Test of tri-direct CP symmetry models by neutrino oscillations

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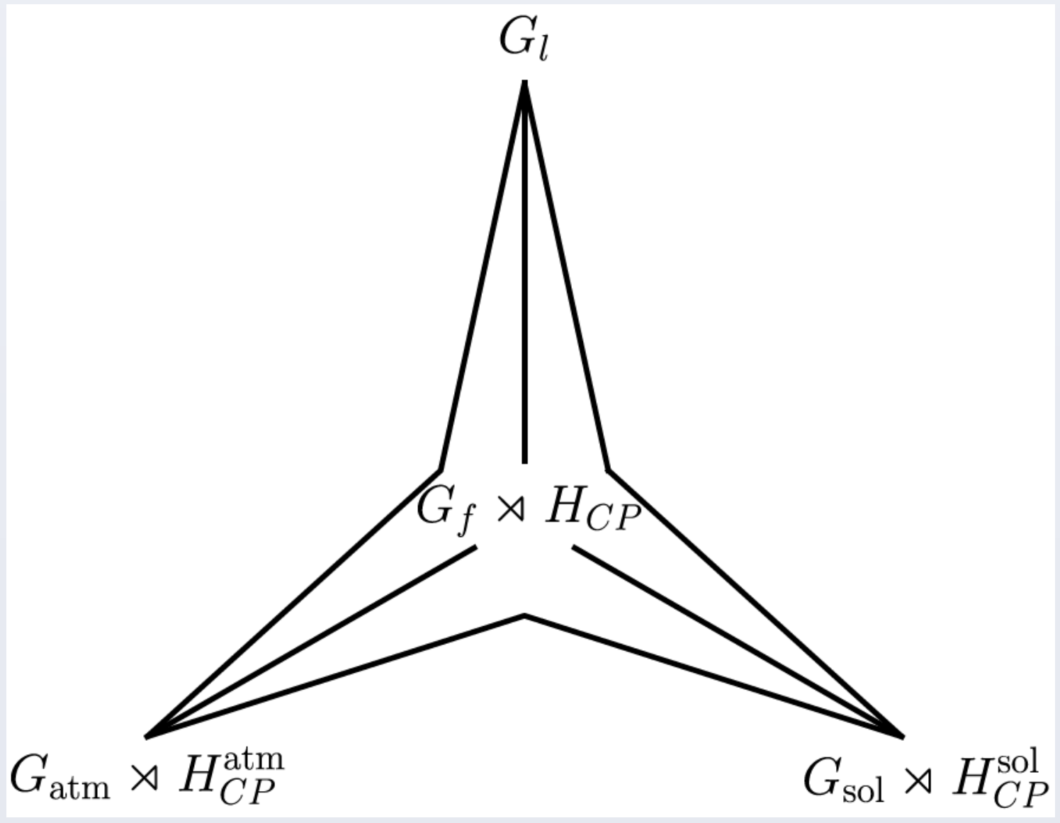
Motivations

1) It is important to extend the Standard Model to naturally generate tiny neutrino masses. Flavor symmetry helps to reduce the degrees of freedom.
2) How powerful is it to reach precision measurement of standard neutrino mixing parameters to test flavor-symmetry models?
3) How can we implement the over-constrained mixing parameters predicted by the flavor-symmetry models?
4) Are there any new features like degeneracy issues and how to break degeneracies?
5) Is it possible to check the sum rules predicted by models?
6) At which level are we able to exclude a class of flavor-symmetry models?

Review of tri-direct CP symmetry models



Sketch of the tri-direct CP approach for two right-handed neutrino models

- The flavor group S4 and CP is broken to the subgroups. The residual symmetries are associated with the atmospheric and solar flavor sectors.
- The charged lepton mass matrix is diagonal.
- Structure of the neutrino and charged lepton mass matrices arise from the vacuum alignment of flavon fields which are fixed by the residual symmetry.
- Only four parameters m_a, m_s, η and x are involved to describe both neutrino masses and lepton mixing parameters.

