



Os vértices $B_s B^* K$ e $B_s BK^*$ pelas Regras de Soma da QCD

A. Cerqueira Jr., B. Osório Rodrigues, M. E. Bracco

XXV RETINHA - IFGW-UNICAMP

7 de Fevereiro de 2014

Sumário

Introdução

Sumário

Introdução

$B_s B^* K$

K off-shell

B_s off-shell

B^* off-shell

Sumário

Introdução

$B_s B^* K$

K off-shell

B_s off-shell

B^* off-shell

$B_s B K^*$

K^* off-shell

B_s off shell

B off shell

Sumário

Introdução

$B_s B^* K$

K off-shell

B_s off-shell

B^* off-shell

$B_s B K^*$

K^* off-shell

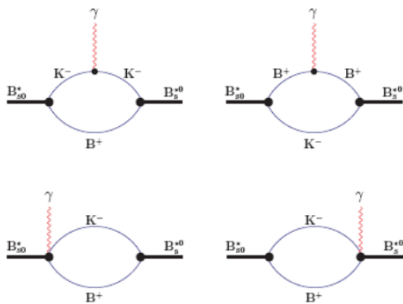
B_s off shell

B off shell

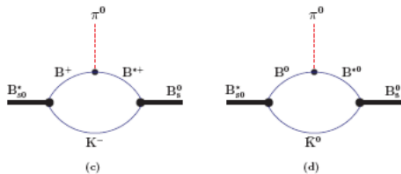
Considerações finais

Introdução

- ▶ Contribuição para o estudo do méson $B_{s1}(5778)$ como uma molécula hadrônica, ou seja, um estado ligado $B^* K$. Neste estudo, são usadas as Lagrangianas efetivas, nas quais estão as constantes dos vértices $B_s^* B K$, $B_s B^* K$, $B_s B K^*$, etc;
- ▶ Aplicação do método à outros vértices que envolvam mésons que contenham quark bottom: $B_s^* B^* K$, $B_s B^* K$.



Diagrams contributing to the radiative transition $B_{s0}^* \rightarrow B_s^* + \gamma$.



Diagrams contributing to the strong transition $B_{s0}^* \rightarrow B_s + \pi^0$.

As Regras de soma da QCD

Função de correlação:

$$\Pi(p, p') = \int d^4x d^4y \langle 0 | T \{ j_1^{M_1}(x) j_2^{M_2^\dagger}(y) j_3^{M_3^\dagger}(0) \} | 0 \rangle e^{ip' \cdot x} e^{-iq \cdot y}$$

Aplicação do princípio da dualidade

Lado da QCD



**Correntes interpolantes
de quarks**

Lado da fenomenologia



**Elementos de matrizes
hadrônicas**

Aplicar a Transformada de Borel em ambos os lados

Lado da QCD = Lado da fenomenologia



**Fatores de forma, massas, constantes
de acoplamento.**

O lado da QCD

Neste caso usamos a função de correlação de três pontos.

$$\Pi(p, p') = \int d^4x d^4y \langle 0 | T \{ j_1^{M_1}(x) j_2^{M_2 \dagger}(y) j_3^{M_3 \dagger}(0) \} | 0 \rangle e^{ip' \cdot x} e^{-iq \cdot y} \quad (1)$$

Nesta função de correlação os quarks são descritos pelas seguintes correntes interpolantes.

$$\begin{aligned} j_{M_1}(x) &= \bar{q}_1 \mathcal{O}_1 q_2 \\ j_{M_2}(y) &= \bar{q}_2 \mathcal{O}_2 q_3 \\ j_{M_3}(0) &= \bar{q}_1 \mathcal{O}_3 q_3 \end{aligned} \quad (2)$$

A integração no correlator resulta na dupla descontinuidade:

$$DD[\Pi] = -3i \int \frac{d^4 k}{(2\pi)^4} (-2\pi i)^3 [\delta((k-p')^2 - m_{q_3}^2) \delta(k^2 - m_{q_1}^2) \delta((k-p)^2 - m_{q_2}^2)] \\ \times \text{Tr}[(\not{k} - \not{p}') + m_{q_3}] \mathcal{O}_1(\not{k} + m_{q_1}) \mathcal{O}_3((\not{k} - \not{p}) + m_{q_2}) \mathcal{O}_2] \theta(k_0 - p'_0) \theta(k_0) \theta(k_0 - p_0) \quad (3)$$

