Flavor-Symmetry based Flavor Violation and CP Violation in Supersymmetry

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at MPI, Heidelberg.

based on:

Babu and JK, PRD71, 056006 (2005);
Itou, Kajiyama and JK, NPB743, 74 (2006);
Kifune, JK and Lenz, PRD77, 076010 (2008);
Araki and JK, IJMod.A24, 5831 (2009);
Kawashima, JK and Lenz, PLB681,60 (2009);
JK and Lenz, PRD82,075001 (2010);
Kaburaki, Konya, JK and Lenz, arXiv:1012.2435;
Babu, Kawashima and Kubo, arXiv:1103.1664

Minimal Flavor Violation (MFV)
versus
Flavor-Symmetry -based Flavor Violation (FSbFV)

<u>The basic idea is similar.</u>

3 Q, 3 uR, 3dR, 3L, 3 eR

(Chivukula+Georgi`87;
Hall+Randall`90;
D'Ambrosio et al,`02 etc)

$$G_F = [\ U(3)\ ]^5 \ \rightarrow U(1)_B \times U(1)_L$$ by Yukawas

MFV

(D'Ambrosio et al,`02)

Yukawas = Aux. fields

CP <= only CKM

Hypothesis

FSbFV

A subgroup of G_F is realized.

CP and FCNC are controlled by a symmetry.

Model

PLAN

I Where do non-abelian discrete family symmetries come from?

II A concrete SUSY model based on Q6 x Z4 x CP

III Flavor-Symmetry based FCNC and $\cancel{CP}$

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$\cancel{CP}$ *in B mixing*

IV Conclusion

I Where do discrete family symmetries come from?

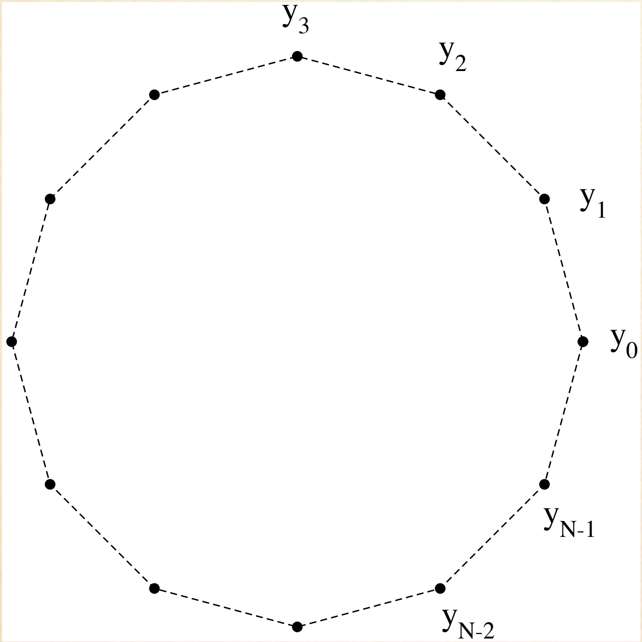
*It is simply there!

*It comes from SSB of a non-abelian continuous G (e.g. Berger, Grossman, `09; Adulpravichai, Blum,Lindner,`09 ; Luhn, `11).

*It comes from the geometry of extra dimensions.

From the geometry of a discrete dimension (dim. deconstruction)

(Kubo, `05)

$M^4 \times$ 

Discrete translational inv.+parity → $\mathrm{D_N}$

$$\phi(x,y) \ \rightarrow \ \phi'(x,y) = \tilde{Q}_{2N}\ \phi(x, \tilde{D}_N^{-1} y), \ \ \tilde{Q}_{2N} \in Q_{2N} \ \text{and} \ \tilde{D}_N \in D_N$$

Flavor group

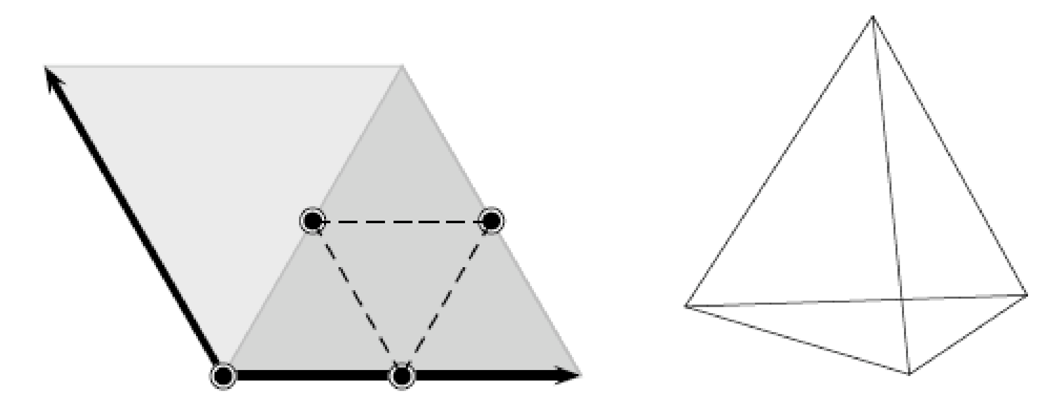
Ma+Rajasekaran, `01; Ma, `02

A4 From orbifolding extra dimensions

In field theory: *(Altarelli,Feruglio+Lin, `06)*

/ Z2

$|\mathbf{e}_1| = |\mathbf{e}_2|$ *with 120 degrees=> root vectors of SU(3)*



(a) $\mathbb{T}^2_{SU(3)}/\mathbb{Z}_2$. (b) Tetrahedron.

Extended by Abe, K-S Choi, Kobayashi, Ohki, Sakai,`10

Orbifold symmetry x Abelian discrete symmetry

$S_1/Z_2\ ,\ T^2/Z_3$

Non-abelian family symmetry

$$D_N \quad Q_{2N} \quad A_4 \quad S_4 \quad \Sigma(2N^2) \qquad \Delta(2N^2, 6N^2)$$

(See also *Adulpravichai, Blum,Lindner,`09)*

orbifold	flavor symmetry
$\mathbb{S}^1/\mathbb{Z}_2$	$D_4 = S_2 \ltimes (\mathbb{Z}_2 \times \mathbb{Z}_2)$
$\mathbb{T}^2/\mathbb{Z}_2$	$(D_4 \times D_4)/\mathbb{Z}_2 = (S_2 \times S_2) \ltimes \mathbb{Z}_2^3$
$\mathbb{T}^2/\mathbb{Z}_3$	$\Delta(54) = S_3 \ltimes (\mathbb{Z}_3 \times \mathbb{Z}_3)$
$\mathbb{T}^2/\mathbb{Z}_4$	$(D_4 \times \mathbb{Z}_4)/\mathbb{Z}_2$
$\mathbb{T}^2/\mathbb{Z}_6$	trivial
$\mathbb{T}^4/\mathbb{Z}_8$	$(D_4 \times \mathbb{Z}_8)/\mathbb{Z}_2$
$\mathbb{T}^4/\mathbb{Z}_{12}$	trivial
$\mathbb{T}^6/\mathbb{Z}_7$	$S_7 \ltimes (\mathbb{Z}_7)^6$

In string theory :

**Kobayashi, Raby+Zhang, `03;`05*

**Kobayashi, Nilles, Plöger, Raby+ Ratz,`06; Abe et al, `09*

Frampton+Kephart,`95; Frampton+Kong, `96

II A concrete SUSY model based on Q6 x Z4 x CP

Babu and JK, PRD71, 056006 (2005); and to appear.

SM non-singlet

SM singlet

	$\{Q, L\}$	$\{Q_3, L_3\}$	$\{u^c, d^c, \nu^c, e^c\}$	$\{u_3^c, d_3^c, \nu_3^c, e_3^c\}$	$H^{u,d}$	$H_3^{u,d}$	S	S_3	T	T_3	U
Q_6	2	$1'$	$2'$	$1'''$	$2'$	$1'''$	2	1	$2'$	$1'$	1
Z_4	$-i$	$-i$	$+$	$+$	i	i	$-$	$-$	$+$	$+$	$+$

2+1=3 structure except U

Each sector, except U, forms a family with parents + one child

The SM singlet sector breaks Q6 x Z4 x CP spontaneously.

Accidental permutation symmetries of V_{Higgs}

Vacuum I: $\langle H_1^{u,d} \rangle = \langle H_2^{u,d} \rangle$ .....

Vacuum II: $\langle H_1^{u,d} \rangle = \langle H_2^{u,d} \rangle^*$ .....

Two minima are physically different.

9 theory parameters for
6 quark masses and 4 CKM parameters.

↓

One sum rule among them

The mass matrix in the quark sector (up and down) is of the nearest neighbor type

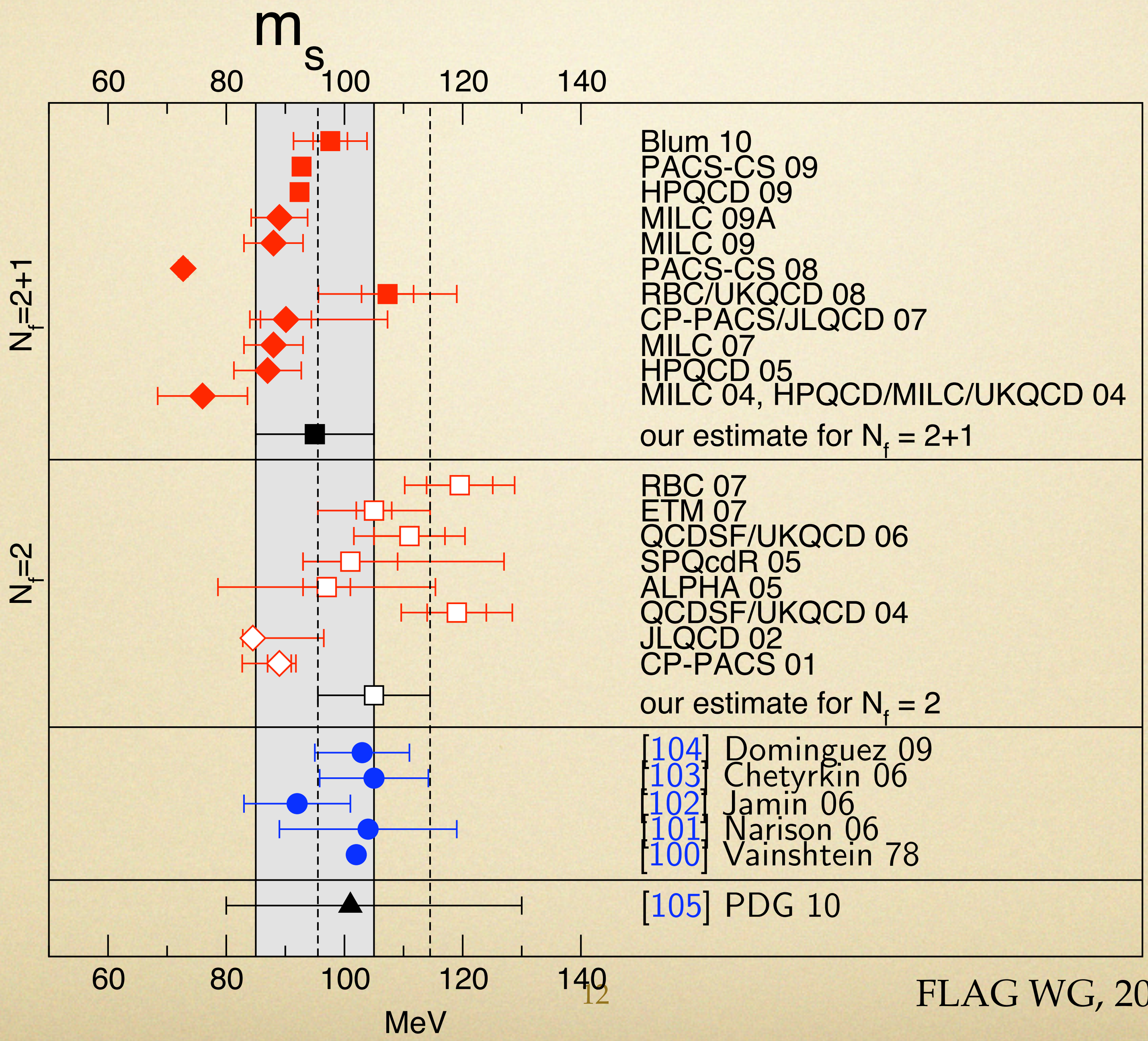
$$M_I = \begin{pmatrix} 0 & C & B \\ -C & 0 & B \\ B' & B' & A \end{pmatrix} \quad , \quad M_{II} = \begin{pmatrix} 0 & C & B \\ -C & 0 & B^* \\ B' & B'^* & A \end{pmatrix}$$

