Determination of the total width of χ_{c0} —BES analysis memo

Yuan Changzheng
yuancz@hpws2.ihep.ac.cn

Jun., 1996
Revised: Feb., 1998

Abstract

$\gamma\pi^+\pi^-$ and γK^+K^- final states are carefully studied with the $\psi(2S)$ data collected by BES at BEPC to measure the resonance parameters of the p-wave charmonium state χ_{c0}. The study gives the best estimate of the total width of χ_{c0} is (14.3 ± 3.6)MeV and the branching fractions of $\chi_{cJ}(J = 0, 2)$ going to $\pi^+\pi^-$, K^+K^- were $B(\chi_{c0} \to \pi^+\pi^-) = (4.79 \pm 0.27 \pm 0.73) \times 10^{-3}$, $B(\chi_{c0} \to K^+K^-) = (5.82 \pm 0.36 \pm 0.94) \times 10^{-3}$, $B(\chi_{c2} \to \pi^+\pi^-) = (1.52 \pm 0.15 \pm 0.24) \times 10^{-3}$ and $B(\chi_{c2} \to K^+K^-) = (0.81 \pm 0.14 \pm 0.14) \times 10^{-3}$, where the first error is statistical and the second one systematic.

1 Introduction

The charmonium p-wave triplet states $\chi_{cJ}(J = 0, 1, 2)$ were found in 1970's and most of their decay parameters were measured before 1980's. By studying the charmonium states formed directly in proton-antiproton annihilation, Fermilab experiment E-760 gave a precision measurement of the total widths of χ_{c1} and χ_{c2} in 1992 [1], but χ_{c0} was still not studied because of its small branching fraction of going to electromagnet final states and its large total width.

The only available data on the total width of χ_{c0} was reported by Crystal Ball (CBAL) [2], which was measured in two different ways – the inclusive process $\psi(2S) \to \gamma X$ (13-21MeV) and the exclusive process $\psi(2S) \to \gamma\pi^0\pi^0 \to 5\gamma$ $(8.8 \pm 1.3 \pm 1.5\text{MeV})$, agree within 2.2 standard deviations. By combining these two measurements, CBAL gave the best estimate of the natural linewidth of the χ_{c0} was $13.5 \pm 3.3 \pm 4.2$MeV.

Beijing Spectrometer (BES) running at Beijing Electron Positron Collider (BEPC) collected $3.7(1 \pm 0.10)$ million $\psi(2S)$'s in its 1993/94 and 1995 running. In this paper we report a measurement of the total width of χ_{c0} and the corresponding branching fractions of χ_{c0} and χ_{c2} decay with these data.

The BES is a conventional cylindrical detector that is described in detail in Ref. [3]. A four-layer central drift chamber (CDC) surrounding the beampipe provides trigger information. A forty-layer main drift chamber (MDC), located radially outside the CDC, provides trajectory and energy loss (dE/dx) information on charged tracks over 85% of the total solid angle. The momentum resolution is $\sigma_p/p = 0.017\sqrt{1+p^2}$ (p in GeV/c), and the dE/dx resolution for hadron tracks is $\sim 11\%$. An array of 48 scintillation counters surrounding the MDC measures the time-of-flight (TOF) of charged tracks with a resolution of ~ 450 ps for hadrons. Outside the TOF system, a 12 radiation length, lead-gas barrel shower counter (BSC), operating in self-quenching streamer mode, measures the energies of electrons and photons over $\sim 80\%$ of the total solid angle with an energy resolution of $\sigma_E/E = 22\%/\sqrt{E}$ (E in GeV), and spatial resolutions of $\sigma_\phi = 7.9$ mrad, $\sigma_z = 3.6$ cm. Surrounding the BSC is a solenoidal magnet coil that provides a 0.4 Tesla magnetic field throughout the central tracking region of the detector. Three double layers of muon counters instrument the magnet flux return and serve to identify muons of momentum greater than 0.5 GeV/c. Endcap time-of-flight and shower counters extend coverage to the forward and backward regions.

2 Techniques

The most important techniques in determination of the total width of a resonance include two aspects: purely selected events and well determined mass resolution. The former make sure that the lineshape of the resonance is not distorted and the latter ensures that the width of the resonance determined is reliable.

To satisfy the above two requirements, the paired pseudoscalar mesonic decay modes of χ_{cJ} ($\pi^+\pi^-$ and K^+K^-) are used in our analysis, because it has the following advantages:

1. With four constrained kinematic fit, we can get relatively pure events. Although the cross contamination of the two channels we studied is inevitable, the effects of the contamination can estimated reliably according to Monte Carlo and the distributions got from data sample, so to compensate the distortions caused by the cross contamination.

2. The Monte Carlo sometimes cannot describe the detector very well because the data taking procedure always going on for a long period of time and status of the detector changes much, while the Monte Carlo can only simulate the detector performance of some certain status. It will be risky to use the mass resolution completely determined from Monte Carlo. Instead in our analysis the mass resolution at χ_{c2} mass region was fitted out with the precisely measured width of χ_{c2} as input [4], and then it was used to calibrate the mass resolution got from Monte Carlo simulation to give the mass resolution expected at χ_{c0} mass region, by fitting χ_{c0} with the mass resolution determined in this way, a more reliable line width of χ_{c0} could be got.

3. The procedure of calibrating mass resolution function can not be used

in some other decay modes of χ_{cJ}'s although the branching fractions are larger, because χ_{c1} lies in the lower mass side of χ_{c2} and the possible existing η_c' lies in the higher mass side will fold together with χ_{c2} to make the procedure of getting the mass resolution at χ_{c2} become very complicated. However, in the two modes selected, the J^P's of χ_{c0} and χ_{c2} are $even^+$ while that of χ_{c1} and η_c' are 1^+ and 0^-, the decay of χ_{c1} and η_c' to 0^-0^- is forbidden by parity conservation, so we can get χ_{c0} and χ_{c2} resonances without any distortion due to the contamination of other resonances.

3 Event Selection

Events selection includes identification of good photon, good charged tracks and separation of the events.

A neutral cluster is regarded as a photon candidate when the angle in xy plane between the nearest charged track and the cluster greater than $15°$, the first hit should be in the beginning 6 radiation length, and the cosine of the angle between cluster develop direction and its emit direction greater than 0.80. When these selection criteria used to select γ candidates in $\psi' \to \pi^+\pi^-\pi^+\pi^-$ and $\psi' \to \pi^+\pi^-K^+K^-$, less than 20% events can find γ's. After identification, at least one and at most three photon candidates are allowed in one events. The candidate has the largest SC energy is considered to be the photon radiated from $\psi(2S)$.

