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International Scoping Study Interim Report

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The ISS Programme Committee

Introduction

The International scoping study of a future Neutrino Factory and Super-beam Facility (ISS) was established at NuFact 05 to survey the possibilities available for a future complex for precision neutrino physics to succeed the super beam experiments (T2K in Japan and Noνa in the USA) currently under construction. The possibilities centre around developments of the superbeam concept with higher power drivers and larger detectors, beta beam proposals where the neutrinos are formed by the decay of ions in a storage ring and the neutrino factory which uses a muon storage ring. The potentials of all three techniques are being investigated, however the accelerator considerations emphasise particularly the neutrino factory and superbeam as the beta beams are investigated elsewhere.

This investigation is different from previous ones as it embraces the physics case, the possible detectors as well as the accelerator developments which will be necessary. Only by considering all three together can the most cost-effective solution be achieved. Thus the study has three main working areas, Accelerators, Detectors and Physics, each with a coordinator and a council of experts in the field. In addition each working area contains a number of working sub-groups.

The study is planned to take one year and present its conclusions at NuFact06. The aim is that it will lay the foundations for a more rigorous International Design Study to take place over the next few years, by providing a limited number of baseline scenarios to be investigated further.

The present note presents short reports from the three working groups at the half way point of the study. Additional details can be found on the ISS website, www.hep.ph.ic.ac.uk/iss/.

ISS Accelerator Working Group

The ISS Accelerator Council M. Zisman (Coodinator), R. Fernow , R. Garoby, Y. Mori, R. Palmer, C. Prior.

The ISS Accelerator Group has been examining alternative designs for a Neutrino Factory facility with the goal of identifying an optimized configuration that could form the starting point for a subsequent detailed engineering study (the "International Design Study"). We report here on progress toward that goal. Within the accelerator group there are five subgroups:

Proton driver
Target
Front end
Acceleration
Decay ring

Proton Driver

The focus of our effort has been on identifying the optimal beam parameters for a Proton Driver. Several key parameters are being explored:

- *Energy*: Here the ultimate consideration is efficiency of muon production. Only those pions that evolve into muons subsequently accepted in the downstream accelerator systems are considered. We define production efficiency in terms of muons produced per unit of proton beam power. We are currently using the U.S. Study 2a as the benchmark for pion production and capture. When analyzed in terms of muons captured per unit beam power, we find that, for a high-*Z* target material (Hg or Ta), the proton beam energy range from 8–16 GeV is optimal. For a low-*Z* material (carbon), we find the optimal energy range is lower, 4–5 GeV, but the high-*Z* target material remains favoured by about 20%. However the results are based solely on simulations and there is a need for experimental data before final optimisation.

- *Pulse length*: Again we use the U.S. Study 2a as the benchmark. By varying the proton beam pulse length we find that the best pulse length is as short as possible. Yield from a 1 ns rms pulse is already reduced from the "0 ns" case by about 5%; yield from a 3 ns rms pulse is reduced by an additional 10–15%. This implies a preference for a proton beam pulse length of 1–2 ns. Such a short pulse length favours a proton energy at the higher end of the 8–16 GeV range and thus disfavours the low-*Z* target solution. As will be seen below, the Front End parameter studies show a similar sensitivity to the proton bunch length.

- *Beam repetition rate*: Here the important factor is the accelerating structure that follows the beam capture. A low repetition rate requires very intense proton beam pulses, which are difficult for targets. A high repetition rate puts heavy demands on downstream rf structures by increasing duty cycle and thus power demands. At present, a 50 Hz repetition rate appears to be a reasonable compromise, but this value has not yet been optimized.

