New Physics Effects in

$B \to J/\Psi K$ and $B \to \phi K$

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Introduction

New Physics in B Decays

- There is a large variety of possible new physics scenarios:
  - Supersymmetric models
  - Left-Right Symmetric models
  - Large extra dimensions
  - ... (Recent review: Ligeti, Nir hep-ph/0202117)
- No generally accepted model for new physics in the Flavour sector

Generic parametrization

- Standard Model is the most general renomalizable model
  "Dimension-four operators"
- Most general ansatz for Physics beyond the Standard model:

$$\mathcal{L}_{new} = \frac{1}{\Lambda^2} \sum_i C_i \mathcal{O}_i$$

  - $\mathcal{O}_i$ Dimension-six operators with Coefficients C_i
  - Λ^2 scale of new physics

Unknown New Physics, Scale Λ

$\downarrow$ Integrate out heavy degrees of freedom $\downarrow$

$\boldsymbol{\mathcal{L} = \mathcal{L}_{\textbf{Standard Model}} + \mathcal{L}_{new}}$, **Scale M_W**

$\downarrow$ Integrate out top-quark , W and Z Bosons $\downarrow$

Four-Fermion Operators, Scale m_b

- Flavour Physics at low energies (Scale m_b):
- Physics of Four Fermion Operators (dim-6)
- Couplings of these operators:
  - Standard Model: $G_F \propto \dfrac{g^2}{M_W^2} \sim \dfrac{1}{< v >^2}$
  - New Physics Contributions: $\dfrac{1}{\Lambda^2}$
- Problem:

  In the most general case there are $\mathcal{O}(100)$ operators parametrizing effects beyond the Standard model in flavour physics !!

  (Buchmüller Wyler)

$\Delta B = 2$ Transitions

- Relevant dimension-six operator:

$$\mathcal{L}_{new}^{\Delta B=2} = \frac{1}{\Lambda^2} \sum C_i \left[(\bar{b}\Gamma_i S_i d_1)(\bar{b}\Gamma_i S_i d_2) \right]$$

with

– Γ_i: arbitrary Dirac Matrix, – S_i: Color Structure

- This can modify: – Frequency of $B - \bar{B}$ Oscillations
  – CP violating phase in the mixing

- Standard Model contributions are small:

$$C_{SM} \sim \frac{G_F}{\sqrt{2}} \left(\frac{G_F M_W^2}{\sqrt{128}\pi^2} \right) (V_{td} V_{tb}^*)^2$$

$\rightarrow$ High Sensitivity to new physics

- A new physics contribution could be as large as the one from the Standard model (CKM and loop suppression !):
- Assume the same coupling as in the Standard model

$$C_{NP} = \frac{G_{\mathrm{F}}}{\sqrt{2}} \left(\frac{G_{\mathrm{F}} M_W^2}{\sqrt{128}\pi^2} \right) \frac{M_W^2}{\Lambda^2} e^{-i2\psi},$$

- 2ψ: New weak phase from new physics
- Rough estimate: Adding the two contributions yields for the mixing phase ϕ_{M}

$$\tan \phi_{\mathrm{M}} = \frac{\sin(2\beta) + \varrho^2 \sin(2\psi)}{\cos(2\beta) + \varrho^2 \cos(2\psi)},$$

with

$$\varrho = \left(\frac{1}{\lambda^3 A R_t} \right) \left(\frac{M_W}{\Lambda} \right) \quad \text{could be} \quad \mathcal{O}(1)$$

- Senistivity up to scales $\Lambda \sim 8$ TeV

Analysis of $B \to J/\Psi K$

- Isospin analysis of $B \to J/\Psi K$ $I = 1/2 \to I = 1/2$

$$\begin{pmatrix} |+1/2\rangle \\ |-1/2\rangle \end{pmatrix} : \quad \underbrace{\begin{pmatrix} |B^+\rangle \\ |B_d^0\rangle \end{pmatrix}, \begin{pmatrix} |\overline{B_d^0}\rangle \\ -|B^-\rangle \end{pmatrix}}_{CP}, \underbrace{\begin{pmatrix} |J/\psi K^+\rangle \\ |J/\psi K^0\rangle \end{pmatrix}, \begin{pmatrix} |J/\psi \overline{K^0}\rangle \\ -|J/\psi K^-\rangle \end{pmatrix}}_{CP}$$

