The Breakdown of Microscopic Time Reversal Invariance, the CKM Paradigm & Cathedrals

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a tale of three paradigms

○ my personal particle physics paradigm

❏ a fundamental question at stake

❏ often long periods of *apparent* stagnation followed by intervals of unexpected twists & turns, even breakthroughs

❏ the conclusion of one chapter often comes with the first message from the next chapter

❏ driven by theory ∕ experiment ∕ new technologies taking the lead in turns

○ the `CKM' paradigm

○ the `Cathedral' paradigm

time reversal **T** $\forall$ reversal of motion

t $\emptyset$ - t   **p** $\emptyset$ - **p**

daily experiences of time reversal violation

represent asymmetries in macroscopic
initial conditions!

yet: microscopic $\not{T}$ has been observed!

CPT

$\not{T}$ / $\not{CP}$

will argue $\not{CP}$ & $\not{T}$ more subtle, fundamental and
profound than $\not{P}$, $\not{C}$!

message

- $\not{CP}$ -- a fundamental phenomenon!
- The past: '64 $\emptyset$ '98: phenomenology & models
- "Triple phase transition" of '99 $\emptyset$ ~ '01
  - conclusion of an epoch: $\epsilon'/\epsilon \sharp 0$
  - establishment of `the CKM Paradigm'
    $\not{CP}$ in beauty decays
  - first smell of New Physics: ν oscill.?!
- "The quest for New Physics" : '02 $\emptyset$ '15 ff
  - the "King Kong" scenario
  - the new challenge: precision probes
- The Cathedral

I. $\cancel{CP}$ -- a Fundamental Phenomenon!

○ $\cancel{CP}$ vs. $\cancel{P}$

discovery of $\cancel{P}$ in 1957 a great shock --
yet theorists quickly recovered

$$\pi^- \not\!\!\emptyset \; e_L^- \, \nu \qquad \text{or} \qquad \pi^+ \not\!\!\emptyset \; e_R^+ \, \nu$$

$$\text{"L"} = f \, (\text{"-"})$$

$$CP: \; (\pi^- \not\!\!\emptyset \; e_L^- \, \nu) \; ? \; (\pi^+ \not\!\!\emptyset \; e_R^+ \, \nu)$$

If CP ∣ (i.e. max. $\cancel{P}$ compensated by max. $\cancel{C}$)

? "L" pure convention!

"the thumb is left on the right hand!"

`Mach principle': laws of physics should not depend
on geometrical coordinate system!

$$1964: \quad BR(K_L \not\!\!\emptyset \; \pi^+ \, \pi^-) \spadesuit 2.3 \; \infty 10^{-3} \; \sharp \; 0$$

very frustrating:

CP invariance a "near-miss" -- in contrast to $\cancel{P}$:

$BR(K_L \not\!\!\emptyset \; \pi^+ \, \pi^-) << 1$ vs.   only ν_L and no

smallest observed violation of a symmetry

$\mathrm{Im} \, M_{12} \spadesuit 1.1 \infty 10^{-8} \, eV \; / \; \mathrm{Im} \, M_{12}/m_K \spadesuit 2.2 \; \infty 10^{-17}$

○ alternatives to ~~CP~~

- ∃ invisible CP odd particle U

$$K_L \not\rightarrow \pi^+ \pi^- [U]$$

a la Pauli's postulate for v's in β decay

$$n \not\rightarrow p\, e\, [v]$$

introduce new invisible particle to save conservation law

U	v
CP	energy-momentum
did not work	did work

- break-down in superposition principle of QM

○

~~CP~~: $\Gamma(K_L \not\rightarrow l^+ v_L \pi^-) > \Gamma(K_L \not\rightarrow l^- v_R \pi^+)$

↪ convention indep. definition of "+" vs. "−"

↪ convention indep. definition of "L" vs. "R"   4

○ maximal symmetry violation?

P̶   maximal ⎫

C̶   maximal ⎭

$$\begin{array}{ccc} \nu_L & \xrightarrow{\ \ P\ \ } & \nu̶_R̶ \\ \Big\updownarrow C̸ & \searrow CPT & \Big\updownarrow C \\ \bar{\nu}̶_L̶ & \xrightarrow{\ \ P\ \ } & \bar{\nu}_R \end{array}$$
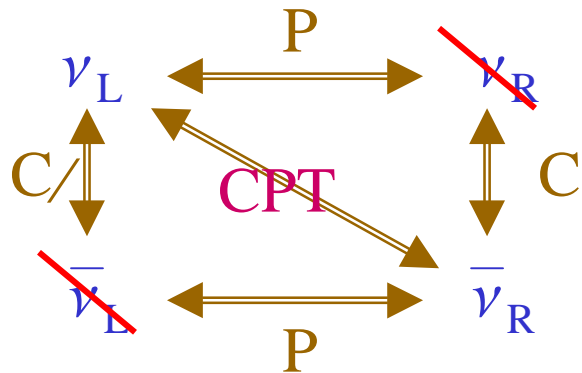
i.e., CPT already enforces presence of $\bar{\nu}_R$

`no future generation'

○ `existence of us', i.e. baryon number of universe

$$\#(\text{photons}) \gg \#(\text{baryons}) - \#(\overline{\text{baryons}}) \gg \#(\overline{\text{baryons}})$$

$10^{10\pm1}$

explain as dynamical quantity rather than

assume as input value:

three essential ingredients (Sakharov) :

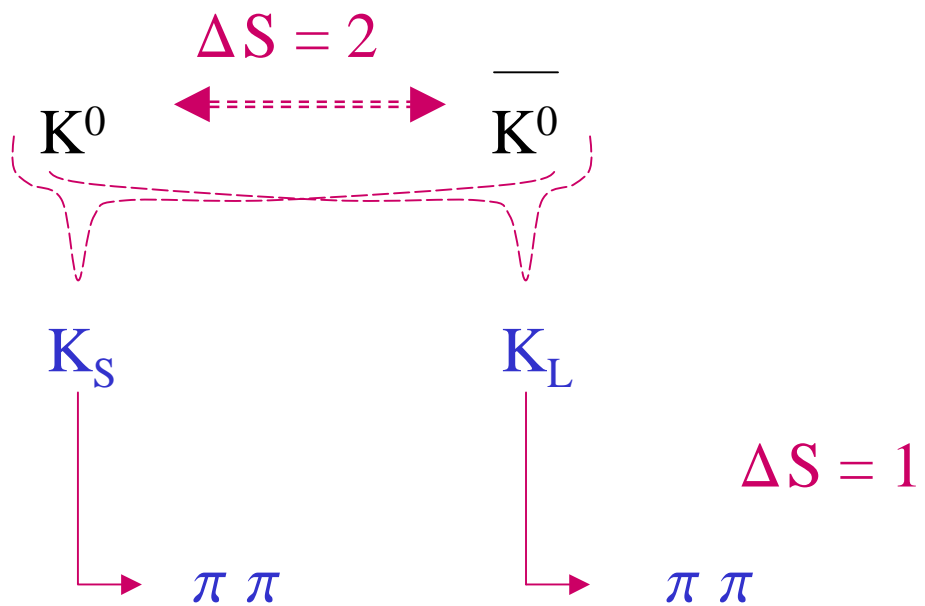❶   baryon # violation

❷   C̶P̶

❸   out of thermal equilibrium

II.1 Basic CP phenomenology

Partial widths

$$K_L \not\rightarrow \pi \pi$$

interplay
of 2
processes

$$\Delta S = 2$$

$$K^0 \quad\longleftrightarrow\quad \overline{K^0}$$

$$K_S \qquad\qquad K_L$$

$$\Delta S = 1$$

$$\pi \pi \qquad\qquad \pi \pi$$

$$\eta_{+-,00} = \frac{A(K_L \not\rightarrow \pi^{+,0} \pi^{-,0})}{A(K_S \not\rightarrow \pi^{+,0} \pi^{-,0})}$$

