# Flavor Physics

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# Lecture 3

## where we discuss B-mesons and B experiments

# Cabibbo-Kobayashi-Maskawa matrix

generalization on the 3-generations case: weak quark mixing 3×3 matrix

$$L_{W^\pm} = -\frac{g}{\sqrt{2}}(\bar{u}, \bar{c}, \bar{t})_L V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_L \gamma^\mu W_\mu^- \ldots \qquad V_{CKM} = V_L^u \cdot V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

KM-parameterization

$$\begin{pmatrix} \cos\theta_1 & -\sin\theta_1\cos\theta_3 & -\sin\theta_1\sin\theta_3 \\ \sin\theta_1\cos\theta_2 & \cos\theta_1\cos\theta_2\cos\theta_3 - \sin\theta_2\sin\theta_3 e^{i\delta} & \cos\theta_1\cos\theta_2\sin\theta_3 + \sin\theta_2\cos\theta_3 e^{i\delta} \\ \sin\theta_1\sin\theta_2 & \cos\theta_1\sin\theta_2\cos\theta_3 + \cos\theta_2\sin\theta_3 e^{i\delta} & \cos\theta_1\sin\theta_2\sin\theta_3 - \cos\theta_2\sin\theta_3 e^{i\delta} \end{pmatrix}$$

PDG-reparameterization

$$\begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

# CPV in the KM Model

KM ansatz is a necessity for CP-violation

Sufficiency for CPV in KM ansatz:

$$\left(m_t^2-m_c^2\right)\times\left(m_t^2-m_u^2\right)\times\left(m_c^2-m_u^2\right)$$
$$\times\left(m_b^2-m_s^2\right)\times\left(m_b^2-m_d^2\right)\times\left(m_s^2-m_d^2\right)\times J_{CP}\neq 0$$

where $J_{CP}$ is Jarlskog determinant

$$J_{CP}=\left|\mathrm{Im}\left(V_{i\alpha}V_{j\beta}V_{i\beta}^*V_{j\alpha}^*\right)\right| \quad (i\neq j,\alpha\neq\beta)$$

*Why are quarks required to have different masses?*

Elements values (PDG)

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 0.9743 & 0.2253 & 0.0035 \\ 0.2252 & 0.9734 & 0.0412 \\ 0.0087 & 0.0404 & 0.9991 \end{pmatrix} \pm \begin{pmatrix} 0.0002 & 0.0007 & 0.0002 \\ 0.0007 & 0.0002 & 0.0010 \\ 0.0003 & 0.0010 & 0.0001 \end{pmatrix}$$

Almost identity

Almost diagonal

Almost symmetric

observe hierarchy $\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}$ where $\lambda=\sin\theta_C\approx 0.23$

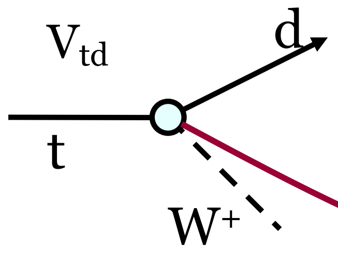
$$J_{CP}=s_{12}s_{13}s_{23}c_{12}c_{13}c_{23}\sin\delta=(2.96^{+0.20}_{-016})\times 10^{-5}$$

CPV is tiny in SM; it is not enough to produce BAU

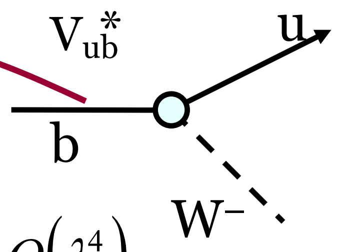
# Wolfenstein parameterization

$$\lambda = s_{12} = \sin\theta_{12} \approx 0.23 \quad A = \frac{s_{23}}{s_{12}^2} \approx 0.8 \quad \rho = \frac{s_{13}\cos\delta}{s_{12}s_{23}} \quad \eta = \frac{s_{13}\sin\delta}{s_{12}s_{23}}$$

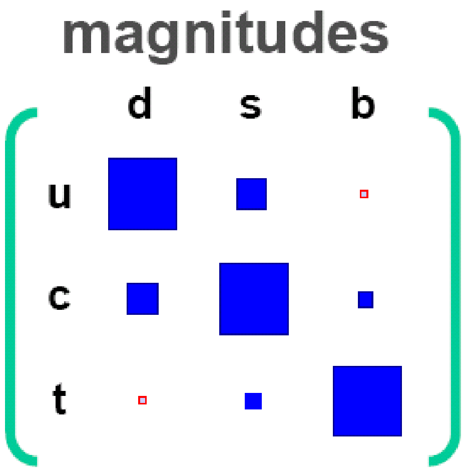
(expansion on a small parameter λ)



