MINOS+

Starts April 2013 for three years

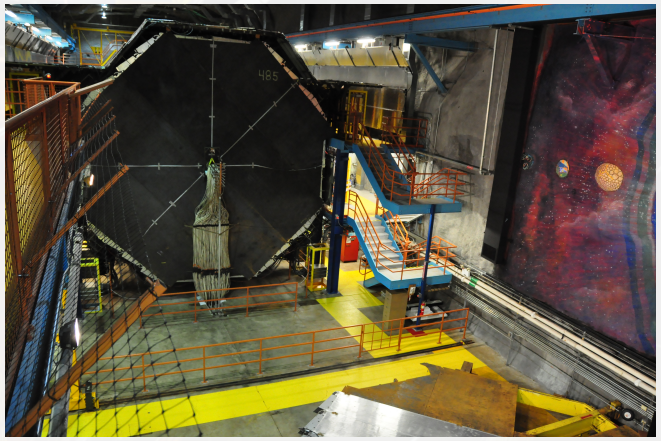
April 2013-2016

MINOS+

Summary of Physics Goals

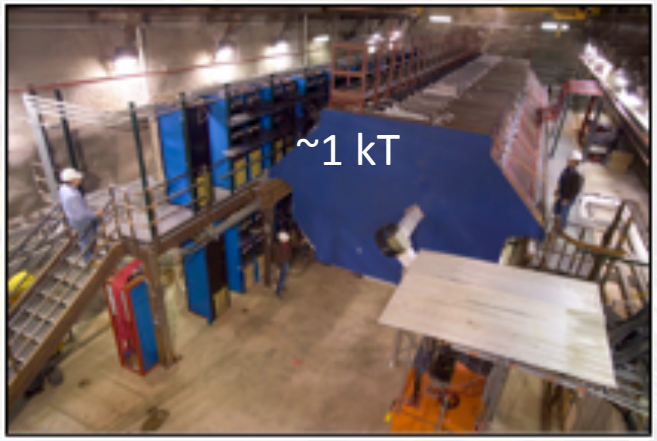
- Search for non-standard 3x3 mixing behaviour
- θ_{23} and Δm^2_{atm} (the new precision frontier)
- Sterile Search
- Non-Standard Interactions & Extra Dimensions
- Atmospherics

The MINOS(+) Experiment



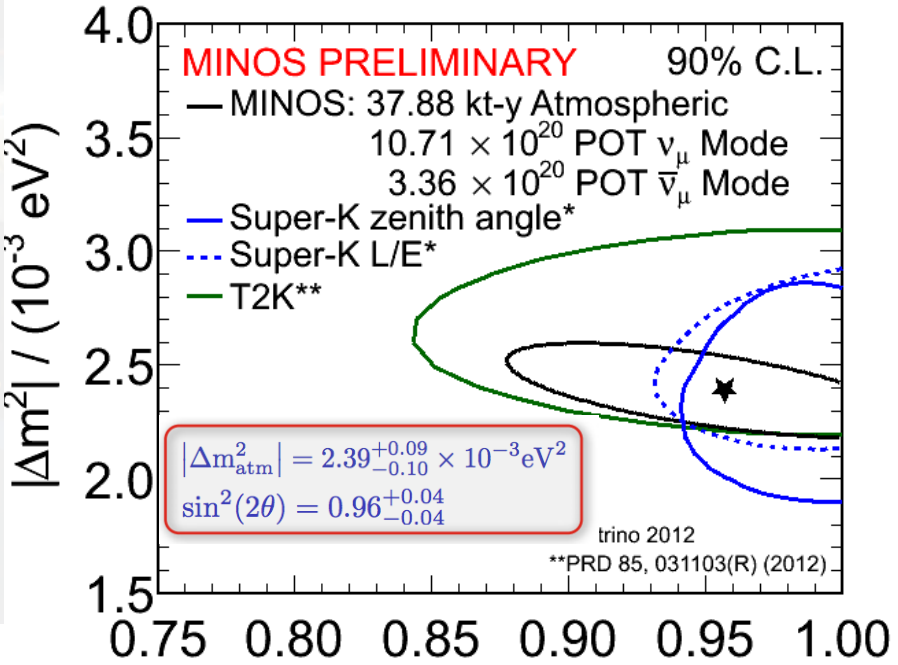
- Two detectors mitigate systematic effects
  - beam flux mis-modeling
  - Neutrino x-sec uncertainties
- L/E ~150-250 km/GeV
- Magnetized:
  - muon energy from range/ curvature
  - distinguish μ^+ from μ^-

