Measurements of branching ratio and angular distribution of $\chi_{cJ} \to p\bar{p}$

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Outline

- ◆Motivation
- ◆Data sample
- ◆Measurement of branching ratio of $\chi_{cJ} \to p\bar{p}$
  - Event selection
  - Background estimation
  - Fit
- ◆Systematic uncertainties of branching ratio
- ◆Measurement of angular distribution of $\chi_{cJ} \to p\bar{p}$
- ◆Systematic uncertainties of angular distribution
- ◆Summary

Motivation

- In theory, the process of $\boldsymbol{\chi_{c0} \to p\bar{p}}$ obeys *helicity selection rule*[1]*, but we observed the larger branching ratio.*
- *The* experimental measurements of the branching ratio are much higher than the predictions by Color Singlet Model (CSM), but it seems to be explained well by Color Octet Mechanism (COM). More accurate experimental measurements will help us in understanding the decay mechanism.
- BESIII has collected 448.1 M ψ(2S) events . With the largest ψ(2S) data sample, we can give more precise results.

	CSM	COM	PDG	BSEIII（09）[3]
$B(\chi_{c1} \to p\bar{p})$ （10^{-5}）	0.29	6.4	7.72±0.35	8.6±0.5±0.5
$B(\chi_{c2} \to p\bar{p})$ （10^{-5}）	0.84	7.7	7.50±0.40	8.4±0.5±0.5

	α（$\chi_{c0} \to p\bar{p}$）	α（$\chi_{c1} \to p\bar{p}$）	α（$\chi_{c2} \to p\bar{p}$）
BSEIII（09）[3]	0.09±0.11(stat.)	0.12±0.20(stat.)	-0.26±0.17(stat.)

[1] PRD 24,2848(1981)

[2] PRD 51 ,1125(1995)

[3] PRD 88.112001(2013)

Data Samples

◆ Data

- ✓ 09 data 156 pb-1 @ 3.686 GeV（107.0M）
- ✓ 12 data 500 pb-1 @ 3.686 GeV（341.1M）
- ✓ 09+13 44 pb-1 @ 3.650 GeV (For continuum background)

◆ Inclusive MC

- ✓ 09 inclusive mc @ 3.686 GeV（106M）
- ✓ 12 inclusive mc @ 3.686 GeV（400M）

◆ Exclusive MC

process	*generation model*
$\psi' \to r\chi_{cJ}(J=0,1,2)$(200k)	PjGCO,1,2
$\chi_{cJ}(J=0,1,2) \to p\bar{p}$(200k)	AngSam

◆ Software

- ✓ BOSS software 6.6.4.p03
- ✓ Monte Carlo events were generated with KKMC +BesEvtGen

