American Conference on Neutron Scattering

Neutron Physics

* Invited Paper

SESSION H02.01: Neutron Physics I

H02.01.01*

A New Measurement of the Electric Dipole Moment of the Neutron

Dieter Ries; Johannes Gutenberg University Mainz, Germany

A non-zero electric dipole moment of the neutron (nEDM) would violate CP symmetry, and thus would be an indication for a new source of CP violation, which might help to explain the matter to antimatter asymmetry in our universe. The nEDM collaboration has taken data at the Paul Scherrer Institute in 2015 and 2016 in order to improve on the previous limit $d_n < 3\times10^{-26}$ *ecm* at 90% C.L. [1]. In total more than 54000 individual measurement cycles were recorded using Ramsey's method of separated oscillating fields to measure the precession frequency of ultra-cold neutrons in electric and magnetic fields. The analysis of this dataset has been carried out in a blind fashion. The collaboration has un-blinded their result at the end of November 2019. The new result will be presented together with a detailed description of the experiment. [1]: J.M. Pendlebury et al. PRD 92, 092003 (2015)

H02.01.02

Quantum Entanglement of Spin, Path and Energy for Individual Neutrons

Roger Pynn; Indiana University, United States

Quantum entanglement is a phenomenon in which the state of a subsystem cannot be described independently of the state of the whole system of which it is part. Einstein famously described quantum entanglement as "spooky interaction at a distance" since it implied that, if two spin-entangled quantum particles were separated in space, measurement of the spin of one of the particles immediately implied knowledge of the spin of the other. As far as we know, it is not feasible to entangle two neutrons in a beam in this way. On the other hand, it should be possible to entangle several distinguishable properties of a single neutron, including spin, path, energy and perhaps orbital angular momentum. In this contribution we will demonstrate that we have achieved tripartite entanglement of neutron spin, path and energy in experiments at the ISIS pulsed source and bipartite entanglement using a beamline at the HFIR in Oak Ridge. While such entanglement has been demonstrated previously using a single-crystal neutron interferometer, our work provides path and energy separation scales that could be exploited in scattering experiments. Our experiments determine the expectation values of various quantum mechanical operators and combine them to calculate entanglement witnesses. We argue that entangled-probe neutron scattering is likely to provide new information about entangled electron states in a variety of interesting materials such as quantum spin liquids and high temperature superconductors.

H02.01.04

Eliminating Thermal Noise inside a Neutron Interferometer

Robert Valdillez[1], Robert W. Haun[2], Benjamin Heacock[3], Colin Heikes[3,4], Shannon F. Hoogerheide[3], Michael G. Huber[3], Connor L. Kapahi[5], Dmitry Pushin[6] and Albert Young[1]; [1]North Carolina State University, United States; [2]University of Maryland, United States; [3]National Institute of Standards and Technology, United States; [4]Joint Quantum Institute, United States; [5]University of Waterloo, Canada; [6]Institute of Quantum Computing, Canada

A perfect-crystal neutron interferometer is a unique device capable of measuring milliradian phase shifts. Typically functioning under STP, it is sensitive to thermal gradients. For instance, a 10 mK temperature difference between a sample inserted into the interferometer and the interferometer crystal itself causes a significant phase change which in turn introduces an often large systematic uncertainty. As interferometry strides to study weaker interactions at increasingly higher precision, temperature gradients will soon become a limiting systematic. We anticipate that the thermal link between the sample and the interferometer crystal can be better limited by performing interferometry experiments in vacuum. The creation of a robust vacuum chamber to house an interferometry setup including sample manipulation, phase flag, and interferometer manipulation will be discussed.

