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Short note on IDS-NF baseline detector mass upgrade

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Abstract

In this short note, I discuss some aspects of upgrading the detector mass and systematics. I partly refer to the existing literature.

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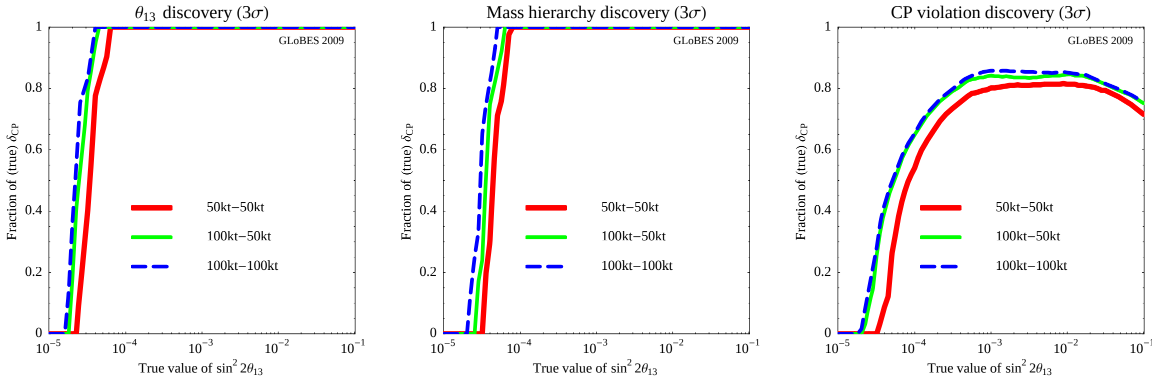

Figure 1: Impact of a detector mass upgrade at the shorter baseline (100kt-50kt) and at both baselines (100kt-100kt) compared to the IDS-NF baseline (50kt-50kt) at the 3σ CL.

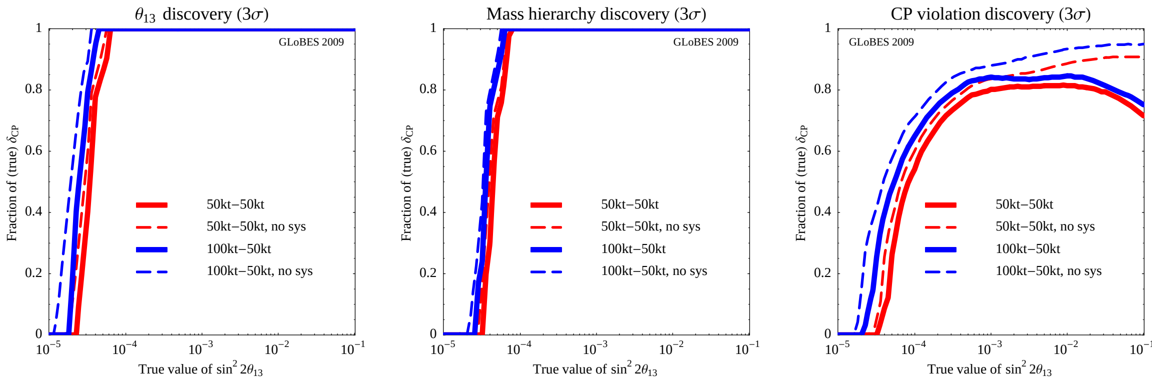

Figure 2: Comparison between IDS-NF standard systematics (solid curves) and no systematical errors (dashed curves) for the (100kt-50kt) and (50kt-50kt) options at the 3σ CL.

1 Upgrading from 50 kt to 100 kt

Fig. 1 illustrates the impact of possible 100kt upgrades on the standard physics measurements. For 100kt at the short baseline, there is a significant improvement of the sensitivities, but the effect is less dramatic as that of systematics (see next section). Upgrading also the long baseline detector (100kt-100kt) does not yield any significant improvement.

2 Some comments on systematics

In Fig. 2, the impact of systematics is illustrated for the most optimistic case, *i.e.*, no systematical errors (however, the efficiencies and backgrounds are assumed to be the ones from the IDS-NF baseline setup), versus the IDS-NF systematics. In the dashed curves of this figure, there are no signal and background normalization errors, and there is no matter density uncertainty. The solid curves use the IDS-NF standard values and a 2% matter density uncertainty. This figure illustrates what the improvement would be in the most optimistic case. Especially for the CP violation measurement for large $\sin^2 2\theta_{13}$, there is a significant impact of systematics.