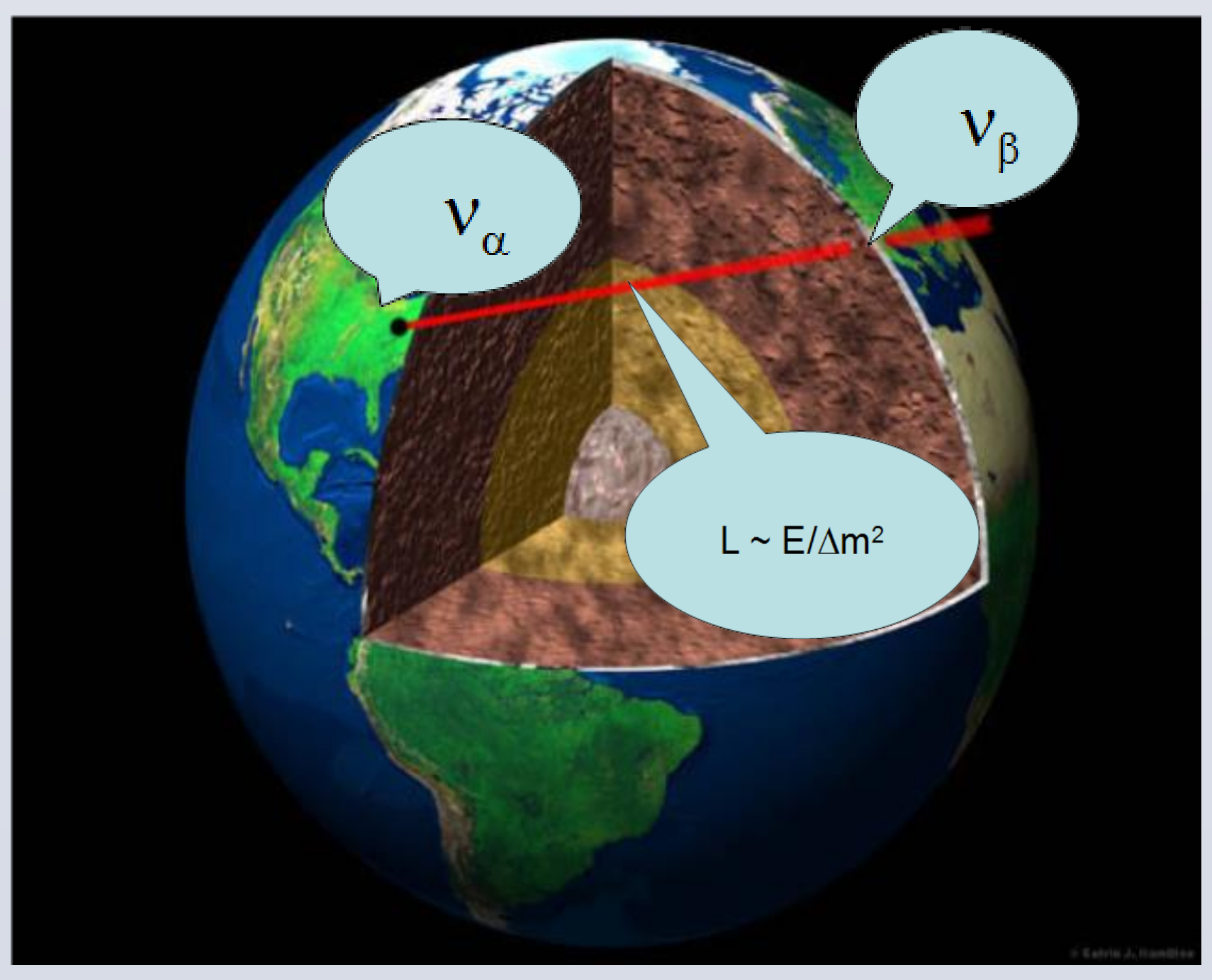
$$m_D = \begin{pmatrix} y_a & y_s \\ \omega y_a & x y_s \\ \omega^2 y_a & x y_s \end{pmatrix}$$

$$m_\nu = m_a \begin{pmatrix} 1 & \omega & \omega^2 \\ \omega & \omega^2 & 1 \\ \omega^2 & 1 & \omega \end{pmatrix} + e^{i\eta} m_s \begin{pmatrix} 1 & x & x \\ x & x^2 & x^2 \\ x & x^2 & x^2 \end{pmatrix}$$

Best-fit values based on the latest global fit NuFit4.0 with priors taken into account.

