



MINOS+
Starts April 2013 for three years

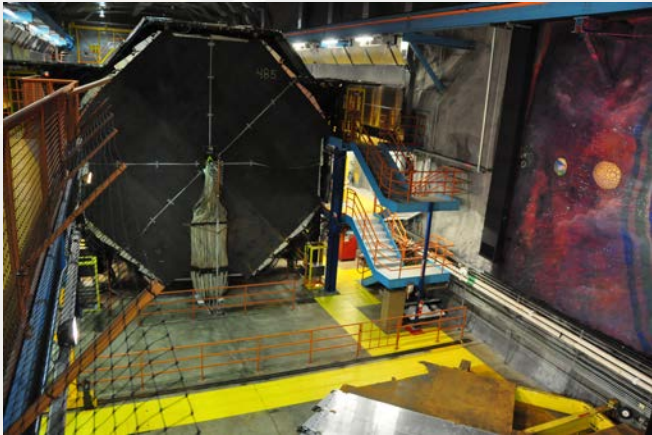
April 2013-2016

MINOS+

Summary of Physics Goals

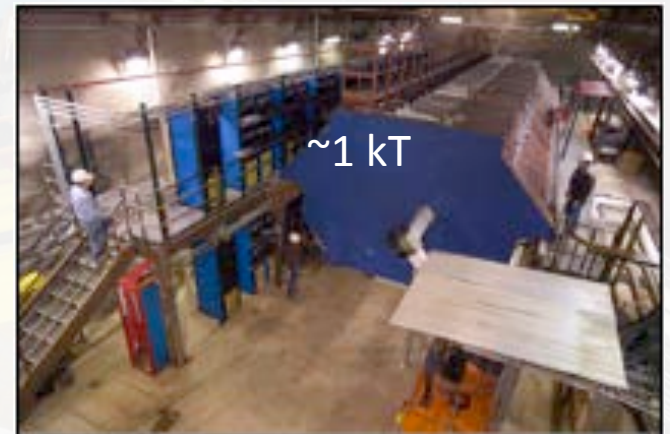
- Search for non-standard 3x3 mixing behaviour
- θ_{23} and Δm^2_{atm} (the new precision frontier)
- Sterile Search
- Non-Standard Interactions & Extra Dimensions
- Atmospheric