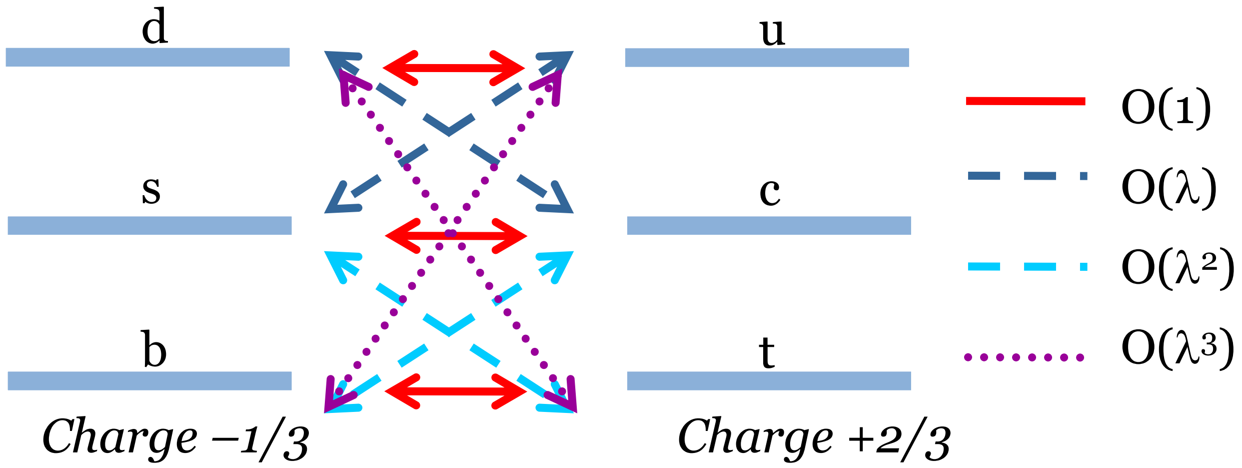

$$V_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

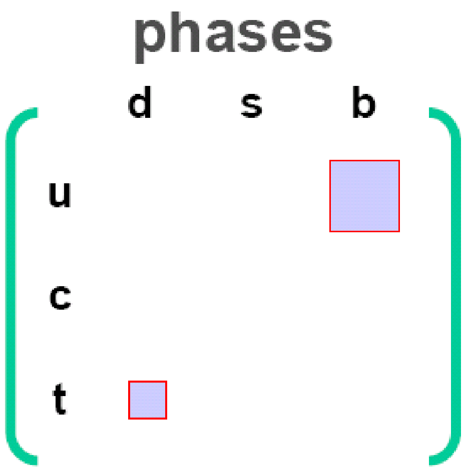



*CPV phases are in the corners*



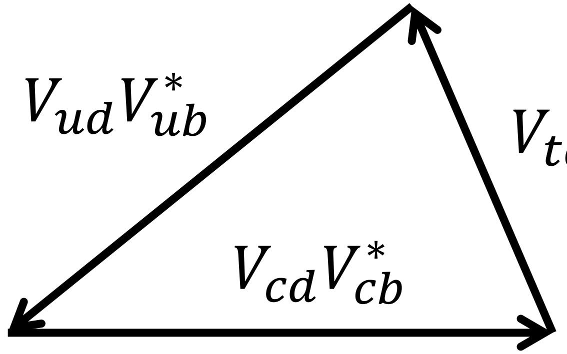

Reflects hierarchy of strengths of quark transitions



# Unitarity triangle

Unitarity condition of CKM matrix $V_{\mathrm{CKM}}^{\dagger} \cdot V_{CKM} = V_{CKM} \cdot V_{\mathrm{CKM}}^{\dagger} = 1$ gives 9 constrains $V_{ij}V_{ik}^{*} = \delta_{jk}$; 3 corresponds to $j = k$ and says that the probability for each quark to couple to $W^{-}$ is summed up to 1; 6 unitarity conditions, when $j \neq k$, can be represented by triangles in the complex plane:



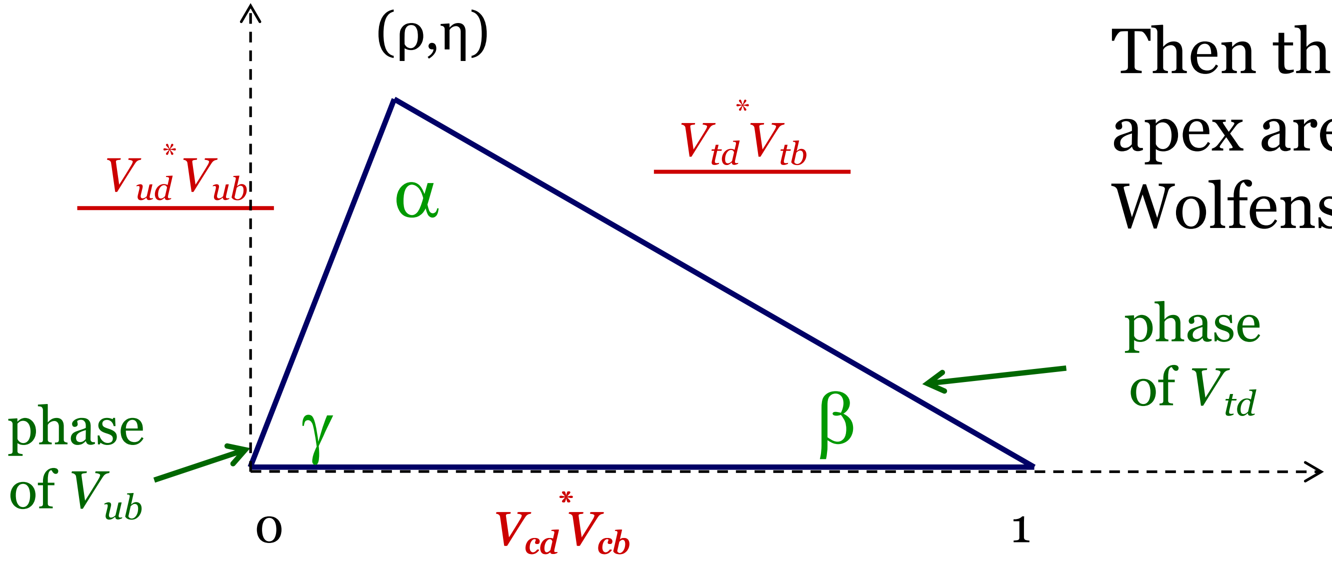

- All six triangles have the same area = ½ Jarlskog determinant
- 4 are degenerated (almost squizeed to a line)
- Only in two triangles all three sides of the same order O($\lambda^3$)
- These two are related to the 3rd quark generation

$$\underbrace{V_{ud}V_{ub}^{*}}_{(\rho+i\eta)A\lambda^3} + \underbrace{V_{cd}V_{cb}^{*}}_{-A\lambda^3} + \underbrace{V_{td}V_{tb}^{*}}_{(1-\rho-i\eta)A\lambda^3} = 0 \qquad \underbrace{V_{ud}^{*}V_{td}}_{(1-\rho-i\eta)A\lambda^3} + \underbrace{V_{us}^{*}V_{ts}}_{-A\lambda^3} + \underbrace{V_{ub}^{*}V_{tb}}_{(\rho+i\eta)A\lambda^3} = 0$$

# One (the most important) Unitarity Triangle

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

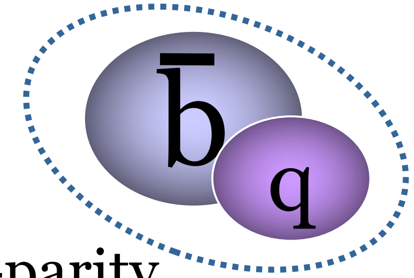
Convenient to normalize all sides to the base of the triangle ($V_{cd}V_{cb}^{*} = \; A\lambda^3$).




Then the coordinates of the upper apex are expressed through Wolfenstein parameters (ρ, η).

We want to study this triangle. Its each side is related to b-quark decay, we thus use B-mesons for our study!

# B-mesons




Spin-parity
$J^P = 0^-$

What are B mesons?

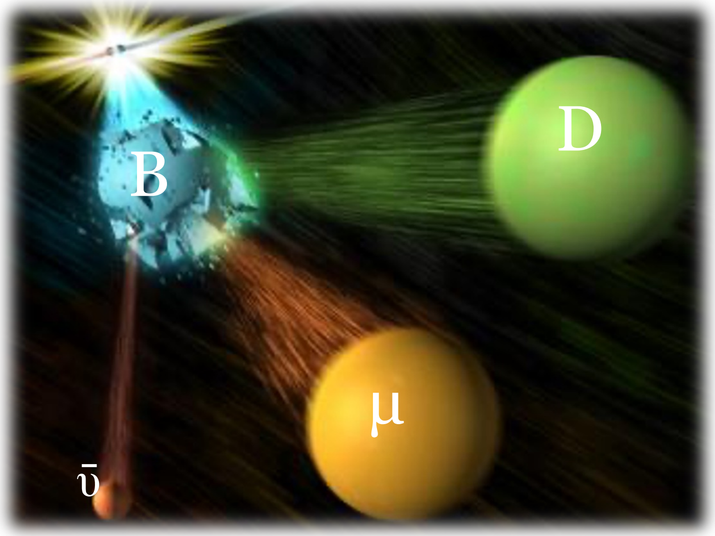
| name | quarks | charge | mass (GeV) | lifetime ($10^{-12}$s) |
|---|---|---|---|---|
| $B_d^0$ or $B^0$ | $\bar{b}d$ | 0 | 5.2796 | 1.519 |
| $B_u^+$ or $B^+$ | $\bar{b}u$ | +1 | 5.2793 | 1.641 |
| $B_s^0$ | $\bar{b}s$ | 0 | 5.3668 | 1.463 |
| $B_c^+$ | $\bar{b}c$ | +1 | 6.277 | 0.45 |

How are they produced?

