

Sterile Neutrinos in MINOS+

Joao Coelho
For the MINOS+ Collaboration

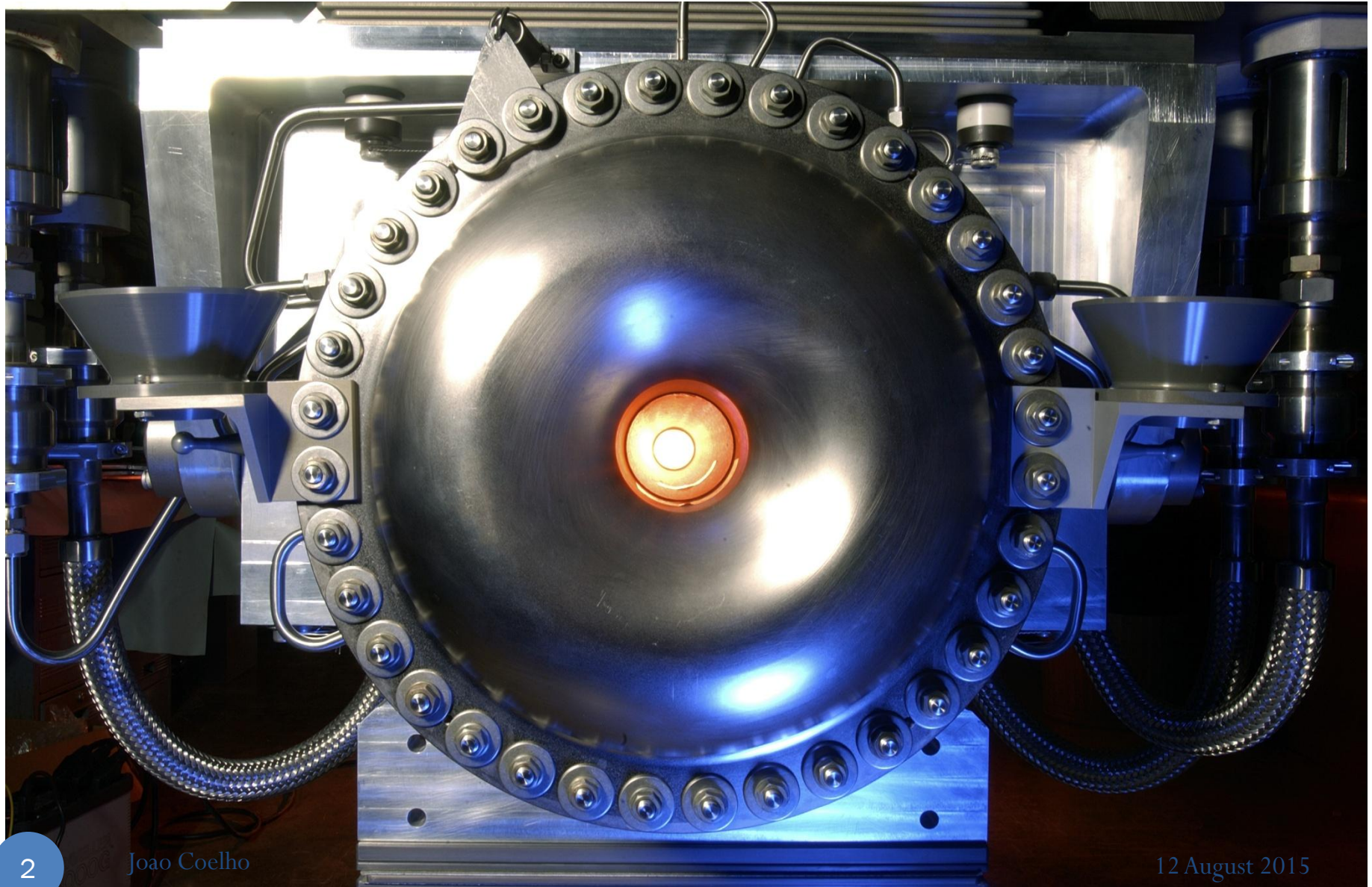


Tufts University



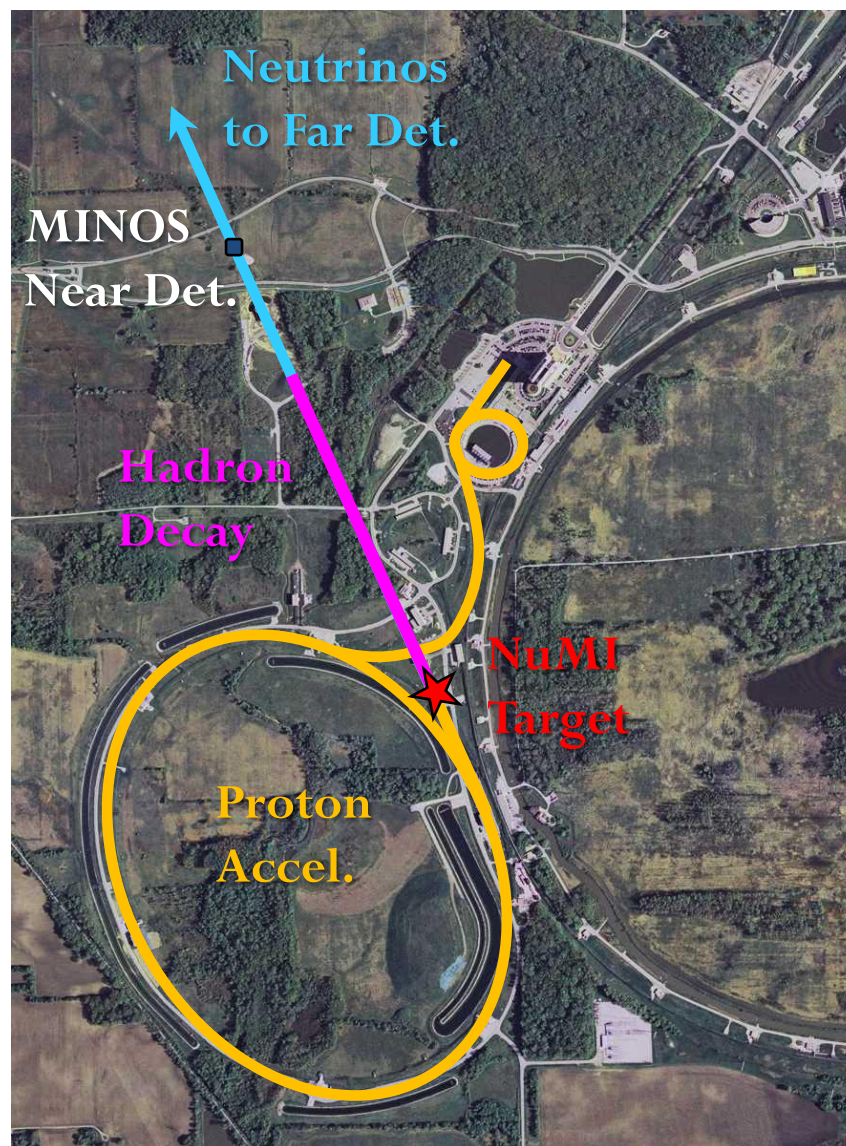
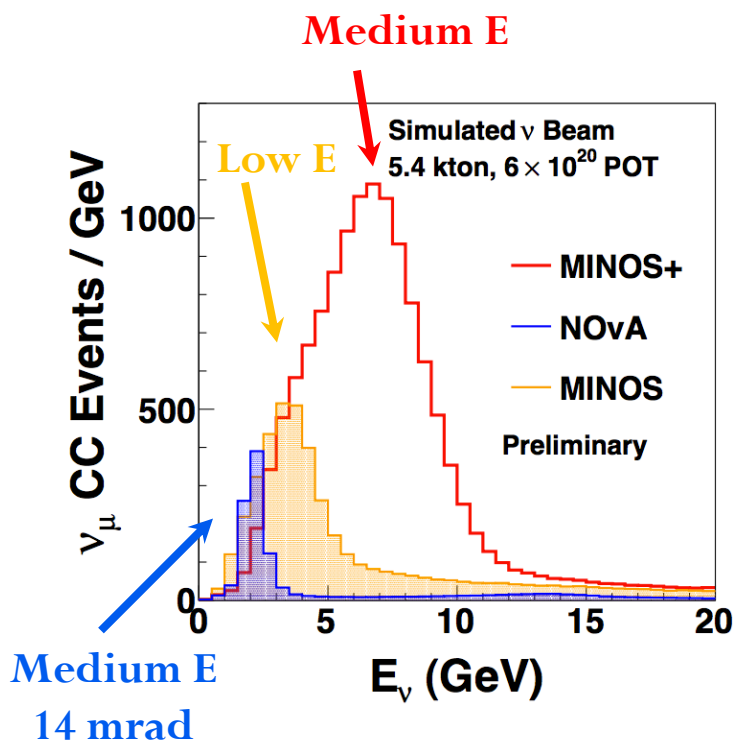
Tufts
UNIVERSITY

The NuMI Beam



NuMI Beam

- New Medium Energy beam
- Optimised for NOvA
- MINOS+ sees **large flux** at **3 - 10 GeV**

