Determine the Total Number of J/ψ from $J/\psi \to \mu^+\mu^-$

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1 Introduction

BES has acquired much high qualified data at BEPC at the C.M. energy of 3.097 GeV from Nov. 1999 to May 2001. There will be lot of intereted physics to be done with the most quantity of J/ψ data sample, such as glueballs, hybrid, baryon spetrum, σ and κ. The total number of J/ψ is a basic parameter for all these physics analysis. Due to the precise branching ratio of $J/\psi \to \mu^+\mu^-$, whose error is 1.7% in PDG2000 [1], this decay channel is analyzed to determine the total number of J/ψ.

The following formular is to calculate the J/ψ number. Because the two processes $J/\psi \to \mu^+\mu^-$ and $e^+e^- \to \mu^+\mu^-$ have the same final states, the latter will be inevitably selected in dimuon candidates. These QED B.G. must be removed.

$$N_{J/\psi} = \frac{N_{\mu\mu} - N_{ee\to\mu\mu}}{\varepsilon_{trg} \times \varepsilon_{\mu\mu} \times BR} \tag{1}$$

$N_{\mu\mu}$: number of selected dimuons;
$N_{ee\to\mu\mu}$: number of B.G. from $ee \to \mu\mu$;
ε_{trg}: trigger efficience;
$\varepsilon_{\mu\mu}$: detection and selection efficience from $J/\psi \to \mu^+\mu^-$;
BR: Branching Ratio of $J/\psi \to \mu^+\mu^-$.

In the whole process of acquring data, the conditions are stable in the main [2]. The status of these data is classified to three kinks, one for good runs, two for good runs with some problems and three for bad runs. Here the total number of J/ψ means to that is in the data from run13691 to run16835 with status of one or two. Totally about 3000 runs of J/ψ data.

2 Selection of Dimuon

The quatity of dimuon is very large and here strict criteria are used to select dimuon to reject any background.

The charged tracks' number is determined by the following cuts: it must hit MDC, Mfit=2 or -19, its vertex must satisfy $r < 1.5cm, |z| < 15cm$. Then we require exact two tracks and they are oppositely charged .

Although a radiative photon can be produced in $J/\psi \to \mu^+\mu^-$, the two muon are almost back-to-back because the photon are mainly with low energy(Fig. 1). So we require that the momentum of the two tracks should be within [1.0,2.1] GeV and their difference of ϕ angle is at a distance of 2^o to 180^o.

To reduce the cosmic background, we require $|T_1 - T_2| < 1.3(ns)$, where T_1 and T_2 are the two track's flight time from interaction point to TOF counter. To enhance muon identification, we also require $|T_1 - T_{exp}| < 1.0(ns)$, $|T_2 - T_{exp}| < 1.0(ns)$, where T_{exp} is obtained by the flight distance divided by the flight speed extracted from the momentum.

The two tracks must both have good hits at the muon detector as defined by routine mymuid.f [3]. Considering 0.67 of the aceptance of muon counter and avoiding the boundary effect, the $cost(\theta) < 0.6$ is demanded for both tracks.

