ENHANCED CORRELATIONS AND WIDE CHARGE DISTRIBUTIONS IN PION PRODUCTION

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Unusual phenomena in pion production are considered. It is argued that pions may be in a squeezed state having enhanced identical pion correlations. Charge distribution in soft chiral pion bremsstrahlung is shown to be very broad.

1 Introduction

High-energy interactions are dominated by multiple production processes. It is of interest to consider possibilities of unusual phenomena in multiple pion production which may shed light on the nature of the process of interaction. Here we consider two such phenomena, concerning identical pion correlations and charge distributions.

2 Enhanced correlations in chaotic squeezed states

Bose-Einstein correlations (BEC) of statistically produced particles are of great interest in particle physics because their measurement gives a possibility to recover space-time region of interaction (the particle source size). According to common belief, the maximal rise of two-particle distributions of identical particles is equal to two (BEC effect). However larger correlations are not excluded. Below it will be demonstrated that this is the case for correlations in chaotic squeezed states.

First we present a simple model of squeezed state production. Consider decay of pionic matter arising in the course of particle collision. Pions in matter (quasiparticles) are described by creation-annihilation operators $b^\dagger, b$ and have a spectrum $E_b$. Free pions at space infinity are described by $a^\dagger, a$ operators and have the usual spectrum $E_a = \sqrt{p^2 + m^2}$. Redecomposing the final state of pionic matter in terms of free pions, we have:

\[ a = b \cosh r + b^\dagger \sinh r, \quad a^\dagger = b \sinh r + b^\dagger \cosh r \]

with

\[ r = \frac{1}{2} \log\left( \frac{E_a}{E_b} \right) \]

This is a squeezing transformation with the squeezing parameter $r(p)$. If the initial quasipions are in coherent state, then the final pions are in squeezed state.
We suggest that pionic matter is chaotic (for example it may be thermal) so it is represented as a random set of coherent (or squeezed) states. The averaging of operators is performed with a Gaussian weight, see Ref. 2. Here the blob of decaying pionic matter is characterized by two quantities entering the weight:

(a) The function \( f(x) \) describing the space form of the pion source (we take here stationary case for simplicity). It has a characteristic size \( R \) (which is of the main interest in BEC study) and its Fourier transform \( f(k) \) represents corresponding form-factor.

(b) Primordial correlator of pionic matter which has its own scale and which reduces to number density \( n(k) \) for stationary source.

Now evaluation of averaged matrix elements is straightforward. Single-particle inclusive cross-section is:

\[
\rho_1(p) = \frac{(2\pi)^3}{\sigma} \frac{d\sigma}{d^3p} = \langle a^\dagger(p)a(p) \rangle
\]

\[
= \int \frac{d^3k}{(2\pi)^3} \left[ nb(k) \cosh 2r(k) + \sinh^2 r(k) \right] f(p-k)f(k-p) \tag{3}
\]

showing enhancement arising due to squeezing. Our main result here is two-particle inclusive distribution:

\[
\rho_2(p_1, p_2) = \rho_1(p_1)\rho_1(p_2) + |\langle a^\dagger(p_1)a(p_2) \rangle|^2 + |\langle a(p_1)a(p_2) \rangle|^2 \tag{4}
\]

with

\[
\langle a^\dagger(p_1)a(p_2) \rangle = \int \frac{d^3k}{(2\pi)^3} \left[ nb(k) \cosh 2r(k) + \sinh^2 r(k) \right] f(p_1-k)f(k-p_2),
\]

\[
\langle a(p_1)a(p_2) \rangle = \int \frac{d^3k}{(2\pi)^3} \left[ nb(k) + \frac{1}{2} \sinh 2r(k) \right] f(k-p_1)f(k-p_2) \tag{5}
\]

The third term in Eq. 4 represents an additional enhancement arising due to squeezing. It is easy to see that relative two-particle inclusive distribution

\[
C_2(p_1, p_2) = \rho_2(p_1, p_2)/\rho_1(p_1)\rho_1(p_2) \tag{7}
\]

may be any in this case, there is no necessity for \( C_2 \) to be less than two.

3 Very broad \( \pi^0 \) and \( \pi^\pm \) distributions

Charge distributions of pions in multiple production processes drew much attention recently. This is due to expectations to detect disoriented chiral condensate (DCC) formation in high energy collisions. 3 The coherent pulses
of semiclassical pion field are suggested to be emitted leading to anomalously large fluctuations in the ratio of neutral to charge pions produced. In particular the probability to produce \( n_0 \) neutral pions is given by inverse square root formula,

\[
w(n_0) \sim 1/\sqrt{n_0}
\]  

(8)

being very flat and so quite different from usual binomial-like distributions.

Now the problem arises—to what extent the Eq. 8 may be considered as a signature of DCC formation. Let us remind in this connection that the distribution of Eq. 8 was found long ago in a model of independent coherent pion production with isotopic spin conservation taken into account. Here we consider soft chiral pion bremsstrahlung accompanying some basic high energy process and estimate charge distribution of the pions. It will be found that neutral pion number distribution again has the form of Eq. 8.

The soft chiral pion bremsstrahlung was studied many years ago. Similarly to photons, soft pions are emitted from external lines of diagrams representing the basic process. The net result for soft pion emission is given by substitution:

\[
\psi_j \rightarrow \exp(-i\pi X)\psi_j
\]  

(9)

for every incoming and outgoing line, where \( \pi_i \) is the pion field, \( X_i = \gamma_5 \tau_i/2f_\pi \) for fermions, \( f_\pi = 93 MeV \) is the pion decay constant.

Here we are interested in charge distribution of the pions and calculate matrix elements

\[
M = <n_+, n_-, n_0|\exp(-i\pi X)\Gamma \exp(i\pi X)|0>
\]  

(10)

for simple two-particle vertices \( \Gamma \). The momentum transfer \( \Delta p \) in the vertex \( \Gamma \) is suggested to be large.

The scalar (\( \Gamma = I \)) and electromagnetic (\( \Gamma = (\tau_3 + N_B)/2 \)) vertices have been considered. In both cases the total pion distribution was found to be narrow (Poisson-like) whereas the neutral (and charged) pion number distributions \( w(n_0) \) appeared to be very flat. In both cases they reproduce inverse square root behaviour of Eq. 8, thus indicating that this distribution is typical for coherent soft pions and do not indicate directly on DCC formation.

So we conclude that one has to look for more delicate criteria of DCC formation. Here the energy distribution of the pions produced may appear helpful. In the case of pion bremsstrahlung it rises sharply with energy, \( dE \sim k^2dk \), and high momentum transfers \( \Delta p \) (and so the presence of high \( p_T \) particles in high-energy events) are highly favourable for copious production of the soft pions.
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