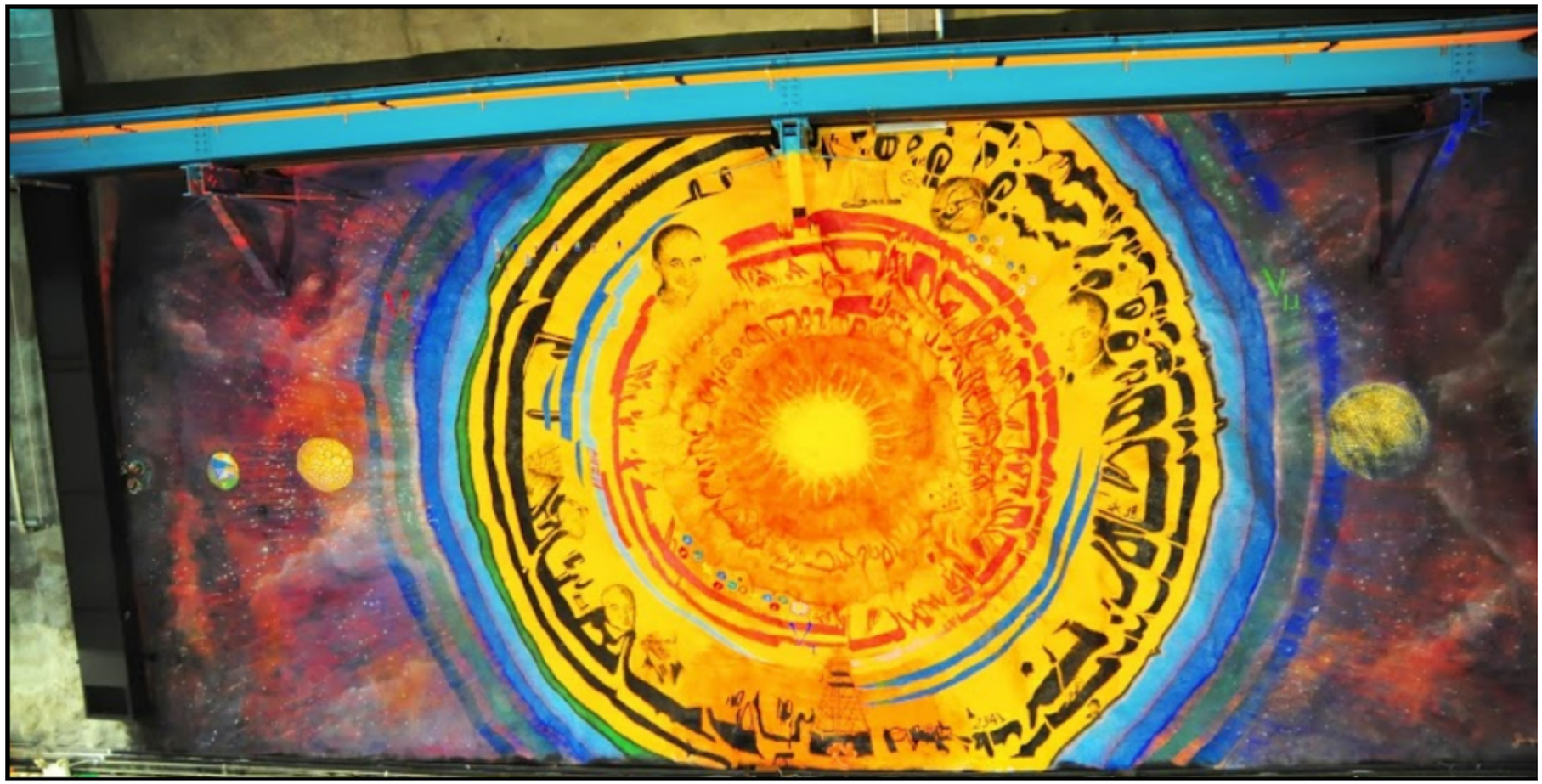
MANCHESTER 1824
The University of Manchester

