Flavour and the New Physics

Ahmed Ali
DESY, Hamburg

Talk, Les Houches '05
May 16, 2005

Plan of Talk

- Flavour Mixing in the SM & The CKM Matrix
- The Minimal Supersymmetric Standard Model and Flavour Mixing
- Synergy of Various Approaches in Search of BSM Physics
- CP Violation in K- and B-Decays sensitive to BSM Physics
- Rare K-Decays and BSM Physics
- Rare B-Decays and BSM Physics
- Searches of BSM Physics in LFV Processes
- Summary and Outlook

Flavour Mixing in the Standard Model

- Flavour mixings in the SM reside in the Yukawa sector of the theory

$$\mathcal{L}_{\rm SM} = \mathcal{L}_{\rm gauge}(A_i, \psi_i) + \mathcal{L}_{\rm Higgs}(\phi_i, A_i, \psi_i)$$

- 3 Quark families: $Q_{L_i} = (u_L,\ d_L); (c_L,\ s_L); (t_L;\ b_L); \bar{u}_R,\ \bar{d}_R; ...$
- Flavour symmetry broken by Yukawa interactions

$$Q_i Y_d^{ij} d_j \phi \ \longrightarrow\ Q_i M_d^{ij} d_j$$

$$Q_i Y_u^{ij} u_j \phi^c \ \longrightarrow\ Q_i M_u^{ij} u_j$$

$$M_d = \mathrm{diag}(m_d,\ m_s,\ m_b);\ \ M_u^\dagger = \mathrm{diag}(m_u,\ m_c,\ m_t) \times V_{\rm CKM}$$

- $V_{\rm CKM}$ a (3×3) unitary matrix is the only source of Flavour Violation, as all gauge interactions (involving $\gamma,\ Z^0,\ g$) are Flavour diagonal
- All observed phenomena involving flavour changes in the hadrons, as well as flavour changing neutral currents, are consistently described by the CKM framework; i.e., in terms of 10 fundamental parameters: 6 quark masses, 3 mixing angles and 1 complex phase
- Understanding the observed patterns of quark masses and mixings (as well as the lepton masses and neutrino mixings) requires an organizing principle which is certainly outside of the SM

The Cabibbo-Kobayashi-Maskawa Matrix

$$V_{\mathrm{CKM}} \equiv \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

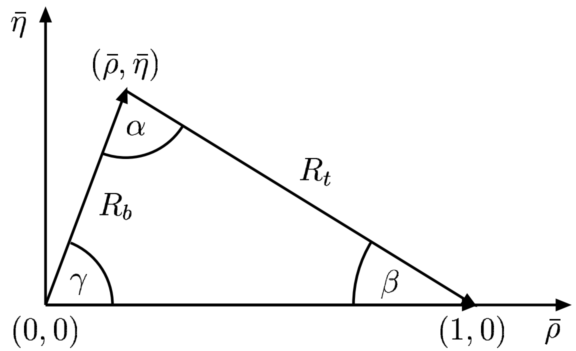
- Customary to use the handy Wolfenstein parametrization

$$V_{\mathrm{CKM}} \simeq \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda(1+iA^2\lambda^4\eta) & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2(1+i\lambda^2\eta) & 1 \end{pmatrix}$$

- Four parameters: $\boldsymbol{A, \ \lambda, \ \ \rho, \ \ \eta}$
- Perturbatively improved version of this parametrization

$$\boldsymbol{\bar{\rho} = \rho(1-\lambda^2/2), \ \ \bar{\eta} = \eta(1-\lambda^2/2)}$$

- The CKM-Unitarity triangle $[\boldsymbol{\phi_1 = \beta; \ \ \phi_2 = \alpha; \ \ \phi_3 = \gamma}]$



Phases and sides of the UT

$$\alpha \equiv \arg\left(-\frac{V_{tb}^* V_{td}}{V_{ub}^* V_{ud}}\right), \qquad \beta \equiv \arg\left(-\frac{V_{cb}^* V_{cd}}{V_{tb}^* V_{td}}\right), \qquad \gamma \equiv \arg\left(-\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}\right)$$

- β and γ have simple interpretation

$$\boldsymbol{V_{td} = |V_{td}| e^{-i\beta}, \qquad V_{ub} = |V_{ub}| e^{-i\gamma}}$$

- α defined by the relation: $\boldsymbol{\alpha = \pi - \beta - \gamma}$

$$R_b \mathrm{e}^{i\gamma} + R_t \mathrm{e}^{-i\beta} = 1$$

$$R_b \equiv \frac{|V_{ub}^* V_{ud}|}{|V_{cb}^* V_{cd}|} = \sqrt{\bar\rho^2 + \bar\eta^2} = \left(1 - \frac{\lambda^2}{2}\right) \frac{1}{\lambda} \left|\frac{V_{ub}}{V_{cb}}\right|$$

$$R_t \equiv \frac{|V_{tb}^* V_{td}|}{|V_{cb}^* V_{cd}|} = \sqrt{(1-\bar\rho)^2 + \bar\eta^2} = \frac{1}{\lambda} \left|\frac{V_{td}}{V_{cb}}\right|$$

The Minimal Supersymmetric Standard Model: MSSM

- Superfields classified according to their $SU(3)_C \otimes SU(2)_I \otimes U(1)_Y$ Quantum Numbers; $i = 1, 2, 3$ a generation index
- Chiral Superfields for Quarks $(\hat{Q}_i, \hat{U}_i^c, \hat{D}_i^c)$

$$\hat{Q}_i(3, 2, 1/6); \quad \hat{U}_i^c(\bar{3}, 1, -2/3); \quad \hat{D}_i^c(\bar{3}, 1, 1/3)$$

$$\hat{Q}_i = (\tilde{Q}_{L_i}, Q_{L_i}); \quad \hat{U}_i^c = (\tilde{U}_{L_i}^c, U_{L_i}^c); \quad \hat{D}_i^c = (\tilde{D}_{L_i}^c, D_{L_i}^c)$$

- Chiral Superfields for Leptons $(\hat{L}_i, \hat{E}_i^c)$

$$\hat{L}_i(1, 2, -1/2); \quad \hat{E}_i^c(1, 1, 1)$$

$$\hat{L}_i = (\tilde{E}_{L_i}, E_{L_i}); \quad \hat{E}_i^c = (\tilde{E}_{L_i}^c, E_{L_i}^c)$$

- Chiral Superfields for Two Higgs Doublets (also denoted as $\hat{H}_1$ & $\hat{H}_2$)

$$\hat{H}_u(1, 2, -1/2); \quad \hat{H}_d(1, 2, 1/2)$$

$$\hat{H}_u = (H_u, \tilde{H}_u); \quad \hat{H}_d = (H_d, \tilde{H}_d)$$

- Vector Superfields $(\hat{G}, \hat{W}, \hat{B})$ (α is an SU(2) index)

$$\hat{G}(8, 1, 1); \quad \hat{W}^\alpha(1, 3, 1); \quad \hat{B}(1, 1, 1)$$

$$\hat{G} = (g, \tilde{g}); \quad \hat{W} = (W^\alpha, \tilde{W}^\alpha); \quad \hat{B} = (B, \tilde{B})$$

Flavour Mixing in the MSSM

- Flavour mixings in the MSSM reside in the Superpotential $W_{\rm MSSM}$ and in the soft supersymmetry-breaking Lagrangian $\mathcal{L}_{\rm soft}$
- $W_{\rm MSSM}$

$$W_{\rm MSSM} = \epsilon_{\alpha\beta}[-\hat{H}_u^\alpha \hat{Q}_i^\beta Y_u^{ij} \hat{U}_j^c + \hat{H}_d^\alpha \hat{Q}_i^\beta Y_d^{ij} \hat{D}_j^c + \hat{H}_d^\alpha \hat{L}_i^\beta Y_e^{ij} \hat{E}_j^c - \mu \hat{H}_d^\alpha \hat{H}_u^\beta]$$

$$\epsilon_{\alpha\beta} = -\epsilon_{\beta\alpha}; \quad \epsilon_{12} = 1$$

- $\mathcal{L}_{\rm soft}$

$$\mathcal{L}_{\rm soft} = \frac{1}{2}[M_3 \tilde{g}\tilde{g} + M_2 \tilde{W}^\alpha \tilde{W}^\alpha + M_1 \tilde{B}\tilde{B} + h.c.]$$
$$+\epsilon_{\alpha\beta}[-bH_d^\alpha H_u^\beta - H_u^\alpha \tilde{Q}_i^\beta \tilde{A}_{u_{ij}} \tilde{U}_j^c + H_d^\alpha \tilde{Q}_i^\beta \tilde{A}_{d_{ij}} \tilde{D}_j^c + H_d^\alpha \tilde{L}_i^\beta \tilde{A}_{e_{ij}} \tilde{E}_j^c + h.c.]$$
$$+m_{H_d}^2 |H_d|^2 + m_{H_u}^2 |H_u|^2 + \tilde{Q}_i^\alpha m_{Q_{ij}}^2 \tilde{Q}_j^{\alpha *}$$
$$+\tilde{L}_i^\alpha m_{L_{ij}}^2 \tilde{L}_j^{\alpha *} + \tilde{U}_i^{c*} m_{U_{ij}}^2 \tilde{U}_j^c + \tilde{D}_i^{c*} m_{D_{ij}}^2 \tilde{D}_j^c + \tilde{E}_i^{c*} m_{E_{ij}}^2 \tilde{E}_j^c$$

- MSSM contains 124 parameters residing in the Superpotential $W_{\rm MSSM}$ (Yukawa couplings) and Soft-SUSY-breaking $\mathcal{L}_{\rm soft}$ (Scalar) terms
- Various realizations of the MSSM differ from each other in the details of $\mathcal{L}_{\rm soft}$

Yasuhiro Okada (Super-B Workshop, Hawaii, '05)

Different assumptions on the SUSY breaking sector

SUSY breaking

- Minimal Flavor Violation (ex. mSUGRA)
  $$V_{squark} \sim V_{CKM}$$
- SUSY GUT with see-saw neutrinos
  $$(m^2_{\tilde{q}})_{ij} \ni c(y^\dagger_\nu y_\nu)_{ij}$$
- Flavor symmetry — U(2) etc. for Y_q and $m^2_{\tilde{q}}$
- Effective SUSY — $m_{\tilde{q}_3} \ll m_{\tilde{q}_1}, m_{\tilde{q}_2}$
- etc.

How to distinguish these models from B factory observables?

8

SUGRA and mSUGRA models

- CKM matrix is the only source of Flavour transitions
- In SUGRA models, this is achieved by assuming that the SUSY-breaking parameters have a simple structure at the GUT scale (m_X)

$$(m_Q^2)^i_j = (m_E^2)^i_j = (m_D^2)^i_j = (m_U^2)^i_j = (m_L^2)^i_j = M_0^2 \delta^i_j$$

$$m_{H_d}^2 = m_{H_u}^2 = \Delta_0^2$$

$$M_1 = M_2 = M_3 = M_{1/2}$$

$$A_{d_{ij}} = A_0 (Y_d)_{ij}; Au_{ij} = A_0 (Y_u)_{ij}; Ae_{ij} = A_0 (Y_e)_{ij}$$

- In MSUGRA model, in addition $\Delta_0^2 = M_0^2$
- RG running $(m_X \to m_W)$ induces flavour non-diagonal terms, but they are small
- This reduces the number of parameters enormously, leaving essentially the parameters: M_0, $M_{1/2}$, $|A_0|$, $\tan\beta$, ϕ_μ, ϕ_A, where the phases are constrained by the EDMs
- These minimal flavour violation (MFV) models are highly predictive, and hence highly constrained

$SU(5)$ SUSY-GUT Models with Right-Handed Neutrino

- Motivation: Unification of the Gauge coupling constants supports supersymmetric GUTs; Neutrino oscillations in the atmospheric and solar neutrino experiments (Superkamiokande, SNO, Kamland,...) have also lent support to $SU(5)$ and $SO(10)$ SUSY-GUT models with right-handed neutrinos
- interesting connections between the quark flavour and lepton flavour physics; in particular, large flavour mixing in the neutrino sector can induce a squark mixing in the right-handed down-type squark sector

Yukawa Couplings & Majorana masses in $SU(5) \otimes \nu_R$

$$W_{SU(5)\nu_R} = \frac{1}{8}\epsilon_{abcde}(\lambda_U)^{ij}(T_i)^{ab}(T_j)^{cd}H^e + (\lambda_D)^{ij}(\bar{F}_i)_a(T_j)^{ab}\bar{H}_b$$

$$+(\lambda_N)^{ij}\bar{N}_i(\bar{F}_j)_a H^a + \frac{1}{2}(m_N)^{ij}\bar{N}_i\bar{N}_j + \frac{(\kappa_D)^{ij}}{M_P}(\bar{F}_i)_a\Sigma^a_b(T_j)^{bc}\bar{H}_c$$

- $(\lambda_U)^{ij}$, $(\lambda_D)^{ij}$ and $(\lambda_N)^{ij}$: Yukawa coupling matrices; $(M_N)^{ij}$: Majorana mass matrix
- Higher dimensional term $\propto$ $(\kappa_D)^{ij}$ is introduced to break the SUSY-GUT relation $(f_E)^{ij} = (f_D)^{ij}$ which is phenomenologically not satisfied for the first two generations of charged lepton and down type quark masses

$$(f_E)^{ij} = (f_D)^{ij} - \frac{5}{6}\xi(\kappa_D)^{ij} \quad \text{with} \;\; \xi = v_G/M_P \simeq 0.01$$

- $(\kappa_D)^{ij}$ in general a non-diagonal matrix $\Longrightarrow$ new mixing angles in the down-quark and charged lepton sectors

$SU(5)$-invariant Soft-SUSY breaking terms

$$-\mathcal{L}_{\rm soft}^{SU(5)} = m_T^2 \tilde{T}^* \tilde{T} + m_{\bar{F}}^2 \tilde{\bar{F}}^* \tilde{\bar{F}} + m_{\bar{N}}^2 \tilde{\bar{N}}^* \tilde{\bar{N}} + m_H^2 H^* H + m_{\bar{H}}^2 \bar{H}^* \bar{H}$$
$$+ W_{SU(5)\nu_R}(T^i \to \tilde{T}^i, \bar{F}^i \to \tilde{\bar{F}}^i, \bar{N}^i \to \tilde{\bar{N}}^i, \kappa_D \to \tilde{\kappa}_D) + \frac{1}{2} M_5 \overline{\tilde{G}}_5 \tilde{G}_5$$

- $\tilde{T}^i$, $\tilde{\bar{F}}^i$ and $\tilde{\bar{N}}^i$ are the scalar components of T^i, $\bar{F}^i$ and $\bar{N}^i$; M_5 is the mass of the $SU(5)$ Gaugino
- Boundary conditions at the Planck scale

$$(m_T^2)^i_j = (m_{\bar{F}}^2)^i_j = (m_{\bar{N}}^2)^i_j = m_0^2 \delta^i_j$$
$$(\tilde{\lambda})^{ij} = m_0 A_0 (\lambda)^{ij}, \quad (\lambda = \lambda_U, \lambda_D, \lambda_N)$$
$$(\tilde{\kappa})^{ij} = m_0 A_0 (\kappa_D)^{ij}$$
$$M_5 = M_{1/2}$$

- Seesaw Model: $(m_\nu)^{ij} = \langle h_2 \rangle^2 (y_\nu)^{ki} (M_N^{-1})^{kl} (y_\nu)^{lj}$

$$(m_\nu)^{ij} = (V^*_{\rm MNS})^{ik} (m_\nu)^k (V^\dagger_{\rm MNS})$$

- Many CPV phases: ϕ_A, ϕ_μ; 3 CPV phases in the (low energy) neutrino sector, 1 Dirac and 2 Majorana phases; GUT CP phases
- Two scenarios: (i) Degenerate $(M_N)^i$;
- Rich FC Structure: $V_{\rm CKM}$, V_{MNS}, and New Mixings due to $\kappa_D \neq 0$ & due to RG Evolutions (ii) Non-degenerate $(M_N)^i$

General Flavour Violating SUSY & The MIA Technique

- In a general SUSY Model, many more sources of Flavour Violation
- A technique to carry out an analysis in a general SUSY framework is the Mass Insertion Approximation (MIA) [Hall, Kostelecky, Raby 1986]
- In the MIA approach, one choses a basis in which the couplings of $\tilde{f}_i \tilde{g} f_j$ are flavour-diagonal ($\propto\ \delta_{ij}$); FC take place on the sfermion propagators by mass insertions: Δ^u_{ij}, Δ^d_{ij} etc.

