Physics at a Super B-Factory

Matthias Neubert – Cornell University

(neubert@mail.lns.cornell.edu)

I. Introductory Remarks
II. Precision CKM Physics
III. Rare and Forbidden B Decays
IV. τ and Charm Physics
V. Conclusions

23rd Advanced ICFA Beam Dynamics Workshop on
High Luminosity e^+e^- Colliders
(Cornell University, Ithaca, New York, 15–19 October 2001)

I. Introductory Remarks

- assessment of the physics potential of a super-high luminosity e^+e^- B-factory ($\mathcal{L} \sim 10^{36}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$) must make assumptions about many unknowns:
  - fate of high-energy physics over next 5–10 years
  - findings and potential of current e^+e^- factories (PEP-II and KEK-B) and future hadronic B-factories (LHC-b and BTeV)
  - developments in theory (QCD)
  - political realities
- will ignore political realities and assume that theory progresses at current paste, but without revolutionary developments (physics case should not rely on "revolution in lattice gauge theory")

∗ will assume that upgrades of present B-factories and operation of future, hadronic B experiments proceed as advertised, and use the projections for Super-BaBar as reported in *Physics at a* 10^{36} *Asymmetric B Factory* (SLAC-PUB-8970, August 2001) [thanks to D. Hitlin]

- for PEP-II and KEK-B, use benchmark integrated luminosities of 30 fb^{-1} (now) and 500 fb^{-1} (2006) per experiment

- for Super B-factories, assume benchmark integrated luminosity of 10,000 fb^{-1} $= 10\,\text{ab}^{-1}$, corresponding to 2×10^{10} B mesons, per Snowmass year (note: Super-KEK-B assumes a factor 10 less than Super-BaBar)

- LHC-b and BTeV performance as described in their proposals

∗ with these assumptions, numbers of reconstructed events in many channels are comparable between hadronic factories and super B-factories

- however, super B-factories profit from cleanliness of e^+e^- environment:
  - advantages in reconstruction of neutrals: π^0, γ, ν
  - huge data samples of tagged B decays: 40 million clean tags (200 million less clean tags) in $10\,\mathrm{ab}^{-1}$
- this offers some advantages in precision CKM physics, and especially in rare decay searches!

Future Scenarios of High-Energy Physics

- I wish I knew!
- past has shown that precision low-energy physics is complementarity to searches for New Physics at the energy frontier

  ⇒ this is most likely to remain true!
- good arguments for incompleteness of the Standard Model exist, which suggest that New Physics should occur close to the TeV scale
- virtually any extension of Standard Model contains new flavor-changing couplings and many new sources of CP violation (MSSM → 43 new CP-violating phases!)
- absence of hints for new flavor physics in present experiments most likely linked to decoupling of New Physics in the electroweak sector

???

CP Problem ↔ EWSB Problem

New (s)particles/interactions found at LHC:

- they will almost certainly have flavor dynamics (flavor-changing couplings) and contribute new sources of CP violation

- these couplings can only be measured with precision physics (recall that top couplings V_{td} and V_{ts} are measured in kaon and B physics)

- advantage that mass scales are known

Only a Higgs found at LHC:

- high-precision flavor physics only window to higher energy scales (e.g., even 10–50 TeV squarks could have an impact on K–$\bar{K}$ mixing, rare K and B decays)

Nothing found at LHC:

- even more burden put on high-sensitivity flavor physics

Future Scenarios of Flavor Physics

- when the Standard Model collapses, flavor physics will not!
- at some level New Physics will show up

Flavor physics totally different from CKM:

⇒ already excluded

Flavor physics $\approx$ *CKM* $+$ *some* $O(1)$ *effects:*

⇒ still possible

Flavor physics $=$ *CKM* $+$ *some small corrections:*

⇒ perhaps most likely scenario

Q : Can BaBar, Belle, LHC-b and BTeV (+ rare kaon decay experiments) exhaust the discovery potential in flavor physics?

II. Precision CKM Physics

- discovery of CP violation in the B-meson system was a triumph for theory
- pattern of CP-violating effects in mixing and weak decays of kaons, charm and B mesons is correctly predicted by Kobayashi–Maskawa (KM) mechanism:
  - CP violation small in K–$\bar{K}$ mixing (ϵ_K) and $K \to \pi\pi$ decay (ϵ'/ϵ)
  - CP violation large in $B \to J/\psi\, K$ ($\sin 2\beta$) but small in B–$\bar{B}$ mixing (ϵ_B)
  - small CP violation in charm decays, below present experimental sensitivity
- now a lot of evidence that KM mechanism is responsible for leading CP violation effects observed in low-energy weak interactions of hadrons
- significance of $\sin 2\beta$ measurement: CP-violating phase is large!

$$\boxed{\text{CP is not an approximate symmetry of Nature}}$$

$\Rightarrow$ pattern of CP violation effects reflects hierarchy of CKM matrix

∗ besides describing CP violation, CKM mechanism explains a vast variety of flavor-changing processes

- semileptonic decays, e.g.:

$$B \to D^* l\,\nu\,(\sim |V_{cb}|) \qquad D \to K\,l\,\nu\,(\sim |V_{cs}|) \qquad K \to \pi\,l\,\nu\,(\sim |V_{us}|)$$

$$B \to \pi\,l\,\nu\,(\sim |V_{ub}|) \qquad D \to \pi\,l\,\nu\,(\sim |V_{cd}|) \qquad n \to p\,l\,\nu\,(\sim |V_{ud}|)$$

- leptonic and nonleptonic decays
- rare decays, e.g.: $B \to X_s\gamma$, $B \to X_s\,l^+l^-$ (?), $K \to \pi\nu\bar{\nu}$ (?), …
- mixing: K–$\bar{K}$, B_d–$\bar{B}_d$, B_s–$\bar{B}_s$ (?), D–$\bar{D}$ (?)