Event selection

- **Tracking**

  $|V_r| < 1\text{cm}, |V_z| < 10\text{cm}$

  |cosθ|<0.93

  NCharge=2

  Total charge=0

- **Official requirements for photon**

  $E_r^{endcup} \geq 50\text{Mev}(0.86 < |\cos| < 0.92)$

  $E_r^{barrel} \geq 25\text{Mev}(|\cos| < 0.80)$

  m_gammaAngleCut>20,

  ngamma>=1

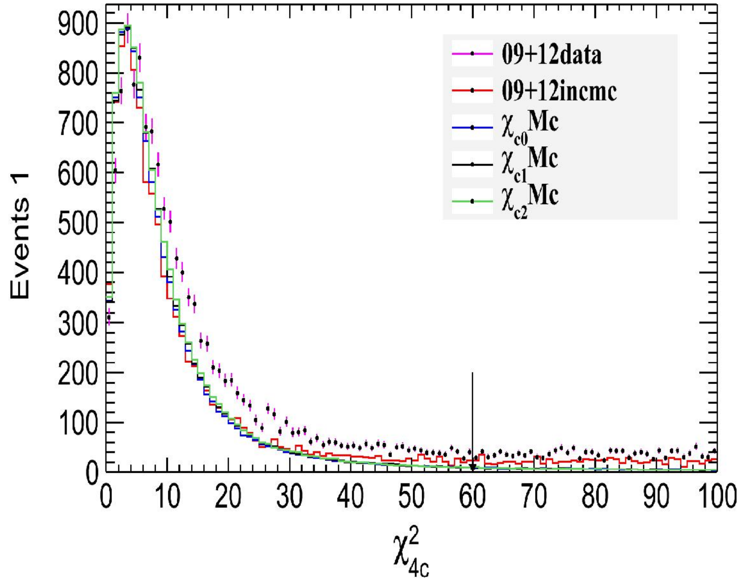
  TOF（0~14）

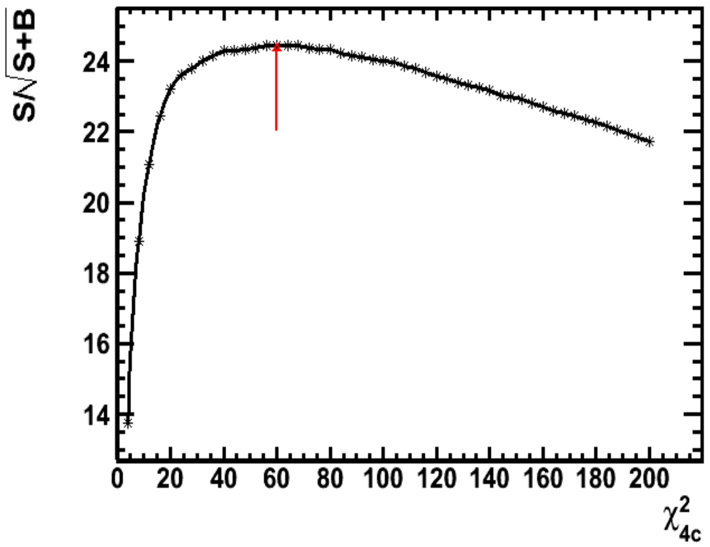
- **PID(use dE/dx and TOF)**

  P(p)>0.001 and P(p)>P(k) and P(p)>P(π) for p,

  Change>0 for p, change<0 for $\bar{p}$

The χ^2_{4c} of kinematic fit optimization

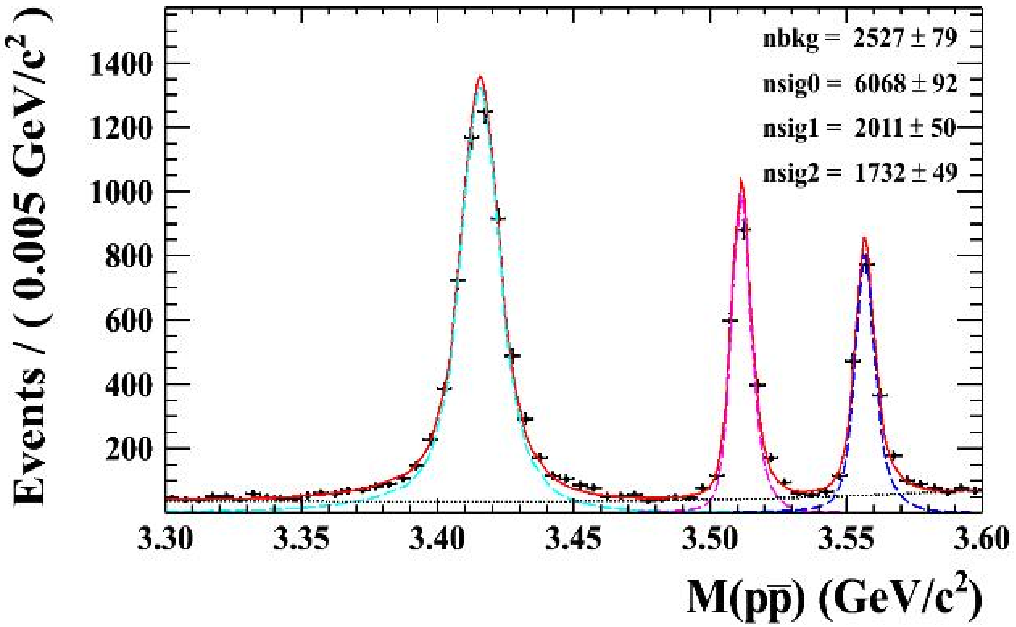




Finally, a four-constraint (4C) kinematic fits are performed to improve resolution and help to suppress background. The left plot shows the distribution of χ^2_{4c}.

The right plot shows the χ^2_{4c} distribution of 4-C fit optimized based on the figure-of-merit(FOM) defined as S$\sqrt{S+B}$. The background(B) and signal(S) are obtained from the inclusive MC simulation. So the $\chi^2_{4\mathrm{c}}$ is determined to be less than 60. The point with error bars are data, the red line denotes inclusive mc, the blue line denotes signal mc of χ_{c0}, the black dotted line denotes signal mc of $\chi_{c1,}$ the green line denotes signal mc of $\chi_{c2,}$

