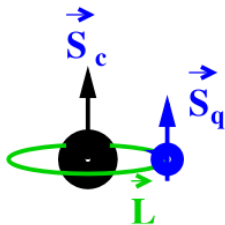# A model of $\bar{B}^0 \to D^{*+}\omega\pi^-$ decay

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The tenth meeting of the Working Group 'Radio Monte CarLow'
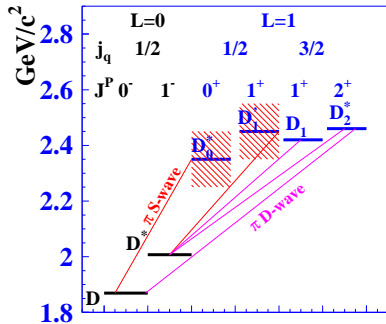
September 23, 2011

# $D^{**}$ spectroscopy

The discovery of excited $D$-states (referred to as $D^{**}$-states) stimulates interest in their spectroscopy and $D^{**} \to D^{(*)}\pi$ decay properties.
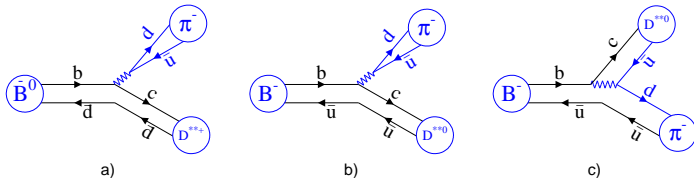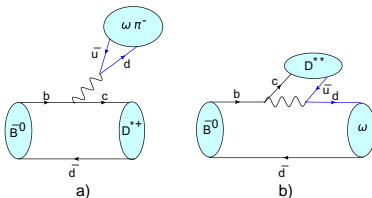
# $D^{**}$ production

- $D^{**}$-states can be produced in $B$-decays. In hadronic decays all final particles can be detected and Dalitz plot analysis can be performed.

- $D^{**}$ production in the $\bar{B}^0 \rightarrow \bar{D}^{(*)0} \pi^+ \pi^-$, $B^- \rightarrow D^{(*)+} \pi^- \pi^-$ modes.



Diagrams for neutral (a) and charged (b and c) $B$-decays.

- $D^{**}$ production in the $\bar{B}^0 \rightarrow D^{(*)+} \pi^- (\omega, \pi^0)$ mode.



Color-favored (a) and color-suppressed (b) channel for our mode.

## Model formulation

- The $\bar{B}^0 \to D^{(*)+}\pi^-(\omega, \pi^0)$ decay is a three-body decay.
- An amplitude of three-body decay can be written as a sum of the contributions corresponding to quasi-two-body resonances.
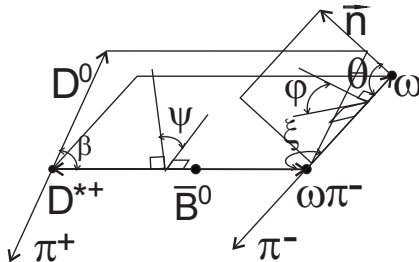
$$A_{\text{tot}} = \sum_R A_{D^*(\omega\pi=R)}(6 \text{ kin.variables}) +$$
$$+ \sum_R A_{\omega(D^{**}=R)}(6 \text{ kin.variables})$$

- We need a set of kinematic variables convenient for Dalitz plot analysis.

- $m_{\omega\pi}^2$ is the invariant mass squared of the $\omega\pi$ pair.



- $\theta$ is the angle between the vector $\vec{n}$ normal to the $\omega$ decay plane and the direction of $\pi$ from $B$-decay in the $\omega$ rest frame.
- $\phi$ is the azimuthal angle between $B$-decay plane and plane normal to the $\omega$-decay plane in the $\omega$ rest frame.
- $\beta$ is the angle between the $D^0$ and the direction of $\omega\pi$ resonance in the $D^*$ rest frame.
- $\psi$ is the azimuthal angle between $B$-decay plane and $D^*$-decay plane in the $D^*$ rest frame.
- $\xi$ is the angle between $\omega$ and $D^*$ directions in the resonance rest frame.

A similar decay scheme takes place for the channel with $D^{**}$ resonance production.