- Hamiltonian for the transition can have $I = 0$ or $I = 1$

- In general

$$\langle J/\psi K^+|\mathcal{H}_{\text{eff}}^{I=0}|B^+\rangle = +\langle J/\psi K^0|\mathcal{H}_{\text{eff}}^{I=0}|B_d^0\rangle$$
$$\langle J/\psi K^+|\mathcal{H}_{\text{eff}}^{I=1}|B^+\rangle = -\langle J/\psi K^0|\mathcal{H}_{\text{eff}}^{I=1}|B_d^0\rangle$$

$B \to J/\Psi K$ in the Standard Model

We have

$$A(B^+ \to J/\psi K^+) = \frac{G_{\rm F}}{\sqrt{2}}\left[V_{cs}V_{cb}^*\left\{A_c^{(0)} - A_c^{(1)}\right\} + V_{us}V_{ub}^*\left\{A_u^{(0)} - A_u^{(1)}\right\}\right]$$

$$A(B_d^0 \to J/\psi K^0) = \frac{G_{\rm F}}{\sqrt{2}}\left[V_{cs}V_{cb}^*\left\{A_c^{(0)} + A_c^{(1)}\right\} + V_{us}V_{ub}^*\left\{A_u^{(0)} + A_u^{(1)}\right\}\right],$$

where

$$A_c^{(0)} = A_{\rm CC}^{c} - A_{\rm QCD}^{\rm pen} - A_{\rm EW}^{(0)}, \quad A_c^{(1)} = -A_{\rm EW}^{(1)}$$

$$A_u^{(0)} = A_{\rm CC}^{u(0)} - A_{\rm QCD}^{\rm pen} - A_{\rm EW}^{(0)}, \quad A_u^{(1)} = A_{\rm CC}^{u(1)} - A_{\rm EW}^{(1)}$$

- CKM (Factor λ^2) and dynamical (Factor $\bar{\lambda} \sim \lambda$) suppression of the phase of V_{ub}

$$A(B^+ \to J/\psi K^+) = A(B_d^0 \to J/\psi K^0) + \mathcal{O}(\lambda^3)$$

- Amplitude in the SM

$$A(B^+ \to J/\psi K^+) = A_{\mathrm{SM}}^{(0)} \equiv \frac{G_{\mathrm{F}}}{\sqrt{2}} \left(1 - \frac{\lambda^2}{2}\right) \lambda^2 A \, A_c^{(0)}$$

New Physics Contributions

- $\Delta B = 2$: mixing phase $\phi_{\mathrm{M}} \neq \beta$
- $\Delta B = 1$: Effective Hamiltonian is decomposed into I=0 and I=1:

$$A(B^+ \to J/\psi K^+) = A_{\mathrm{SM}}^{(0)} \left[1 + \sum_k r_0^{(k)} e^{i\delta_0^{(k)}} e^{i\varphi_0^{(k)}} - \sum_j r_1^{(j)} e^{i\delta_1^{(j)}} e^{i\varphi_1^{(j)}} \right]$$

$$A(B_d^0 \to J/\psi K^0) = A_{\mathrm{SM}}^{(0)} \left[1 + \sum_k r_0^{(k)} e^{i\delta_0^{(k)}} e^{i\varphi_0^{(k)}} + \sum_j r_1^{(j)} e^{i\delta_1^{(j)}} e^{i\varphi_1^{(j)}} \right]$$

- $r_I^{(l)}$ is the Modulus, $\delta_I^{(l)}$ is the strong and $\varphi_I^{(l)}$ the weak phase of the l^{th} contribution with Isospin I, $\quad r_I^{(l)} \sim \mathcal{O}(M_W^2/\Lambda^2)$

Definition of Observables

- Standard set of Observables

$$\mathcal{A}_{\rm CP}^{(+)} \equiv \frac{|A(B^+ \to J/\psi K^+)|^2 - |A(B^- \to J/\psi K^-)|^2}{|A(B^+ \to J/\psi K^+)|^2 + |A(B^- \to J/\psi K^-)|^2}$$

$$\mathcal{A}_{\rm CP}^{\rm dir} \equiv \frac{|A(B^0_d \to J/\psi K^0)|^2 - |A(\overline{B^0_d} \to J/\psi \overline{K^0})|^2}{|A(B^0_d \to J/\psi K^0)|^2 + |A(\overline{B^0_d} \to J/\psi \overline{K^0})|^2}$$

$$B \equiv \frac{\langle |A(B_d \to J/\psi K)|^2\rangle - \langle |A(B^\pm \to J/\psi K^\pm)|^2\rangle}{\langle |A(B_d \to J/\psi K)|^2\rangle + \langle |A(B^\pm \to J/\psi K^\pm)|^2\rangle}$$

$$a_{\rm CP}(t) = \mathcal{A}_{\rm CP}^{\rm dir} \cos(\Delta M_d t) + \mathcal{A}_{\rm CP}^{\rm mix} \sin(\Delta M_d t)$$

