Hadoronic CP violation from strangeness and constraints on CP phases

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The 21st Century COE program of Tohoku University Symposium 2005.3.3-5

INTRODUCTION

- CP symmetry (particle ⇔antiparticle)

  CP is violated by the Kobayashi Maskawa phase in the standard model

- Baryon asymmetry in universe(BAU)

$$(n_B - n_{\overline{B}})/s \sim 10^{-10}$$

Zhakarov's 3 condition

1. B violation
2. C,CP violation
3. Out of equilibrium

It is known that BAU cannont be explained by the standard model

New CP violating phases are required to explain BAU

Search for hadronic CP violation

- Electric Dipole Moments(EDM)

$$|d_{\rm n}| < 6.3 \times 10^{-26} ecm \qquad |d_{\rm Hg}| < 2.1 \times 10^{-28} ecm$$

- CP violation in B decays
  B factory experiments (Babar, Belle)

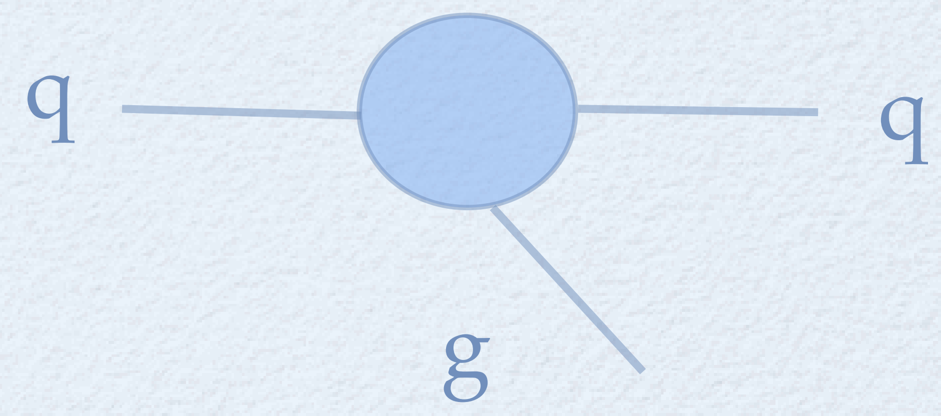
- The CP violation involving strange quark has not been considered seriously.
  → We have found the strange contribution is important.

Quark CEDMs

$$\mathcal{L} = \sum_{q=u,d,s} i\frac{\tilde{d}_q}{2}\overline{q} g_s (G^a_{\mu\nu} T^a \sigma^{\mu\nu})\gamma_5 q$$

G: gluon field strength

$\tilde{d}_q$ quark chromoelectri dipole moment (CEDM)



$\tilde{d}_q \neq 0$ → CP, T violation

Quark CEDMs induces various hadronic CP violation

CHIRAL LAGRANGIN

We need the CP violating nucleon interactions from the quark CEDMs

$$\mathcal{L}_{\rm CPV}(u,d,s,..) \longrightarrow \mathcal{L}_{\rm CPV}(\pi,K,\eta,p,n,...)$$

It is very difficult to write down the CP violating interactions

We use the SU(3) chiral Lagrangian

QCD: SU(3)L X SU(3)R symmetry

$$M = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta^0}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta^0}{\sqrt{6}} & K^0 \\ K^- & \overline{K^0} & -2\frac{\eta^0}{\sqrt{6}} \end{pmatrix} \qquad B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda^0}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda^0}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & -2\frac{\Lambda^0}{\sqrt{6}} \end{pmatrix}$$

$$\mathcal{L}_{\rm CPV} = \frac{1}{\sqrt{2}f_\pi}(Xtr(\overline{B}B\{M,A\}) + Ytr(\overline{B}\{M,A\}B) \ +Ytr\left(\overline{B}\{M,A\}B\right)$$

X=-1.35, Y=0.72, Z=0.77 $\quad A = \mathrm{diag}(-0.27\tilde{d}_u, -0.27\tilde{d}_d, -0.27\tilde{d}_s)$

HG ATOMIC EDM

^{199}Hg atom

- closed electric shell (J=0)
- nuclear spin (I=1/2)

