EMBRY-RIDDLE
Aeronautical University
PRESCOTT, ARIZONA

Coherent Captain Mills:
The Search for Sterile Neutrinos

Ashley Elliott[1], Jeramy Gordon[1], Jonah Greenwood[1], and Ryder Moreno[1]
Dr. Darrel Smith[1], Emily Strawn[1], Kate Walker[1]

[1]Department of Physics and Astronomy, Embry-Riddle Aeronautical University, Prescott, AZ

EMBRY-RIDDLE URI UNDERGRADUATE RESEARCH INSTITUTE

Neutrino Oscillations

What is a Neutrino?:

Simply put, a neutrino is a subatomic particle that is very similar to an electron, but has no electrical charge and a mass less than 1/500,000 of an electron mass. They are some of the most abundant particles in the universe but have almost no interactions with matter, aside from the weak force and gravity.

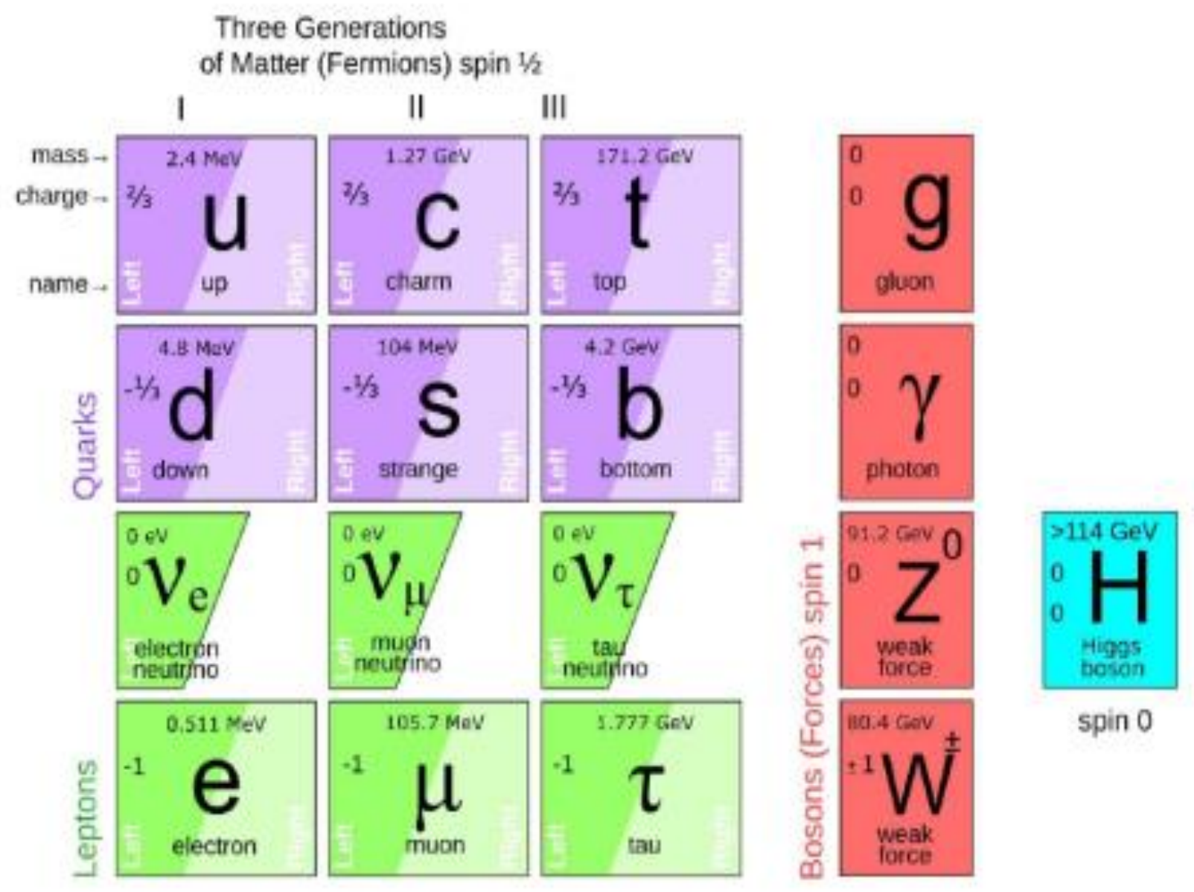


Fig.1: Standard model

There are currently three active neutrinos, as seen in the standard model to the left; not shown here are the anti-neutrinos. With the existence of a sterile neutrino, the standard model would have to be expanded to include its unique characteristics.