The number of charged tracks in the events is required to be two with net charge zero and each track with high quality in track fitting(MFIT=2, -9 or -19); to remove events with electron or with muon, we require the total XSE of the two tracks less than -3.6 (for Monte Carlo, the value is changed to -1.7 to ensure same fraction of good events be removed) and $Mustatus^+ + Mustatus^- < 4$ [5]; because no polar angle cut imposed to the data set, there will be still some lepton pair events remains in the sample, especially some events with $\mu\mu$ tracks (neutrals + J/ψ with $J/\psi \to \mu^+\mu^-$) due to the limited geometry coverage of the muon counter, these events will not affect the mass spectrum of $\pi^+\pi^-$ channel, but they contribute most background to the lower mass side of χ_{c0} in K^+K^- mode and makes the shape of the background in K^+K^- mode unusual, we will have to deal with it particularly. TOF and dE/dx information is used for charged particle identification. The probabilities of the particle to be identified as a pion, kaon and proton were assigned to each track ($Prob_\pi, Prob_K, Prob_p$), both tracks must have $Prob_\pi > 0.01$ (for $\pi^+\pi^-$) or $Prob_K > 0.01$ (for K^+K^-); do four constrained kinematic fit to $\psi(2S) \to \gamma\pi^+\pi^-$ and $\psi(2S) \to \gamma K^+K^-$ with the photon candidate and the two charged tracks, the probability of the fit P_{χ^2} should greater than 1%.

To separate $\gamma\pi^+\pi^-$ and γK^+K^- from each other, we define

$$Prob_{all}^{P^+P^-} = Prob(\chi^2_{4C} + \chi^2_{TOF} + \chi^2_{dE/dx}, ndf_{4C} + ndf_{TOF} + ndf_{dE/dx})$$

where χ^2_{4C}, χ^2_{TOF} and $\chi^2_{dE/dx}$ are the χ^2's of 4-constrains kinematic fit, of TOF time from π or K hypothesis and of the dE/dx from π or K hypothesis; ndf_{4C},

Table 1: Events number after each cut (pre-selection).

Cut	Real data	$\gamma\pi^+\pi^-$ and γK^+K^- Monte Carlo
Total events	5575465	60000
IJK .GT. 0	5393483	60000
NCHRG=2 & NCHRGX=0	4460634	51776
0<NNEU<9	4373313	51776
ISUB3>0	4373313	51776
ICHRG=+-1	4373313	51776
MFIT=2,-19,-9	4323459	51610
NET CHRG zero	3553217	50630
0<NGamma<5	643570	30733
Pass Kinematic Fit	104369	27909

Table 2: Events number after each cut (after pre-selection).

Cut	$\gamma\pi^+\pi^-$ DT (3.2<m<3.6)	γK^+K^- DT (3.2<m<3.6)	$\gamma\pi^+\pi^-$ MC	γK^+K^- MC
Pass Kinematic Fit	17008	20914	14759	12815
Prob4C $>$ 0.01	9830	10355	13714	11935
Remove electrons	3036	3521	13518	11935
Remove Muons	2271	2436	13517	11935
NGamma=1,2,3	2235	2386	13513	11935
ProbID $>$ 0.01	2068	2306	13299	11769
$\gamma\pi^+\pi^-$	1264	–	11276	1710
γK^+K^-	–	1268	2170	10056

ndf_{TOF} and $ndf_{dE/dx}$ are corresponding number of degrees of the freedom of χ^2 distribution. If $Prob_{all}^{\pi^+\pi^-} > Prob_{all}^{K^+K^-}$ the event is regarded as a $\gamma\pi^+\pi^-$ event, and if $Prob_{all}^{K^+K^-} > Prob_{all}^{\pi^+\pi^-}$ is a γK^+K^- event. Tab. 1, Tab. 2, and Figure 1 shows the events number after each step of the cut and some of the distributions.

After imposing all above selections to the data, the invariant mass distributions are show in figure 2, fitting of the mass plots of $\pi^+\pi^-$ and K^+K^- with two Breit-Wigners folding a gaussian like mass resolution (all parameters free) shows that the mass of χ_{c0} (3.4130GeV) and χ_{c2} (3.5557GeV) in $\pi^+\pi^-$ mass plot is lower than the world average while that in K^+K^- mass plot is higher (3.4163GeV and 3.5575GeV), which means that the events in our two samples are cross contaminated and the effect of contaminated parts to the mass spectra should be estimated before fitting to get χ_{c0} parameters. From the mass plot, we see the events of $\chi_{c2} \to K^+K^-$ is too few, it is hard to use it for callibration of the mass resolution as described in following section, to determine the width of χ_{c0}, only $\pi^+\pi^-$ channel is used.

