Observation of $\chi_{CJ} \to K_S^0 K_S^0 K_S^0 K_S^0$

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Outline

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2. Data sample
3. Event selection
4. Branching fraction
5. Summary

Motivation

Theoretical work indicates that the color octet mechanism could have large contributions to the decays of the P-wave charmonium states.

However, Many theoretical calculations and experimental measurements still have large errors. more precise experimental data besides more theoretical efforts are mandatory to further understand χ_{CJ} decay dynamics.

Thus, the measurement of as many exclusive hadronic χ_{CJ} decay as possible is valuable.

First observations of $\chi_{CJ} \to K_S^0 K_S^0 K_S^0 K_S^0$

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Data Sample

1. DATA : 447.9M Ψ(3686) (106.8M(2009) + 341.1M(2012))

2. Inclusive MC : 506M Ψ(3686) (106M(2009) + 400M (2012))

$\psi(3686) \rightarrow anything$

3. Exclusive MC : (P2GC0/P2GC1/P2GC2 PHSP)

100K for J = 0,1,2 $\psi(3686) \rightarrow \gamma\chi_{CJ} \rightarrow \gamma K_S^0 K_S^0 K_S^0 K_S^0$

1000K for $\psi(3686) \rightarrow K^{*bar} K_S f_0(1710)$

1000K for $\psi(3686) \rightarrow K^{*bar} K_S f_2^{'}$

Boss Version: 6.6.4

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Event selection

Charged track selection :

1. $|\cos\theta| < 0.93$
2. Momentum cut : $P < 2.0$Gev
3. Charge cut : $|Q| = 1$; $Sum(Q) = 0$
4. nGood = 8

K_S^0 **reconstruction** :

1. Second vertex fit applied
2. DecayLength/DecayLengthError > 2
3. $|M_{\pi\pi} - 0.4976| < 0.012$GeV
4. $nK_S^0 = 4$

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Event selection

Good photon :

1. The timing information of the EMC should be within $0 \leqslant t \leqslant 14$ (in the unit of 50 ns).

2. The deposited energy should be larger than 25 MeV in the endcap $|\cos\theta| < 0.8$ and larger than 50 MeV in the barrel ($0.86 < |\cos\theta| < 0.92$);

3. The angle between the photon and the nearest charged track must be larger than 20 to distinguish the shower from charged particles

KinematicFit

If more than one combination survived in one event, the one with the smallest χ^2 is retained.

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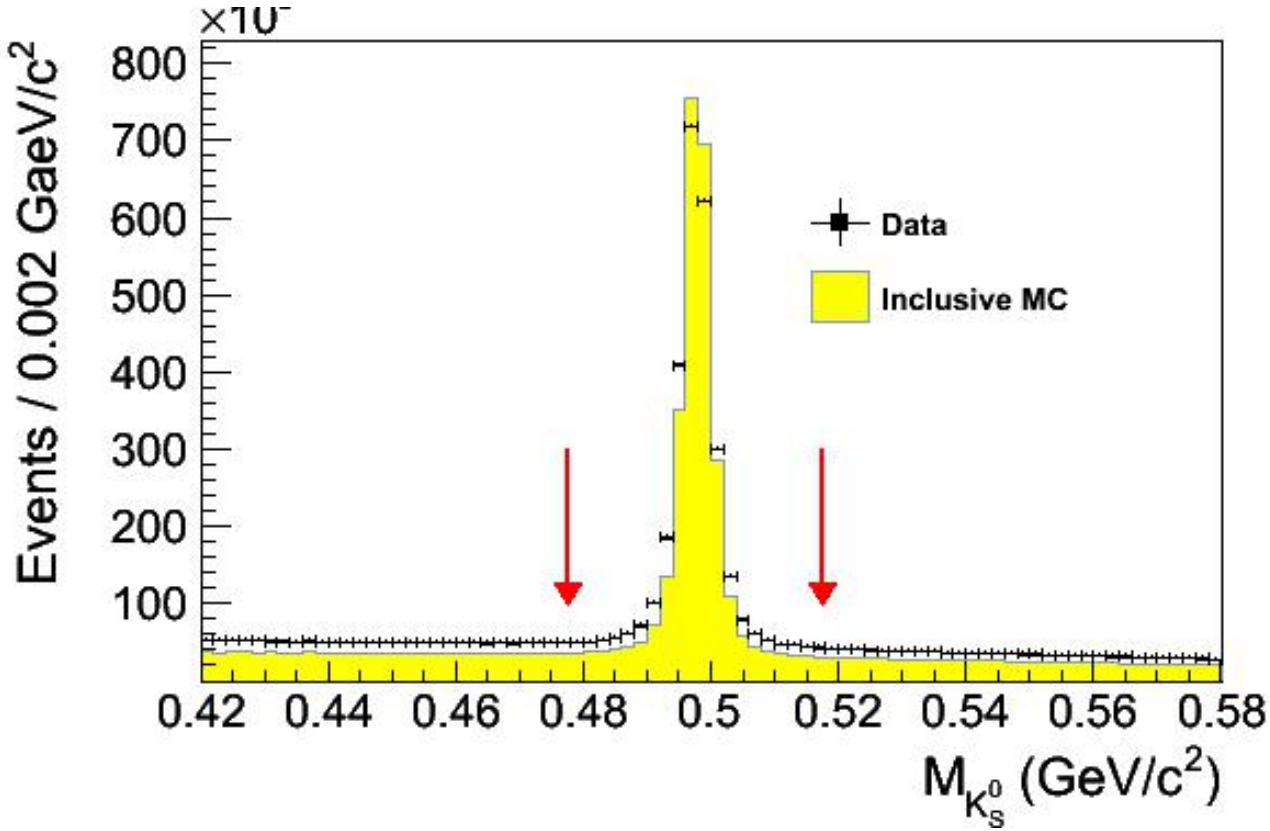
K_S^0 reconstruction



