STUDY ON THE ENERGY DEPENDENCE OF THE SOURCE SIZE OF JETS BY THE HBT CORRELATION METHOD IN e^+e^- COLLISIONS*

Chen Zheng-Yu, Chen Gang†, Wang Mei-Juan, Xie Yi-Long
Liang Zhu

Physics Department, School of Mathematics and Physics
China University of Geosciences
430074 Wuhan, China

(Received March 11, 2013; revised version received May 29, 2013; final version received November 4, 2013)

The energy dependence of the source size of jets are studied in detail by the HBT correlation method using Monte Carlo Simulation generator Jetset7.4 to produce 40,000,000 events of e^+e^- collisions at $\sqrt{s} = 30$, 50, 70, 91.2, 110, 130, 150 and 170 GeV, respectively. The source size of jets are measured using the HBT correlation method with the indistinguishability of identical final state pions. The average source radii of quark-jets and gluon-jets in e^+e^- collisions are obtained at the end of parton evolvement. It is found that the average source radii of quark-jets are obviously larger than those of gluon-jets and the average source radii measured with π^0 meson are smaller than those with π^+ or π^- meson.

DOI:10.5506/APhysPolB.45.1089
PACS numbers: 13.87.Fh, 13.66.Bc

1. Introduction

It was well-known that Hanbury-Brown and Twiss had brought forward HBT correlation in the process of measuring the angular radii of the emitting sources in 1956 [1–3]. Later, the HBT correlation was widely used in subatom studies [4–6]. The HBT correlation method has been an important way to measure the size of the emitting sources in high energy collisions. Due to "color confinement", we cannot observe free quarks and gluons, and cannot yet measure the size of them directly. However, the HBT correlation

* Funded by SCOAP³ under Creative Commons License, CC-BY 3.0.
† Corresponding author: chengang1@cug.edu.cn

method offers a viable indirectly method, by applying this method to the high energy collisions we could obtain some geometrical characteristics of quarks and gluons.

Historically, the discovery in 1975 of a two-jet structure [7] in e^+e^- collisions at center-of-mass (c.m.) energy ≥ 6 GeV had been taken as an experimental confirmation of the parton model [8], and the observation in 1979 of a three-jet structure in e^+e^- collisions at 17–30 GeV had been recognized as the first experimental evidence of the gluon [9–12]. In the early 1990s, the production of jets in hadron–hadron collisions was widely studied [13–15] and had been considered as an efficient way to obtain the strong coupling constant α_{s} [16]. The method of distinguishing jets and the study on jets are also very important, in relativistic heavy ion collisions [17, 18].

In e^+e^- collisions [19], firstly, the e^+e^- pair is annihilated into a virtual γ^*/Z^0 resonance. The virtual γ^*/Z^0, in turn, decays into a $q\bar{q}$ pair. Then, the initial $q\bar{q}$ may radiate other gluons and $q\bar{q}$ pairs, giving rise to a cascade process. This stage is responsible for the formation of hadronic jets. Further, the unstable hadrons decay into experimentally observable particles (mostly pions). It has been found that the majority of e^+e^- collision events have a 2-jet structure. If an initial quark or anti-quark emits a hard gluon with sufficiently large transverse momentum, a 3-jet structure can be formed.

Although the quark and gluon, before being observed, have fragmented into the final state hadrons, the final state particles inside the jets still carry a lot of information about the parent quarks and gluons. Since the source of a single jet is from a single initial quark (or anti-quark) or gluon, so we may obtain some information about the quark or gluon through studying characteristics of the final state hadrons inside a jet. The source size of a jet measured by HBT correlation method really reflects the geometrical characteristics of the quark or gluon producing this jet. The quark and gluon are two different types of particles. For example, the quark is a fermion with color charge equal to 4/3, while the gluon is a boson, carrying color charge 3. These differences will certainly influence their fragmentation, resulting in different properties of quark-jets and gluon-jets. So, the study of the geometrical characteristics of the jets would be helpful in understanding of the perturbative/nonperturbative properties of QCD.

In Ref. [20], a space-time parton-shower model was used to reproduce successfully the size of the hadron emission region for e^+e^- annihilation into hadrons. The geometrical characteristics of quark-jets and gluon-jets have been studied with the HBT correlation method using Monte Carlo Simulation generator Jetset7.4 producing quark-jets and gluon-jets in 3-jet events of e^+e^- collisions at $\sqrt{s} = 91.2$ GeV [21]. In the experiment, HBT correlations have been studied [22–24] in e^+e^- annihilations at LEP $\sqrt{s} = 91.2$ GeV. However, do the sizes of quark-jets and gluon-jets depend on the c.m. energy of e^+e^- collisions producing these jets? Are the sizes of quark-jets measured in 3- and 2-jets events of e^+e^- collisions the same? Our work will focus on these questions.

