Measurement of $\sin(2\beta)$ at Belle II using $B^0 \to J/\psi K_S^0$ and $\psi(2S)K_S^0$ Decays

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1. The Belle II Experiment

The **Belle II** experiment at the SuperKEKB e^+e^- collider (KEK, Japan) is designed to search for **New Physics** (NP) in heavy flavor decays.

- **SuperKEKB**: World's highest luminosity ($\sim 5.1 \times 10^{34}$ cm^{-2}s^{-1}), produces $B\bar{B}$ pairs at the $\Upsilon(4S)$ resonance ($\sqrt{s} \approx 10.58$ GeV).
- **Detector**: Features excellent vertexing and particle ID.
  - **Vertex Detector (PXD+SVD)**: Precise Δt measurement.
  - **CDC, TOP, ARICH**: Tracking and PID.
  - **ECL**: Photon/electron detection.
- **Goal**: Perform high-precision studies of **CP violation** and rare decays.

2. The Theory of $\sin(2\beta)$

In the Standard Model (SM), CP violation is described by the CKM matrix. The angle β (ϕ_1) is a key parameter.

- **The "Golden Channel"**: The decay $B^0 \to J/\psi K_S^0$ is ideal for measuring $\sin(2\beta)$. It is a **CP eigenstate** with low theoretical uncertainty.
- **Time-Dependent CP Asymmetry**:

  $$A_{CP}(\Delta t) = \frac{N(\Delta t) - \bar{N}(\Delta t)}{N(\Delta t) + \bar{N}(\Delta t)} = S \sin(\Delta m_d \Delta t)$$

  For the $b \to c\bar{c}s$ transition, the mixing parameter $S = \sin(2\beta)$.
- **NP Sensitivity**: The global CKM fit predicts $\sin(2\beta) = 0.699 \pm 0.011$. A significant deviation would be a clear sign of **New Physics**.

3. My Analysis: $\sin(2\beta)$ with $J/\psi K_S^0$ and $\psi(2S)K_S^0$

I measure $\sin(2\beta)$ using:

- $B^0 \to J/\psi K_S^0$ ($J/\psi \to \ell^+\ell^-$, $K_S^0 \to \pi^+\pi^-/\pi^0\pi^0$)
- $B^0 \to \psi(2S)K_S^0$ ($\psi(2S) \to J/\psi\pi^+\pi^-$, $J/\psi \to \ell^+\ell^-$)

The analysis is developed and validated on **Monte Carlo (MC)** simulation.

3.1 Signal Selection & Background Analysis

A robust event selection is crucial.

- **Selection Criteria**:
  - **Kinematic Variables**: Beam-constrained mass (M_{bc}) and energy difference (ΔE).

$$M_{\text{bc}} = \sqrt{E_{\text{beam}}^2 - p_B^2} \qquad \text{(Peaks at } M_B\text{)}$$

$$\Delta E = E_B - E_{\text{beam}} \qquad \text{(Peaks at 0)}$$

  - **Particle ID (PID)**: Efficient K/π separation.
  - **Vertex Quality**: For precise Δt measurement.
- **Backgrounds**:
  - **Continuum** ($e^+e^- \to q\bar{q}$): Suppressed with event shape variables (e.g., R_2).
  - **Generic** $B\bar{B}$: Studied using MC and sideband data.

3.2 Fitting Strategy & Δt Fit

- We performed fits on ΔE and M_{bc} distributions to extract the signal.
- Background estimation in the signal region was derived using the sideband regions, allowing for a cleaner extraction of the signal for the final Δt fit.

3.3 Conclusion & Outlook

- **Conclusion**: The final results indicate that our method of MC does not bias the extraction of $\sin(2\beta)$, which can be used for subsequent data processing. The analysis results will be crucial for refining measurement techniques and improving sensitivity to CP violation signals in future experiments.
- **Outlook**: This method will yield a world-leading precision measurement of $\sin(2\beta)$ with Belle II data, providing a powerful test of the SM.