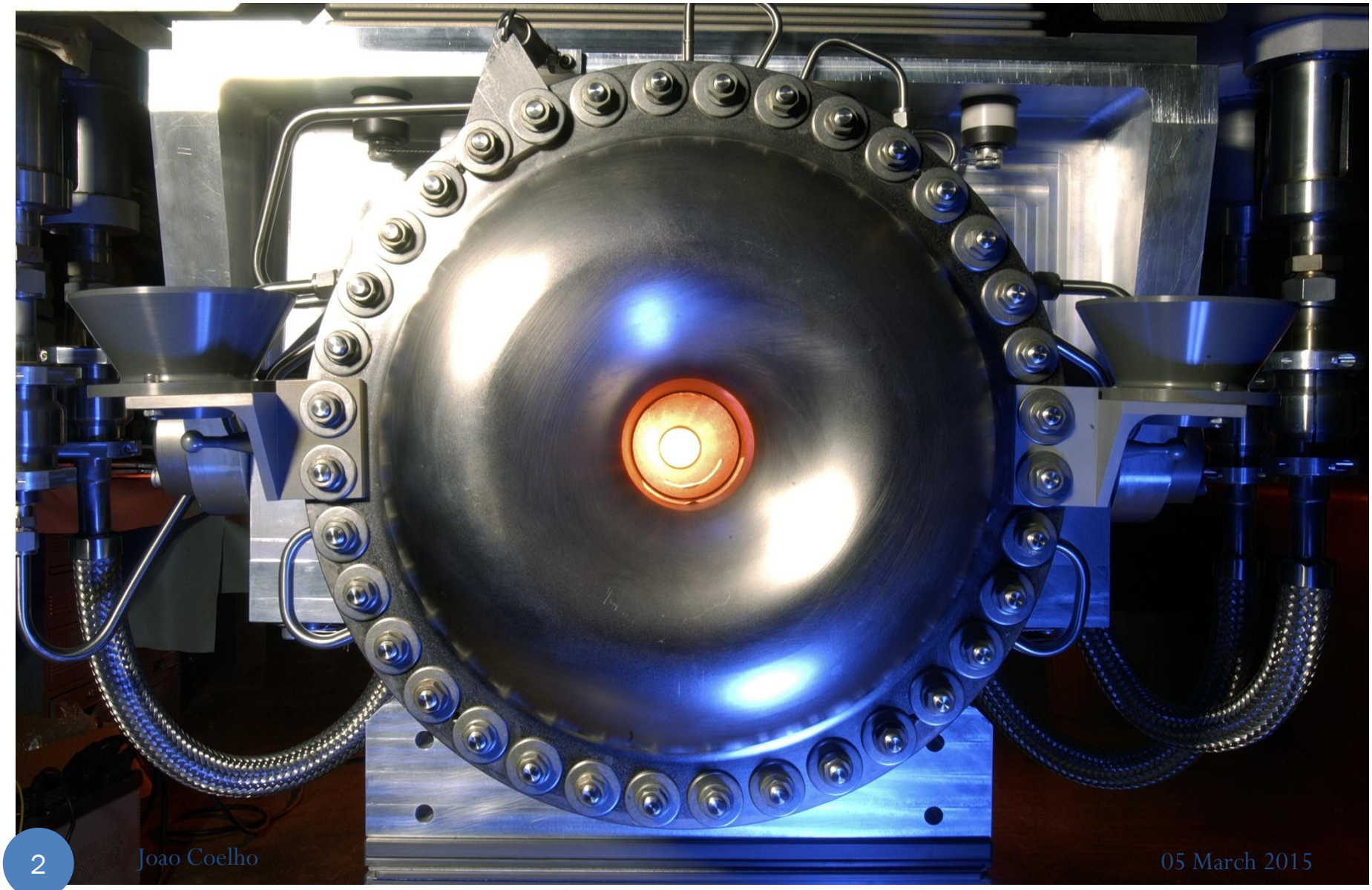
Status of MINOS and MINOS+

Joao Coelho

For the MINOS+ Collaboration

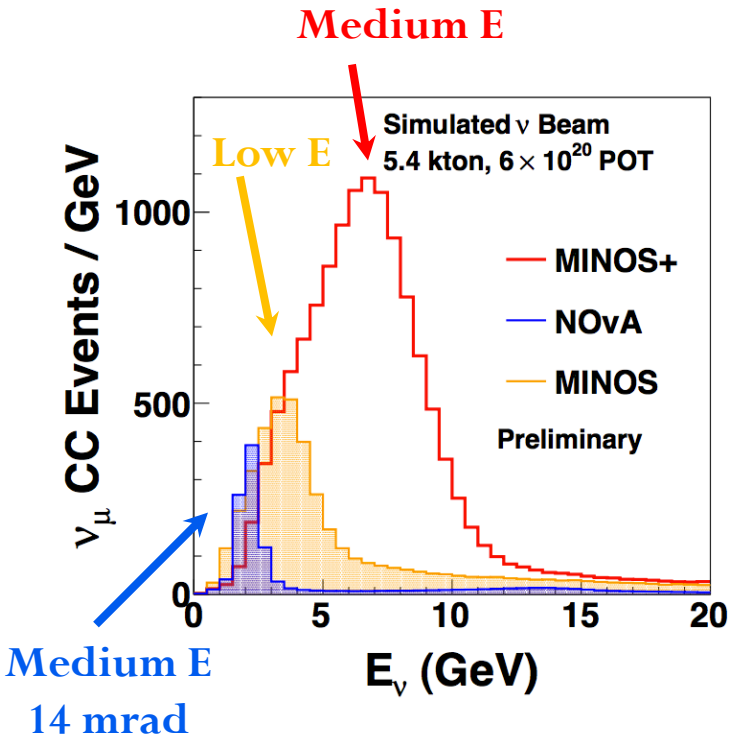
Tufts University

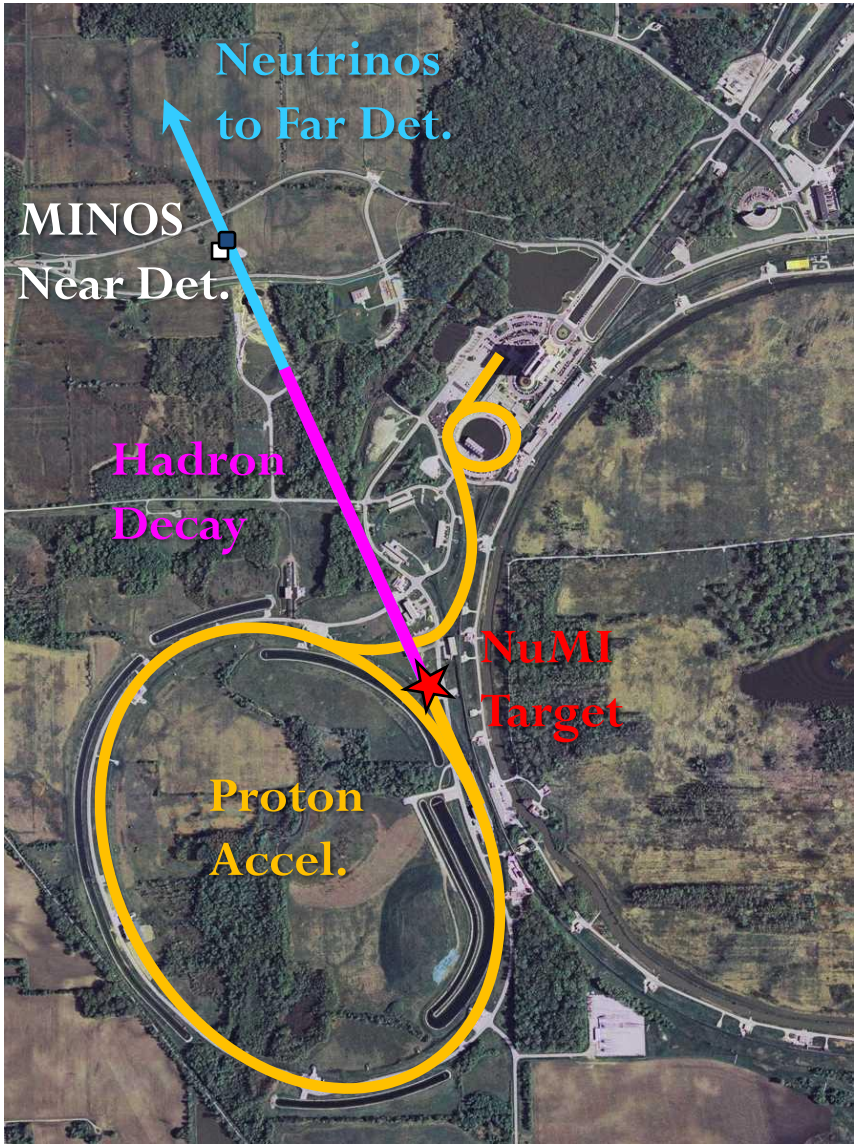
The NuMI Beam



NuMI Beam

- Currently at ~350 kW
- Capable of 700 kW



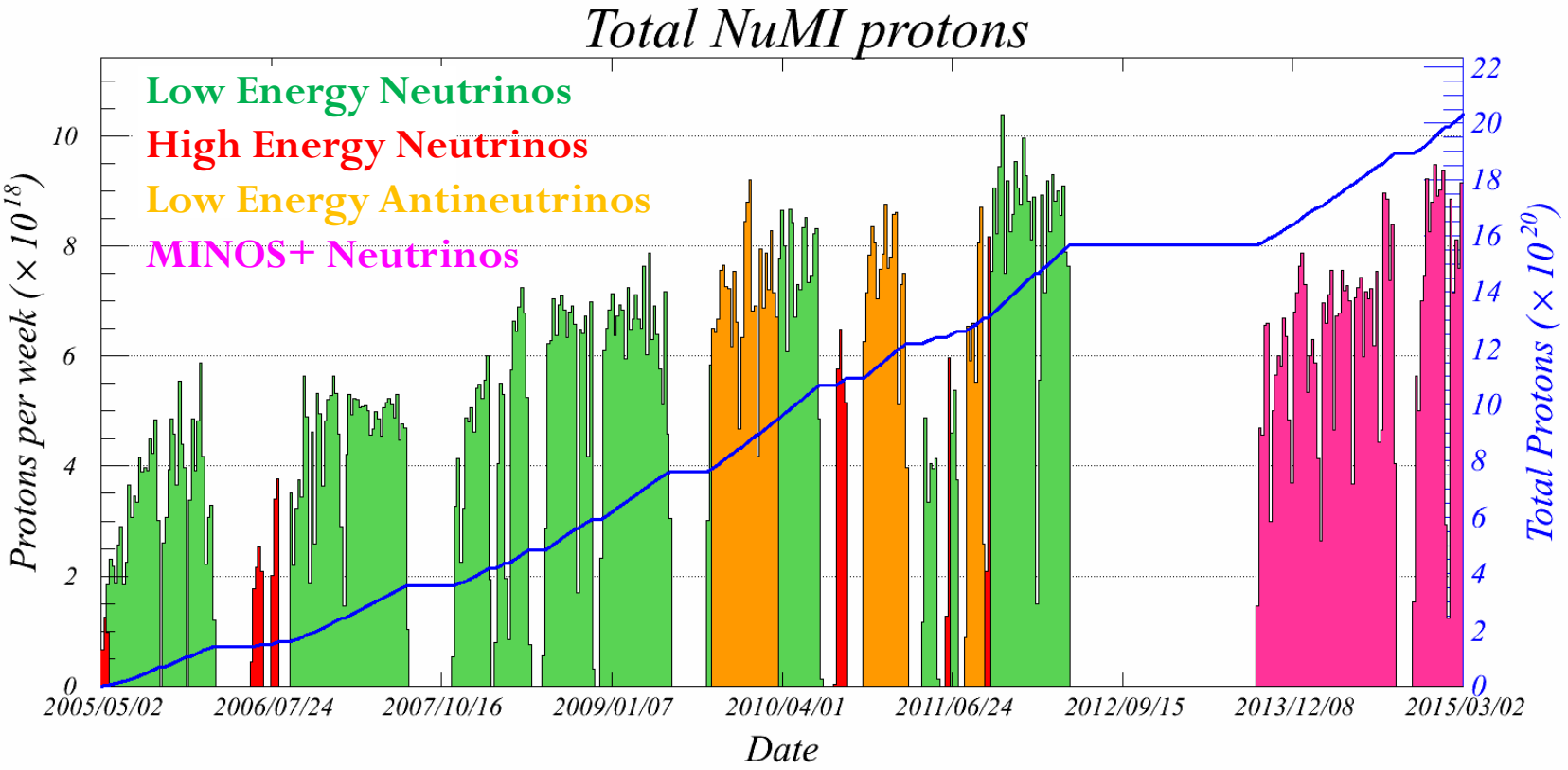


NuMI Beam


Lake Winnipeg
Canadian Shield
Hudson Bay
North Dakota
NOvA
MINOS+
Lake Nipigon
Ontario
Minnesota
Lake Superior
MINOS+
735 km
Green Bay
Wisconsin
Michigan
Lake Michigan
Iowa
Fermilab
Illinois

NuMI Beam

- Over 20 x 10^{20} Protons on Target (PoT) delivered to date
- ~4.6 x 10^{20} PoT with the new beam for MINOS+