It is noteworthy that several theoretical predictions exist for differences in BEC for pairs of bosons in the pion isospin triplet (π^+, π^-, π^0). Such as from the string model [25] a smaller spatial emission region, *i.e.*, a wider momentum correlation distribution is expected for $\pi^0\pi^0$, than for $\pi^\pm\pi^\pm$. This follows from the break-up of the string into $q\bar{q}$ pairs, which forbids two equally charged pions to lie next to each other on the string, whereas two neutral pions can. The same effect is found when the probabilistic string break-up rule is interpreted as the square of a quantum mechanical amplitude [26]. From a quantum statistical approach to Bose–Einstein symmetry [27], a small difference between $\pi^\pm\pi^\pm$ and $\pi^0\pi^0$ correlation is expected. The size and shape of this difference is predicted to be similar to an expected Bose–Einstein correlation of $\pi^\pm$ pairs. These have been also confirmed experimentally [23].

The paper is organized as follows: In Sec. 2, we briefly introduce the method of identifying jets and the HBT correlation function. In Sec. 3, the average source radius of quark-jets and gluon-jets in 2-jet events are calculated. In Sec. 4, the average source radius of quark-jets and gluon-jets in 3-jet events are calculated. A short summary is the content of Sec. 5.

2. Jet identification method and the HBT correlation function

In our work, the data of e^+e^- collision events are produced by Monte Carlo Simulation generator Jetset7.4. The 2-jet events and the 3-jet events are selected using the Durham jet algorithm [28]. The jet resolution parameter $y_{\rm cut}$ used in this algorithm is essentially the relative transverse momentum squared of the jets that are being combined [29],

$$k_{\rm t} = \sqrt{y_{\rm cut}} \times \sqrt{s}\,, \tag{1}$$

where $\sqrt{s}$ is the c.m. energy of the collision. The fraction of 2-jet events or 3-jet events obtained with the jet-algorithm depends on the parameter $y_{\rm cut}$ [30]. From the point of experiments, $k_{\rm t}$ can be taken as the transition scale between the hard and soft processes [31]. Its value depends on the definition of "jet". It should be noted that this parameter's dependence on $y_{\rm cut}$ will have some impacts on our results.

The single quark-jet and single gluon-jet are identified from 3-jet events using the angular rule [32]. We assume that the three jets in a 3-jet event come from quark, anti-quark and gluon, respectively. Because of energy-momentum conservation, the three jets in one event must lie in a plane, which is shown in Fig. 1, where $P_i (i = 1, 2, 3)$ is the total momentum of all particles in jet-i. The jets are tagged using the angles between them:

$$\theta_i = \arccos\left(\frac{P_{j1}P_{k1} + P_{j2}P_{k2} + P_{j3}P_{k3}}{\sqrt{P_{j1}^2 + P_{j2}^2 + P_{j3}^2}\sqrt{P_{k1}^2 + P_{k2}^2 + P_{k3}^2}}\right), \quad (i, j, k = 1, 2, 3;\ i \neq j;\ j \neq k;\ k \neq i)\,, \tag{2}$$

where the largest angle, θ_3, faces the gluon jet; the smallest angle, θ_1, faces the jet formed by an initial quark without emitting a hard gluon; and the middle one, θ_2, faces the mother-quark-jet.

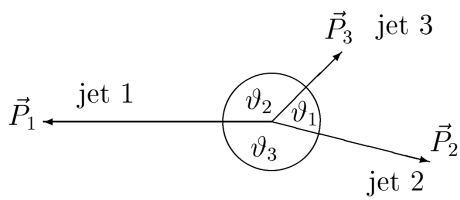

Fig. 1. The sketchy map of the 3-jet distribution.

According to the requirement of momentum conservation, the three jets must lie in a plane, and we add the condition: $\theta_1 + \theta_2 + \theta_3 > 359^\circ$ [32].

