Testing the molecular nature of $D^*_{s0}(2317)$ and $D^*_0(2400)$ in semileptonic B_s and B decays

F. Navarra, M. Nielsen, E. Oset and T. Sekihara, PRD 2015

The weak decay process

Hadronization to get two mesons and FSI of the mesons

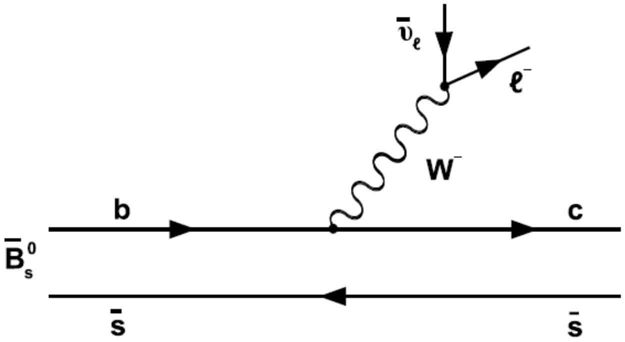
Coalescence and rescattering

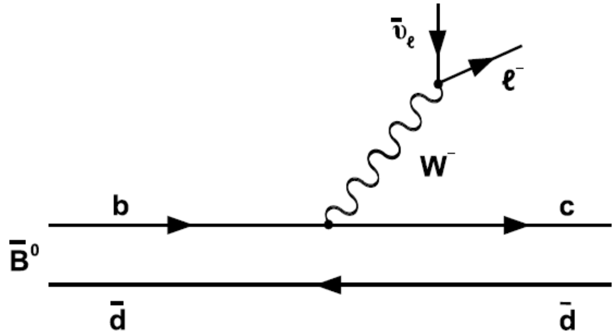
The D_{s0}*(2317) as a mostly DK molecule

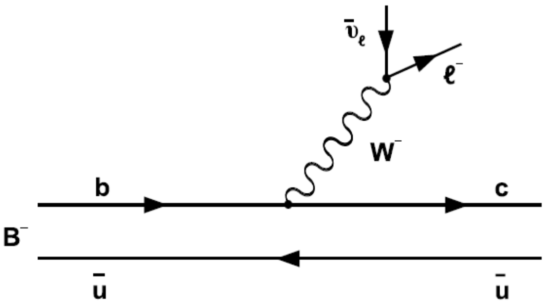
Using the semileptonic decays widths and mass distributions to determine the compositeness of the D_{s0}*(2317)

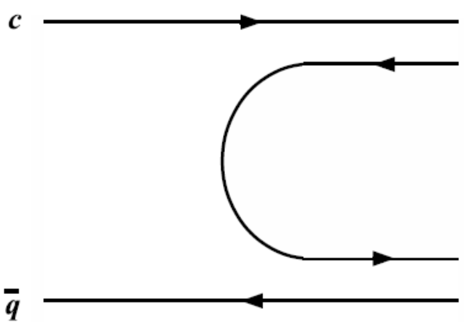
Testing the molecular nature of $D_{s0}^*(2317)$ and $D_0^*(2400)$ in semileptonic B_s and B decays

F.S. Navarra, M.Nielsen, E. O, and T. Sekihara, PRD 2015







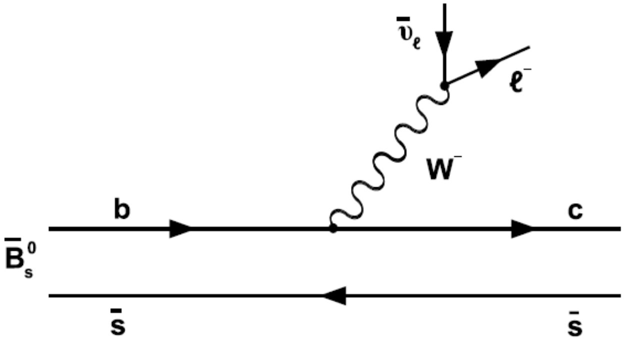


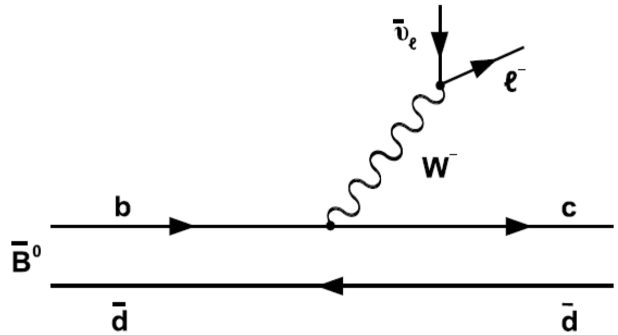
$c\bar{q}\ (\bar{u}u+\bar{d}d+\bar{s}s+\bar{c}c)$