Although each neutrino is unique and distinct, they have been detected to change or oscillate into other neutrinos; some of these oscillations are shown below:

Observed Oscillations:

1. Solar Neutrinos ($\nu_e \rightarrow \nu_\mu$ appearance)
2. Atmospheric ($\nu_\mu \rightarrow \nu_e$ disappearance)
3. Accelerator (Long Baseline)
4. Accelerator (Short Baseline)

- LSND/MiniBooNE - observe an enhanced production of $\nu_\mu \rightarrow \nu_e$ at low (L/E_ν) in short baseline experiments

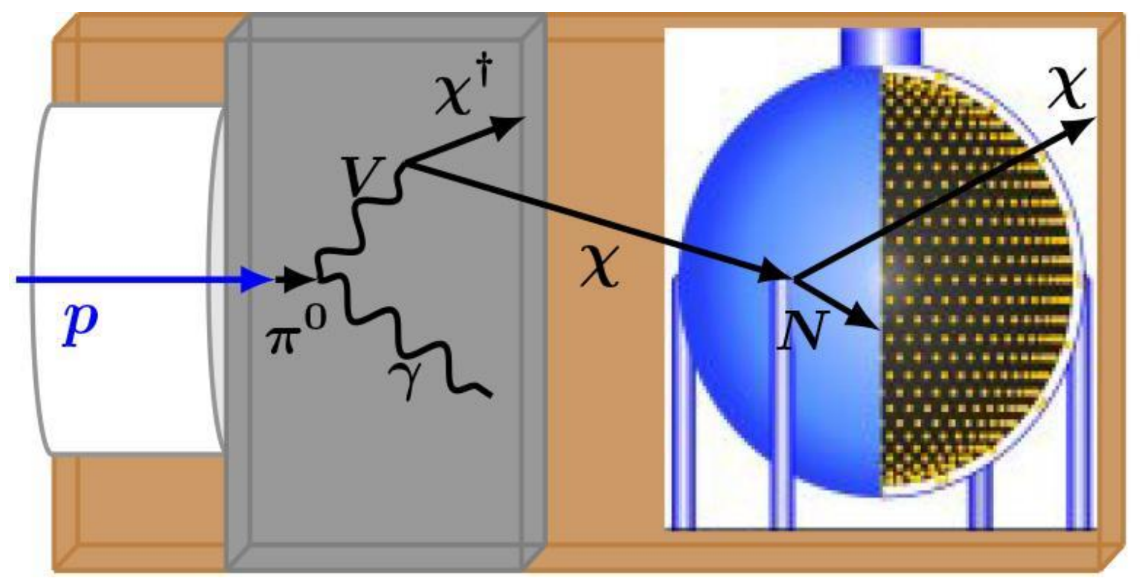


Fig. 2: Diagram of neutrino oscillations inside of the MiniBooNE detector

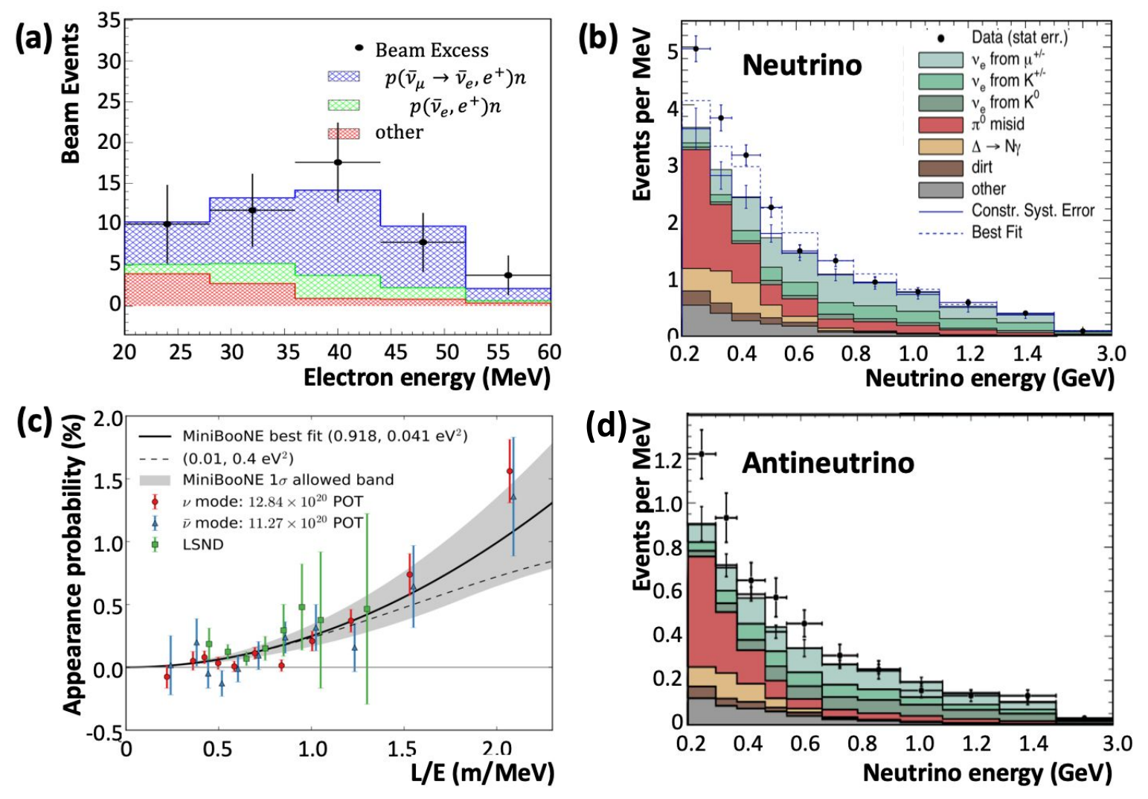


Fig. 3: (to the left): Part A shows an excess of positrons due to antineutrino oscillation. Part B shows an excess of electron neutrinos compared to all known backgrounds. Part C shows the range of the parameter space for short baseline experiments observing neutrino oscillations. Part D shows the excess of antineutrino events compared to all known backgrounds.