O correlator é recuperado através da relação de dispersão .

$$\Pi^{QCD}(p, p', q) = -\frac{1}{4\pi^2} \int_{s_{min}}^{\infty} \int_{u_{min}}^{\infty} dsdu \frac{DD[\Pi]}{(s-p^2)(u-p'^2)} \quad (4)$$

Finalmente, o lado da OPE ou lado da QCD é obtido aplicando a dupla transformada de Borel.

$$B_{M^2} B_{M'^2} [\Pi^{QCD}(Q^2)] = -\frac{1}{4\pi^2} \int_{s_{min}}^{\infty} \int_{u_{min}}^{\infty} dsdu DD[\Pi] e^{-s/M^2} e^{-u/M'^2} \quad (5)$$

Lado da Fenomenologia

A função de correlação é relacionada aos estados hadrônicos.

$$\begin{aligned}
 \langle 0 | j_\mu^V | V \rangle &= m_V f_V \epsilon_\mu \\
 \langle 0 | j_\mu^A | A \rangle &= m_A f_A \epsilon_\mu \\
 \langle 0 | j_5 | P \rangle &= \frac{m_P^2}{m_q} f_P \\
 \langle 0 | j_\mu^A | P \rangle &= i f_P p^\mu
 \end{aligned} \tag{6}$$

Expressão final obtida pelo lado da fenomenologia.

$$\Pi_{\mu\nu}^{Fen}(p, p') = \frac{f_{M_1} f_{M_2} f_{M_3} g_{M_1 M_2 M_3} \langle M_1 M_2 M_3 \rangle_i}{(p'^2 - m_2^2)(p^2 - m_1^2)(q^2 + m_3^2)} + \text{“ressonâncias”} \tag{7}$$

A Regra de Soma

Aplicando o princípio da dualidade quark-hádron, o lado da OPE é igualado ao lado da fenomenologia:

$$\Pi_i^{OPE}(p, p', q) = \Pi_i^{fen}(p, p', q) \quad (8)$$

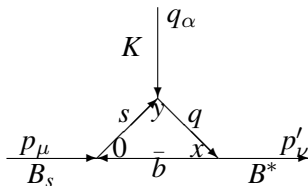
$$\frac{f_{M_1} f_{M_2} f_{M_3} g_{M_1 M_2 M_3} \langle M_1 M_2 M_3 \rangle_i}{(p'^2 - m_2^2)(p^2 - m_1^2)(q^2 + m_3^2)} + \text{"ressonâncias"} = \frac{1}{4\pi^2} \int_{s_{min}}^{\infty} ds \times \int_{u_{min}}^{\infty} du \frac{\rho_i^{OPE}(s, u, Q^2)}{(s - p^2)(u - p'^2)} \quad (9)$$

Aplicando a Dupla Transformada de Borel em ambos os lados.

$$\frac{f_{M_1} f_{M_2} f_{M_3} g_{M_1 M_2 M_3} \langle M_1 M_2 M_3 \rangle_i}{(Q^2 + m_3^2)} e^{-m_1^2/M^2} e^{-m_2^2/M'^2} = \frac{1}{4\pi^2} \int_{s_{min}}^{s_0} ds \times \int_{u_{min}}^{u_0} du \rho_i^{OPE}(s, u, Q^2) e^{-s/M^2} e^{-u/M'^2} \quad (10)$$

Vértice $B_s B^* K$

K off-shell.