Check the algorithm

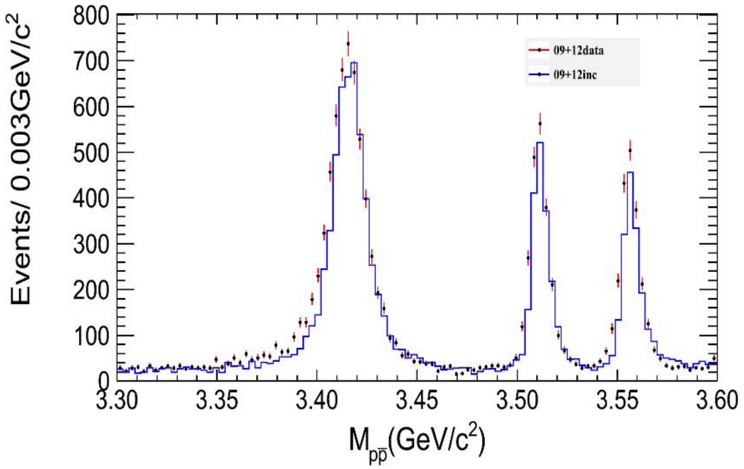


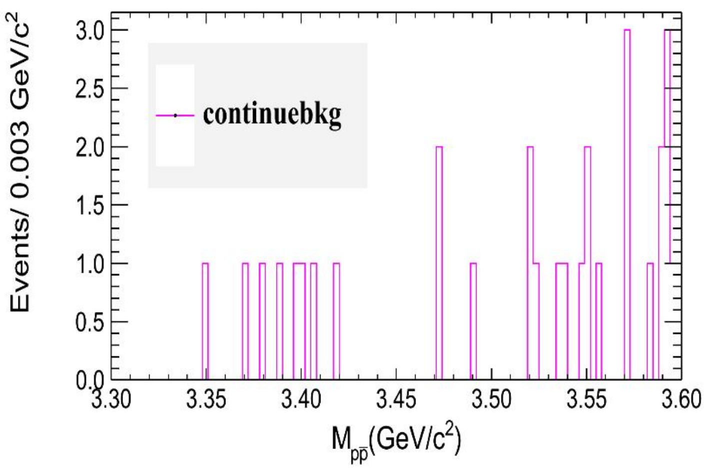
Channel	N（fit）	N(inclusive mc)
$\chi_{c0} \to p\bar{p}$	6068±92	6092
$\chi_{c1} \to p\bar{p}$	2011±50	2031
$\chi_{c2} \to p\bar{p}$	1732±49	1796

Background Study

Main Backgrounds：

1. $\psi' \to \gamma p\bar{p}$
2. $\psi' \to p\bar{p}\gamma_{FSR}$
3. $\psi' \to \pi^0 p\bar{p}$
4. Continuum background





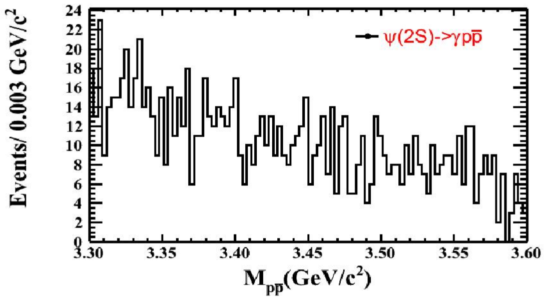
The left plot shows the distribution of M($p\bar{p}$) compared with data and MC in the $\chi_{cJ}(J=0,1,2)$ mass range from 3.30GeV to 3.60GeV.

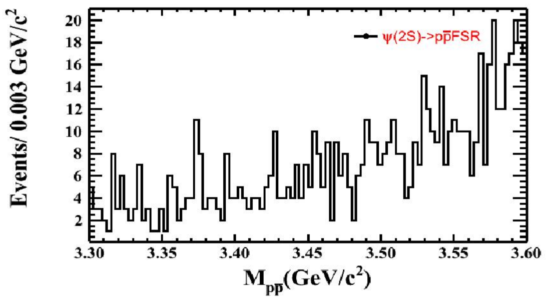
We use the data taken at the energy point 3.65GeV to estimate the contribution from continuum background and the right plot shows the invariant mass spectrum after shifting and scaling. The scale factor is:

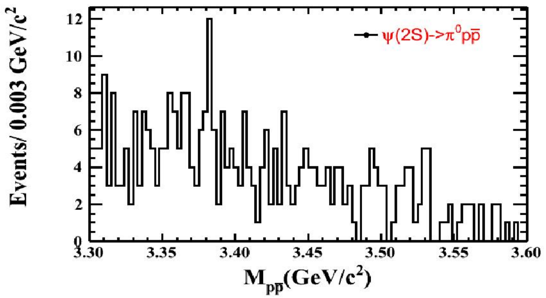
$$f_{continuum} = \frac{156.4pb^{-1}+500pb^{-1}}{44pb^{-1}} * \left(\frac{3.65Gev}{3.686\ Gev}\right)^2 = 12.1$$

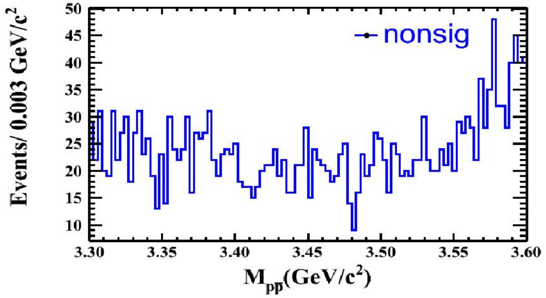
Considering the energy difference, we shift the mass according to the operation, m->$\frac{(3.686-m_0)}{(3.65-m_0)}$(m-$m_0$)+$m_0$

