$\cancel{CP}$ in B mesons

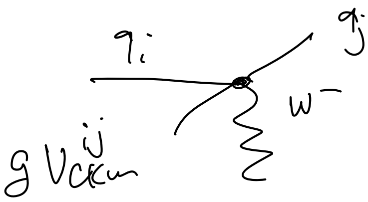
1964 $\cancel{CP}$ in K^0 decays. 1/1000 effect.

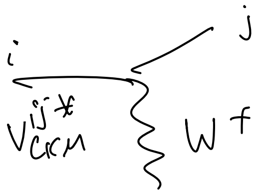
$K_S \to \pi^+\pi^-$ $\quad K_L \to \pi^+\pi^-$

1973: KM mechanism for $\cancel{CP}$ in SM.

1977: discovery of b quark (necessary but not suff.).

CKM matrix





Conditions for V_{CKM}: $V^\dagger V = V V^\dagger = \mathbb{1}$

3x3 unitary matrix. $\Rightarrow$ 3 real parameters/angles.

1 complex phase.

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

$$V^\dagger = \begin{pmatrix} V_{ud}^* & - & - \\ V_{us}^* & - & - \\ V_{ub}^* & - & - \end{pmatrix}$$

$V^\dagger V = \mathbb{1} \Rightarrow 9$ conditions on elements.

$$\mathbf{V}_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

wolfenstein param.

$\lambda \simeq V_{us} \sim \sin\theta_C \sim 0.22$

$$\begin{aligned} |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 &= 1 \\ |V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2 &= 1 \\ |V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2 &= 1 \end{aligned}$$

Diagonal elements of $V^\dagger V = \mathbb{1}$

$$V_{ud}^* V_{us} + V_{cd}^* V_{cs} + V_{td}^* V_{ts} = 0 \qquad \lambda \;\; \lambda \;\; \lambda^5$$

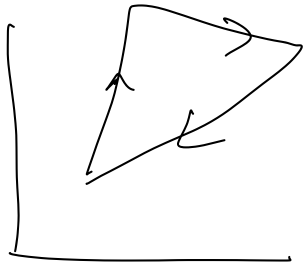
$$\boxed{V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0} \qquad \underline{\lambda^3 \;\; \lambda^3 \;\; \lambda^3}$$

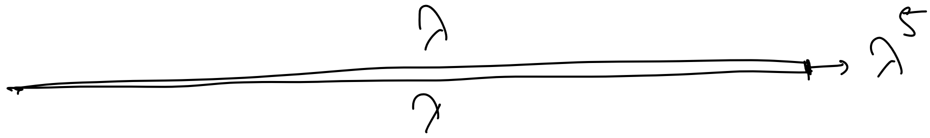
$$V_{us}^* V_{ub} + V_{cs}^* V_{cb} + V_{ts}^* V_{tb} = 0 \qquad \lambda^4 \;\; \lambda^2 \;\; \lambda^2$$

$$V_{ud}^* V_{td} + V_{us}^* V_{ts} + V_{ub}^* V_{tb} = 0 \qquad \lambda^3 \;\; \lambda^3 \;\; \lambda^3$$

$$V_{td}^* V_{cd} + V_{ts}^* V_{cs} + V_{tb}^* V_{cb} = 0 \qquad \lambda^4 \;\; \lambda^2 \;\; \lambda^2$$

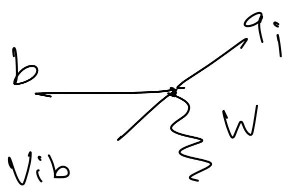
$$V_{ud}^* V_{cd} + V_{us}^* V_{cs} + V_{ub}^* V_{cb} = 0 \qquad \lambda \;\; \lambda \;\; \lambda^5$$





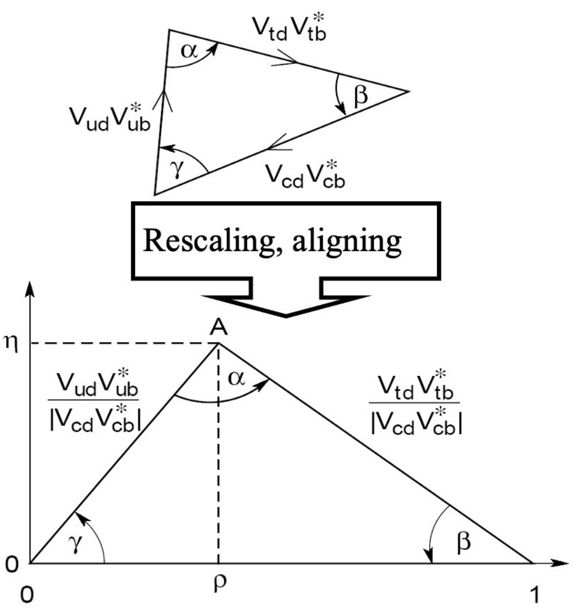
1) has all sides of same order λ^3

2) contain V_{ib}.



