Measurement of the Luminosity with Large Angle Bhabha Events for the Data Around 3.55 GeV Collected with BES at BEPC

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Abstract

Integrated luminosities for the data collected around 3.55 GeV with BES are determined according to large-angle Bhabha events selected by different criteria. The measured luminosities agree with each other within 1%. As a cross check, the information from Endcap Shower Counter(ESC) was used for the first time at BES to measure the luminosity. The results agree with that given by large-angle Bhabha events around 6% on average.

1 Introduction

BES has been planning to measure the values of R at center-of-mass energies between 2 and 5 GeV with a precission close down to 5%. R is defined as

$$R = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}, \tag{1}$$

where the cross section of pure QED process $e^+e^- \to \mu^+\mu^-$ can be precisely calculated, which is the Born cross section $\sigma(e^+e^- \to \mu^+\mu^-) = 4\pi\alpha^2/3s = 86.8\ (nb^{-1})/s(GeV)$, $(s = 4E^2_{beam})$. Therefore the measurement of the values of R is eventually to measure the total cross section of the process $e^+e^- \to hadrons$.

From the experimental aspect, one must take into account the beam luminosity (L); the radiative correction of the initial state(δ); the detection efficiency for the hadronic events(ε_{had}); the misidentification of the hadrons from the lepton pair production (N_{ll}, $l = e, \mu, \tau$) and two-photon process($N_{\gamma\gamma}$). R can then be expressed as,

$$R = \frac{\sigma^0_{had}}{\sigma^0_{\mu\mu}} = \frac{1}{\sigma^0_{\mu\mu}\bar{\varepsilon}_{had} \cdot (1+\delta)} \cdot \frac{N^{obs}_{had} - N_{bg} - \sum_l N_{ll} - N_{\gamma\gamma}}{L}, \tag{2}$$

from which one can see that the uncertainty of L will directly propagate into that of the value of R. Because of this reason, like $\bar{\varepsilon}_{had}$, L is one of the key factors directly affecting the value of R. For a value of R with 5% accuracy to be measured with BES, L must be measured to be better than 3%.

Using the data collected with BES at center-of-mass energies around 3.55 GeV for the measurement of the mass of τ[1], we have been trying to measure the values of R at all

12 scanned energy points. The total integral luminosity given by luminosity monitor was 5067.6 nb^{-1}. However, we cannot judge the relibility of the luminosities measured with small-angle Bhabha luminosity monitor since the data was collected in 1992 and some of the first hand information are not available, e.g. there are missing runs in several points and L run by run determined via luminosity monitor data is not available. This work is to determine the luminosities via large-angle Bhabha using different events selection criteria for all the scanned points. In the meantime, other methods using $e^+e^- \rightarrow \mu^+\mu^-, \gamma\gamma$ processes as well as making use of the information from the endcaps of BES to measure L as cross checks are investigated.

2 Data set

A scan with 12 energy points in the immediate vicinity of the τ pair production threshold was performed with BES at BEPC to measure the mass of tau at center-of-mass energies between 3.54418 GeV and 3.59902 GeV. Table 1 lists all the scan points, of which 6 points are below and above the τ pair production threshold. The energy region covering all scan points is 54.84 MeV, and the energy spread for each point is less than 1.5 MeV.

Table 1: Data collected at the energies around 3.55 GeV with BES at BEPC for the τ mass measurement

#	E_{cm} (GeV)	ΔE (GeV)	L_{ADC} (nb^{-1})	Run range	N_{runs}	Excluded Runs	Missing Runs
1	3.56838	0.00134	245.8	2530-2555	26		2542, 2550
2	3.56198	0.00133	248.9	2556-2577	22		2565
3	3.54418	0.00136	232.8	2578-2596	19		
4	3.55314	0.00137	323.0	2597-2626	30		2603
5	3.55698	0.00144	322.5	2627-2651	25		2640
6	3.55190	0.00143	296.9	2652-2673	22	2660	
7	3.55350	0.00147	384.0	2674-2701	28		2681
8	3.55396	0.00147	360.8	2702-2724	23		
9	3.55290	0.00144	794.1	2745-2793	48	2786	
				2908-2909	2		
				Σ	50		
10	3.55324	0.00140	1109.1	2794-2834	41		
				2849-2871	23		
				2894-2907	14		
				2910-2911	2		
				Σ	80		
11	3.59902	0.00144	499.7	2912-2935	24		
				3058-3067	10		
				Σ	34		
12	3.57910	0.00143	250.0	3040-3057	18		

3 Large-angle Bhabha Events Selection

The criteria for selecting two charged tracks are:

• two charged tracks with opposite charge and the net charge is zero;

• good tracks in the MDC (MFIT=2), meaning that the fitted track has at least 10 chamber hits and the quality of the track fit is good;

• the closest distance of the track to the beam in the transverse plane and along the beam direction must be less than 1.5 cm and 15 cm respectively, i.e. $V_r < 1.5\ cm$ (fig.1.a) and $\mid V_z \mid < 15\ cm$ (fig.1.b). In addition, the difference of the z components of the position for the two tracks is less than 5 cm(fig.1.c);