(Fritzsch, `78)

Spontaneous ~~CP~~

C and A are real and $\arg[B] = \arg[B']$

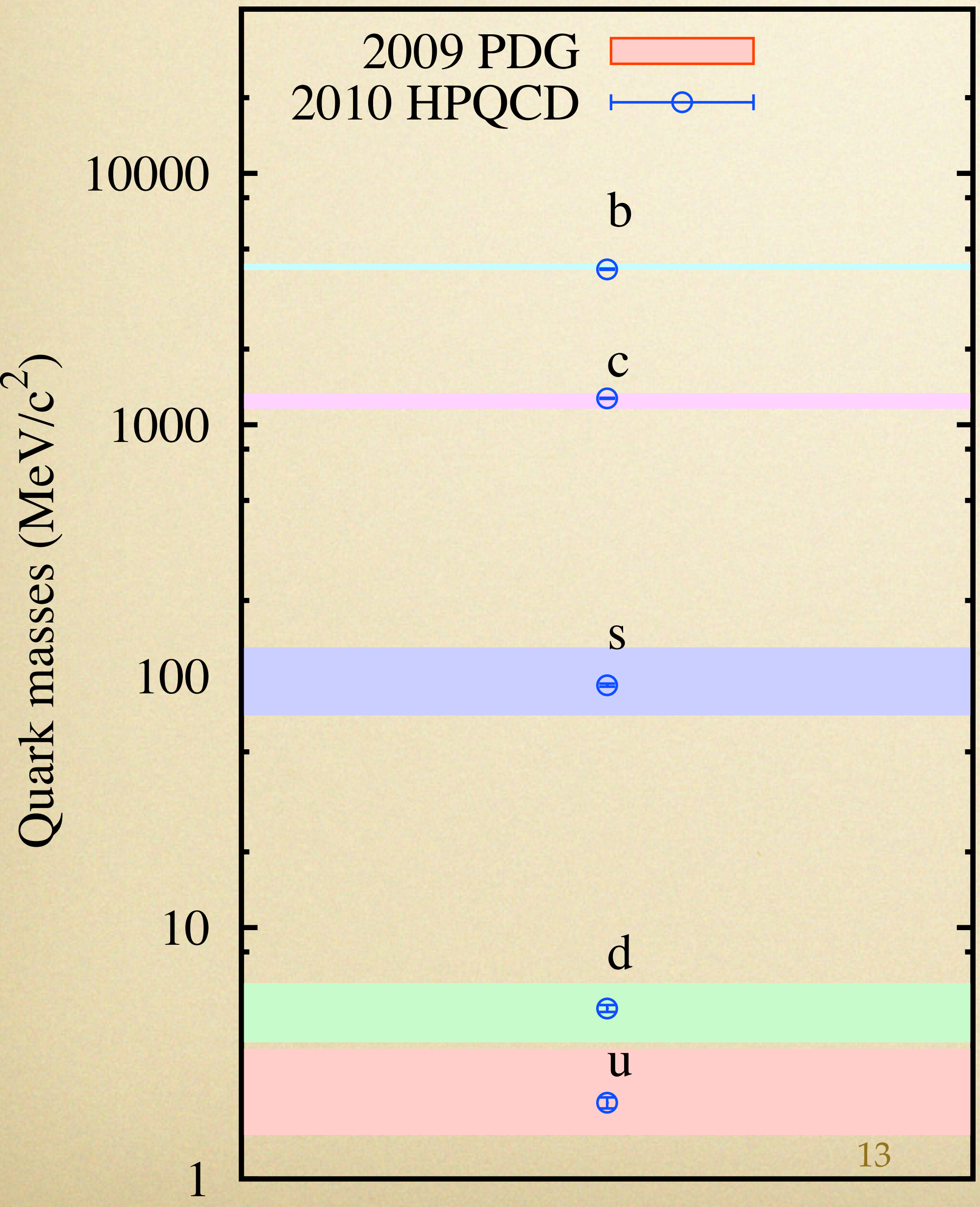
(Precise) quark masses



FLAG WG, 2010

HPQCD, **arXiv:1004.4285** [hep-lat]

Conlangelo in this conference



$$\Delta m_b \ : \ 4\% \rightarrow 0.7\%$$

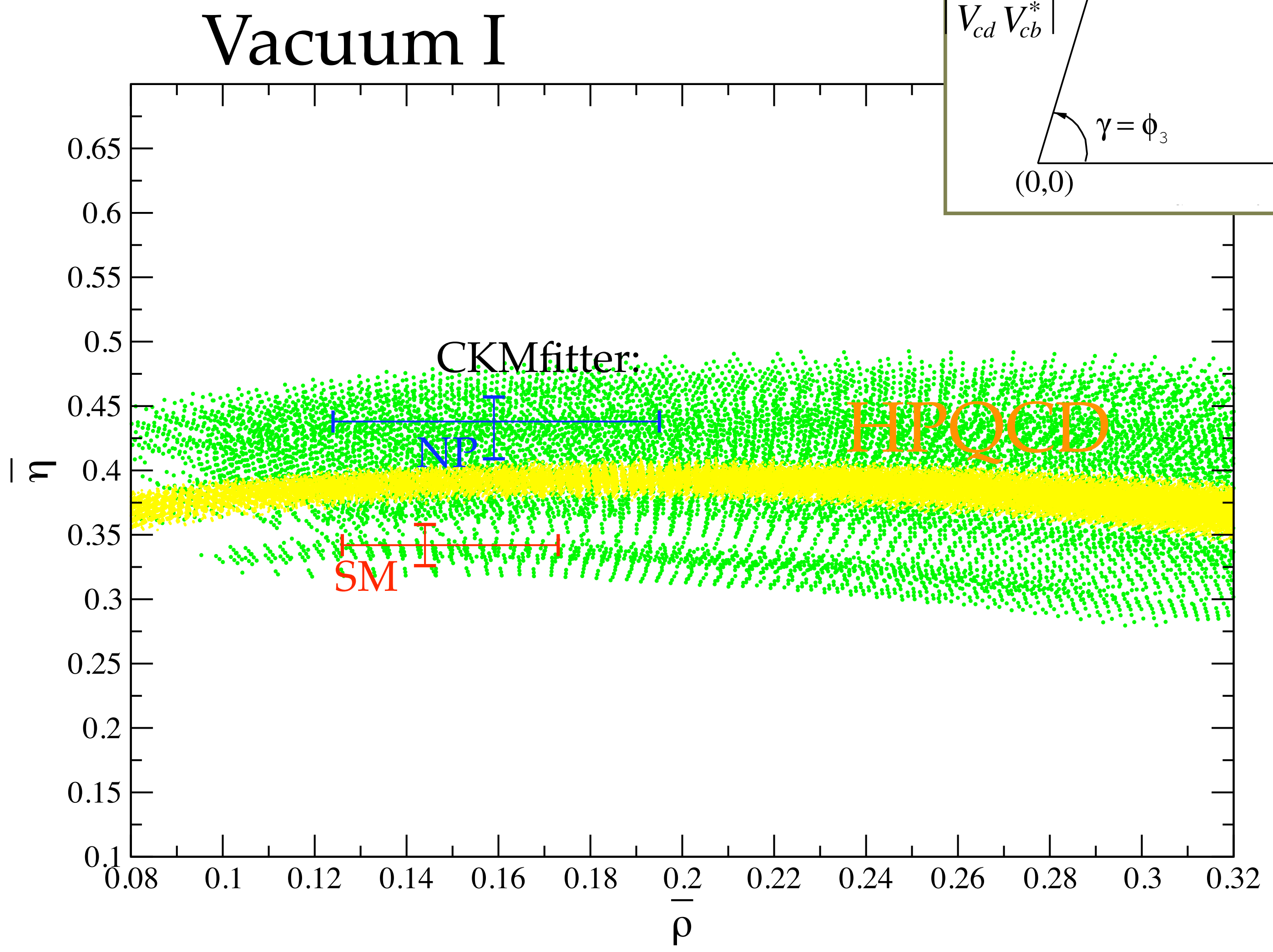
$$\Delta m_c \ : \ 9\% \rightarrow 1.3\%$$

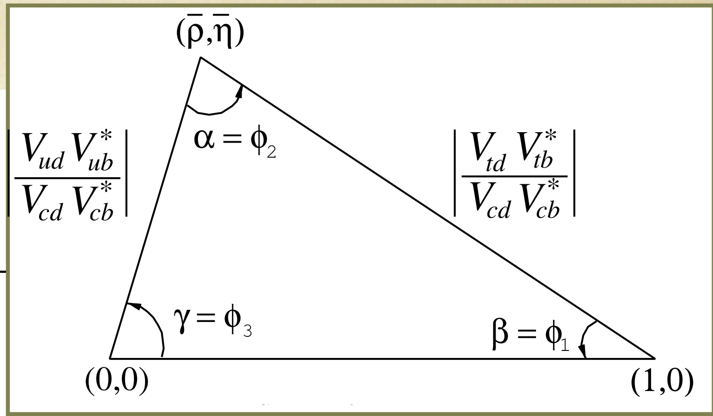
$$\Delta m_s \ : \ 33\% \rightarrow 1.4\%$$