Target

The favoured solution is the use of a free jet of liquid mercury with the proton beam passing through it at an angle of 30 mrad. The use of a mercury jet target avoids the shock, radiation damage, and cooling problems associated with the use of solid targets. After a bunch interacts with the mercury jet, the target material will be dispersed into a spray, collected in a sump, cooled, and finally returned to the nozzle forming the jet. It will be possible, if needed, to periodically distil the mercury to remove radioactive products, thus easing subsequent radioactive-waste disposal problems. This is the concept adopted in both the U.S. Study 2a, and in the corresponding CERN Neutrino Factory studies, and relatively little new work has been required. We note that the international MERIT experiment at CERN will study most, if not all, of the remaining technical questions in this approach. Alternative systems using a fixed carbon rod or a moving solid metal target have been considered, but are not favoured because of their perceived technical difficulties.

The target would be located in a roughly 20 T hybrid solenoid that captures the produced pions. These are then transported through a smoothly decreasing field to the downstream decay and phase rotation systems. The solenoid is located outside the beam pipe and has sufficient surrounding shielding that it will not be damaged by radiation. We have also considered the option of a horn capture system in place of the high field solenoid. The horn gives worse performance and is thus not favoured. Moreover, a horn—being directly exposed to radiation from the target and having to operate at a high repetition rate—is technically very challenging.

Front End

A comparison of the performance of previously designed Neutrino Factory front ends was made using a standard set of beam files, similar levels of approximation, and the same simulation code. The figure-of-merit (FOM) for the comparison is the number of muons at the end of the front end that are within the accelerator acceptance, normalized by the proton beam energy (hence representing a value per unit of proton beam power). For Study 2a, using 24 GeV protons with a mercury target, the FOM was 0.007 for each sign muon. FOMs for the CERN front end were about a factor of six smaller than these.

We have also carried out comparisons for various target materials. The FOM for positive (negative) muons from 10 GeV Ta interactions was 24% (54%) higher, while that for positive and negative muons from 4 GeV C interactions was 63% higher. It must be noted, of course, that the power handling capability of the various materials is not the same. In particular, the use of solid targets at power levels in excess of 1 MW has not yet been demonstrated.

A trade-off study was made of a Study 2a configuration where the maximum operating gradient in the cooling channel was reduced from 15.25 to 10.25 MV/m. The FOM dropped by 20%. Another study looked at the Study 2a FOM as a function of the initial proton pulse length at the target. The FOM drops sharply for rms bunch lengths longer than 3 ns, and increases by about 12% when the pulse length is reduced from 3 to 1 ns. This result is consistent with the studies of the bunch length dependence carried out by the Proton Driver group.

Several new front-end concepts have been investigated. Substituting “spiral” cooling for the normal linear cooling channel configuration provides longitudinal cooling. A spiral version of the RFOFO cooling ring is being simulated. Another study removed the separate cooling channel from Study 2a. In its place, 150 atm of hydrogen gas were introduced in the phase rotator and the rf gradient was increased to 24 MV/m. This produced the same performance as a simplified model of Study 2a, although pressure windows for the gas have not yet been included in the simulations.

The longitudinal behaviour of the phase rotation process was studied in a simplified model. It was found that shorter (30 m) channels perform worse because they do not have sufficient integrated gradient. It was also found that adjusting the reference particle momentum adiabatically along the channel gives better performance than Study 2a.

Acceleration

After cooling, the muons are accelerated to 20 GeV before being injected into the decay ring. The presently favoured method is to use a sequence of: 1) a linac; 2) a dogbone-shaped Recirculating Linear Accelerator (RLA); and 3) a pair of non-scaling Fixed-Field Alternating Gradient (FFAG) rings. There are currently two different sets of specifications for these systems, and optimum parameters have not yet been determined. Studies are under way on design, costing, and simulation of these alternatives. We will also explore the implications of increasing the final energy to 30 or 40 GeV. Some tracking studies of the linac have been completed, but more are needed. One RLA design has been tracked for on-momentum particles, but the needed sextupole systems for offmomentum particles have not yet been specified. Tracking of the FFAGs with ideal magnets has been done using several codes; work on tracking with errors has started. Longitudinal emittance growth at large transverse amplitudes has been noted, and is being studied.