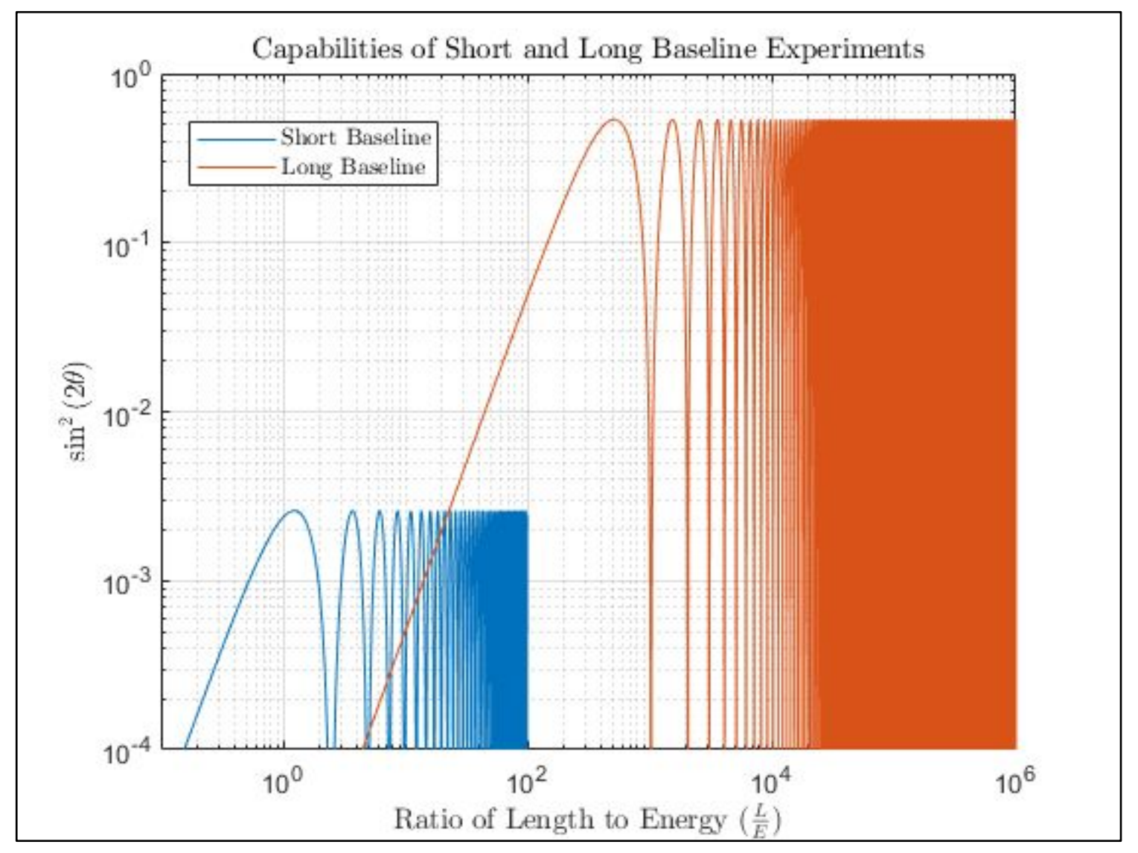
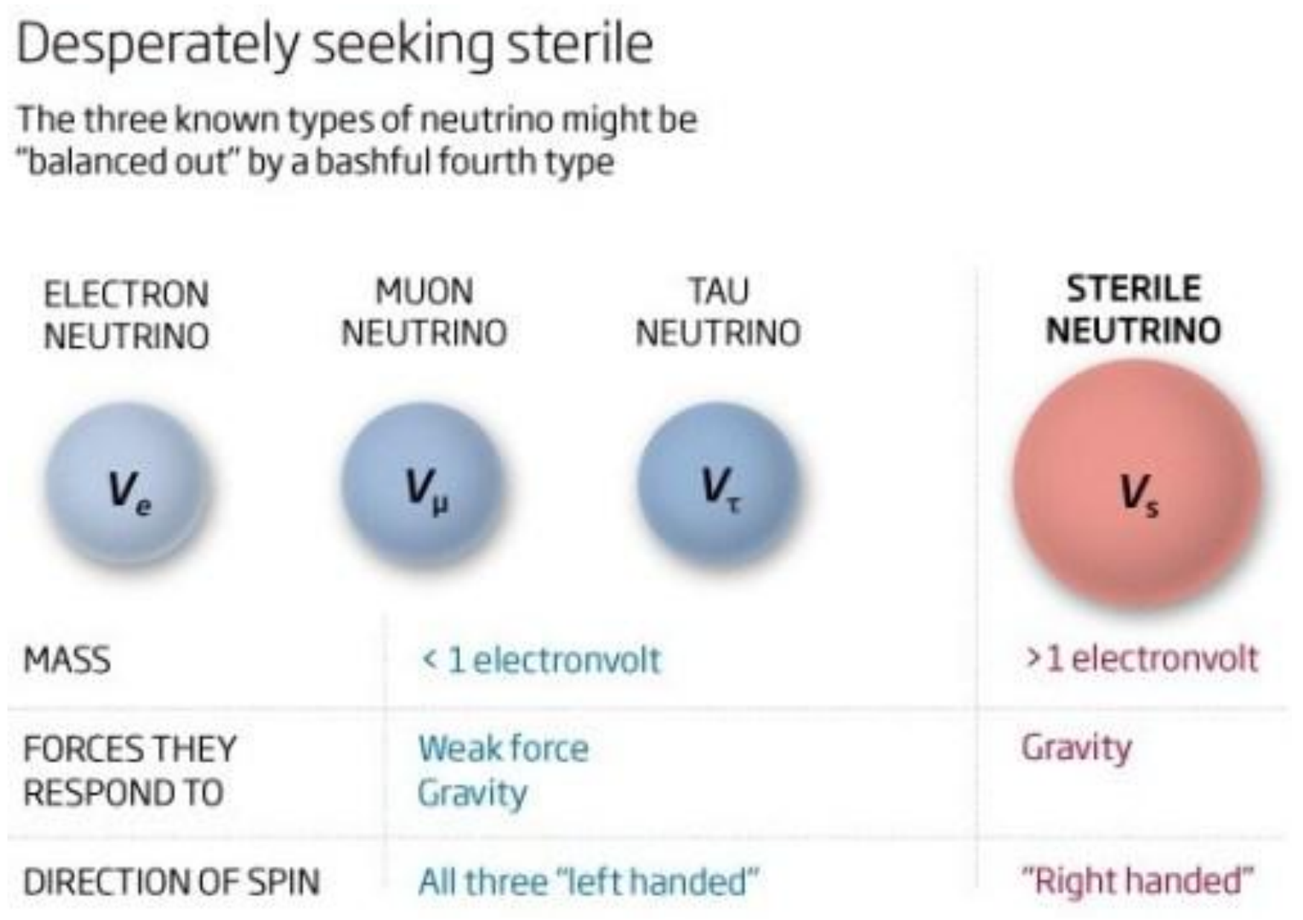


