Nonfactorizable charm – loop effects in exclusive FCNC B – decays

Dmitri Melikhov

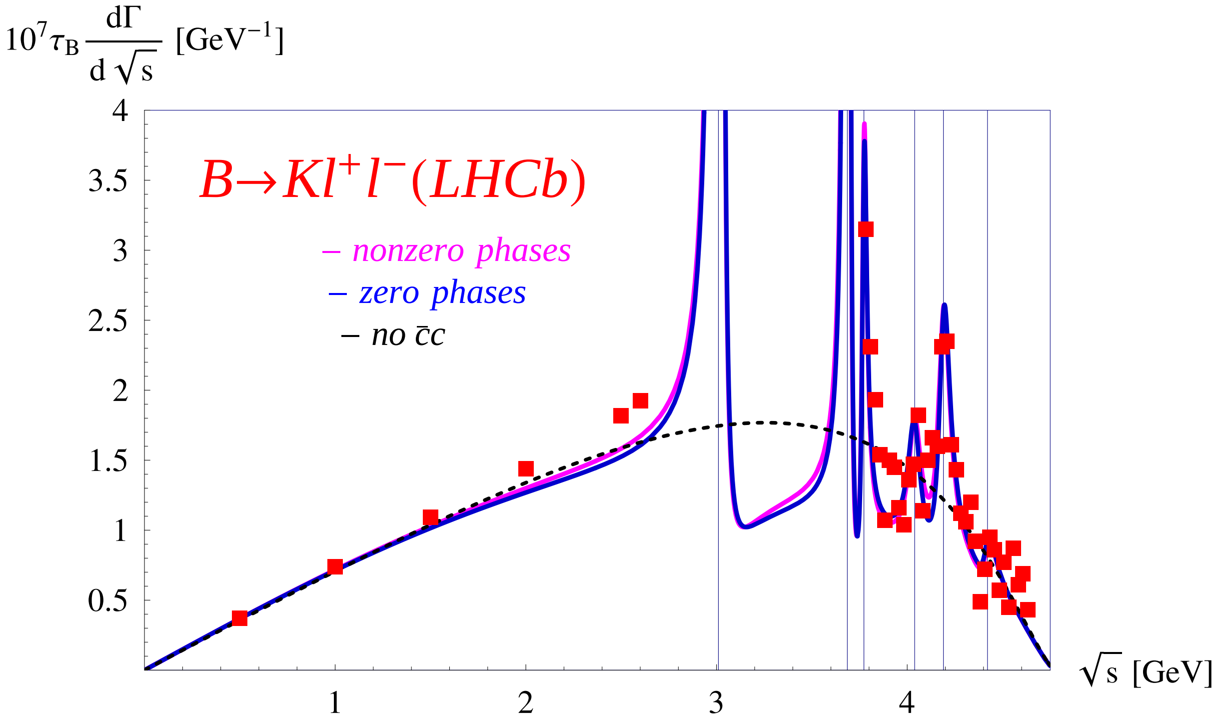
SINP, Moscow State University & HEPHY, Austrian Academy of Sciences, Vienna

We revisit the calculation of nonfactorizable contributions induced by charm-quark loops to the amplitudes of exclusive FCNC B-decays. Nonfactorizable contributions may be expressed via the three-particle quark-antiquark-gluon distribution amplitude (3DA) of the B-meson $\langle 0|\bar{q}(x)G_{\mu\nu}(y)b(0)|B(p)\rangle$. We show that the knowledge of the full generic 3DA with non-aligned arguments, is necessary for a proper summation of large $\left(\Lambda_{QCD}m_b/m_c^2\right)^n$ corrections. In particular, the dependence of 3DA on variable $(x-y)^2$ is crucial.

Based on: A. Kozachuk, D. M., PLB786, 378 (2018).

FCNC $b \to s$ and $b \to d$ transitions do not occur at the tree level in SM and proceed via loops, where t, c and u-quarks contribute. BRs of FCNC decays are small; on the other hand, new particles may show up virtually in the loops. Therefore, FCNC decays are most popular candidates for indirect search of physics BSM.

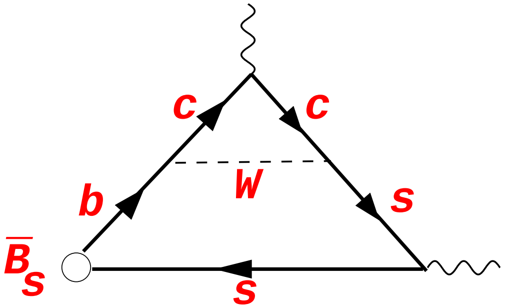
Illustration: $B \to K l^+ l^-$ decay $0 < \sqrt{s} < (M_B - M_K)$, s - momentum squared of $l^+ l^-$ pair.



