The MINOS Experiment at Fermilab

The MINOS experiment (**M**ain **I**njector **N**eutrino **O**scillation **S**earch), initially conceived over 10 years ago, has this year published its first results on the properties of neutrinos from the NuMI beamline (**Neu**trinos from the **M**ain **I**njector). The construction, installation and commissioning of the detectors and beamline finished in April 2005. A rapid understanding and analysis of the data has allowed the collaboration to produce world competitive results based only on the first year of NuMI beam running. UCL physicist Jennifer Thomas spearheaded the first MINOS analysis and led the collaboration-wide effort to produce the first publication.

The experiment begins with the NuMI beamline, part of the accelerator complex at Fermilab in the USA, which produces the highest intensity neutrino beam in the world. A beam of 120 GeV protons extracted from Fermilab's Main Injector accelerator are focussed onto a thin graphite target. The resulting interactions produce many secondary particles which are focussed using two magnetic horns and the decay of these particles then produces the neutrino beam. Figure 1 is a photograph of one of the two magnetic horns used to focus the secondary particles from the target.

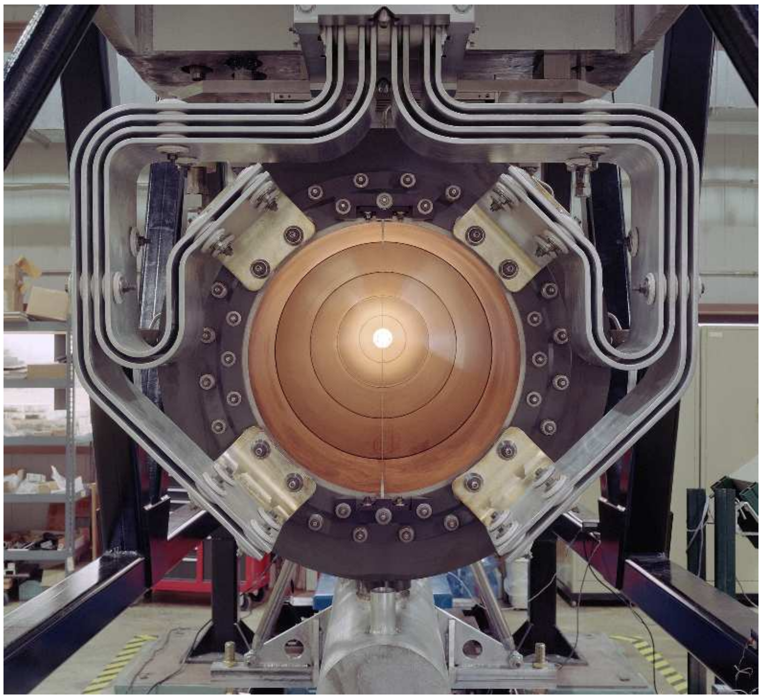

Figure 1: One of the two magnetic focussing horns used to produce the neutrino beam.

The MINOS experiment uses two detectors constructed in the line of sight of the beam to measure fundamental properties of the neutrinos. The first detector, the 980 ton Near detector, is located on the Fermilab site at a distance of 1 km from the beam production point. This detector is designed to make precise measurements of the neutrinos just after they have been produced and collects data on thousands of neutrino interactions every day. The 5.4 kton Far detector is located 735 km away in the Soudan Underground Laboratory in Northern Minnesota, USA and is shown in Figure 2. This detector was constructed to probe the curious nature of neutrino oscillations - the ability of a neutrino to change its "flavour" as it propagates. By measuring the neutrino beam at the Far detector and comparing with the measurements made at the Near detector, the MINOS experiment can conclusively say whether or not the neutrinos have indeed changed flavour during their flight.

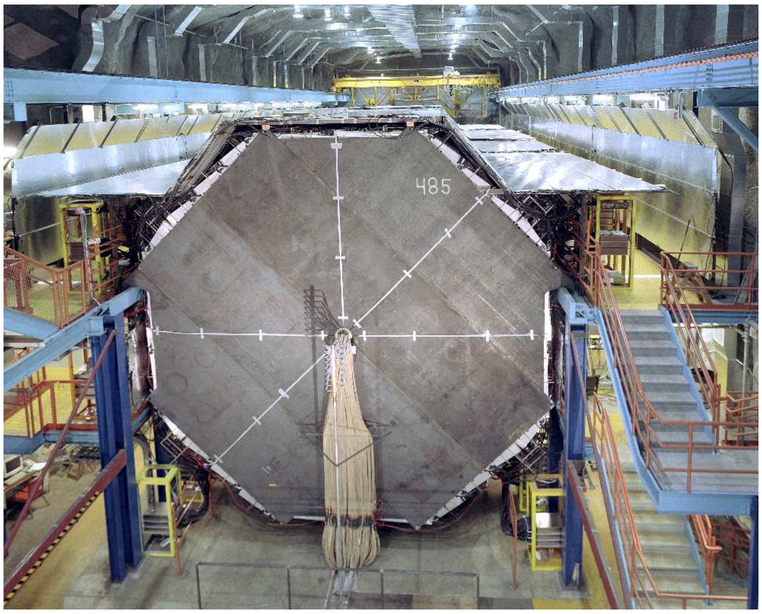

Figure 2: The MINOS Far Detector located half a mile underground in the Soudan Laboratory, Minnesota, USA.

