Measurement of the branching fraction of $\eta_c \to K_S^0 K \pi$

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Overview

Motivation

- The branching fraction of $\eta_c \to K_S^0 K^{\pm}\pi^{\mp}$ with higher accuracy is essential to measure the parameters of the M1 transition.
- Current branching fraction measures have relatively large error.
  - $Br(\eta_c \to K_S^0 K^{\pm}\pi^{\mp}) = (2.60 \pm 0.29 \pm 0.34 \pm 0.25)\%$ (PR D86 092009 (BESIII))
  - $Br(\eta_c \to K\bar{K}\pi) = (8.5 \pm 1.8)\%$ (PRL 96 052002 (BABR))
- We have taken $\sim 10^9$ J/ψ data, however $\Delta Br(J/\psi \to \gamma\eta_c) \sim 25\%$ if we use the J/ψ data directly.
- While if we use XYZ data with the process $e^+e^- \to \pi^+\pi^- h_c$, $h_c \to \gamma\eta_c$, η_c can be observed using $RM(\pi^+\pi^-\gamma)$ with $RM(\pi^+\pi^-)$ falling into the h_c mass region.

Methods

Methods to measure the braching fraction

- We measure the branching fraction via the decay
  - $e^+e^- \to \pi^+\pi^- h_c, h_c \to \gamma\eta_c, \eta_c \to K_S^0 K^\pm \pi^\mp$(exlucisve mode)
  - $e^+e^- \to \pi^+\pi^- h_c, h_c \to \gamma\eta_c, \eta_c \to anything$(inlucisve mode)

- Recoil the η_c signal with $\pi^+\pi^-\gamma$ (Inclusive Mode).
- Recoil the η_c signal with η_c reconstructed with $K_S^0 K^\pm \pi^\mp$(Exclusive Mode).

- The Branching fraction is

$$Br(\eta_c \to K_S K^\pm \pi^\mp) = \frac{N_{signal}^{exclusive}}{N_{signal}^{inclusive}} \bullet \frac{\epsilon^{inclusive}}{\epsilon^{exclusive}} \bullet \frac{1}{Br(K_S^0 \to \pi^+\pi^-)}.$$

And via this method we can also cancel part of the system errors.

Data Sets and Monto Carlo Samples

BOSS version

6.6.4.p01

Data Sets

We used the XYZ data at the energy points of $4.23GeV$, $4.26GeV$, $4.36GeV$ and $4.42GeV$.

Monto Carlo Samples

$200K$ Monto Carlo Samples are generated at each of the four energy points of $4.23GeV$, $4.26GeV$, $4.36GeV$ and $4.42GeV$.

Exclusie Mode

Event Selections

Good Charged tracks selections

- $V_{xy} < 1cm$, $|V_z| < 10cm$ (except for the two tracks from K_S^0)
- $|\cos\theta < 0.93|$

Good phton selections($1 \leq N_\gamma \leq 20$)

- $E_\gamma > 25MeV$ for $|\cos\theta| < 0.8$
- $E_\gamma > 50MeV$ for $0.86 < |\cos\theta| < 0.92$
- $0 \leq TDC \leq 14$(in unit of $50ns$)

Event Selections

To improve the efficiency of selections, we assume the following charged tracks as pions

K_S^0 Reconstruction($N_{K_S^0} \geq 1$)

- $L/\sigma_L > 2$ (L: decay length; σ_L: error of decay length)
- $|m_{\pi^+\pi^-}^{invariant} - m_{K_S^0}| \leq 20 MeV$

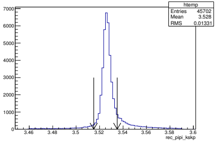
We Choose the K_S^0 candidate as the one with the minimum χ^2_{vertex}.

