"1/2 vs. 3/2" puzzle in $\overline{B} \to X_c l \bar{\nu}$

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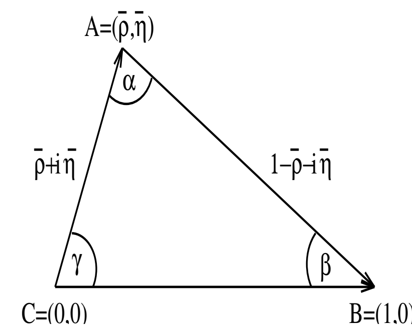
[I. Bigi, B. B., A. Le Yaouanc, L. Oliver, A. Oyanguren,
O. Pène, J.C. Raynal, P. Roudeau, arXiv:0708.1621]

Motivations

$$\underbrace{\begin{pmatrix} \text{d'} \\ \text{s'} \\ \text{b'} \end{pmatrix}}_{\text{weak int.}} = V_{\rm CKM} \underbrace{\begin{pmatrix} \text{d} \\ \text{s} \\ \text{b} \end{pmatrix}}_{\text{strong int.}} \qquad V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}.$$



Without constraint: $\delta V_{ij} < 5\%$, $\delta V_{ij} > 5\%$, $\delta V_{cb} \sim 1.5\%$

$$|\epsilon_K| = \bar\eta A^2 \hat B_K [1.11(5) A^2 (1-\bar\rho) + 0.31(5)], \quad V_{cb} \sim \lambda^2 A$$

$$\delta\epsilon_K < 1\%, \quad \delta \hat B_K \sim 10\%, \quad \delta\bar\eta(V_{cb}) \sim 6\%$$

$|V_{cb}|(\bar B \to D^* l \bar\nu) = (37.7 \pm 0.3 \pm 1.2 \pm^{1.2}_{1.4}) \times 10^{-3}$ [BABAR, '07]

$|V_{cb}|(\text{incl.}) = (41.7 \pm 0.7) \times 10^{-3}$ [PDG, '06]

It is relevant to better figure out the QCD nonperturbative dynamics which enters in all processes involving bounded quarks $\Longrightarrow$ their SM contribution can be more easily distinguished from the contribution coming from a new physics.

What is the composition of the hadronic final state X_c in $\bar{B} \to X_c l \bar{\nu}$?

$$\mathrm{BR}(\bar{B}_d \to X_c l^- \bar{\nu}) = (10.33 \pm 0.28)\%$$
$$\mathrm{BR}(\bar{B}_u \to X_c l^- \bar{\nu}) = (10.99 \pm 0.28)\%$$

		Mass (MeV)	Width (MeV)	J^P	j_l^P
S: $D^{(*)}$	$D^{\pm}$	1869±0.5	-	0^-	$\frac{1}{2}^-$
	$D^{*\pm}$	2010±0.2	96±25	1^-	
P: D^{**}	D_0^*	2352± 50	261 ± 50	0^+	$\frac{1}{2}^+$
	D_1^*	2427± 26 ± 25	$384^{+107}_{-75} \pm 74$	1^+	
	D_1	2422.3 ± 1.3	20.4 ± 1.7	1^+	$\frac{3}{2}^+$
	D_2^*	2461.1± 1.6	43± 4	2^+	

$D^{**} \to D^{(*)}\pi$ is the main decay channel: parity and orbital momentum conservations
$\Longrightarrow$ the decay occurs with the pion in a S wave or in a D wave

$D^*_{0,1} \to D^{(*)}\pi$: S wave $\quad D_2^* \to D^{(*)}\pi$: D wave
$D_1 \to D^*\pi$: S and D wave are *a priori* allowed; however the S wave is forbidden by HQS

Corroborated features

Theory: – OPE and HQE $\Longrightarrow$ Bjorken, Uraltsev, Voloshin and moments sum rules

– Quark models that are covariant in the $m_Q \to \infty$ limit

example: models *à la* Bakamijan-Thomas

– Lattice QCD

Experiment: B factories, LEP, Tevatron

States	% of $\Gamma(\bar{B} \to X_c l \bar{\nu})$
D, D^*	75 %
$D(3/2)$	$\sim$ 10 %

[BABAR, '07]
[HFAG, '07]
[ALEPH, '97]
[DELPHI, '06]
[D0, '05]
[V. Morénas *et al*, '97] BT models

D, D^* and $D(3/2)$ do not saturate the total width; $\sim$ 15 % is composed of an unknown part D_X .