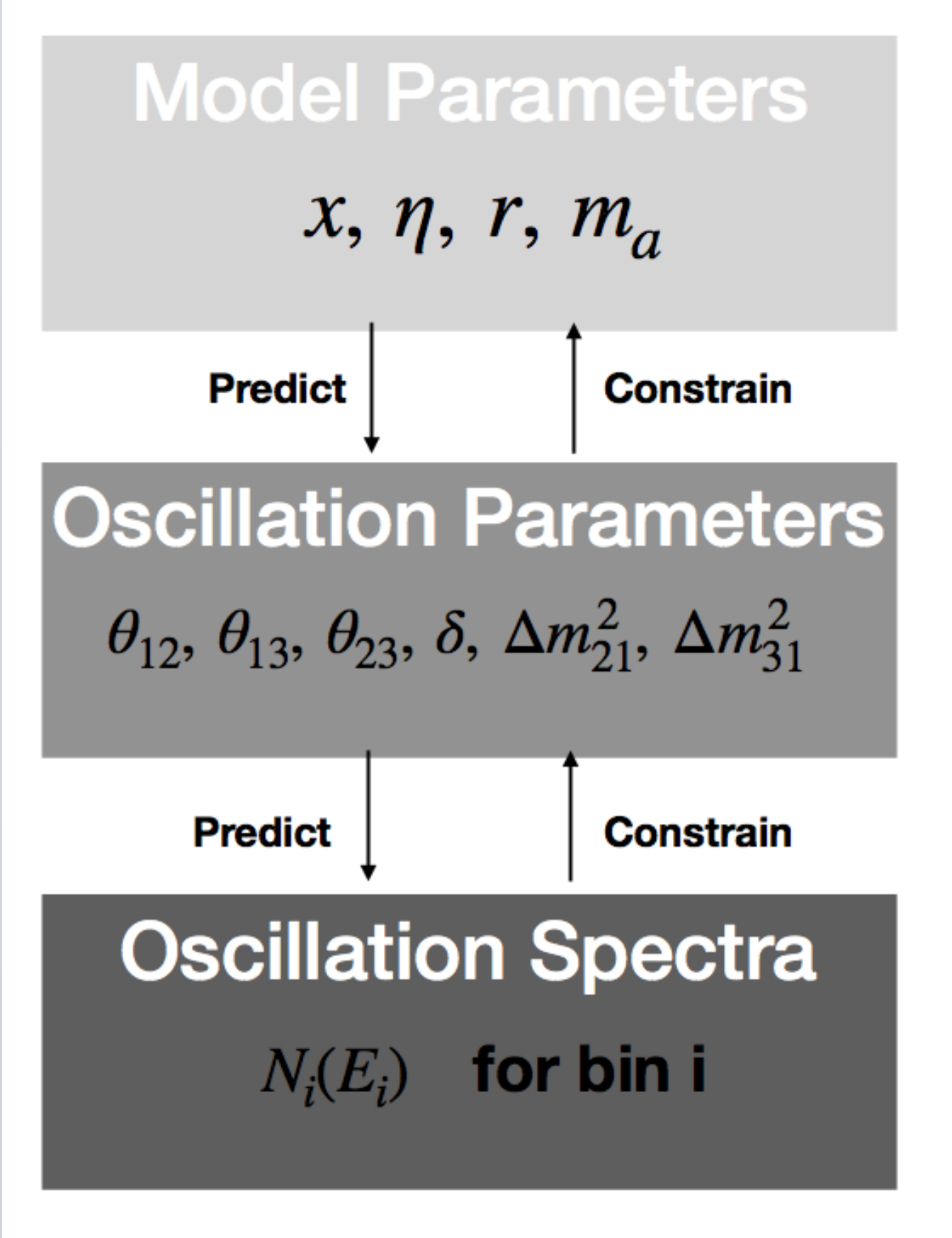
$\Delta\chi^2$	x	η/π	r	$m_a/$ meV	$\theta_{12}/^\circ$	$\theta_{13}/^\circ$	$\theta_{23}/^\circ$	$\delta/^\circ$	$\Delta m^2_{21}/10^{-5}{\rm eV}^2$	$\Delta m^2_{31}/10^{-3}{\rm eV}^2$
4.98	−3.65	1.13	0.511	3.71	35.25	8.63	46.98	278.96	7.39	2.525

Working principle of neutrino oscillations



1) Neutrino source: reactor power plants, high-energy protons hit the target station to produce charged mesons which can decay to generate neutrinos.
2) Near detector: flux measurements, cancellation of the systematic uncertainties…
3) Far detector: detection of oscillated neutrinos, reconstruction of oscillation probabilities, conduct physics analysis.
4) Running experiments: T2K, NOνA
5) Next generations: T2HK, DUNE, JUNO

Strategies to test the flavor-symmetry models



Model Parameters
$x,\ \eta,\ r,\ m_a$

Predict ↓ ↑ Constrain

Oscillation Parameters
$\theta_{12},\ \theta_{13},\ \theta_{23},\ \delta,\ \Delta m^2_{21},\ \Delta m^2_{31}$

