New physics implications of $B \to K^* \ell \ell$ and ε'/ε anomalies

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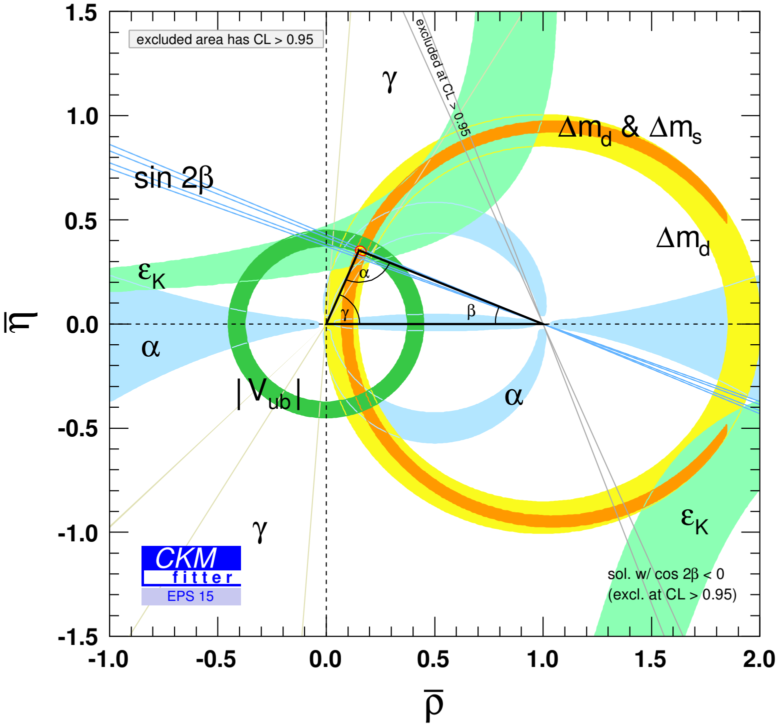
collaborated with **Satoshi Mishima (KEK IPNS)**

Current status of Flavor physics

- Unitarity triangle



★ほぼ標準模型と合っている

- Flavor anomaly

$\sim$2-3σ $\quad \frac{\epsilon'}{\epsilon}$

$\sim$2-3σ $\quad P_5'\ [BR(B^0 \to K^* \mu^+ \mu^-)]$

$\sim$4σ $\quad BR(B \to D^* \tau \nu)$

$\sim$3σ $\quad$ inclusive vs.exclusive $|V_{cb}|\&|V_{ub}|$

★いくつかの2-3σのずれ

新物理のフレーバーの破れ

- 新物理では、フレーバーを破る寄与はたくさん出てくる

  例）MSSM　スクォークの質量行列　⇒　NP flavor problem

- possible solutions :
  - 新物理のスケールが高くて見えていない
  - 新物理のFCNC processesの構造が標準模型と一緒

Minimal Flavor Violation

Minimal Flavor Violation

[G.D'Ambrosio, G.F.Giudice, G.Isidori & A.Strumia, hep-ph/0207036]

- ＳＭゲージ相互作用はフレーバーに依存しない

フレーバー対称性： $SU(3)_{Q_L} \times SU(3)_{U_R} \times SU(3)_{D_R}$

- ＳＭでは、湯川相互作用でのみこの対称性が破れている

$$\mathcal{L} = \bar{Q}_L Y_D D_R H + \bar{Q}_L Y_U U_R H_c + \mathrm{h.c.}$$

$\overline{Q_L} : (\bar{3}, 1, 1)$
$U_R : (1, 3, 1)$
$D_R : (1, 1, 3)$

$Y_U \ : \ (3, \bar{3}, 1) \quad Y_D \ : \ (3, 1, \bar{3})$ とすると、上記のフレーバー対称性に対して不変

- ＮＰの低エネルギー有効理論高次元operatorsが、フレーバー対称性不変と仮定

e.g. $$\mathcal{O}_0 = \frac{1}{2}\left(\bar{Q}_L Y_U Y_U^\dagger \gamma_\mu Q_L\right)^2$$

- このときＮＰのフレーバーを破る起源は湯川相互作用と同じ起源（Minimal Flavor Violation）

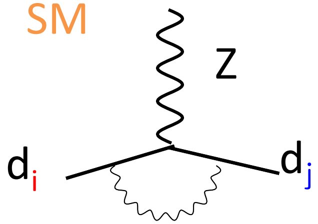
$$\left[Y^u (Y^u)^\dagger\right]^n_{i \neq j} \approx y_t^{2n} V_{ti}^* V_{tj} \quad \rightarrow \quad A(d_i \to d_j)_{MFV} = V_{ti}^* V_{tj} \left(A_{SM} + A_{NP}\right)$$

もしMFVからのずれが見つかれば、湯川相互作用が起源ではない新しいフレーバー構造の示唆になる

Constrained Minimal Flavor Violation

- SMでは、フレーバーの違いはCKMから来る

SM

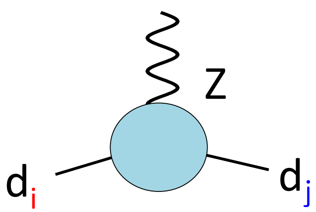


$$i\frac{G_F}{\sqrt{2}}\frac{g_2}{2\pi^2}\frac{M_W^2}{\cos\theta_w}\left(V_{ti}^{*}V_{tj}\right)C(x_t)\left[\bar{d}_i\gamma^\mu(1-\gamma_5)d_j\right]Z_\mu$$

$$x_t=\frac{m_t^2}{M_W^2}$$

- NPでも、同じ構造をしていると仮定

SM+NP



$$i\frac{G_F}{\sqrt{2}}\frac{g_2}{2\pi^2}\frac{M_W^2}{\cos\theta_w}\left(V_{ti}^{*}V_{tj}\right)\left(C(x_t)+\delta C\right)\left[\bar{d}_i\gamma^\mu(1-\gamma_5)d_j\right]Z_\mu$$

Ｋ中間子、Ｂ中間子の物理量が同じ量で記述できる

- operatorの係数でＣＫＭなどを除いたもの：Ｃ　⇦　flavor-universal variable

Constrained Minimal Flavor Violation

[G. Buchalla, A. J. Buras, M.K. Harlander, '91]

