Study of J/ψ and $\psi(3686) \to \Sigma^+\bar{\Sigma}^-$

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On behalf of BESIII collaboration

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Outline

- Introduction
- Branching fraction measurement
- Polarization
- Summary

Motivation

- Polarization
  - Studies of two-body hyperon weak decays plays an important role in the study of the fundamental symmetries P and CP.
  - The polarization of spin ½ hyperon can be determined in two-body weak decays by $(1 + \alpha_0 \mathbf{P}_{\Sigma^+} \hat{\mathbf{p}}/4\pi)$, where $\alpha_0 = -0.980^{+0.017}_{-0.013}$

The decay of $\Sigma^+ \to p\,\pi^0$

Parity violation S state

Parity conservation P state

$$\alpha = \frac{2\,\mathrm{Re}(S^* P)}{|S|^2 + |P|^2}, \quad \beta = \frac{2\,\mathrm{Im}(S^* P)}{|S|^2 + |P|^2}, \quad \gamma = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}$$

α, β, γ could be determined experimentally.

T. D. Lee and C. N. Yang, Phys. Rev. 108,1645 (1957).

F. Harris, O. E. Overseth, L. Pondrom and E. Dettmann,Phys. Rev. Lett. 24, 165 (1970).

Motivation

- Polarization
  - Studies of two-body hyperon weak decays plays an important role in the study of the fundamental symmetries P and CP.
  - The polarization of spin ½ hyperon can be determined in two-body weak decays by $(1+\alpha_0 \mathbf{P}_{\Sigma^+}\hat{\mathbf{p}}/4\pi)$, where $\alpha_0 = -0.980^{+0.017}_{-0.013}$
  - If the relative phase between hadronic form factor is not zero(Polarized), the decay parameters α_0 and $\bar{\alpha}_0$ could be simultaneous and direct measured, then test CP symmetry.

(details in slide 13)

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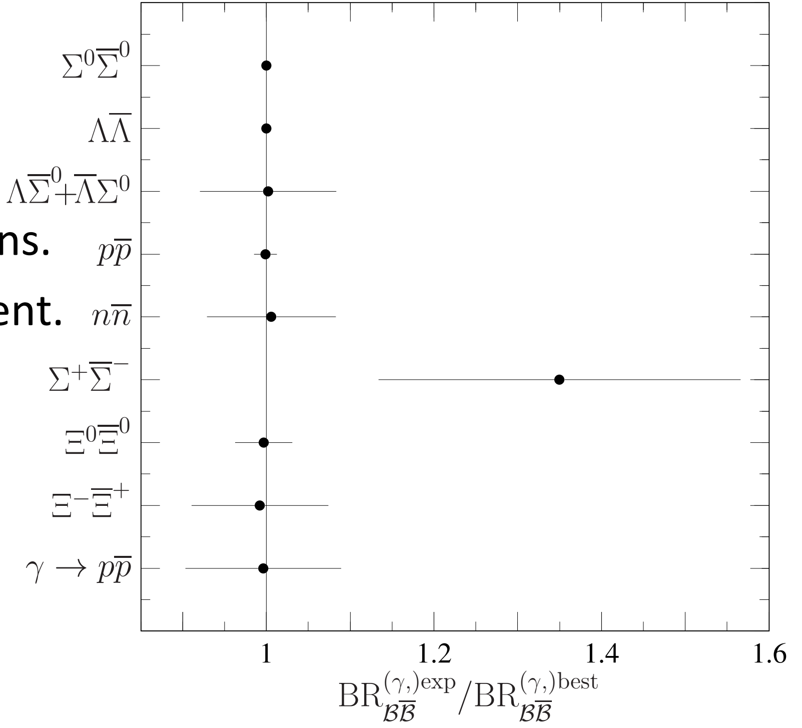
Motivation

- Branching fractions
  - Two-body baryonic decays of charmonium provide a good laboratory for both testing pQCD and studying the properties of baryons.
  - Improve the branching fraction measurement.
  - Test 12% rule for J/ψ and ψ(3686) decays.

