Study of the ppη system using the HBT interferometry method

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Is is quite interesting to know, what is the dependence between the reaction mechanism and the size of the particles emission source. We try to establish to what extent this knowledge may be useful for determining the mechanism of the η meson production in the collisions of nucleons. One of the possible mechanisms of the η meson production via the $pp \rightarrow pp\eta$ reaction is a direct production of the η meson at the interaction region and the other creation possibility believed to be dominant is the production of this meson via the resonant state $S_{11}(1535)$ [1, 2, 3]. In the latter scenario, the effective size of the emission region is expected to be larger than in the former one.

A large enhancement in the excitation function of the $pp \rightarrow pp\eta$ reaction observed close to the kinematical threshold indicates a strong attractive interaction within the $pp\eta$ system [1]. The effect can be described assuming, that the proton-proton pair is produced from a large object of a 4 fm radius [4]. Therefore, a study of the $pp\eta$ system is particularly interesting in the context of the search for the Borromean states. As Borromean we call a bound three-body system in which none of the two-body subsystems is bound. In nuclear physics the ^{11}Li ($^{9}Li + n + n$) and ^{6}He ($\alpha + n + n$) nuclei have been found to have such a property [5], and recently a nanoscale Borromean rings were constructed in a wholly synthetic molecular form [6, 7].

At present it is still not established whether the low energy $pp\eta$ system can form a Borromean or resonant state. Recently the COSY-11 collaboration published high statistics data for the $pp \rightarrow pp\eta$ reaction which will be used to elucidate this question [8]. These data are presently evaluated using the well known intensity interferometry method, commonly referred to as the HBT effect [9]. This technique permits to determine the size of the source from which the protons are emitted. It is based on the correlation function of the relative momenta between the two protons, which relates the space-time separation of the particles at the emission time to their momenta p_1 and p_2. This function can be expressed in terms of pair-

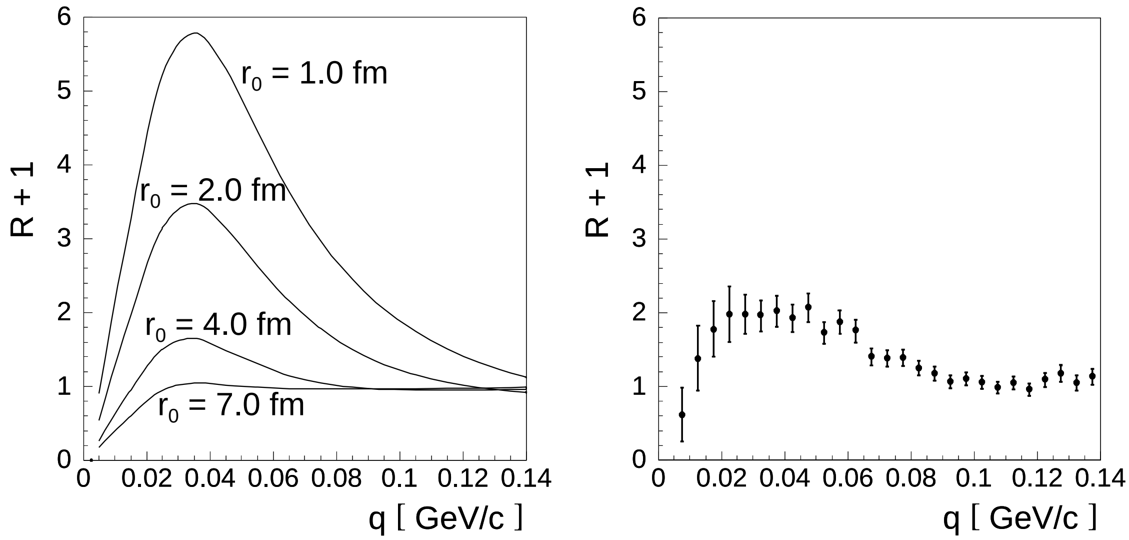


Figure 1: **Left:** Theoretical correlation functions of two protons for $r_0 = 1.0,\ 2.0,\ 4.0$ and 7.0 fm. **Right:** The experimental two protons correlation function calculated from data [8] for the $pp \rightarrow ppX$ reaction.

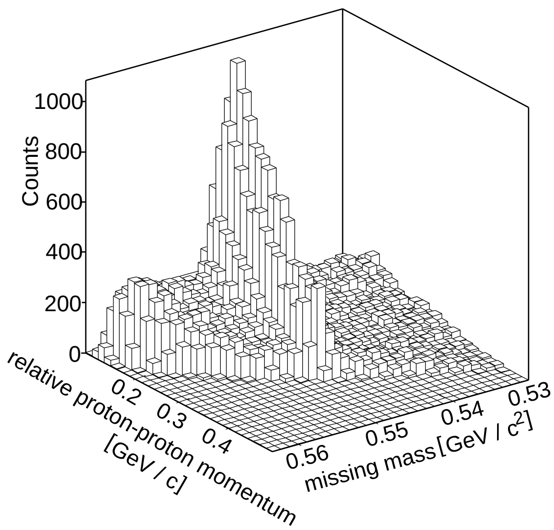
and single-particle cross section [9]:

