QCD因子化框架下B_s介子两体非轻衰变$b \to s$过程的唯象研究

答辩人：韩琳

指导老师：常钦　教授

主要内容：

研究背景

B_s介子两体非轻衰变$b \to s$过程的研究

总结与展望

研究背景

实验方面

1.随着探测器的不断升级与改造，未来Belle-II探测器的亮度将会达到50ab^{-1}，升级后的LHCb II探测器的亮度将会达到300fb^{-1}。

2.探测技术也在不断地提高，探测器的测量精度将会大大提升，并且能够收集更多关于B介子的数据。

3.对粒子物理标准模型提出更严格的检验，同时也会为探索与B介子相关的潜在的机制和可能的新物理信号创造有利条件。

研究背景

理论方面

1.计算强子矩阵元，硬旁观散射和湮灭图有端点发散。

2.$Bs \to V\,V$ 过程中，通过探测矢量介子三个螺旋度振幅，揭示B_s介子的动力学信息。

B_s介子两体非轻衰变$b \to s$过程的研究

Experimental	Exp.			SM
Observable	LHCb	CDF	HFVG	QCDF
$\mathcal{B}(\bar{B}_s \to \pi^+\pi^-)[\times 10^{-6}]$	$0.95^{+0.21}_{-0.17} \pm 0.13$	$0.57 \pm 0.15 \pm 0.10$	$\boxed{0.73 \pm 0.14}$	$\boxed{0.155}$
$\mathcal{B}(\bar{B}_s \to K^{*0}\bar{K}^{*0})[\times 10^{-6}]$	$28.1 \pm 4.6 \pm 4.5 \pm 3.4(f_s/f_d))$	—	$\boxed{28.1 \pm 7.2}$	$\boxed{7.9^{+0.4+4.3}_{-0.4-3.9}}$
$f_L(\bar{B}_s \to K^{*0}\bar{K}^{*0})[\times 10^{-2}]$	$31 \pm 12 \pm 4$	—	31 ± 13	72^{+0+16}_{-0-21}
$f_\perp(\bar{B}_s \to K^{*0}\bar{K}^{*0})[\times 10^{-2}]$	$38 \pm 11 \pm 4$	—	—	—
$\mathcal{B}(\bar{B}_s \to \phi\phi)[\times 10^{-6}]$	—	$23.2 \pm 1.8 \pm 8.2$	19 ± 5	$19.5^{+1.0+13.1}_{-1.0-8.0}$
$f_L(\bar{B}_s \to \phi\phi)[\times 10^{-2}]$	$36.5 \pm 2.2 \pm 1.2$	$34.8 \pm 4.1 \pm 2.1$	36.1 ± 2.2	48^{+0+26}_{-0-27}
$f_\perp(\bar{B}_s \to \phi\phi)[\times 10^{-2}]$	$29.1 \pm 2.4 \pm 1.0$	$36.5 \pm 4.4 \pm 2.7$	30.6 ± 2.3	—
$f_\parallel(\bar{B}_s \to \phi\phi)[\times 10^{-2}]$	$34.4 \pm 2.4 \pm 1.4$	$28.7 \pm 4.3 \pm 1.1$	—	—

原因：B_s介子衰变过程中强相互作用机制的有限理解；

存在新物理。

处理端点发散的方法：

Scheme I: 参数化

$$\int_0^1 \frac{dx}{x} \to X_A = (1+\rho_A e^{i\phi_A}) \ln \frac{m_B}{\Lambda_h}, \qquad \int_0^1 dy \frac{\ln y}{y} \to -\frac{1}{2}(X_A)^2$$

$$\rho_A^{PP}=1, \phi_A^{PP}=-55^\circ; \rho_A^{PV}=1, \phi_A^{PV}=-20^\circ;\ \rho_A^{VP}=1, \phi_A^{VP}=-70^\circ.$$

Scheme II: 红外有限胶子传播子

Cornwall 描述：

$$D(q^2)=\frac{1}{q^2-M_g^2(q^2)+i\epsilon}$$

对应的强耦合常数：

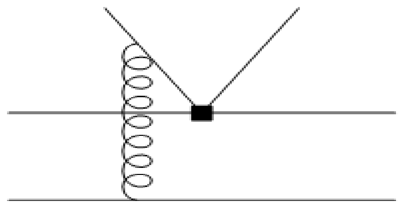
$$\alpha_s(q^2)=\frac{4\pi}{\beta_0 \ln\left(\frac{q^2+4M_g^2(q^2)}{\Lambda_{QCD}^2}\right)}$$

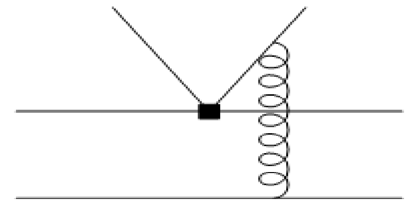
动力学胶子质量：

$$M_g^2(q^2)=m_g^2\left[\frac{\ln\left(\frac{q^2+4m_g^2}{\Lambda_{QCD}^2}\right)}{\ln\left(\frac{4m_g^2}{\Lambda_{QCD}^2}\right)}\right]^{-\frac{12}{11}}$$

$B \to VV$过程

硬旁观散射：





$i = 1-4, 9, 10$，

$$H_i^- = -\frac{2 f_B f_V^\perp}{m_B m_b F_-^{B\to V}(0)} \int_0^1 dx\,dy\,d\xi\,\alpha_s(q^2) \frac{\Phi_{B1}(\xi)\phi_1^\perp(x)\phi_{b2}(y)}{(\xi\bar{x}\boxed{+\omega^2(q^2)})\bar{x}y}$$