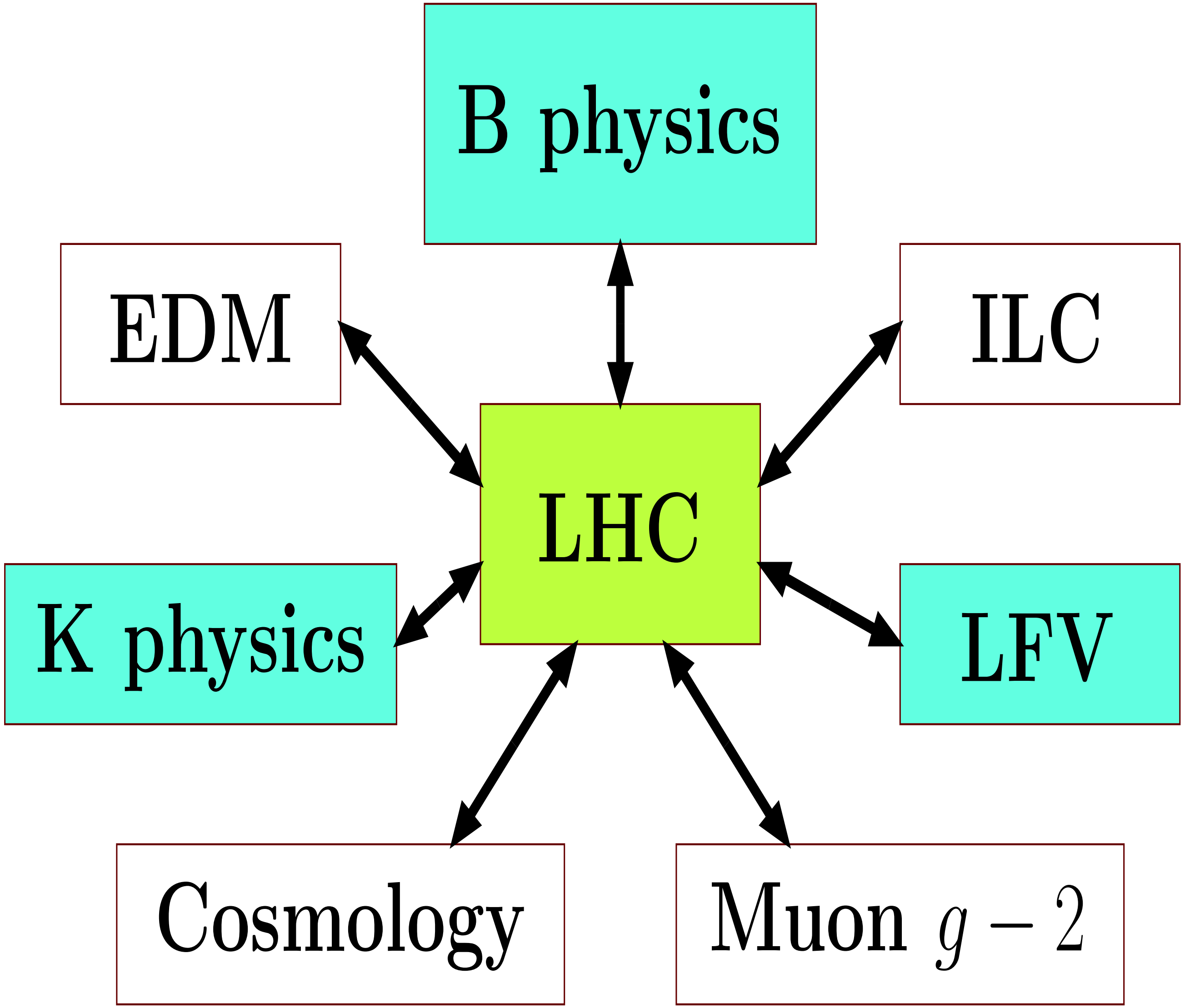
$$(m_0^2)_i \delta_{ij} + \Delta_{ij}$$

- Need not know the full diagonalization of the sfermion $(\tilde{f})$ mass matrices; sufficient to compute the ratios ($\langle m_0^2 \rangle$ is an average sfermion mass squared):

$$\delta_{ij} = \frac{\Delta_{ij}}{\langle m_0^2 \rangle}$$

- All FC effects can be parametrized in terms of a limited number of complex MIA parameters: $(\delta^u_{ij})_{AB}$ & $(\delta^u_{ij})_{AB}$, $(A, B = L, R)$
- Typically, one expects $(\delta^f_{ij})_{AB} \leq 1$
- Analysis for FV processes can then be carried out in terms of the SUSY-MFV contributions and the MIA parameters [Masiero et al.,...]

Synergy of Various Approaches in Search of BSM Physics



LHC/B-Physics Synergy?

B Physics in LHC Era

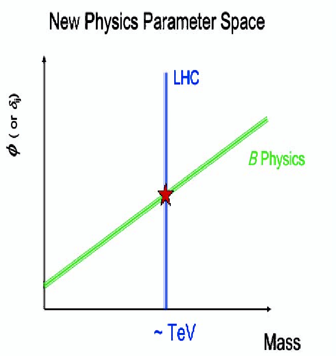
- Once NP found in B/LHC, the next question would be

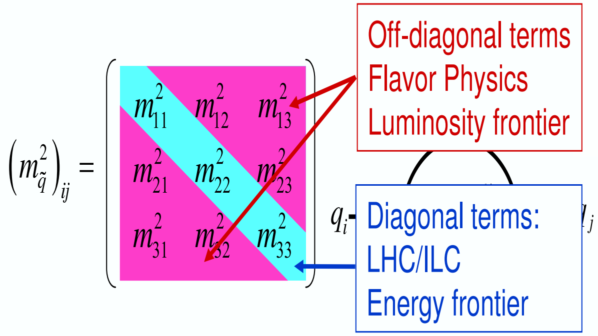
  What is the NP scenario ?

- Orthogonality of B physics to LHC

  The squark/slepton mass matrix

  Sensitive to SUSY breaking mechanism.





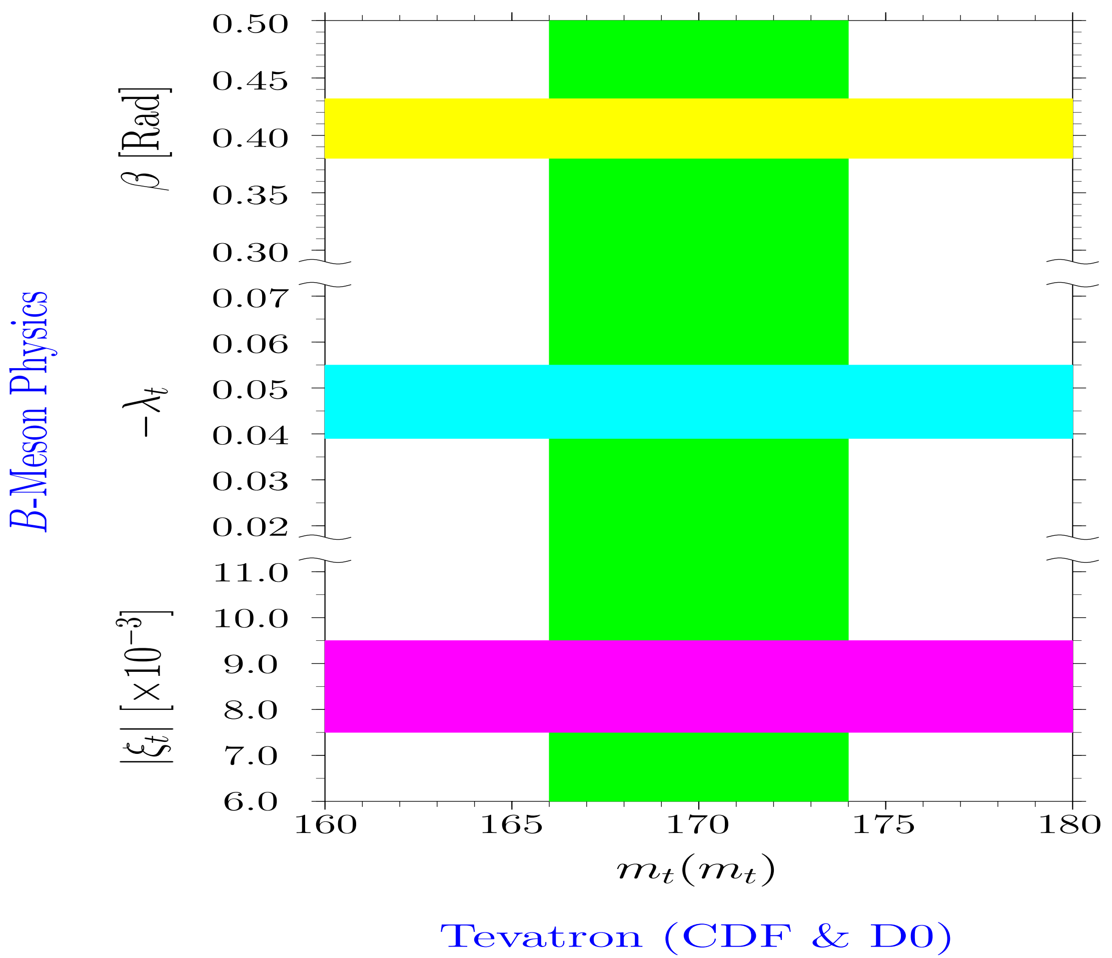
cf) Top quark:
Mass/width by Tevatron
Mixing/phase by B factories

B and τ are in the 3rd generation ("hub" quark & lepton)
⇨ probe for both 3→2, 3→1 transitions.

6

Complentarity of Tevatron & B-Physics Experiments

- m_t measured by Tevatron experiments
- Off-diagonal V_{tj} measured in B-decays



Courtesy: G. Isidori (FNAL '05 Talk)

Towards a model independent approach to the flavour problem:

th. error $\lesssim 10\%$
= exp. error $\lesssim 10\%$
= exp. error ~ 30%

FLAVOUR COUPLING:

ELECTROWEAK STRUCTURE

	$b \to s$ $(\sim\lambda^2)$	$b \to d$ $(\sim\lambda^3)$	$s \to d$ $(\sim\lambda^5)$
$\Delta F=2$ box	ΔM_{Bs} $A_{CP}(B_s\to\psi\phi)$	ΔM_{Bd} $A_{CP}(B_d\to\psi K)$	ΔM_K, ε_K
$\Delta F=1$ 4-quark box	$B_d\to\phi K$, $B_d\to K\pi$, ...	$B_d\to\pi\pi$, $B_d\to\rho\pi$, ...	ε'/ε, $K\to 3\pi$, ...
gluon penguin	$B_d\to X_s\gamma$, $B_d\to\phi K$, $B_d\to K\pi$, ...	$B_d\to X_d\gamma$, $B_d\to\pi\pi$, ...	ε'/ε, $K_L\to\pi^0\ell^+\ell^-$, ...
γ penguin	$B_d\to X_s\ell^+\ell^-$, $B_d\to X_s\gamma$ $B_d\to\phi K$, $B_d\to K\pi$, ...	$B_d\to X_d\ell^+\ell^-$, $B_d\to X_d\gamma$ $B_d\to\pi\pi$, ...	ε'/ε, $K_L\to\pi^0\ell^+\ell^-$, ...
Z^0 penguin	$B_d\to X_s\ell^+\ell^-$, $B_s\to\mu\mu$ $B_d\to\phi K$, $B_d\to K\pi$, ...	$B_d\to X_d\ell^+\ell^-$, $B_d\to\mu\mu$ $B_d\to\pi\pi$, ...	ε'/ε, $K_L\to\pi^0\ell^+\ell^-$, $K\to\pi\nu\nu$, $K\to\mu\mu$, ...
H^0 penguin	$B_s\to\mu\mu$	$B_d\to\mu\mu$	

Mandatory to explore this corner of the table!

CP Violation in K- & B-decays sensitive to BSM Effects

- $|\epsilon_K| = (2.280 \pm 0.013) \times 10^{-3}$

$$\bar{\eta}[(1-\bar{\rho})\eta_2^{\rm QCD} S_0(x_t) + P_c] A^2 \hat{B}_K = 0.187$$

  $P_c = 0.29 \pm 0.07$ [Herrlich, Jamin, Nierste]; $S_0(x_t) \simeq 2.4$; $\eta_2^{\rm QCD} = 0.57 \pm 0.01$ [Buras et al.]

- $\Delta M_d = (0.502 \pm 0.006)$ ps^{-1}

$$|V_{td}V_{tb}^*| = 8.5 \times 10^{-3} [\frac{210 \text{ MeV}}{\sqrt{B_{B_d}F_{B_d}}}] \sqrt{\frac{2.40}{S_0(x_t)}}$$

  - Lattice-QCD & SM $\Longrightarrow$ $|V_{td}V_{tb}^*| = (8.5 \pm 1.0) \times 10^{-3}$

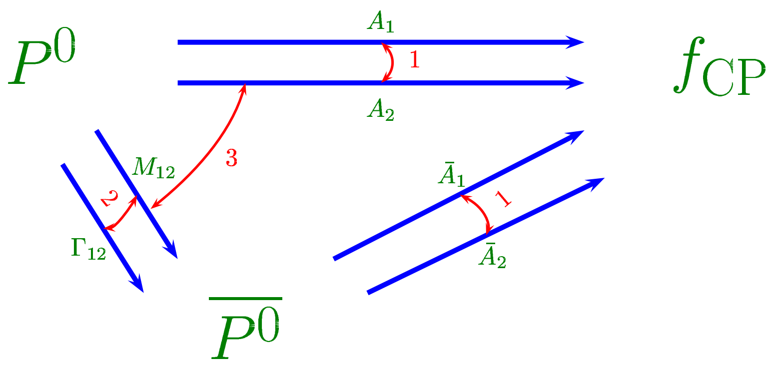
- $\Delta M_s > 14.4$ ps^{-1} (at 95% CL)
  - Lattice-QCD & SM $\Longrightarrow$ $|V_{ts}V_{tb}^*| > 0.033$;

  [SM Unitarity $\Longrightarrow$ $|V_{ts}V_{tb}^*| \simeq 0.04$]

- These measurements ($+|V_{ub}|$ & $|V_{cb}|$) $\Longrightarrow$ $\sin 2\beta(c\bar{c}s) = 0.7$ - 0.8 (Unitarity fits in the SM)
  - in remarkable agreement with $\sin 2\beta(c\bar{c}s) = 0.726 \pm 0.037$

- Compatibility between the SM & Experiment implies that CP Violation in the $|\Delta S| = 2$ & $|\Delta B| = 2$ transitions is dominated by the phase of the CKM matrix, but current errors do admit an additional subdominant contribution in $M_{12}(K)$ and $M_{12}(B_d, B_s)$

CP violation in neutral meson decay into a CP eigenstate



1. In decay: $\bar{A}/A \neq 1$ $\left(\frac{\bar{A}}{A} = \frac{\bar{A}_1+\bar{A}_2}{A_1+A_2}\right)$
   (For example, A_1 is a Tree amplitude & A_2 is Penguin)
2. In mixing: $|q/p| \neq 1$ $\left(\frac{q}{p} = \frac{2M_{12}^* - i\Gamma_{12}^*}{\Delta m - (i/2)\Delta\Gamma}\right)$
3. In interference: $\mathcal{I}m\lambda \neq 1$ $\left(\lambda = \frac{q}{p}\frac{\bar{A}}{A}\right)$

- <u>The case theorists love!</u>
  - Decay dominated by a single CPV phase: $|\frac{\bar{A}}{A}| = 1$;
  - CPV in mixing negligible $|\frac{q}{p}| = 1$;
  - The remaining eefect is: $S_f \sim \sin[\arg(M_{12}) - 2\arg(A)] = 1$

Interplay of Mixing & Decays of B^0 and $\overline{B^0}$ to CP Eigenstate

- Involving tree-dominated B-decays ($b \to c\bar{c}s$), such as $B^0/\overline{B^0} \to J/\psi K_s;\ J/\psi K_L$

$$\mathcal{A}_f(t) = \frac{\Gamma(\overline{B^0}(t) \to f) - \Gamma(B^0(t) \to f)}{\Gamma(\overline{B^0}(t) \to f) + \Gamma(B^0(t) \to f)}$$

$$= C_f \cos(\Delta M_B t) + S_f \sin(\Delta M_B t)$$

$$C_f = \frac{(|\lambda_f|^2) - 1}{(|\lambda_f|^2 + 1)}; \quad S_f = \frac{2\ \mathrm{Im}\lambda_f}{(|\lambda_f|^2 + 1)}$$

- Definitions:

$$\lambda_f \equiv (q/p)\ \rho(f); \quad \rho(f) = \frac{\bar{A}(f)}{A(f)}$$

$$A(f) = \langle f|H|B^0\rangle; \quad \bar{A}(f) = \langle f|H|\overline{B^0}\rangle$$

$$q/p = \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} = \mathrm{e}^{-2i\phi_{\mathrm{mixing}}} = \mathrm{e}^{-2i\beta}$$

- If only a Single Amplitude dominant, then one can write:

$$\rho(f) = \eta_f \mathrm{e}^{-2i\phi_{\mathrm{decay}}}$$

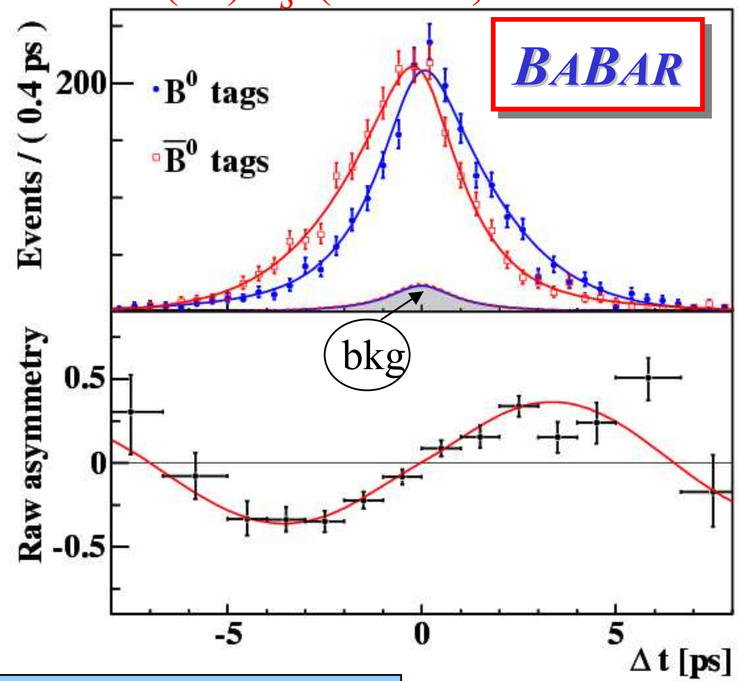
where $\eta_f = \pm 1$ is the intrinsic CP-Parity of the state $f \Rightarrow |\rho(f)| = 1$