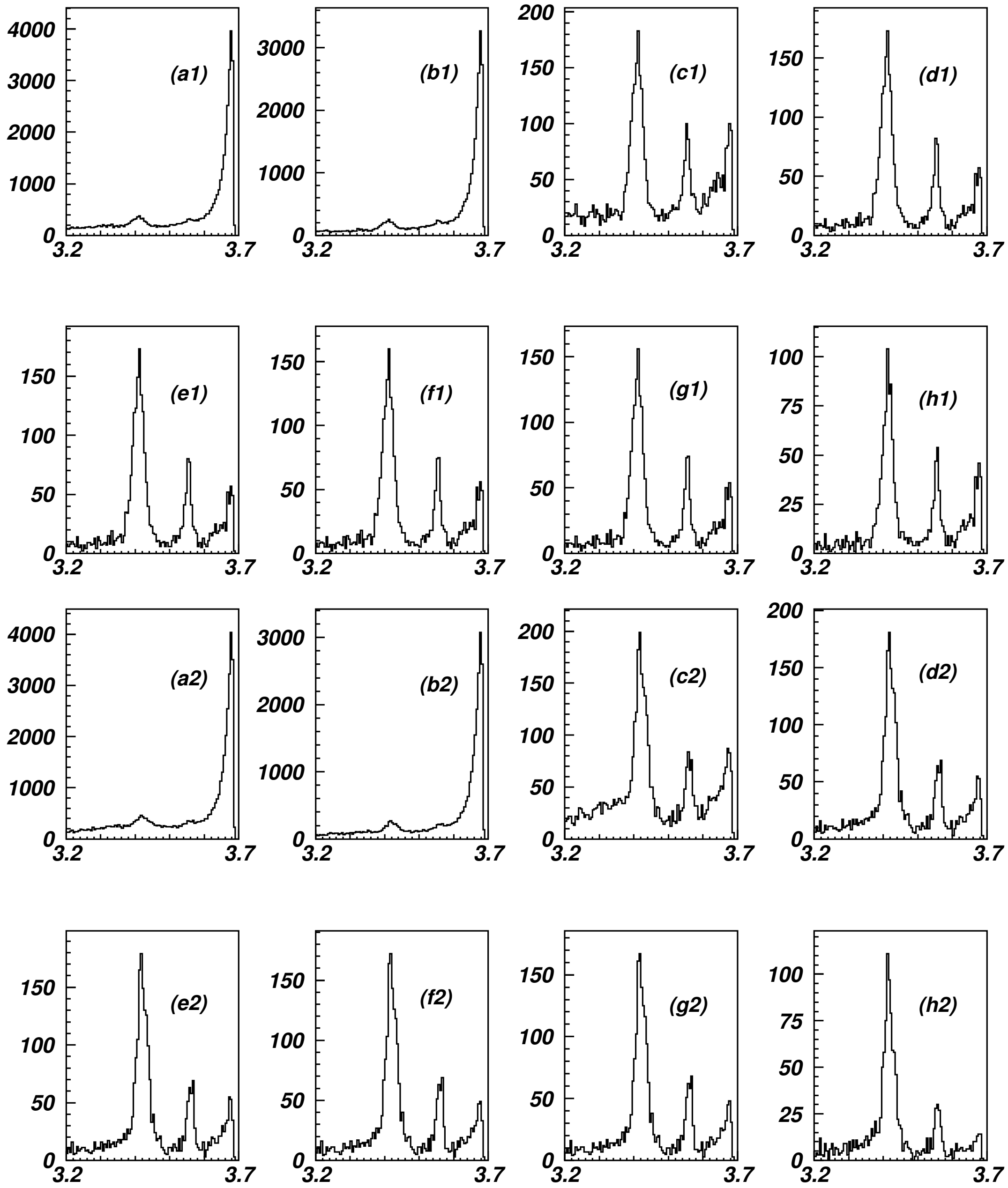


Figure 1: Meson pair mass distribution after each cut, (a1,b1,c1,d1,e1,f1,g1,h1) for $\gamma\pi^+\pi^-$, (a2,b2,c2,d2,e2,f2,g2,h2) for γK^+K^-. a) after preselection, b) after Prob4C cut, c) after removing elcetron, d) after removing muons, e) number of gamma cut, f) after PartID, g) after proball cut, h) seperate $\pi^+\pi^-$ and K^+K^- from each other.

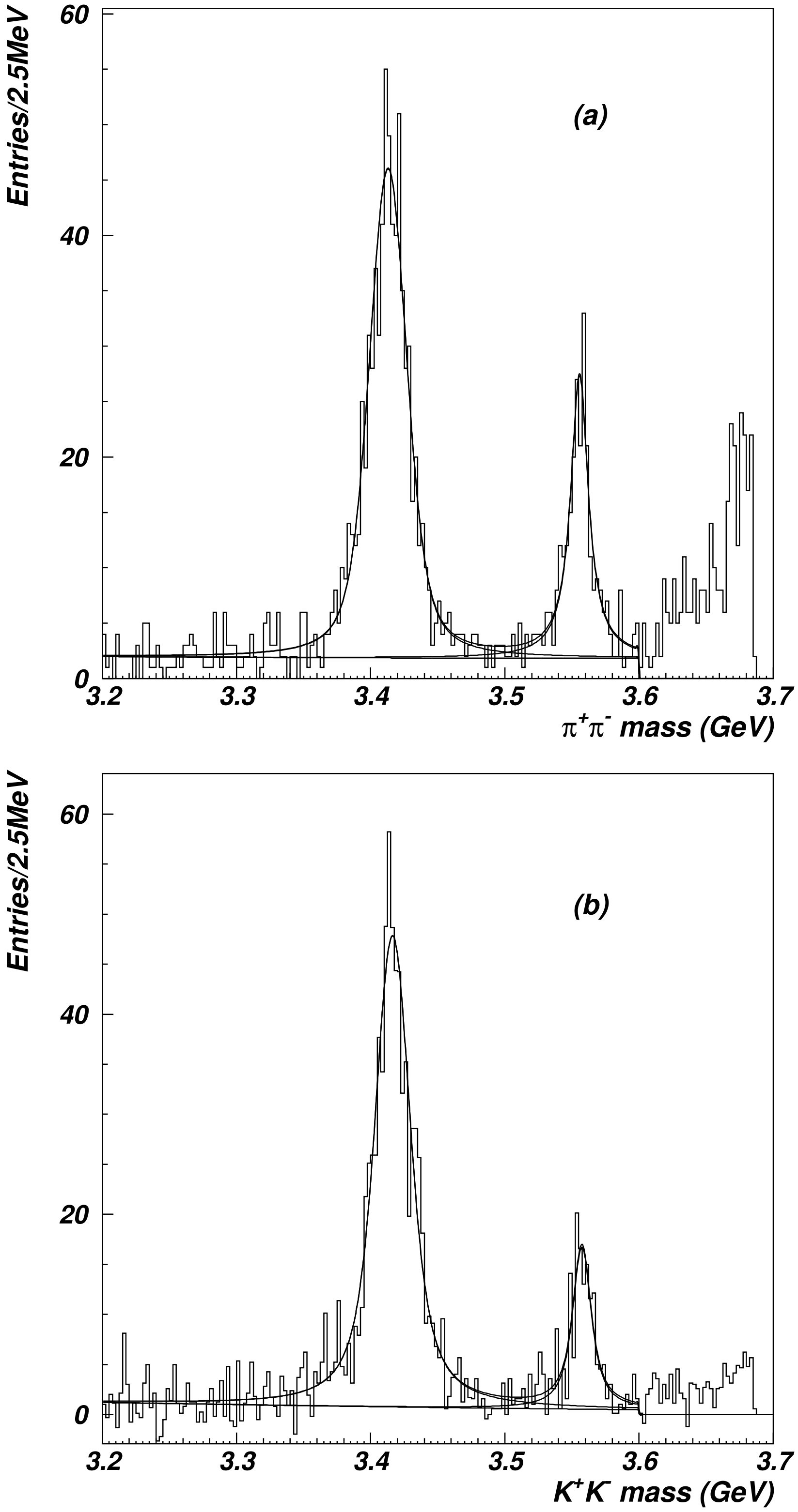


Figure 2: Fit to the invariant mass distributions of the meson pairs with all parameters free, a) $\gamma\pi^+\pi^-$, b) γK^+K^-, for γK^+K^- mode, the background from $\mu^+\mu^-$ is estimated and removed as described in text.

4 Monte Carlo

We use Monte carlo simulation to get the probabilities of cross contamination of the two channels as well as the detection efficiencies and mass resolution.

In the Monte carlo generator, the χ_{cJ}'s are assumed to be generated via pure E1 transition of $\psi(2S)$ [6], χ_{cJ} decaying to 0^-0^- meson pairs has only one independent helicity amplitude and so the whole process is determined [7].

Events with χ_{c0} and χ_{c2} (mass and width from PDG) intermidiate and events at different meson pair mass between 3.3 and 3.6GeV (3.330, 3.355, 3.375, 3.390, 3.400, 3.405, 3.410, 3.415, 3.420, 3.425, 3.430, 3.440, 3.455, 3.475, 3.500, 3.547, 3.551, 3.553, 3.555, 3.556, 3.557, 3.559 , 3.561, 3.565) and zero width were generated, assuming χ_{c1} is absolutely missing, the spin-parity of the resonance is assigned to 0^+ when mass less than 3.5GeV and to 2^+ when mass greater than 3.5GeV. The events number generated are 20000 for $\psi' \to \gamma\chi_{c0}$, $\chi_{c0} \to \pi^+\pi^-$ or K^+K^-, 10000 for $\psi' \to \gamma\chi_{c2}$, $\chi_{c2} \to \pi^+\pi^-$ or K^+K^-, 2500 at each points with zero width for $\pi^+\pi^-$ or K^+K^- decay modes of the resonance.

