# Short baseline physics with NOvA

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Future Short Baseline Neutrino Experiments - Needs and Options
Fermilab
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# Short baseline options using NuMI

There are three options using the NuMI beamline that are worth study. None of these have been pursued in any great detail, however. In fact one of these (3) is something I started thinking about last week prompted by this workshop.

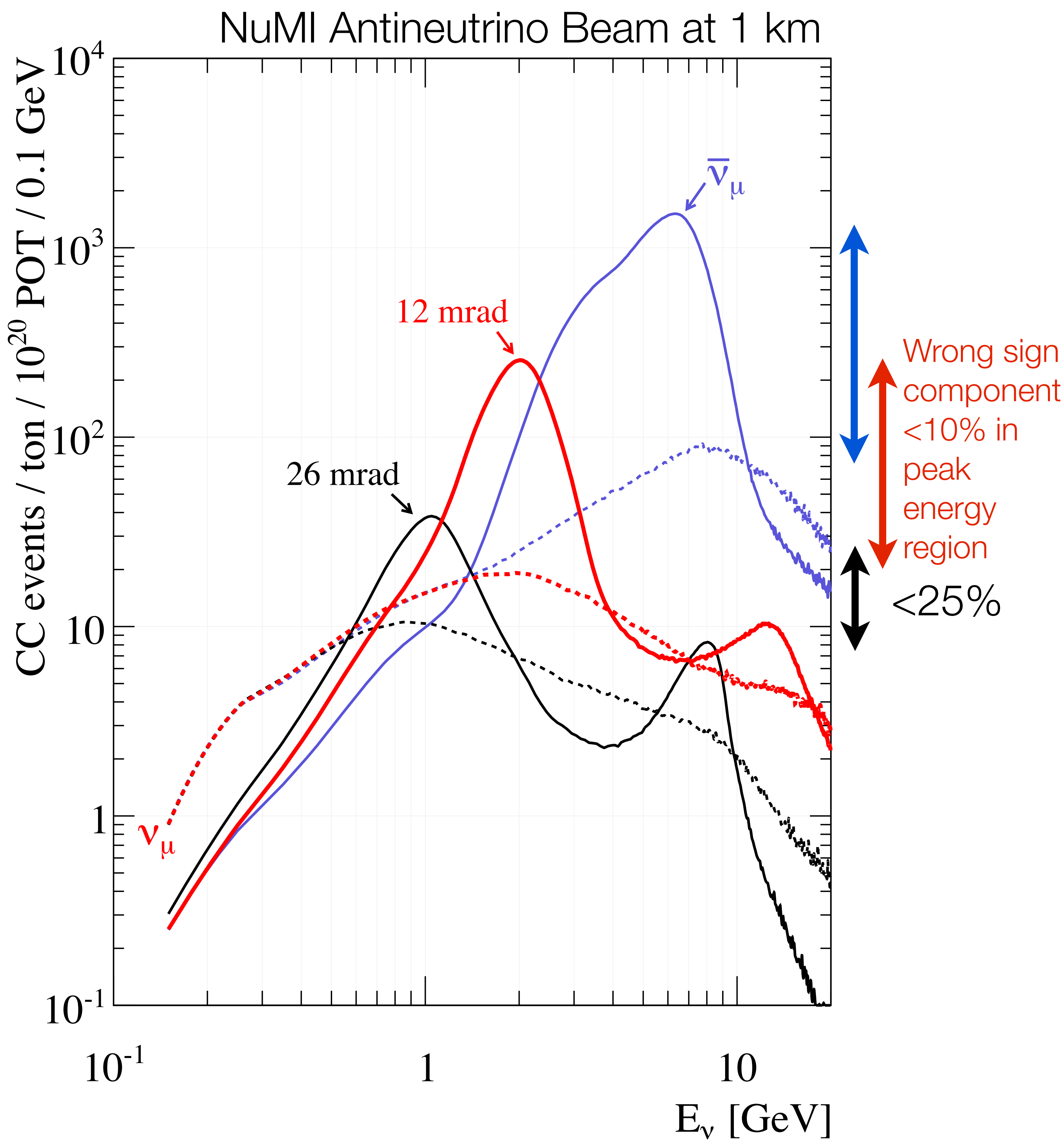
(1) Using existing NOvA prototype detector underground in a new cavern at L~1 km excavated far off-axis (24 mrad) to reduce neutrino energy to ~1 GeV. Compare rates between that detector and NOvA near detector at 14 mrad off-axis (L~1 km, E=2 GeV).

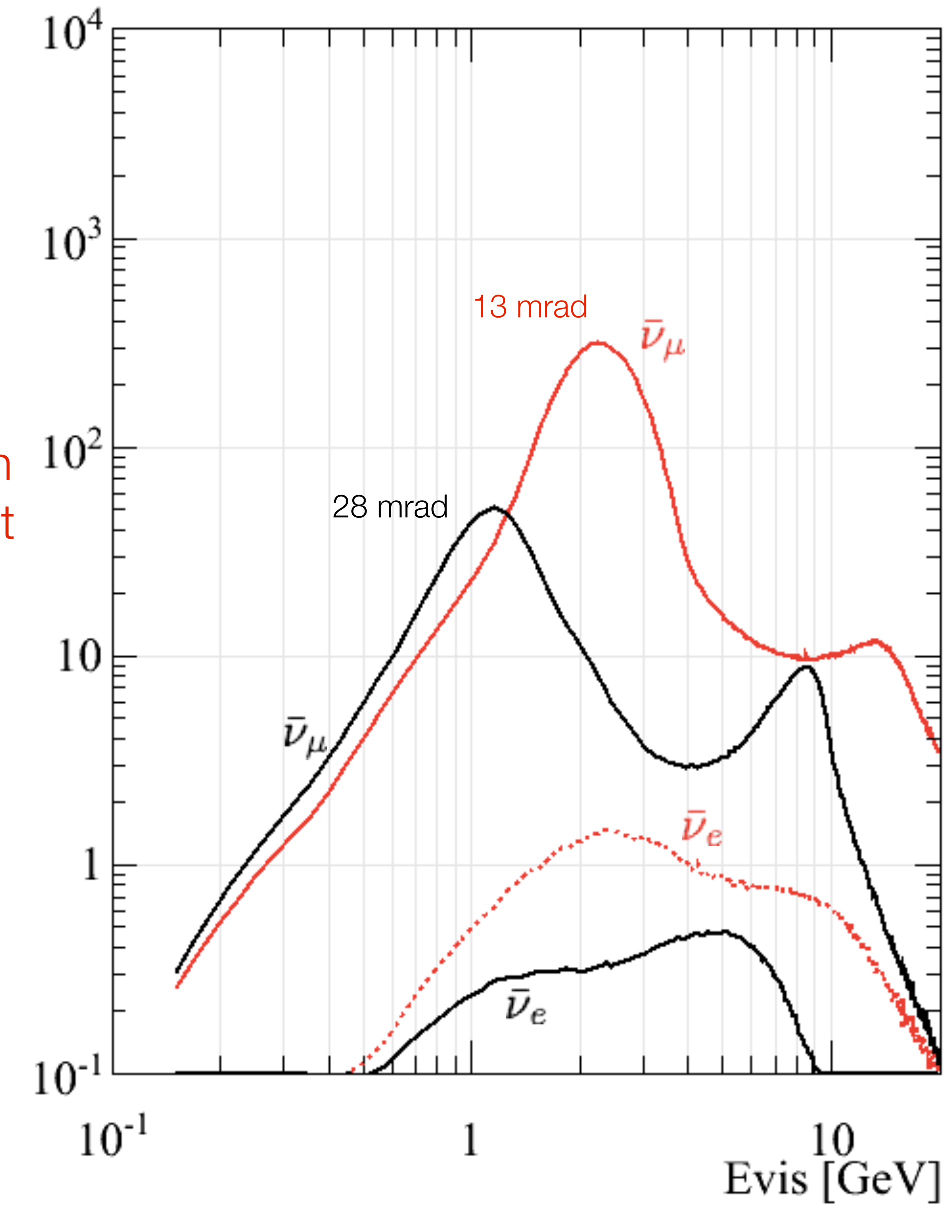
(2) Construct a new cavern at L=1.6 km and E=2 GeV (depth below surface of ~110 m). Compare rates to a near detector in the NOvA near detector cavern at L=1 km and E=2 GeV.