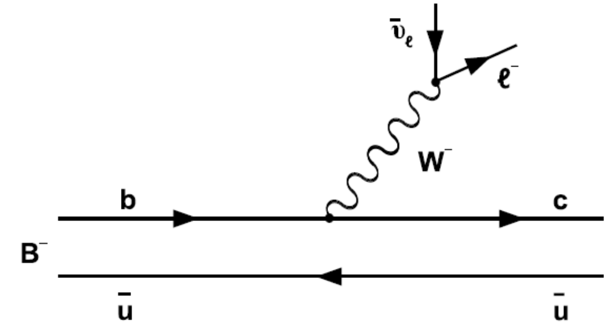
One hadronizes the q qbar pair introducing an extra q qbar with the quantum numbers of the vacuum.

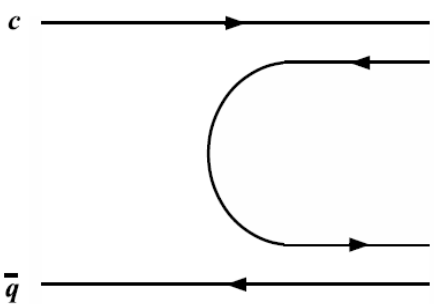
$$M = \begin{pmatrix} u\bar{u} & u\bar{d} & u\bar{s} & u\bar{c} \\ d\bar{u} & d\bar{d} & d\bar{s} & d\bar{c} \\ s\bar{u} & s\bar{d} & s\bar{s} & s\bar{c} \\ c\bar{u} & c\bar{d} & c\bar{s} & c\bar{c} \end{pmatrix}$$

$$M \cdot M = M \times (\bar{u}u + \bar{d}d + \bar{s}s + \bar{c}c)$$









$c\bar{q}\;(\bar{u}u+\bar{d}d+\bar{s}s+\bar{c}c)$

Next one writes the q qbar matrix M in terms of physical mesons, ϕ

$$\phi = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{3}}\eta + \frac{1}{\sqrt{6}}\eta' & \pi^+ & K^+ & \bar{D}^0 \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{3}}\eta + \frac{1}{\sqrt{6}}\eta' & K^0 & D^- \\ K^- & \bar{K}^0 & -\frac{1}{\sqrt{3}}\eta + \sqrt{\frac{2}{3}}\eta' & D_s^- \\ D^0 & D^+ & D_s^+ & \eta_c \end{pmatrix}$$

$$c\bar{s}\left(\bar{u}u + \bar{d}d + \bar{s}s + \bar{c}c\right) \equiv (\phi\cdot\phi)_{43} = D^0K^+ + D^+K^0 + D_s^+\left(-\frac{1}{\sqrt{3}}\eta + \sqrt{\frac{2}{3}}\eta'\right) + \eta_c D_s^+$$

$$c\bar{d}\left(\bar{u}u + \bar{d}d + \bar{s}s + \bar{c}c\right) \equiv (\phi\cdot\phi)_{42} = D^0\pi^+ + D^+\left(-\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{3}}\eta + \frac{1}{\sqrt{6}}\eta'\right) + D_s^+\bar{K}^0 + \eta_c D^+$$

$$c\bar{u}\left(\bar{u}u + \bar{d}d + \bar{s}s + \bar{c}c\right) \equiv (\phi\cdot\phi)_{41} = D^0\left(\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{3}}\eta + \frac{1}{\sqrt{6}}\eta'\right) + D^+\pi^- + D_s^+K^- + \eta_c D^0$$

We want to study the reactions:

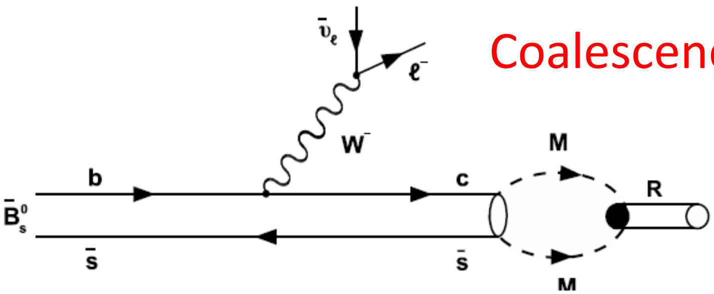
$$\bar{B}_s^0 \to D_{s0}^*(2317)^+ \bar{\nu}_l l^-,$$
$$\bar{B}^0 \to D_0^*(2400)^+ \bar{\nu}_l l^-,$$
$$B^- \to D_0^*(2400)^0 \bar{\nu}_l l^-,$$

$$T_B = -i\frac{G_{\mathrm{F}} V_{bc}}{\sqrt{2}} L^\alpha Q_\alpha \times V_{\mathrm{had}}$$

$$L^\alpha \equiv \overline{u}_l \gamma^\alpha (1-\gamma_5) v_\nu, \quad Q_\alpha \equiv \overline{u}_c \gamma_\alpha (1-\gamma_5) u_b$$

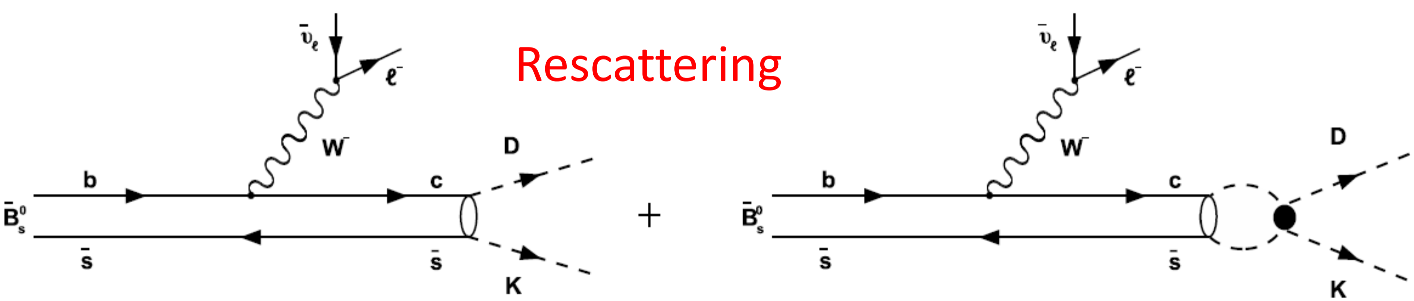
$$\sum_{\mathrm{pol}} |L^\alpha Q_\alpha|^2 = \frac{16 (p_B \cdot p_\nu)(p_R \cdot p_l)}{m_\nu m_l m_B m_R}$$

Coalescence



$$V_{\mathrm{had}}(D_{s0}^*(2317)) = C\left(\sqrt{2} G_{DK} g_{DK} - \frac{1}{\sqrt{3}} G_{D_s\eta} g_{D_s\eta}\right)$$

Rescattering



$$V_{\mathrm{had}}(DK) = C\left(\sqrt{2} + \sqrt{2} G_{DK} T_{DK\to DK} - \frac{1}{\sqrt{3}} G_{D_s\eta} T_{D_s\eta \to DK}\right)$$

Taking C constant in the whole range of invariant masses of the lepton pair and the two mesons finds justification in the works:

At the small recoil, namely the final pseudo-scalars move slow, it can be explored in the heavy meson chiral perturbation theory (HMxPT), Aneesh V. Manohar, and Mark B. Wise

X. W. Kang, B. Kubis, C. Hanhart and U. G. Meiner, Phys. Rev. D **89**, 053015 (2014).

This is our case

At large recoil, an approach that combines both hard-scattering and low-energy interactions can be developed. U.~G.~Meißner and W.~Wang, %``Generalized Heavy-to-Light Form Factors in Light-Cone Sum Rules,'' Phys.\ Lett.\ B {\bf 730}, 336 (2014)