Fig. 4: (to the right) compares the observations of short baseline experiments and long baseline experiments. This demonstrates the sensitivity of short baseline experiments to sterile neutrino oscillations while long baseline experiments are more sensitive to neutrino oscillations between active neutrinos.

Sterile Neutrinos



Desperately seeking sterile

The three known types of neutrino might be "balanced out" by a bashful fourth type

	ELECTRON NEUTRINO ν_e	MUON NEUTRINO ν_μ	TAU NEUTRINO ν_τ	STERILE NEUTRINO ν_s
MASS	< 1 electronvolt			>1 electronvolt
FORCES THEY RESPOND TO	Weak force Gravity			Gravity
DIRECTION OF SPIN	All three "left handed"			"Right handed"

Fig.5

What is a sterile neutrino?

In 1995, LSND reported the first observation of neutrino oscillations occurring in a short baseline experiment. These measurements were not compatible with the theoretical parameters (($\sin^2(2\theta)$, Δm^2) observed in solar and atmospheric neutrino oscillations in long baseline experiments. This led to the supposition that there must be a fourth neutrino, a "sterile" neutrino, with a mass greater than the active neutrinos currently in the standard model. The "sterile" neutrino is similar to the active neutrinos (spin ½, neutrally charged). However, it does not participate in the three forces described in the standard model It only interacts via gravity.

The theoretical sterile neutrino would have a very small component in the first three mass eigenstates; however, it is the major component of the proposed fourth mass eigenstate. In order to measure this fourth mass eigenstate, an experiment must be sensitive to the presence of sterile neutrinos (i.e., measure the decreasing flux of the active neutrinos due to their oscillation into sterile neutrinos). The CCM experiment is designed to measure this phenomenon.