$i = 5.7$，

$$H_i^- = -\frac{2 f_B f_V^\perp}{m_B m_b F_-^{B\to V}(0)} \int_0^1 dx\,dy\,d\xi\,\alpha_s(q^2) \frac{\Phi_{B1}(\xi)\phi_1^\perp(x)\phi_{a2}(y)}{(\xi\bar{x}\boxed{+\omega^2(q^2)})\bar{x}\bar{y}}$$

$i = 6.8$

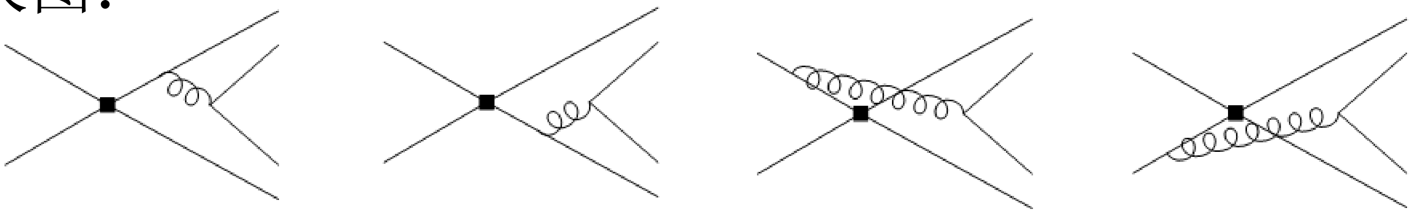
$$H_i^- = -\frac{f_B f_V}{m_B F_-^{B\to V}(0)} \frac{m_1}{m_2^2} \int_0^1 dx\,dy\,d\xi\,\alpha_s(q^2) \frac{\Phi_{B1}(\xi)\phi_{a1}(x)\phi_2^\perp(y)}{(\xi\bar{x}\boxed{+\omega^2(q^2)})\bar{y}y}$$

$$\omega^2(q^2) = M_g^2(q^2)/M_B^2$$

类空

实的

湮灭图：



纵向部分

$$A_1^{i,0} = \pi\int_0^1 dxdy\alpha_s(q^2)\Big\{\Phi_{V1}(x)\Phi_{V2}(y)\Big[\frac{\bar{y}}{(x\bar{y}\boxed{-\omega^2(q^2)+i\epsilon})(1-\bar{x}y)}+\frac{1}{\bar{y}(x\bar{y}-\omega^2(q^2)+i\epsilon)}\Big] - r_\chi^{V2}r_\chi^{V1}\phi_{v1}(x)\phi_{v2}(y)\frac{2}{x\bar{y}-\omega^2(q^2)+i\epsilon}\Big\},$$

$$A_2^{i,0} = \pi\int_0^1 dxdy\alpha_s(q^2)\Big\{\Phi_{V1}(x)\Phi_{V2}(y)\Big[\frac{x}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)}+\frac{1}{x(x\bar{y}-\omega^2(q^2)+i\epsilon)}\Big] - r_\chi^{V2}r_\chi^{V1}\phi_{v1}(x)\phi_{v2}(y)\frac{2}{x\bar{y}-\omega^2(q^2)+i\epsilon}\Big\},$$

$$A_3^{i,0} = \pi\int_0^1 dxdy\alpha_s(q^2)\Big\{\Phi_{v1}(x)\Phi_{V2}(y)\frac{2\bar{x}}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)} + r_\chi^{V2}\phi_{V1}(x)\phi_{v2}(y)\frac{2y}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)}\Big\},$$

$$A_1^{f,0} = A_2^{f,0} = 0$$

$$A_3^{f,0} = \pi\int_0^1 dxdy\alpha_s(q^2)\Big\{r_\chi^{V1}\Phi_{v1}(x)\Phi_{V2}(y)\frac{2(1+\bar{y})}{\bar{y}(x\bar{y}-\omega^2(q^2)+i\epsilon)} - r_\chi^{V2}\phi_{V1}(x)\phi_{v2}(y)\frac{2(1+x)}{x(x\bar{y}-\omega^2(q^2)+i\epsilon)}\Big\},$$

类时

虚的

不为零的横向部分

$$A_1^{i,-} = \pi \frac{2m_1 m_2}{m_B^2} \int_0^1 dx dy \alpha_s(q^2) \Big\{ \phi_{b1}(x)\phi_{b2}(y) \Big[\frac{1+\bar{y}}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)} + \frac{\bar{x}\bar{y}^2}{(x\bar{y}-\omega^2(q^2)+i\epsilon)^2(1-\bar{x}y)} - \frac{\bar{x}\bar{y}^2}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)^2} + \frac{\bar{x}}{(x\bar{y}-\omega^2(q^2)+i\epsilon)^2} \Big] \Big\},$$

$$A_2^{i,-} = \pi \frac{2m_1 m_2}{m_B^2} \int_0^1 dx dy \alpha_s(q^2) \Big\{ \phi_{a1}(x)\phi_{a2}(y) \Big[\frac{1+x}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)} + \frac{x^2 y}{(x\bar{y}-\omega^2(q^2)+i\epsilon)^2(1-\bar{x}y)} - \frac{x^2 y}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)^2} + \frac{y}{(x\bar{y}-\omega^2(q^2)+i\epsilon)^2} \Big] \Big\},$$

$$A_3^{i,-} = \pi \int_0^1 dx dy \alpha_s(q^2) \Big\{ \frac{2m_1}{m_2} r_\chi^{V2} \phi_{a1}(x)\phi_2^\perp(y) \frac{1}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)} - \frac{2m_2}{m_1} r_\chi^{V1} \phi_1^\perp(x)\phi_{b2}(y) \frac{1}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)} \Big\},$$