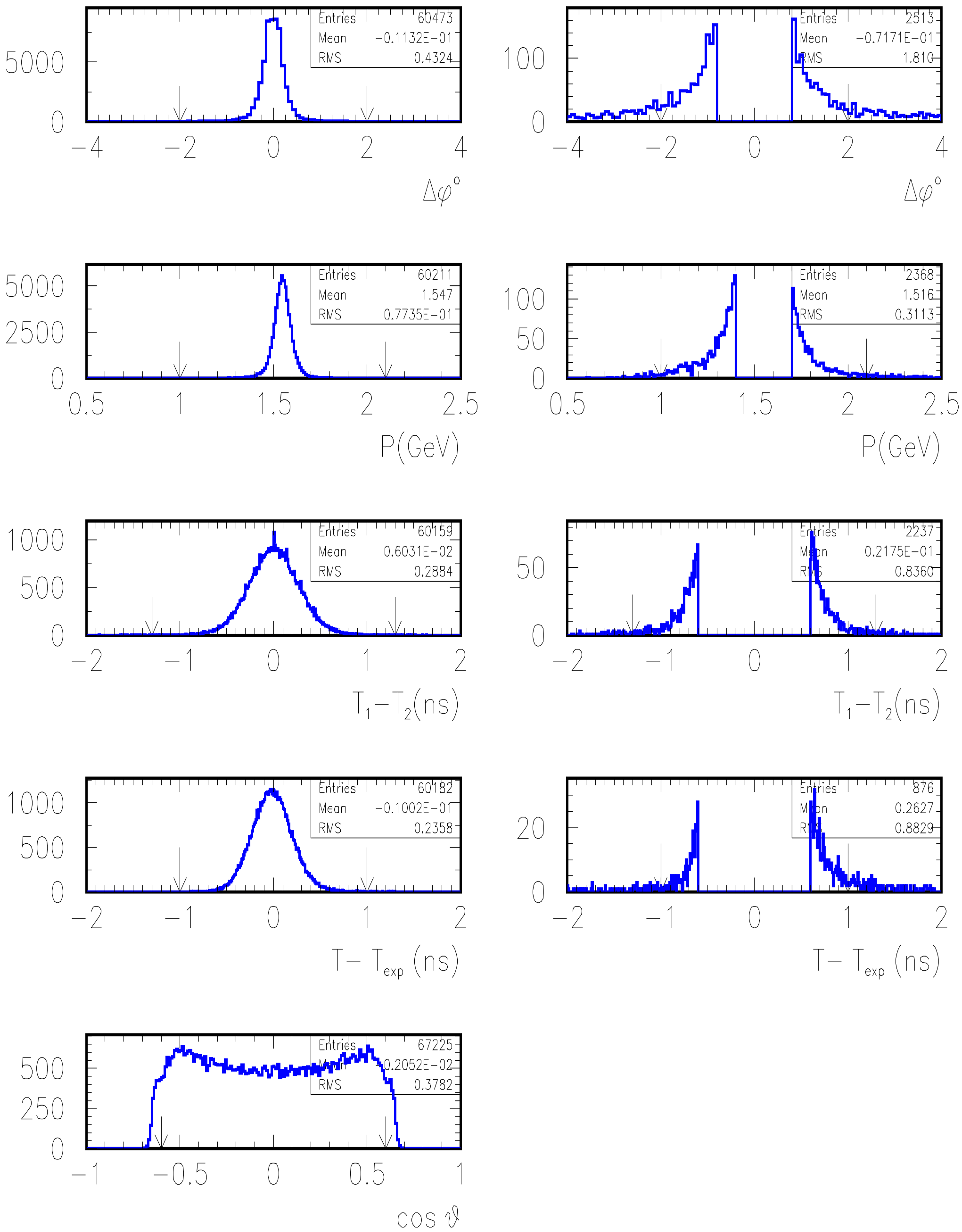

Figure 1: The cuts to select real dimuon sample.

3 Triger Efficiency

3.1 Trigger channel and formula

Though Dr. Li De has calculated the trigger efficiency of $J/\psi \to \mu^+\mu^-$, I do it again for a check.

Dimuon events can be triggered from three trigger channels while acquiring J/ψ data in 99-00, which are

- Charged channel:$N_{tof} \geq 1$, $N_{vc} \geq 1$, $N_{trk} \geq 1$ and E_{totl};

- Charged-2 channel:$N_{tof} \geq 2$, $N_{vc} \geq 1$ and $N_{trk} \geq 2$;

- Neutral channel:$Radial$ and E_{toth}.

With the independent dimuon sample, the efficiency of every trigger condition can be determined and then the trigger efficiency of dimuon is calculated by the formular:

$$\varepsilon = \varepsilon_0 + \varepsilon_1 + \varepsilon_2$$

$$\varepsilon_0 = \varepsilon_{N_{tof}\geq 1}\varepsilon_{N_{vc}\geq 1}\varepsilon_{N_{trk}\geq 1}\varepsilon_{E_{totl}}$$

$$\varepsilon_1 = (1 - \varepsilon_{E_{totl}}) \times \varepsilon_{N_{tof}\geq 2}\varepsilon_{N_{vc}\geq 1}\varepsilon_{N_{tof}\geq 2}$$

$$\varepsilon_2 = (1 - \varepsilon_{N_{tof}\geq 1}\varepsilon_{N_{vc}\geq 1}\varepsilon_{N_{trk}\geq 1}) \times \varepsilon_{Radial}\varepsilon_{E_{toth}}$$

where the ε_0 is major part and it comes from charged channel, ε_1 from charged-2 channel, ε_2 from neutral channel. Due to the small deposited energy of dimuon events, they hardly can be triggered through neutral channel and ε_2 is almost zero.

3.2 Selection of Dimuon Sample

The efficiency of a certain trigger condition of a subdetector should be obtained through a sample which is independent to this subdetector in both event trigger and offline selection. In the work of Dr. Li D, I found that the dimuon sample to determine efficiency of the trigger condition from MDC and TOF are selected by the MDC and TOF infomation at the same time. This is a problem. I correct it to select the sample independdently.

My dimuon selection criteria from some subdetector information are as following:

1)Muon detector: There are only two tracks hitting muon detector and they both hitting three lays; the hitting position in the three lays of the two trackstwo satisfy back-to-back conditions: $|\Delta\phi_{layone}| \in [8, 14]$, $|\Delta\phi_{laytwo}| \in [7, 15]$, $|\Delta\phi_{laythr}| \in [6, 16]$, $|zmu1_{layone} + zmu2_{layone}| < 0.32(m)$, $|zmu1_{laytwo} + zmu2_{laytwo}| < 0.45(m)$ and $|zmu1_{laythr} + zmu2_{laythr}| < 0.58(m)$.

2)MDC and VC: One charge is positive and the other negtive of the two tracks;their vertex satisfy $r_{vtx} < 0.01$ and $|z_{vtx}| < 0.1$; their momentum between 1.0 and 2.1 GeV;there polar angle satisfy $|cos\theta| < 0.6$.

3)TOF: The two tracks' TOF is between 3.0 and 6.0 ns and their difference is less than 1.0 ns; The hitting position in TOF satisfy $|ztof1 + ztof2| < 0.25$ m.

4)BSC: The deposited energy of the two tracks are lower than 0.6 GeV and $|\Delta\phi_{sc}|$ got by the hitting position in BSC is between 4.5 and 8.0 degrees.

While selecting dimuon sample to calculate the trigger efficiency for the $N_{vc} \geq 1$, $N_{trk} \geq 1$ and $N_{trk} \geq 2$, we use the above criteria except that from the MDC and VC; to do that for the $N_{tof} \geq 1$ and $N_{tof} \geq 2$, we use the above criteria except that from the TOF; To do that for the E_{totl}, E_{toth} and $Radial$, we use the above criteria except that from the BSC. All these work is to ensure the independence of sample.

3.3 Results of trigger efficience

The following table compares the trigger efficiency of the trigger data(run13931-run13939, the E_{totl} is 20) from me and Dr. Li D.