The HBT correlation, also called the Bose–Einstein correlation, results from the indistinguishability of identical final state particles. Most of the final state particles produced in e^+e^- collisions are π mesons, so we choose π mesons (π^+, π^-, π^0) as the identical particles to study. If $P(k_1, k_2)$ is defined as the probability of observing two identical pions at the same time with momentum k_1 and k_2, and $P(k_1)$ and $P(k_2)$ are defined as the probability of observing pions with the momentum k_1 and k_2, respectively. The correlation function $C_2(k_1, k_2)$ is defined as

$$C_2(k_1, k_2) = \frac{P(k_1, k_2)}{P(k_1)P(k_2)}\,. \tag{3}$$

If the equivalent density function of the source is parameterized with the Gaussian form, we have

$$C_2(k_1, k_2) = 1 + \lambda \exp\left\{-R_x^2 q_x^2 - R_y^2 q_y^2 - R_z^2 q_z^2 - \sigma_t^2 q_t^2\right\}\,, \tag{4}$$

where $q = k_1 - k_2$ is the four-dimensional momentum difference.

If only the spatial part of the source is considered and assume that the distribution of the source is isotropic, the correlation function can be simplified as

$$C_2(k_1, k_2) = 1 + \alpha \exp\left\{-R^2 Q^2\right\}\,, \tag{5}$$

where $\vec{Q} = \vec{k_1} - \vec{k_2}$ is the three-dimensional momentum difference. According to the definition, jets do not possess spherical symmetry, but are axially symmetric instead. So the distribution of jet source may be elliptical symmetry. In order to simplify the calculation, we assume that the distribution of the source is "spherically symmetric", then the results as following are all amounts to measuring "average size" of the jet source for the longitudinal and transverse. Furthermore, in this paper, we study the average source radii R of jets only through the spatial distribution function of the pion meson, which should be the result of a certain impact.

The three-dimensional momentum interval region chosen is $Q = 0 \sim 2.5$ GeV/c, and is equally divided into 50 cells. We use Monte Carlo simulation generator Jetset7.4 to produce e^+e^- collision events both with and without HBT correlation, and then select suitable events for study. Identical π mesons are selected from the final state particles to make pion pairs after any two π mesons are grouped with each other. The three-dimensional momentum difference of the π meson pairs are calculated. The correlation function (also called correlation coefficient) with statistical method is

$$C_2(k_1, k_2) = C_2(Q) = \frac{F_c(Q)}{F(Q)}\,, \tag{6}$$

where $F_c(Q)$ is the three-dimensional distribution function of the identical particles with HBT correlation inside the jets and $F(Q)$ is the three-dimensional distribution function of the identical particles without HBT correlation inside the jets. Since the correlation among identical particles with large momentum difference is close to zero, the distribution here with the HBT correlation should be almost the same as the distribution without the HBT correlation. So the $C_2(Q)$ can be multiplied by a coefficient to make the value of it equal to 1. Thus, using Eq. (5) to calculate the average source radii R, the Eq. (6) can be expressed as

$$C_2(Q) = \frac{F_c(Q)}{F(Q)} = \eta\left(1 + \alpha \exp\left(-R^2Q^2\right)\right)\,, \tag{7}$$

where η is the value of the correlation function $C_2(Q)$ at a large momentum interval.

3. The measurement of source radii inside jets of 2-jet events

We use Monte Carlo simulation generator Jetset7.4 to produce 40 millions e^+e^- collisions events for each energy separately at energies $\sqrt{s} = 30$, 50, 70, 91.2, 110, 130, 150, 170 GeV. Then the 2-jet events are selected from above event samples using the Durham jet algorithm to form event sub-samples, and the corresponding number of events are about 17.83,21.60, 23.46, 23.85, 25.67, 25.92, 25.91 and 25.74 millions with the c.m. energy as above, respectively.

The 2-jet event is constituted by the two jets which are formed by the fragmentation of the back-to-back $q\bar{q}$. And the two jets are called quark jet-1 and quark jet-2, respectively. Due to the back-to-back symmetry of the two jets formed by the fragmentation of the $q\bar{q}$, the distribution patterns of the two jets should be totally the same. So, we just need to study one of the two jets. We will choose quark jet-1 which is referred to as quark-jet.

The process of measuring average source radii of quark-jets by HBT method using π^+ mesons, for instance, is as following:

Firstly, the π^+ mesons are selected from final state particles within the quark jets as the identical particles. Then, the correlation function is produced both with and without HBT correlations for π^+ mesons, where the three-dimensional momentum interval region of the identical π^+ mesons is chosen as $Q = 0 \sim 2.5$ GeV and is equally divided into 50 cells. An average over events is required at the end. According to Eq. (6), we calculate the value of the correlation function $C_2(Q)$ of π^+ mesons inside quark-jets from 2-jet events. At last, the average radii of emitting source for quark-jet can be obtained through fitting the correlation functions $C_2(Q)$ of π^+ meson inside quark-jet using Eq. (7). In the same way, we can also get average source radii of quark-jets from 2-jet events with π^-, π^0 mesons at all the 8 different c.m. energies, respectively. All results are shown in Table I, respectively. As an example, the results for 3 c.m. energies are shown in Fig. 2.