$$Q = \frac{\mathcal{B}_{\psi(3686)\to h}}{\mathcal{B}_{J/\psi\to h}} = \frac{\mathcal{B}_{\psi(3686)\to l^+l^-}}{\mathcal{B}_{J/\psi\to l^+l^-}} \approx (12.4 \pm 0.4)\%$$

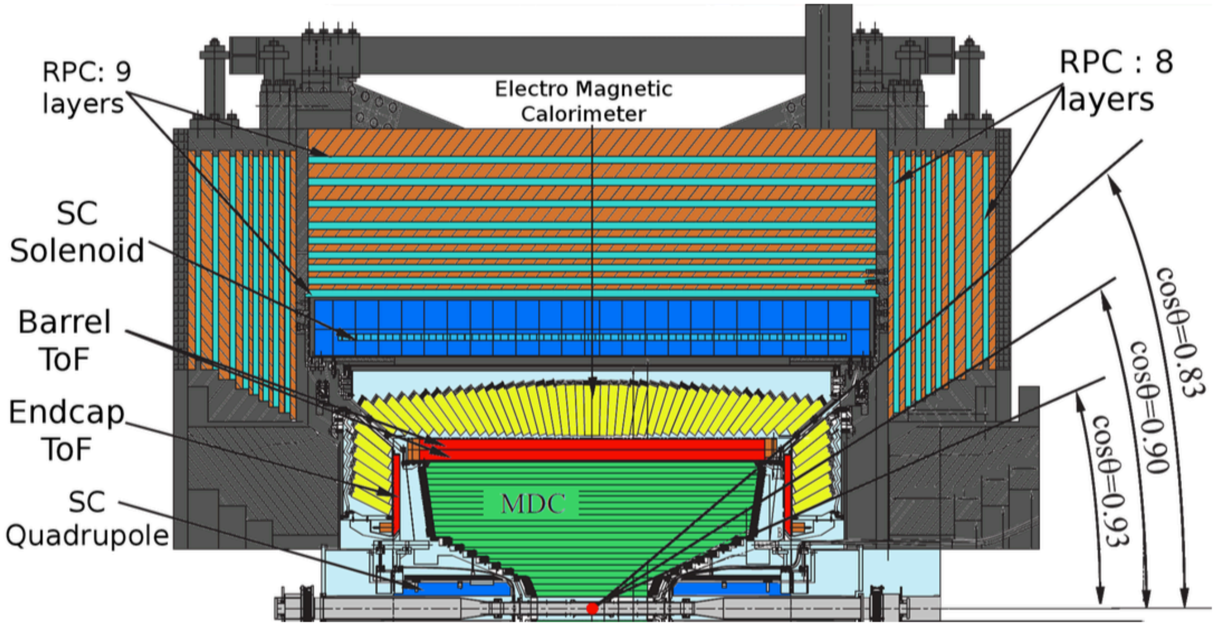
The larger difference in the branching fraction measurement for J/ψ -> $\Sigma^+ \bar{\Sigma}^-$ between theory and experiment comparing other baryons

BR(J/ψ-> $\Sigma^+ \bar{\Sigma}^-$) =(15.0±2.4) x 10^{-4} (PDG)



Rinaldo baldini Ferroli, Alessio Mangoni, Simone Pacetti and Kai Zhu, arXiv: 1905.01069

BESIII Experiment



- Main Drift Chamber (MDC)
  $\sigma(p)/p = 0.5\%$
  $\sigma_{dE/dX} = 5.0\%$
- Time-of-flight (TOF)
  $\sigma(t) = 80\text{ps}$ (barrel)
  $\sigma(t) = 70\text{ps}$ (endcap)
- Electro Magnetic Calorimeter (EMC)
  $\sigma(E)/E = 2.5\%$
  $\sigma_{z,\phi}(E) = 0.5 – 0.7$ cm
- RPC MUON Detector
  $\sigma(xy) < 2$ cm