H02.01.05

Interferometric Measurement of the of n-^{4}He Coherent Scattering Length

Michael G. Huber[1], Tim Black[2], Robert W. Haun[3], Benjamin Heacock[1], Dmitry Pushin[4,4], Chandra B. Shahi[5] and Fred E. Wietfeldt[3]; [1]National Institute of Standards and Technology, United States; [2]University of North Carolina, United States; [3]Tulane University, United States; [4]University of Waterloo, Canada; [5]University of Maryland, United States

Our recent work measured the bound coherent scattering length (b_c) of the n-^{4}He interaction to 0.08% [1]. Precision values of bound coherent scattering lengths are needed for advancing our understanding of nuclear structure. Specifically, neutron scattering data provides useful tests of phenomenological nuclear potential models and serve as needed inputs for nuclear effective field theories. This work was carried out at NCNR's Neutron Interferometry and Optics Facility which has previously performed <0.1% measurements of ^{1}H, ^{2}H, ^{3}He and the incoherent scattering length of ^{3}He. We utilize a monolithic, perfect-silicon neutron interferometer to spatially sperate the wavefunction of a single neutron, via Bragg diffraction, into two coherent paths. These paths interfere with each other as the neutron exits the interferometer. The phase difference between the two paths manifests as a modulation of the intensity measured via two proportional counters located downstream of the interferometer. An aluminum cell filled with ^{4}He gas is placed in one path of the interferometer. The phase shift due to the neuron-helium interaction is proportional to the gas density and the ^{4}He coherent scattering length. The gas density was determined from the known temperature and pressure of the gas. This experiment was performed at several different gas pressures which helped shed light on previously underappreciated systematics. Our result of b_c= (3.0982 ± 0.0021 [stat] ± 0.0014 [syst]) fm represents a factor of 10 improvement in precision over previous efforts and is in good agreement with earlier measurements using neutron transmission.

[1] Phys. Rev. Lett. 124, 012501 (2020)

SESSION H04.01: Neutron Physics II

H04.01.01*

Studying Fundamental Symmetries of Nature with Neutrons

Jason A. Fry; Eastern Kentucky University, United States

The neutron can be used as a powerful tool to study a wide range of phenomena through many disciplines of physics including condensed matter, nuclear, and particle physics, with deep connections to cosmology. The free neutron decays into a proton, electron, and anti-neutrino and its decay correlations can provide sensitive means to uncover the details of the weak interaction, namely the ratio of axial-vector to vector coupling constants in the standard model, $\lambda = G_A/G_V$. The neutron lifetime, which is of significant interest currently, not only helps determine how the light elements formed in the early universe, but, together with an extraction of λ from neutron decay correlations, has the potential to set model-independent limits on the CKM quark mixing matrix element V_{ud}, testing unitarity and beyond standard model physics. Measurements of the neutron electric dipole moment and T-odd neutron-nucleus resonances give insight into T and CP symmetry violations and test for a possible mechanism for the observed matter/anti-matter asymmetry of the universe. In this talk I will discuss and overview of how neutrons can be used for precise input into the standard model and beyond.

H04.01.02

Final Results for the n3He Parity Violating Asymmetry Measurement

Mark McCrea; University of Winnipeg, Canada

The goal of the n3He experiment was to measure the parity-violating directional asymmetry in the proton emission direction relative to the initial neutron polarization in the capture of polarized cold neutron in the reaction $n+{}^3He \rightarrow T+p$. Data taking was completed at the end of 2015, and analysis of the proton parity asymmetry have since been completed. I will present the methods used to calculate the asymmetry, and the final results with systematic and statistical uncertainties.

H04.01.03

Update on the BL2 Experiment—An In-Beam Measurement of the Neutron Lifetime

Shannon F. Hoogerheide; National Institute of Standards and Technology, United States

Neutron beta decay is the simplest example of semi-leptonic beta decay. The neutron lifetime is the largest experimental uncertainty in Big Bang Nucleosynthesis calculations of light element abundances. Precise measurements of both the neutron lifetime and λ, the ratio of axial vector and vector coupling constants, allow for a determination of the CKM matrix element V_{ud} that is free from nuclear structure effects. This provides an important test of unitarily and consistency within the Standard Model. A new measurement of the neutron lifetime, utilizing the in-beam method, is underway at the National Institute of Standards and Technology Center for Neutron Research. Improvements to the neutron and proton detection systems, increased apparatus stability, and new data analysis techniques should enable thorough testing of major systematic effects. An overview of the beam method will be presented. The status of the experiment, technical improvements, analysis techniques, and early data will be discussed.