Background Study









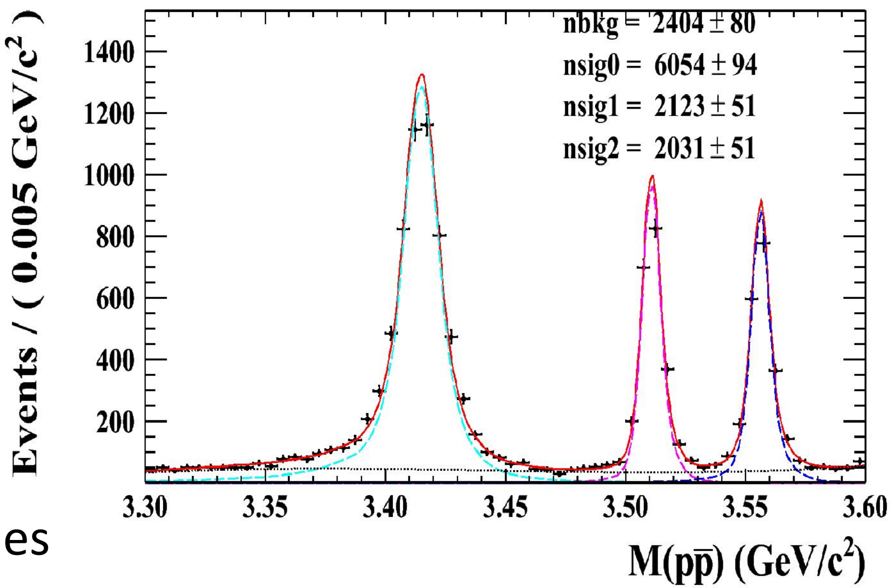
The black histograms show the backgrounds from inclusive MC, respectively. The blue histogram shows all backgrounds from inclusive MC after the signals are removed. The number of backgrounds from inclusive MC after all event selections is less than the number of signals. All of these backgrounds in the signal region are smooth. they can not contribute peaking in M($p\bar{p}$) signal region, they are not affect the estimate of the signal. These background shapes can be described using third order chebyshev polynomials.

Fitting

The line-shape of χ_{cJ}:

$(E_\gamma^3 \times \text{Mcshape} \times fdamp(E\gamma)) \otimes Gaussian(\delta m, \sigma)$

These background shapes : using third order chebyshev



Considering the resolution of the detector , we use Mcshape to describ the sigle .And modified by a factor E_γ^3($E\gamma$:the energy of the transition photon), but leads to a diverging tail at lower energies

To damp the E_γ^3,an additional factor of $f_{damp} = \exp(-\frac{E_r^2}{8\beta^2})$ $\beta = 0.273\text{GeV}$ is added (which is used by CLEO_c, it is a empirical equation)

The chi2/ndf : 1.47

The gauss represent the possible difference in the invariant mass resolution between data and mc

Parameters of smearing Gaussian for χ_{cJ} are float.

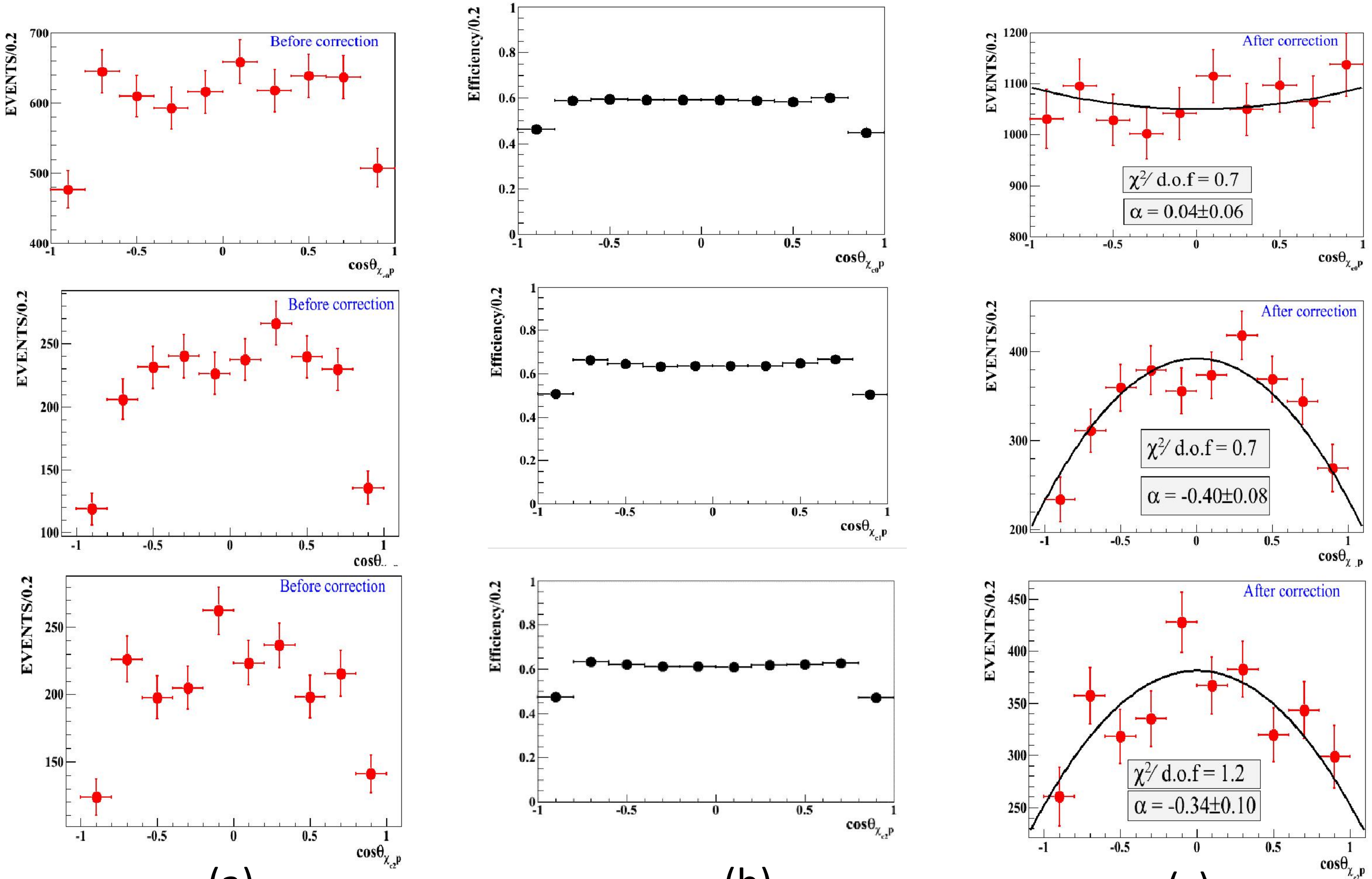
	ϵ (%)	N	B ($\chi_{cJ} \to p\bar{p}$) (10^{-5})
χ_{c0}	56.21	6054±94	24.21±0.38±1.06
χ_{c1}	62.41	2123±51	8.02±0.19±0.41
χ_{c2}	59.68	2031±51	8.35±0.21±0.41

