

MEASUREMENT OF CP ASYMMETRIES IN $B^0 \rightarrow \eta' K^0$ DECAYS

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Review of CP violation in the Standard Model

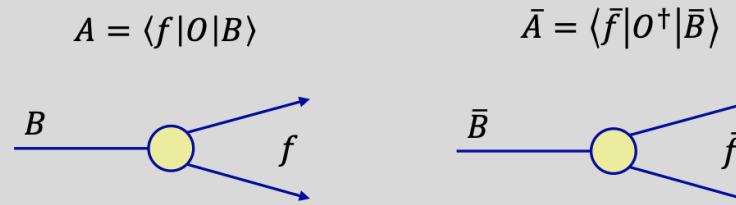
- See [Valeria's talk](#)
- There is more matter than anti-matter in the universe
- Sakharov 1967: generation of matter/anti-matter asymmetry requires C and CP violation (and 2 other conditions)
 - CP violation from New Physics may have played a role in the early universe, producing the matter/anti-matter asymmetry!
- A single parameter generates all CP violation in the Standard Model

C : charge conjugation

CP : charge-parity (particle $\rightarrow$ anti-particle)

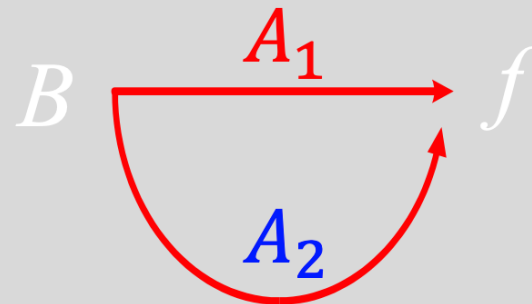
Measuring CP violation

- CP violation can be generated in decay: C_f



- “Direct CP violation”: $|A| \neq |\bar{A}|$

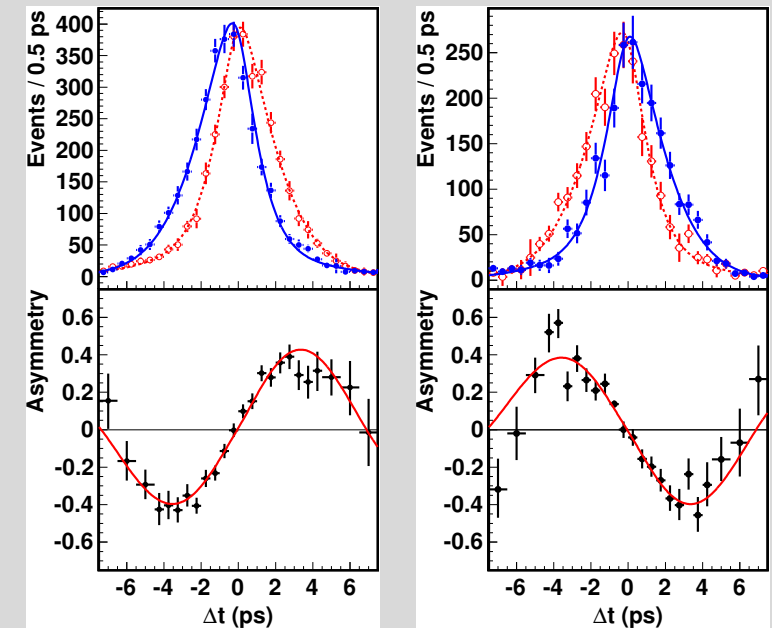
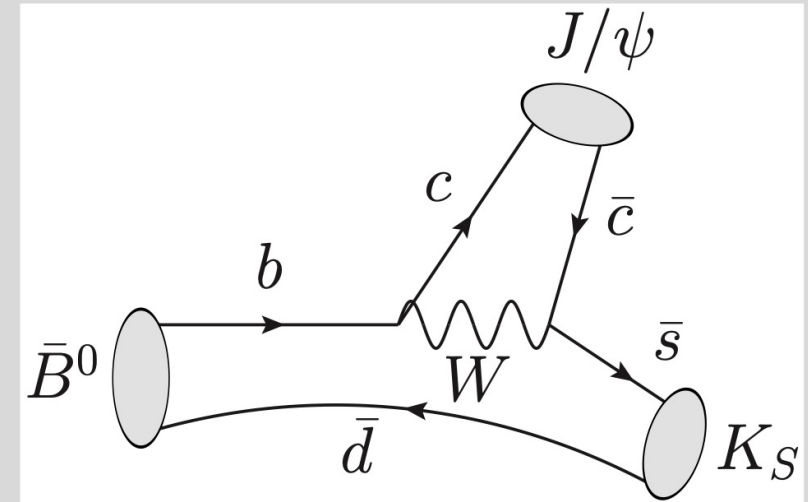
- Or through interference in mixing: S_f



