STUDY ON THE ENERGY DEPENDENCE OF THE RADII OF JETS BY THE HBT CORRELATION METHOD IN $e^+e^-$ COLLISIONS

CHEN ZHENG-YU, WANG MEI-JUAN, XIE YI-LONG, LIANG ZHU AND CHEN GANG†
Physical Department, School of Mathematics and Physics, China University of Geosciences
Wuhan, China, 430074
†chengang1@cug.edu.cn

The energy dependence of the radii 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. The radii of jets are measured using the HBT correlation method with the indistinguishability of identical final state pions. It is found that the average radii of quark-jets and gluon-jets are independent of the c.m. energy of $e^+e^-$ collisions. The average radius of quark-jets are obviously larger than that of gluon-jets. The invariable average radii of quark-jets and gluon-jets in $e^+e^-$ collisions are obtained at the end of parton evolvement.

Keywords: $e^+e^-$ collisions; HBT correlation; average radius of jets; the energy dependence

1. Introduction

It was well-known that Hanbury-Brown and Twis had brought forward HBT correlation in the process of measuring the angular radii of the emitting sources in 1956. Later, the HBT correlation was widely used in subatom studies. The HBT correlation method has been an important way to measure the size of the emitting source 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 method offers a viable indirectly method, and applying this method into the high energy collisions we can obtain some characteristics of strong interaction for quarks and gluons.

Historically, the discovery in 1975 of a two-jet structure in $e^+e^-$ collisions at center of mass (c.m.) energy $\geq 6$ GeV had been taken as an experimental confirmation of the parton model, and the observation in 1979 of a third jet in $e^+e^-$ collisions at $17 - 30$ GeV had been recognized as the first experimental evidence of the gluon. In the early 1990s, the production of jets in hadron-hadron collisions was widely studied and had been considered as an efficient way to obtain the strong coupling constant $\alpha_s$. How to distinguish jets and the study on jets are also very important, in relative high energy ion collisions. Based on this idea we can get information about quarks and strong interactions from the study of jets by using the HBT correlation method.
In $e^+e^-$ collisions\cite{19}, firstly, the $e^+e^-$ pair is annihilated into a virtual $\gamma^*/Z^0$ resonance. The virtual $\gamma^*/Z^0$, in turn, decays into a $q\bar{q}$ pair. Then the initial $q\bar{q}$ may radiate other gluon 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. Thus, the source of a single jet is from a single initial quark (or anti-quark) or gluon.

Although the quark and gluon, before being observed, have been fragmented into the final state hadrons, the final state particles inside the jets still carry a lot of information about the parent quark and gluon. The quark and gluon are two different types of particle. For example, the quark is a fermion with colour charge equal to $4/3$, while the gluon is a boson, carrying colour charge $3$. These differences will certainly influence their fragmentation, resulting in different properties of quark-jets and gluon-jets. Some characteristics of quarks (anti-quarks) or gluons is reflected by the geometrical characteristics of jets. So, the study of the geometrical characteristics of the jets is helpful in the understanding of the perturbative/nonperturbative properties of QCD.

In the ref\cite{20}, the geometrical characters of quark-jets and gluon-jet have been studied with the HBT correlation method using MC generator producing quark-jets and gluon-jets in 3-jet events of $e^+e^-$ collisions at $\sqrt{s} = 91.2$ GeV. However, do the size of quark-jets and gluon-jets depend on the c.m. energy of $e^+e^-$ collisions producing these jets? Are the size of quark-jets measuring in 3- and 2-jets events of $e^+e^-$ collisions the same? Our work will focus on these questions.

The paper is organized as follows: In Sec. II, we briefly introduce the method of identification jets and the HBT correlation function. In Sec. III, the average radius of quark-jets and gluon-jets in 2-jet Events are calculated. In Sec. IV, the average radius of quark-jets and gluon-jets in 3-jet Events are calculated. A short summary is the content of Sec. V.

2. The method of identification jets and 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\cite{21}. In these methods, there is a cutting parameter $y_{cut}$, which, in the case of the Durham algorithm, is related to the relative transverse momentum $k_t$ as\cite{22}

$$k_t = \sqrt{y_{cut} \cdot \sqrt{s}},$$

where $\sqrt{s}$ is the c.m. energy of the collision. From the experimental point of view, $k_t$ can be taken as the transition scale between the hard and soft processes. Its
value depends on the definition of "jet".

