Transitions of active neutrino flavors to sterile neutrinos would result in a deficit of neutral current events observed at the MINOS Far Detector.

Observed MINOS neutral current spectrum is shown on the right, along with spectra predicted from the Near Detector for oscillations among three active neutrinos with $\nu_e$ appearance set at the global fit value from P. A. N. Machado et al., Journal of High Energy Physics, 2012, Number 5, 23.

Agreement between the observed and predicted neutral-current spectra is quantified using the statistic $R$, tabulated on the right for different ranges of the calorimetrically reconstructed energy $E_{\text{reco}}$.

$$ R = \frac{N_{\text{Data}} - \sum B_{CC}}{S_{NC}} $$
MINOS Search for Sterile Neutrino Mixing

Results of fitting the data with a 3+1 model including one sterile neutrino and a new mass eigenstate $\nu_4$. Stringent constraints are placed on the sterile mixing angles.

- 90% C.L. Limits from 1-D $\Delta\chi^2$ projections

<table>
<thead>
<tr>
<th>Model</th>
<th>$\theta_{13}$</th>
<th>$\chi^2$/d.o.f.</th>
<th>$\theta_{23}$</th>
<th>$\theta_{24}$</th>
<th>$\theta_{34}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_4 \gg m_3$</td>
<td>0</td>
<td>130.4/122</td>
<td>$45.0^{+7}_{-7}$</td>
<td>$0.0^{+5}_{-0.0}$</td>
<td>$0.0^{+17}_{-0.0}$</td>
</tr>
<tr>
<td></td>
<td>11.5</td>
<td>128.5/122</td>
<td>$45.6^{+7}_{-7}$</td>
<td>$0.0^{+5}_{-0.0}$</td>
<td>$0.0^{+25}_{-0.0}$</td>
</tr>
</tbody>
</table>

- 90% C.L. Limits from 1-D $\Delta\chi^2$ projections

- $\theta_{34} < 26^\circ$ (37° $\nu_e$) (90% C.L.)
- $\theta_{24} < 7^\circ$ (8° $\nu_e$) (90% C.L.)

This 4-flavor analysis is being refined with the inclusion of Near Detector oscillations, relevant for values of $\Delta m^2_{43}>1$ eV$^2$. Results are expected in Summer 2012.

The new model has been used to assess the reach of MINOS+ in excluding sterile neutrino mixing, as shown in the next slide.
MINOS Search for Sterile Neutrino Mixing

MINOS+ 90% CL exclusion of $\sin^2(2\theta_{24})$ compared to MiniBooNE, CDHS, and CCFR $\nu_\mu$ disappearance results. The MiniBooNE, CDHS, and CCFR contours come from Phys. Rev. Lett. 103 (2009) 061802 and show the MiniBooNE disappearance result. The $\Delta m^2$ value for CDHS, MiniBooNE and CCFR is for mass states $m_2$ and $m_4$. Because $m_4 >> m_3$, $\Delta m^2_{42}$ is nearly the same as $\Delta m^2_{43}$.

MINOS+ and Bugey combined 90% CL limit on the sterile parameter $\sin^2(2\theta_{\mu e})=4|U_{e4}|^2|U_{\mu 4}|^2$, obtained from the disappearance limits of each experiment on the size of $|U_{\mu 4}|^2$ and $|U_{e4}|^2$. The Bugey limit is computed from a GLoBES 2012 fit provided by P. Huber.

The combined limit excludes large portions of the LSND signal region.