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

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June 10, 2015

Overview

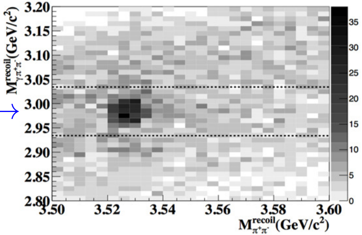
Motivation

- The experimental measurement on the M1 transition processes can be used to test QCD and other theoretical models. And the branching fractions of the η_c decays are essential for the M1 transition measurement.
- However the current measured precision for the η_c decays is not high.
  - $Br(\eta_c \to K_S^0 K^{\pm} \pi^{\mp}) = (2.60 \pm 0.29 \pm 0.34 \pm 0.25)\%$ (PR D86 092009 (BESIII))
  - $Br(\eta_c \to K \bar{K} \pi) = (8.5 \pm 1.8)\%$ (PRL 96 052002 (BABR))

Motivation

- The awfully large uncertainty from $Br(J/\psi \to \gamma\eta_c)$ is hard to avoid, though we have the most sizable J/ψ sample in the world. The statistics if not large if we use the $\psi\prime \to \gamma\eta_c$ process. In addition, the interference problem should be considered with both J/ψ and $\psi\prime$ data samples.
- Up to now, we have collected a large XYZ data sample around $4.26GeV$. And the process $e^+e^- \to \gamma h_c$, $h_c \to \gamma\eta_c$ has been observed. In principle, the signal can be extracted by recoil mass (RM) of $\gamma\pi^+\pi^-$ by limiting $RM(\pi^+\pi^-)$ in the h_c mass region.

η_c **signal** $\longrightarrow$



Methods

Methods to measure the branching fraction

- We measure the branching fraction of $\eta_c \to K_S^0 K^\pm \pi^\mp$ via the decays
  - $e^+e^- \to \pi^+\pi^- h_c, h_c \to \gamma\eta_c, \eta_c \to K_S^0 K^\pm \pi^\mp$(exclusive mode)
  - $e^+e^- \to \pi^+\pi^- h_c, h_c \to \gamma\eta_c, \eta_c \to X$(inclusive 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 parts of the system errors.
- However it is a little bit hard to determine the efficiency of inclusive process. So far we have not known all η_c decays well.

Data Sets and Monto Carlo Samples

BOSS version

6.6.4.p01

Data Sets

We currently used the XYZ data at the energy points of

$$4.23GeV,\ 4.26GeV,\ 4.36GeV \text{ and } 4.42GeV,$$

with a total integrated Lum. $\sim 3.1nb^{-1}$

Monto Carlo Samples

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

Exclusive Method

Event Selections

Good Charged tracks selections

- $V_{xy} < 1cm$, $|V_z| < 10cm$ (except for the two tracks from K_S^0)
- $|\cos\theta < 0.93|$
- $N_{good} \geq 6$

Good photon 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)
- $|m_{\pi^+\pi^-}^{invariant} - m_{K_S^0}| \leq 20MeV$

We choose the one with the minimum $\chi^2_{K_S^0} = \chi^2_{1^{st}V} + \chi^2_{2^{nd}V}$.

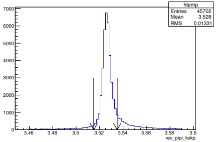
preliminary $\gamma\pi^+\pi^-$ list

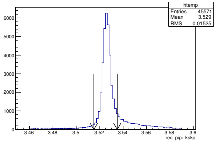
- $3.46 < m_{\pi^+\pi^-}^{recoil} < 3.59GeV$ (h_c mass region)
- $2.5 < m_{\pi^+\pi^-\gamma}^{recoil} < 3.4GeV$ (η_c mass region)

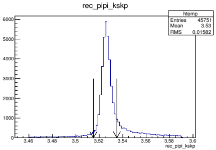
Another π^+K^- or π^-K^+ pair is required
Combination with the minimum $\chi^2 = \chi^2_{4C} + \sum_{i=1}^{N} \chi^2_{PID}(i)$ is kept