Predict ↓ ↑ Constrain

Oscillation Spectra
$N_i(E_i)$ **for bin i**

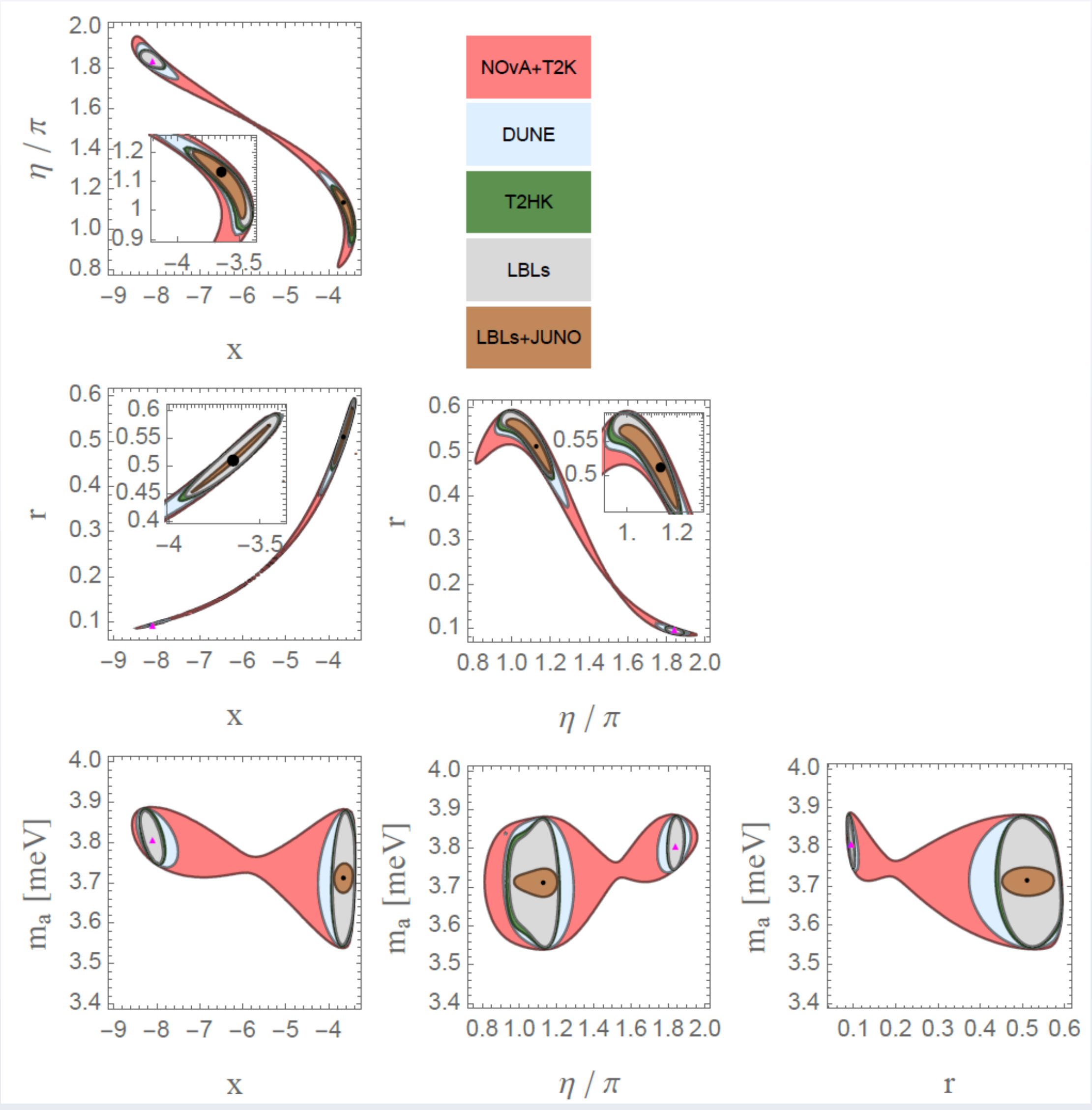
$$\vec{\mathcal{M}} = \{x\,, \eta\,, m_a\,, r\}$$

$$\chi^2(\vec{\mathcal{M}}) = \sum_{i=1}^{N} \frac{\left[\mu_i(\vec{\mathcal{O}}(\vec{\mathcal{M}})) - n_i\right]^2}{\sigma_i^2}$$

$$\vec{\mathcal{O}} = \{\theta_{12}\,, \theta_{13}\,, \theta_{23}\,, \delta_{\rm CP}\,, \Delta m^2_{21}\,, \Delta m^2_{31}\}$$

