Topical discussion (3): Methodologies and experimental inputs for the Unitarity test

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Very brief on (non-)unitarity

- Leptonic mixing matrix must be unitary due to the orthogonality of the flavor-definite neutrino states and the mass eigenstates
  - But it's not necessary to be 3x3 matrix. The see-saw mechanism, for example, imply the existence of the heavy neutral leptons. In this case, the size of the leptonic mixing matrix is larger than 3.
- The observed leptonic mixing matrix with three active flavor-definite neutrinos $(\nu_e, \nu_\mu, \nu_\tau)$ may be just an "*effective*" sub-matrix of the bigger one

$$U \to \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} & \cdots \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} & \cdots \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} & \cdots \\ U_{a1} & U_{a2} & U_{a3} & U_{a4} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

In principle, we want to test the unity of probability sum

$$P(\nu_\mu \to \nu_e) + P(\nu_\mu \to \nu_\mu + P(\nu_\mu \to \nu_\tau)) = 1 \ ?$$

And counterpart with antineutrinos

If we can build a beta beam

$$P(\nu_e \to \nu_e) + P(\nu_e \to \nu_\mu + P(\nu_e \to \nu_\tau)) = 1 \ ?$$

And counterpart with antineutrinos

Practical methodologies

- **Consistency** test where *all* data can be described within 3x3 "standard" PMNS framework (3 mixing angles and one CP-violating phase)
  - ***Big issue:*** Limited measurement of oscillation channels and one individual experiment cannot be sensitive to all parameters.
  - Multiple data set with different setup (baseline/energy/...) are desired for redundant check
  - Which channel(s) we should focus?
  - Possibility to reconstruct the unitarity triangle similar to the way we reconstructed for quark mixing?
- **Unitarity-deviation** test: Model with *extra* parameters, typically with 13 para. Then estimate the constraint on these parameters.
  - It seems impossible for single experiment to do this test?
  - Do we need to worry about the parameter degeneracy in the extended model s
  - Computing time for computing the statistical significance?
- **Anything else?**

Experimental inputs for unitarity test

- *(Of course, we need precision measurement on all parameters)*
- We definitely need more **tau** data (?)
  - Is DUNE's tau sample sufficient to provide a significant test?
  - Prospect of the IceCube upgrade and the like for measuring high-energy tau neutrinos?
  - Shall we think of **neutrino factory** more seriously as
- We definitely need to measure CP with high precision (?)