Flavor symmetry combined with spontaneous CP breaking to suppress FCNCs and CP violations

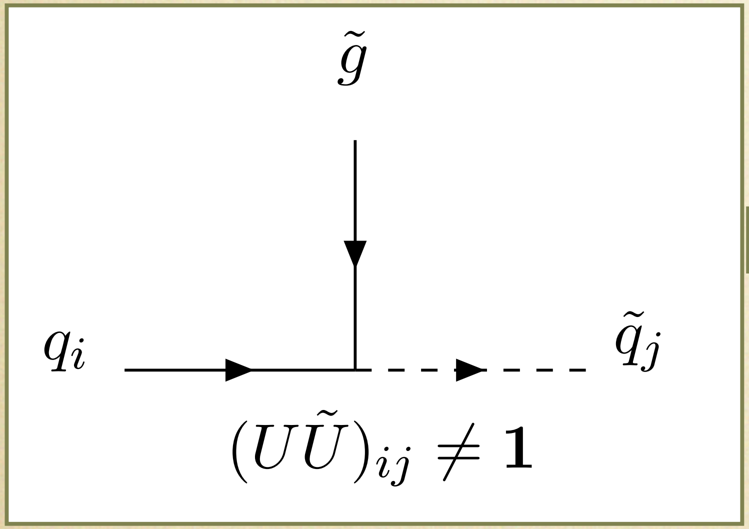
Jisuke Kubo (kanazawa Univ.)
at SUSY 2010

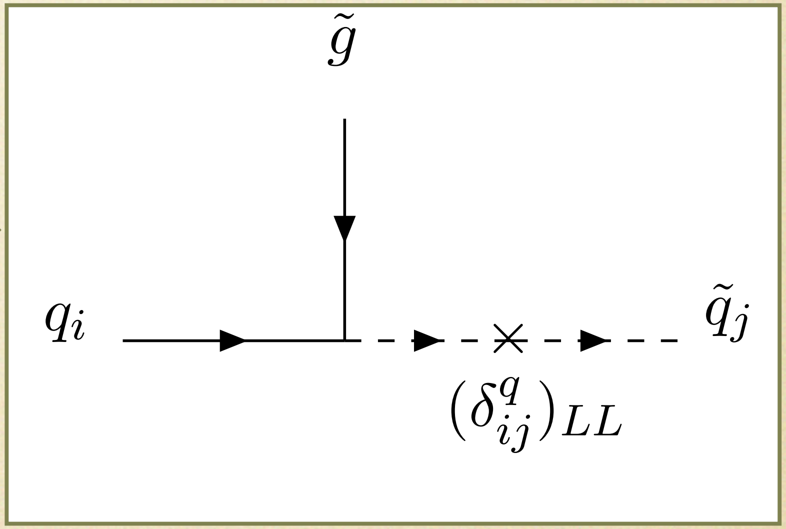
based on:

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, arXiv:1007.0680;
Babu and JK, to appear

The minimality of the Higgs sector does not help to suppress FCNCs and ~~CP~~.

Mismatch between flavors Soft mass insertions





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

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

We use:

a flavor symmetry to suppress FCNCs,

and break CP spontaneously to suppress ~~CP~~

A SUSY model based on Q6 x Z4

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

SM non-singlet | *SM singlet*

	Q, L	Q_3, L_3	U^c, D^c, N^c, E^c	$U_3^c, D_3^c, N_3^c, E_3^c$	$H^{u,d}$	$H_3^{u,d}$	S	S_3	T	T_3	U
Q_6	$\mathbf{2}_1$	$\mathbf{1}_{+2}$	$\mathbf{2}_2$	$\mathbf{1}_{-,1}$	$\mathbf{2}_2$	$\mathbf{1}_{-1}$	$\mathbf{2}_1$	$\mathbf{1}_{+,0}$	$\mathbf{2}_2$	$\mathbf{1}_{+2}$	$\mathbf{1}_{+,0}$
Z_4	$-i$	$-i$	$+$	$+$	i	i	$-$	$-$	$+$	$+$	$+$

2+1=3 structure except U

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

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.

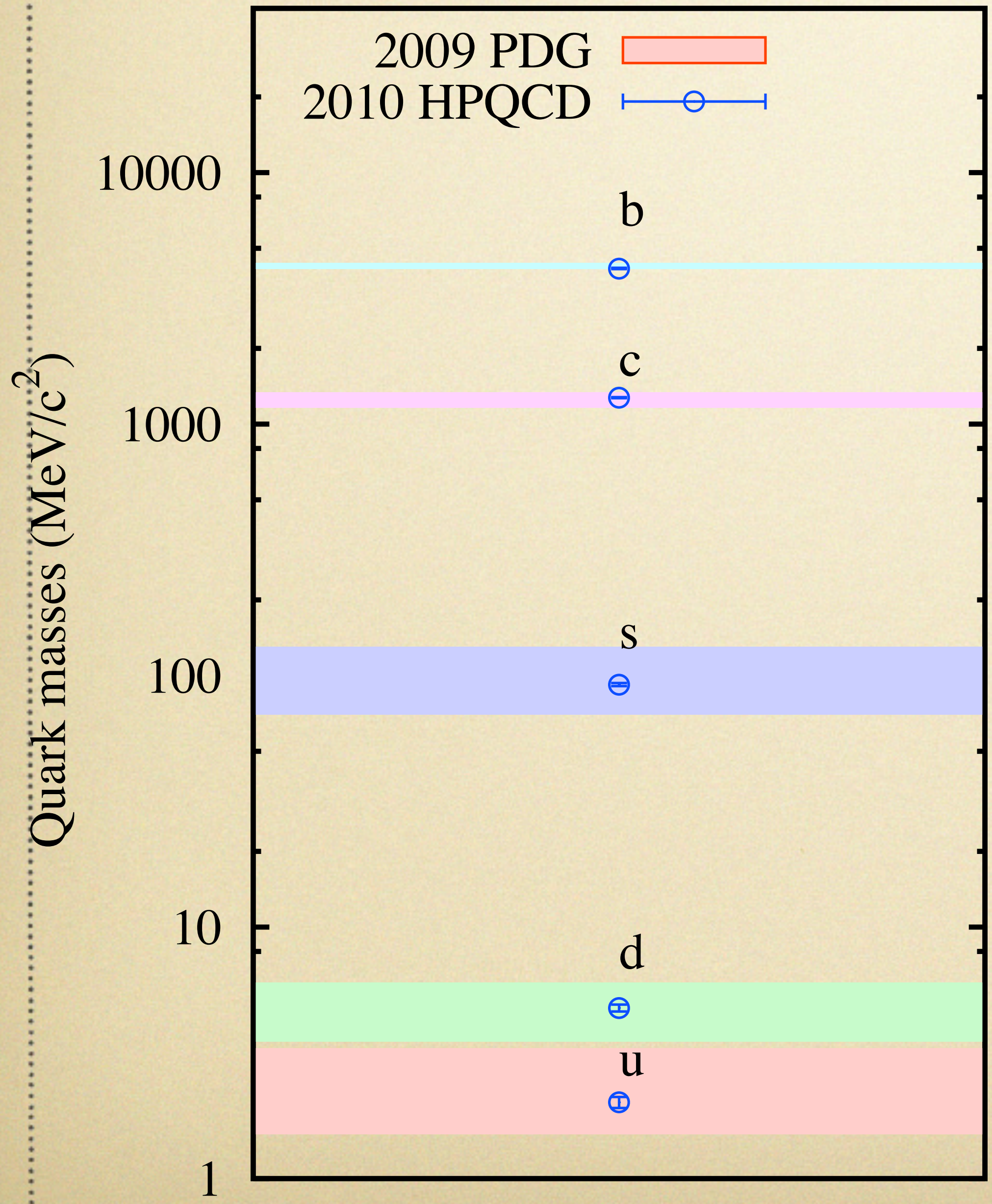
9 theory parameters for
6 quark masses and 4 CKM parameters.

↓

One sum rule among them

Precise quark masses

HPQCD, **arXiv:1004.4285** [hep-lat] **and P.R.L.104: 132003, 2010**.



