B中間子物理の理論

田中 実（阪大）

関西中部 B中間子の物理研究会

奈良女子大, 2009.11.05

INTRODUCTION

標準模型

Gauge sector

gauge symmetry

$\alpha\,,\ \sin\theta_W\,,\ \alpha_s$

LEP, ...

Spontaneous
Symmetry
Breaking

Yukawa sector

$m_u\,,\ m_d\,,\cdots$

$V_{\rm CKM}$ quark mixing

CP violation

B factories

quark, lepton
masses

Higgs sector

$G_F\,,\ m_H$

LHC

Neutrino sector

$m_\nu\,,\ V_{\rm PNMS}$

Why Yukawa sector?

Lots of parameters: 9 masses, 3 angles, and a phase.

Determined with some precision.

Hierarchy, but .....

No principle at present.

History

CPV in K decays ——KM——→ 3rd gen.

Future

B (Flavor) physics - - - - - → New physics

SUSY, Extra Dim., ...

目次

CKM and B PHYSICS

荷電カレント相互作用

ゲージ相互作用の固有状態 $d'_L \,, u'_L$

$$\mathcal{L}_{CC} = \frac{g_2}{\sqrt{2}} W^+_\mu \, \bar{u}'_{Li} \gamma^\mu d'_{Li} + \frac{g_2}{\sqrt{2}} W^-_\mu \, \bar{d}'_{Li} \gamma^\mu u'_{Li}$$

質量の固有状態 $d_L \,, u_L$

Yukawa sector

$$d'_L = U_d \, d_L \,, \;\; u'_L = U_u \, u_L$$

$U_{d,u}$ ユニタリー行列

$$\mathcal{L}_{CC} = \frac{g_2}{\sqrt{2}} W^+_\mu \, \bar{u}_L \gamma^\mu V d_L + \frac{g_2}{\sqrt{2}} W^-_\mu \, \bar{d}_L \gamma^\mu V^\dagger u_L$$

$V \equiv U_u^\dagger U_d$ Cabibbo-Kobayashi-Maskawa 行列

CKM行列の構造

$$V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$= \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{13}} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta_{13}} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta_{13}} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta_{13}} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta_{13}} & c_{23}c_{13} \end{pmatrix}$$

$$c_{ij} = \cos\theta_{ij}, \; s_{ij} = \sin\theta_{ij}$$

PDG parameterization

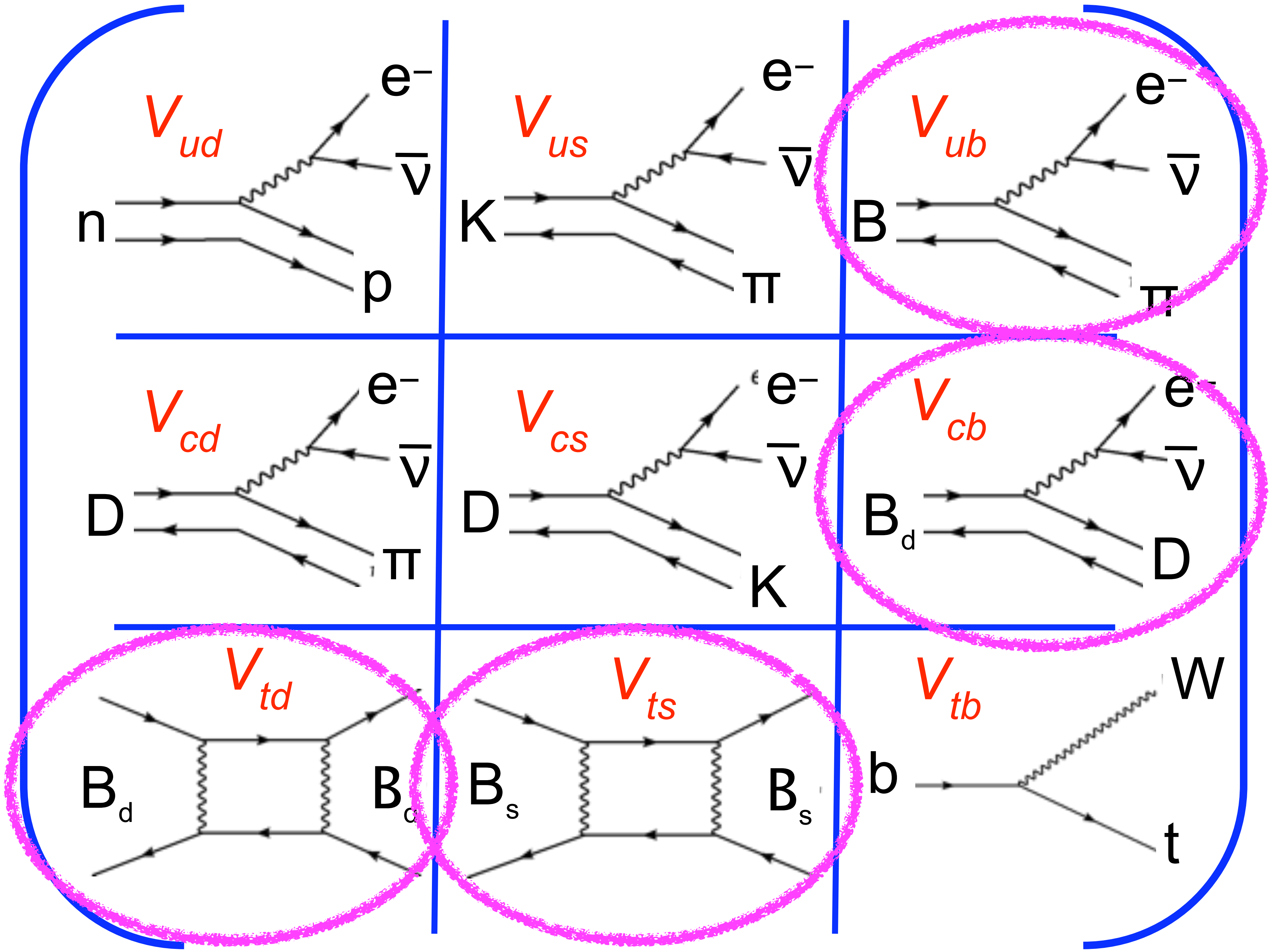
Wolfenstein parametrization

実験: $1 \gg |V_{us}| \gg |V_{cb}| \gg |V_{ub}|$

$$s_{12} = \lambda \simeq 0.22,\ s_{23} = \lambda^2 A,\ s_{13} e^{-i\delta_{13}} = \lambda^3 A(\rho - i\eta)$$

$$\begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} & \lambda^2 A \\ \lambda^3 A(1 - \rho - i\eta) & -\lambda^2 A & 1 \end{pmatrix} + O(\lambda^4)$$

