PHYSICAL REVIEW D VOLUME 13, NUMBER 11 1 JUNE 1976

Recent observation of $p+p\to N^*(1688)$ at CERN Intersecting Storage Rings and the nature of the Pomeron singularity*

Bipin R. Desai and Benjamin C. Shen
Department of Physics, University of California, Riverside, California 92502
(Received 23 June 1975; revised manuscript received 26 January 1976)

Recent experimental results on the exclusive reactions $p+p\to p+N^*$ at CERN ISR are analyzed for the case of $N^*(1688)$. The s dependence of the $N^*(1688)$ cross section is compared with that of the elastic and found to be remarkably similar, the σ_{N^*} remaining a constant fraction of σ_{el} up to ISR energies. The interpretation of the data in terms of a bare Pomeron of intercept greater than one is discussed.

Experimental results at CERN ISR on the exclusive reactions $pp\to pN^*$ are now available.[1,2] Since these are the highest-energy measurements so far, it is of great interest to compare them with the lower-energy results and determine, principally, the nature of the Pomeron contribution. We shall concentrate only on the production of $N^*(1688)$ since it is relatively isolated from other resonances and since it suffers the least from the ambiguities of the Deck-type production.

We would like to point out a striking feature of the cross section, σ_{N^*}, for $pp\to pN^*(1688)$. In Fig. 1(a) we have plotted σ_{el} and σ_{N^*} from $s=10$ GeV^2 to $s=3000$ GeV^2. We note that there is remarkable similarity in the s dependence between the two over the entire energy range including ISR. In Fig. 1(b) we have plotted $d\sigma_{el}/dt$ at $t=0$ and compared it with the *extrapolated* value of $d\sigma_{N^*}/dt$ at $t=0$. The similarity is again evident. We note that the extrapolation to $t=0$ for the N^* production is subject to the uncertainty that the true $d\sigma_{N^*}/dt$ may turn around and vanish at $t=0$ (or may sharply rise near $t=0$ as $d\sigma_{el}/dt$). In our opinion, Fig. 1(a) provides more solid evidence in favor of the similarity between the two reactions. The s dependence of the slope parameters of $d\sigma/dt$ is compared in Fig. 1(c) and found to be roughly parallel. This again implies a similar s dependence.

The observation made above suggests that within the currently available experimental accuracy the Pomeron singularity contributes in the same way to $pp\to pp$ and $pp\to pN^*$.

We now consider some of the models for the Pomeron. One alternative that has been proposed is to assume the Pomeron to be a simple pole of unit intercept as far as nonelastic $pp\to pX$ is concerned. This has been the basis of the triple-Regge analysis of inclusive reactions by Roy and Roberts,[4] Field and Fox,[5] and others.[6] Here the rise in the pp total cross section is attributed (partially or wholly) to the summation over the mass of the X system in diffractive $pp\to pX$ and it is proportional to $G_{PPP}(0)\ln\ln s$, where $G_{PPP}(t)$ is the triple-Pomeron coupling. The diffractive resonance production $pp\to pN^*$ is therefore treated on a separate footing from the elastic $pp\to pp$. The former is a part of $pp\to pX$ and is determined by a simple pole of unit intercept and consequently the cross section, σ_{N^*}, is predicted to have the behavior

$$\sigma_{N^*}\propto 1/\ln s\,. \tag{1}$$

Thus σ_{N^*} must decrease for large s. The elastic amplitude, on the other hand, has a different behavior because it is related, through the optical theorem, to the rising total cross section. Indeed, experimentally, the elastic cross section is found *not* to fall in the manner given by (1); in fact it may be slightly increasing.

In order to illustrate the above statements more quantitatively, we compare the ISR data with the predictions of the triple-Regge analysis. To extract information about $pp\to pN^*$ one must use FMSR (finite mass sum rule) and duality. Field and Fox[5] (FF) have investigated this question in detail and have observed that for the case where the triple-Pomeron coupling $G_{PPP}(t)$ does not vanish at $t=0$ (their solution No. 1) it is a consistent possibility for the resonance production to be dual to the combination $PPP+RRR+\pi\pi R$ (extreme abnormal duality). For a vanishing $G_{PPP}(t)$ at $t=0$ (their solution No. 2) the resonance production is dual to an appropriate mixture of PPP and PPR (mixed abnormal duality). In what follows we consider only their solution 1.[7]