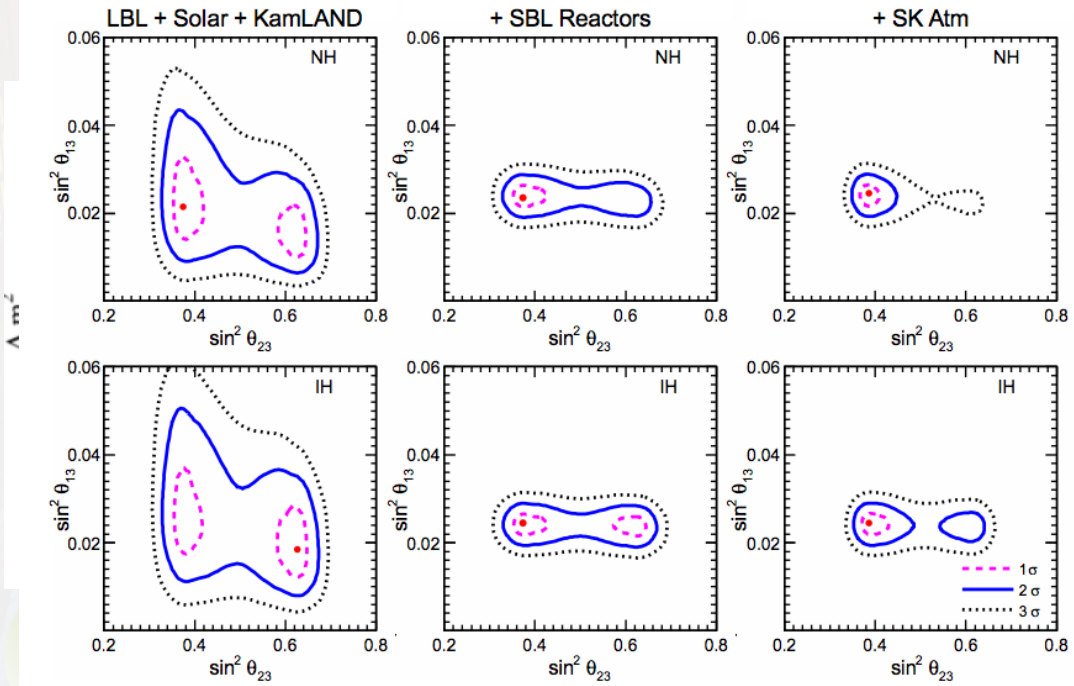
- Tracking sampling calorimeters
  - steel absorber 2.54 cm thick (1.4 X_0)
  - scintillator strips 4.1 cm wide (1.1 Moliere radii)
  - 1 GeV muons penetrate 28 layers
- Functionally equivalent
  - same segmentation
  - same materials
  - same mean B field (1.3 T)

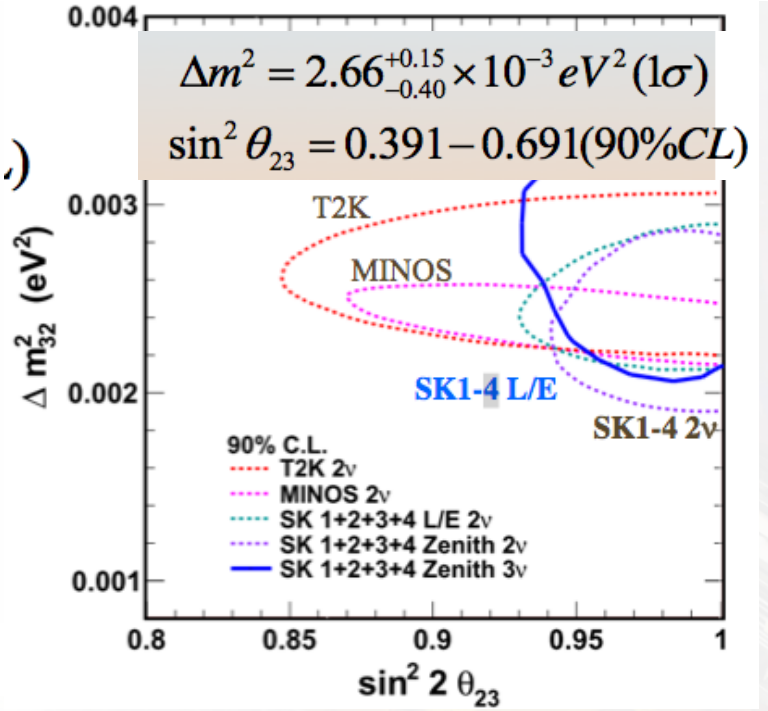


θ_{23}

- 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 $\sin^2\theta_{23} < 0.5$

