LIKE PARTICLE CORRELATIONS AS A TOOL TO STUDY THE MULTIPLE PRODUCTION MECHANISM

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The measurement of correlations between like pions in the inclusive processes a + b → $\pi^\pm + \pi^\pm$ + X permits us to study the space-time mechanism of multiple production. Similar measurements for neutrons evaporated from highly excited nuclei give the shape of nuclei and their mean lives; for pions from the resonance decay – the mean resonance life.

A large amount of information has recently appeared concerning particle correlations in inclusive processes, especially in counter experiments [1]. But the theoretical conclusions drawn from these experiments are comparatively poor; the usual correlation coefficient $C(y_1, y_2)$ has no deep meaning. We want here to focus attention on another type of correlations which can be extracted from the same statistics and give physical information about the space-time properties of multiple production.

In a number of papers of Podgoretsky and his coworkers it is shown [2–7,12] that there exist the so-called interference correlations between like particles. These correlations generalize the idea of famous Brown-Twiss correlation experiment in astronomy [8] and Goldhaber-Goldhaber-Lee-Pais effect [9] in meson physics.

Let us consider two sources which emit identical particles with four-momenta p_1, p_2. These sources are so close that we cannot distinguish which of them emits this or that particle. Therefore the amplitude A of double counts consists of two terms, and an interference term in $|A|^2$ depends, for $p_1 \approx p_2$, on the four-difference $q = p_1 - p_2$, more exactly, on the dimensionless combination sq/h where s is some characteristic space-time interval between the sources. So the measurement of correlations in double counts of like particles makes it possible to determine the space-time conditions of their generation. This main idea can be used in various physical conditions differently.

Multiple production. Consider the reaction a + b → $\pi_1^\pm + \pi_2^\pm$ + X and calculate for each event the pion energy difference $q_0 = \omega_1 - \omega_2$ and the projection of $\boldsymbol{q} = \boldsymbol{p}_1 - \boldsymbol{p}_2$ onto the plane perpendicular to $\boldsymbol{p}_1 + \boldsymbol{p}_2$: $\boldsymbol{q}_T = \boldsymbol{q} - \boldsymbol{n}(\boldsymbol{q}\cdot\boldsymbol{n})$ where $\boldsymbol{n} = (\boldsymbol{p}_1 + \boldsymbol{p}_2)|\boldsymbol{p}_1 + \boldsymbol{p}_2|^{-1}$. Let us imagine that we can switch on and off the interference between like pions at our own will. Then it can be shown (following [6]; see also [10]) that the distribution

$$w(q_T^2, q_0)_{\text{on}} \equiv \left.\frac{d^2\sigma}{dq_T^2\, dq_0}\right|_{\text{with interference}}$$

is connected with a smooth function $w(q_T^2, q_0)_{\text{off}}$ by the relation

$$w(q_T^2, q_0)_{\text{on}} = w(q_T^2, q_0)_{\text{off}} \times [1 + I^2(q_T R)(1 + q_0^2\tau^2)^{-1}]. \quad (1)$$

Here $I(x) = 2J_1(x)/x$, J_1 being the first Bessel function, $I(0) = 1$, $I(\infty) = 0$. We see that the interference gives the peak at the origin on the plane (q_T^2, q_0). The width of this peak gives the radius of multiple generation region R and the duration of generation process τ.

There exist the ways to switch the interference on and off. If the pions are generated in accordance with the statistical theory of Pomeranchuk or Fermi (i.e. independently; it is widely believed that this theory holds in $\bar{p}p$ annihilations), then the interference is switched on between like pions and off between unlike ones. That is why for $\bar{p}p$ annihilation we can write (1) in the form

$$w(q_T^2, q_0)_{\pi^\pm\pi^\pm} = Cw(q_T^2, q_0)_{\pi^+\pi^-}[1 + I^2(q_T R)(1 + q_0^2\tau^2)^{-1}] \quad (2)$$

where C is the normalization constant. This is the generalization of GGLP-effect [9] taking into account the duration of multiple production process: see the criticism of the GGLP-effect theory in refs. [6, 12].

