Aims of the Workshop

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Abstract
There are challenges and opportunities for the European particle physics community to engage with innovative and exciting developments which could lead to precision measurements in the neutrino sector. These have the potential to yield significant advances in the understanding of CP violation, the flavour riddle and theories beyond the Standard Model. This workshop aims to start the process of a dialogue in Europe so that informed decisions on the appropriate directions to pursue can be made in a few years time.

1 The Importance of Neutrino Physics

Neutrinos have already contributed much to our understanding of the quantum world yet our evolving knowledge of their parameters and their importance is still in its infancy. Their ability to surprise has been one of the highlights of the development of particle physics ever since Pauli postulated their existence in 1930 Repeatedly ideas and theories concerning their nature and role have had to be modified or even abandoned as experimental measurements have had unexpected consequences. The enigmatic nature of the neutrino and its place in the theory of matter remains and unforeseen developments in the neutrino area are likely to continue to excite as experimental data become more precise.

We are now fully aware that neutrinos are not correctly described in the basic Standard Model but what is not known is whether this can be accommodated by a small tweaking of that model or it is the first sign of the long awaited direction particle physics must take to go beyond the Standard Model. Even the nature of the neutrino is unknown; unless lepton number has some deeper significance than has so far been appreciated it could well be that neutrinos are not Dirac but Majorana states and the possible consequences of this are quite mind-blowing.

Neutrino properties are intimately connected with the unexplained role of flavour in particle physics, which, despite many years of exacting work in the quark sector, remains a mystery. Neutrino oscillations, manifestly beyond the Standard model, are intimately connected with flavour transitions and it is diffciult to believe that the flavour problem will be solved without an equally exhaustive study of flavour transitions in the lepton sector. Closely connected with this and arguably of even greater importance than the flavour riddle is that of CP violation. It is a crucial ingredient of any explanation of the baryon asymmetry but has so far only been observed in flavour transitions in the quark sector. Discovering additional sources of CP violation in the lepton sector would be a major advance.

Finally, it would seem obvious that the ultimate theory of particle physics must intimately connect lepton and quark sectors. Many models encompassing such a connection are now emerging but only precise experimental data can provide the necessary discrimination for a major breakthrough.

2 This workshop

Although not a neutrino conference the workshop will start with short reviews of the current experimental and theoretical situation and what can be expected within the next five years. However the main aim is to look to the longer term future and in particular to start a process which will enable the European Particle Physics Community to be major players in the quest to establish neutrino properties and develop the theories which could take place in the 2015 to 2030 period.

The emphasis will be on accelerator-based neutrino oscillation experiments. Whilst it would appear feasible to achieve precisions similar to those currently being obtained for the mixings in the quark sector it will certainly need substantial R & D and planning on a global scale. Here CERN has much expertise which should be exploited.

Non-oscillation neutrino experiments also have the potential to make very major advances relating to the mass and nature of the neutrino. There are substantial European initiatives in these areas and traditionally CERN has not been involved, however this may have to change should results over the next few years prove inconclusive. The situation in these areas will be briefly reviewed as will the place neutrinos can play in astrophysical investigations.

3 CERN, Europe & Neutrino Physics

During the latter half of the last century neutrino physics was a major item on the CERN agenda and included one of CERN's major discoveries, the first observation of a neutral current interaction in the Gargamelle bubble chamber, Fig.1a. Regrettably, despite the construction and operation of the CNGS beam to the OPERA and ICARUS experiments in the Gran Sasso laboratory, there has been no CERN physicist involvement in an active neutrino physics experiment over the last decade during which the important revelations concerning neutrino oscillations has taken place.