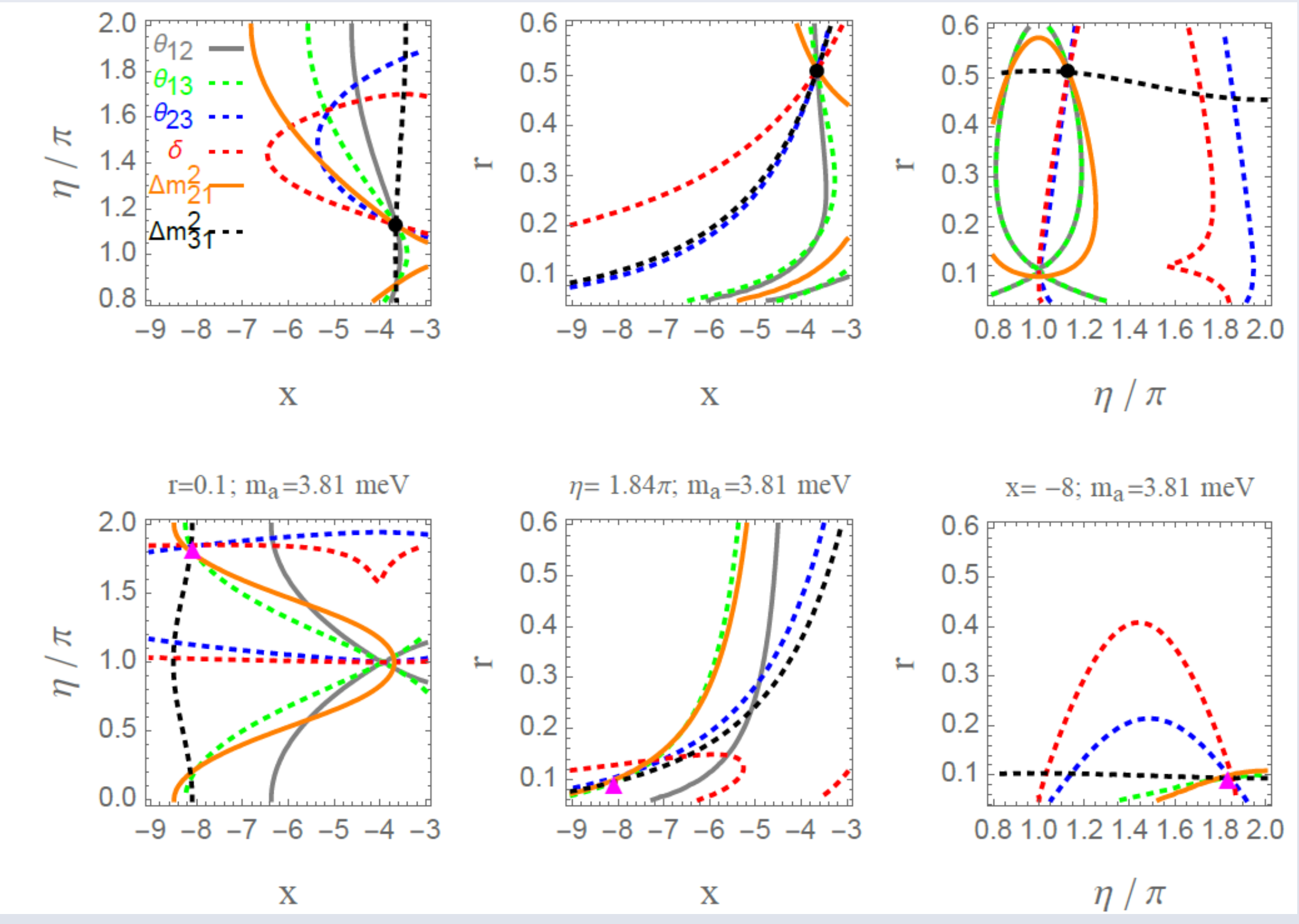
$$\chi^2(\vec{\mathcal{O}}) = \sum_{i=1}^{N} \frac{\left[\mu_i(\vec{\mathcal{O}}) - n_i\right]^2}{\sigma_i^2}$$

