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Flavour mixing predictions from generalized CP symmetries

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Outline

- Introduction: Generalized CP Symmetries.
- Generalized $\mu\tau$ reflection in the neutrino sector.
- Generalized $e\mu$, $e\tau$ and $\mu\tau$ reflections in the charged lepton sector.
- Revamped TBM from generalized CP symmetries.

Generalized CP Symmetries

- Definition:

$$\psi \to iX_\psi \psi^c,\ \psi \in \{\nu_L, \nu_R, l_L, l_R\}$$

- If this (remnant) symmetry is conserved in the Lagrangian (after SSB), it implies:

$$X_\psi^T m_\psi X_\psi = m_\psi^*, \qquad \text{for Majorana fields}$$

$$X_\psi^\dagger M_\psi^2 X_\psi = M_\psi^{2*}, \qquad \text{for Dirac fields}$$

Where $M_\psi^2 \equiv m_\psi^\dagger m_\psi$

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Generalized CP symmetries

- After some algebra, we can find a constraint for the mixing matrix given the gCP symmetry:

$$U_\psi^\dagger X_\psi U_\psi^* \equiv P = \begin{cases} \mathrm{diag}(\pm 1, \pm 1, \pm 1), & \text{for Majorana fields,} \\ \mathrm{diag}(e^{i\delta_e}, e^{i\delta_\mu}, e^{i\delta_\tau}), & \text{for Dirac fields}\,, \end{cases}$$

- We can Takagi decompose X: $X_\psi = \Sigma \cdot \Sigma^T$
- Which leads to the 'master formula':

$$U_\psi = \Sigma O_3^\dagger P^{-\frac{1}{2}}$$

Generalized μτ reflection

- Assumptions:

  Neutrinos are Majorana fields.

  The charged lepton mass matrix is diagonal.

  We impose a generalized μτ reflection in the neutrino sector:

$$X_{\mu\tau} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\beta}\cos\Theta & ie^{\frac{1}{2}i(\beta+\gamma)}\sin\Theta \\ 0 & ie^{\frac{1}{2}i(\beta+\gamma)}\sin\Theta & e^{i\gamma}\cos\Theta \end{pmatrix}$$

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Generalized μτ reflection

- Imposing generalized μτ reflection leads to:

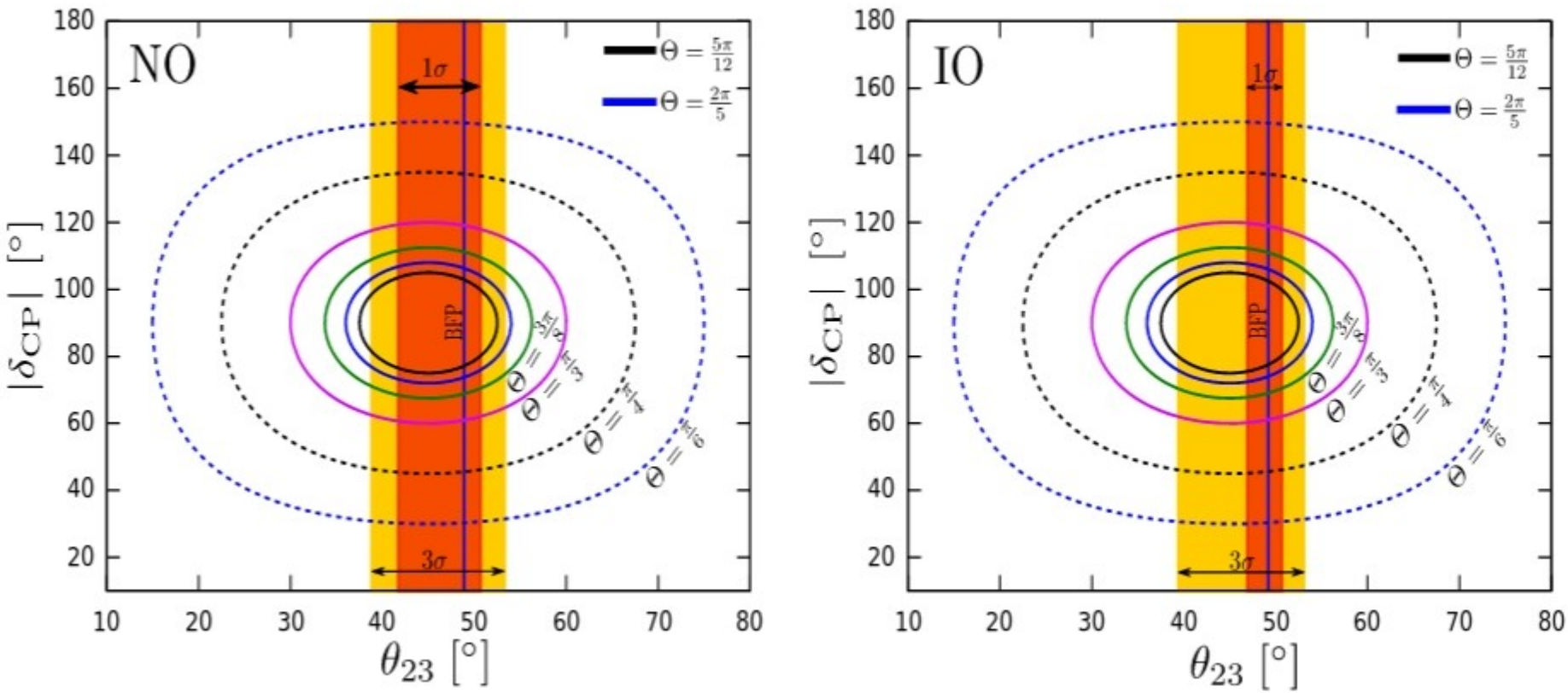
$$\sin^2\theta_{13} = \sin^2\theta_2, \quad \sin^2\theta_{12} = \sin^2\theta_3, \quad \sin^2\theta_{23} = \frac{1}{2}\left(1 - \cos\Theta\cos 2\theta_1\right)$$

