BES Analysis Note: Integrated Luminosity of Ψ' Data

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1 Introduction

This analysis note details the determination of the integrated luminosity ($\mathcal{L}$) of the Ψ' data runs of 1993/94 and 1995 at the Beijing Electron-Positron Collider/Beijing Electron Spectrometer (BEPC/BES). We obtained the following results for run status >1: for 93-94 data set, $\mathcal{L} = 2039 \pm 12 \pm 35$ nb^{-1} and for the 95 data set, $\mathcal{L} = 3794 \pm 17 \pm 57$ nb^{-1}; for run status >0: for the 93-94 data set, $\mathcal{L} = 2086 \pm 12 \pm 55$ nb^{-1} and for the 95 data set, $\mathcal{L} = 3925 \pm 18 \pm 125$ nb^{-1}.

2 Method

The luminosity was calculated via a count of large-angle Bhabha events ($e^+ + e^- \to e^+ + e^-[+\gamma]$). Two prong events satisfying basic cuts geometric cuts (see Cuts) were passed through a particle identification cut (see Particle Identification) and then a cut to determine background (see Backgrounds). The integrated luminosity was then

$$\mathcal{L} = \frac{N_{obs} - N_{back}}{\sigma_{tot} \times \epsilon_{PID} \times \epsilon_{accept} \times \epsilon_{trig}}, \quad (1)$$

where N_{obs} is the observed number of Bhabha events after all cuts and selections, N_{back} is the number of fake Bhabha events resulting from backgrounds, σ_{tot} is the total Bhabha cross-section, ϵ_{PID} is the particle ID efficiency, ϵ_{accept} is the geometric acceptance, and ϵ_{trig} is the trigger efficiency for Bhabha events.

Separate calculations were performed for two different run status selections (from the `ppruns.f` routine): STATUS>0 and STATUS>1.

Unless explicitly stated, all references to tracks in this memo refer to charged tracks.

3 Analysis

3.1 Reconstruction

The data were reconstructed in Hawaii using version 8.6 of the BES software. No filter was used, but events were required to satisfy:

- $|z_{min}| < 0.15$ m
- $|r_{min}| < 0.015$ m

where z_{min} and r_{min} are the minimum values (closest approach to the interaction point (IP)) of z and r for each track in the event.

3.2 Track Corrections

3.2.1 Momentum Corrections

Before any cuts were applied, two types of corrections were applied to the momenta of the data tracks: A magnetic (B) field correction, and a beampipe correction.

For the B-field correction, a factor of $0.9970 * p$ was used to adjust all charged track momenta.[1] For the beampipe correction, the routine BPFRAC from the BES library was used, assuming all particles were electrons/positrons.

3.2.2 dE/dx Corrections

A further correction to the dE/dx information of each track was applied via the `dedxpsip.f` routine.[2] The routine was NOT used on Monte Carlo (MC) events, as version 1 of the routine was unable to handle them. A later version with a special MC handling routine (`phmpmc.f`) was examined, but not used.

3.3 Cuts

The following basic cuts were applied to the data and MC to form the geometric acceptance:

- Exactly two charged tracks were required, with a total charge of 0 for the event.
- Both tracks were required to have MFIT=2 (good helix fit for each track).
- The absolute difference between the z_{min} of the tracks were required to be ≤ 0.05m.
- The z coordinate of each track at the radius of the first shower counter layer (1.235m) was required to be ≤ 1.5m. This cut ensured that events fell within the shower counter without exiting the sides or hitting the outer ribs. A z cut was used instead of a $\cos\theta$cut to eliminate the variances in $\cos\theta$due to vertex position variations. The z position was determined using a helix fit to the track via the routine `ttintsec.f` from Bill Dunwoodie.[3]

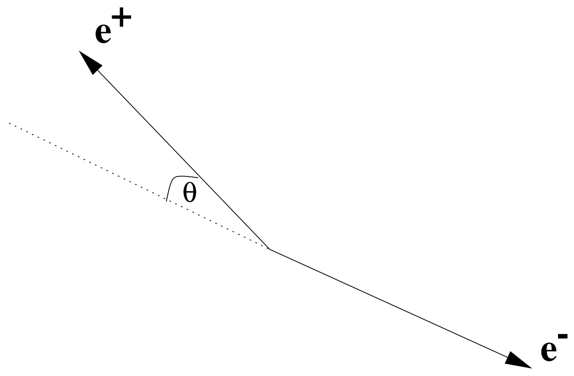

Figure 1: Definition of acollinarity angle. The acollinarity angle, θ is the angle between one track and the negative vector of the other track.