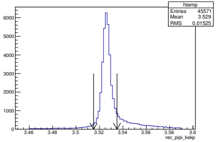
preliminary $\gamma\pi^+\pi^-$ list

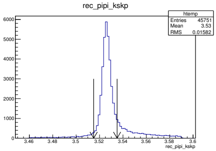
- $3.46 < m_{\pi^+\pi^-}^{recoil} < 3.59 GeV$ (h_c mass region)
- $2.5 < m_{\pi^+\pi^-\gamma}^{recoil} < 3.4 GeV$ (η_c mass region)

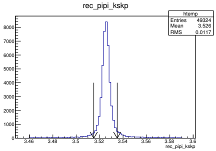
Another π^+K^- or π^-K^+ pair is required
Combination with the minimum $\chi^2 = \chi^2_{4C} + \sum_{i=1}^{N} \chi^2_{PID}(i)$ is kept

- $3.515 < M^{recoil}_{\pi^+\pi^-} < 3.535$ ($M_{h_c} \pm 3\sigma$)

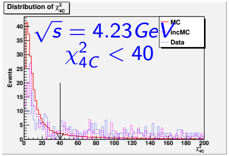


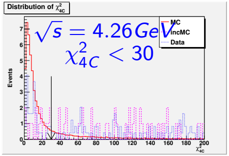


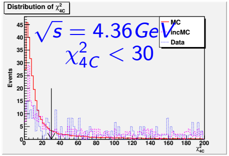


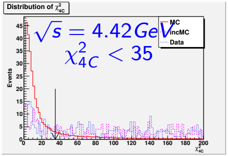


- The χ^2_{4C} cut is optimized with the figure of merit$(FOM)\frac{S}{\sqrt{S+B}}$









Inclusie Mode

Event Selections

Good Charged tracks selections

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Good phton selections($1 \leq N_\gamma \leq 20$)

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- $0 \leq TDC \leq 14$(in unit of $50ns$)

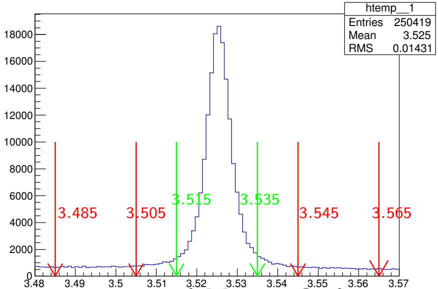
We use the $\gamma\pi^+\pi^-$list to recoil the η_c and h_c signal

preliminary $\gamma\pi^+\pi^-$ list

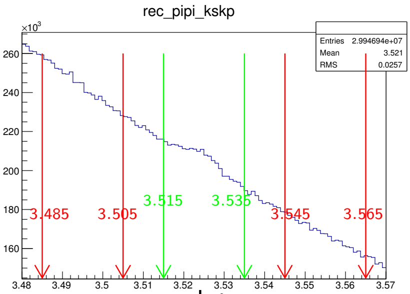
- $3.46 < m^{recoil}_{\pi^+\pi^-} < 3.59GeV$ (h_c mass region)
- $2.5 < m^{recoil}_{\pi^+\pi^-\gamma} < 3.4GeV$ (η_c mass region)

sideband

We use the sideband method to analyze the results ($M^{recoil}_{\pi^+\pi^-}$), and we choose the same range of $M^{recoil}_{\pi^+\pi^-}$ as the exlcusive processes.



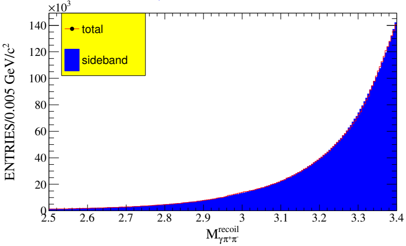
signal Monto Carlo

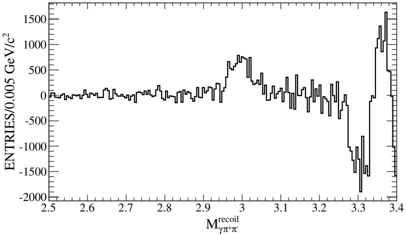


data

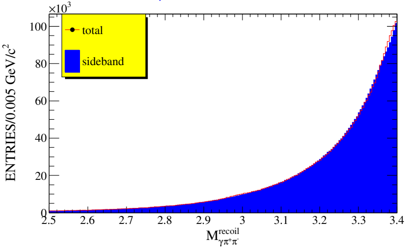
results of sideband $M^{recoil}_{\pi^+\pi^-\gamma}$

