Direct Determination of the Number of ψ' Events

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1 Introduction

BES has collected more than 3.5 million ψ' events, this is the largest ψ' sample so far in the world. Based on this, it is necessary to obtain the absolute branching fractions of ψ' decay channels, and possible to reduce the systematic error. So, the directly determined total number of ψ' events($e^+e^- \to \psi'$, under the peak at 3.686 GeV, see fig.1) must be obtained.

According to PDG, Br($\psi' \to \pi^+\pi^- J/\psi$) = (32.4 $\pm$ 2.6)%, the error is bigger than 8%; recently, E760[1] has reported the branching fraction for the same channel as 0.283$\pm$0.021$\pm$0.020, the difference is more than 14%, so the importance for us to directly determine the total number is obvious.

The main backgrounds are as follows:
a, Cosmic Rays;
b, Contamination due to beam-gas/beam-pipe interaction;
c, Due to electro-weak interaction between electron and positron:
$e^+e^- \to$ electrons(fig.2 (a) $\to$ (j)),
$\to$ leptons(l = μ, τ, fig.2 (k) $\to$ (p)),
$\to$ photons(fig.3 (q), (r)),
especially Bhabha: $e^+e^- \to e^+e^-$ (photon), fig.2 (a) $\to$ (h);
d, Continuum, it means not via resonance;
e, Two photon process, fig.3(s);
f, Junk and other backgrounds.

The beam energy spread for BEPC is about 1.4 MeV, and the long tail due to hard photon radiation is small, so the number of events for the channels of $e^+e^- \to J/\psi$ and other resonances(fig.1 and fig.3(t)) is negligible.

2 Removing and Subtracting

It is necessary to make a program with suitable cuts to remove the backgrounds at first, then to subtract the number of remaining backgrounds by means of fitting and calculation.

[1]T. A. Armstrong et al., Phys. Rev. D55, No.3, 1153(1997)

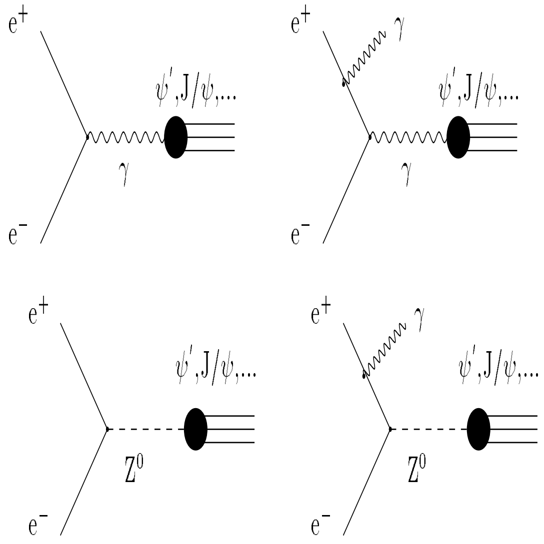

Figure 1: Hadronic final states

2.1 Removing: Program

Using the cuts as follows in the program for removing backgrounds, we select out good charged tracks at first:
Mfit = 2, -19, -9;
P$\geq$ 0.1 GeV/C;
$|Cos(Theta)_{MDC}|$ $\leq$0.8;
and select out good photons:
$E_\gamma \geq$ 0.025GeV;
$|Cos(\Theta_{Ch\gamma})| \leq$ 0.96, $\Theta_{Ch\gamma}$ is the angle between the photon emitting direction and each charged track of the event;
$|Cos(\Theta_{\gamma\gamma})| \leq$ 0.98, $\Theta_{\gamma\gamma}$ is the angle between any two photons of the event;
number of first layer where the shower develops$\leq$ 3;
$|Cos(\Theta_{emit}) - Cos(\Theta_{develop})|_i$ $\leq$0.2, i = x, y, z.
We use dE/dX and/or TOF to identifier a particle, then to set up a corresponding mass to the particle and calculate:
Evis = $\sqrt{p^2 + m^2}$, Erat = Evis / Ecm. Evis is the energy visible for an event.
The cuts used for removing the backgrounds in this program are as follows:
$r_m < 0.015m$ to remove Beam-Gas;
$\Delta TOF \leq$ 4 ns to remove cosmic rays;
$\bar{P} \geq$ 0.2 GeV/C to remove Junk;
During offline procedure, $'95\psi'$ events have been distributed into .0pn, .1pn, .2pn, .bb, .4pn, or .6pn files respectively according to Mfit=2 or -19, .0pn means zero prong events, .1pn means one prong, ..., .4pn: 3 and 4 prongs, .6pn: more than 4 prong.

