Beam line 13 fuels discovery fever for fundamental physicists

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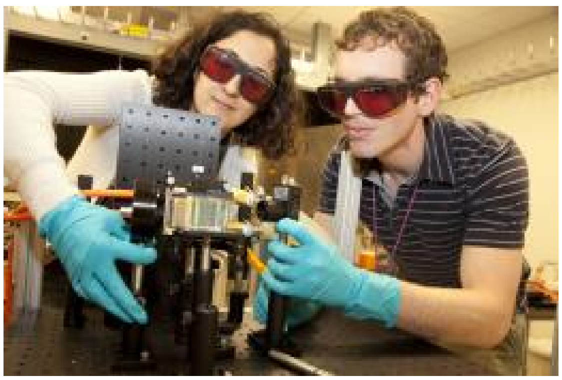

Serpil Kucuker Dogan and Matthew Musgrave work on a helium-3 cell that is used to measure the angle at which the neutron beam strikes the liquid hydrogen sample.

(PhysOrg.com) -- The simplest, most sensible "Big Bang" universe, theoretical physicists believe, would be one in which equal numbers of particles and antiparticles are formed in pairs. As the universe cools, most of these particles would encounter their antiparticles, and they would annihilate.

"In many ways, the most reasonable universe would be one in which there is no matter," says the University of Tennessee's Geoff Greene. "But that is manifestly not the universe we see. So something is wrong with the simple picture, and it is not understood why the universe actually has matter, instead of no matter, which makes more sense." This question, and others like it, are at the heart of the science that will be addressed at the Fundamental Physics Beam Line now being commissioned at SNS.

Beam line 13 is a cooperative venture between Basic Energy Sciences at DOE, which granted a beam line to nuclear physics, and the Nuclear Physics Program Office, which supported the construction of the FNPB and supports operation of the experiments.

Beam line 13 has an atypical user program. As with other beam lines, selection of approved experiments is made by a proposal-driven process, with the key criterion being scientific merit as determined by peer review. But at FNPB, a single experiment doesn't necessarily run for a few days, as most do at SNS and HFIR. Instead, it may run continuously for several years.

There may be as many as 100 collaborators. "They may come for an extended stay. They may send students. But each experiment may take a year or years to construct, a year or years to collect the data, and then it's taken down and something else of similar scope will be put in place," Greene explains.

There are two classes of experiment that the scientists will undertake. One is to determine the fundamental properties of the neutron itself. The other will investigate the interaction of the neutron in very simple nuclear systems.

The first experiment at beam line 13, which is now in place, is of the second type: A very simple nuclear reaction is studied to investigate what happens when a proton captures a polarized neutron—a neutron with an oriented spin. In this interaction a gamma ray is emitted. Is it emitted randomly, in any direction, or is there a slight preference for the direction of the emitted gamma ray to lie along the spin axis of the neutron?

"Why do we care about this? Because only one of the four forces of nature—weak, strong, electromagnetic, and gravitation—is known to violate parity, to be 'handed'," Greene says. That is the weak force, which is "left-handed," and which is normally studied in particle decays. But very little is actually known about the operation of the weak force between pairs of nucleons (neutrons and protons, the particles within the nucleus of an atom). David Bowman and Seppo Penttila of the ORNL Physics Division are the principal investigators on this first experiment, which is a collaboration between ORNL, Los Alamos National Laboratory, and the Universities of Tennessee, Virginia, Manitoba (Canada), Arizona State, Kentucky, Michigan and others.
The target for the SNS neutron beam in this experiment is a sample of liquid hydrogen; this is effectively a target of protons, since each hydrogen atom has a single proton as its nucleus. The SNS pulsed neutron beam is fired at the target, which is surrounded by gamma ray detectors. The neutrons are polarized and are either "spin-up" or "spin-down." SNS provides 60 neutron pulses per second, and the researchers select the incoming beam's spin orientation to give an alternating orientation at the target. They then check whether the detectors see a corresponding alternating pattern of emitted gamma rays (less, more, less, etc.), correlated with the direction of the incident neutrons' spins.

Unless they observe a large sample of such incident beam spin reversals (more than 100 million), they won't see a discernible 'handedness' in the direction the gamma rays emitted from the nucleus because the "weak" force is so very weak relative to the dominant nuclear force (the "strong interaction"). Greene compares this to the flipping of a coin. To see if it is a 'fair coin,' it must be flipped a great many times to determine if there is a statistically significant bias between heads and tails. Once the direction of gamma ray emission is measured with sufficient accuracy, "we expect to see something. It is predicted at somewhere between 1 part in 108 and 1 part in 107. That means we capture on the order of 1016 neutrons. That, of course, is why we are at SNS-the most intense pulsed neutron source in the world."

The early results of this experiment, conducted at Los Alamos, were recently published in *Physical Review C*.

A second experiment is in preparation to look at one of the fundamental properties of the neutron-its electric dipole moment.

Here, physicists want to determine whether the neutron is uniformly electrically neutral or its positive and negative charges are actually displaced slightly with respect to one another. "If it has such an electric dipole moment, that has a very profound implication. Because to have an electric dipole moment would require a violation of time reversal symmetry."

In physics, symmetry under time reversal (T) tests whether physical laws can distinguish between forward and backwards directions of the passage of time (the direction is sometimes referred to as the "arrow" of time). To a good approximation the laws of physics are symmetric (invariant, unchanged) under T.

If the neutron electric dipole is not zero, "that could shed light on a really fundamental interesting question, which is, why does the universe have matter at all," Greene says, "for most theories that seek to explain the matter-anti-matter asymmetry require a violation of time reversal symmetry."

Construction of FNPB began in 2002. The instrument team first opened the shutter for testing in 2008. The current neutron/proton capture experiment took its first beam in December 2010.

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