Precision tests at the LENF: constraining discrete leptonic flavour symmetries

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Outline of talk

The present, the future, and the role of precision

Phenomenological approach to discrete flavour symmetries

Constraining atmospheric sum-rules

Conclusions

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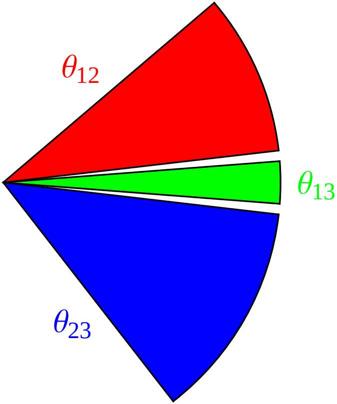
The present, the future...

- Thanks to decades of experimental work, including the discovery last year of θ_{13}, we now know all three of the angles which parameterize the PMNS matrix, and the magnitudes of both mass squared splittings.



$$\Delta m^2_{21} \approx 7.59 \times 10^{-5}$$
$$\left|\Delta m^2_{32}\right| \approx 2.50 \times 10^{-3}.$$

- Naturally, the next big goals are to identify the mass hierarchy and the value of the CP-violating phase δ.

New physics at the LENF

- Precision searches allow us to test the current paradigm (νSM) and to search for new physics effects.

- A key focus of any next-generation facility must be to push the boundaries of precision. There are two generic types of discovery that can be made thanks to increased precision:

New physics at the LENF

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θ_{12}, θ_{23}, θ_{13},
Δm^2_{12}, Δm^2_{13}, δ,
$+?$

νSM too small

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$$\theta_{12},\ \theta_{23},\ \theta_{13},\ \Delta m^2_{12},\ \Delta m^2_{13},\ \delta,\ +?$$

νSM too small

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

νSM too big

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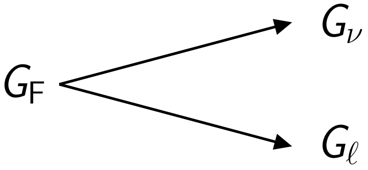
Discrete leptonic flavour symmetries

- As we have seen already, models of discrete flavour symmetries make predictive statements of correlations amongst the neutrino flavour parameters.
- With such a *large body of theoretical predictions*, constraining and excluding these correlations should be an aim of any next-generation facility.
- To focus our discussion, we have restricted our attention to a class of models based on a bottom-up approach due to Hernandez and Smirnov (see 1204.0445 and 1212.2149).

