

Impact of theoretical reactor flux uncertainties and of the near detector on the JUNO measurements

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Abstract. JUNO is medium-baseline reactor neutrino experiment that will probe the neutrino spectrum mass ordering (MO) and will measure the mass-mixing oscillation parameters with unprecedented sub-percent precision. It will be complemented with a ton-level, high energy resolution liquid scintillator reference detector, TAO, that will measure the reactor neutrino spectrum with unprecedented accuracy. In this work we study if the limited knowledge of the reactor antineutrino spectrum and of its fine structure can have a significant effect on the mass ordering determination and on the precision measurements of the oscillation parameters, and try to assess the advantages of having the TAO reference detector.

1. Introduction

JUNO is a medium-baseline reactor neutrino experiment that will probe the mass ordering and will measure the mass-mixing oscillation parameters with unprecedented sub-percent precision. It will be complemented with a ton-level, high energy resolution liquid scintillator reference detector, TAO, that will measure the reactor neutrino spectrum with great accuracy. For details about the detectors and the rich physics program see [1, 2]. JUNO will probe the mass ordering by measuring neutrino oscillations at a medium baseline distance, where long and short-wavelength oscillations interfere. The MO will affect the position of the fast oscillation peaks in the low energy region (2-4 MeV). We examine the following important questions: can the limited knowledge of the reactor antineutrino spectrum and of its fine structure have a

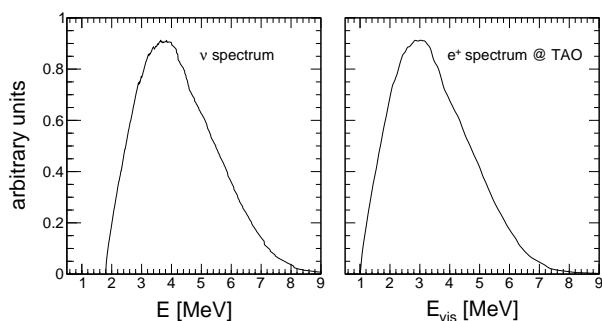


Figure 1. Reactor $\bar{\nu}_e$ spectrum (left) and the observable positron spectrum as a function of the measured visible energy of the event E_{vis} (right).

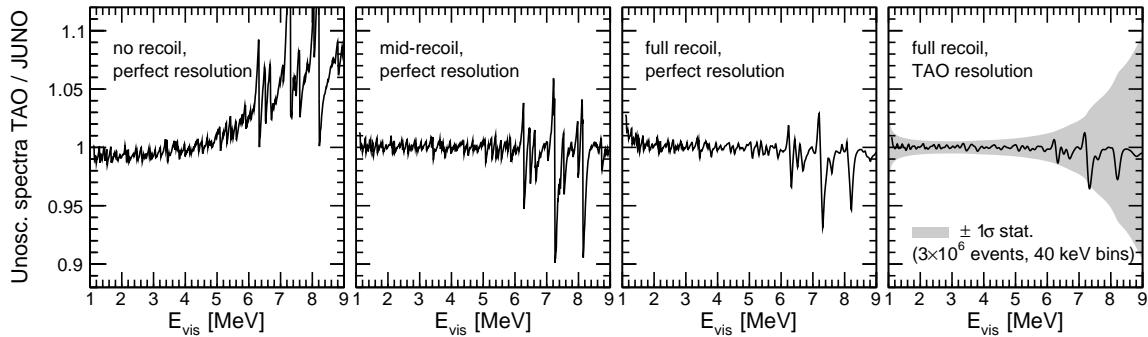


Figure 2. Ratio between the TAO and JUNO unoscillated spectra in different approximation for the calculation of the TAO spectrum. From left to right: 1) no recoil, perfect resolution; 2) mid-recoil, perfect resolution; 3) full recoil, perfect resolution; 4) full recoil, TAO resolution.

significant effect on the MO determination and on the precision measurements of the oscillation parameters? What will be the advantages of the TAO detector? There is a rich recent literature on reactor neutrino flux theoretical predictions and uncertainties on one side and their impact on the JUNO physics program on the other (see for instance [3, 4, 5, 6])

