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Measurement of the Bunch Length of Beijing Electron Positron Collider

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The method of determining the bunch length of collider by the vertex of charged particles which come from J/ψ decay is discussed. The bunch length of Beijing electron positron collider (BEPC) at the colliding region is presented.

1. INTRODUCTION

The bunch length of beam, the electron or positron distribution in the bunch, the position of beam crossing and its stability in the e^+e^- collision machine are important subjects. It is significant to measure the bunch length for beam dynamics and high energy particle physics.

There are many different methods to measure the bunch length [1]. Currently the synchrotron radiation method, particle life-time method, beam pipe wall current method are used for measuring bunch length of BEPC. In this paper, a method of bunch length measurement by the vertex of charged particle track is introduced and the bunch length of BEPC at the crossing point is given. Compared with other methods, it has two special features:

1) It is a direct measurement because the vertex of charged particle tracks is the position where the collision of e^+e^- takes place.

2) The method measures the luminosity length at the collision area. So it is a significant method for the physical experiment because this length directly affects the time resolution of the time flight counter of Beijing Spectrometer (BES), the selection of the good events and elimination of background. Other methods are used to measure the single bunch length outside the collision area only.

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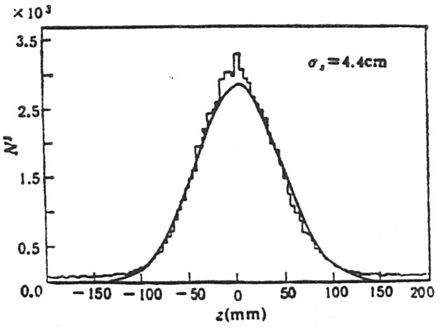

Fig. 1
Distribution of vertexes
of the hadronic events.

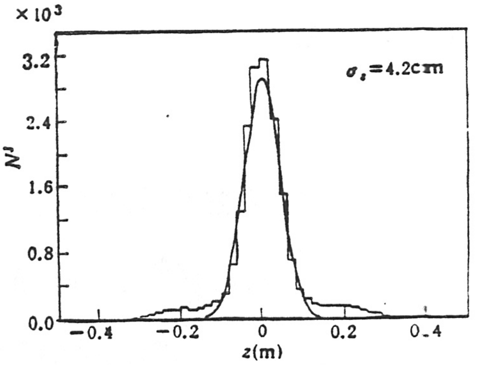

Fig. 2
Distribution of vertexes of e^+e^-,
$\mu^+\mu^-$, and the hadronic events.

2. PRINCIPLE AND METHOD

The J/ψ particles produced at the collision point are at rest, while the total energy of e^+ and e^- equals the mass of J/ψ of 3.1 GeV. The J/ψ almost decays immediately into e^+e^-, $\mu^+\mu^-$ or hadrons. The position of vertex of second particles is the place where J/ψ is produced, or the position of e^+e^- collision.

Suppose the position of collision is the origin point for the electrons coming from the negative direction, the z distribution of electron in a bunch at time t is

$$N^-(z, t) = \frac{N_0^-}{\sqrt{2\pi}\sigma_z^-} e^{-\frac{(z-ct)^2}{2(\sigma_z^-)^2}}, \tag{1}$$

where N_0^- is the number of electrons in the bunch, σ_z^- is the width of Gaussian distribution, c is the velocity of the bunch movement.

Symmetrically, the z distribution of positron in a bunch at time t is

$$N^+(z, t) = \frac{N_0^+}{\sqrt{2\pi}\sigma_z^+} e^{-\frac{(z+ct)^2}{2(\sigma_z^+)^2}}, \tag{2}$$

where N_0^+ is the number of positron in the bunch, σ_z^+ is the width of Gaussian distribution.