The normalized acceptance of the accelerators is taken as 30π mm-rad, but a study is under way to explore higher or lower acceptances while reducing or increasing the amount of cooling to achieve the same throughput.

An alternative scheme using a linac followed by two RLAs has also been considered, but is not currently favoured because of its higher estimated cost. More study is planned to verify this. Initial costing studies also disfavour the use of a scaling FFAG system.

Decay Ring

The muon decay rings are presently being designed for an initial energy of 20 GeV, but with the potential for reaching 50 GeV. Two types of rings are being studied, one of a racetrack shape, the other that of an isosceles triangle. Separate rings are being considered for the μ^+ and μ^- beams, with one stacked above the other. The circumference of the rings will be in the range of 1200–1600 m. The racetrack ring will have one production straight of length about 500 m, while the racetrack will have two, each with a length in the range of 300–400 m. A number of apex angles are available for the isosceles triangle design and it is this, together with the tilt of the plane of the triangle, that determines the directions to the two detector sites. Surveys are commencing for a wide range of accelerator and detector locations. Tracking studies with errors will soon commence for the two ring designs.

The muon bunch pattern envisaged for the rings is of the form of *n* separate trains of 80 bunches, at 5 ns bunch intervals, with *n* in the range from 1–5, dependent on the choice of Proton Driver and muon acceleration scheme. The bunch trains in one ring are interleaved in time with the bunch train gaps of the second, with an additional allowance of 100 ns between the ends of the trains. Each train of 80 muon bunches is formed from a single initial proton bunch.

A change from n =1 to n = 5 at 50 Hz, was suggested in a Proton Driver design presented at NuFact05. It has the advantage of lowering the beam loading power levels in the muon accelerators by a factor of 50/3 compared with earlier designs at n =1 and 15 Hz, bringing them to the levels handled in superconducting linac rf systems, such as that of the SNS at ORNL. A disadvantage is that it requires a longer circumference for the ring. The length *per se* is not a major issue, but the ring must be tilted considerably to aim at a site 7000 km away and this makes the lower end of the ring inconveniently deep. Thus far the use of the CERN SPL, with an accumulator and compressor ring, to provide such long bunch trains appears a more difficult task than some higher energy proton driver configurations.

ISS Detector Working Group

The ISS Detector Council Alain Blondel (Coordinator), Alan Bross, Kenji Kaneyuki, Paolo Strolin, Dave Wark, Mauro Mezzetto, Paul Sole,r J.-E.Campagne.

The systematic investigation of detector options for future long base line neutrino experiments is one of the novel characteristics of the ISS with respect to previous studies. In addition it was felt necessary to add a study of the indispensable near detectors and instrumentation of the primary beam line, either the Beta-beam or Neutrino Factory storage ring, or the Superbeam decay tunnel. Following the initial guidelines given at NUFACT05, the working groups have so far largely built on existing studies to delineate the main avenues where further investigations would be most beneficial, and initiated the required simulation work. The work is carried out in five working groups:

Segmented magnetic detectors;
Large Water Cherenkov detectors;
Large Liquid Argon TPC;
Emulsion-based detectors;
Near detector and beam instrumentation.

The important issue of novel detector techniques of common interest (such as Silicon Photo Multipliers and large area photo-detectors) has been treated in common sessions of the working group. In the following the status and priorities of the groups are reviewed. More details can be found on the detector study web site.

Segmented magnetic detectors

Magnetized iron calorimeter

The most studied Neutrino Factory detector so far has been the magnetized iron detector. The MINOS detector (5.6 kton) and the MONOLITH and INO projects (30kton) are examples of the concept, for which the following questions can naturally be asked: up to which mass can one extrapolate? Can one increase the sampling so as to lower the interesting muon detection threshold, i.e. the momentum for which a muon can be both identified against backgrounds from hadrons, and its charge reliably determined?