$$
\begin{aligned}
A_3^{f,-} &= \pi \int_0^1 dxdy\alpha_s(q^2)\left\{\frac{2m_1}{m_2} r_\chi^{V2}\phi_{a1}(x)\phi_2^\perp(y)\frac{1}{\bar{y}(x\bar{y}-\omega^2(q^2)+i\epsilon)}\right. \\
&\left. + \frac{2m_2}{m_1} r_\chi^{V1}\phi_1^\perp(x)\phi_{b2}(y)\frac{1}{x(x\bar{y}-\omega^2(q^2)+i\epsilon)}\right\},
\end{aligned}
$$

$$
\begin{aligned}
A_1^{i,+} &= \pi\frac{2m_1m_2}{m_B^2}\int_0^1 dxdy\alpha_s(q^2)\left\{\phi_{a1}(x)\phi_{a2}(y)\left[\frac{\bar{y}}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)}\right.\right. \\
&+ \frac{xy\bar{y}}{(x\bar{y}-\omega^2(q^2)+i\epsilon)^2(1-\bar{x}y)} - \frac{xy\bar{y}}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)^2} \\
&\left.\left. + \frac{1}{\bar{y}^2(x\bar{y}-\omega^2(q^2)+i\epsilon)} + \frac{xy}{\bar{y}(x\bar{y}-\omega^2(q^2)+i\epsilon)^2}\right]\right\},
\end{aligned}
$$

$$
\begin{aligned}
A_2^{i,+} &= \pi\frac{2m_1m_2}{m_B^2}\int_0^1 dxdy\alpha_s(q^2)\left\{\phi_{b1}(x)\phi_{b2}(y)\left[\frac{x}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)}\right.\right. \\
&+ \frac{x\bar{x}\bar{y}}{(x\bar{y}-\omega^2(q^2)+i\epsilon)^2(1-\bar{x}y)} - \frac{x\bar{x}\bar{y}}{(x\bar{y}-\omega^2(q^2)+i\epsilon)(1-\bar{x}y)^2} \\
&\left.\left. + \frac{1}{x^2(x\bar{y}-\omega^2(q^2)+i\epsilon)} + \frac{\bar{x}\bar{y}}{x(x\bar{y}-\omega^2(q^2)+i\epsilon)^2}\right]\right\},
\end{aligned}
$$

代非普适 Z'模型下 $b \to s\bar{q}q(q=u,d)$ 过程的有效哈密顿：

$$\mathcal{H}_{eff}^{Z'} = -\frac{G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_q (\Delta C_3 O_3^q + \Delta C_5 O_5^q + \Delta C_7 O_7^q + \Delta C_9 O_9^q) + h.c.$$

$$\begin{aligned}
\Delta C_{3,5} &= -\frac{2}{3}\left(\frac{g' M_Z}{g_1 M_{Z'}}\right)^2 \frac{P^{L,R}}{V_{ts}^* V_{tb}} e^{i\phi_s^L}, \quad P^{L,R} = |B_{sb}^L|(B_{uu}^{L,R} + 2B_{dd}^{L,R}) \\
\Delta C_{9,7} &= -\frac{4}{3}\left(\frac{g' M_Z}{g_1 M_{Z'}}\right)^2 \frac{D^{L,R}}{V_{ts}^* V_{tb}} e^{i\phi_s^L}, \quad D^{L,R} = |B_{sb}^L|(B_{uu}^{L,R} - B_{dd}^{L,R}) \\
\phi_s^L &= \mathrm{Arg}[B_{sb}^L],
\end{aligned}$$

$b \to ss\bar{s}$过程的有效哈密顿：

$$\mathcal{H}_{eff}^{Z'} = -\frac{G_F}{\sqrt{2}} V_{ts}^* V_{tb} (\Delta C_7 O_7 + \Delta C_9 O_9) + h.c.$$

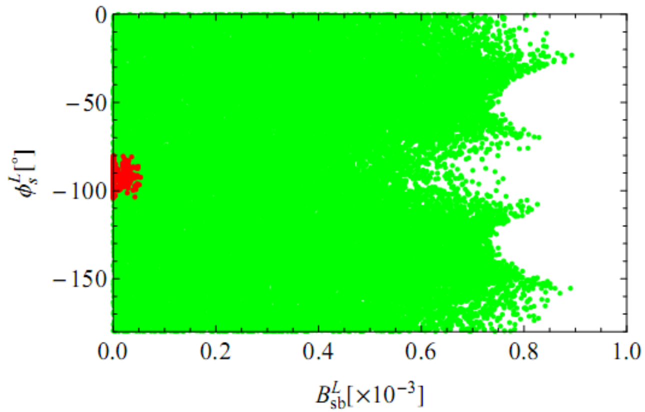
$$\begin{aligned}
\Delta C_{9,7} &= 4\left(\frac{g' M_Z}{g_1 M_{Z'}}\right)^2 \frac{S^{L,R}}{V_{ts}^* V_{tb}} e^{i\phi_s^L}, \quad S^{L,R} = |B_{sb}^L| B_{ss}^{L,R} \\
\phi_s^L &= \mathrm{Arg}[B_{sb}^L].
\end{aligned}$$

