New Physics in B and K Decays

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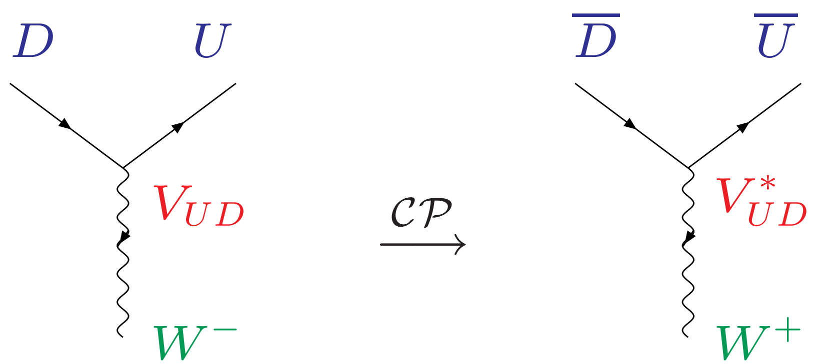
- Setting the Stage
- Moving towards New Physics:
  - Low-energy effective Hamiltonians
  - Theoretical challenges
  - Impact of new physics on the roadmap of quark-flavour physics
- Puzzles in the B-Factory Data and Interplay with Rare B, K Decays
- New Perspectives in the LHC Era

Setting the Stage

- <u>Kobayashi–Maskawa mechanism of CP violation:</u> $\rightarrow$ Standard Model



Recent review: R.F., *J. Phys.* **G32** (2006) R71 [hep-ph/0512253]

Why are Studies of Flavour Physics Interesting?

- "New" Physics (NP), i.e. physics beyond the Standard Model (SM):

  $\Rightarrow$ typically new sources of flavour and CP violation

  – Supersymmetry (SUSY), Models with extended Higgs sectors, models with extra Z' bosons, left–right-symmetric models ...

- Cosmological baryon asymmetry: $\longrightarrow$ *requires* CP violation [Sacharov 1967]

  – Model calculations $\Rightarrow$ CP violation in the SM appears too small!?

- ν masses: $\longrightarrow$ origin beyond the Standard Model

  – CP violation in the neutrino sector? Neutrino factories ...

- Note: the origins of the pattern of the fermion masses, the structure of flavour mixing and CP violation lie still completely in the dark ...

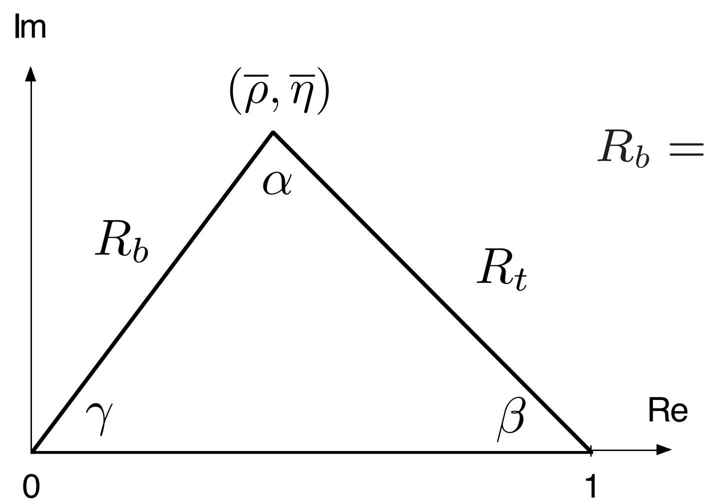
Central Target: Unitarity Triangle (UT)

- Application of the Wolfenstein parametrization: [Wolfenstein (1984)]

$$\hat{V}_{\text{CKM}} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\,\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\,\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

$\longrightarrow$ phenomenological expansion in $\lambda \equiv |V_{us}| = 0.22$ [from $K \to \pi \ell \bar{\nu}_\ell$]

- Unitarity of the CKM matrix: $\hat{V}^\dagger_{\text{CKM}} \cdot \hat{V}_{\text{CKM}} = \hat{1} = \hat{V}_{\text{CKM}} \cdot \hat{V}^\dagger_{\text{CKM}}$ $\Rightarrow$



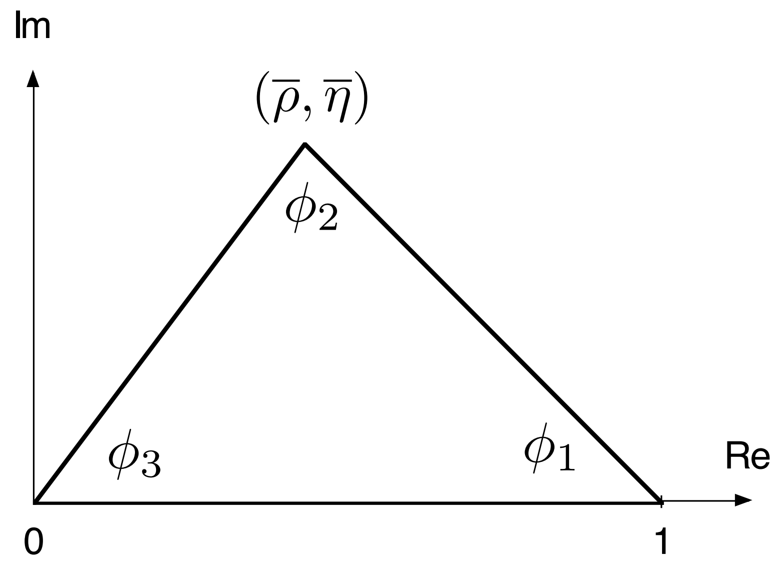
$$R_b = \left(1-\frac{\lambda^2}{2}\right)\frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right|$$

$$R_t = \frac{1}{\lambda}\left|\frac{V_{td}}{V_{cb}}\right|$$

$$\overline{\rho} \equiv (1-\lambda^2/2)\rho, \quad \overline{\eta} \equiv (1-\lambda^2/2)\eta$$

$\longrightarrow$ NLO corrections [Buras *et al.* (1994)]