The interference always exists in the πp- and pp-interaction because the pion generation in these processes is believed to be described by diagram (e.g., multiperipheral) technique (not statistically as $\bar{\mathrm{p}}$p). In order to switch off the interference, we propose to take the pions from different events: the first pion from the nth event, the second from the $(n+1)$th etc. Consequently, in these processes one can put

$$w(q_\mathrm{T}^2, q_\mathrm{o})\Big|_{\substack{\text{both pions}\\ \text{from one event}}} =$$

$$= Cw(q_\mathrm{T}^2, q_\mathrm{o})\Big|_{\substack{\text{pions from}\\ \text{two events}}} [1+|b(qR, q_\mathrm{o}\tau)|^2] \tag{3}$$

where the function $b(\xi, \eta)$ has properties similar to $I^2(q_\mathrm{T}R)(1+q_\mathrm{o}^2\tau^2)^{-1}$ in (4): $b(0,0)^2 = 1$, $|b(\infty, 0)|^2 = |b(0,\infty)|^2 = 0$. As a first step, one can put $|b(\xi,\eta)|^2 = I^2(\xi)/(1+\eta^2)$.

To extract the correlation effect from (2), (3), it is necessary to divide $w(q_\mathrm{T}^2, q_\mathrm{o})_\mathrm{on}$ by $w(q_\mathrm{T}^2, q_\mathrm{o})_\mathrm{off}$ and to fit the quotient to the expression in brackets. The effect is sufficiently two- or more-dimensional, it can be seen in the neighbourhood of the origin only; the integration over q_o or q_T can cancel it. Probably, that is why this effect has not been seen previously (and why the data on GGLP-effect taken from one-dimensional measurements are so contradictory). The second reason is a necessity to compare the results of "on" and "off" experiments.

Formulae (2), (3) were derived in the framework of the model in which the surface of the excited generation volume filled with point-like heavy pion oscillators emit pions randomly according to the Lambert law. Besides, it was assumed that $c\tau \gg R$. In ref. [6] were considered other emission models (from transparent sphere of pion sources, non-point like sources, sources moving randomly or as fireballs); in all cases the general structure of (1) conserves, only the meaning of parameters changes. If the oscillators are nonuniformly distributed in the volume, some function $\phi(\xi)$ should be put instead of the factor $I^2(\xi)$ in (1)‡. Having found it from the experiment, we can obtain the distribution of the distances $r_2 - r_1$ between the pion sources

$$\rho(r_2 - r_1) = \int \phi(q) \cos(q\cdot(r_1 - r_2))\, \mathrm{d}q.$$

The three- or four-pion correlations (observed in [11]) were considered by this method in ref. [7].

Let us consider some details of possible experiments.

1) Taking the pairs of like mesons with $p_1 + p_2$ looking in a given direction, one can measure R in a perpendicular plane. Varying these directions, it is possible to determine the shape of the interaction volume V and check various models of multiple production (such as Fermi's or Pomeranchuk's or Landau's or fireballs) because they predict different shapes of V. In particular, the question on the real existence of fireballs in the coordinate (not momentum) space can be solved.

2) The diagram mechanism of multiple production (for example, multiperipheral) predicts the existence of the correlations between unlike pions. They can be described by formula (3) (if they indeed exist), but the meaning of the parameters R, τ which make the arguments of b dimensionless is not clear now (in any case R does not coincide with the correlation length L resulting from $C(y_1, y_2)$).

3) It would be better to study the interference effect not in the inclusive reactions but in the exclusive processes where the influence of uncontrolled factor is much weaker.

The application of these ideas for nuclear and resonance physics is seen in refs. [2–5].

‡ For example, if random sources are distributed in a gauss-like manner $g(r_i) \sim \exp(-r_i^2/2R^2)$, $i = 1, 2$, then $\phi(q) \sim \exp(-q^2R^2)$. In this case the two-dimensional plot $(q_\mathrm{T}^2, q_\mathrm{o})$ gives the effective values of parameters R^2 and $\tau^2 + R^2/v^2$ where v is the velocity of particles.

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