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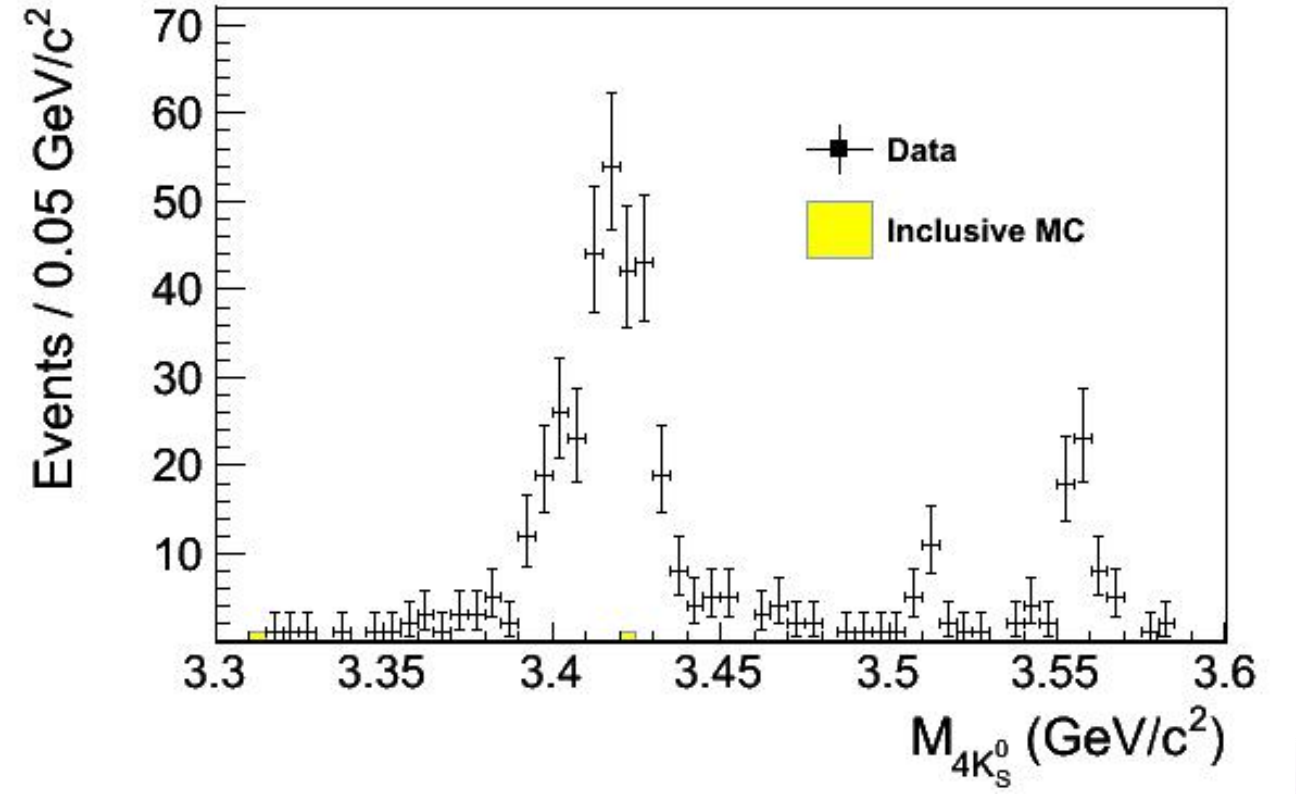
χ_{cJ} candidates after event selection



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Backgrounds

No.	Decay Chain	Final states	nEvt
0	$\varphi' \to \bar{K}^* K_S f_2', \bar{K}^* \to \pi^0 K_S$ $f_2' \to K_S K_S, K_S \to \pi^+\pi^-$	$\varphi' \to \pi^+\pi^+\pi^+\pi^+\pi^0\pi^-\pi^-\pi^-\pi^-$	1
1	$\varphi' \to \bar{K}^* K_S f_0(1710), \bar{K}^* \to \pi^0 K_S$ $f_0(1710) \to K_S K_S, K_S \to \pi^+\pi^-$	$\varphi' \to \pi^+\pi^+\pi^+\pi^+\pi^0\pi^-\pi^-\pi^-\pi^-$	1
Total: 2			Total: 2