Much of the progress has come from the application of Low-Z Tracking Calorimetry technique recently developed for NOνA. The design of toroids with radius up to 10 m can be extrapolated from MINOS, while the NOνA liquid scintillator or MINERVA solid scintillator technology with APD readout (or SiPM readout as in the case of the T2K ND280 fine grained detector) allows readout of fine grained sensitive detectors of the corresponding size. An iron-scintillator detector of 100 kton with magnetized iron plates of 1cm thickness seems feasible, for a cost of ~200M$. The simulation of such a detector has begun. A clear R&D project would be the constuction and beam test of a small module of such a detector with a variety of readout schemes; at the same time the engineering study of the full size detector is required.

Fully active magnetized detector

Another possibility based on the NOνA development would be to surround a fully active scintillator detector of this type with coils providing a moderate magnetic field (0.4 T or so). The goal is here a good detection and sign determination of low energy (up to a few GeV) electrons, to study the 'platinum channel' $\nu_\mu \rightarrow \nu_e$. A design and cost study of such coils would be required.

Water Cherenkov detectors

Water Cherenkov detectors can provide a very large target mass and, with sufficient photo-sensor coverage, sensitivity down to the low energies of solar neutrinos. The physics programme is very wide, concerning ν astrophysics, ν oscillations and proton decay. Above a few GeV, inelastic reactions dominate and the suitability of such a detector for precision measurements degrades. The technique is thus suitable for single-flavor neutrino beams, such as low energy Superbeam or Beta-beam, but not for the Neutrino Factory. The low neutrino cross-section at low energies and the difficulties associated with nuclear effects and the poorly known exclusive cross-sections (for the simulation of backgrounds to ν_e and ν_μ appearance) are the object of intense activity in conjunction with the near detector group and the physics group.

The detectors presently under study follow generations of successful detectors. The performance of Super-KamiokaNDE has been widely simulated and observed, providing a basis for a mass extrapolation by one order of magnitude. The studies are being carried out in the context of a dedicated international effort punctuated by the NNN workshops. Three detector designs are being carried out, Hyper-KamiokaNDE in Japan, UNO in the US and MEMPHYS in Europe. The critical issues are: i) is an underground cavern hosting a megaton of water feasible? ii) what can one do to provide an affordable photo-sensor coverage? And of course, iii) what is the cost of such a project? A preliminary answer has been provided for the UNO project and more recently for MEMPHYS, where a recent civil engineering pre-study has allowed a first cost estimate, Table 1.

Table 1

Preliminary cost estimate of the MEMPHYS detector	
3 Shafts, ϕ=65 m h=65 m	240 M€
250k 12” PMTs	250 M€
Infrastructure, electronics	100 M€
Total	590 M€

Much study remains and here again the key to an affordable detector will be R&D on large area, high quantum efficiency photo-detectors, which is presently carried out in all three regions. The study should also seek practical engineering solutions for the inner detector and its lining and protection against natural radioactivity.

Large Liquid Argon Detectors

A very large liquid argon TPC with a mass ranging from 10 to 100 kton would be a powerful instrument owing to the excellent event reconstruction capabilities. Versions of the concept exist for Super Beams, Beta Beams or Neutrino Factory; for the latter, the need for magnetic field constitutes an additional challenge, but the combined possibilities of precise event kinematic reconstruction and electron charge identification in the few GeV range constitute strong motivation. The typical magnet needed has a stored energy of the same order of that of the CMS solenoid. A Large Liquid argon detector would also allow a programme of experiments in Astroparticle physics and proton decay to be conducted. The concept is being studied by active collaborations in Europe and the USA.

The ISS Liquid Argon working group aims are to follow the ongoing R&D, identify specific needs related to the neutrino programme and to produce the necessary simulations as input to the physics studies.