Some improvement for large $\sin^2 2\theta_{13}$ can be achieved by a number of factors (such as a better known matter density profile). However, most importantly, the systematics implementation is a key issue. So far, only uncorrelated errors among all oscillation channels are used. However, some of the errors (such as cross section errors) will be correlated among all detectors measuring the same flavor and polarity of neutrinos. Therefore, already an alternative cross section implementation can improve the results. This is illustrated in detail for such an alternative approach in Sec. 4 (description and comparison to IDS-NF baseline) and Sec. 5.3 (impact on CP violation measurement) – see Fig. 9 – of Ref. [1]. For a realistic systematics implementation, both a realistic cross section model (and an estimate for the knowledge at that time) and a list of systematical errors has to be provided. The following details are required as input from the accelerator and detector working groups:

- What types of signal and background normalization errors are there? What are realistic numbers for these?
- Are they correlated among different bins, channels, detectors, or uncorrelated?

For example, an error on the efficiencies (such as a fiducial volume error) may be regarded as uncorrelated among all different detectors but correlated among all bins, whereas cross section errors are typically correlated among all measurements depending on the same cross sections, but there can be shape errors, *i.e.*, a bin dependence.

For the cross sections, the situation is more complicated. It may be useful to use a parameterization of the systematical errors (such as a normalization and tilt error). In this case, realistic projections for these systematical errors are needed for the time of the neutrino factory measurement. In addition, the cross section errors could be partly correlated between different flavors and neutrinos or antineutrinos, depending on the model. In Ref. [1], the most conservative apporach is used: Uncorrelated errors among all bins with relatively little external input, but the cross sections are assumed to be measured by the near detectors.

3 One versus two baselines?

Here I quickly review the physics case for the very long baseline, even in the presence of a larger 100kt MIND. For of all, Fig. 3 illustrates the complementarity of the two very different physics measurements. In this case, it is even assumed that the useful number of ions decays is, in the combination of the two baselines, only half of that of one storage ring only. The magic baseline is an efficient degeneracy resolver [2]. Of course, the presence of these degeneracies depends on the confidence level chosen and on the statistics. However, even then, the magic baseline increases the robustness of the results (*e.g.*, with respect to a lower than anticipated statistics).

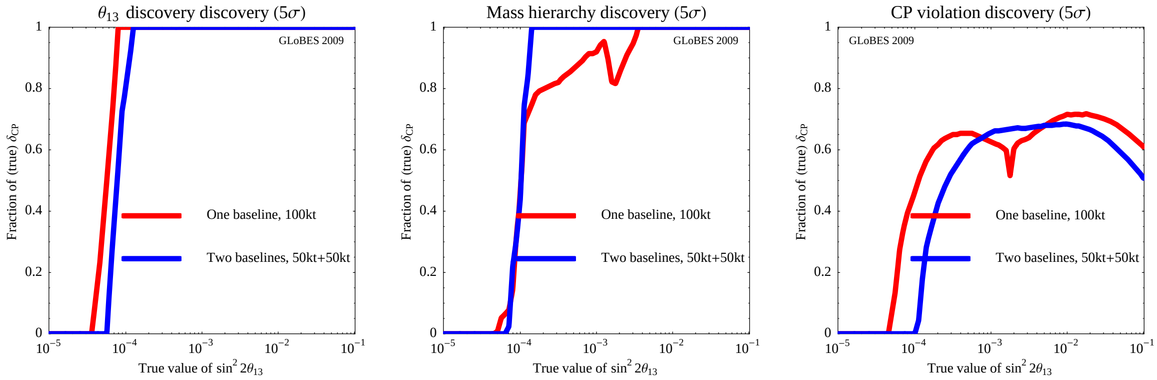

Figure 3: Comparison between a one baseline option (100kt detector mass, $5.0 \cdot 10^{20}$ useful ion decay per year and polarity) and two baseline option (50kt-50kt detector mass, $2.5 \cdot 10^{20}$ useful ion decay per year and polarity) at the 5σ CL. Note that the two baseline option has effectively half the luminosity of the one baseline option, since in the one baseline case, all muons are assumed to be injected in one storage ring.