CKM Matrix and the Magic Triangle:

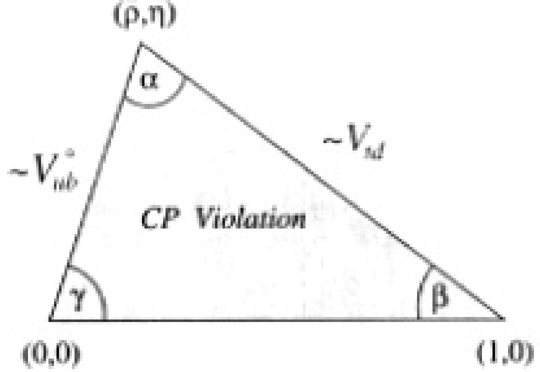
- $V_{\rm CKM} = 3 \times 3$ unitary matrix connecting mass eigenstates of down-type quarks with interaction eigenstates (contains 4 physical parameters):

$$V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar\rho - i\bar\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar\rho-i\bar\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

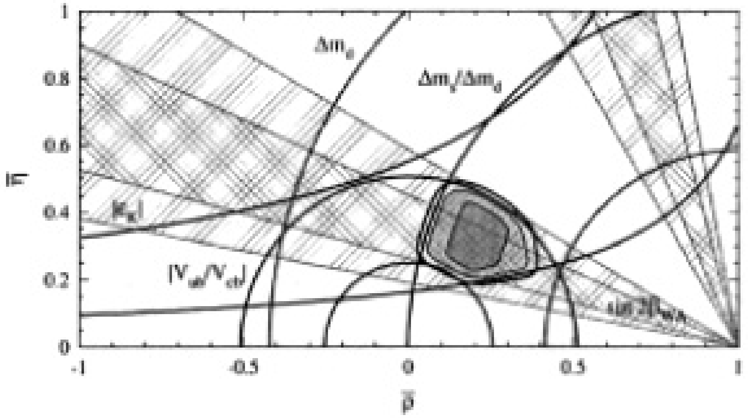
- accurately known: $|V_{us}|$ and $|V_{cb}|$ ($\lambda = 0.224 \pm 0.003$ and $A = 0.82 \pm 0.04$)
- more uncertain: $|V_{ub}|$ and $|V_{td}|$ ($\bar\rho$ and $\bar\eta$)
- with standard phase conventions, complex phases appear in smallest matrix elements (requires ≥ 3 generations)

Unitarity triangle:

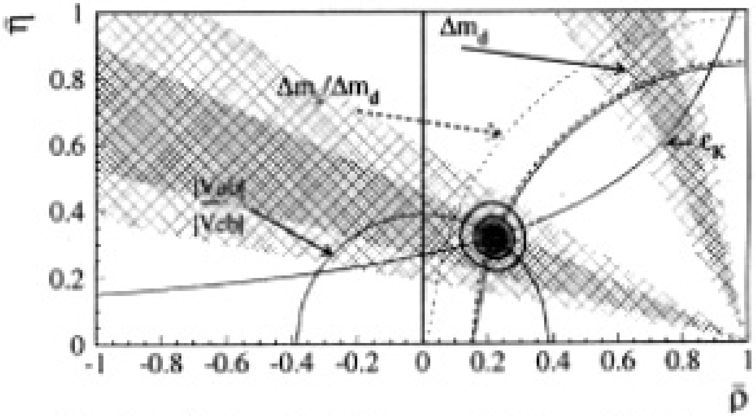
$$\boxed{V_{ub}^{*}V_{ud} + V_{cb}^{*}V_{cd} + V_{tb}^{*}V_{td} = 0}$$



- combining measurements of $|V_{ub}|$ in semileptonic decays, $|V_{td}|$ in B–$\bar{B}$ mixing, and Im(V_{td}^{2}) in K–$\bar{K}$ mixing, the parameters of the unitarity triangle were determined already with great accuracy before summer 2001:



[Höcker, Lacker, Laplace, Le Diberder]



[Ciuchini, Agostini, Franco, Lubicz, Martinelli, ...]

- has established existence of a complex phase in the top sector (Im(V_{td}) $\neq 0$)
- ranges at 95% CL (without $\sin 2\beta$): [Höcker et al.]

$$\bar\rho = 0.21 \pm 0.17 \qquad \bar\eta = 0.35 \pm 0.14$$

$$\sin 2\beta = 0.68 \pm 0.21 \qquad \sin 2\alpha = -0.23 \pm 0.73$$

$$\gamma = 58^\circ \pm 24^\circ$$

($\gamma < 90^\circ$ due to $\Delta m_s/\Delta m_d$ constraint!)

