Weak decays of B_s mesons

C. Albertus(1), E. Hernández(2), C. Hidalgo, J. Nieves(3)

(1) Departamento de Física Atómica, Molecular y Nuclear
Universidad de Granada
(2) Departamento de Física Fundamental. Universidad de Salamanca
(3) IFIC. CSIC-Universidad de Valencia

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- $B_s \to D$ semileptonic decays and some non leptonic decays
  - Based on C. Albertus, Phys. Rev. D 89 (2014) 065042

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  - Based on C. A., E. Hernández, C. Hidalgo, J. Nieves, hep-ph/1404.1001

D_s states

	Mass (MeV)
$\bar{B}_s(0^-)$	5366.77
$D_s^+(0^-)$	1968.49
$D_{s0}^{*+}(2317)(0^+)$	2317.8
$D_s^{*+}(1^-)$	2112.3
$D_{s1}(2460)$	2459.6
$D_{s1}(2536)$	2535.12
$c\bar{s}(2^-)$	2806.9
$D_{s2}(2573)^+(2^+)$	2571.9

Meson states

$$\hat{\phi}^{(M(0^+))}_{\alpha_1,\alpha_2}(\vec{p}) = \frac{1}{\sqrt{3}}\delta_{c_1 c_2}\hat{\phi}^{(M(0^+))}_{(s_1,f_1),(s_2,f_2)}(\vec{p})$$

$$= \frac{i}{\sqrt{3}}\delta_{c_1 c_2}\hat{\phi}^{(M(0^+))}_{f_1,f_2}(|\vec{p}|)\sum_m (1/2,1/2,1;s_1,s_2,-m)(1,1,0;m,-m,0)Y_{1m}(\hat{p})$$

$$\hat{\phi}^{(M(0^-))}_{\alpha_1,\alpha_2}(\vec{p}) = \frac{1}{\sqrt{3}}\delta_{c_1 c_2}\hat{\phi}^{(M(0^-))}_{(s_1,f_1),(s_2,f_2)}(\vec{p})$$

$$= \frac{-i}{\sqrt{3}}\delta_{c_1 c_2}\hat{\phi}^{(M(0^-))}_{f_1,f_2}(|\vec{p}|)(1/2,1/2,0;s_1,s_2,0)Y_{00}(\hat{p})$$

$$\hat{\phi}^{(M(1^-),\lambda)}_{\alpha_1,\alpha_2}(\vec{p}) = \frac{1}{\sqrt{3}}\delta_{c_1 c_2}\hat{\phi}^{(M(1^-),\lambda)}_{(s_1,f_1),(s_2,f_2)}(\vec{p})$$

$$= \frac{-1}{\sqrt{3}}\delta_{c_1 c_2}\hat{\phi}^{(M(1^-))}_{f_1,f_2}(|\vec{p}|)(1/2,1/2,1;s_1,s_2,0)Y_{00}(\hat{p}),$$

Meson states

$$\hat{\phi}^{(M(1^+),S_{q\bar{q}}=0,\lambda)}_{\alpha_1,\alpha_2}(\vec{p}) = \frac{1}{\sqrt{3}}\delta_{c_1c_2}\hat{\phi}^{(M(1^+),S_{q\bar{q}}=0,\lambda)}_{(s_1,f_1),(s_2,f_2)}(\vec{p}) = \frac{-1}{\sqrt{3}}\delta_{c_1c_2}\hat{\phi}^{(M(1^+),S_{q\bar{q}}=0)}_{f_1,f_2}(|\vec{p}|)(1/2,1/2,0;s_1,s_2,0)Y_{1\lambda}(\hat{p})$$

$$\hat{\phi}^{(M(1^+),S_{q\bar{q}}=1,\lambda)}_{\alpha_1,\alpha_2}(\vec{p}) = \frac{1}{\sqrt{3}}\delta_{c_1c_2}\hat{\phi}^{(M(1^+),S_{q\bar{q}}=1,\lambda)}_{(s_1,f_1),(s_2,f_2)}(\vec{p})$$

$$= \frac{-1}{\sqrt{3}}\delta_{c_1c_2}\hat{\phi}^{(M(1^+),S_{q\bar{q}}=1)}_{f_1,f_2}(|\vec{p}|)\sum_m(1/2,1/2,1;s_1,s_2,\lambda-m)(1,1,1;m,\lambda-m,\lambda)Y_{1m}(\hat{p}).$$

$$\hat{\phi}^{(M(D^*_{s2}),\lambda)}_{\alpha_1,\alpha_2}(\vec{p}) = \frac{1}{\sqrt{3}}\delta_{c_1c_2}\hat{\phi}^{(M(D^*_{s2}),\lambda)}_{(s_1,f_1),(s_2,f_2)}(\vec{p})$$

$$= \frac{1}{\sqrt{3}}\delta_{c_1c_2}\hat{\phi}^{(M(D^*_{s2}))}_{f_1,f_2}(|\vec{p}|)\sum_m(1/2,1/2,1;s_1,s_2,\lambda-m)(1,1,2;m,\lambda-m,\lambda)Y_{1m}(\hat{p})$$

$$\hat{\phi}^{(M(2^-),\lambda)}_{\alpha_1,\alpha_2}(\vec{p}) = \frac{1}{\sqrt{3}}\delta_{c_1c_2}\hat{\phi}^{(M(2^-),\lambda)}_{(s_1,f_1),(s_2,f_2)}(\vec{p})$$

$$= \frac{-1}{\sqrt{3}}\delta_{c_1c_2}\hat{\phi}^{(M(2^-))}_{f_1,f_2}(|\vec{p}|)\sum_m(1/2,1/2,1;s_1,s_2,\lambda-m)(2,1,2;m,\lambda-m,\lambda)Y_{2m}(\hat{p})$$

