Flavour physics, current projects and prospects

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Outline

- The decays $\bar{B}^0 \to \bar{K}^{*0}\,\mu^+\,\mu^-$ and $\bar{B}^0 \to \bar{K}^{*0}\,e^+\,e^-$ have been experimentally analyzed last years by the LHCb collaboration at the LHC.
- I. We calculated angular distribution and asymmetries in the FCNC decay

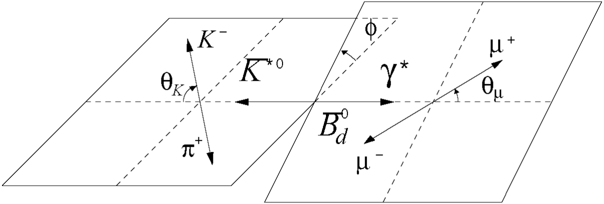
$$\bar{B}^0 \to \bar{K}^{*0}\,\ell^+\,\ell^- \to K^-\,\pi^+\,\ell^+\,\ell^-$$

  where $\ell = e,\, \mu$, and studied contribution of vector resonances.
- II. Estimate of the CP violation and effects of new physics in

$$\bar{B}^0 \to \bar{K}^{*0}\,\ell^+\,\ell^- \to K^-\,\pi^+\,\ell^+\,\ell^-.$$

- III. Future prospects:
  (i) Study of the T asymmetry in this decay,
  (ii) Decay $B_s \to \mu^+\mu^-(\gamma)$ – role of resonances and effects of new physics.

Angular distribution of final particles



The decay $\bar{B}_d^0 \to \bar{K}^{*0}(\to K^- \pi^+)\,\mu^+\mu^-$ is described by three angles θ_μ, θ_K and ϕ, and the muon pair invariant mass q^2

$$\frac{d^4\Gamma}{d\hat{q}^2\, d\cos\theta_\mu\, d\cos\theta_K\, d\phi} \sim \frac{9}{64\,\pi}\sum_{k=1}^{11} a_k(q^2) g_k(\theta_\mu, \theta_K, \phi)\,,$$

$$g_1 = 4\sin^2\theta_\mu\cos^2\theta_K\,,\ g_2 = (1+\cos^2\theta_\mu)\sin^2\theta_K\,, \qquad etc.$$

and $a_k(q^2)$ are combinations of amplitudes.

We studied contribution of low-lying vector resonances, decaying to lepton pair. They can modify predictions of the Standard model.

Vector resonances ($J^{PC} = 1^{--}$, long-distance effect, $r \sim 1$ GeV$^{-1} \sim 0.2$ fm) contribute through processes:

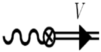
$$\bar{B}^0 \to \bar{K}^{*0}\, V \to \bar{K}^{*0}\ell^+\ell^- ,$$

where $V = \rho^0, \omega, \phi = s\bar{s}$ and charmonia $c\bar{c}$ resonances $J/\psi(1S)(3097),\ \psi(2S)(3686), \ldots$ which decay into $\ell^+\ell^-$ pair.

Schematically the contribution of intermediate vector resonances

Vector meson dominance models (VMD)

The important ingredient is $\gamma\, V$ transition vertex for arbitrary q^2:



- Version VMD1 (Sakurai model) :

$$\mathcal{L}_{\gamma V} = -ef_V\, Q_V\, m_V\, A^{\mu}\, V_{\mu}\,.$$

and $\gamma\, V$ vertex

$$\langle \gamma(q);\, \mu | V(q);\, \nu \rangle = -ef_V\, Q_V\, m_V\, g^{\mu\nu},$$

- Version VMD2 (in chiral models) :

$$\mathcal{L}_{\gamma V} = -\frac{ef_V\, Q_V}{2m_V}\,(\partial^{\mu} A^{\nu} - \partial^{\nu} A^{\mu})\,(\partial_{\mu} V_{\nu} - \partial_{\nu} V_{\mu})\,,$$

and $\gamma\, V$ vertex is explicitly gauge invariant

$$\langle\, \gamma(q);\, \mu | V(q);\, \nu\, \rangle = -\frac{ef_V\, Q_V}{m_V}\,(q^2 g^{\mu\nu} - q^{\mu} q^{\nu})\,,$$

(Q_V is "effective" electric charge of quarks in vector meson).

