A Fermilab to Homestake (or Henderson) Experiment?

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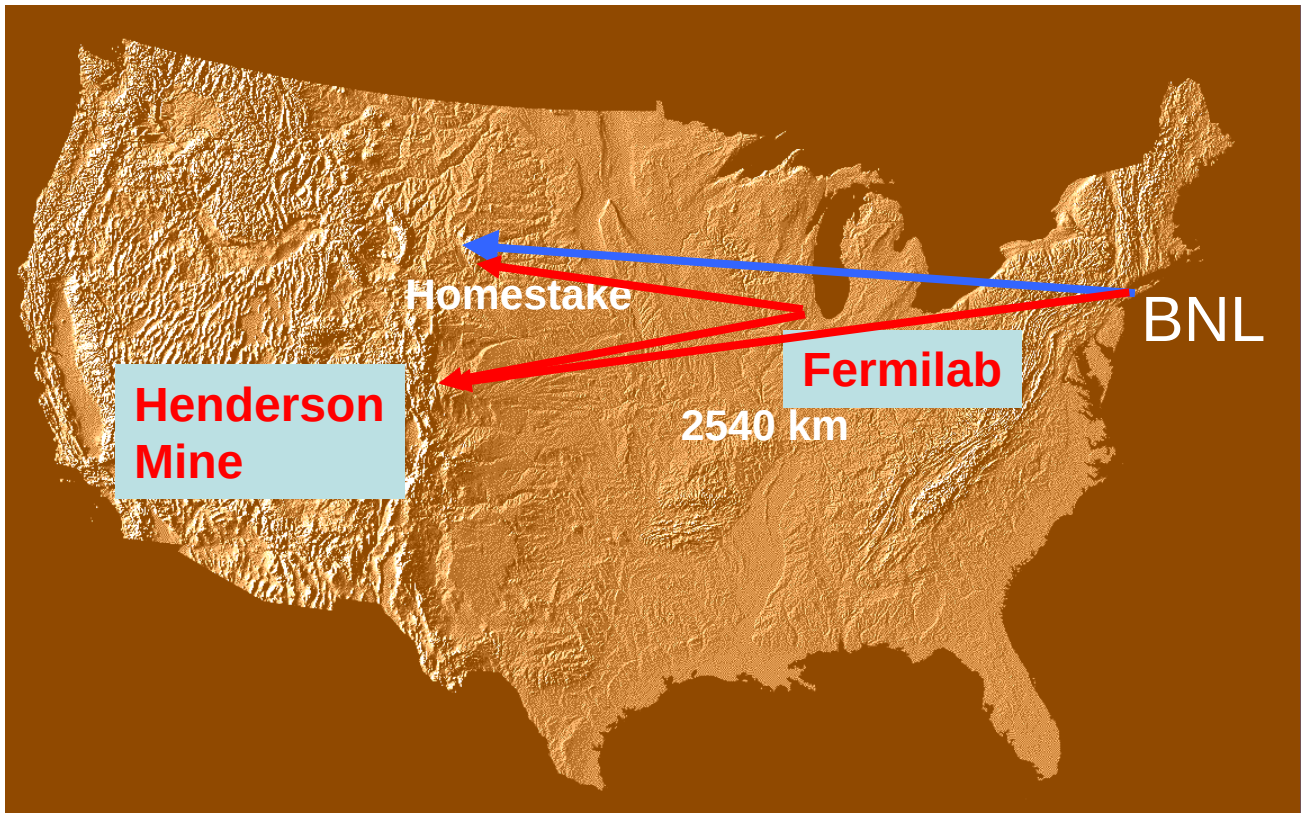
Assumptions for beyond Off Axis

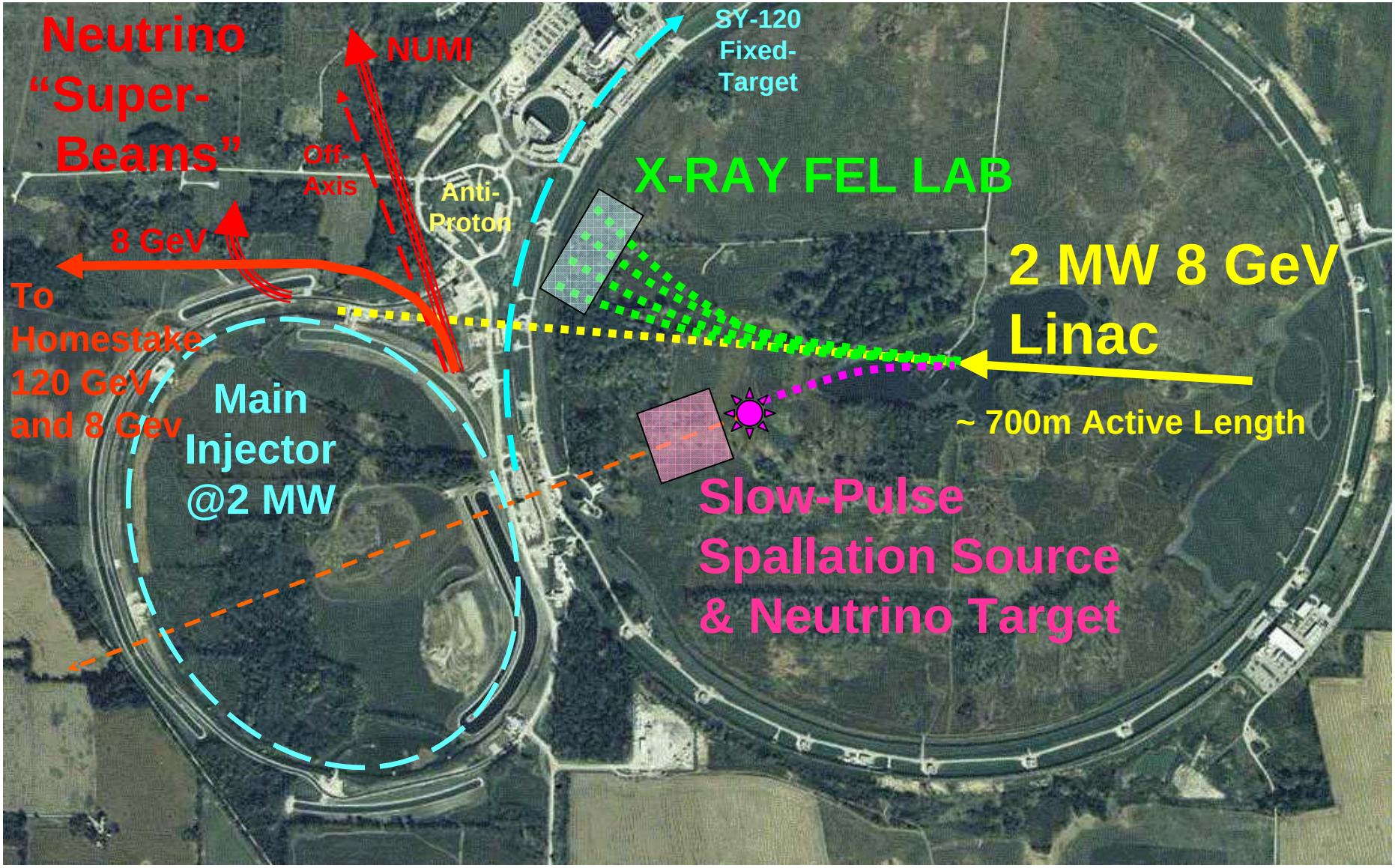
- I don't see this as an alternative proposal to starting with an Off Axis experiment at Fermilab. Rather, it is a longer term way of building on investments and offering the best possible physics measurements.
- We assume that the following resources will be available:
  - A new 2 MW 8 GeV proton source at Fermilab
  - Corresponding 2 MW of 120 GeV protons from the Main Injector
  - A new beamline, with whatever characteristics we need aimed in the direction of Lead.
  - An underground laboratory at Homestake (1290 km from Fermilab).
  - A 500 kT water Cerenkov detector at Homestake with Super-K type capabilities. (Alternatively, a 125 kT fine-grained calorimeter, liquid argon or scintillator.)
- It is clear that we are talking about an experiment that will start later than 2015.
- Other paths/approaches can be imagined, but this gives a idea of what might be possible.

A few possible choices for new beamlines



Here, we will consider shorter baselines than the Brookhaven proposal, But higher proton power (x2-4) and higher beam intensity (~x16) due to both the higher proton power and shorter baseline.

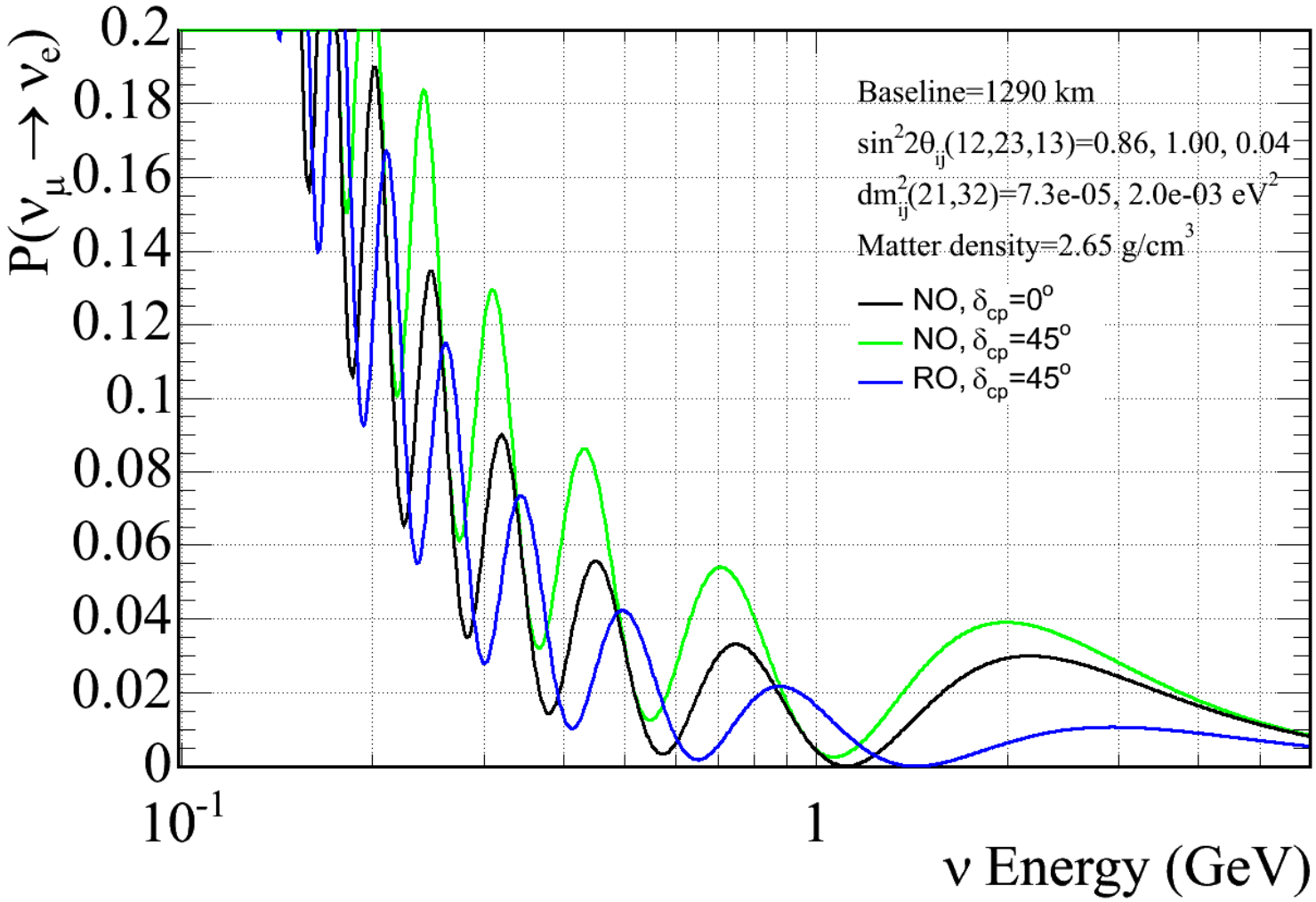
A new proton driver at Fermilab?