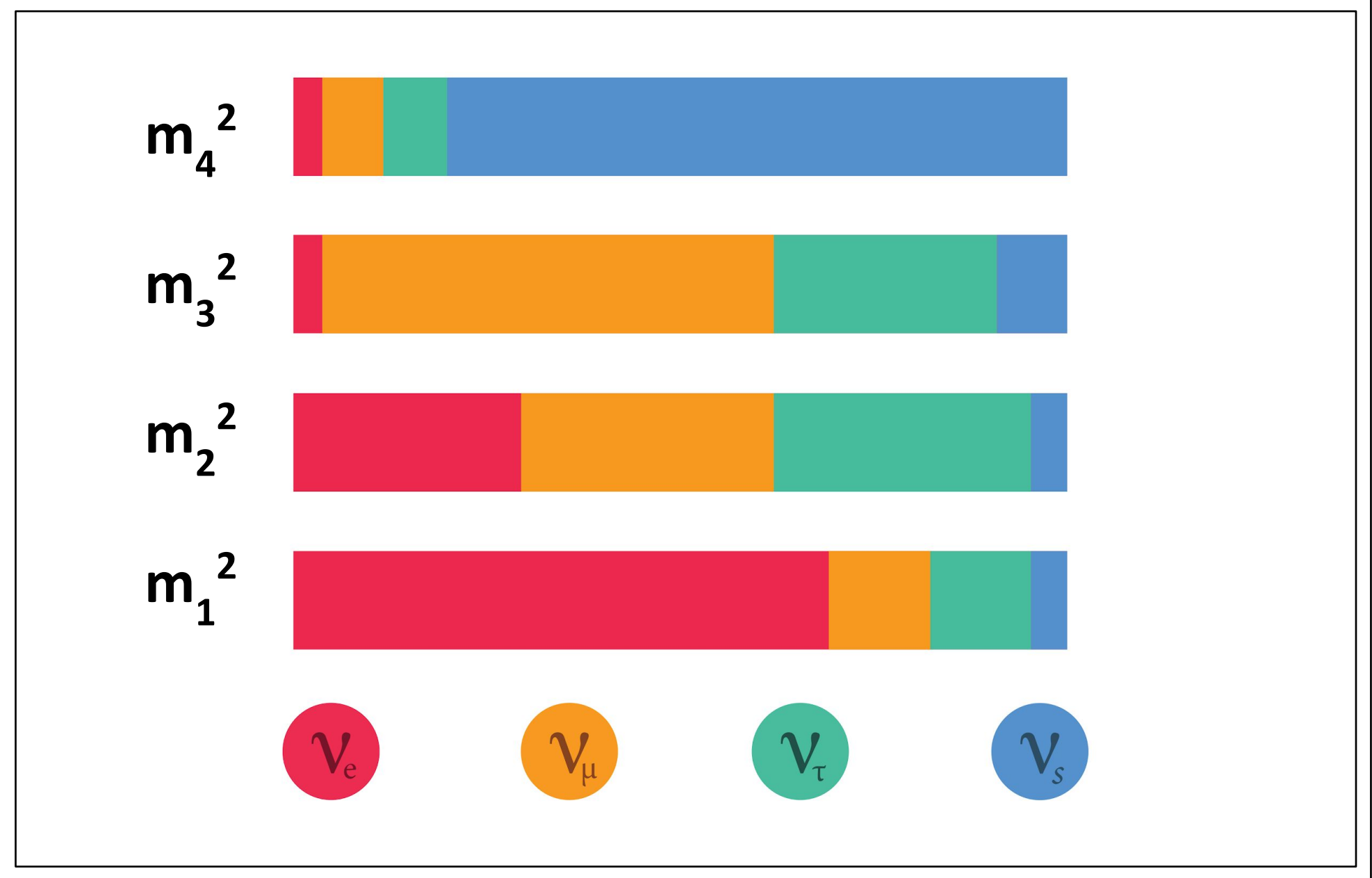


Fig.6: Neutrino Mixing Angles [IceCube]