Augular distribution

$\chi_{c0} \to p\bar{p}$

$\chi_{c1} \to p\bar{p}$

$\chi_{c2} \to p\bar{p}$



(a) (b) (c)

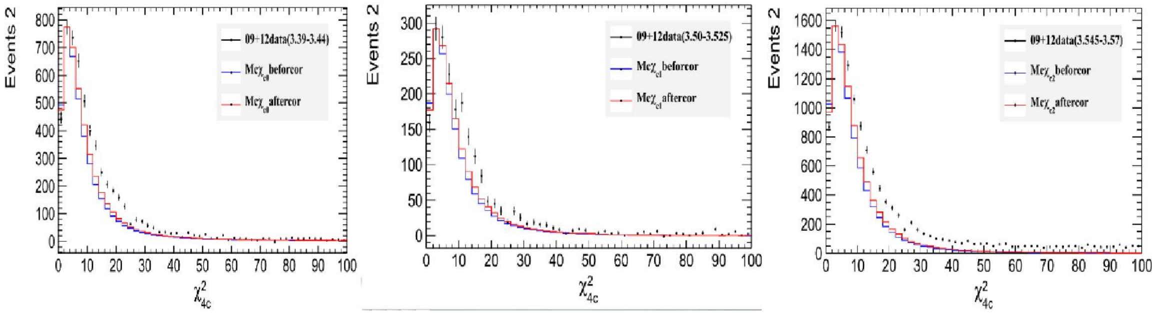
cosθ distribution observed in data (a), efficiency correction curve (b), cosθ distribution after efficiency correction, the formula $1+\alpha cos^2\theta$ is used to describe these distribution The α values are put in the MC simulation to extract the corresponding efficiencies (56.21%, 62.41%, 59.68%).(c).

Systematic uncertainty for branching ratio

- Source of efficiency
  - Tracking efficiency
  - Photon detection
  - Particle ID
  - Kinematic fit
- Source of fitting
  - Damping factor
  - Fitting region
  - Background
- Augular distribution
- Total number of ψ'
- $B(\psi' \to \gamma\chi_{cJ})$

Systematic uncertainty for branching ratio

- **Kinematic fit**
  - •Correct the helix parameters of tracks in MC simulation.
  - •Take the difference of before and after the correction as systematic uncertainty.