Recent measurements of $\sin 2\beta$:

BaBar: $0.59 \pm 0.14 \pm 0.05$

Belle: $0.99 \pm 0.14 \pm 0.06$

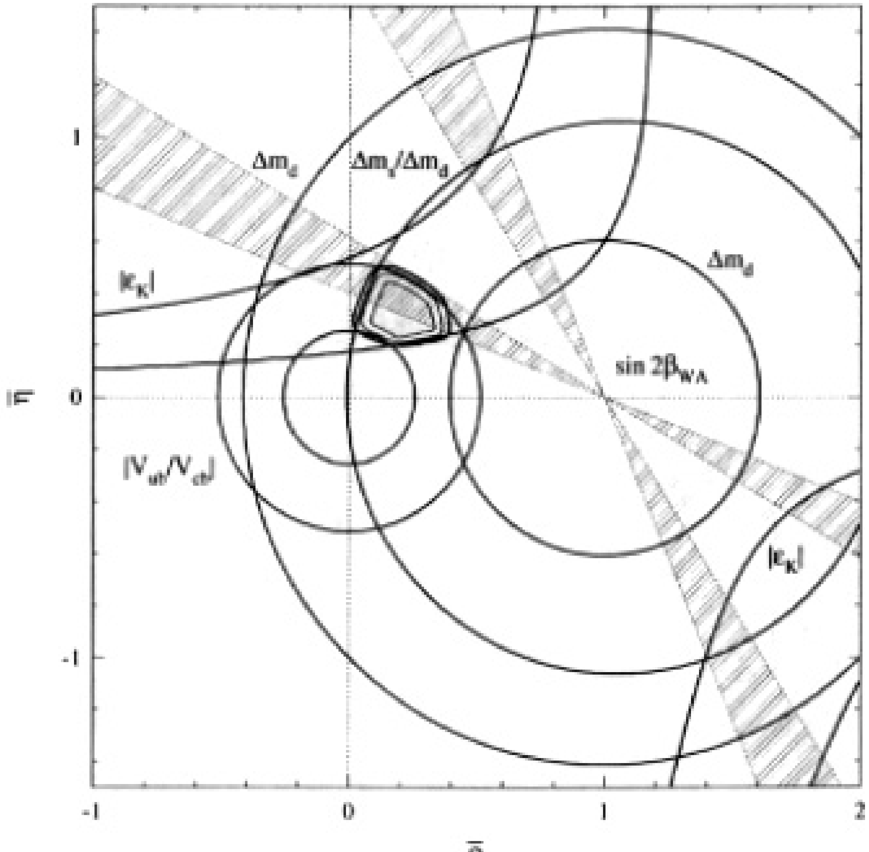
- ranges at 95% CL (including $\sin 2\beta$): [Höcker et al.]

$$\bar\rho = 0.22 \pm 0.15 \qquad \bar\eta = 0.37 \pm 0.12$$

$$\sin 2\beta = 0.73 \pm 0.14 \qquad \sin 2\alpha = -0.19 \pm 0.70$$

$$\gamma = 58^\circ \pm 22^\circ$$

- current picture is all too consistent:



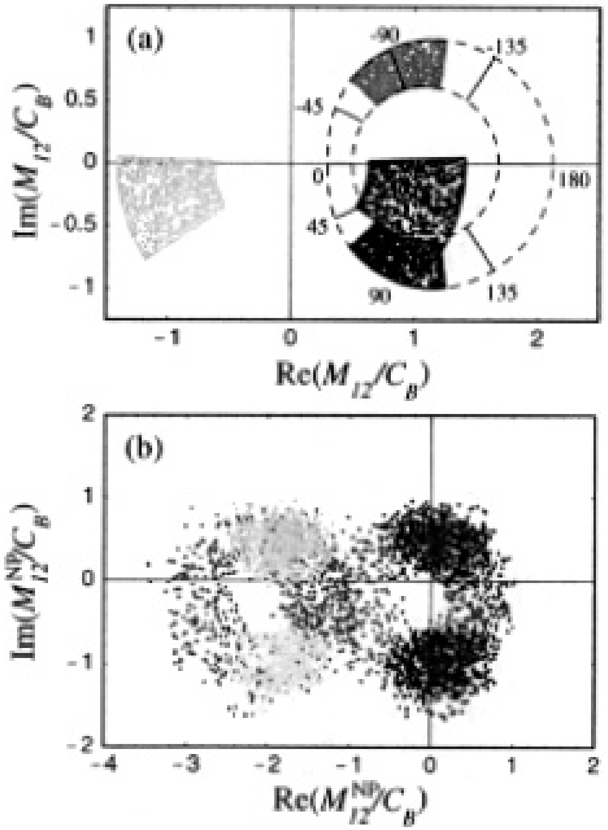
- but nothing is known about CP violation in the bottom sector ($\gamma = \arg(V_{ub}^*)$)