$B^* - B$ splitting: $\mu_G^2(1\,\mathrm{GeV}) = 0.35(3)\,\mathrm{GeV}^2$

$\mu_\pi^2(\mu) > \mu_G^2(\mu)$

$\mu_\pi^2(1\,\mathrm{GeV})|_{\mathrm{ref}} = 0.45\,\mathrm{GeV}^2$

[O. Buchmüller, H, Flächer, '05]
[Belle, '06]
[BABAR, 07]
[I. Bigi *et al*, '95] OPE

OPE treatment is successful for subclasses of inclusive transitions .

Generalisation of the IW function $\xi(w)$

$$\Gamma(\bar{B} \to D^{(n)}_{1/2[3/2]} l\bar{\nu}) \propto |\tau^{(n)}_{1/2[3/2]}(w_n)|^2$$

[V. Morénas *et al*, '97] BT models

[A. K. Leibovich *et al*, '98]

$$\sum_n \left[\tau^{(n)}_{3/2}(1)\right]^2 - \sum_n \left[\tau^{(n)}_{1/2}(1)\right]^2 = \frac{1}{4}$$

[D. Ebert *et al*, '98] Relativistic model

[N. Uraltsev, '01] Uraltsev sum rule

$$\tau^0_{3/2}(1) > \tau^0_{1/2}(1)$$

[D. Bećirević *et al*, '05] Lattice

$$\tau^0_{1/2}(1) \in [0.20, 0.40],\ \tau^0_{3/2}(1) \in [0.55, 0.70]$$

Suppression of $D(1/2)$ with respect to $D(3/2)$ due to kinematics

Factorisation in the Class I $\bar{B} \to D^{**}\pi$: from an analysis by Belle it is expected that $\tau^0_{3/2} > \tau^0_{1/2}$ as well

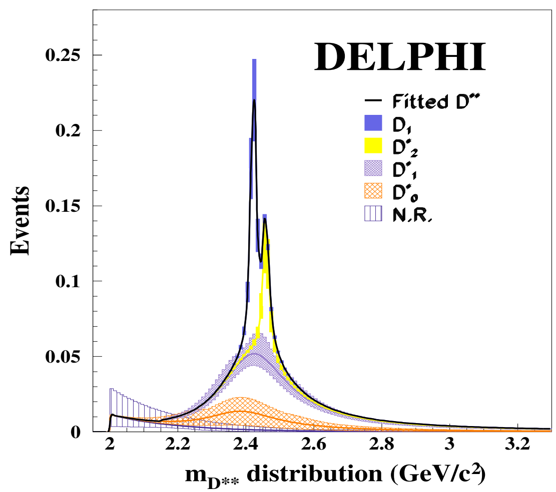
[Belle, '04]

$D(3/2)$ is expected to dominate $D(1/2)$ in $\bar{B} \to X_c l\bar{\nu}$.

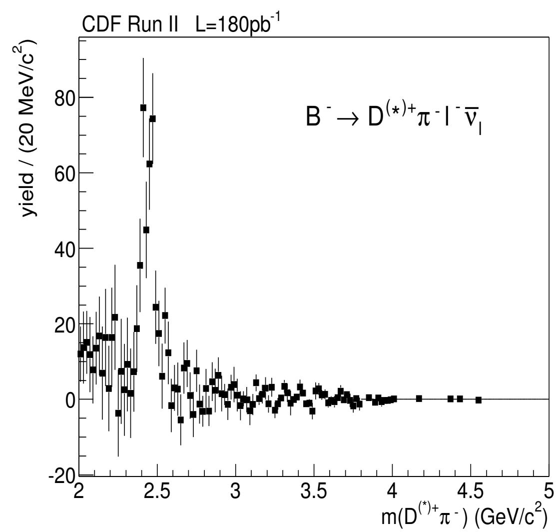
Issues

DELPHI found a larger component of broad states than of the narrow states. Interpretation as D_0^* and D_1^*?? $\Longrightarrow$ Clear conflict with theory, '1/2' vs. '3/2' puzzle [V. Morénas et al, '01], [N. Uraltsev, '04]