- $e^+e^- \to \Upsilon(4S) \to B\bar{B}$ is the cleanest process (large $B\bar{B}$ /other cross section; no extra particles; quantum correlations)
- also at hadron machines: $pp \to B + \bar{B} +$ anything

How are they decay?

- usually to charm $b \to c$, $e.g.$ $B \to D\mu\bar{\upsilon}, D^*\pi$, etc
- much rarely to light quarks $B \to \pi\pi$ ($\frac{|b \to c|^2}{|b \to u|^2} \sim 100$)



# Neutral mesons oscillations

Time evolution of $B^0$ and $\bar{B}^0$ can be described by an effective Hamiltonian:

$$i\frac{\partial}{\partial t}\Psi = H\Psi$$

*Hamiltonian is just a numerical (complex) matrix 2×2*

$$\Psi(t) = a(t)\left|B^0\right\rangle + b(t)\left|\bar{B}^0\right\rangle \equiv \begin{pmatrix} a(t) \\ b(t) \end{pmatrix}$$

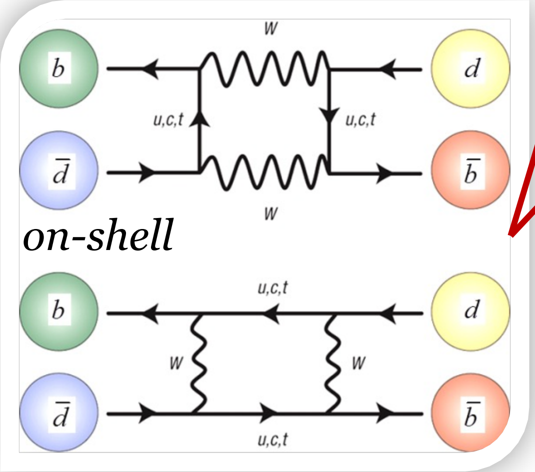
$$H = \underbrace{\begin{pmatrix} M & 0 \\ 0 & M \end{pmatrix}}_{\text{hermitian}} - \frac{i}{2}\underbrace{\begin{pmatrix} \Gamma & 0 \\ 0 & \Gamma \end{pmatrix}}_{\text{hermitian}}$$

*Here we still have no mixing (no off-diagonal terms); note, that Hamiltoniam is not Hermitian! because of decay, probability of observing either $B^0$ or $B^0$ must decrease with time* $\Rightarrow \Gamma > 0$

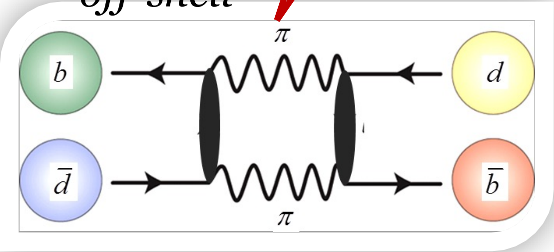
<u>Add mixing</u>

$$H = \underbrace{\begin{pmatrix} M & M_{12} \\ M_{12}^* & M \end{pmatrix}}_{\text{hermitian}} - \frac{i}{2}\underbrace{\begin{pmatrix} \Gamma & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma \end{pmatrix}}_{\text{hermitian}}$$

*note, $M_{21} = M_{12}^*$ and $\Gamma_{21} = \Gamma_{12}^*$ from CPT invariance*




off-shell




*off-diagonal $M$ term is due to off-shell states like box diagram*

*off-diagonal $\Gamma$ is due to on-shell states, e.g. ππ, DD…*

# Find eigenstates

Mass and lifetime of physical states: mass eigenstates

$$i\partial_t \psi(t) = \begin{pmatrix} M - \frac{i}{2}\Gamma & M_{12} - \frac{i}{2}\Gamma_{12} \\ M_{12}^* - \frac{i}{2}\Gamma_{12}^* & M - \frac{i}{2}\Gamma \end{pmatrix} \psi(t)$$

*Eigenstates are linear combinations of meson-antimeson*

$$|P_1\rangle = p|P^0\rangle - q|\overline{P}^0\rangle$$

$$|P_2\rangle = p|P^0\rangle + q|\overline{P}^0\rangle$$

*to find p and q solve the equation*

$$\begin{pmatrix} M - \frac{i}{2}\Gamma & M_{12} - \frac{i}{2}\Gamma_{12} \\ M_{12}^* - \frac{i}{2}\Gamma_{12}^* & M - \frac{i}{2}\Gamma \end{pmatrix} \begin{pmatrix} p \\ q \end{pmatrix} = \lambda_\pm \begin{pmatrix} p \\ q \end{pmatrix}$$