The events loaded in .bb files are two prong back-to-back events, they contain:
Bhabha;

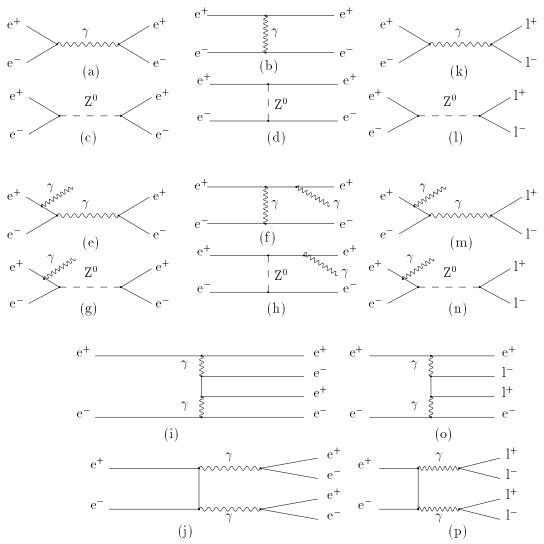

Figure 2: Backgrounds(1)

Cosmic Rays;
$e^+e^- \to l^+l^-, l = e, \mu, \tau$;
$e^+e^- \to \psi` \to l^+l^-, l = e, \mu, \tau$;
$e^+e^- \to \psi` \to \pi^0\pi^0 J/\psi$(in part),
and so on.

A small part of good events loaded in .bb files, can be identified by Hand Scan, such as $\psi` \to \pi^0\pi^0 J/\psi$, we will add the number of these good events into Nd2(see below). This portion is estimated to be less than 1% among $\psi`$ events.

For Bhabha events:
Most Bhabha events have been lost owing to dead region of BES detector; and, most observed Bhabha events have been loaded in .bb files during offline procedure.

A small part of Bhabha events have been loaded in .0pn, .1pn, .2pn, .4pn, or .6pn files during offline procedure. We use the cuts as follows to remove these Bhabha events:
Nch=2, Nch is the number of good charged tracks in an event;
Ngm $\leq$ 1, Ngm is the number of good photons in an event;
Evis $\geq$ 1.65GeV;
Sin(θ) $\leq$ 0.05; θ is the angle between two charged tracks of the event;
and, both charged particles identified as electrons according to dE/dX and/or TOF.

Futhermore, we use Monte-Carlo to estimate/subtract the number of those Bhabha events among .0pn, .1pn, .2pn, .4pn and .6pn files which still pass through the cuts mentioned above.

Let $\psi`$ events(DATA) pass through the program to remove the backgrounds, several NTUPLE files will be formed, which contain the information as follows:
KJI, IRUN, NCH, ASYM, ZV, ERAT, MFIT, Phi, and so on.

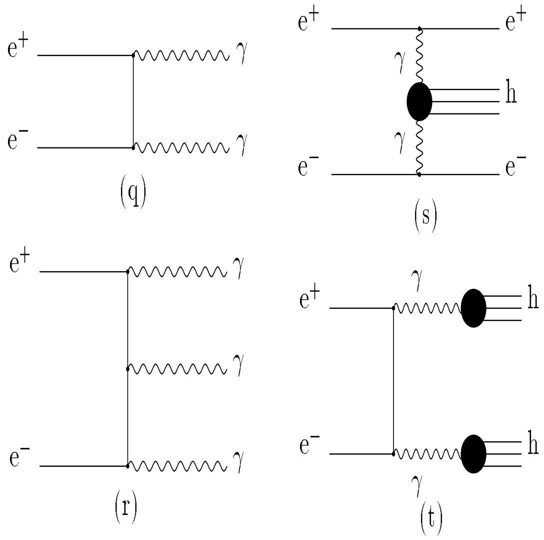

Figure 3: Backgrounds(2)

where:
KJI: a parameter to represent the quality of a run, KJI$\geq$1 means good runs;
ASYM = Pztot / Ptot: momentum balance of an event;
ZV: Z position of the vertex of an event,
or nearest point on the track to the Interaction Point for an one prong event;
ERAT = Evis / Ecm;
MFIT: a parameter to represent the quality of track fitting;
Phi: Phi angle of single charged track for two prong events.