- Time-dependent

Measuring CP violation

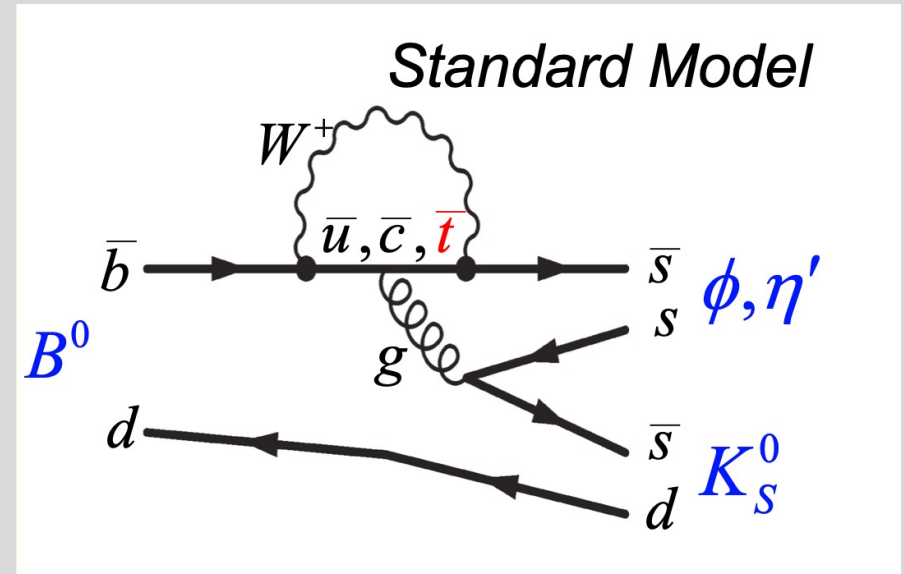
- CP violation golden mode: $B^0 \rightarrow J/\psi K^0$
($b \rightarrow c\bar{c}s$)
 - Large branching fraction, low background, small theoretical uncertainties
 - Tree level; clean measurement of S_f



Left: CP -odd modes,
Right: CP -even mode

Measuring CP violation

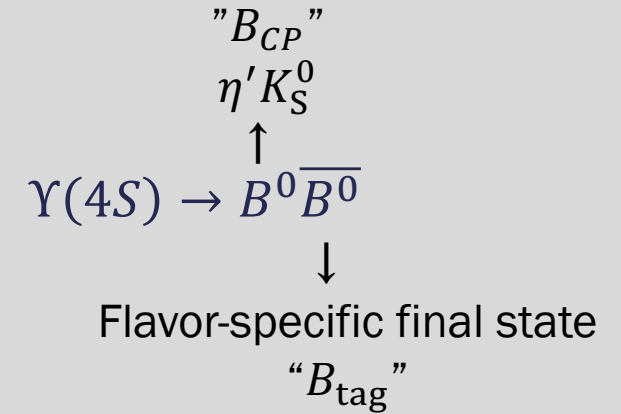
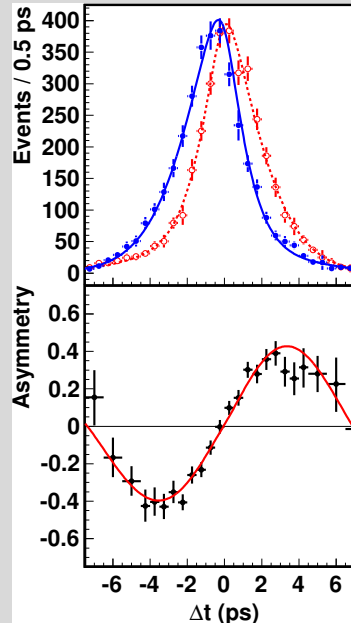
- Adjacent mode: $B^0 \rightarrow \eta' K^0$ ($b \rightarrow q \bar{q} s$)
 - Same weak phase as $B^0 \rightarrow J/\psi K^0$ in SM
 - Can compare CP asymmetries in the modes
 - CKM suppression $\rightarrow$ penguin-dominated amplitude $\rightarrow$ sensitive to New Physics in loop
 - Reasonable branching fraction, clean final state