$$\frac{q}{p} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}}$$

*Eigenstates's evolution is normal decay law without oscillations!*

$$|P_1(t)\rangle = e^{-im_1 t - \frac{1}{2}\Gamma_1 t}|P_1(0)\rangle$$

$$|P_2(t)\rangle = e^{-im_2 t - \frac{1}{2}\Gamma_2 t}|P_2(0)\rangle$$

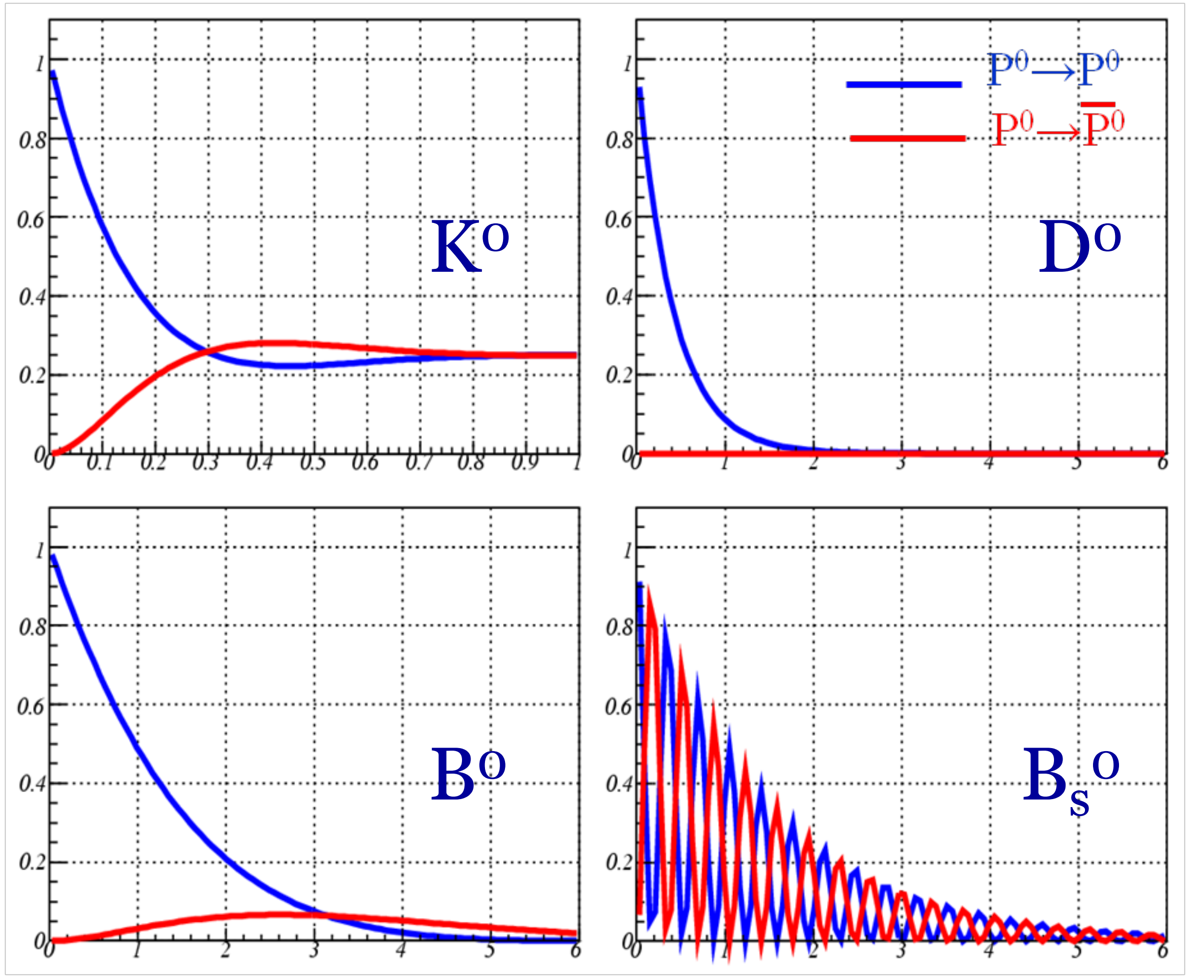
*$P_1$ and $P_2$ have proper masses and lifetimes*

*Evolution of the flavor eigenstates is a little bit more complicated*

$$|P^0(t)\rangle = \frac{1}{2}\left(e^{-im_1 t - \frac{1}{2}\Gamma_1 t} + e^{-im_2 t - \frac{1}{2}\Gamma_2 t}\right)|P^0(0)\rangle + \frac{q}{2p}\left(e^{-im_1 t - \frac{1}{2}\Gamma_1 t} - e^{-im_2 t - \frac{1}{2}\Gamma_2 t}\right)|\overline{P}^0(0)\rangle$$

# We know 4 neutral mesons that can oscillate

Probability to find $P^0$ or $\bar{P}^0$, when start with pure $P^0$-beam




Their oscillations looks so much different…
but this is just different numerical values

$$m = \frac{m_1 + m_2}{2}, \quad \Delta m = m_1 - m_2$$

$$\Gamma = \frac{\Gamma_1 + \Gamma_2}{2}, \quad \Delta\Gamma = \Gamma_1 - \Gamma_2$$

| | <τ> [s] | Δm | x=Δm/Γ | y=ΔΓ/2Γ |
|---|---|---|---|---|
| $K^0$ | $2.6\times10^{-8}$ | 5.29 $ns^{-1}$ | $\Delta m/\Gamma_S$=0.49 | ~1 |
| $D^0$ | $0.41\times10^{-12}$ | 0.001 $fs^{-1}$ | ~0 | 0.01 |
| $B^0$ | $1.53\times10^{-12}$ | 0.507 $ps^{-1}$ | 0.78 | ~0 |
| $B_s^0$ | $1.47\times10^{-12}$ | 17.8 $ps^{-1}$ | 12.1 | ~0.05 |

x=Δm/Γ measures, how many times
meson oscillates before decay (average lifetime)

# B-meson system

$$\Delta\Gamma \ll \Delta m \sim \Gamma$$

$$\Delta m \sim G_F^2 m_t^2 f_B^2 m_B \,\mathrm{Re}\left(V_{td}^* V_{tb}\right)$$

*Common CP final states for $B^0$ and $\bar{B}^0$: not many – mainly flavor specific modes*

*Box diagram*

This slightly simplify the evolution formula

$$\left|B^0(t)\right\rangle = e^{-imt} e^{-\frac{1}{2}\Gamma t}\left(\cos\frac{\Delta m t}{2}\left|B^0(0)\right\rangle + \frac{q}{p} i \sin\frac{\Delta m t}{2}\left|\overline{B}^0(0)\right\rangle\right)$$

