Final technical report, “Neutrino Physics at Drexel”, DE-SC0007988 (Apr 2012-May 2014):

The early part of this grant had significant effort by Ph.D candidate students Ms. Erica Caden (now a postdoc on SNO+) and Mr. Edward Damon (now working in industry) to analyze data from the Double Chooz reactor neutrino experiment. Please note that the DOE-funding of our “Double Chooz” effort terminated during this period, although students certainly continued until graduation. Hardware was funded via NSF. This report focuses on the overall technical and scientific results, not the details of exactly which funding agency paid for what item.

Ms. Caden was able to refine the Double Chooz calibration measurements sufficiently to be able to perform a measurement of neutrino directionality with Double Chooz far detector data. It should be noted that this required some very significant reduction in the event position reconstruction errors (which have energy- , radius- and z-dependence) because the directionality uses the position offset between positron and neutron position measurements that are typically only a few mm apart. Her analysis techniques were fed back into the methods used for the neutrino oscillation analysis, to reduce systematic errors.

Mr. Damon conducted a search for “paraphoton” signals with the Double Chooz detector. Paraphotons are hypothesized uncharged particles, rather similar to axions in experimental signature, that would be produced in nuclear reactors and decay in flight into an odd number of photons (3 being most probable). The signal in the Double Chooz detector would be correlated with the reactor power output, showing 3 separated energy depositions with no neutron capture signature. This analysis required improvements in the event timing reconstruction to distinguish spatially separated energy depositions. Most such searches for hypothesized new particles only result in a detection limit, and Mr. Damon’s search was no exception. The event reconstruction timing improvements, however, did assist with the overall analysis effort, such that Double Chooz was able to report a first detection of ortho-positronium signatures in reactor neutrino events.

Ms. Erica Smith began as a graduate student working on Double Chooz, and she (and an undergraduate co-op student, Mr. Jacob Zettlemoyer, now a physics grad student at Indiana) did outstanding work in preparing the Front-End cabling for the Double Chooz Near Detector. The Double Chooz Front-End electronics was finished, installed and commissioned. Ms. Smith transitioned to EXO-200 for her thesis, which she will be defending within days of the submission of this report.

The work on LBNE (now called ‘DUNE’) has been focused on the development of small cherenkov detectors for beamline monitoring, and their associated PMTs capable of being `gated’ to escape the saturation from FNAL beam pulses, while measuring the flux, capture lifetime, and subsequent induced radioactivity from stopping muons.

There has been results in two fronts in the DUNE beamline monitoring effort at Drexel: a gated PMT base design has been prototyped, demonstrating fast (<25ns) gating of a PMT focusing electrode over a voltage swing of 400V. Since “high voltage components aren’t fast”, and “fast components aren’t high-voltage”, this was roughly 10 times faster than originally expected.

We originally attempted to use both distilled water in the cherenkov detectors, and water with $CaCl_2$ dissolved in the water, where the calcium chloride would preferentially capture negative muons, giving them a shorter lifetime, so that the +/- muon content of the beam could be measured. The difficulty with this scheme was one of chemistry: Ca++ isn’t very soluble, and tended to combine with dissolved atmospheric CO_2 to precipitate out of solution. It was necessary to use an unacceptable amount of HCl to keep the Ca in solution, and it became clear that a sufficiently concentrated solution would not be feasible.

Since then, we have concentrated on the use of KCl for negative muon capture; the chemistry is much more favorable, the muon capture probabilities just as favorable (K and Cl differing in Z by only 2 means that they have essentially the same negative muon capture lifetime). The only “downside” is the presence of ^{40}K in the KCl, however a calculation of the background rate for a completely saturated solution in a 5gal detector is about 10^6/s. That sounds large, until it is compared to the much larger rate of muon decays after a beam pulse, where the KCl would add only ~10 extra pulses over a few muon lifetimes. The KCl does provide a built-in “calibration source”, since the electrons and positrons from the ^{40}K decay are energetic enough to make a reasonable cherenkov signal.

Work began on some short-baseline neutrino experiment efforts, with the goal of resolving the `reactor neutrino anomaly’ of a ~3% discrepancy between measured flux and detailed reactor neutrino production calculations. If this were a result of `physics’ (such as, sterile neutrinos), the experimental signature would be found at short baselines, preferably < 10m from the center of a compact reactor core. The early stage effort eventually turned into the PROSPECT experiment, making use of ^6Li-loaded liquid scintillator detectors at the Oak Ridge HFIR reactor.

An alternative detector configuration was explored, with plastic scintillator plates and wavelength-shifting optical fibers: the idea was that the plates (~2mm thick) would be ganged together at a single PMT for `overall energy deposition’ measurement, while the optical fibers along the edges of the plates would provide segmentation information as to which plates had activity. Between the plates, a thin optical barrier containing Gd would provide neutron capture tagging. A prototype was constructed and tested, but it was found that the scintillator plates did not put out sufficient light to make a useful detector. Improvements to the scintillator (pre-existing at Drexel) were considered, but estimated that a sufficiently efficient scintillator would not be a cost-effective option, in comparison with the liquid scintillator PROSPECT was considering in its “long tube” geometry.