Data taken at J/ψ and $\psi(3686)$ in 2009 and 2012

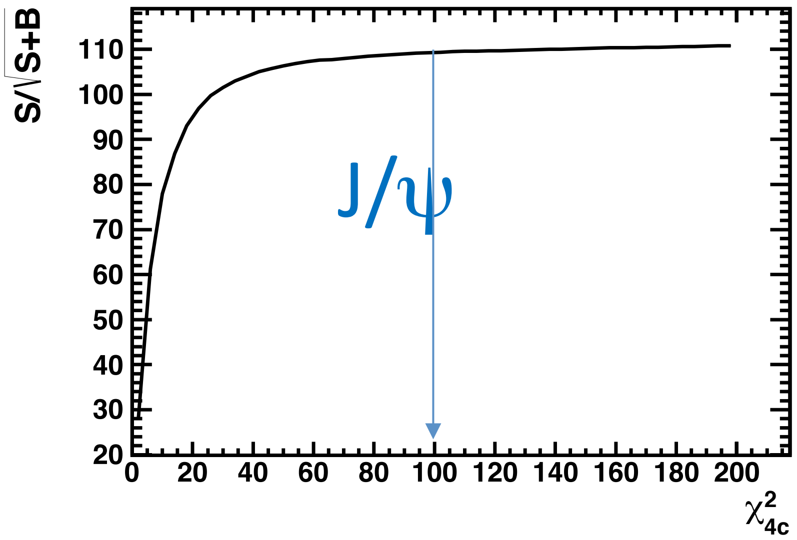
1.31 Billion (J/ψ) and 448 million ($\psi(3686)$)

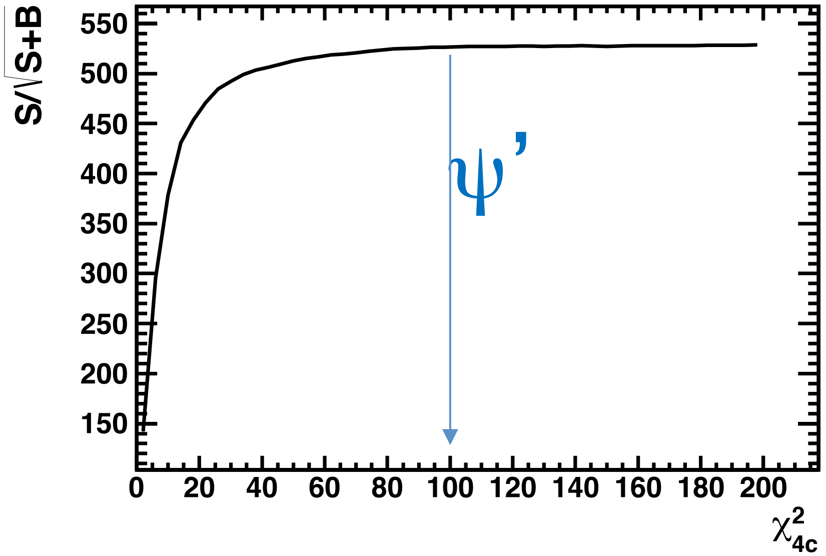
Event selections

- Charged tracks
  - ✓ $|Vr|<2$ cm, $|Vz|<10$ cm, $|\cos\theta|<0.93$
  - ✓ nGood ＝2
- Particle identification
  - ✓ $N_p = N_{\bar{p}} = 1$
- At least 4 good photons
- At least 2 π^0 candidates
- Kinematic fit ($\chi^2_{4c} < 100$)

- Minimize the combination of
  - ✓ $(M_{p\pi 0} - M_\Sigma)^2 + (M_{\bar{p}\pi 0} - M_\Sigma)^2$
- J/ψ mass window cut (for $\psi(3686)$ decay)
  - ✓ Remove $\psi(3686) \to \pi^0 \pi^0 J/\psi$, $J/\psi \to p\bar{p}$ events