Fermilab

Searching for Sterile Neutrinos with MINOS

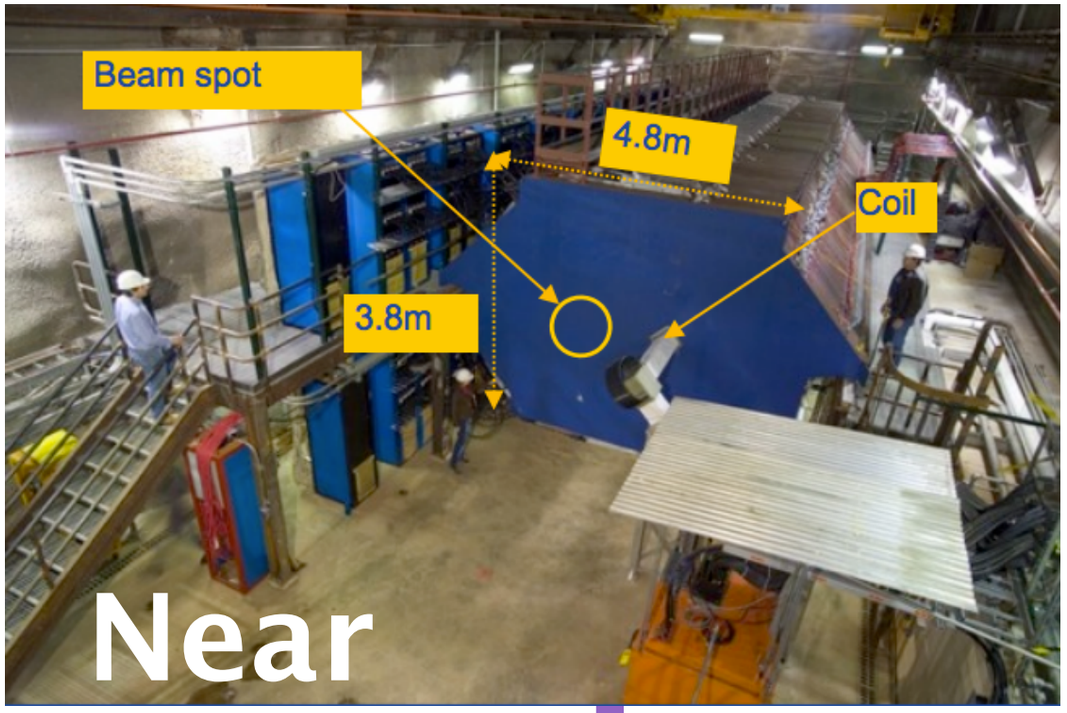


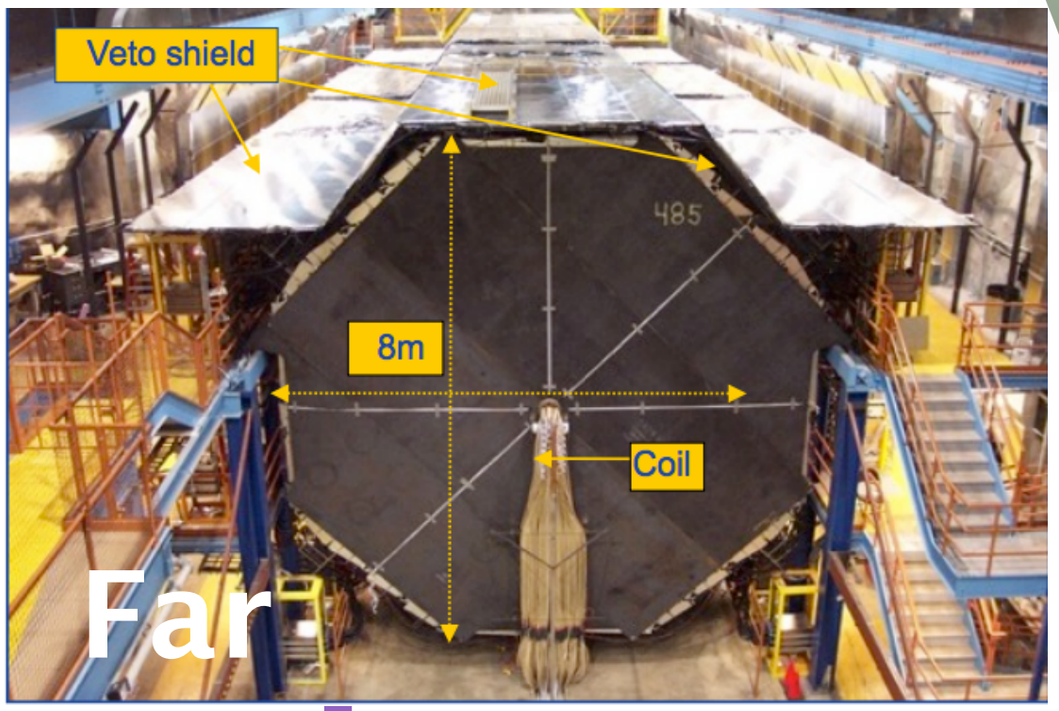
Ashley Timmons

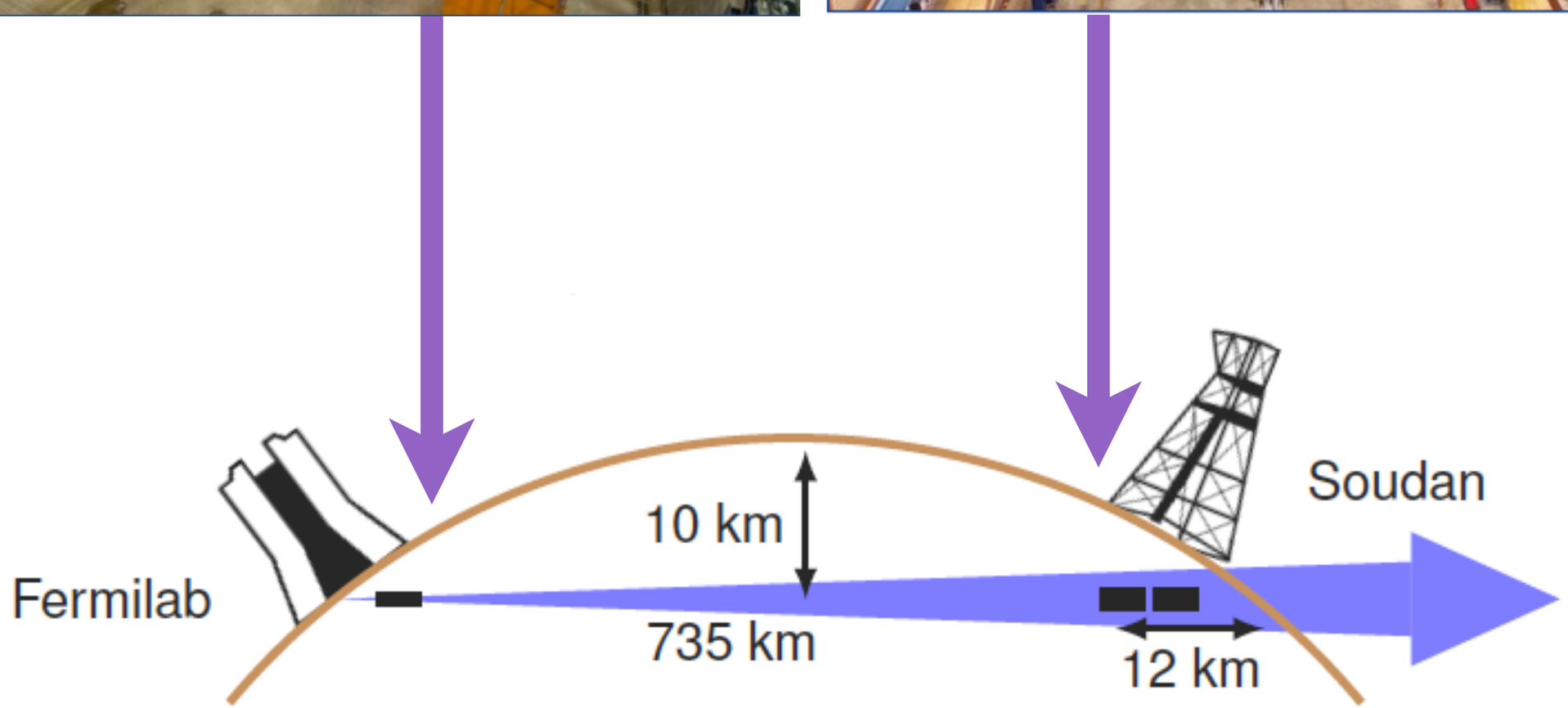
on behalf of the MINOS/MINOS+ collaboration

