Measurement of the Branching Fraction of the decay $J/\psi \to \bar{p}\Sigma^+ K_S^0$ using BESIII data

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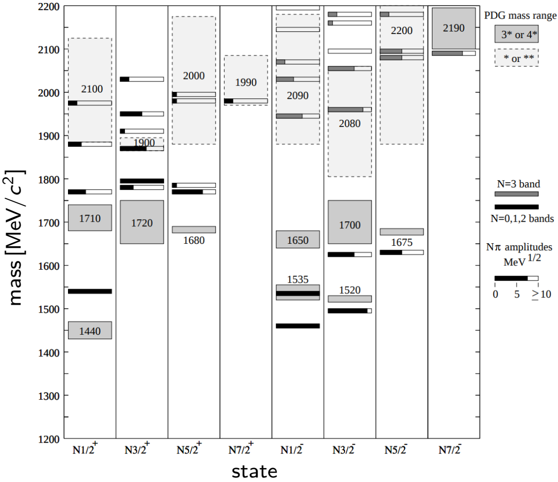
Motivation

- Investigate the last secrets of the strong interaction
- E.g. many nucleon resonances predicted
- Still many empty spaces

- Huge J/ψ dataset of BESIII

Exitied Nucleon Resonances



Motivation

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Decay Channel :

$$J/\psi \longrightarrow \bar{p}\,\Sigma^+\,K^0_S + c.c.$$

$$K^0_S \to \pi^+\pi^-$$

$$\Sigma^+ \to \pi^0\,p, \quad \pi^0 \to \gamma\gamma$$

K^0_S ($c\tau \approx 2.8$ cm) and
Σ^+ ($c\tau \approx 2.4$ cm) are long lived

- first measurement
- search for resonances in the decay
- expected branching ratio of $\sim 10^{-4}$ calculated by isospin symmetry ($J/\psi \to \bar{p}K^+\Sigma^0$)

BESIII experiment

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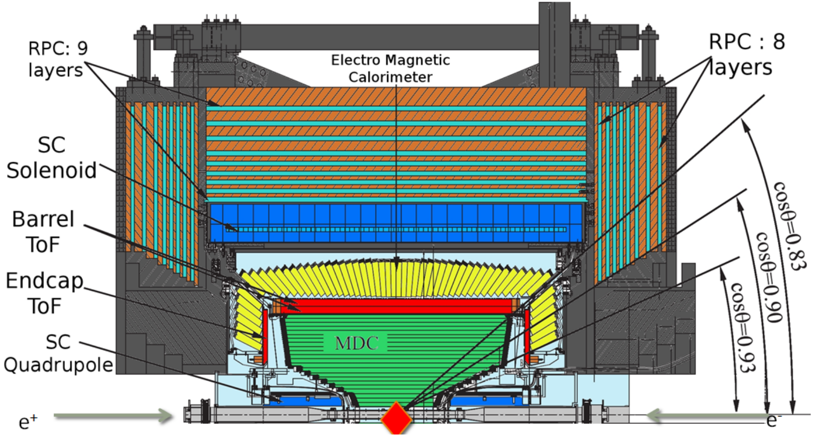


- Main Drift Chamber
- Time of Flight System
- Electromagnetic Calorimeter
- Muon Chamber

Event Selection

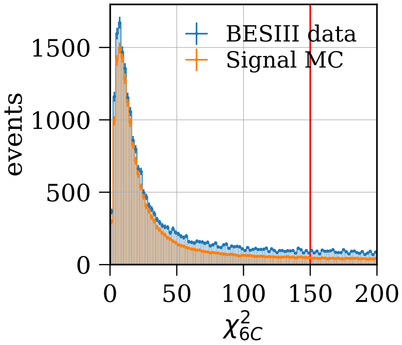
$$J/\psi \longrightarrow \bar{p}\,\Sigma^+\,K_S^0 + c.c.$$

$K_S^0 \rightarrow \pi^+\pi^-$

$\Sigma^+ \rightarrow \pi^0 p$

$\pi^0 \rightarrow \gamma\gamma$

- exact 4 charged tracks
  - 2 identified as proton/antiproton
  - net charge 0
- at least 2 photons
- constrained kinematic fit :
  - → m_{Σ^+}
  - → m_{π^0}
  - → $P_{J/\psi}$
- $\chi^2_{6C} < 150$