One can write down the FMSR for $pp\to pX$, which, as is well known, is meaningful only for the odd moments.[4,5] We will consider only the first moment. For $pp\to pN^*(1688)$ we use duality in a semilocal sense. Thus the interval in $\nu(=M^2-t-m_p^2)$ we choose corresponds to twice the width, i.e., $\Delta\nu=\Delta M^2=(2M_R)(2\Gamma)$. The differential cross section is then given by

$$\frac{d}{dt}(pp\to pN^*)=\frac{2}{s^2}\,\frac{1}{\nu_R}\int_{\nu_1}^{\nu_2}d\nu\,\nu\left[G_{PPP}(t)\left(\frac{s}{\nu}\right)^{2\alpha_P(t)}\nu^{\alpha_P(0)}+G_{RRR}(t)\left(\frac{s}{\nu}\right)^{2\alpha_R(t)}\nu^{\alpha_R(0)}+G_{\pi\pi R}(t)\left(\frac{s}{\nu}\right)^{2\alpha_\pi(t)}\nu^{\alpha_R(0)}\right], \qquad (2)$$

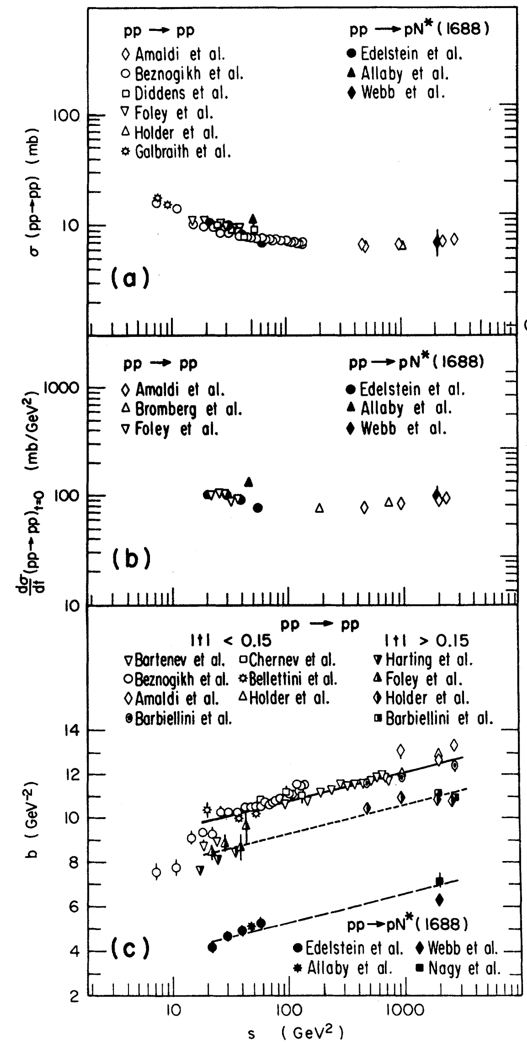

FIG. 1. Comparison of $pp\to pN^*(1688)$ with $pp\to pp$ in (a) cross section, (b) differential cross section at $t=0$, and (c) slope parameter b for $d\sigma/dt \propto e^{bt}$. The solid line corresponds to $b(s)=b_0+2\alpha'\ln s$ with $b_0=8.23$ GeV^{-2} and $\alpha'=0.278$ GeV^{-2} from a fit to $d\sigma_{el}/dt$ for $-t$ <0.15 GeV^2 obtained by V. Bartenev *et al.* [Phys. Rev. Lett. 31, 1088 (1973)]. The dashed lines for $pp\to pp$ with $-t$ <0.15 GeV^2, and $pp\to pN^*$, which are parallel to the solid line, are drawn for the purpose of comparison.

where $\nu_R=M_R^2-t-m_p^2$, M_R is the mass of N^*, $\nu_1=\nu_R-2M_R\Gamma$, $\nu_2=\nu_R+2M_R\Gamma$.

In their analysis, FF considered the ν range corresponding to the entire spectrum of low-mass N^*'s. To verify that our prescription of using semilocal duality in calculating $d\sigma/dt$ for $pp\to pN^*(1688)$ is consistent with FF we compare in Fig. 2(a) the data of Edelstein *et al.*[8] for $pp\to pN^*(1688)$ with the right-hand side of Eq. (2). *All the parameters* used here are those given by solution 1 of FF [in particular, $\alpha_P(0)=1$]. As we see from Fig. 2(a), Eq. (2) is in good agreement with data at $s=57.5$ GeV^2.