June 10th, 2014

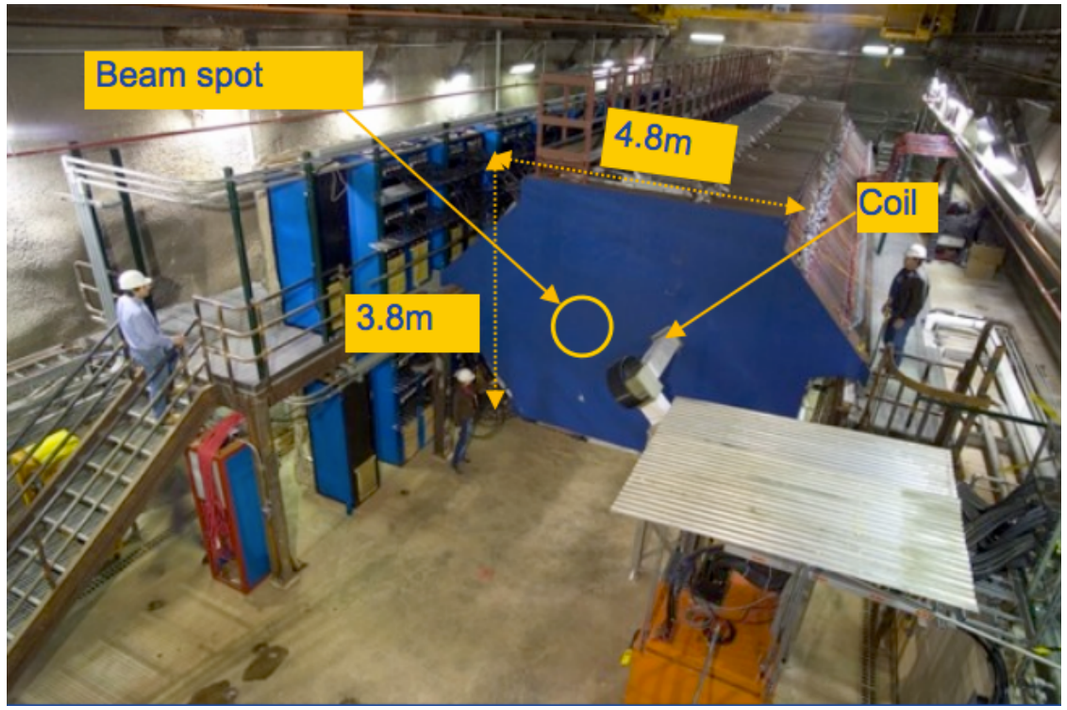
Experimental Setup

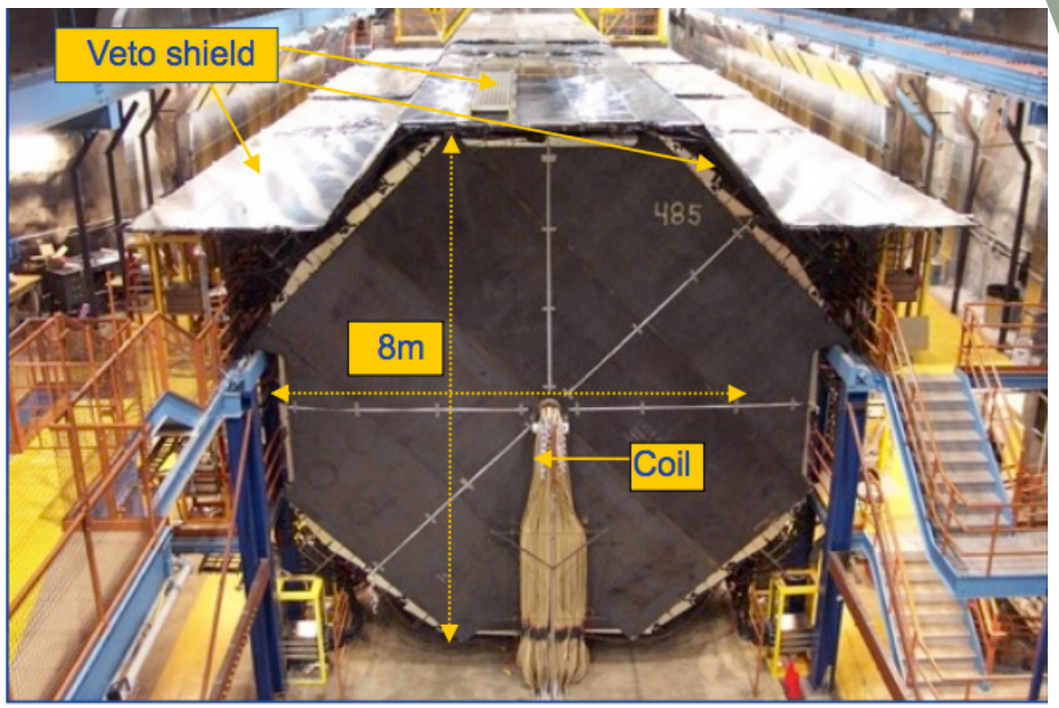






Detectors





Near

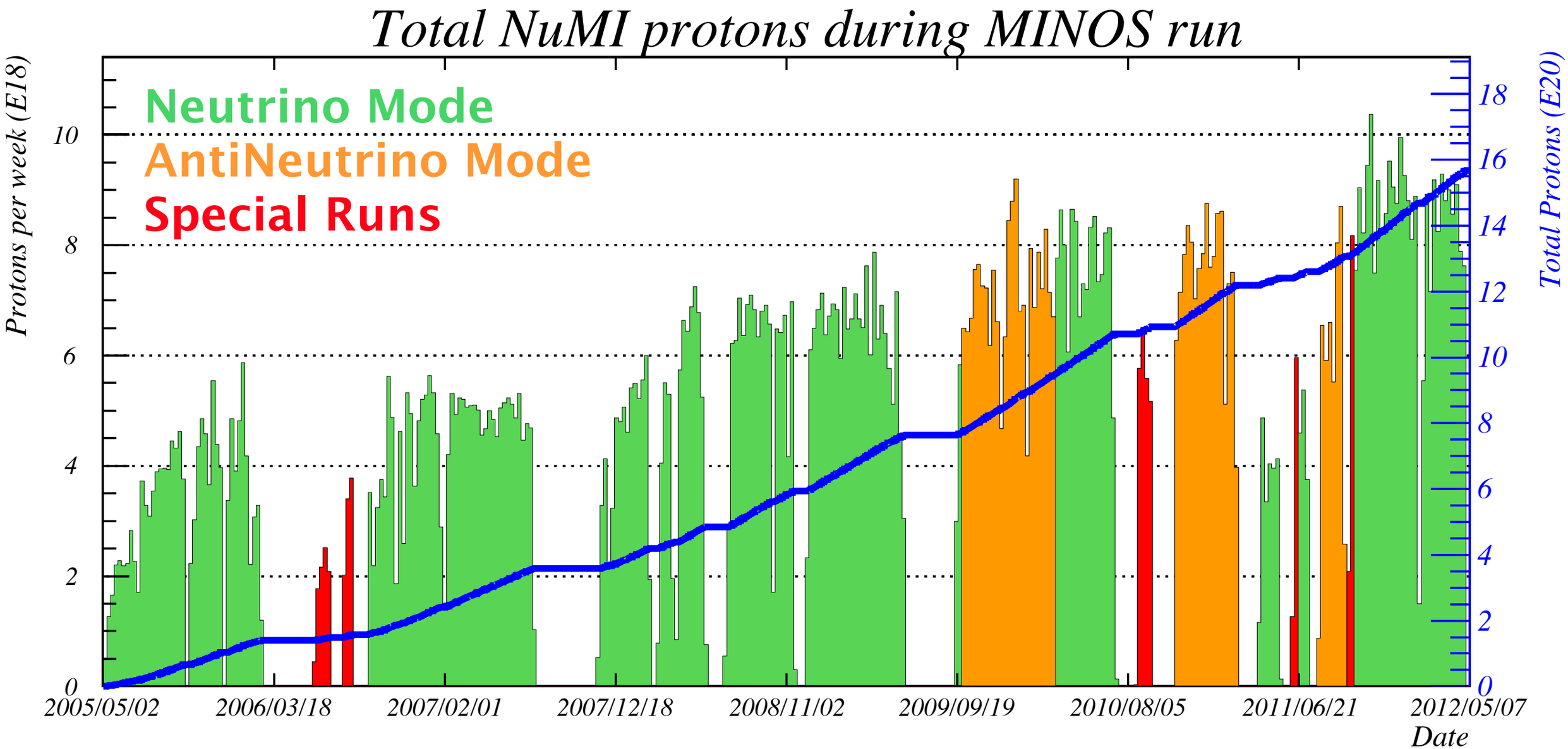
- 23.7 ton fiducial mass
- 1.04 km downstream from target

Far

- 4.2 kiloton fiducial mass
- Veto shield for cosmic suppression
- 705m underground

- Both detectors are **magnetised** tracking/sampling calorimeters, segmented into planes composed of 2.54 cm-thick steel planes and 1 cm-thick scintillator strips
- Detectors designed to be functionality equivalent, cancels systematics uncertainties in flux modelling and cross section to first order.

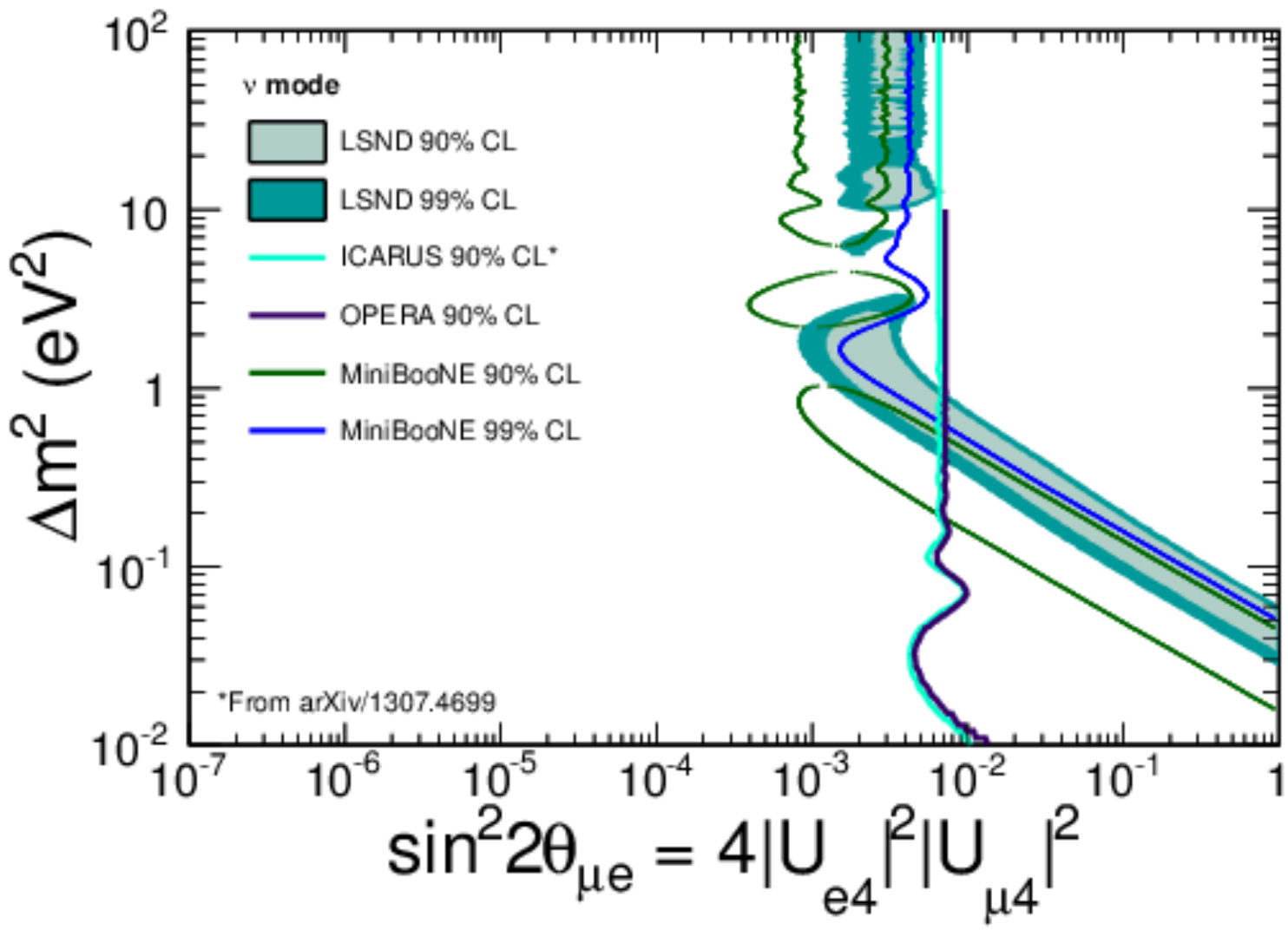
MINOS Data Set



- NuMI beam:
  - 10.56×10^{20} POT in neutrino mode used in this analysis
  - 3.36×10^{20} POT in antineutrino mode

Sterile Neutrinos

- Oscillations into light sterile neutrinos may explain anomalies in SBL, reactor and radiochemical experiments
- Evidence for sterile neutrinos remains inconclusive – tension between measurements between appearance and disappearance experiments

