Quasi-two-body decays $B_{(s)} \to K^*\gamma \to K\pi\gamma$ in perturbative QCD approach

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文献分享

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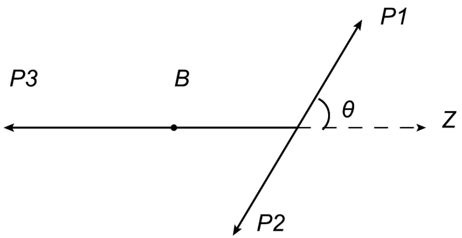
目录

研究背景和动机

- 实验上在三体衰变的不变质量分布发现了大量新的共振态，这些奇异态的内部结构尚不明确。（假设：四、五夸克态；强子-分子态；胶球混杂态等）；
- 三体衰变的计算，理论学家提出了多种计算方法，PQCD 方法基于准两体衰变机制，引入了双粒子分布：（两粒子共线运动，单粒子反冲）；

其中，$|P3| = |P12|, P12 = P1 + P2$. 则衰变振幅 $\mathcal{M} = \Phi_B \otimes H \otimes \Phi_{P1P2} \otimes \Phi_{P3}$.



研究背景和动机

B 介子波函数:

$$\Phi_{B_{(s)}}(x,b)=\frac{1}{\sqrt{2N_c}}\left(\not{P}_{B_{(s)}}+m_{B_{(s)}}\right)\gamma_5\phi_{B_{(s)}}(x,b).$$

$$\phi_{B_{(s)}}(x,b)=N_{B_{(s)}}x^2(1-x)^2 exp\left(-\frac{x^2m^2_{B_{(s)}}}{2\omega_b^2}-\frac{\omega_b^2b^2}{2}\right),$$

$K\pi$ 两介子波函数:

$$\Phi^T_{K\pi}(z,\zeta,\omega)=\frac{1}{\sqrt{2N_c}}\left[\gamma_5\not{\epsilon}_T\not{p}\phi^T_{K\pi}\left(z,\omega^2\right)+\omega\gamma_5\not{\epsilon}_T\phi^a_{K\pi}\left(z,\omega^2\right)+i\omega\frac{\epsilon^{\mu\nu\rho\sigma}\gamma_\mu\epsilon_{T\nu}p_\rho n_{-\sigma}}{p\cdot n_-}\phi^v_{K\pi}\left(z,\omega^2\right)\right]\sqrt{\zeta(1-\zeta)},$$

$$\phi^T_{K\pi}(z,\omega^2)=\frac{3F^\perp_{K\pi}(\omega^2)}{\sqrt{2N_c}}z(1-z)[1+a^\perp_{1K^*}3t+a^\perp_{2K^*}\frac{3}{2}(5t^2-1)],$$

$$\phi^a_{K\pi}(z,\omega^2)=\frac{3F^\parallel_{K\pi}(\omega^2)}{4\sqrt{2N_c}}t,$$

$$\phi^v_{K\pi}(z,\omega^2)=\frac{3F^\parallel_{K\pi}(\omega^2)}{8\sqrt{2N_c}}(1+t^2),$$

[Z. Rui, Y.Li, H.n.Li, Phys. Rev. D 98, 113003(2018)]

研究背景和动机

Branching Ratios (Exp):

$$
\begin{aligned}
Br\left(B^0 \to K^{*0}[K^+\pi^-]\gamma\right) &= (4.5 \pm 0.3 \pm 0.2) \times 10^{-5}, \\
Br\left(B^0 \to K^{*0}[K^0\pi^0]\gamma\right) &= (4.4 \pm 0.9 \pm 0.6) \times 10^{-5}, \\
Br\left(B^+ \to K^{*+}[K^+\pi^0]\gamma\right) &= (5.0 \pm 0.5 \pm 0.4) \times 10^{-5}, \\
Br\left(B^+ \to K^{*+}[K^0\pi^+]\gamma\right) &= (5.4 \pm 0.6 \pm 0.4) \times 10^{-5}.
\end{aligned}
$$

[F.Abudinen et al.(Belle Collaboration),arXiv:2110.08219(2021)]