Table 1: Trigger Efficiency

	Heng YK (%)	Li D (%)
$\varepsilon_{N_{vc}\geq 1}$	100.00	99.77
$\varepsilon_{N_{trk}\geq 1}$	100.00	100.00
$\varepsilon_{N_{trk}\geq 2}$	97.96	97.97
$\varepsilon_{N_{tof}\geq 1}$	99.88	100.00
$\varepsilon_{N_{tof}\geq 2}$	96.50	97.25
$\varepsilon_{E_{totl}}$	96.38	97.27
$\varepsilon_{E_{toth}}$	0.00	1.53
ε_{Radial}	16.77	23.96
ε_{trg}	99.69	99.64

The BSC trigger conditions changed several times during the half year while acquiring J/ψ data [1]. We use the data of run14140-run14149(The E_{totl} is 15, versus 20 for run13931-run13939) calculating the $\varepsilon_{E_{totl}}$ again and get $\varepsilon_{E_{totl}} = 100\%$. The trigger efficiency for dimuon becomes 99.88%.

At last we can conclude that the trigger efficiency for dimuon is almost one and it is stable during the period of acquring data.We average the three results and get $\varepsilon_{trg} = (99.74 \pm 0.26)\%$, where the error is taken as its difference to one.

4 Monte Carlo simulation

To get preticise efficiency of detection and selection of dimuon events, we must do a preticise MC simulation, including the genetor of J/ψ to and every sub-detectors' performance.

[1] Other trigger conditions has no changes.

4.1 Generator

There is a generator of $J/\psi \to \mu^+\mu^-(\gamma)$ in BES lib. It only considers the α^2 order without radiative photon and produce $\mu^+\mu^-$ in space of $1 + cos^2\theta$. Dr. Wang Ping wrote a generator of $V \to l^+l^-(\gamma)$ generator. It calculate to the α^3 order, and the radiative photon is considered when its energy is greater than 1% of the c. m. energy. I linked it to BES lib to do the simulation of BES.

I use this generator to generate 120000 events of $J/\psi \to \mu^+\mu^-$, where 12311 events have a radiative photon with energy above 31MeV. The fig. 2 shows the kinematic information of the generated muon and the radiative photons in $J/\psi \to \mu^+\mu^-(\gamma)$. Most of the photons have low energy and are close to the direction of one of the muons. The majority of the dimuons have momentum of 1.55GeV and are almost back-to-back.

4.2 Correction of TOF resolution

Firstly we find that there is big difference between data and MC in the resolution of TOF for a muon track(see fig. 3). In MC simulation, there are 48 parameters to determine the TOF resolution, they are correspondent to 48 blocks of barrel TOF. We then check them again, find the differences also. The reason is using the bhabha events to get the 48 parameters and not considering the e^+e^- interaction region in old MC.

So we use a muon sample to get the 48 parameters of the resolutions and use them to correct the old one. After that, the new MC is cosistent with the data.

4.3 Correction of MDC efficiency

It is known the MDC has 40 lays. In MC there are ten parameters to descripe the hitted efficency for a charged track,respectively for lays of 1-4,5-8,9-12,......,37-40, 4 lays as a group. Here we check them again.

During a charged track being reconstructed by MDC infomation, some bad hitted points are throwed away according to the fitting χ^2. To descripe the MDC efficiency including hardware and software for a charged track, we define a parameter of efficiency as the remained hitted points' number divided by 40, the most possiple hitted points(40 lays in MDC). Then we compare this efficency between data and MC for muon tracks(see fig. 5. It is found that not only their values are different but also the efficiency is varied with $cos\theta$.

Then the ten fixed parameter in MC are changed to be a function of $cos\theta$. After this correction the results are cosistent with data(see fig. 5).

4.4 Correction of tube efficiency of muon detector

The muon detector of BES has three lays and every lay has two lays of tubes to detector a particle. In MC there are a parameter to describe the hitted efficiency of a tube, which is 0.98 in old MC.