Recent highlights of the Liquid Argon R&D programme include the realization and operation of a 300-ton prototype in Pavia and the operation of a 10-liter prototype in a magnetic field. Preparations are underway to test the feasibility of very long drifts using a 5m vertical tube, followed by readout in the gaseous phase, using e.g. LEM devices. The issue of delivering the necessary high voltage (up to 2 MV In a 20m drift hypothesis) is also being addressed, and a first look was given to the possibility offered by high T_c superconductors for the coils. At the same time, engineering studies have begun in collaboration with industry specialized in the construction of very large tanks of liquid methane. This work should proceed by more elaborate and detailed industrial design of the large underground (deep or shallow depth) tank and the details of the detector instrumentation. Finally, the study of logistics, infrastructure and safety issues related to underground sites should also progress, possibly in view of the two typical geographical configurations: a tunnel-access underground laboratory and a vertical mine-type-access underground laboratory.

It is felt that a necessary step, both from the point of view of the development of the technique and because it would provide valuable physics results, will be the construction of a liquid argon near detector for one of the ongoing neutrino beams. Such a proposal exists for the T2K experiment, and plans have been made for a NUMI off-axis detector. The typical mass of these projects amounts to about 100 tons.

Emulsion-based detectors

The ideal set of Neutrino Factory detectors should be able to exploit all available channels of Table 2 over a large energy range (1-20 GeV). The τ-appearance channel plays an important role.

Table 2 Channels available at a Neutrino Factory

$\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$	$\mu^- \to e^- \nu_\mu \bar{\nu}_e$	Reaction	
$\bar{\nu}_\mu \to \bar{\nu}_\mu$	$\nu_\mu \to \nu_\mu$	CC	Disappearance
$\bar{\nu}_\mu \to \bar{\nu}_e$	$\nu_\mu \to \nu_e$	CC	Appearance ('platinum' channel)
$\bar{\nu}_\mu \to \bar{\nu}_\tau$	$\nu_\mu \to \nu_\tau$	CC	Appearance (atmospheric oscillation)
$\nu_e \to \nu_e$	$\bar{\nu}_e \to \bar{\nu}_e$	CC	Disappearance
$\nu_e \to \nu_\mu$	$\bar{\nu}_e \to \bar{\nu}_\mu$	CC	Appearance: 'golden' channel
$\nu_e \to \nu_\tau$	$\bar{\nu}_e \to \bar{\nu}_\tau$	CC	Appearance: 'silver' channel
$\nu \to \nu_s$	$\bar{\nu} \to \nu_s$	NC	Global disappearance, sterile neutrinos

The use of Emulsion Cloud Chamber (ECC) has been proposed to detect these "silver events”. The model is the ECC of OPERA, which consists of a multiple sandwich of lead and nuclear emulsion sheets. For operation in a Neutrino Factory the emulsion target area would need to be surrounded by a magnet (in a way similar to those suggested for the fully active fine grained calorimeter or the Liquid argon TPC), and the lead-emulsion sandwich would have to be upgraded with a series of gaps with light material for precise momentum measurement and with scintillator to provide the time stamp of the events, this being particularly important if the Neutrino Factory is run with both signs of muons simultaneously separated by a O(100ns).

The first simulations of such a detector have revealed that not only would the Magnetized ECC (MECC) performed very efficiently for τ leptons, but also for (charge) identification of muons and electrons. The physics reach of such a detector seems impressive, but it Is necessary to quantify the maximum mass affordable in terms of scanning power and costs. A smaller scale MECC detector would be ideal for the near detector as well.

In the near future, realistic assessment of the physics reach is needed. This implies:

- Study of use of a lighter material (aluminum, iron) instead of lead;
- Study of the scanning issues;
- Proposal of a realistic and cost effective design of the detector magnet;

- Proposal of a realistic and cost effective design of the electron/pion analyzer.
- Study of the performance of the electron/pion analyzer for the golden channel;
- A full simulation with neutrino events in order to evaluate the detector sensitivity for golden, silver and platinum channels.

On the time scale of a few years, the study and test beam exposure of a moderate size magnetized prototype will be necessary.