## Matrix element parametrization

- A total amplitude is a coherent sum of quasi-two-body amplitudes.
- Each resonant amplitude is parametrized using the basis of covariant amplitudes, which describe the decay with fixed angular orbital momenta in the $B$ and resonance rest frames.
- Each resonant amplitude is expressed via a set of selected kinematic variables.

  The different intermediate states are included in our model.

| $\omega\pi$-states | $D^{**}$-states |
|---|---|
| $J^P = 0^-$ | $J_{j_u}^P = 1_{1/2}^+ \ (D_1^0)$ |
| $J^P = 1^- \ (\rho(1450)^-)$ | $J_{j_u}^P = 1_{3/2}^+ \ (D_1^{'0})$ |
| $J^P = 1^+ \ (b_1(1235)^-)$ | $J_{j_u}^P = 2_{3/2}^+ \ (D_2^0)$ |
| $J^P = 2^-$ | $J_{j_u}^P = 1_{3/2}^-$ |
| $J^P = 2^+$ | $J_{j_u}^P = 2_{3/2}^-$ |
| $J^P = 3^- \ (\rho_3(1690)^-)$ | $J_{j_u}^P = 2_{5/2}^-$ |
| | $J_{j_u}^P = 3_{5/2}^-$ |

# Covariant amplitudes
For details see arxiv eprint:1108.2862 (accepted to JHEP)

● The total decay rate for $\omega\pi$ resonance production is as follows:

$$d\Gamma = \frac{6\mathcal{B}_{D^{*+}\to D^0\pi^+}}{(4\pi)^{10}m_B^2} \frac{|M|^2 \mathbf{pQ}}{\sqrt{q^2}} \frac{W(p^2)}{|D_\omega(p^2)|^2} dp^2 \ (d\cos\theta \ d\phi) \ (d\cos\beta \ d\psi) \ (dq^2 \ d\cos\xi)$$

● The matrix element for the $\bar{B} \to D^{*+}\rho(1450)^-$ transition is as follows:

$$\begin{aligned}
M_{\bar{B}\to D^*\rho(1450)} = \frac{G_F}{\sqrt{2}} V_{cb} V_{ud}^* a_1 f_{\rho(1450)} & \left[ C_P \epsilon^{\mu\nu\rho\sigma} \varepsilon_\mu^{'*} \varepsilon_\nu^* q_\rho Q_\sigma F_P(q^2) + \right. \\
& + im_B^2 C_S((\varepsilon^{'*}\varepsilon^*) - \frac{1}{f_{P,S}(q^2)}(\varepsilon^{'*}Q)(\varepsilon^* q))F_S(q^2) + \\
& \left. + iC_D((\varepsilon^{'*}Q)(\varepsilon^* q) - f_{P,D}(q^2)(\varepsilon^{'*}\varepsilon^*))F_D(q^2) \right]
\end{aligned}$$

● The matrix element for the $\rho(1450)^- \to \omega\pi^-$ transition is as follows:

$$M_{\rho(1450)\to\omega\pi} = g\,\epsilon^{\mu\nu\rho\sigma} \varepsilon_\mu^{'} v_\nu^* q_\rho p_\sigma \tilde{F}_P(q^2, p^2)$$

● We move from the covariant amplitudes to the expressions depending on the selected angles, which are defined in the intermediate particle rest frames.
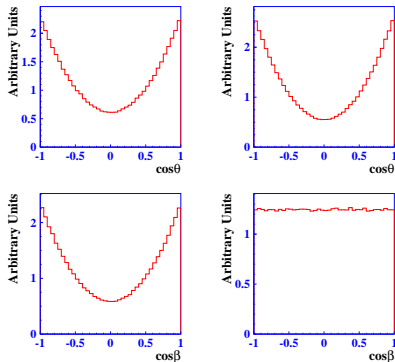
# Angular distributions

The angular distributions are demonstrated for $\rho(1450)^-$- and pure $D_1^{'0}$-states. These states were observed in this channel by the BaBar Collaboration. (Phys. Rev. D **74** (2006) 012001.)