THE DK-$D_s\eta$ AND $D\pi$-$D_s\bar{K}$ SCATTERING AMPLITUDES

In the work of D. Gamermann, E.O. , D. Strottman, M.J. Vicente Vacas, PRD 2007

it was found that the couplings to DK and $D_s\eta$ are dominant for $D^*_{s0}(2317)$

and the couplings to $D\pi$ and $D_s\bar{K}$ are dominant for $D^*_0(2400)$

Bethe Salpeter eqn.
In coupled channels

$$T = (1-VG)^{-1} V$$

V are obtained in that work from extensions of chiral Lagrangians

$$T_{ij}(s) = \frac{g_i g_j}{s - s_{\rm pole}} + (\text{regular at } s = s_{\rm pole})$$

Sum rule,
Gamermann, Nieves, E. O, Ruiz Arriola
Hyodo, Jido, Sekihara

$$\sum_i X_i + Z = 1$$

$$Z = -\sum_{i,j} g_j g_i \left[G_i \frac{dV_{ij}}{ds} G_j \right]_{s=s_{\rm pole}}$$

$$X_i = -g_i^2 \left[\frac{dG_i}{ds} \right]_{s=s_{\rm pole}}$$

Probability of channel i, for bound states

Probability of non mesonic components or missing meson-meson channels

$D^*_{s0}(2317)$		$D^*_0(2400)$	
$\sqrt{s_{\rm pole}}$	2317 MeV	$\sqrt{s_{\rm pole}}$	$2128 - 160i$ MeV
g_{DK}	10.58 GeV	$g_{D\pi}$	$9.00 - 6.18i$ GeV
$g_{D_s\eta}$	-6.11 GeV	$g_{D_s\bar{K}}$	$-7.68 + 4.35i$ GeV
X_{DK}	0.69	$X_{D\pi}$	$0.34 + 0.41i$
$X_{D_s\eta}$	0.09	$X_{D_s\bar{K}}$	$0.03 - 0.12i$
Z	0.22	Z	$0.63 - 0.28i$

These numbers are supported by recent QCD lattice results in Martinez Torres, E.O. , S. Prelovsek and A. Ramos, JHEP 2015

Coalescence

$$\Gamma_{\rm coal} = \frac{|G_{\rm F} V_{bc} V_{\rm had}(D^*)|^2}{2\pi^3 m_B^2} \int dM_{\rm inv}^{(\nu l)} p_D^{\rm cm} \tilde{p}_\nu \overline{(E_\nu E_l)_{B\ \rm rest}},$$

Rescattering

$$\frac{d\Gamma_i}{dM_{\rm inv}^{(i)}} = \frac{|G_{\rm F} V_{bc} V_{\rm had}(i)|^2}{8\pi^5 m_B^2} \int dM_{\rm inv}^{(\nu l)} P^{\rm cm} \tilde{p}_\nu \tilde{p}_i \overline{(E_\nu E_l)_{B\ \rm rest}},$$

$R = \Gamma_{\bar{B}_s^0 \to D_{s0}^*(2317)^+ \bar{\nu}_l l^-} / \Gamma_{\bar{B}^0 \to D_0^*(2400)^+ \bar{\nu}_l l^-}$ in the coalescence treatment

The factor C cancels in the ratio and we get : $R = 0.45.$

the branching fraction of the semileptonic decay $\bar{B}^0 \to D_0^*(2400)^+ \bar{\nu}_l l^-$ is

$$(3.0 \pm 1.2) \times 10^{-3}$$

By using this mean value we find $C = 7.28$.