(3) Place multiple detectors on surface in NuMI with L's varying between 1 and 2 km

# A few general comments

- It is assumed that the signals are present in anti-neutrino beams only and hence results are shown for anti-neutrino running only, typically for 3 years of NuMI operation at 700 kW.
- Signals are assumed to be from L/E driven oscillations.
- I am most interested in the 5 sigma sensitivity curves.



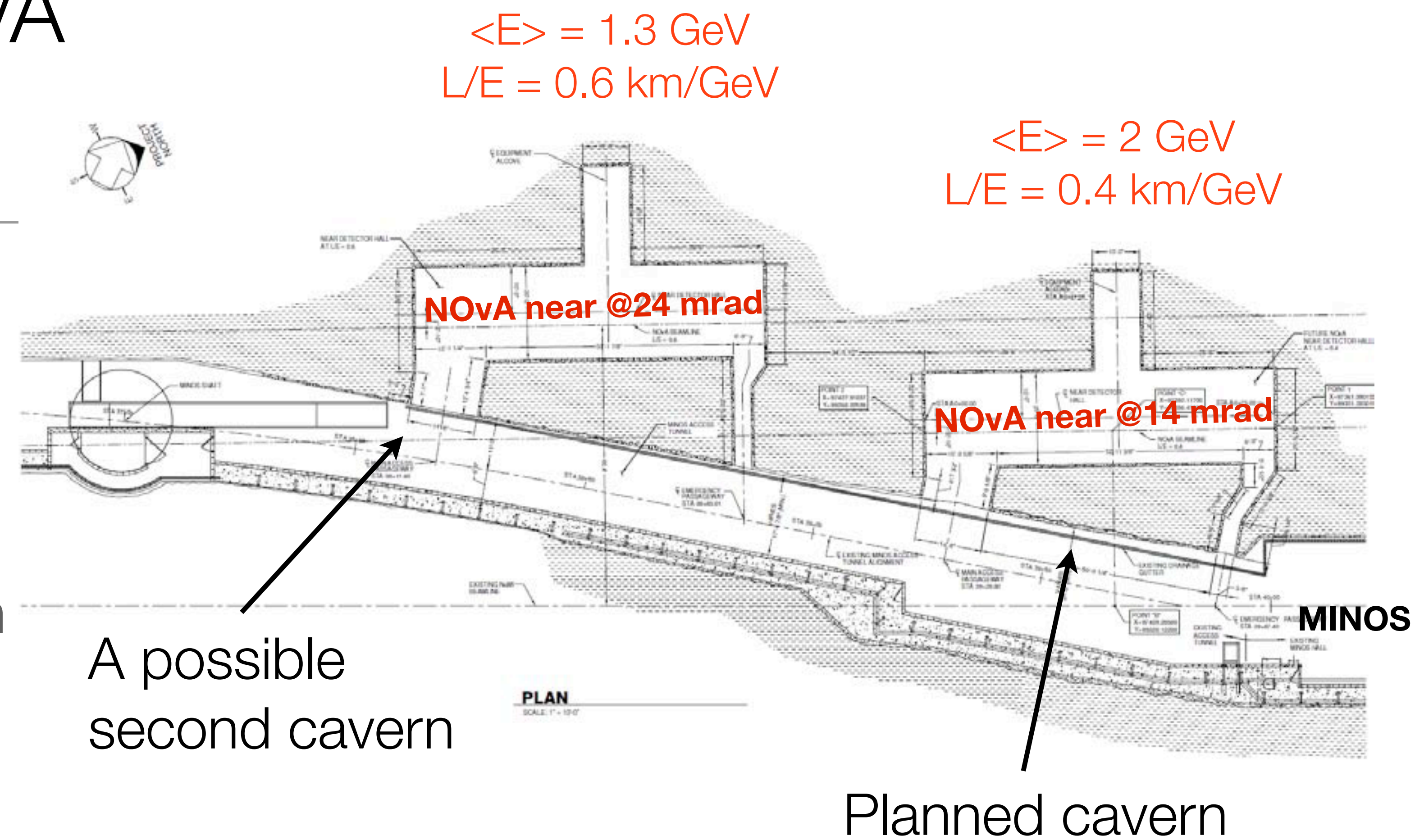

$\nu_e$ component ~1%