“Japanese” Conventions for the Angles of the UT

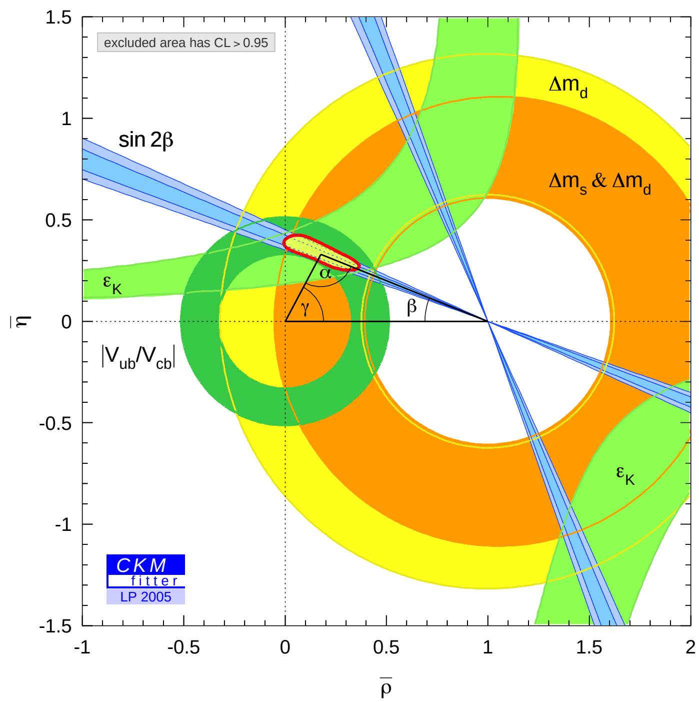


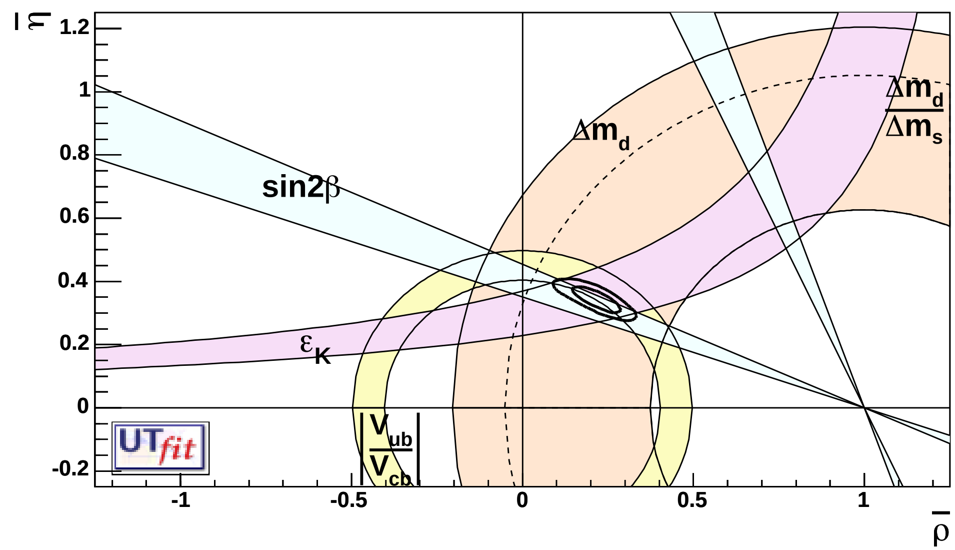
- Dictionary for the translation into the “American/European” conventions:

$$\boxed{\phi_1 \equiv \beta, \quad \phi_2 \equiv \alpha, \quad \phi_3 \equiv \gamma}$$

Current Status of the Unitarity Triangle

- Two competing groups:
  - *CKMfitter* Collaboration [http://ckmfitter.in2p3.fr/];
  - *UTfit* Collaboration [http://www.utfit.org]:





⇒ impressive global agreement with KM, but no longer "perfect" ...

Moving towards

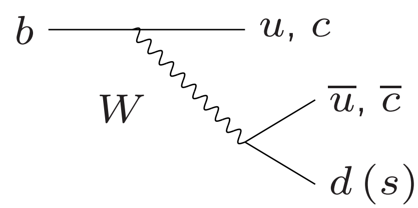
New Physics

$\longrightarrow$ discussion for the B system (analogous for K):

Key Processes for the Exploration of CP Violation

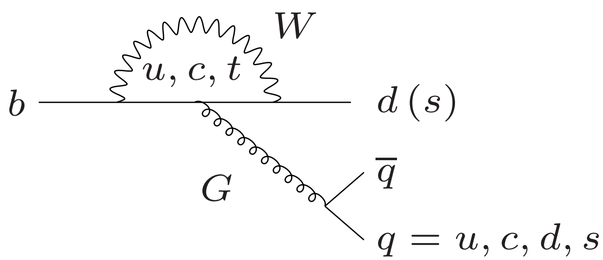
$\longrightarrow$ non-leptonic B decays:

- Tree diagrams:

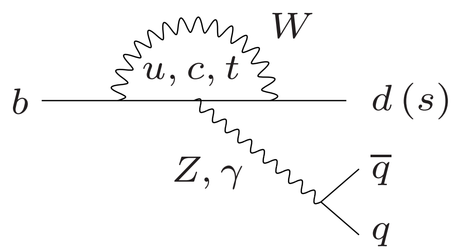


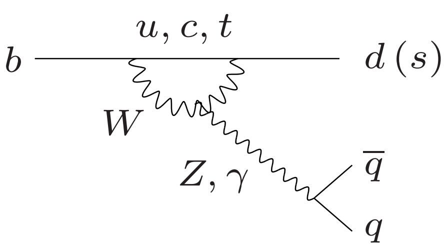
- Penguin diagrams:

◇ QCD penguins:



◇ Electroweak (EW) penguins:





Low-Energy Effective Hamiltonians

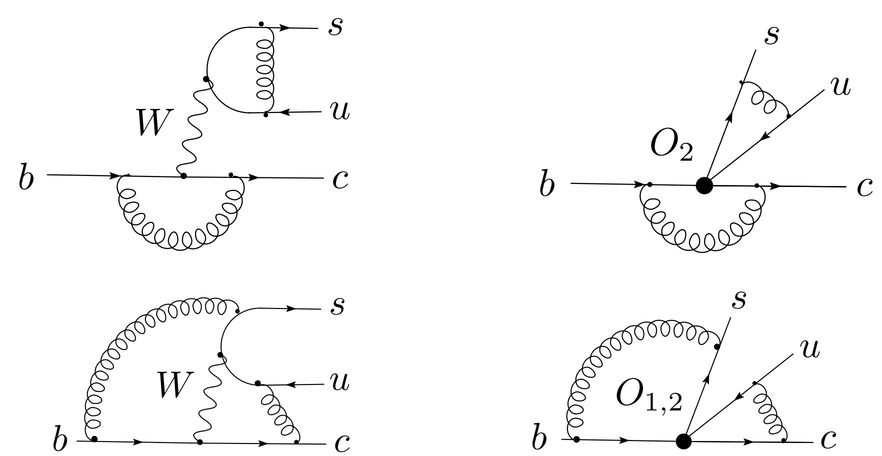
- The operator product expansion allows a systematic separation of the short-distance from the long-distance contributions to $B \to f$:

$$\boxed{\langle f|\mathcal{H}_{\text{eff}}|B\rangle = \frac{G_{\rm F}}{\sqrt{2}} \sum_j \lambda^j_{\rm CKM} \sum_k C_k(\mu)\, \langle f|Q^j_k(\mu)|B\rangle}$$

[$G_{\rm F}$: Fermi's constant, $\lambda^j_{\rm CKM}$: CKM factors, μ: renormalization scale]

- Short-distance physics: [Buras *et al.*; ...]

$\to$ Wilson-Koeffizienten $C_k(\mu)$ $\to$ *perturbative* $\to$ known



- Long-distance physics:

$\to$ matrix elements $\langle f|Q^j_k(\mu)|B\rangle$ $\to$ *non-perturbative* $\to$ "unknown"

Impact of New Physics

- Possibility I: **Modification of the "Strength" of the SM Operators**

  – New short-distance functions, which depend on the NP parameters, such as masses of charginos, squarks, $\tan\bar{\beta} \equiv v_2/v_1$ in the MSSM.

  – The NP particles enter in new box and penguin diagrams, and are "integrated out", as the W boson and the top quark in the SM:

$$\underbrace{C_k(\mu = M_W) \to C_k^{\rm SM} + C_k^{\rm NP}}_{\text{initial conditions for RG evolution}}$$

  – The $C_k^{\rm NP}$ may also involve new CP-violating phases.

- Possibility II: **New Operators**

  – Operators, which are absent or strongly suppressed in the SM, may actually play an important rôle:

$$\underbrace{\{Q_k\} \to \{Q_k^{\rm SM}, Q_l^{\rm NP}\}}_{\text{operator basis}}$$

  – In general, new sources of flavour and CP violation.

Specific New-Physics Analyses

- SUSY models have received a lot of attention:

  Goto *et al.* ('04); Jäger & Nierste ('04); Ciuchini *et al.* ('04); Ball, Khalil & Kou ('04); Ko ('04); Gabrielli, Huitu, Khalil ('05); ...

- Examples of other fashionable NP scenarios:

  – Left–right-symmetric models [Ball *et al.* ('00); Ball & R.F. ('00); ...]

  – Scenarios with extra dimensions [Buras *et al.* ('03); Agashe *et al.* ('04); ...]

  – Models with an extra Z' boson [Barger *et al.* ('04); ...]

  – "Little Higgs" scenarios [Choudhury *et al.* ('04); Buras *et al.* ('05); ...]

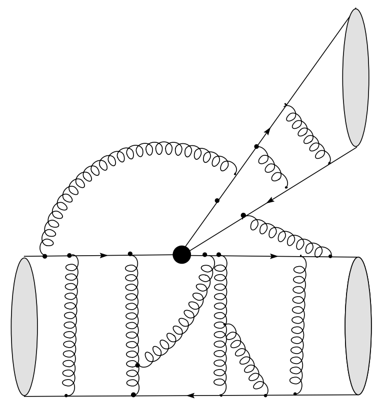
  – Models with a fourth generation [Hou, Nagashima & Soddu ('05)]

- Suffer, in general, from the following problems:

  – Choice of NP model governed by personal "biases".