- SMでの flavor-universal variable

$$S(x_t) \;:\; (\bar{d}_i d_j)_{V-A}(\bar{d}_i d_j)_{V-A}$$ *ΔF=2 Box*

$$X(x_t) \;:\; (\bar{d}_i d_j)_{V-A}(\bar{\nu}\nu)_{V-A},\, (\bar{d}_i d_j)_{V-A}(\bar{u}u)_{V-A}$$ *Z penguin + ΔF=1 Box*

$$Y(x_t) \;:\; (\bar{d}_i d_j)_{V-A}(\bar{d}d)_{V-A},\, (\bar{d}_i d_j)_{V-A}(\bar{e}e)_{V-A}$$ *Z penguin + ΔF=1 Box*

$$Z(x_t) \;:\; (\bar{d}_i d_j)_{V-A}(\bar{u}u)_{V},\, (\bar{d}_i d_j)_{V-A}(\bar{d}d)_{V},\, (\bar{d}_i d_j)_{V-A}(\bar{e}e)_{V}$$ *Z penguin + γ penguin*

$$E(x_t) \;:\; (\bar{d}_i d_j)_{V-A}\sum(\bar{q}q)_V,\, (\bar{d}_{i,\alpha} d_{j,\beta})_{V-A}\sum(\bar{q}_\beta q_\alpha)_V$$ *gluon penguin*

$$D'(x_t) \;:\; \bar{d}_i[i\sigma_{\mu\nu}q^\lambda m_b(1+\gamma_5)]d_j$$ *γ-magnetic penguin*

$$E'(x_t) \;:\; \bar{d}_{i,\alpha}[i\sigma_{\mu\nu}q^\lambda m_b(1+\gamma_5)]T^a_{\alpha\beta}d_{j,\beta}$$ *chromomagnetic penguin*

- NP を考えたとき、FCNC processes に効く operators が SM と同じであると仮定

$\Rightarrow$ constrained MFV

$$S,\ X,\ Y,\ Z,\ E,\ D',\ E'$$

e.g. $X = X_{SM} + \delta X$ (SM: X_{SM}, NP: δX)

CMFV type NPの例： 2HDM at low tanβ

Constrained Minimal Flavor Violation

[G. Buchalla, A. J. Buras, M K. Harlander, '91]

- Ｋ中間子、Ｂ中間子の様々な物理量が、同じ flavor-universal variable で記述できる

$K^0 - \bar{K}^0$-mixing (ε_K)	$S(v)$
$B^0_{d,s} - \bar{B}^0_{d,s}$-mixing $(\Delta M_{s,d})$	$S(v)$
$K \to \pi\nu\bar{\nu}$, $B \to X_{d,s}\nu\bar{\nu}$	$X(v)$
$K_\mathrm{L} \to \mu\bar{\mu}$, $B_{d,s} \to l\bar{l}$	$Y(v)$
$K_\mathrm{L} \to \pi^0 e^+ e^-$	$Y(v)$, $Z(v)$, $E(v)$
ε', Nonleptonic $\Delta B = 1$, $\Delta S = 1$	$X(v)$, $Y(v)$, $Z(v)$, $E(v)$
$B \to X_s\gamma$	$D'(v)$, $E'(v)$
$B \to X_s$ gluon	$E'(v)$
$B \to X_s l^+ l^-$	$Y(v)$, $Z(v)$, $E(v)$, $D'(v)$, $E'(v)$

注目する物理量

標準模型からのずれが報告されている以下の物理量に注目

★ ***B->K*ll*** における角度依存分布

$$
\begin{aligned}
Y &: (\bar{d}_i d_j)_{V-A}(\bar{e}e)_{V-A} \\
Z &: (\bar{d}_i d_j)_{V-A}(\bar{e}e)_{V} \\
D' &: \bar{d}_i[i\sigma_{\mu\nu}q^\lambda m_b(1+\gamma_5)]d_j
\end{aligned}
$$

★ ***ε'/ε*** K->ππ decayにおけるＫ中間子の直接的ＣＰ非対称度

$$
\begin{aligned}
X &: (\bar{d}_i d_j)_{V-A}(\bar{u}u)_{V-A} \\
Y &: (\bar{d}_i d_j)_{V-A}(\bar{d}d)_{V-A} \\
Z &: (\bar{d}_i d_j)_{V-A}(\bar{u}u)_{V},\, (\bar{d}_i d_j)_{V-A}(\bar{d}d)_{V} \\
E &: (\bar{d}_i d_j)_{V-A}\sum(\bar{q}q)_{V},\, (\bar{d}_{i,\alpha} d_{j,\beta})_{V-A}\sum(\bar{q}_\beta q_\alpha)_{V}
\end{aligned}
$$

同じflavor-universal variableで書ける

CMFVだと、B->K*llとε'/εが同じ flavor-universal variable で記述できるため、関係付く

CMFVタイプのNPでこれらのアノマリーを同時に説明できるか？

$B \to K^*\mu^+\mu^-$

&

ε'/ε

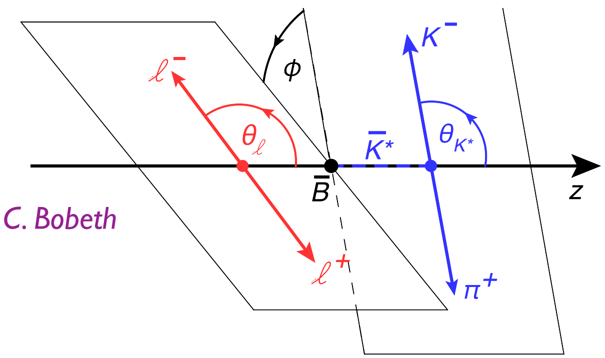
$B \rightarrow K^*\mu^+\mu^-$

&

ε'/ε

Angular observables $\bar{B}^0 \to \bar{K}^{*0}(\to K^-\pi^+)\mu^+\mu^-$

$$\frac{d^{(4)}\Gamma}{dq^2 d(\cos\theta_\ell) d(\cos\theta_K) d\phi} = \frac{9}{32\pi}\Big(I_1^s \sin^2\theta_K + I_1^c \cos^2\theta_K + (I_2^s \sin^2\theta_K + I_2^c \cos^2\theta_K)\cos 2\theta_\ell$$
$$+ I_3 \sin^2\theta_K \sin^2\theta_\ell \cos 2\phi + I_4 \sin 2\theta_K \sin 2\theta_\ell \cos\phi$$
$$+ I_5 \sin 2\theta_K \sin\theta_\ell \cos\phi + (I_6^s \sin^2\theta_K + I_6^c \cos^2\theta_K)\cos\theta_\ell$$
$$+ I_7 \sin 2\theta_K \sin\theta_\ell \sin\phi + I_8 \sin 2\theta_K \sin 2\theta_\ell \sin\phi$$
$$+ I_9 \sin^2\theta_K \sin^2\theta_\ell \sin 2\phi \Big) .$$