# The NuMI beam off-axis

# Possible additional NOvA cavern at 24 mrad

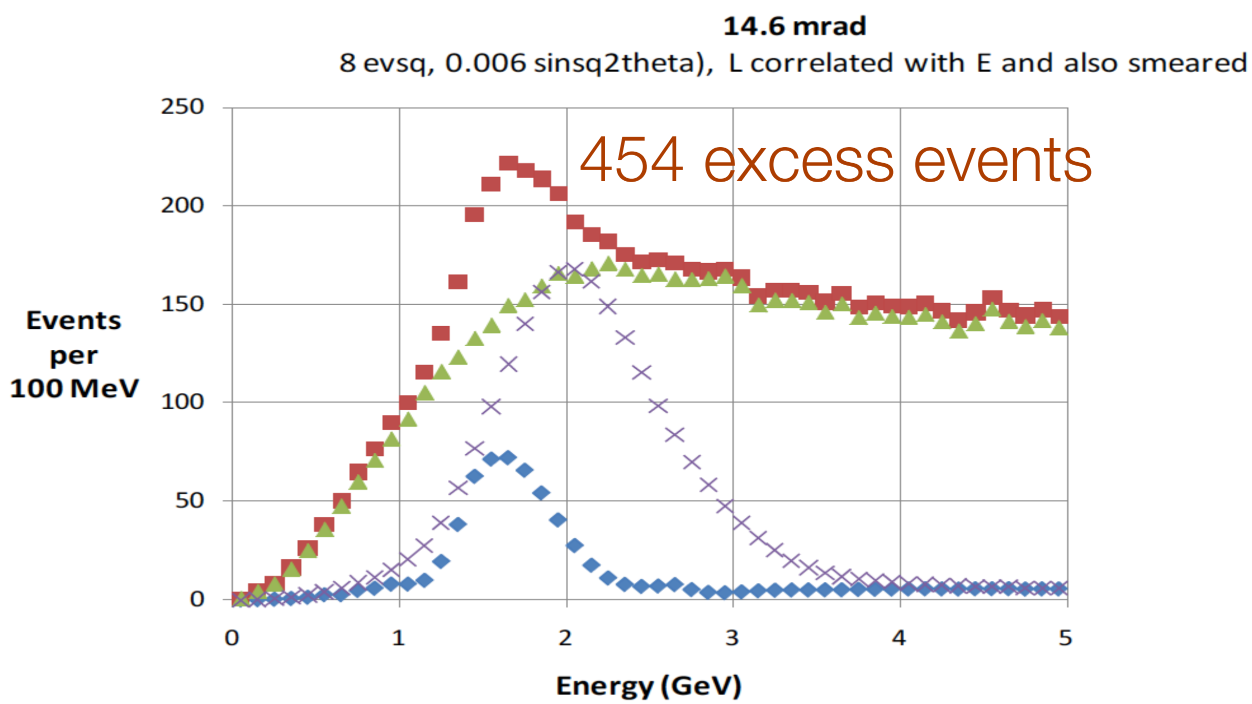
Option 1: Second NOvA near detector further off-axis

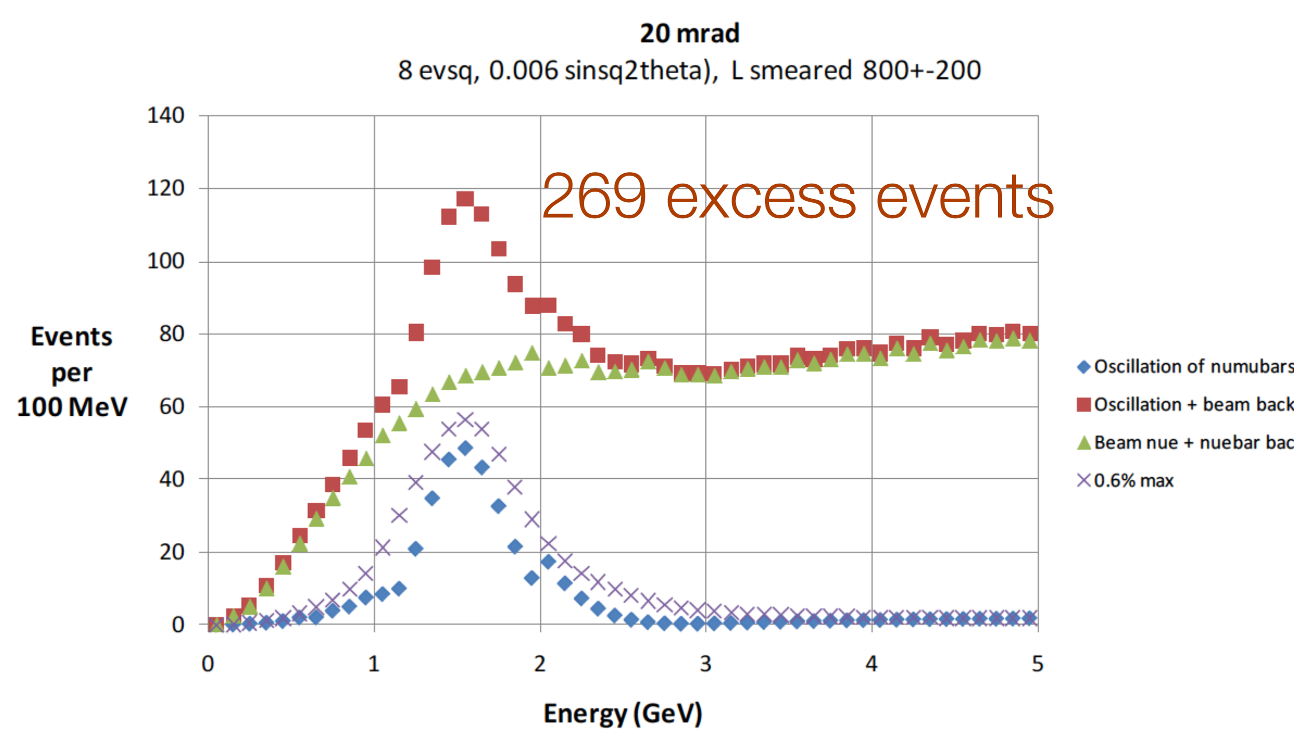
The request for proposals for the 14.6 mrad cavern has an option in it to add a second cavern at 24 mrad where the beam energy peaks at 1.3 GeV. Bids for this RPF are in, no decision yet. Decision to go ahead with second cavern is ~October of 2012.