- The tracks were required to have an acollinarity angle of ≤ 0.05 radians. The acollinearity angle is defined in figure 1. This back to back cut is characteristic of Bhabha events. A comparison of acollinearity angle for data vs Monte Carlo events is in figure 2.

- If both tracks fell in the active TOF region (z position at the TOF radius $\leq$ 1.4m), and good TOF information existed for both tracks, then the difference in the times was required to be $\leq$ 4.0ns. A plot of TOF differences for the data and MC is shown in figure˜reffig:tofdiff.

- A loose momemtum cut, where $0.01 < ptot < 3.5$ GeV/c, ($ptot$ is the total momentum) was imposed to remove obviously spurious tracks.

- At least one track was required to have $ptot > 1.7$ GeV/c. This cut was designed to remove electrons/positrons resulting from the process: $\psi' \rightarrow \text{neutral} + \text{j}/\psi, \text{j}/\psi \rightarrow e^+ + e^-$, which results from approximately 1.7% of ψ' decays.

3.4 Particle Identification (PID)

Because the shower counter (SC) contained several regions which have support ribs, we defined rib regions to be $|zsc| < 0.04$m and $0.8 < |zsc| < 1.0$m, where zsc was the z position of the track at the first shower counter layer. In such rib regions, the SC information is considered to be unreliable.

As a result, two different types of cuts were applied to the data for purposes of particle identification. The first was a cut on the ratio of energy deposited in the shower counter (ESC) of each track divided by the total momentum. This quantity, E/p, was plotted (for 93-94 data) for each event in the upper half of figure 4, where the value for the positive track, $(\text{E/p})_1$, was plotted against the value for the negative track, $(\text{E/p})_2$. The cut used was defined as:

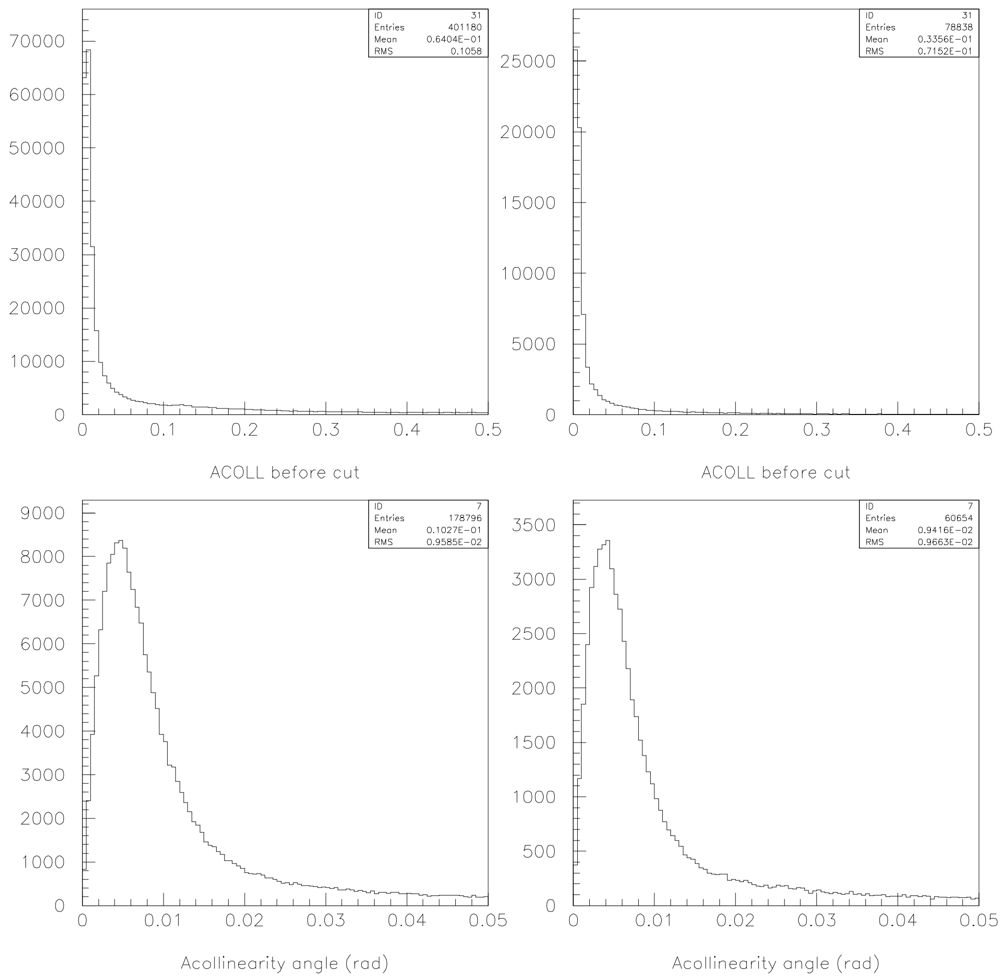

Figure 2: Comparison of acollinarity angle for 93-94 data and Monte Carlo. Data is on the left and the MC is on the right, each with two different scales on the x-axis. The cut is at 0.05 radians.

- $(E/p)_1 > 0.5$ and $(E/p)_2 > 1.0$ OR
- $(E/p)_1 > 1.0$ and $(E/p)_2 > 0.5$ OR
- $\sqrt{((E/p)_1 - 1.0)^2 + ((E/p)_2 - 1.0)^2} < 0.7$

For events in which both tracks fell in the defined rib regions, a different cut was used. We defined the variable XSE as

$$XSE = \frac{dE/dx(meas) - dE/dx(calc)}{\sigma(dE/dx(calc))}, \tag{2}$$

where dE/dx(meas) was the observed dE/dx value, dE/dx(calc) was the calculated dE/dx value for a particular particle hypothesis, and σ(dE/dx) was the width of the calculated dE/dx distribution.[2]

The particular XSE cuts used were:

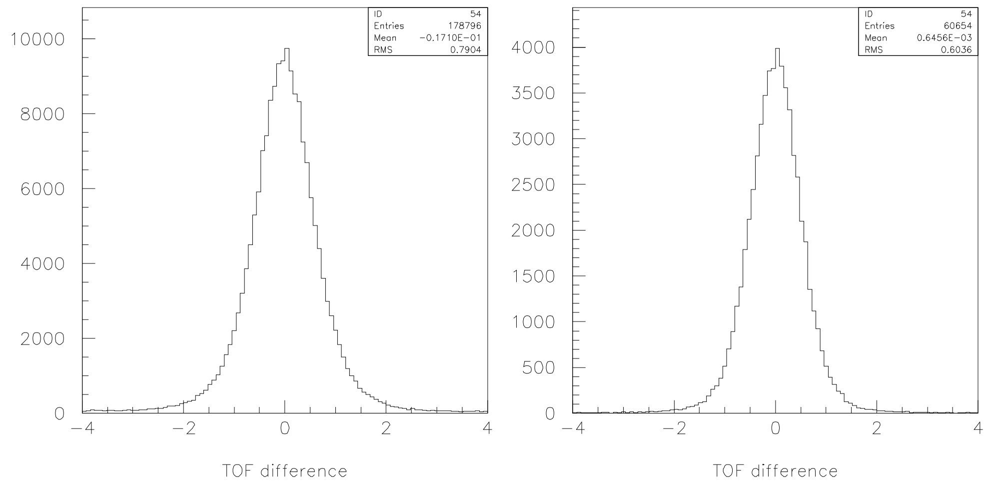

Figure 3: TOF difference between tracks. 93-94 data is on the left and MC is on the right. Essentially all MC events fall within ±4ns, which is the cut imposed.

- $XSE_1 > 0.0$ OR
- $XSE_2 > 0.0$ OR
- $\sqrt{XSE_1^2 + XSE_2^2} < 2.83$.