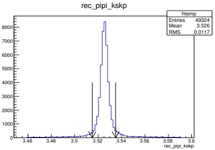
Optimized Selections

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

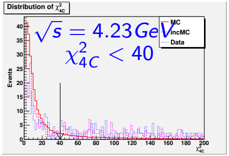


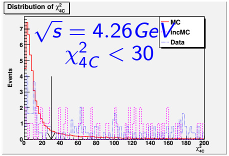


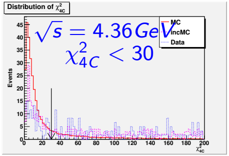


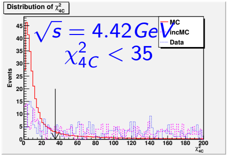


- The χ^2_{4C} cut is optimized with the figure of merit(FOM)$\frac{S}{\sqrt{S+B}}$









Inclusive Method

Event Selections

Good Charged tracks selections

- $V_{xy} < 1cm$, $|V_z| < 10cm$
- $|\cos\theta < 0.93|$

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

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

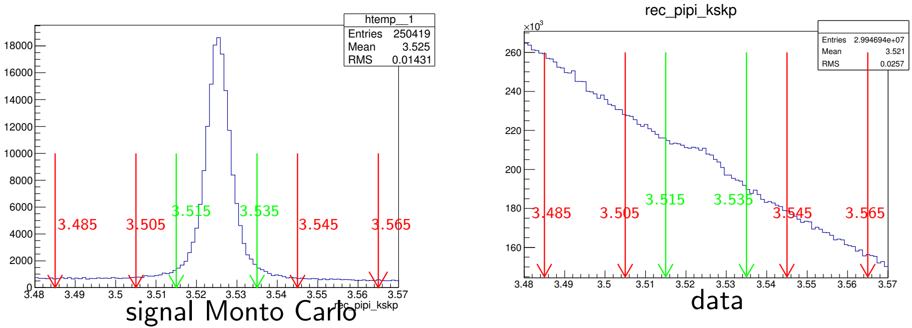
We use the $\gamma\pi^+\pi^-$list to recoil the η_c and h_c signal

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)

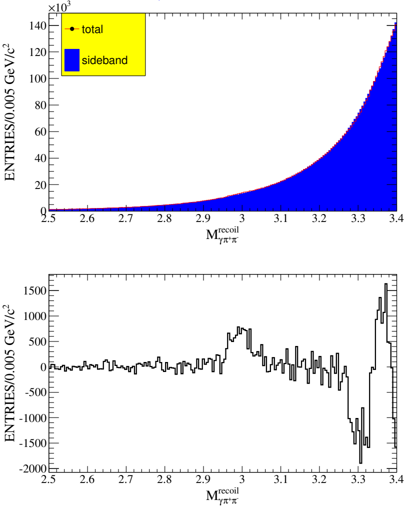
Study of Background Shape

We use the sideband method to analyze the background shape, and we choose the same range of $M_{\pi^+\pi^-}^{recoil}$ for both inclusive and exclusive processes.

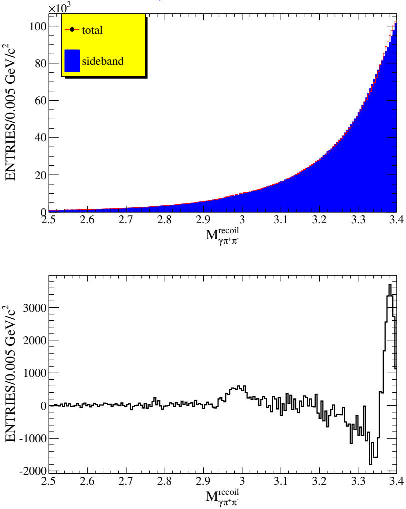


results of sideband $M^{recoil}_{\pi^+\pi^-\gamma}$

$\sqrt{s} = 4.23GeV$



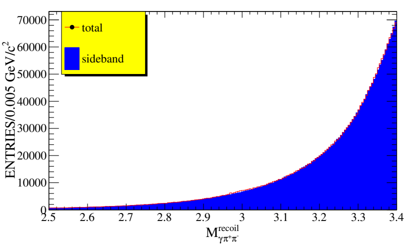
$\sqrt{s} = 4.26GeV$

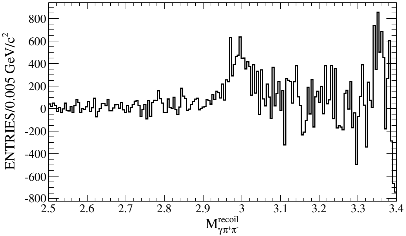


The upper ones draw the sideband and signal regions together, while the lower ones draw net events