Also includes upgrades to Main Injector for current and cycle

Appearance Probabilities at 1290 km

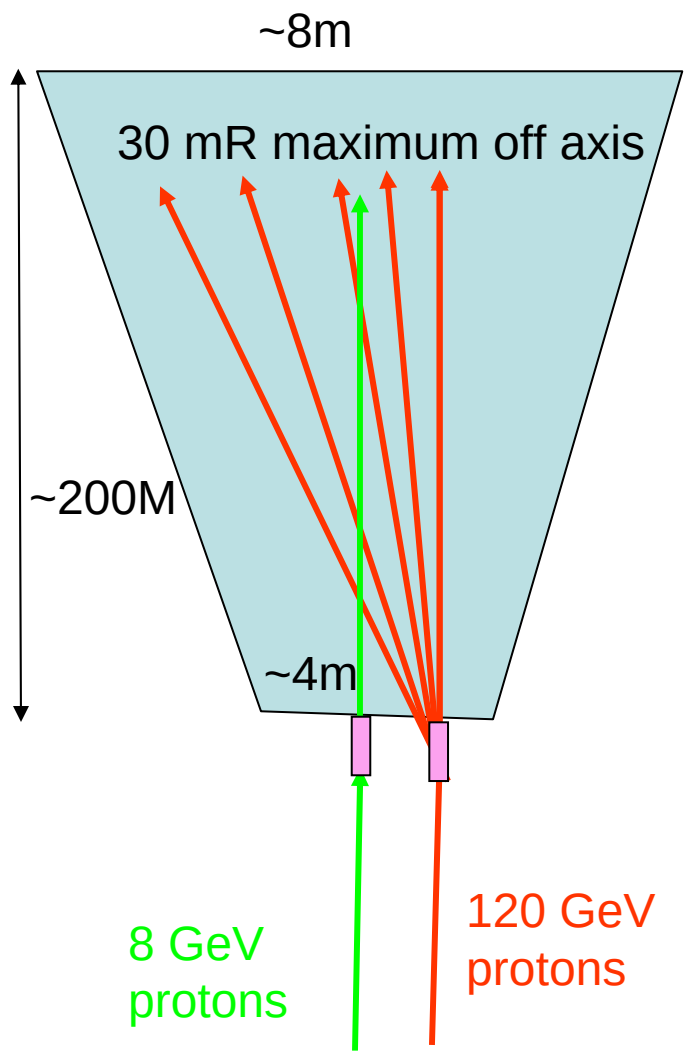
ν_e **Appearance Probability**



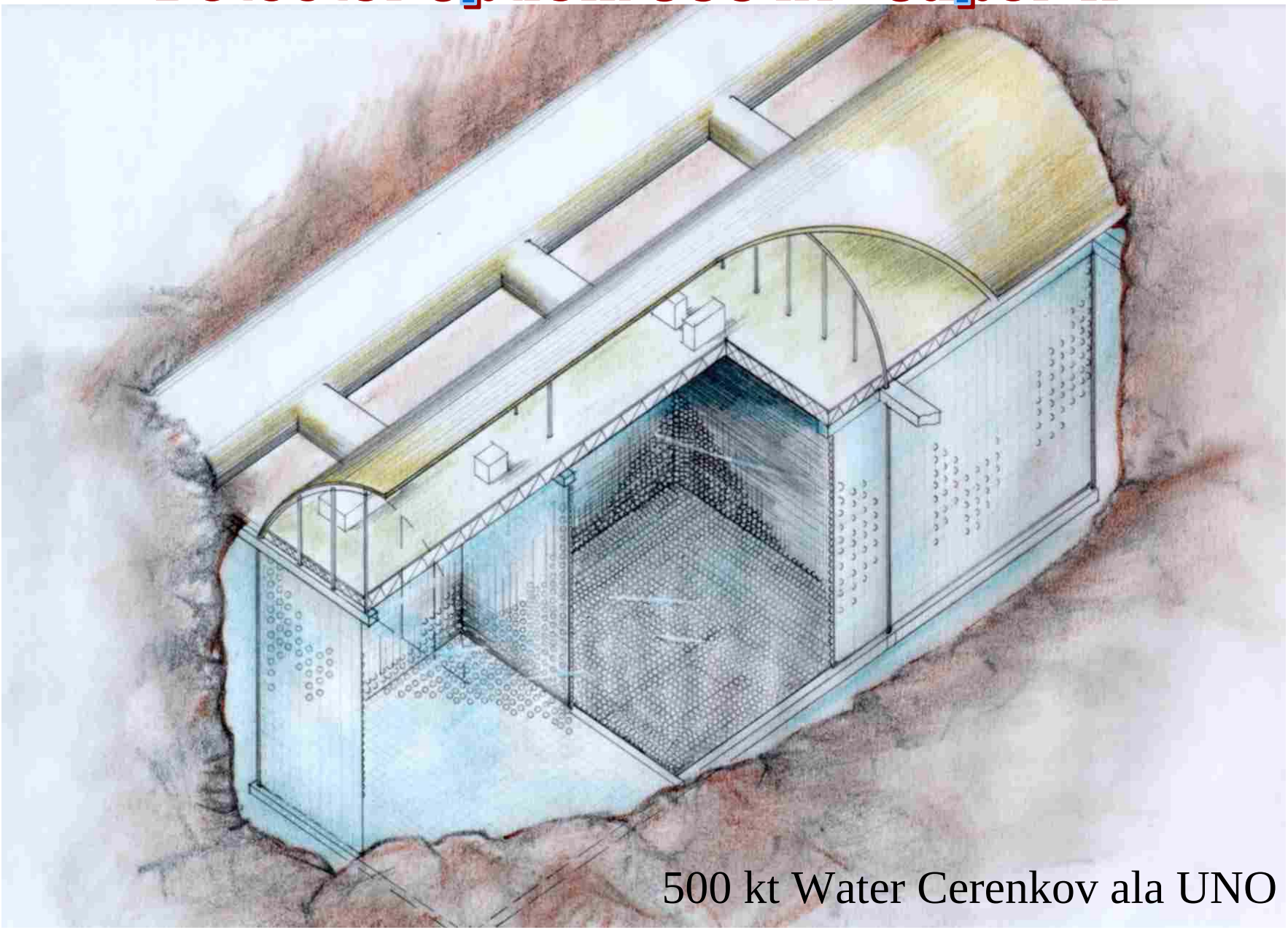
The FeHo Beamline

(FErmilab to HOmestake)

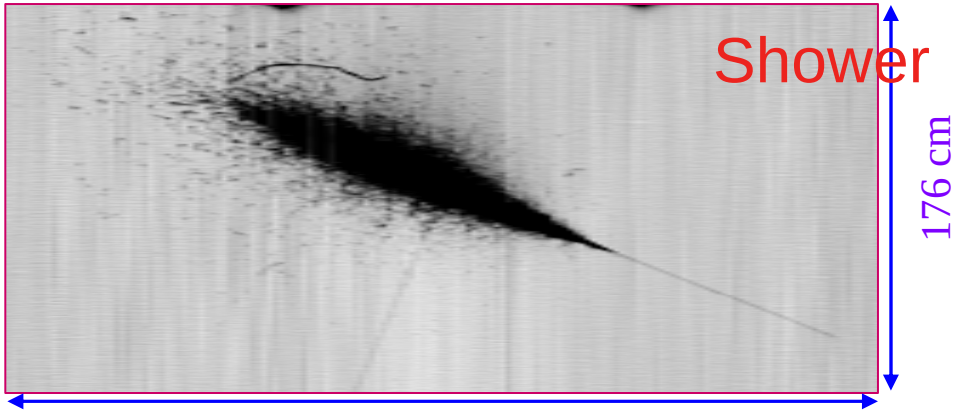
- A new neutrino beamline using the same 120 GeV extraction line as the current NuMI beam but then redirecting towards Homestake.
- In addition, a beamline to deliver 8 GeV protons from the (assumed) new proton driver.
- Dual targeting/focussing stations
- Decay region ~200 m in length, 4 m tall and 8 m wide. (Roughly the same scale as NuMI construction.)
- Tunable Off Axis beams for 120 GeV protons. On axis beam for 8 GeV protons.
- 2 MW of proton power at both 120 GeV and 8 GeV.

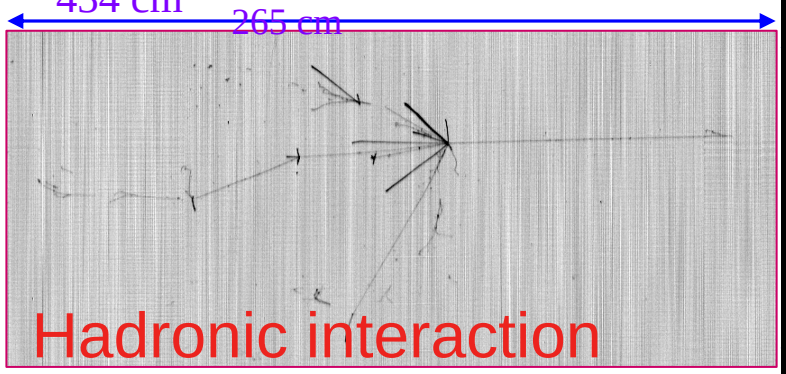


Detector Option: 500 kT "Super-K"