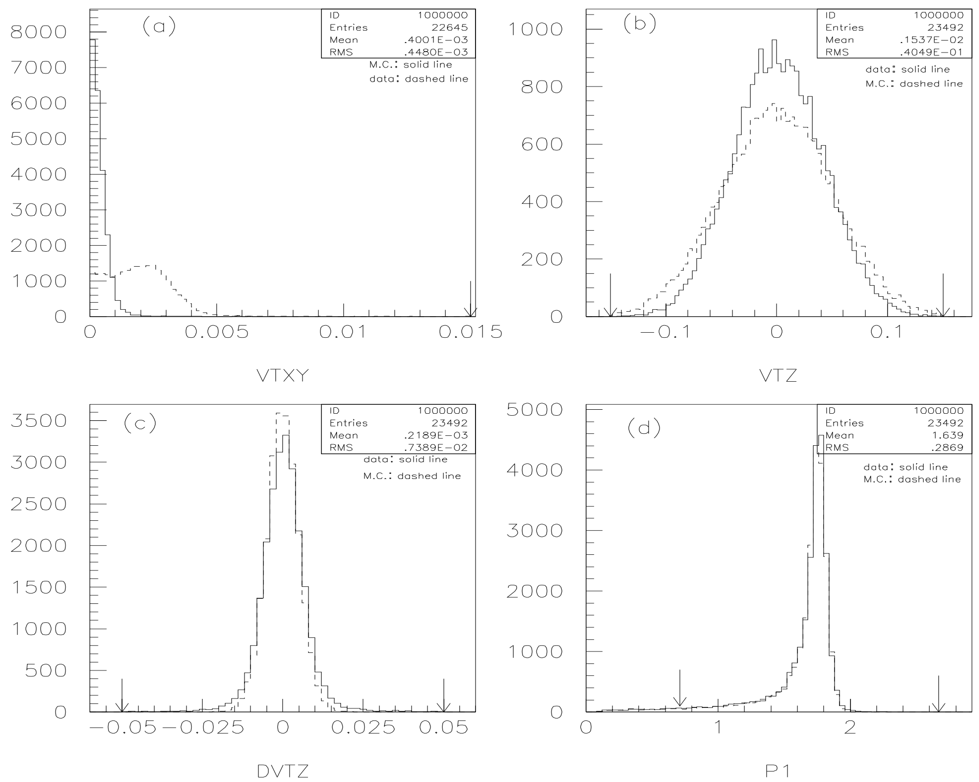

Figure 1: Comparison between data and Monte Carlo: (a)distance between vertex to beam line; (b)z coordinates of vertex; (c)difference of z coordinates of the two tracks; (d)momentum of one track

• $\mid cos(\theta) \mid < 0.75$, where θ is the track polar angle;

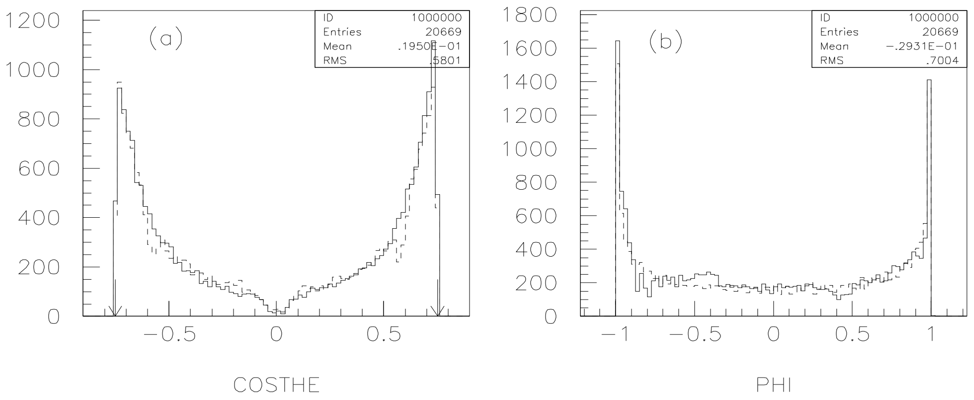

Figure 2: Distribution of $cos\theta$ and $cos\phi$ of data (solid line) and M.C. (dashed line)

• the difference of flight time between the two tracks is less than 4.0 ns, and at least one of the tracks has a flight time within 3.0 ns deviation from its expected value;

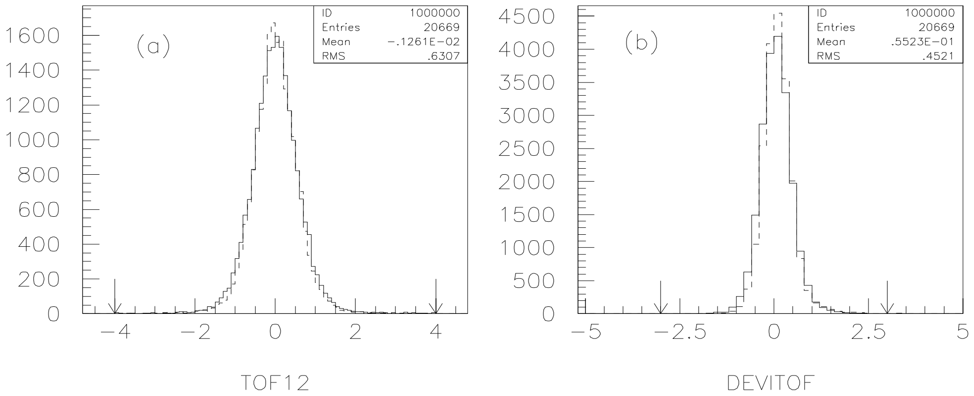

Figure 3: Difference of flight time between the two tracks and deviation from the expected value. solid line: data, dashed line: M.C.

After applying all the cuts described above, we then select Bhabha events using following different criteria

1. so called traditional cuts commenly accepted at BES, which makes use of the informations in MDC, BSC and μ counter. The criteria are

(a) the momentum of each track is required to be greater than $0.4P_{beam}$ and less than $1.5P_{beam}$ (fig.1.d);

(b) the momentum in xy plane of each track is greater than 0.2 GeV to avoid loop track in MDC;

(c) both the acollinear and acoplanar angle between the two tracks are required to be less than $10°$;

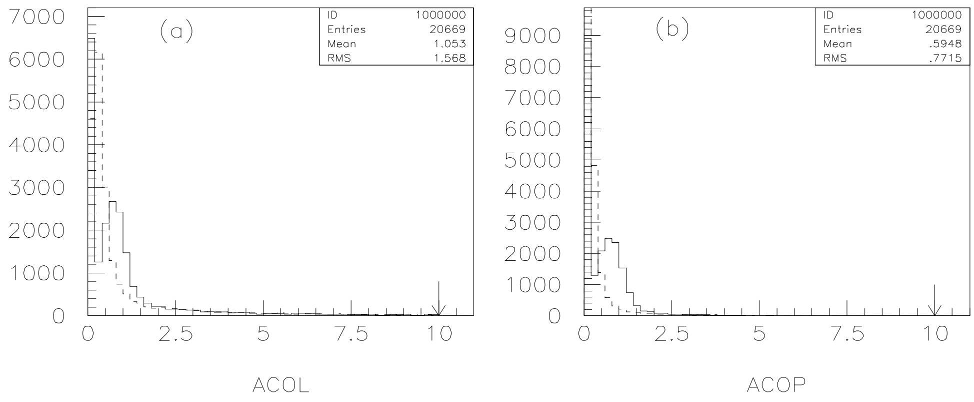

Figure 4: Distribution of acollinear and acoplanary angle between the two tracks. data: solid line, M.C.: dashed line

