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DISCONTINUITY IN LARGE ANGLE PROTON-PROTON SCATTERING
AND PRODUCTION OF ANTIBARYONS

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A B S T R A C T

The rapid change observed in the large angle pp elastic scattering in the laboratory momentum interval $8 \lesssim p_L \lesssim 11$ GeV/c is discussed as a shadow effect of baryon-antibaryon pair creation.

At $p_L = 10$ GeV/c, assuming S wave pair creation, we estimate from the measured pp elastic data that the $\bar{B}B$ pair creation cross-section must be about $2\mu\text{b.}$

1. - A recent CERN experiment ¹⁾ has revealed a rapid change in the large angle differential cross-section for elastic pp scattering in the laboratory momentum interval $8 \lesssim p_L \lesssim 11$ GeV/c. The measurements cover a c.m. angular range $67^\circ \lesssim \theta \lesssim 90^\circ$. The data are fitted by a function

$$\frac{d\sigma}{dt} = A(p_L) \exp[-s \sin\Theta / b(p_L)] , \quad s = (\text{c.m. energy})^2 . \quad (1)$$

For $3 \lesssim p_L \lesssim 8$ GeV/c, one has practically constant values for the parameters

$$A(p_L) = 134.6 \text{ mb}(\text{GeV/c})^{-2}, \quad b(p_L) = 1.24 \text{ GeV}^2 . \quad (2)$$

For $11 \lesssim p_L \lesssim 21$ GeV/c, the values are again constant but very different

$$A(p_L) = 56.4 \text{ } \mu\text{b}(\text{GeV/c})^{-2}, \quad b(p_L) = 2.77 \text{ GeV}^2 . \quad (3)$$

A and b change abruptly from the values (2) to (3) in the intermediate interval.

As mentioned by the authors of the experiment [see also Ref. ²⁾], it is natural to speculate that this sharp change is connected with the opening of many antibaryon-baryon pair creation channels. A few threshold values of p_L are :

$$\begin{aligned} \bar{p}p & : 6.5 \text{ GeV/c} , \\ \bar{N}^*(1238) N^*(1238) & : 9.2 \text{ GeV/c} , \\ \bar{N}^*(1400) N^*(1400) & : 10.7 \text{ GeV/c} . \end{aligned}$$

It is reasonable to assume that, in the threshold region, $\bar{B}B$ pair creation would occur in low partial waves, so that its shadow effect on elastic scattering would have the same property and extend to larger angles than is the case for the shadow scattering of the highly peripheral meson production processes. As one goes up in energy above $p_L \simeq 10$ GeV/c, $\bar{B}B$ production would spread over an increasing interval of values of the angular momentum ℓ , but this interval might well remain much narrower than the one in which meson production takes place, so that it is conceivable that pp elastic scattering for θ near 90° would be dominated by the shadow effect of $\bar{B}B$ production at all momenta $p_L \gtrsim 10$ GeV/c.

2. - The mathematical formulation of these ideas is extremely simple when the elastic pp scattering amplitude T is assumed to be spin-independent and purely imaginary at all angles for the p_L values concerned. T can be written ($k = \text{c.m. momentum}$)

$$T(p_L, \theta) = \frac{i s^{1/2}}{4\pi k} \sum (2\ell+1) \eta_\ell P_\ell(\cos \theta), \quad (4)$$

where the sum extends over even ℓ only, and where the real amplitudes η_ℓ are related to inelastic collisions by the formula ³⁾

$$\eta_\ell = 1 - (1 - 2f_\ell)^{1/2}, \quad (5)$$

where f_ℓ is the ℓ th component of the overlap function

$$F(p_L, \theta) = \sum (2\ell+1) f_\ell P_\ell(\cos \theta) \propto \langle \psi | \psi' \rangle,$$

describing the contribution of all inelastic final states to the unitarity condition for elastic scattering. ψ, ψ' represent the complete inelastic final states of two pp collisions of same momentum p_L ; these collisions are taken in the same c.m. system and θ is the angle between their incident directions.

For $p_L \gtrsim 8$ GeV/c, Ψ begins to contain a non-negligible component $\Psi_{\bar{B}}$ for $\bar{B}B$ creation, and we write $\Psi = \Psi_M + \Psi_{\bar{B}}$, $\Psi' = \Psi'_M + \Psi'_{\bar{B}}$, Ψ_M and Ψ'_M referring to all meson production processes without antibaryons. Hence the overlap function consists of two additive parts

$$F = F_M + F_{\bar{B}}, \quad F_M \propto \langle \Psi_M | \Psi'_M \rangle, \quad F_{\bar{B}} \propto \langle \Psi_{\bar{B}} | \Psi'_{\bar{B}} \rangle,$$

and similarly $f_\ell = f_\ell^M + f_\ell^{\bar{B}}$. It is easy to show that

$$f_\ell^M \geq 0, \quad f_\ell^{\bar{B}} \geq 0, \quad f_\ell^M + f_\ell^{\bar{B}} \leq \frac{1}{2}$$