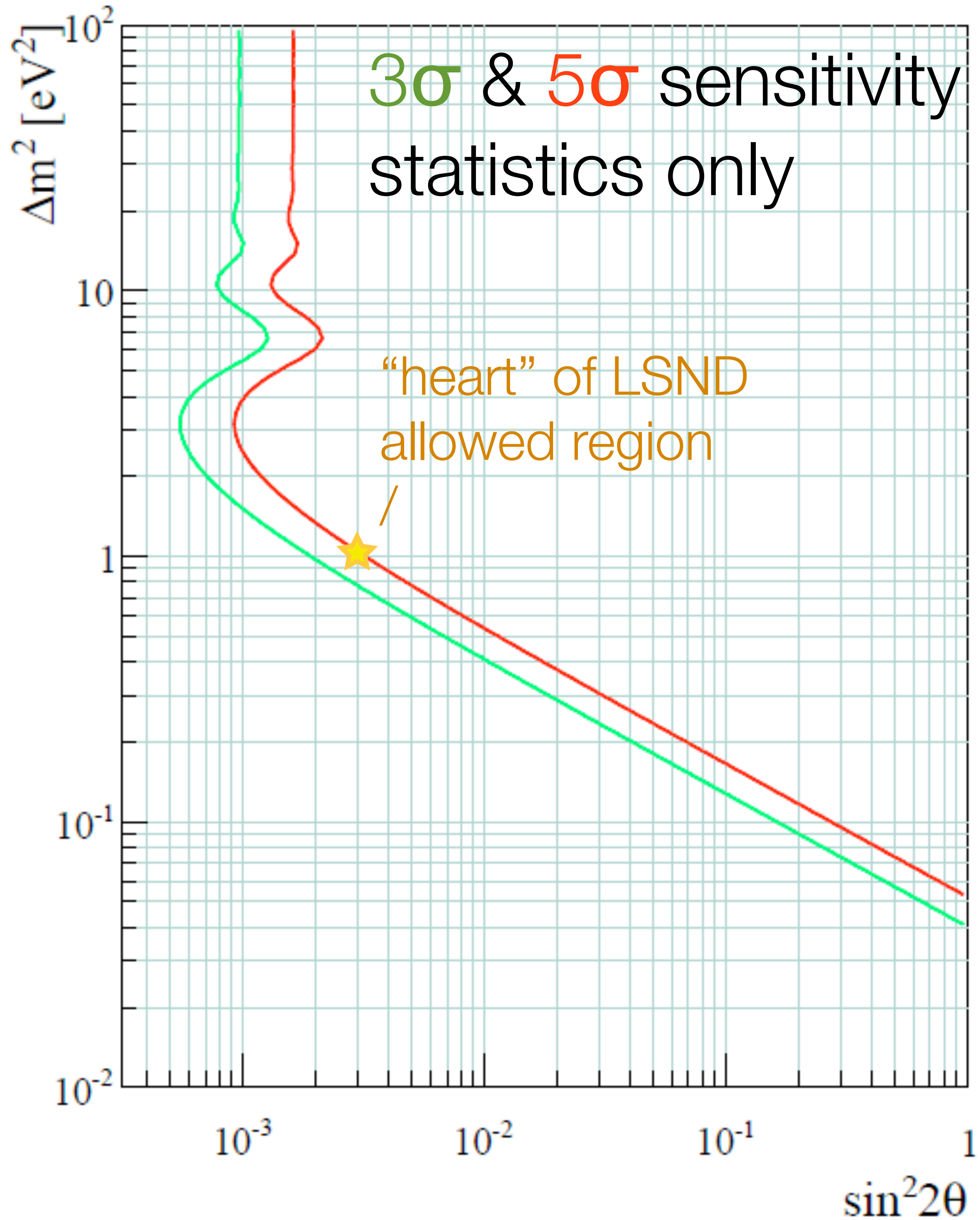



For more details see John Cooper's talk at last year's short baseline workshop https://indico.fnal.gov/conferenceTimeTable.py?confId=4157#20110512.detailed