We now use the above prescription [Eq. (2)] to analyze the N^* production at ISR where $s\simeq 2000$ GeV^2. At the ISR energies only the G_{PPP} term survives since the R and π intercepts are much lower. Therefore, one has an essentially pure Pomeron term dual to N^* production at ISR energies. In Fig. 2(b) a comparison with the predictions of FF (dashed line) is given. We observe that the FF curve is significantly lower than the experimental data. And the cross section for $pp\to pN^*$ at $s=2000$ GeV^2 obtained with solution 1 of FF is *smaller than the experimental value by a factor of 2.* Thus the triple-Regge analysis with

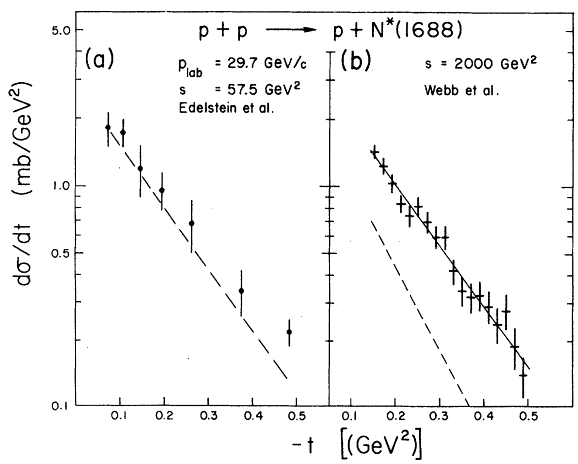

FIG. 2. Differential cross section for $pp\to pN^*(1688)$ at (a) $s=57.5$ GeV^2 (Ref. 8), and at (b) $s=2000$ GeV^2 (Ref. 1). The dashed lines correspond to the triple-Regge prescription [Eq. (2)] with the parameters of FF solution 1 (Ref. 5).

unit Pomeron intercept which does well at lower energies appears inconsistent with the ISR experiment.

It is very important to emphasize here again that the crucial question is the s dependence. For instance, even if one had used another form of duality than the one used above, the prediction regarding the s dependence would remain the same. A Pomeron which is a simple pole of unit intercept would give a very different s dependence for σ_{N^*} from the dependence observed experimentally.

One possible way to remedy the situation, within the unit-intercept scheme for the Pomeron, would be to add to the N^*-production amplitude the appropriate triple-Regge corrections. These correction terms will be proportional to $G_{PPP}{}^2(0)$ [the basic N^*-production amplitude, as discussed earlier, is proportional to $G_{PPP}(0)$]. If necessary, one can continue adding higher-order diagrams involving higher powers of $G_{PPP}(0)$. The same thing, of course, must be done for $pp \to pX$ and, very importantly, for pp elastic scattering also since $pp \to pX$ and $pp \to pN^*$ appear as intermediate states in the elastic amplitude. Such a scheme will clearly lose the simplicity of the initial model. Moreover, there is no guarantee at all that it will reproduce, from low to ISR energies, the experimentally observed σ_{el}, σ_{N^*}, and the total pp cross section.

In view of the foregoing discussions a more appropriate model is, therefore, one that is simple and in which the Pomeron contributes in the same way to the s dependence of σ_{el} and σ_{N^*}, and which, at the same time, correctly describes the rise in the total cross section. There are some potential candidates for such a model.[9,10]

One very interesting possibility is that we are observing at these energies a "bare" Pomeron of intercept *greater* than unity with a triple-Pomeron coupling which does not vanish at $t=0$.[10] Such a possibility is consistent with the strong coupling solution of the Reggeon field theory if one uses a perturbation expansion in powers of the triple-Pomeron coupling. The leading term is then the bare Pomeron pole which at currently available energies is the dominant contributor (at least for small t). The contributions of the leading term to the various amplitudes and the total cross section are of the forms

$$A(pp \to pp) = \beta_1 s^{\alpha_0},$$

$$A(pp \to pN^*) = \beta_2 s^{\alpha_0},$$

$$A(pp \to pX) = \beta_3 s^{\alpha_0},$$

$$\sigma_T \propto s^{\epsilon},$$

where $\alpha_0(t) = 1+\epsilon+\alpha' t$, and $\epsilon > 0$.