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- All free parameters have been adjusted to reproduce light and heavy-light meson spectra. We have successfully used these potentials before to describe the spectra and decays of charmed and bottom baryons.

Semileptonic decays

- We consider the semileptonic decays of $\bar{B}_S$ meson into different D_S states.
- This decays are governed by the current

$$J_\mu^{cb}(0) = J_{V\mu}^{cb}(0) - J_{A\mu}^{cb}(0) = \bar{\Psi}_c(0)\gamma_\mu(I - \gamma_5)\Psi_b(0),$$

Form factor decomposition

$$\left\langle D_s^{+}, \vec{P}_{D_s} \left| J_\mu^{bc}(0) \right| \bar{B}_s, \vec{P}_{\bar{B}_s} \right\rangle = P_\mu F_+(q^2) + q_\mu F_-(q^2)$$

$$\left\langle D_s^{*+}, \lambda \vec{P}_{D_s^*} \left| J_\mu^{bc}(0) \right| \bar{B}_s, \vec{P}_{\bar{B}_s} \right\rangle = \frac{-1}{m_{\bar{B}_s} + m_{D_s^*}} \epsilon_{\mu\nu\alpha\beta} \epsilon^{\nu *}_{(\lambda)}(\vec{P}_{c\bar{s}}) P^\alpha q^\beta V(q^2)$$

$$- i \left\{ (m_{\bar{B}_s} - m_{D_s^*}) \epsilon^*_{(\lambda)\mu}(\vec{P}_{c\bar{s}}) A_0(q^2) - \frac{P \cdot \epsilon^*_{(\lambda)}(\vec{P}_{D_s^*})}{m_{\bar{B}_s} + m_{D_s^*}} (P_\mu A_+(q^2) + q_\mu A_-(q^2)) \right\}$$

$$\left\langle D_{s2}^{*+}, \lambda \vec{P}_{D_{s2}^*} \left| J_\mu^{bc}(0) \right| \bar{B}_s, \vec{P}_{\bar{B}_s} \right\rangle = \epsilon_{\mu\nu\alpha\beta} \epsilon^{\nu\delta *}_{(\lambda)}(\vec{P}_{D_{s2}^*}) P_\delta P^\alpha q^\beta T_4(q^2)$$

$$- i \left\{ \epsilon^*_{(\lambda)\mu\delta}(\vec{P}_{D_{s2}^*}) P^\delta T_1(q^2) + P^\nu P^\delta \epsilon^*_{(\lambda)\nu\delta}(\vec{P}_{D_{s2}^*})(P_\mu T_2(q^2) + q_\mu T_3(q^2)) \right\},$$

Decay width

$$\frac{d^2\Gamma}{dx_l dq^2} = \frac{G_F^2}{64 m_{\bar{B}_s}^2} \frac{|V_{bc}|^2}{8\pi^3} \frac{\lambda^{1/2}(q^2, m_{\bar{B}_s}^2, m_{c\bar{s}}^2)}{2 m_{\bar{B}_s}} \frac{q^2 - m_l^2}{q^2} \times$$
$$\mathcal{H}_{\alpha\beta}(P_{\bar{B}_s}, P_{c\bar{s}}) \mathcal{L}^{\alpha\beta}(p_l, p_\nu)$$

Decay widths

$\bar{B}_S \to M' l^- \bar{\nu}_l$	$\Gamma[10^{-15}\text{GeV}]$		
M'	$l = e$	$l = \mu$	$l = \tau$
D_s^+	$10.37^{+0.15}_{-0.2}$	$10.32^{+0.16}_{-0.10}$	$2.99^{+0.01}_{-0.03}$
D_{s0}^{*+}	$1.75^{+0.03}_{-0.07}$	$1.74^{+0.03}_{-0.08}$	$0.20^{+0.003}_{-0.003}$
D_s^{*+}	$28.02^{+0.24}_{-0.48}$	$27.90^{+0.86}_{-0.48}$	$6.86^{+0.12}_{-0.09}$
$D_{s1}^+(2460)$	$2.07_{-0.09}$	$2.05_{-0.08}$	$0.17_{-0.008}$
$D_{s1}^+(2536)$	$1.40_{-0.07}$	$1.39_{-0.07}$	$0.12_{-0.006}$
$c\bar{s}(2^-)$	$4.11_{-0.56}\ 10^{-2}$	$4.06_{-0.64}\ 10^{-2}$	$9.02_{-2.39}\ 10^{-4}$
D_{s2}^{*+}	$1.97_{-0.15}$	$1.95_{-0.14}$	$0.12_{-0.02}$

