RESEARCH STATEMENT

Project: measurement of the muon anomalous magnetic moment at the 0.14 ppm level with the Fermilab E-989 Muon g-2 experiment.

1. The Standard Model of particle physics and beyond

The Standard Model (SM) of particle physics has been built over many decades and showed to be extremely fruitful in its predictions that were impressively well confirmed experimentally. However, there are theoretical and experimental indications that the SM does not represent the full picture. Such experimental indications come from precision measurements that allow to test the SM at a deep level and thus represent a window to physics beyond the SM (BSM).
Precision measurements in flavor physics show several discrepancies with the SM expectation. We can cite the measurement of the angular distribution of the decay products for the process $B^0 \to K^{*0}\mu\mu$, the forward-backward asymmetry of the *b* quark A^0_{FB} or the partial width of the *Z* boson R^0_b. An other one is the measurement of the anomalous magnetic moment (*g-2*) of the muon. The high-precision measurement (0.54 ppm) performed at Brookhaven National Laboratory in 2004 disagrees with the SM prediction at a level exceeding 3.5 standard deviations. This difference could be a hint of unknown physics. The new *g-2* experiment at Fermilab aims to improve the precision by a factor of about four (0.14 ppm), which opens the potential for at least a five standard deviation difference with the SM prediction. My work as a post-doctoral researcher in the Cornell *g-2* group is integral to our effort to achieve this level of precision (see Section 3).

2. Searching for New Physics with the top quark (PhD work)

The top quark is the heaviest known elementary particle. Therefore it has a coupling to the Higgs boson close to unity and a dominant contribution to various loop processes through which for instance could decay BSM particles. The study of the top quark could therefore allow for indirect measurement of BMS physics as well as a better understanding of the electroweak symmetry breaking. I joined both D0 and ATLAS collaborations as a PhD student to contribute to the top quark physics program.

2.1 Probing the New Physics with the top quark at the Fermilab Tevatron collider

In 2011 the CDF and D0 collaborations reported measurements of the top-quark pair forward-backward asymmetry. This property measurement tests the SM to high precision. The measurements from CDF and D0 were found to be significantly higher than the SM predictions. These deviations are one of the few observed and represent a great opportunity to look for New Physics.
As a PhD student in the D0 collaboration, I performed the measurement of the forward-backward asymmetry of top-quark pair production in the dilepton final state, using the full dataset recorded by D0. My work therefore contributed to a legacy measurement of the Tevatron that may unveil New Physics. As the main analyzer, I had to deal with all the required steps needed to achieve a robust measurement. For example, I optimized the event selection, performed the raw measurement of the asymmetry and corrected it for detector and acceptance effects. I also took care of the treatment of the systematic uncertainties and studied predictions for relevant new physics models. Finally, I was in the forefront for the whole internal review process for the publication of this analysis. This result has been published by the APS journal Physical Review D. I also played a major role in the combination of dileptonic/semileptonic decay channels at D0 which was published in Physical Review D. I am now contributing to the combination of the different asymmetry measurements from CDF and D0 to achieve the best possible precision.

2.2 Probing the New Physics in a complementary way with the top quark at the LHC

I joined the ATLAS collaboration for the last year of my PhD and worked on the measurement of the charge asymmetry at the LHC collider. The Tevatron and LHC being respectively proton-antiproton and proton-proton colliders, the top-quark pair charge asymmetry measurements are complementary between the two machines. The expertise developed in the D0 collaboration allowed me to play a leading role within the analysis team. I contributed to all the different studies and aspects and I led the efforts taking care of the organization/planning (task assignments, meetings etc…). The measurement to which I contributed is still ongoing within the ATLAS collaboration and should be published in early 2016.

3. Searching for New Physics with the Fermilab E989 Muon g-2 experiment (current work)

3.1 Work based at Cornell University (until June '16)

In August 2014 I joined the Muon *g-2* group at Cornell University to contribute to the substantial ongoing efforts to achieve the most sensitive measurement of the muon anomalous magnetic moment a_μ. Polarized muons will be stored in a magnetic storage ring in which the muon spin precesses at the frequency $\omega_s = \omega_a + \omega_c$ where ω_c is the precession due to the cyclotron motion and ω_a the anomalous spin precession frequency. The value of a_μ is obtained via the relation $\omega_a = -Q/m \cdot a_\mu \cdot B$. The magnetic field intensity will be measured via nuclear magnetic resonance techniques in terms of the Larmor precession frequency of a free proton ω_p.

I am, with the Cornell group, largely contributing to the ω_a measurement. The key point for this measurement is the development of the Čerenkov electromagnetic calorimetry that will detect the positrons coming from the decay of the muons. These positrons act like proxies to measure ω_a thanks to the parity-violating V-A decay of the muon that leads to the positron rate to oscillate at the *g-2* period of a 4.6 μs ($\omega_a = 1.5$MHz) for high-energy positrons (typically energy above 1.8 GeV for a maximum energy of 3.1 GeV). The 70 ppb systematic uncertainty budget on ω_a requires to know the arrival time of each positron with an accuracy far better than one nanosecond and the energy with a 5% resolution.
The Cornell group has developed the calorimeter readout electronics that samples the analog signals from the calorimeter. I have the responsibility to lead and oversee the development, testings and eventually the mass production (about 330 units corresponding to about 1,650 readout channels) and quality control of the waveform digitizers (WFD) that are the central pieces of the readout electronics. The final design of the WFD is a 5-channel digitizer with a 12-bit analog-to-digital converter resolution sampling at 800 MSPS and a required intrinsic below 1.5 mV for a full scale of 1 Vpp. The typical lifetime of the muon beams of 700 μs (entirely digitized) and their injected rate into the ring of 12 Hz average sets the readout rate per WFD to be at least 3 Gbit/s and we achieved 4 Gbit/s.

