Separation of the Beam Associated Sample from Raw Data*

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Abstract The uncertainty of the treatment for the beam associated backgrounds is one of the dominant errors in the previous R measurement at BES/BEPC. A new method is developed to separate the beam associated sample from the raw data, and this sample is used in tuning the parameters of the hadronic generator LUARLW. This improvement can decrease the systematic error of the selection efficiency of hadronic events, and improve the precision of the R value.

Key words R value, background, generator

1 Introduction

R value, defined as the ratio of the lowest order hadronic cross section to the Born level cross section of $e^+e^- \to \mu^+\mu^-$, is very important for the precise test of the Standard Model (SM)[1]. In 1998 and 1999, two rounds of scan for the R measurement were made with the upgraded BES detector, the typical statistical error was about 3%, and the systematic error was 5%—8%. In 2004, data samples at 2.2, 2.6, 3.07, and 3.65GeV with about 10pb^{-1} integrated luminosity were taken, and the main goal for these new data is to measure the R value with higher precision about 3%. In the future, high luminosity ($10^{33}\text{cm}^{-2}\cdot\text{s}^{-1}$) at BEPCⅡ and excellent detector performance of BESⅢ will insure the accurate measurement of R.

In experiment, the dominant systematic error arises from the hadronic event selection, the background deduction, and the reliability of hadron production model. These problems are correlative, and all of them are related to the beam associated background. However, the production mechanism of beam associated background is very complicated. During the operation of the collider, the typical pressure in the beam pipe is 10^{-7}Torr. But the electrons and positrons in the beam frequently collide with the residual molecules of the gas or the walls of beam pipes, and the elastic scattering will occur among electrons or positrons (Thouschek effect), all of which can be recorded in the raw data and bring about the beam associated backgrounds. At present, there is neither reliable theoretical calculation nor trustful Monte Carlo (MC) simulation, hence it cannot be treated in the way we deal with the QED background[2, 3].

This work aims to develop new methods to separate the beam associated background from the raw data, apply it to tune the phenomenal parameters of the hadronic generator, and suppress the systematic uncertainty of the detection efficiency of hadronic events.

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2 Previous methods

In previous experiments, the separated beam mode (electrons and positrons do not collide) was performed to obtain the beam associated backgrounds. In Fig. 1, the left one is the original distribution of event vertex of the separated beam data at $\sqrt{s}=$ 3.65GeV along the beam direction. They are not smooth along the z direction, but two camel-back peaks appear near ±25cm. This effect becomes unobvious with the decrease in energy. The right one is the distribution of the multiplicity of charged track, in which most events have few tracks.

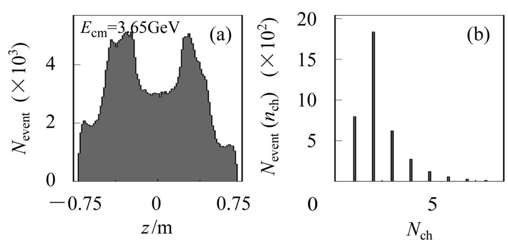

Fig. 1. The original distributions for separated beam data at $\sqrt{s}=3.65$GeV (a) vertex in z direction (b) multiplicity.

In R measurements, the hadronic event selection criteria are applied to the separated beam data, and the number of the survived separated beam events N_{sep} is obtained. The survived number of the beam associated events N_{bg} in the colliding data is estimated by[4, 5]

$$N_{bg}=f\cdot N_{sep} \ . \quad (1)$$

The constant proportionality

$$f=\frac{\int_0^{T_{dt}} P\cdot I\mathrm{d}t}{\int_0^{T_{sp}} P\cdot I\mathrm{d}t}, \quad (2)$$

where, P is the pressure at the collision region, I is the electric current of the beam, T_{dt} and T_{sp} are the time of acquiring the colliding data and the separated beam data. The values of these parameters cannot be recorded at every moment and have large uncertainties. Generally, $T_{dt}\gg T_{sp}$, so f always reaches to $10^2\sim10^3$ order. The statistical fluctuations of the sample of the beam associated backgrounds are largely enlarged through Eq. (1). When tuning the parameters of the generator, this amplified statistic error can be transferred to the systematic uncertainty of the hadronic model parameters, and cause a large systematic uncertainty of the hadronic detection efficiency.