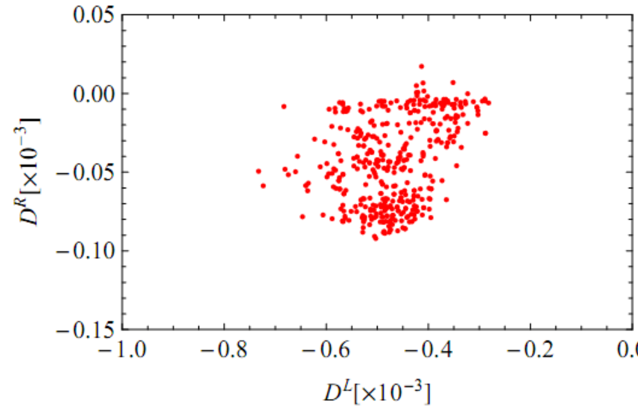
Z' 耦合参数的限制

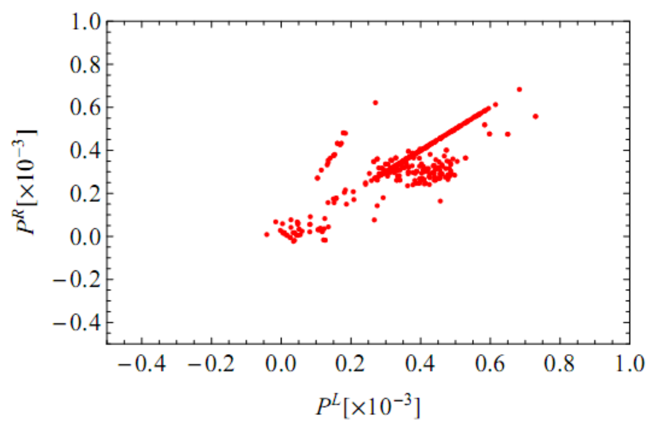
Experimental Observable	Exp. old data	Exp. current data	SM data
$\phi_s[\mathrm{rad}]$	0.73 ± 0.14	$-0.001 \pm 0.17 \pm 0.06$	$-0.0363^{+0.0016}_{-0.0015}$
$\Delta m_s[\mathrm{ps}^{-1}]$	17.42 ± 2.40	17.63 ± 0.11	17.3 ± 2.6
$\mathcal{B}(B_u^- \to \pi^- \bar{K}^0)[\times 10^{-6}]$	23.1 ± 1.0	23.80 ± 0.74	20.3
$\mathcal{B}(B_u^- \to \pi^0 K^-)[\times 10^{-6}]$	12.9 ± 0.6	12.94 ± 0.51	11.7
$\mathcal{B}(\bar{B}_d^0 \to \pi^+ K^-)[\times 10^{-6}]$	19.4 ± 0.6	19.55 ± 0.53	18.4
$\mathcal{B}(\bar{B}_d^0 \to \pi^0 \bar{K}^0)[\times 10^{-6}]$	9.8 ± 0.6	9.92 ± 0.48	8.0
$\mathcal{B}(\bar{B}_u^- \to \phi K^-)[\times 10^{-6}]$	—	8.8 ± 0.5	11.6
$\mathcal{B}(\bar{B}_d^0 \to \phi \bar{K}^0)[\times 10^{-6}]$	—	7.3 ± 0.6	10.5
$A_{CP}^{dir}(B_u^- \to \pi^- \bar{K}^0)[\times 10^{-2}]$	0.9 ± 2.5	-1.5 ± 1.2	0.3
$A_{CP}^{dir}(B_u^- \to \pi^0 K^-)[\times 10^{-2}]$	5.0 ± 2.5	4.0 ± 2.1	-3.6
$A_{CP}^{dir}(\bar{B}_d^0 \to \pi^+ K^-)[\times 10^{-2}]$	$-9.8^{+1.2}_{-1.1}$	-8.6 ± 0.7	-4.1
$A_{CP}^{dir}(\bar{B}_d^0 \to \pi^0 \bar{K}^0)[\times 10^{-2}]$	-1 ± 10	-1 ± 10	0.8
$A_{CP}^{dir}(\bar{B}_u^- \to \phi K^-)[\times 10^{-2}]$	—	10.4 ± 4.2	0.7
$A_{CP}^{dir}(\bar{B}_d^0 \to \phi \bar{K}^0)[\times 10^{-2}]$	—	1 ± 14	0.8

$B_s - \bar{B}_s$ 混合和 $B_{u,d} \to \pi K(\phi K)$ 衰变过程的数据

$b \to sq\bar{q}(q=u,d)$过程对应的新物理参数$P^{L,R}$、$D^{L,R}$和ϕ_s^L，由$B_s-\bar{B}_s$混合和$B_{u,d}\to\pi K$衰变进行限制。