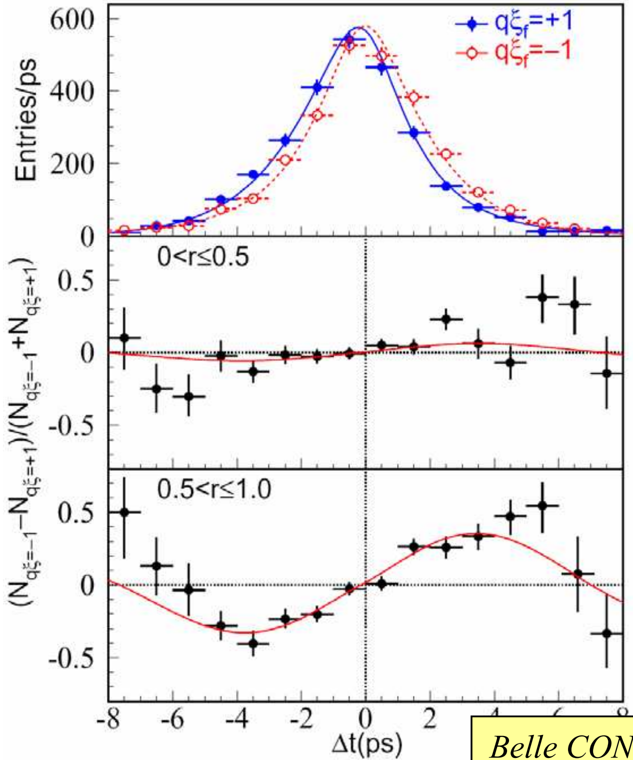
$$\mathcal{A}_f(t) = S_f \sin(\Delta M_B t);\ S_f = -\eta_f \sin 2(\phi_{\mathrm{mixing}} + \phi_{\mathrm{decay}});\ C_f = 0$$

CPV in B-Decays-1

$\sin 2\beta$ results from charmonium modes

$(c\bar{c})K_S^0$ (CP odd) modes





Belle 2003

Update for ICHEP04 *BABAR PUB-04/038* *Belle CONF-0436*

BABAR		Belle
$\sin 2\beta = +0.722 \pm 0.040 \pm 0.023$	$(c\bar{c})K_S^0 +$	$\sin 2\beta = +0.728 \pm 0.056 \pm 0.023$
$\lvert\lambda\rvert = \lvert\bar{A}/A\rvert = 0.950 \pm 0.031 \pm 0.013$	$(c\bar{c})K_L^0$	$\lvert\lambda\rvert = \lvert\bar{A}/A\rvert = 1.007 \pm 0.041 \pm 0.033$

Limit on direct CPV

$205\,fb^{-1}$ on peak or $227M\ B\bar{B}$ pairs — 7730 CP events (tagged signal)

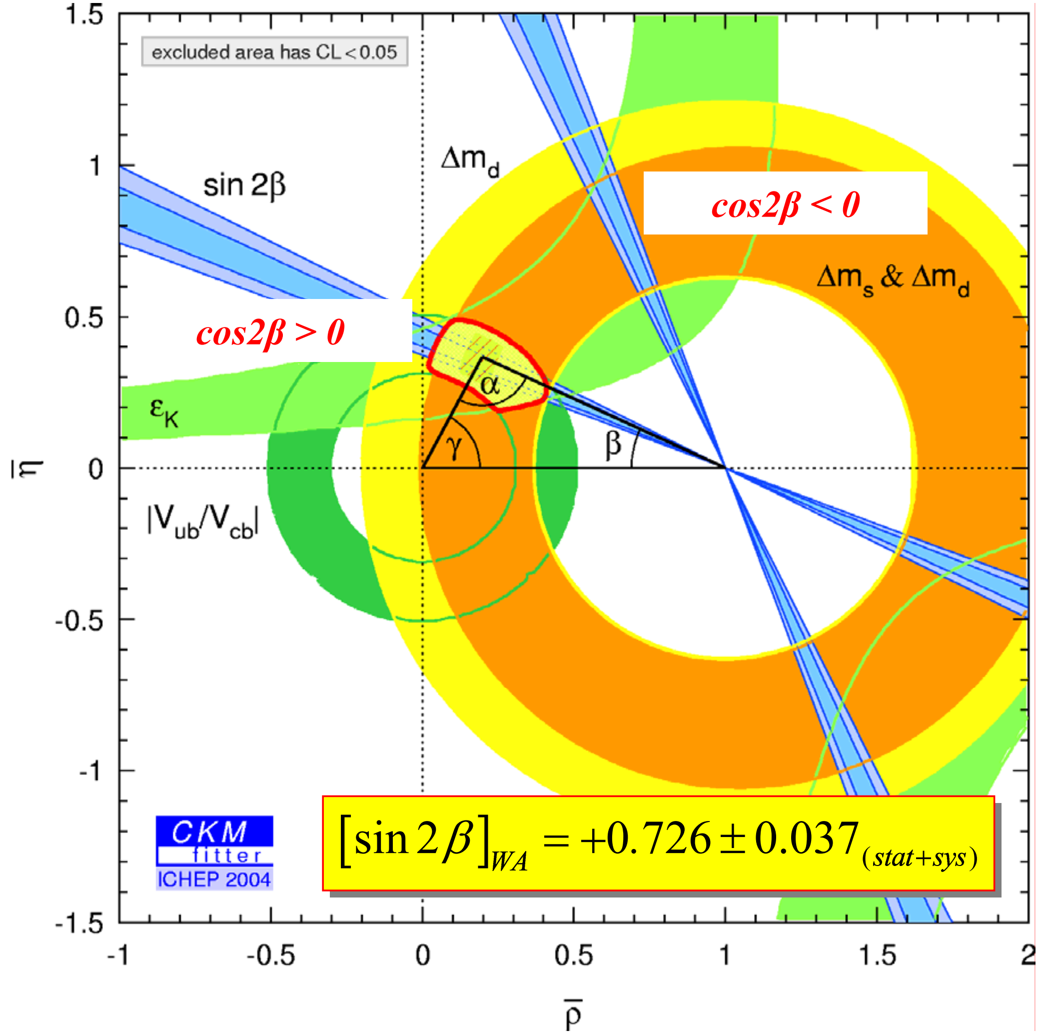
$140\,fb^{-1}$ on peak or $152M\ B\bar{B}$ pairs — 4347 CP events (tagged signal)

ICHEP04-北京
August 20, 2004

Marcello A. Giorgi *M.Bruinsma, T. Higuchi, CP-3* 9

SM confronts $\sin 2\beta$ measurements

$\sin 2\beta$, $\cos 2\beta$ and CKM constraints



BABAR

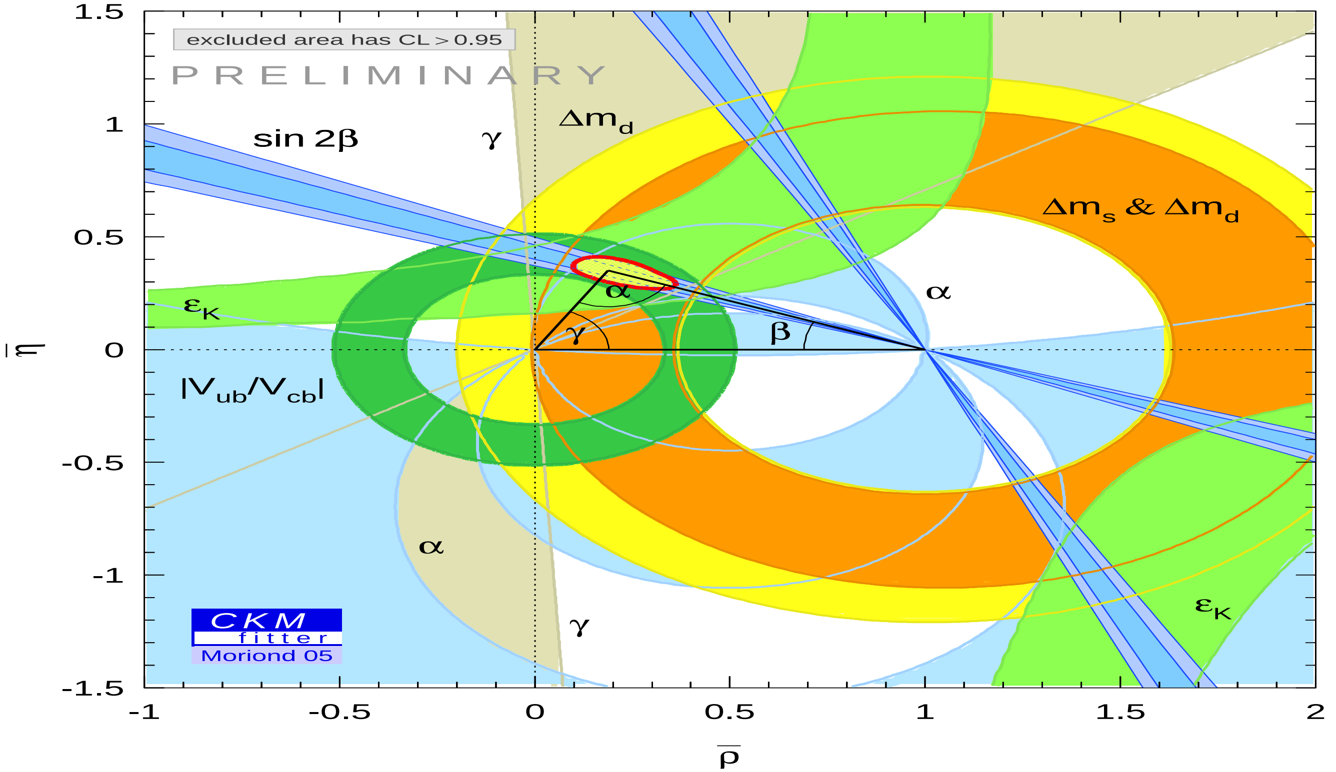
$\cos 2\beta < 0$ ruled out at 87% CL by s- and p-wave interference in angular analysis of $B\ J/\psi K^{*0}\ (K_S\pi^0)$

M.Bruinsma, CP-3

CKM fit to indirect constraints overlaid with $\sin 2\beta_{WA}$ measurement

ICHEP04-北京
August 20, 2004 Marcello A. Giorgi 10

SM confronts measurements of $\sin 2\beta, \quad \alpha, \quad \gamma$



- $\sin 2\beta = 0.725 \pm 0.037 (\beta = [23.2 \pm 1.5]^\circ)$
- $\alpha = [101^{+16}_{-9}]^\circ$
- $\gamma = [63^{+15}_{-13}]^\circ$
- Direct and indirect measurements of angles agree very well
- Unconstrained sum of angles $= 187^\circ$, consistent with unitarity sum within errors

Specific realizations of MFV Models

[Ciuchini et al.; Degrassi et al.; Carena et al.; London, AA; Buras et al.; Bartl et al.; Bobeth et al.;...]

- CKM matrix is the only source of Flavour transitions
- Effective Lagrangian in MFV models consists of the same operator basis as in the SM (except for Higgs-induced operators in large-$\tan\beta$-regime)

$$\mathcal{H}_{\rm eff}(\Delta F=2) = -\frac{G_F^2 m_W^2}{(2\pi)^2}(V_{tq}^* V_{tq})^2[C_1(Q)\mathcal{O}_1 + C_2(Q)\mathcal{O}_2 + C_3(Q)\mathcal{O}_3]$$

$$\mathcal{O}_1(|\Delta B|=2) = \mathcal{O}_1^{\rm SM} = \bar{d}_L^\alpha \gamma_\mu b_L^\alpha \cdot \bar{d}_L^\beta \gamma^\mu b_L^\beta$$

$$\mathcal{O}_2(|\Delta B|=2) = \bar{d}_L^\alpha b_R^\alpha \bar{d}_L^\beta b_R^\beta$$

$$\mathcal{O}_3(|\Delta B|=2) = \bar{d}_L^\alpha b_R^\beta \bar{d}_L^\beta b_R^\alpha$$

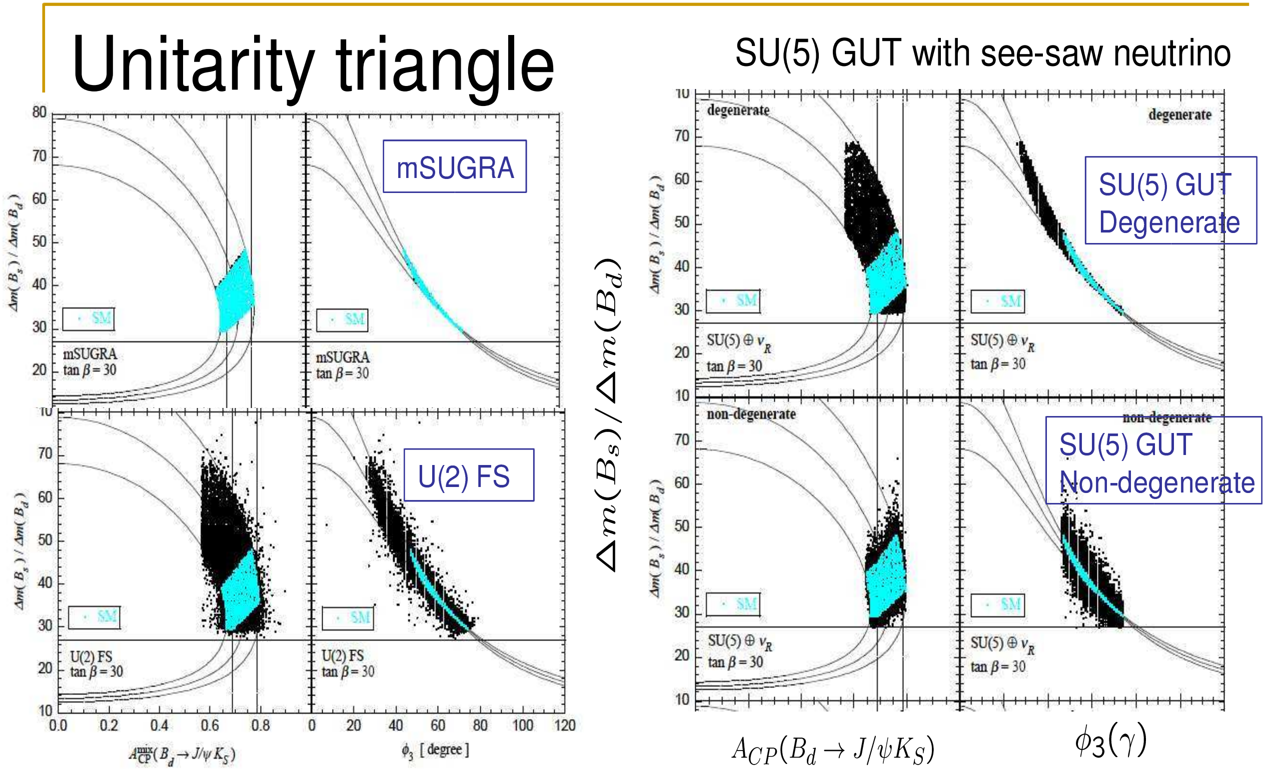
- SUSY effects are encoded in Wilson coefficients or, equivalently, in terms of a limited set of Inami-Lim functions which depend on the SUSY parameters

$$C_1(m_W) = C_1^W(m_W) + C_1^\chi(m_W, m_\chi) + C_1^H(m_W, m_H)$$

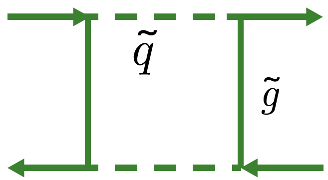
$$C_2(m_W) \propto m_b^2/m_W^2; \quad C_3(m_W) \propto m_b^2/(m_W^2 \cos^2\beta)$$

- Typically, $C_2(m_W)/C_1(m_W), C_3(m_W)/C_1(m_W) \ll 1$
- In constrained MSSM models, $C_1(m_W)^{\rm SUSY}/C_1(m_W)^{\rm SM} = 1+\delta$, with $\delta \ll 1 \Longrightarrow$ UT(MFV) similar to UT(SM)

Y. Okada et al. (Super-B Workshop, Hawaii, '05)



Inconsistency among A_CP(B->J/ψ Ks), Δm(Bs),
φ3 (γ) and εK in SUSY GUT with the degenerate RHN case.
=> A large SUSY contribution in the CPV of K-K mixing.