$$\Delta m_u \ : \ 38\% \rightarrow 5\%$$

$$\Delta m_d \ : \ 27\% \rightarrow 3\%$$

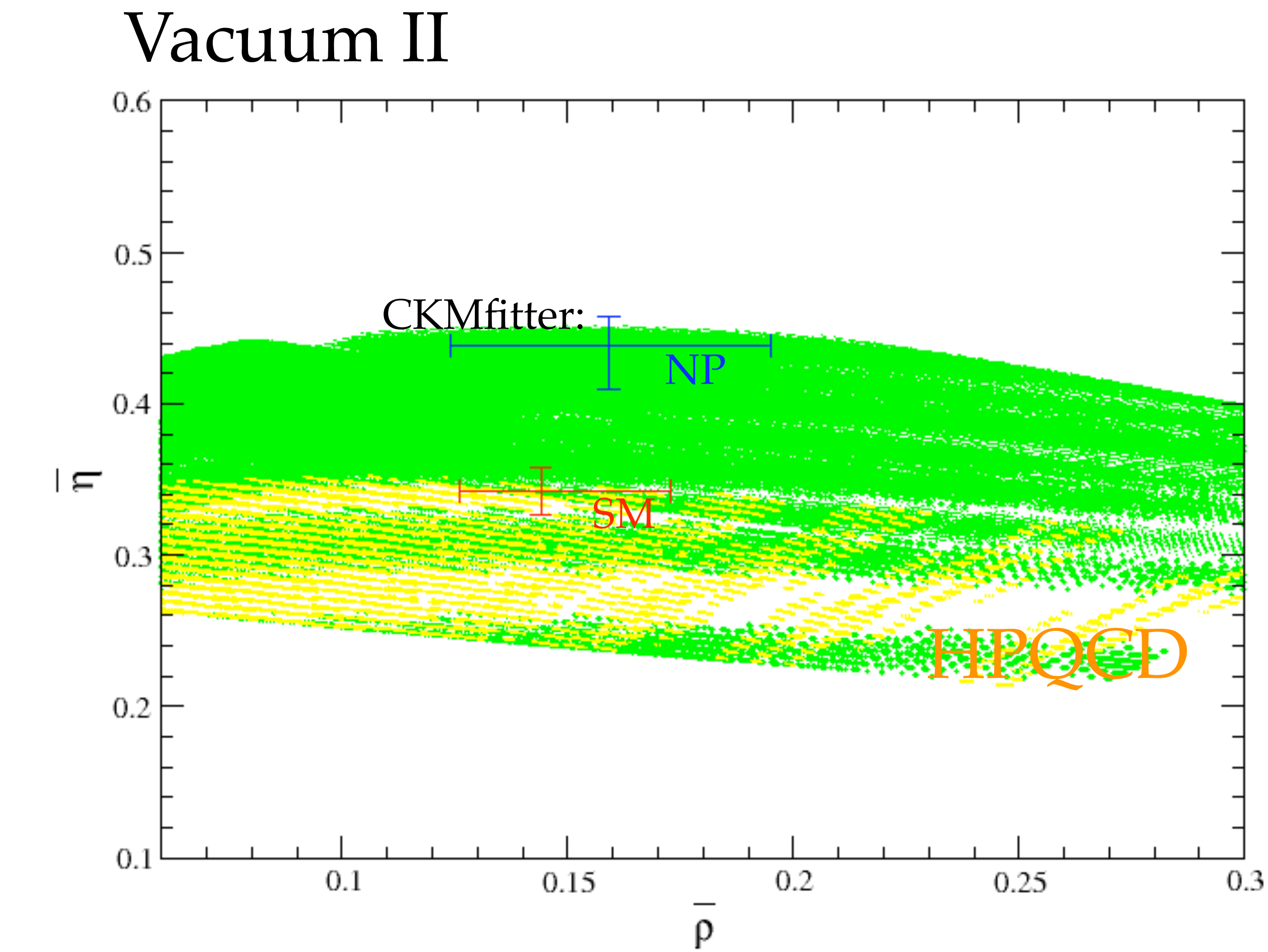
Q6 prediction





$$\text{Input} : \lambda = 0.22465 \sim 0.22619 \ , \ \ A = 0.784 \sim 0.825$$

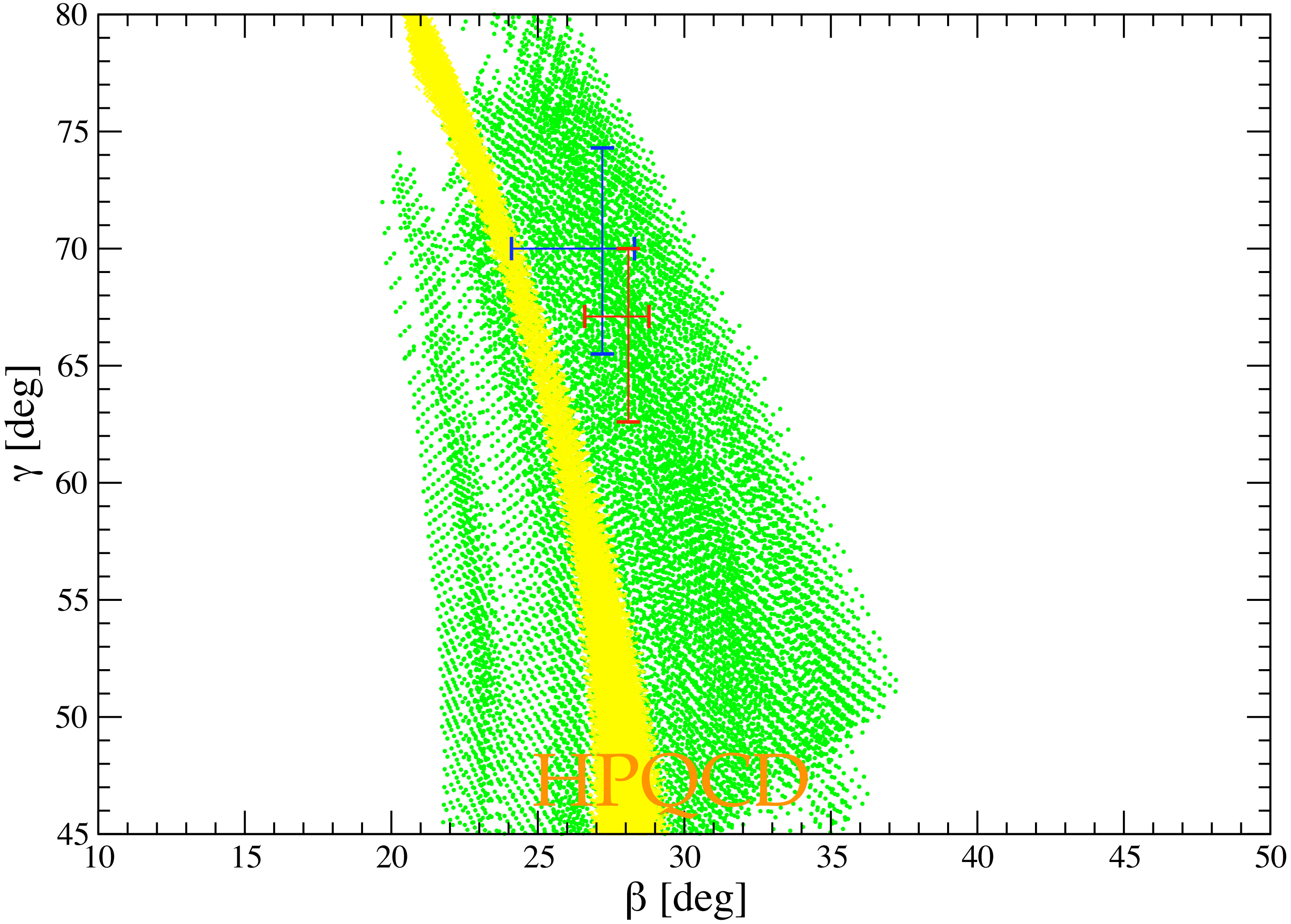
Q6 prediction



$$\text{Input}: \lambda = 0.22465 \sim 0.22619\ ,\ \ A = 0.784 \sim 0.825$$

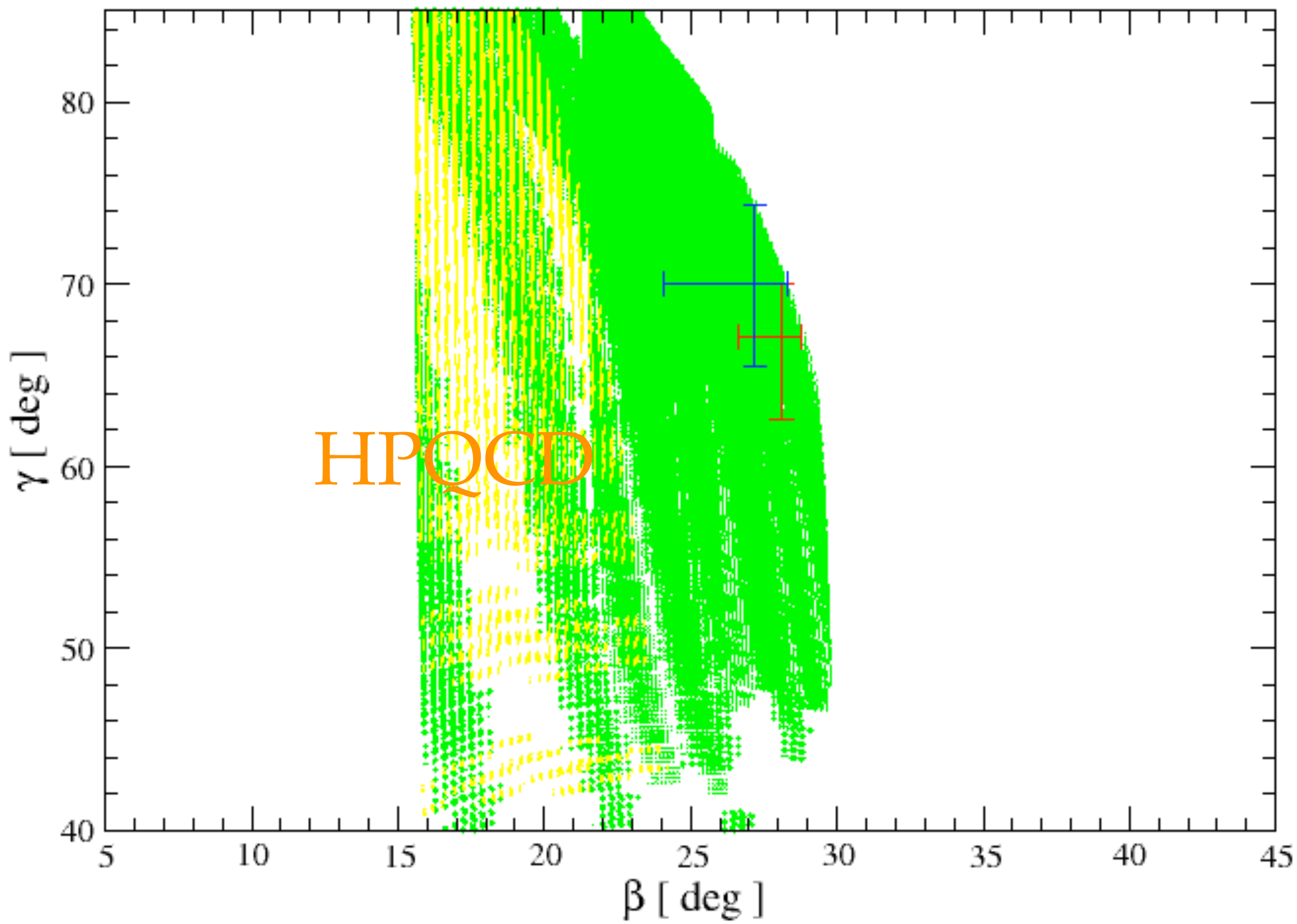
Q6 prediction

Vacuum I



Q6 prediction

Vacuum II



Lepton sector:

