**Background:**

- RF and optical communications require direct line-of-sight for reliable communications
- Neutrinos move at speeds near the speed of light, are low-mass and have no electric charge. They have very low interaction with normal matter.
- Neutrino beam communication could enable communication and time dissemination with buried or submerged crafts on distant planets, without the need to deploy antennas.
- Neutrino beam communication could enable continuous communication, time dissemination and navigation signaling with far side of the moon, communication *through mars without relay satellites*

**Approach:**

- Perform experiment that demonstrates communication with neutrino beam generated with Fermi particle accelerator
- Code/decode message, estimate neutrino beam channel parameters.
- Develop “link budget” for neutrino beam communications

The project is grateful for the support of Phil Adamson and Dave Capista of Fermilab as well as the support of the MINERvA collaboration (c.f. http://minerva.fnal.gov).
**Results:**

- Repeatedly transmitted message “NEUTRINO” from Fermi accelerator using a neutrino beam through Neutrino at Main Inject (NuMI) horn to Main Injector ExpeRiment for ν-A (MINERvA) detector.
- Neutrino beam passed through 240m of dolomite rock
- Analysis of sequence of neutrino detections produced error free decoding of transmitted message using FEC and 3 repetitions of message.
- Analysis of sequence of neutrino detections verified prediction of Poisson channel with near zero likelihood of false positive (Z-channel), estimate of channel parameters, Bit Error Rate (BER) and Frame Error Rate (FER) estimates
- Analysis of NuMI beam design yielded expression for transmitter far field gain in terms of Lorentz boost parameter, tunnel length and pion lifetime. Expression for detector gain depends on detection
- Link analysis expressions verified with Monte Carlo simulation
**Future Expectations:**

- Advances in particle accelerators could improve practicality
- Fission reactors produce anti-neutrinos which could be detected at short range— a suitably modified reactor could modulate its anti-neutrino output to carry information
- Alternate: Weakly Interacting Sub-eV Particles (WiSP)

<table>
<thead>
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<th>Difficulty</th>
<th>May Exist</th>
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<tr>
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Concept for detecting and generating speculative WISPs