  – Predictivity inversely proportional to the number of NP parameters.

But Central Problem for NP Searches: $\langle f|Q_k^j(\mu)|B\rangle$



- Interesting recent developments:
  - QCD Factorization (QCDF):
    Beneke, Buchalla, Neubert & Sachrajda (1999–2001); ...
  - Perturbative Hard-Scattering (PQCD) Approach:
    Li & Yu ('95); Cheng, Li & Yang ('99); Keum, Li & Sanda ('00); ...
  - Soft Collinear Effective Theory (SCET):
    Bauer, Pirjol & Stewart (2001); Bauer, Grinstein, Pirjol & Stewart (2003); ...
  - QCD light-cone sum-rule methods:
    Khodjamirian (2001); Khodjamirian, Mannel & Melic (2003); ...

Data $\Rightarrow$ theoretical challenge remains ...

$\Rightarrow$ Circumvent the Calculation of the $\langle f|Q_k^j(\mu)|B\rangle$:

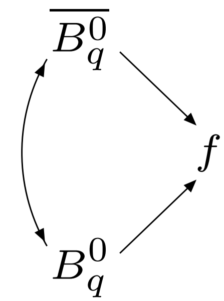
- Amplitude relations allow us in fortunate cases to eliminate the hadronic matrix elements ($\to$ typically strategies to determine the UT angle γ):

  – *Exact* relations: class of pure "tree" decays (e.g. $B \to DK$).

  – *Approximate* relations, which follow from the *flavour symmetries* of strong interactions, i.e. $SU(2)$ isospin or $SU(3)_{\rm F}$:

$$B \to \pi\pi,\ B \to \pi K,\ B_{(s)} \to KK.$$

- Decays of neutral B_d and B_s mesons:



Interference effects through B^0_q–$\overline{B^0_q}$ mixing:

  – Lead to "mixing-induced" CP violation $\mathcal{A}_{\rm CP}^{\rm mix}$!

  – If one CKM amplitude dominates:

$$\Rightarrow\ \textit{hadronic matrix elements cancel!}$$

  ∗ Example: $B^0_d \to J/\psi\, K_{\rm S} \quad \Rightarrow \quad \sin 2\beta$ [Bigi, Carter & Sanda ('80–'81)]

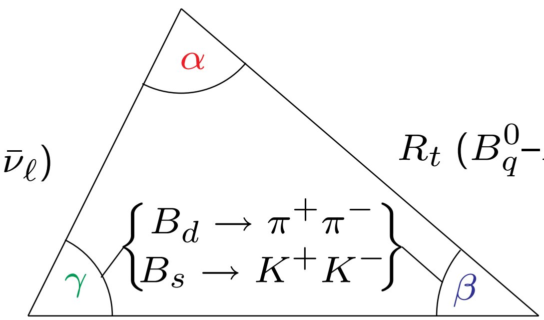
A Brief Roadmap of Quark-Flavour Physics

- CP-B studies through various processes and strategies:

$B \to \pi\pi$ (isospin), $B \to \rho\pi$, $B \to \rho\rho$

R_b $(b \to u, c\ell\bar{\nu}_\ell)$

R_t (B_q^0–$\bar{B}_q^0$ mixing)



$B \to \pi K$ (penguins)

$\left.\begin{matrix} B_u^\pm \to K^\pm D \\ B_d \to K^{*0} D \\ B_c^\pm \to D_s^\pm D \end{matrix}\right\}$ only trees

$B_d \to \psi K_S$ $(B_s \to \psi\phi : \phi_s \approx 0)$

$B_d \to \phi K_S$ (pure penguin)

$\left.\begin{matrix} B_d \to D^{(*)\pm}\pi^\mp : \gamma + 2\beta \\ B_s \to D_s^\pm K^\mp : \gamma + \phi_s \end{matrix}\right\}$ only trees

- Moreover "rare" decays: $B \to K^*\gamma$, $B_{d,s} \to \mu^+\mu^-$, $K \to \pi\nu\overline{\nu}$, ...
  - Originate from loop processes in the SM.
  - Interesting correlations with CP-B studies.

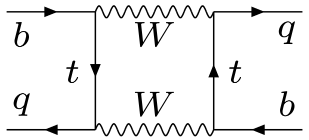
New Physics $\Rightarrow$ Discrepancies

Preferred Mechanisms

for New Physics to

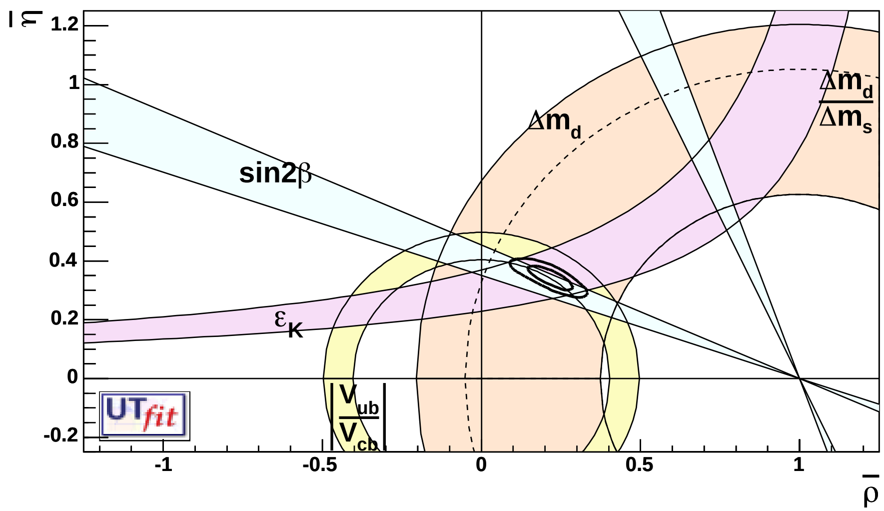
enter this roadmap:

1. New Physics in B_q^0–$\overline{B_q^0}$ Mixing:



- Exchange of new particles in box diagrams or new tree contributions:
  - Mass difference: $\Delta M_q = \Delta M_q^{\mathrm{SM}} + \Delta M_q^{\mathrm{NP}}$ $(\to R_t)$
  - CP-violating mixing phase: $\phi_q = \phi_q^{\mathrm{SM}} + \phi_q^{\mathrm{NP}}$ $(\to \mathcal{A}_{\mathrm{CP}}^{\mathrm{mix}})$

- B_d system:



$\Rightarrow$ $\boxed{\phi_d^{\mathrm{NP}} = -(8.2 \pm 3.5)^\circ}$ [Buras, R.F., Recksiegel & Schwab ('05)]

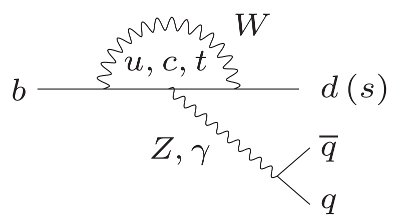
- B_s system: $\to$ essentially *unexplored* $\to$ key target of LHCb!

2. New Physics in Decay Amplitudes:

- Typically *small* NP effects if SM tree processes play the dominant role:
  - Examples: $B \to J/\psi K$, $B_s \to J/\psi \phi$, $B_s \to D_s^{\pm} K^{\mp}$

- Potentially *large* NP effects in the penguin/box sector through new particles in the loop diagrams or new contributions at the tree level:
  - General fieldtheoretical arguments;
  - Specific models: SUSY, models with extra Z' bosons, ...

- Hints for such a NP scenario in the B-factory data:



♢ $B_d \to \phi K_S$: $(\sin 2\beta)_{\phi K_S} \stackrel{?}{=} (\sin 2\beta)_{\psi K_S}$

♡ $B \to \pi K$: puzzling pattern of certain BRs (!?)