10

More on CP Violation in B-decays sensitive to BSM Effects

- In addition to the $c\bar{c}s$ final state, CP asymmetries have been measured in a number of B decays, involving direct CP violation & interplay of mixings and decay amplitudes
- Direct CP asymmetries provide tests of QCD dynamics in B-decays

$$A_{\text{CP}}(K^{\pm}\pi^{\mp}) = -0.101 \pm 0.020 \quad [\text{BABAR \& BELLE}]$$

- More interesting for the BSM searches are measurements involving penguin amplitudes and B^0 -$\overline{B^0}$ mixing in CP eigenstates
  - $B^0 \to \phi K_s^0$; $B^0 \to \eta' K_S^0$; $B \to f_o K_s^0$;...
- Current experiments (BELLE & BABAR) seem to measure a different effective angle $\sin 2\beta_{\text{eff}}$ in the Penguin-dominated amplitudes $b \to s\bar{s}s$

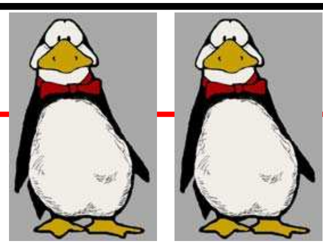
$$\sin 2\beta_{\text{eff}}(s\bar{s}s; s\bar{d}d) = 0.43 \pm 0.07 \quad (\sim 3.7\sigma \text{ BSM Effect, theor. uncertainties??})$$

- If confirmed by more data, this would imply the existence of BSM physics in $b \to s$ transitions

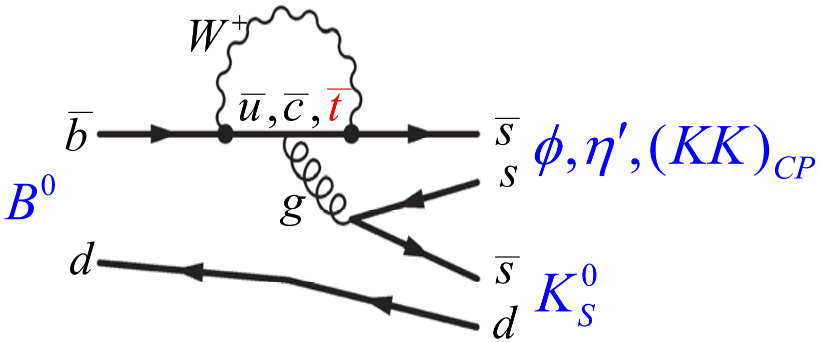
Feynman Diagrams for $\sin 2\beta$ from Penguins

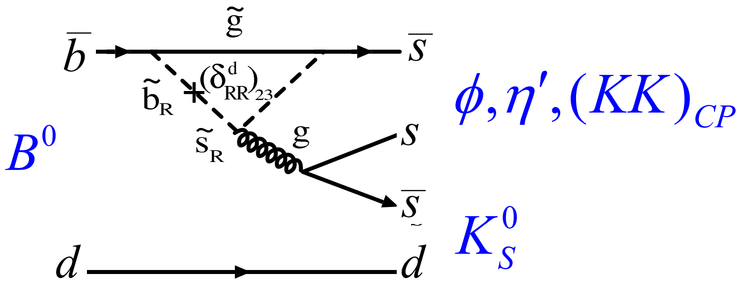
$\sin 2\beta$ and...

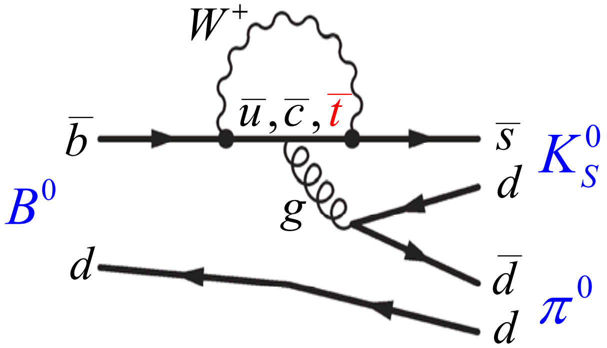
and....



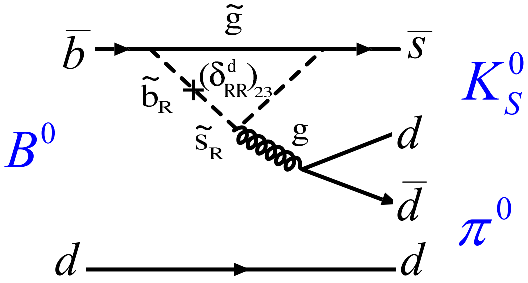
In SM interference between B mixing, K mixing and Penguin $b\to s\bar{s}s$ or $b\to s\bar{d}d$ gives the same $e^{-2i\beta}$ as in tree process $b\to c\bar{c}s$. However loops can also be sensitive to New Physics!







New phases from SUSY?

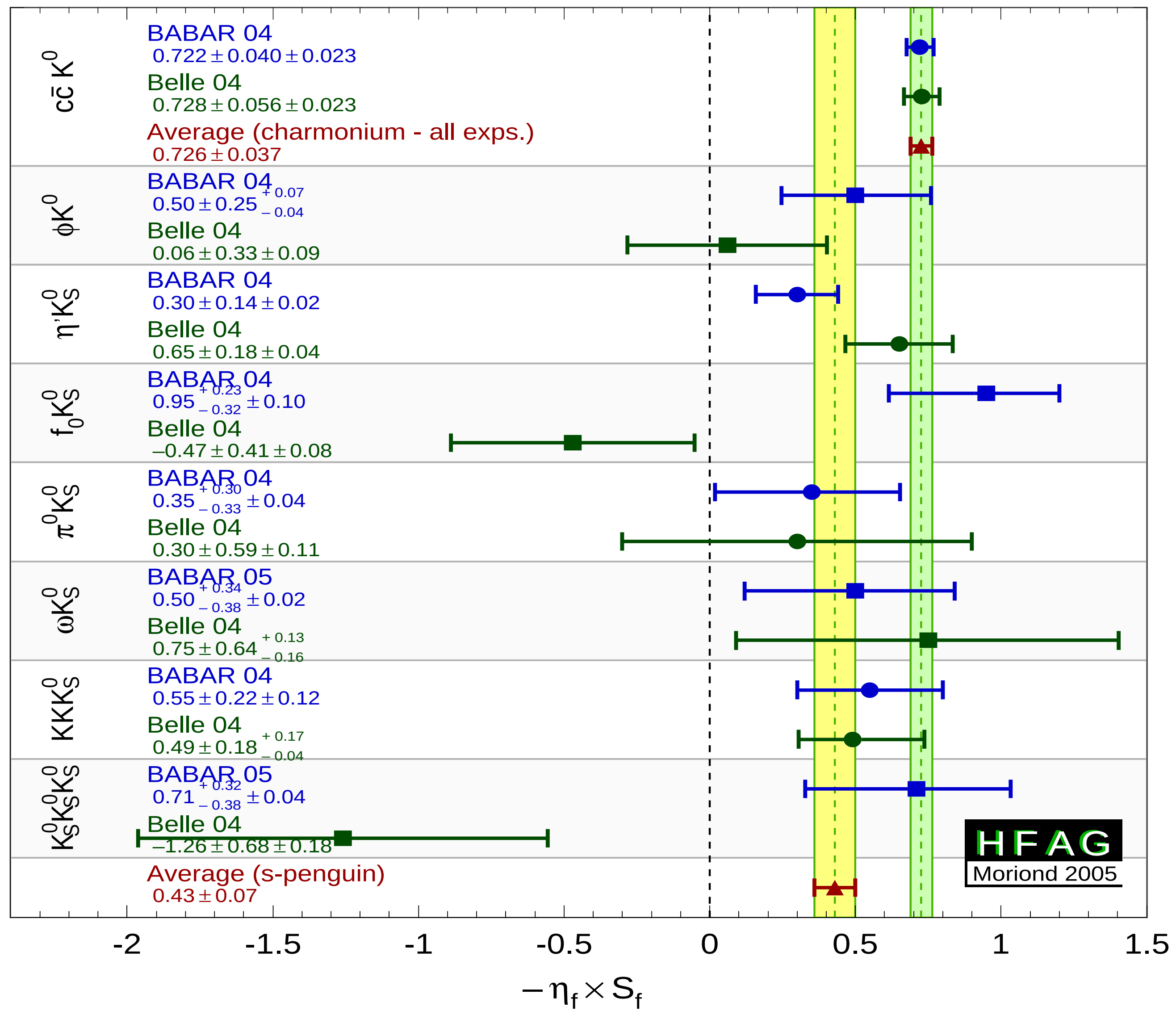


ICHEP04-北京
August 20, 2004

Marcello A. Giorgi

25

Comparison of $\sin 2\beta(c\bar{c})$ and $\sin 2\beta(s\text{-penguins})$



Rare K-Decays sensitive to BSM Physics; G. Isidori (FNAL '05)

Present status and impact on the UT plane:

$K^+ \to \pi^+ \nu\nu$ $\quad BR(K^+)^{[SM]} = C_+ |V_{cb}|^4 [(\bar\rho - \rho_c)^2 + (\sigma\bar\eta)^2] = (8.0 \pm 1.0) \times 10^{-11}$

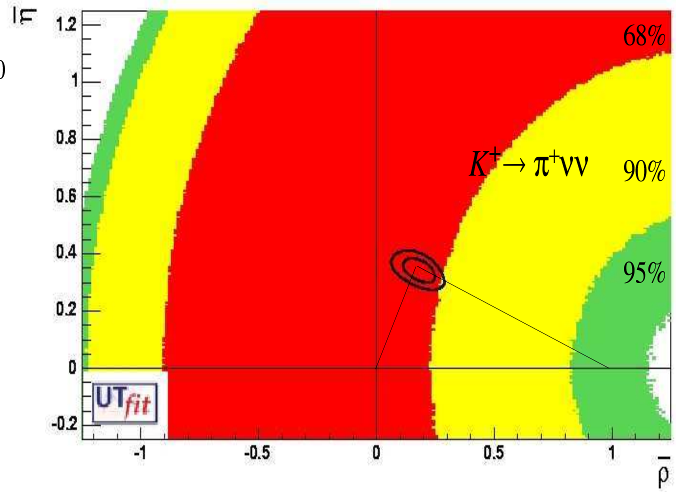
$K_L \to \pi^0 \nu\nu$ $\quad BR(K_L)^{[SM]} = C_0 \left[\frac{\mathrm{Im}(V_{ts}^* V_{td})}{10^{-4}}\right]^2 = (3.0 \pm 0.6) \times 10^{-11}$

$BR(K^+)^{exp} = (1.47^{+1.9}_{-0.9}) \times 10^{-10}$

E787+E949 [BNL] '04

$BR(K_L)^{exp} < 5.9 \times 10^{-7}$

KTeV '99



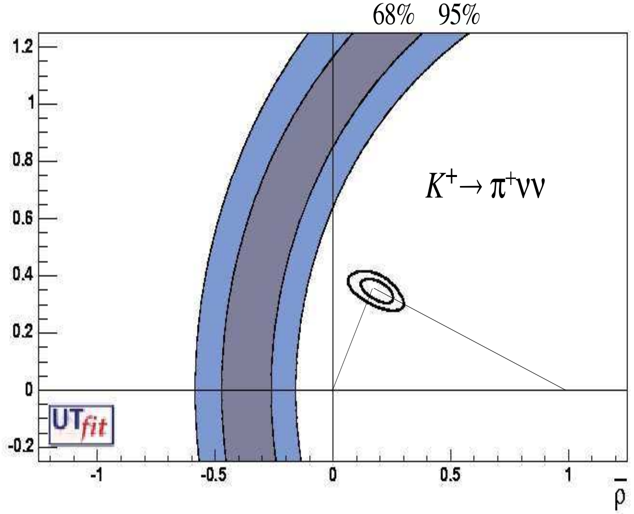
G. Isidori (FNAL '05)

Possible (optimistic...) future scenario:

$K^+ \to \pi^+ \nu\nu$ $\quad \mathrm{BR}(K^+)^{[SM]} = C_+ \, |V_{cb}|^4 \, [(\bar{\rho} - \rho_c)^2 + (\sigma\bar{\eta})^2] = (8.0 \pm 1.0) \times 10^{-11}$

$K_L \to \pi^0 \nu\nu$ $\quad \mathrm{BR}(K_L)^{[SM]} = C_0 \left[\frac{\mathrm{Im}(V_{ts}^* V_{td})}{10^{-4}} \right]^2 = (3.0 \pm 0.6) \times 10^{-11}$

$\mathrm{BR}(K^+)^{exp} = (1.47^{+1.9}_{-0.9}) \times 10^{-10}$ → $\pm 10\,\%$



Electromagnetic Radiative Penguins $b \to s\gamma$

- $b \to s\gamma$ decay rate

$$\mathcal{B}(B \to X_s\gamma) = (3.52 \pm 0.29) \times 10^{-4} \quad [\mathrm{HFAG'05}]$$

$$SM: (3.70 \pm 0.30) \times 10^{-4} \quad [\mathrm{NLO}; \overline{\mathrm{MS}}]$$

$\Longrightarrow \;\; \lambda_t \equiv V_{tb}V_{ts}^* = -(47.0 \pm 8.0) \times 10^{-3}$; in agreement with $\lambda_t \simeq -\lambda_c$

- CP Asymmetry in $b \to s\gamma$ transition
  - Direct CPV

$$A_{\mathrm{CP}}(X_s\gamma) \equiv \frac{\Gamma(b \to s\gamma) - \Gamma(\bar{b} \to \bar{s}\gamma)}{\Gamma(b \to s\gamma) + \Gamma(\bar{b} \to \bar{s}\gamma)} = (4.2^{+1.7}_{-1.2}) \times 10^{-3} \quad [\mathrm{SM}]$$

$$A_{\mathrm{CP}}(X_s\gamma) = (5 \pm 36) \times 10^{-3} \quad [\mathrm{HFAG'04}]$$

$$A_{\mathrm{CP}}(K^*\gamma) \leq -0.5\% \quad [\mathrm{SM}]; \quad -0.010 \pm 0.028 \quad [\mathrm{BELLE\ \&\ BABAR}]$$

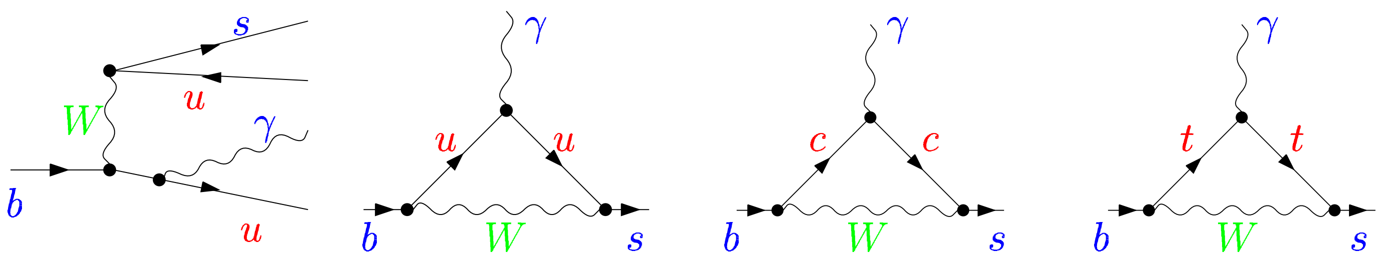
  - Time-dependent CPV in $B^0 \to K^{*0}\gamma$

$$A_{\mathrm{CP}}(t) = S\sin(\Delta m \Delta t) + A\cos(\Delta m \Delta t)$$

$S \;\sim 0.04 - 0.10,\;\; A \;\sim 0$ [SM]; $\;S = -0.58^{+0.46}_{-0.38} \pm 0.11; A = 0.03 \pm 0.34 \pm 0.11$[CKM'05]

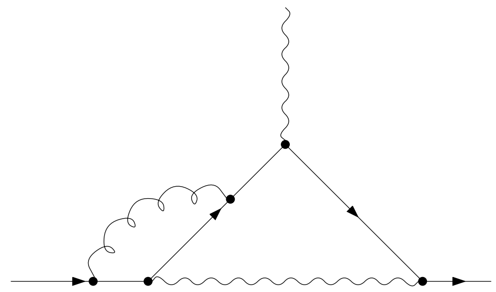
- ALL CPV measurements in $b \to s\gamma$, $B \to K^*\gamma$ are in agreement with the SM, but still significantly larger than SM CPV effects allowed by data

Examples of the leading electroweak diagrams for $\bar{B} \to X_s \gamma$:



$$\left|\frac{V_{ub}V_{us}}{V_{cb}}\right| \simeq \left|\frac{V_{ub}V_{us}}{V_{ts}}\right| \simeq 2\% \qquad \underbrace{\sim +200\% \qquad \sim -100\%}$$

In the amplitude, after including LO QCD effects.



QCD logarithms $\alpha_s \ln \frac{M_W^2}{m_b^2}$ enhance BR($\bar{B} \to X_s\gamma$) more than twice.

Effective field theory method is the most convenient for resummation of such large logarithms.