# Possible signals in a new cavern

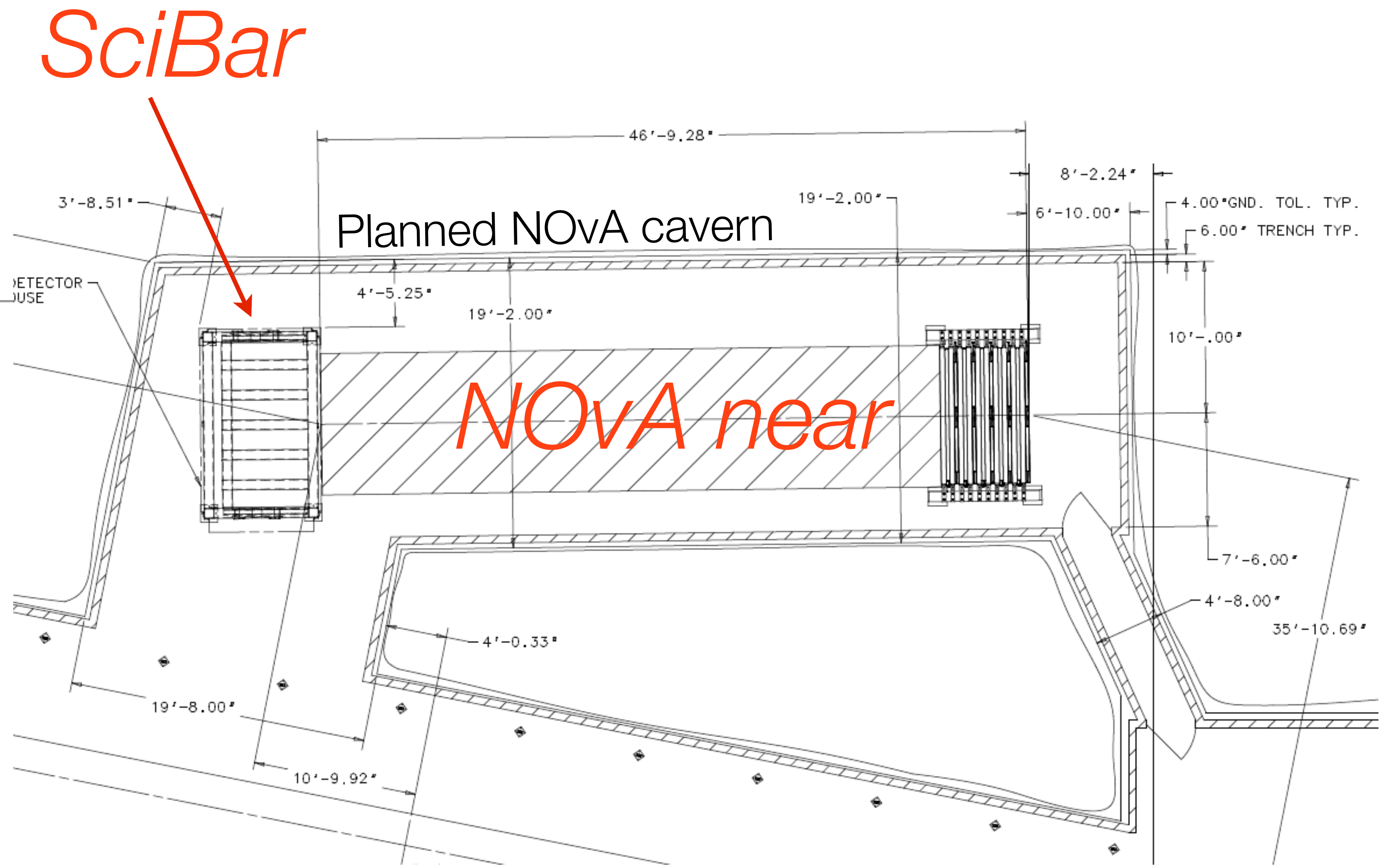


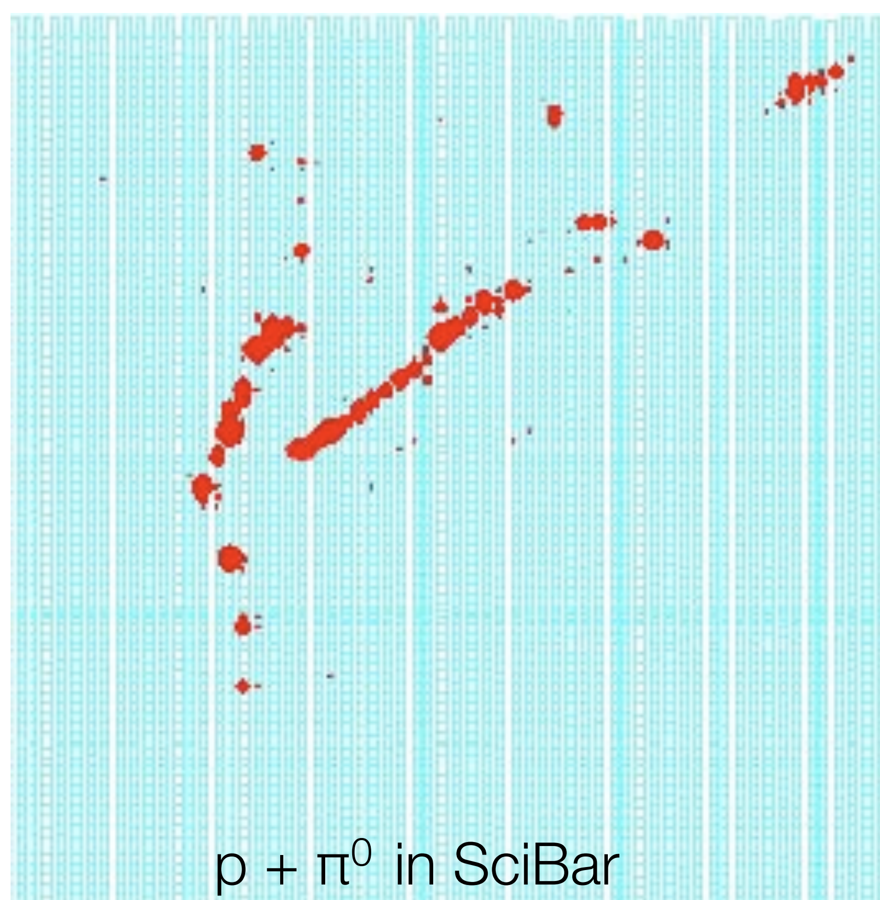



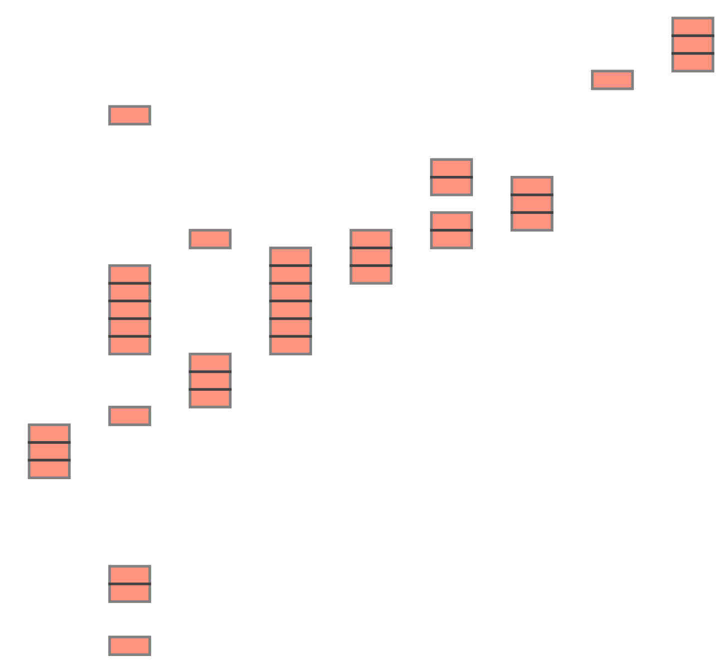



# SciNOvA

- SciNOvA is an idea to rebuild the SciBar detector used by K2K and SciBooNE and deploy it in front of NOvA near detector.
- Main motivation is to allow an in situ check of NOvA backgrounds by sampling the same beam using very similar target material, but with higher granularity. Can nearly eliminate the need for Monte Carlo estimates of instrumental background rates.
- Also enables cross-section measurements in a narrow band beam at 2 GeV





