Status
and
Future Progress of B Physics

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Physics at LHC2004 Vienna July 13-17

This is not a comprehensive review.
Who did what first please see
David McFarlane's talk.

Contents

- Past
- Present
- Future
- Remote future

Of B physics

Past

Major discoveries in B and K systems

				discoveries
1980	$\Upsilon(4S) \to B\bar{B}$	1947	K^0	particle
+6	$B-\bar{B}$ mixing	+9	$K-\bar{K}$ mixing	mixing
+19	$B \to \psi K_S$	+17	$K_L \to \pi^+\pi^-$	CP violation
	CPV in $B \to \pi\ \pi$	+41	ε'/ε	
	$B \to \phi K_S$	+52	T violation	
	$\phi_2,\ \phi_3$	+57	$K^+ \to \pi^+ \nu\bar{\nu}$	
	CPTV…	??	$K_L \to \pi^0 \nu\bar{\nu}$	

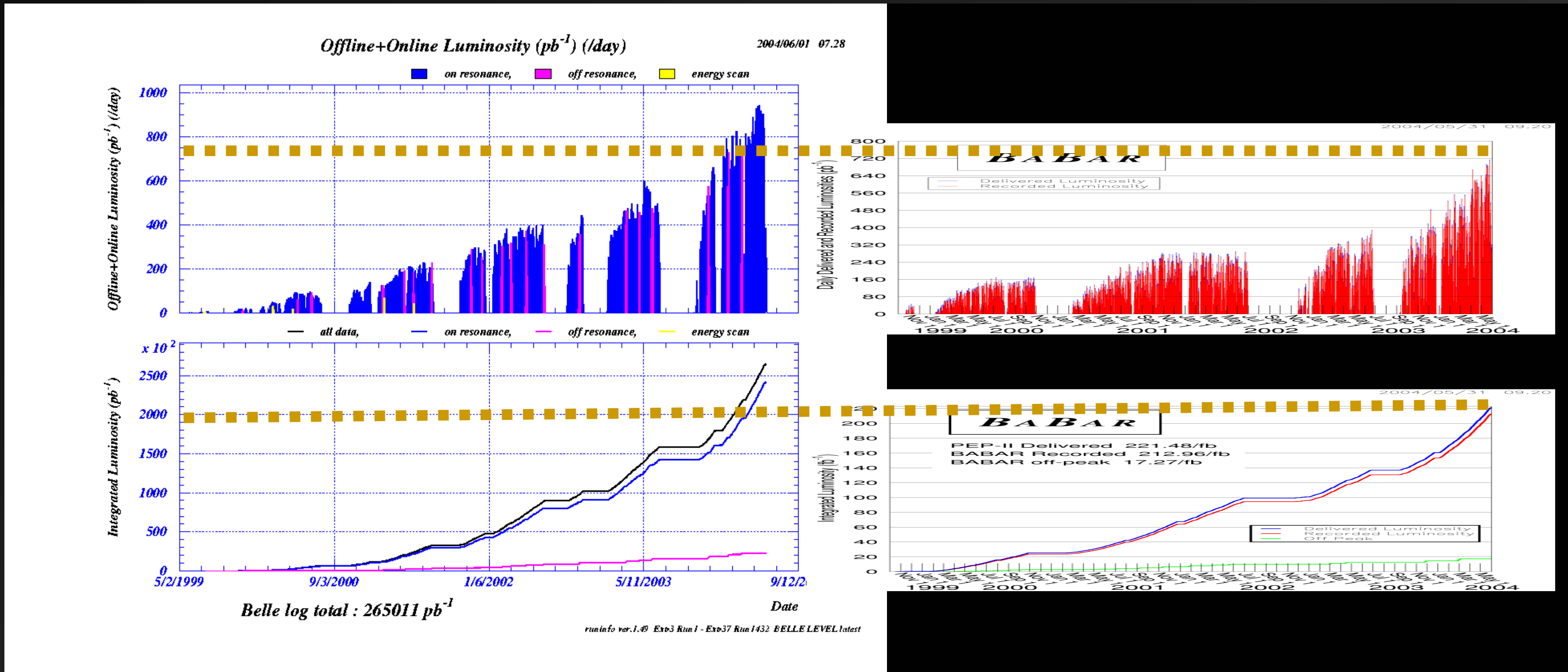
Nearly 60 years of intensive investigation

B decays will be promising area of research for many many years to come!

Selected results from B factories

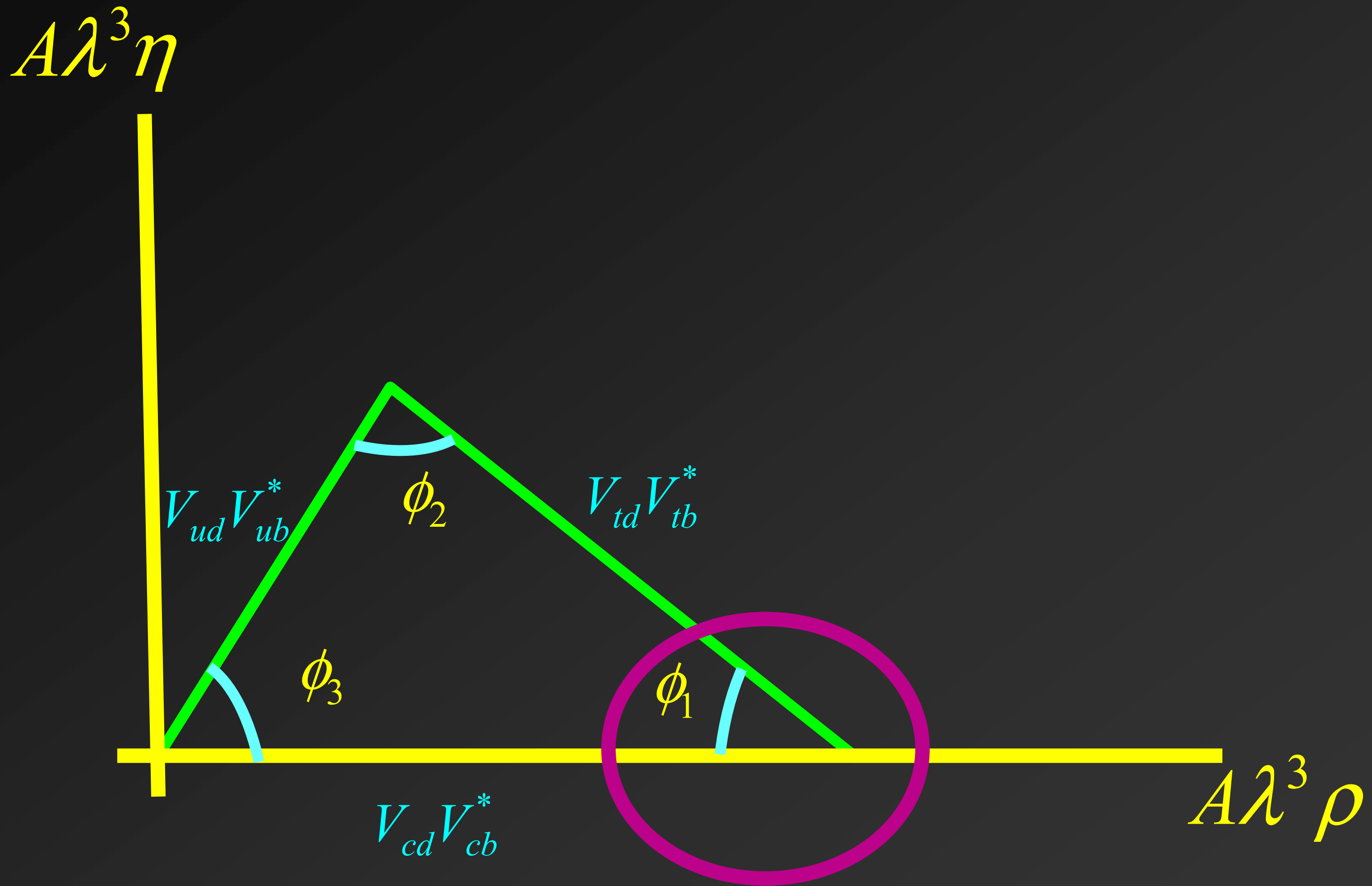
Present

KEKB PEPII



Intense competition has been extremely good for high energy physics!

