Advantages of a Second Detector In the Neutrino Mass Hierarchy Determination

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Advantages of a Second Detector

We studied the possibility to determine the mass hierarchy using reactor neutrino experiments at intermediate baselines, like JUNO or RENO 50. We will compare the performances of **two 10 ktons** detectors vs. **one 20 ktons** detector ($\Rightarrow$the *total mass* is the *same*). The second detector

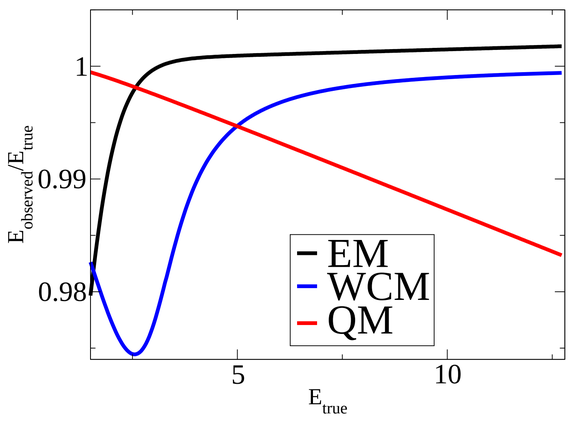
- **Breaks the degeneracy** between a shift of Δm^2_{23} and a change of the hierarchy
- **Reduces** significantly the impact of **systematics due to non-linear energy response**
- With the addition of a cyclotron complex $\Rightarrow$ **precise (and cheap) measurement of** δ_{CP}
- Smaller detectors $\Rightarrow$ **Less background** due to cosmogenic muons (see poster by M. Grassi)

We tested several possible locations for the detectors. One of our results is that the sites near the DayaBay complex are affected by a severe interference effect, which reduce the sensitivity to the hierarchy, and the optimal location is in the DongKeng region[1, 3]; the JUNO detector is now planned to be built there.

Non-linear Response[2, 3]

Even a small non-linear energy response (2-3%) can significantly affect the sensitivity of the experiment. We consider three different models of non-linearity:

- **"Worst-Case" model (WCM)**: the non-linearity is tuned to mimic the behavior of the inverted hierarchy
- **Exponential mode (EM)**: ΔE decreases exponentially
- **Quadratic model (QM)**: ΔE is proportional to E^2,



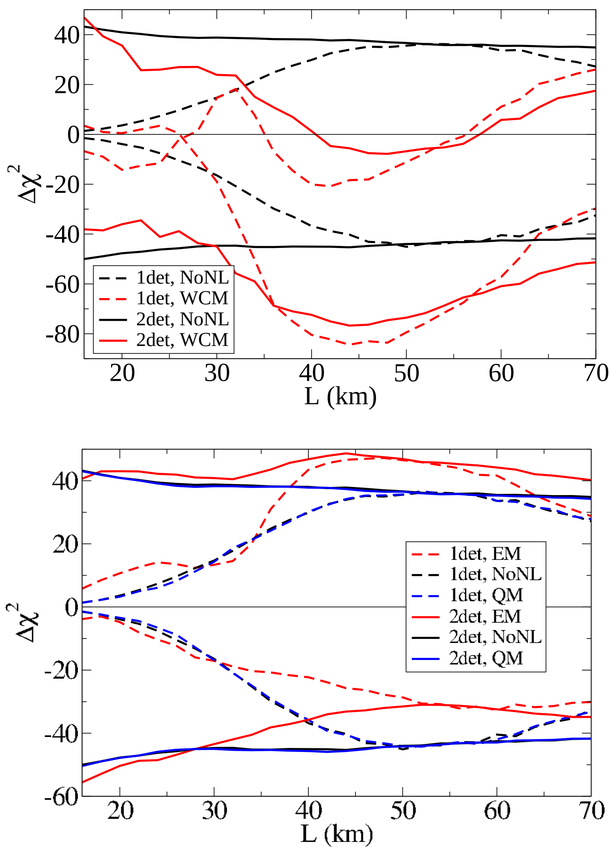


Figure 1: $\Delta\chi^2$ for different models of non-linearity. 6 years running.

δ_{CP} Determination[4]

2 detectors + 1 μDAR source $\Rightarrow$ it is possible to measure δ_{CP}

- With respect to the DAEδLUS project, it requires only one cyclotron complex
  - Cheaper
  - Technically easier
  - BUT it requires TWO detectors!
- Run the two detectors at the same time
  - In principle 100% duty factor (as compared with 20% in DAEδALUS)
  - Lower intensity required:$\simeq$ 9mA
- Possible synergy with other experiments, like T2K

Figure 2: Potential site for the cyclotron complex between the JUNO detector sites DongKeng [3] and ZiLuoShan [1].

