SBL Focus Group

Options

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Goals

- In the context of world-wide sources and detectors being explored, determine if a set of source and detector options that Fermilab could implement would determine whether or not existing anomalies in neutrino physics are due to oscillations to sterile states (e.g. Reactor, source, LSND, MiniBooNE, cosmology)
- Look at immediate opportunities but also consider what future options might be available with, for example, LBNE and/or Project X

Options cont.

- What are the variables when considering options?
  - Facilities (wide-band beams, DAR sources, Nu factories, …)
  - Physics (appearance, disappearance, flavor of neutrino)
  - Detector technology (liquid argon, mineral oil, water, …)
- Would like to have at least two detector locations so that systematic errors may be largely cancelled
- Point out near-term opportunities that use existing or already planned beams

Sterile Neutrino Characteristics

- All experiments produce an active neutrino and detect an active neutrino
- If there are extra sterile states they are never observed directly, but they do add extra mass states to the picture
- The result of this is that the active-active oscillations are not unitary, because of the presence of the sterile state in the neutrino beam
- Disappearance will in general be much larger than appearance when considering active-active transitions with sterile states present

  - Disappearance: ~ $|U_{es}|^2 + |U_{\mu s}|^2$ - first order amplitude (large)
  - Appearance: ~ $|U_{es}U_{\mu s}|^2$ - second order amplitude (small)

- For example an appearance of <1% can imply a disappearance of ≈ 10%

SBL Beam Technology Options

	ν_e	$\bar{\nu}_e$	ν_μ	$\bar{\nu}_\mu$	ν_τ
Radioactive sources	Disapp	Disapp	No	No	No
Reactor sources	No	Disapp	No	No	No
Spallation sources	Disapp	App	Yes (NC)	Disapp(?)	No
Medium energy proton source s (e.g. Fermilab Booster, Off-axis NuMI	App	App(rate?)	Disapp	Disapp	No
High energy proton source s(e.g. Main Injector, SPS)	App	App	Disapp	Disapp	App
Low intensity muon storage rings	Disapp /App	Disapp/App	Disapp/App	Disapp/App	No
Beta beams	Disapp	Disapp	App	App	App(?)
Neutrino Factory	Disapp /App	Disapp/App	Disapp/App	Disapp/App	App?

One or more experiments?

- Wide-band beam (liquid argon TPC at BNB):
  - $\nu_\mu \rightarrow \nu_\mu$
  - $\nu_\mu \rightarrow \nu_e$
  - Photons?
- Decay-at-rest stopped muons (oil+scintillator at FNAL/SNS):
  - $\nu_\mu \rightarrow \nu_\mu$ (stopped π decay, single energy 30 MeV)
  - $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
  - $\nu_e \rightarrow \nu_e$ (e.g. $^{12}N_{gs}$)
- Long baseline beam (MINOS+)
  - $\nu_\mu \rightarrow \nu_\mu$ (especially good at $\Delta m^2 < 1 eV^2$)
- Source and reactor experiments
  - $\nu_e \rightarrow \nu_e$