After requiring the events satisfy the same selection criteria as for data, the detection efficiency, the probability of cross contamination and the mass resolution at each mass point are got. From these Monte Carlo simulated data samples, the following studies are performed and corresponding conclusions are got.

4.1 Mass resolution

The response of the detector and the selection procedure to a fixed input mass is always assumed to be distributed as a Gaussian, the standard deviation of the Gaussian is the so called mass resolution. The mass resolution at different mass may no be the same, especially for two points not too near. For the resonances we interested in, the width of χ_{c0} is about 15MeV and that of χ_{c2} is only 2MeV, both are not two large, the following of this subsection will answer two questions: one, is the Gaussian assumption reliable, and two, can we assume the mass resolution in our case all the same for the whole mass region we interested in.

4.1.1 Gaussian like mass response

Using the Monte Carlo data sample of $\psi' \to \gamma\chi_{c0}$, $\chi_{c0} \to \pi^+\pi^-$, after selection, the invariant mass of $\pi^+\pi^-$ is fitted with Breit-Wigner folded with a gaussian like mass resolution function. Since the input width of χ_{c0} is 13.5MeV, the width is first fixed to fit the mass resolution out as 8.12MeV, then we fix the mass resolution and free the width, fitted out result is 13.82 ± 0.34MeV, which is in agreement with the input width. The fitted out mass of χ_{c0} is 3415.1 ± 0.2MeV, consistant with the input value of 3415.1MeV.

So we draw the conclusion that the mass response of the process we studied can be assumed as a Gaussian.

Table 3: Mass resolution at different resonance mass compared to those of χ_{c0} or χ_{c2}.

	$\gamma\pi^+\pi^-$		γK^+K^-	
Mass (GeV)	Prob	Max. Dist.	Prob	Max. Dist.
3.330	0.5214	0.0382	0.9421	0.0264
3.355	0.9262	0.0256	0.6533	0.0369
3.375	0.9831	0.0213	0.8579	0.0298
3.390	0.3632	0.0428	0.5529	0.0391
3.400	0.9958	0.0192	0.4696	0.0420
3.405	0.9574	0.0236	0.0684	0.0636
3.410	0.4433	0.0405	0.7746	0.0327
3.415	1.0000	0.0000	1.0000	0.0000
3.420	0.9986	0.0181	0.8199	0.0313
3.425	0.8928	0.0272	0.9882	0.0222
3.430	0.8828	0.0276	0.6130	0.0378
3.440	0.9489	0.0243	0.9804	0.0231
3.455	0.7130	0.0329	0.9321	0.0269
3.475	0.9469	0.0245	0.9010	0.0282
3.500	0.4435	0.0409	0.5060	0.0413
3.547	0.2801	0.0451	0.9767	0.0232
3.551	0.8018	0.0290	0.5947	0.0366
3.553	0.6868	0.0326	0.3818	0.0436
3.555	0.9197	0.0249	0.9461	0.0251
3.556	1.0000	0.0000	1.0000	0.0000
3.557	0.3443	0.0426	0.8769	0.0282
3.559	0.9991	0.0171	0.9527	0.0249
3.561	0.9309	0.0247	0.9807	0.0226
3.565	0.3327	0.0432	0.9998	0.0164

4.1.2 Mass resolution changes small as mass runs

The mass spectra at different mass points between 3.3 and 3.5GeV are compared to the mass spectrum gets from mass point 3.415GeV, and those between 3.5 and 3.6GeV are compared to the mass spectrum gets from mass point 3.556GeV, the similiarity in shape of the two plot are listed in Tab. 3, the maximum distance in one bin is also listed, from the table, it is obvious that the shape of the mass response with different mass input are very similiar, shows that the mass resolution at different mass points can be treated as the same as that got near the resonance peak.

Fit the Monte Carlo mass spectra with Breit-Wigner folds Gaussian like mass resolution function, fix the width to the input values, one gets the mass resolutions of 8.12 ± 0.23MeV, 6.31 ± 0.11MeV, 7.59 ± 0.24MeV and 6.60 ± 0.12MeV for $\chi_{c0} \to \pi^+\pi^-$, $\chi_{c2} \to \pi^+\pi^-$, $\chi_{c0} \to K^+K^-$ and $\chi_{c2} \to K^+K^-$ respectively.

Table 4: Monte Carlo efficiency and cross contamination probability at different mass

0^+ resonance				
mass	piaspi	kaaska	piaska	kaaspi
3.3000	0.3716	0.3264	0.0684	0.0604
3.3550	0.3720	0.3144	0.0668	0.0572
3.3750	0.3976	0.3424	0.0608	0.0512
3.3900	0.3876	0.3404	0.0692	0.0592
3.4000	0.3776	0.3324	0.0700	0.0548
3.4050	0.3884	0.3496	0.0680	0.0584
3.4100	0.3712	0.3344	0.0656	0.0512
3.4150	0.3596	0.3248	0.0716	0.0596
3.4200	0.3580	0.3344	0.0676	0.0456
3.4250	0.3624	0.3276	0.0708	0.0556
3.4300	0.3616	0.3248	0.0724	0.0580
3.4400	0.3784	0.3384	0.0780	0.0588
3.4550	0.3672	0.3280	0.0668	0.0484
3.4750	0.3720	0.3316	0.0704	0.0536
3.5000	0.3580	0.3148	0.0628	0.0532
2^+ resonance				
3.5470	0.3880	0.3356	0.0744	0.0700
3.5510	0.4012	0.3668	0.0708	0.0524
3.5530	0.3836	0.3528	0.0788	0.0592
3.5550	0.4028	0.3564	0.0724	0.0576
3.5560	0.3868	0.3424	0.0688	0.0628
3.5570	0.3876	0.3604	0.0816	0.0540
3.5590	0.3776	0.3464	0.0776	0.0576
3.5610	0.3840	0.3468	0.0756	0.0532
3.5650	0.3812	0.3452	0.0664	0.0524

So, we will treat the mass resolution in the mass region we interested in as the same and is Gaussian like.

4.2 Detection efficiency

The detection efficiencies at different mass points are show in Tab. 4 and Fig. 3, one can see that the efficiency decreases as the mass goes up. It is also obvious the changes of the efficiency is very small, following we will check how much it affects the resonance parameters.