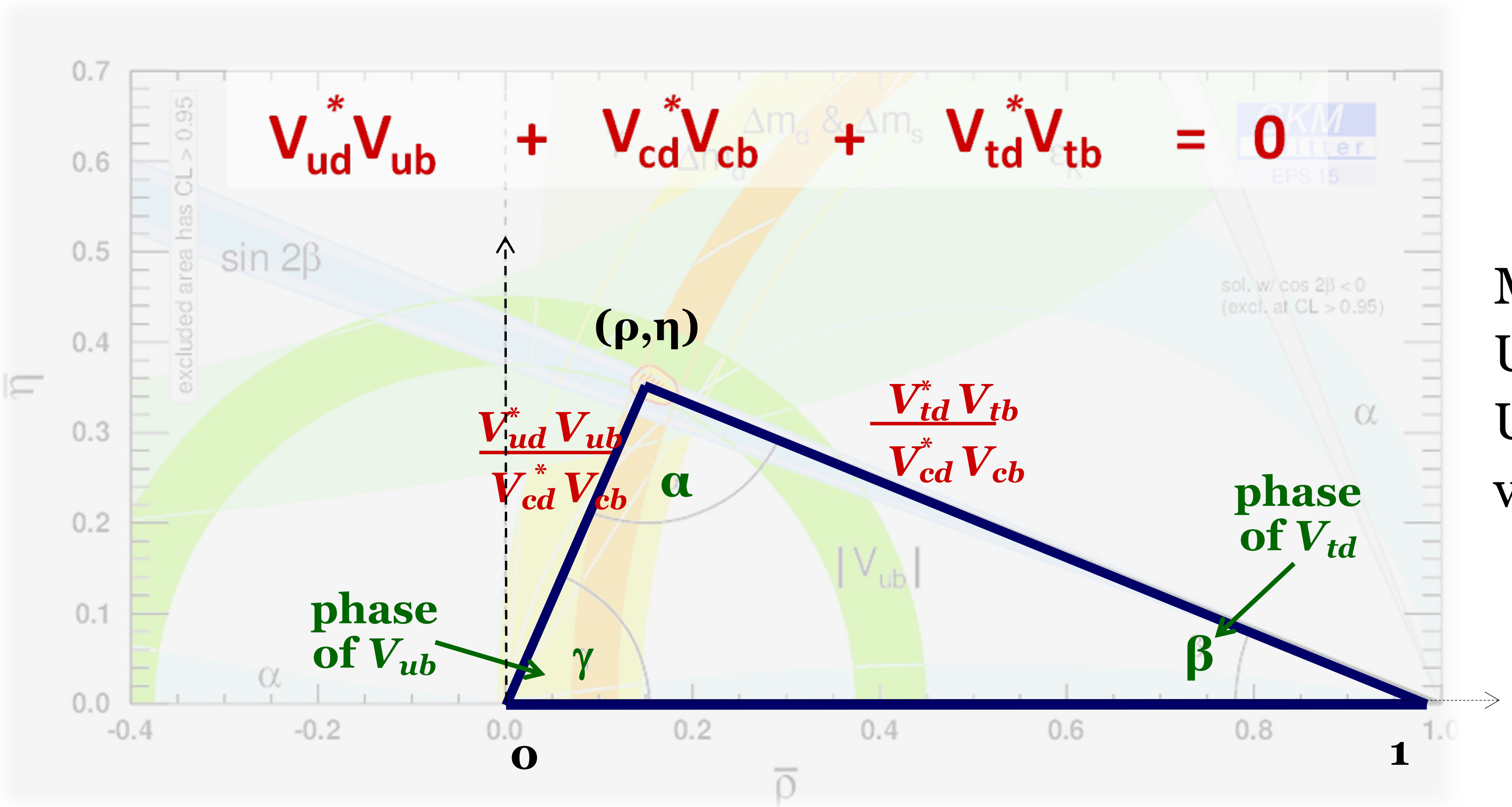
$$\left|B^0(t)\right\rangle = e^{-imt} e^{-\frac{1}{2}\Gamma t}\left(\cos\frac{\Delta m t}{2}\left|\overline{B}^0(0)\right\rangle + \frac{p}{q} i \sin\frac{\Delta m t}{2}\left|B^0(0)\right\rangle\right)$$

$$\left|\frac{q}{p}\right| \approx 1$$

$$\frac{q}{p} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}} \approx \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}$$

*Contains weak phase*

# Search for New Physics in CP violation




Measure:
UT Sides from Br's
UT angles from CP violation

Consistency of Unitarity triangle = probe for New Physics at *O*(1TeV) (B-factories) and *O*(5-10TeV) (SuperB-factory + LHCb)

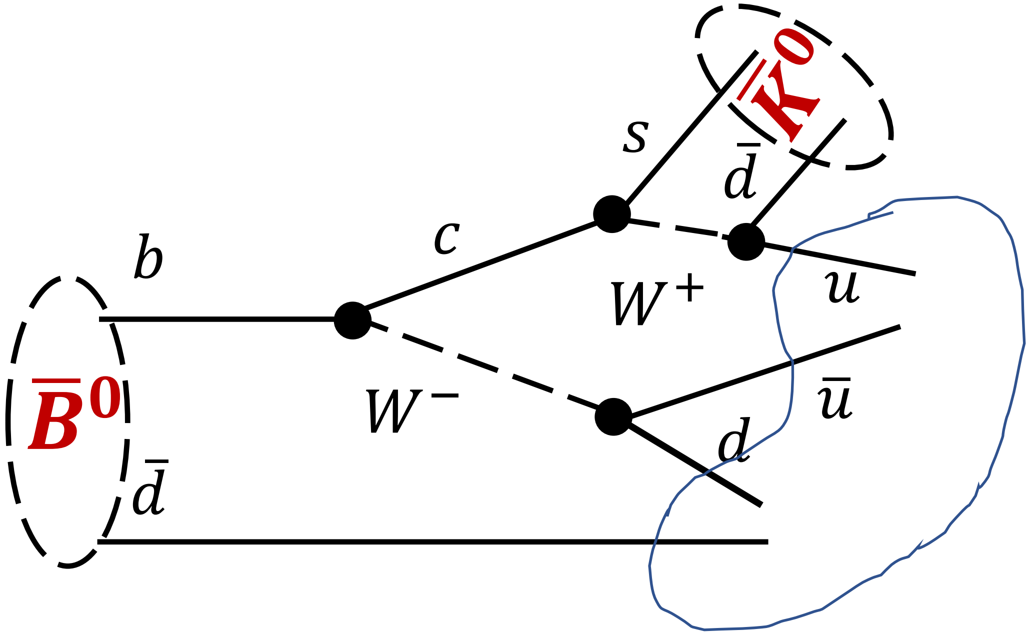
# How to study CP violation in B mesons

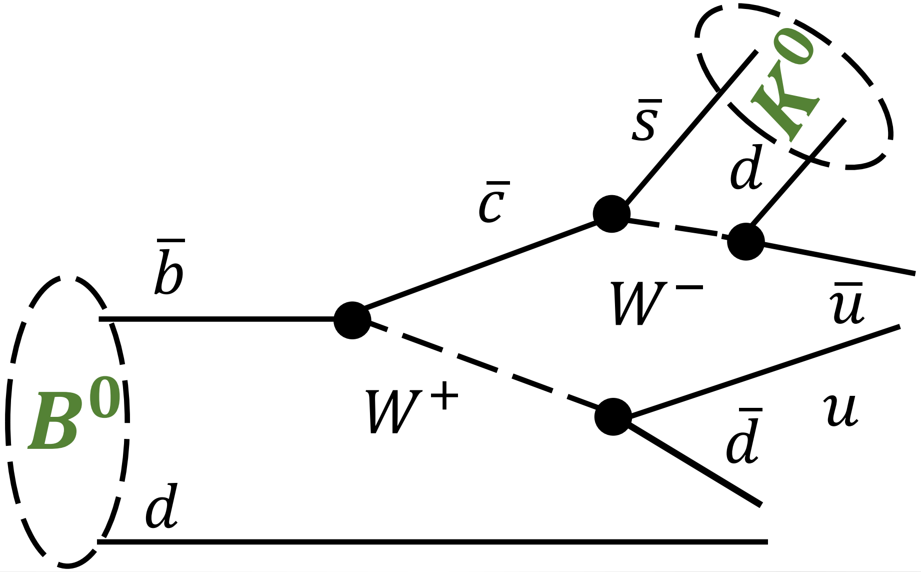
- No "$K_L$" methods applicable!
  - Lifetime difference is tiny, $\tau(B_H) - \tau(B_L)/\tau(B)$ ~1%: no way to work with a beam of long lived B's.
  - Semileptonic asymmetry also vanishes.
- New ideas required!
  - Sanda & Carter (1980): consider a final state *f* common for both $B^0$ and $\bar{B}^0$:

$$B^0 \to f_{\text{common}} \leftarrow \overline{B}^0$$

  - … in this place you can diagnose: they are crazy! In 1980, B mesons had not been discovered yet, only little can be hypothesized about their decay and lifetimes, but $B^0\bar{B}^0$ mixing was certainly expected to be tiny, as top quark was theoretically proven to be lighter than 20 GeV! The evidence was so compelling that the finance ministers of many countries are allocating billions of dollars, marks, oku-yens to build an experiment for top observation and expected Nobel prize…