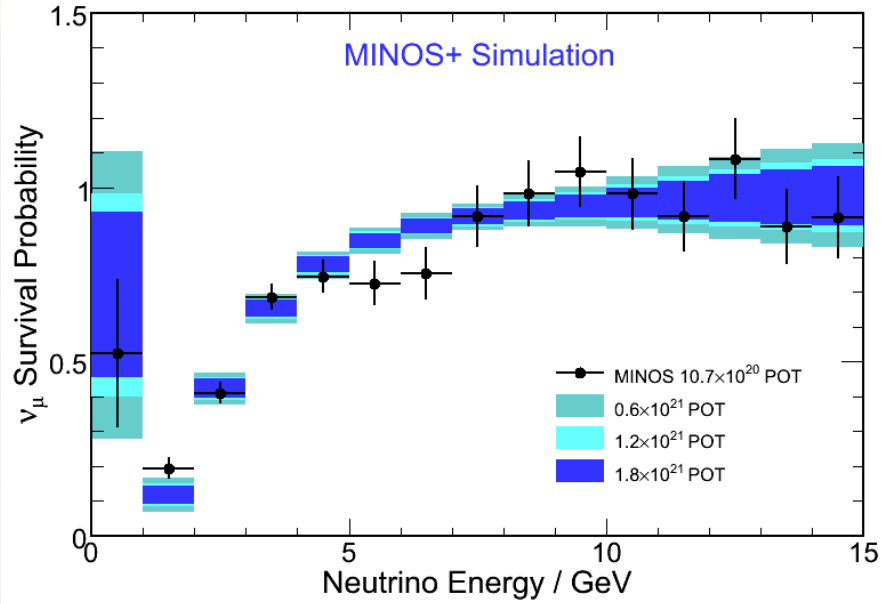


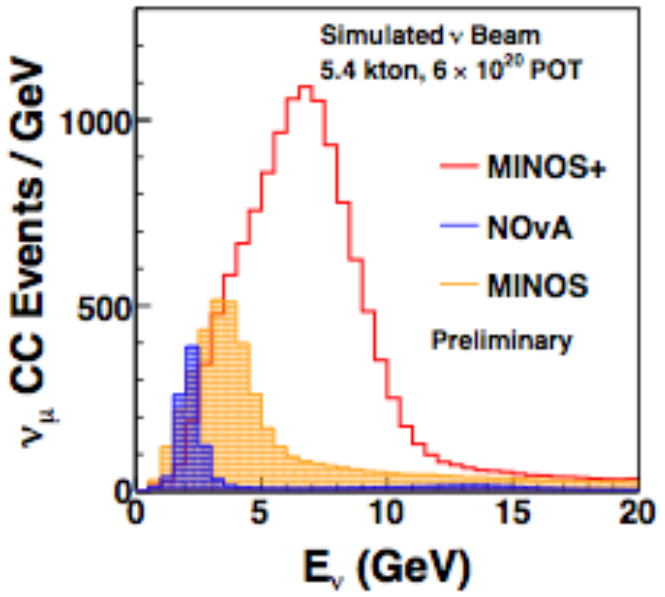




Non-Standard 3x3 Mixing

- The overarching reason to run MINOS in the NuMI-NOνA 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