(d) the energy of each track is greater than $0.4E_{beam}$ (fig.5.c, d), and the total energy is greater than $1.2E_{beam}$;

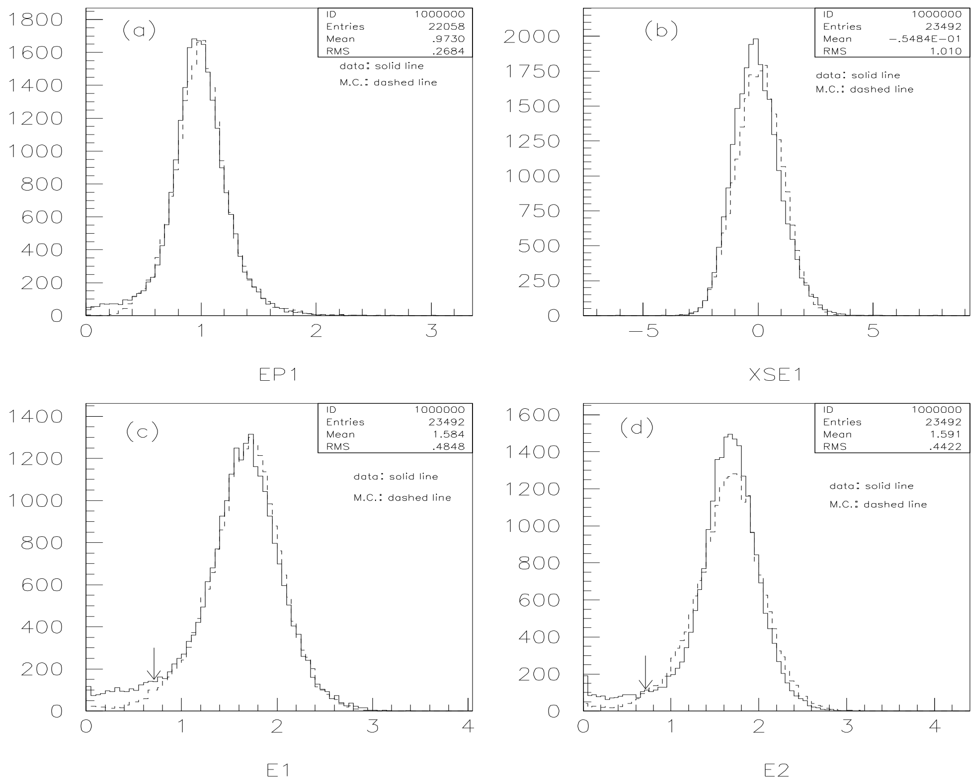

Figure 5: Comparison between data and Monte Carlo

(e) events with tracks in central ribbon area (with the projected coordinates of MDC tracks at BSC entrance less than 4cm to the central transverse plane) are discarded;

(f) both tracks leave no signature in muon counter.

2. using both dE/dx information from MDC and energy deposited in BSC. The momentum resolution given by MDC in BES is pretty good, whereas the energy resolution of BSC is poor. In the momentum range above 1.4 GeV/c, e^+ or e^- can be clearly distinguished from other particles according to their dE/dx pulse height(PHMP). It has relative high selection efficiency and the selection criteria are simple, i.e.

(a) the energy of each track is greater than $0.4E_{beam}$ (fig.5.c, d), and the total energy is greater than $1.2E_{beam}$;

and then, events satisfying the cut either (b) or (c) are regarded as Bhabha events,

(b) the momentum of at least one track is greater than 1.5 GeV/c; and $\chi_{se} \equiv \frac{PHMP(EXP)-PHMP(calc.)}{\sigma} > 0$, or the confidence level of e^+ or e^- determined by χ_{se} is greater than 0.05 $((prob(\chi^2_{se1}+\chi^2_{se1}), 2) > 0.05)$ (area above the cut line in fig.6.b);

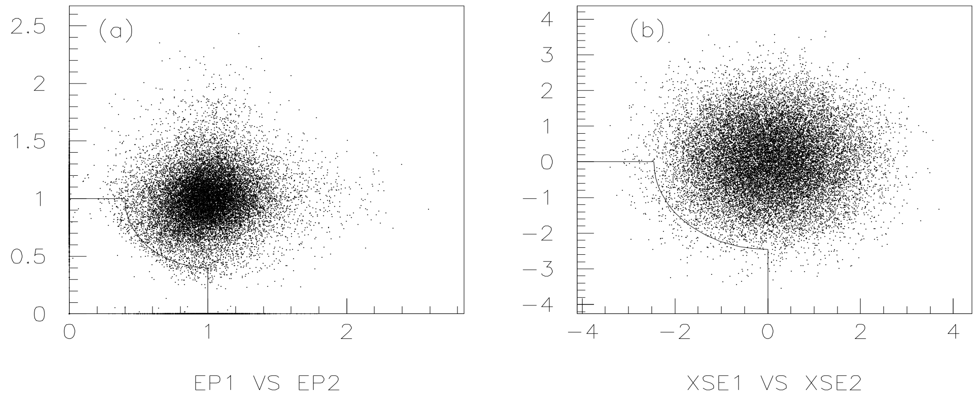

Figure 6: Two-dimensional distribution of E/p and χ_{se}

(c) the ratio of energy to momentum $E/P > 1$, or in the two-dimensional histogram of E_1/P_1 vs E_2/P_2, events in the range within radius less than 0.6 ((1,1) as center). (see the area above the cut line in fig.6.a)

3. purely rely on dE/dx information.