C. Bobeth

$$\Sigma_i \equiv \frac{I_i + \bar{I}_i}{2}$$

$I(q^2)$: angular observables

$\bar{I}(q^2)$: all weak phase conjugated

"optimized" observables : form factors drop out in the heavy quark limit

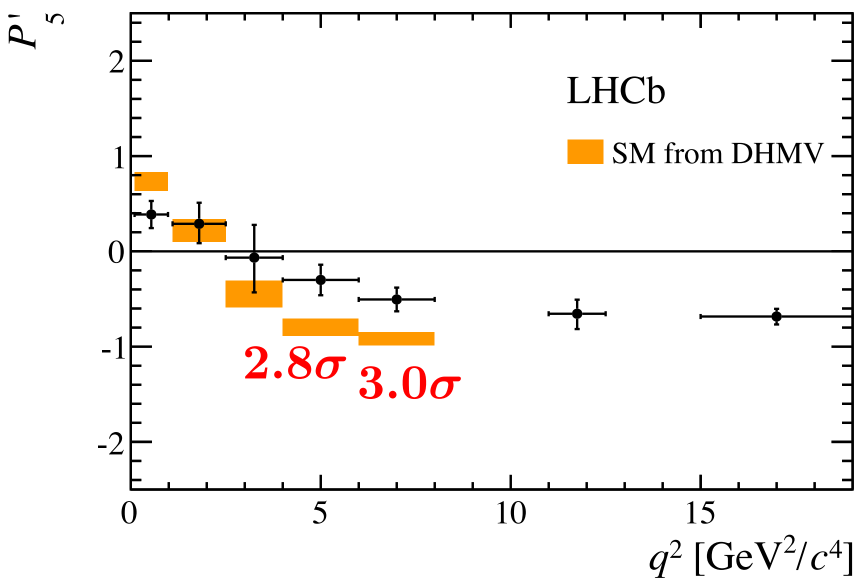
$$\{P_1, P_2, P_3, P_4', P_5', P_6', P_8'\}$$

$$P_1 = \frac{\Sigma_3}{2\Sigma_{2s}}, \quad P_2 = \frac{\Sigma_{6s}}{8\Sigma_{2s}}, \quad P_3 = -\frac{\Sigma_9}{4\Sigma_{2s}}, \quad P_4' = \frac{\Sigma_4}{\sqrt{-\Sigma_{2s}\Sigma_{2c}}},$$
$$P_5' = \frac{\Sigma_5}{2\sqrt{-\Sigma_{2s}\Sigma_{2c}}}, \quad P_6' = -\frac{\Sigma_7}{2\sqrt{-\Sigma_{2s}\Sigma_{2c}}}, \quad P_8' = -\frac{\Sigma_8}{\sqrt{-\Sigma_{2s}\Sigma_{2c}}}.$$

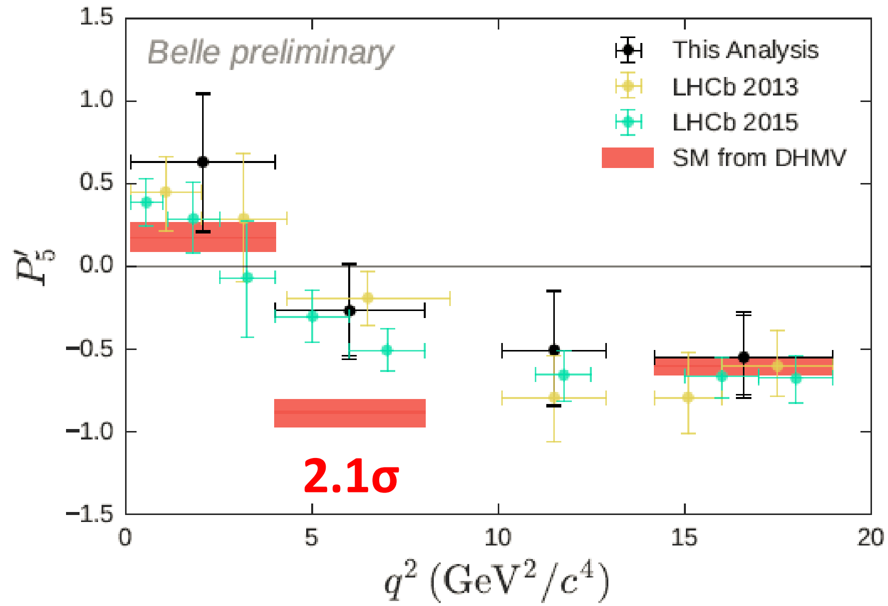
Kruger, Matias (05); Egede et al. (08); Descotes-Genon et al. (13)

P'$_5$ anomaly in LHCb & Belle

LHCb(3 fb^-1) 1512.04442



Belle 1604.04042



DHMV : [S.Descotes-Genon, L.Hofer, J.Matias and J.Virto 1510.04239]

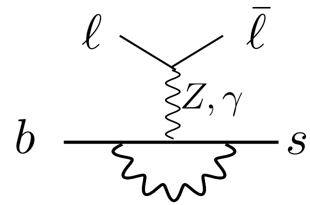
- B → K*μ+μ- is golden channel in LHCb
  LHCb : ~2500 events, Belle : ~200 events
- Belle confirmed LHCb result
  LHCb : 2.8σ and 3.0σ, Belle: 2.1 σ

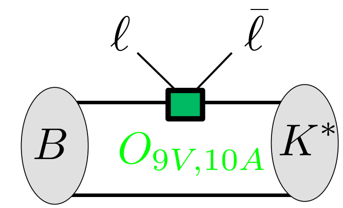
$B \to K^*\mu^+\mu^-$ & flavor-universal variables

Semi-leptonic operators

$$O_{9V} = \frac{\alpha}{4\pi}(\bar{s}_L\gamma_\mu d_L)(\bar{l}\gamma^\mu l)$$

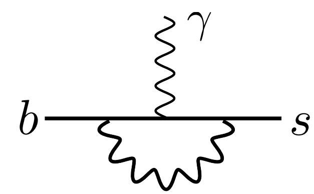
$$O_{10A} = \frac{\alpha}{4\pi}(\bar{s}_L\gamma_\mu d_L)(\bar{l}\gamma^\mu\gamma_5 l)$$

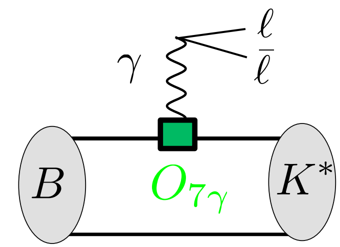




Dipole operator

$$O_{7\gamma} = \frac{e}{16\pi^2} m_b \bar{s}_L \sigma_{\mu\nu} F^{\mu\nu} b_R$$





$$\delta C_{9V}(\mu_b) \approx 4.32\ \delta Y - 4.0\ \delta Z - 0.03\ \delta E$$

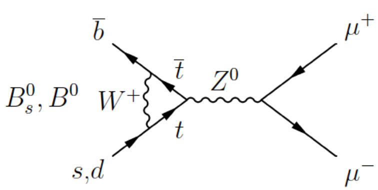
$$\delta C_{10A}(\mu_b) \approx -4.32\ \delta Y$$