H04.01.04

Novel Cross Section Measurements through Absolute High-Precision Cold Neutron Fluence Determination

Hans P. Mumm; National Institute of Standards and Technology, United States

The Alpha-Gamma device at the National Institute of Standards and Technology utilizes the interaction of neutrons with a totally absorbing ^{10}B target to precisely measure the flux of a monochromatic neutron beam. This measurement provides a calibration of the ^{6}Li(n,α)^{3}H based flux monitor used in the NIST neutron lifetime experiment to better than 0.1% and is now being utilized in novel, 0.2% level, measurements of the ^{235}U neutron-induced fission and ^{6}Li cross sections in an effort to provide systematically independent determinations of these important quantities. The results of recent and ongoing measurements will be presented, and planned operations will be discussed.

H04.01.05

Opportunities for Beyond Standard Model Physics Searches Using Neutrons

Joshua L. Barrow[1], Leah Broussard[2], Yuri Kamyshkov[1] and Michael Fitzsimmons[1,2]; [1]The University of Tennessee, Knoxville, United States; [2]Oak Ridge National Laboratory, United States

Several of the most important open questions at the frontier of beyond Standard Model (BSM) physics are (i) the unknown (particle) nature of dark matter (DM), and (ii) the seeming necessity of baryon (B) number violation (BNV, △B); each appears essential to explain the current state of the universe. Cold neutron beams offer a unique portal onto these exciting BSM physics searches, yet remain an under-utilized resource within the particle physics community. Theories of observable "light" dark matter include the prospect of a dark, or sterile, "mirror" sector, where the hypothetical dark matter shares the same gauge symmetry as the SM, predicting particles of (roughly) equivalent masses to our own. Such models offer rich phenomenologies to probe using neutral particles such as (mirror) neutrons, including observable (fast) BSM neutron oscillation phenomena (such as neutron disappearance, △B=1, and neutron regeneration, △B=0) induced through precise magnetic field control. Beyond unique explorations of the dark matter, such searches may also offer explanations of the neutron lifetime anomaly. Active analyses, research and design initiatives, large-scale computational simulations, and forthcoming experimental searches for this new physics are currently underway at Oak Ridge National Laboratory's (ORNL's) Spallation Neutron Source (SNS) and High Flux Isotope Reactor (HFIR). Compelling BSM theories of low scale, observable (post-sphaleron) baryogenesis propose BNV (or, more specifically, baryon minus lepton number violation) as the dominant mechanism for generating the matter-antimatter asymmetry of the universe we observe today. Such models propose that spontaneous neutron-antineutron oscillations (△B=2) would be the key experimental search to probe such primordial physics. Research and design pertaining to the upcoming HIBEAM/ANNI and prospective worldleading NNBAR experiments at the European Spallation Source are underway with key cold neutron and nuclear physics collaborators at ORNL, the University of Tennessee, the University of Kentucky, Indiana University, North Carolina State University, Stockholm University, and Lund University. Taken together, these parallel programs utilizing the power of cold neutrons promise much progress toward discovery in the fields of fundamental physics. Each neutron oscillation search interleaves with and complements the other, offering collaborative detector, neutron guide, neutron reflector, and data acquisition research, design, and analysis initiatives across a multitude of physics sectors and (inter)national laboratories. We are excited to see what the future holds for such important searches.

Poster Session: Neutron Physics

PH.01.01

Photons, Orbital Angular Momentum and Neutrons

Ronald L. Cappelletti and John Vinson; National Institute of Standards and Technology, United States

A traveling wave or wave packet may possess orbital angular momentum (OAM) in the form of a phase vortex about its axis of propagation. These OAM states are a general wave property and can exist in single-particle wave packets, in a beam of unstructured wave packets of particles, or a mixture. While OAM states of photons were first created almost thirty years ago, more recently work has been done to create these states with massive particles: electrons and neutrons. OAM waves can be generated by various techniques, including by passing an unstructured wave through a vortex phase plate. This technique is reliant on each particle adequately sampling the area of the vortex plate. While laser sources provide sufficient transverse coherence, beams of massive particles are more challenging. If incident wave packets do not interrogate the discontinuity at the center of the vortex phase plate, the probability of detecting a single particle having a unit of orbital angular momentum vanishes. Here, using laser light, we examine restricting the transverse size of a beam to either illuminate the discontinuity or not and consider the implications for producing orbital angular momentum in individual neutrons.