- Running at 320 kW since August 2014. Ramping to 400 kW now.

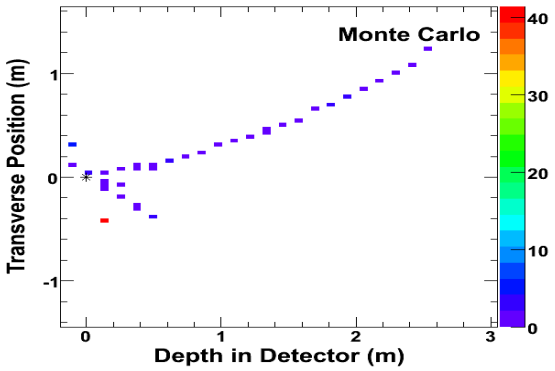


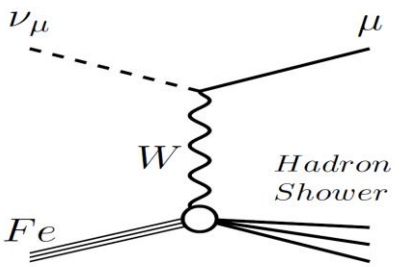
MINOS+

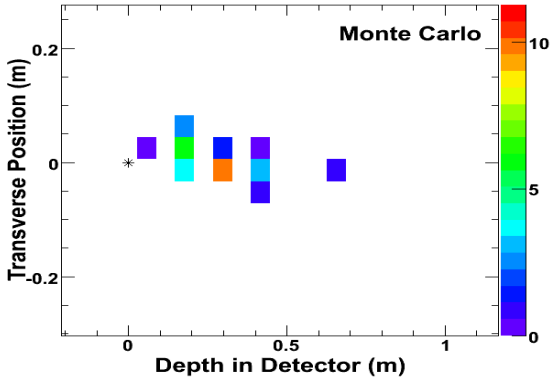
MINOS+

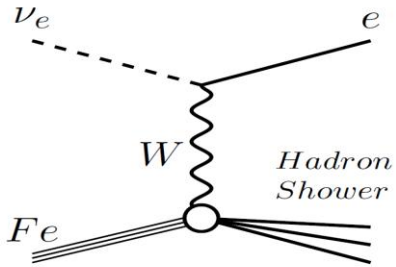
Magnetized steel-scintillator tracking calorimeters

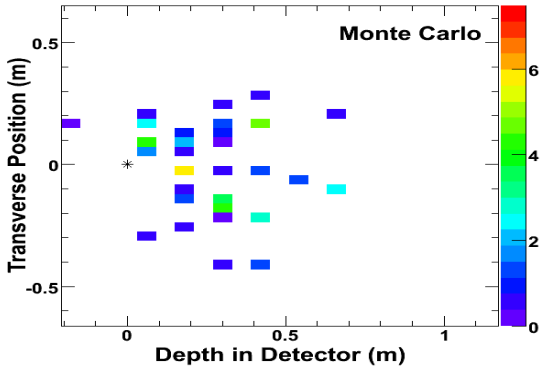
Far Detector: 5.4 kton
Near Detector: 0.98 kton

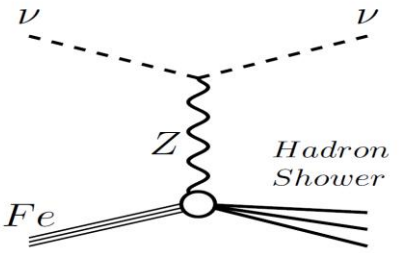




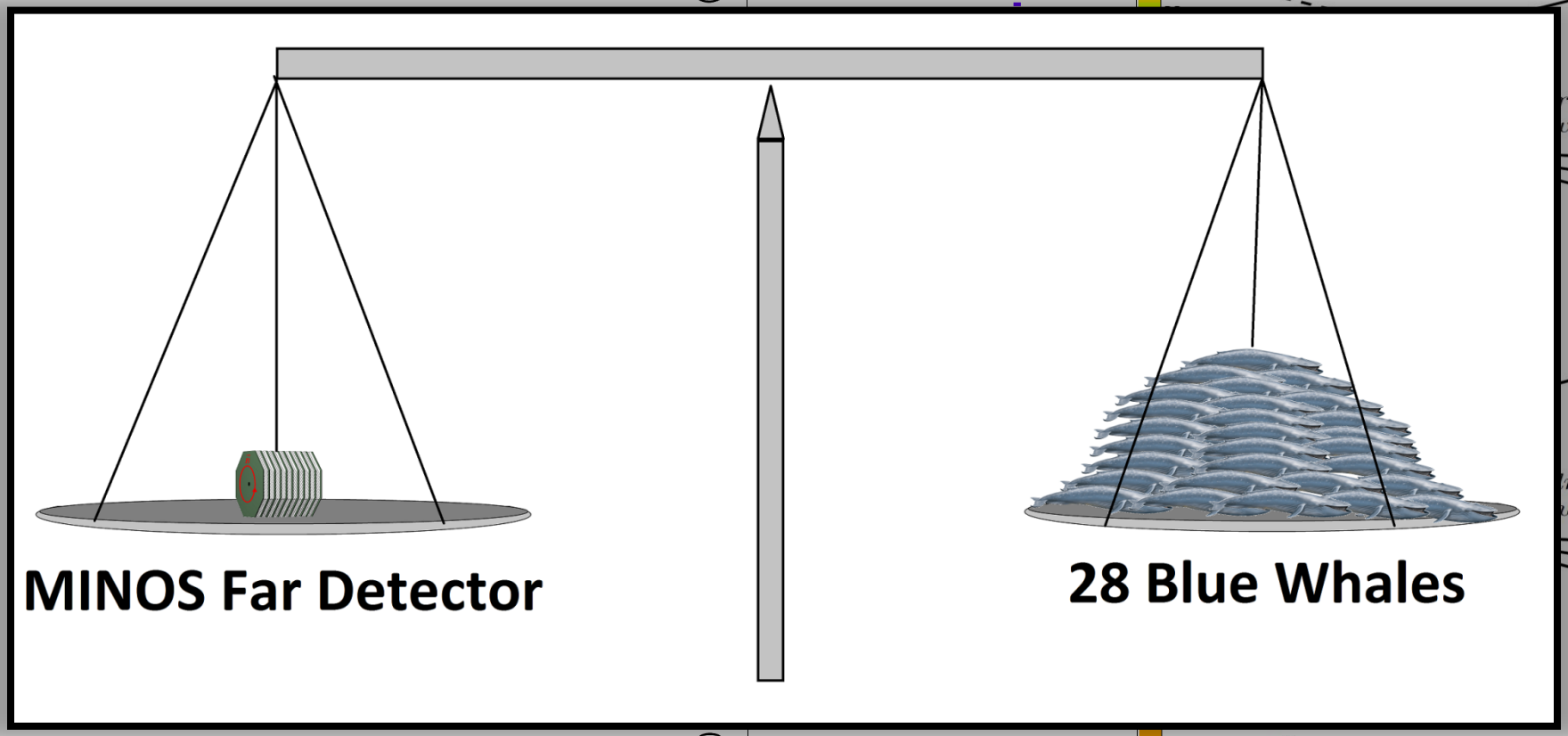








MINOS+



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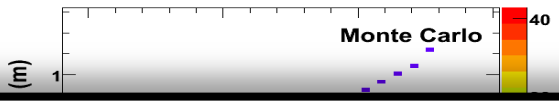
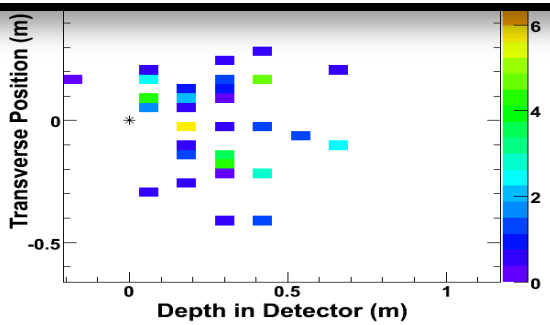
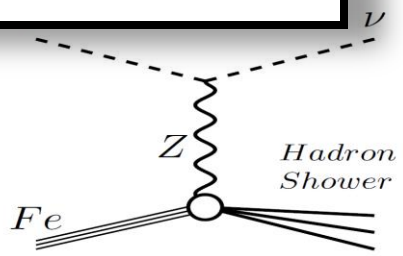
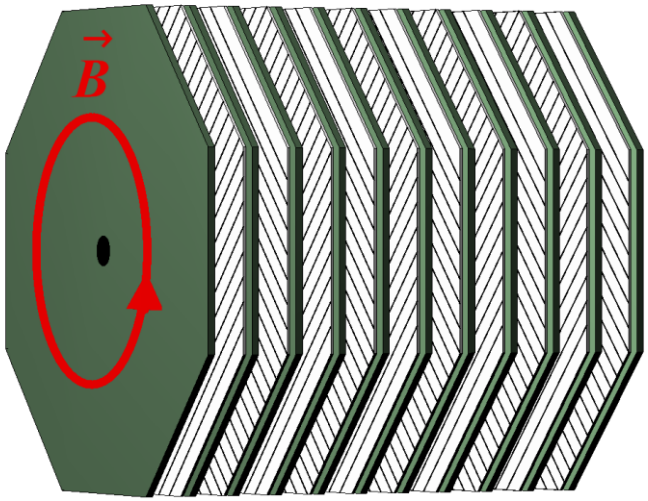