A more predictive assignment

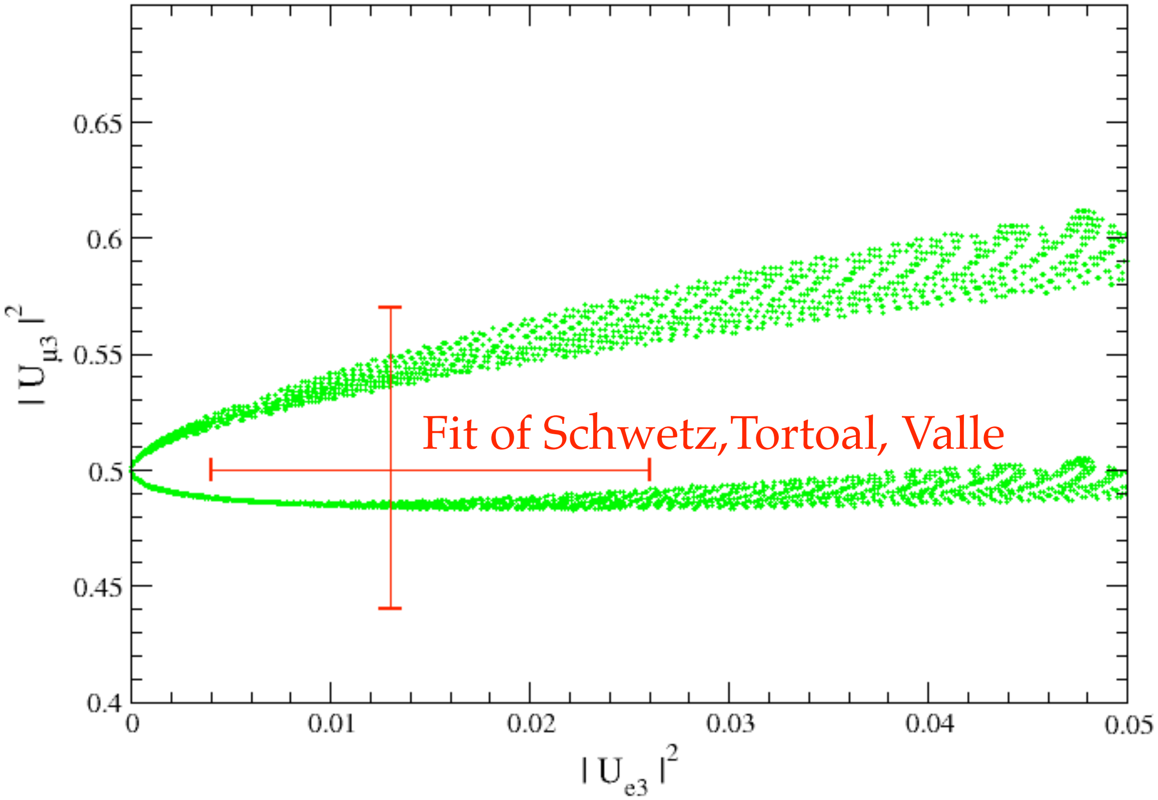
	L	$\{e^c, \nu^c\}$	L_3	e_3^c	ν_3^c
Q_6	$2'$	$2'$	1	1	$1''$
Z_4	$-i$	$+$	$-i$	$+$	$+$

The flavor and CP symmetry allow <u>6 + 1(2)=7 (8)</u> theory parameters for <u>3+3</u> masses and <u>1+2</u> phases.

Only an inverted ν mass spectrum is consistent!

$$\text{Vacuum I}: \quad \begin{aligned} \sin^2\theta_{13} &= \frac{1}{2}(m_e/m_\mu)^2 \simeq 10^{-5} \\ \sin^2\theta_{23} &= \frac{1}{2} + O((m_e/m_\mu)^2) \end{aligned}$$

Vacuum II :



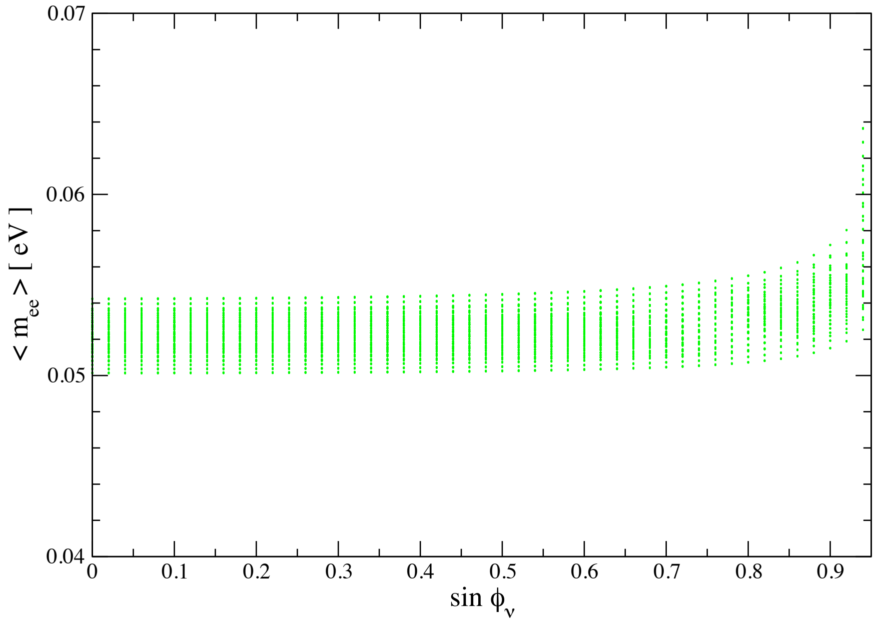
Input (Schwetz,Tortoal, Valle)**:**

$$\sin^2\theta_{12} = 0.318^{+0.019}_{-0.016}\ ,\ \Delta m^2_{21} = (7.59^{+0.23}_{-0.18}) \cdot 10^{-5}\ \text{eV}^2\ ,\ \Delta m^2_{31} = (2.4^{+0.12}_{-0.11}) \cdot 10^{-3}\ \text{eV}^2$$

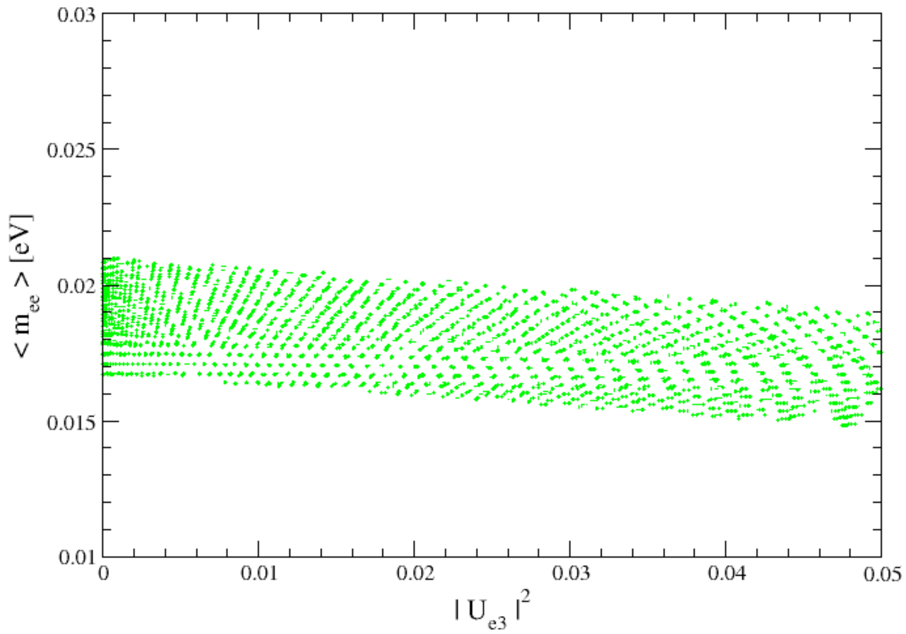
The Majorana phases are not independent.

$\boxed{<m_{ee}>}$

Vacuum I



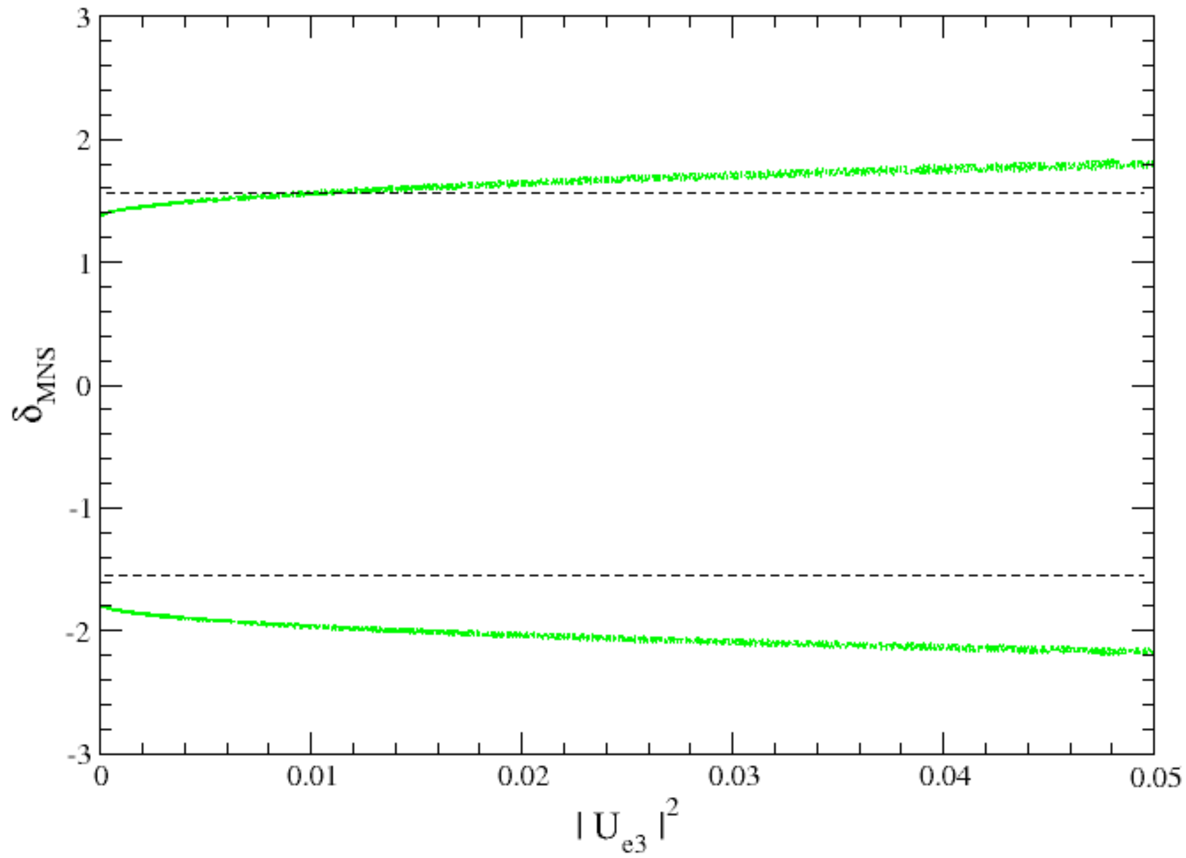
Vacuum II



Dirac phase

Vacuum I: negligible because $\sin\theta_{13} \simeq 0$

Vacuum II



III Flavor-Symmetry based FCNC and ~~CP~~

Two Sources:

1. <u>Multi Higgs Structure</u> ← Higgs Family

Tree, loop-level FCNC and ~~CP~~

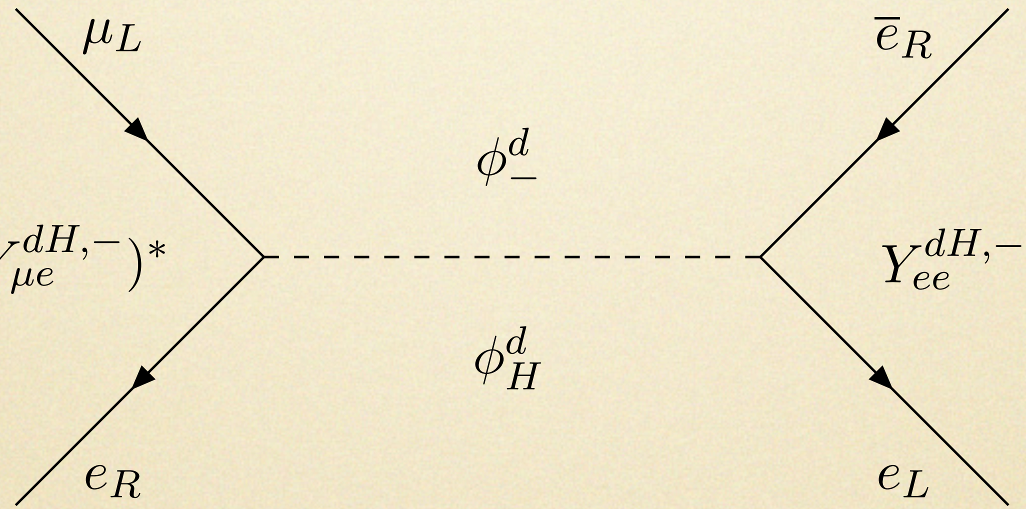
2. <u>SUSY sector</u>

Loop-level FCNC and ~~CP~~ ← SUSY breaking

FCNC from Multi Higgs Structure

$$\mu \to 3e$$

$$m_\mu \sim (Y_{\mu e}^{dH,-})^* \qquad Y_{ee}^{dH,-} \sim m_e$$



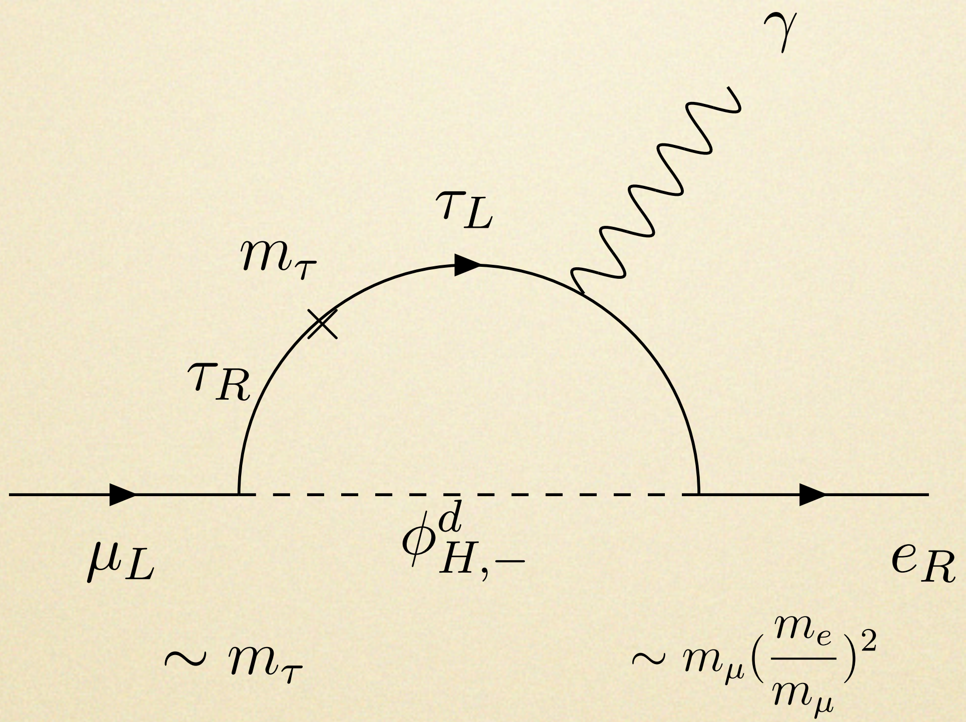
$$B(\mu \to 3e) \sim [\frac{m_\mu m_e}{M_H^2}]^2 \sim 10^{-17} \text{ for } \; M_H = 120 \;\; \text{GeV}$$

Mondragon x2, Peinado,`07

$$B(\mu \to 3e)^{\text{exp}} < 1.0 \times 10^{-12}$$

$$B(K_L \to e^+ \; e^- \;\; (\mu^+ \; \mu -)) < 10^{-23(-19)}$$

$$\mu \to e\gamma$$



$$B(\mu \to e\gamma) \sim \frac{\alpha}{\pi}(\frac{m_e}{m_\mu})^4(\frac{m_\tau}{M_H})^4 \sim 10^{-20} \quad \text{for} \quad M_H = 120 \quad \text{GeV}$$

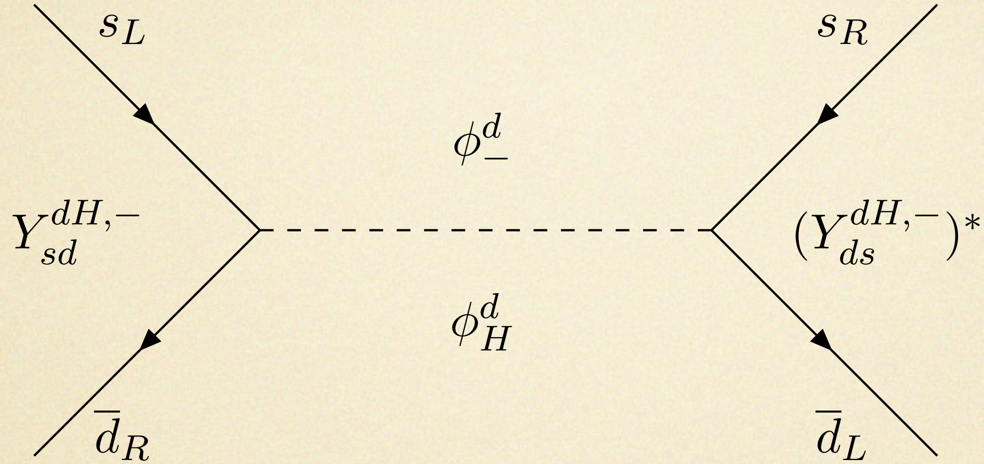
$$B(\mu \to e\gamma)^{\text{exp}} < 1.2 \times 10^{-11}$$

