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

San-Qiang Qu Ming-gang Zhao Hai-long Ma
Nankai University
Institute of High Energy Physics
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Outline

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

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

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

Boss Version: 6.6.4

Event selection

Charged track selection :

1. | cosθ | < 0.93
2. Momentum cut : P < 2.0Gev
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 | < 0.012GeV
4. nK_S^0 = 4

Event selection

Good photon :

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

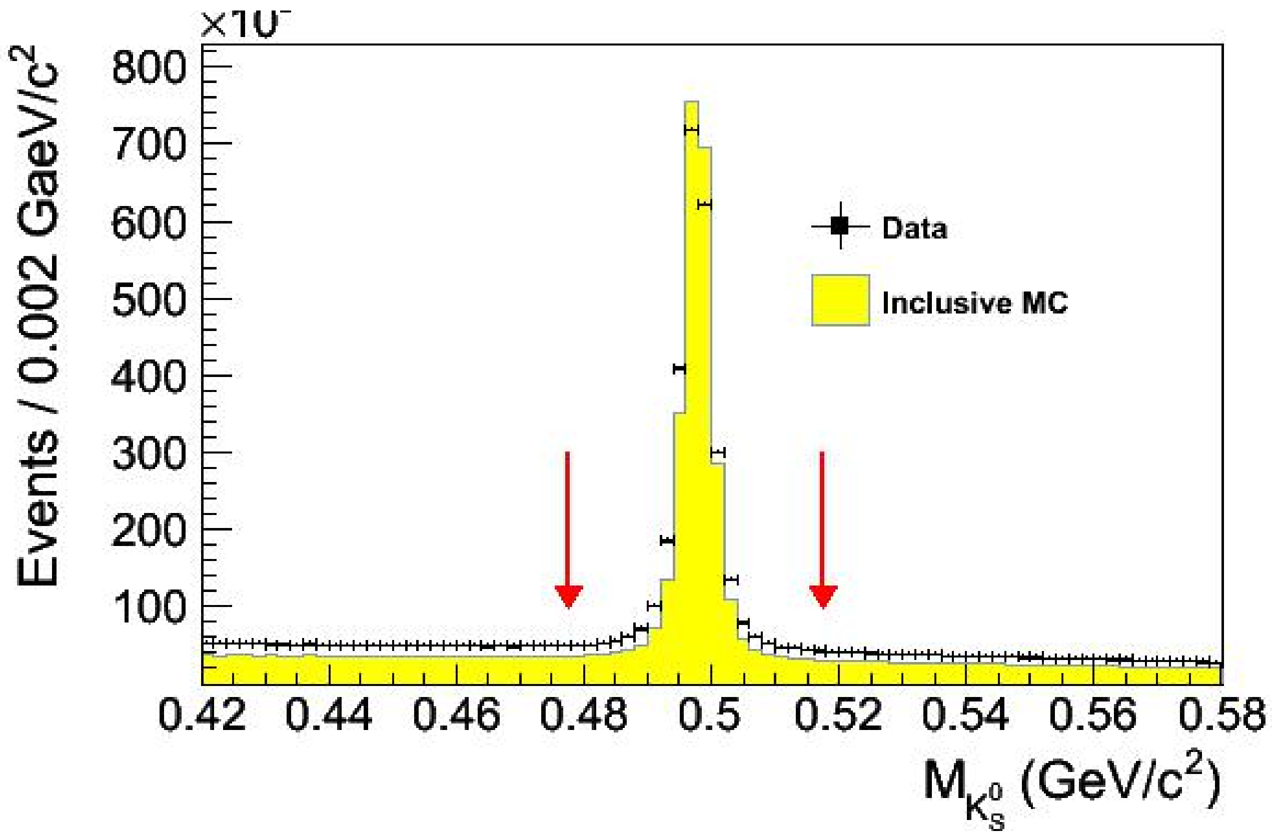
2. The deposited energy should be larger than 25 MeV in the endcap | cos θ |<0.8 and larger than 50 MeV in the barrel (0.86<| cosθ |<0.92);

