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ANALYSIS OF TRANSVERSE MASS DEPENDENCE OF BOSE-EINSTEIN CORRELATION RADII USING THE DELPHI DATA

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The study of the directional dependence of two-particle correlations in the hadronic decays of the Z boson is performed, using the data collected by the DELPHI experiment. Investigation of the dependence of correlation radii on the transverse mass reveals a behaviour similar to that in heavy ion collisions, namely, an approximate $1/\sqrt{m_t}$ dependence. Comparison to a simple Monte Carlo model shows a similar tendency.

The investigation has been performed at the Lund University and at the Laboratory of Nuclear Problems, JINR.

Анализ зависимости радиусов корреляций Бозе–Эйнштейна от поперечной массы с использованием данных ДЕЛФИ

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При использовании данных, собранных на установке ДЕЛФИ, проводится изучение зависимости двухчастичных корреляций от выбранного направления в адронных распадах Z-бозона. Исследование зависимости радиусов корреляции от поперечной массы обнаруживает поведение, сходное с тенденцией, наблюдаемой в столкновениях тяжелых ионов, а именно приблизительную пропорциональность радиусов $1/\sqrt{m_t}$. Сравнение с простой моделью Монте-Карло дает аналогичные результаты.

Работа выполнена в Университете Лунд и в Лаборатории ядерных проблем ОИЯИ.

1. Introduction

Recent interest in profound studies of the Bose–Einstein correlations in Z^0 hadronic decays in e^+e^- annihilation arose mainly in connection to the predictions that the W mass measured in hadronic W^+W^- events can have a shift of about 100 MeV due to the Bose-Einstein effects [1]. Being separated in space and time by distances much smaller than typical source radii, the W^+ and W^- source regions overlap, which means that the Bose-Einstein effects on the hadronization stage can couple identical bosons from $W^+$and W^-.

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So far, only phenomenological models are used to describe the hadronization process and Bose-Einstein effects in particular. Studies of the identical-boson correlations in e^+e^- annihilation processes at LEP energies up to now were concentrated on the shape of the correlation function in terms of the invariant four-momentum difference of particles Q, [2—4] while at lower energies several collaborations studied Bose-Einstein correlations using two-dimensional distributions in components of Q [5].

High-energy heavy-ion collision experiments developed precision methods for the boson interferometry studies [6—7] to obtain information on the space-time development of the particle emitting source. Analysis performed for three components of the momentum difference of two identical bosons shows a transverse mass dependence of the correlation radii, [7,8] which is described by hydrodynamical models of the particle source expansion.

Here, a similar analysis of the Z^0 hadronic decays is presented. Two-particle correlations are studied as a function of three components of the four-momentum difference in different transverse mass m_t intervals. Results are compared to those obtained from the analysis of JETSET [9] generated events.

2. Data Selection

Data collected by the DELPHI detector [10] in 1991—1994 at centre-of-mass energies around $\sqrt{s} = 91.2$ GeV ($86.2 \leq \sqrt{s} \leq 94.2$ GeV) are used.

Only charged particles in hadronic events are involved in the analysis. In the barrel region they are measured by a set of cylindrical tracking detectors in the solenoidal magnetic field of 1.2 T. The main tracking device was the Time Projection Chamber (TPC). Additional $R\varphi$ measurements are provided by the Outer Detector (OD) and the Inner Detector (ID). In the forward direction (θ between 11° and 33° and between 147° and 169°) charged particles are measured by a set of planar drift chambers FCA and FCB.

Tracks were taken into account if their impact parameter was below 5 cm in the transverse plane and below 10 cm along the beam axis, measured track length was above 50 cm, momentum between 0.1 GeV/c and 50 GeV/c and polar angle between 11° and 169°.

Hadronic events were then selected by requiring that they contain at least 5 charged particles with momentum above 0.2 GeV/c, the total energy of all charged particles exceeded 15 GeV (assuming the $\pi^\pm$ mass for particles), having at least 3 GeV in each hemisphere with respect to the sphericity axis, the latter with a polar angle between 26° and 154°. The momentum imbalance was restricted to 20 GeV/c.