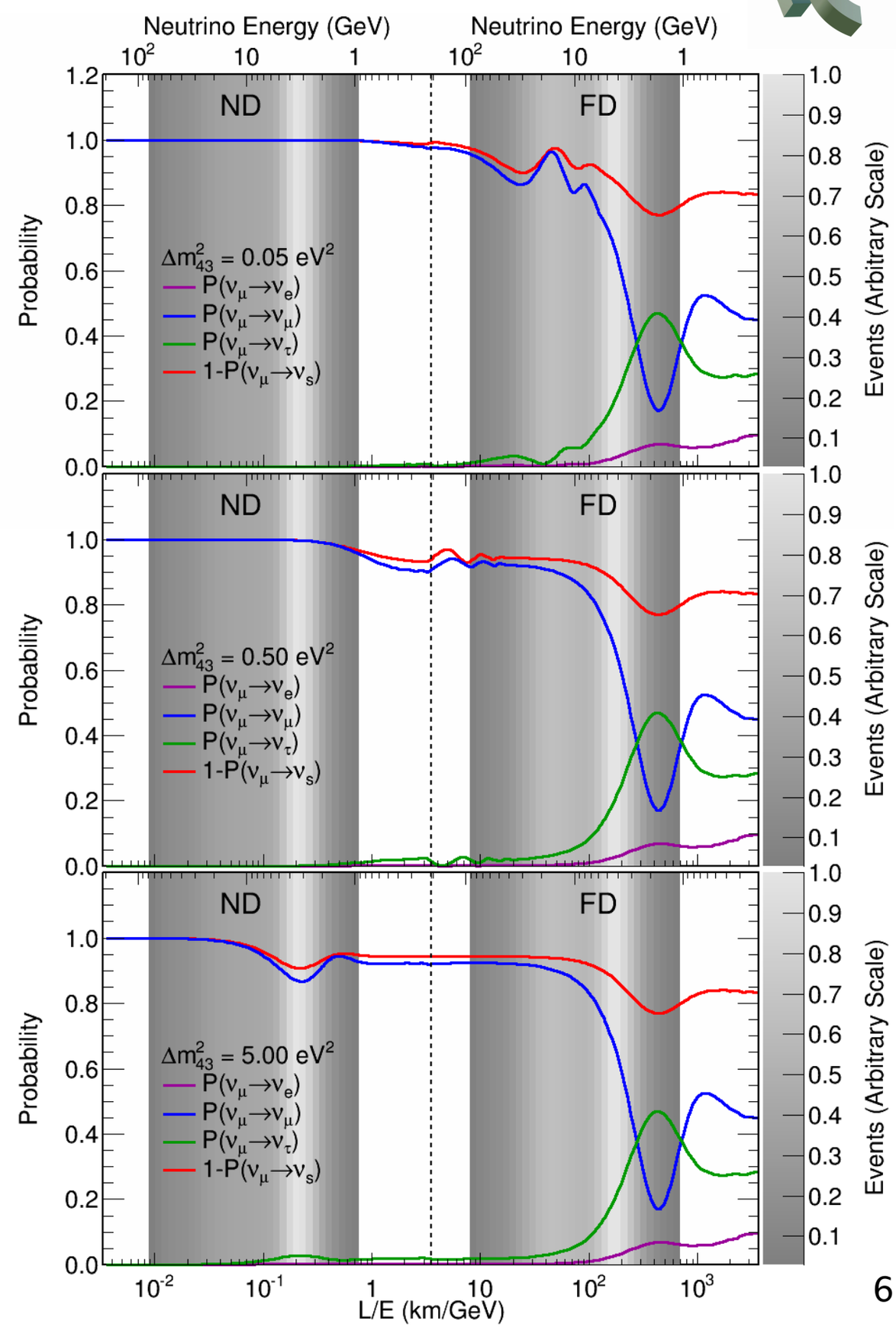


Sterile Neutrinos

- Small Δm^2_{43} (> Δm^2_{32}):
  - FD spectral distortions at energies above 3-flavour oscillation maximum
  - No ND effects

- Medium Δm^2_{43}:
  - Rapid oscillations at FD average out
  - No ND effects
  - Counting experiment

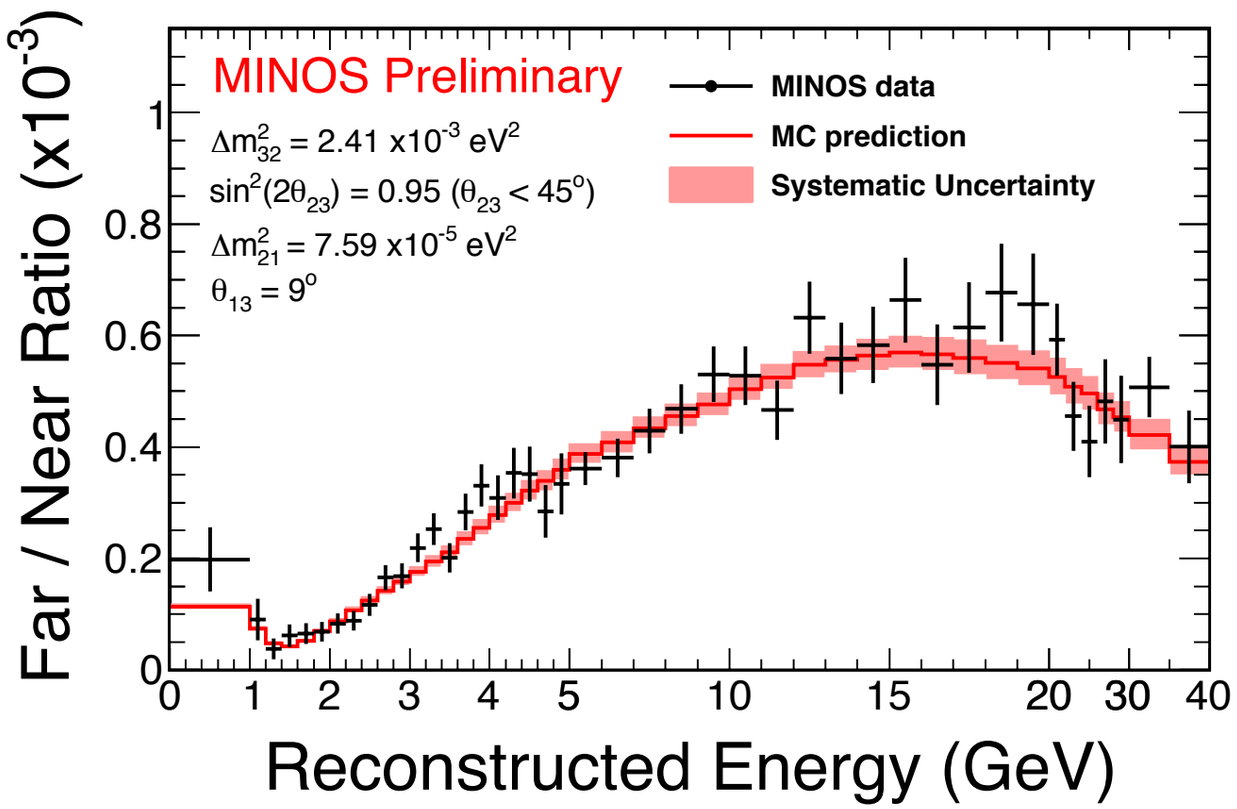
- Large Δm^2_{43}:
  - Rapid oscillations at FD average out
  - ND spectral distortions affect extrapolation to FD

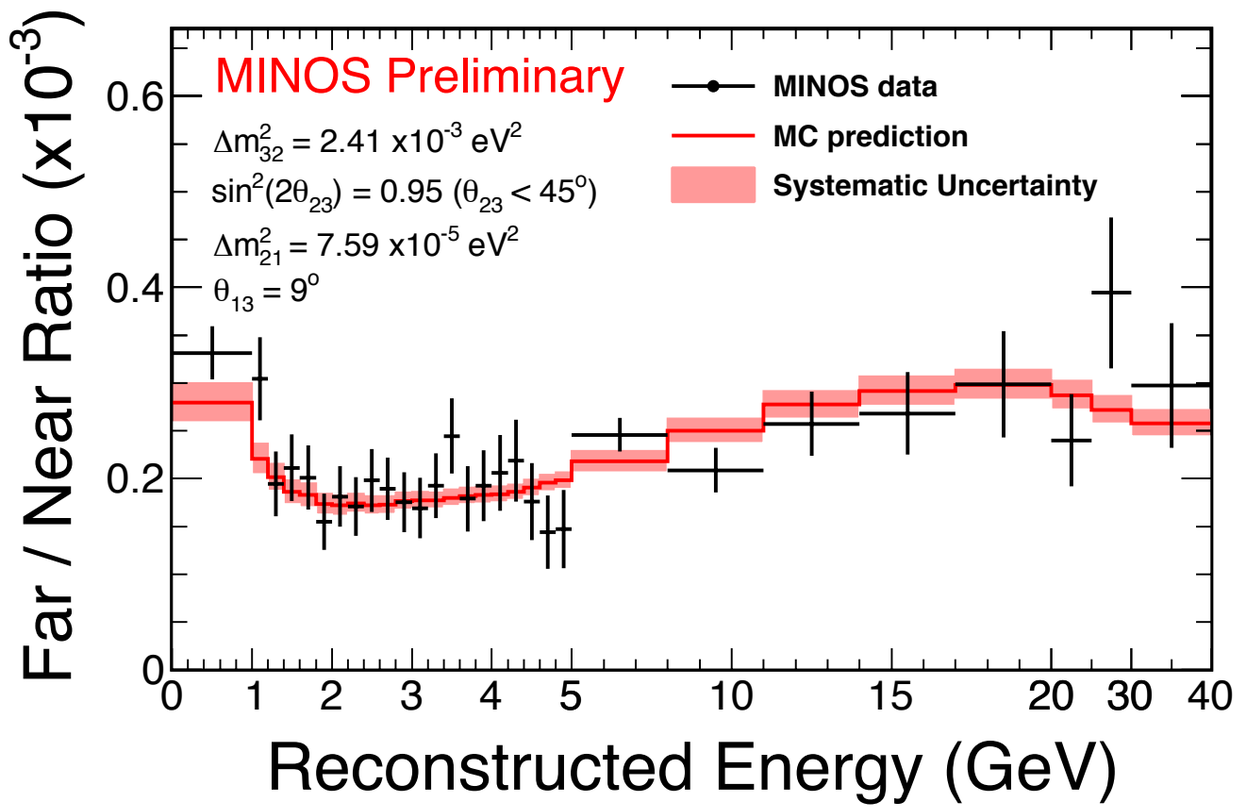


What MINOS Measures

Disappearance – neutrinos from NuMI beam

- Assume 3+1 mode. Look at CC and NC energy distortions compared to three flavour formalism
- Account for ND oscillations by fitting the F/N ratio, including a constraint on the ND rate





Systematics

- Reassessed systematics affecting the high energy tail
- Included as a covariance matrix in a χ^2 fit.