MINOS+



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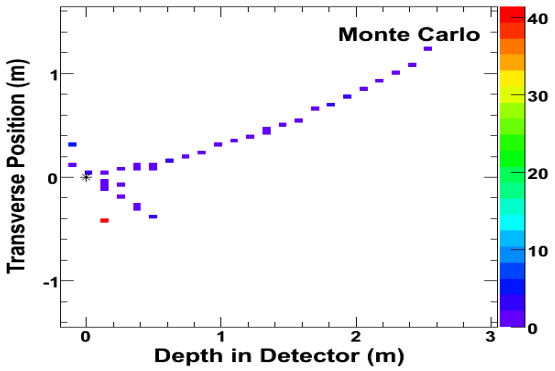
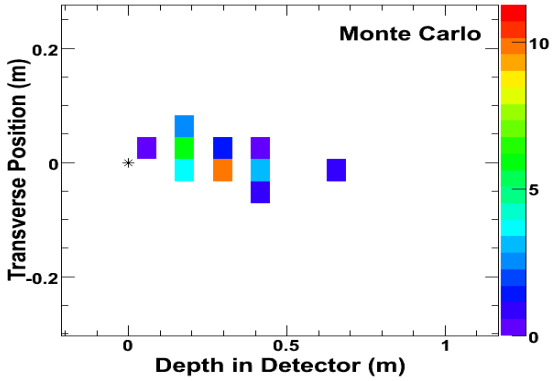
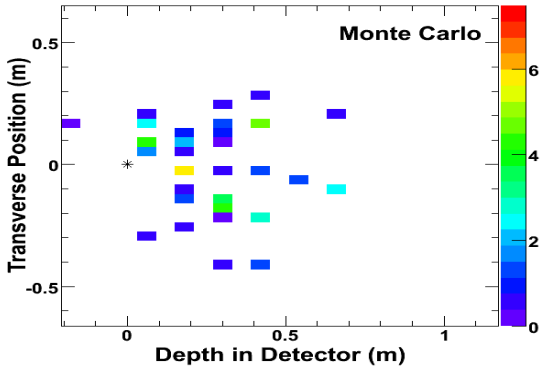
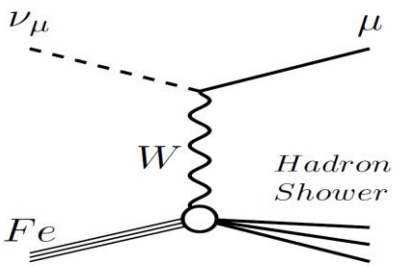
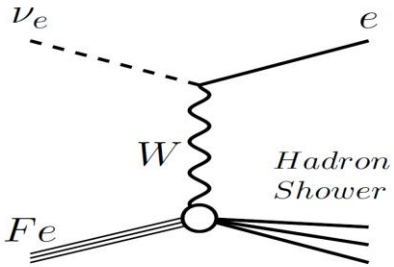
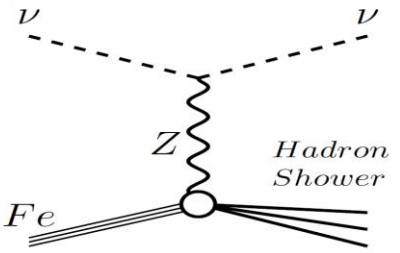




