Determination of $\mathcal{B}(\chi_{cJ} \to p\bar{p})$ —BES analysis memo

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Jan., 1996
Revised: Mar. 1998

Abstract

ψ' decays to $\gamma p\bar{p}$ final state was studied to get the branching fractions of $\chi_{cJ}(J = 0, 1, 2)$ going to $p\bar{p}$ with the ψ' data taken by BES at BEPC. Very clear χ_{c0}, χ_{c1} and χ_{c2} signals were seen and the branching fractions were determined to be $B(\chi_{c0} \to p\bar{p}) = (15.5 \pm 4.5 \pm 5.2) \times 10^{-5}$, $B(\chi_{c1} \to p\bar{p}) = (4.0 \pm 2.3 \pm 2.7) \times 10^{-5}$ and $B(\chi_{c2} \to p\bar{p}) = (11.5 \pm 4.4 \pm 6.4) \times 10^{-5}$, 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 in e^+e^- annihilation and the partial width of χ_{c1} and χ_{c2} decay to $p\bar{p}$ were measured by studying the charmonium states formed directly in proton-antiproton annihilation by R704 [1] and E760 [2], but the scan of χ_{c0} was not performed because of its small branching fraction of going to electromagnetic final states and its large total width. The decay of $\chi_{c0} \to p\bar{p}$ was forbidden by the massless helicity conservation law, the only measurement of its branching fraction is an upper limit given by DASP collaboration [3], $B(\chi_{c0} \to p\bar{p}) < 9.0 \times 10^{-4}$ at 90% confidence level.

Beijing Spectrometer (BES) running at Beijing Electron Positron Collider (BEPC) collected $3.7(1 \pm 0.10)$ million ψ''s in its 1993/94 and 1995 running. In this note we report a measurement of the branching fraction of $\chi_{cJ} \to p\bar{p}$ with these data.

The BES is a conventional cylindrical detector that is described in detail in Ref. [4]. 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 Event Selection

Events selection includes identification of good photon and good charged tracks.

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 four photon candidates are allowed in one event. The candidate has the largest SC energy is considered to be the photon radiated from ψ'.

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 some of the events with electron, the total energy of the two tracks in BSC is required to be less than 3GeV; 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 $Prob_p > 5\%$; do four constrained kinematic fit to $\psi' \to \gamma p\bar{p}$ to the two charged tracks and the gamma candidates with largest BSC energy, the χ^2 probability of the fit is required to be greater than 5%.

The most important background left in the data sample after previous selection is those events with $\mu\mu$ tracks, especially those from J/ψ decays. Due to the limited geometry coverage of the muon counter and the small signal to noise ratio in the mass region we interested in, only those events with two tracks satisfy $|\cos\theta_{MDC}| < 0.65$ and $Mustatus^+ + Mustatus^- < 4$ [5] are kept.

After above selection, the invariant mass of proton and anti-proton is shown in figure 2, clear χ_c signal can be seen in the plot. Tab. 1, Tab. 2 and Figure 1 show the events number and the invariant mass of proton and anti-proton distribution after each step of the cut.

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

	Real data	$\gamma p\bar{p}$ and $p\bar{p}$ Monte Carlo
Total events	5575465	27000
IJK .GT. 0	5393483	27000
NCHRG=2 & NCHRGX=0	4460634	23149
NNEU<9	4373313	23149
ISUB3>0	4373313	23149
ICHRG=+-1	4373313	23149
MFIT=2,-19,-9	4323459	23105
NET CHRG zero	3553217	22994
total SCE< 3.0	2826587	22994
NGamma<5	2718810	22994
Pass Kinematic Fit	100655	14449

Table 2: Events number after each cut (after pre-selection and $p\bar{p}$ mass between 3.2 and 3.6GeV).

	DT	χ_{c0} MC	χ_{c1} MC	χ_{c2} MC
Pre-selection	9838	2521	2718	2400
Prob4C $>$ 0.05	1326	2072	2288	2060
ProbID $>$ 0.05	497	1865	2054	1869
NGamma=1,2,3,4	497	1865	2054	1869
$\vert\cos\theta\vert < 0.65$	131	1356	1516	1380
Remove Muons	51	1356	1516	1380