2.2 Subtracting: formula

$$\mathrm{N}\psi^{'} = \frac{\frac{(Nobs-Ncsr-Nbg-Nel\gamma)}{efficiency}-Nnonres}{1.0-Br(\psi^{'}\to l^{+}l^{-})}$$

where,
N$\psi^{'}$: the number we want to determine;
Nobs: number of observed events;
Ncsr: number of remaining cosmic rays;
Nbg: number of remaining Beam-Gas;
Nelγ: total number of remaining events for the channels of $e^+e^- \to$ electrons(fig.2 (a) $\to$ (j), leptons(fig.2 (k) $\to$ (p), photons(fig.3 (q), (r) due to Electro-Weak interaction;
Efficiency is a matrix, obtained from Monte-Carlo;
Nnonres: the number of events in the continuum, not via $\psi^{'}$ resonance, it contains:
a, $e^+e^- \to$ Hadrons;
b, $e^+e^- \to$ Leptons(e, μ, τ);
c, $e^+e^- \to$ Photons.

The number of events for the hadronic channel(a) equals to:
R$\times\sigma(e^+e^- \to \mu^+\mu^-)\times$L, R=2.4$\pm$0.4, obtained from PDG; L=$4.0\times10^3 nb^{-1}$, the integrated luminosity for ψ' data taking in 1995, obtained from Prof. Gu Yifan, estimated according to wide angle Bhabha, very preliminary;

1.0-Br($\psi' \to l^+l^-$): For the leptonic channel(b), because ($e^+e^- \to \psi' \to l^+l^-$) has the same final states as ($e^+e^- \to l^+l^-$), both they have been loaded in .bb files, this means that they have lost. They can not be distinguished either by program, or by Hand Scan, even, hard to estimate using Monte-Carlo. So, it is necessary to be divided by 1.0-Br($\psi' \to l^+l^-) = 0.9835$ to pick up the lost portion ($\psi' \to l^+l^-$).

Futhermore, the number of remaining ($\psi' \to \tau^+\tau^-$) is negligible here, so, just $\psi' \to e^+e^-$ and $\psi' \to \mu^+\mu^-$ have been taken into account.

For the photon channel(c): we use Monte-Carlo to subtract the number of remaining events for the channels of $e^+e^- \to$ photons.

Two photon process is temporarily ignored.

3 Fitting and Calculation

3.1 Fitting:

3.1.1 Data:

For those events with zero good charged tracks(Nch=0), the only way is to use ASYM distribution to distinguish good events from backgrounds.

The events with Nch=0 may be:
Beam-Gas;
Cosmic rays;
$e^+e^- \to \gamma\gamma$, 129.2nb(fig.3 (q);
$e^+e^- \to \gamma\gamma\gamma$, 51.5nb(fig.3(r);
$e^+e^- \to \gamma\gamma\gamma\gamma$, $e^+e^- \to \gamma\gamma\gamma\gamma\gamma$, ..., very scarce;
And signals: $e^+e^- \to \psi' \to \gamma\gamma\gamma$, important;
$e^+e^- \to \psi' \to \gamma\gamma\gamma\gamma\gamma$, $e^+e^- \to \psi' \to \gamma\gamma\gamma\gamma\gamma\gamma\gamma$, ..., very scarce;
$e^+e^- \to \psi' \to \gamma\gamma$, $e^+e^- \to \psi' \to \gamma\gamma\gamma\gamma$, ..., forbidden.

According to the ASYM distribution obtained from Separated Beam experiment, which contains Beam-Gas and Cosmic Rays, it is reasonable to use Gaussian + Polynomial to fit the ASYM distribution, the good events and those remaining events for the channels of $e^+e^- \to \gamma\gamma$ and $e^+e^- \to \gamma\gamma\gamma$ are inside the Gaussian; several ways have been used for calculating the area under the Gaussian and Polynomial, the total area (Gaussian + Polynomial) should meet the "Entries", usually, the difference is much less than 1%. Then, we use Monte-Carlo to subtract the number of remaining events for the channels of $e^+e^- \to \gamma\gamma$ and $e^+e^- \to \gamma\gamma\gamma$ from the area of Gaussian, then Nd0 will be obtained, which is the number of good events with Nch=0. Fig.4 shows one of ASYM distributions obtained from Data(.0pn $\to$ Nch=0).