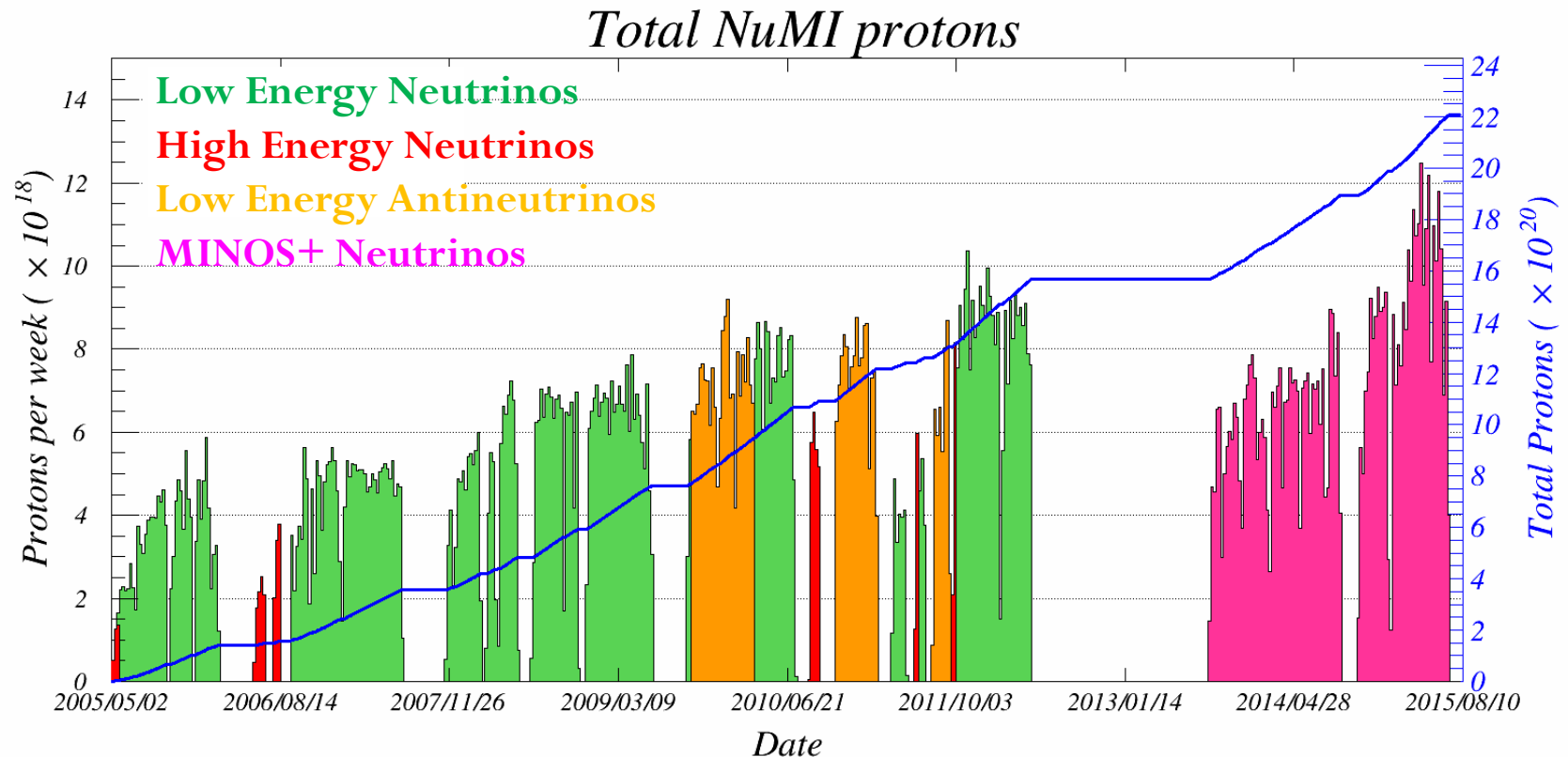


NuMI Beam



NuMI Beam

- Over 22×10^{20} Protons on Target (PoT) delivered to date
- $\sim 6.4 \times 10^{20}$ PoT with the new beam for MINOS+
- Running at 470 kW since March 2015. 700 kW by mid 2016.



MINOS+



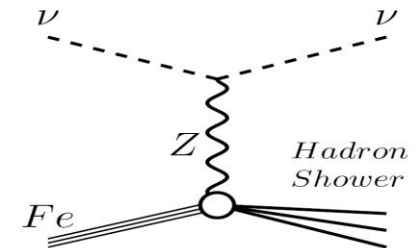
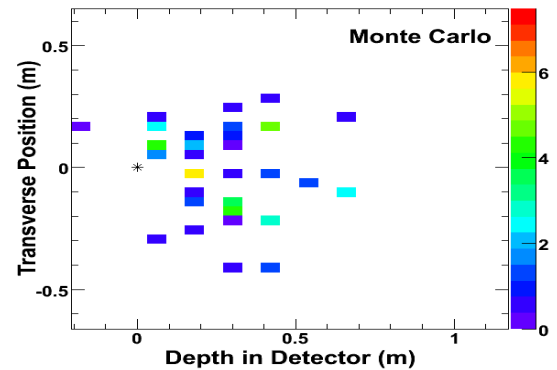
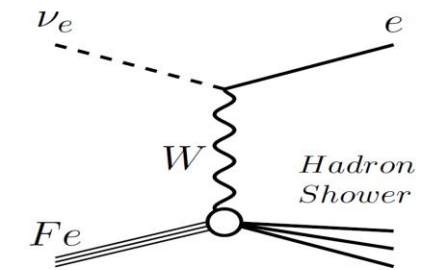
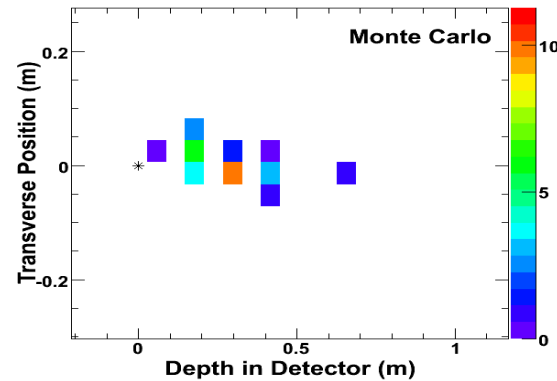
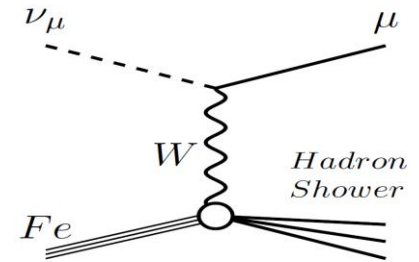
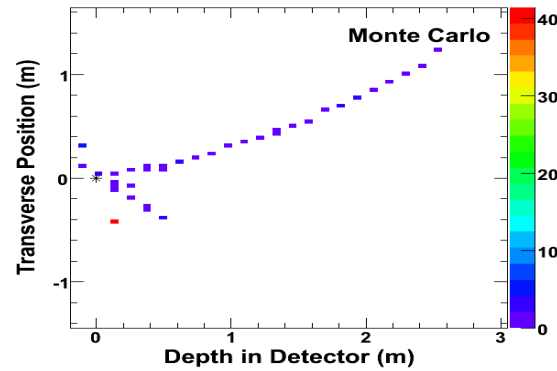
MINOS+



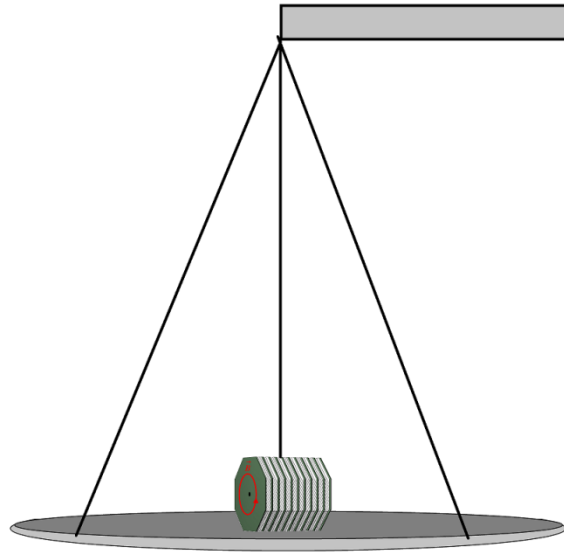
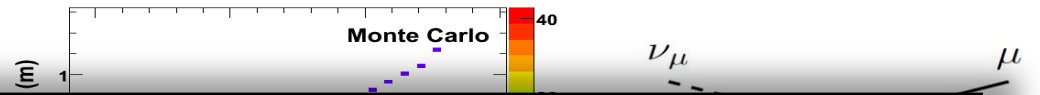
Magnetized steel-scintillator
tracking calorimeters