Hernandez-Smirnov approach



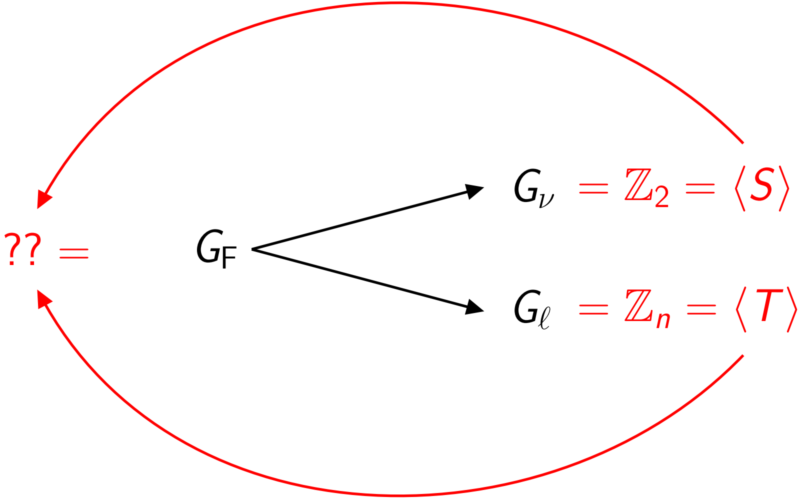
Hernandez-Smirnov approach

$$G_\nu = \mathbb{Z}_2 = \langle S \rangle$$

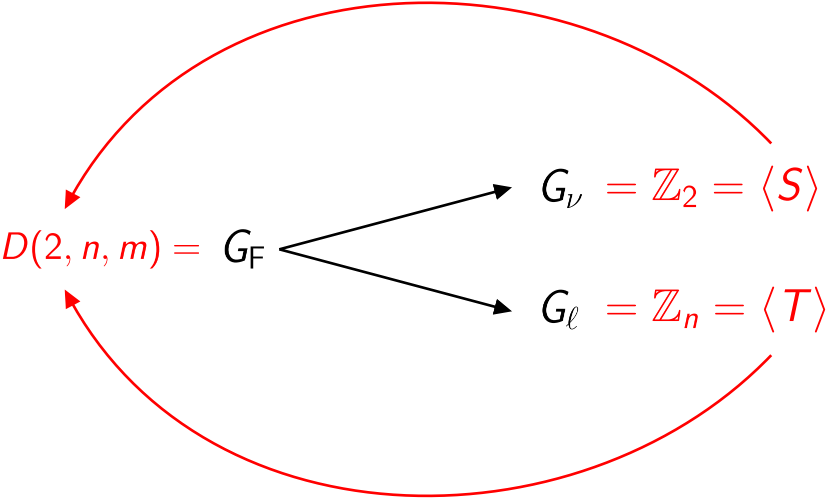
$$G_F \nearrow \qquad \searrow$$

$$G_\ell = \mathbb{Z}_n = \langle T \rangle$$

Hernandez-Smirnov approach



Hernandez-Smirnov approach



Constraints and correlations

- In the framework that I've discussed, the symmetries can be shown to fix a column of the PMNS matrix. This leads to two constraints on the PMNS matrix parameters

$$e.g. \qquad \begin{pmatrix} |U_{e1}|^2 \\ |U_{\mu 1}|^2 \\ |U_{\tau 1}|^2 \end{pmatrix} = \begin{pmatrix} \frac{1-\eta}{2} \\ \frac{1-\eta}{2} \\ \eta \end{pmatrix}.$$

- For the models that we are interested in, these constraints can be expressed as a definition of θ_{12} in terms of θ_{13}, called a *solar sum-rule*, and a correlation between θ_{23}, θ_{13} and $\cos\delta$, which is called the atmospheric sum-rule

$$e.g. \qquad |U_{e1}|^2 = \frac{1-\eta}{2} \quad \Longrightarrow \quad \cos^2\theta_{12} = \frac{1-\eta}{2\cos^2\theta_{13}}.$$

Atmospheric sum-rules

- To simplify our expressions we introduce the following parameters (King 2007)

$$\sin\theta_{12} \equiv \frac{1+s}{\sqrt{3}}, \qquad \sin\theta_{23} \equiv \frac{1+a}{\sqrt{2}}, \qquad \sin\theta_{13} = \frac{r}{\sqrt{2}},$$

which have the following 1σ ranges (Fogli 2012)

$$-0.07 \leq s \leq -0.01, \qquad 0.21 \leq r \leq 0.23, \qquad -0.15 \leq a \leq -0.07.$$

- We then expand the atmospheric sum-rule to first order in r, this allows us to express *all phenomenologically interesting* models by the constraint

$$a = a_0 + \lambda r \cos\delta + \mathcal{O}(r^2, a^2).$$

Viable atmospheric sum-rules

Type	Group	Sum-rule
$\lambda \approx 1$	S_4	$a = r\cos\delta$
	A_5	$a = \sqrt{\frac{1+\varphi}{2}}\,r\cos\delta$
$\lambda \approx -\frac{1}{2}$	A_4	$a = -\frac{1}{2}r\cos\delta$
	S_4	$a = -\frac{1}{\sqrt{6}}r\cos\delta \pm \frac{2}{3}(\sqrt{3}-2)$
	A_5	$a = -\frac{1}{\sqrt{2(1+\varphi)}}r\cos\delta$
	A_5	$a = -\sqrt{\frac{3+2\varphi}{22}}\,r\cos\delta \pm \frac{2}{11}(7+\varphi)s$

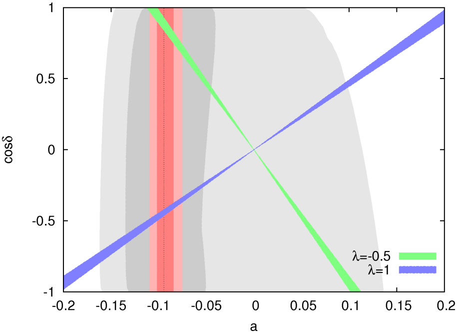
We find 8 viable sum-rules from the construction discussed above. These divide neatly into two classes based on their approximate values of λ.