Optimization of χ^2_{4c}





S is MC signal, B is from the inclusive MC study

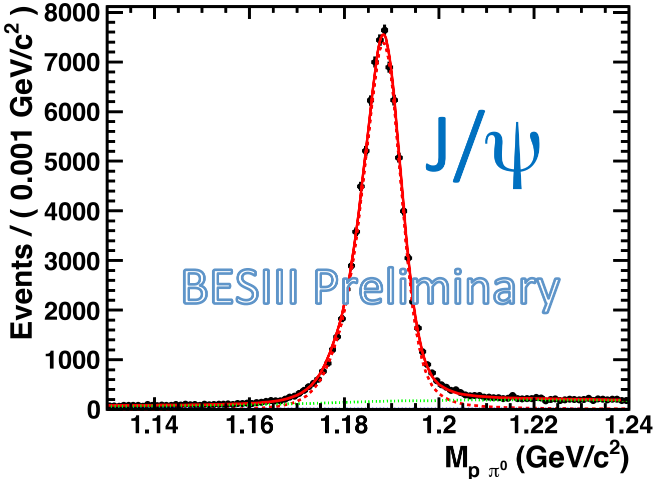
Background analysis

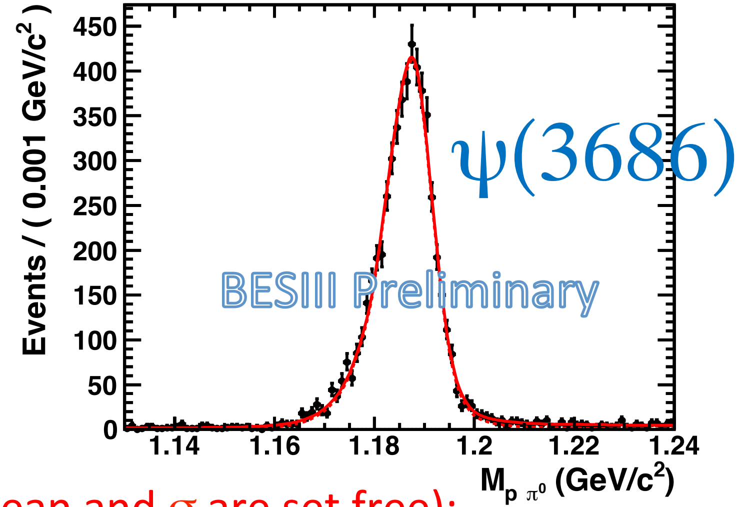
- The background channels are studied by the inclusive MC sample of J/ψ and $\psi(3686)$, and there are no peaking background channels.

- The background levels are estimated to be 4.7% for J/ψ and 1.4% for $\psi(3686)$.

- The QED background is negligible by analyzing the continuum data.

Branching fractions





Signal: MC shape ⊗ Gaussian function(mean and σ are set free);
Background: 2nd order polynomial function

Channel	N_{sig}	$\varepsilon_{MC}(\%)$
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	83432 ± 355	23.4
$\psi(3686) \to \Sigma^+\bar{\Sigma}^-$	5356 ± 81	19.2

By requiring $M_{(\bar{p}\ \pi 0)}$ in (1.17 – 1.2 GeV),
Fit the invariant mass of p and π^0

Branching fractions

$$\mathscr{B}(X) = \frac{N_{sig}(X)}{\varepsilon(X) \times \Pi\mathscr{B}_i \times N_{total}}$$