Other arguments in favor of the magic baseline are (which cannot or only in parts of the parameter space done with the shorter baseline):

- Systematics cancellations, if similar far detectors are used – even in the absence of near detectors; see Fig. 9 (right) in Ref. [1].
- In the presence of non-standard physics, the physics potential of both standard and NSI measurements highly depend on the presence of the magic baseline [3, 4].
- Risk-minimized (with respect to the true δ_{CP}) θ_{13} precision measurement; see Fig. 6 of Ref. [5].
- Risk-minimized (with respect to the true δ_{CP}) δ_{CP} precision measurement; see Fig. 7 (right) of Ref. [6].
- High CL MSW effect confirmation in Earth matter: Ref. [7].
- Octant resolution; see Fig. 7 of Ref. [5].
- Matter density measurement; see Sec. 8 of Ref. [5] and Ref. [8].
- Leading atmospheric parameter measurements; see Figs. 7 and 8 of Ref. [9].
- Mass hierarchy determination for θ_{13} (may contribute somewhat); see Ref. [10].

These examples illustrate, that the physics case for the magic baseline is not only based on a performance comparison of the standard measurements, but also on complemetary physics.

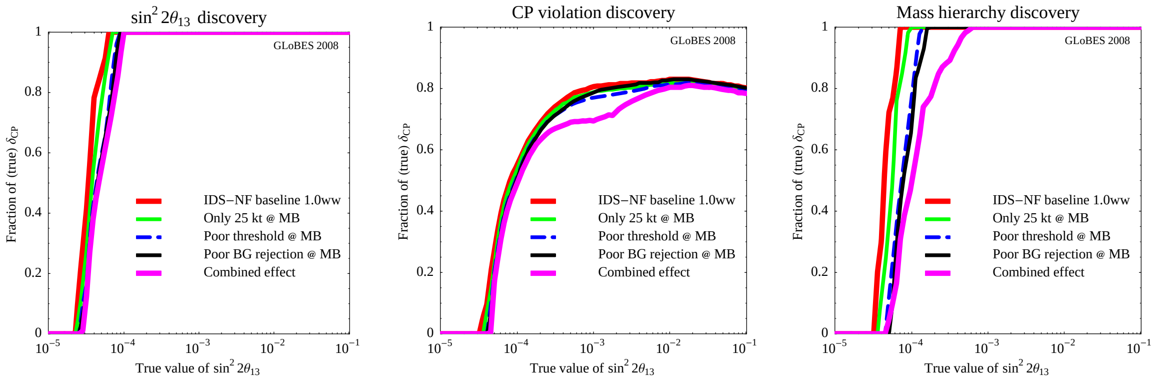

Figure 4: Impact of certain changes in the properties of the magic baseline detector compared to the MIND of the IDS-NF baseline (old calculation, do not compare with the other plots). The different curves correspond to the following scenarios: IDS-NF baseline, magic baseline detector mass reduced to 25kt, poor threshold at magic baseline (threshold increasing linearly from 4 to 20 GeV from 0 to 0.5, then constant), poor background rejection at magic baseline (backgrounds increased by a factor of ten), and the combined effect.

4 Detector properties at the magic baseline

Fig. 4 illustrates the impact of several factors which could affect the detector at the magic baseline, if a different detector than the IDS-NF MIND is used (see figure caption for more details). Obviously, the individual effects are small, but the combination of several factors would lead to significantly worse sensitivities.

For the impact of a smaller detector mass at the long baseline, see also Fig. 11 in Ref. [5] for the $\sin^2 2\theta_{13}$ sensitivity.

5 Conclusions

A 100kt MIND (instead of 50kt) at the short baseline significantly improves the results, it is certainly useful from the physics point of view. However, understanding the systematics better is also important. In particular, the systematics model should be reviewed. The impact of different systematics in the current systematics implementation is, for example, illustrated in Figs 13 and 14 of Ref [9]. However, this systematics implementation may not be very accurate in the sense that all errors are assumed to be uncorrelated effective errors. Therefore, one should discuss the systematics model first, and then the improvement which can be achieved by reducing certain systematical errors.

The physics case for the magic baseline is robust and does not depend on details of the detector implementation, as long as some minimum criteria are met.

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