Only two-jet events were selected for this analysis. The selection was done using the LUCLUS [9] clustering algorithm (with parameter $d_{\mathrm{join}} = 2.7$), requiring also the thrust value to be more than 0.95 and the jet opening angle to be at least 175°. A total of about 670,000 events satisfied those criteria.

For reason of comparison, the same analysis was performed using DELPHI tuned [11] JETSET PS generated events (Bose-Einstein effects included) with the SELSIM [12] detector simulation.

3. Analysis and Results

The correlation function of two identical bosons is defined as

$$C(p_1, p_2) = \frac{P(p_1, p_2)}{P(p_1)\, P(p_2)}, \qquad (1)$$

where p_1 and p_2 are four-momenta of two particles, $P(p_1, p_2)$ is the two-particle probability density, while $P(p_1)$ and $P(p_2)$ represent single-particle probability densities. In the hypothetical case of absence of two-particle correlations, the product $P(p_1)\, P(p_2)$ is equivalent to $P(p_1, p_2)$. Therefore it is convenient to use as the denominator in (1) an artificially created Bose–Einstein correlation-free two-particle distribution.

Measuring the four-momentum differences $Q = \sqrt{-(p_1 - p_2)^2}$, one can rewrite Eq.(1) in the form

$$C(Q) = \frac{N^{\pm\pm}(Q)}{N^{\pm\pm}_{\text{mix}}(Q)}, \qquad (2)$$

where $N^{\pm\pm}(Q)$ is the number of like-charge particles with four-momentum difference Q, and $N^{\pm\pm}_{\text{mix}}(Q)$ is the same quantity built from a sample of non-correlated particles. Such a sample was constructed by picking particles randomly from different events. Since this procedure of mixing particles violates energy-momentum conservation and affects the normalization, the correlation function (2) is corrected with the help of JETSET generated events without Bose–Einstein effects included. Thus the two-particle correlation function used in this analysis is defined as

$$C(Q) = \frac{[N^{\pm\pm}(Q) / N^{\pm\pm}_{\text{mix}}(Q)]_{\text{data}}}{[N^{\pm\pm}(Q) / N^{\pm\pm}_{\text{mix}}(Q)]_{\text{JETSET}}}. \qquad (3)$$

The analysis is done in the Longitudinal Centre-of-Mass System (LCMS) of the pair. This is the system in which the sum of the two particles momenta is perpendicular to the jet axis. The momentum difference of the particle pair Q is resolved into Q_{long}, parallel to the jet axis, $Q_{t,\,\text{out}}$, collinear with the pair momentum sum, and complementary $Q_{t,\,\text{side}}$, perpendicular to Q_{long} and $Q_{t,\,\text{out}}$. A schematic picture of LCMS is shown in Fig.1 in projection into the (Q_{long}, $Q_{t,\,\text{out}}$) plane. In this system, projections of the total momentum of the pair into the «longitudinal» and «side» directions are equal to zero.