There exists some problems in shower counter, such as too many dead channels; dead area due to the 5 ribbons used; the radiation length are not long enough and thus the energy resolution is not good. Using only the dE/dx information to select Bhabha events can avoid these problems and has its unique advantages. The criteria are simply cut (b) in method 2 mentioned previously.

4 Luminosities Measured by Large-angle Bhabha

The integral luminosity can be determined by the following formula,

$$L = \frac{N_{obs}}{\sigma \cdot \varepsilon \cdot \varepsilon_{trg}} \tag{3}$$

where N_{obs} is the number of Bhabha events observed, σ is the production cross section of Bhabha events in specified polar angle range given by Monte Carlo simulation, ε is the detection efficiency for the Bhabha events, and ε_{trg} the trigger efficiency.

The detection efficiency ε can be obtained by

$$\varepsilon = \frac{N^{obs}_{mc}}{N^{total}_{mc}} \tag{4}$$

where N_{mc}^{total} is the total number of Bhabha events produced by Monte Carlo, N_{mc}^{obs} is the number of Bhabha events survived after applying Bhabha events selection ceriteria

insert (4) into (5) one has

$$L = \frac{N_{obs}}{N_{mc}^{obs}} \cdot \frac{N_{mc}^{total}}{\sigma \cdot \varepsilon_{trg}} = r \cdot \frac{N_{mc}^{total}}{\sigma \cdot \varepsilon_{trg}} \tag{5}$$

where

$$r \equiv \frac{N_{obs}}{N_{mc}^{obs}} \tag{6}$$

The error of L can then be expressed by

$$(\frac{\Delta L}{L})^2 = (\frac{\Delta \sigma}{\sigma})^2 + (\frac{\Delta \varepsilon_{trg}}{\varepsilon_{trg}})^2 + (\frac{\Delta r}{r})^2 + (\frac{\Delta N_{mc}^{total}}{N_{mc}^{total}})^2 \tag{7}$$

The luminosities measured with different events selection methods are listed in Table 2, where L_1, L_2 and L_3 are the luminosities determined respectively by the events selection method 1, 2 and 3 described previousely. The trigger efficiency was measured to be 96.3% [2], we then assign 3.7% uncertainty to the trigger efficiency, which is the largest error contribution to the luminosity. By varying the cuts we found that the error arising from the events selection is about 2%. The errors of the Bhabha events production cross section and of statistics are 0.02% and 0.22% respectively, which are neglegible. On average, L_2 is 0.3% larger and L_3 is 0.8% smaller than L_1 systematically.

We point out that after improving the trigger condition, the trigger efficiency for the Bhabha enents has been increased to ~100% as claimed by a measurement for studying the trigger efficiency at BES[3]. Therefore, the uncertainties on the luminosity contributed from trigger efficiency will no longer be the dominent part in our planned measurement of the values of R.

Table 2: Luminosities measured via large-angle Bhabha with different events selection criteria

#	E_{cm} (GeV)	$L_{ADC}(nb^{-1})$	$L_1(nb^{-1})$	$\frac{\Delta L_1}{L_1}(\%)$	$L_2(nb^{-1})$	$\frac{\Delta L_2}{L_2}(\%)$	$L_3(nb^{-1})$
1	3.56838	245.8	200.18	4.53	201.64	4.11	200.73
2	3.56198	248.9	197.70	4.51	198.88	4.11	198.57
3	3.54418	232.8	188.51	4.51	190.09	4.11	193.49
4	3.55314	323.0	259.70	4.51	260.78	4.10	259.15
5	3.55698	322.5	260.22	4.51	261.00	4.10	259.69
6	3.55190	296.9	223.80	4.52	223.84	4.11	221.34
7	3.55350	384.0	311.13	4.50	311.02	4.08	307.86
8	3.55396	360.8	283.63	4.50	284.25	4.09	283.10
9	3.55290	794.1	672.55	4.48	676.65	4.07	673.99
10	3.55324	1109.1	971.89	4.47	967.65	4.06	948.84
11	3.59902	499.7	434.92	4.49	435.23	4.07	425.69
12	3.57910	250.0	216.42	4.53	221.33	4.11	215.37

