Intensity Frontier Fellowship Closeout Report

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The storage ring magnet from the decade old Brookhaven experiment E821 has been re-assembled on the muon campus, cooled and now operates at full field for hours at a time. As stated in my research proposal, the field averaged over all muon trajectories must be known to better than 70 ppb for the upcoming muon g-2 experiment E989. This requires shimming the magnet to a high degree of homogeneity which can only be done onsite at Fermilab. The Intensity Frontier fellowship provided the means to spend extensive time here to construct the measurement apparatus and begin the process of shimming.

Field measurements use NMR probes constructed at the University of Washington along with re-furbished electronics from the E821 experiment. The probes sample the volume in the pole gap where future muons will eventually orbit. They are mounted in a trolley that rides on rails formed by shims mounted on the edges of the poles. When I came to Fermilab in June, I brought along two graduate students Matthias Smith and Rachel Osofsky. Our initial tasks included building a motion control system to pull the trolley around the ring and integrating that with our data acquisition system. The trolley's azimuthal position is monitored by a laser tracking system provided by Horst Friedman's metrology group. I've had many fruitful discussions with Horst in proposing this system for reading out the trolley's position. Each aspect of the measurement apparatus had to be integrated into the MIDAS framework which is used throughout the collaboration. Interns from local high schools and the UK worked with us to complete this construction phase. The system is now operational and we typically complete a scan of the entire ring including analysis in less than a day.

When the magnet operated at full field for the first time here at Fermilab, the measured field map showed similar variations in field to the map made at BNL when it was first powered. Since then we have calibrated the effects of moving shims and repositioning poles. We have to date made 10 field mapping runs around the entire ring and with the help of Aria Soha, Kelly L Hardin and John J Najdzion have made almost that many changes to the magnet's configuration. We have so far reduced the total field variation by more than a factor of 2 but more importantly we know the effect of each tool in the shimming kit and will be able to produce more global optimizations in the future. The one surprise came from NMR probes operating in the vicinity of pole or yoke boundaries. We were aware of problems E821 had in these regions. The normally 4 millisecond long NMR waveforms shortened to less than 10% of this value but unlike with the BNL measurement system we were still able to extract usable frequency information.

After our first few magnet on runs the magnet quenched for no apparent reason. The magnet was locked out pending a quench analysis. I joined a working group to try and figure this out which included Cryo engineers, Steve Chappa, Hogan Nguyen, Del Allspach, Chris Polly and Bill Morse at BNL. It became clear that cryogenic helium was leaking into the cryostat vacuum. Cryopanels installed when the magnet was first constructed at BNL were pumping this leak and at fairly regular intervals would spontaneously release gas into the vacuum. If the magnet was powered on when this happened, the magnet would quench. We determined a safe period of time the magnet could be powered after manually regenerating the cryopanels and this allows us to complete shimming putting off the leak repair until we are done. An outcome of the formal quench analysis was the requirement of a run coordinator to authorize returning the magnet to operation after a quench and I was appointed to that position by the collaboration.

In summary constructing the field measurement apparatus and pulling together our team to map the storage ring field and calculate changes to shim and pole positions are significant achievements made during my time at Fermilab. I can't stress enough the value of being here working together in face to face meetings with Precision Field Team colleagues like Brendan Kiburg, Peter Winter and Joe Grange. In a very short time we developed run plans and with their skills in Root developed tools to visualize the large data sets acquired from mapping the field. We can make quantitative comparisons of dipole and higher order moments of the field for each change in shim or pole configuration. Much of the analysis is scripted and results are available soon after a data run is completed. Delays in bringing the magnet to full field have extended the shimming period until the spring of next year and as a result we haven't yet reached homogeneity goals set out in my research statement. The way forward is clear and I will continue working towards these goals past the current period of my fellowship.