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

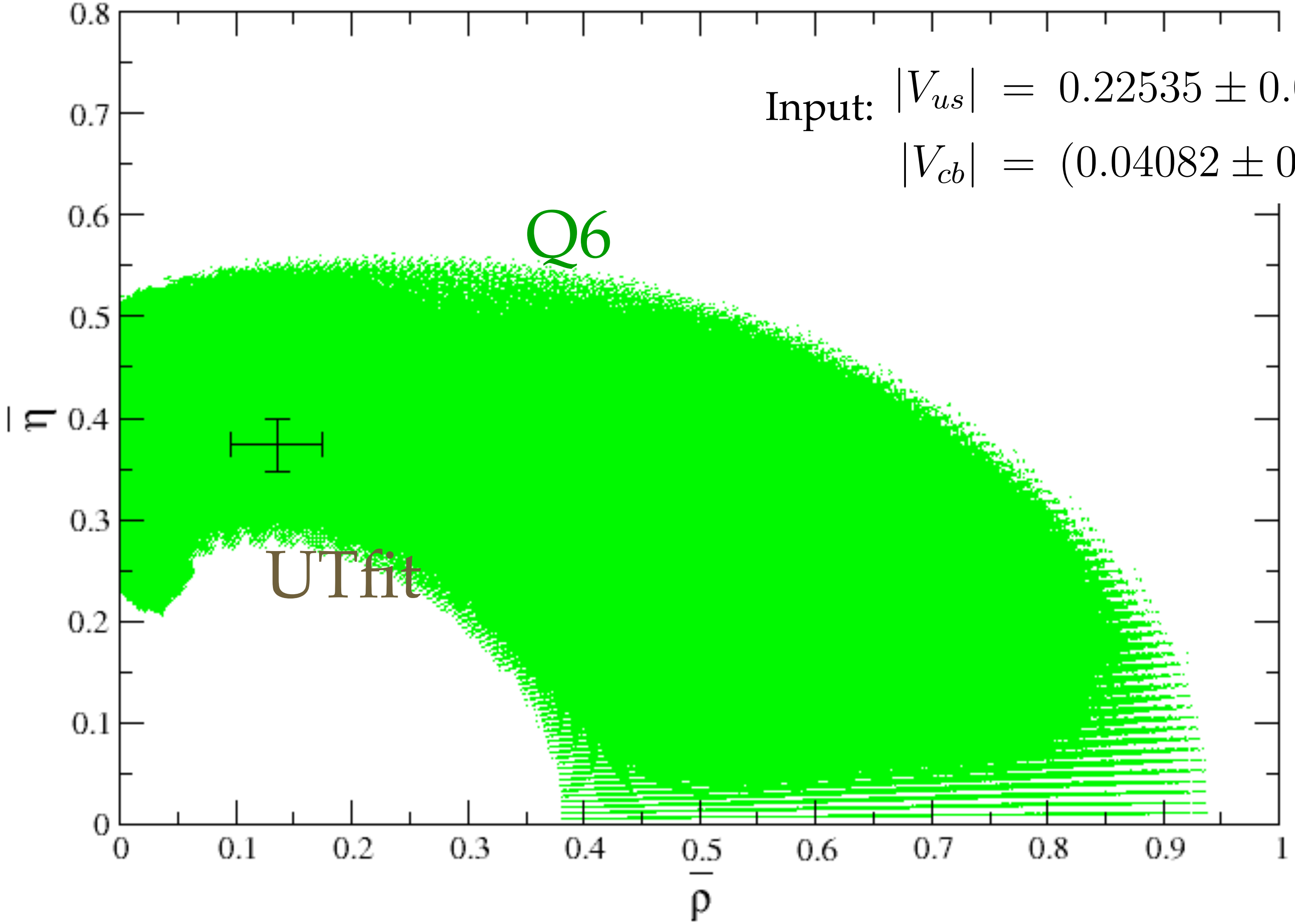
$$\Delta m_c \;:\; 9\% \rightarrow 1.3\%$$

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

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

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

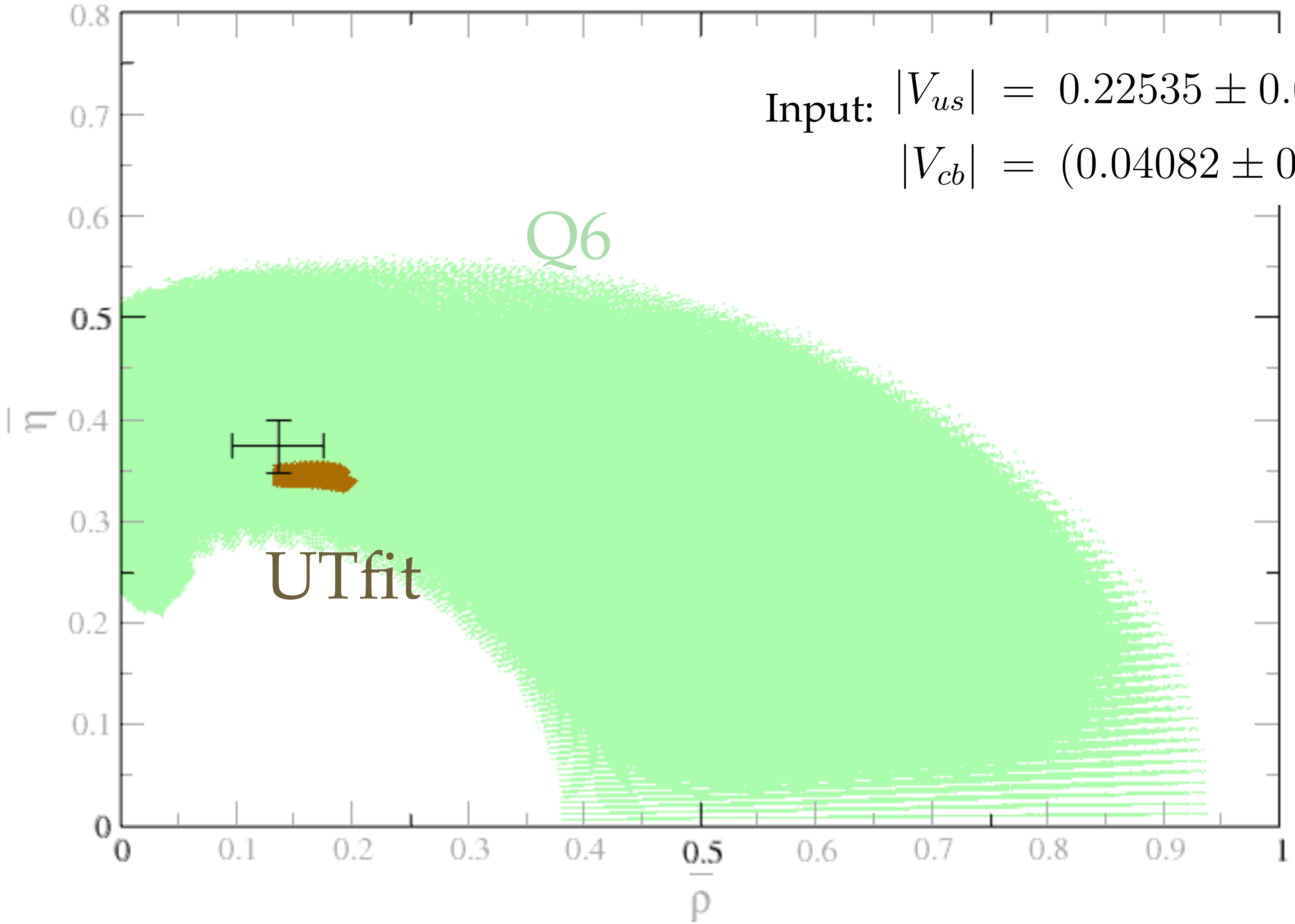
Q6 sum rule (Vacuum I)