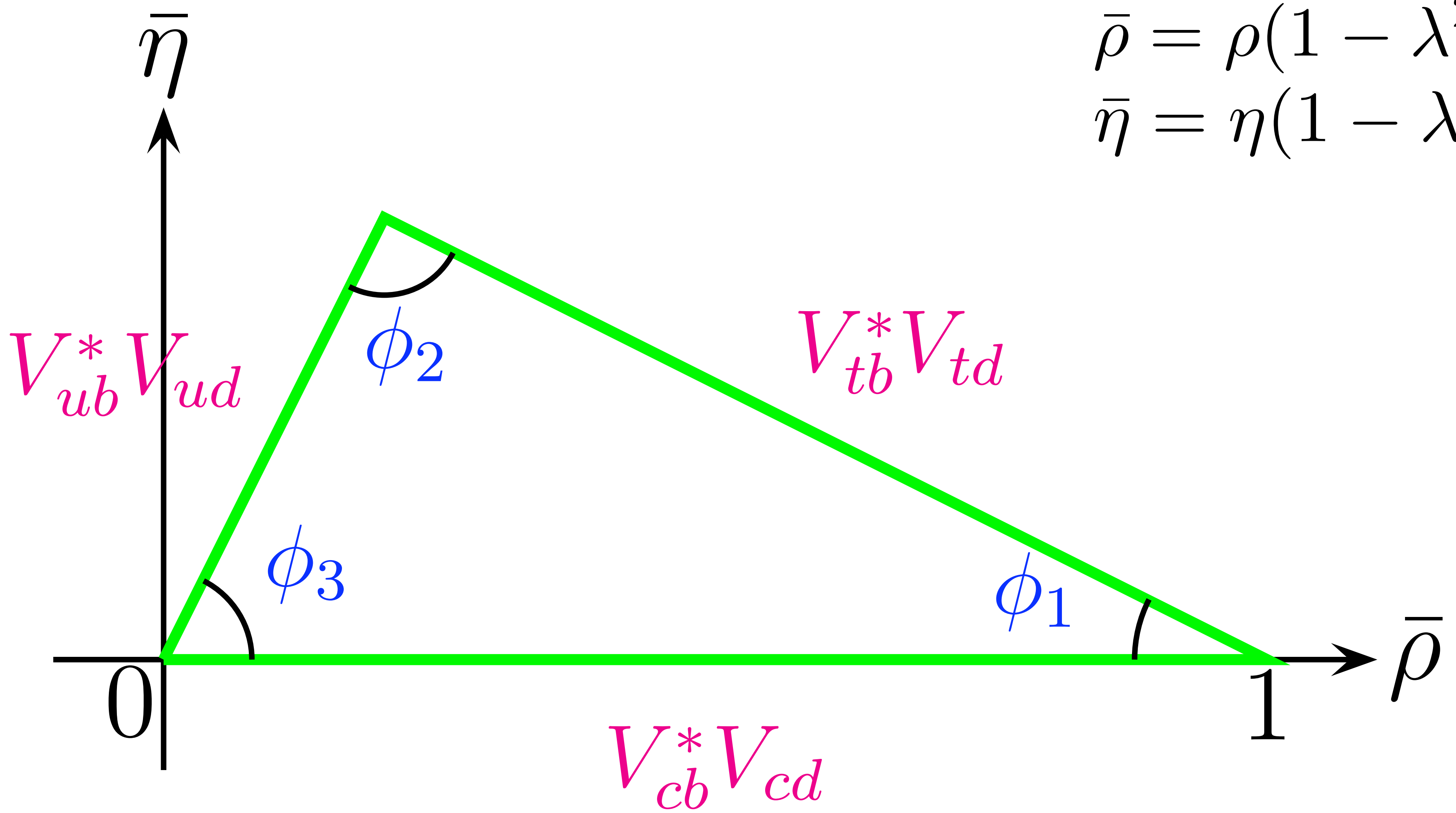
CKM Matrix Element Magnitudes

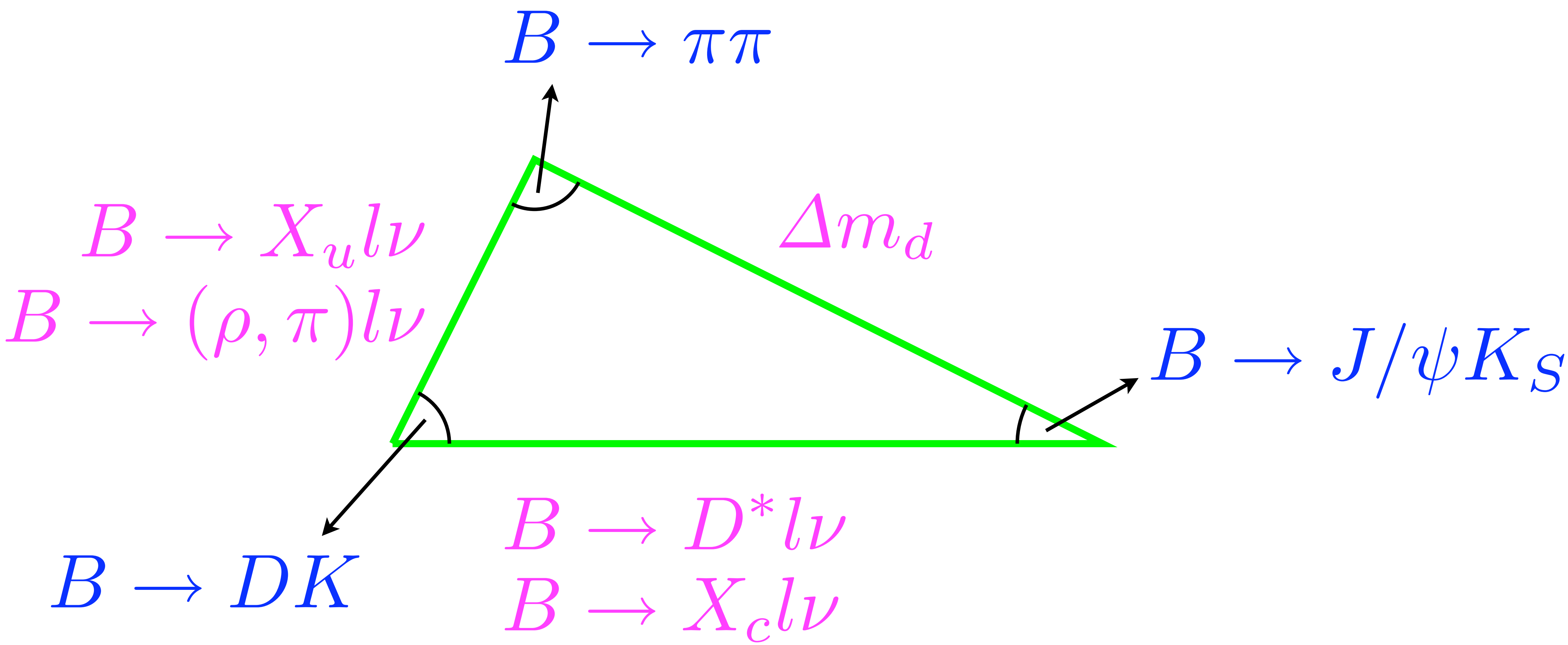


B中間子とUnitarity Triangle

$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$$

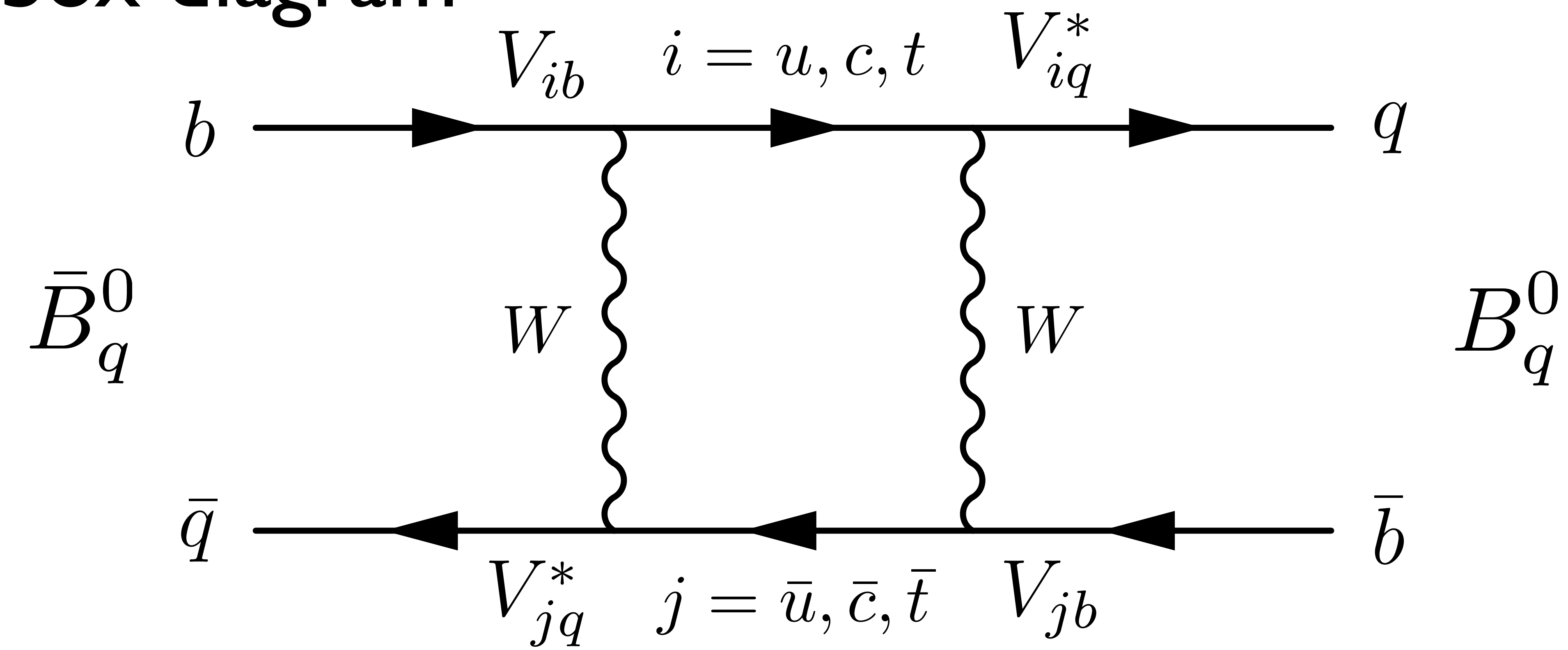
$$\bar{\rho} = \rho(1 - \lambda^2/2 + \cdots)$$
$$\bar{\eta} = \eta(1 - \lambda^2/2 + \cdots)$$




$B \to \pi\pi$
$B \to X_u l\nu$
$B \to (\rho, \pi) l\nu$
Δm_d
$B \to J/\psi K_S$
$B \to DK$
$B \to D^* l\nu$
$B \to X_c l\nu$