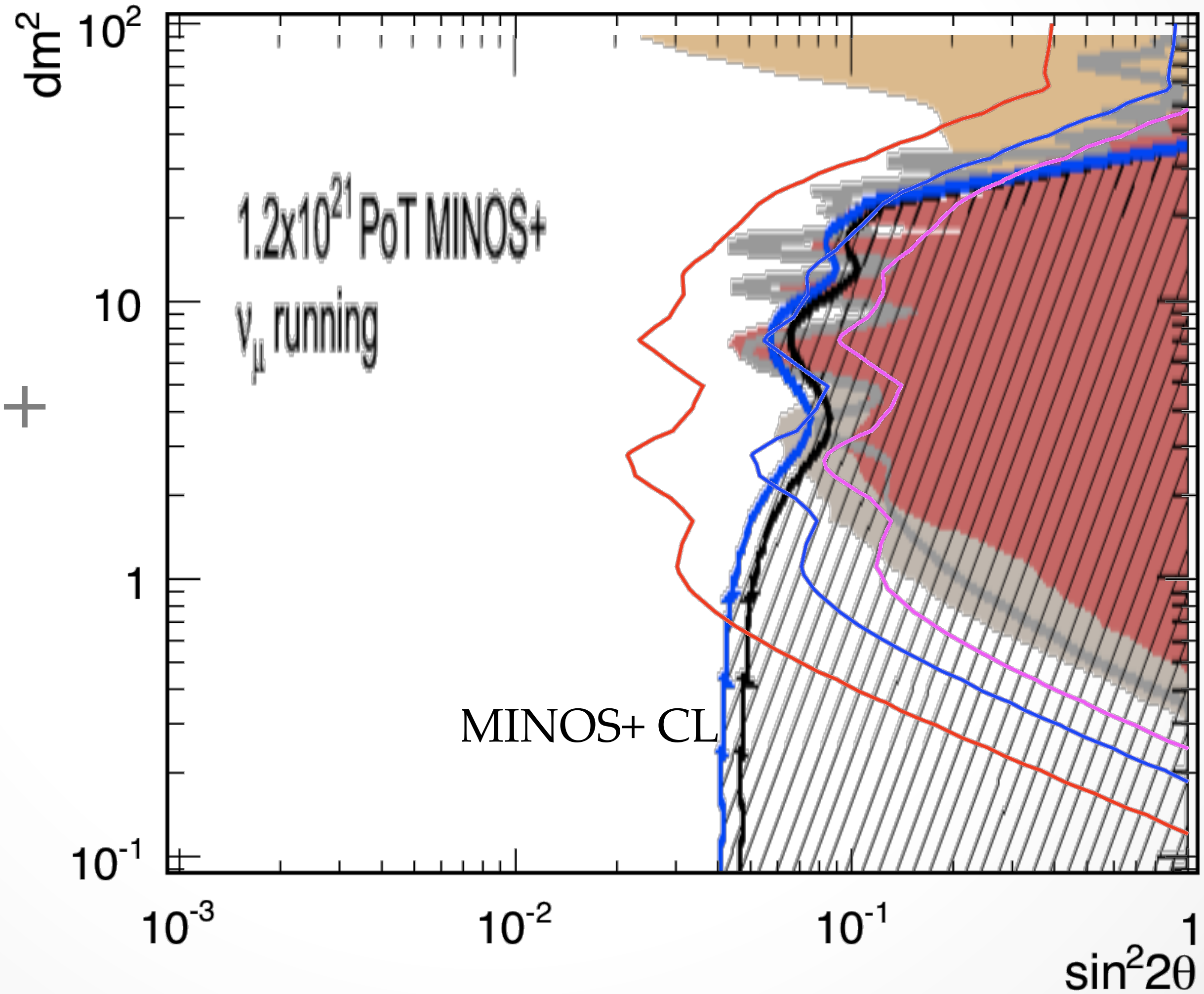
- What combinations are the most effective?

Many Interesting Ideas

- BooNE: constructing a second MiniBooNE detector on the BNB
- μ BooNE & LAr 1
- Nova beam, LBNE beam
- Stopped muon sources SNS/FNAL
- Muon storage rings
- Nu-tau appearance
- Reactor experiments
- Source experiments
- Coherent scattering
- … many others