using mq of PDG

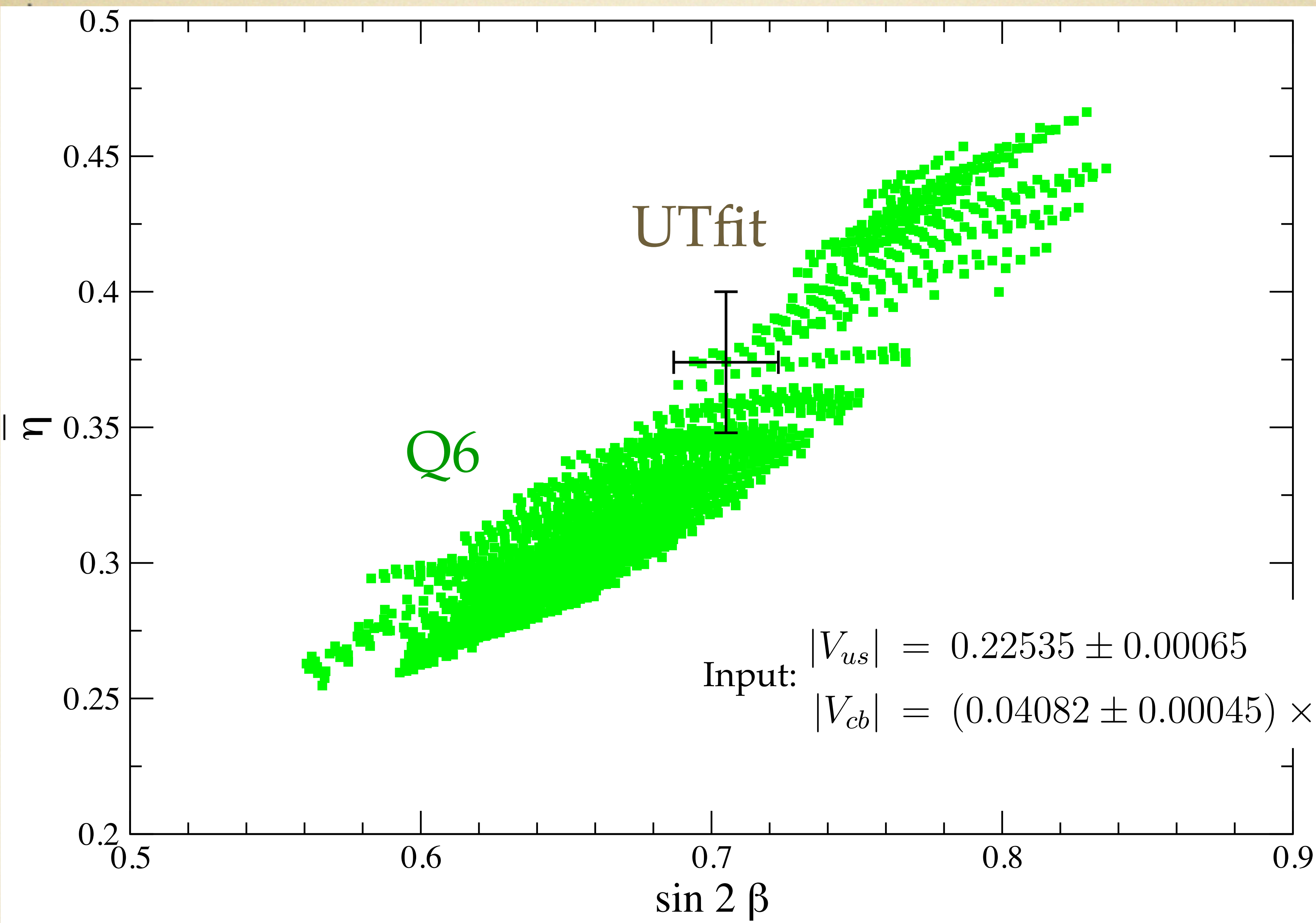
Q6 sum rule (Vacuum I)

Input: $$\begin{aligned}|V_{us}| &= 0.22535 \pm 0.00065 \\ |V_{cb}| &= (0.04082 \pm 0.00045) \times 1.015\end{aligned}$$



using HPQCD mq with 2 sigma

Q6 sum rule (Vacuum I)

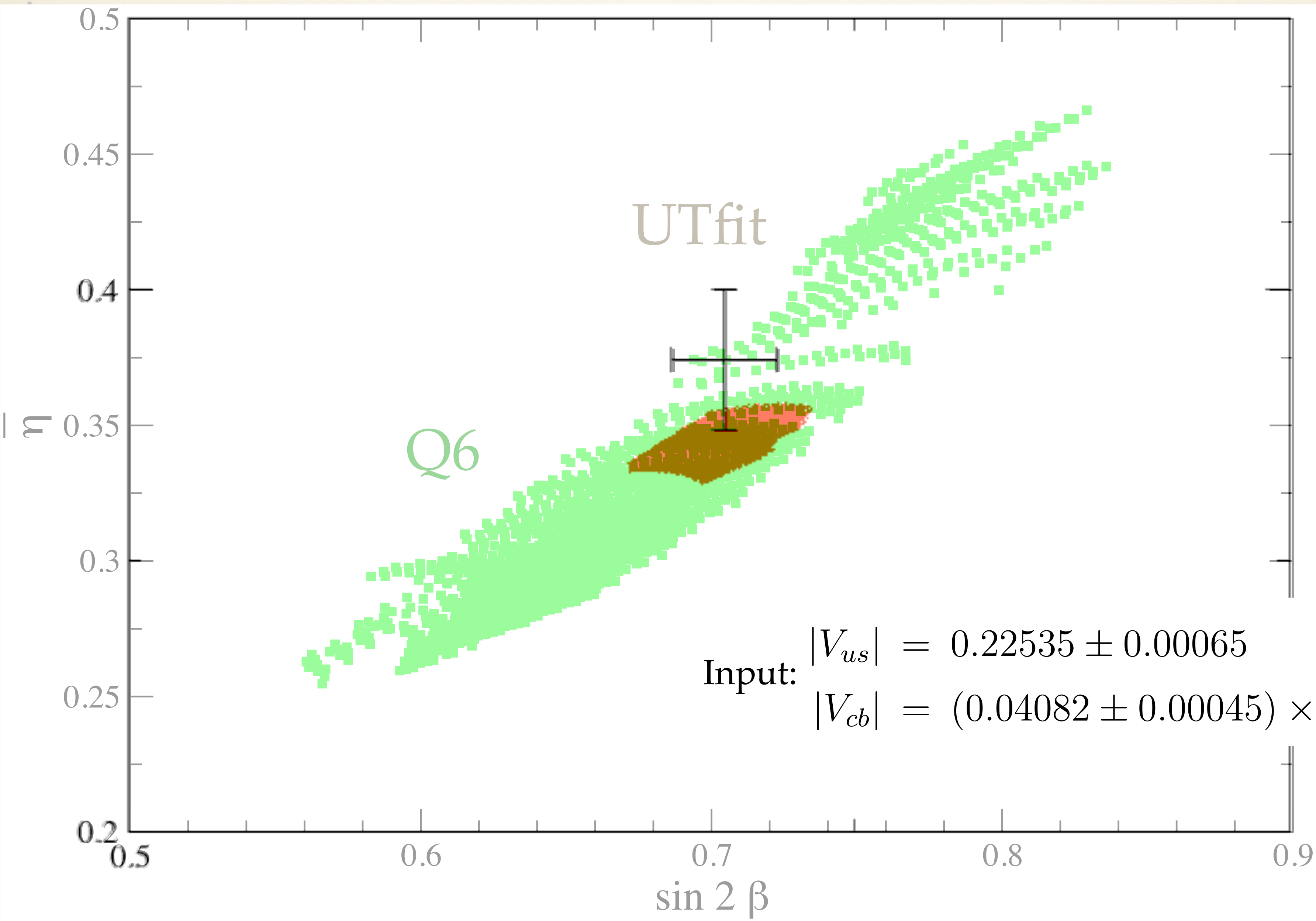


Input: $|V_{us}| = 0.22535 \pm 0.00065$

$|V_{cb}| = (0.04082 \pm 0.00045) \times 1.015$

using mq of PDG

Q6 sum rule (Vacuum I)



