Problems With the MINOS/MINOS+ Sterile Neutrino $\nu_\mu$ Disappearance Result

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(Dated: April 2, 2018)

The MINOS/MINOS+ experiment has recently reported stringent limits on $\nu_\mu$ disappearance that appear to rule out the 3+1 sterile neutrino model. However, in this paper we wish to point out problems associated with the MINOS/MINOS+ analysis. In particular, we find that MINOS/MINOS+ has either underestimated their systematic errors and/or has obtained evidence for physics beyond the 3-neutrino paradigm. Either case would invalidate the limits on $\nu_\mu$ disappearance.

PACS numbers: 14.60.Pq,14.60.St

I. INTRODUCTION

The MINOS/MINOS+ collaboration has recently presented stringent limits on short-baseline $\nu_\mu$ disappearance [1] in the $\Delta m^2$ region from $0.0001$ eV$^2$ to $1000$ eV$^2$. At moderate values of $\Delta m^2$ around $1$ eV$^2$, the experimental procedure makes use of the relative rate of neutral current (NC) and charged current (CC) events in the far and near detectors. At high values of $\Delta m^2$ around $1000$ eV$^2$, the near and far detectors will see identical oscillation effects that will vanish in the ratio. In that case, the experiment must rely upon comparing neutrino data to an absolute prediction, which we will call “dead reckoning” in this article.

However, the MINOS/MINOS+ analysis has two significant problems that make the limits dramatically too good. First, the systematic uncertainties used in the analysis appear to be much too low. Second, there appears to be an unknown systematic bias that results in relatively more NC events in the far detector than in the near detector.

II. SYSTEMATIC UNCERTAINTY PROBLEM

The MINOS/MINOS+ limit plot is shown in Fig. 1. At $1000$ eV$^2$, the limit (sensitivity) for $\sin^2 \theta_{24}$ is $\sim 1.2\%$ ($\sim 4\%$). This corresponds to a fractional error for the absolute, dead-reckoning prediction of the event rate to be $\sim 2\%$ ($\sim 6\%$), which is too low to be credible. The total systematic error needs to include the systematic errors on the neutrino flux, the neutrino cross section, the detector efficiency, the DAQ efficiency, and many other contributions, and it seems impossible that the cumulative value for all of these systematic errors is $2\%$ ($6\%$). Based on the experience of other neutrino experiments around the world, one would expect a total systematic error $>15\%$.

III. SYSTEMATIC BIAS PROBLEM

The MINOS/MINOS+ data-to-prediction plots in Fig. 2 show the ratio of data to the no-oscillation prediction for, from left to right, CC far detector, NC far detector, CC near detector and NC near detector. As can be seen in the figure, the NC data events appear to be above (below) the Monte Carlo prediction in the far (near) detector, which implies that there are relatively more NC events in the far detector than the near detector. To quantify this effect, we calculate the ratio of ratios, $R$, to be the ratio of NC events observed to expected in the far detector compared to the near detector. A fit to the data, using only statistical uncertainties, yields $R = 1.062 \pm 0.019$, which corresponds to a $3.3 \sigma$ statistical effect. The $\chi^2 = 21.1/12$ DF for $R = 1$ and $\chi^2 = 10.1/11$ DF for $R = 1.062$, giving $\Delta \chi^2 = 11.0$ or a probability of $9 \times 10^{-4}$ for the expected value of $R = 1$. This clearly shows that either there is a large systematic error and/or there is evidence for neutrino appearance from physics beyond the 3-neutrino paradigm. Note that this cannot be explained by 3-active neutrino oscillations. Note also that the MINOS/MINOS+ analysis assumes that the probability of $\nu_\mu \rightarrow \nu_e$ oscillations is zero. However, in 3+N models with three active neutrinos and N
FIG. 2: The summed MINOS/MINOS+ reconstructed energy spectra from reference [1].

Sterile neutrinos, there will, in general, be both $\nu_\mu$ disappearance and $\nu_e$ appearance.

IV. CONCLUSIONS

In summary, we note the following two problems with the MINOS/MINOS+ analysis.

- The limit (sensitivity) at high $\Delta m^2$ indicates an $\sim 2\%$ ($\sim 6\%$) uncertainty on the absolute, dead-reckoning determination of the event rates in the near detector, which is not credible given that one would expect an uncertainty $> 15\%$ based on other neutrino experiments.

- The ratio of NC events observed to expected in the far detector to the near detector is $1.062 \pm 0.019$, assuming statistical uncertainties. This is $\sim 3.3\sigma$ from unity.

MINOS/MINOS+ has either underestimated their systematic errors and/or has obtained evidence for physics beyond the 3-neutrino paradigm. Either case would invalidate the limits on $\nu_\mu$ disappearance.

[1] P. Adamson et al., arXiv:1710.06488