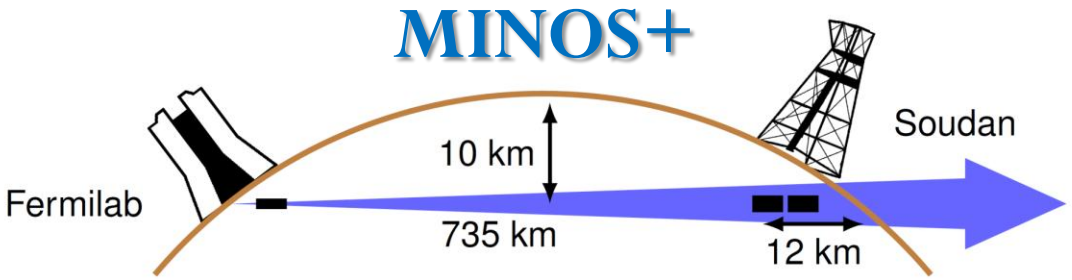


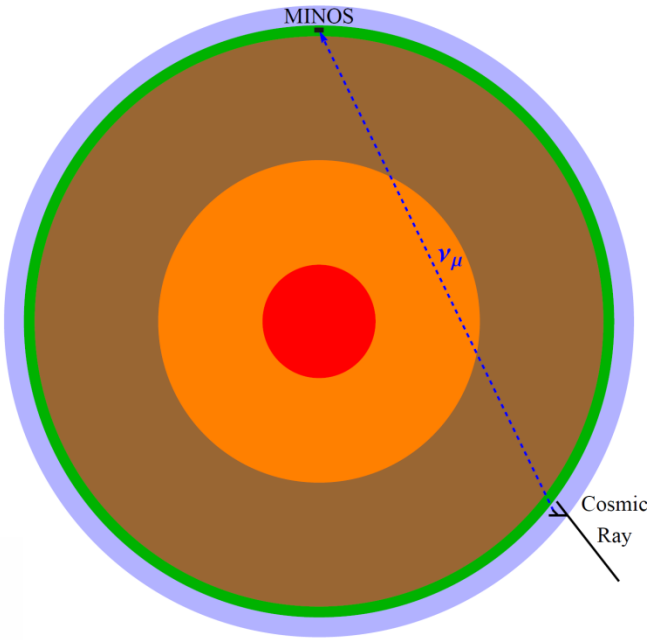


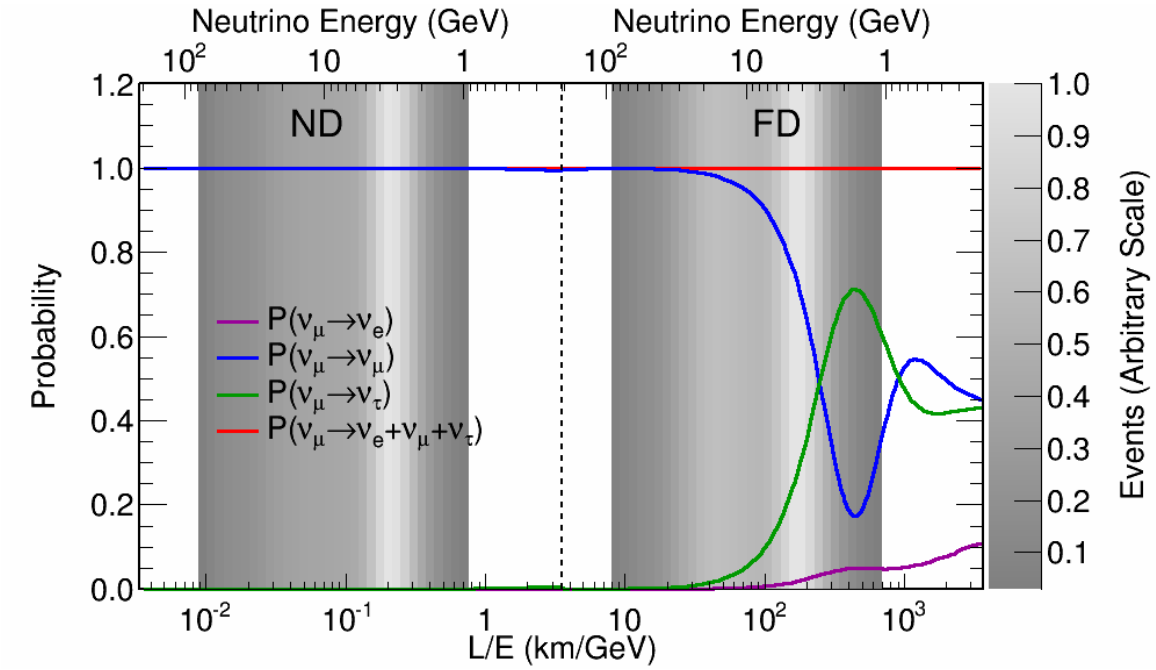




Neutrino Oscillation





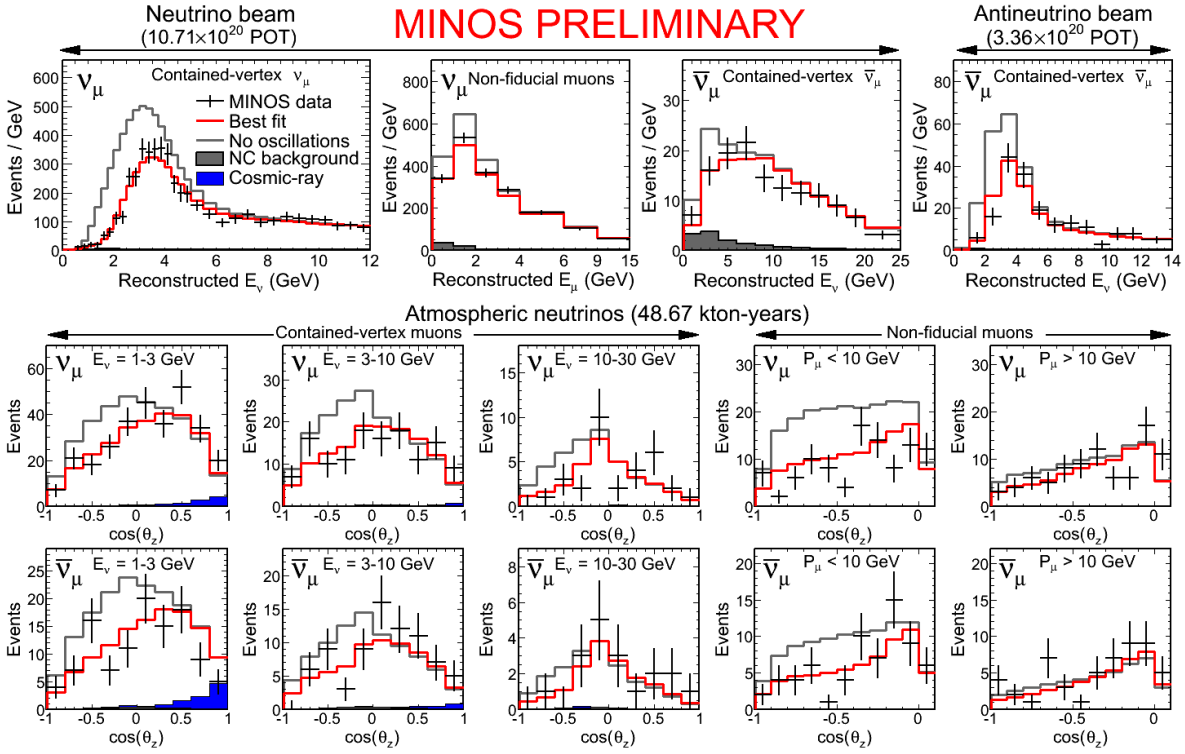


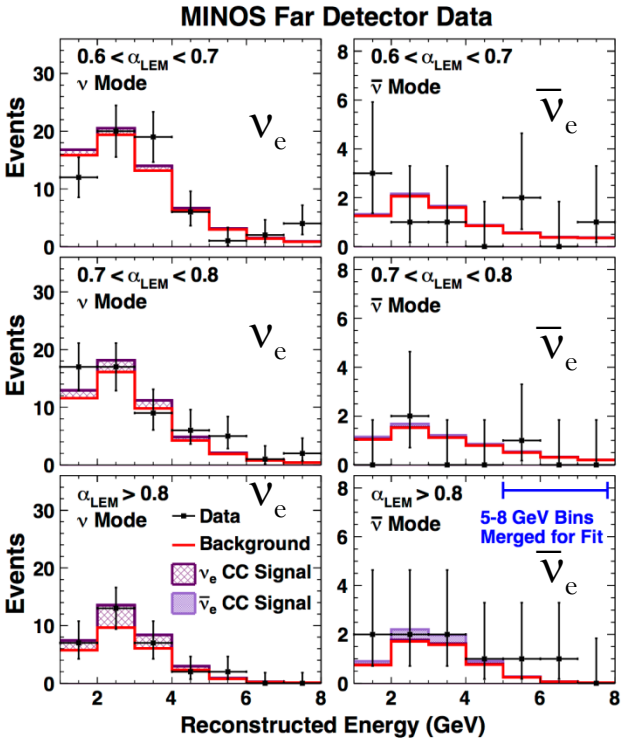
- ν_μ disappearance
- ν_e appearance
- NC to infer ν_τ
- ν_τ appearance?

Maybe in MINOS+

Results from MINOS

- Combine **ALL** neutrino data
- Neutrinos and antineutrinos
- ν_μ disappearance and ν_e appearance
- Beam and atmospheric neutrinos
- +10.8 kton-years of atmospheric data in the MINOS+ era (28% increase)





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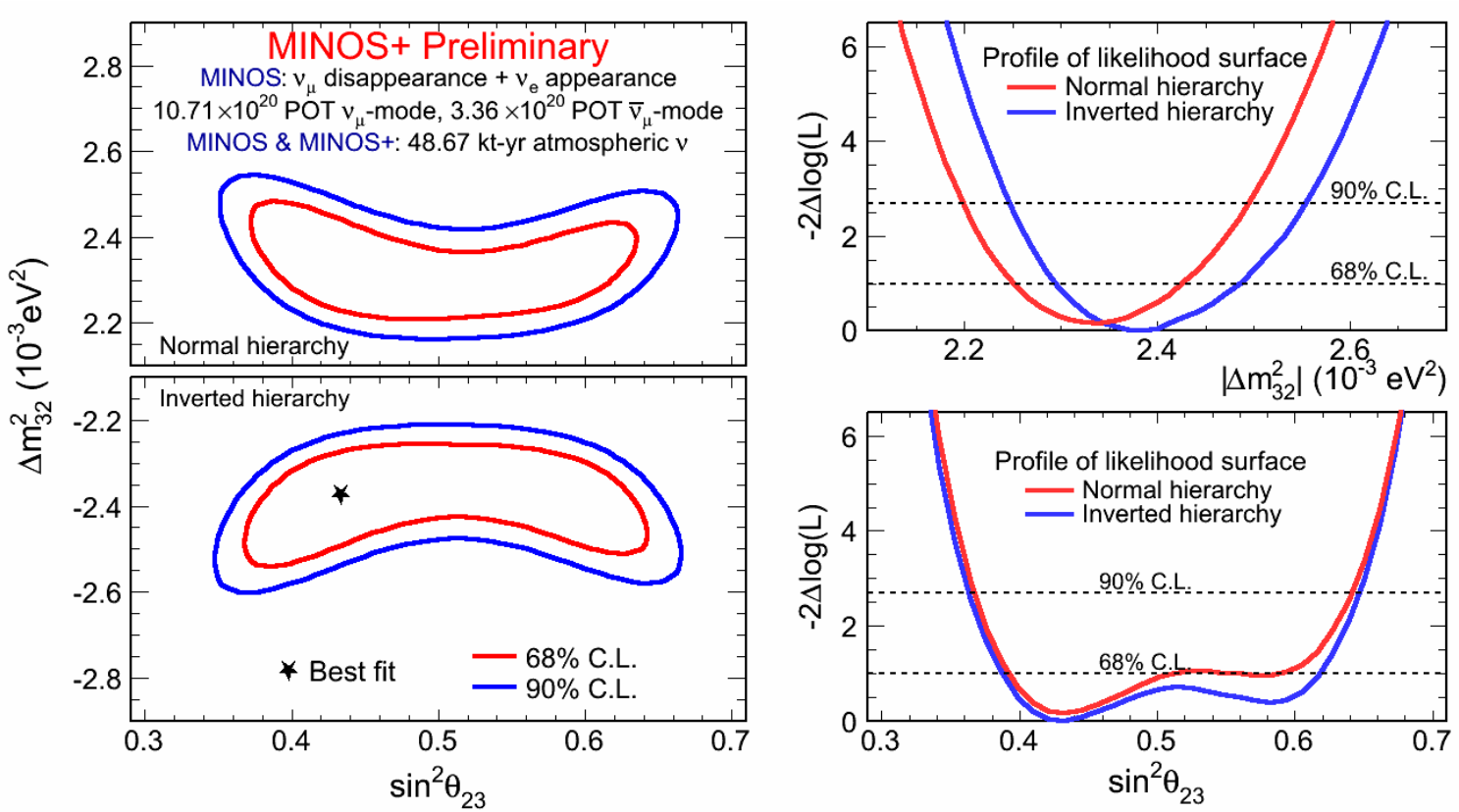

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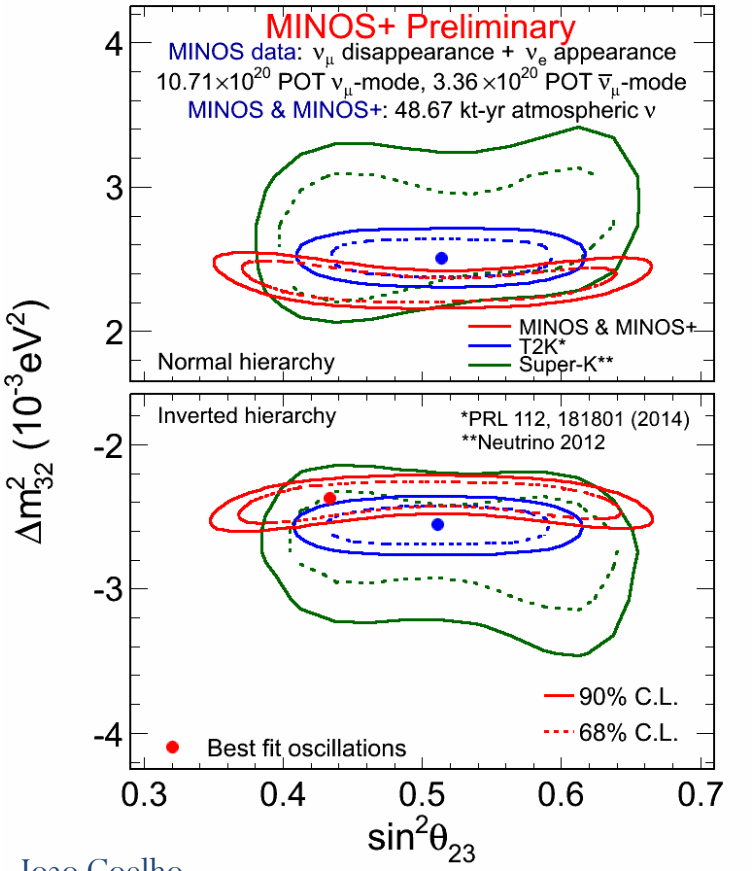
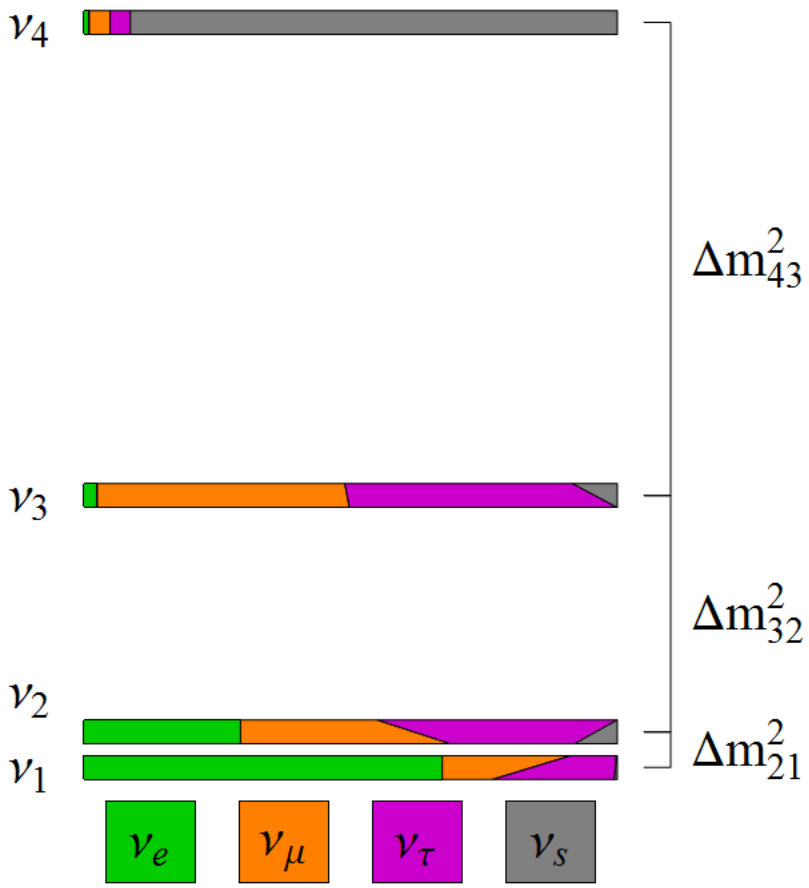
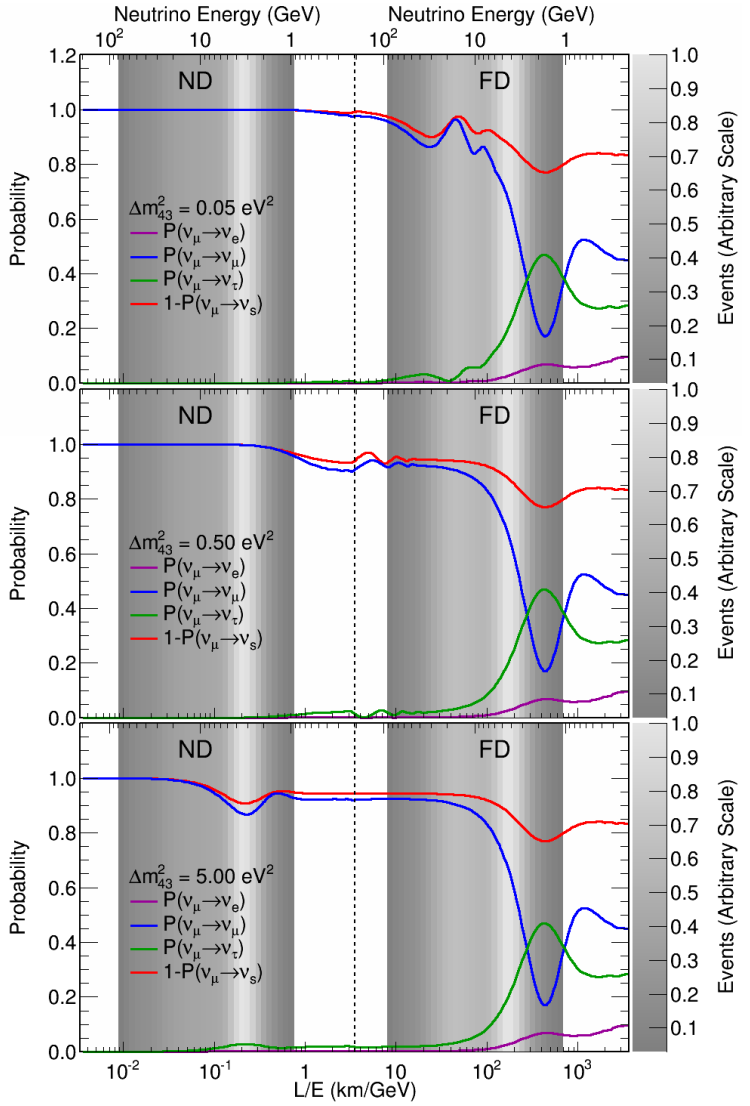