Branching fractions

	This work	Faustov(2012)	Chen(2012)	Li(2009)	Blasi(1993)	Z
$\bar{B}_s \to D_s^+ e^- \bar{\nu}_e$	2.32	2.1 ± 0.2	1.4-1.7	$1.0^{+0.4}_{-0.3}$	1.35 ± 0.21	
$\bar{B}_s \to D_s^{*+} e^- \bar{\nu}_e$	6.26	5.3 ± 0.5	5.1-5.8		2.5 ± 0.1	
$\bar{B}_s \to D_s^+ \tau^- \bar{\nu}_\tau$	0.67	0.62 ± 0.05	0.47-0.55	$0.33^{+0.14}_{-0.11}$		
$\bar{B}_s \to D_s^{*+} \tau^- \bar{\nu}_\tau$	1.53	1.3 ± 0.1	1.2-1.3			
$\bar{B}_s \to D_{s0}^{*+} \mu^- \bar{\nu}_\mu$	0.39					
$\bar{B}_s \to D_{s1}^{*+}(2460) \mu^- \bar{\nu}_\mu$	0.47					
$\bar{B}_s \to D_{s1}^{*+}(2536) \mu^- \bar{\nu}_\mu$	0.32					
$\bar{B}_s \to D_{s2}^{*+} \mu^- \bar{\nu}_\mu$	0.44					

Heavy Quark Symmetry

$$h_+(\omega) = h_V(\omega) = h_{A_1}(\omega) = h_{A_3}(\omega) = \xi(\omega)$$
$$h_-(\omega) = h_{A_2}(\omega) = 0.$$

$$h_\pm(\omega) = \frac{2m_{\bar{B}_s}}{\sqrt{2m_{\bar{B}_s} m_{c\bar{s}}}} f_\pm(\omega)$$

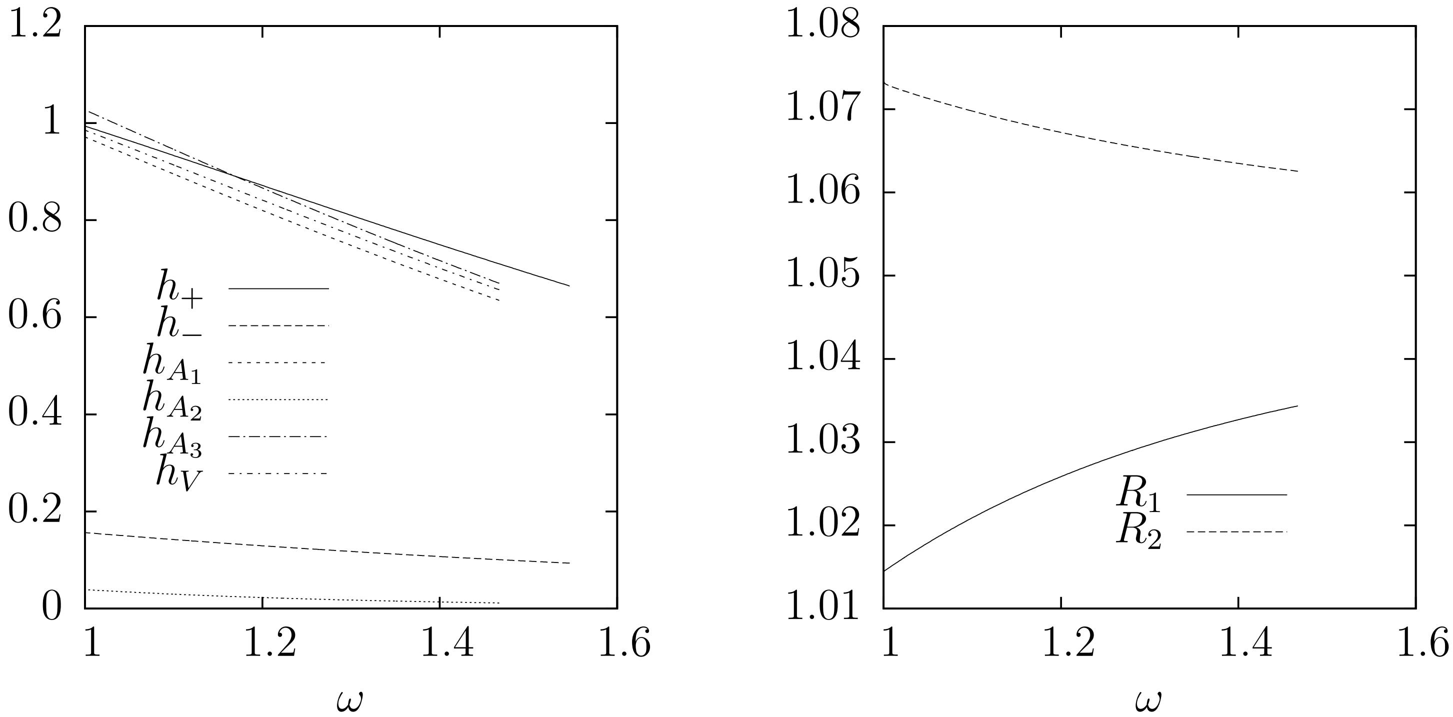
$$h_V(\omega) = \sqrt{2}\sqrt{\frac{M_{D_s^*}}{M_{\bar{B}_s}}} \frac{V^2_{\lambda=-1}(|\vec{q}|)}{|\vec{q}|}$$