| Resonance | $L_1$ | $L_2$ | $A_{L_1 L_2}$ |
|---|---|---|---|
| $\rho(1450)^-$ | S | P | $-s_\theta s_\phi c_\beta s_\xi + s_\theta c_\phi s_\beta s_\psi - s_\theta s_\phi s_\beta c_\psi c_\xi$ |
| | P | P | $s_\theta s_\phi s_\beta s_\psi c_\xi + s_\theta c_\phi s_\beta c_\psi$ |
| | D | P | $2s_\theta s_\phi c_\beta s_\xi + s_\theta c_\phi s_\beta s_\psi - s_\theta s_\phi s_\beta c_\psi c_\xi$ |
| $D_1^{'0}$ | S | S | $-c_\theta c_\beta c_\xi + s_\theta c_\phi c_\beta s_\xi - s_\theta s_\phi s_\beta s_\psi + $ $+ s_\theta c_\phi s_\beta c_\psi c_\xi + c_\theta s_\beta c_\psi s_\xi$ |
| | P | S | $-s_\theta s_\phi c_\beta s_\xi - s_\theta s_\phi s_\beta c_\psi c_\xi + s_\theta c_\phi s_\beta s_\psi$ |
| | D | S | $2c_\theta c_\beta c_\xi + s_\theta c_\phi c_\beta s_\xi - s_\theta s_\phi s_\beta s_\psi + $ $+ s_\theta c_\phi s_\beta c_\psi c_\xi - 2c_\theta s_\beta c_\psi s_\xi$ |

Here, $L_1$ and $L_2$ are the angular orbital momenta in the $\bar{B}^0$ rest frame and intermediate resonance ($\rho(1450)^-$ and $D_1^{'0}$ ) rest frame, respectively; $A_{L_1 L_2}$ is the expression for the angular dependence, $c_\alpha = \cos \alpha$ and $s_\alpha = \sin \alpha$.

# Monte Carlo Simulation

- To demonstrate the angular distributions for each intermediate resonance in the $D^* \omega \pi$ final state, Monte Carlo Simulation is performed.

- If we consider one angular variable only, the distributions can be the same for different resonant hypotheses. Efficient separation between resonances is possible, when all angular variables are taken into account. This statement is demonstrated here for pure $D_1^{'0}$ and pure $D_1^0$.



The distributions over $\cos \theta$ are the same, however, the distributions over $\cos \beta$ differ from each other.

- The plot boundaries in bins of angular variables are fixed, and these angular variables are convenient and optimal for creation of the Monte Carlo generators.

# Interference effects

For Dalitz plot analysis, interference between resonances in a one-dimensional distributions, after the integration over other variables, should be taken into account. Here, the interference between $b_1(1235)^-$ and pure $D_1^0$ is demonstrated. We show the distributions over angles $\cos \xi_1$ and $\cos \xi_2$ for different relative phases $\Delta\varphi$ between resonances, such as $0$, $\pi/2$, $\pi$, $3\pi/2$ and the distribution without interference. The subscripts 1 and 2 correspond to the $b_1(1235)^-$ - and the $D_1^0$-resonances, respectively.
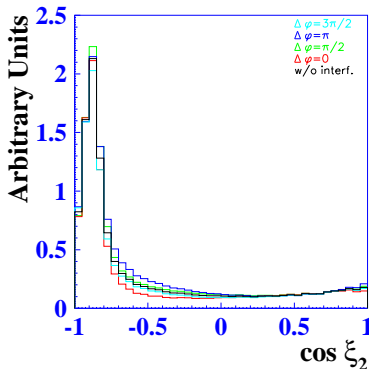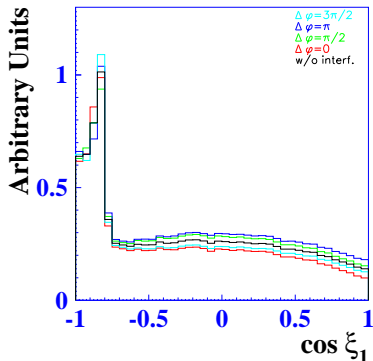


Although small, the interference effects are not negligible.

- A model of the $\bar{B}^0 \to D^{*+}\omega\pi^-$ decay was described. A total amplitude in our model is a sum of quasi-two-body amplitudes, which describe different intermediate resonances.

- The different $\omega\pi$ and $D^{**}$ resonances up to spin of three have been included in our model.

- The resonant matrix elements are parameterized in the angular basis, which is convenient for the experimental Dalitz plot analysis.

- Monte-Carlo simulation based on the obtained expressions has been performed.

- The angular distributions and interference effects are demonstrated.