The effective Lagrangian:

$$\mathcal{L} = \mathcal{L}_{QCD\times QED}(q,l) + \frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{10} C_i(\mu) O_i$$

$(q = u, d, s, c, b, \; l = e, \mu)$

$$O_i = \begin{cases} (\bar{s}\Gamma_i c)(\bar{c}\Gamma'_i b), & i = 1,2, & |C_i(m_b)| \sim 1 \\ (\bar{s}\Gamma_i b)\Sigma_q(\bar{q}\Gamma'_i q), & i = 3,4,5,6, & |C_i(m_b)| < 0.07 \\ \frac{e m_b}{16\pi^2}\bar{s}_L \sigma^{\mu\nu} b_R F_{\mu\nu}, & i = 7, & C_7(m_b) \sim -0.3 \\ \frac{g m_b}{16\pi^2}\bar{s}_L \sigma^{\mu\nu} T^a b_R G^a_{\mu\nu}, & i = 8, & C_8(m_b) \sim -0.15 \\ \frac{e^2}{16\pi^2}(\bar{s}_L \gamma_\mu b_L)(\bar{l}\gamma^\mu \gamma_5 l), & i = 9, \mathbf{10} & |C_i(m_b)| \sim 4 \end{cases}$$

Three steps of the calculation:

Matching: Evaluating $C_i(\mu_0)$ at $\mu_0 \sim M_W$ by requiring equality of the SM and the effective theory Green functions

Mixing: Deriving the effective theory RGE and evolving $C_i(\mu)$ from μ_0 to $\mu_b \sim m_b$

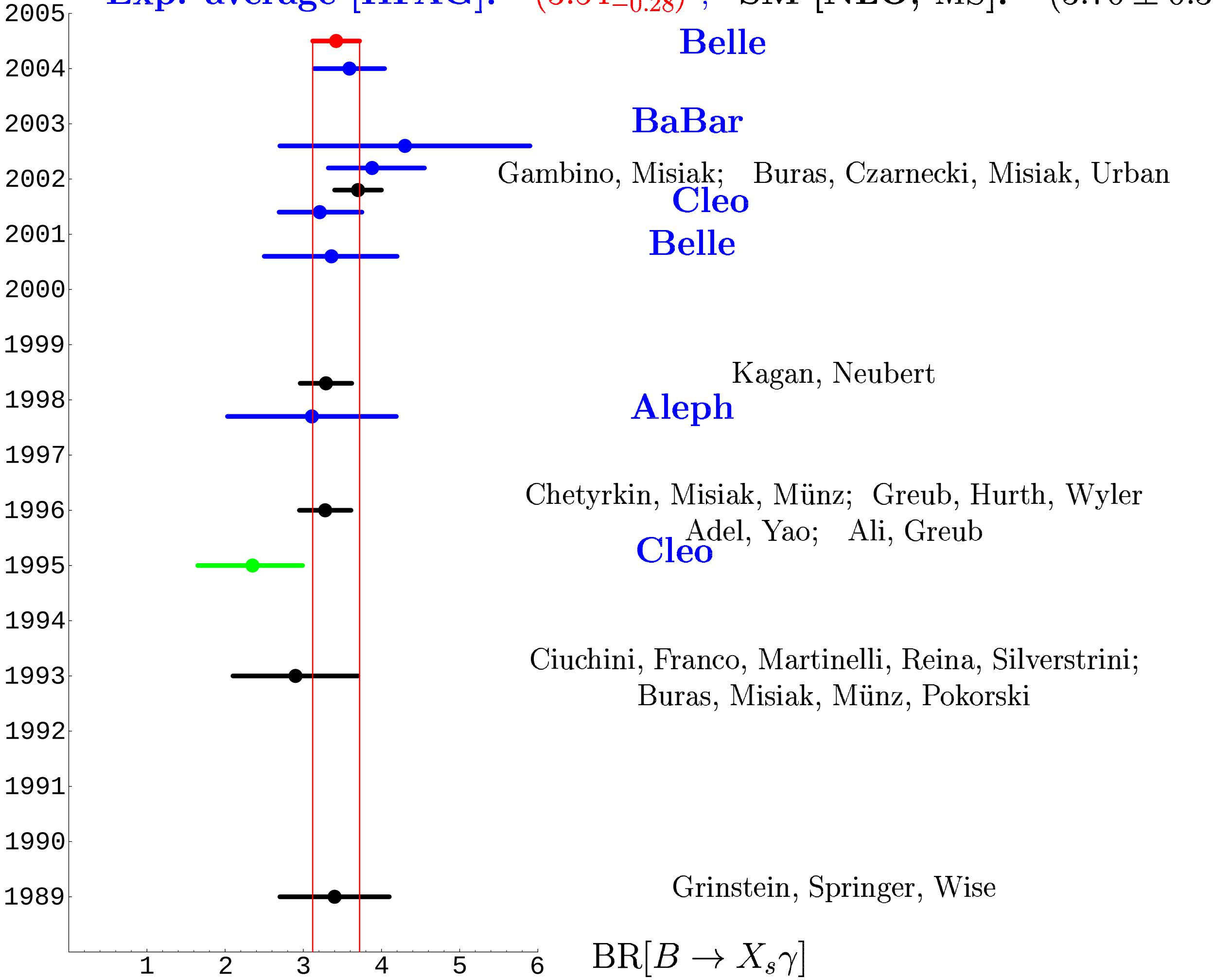
Matrix elements: Evaluating the on-shell amplitudes at $\mu_b \sim m_b$

Evolution in time

$\mathrm{BR}[\bar{B} \to X_s\gamma]$ **(units:** 10^{-4}**)**

Measurements & the SM calculations

Exp. average [HFAG]: $(3.54^{+0.30}_{-0.28})$; **SM [NLO;** $\overline{\mathrm{MS}}$**]:** (3.70 ± 0.30)



Determination of V_{ts} from BR $(\bar{B} \to X_s\gamma)$

- Unitarity of the CKM Matrix

$$\sum_{u,c,t} \lambda_i = 0, \quad \text{with} \quad \lambda_i = V_{ib}V_{is}^*$$

- $\lambda_u = V_{ub}V_{us}^* \simeq A\lambda^4(\bar{\rho} - i\bar{\eta}) \simeq O(10^{-2})$
- $\lambda_t = -\lambda_c = -A\lambda^2 + ... = -(41.0 \pm 2.1) \times 10^{-3}$
- Without invoking the CKM unitarity, NLO SM-calculations in the $\overline{\mathbf{MS}}$ scheme and current data imply the following constraint

[Misiak, AA]

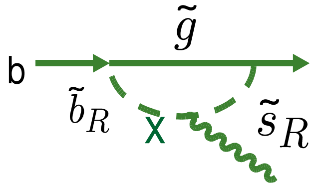
$$|1.69\lambda_u + 1.60\lambda_c + 0.60\lambda_t| = (0.94 \pm 0.07)|V_{cb}|$$

$$\Longrightarrow \lambda_t = V_{tb}V_{ts}^* = -(47.0 \pm 8.0) \times 10^{-3}$$

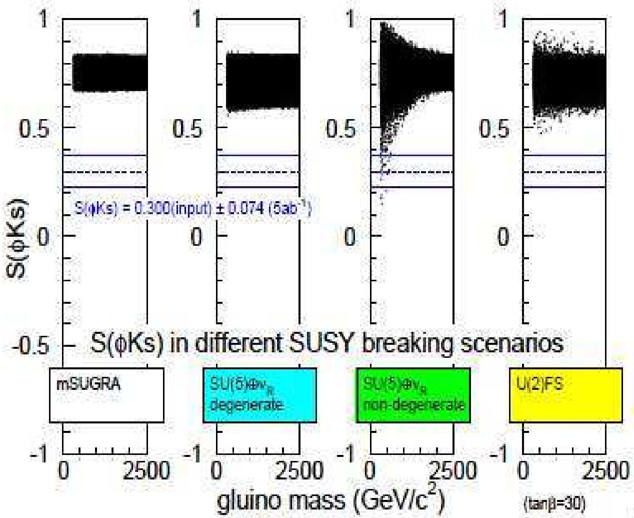
- In future, NNLO calculations will lead to a determination of BR$(\bar{B} \to X_s\gamma)$ to an accuracy of 5%
- With improved data, this will determine V_{ts} to an accuracy of about 10%

Y. Okada et al. (Super-B Workshop, Hawaii, ’05)

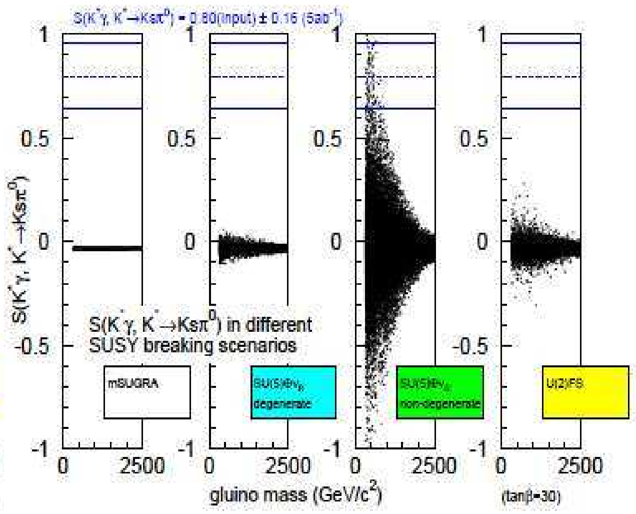
Mixing-induced CP asymmetries in B →φKs and B→K*γ



A_CP(B →φ Ks)



A_CP(B → K*γ)



Large CPV in φKs and K*γ for the SUSY GUT with non-degenerate RHN.

11

Electroweak Penguins $b \to s\ell^+\ell^-$

- $B \to X_s\ell^+\ell^-$ decay rate

$$\mathcal{B}(B \to X_s\ell^+\ell^-) = (4.46^{+0.98}_{-0.96}) \times 10^{-6} \quad [\text{HFAG}'05]$$

$$SM : (4.2 \pm 0.7) \times 10^{-4} \quad [\text{NNLO}]$$

- Differential distributions in $B \to X_s\ell^+\ell^-$

• $M(X_s)$-distribution: tests $s \to X_s$ fragmentation model; current FMs provide reasonable fit to data

• $q^2 = M^2_{\ell^+\ell^-}$-distribution away from the $J/\psi, \psi', ...$ resonances is sensitive to short-distance physics; current data in agreement with the SM estimates but the precision is not better than 25%

• Forward-Backward Asymmetry (FBA) is likewise sensitive to the SM and BSM effects, in particular encoded in the Wilson coefficients C_7, C_9 and C_{10}

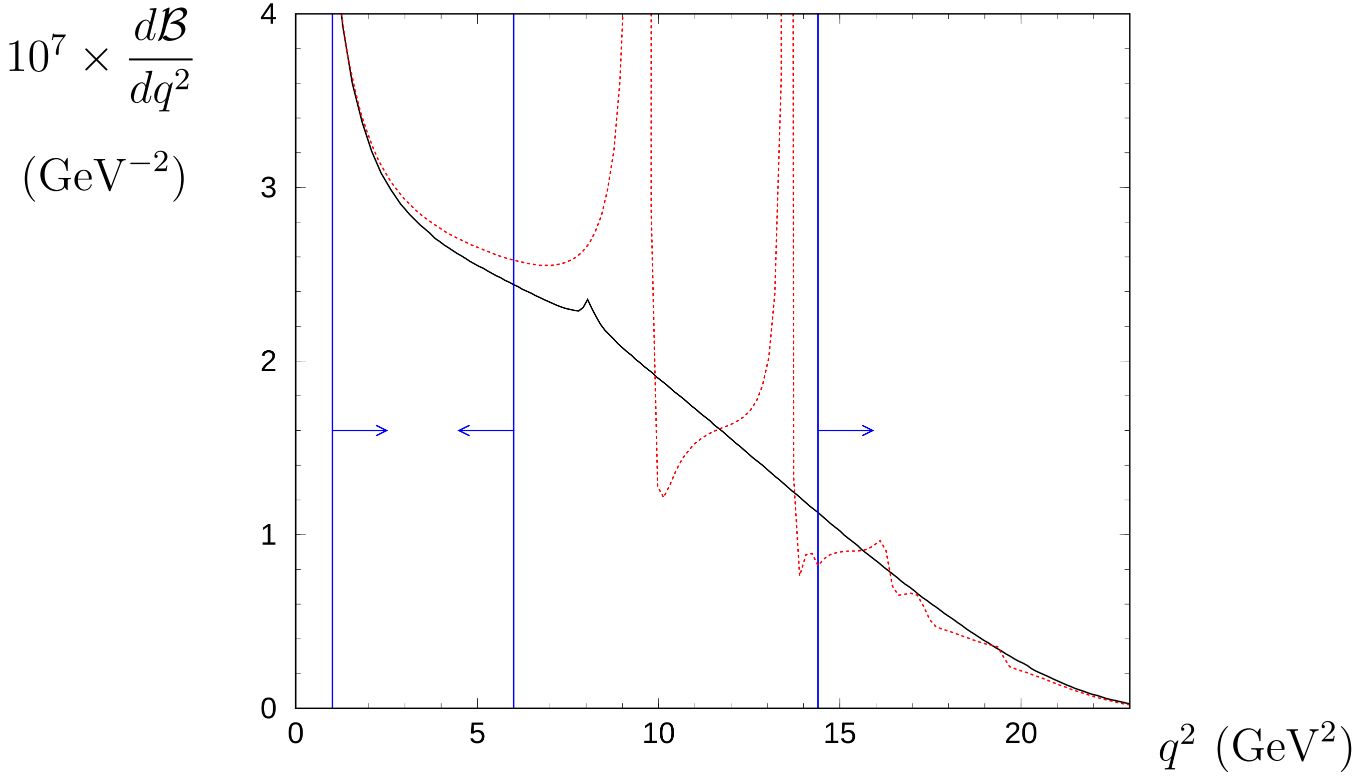
$$A_{\text{FB}}(\hat{s} \sim C_{10}(2C_7 + C_9(\hat{s})\hat{s}); \quad \hat{s} = q^2/M_B^2$$

• $A_{\text{FB}}(\hat{s})$ in $B \to K^*\ell^+\ell^-$ qualitatively similar to $A_{\text{FB}}(\hat{s})$ in $B \to X_s\ell^+\ell^-$, except for FF complication; First measurements from BELLE at hand, appear SM-like; Super-B and LHC-B will measure $A_{\text{FB}}(\hat{s})$ precisely

• $A_{\text{FB}}(\hat{s})[B \to K\ell^+\ell^-] \simeq 0$ in the SM and most BSM extensions; in agreement with data which is used as a control sample to measure $A_{\text{FB}}(\hat{s})[B \to K^*\ell^+\ell^-]$

Dilepton invariant mass distribution in $\bar{B} \to X_s \ell^+ \ell^-$:

[Ghinculov, Hurth, Isidori, Yao 2004]

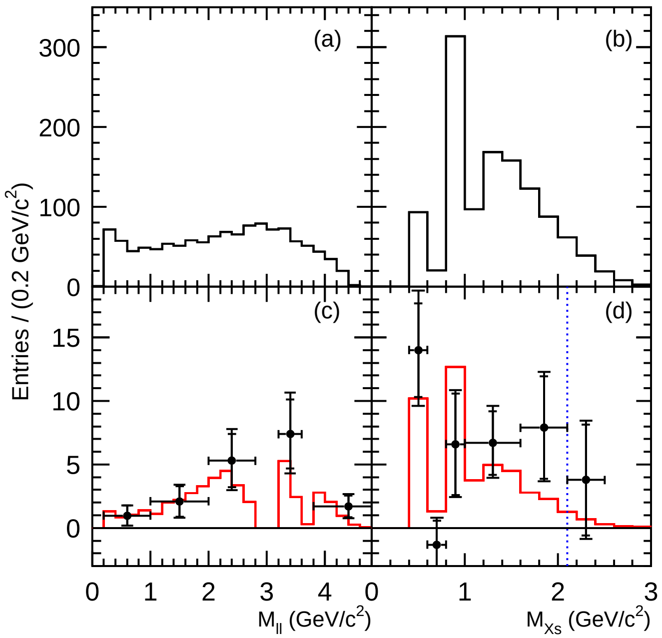


- $\mathbf{BR}(\bar{B} \to X_s \ell^+ \ell^-)$; $\quad q^2 \in [1, 6]\ \mathrm{GeV}^2 = (1.63 \pm 0.20) \times 10^{-6}$
- $\mathbf{BR}(\bar{B} \to X_s \ell^+ \ell^-)$; $\quad q^2 > 14\ \mathrm{GeV}^2 = (4.04 \pm 0.78) \times 10^{-7}$
- $\mathbf{BR}(\bar{B} \to X_s \mu^+ \mu^-)$; $\quad q^2 > 4 m_\mu^2 = (4.6 \pm 0.8) \times 10^{-6}$,
  in agreement with the earlier NNLO analysis
  [AA, Greub, Hiller, Lunghi 2001; Bobeth, Gambino, Gorbahn, Haisch, 2003]

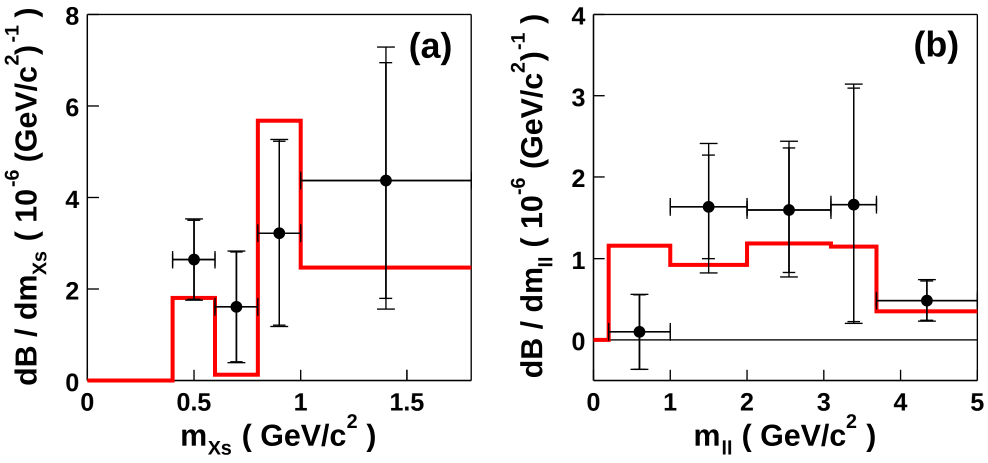
Decay distributions in $\bar{B} \to X_s \ell^+ \ell^-$

$M_{\ell\ell}$ and M_{X_s} Spectra

[BELLE]



[BABAR]



- In agreement with the NNLO SM calculations

Sakai (FPCP 2004)

$B \to K^{(*)} l^+ l^-$

[Belle-conf-0415]

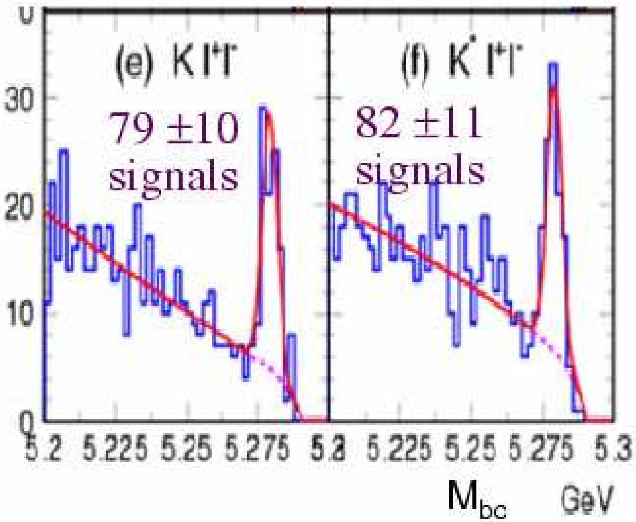
LP03: $B \to X_s ll$, $K^{(*)} ll$: Belle/BaBar