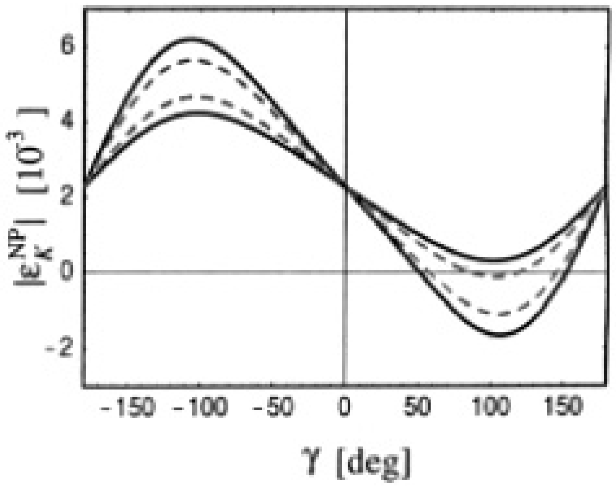
- much could have happened to the B_d–$\bar{B}_d$ mixing phase, but didn't ...
- some possibilities for potentially large effects:
  - models with iso-singlet down-type quarks and tree-level FCNCs
  - left-right symmetric models with spontaneous CP violation (now excluded!)
  - SUSY with extended minimal flavor violation
- on the contrary, only small modifications are allowed in models with minimal flavor violation:

  ⇒ model-independent bound $\sin 2\beta > 0.42$; estimate $0.52 < \sin 2\beta < 0.78$

- still plenty of room for New Physics in both mixing and weak decays
- e.g., possible New Physics contributions to B–$\bar{B}$ and K–$\bar{K}$ mixing amplitudes:

[Kagan, M.N.]





Success and Embarrassment

∗ much like the stunning success of Standard Model in explaining electroweak precision data, the lack of deviations from KM mechanism gives rise to theoretical puzzles:

- KM does not explain the baryon asymmetry in Universe
- KM does not explain why $\theta_{\rm QCD} = 0$
- basically all extensions of Standard Model contain many new CP-violating parameters
- surprising that these effects have not yet been seen

"CP Problem"

⇒ need to keep searching for (probably small) deviations from KM with precision measurements

Magnitudes of CKM Elements

- already limited by theoretical uncertainties (mainly lattice QCD):

V_{ij}	Experimental Measurement	σ 2001 stat/sys	σ 2006 stat/sys	σ 2011 stat/sys	Theoretical Quantity	σ 2001 quenched	σ 2-5 years unquenched	σ 4-10 years unquenched
V_{ub}	$B(B \to \rho l\nu)$	4.3%/8%	8.6%/2.4%	1.4%/2.4%	$f_+(E_\pi)$	18%	15%	5%
	$B(B \to u l\nu)$	3.4%/16%	4.0%/2.4%	2.8%/2.4%	f_B †	10-15%	10%	2%
	$B(B \to \tau\nu)$		24%	5%	$\overline{\Lambda}$, λ_1, λ_2' *	see note	see note	see note
V_{cb} ($\mathcal{F}(1)$)	$B(B \to D l\nu)$	3.1%/4%	0.4%/2%	0.10%/1%	$\mathcal{F}(1)$ ‡	2-4%	2-4%	1%
V_{cb}	$B(B \to c l\nu)$	2.5%/2%	0.3%/1%	0.07/0.5%%	$\overline{\Lambda}$, λ_1, λ_2' *	25%	15%	5%
V_{us}	$B(K \to \pi l\nu)$	0.8%	0.8%	0.8%	$f_+(q^2)$	15%	15%	2-5%
V_{cd}	$B(D \to \pi l\nu)$	7.1%	1%		$f_+(E_\pi)$	15%	15%	2-5%
	$B(D \to l\nu)$		2%		f_D †	10-15%	10%	2%
V_{cs}	$B(D \to K l\nu)$		0.4%		$f_+(E_K)$	15%	15%	2-5%
	$B(D_s \to l\nu)$		1%		f_{D_s} †	10-15%	10%	2%
V_{td}	Δm_d	1%/1%	0.2%/0.5%	0.05%/0.2%	$f_{B_d}\sqrt{B_{B_d}}$ ‡	~20%	15%	5%
V_{ts}	Δm_s				$f_{B_s}\sqrt{B_{B_s}}$ ‡	~20%	15%	5%

[Eigen, Kronfeld, Mackenzie]

Improvements on $|V_{ub}|$

- all determinations of $|V_{ub}|$ are difficult and have significant theoretical uncertainties
- inclusive $B \to X\, l\, \nu$ decays (OPE $\Rightarrow 1/m_b$ expansion)
  - lepton-energy spectrum (10–20%)
  - hadronic invariant mass spectrum (10–20%)
  - leptonic invariant mass spectrum (10%)
  - optimized combined cuts (5–10%)
- exclusive decays $B \to \pi\, l\, \nu$ and $B \to \rho\, l\, \nu$
  - theoretical precision limited by lattice gauge theory
  - conservative (?) projection gives 5% on time scale of 4–10 years [Kronfeld], but optimists envision 1% precision [Lepage]

- some projections:

method	$\int \mathcal{L}$ fb^{-1}	S	B	$\delta V_{\rm ub}$ (%)		
				stat.	sys.	tot.
$m_{\rm had}$	100	335	127	3.2	2.2	3.9
	500	1675	635	1.5	1.5	2.1
	1000	3350	1270	1.0	1.5	1.8
q^2	100	127	7	4.6	3.0	5.5
	500	635	36	2.0	1.2	2.3
	1000	1270	72	1.4	1.2	1.8
exclusive	1000	590	59	4.3	1.2	4.5
	10000	5900	590	0.7	1.2	1.4

[Super-BaBar Proposal]