Vector meson dominance model (VMD)

- Version VMD3 : A more realistic model would include q^2 dependence of the $\gamma\, V$ coupling f_V, i.e.

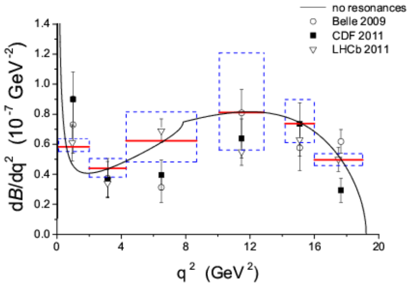
$$\langle\, \gamma(q);\, \mu | V(q);\, \nu\, \rangle = -\frac{e f_V(q^2) Q_V}{m_V}\,(q^2 g^{\mu\nu} - q^\mu q^\nu)\,,$$

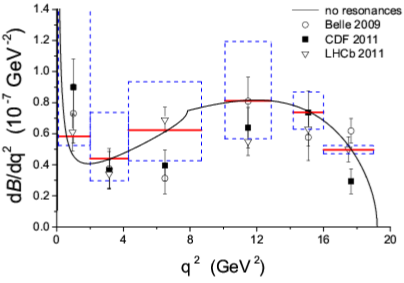
where q^2 dependence of $f_V(q^2)$ can be calculated in a model like constituent quark model, or based on one-loop intermediate states, for example, $D\bar{D}$, $D^*\bar{D}^*$ for $c\bar{c}$ meson. A model of such type is being developed.

Decay constants for vector meson, f_V, can be extracted from the experimental decay rate $\Gamma_{V\to e^+e^-}$.

Differential branching ratio (averaged over bins)

VMD2 (left) and VMD1 (right) models



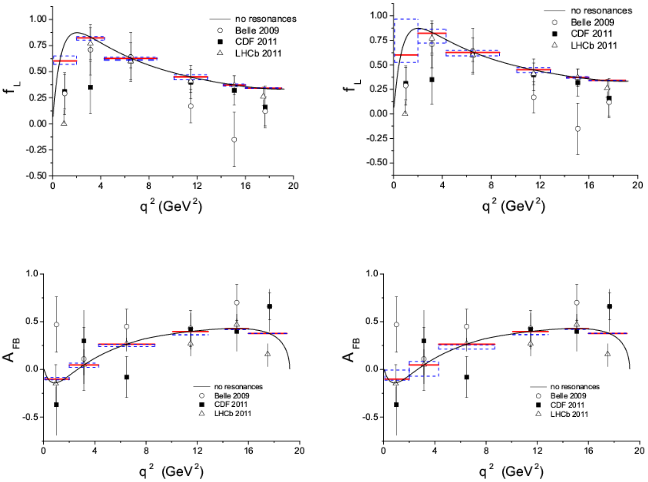


Branching ratio as a function of q^2. Solid lines – SM without resonances, red bars – binned results (averaged over experimental bins).

The dashed blue rectangles show contribution of the resonances. The uncertainty of the resonance contribution is related to the unknown phase δ_0^V of the resonance amplitudes.

Longitudinal polarization of K^* meson and forward-backward asymmetry (averaged over bins)

VMD2 (left) and VMD1 (right).



Part I. Conclusions

- Contribution of the vector mesons $\rho(770)$, $\omega(782)$, $\phi(1020)$, J/ψ, $\psi(2S)$ to various observables in the $|\Delta B| = |\Delta S| = 1$ decay

$$\bar{B}_d^0 \to \bar{K}^{*0}\,\mu^+\,\mu^- \to K^-\,\pi^+\,\mu^+\,\mu^-$$

  is calculated based on information on $B_d^0 \to K^{*0}\,V$ decays. The resonance contribution may imitate effects of new physics, the search for which is one of the main goals of experiments.

- Calculations are compared with recent data from LHCb (also with data from Belle, CDF (Tevatron)).

- We emphasize importance of measurement of amplitudes $\bar{B}_d^0 \to \bar{K}^{*0}\,V$, especially, the phases δ_0^V of the amplitudes for $c\bar{c}$ mesons with zero helicity.

- Our publications:
  A.Yu. Korchin and V.A. Kovalchuk, Phys. Rev. D **82**, 034013 (2010).
  A.Yu. Korchin and V.A. Kovalchuk, e-Print: arXiv:1111.4093 [hep-ph].
  A.Yu. Korchin and V.A. Kovalchuk, Eur. Phys. J. C **72**, 2155 (2012).