$$J_{\rm CP} = \frac{1}{4}\sin\Theta\sin\theta_2\sin 2\theta_3\cos^2\theta_2\,, \quad \sin\delta_{\rm CP} = \frac{\sin\Theta\ \mathrm{sign}[\sin\theta_2\sin 2\theta_3]}{\sqrt{1-\cos^2\Theta\cos^2 2\theta_1}}\,,$$

$$\tan\delta_{\rm CP} = \tan\Theta\csc 2\theta_1\,, \quad \phi_{12} = \frac{k_2-k_1}{2}\pi\,, \quad \phi_{13} = \frac{k_3-k_1}{2}\pi\,, \quad \delta_{\rm CP} = \frac{k_3-k_2}{2}\pi - \phi_{23}$$

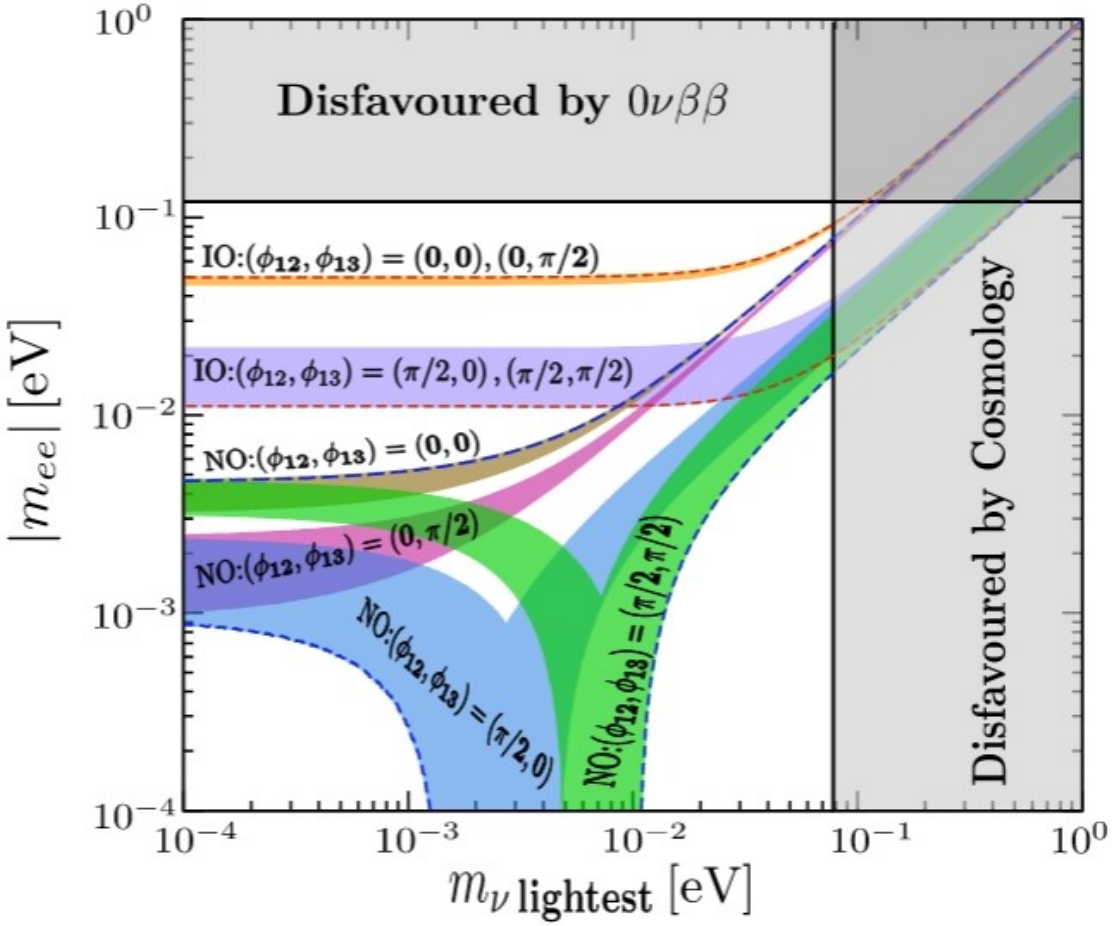
Generalized μτ reflection

- Imposing generalized μτ reflection leads to:



Generalized μτ reflection

- Imposing generalized μτ reflection leads to:



Charged lepton sector: generalized eμ reflection

- Same spirit, now in the charged lepton sector.
