Full Name: Wen-jing Zheng   Position: Ph.D. candidate   Supervisor: Shuang-shi Fang
Research Interests: Experimental particle physics (BESIII Collaboration)

Research topics:

1. Novel method to extract the femtometer structure of strange baryons using the vacuum polarization effect.
2. Partial wave analysis of $J/\psi \to \gamma\pi^0\pi^0\pi^0\pi^0$.
3. Measurement of the polarization of $\Lambda(1520)$ in $\Lambda(1520) \to \gamma\Lambda$.
4. Measurement of the branching fraction $\mathcal{B}(\Lambda(1520) \to \gamma\Sigma^0)$.

Novel method to extract the femtometer structure of strange baryons using the vacuum polarization effect

Wen-jing Zheng[1], Shuang-li Yang[1], Shuang-shi Fang[1] and Jian-ping Dai[2]

[1]Institute of High Energy Physics, [2]Yunnan University [3]IHEP

1. Abstract

One of the fundamental goals of particle physics is to gain microscopic understanding of the strong interaction. Electromagnetic form factors quantify the structure of hadrons in terms of charge and magnetization distributions. While the nucleon structure has been investigated extensively, data on hyperons is still scarce. It has recently been demonstrated that electron-positron annihilations into hyperon-antihyperon pairs provide a powerful tools to investigate their inner structure. We present a novel method useful for hyperon-antihyperon pairs of different types which exploits the cross section enhancement due to the vacuum polarization effect at the J/ψ resonance. Using the 10 billion J/ψ events collected with the BESIII detector, this allows a thorough determination of the hyperon structure. The result is essentially a precise snapshot of a $\bar{\Lambda}\Sigma^0$ ($\Lambda\bar{\Sigma}^0$) pair in the making, encoded in the form factor ratio and the phase. Their values are measured to be $R = 0.860 \pm 0.029(stat.) \pm 0.010(syst.)$, $\Delta\Phi_1 = (1.011 \pm 0.094(stat.) \pm 0.010(syst.))\ rad$ for $\bar{\Lambda}\Sigma^0$ and $\Delta\Phi_2 = (2.128 \pm 0.094(stat.) \pm 0.010(syst.))\ rad$ for $\Lambda\bar{\Sigma}^0$, respectively. Furthermore, charge-parity (CP) breaking is investigated for the first time in this reaction and found to be consistent with CP symmetry.

2. Introduction

- Hyperons timelike form factors can be accessed in electron-positron annihilations with the subsequent production of a hyperon-antihyperon pair.
- The timelike form factors can be seen as "snapshots" of the time evolution of a hyperon-antihyperon pair, carrying information about the space-like structure.
- The self-analyzing hyperon decays can be used to measure the hyperon polarization, thereby completely determining the form factors.
- For a hyperon-antihyperon pair of the same type, e.g. $\Lambda\bar{\Lambda}$, must occur from vector meson resonances that can decay strongly into a hyperon-antihyperon pair, as shown in Fig. 1(a).
- $e^+e^- \to J/\psi \to \bar{\Lambda}\Sigma^0$ is a purely electromagnetic process, as depicted in Fig. 1(b), which has the same final production vertex as Fig. 1(c).
- The electric and magnetic form factors of Fig. 1(c) can be extracted from Fig. 1(b) by correcting for the well known vacuum polarization.

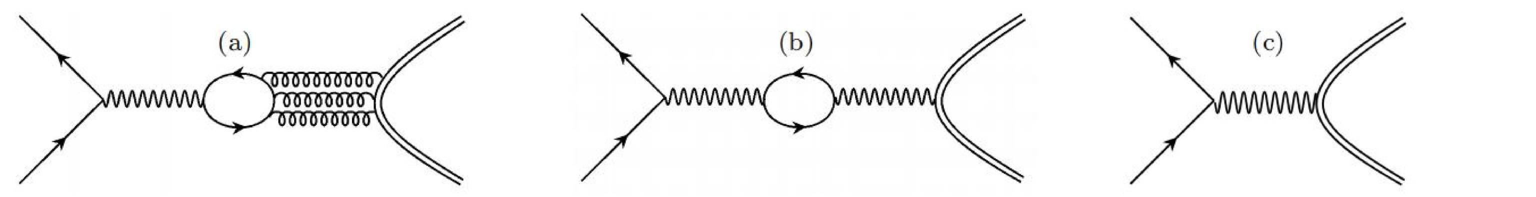
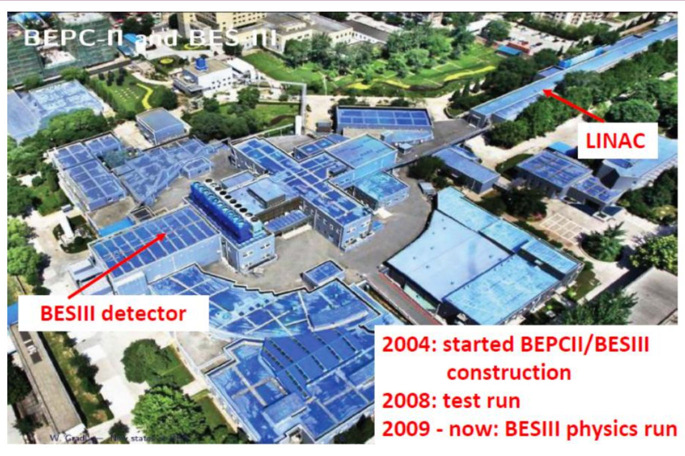