Best measurement of Δm^2_{32} 3.8% prec.

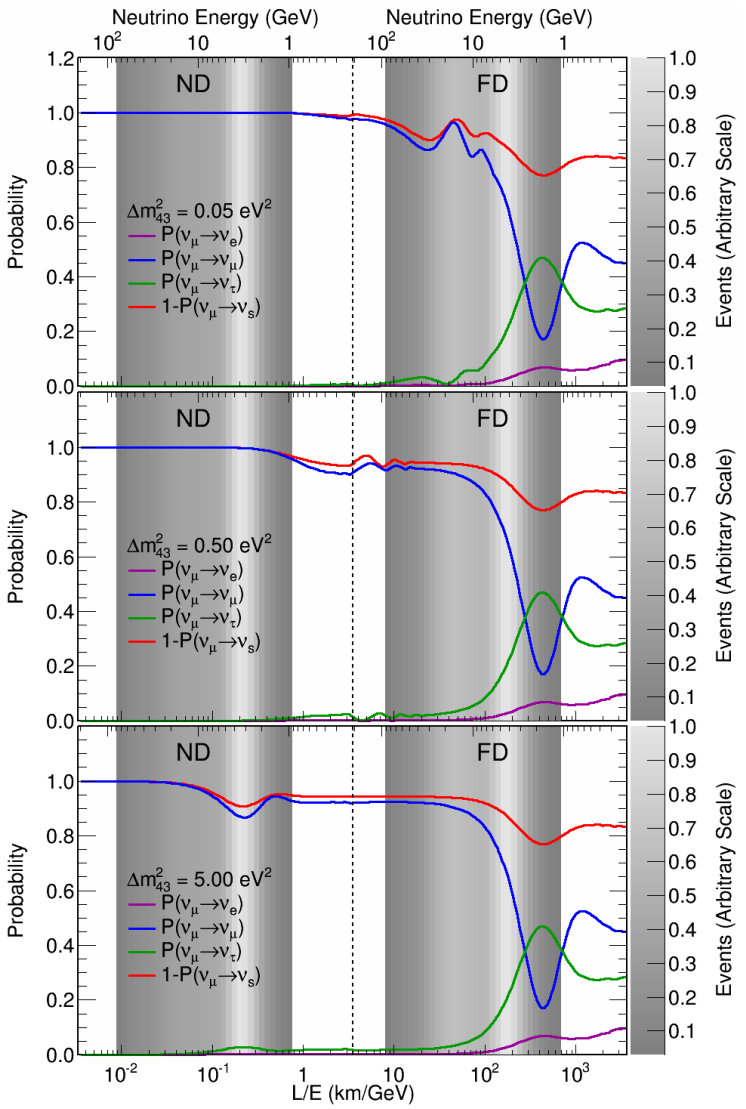
Sterile Neutrinos



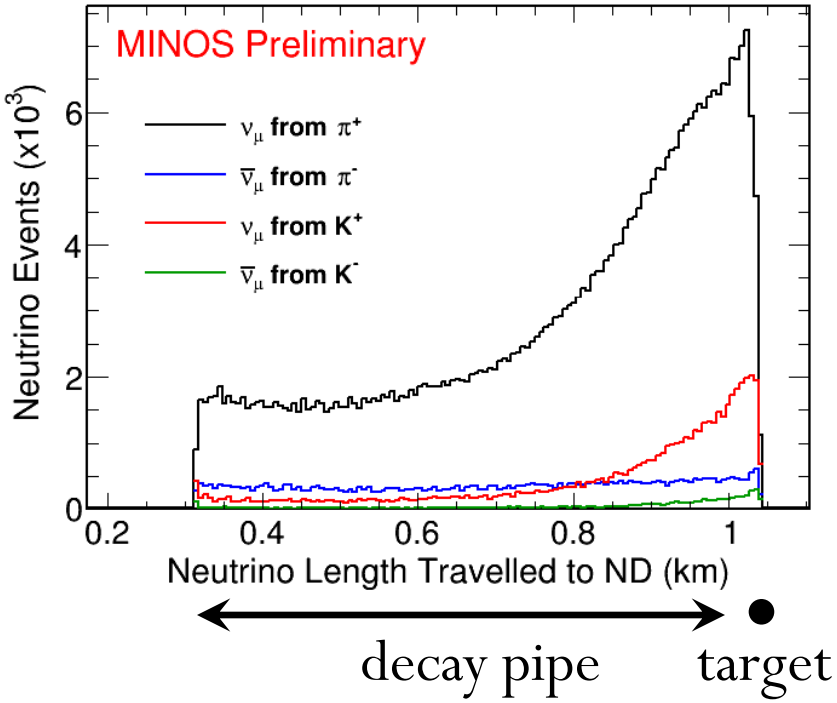


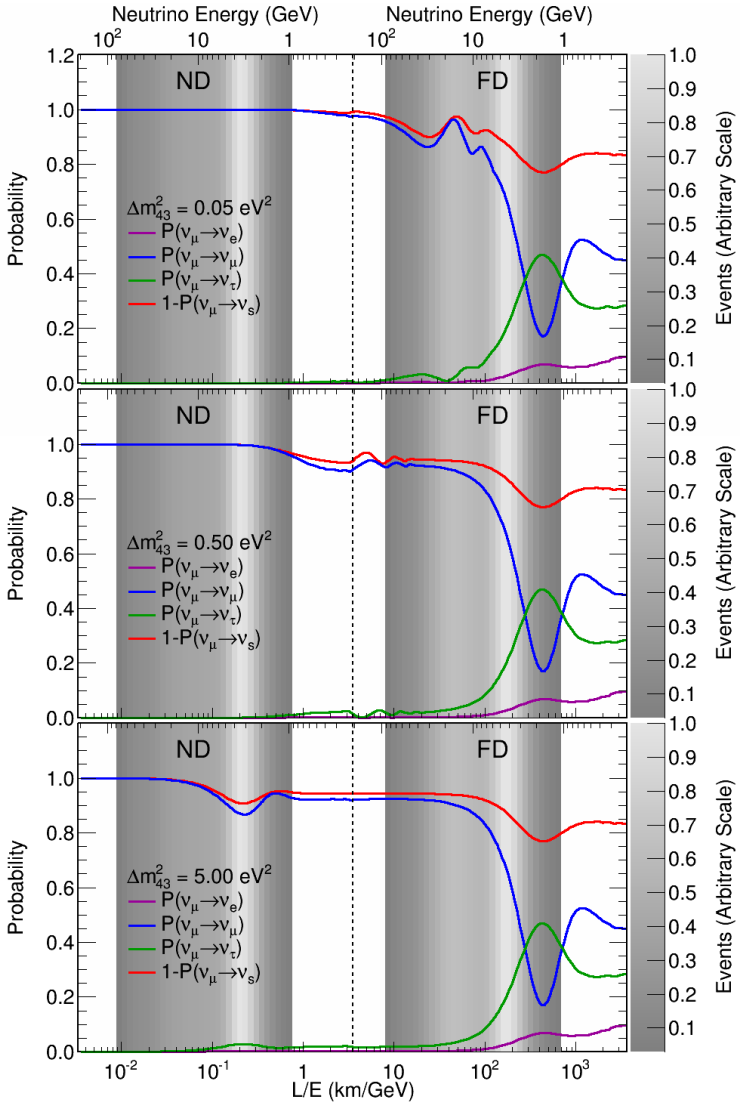
Sterile Neutrinos

- $\Delta m^2_{43} << 0.5\ eV^2$:
  - Distortions at the FD
  - High energy tail
- $\Delta m^2_{43} \sim 0.5\ eV^2$:
  - No distortions
  - Rate measurement
- $\Delta m^2_{43} >> 0.5\ eV^2$:
  - Distortions at ND
  - Most sensitive at low energies