On the other side, it is impossible to obtain the separated beam data at every energy point during scanning. And the accelerator status of the separated beams running is much different from that of the colliding beams, and the uncertainty brought by this difference is hard to estimate. Therefore, the possibility to reliably tune the parameters of the hadronic generator is limited.

3 New method

The distribution of the event vertex, which passes the hadronic criteria, is approximately smooth in a quite wide region along the beam direction, see Fig. 2. It indicates that the beam associated background along the z direction with the same range has the same statistics.

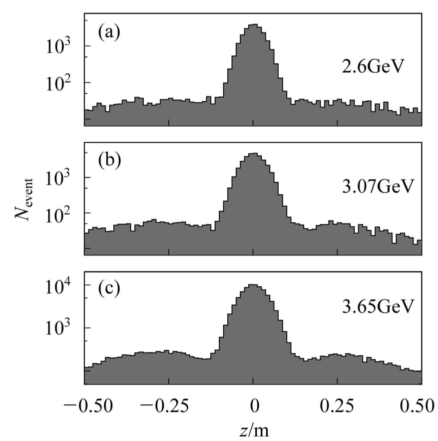

Fig. 2. Distributions of event vertex of the colliding beam data at $\sqrt{s}$=2.6, 3.07 and 3.65GeV.

Through the analyses of the separated beam data and the colliding beam data, it can be found that the distance between the vertices of the good charged tracks in one event is less than 2cm, which indicates that they are produced from the same point. Fig. 3 shows the distributions of the difference of the z coordinates between the vertices of two tracks of hadron events in the real data and MC. Therefore, if a vertex of one track is outside 2cm from the aggregation region of the other vertices, it may be viewed as a bad track due to mis-reconstruction or other reasons, and is not taken into account when calculating the event vertex. Fig. 4(a) shows an example of the tracks useful to ascertain the vertex of the event and the fake tracks which are neglected. The vertices of track 1, 5, 7 are far away from each other，distributing 2cm outside the cluster, and have no contribution to the calculation of the event vertex. The vertices of track 2, 3, 4 are distributed within 2cm, so the event vertex is determined by these vertices.

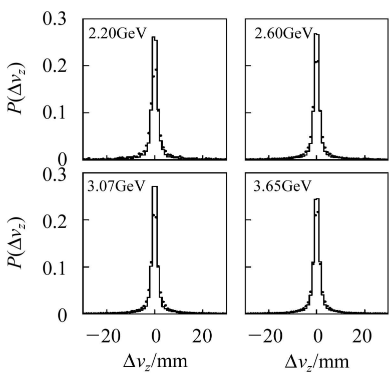

Fig. 3. The normalized distributions of the distance (in z direction) between vertexes of the two tracks in hadron events of data (dots) and MC (histograms).

According to the experimental data and the MC simulation sample, the z coordinates of event vertices of e^+e^- annihilation are less than 18cm, like in Fig. 5. In the calculation of the event vertex, the distance between two track vertices should be less than 2cm, and the weighted-average of the track vertices is calculated as follows

$$\bar{V}_z = \frac{\sum\limits_{i=1}^{n} V_z(i)/\tilde{\chi}_i^2}{\sum\limits_{i=1}^{n} 1/\tilde{\chi}_i^2} \, , \tag{3}$$

where, n is the number of the tracks satisfying the above requirements in one event, $\tilde{\chi}_i^2 = \chi_i^2/n_{\mathrm{d.o.f}}$, and χ_i^2 is from the track fitting in the reconstruction of track i. If the calculated vertex is outside 18cm, this event would be regarded as the beam associated background without any other criteria. So the beam associated background events can be separated from the raw data in this way. Fig. 4(b) shows the typical beam associated backgrounds separated from the colliding data, in which all tracks are on the same side.

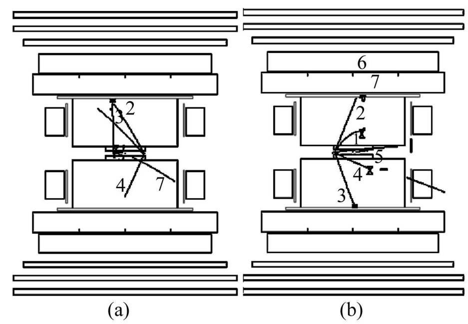

Fig. 4. The single event displays of two typical beam associated background events.