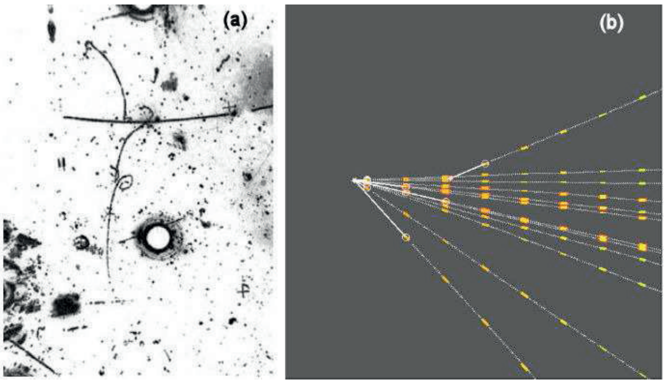

Fig. 1. a. An early neutral current neutrino event in the Gargamelle bubble chamber, b. Charm production in the OPERA emulsion from the CNGS beam

The OPERA experiment, which has the limited, although important, goal of observing a tau from an oscillated muon neutrino is now taking data. This will verify that the deficit observed in both atmospheric and accelerator based long baseline muon neutrino experiments, is definitely due to ν_μ to ν_τ oscillation. The sensitivity of the experiment to short lived particles is beautifully illustrated by the charm decay shown in Fig.1b although so far no taus have been observed; however this is consistent with expectation. Tau observation will be significant as, to this day, if one excludes the controversial LSND result, the flavour of an oscillated neutrino has yet to be unambiguously recorded.

The lack of direct involvement by CERN physicists does not reflect the wider European interest in the neutrino area. The primary goal of oscillation investigations over the next few years is to determine or put a much more restrictive upper limit on the oscillation angle θ_{13}. For this one of the major experiments is the Double Chooz reactor experiment in France, whilst the largest geographical group in the T2K accelerator experiment in Japan is from Europe. In addition KATRIN is the leading experiment for the direct determination of the neutrino mass from the end point of the tritium beta spectrum and to investigate if neutrinos could be Majorana states there are a number of future

European hosted neutrinoless double beta decay experiments such as GERDA, CUORE, SuperNEMO and COBRA. Neutrino astronomy experiments, ICECUBE, ANTARES, NESTOR, NEMO amd KM3NeT are also part of future European neutrino activity. Finally the level of enthusiasm can be judged by the high number of registrants and posters for this workshop

However if accelerator-neutrino experiments are to advance to a precision phase innovative new techniques for both producing the neutrinos and detecting them will be necessary. For Europe to either host such a facility for the 2020's, or even for the community to be in a position to make effective intellectual and technical input to the decisions expected to be made around 2013, substantial R&D is required over the next few years. For this to be successful, the expertise and resources of CERN are vital.

The only current activity at CERN in the neutrino area is the operation of the CNGS beam and a small amount of design activity associated with the FP7 EUROnu programme. The CNGS beam was discussed at the May Workshop 'New Opportunities in the Physics Landscape at CERN' and it would appear impracticable to significantly improve the intensity and establish a near detector station on the necessary time-scale to produce an internationally competitive experiment. The EUROnu activity is valuable but it needs boosting, even to reach the EUROnu goals.

Precision neutrino measurements require a very intense neutrino beam on account of the small neutrino cross section. This demands a high power proton driver as the first element in the chain but this can have many uses in addition to producing neutrinos. It has motivated the SPL plan, primarily as part of an improved injection chain for the LHC, but also with the potential to produce neutrino beams and exotic ions. Whilst the high power is not required for the LHC injection the SPL would prove to be an effective replacement for the current PS Booster and it can be constructed so that it could be upgraded to ~ 4MW. If this route is taken CERN would have the necessary starting point for an active neutrino programme based on a new superbeam, a beta beam or a neutrino factory. An SPL, or possibly a different proton driver, is essential for a future competitive accelerator neutrino programme at CERN.

