$\bar{B}_s^0 \longrightarrow PP, PV$衰变的研究

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October 13, 2022

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研究背景

随着大型强子对撞机LHC 投入运行，除了$B_{(u,d)}$ 介子以外，越来越多的B_s/B_c 介子产生和衰变事例被LHCb 实验组收集，一些小分支比的衰变道也已被观测到。未来随着LHCb 和Belle-II 的进一步运行，B介子事例数的收集将大为提高，这将促使B物理研究进入一个新的“黄金时代”。

用PQCD方法计算$\bar{B}_s^0 \longrightarrow PP, PV$(考虑分布振幅$\varphi B2$ 贡献)

我们用微扰QCD 方法重新研究$\bar{B}_s^0 \longrightarrow PP, PV$ 衰变，并考虑了B介子波函数$\varphi B2$的贡献，因为以往别人的计算都很少考虑$\varphi B2$的贡献。

在标准模型理论框架下，B介子的两体弱作用强子衰变振幅可以写成:

$A(B \to M_1 M_2) =< M_1 M_2 \mid \mathcal{H}_{\text{eff}} \mid B >= \frac{G_F}{\sqrt{2}} \sum_i V_i C_i(\mu) < M_1 M_2 \mid O_i(\mu) \mid B >$

其中V_i是与具体衰变过程相对应的CKM矩阵元，$M_{1,2}$是两个末态强子，$C_i(\mu)$是Wilson系数，它们的表达式在(NLO)是已知的。

在夸克水平上，基于算子积展开和重整化群(RG)方法，
将$\bar{B}_s^0 \longrightarrow PP, PV$衰变的有效哈密顿量写成：

$$\mathcal{H}_{\rm eff} = \frac{G_F}{\sqrt{2}} \sum_{q=d,s} \left\{ V_{ub}V_{uq}^* \sum_{i=1}^{2} C_i O_i - V_{tb}V_{tq}^* \sum_{j=3}^{10} C_j O_j \right\} + h.c..$$

相关的CKM因子：

$$V_{ub}V_{ud}^* = A\lambda^3(\rho - i\eta)\left(1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4\right) + \mathcal{O}\left(\lambda^8\right)$$

$$V_{tb}V_{td}^* = A\lambda^3 + A^3\lambda^7\left(\rho - i\eta - \frac{1}{2}\right) - V_{ub}V_{ud}^* + \mathcal{O}\left(\lambda^8\right)$$

$$V_{ub}V_{us}^* = A\lambda^4(\rho - i\eta) + \mathcal{O}\left(\lambda^8\right)$$

$$V_{tb}V_{ts}^* = -A\lambda^2\left(1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4\right) + \frac{1}{2}A^3\lambda^6 - V_{ub}V_{us}^* + \mathcal{O}\left(\lambda^8\right)$$

算符:

$$O_1 = (\bar{u}_\alpha b_\alpha)_{V-A}(\bar{q}_\beta u_\beta)_{V-A}$$
$$O_2 = (\bar{u}_\alpha b_\beta)_{V-A}(\bar{q}_\beta u_\alpha)_{V-A}$$
$$O_3 = (\bar{q}_\alpha b_\alpha)_{V-A}\sum_{q'}\left(\bar{q}'_\beta q'_\beta\right)_{V-A}$$
$$O_4 = (\bar{q}_\alpha b_\beta)_{V-A}\sum_{q'}\left(\bar{q}'_\beta q'_\alpha\right)_{V-A}$$
$$O_5 = (\bar{q}_\alpha b_\alpha)_{V-A}\sum_{q'}\left(\bar{q}'_\beta q'_\beta\right)_{V+A}$$

$$O_6 = (\bar{q}_\alpha b_\beta)_{V-A} \sum_{q'} (\bar{q}'_\beta q'_\alpha)_{V+A},$$

$$O_7 = (\bar{q}_\alpha b_\alpha)_{V-A} \sum_{q'} \frac{3}{2} Q_{q'} (\bar{q}'_\beta q'_\beta)_{V+A},$$

$$O_8 = (\bar{q}_\alpha b_\beta)_{V-A} \sum_{q'} \frac{3}{2} Q_{q'} (\bar{q}'_\beta q'_\alpha)_{V+A},$$

$$O_9 = (\bar{q}_\alpha b_\alpha)_{V-A} \sum_{q'} \frac{3}{2} Q_{q'} (\bar{q}'_\beta q'_\beta)_{V-A},$$

$$O_{10} = (\bar{q}_\alpha b_\beta)_{V-A} \sum_{q'} \frac{3}{2} Q_{q'} (\bar{q}'_\beta q'_\alpha)_{V-A},$$

我们取反冲介子为M_2,发射介子为M_3。并定义两个类光向量$n_+ = (1, 0, 0_T)$ $n_- = (0, 1, 0_T)$
x_i 表示每个介子中反夸克的动量分数，$k_{i\perp}$表示反夸克的横向动量
末态粒子动量:

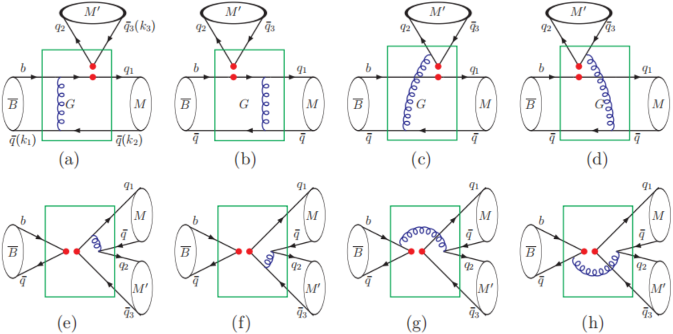
$$p_B = p_1 = \frac{m_B}{\sqrt{2}}(1,1,0) \quad p_P = p_2 = \frac{m_B}{\sqrt{2}}\left(0, 1 - r_V^2, 0\right)$$

$$p_V = p_3 = \frac{m_B}{\sqrt{2}}\left(1, r_V^2, 0\right)$$

$$k_1 = x_1 p_1 + \left(0, 0, \vec{k}_{1\perp}\right) \quad k_2 = \frac{m_B}{\sqrt{2}}\left(0, x_2, \vec{k}_{2\perp}\right)$$

$$k_3 = \frac{m_B}{\sqrt{2}}\left(x_3, 0, \vec{k}_{3\perp}\right)$$

$$e_V^{\parallel} = \frac{p_V}{m_V} - \frac{m_V}{p_V \cdot n_-} n_-$$


M′
q2
q̄3(k3)
b
q1
B̄
G
M
q̄(k1)
q̄(k2)
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)

$$
\begin{aligned}
\mathcal{A}_a^{LL}(P,V) &= \mathcal{C}\int \mathrm{d}x_1\,\mathrm{d}x_3\,\mathrm{d}b_1\,\mathrm{d}b_3\,H_{ab}(\alpha_g^V,\beta_a^V,b_1,b_3)\,\alpha_s(t_a^V)\,C_i(t_a^V)\\
&\quad \{\phi_{B1}\left[\phi_V^v\,(1+x_3)+\left(\phi_V^t+\phi_V^s\right)(\bar{x}_3-x_3)\right]\\
&\quad -\phi_{B2}\left[\phi_V^v-\left(\phi_V^t+\phi_V^s\right)x_3\right]\}\,S_t(x_3),
\end{aligned}
$$

$$
\mathcal{A}_a^{LR}(P,V) = -\mathcal{A}_a^{LL}(P,V),
$$

$$
\begin{aligned}
\mathcal{A}_a^{SP}(P,V) &= \mathcal{C}\int \mathrm{d}x_1\,\mathrm{d}x_3\,\mathrm{d}b_1\,\mathrm{d}b_3\,H_{ab}(\alpha_g^V,\beta_a^V,b_1,b_3)\,\alpha_s(t_a^V)\,C_i(t_a^V)\\
&\quad 2\,r_P\,\{\phi_{B1}\left[-\phi_V^v+\phi_V^t\,x_3-\phi_V^s\,(2+x_3)\right]\\
&\quad +\phi_{B2}\left[\phi_V^v-\phi_V^t+\phi_V^s\right]\}\,S_t(x_3),
\end{aligned}
$$

用PQCD方法将$\bar{B}_s^0 \to PV$ 衰变的衰变振幅表示为几个波函数卷积的形式:

$$\mathcal{A}(B \to PV) = \langle PV \left|\mathcal{H}_{\rm eff}\right| B \rangle$$
$$= \frac{G_F}{\sqrt{2}} \sum_i \mathcal{F}_i \int dx_1 dx_2 dx_3 db_1 db_2 db_3 \mathcal{T}_i \left(t_i, x_1, b_1, x_2, b_2, x_3, b_3\right)$$
$$C_i\left(t_i\right) \Phi_B\left(x_1, b_1\right) e^{-S_B} \Phi_P\left(x_2, b_2\right) e^{-S_P} \Phi_V\left(x_3, b_3\right) e^{-S_V}$$

对于$\bar{B}_s^0 \to PV$ 衰变, 它的CP 平均的分支比可以定义为:

$$BR = \frac{\tau_{B_s} p_{cm}}{16\pi m_{B_s}^2} \left[\left|\mathcal{A}\left(\bar{B}_s^0 \to f\right)\right|^2 + \left|\mathcal{A}\left(B_s^0 \to \bar{f}\right)\right|^2\right],$$