As we know, the number of J/ψ produced at position z and time t is proportioned to collision cross-section σ_J and the luminosity $\mathscr{L}(z, t)$.

$$N^J(z, t) = \sigma_J \mathscr{L}(z, t), \tag{3}$$

and

$$\mathscr{L}(z, t) = \frac{fN^+(z,t)N^-(z, t)}{4\pi\sigma_x(z)\sigma_y(z)}, \tag{4}$$

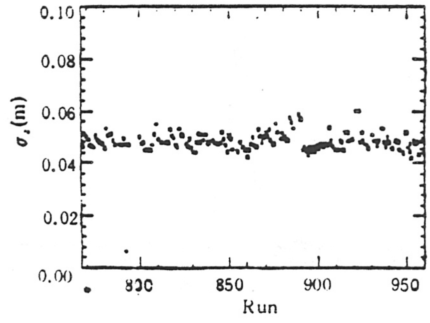

Fig. 3
The changes of bunch length
σ_z vs. Run (time).

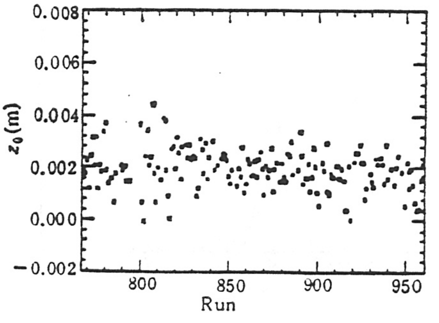

Fig. 4
The changes of collision
point z_0 vs. Run (time).

where f is the circulation frequency of bunch, $\sigma_x(z)$ and $\sigma_y(z)$ are the width of the two bunches in the horizontal and perpendicular direction, respectively.

The total number of J/ψ produced in the whole collision process of the two bunches can be obtained by integrating the $N^J(z, t)$ over t through Eqs. (1), (2) and (4). When the two bunch lengths are almost the same, $|\sigma_z^+ - \sigma_z^-| \ll (\sigma_z^+ + \sigma_z^-)$, let

$$\sigma_z = \frac{\sigma_z^+ \sigma_z^-}{\sqrt{\sigma_z^{+2} + \sigma_z^{-2}}}, \tag{5}$$

we obtain J/ψ distribution

$$N^J(z) = K e^{-\frac{z^2}{2\sigma_z^2}}, \tag{6}$$

where constant $K = \dfrac{\sigma_J f N_0^+ N_0^-}{(2\pi)^{3/2} \sigma_x(z) \sigma_y(z) (\sigma_z^{+2} + \sigma_z^{-2})^{1/2} c}.$

Eqs. (5) and (6) show that

1) J/ψ distribution $N^J(z)$ is Gaussian;

2) if $\sigma_z^+ = \sigma_z^-$, i.e., electron bunch length equals positron bunch length, and if variation of $\sigma_x(z)$, $\sigma_y(z)$ along z is very small, we have:

$$\sigma_z^+ = \sigma_z^- = \sqrt{2}\,\sigma_z. \tag{7}$$

where σ_z is double bunch length, or luminosity length, and σ_z and σ_z are single beam bunch lengths.

The decays of J/ψ are measured by BES [2,4], which is located at the first collision point of BEPC. BES is a general multi-particle magnetic spectrometer. It consists of CDC (Central Drift Chamber), MDC (Main Drift Chamber), SC (Shower Counter), TOF (Time Of Flight counter) and muon counter. All of the detectors are in the solenoid magnetic field except muon counter. The CDC

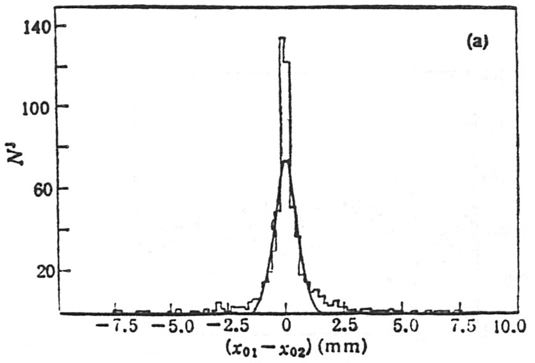

Fig. 5(a)
The difference between the vertexes (x-direction) of the two tracks in e^+e^- events.

