Did the ARGUS group discover a new physical phenomenon in the reaction $\gamma\gamma\rightarrow\rho^0\phi$?

N. N. Achasov and G. N. Shestakov
*Laboratory of Theoretical Physics, Institute of Mathematics, 630090 Novosibirsk 90, Russia **

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The factorization model at high energies gives the estimate for the $\gamma\gamma\rightarrow\rho^0\phi$ reaction cross section in the $W_{\gamma\gamma}$ energy region between 11.5 and 18.4 GeV: $\sigma(\gamma\gamma\rightarrow\rho^0\phi)=1.2\text{–}2.4$ nb. A comparison of this estimate with the recent ARGUS data, $\sigma(\gamma\gamma\rightarrow\rho^0\phi)=0.16\pm0.16$ nb for $3.25\leqslant W_{\gamma\gamma}\leqslant 3.5$ GeV, shows that between 3.5 and 11.5 GeV the $\gamma\gamma\rightarrow\rho^0\phi$ reaction cross section must increase an order of magnitude. A similar increase would be a real challenge for our current knowledge about the dynamics of quasi-two-body reactions and would also signify that in the reaction $\gamma\gamma\rightarrow\rho^0\phi$ at $W_{\gamma\gamma}\approx 3.5$ GeV one is up against a new unknown phenomenon.© *1995 American Institute of Physics.*

The first data on the cross section for the reaction $\gamma\gamma\rightarrow\rho^0\phi$ were recently obtained by the ARGUS group.[1] The measurements covered the $W_{\gamma\gamma}$ interval between 1.5 and 3.5 GeV. According to Ref. 1, the $\gamma\gamma\rightarrow\rho^0\phi$ cross section has a broad maximum in the region of the nominal $\rho^0\phi$ threshold and reaches 2–3 nb. At $W_{\gamma\gamma}>2$ GeV, the cross section decreases smoothly and turns out to be as low as 0.16 ± 0.16 nb at maximum attainable energies $3.25\leqslant W_{\gamma\gamma}\leqslant 3.5$ GeV (see Fig. 1). At high energies, the $\gamma\gamma\rightarrow\rho^0\phi$ cross section can be estimated from the known cross sections of the processes $\gamma p\rightarrow\rho^0 p, \gamma p\rightarrow\phi p$, and $pp\rightarrow pp$ by using the factorization model for the main asymptotic (Pomeron) contributions to the reaction amplitudes. This estimate shows that the cross section for $\gamma\gamma\rightarrow\rho^0\phi$ in the $W_{\gamma\gamma}$ energy region between 11.5 and 18.4 GeV must be about an order of magnitude larger than the ARGUS data for $3.25\leqslant W_{\gamma\gamma}\leqslant 3.5$ GeV.

As is known, when $\sqrt{s}$ is increased from 3.5 to 11.5 GeV, the $\gamma p\rightarrow\phi p$ cross section increases smoothly by a factor of 1.5 (Ref. 2). When $\sqrt{s}$ is increased from 11.5 to 18.4 GeV (this corresponds to the variation of P_{lab} for γ beam from 70 to 180 GeV/c), the $\sigma(\gamma p\rightarrow\phi p)$ value is constant within the experimental uncertainties.[2–4] We note that the reaction $\gamma p\rightarrow\phi p$ is dominated by a so-called pure Pomeron exchange.[5,6] According to the OZI rule, the qqq resonance production at low energies and the ideally mixed f and f' Regge trajectory exchanges at high energies in $\gamma p\rightarrow\phi p$ with $\phi=s\bar{s}$ are forbidden. The $\gamma p\rightarrow\phi p$ reaction therefore exhibits an asymptotic behavior at lower energies than for all other reactions, in qualitative agreement with the dual picture.[5–9] It would be quite reasonable if such a situation could also take place in the reaction $\gamma\gamma\rightarrow\rho^0\phi$. However, the ARGUS data[1] and the factorization model allow us to expect an order-of-magnitude increase of the $\gamma\gamma\rightarrow\rho^0\phi$ reaction cross section in the region $3.5\leqslant W_{\gamma\gamma}\leqslant 11.5$ GeV. Nothing of the kind has yet happened to elastic and quasi-elastic reactions with the Pomeron exchange involving light quarks.