A precise determination of ϵ and the various triple couplings requires a detailed analysis of all the available data including the total pp cross section as well as $pp \to pp$, $pp \to pN^*$, and $pp \to pX$ scattering. However, on the basis of the total-cross-section data and elastic scattering Collins *et al.* have obtained $\epsilon = 0.07$ for a Pomeron of slope $\alpha' = 0.22$.[11,12] It would, therefore, be most instructive to obtain an estimate of the triple-Pomeron coupling, G_{PPP}, from the ISR data on $N^*(1688)$ production using formula (2) where because of the high ISR energy involved the RRR and $\pi\pi R$ terms are negligible. Putting $\epsilon = 0.07$ and $\alpha' = 0.22$ in (2) we obtain[13]

$$G_{PPP}(t) = 1.42 e^{2.85t} \text{ mb GeV}^{-2}.$$

We thank A. Kernan for discussions and G. K. Chang for assistance in the data analysis.

*Work supported in part by the National Science Foundation and in part by the U. S. Atomic Energy Commission.

[1] R. Webb, G. Trilling, V. Telegdi, P. Strolin, B. Shen, P. Schlein, J. Rander, B. Naroska, T. Meyer, W. Marsh, W. Lockman, J. Layter, A. Kernan, M. Hansroul, S.-Y. Fung, H. Foeth, R. Ellis, A. Derevshchikov, B. Bozzo, A. Böhm, and L. Baksay, Phys. Lett. 55B, 331 (1975).

[2] E. Nagy, M. Regler, W. Schmidt-Parzefall, K. Winter, A. Brandt, G. Flügge, F. Niebergall, K. R. Schubert, P. E. Schumacher, C. Broll, G. Coignet, J. Favier, L. Massonnet, M. Vivargent, W. Bartl, H. Dibon, Ch. Gottfried, and G. Neuhofer, paper submitted to the XVII International Conference on High Energy Physics, London, 1974 (unpublished).

[3] For a complete list of references of the elastic scattering data, see D. W. G. S. Leith, Proceedings of the 1974 SLAC Summer Institute on Particle Physics, SLAC report (unpublished).

[4] D. P. Roy and R. G. Roberts, Nucl. Phys. B77, 240 (1974).

[5] R. D. Field and G. E. Fox, Nucl. Phys. B80, 367 (1974).

[6] Earlier works are referred to in Refs. 4 and 5 above. Also see V. A. Tsarev, Phys. Rev. D 11, 1864 (1975); 11, 1875 (1975).

[7] The recently revised lower-energy data indicate that solution no. 1 of FF is the only possible solution (see Ref. 5). This also appears to exclude through FMSR the possibility that $d\sigma/dt$ for $pp \to pN^*$ would vanish at $t=0$.

[8] R. M. Edelstein *et al.*, Phys. Rev. D 5, 1073 (1972); J. V. Allaby *et al.* Nucl. Phys. B52, 316 (1973).

[9] There are several models of this type. We name a few:

H. Cheng and T. T. Wu, Phys. Rev. Lett. 24, 1456 (1970); D. Amati, L. Caneschi, and M. Ciafoloni, Nucl. Phys. B71, 493 (1974); J. S. Ball and F. Zachariasen, Phys. Lett. 40B, 411 (1972), J. Arthur, J. Skard, and J. Fulco, Phys. Rev. D 8, 312 (1974); J. B. Bronzan and J. W. Dash, *ibid.* 10, 4208 (1974); 12, 1850 (E) (1975).

[10]For a recent review of the Reggeon calculus results see A. R. White, Fermilab Report No. 74/77 (unpublished).

[11]P. D. B. Collins, F. D. Gault, and A. Martin, Nucl. Phys. B83, 241 (1974). References to their earlier works are given here.

[12]We note that in Ref. 11 the effect of $G_{ppp}(t)$ through $pp \to pX$ was not considered in their analysis of elastic and total cross-section data. However, since $G_{ppp}(t)$ is quite small their analysis of low-t data and, therefore, their determination of ϵ should not be affected by the absence of the triple-coupling corrections.

[13]For comparison we note the following values obtained for the Pomeron with $\alpha_P(0)=1$: $G_{PPP}(t)=6e^{18t}+2e^{3t}$ (Ref. 4) and $G_{PPP}(t)=2.32\,e^{3.94t}+0.33\,e^{1.12t}$ (Ref. 5).