Hg atomic EDM is sensitive to the nuclear EDM induced by the Shiff moment(S), which induce the T-odd potential

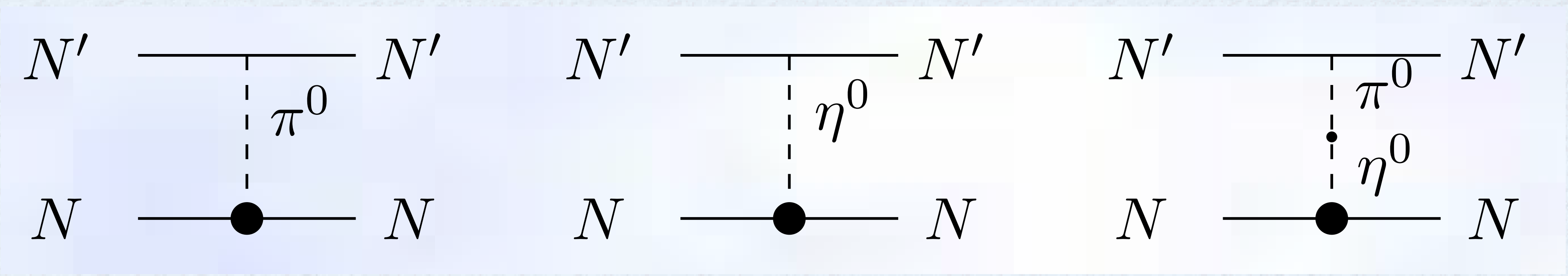
$(V=4\pi S\, I \cdot \nabla\delta(r))$

$$d_{\rm Hg} = -2.8 \times 10^{-17}\, S(^{199}{\rm Hg})\ e\ cm$$

$$< \ 2.1 \times 10^{-28} ecm$$

Shiff Moment

Shiff moment is induced by π,η exchange diagram



• CP violating couplings

Hg EDM depends on strange CEDM through η contribution

From the Hg EDM experimental bound

$$e|\tilde{d}_u - \tilde{d}_d + 0.0051\tilde{d}_s| < 2.4 \times 10^{-26} e\ cm,$$