- only under very optimistic assumptions about theory would a data sample of 10 ab^{-1} help to reduce the error on $|V_{ub}|$

Angles of the Unitarity Triangle

- still terra incognita, much room for improvements

Measurement of $\sin 2\beta$*:*

- estimated precision is $\sigma_{\sin 2\beta} = 0.037$ for 500 fb^{-1}, and $\sigma_{\sin 2\beta} = 0.008$ for 10 ab^{-1}

  ⇒ comparable or better than hadronic B-factories

- at super B-factories, a competitive measurement of $\sin 2\beta$ can be made in the penguin-dominated decay mode $B \to \phi K_S$, with $\sigma_{\sin 2\beta} = 0.056$ for 10 ab^{-1} (cf. $\sigma_{\sin 2\beta} = 0.25$ for 500 fb^{-1})

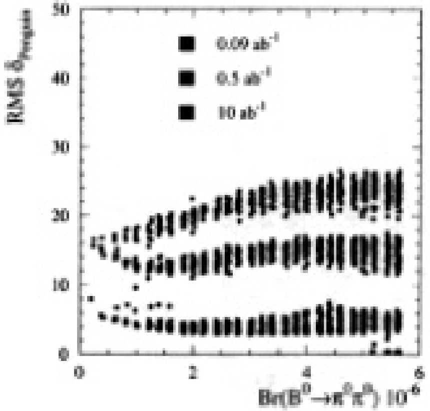
  ⇒ very hard (impossible?) at hadronic machines

  ⇒ important for New Physics searches!

Measurement of $\sin 2\alpha$*:*

- time-dependent CP asymmetry in $B \to \pi^+\pi^-$ determines "effective" parameter $S_{\pi\pi} = \sin 2\alpha_{\mathrm{eff}}$, which differs from "true" $\sin 2\alpha$ due to penguin contamination
- estimated precision is $\sigma_{S_{\pi\pi}} = 0.14$ for 500 fb^{-1}, and $\sigma_{S_{\pi\pi}} = 0.032$ for 10 ab^{-1}

  ⇒ comparable or better than hadronic B-factories
- at super B-factories the penguin contamination can be eliminated using isospin analysis and a precision measurement of $B^0, \bar{B}^0 \to \pi^0\pi^0$, which determines $\delta_{\mathrm{penguin}} = \alpha_{\mathrm{eff}} - \alpha$ with an error of less than 5°:

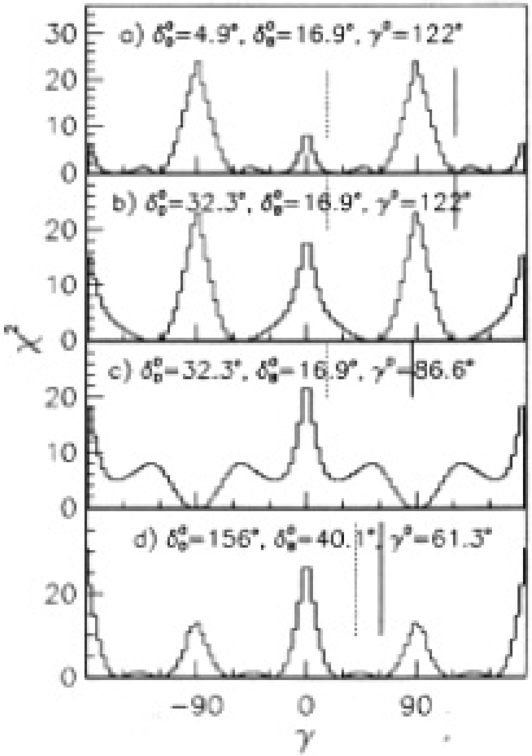


⇒ unique measurement!

⇒ "clean" determination of α with precision of about 5°

Measurements of γ:

- clean determination of γ using $B \to D K$ decays, with interference of the tree topologies $b \to c\bar{u}s$ and $b \to u\bar{c}s$
- method is marginal at present e^+e^- B-factories due to discrete ambiguities, despite the fact that $\sigma_\gamma \sim 5^\circ$–$10^\circ$ [Soffer]



- expected precision with 10 ab^{-1} is $\sigma_\gamma \sim 1°$–$2.5°$, which is comparable or better than what can be achieved at hadronic B-factories
- in addition, $\sin(2\beta+\gamma)$ can be determined using interference of $b \to c\bar{u}d$ and $\bar{b} \to \bar{u}c\bar{d}$ in decays such as $B \to D^{*\pm}\pi^{\mp}$
- exploratory study gives $\sigma_{\sin(2\beta+\gamma)} \sim 0.15$ with 500 fb^{-1}, and $\sigma_{\sin(2\beta+\gamma)} \sim 0.03$ with 10 ab^{-1}

  $\Rightarrow$ clean measurement, which would help to resolve discrete ambiguities
- additional strategies using B_s mesons would require extensive running on the $\Upsilon(5S)$, but would not be competitive with hadronic B-factories