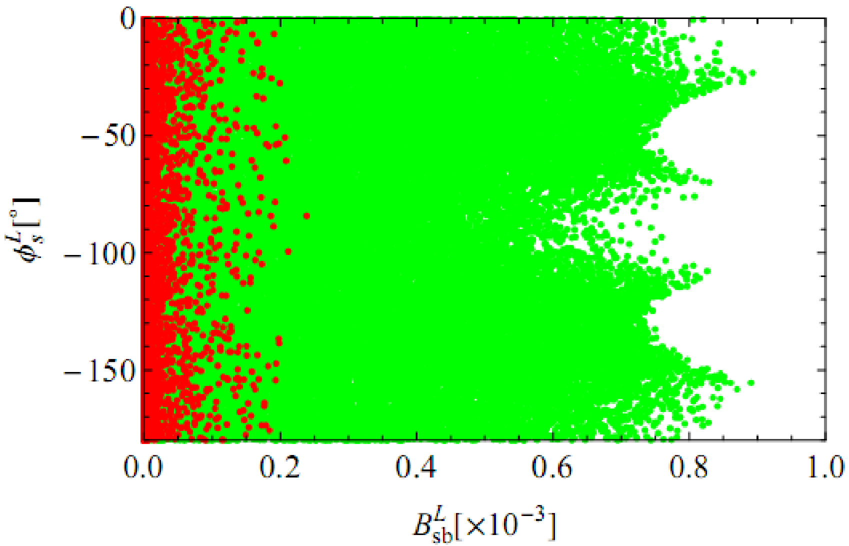


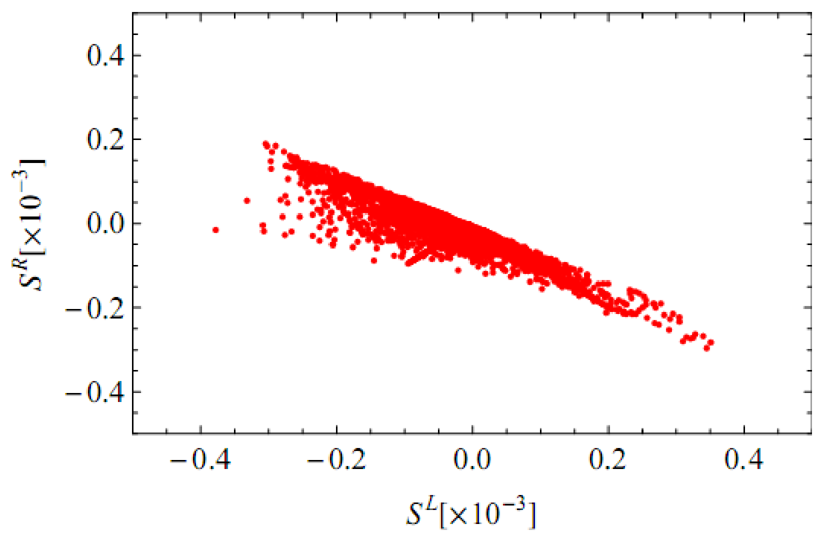


$\lvert B_{sb}^L\rvert[\times10^{-3}]$	$\phi_s^L[°]$	$P^L[\times10^{-3}]$	$P^R[\times10^{-3}]$	$D^L[\times10^{-3}]$	$D^R[\times10^{-3}]$
[0, 0.053]	[-104.3, -80.1]	[-0.04, 0.73]	[-0.02, 0.68]	[-0.73, -0.28]	[-0.092, 0.017]

由$B_s-\bar{B}_s$和 $B_{u,d}\to\pi K$ 衰变共同限制的 Z' 参数

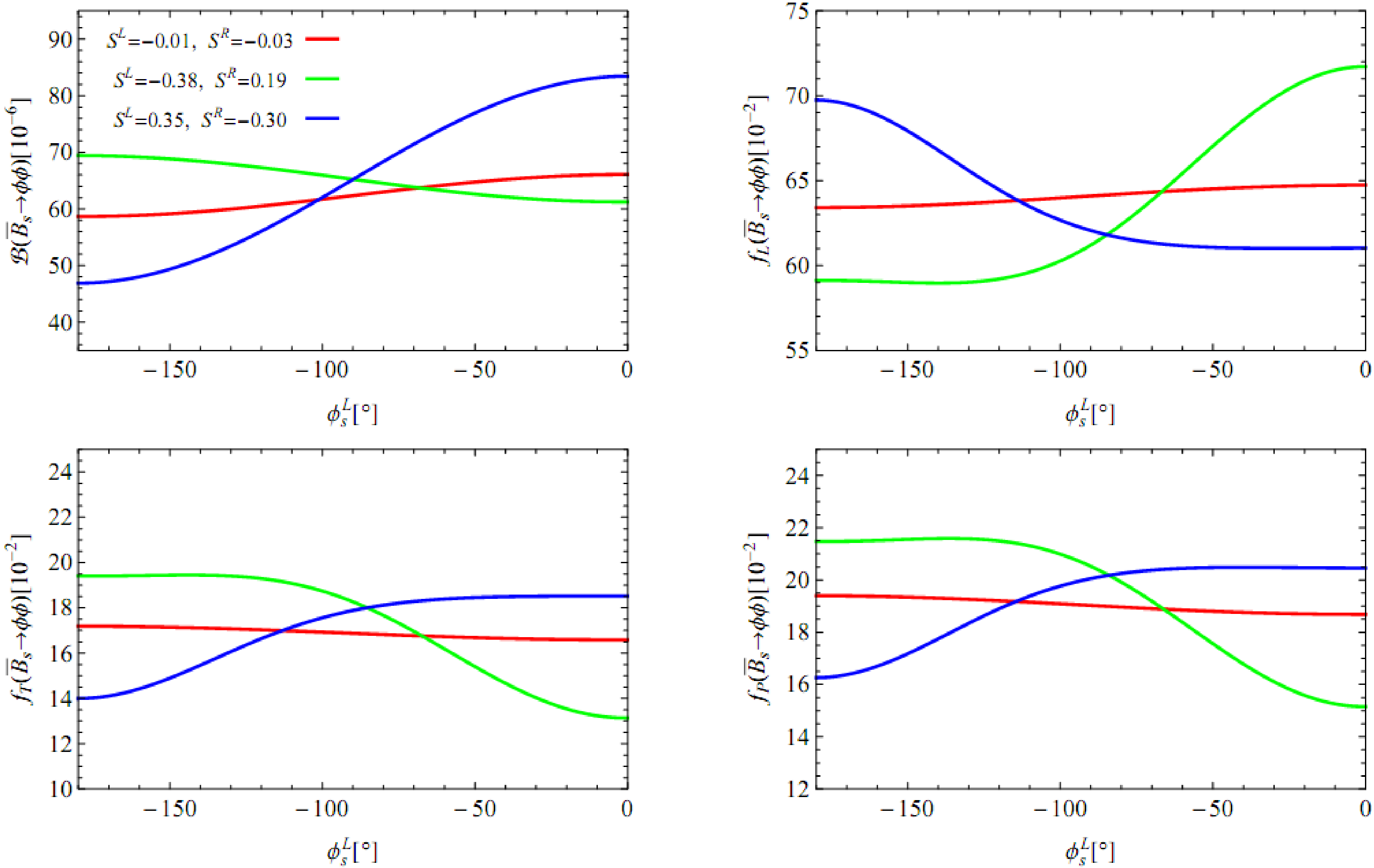
$b \to s s \bar{s}$ 过程对应的新物理参数$S^{L,R}$和 ϕ_s^L ，由$B_s - \bar{B}_s$混合和 $B_{u,d} \to \phi K$ 衰变进行限制。