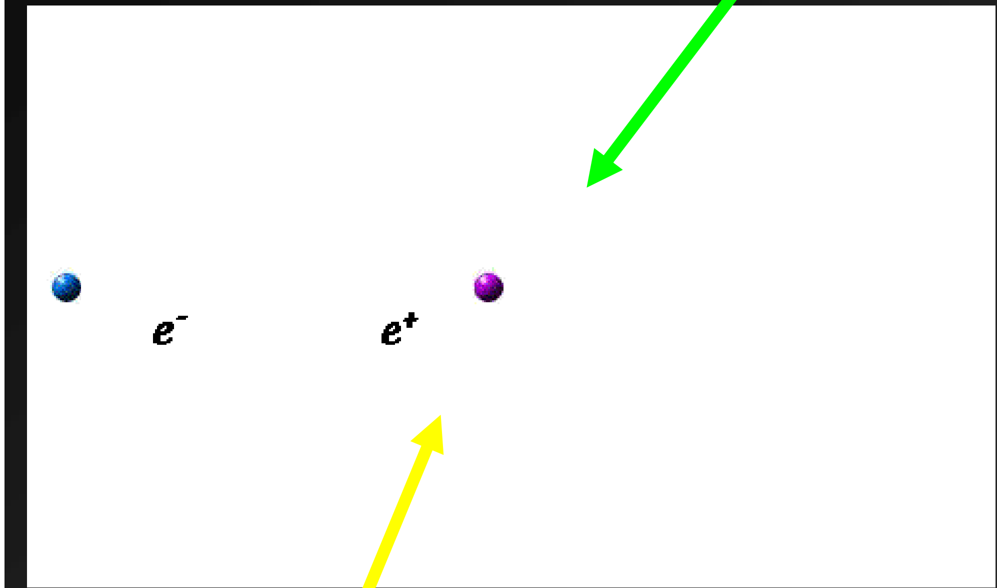
Unitarity triangle

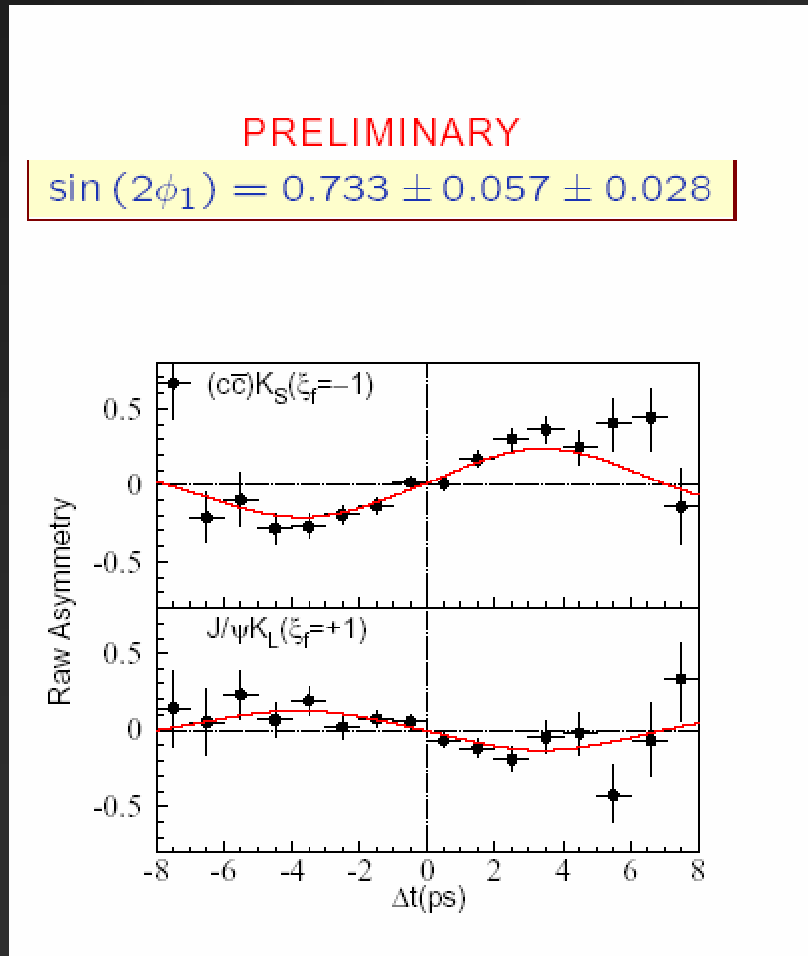


$\sin\phi_1$

ψK_S decay

$$\Gamma^{\pm}(t_1-t_2)=\Gamma(B\bar{B}\rightarrow\psi K_S(t_1)+l^{\pm}(t_2)+\ldots)$$



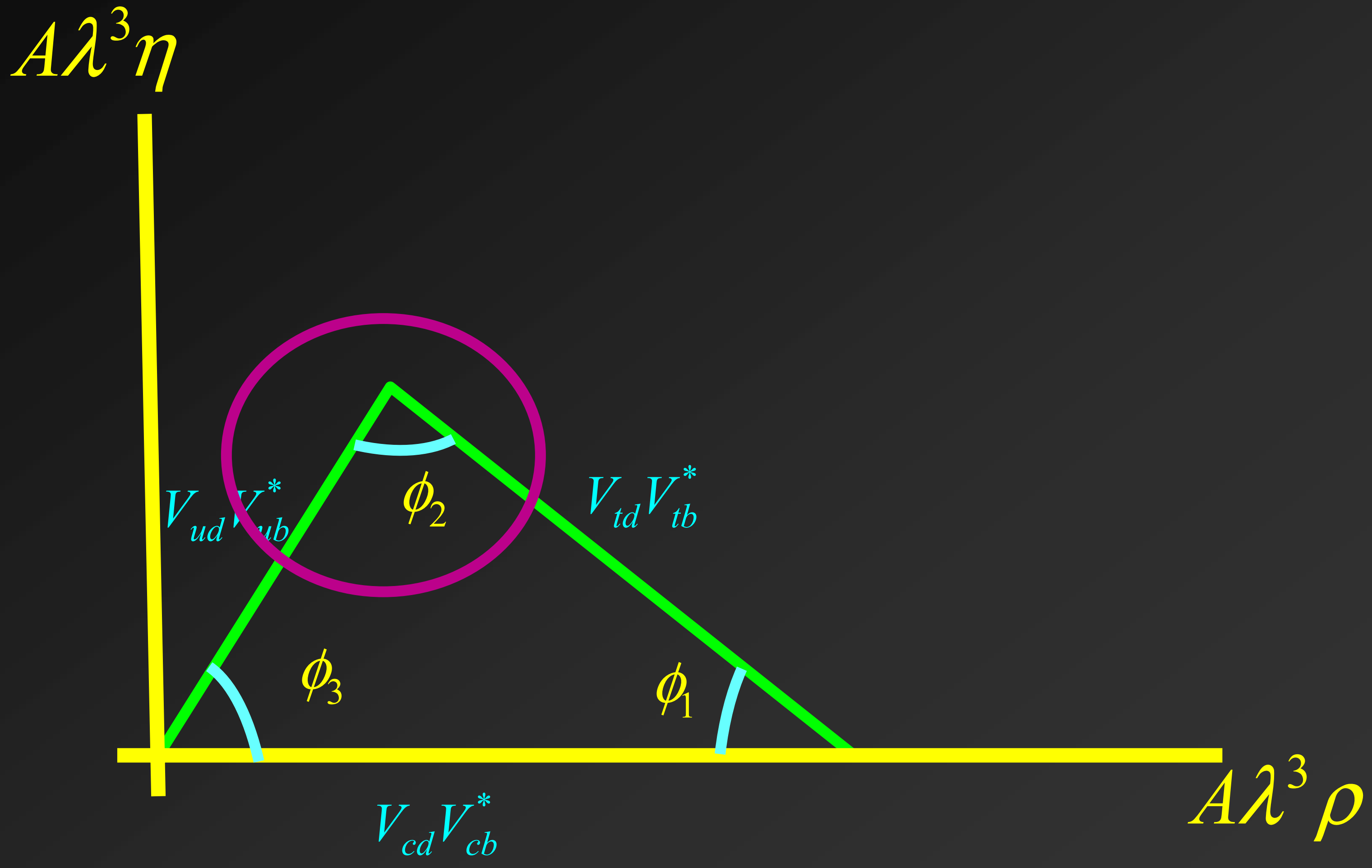


$$\frac{\Gamma^{-}(\Delta t)-\Gamma^{+}(\Delta t)}{\Gamma^{-}(\Delta t)+\Gamma^{+}(\Delta t)}=\sin 2\phi_1 \sin\Delta M\,\Delta t$$

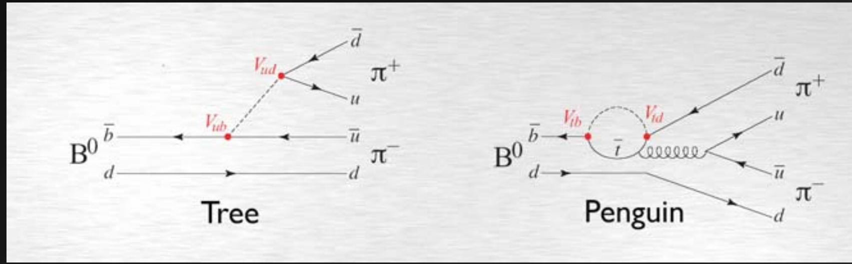
tag

Belle

Unitarity triangle



$\sin\phi_2$



$$\bar{\rho}(\pi^+\pi^-) = \frac{A(\bar{B}\to\pi^+\pi^-)}{A(B\to\pi^+\pi^-)} = \frac{V_{ub}V_{ud}^*T + V_{tb}V_{td}^*P}{V_{ub}^*V_{ud}T + V_{tb}^*V_{td}P}$$