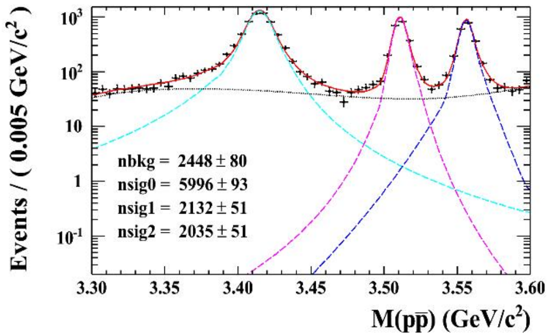


- Tracking (1% per track)
- Photon (1% per photon)
- Particle ID(1% per track)

- $B(\psi' \to \gamma\chi_{cJ})$
  - The systematic uncertainty of the branching fraction is quoted from PDG.
- Background shape
  - Chebyshev three term equation to take the place of polynomial two term equation to get the systematic uncertainty
- Fit range
  - Varying the limit of the fit range by $\pm$2MeV/c 2 to get the systematic uncertainty.
- Total number of ψ'
  - Chinese Phys. C 42 023001

Systematic uncertainty for branching ratio

- Damping factor: another damping factor used by KEDR

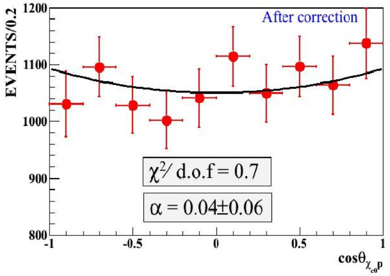


- The line-shape of χcJ:

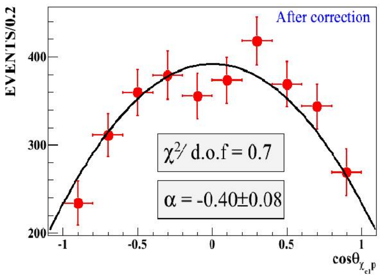
$$(E_\gamma^3 \times \mathrm{Mcshape} \times fdamp(E\gamma)) \otimes Gaussian(\delta m, \sigma)$$

$$\mathrm{f_{damp}} = \frac{\mathrm{E_0^2}}{\mathrm{E_r E_0} + (\mathrm{E_r} - \mathrm{E_0})^2}$$

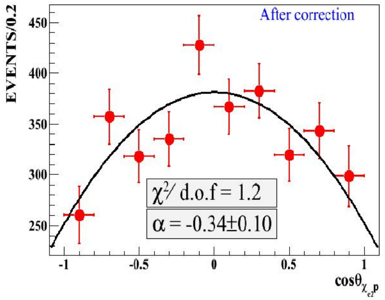
- generator model
  - Measurement the angular distribution of proton in χ_{cJ} center-of-mass system in data obtain the α value.
  - The α value is varied in 1δ and the difference is taken as the systematic uncertainty due to the generator model.
  - For χ_{cJ}, the corresponding errors are 0.2%, 0.4%, 0.4%,respectively.



$\chi_{c0} \to p\bar{p}$



$\chi_{c1} \to p\bar{p}$



$\chi_{c2} \to p\bar{p}$

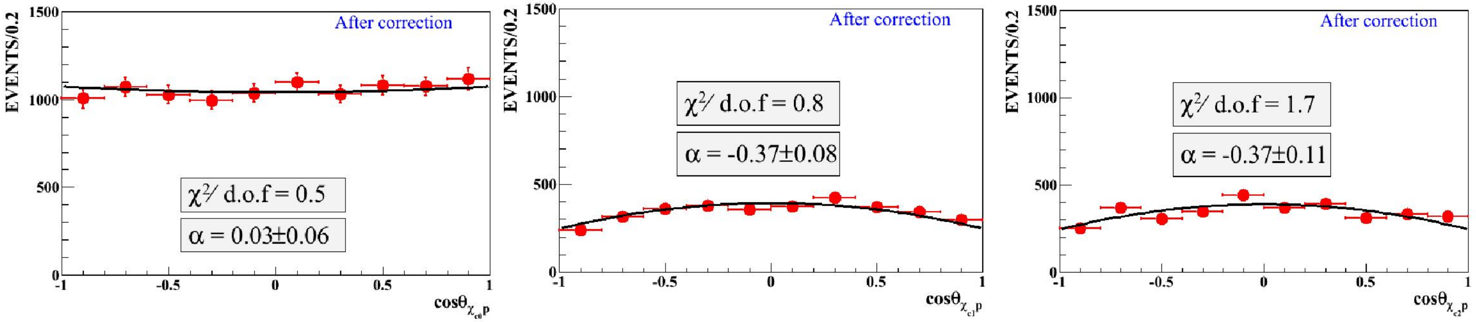
Total systematic uncertainty （%）

	χ_{c0}	χ_{c1}	χ_{c2}
Tracking	2.0	2.0	2.0
Photon detection	1.0	1.0	1.0
PID	2.0	2.0	2.0
Kinematic fit	0.1	0.1	0.1
Damping factor	0.9	0.4	0.2
Fitting region	0.3	0.2	0.6
Background	0.9	2.3	1.5
Augular distribution	0.2	0.4	0.4
Total number of ψ'	0.7	0.7	0.7
B$(\psi' \to \gamma\chi_{cJ})$	2.7	3.2	3.4
Total	4.4	5.1	4.9