Since $\bar{B}B$ production is never abundant, we expect $f_\ell^{\bar{B}} \ll f_\ell^M$ and (5) gives

$$\eta_\ell = \eta_\ell^M + \eta_\ell^{\bar{B}}, \quad \eta_\ell^M = 1 - (1 - 2f_\ell^M)^{1/2}, \quad \eta_\ell^{\bar{B}} = f_\ell^{\bar{B}} (1 - 2f_\ell^M)^{-1/2} \quad (6)$$

Assuming the model described in Section 1, one can determine η_ℓ^M and f_ℓ^M by using the experimental values of $d\sigma/dt$ for all θ at $p_L \lesssim 8$ GeV/c, where the effect of $\bar{B}B$ production is negligible, and by extrapolating to $p_L > 8$ GeV/c. This extrapolation is rather unambiguous thanks to the smooth p_L variation for $p_L < 8$ GeV/c and the sharpness of the change in the interval $p_L = 8 - 11$ GeV/c. Using the experimental values of $d\sigma/dt$ for $p_L > 8$ GeV/c, one can then determine η_ℓ and hence $\eta_\ell^{\bar{B}}$, $f_\ell^{\bar{B}}$, thereby predicting some aspects of $\bar{B}B$ pair creation which can in principle be checked by experiments on antibaryon production.

3. - The programme sketched above cannot be carried out at present because the elastic differential cross-section $d\sigma/dt$ is not measured at all angles. What we have done is to limit ourselves to the threshold region itself, choosing $p_L = 10$ GeV/c, and to assume that $\bar{B}B$ production there occurs mainly in the S state, i.e., $f_\ell^{\bar{B}} = \eta_\ell^{\bar{B}} = 0$ for $\ell > 0$. $\eta_0^{\bar{B}}$ is then simply given by

$$\begin{aligned} \eta_0^{\bar{B}} &= \frac{4\pi k}{s^{1/2}} \left[T(p_L, \frac{\pi}{2}) - T_M(p_L, \frac{\pi}{2}) \right] , \\ &= \frac{2k^2}{\pi^{1/2}} \left[\left(\frac{d\sigma}{dt} \right)^{1/2} - \left(\frac{d\sigma_M}{dt} \right)^{1/2} \right]_{\theta = \pi/2} , \end{aligned} \quad (7)$$

where T_M and $d\sigma_M/dt$ are the extrapolation of T and $d\sigma/dt$ from the region $p_L < 8$ GeV/c to $p_L = 10$ GeV/c. This gives $\eta_0^{\bar{B}} \simeq 0.022$. A consistency check of our assumption on S state $\bar{B}B$ production lies in the fact that the right-hand side of (7) should remain practically constant for $\theta \neq 90^\circ$; the data at $p_L = 10$ GeV/c show indeed a considerable amount of cancellation between the θ dependence of $(d\sigma/dt)^{1/2}$ and $(d\sigma_M/dt)^{1/2}$ for θ near 90° .

For the values of η_ℓ^M and f_ℓ^M at $p_L = 10$ GeV/c, we have used a partial wave analysis of small angle pp elastic scattering data similar to the one given in Ref. 4). We find

$$f_\ell^M \simeq 0.49 \exp(-\ell^2/109) .$$

Hence from (6) and the above value of $\eta_0^{\bar{B}}$, one obtains $f_0^{\bar{B}} = 3 \cdot 10^{-3}$. This rather small value results from the smallness of $1 - 2f_0^M$ and is very sensitive to it, so that it is affected by a considerable uncertainty. The value of $f_0^{\bar{B}}$ allows to calculate in our model the total antibaryon production cross-section at 10 GeV/c, with the result

$$\sigma_{\bar{B}} = \frac{2\pi}{k^2} f_0^{\bar{B}} \simeq 2 \mu b .$$

This value is of the right order of magnitude if one considers that Ratner et al.⁵⁾ have measured at $p_L = 12.5$ GeV/c the following differential cross-sections for $\bar{p}$ production

$$\frac{d^2\sigma}{d\Omega dk} \simeq 2 \exp(-6 k_{\perp}^2) \mu b [\text{ster} \times \text{GeV/c}]^{-1},$$

where $k_{\perp}$ is the transverse momentum in GeV/c and where the longitudinal c.m. momentum had the value $k_{\parallel} = 0.6$ GeV/c. Using this cross-section for $|k_{\parallel}| \lesssim 1$ GeV/c, one finds an estimate of $6 \mu b$ for the total $\bar{p}$ production cross-section at 12.5 GeV/c.

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R E F E R E N C E S

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