The MINOS(+) Experiment



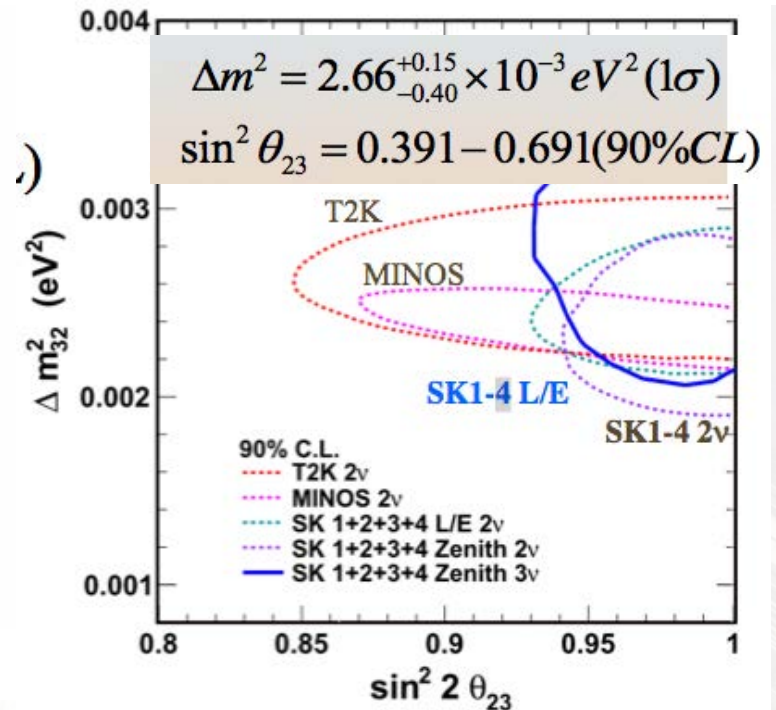
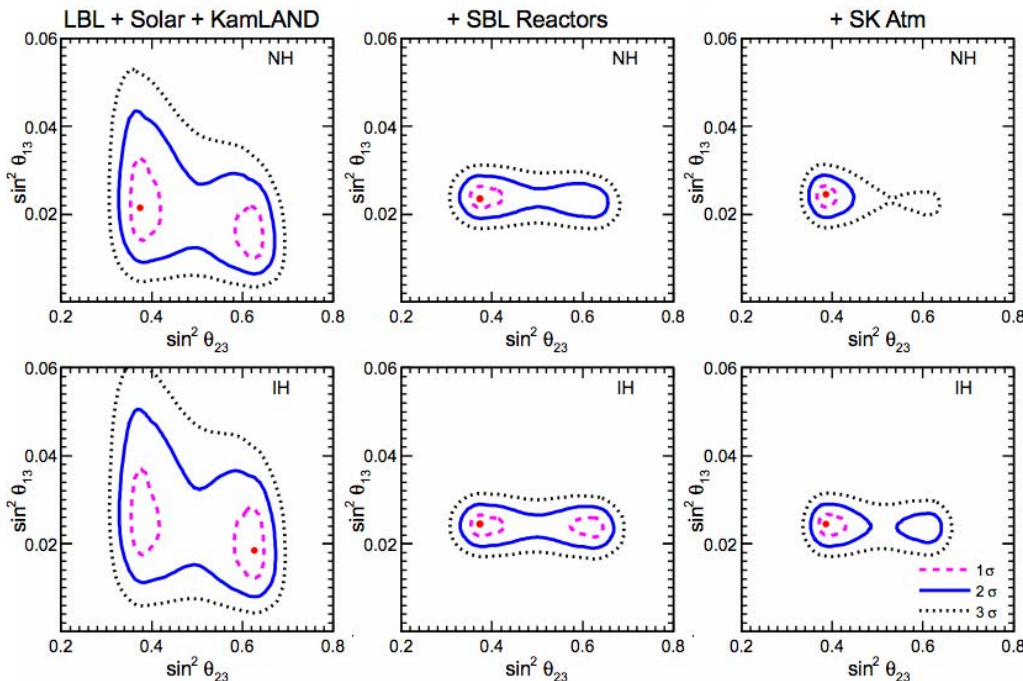
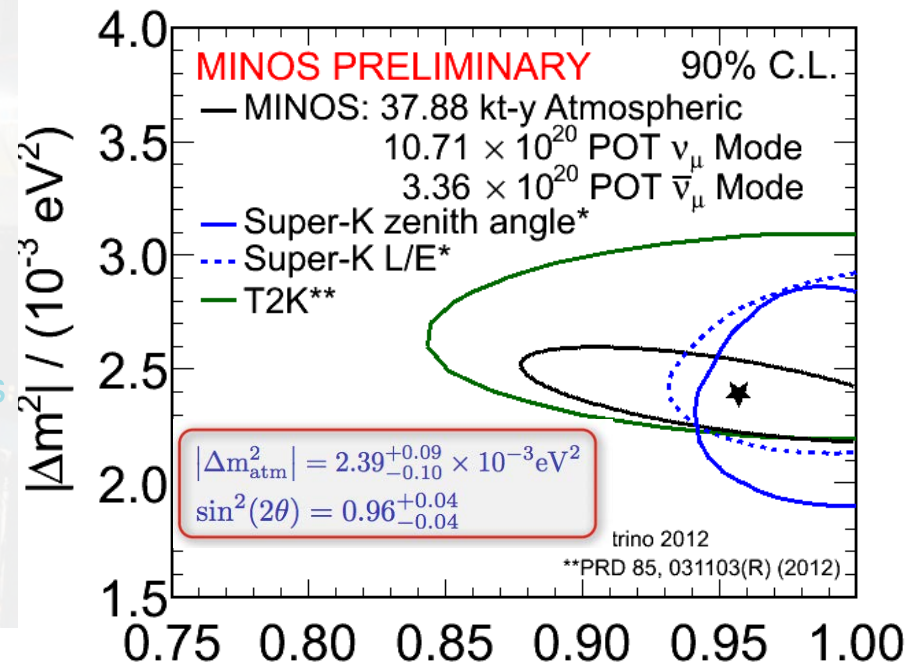
- Tracking sampling calorimeters
 - steel absorber 2.54 cm thick ($1.4 X_0$)
 - scintillator strips 4.1 cm wide (1.1 Moliere radii)
 - 1 GeV muons penetrate 28 layers
- Functionally equivalent
 - same segmentation
 - same materials
 - same mean B field (1.3 T)

- Two detectors mitigate systematic effects
 - beam flux mis-modeling
 - Neutrino x-sec uncertainties
- L/E \sim 150-250 km/GeV
- Magnetized:
 - muon energy from range/curvature
 - distinguish μ^+ from μ^-



