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Measuring θ_{12} despite an uncertain reactor neutrino spectrum

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Abstract

The recently discovered 5–7 MeV excess in the reactor neutrino spectral structure, corresponding to a prompt energy of 4–6 MeV, highlights that the uncertainty in the reactor neutrino spectrum is far greater than some theoretical estimates. Medium baseline (about 50 km) reactor neutrino experiments will deliver by far the most precise ever measurements of θ_{12}. However, the theoretical reactor neutrino spectra, as they were recalculated in 2011, do not reproduce this excess. As a result, if a medium baseline experiment attempted to determine $\sin^2(2\theta_{12})$ using the theoretical spectrum, the result would have a systematic upward bias of 1%, much larger than the expected uncertainty. We show that by using recent measurements of the reactor neutrino spectrum the precision of a measurement of θ_{12} at a medium baseline reactor neutrino experiment can be improved appreciably. We estimate this precision as a function of the ^{9}Li spallation background veto efficiency and dead time.

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1. Introduction

In about 5 years the largest liquid scintillator detectors ever built will be used to detect reactor neutrinos at the experiments JUNO [1] and RENO 50 [2]. The often-stated goal of these experiments is the determination of the neutrino mass hierarchy, following the strategy of Petcov and Piai [3]. Obtaining the required precision for a determination of the hierarchy will be very challenging [4–7]. On the other hand, whether or not this precision can be achieved, there is no doubt that such experiments can provide by far the most precise measurement yet of θ_{12} [8].

In this note we will show that imperfect knowledge of the shape of the reactor neutrino spectrum is a leading source of uncertainty in the measurement of θ_{12} and that this uncertainty has been systematically underestimated in the literature [9,10]. Studies of this measurement use the latest reactor neutrino flux model from Ref. [11], as improved in Ref. [12] with the inclusion of several additional effects. They also use the uncertainties quoted in that paper. Nonetheless, as the author clearly stated in Ref. [13], the uncertainty quoted in Ref. [12] reflects only a subset of the sources of uncertainty in the analysis and so in fact yields only a lower bound on the true uncertainty. As described in [13], without individually analyzing all of the decay chains, it is difficult even to determine how large the total uncertainty should be or what might provide the largest contributions.

One proposal for a source of the excess, and so the uncertainty in the original calculation, has been presented in Ref. [14]. In Ref. [15] the authors study ^{92}Rb decays, which provide large contributions to reactor spectra in the energy range of the excess. They find a ground state to ground state feeding that is in strong disagreement with standard value of Ref. [16], which was used in Ref. [14], but would itself lead to an excess of the observed form. In either case, the reactor anomaly of Ref. [17] appears to reflect a systematic underestimation of the uncertainty in estimates of reactor neutrino fluxes.

Our analysis will yield its own estimate of the expected uncertainty in θ_{12}. While this estimate is necessarily quite precise, it will not be accurate. An accurate determination would require the full covariance matrix of uncertainties for the spectrum generated by each isotope 10 years from now, when the data from these experiments is analyzed. However such a covariance matrix or isotope by isotope analysis is not available even now. Of course a *theoretical* covariance matrix was already proposed in Refs. [11,12] and used in the analysis of Ref. [10]. However, as was described above, those uncertainties appear to have been underestimated and indeed are quite challenging to estimate, and so JUNO will instead use a covariance matrix which is determined experimentally.

Our motivation for writing this paper now, when an experimentally determined covariance matrix for the uncertainties is not yet available, is as follows. In a companion paper [18] we consider the tracking requirements for cosmogenic muons for such experiments. For this, we need to know not the absolute value of the uncertainty in θ_{12}, but rather its expected dependence on the background rejection efficiency. While the absolute value of the uncertainty that we will obtain is quite approximate, the current paper nonetheless demonstrates that the uncertainty in θ_{12} receives a large contribution from systematic errors. This means that little is lost by increasing the statistical fluctuations via a veto strategy with a large dead time. In Ref. [18] we demonstrate that, as a consequence, a very high spallation background rejection efficiency is optimal for the θ_{12} measurement, higher than that for the mass hierarchy. This result is quite robust.