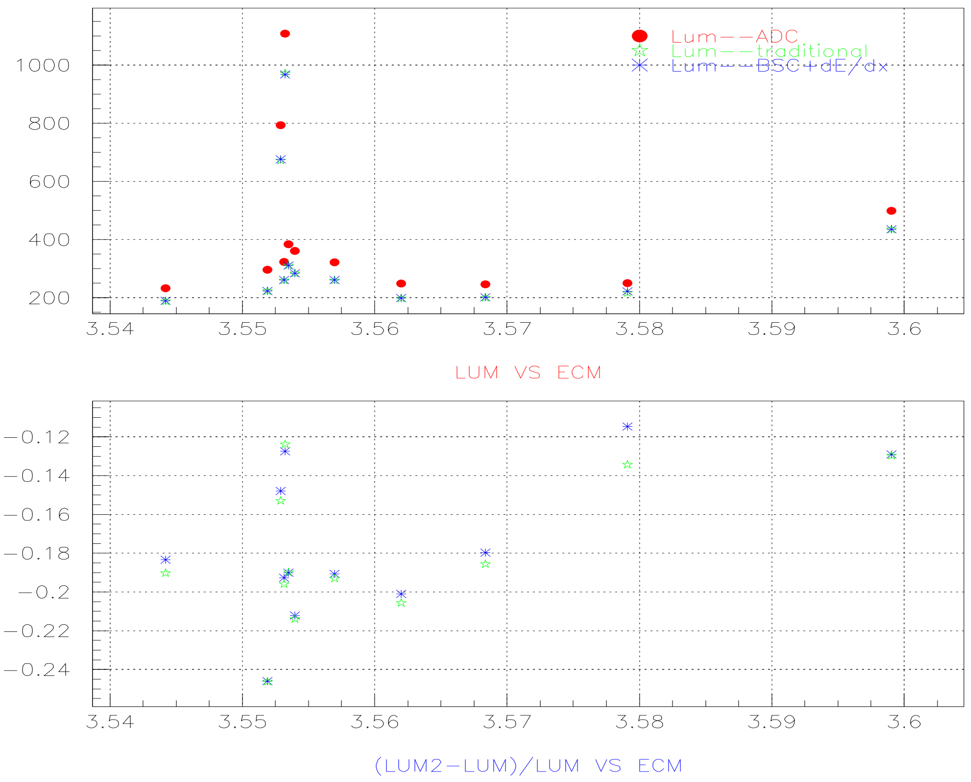

Figure 7: Comparison between large and small angle luminosity

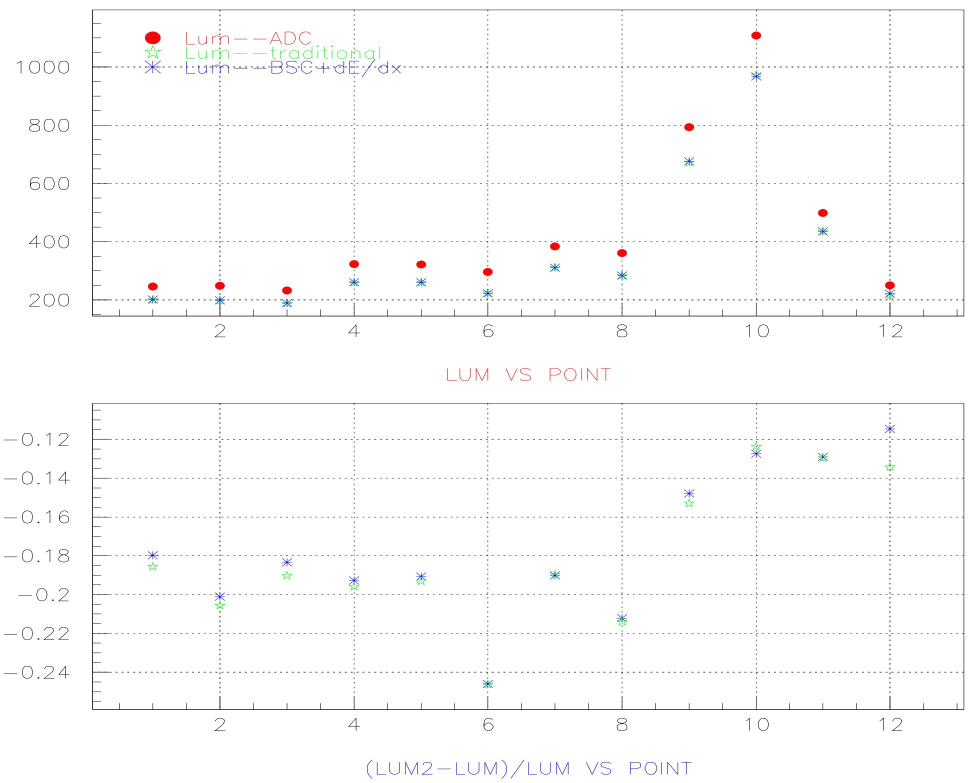

Figure 8: Comparison between large and small angle luminosity

5 Other Means to Measure Luminosity

As mentioned previously, different methods has been utilized to select Bhabha event and the luminosities obtained agree with each other within 1%. However, it's worthwhile finding other means to cross check the results from the large-angle Bhabha.

In fact, the observed events N_{obs} is given by

$$N_{obs} = L \cdot \sigma \cdot \varepsilon \cdot \varepsilon_{trg}, \tag{8}$$

where L and σ are luminosity and the cross section of the physics channel producing events N_{obs}. ε is the corresponding detection efficience and ε_{trg} the trigger efficiency. It is possible, in principle, to use any physics channels other than Bhabha to determine luminosity as long as the cross section is large enough and been known fairly well.

5.1 Dimu Channel

Dimu events are often used to determine luminosity. We have tried to use dimu events to measure L for tau mass scan data, but the result is disappointing because a large fraction of dimu events is lost due to the high threshold trigger condition applied during data collection. Following cuts are used to select dimuon events:

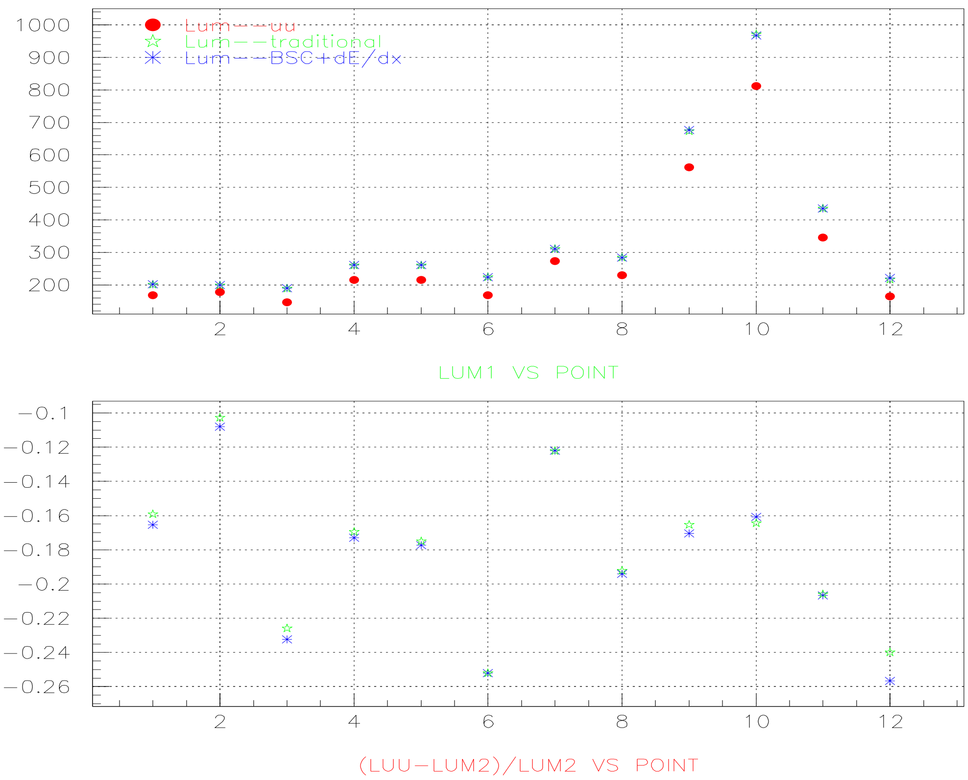

Figure 9: Luminosity from dimu events and comparison with Bhabha

- two charged tracks with opposite charge and the net charge is zero;
- good tracks in the MDC (MFIT=2, -19);
- the closest distance of the track to the beam in the transverse plane and along the