Sterile Neutrinos

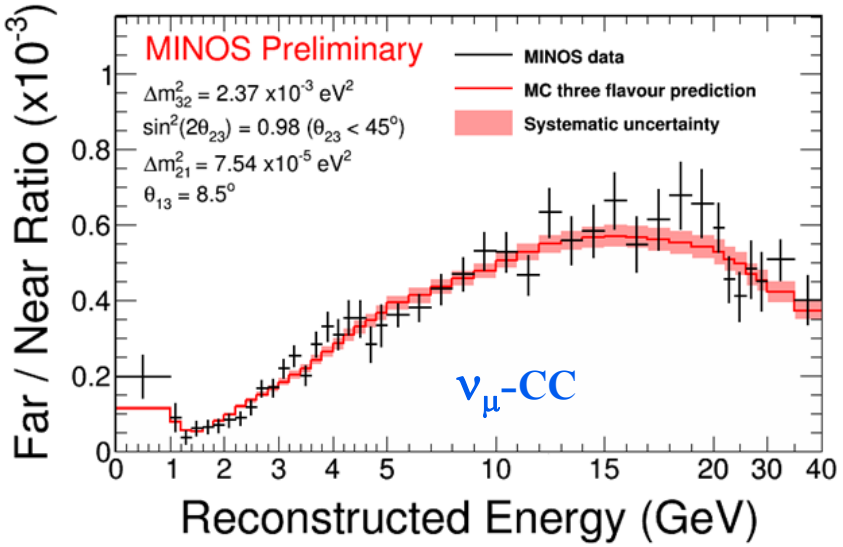


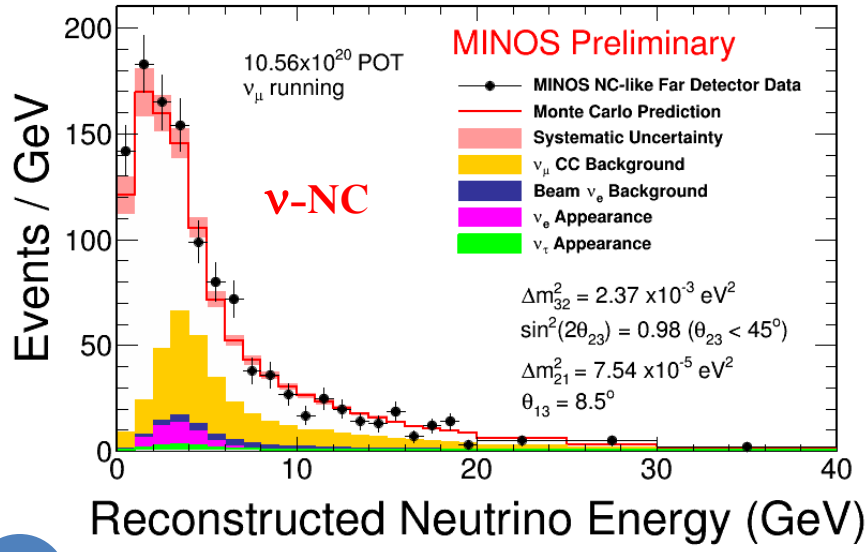


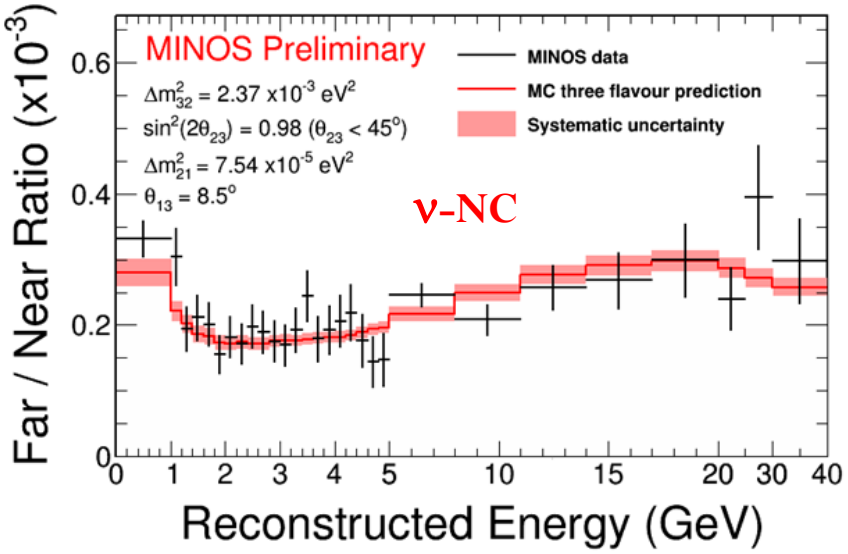
- $\Delta m^2_{43} >> 0.5$ eV^2:
  - Distortions at ND
  - Most sensitive at low energies
  - Smeared by parent decay position

Sterile Neutrinos

- Ratios of Far and Near detectors consistent with no active-sterile mixing
- ν_μ must be transforming into ν_τ
- ν_e appearance is a background in the NC sample

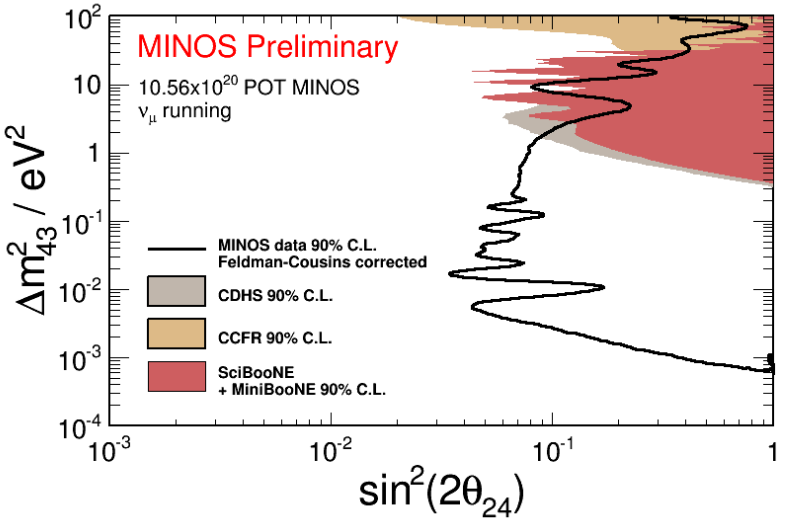


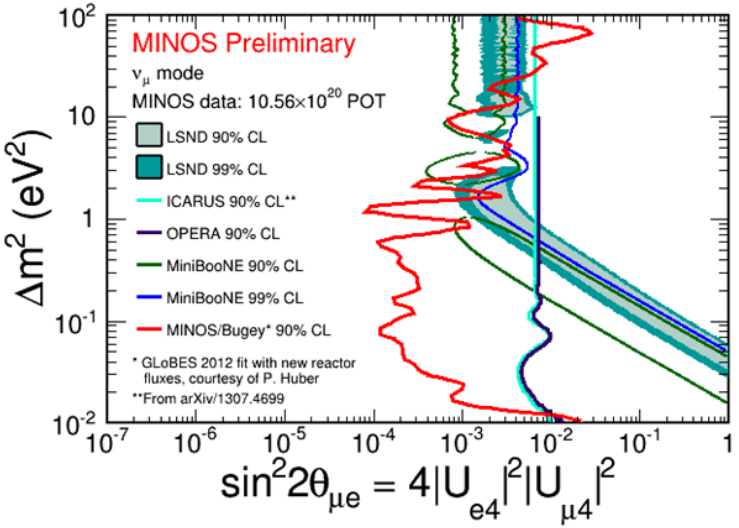




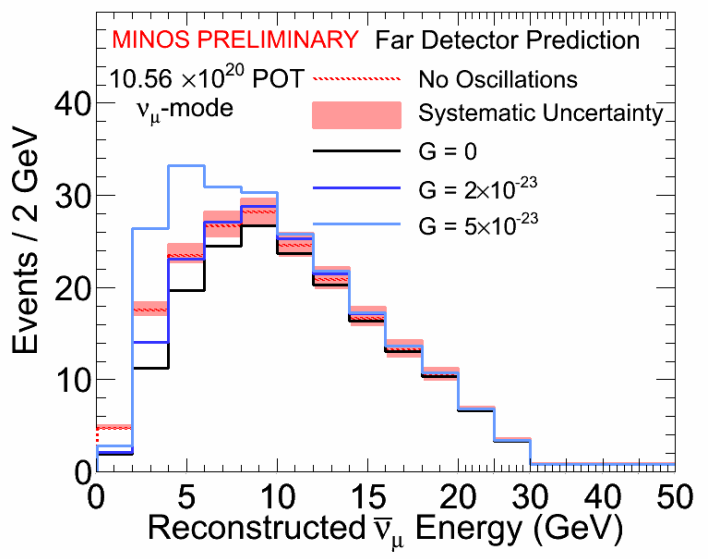
Sterile Neutrinos

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





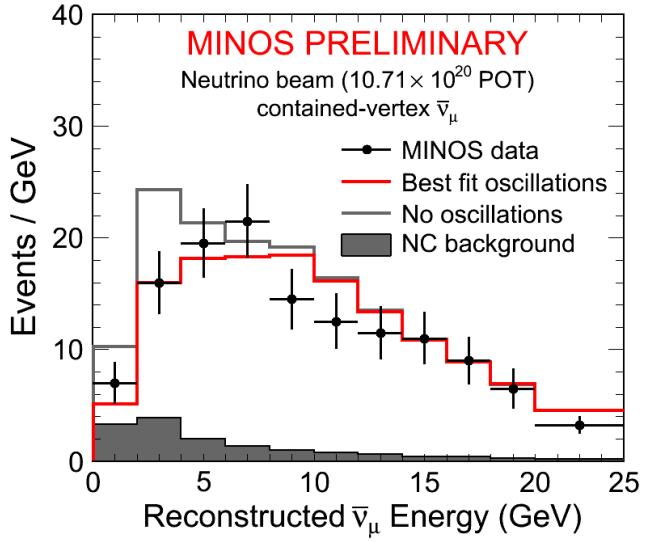
Lorentz and CPT violation

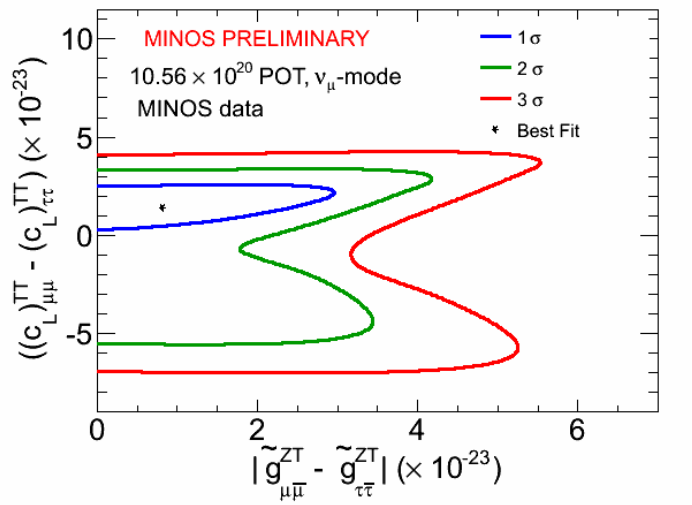


- Within the **SME** context, **CPT violation** can lead to ν-$\bar{\nu}$ transitions

