Right unitarity triangles from discrete symmetries and unification

Martin Spinrath

PLANCK 2012 - 30th May

Based on collaborations with S. Antusch, S.F. King, C. Luhn and M. Malinsky:
PRD 81 (2010) 033008, PRD 83 (2011) 013005, NPB 850 (2011) 477

The Sum Rules

[Antusch, King, Malinsky, MS 2010]

$$\theta_{12}^u = \frac{\theta_{13}}{\theta_{23}} = (4.96 \pm 0.30)^\circ$$

$$\theta_{12}^d = \left| \theta_{12} - \frac{\theta_{13}}{\theta_{23}} e^{-i\delta_{\rm CKM}} \right| = \left(12.0^{+0.39}_{-0.22}\right)^\circ$$

$$\alpha = \delta_{12}^d - \delta_{12}^u = \left(89.0^{+4.4}_{-4.2}\right)^\circ$$

[Numbers based on PDG]

Idea: Mass matrices with purely real/imaginary elements!

[Antusch, King, Malinsky, MS 2010]
see also [Fritzsch and Xing; Masina and Savoy 2006; Harrison, Dallison, Roythorne, Scott 2009]

The Method

[Antusch, King, Luhn, MS 2011]

- Use family symmetry to align flavon, e.g.:

$$\langle\phi\rangle \propto (0,0,x)^T \quad \text{or} \quad \langle\phi\rangle \propto (x,x,x)^T$$

- Add term to W compatible with shaping symmetry:

$$P\left(\frac{\phi^n}{\Lambda^{n-2}} \mp M^2\right)$$

- Solve F-term condtions ($|F_P|=0$)

$$\arg(\langle\phi\rangle) = \arg(x) = \begin{cases} \frac{2\pi}{n}q\,, \quad q=1,\ldots,n & \text{for } \text{“}-\text{”} \\ \frac{2\pi}{n}q+\frac{\pi}{n}\,, \quad q=1,\ldots,n & \text{for } \text{“}+\text{”} \end{cases}$$

[Real alignment used in Meroni, Petcov, MS 2012, see also talk by A. Meroni]

And now for something (completely) different...

Two Approaches for Flavour Models with Large θ_{13}

Martin Spinrath

PLANCK 2012 - 30th May

Based on D. Marzocca, S. T. Petcov, A. Romanino, MS JHEP 1111 (2011) 009 [arXiv:1108.0614]
S. Antusch, S.F. King, C. Luhn, MS Nucl. Phys. B856 (2012) 328-341 [arXiv:1108.4278]

Outline

- Status
- Possibility I: Charged Lepton Corrections
- Possibility II: Trimaximal Mixing
- Summary and Conclusions

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May 2012

	March 2011, NH	May 2012, NH
$\sin^2\theta_{12}$	$0.312^{+0.017}_{-0.015}$	$0.320^{+0.015}_{-0.017}$
$\sin^2\theta_{23}$	0.51 ± 0.06	$0.49^{+0.08}_{-0.05}$
$\sin^2\theta_{13}$	$0.010^{+0.009}_{-0.006}$	$0.026^{+0.003}_{-0.004}$
δ	?	$(0.83^{+0.54}_{-0.64})\pi$
	[Schwetz, Tortola, Valle 2011]	**[Tortola, Valle, Vanegas 2012]**

So what?

- Very popular before: (Tri-)Bimaximal Mixing

$$\sin^2\theta_{12} = \left(\frac{1}{3}\right)\frac{1}{2}\,, \quad \sin^2\theta_{23} = \frac{1}{2}\,, \quad \sin^2\theta_{13} = 0$$

- Possible modifications? Plenty...
  - Solution I: Charged Lepton Sector Corrections

    [Antusch, Maurer `11; Marzocca, Petcov, Romanino, MS `11]
  - Solution II: Trimaximal Mixing

    [Antusch, King, Luhn, MS `11]

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The Setup

[Marzocca et al.`11, see also Antusch, Maurer`11]

- No 1-3 mixing in the neutrino and only 1-2 mixing in the charged lepton sector:

$$\sin\theta_{13} \approx \sin\theta_{12}^{e} \sin\theta_{23}^{\nu} \approx \frac{1}{\sqrt{2}} \frac{\beta'}{\gamma} \frac{b'}{c}$$

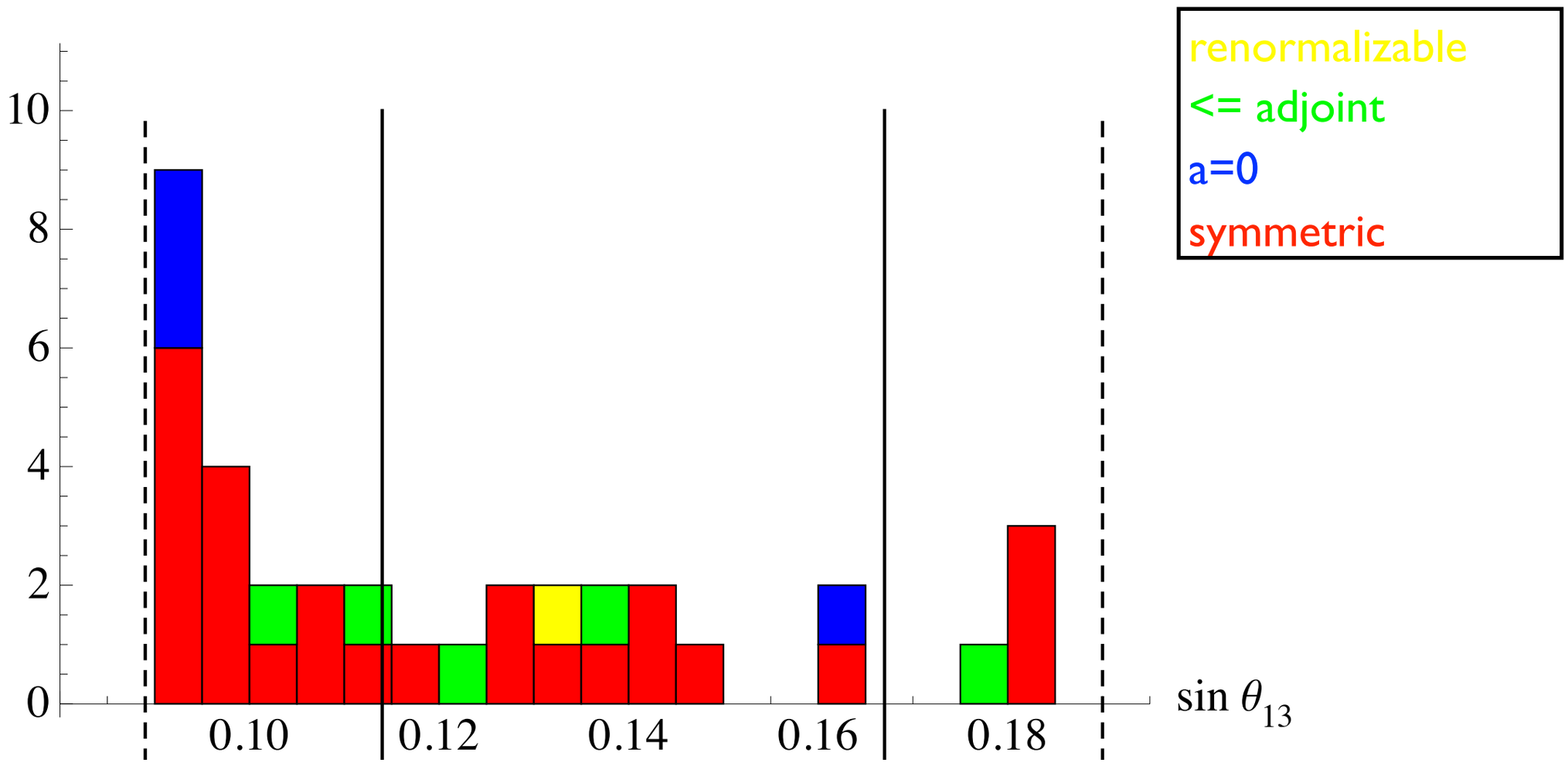
- Assume SU(5):

$$\hat{\lambda}^{D}_{[12]} = \begin{pmatrix} a & b' \\ b & c \end{pmatrix} \qquad \hat{\lambda}^{E}_{[12]} = \begin{pmatrix} \alpha a & \beta b \\ \beta' b' & \gamma c \end{pmatrix}$$

- $\alpha, \beta, \beta', \gamma$ are SU(5) Clebsch-Gordan coefficients (1, -3/2, -3 , 9/2, 6, ...)

