Cylindrical Apertures to Measure Neutron Lifetime

A Prospectus By
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1 Introduction

The decay lifetime of an isolated Neutron, τ_n, has been studied extensively in the past, however both scrutinized results do not agree on the precise value. The 2 main studies took place at the Institute Laue-Langevin using the “Bottle” method, and at the National Institute of Standards and Technology Center for Neutron Research using the “Beam” method. The “Bottle” method uses ultracold neutrons confined in a bottle and counts the remaining neutrons to record decay, and the “Beam” method passes neutrons through a magnetic field and counting the fraction of decay products per neutron passing through. These studies were both verified, but their results are significantly different. The studies report a difference of 8.7$\pm$2.0 seconds, a value far outside of the bounds of uncertainty of both experiments. The puzzling thing about this difference is that in studies targeting other particles, the “Beam” and “Bottle’ methods produce agreeing results. There are a few possible explanations that are very exciting, such as some interaction of the weak force interfering, or some “exotic” process unknown to us occurring in the experiments. However, on a much duller note, this difference, while unlikely, could be the result of error. To eliminate this possibility, the experiment needs to be repeated with more accurate apparatuses to rule out any significant chance that this observed difference is the result of error.

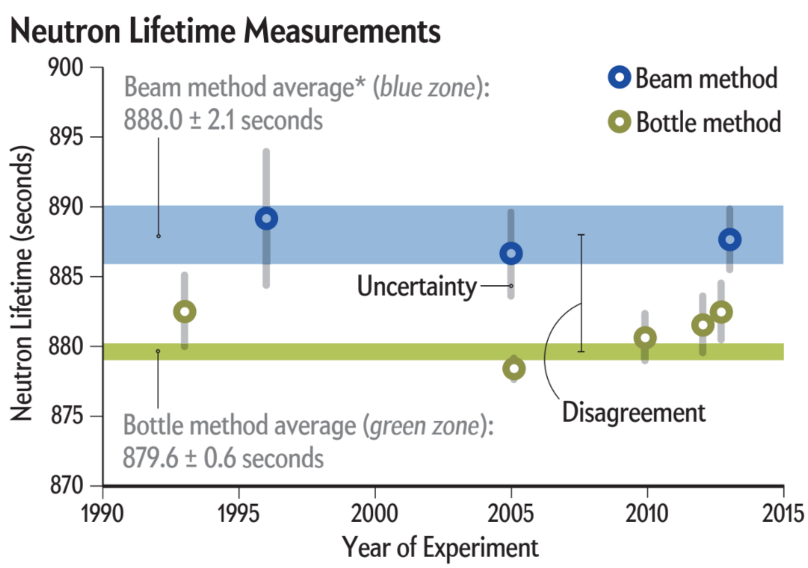

Figure 1: [1] *Diagram showing the disagreement of the 2 experiments over time, demonstrating the need for more accurate experimental methods*

2 Problem and Objectives

As sees above in figure 1, the beam method is naturally more susceptible to error with the nature of how the experiment is conducted, and to move forward in determining the precise lifetime of the neutron we need to find better experimental methods for the beam method. A contributor to the experimental error of the beam method is the detectors located outside of the beam trap. The

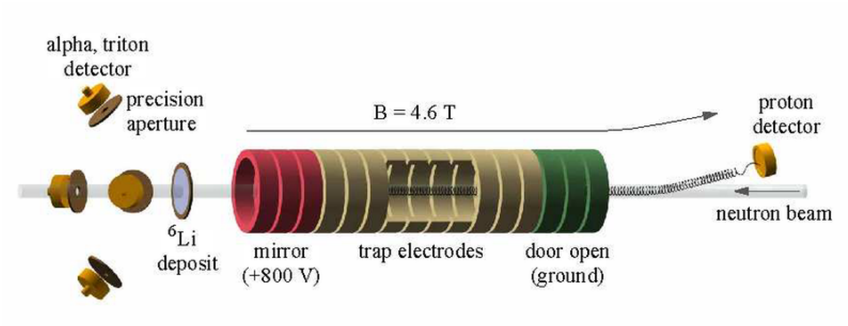

Figure 2: [2] *Schematic showing the detectors and apertures positioned with the proton trap*

width of the neutron beam results in a variation of the origin when considering the solid angle of incident particles to the apertures, therefore particles leaving the trap to be detected all have a differing solid angle to the detectors. This leads to an inaccurate measurement of total neutron flux, and therefore a less accurate experimental result. My mentor, Dr. Christopher Crawford, believes that it is possible to design apertures that create a uniform solid angle for all particles leaving the system, by limiting the solid angle of certain paths using caustics. Therefore my goal is to design precise azimuthally-symmetric apertures for the proposed BL3 experiment to reduce experimental error. Under the guidance of Dr. Crawford, I will work to develop a set of apertures that provides uniform solid angle, and therefore uniform acceptance for every detector, across the width of the neutron beam. My objectives to accomplish this are developing a repeatable coded process for accurately deriving solid angle of a parametric surface, creating an optimization problem with this process, and then producing CAD models using the best results from the optimization problem.