The primary MINOS measurement makes use of Charged Current (CC) neutrino interactions of the "muon" flavoured neutrinos that dominate the composition of the beam at production. A diagram of a muon neutrino CC interation with a nucleon is shown in Figure 3 (left) and is typified by the exchange of a charged W boson. The final products of the interaction are a spray of hadronic particles from the nucleon and a muon. Muons are easily identifiable in the MINOS detectors and appear as long, narrow "tracks" as can be seen in Figure 3 (right). The spray of hadronic particles can be identified as the cluster of hits at the track vertex. The characteristic long track is only produced in CC interactions of muon neutrinos. If another neutrino flavour interacts (an electron or tau neutrino), a different hit pattern is observed in the detector. Given that the beam is initially dominated by muon neutrinos, a disappearance of this flavour of neutrino at the Far detector relative to the number observed at the Near detector, would then indicate oscillations. Furthermore, looking at the dependence of muon neutrino disappearance on the energy of the neutrinos allows us to make fundamental measurements of their properties.

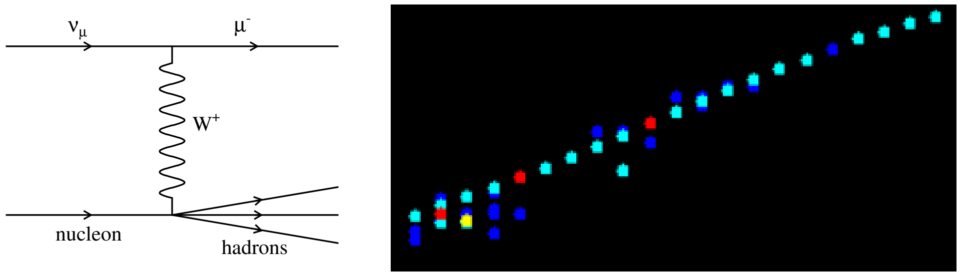

Figure 3: Left: a Feynman diagram showing the interaction of a muon neutrino with a nucleon. Right: the final products of the interaction are a muon, which is easily identifiable as a long track in the detector; and a spray of hadronic particles, which are observed as a cluster of hits close to the track vertex (at the left end of the track).

However, turning the raw data into measurements of fundamental parameters requires an enormous amount of effort on several fronts and UCL physicists continue to be involved at every stage. From working on the accelerator complex to ensure that the neutrino beam is well controlled and as intense as possible; to striving to fully understand the neutrino composition of the beam by studying the Near detector data. From working on the algorithms used to identify the hit patterns observed in the raw data as final interaction products (as described in Figure 3); to identifying and developing viable analysis techniques for extracting the fundamental oscillation parameters. UCL physicists played important roles in each of these areas for the first analysis and contributed significantly to the resulting paper.

The measurement reported in the paper is summarized in Figure 4 which shows the results from MINOS compared to previous experiments. It shows a range of possible values for two of the fundamental oscillation parameters: $sin^2 2\theta_{23}$ and $|\Delta m^2_{32}|$. The area enclosed within the lines, or contours, represents the range of values that the experiment considers favourable. This area will reduce with more data and with more experiments, and the favourable region will eventually close in on the true values in nature. Over the next few years, as MINOS continues to collect data, UCL will continue to play a strong role in the oscillation analyses and will also begin making other important measurements with the large amount of neutrino interaction data in the Near detector. The MINOS measurements will soon become the best in the world and will help guide the next generation of experiments seeking to unravel the mysteries of the neutrino.

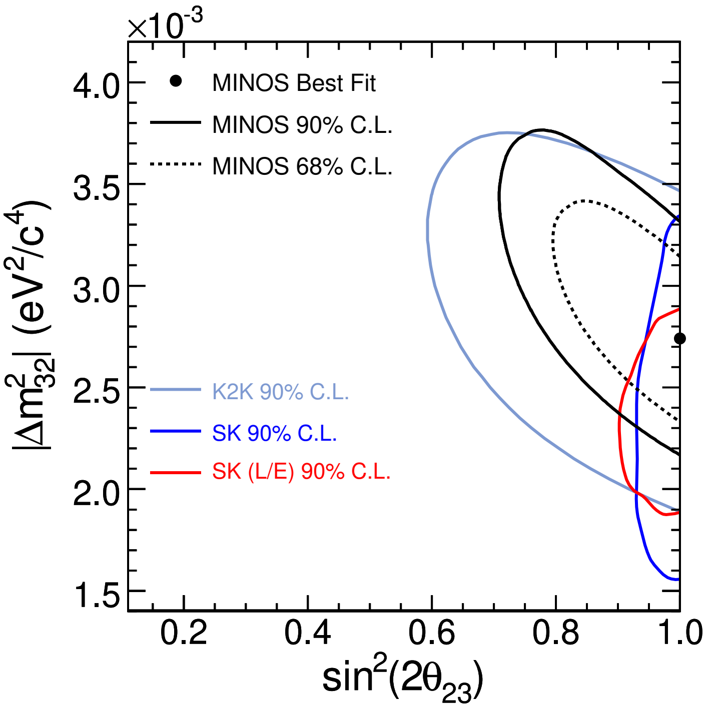

Figure 4: The final measurement from the first year of MINOS data taking with the NuMI beam. The area within the black contours represents the most favourable values for the oscillation parameters: $sin^2 2\theta_{23}$ and $|\Delta m^2_{32}|$. The other coloured lines represent the same measurement for previous experiments. MINOS is competitive with these after only 1 year of NuMI beam running.