Constrain model parameters



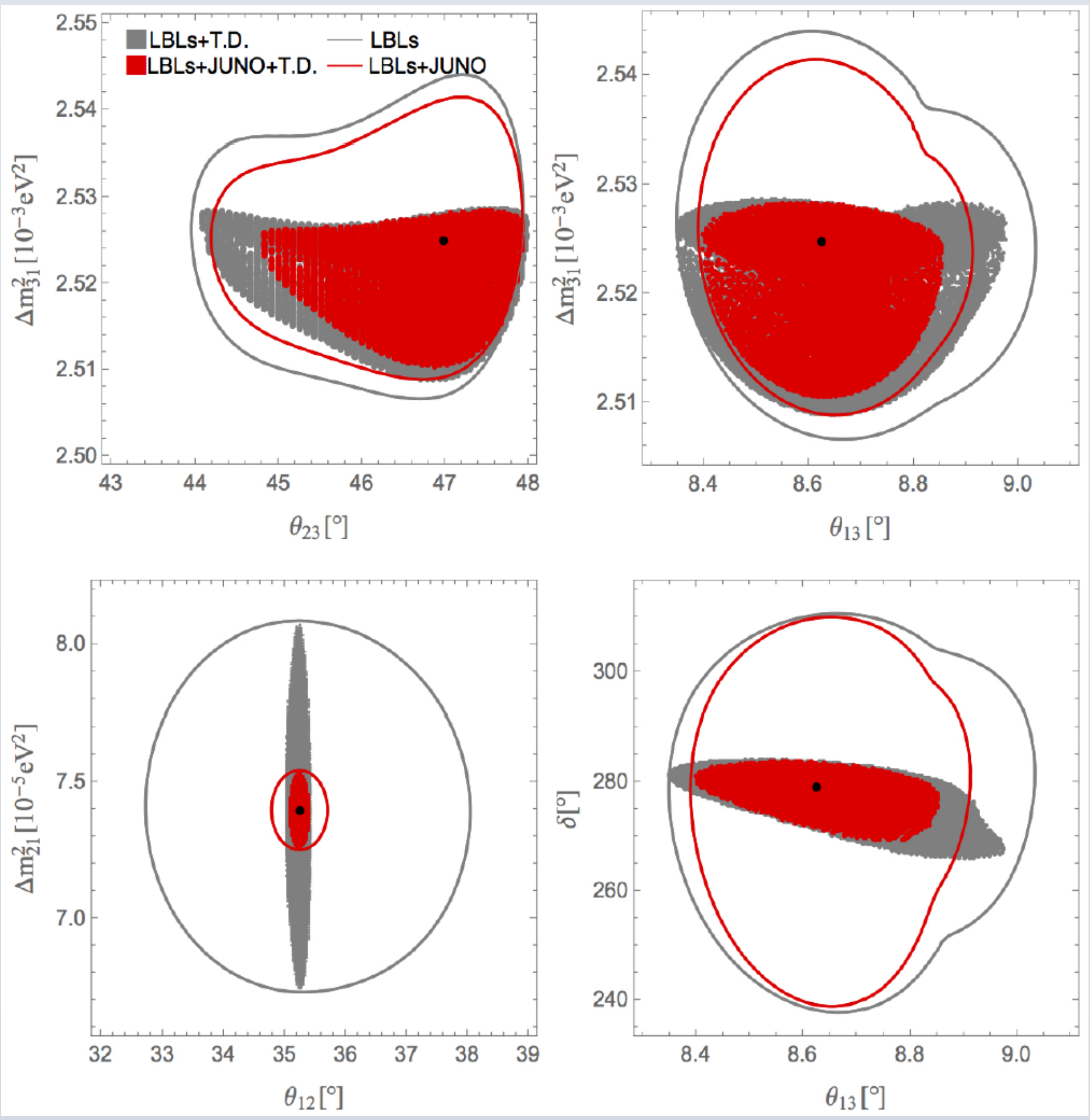
♥ We are able to measure model parameters at the a very high precision.
♥ A great improvement at DUNE compared to the combination T2K&NOνA.
♥ T2HK further improves measurements.
♥ Degenerate solutions show up in the 2D projections.

Origin of degeneracy issues



♥ Symmetry introduces correlations between standard mixing parameters and model parameters.
♥ The degeneracy is mainly caused by the poor measurement of θ_{12}.

Precision requirements from flavor symmetries



♥ Shaded regions incorporate the model symmetry.
♥ JUNO is good at precision measurement of θ_{12} and might help to break degeneracies.
♥ Gray and red regions highlights the contribution by JUNO.
♥ Shape of contours in the projected parameter space can give us hints of the underlying theory.

References

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