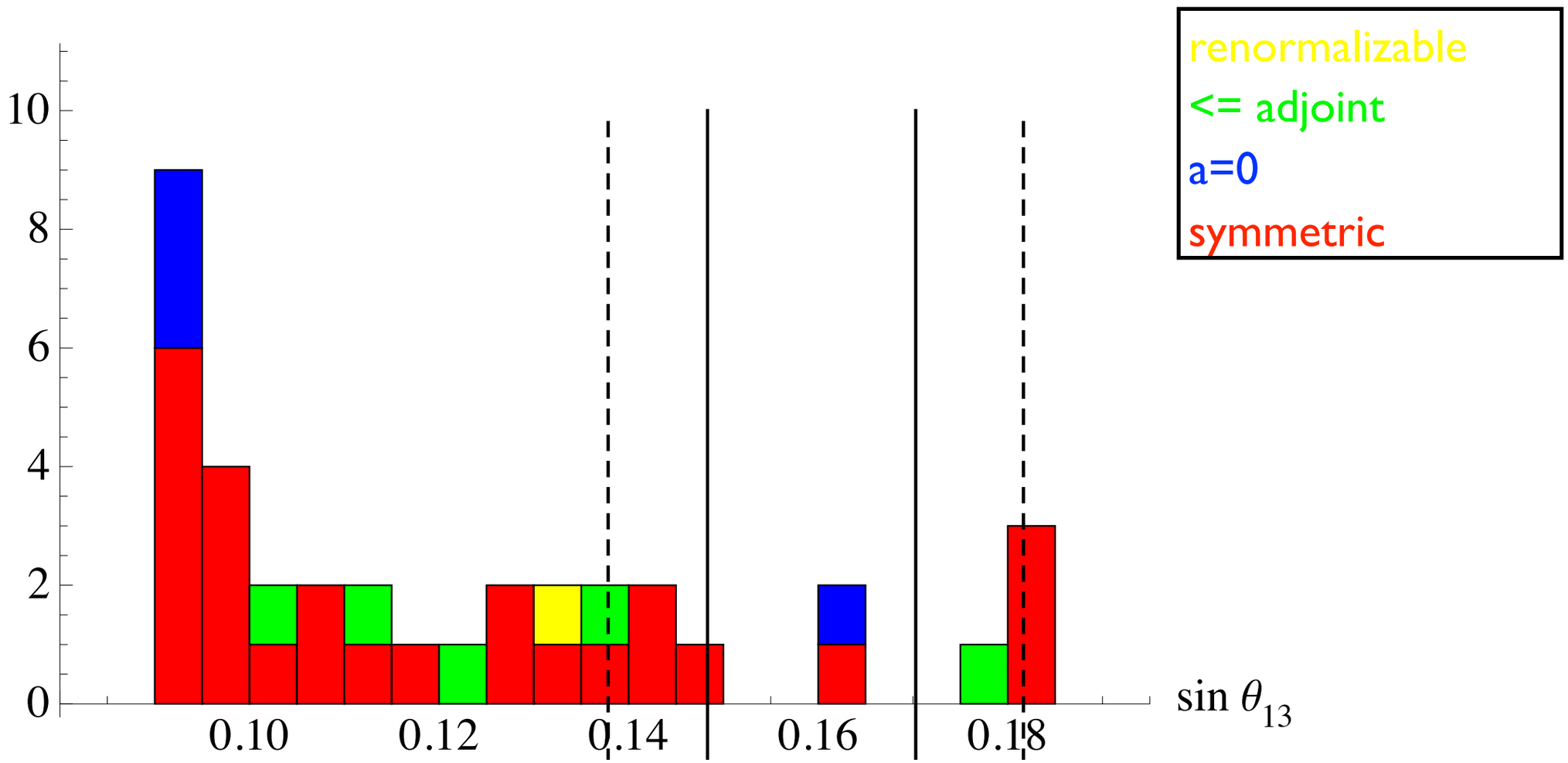
[For non-standard relations, see Antusch, MS `09]

After Fitting to Exp. Data (June `11)



[Taken from Marzocca *et al.* `11, based on the global fit by Fogli *et al.* `11]

After Fitting to Exp. Data (May `12)



[Based on the global fit by Tortola, Valle, Vanegas `11, Thanks to D. Marzocca for providing this plot]

The Good Cases

$\{\alpha, \beta, \beta', \gamma\}$	$\sin\theta_{13}$
$\{-, -1/2, 6, 6\}$	0.164 ± 0.013
$\{-3/2, -3, -3, -3\}$	0.164 ± 0.007
$\{-18, 9/2, 9/2, 9/2\}$	0.149 ± 0.003

[Taken from Marzocca *et al.* `11]

For a model implementation see talk by A. Meroni

[A. Meroni, S. T. Petcov, MS `11]

Corrections to other Mixing Angles

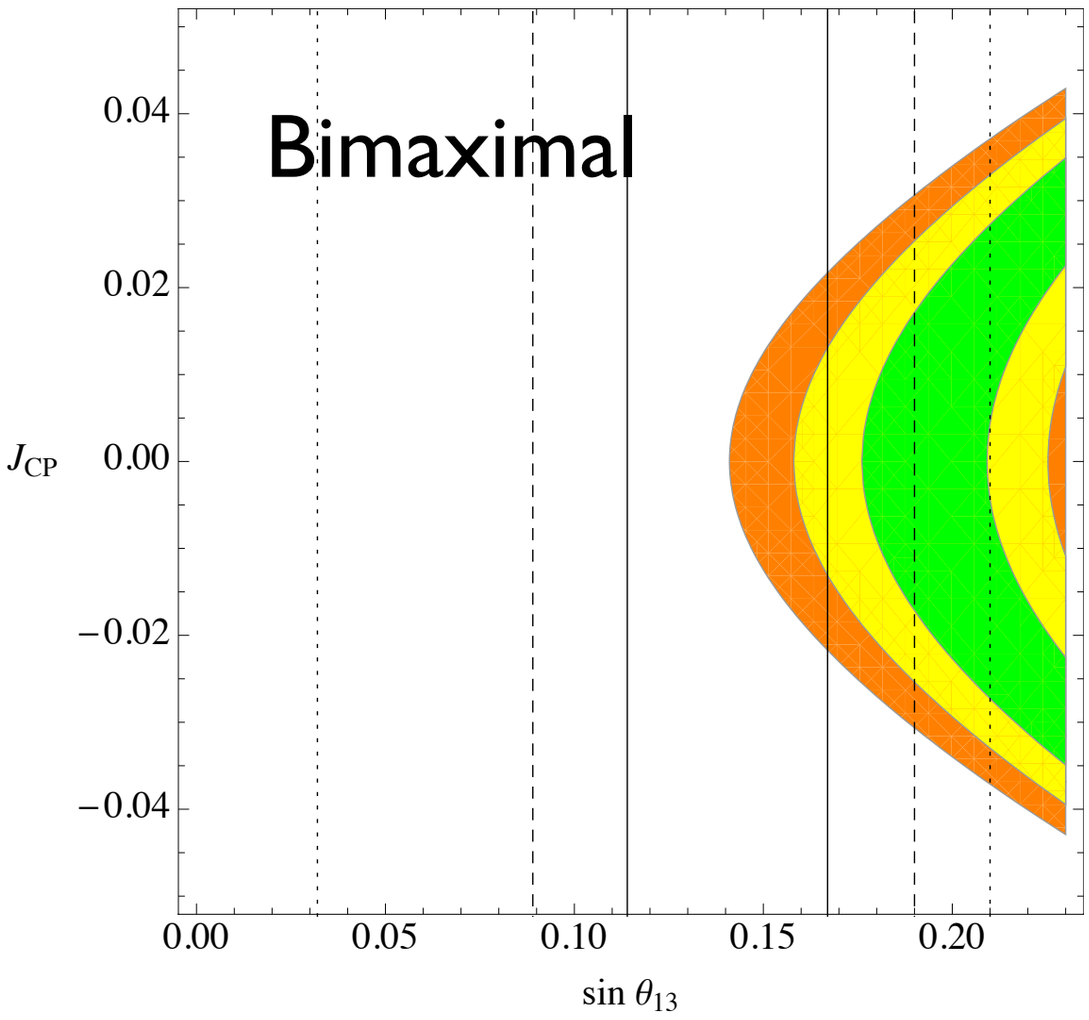
- For Bimaximal mixing:

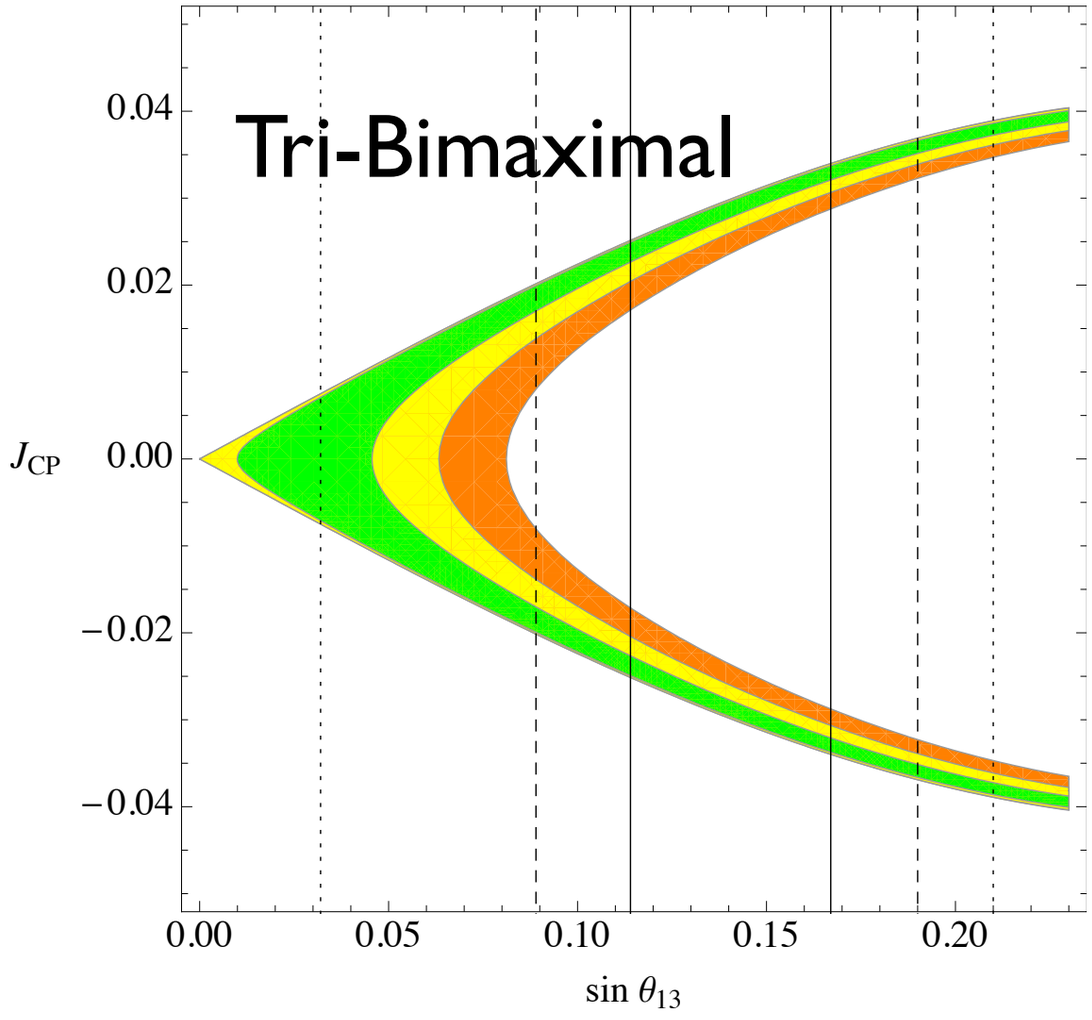
$$\sin^2\theta_{12} \approx \frac{1}{2} + \sin\theta_{13}\cos\delta$$

- For Tri-Bimaximal mixing:

$$\sin^2\theta_{12} \approx \frac{1}{3} + \frac{2\sqrt{2}}{3}\sin\theta_{13}\cos\delta$$

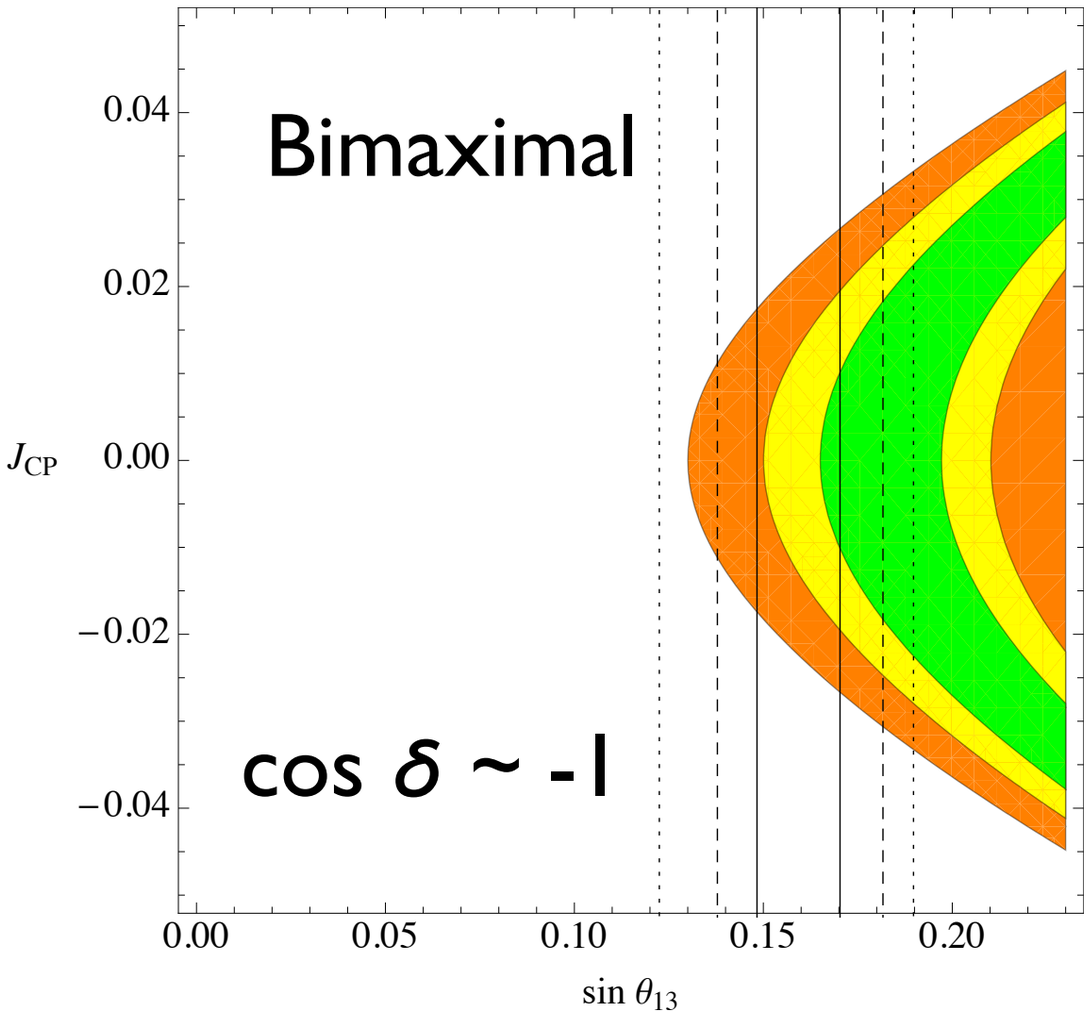
Implications for J_{CP} (June `11)