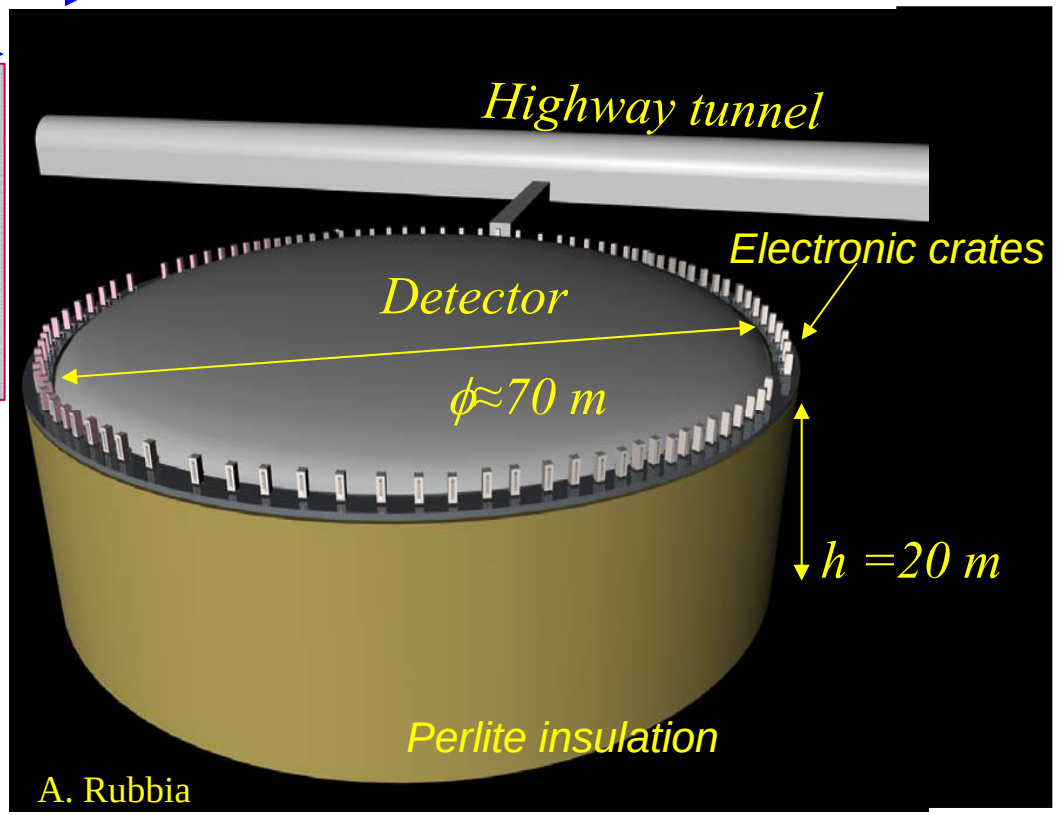


Detector Option: 125 kT Liquid Argon



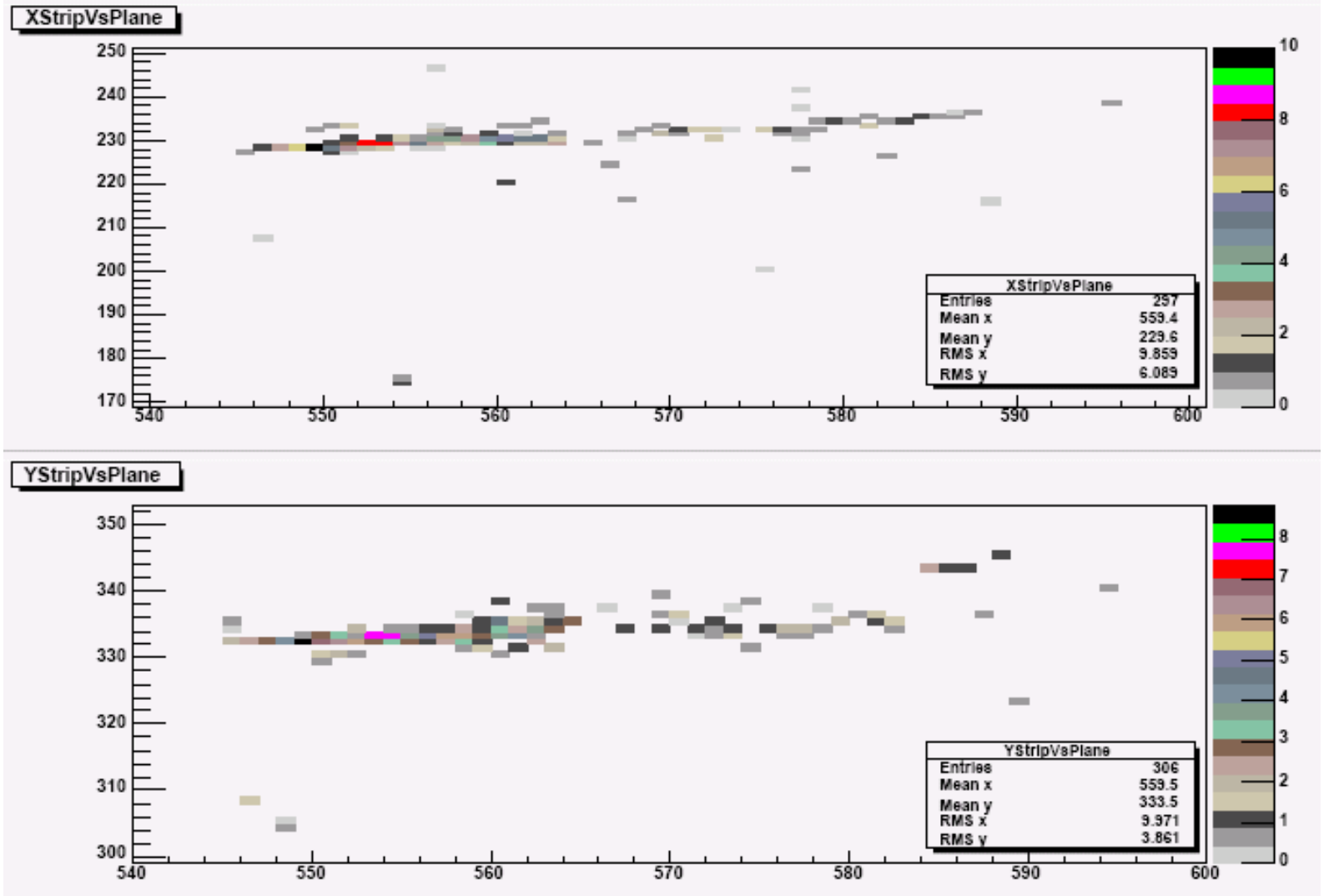


Run 308, Event 160 Collection Left



Andre Rubbia's concept for 100 kT liquid argon in Frejus Tunnel.

Detector Option: Totally Active Scintillator Detector



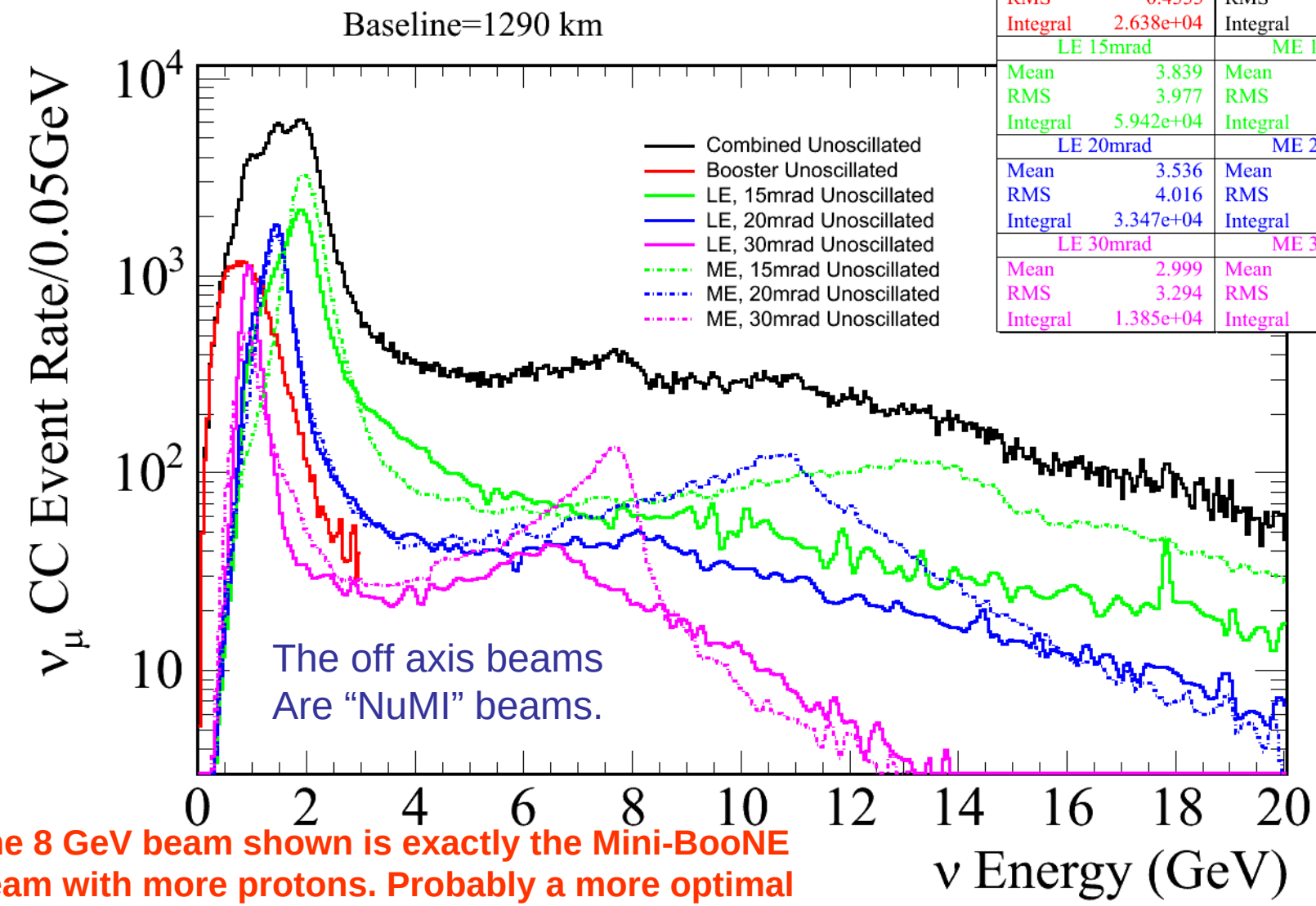
An example 700 MeV ν_e CC event in a 4cm pitch totally active scintillator detector

Courtesy Leon Mualem

100 kT detector for ~$400M?