Table1: topological analysis for Inclusive MC

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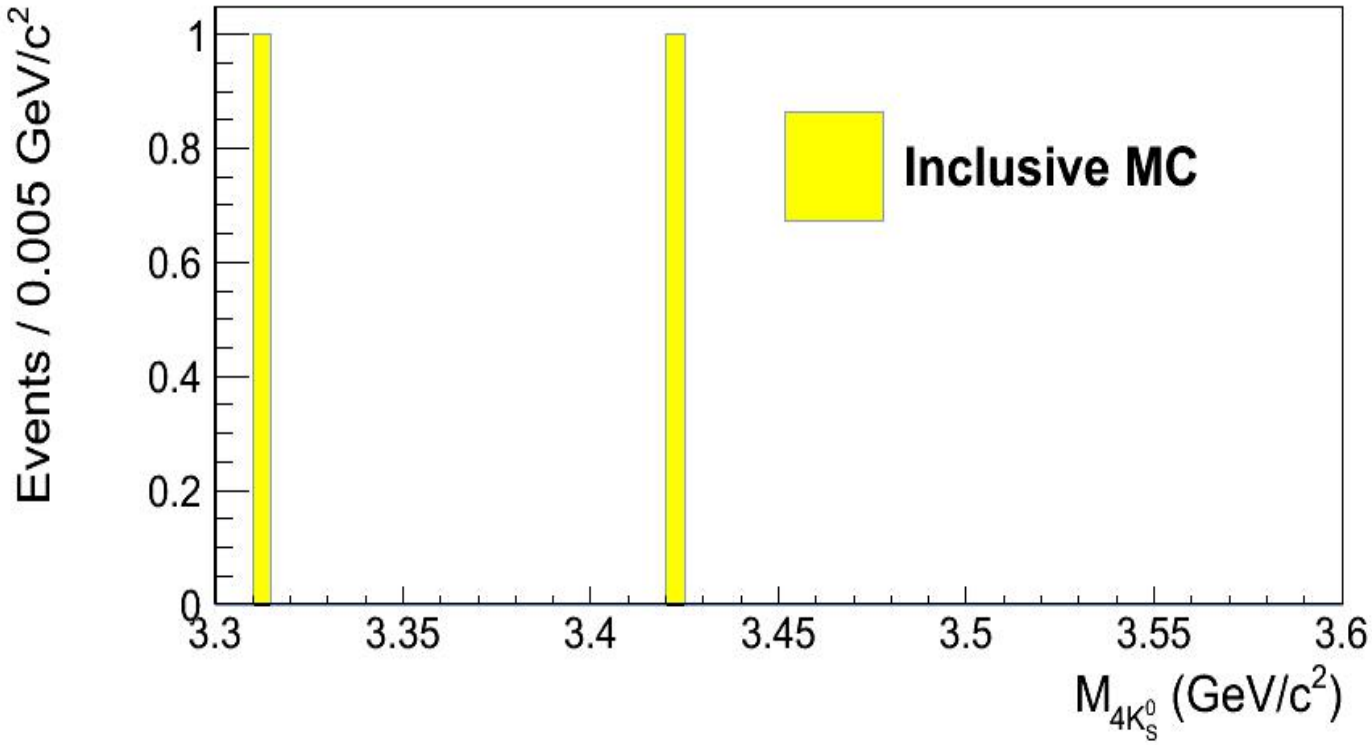
Backgrounds



Distribution of invariant mass of backgrounds

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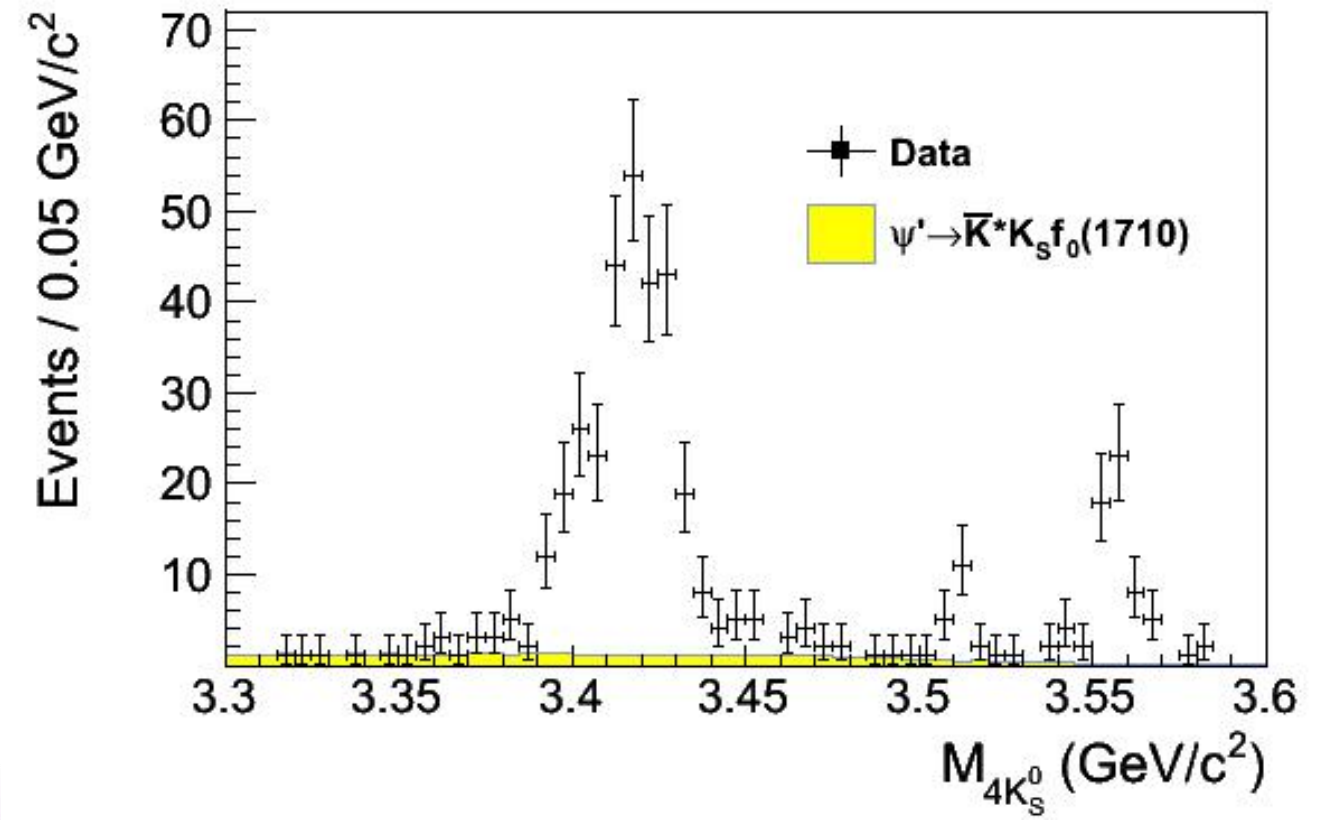
Backgrounds