Lado da QCD:

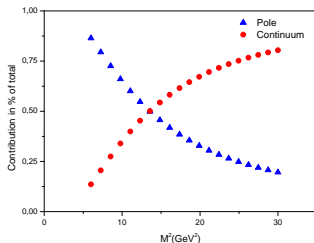
$$\begin{aligned}
 B_{M^2} B_{M'^2} [\Pi^{QCD}(Q^2)] &= -\frac{1}{4\pi^2} \int_{s_{min}}^{\infty} \int_{u_{min}}^{\infty} ds du \frac{3}{2\pi\sqrt{\lambda}} \{p_\mu [A(p \cdot p' - 2k \cdot p - m_b m_s + m_b^2) + 2\pi(m_b^2 - k \cdot p')] \\
 &+ p'_\mu [B(p \cdot p' - 2k \cdot p - m_b m_s + m_b^2) + 2\pi(k \cdot p - m_b^2 + m_b m_s)] e^{-s/M^2} e^{-u/M'^2} \}
 \end{aligned} \quad (11)$$

Lado da fenomenologia:

$$\begin{aligned}
 B_{M^2} B_{M'^2} [\Pi_{\mu}^{Fen}(p, p', q)] &= \frac{f_{B^*} f_K f_{B_s} m_{B^*} m_{B_s}^2 m_K^2 g_{B_s^* B K}(q^2)}{(m_b + m_s) m_s (Q^2 + m_K^2)} \\
 &\times \left[-2p_\mu + p'_\mu \left(1 + \frac{(m_{B_s}^2 + Q^2)}{m_{B^*}^2} \right) \right] e^{-m_{B_s}^2/M^2} e^{-m_{B^*}^2/M'^2}
 \end{aligned} \quad (12)$$

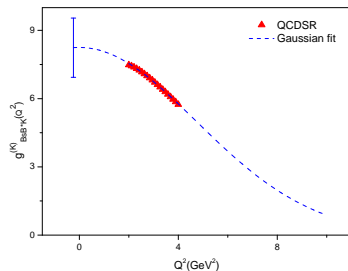
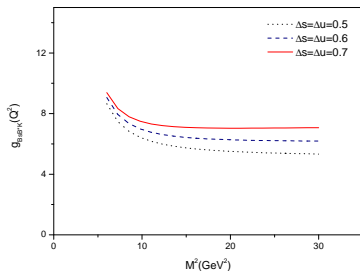
K off-shell

Estrutura p .



partícula	q	s	b	K	B_s	B^*
m (GeV)	0	0.13	4.20	0.49	5.4	5.2
f (MeV)	-	-	-	160	204	196

grandeza	constante	desvio	desvio percentual(%)
f_K (GeV)	8.24	0.08	0.99
f_{B^*} (GeV)	7.99	1.34	16.30
f_{B_s} (GeV)	7.91	0.99	12.07
M^2 (GeV)	8.26	0.15	1.85
m_b (GeV)	7.74	1.93	23.39
m_s (GeV)	8.03	2.03	24.71
Δs e Δu	8.20	0.40	4.90

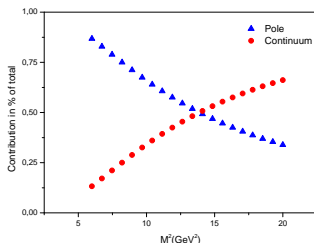


$\Delta s = \Delta u = 0.6$; $M^2 = 9 \text{ GeV}^2$. Ajuste gaussiano. Desvio padrão é igual a $\sigma = 1.3$, e o desvio percentual igual a 15.47%. O valor da constante é dado por:

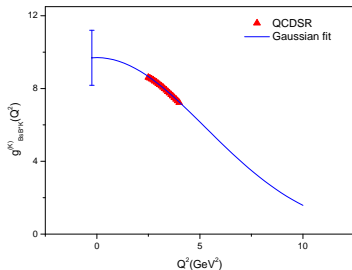
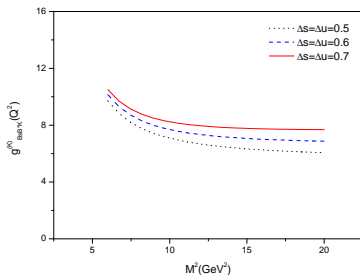
$$g_{B_s B^* K}^{(K)} = 8.0 \pm 1.3$$

K off-shell

Estrutura p' .