The single quark-jet and single gluon-jet are identified from 3-jet events using the angular rule. 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:

\[
\theta_i = \arccos \left( \frac{P_{j1}P_{k1}+P_{j2}P_{k2}+P_{j3}P_{k3}}{\sqrt{P^2_{j1}+P^2_{j2}+P^2_{j3}}\sqrt{P^2_{k1}+P^2_{k2}+P^2_{k3}}} \right),
\]

where the largest angle, \( \theta_3 \), faces the gluon jet; the smallest angle, \( \theta_1 \), faces the jet formed by an initial quark without emitting a hard gluon; and the middle one, \( \theta_2 \), faces the mother-quark-jet.

According to the requirement of momentum conservation, the three jets should be in one plane, and we add the condition:

\[ \theta_1 + \theta_2 + \theta_3 > 359^\circ. \]

It should be noticed that the angle opposite to the mother-quark-jet is very close to that opposite to the gluon-jet, i.e. \( \theta_2 \approx \theta_3 \), so they are easily confused. Therefore, we demand a cut condition:

\[ \theta_3 - \theta_2 \geq \theta_{cut} \], here \( \theta_{cut} = 10^\circ \). This cut rejects about 12% events.

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 \( \pi \) mesons, so we choose \( \pi \) mesons (\( \pi^+, \pi^-, \pi^0 \)) 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 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:

\[
C_2(k_1, k_2) = \frac{P(k_1, k_2)}{P(k_1)P(k_2)},
\]

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

\[
C_2(k_1, k_2) = C_2(q, k_1, k_2) = 1 + \lambda \exp \{-R^2q_x^2 - R^2q_y^2 - R^2q_z^2 - \sigma^2q_t^2 \},
\]
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:

\[
C_2(k_1, k_2) = C_2(q, k_1, k_2) = 1 + \alpha \exp\{-R^2Q^2\},
\]

(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 parameter \( R \) characterizing the geometrical properties of the jets is actually the average radius of jets.

In this paper, we study the average radius \( R \) of the pion source only through the spatial distribution function of the source, which is taken as spherically symmetric. Then, the information about the average size of the emitting source for the final state particles can be obtained.

The three-dimensional momentum interval region chosen is \( Q = 0 \sim 2.5 \text{ GeV/c} \), 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 out suitable events for study. Identical \( \pi \) mesons are selected from the final state particles to make pion pairs after any two \( \pi \) mesons are grouped with each other. The three-dimensional momentum difference of the \( \pi \) meson pairs are calculated. The correlation function (also called correlation coefficient) with statistical method is:

\[
C_2(Q) = \frac{F_c(Q)}{F(Q)} = \eta(1 + \alpha \exp(-R^2Q^2)),
\]

(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 quite weak, the distribution here with the HBT correlation should be almost the same as the distribution without the HBT correlation. Thus 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 radius \( R \), the Eq(6) can be expressed as:

\[
C_2(Q) = \frac{F_c(Q)}{F(Q)} = \eta(1 + \alpha \exp(-R^2Q^2)),
\]

(7)

where \( \eta \) 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 40,000,000 events of \( e^+e^- \) collisions both with and without HBT correlation, which the c.m. energies are \( \sqrt{s} = 30, 50, 70, 91.2, 110, 130, 150, 170 \text{ GeV} \), respectively. The final state \( \pi \)
mesons ($\pi^+, \pi^-, \pi^0$) as the identical particles are chosen from event samples to study. We just select out the final state identical $\pi$ mesons emitted from vertex at origin, because some of them are secondary emitted or even multistage emitted. Thus, the calculated result is able to reflect the characteristics of the source of jets properly. The 2-jet events are selected using the Durham jet algorithm, and the cutting parameters at different c.m. energies are selected as Table 1.

Table 1. The cutting parameters of selection 2-jet events from $e^+e^-$ collision events.

| $\sqrt{s}$ (GeV) | 30  | 50  | 70  | 91.2 | 110 | 130 | 150 | 170 |
|------------------|-----|-----|-----|------|-----|-----|-----|-----|
| $y_{\text{cut}}$ | 0.07| 0.06| 0.06| 0.05 | 0.078| 0.078| 0.078| 0.078|

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 correlation function is produced both with and without HBT correlations when the three-dimensional momentum interval region of the identical $\pi$ mesons is chosen as $Q = 0 \sim 2.5$ GeV. According to equation (6) we calculate the value of the correlation function $C_2(Q)$ of $\pi$ ($\pi^+, \pi^-$ and $\pi^0$) mesons inside quark-jets from 2-jet events for all the 8 c.m. energies. Then, the average radii size of emitting source of pion meson inside single jet can be obtained through fitting the correlation functions $C_2(Q)$ using Eq.(7) for $\pi^+, \pi^-$ and $\pi^0$, as shown in Table 2, respectively. As an example, the results for 3 c.m. energies are shown in Fig.2.