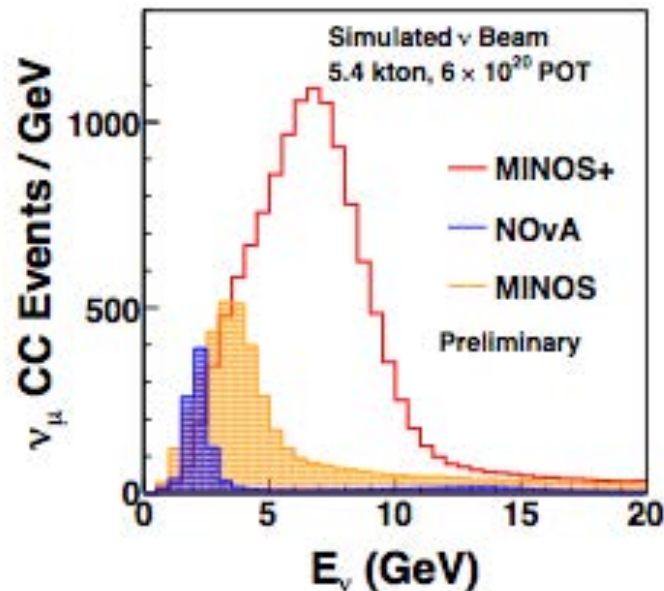
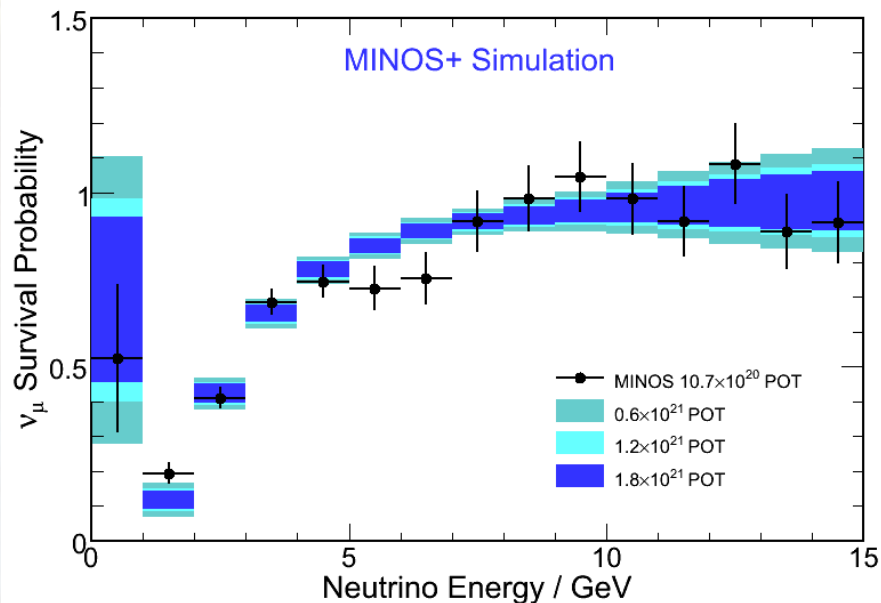
θ_{23}

- MINOS have combined atmospheric and beam neutrinos and anti-neutrinos for most precise Δm^2 and $\sin^2 2\theta_{23} < 1.0$
- Super-K have done full 3-flavor analysis
- Information about which octant θ_{23} in
- θ_{23} is the new θ_{13} !!!
- Global fit (Fogli et al.) prefers $\sin^2 \theta_{23} < 0.5$



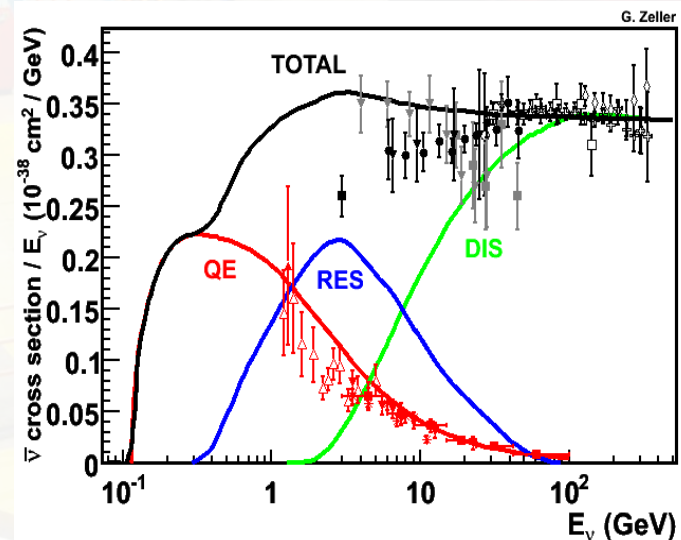
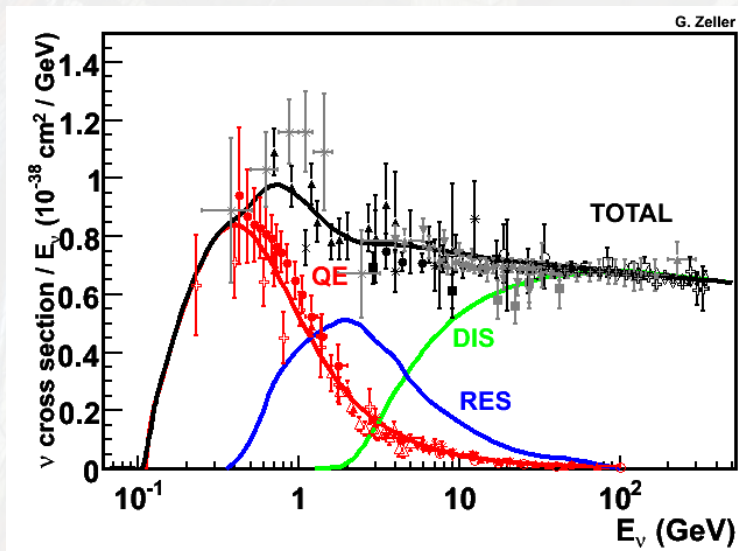
Non-Standard 3x3 Mixing