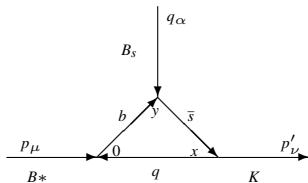


grandeza	constante	desvio	desvio percentual(%)
f_K (GeV)	9.69	0.1	1.01
f_{B^*} (GeV)	9.39	1.58	16.33
f_{B_s} (GeV)	9.30	1.17	12.08
M^2 (GeV)	9.71	0.16	1.70
m_b (GeV)	9.10	2.30	23.78
m_s (GeV)	9.45	2.41	24.90
Δs e Δu	9.65	0.46	4.80



$\Delta u = 0.6$; $M^2 = 9 \text{ GeV}^2$. Ajuste gaussiano. Desvio padrão é igual a $\sigma = 1.5$, e o desvio percentual igual a 15.59%. O valor da constante é dado por:

$$g_{B_s B^* K}^{(K)} = 9.5 \pm 1.5$$

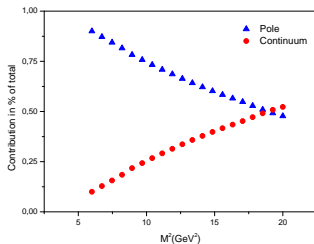
B_s off-shell

Lado da QCD:

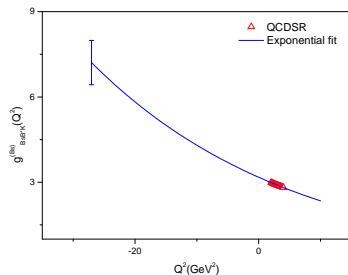
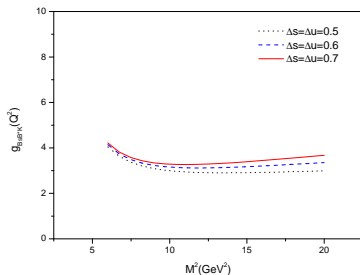
$$\begin{aligned}
 B_{M^2} B_{M'^2} [\Pi_{\mu\nu}^{QCD}] &= -\frac{1}{4\pi^2} \int_{s_{min}}^{\infty} \int_{u_{min}}^{\infty} ds du - \frac{3i}{2\pi\sqrt{\lambda}} \{g_{\nu\mu} [F(u, s, t) + 2m_b D - 2m_s D] \\
 &+ p'_{\nu} p_{\mu} [2m_b C - 2m_s C + m_s B - m_b A] + p'_{\mu} p'_{\nu} [2m_b E - 2m_s E - 2m_b B] \\
 &+ p'_{\mu} p_{\nu} [2m_b C - 2m_s C + m_s B - m_b A] \\
 &+ p_{\mu} p_{\nu} [2m_b F - 2m_s F + 2m_s A]\} e^{-s/M^2} e^{-u/M'^2}
 \end{aligned} \quad (13)$$

Lado da fenomenologia:

$$\begin{aligned}
 B_{M^2} B_{M'^2} [\Pi^{Fen}] &= \frac{f_K f_{B_s} f_B m_{B^*} m_{B_s}^2 g_{B_s^* B K}}{(m_s + m_b)(Q^2 + m_{B_s}^2)} \left[-2p'_{\mu} p'_{\nu} \right. \\
 &\left. + p_{\mu} p'_{\nu} \left(1 + \frac{(m_K^2 + Q^2)}{m_{B^*}^2} \right) \right] e^{-m_{B^*}^2/M^2} e^{-m_K^2/M'^2}
 \end{aligned} \quad (14)$$

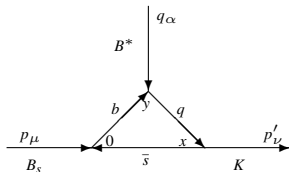
B_s off-shellEstrutura tensorial $p'_\mu p'_\mu$.

grandeza	constante	desvio	desvio percentual(%)
f_K (GeV)	7.70	0.10	1.35
f_{B^*} (GeV)	7.45	1.25	16.29
\widehat{f}_{B_s} (GeV)	7.38	0.93	12.06
M^2 (GeV)	7.74	0.33	4.29
m_b (GeV)	7.35	1.21	15.81
m_s (GeV)	7.68	0.21	2.71
Δs e Δu	7.65	0.09	1.23