Sum-rules and current data

- The linearized sum-rule can be seen as a prediction of the model for the parameter $\cos\delta$.

$$\cos\delta = \frac{a}{\lambda r}$$

- The grey bands show the current global-fit data (NuFit 1.0 2012), whilst the pink bands show the projected sensitivity to a in 2025 with the current generation of experiments (Huber et al. 2009).



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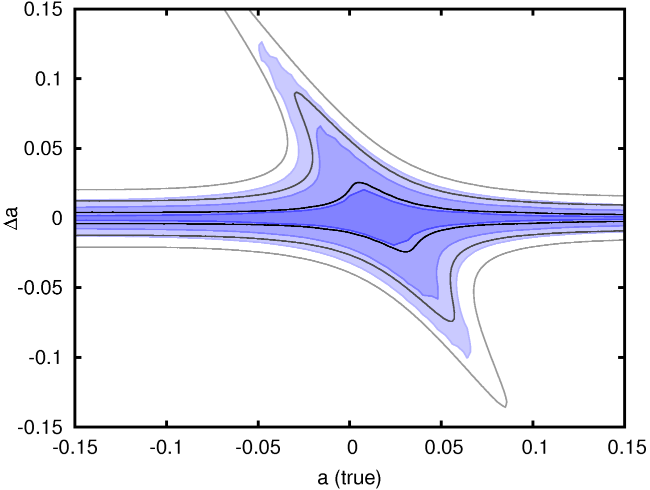
Simulation details

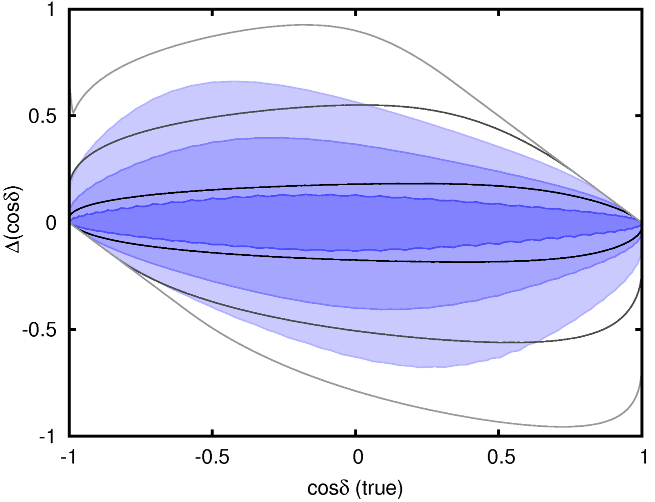
- We have simulated the measurement of sum-rules for some representative next-generation facilities using the GLoBES package (see 0407333 and 0701187).
- We also consider a Low-Energy Neutrino Factory (LENF) with a baseline of 2000 km and a stored-muon energy of 10 GeV. We have run simulations for both a 100 kton MIND and a 20 kton Totally-Active Scintillator Detector (TASD) (see 1112.2853).
- A superbeam based on the LAGUNA-LBNO proposal of a beam from CERN to Pyhäsalmi (Finland). This has a baseline distance of 2300 km and a 100 kton liquid Argon detector (for more info. see CERN-SPSC-2012-021).

Precision in relevant parameters: a



The 1, 3 and 5σ allowed regions for $a = \sqrt{2}\sin\theta_{23} - 1$ as a function of the true value of a. Solid regions are for the LENF, empty regions for the superbeam.