Near detector and beam instrumentation

While the design and construction of the large far detectors will be a considerable technological challenge, the near detectors and beam instrumentation will have to provide basic information for the extraction of the physics results, such as neutrino cross-sections, neutrino event properties and determination of the neutrino beam flux and composition. Present experiments aim at disappearance measurements or at the appearance of a new signal over background, and it is sufficient to fold neutrino cross-sections and flux in a 'near-to-far detector' extrapolation. Future experiments, on the contrary, will aim at a precise determination of appearance probabilities and will require precise knowledge of the flux of the initial flavour neutrinos and of the final flavour cross-sections separately. This is a considerable challenge and, for the first time, understanding of neutrino fluxes with permil precision is being discussed.

In addition, as was extensively studied in the CERN yellow report, there is valuable neutrino physics in its own right to be performed in the near detectors at a neutrino factory, thanks to the extraordinary concentration of flux.

Absolute flux monitoring for the Neutrino Factory and Beta-beam

Two methods have been identified to do this: absolute knowledge of the flux from beam instrumentation, and normalization to known processes in the near detector.

First, the absolute flux can be derived from the known decay and the number of decaying particles. The requirements for a safe determination of the flux are then: i) precise counting of the number of particles circulating in the ring; ii) precise determination of the beam polarization (for NF only); iii) precise determination of the beam direction, angular divergence, energy and energy spread. These require specific instrumentation of the storage ring, and place requirements on the beam optics. Beam monitoring with beam current transformers, ring imaging Cherenkov and a polarimeter have been discussed in the ECFA/CERN Studies of a European Neutrino Factory Complex. The actual implementation needs to be studied and prototypes of the concepts will need to be defined.

To validate the good knowledge of the flux, a necessary condition is the availability of a reference process (this is similar to the Bhabha process in e^+eannihilation). Thanks to the impressive concentration of flux in the near detectors, neutrino interactions on electrons ($\nu+e \rightarrow \nu+e$or μ^-) offer this possibility provided a suitable detector could be built to perform this measurement with the required accuracy. The conceptual design of such a detector needs to elaborated, a simulation performed and possibly prototyping will be necessary. Work on this subject has been initiated.

It is clear that such possibilities are absent for conventional hadron decay beams, and that the use of the full statistical power of the Superbeam will hinge on hadro-production experiments, with a precision that remains to be demonstrated.

Cross-section measurements and physics of neutrino interactions

The requirements of neutrino oscillation experiments such as the CP asymmetry require a precise knowledge of exclusive processes and cross-sections for the appearance channel and for the backgrounds. It will be the task of near detectors to establish those.

For the low energy (sub-GeV Superbeam + Beta-beam option), the emphasis will be on the understanding of nuclear target and muon mass effects which e.g. affect the ν_e / ν_μ cross-section ratio differently for neutrinos and anti-neutrinos. At slightly higher energies, pion production is also sensitive to these effects, and precise measurements as function of ν_e or ν_μ energy may be necessary. A survey of the theoretical and experimental knowledge is performed in the framework of the NUINT conferences

For the Neutrino Factory the simultaneous availability of all flavours in the same detectors offers many advantages. The study of purely leptonic processes and of Neutral Current production is of interest for precision tests of the SM. The backgrounds to the various oscillation channels will need to be studied carefully, in particular charm production. There are many choices for a detector technology that could be implemented. Liquid argon TPCs in a magnetic field would be able to carry out most of the near detector programme. More conventional scintillator technology (similar to Minerva), a scintillating fibre tracker or a gas TPC (like in the T2K near detector) would also be able to perform cross-section and flux control measurements. However, it seems likely that only silicon or emulsion detectors can achieve the necessary spatial resolution to perform the charm measurements needed to determine the background for the oscillation search. These options will be further studied and a programme of R&D will be established.

ISS Physics Working Group

The ISS Physics Council Yori Nagashima (Coordinator), Debbie Harris, Pilar Hernandez, Steve King, Manfred Lindner, Ken Long, Mauro Mezzetto, Hitoshi Murayama, Lee Roberts, Osamu Yasuda, William Marciano, Kenzo Nakamura.