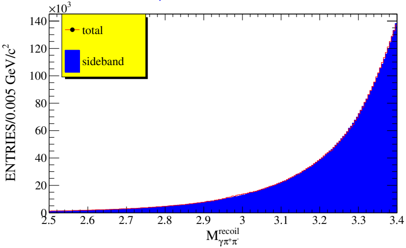
results of sideband $M^{recoil}_{\pi^+\pi^-\gamma}$

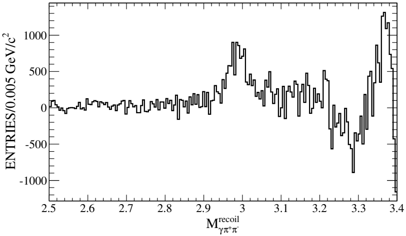
$\sqrt{s} = 4.36 GeV$





$\sqrt{s} = 4.42 GeV$





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

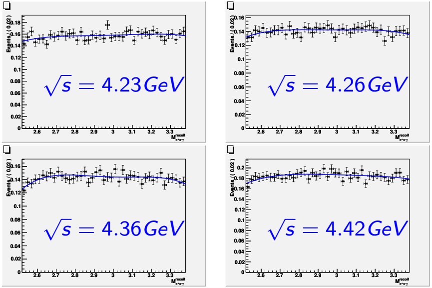
$$F(m) = \sigma \otimes [\epsilon(m) \times |S(m)|^2 \times E_\gamma^3 \times d(E_\gamma)] + B(m),$$

where

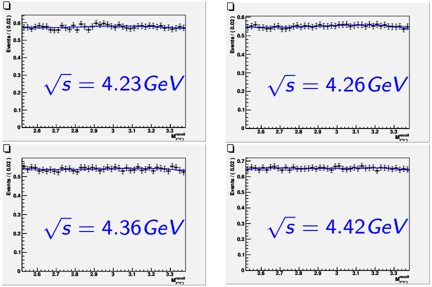
- $d(E_\gamma) = \frac{E_0^2}{E_\gamma E_0 + (E_\gamma - E_0)^2}$,
- $\sigma \rightarrow$ Double-Gaussians,
- $S(m) \rightarrow$Breit-Wigner shapes with common fixed M and σ,
- $B(m) \rightarrow$
  - Chebyshev Polynomial for the exclusive mode,
  - Events from sideband of h_c for inclusive mode.

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

Exclusive Processes



Inclusive Processes

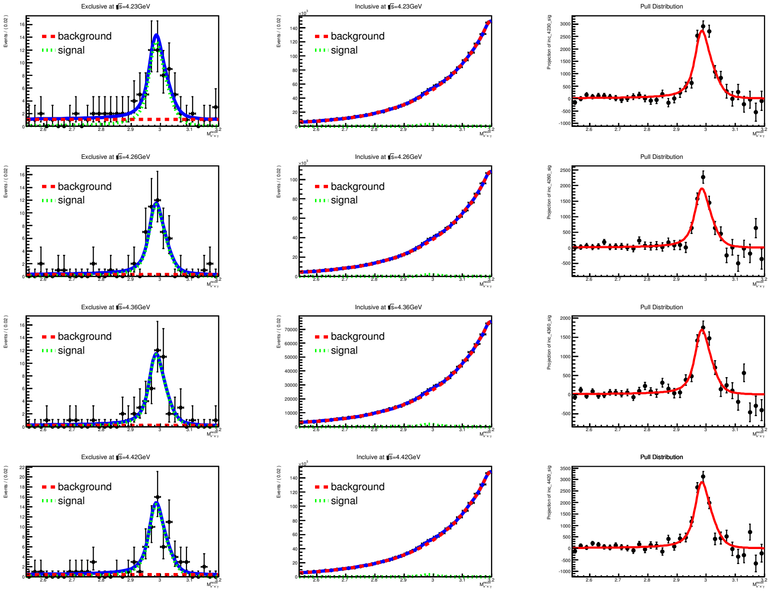


Resolution

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 branching 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

We can see that we improve the accuracy comparing with earlier measurements, e.g.

$$Br(\eta_c \to K_S^0 K^{\pm}\pi^{\mp}) = (2.60 \pm 0.29 \pm 0.34 \pm 0.25)\%$$

(PR D86 092009 (BESIII))

Summary

Summary

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

Plans

- Optimize the analysis
- More energy points can be used to increase the statistics
- System errors
- We can apply this method to others η_c decays.