$$\delta C_{7\gamma}(\mu_b) \approx -0.323\ \delta D' - 0.048\ \delta E'$$

Other observables

	$B \to K^* \mu^+ \mu^-$	$B_{d,s} \to \mu^+ \mu^-$	$b \to s\gamma$
$O_{9V} = \frac{\alpha}{4\pi}(\bar{s}_L \gamma_\mu d_L)(\bar{l}\gamma^\mu l)$	✔		
$O_{10A} = \frac{\alpha}{4\pi}(\bar{s}_L \gamma_\mu d_L)(\bar{l}\gamma^\mu \gamma_5 l)$	✔	✔	
$O_{7\gamma} = \frac{e}{16\pi^2} m_b \bar{s}_L \sigma_{\mu\nu} F^{\mu\nu} b_R$	✔		✔

leptonic decays



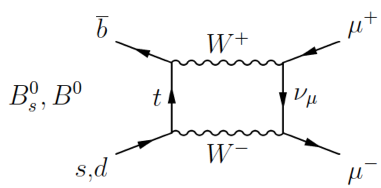
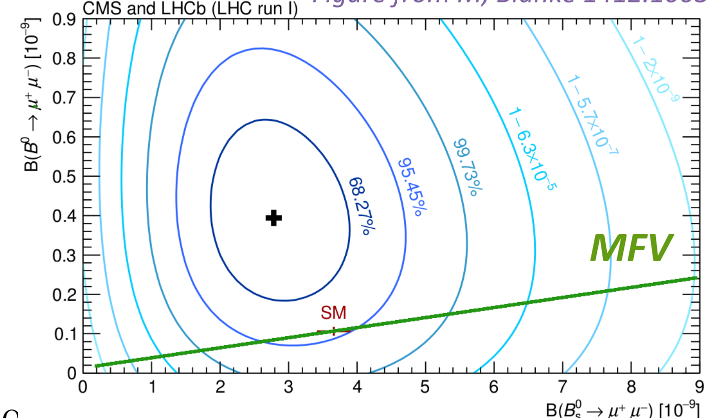


Figure from M, Blanke 1412.1003



	SM	exp
$\mathrm{BR}(B^0 \to \mu^+\mu^-)$	$(1.06 \pm 0.09) \times 10^{-10}$	$(3.9^{+1.6}_{-1.4}) \times 10$
$\mathrm{BR}(B_s \to \mu^+\mu^-)$	$(3.65 \pm 0.23) \times 10^{-9}$	$(2.8^{+0.7}_{-0.6}) \times 10^{-9}$

MFV:

$$R = \frac{B(B_d \to \mu\mu)}{B(B_s \to \mu\mu)} \propto \frac{|V_{td}|^2}{|V_{ts}|^2} \frac{f_{B_d}^2}{f_{B_s}^2}$$

radiative decay

	SM	exp
$\mathrm{BR}(b \to s\gamma)$	$(3.36 \pm 0.23) \times 10^{-4}$	$(3.43 \pm 0.21 \pm 0.07) \times 10^{-4}$

Fit of δC_{9V}-δC_{10A}-$\delta C_{7\gamma}$ from $B \to K^* \mu^+ \mu^-$

- Data
  - angular observables $\{P_1, P_2, P_3, P_4', P_5', P_6', P_8'\}$

    at q^2 bins : [0.1,0.98] [1.1,2.5] [2.5,4] [4,6] [6,8] GeV^2
  - leptonic decays $\mathrm{BR}(B_s \to \mu^+ \mu^-)$ $\mathrm{BR}(B_d \to \mu^+ \mu^-)$
  - radiative decay $\mathrm{BR}(b \to s\gamma)$
- chi2

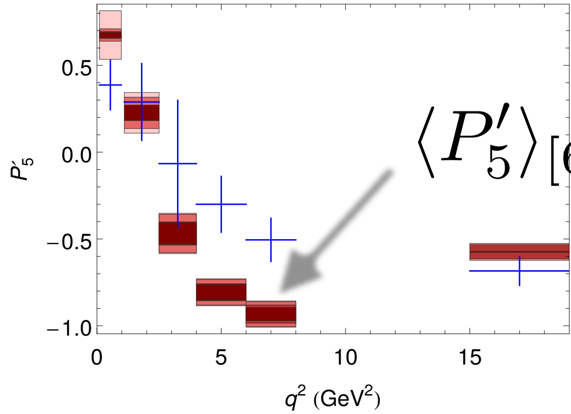
$$\chi^2 = \sum_i \frac{(O_i^{exp} - O_i^{th})^2}{(\sigma_i^{exp})^2 + (\sigma_i^{th})^2}$$

- Correlations

Not include exp. and theory correlations, but they do not alter our fit results

Theoretical errors in $B \to K^*\mu^+\mu^-$

[S.Descotes-Genon, L.Hofer, J.Matias and J.Virto 1510.04239]



$$\langle P_5' \rangle_{[6,8]} \quad -0.934^{+0.024}_{-0.047}{}^{+0.021}_{-0.022}{}^{+0.039}_{-0.038}{}^{+0.058}_{-0.078}$$

- **parametric**

  all input parameters except form factors
  (e.g. masses, decay constants, renormalization scale)

- **Form factor** [Bharucha et al. 1503.05534]

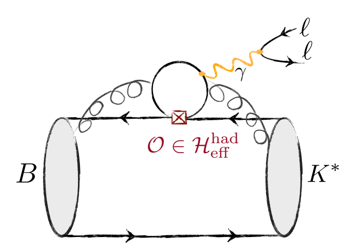
  depend on 7 form factors, calculated by ight-cone sum rules (LCSR)

- **power correction**

  O(ΛQCD/mb) correction

- **Non-local contribution**

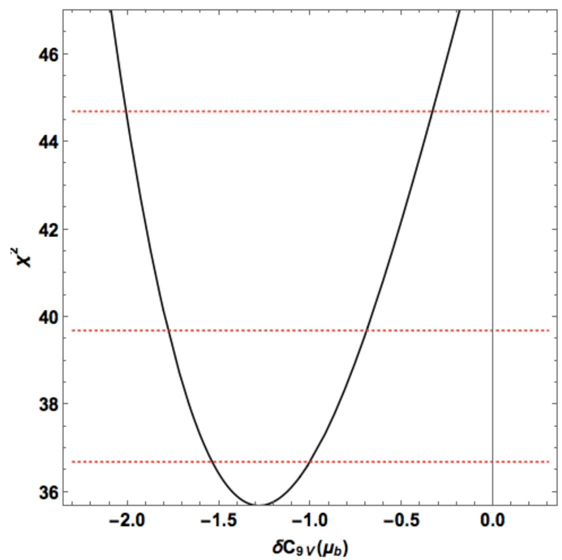
  charm loop contribution (LCSR)
  [Khodjamirian et al. 1006.4945]