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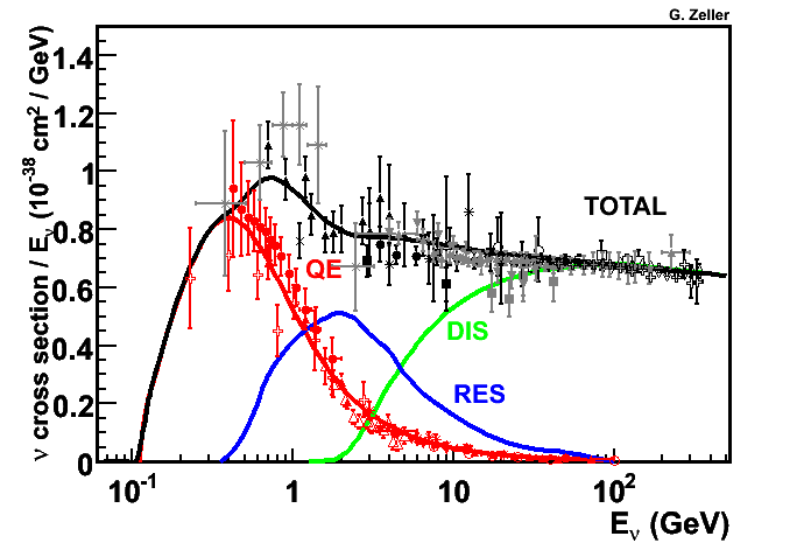
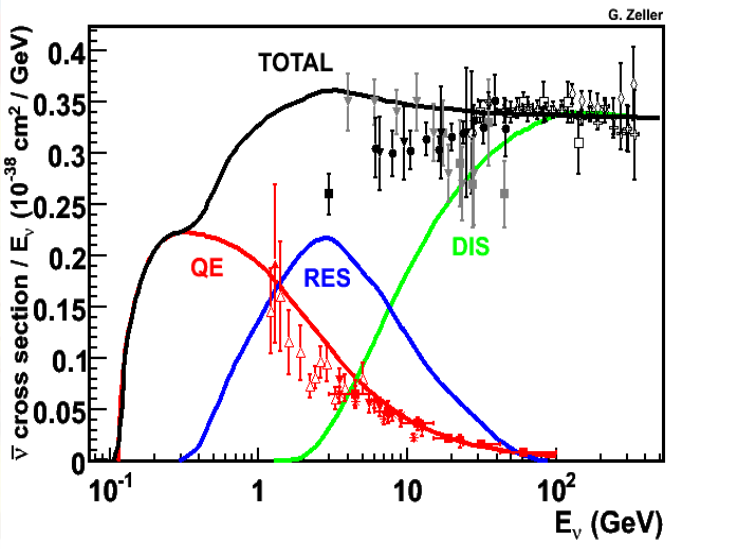
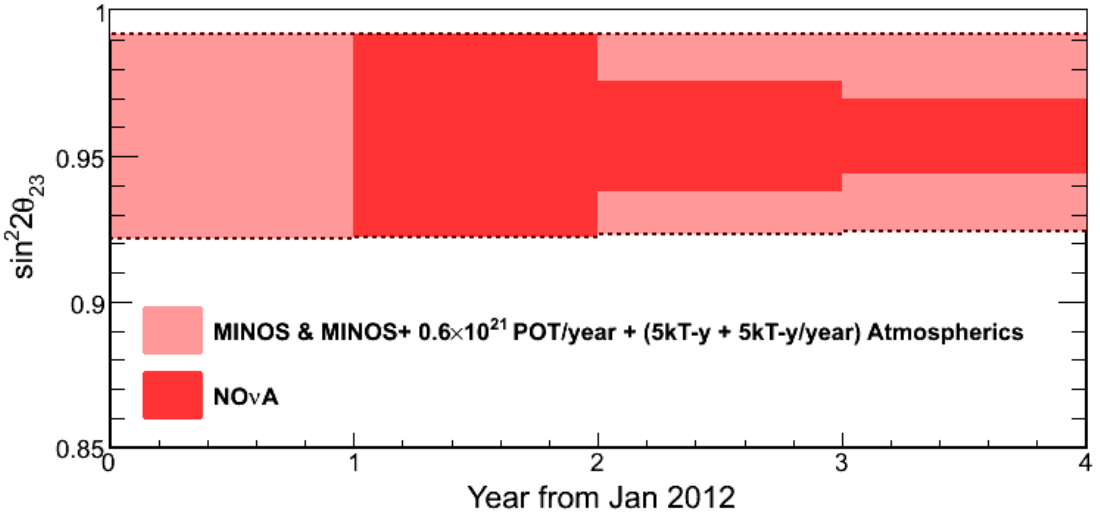
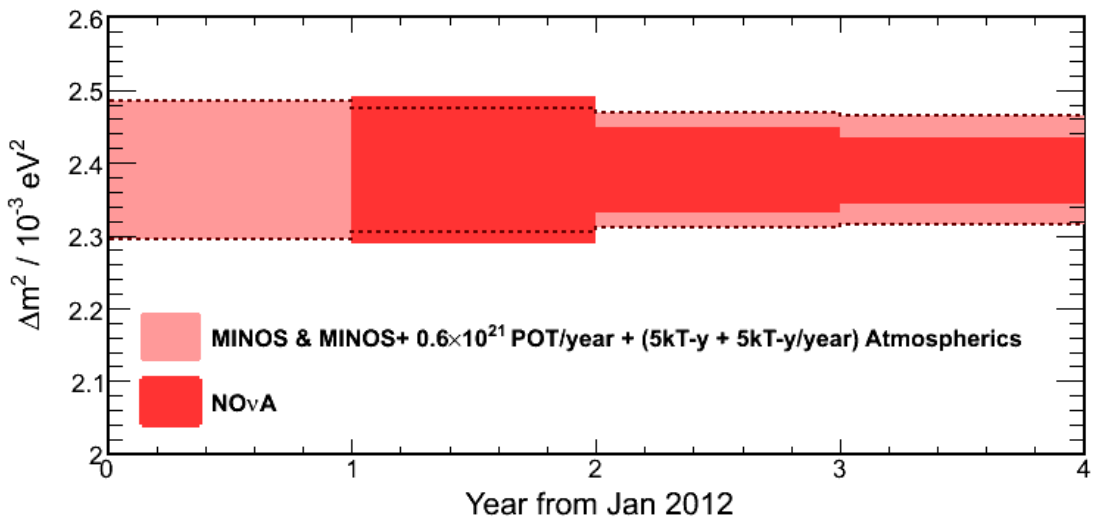