Branching Ratios (PQCD):

$$Br(B^0 \to K^{*0}\gamma) = (3.81^{+1.73+0.55+0.11}_{-1.27-0.38-0.11}) \times 10^{-5}, (\sim 50\%) \tag{1}$$

$$Br(B^+ \to K^{*+}\gamma) = (3.58^{+1.76+0.54+0.11}_{-1.28-0.40-0.11}) \times 10^{-5}, (\sim 55\%) \tag{2}$$

[W.Wang, R.H.Li, C.D.Lü, arXiv:0711.0432(2007)]

研究内容

Branching Ratios(This work):

$$Br\left(B^0 \to K^{*0}\gamma \to K^+\pi^-\gamma\right) = \left(3.08^{+1.29+0.33+0.24+0.12}_{-0.86-0.30-0.36-0.08}\right) \times 10^{-5},$$
$$Br\left(B^0 \to K^{*0}\gamma \to K^0\pi^0\gamma\right) = \left(1.55^{+0.64+0.16+0.12+0.06}_{-0.44-0.15-0.19-0.04}\right) \times 10^{-5},$$
$$Br\left(B^+ \to K^{*+}\gamma \to K^+\pi^0\gamma\right) = \left(1.72^{+0.67+0.20+0.08+0.10}_{-0.46-0.17-0.12-0.07}\right) \times 10^{-5},$$
$$Br\left(B^+ \to K^{*+}\gamma \to K^0\pi^+\gamma\right) = \left(3.21^{+1.25+0.36+0.20+0.15}_{-0.87-0.31-0.23-0.12}\right) \times 10^{-5},$$

Branching Ratios(EXP):

$$Br\left(B^0 \to K^{*0}\gamma \to K^+\pi^-\gamma\right) = (3.00 \pm 0.20 \pm 0.13) \times 10^{-5},$$
$$Br\left(B^0 \to K^{*0}\gamma \to K^0\pi^0\gamma\right) = (1.47 \pm 0.30 \pm 0.20) \times 10^{-5},$$
$$Br\left(B^+ \to K^{*+}\gamma \to K^+\pi^0\gamma\right) = (1.67 \pm 0.17 \pm 0.13) \times 10^{-5},$$
$$Br\left(B^+ \to K^{*+}\gamma \to K^0\pi^+\gamma\right) = (3.60 \pm 0.40 \pm 0.27) \times 10^{-5}.$$

[F.Abudinen et al.(Belle Collaboration),arXiv:2110.08219(2021)]

研究内容

分支比比值 (This work):

$$R_1 = \frac{Br\left(B^+ \to K^{*+}\gamma \to K^0\pi^+\gamma\right)}{Br\left(B^0 \to K^{*0}\gamma \to K^+\pi^-\gamma\right)} = 1.04^{+0.63}_{-0.46},$$

$$R_2 = \frac{Br\left(B^+ \to K^{*+}\gamma \to K^+\pi^0\gamma\right)}{Br\left(B^0 \to K^{*0}\gamma \to K^0\pi^0\gamma\right)} = 1.11^{+0.67}_{-0.49}.$$

分支比比值 (PDG，Belle II):

$$R^*_{\rm PDG} = \frac{Br(B^+ \to K^{*+}\gamma)}{B^0 \to K^{*0}\gamma} = 0.94 \pm 0.08, \quad R^*_{\rm Brlle\ II} = \frac{Br(B^+ \to K^{*+}\gamma)}{B^0 \to K^{*0}\gamma} = 1.16 \pm 0.14.$$

本文理论预言的分支比及其比值更接近实验数据.

$b \to d$ 过程

$$Br\left(B_s^0 \to \bar{K}^{*0}\gamma \to K^0\pi^0\gamma\right) = \left(0.35^{+0.16+0.04+0.00+0.02}_{-0.11-0.03-0.02-0.02}\right) \times 10^{-6},$$
$$Br\left(B_s^0 \to \bar{K}^{*0}\gamma \to K^-\pi^+\gamma\right) = \left(0.69^{+0.33+0.08+0.00+0.04}_{-0.21-0.07-0.03-0.03}\right) \times 10^{-6}.$$