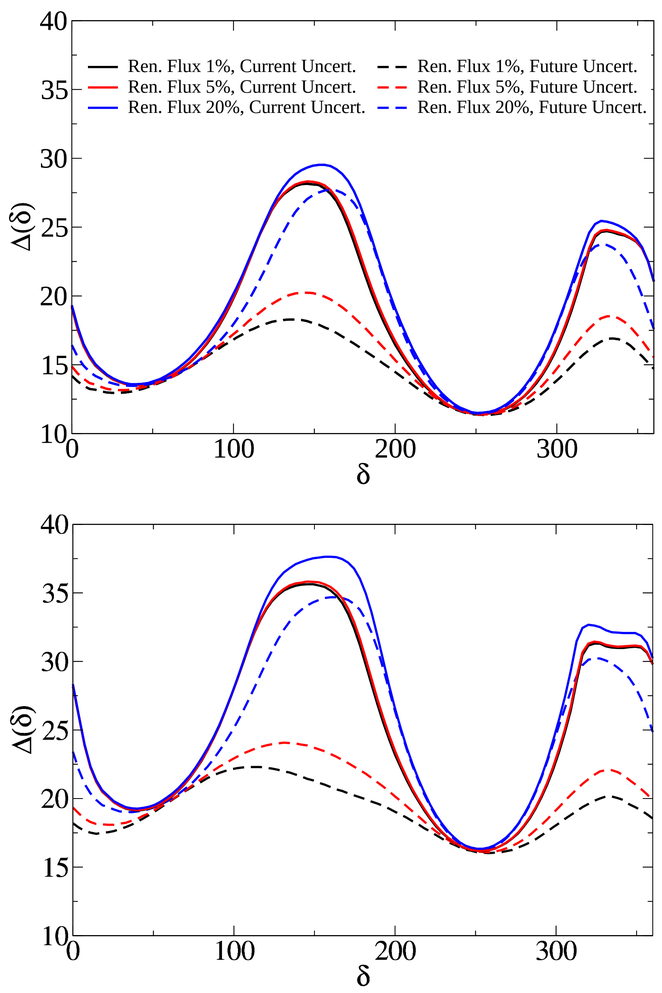


Figure 3: Precision in the determination of δ_{CP}; we used different precisions for the total flux renormalization and the actual and predicted uncertainties on the mixing parameters. Top panel: 12 years running. Bottom Panel: 6 years running

Statistical Distribution[5, 6]

The "factor 2"

The two hierarchies are non-nested hypothesis, hence the Wilks theorem cannot be applied. This means that the $\Delta\chi^2$ does not follow a one-degree-of-freedom χ^2 distribution. It follows a Gaussian distribution with standard deviation $\sqrt{\overline{\Delta\chi^2}}/2$ instead of $\sqrt{\overline{\Delta\chi^2}}$ (where $\overline{\Delta\chi^2}$ is the expected $\Delta\chi^2$).

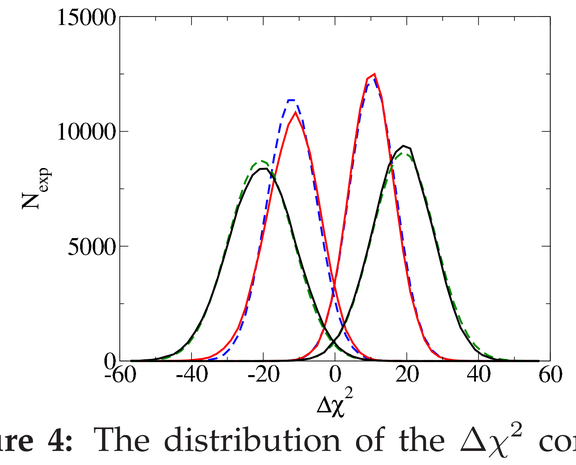


Figure 4: The distribution of the $\Delta\chi^2$ combining the result of the experiment with the MINOS' 4% determination of the atmospheric mass splitting (black curve) or an optimistic 1% determination at NOνA (red curve). The dashed curves (green and blue) are the result of the MC simulation.

What is the sensitivity to the hierarchy for a given $\overline{\Delta\chi^2}$?

- We define the *sensitivity* of an experiment to be the probability that a $\Delta\chi^2$ test will find the right hierarchy. Using the error function, we express this quantity as the number s of σ's.
- We call **mean sensitivity** the probability of determining the correct hierarchy in a set of simulations.
- We call **median sensitivity** the probability that the median experiment (where $\Delta\chi^2 = \overline{\Delta\chi^2}$) will determine the right hierarchy.

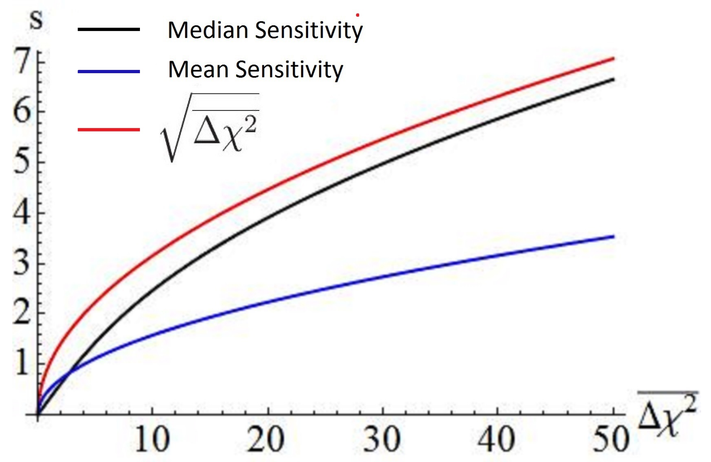


Figure 5: The mean (blue) and median (black) sensitivity on the hierarchy determination as a function of $\overline{\Delta\chi^2}$. For a comparison, also $\sqrt{\overline{\Delta\chi^2}}$ (red) is shown.

References

[1] E. Ciuffoli, J. Evslin and X. Zhang, JHEP **1212** (2012) 004.

[2] E. Ciuffoli, J. Evslin, Z. Wang, C. Yang, X. Zhang and W. Zhong, arXiv:1211.6818 [hep-ph].

[3] E. Ciuffoli, J. Evslin, Z. Wang, C. Yang, X. Zhang and W. Zhong, arXiv:1308.0591 [hep-ph].

[4] E. Ciuffoli, J. Evslin and X. Zhang, arXiv:1401.3977 .

[5] E. Ciuffoli, J. Evslin and X. Zhang, arXiv:1305.5150 [hep-ph].

[6] X. Qian, A. Tan, W. Wang, J. J. Ling, R. D. McKeown and C. Zhang, Phys.Rev.**D**86 (2012) 113011.