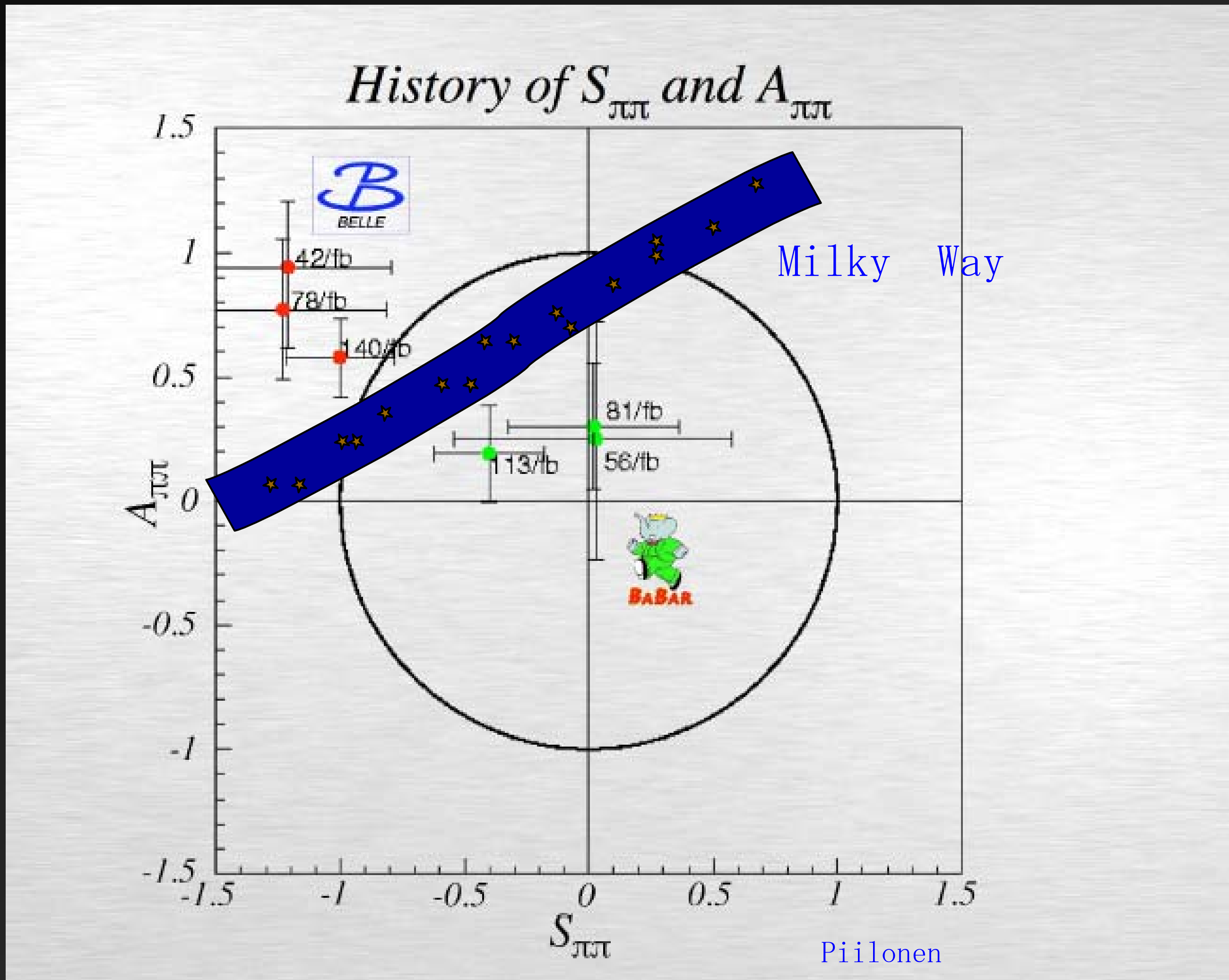
Independent of ST INT
(1) T or P =0
(2) KM factors have same phase

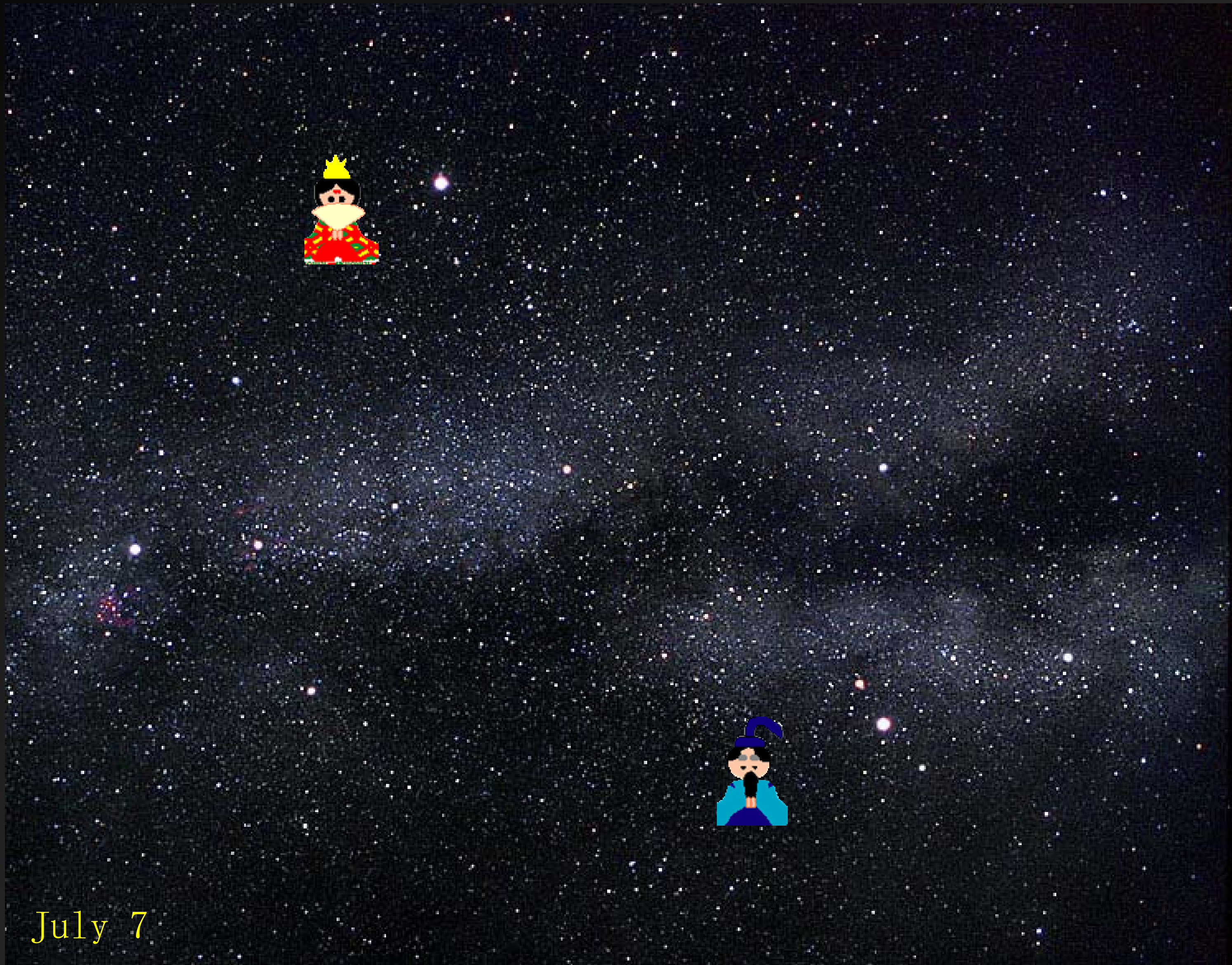
$$\frac{\bar{\Gamma}_{\pi^+\pi^-}(t) - \Gamma_{\pi^+\pi^-}(t)}{\bar{\Gamma}_{\pi^+\pi^-}(t) + \Gamma_{\pi^+\pi^-}(t)} = \underbrace{\frac{|\bar{\rho}(\pi^+\pi^-)|^2 - 1}{|\bar{\rho}(\pi^+\pi^-)|^2 + 1}}_{A_{\pi\pi}}\cos\Delta Mt + \underbrace{2\frac{\mathrm{Im}(\frac{q}{p}\bar{\rho}(\pi^+\pi^-))}{1+|\bar{\rho}(\pi^+\pi^-)|^2}}_{S_{\pi\pi}}\sin\Delta Mt$$

$$\mathrm{Im}(\tfrac{q}{p}\bar{\rho}(\pi^+\pi^-)) = |\bar{\rho}(\pi^+\pi^-)|\sin(2\phi_2 + \theta)$$