For those events with one good charged track(Nch=1), it has been estimated, a small part of them come from zero prong events, due to gamma conversion; most of them come from cosmic rays and multi-prong events. So it is reasonable to use ZV distribution to distinguish good events.

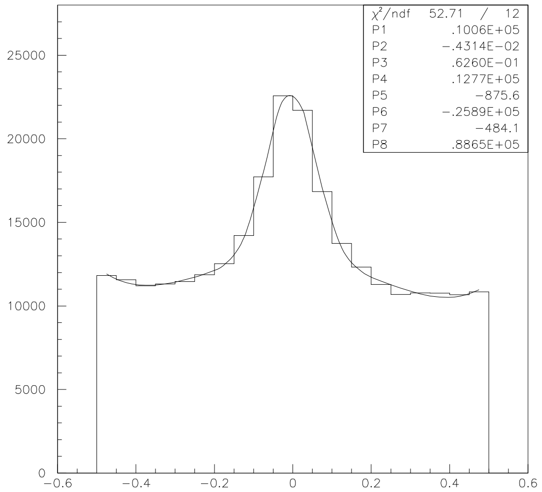

Figure 4: ASYM(Nch=0), DATA(.0pn)

According to the ZV distribution obtained from Separated Beam experiment, it is reasonable to use Gaussian + Polynomial to fit the ZV distribution, good events are inside the Gaussian. We use the same ways as for ASYM distribution to calculate the area of Gaussian, then Nd1 will be obtained. Fig.5 shows one of ZV distributions obtained from Data(.1pn $\rightarrow$ Nch=1).

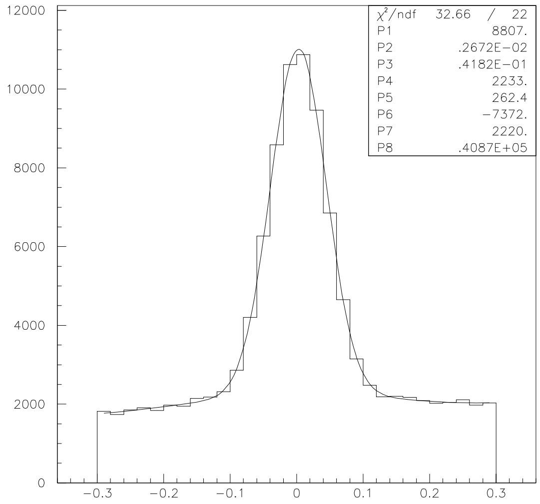

Figure 5: ZV(Nch=1), DATA(.1pn)

For those events with two or more charged tracks(Nch=2, ..., Nch=12), we also use Gaussian + Polynomial to fit the ZV distribution, then Nd2, ..., Nd12 will be obtained respectively. Fig.6 shows another ZV distribution obtained from Data(.1pn .2pn .4pn and .6pn $\rightarrow$ Nch=2).

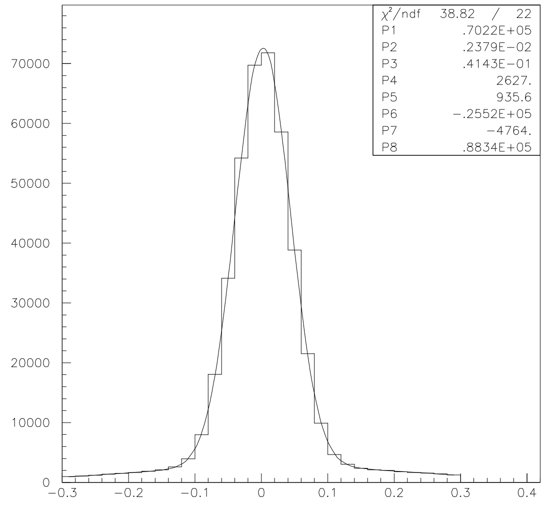

Figure 6: ZV(Nch=2), DATA(obtained from .1pn, .2pn, .4pn, and .6pn)

3.1.2 Monte-Carlo:

In order to get correct efficiency, it is necessary to treat MC the same way as for DATA;

It is better to use main decay channels of $\psi^{`}$ to determine the efficiency, for example,
$\psi^{`} \to \pi^+\pi^- J/\psi$,
$\psi^{`} \to \pi^0\pi^0 J/\psi$,
and so on.