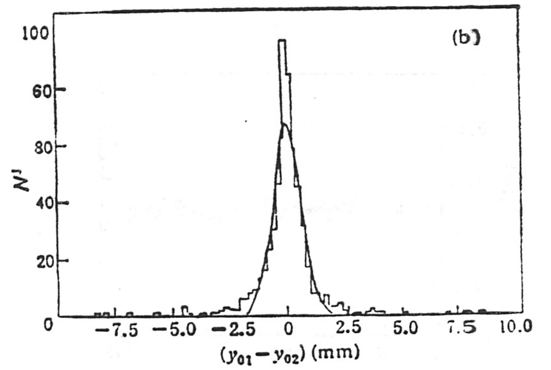

Fig. 5(b)
The difference between the vertexes (y-direction) of the two tracks in e^+e^- events.

and MDC are used to select and measure the charged particles tracks. SC is a energy measurement counter for electron and gamma. When the e^+e^- collision occurs, the trigger system selects the good events and the information of the events are recorded by an on-line computer. The whole data-taking process is controlled by the on-line computer VAX11/785. The steps to obtain distribution $N^J(z)$ and bunch length σ_z are as follows:

1) selecting certain decay channel of J/ψ , e.g., $J/\psi \rightarrow e^+e^-$, $J/\psi \rightarrow \mu^+\mu^-$ or $J/\psi \rightarrow$ hadrons. Whichever decay channel is selected, we need eliminate the background such as "beam gas", "beam wall" events and cosmic ray, etc.;

2) fitting the charged particle tracks of good event, and calculating the vertexes;

3) keeping record of the vertexes position z of all charged particle tracks to obtain the distribution of $N^J(z)$;

4) after Gaussian function fitting for the vertexes $N^J(z)$, obtaining the luminosity length σ_z of BEPC beam at the collision point; and

5) calculating the bunch length of single beam σ_z^+ (or σ_z^-) at the collision point through Eq. (7).

3. RESULTS

1) The distribution $N^J(z)$ of the vertex of charged particle tracks acquired by selecting the $J/\psi \rightarrow$ hadrons decay channel only is shown in Fig. 1. It is Gaussian distribution with a small background. After fitting we obtain

$$\sigma_z = 4.4\text{cm};$$

$$\sigma_z^+ = \sigma_z^- = 6.2\text{cm}.$$

The non-zero mean value of Gaussian distribution means that the collision point is not at the origin, and the deviation is

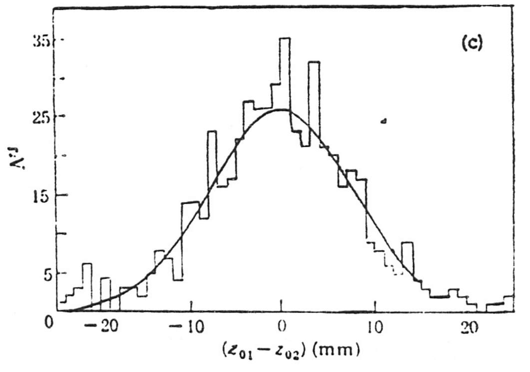

Fig. 5(c)
The difference between the vertexes
(z-direction) of the two tracks
in e^+e^- events.

$$\Delta = +1.2\text{mm}.$$

This result was derived from the J/ψ data during June 6-9, 1990. In this period the mean bunch length of BEPC was 6.2 cm, and the deviation of the collision point from origin was 1.2 mm.

2) The vertex distribution $N^J(z)$ of all secondary charged particles tracks, including all decay channels of J/ψ, is shown in Fig. 2. It is easy to find that the background is larger, but the data are still good to fit with Gaussian distribution, the result is

$$\sigma_z = 4.4\text{cm};$$

$$\sigma_z^+ = \sigma_z^- = 6.2\text{cm}$$

and the deviation of the collision point is

$$\Delta = +1.9 \text{ mm}.$$

This is the bunch length and deviation of BEPC beam on June 8, 1990. We selected the hadronic decay channel from the same J/ψ data and obtained the bunch length $\sigma_z = 4.3$ cm, and the deviation of the collision point from origin $\delta = +1.7$ mm. We can see that the results either from all charged particle tracks of all J/ψ decay channel or that of hadronic channel are almost the same. Because the analysis of all J/ψ decay channels is easier, and it is not necessary to eliminate $J/\psi \rightarrow \mu^+\mu^-$ and $J/\psi \rightarrow e^+e^-$, it is adopted to study the stability of BEPC beam status.