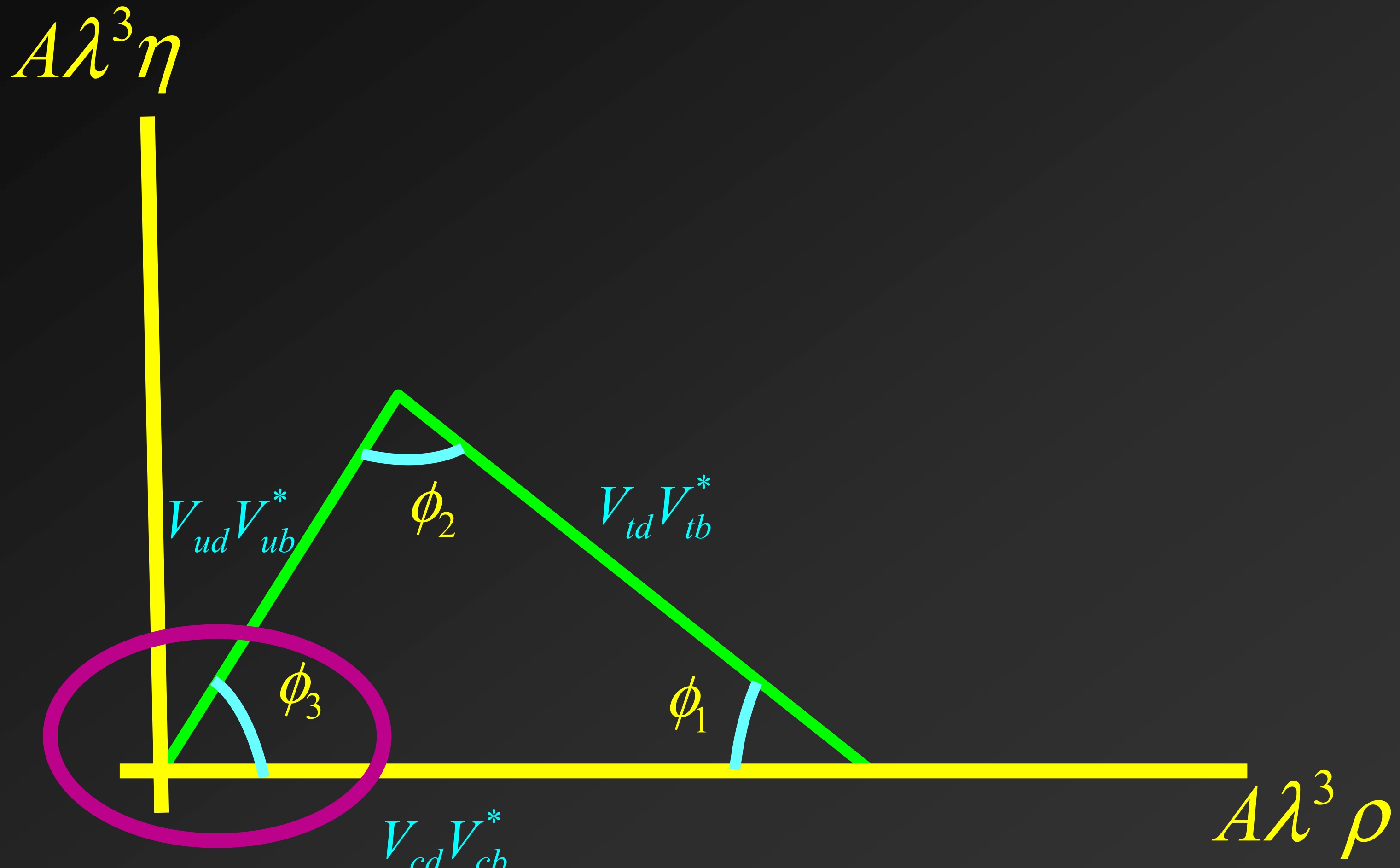
$$\theta = \arg\left(\frac{1+e^{i\phi_2}\left|\frac{V_{tb}V_{td}^*}{V_{ub}V_{ud}^*}\right|\left|\frac{P}{T}\right|e^{i\delta}}{1+e^{-i\phi_2}\left|\frac{V_{tb}V_{td}^*}{V_{ub}V_{ud}^*}\right|\left|\frac{P}{T}\right|e^{i\delta}}\right)$$

Unknowns: $\left|\frac{P}{T}\right|, \delta, \phi_2$ 2 constraints


History of $S_{\pi\pi}$ and $A_{\pi\pi}$
BELLE
42/fb
78/fb
140/fb
81/fb
56/fb
113/fb
BABAR
Milky Way
$A_{\pi\pi}$
$S_{\pi\pi}$
Piilonen


July 7

Unitarity triangle



$$B^{\pm} \to D^{(0^*)} K^{\pm}$$

$B^{\pm}$ → $D^0 K^{\pm}$ → $K_S \pi\pi \quad K^{\pm}$

$B^{\pm}$ → $\bar{D}^0 K^{\pm}$ → $K_S \pi\pi \quad K^{\pm}$

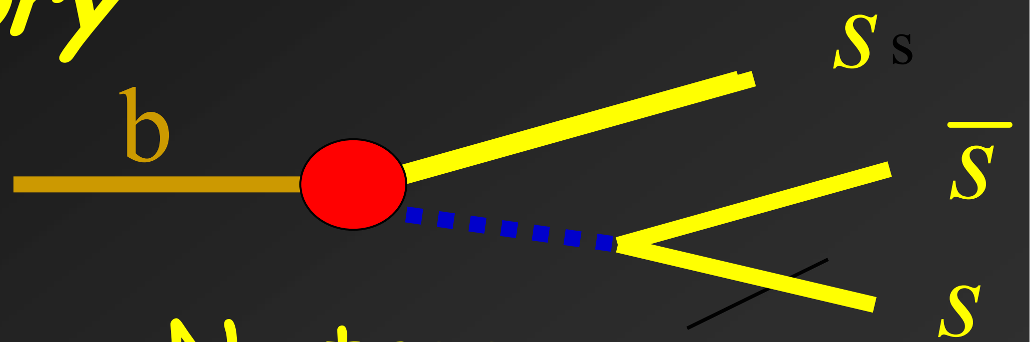
$$\phi_3 = (77^{+17}_{-19}(\text{stat}) \pm 13(\text{syst}) \pm 11(\text{model}))^0$$

$$26^0 < \phi_3 < 126^0 \quad 2\sigma$$

Belle
Hep-ex/0406067
July2, 2004

Puzzle

For $B \to \phi K_S$ decay, its another story



No tree

$$\frac{A(B \to f)}{A(\bar{B} \to \bar{f})} = \frac{V_T T + V_P P e^{i\delta}}{V_T^* T + V_P^* P e^{i\delta}}$$

c

Ratio is independent of strong interaction.

$$\frac{A(B \to \phi K_S)}{A(\bar{B} \to \phi K_S)} = \frac{V_{tb} V_{ts}^*}{V_{tb}^* V_{ts}}$$

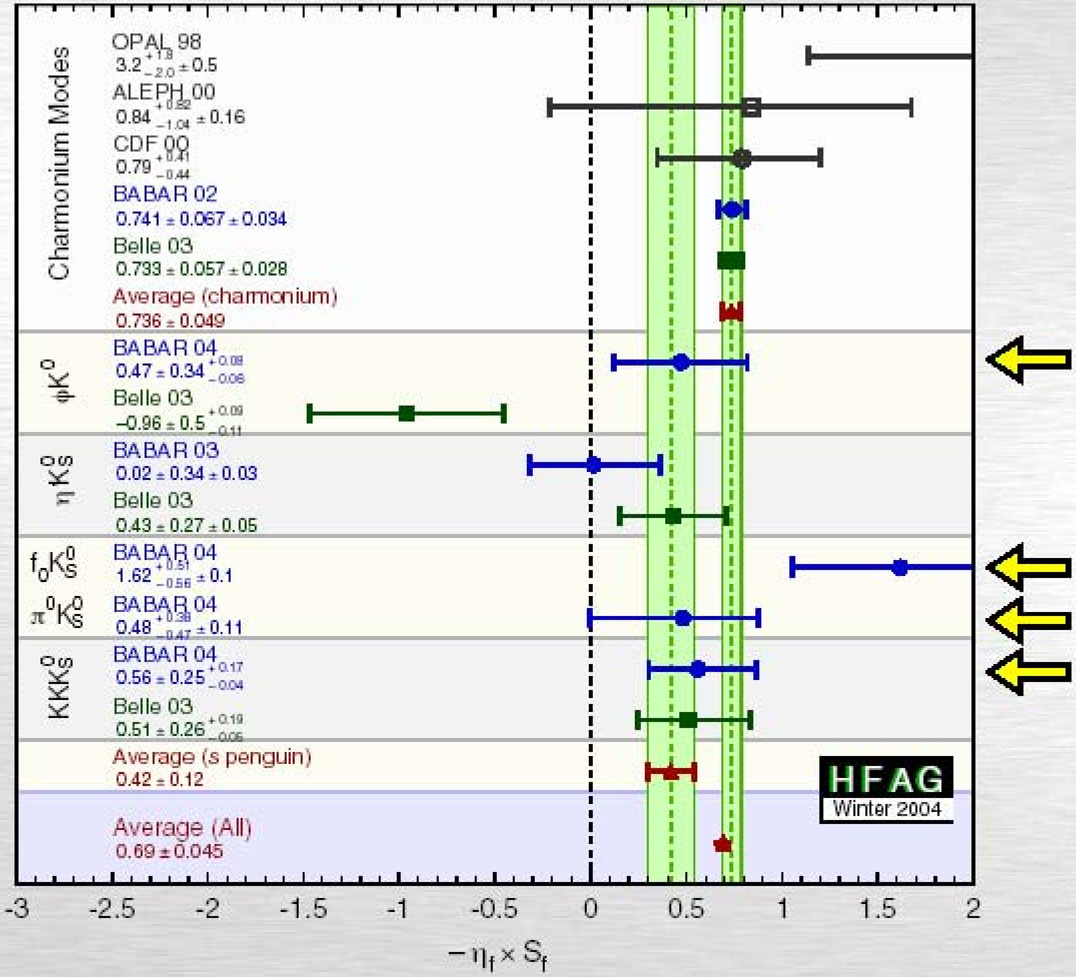
$$= \frac{V_{cb} V_{cs}^*}{V_{cb}^* V_{cs}} = \frac{A(B \to \psi K_S)}{A(\bar{B} \to \psi K_S)}$$