1dim. fits $\{C_i\}$

preliminary

best fit value : δC_{9V} = -1.3



	ndf	χ^2	p value
$\delta C_{9V}(\mu_b)$	34(ang.)	35.7	0.38
$\delta C_{10A}(\mu_b)$	34(ang.)	44.3	0.11
	36(ang.+leptonic)	54.2	0.03
$\delta C_{7\gamma}(\mu_b)$	34(ang.)	38.8	0.26
	35(ang.+radiative)	47.7	0.074
SM	35(ang.)	50.6	0.043

$$C_{9V}^{SM}(\mu_b) = 4.114$$
$$C_{10A}^{SM}(\mu_b) = -4.193$$
$$C_{7\gamma}^{eff,SM}(\mu_b) = -0.2957$$

where $\mu_b = 4.2\ \mathrm{GeV}$

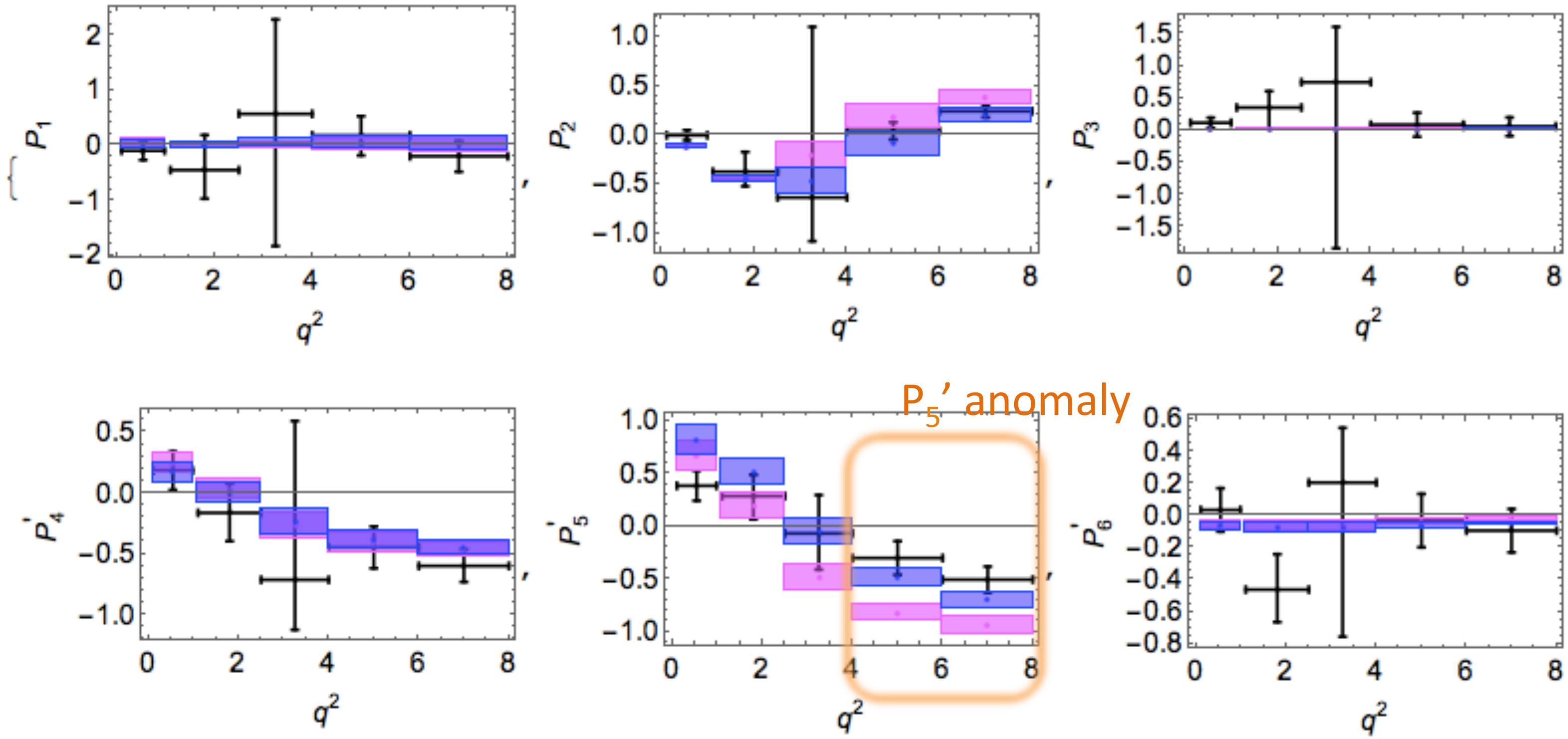
★δC_{9V}が最もよい fit。δC_{9V} ～ -1 is favored

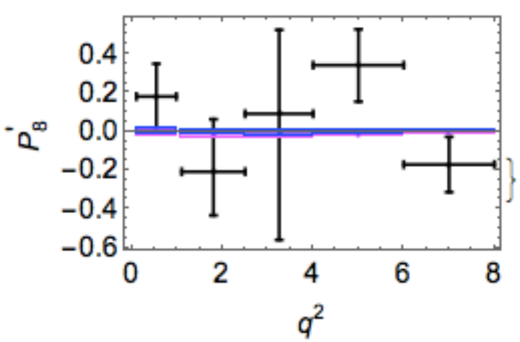
★$\delta C_{7\gamma}$も ang.のみだとよいfitを与えるが、b->sγを考慮すると制限がつき、fitが悪くなる