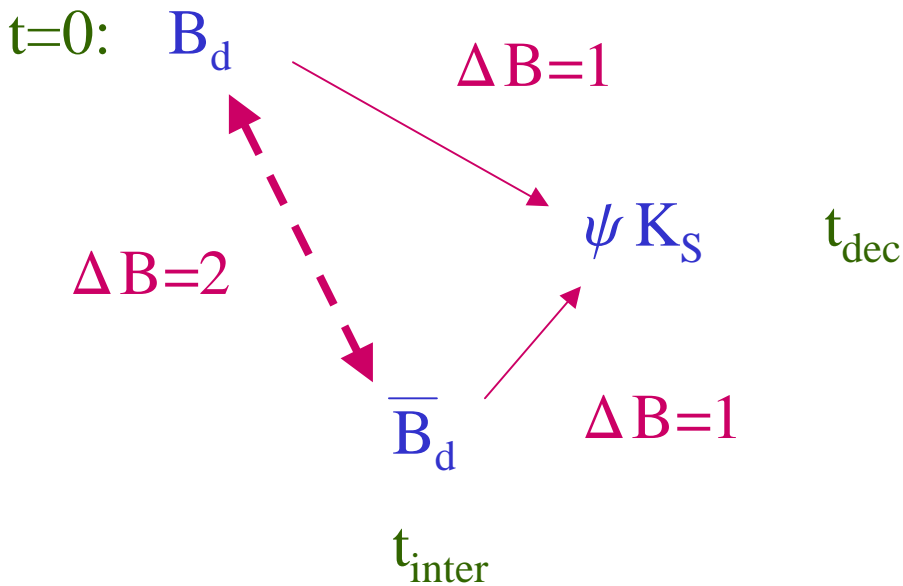$$\eta_{+-} = \epsilon + \epsilon', \quad \eta_{00} = \epsilon - 2\epsilon'$$

indirect   direct

$\not{CP}$

$$\Phi(\Delta S = 1) = \arg(A_{I=2}/A_{I=0})$$

$$\Phi(\Delta S = 2) = \arg(M_{12}/\Gamma_{12})$$

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$$\boxed{B_d \not{\phi} \ \psi K_S}$$

t=0: B_d

$\Delta B=1$

ψK_S t_{dec}

$\Delta B=2$

$\overline{B}_d$ $\Delta B=1$

t_{inter}

rate(B_d [$\overline{B}_d$](t_{dec}) $\not{\phi}$ ψK_S) $\propto e^{-\Gamma t}(1- [+] A\sin\Delta m_d t)$

Electric dipole moments   e.g., static quantities

energy shift $\Delta\mathcal{E}$ of system inside electric field E :

$$\Delta\mathcal{E} = d_i E_i + d_{ij} E_i E_j + \ldots$$

linear in E

d $\propto$ **s** ?   **d** $\sharp$ 0 $\diagup$ T violation !

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II.2   Theory of C̶P̶

○ '64: discovery caused consternation among theorists yet accepted as fact

○ `superweak' model: C̶P̶ in $\Delta S=2$ only classification, not a dynamical realization!

○ '70: renormalizability of SU(2)⊗U(1)

  ❏   no theory of C̶P̶!

  ❏   lack of theory not realized!!

○ '73: Kobayashi-Maskawa paper

  ☞   stated absence of theory

  ☞   gave criteria necessary for theory
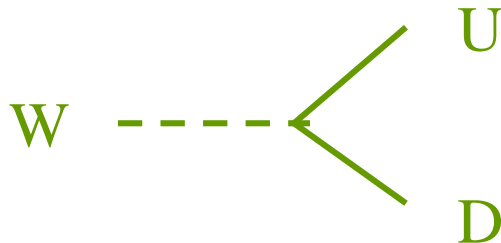
  ☞   listed classes of theories, among them KM ansatz with > 2 families

○ `79: `Strong CP Problem'

   QCD has a source of flavour-diagonal T̶ in dim = 4 operator inducing $d_N \neq 0$
   experim. bound ? $\theta < O(10^{-9})$ `unnatural'!

no theory of C̶P̶!

Mohapatra '72

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CPT:

C̶P̶ / complex phases in weak CC couplings

☞ need dynamical substrate to be sufficiently complex

W - - - - < U
            D

quark families (existence central mystery of SM)

U   D

$\begin{bmatrix} u \\ c \\ .. \end{bmatrix}$ $\begin{bmatrix} d \\ s \\ .. \end{bmatrix}$ mass eigenstates

♯

interaction eigenstates !

unitary NxN matrices $T_{U,D}$ connect the two

$V_{CKM} = T_{UL} \, T^+_{DL}$ nontrivial -- unless alignment!
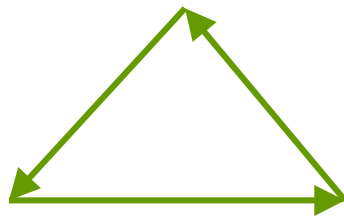
➥ weak *charged* currents couplings affected

CKM parameters intrinsically connected
with mass generation for quarks

central mystery of SM

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3 families:

$$\mathbf{V} = \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix}, \qquad \mathbf{V*V} = \mathbf{1} \quad \text{'weak universal.'}$$

➡ a*b + d*e + g*h = 0

i.e., triangle in complex plane

unitarity

➡   3 universality + 6 triangle relations with many correlations among them:

$\mathbf{V}_{CKM}$: contains 4 physical parameters

➡ 3 Euler angles

➡ 1 phase ?   C̸P̸ !

II.3 '98 landscape of CP data

❍ $BR(K_L \not\Phi \pi^+\pi^-) = 2.3 \propto 10^{-3}$ ♯ 0

$$\frac{BR(K_L \rightarrow l^+\nu\pi^-)}{BR(K_L \rightarrow l^-\nu\pi^+)} \approx 1.006 \neq 1$$

❍ $\eta_{+-[00]} =$

$$= T(K_L \not\Phi \pi^{+[0]}\pi^{-[0]})/T(K_S \not\Phi \pi^{+[0]}\pi^{-[0]})$$

$$= \epsilon + \epsilon' [\epsilon - 2\epsilon']$$

$$\epsilon'/\epsilon = \begin{cases} (2.30 \pm 0.65) \propto 10^{-3} & \text{NA31} \\ (0.74 \pm 0.59) \propto 10^{-3} & \text{E731} \end{cases}$$

both launched by theory predictions
and done in the '80's

❍ $d_N < 6.3 \propto 10^{-26}$ e cm
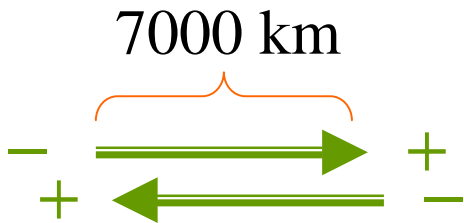
from ultracold neutrons

❍ $d_e = (-0.3 \pm 0.8) \propto 10^{-26}$ e cm

from atomic EDM

to visualize the sensitivity achieved

☞ $d_N = 6.3 \propto 10^{-26}$ e cm   /   radius $r_N \sim 10^{-13}$ cm

7000 km

$$- \xrightarrow{\hspace{3cm}} +$$
$$+ \xleftarrow{\hspace{3cm}} -$$

search for displacement of 10^{-12} $R_e \sim 7 \mu$!

☞ $d_e = (-0.3 \pm 0.8) \propto 10^{-26}$ e cm

/ $\delta[(g-2)/2] \sim 10^{-11}$

/ $\delta(F_2(0)/2m_e) \spadesuit 2 \propto 10^{-22}$ e cm !