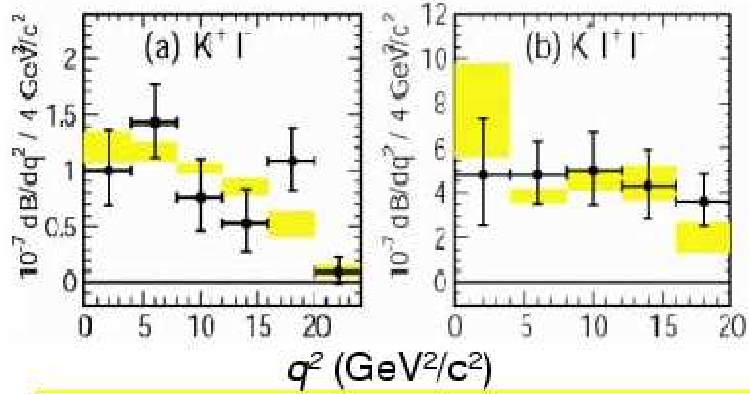
Br, A_{CP} ~SM

275M $B\bar{B}$ update **>10σ signals**

$\mathcal{B}$(Kll)= $(5.50 \pm {}^{0.75}_{0.70} \pm 0.27 \pm 0.02)$

$\mathcal{B}$(K*ll)= $(16.5 \pm {}^{2.3}_{2.2} \pm 0.9 \pm 0.4)$ x 10^{-7}





ICHEP 2004, Beijing 26

Comparison of $\mathcal{B}(B \to (K, K^*)\ell^+\ell^-$ with SM-1

$B \to K\ell^+\ell^-$ and $B \to K^*\ell^+\ell^-$

Belle branching fractions (253 fb^{-1})

– $K\ell^+\ell^-$: $(5.50\,^{+0.75}_{-0.70} \pm 0.27 \pm 0.02) \times 10^{-7}$

– $K^*\ell^+\ell^-$: $(16.5\,^{+2.3}_{-2.2} \pm 0.9 \pm 0.4) \times 10^{-7}$

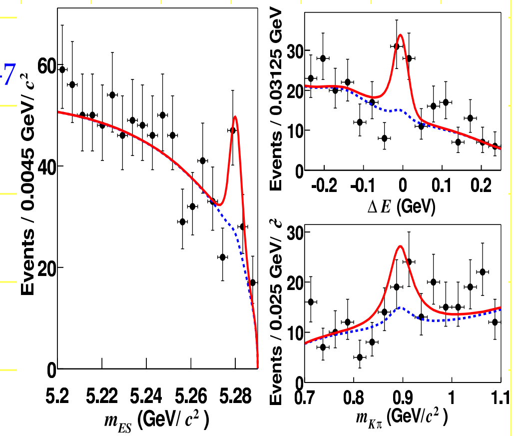
New BaBar results (208 fb^{-1})

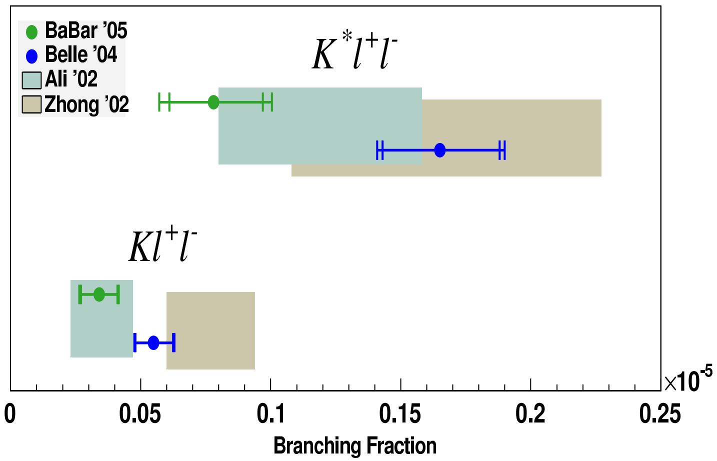
– $K\ell^+\ell^-$: $(3.4 \pm 0.7 \pm 0.3) \times 10^{-7}$

– $K^*\ell^+\ell^-$: $(7.8\,^{+1.9}_{-1.7} \pm 1.2) \times 10^{-7}$

$A_{CP}(B^+ \to K^+\ell^+\ell^-) = -0.08 \pm 0.22 \pm 0.11$

$A_{CP}(B \to K^*\ell^+\ell^-) = +0.03 \pm 0.23 \pm 0.12$

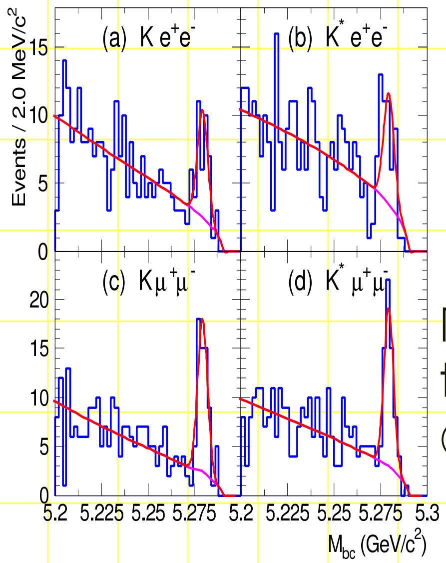


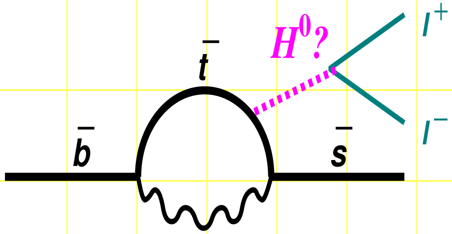


Radiative Pengiuns — Mikihiko Nakao — p.25

Comparison of $\mathcal{B}(B \to (K, K^*)\ell^+\ell^-$ with SM-2

$B \to K^{(*)}e^+e^-$ vs $B \to K^{(*)}\mu^+\mu^-$





Ratio of $K^{(*)}\mu^+\mu^-$ to $K^{(*)}e^+e^-$ is sensitive to neutral SUSY Higgs if $\tan\beta$ is large

($O(1)$ enhancement if $\tan\beta \sim 30$)

Belle ratios:

$\mathcal{B}(B \to K\mu^+\mu^-)/\mathcal{B}(B \to Ke^+e^-) = 1.38 \,^{+0.39}_{-0.41}\,^{+0.06}_{-0.07}$ (1.00 in SM)

$\mathcal{B}(B \to K^*\mu^+\mu^-)/\mathcal{B}(B \to K^*e^+e^-) = 0.98 \,^{+0.30}_{-0.31} \pm 0.08$ ($\sim$ 0.75 in SM)

Babar ratios:

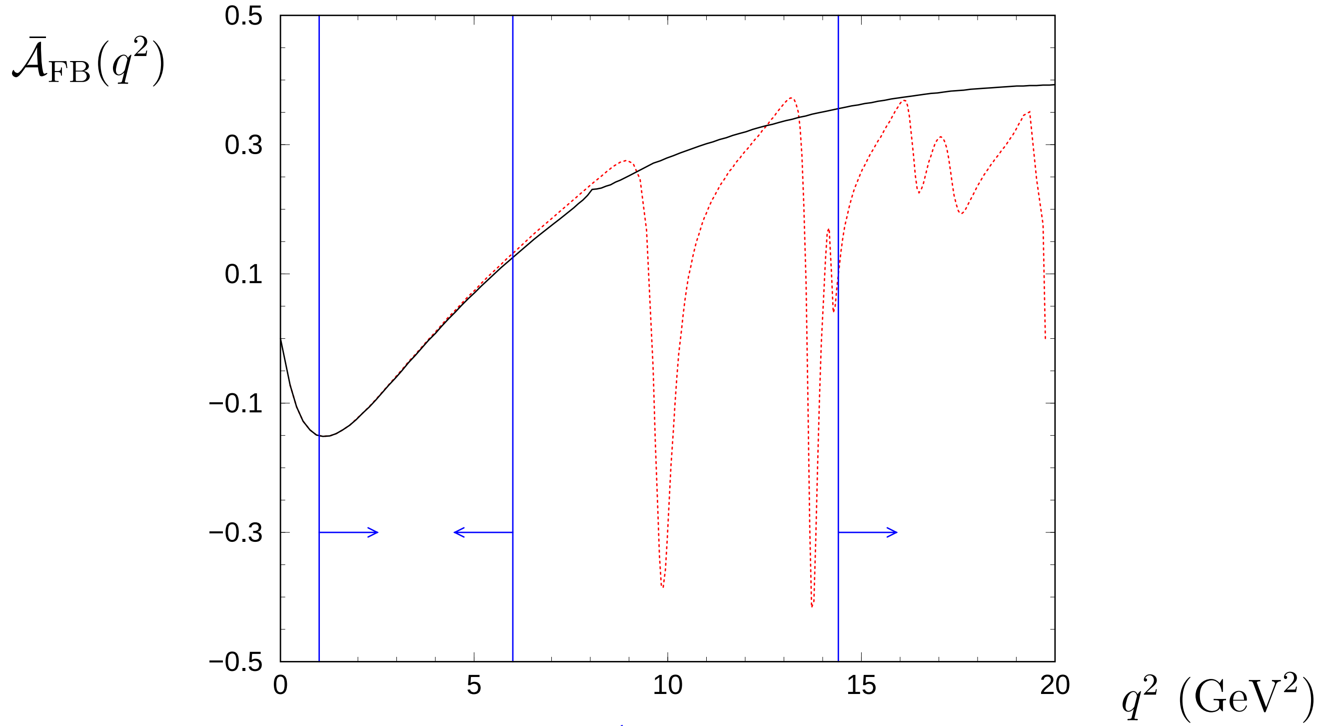
$\mathcal{B}(B \to K\mu^+\mu^-)/\mathcal{B}(B \to Ke^+e^-) = 1.06 \pm 0.48 \pm 0.05$ (1.00 in SM)

$\mathcal{B}(B \to K^*\mu^+\mu^-)/\mathcal{B}(B \to K^*e^+e^-) = 0.93 \pm 0.46 \pm 0.06$ ($\sim$ 0.75 in SM)

Radiative Pengiuns — Mikihiko Nakao — p.26

Normalized FB-Asymmetry in $\bar{B} \to X_s \ell^+ \ell^-$:

[Ghinculov, Hurth, Isidori, Yao 2004]



$$\bar{\mathcal{A}}_{\rm FB}(q^2) = \frac{1}{d\mathcal{B}(B \to X_s \ell^+ \ell^-)/dq^2} \int_{-1}^{1} d\cos\theta_\ell \, \frac{d^2\mathcal{B}(B \to X_s \ell^+ \ell^-)}{dq^2 \, d\cos\theta_\ell} \mathrm{sgn}(\cos\theta_\ell)$$

- Zero of the FB-Asymmetry is a precision test of the SM

$q_0^2 = (3.90 \pm 0.25)$ GeV^2 [Ghinculov, Hurth, Isidori, Yao 2004]

$q_0^2 = (3.76 \pm 0.22_{\rm theory} \pm 0.24_{m_b})$ GeV^2 [Bobeth, Gambino, Gorbahn, Haisch 2003]

Forward-Backward Asymmetry in $B \to K^* \ell^+ \ell^-$

$$\frac{dA_{FB}}{d\hat{s}} = -\int_0^{\hat{u}(\hat{s})} d\hat{u} \frac{d\Gamma}{d\hat{u}d\hat{s}} + \int_{-\hat{u}(\hat{s})}^{0} d\hat{u} \frac{d\Gamma}{d\hat{u}d\hat{s}}$$

$$\sim C_{10}[\mathrm{Re}(C_9^{eff}) V A_1 + \frac{\hat{m}_b}{\hat{s}} C_7^{eff} (V T_2 (1 - \hat{m}_V) + A_1 T_1 (1 + \hat{m}_V))]$$

- $\boldsymbol{T_1, T_2, V, A_1}$ form factors
  - Probes different combinations of WC's than dilepton mass spectrum; has a characteristic zero in the SM $(\hat{s}_0)$ below $m^2_{J/\psi}$

Position of the $A_{FB}(\hat{s})$ zero $(\hat{s}_0)$ in $B \to K^* \ell^+ \ell^-$

$$\mathrm{Re}(\mathrm{C_9^{eff}}(\hat{\mathrm{s}}_0)) = -\frac{\hat{\mathrm{m}}_\mathrm{b}}{\hat{\mathrm{s}}_0} \mathrm{C_7^{eff}} (\frac{\mathrm{T_2}(\hat{\mathrm{s}}_0)}{\mathrm{A_1}(\hat{\mathrm{s}}_0)} (1 - \hat{\mathrm{m}}_\mathrm{V}) + \frac{\mathrm{T_1}(\hat{\mathrm{s}}_0)}{\mathrm{V}(\hat{\mathrm{s}}_0)} (1 + \hat{\mathrm{m}}_\mathrm{V}))$$

- Model-dependent studies $\Longrightarrow$ small FF-related uncertainties in $\hat{s}_0$ [Burdman '98]
- HQET provides a symmetry argument why the uncertainty in $\hat{s}_0$ is small. In leading order in $1/m_B$, $1/E$ ($E = \frac{m_B^2 + m_{K^*}^2 - q^2}{2m_B}$) and $O(\alpha_s)$:

$$\frac{T_2}{A_1} = \frac{1 + \hat{m}_V}{1 + \hat{m}_V^2 - \hat{s}} (1 - \frac{\hat{s}}{1 - \hat{m}_V^2}); \quad \frac{T_1}{V} = \frac{1}{1 + \hat{m}_V}$$

- No hadronic uncertainty in $\hat{s}_0$ [AA, Ball, Handoko, Hiller '99]:
  $C_9^{eff}(\hat{s}_0) = -\frac{2m_b M_B}{s_0} C_7^{eff}$

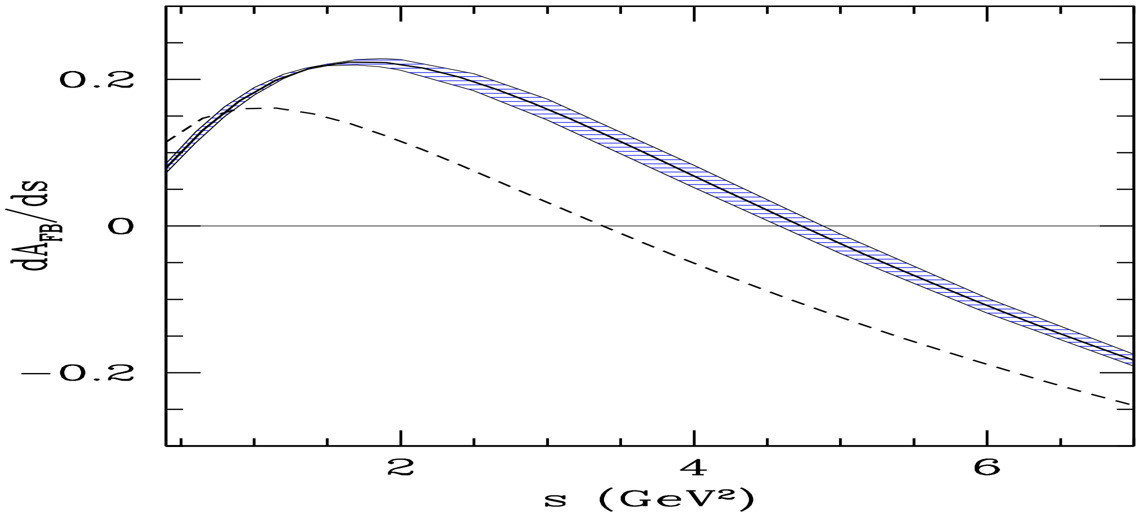
$O(\alpha_s)$ corrections to FB-Asymmetry in $B \to K^* \ell^+ \ell^-$

- $O(\alpha_s)$ corrections to the LEET-symmetry relations lead to substantial perturbative shift in $\hat{s}_0$ [Beneke, Feldmann, Seidel '01]

$$C_9^{eff}(\hat{s}_0) = -\frac{2m_b M_B}{s_0} C_7^{eff}(1 + \frac{\alpha_s C_F}{4\pi}[\ln \frac{m_b^2}{\mu^2} - L] + \frac{\alpha_s C_F}{4\pi} \frac{\Delta F_\perp}{\xi_\perp(s_0)})$$

[AA, A.S. Safir (hep-ph/02054)]

H



Forward-backward asymmetry $dA_{FB}(B \to K^* l^+ l^-)/ds$ at next-to-leading order (solid center line) and leading order (dashed)

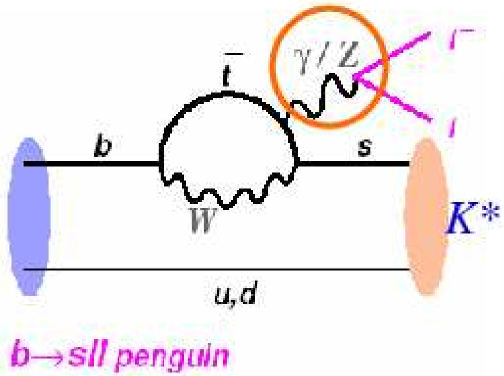
Sakai (FPCP 2004)

$B \to K^* l^+ l^-$:FB Asymmetry

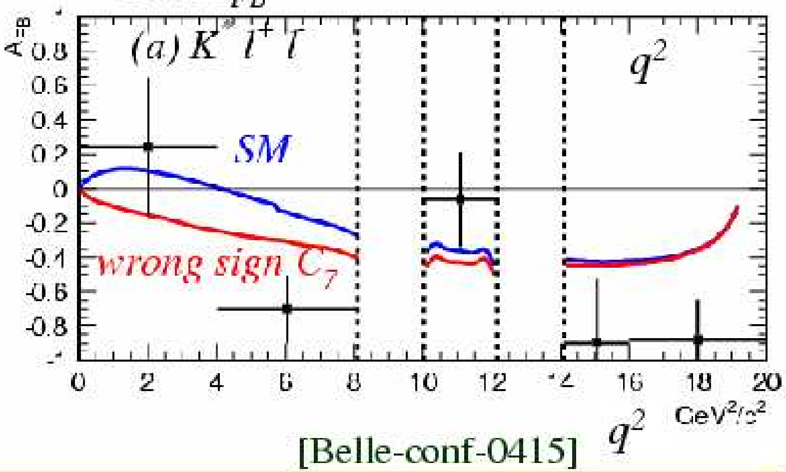
275M $B\bar{B}$

$A_{FB}(K^*ll)$: very sensitive to NP
that may not be seen in $\mathcal{B}(b \to s\gamma)$

$$A_{FB} = \frac{\Gamma(\theta_{Bl^+} < \pi/2) - \Gamma(\theta_{Bl^+} > \pi/2)}{\Gamma(\theta_{Bl^+} < \pi/2) + \Gamma(\theta_{Bl^+} > \pi/2)}$$



raw A_{FB}



First Look !