Systematic uncertainties for angular distribution

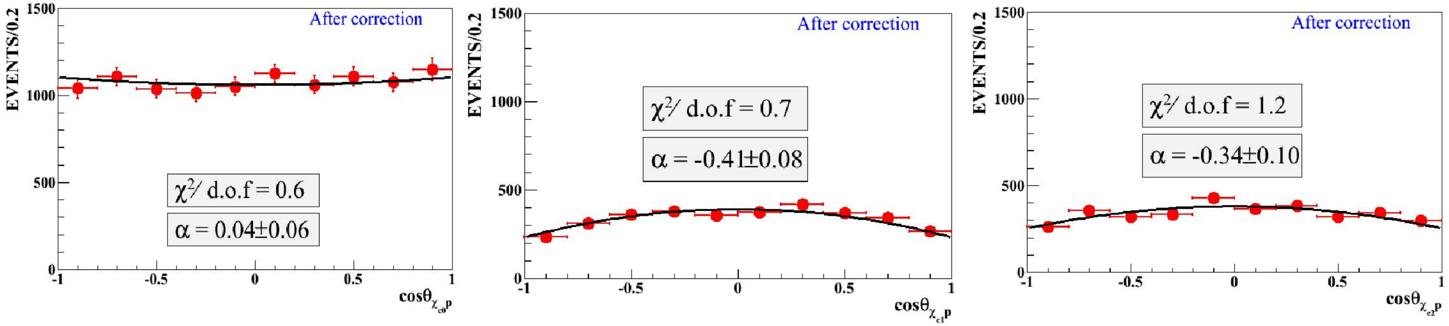
$\chi_{c0} \rightarrow p\bar{p}$ $\chi_{c1} \rightarrow p\bar{p}$ $\chi_{c2} \rightarrow p\bar{p}$

- Background shape



Chebyshev three term equation is taked place of polynomial two term equation to get the systematic uncertainty

- Fit range

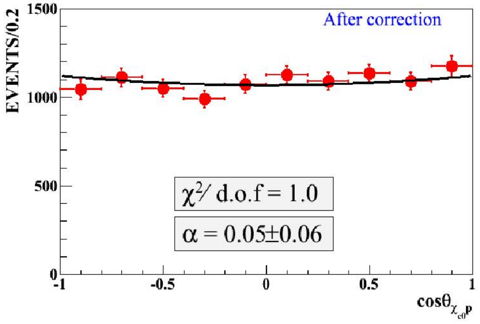


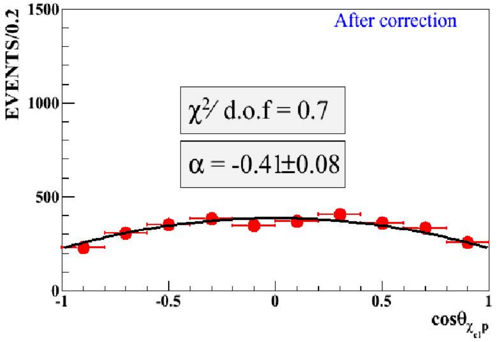
Varying the limit of the fit range by $\pm 2\text{MeV}/c^2$ to get the systematic uncertainty

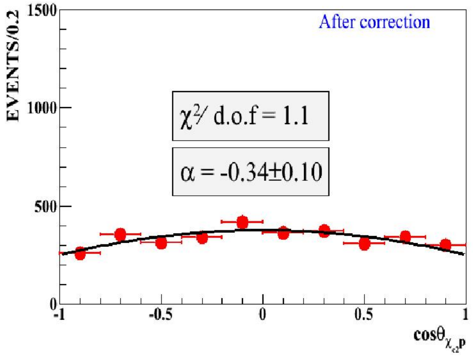
Systematic uncertainties for angular distribution

- Damping factor

(another damping factor used by KEDR)

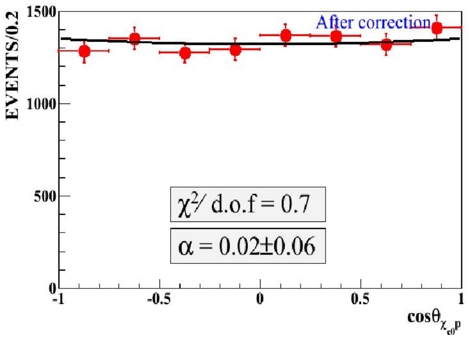


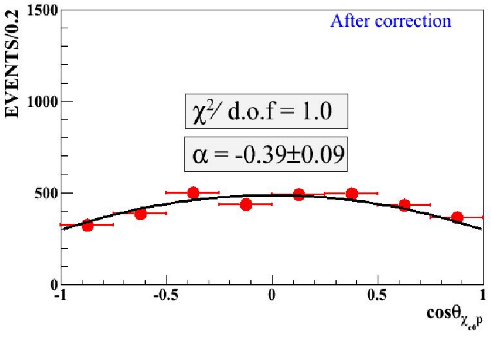


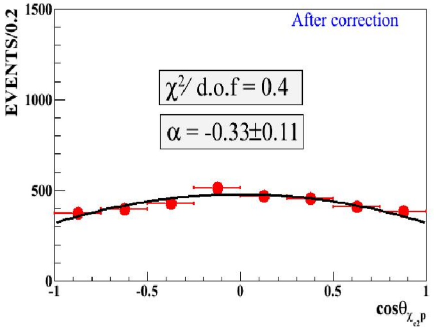


- The bin numbers of $\cos\theta$

(The number varies from 10 to 8)







The numerical uncertainties are shown below

Notes: the uncertainties are absolute!