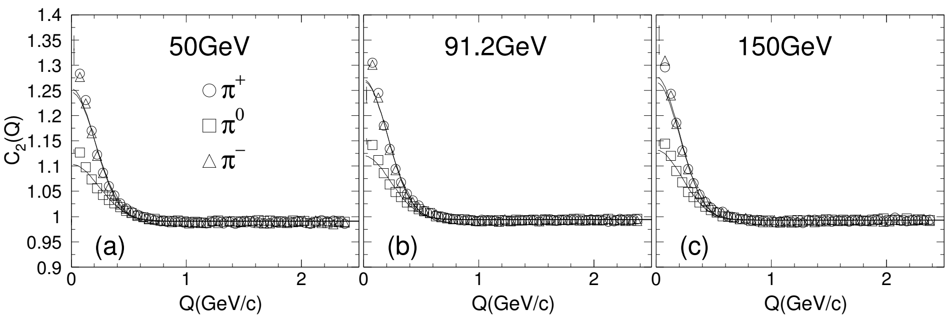

Fig. 2. The distributions of correlation functions of quark-jet from 2-jet events in e^+e^- collisions at different c.m. energies. The values of c.m. energies are (a) 50 GeV, (b) 91.2 GeV, (c) 150 GeV, respectively. The data are produced by Monte Carlo simulation generator Jetset7.4. The curves are fitted by Eq. (7).

TABLE I

The parameters fitted by Eq. (7) from quark-jets in 2-jet events at different c.m. energies for π^+, π^0 and π^- mesons, respectively.

π	$\sqrt{s}$ [GeV]	η	α	R [fm]
π^+	30	0.9852±0.0003	0.258±0.003	0.704±0.006
	50	0.9903±0.0002	0.258±0.002	0.662±0.004
	70	0.9932±0.0002	0.280±0.002	0.703±0.004
	91.2	0.9937±0.0002	0.276±0.002	0.672±0.003
	110	0.9934±0.0002	0.289±0.002	0.697±0.003
	130	0.9930±0.0002	0.286±0.002	0.710±0.004
	150	0.9930±0.0003	0.285±0.003	0.693±0.005
	170	0.9945±0.0003	0.288±0.003	0.705±0.004
π^-	30	0.9845±0.0003	0.266±0.003	0.708±0.006
	50	0.9913±0.0003	0.264±0.002	0.686±0.004
	70	0.9919±0.0002	0.281±0.002	0.688±0.004
	91.2	0.9947±0.0002	0.277±0.002	0.684±0.004
	110	0.9932±0.0002	0.272±0.003	0.678±0.004
	130	0.9932±0.0002	0.283±0.002	0.679±0.003
	150	0.9934±0.0003	0.274±0.003	0.685±0.005
	170	0.9944±0.0002	0.299±0.003	0.715±0.004
π^0	30	0.9877±0.0003	0.103±0.001	0.553±0.007
	50	0.9912±0.0002	0.114±0.001	0.580±0.006
	70	0.9931±0.0002	0.120±0.001	0.577±0.005
	91.2	0.9940±0.0002	0.127±0.001	0.607±0.006
	110	0.9932±0.0002	0.126±0.001	0.593±0.004
	130	0.9939±0.0002	0.131±0.001	0.616±0.005
	150	0.9933±0.0002	0.139±0.002	0.624±0.007
	170	0.9944±0.0002	0.142±0.002	0.650±0.008

From Fig. 2 it is clear that the distributions of correlation functions of the π mesons inside quark-jets at different c.m. energies are similar. Especially, the distributions of π^+ and π^- mesons are in superposition. However, the distributions of identical particles π^0 mesons are different to those of π^+ and π^- mesons.

Furthermore, we can see from Table I that the correlation strength α and the average source radii R for π^+ mesons are close to those of π^-, and the correlation strength α and the average source radii R for π^0 mesons are less than those of charged pions. The correlation strength for charged pions π^+ or π^- is over twice as that for neutral pions π^0.

For the convenience, we draw the average source radii of the three kinds of π mesons inside quark-jets for all c.m. energies in Fig. 3. The figure shows that the average source radii R of quark-jets measured using π^+ or

π^- mesons at different c.m. energies are in a narrow region fluctuations, and the average source radii R for π^0 mesons is linearly growing with c.m. energy. Their mean radii for all the c.m. energies calculated from Table I are $\overline{R}_{q,\pi^+} = 0.693 \pm 0.003$ fm, $\overline{R}_{q,\pi^-} = 0.690 \pm 0.004$ fm and $\overline{R}_{q,\pi^0} = 0.600 \pm 0.006$ fm.