$$Asym(\phi K_S) = Asym(\psi K_S)$$

$$V_{tb} V_{ts}^* + V_{cb} V_{cs}^* + V_{ub} V_{us}^* = 0$$

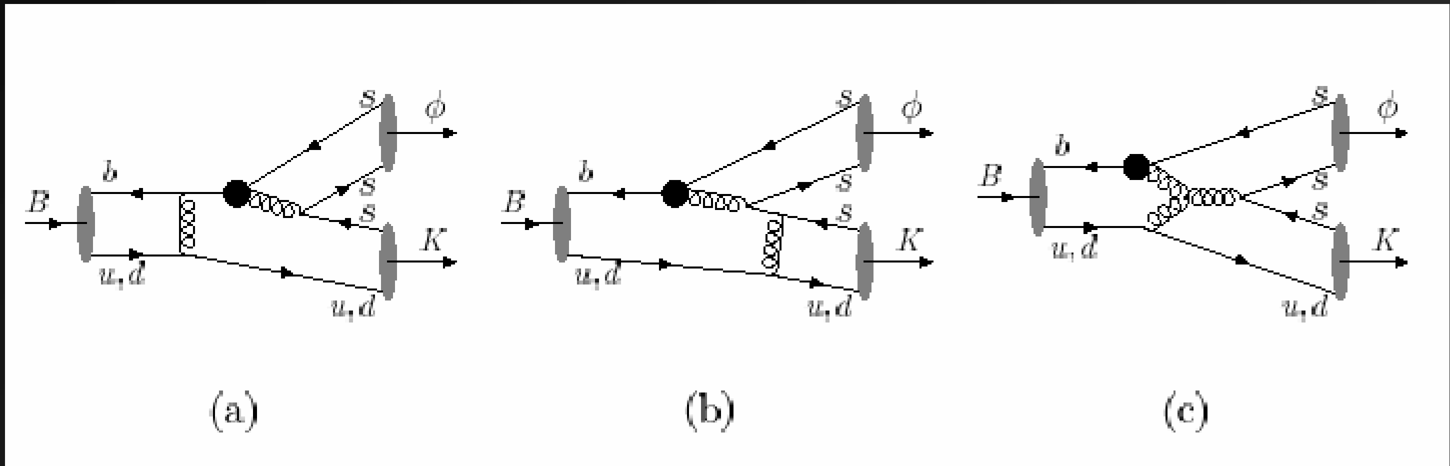
$$\lambda^2 \qquad \lambda^2 \qquad \lambda^4$$

$\sin 2\phi_1$ (β) Summary



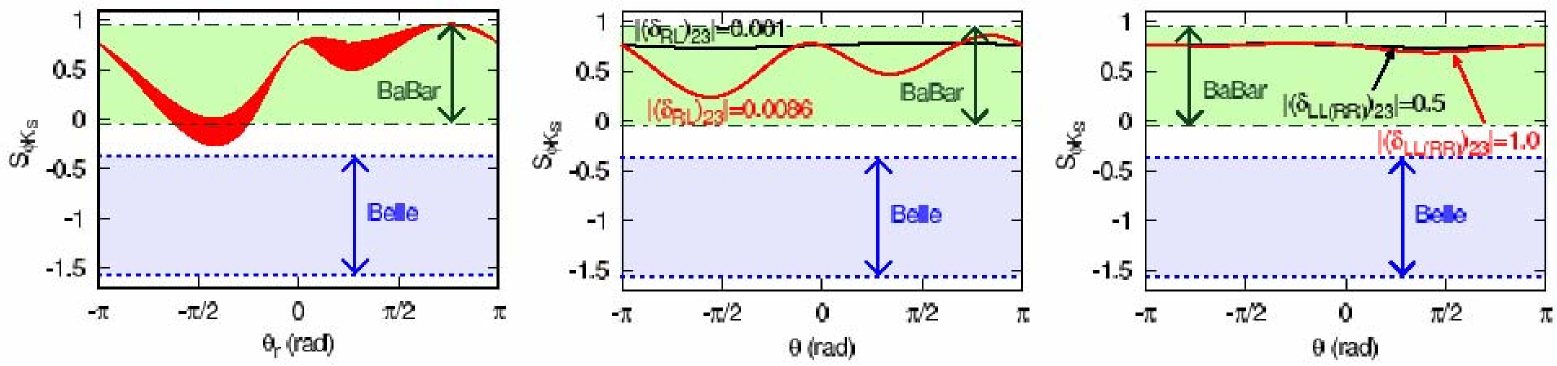
New or updated from BaBar

3 sigma effect goes away half of the time.
W.-Y. Lee



Mishima Sanda

After making sure that $B \rightarrow K^* \gamma$ BR is OK



(a) $S_{\phi K_S}$ with LR insertion (b) $S_{\phi K_S}$ with RL insertion (c) $S_{\phi K_S}$ with LL or RR insertion

Too early to conclude

Clarify the existing physics beyond the standard model

$$|A|^2 + |S|^2 > 1 \quad in\ \mathrm{B} \to \pi\pi$$

violation of quantum mechanics

$$a_{CP}(B \to \psi K_S) \approx -a_{CP}(B \to \phi K_S)$$

Gross violation of the SM unlikely?

A concrete lesson from Belle and Babar

Kobayashi-Maskawa scheme is correct

CP may be broken spontaneously or explicitly at some high energy.

In any case, in low energy effective theory, it is likely that any coupling constant that can obtain a phase will have a phase.

You may see CP violation everywhere once new physics is found!

Future

SuperKEKB-SuperPEPII

SuperKEKB LIO is on the Web
hep-ex/0406071

SuperKEKB Goal

$$L = 5 \times 10^{35}\, cm^{-2}\, sec^{-1}$$

Totsuka's comment I

Considering all these research programs other than the B factory, the funding for the luminosity upgrade of a B-factory is not an easy task for KEK, and for other laboratories, too.

$80M/year is available for KEK particle physics experimental program. So, in principle, we can build Super KEKB with exiting budget.

Presently KEKB, and Belle are using only 5/8 of this funding.

Problem is that there can be no Linear Collider R&D

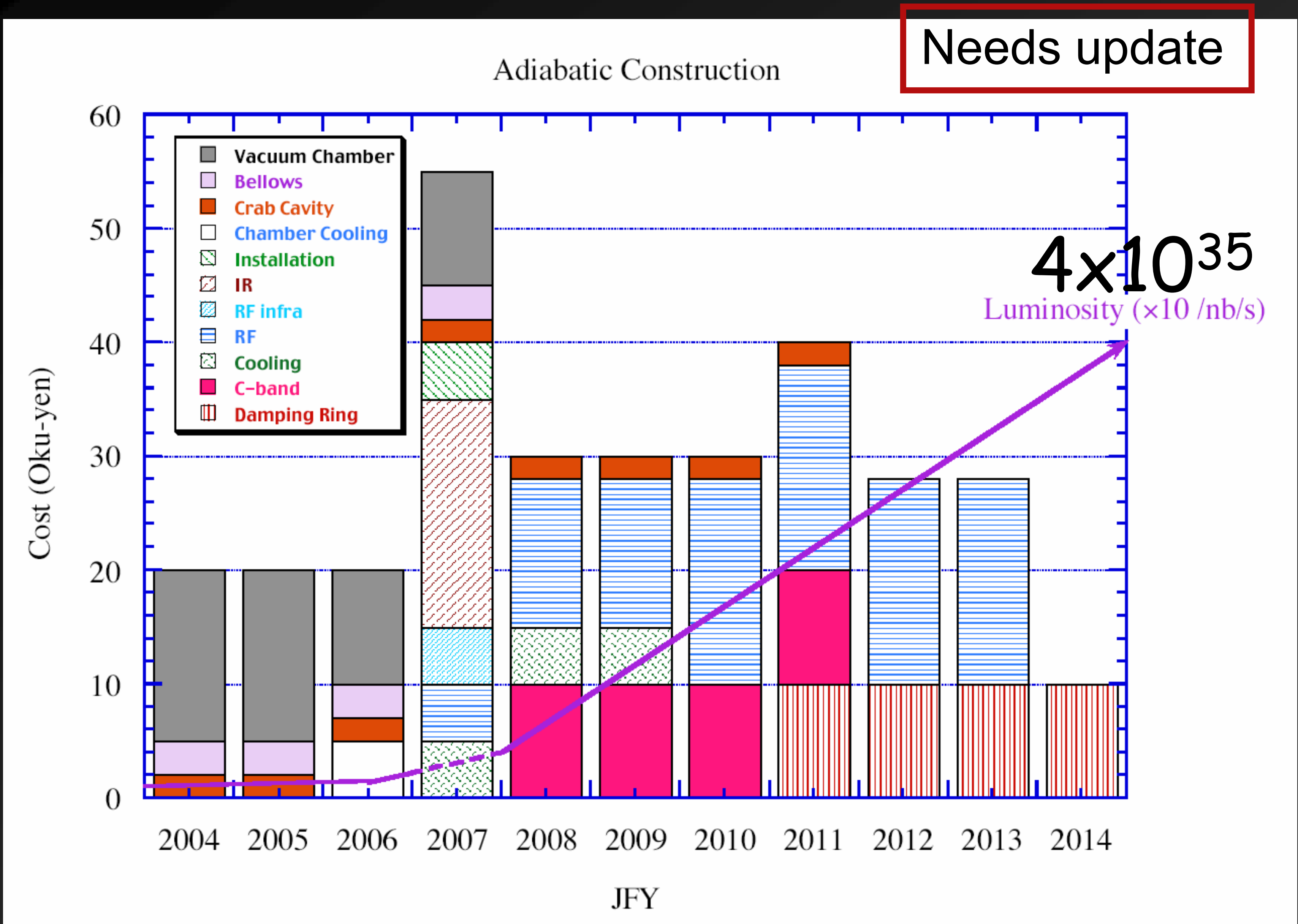
Linear-collider people have been waiting. The next major project in Japan will be LC.

