The results presented are obtained using the complete MINOS beam data sample collected between 2005 and 2012.

A total of $10.71 \times 10^{20}$ POT collected in neutrino mode and $3.36 \times 10^{20}$ POT collected in antineutrino-enhanced mode are used in the analysis.

Muons from $\nu_\mu$, $\bar{\nu}_\mu$ charged-current (CC) interactions are selected by multivariate algorithm based on a k-Nearest-Neighbor technique.

The MINOS detectors are magnetized, enabling $\nu_\mu$ and $\bar{\nu}_\mu$ to be separated on an event-by-event basis, by analyzing the muon curvature. $\bar{\nu}_\mu$ CC events are identified by a positive muon charge sign.

The neutrino energy is reconstructed by summing the muon momentum and hadronic shower energy. The plot on the right shows the energy spectrum in the Near Detector (ND) for selected $\nu_\mu$ CC events. The extrapolated ND spectrum is used to obtain the Far Detector unoscillated spectrum.
\( \nu_\mu \) Charged-Current Disappearance Results

For \( 0 < E_{\text{reco}} < 200 \) GeV

Prediction, No Oscillations: \textbf{3564 events}

Observed: \textbf{2891 events}
ν̄_μ Charged-Current Disappearance Results

For 0 < E_{reco} < 200 GeV
Prediction, No Oscillations: **313 events**
Observed: **226 events**

Effect of Systematics
**Combined Beam+Atmospherics Disappearance Results**

- Red histogram shows the result from fitting a two-neutrino flavor oscillation scenario to the combined beam and atmospheric neutrino and antineutrino data samples. Fit includes 15 sources of systematic uncertainty as nuisance parameters.

- Oscillations are a good fit: 19.1% of pseudo-experiments have worse $\chi^2$. 
The MINOS beam and atmospheric neutrinos and antineutrinos are combined into a single oscillation analysis using an extended version of the fitting framework developed for the previous analysis.

The analysis includes 15 sources of systematic uncertainty, fitted as nuisance parameters,

A maximum-likelihood fit is used to determine the two-flavour oscillation parameters.

An extension of the analysis from two to three-flavour oscillations is in progress.

\[ |\Delta m^2| = 2.41^{+0.09}_{-0.10} \times 10^{-3} \text{eV}^2 \]

\[ \sin^2(2\theta) = 0.950^{+0.035}_{-0.036} \]
MINOS makes the leading measurement of $|\Delta m^2_{\text{atm}}|$ with 4.1% precision.

$|\Delta m^2| = 2.41^{+0.09}_{-0.10} \times 10^{-3} \text{eV}^2$

$\sin^2(2\theta) = 0.950^{+0.035}_{-0.036}$

$\sin^2(2\theta) > 0.890$ (90% C.L.)
Combined Beam+Atmospherics Disappearance Results

- The MINOS oscillation fit is extended to allow different oscillation parameters for $\nu_\mu$ and $\bar{\nu}_\mu$.
- The extended fit is used to determine confidence limits on the antineutrino oscillation parameters by marginalizing over the neutrino oscillation parameters.

\[ |\Delta m^2| = 2.50^{+0.23}_{-0.25} \times 10^{-3} \text{eV}^2 \]
\[ \sin^2(2\bar{\theta}) = 0.97^{+0.03}_{-0.08} \]

Plot above shows a comparison of MINOS antineutrino results for beam, atmospheric and beam+atmospheric samples with results from the Super-Kamiokande experiment.
MINOS finds consistent values for neutrinos and antineutrino oscillation parameters measured via charged-current disappearance.

\[ |\Delta m^2| - |\Delta \bar{m}^2| \approx 0.12^{+0.24}_{-0.26} \times 10^{-3} \text{eV}^2 \]