Background contributions

Investigation of $J/\psi \rightarrow$ *anything* MC simulation samples

$\rightarrow$ Large discrepancies

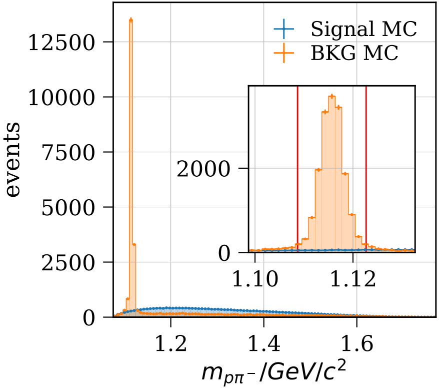
$\rightarrow$ Identification of various potential background channels

List of main distributions

Decay Channel		fraction
$J/\psi \rightarrow \bar{p}\Sigma^+ K_S^0$ +c.c.		9.3%
$J/\psi \rightarrow \bar{\Lambda}^0\Sigma^+\pi^-$ +c.c.	$\bar{\Lambda}^0 \rightarrow \bar{p}\pi^+$	33.4%
$J/\psi \rightarrow \Sigma(1385)^+\bar{\Sigma}^-$ +c.c.	$\Sigma(1385)^+ \rightarrow \Lambda^0\pi^+$	25.0%
$J/\psi \rightarrow \bar{p}p\pi^+\pi^-\pi^0$		10.0%
$J/\psi \rightarrow \bar{p}p\omega$	$\omega \rightarrow \pi^+\pi^-\pi^0$	7.7%
$J/\psi \rightarrow X$		14.6%

All channels decay in the same final state

- Large fractions of channels with Λ^0
- cut away Λ^0 background channels
- $|m_{\Lambda^0} - m_{p\pi^-}| > 7\,\mathrm{MeV/c^2}$

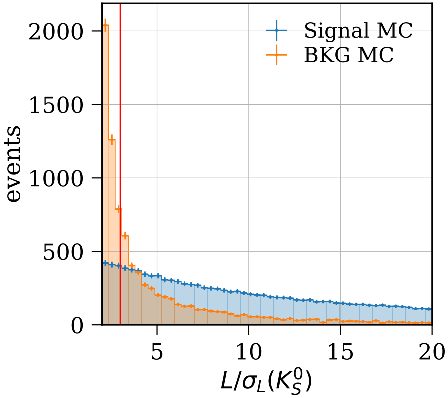


Background contributions

None of background channels contains K_S^0

$\rightarrow$ increase quality of reconstructed K_S^0 decay length L

$\rightarrow$ $L/\sigma_L(K_S^0) > 3$



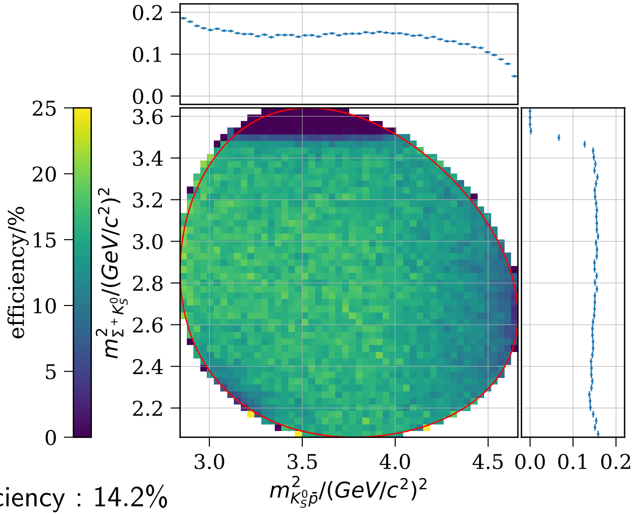
Background contributions

Decay Channel	suppression	fraction
$J/\psi \to \bar{p}\Sigma^+ K^0_S$+c.c.	9.9%	33.5%
$J/\psi \to \bar{\Lambda}^0\Sigma^+\pi^-$ +c.c.	94.1%	7.9%
$J/\psi \to \Sigma(1385)^+\bar{\Sigma}^-$ +c.c.	96.6%	3.3%
$J/\psi \to \bar{p}p\pi^+\pi^-\pi^0$	52.5%	19.0%
$J/\psi \to \bar{p}p\omega$	53.7%	14.2%
$J/\psi \to X$	62.2%	22.0%

- decay $J/\psi \to \Sigma(1385)^+\bar{\Sigma}^-$ is over estimated in this simulation
- Background suppression 81.7%

Efficiency

MC simulation of signal events (phase space)