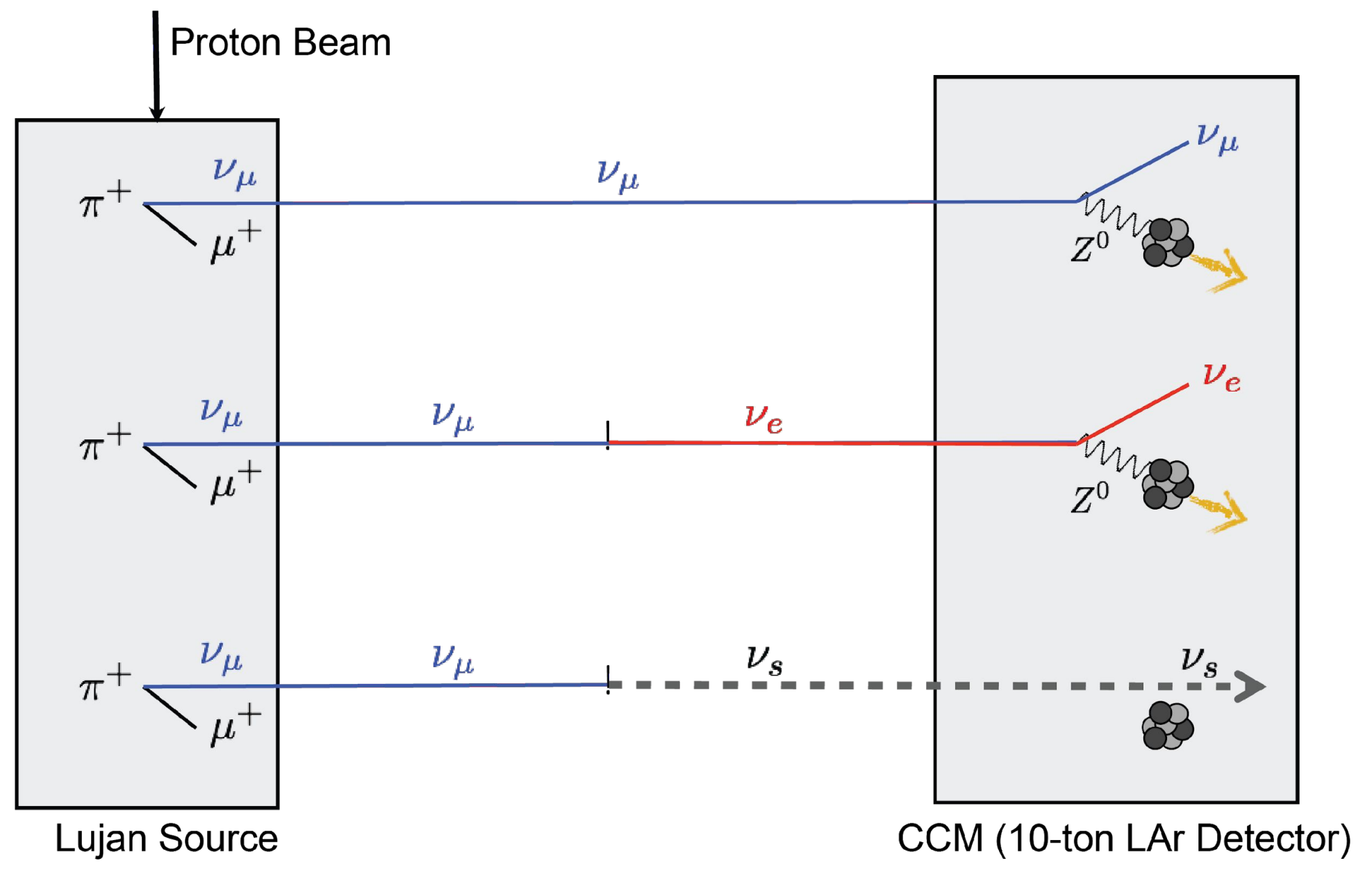
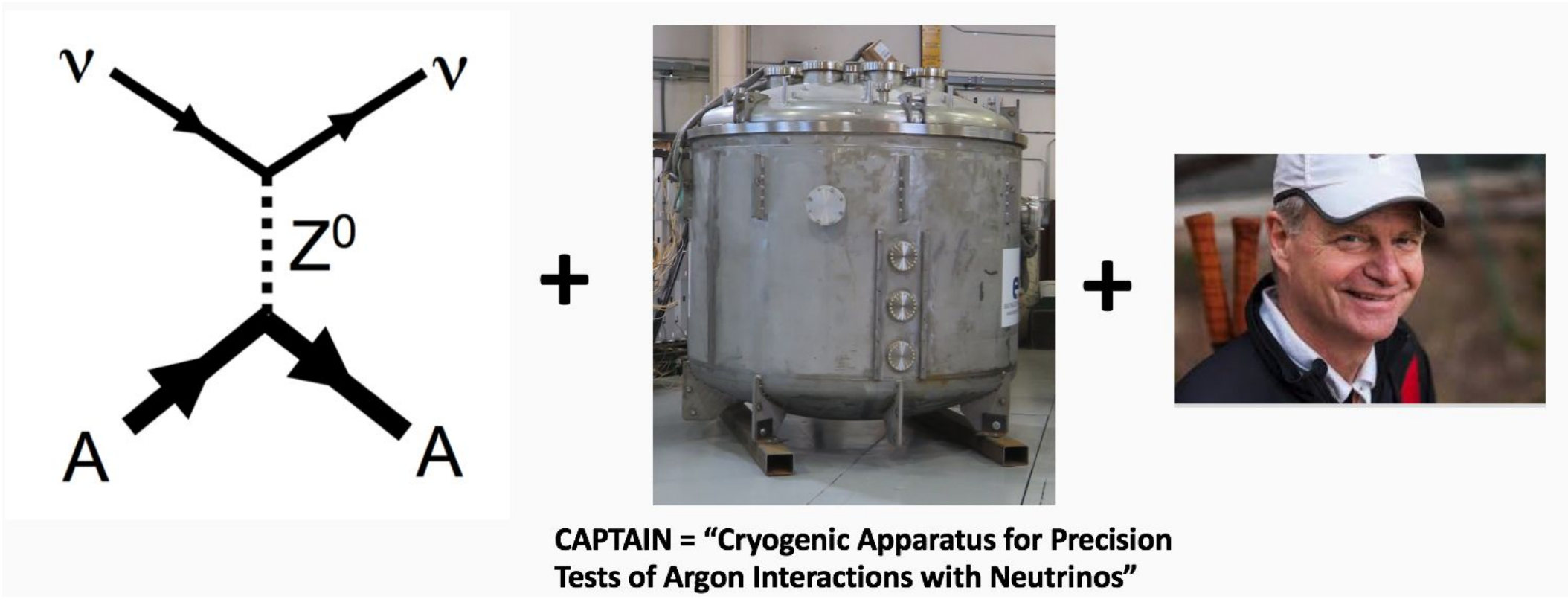


Fig. 7: shows the neutrino oscillations observed in the CCM experiment. The 800 MeV proton beam (located at Los Alamos National Laboratory) strikes a tungsten target producing stopped pions. The stopped pions subsequently decay into muons (μ^+ and μ^-) while producing muon neutrinos (ν_μ). Three possibilities of the muon neutrino oscillations are shown in the figure to the left. In the first case, there is no oscillation. However, it is observed in the CCM detector. In the second case, it oscillates into an electron neutrino, and again is observed in the CCM detector. In the third case, it oscillated into a sterile neutrino and is not observed in the CCM detector.

The CCM detector is sensitive to all neutrino oscillations when they oscillate into active neutrinos. In other words, the initial neutrino flux is observed in the CCM experiment for all active neutrinos. If a sterile neutrino exists, there will be a reduction in flux and we estimate this to about 10%, given the observations made by other neutrino experiments.