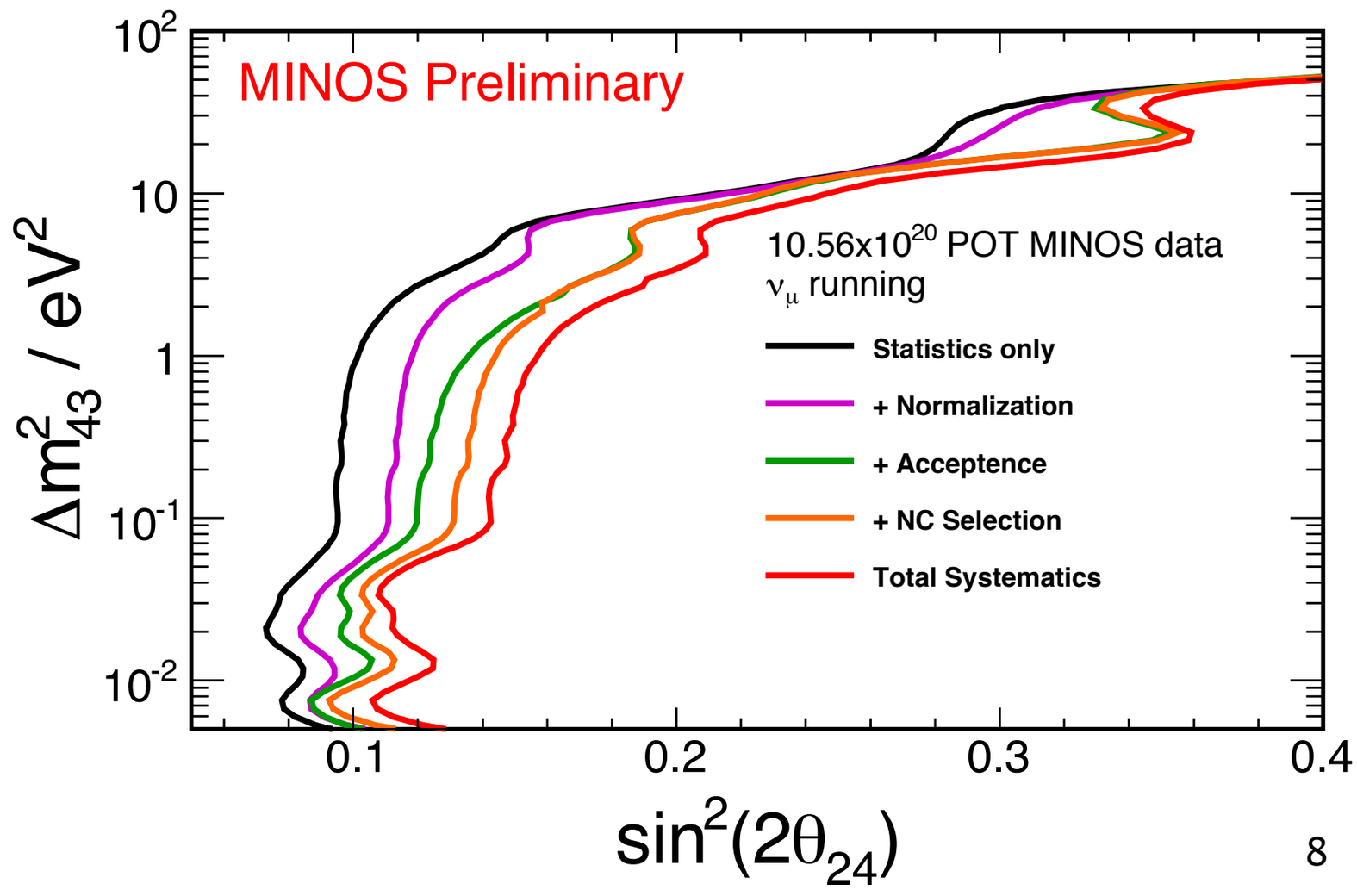
$$\chi^2 = \sum_{i=1}^{N}\sum_{j=1}^{N}(o_i - e_i)^T[V^{-1}]_{ij}(o_j - e_j)$$

o_i : Observed events in bin i

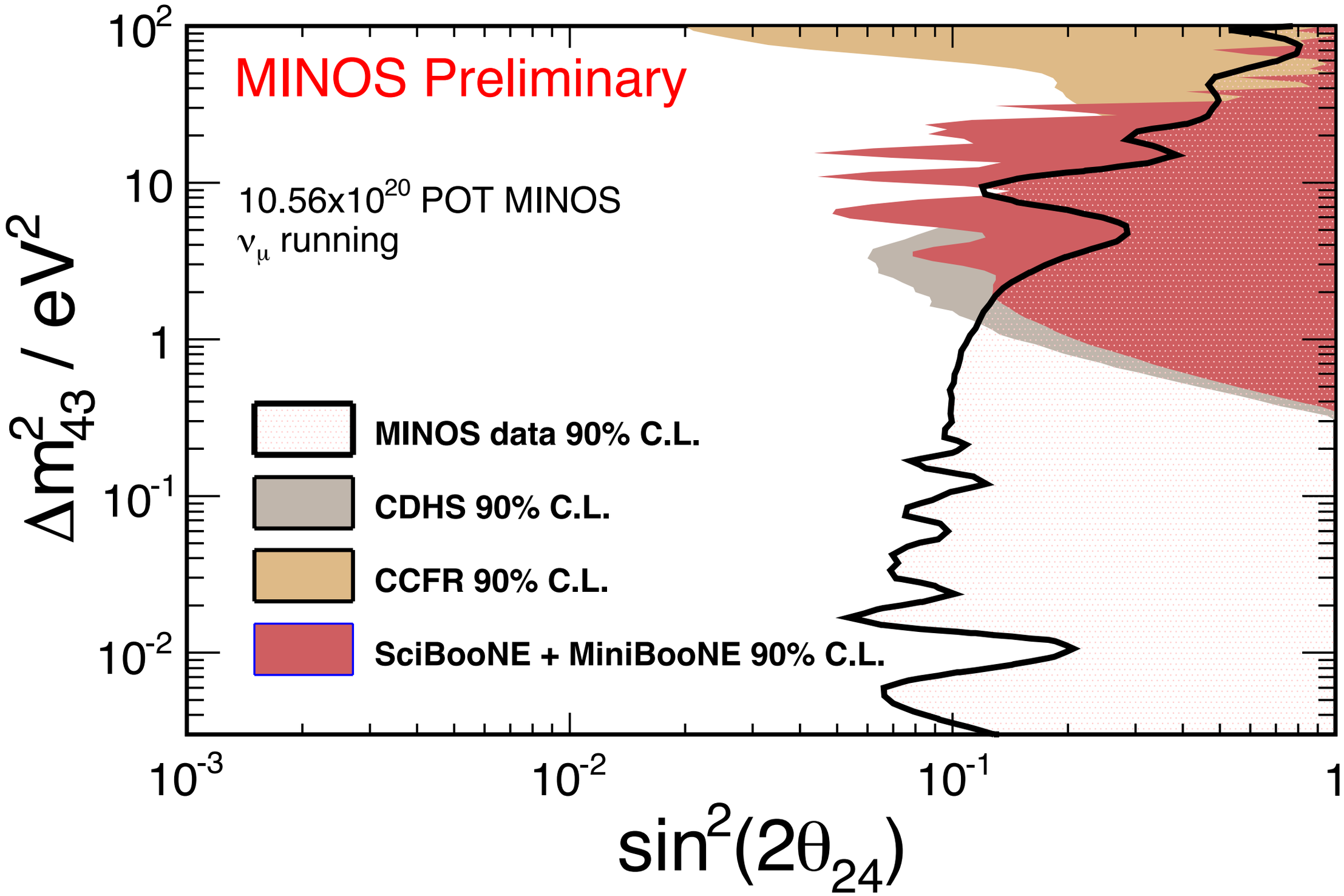
e_i : Predicted events in bin i

V : Covariance matrix

- 26 systematics included in matrix
  - Normalisation
  - Acceptance
  - NC selection
  - Hadron production, beam optics, cross sections, energy scales and background