TABLE III: Branching fraction of the process $\bar{B}_s^0 \to D_{s0}^*(2317)^+\bar{\nu}_l l^-$ in percentage

Approach	$\mathcal{B}[\bar{B}_s^0 \to D_{s0}^*(2317)^+\bar{\nu}_l l^-]$
This work	0.13
QCDSR + HQET [14]	0.09 – 0.20
QCDSR (SVZ) [15]	0.10
LCSR [17]	0.23 ± 0.11
CQM [16]	0.49 – 0.57
CQM [18]	0.44
CQM [19]	0.39

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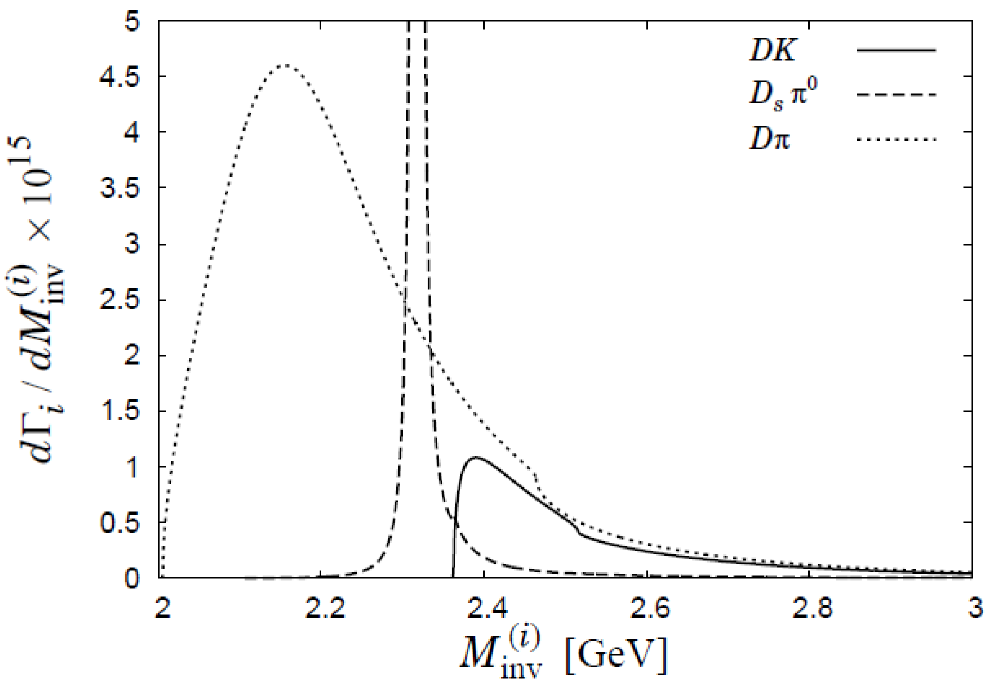

The concentration of strength for DK close to threshold and the fall down are tied to the strong coupling of the D_{s0}*(2317) to DK.

The D_{s0}*(2317) is seen in the, open, isospin forbidden, $D_s\,\pi^0$ state.

$d\,\Gamma_{B\to R} / d\,M_{inv}(D_s\,\pi^0) = -2M_R/\pi\ .\ \Gamma_{B\to R}\ \mathrm{Im}\ 1/\,(M_{inv}^2 - M_R^2 + iM_R\,\Gamma_R)$

Comparing the strength of DK invariant mass distribution with the strength of the D_{s0}*(2317) production we can deduce the amount of DK molecular component in the wave function of the D_{s0}*(2317)

Conclusions

Semileptonic decays are useful to learn about meson-meson interaction since there are just two hadrons in the final state.

They are ideal to determine the compositeness of some states looking simultaneously for the rate of the resonance production and the mass distribution of the meson-meson components that build the state.

The B^0_s semileptonic decay is an ideal reaction to learn about the nature of the $D_{s0}^*(2317)$ as a molecular state of mostly KD.

Alternative approaches:

Leitner, Dedonder, Loiseau, El-Bennich, PRD2010, $B_s \rightarrow f_0(980)$ J/psi
Dedonder, Kaminski, Lesniak, Loiseau, PRD2014, $D_0 \rightarrow K_S\, \pi^+\, \pi^-$

They parametrize the whole spectrum, introducing resonances. The unitarization of $\pi\pi$ is taken into account by means of form factors that are evaluated using chiral dynamics, but the strength is a fit parameter.

Yu-Ji Shi, Wei Wang , arXiv 1507.07692, D and D_s decays
Wen Fei Wang, Wei Wang, PRD2015, Bs $\rightarrow$ J/psi π^+ π-

Boito, Escribano, PRD 2009, D $\rightarrow$ K π π