δC_{9V}, $\delta C_{7\gamma}$, δC_{10A} の順でよいfit

1dim. fits $\{C_i\}$

best fit value : δC_{9V} = -1.3



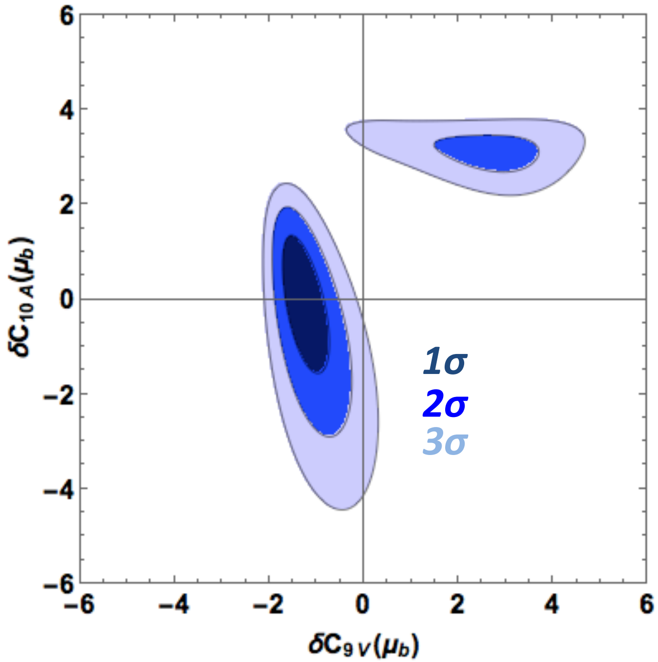


★δC_{9V}=-1.3をいれると、P5'のずれを説明でき、
P5'以外もエラーの範囲でconsistent

preliminary

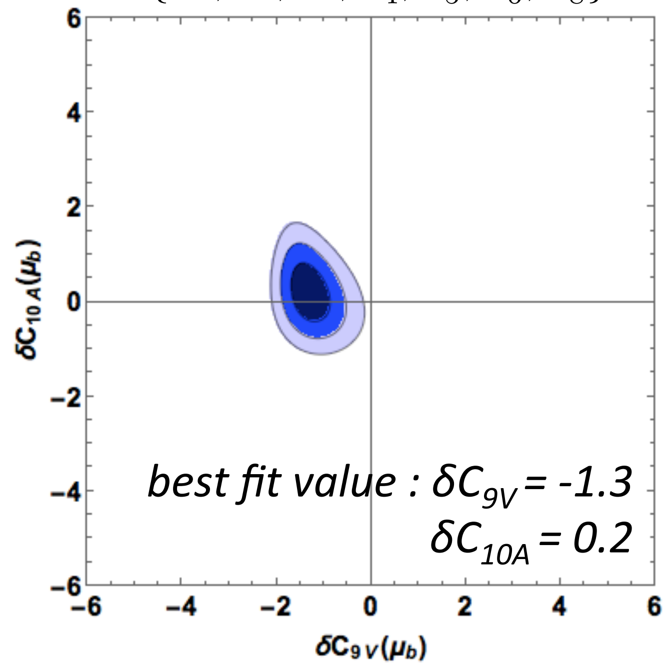
2dim. fits $\{C_i, C_j\}$

$\{P_1, P_2, P_3, P'_4, P'_5, P'_6, P'_8\}$



$\mathrm{BR}(B_s \to \mu^+\mu^-)$ $\mathrm{BR}(B_d \to \mu^+\mu^-)$

$\{P_1, P_2, P_3, P'_4, P'_5, P'_6, P'_8\}$



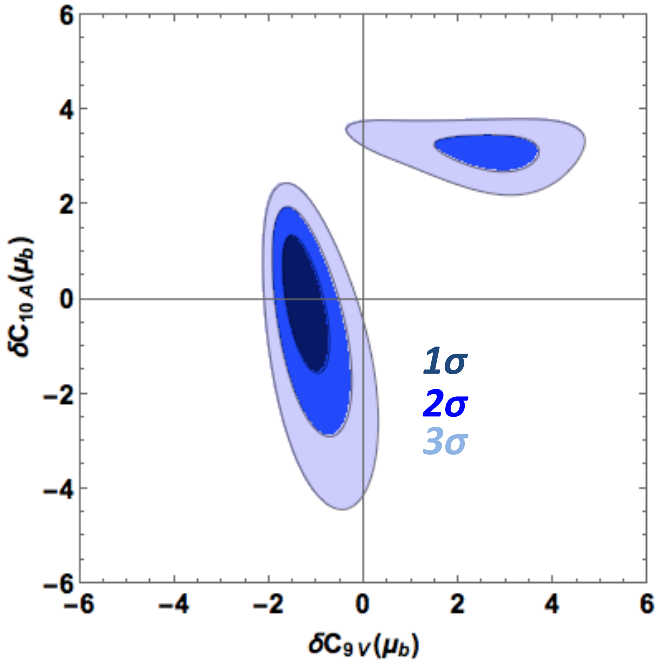
	ndf	χ^2	p value
$\{\delta C_{9V}, \delta C_{10A}\}$	33(ang.)	35.7	0.34
	35(ang.+leptonic)	40.2	0.25
$\{\delta C_{9V}, \delta C_{7\gamma}\}$	33(ang.)	35.7	0.34
	34(ang.+radiative)	35.7	0.39
$\{\delta C_{10A}, \delta C_{7\gamma}\}$	33(ang.)	36.2	0.32
	36(ang.+lept.+rad.)	52.0	0.04

★ *δC_{9V} -δC_{10A} plane :*
negative δC_{9V} & $\delta C_{10A} \sim 0$ are favored

2dim. fits $\{C_i, C_j\}$

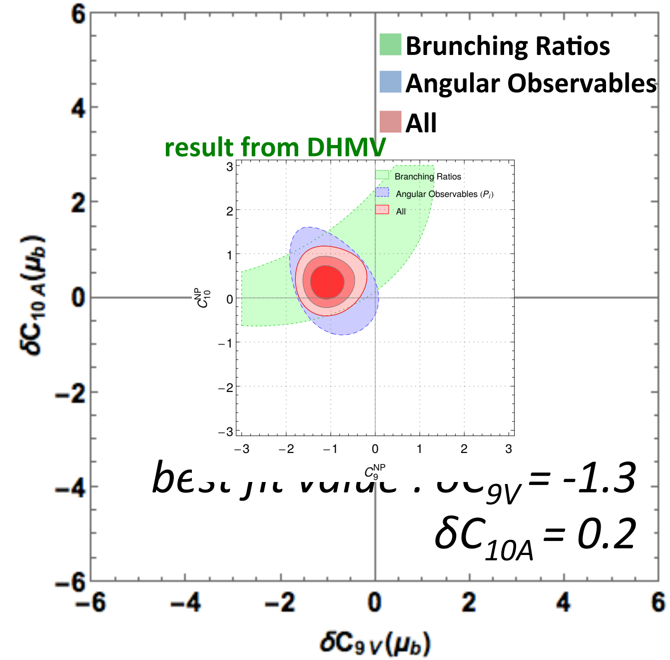
preliminary

$\{P_1, P_2, P_3, P_4', P_5', P_6', P_8'\}$



$\text{BR}(B_s \to \mu^+\mu^-)$ $\text{BR}(B_d \to \mu^+\mu^-)$

$\{P_1, P_2, P_3, P_4', P_5', P_6', P_8'\}$



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$\{\delta C_{9V}, \delta C_{7\gamma}\}$	33(ang.)	35.7	0.34
	34(ang.+radiative)	35.7	0.39
$\{\delta C_{10A}, \delta C_{7\gamma}\}$	33(ang.)	36.2	0.32
	36(ang.+lept.+rad.)	52.0	0.04