A plot of this distribution and cut for the 93-94 data appears in the upper half of figure 5. In this figure, only tracks NOT in the rib region were used. These samples were chosen to allow an efficiency determination; for calculation purposes, the XSE cuts were only made to tracks in the rib region.

Finally, in the case where one track fell in the rib region and the other track did not, a combination cut was made, where an XSE cut made on the event as well as a E/p cut (requiring E/p > 0.5) on the track outside the rib region. Again, see the upper half of figure 6 for a plot of this cut.

To determine the efficiency of these cuts, the data were observed in the non-cut variable. For example, in figure 4, the lower half shows the events passing and failing the E/p cut when plotted according to XSE. The events passing the E/p cut (on the left) look extremely clean in XSE, indicating a very low false event rate. On the other hand, the events which fail the E/p cut (on the right) do show a number of events that appear to be good Bhabhas according to the dE/dx system. A count of these events gives a background rate (factored into the systematic error) and an efficiency number, respectively.

A similar procedure (but in reverse) is conducted for the events selected by XSE and by the combination cut. See the lower halves of figures 5 and 6 for the results.

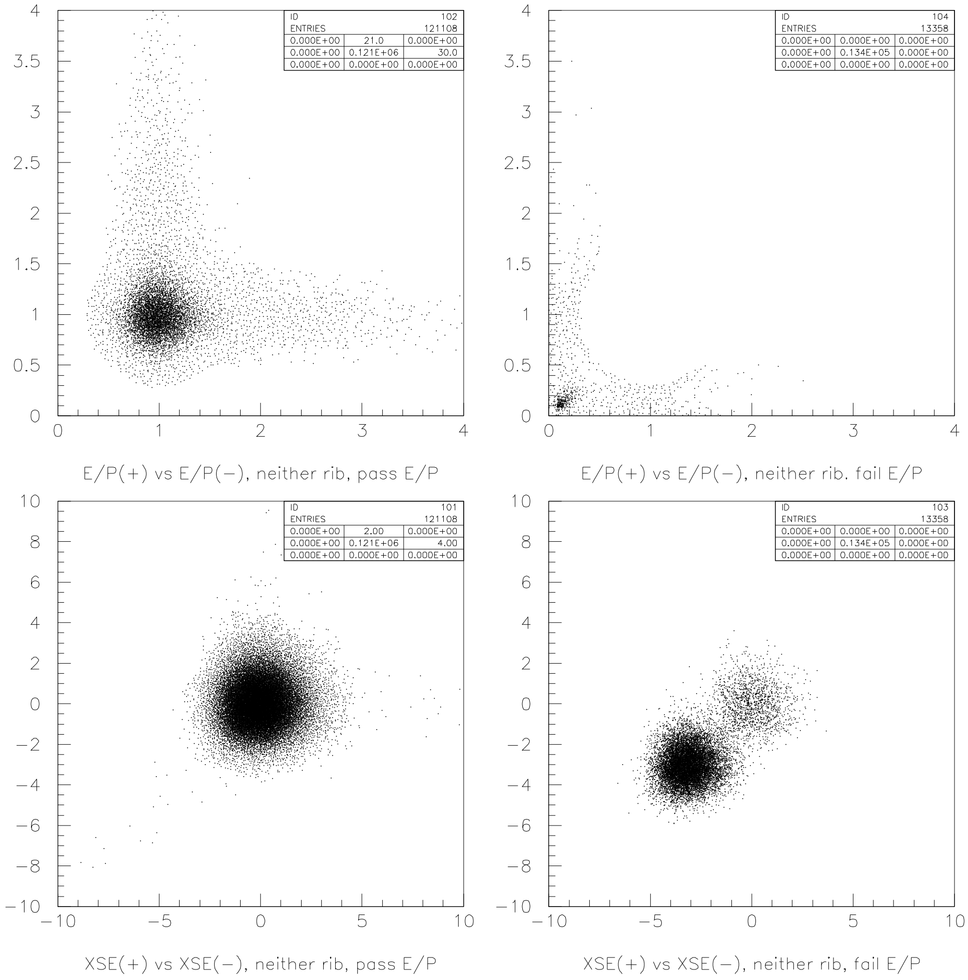

Figure 4: Upper half: Plots of E/p for positive tracks vs E/p for negative tracks, 93-94 data set, all tracks NOT in the rib region. Events which pass the cut are on the left, events which fail the cut are on the right. Lower half: Each graph in the lower half corresponds to the same events in the adjoining upper graph, but plotted according to XSE values.