θ_{23} and Δm^2

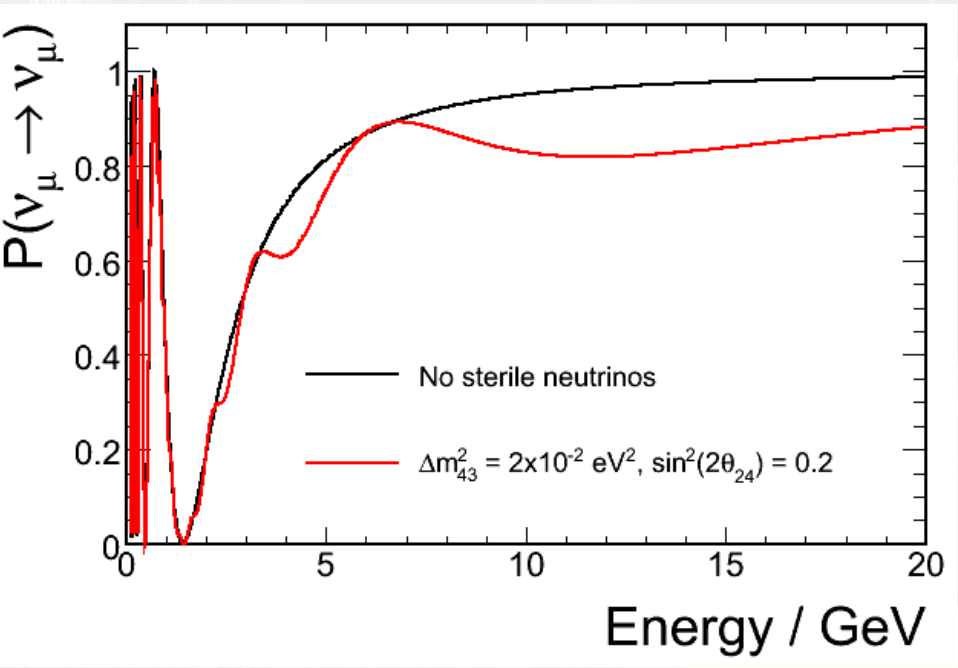


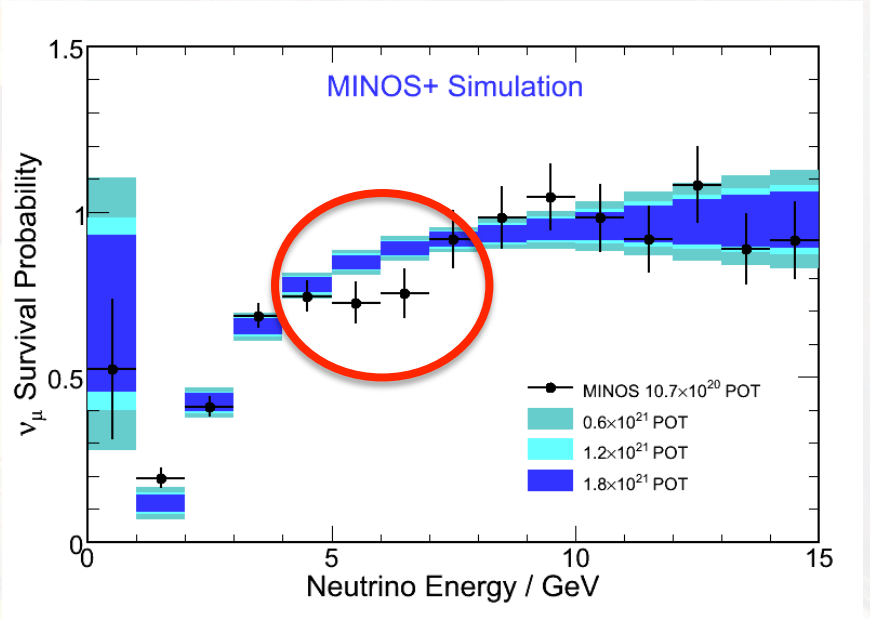


- Very precise measure of Δm^2_{23} can be achieved
- Combined with Nova and T2K, ~1% measurement of this parameter
- 1% measurements of Δm^2_{32} and Δm^2_{31} can give mass hierarchy (http://arxiv.org/pdf/1206.6017v1.pdf)
- Some contribution to knowledge of $\sin^2 2\theta_{23}$