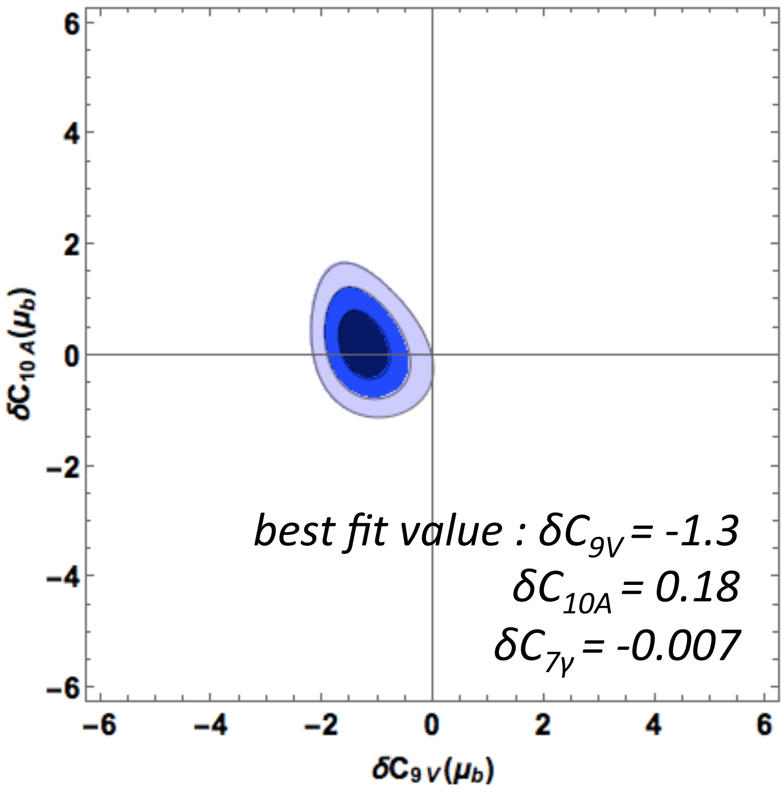
★ *δC_{9V} -δC_{10A} plane :*
negative δC_{9V} & $\delta C_{10A} \sim 0$ are favored

★ *consistent* with the *global fit result by DHMV*

[S.Descotes-Genon, L.Hofer, J.Matias and J.Virto 1510.04239]

3dim. fit $\{C_{9V}, C_{10A}, C_{7\gamma}\}$

preliminary



★ *negative* δC_{9V} & $\delta C_{10A} \sim 0$ are favored

	ndf	χ^2	p value
$\{\delta C_{9V}, \delta C_{10A}, \delta C_{7\gamma}\}$	35 (ang.+lept.+rad.)	40.3	0.25

$B \rightarrow K^{*}\mu^{+}\mu^{-}$

&

ε'/ε

Direct CPV (K->ππ decays) : ε'/ε

→talk by Kitahara

$$\frac{\epsilon'_K}{\epsilon_K} = -\frac{\omega}{\sqrt{2}\,|\epsilon_K|_{\exp}\,\mathrm{Re}A_0}\left(\mathrm{Im}A_0 - \frac{1}{\omega}\,\mathrm{Im}A_2\right)$$

QCD penguin (ImA_0) EW penguin (ImA_2)

$$A_{0,2} = A(K_L \to (\pi\pi)_{I=0,2})$$

- In SM, there is accidental cancellation between ImA0 and ImA2 due to the enhancement factor 1/ω

ΔI=1/2 rule $\quad \frac{\mathrm{Re}A_0}{\mathrm{Re}A_2} \equiv \frac{1}{\omega} = 22.46$

SM prediction for ε’/ε

→talk by Kitahara

Recently, RBC-UKQCD collaboration have reported the first lattice result of ε’/ε

B6, B8 : Non-perturbative parameters

$$B_6^{(1/2)}(m_c) = 0.57 \pm 0.15 \qquad B_8^{(3/2)}(m_c) = 0.76 \pm 0.05$$

QCD penguin $Q_6 = (\bar{s}_\alpha d_\beta)_{V-A} \sum_{q=u,d,s,c,b} (\bar{q}_\beta q_\alpha)_{V+A}$

EW penguin $Q_8 = \frac{3}{2} (\bar{s}_\alpha d_\beta)_{V-A} \sum_{q=u,d,s,c,b} e_q (\bar{q}_\beta q_\alpha)_{V+A}$

★SM

[RBC-UKQCD’15]

$$(\epsilon'/\epsilon)_{\rm SM} = (1.38 \pm 6.90) \times 10^{-4}$$

～2.1σ difference

[Buras et.al‘15]

$$(\epsilon'/\epsilon)_{\rm SM} = (1.9 \pm 4.5) \times 10^{-4}$$

～2.9σ difference

[Kitahara et.al ‘16]

$$(\epsilon'/\epsilon)_{\rm SM} = (0.96 \pm 4.96) \times 10^{-4}$$

～2.9σ difference

10*10^-4 のオーダーのNPが必要

★Exp

[NA48, KTeV]

$$(\varepsilon'/\varepsilon)_{\rm exp} = (16.6 \pm 2.3) \times 10^{-4}$$

ε’/ε & flavor-universal variables

$$\delta\frac{\epsilon'}{\epsilon} \sim (\delta X + 0.8\ \delta Y - 16\ \delta Z - 0.4\ \delta E) \times 10^{-4}$$

$X_{SM} = 1.48$
$Y_{SM} = 0.94$
$Z_{SM} = 0.65$
$E_{SM} = 0.27$

- 実験値を説明できるくらい ε’/ε を大きくするには、negative δZ が有効。
  δX , δY & δE にはinsensitive

- δXは、BR(K^+ -> π^+νν)から決めることができる

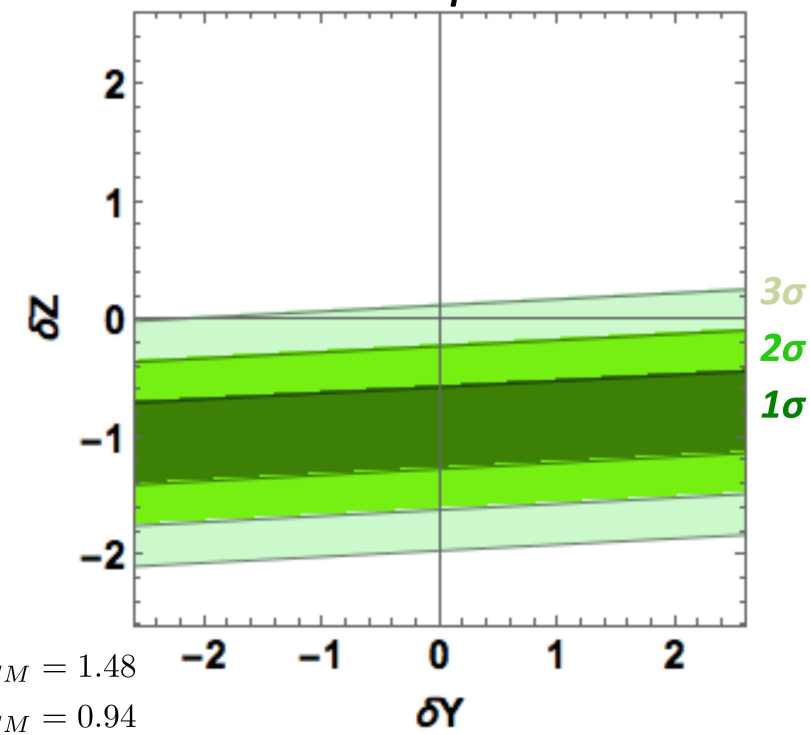
$$B(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+ (1 + \Delta_{\rm EM}) \left[\left(\frac{{\rm Im}\lambda_t}{\lambda^5} X(v) \right)^2 + \left(\frac{{\rm Re}\lambda_c}{\lambda} P_c(X) + \frac{{\rm Re}\lambda_t}{\lambda^5} X(v) \right)^2 \right]$$

$$BR(K^+ \to \pi^+ \nu\bar{\nu})_{\rm exp} = (1.73^{+1.15}_{-1.05}) \times 10^{-10} \longrightarrow \delta X = 0.92$$