Far Detector: 5.4 kton

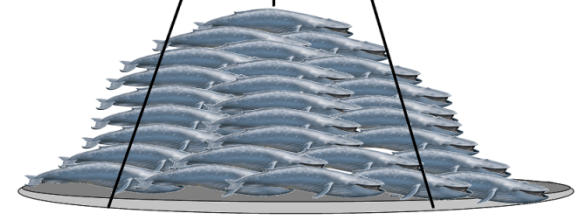
Near Detector: 0.98 kton



MINOS+



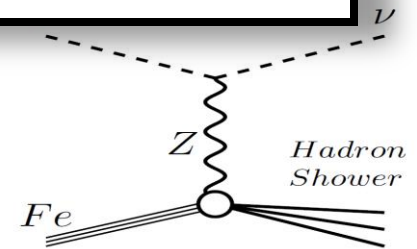
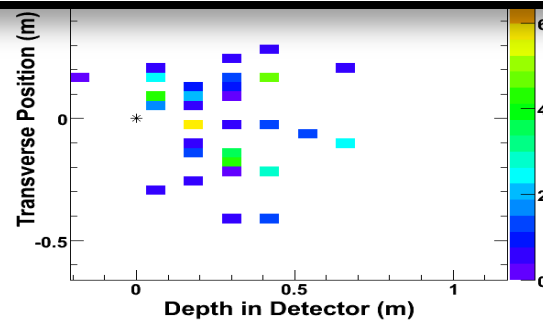
MINOS Far Detector



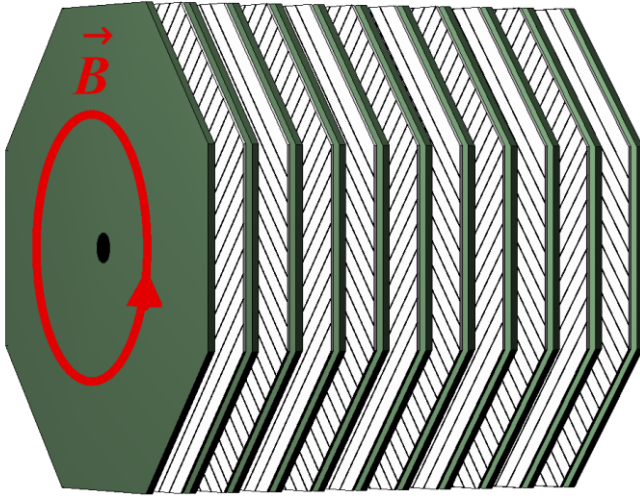
28 Blue Whales

Far Detector: 5.4 kton

Near Detector: 0.98 kton



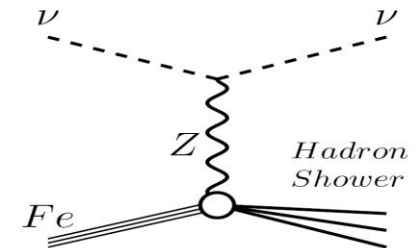
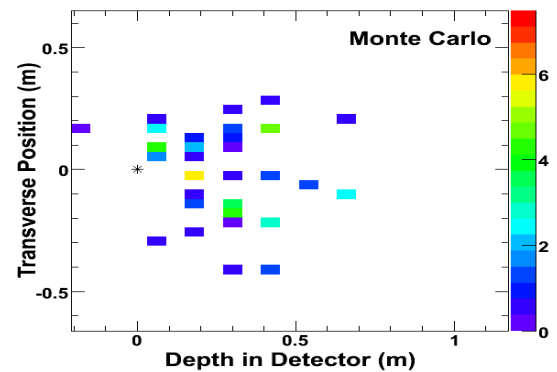
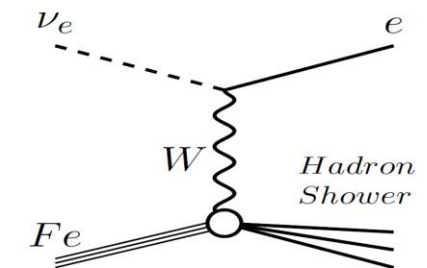
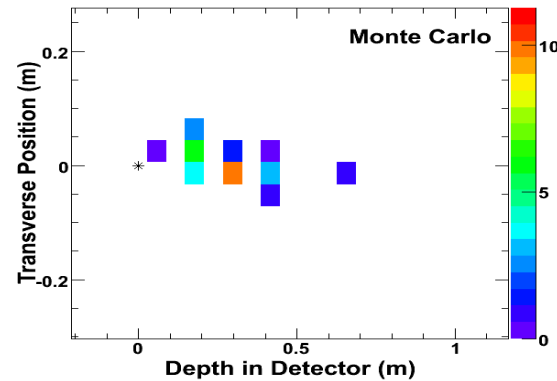
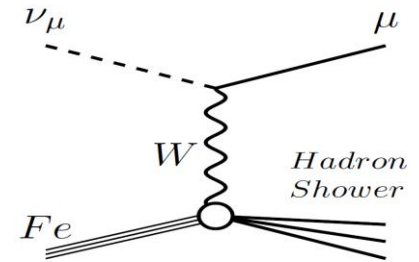
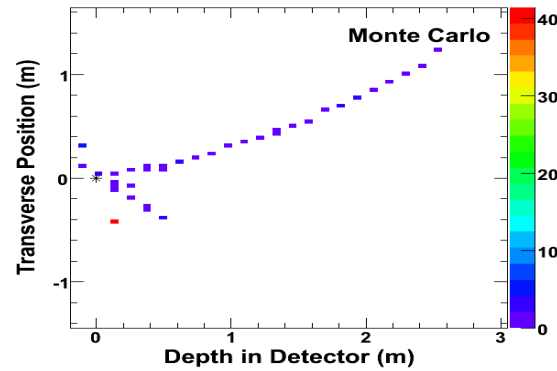
MINOS+



