RS Model Effects on B_s CP Violation

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Observables in the B_s^0-$\bar{B}_s^0$ System

There exist heavy and light meson states $|B_H\rangle$ and $|B_L\rangle$, which are linear combinations of the CP eigenstates $|B_s^0\rangle$ and $|\bar{B}_s^0\rangle$.

You can measure (for instance):

- **Mass -and width difference** between $|B_H\rangle$ and $|B_L\rangle$: Δm_{B_s} and $\Delta\Gamma_s$
- **Time-dependent CP asymmetry** in $B_s \to \psi\phi$ decays

$$A_{\rm CP}^s(\psi\phi, t) = \frac{\Gamma(\bar{B}_s^0(t) \to \psi\phi) - \Gamma(B_s^0(t) \to \psi\phi)}{\Gamma(\bar{B}_s^0(t) \to \psi\phi) + \Gamma(B_s^0(t) \to \psi\phi)} \equiv S_{\psi\phi} \sin(\Delta m_{B_s} t)$$

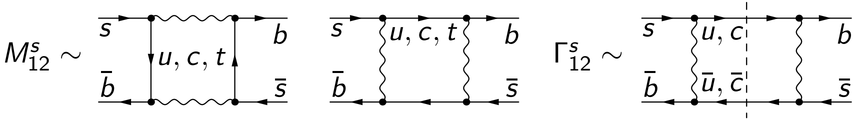
- **CP asymmetry** in semileptonic B_s decays

$$A_{\rm SL}^s = \frac{\Gamma(\bar{B}_s^0 \to l^+ X) - \Gamma(B_s^0 \to l^- X)}{\Gamma(\bar{B}_s^0 \to l^+ X) + \Gamma(B_s^0 \to l^- X)}$$

Observables in the B_s^0-$\bar{B}_s^0$ System

In theory, you compute the **dispersive part $\mathbf{M_{12}^s}$** and the **absorptive part $\mathbf{\Gamma_{12}^s}$** of the **$\mathbf{B_s^0}$-$\mathbf{\bar{B}_s^0}$ mixing amplitude**.
Up to so-called bag factors, which have to be computed on the lattice, you can use perturbation theory:

Example: LO SM



For $|M_{12}^s| \gg |\Gamma_{12}^s|$:

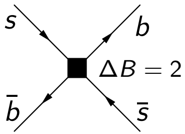
$$\Delta m_{B_s} = 2|M_{12}^s| \qquad \Delta\Gamma_s = -\frac{2\,\mathrm{Re}(M_{12}^s \Gamma_{12}^{s*})}{|M_{12}^s|} = 2|\Gamma_{12}^s| \cos\phi_s$$

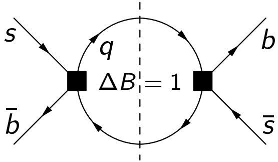
$$S_{\psi\phi} = \sin 2\,\beta_s^{J/\psi\phi} \qquad A_{\mathrm{SL}}^s = \mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right) \qquad \phi_s = 2\,\beta_s^{J/\psi\phi} = \arg(-M_{12}^s \Gamma_{12}^{s*}) \approx 2^\circ$$

General Strategy for the Calculation (SM and NP)

$\mathbf{M_{12}^s}$: Compute the **Wilson coefficients for effective $\Delta B = 2$ four-fermion operators**. Evaluate the coefficients (valid at the weak scale M_W or the new physics scale Λ_{NP}) down to $\mu \approx m_b$. Take the B-meson matrix elements of the $\Delta B = 2$ operators from lattice QCD.

$\mathbf{\Gamma_{12}^s}$: Compute the **Wilson coefficients for effective $\Delta B = 1$ four-fermion operators**. Calculate the interference of the various insertions. Run down to $\mu \approx m_b$. The result is given in terms of matrix elements of $\Delta B = 2$ operators.



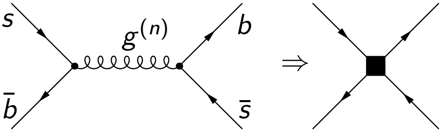


Impact of Randall-Sundrum (RS) Models

L. Randall and R. Sundrum, Phys. Rev. Lett. **83**, 3370 (1999) [arXiv:hep-ph/9905221].

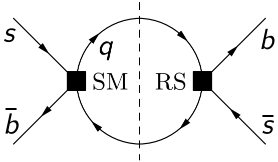
- One **compactified extra dimension** leads to an infinite tower of **massive** so-called **Kaluza-Klein particles** for any SM field, $\Lambda_{\mathrm{NP}} = M_{\mathrm{KK}} \approx$few TeV.
- The couplings of fermions to heavy neutral gauge bosons $Z^0, Z^{(n)}, \gamma^{(n)}, g^{(n)}$ depend on flavor! $\rightarrow$ **tree level FCNCs**!