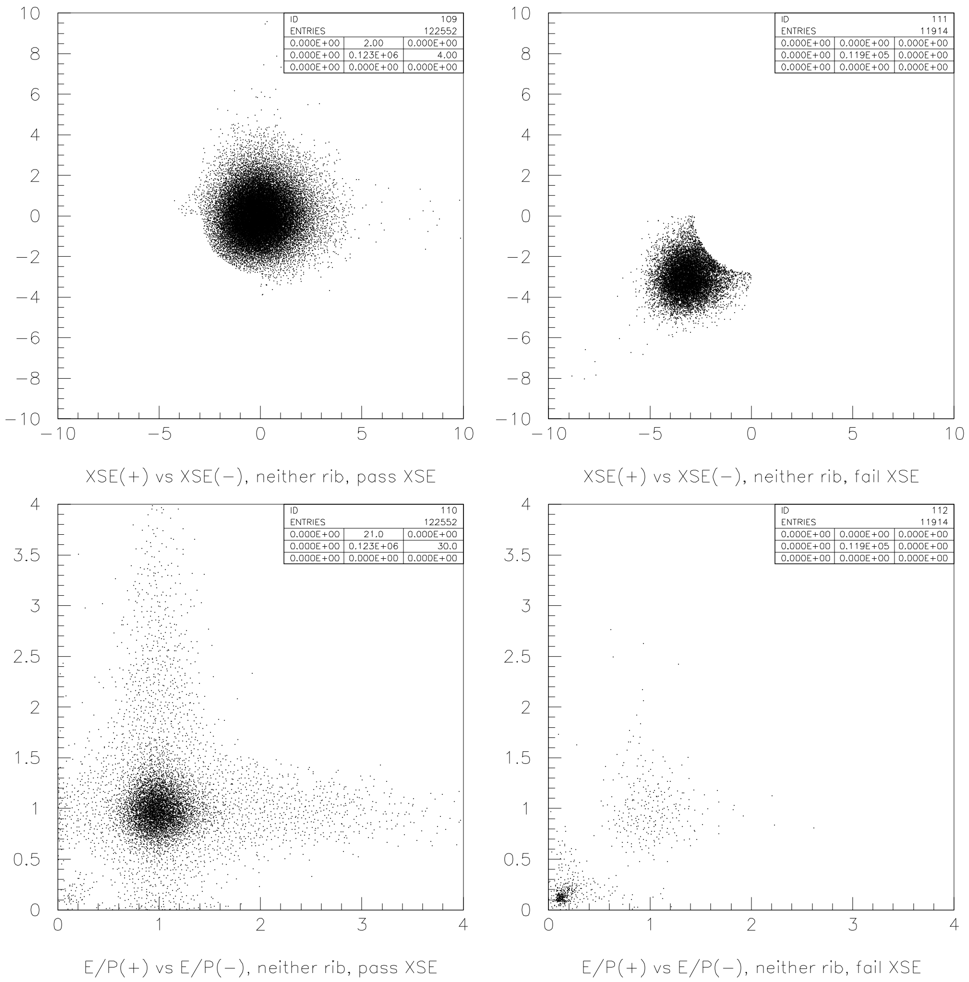

Figure 5: Upper half: Plots of XSE for positive tracks vs XSE of negative tracks, 93-94 data set, all tracks NOT in rib region. Events which pass the XSE cut are on the left, events which fail are on the right. Lower half: Each graph in the lower half corresponds to the same events in the adjoining upper graph, but plotted according to E/p values.