$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{bmatrix} \text{large green square} & \text{small light green square} & \text{dot} \\ \text{small light green square} & \text{large green square} & \text{small light green square} \\ \text{dot} & \text{small light green square} & \text{large green square} \end{bmatrix}$$

Extracting $\sin 2\beta^{(eff)}$ from $B^0 \rightarrow \eta' K_S^0$

- Reconstruct signal decay: $B^0 \rightarrow \eta' K_S^0$
- Then from remaining tracks, reconstruct decay vertex of flavor-specific final state
- Decay time difference Δt between B_{CP} and B_{tag} distributed as $\frac{e^{-\frac{|\Delta t|}{\tau}}}{4\tau} \{1 \pm [S_f \sin(\Delta m_d \Delta t) - C_f \cos(\Delta m_d \Delta t)]\}$
 - τ : mean B^0 lifetime
 - $+$: B^0 tag, $-$: $\overline{B}^0$ tag
 - Asymmetry $\sim S_f \sin(\Delta m_d \Delta t)$



Flavor specific example:

$$B^0 \rightarrow D^{(*)-} \pi^+$$

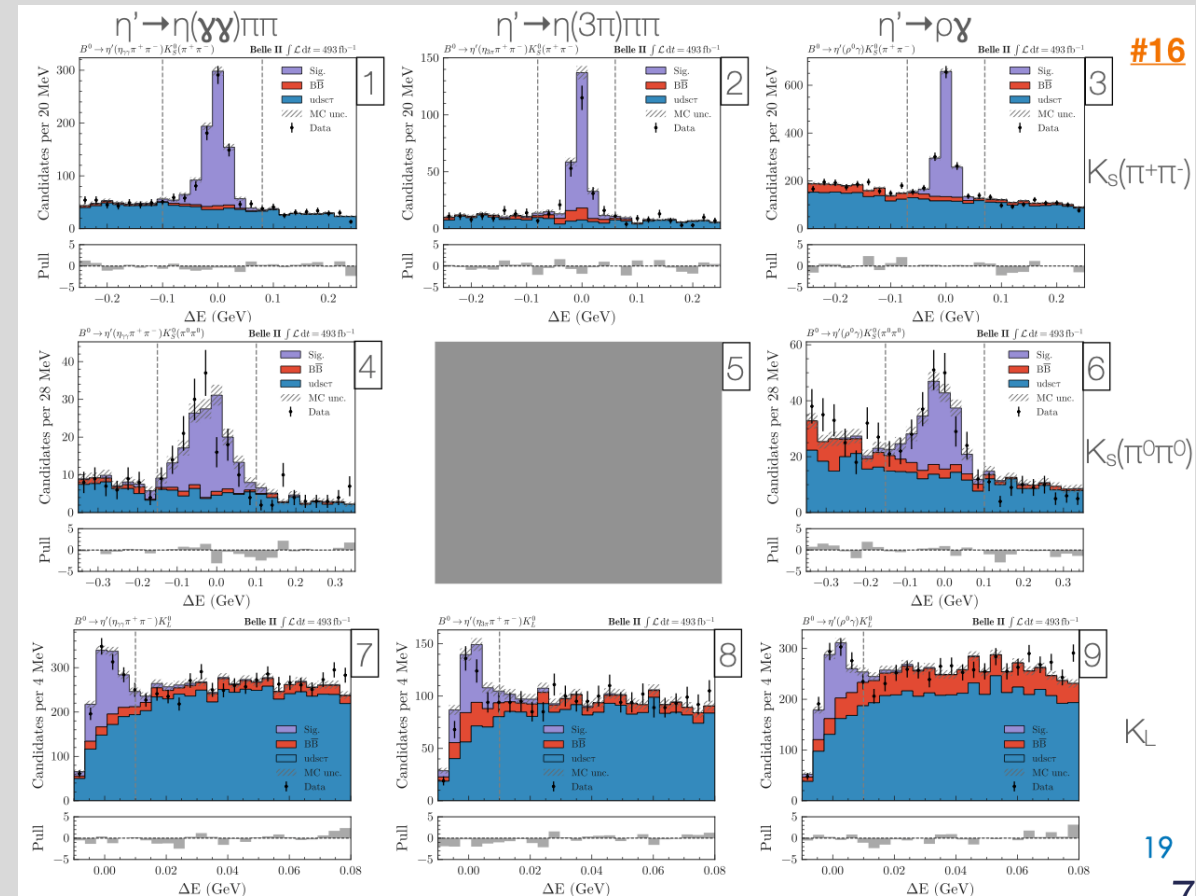
$$\overline{B}^0 \rightarrow D^{(*)+} \pi^-$$