Magnetized steel-scintillator
tracking calorimeters

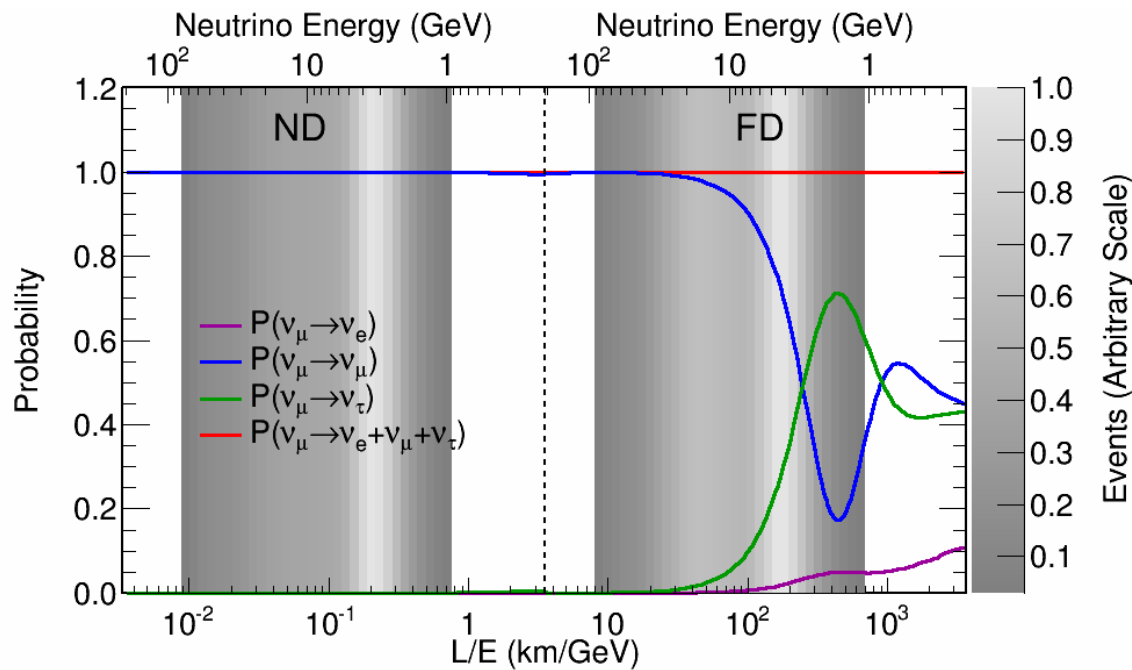
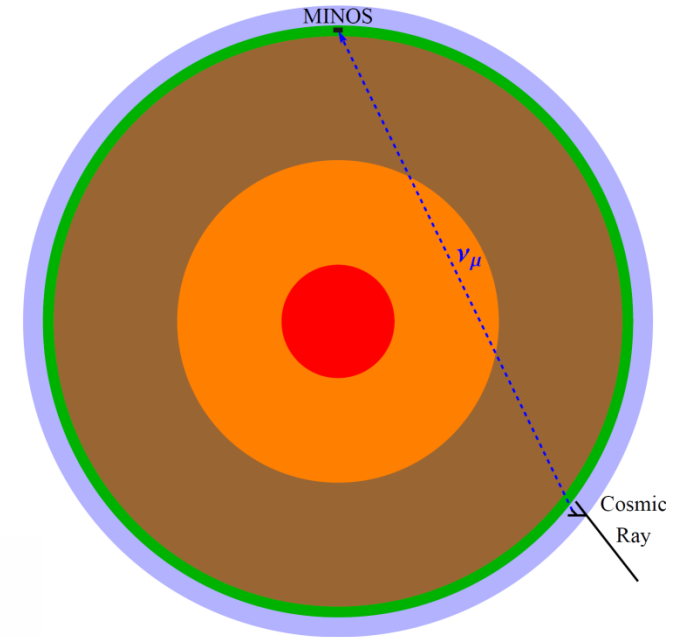
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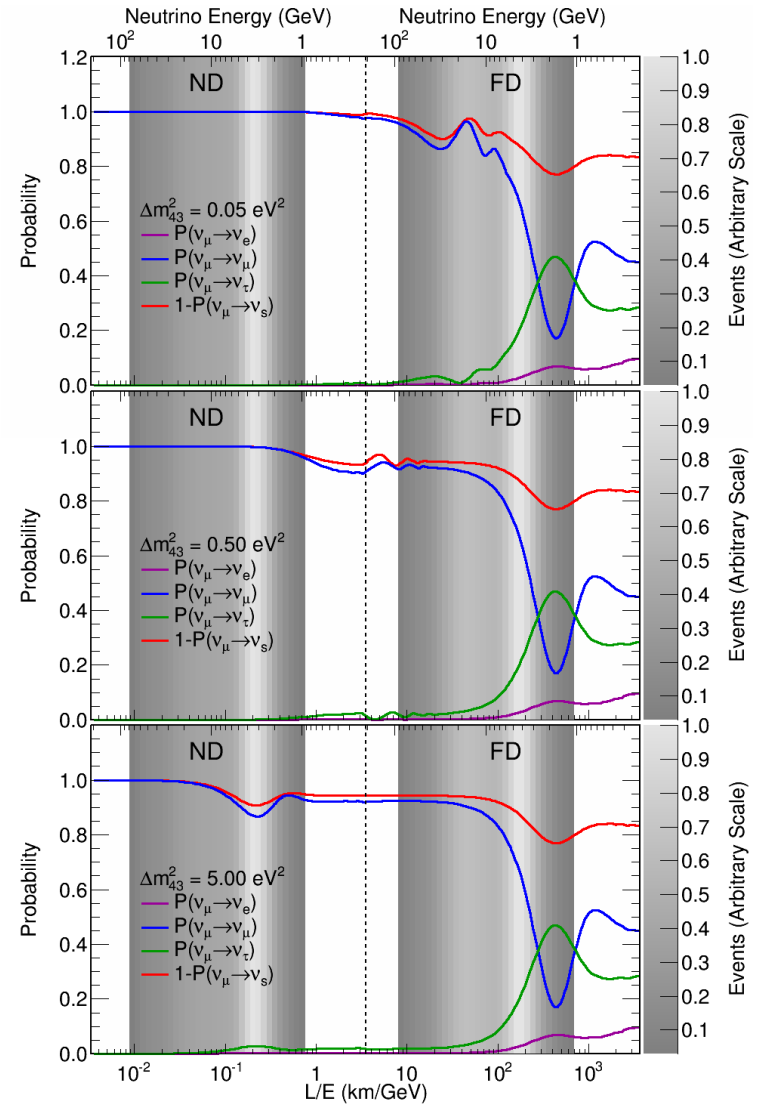
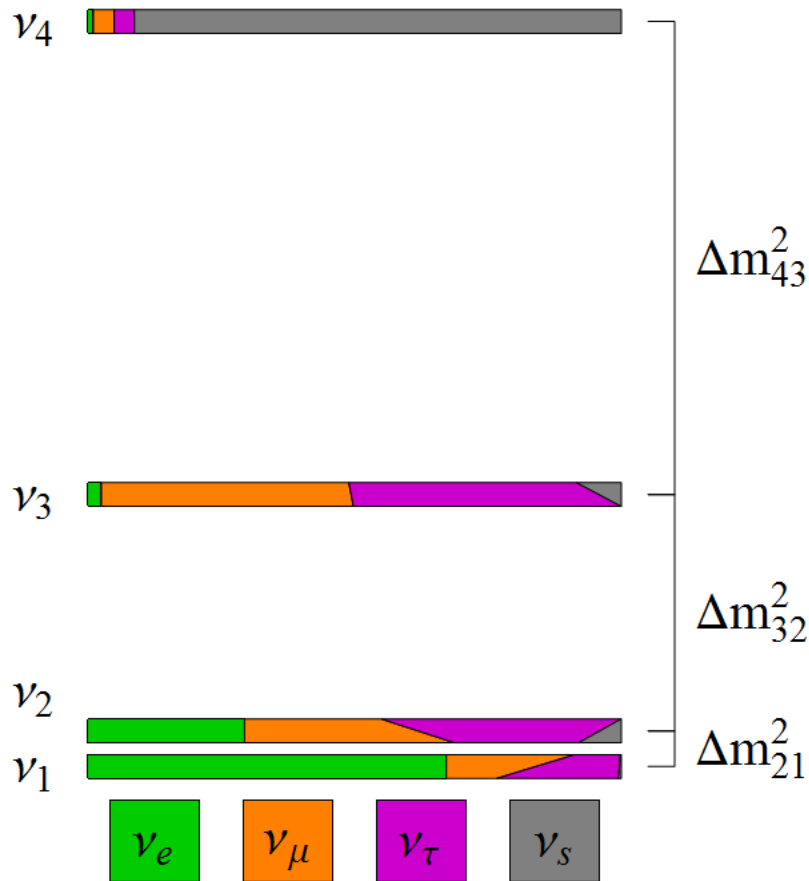
Neutrino Oscillation

MINOS+



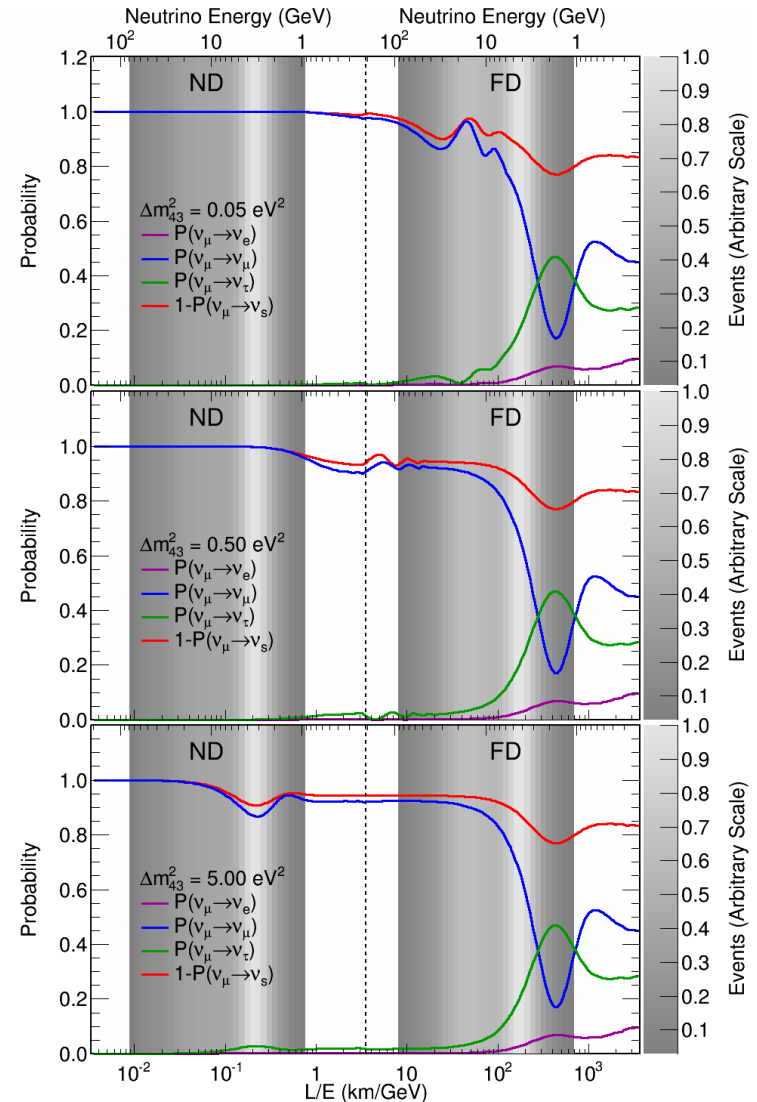
- ν_μ disappearance
- ν_e appearance
- NC to infer ν_τ