- The overarching reason to run MINOS in the NuMI-NOvA beam is to look for new physics in a previously unexplored region
- 3000 events/year between 4-10 GeV near oscillation maximum
- Unique high statistics experiment with charge sign measurement
 - different energy region
 - different systematics (beam, x-sec comp)

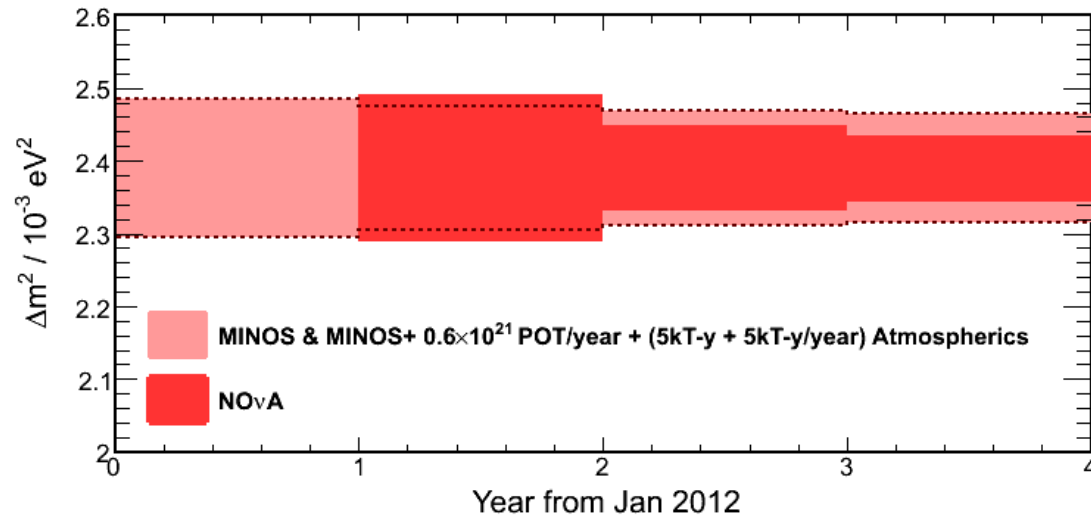
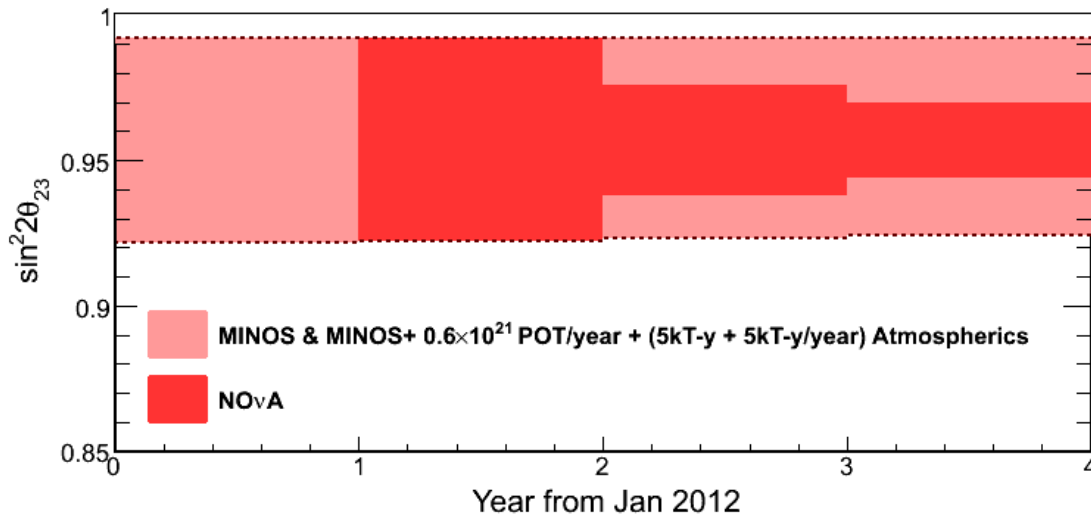