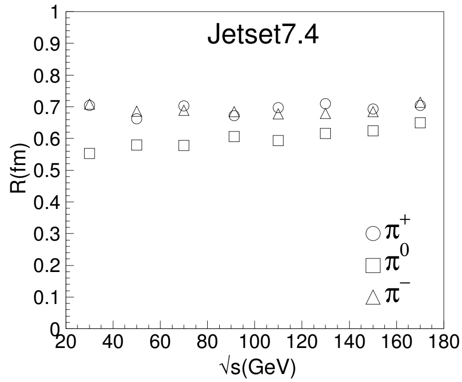

Fig. 3. The comparison of the values of the average source radii R of quark-jet from 2-jet events for different types of π mesons (π^+, π^-, π^0) at different c.m. energies.

4. The measurement of source radii inside jets of 3-jet events

In the same way, we use Monte Carlo simulation generator Jetset7.4 to produce 40 millions events of e^+e^- collisions for 8 c.m. energies separately. Then the 3-jet events are selected from above event samples using the Durham jet algorithm to form event sub-samples, and the corresponding number of events are about 1.033, 2.270, 3.381, 3.355, 3.637, 3.404, 3.485 and 3.646 millions with the energy of $\sqrt{s} = 30$, 50, 70, 91.2, 110, 130, 150, 170 GeV, respectively. At last, the quark-jet, mother quark-jet and gluon-jet are identified from 3-jet events using the angular rule.

After the final state pions (π^+, π^-, π^0) chosen from the quark-jet, mother quark-jet and gluon-jet as the identical particles are identified, the correlation function is produced both for the case with and without HBT correlation when the three-dimensional momentum interval region of the identical π mesons is chosen as $Q = 0 \sim 2.5$ GeV$/c$. We calculate the value of $C_2(Q)$ according to Eq. (6), then the average radius size of emitting source of pion inside single jet can be obtained through fitting the correlation functions $C_2(Q)$ using Eq. (7) with π^+, π^- and π^0 mesons, respectively. The results of quark-jet and gluon-jet are listed in Table II and Table III. As an example, the results for 3 c.m. energies are shown in Fig. 4.

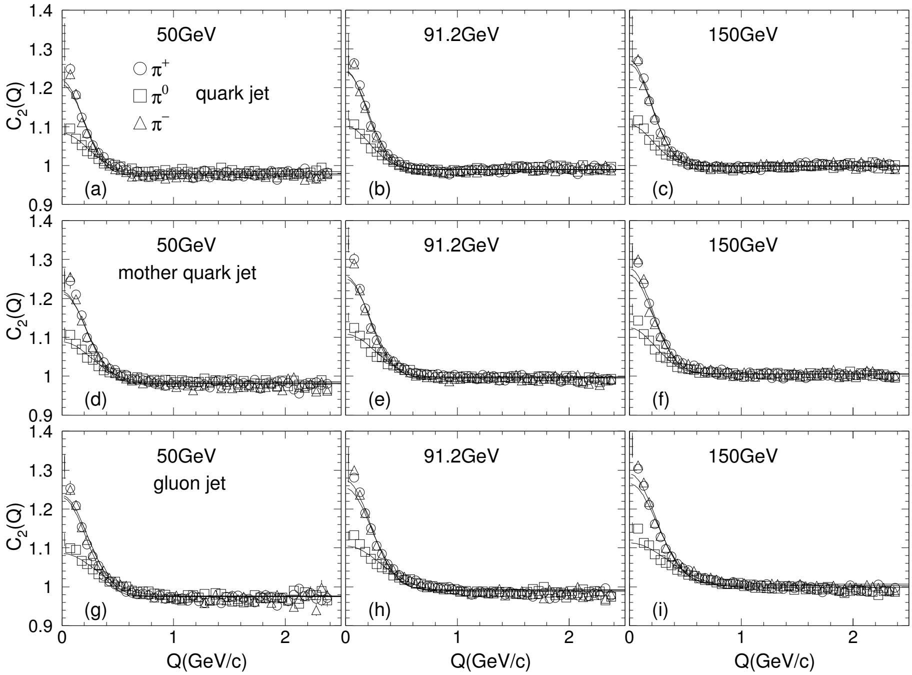

Fig. 4. The distributions of π meson correlation functions of the three kinds of jets from 3-jet events in e^+e^- collisions at different c.m. energies. The first row is for the case of quark-jets; the second row is for the case of mother quark-jets; the third row is for the case of gluon-jets. The c.m. energies of (a), (d) and (g) are 50 GeV; (b), (e) and (h) are 91.2 GeV; (c), (f) and (i) are 150 GeV, respectively. The data are produced by Monte Carlo simulation generator Jetset7.4. The curves are fitted by Eq. (7).