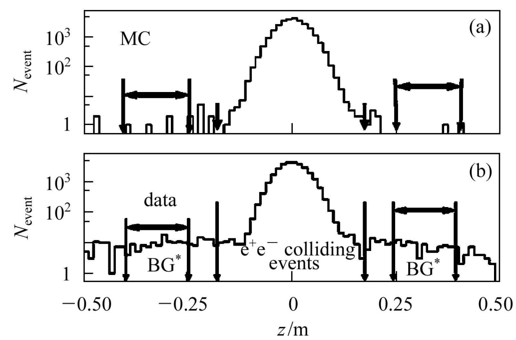

Fig. 5. (a) The vertex distribution of simulated hadronic events by LUARLW, the colliding range aggregates within $|\bar{V}_z| < 18$cm; (b) The vertex distribution of the real data, the events with $|\bar{V}_z| > 18$cm can be regarded as the beam associated backgrounds.

To obtain the sample BG* of the beam associated background with the approximate same statistics as in the colliding region, i.e. the area below Gaussian peak in Fig. 5(a) and (b), one may choose the events away from the center 25—43cm, and separate them from the raw data. The range between 25—43cm is an approximate estimation under the assumption of the vertex distribution of the beam associated background which is smooth along the z direction, its error will be accounted in the systematic error of the tuned parameters and the hadronic detection efficiency. For the data at 3.65GeV, the range for separating BG* is about 0.75×18cm, i.e. the range is about 25—38.5cm considering the two obvious camel-back peaks. It should also be realized that different cut condition for the distance between two tracks and different range we choose BG* will cause the systematic errors.

The energy deposition of the beam associated backgrounds in colliding region is very similar to that of the outside, see Fig. 6. Hence its effect of the separated sample BG* is the same as the beam associated backgrounds in the colliding region.

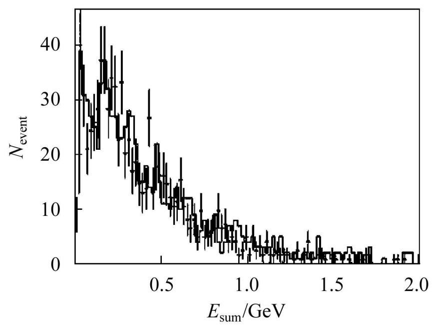

Fig. 6. Comparison of the distribution of the energy deposited in Barrel Shower Counter (BSC) for the beam associated backgrounds in the colliding region (dots with error bars) with that of the outside region (histogram).

4 Tuning of LUARLW parameters

In the low and medium energy region below the production threshold of charm mesons, the physical processes for the e^+e^- collision are $e^+e^- \to e^+e^-$, $\mu^+\mu^-$, $\tau^+\tau^-$, $\gamma\gamma$ and hadrons. The QED processes can be calculated and simulated accurately by Monte Carlo generators, which have no free parameters and the precision is very high. And the separated sample BG* can be used as the beam associated backgrounds. Only the parameters in the hadronic generator need to be tuned.

Hadronic generator LUARLW[6, 7] is used to estimate the hadronic efficiency in the R measurement. LUARLW is strictly written based on the Lund area law, but it contains many free phenomenological parameters, so their values should be tuned by comparing the data. We tune the parameters to make all the distributions related to the hadronic criteria (i.e. multiplicity, polar-angle, momentum, energy deposition, π and K ratios, vertex and time of flight (TOF) distribution, and so on) of both data and MC well consistent, and take their differences as systematic uncertainties. The main parameters to be tuned are: PARJ(1-3), PARJ(11-17) in JETSET[8] and the parameters in LUARLW. When tuning the parameters of LUARLW, the proportion of all kinds of events (hadronic events, QED backgrounds and beam associated background) in MC sample should be the same as that in data, which can be met by

$$\text{MC sample}\begin{cases}\text{beam associated background} & \text{BG}^* \\ \mu^+\mu^- & L\cdot\sigma_{\mu\mu} \\ e^+e^- & L\cdot\sigma_{ee} \\ \tau^+\tau^- & L\cdot\sigma_{\tau\tau} \\ \gamma\gamma & L\cdot\sigma_{\gamma\gamma} \\ \text{hadrons} & L\cdot\sigma_{\text{had}}\end{cases}$$

where, L is the integrated luminosity, σ_{ee}, $\sigma_{\mu\mu}$, $\sigma_{\tau\tau}$, $\sigma_{\gamma\gamma}$ and σ_{had} are the cross sections of the QED backgrounds and hadrons respectively. The number of QED background events can be obtained by MC simulation according to the cross section and the luminosity at relevant energy points, and the beam associated sample is the separated BG* described as above.