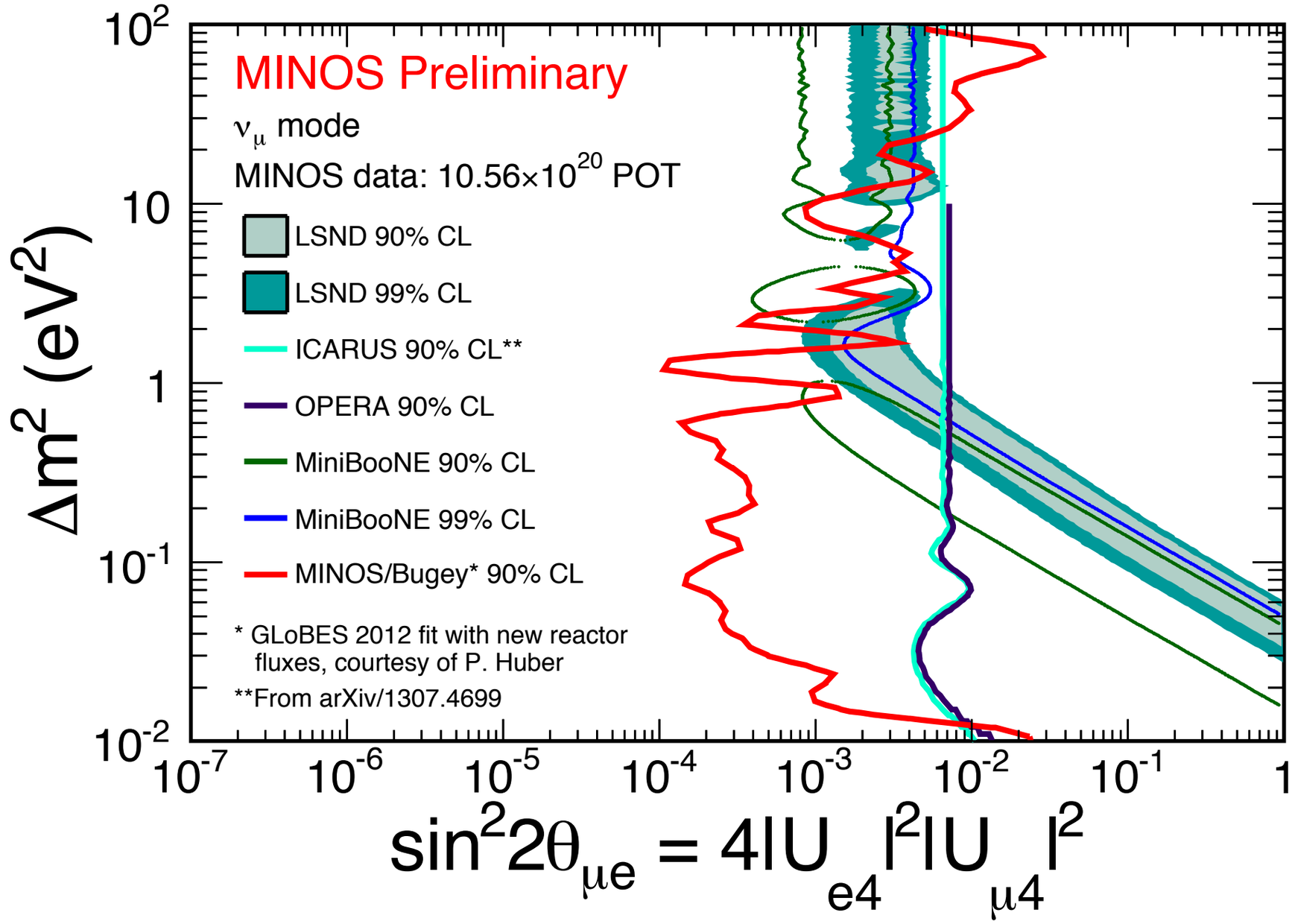
Results



- MINOS limit covers over 4 orders of magnitude in Δm^2_{43}.

- FC Corrected

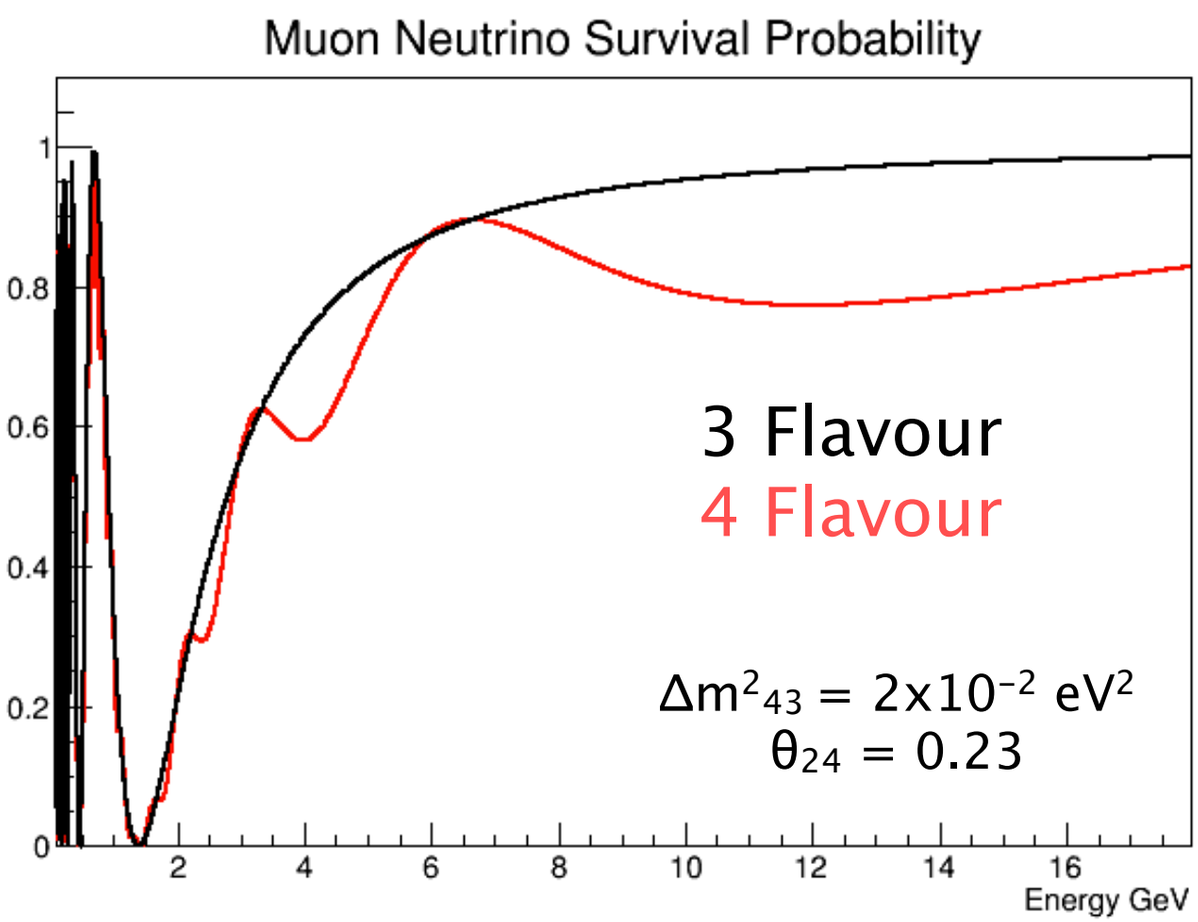
Results

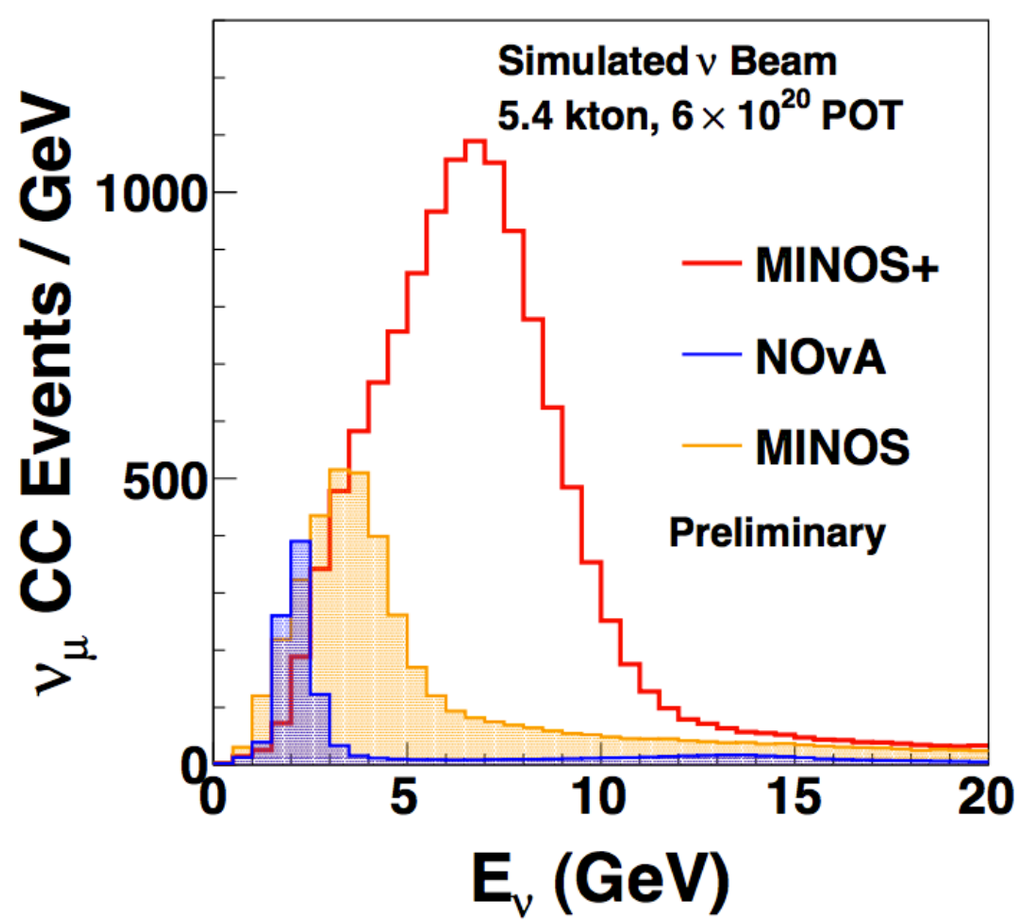


- Assuming 3+1 model, combine MINOS disappearance 90% C.L. limit in θ_{24} to Bugey reactor experiment 90% C.L. disappearance limit in θ_{14}