4 The Political Picture

In Lisbon in 2006, at a special meeting of the CERN Counci,l the CERN member states established a European Strategy for Particle Physics and agreed that CERN Council should have the additional role of coordinating the European particle physics programme. The recommendations recognised the importance of an active future neutrino programme and included the following

> 'Studies of the scientific case for future neutrino facilities and the R&D into associated technologies are required to be in a position to define the optimal neutrino programme based on the information available in around 2012; *Council will play an active role in promoting a coordinated European participation in a global neutrino programme'*

and

> […] it is vital to strengthen the advanced accelerator R&D programme; a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.

Unfortunately little progress has been made. Consequently the Council took advantage of their right to pose question to the SPC and in December 2008 asked the SPC to comment on the following

> What is the view of the SPC on the importance of the neutrino oscillation parameters, in particular the CP violating phase and mass hierarchy?

One of the most promising techniques for such measurements is the neutrino factory and there is currently an international design Study (IDS) to produce a conceptual design report for a neutrino factory by 2012. This is not site specific. What is the view of the SPC on the overall value of the IDS for the future of the subject? Should CERN take a more active role in enabling the study to reach its goals, irrespective of where such a facility would be sited?

What is the view of the SPC on the merit of a European strategy in this phase of neutrino experimentation and whether it should have a place on the future CERN road map?

In response the SPC set up a panel to investigate the neutrino situation both at CERN and in the wider European context. The panel members were originally Agnieszka Zalewska (Chair), Roy Aleksan, Alain Blondel, Peter Dornan, Karlheinz Meier and Fabio Zwirner. Tatsuya Nakada replaced Karlheinz Meier in August when he replaced him as ECFA Chair. The panel was asked to report to the SPC by Dec 2009.

Concurrently the CERN management decided to review the non-LHC programme with two workshops. The first in May 2009 on 'New Opportunities in the Physics Landscape at CERN' and this one, in conjunction with the SPC neutrino panel, on 'European strategy for Future Neutrino Physics'. This workshop will be a major input for the SPC panel report.

5 Options for the 2020's

5.1 Accelerator produced Neutrino Beams for Oscillation Experiments

Of the three angles in the neutrino mixing matrix there is now only an upper limit on θ_{13} and no information at all on the Dirac phase, δ. If both θ_{13} and δ are non-zero then a new source of CP violation will have been discovered but only with precision information can the full significance of this be realised. Similarly, distinguishing new models and theories, which aim at the prediction of the rate of neutrino oscillation will only be possible with accurate knowledge of all the oscillation parameters. In addition, establishing the correct mass hierarchy is necessary as it reduces ambiguities in the oscillation measurements and reduces possibilities for model building as well as the intrinsic importance of understanding the neutrino spectrum.

Three distinct techniques are under consideration to provide the intense neutrino source required for a precision phase of accelerator neutrino experiments. They will be discussed in detail during the workshop

5.1.1 A next generation Superbeam

This is essentially an upgrade on the present superbeam experiments with a high power proton driver of around 4 MW. Difficulties arise from handling the high power driver and the following targetry and horn assembly.

5.1.2 A Betabeam Facility

Beta decaying ions, held in a storage ring, produce very pure electron neutrino or electron antineutrino beams when they decay. Difficulties here relate to producing an adequate number of ions to give the desired intensity, particularly in the case of β^+ decays yielding neutrinos. It is a main goal for future R&D. Bunching the ion beam is also challenging. A betabeam facility examined within the Eurisol design study is shown in Fig.2a.

5.1.3 A Neutrino Factory

The neutrino factory is the most ambitious plan and relies upon muons decaying in a storage ring. A positive muon will yield an anti muon neutrino and an electron neutrino and the reverse for the negative muon. An advantage is that μ^+ bunches and μ^- bunches of both signs can be handled together and hence beams of $\nu_e, \bar{\nu}_e, \nu_\mu$, and $\bar{\nu}_\mu$ can be investigated in an identical environment. As with the superbeam a ~ 4MW source is required and so targetry is again an issue. Difficulties also arise from the need to cool the muon beam to achieve adequate intensity at the aperture of the accelerating system and the need for fast acceleration due to the short muon lifetime. A diagrammatic representation of a neutrino factory facility resulting from the ISS study described below is shown in Fig.2b.