# Carter-Sanda idea




In 1980 nobody could think of golden mode ($J/\psi\ K_S^0$). But Carter & Sanda realized that two succeeding CKM-favored W emitions may result in (almost, up to s-d replacement) same quark configuration. s-d difference is hidden in $K_S^0$. Thus, both $B^0$ and $\bar{B}^0$ decay into the indistinguishable final state (even if intermediate states $D^0$ / $\bar{D}^0$ are different). They estimated the CP violation effect may be as large as 10% (obviously, they pulled the effect up), but the Nature is very generous: in reality the effect is ~100%.

# How to study CP violation in B mesons

- Sanda & Carter (1980): consider a final state $f$ common for both $B^0$ and $\bar{B}^0$:

$$B^0 \rightarrow f_{\text{common}} \leftarrow \overline{B}^0$$

- We arrive at decay rate asymmetry for the $B^0(t = 0)$ and $\bar{B}^0(\mathrm{t} = 0)$ because of interference of two amplitudes with different weak phases

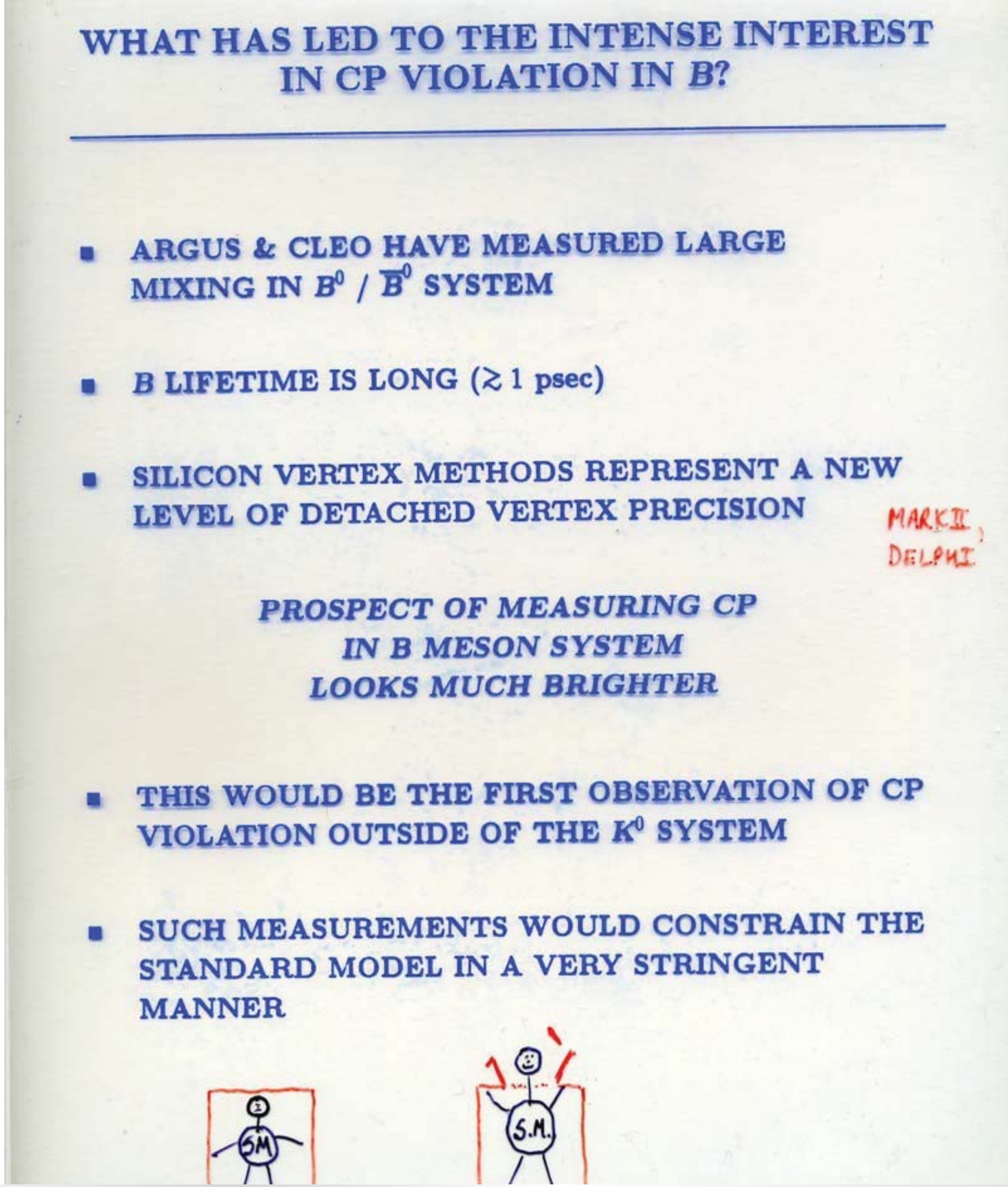
$$B^0 \rightarrow f \leftarrow \overline{B}^0 \leftarrow B^0 \qquad\qquad Br(B^0 \rightarrow f) \neq Br(\overline{B}^0 \rightarrow f)$$

- The idea was hopeless, but it is ridiculous that it was successfully implemented in 20 years (while experiments to realize it began to be built just 10 years later). Sanda & Carter overestimated the effect as much as they could (by the standards of 1980), but it turned out that the effect is much greater.

- It's funny that the tunnels of those accelerators for the discovery of the top quark (which was not discovered on them) served to create B-factories…

# 1980-1989

- From a crazy idea to realistic scenario:
- B-mesons had been discovered
- Large lifetime
- There are flavour blind modes, e.g. $J/\psi K_S^0$, which is in addition free of theoretical uncertainties -- “golden mode”
- $B^0\bar{B}^0$ mixing is large: this is not only good for Sanda-Karter idea realization, but also kills an idea to find top quark at $e^+e^-$ colliders: many built already accelerator tunnels cleared for new tasks (PEP at SLAC, PETRA at DESY, TRISTAN at KEK


WHAT HAS LED TO THE INTENSE INTEREST IN CP VIOLATION IN *B*?