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

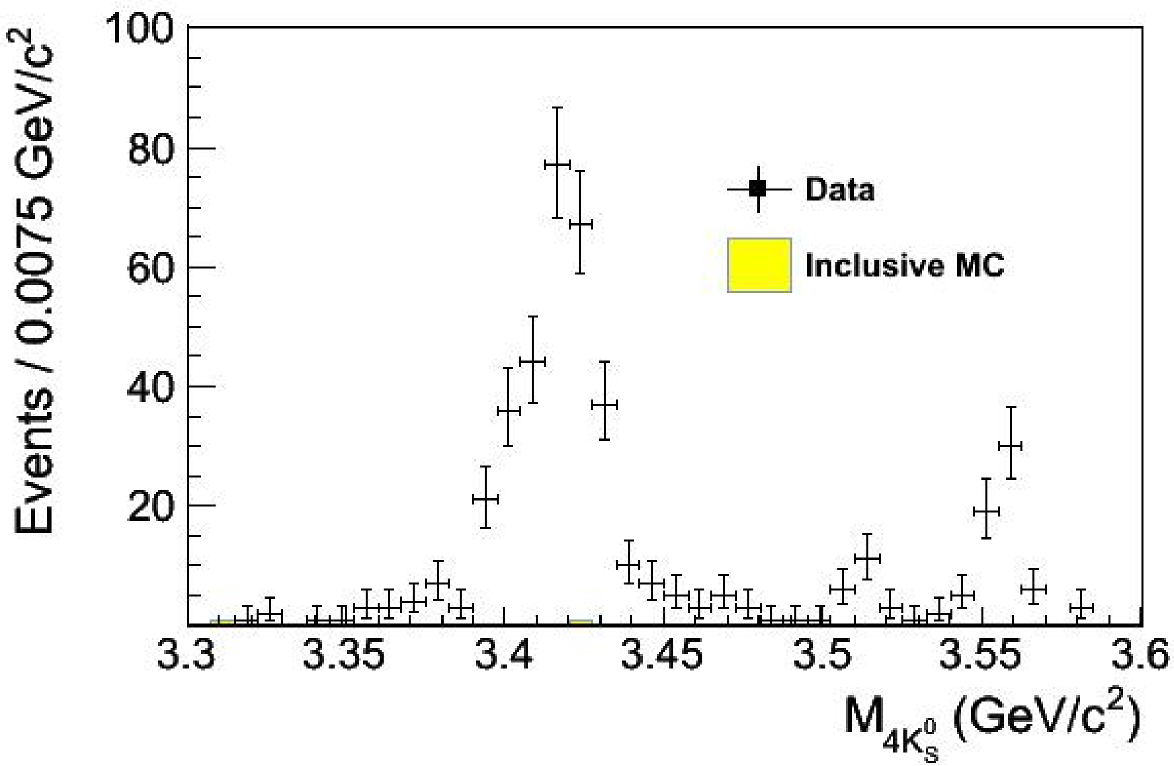
KinematicFit

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

K_S^0 reconstruction



χ_{CJ} candidates after event selection

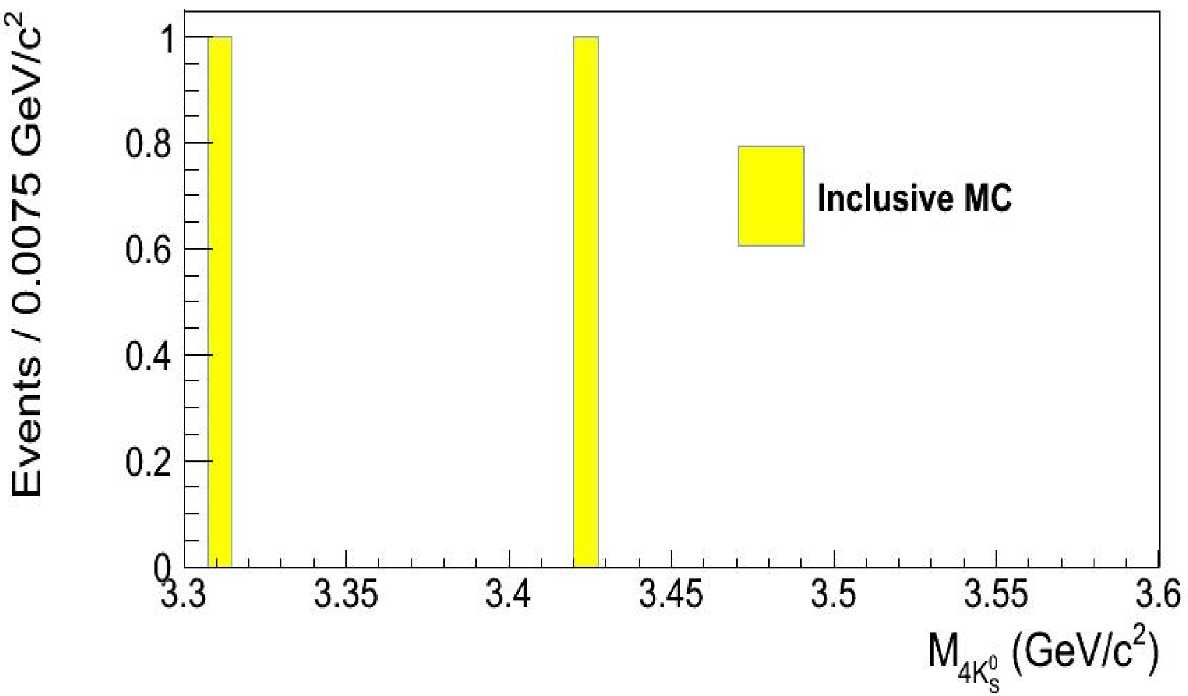


Backgrounds

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

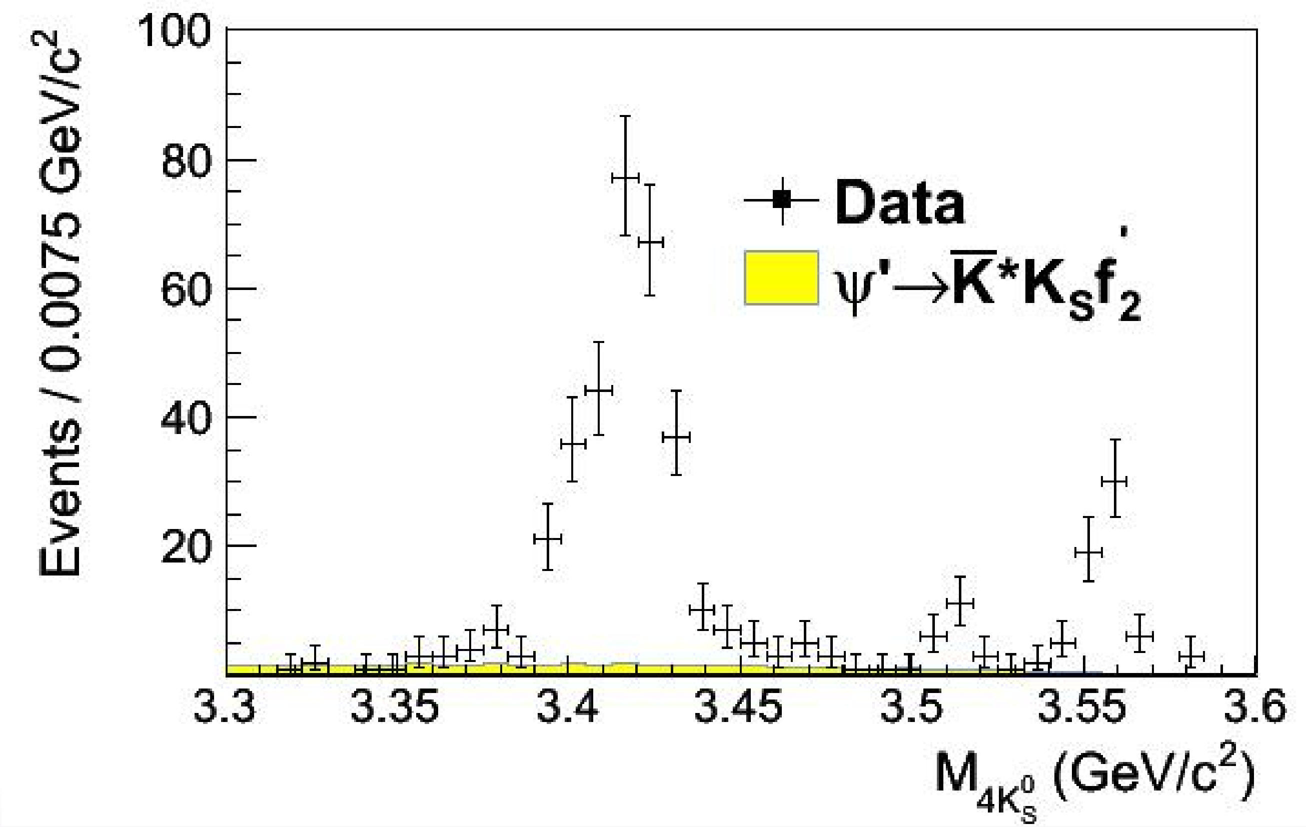
Table1: topological analysis for Inclusive MC