Input: $|V_{us}| = 0.22535 \pm 0.00065$

$|V_{cb}| = (0.04082 \pm 0.00045) \times 1.015$

using HPQCD mq with 2 sigma

Prediction in

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

Lenz-Nierste parameterization

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

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

Master equations for observables

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

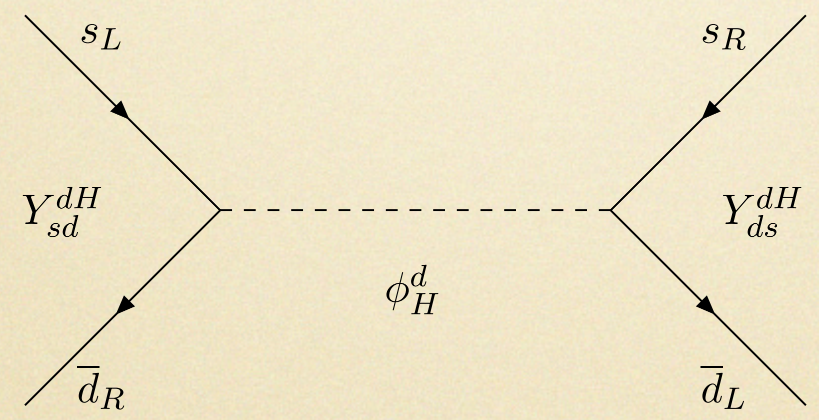
$$a_{sl}^q = \frac{|\Gamma_{12}^q|}{|M_{12}^{SM,q}|} \cdot \frac{\sin\left(\phi_q^{SM} + \phi_q^\Delta\right)}{|\Delta_q|}$$

In the Q6 model:

I. <u>Extra Higgs sector</u>

Tree-level contributions with real Yukawas

phase alignment



only real contribution to M^q_{12}

$\Delta M_q \sim M_H^{-2}$ but small ϕ_q^Δ

II. SUSY breaking (at tree-level)

$$(\delta_{ij})_{LL,RR} = U^{q\dagger}_{L,R} \begin{pmatrix} a_{L,R} & 0 & 0 \\ 0 & a_{L,R} & 0 \\ 0 & 0 & b_{L,R} \end{pmatrix} U^{q}_{L,R}$$ ◀ 2+1 family structure

real → $(\delta_{ij})_{LL,RR}$

phase alignment

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

→ EDMs

→ small μ s

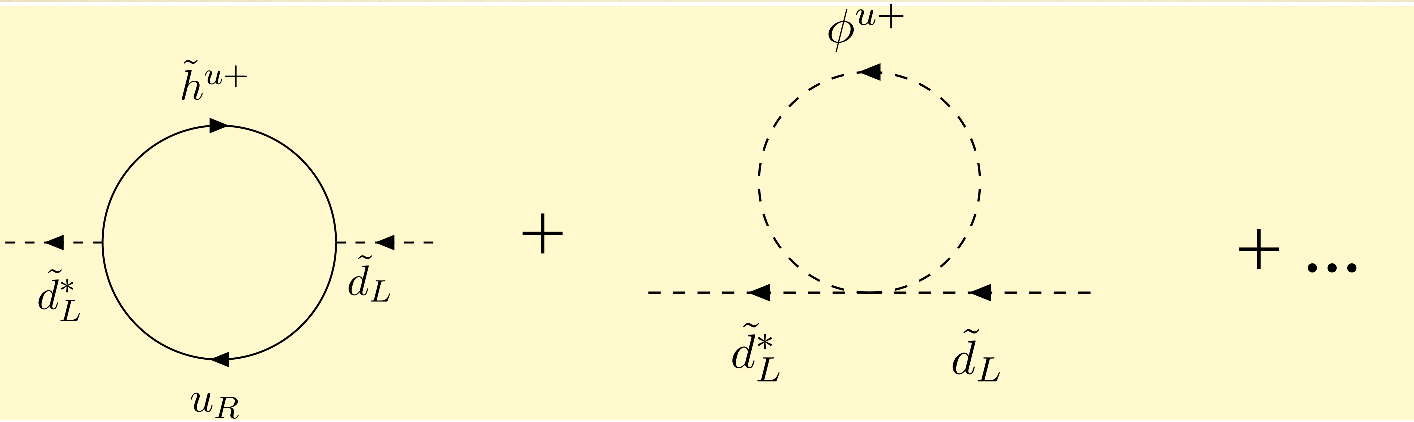
→ little contribution to $\mathrm{Im}\, M^q_{12}$

$\mathrm{I} + \mathrm{II} \quad \Rightarrow \quad -0.023 \lesssim \phi_s^\Delta \lesssim 0.009$

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

III. Loop effects to (δ_{ij})

JK and Lenz, arXiv:1007.0680



quadratic and logarithmic ∞ cancel.

softness

flavor symmetry

However, large finite terms.

