ROUND TABLE

KEN PEACH
CCLRC Rutherford Appleton Labratory, Chilton, Didcot, Oxfordshire OX11 0QX, UK
E-mail: Ken.Peach@rl.ac.uk

Before making some remarks about measurement of the parameters of neutrino oscillations and the neutrino mixing matrix, I would just like to echo the remarks made by Manfred Lindner about the importance of the measurements of the absolute neutrino mass scale, both through the direct measurement of the "electron" neutrino mass in tritium β decay and the indirect measurement of an "average" neutrino mass through neutrinoless double-β decay. The only additional comment that I would like to make is to stress the importance of measuring neutrinoless double-β decay in several nuclei. Of course, the first observation of neutrinoless double-β decay would be a very important discovery, establishing that the neutrino had a Majorana component. However, it is essential to measure neutrinoless double-β decay in several nuclei, in order to show that the uncertainties in the calculation of the nuclear matrix elements, needed to extract the weighted average mass, are under control.

The main focus of this discussion is the precision measurement of the neutrino oscillation parameters - two mass differences squared, the three mixing angles and the CP-violating phase. The emphasis here is on *precision* measurements. The parameters that govern neutrino mixing are probably determined at some very high energy symmetry-breaking scale, and the only experimental check that we are likely to have on any theories developed to explain the phenomenon is through the precision with which these parameters are predicted. The aim should therefore be to measure the mxing angles *and the phase* of the neutrino mixing matrix as precisely as possible. There are many ideas for making such measurements, but in my view there are two important steps. Firstly, it is essential to establish that θ_{13} is non-zero and not too small - if θ_{13} is zero then there is no CP-violation in the lepton sector, and if it is very small (much less than a degree) then the phase angle δ in the neutrino mixing matrix will be very difficult to measure. The facilities currently planned or under construction (perhaps with some upgrades) should be able to measure the other parameters with adequate precision. Secondly (and assuming that θ_{13} is not too small), we should design and build a neutrino factory. The neutrino factory is the ultimate facility for making the precision measurements of the neutrino mixing matrix.

Between these two steps - demonstrating that θ_{13} is non-zero and building a neutrino factory - there are numerous other projects that could be built, which could address these issues. A combination of these facilities could eventually reach a precision approaching that of the neutrino factory. However, although many of these projects are innovative, none of them is cheap. In general, funding for particle physics is tight, and the combination of building the LHC and its detectors and preparing for the linear collider (which has been declared in several reports from the particle physics community to be the highest priority project after the LHC) is putting the available and likely funding under great strain. This means that the world-wide neutrino community needs to have a very clear focus for its future programme. There is also, in my view, a need to maintain a "regional balance" the particle physics portfolio of facilities, including the neutrino sector. The resources required for a precision measurement of the neutrino mixing matrix are likely to be well beyond those available in any single region, and a full neutrino factory (with two distant detectors) is inevitably an inter-regional machine. The neutrino factory community, through the annual workshops, has developed a global approach, with a coordinated research programme to address the technical challenges. This cooperation is highly desireable in itself, but more importantly is essential if we are to be able to raise the considerable resources that will be required to achieve the long-term objectives.

The neutrino factory community has developed, over the past few years, a coherent "Road Map" for the development of such a facility, in the five well attended NuFACT workshops held in Lyon (1999), Monterey (2000), Tsukuba (2001), London (2002) and New York (2003). It is less clear which organisation could foster the evolution of this Road Map - ICFA (to take just one obvious possibility) is currently fully engaged with the preparations for the linear collider, and it is unrealistic to expect that it could at the same time engage as fully with the neutrino factory debate. However, we do need to find a way of preparing the arguments in favour of a neutrino factory for our colleagues, the funding agencies and the politicians, particularly since this is a very long term programme. It will surely take at least twenty years before we can complete the precision measurement of the neutrino mixing matrix. Given the cost of these facilities, we have to be convinced, and to convince others, that the programme that we propose is comprehensive but not extravangant. There are many good ideas. What we need is a mechanism for deciding which combination of projects delivers the required precision in the most cost-effective way.

In the meantime, it is vitally important that there is continued R&D into the difficult technologies (the proton driver, targetry, cooling) needed for the neutrino factory. By about 2010 or 2011, we can hope that there will be indications that θ_{13} is not zero. At that time, we need to be able to demonstrate that a neutrino factory with adequate performance is feasible and affordable, so that the particle physics community and the funding agencies have the opportunity to decide whether or not to construct it. Equally, there is an urgent need for R&D into new detector technologies. Even with this, it will not be possible to have a neutrino factory operating before 2018 or 2020.

Neutrino physics is very exciting, and it is good to see so many younger physicists attracted to the field - this is both very important and very healthy, particularly given the number of significant challenges. It is equally important that there are real projects for these young physicists to work on, leading to full publications, so that they may advance in their careers. I have been very encouraged by this workshop, and I would like to thank Milla and her colleagues for organising it.