B^0–$\bar{B}^0$ 混合

box diagram



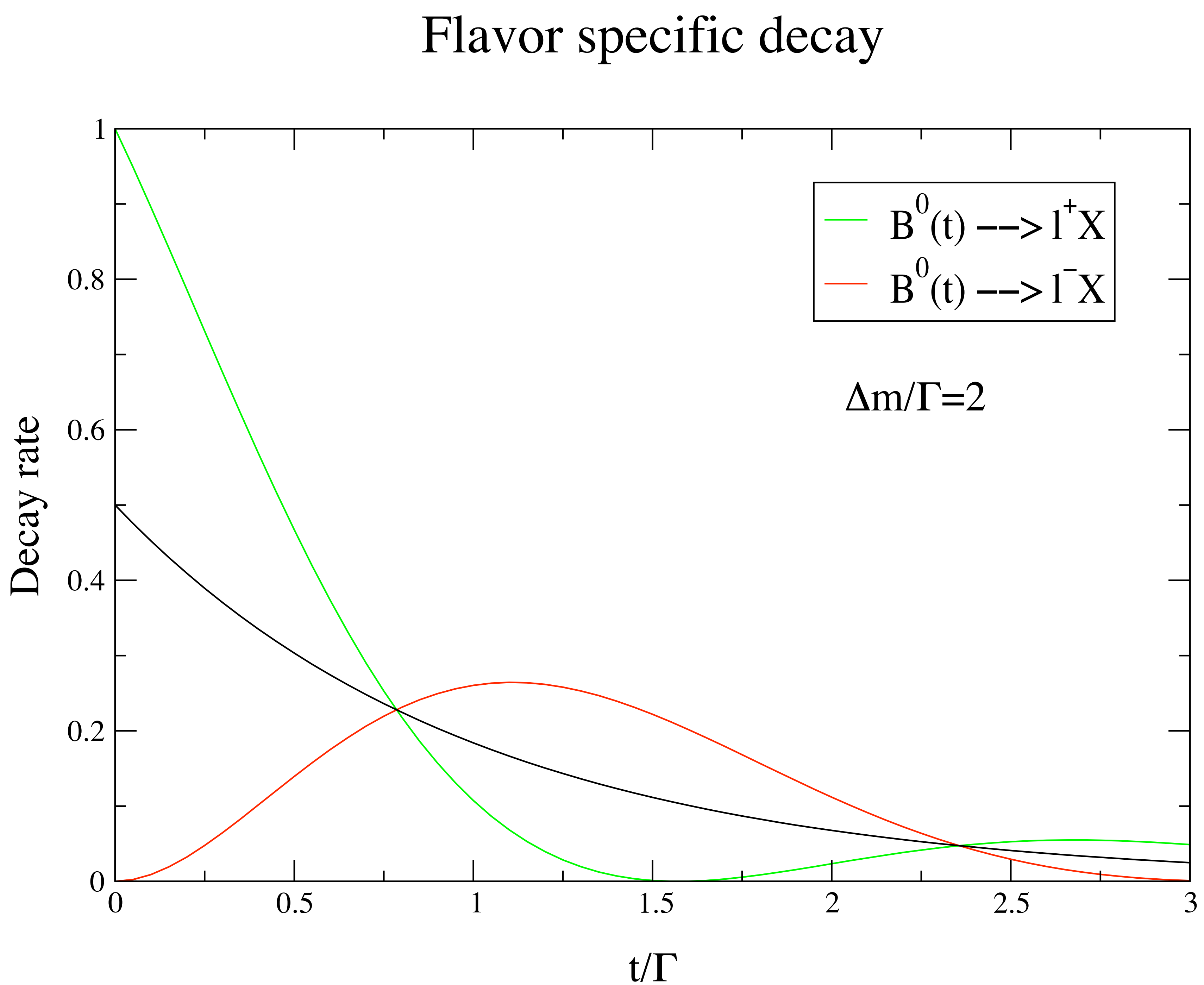
topの寄与が支配的

$$M_{12}(B_d) \propto (V_{tb} V_{td}^*)^2$$

$$M_{12}(B_s) \propto (V_{tb} V_{ts}^*)^2$$

質量差

$$\Delta m_q \simeq 2|M_{12}(B_q)| \quad (q = d, s)$$



実験値: $\Delta m_d = 0.507 \pm 0.005\,\mathrm{ps}^{-1}$

$$\Delta m_s = 17.77 \pm 0.10 \pm 0.07\,\mathrm{ps}^{-1}$$

$$\frac{\Delta m_d}{\Delta m_s} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \xi^2$$

ξ : SU(3)の破れ

$$\xi = 1.23 \pm 0.02 \pm 0.03$$

lattice QCD

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.209 \pm 0.001 \pm 0.006$$

CP非対称性

$$\Gamma(B^0(t)\to f)\propto 1+|\lambda_f|^2 \;+\; (1-|\lambda_f|^2)\cos\Delta m\, t \;+\; 2\,\mathrm{Im}\lambda_f\ \sin\Delta m\, t$$

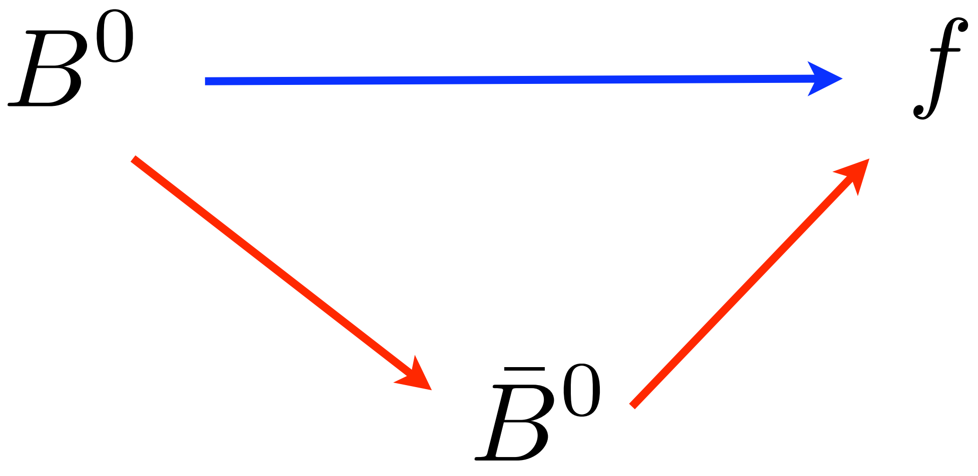
$$\Gamma(\bar{B}^0(t)\to f)\propto 1+|\lambda_f|^2 \;-\; (1-|\lambda_f|^2)\cos\Delta m\, t \;-\; 2\,\mathrm{Im}\lambda_f\ \sin\Delta m\, t$$

$$\lambda_f = \frac{q}{p}\frac{\langle f|\bar{B}^0\rangle}{\langle f|B^0\rangle} \simeq \frac{M_{12}^*}{|M_{12}|}\frac{\langle f|\bar{B}^0\rangle}{\langle f|B^0\rangle}$$

$$\begin{aligned}\mathcal{A}_f &= \frac{\Gamma(\bar{B}^0(t)\to f)-\Gamma(B^0(t)\to f)}{\Gamma(\bar{B}^0(t)\to f)+\Gamma(B^0(t)\to f)}\\ &= S_f\sin\Delta m\, t - C_f\cos\Delta m\, t\end{aligned}$$

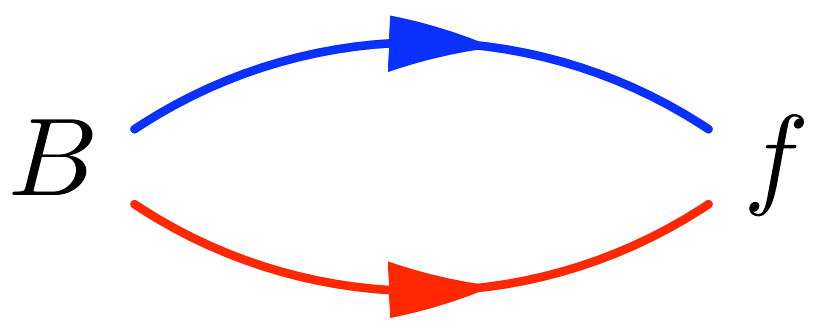
$$S_f = -\frac{2\,\mathrm{Im}\lambda_f}{1+|\lambda_f|^2}$$