$\Delta s = \Delta u = 0.5$; $M^2 = 9 \text{ GeV}^2$. Ajuste exponencial. Desvio padrão é igual a $\sigma = 0.78$, e o desvio percentual igual a 10.13% . O valor da constante é dado por:

$$g_{B_s B^* K}^{(B_s)} = 7.6 \pm 0.8$$

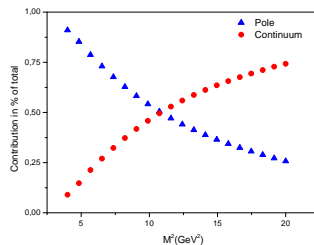
B^* off-shell

Lado da QCD:

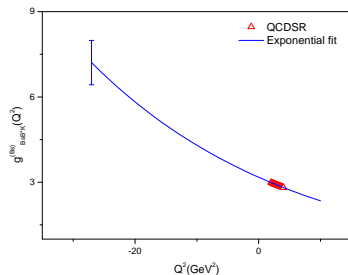
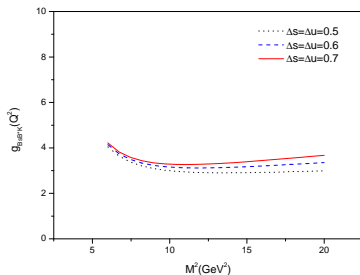
$$\begin{aligned}
 B_{M^2} B_{M'^2} [\Pi_{\mu\nu}^{QCD}] &= -\frac{1}{4\pi^2} \int_{s_{\min}}^{\infty} \int_{u_{\min}}^{\infty} ds du - \frac{3i}{2\pi\sqrt{\lambda}} \left\{ g_{\nu\mu} [F(u, s, t) + 2m_b D - 2m_s D] \right. \\
 &+ p'_{\nu} p_{\mu} [2m_b C - 2m_s C + A(m_s - m_b) + m_s B - m_s] \\
 &+ p'_{\mu} p'_{\nu} [2E(m_b - m_s) + 2m_s B] + p_{\mu} p_{\nu} [2F(m_b - m_s) + 2m_s A] \\
 &\left. + p'_{\mu} p_{\nu} [2C(m_b - m_s) + A(m_s - m_b) + m_s B - m_s] \right\} e^{-s/M^2} e^{-u/M'^2} \quad (15)
 \end{aligned}$$

Lado da fenomenologia:

$$\begin{aligned}
 B_{M^2} B_{M'^2} [\Pi_{\mu}^{Fen}(p, p', q)] &= \frac{f_{B^*} f_K f_{B_s} m_{B^*} m_{B_s}^2 g_{B_s^* B K}(q^2)}{(m_b + m_s)(Q^2 + m_{B^*}^2)} \\
 &\times \left[p_{\mu} p'_{\nu} \left(\frac{m_{B_s}^2}{m_{B^*}^2} - 1 \right) + p'_{\mu} p'_{\nu} \left(1 - \frac{m_{B_s}^2}{m_{B^*}^2} \right) \right] e^{-m_{B_s}^2/M^2} e^{-m_K^2/M'^2} \quad (15)
 \end{aligned}$$

B^* off-shellEstrutura tensorial $p'_\mu p'_\mu$.

grandeza	constante	desvio	desvio percentual(%)
f_K (GeV)	8.79	0.08	0.96
f_{B^*} (GeV)	8.52	1.43	16.33
f_{B_s} (GeV)	8.44	1.06	12.08
M^2 (GeV)	8.88	0.49	5.58
m_b (GeV)	8.30	2.25	25.67
m_s (GeV)	8.79	0.19	2.20
Δ_s e Δ_u	8.78	0.19	2.11

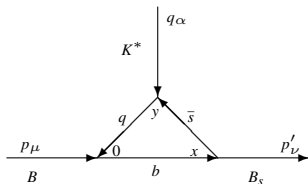


$\Delta s = \Delta u = 0.5$; $M^2 = 8 \text{ GeV}^2$. Ajuste exponencial. Desvio padrão é igual a $\sigma = 1.1$, e o desvio percentual igual a 12.88%. O valor da constante é dado por:

$$g_{B_s B^* K}^{(B_s)} = 8.6 \pm 1.1$$

Vértice $B_s B K^*$

K^* off-shell.