It is clear to see from Fig.2 that the distributions of correlation functions of the $\pi$ meson inside quark-jets at different c.m. energies are similar. Especially, the distributions of particle both for $\pi^+$ and $\pi^-$ mesons at the same energies are in superposition. However, the distributions of identical particles for $\pi^0$ mesons is different to $\pi^+$ and $\pi^-$ mesons owing to the electromagnetic interaction among $\pi^+$ and $\pi^-$ mesons in the process of hadronization. The mean radii $R$ of jets for all various c.m. energies are listed in Table 2 at the last line.

For the convenience of comparison, we draw the source radii of the three kinds of $\pi$ mesons inside quark-jets for all energies in Fig.3.

It can be seen from Table 2 or Fig.3 that the values of the radii $R$ of jets for one meson from different c.m. energies are nearly the same within the error range; the radii $R$ of jets for the same c.m. energy both $\pi^+$ and $\pi^-$ mesons are approximately the same within the error range, i.e. their means $\bar{R}_{q,\pi^+} = 0.693 \pm 0.003$ fm, $\bar{R}_{q,\pi^-} = 0.690 \pm 0.004$ fm; But there are some difference between the $\pi^+$ or $\pi^-$ mesons and $\pi^0$ mesons for the $\bar{R}_{q,\pi^0} = 0.6000 \pm 0.006$ fm. This is due to the electromagnetic
Fig. 2. The distributions of correlation functions of quark-jet from 2-jet events 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 for the $e^+e^-$ collisions are produced by MC Jetset7.4 generator.

Table 2. The radii $R_q$ of quark-jets from 2-jet events at different c.m. energies, measured by HBT using $\pi^+$, $\pi^0$ and $\pi^-$ mesons, respectively.

| $\sqrt{s}$ (GeV) | $R_{q, \pi^+}$ (fm) | $R_{q, \pi^0}$ (fm) | $R_{q, \pi^-}$ (fm) |
|-----------------|---------------------|---------------------|---------------------|
| 30              | 0.704±0.006         | 0.553±0.007         | 0.708±0.006         |
| 50              | 0.662±0.004         | 0.580±0.006         | 0.686±0.004         |
| 70              | 0.703±0.004         | 0.577±0.005         | 0.688±0.004         |
| 91.2            | 0.672±0.003         | 0.607±0.006         | 0.684±0.004         |
| 110             | 0.697±0.003         | 0.593±0.004         | 0.678±0.004         |
| 130             | 0.710±0.004         | 0.616±0.005         | 0.679±0.003         |
| 150             | 0.693±0.005         | 0.624±0.007         | 0.685±0.005         |
| 170             | 0.705±0.004         | 0.650±0.008         | 0.715±0.004         |
| $R_{ave}$       | 0.693±0.004         | 0.600±0.006         | 0.690±0.004         |

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

interaction among $\pi^+$ and $\pi^-$ mesons in the process of hadronization. So, the results for $\pi^0$ mesons are more authentic.
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 40,000,000 events of $e^+e^-$ collisions both with and without HBT correlation for 8 c.m. energies. And we choose the final state $\pi$ mesons ($\pi^+,\pi^-,\pi^0$) emitted from the vertex at origin as the identical particles to study. The 3-jet events are selected using the Durham jet algorithm, which the cutting parameters for 8 energies are listed in Table 3.

| $\sqrt{s}$ (GeV) | 30 | 50 | 70 | 91.2 | 110 | 130 | 150 | 170 |
|------------------|----|----|----|------|-----|-----|-----|-----|
| $y_{\text{cut}}$ | 0.008 | 0.005 | 0.004 | 0.002 | 0.0015 | 0.001 | 0.0008 | 0.0005 |

After the quark-jet, mother quark-jet and gluon-jet are identified from 3-jet events using the angular rule, the correlation function is produced both for the case with and without HBT correlation when the three-dimensional momentum interval region of the identical $\pi$ mesons is chosen as $Q = 0 \sim 2.5$ GeV/c. We calculate the value of $C_2(Q)$ according to formula (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 $\pi^+,\pi^-$ and $\pi^0$ meson, respectively. The results are listed in Table 4. As an example, the results for 3 c.m. energies are shown in Fig.4.

It is easy to come to the conclusion from Fig.4 that the three type of $\pi$ meson correlation functions for quark-jets, mother quark-jets and gluon-jets are all similar. And the distributions of different identical particles, for $\pi^+$ and $\pi^-$ mesons, formed at the same energy are nearly in superposition. However, the distributions of identical particles for $\pi^0$ mesons are different to $\pi^+$ and $\pi^-$ mesons.