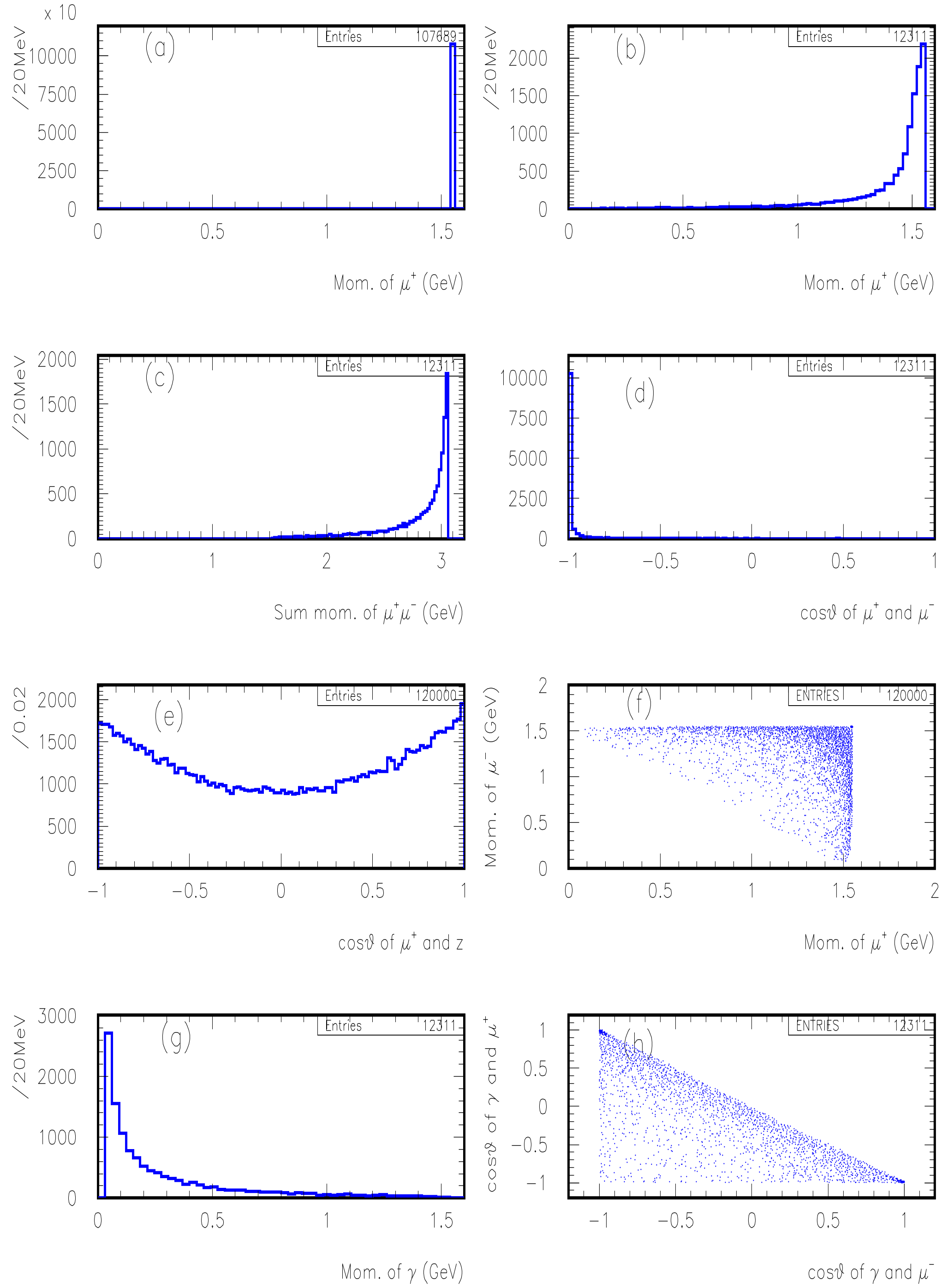

Figure 2: The kinematic quantities of the dimuon and photon produced from the generator of $J/\psi \to \mu^+\mu^-(\gamma)$. (a) without radiative photon above 31MeV, which is about 90% of all events; (b) (c) (d) (g) (h) with radiative photon above 31MeV, which is about 10% ; (e) (f) all events.

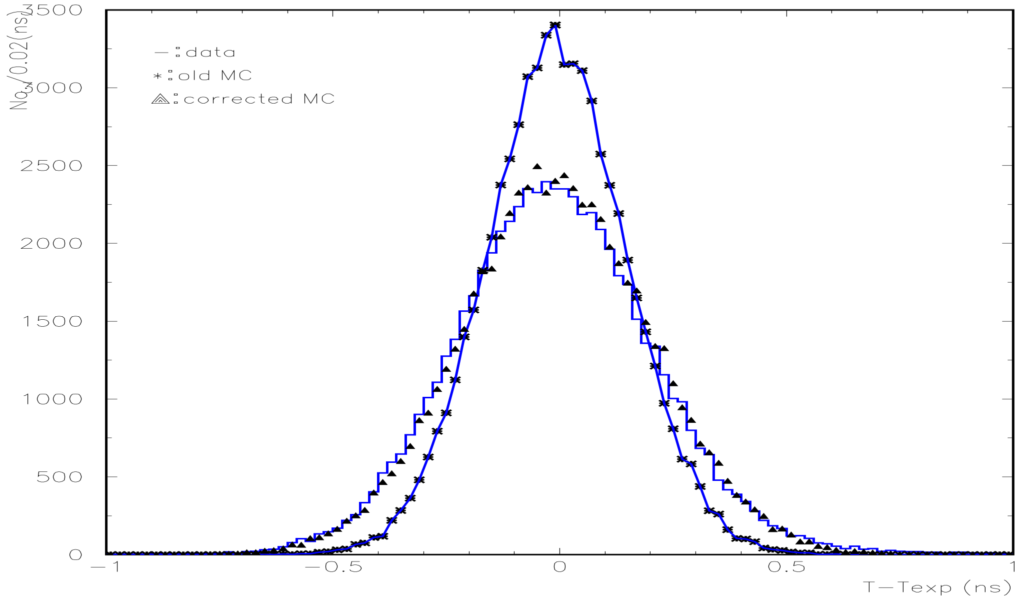

Figure 3: The difference between measured TOF and expected TOF of muon track.

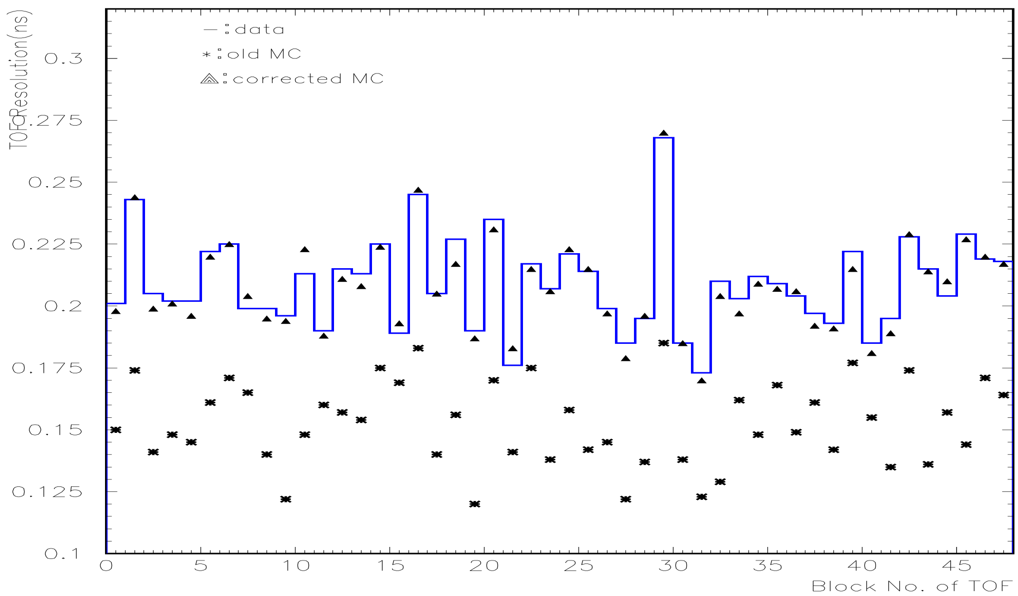

Figure 4: The TOF resolution of muon track for 48 blocks of TOF detector.