The role of the physics working group of the ISS is to establish the physics case for a future precision neutrino facility. In order to address specific questions, it has further divided itself into four subgroups,

Theoretical,
Phenomenological,
Experimental
Muon.

A brief summary of the discussions made in the past two plenary meetings at CERN (September 22-24, 05), KEK (January 23-25, 06) and a Physics group workshop at London (November 14-21, 05) are described below.

Theoretical subgroup

The Theoretical subgroup is targeted towards answering the big ”questions” posed by neutrino physics, such as the origin of neutrino mass, its role in the birth of the universe and what it can tell us about the unification of matter and force. They lay down bases for clarifying physics cases for various neutrino facilities. Since it is not (yet) possible to answer these questions in general, studies so far have concentrated to more specific issues that may be useful for constructing a global picture, such as

1. the relevance of neutrino physics to questions of dark matter and dark energy, the connection of neutrino mass to leptogenesis and galaxy cluster formation.

2. the connection of predictions at the grand unification scale with low energy phenomena in the framework of see-saw mechanism and supersymmetric extension of the standard model, specifically the relevance of measuring the low energy CP phase in the future experiments.

3. the understanding of flavour and the connection between quarks and leptons, possible existence of hidden flavour quantum number in connection with small mixings and mass hierarchy of quarks and charged leptons and its relation with the neutrino mass matrix.

It was agreed that it would be necessary for the different overlapping physics subjects to be presented correctly as a whole and described coherently in the roadmap of neutrino physics toward the unification.

Phenomenological subgroup

The phenomenological subgroup, while inseparable from the theoretical subgroup in many aspects, is also concerned with whether there is anything else beyond the standard three flavour neutrino oscillations that is relevant for precision neutrino measurement.

One such test is the unitary triangle. While the CKM matrix in the quark sector is constrained to be unitary in the standard model, the MNS matrix in the lepton sector originates from physics beyond the standard model and may not be exactly unitary. Another test is the existence of flavour changing interactions that might appear at either the production point or the detection point. Possible strong correlations between lepton flavour violation and neutrino oscillation were also discussed.

Other topics, which also affect the experimental subgroup, are the examination of different approaches (i.e. non accelerator physics) in determining the standard three flavour parameters. For example, possibilities have been discussed of a new long baseline reactor experiment and Gadolinium loaded Super-Kamiokande to improve the solar neutrino parameters, or an underground large magnetized iron detector to improve the atmospheric neutrino parameters and test deviations from maximal mixing and octant degeneracy.

Experimental subgroup

The goals of the Experimental subgroup are to evaluate the performance of the various neutrino facilities, to find an optimum combination of baseline and neutrino energy and examine scenarios of staging approaches. For meaningful comparisons to be performed, it is essential that realistic assumptions are made for the fluxes, for the performance of the various detectors, and for the systematic errors etc.

A large number of independent studies are required and cooperation of groups from different regions who use different codes is essential. In order to benchmark the code against one another, a single reference input was provided and the performance of experiments using the super-beam, beta-beam and neutrino factory were compared. The results of the codes, GLoBES, Valencia and Madrid, showed good agreement. It was concluded that the results obtained with the various packages, at the level of rates and statistical errors, would be directly comparable.

Updates on neutrino oscillation facilities using a Water Cherenkov detector showed that as a beta beam is not intrinsically limited by the beam background it can be employed, in principle, beyond $\sin^2 2\theta_{13} < 10^{-3}$ and thus is a potential competitor for the NF. A new idea of "T2KK" was proposed. It is an experiment using the T2K neutrino beam targeted towards two identical half mega-ton Water Cherenkov detectors at the same off-axis angle. One of the detectors is to be operated at the Kamioka site (L=295km), whereas the other one is supposed to be located at a much longer baseline (L≃1050km) in Korea. It enhances correlation/degeneracy resolution capability and reaches the sensitivity in mass hierarchy comparable to NOνA.