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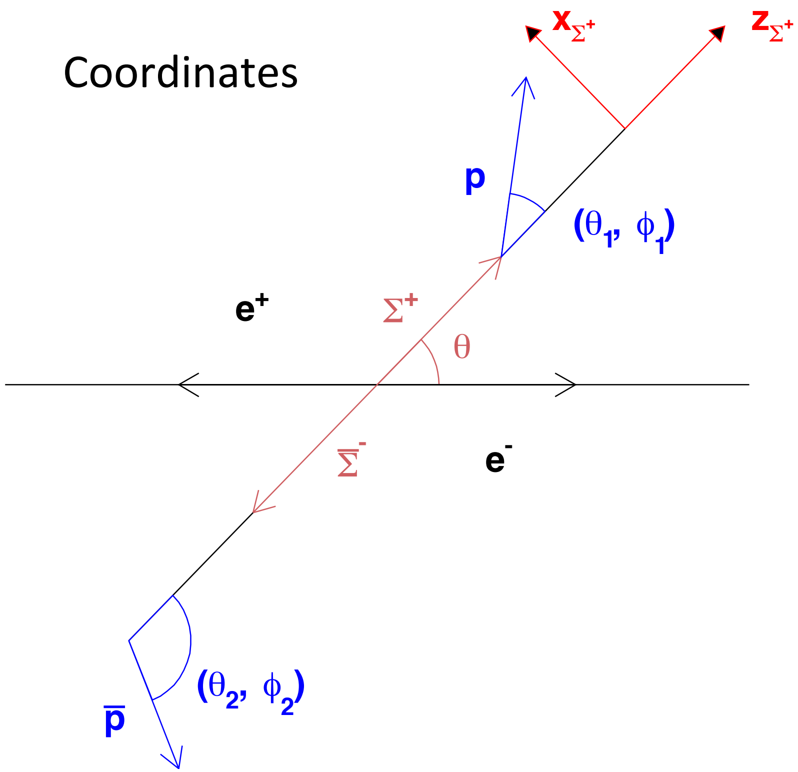
Channel	Branching fraction (10^{-4})
$J/\psi \to \Sigma^+\bar{\Sigma}^-$ (Prediction)	11.15±0.05(stat) (11.10±0.86)
$J/\psi \to \Sigma^+\bar{\Sigma}^-$ (PDG)	15.0±2.4
$\psi(3686) \to \Sigma^+\bar{\Sigma}^-$	2.52±0.04(stat)
$\psi(3686) \to \Sigma^+\bar{\Sigma}^-$ (PDG)	2.51±0.21

The total systematic uncertainty studies are on going, and the size is less than 5%.

Polarization

Coordinates



θ1, ϕ1, θ2, ϕ2 are read in this coordinate.

$$\mathbf{e}_z = \hat{\mathbf{p}},$$
$$\mathbf{e}_y = \frac{1}{\sin\theta}(\hat{\mathbf{p}} \times \hat{\mathbf{k}}),$$
$$\mathbf{e}_x = \frac{1}{\sin\theta}(\hat{\mathbf{p}} \times \hat{\mathbf{k}}) \times \hat{\mathbf{p}}.$$

where p is the direction of Σ^+, k is the direction of electron beam.

Formulas

$$d\sigma \propto \mathcal{W}(\boldsymbol{\xi})d\boldsymbol{\xi} \qquad \boldsymbol{\xi} = (\theta, \theta_p, \phi_p, \theta_{\bar{p}}, \phi_{\bar{p}})$$

Phys. Lett. B 772, 16 (2017)

$$\begin{aligned}\mathcal{W}(\boldsymbol{\xi}) =& \mathcal{T}_0(\boldsymbol{\xi}) + \alpha_\psi \mathcal{T}_5(\boldsymbol{\xi}) \\ & \boxed{-\alpha_0\bar{\alpha}_0 \left(\mathcal{T}_1(\boldsymbol{\xi}) + \sqrt{1-\alpha_\psi{}^2}\cos(\Delta\Phi)\mathcal{T}_2(\boldsymbol{\xi}) + \alpha_\psi \mathcal{T}_6(\boldsymbol{\xi})\right)} \\ & \boxed{+\sqrt{1-\alpha_\psi{}^2}\sin(\Delta\Phi)\left(\alpha_0\mathcal{T}_3(\boldsymbol{\xi}) - \bar{\alpha}_0\mathcal{T}_4(\boldsymbol{\xi})\right)}\end{aligned}$$