Backgrounds

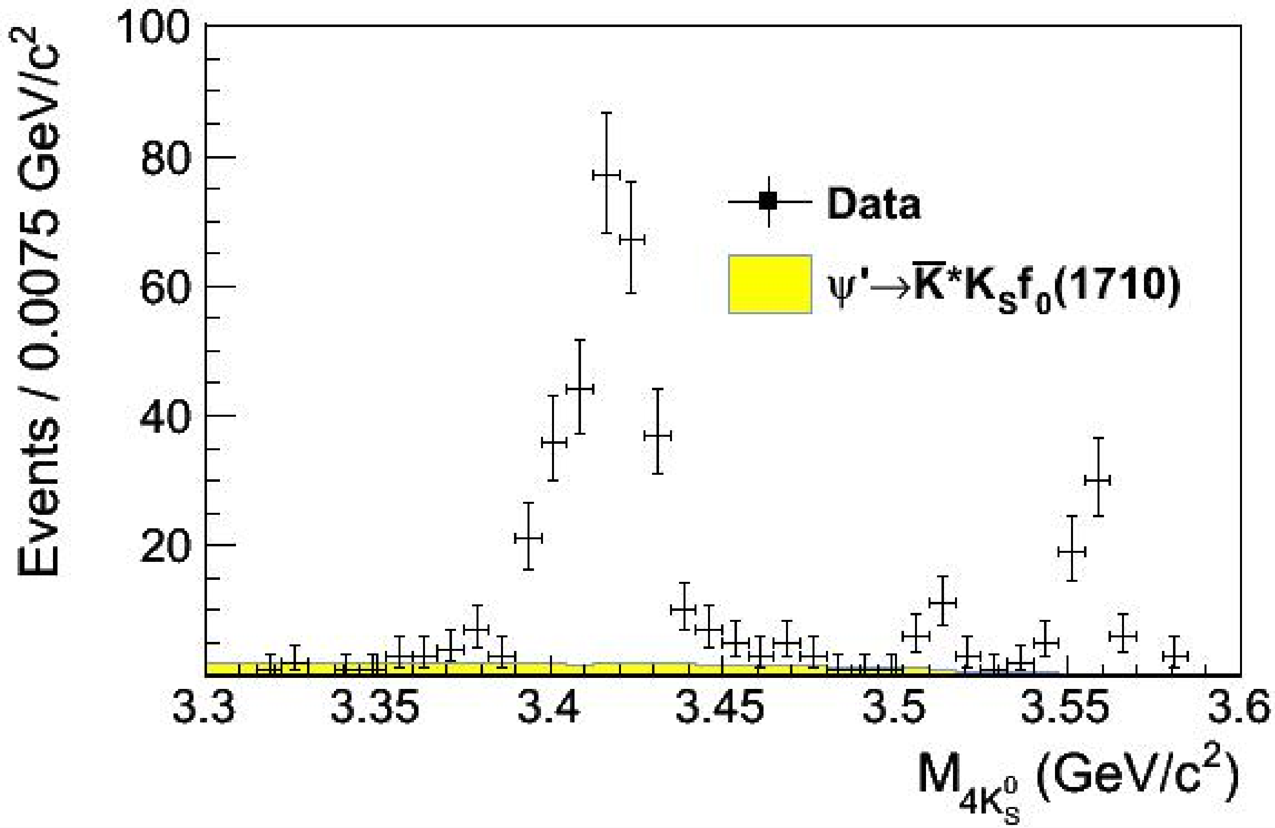


Distribution of invariant mass of backgrounds

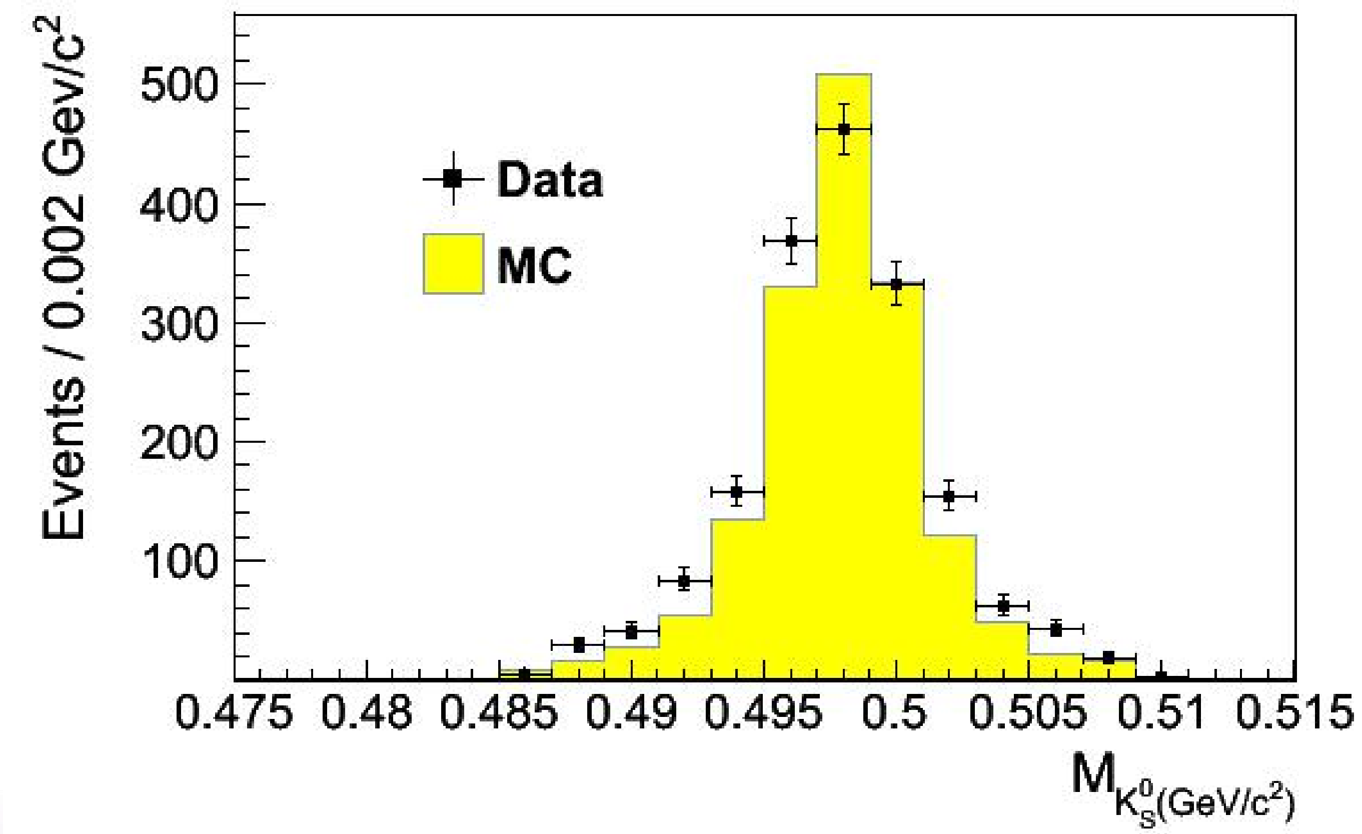
Backgrounds



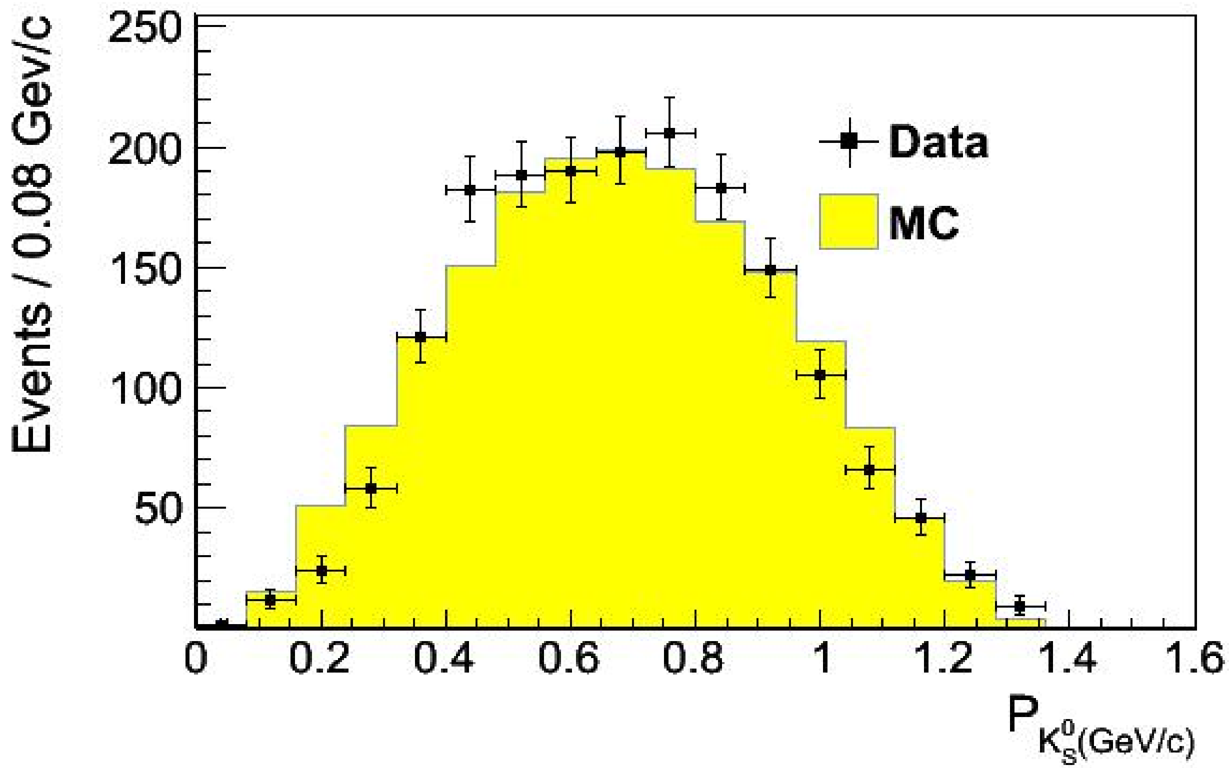
Backgrounds



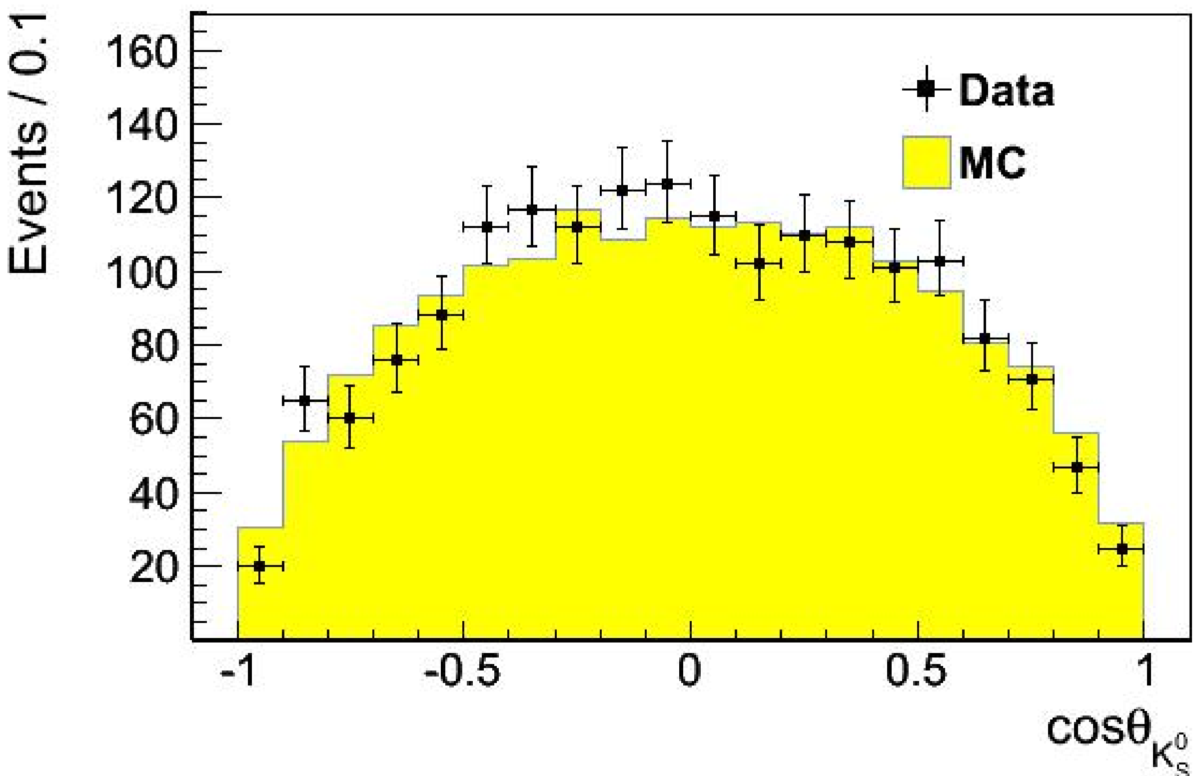
Comparison of $M_{\pi^+\pi^-}$



Comparison of K_S^0 momentum

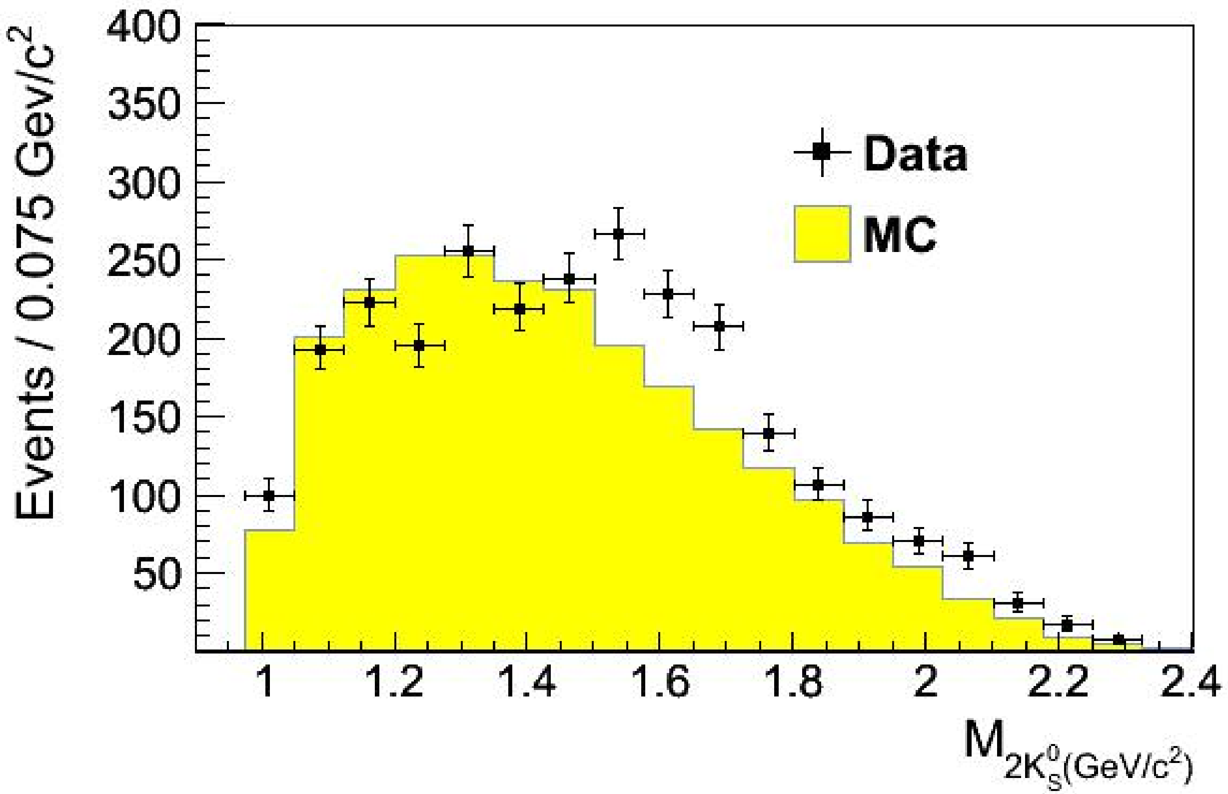


Comparison of K_S^0 cosθ



Update

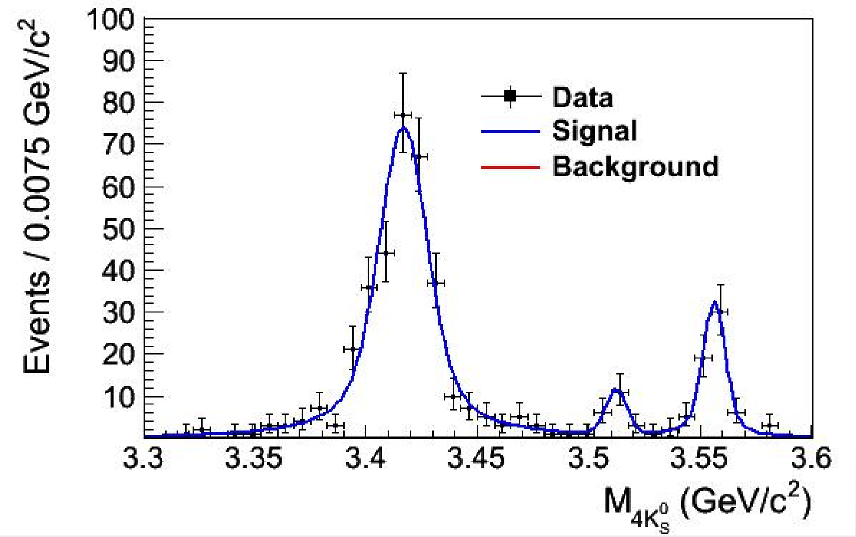
Comparison of $2M_{\pi^+\pi^-}$



Fitting

1. Signal shape: *Breit-Wigner convoluted with double Gaussian, where the widths are fixed to the PDG value and resolution is not fixed.*

2. Background shape: *polynomial function*



Branching fraction

Update

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