- The analogous situation to μτ in the neutrino sector is eμ in the charged lepton sector.

$$X_{e\mu} = \begin{pmatrix} e^{i\alpha}\cos\Theta & ie^{\frac{1}{2}i(\alpha+\beta)}\sin\Theta & 0 \\ ie^{\frac{1}{2}i(\alpha+\beta)}\sin\Theta & e^{i\beta}\cos\Theta & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

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Charged lepton sector: generalized eμ reflection

- Analogue predictions for mixing angles changing 23←→12:

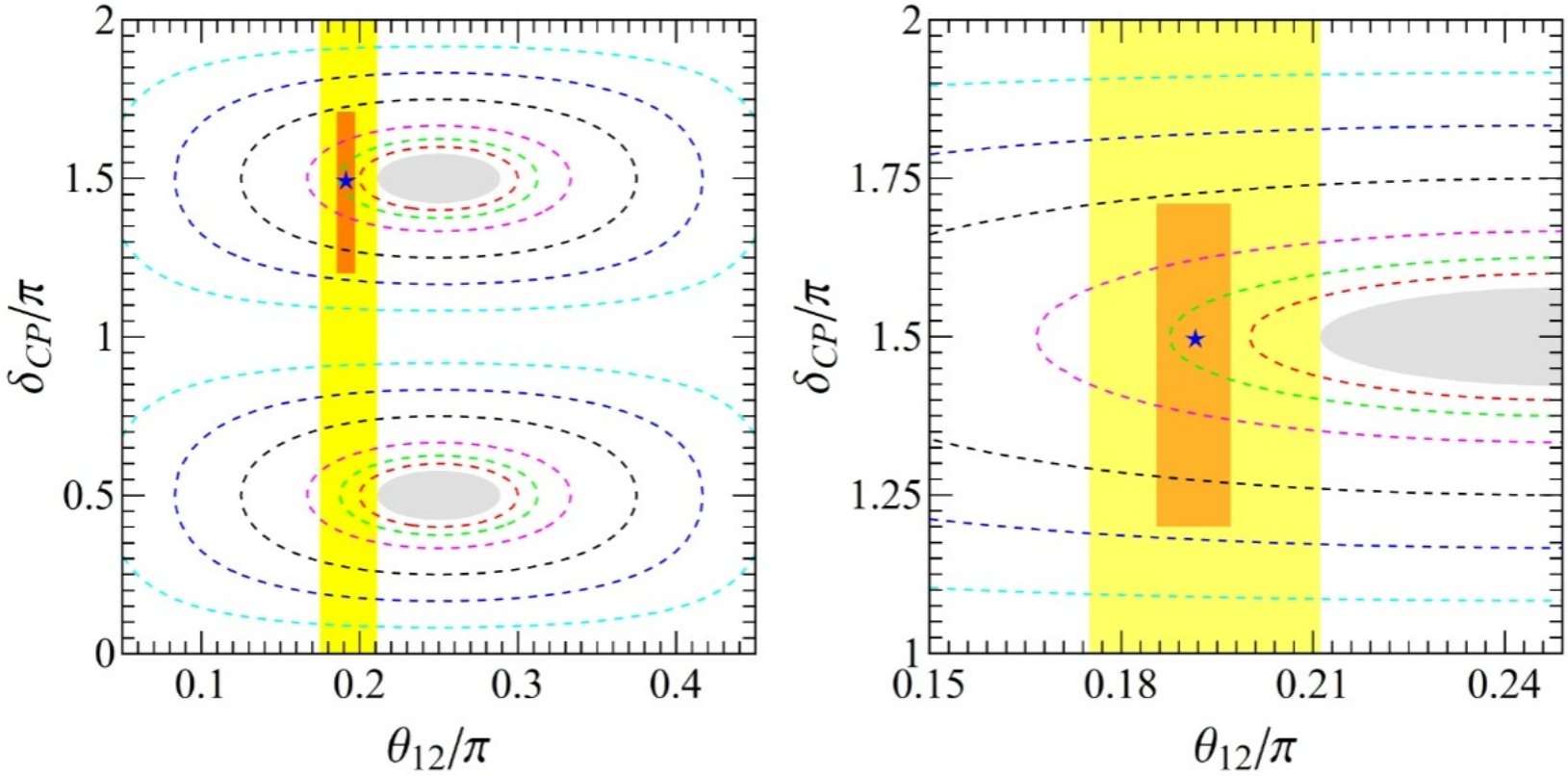
$$\sin^2\theta_{13} = \sin^2\theta_2, \qquad \sin^2\theta_{12} = \frac{1}{2}\left(1 - \cos 2\theta_3 \cos\Theta\right), \qquad \sin^2\theta_{23} = \sin^2\theta_1$$

