Response to the report of the ECFA review panel for future large infrastructures for neutrino oscillation experiments

On behalf of the IDS-NF and EUROnu collaborations, the IDS-NF Steering Group and the EUROnu Management Board welcome the report of the ECFA review panel for future large infrastructures for neutrino oscillation experiments and the detailed analysis of the Interim Design Report that it contains. The Steering Group and Management Board would like to bring the following points to the attention of the Panel. The points relating to the Neutrino Factory are made on behalf of both the IDS-NF and EUROnu while the points made on the beta-beam and super-beam are made on behalf of EUROnu.

Executive summary

1. ***From Super-beam to Beta-beam and Neutrino Factory, it seems reasonably clear that cost, complexity and risk all increase together in this order. It is also reasonably clear that the physics reach of the three schemes increases in the same order — so that, for example, while the Neutrino Factory would be the most expensive, complex and risky, it would also provide the most scientific information.***

Both the IDS-NF and the EUROnu collaborations are working towards final reports in which the cost and risk presented by the facilities under study will be presented. We therefore feel that it is premature to draw definitive conclusions about the relative cost and complexity. In particular, while we recognize that the Neutrino Factory accelerator facility has greater complexity than that of the super-beam, we also note the Panel's comment in its "Final comments" that:

> *"The committee is aware of the fact that the Beta-beam community has in the meantime produced a concept for the complete facility, from ion source to decay ring. It illustrates the challenges and reveals the possibility that the scope and cost may approach those of a Neutrino Factory."*

We therefore urge the Panel to consider a revision of the definitive wording of its conclusions regarding cost and complexity.

2 ***For the specific beam options presented in the reports under review, the relatively short baseline from CERN to Fréjus is not optimal (page 2).***

The sensitivity plots presented in the reports show that, for relatively large θ_{13} (~8^o), the proposed CERN to Frejus super-beam has sensitivity to leptonic CP violation over 75% of all possible values of δ. The CERN to Frejus proposal has been developed specifically to cover the relatively large θ_{13} range using a facility that may be delivered by incremental development of present technology.

3. ***It is to the advantage of both Super-beam and Beta-beam projects to develop a complete end-to-end conceptual design that can be confronted with the reality of CERN policy. This is especially the case for the Beta-beam, for which the focus of the presentations was the ion source and not the accelerator complex.***

The EUROnu mid-term report was, by its nature, intended for the European Commission and only really discussed the activities of the preceding year. Hence, it was not an ideal document for this review. As a result, it did not give a full overview of the work on the super-beam and beta-beam and incorrectly gave the impression that the studies of these facilities are not as complete as those for the Neutrino Factory. The EUROnu final report will include complete conceptual designs for all three facilities and will form a much better basis for such a review.

The Science case

4. ***It is quite evident from the figure that the value of $\sin^2 2\theta_{13}$ acts as a watershed. If θ_{13} is close to the present limit referred to earlier, we may reasonably expect that the present generation of experiments will do a large part of the science.***

The Steering Group would like to draw the Panel's attention to the analysis presented in JHEP 11 044 (2009) and summarised in the IDR (pages 17 to 19) which demonstrates that there is a substantial risk that the present generation of experiments will not be able to resolve the mass hierarchy or demonstrate that $\delta_{CP} \neq 0,\pi$. It is for this reason that the Steering Group agrees with the Panel when it concludes:

> *"It may appear that extending the presently available technologies (for the accelerator, beam and large detector) looks faster and easier than introducing new concepts. However, to improve mature technologies substantially may eventually need much more work than introducing new technologies will."*

5. ***Their science reach is illustrated in Fig. 2, where they are compared with the physics reach of the LBNE project and with the limits that can be reached by the present generation of experiments.***

Please note that the ion intensities used in figure 2 are from the EURISOL study and therefore significantly under-estimates what we now believe can be achieved for ^{18}Ne.

The Technologies

6. ***For the three schemes presented, Super-beam, Beta-beam and Neutrino Factory, it seems reasonably clear that cost, complexity and risk all increase together in the same order (i.e. in the order Super-beam, Beta-beam and Neutrino Factory).***

See comments made under point 1 above.

Neutrino Factory

Proton driver

7. ***An SPL-type linac, though at twice the nominal energy, or a Project X (FNAL)-type linac could be candidates.***

The specification for the proton-driver beam energy is that it be in the range 5 GeV to 15 GeV. The present design of the SPL delivers a beam energy of 5 GeV, i.e. at the bottom end of the range specified.

Target

8. ***As in the case of a Super-beam, the problems of thermal shock and cooling are considerable. As solid targets are excluded at this power level, the collaboration envisages a free-flowing liquid mercury jet.***

The free liquid-mercury-jet target has been adopted as the baseline for the Neutrino Factory target for the reasons outlined in the Panel's report. The studies of shock in solid targets, summarized in the IDR and briefly presented to the Panel, indicate that solid tungsten can withstand the beam induced shock if a mechanism to exchange the target rods and a sufficient rate can be demonstrated. The absence of such a rod-exchange mechanism presently excludes consideration of solid targets as the baseline option at the Neutrino Factory.

Alternatives to the liquid-mercury jet are being studied. Experiments suggest that solid targets are an option for the Neutrino Factory target it a suitable target-exchange mechanism can be devised.