$\chi_{CJ} \to K_S^0 K_S^0 K_S^0 K_S^0$	N^{obs}	Efficiency [%]	$Significance$	$B.F[10^{-4}]$
χ_{C0}	347 ± 18	6.54	6.6	5.22 ± 0.27
χ_{C1}	18 ± 5	7.49	3.6	0.25 ± 0.07
χ_{C2}	65 ± 8	6.74	5.1	1.03 ± 0.13

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

FCN1: fitting data

FCN2: fitting data without the corresponding peak

Update

Systematic uncertainty

	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
MC model	3.2	4.2	1.5	following slide
Kinematic fit	1.3	6.2	7.7	following slide
Fitting range	0.3	4.5	1.4	following slide
Signal shape	1.9	0.0	3.5	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	11.3	11.2	12.0	Add in quadratic

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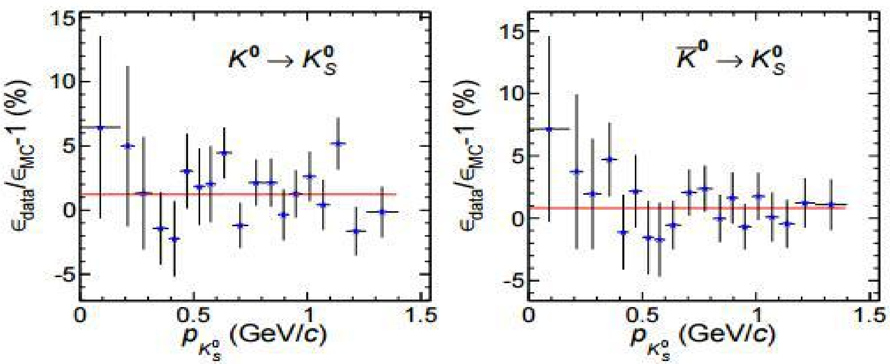