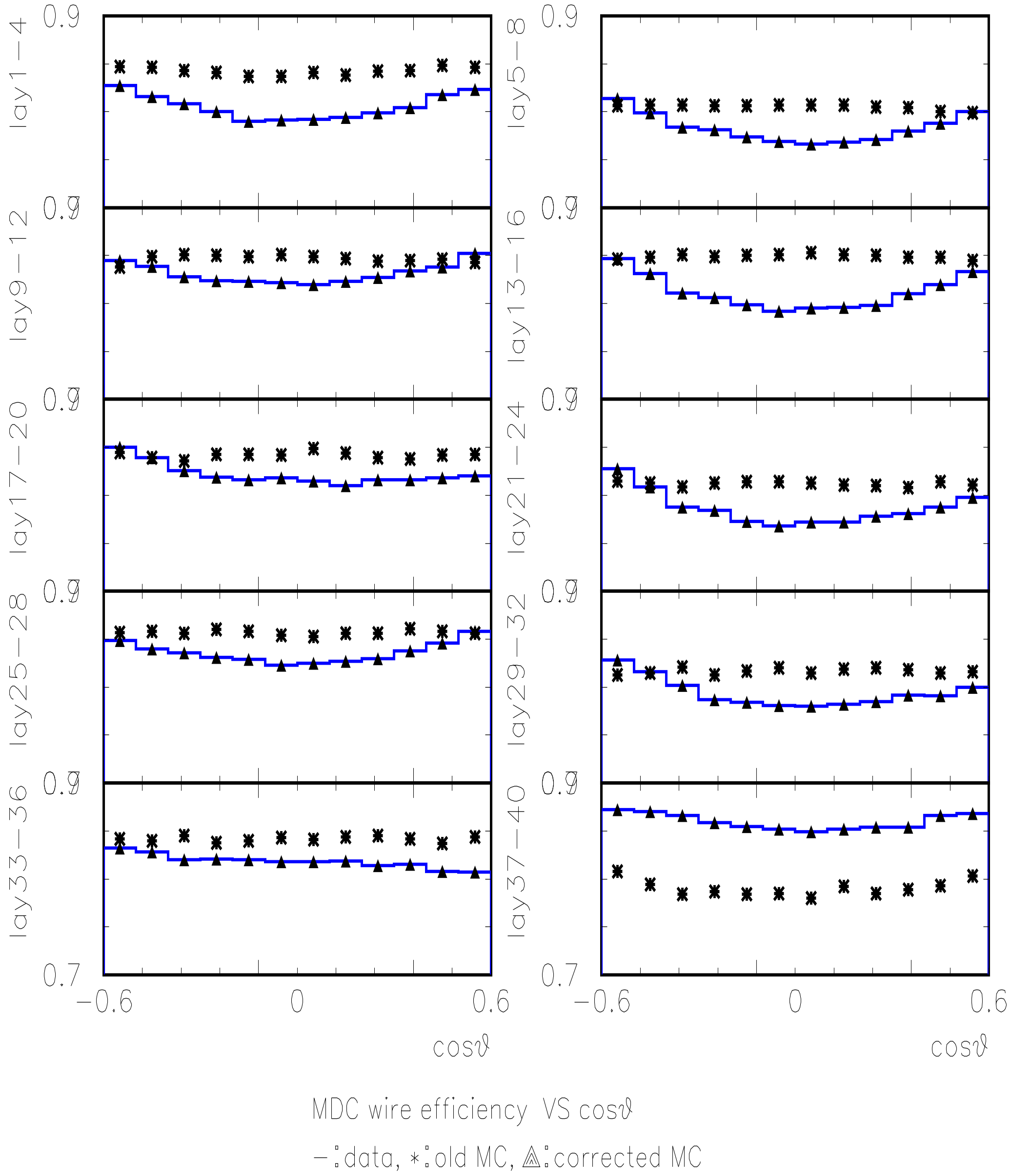

Figure 5: The MDC efficiency of muon sample VS $cos\theta$ for different lays.

We define a parameter to check the tube efficiency, which is the hitted and reconstructed number of hitted tubes of a good muon track divided by 6, the total number of lays of the tubes. To get it, a muon track sample is selected from dimuon events under the following strict cuts.

- There are exactly two tracks, their mfit=2 or -19
- Their momentums are within [1.4,1.7]GeV
- They are back-to-back and satisfy $||\delta\phi| - 180^o| < 0.6^o$
- Their TOFs are within [3,6]ns and satisfy $|TOF - TOF_{exp}| < 1$ns
- One track must have three good hits on muon detector
- Then the other track is as the muon sample.

As a result, we find the difference of this parameter between MC and data and then we correct the tube efficiency of 0.98 in old MC with 0.94. At last the consistency is obtained(see fig. 6).