Mixing-induced CPV



$$C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}$$

Direct CPV



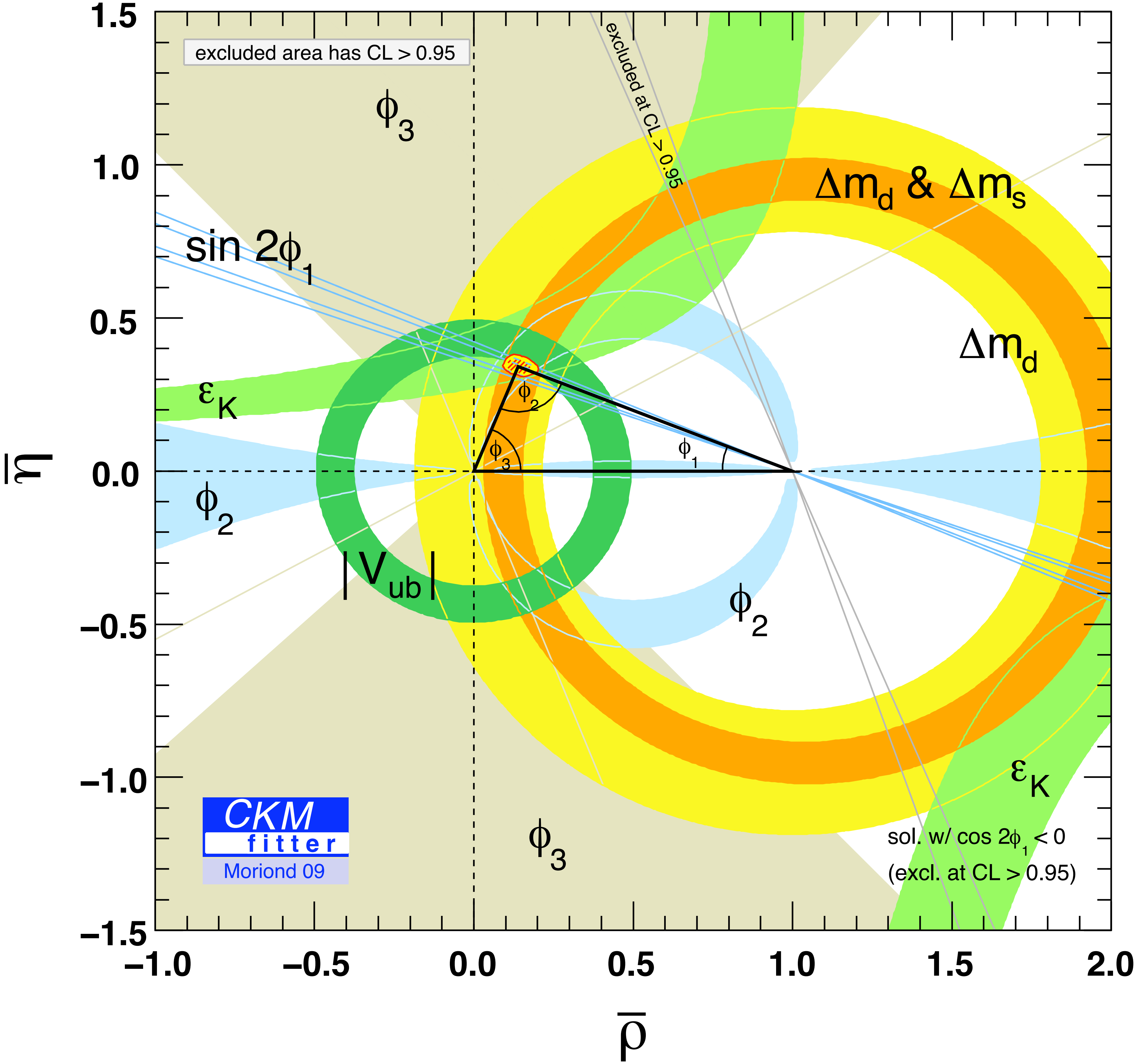
$$f = J/\psi\, K_S$$ (CP odd)

$$\lambda_{J/\psi K_S} = \frac{M_{12}^*}{|M_{12}|} = \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} = e^{-2i\phi_1}$$

$$S_{J/\psi K_S} = \sin 2\phi_1 \qquad\qquad C_{J/\psi K_S} = 0$$

実験値

$$\sin 2\phi_1 = 0.681 \pm 0.025$$



Moriond 2009

Good in ~10% accuracy

NEW PHYSICS

Flavor Structure of the Standard Model

Flavor symmetry of the SM gauge sector
(i.e. turning off the Yukawa couplings)

$$l_{Li},\ e_{Ri},\ q_{Li},\ u_{Ri},\ d_{Ri} \quad (i=1,2,3)$$

$$\begin{aligned}\mathcal{G}_F &= U(3)^5 \\ &= SU(3)^5 \times U(1)_B \times U(1)_L \times U(1)_Y \times U(1)_{\mathrm{PQ}} \times U(1)_{e_R}\end{aligned}$$

Turning on the Yukawa couplings,

$$\mathcal{G}_F \xrightarrow[\mathcal{L}_Y]{} U(1)_B \times U(1)_L \times U(1)_Y$$

What about new physics at the TeV scale?

Minimal Flavor Violation

$\mathcal{G}_F$ and CP are broken solely by Yukawa as in the SM.

All flavor and CP violations are controlled by Y.

Ex. MSSM with real and universal soft breakings (minimal supergravity model)

Rather small deviations from the SM.

→ More precise measurements at super B factory.

Non-Minimal Flavor Violation

New sources of flavor and CP violation

Ex. SU(5) SUSY GUT with ν_R

Neutrino Yukawa breaks $\mathcal{G}_F$.