	χ_{c0}	χ_{c1}	χ_{c2}
Damping factor	0.01	0.01	0.01
Background shape	0.02	0.01	0.01
Fit range	0.01	0.03	0.03
Bin number	0.01	0.01	0.01
sum	0.03	0.04	0.04

Summary

Using a data sample of 448.1 M ψ' event with the BESIII detector in2009 and 2012, we measure the branching ratio and angular distribution of $\chi_{cJ} \to p\bar{p}$.which are listed in the following table.

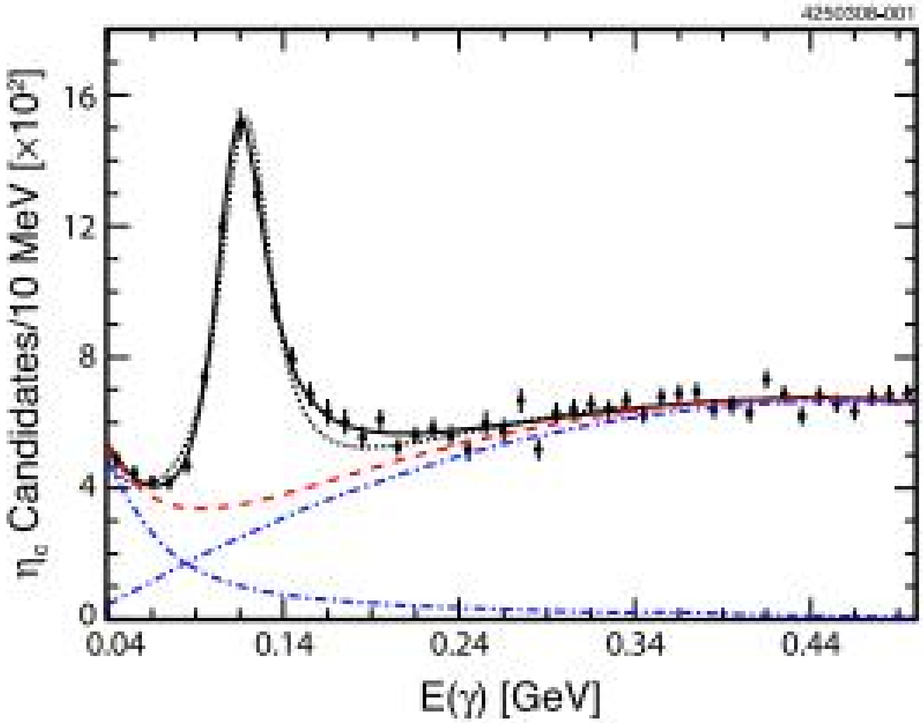
BESIII (09+12)	**ε (%)**	**Signal number**	**B $(\chi_{cJ} \to p\bar{p})$ (10^{-5})**	**BESIII (09)**	**ε (%)**	**Signal number**	**B$(\chi_{cJ} \to p\bar{p})$ (10^{-5})**	**PDG (10^{-5})**
χ_{c0}	56.21	6054$\pm$94	24.21$\pm$0.38$\pm$1.06	χ_{c0}	48.5	1222$\pm$39	24.5$\pm$0.8$\pm$1.3	22.5$\pm$0.9
χ_{c1}	62.41	2123$\pm$51	8.02$\pm$0.19$\pm$0.41	χ_{c1}	53.8	453$\pm$23	8.6$\pm$0.5$\pm$0.5	7.72$\pm$0.35
χ_{c2}	59.68	2031$\pm$51	8.35$\pm$0.21$\pm$0.41	χ_{c2}	52.0	405$\pm$21	8.4$\pm$0.5$\pm$0.5	7.5$\pm$0.4

	α $(\chi_{c0} \to p\bar{p})$	**α $(\chi_{c1} \to p\bar{p})$**	**α $(\chi_{c2} \to p\bar{p})$**
BSEIII（09）	0.09$\pm$0.11(stat.)	0.12$\pm$0.20(stat.)	-0.26$\pm$0.17(stat.)
BSEIII（09+12）	0.04$\pm$0.06$\pm$0.03	$-$0.40$\pm$0.08$\pm$0.04	$-$0.34$\pm$0.10$\pm$0.04

Thank you!

Source of fitting formula

Back up



PhysRevLett. 102. 011801

Fits to the resulting photon-energy spectrum

A fit using a relativistic Breit-Wigner distribution modified by a factor of E_γ^3 improves the fit around the peak but leads to a diverging tail at higher energies . To damp the E_γ^3 , an additional factor of $\exp(-\frac{E_r^2}{8\beta^2})$ $\beta = 0.273\mathrm{GeV}$ is added.