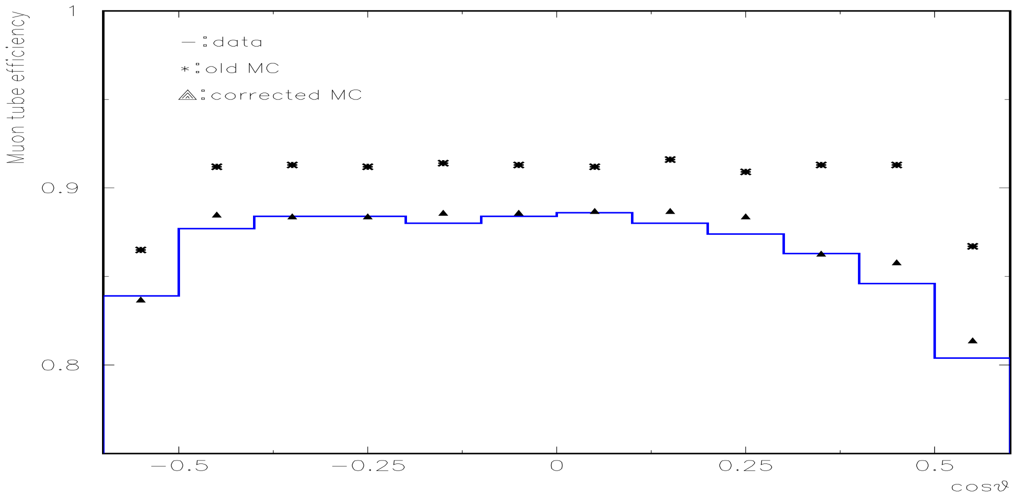

Figure 6: The parameter of muon detector tube efficiency of a muon VS $cos\theta$.

5 Background Estimate

5.1 Bhabha Events

Bhabha events and dimuon events both have two back-to-back tracks and their momentums are about energy of beam. Are there some pollutions in my selecting dimuon from bhabha? Here two checks are made. One is mu sample's deposited energy at shower counter; the other is number of good hitted layers at muon detector from bhabha electrons. In a dimuon sample of about 60000, there are only 49 events having one muon track's $E_{sc} > 0.7GeV$ and no events having both muon track's $E_{sc} > 0.7GeV$; in a bhahba sample of about 160000, there are only 408 events having good hits at muon detector for one track and 5 events for both two tracks (fig. 7). So the misidentification from bhabha is negligible.

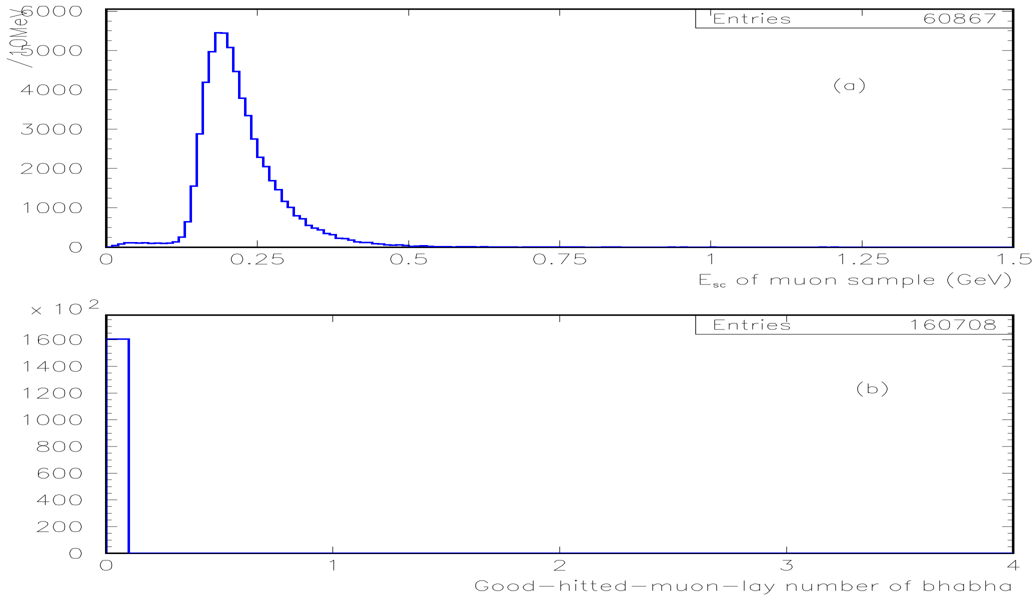

Figure 7: Checks of pollution from bhabha for dimuon selection. (a) dimuon sample, (b) bhabha sample.

5.2 Hadron Events

It is known that most decays of J/ψ are hadronic, i.e., 87%. Especially the pions of high momentum can hit muon detector. The $J/\psi \to \pi^+\pi^-\pi^0$ is the most possible decay mode that may be misidentified as dimuons in all hadronic decays.

A MC sample of 200,000 $J/\psi \to \pi^+\pi^-\pi^0$ is generated. We use our programm to pass through it. As a result, there is only 1 event being misidentified as a dimuon. As we know, the misidentified ratio of hadron should be less than $\frac{1}{200000} \times \frac{BR(J/\psi \to hadrons)}{BR(J/\psi \to \pi^+\pi^-\pi^0)} \simeq 0.0003$. Thus the misidentification from hadrons is negligible too.

5.3 $e^+e^- \to \mu^+\mu^-$

The QED process of $e^+e^- \to \mu^+\mu^-(\gamma)$ has the same final state with $J/\psi \to \mu^+\mu^-(\gamma)$ and it can't be rejected by any selection. Here we calculate their nubmber and reduce them from the all dimuon(see the equation 1).

The data of 47 runs are acquired at 3.0 GeV in 99-00 and they can be used to analysize this background. It is known that the Branching Ratio of $J/\psi \to \gamma\gamma(\gamma)$ is very small and negligible. According to the cross section of the two QED processes, $e^+e^- \to \mu^+\mu^-(\gamma)$ and $e^+e^- \to \gamma\gamma(\gamma)$, we have

$$R_{qed} = \frac{N^{3.097}_{ee\to\mu\mu}}{N^{3.0}_{ee\to\mu\mu}} = \frac{N^{3.097}_{ee\to\gamma\gamma(\gamma)}}{N^{3.0}_{ee\to\gamma\gamma(\gamma)}} \tag{2}$$

That is to say, we can select the $e^+e^- \to \gamma\gamma(\gamma)$ to get the total number of the background, $N^{3.097}_{ee\to\mu\mu}$.