p + $\pi^0$ in SciBar

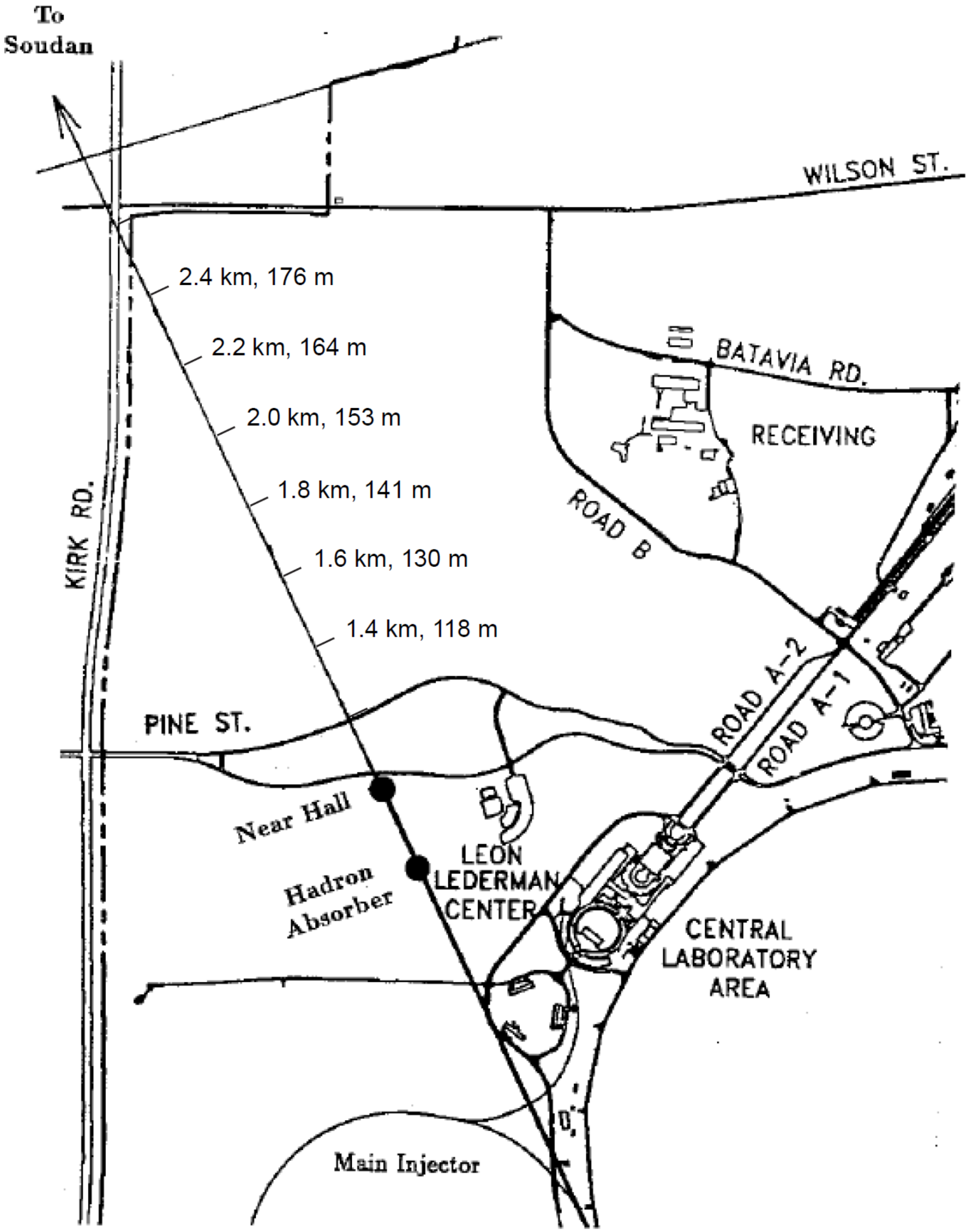

Same event resampled in NOvA

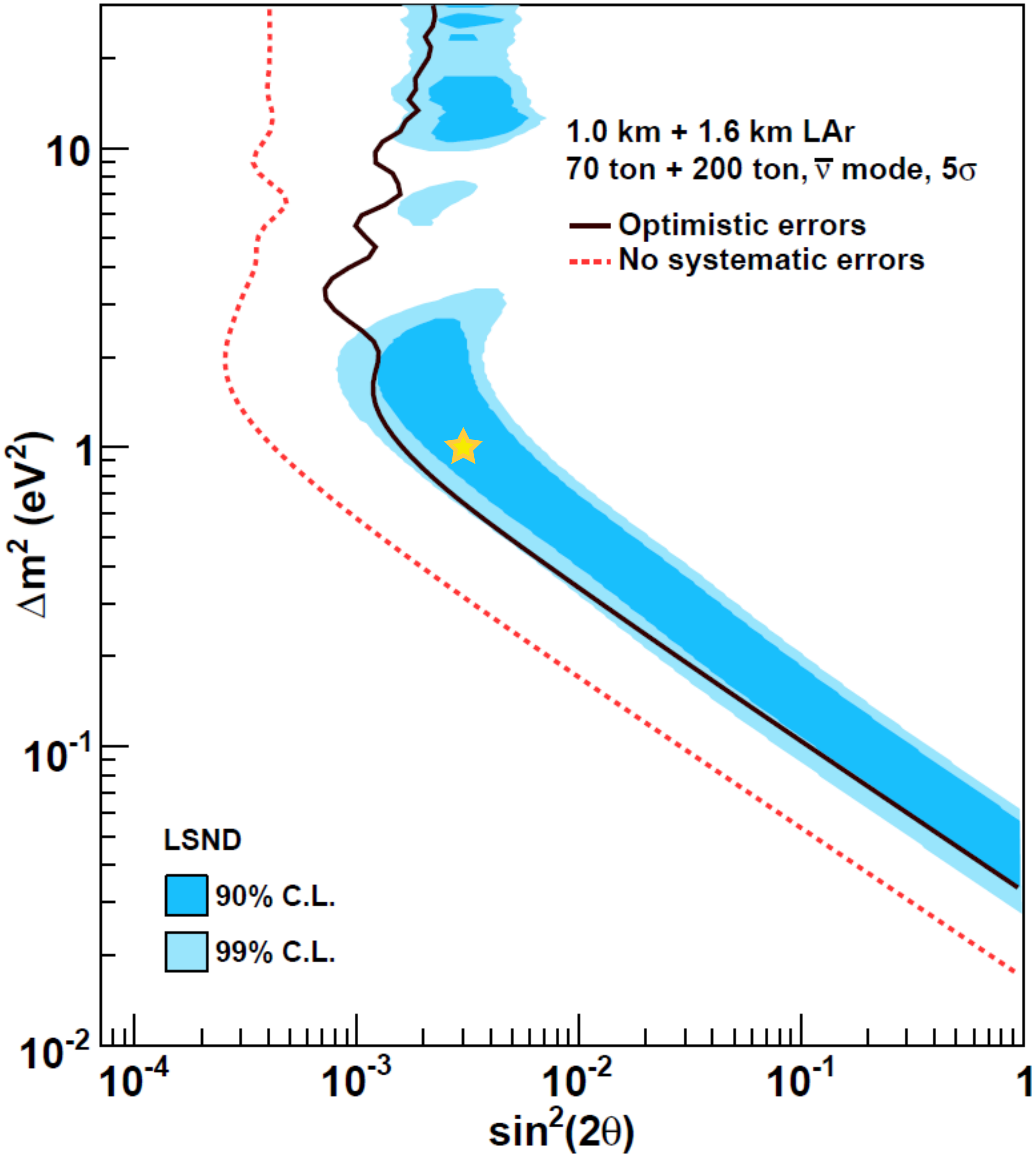
# SciNOvA event rates

| | Charged-current | Neutral-current |
|---|---|---|
| elastic | 220 | 86 |
| resonant | 327 | 115 |
| DIS | 289 | 96 |
| coherent | 8 | 5 |
| total | 845 | 302 |
| $\nu + A \rightarrow \pi^0 + X$ | 204 | 106 |

Table 1: Event rates for elastic, resonant, deep-inelastic (DIS) and coherent neutrino scattering processes for one year of running in neutrino mode for the 10 ton SciBar fiducial volume. Units are 1000's of events. Event rates for inclusive $\pi^0$ production are also shown. Rates were calculated using the GENIE [1] neutrino generator.