Summary on Unitarity Triangle Angles

CKM Angle	BaBar (0.5 ab^{-1})	Super-BaBar (10 ab^{-1})	BTeV	LHC-b	Atlas/CMS
$\sin 2\beta\ (B \to J/\psi\, K_S)$	0.037	0.008	0.011	0.014	0.021/0.025
$\sin 2\beta\ (B \to \phi\, K_S)$	0.25	0.056			
$\sin 2\alpha_{\rm eff}\ (B \to \pi^+\pi^-)$	0.14	0.032	0.05	0.056	0.10/0.17
$\alpha_{\rm eff} - \alpha\ (B \to \pi^0\pi^0)$	$< 18^\circ$	$< 7^\circ$	–	–	–
$\sin(2\beta + \gamma)\ (B \to D^*\pi)$	0.15	0.03			
$\gamma\ (B \to D\, K)$	–	$< 2.5^\circ$	2°	$< 19^\circ$	
$\gamma\ (B_s \to D_s K)$	–	$< 15^\circ$	7°	$< 13^\circ$	

[Super-BaBar Proposal]

- super B-factories offer advantages in the determination of γ (from $B \to D^*\pi$ decays) and α (unique $B \to \pi^0\pi^0$ measurement), and allow for a precise measurement of $\sin 2\beta$ in $B \to \phi K_S$ decays (test for New Physics!)

- however, important to realize that there are only two independent angles ($\alpha = \pi - \beta - \gamma$ even with New Physics!), and without having a precision determination of the sides ($|V_{ub}|$ and $|V_{td}|$) one cannot over-constrain the unitarity triangle!

- after BaBar, Belle, LHC-b and BTeV running, we will probably know the angles of the unitarity triangle with a precision $\sigma_{\sin 2\beta} \sim 0.02$, $\sigma_\gamma \sim 5^\circ$, and $\sigma_\chi \sim 1^\circ$ (B_s mixing phase, only at hadron machines), which is better than the precision $\sim 5\%$ on the length of the sides

- if deviations from the CKM mechanism have not appeared at this point, there will be little more to be gained from precision CKM physics

- case for super B-factories must be made based on other measurements:

comprehensive exploration of rare B decays

III. Rare and Forbidden B Decays

∗ systematic study of rare B decays is much richer than unitarity triangle physics

- many clean tests for New Physics can be performed

- processes that are strongly suppressed or forbidden in Standard Model offer a farther reach than the relatively abundant processes used for the unitarity triangle analyses

- lots of room for surprises

∗ cleanliness of e^+e^- environment, advantages in neutrino and photon reconstruction, and possibility for obtaining huge samples of tagged B decays make this the super B-factory's playground

Theoretical Framework

∗ effective weak Hamiltonians provide a model-independent parameterization of rare decay amplitudes in terms of hadronic matrix elements of local operators multiplied by calculable, complex running coupling constants:

$$\boxed{\langle \mathcal{H}_{\text{eff}} \rangle = \sum_i C_i(M_{\text{heavy}})\, \langle O_i \rangle}$$

- in Standard Model about 20 operators appear, whose couplings are functions of $x_t = (m_t/m_W)^2$ and CKM parameters: $C_i \sim (g_W^2/m_W^2) \times$ [CKM elements]

- with New Physics many more operators can be present, whose couplings probe the short-distance physics and are functions of the masses of new heavy particles and their flavor-violating couplings, including new CP-violating phases: $C_i \sim g^2_{\text{fl. chg.}}/m^2_{\text{NP}}$

- ∗ in cases where the Standard Model amplitude is strongly suppressed, the New Physics contribution may be relevant even if $m_{\rm NP} \gg m_W$

  • e.g., flavor-changing gluino–squark couplings in SUSY can lead to FCNC transitions $b \to s\bar{q}q$ and $b \to d\bar{q}q$ via box diagrams for which $g^2_{\rm fl.\,chg.} \sim \alpha_s$, in which case SUSY masses of several TeV can be probed

  • if SUSY masses were known from LHC, then the new couplings could be measured directly

- ∗ ultimate goal is to probe these couplings in a surgical, selective way by analysis of a large variety of rare decay processes

- in cases where the Standard Model amplitude is strongly suppressed, the New Physics contribution may be relevant even if $m_{\rm NP} \gg m_W$

  - e.g., flavor-changing gluino–squark couplings in SUSY can lead to FCNC transitions $b \to s\bar{q}q$ and $b \to d\bar{q}q$ via box diagrams for which $g^2_{\rm fl.\,chg.} \sim \alpha_s$, in which case SUSY masses of several TeV can be probed

  - if SUSY masses were known from LHC, then the new couplings could be measured directly

- ultimate goal is to probe these couplings in a surgical, selective way by analysis of a large variety of rare decay processes

- several strategies exist for reducing (often eliminating) theoretical uncertainties, e.g.:

  - Standard Model prediction known from independent measurements (e.g.: $\sin 2\beta$ from $B \to \phi K_S$)

  - zero effects expected in Standard Model (e.g.: CP asymmetry in $B \to X_s\gamma$; very rare or forbidden decays)

