INELASTIC PERIPHERAL COLLISIONS AT ULTRA-HIGH ENERGIES

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The asymptotic values for inelastic peripheral collisions are calculated in the one-meson approximation. The asymptotic values of the mean inelasticity coefficient and of the transverse momentum of the recoil nucleus are calculated under the assumption that at energies above resonance the π-N interactions are completely due to exchange of a single pion. The values for the total cross sections $\sigma_{NN} = 40$ mb and $\sigma_{\pi N} = 22.5$ mb yield $\bar{K} = 0.36$ and $\bar{P}_{\perp} = 0.47$ GeV/c.

ASSUMING that π-N interactions at energies above resonance are wholly due to one-pion-exchange, all the peripheral N-N and π-N interactions can be represented in the form of diagrams (see the figure) with only a nucleon or a π-N resonon in one of the vertices (see [1]). Neglecting the dependence of the resonance cross sections on Δ^2, we can write

$$\sigma_{NN}^{(1)}(U) = \frac{2}{(2\pi)^3}\frac{1}{p_U^2U^2}\int dW_r\,dW\,d\Delta^2\,p_{W_r}W_r^2 \times \sigma_{\pi N}^r(W_r)\,p_W W^2\sigma_{\pi N}(W,\Delta^2)\frac{1}{(\Delta^2+\mu^2)^2}, \qquad (1)$$

$$\sigma_{NN}^{(2)}(U) = \frac{g^2}{4\pi}\frac{1}{p_U^2U^2}\int dW d\Delta^2 p_W\,W^2\,\sigma_{\pi N}(W,\Delta^2)\,\frac{\Delta^2F(\Delta^2)}{(\Delta^2+\mu^2)^2}, \qquad (2)$$

$$\sigma_{\pi N}^{(1)}(U) = \frac{2}{(2\pi)^3}\frac{1}{p_U^2U^2}\int dW_r\,dW\,d\Delta^2\,p_{W_r}W_r^2 \times \sigma_{\pi N}^r(W_r)\,p_W W^2\sigma_{\pi\pi}(W,\Delta^2)\frac{1}{(\Delta^2+\mu^2)^2}; \qquad (3)$$

$$\sigma_{\pi N}^{(2)}(U) = \frac{g^2}{4\pi}\frac{1}{p_U^2U^2}\int dW d\Delta^2\,p_W\,W^2\sigma_{\pi\pi}(W,\Delta^2)\,\frac{\Delta^2F(\Delta^2)}{(\Delta^2+\mu^2)^2}, \qquad (4)$$

where $F(\Delta^2)$ —form factor of the nucleon, $\sigma_{\pi\pi}(W, -\mu^2)$ —total cross section of π-π interaction at energy W, $\sigma_{\pi N}(W, -\mu^2) = \sigma_{\pi N}(W)$ —total cross section of π-N interactions, Δ^2 —square of the momentum of the intermediate pion, U —total energy of collision in the center of mass system, p_U and p_W —momentum of primary particle in the c.m.s. of the N-N(π-N) and π-π interactions, respectively, μ —pion mass, p_{W_r} —momentum of virtual meson in the c.m.s. of the resonant π-N collision, and the index r denotes in general that the quantities correspond to the resonant π-N collision.

We retain the usual assumption of the one-meson model $\sigma(W, \Delta^2) = \sigma(W, -\Delta^2)$. Approximating the form factor of the nucleon by means of a unit step, we find from (1) and (2) that in the asymptotic relation

$$F(\Delta^2) = 1 \quad (\Delta^2 < \Delta_0^2), \qquad F(\Delta^2) = 0 \quad (\Delta^2 > \Delta_0^2), \qquad (5)$$

$$\sigma_{NN}^{(1)}(U\to\infty) = \frac{1}{2(2\pi)^3}\frac{1}{p_U^2U^2}\int p_{W_r}\,W_r^2\sigma_{\pi N}^r(W_r)\,dW_r\int_0^{U^2} d(W^2) \times \frac{(U^2-W^2)\,W^2}{W^2(W_r^2-m^2)+W^4m^2/U^2}\,\sigma_{\pi N}(W,-\mu^2), \qquad (6)$$

$$\sigma_{NN}^{(2)}(U\to\infty) = \frac{g^2}{4\pi}\frac{1}{4p_U^2U^2}\int_0^{U^2} W^2\sigma_{\pi N}(W,-\mu^2) \times \left\{\ln\frac{\Delta_0^2+\mu^2}{\Delta_{min}^2+\mu^2} - \mu^2\frac{\Delta_0^2-\Delta_{min}^2}{(\Delta_0^2+\mu^2)(\Delta_{min}^2+\mu^2)}\right\}d(W^2), \qquad (7)$$