$$h_{A_1}(\omega) = i\frac{\sqrt{2}}{w+1}\frac{1}{\sqrt{M_{\bar{B}_s} M_{D_s^*}}} A^1_{\lambda=-1}(|\vec{q}|)$$

$$h_{A_2}(\omega) = i\sqrt{\frac{M_{D_s^*}}{M_{\bar{B}_s}}}\left(-\frac{A^0_{\lambda=0}(|\vec{q}|)}{|\vec{q}|} + \frac{E_{D_s^*}(|\vec{q}|)A^3_{\lambda=0}(|\vec{q}|)}{|\vec{q}|^2} - \sqrt{2}M_{D^*}\frac{A^1_{\lambda=-1}(|\vec{q}|)}{|\vec{q}|^2}\right)$$

$$h_{A_3}(\omega) = i\frac{M^2_{D_s^*}}{\sqrt{M_{D_s^*} M_{\bar{B}_s}}}\left(-\frac{A^3_{\lambda=0}(|\vec{q}|)}{|\vec{q}|^2} + \frac{\sqrt{2}}{M_{D^*}}\frac{A^1_{\lambda=-1}(|\vec{q}|)}{|\vec{q}|^2}\right)$$

Heavy Quark Symmetry



$B_s \to B$ decays

- the only decay modes allowed are the semileptonic $\bar{B}_s \to B^- e^+ \nu_e$

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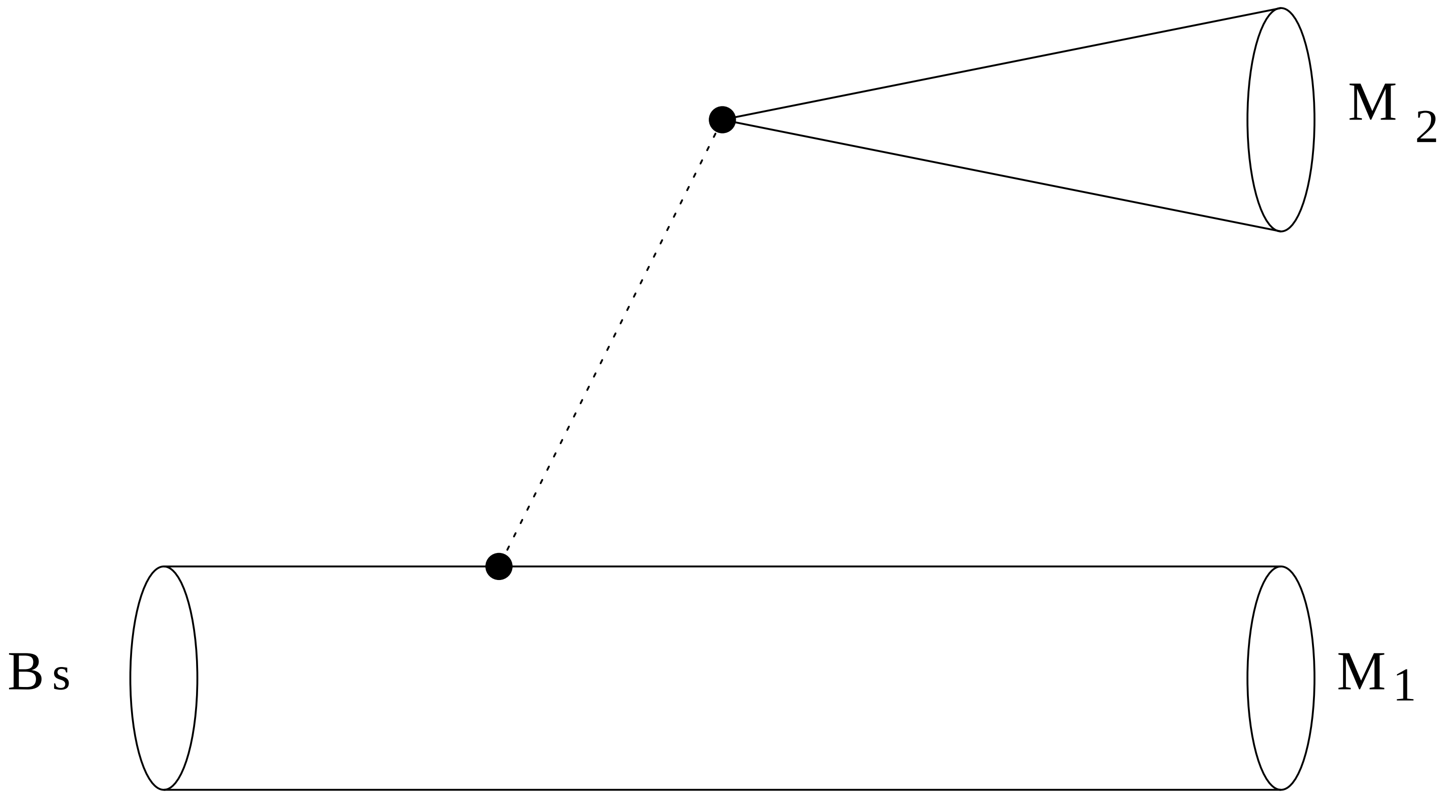
- the only decay modes allowed are the semileptonic $\bar{B}_s \to B^- e^+ \nu_e$
- $$\Gamma_{B_s \to B^- e^+ \nu_e} = 1.7\ 10^{-20}\ \mathrm{GeV}$$