Sterile Neutrinos

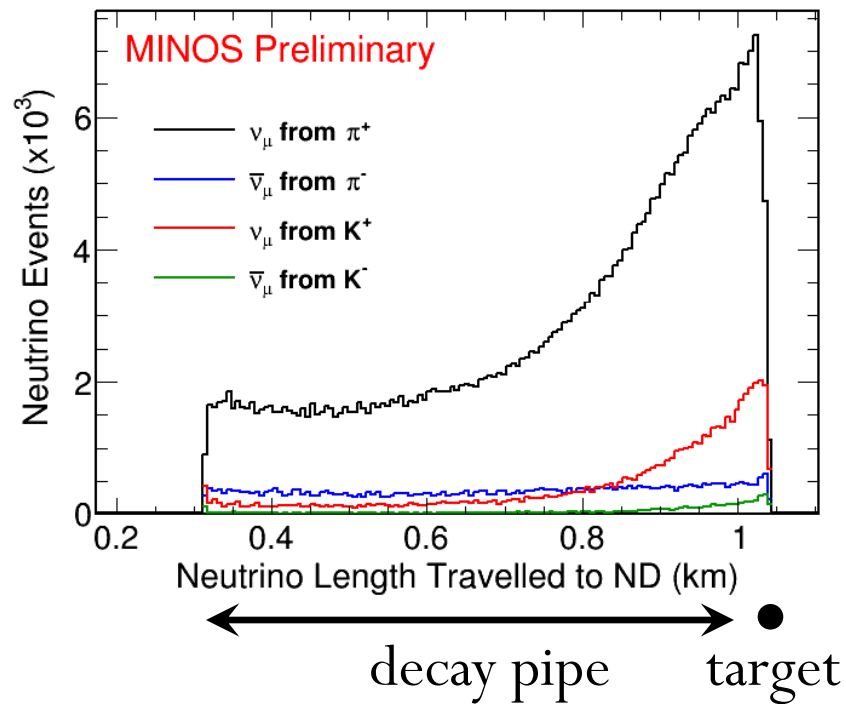


Sterile Neutrinos

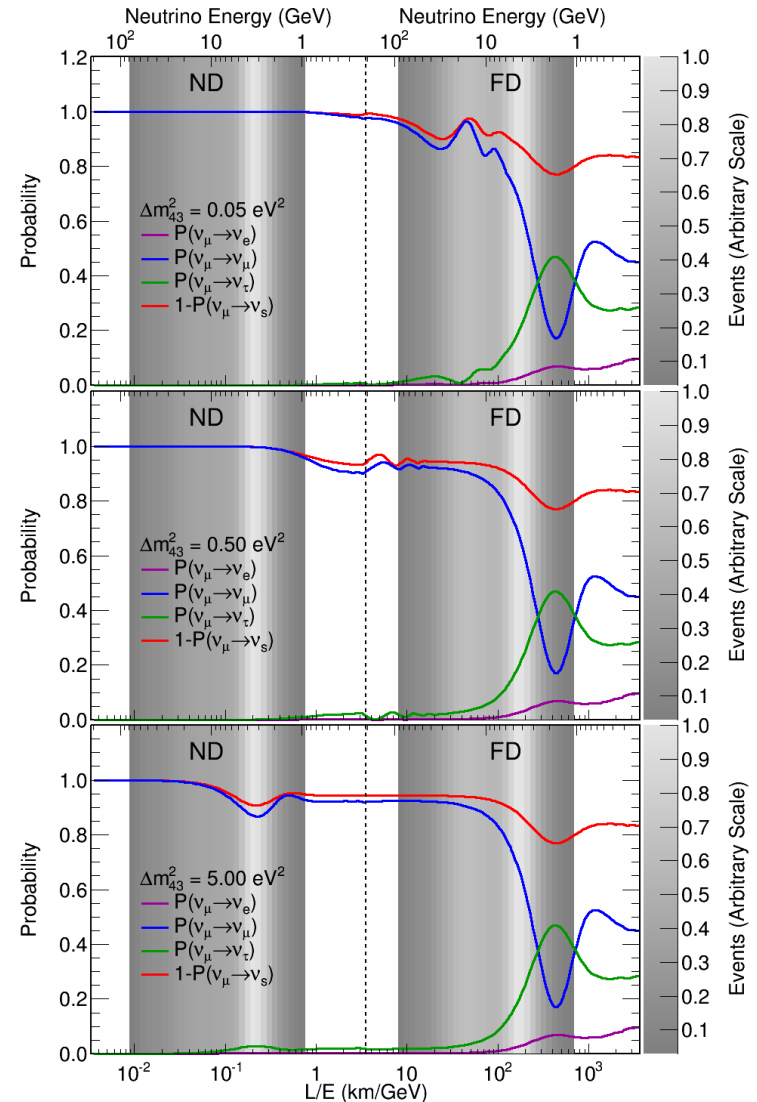
- $\Delta m_{43}^2 \ll 0.5 \text{ eV}^2$:
 - Distortions at the FD
 - High energy tail
- $\Delta m_{43}^2 \sim 0.5 \text{ eV}^2$:
 - No distortions
 - Rate measurement
- $\Delta m_{43}^2 \gg 0.5 \text{ eV}^2$:
 - Distortions at ND
 - Most sensitive at low energies



Sterile Neutrinos

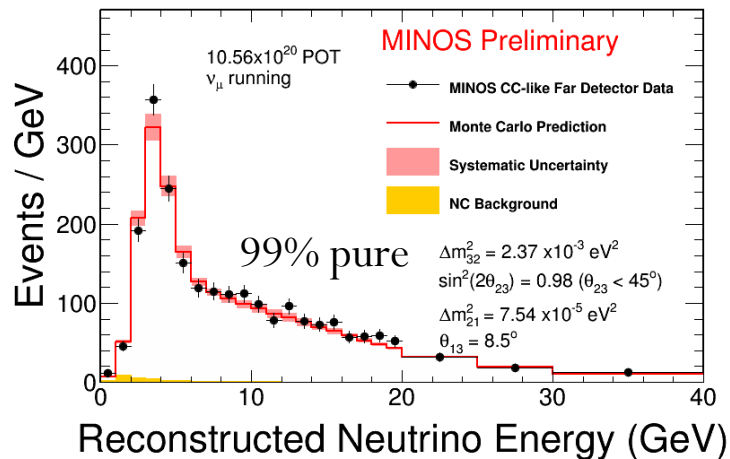


- $\Delta m_{43}^2 \gg 0.5 \text{ eV}^2$:
 - Distortions at ND
 - Most sensitive at low energies
 - Smeared by parent decay position

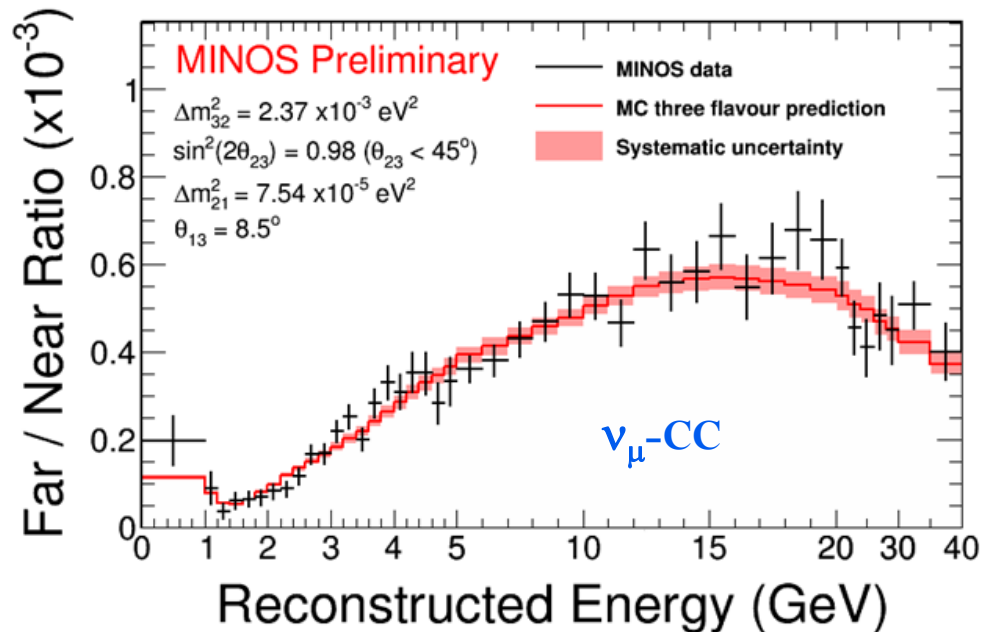
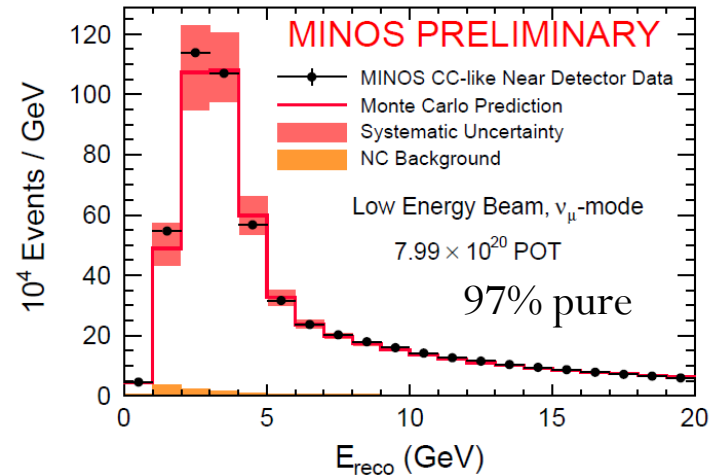


