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* Physical Institute, Yerevan.

Буяк А., Филиппов А.Т., Огиевецкий В.И., Заславский А.Н.

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Спиновые эффекты при очень высоких энергиях и $X\,(960)$-мезон

Обсуждается траектория Редже, на которой может лежать $X\,(960)$ -мезон, если его спин-четность равна 2^-. В этом случае X-траектория имела бы интерсепт $a(0)=1$, как траектория Померанчука. Обмен X полюсом приводит к спиновым эффектам в упругом pp-рассеянии при сверхвысоких энергиях, которые могут объяснить заметные изменения параметра наклона, зарегистрированные недавно в ISR-эксперименте.

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Bujak A., Filippov A., Ogievetsky V., Zaslavsky A.

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Spin Effects at Very High Energies and $X(960)$ Meson

A Regge trajectory is discussed on which the $X^0(960)$ meson can lie if its spin-parity is 2^-. The intercept of this X trajectory would be $a(0)=1$ as for the pomeron. Such a possibility is not excluded by the experimental data available. X pole exchange results in spin effects in elastic pp scattering at very high energies which may explain the marked slope parameter change observed recently in the ISR experiment.

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At present there still exists an uncertainty in the spin-parity assignment of the $X(960)$ meson, its J^P may be equal to 0^- or 2^- /1,2/. We consider a Regge trajectory on which the $X^0(960)$ meson can lie if its spin-parity will be 2^-. Then

$$\alpha_X(t) = \alpha_X(0) + \alpha_X' t ; \qquad 2 = \alpha_X(0) + \alpha_X' m_X^2 . \tag{1}$$

We suppose that the X trajectory has a slope $\alpha_X' \sim 1\,(\mathrm{GeV})^{-2}$ like most other Regge trajectories. Then we obtain from Eq. 1

$$\alpha_X(0) \sim 1 . \tag{2}$$

Thus the intercept of the X trajectory is expected to be equal to unity just as for the Pomeranchuk trajectory. The quantum numbers for the X-trajectory are the same as for the pomeron except parity ($T=0, G=1, \sigma=1$, but $P=-1$). Such an interesting possibility does not contradict the phenomenological Regge analysis of the available experimental data in the intermediate energy range. Dut to unnatural parity, the X-trajectory does not contribute to the spin independent part of the forward elastic scattering amplitudes. Therefore the asymptotic behaviour of the total cross-sections if particles involved are unpolarized is defined only by the pomeron. It is also clear that the X pole exchange does not contribute to the scattering of pseudoscalar mesons.

At the same time the model with X-trajectory gives definite predictions for elastic pp-scattering, photoproduction of vector mesons, the Compton effect, etc., at very high energies. Of interest are also the reactions in which the pomeron contribution is somewhat suppressed, e.g. $\pi^\pm p \to A^\pm p$, $K p \to K^*(1420) p$, etc.

Below we show that for elastic pp-scattering at very high energies the existence of X-trajectory with unit intercept results in the appearance of the spin structure /3/ of the forward scattering amplitude. These spin effects can lead to the marked change of the slope parameter at small momentum transfers which has been observed in the ISR experiment /4,5/ and has widely been discussed /6/.

The pomeron gives a contribution to the s-channel helicity amplitudes /7/ $\phi_1 = \langle ++|++\rangle$ and $\phi_3 = \langle +-|+-\rangle$. The X pole contributes to the amplitudes $\phi_2 = \langle ++|--\rangle$ and $\phi_4 = \langle +-|-+\rangle$. For the evasive solution the X exchange contribution to ϕ_2 is proportional to the momentum transfer t. However for the conspiratorial solution /3,7/ the amplitude ϕ_2 survives at $t = 0$ if one introduces a conspiratorial trajectory $a_c(t) = 1 + a_c' t$ with vacuum quantum numbers. In this case the forward pp-scattering amplitude becomes spin-dependent and these spin effects survive at asymptotic energies. The differential pp cross-section at small $|t|$ is written down as

$$\frac{d\sigma}{dt} \sim \{ 2U_p^2(t) \exp(2a_p' t \ln \frac{s}{s_0}) +$$

$$+ | U_x(t) \exp[(-\frac{i\pi}{2} + \ln \frac{s}{s_0}) a_x' t] + \tag{3}$$

$$+ U_c(t) \exp[(-\frac{i\pi}{2} + \ln \frac{s}{s_0}) a_c' t] |^2 + 0[(\frac{t}{s_0})^2] ,$$

where a_p', a_x', a_c' are the slopes of corresponding Regge trajectories and $U_p(t)$, $U_x(t)$, $U_c(t)$ are connected with the residues of the trajectories $r_p(t)$, $r_x(t)$, $r_c(t)$ by the relation $U(t) = \sec(\frac{\pi}{2} a'(t)) r(t)$. The conspiracy condition gives