Non leptonic decays



Non leptonic decays

$$H_{\text{eff}} = \frac{G_F}{\sqrt{2}} \left(V_{cb} \left[c_1(\mu) Q_1^{cb} + c_2(\mu) Q_2^{cb} \right] + H.c. \right),$$

$$\begin{aligned} Q_1^{cb} =& \bar{\Psi}_c(0)\gamma_\mu(I-\gamma_5)\Psi_b(0) \left[V_{ud}^* \bar{\Psi}_d(0)\gamma^\mu(I-\gamma_5)\Psi_u(0) + V_{us}^* \bar{\Psi}_s(0)\gamma^\mu(I-\gamma_5)\Psi_u(0) \right. \\ & \left. + V_{cd}^* \bar{\Psi}_d(0)\gamma^\mu(I-\gamma_5)\Psi_c(0) + V_{cs}^* \bar{\Psi}_s(0)\gamma^\mu(I-\gamma_5)\Psi_c(0) \right] \\ Q_2^{cb} =& \bar{\Psi}_d(0)\gamma_\mu(I-\gamma_5)\Psi_b(0) \left[V_{ud}^* \bar{\Psi}_c(0)\gamma^\mu(I-\gamma_5)\Psi_u(0) + V_{cd}^* \bar{\Psi}_c(0)\gamma^\mu(I-\gamma_5)\Psi_c(0) \right] \\ & + \bar{\Psi}_s(0)\gamma_\mu(I-\gamma_5)\Psi_b(0) \left[V_{us}^* \bar{\Psi}_c(0)\gamma^\mu(I-\gamma_5)\Psi_u(0) + V_{cs}^* \bar{\Psi}_c(0)\gamma^\mu(I-\gamma_5)\Psi_c(0) \right], \end{aligned}$$

$$\begin{aligned} a_1(\mu) &= c_1(\mu) + \frac{1}{N_C} c_2(\mu) \\ a_2(\mu) &= c_2(\mu) + \frac{1}{N_C} c_1(\mu) \end{aligned}$$

Non leptonic decays

	This work	Faustov(2012)	Blasi(1993)	Chen(2012)	Li(2009)
$\bar{B}_s \to D_s^+ \pi^-$	0.53	0.35	0.5	$0.27^{+0.07}_{-0.03}$	$0.17^{+0.07}_{-0.06}$
$\bar{B}_s \to D_s^+ \rho^-$	1.26	0.94	1.3	$0.64^{+0.17}_{-0.11}$	$0.42^{+1.7}_{-1.4}$
$\bar{B}_s \to D_s^+ K^-$	0.04	0.028	0.04	$0.021^{+0.002}_{-0.002}$	$0.013^{+0.005}_{-0.004}$
$\bar{B}_s \to D_s^+ K^{*-}$	0.08	0.047	0.06	$0.038^{+0.005}_{-0.005}$	$0.028^{+0.01}_{-0.08}$
$\bar{B}_s \to D_{s0}^{*+} \pi^-$	0.10	0.09	$0.052^{+0.25}_{-0.021}$		
$\bar{B}_s \to D_{s0}^{*+} \rho^-$	0.27	0.22	$0.013^{+0.06}_{-0.05}$		
$\bar{B}_s \to D_{s0}^{*+} K^-$	0.009	0.007	$0.004^{+0.002}_{-0.002}$		
$\bar{B}_s \to D_{s0}^{*+} K^{*-}$	0.16	0.012	$0.008^{+0.004}_{-0.003}$		
$\bar{B}_s \to D_s^{*+} \pi^-$	0.45	0.27	0.2	$0.31^{+0.03}_{-0.02}$	
$\bar{B}_s \to D_s^{*+} \rho^-$	1.35	0.87	1.3	$0.9^{+1.5}_{-1.5}$	
$\bar{B}_s \to D_s^{*+} K^-$	0.04	0.021	0.02	$0.024^{+0.002}_{-0.002}$	
$\bar{B}_s \to D_s^{*+} K^{*-}$	0.08	0.048	0.06	$0.056^{+0.006}_{-0.007}$	
$\bar{B}_s \to D_{s1}^+(2460) \pi^-$	0.15	0.19			
$\bar{B}_s \to D_{s1}^+(2460) \rho^-$	0.36	0.49			
$\bar{B}_s \to D_{s1}^+(2460) K^-$	0.012	0.014			
$\bar{B}_s \to D_{s1}^+(2460) K^{*-}$	0.020	0.026			