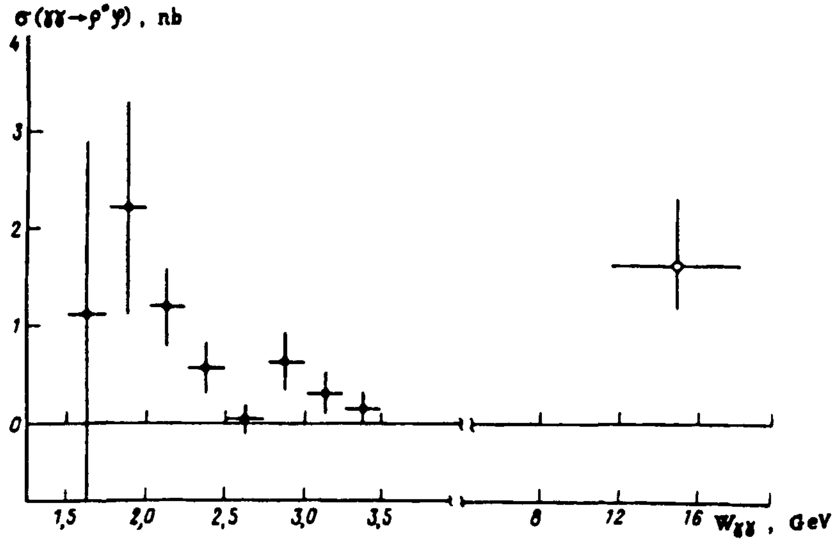

FIG. 1. Cross section for the reaction $\gamma\gamma\rightarrow\rho^0\phi$: the ARGUS data for $1.5\leq W_{\gamma\gamma}\leq 3.5$ (Ref. 1) (●), and the prediction of the factorization model for the high energy region (○).

Let us write the factorization assumption[10,11] for the differential cross section of the reaction $\gamma\gamma\rightarrow\rho^0\phi$. The usual approximation in the small t region, $d\sigma/dt=A\exp(Bt)$ [where $A=(d\sigma/dt)_{t=0}$, and B is the slope of the diffractive peak at $t\approx 0$ (see below)], gives

$$\frac{d\sigma(\gamma\gamma\rightarrow\rho^0\phi)}{dt}=\frac{[d\sigma(\gamma p\rightarrow\rho^0 p)/dt]_{t=0}[d\sigma(\gamma p\rightarrow\phi p)/dt]_{t=0}}{[d\sigma(pp\rightarrow pp)/dt]_{t=0}}\exp(B_{\gamma\gamma\rightarrow\rho^0\phi}t), \tag{1}$$

$$B_{\gamma\gamma\rightarrow\rho^0\phi}=B_{\gamma p\rightarrow\rho^0 p}+B_{\gamma p\rightarrow\phi p}-B_{pp\rightarrow pp}\,. \tag{2}$$

Hence, for the integrated cross section we obtain

$$\sigma(\gamma\gamma\rightarrow\rho^0\phi)=2\times\frac{[d\sigma(\gamma p\rightarrow\rho^0 p)/dt]_{t=0}[d\sigma(\gamma p\rightarrow\phi p)/dt]_{t=0}}{B_{\gamma\gamma\rightarrow\rho^0\phi}[d\sigma(pp\rightarrow pp)/dt]_{t=0}}\,. \tag{3}$$

The factor 2 in Eq. (3) is explained by the two identical Pomeron peaks in the forward and backward directions in the reactions $\gamma\gamma\rightarrow VV'$ [where $V(V')=\rho^0$, ω, ϕ]. In the cases of different vector mesons in the final state we therefore have $\sigma(\gamma\gamma\rightarrow VV')=2\times[d\sigma(\gamma\gamma\rightarrow VV')/dt]_{t=0}/B_{\gamma\gamma\rightarrow VV'}$.