KM: predict existence of a complex phase in CKM matrix.

$\Rightarrow$ Exp. proof of at least one complex phase in CKM.



$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

$$\begin{pmatrix} 1 & 1 & e^{-i\gamma} \\ 1 & 1 & 1 \\ e^{-i\beta} & 1 & 1 \end{pmatrix}$$

V_{ub}.

V_{td}

$\Rightarrow$ produce many many B mesons.

$$\underbrace{B^0 \longrightarrow f}_{N} \quad \overset{CP}{\Longleftrightarrow} \quad \underset{\bar{N}}{\bar{B}^0 \longrightarrow \bar{f}}$$

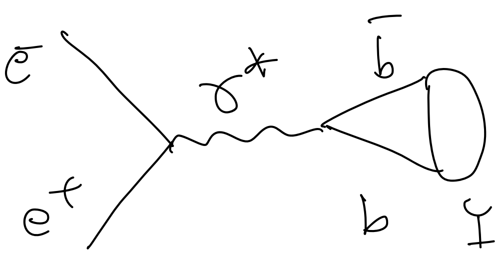
$$N \neq \bar{N} \Rightarrow \cancel{CP}$$

prediction: $\cancel{CP}$ much larger in B meson systems

produce many B mesons?

$\begin{pmatrix} \bar{b} \\ d \end{pmatrix} B^0 \quad \begin{pmatrix} b \\ \bar{d} \end{pmatrix} \bar{B}^0$

$\begin{pmatrix} \bar{b} \\ u \end{pmatrix} B^+ \quad \begin{pmatrix} b \\ \bar{u} \end{pmatrix} B^-$

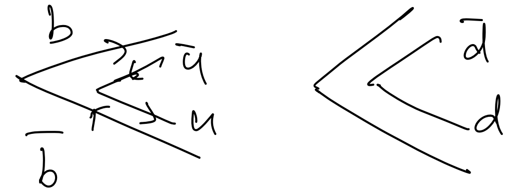


$\Upsilon(4S)$. bound state of $(b\bar{b})$ quarks.

$m = 10.580$ GeV

$e^+e^- \rightarrow \Upsilon(4S)$

$\sqrt{s} = M_{\Upsilon(4S)}$.



$\Upsilon(4S) \longrightarrow B^0\bar{B}^0$

B^+B^-

$m_B = 5.279$.

$e^+e^- \xrightarrow{\sqrt{s}=10.58.} \Upsilon(4S) \rightarrow B^0\bar{B}^0 / B^+B^-$