Systematic uncertainty

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.



the uncertainty includes differences between data and MC in tracking efficiency, decay length cut, mass spectra cut, vertex and second vertex fitting.

Update

Systematic uncertainty

2. MC model

The uncertainty in MC model is assigned by comparing the MC efficiencies with the ones involving possible sub-resonances.

Channel	χ_{C0} [%]	χ_{C0} [%]	χ_{C0} [%]
$\chi_{CJ} \to K_S^0 K_S^0 K_S^0 K_S^0$	6.5	7.5	6.7
$\chi_{CJ} \to f_0(1500) f_0(1500)$	6.5	7.3	6.6
$\chi_{CJ} \to K_S^0 K_S^0 f_0(1500)$	6.4	7.4	6.7
$\chi_{CJ} \to K_S^0 K_S^0 f_2^{'}(1525)$	6.3	7.2	6.7
$\chi_{CJ} \to f_0(1500) f_2^{'}(1525)$	6.4	7.3	6.7
$\chi_{CJ} \to f_0(1500) f_0(1710)$	6.5	7.4	6.7
$\chi_{CJ} \to K_S^0 K_S^0 f_2(1565)$	6.5	7.3	6.7
$\chi_{CJ} \to f_0(1500) f_2(1565)$	6.4	7.3	6.7
$\chi_{CJ} \to f_2^{'}(1525) f_2(1565)$	6.4	7.3	6.7
systematic uncertainty	3.2	4.2	1.5

Update

Systematic uncertainty

3. 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	345	6.50	5.22	21	7.59	0.28	82	7.35	1.19
2000	362	7.00	5.09	18	7.57	0.24	71	7.30	1.03
1500	360	6.94	5.10	20	8.22	0.25	67	7.24	0.99
1000	362	6.89	5.17	19	8.05	0.24	69	7.15	1.03
500	351	6.79	5.08	18	7.80	0.24	63	6.98	0.96
200	347	6.54	5.22	18	7.49	0.25	65	6.74	1.03
Kinfit err	1.3			6.2			7.7		

Update

Systematic uncertainty

Too loose χ^2 cut may lead to too many mis-combinations among the 8 pions.