SPIN CORRELATIONS

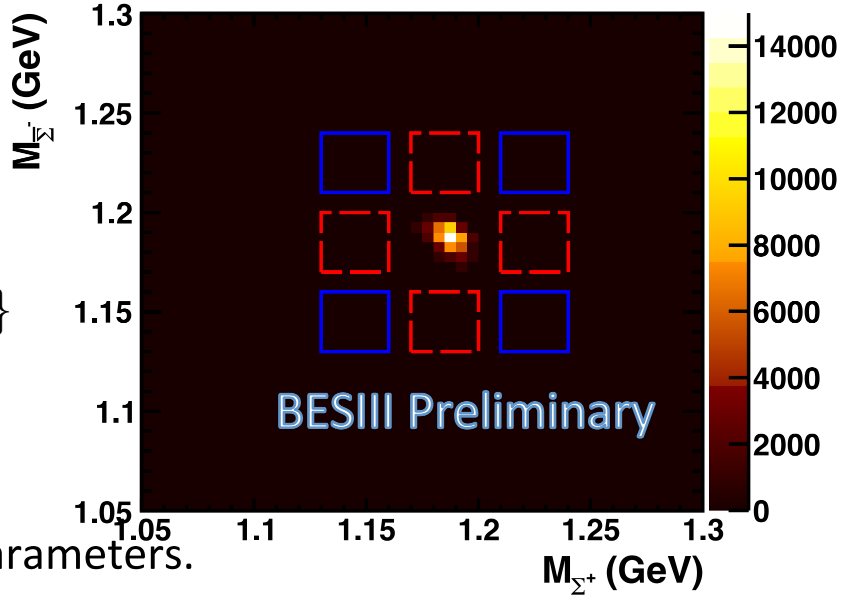
POLARIZATIONS

$$\begin{aligned}\mathcal{T}_0(\boldsymbol{\xi}) =& 1 \\ \mathcal{T}_1(\boldsymbol{\xi}) =& \sin^2\theta\sin\theta_p\sin\theta_{\bar{p}}\cos\phi_p\cos\phi_{\bar{p}} + \cos^2\theta\cos\theta_p\cos\theta_{\bar{p}} \\ \mathcal{T}_2(\boldsymbol{\xi}) =& \sin\theta\cos\theta\left(\sin\theta_p\cos\theta_{\bar{p}}\cos\phi_p + \cos\theta_p\sin\theta_{\bar{p}}\cos\phi_{\bar{p}}\right) \\ \mathcal{T}_3(\boldsymbol{\xi}) =& \sin\theta\cos\theta\sin\theta_p\sin\phi_p \\ \mathcal{T}_4(\boldsymbol{\xi}) =& \sin\theta\cos\theta\sin\theta_{\bar{p}}\sin\phi_{\bar{p}} \\ \mathcal{T}_5(\boldsymbol{\xi}) =& \cos^2\theta \\ \mathcal{T}_6(\boldsymbol{\xi}) =& \cos\theta_p\cos\theta_{\bar{p}} - \sin^2\theta\sin\theta_p\sin\theta_{\bar{p}}\sin\phi_p\sin\phi_{\bar{p}}.\end{aligned}$$

Fitting method

$$\mathscr{L} = \prod_{i=1}^{n} Prob(\boldsymbol{\xi}_i, \boldsymbol{\Omega}) = \prod_{i=1}^{n} \frac{\mathcal{W}(\boldsymbol{\xi_i}, \boldsymbol{\Omega})}{\mathcal{N}}$$

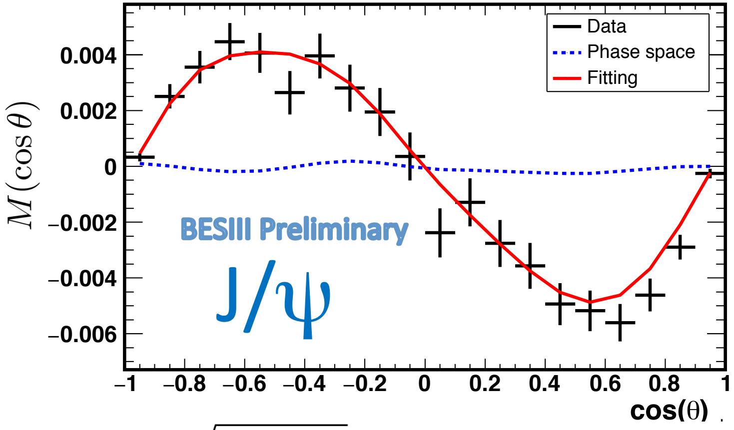
$$\boldsymbol{\Omega} \;=\; \{\alpha_{J/\psi}, \alpha_{\psi(3686)}, \Delta\Phi_{J/\psi}, \Delta\Phi_{\psi(3686)}, \alpha_0, \bar{\alpha}_0\}$$