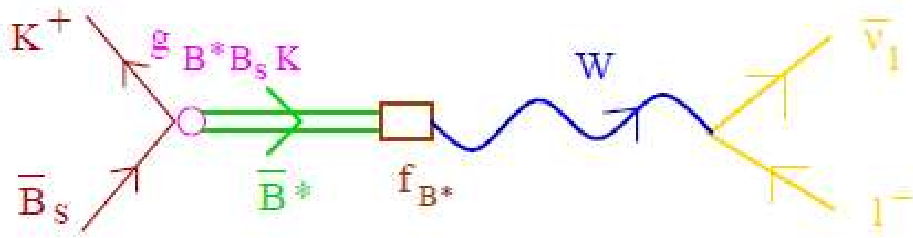
Non leptonic decays

	This work	Faustov(2012)	Blasi(1993)	Chen(2012)	Li(2009)
$\bar{B}_s \to D_s^+ D_s^-$	2.1	1.1	1.0	$0.83^{+0.1}_{-0.1}$	1.65
$\bar{B}_s \to D_s^+ D_s^{*-}$	2.0	1.0	0.8	$0.84^{+0.12}_{-0.12}$	
$\bar{B}_s \to D_s^{*+} D_s^-$	1.24	0.61	0.4	$0.7^{+1.6}_{-0.15}$	
$\bar{B}_s \to D_s^+ D_s^{*-} + D_s^{*+} D_s^-$	3.24	1.61	1.2	$1.54^{+0.2}_{-0.19}$	2.4
$\bar{B}_s \to D_s^{*+} D_s^{*-}$	5.45	2.5	1.6	$2.4^{+0.4}_{-0.4}$	3.18
$\bar{B}_s \to D_s^{(*)+} D_s^{(*)-}$	10.8	5.21	3.8	$4.77^{+0.46}_{-0.46}$	7.23
$\bar{B}_s \to D_s^+ D^-$	0.08				
$\bar{B}_s \to D_s^+ D^{*-}$	0.05				
$\bar{B}_s \to D_s^{*+} D^-$	0.04				
$\bar{B}_s \to D_s^{*+} D^{*-}$	0.13				

Other non leptonic decays

	Γ [10^{-15} GeV]	BR in %	Experiment
$\bar{B}_s \to \phi J/\Psi$	$11.80^{+1.9}_{-0.8}\, a_2^2$	0.11	$(0.109^{+0.28}_{-0.23})$
$\bar{B}_s \to K^0 J/\Psi$	$8.1^{+0.5}_{-1.3}\; 10^{-2}\, a_2^2$	$7.25\; 10^{-4}$	$(3.6 \pm 0.8)\; 10^{-3}$
$\bar{B}_s \to K^{*0} J/\Psi$	$0.51_{-0.3}\, a_2^2$	$4.6\; 10^{-3}$	$(9 \pm 4)\; 10^{-3}$

$B_s \to K$ semileptonic decays



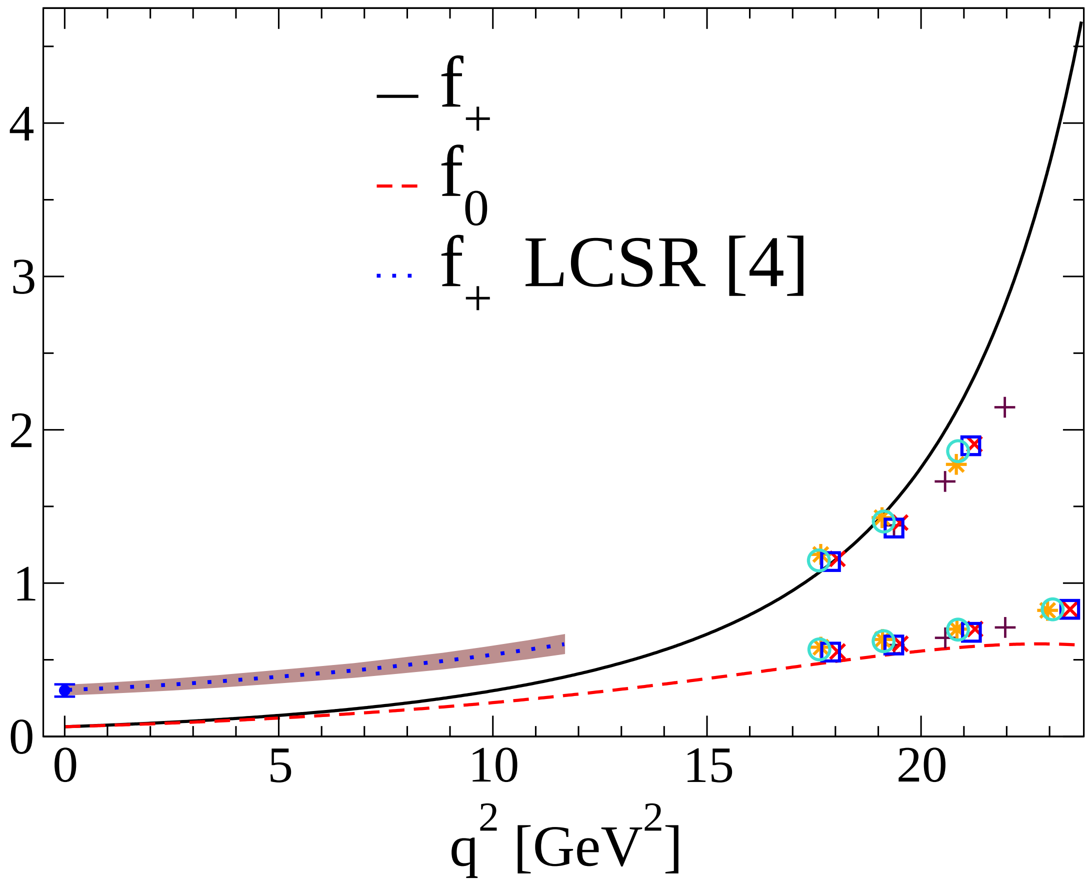
$$f_+^{\rm pole}(q^2) = \frac{g_{B^*B_sK}(q^2)}{2}\sqrt{q^2}f_{B^*}(q^2)\frac{1}{M_{B^*}^2-q^2},$$