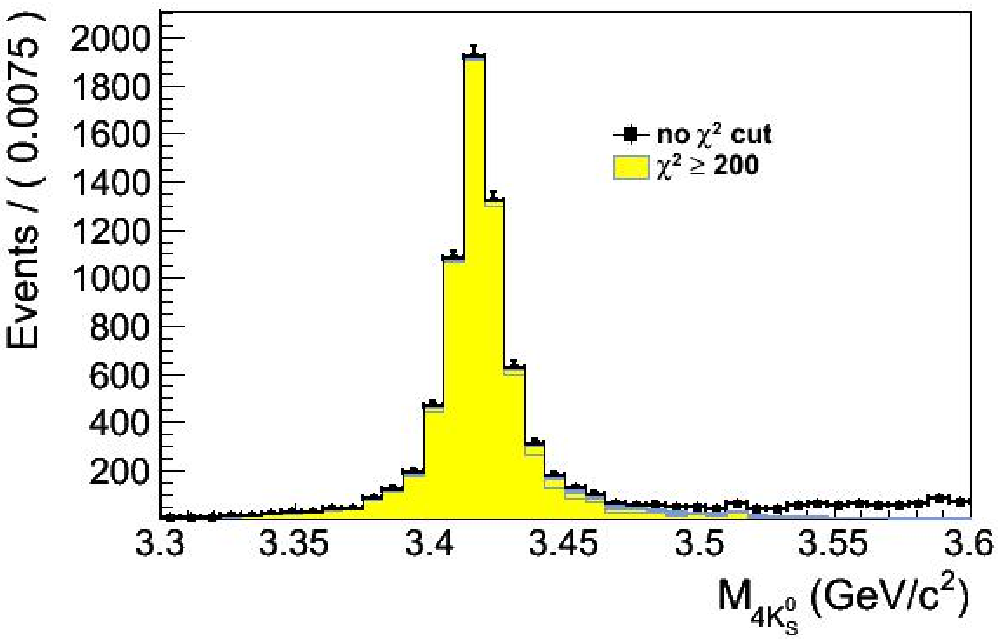


Figure: efficiency fitting for χ_{C0} under different χ^2 cut

Update

Systematic uncertainty

4. 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. [%]
[3.30, 3.59]	347	6.54	5.22	17	7.49	0.23	65	6.69	1.01
[3.30, 3.60]	347	6.54	5.22	18	7.49	0.25	65	6.74	1.03
[3.30, 3.61]	345	6.54	5.19	19	7.49	0.26	63	6.75	1.00
[3.30, 3.62]	348	6.54	5.23	18	7.49	0.25	63	6.76	1.00
[3.28, 3.60]	348	6.54	5.23	18	7.48	0.25	64	6.74	1.01
[3.29, 3.60]	346	6.54	5.20	18	7.49	0.25	65	6.74	1.03
[3.31, 3.60]	346	6.54	5.20	18	7.49	0.25	64	6.74	1.01
[3.32, 3.60]	346	6.54	5.20	17	7.49	0.23	65	6.74	1.03
range err [%]	0.3			4.5			1.4		

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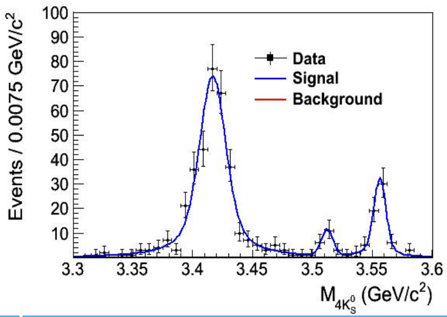
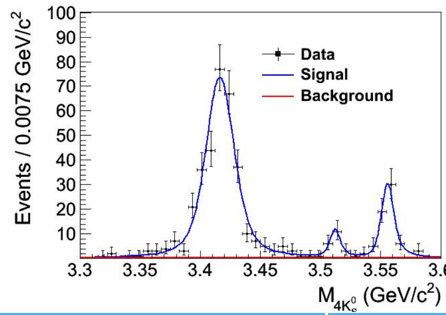
Update

Systematic uncertainty

5. Signal shape

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





	χ_{C0}			χ_{C1}			χ_{C2}		
signal shape	signal	eff [%]	B.F. [%]	signal	eff [%]	B.F. [%]	signal	eff [%]	B.F. [%]
BW with double Gauss	347	6.54	5.22	18	7.49	0.25	65	6.74	1.03
MC pdf with Gauss	338	6.54	5.03	18	7.49	0.25	62	6.74	0.98
uncertainty	1.9			0.0			3.5		

Update

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}	$5.22 \pm 0.27 \pm 0.59$
χ_{C1}	$0.25 \pm 0.07 \pm 0.03$
χ_{C2}	$1.03 \pm 0.13 \pm 0.12$

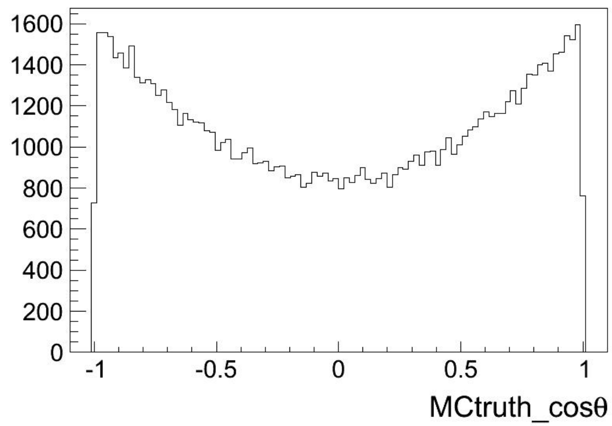
Thank you !!