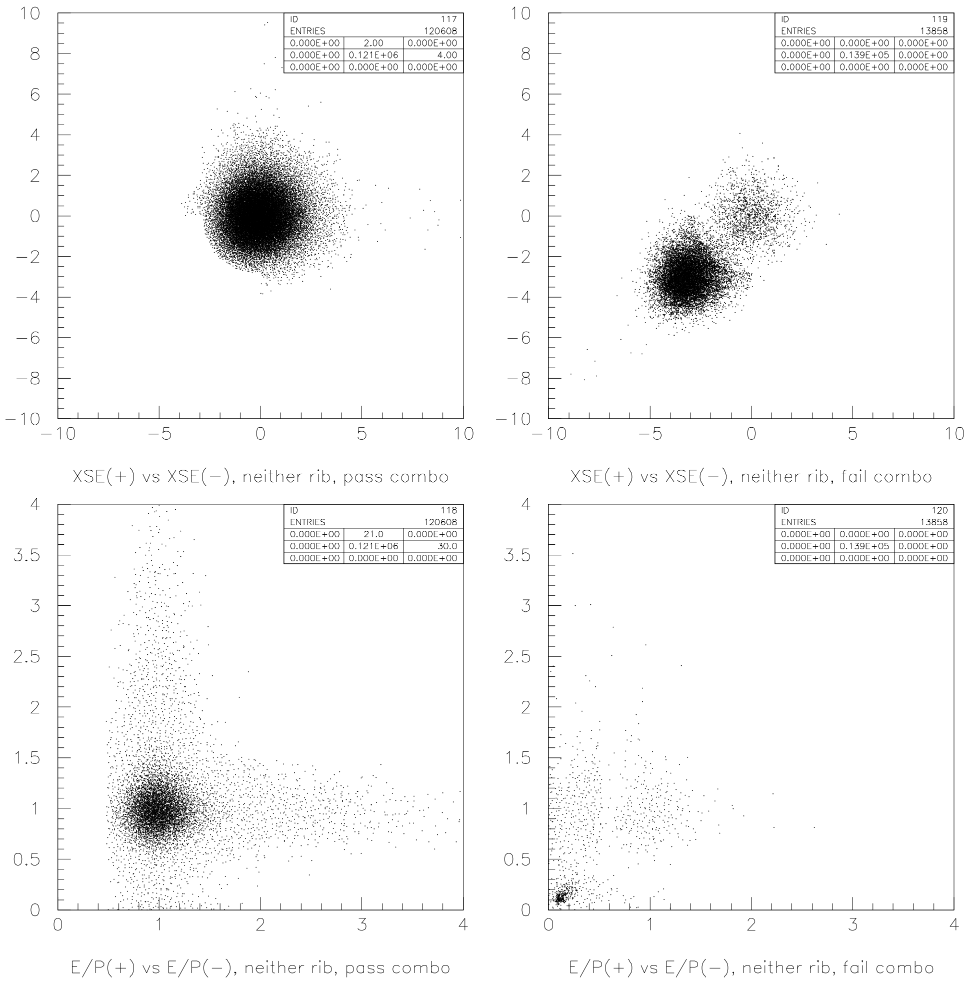

Figure 6: Upper half: Plots of XSE for positive tracks vs XSE of negative tracks, 93-94 data set, all tracks NOT in rib region. Events which pass the combination XSE and E/p cut are on the left, events which fail are on the right. Lower half: Each graph in the lower half corresponds to the same events in the adjoining upper graph, but plotted according to E/p values.

4 Geometric Efficiency (MC)

To determine the geometric efficiency and background estimation, the Monte Carlo generator bhagen (EVT_TYPE 20 in sober) was used. A total of 100,000 events were generated with the parameters listed in table 1 in the sobcard file:

Parameter	Value	Note
ECM	3.686	
NEV	100000	
NEVTIM	1000000000	
XPARAM(1)	0.01	Max photon energy
XPARAM(2)	0.80	Max $\lvert\cos\theta\rvert$

Table 1: Sobcard parameters.

The same geometric cuts for the data were applied to the MC to obtain the geometric efficiency.

A similar data set ($\cos\theta < 0.8$, 100,000 events) was generated using the radee MC generator (EVT_TYPE 12) and found to be essentially identical to the bhagen generator.

5 Physics Background

Background from three possible physics sources was considered:

1. Events of the form $e^+ + e^- \to \psi' \to e^+ + e^-$.
2. Events of the form $e^+ + e^- \to \psi' \to \mathrm{j}/\psi + \mathrm{neutral/missing}, \mathrm{j}/\psi \to e^+ + e^-$.
3. Interference between process 1 and the Bhabha diagram.