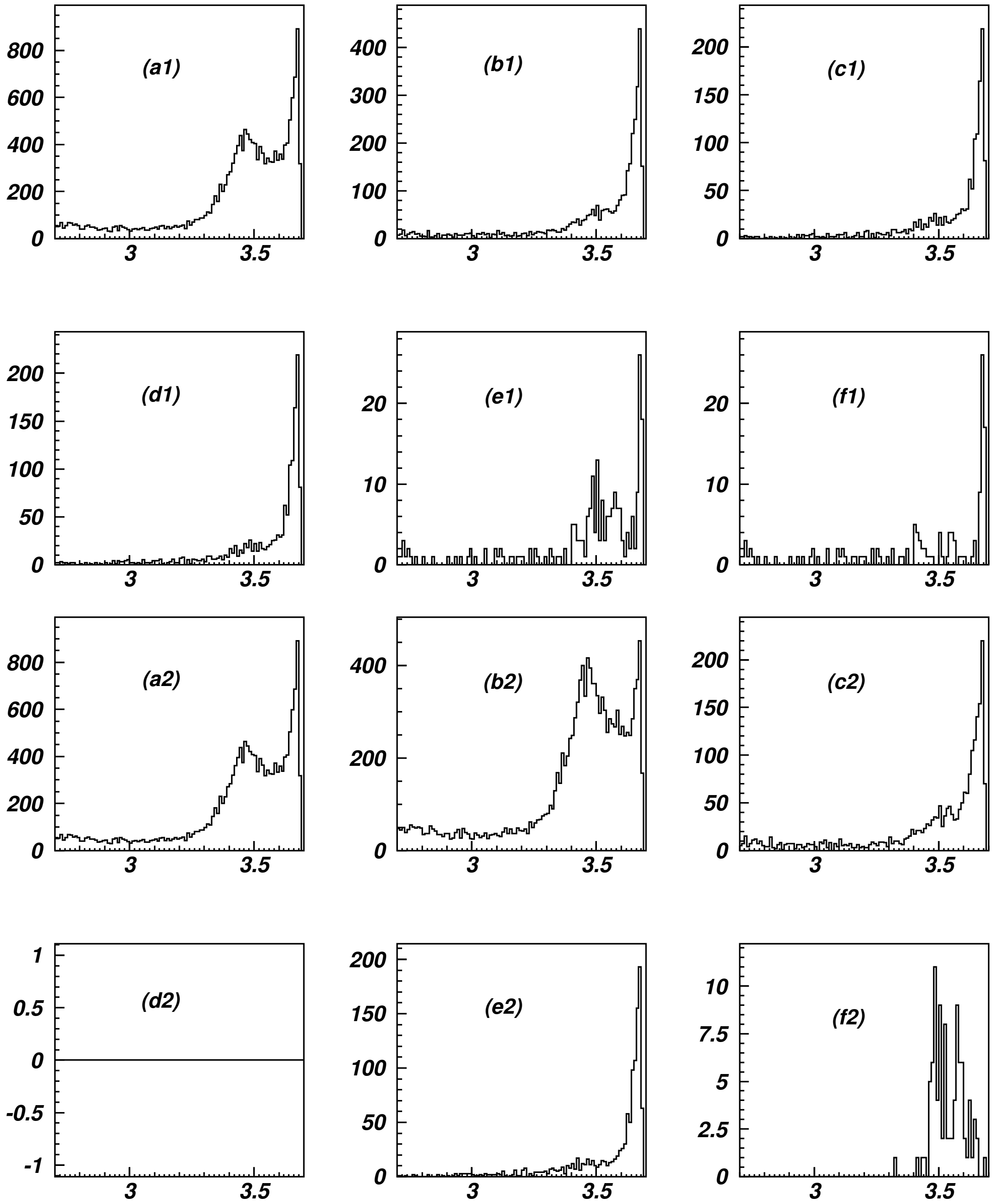


Figure 1: $p\bar{p}$ mass distribution after each cut, (a1,b1,c1,d1,e1,f1) events survived the cut, (a2,b2,c2,d2,e2,f2) events removed by the cut. a) after preselection, b) Prob4C cut, c) PartID, d) number of gamma cut, e) polar angle cut, g) remove muon.

3 Monte Carlo

The angular distribution of $\psi' \to \gamma X$ is simulated assuming pure E1 transition, namely $1+\cos^2\theta$, $1-\frac{1}{3}\cos^2\theta$ and $1+\frac{1}{13}\cos^2\theta$ for the spin of X resonance $J=0,1$ and 2 respectively, and X decays to $p\bar{p}$ are simulated according to phase space. 5000 events are simulated for each decay channel, after the same selection as for real data, the detection efficiencies of each channel are estimated to be $\varepsilon_{\chi_{c0}}=27.1\%$, $\varepsilon_{\chi_{c1}}=30.3\%$ and $\varepsilon_{\chi_{c2}}=27.6\%$, the mass resolution at χ_{c0}, χ_{c1} and χ_{c2} are 7.3, 6.8 and 6.7MeV respectively.

