The Intensity Frontier Fellowship Research Proposal

The g2Sim Simulation Package

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In order to achieve a precision of 140 ppb E989 will need to reduce the systematic errors on the E821 measurement of a_μ by a factor of 2-3. Many of these reductions will come from hardware upgrades, such as improved collimators to reduce the number of lost muons, increased calorimeter segmentation to aid in the detection of multi-positron events and the implementation of three straw trackers to monitor the muon beam distribution on a fill-by-fill basis. In addition to hardware improvements E989 is developing a complete simulation package to aid in algorithm development and the estimation of the size and bias of systematic effects. This package, g2Sim, is based on GEANT4 representations of the storage ring, ring components and detector modules implemented within the FNAL ART analysis framework. To date this framework has been used to optimize the design of various ring components, such as the quadrupole plates and the material of the trolley rail stand-offs.

In preparation for the first E989 run in the spring 2017 the simulation group has initiated a series of mock data challenges aimed at 1) finalizing the muon gun, ring and detector components 2) validating these components against final design parameters and blueprints 3) coding and testing the data structures that will ultimately be used in both data and simulation analysis streams to record detector responses. The culmination of these data challenges will be the production of two physics quality simulation sets. The first set will be composed of 100B muon events, chosen to match the size of the final E821 data sample, and will be used to develop positron identification algorithms and study the systematic effects of overlapping events and gain changes on the extraction of the muon precession frequency ω_a. The second sample, composed of 100M muon events, will employ the inflector gun and will be used to study the dynamics of the muon beam as it orbits the storage ring and estimate systematic effects such as lost muons. Both of these sets will play an essential role in developing the codes that will be used to analyze the data from the first E989 run.

During the past year my group has focused on aspects 1) and 2) described above, i.e. the development and verification of the ring and detector components in the g2Sim package. Development and verification are ongoing and iterative tasks and will require an increase in manpower during the summer and fall months. The final, as-built detector and ring component designs need to be ported to the simulation and/or verified using the Paraview package. Field maps of the pole magnets after shimming is complete and alignments from final surveys must be incorporated and checked. This fellowship will allow me to maintain an onsite presence during this critical time. The ability to physically see the equipment, talk with the technicians and access the engineering drawings will vastly increase the efficiency and accuracy of the implementation in the simulation.

As a parallel effort, my group is developing an automated simulation verification package. This package consists of a set of Art modules that analyze, plot and display the output of the g2Sim package. The verification package has been used at each stage of development to monitor updates, identify newly introduced bugs and document the consistency of the evolving g2Sim simulation package. This fellowship will support my groups efforts to extend this package to components as they come online and work towards full automation so that it can ultimately be included in a nightly build and code release. Our implementation will include

a suite of diagnostic histograms and tests for compatibility with previous simulation samples, all accessible via a searchable display interface on an internal FNAL server.

As the simulation samples come online I plan to use them to develop pile-up identification algorithms. Pile-up refers to the overlap, in both space and time, of events from two muon decays. The categorization of two positrons as a single positron results in mis-identification of the energy and the muon spin precession phase. These errors distort the ω_a fit and must be accounted for in the systematic errors. The improved timing and spatial resolution of the calorimeters in E989, along with the three tracking stations, will provide several new handles on identifying pile-up events. One way to discriminate between two data samples is through the use of multivariate classifiers. This class of tools, in particular boosted decision trees and neural networks, require "training" on high purity data samples or simulations of the unique sample types. The significant hardware improvements combined with the substantial sample of realistic simulation data, make it an ideal time to implement the multivariate classifier techniques that have been successfully utilized in particle physics for many years.

Finally, support from this fellowship would allow me to participate fully in the first E989 run currently scheduled to start in March of 2017. The experimental goal for this run is to make an initial measurement of a_μ at the same precision as the final result from E821. Detectors and final ring components will be integrated into the muon storage ring structure by late fall. The data acquisition (DAQ) system will be functional by late summer and will incorporate detector systems as they come online. During this time there will be a many opportunities to contribute to the ongoing installation and commissioning activities. The list of tasks is long and includes modifying the DAQ system to process data from the newly developed inflector beam monitoring system and the fiber harps, developing code to provide fast feedback for the calibration of these and other detectors and assisting in building the database protocols needed to store the vast amount of data collected by the slow controls. My software experience should allow me to fill in the manpower gaps that inevitably arise during the hectic installation and commissioning period.