Linear-collider costs: $50 for every Japanese

National deficit: every Japanese owe $70,000

Retirement benefit is a big issue

Party almost went out of power



"Crab cavities will be in by 2005" L becomes X2

Totsuka's comment II

- In any case I agree that one super-B factory should be built in the world.
- And it may be a good idea for you to jointly work for the best scheme of the super-B factory.

My prediction:
SUPERKEKB upgrade will be funded if Babar joins Belle

Don't kill the goose that lay golden eggs!

ϕK_S ψK_S

Thing to push

New Physics search

- Determination of the triangle
- Rare decays
- Lepton number violation

Strategy depends a lot on LHC discoveries

Pattern of the deviation from the SM in various SUSY models.

√√ large deviation

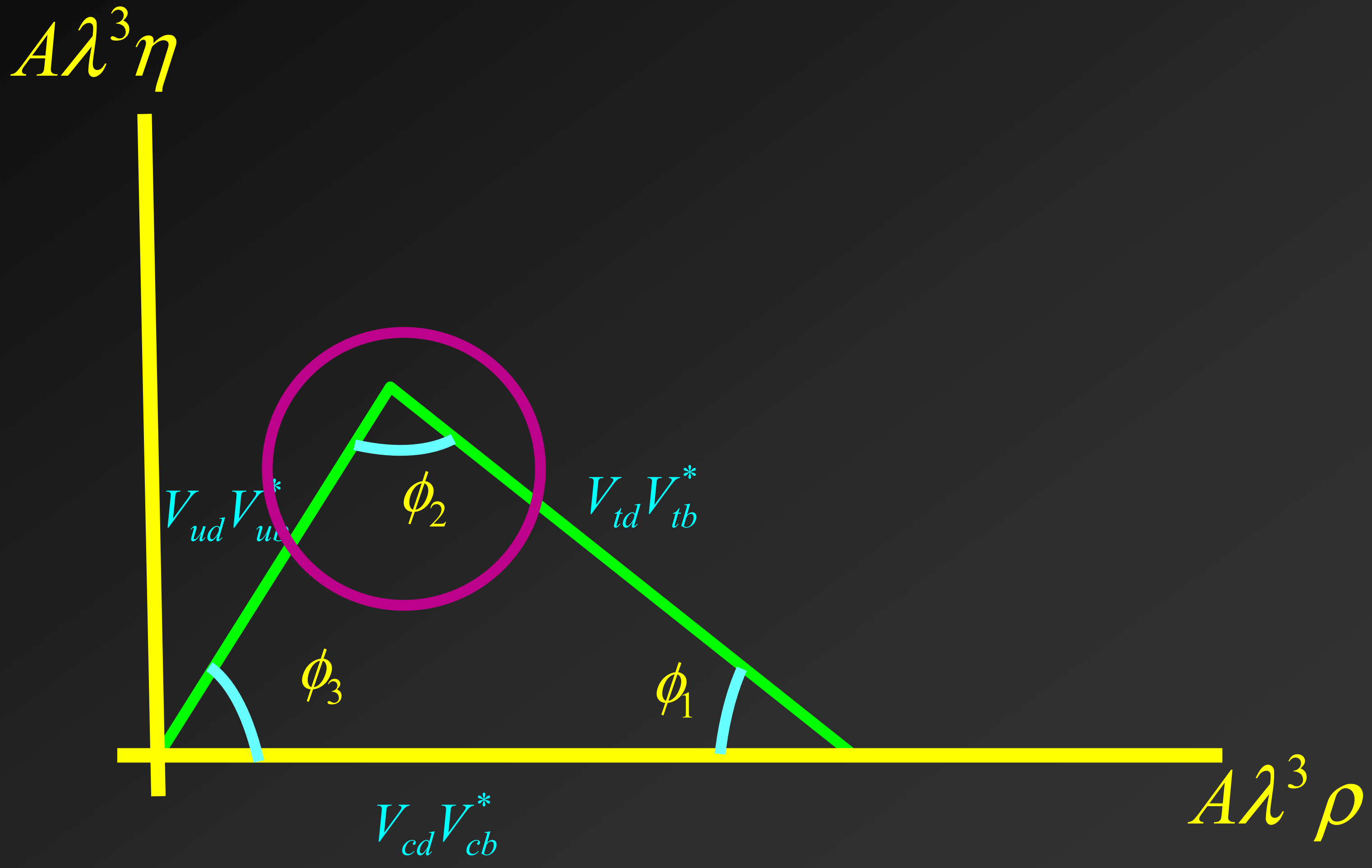
√ sizable deviation

— small deviation

	Bd-unitarity	ε	Δ m(Bs)	B->ϕKs	B->Msγ indirect CP	b->sγ direct CP
mSUGRA	closed	—	—	—	—	√
SU(5)SUSY GUT + ν_R (degenerate)	closed	√√	—	—	√	—
SU(5)SUSY GUT + ν_R (non-degenerate)	closed	—	√√	√	√√	√
U(2) Flavor symmetry	√√	√√	√√	√√	√√	√√

T.Goto, Y.Shimizu, T.Shindo, Y.Okada and M.Tanaka

Unitarity triangle



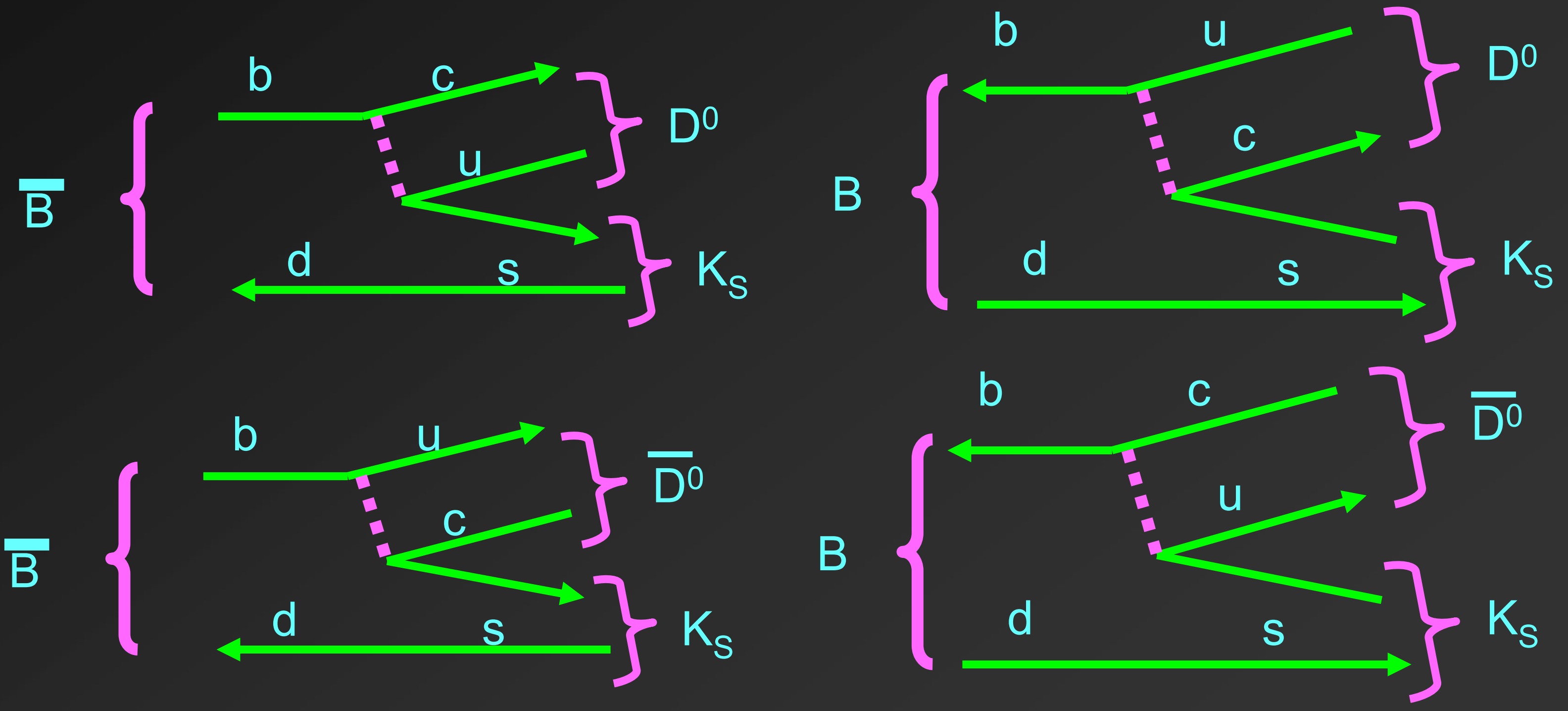
Clean determination of $2\phi_1 + \phi_3$