Mondragon x2, Pained,`**07**

$K^0 - \overline{K}^0$ mixing

Kifune, JK and Lenz, `08

$10^{-5} \sim$

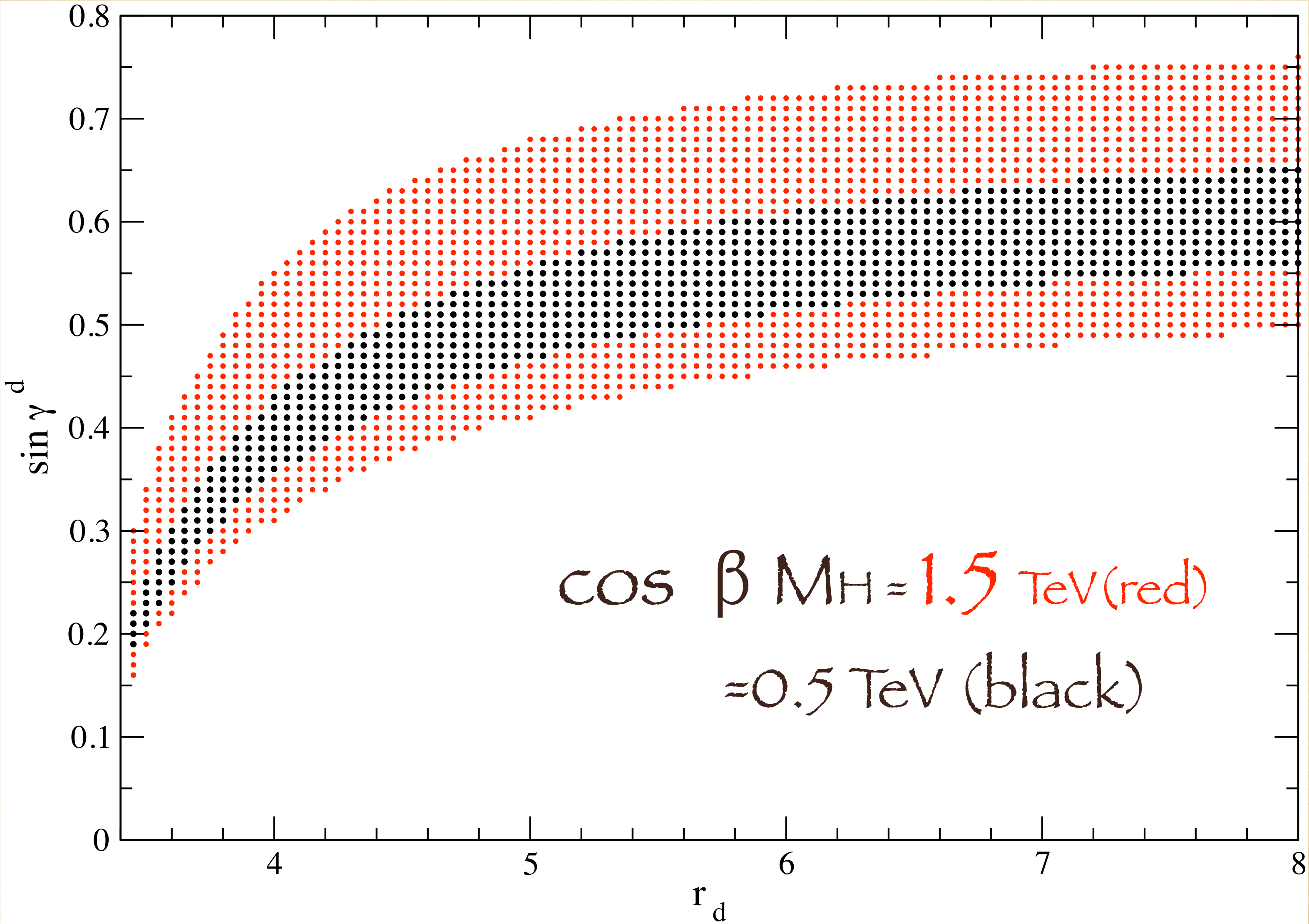


$\sim 10^{-4}$

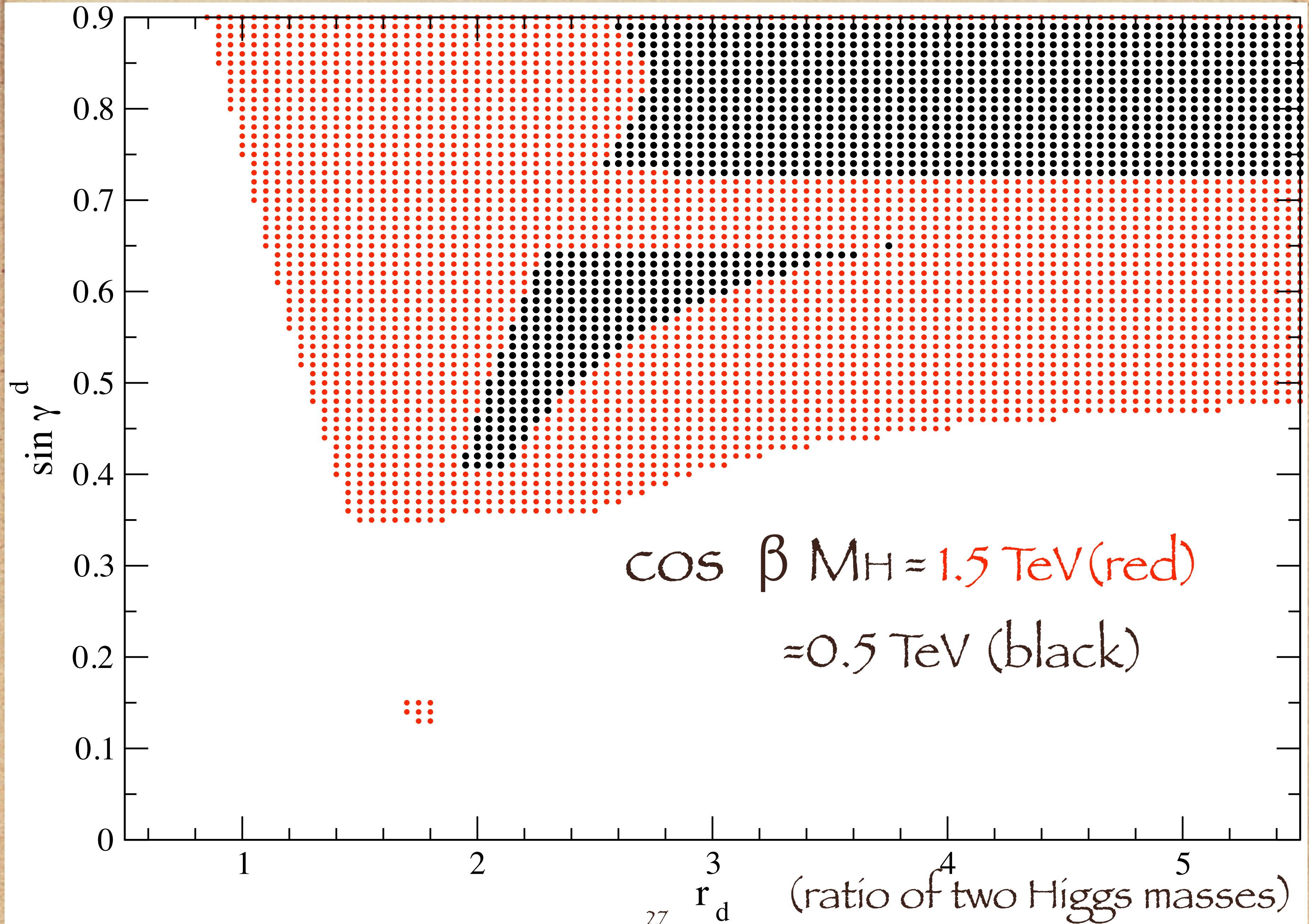
$$\Delta M_K \;=\; 2 \times 0.28 \times C_K \,\text{GeV} < \Delta M_K^{\text{exp}} \simeq 3.49 \times 10^{-15}\ \text{GeV}$$

$$\begin{aligned} C_K \;&=\; \left[\frac{Y_{ds}^{dH}(Y_{sd}^{dH})^*}{(M_H^d)^2} + \frac{Y_{ds}^{d-}(Y_{sd}^{d-})^*}{(M_-^d)^2}\right] \\ &= \frac{1}{\cos^2\beta}\left[\frac{1\,\text{TeV}}{M_H^d}\right]^2 \times 10^{-14} \\ &\times \left(\frac{5.617}{r_d^2 \sin^2\gamma^d} - \frac{0.514}{\tan^2\gamma^d} - 0.539 + 0.224\tan^2\gamma^d\right)\ \text{GeV}^{-2}, \end{aligned}$$

$$|\Delta M_K^{\mathrm{EXTRA}}| < \Delta M_K^{\mathrm{exp}}$$



$$\Delta M_{s,d} = \Delta M_{s,d}^{\rm SM} + \Delta M_{s,d}^{\rm EXTRA} = \Delta M_{s,d}^{\rm exp}$$



$\cancel{CP}$ from Multi Higgs Structure

Babu+Meng, `09
Kaburaki,Konya, Kubo, Lenz,`10

For $\quad \cos\beta M_H^d \sim 1.2 \quad \text{TeV} \qquad \sin\beta M_H^u \sim 4.3 \quad \text{TeV}$

$$0 \lesssim d_n \lesssim \times 10^{-24} \quad [\text{e cm}]$$

$$d_n^{\text{exp}} < 6.3 \times 10^{-26} \quad [\text{e cm}]$$

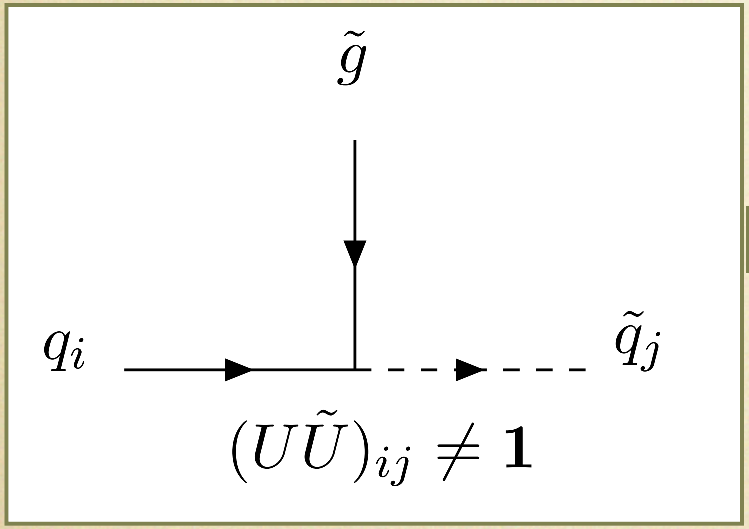
Flavor symmetry with spontaneous $\cancel{CP}$

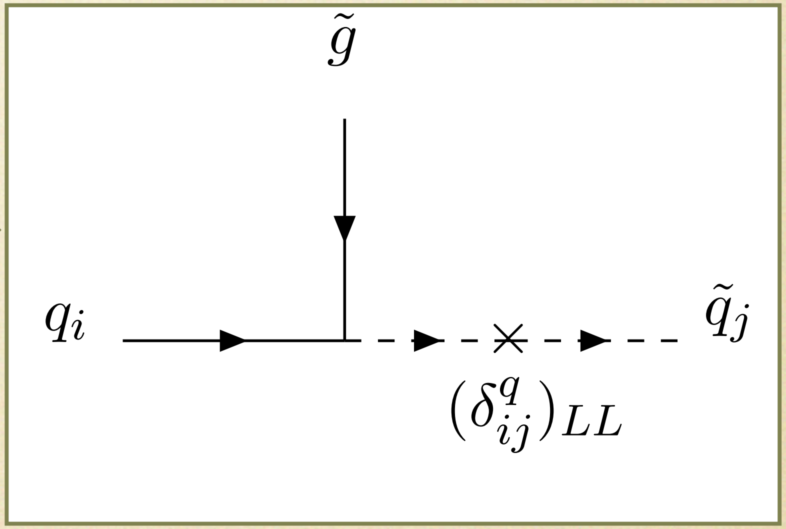
FCNC and ~~CP~~ in the SUSY sector

Mismatch between flavors

Soft mass insertions

Hall, Kostelecky and Raby





$$\Delta m_K = 3.5 \times 10^{-15}\ \mathrm{GeV} \longrightarrow |(\delta^d_{12})_{LR}| < 10^{-3}$$

$$d_e < 10^{-27}\ \mathrm{e\ cm} \longrightarrow \mathrm{Im}(\delta^l_{11})_{LR} < 10^{-7}$$

Susy Flavor Problem

Introduce low-energy family symmetry

to constrain the Yukawa sector, and simultaneously to soften the SUSY flavor problem.

(Dine,Leigh+Kagan,`93; Pouliot+Seiberg,`93; Kaplan+Schmalz,`94; Hall+Murayama, `95; Carone, Hall+Murayama, `96; Babu+Barr,`96; Babu+Mohapatra,`99; Chen+Mahanthappa`02; Babu, Kobayashi+Kubo, `03; Hamaguchi,Kakizaki+Yamaguchi, `03; Ross, Velasco-Sevilla+Vives, `03; King+Ross,`03; Maekawa+Yamashita, `04; Ross, Velasco-Sevilla+Vives, `04; ....)

Combine spontaneous CP violation to suppress ~~CP~~ , Babu+JK,`05

Soft-SUSY- breaking mass insertions:

Q_6 with spontaneous $\cancel{CP}$

$$\boxed{(\delta_{ij})_{LL,RR}} = U^{q\dagger}_{L,R} \begin{pmatrix} a_{L,R} & 0 & 0 \\ 0 & a_{L,R} & 0 \\ 0 & 0 & b_{L,R} \end{pmatrix} U^{q}_{L,R}$$

2+1 family structure

real

phase alignment

$$\boxed{(\delta_{ij})_{LR}} \sim A \text{ tems} + \mu \text{ tems}$$

(complex VEV from the SM singlet sector)

EDMs

Q6 **FCNCs induced by the soft terms**

Kobayashi, JK+Terao,`03;
Itou,Kajiyama+JK,`05

Lepton sector

	Exp. bound	Q_6 Model
$\lvert(\delta^e_{12})_{LL}\rvert$	$4.0\times10^{-5}\ \tilde{m}^2_{\tilde{\ell}}$	$4.9\times10^{-3}\Delta a^\ell_L$
$\lvert(\delta^e_{12})_{RR}\rvert$	$9\times10^{-4}\ \tilde{m}^2_{\tilde{\ell}}$	$8.4\times10^{-8}\Delta a^e_R$
$\lvert(\delta^e_{12})_{LR}\rvert$	$8.4\times10^{-7}\ \tilde{m}^2_{\tilde{\ell}}$	$\sim5\times10^{-6}\tilde{m}^{-1}_{\tilde{\ell}}$
$\lvert(\delta^e_{13})_{LL}\rvert$	$2\times10^{-2}\ \tilde{m}^2_{\tilde{\ell}}$	$1.7\times10^{-5}\Delta a^\ell_L$
$\lvert(\delta^e_{13})_{RR}\rvert$	$3\times10^{-1}\ \tilde{m}^2_{\tilde{\ell}}$	$5.9\times10^{-2}\Delta a^e_R$
$\lvert(\delta^e_{13})_{LR}\rvert$	$1.7\times10^{-2}\ \tilde{m}^2_{\tilde{\ell}}$	$\sim3\times10^{-7}\tilde{m}^{-1}_{\tilde{\ell}}$
$\lvert(\delta^e_{23})_{LL}\rvert$	$2\times10^{-2}\ \tilde{m}^2_{\tilde{\ell}}$	$8.4\times10^{-8}\Delta a^\ell_L$
$\lvert(\delta^e_{23})_{RR}\rvert$	$3\times10^{-1}\ \tilde{m}^2_{\tilde{\ell}}$	$1.4\times10^{-6}\Delta a^e_R$
$\lvert(\delta^e_{23})_{LR}\rvert$	$1\times10^{-2}\ \tilde{m}^2_{\tilde{\ell}}$	$\sim2\times10^{-9}\tilde{m}^{-1}_{\tilde{\ell}}$
$\lvert(\delta^e_{23})_{LL}(\delta^e_{13})_{LL}\rvert$	$1\times10^{-4}\ \tilde{m}^2_{\tilde{\ell}}$	$1.4\times10^{-12}(\Delta a^\ell_L)^2$
$\lvert(\delta^e_{23})_{RR}(\delta^e_{13})_{RR}\rvert$	$9\times10^{-4}\ \tilde{m}^2_{\tilde{\ell}}$	$8.4\times10^{-8}(\Delta a^e_R)^2$
$\lvert(\delta^e_{23})_{LL}(\delta^e_{13})_{RR}\rvert$	$2\times10^{-5}\ \tilde{m}^2_{\tilde{\ell}}$	$5.0\times10^{-9}\Delta a^\ell_L\Delta a^e_R$
$\lvert(\delta^e_{23})_{RR}(\delta^e_{13})_{LL}\rvert$	$2\times10^{-5}\ \tilde{m}^2_{\tilde{\ell}}$	$2.4\times10^{-11}\Delta a^\ell_L\Delta a^e_R$

$$\frac{m_e}{m_\mu}$$

$$\frac{m_e m_\mu}{m_\tau^2}$$

(Gbbiani et al, Abel, Khalil + Lebedev, Endo, Kakizaki +Yamaguchi, Hisano + Shimizu; Hisano.............)