3) Analyses of the bunch length and collision point position of BEPC at different times show the stability of BEPC's operation. From April 22 to June 9 in 1990, we analyzed 194 Run data, the bunch length σ_z and the deviation of the collision point Δ are shown in Fig. 3 and Fig. 4, respectively. The figures indicate that

a) the change of luminosity length σ_z is within the range of 4.4-5.6 cm;

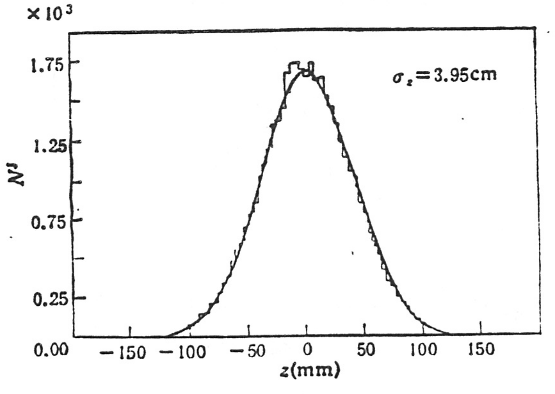

Fig. 6
The distribution the vertexes (z-direction) of good hadronic events.

b) the change of bunch length from Run 880 to Run 890 is bigger except for some special Runs; and

c) the deviation of the collision point is generally about 2 mm, and the maximum deviation is 4 mm, which is mainly in Run 800-820. This result is significant for analyzing the status and stability of BEPC's operation.

4. ERROR ANALYSIS

There are three main errors in this measurement:

1) The position resolution of MDC is about 200 μm in xy plane, and 2-5 mm in z-direction, and position z of the tracks reconstructed by the track-finding program has certain fluctuations against the real tracks. The vertexes of tracks also have deviation against the real vertex of J/ψ.

2) The pulsed magnetic field produced by the passing through of the bunches is very strong and would affect the charged particle track. We ignored this effect in the track fitting.

These two kinds of errors can be measured by the following method: the e^+ and e^- tracks should come from the same vertex in $J/\psi \to \mu^+\mu^-$ and $J/\psi \to e^+e^-$ events. In other words, the difference of two vertexes should be zero. But the vertexes of two tracks determined by the fitting are not the same due to the above reason. This difference of two fitted vertex of e^+ and e^- track can be used to measure the error. Figs. 5(a),(b), and (c) show the differences between the two vertexes in direction x, y, z — $(x_{01} - x_{02})$, $(y_{01} - y_{02})$ and $(z_{01} - z_{02})$. After fitting the distribution we obtain the errors in different directions. The error in x direction is 0.45 mm, 0.65 mm in y direction and 0.69 cm in z direction. The data of Runs 935-960 were used in this analysis.

3) Errors will result when the $J/\psi \to e^+e^-$ event is selected. Because both e^+ and e^- has high energy, it is easy to eliminate background, but the event number is not enough to find statistical errors. If hadronic events are selected, there will be many events and fewer statistical errors, but event selection and track selection are more difficult. If the tracks are selected without tight cut, we can obtain σ_z = 4.4 cm (Fig. 1). After tight track selection cut, we obtain σ_z = 3.95 cm (Fig. 6). The

difference is 0.35 cm, which means that the errors come from the event selection or track selection. But these are not big errors.

5. DISCUSSION

1) Compared with other methods, our method gives more accurate results, which are consistent with the designed value of the bunch length of BEPC.

2) The result obtained by this method is the bunch length of a Run in which the bunch length changes as beam current changes. Although this method cannot give the change of the bunch length in a Run, it can still give the variation of the bunch length between different Runs.

3) The relation between $\sigma_x(z)$ or $\sigma_y(z)$ and z has been ignored. $\sigma_y(z)$ and $\sigma_x(z)$ increase with the growth of $|z|$, while the luminosity decreases with the growth of $|z|$, and so does σ_z. The details have been discussed by Zhang [3]. This effect is very small in the current range of our measurement and can be ignored.

ACKNOWLEDGMENTS

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