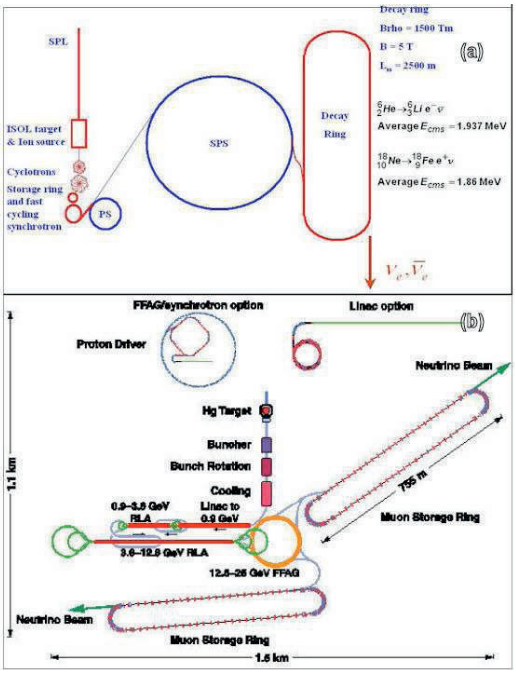

Fig. 2. a. The Betabeam facilty investigated in the Eurisol Study b. The Neutrino Factory layout from the ISS study.

5.1.4 Detectors

An appropriate detector system is as vital for the success of these experiments as the production of the neutrino beam. Much larger detectors than have so far been employed will need to be developed. In the case of the neutrino factory a magnetised detector is mandatory as each bunch will give rise to both neutrinos and (different flavour) antineutrinos.

5.2 Design and R&D Activities

A number of activities have been taking place over the last few years and others are active now.

5.2.1 European programmes

The European Framework Programmes have included components related to future neutrino activities. Under FP6 these have included

BENE (Beams for European Neutrino Experiments) was part of the CARE programme

The EURISOL design study for the production of exotic ions included an investigation of the betabeam concept..

and currently under FP7

EUROnu is a design study specifically for a future neutrino facility. Workpackages investigate specific aspects of the developments required for a viable superbeam, betabeam or neutrino factory facility.

Within the EUCARD programme there are two relevant activities. Neutrino2012 is a network to facilitate the production of a strategy for European neutrino activities and there is a transnational activity to enable European participation in the MICE experiment.

The LAGUNA programme is dedicated to establishing the feasibility of large underground detector sites and specifically investigates large water Cerencov, liquid argon and scintillator detectors. One of the uses of such detectors is to act as a far detector for a long baseline neutrino beam.

5.2.2 International Programmes with European Participation

The ISS (International Scoping Study of a Future Neutrino Factory and Superbeam Facility) took place between 2005 and 2007 and produced three published reports, for accelerators, detectors and physics. The accelerator report concentrated mainly on the neutrino factory but the others embraced all three techniques and the physics report produced the most realistic comparison of performance currently available. The ISS also produced a baseline for a neutrino factory facility for the subsequent IDS-NF study.

The IDS-NF (International Design study for a Neutrino Factory) followed the ISS and is currently active. The aim is to produce a CDR for a neutrino factory by 2012/13. Within Europe there is significant overlap with the neutrino factory part of the EUROnu design study.

The NFMCC (Neutrino Factory and Muon Collider Design Study) is basically a US activity with European participation.

There is also European participation in the T2K upgrade plans for a next generation superbeam facility in Japan.

Unfortunately in general these studies lack the necessary effort and expertise to achieve their goals on the necessary timescale. Additional support from CERN would definitely increase their chance of success.

5.2.3 Current Prototyping

The major activities are as follows. All will be discussed in more detail during the workshop.