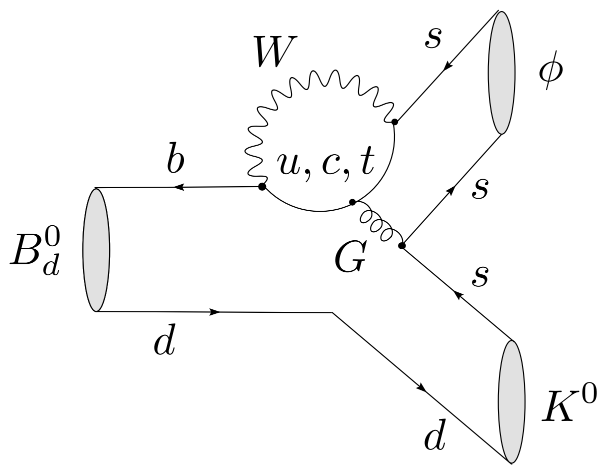
Puzzles in the B-Factory Data

and Interplay with

Rare B and K Decays

Challenging the SM

through $B_d \to \phi K_{\rm S}$:



$\Rightarrow$ $b \to s$ penguin process

CP Asymmetries & Impact of New Physics

$$\frac{\Gamma(B^0_d(t)\to f)-\Gamma(\overline{B^0_d}(t)\to \overline{f})}{\Gamma(B^0_d(t)\to f)+\Gamma(\overline{B^0_d}(t)\to \overline{f})}=\mathcal{A}_{\rm CP}^{\rm dir}\cos(\Delta M_d t)+\mathcal{A}_{\rm CP}^{\rm mix}\sin(\Delta M_d t)$$

- SM relations:

$$\mathcal{A}_{\rm CP}^{\rm dir}(B_d\to\phi K_{\rm S})=0+\mathcal{O}(\lambda^2)\;\;[\lambda\equiv|V_{us}|=0.22]$$

$$\underbrace{\mathcal{A}_{\rm CP}^{\rm mix}(B_d\to\phi K_{\rm S})}_{\equiv-(\sin 2\beta)_{\phi K_{\rm S}}}=\underbrace{\mathcal{A}_{\rm CP}^{\rm mix}(B_d\to\psi K_{\rm S})}_{\equiv-(\sin 2\beta)_{\psi K_{\rm S}}}+\mathcal{O}(\lambda^2) \quad (1)$$

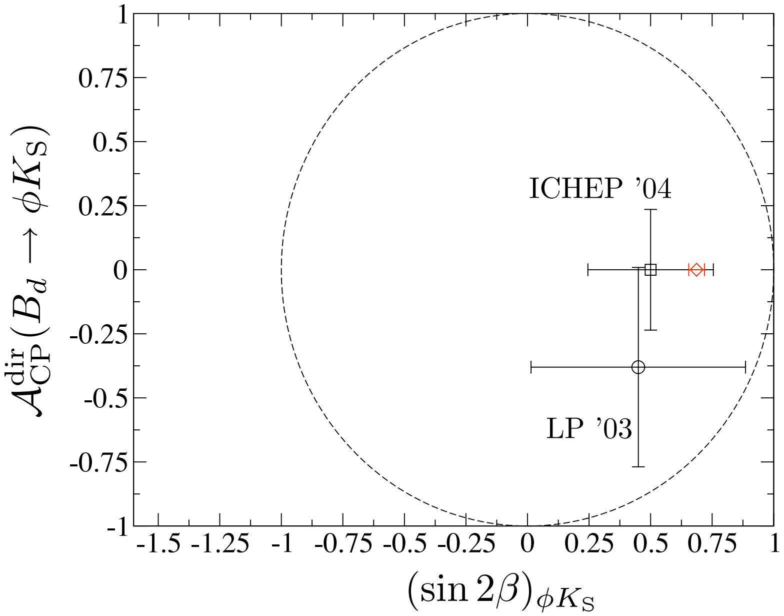
[R.F. ('97); Grossman & Worah ('97)]

- $B_d\to\phi K_{\rm S}$ is a sensitive probe for the search for new physics:
  - Decay is dominated by QCD penguins.
  - Electroweak penguins have a significant impact as well [R.F. ('94)]
  - Model-independent studies of new physics [R.F. & Mannel ('01)]

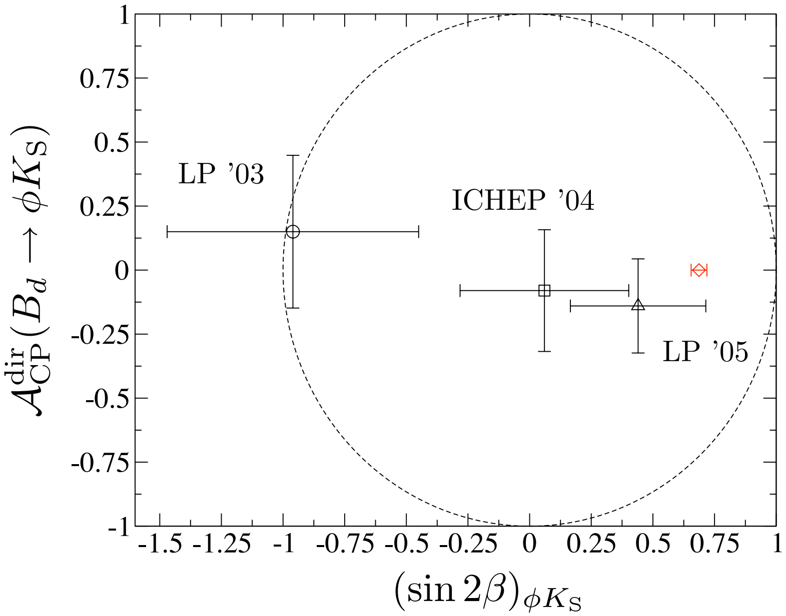
$\longrightarrow$ (1) may well be violated through new physics!

Time Evolution of the $B \to \phi K$ Data

- BaBar:



- Belle:



- Compilation of the "Heavy Flavour Averaging Group" (HFAG):

$$\mathcal{A}_{\rm CP}^{\rm dir}(B_d \to \phi K_{\rm S}) = -0.09 \pm 0.14, \quad (\sin 2\beta)_{\phi K_{\rm S}} = 0.47 \pm 0.19$$

$$\Rightarrow \mathcal{S}_{\phi K} \equiv (\sin 2\beta)_{\phi K_{\rm S}} - (\sin 2\beta)_{\psi K_{\rm S}} = -0.22 \pm 0.19$$

$\Rightarrow$ stay tuned & monitor similar modes!

NP may originate in the EW penguin sector:

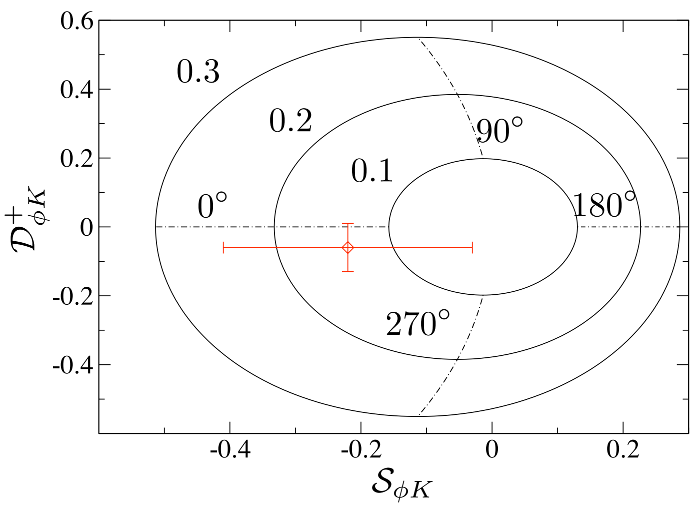
- Assume that NP enters the $I = 0$ isospin sector ($I = 1$ is dynamically suppressed), involving a CP-violating NP phase ϕ_0:

$$A(B_d^0 \to \phi K^0) = \tilde{A}_0 \left[1 + \tilde{v}_0 e^{i(\tilde{\Delta}_0 + \phi_0)}\right] = A(B^+ \to \phi K^+)$$

