Probe the Form Factors in decay $J/\psi \rightarrow \Sigma^0\bar{\Sigma}^0$

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Outline

1. *The angular distribution*
2. *The effect of magnetic field*
3. *Determine the $\alpha_{J/\psi}$ and Φ*
4. *Summary*

Update

$M(\Sigma^0 \to \Lambda\gamma)$

A) The amplitude of $\Sigma^0 \to \Lambda\gamma$ decay

$$M(\Sigma^0 \to \Lambda\gamma) \backsim (q \cdot p_\Lambda)(q \cdot p_\Sigma) - m_\Lambda m_\Sigma q \cdot s_\Lambda q \cdot s_\Sigma \tag{1}$$

B) Consider the decay of Λ

$$M(\Sigma^0 \to \Lambda\gamma) \sim 1 + \beta s_\Sigma \cdot p_\Lambda \tag{2}$$

The β replies α_Λ and the momentum of proton

$$\beta = -\alpha_\Lambda \frac{2m_\Sigma \left(\left(m_\Lambda^2 + m_\Sigma^2\right)\left(m_\Lambda^2 + m_p^2 - m_\pi^2\right) - 4m_\Lambda^2 p_p \cdot p_\Sigma\right)}{m_\Lambda \left(m_\Lambda^2 - m_\Sigma^2\right)^2 \sqrt{\frac{\left(m_\pi^2 - m_\Lambda^2\right)^2 - 2\left(m_\Lambda^2 + m_\pi^2\right)m_p^2 + m_p^4}{m_\Lambda^2}}} \tag{3}$$

C) β satisfies

$$\int d^3 p_p \beta = 0 \tag{4}$$

The angular distribution

A) The distribution is

$$\alpha_\Lambda \alpha_{\bar{\Lambda}} \Big(\sqrt{1-\alpha_\psi^2}\, \sin(2\theta) \cos(\Phi) \left(\sin(\theta_\Lambda)\cos(\phi_\Lambda)\cos(\theta_{\bar{\Lambda}}) - \cos(\theta_\Lambda)\sin(\theta_{\bar{\Lambda}})\cos(\phi_{\bar{\Lambda}})\right) +$$
$$\cos^2(\theta) \left(-(\sin(\theta_\Lambda)\sin(\theta_{\bar{\Lambda}})(\alpha_\psi \sin(\phi_\Lambda)\sin(\phi_{\bar{\Lambda}}) + \cos(\phi_\Lambda)\cos(\phi_{\bar{\Lambda}})) + \cos(\theta_\Lambda)\cos(\theta_{\bar{\Lambda}}))\right) +$$
$$\sin^2(\theta) \left(\sin(\theta_\Lambda)\sin(\theta_{\bar{\Lambda}})(\alpha_\psi \sin(\phi_\Lambda)\sin(\phi_{\bar{\Lambda}}) + \cos(\phi_\Lambda)\cos(\phi_{\bar{\Lambda}})) + \cos(\theta_\Lambda)\cos(\theta_{\bar{\Lambda}})\right)\Big) -$$
$$2\sqrt{1-\alpha_\psi^2}\, \sin(\theta)\cos(\theta)\sin(\Phi)\, \alpha_{\bar{\Lambda}} \sin(\theta_{\bar{\Lambda}})\sin(\phi_{\bar{\Lambda}}) +$$
$$\alpha_\Lambda \sqrt{1-\alpha_\psi^2}\, \sin(2\theta)\sin(\Phi)\sin(\theta_\Lambda)\sin(\phi_\Lambda) +$$
$$\alpha_\psi \cos(2\theta) + \alpha_\psi + 2$$

B) Replace α with β, we get the distribution for $J/\psi \to \Sigma^0\bar{\Sigma}^0$

The effect of magnetic field

A) The spin direction will rotate around the $\vec{B}$

$$H_I = -\vec{\mu} \cdot \vec{B} \tag{5}$$

$$|\psi(t)> = exp(-\frac{iH_I t}{\hbar})|\psi(0)>$$

B) The interaction time is $\tau = \frac{l}{v}$

C)

$$\begin{aligned} \vec{s}' &= e^{i\vec{\sigma}\cdot\vec{n}}\vec{s}e^{-i\vec{\sigma}\cdot\vec{n}} \\ &= \vec{s} + 2n(\hat{n} \times \vec{s}) \end{aligned} \tag{6}$$

where $\vec{n} = -\frac{e\hbar\tau}{4m_p}\vec{B}, \; n \sim 0.009$

The correction term

A) The distribution

$$\mathcal{W}' = \mathcal{W}_0 + \mathcal{T} + \bar{\mathcal{T}} \tag{7}$$

B)

$$\begin{aligned} \mathcal{T} &= \beta\lambda T_{\beta} + \lambda \cdot T_{\lambda} \\ \bar{\mathcal{T}} &= \bar{\beta}\bar{\lambda} T_{\bar{\beta}} + \bar{\lambda} \cdot T_{\bar{\lambda}} \end{aligned} \tag{8}$$

where the $\lambda = -\frac{e\hbar t B}{2m_p}$ replies the left of Λ and magnetic field