See Ryan Patterson's talk at Short Baseline Workshop
https://indico.fnal.gov/conferenceTimeTable.py?confId=4157#20110512.detailed

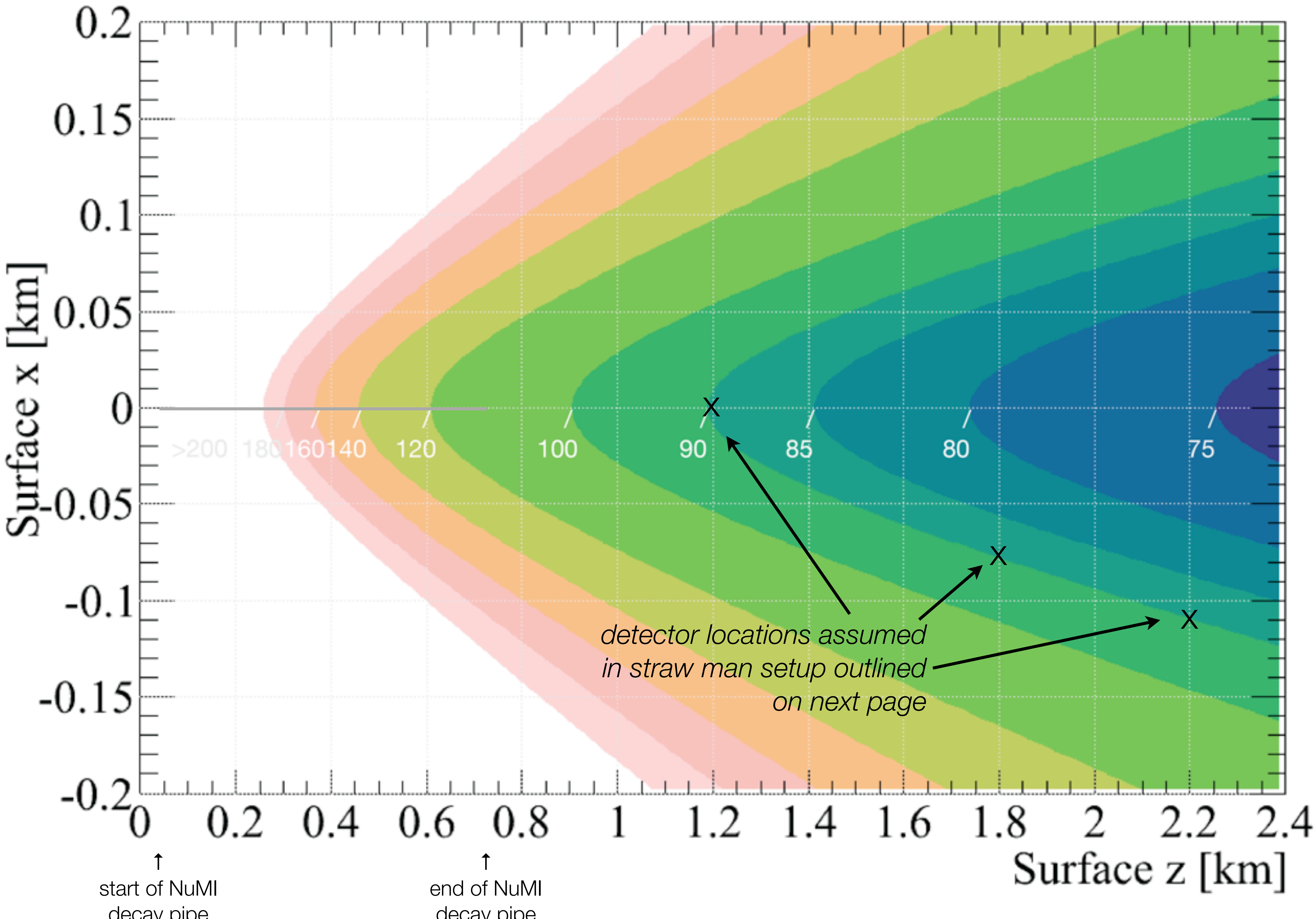



# Option 2: Second detector at 2 km

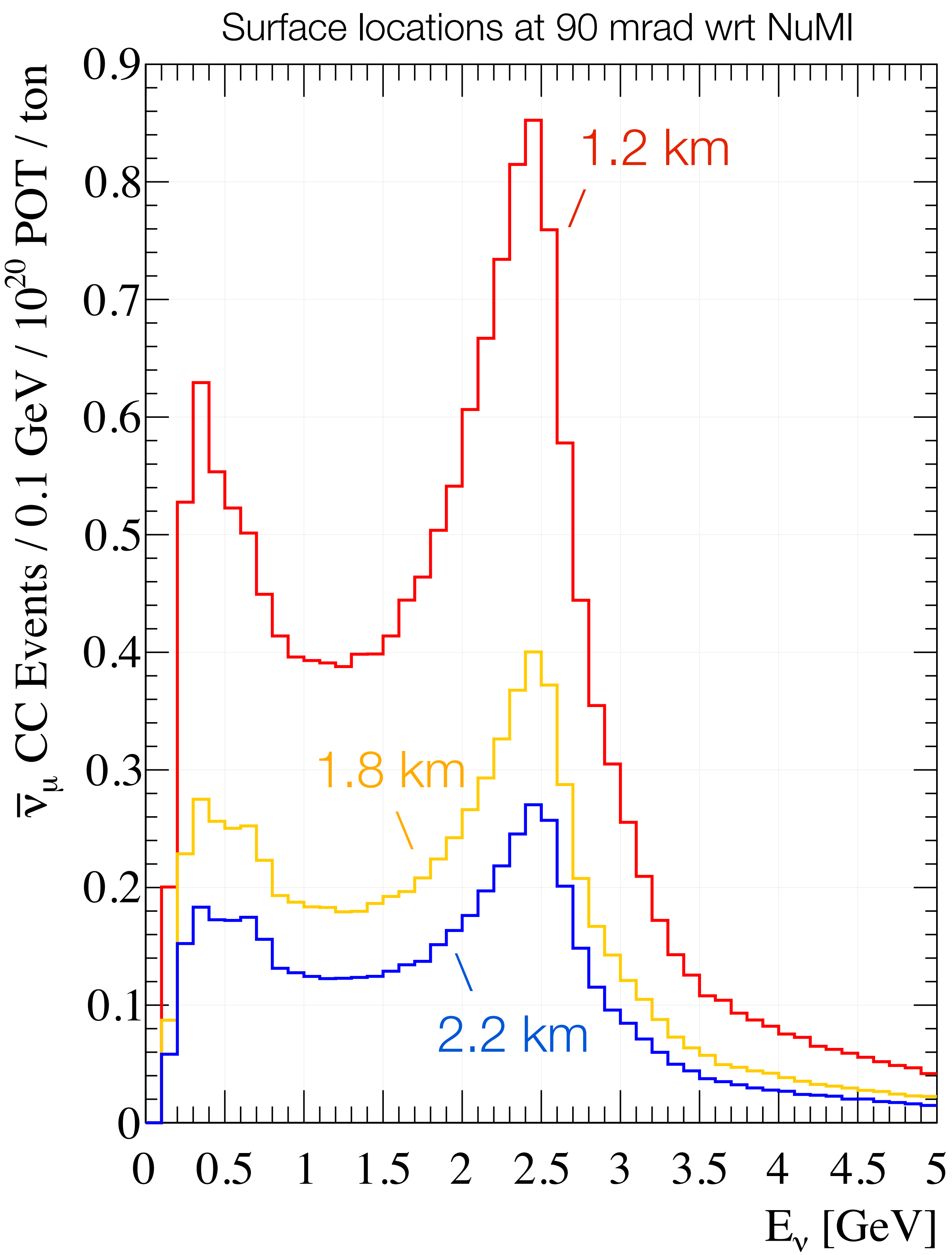
## Using NuMI at 2 km to test LSND / MiniBooNE