ν_μ -CC Sample

Far

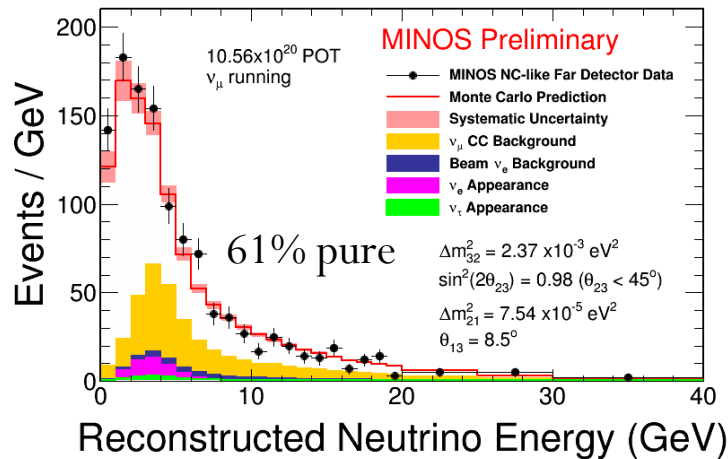


Near

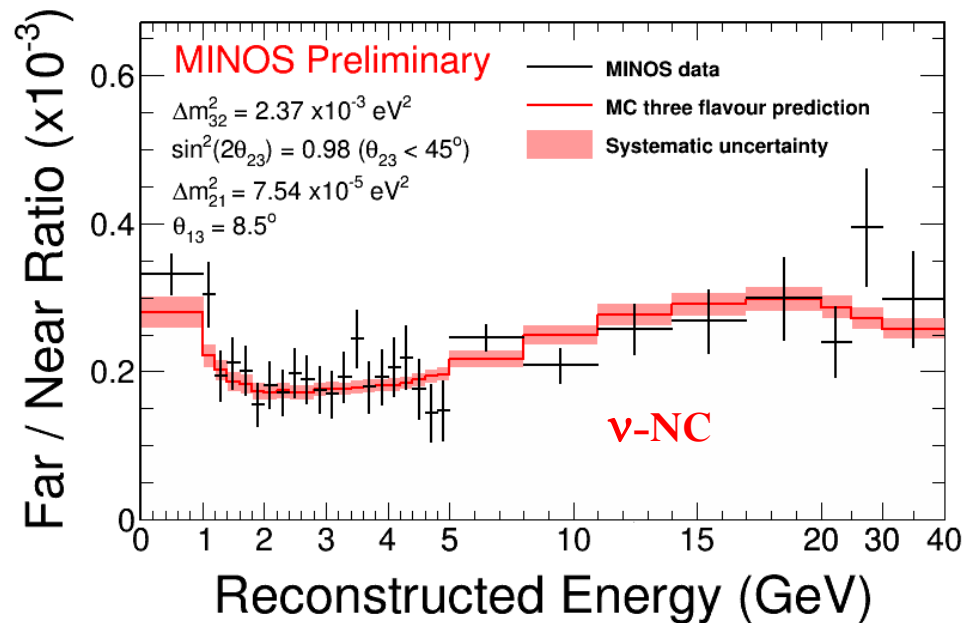
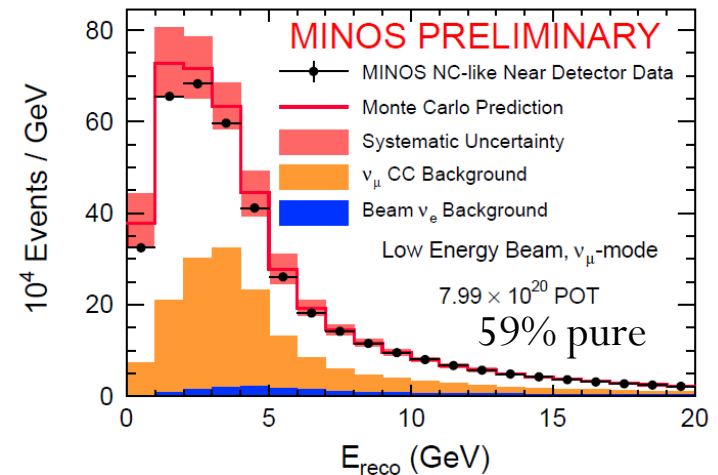


ν -NC Sample

Far

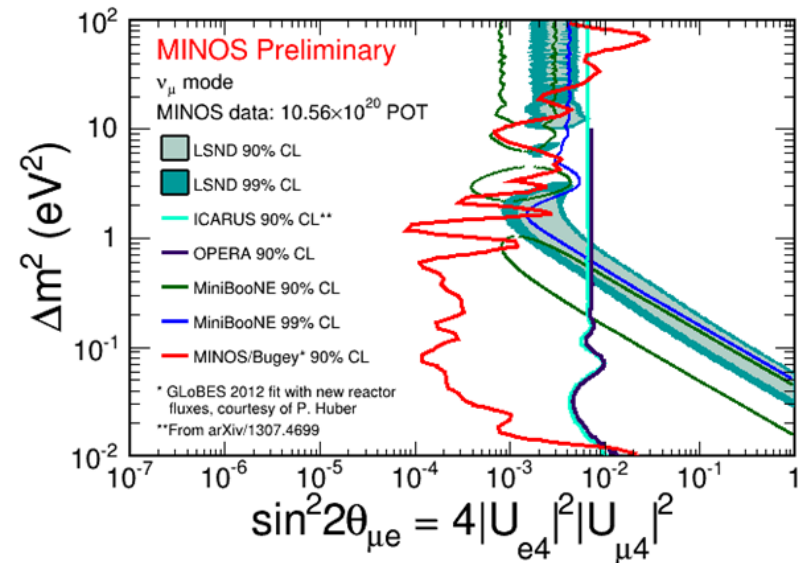
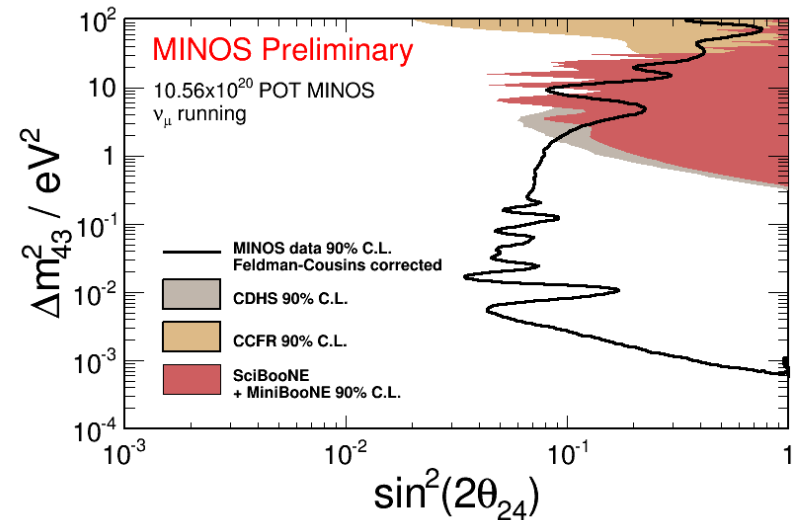


Near



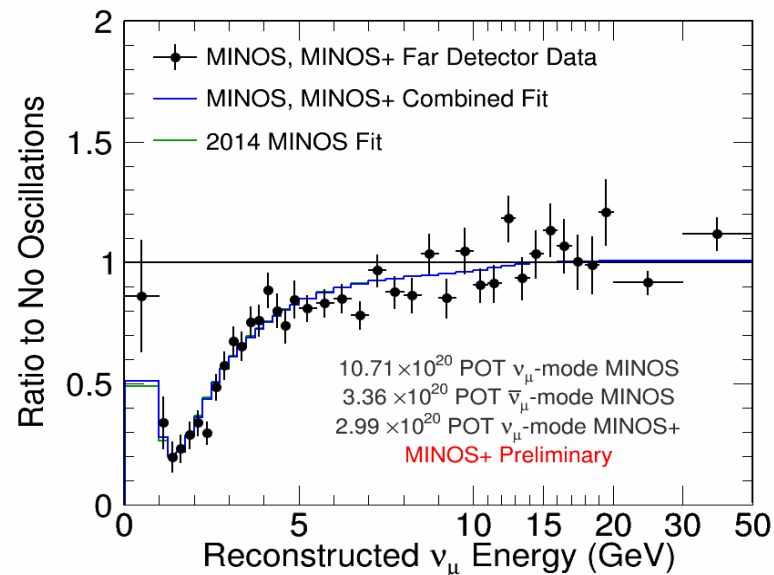
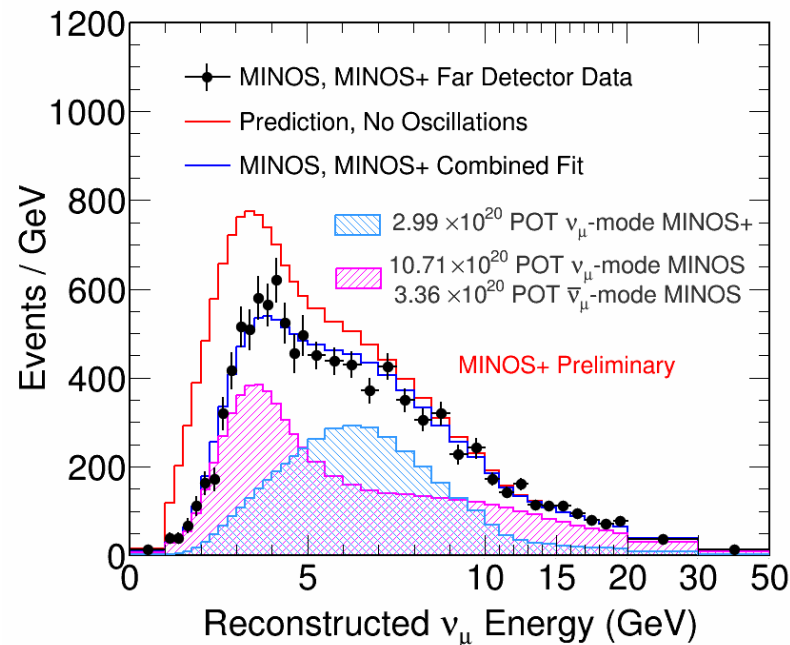
Sterile Neutrinos