For the estimates we use the available data on the reactions $\gamma p\rightarrow\rho^0 p$ (Refs. 3, 12, and 13), $\gamma p\rightarrow\phi p$ (Refs. 3 and 4), and $pp\rightarrow pp$ (Ref. 7) in the region of P_{lab} from 70 to 180 GeV/c ($11.5\leq\sqrt{s}\leq 18.4$ GeV). It is clearly an asymptotic region in which the

Pomeron contribution dominates and in which the differences in the kinematics of the reactions are negligible. At higher P_{lab} the data for the three reactions are not available simultaneously.

The experimental data on the differential cross sections of the processes $\pi^{\pm}p \to \pi^{\pm}p$, $pp \to pp$, $\gamma p \to \rho^0 p$, $\gamma p \to \phi p$, etc. in a wide range of t $(0<|t|<1\ \text{GeV}^2$, which accounts for virtually the total cross section) are parametrized, as a rule, by the quadratic exponential form,[2,4,7,12] $d\sigma/dt = A\exp(Bt+Ct^2)$. We use the results of such parametrization for the reactions $pp \to pp$ (Ref. 7), $\gamma p \to \rho^0 p$ (Ref. 12), and $\gamma p \to \phi p$ (Ref. 4) and also the parametrization of the form $d\sigma/dt = A\exp(Bt)$, which is appropriate in the small t region[13] $(|t|\leq 0.1\ \text{GeV}^2)$. The slope $B_{\gamma\gamma \to \rho^0\phi}$, which is defined by Eq. (2), therefore applies to $t \approx 0$. As is evident from Eqs. (1) and (3), this slope can be used for all t. At the same time, it is natural to assume that the slope of the diffractive cone in $\gamma\gamma \to \rho^0\phi$ is at a maximum at $t \approx 0$ and decreases with increasing $|t|$, as is the case in other reactions. For example, an observed decrease of the slopes in the reactions $pp \to pp$, $\gamma p \to \rho^0 p$, and $\gamma p \to \phi p$ leads to an increase of the integrated cross sections by 5–10% in comparison with an estimate $\sigma = (d\sigma/dt)_{t=0}/B$ in which the slope at $t \approx 0$ is used. One can hope, therefore, that Eq. (3) with the slope $B_{\gamma\gamma \to \rho^0\phi}$ determined at $t \approx 0$ does not overestimate $\sigma(\gamma\gamma \to \rho^0\phi)$.

If the total cross sections for $\gamma p \to \phi p$ (Ref. 3) and $\gamma p \to \rho^0 p$ (Ref. 3) are available, we can estimate the values of $A = (d\sigma/dt)_{t=0}$ from the relation

$$A = \left(\frac{d\sigma}{dt}\right)_{t=0} = \sigma \times \left(\int_0^{1\,\text{GeV}^2} \exp(Bt+Ct^2)\,dt\right)^{-1},$$

using the central values of the parameters B and C found in other experiments.[4,12,13]

Taking into account all nine possible combinations of the data on the reactions $\gamma p \to \rho^0 p$, $\gamma p \to \phi p$, and $pp \to pp$ in the P_{lab} range from 70 to 180 GeV/c and using Eqs. (2) and (3), we obtain for the $W_{\gamma\gamma}$ energy range between 11.5 and 18.4 GeV the cross section

$$\sigma(\gamma\gamma \to \rho^0\phi) \approx 1.18\text{–}2.36\ \text{nb} \tag{4}$$

and its average value of 1.66 nb (see Fig. 1), which is about an order of magnitude larger than the ARGUS data[1] for $3.25 \leq W_{\gamma\gamma} \leq 3.5$ GeV. A low bound on the estimate (4) is more than the data by 6.4 standard deviations.

We note that an estimate which combines the vector-meson-dominance model with the additive-quark model gives, at high energies, $\sigma(\gamma\gamma \to \rho^0\phi) \approx 4.1\text{–}4.5$ nb and $\sigma(\gamma\gamma \to \rho^0\phi) \approx 2\text{–}2.2$ nb, with the $\gamma - \rho^0$ and $\gamma - \phi$ coupling constants determined from e^+e^- annihilation[14] and photoproduction on nuclei,[2] respectively.