☞   side remark

$d_{atom} = 0$ in non-relativistic limit

" Schiff's theorem "

vitiated by relativistic corrections

$$d_{atom} = ENH \propto d_e$$

$\sim O (100 - 600)$!

o   discovered: charm 1971(1974)1976, beauty 1977,
        top 1995

? $m_{top} \sim 36\ m_b \sim 180\ M_p$?   1st surprise

o $|b \not\!\phi\ c|^2 >> |b \not\!\phi\ u|^2$

o $\tau(b) \sim 10^{-12}$ sec $>> 10^{-14}$ sec   2nd surprise
    `long beauty lifetime'

μ vertex technology on the `shelves' from charm!

$$\blacktriangleright \quad |V_{CKM}| \sim \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}$$

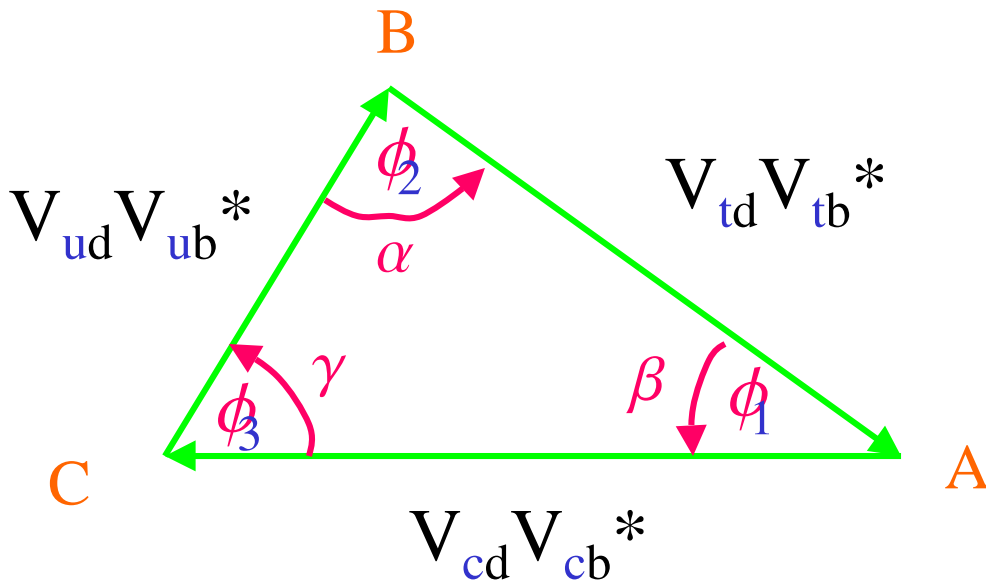Schlaeft ein Lied in allen Dingen,

Die da traeumen fort und fort,

Und die Welt hebt an zu singen,

Findst Du nur das Zauberwort.

                J. v. Eichendorff

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one triangle has its sides of same order in λ

➡ naturally large angles

➡ CP asymmetries of order unity

➡ it controls beauty transitions!

`the' KM unitarity triangle

$$\text{rate}(B_d\ [\overline{B}_d](t_{dec})\ \emptyset\ \psi K_S) \propto e^{-\Gamma t}(1-\ [+]\ A\ \sin\Delta m_d t)$$

$$A = \sin 2\phi_1$$

predictions within KM in '98

○ ϵ_K can be reproduced

○ $\epsilon'/\epsilon \leq 10^{-3}$ due to cancellations (except for a
   few heretics)

○ EDM's: $d_N, d_e < 10^{-30}$ e cm
○ CP asymmetries in B decays:

❑ some ~ $O(1)$ "no plausible deniability!"

❑ early '90's (before discovery of top):
   $$\sin2\phi_1 [\beta] = \quad 0.6 - 0.7$$

❑ more specifically in '98
   $$\sin2\phi_1 [\beta] = \quad 0.716 \pm 0.070$$

❑ attractions for experimentalists
   ✎ sizeable B^0-$\overline{B}^0$ oscillations established
   ✎ "long" B lifetime
   ✎ "clean" tests of the Standard Model

III. "Triple Phase Transition" of '99 - '01

III.1   The New Measurements

○   direct CP was established in 1999!

status summer '01:

NA48:   Re $\epsilon'/\epsilon = (1.50\pm0.21 \pm0.17) \times 10^{-3}$

KTeV: Re $\epsilon'/\epsilon = (2.07\pm0.28) \times 10^{-3}$

_____

WA: Re $\epsilon'/\epsilon = (1.72\pm0.18) \times 10^{-3}$

(14 % consistency)

$$\frac{\Gamma(K^0\phi\ \pi^+\pi^-) - \Gamma(\overline{K^0}\phi\ \pi^+\pi^-)}{\Gamma(K^0\phi\ \pi^+\pi^-) + \Gamma(\overline{K^0}\phi\ \pi^+\pi^-)} = (5.7\ \pm0.6) \times 10^{-6} \ !$$

○ deserve our respect -- earned my admiration

○ a discovery of the first rank -- no matter

what theory does or does not say

○ do not expect quick reply from theory

standard for CPT tests![16]

❍ direct evidence for ~~T~~

of course   ~~CP~~   ?   ~~T~~   due to CPT ▪

The 'Kabir Test': K^0 ? $\overline{K^0}$ vs. $\overline{K^0}$? K^0

associated production ▪

$$A_T = \frac{\Gamma(K^0 \to \overline{K^0}) - \Gamma(\overline{K^0} \to K^0)}{\Gamma(K^0 \to \overline{K^0}) + \Gamma(\overline{K^0} \to K^0)}$$

semilept. K_{neut} $\emptyset$ $l^{\pm} \nu \pi$,   CPT

CPLEAR:

$A_T = (6.6 \pm 1.3 \pm 1.0) \infty 10^{-3}$ ♯ 0

vs. $(6.54 \pm 0.24) \infty 10^{-3}$ ▪

○ The Era of Beauty Factories

BABAR, BELLE, CDF, [D0]

B $\emptyset$ ψ K$_S$ predicted in 1980

❑ 1999

CDF: $\sin 2 \phi_1 = 0.79 \pm 0.44$

❑ Summer of 2000

BELLE: $\sin 2 \phi_1 = 0.45 \pm 0.44 \pm 0.09$

BABAR: $\sin 2 \phi_1 = 0.12 \pm 0.37 \pm 0.09$

❑ Spring of 2001

BELLE: $\sin 2 \phi_1 = 0.58 \pm 0.33 \pm 0.10$

BABAR: $\sin 2 \phi_1 = 0.34 \pm 0.20 \pm 0.05$

world average Spring 2001
$\sin 2 \phi_1 = 0.48 \pm 0.16$

❏ Summer of 2001

0.06 BELLE: $\sin 2\phi_1 = 0.99 \pm 0.14 \pm$

0.05 BABAR: $\sin 2\phi_1 = 0.59 \pm 0.14 \pm$

world average $\sin 2\phi_1 = 0.79 \pm 0.10$

❏ Spring 2002

0.05 BELLE: $\sin 2\phi_1 = 0.82 \pm 0.12 \pm$

0.04 BABAR: $\sin 2\phi_1 = 0.75 \pm 0.09 \pm$

❏ Summer 2002

BELLE: $\sin 2\phi_1 = 0.719 \pm 0.074 \pm$ 0.035

0.033 BABAR: $\sin 2\phi_1 = 0.741 \pm 0.067 \pm$

➥ it is there and

➥ it is huge --

➥ as expected!

❑ CP asymmetry coupled with $\not{T}$

BELLE
'01

$\sin\Delta m_d t$

$\not{\phi}$
$\sin\Delta m_d \bar{t}$

~~under t $\not{\phi}$ -t~~

QuickTime™ and a
GIF decompressor
are needed to see this picture.

$(\Gamma_B \not{\phi}$
$0)$

$e^+e^- \emptyset \ B^0 \ \overline{B}^0$

Bose-Einstein:

$B_1 \perp B_2$ (C=-)

-- till decay!

EPR correlat.