[Belle-conf-0415]

ICHEP 2004, Beijing 27

LHC-B MC Studies

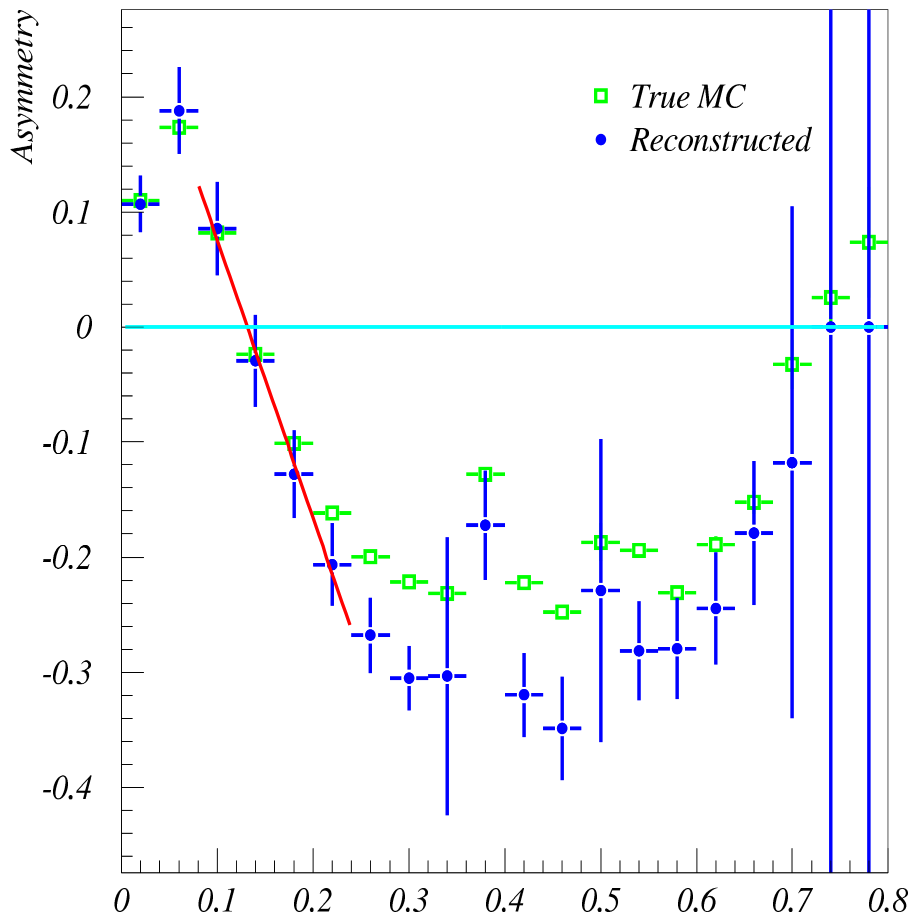


Figure 4: FB Asymmetry versus $\hat{s}$ **for** $B \xrightarrow{\hat{s}} \mu^+\mu^- K^*$ **(from Koppenburg)**

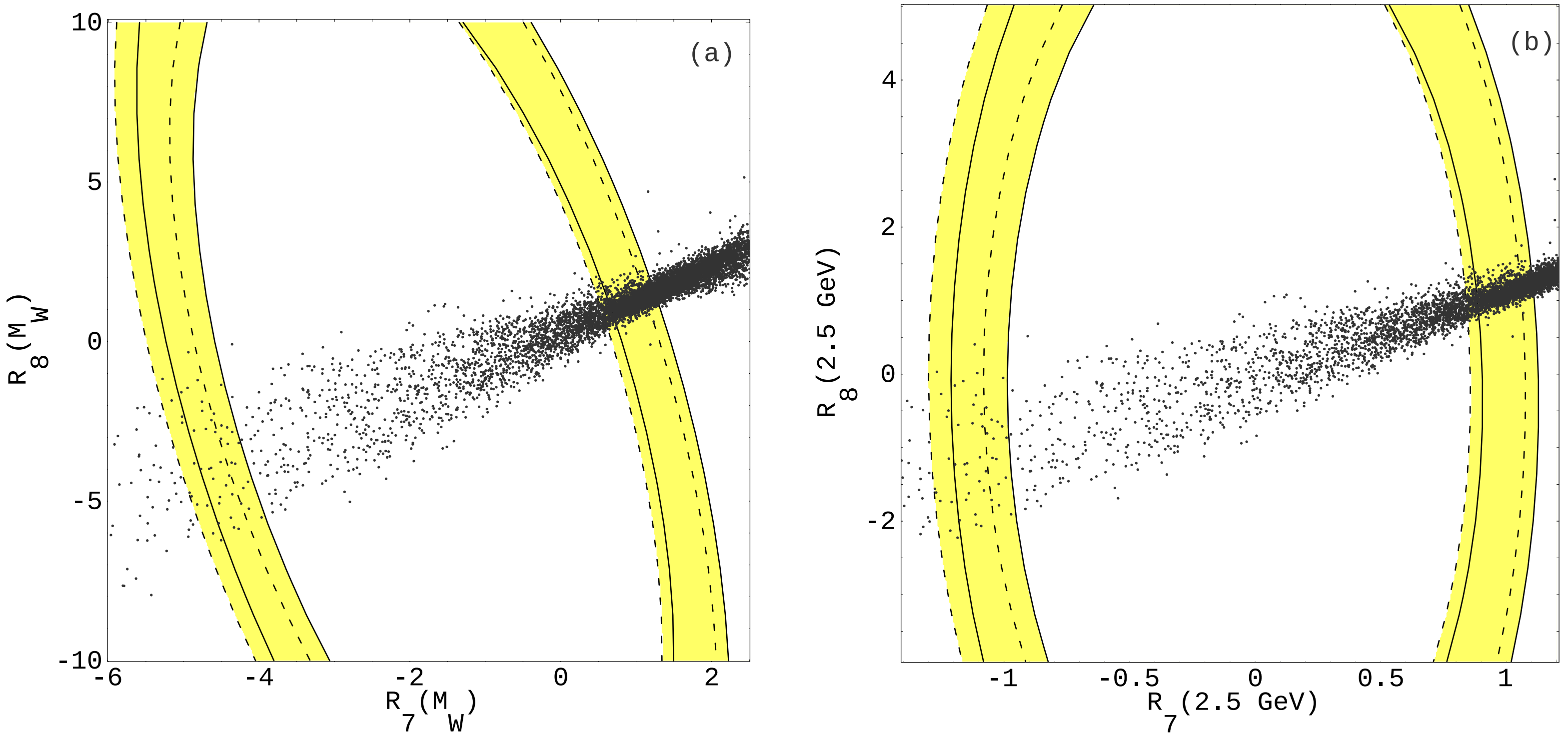
A Model-independent Analysis of $B \to X_s\gamma$ & $B \to X_s\ell^+\ell^-$

- Assume $\mathcal{H}_{eff}^{\rm SM}$ a sufficient operator basis also for Beyond-the-SM physics
- Shifts due to Beyond-the-SM [BSM] physics only in $C_7(\mu_W)$,$C_8(\mu_W)$, $C_9(\mu_W)$, and $C_{10}(\mu_W)$
- BSM Coefficients: $R_7 - 1$, $R_8 - 1$, $C_9^{\rm NP}$, & $C_{10}^{\rm NP}$
- Define: $R_{7,8}(\mu_W) \equiv \frac{C_{7,8}^{\rm tot}(\mu_W)}{C_{7,8}^{\rm SM}(\mu_W)}$
  with $C_{7,8}^{\rm tot}(\mu_W) = C_{7,8}^{\rm SM}(\mu_W) + C_{7,8}^{\rm NP}(\mu_W)$
- Set the scale $\mu_W = M_W$, and use RGE to evolve
  $$R_{7,8}(\mu_W) \to R_{7,8}(\mu_b) = \frac{A_{7,8}^{\rm tot}(\mu_b)}{A_{7,8}^{\rm SM}(\mu_b)}$$
- Impose constraints from $R_7(\mu_b)$ and $R_8(\mu_b)$ from $B \to X_s\gamma$ Data
- Use Data on $B \to (X_s, K^*, K)\ell^+\ell^-$ BRs to constrain $C_9^{\rm NP}$ and $C_{10}^{\rm NP}$
- Two-fold ambiguity due to the sign of C_7^{eff} can be resolved by data on $\boldsymbol{B \to (X_s, K, K^*)\ell^+\ell^-}$

Simulation of $B \to X_s\gamma$ in SUSY-MFV Models

- 90% C.L. bounds in the $[R_7(\mu), R_8(\mu)]$ plane from the $\mathcal{B}(B \to X_s\gamma)$

  $\mu = m_W$ (left-hand plot); $\mu = 2.5$ GeV (right-hand plot)



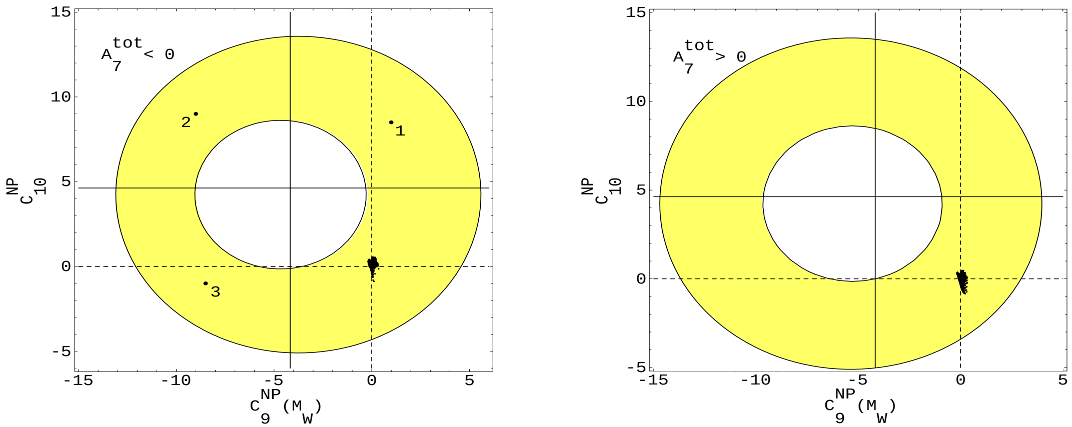
$$A_7^{\rm tot} - \text{negative} : -0.37 \leq A_7^{{\rm tot},<0}(2.5\ \text{GeV}) \leq -0.17$$

$$A_7^{\rm tot} - \text{positive} : 0.21 \leq A_7^{{\rm tot},>0}(2.5\ \text{GeV}) \leq 0.43$$

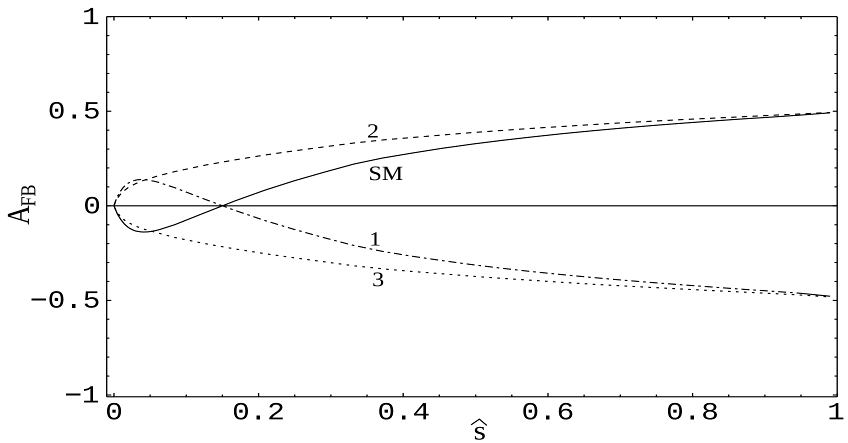
Combined analysis of $B \to X_s\gamma$ & $B \to (X_s, K, K^*)\ell^+\ell^-$

[A.A., Lunghi, Greub, Hiller; DESY 01-217; hep-ph/0112300]

- Constraints from radiative and semileptonic rare decays (Points: SUSY-MFV Model)



- FB asymmetry for $\bar{B} \to X_s\ell^+\ell^-$, corresponding to the points indicated above

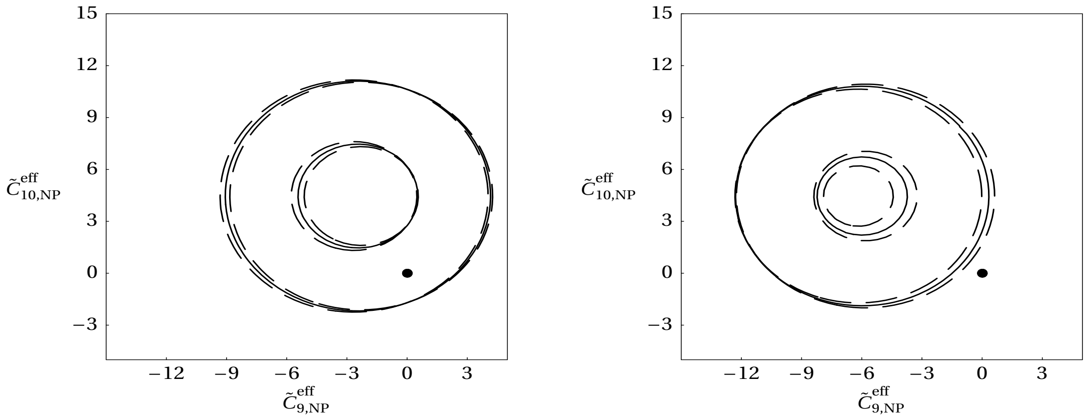


First hints on the sign of the $B \to X_s\gamma$ amplitude

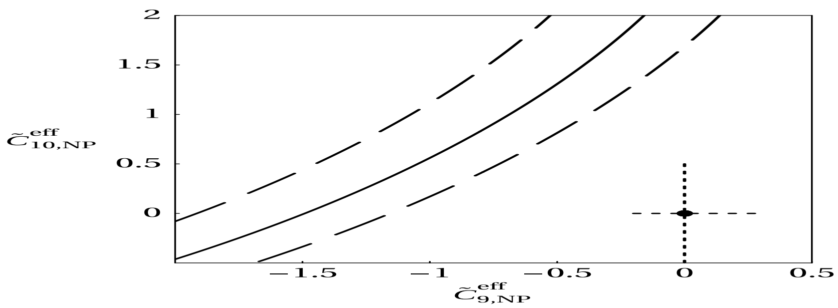
[Gambino, Haisch, Misiak; hep-ph/0410155]

90% C.L. constraints from $B \to X_s\gamma$ and $B \to X_s\ell^+\ell^-$

C_7 SM-like (left frame) C_7 opposite sign (right frame)



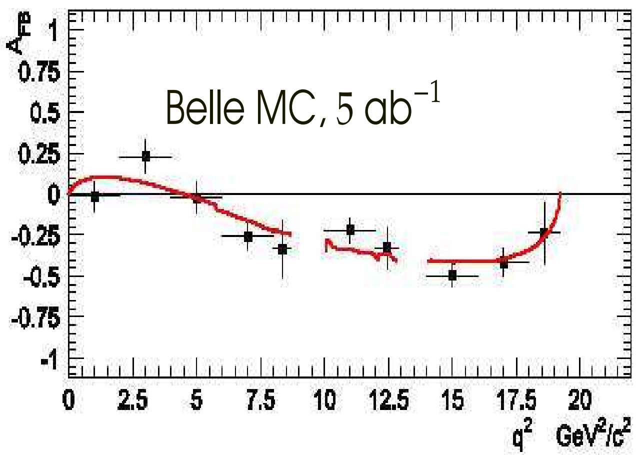
Surroundings of the origin in the right frame above; dashed lines: MFV-MSSM

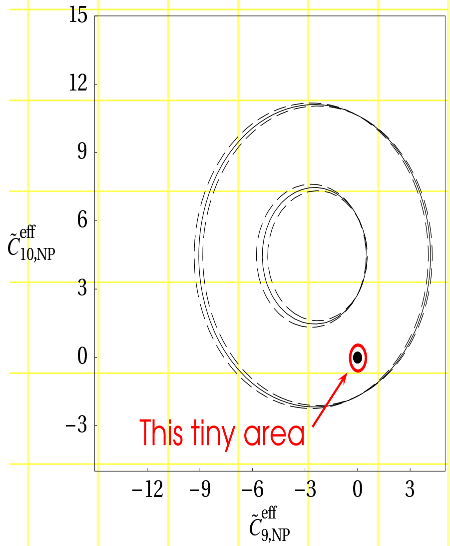


Prospects of precise determination of C_9, C_{10} at Super-B Factory

Extracting C_9 and C_{10} from $B \to K^* \ell^+ \ell^-$

- Precise determination of C_9 and C_{10} is possible
- $\Delta C_9/C_9 \sim 11\%$, $\Delta C_{10}/C_{10} \sim 13\%$ at 5 ab^{-1}, C_7 fixed from $b \to s\gamma$
  - Current branching fraction / background extrapolated
  - Fit to 2-dim q^2 vs angular distribution, not simple A_{FB}
  - Systematic error is neglected