FIG. 1. **The Feynman diagrams for $e^+e^- \to hadrons$ in the vicinity of the J/ψ.** (a) strong process with intermediate J/ψ mediated by gluons, (b) electromagnetic process through the vacuum polarization of one virtual photon to a J/ψ, (c) continuum process without the J/ψ intermediate state but only one virtual photon.

3. Experimental Setup

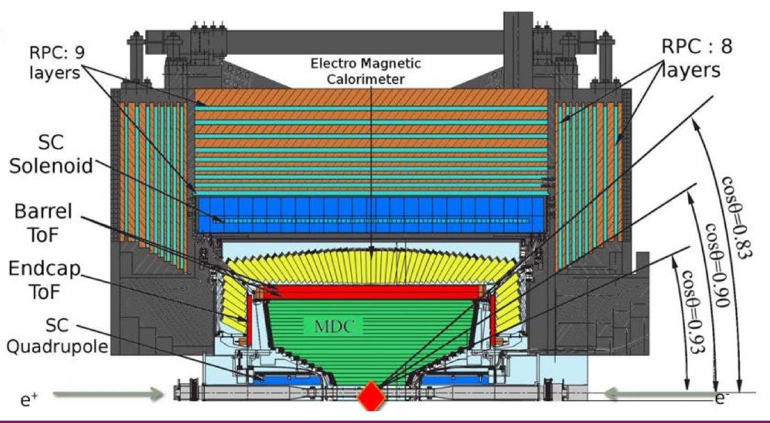


Beijing Electron Positron Collider (BEPCII)

Beam energy: 1-2.5 GeV
Design luminosity: 1×10^{33} cm^{-2}s^{-1}
Optimum energy: 1.89 GeV
Energy spread: 5.16 $\times10^{-4}$
Linac: ~200m Circular: ~240m
Double rings with tiny crossing angle

Beijing Spectrometer (BESIII)

Charged-particle momentum resolution:
0.5% @1GeV
Photon energy resolution:
2.5% (5%) for barrel (endcap) @1 GeV
dE/dx resolution:
6% for electrons from Bhabha process



4. Event Selection

- Tracks of charged particles are reconstructed from track-induced signals and the momenta are determined from the track curvature in the main drift chamber (MDC).
- The flight time of charged particles is recorded by a plastic scintillator time-of-flight system (TOF).
- Showers from photon clusters are reconstructed and energy deposits are measured in the electromagnetic calorimeter (EMC).
- Candidates for $\bar{\Lambda}(\to \bar{p}\pi^+)\Sigma^0(\to \gamma\Lambda \to p\pi^-)$ are required to have four charged tracks with net zero charge and at least one photon.
- The signal of $e^+e^- \to J/\psi \to \bar{\Lambda}(\to \bar{p}\pi^+)\Sigma^0(\to \gamma\Lambda \to \gamma p\pi^-)$ is extracted from $(10087 \pm 44) \times 10^6$ J/ψ events at $\sqrt{s} = 3.097$ GeV. The resulting signals of $\bar{\Lambda}(\Lambda)$ and $\Sigma^0(\bar{\Sigma}^0)$ are clearly observed, as shown in Figs. 2 and 3.

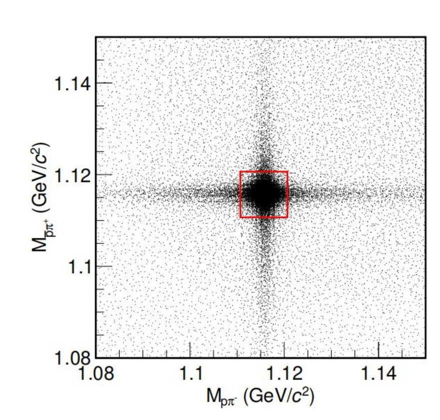


FIG. 2. **Distribution of $M_{p\pi^-}$ versus $M_{\bar{p}\pi^+}$ of the accepted candidates from data.** The red box denotes the signal region. The clusters of Λ and $\bar{\Lambda}$ are clearly observed.