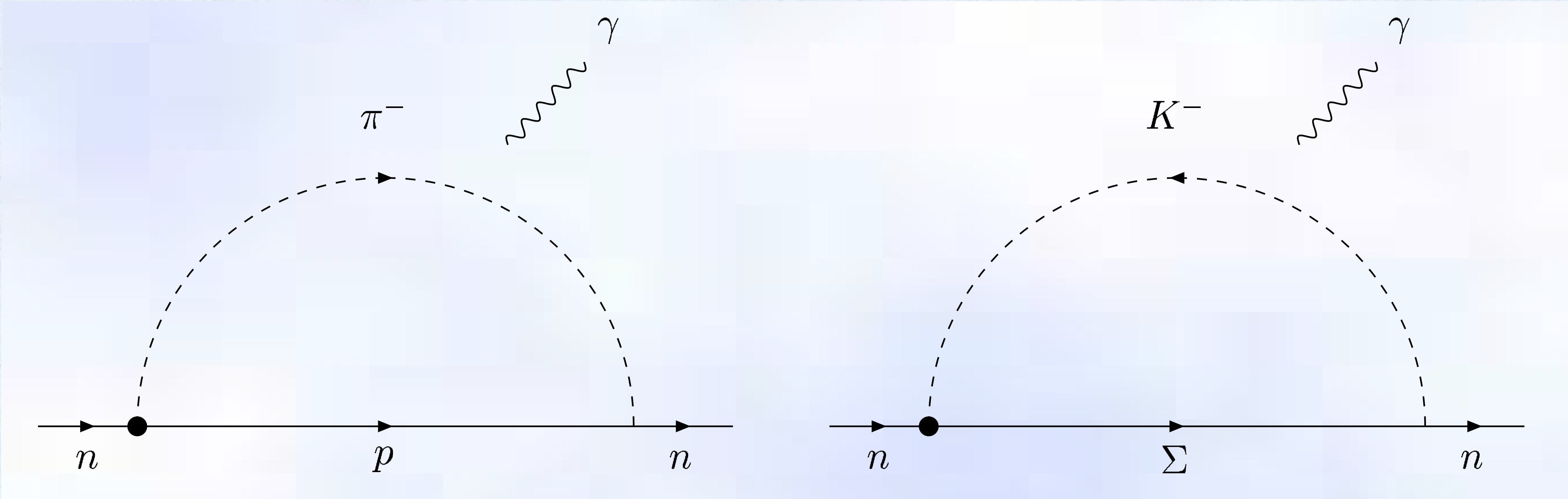
For strangeness

$$e|\tilde{d}_s| < 4.7 \times 10^{-24} e\ cm.$$

Neutron EDM

$$\mathcal{L}_{\mathrm{EDM}} = -\frac{d_n}{2}\overline{n}\sigma_{\mu\nu}\gamma_5 n F^{\mu\nu}$$

Neutron EDM is induced by 1 loop diagram



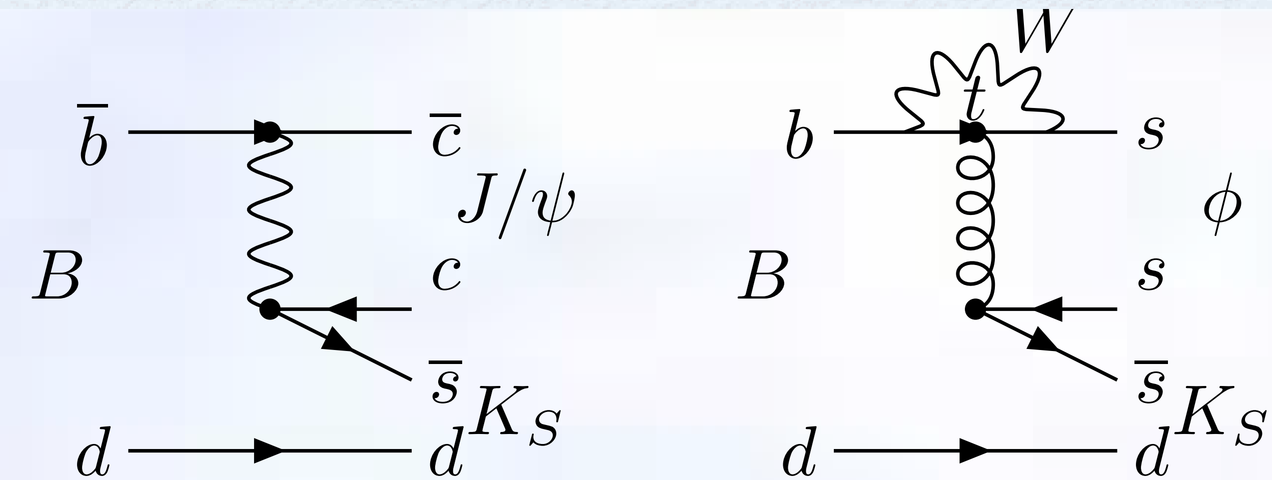
Neutron EDM depends on strange through kaon loop

$$d_n = -(1.6\times\tilde{d}_u + 1.3\times\tilde{d}_d + 0.26\times\tilde{d}_s)ecm < 6.3 < 10^{26}ecm$$