Precision in relevant parameters: $\cos\delta$

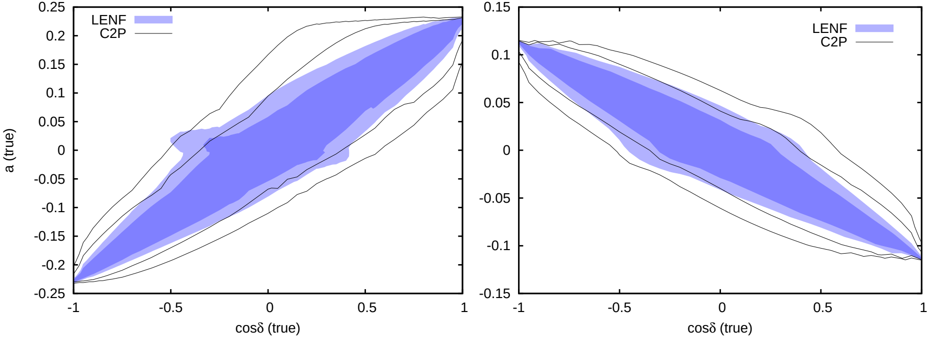


The 1, 3 and 5σ allowed regions for $\cos\delta$ as a function of the true value of $\cos\delta$. Solid regions are for the LENF, empty regions for the superbeam.

Excluding sum-rules

- Combining single parameter determinations (as in the previous slide) can only tell us so much about the ability to exclude parameter combinations.
- In general, parameter correlations can lead these sensitivities to change.
- We have scanned over true values of a and $\cos\delta$. For each pair, we have plotted the $\Delta\chi^2$ value of the best-fitting solution obeying a given sum-rule. When this becomes higher than a certain significance threshold, we can say that the sum-rule hypothesis is excluded.

Excluding $a = r\cos\delta$ and $a = -\frac{1}{2}r\cos\delta$



- These plots show 2 and 3σ allowed regions for the given sum-rules as a function of the true parameters.
- There is a central bump which is due to trivial solutions to the sum-rule close to the origin with $a \approx 0$ and $\cos\delta \approx 0$.

PB et al. (2013) *in preparation.*

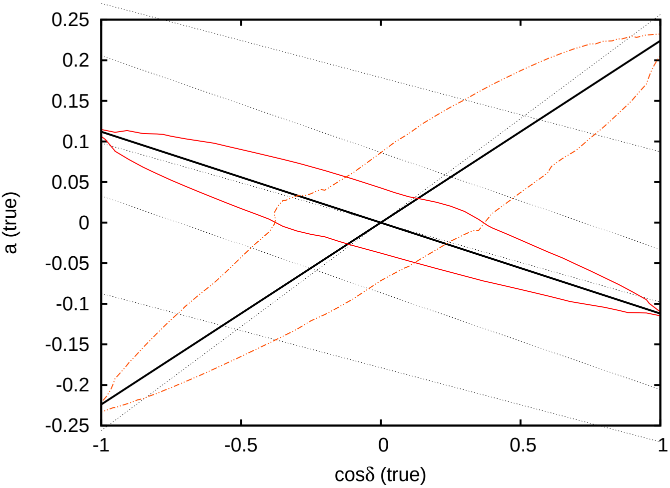
Discriminating between sum-rules

- We have seen that the 8 sum-rules of interest can be classified into one of two types $\lambda \approx 1$ and $\lambda \approx -\frac{1}{2}$.
- What kind of precision would be necessary to discriminate between close lying sum-rules?

$\lambda \approx 1$	$a = r\cos\delta$ $a = \sqrt{\frac{1+\varphi}{2}}\, r\cos\delta$	$\Longrightarrow$	$\Delta\lambda \approx 0.144$
$\lambda \approx -\frac{1}{2}$	$a = -\frac{1}{2} r\cos\delta$ $a = -\frac{1}{\sqrt{2(1+\varphi)}}\, r\cos\delta$	$\Longrightarrow$	$\Delta\lambda \approx 0.063$

Excluding competing sum-rules

PRELIMINARY



To exclude all sum-rules of this type will be very challenging. However, for large parts of parameter space the problem may be reduced to a low-multiplicity degeneracy.

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Conclusions

- With increased precision in the neutrino flavour sector, a LENF will enable us to start to test a number of proposed new physics models which address leptonic flavour.
- There is a large literature of models which use discrete symmetries to predict correlations amongst the parameters of the PMNS matrix. A quite general class of models can have these constraints expressed as atmospheric sum-rules.
- Individual sum-rules can be excluded for a significant fraction of the parameter space. However, excluding all sum-rules of the types that we have identified will be very challenging.

Thank you.