Regge trajectory of the ψ (J) particles and pp elastic scattering at large angles*

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(Received 3 March 1975)

It is shown that the proton-proton elastic scattering data at large angles can be described by a trajectory with the same shape as the ψ (J) trajectory.

Many detailed theoretical models of the ψ (J) particles[1] have been proposed since their first discovery. The experimental status at the present does not allow us to tell which one (or perhaps none) of these models is correct. The underlying philosophy of the present work is to commit ourselves to no specific model, but to assume that $\psi(3.7)$ is a Regge recurrence (or a daughter recurrence) of $J(3.1)$, and to study the consequences of this one assumption. Besides the high masses of the resonances, one obvious feature of the Regge trajectory associated with the ψ (J) particles is that it is unusually flat. Assuming that the $\psi(3.7)$ is associated with the next Regge recurrence of $J(3.1)$, the slope is about $\frac{1}{4}$.

It is quite interesting that a comparably flat trajectory has already been observed in a most well-known process, namely, proton-proton elastic scattering at large angles.[2] Consistent with this observation, a recent precise fit[3] to all the nondiffractive pp data indicates that two trajectories are needed, one with a conventional slope, which dominates at small momentum transfers, and another with a much smaller slope, which dominates at large momentum transfers.

It is tempting to identify the ψ (J) particles as bound states on the flat trajectory which dominates at large momentum transfer in pp scattering.

One additional feature of pp scattering could be consistent with this identification: The differential cross section at large angles is several orders of magnitude below that at smaller angles. Thus, the flat trajectory may be much more weakly coupled to pp than the conventional (ρ, ω) trajectory. This, in turn, would be consistent with the narrow widths of the ψ (J) particles.

We will see that the shape of the ψ (J) trajectory matches very well with the shape of the trajectory which dominates in large-angle pp elastic scattering. However, the present study indicates that it is possible that the latter trajectory is a broad-width degenerate partner of the ψ (J). The intriguing aspect of this possibility is that there exists exchange degeneracy involving the ψ (J) and a trajectory which couples more strongly to $p\bar{p}$.

To explore these ideas quantitatively, one must extrapolate the pp data from the scattering region into the resonance region. There is no model-independent way of doing this. However, since dual models have crossing and analyticity built in, they offer a very natural tool for such purposes. Unfortunately, the Veneziano model falls off too fast at large angles to be phenomenologically useful. A generalization of the Veneziano model, on the other hand, has been shown[3] to provide an excellent framework for fits to pp data. In addition, it is superior to a single-effective-trajectory analysis. We will, therefore, again use this amplitude for the purpose of extrapolation.

The basic four-point function[4] which we will use to construct the amplitude has the form

$$B(\alpha(s),\ \alpha(t)) = q^{\alpha(s)\alpha(t)}\,\frac{G(q/\sigma\tau)}{G(q/\sigma)G(q/\tau)}\ ,$$

where

$$G(x) = \prod_{n=0}^{\infty}(1 - xq^n)\ ,$$

$$\sigma = q^{\alpha(s)} = -As + B\ ,$$

$$\tau = q^{\alpha(t)} = -Ct + D\ .$$

Here, q, A, B, C, D are parameters.

In applying this amplitude to pp scattering, duality diagrams would lead us to associate $\alpha(s)$ and $\alpha(t)$ with two different trajectories, corresponding to a quark-antiquark and diquark-antidiquark state, respectively. As a first try, one might make the economical but unconventional identification of these two dual trajectories with the (ρ, ω) and ψ (J), respectively. The implicit assumption then is that ψ (J) is an exotic diquark-antidiquark state. The full amplitude will take on the form

$$A_1 = N[B(\alpha_\rho(t), \alpha_\psi(u)) + B(\alpha_\psi(t), \alpha_\rho(u))],$$

where N is a normalization constant. Two terms are needed to maintain t-u symmetry in pp scattering.

The alternative possibility is that the (ρ, ω) trajectory is *not* dual to the $\psi(J)$ trajectory. The amplitude then takes on the form

$$A_2 = N_1[B(\alpha_\rho(t), \alpha_{ex}(u)) + B(\alpha_{ex}(t), \alpha_\rho(u))] + N_2[B(\alpha_\psi(t), \alpha_{ex'}(u)) + B(\alpha_{ex'}(t), \alpha_\psi(u))].$$

In this form, the $\psi(J)$ may be identified with a more conventional quark-antiquark state. Two additional exotic trajectories α_{ex} and $\alpha_{ex'}$ must be introduced. These trajectories may be accommodated provided they are sufficiently low lying so as not to introduce unobserved low-mass particles.

With the amplitude A_1, we were able to fit all pp scattering data with $|t| > 7$ $(\mathrm{GeV}/c)^2$, subject to the constraint that the trajectories pass through (ρ, ω), (f, A_2), (g, ω') in one channel, and $J(3.1)$ and $\psi(3.7)$ in the other. However, for $|t| < 7$, the fit fails. Since this amplitude contains the (ρ, ω)