MINOS+

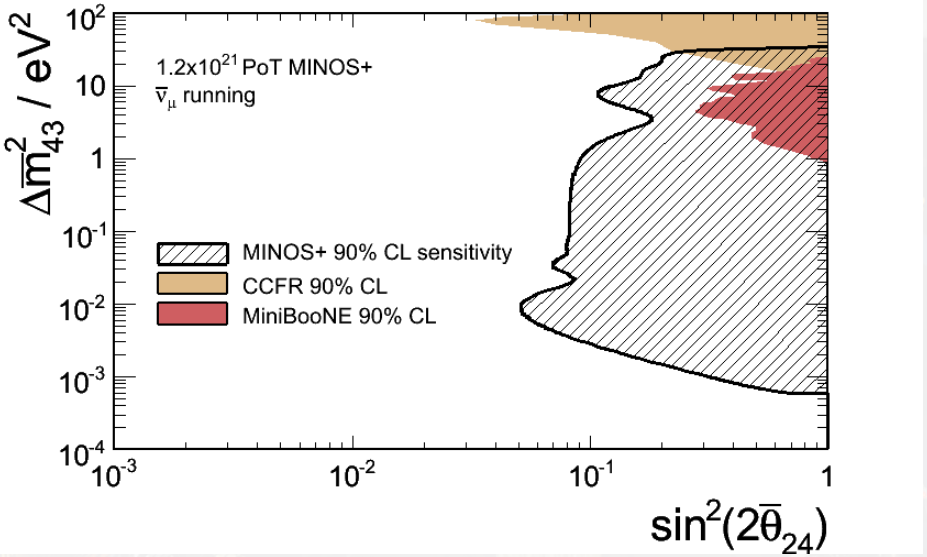
- Powerful search for sterile neutrinos
- Odd dip will have to wait for MINOS+ for more study
- Oscillation spectrum pretty insensitive to primary oscillation parameters in this region