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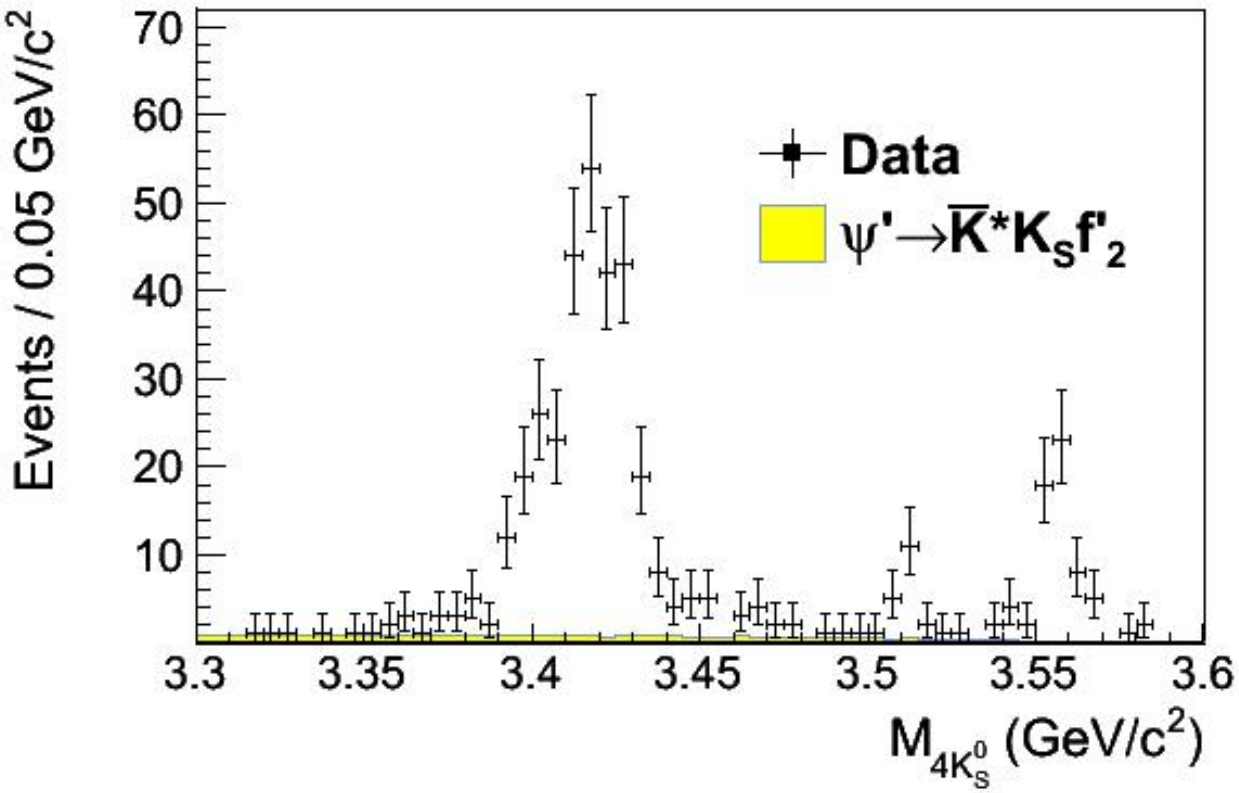
Backgrounds



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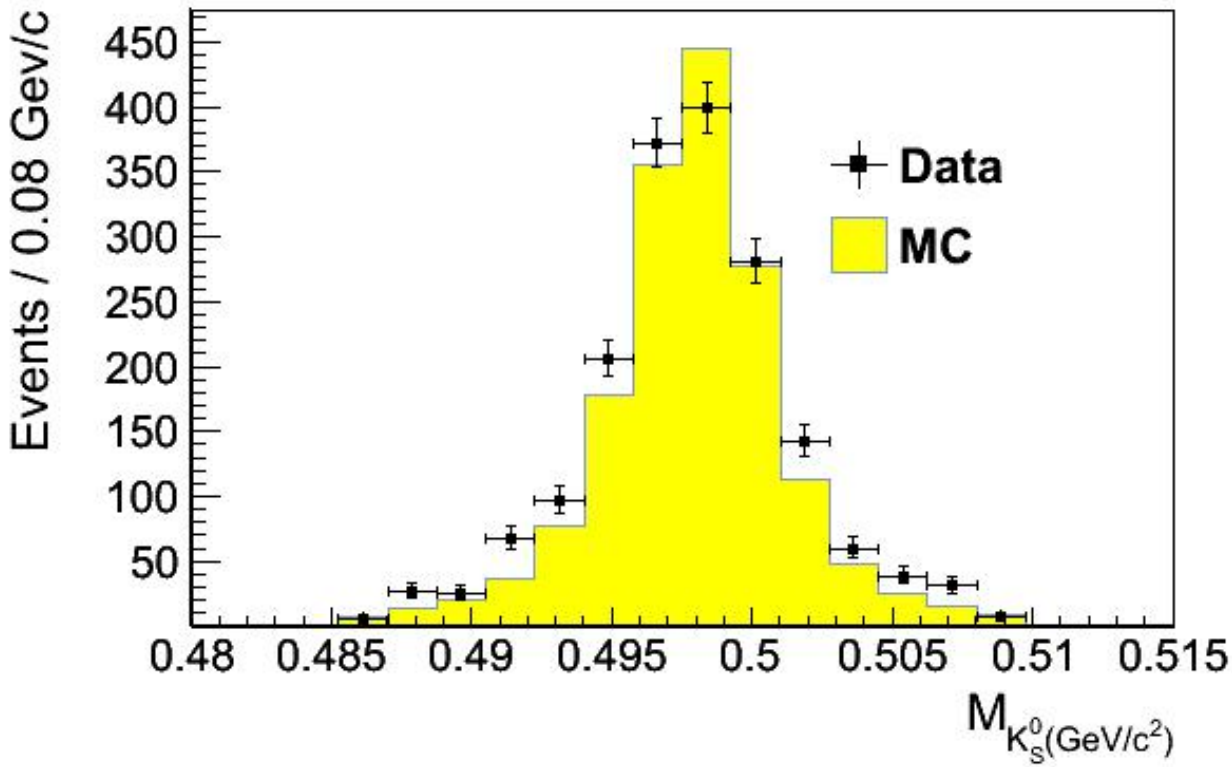
Comparison of $M_{\pi^+\pi^-}$