We use $e^+e^- \to \psi^{`} \to \gamma\gamma\gamma$ to determine 0 prong efficiency.

100000 $e^+e^- \to \psi^{`} \to \gamma\gamma\gamma$ events have been generated, let them pass through the program to remove those events like backgrounds, and to fit/calculate the same way as for DATA, then Nmc0, Nmc1, ..., Nmc12 will be obtained respectively, where, Nmc0 the number of MC events with Nch=0, which have passed through all cuts.

Let t(1,1) = Nmc0 / 100000, this is the first element of the efficiency matrix, corresponding to the efficiency for 0 prong $\to Nch = 0$; similarly, t(2,1) = Nmc1/100000, 0 prong $\to Nch = 1$; ...; then, t(1,1), t(2,1), ..., t(13,1) form the first column of the efficiency matrix.

Fig.7 shows one of the ASYM distributions obtained from Monte-Carlo($\gamma\gamma\gamma \to$ Nch=0).

Fig.8 shows one of the ZV distributions obtained from Monte-Carlo($\gamma\gamma\gamma \to$ Nch=1).

$\psi^{`} \to \pi^0\pi^0 J/\psi$ has been used for obtaining the second column of the efficiency matrix.

$\psi^{`} \to \pi^+\pi^- J/\psi$ has been used for obtaining the third column of the efficiency matrix.

We use $\psi^{`} \to \bar{\Lambda}\Lambda$, $\psi^{`} \to \bar{\Xi}^+\Xi^-$ to represent those channels with many neutral final states or those channels we haven't found yet.

Finally, an efficiency matrix with 6 $\times$ 13 elements will be obtained:

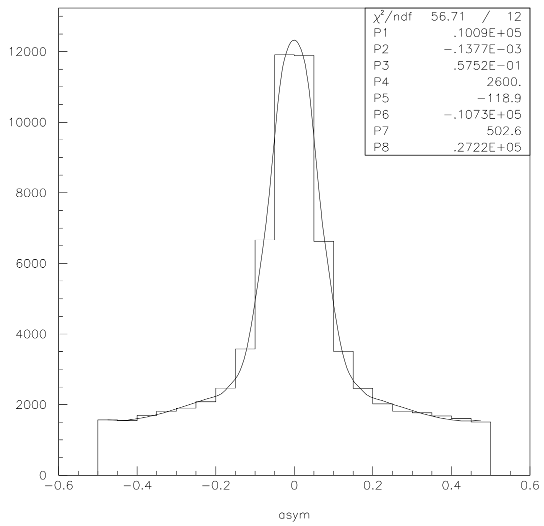

Figure 7: ASYM(Nch=0), MC

3.2 Calculation

3.2.1 Least χ^2:

Let the efficiency matrix multiply a column of assumed numbers: Nas1, Nas2, ..., Nas6 to get a column of calculated numbers: Nc0, Nc1, ..., Nc12;
Nas1: number of $e^+e^- \to \psi^{`} \to \gamma\gamma\gamma$ type events;
Nas2: number of $\psi^{`} \to \pi^0\pi^0 J/\psi$ type events;
and so on.

$$\begin{pmatrix} Nc0 \\ Nc1 \\ \vdots \\ Nc12 \end{pmatrix} = \begin{pmatrix} Efficiency \end{pmatrix} \begin{pmatrix} Nas1 \\ Nas2 \\ \vdots \\ Nas6 \end{pmatrix}$$

Then, we compare the column of calculated numbers: Nc0, Nc1, ..., Nc12 with the column obtained from data: Nd0, Nd1,..., Nd12.

In principle, $\chi^2 = \Sigma_{i=1}^{12} \frac{(Nci-Ndi)^2}{\sigma_i^2}$, we use $\chi^2 = \Sigma_{i=1}^{12}(Nci - Ndi)^2$ to instead.