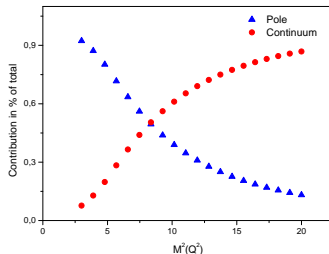
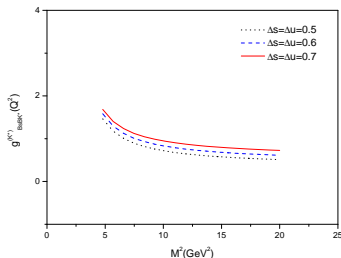


Lado da QCD:

$$\begin{aligned}
 B_{M^2} B_{M'^2} [\Pi_\mu^{QCD}] &= -\frac{1}{4\pi^2} \int_{s_{min}}^{\infty} \int_{u_{min}}^{\infty} ds du \frac{3}{\sqrt{\lambda}} \{ p_\mu [A(p \cdot p' + m_b m_s - m_b^2) + m_b^2 - k \cdot p' - m_b m_s] \\
 &+ p'_\mu [B(p \cdot p' + m_b m_s - m_b^2) - k \cdot p + m_b^2] e^{-s/M^2} e^{-u/M'^2} \}
 \end{aligned} \quad (16)$$

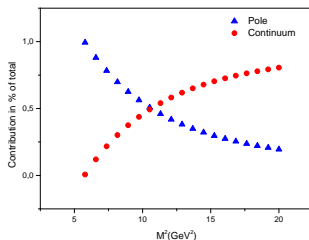
Lado da fenomenologia:

$$\begin{aligned}
 B_{M^2} B_{M'^2} [\Pi_\mu^{Fen}(p, p', q)] &= -\frac{f_B f_{K^*} f_{B_s} m_{K^*} m_{B_s}^2 m_B^2 g_{B_s^* B K}(Q^2)}{(m_s m_b + m_b^2)(p^2 - m_B^2)(p'^2 - m_{B_s}^2)(Q^2 + m_{K^*}^2)} \\
 &\times \left[p_\mu \left(1 - \frac{(m_B^2 - m_{B_s}^2)}{m_{K^*}^2} \right) + p'_\mu \left(1 - \frac{(m_{B_s}^2 - m_B^2)}{m_{K^*}^2} \right) \right] e^{-m_B^2/M^2} e^{-m_{B_s}^2/M'^2}
 \end{aligned} \quad (17)$$

K^* off shellEstrutura p :

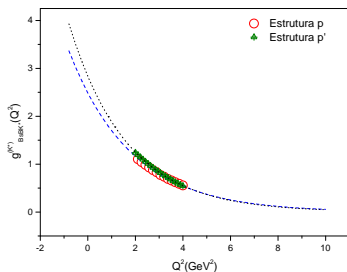
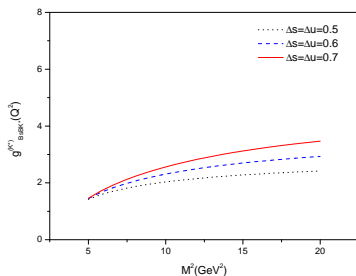
$\Delta s = \Delta u = 0.7$; $M^2 = 4.7 \text{ GeV}^2$. Ajuste exponencial. Desvio padrão é igual a $\sigma = 0.6$, e o desvio percentual igual a 17.24%. O valor da constante é dado por:

$$g_{B_s B K^*}^{(K^*)} = 3.4 \pm 0.6$$

K^* off shellEstrutura p' :

partícula	q	s	b	K^*	B_s	B
m (GeV)	0	0.13	4.20	0.89	5.4	5.2
f (MeV)	-	-	-	220	227	191

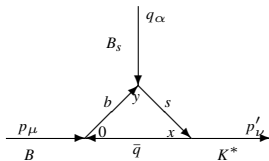
$\Delta s = \Delta u = 0.5$; $M^2 = 7.5 \text{ GeV}^2$.
 Desvio padrão é igual a $\sigma = 0.97$, e o desvio percentual igual a 24.77%.