$$e|\tilde{d}_s| < 2.4\times 10^{-25}ecm$$

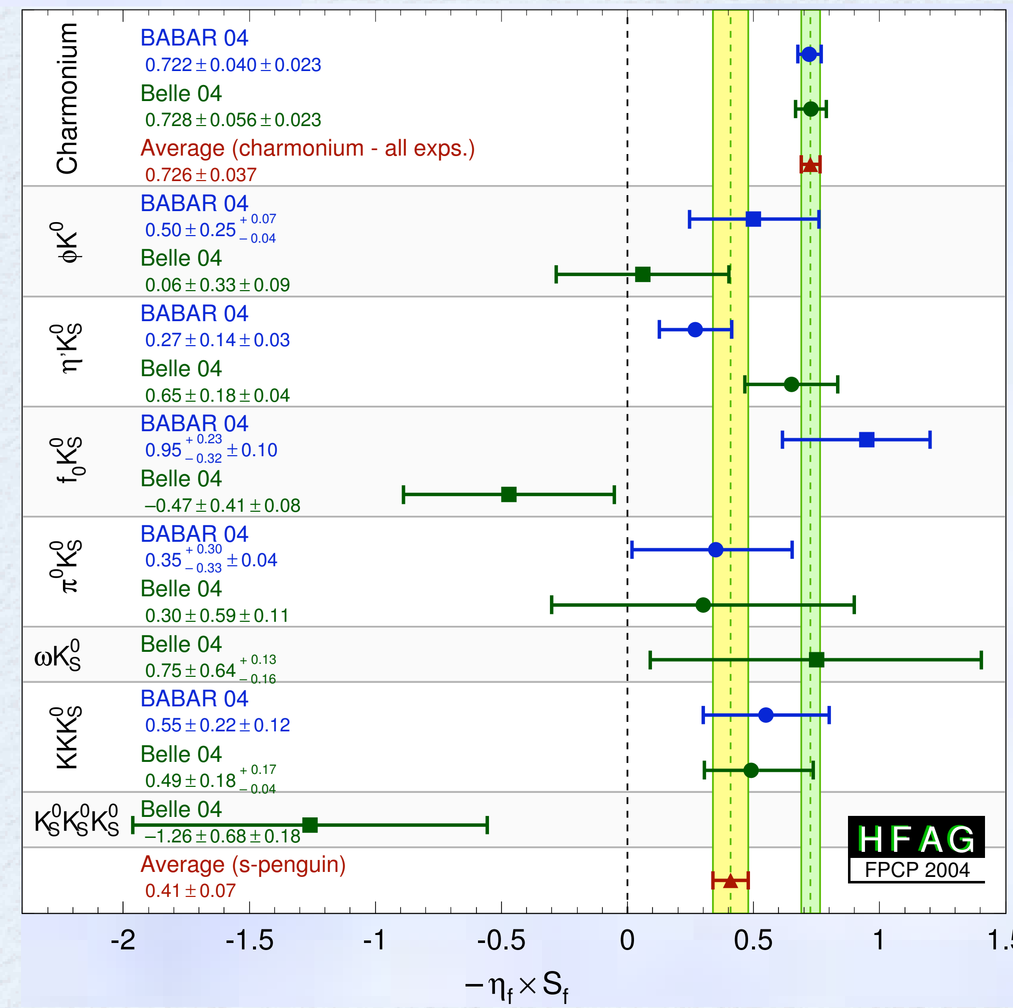
CP Violation in B Decay

$$\frac{\Gamma(\overline{B}^0(t)\to f)-\Gamma(B^0(t)\to f)}{\Gamma(\overline{B}^0(t)\to f)+\Gamma(B^0(t)\to f)} = \sin(-2i\phi_1)\sin(\Delta M_B t)$$



$V_{cb}^{*}V_{cs} \simeq \lambda^2$ $\qquad$ $V_{tb}^{*}V_{ts} \simeq -\lambda^2$