MERIT. This is a joint US-Europe collaboration to study the use of a liquid metal jet target with a high power proton beam. The experiment took place this year in the nToF beamline at CERN and very successfully demonstrated the viability of a liquid mercury jet for such operation.

MICE. This is to provide the first actual demonstration of ionisation cooling of a muon beam which is crucial both for a neutrino factory and also a muon collider. The experiment is now setting up at RAL in the UK with first data taking in 2010 and final results expected in 2013.

EMMA. The main accelerator envisaged for the neutrino factory is a non-scaling FFAG (Fixed Field Alternating Gradient), however such a device has yet to be constructed and operated. EMMA (Electron Machine with Many Applications) is an electron prototype of a non-scaling FFAG being constructed at Daresbury Laboratory in the UK.

MUCOOL. This takes place at FNAL and is also investigating the components needed for ionisation cooling of a muon beam, in particular the performance of rf cavities in a high magnetic field.

5.3 Potential Discovery Domains

The ISS physics report, Ref [1], made the first serious effort to compare the potential performance of the differing techniques. In Fig.3 the relative performance is compared for the determination of $\sin^2 2\theta_{13}$, the mass hierarchy and the CP violating phase, δ, as a function of $\sin^2 2\theta_{13}$. The regions of sensitivity are to the right of the lines and the bands represent optimistic and conservative realisations of the techniques. Full details can be found in the ISS physics report. In all cases the leftmost band corresponds to the neutrino factory and it is clear that for very low values of $\sin^2 2\theta_{13}$ it is easily superior but this is less marked as $\sin^2 2\theta_{13}$ approaches the current upper limit. All these plots will require revision as the input parameters become more realistic and there is further optimisation over the next few years.

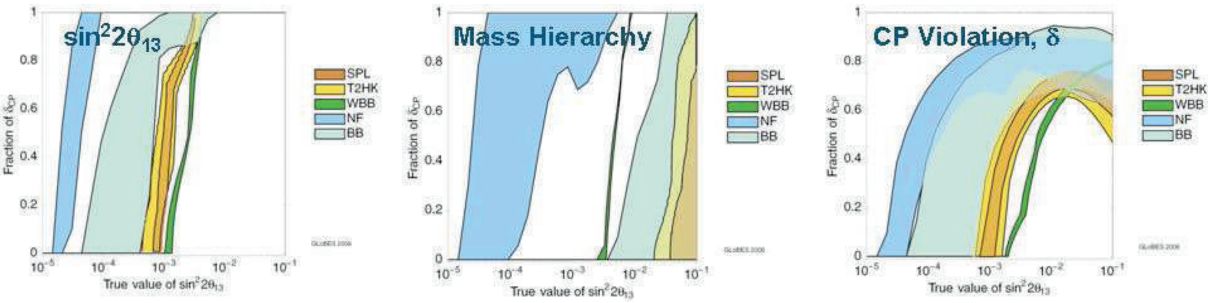

Fig. 3. Performance comparisons for the deterrmination of $\sin^2 2\theta_{13}$, the mass hierarchy and δ, for the possible neutrino production techniques, from the ISS study

5.4 Non-accelerator Experiments

The role of CERN for non-accelerator experiments is much less clear as the expertise is in the external community. Nevertheless these experiments do fall within the European strategy approved by CERN Council and so the situation could change as the experiments become more challenging in the future.

The future for solar and reactor beyond the present generation is hard to see. Reactor experiments depending upon electron antineutrino disappearance have no sensitivity for δ, however they could provide the best approach for improving the value of θ_{12} with a distant detector.

For the non-oscillation experiments future directions are difficult to predict should KATRIN find only an upper limit for the absolute mass and none of the planned neutrinoless double beta decay experiments find a signal. At the present time it is very difficult to foresee a substantial improvement on KATRIN whilst the ability to extend current neutrinoless double beta decay experiments will only be understood after some years with the upcoming ones. However, should a further increase in sensitivity be required, it will almost certainly necessitate a more united, probably global, effort in which CERN will be involved.