Ajuste exponencial. O valor da constante é dado por:

$$g_{B_s B K^*}^{(K^*)} = 3.9 \pm 1.0$$

B_s off shell



Lado da QCD:

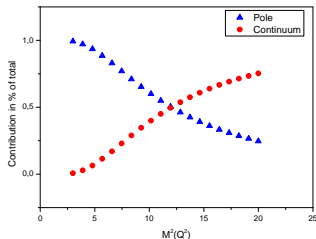
$$\begin{aligned}
 B_{M^2} B_{M'^2} [\Pi_{\mu}^{QCD}] &= -\frac{1}{4\pi^2} \int_{s_{min}}^{\infty} \int_{u_{min}}^{\infty} ds du \frac{3}{2\pi\sqrt{\lambda}} \{p_{\mu} [A(p \cdot p' - m_b m_s - 2p \cdot k) - k \cdot p'] \\
 &+ p'_{\mu} [B(p \cdot p' - m_b m_s - 2p \cdot k) + k \cdot p] e^{-s/M^2} e^{-u/M^2}
 \end{aligned} \quad (18)$$

Condensado $\langle q\bar{q} \rangle$:

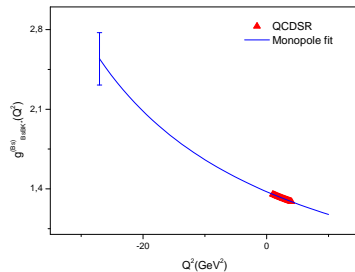
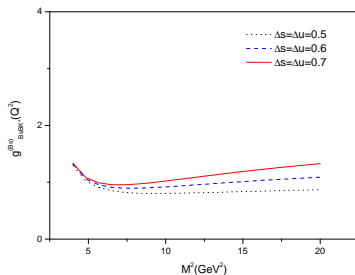
$$B_{M^2} B_{M'^2} [\Pi] = \langle q\bar{q} \rangle [m_b p'_{\mu} - m_s p_{\mu}] e^{-m_b/M^2} e^{-m_s/M^2} \quad (19)$$

Lado da fenomenologia:

$$\begin{aligned}
 B_{M^2} B_{M'^2} [\Pi_{\mu}^{Fen}(p, p', q)] &= -i \frac{f_{K^*} f_{B_s} m_{K^*} m_{B_s}^2 m_{B_s}^2 m_{B_s B K^*} (Q^2)}{(m_b^2 + m_s m_b)(Q^2 + m_{B_s}^2)} \\
 &\times \left[-2p_{\mu} + p'_{\mu} \left(1 - \frac{m_B^2 - m_{B_s}^2}{m_{K^*}^2} \right) \right] e^{-m_B^2/M^2} e^{-m_{K^*}^2/M^2} \quad (20)
 \end{aligned}$$

B_s off shellEstrutura tensorial p_μ .

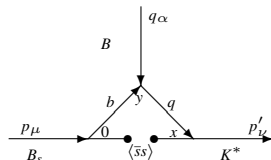
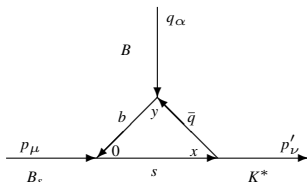
$\Delta s = \Delta u = 0.7$; $M^2 = 14 \text{ GeV}^2$. Desvio padrão é igual a $\sigma = 0.23$, e o desvio percentual igual a 8,42%.