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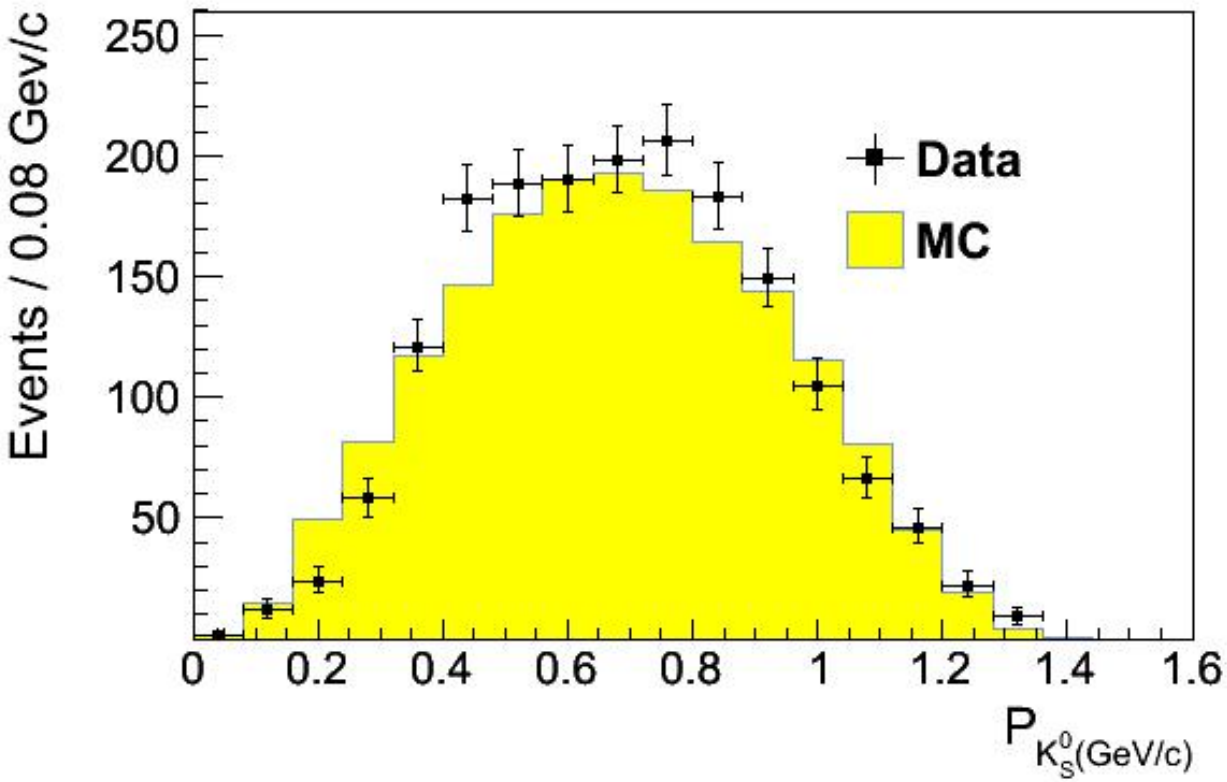
Comparison of K_S^0 momentum