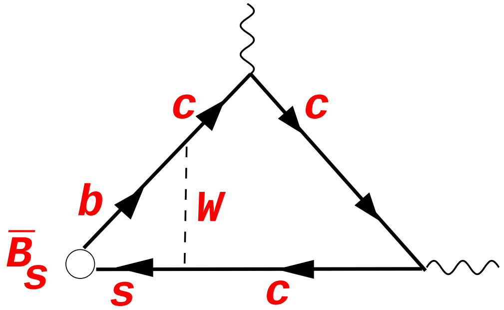
• Charmonia appear in the kinematical decay region. In the charmonia region, charm contribution dynamically enhanced and dominates.

• Far from the charmonia region, top dominates (black dashed). Still, to study possible NP effects,
Need to gain theoretical control over charm contributions

Charm generates two different topologies: (a) penguin topology (b) weak annihilation topology



(a)



(b)

• **Account of hard gluon exchanges lead to the four-quark operators**

$$H_{\rm eff}^{b\to s\bar{c}c} = -\frac{G_F}{\sqrt{2}} V_{cb}V_{cs}^* \; \{C_1(\mu)O_1 + C_2(\mu)O_2\}$$

with

$$O_1 = \bar{s}^j\gamma_\mu(1-\gamma_5)c^i\,\bar{c}^i\gamma^\mu(1-\gamma_5)b^j, \qquad O_2 = \bar{s}^i\gamma_\mu(1-\gamma_5)c^i\,\bar{c}^j\gamma^\mu(1-\gamma_5)b^j,$$

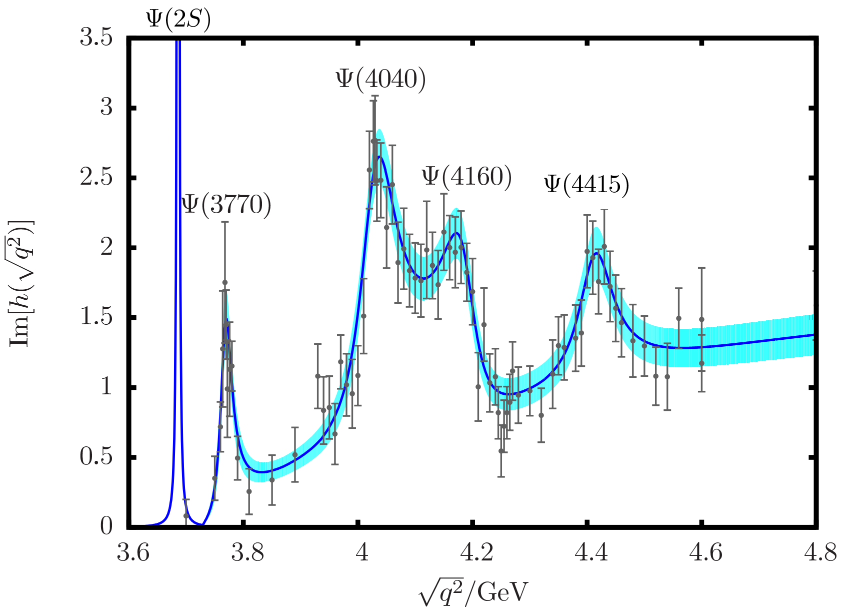
and the similar terms with $c \to u$ (i, j color indices). The SM Wilson coefficients at the scale $\mu_0 = 5$ GeV [corresponding to $C_2(M_W) = -1$]: $C_1(\mu_0) = 0.241$, $C_2(\mu_0) = -1.1$.