Fluidised tungsten powder is also being considered as an alternative. The feasibility of such a concept has been demonstrated off-line in a test rig configuration.

Muon front-end; The cooling section

9. MICE will be a scaled-down version of the channel required for the Neutrino Factory.

The MICE collaboration has designed and will construct a single lattice cell of the ionization-cooling channel described in the US Neutrino Factory Feasibility Study II. That is to say that the MICE cooling channel will not be "scaled down", rather the length of channel constructed will be the minimum to demonstrate all the properties of the lattice cell and to allow all the relevant effects to be studied.

Accelerating complex; Fixed-field Alternating Gradient synchrotron

We agree with the comments made by the Panel and notes that the independent engineering analysis and cost estimation is being carried out in preparation for the costing to be presented in the Reference Design Report. We note that the Electron Model of Muon Acceleration (EMMA) proof-of-principle machine at the Daresbury Laboratory has delivered an initial demonstration of serpentine acceleration and will be exploited to address a number of the issues raised by the Panel.

The decay ring

10. Although not explicitly mentioned in the Interim Design report, an important strategic issue of the Neutrino Factory was pointed out in an oral presentation: namely, the possible synergy with a future muon collider.

The place of the Neutrino Factory in a muon-accelerator based particle-physics programme is discussed in the last section of the Executive Summary of the IDR (pages 6 and 7). The synergies with the programme envisaged by those who seek to discover charged-lepton-flavour violation and with the development of the Muon Collider are addressed. The potential of a muon storage ring to serve the next generation of super-beam experiments by allowing the measurement of electron-neutrino cross sections is recognised by the IDS-NF collaboration but not discussed in the Executive Summary of the IDR.

Detectors for the Neutrino Factory

11. The near detector will be necessary in order to measure the absolute neutrino flux from the Neutrino Factory. It will be placed ~100 m from the end of the straight neutrino decay section.

The near detector will be used to make a measurement of the neutrino flux in addition to that made using the instrumentation of the storage ring. It is essential that the near detector is able to measure precisely the neutrino scattering cross sections, including the charm cross section.

Detectors for the Neutrino Factory; Near detector

12. The near detector is essential to measure the absolute neutrino flux. In addition, it will be useful for neutrino cross section measurements and essential to estimate the background in the far detector.

As noted in point 11 above, it is essential that the near detector be capable of making precise measurements of neutrino-scattering cross sections. It will also be used to make a measurement of the neutrino flux independent of that made by instrumentation in the storage ring.

Super-beam

Target

The thermal shock in the super-beam target is significantly less than in a Neutrino Factory target and modelling, based on experience with the T2K target, suggests that the heat deposited in the target can be removed. An experiment to demonstrate this is planned.

Horn

R&D is already underway or planned for the target, horn and pulser.

Beta Beam

The production mechanisms for the baseline ions are largely based on established techniques, though with significant extrapolations in flux. Further, experiments have been carried out to measure the differential production cross-sections for all the ions.

The γ=350 option is not being considered in EUROnu. However, higher γs are possible in the SPS and are being studied, along with a longer baseline for the super-beam, as a method of optimising CP-sensitivity for large θ_{13}. The optimization of the beta-beam for large θ_{13} is still to be performed. Significant increases in physics performance can be achieved, for example, by delivering larger ion fluxes or by using the beta-beam in conjunction with a super-beam.

The CERN-based beta-beam team are involved in the discussion of the upgrades to the PS and SPS that are required for the LHC so that, as far as possible, the solutions that are adopted take into account the constraints imposed by beta-beam.

The beta-beam has developed (see the Beta-beam web-based parameter database) and is continuing to study an end-to-end conceptual design. The focus of activities in the second year of EUROnu has, however, been on ion production and optimizations in the decay ring for maximum neutrino flux with a stable ion beam. These points were was not as apparent as they should have been!

Water Cherenkov detector

A near detector is being studied for the super-beam and beta-beam, which is very similar to that for the Neutrino Factory.

Final comments

13. The recent "interesting indications" that θ_{13} may not vanish have created renewed interest in building a Superbeam at CERN to an underground laboratory at a favorable distance of ~2500 km, e.g. in Pyhäsalmi, Finland (and not Frejus). Such a plan makes the still-risky bet that θ_{13} is actually close to its present limits. If not, very large running times and/or huge detectors will be required for significant results.

We note that the CERN to Pyhäsalmi baseline is also favourable for a Neutrino Factory sited at CERN. In addition, we note that the limit to the sensitivity to CP violation at large θ_{13} will be limited by the degree to which systematic effects can be controlled as the relative size of the CP-violating effect decreases as θ_{13} increases. We believe this to be one of the strengths of the Neutrino Factory optimized for large θ_{13} and presented in the IDR.

The Panel draws comparisons between the facilities being studied within EUROnu and other recent ideas that have not yet achieved the same level of maturity. We therefore urge the Panel to take into account the degree of development of the various scenarios considered when assessing the reliability of their performance estimates.

One of the main objectives of EUROnu is to bring together the R&D on the three facilities in question and allow a direct comparison between them. It is planned to continue to do this beyond the end of the current project, if it proves too early to make a selection between them.