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 $\pi$ mesons in Fig.5.

It can be seen from Table 4 and Fig.5 that: the values of radii $R$ of quark-jets or mother quark-jets and or gluon-jets at different c.m. energies are all nearly the same within the error range, respectively; the average radii of quark-jets are obviously larger than that of gluon-jets, and the average radii of quark-jets are also larger than that of mother quark-jets. The mean radius of quark-jets for $\pi^+$ mesons is $0.71 \pm 0.02$ fm, that of mother quark-jets is $0.67 \pm 0.01$ fm, and that of gluon-jets is $0.59 \pm 0.01$ fm. The mean radius of quark-jets for $\pi^0$ mesons is $0.61 \pm 0.02$ fm, that of mother quark-jets is $0.55 \pm 0.02$ fm, and that of gluon-jets is $0.43 \pm 0.01$ fm. The mean radius of quark-jets for $\pi^-$ mesons is $0.74 \pm 0.01$ fm, that of mother quark-jets is $0.68 \pm 0.02$ fm, and that of gluon-jets is $0.60 \pm 0.01$ fm, respectively.
Fig. 4. The distributions of $\pi$ meson correlation functions of the three kinds of jets from 3-jet events 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 line 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 for the $e^+e^-$ collisions are produced by MC Jetset7.4 generator.

Fig. 5. The comparison of the values of the radii $R$ of the three kinds of jets from 3-jet events at different c.m. energies for different $\pi$ mesons, (a) $\pi^+$, (b) $\pi^0$, (c) $\pi^-$. 
Table 4. The values of the source radii $R$ of the three types of jets at different c.m. energies calculated with the three kinds of $\pi$ mesons ($\pi^+, \pi^-, \pi^0$).

| $\pi$ mesons | $\sqrt{s}$ (GeV) | $R_{\text{quark}}$ (fm) | $R_{\text{m-quark}}$ (fm) | $R_{\text{gluon}}$ (fm) |
|--------------|-----------------|------------------|------------------|------------------|
| $\pi^+$      | 30              | 0.60±0.03        | 0.63±0.02        | 0.69±0.02        |
|              | 50              | 0.72±0.02        | 0.64±0.02        | 0.66±0.01        |
|              | 70              | 0.73±0.01        | 0.70±0.01        | 0.54±0.01        |
|              | 91.2            | 0.71±0.01        | 0.68±0.01        | 0.64±0.01        |
|              | 110             | 0.74±0.01        | 0.64±0.01        | 0.55±0.01        |
|              | 130             | 0.74±0.01        | 0.66±0.01        | 0.56±0.01        |
|              | 150             | 0.73±0.01        | 0.68±0.01        | 0.56±0.01        |
|              | 170             | 0.75±0.01        | 0.70±0.02        | 0.55±0.01        |
| $R_{\text{aver}}$ |                | 0.71±0.02        | 0.67±0.01        | 0.59±0.01        |
| $\pi^0$      | 30              | 0.64±0.02        | 0.41±0.02        | 0.48±0.02        |
|              | 50              | 0.66±0.01        | 0.54±0.02        | 0.46±0.01        |
|              | 70              | 0.61±0.01        | 0.53±0.01        | 0.42±0.01        |
|              | 91.2            | 0.67±0.02        | 0.53±0.01        | 0.44±0.01        |
|              | 110             | 0.64±0.02        | 0.60±0.01        | 0.42±0.01        |
|              | 130             | 0.60±0.01        | 0.57±0.02        | 0.41±0.01        |
|              | 150             | 0.67±0.02        | 0.61±0.02        | 0.41±0.01        |
|              | 170             | 0.66±0.02        | 0.59±0.02        | 0.44±0.01        |
| $R_{\text{aver}}$ |                | 0.61±0.02        | 0.55±0.02        | 0.43±0.01        |
| $\pi^-$      | 30              | 0.76±0.02        | 0.65±0.03        | 0.67±0.02        |
|              | 50              | 0.75±0.02        | 0.66±0.01        | 0.62±0.01        |
|              | 70              | 0.72±0.01        | 0.70±0.02        | 0.60±0.01        |
|              | 91.2            | 0.75±0.01        | 0.65±0.02        | 0.61±0.01        |
|              | 110             | 0.73±0.01        | 0.67±0.01        | 0.55±0.01        |
|              | 130             | 0.75±0.01        | 0.69±0.01        | 0.57±0.01        |
|              | 150             | 0.74±0.01        | 0.67±0.01        | 0.60±0.01        |
|              | 170             | 0.72±0.01        | 0.72±0.02        | 0.59±0.01        |
| $R_{\text{aver}}$ |                | 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, which the c.m. energies are $\sqrt{s} = 30, 50, 70, 91.2, 110, 130, 150, 170$ GeV. The 2-jet events and 3-jet events are selected using the Durham jet algorithm. The geometrical characters of quark-jets and gluon-jets are studied in detail using the HBT correlation method. The conclusions are as follows:

