Bose-Einstein and Fermi-Dirac Correlations: Measurements versus Implementation in Monte Carlo Simulations

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Correlations in phase space between identical hadrons have been investigated over a wide range of centre-of-mass energies and different initial state reactions. They are interpreted to be a consequence of Bose-Einstein (BE) statistics for bosons or Fermi-Dirac (FD) statistics for fermions. The measured correlation distributions are often parametrised using the expression for a static sphere of emitters with a Gaussian density: $C(Q) = N(1 + S\lambda \exp(-R^2Q^2))$. Here S =+1 for bosons and -1 for fermions, λ is the strength of the correlation, R is the radius of the source and N a normalisation factor. The experimental difficulty lies in the dependence of the measured $C(Q)$ on the method used to construct a reference sample, for which only approximative methods exist [1].

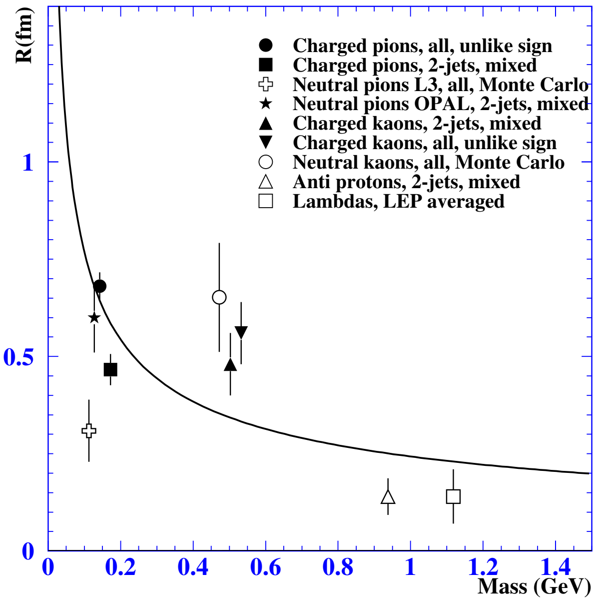

Fig. 1: Compilation of the measurements of the source radius R versus the hadron mass in Z^0 decays. The curve is from the Heisenberg uncertainty principle [1]. For the same hadron mass, the measurements are displayed with a small horizontal shift for clarity.

The measured results for the parameters λ and R are known to depend on the choice of the reference distribution. In addition, the meaning of λ and its value changes depending on correction factors introduced sometimes to the parametrisation of $C(Q)$. These corrections result in a large spread of the parameter λ, while they do not affect dramatically the value of R. Therefore, it seems more useful to compare different measurements using the parameter R only. Figure 1 shows a compilation of the available data for hadron pairs produced in Z^0 decays as a function of the hadron mass. Averaging is done only for the set of measurements that concerns the same hadron and for which the same method for defining the reference sample is used. The compilation indicates that the source radius is much smaller for baryons ($\bar{\mathrm{p}}$, Λ) than for mesons (π, K), it suggests a constant radius, $R \simeq 0.6$ fm, for mesons and a constant radius $R \simeq 0.14$ fm for baryons. A previous compilation of the data [1] has concluded that the source radius decreases with the increasing of the hadron mass and was explained qualitatively with the Heisenberg uncertainty principle. An analysis [2,3] has shown that the source radius can be considered as independent of the centre-of-mass energy $\sqrt{s}$ while it increases with the increasing of the average final state multiplicity in Z^0 decays. Since the average final state multiplicity increases with $\sqrt{s}$, these last two observations can be reconciled if the source radius increases with the increasing of the initial number of hard parton (i.e. number of jets).

The BEC (FD) effect, being of an intrinsically quantum mechanical nature, is not easily included in the event generator programs. Simulation programs like JETSET and HERWIG are built in accordance with a classical stochastic process, i.e. they produce a probability weight for an event without any quantum mechanical interference effect for the final state particles. In JETSET, the BEC effect is simulated as a mean field potential attraction between identical bosons. This implementation offers no possibility to study the dynamics of the effect or the space-time structure of the emitter source. An attempt to model the BEC effect within the framework of a production matrix elements with well defined phases at the string break-up level (i.e. hadronisation) was made [4]. This method, referred to as the weight method, has difficulties in the implementation from a computational point a view. An approximation of the method was implemented [5] but had no satisfactory success in describing the data.

The above Monte Carlo implementations fail to reproduce any of the following observed trends in data: the difference between the baryons and the mesons, the apparent independence of the emitter source radius on the centre-of-mass-energy and its dependence on the average final state multiplicity. In addition, using a typical LEP detector in the simulation, we performed a detailed Monte Carlo analysis, for charged as well as for neutral pions and kaons, and concluded that the existing experimental analyses of the BEC effect cannot be sensitive to hadron pairs produced at the string break-up (JETSET) or at the cluster decay (HERWIG). This would suggest that the observed BEC effects in data so far is mostly due to cases where each hadron of the pair is issued from a different strong resonance decay. Thus a comprehensive implementation of the effect in Monte Carlo simulation should start with considering interference and coherence effects between secondary hadrons from decay products of different resonances.

References

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