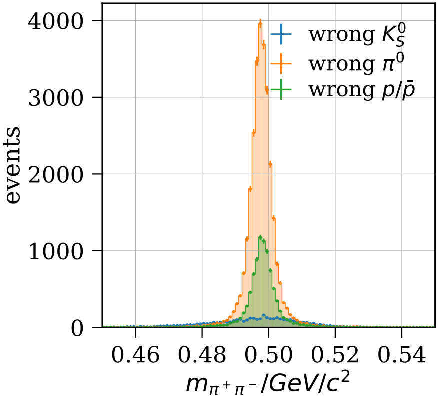


overall efficiency : 14.2%

Correctness of reconstructed events

- test on signal MC
- correctness of reconstructed events (86.2%)
  - K_S^0 : 98.6%
  - $p_{\Sigma^+}/\bar{p}_{J/\psi}$: 96.8%
  - π^0 : 90.0%
- all peaking at $m_{K_S^0}$

$\rightarrow$ counted as signal



Extraction of event yield

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Fit to invariant $m_{\pi^+\pi^-}$

$\rightarrow$ Extract the number of K_S^0

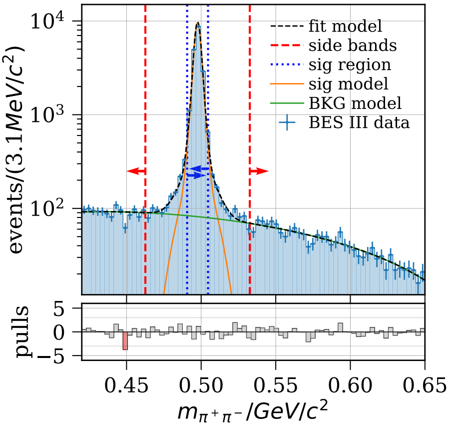
constrain background shape

$\rightarrow$ fit to K_S^0 side bands

Extract signal yield by fit signal shape (3 Gaussians) to data with background parameters fixed

$$N_{\text{sig}} = 18\,799 \pm 142$$

$\rightarrow$ purity is 98% in the $\sim 2\sigma$



Branching fraction determination

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$$\mathcal{BF}(J/\psi \to \bar{p}\Sigma^{+}K_S^0) = \frac{N_{sig}}{N_{J/\psi}} \cdot \frac{1}{\epsilon_{\text{rec}}} \cdot \frac{1}{\prod_i \mathcal{BF}i}$$

- $N_{\text{sig}} = 18\,799 \pm 142$
- $N_{J/\psi} = (1310.6 \pm 7.0) \times 10^6$
- ϵ_{rec}=(14.199 ± 0.029)% calculated on PHSP MC

$\prod_i \mathcal{BF}i = \mathcal{BF}(K_S^0 \to \pi^+\pi^-) \cdot \mathcal{BF}(\Sigma^+ \to p\pi^0) \cdot \mathcal{BF}(\pi^0 \to \gamma\gamma)$

- $\mathcal{BF}(K_S^0 \to \pi^+\pi^-) = (69.20 \pm 0.05)\%$
- $\mathcal{BF}(\Sigma^+ \to p\pi^0) = (51.57 \pm 0.30)\%$
- $\mathcal{BF}(\pi^0 \to \gamma\gamma) = (98.823 \pm 0.034)\%$

$$\mathcal{BF}(J/\psi \to \bar{p}\Sigma^{+}K_S^0) = (X.XXX \pm 0.022_{\text{stat.}}) \cdot 10^{-4}$$

Fitting

Fit range	0.20%
Sideband	0.30%
Signal Model	0.54%
BKG Model	0.34%

Selection

$L/\sigma_L(K^0_S) > 3$	0.39%
$\lvert m_{\bar{p}\pi^+} - m_{\Lambda^0} \rvert > 7\,\mathrm{MeV}/c^2$	0.07%
$\chi^2_{6c} < 150$	0.39%

efficiency

Signal MC Model	$< 5.00\%$
Signal MC statistic	0.20%

Decay Reconstruction

2 charged tracks	2.00%
2 good photons	2.00%
2 PID	2.00%
Σ^+	"prompt"
K^0_S	1.22%
π^0	1.05%

External

$N_{J/\psi}$	0.54%
$\mathcal{BF}(K^0_S \to \pi^+\pi^-)$	0.07%
$\mathcal{BF}(\Sigma^+ \to p\pi^0)$	0.06%
$\mathcal{BF}(\pi^0 \to \gamma\gamma)$	0.03%

