotted in Fig. 4.

The trajectories are $\alpha_1 = -1.85+1.25u$, $\alpha_2 = -3.52+0.4u$ and are both of even signature. The correlation factors which, as mentioned in Section 2, indicate the consistency with the low energy data, are between 0.9 and 1. Thus, both the right hand side of the

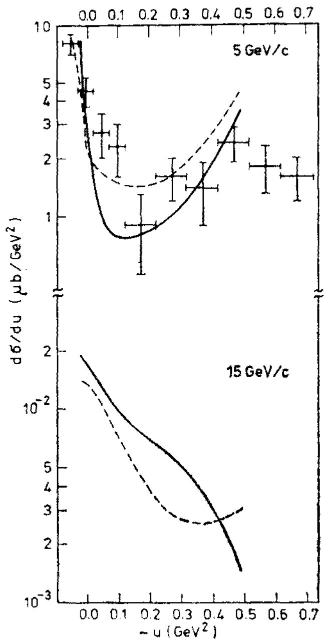

Fig. 2

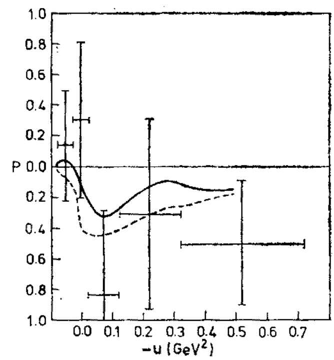

Fig. 3

Fig. 2. $K^-p \to \Lambda\pi^0$ backward differential cross sections at 5 GeV/c. Data points are from Ref. [6]. ---- without N_α, ——— N_α included

Fig. 3. $K^-p \to \Lambda\pi^0$ polarization near the backward direction at 5 GeV/c. Data points are from Ref. [6]. ---- without N_α, ——— N_α included

FESR and the data at 5 GeV/c are practically saturated by the surprisingly low lying trajectories α_1, α_2.

Taking into account N_α as a third trajectory with $\alpha_3 = -0.4+u$ leads to a slight improvement of the fits, especially for the polarization, yielding a small positive polarization near the backward direction. The very good description of polarization strongly supports the subsequent conclusions of this work. Indeed, it is precisely with polarization data that Regge pole models usually run into difficulties.

The N_α residues are small compared to the residues of the other two trajectories and this again indicates that α_1, α_2 nearly saturate the data.

For $u \leqslant -0.45$ the calculated cross sections are too large for both (two- and three trajectory) solutions, which is the expected consequence of neglecting the meson trajectories.

Qualitatively the two solutions offer similar results at 5 GeV/c. At 15 GeV/c however they are quite different, the two trajectory solution displaying a dip while the three trajectory one has a shoulder. Further experimental information is needed to decide which one has the correct behaviour.

It is very interesting that the most prominent feature of the cross section, the dip at $u \approx -0.15\ \mathrm{GeV}^2$, is well reproduced although none of the residues is vanishing at this (or any other) point. Actually, as Fig. 4 shows, for $u \geqslant -0.3$ the residues are rather slowly varying with u. Here the dip results from the destructive interference of the various pole

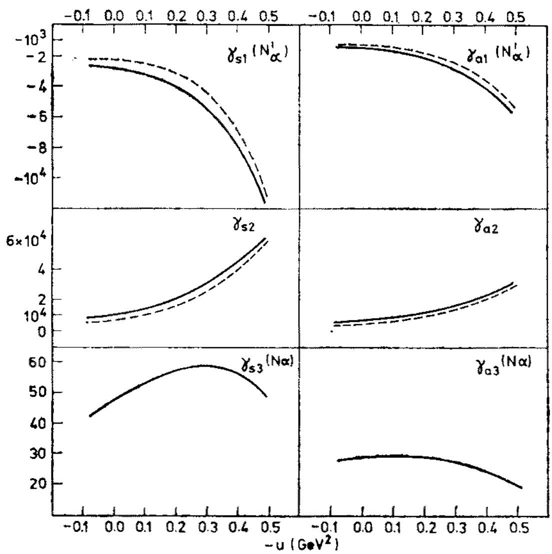

Fig. 4. Residue functions versus u, determined as explained in the text. ---- without N_α, ——— N_α included

contributions. Of course, a dip produced this way will move with energy. Whether it really moves or not is another point to be clarified by further experimental investigation.