Unoscillated Rate of CC Events at 1290 km

CC Events: 1000e20 POT Booster, 100e20 POT MI, 500kT Detector

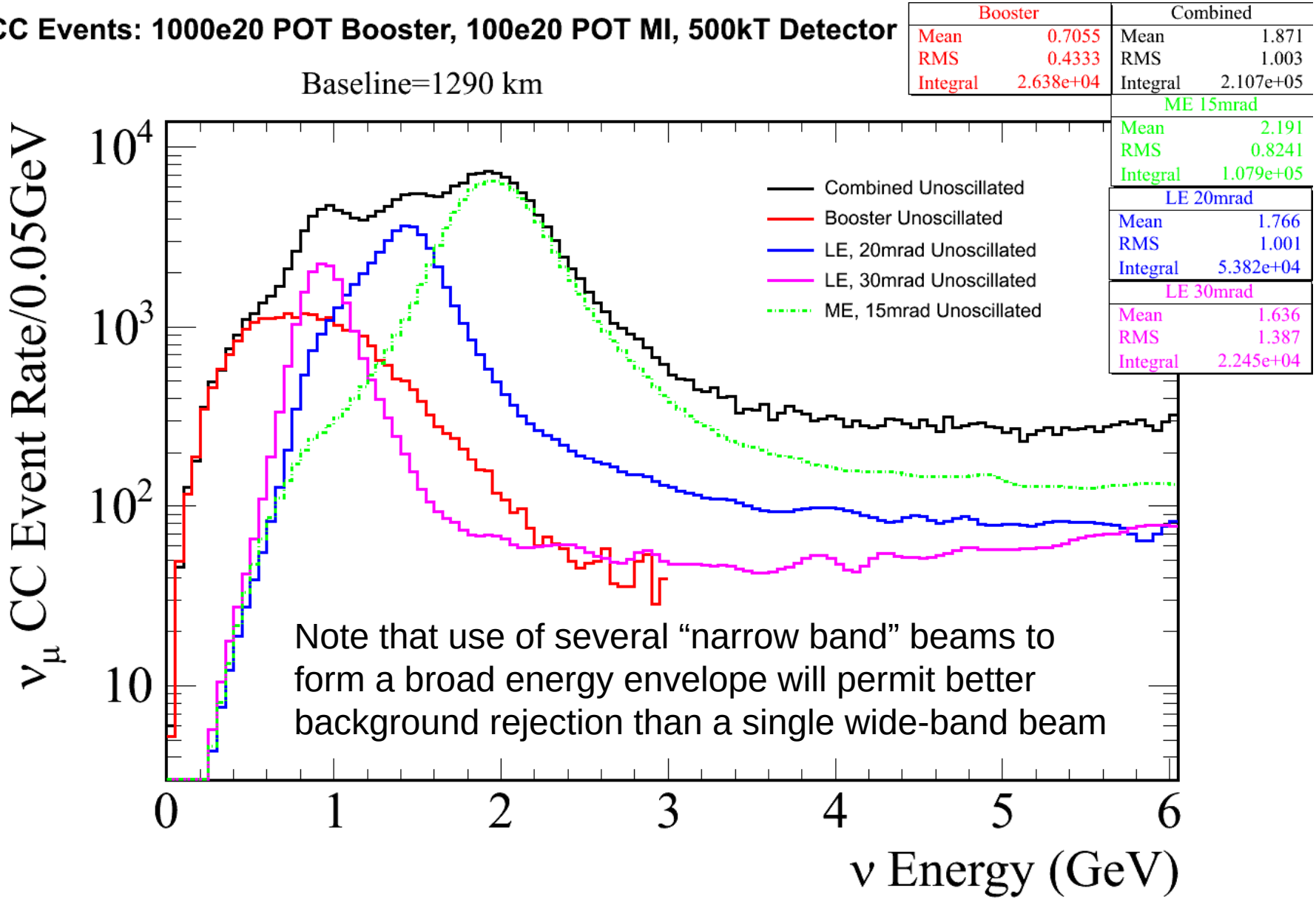


Booster		Combined	
Mean	0.7055	Mean	3.948
RMS	0.4333	RMS	4.278
Integral	2.638e+04	Integral	2.585e+05
LE 15mrad		ME 15mrad	
Mean	3.839	Mean	4.962
RMS	3.977	RMS	4.93
Integral	5.942e+04	Integral	7.419e+04
LE 20mrad		ME 20mrad	
Mean	3.536	Mean	4.812
RMS	4.016	RMS	4.486
Integral	3.347e+04	Integral	3.715e+04
LE 30mrad		ME 30mrad	
Mean	2.999	Mean	4.107
RMS	3.294	RMS	3.356
Integral	1.385e+04	Integral	1.401e+04

The 8 GeV beam shown is exactly the Mini-BooNE beam with more protons. Probably a more optimal beam will be possible.

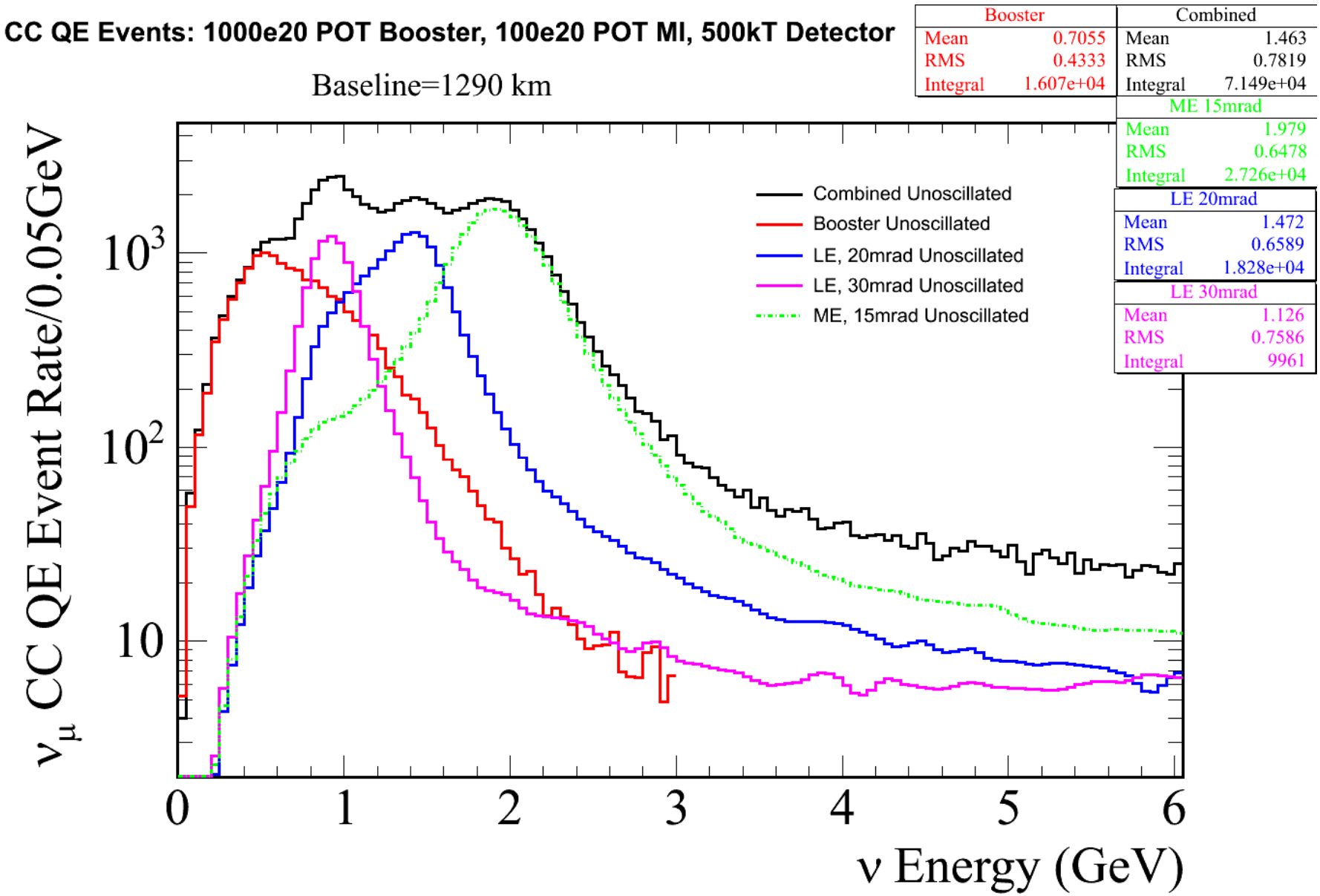
"Optimized" Unoscillated Rate of CC Events at 1290 km

CC Events: 1000e20 POT Booster, 100e20 POT MI, 500kT Detector

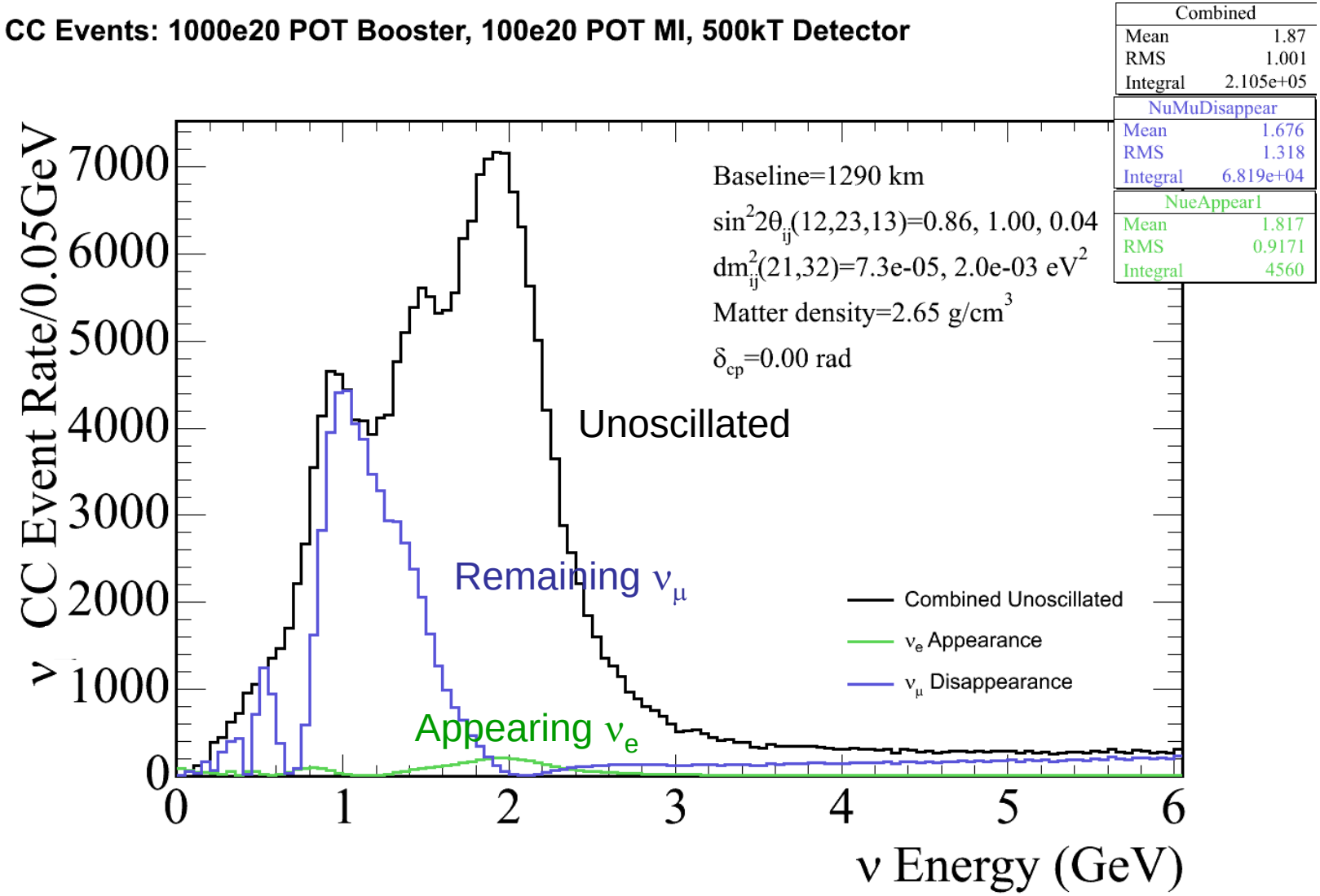


Note that use of several "narrow band" beams to form a broad energy envelope will permit better background rejection than a single wide-band beam