数值结果及讨论

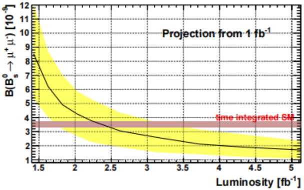
Mode	Class	*QCDF*	$\mathrm{PQCD_{LO}}$	*Thiswork*	*LHCb*
$\bar{B}_s^0 \to \pi^- K^{*+}$	T	$8.7^{+4.6}_{-3.7}$	$7.6^{+3.0}_{-2.3}$	6.7482	3.3 ± 1.2
$\bar{B}_s^0 \to K^+ \rho^-$	T	$24.5^{+11.9}_{-9.7}$	$17.8^{+7.89}_{-5.89}$	16.7021	
$\bar{B}_s^0 \to \pi^0 K^{*0}$	C	$0.25^{+0.08}_{-0.08}$	$0.07^{+0.02}_{-0.02}$	0.2177	
$\bar{B}_s^0 \to \rho^0 K^0$	C	$0.61^{+0.33}_{-0.26}$	$0.08^{+0.02}_{-0.01}$	0.3259	
$\bar{B}_s^0 \to K^0 \omega$	C	$0.51^{+0.20}_{-0.18}$	$0.15^{+0.05}_{-0.04}$	0.3517	
$\bar{B}_s^0 \to K^+ K^{*-}$	P	$4.1^{+1.7}_{-1.5}$	$6.0^{+1.7}_{-1.2}$	12.1576	12.5 ± 2.6
$\bar{B}_s^0 \to K^- K^{*+}$	P	$5.5^{+1.3}_{-1.4}$	$4.7^{+1.1}_{-0.8}$	9.3413	
$\bar{B}_s^0 \to K^0 \bar{K}^{*0}$	P	$3.9^{+0.4}_{-0.4}$	$7.3^{+2.5}_{-1.7}$	9.9538	16.4 ± 4.1
$\bar{B}_s^0 \to \bar{K}^0 K^{*0}$	P	$4.2^{+0.4}_{-0.4}$	$4.3^{+0.7}_{-0.7}$	7.6146	

[1]R.Aaij et al., (LHCb collaboration), Observation of $B_s^0 \to K^{*\pm} K^{\mp}$and evidence for $B_s^0 \to K^{*-} \pi^{+}$decays , New J. Phys. 16,123001 (2014).

Searches for very rare decays to purely leptonic final states at LHCb
DOI: https://doi.org/10.22323/1.174.0358

Mode	$B_s^0 \to \mu^+\mu^-$		$B^0 \to \mu^+\mu^-$	
Limit	at 90 % C.L.	at 95 % C.L.	at 90 % C.L.	at 95 % C.L.
Exp. bkg+SM	6.3×10^{-9}	7.2×10^{-9}		
Exp. bkg	2.8×10^{-9}	3.4×10^{-9}	0.91×10^{-9}	1.1×10^{-9}
Observed	3.8×10^{-9}	4.5×10^{-9}	0.81×10^{-9}	1.0×10^{-9}

Table 1: Expected and observed limits on $\mathscr{B}(B^0_{(s)} \to \mu^+\mu^-)$.



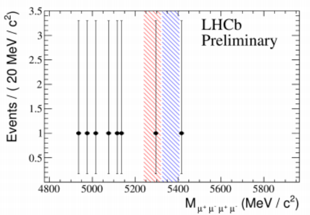


Figure 4: Observed invariant mass distribution of the $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$ candidates. The blue (red) dashed area is the $B^0_s(B^0)$ mass window.

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-\mu^+\mu^-) < 1.3 \times 10^{-8}$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-\mu^+\mu^-) < 5.4 \times 10^{-9}$$

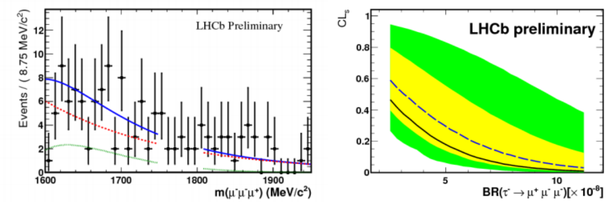


Figure 5: (left) Observed invariant mass distribution of the $\tau^- \to \mu^-\mu^-\mu^+$ candidates in the most signal like merged bins. The solid line is the fit to the data of the sum of the combinatorial exponential contribution (dashed red line) and of the $D_s^- \to \eta(\mu^+\mu^-\gamma)\mu^-\overline{\nu}_\mu$ one (dashed green line). (right) CL_S as a function of the assumed $\mathscr{B}$. The long dashed blue curves are the medians of the expected CL_S distributions for $\tau^- \to \mu^-\mu^-\mu^+$ if background only was observed. The yellow (green) areas cover, for each $\mathscr{B}$, 34% (48%) of the expected CL_S distribution on each side of its median. The solid black curves are the observed CL_S.

$$\mathcal{B}(\tau^- \to \mu^-\mu^-\mu^+) < 7.8(6.3) \times 10^{-8}$$