$B_c \longrightarrow J/\psi(B_s, B_s^*) + n\pi$ Decays

A. Berezhnoy, A. Likhoded, A. Luchinsky

27.09.2011

Aims of research

- To estimate the branching ratios for the decays $B_c \to J/\psi(B_s, B_s^*) + n\pi$
- To develop the package for simulation these decays within standard LHCb software GAUSS

Fast facts about B_c-mesons

Heavy quarkonium with open flavour

$$B_c^+ = (\bar{b}c) \qquad B_c^- = (b\bar{c})$$

$$m_{B_c}^{\rm CDF} = 6.2756 \pm 0.0029({\rm stat.}) \pm 0.0025({\rm sys.})\ {\rm GeV}$$

$$m_{B_c}^{\rm D0} = 6.3000 \pm 0.0014({\rm stat.}) \pm 0.0005({\rm sys.})\ {\rm GeV}$$

$$m_{B_c}^{\rm theor} = 6.25 \pm 0.03\ {\rm GeV}$$

$$\tau_{B_c}^{\rm CDF} = 0.448^{+0.038}_{-0.036}({\rm stat.}) \pm 0.032({\rm sys.})\ {\rm ps}$$

$$\tau_{B_c}^{\rm D0} = 0.475^{+0.053}_{-0.049}({\rm stat.}) \pm 0.018({\rm sys.})\ {\rm ps}$$

$$\tau_{B_c}^{\rm theor} = 0.48 \pm 0.05\ {\rm ps}.$$

- Independent check of models describing charmonia and bottomonia
- The ground state can decay only through weak interaction
- Mass, lifetime and branching fractions of $B_c \to J/\psi\ell\nu$, $J/\psi\pi$, $J/\psi + 3\pi$ (LHCb) decays are known experimentally
- about 10^9 of B_c is expected at LHC

Factorization approach

$$\mathcal{M}[B_c \to J/\psi + n\pi] = \frac{G_F V_{cb}}{\sqrt{2}} a_1(\mu_R) \mathcal{H}_\mu^{J/\psi} \epsilon_W^\mu,$$

$$\mathcal{H}_\mu = \langle J/\psi | \bar{c}\gamma_\mu (1-\gamma_5) b | B_c \rangle = \mathcal{V}_\mu - \mathcal{A}_\mu$$

$$\mathcal{V}_\mu = \langle J/\psi | \bar{c}\gamma_\mu b | B_c \rangle = i\epsilon^{\mu\nu\alpha\beta} \epsilon_\nu^\psi p_\alpha q_\beta F_V\left(q^2\right),$$

$$\mathcal{A}_\mu = \langle J/\psi | \bar{c}\gamma_\mu \gamma_5 b | B_c \rangle =$$

$$= \epsilon_\mu^\psi F_0^A\left(q^2\right) + p_\mu \left(\epsilon^\psi p_{B_c}\right) F_+^A\left(q^2\right) + q_\mu \left(\epsilon^\psi p_{B_c}\right) F_-^A\left(q^2\right)$$

where p_{B_c} and $p_{J/\psi}$ are the momenta of B_c- and J/ψ-mesons;
$q = p_{B_c} - p_{J/\psi}$ is the momentum of virtual W-boson;
$p = p_{B_c} + p_{J/\psi}$;
$\epsilon_\mu^{J/\psi}$ is the polarization vector of J/ψ meson;
and $F_V(q^2)$, $F_0^A(q^2)$, $F_+^A(q^2)$, $F_-^A(q^2)$ and $F_V(q^2)$ are form-factors of $B_c \to J/\psi + W^*$ decays.

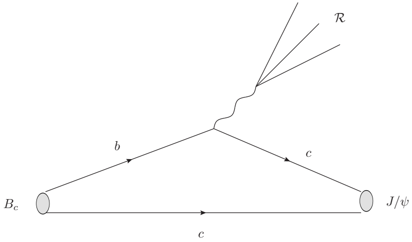


Figure: Diagram for $B_c \to J/\psi + n\pi$ decay.