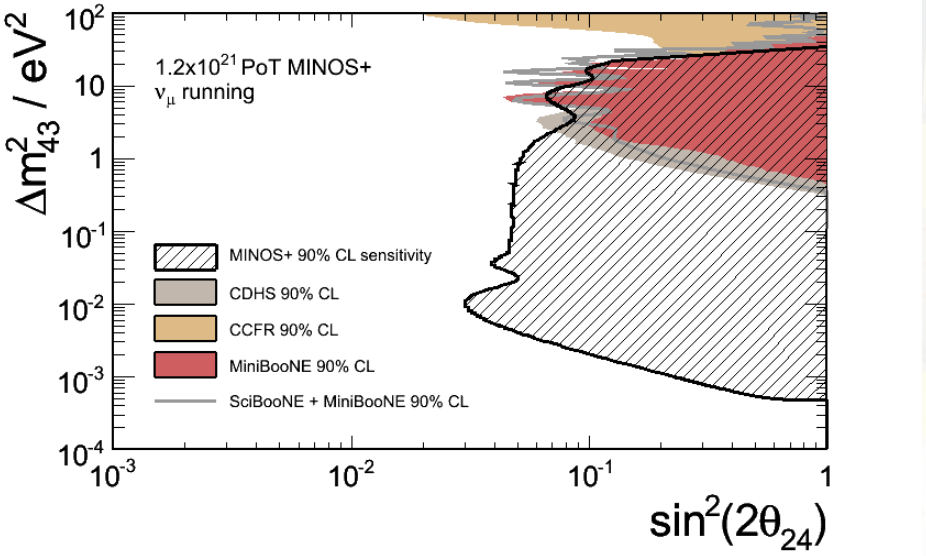


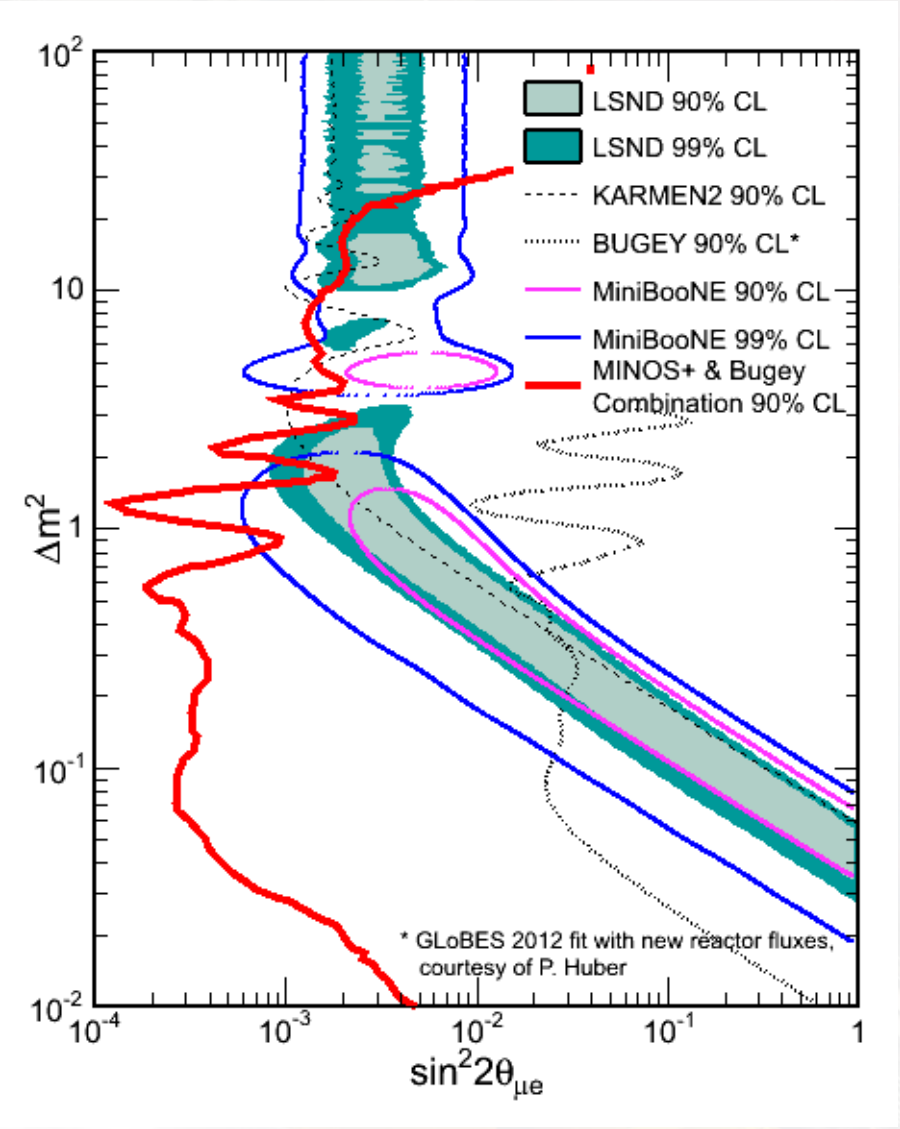


MINOS+ sterile reach

$|U_{e4}|^2 = \sin^2\theta_{14}$
$|U_{\mu 4}|^2 = \cos^2\theta_{24} * \sin^2\theta_{24}$
$\sin^2(2\theta_{\mu e}) = 4|U_{e4}|^2 * |U_{\mu 4}|^2$