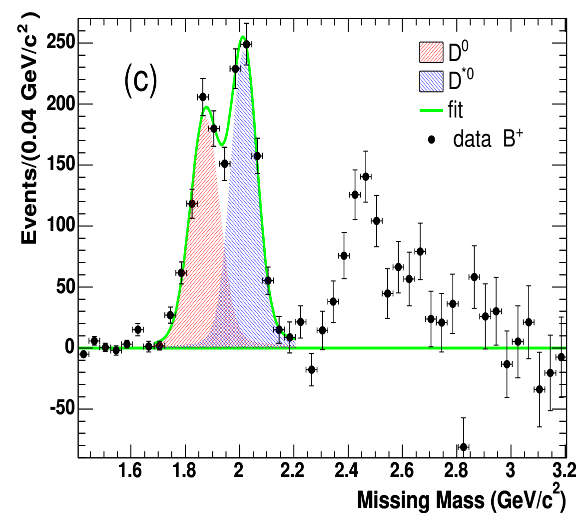
[DELPHI, '06]



[CDF, '05]



[BABAR: '06]



Up to now the experimental verdict about $\bar{B} \to [D/D^*\pi]_{\rm broad} l\bar{\nu}$ is not clear.

No obvious theoretical candidates for those broad states if the mass distribution is centered below 2.5 GeV.

An important check of the theory is $\langle M(D_X)\rangle$: depending on BR ($\bar{B} \to D^* l\bar{\nu}$) it varies from 2.4 and 2.7.

The extension of BT models to finite quark masses just started: predictions concerning the relative weight of $\tau^0_{1/2}$ and $\tau^0_{3/2}$ could change by including those corrections.

Some "exotic" possibilities similar to the nucleons Roper resonance could be investigated.

The study of the spectrum of radial and orbital excitations of the D meson on the lattice must be pursued. [A. Green *et al*, '03] [J. Foley *et al*, '07]

Nice results concerning $\bar{B} \to D/D^* l\bar{\nu}$ are already available. [G. M. de Divitiis *et al*, '07] [J. Laiho, '07] [S. Simula, '07]

The extension to D^{**} seems to be the next step, beyond the exploratory study performed before, in order to conclude about the relative weight of $\tau^0_{1/2}$ and $\tau^0_{3/2}$. [D. Bećirević *et al*, '05]

Outlook

- The composition of the final state X_c in $\bar{B} \to X_c l\bar{\nu}$ has received some attention since 10 years.
- Theoretically, it is expected that the states D, D^* and the 4 P wave states D^{**} do not saturate the total width. Moreover, covariant quark models and sum rules extracted from the OPE in the $m_Q \to \infty$ limit lead to $[\Gamma(\bar{B} \to D\left(\frac{1}{2}\right) l\bar{\nu}) < \Gamma(\bar{B} \to D\left(\frac{3}{2}\right) l\bar{\nu})]^{\mathrm{TH}}$.
- Experimentally, it was found at LEP that the total width is saturated by D, D^*, D^{**} and the measured branching ratios read $[\Gamma(\bar{B} \to D\left(\frac{1}{2}\right) l\bar{\nu}) > \Gamma(\bar{B} \to D\left(\frac{3}{2}\right) l\bar{\nu})]^{\mathrm{EXP}}$.
- However there are strong theoretical assumptions that the broad states observed in the $\bar{B} \to D^{**} l\bar{\nu}$ mass distribution are not the P wave states.
- An important experimental effort is demanded, in particular to have a better knowledge of the quantum numbers of those broad states.
- The answer will have an impact on the theoretical control over QCD nonperturbative dynamics of the heavy-light systems.
- On the theoretical side, taking account of $1/m_Q$ corrections is crucial, either in the analytical treatement of QCD (OPE, quark models) or in its numerical one (lattice).