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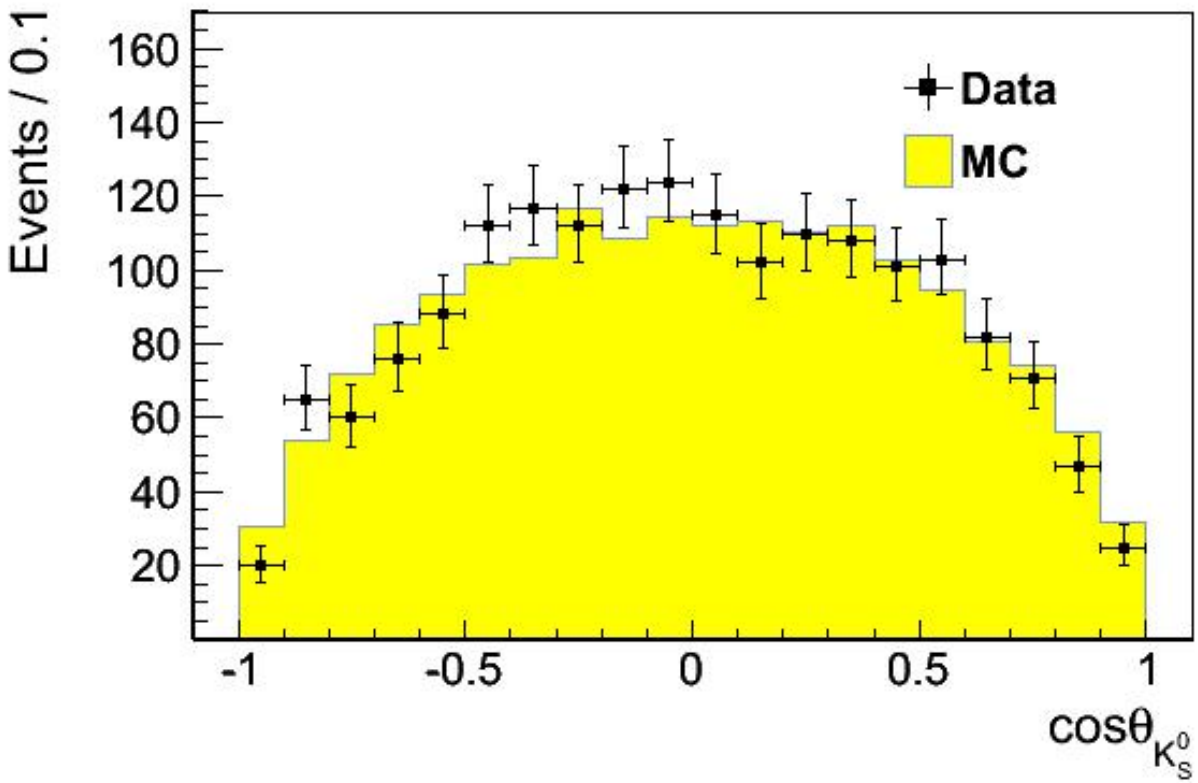
Comparison of K_S^0 cosθ



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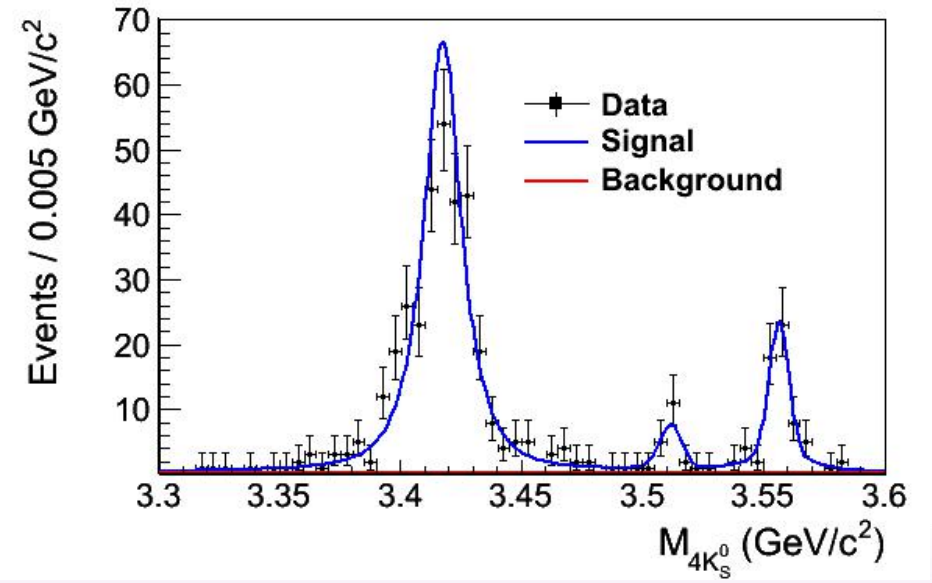
Fitting

1. Signal shape: *Breit-Wigner convoluted with double Gaussian, where the widths are fixed to the PDG value.*

2. Background shape: *polynomial function*



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Branching fraction

$$B(\chi_{CJ} \to 4K_S^0) = \frac{N^{obs}}{N_{\psi(3686)} \times B(\psi(3686) \to \gamma\chi_{CJ}) \times B^4(K_S^0 \to \pi^+\pi^-) \times \varepsilon}$$

$\chi_{CJ} \to K_S^0 K_S^0 K_S^0 K_S^0$	N^{obs}	Efficiency [%]	*Significance*	$B.F[10^{-4}]$
χ_{C0}	332 ± 19	6.54	6.6	4.99 ± 0.29
χ_{C1}	18 ± 4	7.48	3.6	0.25 ± 0.05
χ_{C2}	61 ± 8	6.74	5.1	0.97 ± 0.12

notes: $Significance = \log_e(2 \times (FCN1 - FCN2))$

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Systematic errors

	χ_{C0}	χ_{C1}	χ_{C2}	Description
ψ(3686) total numbers		0.8		CPC37 (2013) 063001
γ detection efficiency		1.0		PRD83-012006
Reconstruction of K_S^0		6.0		PRD92-072012
Kinematic fit	2.0	4.4	3.6	following slide
Fitting range	1.4	3.6	2.5	following slide
Signal shape	0.4	0.8	2.2	following slide
Background shape	0.1	1.0	1.0	following slide
MC statistics	1.1	1.0	1.0	binomial
$B(\varphi' \to \gamma\chi_{CJ})$	2.7	3.2	3.4	PDG2016
$B(K_S^0 \to \pi^+\pi^-)$		0.3		PDG2016
Total	7.2	9.1	8.7	Add in quadratic