- Different predictions for the Majorana phases:

$$\tan\delta_{CP} = -\csc 2\theta_3 \tan\Theta\,,$$
$$\sin 2\phi_{12} = -\frac{\sin 4\theta_3 \sin\Theta}{\cos^2 2\theta_3 \cos^2\Theta - 1}\,,$$
$$\sin 2\phi_{13} = -\frac{\sin 2\theta_3 \sin\Theta}{\cos 2\theta_3 \cos\Theta + 1}\,.$$

Charged lepton sector: generalized eμ reflection

- Analogue predictions for mixing angles changing 23←→12:



Charged lepton sector: generalized eμ reflection

- Very different predictions for the phases:

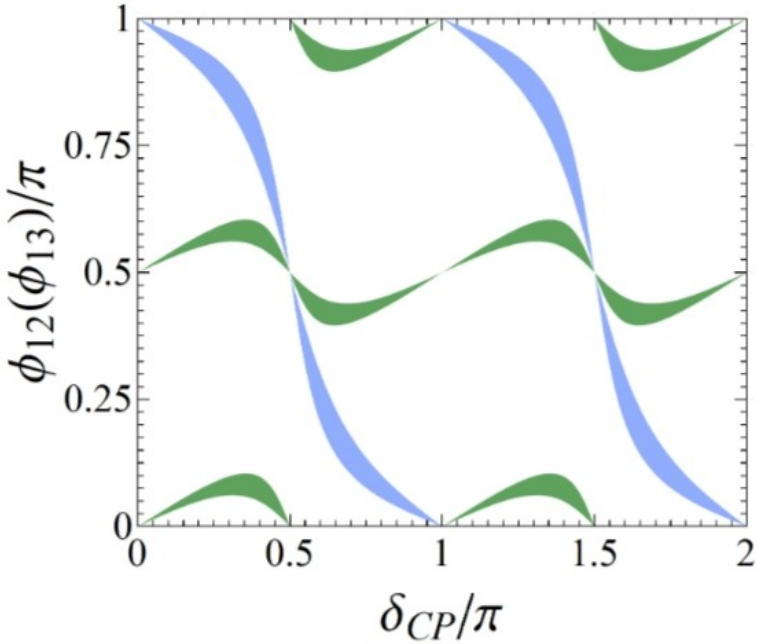
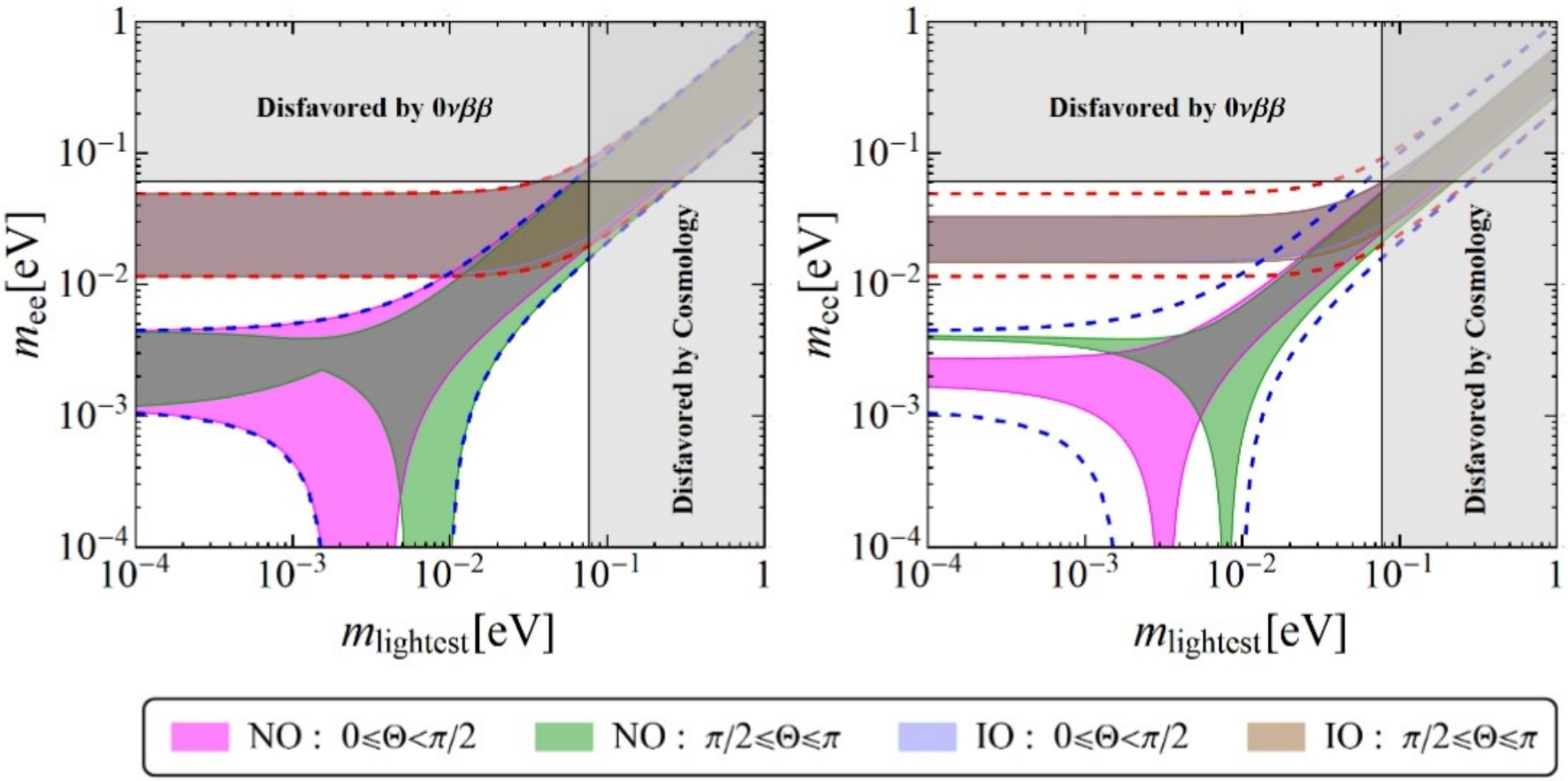


Figure 3. Correlations among the CP violation phases δ_{CP}, ϕ_{12} and ϕ_{13} for the generalized $e-\mu$ reflection in the charged lepton sector, taking $\alpha = \beta = 0$. The light blue and green areas correspond to $\phi_{12} - \delta_{CP}$ and $\phi_{13} - \delta_{CP}$ respectively.