total $\sim$6.40%

Summary

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Presented

- Branching fraction measurement
- Systematic studies almost finished

Results

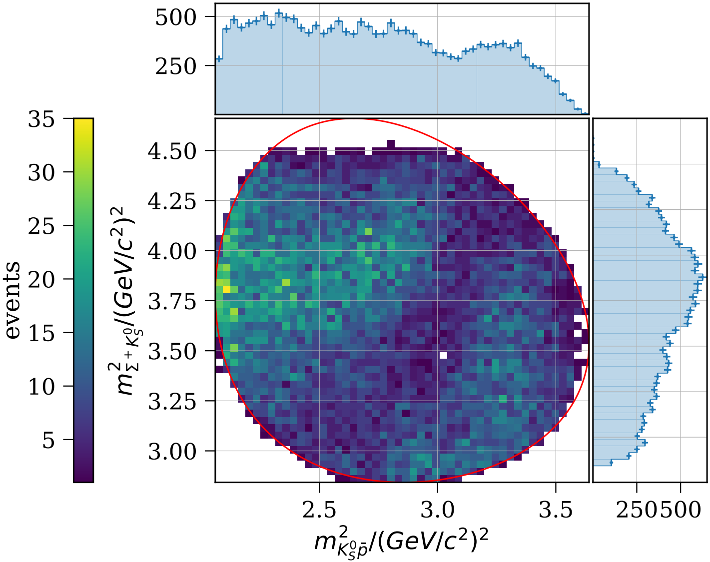
- First measurement
  $\mathcal{BF}(J/\psi \to \bar{p}\Sigma^+ K_S^0) = (X.XX \pm 0.02_{\text{stat.}} \pm 0.18_{\text{sys.}}) \cdot 10^{-4}$
- high purity : $98.21 \pm 0.04\%$

What's next ?

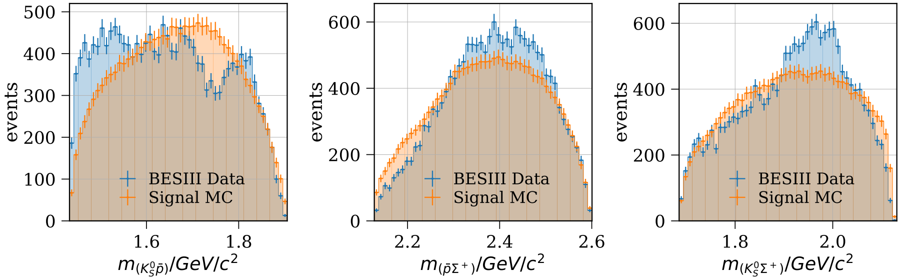
- Use amplitude model for signal Monte Carlo
- Use the complete J/ψ datasets from BESIII

Backup

Dalitz Plot


500
250
35
30
25
20
15
10
5
events
4.50
4.25
4.00
3.75
3.50
3.25
3.00
$m^2_{\Sigma^+ K^0_S}/(GeV/c^2)^2$
2.5
3.0
3.5
$m^2_{K^0_S \bar{p}}/(GeV/c^2)^2$
250500

Invariant Masses



Σ^* resonances

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Resonances	Quantennumbers	mass	width	Decay Fraction	Status
		$\Sigma^* \rightarrow N\bar{K}$			
$\Sigma(1385)^+$	$I(J^p) = 1(\frac{3}{2}^+)$	1.383	0.036	-%	****
$\Sigma(1660)$	$I(J^p) = 1(\frac{1}{2}^+)$	1.660	0.100	(10-30)%	***
$\Sigma(1670)$	$I(J^p) = 1(\frac{3}{2}^-)$	1.670	0.060	(7-13)%	****
$\Sigma(1750)$	$I(J^p) = 1(\frac{1}{2}^-)$	1.750	0.090	(10-40)%	****
$\Sigma(1775)$	$I(J^p) = 1(\frac{5}{2}^-)$	1.775	0.120	(37-43)%	****
$\Sigma(1915)$	$I(J^p) = 1(\frac{5}{2}^+)$	1.915	0.120	(5-15)%	****
$\Sigma(1940)$	$I(J^p) = 1(\frac{3}{2}^-)$	1.940	0.220	<20%	***
$\Sigma(2030)$	$I(J^p) = 1(\frac{7}{2}^+)$	2.025	0.120	(17-23)%	****

- only showing resonances with a status at least ***

N^* resonances

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Resonances	Quantennumbers	mass	width	Decay Fraction	Status
		$N^* \to \Sigma K$			
$N(1875)$	$I(J^p) = \frac{1}{2}(\frac{3}{2}^-)$	1.875	0.120	seen	***
$N(1880)$	$I(J^p) = \frac{1}{2}(\frac{1}{2}^+)$	1.880	0.300	(10-24)%	***
$N(1895)$	$I(J^p) = \frac{1}{2}(\frac{1}{2}^-)$	1.895	0.120	(6-20)%	****
$N(1900)$	$I(J^p) = \frac{1}{2}(\frac{3}{2}^+)$	1.920	0.200	(3-7)%	****
$N(2060)$	$I(J^p) = \frac{1}{2}(\frac{5}{2}^-)$	2.070	0.400	(1-5)%	***

- only showing resonances with a status at least ***