Ajuste monopolar. O valor da constante é dado por:

$$g_{B_s B K^*}^{(B_s)} = 2.7 \pm 0.2$$

B off shell



Lado da QCD:

$$\begin{aligned}
 B_{M^2} B_{M'^2} [\Pi_\mu^{QCD}] &= -\frac{1}{4\pi^2} \int_{s_{min}}^{\infty} \int_{u_{min}}^{\infty} ds du \frac{3}{2\pi\sqrt{\lambda}} \{ p_\mu [A(2p \cdot k - p \cdot p' + m_b m_s - m_s^2) - k \cdot p' + m_s^2] \\
 &+ p'_{\mu} [B(2p \cdot k - p \cdot p' + m_b m_s - m_s^2) + k \cdot p - m_s^2 + m_s m_b] e^{-s/M^2} e^{-u/M'^2} \}
 \end{aligned} \quad (21)$$

Condensado de quark strange

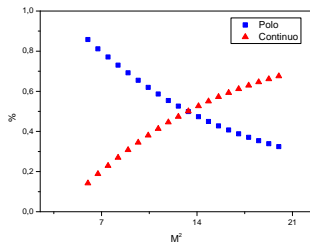
$$B_{M^2} B_{M'^2} [\Pi] = -m_b \langle \bar{s}s \rangle e^{-m_b/M^2} p'_{\mu} \quad (22)$$

Lado da fenomenologia:

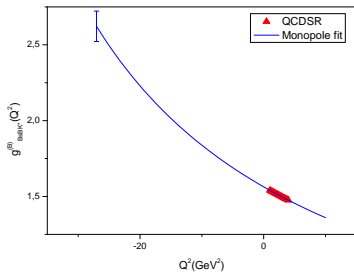
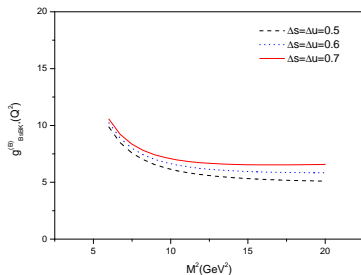
$$\begin{aligned}
 B_{M^2} B_{M'^2} [\Pi_\mu^{Fen}] &= -i \frac{f_{K^*} f_{B_s} m_{K^*} m_{B_s}^2 m_B^2 g_{B_s B K^*}(Q^2)}{(m_b m_s + m_b^2)(Q^2 + m_B^2)} \\
 &\times \left[-2p_\mu + p'_{\mu} \left(\frac{m_B^2 - m_{B_s}^2}{m_{K^*}^2} + 1 \right) \right] e^{-m_{B_s}^2/M^2} e^{-m_{K^*}^2/M'^2}
 \end{aligned} \quad (23)$$

B off shell

Estrutura tensorial p'_μ .



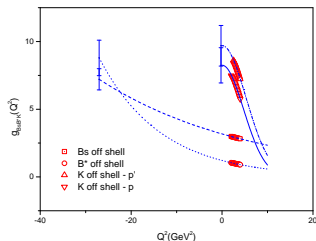
$$\Delta s = 0.6 \text{ e } \Delta u = 0.7; M^2 = 15 \text{ GeV}^2.$$



Ajuste monopolar. O valor da constante é dado por:

$$g_{B_s B K^*}^{(B)} = 2.8 \pm 0.1$$

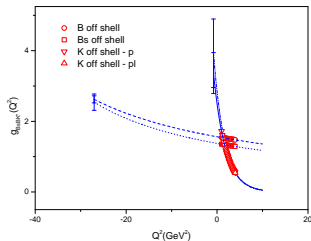
Fatores de forma dos dois vértices.



Valores das constantes de acoplamento:

$$g_{B_s B^* K} = 8,4 \pm 1,2$$

$$g_{B_s B K^*} = 3,3 \pm 0,5$$



Considerações finais

- ▶ No vértice $B_s B^* K$ o resultado concorda com a estimativa da HHChPT,

$$g_{B_1 B_2 L} = g_{D_1 D_2 L} \frac{m_B}{m_D}$$

através da analogia com méson D ;

- ▶ Incertezas em torno de 20%;
- ▶ Motivação para os cálculo dos vértices: $D_s D K^*$, $B_s B^* \gamma$.