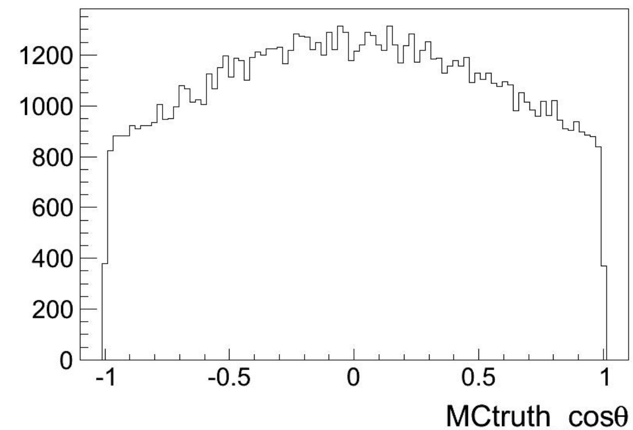
Backup

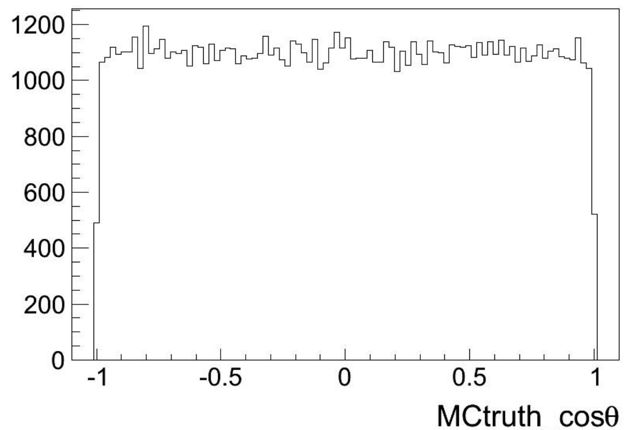
Cosθ of χ_{CJ} in MCtruth

check efficiency of χ_{C0}

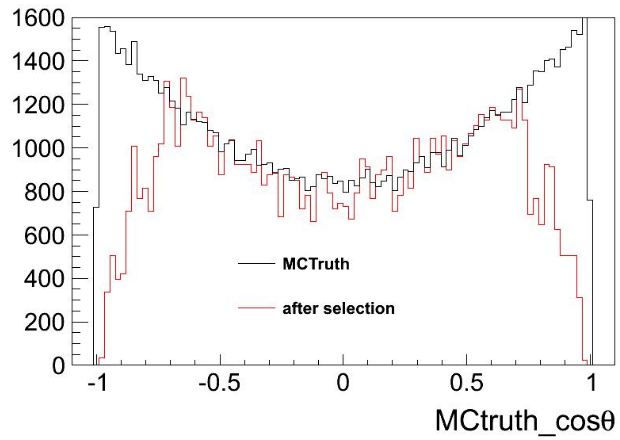
Cosθ of χ_{CJ} in MCtruth

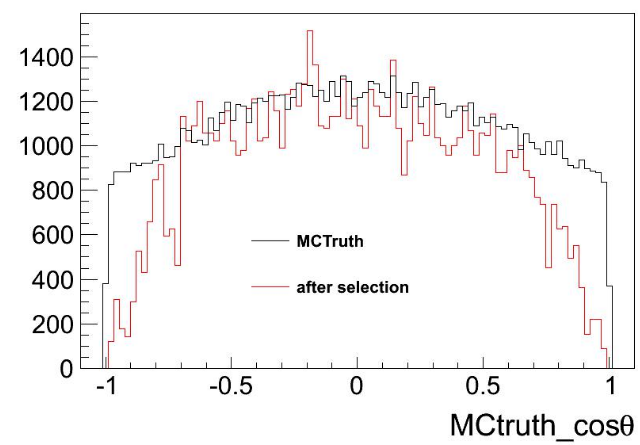


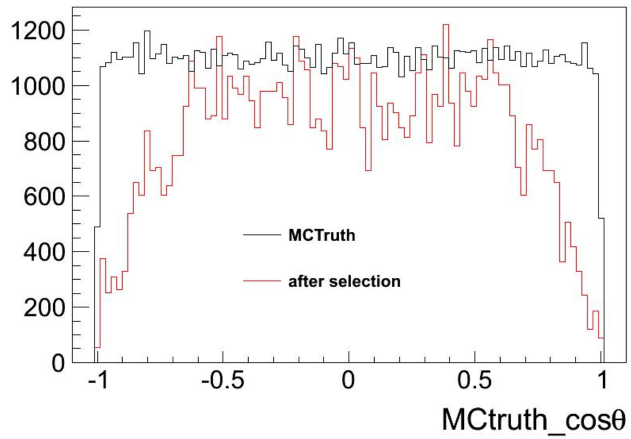




Cosθ of χ_{CJ} in MCtruth







Update

Check efficiency of χ_{C0}

We found the efficiency decreased when Kinematic fit χ^2 is not restricted. So we check the histogram of MC simulation for χ_{CJ} , and then we get the result.

	range	no χ^2 cut entries	$\chi^2 < 2000$ entries
χ_{C0}	[3.30 3.60]	8434	7021
	[3.30 3.44]	6218	6208
χ_{C1}	[3.30 3.60]	8471	8309
	[3.45 3.52]	6634	6618
χ_{C2}	[3.30 3.60]	7350	7303
	[3.50 3.57]	6440	6428