$\overline{B}^0$

time

B_2

B_1

B^0

Q=+: B^0; $\overline{B}^0 \emptyset \psi K_S$

Q=-: $\overline{B}^0$; $B^0 \emptyset \psi K_S$

l^Q

ψ

e^- e^+

K_S

t = 0

Δt

t
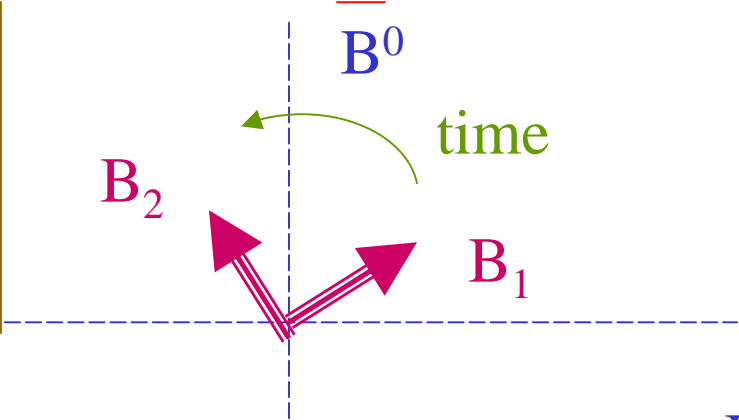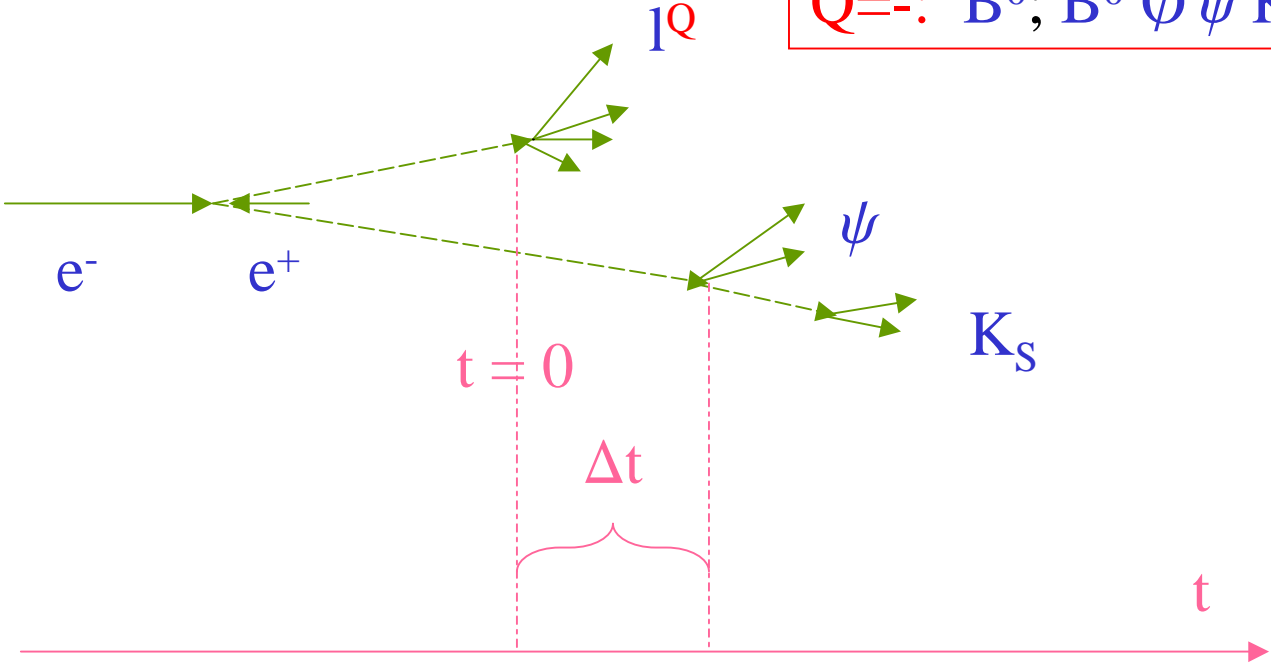
"translate space into time"

at $\Delta t = 0$:   no CP asymmetry (unless direct)!

EPR correlat.

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l$^+$

e$^-$ e$^+$

ψ

K$_S$

t = 0

Δt

t

l$^-$

e$^-$ e$^+$

ψ

K$_S$

t = 0

Δt

t
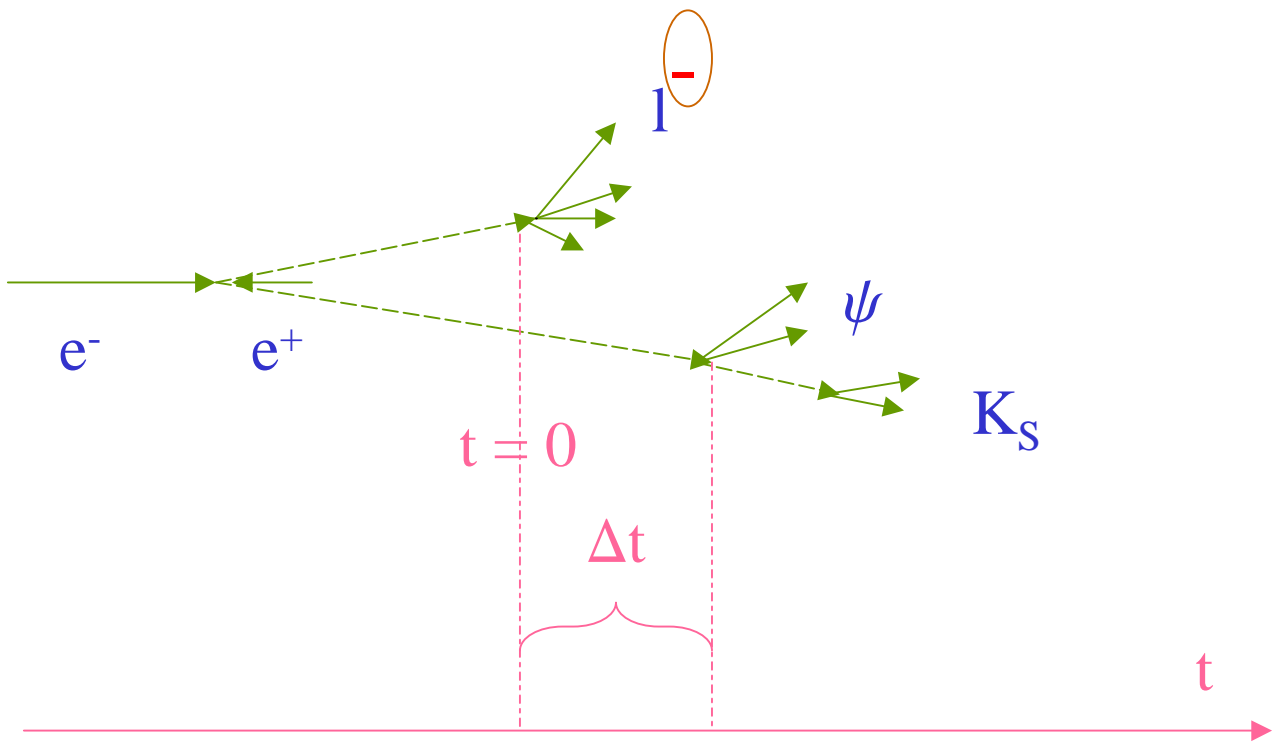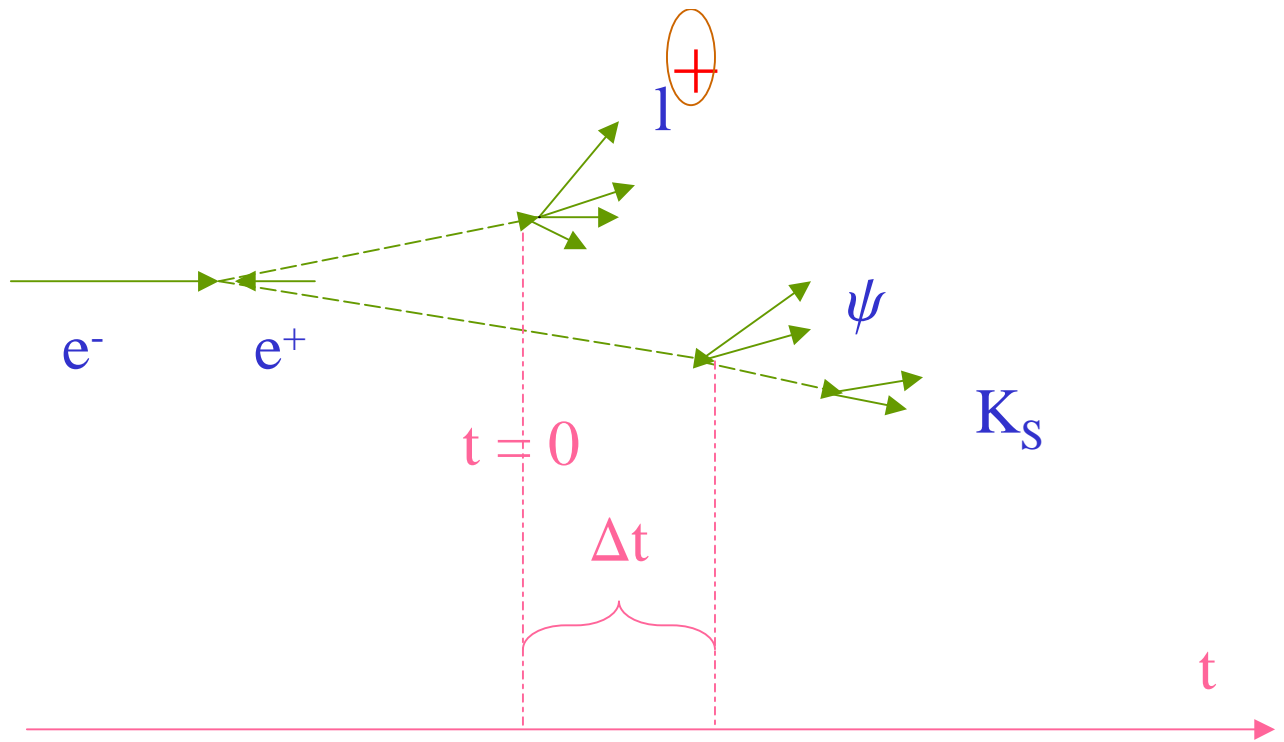
○ if $e^+e^- \not\phi\, l^+ X + \psi K_S \neq e^+e^- \not\phi\, l^- X + \psi K_S$