For process 1 ($e^+ + e^- \to \psi' \to e^+ + e^-$), we can realize that this will be a forward-backward symmetric process (statistically, equal numbers of electrons and positrons should scatter into each differential cross-sectional area), while the Bhabha diagram results in strong forward scattering of the incoming particles. As a result, we can subtract off a symmetric part from the expected Bhabha distribution.

The number of background events, b, in each half of the distribution can be calculated via

$$\frac{A1_{dat} - b}{A2_{dat} - b} = \frac{A1_{MC}}{A2_{MC}}, \tag{3}$$

where $A1$ and $A2$ are the total number of events in each side of the distribution for data and MC respectively. The true number of Bhabha events is the total number in the distribution minus background, $N - 2b$.

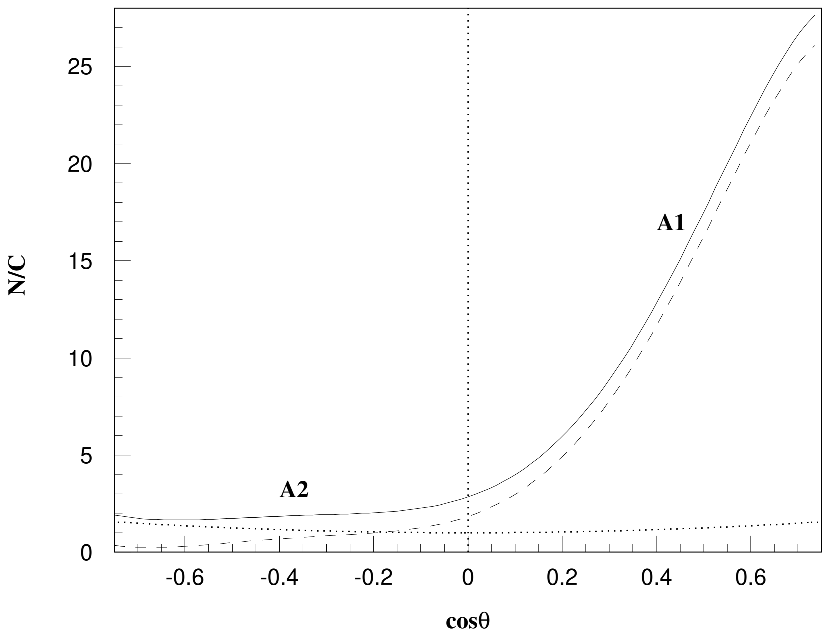

Figure 7: Schematic diagram of angular distributions of electrons (or positrons) produced in $e^+ + e^- \to e^+ + e^-$ at $\sqrt{s} = 3.686$ GeV. The dashed curve represents Bhabha scattering; the dotted curve represents resonant $e^+ + e^-$prduction of the ψ' and of the j/$\psi$from $\psi' \to$ j/$\psi+$ neutrals decays; the solid curve shows their sum. (Figure taken from [4].)

For process 2, the cut requiring at least one track to have a total momentum of ≥ 1.7 GeV/c is imposed to remove such events. Any remaining events after such a cut should also be filtered by the symmetry cut for process 1.

Finally, for process 3, the interference effect is calculated to be very small. Theoretically, for a zero width j/ψ, the effect would be zero, and in reality, the small width of the j/ψgives a negligible result.

6 Error Calculation

To calculate the systematic error, several factors were used: The varying of geometric cuts, contribution from the Monte Carlo generator, varying PID cuts, contribution from PID background, and trigger efficiency. Summaries of the contributions from each effect are listed in tables 2 and 3.

Also included in the systematic error was a contribution from the difference between the Hawaii result and the IHEP values. The IHEP central values (obtained by Cui Xiangzhong)[5] are listed in table 4.