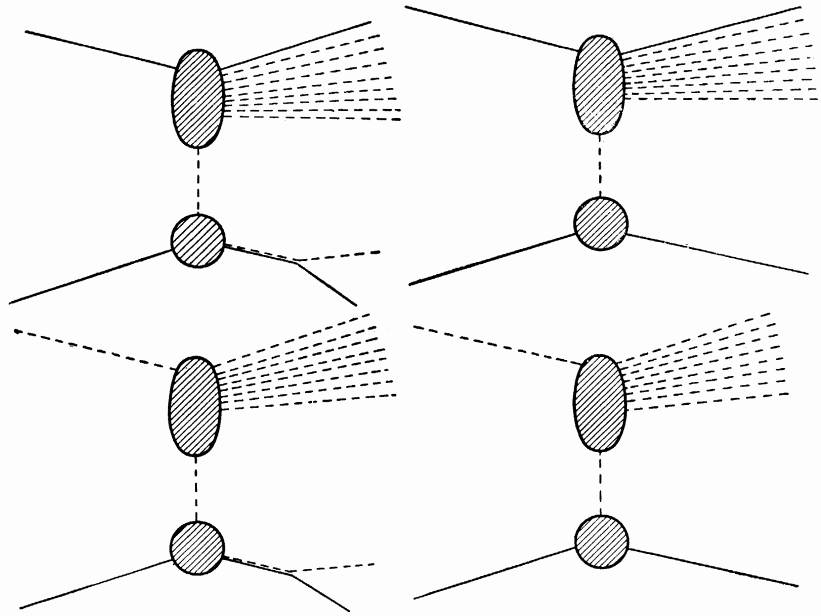
where

$$\Delta^2_{min} = m^2W^4 / U^2(U^2-W^2).$$

Similar relations are obtained from (3) and (4) also for $\sigma_{\pi N}$. We see that in this case the assumption $\sigma_{\pi\pi}(W\to\infty)\to$ const leads to constant $\sigma_{\pi N}$ and σ_{NN} in the asymptotic expression. In addition, with the aid of the formulas

$$P_0 = \frac{U^2+m^2-W^2}{2U}, \quad \Delta^2 = \frac{U}{2P_{\parallel}}\left(P_{\perp}^2 + m^2\frac{(U-2P_{\parallel})^2}{U^2}\right) \qquad (8)$$

we can obtain, for example from (2), the distribution of the transverse momentum of the nucleon



Diagrams describing peripheral N-N and π-N interactions at ultrahigh energies.

$P_\perp$ and of the recoil-nucleon energy P_0 in the center-of-mass system:

$$\frac{\partial\sigma_{NN}^{(2)}}{\partial P_0} \approx \frac{W^2}{U^3}\left\{\ln\frac{\Delta_0^2+\mu^2}{\Delta_{min}^2+\mu^2} - \mu^2\frac{\Delta_0^2-\Delta_{min}^2}{(\Delta_0^2+\mu^2)(\Delta_{min}^2+\mu^2)}\right\}, \tag{9}$$

$$\frac{\partial\sigma_{NN}^{(2)}}{\partial P_\perp} \approx P_\perp \int \frac{U-2P_\parallel}{P_\parallel}\frac{\Delta^2 F(\Delta^2)}{(\Delta^2+\mu^2)^2}\,dP_\parallel. \tag{10}$$

Similar formulas are obtained for (1), (3), and (4).

We see from (9) and (10) that the distributions of the quantities P_0/U and $P_\perp$ are constant in the asymptotic expression, signifying the constancy of the average value of the inelasticity coefficient and of the average transverse momentum of the nucleon. Thus, in the case of constant cross sections, the inelasticity coefficient and the transverse momentum are constant, and on the basis of the ratio $\sigma_{NN}/\sigma_{\pi N}$ we can calculate in this case their average asymptotic values.

Formula (6) yields, with account of five resonances:

$$\sigma_{NN}^{(1)} = 0.44\,\sigma_{\pi N}. \tag{11}$$

Inasmuch as $\sigma_{NN}/\sigma_{\pi N} = 40/22.5 = 1.78$, the one-meson model will describe all the N-N collisions in the asymptotic expression only if

$$\sigma_{NN}^{(2)} = 1.34\,\sigma_{\pi N}, \tag{12}$$

corresponding to $\Delta_0^2 = 1.75\ \mathrm{GeV}^2$. For the mean values of the inelasticity coefficient and of the transverse momentum of the nucleon we obtain

$$\bar{K} \equiv (U - 2\bar{P}_0)/U = 0.36, \quad \bar{P}_\perp = 0.47\ \mathrm{GeV}/c.$$

A decrease in the ratio $\sigma_{NN}/\sigma_{\pi N}$ causes also a reduction in these two quantities.

It must be noted that the principal uncertainty lies in the assumption that the total cross sections depend on the virtuality of the intermediate pion Δ^2. To determine such a dependence we must know the structure of the pion-pion vertex, which is so far unknown. The resolution of the pion-pion vertex into elementary vertices which are determined only by the low-energy π-π resonances, on which the multiperipheral model is based[2], is apparently not in agreement with the experimental data[3].

An interesting fact is that the one-meson model leads, under very simple assumptions, to reasonable values of the transverse momentum of the recoil nucleon and of the inelasticity coefficients. To determine these quantities we used only the ratio $\sigma_{NN}/\sigma_{\pi N}$, which is a quantity that has been experimentally determined relatively well.

[1] F. Salzman, Phys. Rev. **131**, 1786 (1963).

[2] Amati, Fubini, Stanghellini, and Tonin, Nuovo cimento **22**, 569 (1961).

[3] Z. Koba and A. Krzywicki, Nucl. Phys. **46**, 485 (1963).

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