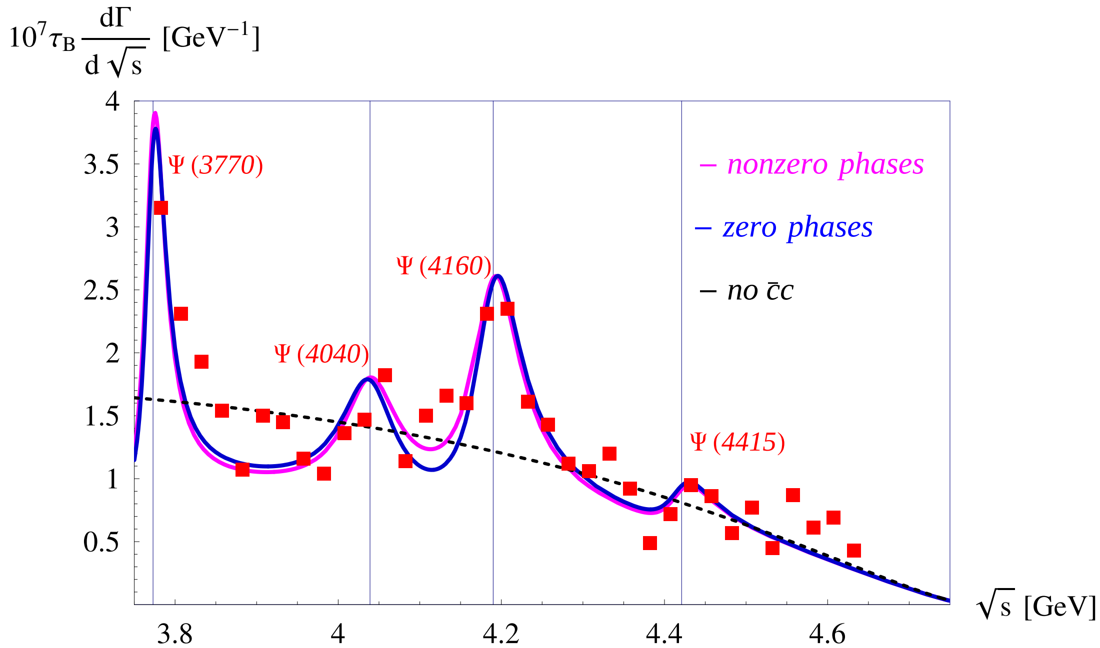
These operators lead to factorizable contributions to the amplitudes of exclusive FCNC B-decays.

• **Soft gluon exchanges between the charm-quark loop and the B-meson loop lead to nonfactorizable contributions to the amplitudes.**

- **Nonfactorizable charm contributions are comparable with factorizable contributions**

How do we know that? Compare charmonia in l^+l^--annihilation and in FCNC B-decays:

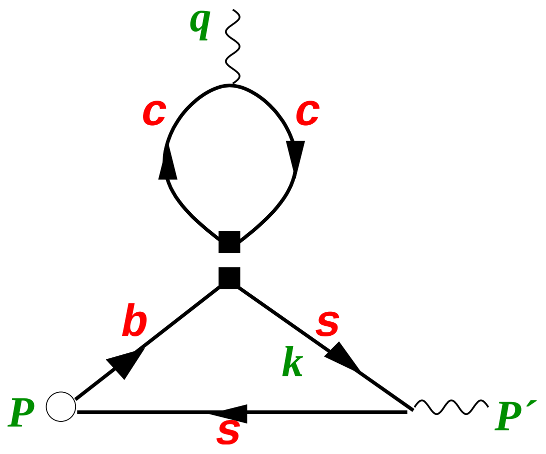


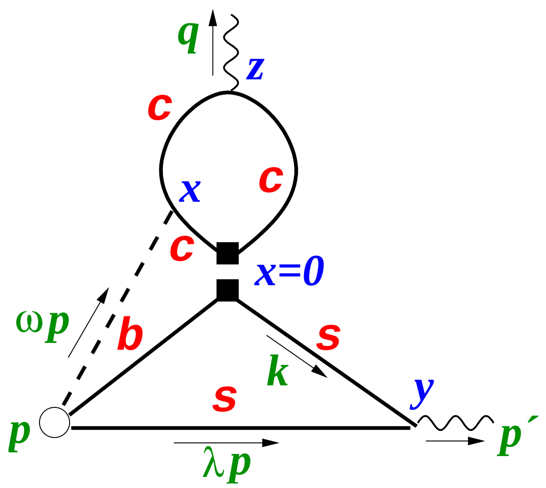


The patterns of charmonia in charm contribution to vacuum polarization (left) and in $B \to K l^+ l^-$ (right) are different. The difference is due to nonfactorizable contributions.

- **In some cases, factorizable charm contribution vanishes and thus only nonfactorizable charm contributes (e.g in $B \to K^* \gamma$)**

We need formalism to calculate nonfactorizable charm effects in QCD.





At $q^2 \ll 4m_c^2$, the charm loop may be calculated in pQCD.

Factorizable part: product of $B \to M_f$ form factor and the charm polarization function.