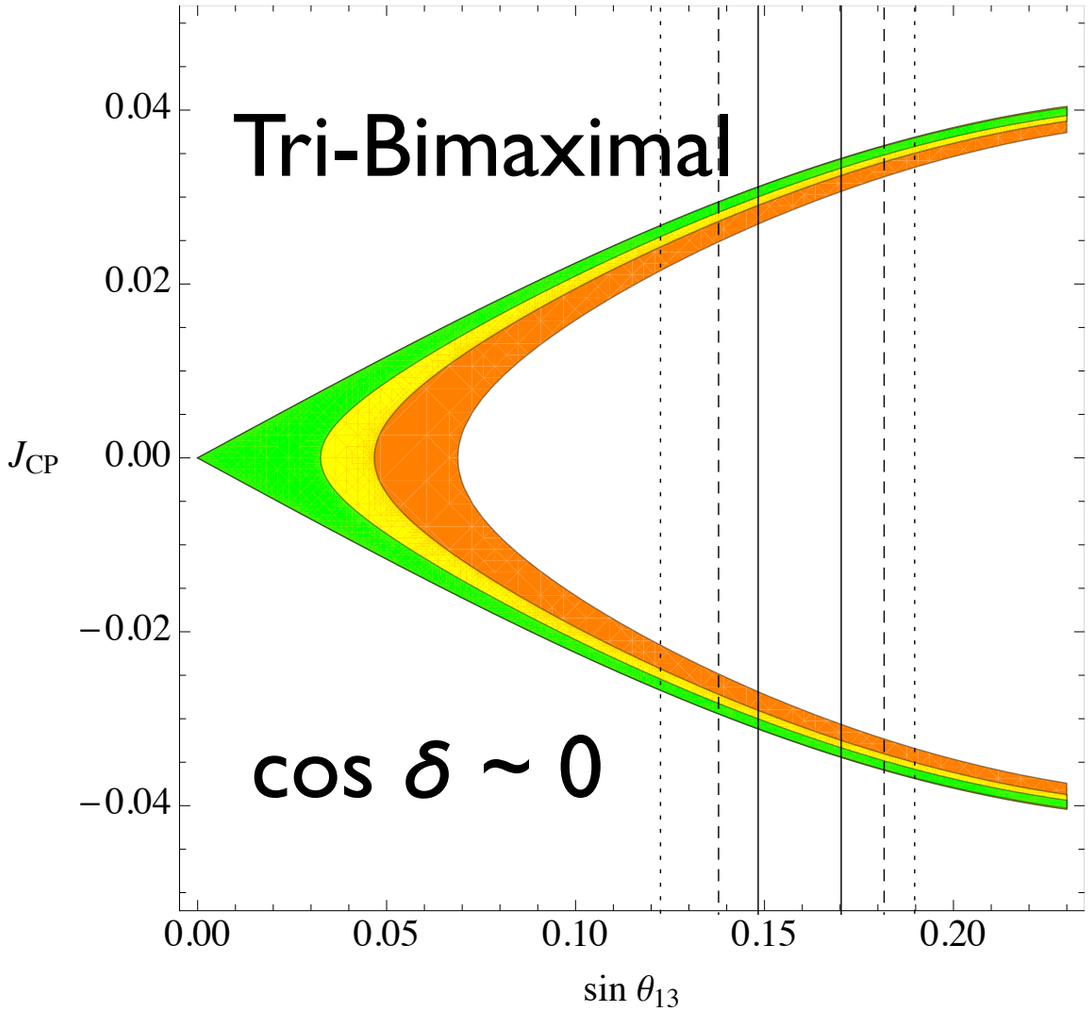




[Taken from Marzocca *et al.* `11, based on the global fit by Fogli *et al.* `11]

Implications for J_{CP} (May `12)





[Based on the global fit by Tortola, Valle, Vanegas `11, Thanks to D. Marzocca for providing this update]

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Pattern for Trimaximal Mixing

[Variant we use based on C. S. Lam `06; C. H. Albright, W. Rodejohann `09; C. H. Albright, A. Dueck, W. Rodejohann `10]

- Minimalistic pattern for TBM:

$$Y_\nu = \begin{pmatrix} 0 & b \\ a & b \\ -a & b \end{pmatrix}, \qquad M_R = \begin{pmatrix} M_A & 0 \\ 0 & M_B \end{pmatrix}$$

- Alternative possibility:

$$Y_\nu = \begin{pmatrix} 0 & b \\ a & 0 \\ -a & 2b \end{pmatrix}, \qquad M_R = \begin{pmatrix} M_A & 0 \\ 0 & M_B \end{pmatrix}$$

[Antusch, King, Luhn, MS `11]

How to get these alignments?

[Antusch, King, Luhn, MS `11]

- Two sets of flavons:

1st column of U_{PMNS} (good θ_{12})

$$\langle \phi_1^\nu \rangle \propto \begin{pmatrix} 0 \\ 1 \\ -1 \end{pmatrix}, \quad \langle \phi_2^\nu \rangle \propto \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}, \quad \langle \phi_3^\nu \rangle \propto \begin{pmatrix} -2 \\ 1 \\ 1 \end{pmatrix}$$

$$\langle \phi_1^e \rangle \propto \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}, \quad \langle \phi_2^e \rangle \propto \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}, \quad \langle \phi_3^e \rangle \propto \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

- Use orthogonality ($F_O = 0$):

$$\mathcal{W} = O_1(\phi_2^e \cdot \phi_{102}) + O_2(\phi_3^\nu \cdot \phi_{102})$$

Phenomenology I

[Antusch, King, Luhn, MS `11]

- The neutrino mass matrix:

$$M_\nu = m_a \begin{pmatrix} \eta & 0 & 2\eta \\ 0 & 1 & -1 \\ 2\eta & -1 & 1+4\eta \end{pmatrix} \ , \quad \eta = \epsilon \ \mathrm{e}^{\mathrm{i}\alpha} \ , \quad \epsilon \ll 1$$