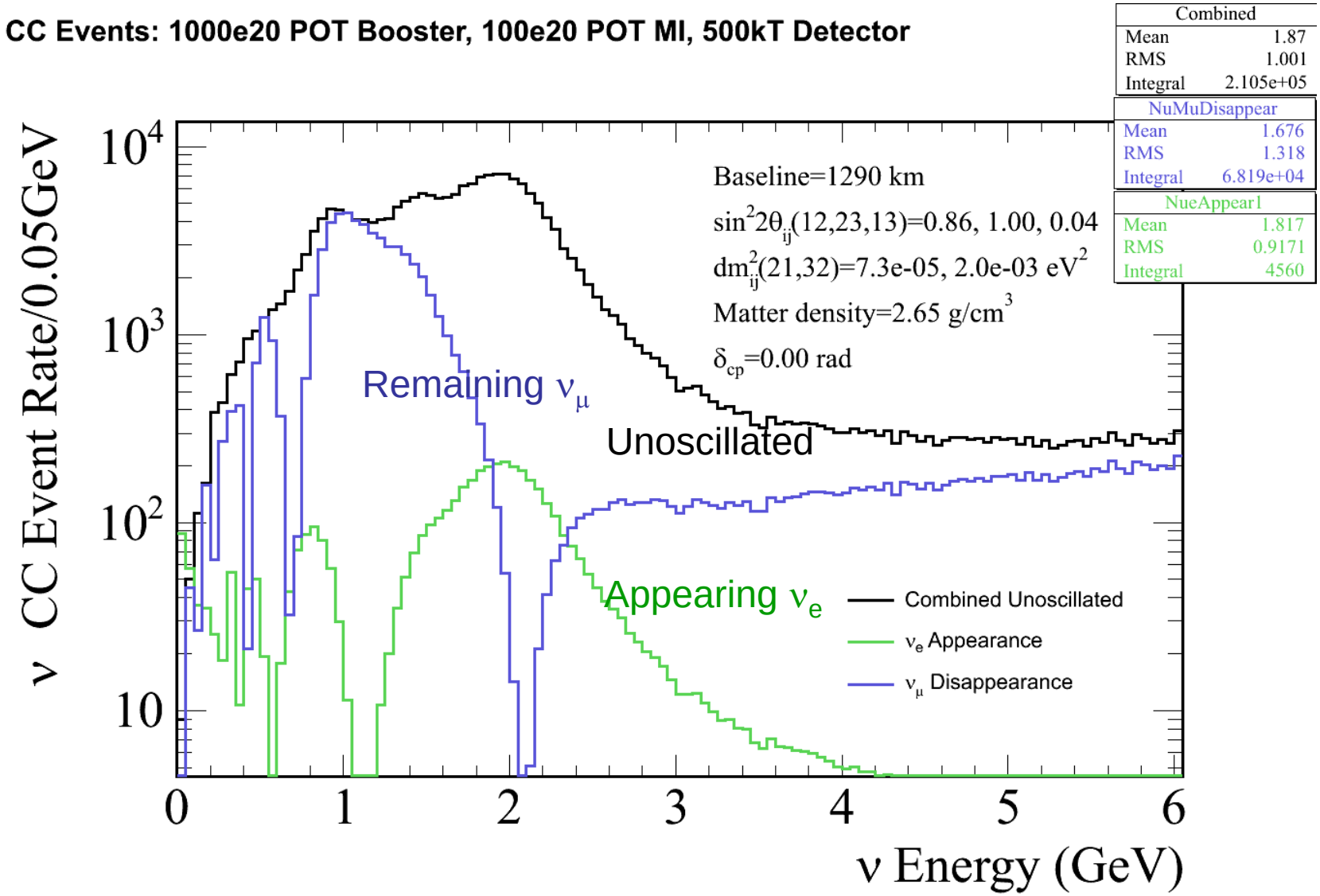
Rate of QE Events Only at 1290 km



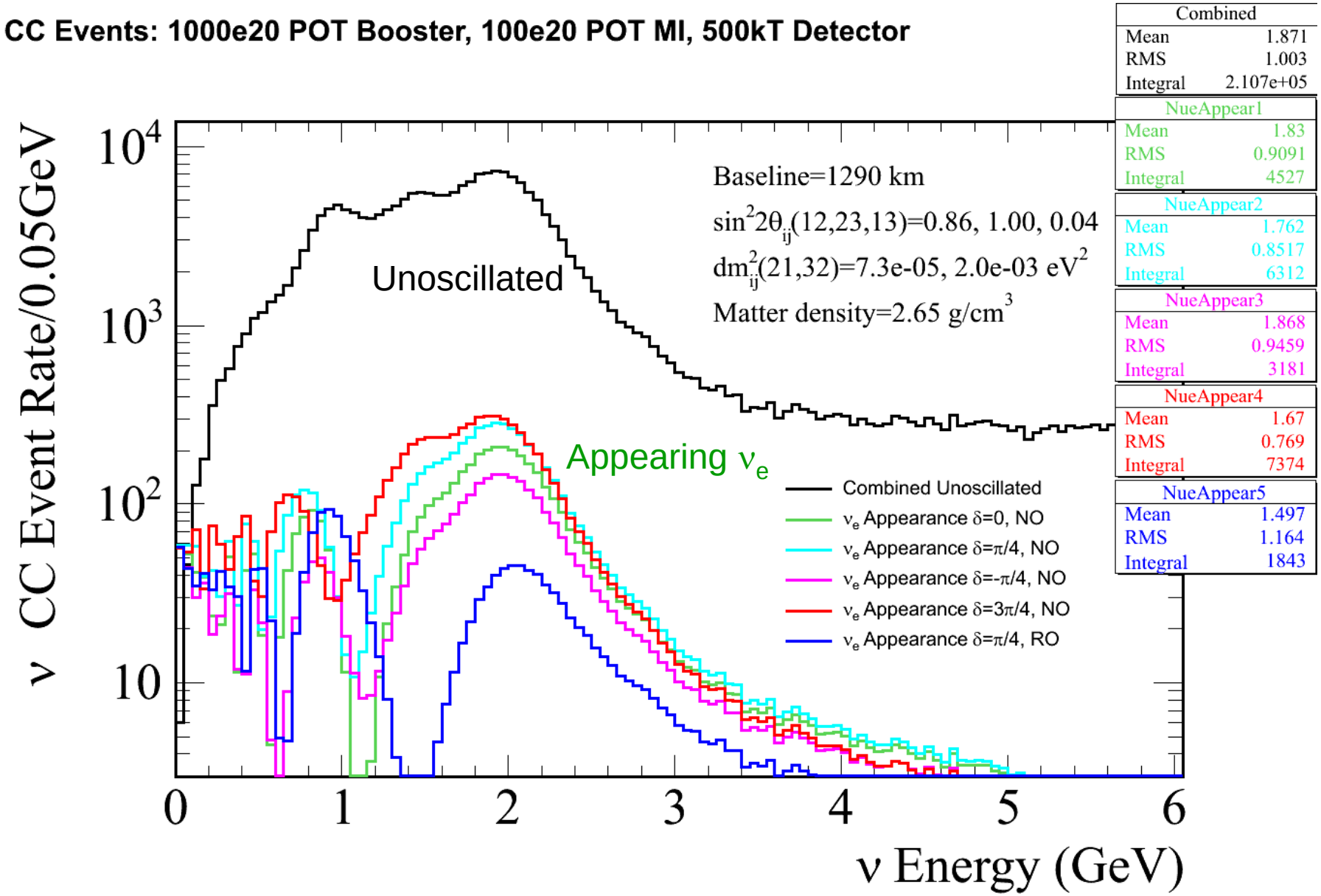
Oscillated rate of neutrino events at 1290 km



Oscillated rate of neutrino events at 1290 km

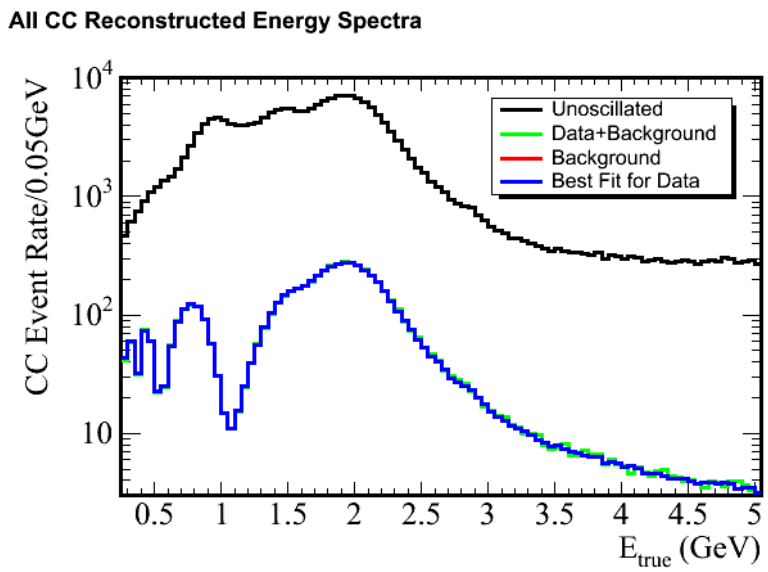


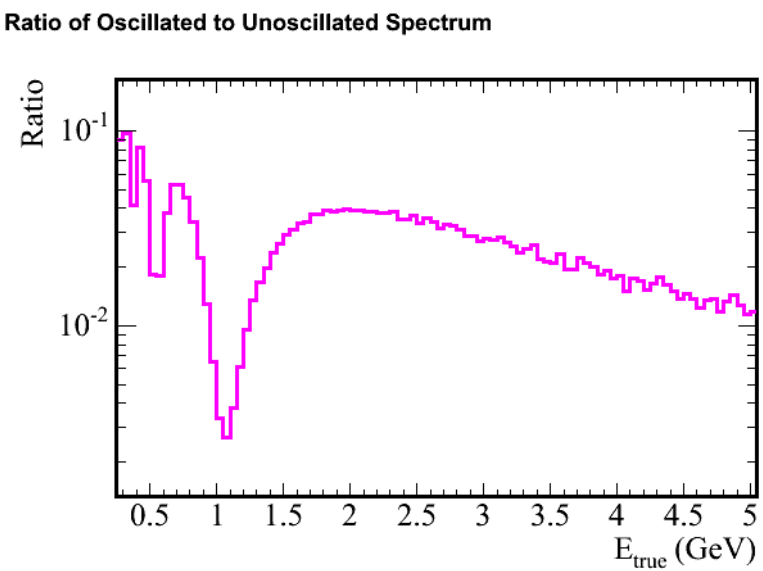
Oscillated rate of neutrino events at 1290 km

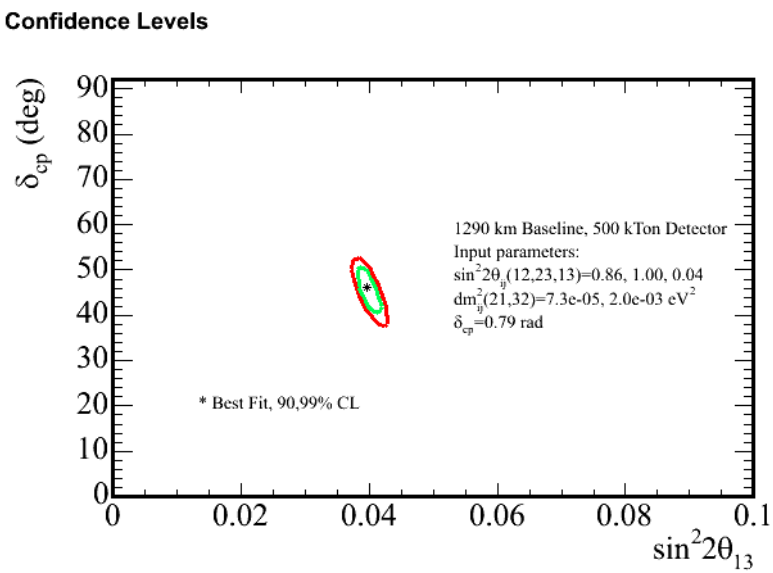


What the statistics permit with an impossible detector

- 500 kT, perfect resolution, perfect efficiency
- Using all ν_e CC events with no background (except intrinsic ν_e) .
- In other words, it only gets
- worse than this.