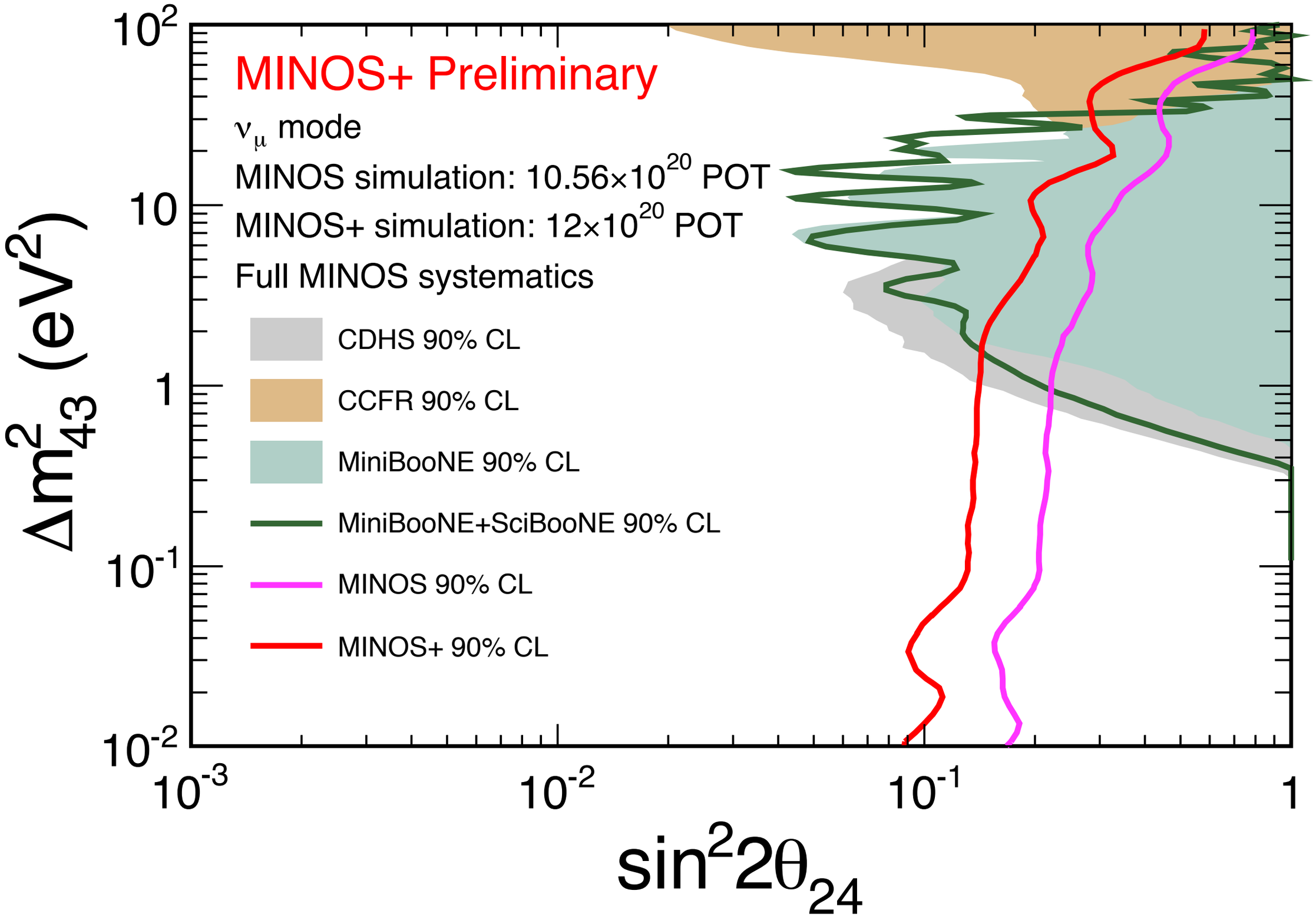
MINOS+

- MINOS+ is the continuation of MINOS with the NuMI beam in the medium energy configuration.
- Search for beyond the standard model in high energy tail using both CC and NC events i.e. sterile neutrino oscillations, large extra dimensions.
- More statistics ~4000 events per year at the far detector





MINOS+

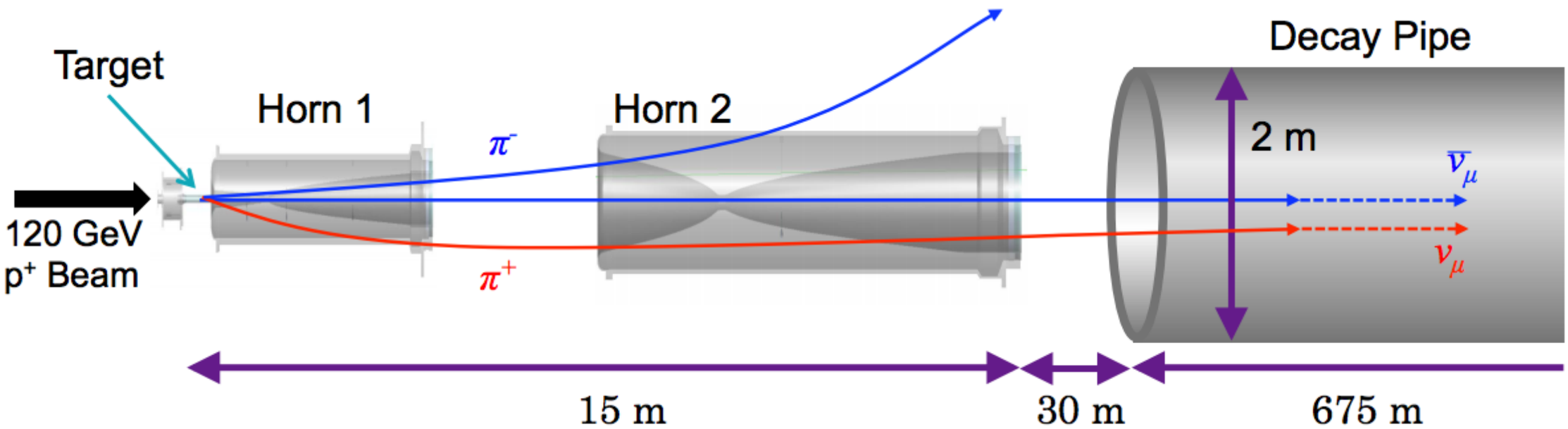

MINOS+ Preliminary
ν_μ mode
MINOS simulation: 10.56×10^{20} POT
MINOS+ simulation: 12×10^{20} POT
Full MINOS systematics
CDHS 90% CL
CCFR 90% CL
MiniBooNE 90% CL
MiniBooNE+SciBooNE 90% CL
MINOS 90% CL
MINOS+ 90% CL
Δm^2_{43} (eV^2)
$\sin^2 2\theta_{24}$
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
1

Summary

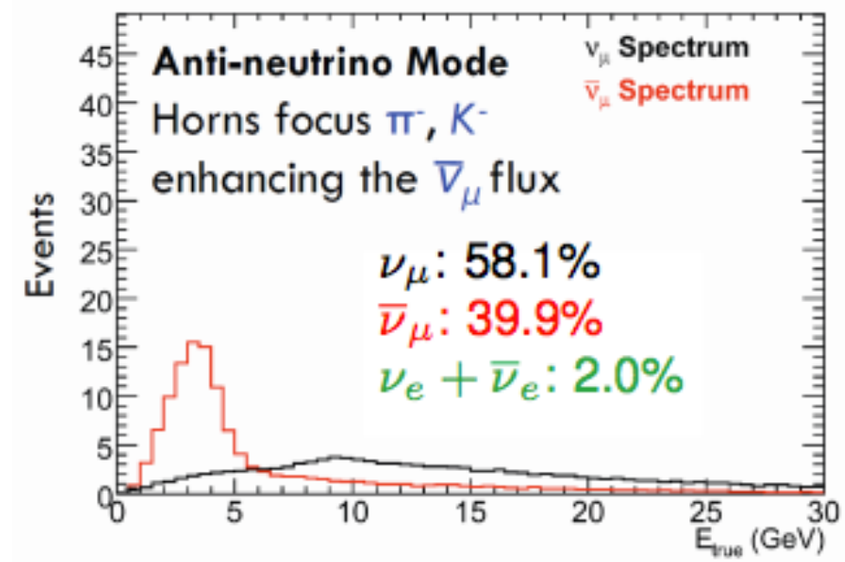
- Fitting the F/N ratio instead of extrapolating to the FD
- Systematics include as covariance matrix in the fit
- A limit spanning several orders of magnitude for the mass splitting
- A look at how MINOS+ will help – statistics in the high energy tail