Flavor determined from charge of pion

Current status

- 8 modes studied
 - Will measure $B^0 \rightarrow \eta'_{\rho\gamma} K_L^0$ mode for the first time
 - Will include $K_S^0 \rightarrow \pi^0 \pi^0$ for the first time at Belle II
- Selection finalized
 - BDT to select true $K_S^0 \rightarrow \pi^0 \pi^0$ based on K_S^0 and π^0 kinematics
 - Bayesian optimization on mass windows, photon energy, etc.
 - Continuum suppression BDT
 - Improved yields and signal purity compared to current measurements

$$\begin{aligned}
 B^0 &\rightarrow \eta'_{\eta(\gamma\gamma)} \pi^+ \pi^- K_{\pi^+ \pi^-}^0 \\
 B^0 &\rightarrow \eta'_{\rho\gamma} K_{\pi^+ \pi^-}^0 \\
 B^0 &\rightarrow \eta'_{\eta(3\pi)} \pi^+ \pi^- K_{\pi^+ \pi^-}^0 \\
 B^0 &\rightarrow \eta'_{\eta(\gamma\gamma)} \pi^+ \pi^- K_{\pi^0 \pi^0}^0 \\
 B^0 &\rightarrow \eta'_{\rho\gamma} K_{\pi^0 \pi^0}^0 \\
 B^0 &\rightarrow \eta'_{\eta(\gamma\gamma)} \pi^+ \pi^- K_L^0 \\
 B^0 &\rightarrow \eta'_{\eta(3\pi)} \pi^+ \pi^- K_L^0 \\
 B^0 &\rightarrow \eta'_{\rho\gamma} K_L^0
 \end{aligned}$$



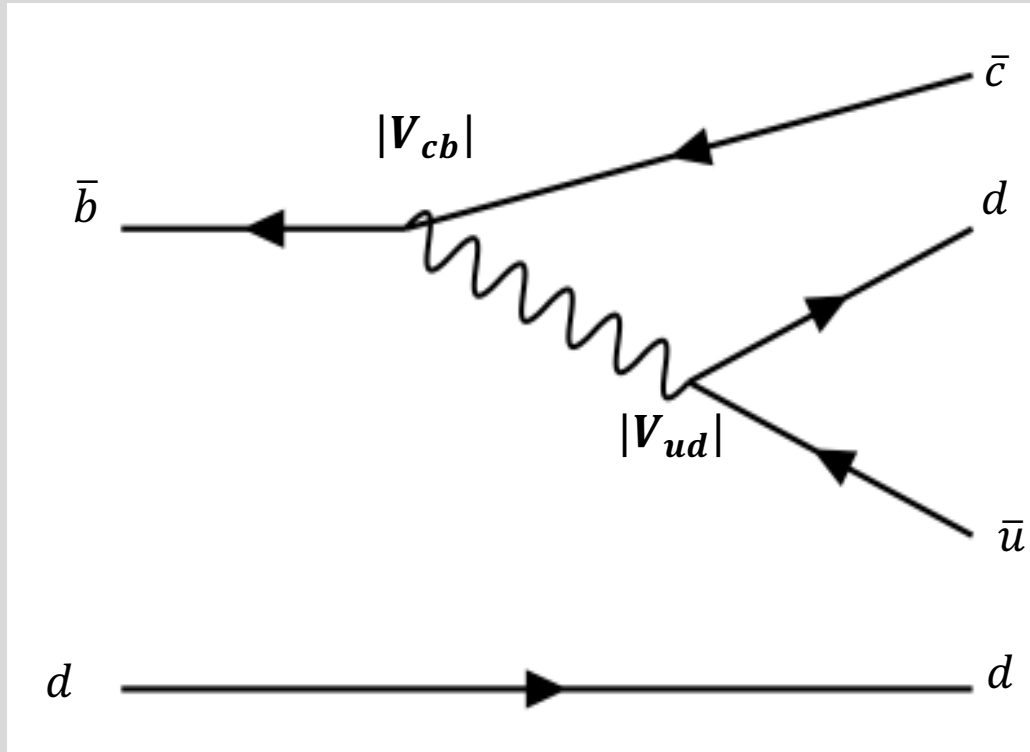
Backup

$$V = \begin{pmatrix} \boxed{V_{ud}} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & \boxed{V_{cb}} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} =$$