$$2\phi_1 + \phi_3 = \pi + \phi_1 - \phi_2$$

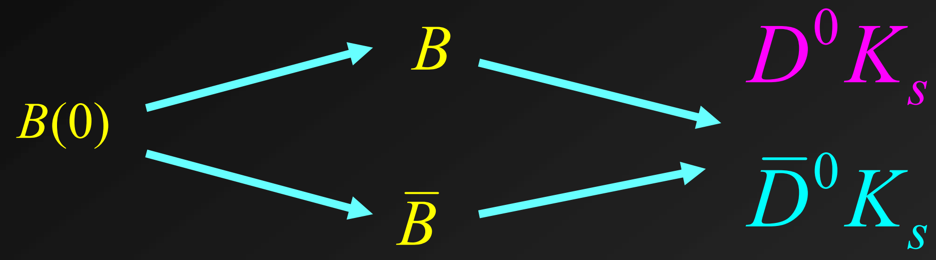
$$B \to \bar{D}^0 K_S$$

$$B \to D^0 K_S$$

$$Br(B \to D^0 K_S) \approx \lambda^2 Br(B \to D^0 \pi^0)$$
$$= O(10^{-5})$$



No penguins



$$\frac{\bar{\Gamma}_f(t) - \Gamma_{\bar{f}}(t)}{\bar{\Gamma}_f(t) + \Gamma_{\bar{f}}(t)} = \frac{|\bar{\rho}_f|^2 - 1}{|\bar{\rho}_f|^2 + 1} \cos \Delta M t + 2 \frac{\mathrm{Im}(\frac{q}{p}\bar{\rho}_f)}{1 + |\bar{\rho}_f|^2} \sin \Delta M t$$

A_f S_f

$$\bar{\rho}_{D^0 K_S} = \frac{A(\bar{B} \to D^0 K_S)}{A(B \to D^0 K_S)} = \frac{a V_{cb} V_{us}^*}{b V_{cs} V_{ub}^*}$$

$$\bar{\rho}_{D^0 K_S} = \frac{a}{b} e^{i\phi_3} e^{i \arg(a/b)}$$

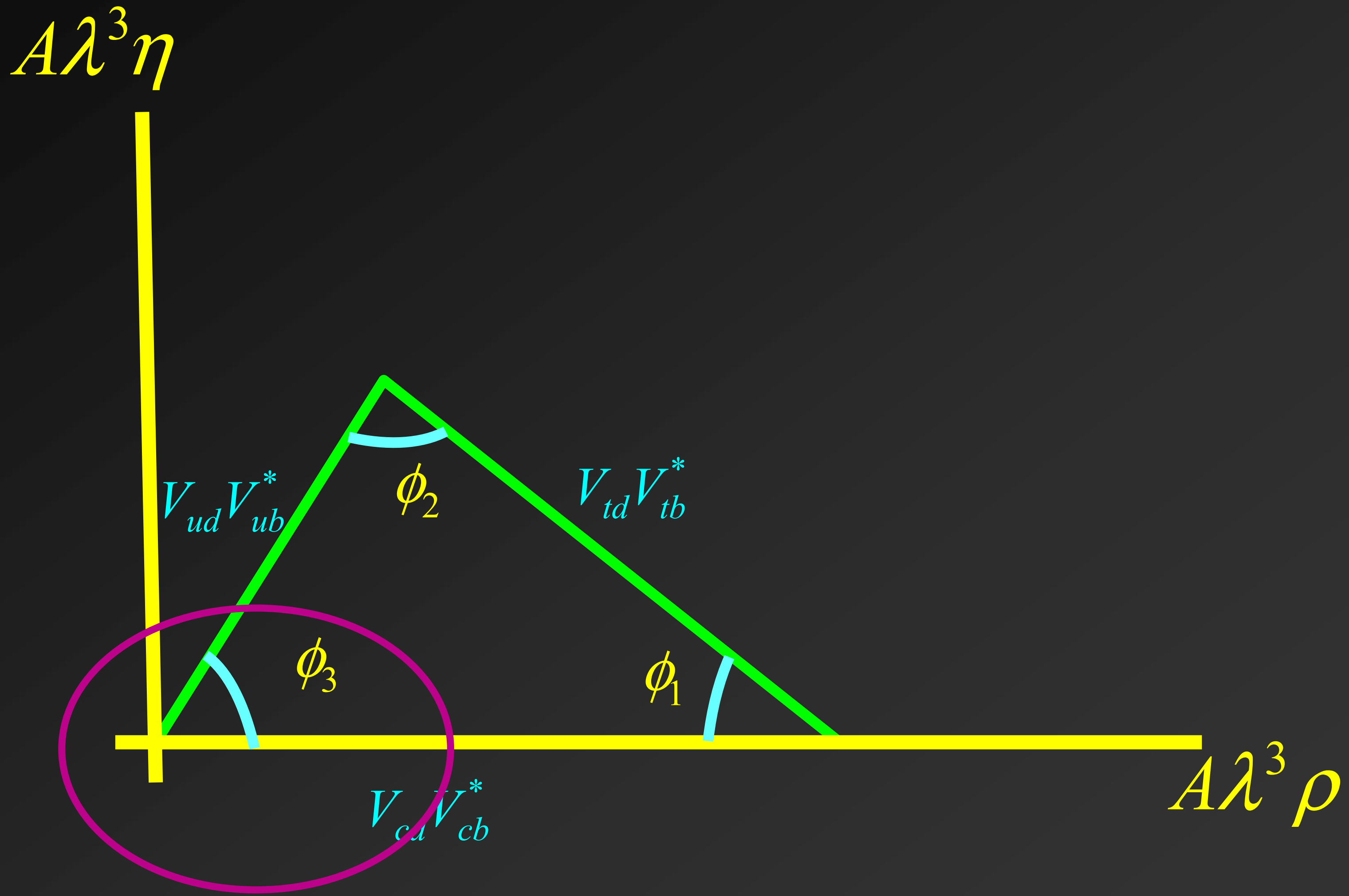
$$\bar{\rho}_{\bar{D}^0 K_S} = \frac{A(\bar{B} \to \bar{D}^0 K_S)}{A(B \to \bar{D}^0 K_S)} = \frac{b V_{ub} V_{cs}^*}{a V^*_{cb} V_{us}}$$

$$\bar{\rho}_{\bar{D}^0 K_S} = \frac{b}{a} e^{i\phi_3} e^{-i \arg(a/b)}$$

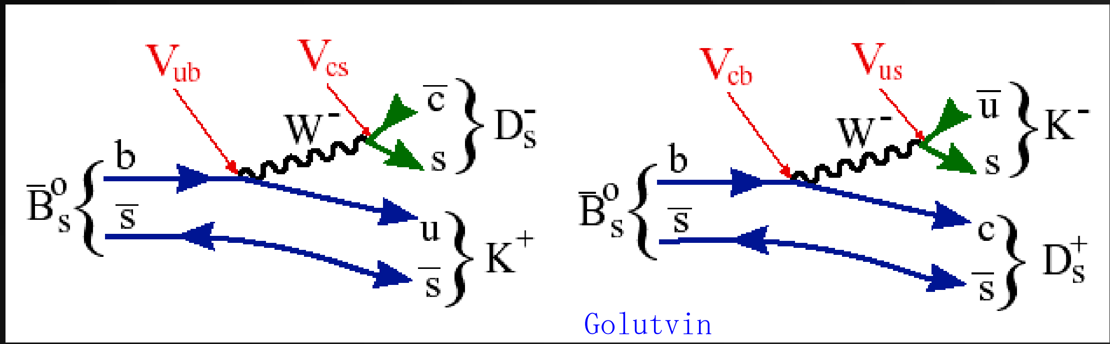
$$S_{D^0 K_S} = \frac{2|\rho_{D^0 K_S}| \sin(2\phi_2 + \phi_3 + \delta)}{1 + |\rho_{D^0 K_S}|^2}$$

$$S_{\bar{D}^0 K_S} = \frac{2|\rho_{\bar{D}^0 K_S}| \sin(2\phi_2 + \phi_3 - \delta)}{1 + |\rho_{\bar{D}^0 K_S}|^2}$$