beam direction must be less than 1.0 cm and 20 cm respectively, i.e. $V_r < 1.0\ cm$ and $| V_z | < 20\ cm$;

• $0.2 < | cos(\theta) | < 0.6$, where θ is the track polar angle (events in large polar angle region are discarded, since there exists big drop);

• the momentum of each track is required to be greater than $0.7P_{beam}$ and less than $1.2P_{beam}$;

• the flight time of each track is less than 7.0ns, and the difference of flight time between the two tracks is less than 4.0 ns;

• the energy of each track is less than 0.7 GeV;

• at least one track leaves signature in muon counter.

Trigger efficiency is taken to be 0.837 [2]. The results from dimu events and comparison with the ones from Bhabha events are shown in fig.9. A rough comparison between L obtained by dimu and Bhabha events shows that they have a discrepancy about 10-25%.

5.2 $e^+e^- \rightarrow \gamma\gamma(\gamma)$ Channel

The integral cross section of $e^+e^- \rightarrow \gamma\gamma(\gamma)$ at $E_{cm} = 3.55GeV$ is about $193nb^{-1}$, it is much bigger than dimu channel, so we could obtain better statistics using this channel. Unfortunately, neutral trigger was not applied and thus this channel is helpless for us to measure L for tau mass scan data.

5.3 Using Endcap Information

ESC can be considered as a large luminosity detector, and it has the obvious advantage that it is not so sensitive to position precision comparing with small angle monitor. Fig.10 is the sketch of ESC and luminosity monitor. Endcap information has never been used before at BES, however it is worthwhile making use of its information.

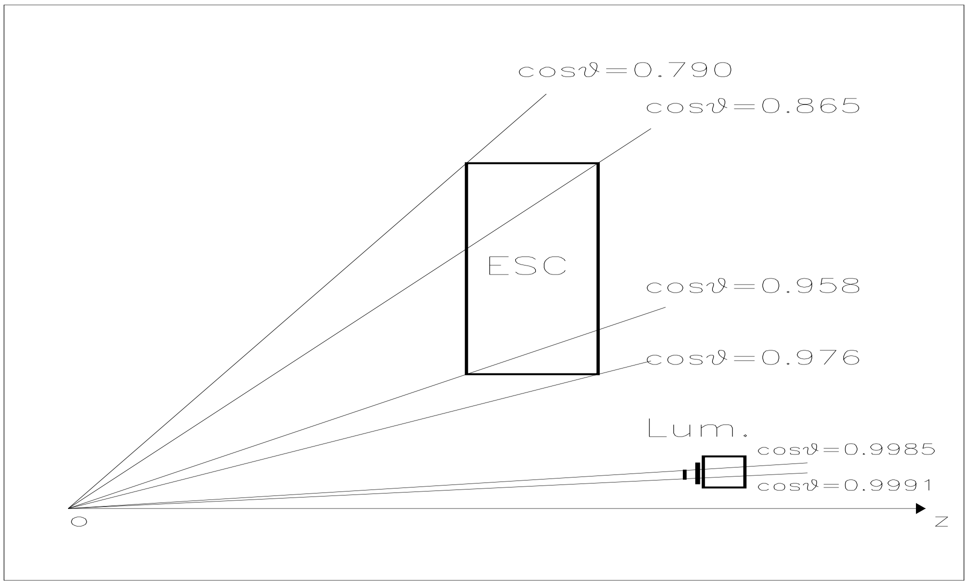

Figure 10: Diagram of Endcap SC and luminosity monitor

It has been taken for granted that Bhabha events and $\gamma\gamma(\gamma)$ events can not be distinguished by ESC. Nevertheless, to measure the luminosity with endcaps in BES, it's not necessary to identify $\gamma\gamma(\gamma)$ and Bhabha events since luminosity can be measured by selecting these two type of events altogether according to the expression

$$N_{obs} = L \cdot (\sigma_1 \cdot \varepsilon_1 \cdot \varepsilon_{trg1} + \sigma_2 \cdot \varepsilon_2 \cdot \varepsilon_{trg2}) \tag{9}$$

In fact, we found that Bhabha and $\gamma\gamma(\gamma)$ events in ESC can be roughly separated by their ϕ distribution shown in Fig.11 and Fig.12.

