Snowmass Whitepaper: Accelerator-based Measurement of Muon-Induced Neutron Background for Underground Sciences

Cheng-Ju Lin, Yuen-Dat Chan, Alan Poon (LBNL), Kam-Biu Luk, Herbert Steiner (UC Berkeley/LBNL), Kwong Lau (U. Houston), Christopher White (Illinois Institute of Tech.), Priscilla Cushman (U. Minnesota), Erik Brubaker, Peter Marleau, David Reyna (Sandia National Laboratory), James Loach (Shanghai Jiaotong U.), Vitaly Kudryavtsev (U. Sheffield), Jason Detwiler (U. Washington).

Many current and future experiments are exploring frontier physics by going deep underground to shield their sensitive detectors from fast neutrons and radioactive isotopes produced by cosmic-ray muons. The cosmogenic backgrounds give rise to false signals that are not easily suppressed. For example, an energetic neutron produced by a cosmic-ray muon could penetrate surrounding rock and detector shielding materials to mimic weakly-interacting-massive-particle (WIMP) recoil in the detector. While the muon flux and muon energy spectrum as a function of underground depth are reasonably well understood, the properties of the backgrounds resulting from muon spallation are poorly known. Most simulation studies yield predictions that do not agree well with the experimental data [1-5]. For some parameter space, the differences are as large as orders of magnitude. Advances in modeling the cosmogenic background have been progressing at a glacial pace largely due to the lack of experimental data. This critical issue was reiterated at recent cosmogenic activities and background workshops [6,7]. To address this long-standing weak spot in our knowledge, we propose to carry out a dedicated muon beam experiment to directly and systematically measure the production of muon related backgrounds, in particular, the production of fast neutrons by muons.

There are two broad categories of muon-induced background. The first category is the production of fast neutrons from primary muon-nuclear spallation or capture and the subsequent cascade multiplications. The second category is the production of radioactive isotopes (e.g. ^{8}He ^{9}Li, ^{11}C, ^{12}B, etc.) in the muon shower. For the first phase of the program, we will focus on the fast neutron production since this is a background common to all underground experiments. It is also one of the most lethal backgrounds for many direct dark matter and neutrinoless double-beta decay searches. We plan to measure parameters such as angular distributions, multiplicity, and energy spectra of the fast neutrons as a function of primary muon beam energy, and also as a function of target thickness for different target materials. It is important to measure neutron production vs. target thickness since a significant fraction of neutrons produced are from secondary production in the target medium. This process is particularly difficult to model. Another important point is that many new underground experiments will be located at deep sites with mean muon energies at about 300 GeV. Therefore, our proposed measurements will need to extend the muon energy range significantly beyond the earlier measurement [8] to the maximum energy allowed by the beam line. The ideal site to perform this experiment is at the CERN SPS M2 beam line. The general experimental layout consists of a target (can be swapped with target of different material and thickness) surrounded by an array of neutron detectors a few meters away. In the fall of 2012, we conducted a feasibility study at this beam line at CERN by placing several different targets in the muon beam and a neutron detector about 1.5m from the target. We measured the neutron production rates at three different polar angles relative to the target and beam axis. We also performed an extensive survey of the background level (e.g. gamma and background neutron) in the experimental area. The feasibility study confirmed that our proposed experimental techniques are well suited to accomplish our physics goals.

Our initial goal is to perform a detailed measurement of muon-induced fast neutrons. However, we plan to design the experimental apparatus with sufficient flexibility to allow measurements of other cosmogenic backgrounds at a later date. The experiment will yield a wealth of data on neutron production properties that are valuable to underground communities in particle/nuclear physics, particle-astrophysics, and also nuclear non-proliferation. The estimated total cost of the project is a few million dollars spread out over several years. We are able to significantly reduce the total cost of this beam experiment by sharing infrastructures with the COMPASS experiment in the detector hall.

References

[1] A. Lindote *et al*., Astropart. Phys. 31, 366 (2009).

[2] Marino *et al*., Nucl. Instrum. Meth. A**582**, 611 (2007).

[3] D.-M. Mei and A. Hime, Phys. Rev. D**73**, 053004 (2006).

[4] H.M. Araujo *et al*., Nucl. Instrum. Meth. A**545**, 398 (2005).

[5] Y.-F. Wang *et al*., Phys. Rev. D**64**, 013012 (2001).

[6] AARM Workshop, U. Minnesota, June 2012, [https://zzz.physics.umn.edu/lowrad/meeting5/talks].

[7] Cosmogenic Activities and Backgrounds Workshop, UC Berkeley, April 2011, [https://docs.sanfordlab.org/docushare/dsweb/View/Wiki-141].

[8] V. Chazal *et al.*, Nucl. Instrum. Methods A**490**, 334 (2002).