$c\bar{c}$

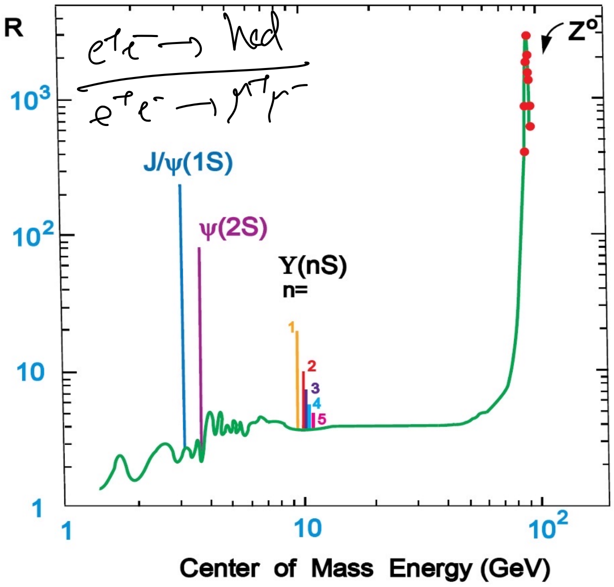
$s\bar{s}$

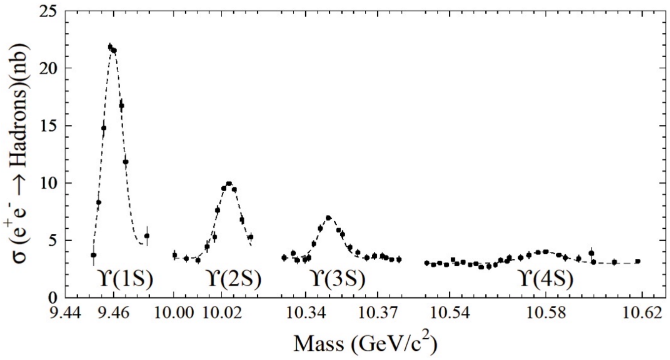
$u\bar{u}$

$d\bar{d}$

$\tau\bar{\tau}$

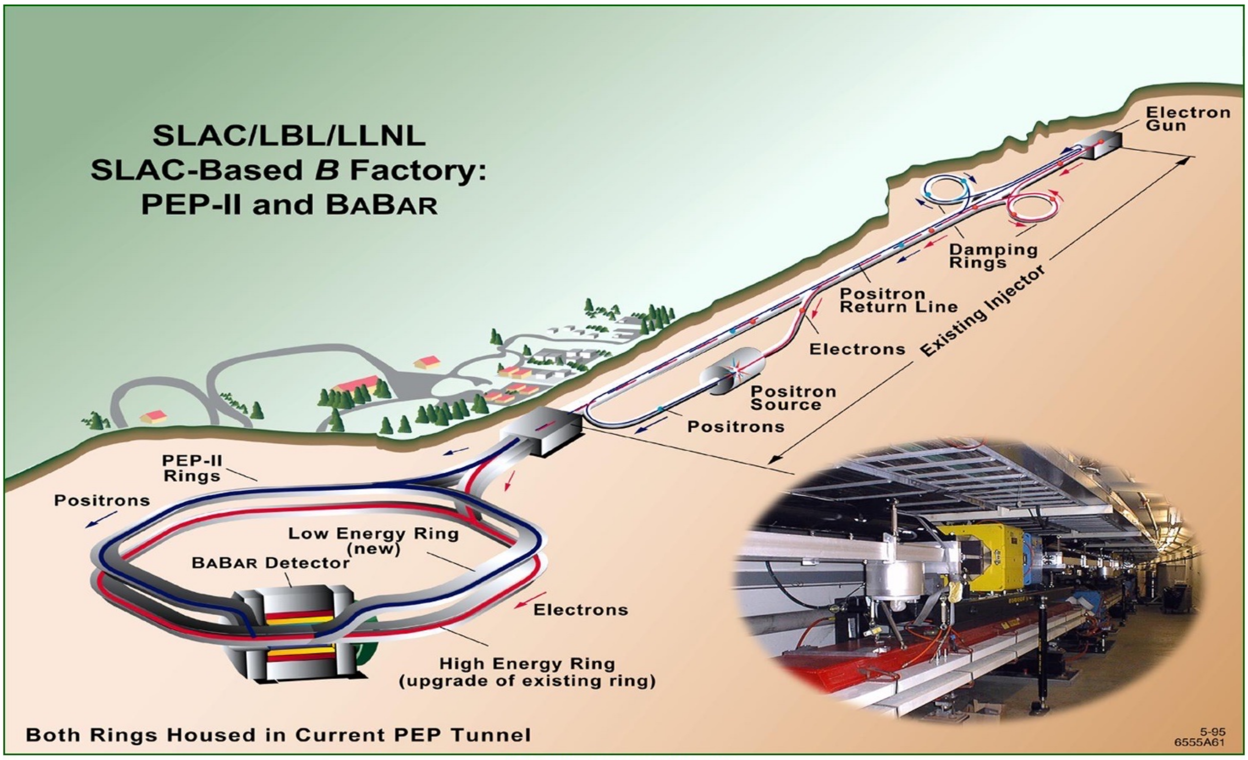
$\mu^+\mu^- \quad e^+e^-$



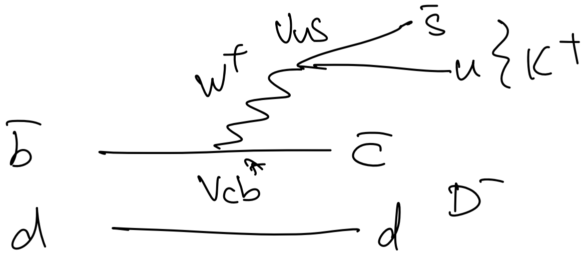


$$\frac{\sigma(e^+e^- \to U(4S) \to bb)}{\sigma(e^+e^- \to U(4S) \to TOT)} = \frac{1.2nb}{3.5nb} = 25\%$$