↪ $\diagdown$ CP !

QuickTime™ and a
GIF decompressor
are needed to see this picture.
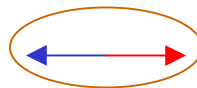
○ $l^- X + \psi K_S$ events: $\langle \Delta t \rangle > 0$
i.e., $\langle \bar{B}_d \not\phi\, \psi K_S$ after $B \not\phi\, lX \rangle$

$l^+ X + \psi K_S$ events: $\langle \Delta t \rangle < 0$
i.e., $\langle B_d \not\phi\, \psi K_S$ before $B \not\phi\, lX \rangle$

EPR crucial for the argument!

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$$B \not{\phi} 1^- X \qquad B_d \not{\phi} \psi K_S$$

× ⟷ ×

EPR

CPT

× ⟷ ×

EPR

$$B_d \not{\phi} \psi K_S \qquad B \not{\phi} 1^+ X$$
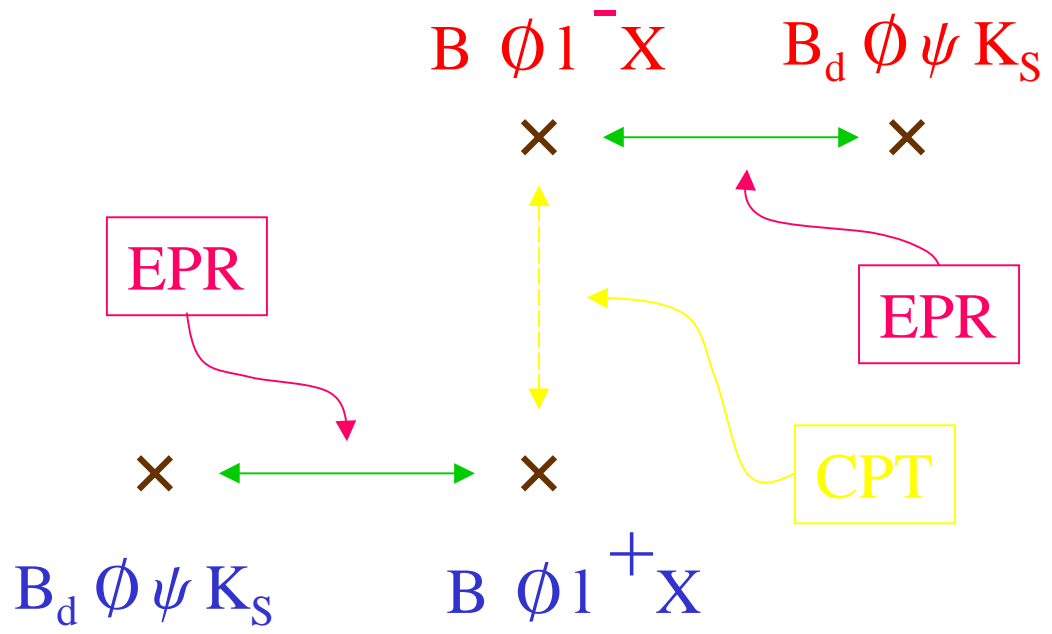
$$B_d \not\!\!\! \phi \, \pi^+\pi^-$$

$$\frac{R_+(\Delta t) - R_-(\Delta t)}{R_+(\Delta t) + R_-(\Delta t)} = S \sin \Delta m_d \Delta t + C \cos \Delta m_d \Delta t$$

$$S = \frac{2 \, \mathrm{Im} \, (q/p)\bar{\rho}(f_{CP})}{1 + |(q/p)\bar{\rho}(f_{CP})|^2} \, , \quad C = \frac{1 - |(q/p)\bar{\rho}(f_{CP})|^2}{1 + |(q/p)\bar{\rho}(f_{CP})|^2}$$

if $S(f_1) \neq \eta(f_1)\,\eta(f_2)\,S(f_2)$ or $C(f) \neq 0$? direct CP̸ !

❏ Spring 2002

BELLE:

$$S = -1.21 \, {}^{+0.38}_{-0.27} \, {}^{+0.16}_{-0.13}$$

$$C = +0.94 \, {}^{+0.25}_{-0.31} \, \pm 0.09$$

BABAR:

$$S = -0.01 \pm 0.37 \pm 0.07$$

$$C = +0.02 \pm 0.29 \pm 0.07$$

however:

from $B \not\!\!\! \phi \, \psi \, K_S$ one can infer from established dynamics

$$S = -(0.75 \, \forall \, 0.82) \qquad \neq \text{BABAR?}$$

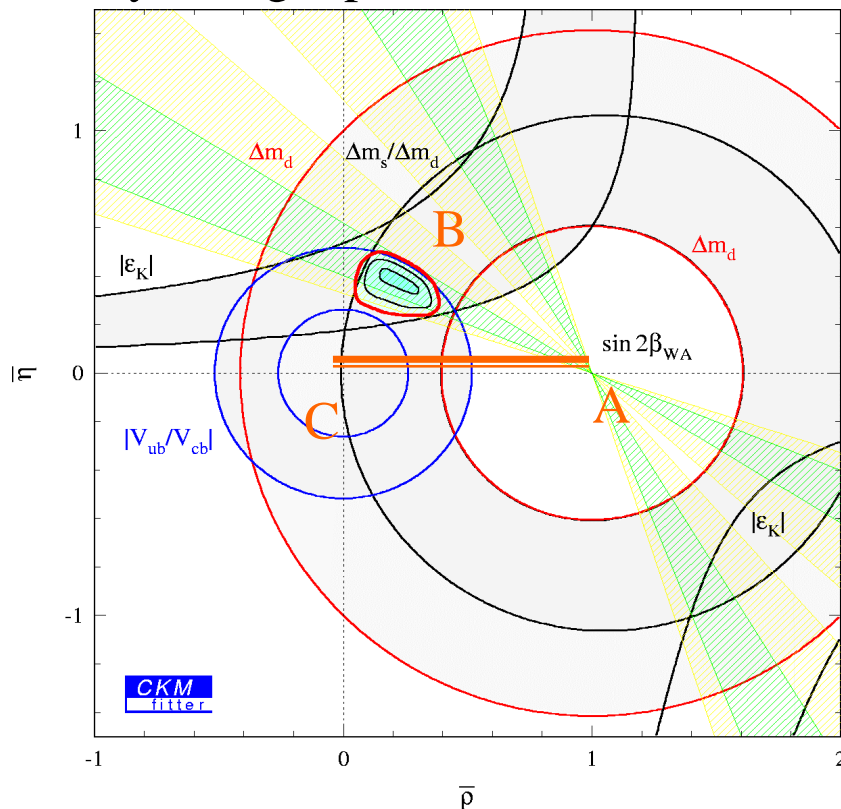$$C = 0 \qquad\qquad\quad \neq \text{BELLE?}$$

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III.2 The unreasonable success of the CKM description