large susy breaking

small μ and large M_H

EDM FCNC

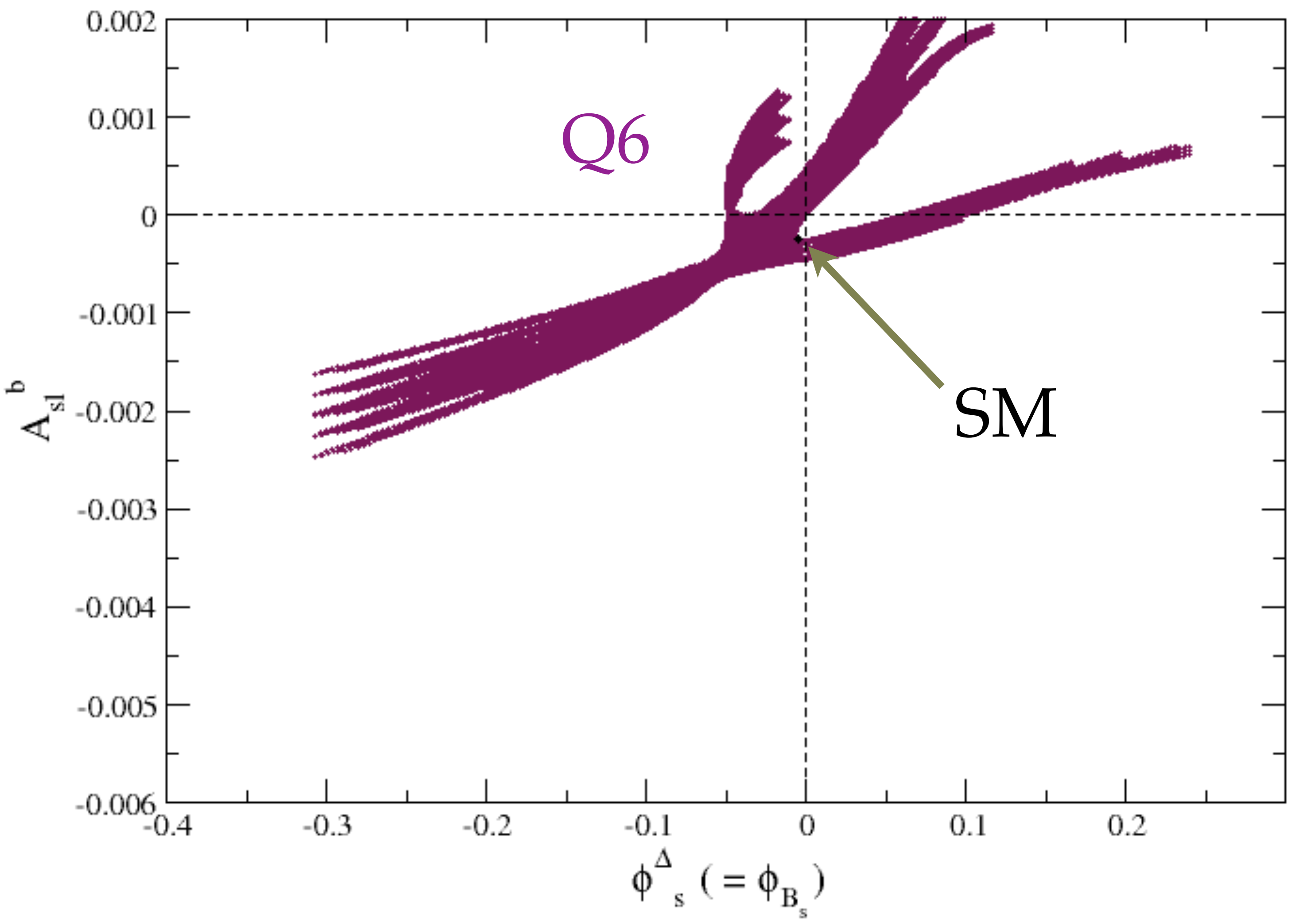
Mass of extra Higgions extra Higgbosons

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

tree

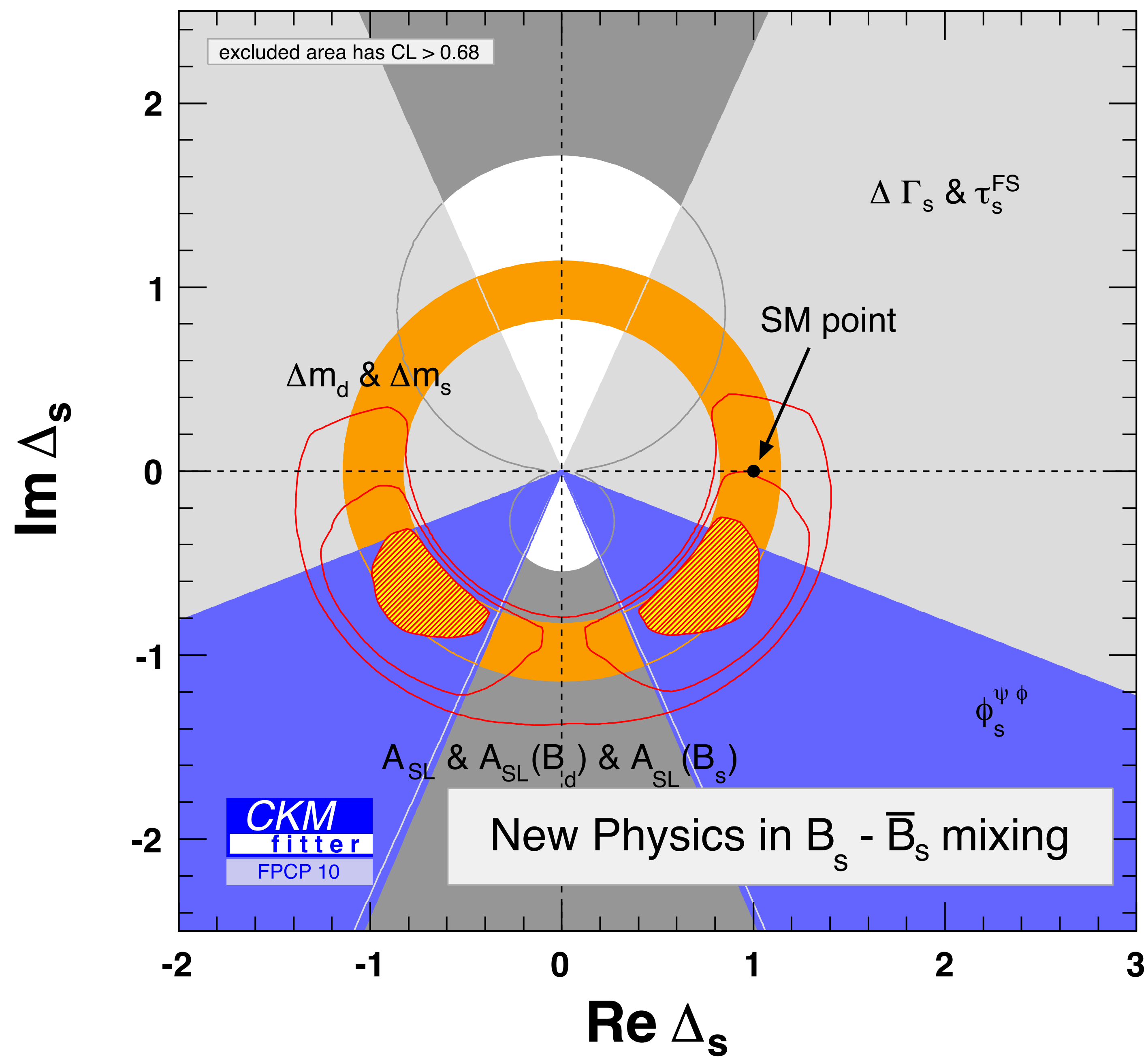
$$+(0.05 - i\,8.6) \times 10^{-2} \left[\frac{0.5 \text{ TeV}}{m_{\tilde{d}}}\right]^2$$