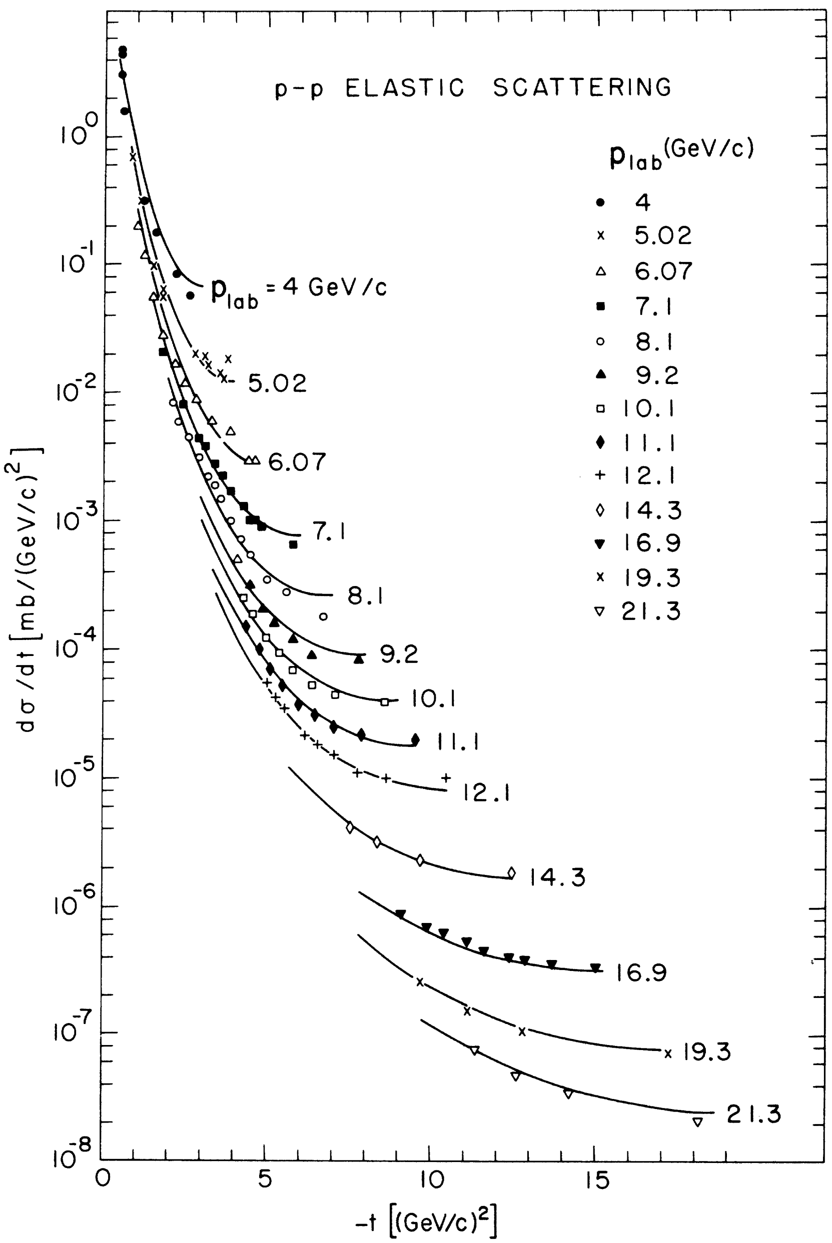

FIG. 1. Our fits to pp large-angle elastic scattering. Also included in the fits were 15 additional data points [G. Cocconi *et al.*, Phys. Rev. 138, B165 (1965)] which are not shown here.

trajectory, and is therefore expected to fit also at smaller momentum transfers, the (ρ, ω) dual to ψ (J) alternative must be rejected.

On the other hand, with the form A_2 we were able to fit all pp data with $\cos\theta < \frac{1}{2}$ (to avoid the Pomeron) and $p_{1ab} \geq 4$ GeV. The final fit has a χ^2 of 0.96 per data point. In Fig. 1 we present our fit to the pp data, and in Fig. 2 we have plotted the trajectories associated with the fit. The fit turns out to be relatively insensitive to the exact locations of the two exotic trajectories. In fact, we have found that setting these two trajectories equal is consistent with our fit. The fitted masses of the first three recurrences on the (ρ, ω) trajectory are given by $m_1^2 = 0.61$, $m_2^2 = 1.73$, $m_3^2 = 2.75$, and on the ψ (J) trajectory by $m_1 = 3.095$, $m_2 = 3.685$, and $m_3 = 4.15$. Apart from these mass values which are determined by our identification of the leading trajectories and apart from the parameters of the exotic trajectories to which our fit is not sensitive, the only free parameters are N_1 and N_2.

In order to decide whether we are dealing with the ψ (J) trajectory or another nearly degenerate trajectory, we can compute the residue of the pole at 3.1 and compare with the small coupling of the ψ (J) to $p\bar{p}$. The residue turns out to be much too large to be compatible with the small ψ (J) $p\bar{p}$ coupling. However, the residues of some daughter poles turn out to be negative by about the same order of magnitude, so that in the end the model cannot convincingly distinguish the ψ (J) from a nearly degenerate broad-width partner.

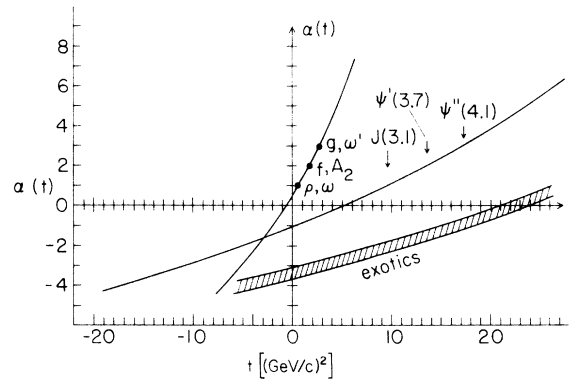

FIG. 2. The nonlinear Regge trajectories of the exchange-degenerate (ρ, ω), (f, A_2), (g, ω') and the ψ (J) particles found in our fit. The exotic trajectories dual to these, to which our fit is not sensitive, are represented by the shaded band.

*Work supported in part by the U. S. Energy Research and Development Administration.

†Work supported in part by the National Science Foundation under Grant No. GP-43713.

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