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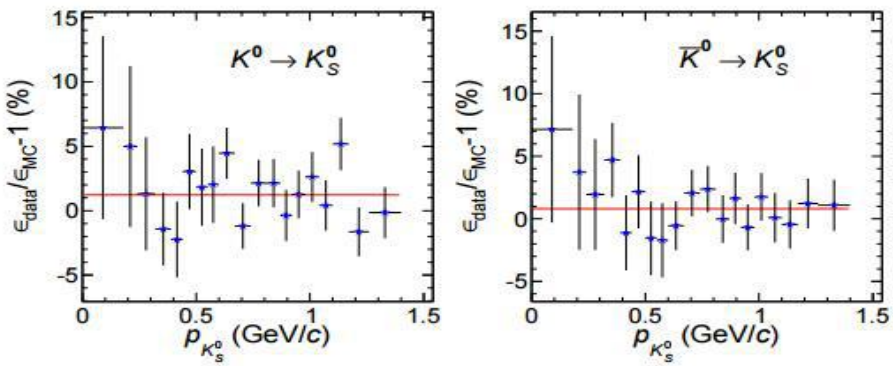
Systematic errors

1. Reconstruction of K_S^0

We use the same K_S^0 selection criteria as used in PRD92-072012. The data-MC different of K_S^0 reconstruction is studied in PRD92-072012 and shown below. The fit give the fitted data-MC difference to be (1.01 ± 0.53)%. So we assign 1.5% as systematic uncertainty per K_S^0.



This figures include that systematic uncertainty of tracking, mass window, vertex fitting and second vertex fitting.

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Systematic errors

2. Kinematic fit systematic error

The uncertainty is assigned by the difference of the branching fractions measured with and without χ^2 cuts. In the case of no χ^2 cut, the χ^2 is set to be 10^9.

Kinfit	χ_{C0}			χ_{C1}			χ_{C2}		
χ^2	signal	eff	B.F	signal	eff	B.F	signal	eff	B.F
no	318	6.50	4.81	20	7.44	0.27	62	6.5	1.02
2000	352	7.00	4.95	21	8.31	0.26	67	7.30	0.98
1500	349	6.94	4.95	20	8.22	0.25	65	7.24	0.96
1000	335	6.89	4.78	20	8.05	0.25	62	7.15	0.93
500	346	6.79	5.01	18	7.81	0.24	64	6.98	0.98
200	332	6.54	4.99	18	7.49	0.25	61	6.74	0.97
Kinfit err	2.0%			4.4%			3.6%		

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Systematic errors

3. Fitting range

The uncertainty is estimated by comparing the branching fractions with the alternative fit ranges of

	χ_{C0}			χ_{C1}			χ_{C2}		
Range	signal	eff	B.F	signal	eff	B.F	signal	eff	B.F
[3.3, 3.6]	332	6.54	4.99	18	7.48	0.25	61	6.74	0.97
[3.32, 3.6]	328	6.54	4.93	18	7.48	0.25	60	6.74	0.95
[3.3, 3.58]	328	6.54	4.93	18	7.49	0.25	57	6.53	0.93
[3.28, 3.6]	338	6.54	5.08	19	7.33	0.27	62	6.74	0.98
[3.3, 3.62]	335	6.54	5.03	18	7.49	0.25	62	6.76	0.98
[3.28, 3.62]	339	6.54	5.10	18	7.49	0.25	63	6.76	1.00
range err	1.4%			3.6%			2.5%		

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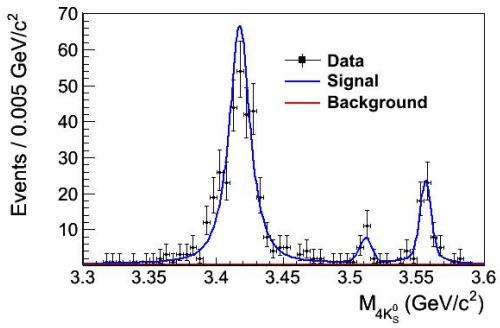
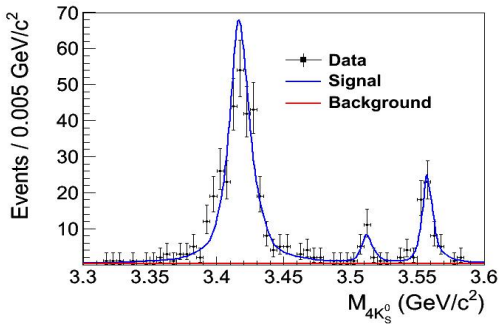
Systematic errors

4. Signal shape

The uncertainty is obtained by comparing the branching fractions measured with the signal shapes of Breit Wigner convolution double Gaussian and PDF generated by the MC histogram.





	χ_{C0}			χ_{C1}			χ_{C2}		
signal shape	signal	eff	B.F		eff	B.F		eff	B.F
BW	332	6.54	4.99	18	7.48	0.25	61	6.74	0.97
MC pdf	330	6.54	4.96	18	7.48	0.25	59	6.74	0.94
uncertainty	0.4%			0.8%			2.2%		

Systematic errors

5. Background shape

The uncertainty is estimated by varying the order of the polynomial.

	χ_{C0}			χ_{C1}			χ_{C2}		
bkg shape	signal	eff	B.F	signal	eff	B.F	signal	eff	B.F
flat	332	6.54	4.99	18	7.48	0.25	61	6.74	0.97
1st order	331	6.54	4.98	19	7.48	0.26	62	6.74	0.98
2nd order	331	6.54	4.98	19	7.48	0.26	63	6.77	0.99
uncertainty	0.1%			1.0%			1.0%		

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Summary

The decays of $\chi_{CJ} \to K_S^0 K_S^0 K_S^0 K_S^0$ are observed and their decay branching fractions are measured for the first time.