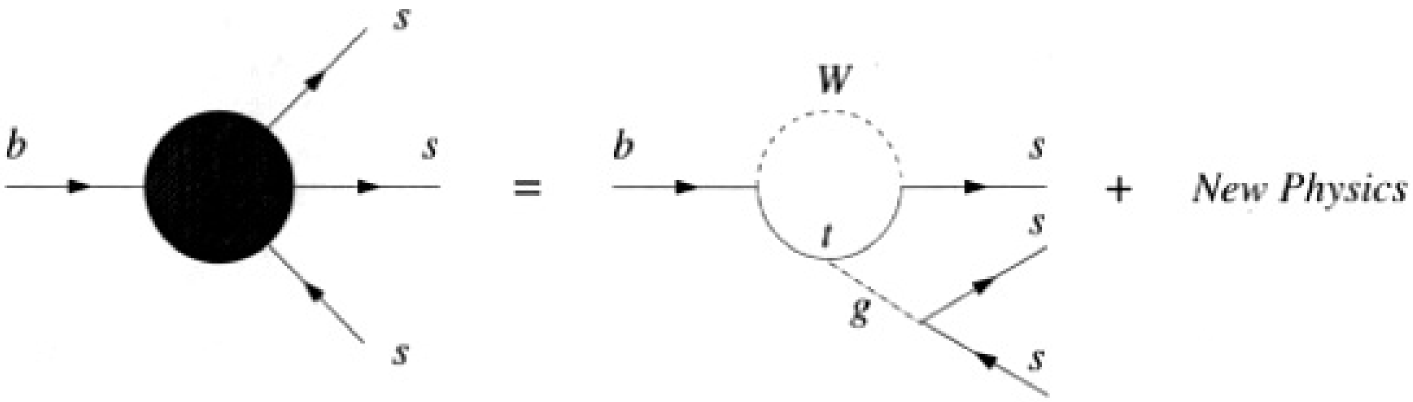
  - heavy-quark expansions (e.g.: rates for inclusive decays $B \to X_s\gamma$, $B \to X_s l^+l^-$, $B \to X_s\nu\bar{\nu}$; form factor zero in $A_{\rm FB}(B \to K^* l^+l^-)$; isospin violation in $B \to K^*\gamma$)

- consider several examples in detail ...

New Physics in $B \to \phi K_S$ decays:

- this is usually mentioned under "measurement of $\sin 2\beta$", but it is really a clean test of New Physics in the penguin decay $b \to s\bar{s}s$
- any difference between $\sin 2\beta_{\psi K}$ and $\sin 2\beta_{\phi K}$ would signal New Physics in penguin transitions, even if there were additional New Physics is B–$\bar{B}$ mixing

  ⇒ based on projected precision $\sigma_{\sin 2\beta_{\phi K}} \sim 0.056$ with 10 ab^{-1}, super B-factories can probe a potential CP-violating phase $\phi_{\rm NP}$ in the $b \to s\bar{s}s$ transition with a precision $\sigma_{\phi_{\rm NP}} \sim 2°$!



New Physics in Radiative B decays:

∗ rich variety of phenomena, including:

- limits on charged Higgs bosons and SUSY particles from $B \to X_s\gamma$ branching ratio

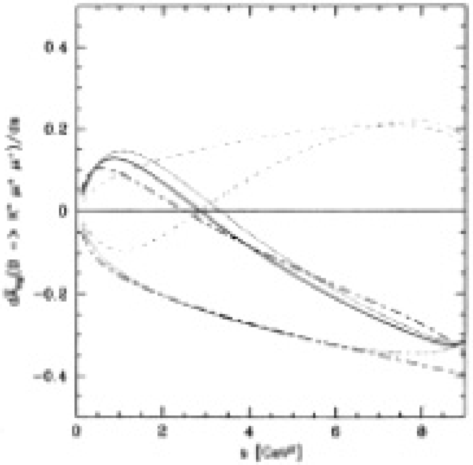
- probes for New Physics in CP asymmetry measurements in $B \to X_s\gamma$, $B \to K^*\gamma$ (with 1% precision!) and $B \to \rho\gamma$ ($\to C_{7\gamma}, C_{8g}$)

- probes for New Physics in isospin violation in $B \to K^*\gamma$ ($\to C_6, C_{7\gamma}$) and $B \to \rho\gamma$ ($\to C_{7\gamma}$)

- high-precision determination of the shape function from a clean measurement of the photon energy spectrum in $B \to X_s\gamma$ down to below 2 GeV, using tagged B decays ⇒ impact on $|V_{ub}|$ determination!

New Physics in $B \to X_s l^+ l^-$ decays:

- sensitive probe of non-Standard Model physics (electromagnetic and Z penguins, and boxes) ($\to C_{7\gamma}, C_{9V}, C_{10A}$, effective $\bar{s}bZ$ vertex)
- super B-factories have capabilities similar to hadronic machines, but may have advantages with respect to measuring decay distributions (rather than just branching ratios), especially in the inclusive modes
- particularly interesting is the prediction of a zero in the forward–backward asymmetry in the exclusive mode $B \to K^* l^+ l^-$, whose position probes the coupling C_{9V}:



New Physics in $B \to X_s \nu\bar{\nu}$ decays:

- these are the beautiful analogues of $K \to \pi\nu\bar{\nu}$, which are very sensitive to New Physics in electroweak penguin transitions
- they can only be measured at super B-factories, with an expected event rate of about 160 per year in the Standard Model

Leptonic decays $B \to l\,\nu$:

- while these have little sensitivity to New Physics, they would allow a direct measurement of the product $|V_{ub}|\,f_B$, providing a benchmark for lattice calculations and a cross check on other $|V_{ub}|$ determinations
- while some events may be seen at BaBar and Belle, only super B-factories could make precise measurements
  - with $10\,\text{ab}^{-1}$, expect accuracy of 5% on $B \to \tau\nu$ and 8% on $B \to \mu\nu$