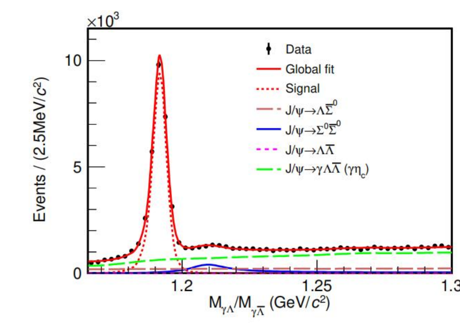


FIG. 3. **Fit to the $M_{\gamma\Lambda}/M_{\gamma\bar{\Lambda}}$ distribution of the accepted candidates from J/ψ data.** The black points with error bars are data, the red curve is the global fit, the red dotted curve is the $\Sigma^0/\bar{\Sigma}^0$ signal, the brown long-dashed curve shows the background from the conjugate channel, the blue curve is from $J/\psi \to \Sigma^0\bar{\Sigma}^0$, the pink dotted curve is from $J/\psi \to \Lambda\bar{\Lambda}$ and the green long-dashed curve is from $J/\psi \to \gamma\Lambda\bar{\Lambda}(\gamma\eta_c)$.

5. Helicity Analysis

- The probability of extracting the form factorsis described by the helicity angles $\xi = (\theta, \theta_\Lambda, \phi_\Lambda, \theta_p, \theta_{\bar{p}}, \phi_{\bar{p}})$ shown in Fig. 4.
- The structure of the six dimensional angular distribution is independent of the Σ^0 scattering angle, θ_{Σ^0}, and is written as $\mathcal{W}(\xi;\boldsymbol{\omega}) = \sum_{\mu,\nu=0}^{3}\sum_{\mu'=0}^{3} C_{\mu\nu} a_{\mu\mu'}^{\Sigma^0} a_{\mu'0}^{\Lambda} a_{\nu 0}^{\bar{\Lambda}}$, where $\omega = (\alpha_{J/\psi}, \Delta\Phi, \alpha_\gamma, \alpha_\Lambda, \alpha_{\bar{\Lambda}})$, the $C_{\mu\nu}(\theta;\alpha_{J/\psi}, \Delta\Phi)$ is a 4 × 4 spin density matrix, describing the spin configuration of the entangled hyperon-antihyperon pair. Here, we denote the angular distribution parameter, the relative phase and decay asymmetries for $\Sigma^0 \to \gamma\Lambda$, $\Lambda \to p\pi^-$, $\bar{\Lambda} \to \bar{p}\pi^+$ as $\alpha_{J/\psi}$, $\Delta\Phi$ α_γ, α_Λ and $\alpha_{\bar{\Lambda}}$, respectively.
- For electric and magnetic form factors, G_E and G_M, the relative phase $\Delta\Phi = arg(G_E/G_M)$ and the angular distribution parameter $\alpha_{J/\psi} = \frac{s-4M_Y^2R^2}{s+4M_Y^2R^2}$, where $R = \left|\frac{G_E}{G_M}\right|$ and M_Y is the mass of the final hyperon.
- These parameters are measured by incorporating the transverse polarization of Σ^0 in the joint angular distribution, as shown in Fig. 5.