$\chi_{CJ} \to K_S^0 K_S^0 K_S^0 K_S^0$	$B.F[10^{-4}]$
χ_{C0}	$4.99 \pm 0.29 \pm 0.36$
χ_{C1}	$0.25 \pm 0.05 \pm 0.02$
χ_{C2}	$0.97 \pm 0.12 \pm 0.08$

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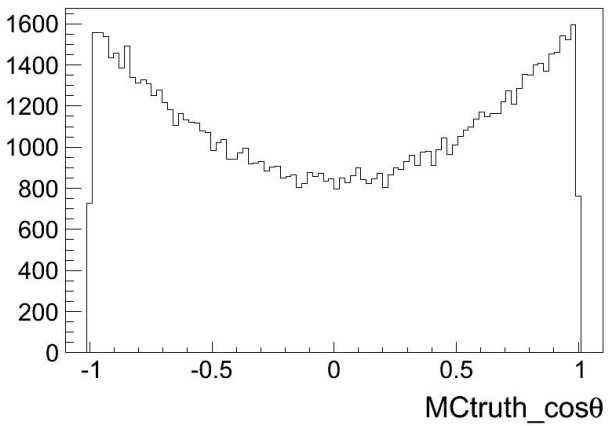
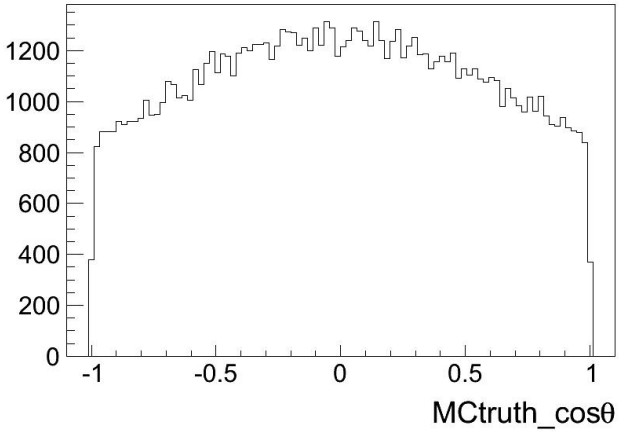
Thank you !!

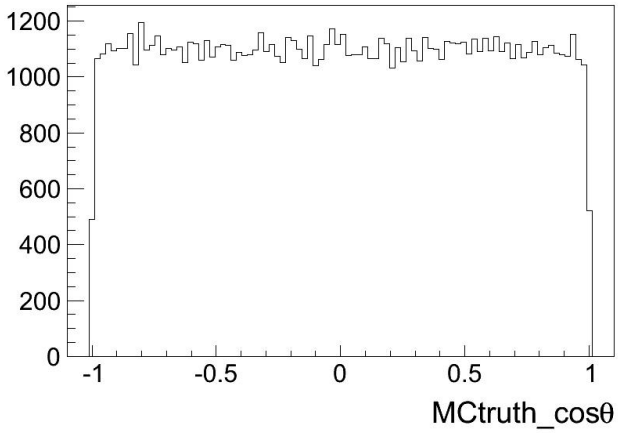
Backup

Cosθ of χ_{CJ} in MCtruth

Cosθ of χ_{CJ} in MCtruth







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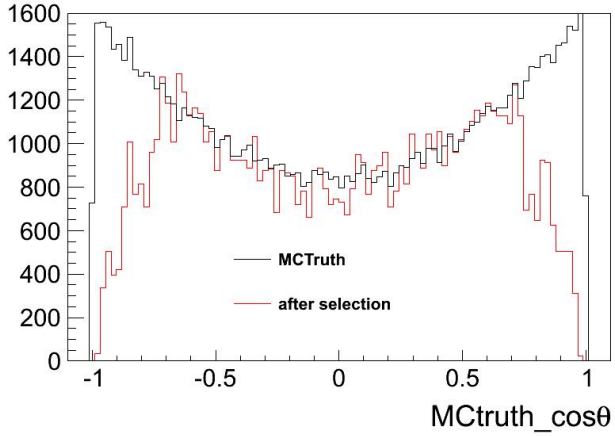
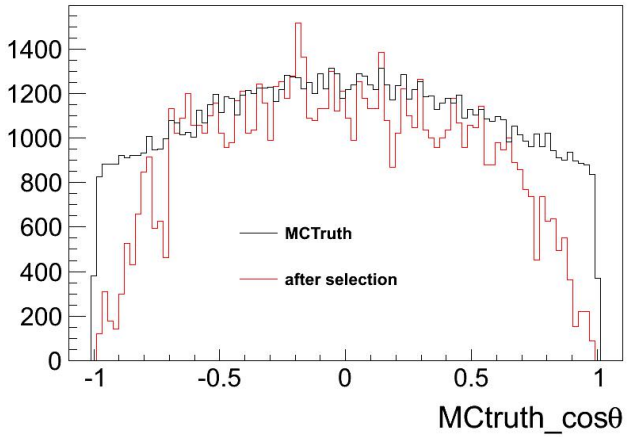
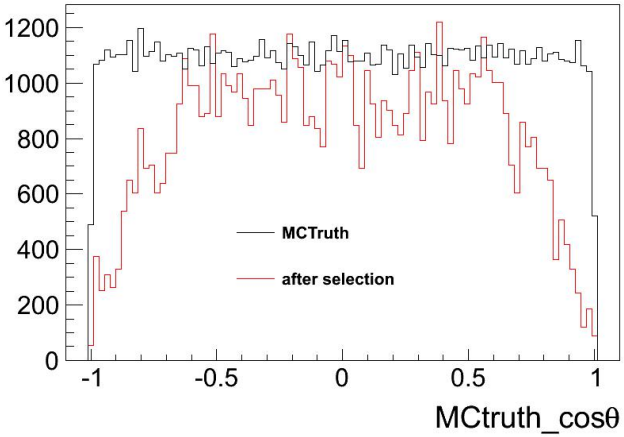
Cosθ of χ_{CJ} in MCtruth







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