MINOS+: Using the NuMI Beam as a Precision Tool for Neutrino Physics

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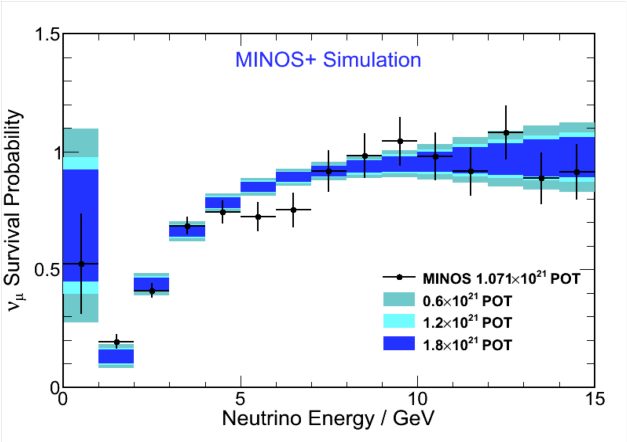

Ratio of oscillated to unoscillated CC rates at the MINOS+ far detector for 1, 2, and 3 years of neutrino running, compared to the full MINOS dataset.

Neutrino physics experiments which extend our fundamental understanding of the lepton sector have, up to now, been able to achieve only a moderate level of precision. The current generation of experiments is changing this situation. The NuMI beam at Fermilab generates a long-baseline neutrino beam with very high intensity. Using NuMI, the MINOS+ experiment, approved to operate at Fermilab for three years, will produce precision studies of the transition region between the first oscillation maximum and the continuum, both enhancing our understanding of the PMNS scheme and bounding or discovering new phenomena which go beyond it.

Operating at 700 kW, the NuMI medium-energy beam will produce a wide-band neutrino beam peaking at about 7 GeV event energy at the location of the MINOS detector. High beam power coupled with the increased neutrino cross-section yields event rates of about 4800 charged-current (CC) events and 1600 neutral-current (NC) events each year. The MINOS collaboration used ~2900 events in total, collected between 2005 and 2012.

Such high rates allow a wide variety of physics measurements. Initially, the experiment will continue to improve knowledge of the fundamental oscillation parameters. The region between 4-10 GeV constrains the shape of the disappearance spectrum and thus enables an improved measurement of Δm^2. Combination with NOvA will provide high precision on the parameters.

Study of the unoscillated continuum region and the detailed shape of the transition region allows bounds on phenomena which go beyond the standard 3-neutrino description. An example is a fourth, sterile neutrino, where the situation remains unclear. The complexity of a four neutrino mixing matrix argues for a variety of complementary approaches. Using CC disappearance, MINOS+ gives a clean limit on the angle θ_{24}. Stringent limits on non-standard interactions, and models of large extra dimensions will be easily obtained. The experiment constrains the range of future theories, much as has occurred with precision electroweak measurements elsewhere. Tau lepton appearance studies may also be possible.

MINOS+ is an excellent example of how new ideas can exploit existing facilities, thereby maximizing HEP benefit for minimal additional investment. The combination of the MINOS detector, designed originally for these energies, and the upgraded NuMI beam, opens a unique window on extensions of the standard neutrino model.