U(2) flavor symmetry model

U(2) breakings in soft SUSY breakings

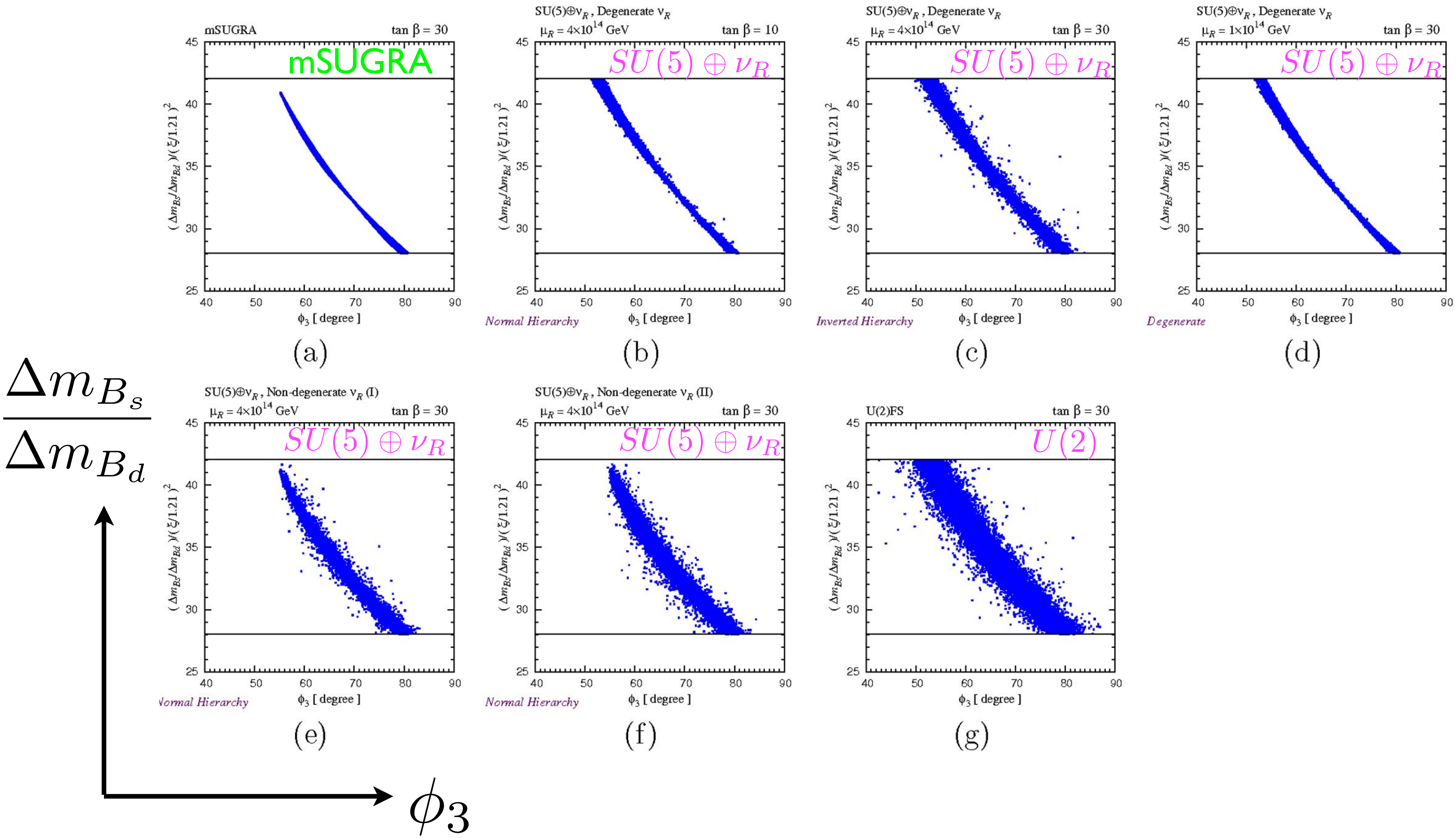
$(U(2) \subset \mathcal{G}_F)$

Larger deviations from the SM.

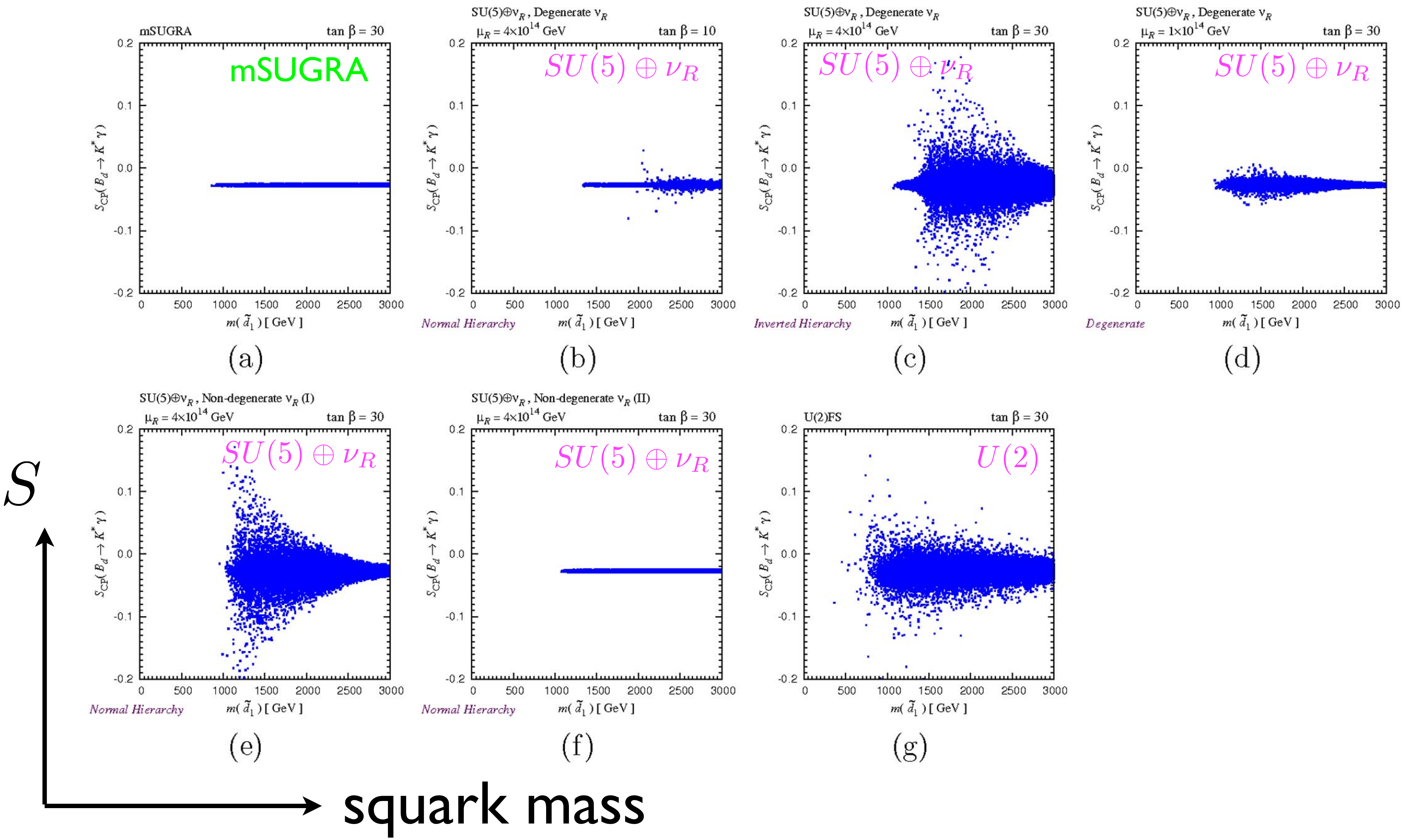
→ Rather restricted.