C)

$$\begin{aligned} T_{\lambda} =& \sqrt{1-\alpha_{\psi}^2}\sin(2\theta)\sin(\Phi)\left(\sin\left(\theta_1\right)\cos(\theta)\cos\left(\phi_1\right) + \sin(\theta)\cos\left(\theta_1\right)\right) \\ T_{\beta} =& p_6\sin^3(\theta) + p_2\sin(\theta) + p_3\cos^3(\theta) + p_1\cos(\theta) + p_4\sin(\theta)\cos^2(\theta) \\ &+ p_5\sin^2(\theta)\cos(\theta) \end{aligned}$$

correction term

$$p_1 = \frac{1}{2}\left(\sin(\theta_1)\cos(\theta_2)\sin(\phi_1)\left(-\sqrt{1-\alpha_\psi^2}\;\cos(\Phi) + 4\,\alpha_\psi + 1\right) + 3\,\alpha_\psi\,\sin(\theta_2)\cos(\theta_1)\sin(\phi_2)\right)$$

$$p_2 = \frac{1}{2}\sin(\theta_1)\sin(\theta_2)\left(\sin(\phi_1)\cos(\phi_2)\left(\sqrt{1-\alpha_\psi^2}\;\cos(\Phi) - 1\right) + \alpha_\psi\,\sin(\phi_2)\cos(\phi_1)\right)$$

$$p_3 = -\frac{1}{2}\sin(\theta_1)\sin(\theta_2)\left(\sin(\phi_1)\cos(\phi_2)\left(\sqrt{1-\alpha_\psi^2}\;\cos(\Phi) - 1\right) + \alpha_\psi\,\sin(\phi_2)\cos(\phi_1)\right)$$

$$p_4 = -\frac{3}{2}\left(\sin(\theta_1)\cos(\theta_2)\sin(\phi_1)\left(\sqrt{1-\alpha_\psi^2}\;\cos(\Phi) - 1\right) + \alpha_\psi\,\sin(\theta_2)\cos(\theta_1)\sin(\phi_2)\right)$$

$$p_5 = \frac{3}{2}\sin(\theta_1)\sin(\theta_2)\left(\sin(\phi_1)\cos(\phi_2)\left(\sqrt{1-\alpha_\psi^2}\;\cos(\Phi) - 1\right) + \alpha_\psi\,\sin(\phi_2)\cos(\phi_1)\right)$$

$$p_6 = \frac{1}{2}\left(\sin(\theta_1)\cos(\theta_2)\sin(\phi_1)\left(\sqrt{1-\alpha_\psi^2}\;\cos(\Phi) - 1\right) + \alpha_\psi\,\sin(\theta_2)\cos(\theta_1)\sin(\phi_2)\right)$$

Likelihood

A) PDF: $\mathcal{W}(\alpha, ...; \theta, ...)$

B) Likelihood

$$\mathcal{L} = \prod_{data} \frac{\mathcal{W}}{\mathcal{N}} \tag{9}$$

✓ The normalization factor $\mathcal{N}$ obtained by MC integral

$$\mathcal{N} = \sum \mathcal{W} \tag{10}$$

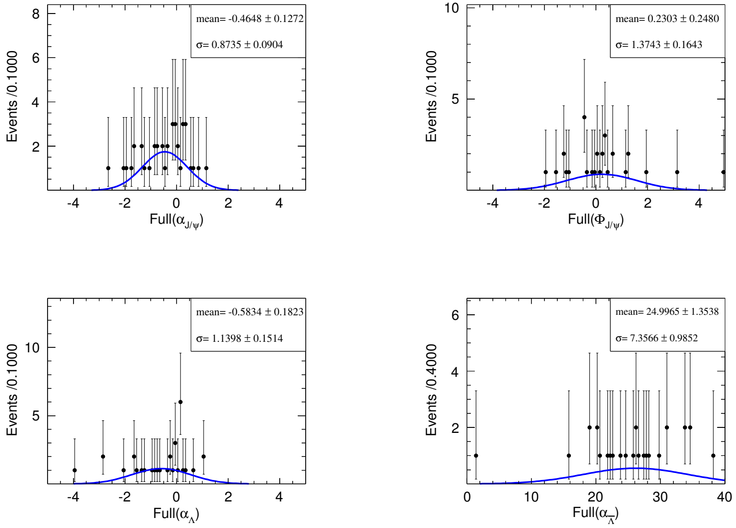
Fit result

parameters	value
$\alpha_{J/\psi}$	-0.425 ± 0.012
Φ	0.13 ± 0.05
α_{Λ}	0.45 ± 0.17
$\alpha_{\bar{\Lambda}}$	-0.09 ± 0.04

I/O check

parameters	input	output
$\alpha_{J/\psi}$	-0.425	-4.26 ± 0.12
Φ	-0.134	-0.156 ± 0.053
α_{Λ}	0.75	0.48 ± 0.16
$\alpha_{\bar{\Lambda}}$	-0.75	-0.84 ± 0.28

I/O check (2)



mean= -0.4648 ± 0.1272
σ= 0.8735 ± 0.0904
Events /0.1000
Full(α_J/ψ)
mean= 0.2303 ± 0.2480
σ= 1.3743 ± 0.1643
Events /0.1000
Full(Φ_J/ψ)
mean= -0.5834 ± 0.1823
σ= 1.1398 ± 0.1514
Events /0.1000
Full(α_Λ)
mean= 24.9965 ± 1.3538
σ= 7.3566 ± 0.9852
Events /0.4000
Full(α_Λ̄)

Summary

A) The α_{Λ} and $\alpha_{\bar{\Lambda}}$ can't be determined well, must be fixed.

B) The phase angle Φ is first measured, and $\alpha_{J/\psi}$ is consisted with the previous value.