2. Analysis and Results

This work discusses some of the issues that are treated in detail in a more general work [7], where we update our previous analyses [8, 9]. In this analysis, we adopt a reactor antineutrino spectrum with sawtooth-like structures to verify that fine structures do not have a negative impact on JUNO sensitivity to MO and on the accuracy of the measured parameters. We also study the usefulness of the reference TAO measured spectrum and, finally, we show how much the central values of the oscillation parameters used in the analysis can affect the sensitivity to the mass ordering. As a reference spectrum we use the one obtained with the toolkit [10]. With this choice, we can verify that also taking into account all the uncertainties in the summation calculation the sensitivity to MO will not be significantly affected [7]. The JUNO and TAO observable is the positron spectrum as a function of the measured visible energy of the event E_{vis} . The initial antineutrino spectrum and the one expected at TAO are shown in Fig. 1. The deconvolution of the positron spectrum to obtain the neutrino spectrum is not possible because of the presence of fine structures. In general one cannot exactly reconstruct the initial

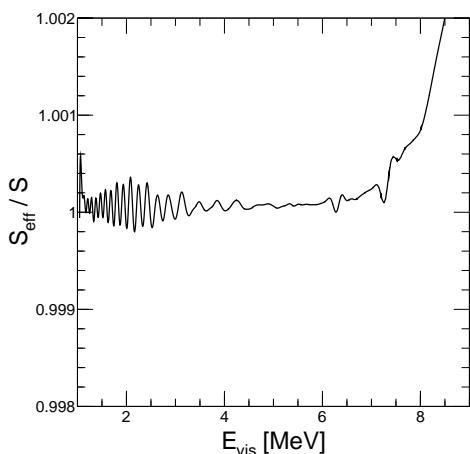


Figure 3. Ratio between the approximated and exact spectrum calculation (best-fit point, NO; similar results for IO and varying oscillation parameters).

$\bar{\nu}_e$ spectrum, going back from E_{vis} to the initial neutrino energy E . Only in the recoilless approximation there is a one-to-one correspondence between the ν energy E and E_{vis} . Taking into account the nucleon recoil, the positron energy E_e is no longer in a direct link with the ν energy, and E_e can vary between two values E_1 and E_2 . This fact produces a kind of smearing of the spectrum. To show how well TAO will measure the unknown features of the spectrum, we plot the ratio between the TAO and JUNO unoscillated spectra for different cases, in Fig. 2. On the left, sawtooth-like structures are perfectly well resolved while on the right fine structures are suppressed but still visible. Going from E to E_{vis} produces a significant loss of information on the initial neutrino spectrum. For this reason it is vital for TAO to achieve the maximal possible resolution.

We have found that one can predict the neutrino spectrum at JUNO by means of the measured spectrum TAO, without the direct knowledge of the initial neutrino spectrum. In particular, it is possible to reconstruct the unoscillated JUNO spectrum without approximations, while the oscillated JUNO spectrum can be calculated with very good accuracy by using a particular ansatz [7]. The ratio between the approximated and exact spectrum calculation is shown in Fig. 4, for the best-fit point in NO (similar results for IO and varying oscillation parameters). In the region of interest for the mass ordering discrimination (2-4 MeV), the approximate calculation is accurate at the level of $< 0.05\%$. Following closely our previous work [9] (but updating priors on oscillation parameters and systematic errors on fluxes and energy scale [7]) we performed two analyses, one with exact numerical calculation of the oscillated JUNO spectrum and a second one using the ansatz and the TAO spectrum. By using the ansatz we obtain almost identical results with respect to the exact calculation, when only errors on oscillation parameters and normalisation are considered. Very good agreement is also obtained when energy scale errors and theoretical flux shape errors are taken into account.

However, the expected improvements on the MO discrimination are not found in Fig. 4 (see for comparison Fig. 7 of [9]). In fact, while systematic uncertainties and errors on oscillation parameters are reduced, the central values of the oscillation parameters have changed, partially compensating the expected increase of sensitivity. To quantitatively understand this effect, the JUNO sensitivity to mass ordering as a function of the oscillation parameter central values is shown in Fig. 5. The two most important parameters in this context are the two squared mass differences, but there is also a sensitivity to changes of the two mixing angles.