New results of physics experiments using an abstract detector with a better low energy threshold and better energy resolution were presented as functions of muon energy and baseline. It was shown that a lower threshold would greatly help all measurements while a better resolution would only be significant for the mass hierarchy and CP violation measurements.

In particular, the better threshold could make the 2000 to 4000 km baseline more efficient for $\sin^2 2\theta_{13}$ sensitivity compared to the magic baseline. For large values of θ_{13}, a better detector could be a key component for a NF facility.

Muon subgroup

The muon subgroup was established after the first plenary meeting at CERN. Although muon experiments are distinct from the neutrino ones, an intense muon beam is a prerequisite for the NF and the underlying physics shares a lot of common aims. Current proton drivers can deliver about 10^8 muons/s (such as for MEG), whereas future megawatt proton drivers could deliver about 10^{11} to 10^{12} muons/s (such as for PRISM). Using a NF front end, up to 10^{14} muons/s could be achievable. In addition, polarized muons could be very useful to reduce backgrounds and to discriminate models.

It was emphasized that flavour physics may be an important component to establish SUSY. The charged LFV (especially the modes ($\tau \to \mu\gamma$, $\mu \to e\gamma$) and EDM of the muon) would provide very independent and complementary information unobtainable using neutrino oscillation, while large mixing angles, in particular large θ_{13}, might enhance charged LFV. This example demonstrates very nicely the synergy and usefulness of different facilities to establish a more complete picture of particle physics. LFV could be also be induced by a Higgs boson which would not be detected at the LHC, yet would give rise to high energy muon or neutrino reaction like $\mu(\nu) \to \tau$.

What remains to be done

Physics-Detector-Accelerator interplay It has becomes increasingly clear that better low energy detection efficiency and possibly higher energy resolution are key components to strengthen the competitiveness of a NF. Additional issues to be worked on by both the Physics and Detector working groups are channel requirement (ν_e, ν_τ), i.e., feasibility, their relevance for the physics case, and their requirements for baseline and muon energy.
One question addressed by the Accelerator working group is what is the minimum energy that will deliver good physics. Recent calculations in the $L-E_\mu$ plane have demonstrated that muon energies around 40 GeV could be sufficient for the main measurements. However, this will require careful baseline tuning. It has also been argued that a lower muon energy could be sufficient if one had a better detector and thus there will be a balance between the muon energy and detector optimization which makes the accelerator/detector complex most cost efficient. Another question from the accelerator working group was how large could flux uncertainties be and still be acceptable; this affects the accelerator optimization.

Another very important aspect is the shape of the storage ring. It needs to be clarified by the physics working group which baseline configurations are necessary and how many different baseline make sense.

Agree on performance indicators In order to compare and contrast the differing approaches to a NF and identify the optimum and/or cost effective ones, it is important to choose proper indicaters. Typical examples for different performance indicators are the θ13 exclusion limit (sensitivity limit) and the θ_{13} discovery limit which emphasizes different aspects of the physics.

For δ_{CP} , the situation is more complicated because the measurement intrinsically depends on more parameters as well as the true value. An often chosen indicator is the sensitivity to maximal CP violation where the value of $\delta_{CP} = \pi/2$, $3\pi/2$ is assumed. However this tends to obscure the problem of degeneracies. Other complementary indicators include ”Allowed region in $\theta_{13} - \delta_{CP}$ plane”, ”Sensitivity to any CP violation”, ”Precision of δ_{CP} and ”CP coverage” and so on.

A new indicator presented at the KEK meeting has visualized the performance of the NF in the $L - E_\mu$ plane and this may be suitable for presenting convincing argument in deciding an optimum energy and baseline.

Presentation of results. The primary object of the final presentation should be to build a strong physics case, i.e.,to identify the relevant physics scenarios, to identify the experiments necessary for these and to link these physics cases to their motivation from theory. While a NF offers many attractive features at low value of θ_{13}, a clear case for large value will be the focus in the coming studies. A better detector with lower threshold may be the key component to establish the NF as the most competitive facility.