- **Excluded large unexplored region** at low values of Δm^2_{43}
- Little sensitivity below $5 \times 10^{-3} \text{ eV}^2$
- Degenerate solutions with atmospheric scale oscillation
- $\nu_\mu \rightarrow \nu_e$ appearance implies ν_μ and ν_e disappearance
- Sensitivity $\sim \text{Reactor} \times \text{LBL}$
- Combined **MINOS & Bugey** data **exclude** most of the region allowed by **LSND & MiniBooNE**

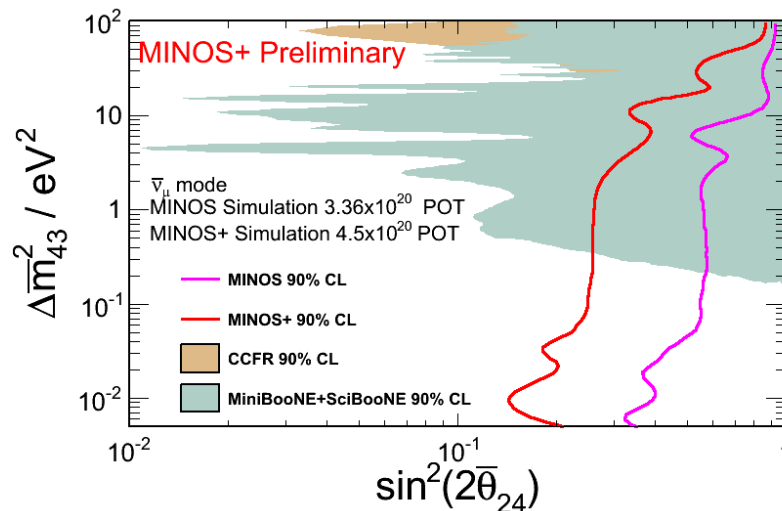
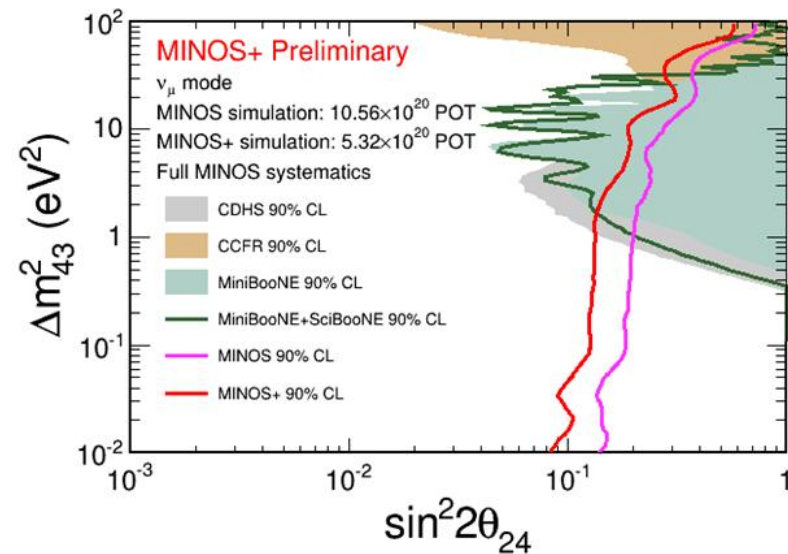


MINOS+ Data

- **More beam data** from MINOS+
- Preliminary look agrees with expectations based on MINOS era
- Already collected 2x more PoT
- Higher energy beam \Rightarrow events in MINOS+ era $>$ MINOS era
- **Improved sensitivity to new physics:** sterile neutrinos, large extra-dimensions, non-standard interactions...



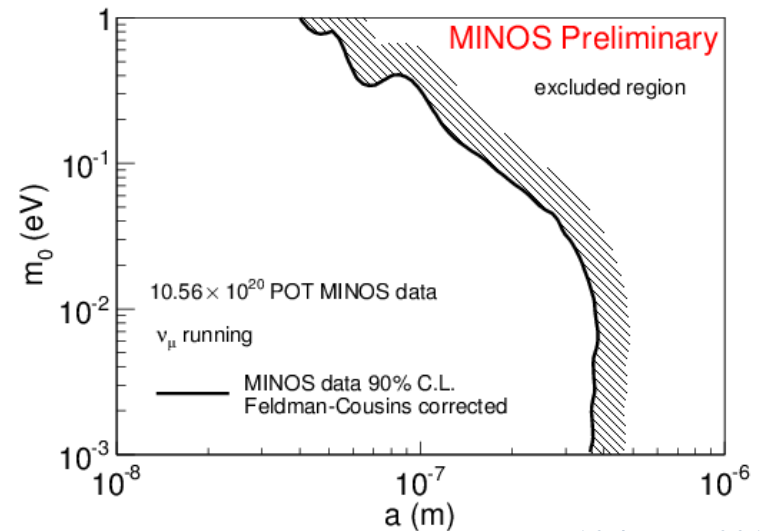
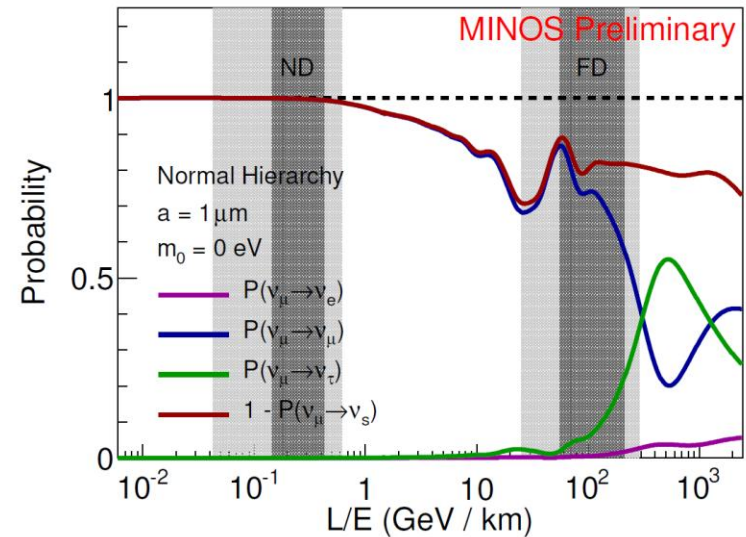
Future Sensitivity



- **Improved limits** with MINOS+
- Different energy spectra, different systematics
- Looking also at antineutrino data
- NC sample sensitive to CP violation
- Test of CPT with CC sample

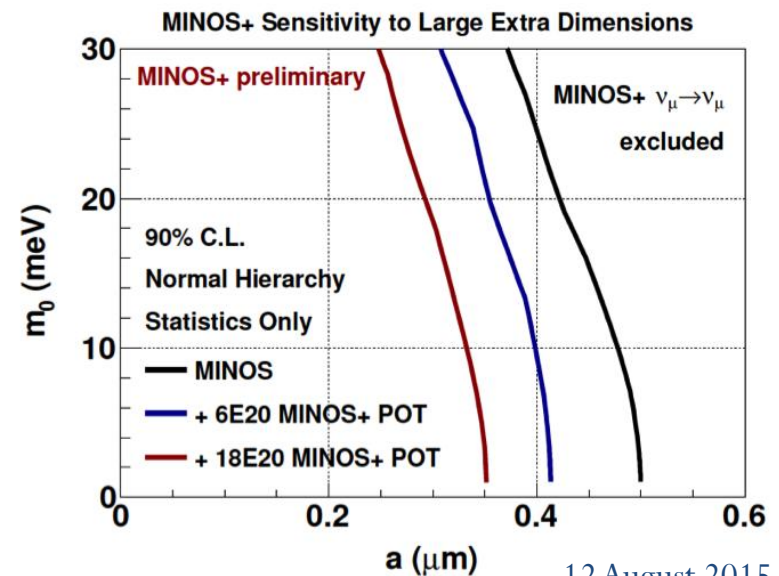
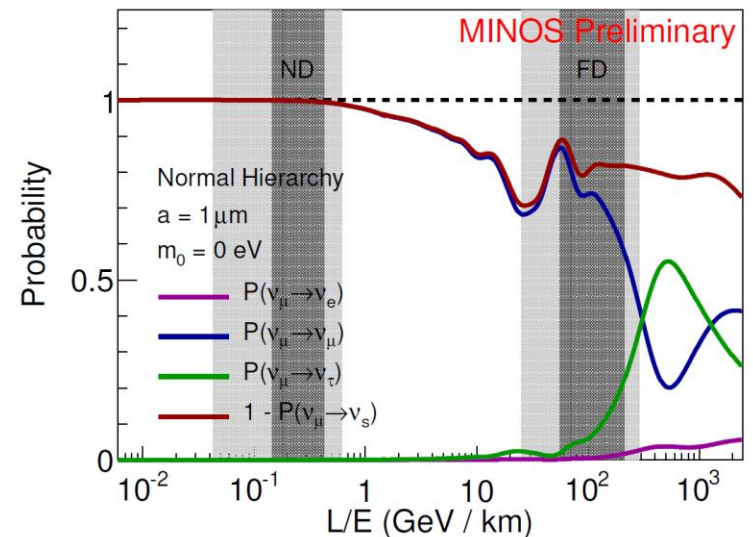
Sterile Neutrinos in LED

