Relativistic effects on estimation of the fire-ball radius on Bose-Einstein correlations

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The shape of the bosonic emitting region in high energy reactions is analized. It is postulated that the relativistic effects are non-negligible in the study of Bose-Einstein correlations and hence disturb the shape of the source region in a way that shrinks the emitting region in the longitudinal direction, resulting in a longitudinal radius to be significantly smaller than the transverse one. In addition, a new particular way for measuring this effect is proposed in terms of the Doppler effect.

Keywords: Bose-Einstein correlations; source region

La forma de la región de emisión de bosones en reacciones de altas energías es analizada. Se postula que los efectos relativistas no son despreciables en el estudio de las correlaciones de Bose-Einstein, por lo que distorsionan la forma de la fuente, de tal manera que la región de emisión se contrae en la dirección longitudinal, resultando en un radio longitudinal significativamente menor que el radio transversal. Además, se propone una nueva forma para medir este efecto, en términos del efecto Doppler.

Descriptores: Correlaciones de Bose-Einstein; región fuente

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1. Introduction

Bose-Einstein correlations are a probability enhancement that identical bosons be produced with small relative four-momentum as compared to non-identical bosons. This effect, due to the symmetric nature of the multiboson wave function, was first observed by Goldhaber *et al.* in 1959 [1]. By studying the ρ meson production in $\bar{p}p$ annihilations, they observe a difference in the angular distributions between like sign pions and unlike sign pions which was attributed to the bosonic interference of the pions. It has been postulated by Kopylov and Podgoretskii [2] that the size and shape of this enhancement can be correlated to the spatial and temporal extension of the bosonic source (fire-ball), and also to the coherence degree at which the bosons are emitted. Different parametrizations have been proposed for Bose-Einstein correlations and the effect has been observed in different reactions, such as, hadron-hadron collisions [3], lepton-hadron collisions [4], and e^+e^- annihilations [5]. In most studies assuming a spherical source region, results are consistent with a fire-ball radius ≈ 1 fm. However, when data suggest the shape of the source region, it is observed that the longitudinal radius is significantly smaller than the transverse one.

In this paper the shape of the bosonic-emitting region in high energy reactions is analized. An interpretation for the possible non-spherical shape and a new method for measuring it is proposed.

2. Parametrization of Bose-Einstein correlations

Bose-Einstein correlations are usually described in terms of the ratio

$$R_{\mathrm{BE}}\left(p_1 p_2\right) = \frac{f\left(p_1 p_2\right)}{f\left(p_1\right) f\left(p_2\right)}, \tag{1}$$

where $f\left(p_1 p_2\right)$ is the joint probability for a pair of identical bosons to be produced, $f\left(p_1\right)$ and $f\left(p_2\right)$ are the single boson probabilities, and p_1 and p_2 are the four momenta of the two particles. Experimentally, it has been observed that the Bose-Einstein effect is a function of the four momentum difference $q = p_1 - p_2$. Hence, Eq. (1) is evaluated through the function

$$R_{\mathrm{BE}}\left(Q^2\right) = \frac{f_{\mathrm{real}}\left(Q^2\right)}{f_{\mathrm{sample}}\left(Q^2\right)}, \tag{2}$$

where $f_{\mathrm{real}}\left(Q^2\right)$ and $f_{\mathrm{sample}}\left(Q^2\right)$ are the Q^2 distributions for a correlated pair of identical bosons and an uncorrelated pair, respectively. This means that the product of the single probabilities in Eq. (1) is experimentally equivalent to considering a reference sample with dynamical properties similar to that of real data, except for the correlation effect. Here, Q^2 is defined as

$$Q^2 = -q^2 = -\left(p_1 - p_2\right)^2. \tag{3}$$

Experimentally, Q^2 is defined as

$$Q_{12}^2 = M_{12}^2 - 4m_b^2, \tag{4}$$

where M_{12} is the invariant mass of the pair of identical bosons and m_b is the boson mass. Eq. (4) can be generalized for any number n of identical bosons as

$$Q_{12\ldots n}^2 = M_{12\ldots n}^2 - n^2 m_b^2. \tag{5}$$

Different parametrizations have been proposed for the correlation function $R_{\mathrm{BE}}\left(Q^2\right)$. In particular, two are widely used: a) the Goldhaber $S_{\mathrm{BE(G)}}$ [6] and b) the Kopylov-Podgoretskii $S_{\mathrm{BE(K-P)}}$ [2], parametrizations. The $S_{\mathrm{BE(G)}}$ parametrization assumes a gaussian distribution for the source region and is given by the correlation function