Near Term Experiments

- MINOS+

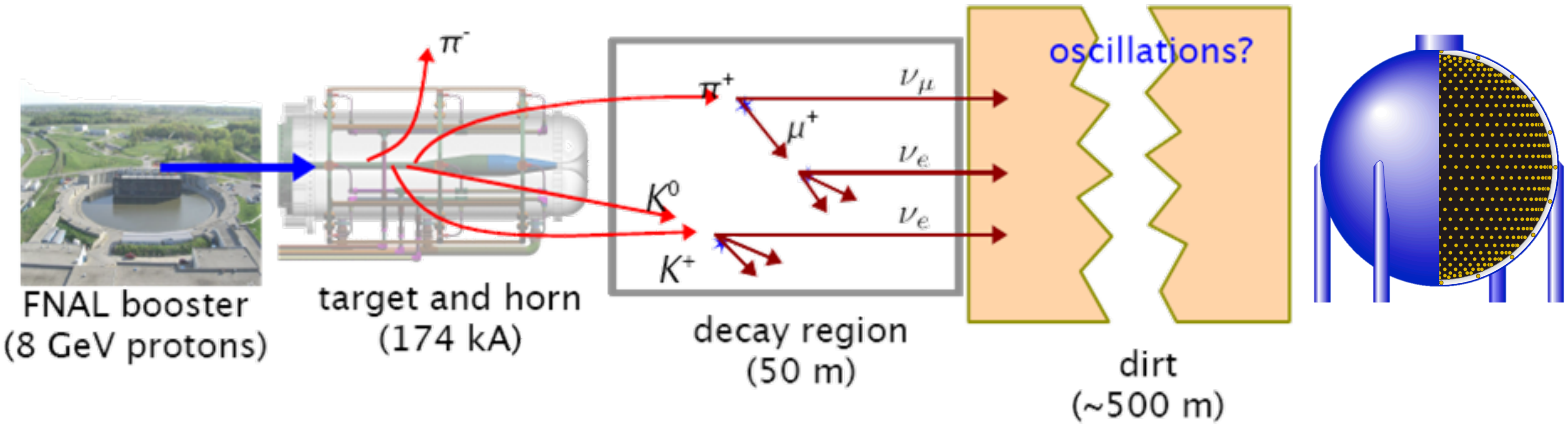


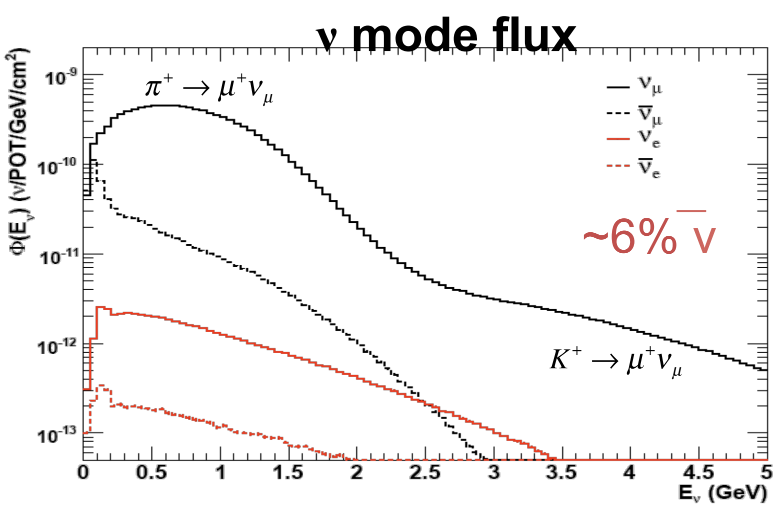
Example: Add a 1 kT Liquid argon detector to Fermilab program

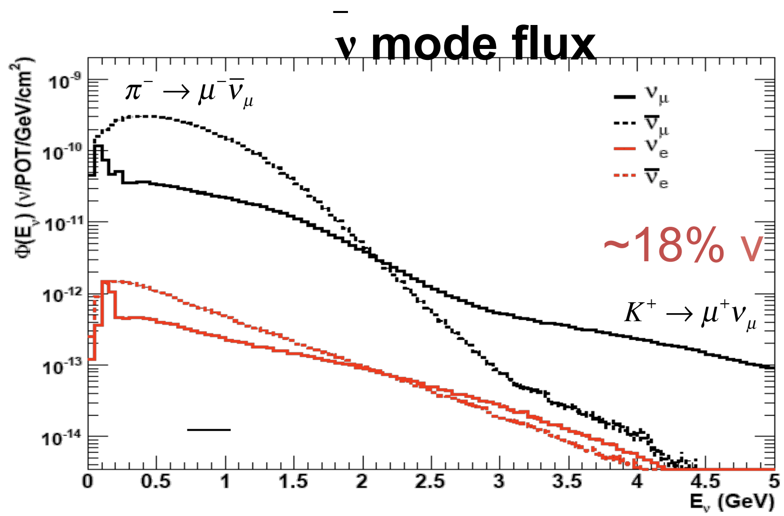
- Suppose, *for the sake of argument*, one had a modest liquid argon detector under construction at Fermilab with a mass of 70 tons
- And suppose, *for the sake of argument,* one were also forced to build a one kiloton liquid argon detector at somewhere Fermilab
- One *could* ask the following question:

"Is there a unique, best place to build the 1 kT detector, such that combined they produce the best short baseline neutrino oscillation physics?"