Yes, indeed …

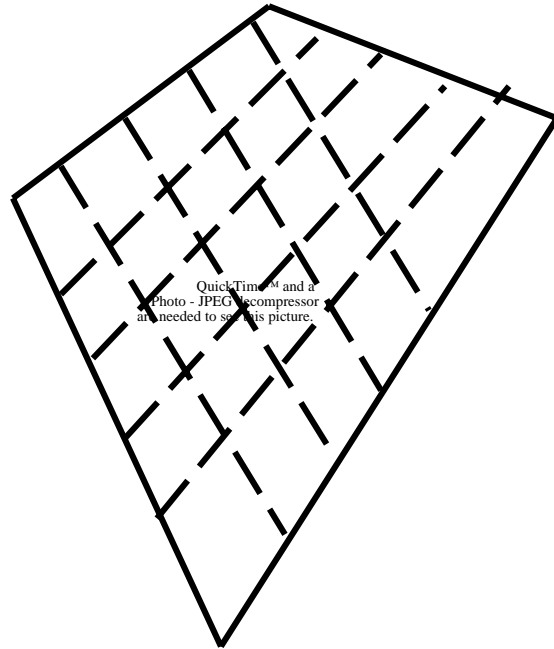large fraction of $\Delta m_K, \epsilon_K, \Delta m_B$ $\Big\}$ could be due

most of ϵ_K ' to New Physics

or equivalently

data constraints translate into `broad' bands

in unitarity triangle plots

yet such a statement misses the real point!

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

Δm_K (box)

Δm_K(observ)

ϵ_K(observ)

Δm_{Bd} (box)

ϵ_K(box)

Δm_{Bd}(observ)

10^{-16} 10^{-14} 10^{-12} 10^{-10} 10^{-8}

ϵ_K '(observ)

MeV

ϵ_K '(SM)

Δm_K(box, *no GIM*)

if m_t=40 GeV

if τ_b= few x 10^{-14} sec

small |V(td)| offset by large m_t
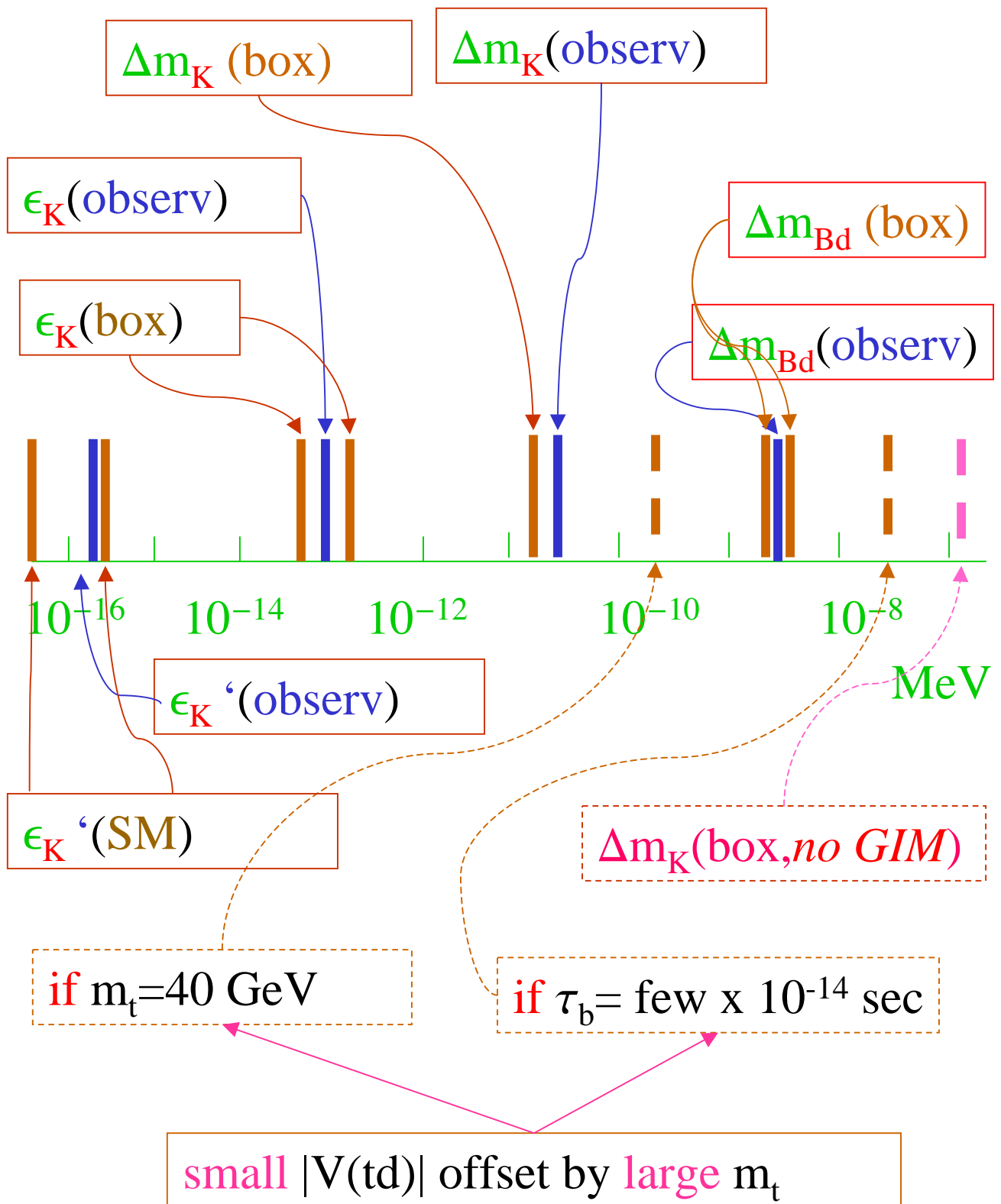
can all be reproduced with

$|V(us)| \sim 0.22$, $|V(ts)| \sim 0.04$, $|V(td)| \sim 0.004$

$m_u \sim 5$ MeV, $m_c \sim 1.2$ GeV, m_t ♠ 180 GeV

$m_d \sim 10$ MeV, $m_s \sim 0.15$ GeV, m_b ♠ 4.6 GeV

observables spanning several orders of magnitude accommodated with parameter choices that a priori would seem frivolous! There could easily have been inconsistencies!

Lacker plot

CKM explains naturally why CP invariance is a `near miss' in K_L decays: 1st & 2nd families almost decoupled from 3rd!

➥ summer '01:

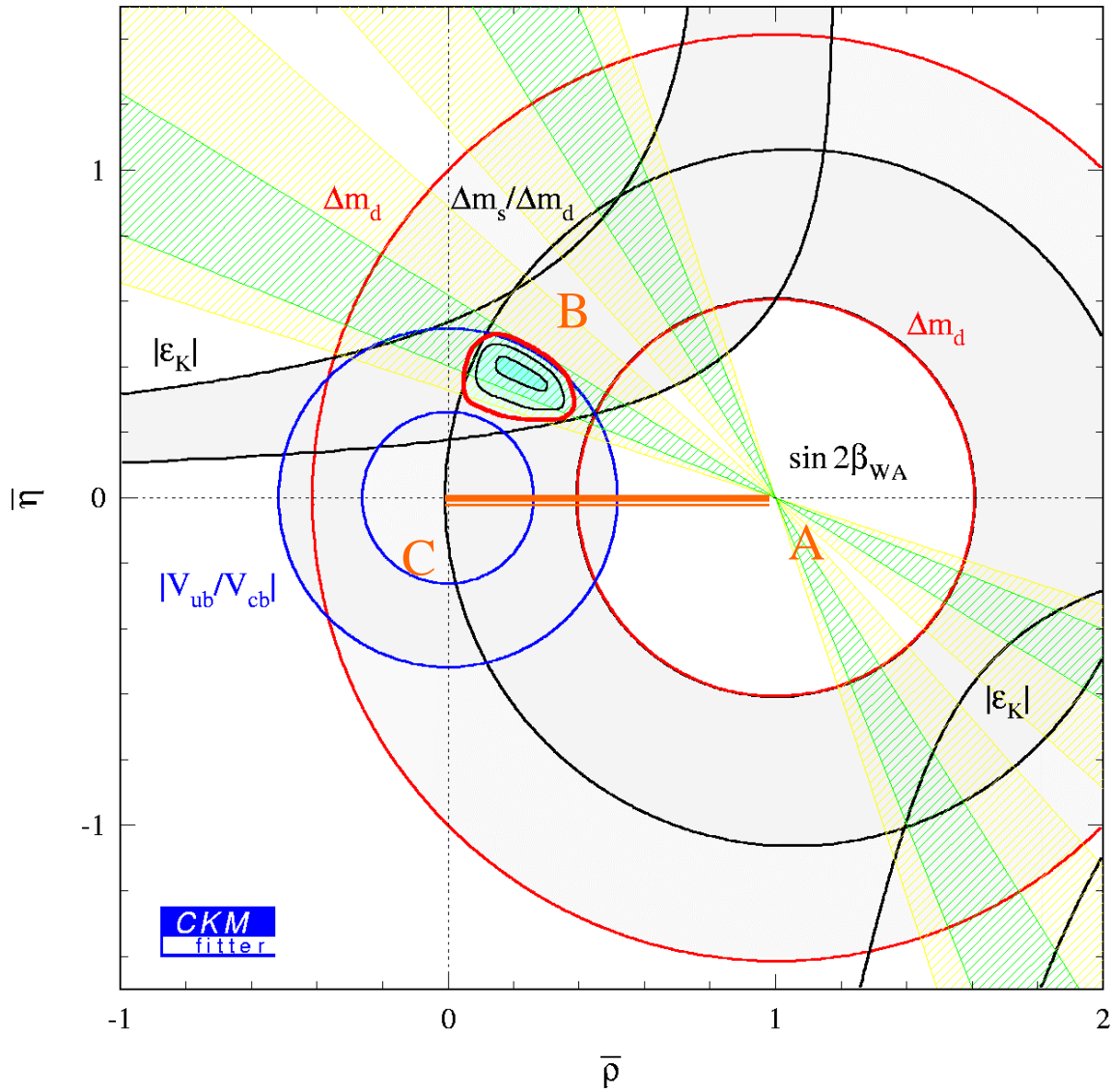○ CKM has become a *tested* theory!

○ `demystification of ~~CP~~':

if dynamics can support ~~CP~~, it can be large!

i.e., observable phases can be large!

next big news expected for '03 (?):

find B_s - B_s oscillations! CDF & D0

test of a prediction

$$\sin 2\phi_1\, [\beta]|_{\text{predict}} = 0.725^{+0.055}_{-0.065}$$

vs.

$$\sin 2\,\phi_1\, [\beta]\,|_{\text{WA}} = 0.734 \pm 0.054$$

intermediate resume

☞ *New dimension to SM successes of '99-'01:*
first decisive tests of the minimal description
of CP - the CKM mechanism - in $B \phi \psi K_S$
last remaining 'terra incognita': Higgs sector

☞ "Know so much, yet understand so little!"
Those successes resolve none of the
central mysteries of the SM -- why more than
1 family, why 3, origin of pattern in fermion
masses and CKM parameters? --
they actually deepen them!

➡ New Physics must exist!

    ↖ evidence for ν oscillations!

    ↖ the `strong CP problem'!

    ↖ CKM cannot generate baryon # of Universe!

an educational comment

when feeling harassed by hadronization …

- ∃ no royal way to knowledge;
- hardship builds character;
- salvation at the (very) end;

✏ blessing in disguise!

for without formation of bound states

👉 no K^0-K^0 oscillations

➥ no indirect ~~CP~~: Im $M_{12} \sim O(10^{-8}\,eV)$!

➥ no direct ~~CP~~ a la ϵ'

👉 no B^0-B^0 oscillations

➥ no ~~CP~~ in $\Delta B=2$: $\sim O(10^{-4}\,eV)$

➥ no New Physics in $\Delta B=2$

e.g.,

$K_L \not\phi\, 3\,\pi$: CP allowed, yet PhSp disfavored ~1/500

$K_L \not\phi\, 2\,\pi$: CP forbidden, yet PhSp favored ~ 1/500

hadronization

☞ reduces CP $K_L \not\phi\, 3\,\pi$ by ~ 500 due to hadronic PhSp

☞ awards `patience';
i.e. you can `wait' for pure K_L beam

☞ generates $\not C$P signal in existence rather than asymmetry

more general:

to observe a CP asymmetry need

✐ 2 different,

✐ yet coherent amplitudes

hadronization achieves both

❑ creates $K^0 ? \overline{K^0} \not\phi\, f$ in addition to $K^0 \not\phi\, f$

❑ `cools' d.o.f. enhancing coherence!

➥ hadronization the hero rather than the villain in the tale of $\not C$P!

try find $\not C$P in ν oscillations!?

IV.1 Qualitative Discrepancies

the `King Kong Scenario' for New Physics Searches:

"One might be unlikely to encounter King Kong; yet once it happens there will be no doubt that one has come across something out of the ordinary!"

historical precedent:

the physics of strange hadrons has been instrumental in the evolution of the SM:

there was always a qualitative discrepancy between data & expectation, i.e. discrepancies by orders of magnitude!

history could repeat itself

○ $K_{\mu 3}$ decays   a clean search for CP via Higgs dyn.

○ EDM's   a definite must

○ charm decays   the best is still to come

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IV.2 Quantitative Discrepancies

CKM predicts many large asymmetries in beauty decays

? quantitative discrepancies

CP asymmetries should be measurable within few % uncertainty

can exploit experimental sensitivity theoretically?

e.g.: predict asymmetry of 40 %

observe

- 40 % ? New Physics !?

60 % ? New Physics ?

45 % ? New Physics ???

meaning of theoretical uncertainties?

a novel challenge not encountered before!

V(cb)

$$|V(cb)|_{excl,CLEO}^{'00} = (47.1 \pm 2.0\ |_{stat} \pm 2.1|_{syst} \pm 4.3|_{th}) \infty 10^{-3}$$

$$|V(cb)|_{excl,BELLE}^{'01} = (39.8 \pm 2.1\ |_{stat} \pm 2.0|_{syst} \pm 3.6|_{th}) \infty 10^{-3}$$

$$|V(cb)|_{excl,LEP}^{'00} = (38.8 \pm 0.8\ |_{stat} \pm 1.8|_{syst} \pm 3.5|_{th}) \infty 10^{-3}$$

$$|V(cb)|_{incl,LEP}^{'98} = (40.76 \pm 0.41|_{exp} \pm 2.0|_{th}) \infty 10^{-3}$$

$$|V_{cb}|_{incl,DELP}^{'02} = (41.90 \pm 0.67|_{meas} \pm 0.63|_{fit} \pm 0.40|_{th}) \infty 10^{-3}$$

$$|V_{cb}|_{incl,CLEO}^{'02} = (40.8 \pm 0.5|_{\Gamma_{SL}} \pm 0.4|_{fit} \pm 0.9|_{th} \pm ??) \infty 10^{-3}$$

○ the values from the exclusive and inclusive
   reactions agree quite well

○ despite the experimental as well as theoret.
   systematics being very different in the 2 cases

○ theoret. uncertainties not much larger than
   experimental ones

○ theoretical corrections highly nontrivial:
  ❏ exclusive
   ✐ symmetry limit
   ✐ pre-asymptotic corrections (~10 % ∀)
  ❏ inclusive
   ✐ QFTh definition of quark mass ($\Gamma \propto m_Q^5!$)   36
   ✐ mature $1/m_Q$ expansion

need for accuracy, part 1

○ conceivable that New Physics impacts on the CP phenom. in *B* decays `massively'

   most promising case:
CP asymmetry in $B_s \emptyset \psi + \phi/\eta$ $< 2\%$ in CKM

yet otherwise *cannot count* on shifts in the asymmetries ~ several ∞ 10 %

because:

❑ success of CKM covers scales differing by many
   orders of magnitude;

❑ unlikely that New Physics

   (unless intrinsically connected to flavour structure)

   can also turn this remarkable trick;

➥ a 10% shift in an asymmetry might be on the large
   side of what can be expected.
                possible exception: SUSY

○ CKM effects are `background' to sought after
   CP dynamics (for baryogenesis etc.)