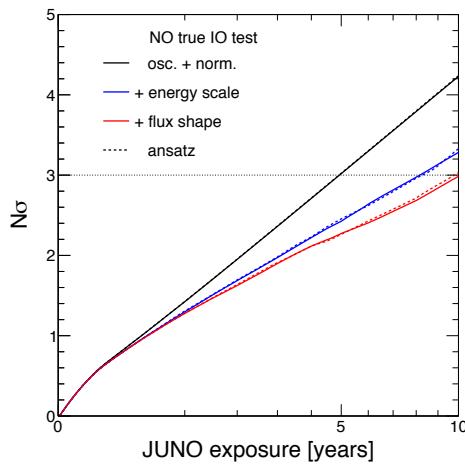


Figure 4. Sensitivity to mass ordering: comparison between exact calculation and ansatz.

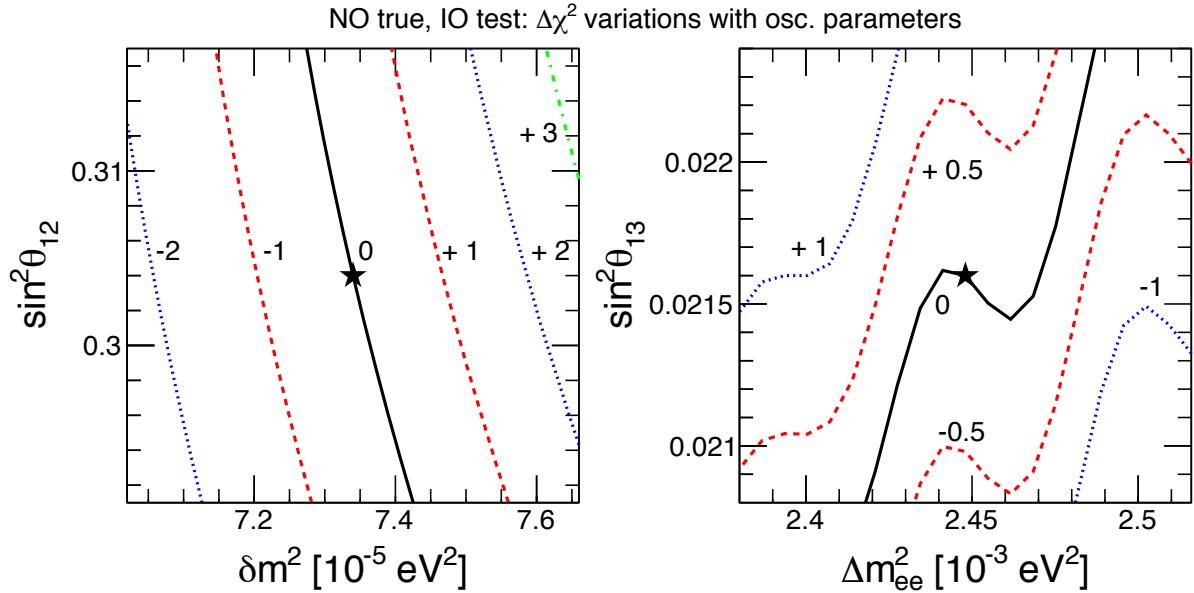


Figure 5. JUNO sensitivity to MO as a function of the oscillation parameter central values.

3. Conclusions

The measured TAO spectrum will allow to calculate with very good accuracy the oscillated $\bar{\nu}_e$ spectrum at JUNO, without any reference to a theoretical prediction. The fine structures of the antineutrino spectrum do not constitute a problem for the mass ordering discrimination nor for the precision measurements of the oscillation parameters, even when all uncertainties in the summation calculation are taken into account. The projected JUNO sensitivity to MO depends more on the central values of the oscillation parameters than on the details of the initial reactor $\bar{\nu}_e$ spectrum.

4. Acknowledgments

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