ϕ_3 vs $\Delta m_{B_s}/\Delta m_{B_d}$

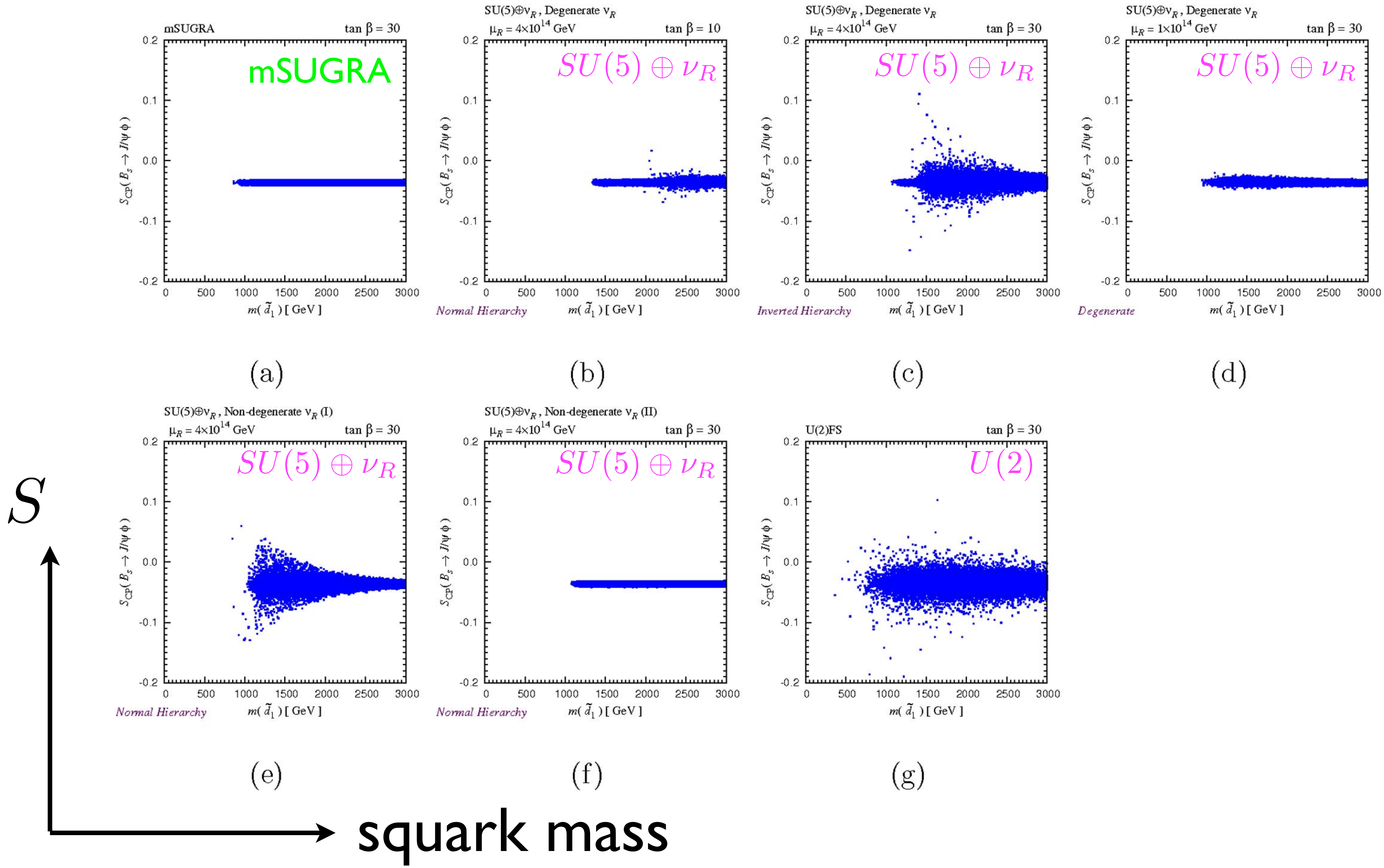
GOTO, OKADA, SHINDOU, AND TANAKA PHYSICAL REVIEW D **77,** 095010 (2008)