Coherent "CAPTAIN" Mills



CAPTAIN = "Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos"

Fig.8

Coherent "CAPTAIN" Mills is a short baseline neutrino experiment located at Los Alamos National Lab in the Lujan Facility. Coherent describes the way the neutrinos interact with the liquid Argon in our detector. CAPTAIN stands for Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos. This experiment was dedicated to Dr. Mills, who came up with this novel idea to search for a sterile neutrino.

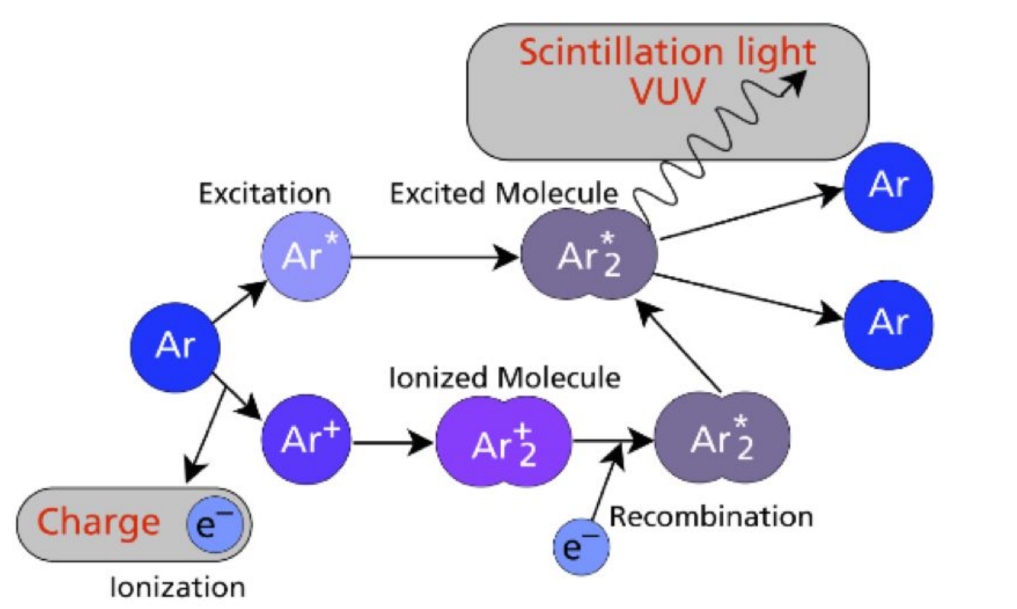


Fig. 9: This shows an Argon atom recoiling from a neutrino interaction and becoming excited or ionized. In either case, it makes an excited Argon molecule composed of two atoms. This molecule de-excites and releases ultraviolet scintillation light observed by photomultiplier tubes (PMTs) in the CCM detector. [Rodgrigues]