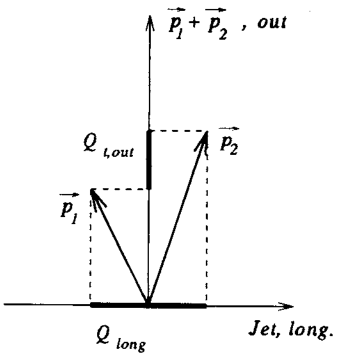

Fig.1. LCMS projection on the (Q_{long}, $Q_{t,\,\text{out}}$) plane

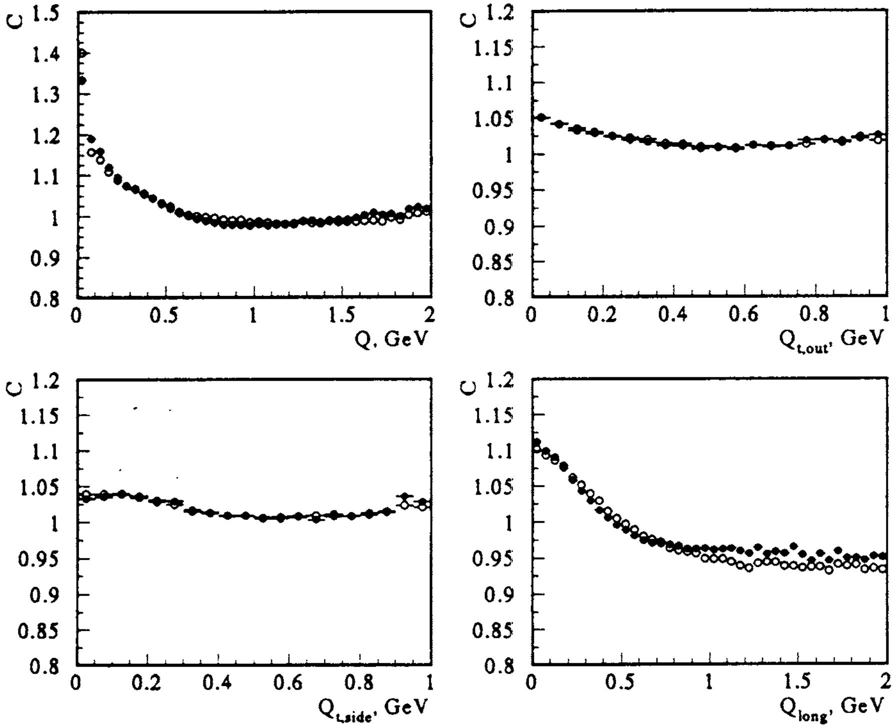

Fig.2. Correlation functions $C(Q)$, $C(Q_{t,\,\mathrm{out}})$, $C(Q_{t\,\mathrm{side}})$ and $C(Q_{\mathrm{long}})$ obtained from the DELPHI data (closed circles)and JETSET + DELSIM simulated events (open circles)

The difference in emission time of the particles couples to the energy difference between the particles only in the $Q_{t,\,\mathrm{out}}$ direction [13].

An example for the behaviour of the correlation function (3) and its components, $C(Q_{t,\,\mathrm{out}})$, $C(Q_{t,\,\mathrm{side}})$ and $C(Q_{\mathrm{long}})$ is shown in Fig.2. Results obtained from the DELPHI data are compared to those from JETSET + DELSIM simulated events. While both transverse components of the total correlation function are in good agreement, the longitudinal component shows slightly different behaviour in data and JETSET.

If three projections of Q are known, it is possible to construct a three-dimensional correlation function $C \equiv C(Q_{t,\,\mathrm{out}}, Q_{t,\,\mathrm{side}}, Q_{\mathrm{long}})$. Using the common assumption about a Gaussian shape of the correlation function in all three dimensions it is convenient to parametrize this three-dimensional function as

$$C = N[1 + \lambda \exp(-R^2_{t,\,\mathrm{out}}Q^2_{t,\,\mathrm{out}} - R^2_{t,\,\mathrm{side}}Q^2_{t,\,\mathrm{side}} - R^2_{\mathrm{long}}Q^2_{\mathrm{long}}] \times$$

$$\times (1 + \delta_{t,\,\mathrm{side}}Q_{t,\,\mathrm{side}} + \delta_{t,\,\mathrm{out}}Q_{t,\,\mathrm{out}} + \delta_{\mathrm{long}}Q_{\mathrm{long}}). \tag{4}$$

By fitting the correlation function by eq.(4) one can extract the correlation radii, $R_{t,\,\mathrm{out}}$, $R_{t,\,\mathrm{side}}$ and R_{long}.