Not part of NOvA, but a new idea for possible future use of NuMI. Configuration assumes 70 ton LAr TPC at 1 km and 200 ton LAr TPC at 1.6 km

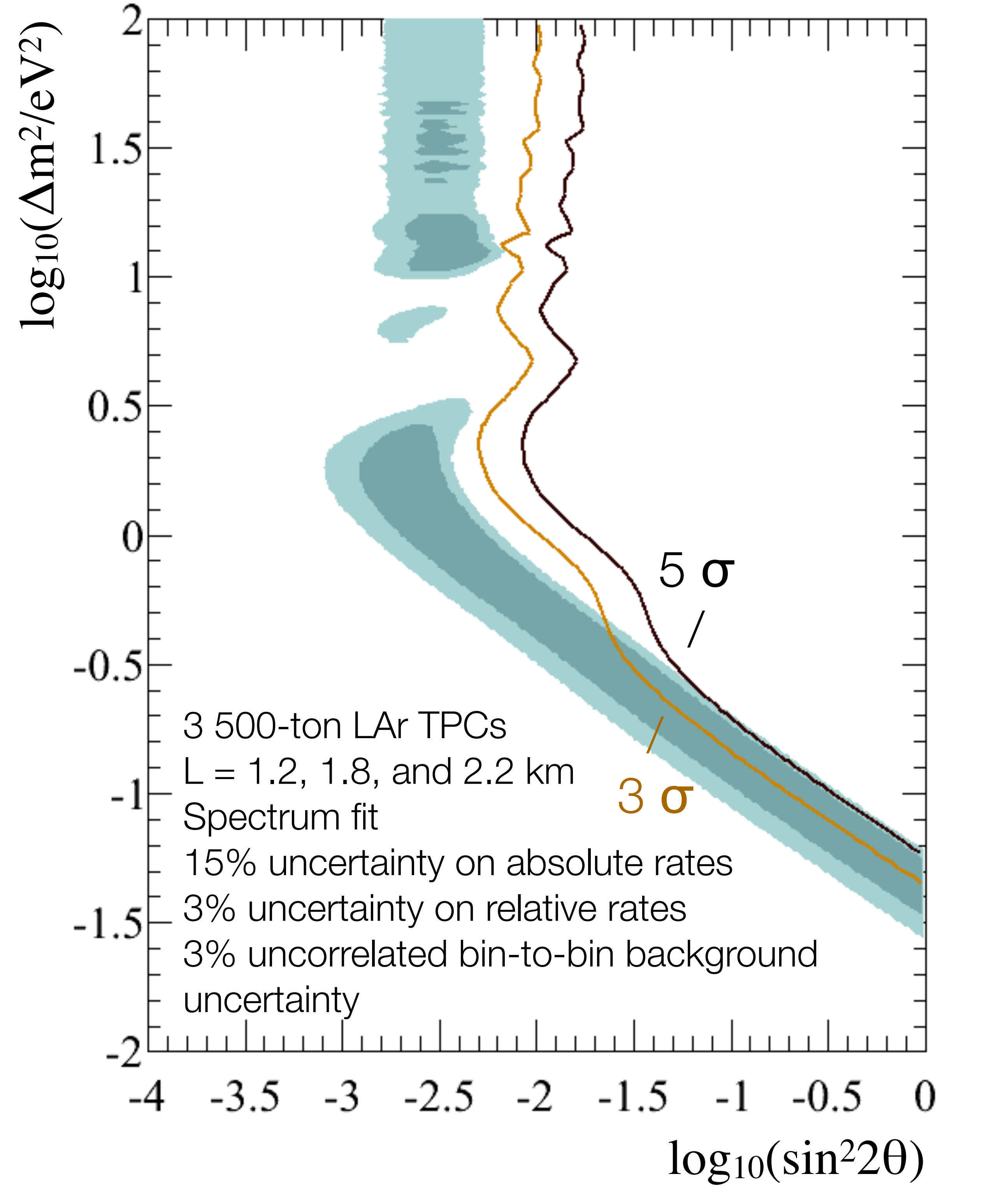



# Option 3: What can one do on the surface?

The plot shows the angle in mrad off the NuMI axis (measured wrt. the target at z=x=0) for locations on the surface above NuMI. Reasonable choices range from 74 - 100 mrad for L's of 2.4 km to 0.7 km.




*Note: The version of this plot shown at the workshop had a serious bug in the calculation of the background spectra. I believe this is fixed now and has a major impact on the projected sensitivity. This idea appears not to be competitive.*




RIGHT: The muon anti-neutrino spectrum for reversed horn running at 90 mrad for L=1.2, 1.8, and 2.2 km surface positions.
LEFT: 3 and 5 sigma sensitivity for a 3 detector configuration on the surface at NuMI (not optimized…)

# Short baseline options using NuMI
# *General comments*

Here's *my personal* take on the NuMI options:

There is a compelling case to continue the search for eV sterile neutrinos with an experiment capable of significant ($5\sigma$ stat.+syst.) reach over the entire LSND allowed region.

Options on the NuMI line have the advantage of the high NuMI power and synergy with NOvA (both will demand protons on the same target, both will demand the same spare targets and horns, both will demand understanding of the same beam, etc.)

Options on the NuMI line have several disadvantages, most of which apply generally to horn-focused pion beams:

- Potential signals are comparable in size (smaller, even) to limit obtainable in a pion beam ($\tau_\pi/\tau_\mu$=1%)
- Beam systematics scale with $L_{\text{Decay Pipe}}/L_{\text{Detector}}$
- With two detectors signal/background roles can swap - signal can appear in near and/or far detector

# Short baseline options using NuMI

| Option | L (km) | E (GeV) | pros* | cons* |
|---|---|---|---|---|
| **2nd NOvA near detector further off-axis** | 0.8 km | 1.3 GeV | Likely that this can happen as part of the NOvA experiment and hence much faster than any new initiative. | Study required to quantify impact of systematic uncertainties on physics reach. Impact may be significant. |
| **2nd NOvA near detector at L ~ 2 km** | 1.6 km | 2 GeV | Could have good sensitivity using LAr detector. Complementary to existing program. | One must work hard to over come limitations of horn-focused pion beam. Detector depth is 110 m. |
| **Multiple detectors on surface** | 1 - 2 km | 0.5 - 3 GeV | As above, but no tunneling is required. | Sensitivity does not appear sufficient. One must work hard to over come limitations of horn-focused pion beam. Large angle requires large detectors. |

- The first two of these have reach into the LSND allowed region.
- All have potential to be improved with additional detailed study.