We also provided a comparison of the estimates based on the factorization model for the $\gamma\gamma \to \rho^0\rho^0$, $\gamma\gamma \to \rho^0\omega$, $\gamma\gamma \to \omega\omega$, $\gamma\gamma \to \omega\phi$, and $\gamma\gamma \to \phi\phi$ reaction cross sections at high energies $(11.5 < W_{\gamma\gamma} < 18.4$ GeV) with the data on these reactions for maximum energies.[15] The available experimental results are not yet sufficient to draw definite conclusions from this comparison (because of the difference between the data from the different groups, and because of the experimental uncertainties).

The factorization model is one of the most well-grounded and good working phenomenological models in the high energy physics. An unusually strong increase in the $\gamma\gamma\rightarrow\rho^0\phi$ reaction cross section expected from this model and from the ARGUS data would therefore be a strong challenge for our current knowledge about the dynamics of quasi-two-body reactions. Why is the cross section $\sigma(\gamma\gamma\rightarrow\rho^0\phi)$ so small near 3.5 GeV? Here either we are dealing with a new physical phenomenon or the ARGUS data[1] have been underestimated for some reason. In any case, direct measurements of the $\gamma\gamma\rightarrow\rho^0\phi$ reaction cross section at high energies and a further study of the $W_{\gamma\gamma}$ energy region near 3.5 GeV are extremely important problems. At present, the electron–positron colliders at DESY and at SLAC, and also KEDR at BINP (Novosibirsk), CLEO II at CESR, TRISTAN at KEK, and LEP at CERN have considerable opportunity to extend research into regions above 3.5 GeV.

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*e-mail: achasov@math.nsk.su

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[1] H. Albrecht, H. Ehrlichmann, T. Hamacher *et al.*, Phys. Lett. B **332**, 451 (1994).

[2] A. M. Eisner, in *Proceedings of the International Symposium on Lepton and Photon Interactions at High Energies, FNAL, 1979, Batavia,* p. 448; E. Paul, in *Proceedings of the International Symposium on Lepton and Photon Interactions at High Energies, 1981, Bonn,* p. 301.

[3] R. M. Egloff, P. J. Davis, G. J. Luste *et al.*, Phys. Rev. Lett. **43**, 657 (1979).

[4] J. Busenitz, C. Olszewski, P. Callahan *et al.*, Phys. Rev. D **40**, 1 (1989).

[5] V. Barger and D. Cline, Phys. Rev. Lett. **24**, 1313 (1970); V. Barger and R. J. N. Phillips, Phys. Lett. B **58**, 197 (1975).

[6] C. Quigg and E. Rabinovici, Phys. Rev. D **13**, 2525 (1976).

[7] D. S. Ayres, R. Diebold, G. J. Maclay *et al.*, Phys. Rev. D **15**, 3105 (1977).

[8] H.-J. Behrend, J. Bodenkamp, W. P. Hesse *et al.*, Nucl. Phys. B **144**, 22 (1978).

[9] D. P. Barber, J. B. Dainton, L. C. Y. Lee *et al.*, Z. Phys. C **12**, 1 (1982).

[10] M. Gell-Mann, Phys. Rev. Lett. **8**, 263 (1962); V. N. Gribov and I. Ya. Pomeranchuk, Phys. Rev. Lett. **8**, 343, 412 (1962).

[11] P. G. O. Freund, Phys. Rev. Lett. **21**, 1375 (1968).

[12] D. Aston, M. Atkinson, R. Bailey *et al.*, Nucl. Phys. B **209**, 56 (1982).

[13] T. J. Chapin, R. L. Cool, K. Goulianos *et al.*, Phys. Rev. D **31**, 17 (1985).

[14] Particle Data Group, M. Aguilar-Benitez, R. M. Barnett, C. Caso *et al.*, Phys. Rev. D **50**, 1173 (1992).

[15] D. Morgan, M. R. Pennington, and M. R. Whalley, J. Phys. G: Nucl. Part. Phys. **20**, Suppl. 8A, Data Review, 1A (1994).

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