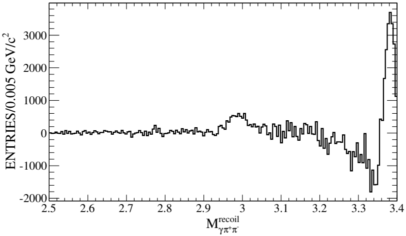
$\sqrt{s} = 4.23GeV$





$\sqrt{s} = 4.26GeV$

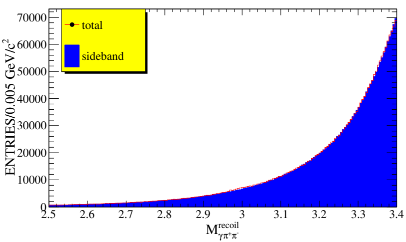


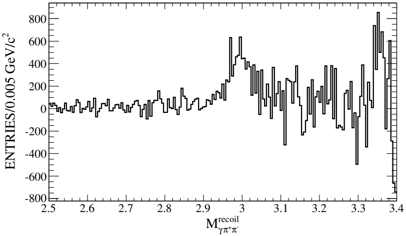


The upper ones draw the sideband and signal regions together,
while the lower ones draw net events

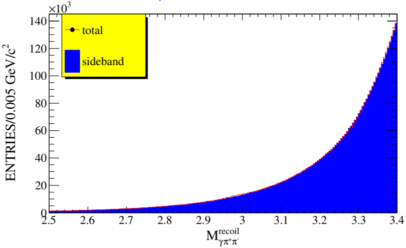
results of sideband $M^{recoil}_{\pi^+\pi^-\gamma}$

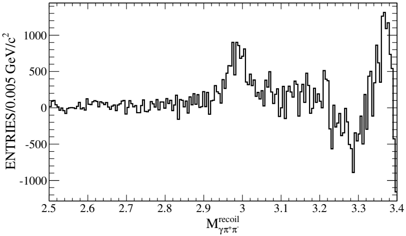
$\sqrt{s} = 4.36GeV$





$\sqrt{s} = 4.42GeV$





The upper ones draw the sideband and signal regions together, while the lower ones draw net events

Fit Simultaneously

To fit the distribution of $M^{recoil}_{\pi^+\pi^-\gamma}$, we use the fit function

$$F(m) = \sigma \otimes [\epsilon(m) \times |S(m)|^2 \times E_\gamma^3 \times d(E_\gamma)] + B(m),$$

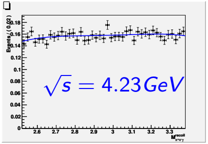
where

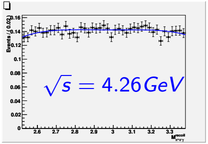
- $d(E_\gamma) = \frac{E_0^2}{E_\gamma E_0 + (E_\gamma - E_0)^2}$,
- $\sigma \rightarrow$ Double-Gaussians,
- $S(m) \rightarrow$Breit-Wigner shapes with common fixed M and σ,
- $B(m) \rightarrow$
  - Chebyshev Polynomial of the first kind for the exclusive mode,
  - sideband for inclusive mode.

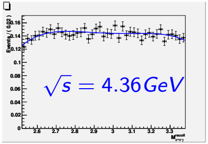
Efficiency Curves

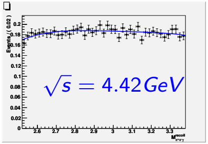
We generate large-width signal Monto Carlo samples,
and divide the MC truth after selection by the truth before selection to get the efficency curve.