Cross check MINOS in different energy region

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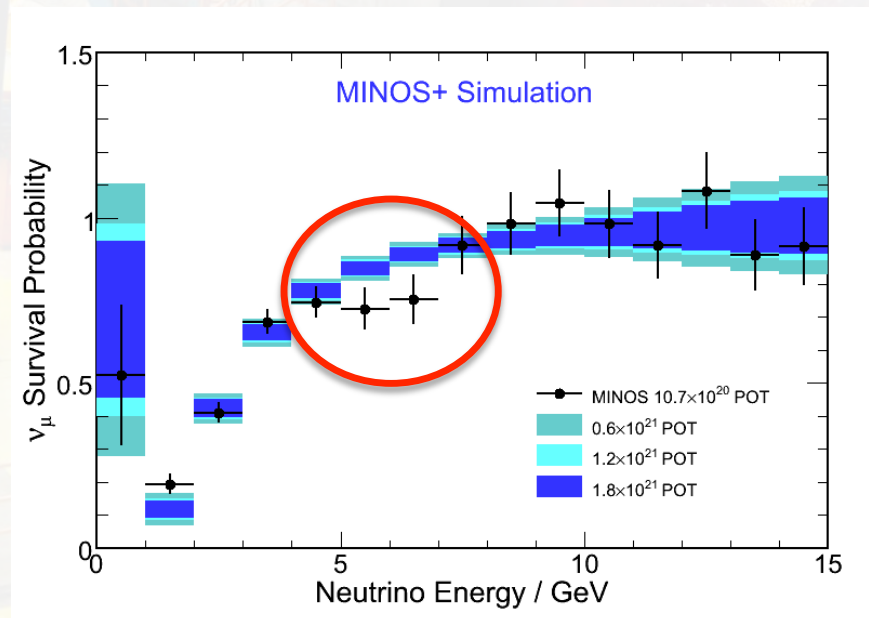
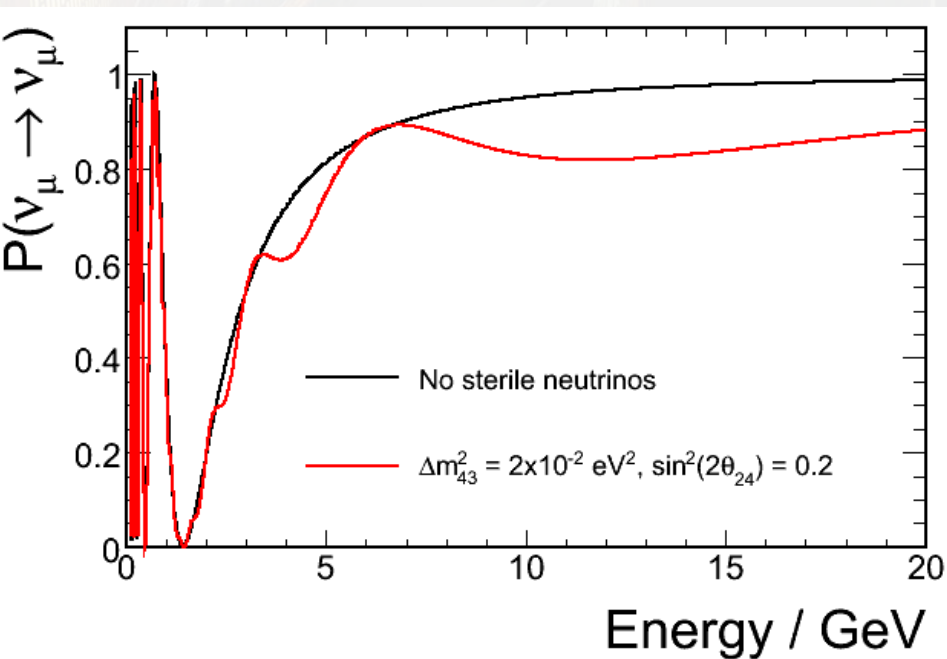
θ_{23} and Δm^2



- Very precise measure of Δm^2_{23} can be achieved
- Combined with Nova and T2K, $\sim 1\%$ measurement of this parameter
- 1% measurements of Δm^2_{32} and Δm^2_{31} can give mass hierarchy (<http://arxiv.org/pdf/1206.6017v1.pdf>)
- Some contribution to knowledge of $\sin^2 2\theta_{23}$

MINOS+

- Powerful search for sterile neutrinos
- Odd dip will have to wait for MINOS+ for more study
- Oscillation spectrum pretty insensitive to primary oscillation parameters in this region