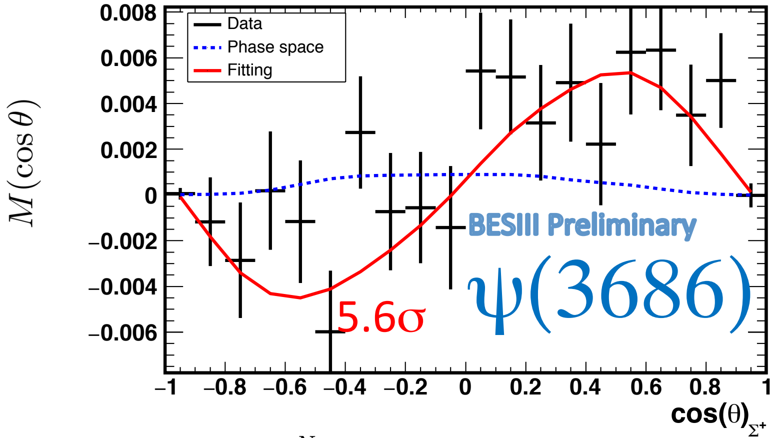


The MINUIT package in CERN library with Log-Likelihood method is used to yield the fitting parameters.

The background events are estimate by two-dimension sidebands of red and blue areas.

Fitting results





$$\frac{dM}{d\cos\theta} \sim \sqrt{1-\alpha_\psi^2}\alpha_0 \sin\Delta\Phi \cos\theta \sin\theta$$

Parameters	These measurements
$\alpha_{J/\psi}$	-0.507 $\pm$ 0.006 $\pm$ 0.002
$\Delta\Phi_{J/\psi}$	-0.269 $\pm$ 0.012 $\pm$ 0.006
$\alpha_{\psi(3686)}$	0.676 $\pm$ 0.03 $\pm$ 0.006
$\Delta\Phi_{\psi(3686)}$	0.376 $\pm$ 0.07 $\pm$ 0.009
α_0	-0.999 $\pm$ 0.037 $\pm$ 0.010
$\bar{\alpha}_0$	0.992 $\pm$ 0.037 $\pm$ 0.008

$$M(\cos\theta) = (m/N)\sum_i^{N_k}(\sin\theta_p^i \cos\phi_p^i - \sin\theta_{\bar{p}}^i \cos\phi_{\bar{p}}^i)$$

The points with error bars are the data, and the solid-line histogram is the global fit result. The dotted histogram is phase space model.

Test CP symmetry

$$A_{\mathrm{CP},\Sigma} = (\alpha_0 + \bar{\alpha}_0)/(\alpha_0 - \bar{\alpha}_0) = -0.015 \pm 0.037 \pm 0.008$$

Systematic uncertainties Decay parameters

Source	Eff correction	Fitting method	Kinematic fitting	BG estimation	Sum
$\alpha_{J/\psi}$	0.000	0.001	0.000	0.002	0.002
$\Delta\Phi_{J/\psi}$	0.001	0.002	0.001	0.005	0.006
$\alpha_{\psi(3686)}$	0.003	0.002	0.003	0.003	0.006
$\Delta\Phi_{\psi(3686)}$	0.000	0.009	0.000	0.002	0.009
α_0	0.000	0.009	0.004	0.002	0.010
$\bar{\alpha}_0$	0.001	0.006	0.005	0.001	0.008

- ✓ Efficiency correction: is estimated by control samples in different momentum and angle regions.
- ✓ Fitting method: is estimated by the input/output check.
- ✓ Kinematic fitting: is estimated by comparing the difference with/without helix parameter corrections
- ✓ Background: is estimated by change the sideband regions which are used to estimate the background events.

Summary

- Improve the precision of branching fractions in J/ψ and $\psi(3686)$ decays.
- The α values for J/ψ and $\psi(3686)$ are measured for the first time.
- α for anti-Σ^- is measured for the first time. CP symmetry has been tested which does not contradict with SM predictions(~3.6×10^{-6}).
- The phase between the hadronic form factors is measured for the first time in J/ψ and $\psi(3686) \to \Sigma^+\bar{\Sigma}^-$.
- The polarization is measured for the first time for any baryons at $\psi(3686)$.

Thanks for your attention!