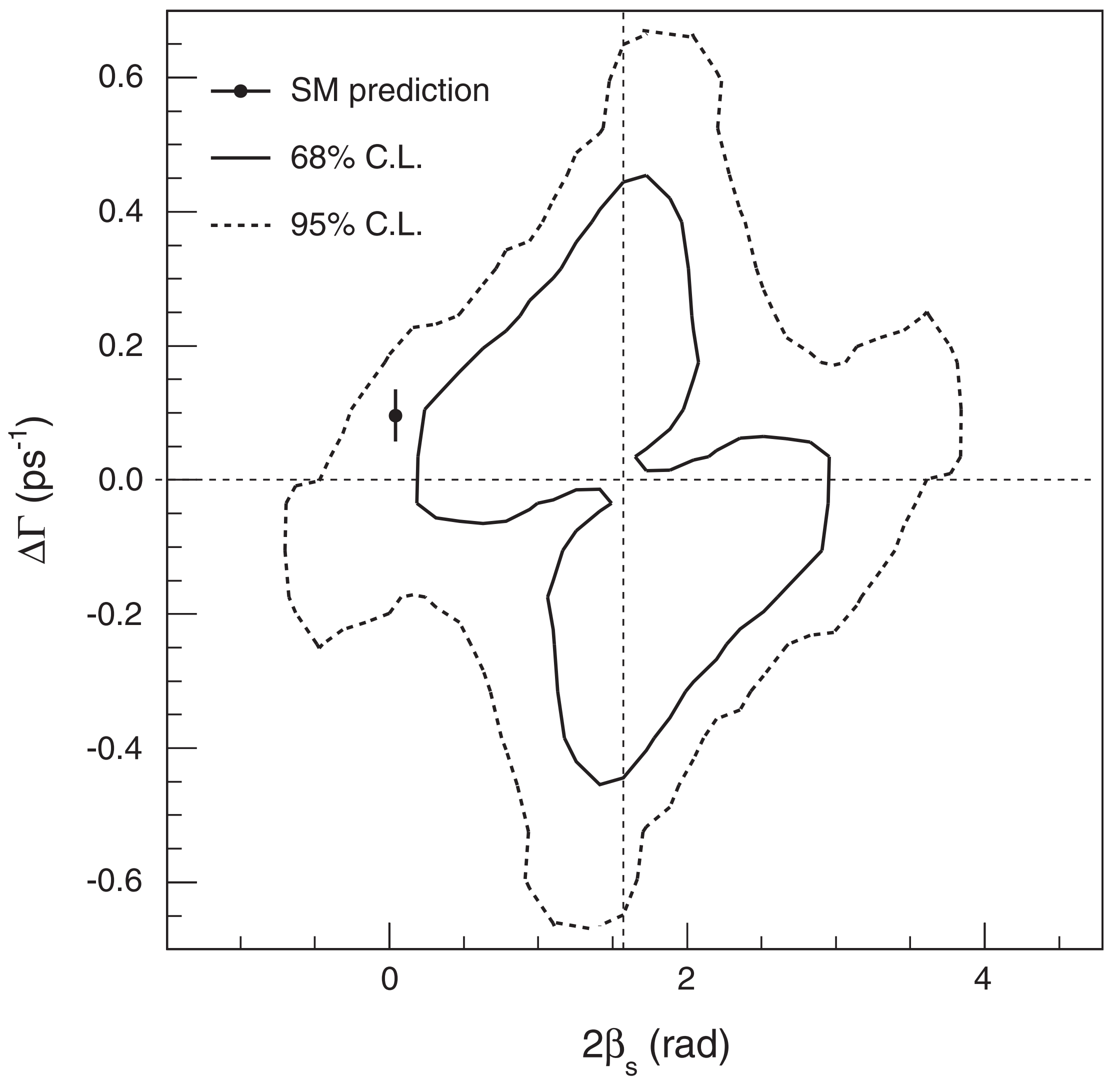
Mixing-induced CPV in $B_d \to K^* \gamma$



CP Violation in $B_s \to J/\psi\,\phi$

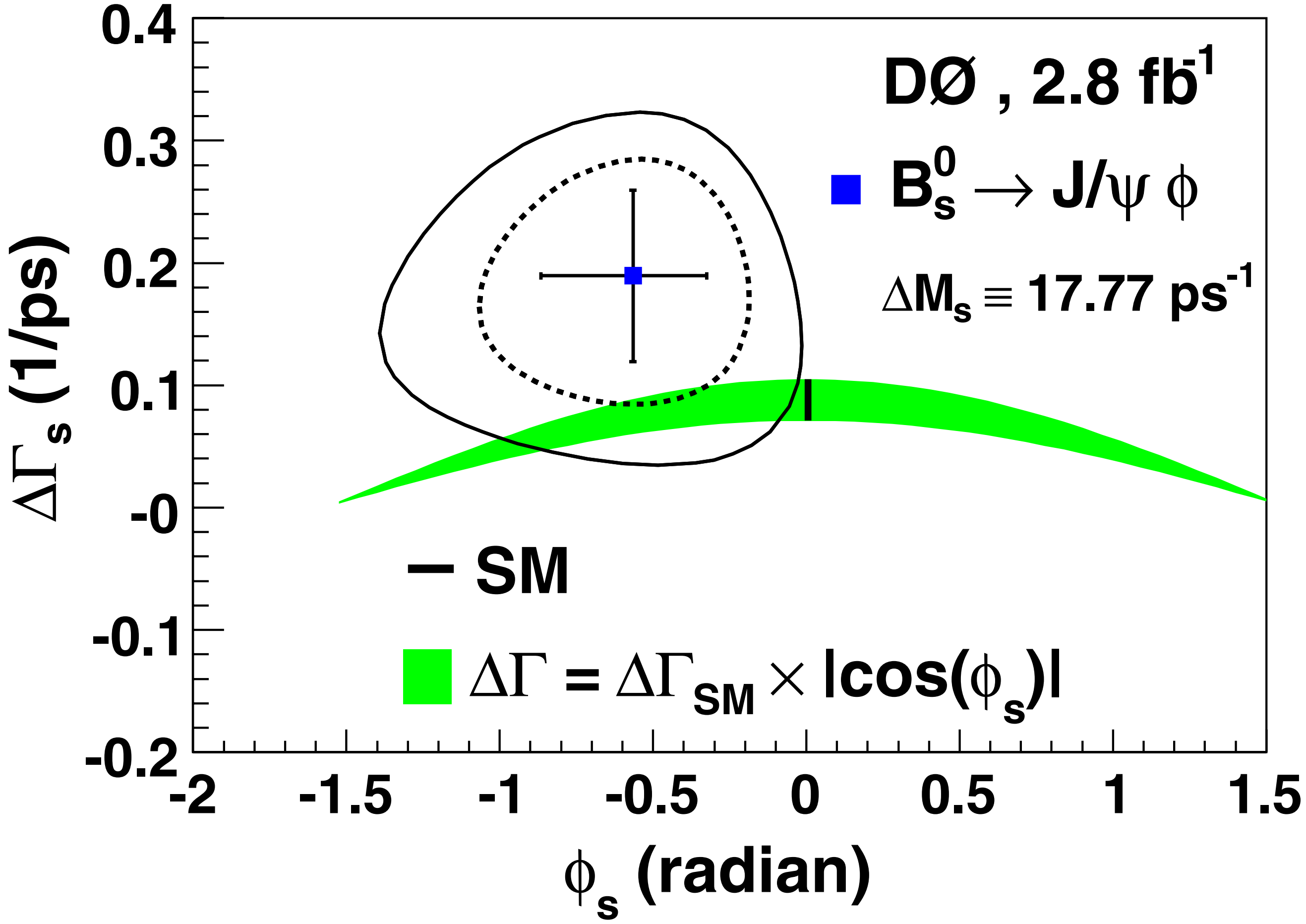


CDF



$= -\phi_s$

D0



Non-MFV in $b \leftrightarrow s$?

SUMMARY

- CKM scheme seems OK at $\sim$10% accuracy.
- A few % new physics might be there.
- Yukawa sector, flavor structure

  → Key issue for new physics

  MFV or Non-MFV
- Interplay between LHC and flavor factories.

  Super KEKB, JPARC K experiments,
  LFV searches, EDM, neutrinos, β decays, etc.