- ARGUS & CLEO HAVE MEASURED LARGE MIXING IN $B^0$ / $\bar{B}^0$ SYSTEM
- *B* LIFETIME IS LONG ($\gtrsim$ 1 psec)
- SILICON VERTEX METHODS REPRESENT A NEW LEVEL OF DETACHED VERTEX PRECISION

MARK II, DELPHI

*PROSPECT OF MEASURING CP IN B MESON SYSTEM LOOKS MUCH BRIGHTER*

- THIS WOULD BE THE FIRST OBSERVATION OF CP VIOLATION OUTSIDE OF THE $K^0$ SYSTEM
- SUCH MEASUREMENTS WOULD CONSTRAIN THE STANDARD MODEL IN A VERY STRINGENT MANNER

# How to measure CPV at $e^+e^-$ collider?

The source of B mesons is the $\Upsilon(4S)$, which has $J^{PC} = 1^{--}$.
The $\Upsilon(4S)$ decays to two bosons with $J^P = 0^-$.
Quantum Mechanics (application of the Einstein-Rosen-Podolsky Effect) tells us that for a C = –1 initial state (Y(4S)) the rate asymmetry:

$$A = \frac{N_{(B_1 \to f_{CP})(\bar{B}_2 \to \bar{f}_{fl})} - N_{(B_1 \to f_{CP})(B_2 \to f_{fl})}}{N_{(B_1 \to f_{CP})(\bar{B}_2 \to \bar{f}_{fl})} + N_{(B_1 \to f_{CP})(B_2 \to f_{fl})}} = 0$$

However, if we measure the time dependence of A we find:

$$A(t_1,t_2) = \frac{N(t_1,t_2)_{(B_1 \to f_{CP})(\bar{B}_2 \to \bar{f}_{fl})} - N(t_1,t_2)_{(B_1 \to f_{CP})(B_2 \to f_{fl})}}{N(t_1,t_2)_{(B_1 \to f_{CP})(\bar{B}_2 \to \bar{f}_{fl})} + N(t_1,t_2)_{(B_1 \to f_{CP})(B_2 \to f_{fl})}} \propto \sin 2\phi_{CP}$$

Need to measure the time dependence of decays to “see” CP violation using the B’s produced at the $\Upsilon(4S)$.

B-meson’s decay flight is only 20μm in $\Upsilon(4S)$ rest frame. No chance to measure such small distance with modern detectors…

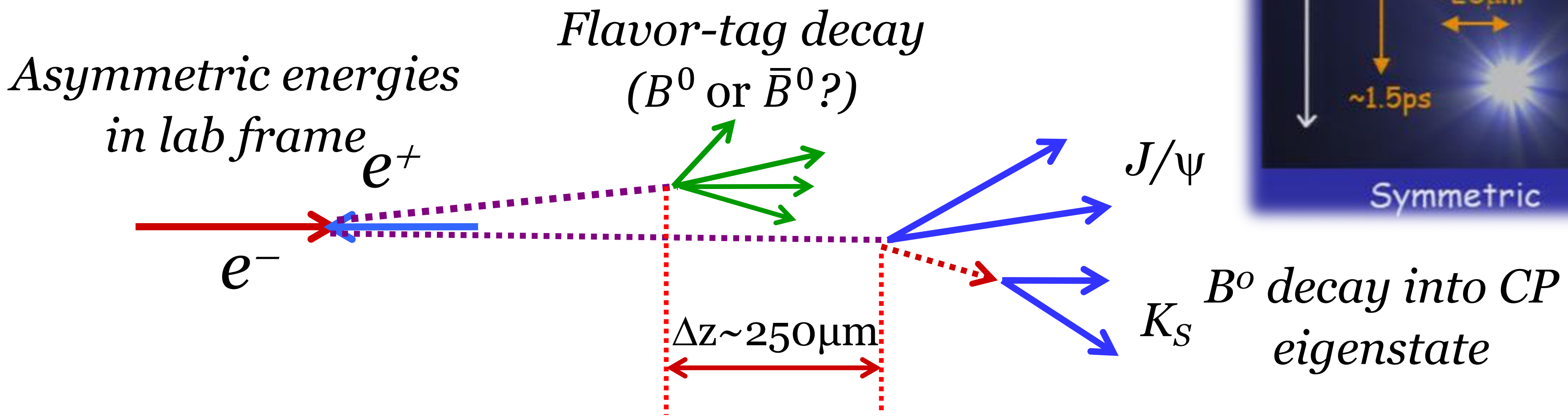
$\Rightarrow$ this kills good idea? No! just requires new idea:

# Asymmetric $e^+e^-$ collider

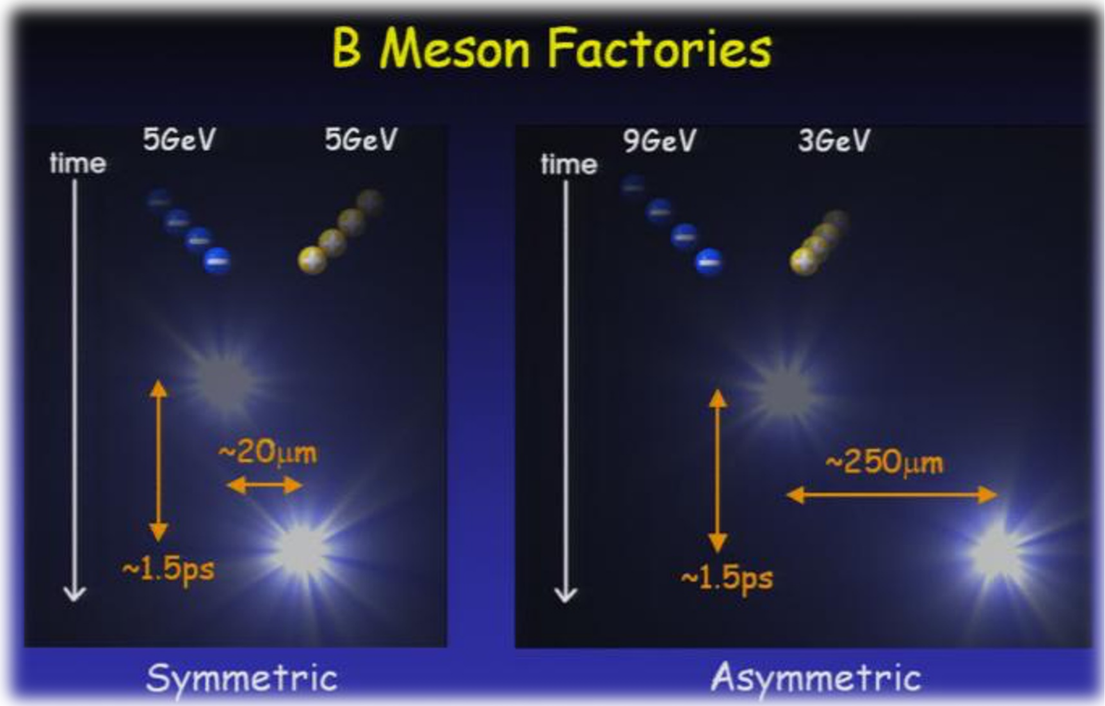
Impossible to reconstruct B-decay vertex because they are too slowly in $\Upsilon(4S)$ frame?

