Reach same final state through decay & mixing + decay

(assume no CPV in mixing and no CPV in decay)

\[ A_1 = A_{\text{mix}}(B^0 \rightarrow B^0) \ast A_{\text{decay}}(B^0 \rightarrow J/\Psi K^0) = A_{\text{mix}}(B^0 \rightarrow B^0) \ast A \ast e^{i\omega} \]

\[ A_2 = A_{\text{mix}}(B^0 \rightarrow B^0) \ast A_{\text{decay}}(B^0 \rightarrow J/\Psi K^0) = A_{\text{mix}}(B^0 \rightarrow B^0) \ast A \ast e^{-i\omega}A_K \ast e^{+i\xi} \]

weak phase difference \( A_2 - A_1 \): \( \Delta\phi = \phi - 2\omega + \xi = 2\beta \)

strong phase difference \( \Delta\delta = \pi \) \( \Leftarrow \) mixing introduces strong phase difference
\[ \Delta \phi = \phi - 2\omega + \xi = \arg \left[ \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \frac{V_{cb} V_{cs}^*}{V_{cb} V_{cs}} \frac{V_{cs} V_{cd}^*}{V_{cs} V_{cd}} \right] \]

\[ = \arg \left[ \frac{V_{tb} V_{td}^*}{V_{tb} V_{td} V_{cb} V_{cd}^*} \right] \]

\[ = 2 \arg \left[ \frac{V_{cb} V_{cd}^*}{V_{tb} V_{td}} \right] = 2\beta \]

t quark dominates $B^0$ mixing box, c quark dominates $K^0$ mixing box diagram
Correlated $B$ Production

$$A(t) = \frac{N(B \to J/\psi K_s)(t) - N(B \to J/\psi K_s)(t)}{N(B \to J/\psi K_s)(t) + N(B \to J/\psi K_s)(t)} = \eta_{CP} \sin(2\beta) \sin \Delta m dt$$

(for $K_s \eta_{CP} = -1$, for $K_L \eta_{CP} = +1$ ... neglecting CP in kaon mixing)

$B - \overline{B}$ pair produced on Y(4S) resonance with well defined quantum numbers.

$\rightarrow$ Correlated $B - \overline{B}$ state till the time of the decay of the first $B$. 

This is how it works at $e^+ e^- - B$ factories
\[ B_d \rightarrow J/\psi K_s \]

\[
A(t) = \frac{N(B^0)(t) - N(\overline{B}^0)(t)}{N(B^0)(t) - N(\overline{B}^0)(t)} = -\sin(2\beta) \sin(\Delta m_d t)
\]

Babar:
\[ \sin(2\beta) = 0.722 \pm 0.040 \pm 0.023 \]

Belle:
\[ \sin(2\beta) = 0.652 \pm 0.039 \pm 0.020 \]
Kobayashi & Maskawa:

"for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature"
Basic idea similar to measurement of $\sin(2\beta)$:

- No CP violation in mixing
- No CP violation in decay (watch out penguin pollution ..)

$$\phi_{mix} = arg((V_{ts} V_{tb}^*)^2) = -2\beta_s \approx 0.04 (SM), \text{ (top quark dominates the box)}$$

$$\omega = arg((V_{cb} V_{cs}^*)^2) = 0$$

$$V_{CKM} = \begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix} = \begin{pmatrix}
\begin{array}{c|c|c|c}
\hline
 & d & s & e^{-i\gamma} \\
 \hline
u & & & \\
 c & & & \\
 t & & & \\
 \hline
\end{array}
\end{pmatrix} \begin{pmatrix}
e^{-i\beta} \\
e^{-i\beta_s}
\end{pmatrix}$$
$B_s \rightarrow J/\psi \phi$

$B_s : J^P = 0^{-1}$ (pseudo scalar)

$J/\psi : J^{CP} = 1^{-1-1}$ (vector)

$\phi : J^{CP} = 1^{-1-1}$ (vector)

Angular momentum conservation:

$0 = J (J/\psi \phi) = |\vec{S} + \vec{L}|; \rightarrow L = 0,1,2$

$P(J/\psi \phi) = P(J/\psi)^* P(\phi)^*(-1)^L$

$CP(J/\psi \phi) = CP(J/\psi)^* CP(\phi)^*(-1)^L$

$L = 0,2 \rightarrow CP$ even final state

$L = 1 \rightarrow CP$ odd final state

Final state no CP eigenstate but linear combination!

Angular analysis, to separate CP even/odd contributions.

Three decay amplitudes: $|A_\perp| (L=1), |A_\parallel|, |A_0| (L=0,2)$

+ two rel. strong phases: $\delta_1 = \arg(A_\parallel(0)A_\perp), \delta_2 = \arg(A_0(0)A_\perp(0))$
Measurement of $\phi_s$

Measurement of modulation in decay time distribution

- amplitude of modulation: $D \sin \phi_s$
- sign of modulation depend on production flavour ($B_s$ or $\bar{B}_s$) and from CP value of final state $\eta_{CP}$

Most important tools: Flavour-Tagging and decay time resolution

$J/\Psi \phi$ is combination of different CP eigenstates
→ combined measurement of $\Gamma$, $\Delta \Gamma$, $\Delta m_s$ and $\phi_s$ possible
$B_s^0 \rightarrow J/\Psi \phi$