Event Selection:

- No charged track and neutral track number is 2 or 3, they all hit at BSC.
- Avoid ribbon and boundary region in BSC:$|z| > 0.1$, $|z \pm 0.955| > 0.1$, $|z| < 1.5$
- Each of the biggest two deposit energy in BSC: $E/E_{beam} > 0.45$
- The whole deposit energy in BSC: $E_{all}/E_{beam} > 1.1$
- Back-to-Back: $||\Delta\phi| - 180^o| < 3$

Fig. 8 shows the distribution of the energy and $\Delta\phi$ of $e^+e^- \to \gamma\gamma(\gamma)$ from the 3.0 GeV data and J/ψ data. And we obtain $R_{qed} = 41.9 \pm 1.0$, where the error include the statical error of 2.2% and selection error of 0.9%. There are 742 ± 27 dimuon events selected from the QED data. So

$$N^{3.097}_{ee\to\mu\mu} = R_{qed} \times N^{3.0}_{ee\to\mu\mu} = 31099 \pm 1342$$

6 Result and error

6.1 No. of J/ψ: $(24.90 \pm 0.87) \times 10^6$

According the data quality and realization parameters in MC, the data is divided into three data sets and so there are three $N_{\mu\mu}$ and $\varepsilon_{\mu\mu}$. At last the total number of J/ψ is $(24.90 \pm 0.87) \times 10^6$.

6.2 Error: 3.5%

Firstly the error from selection criteria are small and they are obtained by varying the cuts and comparing the results. Secondly the QED B.G. is about 4.6% in the total dimuon candidates and so the error from it is small too.

The biggest error comes from efficiency by MC. The generator is consider to the three order items and its error is less than 1%. Fig. 9 shows the comparison of some quantities of real data and MC data for dimuon data. It is found that the $cos\theta$ distribution in real data is a little inconsistent with MC. Theoretically the

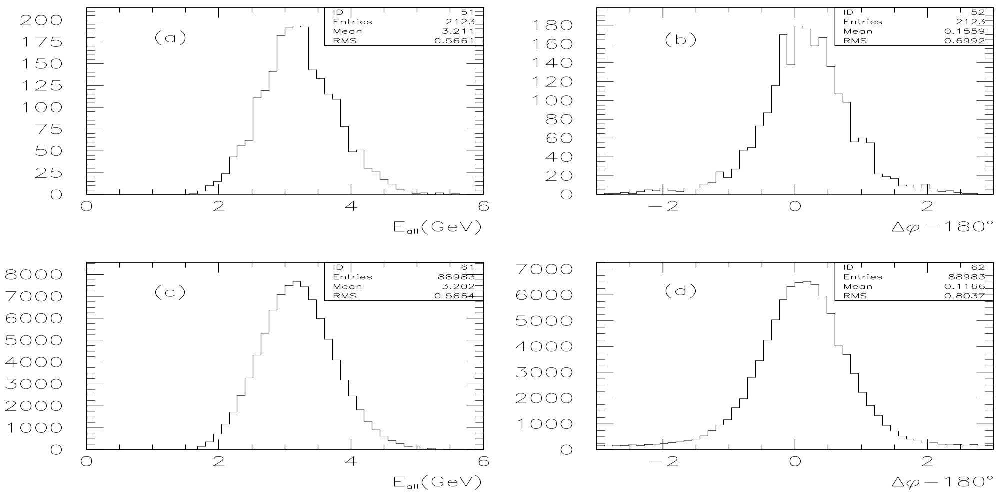

Figure 8: The total deposit energy and $\Delta\phi$ in the process of $e^+e^- \to \gamma\gamma(\gamma)$. (a)(b) is from QED data; (c)(d) is from the J/ψ data.

Table 2: Results

DataData	$N_{\mu\mu}(\times 10^3)$	$N_{ee\to\mu\mu}(\times 10^3)$	$\varepsilon_{\mu\mu}$	$N_{J/\psi}(\times 10^6)$
Run13691-run15797	$435.5\pm^{3.2}_{5.1}$	20.1 ± 0.8	0.4424 ± 0.0128	16.01 ± 0.56
Run15798-run16242	$102.9\pm^{0.7}_{1.2}$	4.7 ± 0.2	0.4431 ± 0.0128	3.78 ± 0.13
Run16243-run16835	$139.3\pm^{1.0}_{1.6}$	6.3 ± 0.3	0.4438 ± 0.0129	5.11 ± 0.18
Total(1stRun)	$677.7\pm^{4.9}_{7.9}$	31.1 ± 1.3	0.4428 ± 0.0128	24.90 ± 0.87
Run17060-run17361	$50.6\pm^{0.4}_{0.6}$	2.1 ± 0.08	0.4431 ± 0.0129	1.87 ± 0.07
Run17362-run17725	$142.4\pm^{1.0}_{1.7}$	6.0 ± 0.24	0.4438 ± 0.0129	5.24 ± 0.18
Run17726-run18086	$136.1\pm^{1.0}_{1.6}$	5.9 ± 0.23	0.4430 ± 0.0128	5.01 ± 0.18
Run18123-run18200	$32.7\pm^{0.2}_{0.4}$	1.5 ± 0.06	0.4422 ± 0.0128	1.20 ± 0.04
Run18201-run18600	$159.7\pm^{1.2}_{1.9}$	6.9 ± 0.28	0.4421 ± 0.0128	5.89 ± 0.21
Run18601-run19000	$171.9\pm^{1.3}_{2.0}$	7.5 ± 0.30	0.4442 ± 0.0129	6.31 ± 0.22
Run19001-run19186	$69.1\pm^{0.5}_{0.8}$	3.0 ± 0.12	0.4434 ± 0.0129	2.54 ± 0.09
Total(2ndRun)	$726.6\pm^{5.3}_{8.5}$	32.9 ± 1.32	0.4431 ± 0.0129	28.06 ± 0.98

distribution should be $1 + cos^2\theta$. But the data is deeper in the middle. We fit it with $1 + \alpha cos^2\theta$ and get $\alpha = 1.07$. The reason has not been found completely and it is considered as a error. Here we vary the MC generator and to match the data and find that the effect is 2.5%. Also considering other differences in the fig. 9 and at last the error from MC is 2.9%.