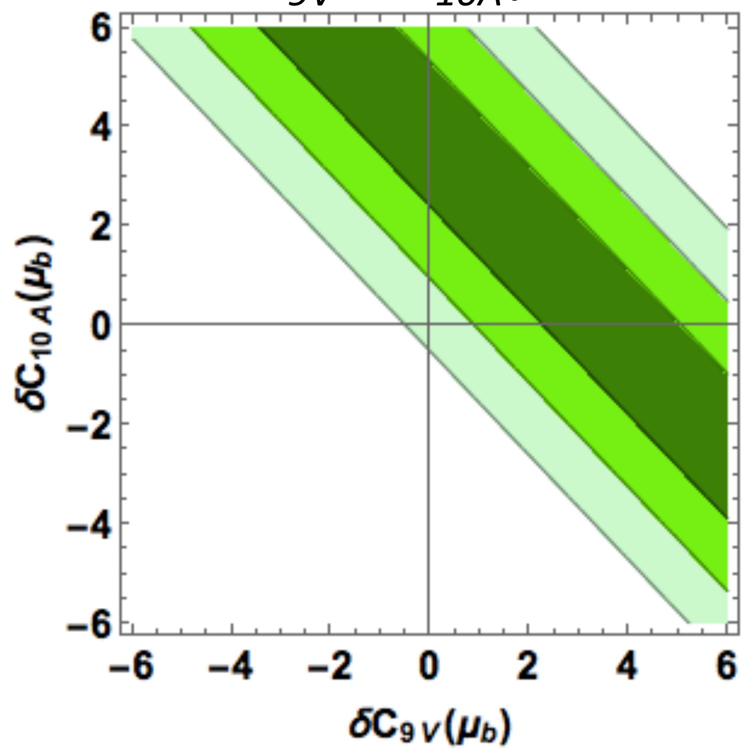
Constraint on δY-δZ from ε'/ε

preliminary

δY-δZ plane



δC_{9V} -δC_{10A} plane



$X_{SM} = 1.48$
$Y_{SM} = 0.94$
$Z_{SM} = 0.65$
$E_{SM} = 0.27$

$$\delta C_{9V}(\mu_b) \approx 4.32\ \delta Y - 4.0\ \delta Z - 0.03\ \delta E$$

$$\delta C_{10A}(\mu_b) \approx -4.32\ \delta Y$$

★*δY-δZ plane :* negative δZ が必要、δY (δE) にはinsensitive

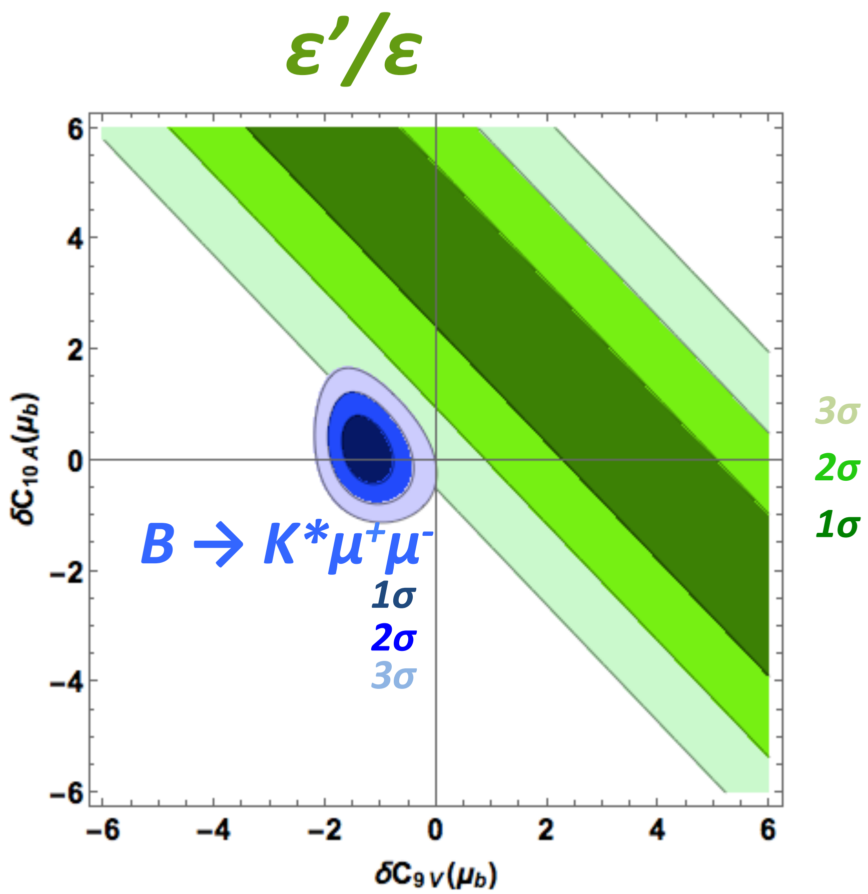
$B \to K^*\mu^+\mu^-$

&

ε'/ε

preliminary

Comparison between $B \to K^*\mu^+\mu^-$ & ε'/ε



★K中間子系、B中間子系、それぞれが示唆する領域間にテンションがある

★CMFVで両方のアノマリーを説明するのは難しい

★beyond CMFVの示唆

Summary

- Ｋ中間子、Ｂ中間子の物理量に、SMから~3σのずれ
  - ε'/ε
  - P5' (B->K*μμ)

- Ｋ中間子、Ｂ中間子の物理量が同じfunctionで記述されるConstrained Minimal Flavor Violationを仮定し、これらのアノマリーを同時に説明できるか検証した

  Ｋ中間子系、Ｂ中間子系、それぞれが示唆する領域にテンションがあることを示した

- beyond CMFVの示唆

  他の例）flavor-universal variable S (ΔF=2) において 2.3 σ のテンション *[M. Blanke, A.J. Buras, 1602.04020]*

$$S(x_t) \;:\; (\bar{d}_i d_j)_{V-A}(\bar{d}_i d_j)_{V-A} \qquad \Delta M_{s,d}, \quad \epsilon_K$$

- 実験&理論エラーの improve が大切
  - 実験：LHCb & Belle2 B->K*ll statistical error
  - 理論：
    - B->K*ll (non-local charm loop contribution)
    - ε'/ε (hadronic matrix element)