CP asymmetries of ΦK and ψK are the same in the SM

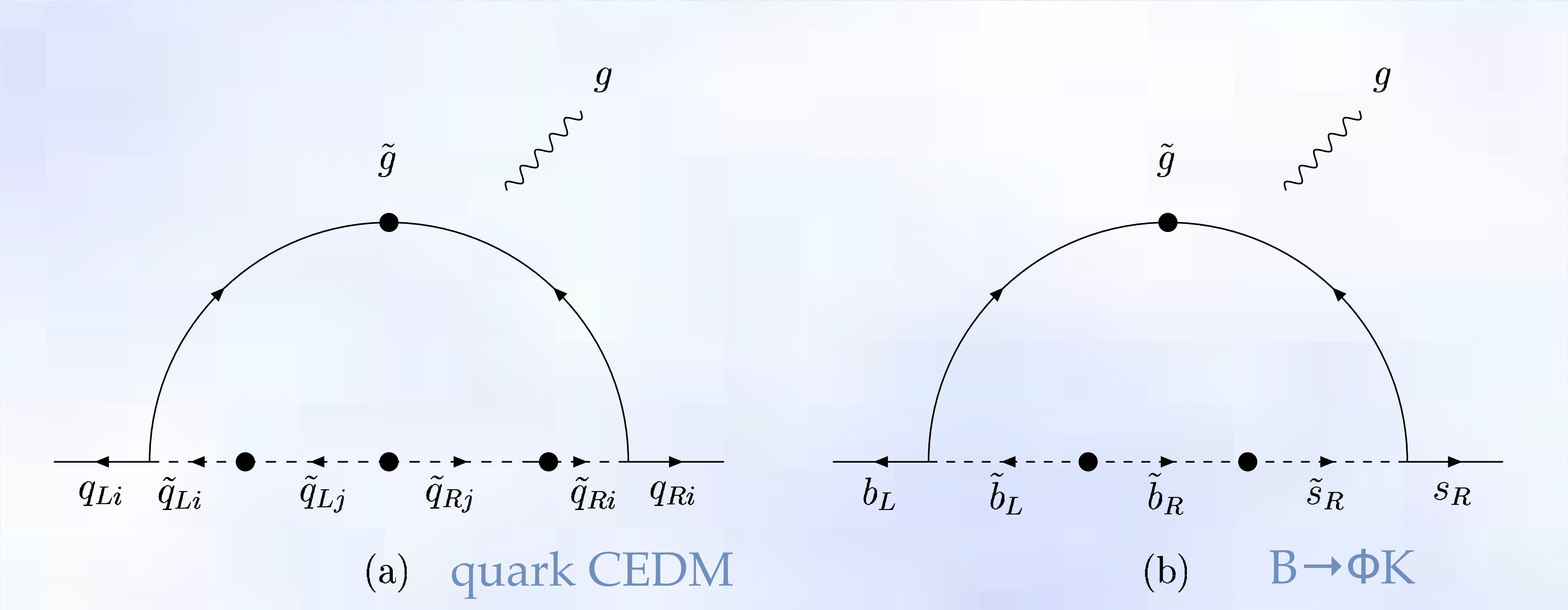


$$\sin 2\phi_1(b\to\bar{c}cs) = 0.726 \pm 0.037$$

$$\sin 2\phi_1(b\to s\bar{q}q) = 0.43 \pm 0.08$$

GLUINO CONTRIBUTION

Supersymmetry: gluon⇔gluino, quark ⇔squark



$$H = -C_8^R \frac{g_s}{8\pi^2} m_b \overline{s_R}(G\sigma)b_L, \qquad C_8^R = \frac{\pi\alpha_s}{m_{\tilde{q}}^2}\frac{m_{\tilde{g}}}{m_b}(\delta_{LR}^{(d)})_{33}(\delta_{RR}^{(d)})_{32} f(x)$$