- Approximate formulas:

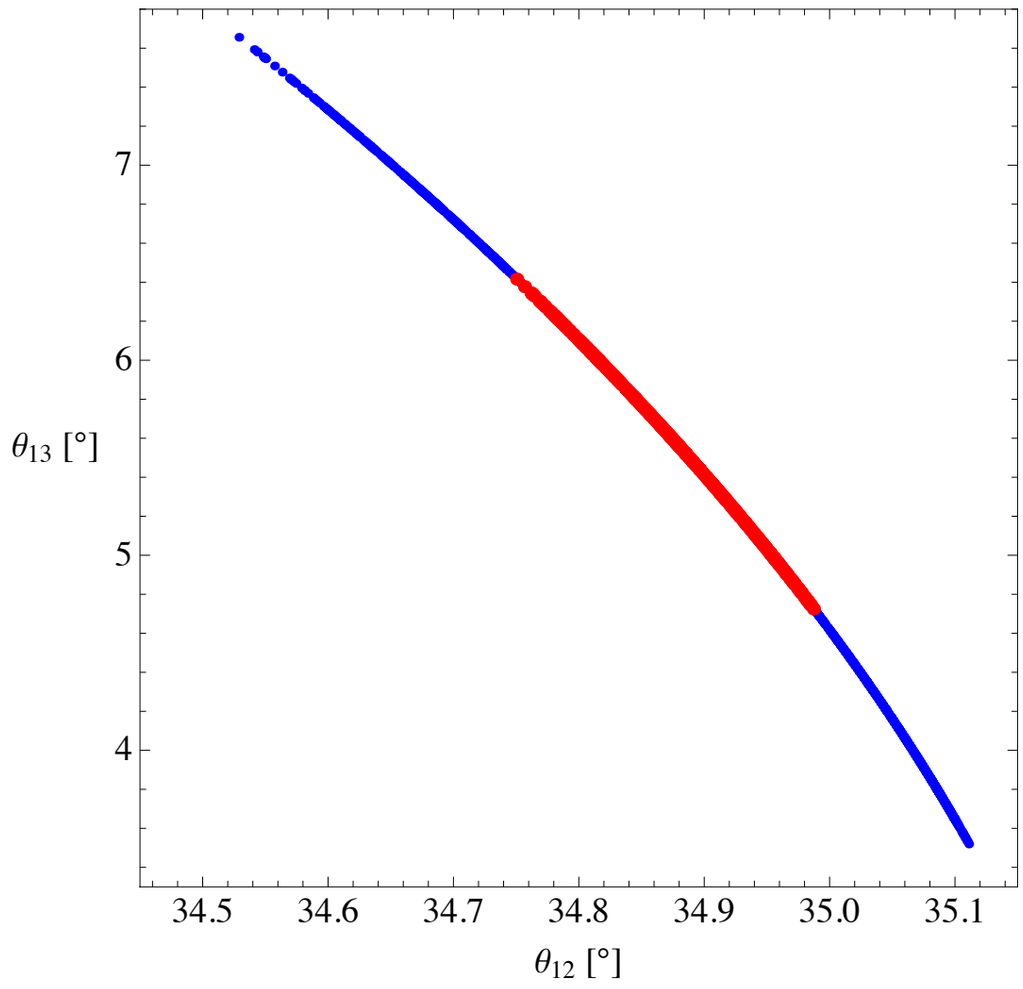
$$m_1^\nu = 0 \ ,$$

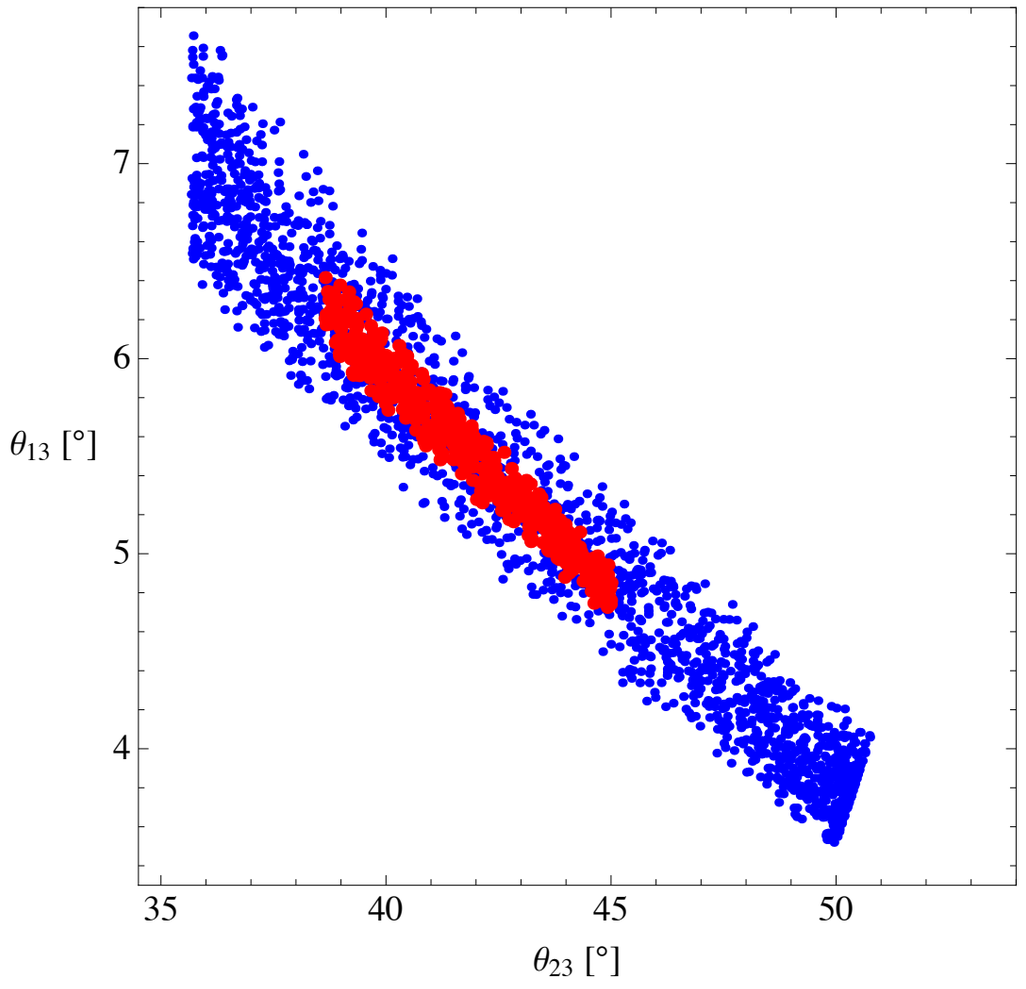
$$m_2^\nu = \left[3\,\epsilon \ - \ 3\,\epsilon^2 \cos\alpha\right] m_a \ ,$$

$$m_3^\nu = \left[2 \ + \ 2\,\epsilon\,\cos\alpha \ + \ \frac{\epsilon^2}{2}\,(7-\cos 2\alpha)\right] m_a \ ,$$