- Definition of the "CP-averaged" amplitudes

$$\langle |A(B_d \to J/\psi K)|^2\rangle \equiv \frac{1}{2}\left[|A(B^0_d \to J/\psi K^0)|^2 + |A(\overline{B^0_d} \to J/\psi \overline{K^0})|^2\right]$$

New Observables

- Find observables which are especially sensitiv to new physics:

$$S \equiv \frac{1}{2}\left[\mathcal{A}_{\rm CP}^{\rm dir} + \mathcal{A}_{\rm CP}^{(+)}\right], \quad D \equiv \frac{1}{2}\left[\mathcal{A}_{\rm CP}^{\rm dir} - \mathcal{A}_{\rm CP}^{(+)}\right]$$

In addition: B (as before)

- S measures the $I = 0$ new physics contribution

$$S = -2 \left[\sum_k r_0^{(k)} \sin \delta_0^{(k)} \sin \varphi_0^{(k)} \right] \left[1 - 2 \sum_l r_0^{(l)} \cos \delta_0^{(l)} \cos \varphi_0^{(l)} \right]$$

- B and D measure the $I = 1$ new physics contribution

$$B = +2 \sum_j r_1^{(j)} \cos \delta_1^{(j)} \cos \varphi_1^{(j)}$$

$$D = -2 \sum_j r_1^{(j)} \sin \delta_1^{(j)} \sin \varphi_1^{(j)}$$

  – The the standard model contribution which is under poor theoretical control is neglected: $\mathcal{O}(\lambda^3)$

  – The new physics contribution has to larger than $\mathcal{O}(\lambda^3)$

Is $a_{\mathrm{CP}}(B \to J/\Psi K_S) = -a_{\mathrm{CP}}(B \to J/\Psi K_L)$?

(Grossman, Kagan, Ligeti, hep-ph/0204212)

- Main (and small) contribution in the Standard Model:

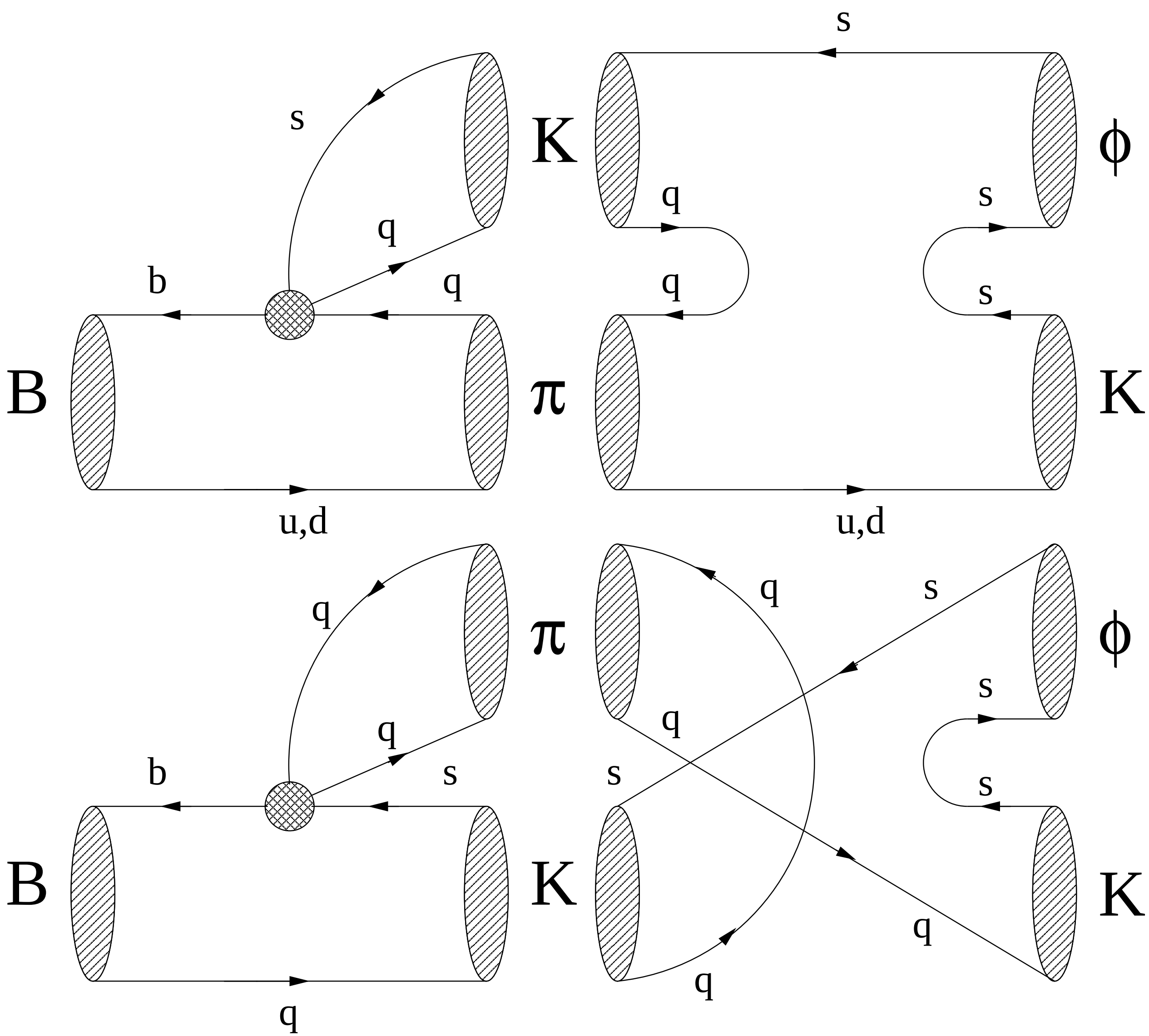
$$a_{\mathrm{CP}}(B \to J/\Psi K_S) = -a_{\mathrm{CP}}(B \to J/\Psi K_L) + \mathcal{O}(\mathrm{Re}\ \epsilon_K)$$

- New Physics effects:
  - dim-6-operator $(\bar{b}d)(\bar{s}d)$ and $\bar{c}c$ from Gluons
  - dim-9-operator $(\bar{b}d)(\bar{s}d)(\bar{c}c)$
- $\longrightarrow$ Too small for reasonable valus of Λ
- Study of $B \to K^* J/\Psi$

Analysis of the Decays $B \longrightarrow \phi K$

- The situation is very similar to the case $B \to J/\Psi K$:
  - The transition is $I = 1/2 \to I = 1/2$
  - The Hamiltonian can have $I = 0$ and $I = 1$
  - The Isospin decomposition looks the same
- The Dynamics are different:
  - The ϕ is almost pure $s\bar{s}$ state
  - The CC operators cannot contribute through tree diagrams
  - Only penguin topologies matter, e.g.

$$B^+ \to [D_s^+ \overline{D}^0, ...] \to \phi K^+$$



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$B \to \phi K$ in the Standard Model

- With the same dynamical assumption as in $B \to J/\Psi K$ we get

$$A(B^+ \to \phi K^+) = \mathcal{A}_{\rm SM}^{(0)}\left[1 + \mathcal{O}(\overline{\lambda}^2)\right] = A(B_d^0 \to \phi K^0),$$

with

$$\mathcal{A}_{\rm SM}^{(0)} \equiv \frac{G_{\rm F}}{\sqrt{2}}\lambda^2 A\,\mathcal{A}_c^{(0)}$$

- The same variables as in $B \to J/\Psi K$ are sensitive to new physics (appearing at the level of $\mathcal{O}(\lambda)$)

Conclusions: Current Situation

- $B \to J/\psi K$: Data as of last summer (Rome Conference) plus some updates from Spring conferences

$$B = \begin{cases} (-6 \pm 3)\% & \text{BaBar data} \\ (-10 \pm 7)\% & \text{Belle data} \end{cases}$$

$$S = -(4 \pm 6)\% \quad D = -(4 \pm 6)\%$$

- $B \to \phi K$: Data is not yet conclusive
- Measurement of charged and neutral modes is needed !!
- No hint at new physics yet !