- Expect excess of positive charged muons in ν-mode

Lorentz and CPT violation

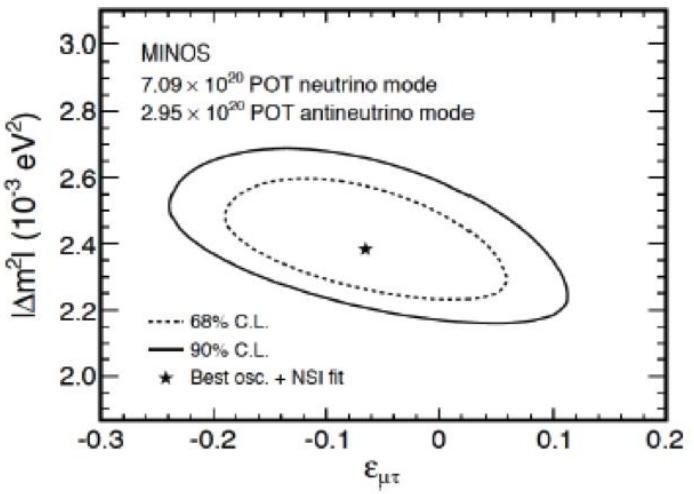


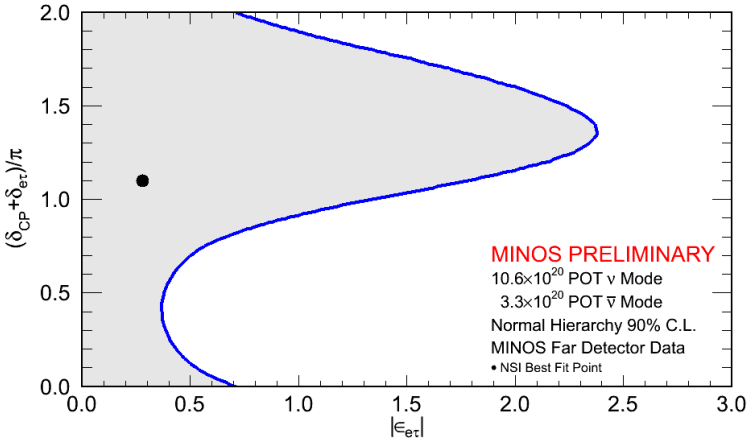


- Within the SME context, CPT violation can lead to ν-$\bar{\nu}$ transitions
- Expect excess of positive charged muons in ν-mode
- No significant excess observed
- **New limits** on SME parameters
- **7 orders of magnitude over previous limits**

Non-Standard Interactions

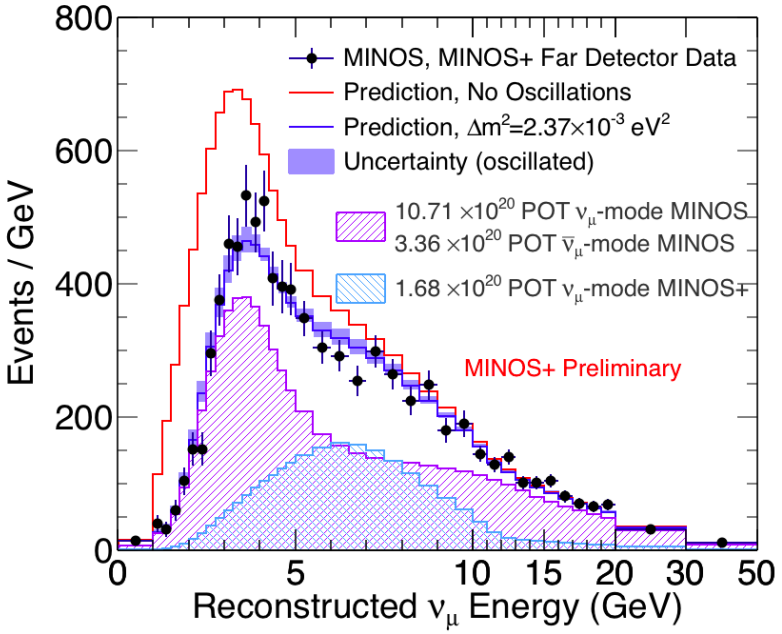
- Matter effects can significantly alter oscillation pattern
- Sensitive to new interactions beyond the Standard Model
- ν_μ **disappearance** most sensitive to μ-τ coupling **($\varepsilon_{\mu\tau}$)**
- Enhanced by comparing ν_μ and $\bar{\nu}_\mu$
- ν_e **appearance** most sensitive to e-τ coupling **($\varepsilon_{e\tau}$)**
- No evidence of non-standard interaction in MINOS data

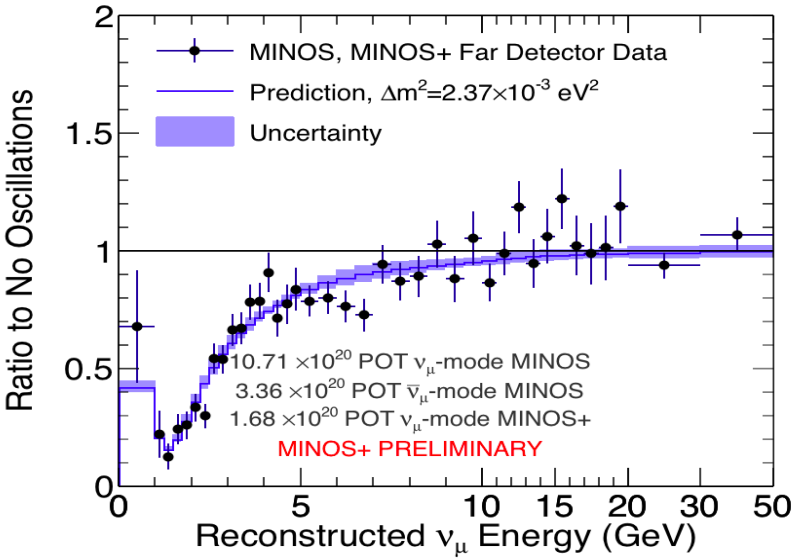




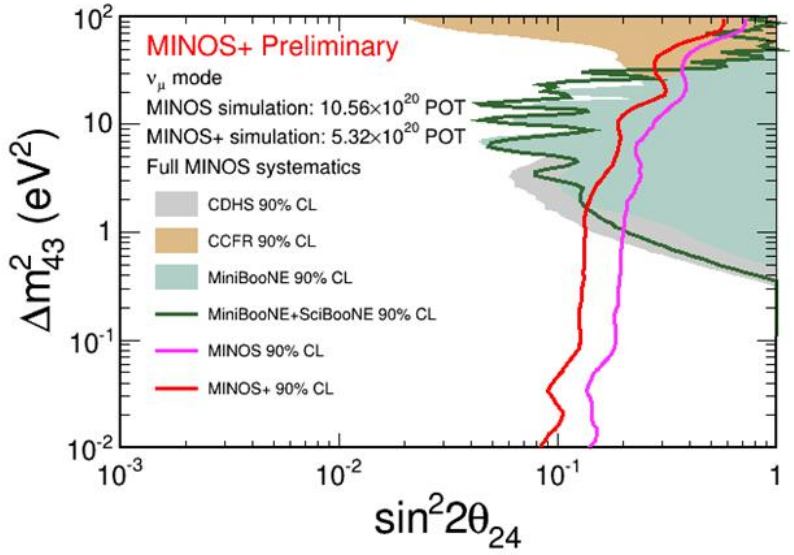
MINOS+ Data

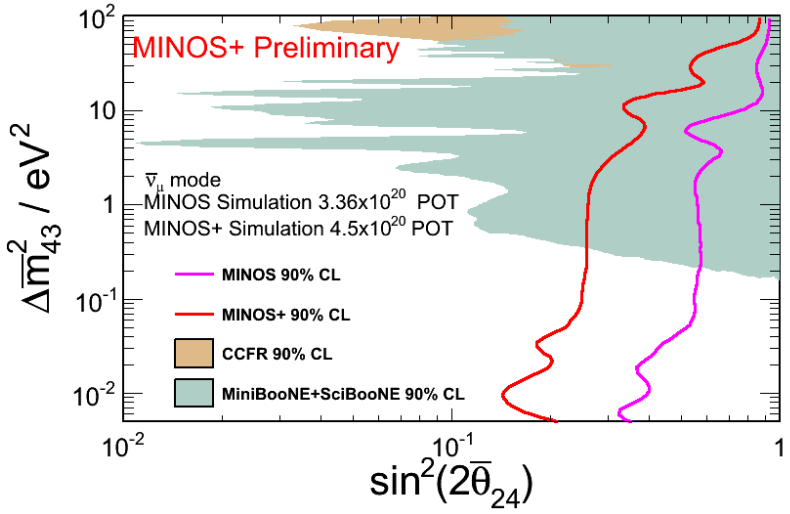
- **More beam data** from MINOS+
- Preliminary look agrees with expectations based on MINOS era
- Already collected 30% more PoT
- Higher energy beam $\Longrightarrow$ events in MINOS+ era > MINOS era
- **Improved sensitivity to new physics:** sterile neutrinos, large extra-dimensions, non-standard interactions…





Future Sensitivity

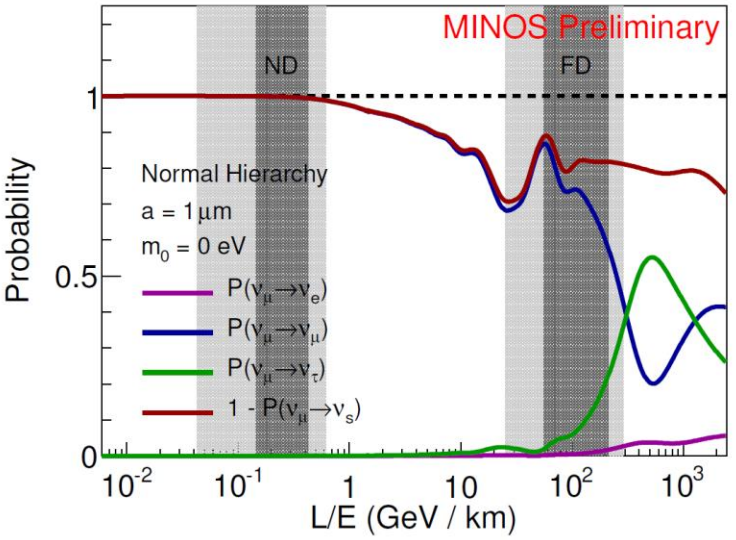


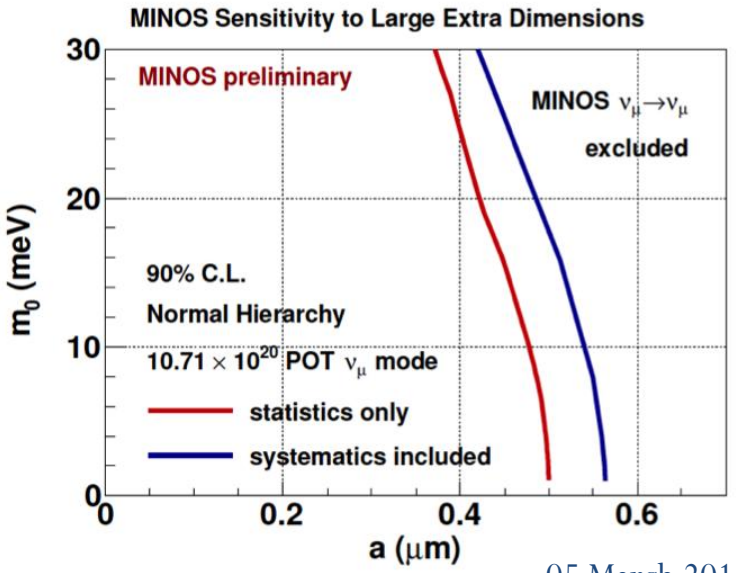


- **Improved limits** with MINOS+
- **Different energy spectra, different systematics**
- Looking also at antineutrino data
- NC sample sensitive to CP violation
- Test of CPT with CC sample