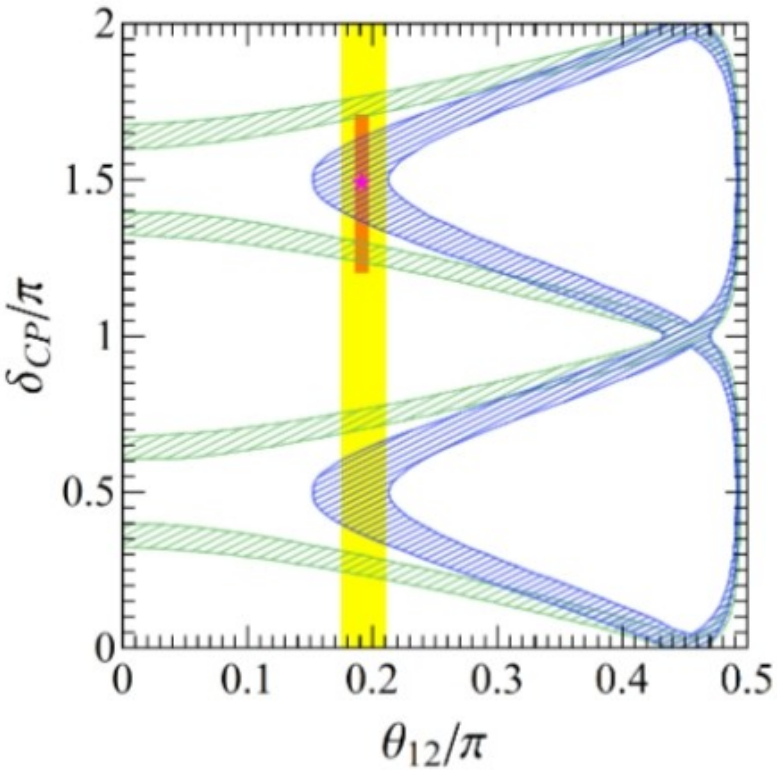
Charged lepton sector: generalized eμ reflection

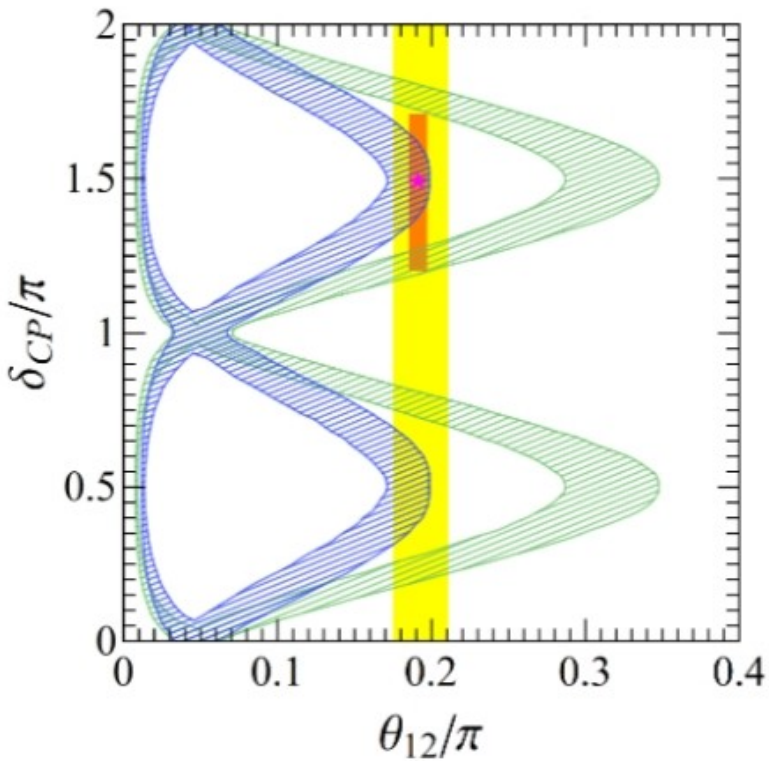
- Neutrinoless double beta decay predictions:



Reflections in the charged lepton sector

- We can also impose generalized eτ and μτ generalized reflections.
- Results are 'messier' but some nice predictions can be obtained. See paper for details 1802.04275.





GCP as guiding posts: generalized TBM mixing

- Given the gCP symmetry you obtain a restricted mixing. But given the mixing you can extract the compatible CP symmetries.
- We can do this exercise with the famous TBM mixing matrix.
- Starting with TBM you can do perturbations to the mass matrix that satisfy just partial symmetry of the full TBM matrix.
- Many possibilities, see future paper for details 1812.xxxxx.