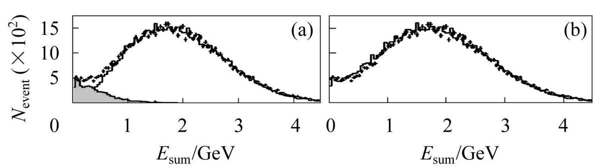

Fig. 7. The distribution of the energy deposition at $\sqrt{s}$=3.65GeV. Dots with error bars and histograms represent experimental data and the MC sample respectively. (a) The MC sample only contains hadrons and QED backgrounds, the grey region is for the beam associated sample BG*; (b) The MC sample contains hadrons, QED and beam-associated backgrounds BG*.

Fig. 7(a) shows the distribution of the energy deposited in BSC of data and MC samples at $\sqrt{s}$= 3.65GeV. The MC sample only contains the simulated events by LUARLW and QED generators, we can see that the energy deposition of the data (dots with error bars) and MC (histogram) are not consistent at the low end. The energy deposition of the separated beam associated sample BG* is shown by the gray region. If the separated beam associated sample BG* is included, the distributions of energy deposition of data and MC agree well, see Fig. 7(b). So the energy deposit cut in the hadronic criteria brings about very small uncertainty. As an example, some distributions, which relate to the hadronic criteria of data and MC with the tuned parameters

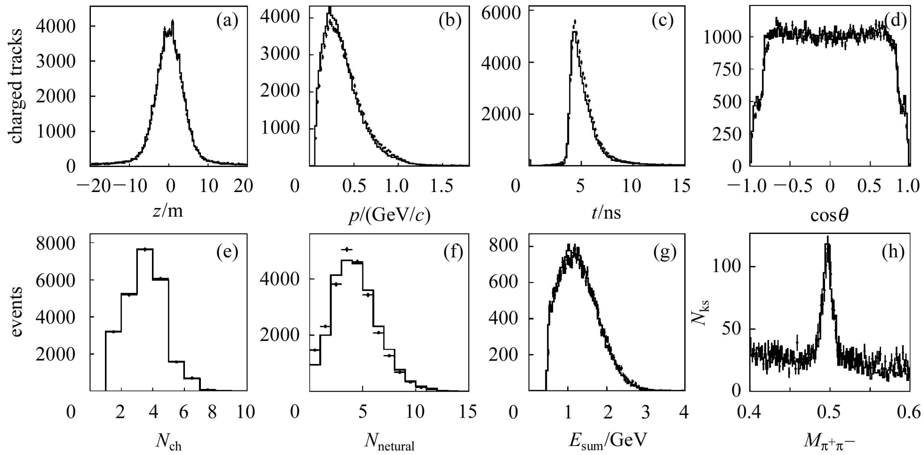

Fig. 8. Distributions for $\sqrt{s}$=2.6GeV of (a) charged track vertex in z direction, (b) momentum of charged tracks, (c) time of flight of charged tracks, (d) polar-angle of charged tracks, (e) number of good charged tracks, (f) number of neutral tracks, (g) energy deposited in BSC, (h) invariant mass of $\pi^+\pi^-$. Dots with error bars and histograms in (a)—(h) represent real data and MC simulation respectively.

at $\sqrt{s}$=2.6GeV, are shown in Fig. 8. The systematic error of the hadronic efficiency is estimated to be about 1.5% by comparing data with MC. The cases at other energies are very similar.

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原始数据中束流相关本底的分离*

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摘要　束流相关本底处理的不确定性是在BES/BEPC上进行R值测量的主要误差来源之一，提出从原始数据中分离出束流相关样本的新方法，并把此样本用于调节强子产生器LUARLW的参数，以减小强子探测效率的系统误差，提高R值的测量精度.

关键词　R值　本底　产生器

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