Booster Neutrino Beam



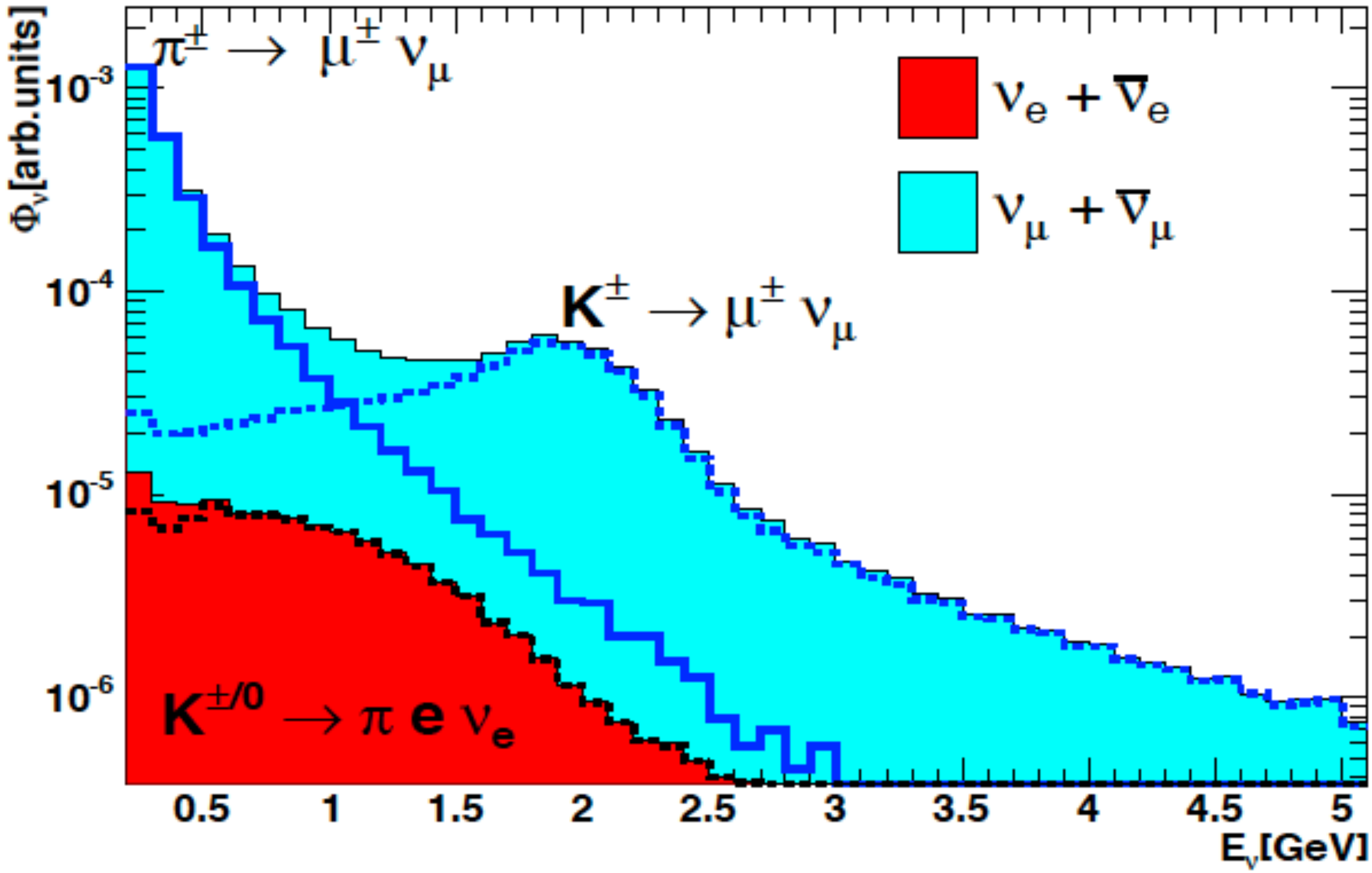




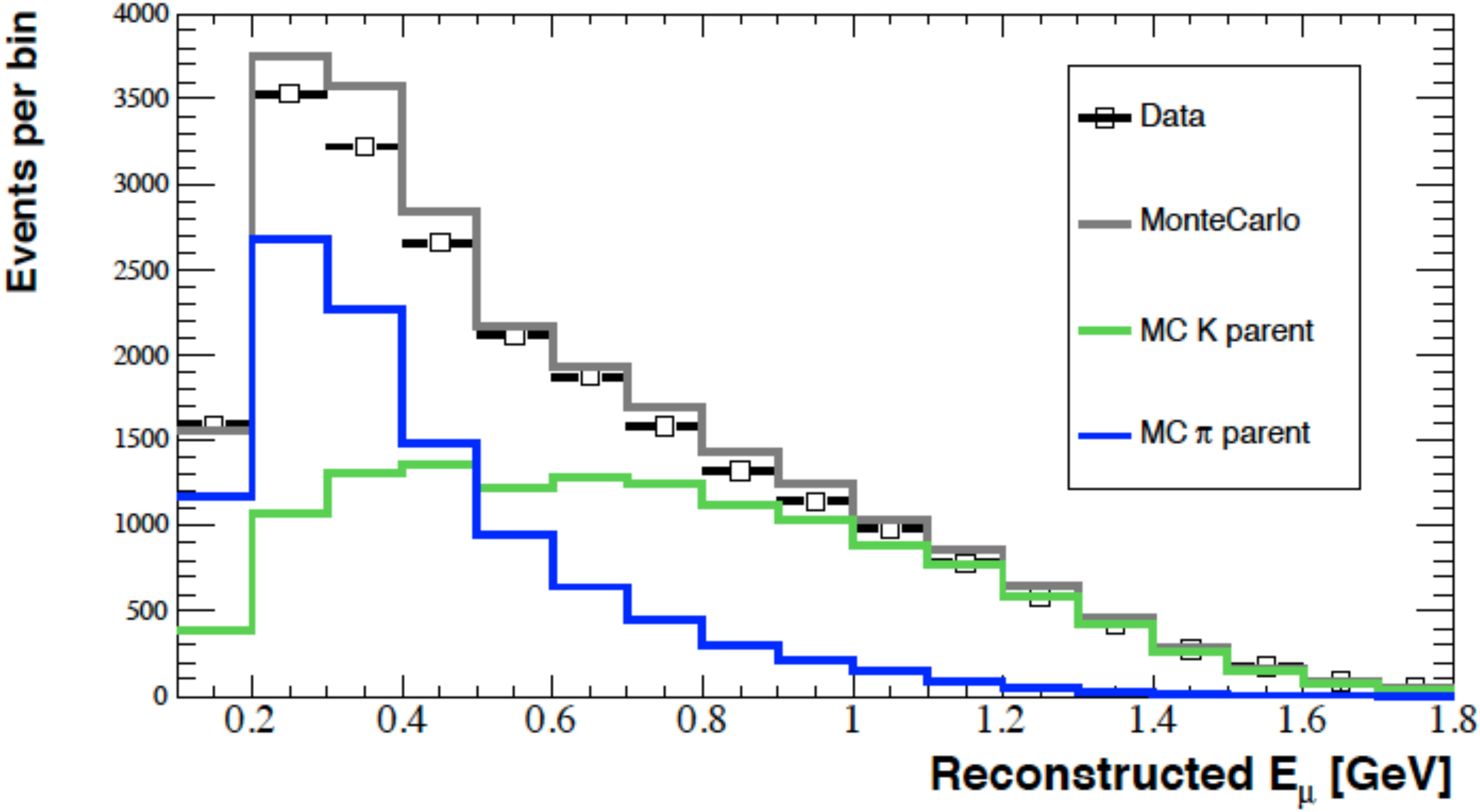
neutrino mode: $\nu_\mu \to \nu_e$ oscillation search

antineutrino mode: $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillation search

