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SYNCHRONIZATION BETWEEN REMOTE SITES FOR THE MINOS EXPERIMENT

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In the context of time-of-flight measurements, the timing at the departure and arrival locations is obviously critical to the outcome of the experiment.
In the case of neutrino time-of-flight experiments, the locations are many hundreds of kilometers apart with synchronization requirements of nanoseconds for several months at a time.
In addition to the already stringent set of requirements outlined above, the location of the origin of the particle beam and the detector are both deep underground.
NIST and USNO have provided the MINOS (Main Injector Neutrino Oscillation Search) collaboration with both hardware and expertise to synchronize the two sites of the experiment, the accelerator at Fermilab in Batavia, IL and the Soudan Mine in northern Minnesota.
Two GPS receivers are installed at each location where the local clocks are commercial Cesium clocks (HP5071, standard performance). Two more GPS receivers are constantly traveling between locations (including NIST in Boulder, CO) to provide multiple differential calibrations of the fixed receivers. The availability of the TWTFST equipment from USNO allowed for one calibration of the GPS-based link between the locations, providing an independent means of determining the accuracy of the synchronization.
Several months of continuous GPS data are now available, including the two-way calibration instance and several differential GPS calibrations. These will be presented in the paper, together with a detailed description of the synchronization apparatus.
The results of data processing yielded synchronization stability below one nanosecond with accuracy at the nanosecond level over several months.

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