Fitting the efficiencies from 3.3 to 3.5GeV for $\pi^+\pi^-$ as a function of meson pair mass gives

$$\varepsilon(m)/\varepsilon_0 = (0.3996 + 0.00707m + 0.004436m^2)/0.3720,$$

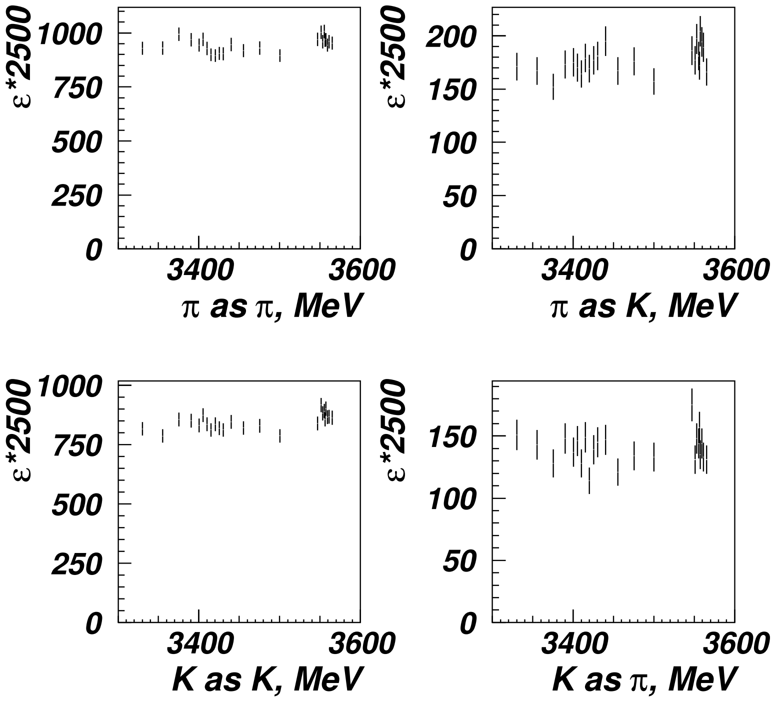


Figure 3: Monte Carlo Efficiency and cross contamination probability at different mass.

correct the mass spectrum of simulated $\psi' \to \gamma\chi_{c0}$, $\chi_{c0} \to \pi^+\pi^-$ events with the efficiency function, and fit the mass spectrum again using Breit-Wigner folded with a Gaussian like mass resolution function, the fitted out width of χ_{c0} is 13.80 ± 0.35MeV, and fitted out mass is 3415.2 ± 0.2MeV, both values in good agreement with those got from the fitting without efficiency corrections. For a resonance as narrow as χ_{c2}, the correction due to the efficiency will be less.

In the following analysis, we will use the directly measured mass spectrum to fit the χ_{c0} resonance parameters, the efficiency is assumed to be the same at all mass region and is the same as that estimated from the χ_{c0} and χ_{c2} events with PDG parameters as input, that is $\varepsilon_{\chi_{c0}\to\pi^+\pi^-} = 36.92\%$, $\varepsilon_{\chi_{c2}\to\pi^+\pi^-} = 38.91\%$, $\varepsilon_{\chi_{c0}\to K^+K^-} = 32.81\%$ and $\varepsilon_{\chi_{c2}\to K^+K^-} = 34.94\%$.

4.3 Cross contamination

Because the momenta of the pions and kaons are very large (average momentum about 1.7GeV), the particle ID and the kinematic fit cannot separate the two modes we studied from each other, so cause the cross contamination of the two channels. The contaminations will distort the line shapes of the χ_{c0} and χ_{c2}, in this section, we try to understand how the contaminations affect the mass spectra and how to remove the effects of the contamination to get the correct resonance parameters from the observed mass spectra.

4.3.1 Cross contamination probability as mass runs

From Tab. 4 and Fig. 3 one can see that the cross contamination probability is around 4∼8%, and the mass dependance is not very significant, especially for the mass region near the resonance peak, as an approximation, we regard it as independent of mass.

Compare the contamination probability with the corresponding efficiency, the contaminated part is about $10 \sim 15\%$ in the observed spectra. The contamination do affect the mass spectra. For example, if we fix the mass resolution to that we got from no contaminated mass spectrum, to fit the $\pi^+\pi^-$ mass spectrum together with 15% K^+K^- events contaminated, the fitted out width is 15.4 ± 0.6MeV for 13.5MeV input and mass moved to 3.4132GeV; for K^+K^- mass spectrum contaminated with 15% $\pi^+\pi^-$ events, the fitted out width and mass are 15.1 ± 0.6MeV and 3.4166GeV.

4.4 remove the effect of Contamination

From previous subsection, it is obvious the K^+K^- contamination in $\pi^+\pi^-$ mass spectrum shift the center mass of the resonance to the lower side and the $\pi^+\pi^-$ contamination in K^+K^- mass spectrum shift the center mass of the resonance to the upper side, and in both cases, it broden the resonance. One way to get the proper mass distribution is subtract the contaminated part from the mass spectrum according to both real data and Monte Carlo data, as we already done in previous analysis memo of this channel [8], but we will have to fit the mass spectrum with binning and so introduce extra systematic error due to the way of binning and also the uncertainty of the shape of the background. Another possible way to conpensate the effect is to increase the mass resolution and then fix the mass resolution to the increased one to fit out the width of the resonance. This method is probable only if we can find the proper way to calibrate the mass resolution of real data.

This is achieved by using the χ_{c2} resonance, since the width of χ_{c2} is known in high precision, fix the width of χ_{c2} to its world average, mass resolution can be fitted out from real data, which includes the effects of both the cross contamination and the inconsistency between Monte Carlo data and real data.

From a Monte Carlo study, we found the mass resolutions of $\chi_{c2} \to \pi^+\pi^-$ are 6.67MeV and 7.74MeV before and after the K^+K^- contamination, the mass resolutions of $\chi_{c0} \to \pi^+\pi^-$ are 8.21MeV and 9.78MeV before and after the K^+K^- contamination, the fractions of the increase of the mass resolution after contamination at χ_{c0} and χ_{c2} are almost the same (1.14 and 1.19), the difference is far less than the error of the width of χ_{c2}, which is used as the standard to calibration the mass resolution.

So comes the conclusion of this subsection: the cross contamination will distort the mass spectrum, if we use the contaminated χ_{c2} spectrum to calibrate the mass resolution at χ_{c0}, the effect of the contamination on the width of χ_{c0} can be compensated. This will be used in our fitting to the real data.

When we calculate the produced events number of each channel, the probabilities of the cross contamination should be used, from Monte Carlo, one estimetes the probabilities of K^+K^- events selected as $\pi^+\pi^-$ are 5.55% and 6.00% for χ_{c0} and χ_{c2} decays, and the probabilities of $\pi^+\pi^-$ events selected as K^+K^- are 7.12% and 7.45% respectively.

5 Fit the Mass Plots

After selection, the $\pi^+\pi^-$ mass plot of $\gamma\pi^+\pi^-$ and K^+K^- mass plot of γK^+K^- events are got. Because of the different shapes of the background in $\pi^+\pi^-$ and K^+K^- channels, the two channels are treated in different methods.

5.1 $\gamma\pi^+\pi^-$ mode

The mass spectrum is fitted event by event using an unbinned maximum likelyhood method:

First, fit the events with $\pi^+\pi^-$ mass between 3.5 and 3.6GeV with $\Gamma_{\chi_{c2}}$ fixed to PDG value 2.00MeV, using one Breit-Weigner folding a Gaussian like mass resolution function, together with a linear background. The fitted out mass resolution is 7.83 ± 1.04MeV, while that of Monte Carlo is 6.31 ± 0.11MeV, from the Monte Carlo simulated mass resolution of 8.12 ± 0.23MeV at χ_{c0} mass, the estimated mass resolution of the data at χ_{c0} mass region is $8.12 \times 7.83/6.31 \sim 10.08$MeV.