Then, we make another program to calculate χ^2. In this program, we make a multi-nested do-loop to vary Nas1, Nas2, ..., Nas6 and to find the least χ^2 automatically. It means(roughly) N$\psi^{`}$ = Nas1 + Nas2 + ... +Nas6

3.2.2 Compensation

The program to calculate least χ^2 may fall into a local minimum, this is possible to influence the N$\psi^{`}$.

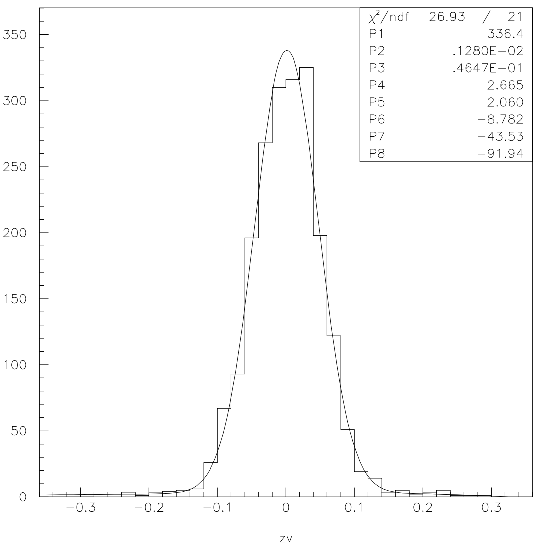

Figure 8: ZV(Nch=1), MC

In order to avoid the influence from the local minimum, this program calculates χ^2 twice: the first time is to store χ^2 into an array, the second time is to compare χ^2 and then to find the least χ^2. Also, the region we search for least χ^2 is big enough at the beginning; then reduces slowly during the calculation.

Futhermore, we add a compensation - $\frac{\Sigma_{i=1}^{12}(Nci-Ndi)}{\epsilon_{1-12}}$ to N$\psi^{`}$:

$$N\psi^{`} = \text{Nas1} + \ldots + \text{Nas6} - \frac{\Sigma_{i=1}^{12}(Nci-Ndi)}{\epsilon_{1-12}}$$

where, ϵ_{1-12} the average efficiency for Nch=1 through Nch=12.

We make an iteration to get accurate ϵ_{1-12}.

4 Preliminary Results

Several sets of Monte-Carlo have been made to confirm the efficiency:

MC1:

a, $\psi^{`} \rightarrow \gamma\gamma\gamma$, 100000;
b, $\psi^{`} \rightarrow \pi^0\pi^0 J/\psi, J/\psi \rightarrow$ Hadrons, 100000;
c, $\psi^{`} \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow$ Hadrons, 100000;
d, $\psi^{`} \rightarrow \gamma\chi_{c0}, \chi_{c0} \rightarrow \pi^+\pi^- K^+K^-$, 100000;
e, $\psi^{`} \rightarrow \bar{\Lambda}\Lambda$, 100000;
f, $e^+e^- \rightarrow \mu^+\mu^-$, 100000;

MC2:

a, b, c, d in MC1 and:
$\psi^{`} \rightarrow \bar{\Xi}^+\Xi^-$, 100000;
$\psi^{`} \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow e^+e^-$, 100000;

MC3:

Erat	*≥0.3*	*≥0.4*	*≥0.5*	*≥0.6*
MC1	*2.287*	*2.350*	*2.400*	*2.526*
MC2	*2.269*	*2.331*	*2.423*	*2.500*
MC3	*2.277*	*2.333*	*2.404*	*2.513*

Table 1: Preliminary Results

a, b, c, e in MC1 and:
$\psi^{`} \to \gamma\chi_{c2}, \chi_{c2} \to \pi^+\pi^-$, 10000;
$\psi^{`} \to \pi^+\pi^- 3(\pi^+\pi^-)\pi^0$, 100000;

Table 1 shows the preliminary results.

If we make an average for the numbers in Table 1, then the total number for

'95 $\psi^{`}$ data(KJI ≥ 1, $|Cos(Theta)_{MDC}| \leq 0.8$):
$N\psi^{`} = 2.38 \times 10^6 \times (1.0 \pm 0.001 \pm 0.06)$

5 Conclusion and Discussion

The preliminary results seems reasonable(according to the number, the production cross-section of $\psi^{`}$ is about 595nb); but the number increases with Erat, so, it is necessary to try to find the reason, especially to check the Monte-Carlo, and it is reasonable to reduce the Erat cut.