$$\begin{bmatrix} \text{large green square} & \text{small light green square} & \text{dot} \\ \text{small light green square} & \text{large green square} & \text{small light green square} \\ \text{dot} & \text{small light green square} & \text{large green square} \end{bmatrix}$$

$B^0 \rightarrow D^{*-} \pi^+$ flavor-specific decay

B^0



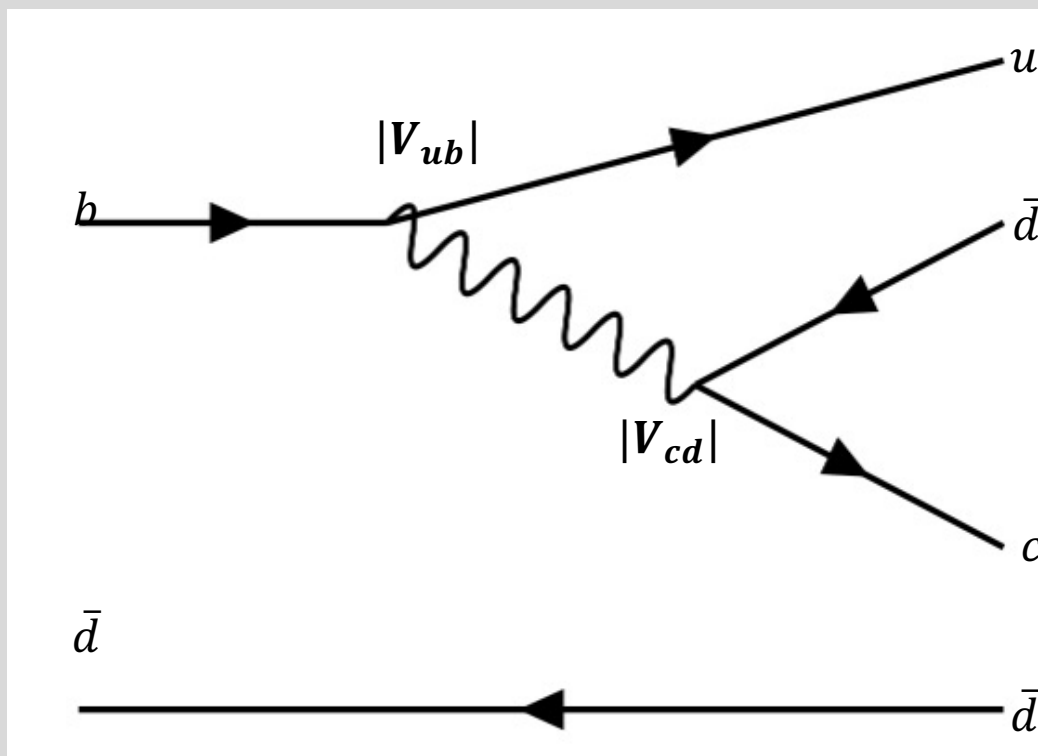
D^{*-}

π^+

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{bmatrix} \text{large green square} & \text{small light green square} & \text{dot} \\ \text{small light green square} & \text{large green square} & \text{small light green square} \\ \text{dot} & \text{small light green square} & \text{large green square} \end{bmatrix}$$

$\overline{B^0} \rightarrow D^{*-} \pi^+$ doubly
CKM suppressed
decay

$\overline{B^0}$



π^+

D^{*-}

KS00 BDT

$$B^0 \rightarrow \eta'[\rightarrow \rho\gamma]K_S^0[\rightarrow \pi^0\pi^0] + B^0 \rightarrow \eta'[\rightarrow \eta[\rightarrow \gamma\gamma]\pi^+\pi^-]K_S^0[\rightarrow \pi^0\pi^0]$$