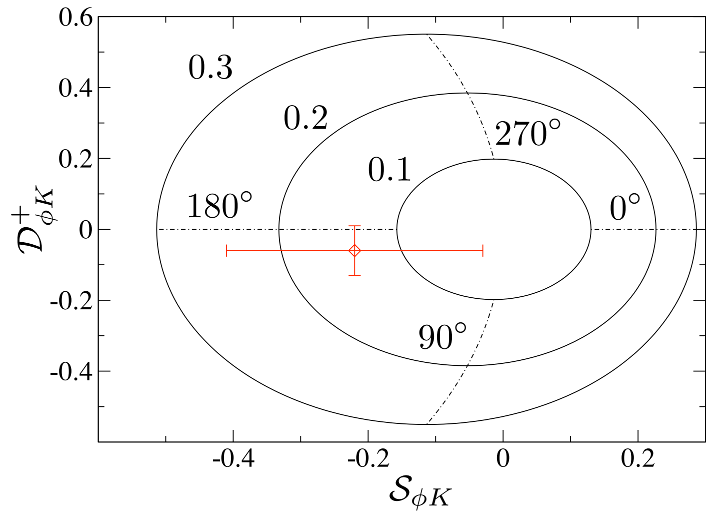
$$\tilde{v}_0 e^{i\tilde{\Delta}_0}\Big|_{\rm fact}^{\rm SM} \approx 0.2 \times e^{i180^\circ}$$

- Observables: $\boxed{\mathcal{S}_{\phi K} \quad \oplus \quad \mathcal{D}_{\phi K}^{+} \equiv [\mathcal{A}_{\rm CP}^{\rm dir}(B_d \to \phi K_{\rm S}) + \mathcal{A}_{\rm CP}^{\rm dir}(B^\pm \to \phi K^\pm)]/2}$

  - $\phi_0 = -90^\circ$:



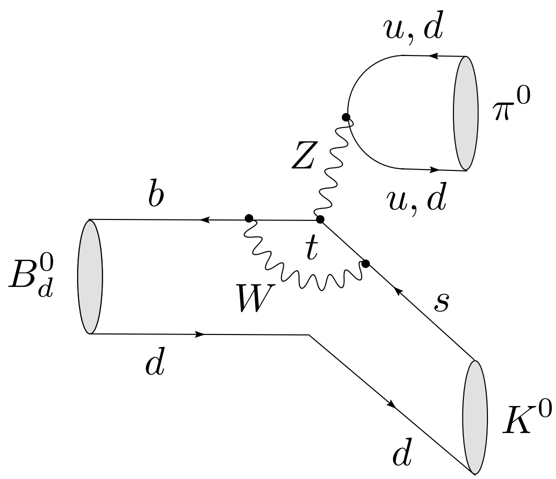
  - $\phi_0 = +90^\circ$: $\longrightarrow$ favoured !?



[Detailed discussion: R.F., hep-ph/0512253]

Challenging the SM

through $B \to \pi K$:



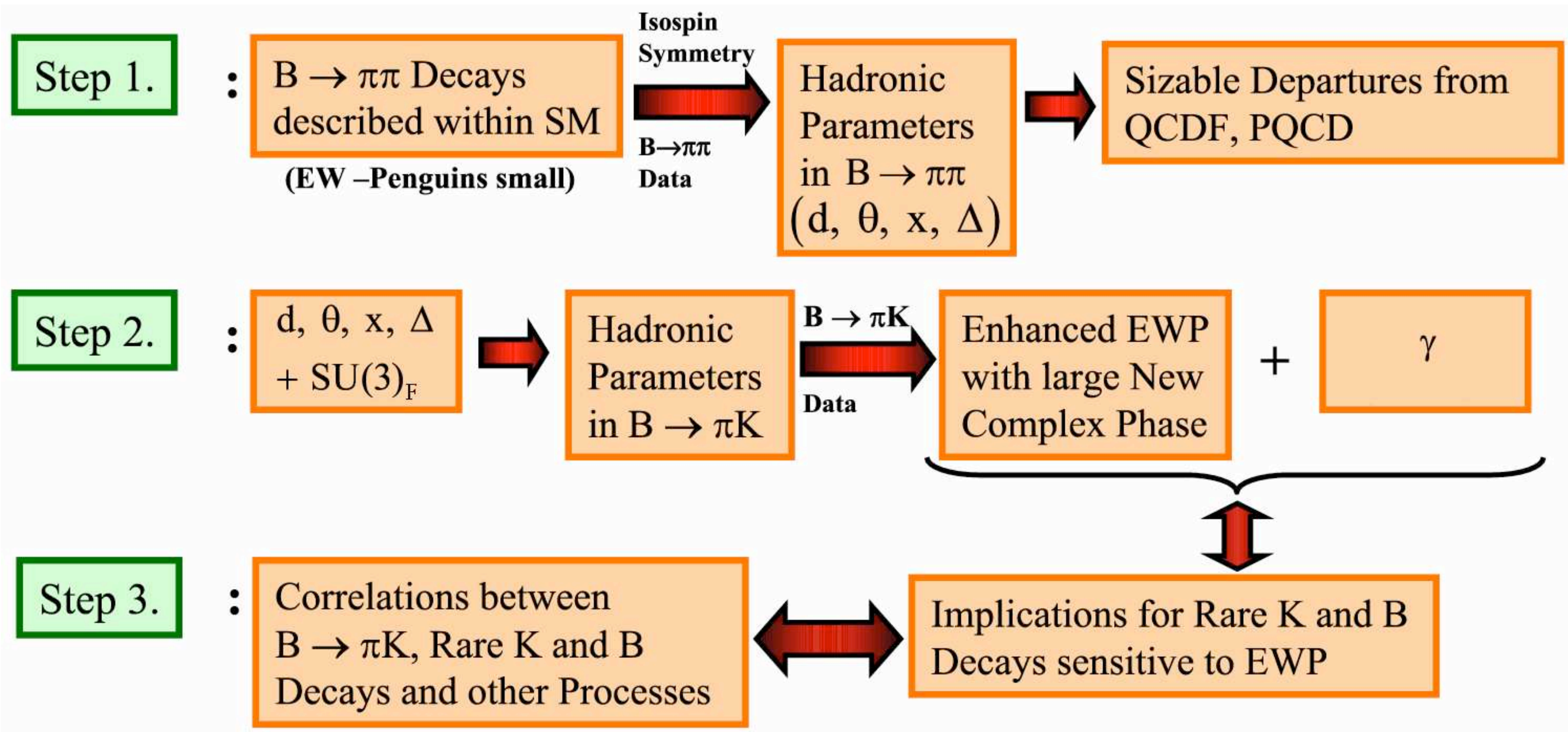
[Long history of $B \to \pi K$ studies: Gronau, Rosner & London ('94); R.F. ('95–'98); R.F. & Mannel ('97); Neubert & Rosner ('98); Buras & R.F. ('98–'00); ...]

EW Penguins and the $B \to \pi K$ Puzzle

- $B \to \pi K$ decays with *tiny* EW penguin contributions:
  - Observables can be accommodated in the Standard Model!
  - Example: direct CP asymmetry of $B_d^0 \to \pi^- K^+$.
- $B \to \pi K$ decays with *sizeable* EW penguin contributions:
  - Branching ratios show a surprising pattern!
  - This "puzzle" emerged already in 2000, when CLEO reported the observation of the $B_d^0 \to \pi^0 K^0$ channel with a remarkably prominent rate, and is now also/still present in the BaBar and Belle data (!?) ... [Buras & R.F. ('00)]
  - Has recently received a lot of attention! Beneke & Neubert ('03); Yoshikawa ('03); Gronau & Rosner ('03); Barger *et al.* ('04); Wu & Zu ('05); ...

What's going on? $\longrightarrow$

A Systematic Strategy in 3 Steps



Comprehensive analysis! Let's here just have a look at ...

