MICE neutrino experiment

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In the quest to unravel the characteristics of the mysterious neutrino particle, millions of which pass through us undetected every day, scientists from several international universities have joined forces with UK research colleagues to build a unique engineering technology demonstrator at the Rutherford Appleton Laboratory in Oxfordshire. Known as MICE [Muon Ionisation Cooling Experiment] the experiment will prove one of the key requirements to produce intense beams of neutrinos at a dedicated Neutrino Factory to be built later this decade.

Announcing funding for the experiment Science and Innovation Minister, Lord Sainsbury said, “It is a testament to the UK’s world class science and facilities that leading experimental physicists from across the globe have supported conducting a project of this calibre in the UK. The Government’s investment in this experiment will provide a unique showcase of UK scientific and engineering technology.The support for using the Rutherford Appleton Laboratory in Oxfordshire is a further demonstration of the UK’s position as a leading base for scientific research and innovation.”

Recent observations of solar neutrinos have shown that they change state [oscillate], between three forms – electron, tau and muon – during their journey from the Sun to the Earth. This discovery is extremely significant since oscillations can only occur if neutrinos have mass. The Standard Model of particle physics, on which our current understanding how our universe was created and is held together, assumes that neutrinos have no mass. The ability for neutrinos to change state, therefore having mass, means the Standard Model is wrong or incomplete.

MICE will study the behaviour of muons as they pass through materials and are then subsequently accelerated. In this way, scientists will learn how to create bunches of muons having similar energies and travelling in the same direction, which can then be accelerated and stored within the Neutrino Factory as part of the process to explore the characteristics of the neutrino to unprecedented accuracy, reshaping our understanding of the structure of nature and the forces which bind it together.

Funding for MICE has been provided by the Government's Large Facilities Capital Fund (£7.5 million), the Particle Physics and Astronomy Research Council [PPARC] £1.28 million and the Council for the Central Laboratory of the Research Councils [CCLRC] £0.92 million.

Professor Ian Halliday, Chief Executive of PPARC said, " Siting MICE here in the UK is a clear recognition of the expertise and infrastructure we already have in place – and this positive investment will position the UK to be a major player in the development and possible hosting of a Neutrino Factory in the future."

In order to make precise measurements of the detailed characteristics of neutrino oscillations a new facility, a Neutrino Factory, is required. Such a facility will produce very intense beams of neutrinos with well known characteristics. The objective of MICE is to show that muons can be assembled into "bunches" with similar energies going in the same direction enabling them to be suitable for subsequent acceleration and storage. The technology for this process of 'ionisation cooling', as it is known, will be demonstrated by MICE. The feasibility of this novel technique is at the root of a whole line of new accelerators from Neutrino Factories to Muon Colliders.

After an exhaustive search, the international collaboration decided that the muon beam from ISIS at the Rutherford Appleton Laboratory provided the most suitable environment for this experiment. The collaboration will design, build and test a section of the realistic cooling channel on a beam line.

Professor John Wood, Chief Executive of the Rutherford Appleton Laboratory said,

“I am delighted that the international Muon Ionisation Cooling Experiment (MICE) will be performed at the CCLRC's Rutherford Appleton Laboratory. This project adds to the already considerable portfolio of world-leading projects hosted on ISIS, the world's most powerful pulsed neutron source, and represents a major step on the way to the design of a future neutrino factory."

Professor Ken Long of Imperial College London, and the UK Spokesperson for MICE said “I am very pleased that MICE is going to be performed in the UK on ISIS. This is a very significant step towards the design of a Neutrino Factory, and could not have been achieved without the dedication and support of the international MICE collaboration, from Europe, the US and Japan. It is also a remarkable success for particle physicists and accelerator scientists in the UK. I would also like to acknowledge the strong support that we have received from many people and organisations, but particularly PPARC and CCLRC, and the contribution from the Large Facilities Capital Fund, without which this would not have been possible.”

The MICE collaboration consists of 150 scientists from the UK, continental Europe, the US and Japan. UK collaborators are from UK collaborators are from Brunel University, University of Edinburgh, Glasgow University, University of Liverpool, Imperial College London, University of Oxford, CCLRC Rutherford Appleton Laboratory, University of Sheffield.

Further details about MICE can be found at
hepunx.rl.ac.uk/uknf/miceuk

Background Information

1. The Standard Model of Particle Physics is built on the fact that the elementary building blocks of matter are divided into three generations of two kinds of particle – quarks and leptons. The leptons consist of the charged electron, muon and tau, together with three electronically neutral particles – the electron neutrino, muon neutrinos and tau neutrinos. The Standard Model predicts that neutrinos have no mass.

These arguments have come to the fore as results from experiments (such as those from the Sudbury Neutrino Observatory in Canada) detecting neutrinos from the Sun, as well as atmospheric neutrinos produced by cosmic rays, do have mass after all.

A deep underground experiment which detected solar neutrinos showed that only one third of the numbers predicted by the theories of how the Sun works were present. The suggestion on why this might be is that solar neutrinos might be changing into something else. i.e. only electron neutrinos are emitted by the Sun and they could be converting into muon and tau neutrinos which were not being detected on Earth. This effect – neutrino oscillation – requires neutrinos to have mass.

As the Standard Model predicts zero mass for neutrinos – the results indicate that there must be new physics going beyond the Standard Model – the question is what?

2. The Neutrino Factory refers to a new way of generating very high intensity beams of high energy neutrinos of known characteristics

(composition, energy) by storing muons in a decay ring with long straight sections pointing to large detectors hundreds or thousands of kilometres away. Studies have shown that such a Neutrino Factory can be built, but that there are a number of technical challenges to be solved before a technical design can be completed.

3. “Ionisation cooling” is the only technique that can “cool” the muons fast enough—muons decay in about 2 millionths of a second. The “cooling” refers to the idea that a cloud of muons that all have different energies and directions looks like a “hot” gas, whereas when they all have about the same energy and move in the same direction, they look like a “cool” gas. In ionisation cooling, the energy of the muon is reduced by passage through matter (probably liquid hydrogen) and one component of the energy is restored by acceleration with radiofrequency (RF) electric fields. While there is no doubt that this works, the efficiency of cooling in this way requires detailed knowledge of the behaviour of muons in many materials—for example, in the windows of the vessel that contains the liquid hydrogen.

4. The Muon Ionisation Cooling Experiment (MICE) will demonstrate that it is possible to design, build and characterise a section of a realistic cooling channel, and obtain the performance expected. Achieving this will give confidence that a full Ionisation Cooling Channel (which will consist of a large number of cooling sections) can be designed and built economically. In order to demonstrate the cooling performance, it will be necessary to characterise the muon beam going into and coming out of the cooling section with unprecedented accuracy.

5. The physics motivation for the Neutrino factory is the study of the properties of neutrinos. In the wake of the spectacular observation of cosmic neutrinos, which gained the Nobel Prize for Physics in 2002 for Ray Davis and Masatoshi Koshiba, it was also discovered that neutrinos have mass and undergo, over astronomical distances, a quantum

phenomenon called “neutrino oscillations”. Much of the excitement arises because there is the possibility within the neutrino oscillation phenomenon that there could be a significant difference between the properties of neutrinos and antineutrinos, and that this might be related to the observation that in the Universe today there is no antimatter, although in the Big Bang, matter and antimatter would have been created in equal amounts. A Neutrino Factory would be the most powerful source of neutrinos suitable for these experiments. The discovery of an asymmetry in the properties of neutrinos and antineutrinos would be one of the most exciting discoveries of the 21st century.

Source: PPARC