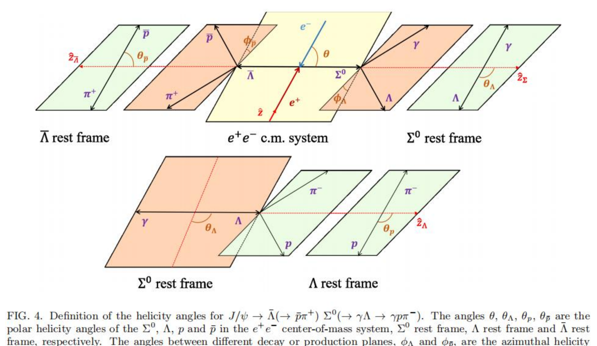


FIG. 4. Definition of the helicity angles for $J/\psi \to \bar{\Lambda}(\to \bar{p}\pi^+)\ \Sigma^0(\to \gamma\Lambda \to \gamma p\pi^-)$. The angles θ, θ_Λ, θ_p, $\theta_{\bar{p}}$ are the polar helicity angles of the Σ^0, Λ, p and $\bar{p}$ in the e^+e^- center-of-mass system, Σ^0 rest frame, Λ rest frame and $\bar{\Lambda}$ rest frame, respectively. The angles between different decay or production planes, ϕ_Λ and $\phi_{\bar{p}}$, are the azimuthal helicity angles of the Λ and $\bar{p}$ in the Σ^0 rest frame and Λ rest frame, respectively. In the e^+e^- center-of-mass system, the $\hat{z}$ is along the e^+ momentum direction, and the $\hat{z}_\Sigma$ is along the Σ^0 outgoing direction. In the Σ^0 rest frame, the polar axis is $\hat{z}_\Sigma$, $\hat{y}_\Sigma$ is along $\hat{z} \times \hat{z}_\Sigma$ and $\hat{z}_\Lambda$ is along the Λ outgoing direction. In the Λ rest frame, the polar axis is $\hat{z}_\Lambda$, and $\hat{y}_\Lambda$ is along $\hat{z}_\Sigma \times \hat{z}_\Lambda$. In the $\bar{\Lambda}$ rest frame, the polar axis is $\hat{z}_{\bar{\Lambda}}$, and $\hat{y}_{\bar{\Lambda}}$ is along $\hat{z} \times \hat{z}_{\bar{\Lambda}}$.

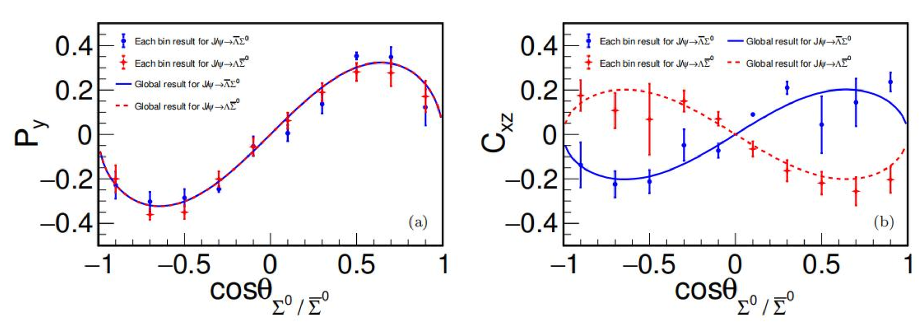


FIG. 5. Polarization P_y and spin correlations C_{xz} in $e^+e^- \to J/\psi \to \bar{\Lambda}\Sigma^0(\Lambda\bar{\Sigma}^0)$. The points with error bars, blue solid dot for $J/\psi \to \bar{\Lambda}\Sigma^0$ and red open double diamond for $J/\psi \to \Lambda\bar{\Sigma}^0$, are extracted in each $\cos\theta_{\Sigma^0}(\cos\theta_{\bar{\Sigma}^0})$ bin, and the blue solid curves denote the global expected dependence on $\cos\theta_{\Sigma^0}$ ($\cos\theta_{\bar{\Sigma}^0}$ for the red dotted curve).

6. Results

The fit yields $\alpha_{J/\psi} = 0.418 \pm 0.028(stat.) \pm 0.010(syst.)$, $\Delta\Phi_1 = (1.011 \pm 0.094(stat.) \pm 0.010(syst.))\ rad$ and $\Delta\Phi_2 = (2.128 \pm 0.094(stat.) \pm 0.010(syst.))\ rad$. The ratio $R = \left|\frac{G_E}{G_M}\right| = \frac{\sqrt{s}}{2M_Y}\sqrt{\frac{1-\alpha_{J/\psi}}{1+\alpha_{J/\psi}}}$ is determined to be $0.860 \pm 0.029(stat.) \pm 0.010(syst.)$ giving the ratio and relative phase of the electric and magnetic form factors GE and GM for $e^+e^- \to J/\psi \to \bar{\Lambda}\Sigma^0(\Lambda\bar{\Sigma}^0)$ at $\sqrt{s} = 3.097$ GeV, with clear transverse spin polarizations of the Σ^0 observed. The $\Delta\Phi_{CP} = |\pi - (\Delta\Phi_1 + \Delta\Phi_2)| = 0.003 \pm 0.133(stat.) \pm 0.014(syst.)$, which is consistent with zero and indicates no evident direct CP violation in the decays of $J/\psi \to \bar{\Lambda}\Sigma^0$ and $J/\psi \to \Lambda\bar{\Sigma}^0$.