Factorization approach

$$F_i(q^2) = F_i(0)\exp\left\{-c_1 q^2 - c_2 q^4\right\}$$

$$d\Gamma\left(B_c \to J/\psi \mathcal{R}\right) =$$

$$= \frac{1}{2M}\frac{G_F^2 V_{cb}^2}{2} a_1^2 \mathcal{H}^{\mu}\mathcal{H}^{*\nu}\epsilon_\mu^{W*}\epsilon_\nu^{W} d\Phi\left(B_c \to J/\psi n\pi\right)$$

$$d\Phi\left(Q \to p_1 \ldots p_n\right) =$$

$$= (2\pi)^4 \delta^4\left(Q - \sum p_i\right)\prod \frac{d^3 p_i}{2E_i(2\pi)^3}$$

$$d\Phi\left(B_c \to J/\psi W^* \to J/\psi n\pi\right) =$$

$$= \frac{dq^2}{2\pi} d\Phi\left(B_c \to J/\psi W^*\right) d\Phi\left(W^* \to n\pi\right)$$

$$\frac{1}{2\pi}\int d\Phi\left(W^* \to n\pi\right)\epsilon_\mu^{W}\epsilon_\nu^{W*} =$$

$$= \left(q_\mu q_\nu - q^2 g_{\mu\nu}\right)\rho_T\left(q^2\right) + q_\mu q_\nu \rho_L\left(q^2\right)$$

For $n \leq 2$ $\rho_L^{\mathcal{R}}$ is negligible due to the vector current conservation and partial axial current conservation.

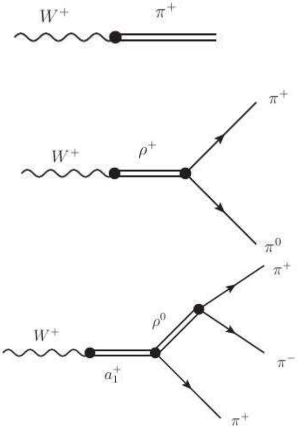
Spectral functions $\rho_T\left(q^2\right)$ are universal and can be determined from theoretical and experimental analysis of some other processes, for example $\tau \to \nu_\tau n\pi$ decay or electron-positron annihilation $e^+e^- \to n\pi$.

$B_c \to J/\psi + n\pi$			
	$F_i(0)$	c_1	c_2
A_0	5.9	0.049	0.0015
A_+	-0.074	0.049	0.0015
V	0.11	0.049	0.0015
$B_c \to B_s^* + n\pi$			
	$F_i(0)$	c_1	c_2
A_0	8.1	0.30	0.069
A_+	0.15	0.30	0.069
V	1.08	0.30	0.069
$B_c \to B_s + n\pi$			
	$f_i(0)$	c_1	c_2
f_+	1.3	0.30	0.069

Table: Form-factor parameterization.

$W \longrightarrow n\pi$ transition model

$W \longrightarrow n\pi$ transition is described by contribution of virtual mesons [J. H. Kuhn and A. Santamaria, Z. Phys. C **48**, 445 (1990)].



$$\epsilon_\mu^{2\pi} = F_\rho(q^2)(k_1 - k_2)_\mu$$

$$\epsilon_\mu^{3\pi} = -i\frac{2\sqrt{2}}{3f_\pi}F_a(q^2)\left\{B_\rho(s_1)V_{1\mu} + B_\rho(s_2)V_{2\mu}\right\}$$

$$V_{1,2\mu} = k_{1,2\mu} - k_{3\mu} - q_\mu\frac{q(k_{1,2} - k_3)}{q^2}$$

In EvtGen package this transition model is realized in TAUHADNU model of EvtGen.

The decays $B_c \longrightarrow B_s^* + n\pi$ is considered by analogy with $B_c \longrightarrow J/\psi + n\pi$.