It is easy to come to the conclusion from Fig. 4 that the distributions of correlation functions with π^+ and π^- mesons for quark-jets, mother quark-jets and gluon-jets are nearly in superposition, and the distributions of correlation functions with π^0 mesons are different to those of π^+ or π^- mesons.

It can be seen from Table II and Table III that the average source radii of quark-jets are obviously larger than those of gluon-jets, and the correlation strength α of quark-jets are approximately equal to those of gluon-jets. However, the correlation strength α and the average source radii R for π^+ mesons are close to those of π^- mesons, and the correlation strength α and the average source radii R for π^0 mesons are less than those of charged π^+ or π^- pions. The correlation strength of the charged π^+ or π^- are over twice as to those of the neutral π^0.

TABLE II

The parameters fitted by Eq. (7) from quark-jets in 3-jet events at different c.m. energies for π^+, π^0 and π^- mesons, respectively.

π	$\sqrt{s}$ [GeV]	η	α	R [fm]
	30	0.957±0.002	0.190±0.009	0.60±0.03
	50	0.9791±0.0009	0.233±0.009	0.72±0.02
	70	0.9775±0.0007	0.262±0.007	0.73±0.02
π^+	91.2	0.9899±0.0007	0.252±0.007	0.71±0.02
	110	0.9884±0.0006	0.260±0.007	0.74±0.02
	130	0.9958±0.0007	0.255±0.006	0.74±0.02
	150	0.9992±0.0006	0.261±0.008	0.73±0.02
	170	1.0041±0.0007	0.254±0.007	0.75±0.02
	30	0.964±0.002	0.23±0.01	0.76±0.03
	50	0.9757±0.0009	0.248±0.008	0.75±0.03
	70	0.9799±0.0006	0.256±0.006	0.72±0.02
π^-	91.2	0.9894±0.0006	0.256±0.006	0.75±0.02
	110	0.9908±0.0006	0.266±0.006	0.73±0.02
	130	0.9950±0.0006	0.266±0.007	0.75±0.02
	170	1.0028±0.0007	0.255±0.006	0.72±0.02
	30	0.972±0.001	0.092±0.004	0.44±0.03
	50	0.9840±0.0007	0.101±0.003	0.60±0.02
	70	0.9811±0.0006	0.109±0.003	0.61±0.02
π^0	91.2	0.9908±0.0005	0.112±0.004	0.67±0.02
	110	0.9908±0.0005	0.116±0.003	0.64±0.02
	130	0.9956±0.0005	0.106±0.003	0.60±0.02
	150	0.9977±0.0005	0.108±0.003	0.67±0.02
	170	1.0023±0.0007	0.113±0.004	0.66±0.03

For the convenience of comparison, we draw the average source radii of the three kinds of jets at different c.m. energies for the three types of π mesons in Fig. 5. It can be seen from Fig. 5 that the average source radii R of quark-jets or mother quark-jets and or gluon-jets are in a narrow region fluctuations, respectively. The mean radius of quark-jets for all c.m. energies with π^+ mesons is 0.71 ± 0.02 fm, the mean radius of mother quark-jets is 0.67 ± 0.01 fm, and the mean radius of gluon-jets is 0.59 ± 0.01 fm. The mean radius of quark-jets for all c.m. energies with π^0 mesons is 0.61 ± 0.02 fm, the mean radius of mother quark-jets is 0.55 ± 0.02 fm, and the mean radius of gluon-jets is 0.43 ± 0.01 fm. The mean radius of quark-jets for all c.m. energies with π^- mesons is 0.74 ± 0.01 fm, the mean radius of mother quark-jets is 0.68 ± 0.02 fm, and the mean radius of gluon-jets is 0.60 ± 0.01 fm, respectively.

TABLE III

The parameters fitted by Eq. (7) from gluon-jets in 3-jet events at different c.m. energies for π^+, π^0 and π^- mesons, respectively.