$$U_x(0) = U_c(0), \quad a_x(0) = a_c(0) = 1 . \tag{4}$$

The X exchange gives an important contribution at small momentum transfers which decreases rapidly with increasing $|t|$ because $a_x' > a_p'$. The formula (3) predicts therefore the change of the slope parameter at small $|t|$. In fact a good agreement with the data in ref. /5/ is achieved if one chooses ($s_0 = 1\ (\mathrm{GeV})^2$)

$$r_p(t) = r_p(0) \exp(3{,}2 \frac{t}{s_0}), \quad r_x(t) \sim r_c(t) = r_x(0) \exp(7{,}9 \frac{t}{s_0}) \tag{5}$$

$$\frac{r_x(0)}{r(0)} \sim 0{,}3 , \quad a_p' = a_c' \sim 0{,}3\ (\mathrm{GeV})^{-2} , \quad a_x' = 1{,}1\ (\mathrm{GeV})^{-2} \ (\mathit{input}).$$

These estimates are preliminary because we dispose now only of Table I and figures in ref. /5/. When the more detailed information is available the results of fitting the differential cross-sections will be reported. The above model with parameters (5) does not contradict the value of the slope parameter at Serpukhov /8/. It gives predictions for the Batavia pp scattering experiment.

In spite of the spin dependence of the amplitude, the proton polarization along the normal to the reaction plane vanishes. The model gives certain predictions for other polarization effects.

Let σ^1, σ_m^3 be the total pp cross-sections in the singlet and triplet states, m being spin projection on the momentum. The unitarity condition gives

$$\sigma^1 = \left(1-2\frac{r_x(0)}{r_p(0)}\right)\sigma_{tot}\ , \quad \sigma_0^3 = \left(1+2\frac{r_x(0)}{r_p(0)}\right)\sigma_{tot}, \quad \sigma_+^3 = \sigma_-^3 = \sigma_{tot}\ , \tag{6}$$

where σ_{tot} is the total cross-section for the reaction with nonpolarized particles. The positivity condition for total cross-sections gives $\left|\frac{r_x(0)}{r_p(0)}\right| \le \frac{1}{2}$. The above estimate $\frac{r_x(0)}{r_p(0)} \sim 0{,}3$ (5) predicts the existence of marked spin effects in pp-scattering. These spin effects are characteristic for our model and they are absent in other attempts to explain the slope parameter break /6/. We predict the absence of a slope parameter break for the elastic scattering of pions and kaons

$$\pi p \to \pi p\ , \quad Kp \to Kp \tag{7}$$

in which X -exchange is impossible, and for the elastic scattering of protons on spinless nuclei, in particular

$$p + {}^4He \to p + {}^4He\ , \tag{8}$$

where spin effects are absent. The situation is quite different in all models which do not involve spin effects, in particular in those based on some modification of the pomeron, etc. /6/. They imply a slope parameter break for reactions (7), (8) unlike our model.

It is important to take into consideration the X exchange effects in the treatment of the $0^- + \frac{1}{2}^+ \to 2^+ + \frac{1}{2}^+$ reactions, in particular

$\pi^{+}p \to A_2^{+} p$ and $K p \to K^*(1420) p$. A slow decrease of the cross-sections of these reactions has recently been discussed /9/, as well as a slow decrease of the cross-section of the photoproduction of the $B(1235)$ meson $(J^P = 1^+)$/10/. In the photoproduction of vector mesons it is worth performing exact measurements of the spin-density matrix element ρ_{00} at high energies. A more detailed paper devoted to related topics will be published elsewhere.

In conclusion we stress once more the importance of an inambiguous determination of the $X^0(960)$ meson spin-parity *. We believe the following experiments to be the most crucial:

1) Adair distribution for the forward $K^- p \to \Lambda X^0$ reaction /11/. The spin alignment will give a marked effect only with cut on small enough angles, $\theta_{c.m.} \sim 0.1$ rad, maximum $\theta_{c.m.} \sim 0.25$ rad. Unfortunately the new excellent data /12,13/ on this reaction do not permit to know the Adair distribution **.

2) Spin correlations in the annihilation $\bar{p}p \to \underset{\swarrow\, \rho\gamma}{X^0}\ \underset{\searrow\, \eta 2\pi}{\rho^0}$ at rest /14/.

3) Measurement of the differential cross-section for the reaction $\gamma + {}^4He \to X^0 + {}^4He$ /15/.

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* Note that for the $M(963)$ meson J^{PC} may also be equal to 2^{-+} /13/.

** After summing over not very small production angles no significant production dependent X decay correlations are observed in /12,13/. In the 2^- case these correlations also can be suppressed. In /12,13/ no upper bounds for polarization effects are given if the $X^0(960)$ meson is 2^-.

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