$$S_{\mathrm{BE(G)}} = 1 + \alpha \exp\left(-\beta Q^2\right), \tag{6}$$

where β is related to the radius R of the emitting region by $R = \hbar c\sqrt{\beta}$ and α, the so-called caoticity parameter, gives the degree of coherence of the emitted bosons. In other words, α is a measure of the strength of the correlation. On the other hand, in the $S_{\mathrm{BE(K-P)}}$ parametrization the source region is assumed to be a radiating sphere of radius R where the bosons are emitted independently. This correlation function has the form

$$S_{\mathrm{BE(K-P)}} = 1 + \lambda \left[\frac{2J_1\left(q_{\mathrm{T}}R\right)^2}{q_{\mathrm{T}}R}\right]\left[\frac{1}{1+\left(q_{\mathrm{L}}\tau c\right)^2}\right], \tag{7}$$

where J_1 is the first order Bessel function, q_T and q_L are the components of $\vec{p_1} - \vec{p_2}$ transverse and longitudinal to $\vec{p_1} + \vec{p_2}$, λ is the coherence parameter, and τc is the depth of the bosonic emitting region.

Both $S_{\mathrm{BE(G)}}$ and $S_{\mathrm{BE(K-P)}}$ parametrizations are related in a such a way that the size obtained for the emitting region seems to depend strongly on the parametrization used, the source size obtained from $S_{\mathrm{BE(K-P)}}$ being about twice as large as that obtained from $S_{\mathrm{BE(G)}}$ [7].

3. Relativistic effects on source radius estimation

Using the $S_{\mathrm{BE(K-P)}}$ parametrization it is possible to obtain detailed information of the source region. In particular, the longitudinal and transverse radii can be estimated independently, allowing one not only to measure the size but also the shape of the emitting region. This parametrization has been used in a wide variety of processes.

The size of the emitting region has been observed to depend on different parameters, such as: a) the parametrization used, b) the background sample and c) the final state multiplicity. It has been also pointed out by Hernández and Herrera [8] that the meson size could affect the measurement of the source radius, since the meson size is of the same order as the source size. However, apart from all of those possible effects, of particular interest is the fact that the source longitudinal radius R_L measured in different reactions is found to be significantly smaller than the source transverse radius R_T [9], this phenomenon being independent of the effects listed above, where R_L and R_T refer to the assigned radii to the bosonic source in both the same and the perpendicular directions to that of the outgoing bosons, respectively. This observation clearly contradicts the basic assumption in the Kopylov-Podgoretskii model, in which a radiating sphere is postulated for the emitting region. Moreover, it is also relevant that the measured longitudinal radius is observed to be a strong function of the boson momenta. A decrease in source size with increasing boson momenta has been reported [10]. In this paper it is proposed that a simple interpretation to this phenomenon is that it is due to the special relativity contraction effect. Specifically, if the fire-ball is supposed to be a moving radiating sphere, relativistic effects contract the sphere in the longitudinal direction giving rise to an ellipsoid with R_L smaller than R_T.

The model proposed has some relevant consequences that must be emphasized. In particular, in such a model the basic assumption that bosons are emitted simultaneouly within the source region could no longer be correct. On the other hand, experimental data reveal that the lifetime during which the fire-ball is emitting is of the order of $\approx 10^{-24}$ seg. [11], *i.e.*, only a fraction of the time during which the fire-ball is within the reaction target. Therefore, these events take place during a significantly tiny period of time, but long enough to produced a measurable effect.

Finally, the shrinking effect is well known in relativity and could also be interpreted in a way similar to the Doppler effect in that the frequency of the electromagnetic field describing a charge distribution moving at relativistic velocities suffers a measurable shift. Therefore, any evidence of shifting of the electromagnetic field frequency associated with the emitted bosons could be related to relativistic effects and the size of this shift could be an indication of the magnitude of the difference $R_T - R_L$.

4. Summary

In conclusion, it is postulated that the relativistic effects in the study of Bose-Einstein correlations are non-negligible and disturb the shape of the source region such as to contract the region in the longitudinal direction, resulting in a longitudinal radius significantly smaller than the transverse one. In addition, a new particular way for measuring this effect is proposed in terms of the Doppler effect. Hence, a simple moving radiating sphere model it is postulated to explain the experimental results.

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