$$\theta_{13} = \frac{\sqrt{2}}{3}\,\frac{m_2^\nu}{m_3^\nu}$$

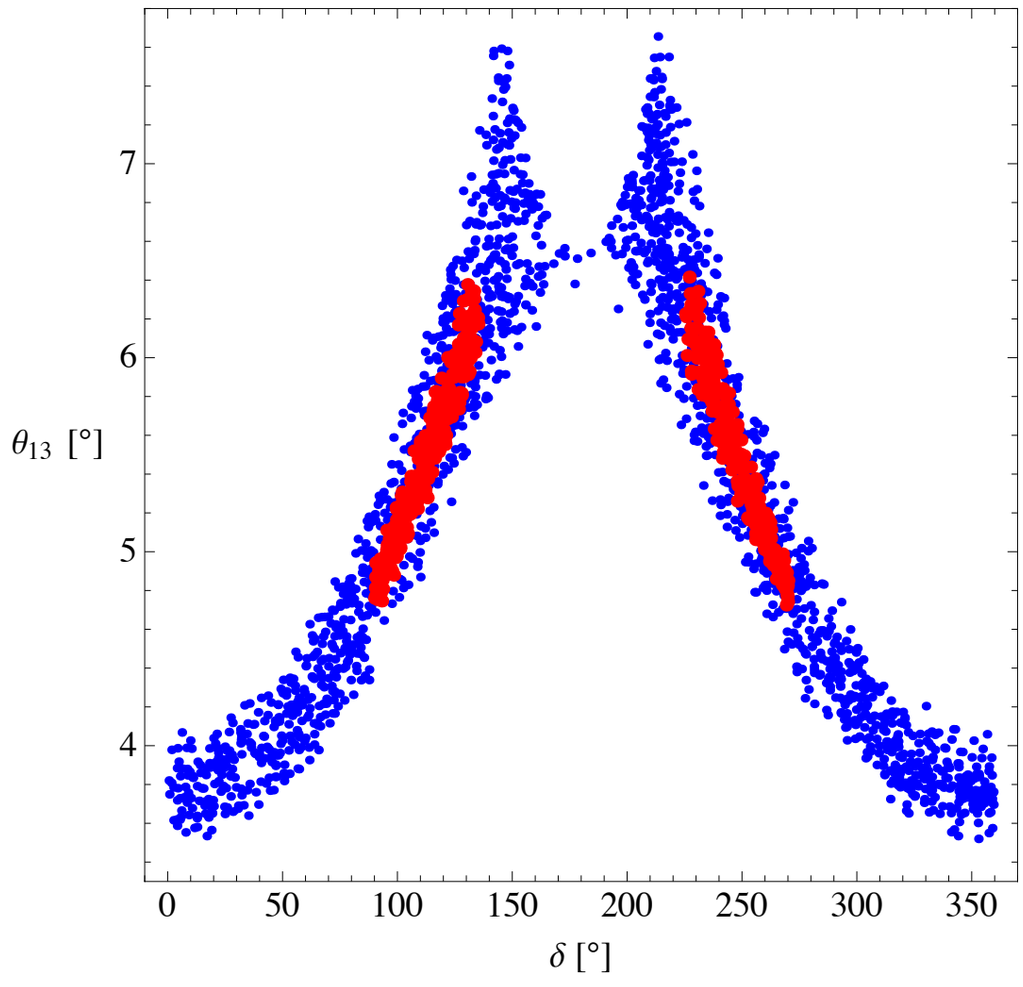
Phenomenology II

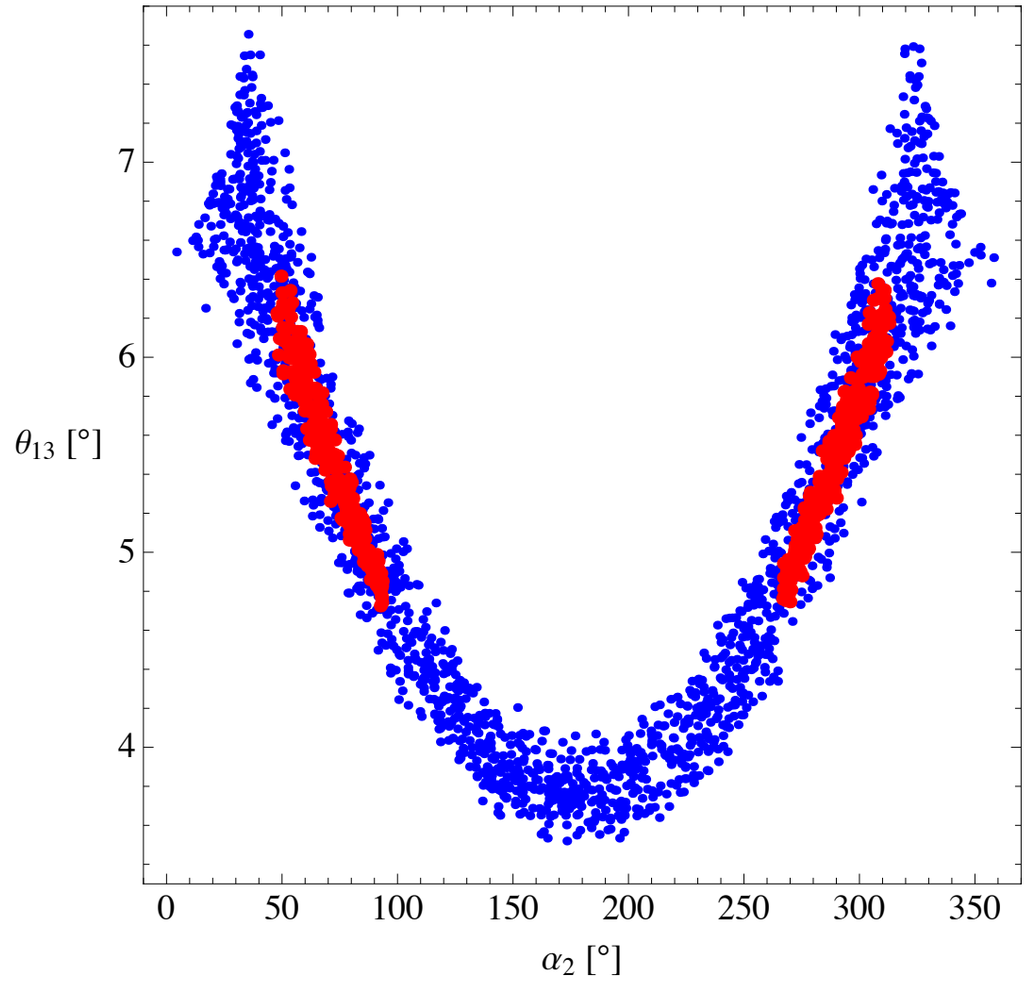




[Antusch, King, Luhn, MS `11]

Phenomenology III





[Antusch, King, Luhn, MS `11]