one-loop

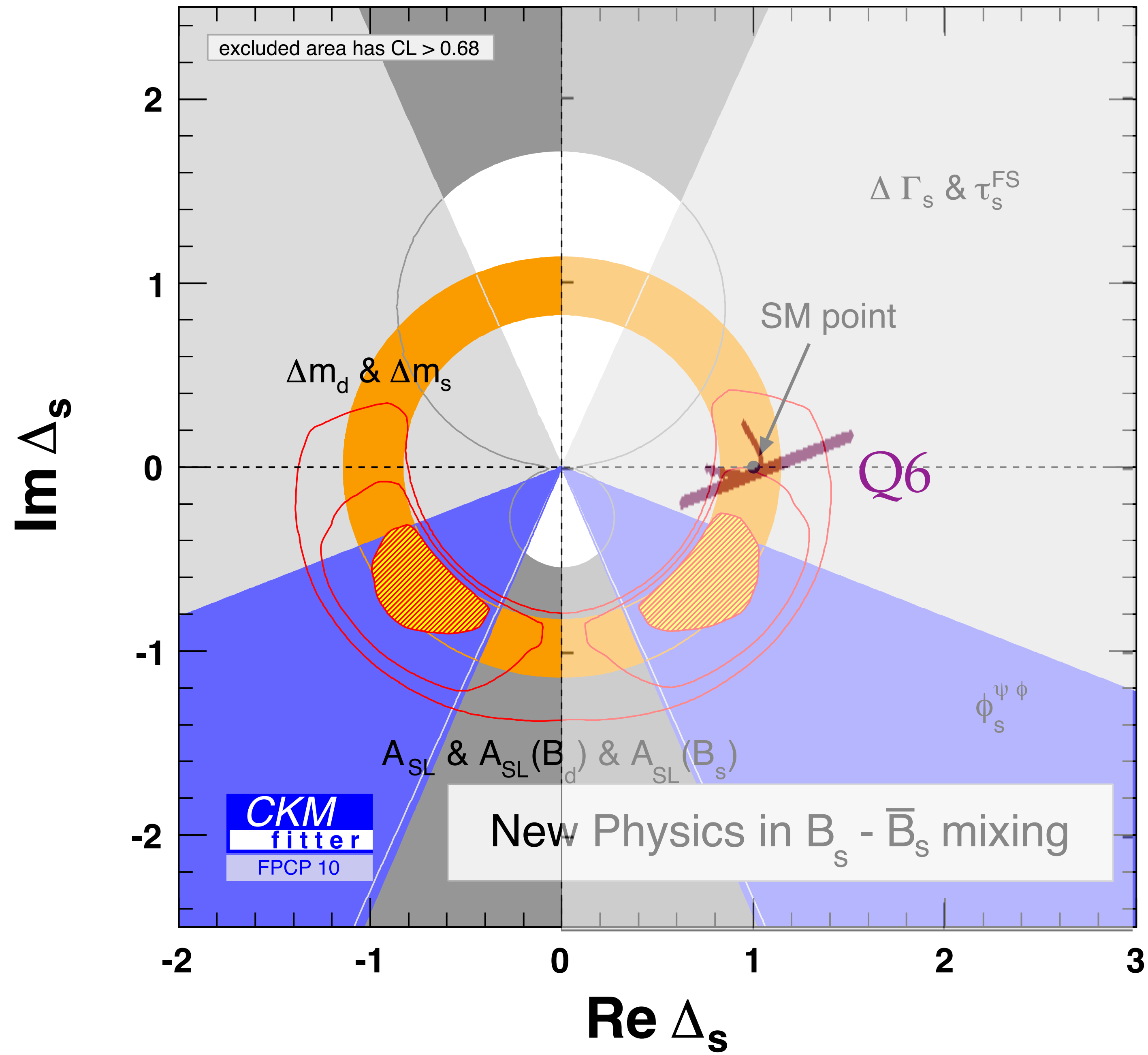


D0: $A_{sl}^{b} = -(9.57 \pm 2.51 \pm 1.46) \cdot 10^{-3}$

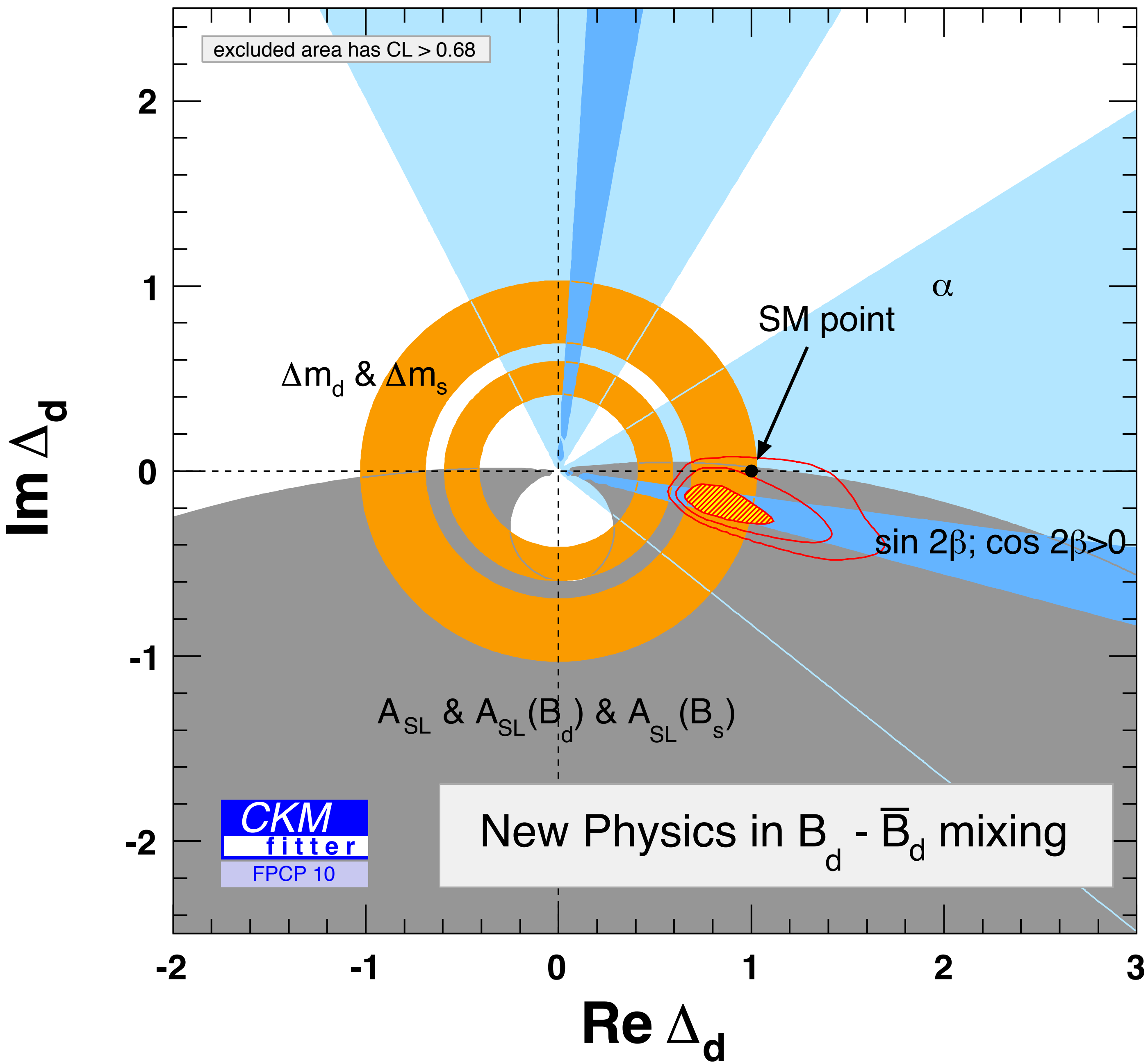
CDF: $\phi_s^{\Delta} \in [0, -1]$



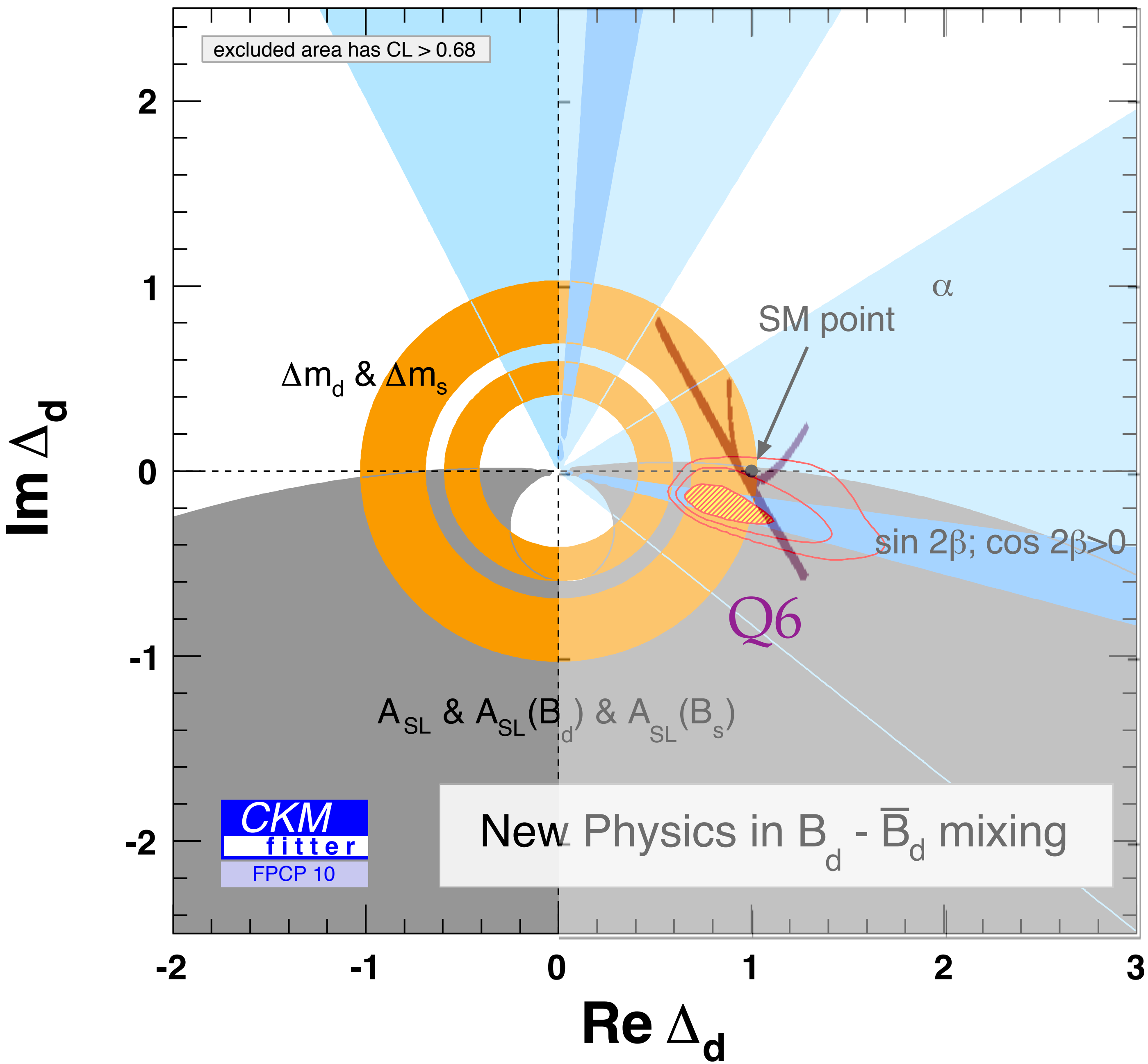
excluded area has CL > 0.68
Δ Γs & τsFS
SM point
Δmd & Δms
ϕsψϕ
ASL & ASL(Bd) & ASL(Bs)
CKM fitter
FPCP 10
New Physics in Bs - B̄s mixing
Im Δs
Re Δs
2
1
0
-1
-2
-2
-1
0
1
2
3