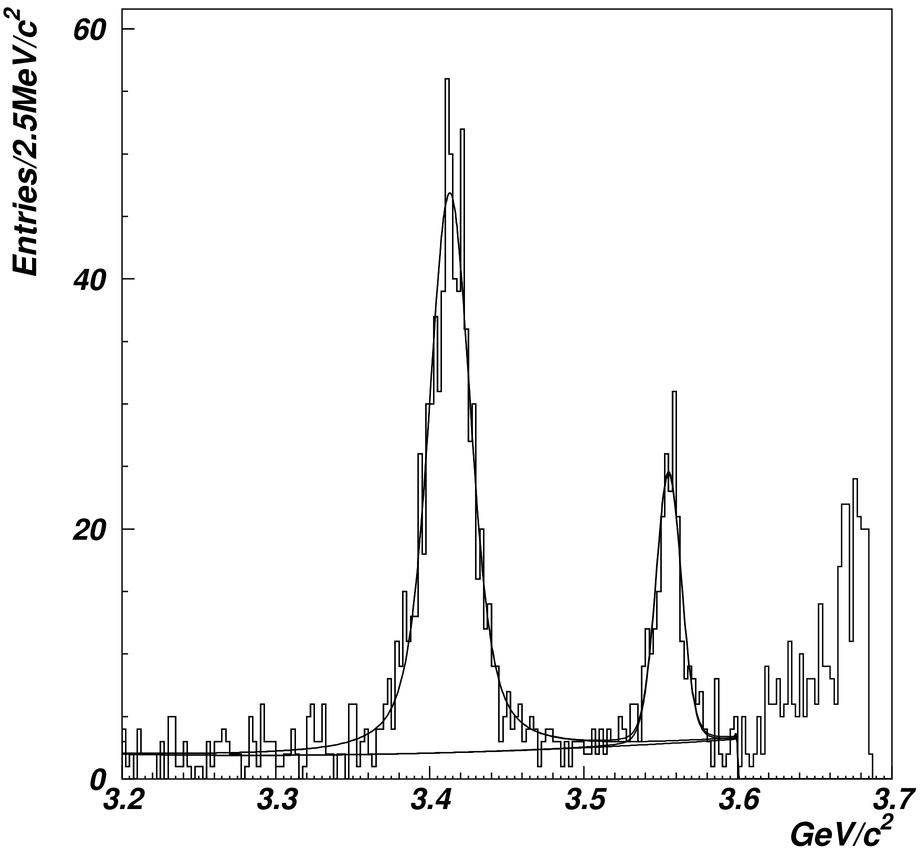
Then fit the events with $\pi^+\pi^-$ mass between 3.2 and 3.6GeV using two Breit-Weigners folding Gaussian like mass resolution function, together with a second order polynomial background, with $\Gamma_{\chi_{c2}}$ fixed to PDG value 2.00MeV, mass resolution at χ_{c0} and χ_{c2} mass region fixed to 10.08 and 7.83MeV respectively and all other papameters free. The fit gives $\Gamma_{\chi_{c0}} = 14.32 \pm 2.02$MeV, where the error is from fitting itself. Fitted mass plot and relevant properties can be seen in Fig. 4.

The events number of $\chi_{cJ} \to \pi^+\pi^-$ are also fitted out for determination of the branching fractions of each channel. we got $n^{obs}_{\chi_{c0}\to\pi^+\pi^-} = 719.5 \pm 32.1$ and $n^{obs}_{\chi_{c2}\to\pi^+\pi^-} = 184.9 \pm 15.8$, where the error is statistical.

5.2 γK^+K^- mode

The mass spectrum is fitted using a binned maximum likelyhood method, the bin of the K^+K^- mass plot is chosen to be 2.5MeV.

As described previously, the $\mu^+\mu^-$ events from J/ψ decays contributes an unusual background to the K^+K^- invariant mass spectrum. To estimate the shape of this kind of background, those events satisfying all the γK^+K^- selection criteria except $Mustatus^+ + Mustatus^- < 4$ are selected and required $Mustatus^+ + Mustatus^- > 3$. It is obvious that these $\mu^+\mu^-$ samples distributed




```
===========================================================================
I                     Summary Of BWFIT Results                            I
===========================================================================
Histogram ID= *****  UnBinned Breit-Wigner Fit using 1263 Points
Fit Parameters:Npoly=   4 Nbw=   2 Namp=   0 Range=      3.200 To      3.600
Hist. Chisq =     150.98 for   7 params & 152 DF.
Chisquare Probability =  50.82%. Mean and S.D. for pulls:  -.0141     .9713
Likelihood ratio and probability            :    158.712        33.81%
Final Value of Log Likelihood               :     -1897.92
Error Correspond to a Function Chage        :      .50
Phase Space limits for tails corrections    :       .280GEV     2.817GEV
Breit-Wigner efficiency correction factors  :      .977         .992
Include Breit-Wigner tails outside fit region :       .003         .000
Efficiency-corrected events in fit region    :  1263.[average eff. :1.000]
---THE FITTED VALUES AND ERRORS OF THE PARAMETERS:---
    LEG_Value :  .26827    Error(Cov,-/+):    .112       .000E+00  .000E+00
    LEG_Value :  .15455    Error(Cov,-/+):    .194       .000E+00  .000E+00
    LEG_Value :  .00000E+00Error(Cov,-/+):    .000E+00  .000E+00  .000E+00
    AREAValue :  .56964    Error(Cov,-/+):    .254E-01  .000E+00  .000E+00
    RESLValue :  .10080E-01Error(Cov,-/+):    .000E+00  .000E+00  .000E+00
    GAMAValue :  .14316E-01Error(Cov,-/+):    .202E-02  .000E+00  .000E+00
    MASSValue :  3.4130    Error(Cov,-/+):    .712E-03  .000E+00  .000E+00
    AREAValue :  .14636    Error(Cov,-/+):    .125E-01  .000E+00  .000E+00
    RESLValue :  .78297E-02Error(Cov,-/+):    .000E+00  .000E+00  .000E+00
    GAMAValue :  .20000E-02Error(Cov,-/+):    .000E+00  .000E+00  .000E+00
    MASSValue :  3.5551    Error(Cov,-/+):    .846E-03  .000E+00  .000E+00
```

Figure 4: Fitted out results of $\gamma\pi^+\pi^-$ channel.

the same as the background survived the selection in the normal procedure, from Fig. 5, one can see clearly the background centered at the lower mass side of χ_{c0} and so cause a long tail in the lower mass side of χ_{c0}. Considering the geometric coverage of the muon counter and the detector and assuming the angular distribution is $1+\cos^2\theta$, the remaining $\mu^+\mu^-$ events in K^+K^- modes are estimated to be about $\frac{0.8+0.8^3/3}{0.6+0.6^3/3}-1 \approx 0.44$ of those in the selected $\mu^+\mu^-$ samples. This part is subtracted directly from the mass spectrum and the resulting plot can be seen in Fig. 6.