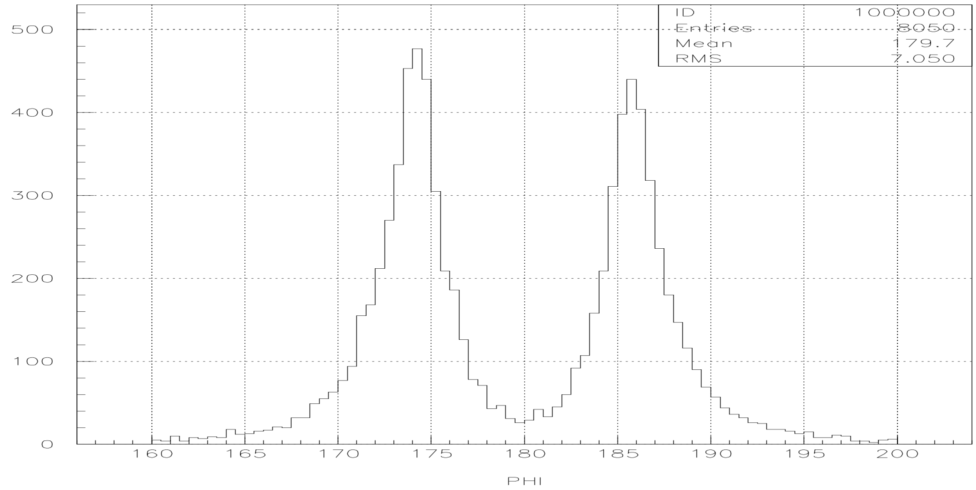

Figure 11: $|\phi_1 - \phi_2|$ distribution in Endcap SC of M.C. Bhabha sample

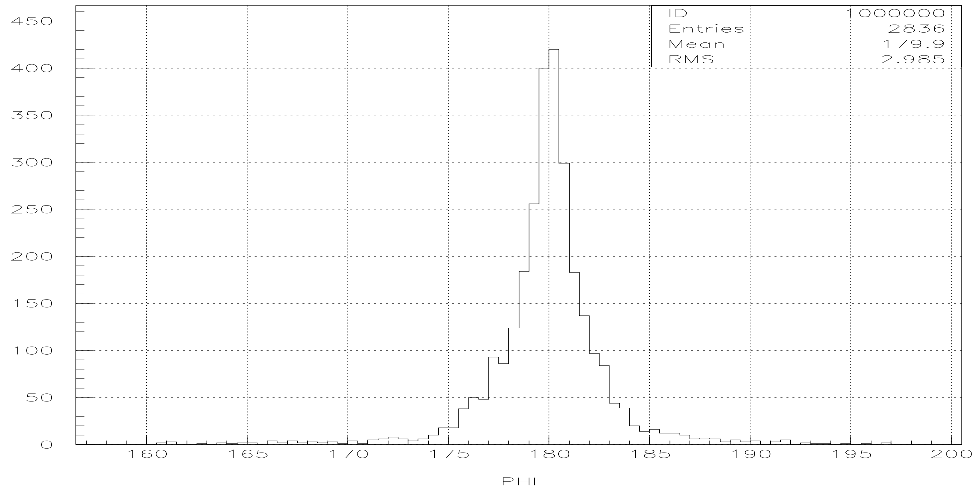

Figure 12: $|\phi_1 - \phi_2|$ distribution in Endcap SC of M.C. $\gamma\gamma(\gamma)$ sample

As neutral trigger was not applied for collecting tau mass scan data, there were no neutral events collected in ESC. Therefore, only Bhabha events were used to calculate luminosity.
The events selection criteria are:

- tracks with the first two largest energies E_{max1} and E_{max2} are from different ends (east and west each)
- $E_{max1} > 0.6E_{beam}$
- $E_{max2}(+E_{max3}) > 0.45E_{beam}$ (E_{max3} is the third largest energy, possible of γ)
- $E_{sum} > 1.15E_{beam}$
- $0.87 <\mid cos\theta \mid< 0.95$
- $\mid \theta_1 + \theta_2 - 180° \mid< 7°$
- $\mid\mid \phi_1 - \phi_2 \mid -180° \mid< 20°$

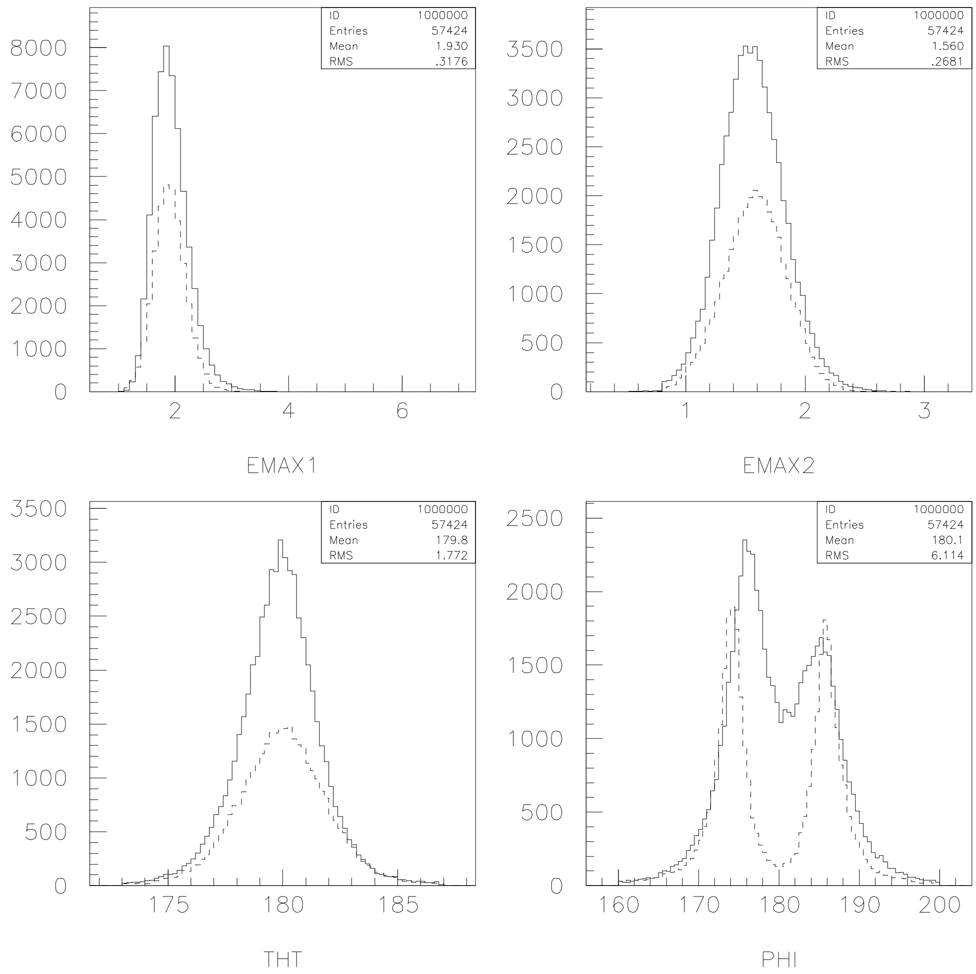

Figure 13: Distribution of M.C. (dashed line) and data (solid line) in ESC

Fig.14 shows the luminosities measured with ESC, which is about 6% lower than that measured via large-angle Bhabha events on average. The reason might be the higher energy threshold applied in the trigger ceriteria. Though the discrepancy is still large, the result is encouraging.