excluded area has CL > 0.68
Δ Γs & τs FS
SM point
Δmd & Δms
Q6
φs ψ φ
ASL & ASL(Bd) & ASL(Bs)
CKM fitter
FPCP 10
New Physics in Bs - B̄s mixing
Im Δs
Re Δs
2
1
0
-1
-2
-2
-1
0
1
2
3



excluded area has CL > 0.68
SM point
α
Δm_d & Δm_s
sin 2β; cos 2β>0
A_{SL} & $A_{SL}(B_d)$ & $A_{SL}(B_s)$
CKM fitter
FPCP 10
New Physics in B_d - $\overline{B}_d$ mixing
Im Δ_d
Re Δ_d
-2
-1
0
1
2
3



excluded area has CL > 0.68
Δm_d & Δm_s
SM point
α
sin 2β; cos 2β>0
Q6
A_SL & A_SL(B_d) & A_SL(B_s)
CKM fitter
FPCP 10
New Physics in B_d - B̄_d mixing
Im Δ_d
Re Δ_d
2
1
0
-1
-2
-2
-1
0
1
2
3

Conclusion

*Flavor symmetry with spontaneous CP can nicely suppress FCNCs and CP in SUSY models.

μ : small to suppress EDMs
M_H : large to suppress FCNC

↓

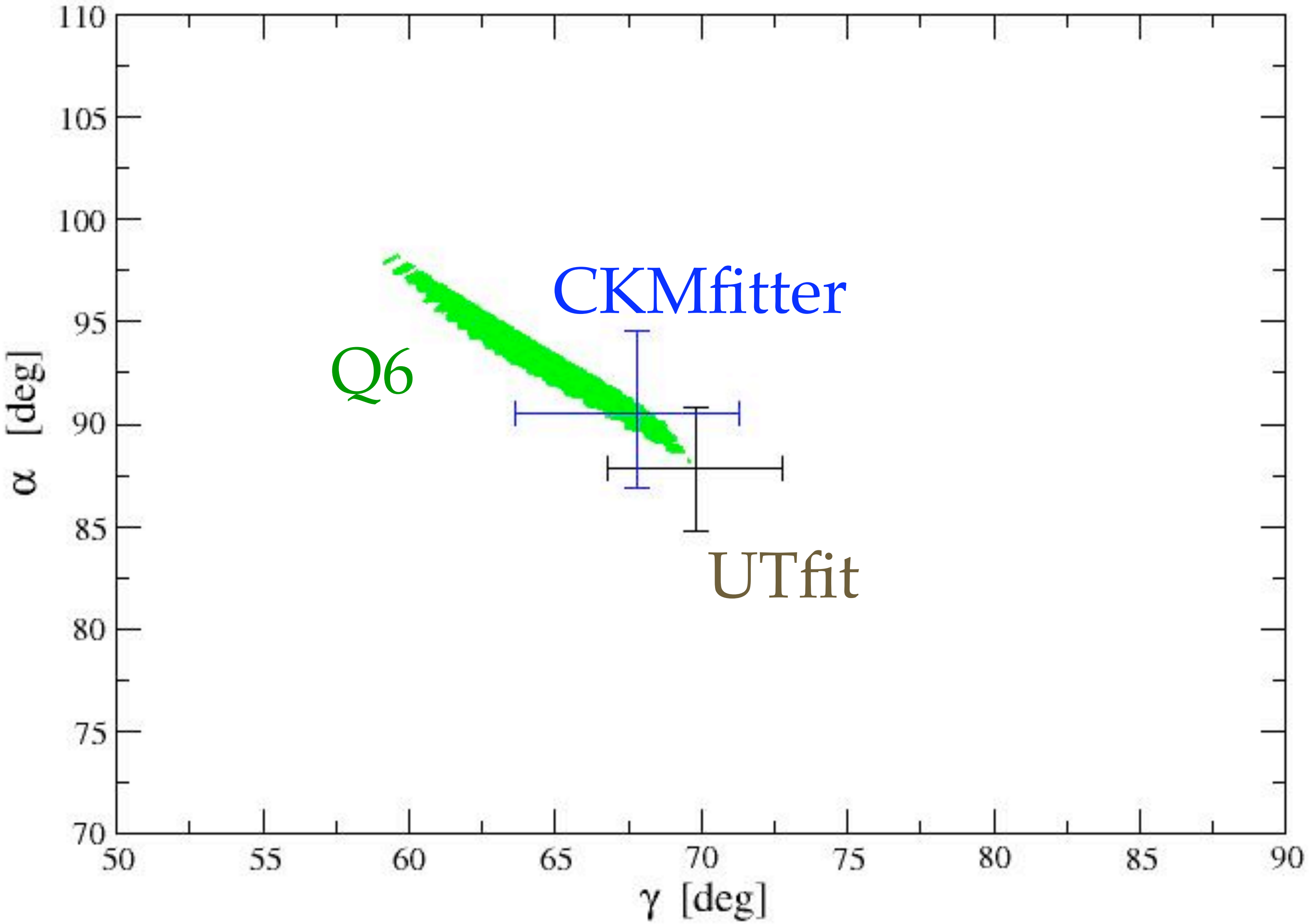
Large SUSY breaking in the extra Higgs sector