Via factorization and SU(3) the above result is also relevant to the dip mechanism in backward πN scattering. It was early recognized that the dip in the charge exchange cross section had another position than the dip in π^+p elastic backward scattering. Later it was found [9] that the position of the πN charge exchange dip is moving with energy. These features are certainly consistent with a mechanism noninvolving a fixed u zero of a residue, like that widely used in pure pole and weak cut models. The first particle on α_1 has spin 1/2 and mass 1370 MeV. It may well be the Roper resonance whose mass is somewhere between 1370 and 1530 MeV [10]. Thus α_1 may be the N'_α trajectory. The first particle on α_2 has spin 1/2 and mass 3160 MeV. There is such a high mass state [10] but its spin and parity are unknown.

Two additional features of both solutions, to be tested by future experiments, are:

— an expanding with energy backward peak,

— a very fast fall-off with energy of the backward cross section, due to the low lying dominant trajectory N'_α. For the three trajectory solution, however, the decrease with energy becomes slower above 9 GeV/c, which is the momentum where N_α becomes dominant because of its higher position. This trend is visible in Fig. 2, where at 15 GeV/c the three trajectory cross section is already higher than the two trajectory one.

For both N_α and N'_α, γ_s and γ_a have the same sign. Because N_α is of positive parity and of even signature, the two terms in Eq. (3b) are additive. For opposite naturality (parity) the two terms will subtract, the unwanted parity partner of the nucleon (which has nucleon mass, as we are working with trajectories even in $\sqrt{u}$) being thus suppressed. For the nucleon, a more quantitative statement is difficult to make because it is not clear how to extrapolate the obtained residues to the positive u region (see Fig. 4). A tentative extrapolation can however be performed for the N'_α residues, as they seem to approach constant values as they enter the positive u region. At the position of the first particle ($\sqrt{u} = 1.37$ GeV) the negative to positive parity residue ratio is 0.09 strongly suggesting that elimination of the negative parity state at this mass occurs through the vanishing of the residue at the right positive value of u. In other words, the structure of the residues of α_1 seems to imply the survival of the positive parity state at 1370 MeV, thus providing additional support to the identification of α_1 with N'_α.

Then, the N_β contribution is not required by our fit. This is in agreement with SU(3) symmetry of the residues and exchange degeneracy in the exotic reaction KN → NK [11].

α_2 also has γ_s and γ_a of the same sign and it was found from the fit to be of even signature. At the position of the first particle on this trajectory ($\sqrt{u} = 3.16$ GeV) the negative to positive parity residue ratio has an extrapolated value of 0.3, suggesting α_2 to carry resonances of positive parity. An extrapolation of this far from u_0 is, however, less reliable.

4. *Conclusions*

The method devised in Secion 2 provides a useful framework to investigate baryon Regge exchange. It allows one to obtain the residue functions and the trajectory parameters and to estimate the number of contributing poles.

It is found that $K^-p \to \Lambda\pi^0$ backward scattering is adequately described by N_α, N'_α (which is the dominant one at 5 GeV/c) and a third, very low lying trajectory. Within the present experimental errors no other trajectories are needed. Moreover, saturation of the FESR by these three trajectories indicates that additional ones will play a minor part even when new, higher statistics experiments will be performed.

In the dip region all the residues are almost constant and definitely do not vanish. The dip is produced by destructive interference between various pole contributions.

It is suggested that a similar dip mechanism is working also in $\pi N \to N\pi$ backward scattering.

The values of the residues seem to indicate that parity partners which are not detected experimentally are eliminated by appropriate zeros of the corresponding residues occurring at the right points.

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