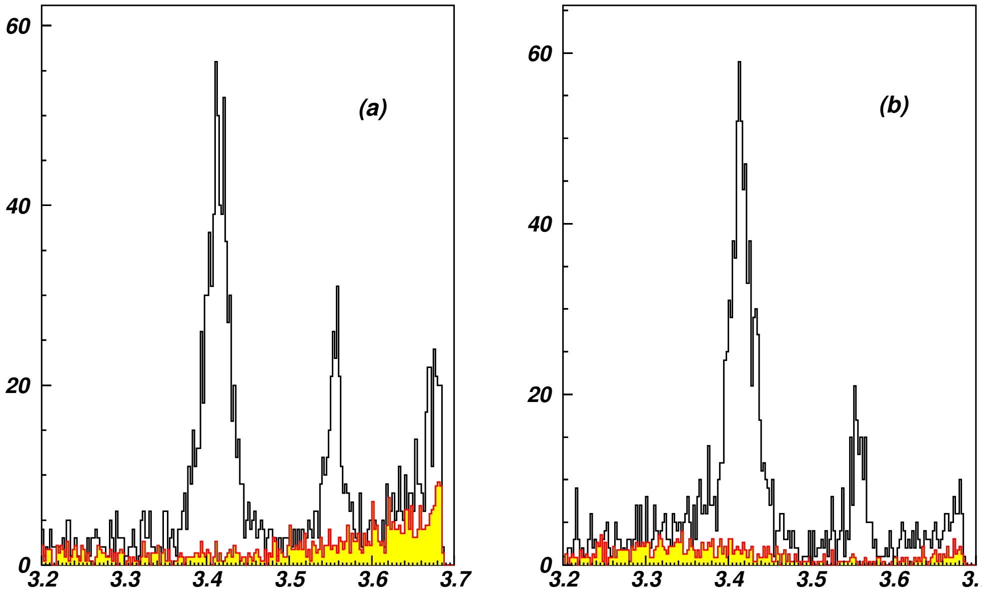


Figure 5: $\mu^+\mu^-$ background (shaded) in $\pi^+\pi^-$ (a) and K^+K^- (b) mass spectra.

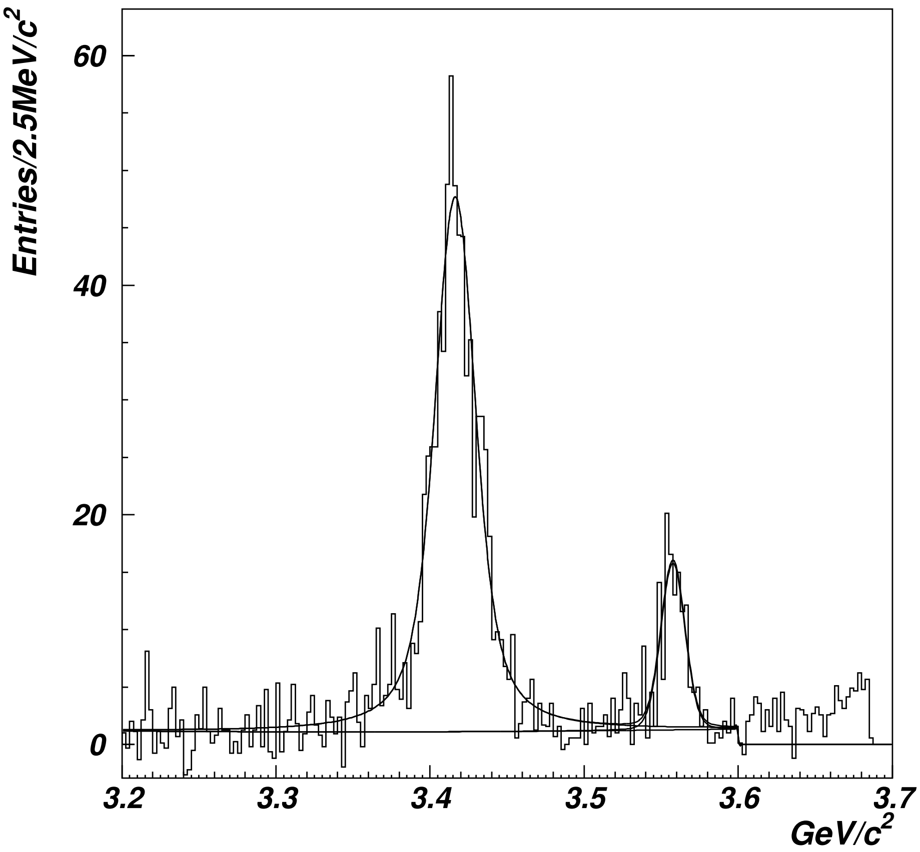
Since the events number in χ_{c2} mass region is only about 100, to use this signal for mass resolution calibration is risky, so we donot use this channel for width determination. To fit the events number out, we need not know the mass resolution in high precision and the change of the mass resolution doesnot affect the events number too much. In our fit, only the width of χ_{c2} is fixed and the fit gives the events numbers of $\chi_{cJ} \to K^+K^-$ are $n^{obs}_{\chi_{c0}\to K^+K^-} = 773.9 \pm 38.4$ and $n^{obs}_{\chi_{c2}\to K^+K^-} = 114.5 \pm 13.0$, where the error is statistical.

6 Calculate the Branching Fractions

The produced events numbers of $\chi_{cJ} \to \pi^+\pi^-$ and K^+K^- can be calculated by solving a linear equations

$$\begin{pmatrix} n_\pi^{obs} \\ n_K^{obs} \end{pmatrix} = \begin{pmatrix} \varepsilon_{\pi\pi} & \varepsilon_{K\pi} \\ \varepsilon_{\pi K} & \varepsilon_{KK} \end{pmatrix} \begin{pmatrix} n_\pi^{prod} \\ n_K^{prod} \end{pmatrix}$$