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Coming soon, stay tuned

Realistic TBM neutrino mixing

- Of those possibilities the golden boy is the "realistic tribimaximal neutrino mixing".
- Derived from generalized CP symmetries principles this matrix takes the form:

$$U = \begin{bmatrix} \sqrt{\frac{2}{3}} & \frac{e^{-i\rho}\cos\theta}{\sqrt{3}} & -\frac{ie^{-i\rho}\sin\theta}{\sqrt{3}} \\ -\frac{e^{i\rho}}{\sqrt{6}} & \frac{\cos\theta}{\sqrt{3}} - \frac{ie^{-i\sigma}\sin\theta}{\sqrt{2}} & \frac{e^{-i\sigma}\cos\theta}{\sqrt{2}} - \frac{i\sin\theta}{\sqrt{3}} \\ \frac{e^{i(\rho+\sigma)}}{\sqrt{6}} & -\frac{e^{i\sigma}\cos\theta}{\sqrt{3}} - \frac{i\sin\theta}{\sqrt{2}} & \frac{\cos\theta}{\sqrt{2}} + \frac{ie^{i\sigma}\sin\theta}{\sqrt{3}} \end{bmatrix}$$

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Realistic TBM neutrino mixing

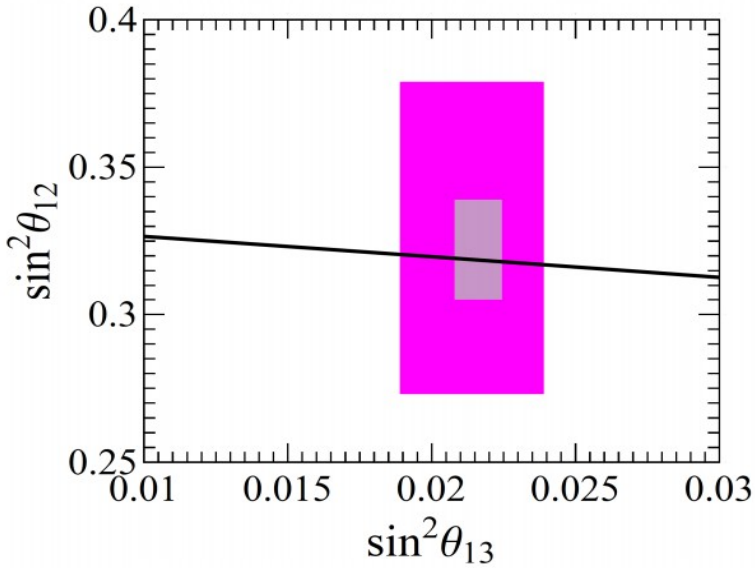
- This matrix has nice correlations between physical observables.
- Several interesting limits (real TBM, μτ reflection, maximal atmospheric mixing...)
- The most general case leads to:

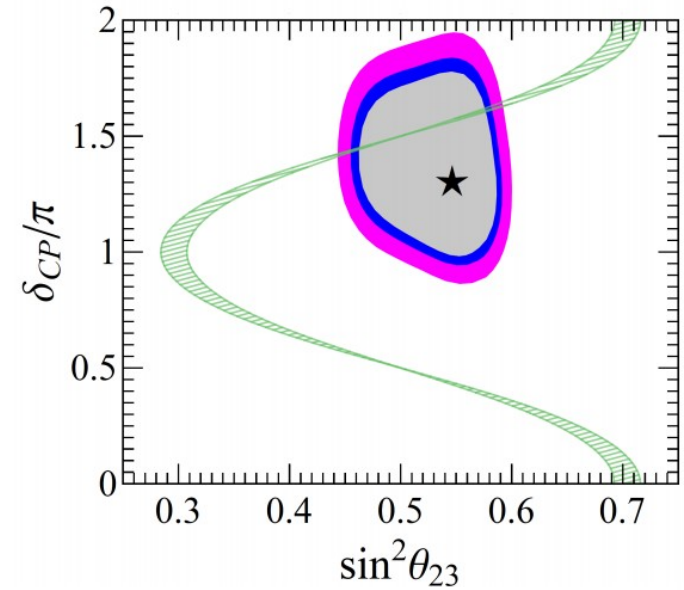
$$\sin^2\theta_{12} = \frac{\cos^2\theta}{\cos^2\theta + 2}\,, \quad \sin^2\theta_{23} = \frac{1}{2} + \frac{\sqrt{6}\sin 2\theta \sin\sigma}{2\cos^2\theta + 4}$$

$$\sin^2\theta_{13} = \frac{\sin^2\theta}{3}\,, \quad \tan\delta_{CP} = \frac{(\cos^2\theta + 2)\cot\sigma}{(5\cos^2\theta - 2)}\,,$$