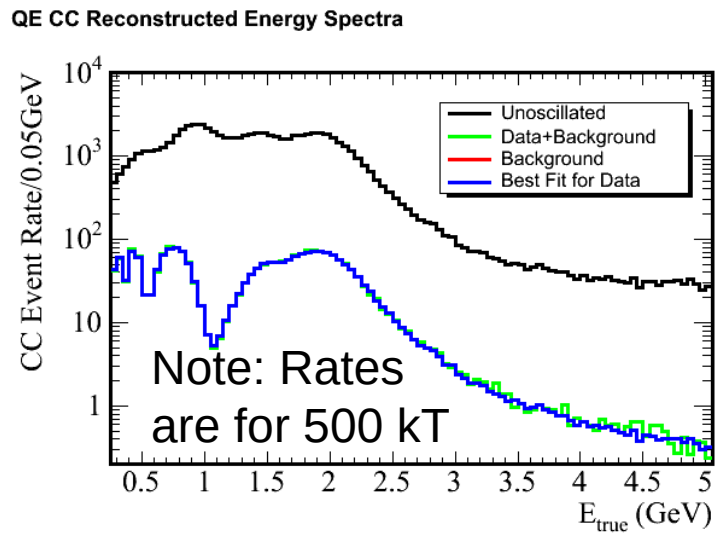


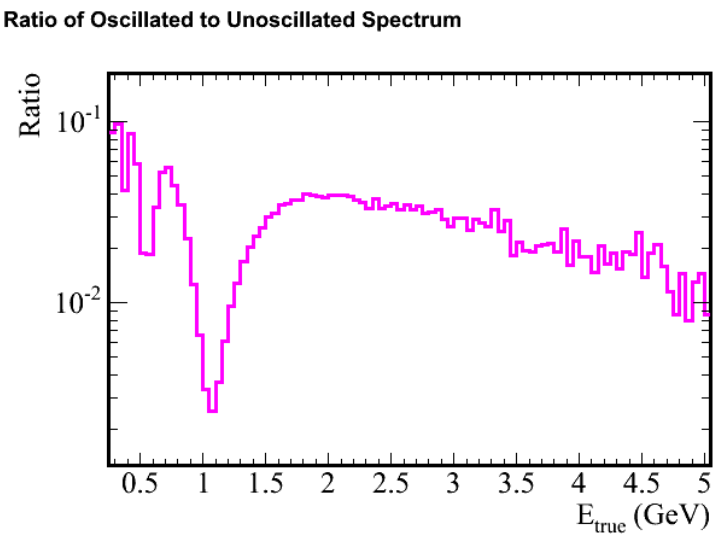


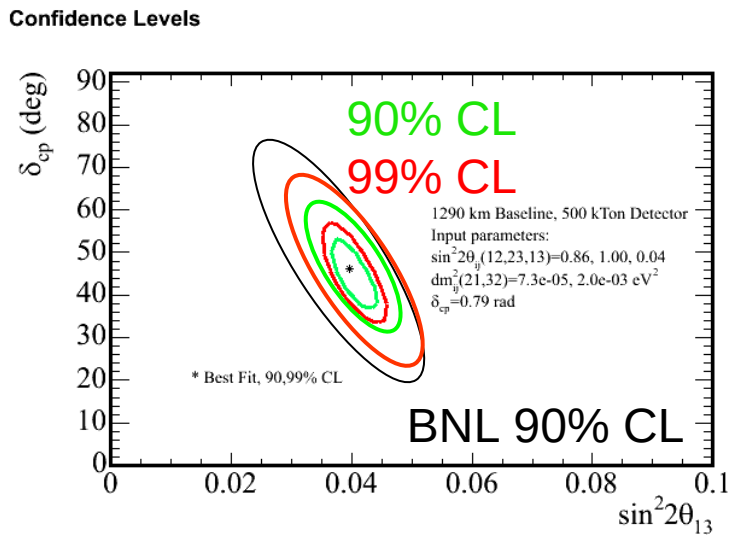


Electron Appearance using a 125 kT "Liquid Argon" Detector

The outer 90% and 99% CL curves are for a fit done using only QE events with no background scaled to a 125 kT detector from a 500 kT detector. More events will be useful, but I'm not sure now what efficiencies, resolutions and backgrounds should be used for an expanded event sample. The inner 90 and 99% CL curves certainly represent the best one could possibly do with 125 kT of liquid argon.