The case of $B_c \longrightarrow B_s^* + n\pi$ is more simple:

$$\mathcal{H}_\mu^{B_s} = \langle B_s\,|\bar{c}\,(1-\gamma_5)\,b|\,B_c\rangle = f_+(q^2)p_\mu + f_-(q^2)q_\mu .$$

Branching fractions

$\mathcal{R}/A$	J/ψ	B_s	B_s^*
π	0.17	18	7
ρ	0.48	7.6	21
2π	0.48	6.1	13
3π	0.77	0.096	0.23
4π	0.4	6.4×10^{-3}	0.015

Table: $\mathrm{Br}(B_c \to A\mathcal{R})$ [A. Likhoded and A. Luchinsky, Phys. Rev. D **81** (2010) 014015, Phys. Rev. D **82**, 014012 (2010),A.V. Berezhnoy, A. K. Likhoded and A. V. Luchinsky, arXiv:1104.0808]

For B_c decay into B_s^* or B_s is it important to take into account the ρ-meson width:

$$\Gamma_\rho = 150\,\mathrm{MeV} \sim M_{B_c} - M_{B_s^*} = 860\,\mathrm{MeV}$$

EvtGen and GAUSS

An EvtGen realization of this model is developed and implemented into the GAUSS package of LHCb collaboration (BC_NPI-model).

- $B_c \to V(P) + n\pi$-decays for $1 \leq n \leq 3$ are described
- Form-factor parameters can be changed
- Special models for J/ψ, B_s^* and B_s final states are supplied

BC_NPI

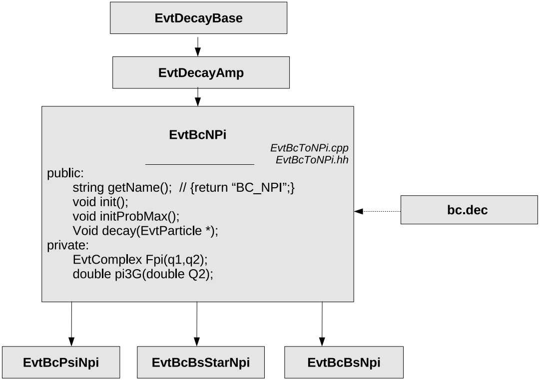


Figure: The program structure.

Distributions from BC_NPI

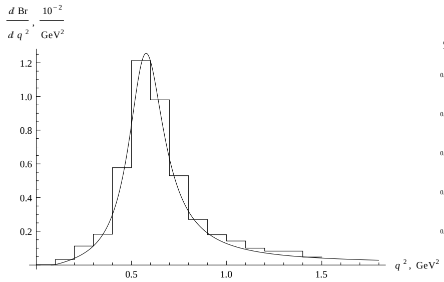


Figure: The distribution over the squared invariant mass $q^2 = m^2_{\pi\pi}$ in $B_c \to J/\psi + 2\pi$ decay generated within BC_NPI-model (histogram) in comparison with the predictions of Likhoded, Luchinsky and Berezhnoy.

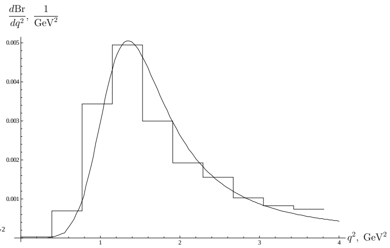


Figure: The distribution over the squared invariant mass $q^2 = m^2_{\pi\pi\pi}$ in $B_c \to J/\psi + 3\pi$ decay generated within BC_NPI-model (histogram) in comparison with the predictions of Likhoded, Luchinsky and Berezhnoy.

Results

- The branching ratios for the decays $B_c \to J/\psi(B_s, B_s^*) + n\pi$ have been estimated
- The width of intermediate mesons must be taken into account
- The package for simulation these decays within standard LHCb software GAUSS has been developed
- The experimental LHCb data on $B_c \to J/\psi + 3\pi$ decay can be described satisfactorily within the model