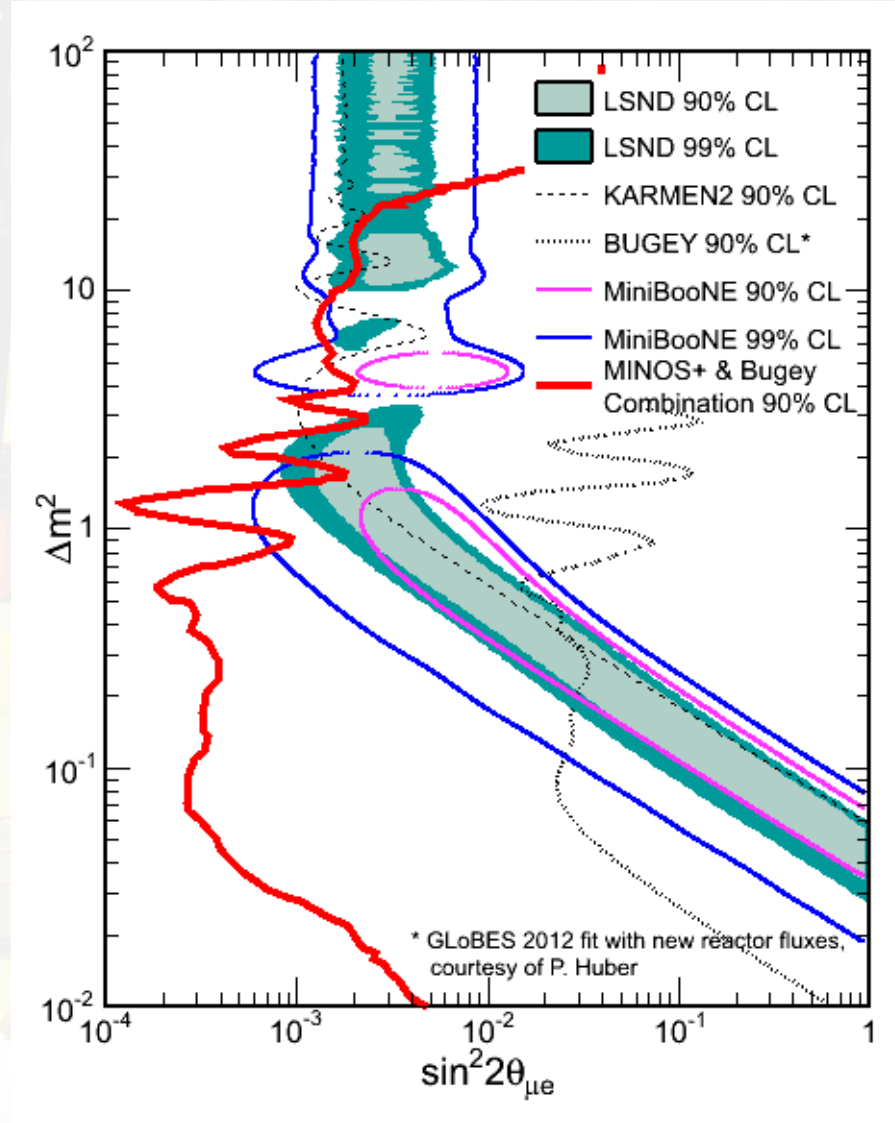
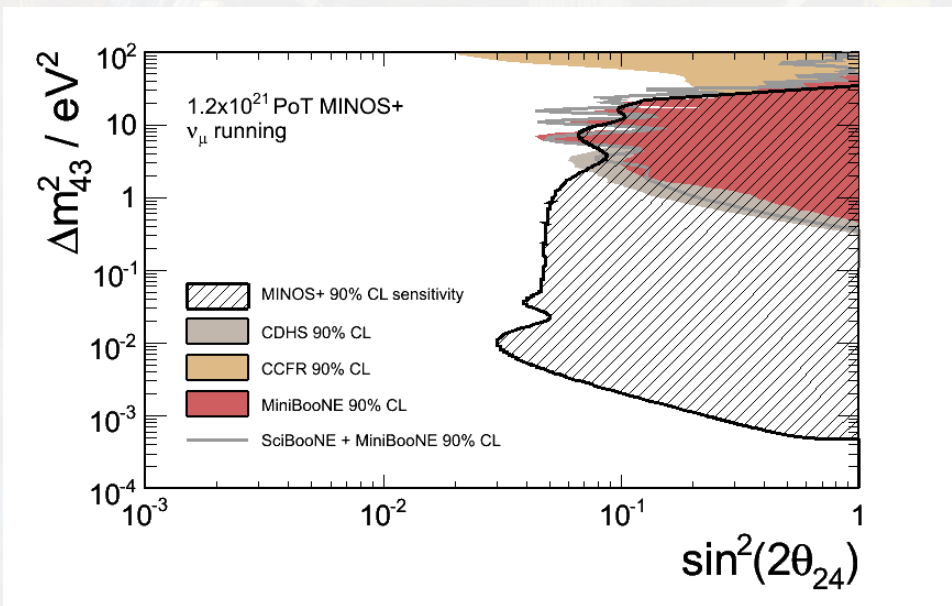
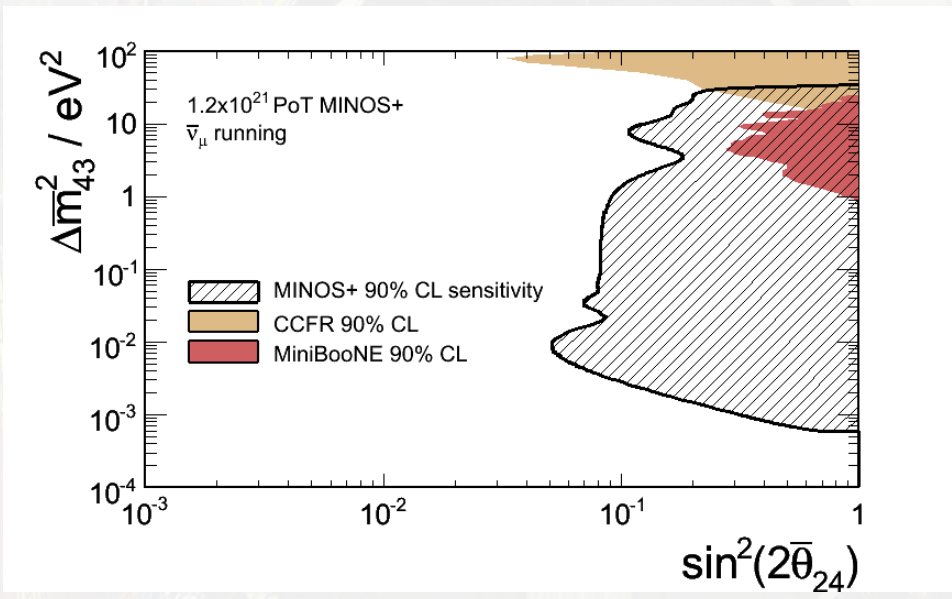