Sterile Neutrinos in LED

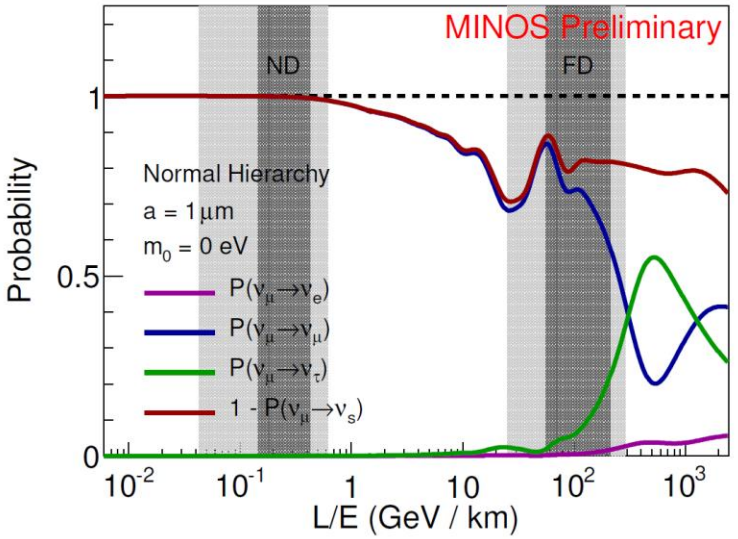
- What if sterile neutrinos travel in **extra dimensions?**
- Probe the size of largest extra dimension
- Also depends on the smallest neutrino mass
- Able to **probe** size of extra dimensions **~0.55 μm**

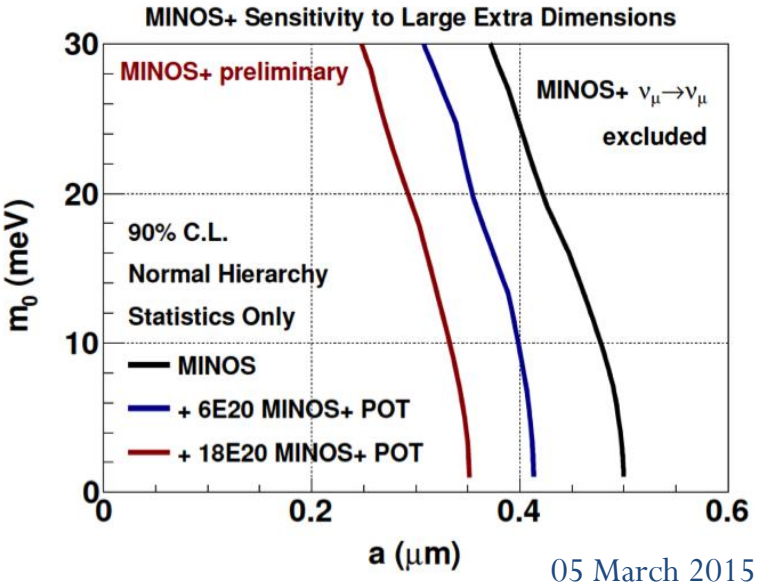




Sterile Neutrinos in LED

- What if sterile neutrinos travel in extra dimensions?
- Probe the size of largest extra dimension
- Also depends on the smallest neutrino mass
- Able to probe size of extra dimensions ~0.55 μm
- MINOS+ will **improve** sensitivity to **~0.4 μm in 3 years**



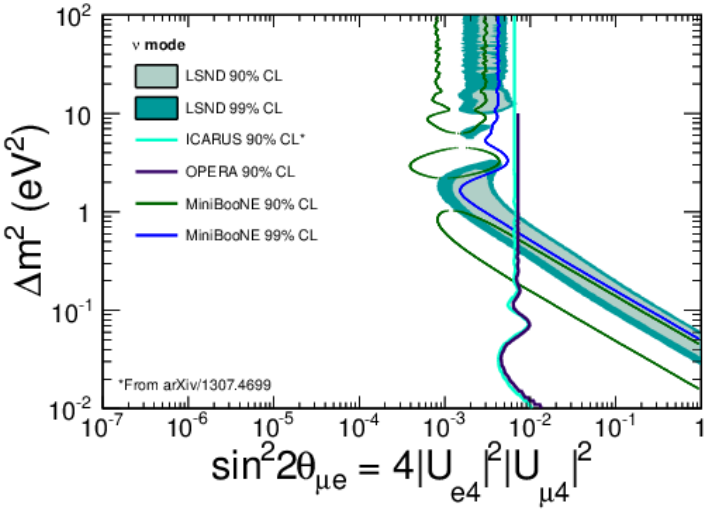


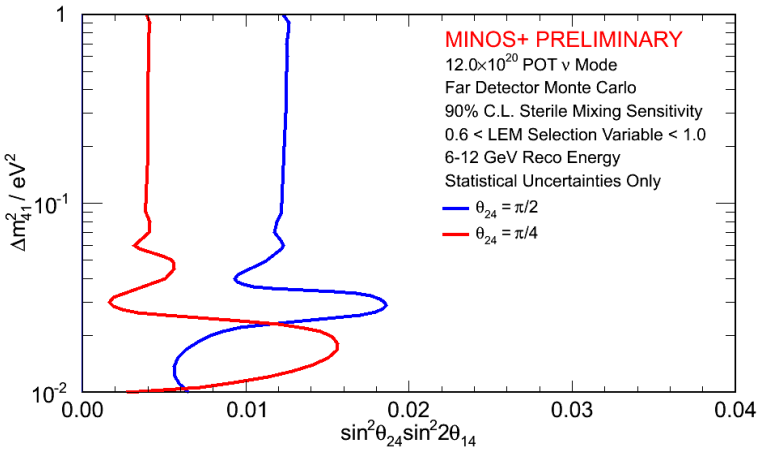
ν_e Appearance

- MINOS+ will also be sensitive to ν_e appearance from active-sterile neutrino mixing

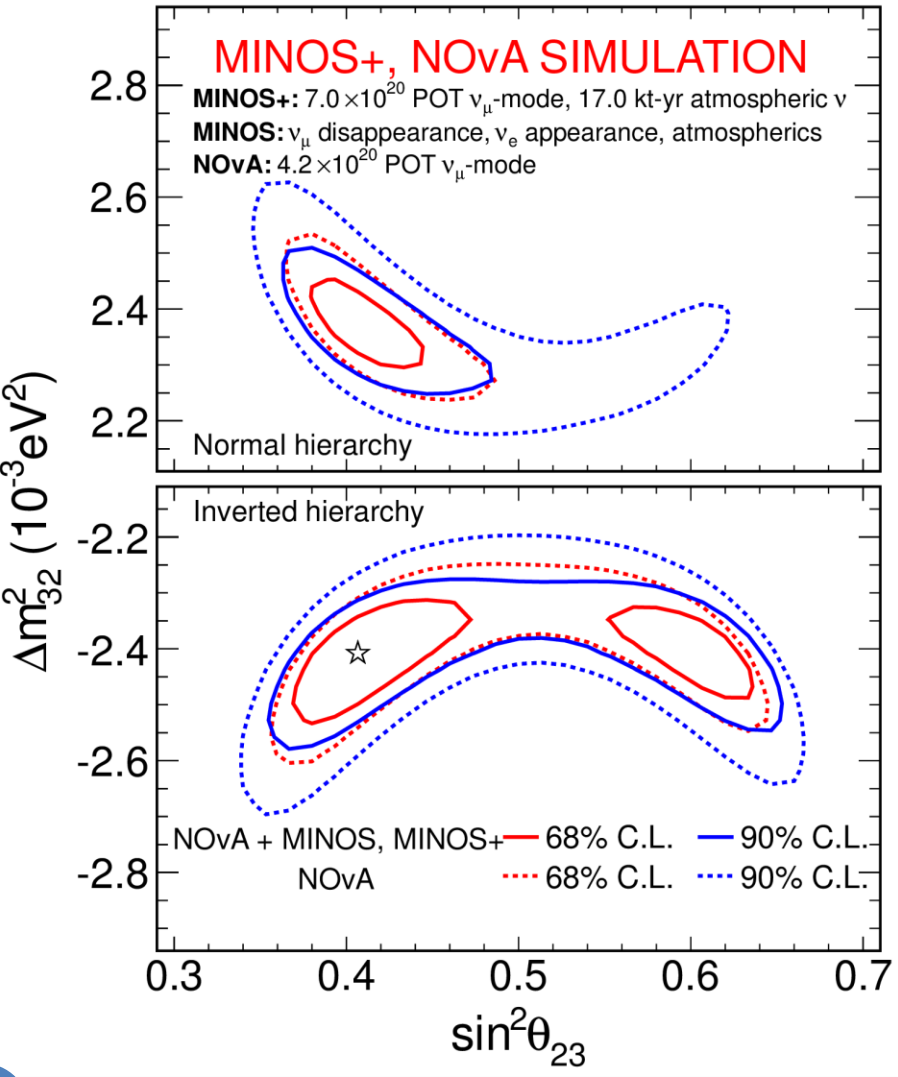
- **Sensitivity similar to ICARUS and OPERA** with 12 x 10^{20} PoT

- Difficult measurement due to interference of 3-flavor and 4-flavor oscillation terms





Sensitivity w/ MINOS+ and NOvA



- Expect this sensitivity by **late 2015**

- Enhanced with NOνA and MINOS+ combination

Summary

• MINOS has made world leading measurements of neutrino oscillations.

• Sterile neutrino search has excluded most of LSND & MiniBooNE allowed regions

• MINOS+ has just started and exciting results on exotic models are coming soon.

• 4.6 x 10^{20} PoT already collected!

• Stay tuned.

Thank you