π	$\sqrt{s}$ [GeV]	η	α	R [fm]
	30	0.951±0.002	0.23±0.01	0.69±0.03
	50	0.974±0.001	0.262±0.007	0.66±0.02
	70	0.9731±0.0006	0.242±0.004	0.54±0.01
π^+	91.2	0.9917±0.0007	0.283±0.004	0.64±0.01
	110	0.9930±0.0007	0.245±0.004	0.55±0.01
	130	1.0005±0.0007	0.245±0.004	0.56±0.01
	150	1.0023±0.0006	0.262±0.004	0.56±0.01
	170	1.0088±0.0008	0.243±0.005	0.55±0.01
	30	0.954±0.002	0.232±0.009	0.67±0.02
	50	0.975±0.001	0.265±0.005	0.62±0.02
	70	0.9792±0.0007	0.276±0.004	0.60±0.01
π^-	91.2	0.9906±0.0007	0.265±0.005	0.61±0.01
	110	0.9930±0.0007	0.246±0.004	0.55±0.01
	130	0.9987±0.0007	0.260±0.005	0.57±0.01
	150	1.0070±0.0007	0.281±0.004	0.60±0.01
	170	1.0113±0.0007	0.254±0.006	0.59±0.01
	30	0.957±0.002	0.120±0.004	0.48±0.02
	50	0.977±0.001	0.111±0.003	0.46±0.02
	70	0.9778±0.0007	0.121±0.002	0.42±0.01
π^0	91.2	0.9882±0.0009	0.118±0.002	0.44±0.02
	110	0.9915±0.0007	0.119±0.002	0.42±0.01
	130	0.9961±0.0008	0.111±0.002	0.41±0.01
	150	0.9987±0.0007	0.114±0.002	0.41±0.01
	170	1.0090±0.0008	0.111±0.002	0.44±0.02

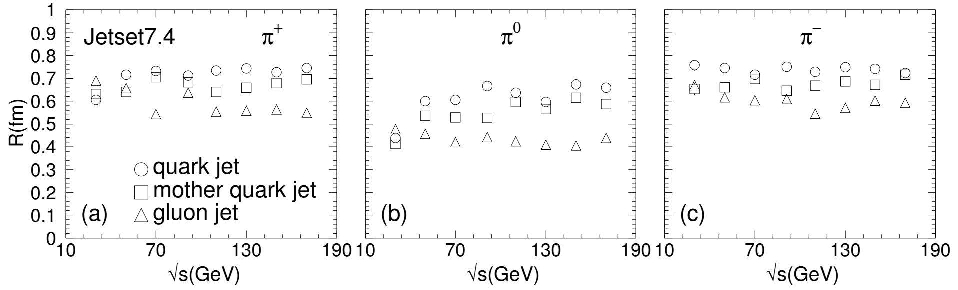

Fig. 5. The comparison of the average values of the source radii R of the three kinds of jets from 3-jet events at different c.m. energies for different π mesons, (a) π^+, (b) π^0, (c) π^-.

In order to compare the results of 2-jet and 3-jet events, the mean radii of jets for all c.m. energies measured using the HBT correlation method from 2-jet events and 3-jet events in e^+e^- collisions are listed in Table IV. It can be seen that the mean radii R_{quark} of the quark-jets measured in the 2-jet events is close to that in 3-jet events.

TABLE IV

The mean radii of jets for all c.m. energies measured using the HBT correlation method from 2-jet events and 3-jet events in e^+e^- collisions.

π mesons	2-jet events	3-jet events		
	R_{quark} [fm]	R_{quark} [fm]	$R_{\text{m-quark}}$ [fm]	R_{gluon} [fm]
π^+	0.693±0.004	0.71±0.02	0.67±0.01	0.59±0.01
π^0	0.600±0.006	0.61±0.02	0.55±0.02	0.43±0.01
π^-	0.690±0.004	0.74±0.01	0.68±0.02	0.60±0.01

5. Conclusion and discussion

We use Monte Carlo simulation generator Jetset7.4 to produce the data of e^+e^- collision events, at the energies $\sqrt{s}$ = 30, 50, 70, 91.2, 110, 130, 150, 170 GeV. The 2-jet events and 3-jet events are selected out using the Durham jet algorithm. The geometrical characteristics of quark-jets and gluon-jets are studied in detail by the HBT correlation method.

The values of the average source radii of quark-jets and gluon-jets are obtained by the HBT correlation method. We found that the average source radii of quark-jets is obviously larger than that of gluon, which indicates that the size of quark is larger than that of gluon. However, the average source radii of mother quark-jets is less than that of quark-jets. This would be due to the mixture of a small amount of gluon-jets and mother-quark-jets in the process of measurement which makes the average source radii of mother quark-jets smaller. In addition, it is pointed out that the source radii of quark-jets or gluon-jets measured at different c.m. energies are in a narrow region fluctuations, which would mean that the average source radii of quark-jets and gluon-jets reflect some intrinsic properties of quarks and gluons.