Quark sector

Kobayashi, JK+Terao,`03;
Itou,Kajiyama+JK,`05

	Exp. bound	Q_6 Model
$\sqrt{\lvert\mathrm{Re}(\delta^d_{12})^2_{LL,RR}\rvert}$	$4.0\times10^{-2}\ \tilde{m}_{\tilde{q}}$	$(LL)1.2\times10^{-4}\Delta a^q_L,(RR)1.7\times10^{-1}\Delta a^d_R$
$\sqrt{\lvert\mathrm{Re}(\delta^d_{12})_{LL}(\delta^d_{12})_{RR}\rvert}$	$2.8\times10^{-3}\ \tilde{m}_{\tilde{q}}$	$4.5\times10^{-3}\sqrt{\Delta a^q_L\Delta a^d_R}$
$\sqrt{\lvert\mathrm{Re}(\delta^d_{12})^2_{LR}\rvert}$	$4.4\times10^{-3}\ \tilde{m}_{\tilde{q}}$	$\sim2\times10^{-5}\tilde{m}^{-1}_{\tilde{q}}$
$\sqrt{\lvert\mathrm{Re}(\delta^d_{13})^2_{LL,RR}\rvert}$	$9.8\times10^{-2}\ \tilde{m}_{\tilde{q}}$	$(LL)7.8\times10^{-3}\Delta a^q_L,(RR)1.4\times10^{-1}\Delta a^d_R$
$\sqrt{\lvert\mathrm{Re}(\delta^d_{13})_{LL}(\delta^d_{13})_{RR}\rvert}$	$1.8\times10^{-2}\ \tilde{m}_{\tilde{q}}$	$3.4\times10^{-2}\sqrt{\Delta a^q_L\Delta a^d_R}$
$\sqrt{\lvert\mathrm{Re}(\delta^d_{13})^2_{LR}\rvert}$	$3.3\times10^{-2}\ \tilde{m}_{\tilde{q}}$	$\sim2\times10^{-5}\tilde{m}^{-1}_{\tilde{q}}$
$\sqrt{\lvert\mathrm{Re}(\delta^u_{12})^2_{LL,RR}\rvert}$	$1.0\times10^{-1}\ \tilde{m}_{\tilde{q}}$	$(LL)1.0\times10^{-4}\Delta a^q_L,(RR)4.5\times10^{-4}\Delta a^u_R$
$\sqrt{\lvert\mathrm{Re}(\delta^u_{12})_{LL}(\delta^u_{12})_{RR}\rvert}$	$1.7\times10^{-2}\ \tilde{m}_{\tilde{q}}$	$2.1\times10^{-4}\sqrt{\Delta a^q_L\Delta a^u_R}$
$\sqrt{\lvert\mathrm{Re}(\delta^u_{12})^2_{LR}\rvert}$	$3.1\times10^{-2}\ \tilde{m}_{\tilde{q}}$	$\sim7\times10^{-5}\tilde{m}^{-1}_{\tilde{q}}$
$\lvert(\delta^d_{23})_{LL,RR}\rvert$	$\sim10^{-1}\ \tilde{m}_{\tilde{q}}$	$(LL)1.5\times10^{-2}\Delta a^q_L,(RR)4.7\times10^{-1}\Delta a^d_R$
$\lvert(\delta^d_{23})_{LR}\rvert$	$1.6\times10^{-2}\ \tilde{m}^2_{\tilde{q}}$	$\sim5\times10^{-5}\tilde{m}^{-1}_{\tilde{q}}$

Flavor symmetry with spontaneous $\cancel{CP}$
suppress FCNCs and $\cancel{CP}$ too much!!

Can one get a large $\cancel{CP}$ in the B^0 mixing?

B^0 mixing

$$i\frac{d}{dt}\begin{pmatrix} |B_q^0(t)> \\ |\bar{B}_q^0(t)> \end{pmatrix} = (\mathbf{M} - i\mathbf{\Gamma}) \begin{pmatrix} |B_q^0(t)> \\ |\bar{B}_q^0(t)> \end{pmatrix} \quad q = d, s$$

Lenz-Nierste parameterization of NP

$$M_{12}^q = M_{12}^{SM,q} \cdot \Delta_q \qquad \Delta_q = |\Delta_q| e^{i\phi_q^\Delta}$$

$$\Gamma_{12}^q = \Gamma_{12}^{SM,q} \qquad \phi_q = \arg\left(-M_{12}^q/\Gamma_{12}^q\right)$$

Master equations for observables

$$\Delta M_q = 2|M_{12}^{SM,q}| \cdot |\Delta_q| \ , \ \Delta\Gamma_q = 2|\Gamma_{12}^q| \cos\left(\phi_q^{SM} + \phi_q^\Delta\right)$$

$$a_{sl}^q = \frac{|\Gamma_{12}^q|}{|M_{12}^{SM,q}|} \cdot \frac{\sin\left(\phi_q^{SM} + \phi_q^\Delta\right)}{|\Delta_q|}$$

I : Tree-level Higgs contribution

Yukawa couplings for neutral Higgses are real even for the mass eigen states.

II: Contributions from the soft mass insertions

$\boxed{(\delta_{ij})_{LL,RR}}$ is real, and

$\boxed{(\delta_{ij})_{LR}} \sim A$ tems $+ \mu$ tems

EDMs

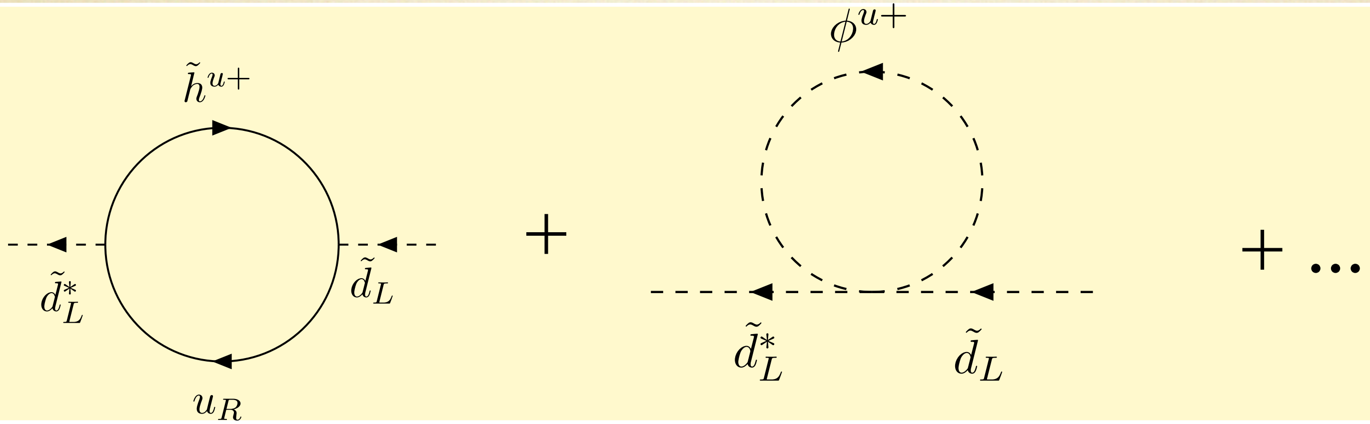
$b \to s\gamma$

I+II $\Rightarrow$ $-0.023 \lesssim \phi_s^\Delta \lesssim 0.009$

Kawashima, JK and Lenz, PLB681,60 (2009)

III. Loop effects to (δ_{ij})

JK and Lenz, **Phys.Rev.D82:075001,2010**

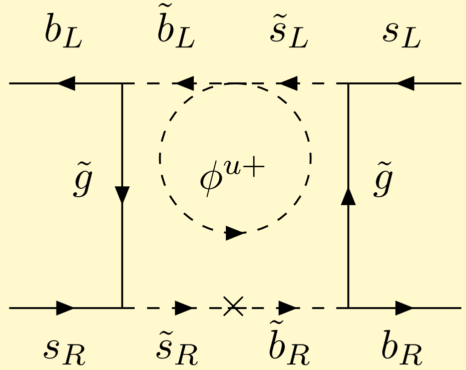


quadratic and logarithmic ∞ cancel.

softness

flavor symmetry

This is a two-loop effect!!



However, large finite terms.