- Contributions from the processes $\bar{B}_d^0 \to \bar{K}^{*0}(\to K^- \pi^+) V$ with vector mesons $V = \rho, \omega, \phi, J/\psi, \psi(2S), \ldots$ to the *CP*-asymmetry in the decay $\bar{B}_d^0 \to \bar{K}^{*0}(\to K^- \pi^+)\mu^+\mu^-$ (with *CP* conjugated process $B_d^0 \to K^{*0}(\to K^+ \pi^-)\mu^+\mu^-$) are calculated:

$$A_{\rm CP} = \left(\frac{d\Gamma}{dq^2} - \frac{d\bar{\Gamma}}{dq^2}\right) / \left(\frac{d\Gamma}{dq^2} + \frac{d\bar{\Gamma}}{dq^2}\right).$$

- For description of transition $b \to s\,\mu^+\mu^-$ the most general form of effective Hamiltonian of weak interaction is applied.
- Predictions for the *CP*-asymmetry in the two scenarios of new physics are made.

  Results are compared with the LHCb data in R. Aaij et al. (LHCb Collaboration), Phys. Rev. Lett. 110, 031801, 2013.
- Our publications:
  V.A. Kovalchuk, A.Yu. Korchin, Ukr. J. Phys., 2014 (to be published).

CP-asymmetry $A_{\rm CP}$ in the SM, and in the two scenarios of new physics. Last column – LHCb data of 2013.
'NR, SM' means no resonances in the SM, 'SM' – complete calculation in the SM, 'a' , 'b' denote two models beyond the SM.

q^2, ГеВ^2	$\langle A_{\rm CP}^{\rm NR,SM} \rangle$	$\langle A_{\rm CP}^{\rm SM} \rangle$	$\langle A_{\rm CP}^{\rm NR,(a)} \rangle$	$\langle A_{\rm CP}^{\rm (a)} \rangle$	$\langle A_{\rm CP}^{\rm NR,(b)} \rangle$	$\langle A_{\rm CP}^{\rm (b)} \rangle$	$A_{\rm CP}^{\rm exp}$ [45]
$0,05 < q^2 < 1,00$	$0,0011$	$0,0016$	$0,0018$	$0,0084$	$0,0008$	$0,0030$	
$0,05 < q^2 < 2,00$	$0,0016$	$0,0024$	$0,0024$	$0,0037$	$0,0013$	$0,0005$	$-0,196 \pm 0,095$
$2,00 < q^2 < 4,30$	$0,0033$	$0,0042$	$0,0039$	$0,0034$	$0,0060$	$-0,0011$	$-0,098 \pm 0,154$
$4,30 < q^2 < 8,68$	$0,0037$	$0,0041$	$0,0041$	$0,0040$	$0,0088$	$0,0032$	$-0,021 \pm 0,075$
$10,09 < q^2 < 12,86$	$0,0032$	$0,0033$	$0,0056$	$0,0046$	$0,036$	$0,021$	$-0,054 \pm 0,098$
$14,18 < q^2 < 16,00$	$0,0015$	$0,0012$	$0,0077$	$0,0077$	$0,089$	$0,077$	$-0,201 \pm 0,104$
$16,00 < q^2 < 19,22$	$0,0011$	$0,0011$	$0,0076$	$0,0075$	$0,091$	$0,083$	$0,089 \pm 0,101$
$1,00 < q^2 < 6,00$	$0,0033$	$0,0041$	$0,0039$	$0,0023$	$0,0056$	$-0,0033$	$-0,058 \pm 0,064$

Part III. Future prospects

- In addition to CP asymmetry in $\bar{B}_d^0 \to \bar{K}^{*0}\,(\to K^-\,\pi^+)\,\mu^+\,\mu^-$, we plan to study the T asymmetry, as a possible signal of T violation.
- Decay $B_s \to \mu^+ + \mu^-\ (+\gamma)$ can be studied with motivation to search for new physics effects. Accurate treatment of vector resonances contribution.
- Collaboration with the LHCb group at Laboratoire de l'Accelerateur Lineaire in Orsay (Drs. Marie-Helene Schune and Emi Kou).