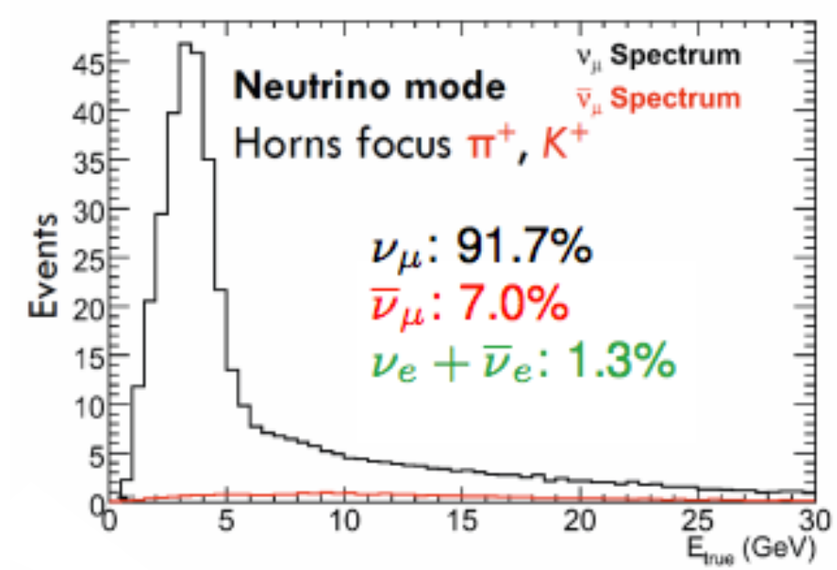
Back Up Slides

NuMI Beam

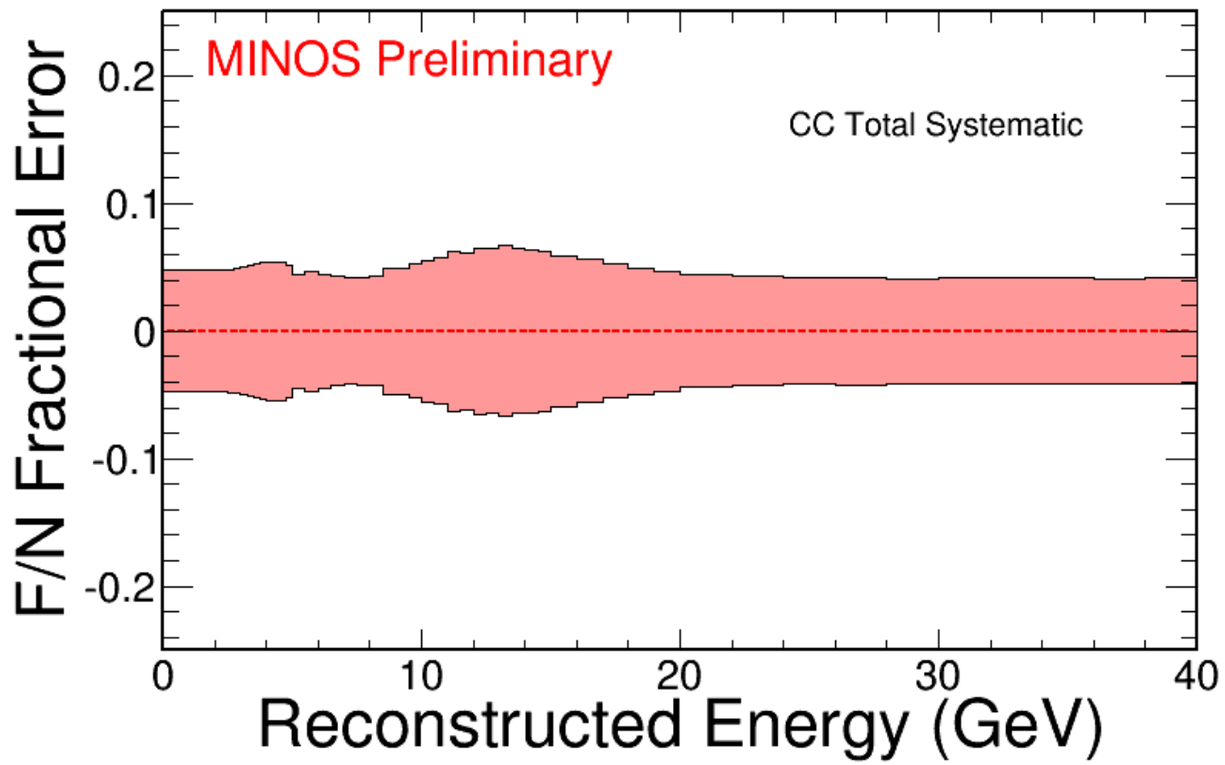


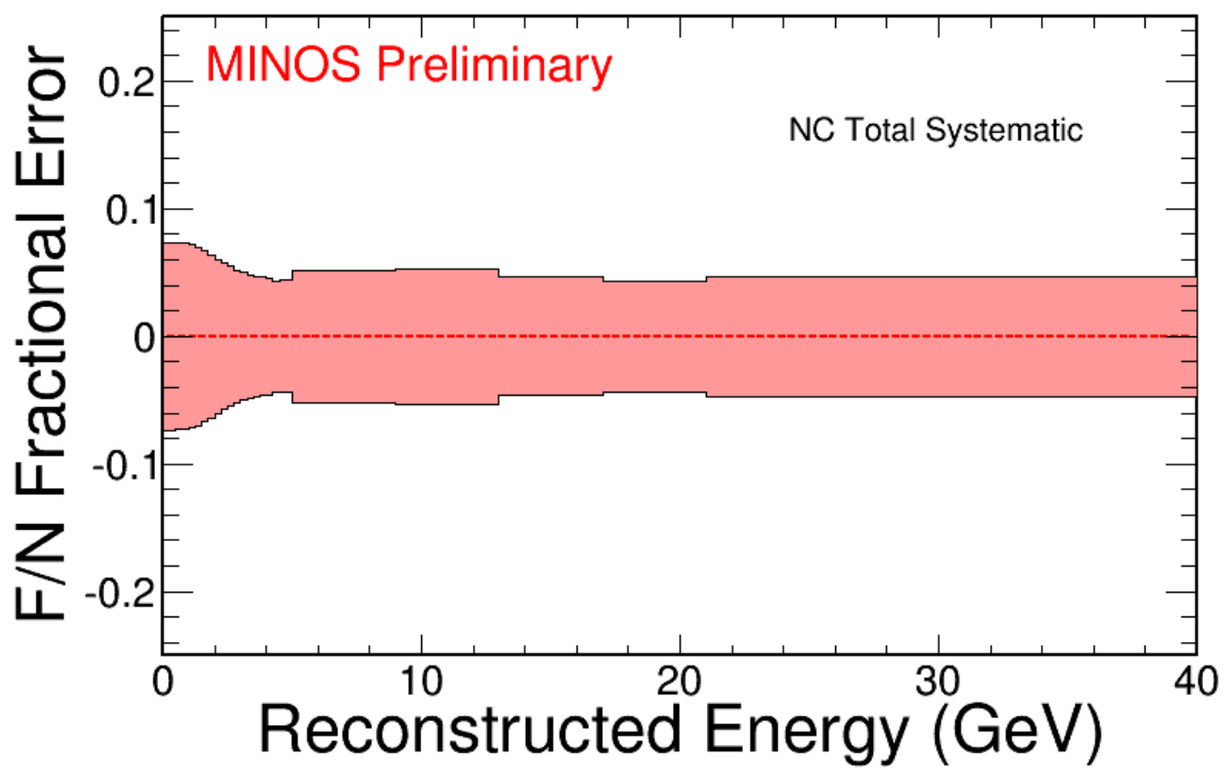
- Protons hit a graphite target producing pions/kaons
- Parent hadrons decay into neutrinos within a 675m decay before encountering a beam stop.
- Horns focus hadrons into a beam.
  - Results in neutrino beam mode.
  - Or antineutrino beam mode.



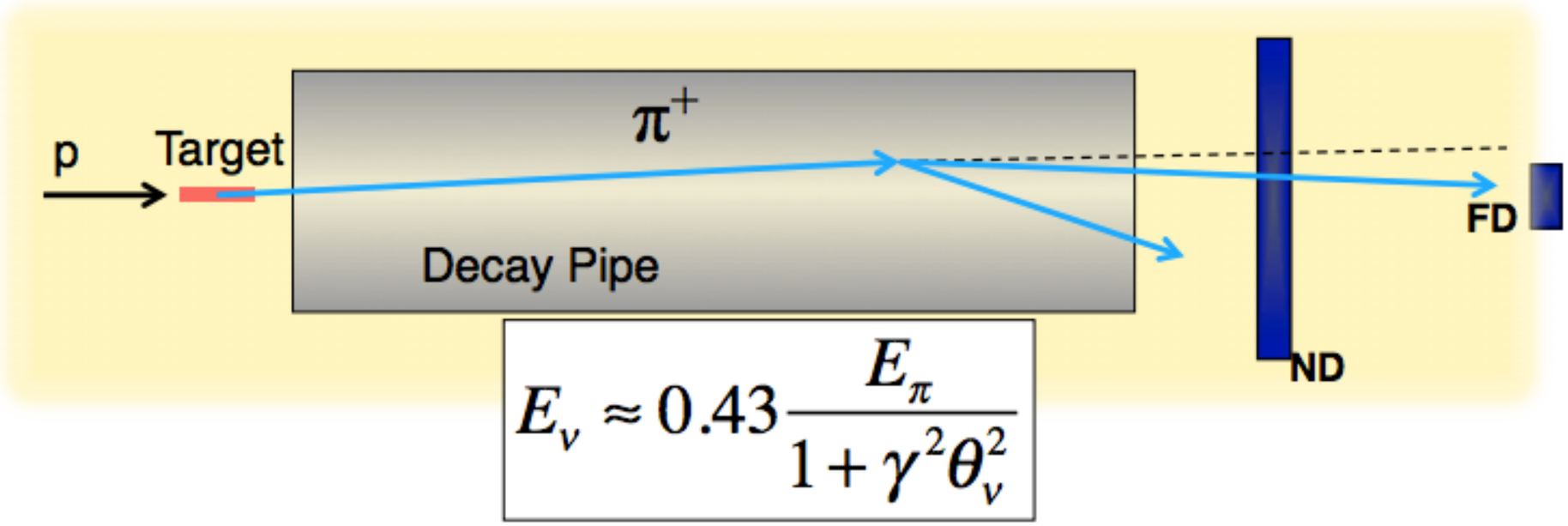


F/N fractional errors





Interflux differences at Near and Far



- Neutrino energy depends on angle w.r.t original pion direction and parent energy
- higher energy pions decay further along decay pipe
- angular distributions different between Near and Far