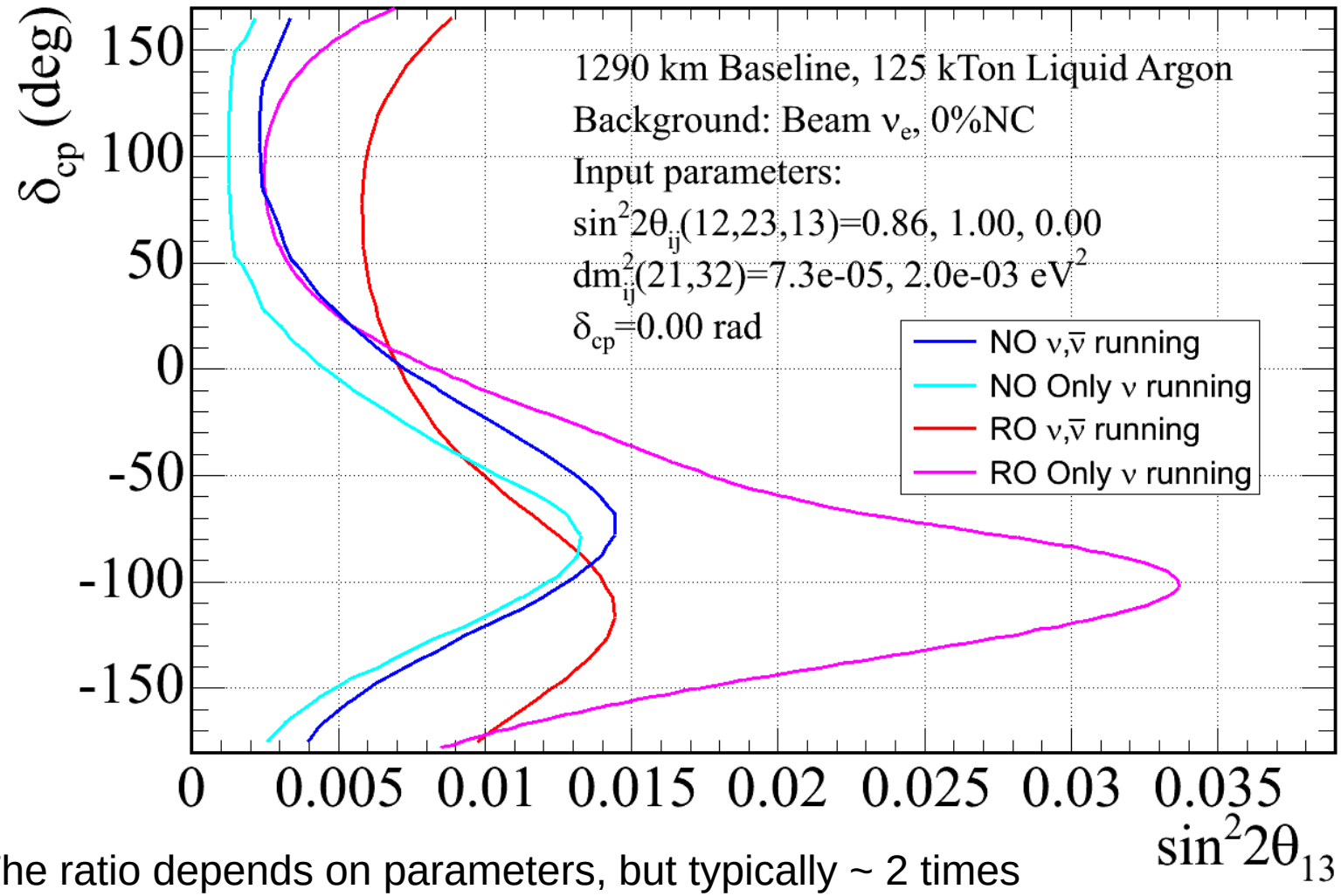




Electron Appearance using a 125 kT "Liquid Argon" Detector

2 σ exclusion curves

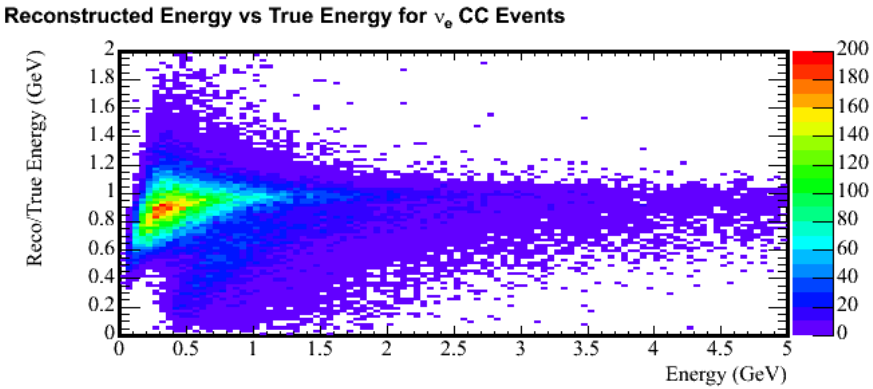
Assumes 25% nue effic for no NC BG

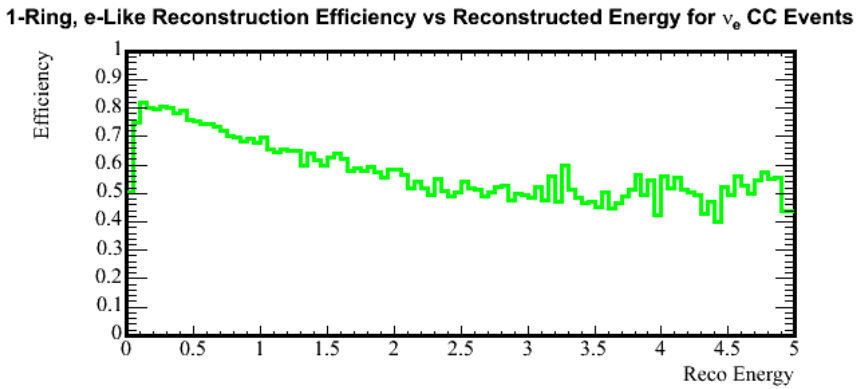


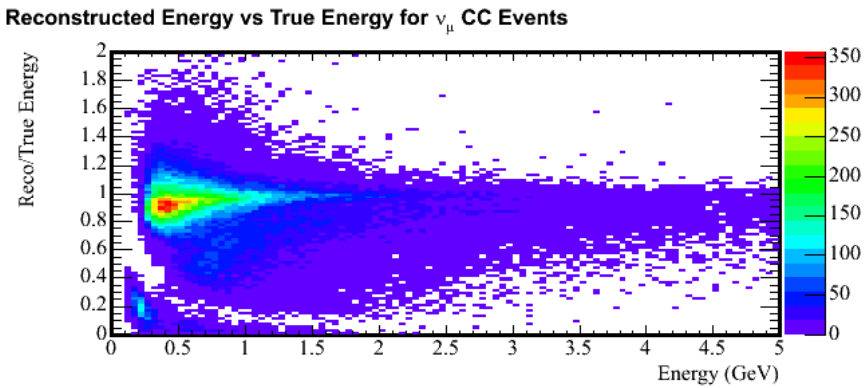
The ratio depends on parameters, but typically ~ 2 times better than NOvA with proton driver. But not 10 times! But depends on intrinsic nue.

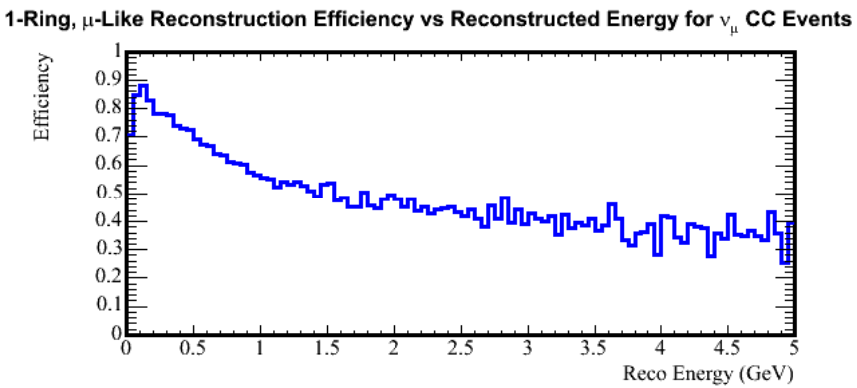
Approximating the Response in Water Cerenkov

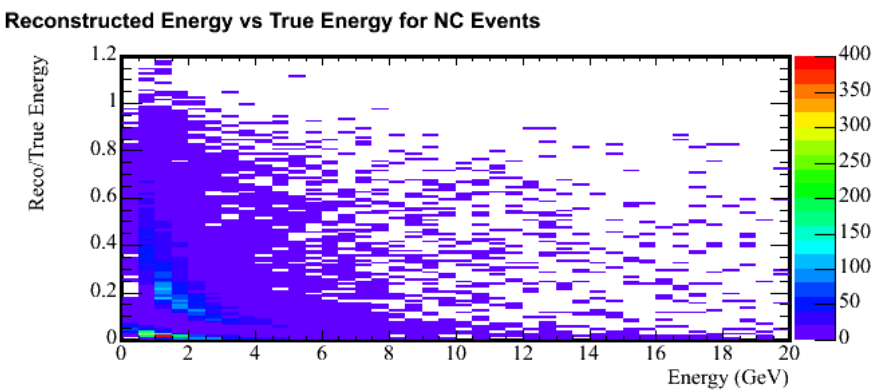
Ala Super-K courtesy of Mark Messier

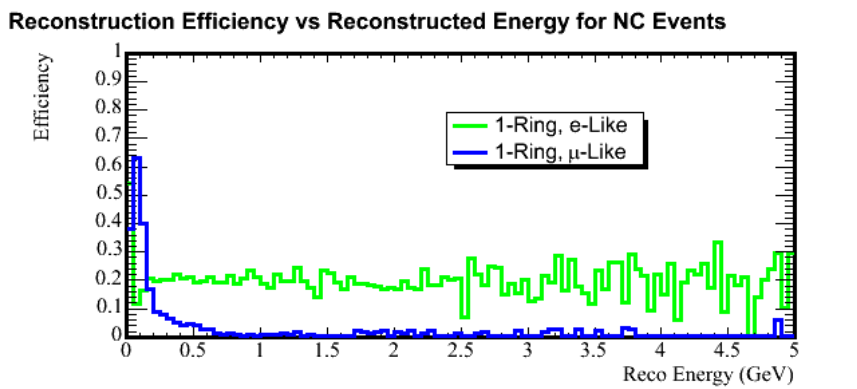








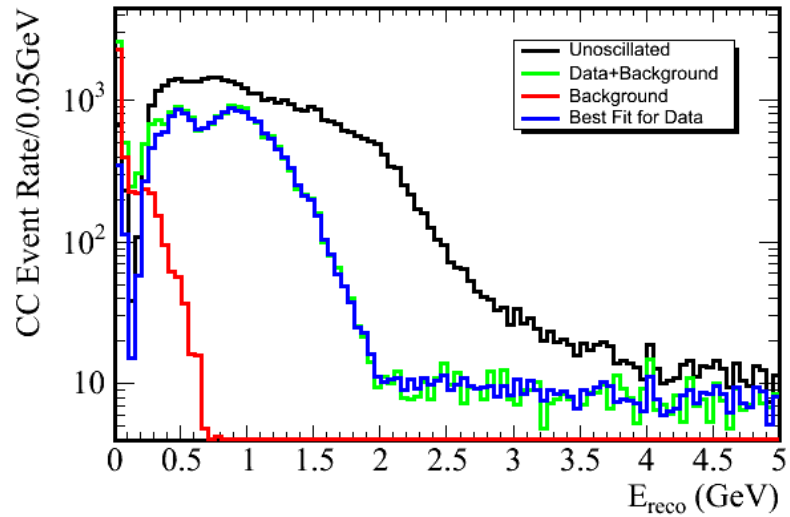




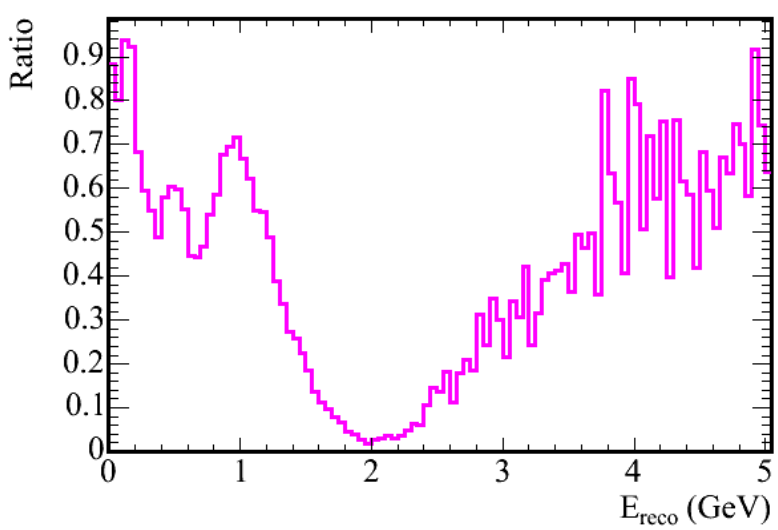
Measured spectrum and fit for single ring, mu-like events

Statistics are based only on QE events but backgrounds come from all events

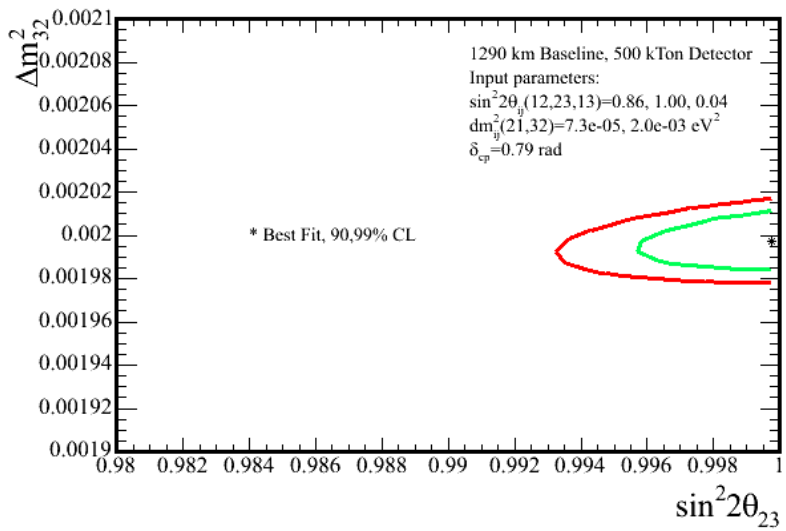
QE CC Reconstructed Energy Spectra



Ratio of Oscillated to Unoscillated Spectrum (Signal + Background)



Confidence Levels

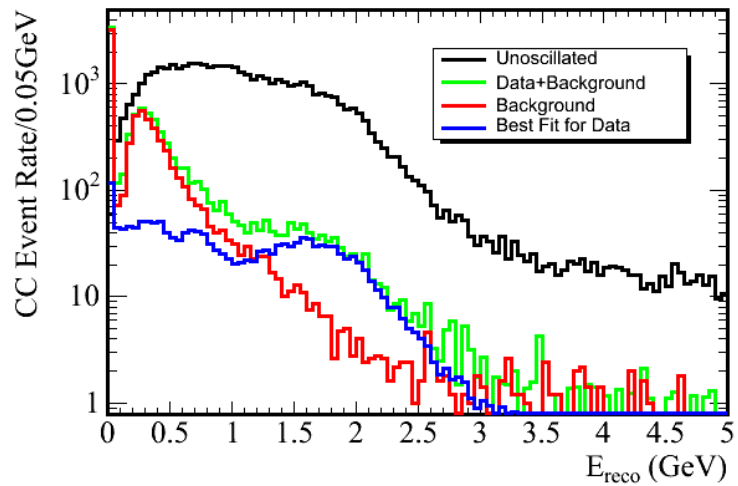


Electron Appearance Using a 500 kT "Super-K"

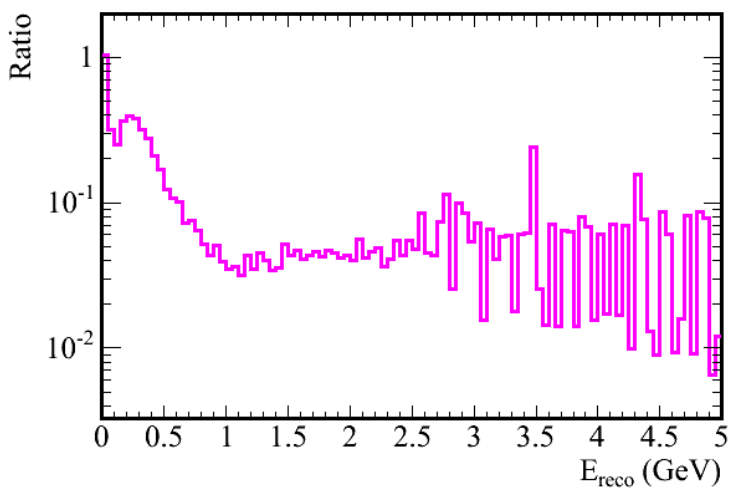
Statistics are based only on QE events but backgrounds come from all events

Note that the “BNL” result assumes approximately 3 times less background Than the “Super-K” performance.