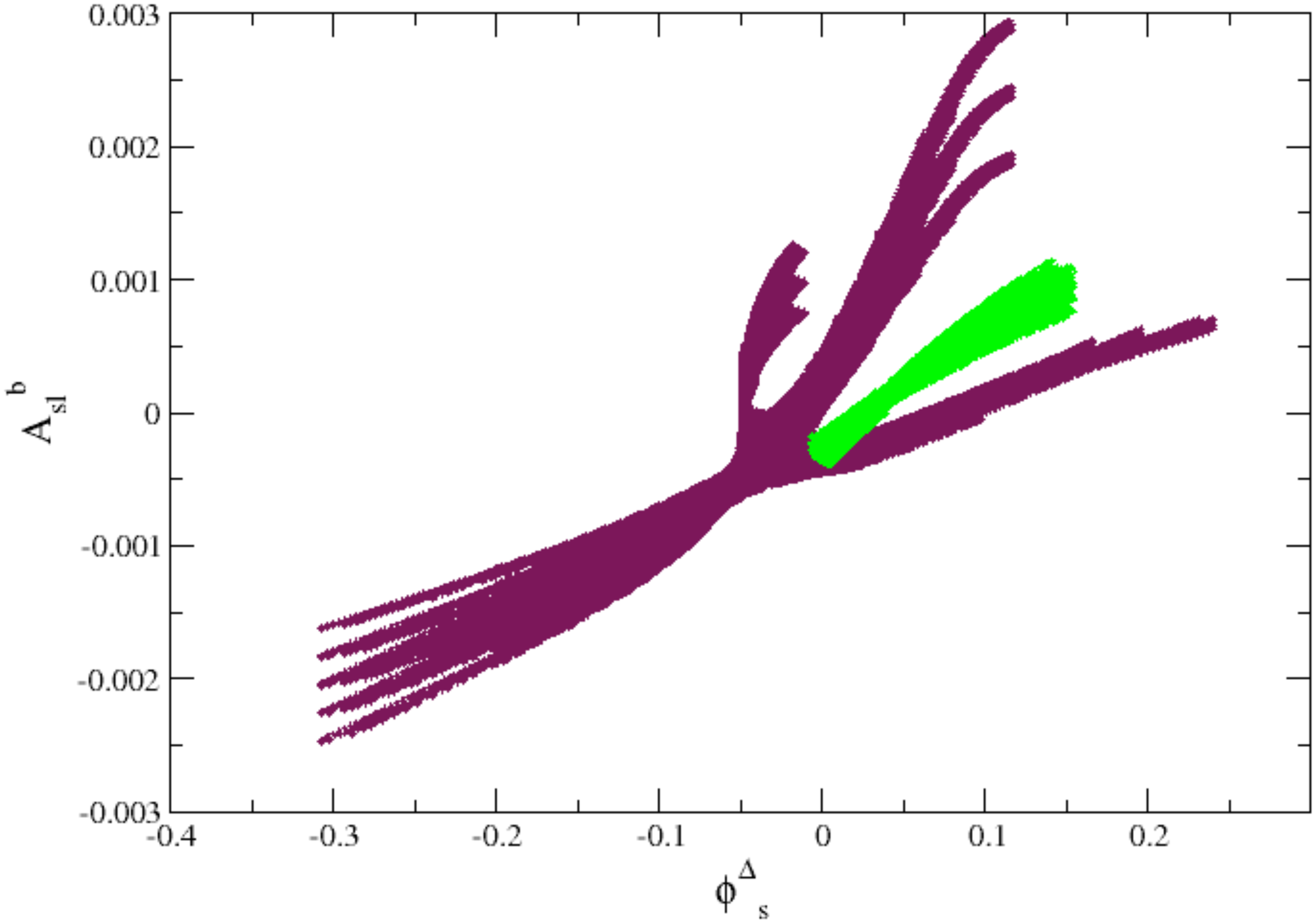
↓

* Large loop effects to large CP in the B mixing

Danke Schön

Q6 sum rules (Vacuum I)





0.003
0.002
0.001
0
-0.001
-0.002
-0.003
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
A_{sl}^{b}
ϕ_s^{Δ}

$$\left\{ \begin{array}{l} \mathrm{Im}(\delta^d_{11})_{LR} = 3.7 \\ \mathrm{Im}(\delta^u_{11})_{LR} = 1.3 \end{array} \right. \times 10^{-6} \times \left[\frac{0.5 \ \mathrm{TeV}}{m_{\tilde{d}}} \right]^2$$

$$\left. \begin{array}{l} 0.6 \\ 0.8 \end{array} \right\} < \frac{\Delta M_{d,s}}{\Delta M^{\mathrm{exp}}_{d,s}} < \left\{ \begin{array}{l} 1.4 \\ 1.2 \end{array} \right. , \quad \frac{2|M^{SUSY,K}_{12}|}{\Delta M^{\mathrm{exp}}_K} < \left\{ \begin{array}{ll} 2 & I \\ 1 & II \end{array} \right.$$

$$\frac{\mathrm{Im} M^{SUSY,K}_{12}}{\sqrt{2} \Delta M^{\mathrm{exp}}_K} < \epsilon_K = 2.2 \times 10^{-3} \ ,$$

Neutrino sector:

1. Inverted neutrino mass spectrum, i.e., $m_{\nu_3} < m_{\nu_1}, m_{\nu_2}$

2. $m_{\nu_2}^2/\Delta m_{23}^2 = \frac{(1+2t_{12}^2+t_{12}^4-rt_{12}^4)^2}{4t_{12}^2(1+t_{12}^2)(1+t_{12}^2-rt_{12}^2)\cos^2\phi_\nu} - \tan^2\phi_\nu$

   $(r = \Delta m_{21}^2/\Delta m_{23}^2,\ t_{12} = \tan\theta_{12})$

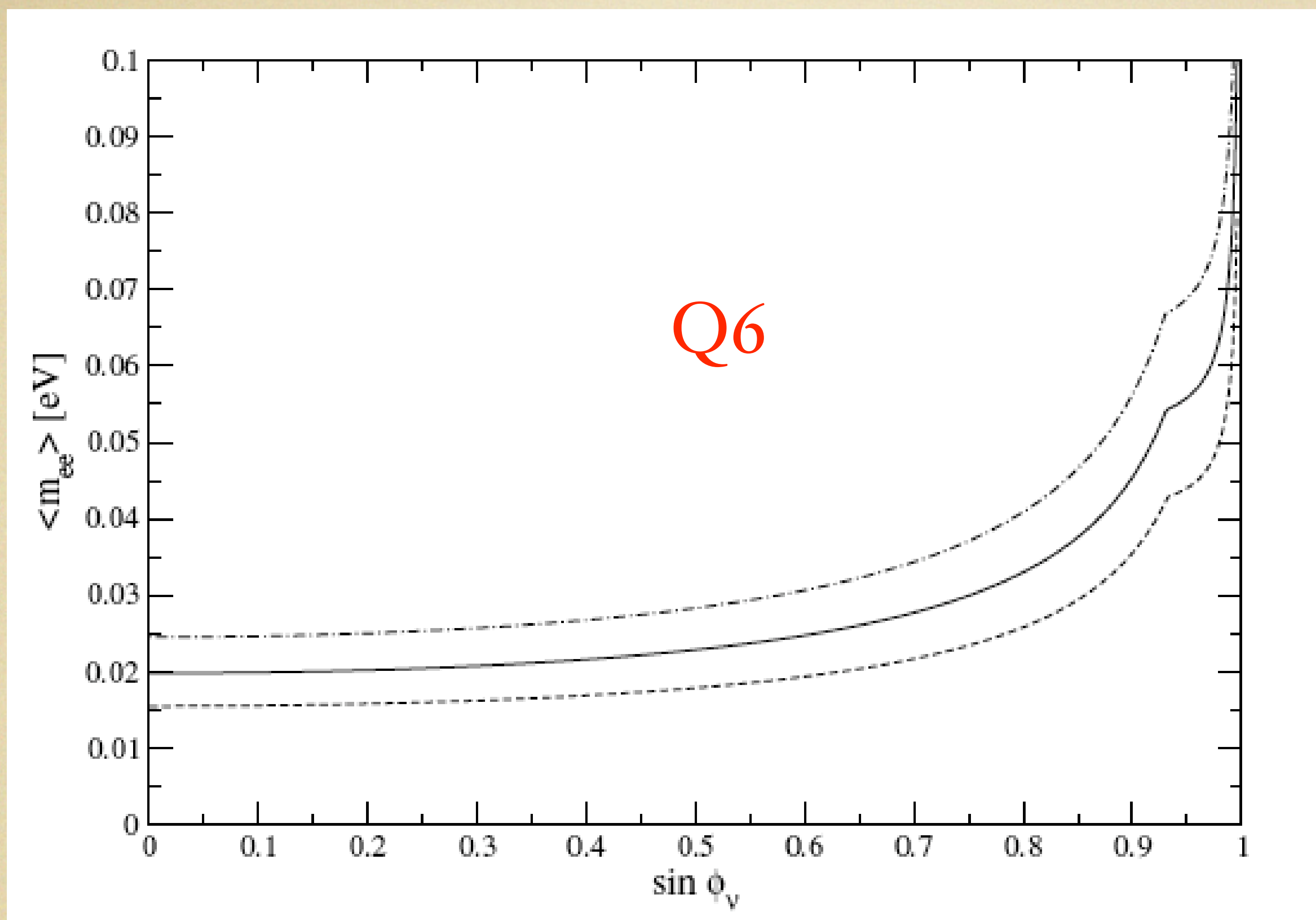
Dirac phase

3. $\sin^2\theta_{13} = \frac{1}{2}(m_e/m_\mu)^2 \simeq 10^{-6}$

   $\sin^2\theta_{23} = \frac{1}{2} + O((m_e/m_\mu)^2)$

Violation of $\mu - \tau$ symmetry

Almost maximal mixing of the atm. neutrinos



$(WMAP : \lesssim 0.17 \text{ eV})$

Input:

$$\sin^2\theta_{12} = 0.3 \text{ and } \Delta m^2_{21} = 6.9 \times 10^{-5} \text{ eV}^2$$

$$\Delta m^2_{23} = 1.4, 2.3 \text{ and } 3.0 \times 10^{-3} \text{ eV}^2$$