4 Fit the Mass Spectrum

The final selected events with $p\bar{p}$ mass between 3.2 and 3.6GeV are fitted with three Breit-Wigner resonances smeared by Gaussian like mass resolution function together with a first order polynomial background using unbinned maximum likelihood method. In the fit, the mass resolutions are fixed to the Monte Carlo values and the width of χ_{c0}, χ_{c1} and χ_{c2} are fixed to 14.3, 0.88 and 2.00MeV coming from BES experiment or PDG [3]. $14.5\pm4.2, 3.9\pm2.2$ and 9.2 ± 3.5 events are fitted out for χ_{c0}, χ_{c1} and χ_{c2} respectively, fitted results are shown in figure 2.

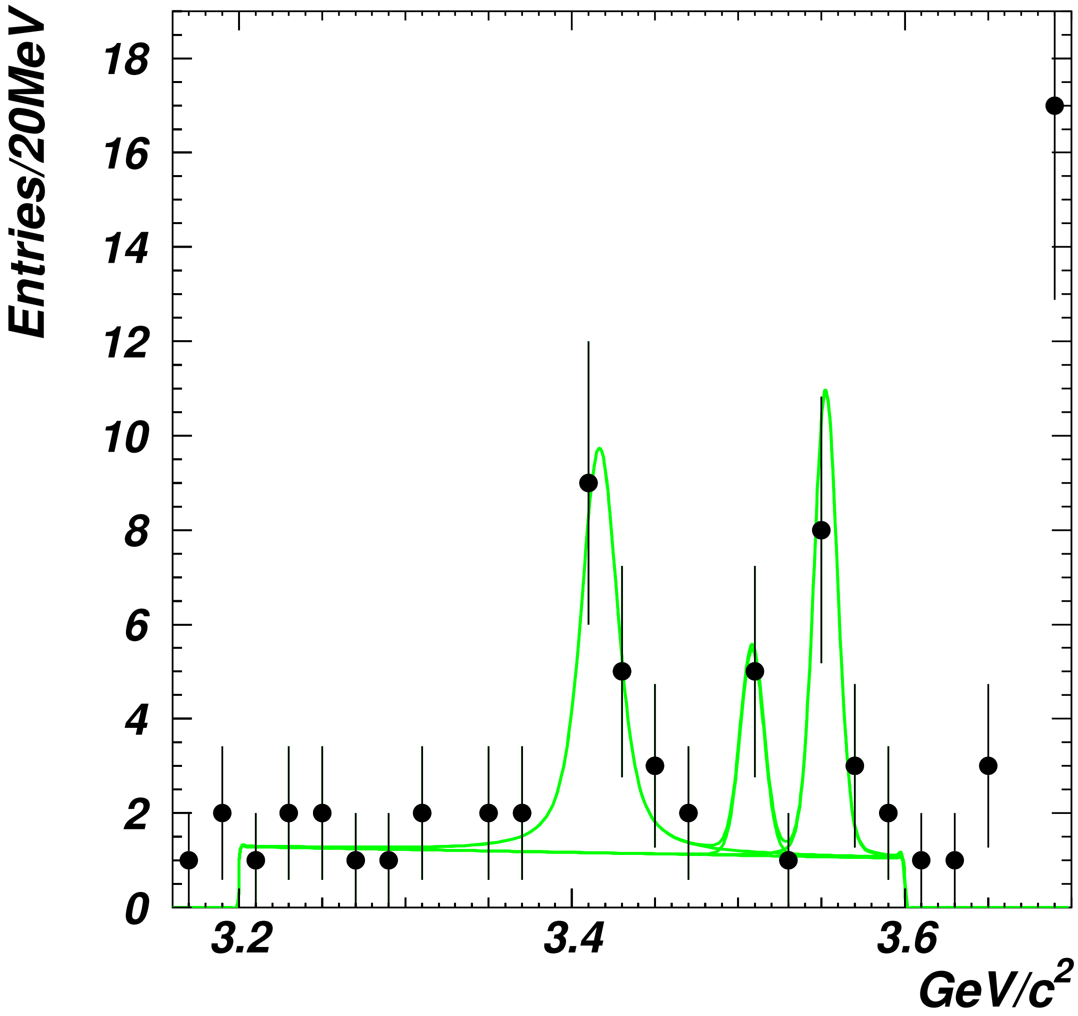
5 Conclusion and Discussion

Combining above analysis, the results are listed in table 3.