6 Goals of the workshop

If Europe wishes to have a long term accelerator neutrino programme a decision on the direction to be taken sholdl be made around 2013, so between now and then the best option - on scientific (and cost) grounds - must be established. A wide consensus will be necessary and support from CERN will be vital to attract the necessary resources. The aim of this workshop is to start this process

Detailed aims are on the website and are repeated here

- **To begin the process of establishing a roadmap for a coherent European participation in future Neutrino PhysicsThe European Strategy Document for particle Physics states**

'Studies of the scientific case for future neutrino facilities and the R&D into associated technologies are required to be in a position to define the optimal neutrino programme based on the information available in around 2012; Council will play an active role in promoting a coordinated European participation in a global neutrino programme.'

but whilst a substantial number of European physicists are involved with neutrino related activities a coherent approach for the longer term has yet to be achieved.

- **To examine those techniques which potentially can substantially improve precision over that expected from current and future experiments in construction.**

  The experiments which will dominate neutrino physics until circa 2015 are either under construction or about to start taking data. However a number of techniques for both accelerator and non-accelerator experiments have been proposed which will enable greatly improved accuracy for the measurable parameters. These experiments could start in the latter half of the next decade or early in the 2020's.

- **To stress the substantial technical problems associated with each technique**

  The viability of some aspects of these future procedures is not fully established and so it will be a major task of the workshop to highlight those areas where major challenges remain. Many of these are substantial and will require the development of technologies of a size and complexity not previously encountered in the neutrino area. For the accelerator experiments this includes both the accelerator and detector developments necessary to achieve the goals.

- **To devise plans for the European contribution to the R&D necessary to enable decisions to be taken around 2012 – 2013.**

  For precision neutrino experiments to commence data taking around 2020 decisions need to be made by ~2013 in keeping with the aims of the European Strategy. An energetic programme incorporating design, R&D and costings is therefore necessary. Neutrino experiments at this level will necessarily be international but it is vital that the European neutrino community has a major impact on the debate for future facilities both within Europe and outside. An important aspect of the workshop is to highlight the areas where R&D is required and evaluate to what extent these are covered by current programmes either within the present European frameworks or on a broader international level.

- **To consider the role of CERN in future international neutrino activities**

  Neutrino physics at CERN has a long and positive history yet today, apart from producing the CNGS beam for the OPERA experiment, there is little activity in the experimental or phenomenological physics areas, the accelerator developments required for the next phase of experiments or the detector technologies needed to fully exploit them.

  CERN has unique expertise and if Europe is to be a major player in this area in the future it would seem essential that CERN re-establishes a viable neutrino activity to participate in a wider European programme. This should be independent of whether future facilities are at CERN, elsewhere in Europe or the rest of the world. Speakers at the workshop will be asked to draw attention to those areas where they consider CERN participation would be most effective.

- **To bring to light synergies between the neutrino area and other areas of physics**

  As experiments become larger and more costly there are obvious merits if the experiments and the technical developments they require have wider application. Obvious examples are the needs of cosmology, theories relating neutrino properties to charged lepton flavour violation, the simultaneous use of large detectors for nucleon decay and the production of intense muon beams which may also be used for lepton flavour violation and a future muon collider. Such synergies will need to be taken into consideration when decisions over future directions are taken.

- **To suggest a procedure for future coordination and development of European activities in the Neutrino area**

  As an integrated part of the implementation of the European strategy for Particle Physics it will be necessary to establish an organisation and follow-up structures for the key R&D areas. This requires coordination with the Strategy Secretariat of the European Session of Council and appropriate means to achieve this will be discussed

  They are ambitious aims but without ambition little progress will be made.

References

[1] A Bandyopadhyay et al., *Rep Prog Phys,* **72** (2009) 10