3 Procedure

To begin, I will work back through the work done by Joshua Young on the 2D proof of concept apertures to bring myself up to speed on the project and try and spot any improvements or inefficiencies in the processes. Then I will derive a series of equations used to create an optimization problem who's solutions

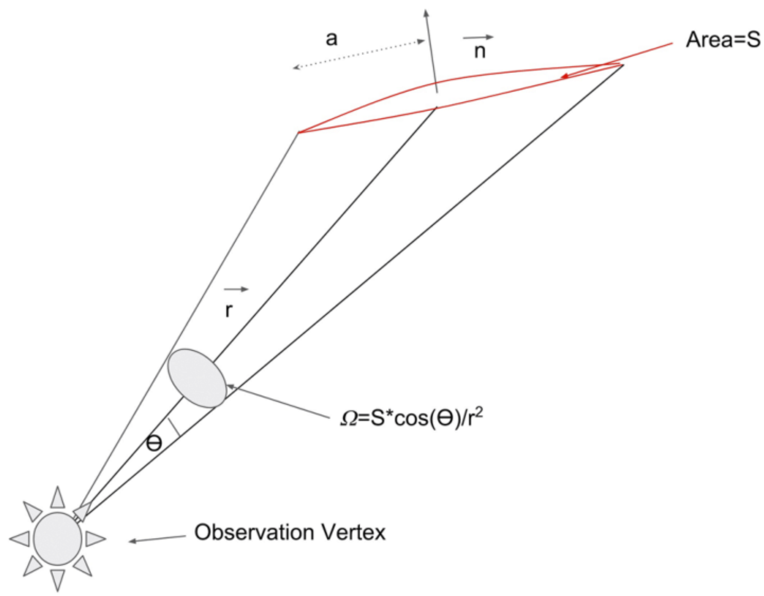

Figure 3: [3] *Graphic showing a similar process of calculating solid angle as proposed, for my work, the area of the surface will be defined as an unsolved integral, allowing for an optimization problem*

will be apertures for uniform or as close to uniform acceptance as possible. This will be done by taking advantage of the relationship between the differential solid angle and the differential equation that represents a cone created by the parameterized surface. With the best possible solutions, I plan on modeling them all with CAD and then 3D printing them, creating models to be used for physical testing of the design. With these models, I can begin to consider the best fit for the BL3 proposal, not just on their acceptance rate and uniformity, but on ease of construction, cost, and implementation into their model.

4 Significance of the Research

The value of this research is its contributions to the BL3 experiment, and working to close the gap between the determined neutron lifetimes. The precise lifetime of the neutron has large implications on nuclear physics as a whole, to include a better understanding of the weak force, possible implications to the big bang theory of creation with its effect on nucleosynthesis, and the potential of discovering new exotic nuclear processes currently unknown to us. The key to all of these discoveries may very well be the discrepancy in the 2 experiments, and narrowing in on whatever discovery the cause of this discrepancy is will have a profound impact on modern nuclear physics.

References

[1] Geoffrey L Greene and Peter Geltenbort. The neutron enigma, Apr 2016.

[2] David Bowman, Leah Broussard, S. Clayton, M. Dewey, N. Fomin, Kyle Grammer, G. Greene, P. Huffman, A. Holley, G.L Jones, C.-Y Liu, Mark Makela, M. Mendenhall, C. Morris, Jonathan Mulholland, K. Nollett, Pattie W., Seppo Penttila, M. Ramsey-Musolf, and Andrew Yue. Determination of the free neutron lifetime. 10 2014.

[3] Glenn Jocher, John Koblanski, Viacheslav Li, Sergey Negrashov, Ryan Dorrill, Kurtis Nishimura, Michinari Sakai, John Learned, and Saeeda Usman. mini-timecube as a neutron scatter camera. *AIP Advances*, 9:035301, 03 2019.