Exclusive Processes

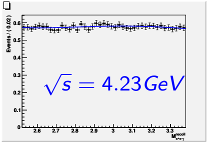


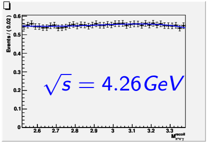


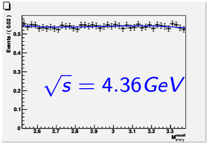


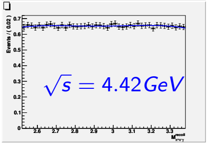


Inclusive Processes







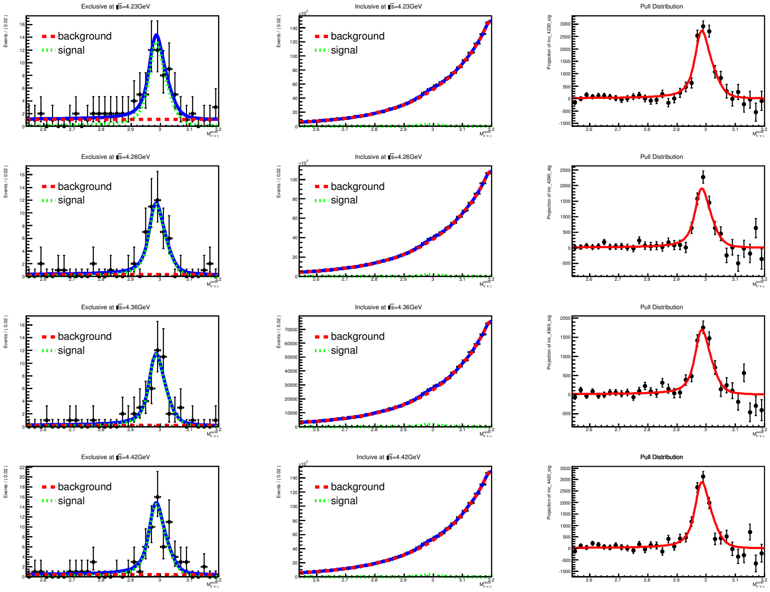


Resolution

We generated 0-width signal Monto Carlo samples, and fit the signal with a double-Gaussians shape.
As the selections are similar, we use the results of the exclusive processes as the inclusive processes

Category		Gaussian 1		Gaussian 2		Coefficient
		$M_1(MeV)$	$\sigma_1(MeV)$	$M_2(MeV)$	$\sigma_2(MeV)$	
Exclusive	4230	2.61	11.29	23.61	26.37	6.44614e-01
	4260	1.73	10.79	20.13	23.70	6.04471e-01
	4360	1.64	10.73	20.54	23.52	6.01291e-01
	4420	2.45	11.28	22.10	25.76	6.34061e-01
Inclusive	4230	2.61	11.29	23.61	26.37	6.44614e-01
	4260	1.73	10.79	20.13	23.70	6.04471e-01
	4360	1.64	10.73	20.54	23.52	6.01291e-01
	4420	2.45	11.28	22.10	25.76	6.34061e-01

Simultaneous Fit



Branching Fraction

Fit Results:

Category		N_{signal}
Exclusive	4230	58.0 ± 9.1
	4260	47.5 ± 7.4
	4360	47.8 ± 7.5
	4420	62.4 ± 8.8
Inclusive	4230	11922.6 ± 719.3
	4260	8030.8 ± 601.4
	4360	7176.5 ± 499.7
	4420	12477.5 ± 708.5

Efficiency:

Category		Efficiency(%)
Exclusive	4230	15.66
	4260	13.94
	4360	14.91
	4420	17.90
Inclusive	4230	48.12
	4260	44.14
	4360	42.59
	4420	51.15

We use the formula on the "Introduction" page to calculate the braching fraction.

And we get the weighted average value, as

Category	Branching fraction(%)
4230	2.16 ± 0.36
4260	2.71 ± 0.47
4360	2.95 ± 0.51
4420	2.34 ± 0.32
average	2.34 ± 0.20

Summary

Summary

- We measured the branching fraction of the process $\eta_c \to K_S^0 K^{\pm}\pi^{\mp}$ via the exclusive and inclusive processes of the four energy points: $4, 23 GeV$, $4.26 GeV$, $4.36 GeV$ and $4.42 GeV$.
- We fit the signal simultaneously.
- We improved the accuracy of the measurement of the branching fraction.
- We can apply this method to others exlcusive analysis.

Plants

- Optimize the analysis
- System errors