- The radii of quark-jets or gluon-jets measured at different c.m. energies are approximately the same within the error range, which shows that the radii of quark-jets and gluon-jets reflect some intrinsic properties of quarks and gluons.
- The values of the mean radii of quark-jets, mother quark-jets and gluon-jets are obtained, shown in Table 5.
- The mean radii of quark-jets measured is obviously larger than that of gluon, which indicates that the size of quark is larger than that of gluon. However, the mean radii of mother quark-jets measured is less than that of quark-jets. This
Table 5. The means radii $R$ of jets measured using the HBT correlation method in 2-jet events and 3-jet events from $e^+e^-$ collision events.

| π mesons | 2-jet events | 3-jet events |
|----------|--------------|--------------|
|          | $R_{\text{quark}}$ (fm) | $R_{\text{m-\text{quark}}}$ (fm) | $R_{\text{gluon}}$ (fm) |
| $\pi^+$  | 0.693±0.004 | 0.71±0.02 | 0.67±0.01 | 0.59±0.01 |
| $\pi^0$  | 0.600±0.006 | 0.64±0.02 | 0.55±0.02 | 0.43±0.01 |
| $\pi^-$  | 0.690±0.004 | 0.74±0.01 | 0.68±0.02 | 0.60±0.01 |

may be due to the mixture of a small amount of gluon-jets and mother-quark-jets in the process of measurement which makes the radii of mother quark-jets measured smaller.

- The results for $\pi^0$ mesons are more authentic than for $\pi^+$ and $\pi^-$ mesons for there are no electromagnetic interactions among $\pi^0$ mesons in the process of hadronization.

Acknowledgments

This work is supported by self-determined and innovative research funds of CUG(1210491B10) and Research Funds for Central Universities (GUGL 100237)

References

1. R Hanbury-Brown and R Q Twiss, Phil. Mag. Nature 45(1954) 633;
2. R Hanbury-Brown and R Q Twiss, Phil. Mag. Nature 177(1956) 27;
3. R Hanbury-Brown and R Q Twiss, Phil. Mag. Nature 178 (1956) 1046.
4. M Gyylassy, S K Kauffman and L W Wilson, Phys. Rev. C20 (1979) 2267.
5. D Boal, C-K Gelbke, and B K Jennings, Rev. Mod. Phys. 62 (1990) 553.
6. W A Zajc, in Particle Production in Highly Excited Matter, ed. New York, 1993, 435.
7. G Hanson, G S Abrams, A M Boyarski, et al. Phys. Rev. Lett.35 (1975) 1609.
8. J. Ellis et al.,Nucl. Phys. B111(1976)253.
9. R Brandelik et al., Phys. Lett.B86 (1979) 243.
10. D P Barber, U Becker,H Benda, et al.,Phys Rev Lett.43 (1979)830833.
11. Ch Berger, H Genzel,R Grigull, et al.,Phys. Lett.B86 (1979)418.
12. W Bartel, T Czajlerc, D Cords, et al.,Phys. Lett.B91(1980)142.
13. F Liu(Y),F LIU,Int. J. Mod. Phys.A13(1998)1969.
14. G Armonjon et al., (UA1 collaboration), Phys. Lett.B123(1983)115.
15. C Albajar et al., (UA1 collaboration), Phys. Lett.B309(1988)405.
16. M Banner et al., (UA2 collaboration),Z. Phys.C27(1985)329.
17. I Arsene et. al., Nuclear PhysicsA757 (2005) 1.
18. D S Li,F G Tian and G Chen, Chinese PhysicsC35 (2011) 833.
19. Paticle Data Group, Review of Particle Physics, Phys. Rev. D54 (1996) 286.
20. WEI Hui-Ling, CHEN Gang, TIAN Feng-Ge,et al., Int. J. L. M. Phys. E17(2008)1467;
21. S Catani et al., Phys. Lett.B269 (1991) 432.
22. Yu L Dokshitzer, G D Leder, L S Moretti,et al.,JHEP08(1997)001.
23. M Derricket al., Phys. Lett.B165 (1985) 449.