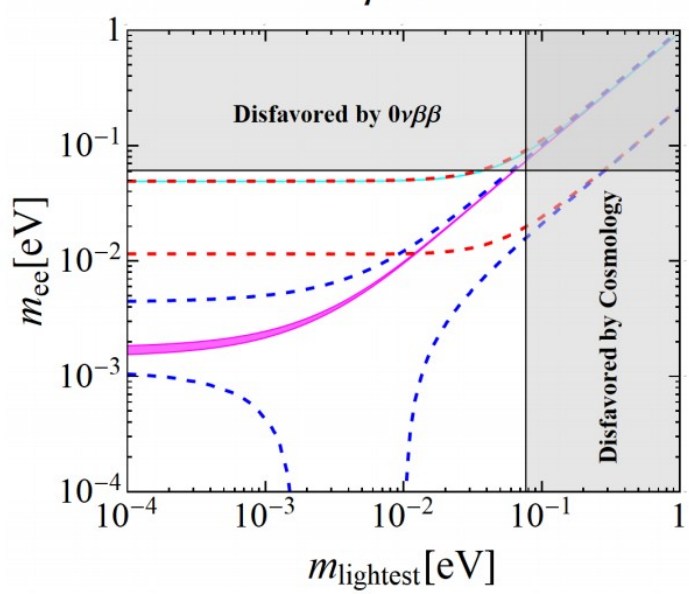
$$\phi_{12} = \rho\,, \quad \phi_{13} = \rho + \frac{\pi}{2}\,,$$

Realistic TBM neutrino mixing

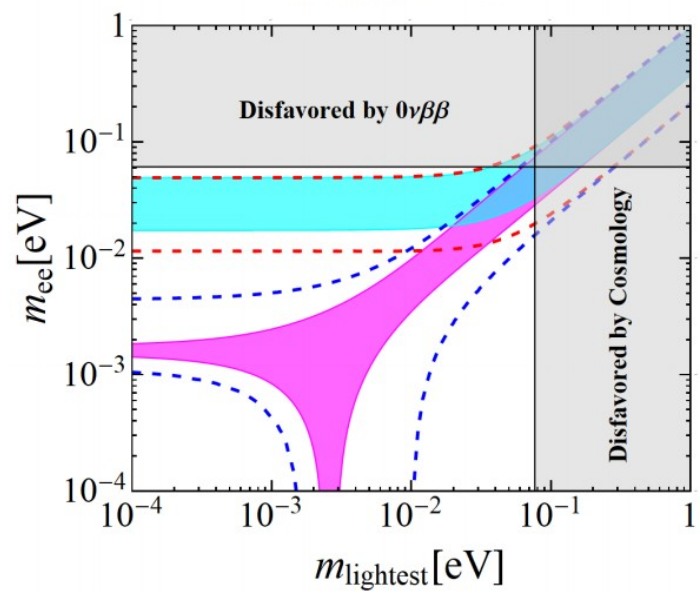




ρ=0



General Case



Conclusions

- Generalized CP symmetries are a powerful method to obtain testable correlations between observables.
- Given a CP symmetry you can restrict the lepton mixing matrix.
- Given a mixing pattern (for example TBM) you can extract the compatible cp symmetries and then do a perturbation that satisfies only partial symmetry.

Thank you for your attention

- References:
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  - 1512.01551 **Generalized μ–τ reflection symmetry and leptonic CP violation** Peng Chen, Gui-Jun Ding, Félix González-Canales, J.W.F. Valle, **j.physletb.2015.12.069**
  - 1802.04275 **Neutrino Predictions from Generalized CP Symmetries of Charged Leptons,** Peng Chen, SCC, Gui-Jun Ding, Rahul Srivastava, J.W.F. Valle, **JHEP07(2018)077**
  - 1806.03367 **Realistic tribimaximal neutrino mixing**, Peng Chen, SCC, Gui-Jun Ding, Rahul Srivastava, J.W.F. Valle, **PhysRevD.98.055019**
  - 1812.xxxxx Peng Chen, SCC, Gui-Jun Ding, Rahul Srivastava, J.W.F. Valle Coming soon, stay tuned