Branching Ratios (PQCD):

$$Br(B_s \to \overline{K}^{*0}\gamma)[\overline{K}^{*0} \to K^-\pi^+] = (1.04^{+0.51}_{-0.34}) \times 10^{-6}, \tag{3}$$

$$Br(B_s \to \overline{K}^{*0}\gamma)[\overline{K}^{*0} \to K^0\pi^0] = (1.05^{+0.50}_{-0.35}) \times 10^{-6}, \tag{4}$$

$$Br(B_s \to \overline{K}^{*0}\gamma) = (1.11^{+0.42+0.15+0.16}_{-0.32-0.12-0.07}) \times 10^{-6}, \tag{5}$$

[W.Wang, R.H.Li, C.D.Lü, arXiv:0711.0432(2007)]

研究内容

直接 CP 破坏：

$$A_{CP}(B^0 \to \overline{K}^{*0}\gamma \to K^+\pi^-\gamma) = (-0.58^{+0.04+0.61+0.06+0.00}_{-0.00-0.65-0.09-0.21}) \times 10^{-2}, \tag{6}$$

$$A_{CP}(B^0 \to \overline{K}^{*0}\gamma \to K^0\pi^0\gamma) = (-0.55^{+0.37+0.68+0.43+0.03}_{-0.00-0.77-0.00-0.08}) \times 10^{-2}, \tag{7}$$

$$A_{CP}(B^+ \to \overline{K}^{*+}\gamma \to K^+\pi^0\gamma) = (-0.79^{+0.24+0.37+0.79+0.18}_{-0.21-0.74-0.00-0.15}) \times 10^{-2}, \tag{8}$$

$$A_{CP}(B^+ \to \overline{K}^{*+}\gamma \to K^0\pi^+\gamma) = (-0.39^{+0.35+0.70+0.02+0.46}_{-0.16-0.80-0.34-0.00}) \times 10^{-2}, \tag{9}$$

PDG(2020)：

$$A_{CP}(B^0 \to K^{*0}\gamma) = (-0.6 \pm 1.1) \times 10^{-2}, \tag{10}$$

$$A_{CP}(B^+ \to K^{*+}\gamma) = (1.4 \pm 1.8) \times 10^{-2}, \tag{11}$$

部分实验结果大于 1% 且与理论预言相反。

结论

- 本文基于准两体衰变机制得到衰变分支比相比以前的数据来看，结果更精确、与实验数据符合的更好;
- 研究较少的 $K\pi$ 的形状因子使用了衰变常数的比值来代替，求分支比时采用了同位旋守恒和窄宽度近似来处理;

附录

根据同位旋守恒 + $C-G$ 系数表:

$$\frac{\Gamma(K^{*0}\to K^+\pi^-)}{\Gamma(K^{*0}\to K\pi)}=2/3,\quad \frac{\Gamma(K^{*0}\to K^0\pi^0)}{\Gamma(K^{*0}\to K\pi)}=1/3,$$
$$\frac{\Gamma(K^{*+}\to K^0\pi^+)}{\Gamma(K^{*+}\to K\pi)}=2/3,\quad \frac{\Gamma(K^{*+}\to K^+\pi^0)}{\Gamma(K^{*+}\to K\pi)}=1/3.$$

窄宽度近似:

$$\begin{aligned}
Br\left(B^0\to K^{*0}\gamma\to K^+\pi^-\gamma\right)&=Br(B^0\to K^{*0}\gamma)\cdot Br(K^{*0}\to K^+\pi^-),\\
Br\left(B^0\to K^{*0}\gamma\to K^0\pi^0\gamma\right)&=Br(B^0\to K^{*0}\gamma)\cdot Br(K^{*0}\to K^0\pi^0),\\
Br\left(B^+\to K^{*+}\gamma\to K^+\pi^0\gamma\right)&=Br(B^+\to K^{*+}\gamma)\cdot Br(K^{*+}\to K^+\pi^0),\\
Br\left(B^+\to K^{*+}\gamma\to K^0\pi^+\gamma\right)&=Br(B^+\to K^{*+}\gamma)\cdot Br(K^{*+}\to K^0\pi^+).
\end{aligned}$$

附录

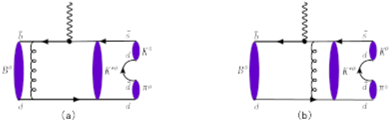


Figure 1: Feynman diagrams from the operator $O_{7\gamma}$.

Figure 2: Quark-loop diagrams from the operator O_2 with the photon being emitted from the quark loop.

$$Thank \quad you$$