Table 3: Branching ratios of $\chi_{cJ} \to p\bar{p}$

	χ_{c0}	χ_{c1}	χ_{c2}
Events number	14.5 ± 4.2	3.9 ± 2.2	9.2 ± 3.5
Mass resolution(MeV)	7.3	6.8	6.7
Detection efficiency(%)	27.1	30.3	27.6
$\mathcal{B}(\chi_{cJ}\to p\bar{p})$ $(\times10^{-5})$	$15.5\pm4.5\pm5.2$	$4.0\pm2.3\pm2.7$	$11.5\pm4.4\pm6.4$
PDG results	<90	8.6 ± 1.2	10.0 ± 1.0

1. The first error in $Br(\chi_{cJ}\to p\bar{p})$ is statistical and the second one systematic. The latter includes those arise from varying cut (27.5%, 57.8% and 48.2%), uncertainties in mass resolution determination and χ_{cJ} width (5.7%, 20.8% and 9.5%), statistic error of Monte Carlo sample(2.3%, 2.1% and 2.3%), angular distribution assumption of the proton in χ_{cJ} system (0, 20% and 20%), the shape of the background (5.9%, 2.1% and 2.6%), the usage of kinematic fit to select events (10% for all), the branching fractions of ψ' going to $\gamma\chi_{cJ}$ (8.6%, 9.2% and 10.3%) and the uncertainty

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===============================================================================
I                          Summary Of BWFIT Results                            I
===============================================================================
Histogram ID= *****  UnBinned Breit-Wigner Fit using   51 Points
Fit Parameters:Npoly=   3 Nbw=   3 Namp=   0 Range=      3.200 To      3.600
Hist. Chisq =       10.79 for    7 params &  12 DF.
Chisquare Probability =  54.71%. Mean and S.D. for pulls:  -.0282     .7339
Likelihood ratio and probability              :  15.464        21.70%
Final Value of Log Likelihood                 : -62.15
Error Correspond to a Function Chage          :    .50
Phase Space limits for tails corrections      :    .280GEV     2.817GEV
Breit-Wigner efficiency correction factors    :    .977      .998      .992
Include Breit-Wigner tails outside fit region :   .003      .000      .000
Efficiency-corrected events in fit region     :  51.[average eff. :1.000]
---THE FITTED VALUES AND ERRORS OF THE PARAMETERS:---
   LEG_1Value : -.10494    Error(Cov,-/+):    .435      -.435       .412
   LEG_1Value :  .00000E+00Error(Cov,-/+):    .000E+00 -.800E-01  .856E-01
   AREA0Value :  .28499    Error(Cov,-/+):    .833E-01 -.417E-02  .427E-02
   RESL0Value :  .73224E-02Error(Cov,-/+):    .000E+00 -.388E-01  .491E-01
   GAMA0Value :  .14300E-01Error(Cov,-/+):    .000E+00 -.365E-02  .365E-02
   MASS0Value :  3.4166    Error(Cov,-/+):    .418E-02 -.652E-01  .721E-01
   AREA1Value :  .76877E-01Error(Cov,-/+):    .439E-01 -.395E-02  .407E-02
   RESL1Value :  .68172E-02Error(Cov,-/+):    .000E+00 -.412E-02  .419E-02
   GAMA1Value :  .88000E-03Error(Cov,-/+):    .000E+00  .000E+00  .000E+00
   MASS1Value :  3.5083    Error(Cov,-/+):    .360E-02  .000E+00  .000E+00
   AREA2Value :  .18086    Error(Cov,-/+):    .689E-01  .000E+00  .000E+00
   RESL2Value :  .66955E-02Error(Cov,-/+):    .000E+00  .000E+00  .000E+00
   GAMA2Value :  .20000E-02Error(Cov,-/+):    .000E+00  .000E+00  .000E+00
   MASS2Value :  3.5525    Error(Cov,-/+):    .386E-02  .000E+00  .000E+00
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Figure 2: Fit result of $p\bar{p}$ invariant mass of $\gamma p\bar{p}$ events.

of ψ' events number (10% for all), add all these errors in quadrature, the total percentage errors are 33.2%, 66.8% and 56.0% for χ_{c0}, χ_{c1} and χ_{c2} respectively.

2. The branching fractions of $\chi_{c1} \to p\bar{p}$ and $\chi_{c2} \to p\bar{p}$ are in agreement with the values listed by PDG [3], which are got from $p\bar{p}$ annihilation experiment with small error.

3. $B(\chi_{c0} \to p\bar{p})$ is the first measurement in the world, which is consistent with the upper limit of PDG [3]. This result will be helpful for $p\bar{p}$ annihilation experiment to determine the time schedule of their χ_{c0} scan.

4. Backgrounds from $\psi' \to \pi^0 p\bar{p} \to \gamma\gamma p\bar{p}$ are negligible according to Monte Carlo study.

Acknowledgment

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

References

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