$\lvert B_{sb}^L \rvert[\times 10^{-3}]$	$\phi_s^L[°]$	$S^L[\times 10^{-3}]$	$S^R[\times 10^{-3}]$
[0, 0.24]	[-180, 0]	[-0.38, 0.35]	[-0.30, 0.19]

由$B_s - \bar{B}_s$和 $B_{u,d} \to \phi K$ 衰变共同限制的Z'参数



$\bar{B}_s \to \phi\phi$衰变的可观测量对Z'参数ϕ_s^L的依赖性，理论输入参数采用了中心值

分支比（10^{-6}）：

Decay Mode	Exp. data	SM Scheme I	SM Scheme II	Z' model data
$\bar{B}_s \to \pi^+\pi^-$	0.73 ± 0.14	$0.21^{+0.07}_{-0.05}$	$0.48^{+0.14}_{-0.11}$	$0.46^{+0.15}_{-0.12}$
$\bar{B}_s \to \pi^0\pi^0$	—	0.11 ± 0.03	$0.24^{+0.07}_{-0.06}$	$0.23^{+0.08}_{-0.06}$
$\bar{B}_s \to \pi^+\rho^-$	—	$0.012^{+0.004}_{-0.003}$	$0.031^{+0.008}_{-0.007}$	$0.028^{+0.017}_{-0.012}$
$\bar{B}_s \to \rho^+\pi^-$	—	0.015 ± 0.004	$0.031^{+0.008}_{-0.007}$	$0.028^{+0.017}_{-0.012}$
$\bar{B}_s \to \pi^0\rho^0$	—	0.013 ± 0.004	$0.031^{+0.008}_{-0.007}$	$0.028^{+0.017}_{-0.012}$
$\bar{B}_s \to \rho^+\rho^-$	—	$0.42^{+0.11}_{-0.09}$	1.5 ± 0.3	1.4 ± 0.4
$\bar{B}_s \to \rho^0\rho^0$	—	$0.21^{+0.06}_{-0.05}$	$0.73^{+0.16}_{-0.13}$	$0.69^{+0.18}_{-0.15}$
$\bar{B}_s \to \omega\rho^0$	—	$0.0036^{+0.0012}_{-0.0011}$	$0.012^{+0.005}_{-0.003}$	$0.022^{+0.021}_{-0.011}$
$\bar{B}_s \to \omega\omega$	—	0.16 ± 0.04	$0.55^{+0.14}_{-0.11}$	$0.52^{+0.15}_{-0.12}$
$\bar{B}_s \to K^{*+}K^{*-}$	—	$7.7^{+2.4}_{-2.0}$	$15.0^{+5.0}_{-3.8}$	$14.5^{+5.8}_{-4.2}$
$\bar{B}_s \to K^{*0}\bar{K}^{*0}$	28.1 ± 6.5	$8.1^{+2.3}_{-1.9}$	$15.7^{+4.7}_{-4.1}$	$14.9^{+5.1}_{-3.9}$
$\bar{B}_s \to \phi\rho^0$	—	0.56 ± 0.12	$0.55^{+0.12}_{-0.11}$	$2.4^{+5.1}_{-1.8}$
$\bar{B}_s \to \omega\phi$	—	$0.030^{+0.022}_{-0.008}$	$0.033^{+0.011}_{-0.008}$	$0.88^{+5.97}_{-0.87}$
$\bar{B}_s \to \phi\phi$	19 ± 5	$25.5^{+4.6}_{-4.8}(16.8^{+9.1}_{-3.8})$	$64.7^{+16.8}_{-13.6}(44.4^{+25.7}_{-14.2})$	$61.2^{+27.4}_{-19.0}(42.8^{+30.1}_{-16.1})$