$$f_0^{\rm pole}(q^2) = \frac{g_{B^*B_sK}(q^2)}{2}\sqrt{q^2}f_{B^*}(q^2)\frac{M_{B_s}^2-M_K^2-q^2}{(M_{B_s}^2-M_K^2)M_{B^*}^2}$$

$$f_{B^*}(q^2) = \frac{\sqrt{6}}{(q^2)^{1/4}\pi}\int_0^\infty d|\vec{p}|\Phi_{B_u^*}(|\vec{p}|)\,|\vec{p}|^2\sqrt{\frac{\widehat{E}_b\widehat{E}_u}{4E_bE_u}}\left(1+\frac{|\vec{p}|^2}{3\widehat{E}_b\widehat{E}_u}\right)$$

$$= f_{B^*}\sqrt{\frac{M_{B^*}}{\sqrt{q^2}}}$$

Valence and resonance contribution



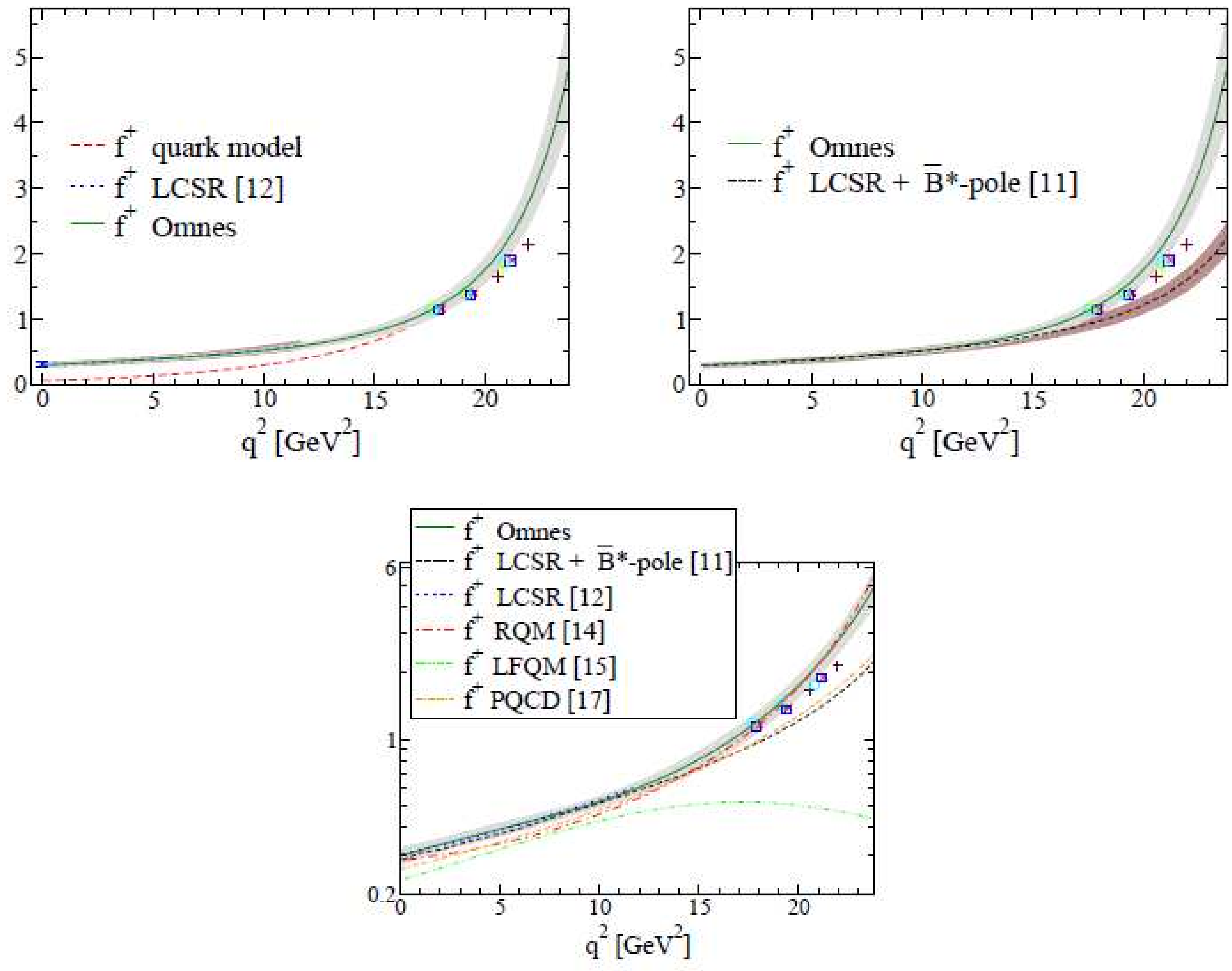
Omnes representation

$$f^+(q^2) \approx \frac{1}{M_{B^*}^2 - q^2} \prod_{j=0}^{n} \left[f_+(q_j^2) \Big(M_{B^*}^2 - q_j^2 \Big) \right]^{\alpha_j(q^2)}$$

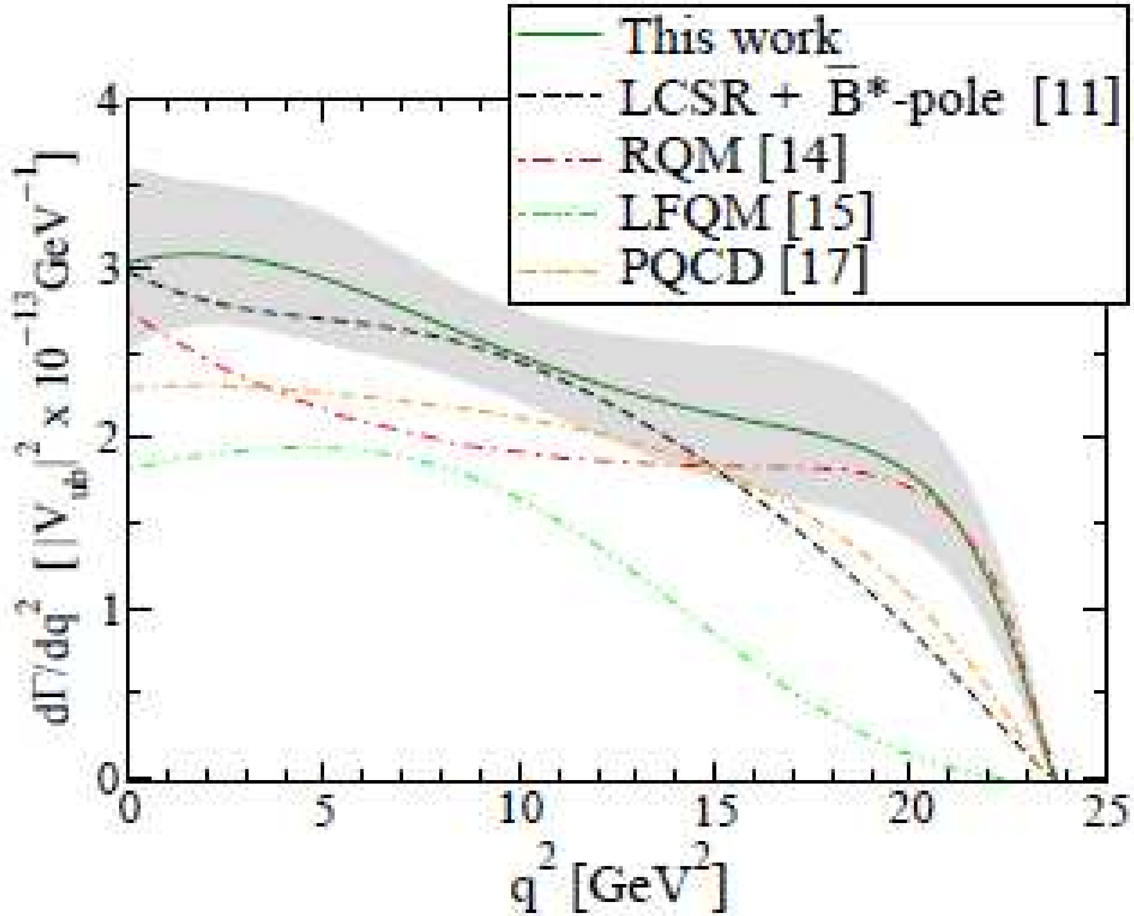
Watson Theorem

$$\frac{f_+(s+i\epsilon)}{f_+(s-i\epsilon)} = e^{2i\delta s}, s > s_{th} = (M_{B_s} + M_K)^2$$

Omnes representation



Omnes representation



	This work	LCSR+$\bar{B}^*$-pole [11]	RQM [14]	LFQM [15]	PQCD [17]
Γ [$\lvert V_{ub}\rvert^2 \times 10^{-9}$ MeV]	$5.45^{+0.83}_{-0.80}$	$4.63^{+0.97}_{-0.88}$	4.50 ± 0.55	3.17 ± 0.24	4.2 ± 2.1

Summary and conclusions

- We have studied the weak decays of B_s mesons within constituent quark model
- We have obtained decay widths that are in general agreement with experiments
- We have obtained the Omnes representation of the f_+ form factor for the $B_s \to K$ decays, and calculated the semileptonic decay width