V. The Cathedral Builders' Paradigm

∃ dynamical ingredients for numerous & multi-layered manifestations of ~~CP~~ & ~~T~~

○ d_N with ultracold neutrons   ← **lowest**

○ d_e [d_{atom}, $d_{molecule}$]

○ $P_T(\mu)$ in $K^+ \not\phi \mu^+ \pi^0 \nu$ KEK

○ ϵ'/ϵ in K_L decays   FNAL, CERN
                              Daϕne

○ ~~CP~~ in ν oscill. ν factories

○ ~~CP~~ in Λ decays   ft FNAL

○ ~~CP~~ in charm decays   ft FNAL
                              e^+e^- B fact.

○ ~~CP~~ in beauty decays e^+e^- B fact.
                               FNAL coll.
                               LHC ← **highest**

temperatures (vertical, right side)

☞ **dedicated** programs at every HEP lab in the world and at several nuclear & atomic physics labs!

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QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

Cathedral =

        a complex, multi-faceted structure

        -- with a coherent theme!

➥   it takes time

  Chartres   begun in 1194

                 completed in 1240

  ~~CP~~   begun in 1964

                 far from completed in 2000

➥   need comprehensive effort!

VI. Fabula Docet (Summary & Outlook)

☞ *SM nontrivially consistent with all data* --
   except for

   ❏   evidence for ν oscillations

   ❏   probably the baryon number of the Universe

   ❏   possibly the *strong CP problem.*

☞   *New dimension due to findings of 1999-2001*
   first decisive tests of the CKM description of
   ~~CP~~ -- in B $\phi \psi$ K$_S$:

   ❏   first observation of CP outside K$_L$ decays
   ❏   it is huge --
   ❏   as predicted!

   ➥   CKM a tested theory rather than an ansatz

☞ *Yet it resolves none of the deep mysteries of the*
   SM in the heavy flavour sector:
   masses and CKM parameters.

   ➥ SM incomplete!

☞ *Heavy flavour studies can never become*
   marginal or obsolete!

✏ CKM dynamics cannot generate the
   baryon number of the Universe;

✏ the non CKM CP dynamics thus required could
   be buried under the huge effects of CKM CP in
   beauty decays;

   "yesterday's sensation $B \phi \psi K_S$
   is today's calibration   for $B \phi \pi\pi$
   and tomorrow's background!" to C̶P̶ for baryon#

✏ their impact on ordinary (light flavour) matter
   would have to deal with hardly a competition
   from CKM dynamics;

✏ we would benefit from expertise and
   opportunities in different areas:
   nuclei & molecules as labs to search for T odd
   effects; primary emphasis on sensitivity rather
   than precision.
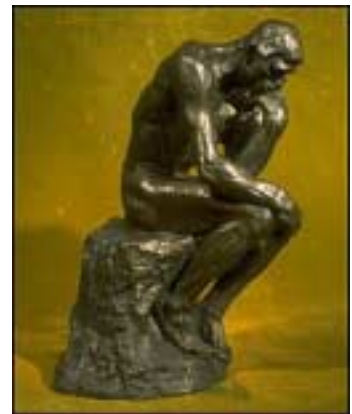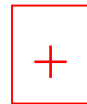
Memento $\Delta S \sharp 0$ dynamics:

○ $\tau - \theta$ puzzle   ?   P̶!

○ production >> decay   ?   families !
        rate   rate

○ no ΔFl $\sharp$0 NC   ?   charm !

○ K$_L$ $\not\phi$ $\pi\pi$?   C̶P̶, top !

        New Physics at that time!

| beginning of an exciting adventure …
and we are privileged to participate! |

Wind on the Hill

No one can tell me
    Nobody knows
Where the wind comes from,
    Where the wind goes.

But if I stopped holding
    The string of my kite,
It would blow with the wind
    For a day and a night.

And then when I found it,
    Wherever it blew,
I should know that the wind
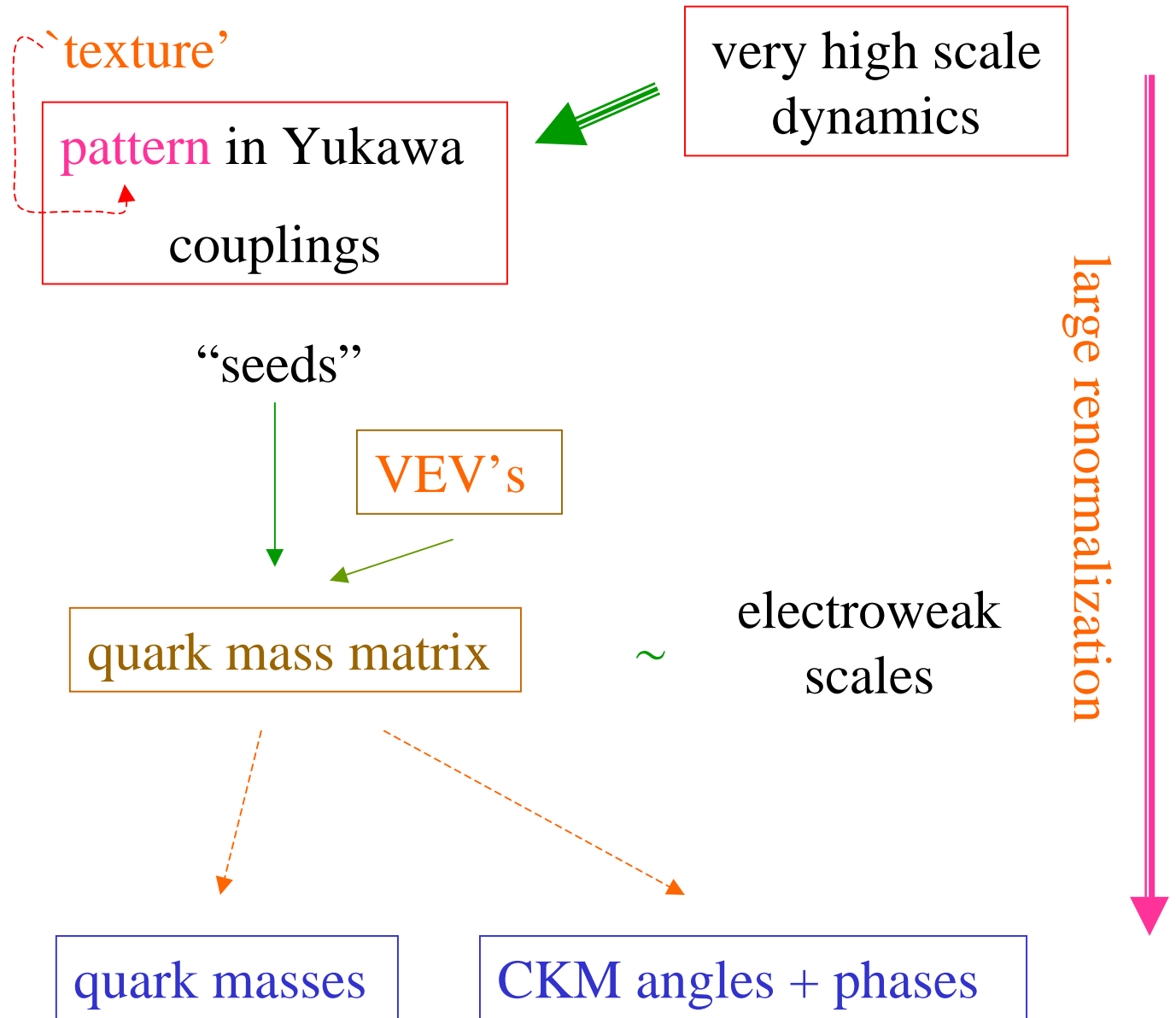   Had been going there, too.

So then I could tell them
    Where the wind goes …
But where the wind comes from
    Nobody knows.

A.A. Milne
[Winnie-the-Pooh 1926]
(with thanks to T.D. Lee)

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

QuickTime™ and a
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are needed to see this picture.

need for accuracy, part 2

`texture'

pattern in Yukawa couplings

very high scale dynamics

large renormalization

"seeds"

VEV's

quark mass matrix ~ electroweak scales

quark masses

CKM angles + phases

personal conjecture/bias:

simple pattern ? special CKM parameters!

yet

high scale ⟶ low scale

washes out

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