It is noted that the correlation strength α and the average source radii R measured by neutral π^0 mesons are less than those of charged π^+ or π^- pions. The weakness of the π^0 meson correlation can be partly explained by the bigger contribution of resonance decays to the Q spectrum. Our results are also consistent with the theoretical expectations [25] and experimental results [23]. In addition, the fitting parameters roughness with Eq. (7) may produce some systematic errors which can be reduced if adding a correction factor $(1+\epsilon Q)$ in Eq. (7) [23].

This work is supported by self-determined and innovative research funds of the China University of Geosciences (1210491B10) and Research Funds for Central Universities (100237). The authors thank Prof. Zhang Wei-Ning for helpful discussions.

REFERENCES

[1] R. Hanbury-Brown, R.Q. Twiss, *Phil. Mag.* **45**, 633 (1954).
[2] R. Hanbury-Brown, R.Q. Twiss, *Nature* **177**, 27 (1956).
[3] R. Hanbury-Brown, R.Q. Twiss, *Nature* **178**, 1046 (1956).
[4] M. Gyylassy, S.K. Kauffman, L.W. Wilson, *Phys. Rev.* **C20**, 2267 (1979).
[5] D. Boal, C.-K. Gelbke, B.K. Jennings, *Rev. Mod. Phys.* **62**, 553 (1990).
[6] W.A. Zajc, in: *Particle Production in Highly Excited Matter*, H.H. Gutbrod, J. Rafelski (Eds.), Plenum Press, New York 1993, pp. 435–459.
[7] G. Hanson *et al.*, *Phys. Rev. Lett.* **35**, 1609 (1975).
[8] J. Ellis *et al.*, *Nucl. Phys.* **B111**, 253 (1976).
[9] R. Brandelik *et al.*, *Phys. Lett.* **B86**, 243 (1979).
[10] D.P. Barber *et al.*, *Phys. Rev. Lett.* **43**, 830 (1979).
[11] Ch. Berger *et al.*, *Phys. Lett.* **B86**, 418 (1979).
[12] W. Bartel *et al.*, *Phys. Lett.* **B91**, 142 (1980).
[13] F. Liu(Y), F. Liu, *Int. J. Mod. Phys.* **A13**, 1969 (1998).
[14] G. Arnisonj *et al.* [UA1 Collaboration], *Phys. Lett.* **B123**, 115 (1983).
[15] C. Albajar *et al.* [UA1 Collaboration], *Nucl. Phys.* **B309**, 405 (1988).
[16] M. Banner *et al.* [UA2 Collaboration], *Z. Phys.* **C27**, 329 (1985).
[17] I. Arsene *et al.*, *Nucl. Phys.* **A757**, 1 (2005).
[18] D.S. Li, F.G. Tian, G. Chen, *Chinese Phys.* **C35**, 833 (2011).
[19] R.M. Barnett *et al.*, *Phys. Rev.* **D54**, 1 (1996).
[20] K. Geiger *et al.*, *Phys. Rev.* **D61**, 054002 (2000).
[21] H.L. Wei *et al.*, *Int. J. Mod. Phys.* **E17**, 1467 (2008).
[22] P.D. Acton *et al.* [OPAL Collaboration], *Phys. Lett.* **B267**, 143 (1991).
[23] P. Achard *et al.* [L3 Collaboration], *Phys. Lett.* **B524**, 55 (2002).
[24] A. Heister *et al.* [ALEPH Collaboration], *Eur. Phys. J.* **C36**, 147 (2004).
[25] B. Andersson *et al.*, *Phys. Rep.* **97**, 31 (1983).
[26] B. Andersson, W. Hofmann, *Phys. Lett.* **B169**, 364 (1986).

[27] I.V. Andreev, M. Plümer, R.M. Weiner, *Phys. Rev. Lett.* **67**, 3475 (1991).
[28] S. Catani *et al.*, *Phys. Lett.* **B269**, 432 (1991).
[29] Yu.L. Dokshitzer *et al.*, *J. High Energy Phys.* **08**, 001 (1997).
[30] Liu Lianshou, Chen Gang, Fu Jinghua, *Phys. Rev.* **D63**, 054002 (2001).
[31] Chen Gang, Yu MeiLing, Liu LianShou, *Chinese Sci. Bull.* **53**, 3808 (2008).
[32] M. Derrick *et al.*, *Phys. Lett.* **B165**, 449 (1985).
[33] A. Bialas *et al.*, *Phys. Rev.* **D62**, 114007 (2000).