New Physics in $B \to l^+l^-$ decays:

- these purely leptonic modes are extremely rare (or forbidden) in the Standard Model, but could be largely enhanced in New Physics models (e.g., models with lepto-quarks or new gauge bosons, or SUSY with R-parity violation)
- whereas hadronic B factories are superior in searches for $B \to e^+e^-$, $\mu^+\mu^-$ and $e^\pm\mu^\mp$, super B-factories can pursue searches for $B \to \tau^+\tau^-$ and $B \to \tau^\pm l^\mp$ with $l = e, \mu$, which are extremely difficult in a hadronic environment
- even with $10\,\mathrm{ab}^{-1}$ no events are expected in the Standard Model, but interesting sensitivity levels can be reached:
  - $ee, \mu\mu, e\mu$: $< 5 \times 10^{-9}$
  - $\tau e, \tau\mu$: $< 5 \times 10^{-7}$
  - $\tau\tau$: $< 2 \times 10^{-6}$
- in some models, this corresponds to mass limits for new particles of order 10 TeV

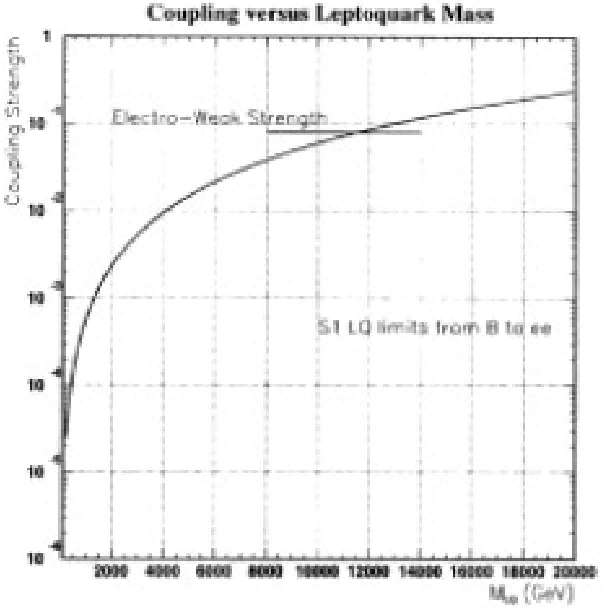


Figure 1: The 90% CL limits on coupling versus leptoquark mass.

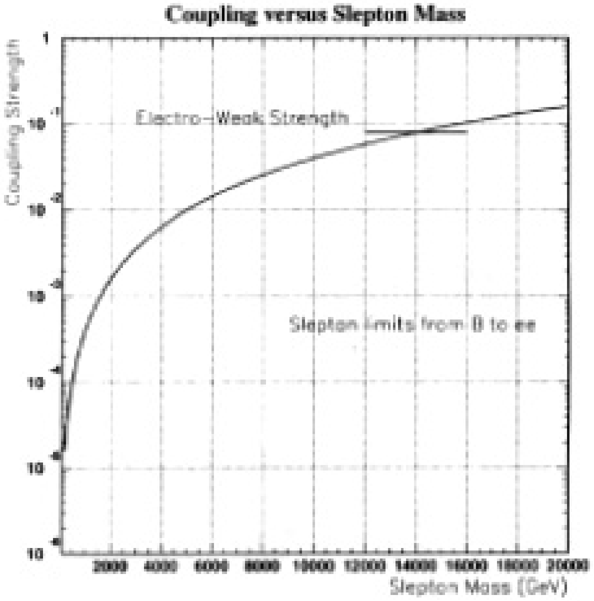


Figure 2: The 90% CL limits on coupling versus slepton mass.

New Physics in $B \to \gamma\gamma$ decays:

- these purely radiative modes are very sensitive to New Physics, and can only be explored with super B-factories
- with $10\,\text{ab}^{-1}$ one expects about 8 events in the Standard Model, but enhancements of up to a factor 100 are possible with New Physics

IV. τ and Charm Physics

- obviously, such a machine would deliver an incredible number of $\tau^+\tau^-$ pairs, and of charm hadrons produced via initial-state radiation

- 10 ab^{-1} corresponds to 10^{10} $\tau^+\tau^-$ events

  ⇒ besides conventional τ physics, this will allow uniquely sensitive searches for lepton flavor violation, e.g., the branching ratio for $\tau \to \mu\gamma$ could be measured down to levels of 10^{-8}, which are realistic in some SUSY models

- for charm physics, the effective e^+e^- luminosity around the charm threshold region would be about 2×10^{33} cm^{-2} s^{-1}

- while τ and charm physics can certainly not be used to nail the physics case for a super B-factory, the abundant production rates are nevertheless impressive!

V. Conclusions

- There is flavor physics beyond the Standard Model, whose origin is most likely linked to the physics that explains electroweak symmetry breaking!
- The long-term future of B physics will not be precision CKM physics, but a comprehensive analysis of a large set of rare and extremely rare decays (processes with low Standard Model background)!
- Super B-factories have distinctive advantages over hadronic machines for such an endeavor!
- $\int \mathcal{L}\, dt =$ several $\times\ 10^{36}$ is not a luxury, but needed to fully exhaust the discovery potential of B physics!