Cut	Change	Error (in %) Old data	New data
Acollinearity angle	0.05 $\rightarrow$0.15 rad	0.431	0.529
MFIT value	2 $\rightarrow$2,-9,-19	0.575	2.369
Z position at SC	1.5 $\rightarrow$1.4 m	1.534	1.070
$\geq$1 trk with p>0.8	Remove	0.000	0.000
E/p cut	0.7 $\rightarrow$0.8	0.000	0.000
dE/dx cut	2.83 $\rightarrow$2.9	0.144	0.051
Max $\cos\theta$ in MC generator	0.8 $\rightarrow$0.9	0.000	0.204
Particle ID background		0.561	0.787
Difference between Hawaii/IHEP		1.678	1.177
Trigger efficiency		1.000	1.000
Total (in quadrature)		2.650	3.176

Table 2: Summary table of systematic error contributions for run status>0.

Cut	Change	Error (in %) Old data	New data
Acollinearity angle	0.05 $\rightarrow$0.15 rad	0.343	0.422
MFIT value	2 $\rightarrow$2,-9,-19	0.245	0.448
Z position at SC	1.5 $\rightarrow$1.4 m	0.441	0.079
$\geq$1 trk with p>0.8	Remove	0.000	0.000
E/p cut	0.7 $\rightarrow$0.8	0.000	0.026
dE/dx cut	2.83 $\rightarrow$2.9	0.049	0.053
Max $\cos\theta$ in MC generator	0.8 $\rightarrow$0.9	0.392	0.395
Particle ID background		0.556	0.799
Difference between Hawaii/IHEP		1.034	0.290
Trigger efficiency		1.000	1.000
Total (in quadrature)		1.705	1.506

Table 3: Summary table of systematic error contributions for run status>1.

Run Status	93 Data (nb^{-1})	95 Data (nb^{-1})
Status> 0	$2121 \pm 9 \pm 62$	$3966 \pm 13 \pm 115$
Status> 1	2063	3805

Table 4: Luminosity results obtained by Cui Xiangzhong.

7 Trigger Efficiency

The trigger efficiency was taken to be $99.5 \pm 1.0\%$.[6]

8 Summary

The final results of the calculations are summarized in table 5.

Run Status	93 Data (nb^{-1})	95 Data (nb^{-1})
Status> 0	$2086 \pm 12 \pm 55$	$3925 \pm 18 \pm 125$
Status> 1	$2039 \pm 12 \pm 35$	$3794 \pm 17 \pm 57$

Table 5: Summary of luminosity results.

9 Appendix

Using the results obtained by Fred Harris and Wang Meng[7], and the luminosity data, we calculated the ψ' cross section. Adding statistical and systematic errors in quadrature, we quote results from [7]:

Run status	93-94 data (x 10^6)	95 data (x 10^6)
STATUS>0	1.325 ± 0.109	2.463 ± 0.200
STATUS>1	1.291 ± 0.106	2.374 ± 0.192

Table 6: Number of ψ' events.

Taking the cross section, σ to be:

$$\sigma = \frac{N}{\mathcal{L}} \tag{4}$$

we obtained the following results:

Run status	93-94 data (x 10^6)	95 data (x 10^6)
STATUS>0	635.2 ± 55.0	627.5 ± 52.1
STATUS>1	633.2 ± 55.9	625.7 ± 51.5

Table 7: ψ' cross section based on [7] and this memo.

10 References

References

[1] See `http://www.phys.hawaii.edu/~fah/ jpsimass.html` for details on the B-field correction.

[2] Bill Dunwoodie and Li Xinhua have studied the dE/dx and TOF information for the Ψ' data and have written routines to correct it. See the slides from Li Xinhua's presentation on Dec 18th, 1996 in Hawaii (UH BES presentation archives). Version 1 of the routine did not handle MC events, but version 2, using `phmpmc.f` did.

[3] Bill Dunwoodie has written a program (`ttintsec.f`) to perform a helix fit to tracks (MFIT=2 only) that allows calculation of coordinates at any radius.

[4] Yu Chunxu, Luo Yong, Qi Nading, Cui Xiangzhong, Gu Yifan, Hu Tau, "Measurement of the Branching Fraction of the Decay $\psi(2S) \to \tau^+\tau^-$" (draft)

[5] Cui Xiangzhong, private communications, 8/18/98 and 8/25/98.

[6] R scan trigger meeting discussion notes.

[7] Harris, F.A., "BES Analysis Note: Number of Ψ' events", May, 1997.