where n_π^{obs} and n_K^{obs} are observed $\chi_{cJ} \to \pi^+\pi^-$ and K^+K^- events numbers, are got from the fitting of the mass spectra; εAB is the probability of a $\chi_{cJ} \to A^+A^-$ event to be identified as a $\chi_{cJ} \to B^+B^-$ event (A and B denote π or K), is got by analyzing Monte Carlo sample.




```
==============================================================================
I                      Summary Of BWFIT Results                              I
==============================================================================
Histogram ID=   199  AdapQuad Breit-Wigner Fit using  160 Points
Fit Parameters:Npoly=   4 Nbw=   2 Namp=   0 Range=      3.200 To      3.600
Hist. Chisq =     332.62 for   9 params & 150 DF.
Chisquare Probability =    .00%. Mean and S.D. for pulls:  -.0056    1.4418
Likelihood ratio and probability            :    299.924          .00%
Final Value of Log Likelihood               :    -1788.03
Error Correspond to a Function Chage        :      .50
Phase Space limits for tails corrections    :       .280GEV     2.817GEV
Breit-Wigner efficiency correction factors  :      .972          .991
Include Breit-Wigner tails outside fit region :       .004         .000
Efficiency-corrected events in fit region   :   1065.[average eff. :1.000]
---THE FITTED VALUES AND ERRORS OF THE PARAMETERS:---
    LEG_Value :  .74325E-01Error(Cov,-/+):    .186       .000E+00  .000E+00
    LEG_Value :  .94469E-01Error(Cov,-/+):    .346       .000E+00  .000E+00
    LEG_Value :  .00000E+00Error(Cov,-/+):    .000E+00  .000E+00  .000E+00
    AREAValue :  .71653    Error(Cov,-/+):    .366E-01  .000E+00  .000E+00
    RESLValue :  .88957E-02Error(Cov,-/+):    .196E-02  .000E+00  .000E+00
    GAMAValue :  .17388E-01Error(Cov,-/+):    .434E-02  .000E+00  .000E+00
    MASSValue :  3.4163    Error(Cov,-/+):    .696E-03  .000E+00  .000E+00
    AREAValue :  .11070    Error(Cov,-/+):    .127E-01  .000E+00  .000E+00
    RESLValue :  .73560E-02Error(Cov,-/+):    .109E-02  .000E+00  .000E+00
    GAMAValue :  .20000E-02Error(Cov,-/+):    .000E+00  .000E+00  .000E+00
    MASSValue :  3.5577    Error(Cov,-/+):    .963E-03  .000E+00  .000E+00
```

Figure 6: Fitted out results of γK^+K^- channel.

From previous sections, we know that for χ_{c0}, $n_\pi^{obs} = 719.5 \pm 32.1$, $n_K^{obs} = 773.9 \pm 38.4$, $\varepsilon_{\pi\pi} = 36.92\%$, $\varepsilon_{KK} = 32.81\%$, $\varepsilon_{K\pi} = 5.55\%$ and $\varepsilon_{\pi K} = 7.12\%$; for χ_{c2}, $n_\pi^{obs} = 184.9 \pm 15.8$, $n_K^{obs} = 114.5 \pm 13.0$, $\varepsilon_{\pi\pi} = 38.91\%$, $\varepsilon_{KK} = 34.94\%$, $\varepsilon_{K\pi} = 6.00\%$ and $\varepsilon_{\pi K} = 7.45\%$.

Solving the equations, we get

$$n^{prod}_{\chi_{c0}\to\pi^+\pi^-} = 1648 \pm 92,$$

$$n^{prod}_{\chi_{c2}\to\pi^+\pi^-} = 439 \pm 42,$$

$$n^{prod}_{\chi_{c0}\to K^+K^-} = 2001 \pm 123,$$

$$n^{prod}_{\chi_{c2}\to K^+K^-} = 234 \pm 40,$$

where the error is statistic only.

7 Error Estimation

The error of $\Gamma_{\chi_{c0}}$ may arise from the uncertainty of $\Gamma_{\chi_{c2}}$, the way of mass resolution determination, the shape of the background, the efficiency correction at different mass and varying cuts, add all these errors and the error caused by the fitting procedure in quadrature, the total percentage error of $\Gamma_{\chi_{c0}}$ is 25%.

The systematic errors of the branching fractions arise from the uncertainty of $\Gamma_{\chi_{c2}}$, uncertainty of the mass resolution, the shape of the background, the efficiency determination and selection criteria are 11.5%, 12.6%, 12.1% and 14.7% for $B(\chi_{c0} \to \pi^+\pi^-)$, $B(\chi_{c0} \to K^+K^-)$, $B(\chi_{c2} \to \pi^+\pi^-)$ and $B(\chi_{c2} \to K^+K^-)$ respectively; the errors caused by the uncertainty of total events number are 10% for all the channels; the uncertainty of $B(\psi(2S) \to \gamma\chi_{cJ})$ cause 8.6% error to χ_{c0} decay channels and 10.3% error to χ_{c2} decay channels. Add all these errors in quadrature, the total percentage errors of $B(\chi_{c0} \to \pi^+\pi^-)$, $B(\chi_{c0} \to K^+K^-)$, $B(\chi_{c2} \to \pi^+\pi^-)$ and $B(\chi_{c2} \to K^+K^-)$ are 15%, 16%, 16% and 18% respectively.

8 Conclusion and Discussion

Combining above analysis, we got

$$\Gamma_{\chi_{c0}} = 14.3 \pm 3.6\text{MeV},$$

This result is consistent with the world average, but with high precision. Compared with the theoretical predictions, it agrees with the expectation of Ref. [9] but has large discrapency to that of Ref. [10].

The results of the branching fractions of χ_{cJ} decays are listed in table 5, the values consistent with the world average in error but with high precision.

Backgrounds from $\psi(2S) \to \gamma\chi_{cJ} \to \gamma p\bar{p}$ are negligible according to Monte Carlo study. Backgrounds from $\psi(2S) \to \pi^+\pi^-\pi^0$ and $\psi(2S) \to K^+K^-\pi^0$ are estimated to be negligible according to their decay branching fractions.

Table 5: Branching ratios of $\chi_{cJ} \to 0^-0^-$

decay modes	Branching Fractions($\times 10^{-3}$)	Observed Events
$\chi_{c0} \to \pi^+\pi^-$	$4.79 \pm 0.27 \pm 0.73$	720 ± 32
$\chi_{c0} \to K^+K^-$	$5.82 \pm 0.36 \pm 0.94$	774 ± 38
$\chi_{c2} \to \pi^+\pi^-$	$1.52 \pm 0.15 \pm 0.24$	185 ± 16
$\chi_{c2} \to K^+K^-$	$0.81 \pm 0.14 \pm 0.14$	115 ± 13

Acknowledgement

We would like to thank the staffs of BEPC and the IHEP computer center for their excellent efforts.

References

[1] T.A.Armstrong et al., Phys.Rev.Lett. **68** (1992) 1468.

[2] J.E.Gaiser et al., Phys.Rev., **D34** (1986) 711.

[3] BES Collab., Nucl. Inst. Meth., **A344** (1994) 319.

[4] Particle Data Group, Phys.Rev., **D50** part I (1994) and references therein.

[5] BES Collab., High Ener. Phys. and nucl. Phys. (in Chinese), **20** (1996) 97.

[6] G.Karl, S.Meshkov and J.L.rosner, Phys.Rev., **D13** (1976) 1203;
W.Tanenbaum et al., Phys.Rev., **D17** (1978) 731;
M.Oreglia et al., Phys.Rev., **D25** (1982) 2259.

[7] P.K. Kabir and A.J.G. Hey, Phys.Rev., **D13** (1976) 3161.

[8] C.Z. Yuan, BES 96, the 5th BES Annual Meeting, 7-12 june 1996, Zhangjiajie, Hunan. pp294-300.

[9] W.Kwong, P.B.Mackenzie, R.Rosenfeld and J.L.Rosner, Phys.Rev., **D37** (1988) 3210.

[10] G.T.Bodwin, E.Braaten and G.P.Lepage, Phys.Rev., **D46** (1992) 1914.