[Buras, R.F., Recksiegel & Schwab (2003–2005)]

Decays with a *Sizeable* Impact of EW Penguins

- The key quantities: [Buras & R.F. ('98)]

$$R_{\rm c} \equiv 2\left[\frac{\text{BR}(B^+\to\pi^0K^+)+\text{BR}(B^-\to\pi^0K^-)}{\text{BR}(B^+\to\pi^+K^0)+\text{BR}(B^-\to\pi^-\bar{K}^0)}\right] \stackrel{\rm Exp}{=} 1.01\pm0.09$$

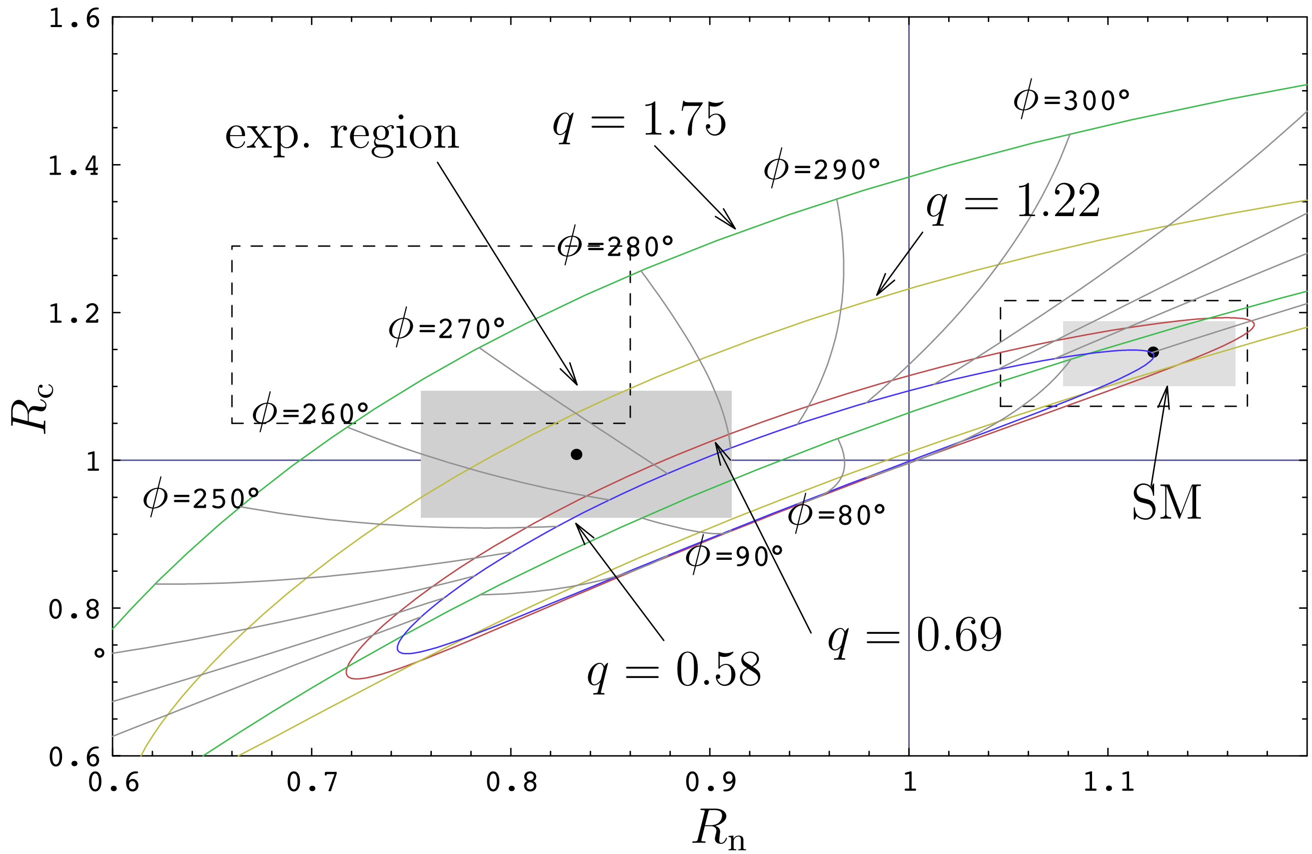
$$R_{\rm n} \equiv \frac{1}{2}\left[\frac{\text{BR}(B^0_d\to\pi^-K^+)+\text{BR}(\bar{B}^0_d\to\pi^+K^-)}{\text{BR}(B^0_d\to\pi^0K^0)+\text{BR}(\bar{B}^0_d\to\pi^0\bar{K}^0)}\right] \stackrel{\rm Exp}{=} 0.83\pm0.08$$

- Features of the EW penguins:
  - Enter in colour-allowed from through the modes involving π^0's.
  - Description through the following parameters:

$$\underbrace{q \stackrel{\rm SM}{=} 0.58 \quad (\to \text{"strength"})}_{SU(3)\ \text{[Neubert \& Rosner ('98)]}}, \quad \phi \stackrel{\rm SM}{=} 0^\circ\ (\to \text{CP-violating phase})$$

  - Provide an interesting avenue for NP to manifest itself ...
    [R.F. & Mannel ('97); Grossman, Neubert & Kagan ('99); ...]

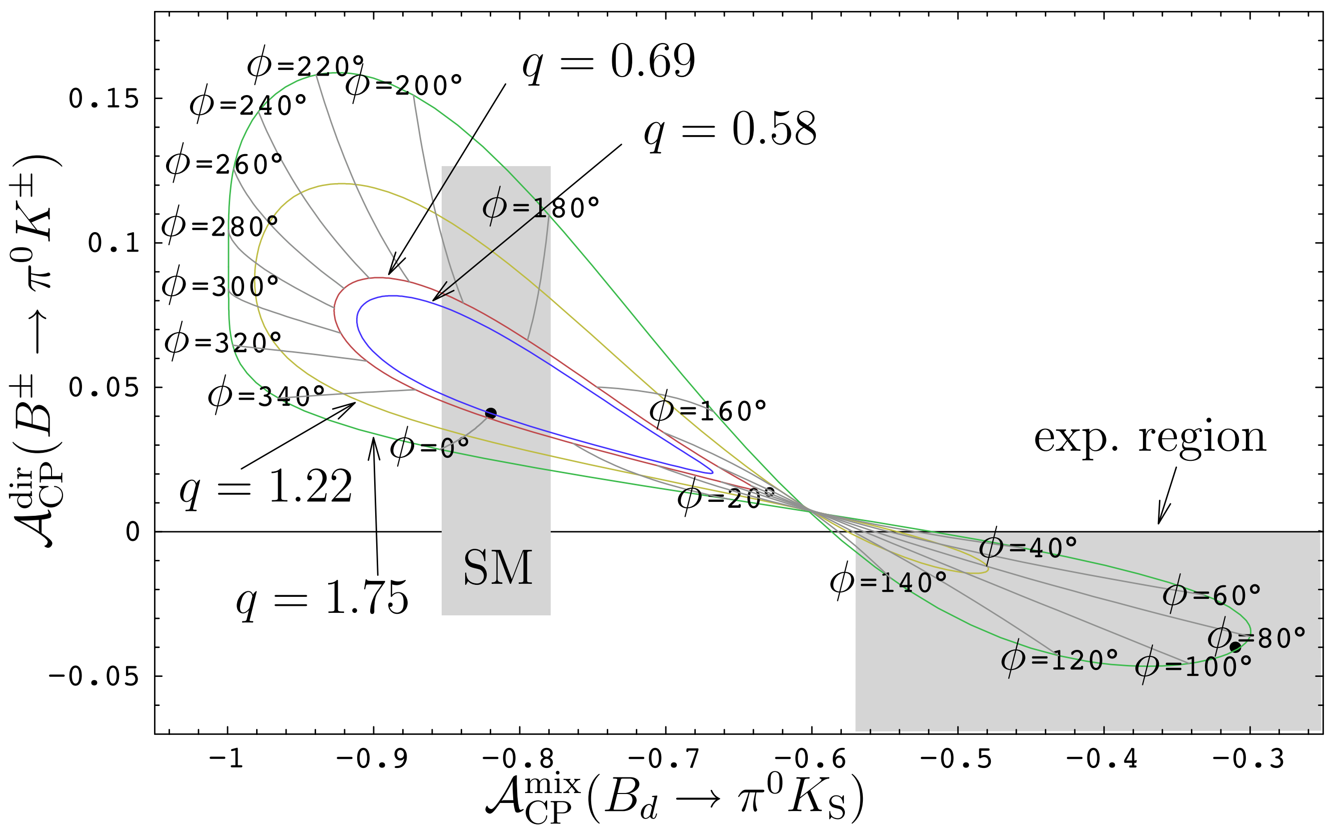
- Situation in the $R_{\rm n}$-$R_{\rm c}$ plane:



- Allow for NP in the EW penguin sector to resolve this "$B \to \pi K$ puzzle":

$$R_{\rm n,c}|_{\rm exp} \quad \Rightarrow \quad \boxed{q = 0.99\,^{+0.66}_{-0.70}, \quad \phi = -(94^{+16}_{-17})^\circ}$$

- *Prediction* of CP violation in $B^\pm \to \pi^0 K^\pm$ and $B_d \to \pi^0 K_S$:

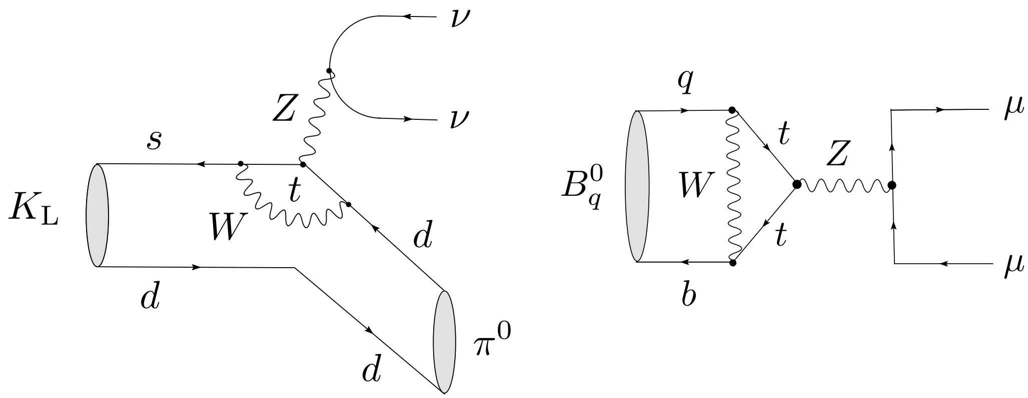


$\Rightarrow$ can reach the experimental central values for $\phi \sim +90^\circ$

- Similar feature also for $(\sin 2\beta)_{\phi K_S}$: $\phi_0 \to \phi$ in the $B \to \phi K$ discussion.

Interplay with Rare K and B Decays

- Attractive possibility for NP to enter EW penguins: Z penguins



  - Modified strength and CP-violating phase!
  - Can be realized, for example, in SUSY ...

- Theoretical considerations allow us to convert the $B \to \pi K$ parameters (q, ϕ) into short-distance functions characterizing rare B and K decays:

"Inami–Lim" functions: $\underbrace{X = |X|e^{i\theta_X}}_{K\to\pi\nu\bar{\nu}}, \quad \underbrace{Y = |Y|e^{i\theta_Y}}_{B_{s,d}\to\mu^+\mu^-}, \quad \ldots$

- Interesting effects: $K^+ \to \pi^+\nu\bar{\nu}$, $K_L \to \pi^0\nu\bar{\nu}$, $B_{s,d} \to \mu^+\mu^-$, ...

$\Rightarrow$ specific patterns for various NP scenarios of this kind $\to$

- Constraints from the data for $B \to X_s \ell^+ \ell^-$ processes:

$$\Rightarrow X \leq 1.95, \quad Y \leq 1.43.$$

- On the other hand, the values of (q, ϕ) preferred by the $R_{\rm n,c}|_{\rm exp}$ require:

$$|X|_{\rm min} \approx |Y|_{\rm min} \approx 2.2.$$

- Scenarios for possible future measurements satisfying the bounds:

Quantity	SM	Scen A	Scen B	Scen C	Experiment
$R_{\rm n}$	1.12	0.88	1.03	1	0.83 ± 0.08
$R_{\rm c}$	1.15	0.96	1.13	1	1.01 ± 0.09

Decay	SM	Scen A	Scen B	Scen C	Exp. bound @ 90% C.L.
BR($K^+ \to \pi^+ \nu\bar{\nu})/10^{-11}$	9.3	2.7	8.3	8.4	$(14.7^{+13.0}_{-8.9})$
BR($K_{\rm L} \to \pi^0 \nu\bar{\nu})/10^{-11}$	4.4	11.6	27.9	7.2	$< 2.9 \times 10^4$
BR($K_{\rm L} \to \pi^0 e^+ e^-)/10^{-11}$	3.6	4.6	7.1	4.9	< 28
BR($B \to X_s \nu\bar{\nu})/10^{-5}$	3.6	2.8	4.8	3.3	< 64
BR($B_s \to \mu^+ \mu^-)/10^{-9}$	3.9	9.2	9.1	7.0	$< 1.5 \times 10^2$

[Details: A. Buras, R.F., S. Recksiegel & F. Schwab, hep-ph/0512032]

We observe the following features:

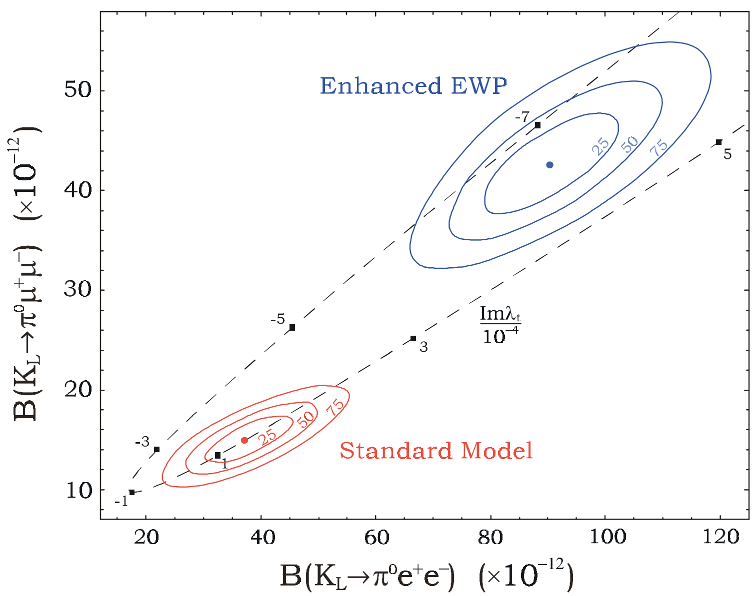
- Rare decays allow us to pin down a modified EW penguin sector with new sources of CP violation (already indicated by $B \to \phi K$, $B \to \pi K$!?).

- In particular rare K decays are very sensitive: $\to$ *measure them!*

  – $K^+ \to \pi^+ \nu\bar{\nu}$ could be suppressed through charm-top interference.

  – $K_{\rm L} \to \pi^0 \nu\bar{\nu}$ may be dramatically enhanced!

  – Interesting correlations between $K_{\rm L} \to \pi^0 e^+ e^-$ and $K_{\rm L} \to \pi^0 \mu^+ \mu^-$:



[Isidori *et al.* ('04)]

  – The enhancements of $B_s \to \mu^+ \mu^-$ could be detected at the LHC: $\to$

New Perspectives

in the LHC Era:

$\longrightarrow$ *full access to the B_s system!*

- At the e^+e^- B factories operating @ $\Upsilon(4S)$, *no* B_s mesons are accessible!

- Could go to the $\Upsilon(5S)$ resonance $\rightarrow$ talk by Alan Schwartz.

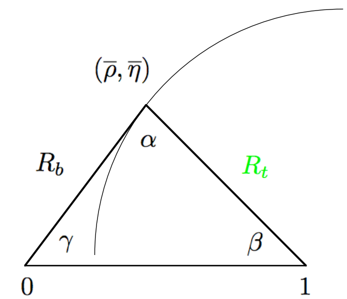
- At hadron colliders, plenty of B_s mesons are produced, which are currently the domain of CDF and D0 at run II of the Tevatron ...

The Mixing Parameters of the B_s System

B_s^0–$\overline{B_s^0}$ oscillations could so far *not* be observed ...