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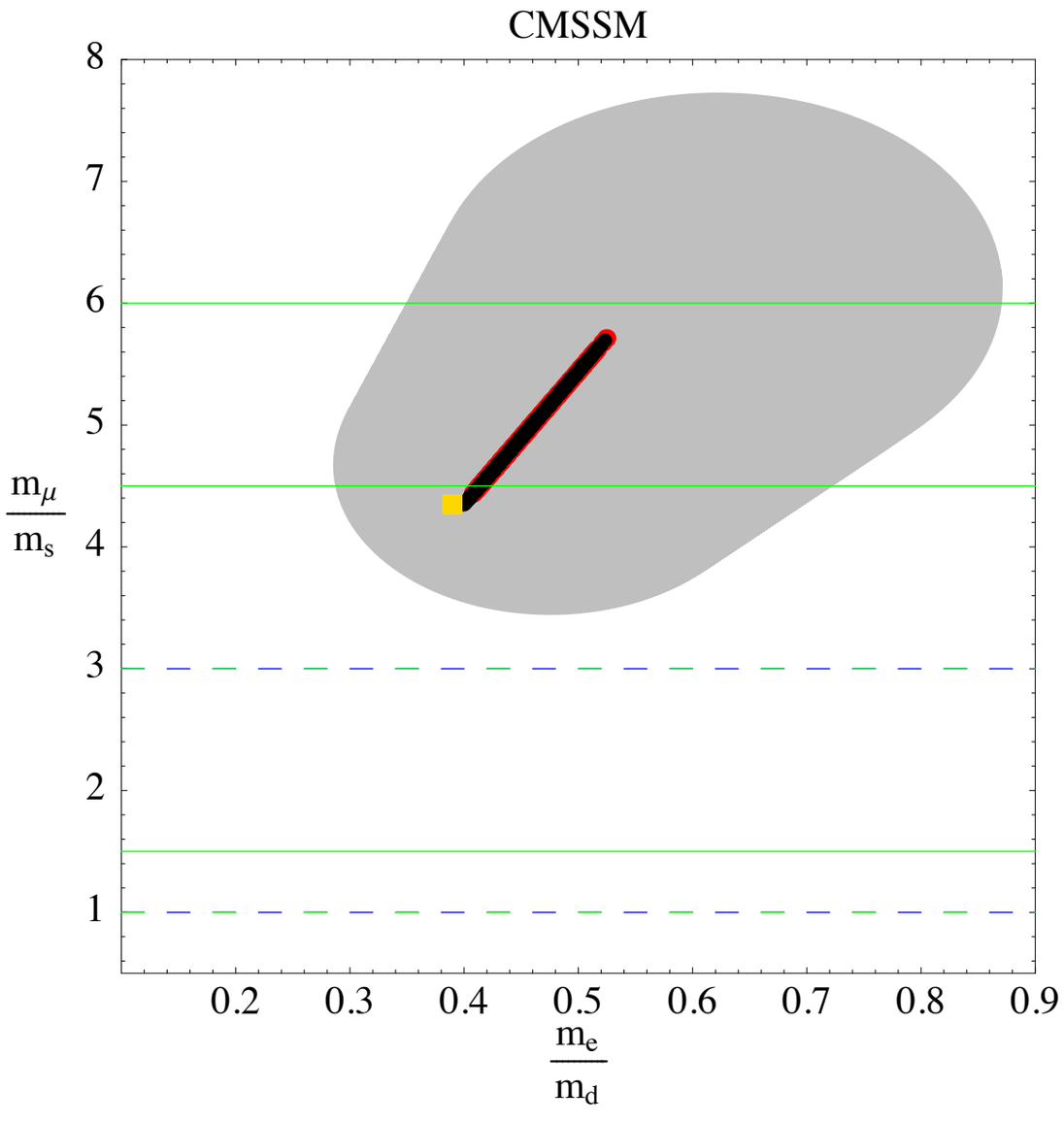
Summary and Conclusions

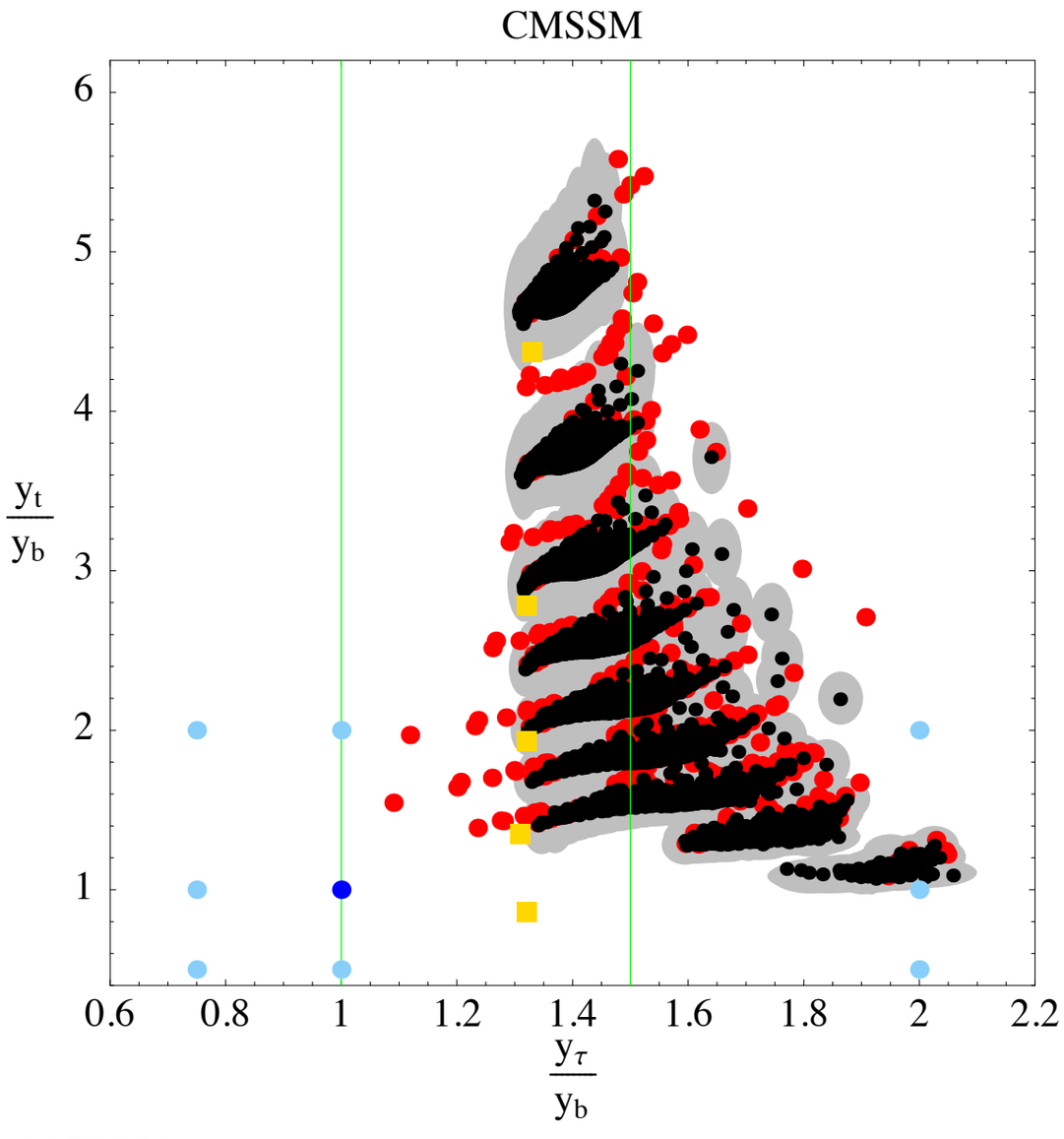
- Many Flavour Models ruled out by new experimental data
- Where to go? 2 possibilites (out of many):
  - Charged Lepton Corrections

    [Antusch, Maurer `11; Marzocca, Petcov, Romanino, MS `11]
  - Tribimaximal Mixing

    [Antusch, King, Luhn, MS `11]
- CP violation?!