I spent a year (Aug '14 – Aug'15) working on the first prototype of the 5-channel WFD alongside with two graduate students. This work included a broad range of activities. I developed and tested the WFD firmware with for instance the implementation of the DDR3 memory buffer. This buffer allows for a fill-asynchronous readout of the data with storage capacity up to 120 muon fills. I conducted various tests and adjustments such as ensuring that the digitized data propagate without corruption, look for temperature dependence and study the noise and look for crosstalk between the 5 channels. An other important test I performed was to look for rate-dependent effect that could bias the energy measurement and thus the ω_a measurement.
The WFD entered its last stage of prototyping during Summer '15. I spent the past months thoroughly characterizing, testing and tuning the prototype in order to assure that it meets with our stringent requirements regarding noise level, signal fidelity and overall performances. I performed the first “calorimeter end-to-end” test at Cornell to start integrating all the different components: silicon photomultiplier, WFD, MIDAS DAQ system and online analysis with ROME. The excellent results that I obtained demonstrated the first operation of the full DAQ system. I am now working toward a more complete and robust integration of all the pieces collaborating with all the involved institutions. This work is of very high importance in preparation for the full calorimeter system beam test at SLAC during Spring '16.

The WFD is composed of the main board that does all the digitization and acquisition logic, the power supply board that delivers all the required analog and digital voltages, and the analog front-end board that receives the analog signal from the SiPM and passes it along to the main board after tuning the signal. The final production of about 330 WFDs started with the production of the power supply board. The full load should be in hand at Cornell at the beginning of January '16. The main board and analog front-end will be sent for production soon and we expect to have them in hand by mid-February '16.
I will coordinate and lead the huge efforts that have to be done regarding the quality control of all the WFDs working with one graduate student and several undergraduate students. All the power supply boards will have to be tested individually and independently of the two other boards to avoid any risk of damaging them. The main board and its analog front-end will have to be scrutinized to ensure that everything is behaving as expected. Each and every WFD will be precisely characterized (noise, pedestal, gain, linearity response...) and those characteristics stored in a database that will be part of the ω_a measurement framework. The quality control will be performed using the MIDAS DAQ system. The MIDAS data will be analyzed within the official *g-2* ART analysis framework for which I will develop an expertise.
I anticipate the testing and characterization of the 330 boards to be done by June '16, date at which they will be moved to Fermilab to start installation alongside the calorimeter station. I will at that time be moving to Fermilab to supervise the deployment and integration of the WFDs.

I am also currently working on interfacing the WFDs with the kicker that is being developed by Cornell for the *g-2* experiment. The WFD will indeed be deployed for the calorimeter stations and also for other sub-systems such as the kicker, the electrostatic quadrupole, the beam position monitor, and the laser calibration system. I am playing a forefront role in this interfacing effort. I will take part as well in studying the noise contribution from the kicker to the WFD and investigate isolation and shielding strategies well in advance the kicker is deployed in the experiment.

Beside the electronics effort I am conducting beam dynamic studies that are important for the ω_a measurement using the BMAD software. I am interested in the correction that has to be applied to the extracted ω_a value due to the imperfection of the beam such as the muons momentum being spread up to 0.2% or the momentum direction not being orthogonal to the storage magnetic field. These imperfections lead to non-negligible contribution (for BNL E812: 0.77 ppm overall correction compared to the total uncertainty of 0.54 ppm). This work allows me to deepen my knowledge in beam dynamics and it will be extremely useful when I get involved in beam commissioning, the last step before the first data taking period for our physics results.

3.2 Work based at Fermilab (starting June '16)

The installation of the 24 calorimeter stations and associated electronics and DAQ system will start at Fermilab in June '16 and will be carried on through summer and fall '16. I will be moving to Fermilab in June '16 with all the operational readout electronics in hand. I will be a key figure for this installation and commissioning phase given my expertise and my current efforts toward the integration of the complete calorimeter chain. The integration and commissioning phase will be complex and will require careful efforts.

Alongside with the hardware campaign I will be heavily involved in data analysis. I will have the responsibility for software/algorithm development calorimeter related such as reconstruction of the positron hit position from Čerenkov clusters and other clustering and reconstruction needs. These tasks will be essential to perform a complete and thorough measurement of ω_a with simulation data beforehand analyzing the real beam data.
There are various ways of analysis the data in order to extract ω_a. I will take the lead for a novel approach that consists in applying an unbinned likelihood fit to the positron decay rate spectrum. This method relies on the definition of a likelihood that encompasses all the physics influencing the muons/positrons. Such an approach therefore requires a very good knowledge of all the pieces of the experiment and their associated systematic uncertainties.
An important input to this ω_a extraction is the effect from the beam imperfection mentioned previously for which I will be a leading force. My presence on-site at Fermilab for the hands-on beam commissioning will give me the best insight and understanding of these kind of effect that will feed back into the ω_a extraction.