- Difference ΔM_s of the mass eigenstates: $\Delta M_s|_{\rm exp} > 16.6\,{\rm ps}^{-1}$ (90% C.L.)
  - Comparison with mass difference ΔM_d:

$$\Rightarrow \quad \boxed{R_t \text{ with the help of a parameter } \quad \xi \stackrel{SU(3)}{\longrightarrow} 1}$$



- Difference $\Delta\Gamma_s$ of the decay widths of the mass eigenstates:
  - $\Delta\Gamma_s/\Gamma_s = \mathcal{O}(10\%)$, whereas $\Delta\Gamma_d/\Gamma_d$ is negligible!
  - Interesting studies with "untagged" rates:

$$\boxed{\langle\Gamma(B_q(t)\to f)\rangle \equiv \Gamma(B_q^0(t)\to f) + \Gamma(\overline{B_q^0}(t)\to f).}$$

[Dunietz (1995); R.F. & Dunietz (1996–97)]

  - *First* results from $B_s \to J/\psi\phi$: [Dighe, Dunietz & R.F. ('99)]

$$\frac{\Delta\Gamma_s}{\Gamma_s} = \begin{cases} 0.65^{+0.25}_{-0.33} \pm 0.01 & \text{[CDF ('04)]} \\ 0.24^{+0.28+0.03}_{-0.38-0.04} & \text{[D0 ('05))} \end{cases}$$

CP Violation in $B_s \to J/\psi\phi$

- $B_s \to J/\psi\phi$ is the B_s counterpart of the "golden" decay $B_d \to J/\psi K_S$, having an admixture of different CP eigenstates in the final state:

$\Rightarrow$ $J/\psi[\to \ell^+\ell^-]\phi[\to K^+K^-]$ angular distribution:

  - Direct CP-violating effects: $\to 0$
  - Mixing-induced CP-violating effects: $\to \sin\phi_s$

[Dighe, Dunietz & R.F. (1999)]

- Standard Model: $\phi_s = -2\lambda^2\eta = \mathcal{O}(10^{-2})$

$\Rightarrow$ *tiny* value of $\sin\phi_s$, i.e. *tiny* mixing-induced CP violation!

- Big Hope: Experiments will find a *sizeable* value of $\sin\phi_s$

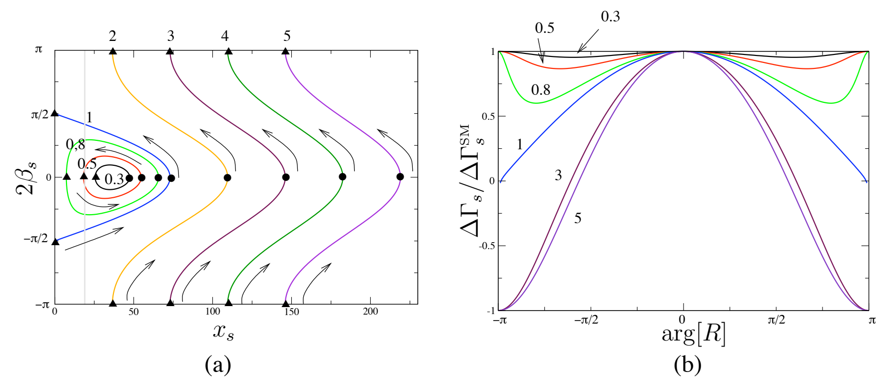
... would give us an *immediate* signal for CP-violating NP!

[Nir & Silverman (1990); Branco *et al.* (1993); ... Dunietz, R.F. & Nierste (2001)]

→ Examples of Specific Model-Dependent NP Analyses:

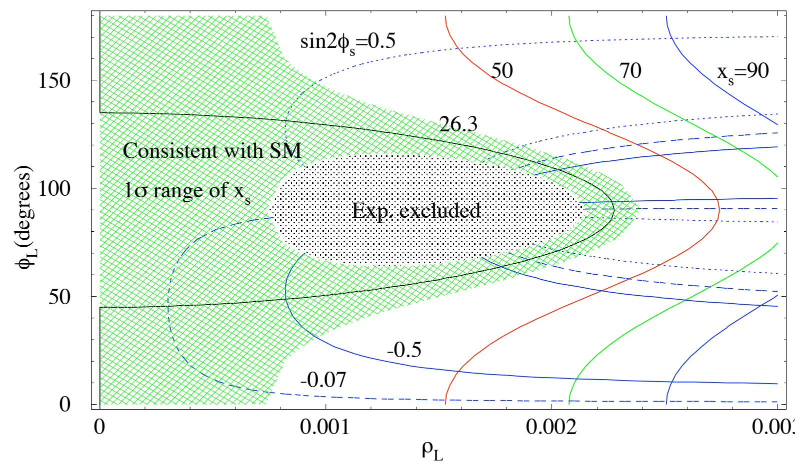
- SUSY scenario:

  [Ball, Khalil & Kou ('03)]



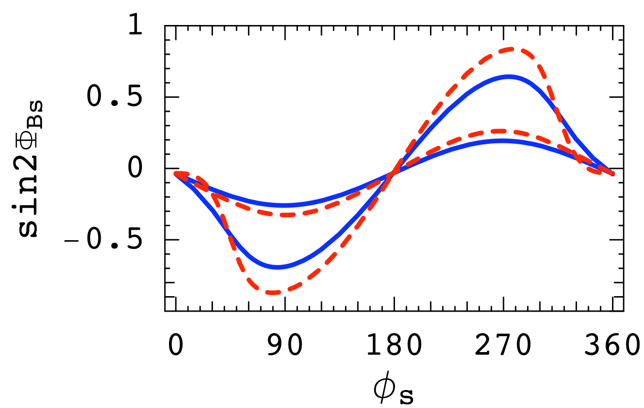
- Models with extra Z':

  [Barger *et al.* ('04)]



- Models with a 4th generation:

  [W.-S. Hou *et al.* ('05)]



Several other exciting aspects of B @ LHC, e.g.:

- Determinations of γ:
  - $B_s \to D_s^{\pm} K^{\mp}$, $B_d \to D^{\pm}\pi^{\mp}$ system: $\longrightarrow$ pure tree decays
  - $B_s \to K^+K^-$, $B_d \to \pi^+\pi^-$ system: $\longrightarrow$ penguins

$\Rightarrow$ will discrepancies arise?

- Rare $B_{s,d} \to \mu^+\mu^-$ decays:
  - Originate from Z^0 penguins and box diagrams in the SM (see above):

    $\Rightarrow$ BRs at the 10^{-9} (B_s) and 10^{-10} (B_d) levels.
  - Even the challenging SM case would be in reach of the LHC, *but* NP may significantly enhance the BRs!
  - Interesting correlations in models with "minimal flavour violation".
  - Bounds on BRs imply constraints for NP parameter spaces.

Conclusions and Outlook

- We are currently in a "golden era" of flavour physics and CP violation:
  - CP violation is now well established in the B-meson system!
  - Remarkable agreement with the Kobayashi–Maskawa picture!
  - *But also hints for discrepancies (NP?):* $\rightarrow$ have to be further studied!
  - Still several essentially *unexplored aspects:* $b \rightarrow d$ penguins observed ...

  $\rightarrow$ go ahead & hopefully further at a super-B factory!

- The LHC will allow exciting new B studies: $\rightarrow$ in particular LHCb
  - Fully exploit the B_s physics potential (taking over from CDF & D0).
  - Many other interesting and promising topics to study ...

- The future of K physics lies in the field or rare decays: $K \rightarrow \pi\nu\bar{\nu}$
  - Very clean and sensitive probes for NP $\rightarrow$ *have to be exploited!*
  - Fortunately plans for experiments @ CERN & KEK/J-PARC.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a Workshop on the interplay of flavour and collider physics
First meeting:
CERN, November 7-10 2005
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• Flavour phenomena in the decays of SUSY particles
• Squark/slepton spectroscopy and family structure
• Flavour aspects of non-SUSY BSM physics
• Flavour physics in the lepton sector
• g-2 and EDMs as BSM probes
• Flavour experiments for the next decade
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