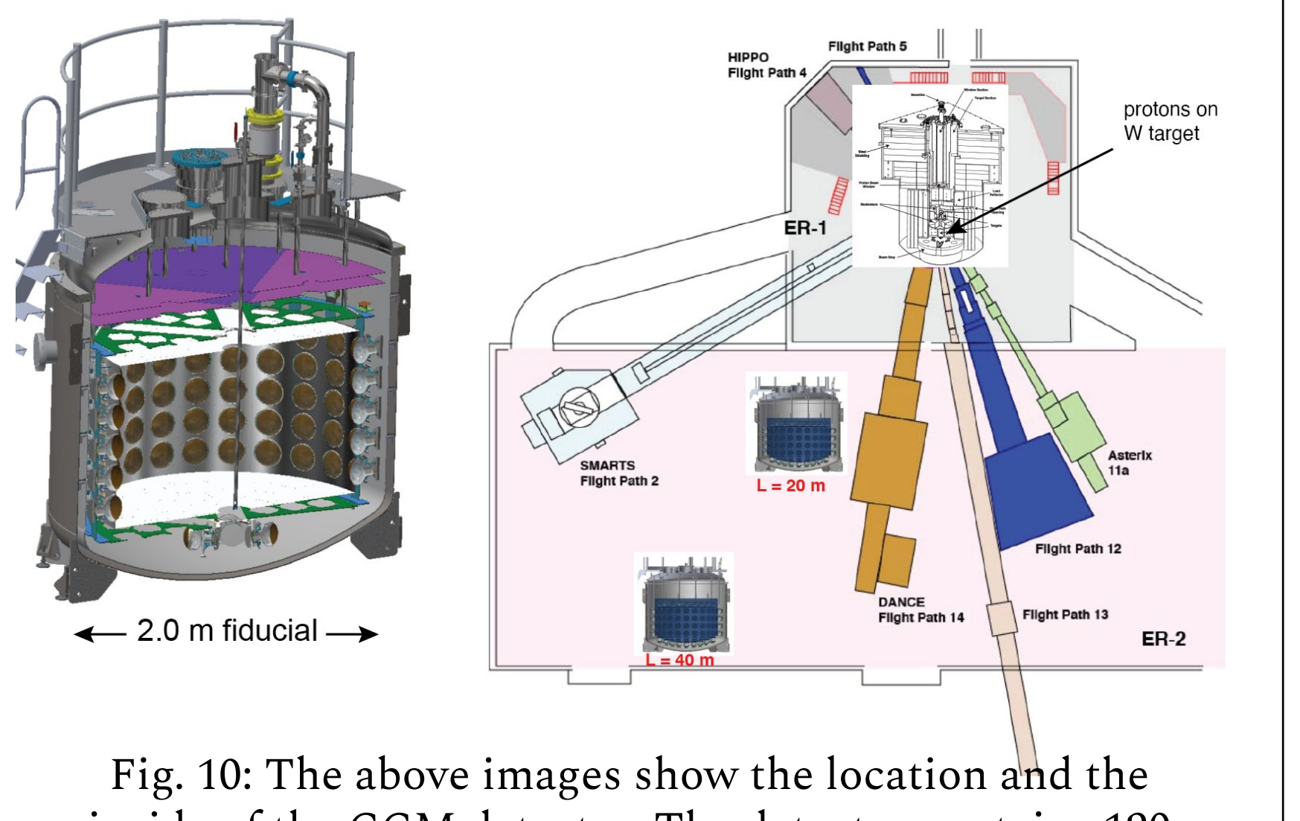


Fig. 10: The above images show the location and the inside of the CCM detector. The detector contains 120 PMTs along the interior wall of the detector with additional veto tubes placed on the top and bottom. A second detector will be added soon at 40 m from the neutrino production as shown in the above diagram. The current detector is 20 m from the neutrino production.

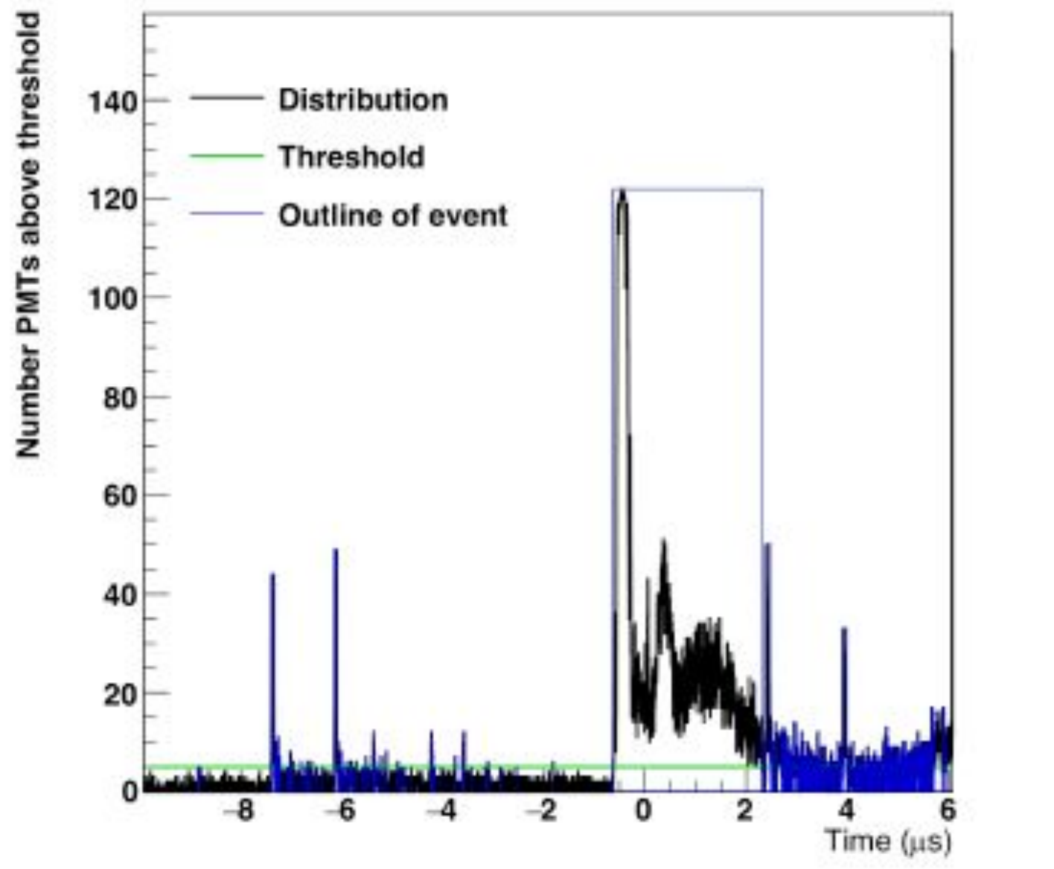


Fig. 11: (to the left): This shows the timing distribution of events observed in the CCM detector. Events before -1 μs are pre-beam events. The events between 0-2 μs are events traveling close to the speed of light (e.g., neutrinos and gamma rays). However, most of the gamma rays are absorbed by the steel and concrete shielding surrounding the CCM experiment, thus leaving neutrinos as the only candidate events in time with the beam. After 2 μs, the events occuring in the CCM detector are contaminated by fast and slow neutrons.

Fig. 12: (to the right): We are currently analyzing data from a germanium detector sensitive to gamma rays. The figure to the right shows the number of counts detected from gamma rays near the CCM detector (uncorrected for live time). The orange line represents data with the beam off and the blue line represents data with the beam on. We investigated 18 of the peaks to measure their energies and widths to determine the elements participating in nuclear transitions that produced gamma rays at these characteristic energies.