括号内外使用的形状因子和衰变常数不同，

P. Ball *et al.*, 2004 (M. Beneke *et al.*, 2006) .

CP破坏（10^{-2}）：

Decay Mode	Exp. data	SM Scheme I	SM Scheme II	Z' model data
$\bar{B}_s \to \pi^+\pi^-$	—	0	0	0
$\bar{B}_s \to \pi^0\pi^0$	—	0	0	0
$\bar{B}_s \to \pi^+\rho^-$	—	$-19.3^{+4.9}_{-5.8}$	0	0
$\bar{B}_s \to \rho^+\pi^-$	—	$15.8^{+3.7}_{-3.5}$	0	0
$\bar{B}_s \to \pi^0\rho^0$	—	0	0	0
$\bar{B}_s \to \rho^+\rho^-$	—	0	0	0
$\bar{B}_s \to \rho^0\rho^0$	—	0	0	0
$\bar{B}_s \to \omega\rho^0$	—	0	0	0
$\bar{B}_s \to \omega\omega$	—	0	0	0
$\bar{B}_s \to K^{*+}K^{*-}$	—	$24.0^{+4.4}_{-3.6}$	$19.3^{+3.7}_{-3.9}$	$16.9^{+10.1}_{-11.4}$
$\bar{B}_s \to K^{*0}\bar{K}^{*0}$	—	$1.0^{+0.1}_{-0.2}$	0.65 ± 0.12	$3.0^{+8.5}_{-8.0}$
$\bar{B}_s \to \phi\rho^0$	—	21.1 ± 2.8	$21.4^{+2.4}_{-2.5}$	$0.2^{+9.8}_{-5.1}$
$\bar{B}_s \to \omega\phi$	—	$44.5^{+26.9}_{-34.9}$	$33.0^{+19.7}_{-15.9}$	$16.7^{+42.4}_{-112.5}$
$\bar{B}_s \to \phi\phi$	—	$1.1 \pm 0.2(1.1^{+0.2}_{-0.3})$	$0.66^{+0.13}_{-0.12}(0.61^{+0.29}_{-0.13})$	$-1.0^{+23.3}_{-24.5}(-0.9^{+20.6}_{-19.3})$

纵向极化分量（10^{-2}）：

Decay Mode	Exp. data	SM Scheme I	SM Scheme II	Z' model data
$\bar{B}_s \to \rho^+\rho^-$	—	98.70 ± 0.04	97.76 ± 0.01	97.76 ± 0.02
$\bar{B}_s \to \rho^0\rho^0$	—	$98.69^{+0.04}_{-0.03}$	97.75 ± 0.01	97.75 ± 0.01
$\bar{B}_s \to \omega\rho^0$	—	98.66 ± 0.03	97.71 ± 0.02	97.71 ± 0.02
$\bar{B}_s \to \omega\omega$	—	$98.64^{+0.03}_{-0.04}$	97.66 ± 0.02	97.66 ± 0.02
$\bar{B}_s \to K^{*+}K^{*-}$	—	$67.0^{+9.8}_{-11.8}$	$65.0^{+6.9}_{-6.6}$	$65.9^{+8.2}_{-8.8}$
$\bar{B}_s \to K^{*0}\bar{K}^{*0}$	31 ± 13	$69.1^{+9.6}_{-12.3}$	$70.3^{+5.9}_{-6.2}$	$70.1^{+6.2}_{-6.9}$
$\bar{B}_s \to \phi\rho^0$	—	$91.3^{+2.4}_{-3.1}$	$91.8^{+2.3}_{-3.1}$	$92.1^{+3.6}_{-9.2}$
$\bar{B}_s \to \omega\phi$	—	$79.2^{+14.2}_{-23.5}$	$86.5^{+4.0}_{-7.7}$	$96.8^{+2.0}_{-60.9}$
$\bar{B}_s \to \phi\phi$	36.1 ± 2.2	$51.4^{+11.4}_{-12.7}(44.5^{+20.2}_{-14.0})$	$64.3^{+4.2}_{-3.9}(60.8^{+10.3}_{-4.6})$	$64.1^{+9.0}_{-6.5}(60.6^{+15.3}_{-6.9})$

横向极化分量（10^{-2}）：

Decay Mode	Exp. data	SM Scheme I	SM Scheme II	Z' model data
$\bar{B}_s \to \rho^+\rho^-$	—	0.20 ± 0.01	1.26 ± 0.01	1.26 ± 0.01
$\bar{B}_s \to \rho^0\rho^0$	—	0.20 ± 0.01	1.27 ± 0.01	1.27 ± 0.01
$\bar{B}_s \to \omega\rho^0$	—	0.21 ± 0.01	1.29 ± 0.01	1.29 ± 0.01
$\bar{B}_s \to \omega\omega$	—	0.21 ± 0.01	1.32 ± 0.01	1.32 ± 0.01
$\bar{B}_s \to K^{*+}K^{*-}$	—	$14.5^{+5.4}_{-4.5}$	$15.2^{+3.0}_{-3.1}$	$14.8^{+4.0}_{-3.8}$
$\bar{B}_s \to K^{*0}\bar{K}^{*0}$	38 ± 12	$13.5^{+5.9}_{-4.2}$	$12.7^{+2.9}_{-2.7}$	$12.8^{+3.2}_{-2.8}$
$\bar{B}_s \to \phi\rho^0$	—	$4.5^{+1.6}_{-1.3}$	$4.3^{+1.6}_{-1.3}$	$3.9^{+4.6}_{-1.9}$
$\bar{B}_s \to \omega\phi$	—	$11.0^{+13.6}_{-7.7}$	$7.1^{+4.2}_{-2.5}$	$1.5^{+29.7}_{-0.9}$
$\bar{B}_s \to \phi\phi$	30.6 ± 2.3	$22.9^{+6.4}_{-5.8}(26.4^{+8.1}_{-10.4})$	$16.8^{+1.9}_{-2.1}(18.4^{+2.3}_{-5.1})$	$16.9^{+3.1}_{-4.4}(18.5^{+3.3}_{-7.3})$