Table 3: Error Analysis

Source	Error (%)
$cos\theta$	0.4
P	0.3
$\Delta\phi$	$\pm^{0.2}_{0.3}$
TOF	$\pm^{0.1}_{0.2}$
Muon ID	$\pm^{0.5}_{1.0}$
QED B.G.	± 0.2
ε_{trg}	± 0.2
$\varepsilon_{\mu\mu}$	± 2.9
BR	± 1.7
Total	± 3.5

At last I want to give my sincere thanks for many meaningful discussion to Prof. Lu J.G., Prof. Shen X.Y., Prof. Zhang C.C., Prof. Zhang D.H., Prof. Liu H.M., Prof. Mao Z.P., Dr. Huang G.S., Dr. Wang Z.Y., etc.

References

[1] PDG 2000

[2] http://gluon.ihep.ac.cn/ ~ jpsi/data-quality/99-00/quality-99-00.html

[3] Mymuid.f is a routine written by Yuan Changzheng. Here the parameters of muon like the resolutions are changed to satisfy the current situtions of data and MC. Also other muon ID programs are used as checks and the results are consistent.

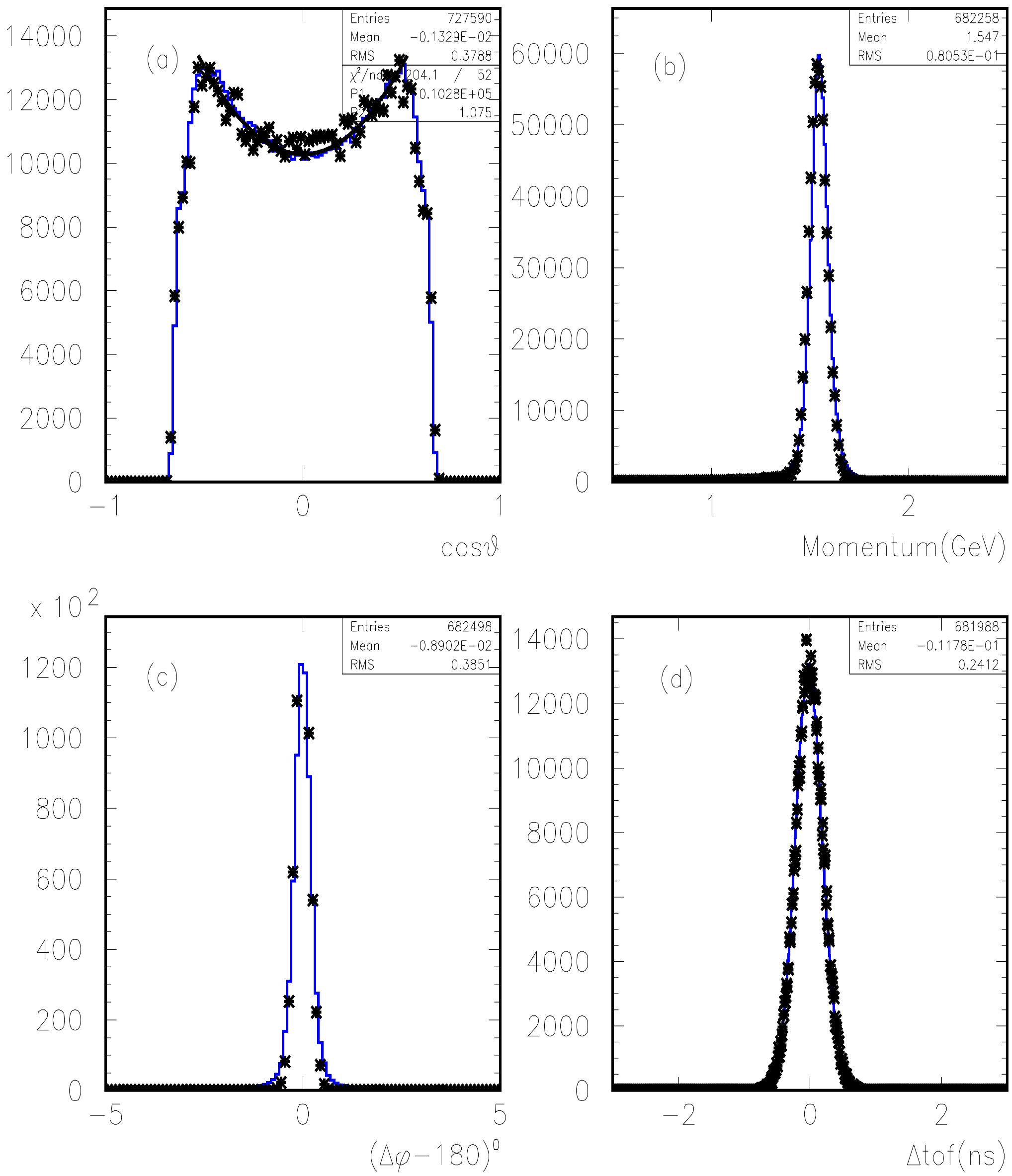

Figure 9: The comparison of real data(line) and MC(star) for dimuon. (a)$cos\theta$; (b)Momentum; (c)$(\Delta\phi - 180)^o$; (d)Δtof. In (a) the data is fitted with $1 + \alpha cos^2\theta$ and $\alpha = 1.07$.