MINOS+ sterile reach

$$|U_{e4}|^2 = \sin^2\theta_{14}$$

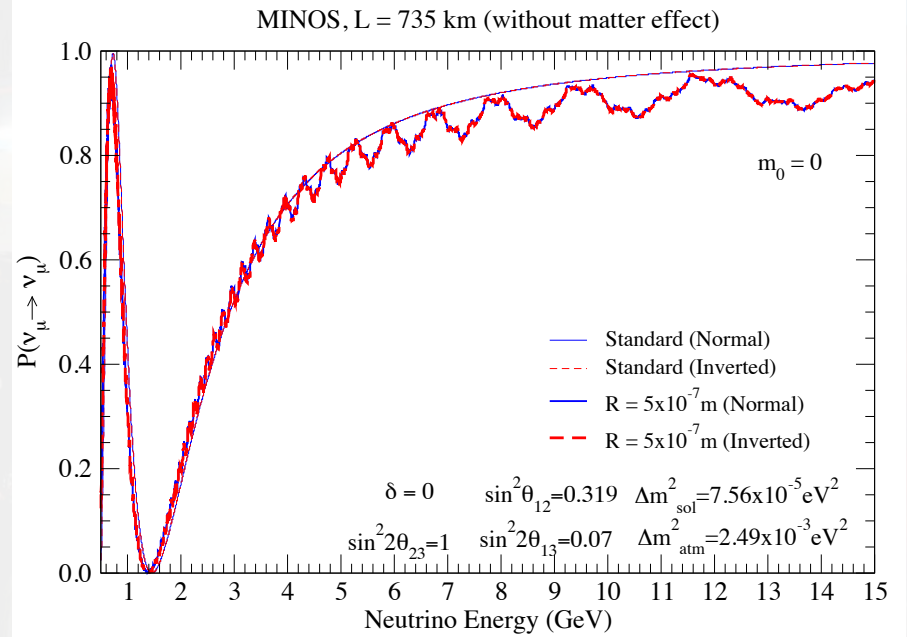
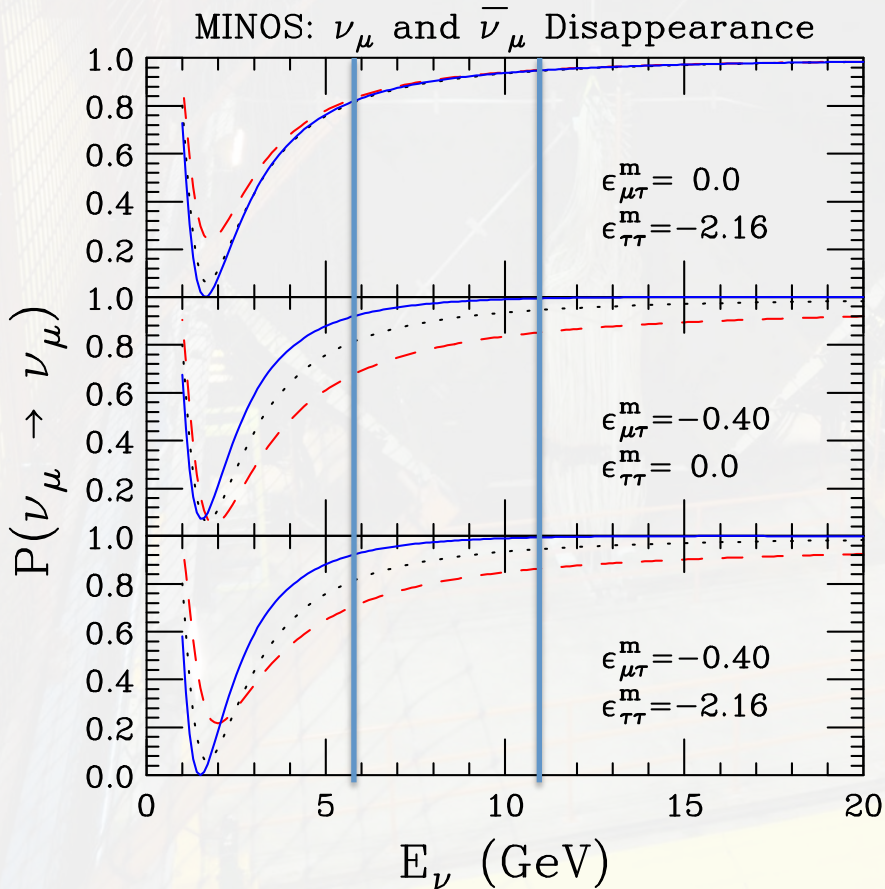
$$|U_{\mu4}|^2 = \cos^2\theta_{24} * \sin^2\theta_{24}$$