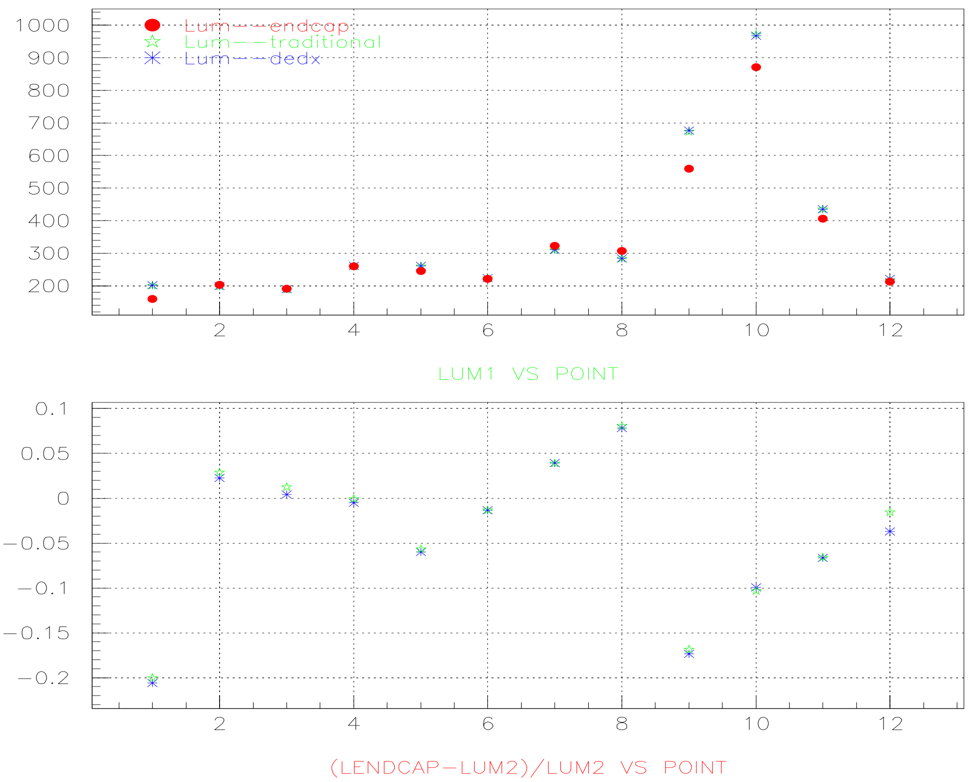

Figure 14: Luminosity from endcap information and comparison with barrel

The luminosities of all 12 points obtained from different methods or information in different detectors are listed in table 3, and the differences relative to traditional results are also given. As a reference, the luminosities measured by small-angle Bhabha luminosity monitor are listed in column 2.

Table 3: Luminosities measured by different methods. L_{ADC} is the luminosities measured by small-angle Bhabha luminosity monitor. L_1, L_2 and L_3 are the luminosities measured by large-angle Bhabha events selected via different criteria. L_{endcap} is the luminosities measured by endcap detector of BES. $L_{\mu\mu}$ is by dimu events.

#	E_{cm} (GeV)	L_{ADC} (nb^{-1})	L_1 (nb^{-1})	L_2 (nb^{-1})	L_3 (nb^{-1})	L_{endcap} (nb^{-1})	$L_{\mu\mu}$ (nb^{-1})
1	3.56838	245.8	200.18	201.64	200.73	160.1	168.3
2	3.56198	248.9	197.70	198.88	198.57	203.4	177.4
3	3.54418	232.8	188.51	190.09	193.49	190.9	145.9
4	3.55314	323.0	259.70	260.78	259.15	259.5	215.7
5	3.55698	322.5	260.22	261.00	259.69	245.4	214.7
6	3.55190	296.9	223.80	223.84	221.34	220.8	167.4
7	3.55350	384.0	311.13	311.02	307.86	323.2	273.1
8	3.55396	360.8	283.63	284.25	283.10	306.5	229.1
9	3.55290	794.1	672.55	676.65	673.99	559.3	561.4
10	3.55324	1109.1	971.89	967.65	948.84	871.5	812.0
11	3.59902	499.7	434.92	435.23	425.69	406.3	345.3
12	3.57910	250.0	216.42	221.33	215.37	213.1	164.5
	sum	5067.6	4220.6	4232.4	4187.8	3960.0	3474.8
	err.	20%	*	0.3%	-0.8%	-6.2%	-17.7%

6 Summary

We measured luminosities of the data collected at arond 3.55 GeV with BES at BEPC by large-angle Bhabha events. Different events selection criteria are applied and the results agree within 1%. Information from ESC are used for the first time at BES to measure the luminosity. The results is 6% systematically lower than that measured by large-angle Bhabha. The largest part of the uncertainty on the luminosity measured are from the trigger efficiency. Fortunately this will no longer be the case for the planed measurement of the values of R at the energies between 2-5 GeV with BESII because of the improvement of the trigger condition. The uncertainty of the luminosity is anticipated to be 2-3% for the measurement of the values of R in planning, provided that the trigger efficiency will be higher than 99%. We conclude that to measure luminosity by large-angle Bhabha for the measurement of the values of R with BESII is acceptable.

References

[1] J.Z. Bai et al., Phys. Rev. D53,20(1995), Measurement of the Mass of the τ Lepton

[2] Yu Zhongqiang, 92' BES Annual Meeting, Chengde

[3] Yu Zhongqiang,et al., Trigger Efficiency Measurement of BES, Chinese High Energy Physics and Nuclear Physics, Vol.19, No.12(1995)