Nuclear Science Division Newsletter

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STAR HFT sees a charming signal

The STAR Heavy Flavor Tracker (HFT), the world's finest and thinnest "digital camera," has convincingly demonstrated its capability to study charm mesons. The HFT is a silicon pixel detector, which was installed in the STAR experiment in January 2014 and is now taking data. Its main physics goal is to study heavy flavor physics (involving charm and bottom quarks) in heavy ion collisions. A group from the RNC group in the Nuclear Science Division, together with collaborators from BNL, Kent State University, MIT, University of Illinois, Chicago and Central China Normal University have been working to finalize the detector calibrations and to fine tune the software in order to analyze several large physics data sets taken last year. The RNC team's efforts have recently passed from calibration to production.

The figure shows the invariant mass distribution of kaon-pion candidate pairs observed in 125 million minimum bias Au+Au collisions at a center of mass energy of 200 GeV. A kaon and a pion are the decay products of the D^0 meson and so a peak in the distribution indicates the mass of the meson. As shown in the sub-panel, the yield of identified D^0 mesons is only significant after applying the precise selection criteria that are enabled by the HFT. The signal-to-background-ratio is increased by more than 3 orders of magnitude by requiring the HFT cuts and thus the significance of the D^0 signal in this sample is about 18σ. The measured mass of the D^0 meson is 1.865 GeV/c^2, consistent with the world average. The complete data set contains a factor of 8 more statistics, compared to the sample shown here, and these additional data are currently being analyzed. Now that we have a substantial yield of D^0 mesons to work with, the RNC group will be studying charmed hadron flow as well as the nuclear modification factor in Au+Au collisions. These novel measurements will offer unique information on the thermalization, as well as energy loss mechanisms, in the Quark Gluon Plasma that is produced at RHIC.

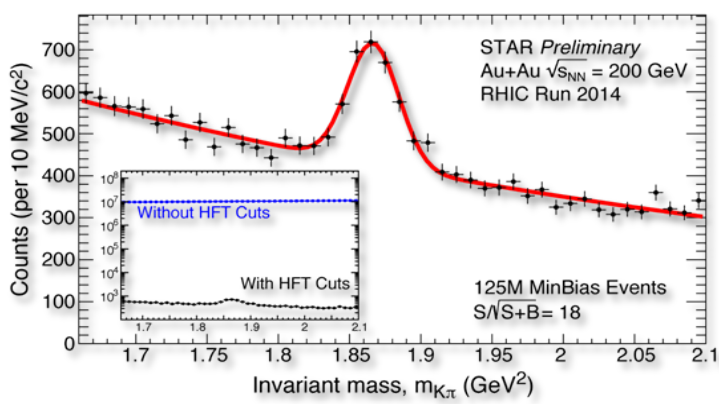


Figure 1 pK invariant mass spectrum for separated vertices selected using the STAR HFT. This is from 125 million events (1/8 of the sample collected in 2014).

CUORE0 tightens limits on neutrinos

On April 9, 2015, CUORE-0 released (CUORE Collaboration, http://arxiv.org/abs/1504.02454) the most stringent limit yet on the neutrino-less double beta decay ($0\nu\beta\beta$) of ^{130}Te. The observation of $0\nu\beta\beta$ would establish that the neutrino is its own antiparticle, i.e. a so-called Majorana fermion, and provide information on the absolute mass scale of the neutrino. CUORE-0 is a fast-track early implementation of CUORE (Cryogenic Underground Observatory for Rare Events), an Italy-US ton scale bolometric detector that is currently under construction at the INFN Laboratori Nationali del Gran Sasso (LNGS) in Italy. The CUORE detector consists of 988 $5\times5\times5$ cm natural tellurium-oxide (TeO_2) crystals mounted in 19 towers with a total mass of about 1 ton. This crystal array is kept at a temperature very near absolute zero. At 6 milliKelvin or -273.144 degrees Celsius, the CUORE cryostat contains the coldest cubic meter in the known universe! Each crystal is instrumented with a Neutron Transmutation Doped (NTD) thermistor to measure the small temperature rise that would result from a $0\nu\beta\beta$ event.