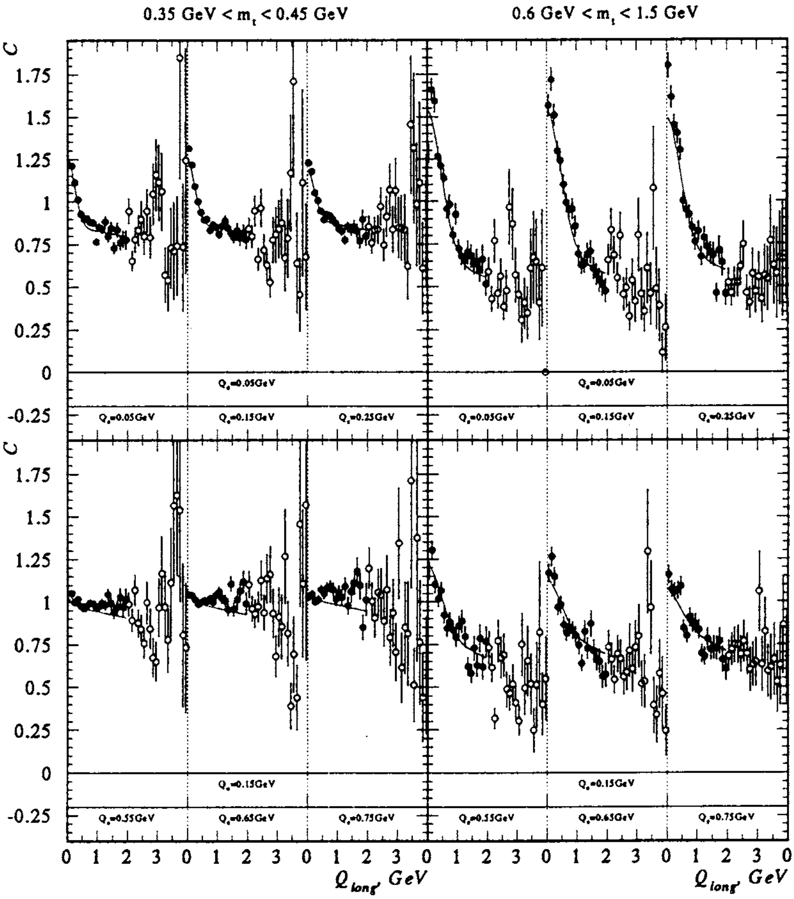

Fig.3. One-dimensional representation of the fit of the correlation function $C(Q_{t,\,\mathrm{out}}, Q_{t,\,\mathrm{side}}, Q_{\mathrm{long}})$ by the formula (4).Only closed circles participated in the fit

Studies of Bose–Einstein effects in heavy-ion collisions at CERN SPS by the experiments NA44 [7] and NA35/NA49 [8] revealed that the extracted radii parameters show an approximate $1/\sqrt{m_t}$ dependence, where m_t is the average transverse mass of two particles. This behaviour is consistent with hydrodynamical models describing the pion source evolution in high-energy heavy-ion collisions. [14]¯ [20]. Thus it is of particular interest to investigate the dependence of the interferometric parameters $R_{t,\,\mathrm{out}}$, $R_{t,\,\mathrm{side}}$ and R_{long} on the transverse mass m_t in electron-positron annihilation.

The available DELPHI statistics allows us to split all the data into five m_t intervals (see the Table). In each of them a fit by the function (4) was performed. An example of the one-dimensional representation of this fit is shown in Fig.3. The fit was done in the region