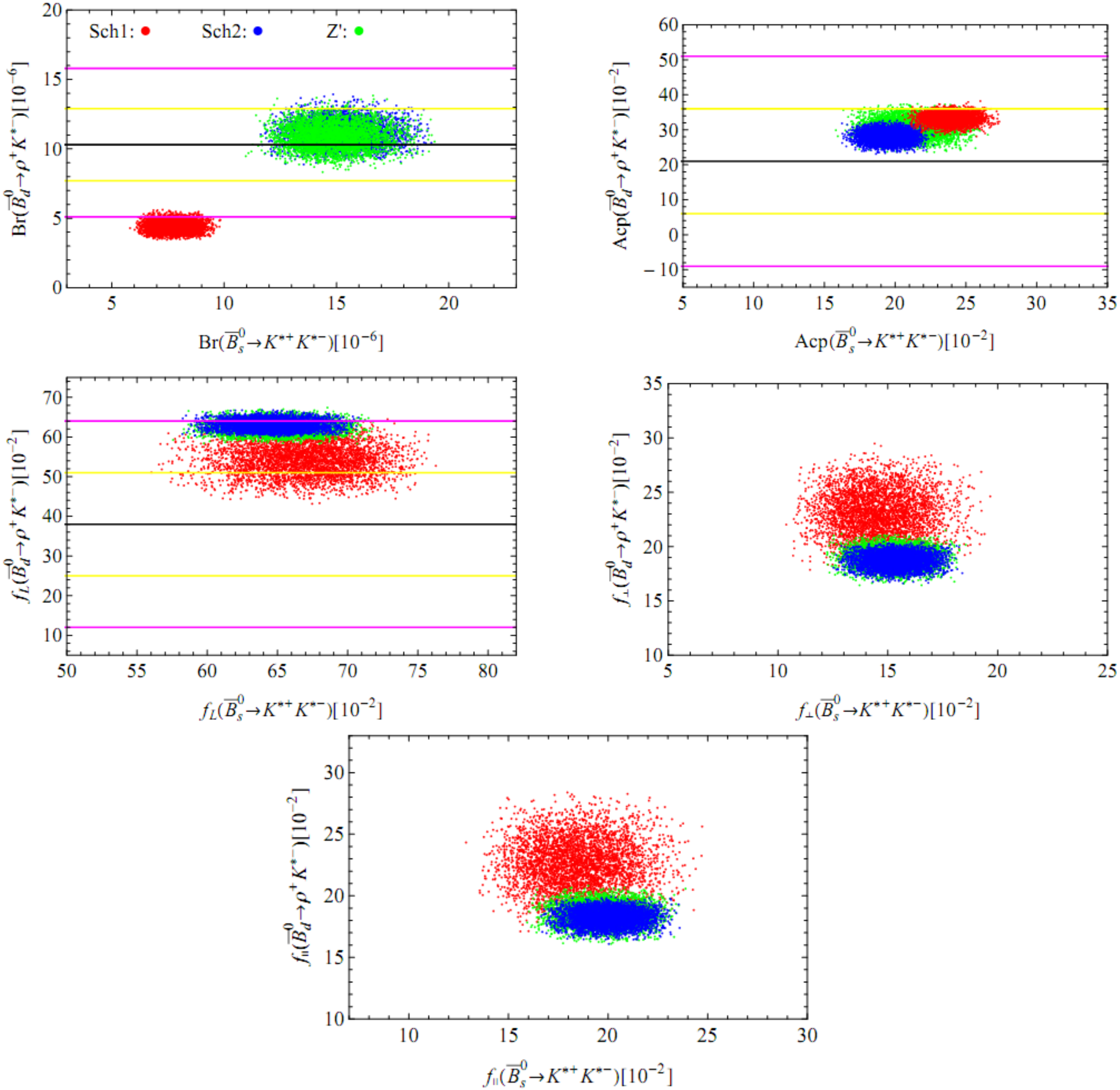
$\bar{B}_d \to \rho^+ K^{*-}$和 $\bar{B}_s \to K^{*+} K^{*-}$衰变的相关性

都属于$b \to s u \bar{u}$跃迁过程，忽略湮灭图的贡献，两过程振幅的差别只体现在强子参数上。

$$\mathcal{B}(\bar{B}_d \to \rho^+ K^{*-}) = (10.3 \pm 2.6) \times 10^{-6}\,,$$

$$A_{CP}(\bar{B}_d \to \rho^+ K^{*-}) = 0.21 \pm 0.15\,,$$

$$f_L(\bar{B}_d \to \rho^+ K^{*-}) = 0.38 \pm 0.13\,.$$



标准模型和代非普适Z' 模型中，$\bar{B}_d \to \rho^+ K^{*-}$ 和$\bar{B}_s \to K^{*+} K^{*-}$ 衰变可观测量间的相关性

小结：

- 利用$B_s-\bar{B}_s$混合和$B_{u,d}\to\pi K$衰变、$B_s-\bar{B}_s$混合和$B_{u,d}\to\phi K$衰变分别限制了两组新物理参数$P^{L,R}$、$D^{L,R}$、ϕ_s^L和$S^{L,R}$、ϕ_s^L。第二组过程无法限制ϕ_s^L的范围。

- Scheme II和Z'模型中，关于$\mathcal{B}(\bar{B}_s\to\pi^+\pi^-,K^{*0}\bar{K}^{*0})$的理论预言值和目前的实验数据符合，但是极化问题依然存在。

- $\bar{B}_s\to\phi\phi,\phi\rho,\omega\phi$衰变过程受$Z'$玻色子的影响大，非常适合验证代非普适$Z'$模型的正确性。

总结与展望

1.理论上，这些工作对我们今后理解B介子衰变提供了很有意义的参考。

2.实验上，升级改造后的LHCb Upgrade II探测器以及Belle II 探测器将会在重味物理以及强子物理多项研究中达到前所未有的灵敏度，高精度检验标准模型并寻找超出标准模型的新物理。

3.理论和实验上的进展都为我们未来更好地研究和理解重味物理奠定了坚实的基础。

Thank you !