Unitarity triangle



Φ_3 from $B_s \to D^-_s K^+$, $D^+_s K^-$



LHCB

$$\begin{tikzcd} & B_S \arrow[dr] & \\ B_S(0) \arrow[ur] \arrow[dr] & & D_S^- K^+ \\ & \bar{B}_S \arrow[ur] & \end{tikzcd}$$

$$paV_{ub}V^*_{cs} + qbV^*_{cb}V_{us}$$

$$\propto e^{i\phi_3}\sqrt{\rho^2+\eta^2}\,\lambda^3 + \frac{q_s}{p_s}\frac{b}{a}\lambda^3$$

$$\frac{\overline{\Gamma}_f(t)-\Gamma_{\bar f}(t)}{\overline{\Gamma}_f(t)+\Gamma_{\bar f}(t)}=\frac{|\bar\rho_f|^2-1}{|\bar\rho_f|^2+1}\cos\Delta Mt+2\frac{\mathrm{Im}(\frac{q}{p}\bar\rho_f)}{1+|\bar\rho_f|^2}\sin\Delta Mt$$

$$A_f \qquad\qquad S_f$$

$$\bar\rho_{D^-{}_S K^+}=\frac{A(\bar B_S\to D^-{}_S K^+)}{A(B_S\to D^-{}_S K^+)}=\frac{aV_{ub}V_{cs}^*}{bV_{us}V_{cb}^*}$$

$$\bar\rho_{D^+{}_S K^-}=\frac{A(\bar B_S\to D^+{}_S K^-)}{A(B_S\to D^+{}_S K^-)}=\frac{bV_{cb}V_{us}^*}{aV^*_{ub}V_{cs}}$$

LHCb:

$\sigma(\gamma)$ ~ 10° for x_s = 15

$\sigma(\gamma)$ ~ 12° for x_s = 30

Golutvin

$$S_{D^-{}_S K^+}=\frac{2|\rho_{D^-{}_S K^+}|\sin(\phi_3+\delta)}{1+|\rho_{D^-{}_S K^+}|^2}$$

$$S_{\bar D_S^+ K^-}=\frac{2|\rho_{\bar D_S^+ K^-}|\sin(\phi_3-\delta)}{1+|\rho_{\bar D_S^+ K^-}|^2}$$

Rare decays

$$\frac{Br(B \to X_s \nu\bar{\nu})}{Br(B \to X_c e\bar{\nu})} = \frac{3\alpha^2}{4\pi^2 \sin^4\theta_W} \left|\frac{V_{ts}}{V_{cs}}\right|^2 \frac{X^2(x_t)}{f(z)}$$

$$\frac{V_{ts}}{V_{cs}} \approx O\left(\lambda^2\right)$$

$$\frac{Br(K \to X_s \nu\bar{\nu})}{Br(K \to X_u e\bar{\nu})} = \frac{3\alpha^2}{2\pi^2 \sin^4\theta_W} \left|\frac{V_{td}^* V_{ts}}{V_{us}}\right|^2 \frac{X^2(x_t)}{f(z)}$$

$$\frac{V_{td} V_{ts}^*}{V_{us}} \approx O\left(\lambda^4\right)$$

$$Br(K^+ \to \pi^+ \upsilon\bar{\upsilon}) = 4.2^{+9.7}_{-3.5} \times 10^{-10}$$

$$Br(B \to X_S \upsilon\bar{\upsilon}) \sim 4\times 10^{-5}$$

B's show the loop effects better than K's

Rare decay reach

Machine	Branching ratio
CLEO	$10^{-6} - 10^{-7}$
Belle & Babar	$10^{-8} - 10^{-9}$
Next gen.	$10^{-10} - 10^{-11}$

B's may be more efficient in showing loop effects these may be equivelant to 10^{-15} for K's ??

Look for new physics

Is there CP asymmetry in

$$B_s \to \psi\phi$$

Sensitive to $\arg\left(\dfrac{M_{12}^{s\,*}}{M_{12}^{s}}\right)$

Same sign dilepton asymmetries

$$\frac{N(++)-N(--)}{N(++)+N(--)}=\frac{1-|p/q|^4}{1+|p/q|^4}=-r\sin\varsigma \qquad \sim 10^{-5}$$

$$r \sim \text{few} \times 10^{-3} \qquad\qquad \sin\varsigma=\frac{8m_c^2}{3m_b^2}\lambda^2\eta$$

$$\mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)\propto \mathrm{Im}\left(\frac{V_{ub}V_{ud}^{*}+V_{cb}V_{cd}^{*}}{V_{tb}V_{td}^{*}}\right)$$

Using free quark model neglecting m_c
Accidental suppression

$$=\mathrm{Im}(-1)$$

O(10^{-3}) if new physics is present!

Lepton Flavor Violation must be there

Non-vanishing $\nu_e - \nu_\mu$ and $\nu_\mu - \nu_\tau$ mixing

Importance of pushing the quark-lepton physics

Quark Physics	$B \to \tau\mu$ $B^{\pm} \to \mu^{\pm}\mu^{+}\mu^{-}$
$\mu \to e\gamma$ $\tau \to 3\mu, \ \ldots$	Neutrino Physics

What luminosity do you need ??

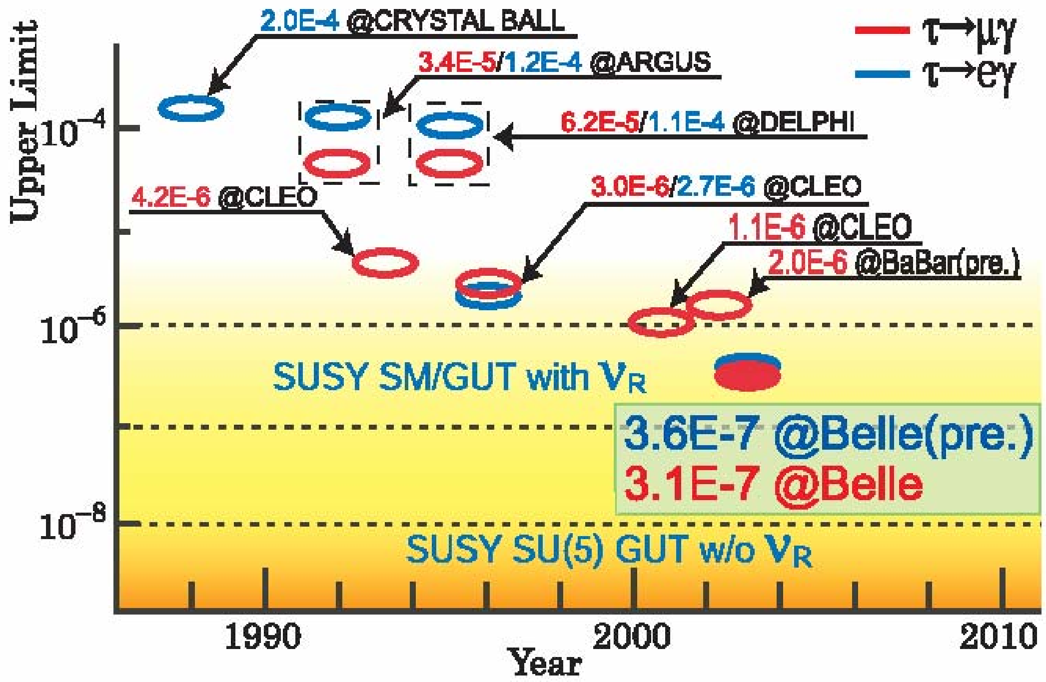


Figure 4.44: Experimental status of the LFV search.

SuperKEKB physics WG

Real reason for building the Super B factory

Past Discoveries

- Parity
- Ω^-
- Particle-anti-particle oscillation in K and B
- W
- Top
- D meson
- B meson
- Large CPV in $B \to \psi K_S$
- Non-vanishing ε'/ε

anicipated

Major Surprises

- *CP violation in K decays*
- *J/ ψ*
- *Neutrino astronomy*
- *Neutrino mixing*
- *Neutrino masses*
- *Large mixing angle*

Early 1970's   Early 2000's

- Gauge theory was discovered but it took some time to settle to SU(2)XU(1)
- Other choices O(3), SU(2)XSU(2)
- How many generations?
- Lepton quark symmetry
- CP violation was not explained

- What is the correct physics beyond the standard model?
- What are the characters?
- What is the origin of CP violation?

We need unanticipated discovery

It may be around the corner

Remote Future

We eventually need SUPER-SUPERB and SUPER-LHCB

Systematic Search

- Precision measurements
  shoot for error less than 1%
- Need as much luminosity as possible
- CPV in B_s decays where no CP is expected by the SM
- Precise measurement of ΔM_d and ΔM_s
- Lepton number violation in τ decays

Provide constraints to NP models

I once stated that instead of 10^{34} we need 10^{43}

I was not that far off!

"Our 1964 experiment can be done with one pulse of the BNL beam!" Cronin

Just 3 years ago Maury Tigner said: "10^{35} is a dream"

State what we need
and hope that machine physicists
Are smart enough to deliver!

Conclusion

1. LHC and B factory compliment each other
2. 4 years from now, we may be looking for quantum effects of particles discovered at LHC
3. Precision experiments can reveal new physics even if it could not be found at LHC.
4. I m certain that, some day, measurements that take one year to make can be done in one day.