Let's make the $\Upsilon(4S)$ to move fast in the laboratory frame, then B-mesons have a sizable path; we need that accelerating electrons and positrons have different energies, but the Energy of center of mass = $M(\Upsilon(4S))$, $2\sqrt{E_+E_-} = M(\Upsilon(4S))$

We can measure t-dependent asymmetry at $\Upsilon(4S)$ !




Pier Oddone (1987) proposed the idea of asymmetric B-factory



# Asymmetric energy $e^+e^-$ collider

$$a_{CPV}(\Delta t) = \frac{\Gamma_{\bar{B}\to\bar{f}}(\Delta t) - \Gamma_{B\to f}(\Delta t)}{\Gamma_{\bar{B}\to\bar{f}}(\Delta t) + \Gamma_{B\to f}(\Delta t)} =$$

$$= S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)$$

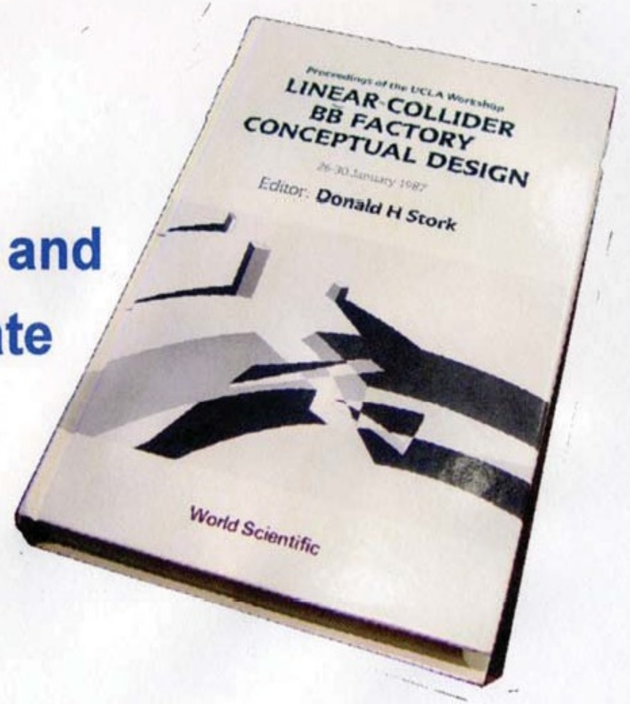
Proposed by P. Oddone for realization at SLAC;

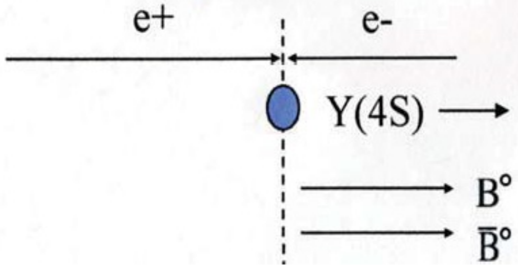
The idea led to **21** conceptual design projects of asymmetric B-factories throughout the world.

Two collider, PEP-II and KEKB, were ultimately built.

## Things Come Together January 1987

- Discussions with Ikaros Bigi and Tony Sanda
- "Crazy Asymmetric Idea" just what was needed for CP studies
- Could be done by modifying PEP
  - Two rings: give high luminosity
  - $\Upsilon(4S)$: gives high cross section and $B^\circ\bar{B}^\circ$ in coherent state
  - Asymmetry: separated vertices give time evolution



# Asymmetric B-factory

TABLE 1.

Future $b\bar{b}$ factories and sweat shops. None of the luminosities shown in the Table have been achieved. Factors of two difference in luminosity are not significant.

| $E_{CM}$ GeV | Class | $E_1 \times E_2$ GeV × GeV | $\sigma_{b\bar{b}}$ | Peak L proposed $cm^{-2}sec^{-1}$ | $b\bar{b}$ events/yr $10^7$sec @ peak L | References |
|---|---|---|---|---|---|---|
| $\Upsilon(4S)$ | CM RING | 5 × 5 | 1 nb | $5 \times 10^{32}$ | $5 \cdot 10^6$ | SIN Proposal[1] |
| | CM LINEAR | 5 × 5 | | $10^{33}$ | $10^7$ | Amaldi & Coignet[2] |
| | BOOSTED LINEAR | 2 × 12.5 | | $5 \times 10^{32}$ | $5 \cdot 10^6$ | Sessler & Wurtele[3] |
| | BOOSTED RING | 2 × 12.5 | | $5 \times 10^{32}$ | $5 \cdot 10^6$ | Oddone[4] |
| Continum 20 GeV | RING | | 0.1 nb | $5 \times 10^{33}$ | $5 \cdot 10^6$ | Bloom[5] |
| | LINEAR | | | $10^{34}$ | $10^7$ | Amaldi & Coignet[2] |
| $Z^0$ | LINEAR SLC | 45 × 45 | 5 nb | $5 \times 10^{30}$ | $2.5 \cdot 10^5$ | SLC Study[6] |
| | LEP | 45 × 45 | | $2 \times 10^{31}$ | $8 \cdot 10^5$ | LEP Study[7] |
| | RING IMAGINARY | 45 × 45 | | $5 \times 10^{33}$ | $2.5 \cdot 10^8$ | |


DETECTOR CONSIDERATIONS

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1 INTRODUCTION

This short note is drawn in large part from the joint deliberations of the detector and physics groups at this workshop. There were many "full time" and "part time" members, among them C. Adolphsen, P. Avery, I. Bigi, E. Bloom, C. Buchanan, G. Coignet, H. Harari, W. Hofmann, N. Lockyer, I. Peruzzi, M. Piccolo, T. Sanda, P. Schlein, A. Soni, D. Stork, S. Weseler, H. Yamamoto, and T. Ypsilantis. In our deliberations we tried to under-

The idea of an Asymmetric B-Factory can be realized relatively economically at SLAC, where a powerful injector, an existing tunnel, and a ring of magnets suitable for the high energy ring already exist. The requirements for the accelerator are,

From Sanda's memories: "I went to KEK.
People said that Oddone's idea is crazy and that the beam will blow up!

# What's required to discover CPV at $e^+e^-$ collider?

Produce B mesons! Need accelerator…

*it's not enough…*

well, produce moving B-mesons, thus asymmetric energy accelerator

*still not enough…*

Produce a huge number of B mesons!

Need asymmetric accelerator with record luminosity!

accelerator

Reconstruct B mesons, tag the flavor and measure vertices

*more required…*

Reconstruct B mesons with maximum efficiency in all possible decays

Correctly determine the flavor of the second B-meson in the event

Precisely reconstruct two decay vertices

detector

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