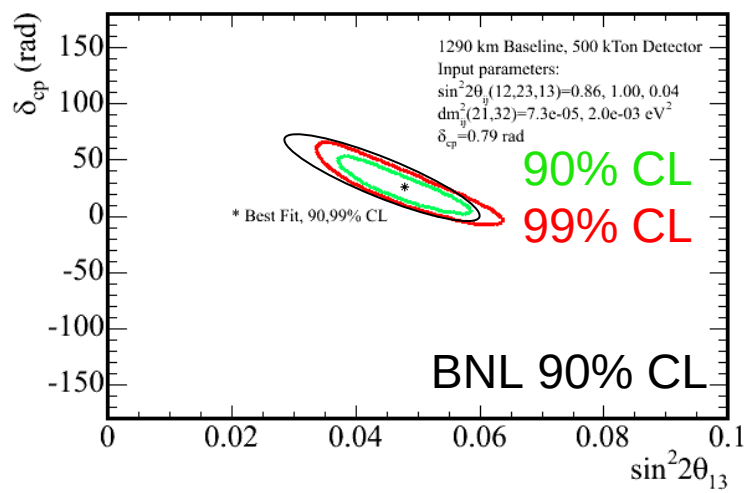
QE CC Reconstructed Energy Spectra



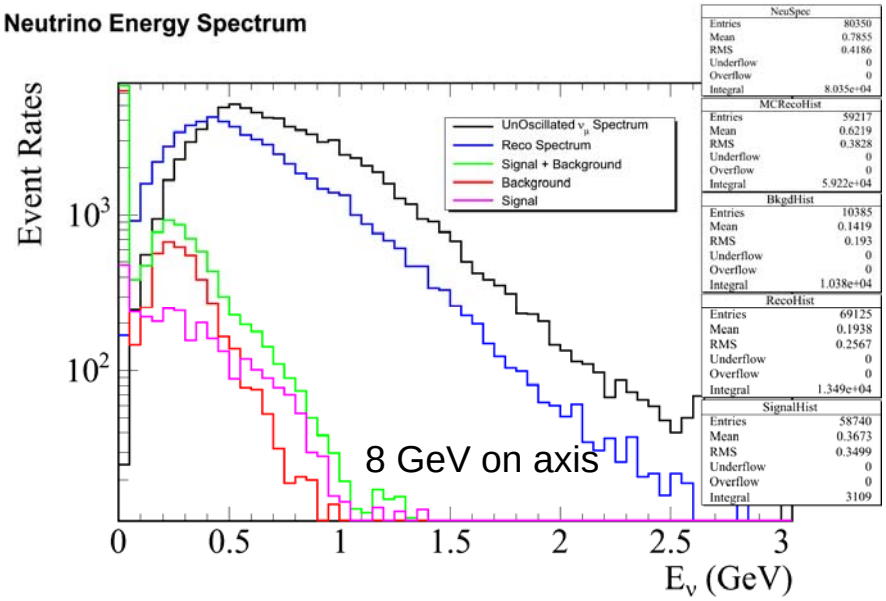
Ratio of Oscillated to Unoscillated Spectrum

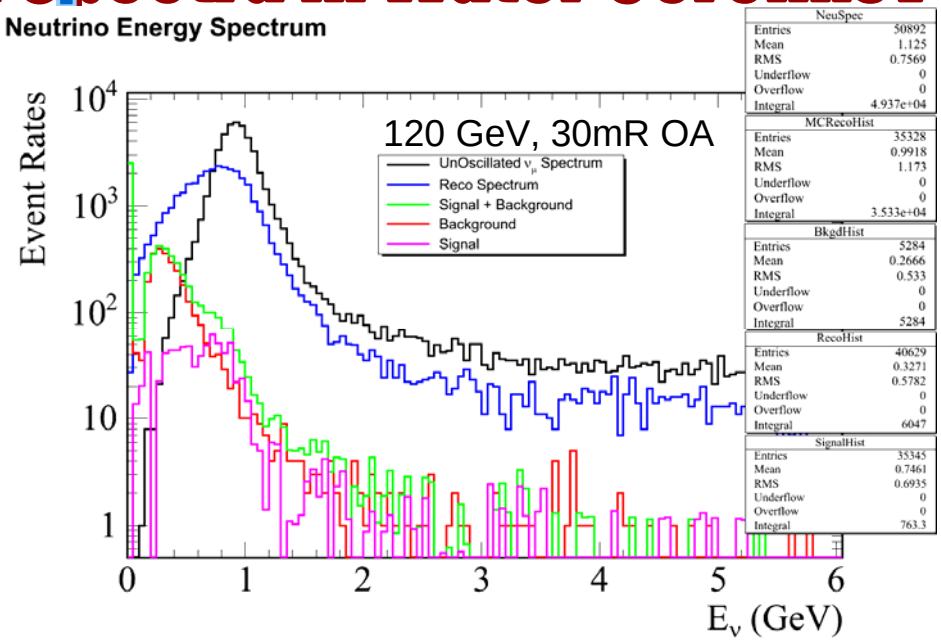


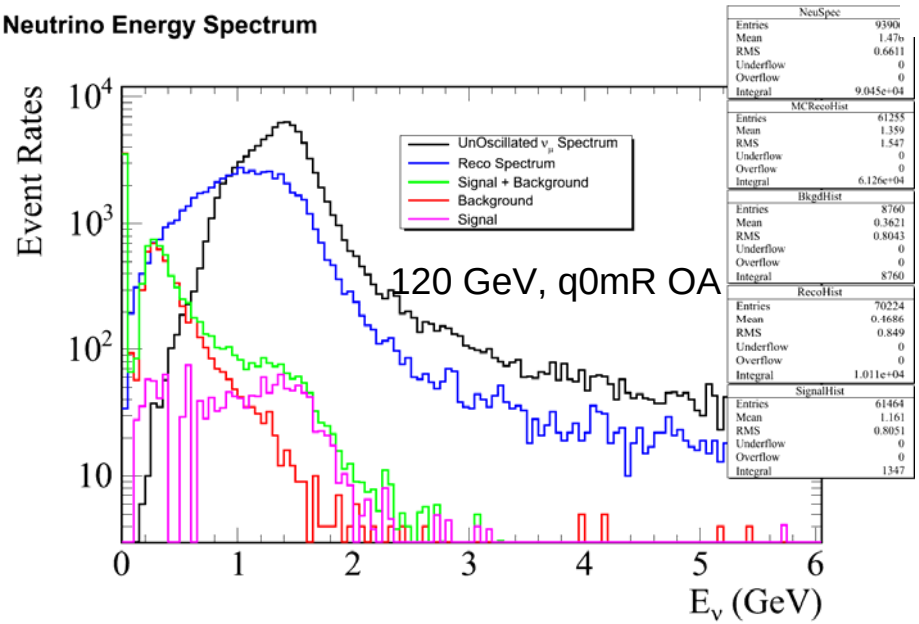
Confidence Levels

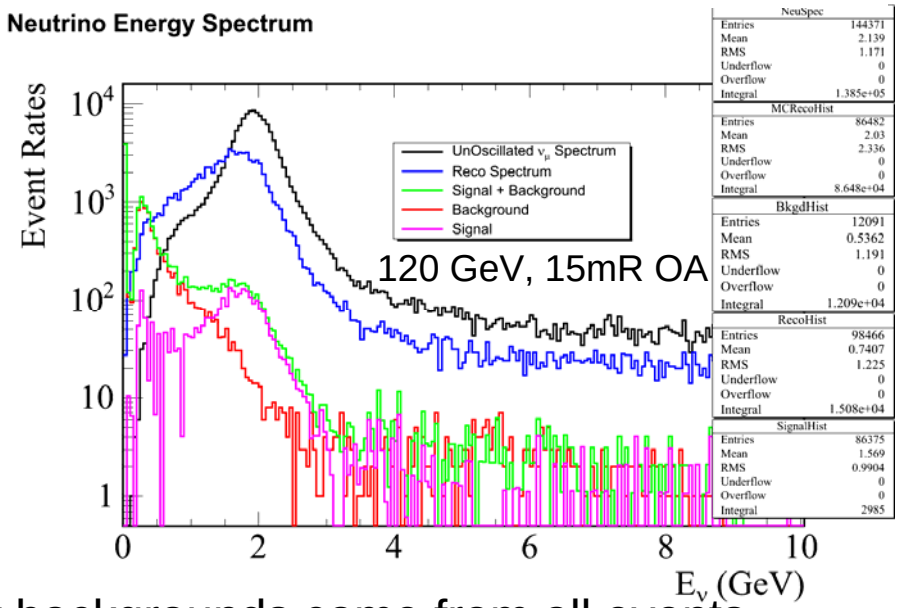


Individual Reconstructed Spectra in Water Cerenkov









Statistics are based only on QE events but backgrounds come from all events

Conclusions

- Use of combined 8 GeV and 120 GeV proton beams with a future Fermilab proton driver permits a very intense, wide/narrow band beam with tunable flux over ~two orders of magnitude in neutrino energy.
- 2 MW at 8 GeV provides an important part of the sensitivity shown here. If only MI protons are available it will be a hit of factor of 2 in statistics as well as not as much lower energy flux. But I'm not sure this is an answer to the Spammers.
- Assuming a large detector at Homestake or Henderson (not yet explicitly simulated but shouldn't be too different), an experiment with very high statistics will be possible. This is true even for a tracking calorimeter detector (liquid argon or scintillator) which may be better suited than water Cerenkov to the event reconstruction needs.
- Such an experiment offers as good or better sensitivity to the parameters of interest as any superbeam experiment under discussion. (It better!)
- Further assuming the detector to be 500 kT water Cerenkov with Super-K-like features permits:
  - Very small errors on ν_μ disappearance parameters. Systematics (not addressed here) may well dominate.
  - OK errors on ν_e appearance parameters but disappointing compared to the statistics due to energy smearing and backgrounds.
  - Hard to get information out of the second oscillation ν_e appearance maximum. Needs more work.
- Better, but not dramatically better than using NuMI beamline with off axis detector(s).
  - But can the NuMI beamline really handle very high proton intensity?
  - Might the use of 8 GeV protons as here down the NuMI beamline be almost as good?
  - Perhaps the most important issue is that it would connect with a large detector useful for proton decay too.