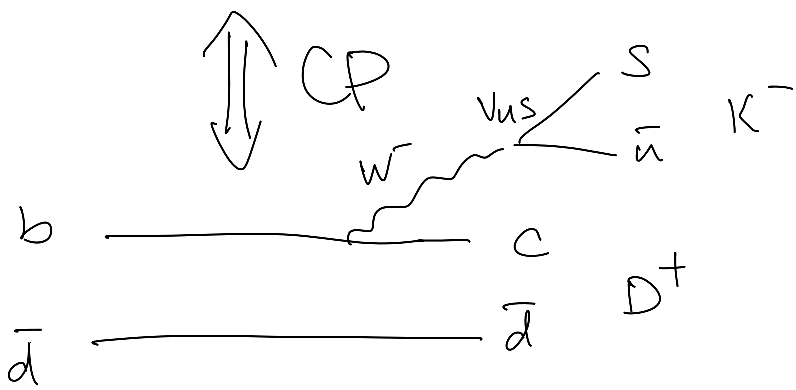
$$N = \sigma \cdot \mathcal{L} \cdot \Delta t$$



PEP-II accelerator schematic and tunnel view

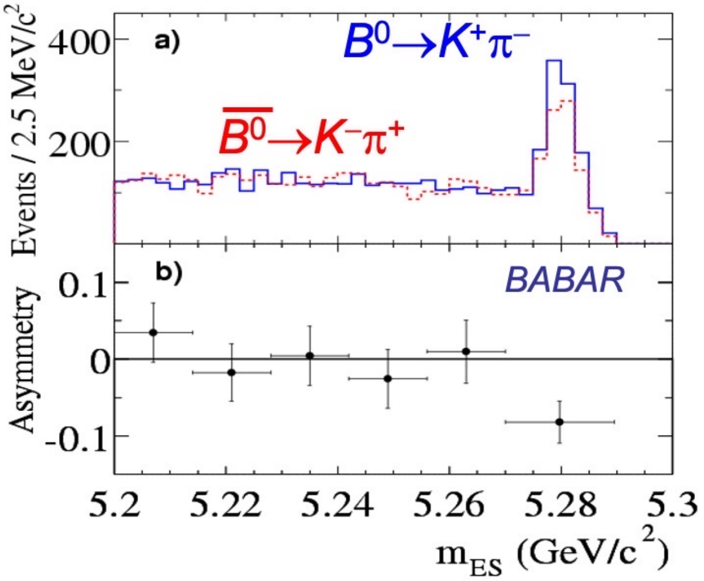


$B^0 \longrightarrow D^- K^+$



$\bar{B}^0 \longrightarrow D^+ K^-$

2004



$n_{K\pi} = 1606 \pm 51$

$A_{K\pi} = -0.133 \pm 0.030 \pm 0.009$

$\rightarrow$ $n(B^0 \to K^+\pi^-) = 910$, $n(\bar{B}^0 \to K^-\pi^+) = 696$

Direct $\cancel{CP}$

B^0 $S = 0$.

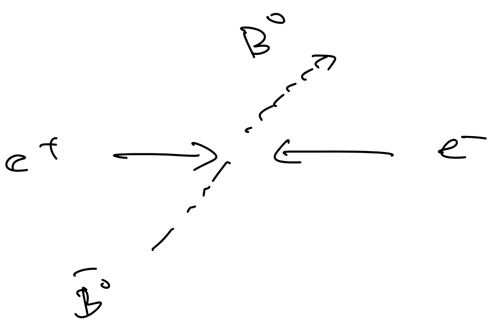
J 1 L = 1 final state.

$L(B^0\bar{B}^0) = 1$.

$$\psi(B^0\bar{B}^0) = \psi_{space}\,\psi_{flavor} = (-1)^L \underbrace{\psi_{flavor}}_{\text{anti-symm. in flavor}}$$

$\hookrightarrow$ symm. function.

$\Rightarrow$ 1 B^0 and 1 $\bar{B}^0$ at all times.



$\tau_B = 1.57$ ps.

if boosted $\Rightarrow$ travel for $\sim$ (10 mm)

Example of Einstein-Podolsky-Rosen Paradox