$M_{12}^{s\mathrm{RS}} \sim$



$$\frac{M_{12}^{s\mathrm{RS}}}{M_{12}^{s\mathrm{SM}}} \sim \frac{m_W^2}{M_{\mathrm{KK}}^2}\, 16\pi^2$$

$\Gamma_{12}^{s\mathrm{RS}} \sim$

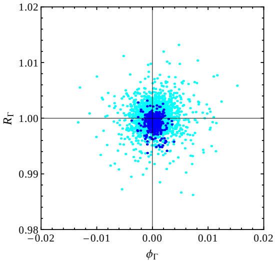


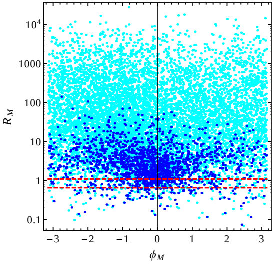
$$\frac{\Gamma_{12}^{s\mathrm{RS}}}{\Gamma_{12}^{s\mathrm{SM}}} \sim \frac{m_W^2}{M_{\mathrm{KK}}^2}$$

Constraints on RS Parameter Space

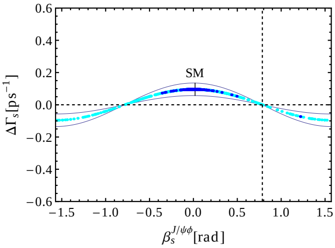
$$M_{12}^s = M_{12}^{s\,\mathrm{SM}} + M_{12}^{s\,\mathrm{RS}} = M_{12}^{s\,\mathrm{SM}} R_M \, e^{i\phi_M} \qquad \Gamma_{12}^s = \Gamma_{12}^{s\,\mathrm{SM}} + \Gamma_{12}^{s\,\mathrm{RS}} = \Gamma_{12}^{s\,\mathrm{SM}} R_\Gamma \, e^{i\phi_\Gamma}$$

- *$Z^0 \longrightarrow b\bar{b}$ pseudo-observables:*
  strong bound for minimal RS model but vanishes for custodial RS model with protection of the $Z^0 b_L \bar{b}_L$ vertex
- *B_s^0-$\bar{B}_s^0$ oscillation frequency Δm_{B_s}:* $R_M \in [0.656, 1.097]$
- ϵ_K: Generically too large, fine-tuning or additional flavor symmetries needed.





RS Corrections in the $\Delta\Gamma_s/\beta_s^{J/\psi\phi}$-Plane



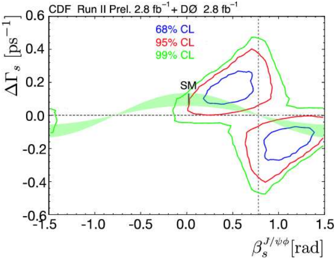
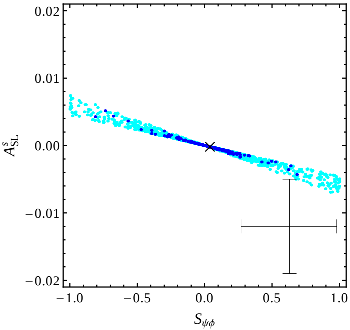


Figure on r.h.s. taken from

T. Aaltonen et al. [CDF collaboration], CDF public note CDF/PHYS/BOTTOM/CDFR/9787, June, 2009

The measured value of the *CP-violating phase* $\beta_s^{J/\psi\phi}$ is obtained from the time-dependent angular analysis of flavor-tagged $B \to J/\psi\phi$ decays.

RS Corrections in the $A^s_{\rm SL}/S_{\psi\phi}$-Plane



$$S_{\psi\phi} = \sin(\phi_s^{J/\psi\phi} + \phi_\Gamma - \phi_M) \qquad A^s_{\rm SL} = {\rm Im}\left(\frac{\Gamma^s_{12}}{M^s_{12}}\right) = -\frac{|\Gamma^{s\,\rm SM}_{12}|}{|M^{s\,\rm SM}_{12}|}\frac{R_\Gamma}{R_M}\,S_{\psi\phi}$$

Experimental values: $S_{\psi\phi} = 0.63 \pm 0.35$ $\quad A^s_{\rm SL} = -0.012 \pm 0.007$

Heavy Flavor Averaging Group, arXiv:0808.1297 [hep-ex]