$$\sin^2(2\theta_{\mu e}) = 4|U_{e4}|^2 * |U_{\mu4}|^2$$



NSI & Extra Dimensions

Dimension 5 non-standard contact interactions show up in the region of study

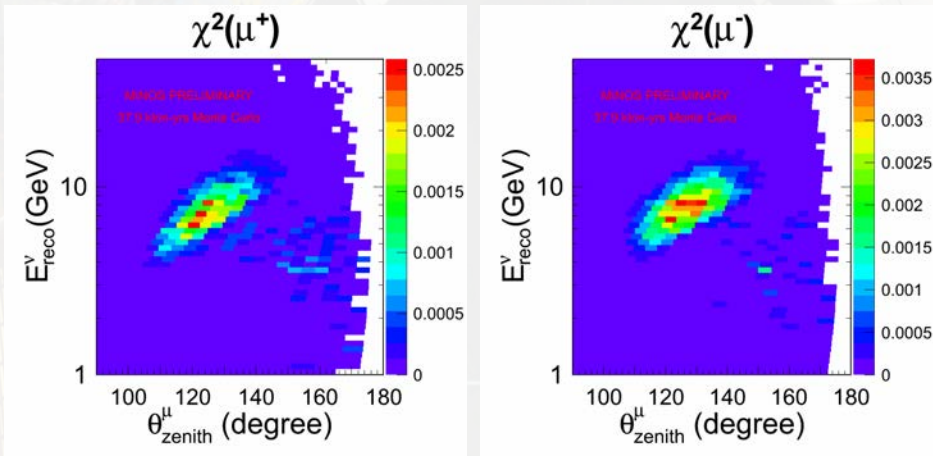


The same ratio could show half micron sized extra dimensions

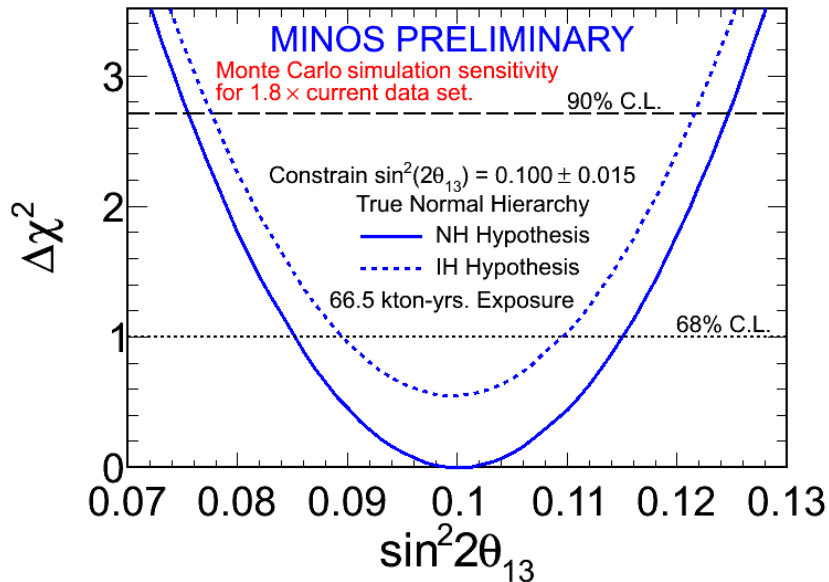
P.A.N.Machado, H.Nunokawa, R.Zukanovich Funchal, hep-ph/1101.003v1

Alexander Friedland, Cecilia Lunardini, Phys. Rev. D74: 033012, 2006.

Atmospherics



- Magnetic field allows identification of m^+ and m^-
- Complementary to SuperK who ID neutrino events
- Alone not conclusive, but combined with SuperK, could give information on mass hierarchy



Summary

- Unique among long baseline neutrino experiments, MINOS+ has high precision and long baseline
- MINOS+ will pick up where MINOS leaves off
 - Large reach in sterile search
 - Any non-standard effects should be seen with MINOS+
- High precision “standard parameter” measurement of Δm^2_{23} may be very important in the future
 - Another way to the mass hierarchy?