Analysis of $B^0 \to \rho^0\rho^0$ decays at Belle II

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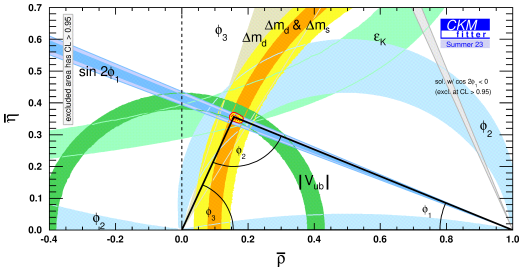
Motivation - CKM Angle ϕ_2

- CKM Angle ϕ_2 is accessible in time-dependent analysis of $b \to u$ transitions, such as $B \to \rho\rho$, if only the tree level amplitude contributes
- Significant penguin level contribution introduces shift
- Disentangle shift via analysis of isospin related $B^0 \to \rho^+\rho^-$, $B^+ \to \rho^+\rho^0$, and $B^0 \to \rho^0\rho^0$ decays



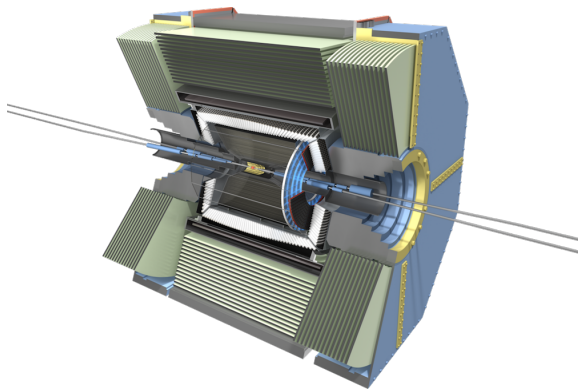
Of all $\rho\rho$ modes, an improved measurement of $\rho^0\rho^0$ has the strongest impact on precision of ϕ_2

SuperKEKB and Belle II

Belle II: general purpose detector situated at the interaction point of SuperKEKB

SuperKEKB: asymmetric $e^+ - e^-$ collider operating at $\Upsilon(4S)$ resonance

$\Rightarrow$ Clean environment
$\Rightarrow$ Constrained beam kinematics
$\Rightarrow$ Good neutral reconstruction



Operation:

- Recorded:
  362 fb^{-1} on-resonance
- Achieved world record:
  $\mathcal{L} = 4.7 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$
  (more than twice of KEKB/Belle)

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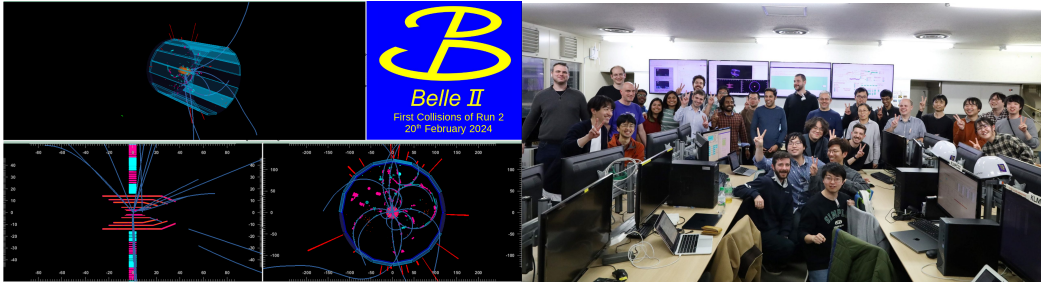

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Interfering Background

Different contributions lead to the same final state, e.g.,

$$B^0 \to \rho^0(\to \pi^+\pi^-)\rho^0(\to \pi^+\pi^-); \quad B^0 \to f_0(\to \pi^+\pi^-)\rho^0(\to \pi^+\pi^-)$$

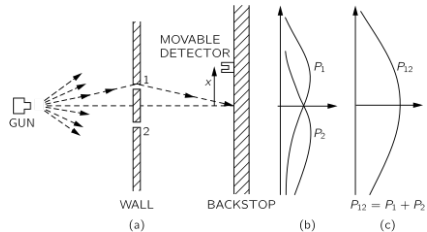
Quantum mechanics: Transition amplitude $\Psi = ae^{i\alpha}$. Observable (decay rate): $|\Psi|^2$

Total amplitude: $\Psi_{\text{tot}} = \Psi_{\rho^0\rho^0} + \Psi_{f_0\rho^0}$
Measured decay rate:

$$|\Psi_{\text{tot}}|^2 = |\Psi_{\rho^0\rho^0}|^2 + |\Psi_{f_0\rho^0}|^2$$

Incoherent sum: $|\Psi_{\rho^0\rho^0}|^2 + |\Psi_{f_0\rho^0}|^2$

Double slit with bullets:



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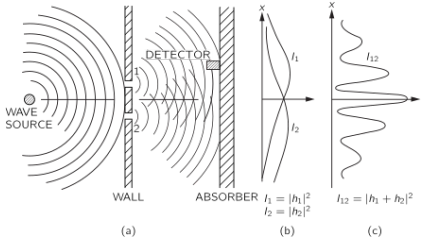
$$|\Psi_{\text{tot}}|^2 = |\Psi_{\rho^0\rho^0}|^2 + |\Psi_{f_0\rho^0}|^2 + 2\mathcal{R}[\Psi_{\rho^0\rho^0}\Psi^*_{f_0\rho^0}]$$

Incoherent sum: $|\Psi_{\rho^0\rho^0}|^2 + |\Psi_{f_0\rho^0}|^2$
Interference: $2\mathcal{R}[\Psi_{\rho^0\rho^0}\Psi^*_{f_0\rho^0}]$

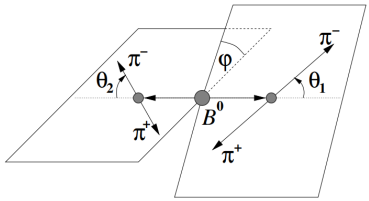
Double slit with waves:



Fit Setup

Decay rate given by

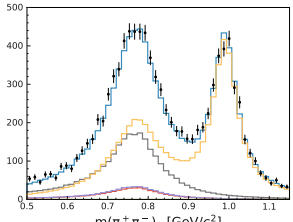
$$\frac{\mathrm{d}(\Gamma+\overline{\Gamma})}{\mathrm{d}cos(\theta_1)\mathrm{d}cos(\theta_2)\mathrm{d}\phi\mathrm{d}m_1^2\mathrm{d}m_2^2} \propto$$
$$|\sum_i \Psi_i f_i(cos(\theta_1), cos(\theta_2), \phi, m_1, m_2)|^2 +$$
$$|\sum_i \overline{\Psi}_i \overline{f}_i(cos(\theta_1), cos(\theta_2), \phi, m_1, m_2)|^2$$

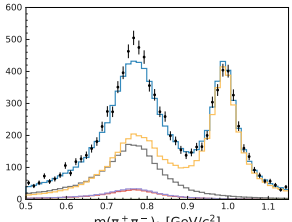


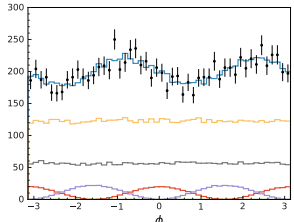
- $cos(\theta_1)$, $cos(\theta_2)$, and ϕ are the helicity angles
- m_1 and m_2 are the $m(\pi^+\pi^-)$ masses
- Ψ_i are complex amplitudes (fit parameter)
- f_i are mass (BW or flat) and angular (spherical harmonics) distributions

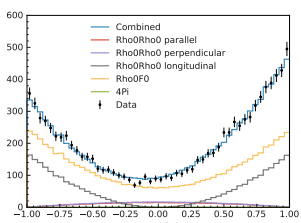
Fit Output

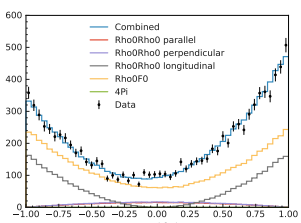
- Generate 10000 events from likelihood and fit them back
- Fitted complex amplitudes agree with those used in generation











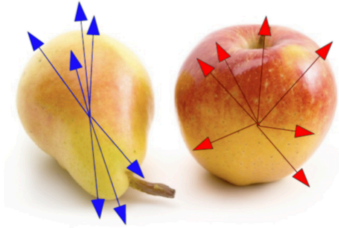
Additional Backgrounds

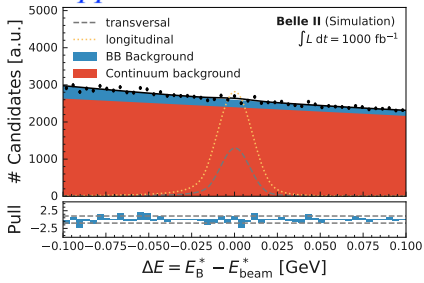
Additional background from "continuum" light-quark production and non-interfering $B\overline{B}$ events.

Continuum background reduced using boosted decision tree (BDT) trained on event topology.

Disentangle continuum and non-interfering $B\overline{B}$ events by adding ΔE and BDT output to fitter.

Fitter currently separate from fit including interference effects.





Conclusion

Belle II is past LS1 :-)

The analysis of $B^0 \to \rho^0\rho^0$ decays is crucial to improve determination of ϕ_2.

Understanding of interference effects is essential for accurate measurement of this decay.

First steps are taken towards development of fit framework that includes these effects.