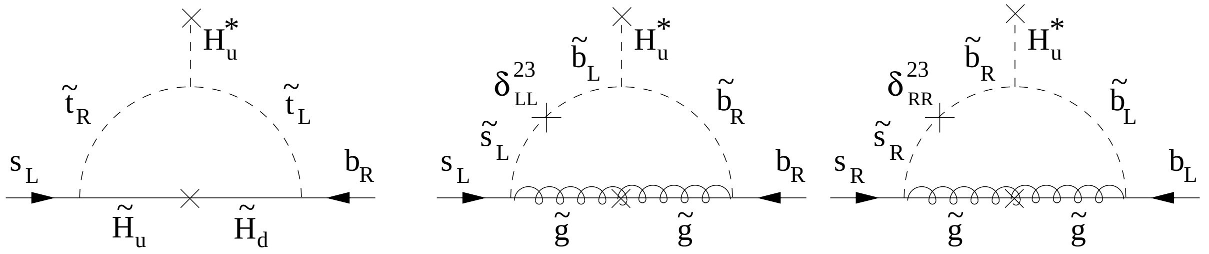
Radiative Pengiuns — Mikihiko Nakao — p.28

$B_s \to \mu^+\mu^-$ in Supersymmetric Models

- The decay $B_s \to \mu^+\mu^-$ probes essentially the Higgs sector of Supersymmetry, a type-II two-Higgs doublet model; One Higgs field (H_u) couples to the up-type quarks, the other (H_d) couples to the down-type quarks

$$\mathcal{L} = \overline{Q} Y_U U_R H_u + \overline{Q}_L Y_D D_R H_d$$

- Supersymmetry does not have discrete symmetries to protect the alignment of the Higgs boson interaction eigenbasis with the fermion mass eigenbasis; Higgs-induced FCNC interactions are generated through loops



(a) (b)

- As H_u gets a VEV (v_u), it contributes an off-diagonal piece to the down-type fermion mass matrix, mixing s_L and b_L by an angle θ

$$\sin\theta = y_b \epsilon v_u / m_b; \quad \text{as } m_b = y_b v_d, \ \sin\theta = \epsilon \tan\beta$$

- $\mathcal{A}(b\bar{s} \to \mu^+\mu^-) \simeq \sin\theta \mathcal{A}(b\bar{b} \to \mu^+\mu^-) \propto \tan\beta / \cos^2\beta \Longrightarrow \tan^3\beta$ for large-$\tan\beta$

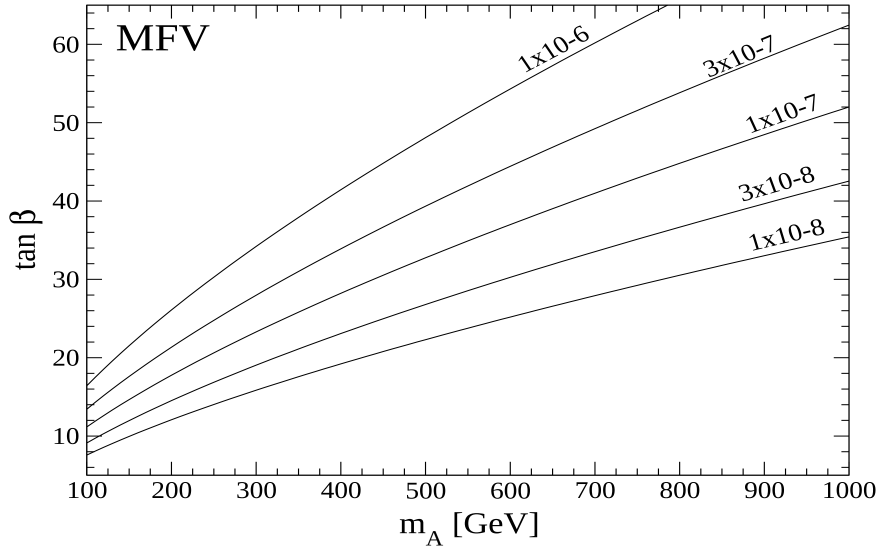
$B_s \to \mu^+\mu^-$ in Minimal Flavor Violation SUSY Models

- Higgsino contribution to $\mathcal{B}(B_s \to \mu^+\mu^-)$ [Babu, Kolda;...]

$$\mathcal{B}(B_s \to \mu\mu) \simeq \frac{G_F^2}{8\pi}\,\eta_{\rm QCD}^2 m_{B_s}^3 f_{B_s}^2 \tau_{B_s} m_b^2\, m_\mu^2 \left(\frac{\tan^2\beta}{\cos^4\beta}\right)\left(\frac{\kappa_{\widetilde{H}}^2}{m_A^4}\right).$$

- $\eta_{\rm QCD} \simeq 1.5$ is the QCD correction due to the RG between the SUSY and B_s scales

$$\kappa_{\widetilde{H}} = -\frac{G_F\, m_t^2\, V_{ts}V_{tb}}{4\sqrt{2}\pi^2\sin^2\beta}\,\mu A_t\, f(\mu^2, m_{\tilde{t}_L}^2, m_{\tilde{t}_R}^2)$$



Constraints from $BR(B_s \to \mu^+\mu^-)$

$B_s \to \mu\mu$: Physics Reach

D0 $B_s \to \mu^+\mu^-$ result: 240pb^{-1}

$$BF(B_s \to \mu^+\mu^-) < 3.8\times10^{-7}\ 90\%\ \text{CL}$$

CDF $B_{(s,d)} \to \mu^+\mu^-$ results: 171pb^{-1}

$$BF(B_s \to \mu^+\mu^-) < 5.8\times10^{-7}\ 90\%\ \text{CL}$$

$$BF(B_d \to \mu^+\mu^-) < 1.5\times10^{-7}\ 90\%\ \text{CL}$$

Combined: Bayesian approach with a flat prior. Systematic error on fs correlated. Combination by M. Herndon

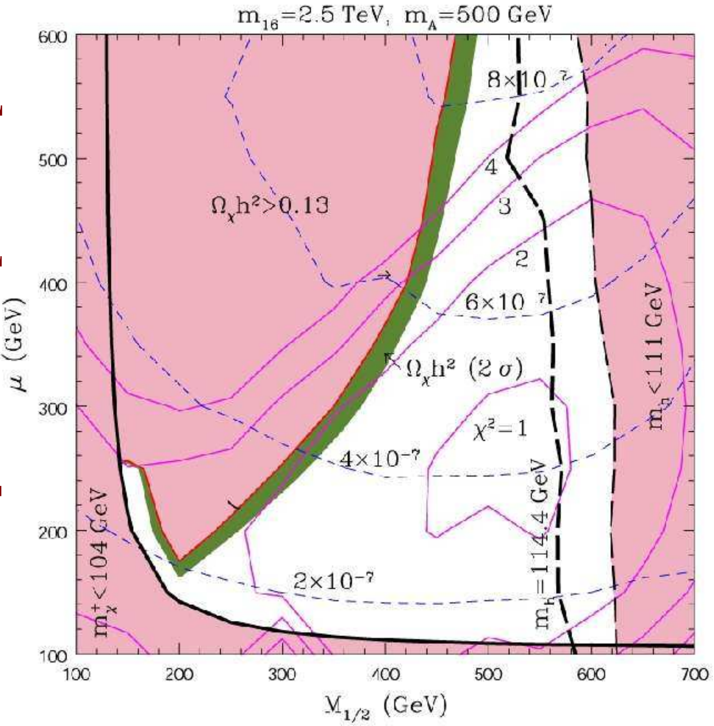
$$BF(B_s \to \mu^+\mu^-) < 2.7\times10^{-7}\ 90\%\ \text{CL}$$

SM predictions

$BF(B_{s(d)} \to \mu^+\mu^-)$ $3.5\text{x}10^{-9}$ ($1.0\text{x}10^{-10}$)

- No sensitivity for SM decay rate

- BSM predictions Limiting many models
- Example SUSY S0(10)
  - Allows for massive neutrino
  - Accounts for relic density of cold dark matter



BF $B_s \to \mu^+\mu^-$: Dashed blue

Excludes scenarios where M_A is light and $\tan\beta \sim 50$: $M_A > 450\text{GeV}/c^2$

R. Dermisek hep-ph/0304101,2003

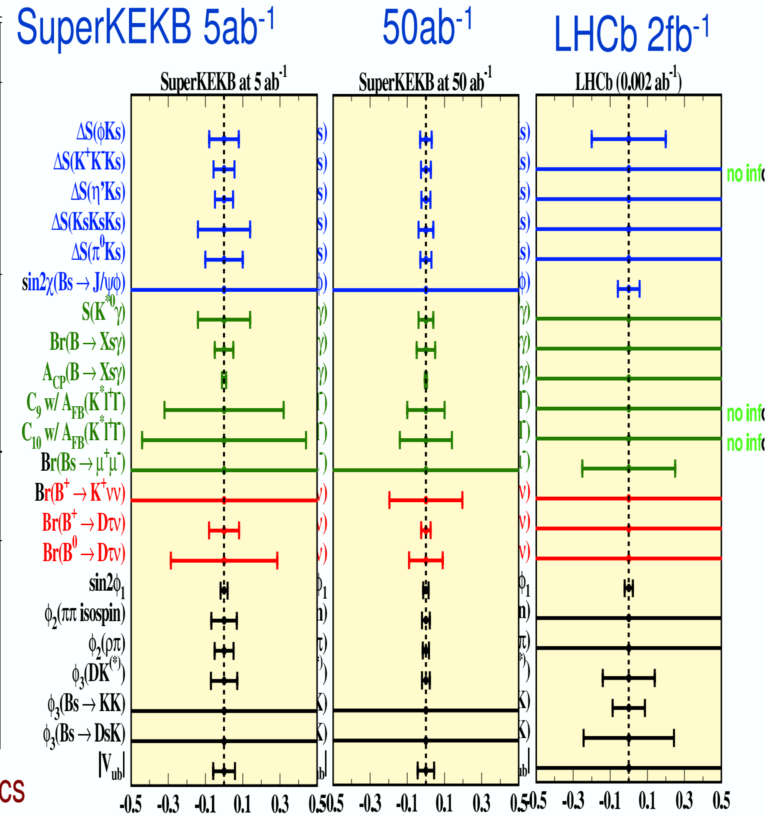
ICHEP 2004 9

Courtesy Iijika San (Super-B Workshop, Hawaii, '05)

Physics Reach at Super-KEKB

	Observable	SuperKEKB (5 ab^{-1})	SuperKEKB (50 ab^{-1})
CPV ($b \to s$)	$\Delta S(\phi K_s)$	0.079	0.031
	$\Delta S(K^+K^-K_s)$	0.056	0.026
	$\Delta S(\eta' K_s)$	0.049	0.024
	$\Delta S(K_sK_sK_s)$	0.14	0.04
	$\Delta S(\pi^0 K_s)$	0.10	0.03
	$\sin 2\chi(B_s \to J/\psi\phi)$	×	×
FCNC	$S(K^{*0}\gamma)$	0.14	0.04
	$Br(B \to X_s\gamma)$	5%	5%
	$A_{CP}(B \to X_s\gamma)$	0.011	5×10^{-3}
	C_9 w/ $A_{FB}(K^*l^+l^-)$	32%	10%
	C_{10} w/ $A_{FB}(K^*l^+l^-)$	44%	14%
	$Br(B_s \to \mu^+\mu^-)$	×	×
w/ ν	$Br(B^+ \to K^+\nu\nu)$		5.1σ
	$Br(B^+ \to D\tau\nu)$	8%	2.5%
	$Br(B^0 \to D\tau\nu)$	3.5σ	9%
CKM	$\sin 2\phi_1$	0.019	0.014
	$\phi_2(\pi\pi$ isospin$)$	3.9°	1.2°
	$\phi_2(\rho\pi)$	2.9°	0.9°
	$\phi_3(DK^{(*)})$	4°	1.2°
	$\phi_3(B_s \to KK)$	×	×
	$\phi_3(B_s \to D_sK)$	×	×
	$\lvert V_{ub}\rvert$	5.8%	4.4%

and rich τ physics



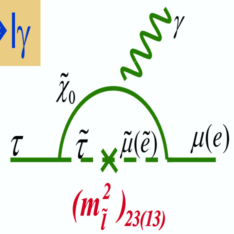
Physics at Super B Factory (hep-ex/0406071) 11

Courtesy Iijika San (Super-B Workshop, Hawaii, '05)

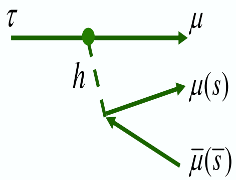
Lepton Flavor Violation

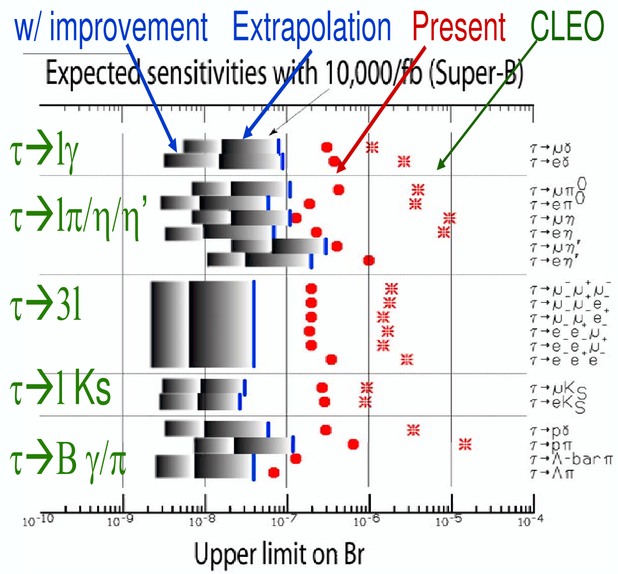
LFV in neutrino sector ⇒LFV in charged leptons ?
Search for "SM Zero"

$\tau \to l\gamma$



$\tau \to 3l$, $l\eta$





B-factory = "Tau-factory" ⟹ 10^{10} τ pairs at $10ab^{-1}$
Search region enters into $O(10^{-8} \to 10^{-9})$

20

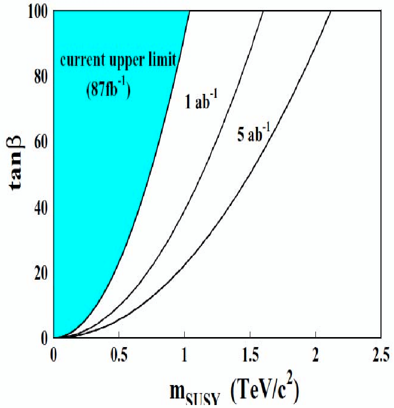
LFV in τ decays

$\tau \to l\gamma/3l, l\eta$

$\tau \to l\gamma$

- SUSY + Seasaw
- Large LFV $Br(\tau \to \mu\gamma) = O(10^{-7\sim 9})$

$$Br(\tau \to \mu\gamma) \simeq 10^{-6} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}} \right) \left(\frac{1\,TeV}{m_{SUSY}} \right)^4 \tan^2\beta$$



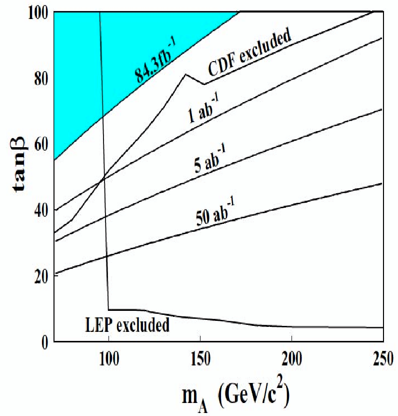
$\tau \to 3l, l\eta$

- Neutral Higgs mediated decay.
- Important when MSUSY >> EW scale.

$$Br(\tau \to 3\mu) =$$

$$4 \times 10^{-7} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}} \right) \left(\frac{\tan\beta}{60} \right)^6 \left(\frac{100\,GeV}{m_A} \right)^4$$

$$Br(\tau \to \mu\eta) : Br(\tau \to 3\mu) : Br(\tau \to \mu\gamma)$$
$$= 5 : 1 : 0.5$$



Summary

- Thanks to dedicated experiments and progress in theory (Lattice QCD, Chiral pertubation theory, HQET) V_{CKM} now well measured
- B-factories have measured all three inner angles of the UT triangle: $\alpha = (100 \pm 11)^\circ$; $\beta = (23.3 \pm 1.5)^\circ$; $\gamma = (63 \pm 14)^\circ$, in agreement with their indirect SM-based predictions
- Likewise, all measurements involving FCNC processes (decay rates and distributions) are in agreement with the SM expectations
- Discovery of SUSY at LHC but continued absence of observable effects in FCNC and CPV beyond SM would point to a flavour-blind SUSY (such as mSUGRA,MFV)
- However, data on CPV in $b \to s\bar{s}s$ penguins puzzling; currently deviation from the SM is a tantalizing $3.5\ \sigma$ effect; $\mathcal{B}(B_s \to \mu^+\mu^-)$ and ΔM_{B_s} remain to be measured
- LFV ($\mu \to e\gamma$, $\tau \to \mu\gamma$) have received renewed theoretical motivation due to the observation of the neutrino mixings and masses; planned experiments (such as MEGA, Super-B factory) will be sensitive to an interesting SUSY parameter space
- Let us hope that the synergy of high energy frontier and low energy precision physics, which worked out so well in piecing together the SM, will continue to hold sway in the LHC/ILC-era, providing valuable information about the flavour aspects of the BSM physics