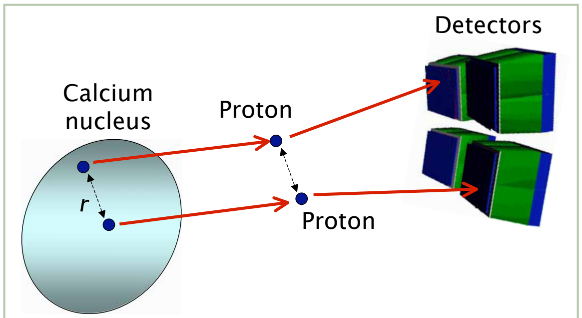
Experiment Explores Elusive Properties of Symmetry Energy

by Geoff Koch, NSCL

After years of preparation, an NSCL-based experiment is poised to help nuclear scientists peer at nucleus-nucleus collisions with unprecedented accuracy. The results of the experiment, which was run at NSCL at the end of 2006 and included collaborators from several institutions around the world, may shed new light on long-standing questions about both basic nuclear properties and neutron stars.

The goal of the experiment is to address questions about symmetry energy, which describes how nuclear properties change with varying degrees of neutron-proton asymmetry. Nuclei with different numbers of protons and neutrons are said to be asymmetric.



The detectors are tuned to gather data on how pairs of protons behave after being expelled from atomic nuclei in a violent collision. In effect, the device can resolve distances – "r" above – on a femtometer scale. That is, if an atom were the size of a city like East Lansing, femtometer resolution would allow taking a picture from space with sharp enough detail to see individual oranges on a table at an outdoor market.

Scientists know that symmetry energy contributes forces that are repulsive between two neutrons and repulsive between two protons but are attractive between protons and neutrons. When the number of protons and neutrons is equal, the symmetry energy vanishes. However, symmetry energy persists in very asymmetric nuclei and in neutron stars, but scientists don't know how large the energy is in such environments.

Think of the nuclei of Calcium-40, with 20 protons and 20 neutrons, and Calcium-48, with 20 protons and 28 neutrons, as tennis balls. If you toss Calcium-40 in the air and hit it on a serve, how easily would it deform? Would Calcium-48, with the extra forces due to the symmetry energy, be harder or easier to deform? Could you even burst it with your racket?

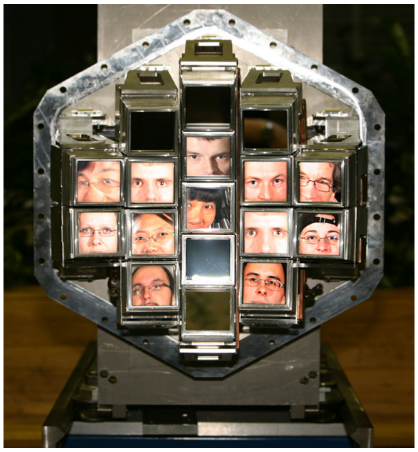
Scientists can't determine these answers with any accuracy because they don't have a clear idea how soft the balls are – the rough analogue to symmetry energy. This uncertainty makes it difficult to fully understand the pressures that support neutron stars and prevent them from collapsing into black holes.

> The experimental technique can resolve details down to the femtometer level, one million times smaller than the dimensions common in the high-tech field of nanotechnology.

In a quest to better describe symmetry energy, nuclear scientists at NSCL, Indiana University in Bloomington, and Washington University in St. Louis built a new device – the High Resolution Array Detector, or HiRA – capable of closely measuring the mini-explosions that take place when atomic nuclei collide at high speeds, become compressed, and then expand. HiRA is tuned to gather data on how pairs of protons – all two-particle systems are linked by the strong nuclear force – behave in the aftermath of a collision.

By measuring proton-proton pairs, researchers, in effect, capture an image of nuclear systems. The technique is made possible by the work of NSCL theorist Pawel Danielewicz, who refined a model commonly used to measure vast distances in astronomy to help experimenters describe the size and shape of a nuclear region that emits two protons.

The experimental technique can reveal details at the size of a femtometer—a scale one million times smaller than the dimensions common in the high-tech field of nanotechnology. A femtometer is equal to one quadrillionth of a meter. (A quadrillion is the mathematical term for 1 followed by fifteen zeroes.)



The NSCL device used in the experiment is composed of removable modules, each of which contains several detectors. (The module shown here contains 17 detectors.) Collectively, these detectors are capable of making fine-grained measurements of careening proton-proton pairs traveling at thousands of different angles, detail that will help nuclear scientists better understand elusive qualities of symmetry energy. Here, in a moment of levity after the conclusion of the experiment, the faces of several NSCL researchers and students are reflected in the aluminum-coated surfaces of the detectors in a single module, which had been removed for calibration and maintenance.
Photo: Brian Cripe, MSU

Scientific and technical innovation, much of which originated at NSCL, is evident in many aspects of the experiment. In work that began several years ago, the NSCL experiment team and several collaborators produced a quarter-sized silicon chip known as an application specific integrated circuit, or ASIC, capable of processing information from the roughly 2,000 data channels in the device. HiRA itself can measure protons careening away from each other at 17,000 different angles, an improvement over an earlier generation NSCL detector capable of measuring just 56 angles.

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Additionally, the team, including MSU physics doctoral student Micha Kilburn who is building her dissertation research around the experiment, will be writing extensive amounts of new software to do the online and offline data analysis.

The experiment has not only provided extensive hands-on research experience to Kilburn, but also to several undergraduates, graduate students, and postdocs. And the roster of experimenters and students reflects the international reach of NSCL, an open user facility that serves more than 700 researchers from 35 countries. Other institutions represented in the collaboration include Western Michigan University, the Joint Institute for Nuclear Research in Russia, the Institute of Modern Physics at the Chinese Academy of Science, and the University of Mainz in Germany.

"The real advance, though, will be our ability to answer a question and get useful physics out of the system," said Giuseppe Verde, a researcher at GANIL in France, another partner institution. Verde began laying the groundwork for this experiment while he was an NSCL postdoc in 2003.

"After we do our measurements, then we have to explain what they tell us about symmetry energy," Verde said. "If we can do it, that's the innovation."

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Additional Reading

G. Verde et al., The European Physical Journal A, **30** (2006), *Correlations and Characterization of Emitting sources*, available online (arxiv.org/PS_cache/nucl-ex/pdf/0609/0609043.pdf)

More information on the High Resolution Array Detector (HiRA) is available online (www.nscl.msu.edu/tech/devices/hira/)