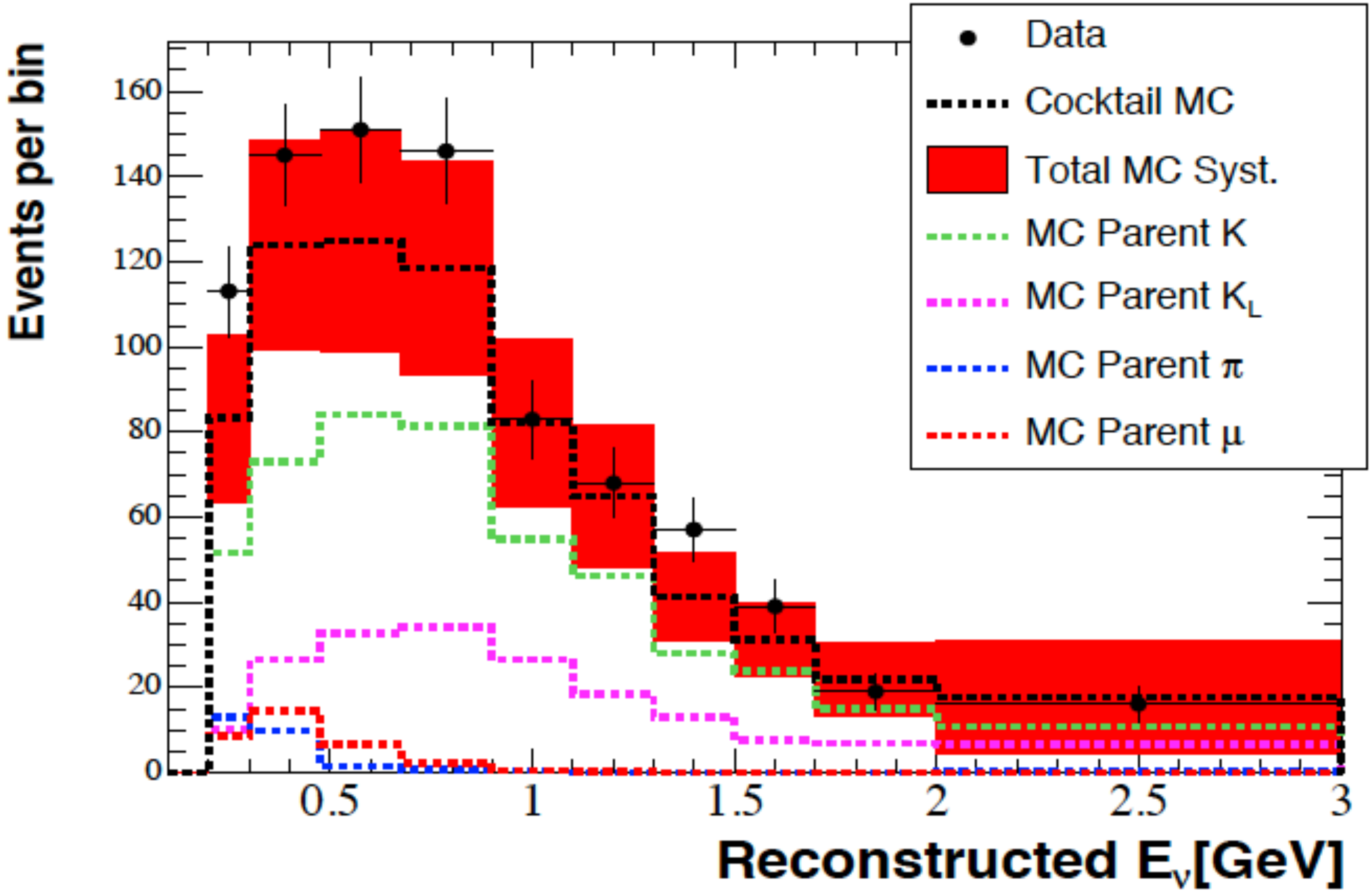
The NuMI Neutrino Beam as Seen By MiniBooNE