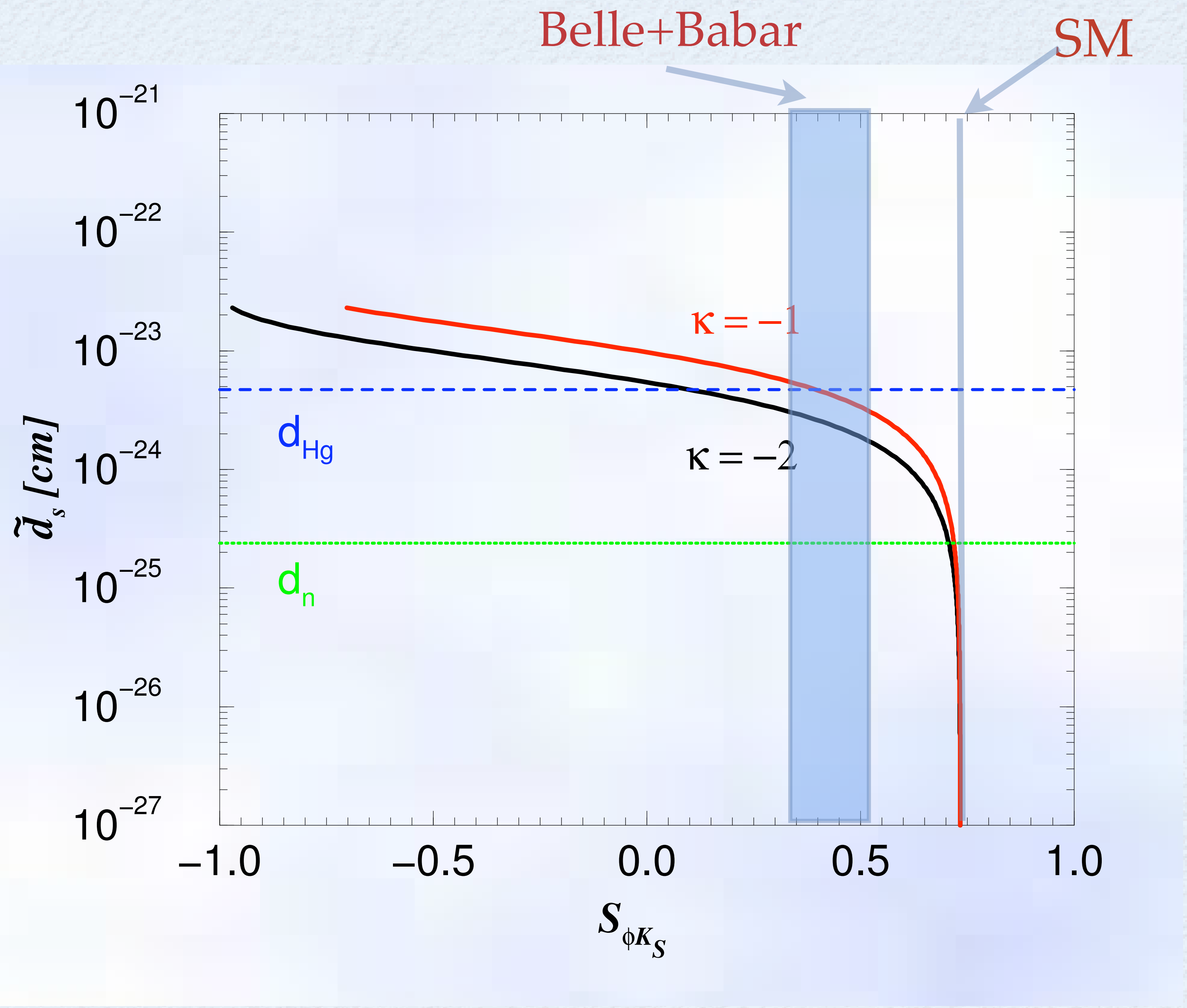
$$(\delta_{LL}^{(d)})_{ij} = (m_{LL}^{\tilde{(d)}2})_{ij}/(m_{LL}^{\tilde{(d)}2})$$

f(x):loop function

Strong correlation between strange CEDM and C8

$$\tilde{d}_s = -\frac{m_b}{4\pi^2}\frac{11}{21}\mathrm{Im}\left[(\delta_{LL}^{(d)})_{23} C_8^R\right] (m_{\tilde{g}} = m_{\tilde{q}}.)$$

Strange EDM vs CP violation in B→ΦK



$\delta_{LL} = 0.04$

$$\langle \phi K_S | \frac{g_s}{8\pi^2} m_b (\bar{s}_i \sigma^{\mu\nu} T^a_{ij} P_R b_j) G^a_{\mu\nu} | \overline{B}_d \rangle = \kappa \frac{4\alpha_s}{9\pi} (\epsilon_\phi p_B) f_\phi m_\phi^2 F_+(m_\phi^2),$$

SUMMARY

- We have considered the hadronic EDMS using the SU(3) chiral Lagrangian
- We have estimated the neutron and mercury EDMs for the strange quark CEDM
- In SUSY models, there is a strong correlation between strange CEDM and CP violation in $B \to \Phi K$