Nonfactorizable part (illustration for scalar "quarks" and scalar "gluon"):

$$A(q,p) \; = \; \frac{1}{(2\pi)^8}\int \frac{dk}{m_s^2-k^2}\int dy e^{-i(k-p')y}\int dx e^{-i\kappa x} d\kappa\, \Gamma_{cc}(\kappa,q)\,\langle 0|\bar{s}(y)G(x)b(0)|B_s(p)\rangle.$$

The 3DA depends on 5 variables xp, yp, x^2, y^2, xy ($p^2=M_B^2$) and may be parametrized as follows:

$$\langle 0|s^\dagger(y)G(x)b(0)|B_s(p)\rangle = \int d\lambda e^{-i\lambda yp}\int d\omega e^{-i\omega xp}\Phi(\omega,\lambda)\left[1+O\left(\Lambda_{\rm QCD}^2 x^2, \Lambda_{\rm QCD}^2 y^2, \Lambda_{\rm QCD}^2 (x-y)^2\right)\right].$$

$\Phi(\omega,\lambda)$ is peaked at $\lambda,\omega \sim \Lambda_{\rm QCD}/m_b$.

The contribution of $\Phi(\omega,\lambda)$ to $A(q,p)$ is easy to calculate (see the right plot).

Notice: the gluon is soft as the major part of the B-meson momentum is carried by b-quark.

Contributions of other terms to the amplitude $A(q, p)$ relative to the $\Phi(\omega, \lambda)$ term:

$$\Lambda^2_{\rm QCD} y^2 \to \frac{\Lambda_{\rm QCD}}{m_b}, \qquad \Lambda^2_{\rm QCD} x^2 \to \frac{\Lambda^3_{\rm QCD} m_b}{m_c^4}, \qquad \Lambda^2_{\rm QCD} xy \to \frac{\Lambda_{\rm QCD} m_b}{m_c^2}.$$

Nonfactorizable corrections are expressed via

$$\langle 0|s^\dagger(y) G(x) b(0)|B_s(p)\rangle = \int d\lambda e^{-i\lambda yp} \int d\omega e^{-i\omega xp} \Phi(\omega,\lambda) \left[1 + O\left(\Lambda^2_{\rm QCD} x^2, \Lambda^2_{\rm QCD} y^2, \Lambda^2_{\rm QCD}(x-y)^2\right)\right],$$

The new result is that the knowledge of its functional dependence on $(x - y)^2$ is essential for a proper resummation of large $\Lambda_{\rm QCD} m_b/m_c^2$ corrections.

Previosuly, it way believed that the 3DA with aligned arguments
$x_\mu = u y_\mu$**, on the LC** $x^2 = 0$**,** $y^2 = 0$ **and** $(x - y)^2 = 0$
is sufficient to calculate nonfactorizabe contributions.

One needs the off-LC contributions. A challenge for future calculations

Conclusions and outlook

• A serious open theoretical problem in FCNC B-decays is the contribution of charming loops which "pollute" the differential distributions.

• At $q^2 \ll 4m_c^2$, a consistent description of charming loops requires the knowledge of off-LC 3DAa.

• In QCD, B-meson 3DAs with non-aligned arguments involve new Lorentz structures compared to LC 3DAs. Respectively, new invariant amplitudes arise.

$$\langle 0|\bar{s}(y)G_{\alpha\beta}(uy)b(0)|B(v)\rangle = \int d\lambda e^{-i\lambda yv}\int d\omega e^{-i\omega uyv}\left[\frac{y_\alpha v_\beta}{yv}-\frac{y_\beta v_\alpha}{yv}\right]\Phi(\lambda,\omega). \tag{1}$$

For non-aligned case, new structures and new amplitudes arise:

$$\langle 0|\bar{s}(y)G_{\alpha\beta}(x)b(0)|B(v)\rangle = \int d\lambda e^{-i\lambda xv}\int d\omega e^{-i\omega yv}$$
$$\times\frac{1}{2}\left[\left(\frac{x_\alpha v_\beta}{xv}-\frac{x_\beta v_\alpha}{xv}+\frac{y_\alpha v_\beta}{yv}-\frac{y_\beta v_\alpha}{yv}\right)\Phi_S(\lambda,\omega)+\left(\frac{x_\alpha v_\beta}{xv}-\frac{x_\beta v_\alpha}{xv}-\frac{y_\alpha v_\beta}{yv}+\frac{y_\beta v_\alpha}{yv}\right)\Phi_A(\lambda,\omega)\right]. \tag{2}$$

$\Phi_S = \Phi$ from (1), whereas Φ_A is new. If the contributions induced by Φ_A are not suppressed, a consistent calculation of the decay amplitude A needs further inputs.

Detailed investigations are necessary.