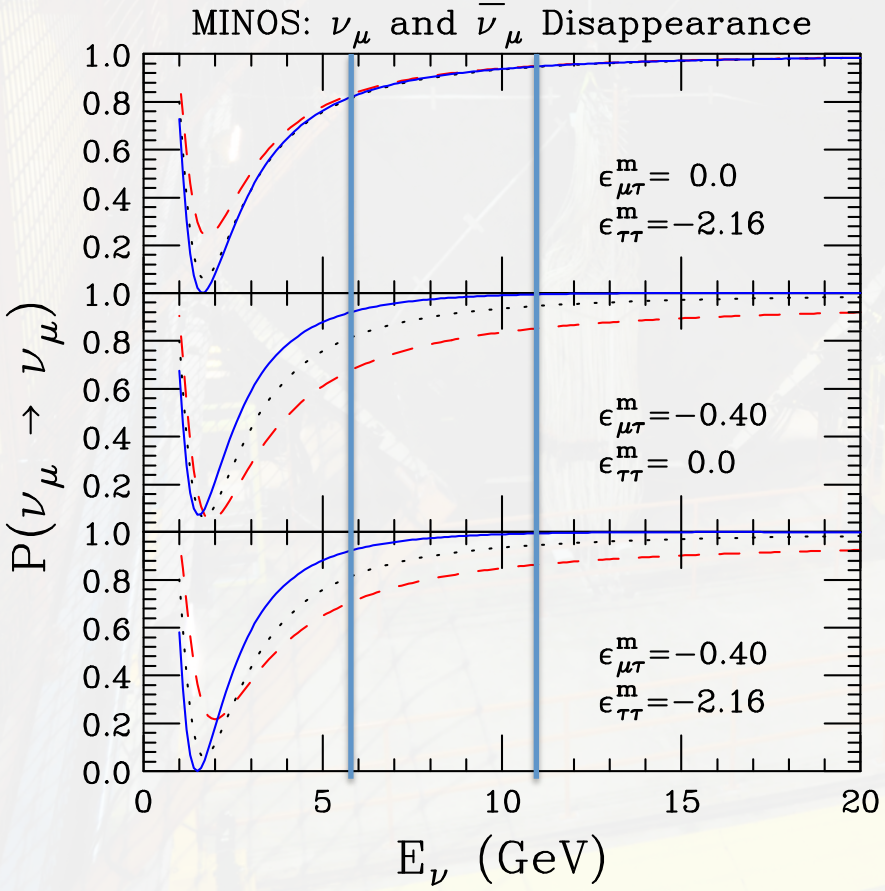




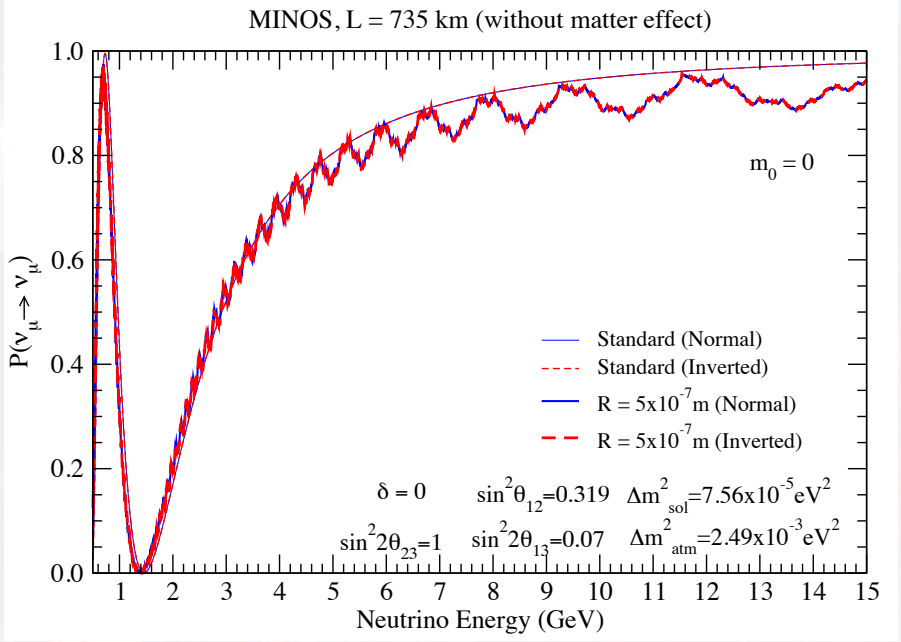


NSI & Extra Dimensions

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



J. Kopp, P.A.N. Machado and S.Parke, Phys.Rev.D82:113002 (2010).

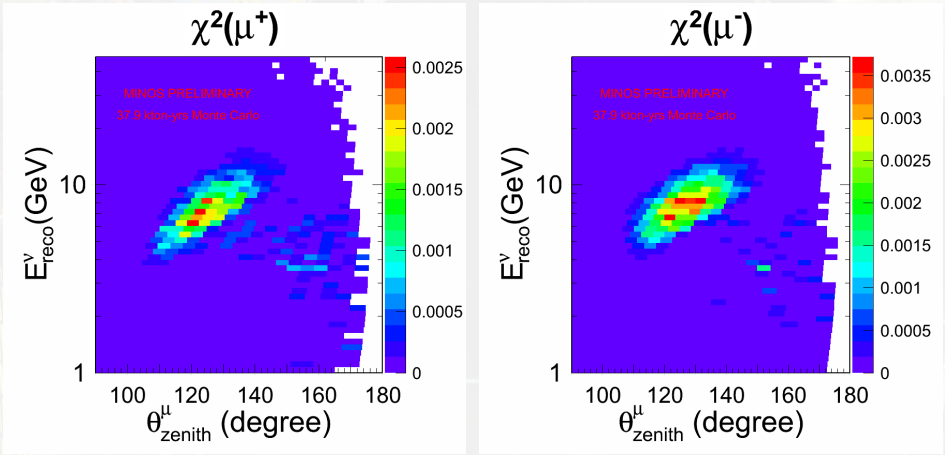


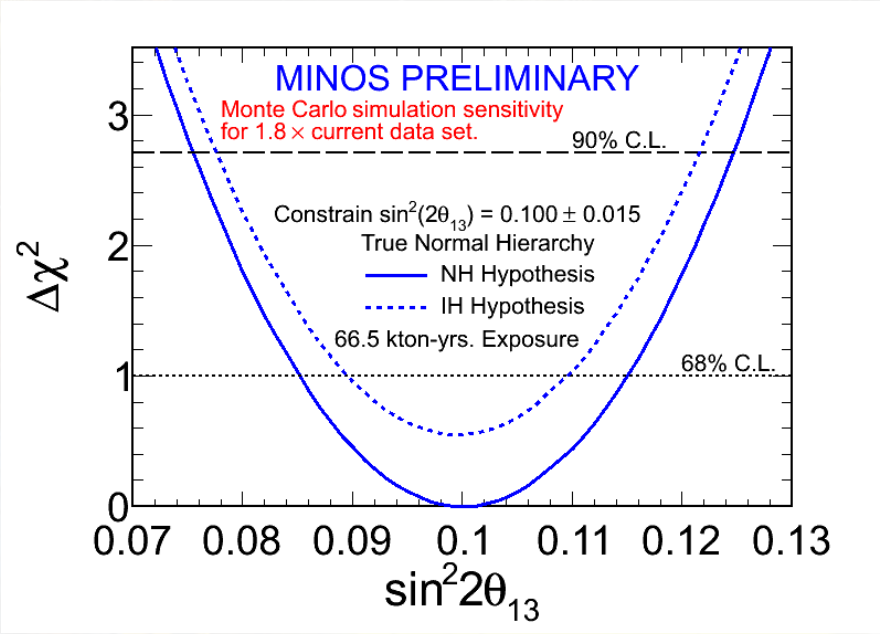
The same ratio could show half micron sized extra dimensions

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 ne events
- Alone not conclusive, but combined with SuperK, could give information on mass hiearchy

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?