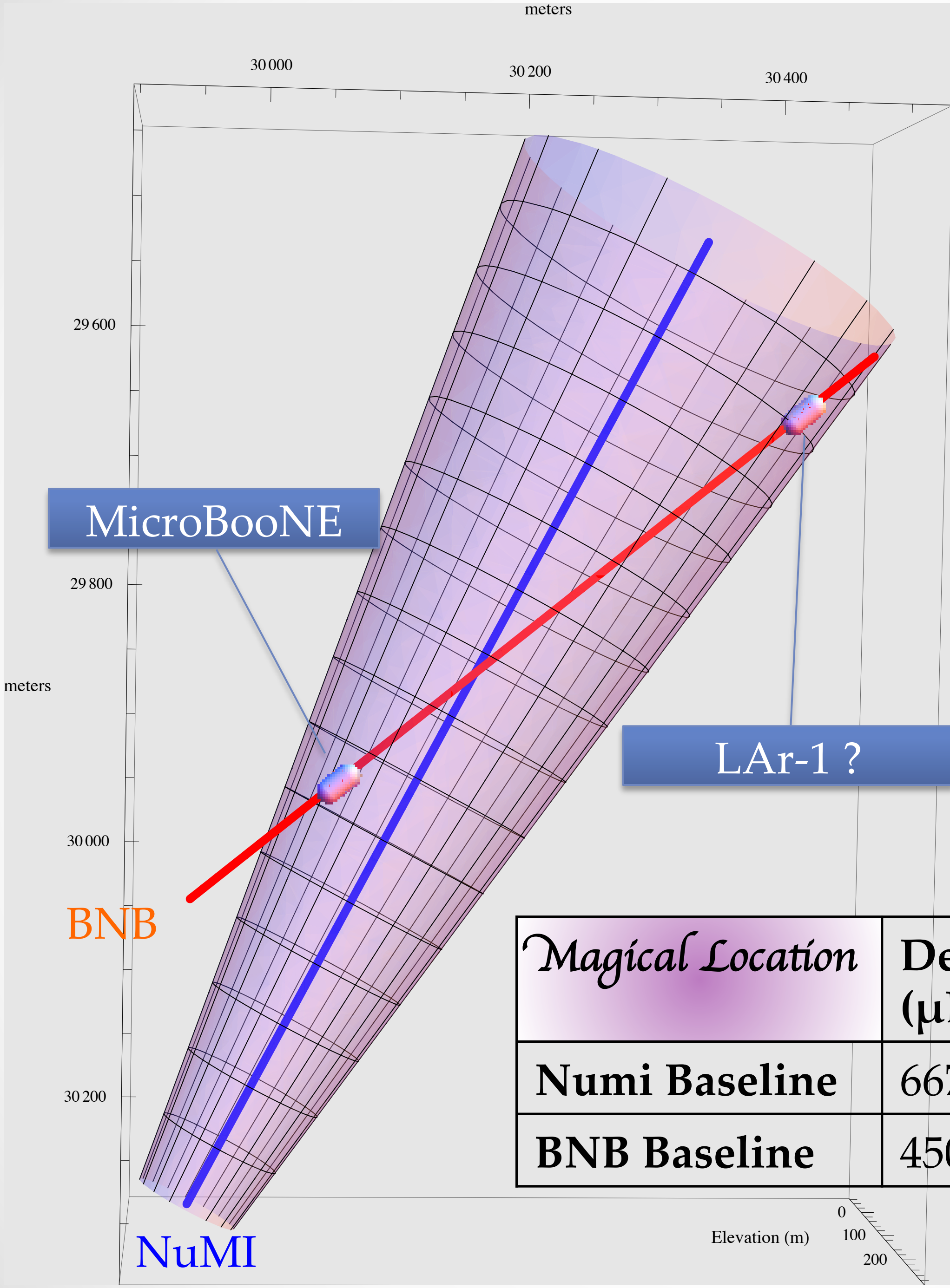


NuMI ν_μ CC Events in MiniBooNE



NuMI ν_e CC Events in MiniBooNE





Two Detectors & Two Neutrino Beams

Locate a far detector for μ BooNE such that it is:

- on-axis for the BNB
- at the same off-axis angle

Magical Location	Detector 1 (μBooNE)	Detector 2 (LAr-1)
Numi Baseline	667 m	1110 m
BNB Baseline	450	925

Possible MicroBooNE-Lar-1 Far Site

LBNE
(Little Baseline Neutrino Experiment?)

- Similar approach could be used to site experiments for LBNE
- Two surface detectors at the same off-axis angle
- Beam dives more quickly so geometry will change slightly
- Decay tunnel is shorter so that extended source size may be less of a problem

Conclusions

- There are many good ideas for approaching this problem and more are welcome
- MINOS+ and μ BooNE will weigh in next on the possibility of sterile states
- If we have left anything out please let us know!

Project X?

- The Project X concept still being developed
- Suppose, *for the sake of argument*, the Higgs is discovered at 120 GeV
- And suppose, *for the sake of argument,* HEP laboratories decided to build a 60 GeV $\mu^- \mu^+$ Higgs factory
- The proton source for such a machine, 1 16 GeV RCS, would provide a 2-5 MW neutrino source!