$$R(p_1, p_2) = C \cdot \frac{d^6\sigma/d^3p_1 d^3p_2}{(d^3\sigma/d^3p_1)(d^3\sigma/d^3p_2)} - 1, \qquad (1)$$

where C denotes the overall normalization constant. The shape of two-proton correlation function calculated including Coulomb interaction and Pauli exclusion principle depends on the spatial size of the source. In a present analysis we consider only the projection of the R function onto one dimension corresponding to the relative momentum of emitted protons $q = |\vec{p_1} - \vec{p_2}|$. In the calculations we tentatively assumed a simultaneous emission of the two protons and approximated the effective spatial shape of the emission zone by the Gaussian distribution. In such case the standard deviation of this distribution - hereafter referred to as r_0 - constitutes the measure of the dimension of the source. For the simulations we adapted a computing procedure written by R. Lednicky [10, 11], which already has been successfully applied (example in ref. [12]). Figure 1 (left panel) displays proton-proton correlation functions calculated for the $pp \rightarrow pp\eta$ reaction, assuming four different sizes of the emission source. One can see that the height of the peak at q $\approx$ 40 MeV/c depends significantly on the value of r_0 and therefore the magnitude of this maximum may serve as a measure of the volume of the reaction zone. Of course, generally the size of the reaction zone can be extracted by the comparison of the experimental and simulated correlation functions treating r_0 as a fitting parameter.

Since in the experiment the single particle yield has not been measured, it is not possible to determine directly the denominator of equation 1. Therefore, in order to facilitate an extraction of the considered correlation function from the data, an alternative function $R(q)$ can be defined [9] as a ratio of the reaction yield $Y_{pp\eta}(q)$ to the uncorrelated yield $Y^*(q)$:

$$R(q) + 1 = C^* \, \frac{Y_{pp\eta}(q)}{Y^*(q)}, \qquad (2)$$



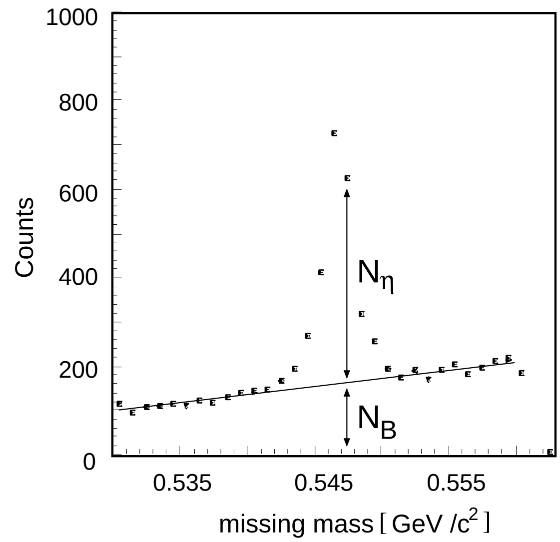


Figure 2: **Left:** The example of high statistics distribution from the close to the η meson production threshold $pp \rightarrow ppX$ reaction [8]. **Right:** The example of missing mass spectrum measured [8] for the $pp \rightarrow ppX$ reaction at $q \in (0.06;\ 0.07)$ GeV/c.

where C^* denotes an appropriate normalization constant. In practice, $Y^*(q)$ can be obtained via event mixing techniques, taking momentum of one proton from event m, and the momentum of the second proton from event m+k, where k is arbitrarily chosen. In the experiment devoted to the $pp \rightarrow pp\eta$ reaction the four-momenta of two protons are being measured and the unobserved meson is identified via the missing mass technique [8, 13, 14]. High statistics in such experiment allows to derive the distributions of differental cross sections free of the multi-meson production background [8, 13]. To demonstrate the quality of the data, an example of the missing mass distribution as a function of q is shown in figure 2 (left panel). The correlation function derived from the data is presented in figure 1 (right panel). A determined experimental spectrum shows a maximum at a value of q as predicted by simulations.

The correlation function for the $pp \rightarrow pp\eta$ reaction was evaluated free of the multi-pion production background, by counting each measured $pp \rightarrow ppX$ event with the weight corresponding to the probability that it is due to the $pp \rightarrow pp\eta$ reaction. This probability was extracted as a function of measured missing mass value separately for each of the 25 studied intervals of relative momentum. Missing mass spectrum for one of protons relative momentum intervals is presented in figure 2 (right panel).

The probability ω_i, that i^{th} $pp \rightarrow ppX$ event with a missing mass m_i, and relative momentum of q_i corresponds to $pp \rightarrow pp\eta$ reaction reads:

$$\omega_i = \frac{N_\eta}{N_\eta + N_B}(m_i, q_i), \tag{3}$$

where N_η stands for the number of events corresponding to the $pp \rightarrow pp\eta$ reaction and N_B is number of multi-pion production background events.

A rough comparison between theoretical correlation functions and the experimental one shown in the figure 1 indicates that the size of the reaction volume can be approximated by the Gaussian distribution with $r_0 \approx 3$ fm. However, in order to draw the final conlusions, we need to take into account an experimental spread in the theoretical calculations and establish how acceptance corrections can modify experimental correlation function.

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