- What if sterile neutrinos travel in **extra dimensions?**
- Probe the size of largest extra dimension
- Also depends on the smallest neutrino mass
- MINOS **limit** on size of extra dimensions: **$a < 0.35 \mu\text{m}$** at 90%CL



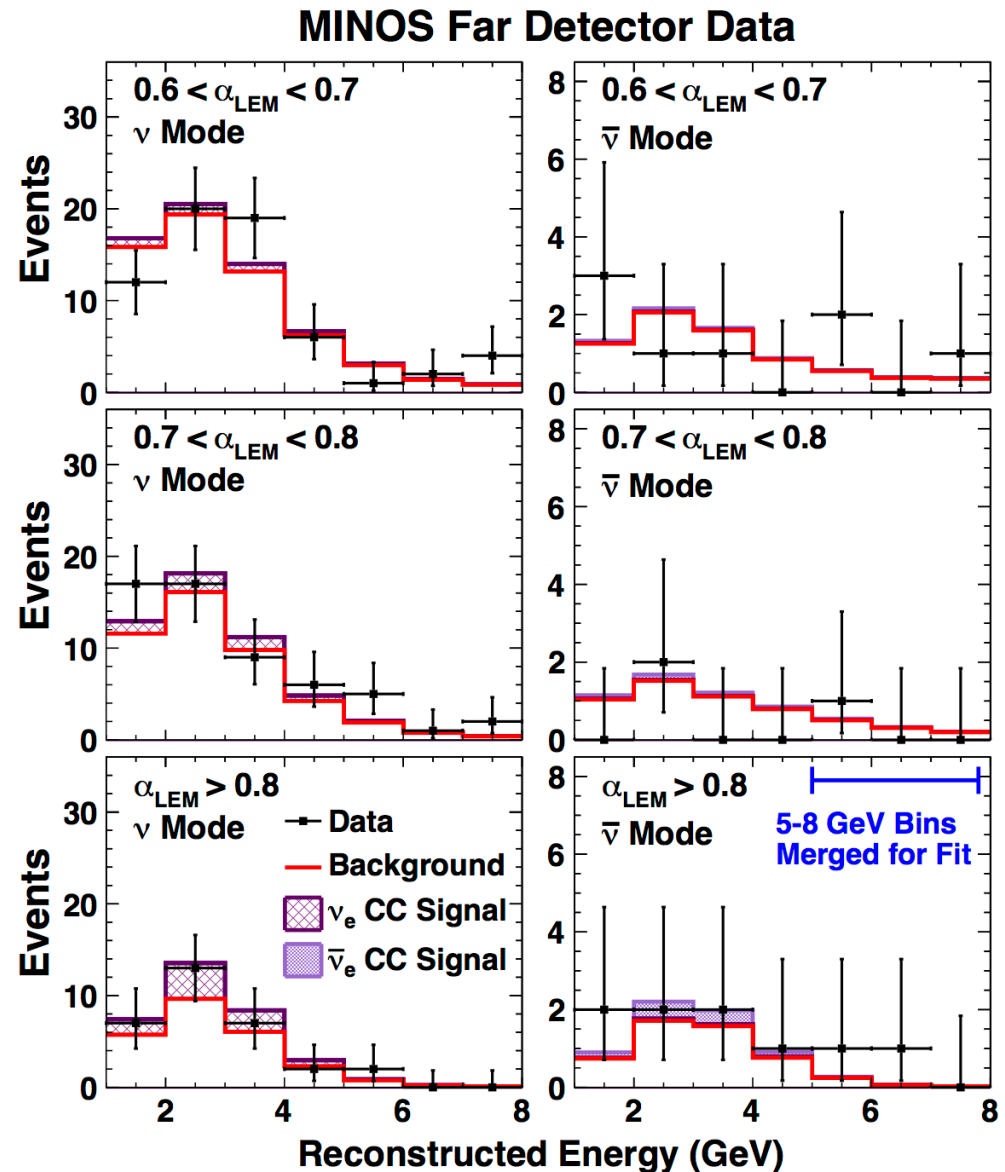
Sterile Neutrinos in LED

- What if sterile neutrinos travel in extra dimensions?
- Probe the size of largest extra dimension
- Also depends on the smallest neutrino mass
- MINOS limit on size of extra dimensions: $a < 0.35 \mu\text{m}$ at 90%CL
- MINOS+ will **improve** sensitivity by **$\sim 30\%$ in 3 years**



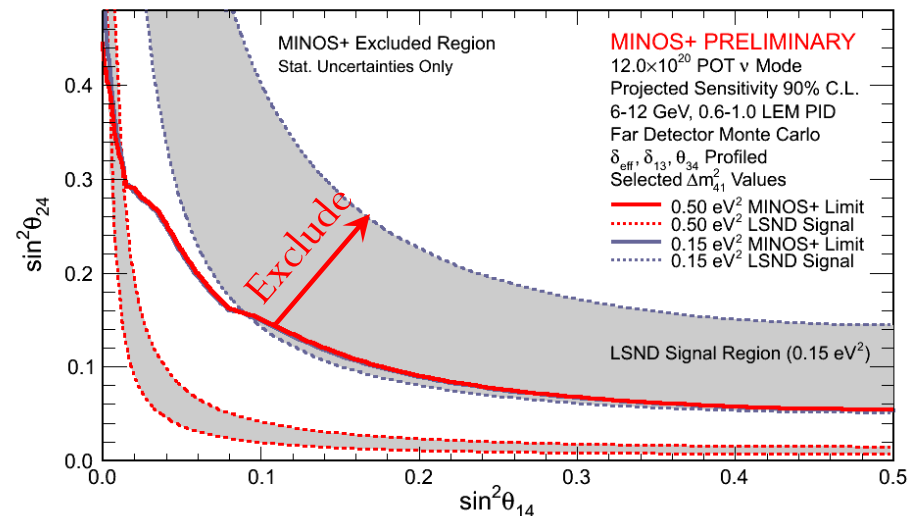
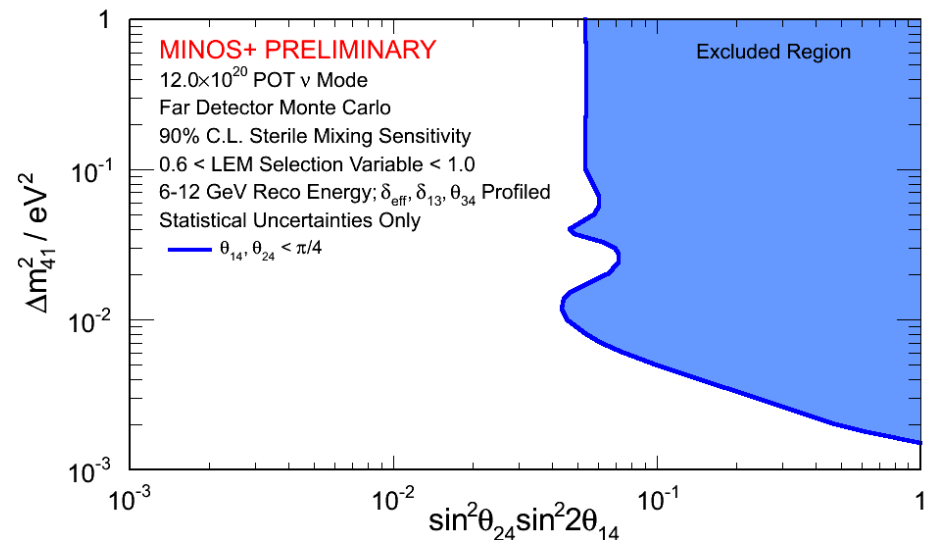
ν_e Appearance

- MINOS can also see ν_e interactions
- Background dominated, but 2σ significance for appearance



ν_e Appearance

- MINOS can also see ν_e interactions
- Background dominated, but 2σ significance for appearance
- Search for ν_e appearance from active-sterile neutrino mixing
- Difficult measurement due to interference of 3-flavor and 4-flavor oscillation terms



Summary

- MINOS' sterile neutrino search has excluded most of LSND & MiniBooNE allowed regions
- MINOS+ has just started and improved results on sterile neutrinos and related models are coming soon.
- 6.4×10^{20} PoT already collected!
- Stay tuned.



Thank you