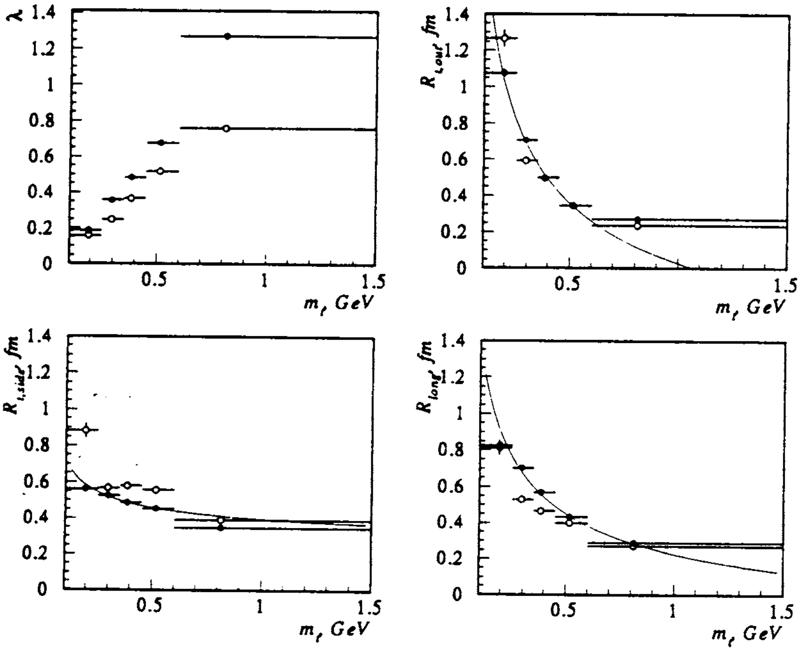

Fig.4. Transverse mass dependence of parameters of the fit of the correlation function $C(Q_{t,\,\mathrm{out}}, Q_{t,\,\mathrm{side}}, Q_{\mathrm{long}})$ by the formula (4). Closed circles represent the DELPHI data, while open circles — JETSET + DELSIM simulation. Points are placed at the mean m_t values in bins indicated with horizontal bars. Curves show the $R \propto 1/\sqrt{m_t}$ fit to the data

Table. Parameters of the fit of the correlation function $C(Q_{t,\,\mathrm{out}}, Q_{t,\,\mathrm{side}}, Q_{\mathrm{long}})$ by the formula (4) for $Q_{t,\,\mathrm{out}} < 1$ GeV, $Q_{t,\,\mathrm{side}} < 1$ GeV and $Q_{\mathrm{long}} < 2$ GeV

$\langle m_t \rangle$ (GeV)	χ^2/ndf	λ	$R_{t,\,\mathrm{out}}$ (fm)	$R_{t,\,\mathrm{side}}$ (fm)	R_{long} (fm)
0.19	834/330	0.187 ± 0.005	1.08 ± 0.04	0.55 ± 0.02	0.83 ± 0.04
0.30	1713/757	0.357 ± 0.006	0.71 ± 0.01	0.526 ± 0.010	0.70 ± 0.01
0.38	3172/1272	0.482 ± 0.009	0.498 ± 0.010	0.487 ± 0.008	0.567 ± 0.010
0.52	4880/1927	0.68 ± 0.01	0.343 ± 0.006	0.451 ± 0.006	0.431 ± 0.006
0.81	3354/1992	1.27 ± 0.03	0.272 ± 0.004	0.366 ± 0.006	0.288 ± 0.004

of $Q_{t,\,\mathrm{out}} < 1$ GeV, $Q_{t,\,\mathrm{side}} < 1$ GeV and $Q_{\mathrm{long}} < 2$ GeV (closed circles in Fig.3), which is statistically well populated.

Results of the fit are listed in the Table and are shown in Fig.4. It is clearly seen that the correlation radii decrease with increasing m_t. This decrease is approximately proportional to $1/\sqrt{m_t}$. Low values of the λ parameter at small m_t can be explained by the presence of resonance decay products in this region. At high m_t their contribution vanishes, thus raising λ.

4. Conclusion

Analysis of the dimensional- and m_t-dependence of the Bose–Einstein effects using the 1991—1994 DELPHI data showed strong dependence of all the components of the correlation radius on m_t. Similar dependence is observed in simulated JETSET events, although in general JETSET fails to give a fair description of the observed effects. Growth of the λ parameter is readily explained by the vanishing of resonance decay contribution with increasing m_t. A popular explanation of the observed m_t dependence of radii in the data is that it is also due to resonance decays: resonances do propagate out of the primary pion source, and pions produced in their decays do have comparatively low momenta. Therefore the effective size of the source increases at low m_t values. This explanation cannot possibly be valid for JETSET generated events, since the resonance propagation is not included in this generator. Therefore, further investigations of the effect have to be done.

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