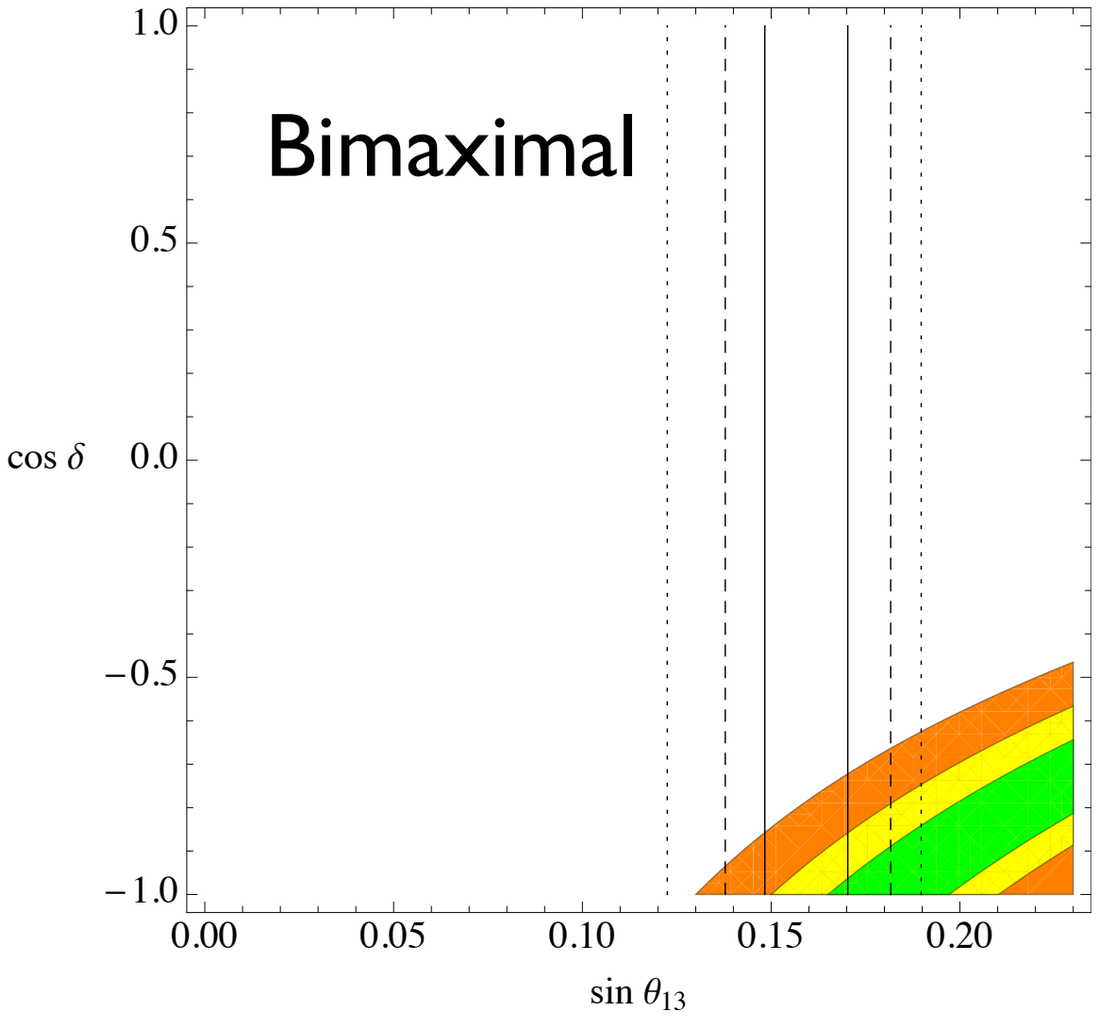
Thanks for your attention!

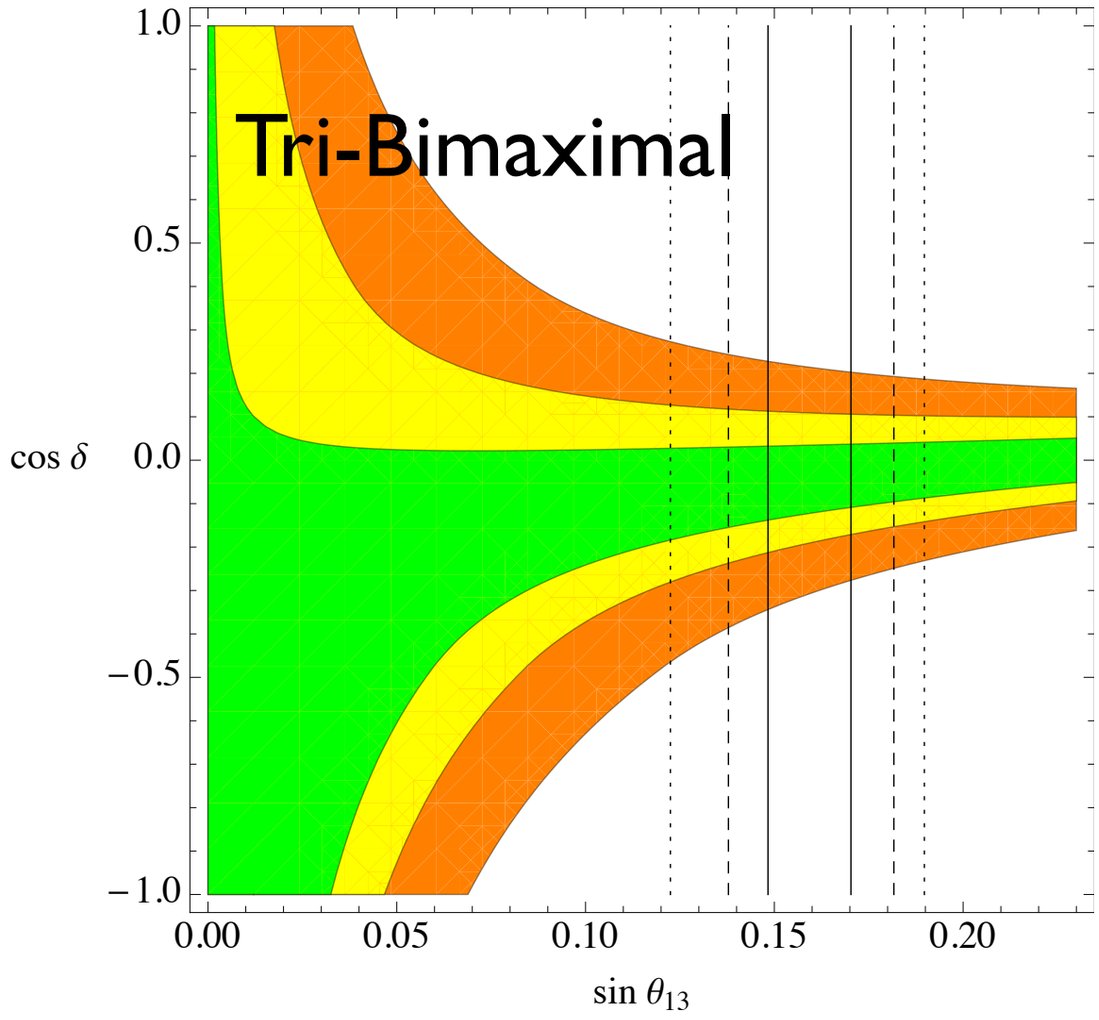




[Antusch, MS `09]

Implications for δ (May `12)





[Based on the global fit by Tortola, Valle, Vanegas `11, Thanks to D. Marzocca for providing this update]

Backup

[Antusch, King, Luhn, MS `11]

$$\theta_{23} = \frac{\pi}{4} + \epsilon \cos\alpha + \epsilon^2 \left(\frac{3}{2} - \cos 2\alpha \right) ,$$

$$\theta_{12} = \arcsin \frac{1}{\sqrt{3}} - \frac{\epsilon^2}{2\sqrt{2}} ,$$

$$\theta_{13} = \frac{\epsilon}{\sqrt{2}} + \frac{\epsilon^2}{2\sqrt{2}} \cos\alpha ,$$

$$\delta = \alpha - \epsilon \frac{5}{2} \sin\alpha \qquad (\text{only up to order } \epsilon) ,$$

$$\alpha_2 = -\alpha + 2\,\epsilon \sin\alpha - 3\,\epsilon^2 \sin 2\alpha ,$$

$$\alpha_3 = 0$$