$\boxed{\text{large susy breaking}}$

$\boxed{\text{small } \mu}$ and $\boxed{\text{large } M_H}$

EDM, b -> s+gamma

FCNC

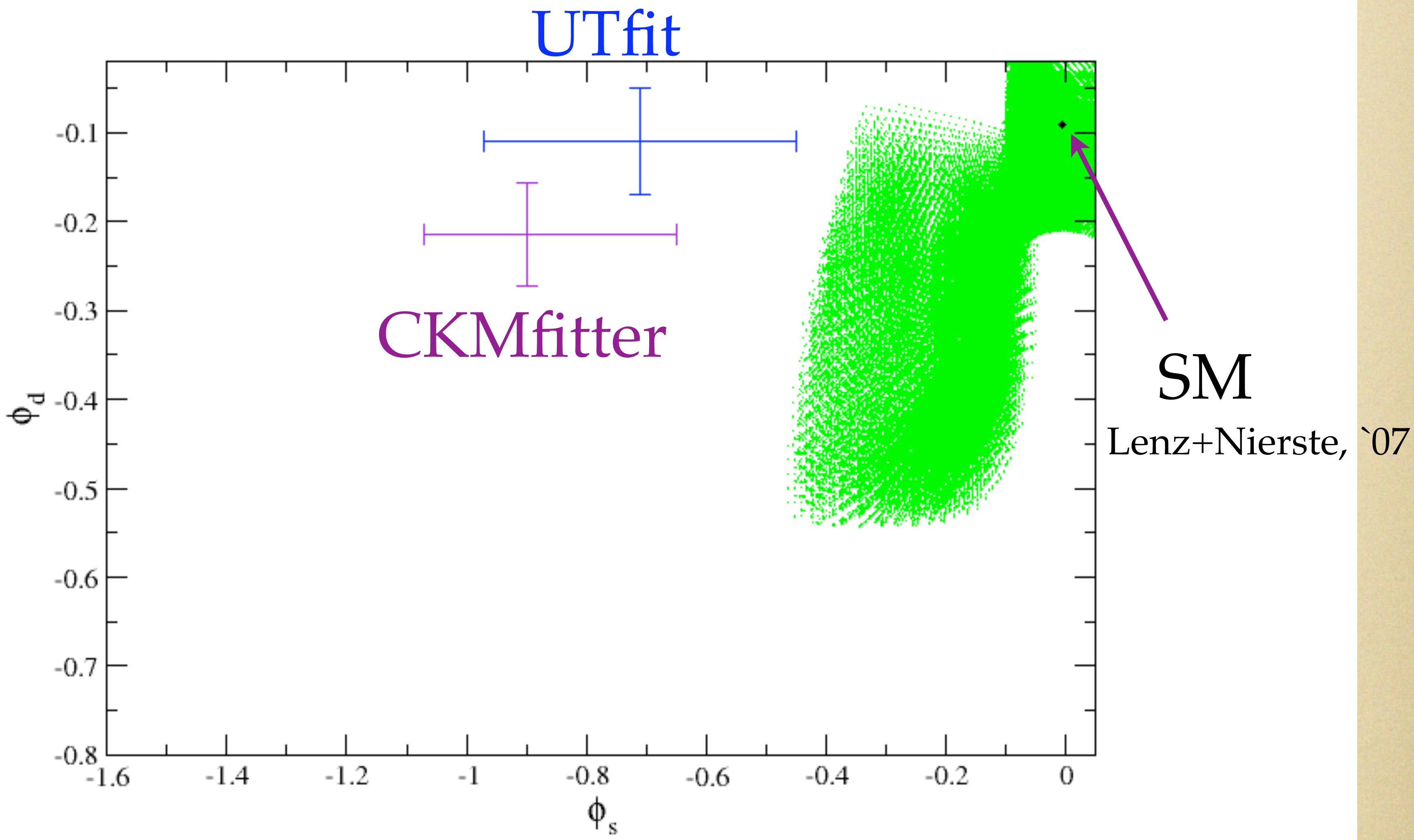
Mass of $\boxed{\text{extra Higgions}}$ $\boxed{\text{extra Higg bosons}}$

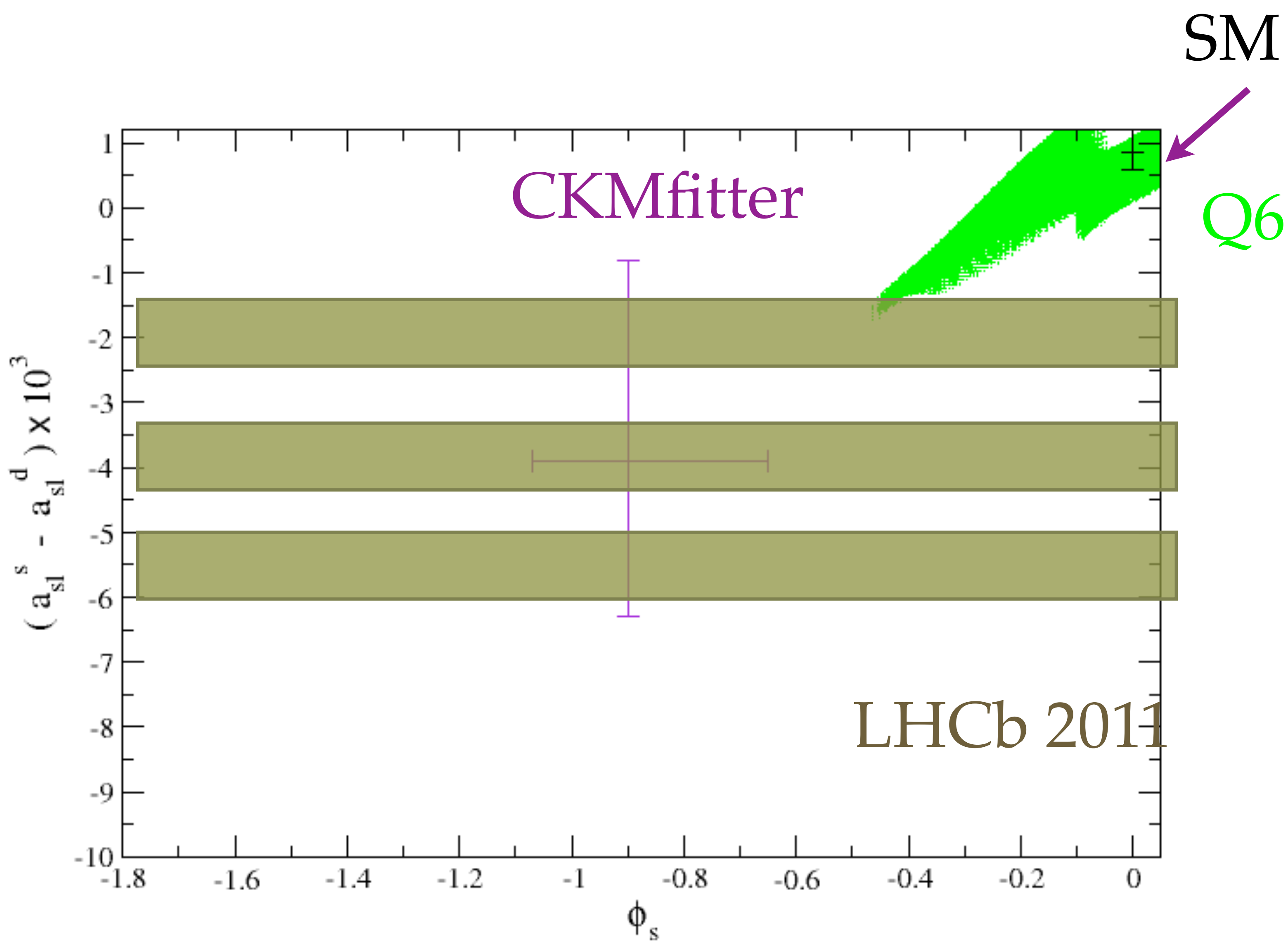
$$(\delta^d_{23})_{LL} \simeq -3.0 \times 10^{-2} \, \Delta a^q_L$$

tree

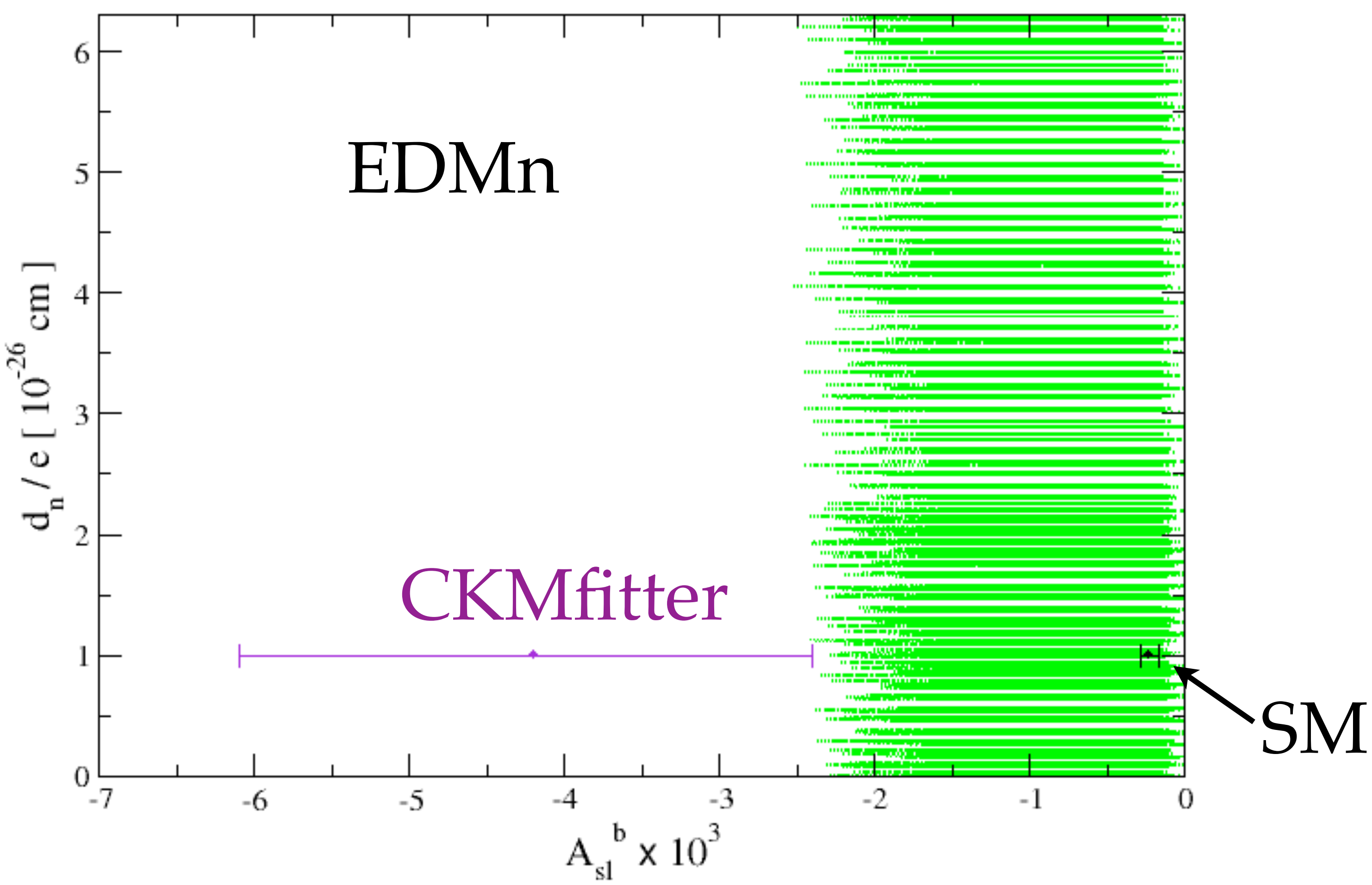
$$+(0.05 - i\, 8.6) \times 10^{-2} \left[\frac{0.5 \text{ TeV}}{m_{\tilde{d}}}\right]^2$$

one-loop


UTfit
CKMfitter
SM
Lenz+Nierste, `07
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
ϕ_d
-1.6
-1.4
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
ϕ_s



CDF: $\phi_s \in [-1, 0]$



D0+CDF : $A_{sl}^b = -(8.5 \pm 2.8) \cdot 10^{-3}$

If the Neutralino LSP = DarkMatter

EDM , $b \to s\gamma$ → small μ

a large CP → large μ

Upper and lower bound of $m_{\mathrm{DarkMatter}}$

$$120\ \mathrm{GeV} \lesssim m_{\mathrm{Dark\ Matter}} \lesssim 330\ \mathrm{GeV}$$

III Conclusion

* Flavor symmetry with spontaneous $\cancel{C}P$ can nicely suppress FCNCs and $\cancel{C}P$ in SUSY models.

$$\boxed{\begin{array}{ll} \mu & \text{: small to suppress EDMs} \\ M_H & \text{: large to suppress FCNC} \end{array}}$$

$$\Downarrow$$

$$\boxed{\text{Large SUSY breaking in the extra Higgs sector}}$$

* Built-in mechanism to keep $\cancel{C}P$ small in the first two generations, but to enhance $\cancel{C}P$ for the third generation.

* $120\ \mathrm{GeV} \lesssim m_{\mathrm{Dark\ Matter}} \lesssim 330\ \mathrm{GeV}$

Danke schön.