CUORE-0 consists of a single tower (52 crystals) of the full CUORE detector and it has been running at LNGS since March 2013. No evidence for $0\nu\beta\beta$ was observed above background and CUORE-0 was able to set a lower limit of 2.7×10^{24} years on the ^{130}Te $0\nu\beta\beta$ half-life. When this result is combined with that from Cuoricino (a prototype for CUORE), the lower limit on the ^{130}Te $0\nu\beta\beta$ half-life becomes 4.0×10^{24} which is the most stringent limit yet obtained for this decay. In addition to setting a limit on Majorana neutrinos, the low background level obtained by CUORE-0 validates the ultraclean assembly techniques and the radiopurity of the materials used to construct CUORE. The full CUORE detector is expected to begin production running in early 2016 where it will be even more sensitive to $0\nu\beta\beta$of ^{130}Te.

Figure 2. Panoramic view of the class 1000 clean room used for CUORE detector assembly and storage. UC Berkeley postdoc and NSD affiliate Tommy O'Donnell performs detector assembly work in an ultraclean glove box.

Red, White, or Blue? Color-coding the Origin of Heavy Nuclei.

Roughly half of the elements heavier than iron were originally formed via rapid neutron captures, but the astrophysical site of this "r-process" remains unclear. With simulations of supernovae struggling to generate sufficiently neutron-rich outflows, attention has turned to the merger of two neutron stars (NS). A better theoretical understanding of these explosive environments is needed to guide and exploit experimental facilities like FRIB.

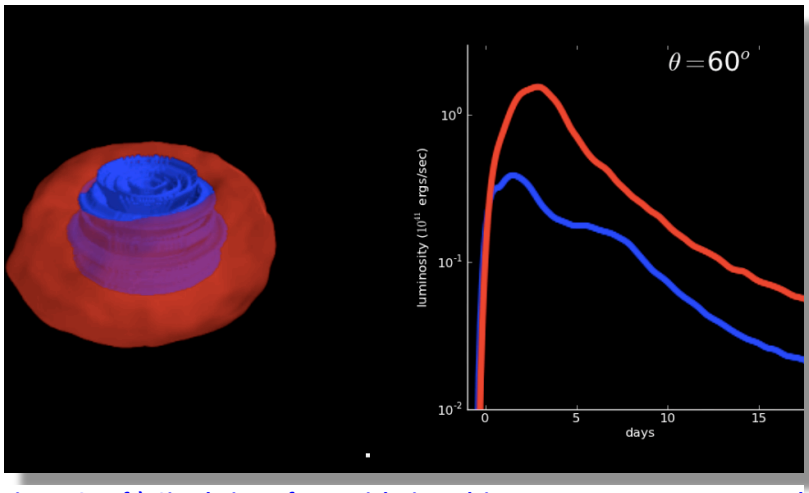


Figure 3 Left) Simulation of material ejected in a neutron star merger. Red denotes dynamically expelled heavy r-process material, while blue denotes lighter r-process elements synthesized in a wind. Right) Calculated brightness of this radioactive ejecta over time. Red shows the luminosity at infrared wavelengths, while blue shows the optical brightness. The image (left) is after one day, when the system has expanded to 100 astronomical units ($1.5*10^{10}$ km) in diameter..

Recent theoretical studies at LBNL (Kasen, Fernandez, and Metzger, Monthly Notices of the Royal Astronomical Society **450**, 1777 (2015).) have changed our understanding of how r-process nuclei are synthesized in NS mergers. While previous work had focused on material expelled during the collision, the LBNL calculations show that even more material may be synthesized *after* the merger, as bits of orbiting gas gradually fall inwards, are heated, and then blown off in a wind.

The conditions in such winds are distinct; weak interactions have time to drive the matter less neutron rich, and nucleosynthesis may stop short of building the heaviest of elements. The final abundance pattern depends on the physics at play -- e.g., the degree of neutrino irradiation and the equation of state of nuclear matter.

The paper provides a "color-chart" for experimentally determining the mode of nucleosynthesis. The isotopes formed in mergers are radioactive, and will glow brightly for days, producing a supernova-like transient called a "kilonova". Gas ejected during the collision is opaque at visible wavelengths, and will glow in the infrared. The wind, on the other hand, consists of less massive, lower opacity isotopes that glow blue. A real merger may have a component of each -- a white kilonova.

With the advanced LIGO experiment gearing up to detect gravitational waves from mergers, FRIB working towards making neutron-rich isotopes on earth, and a host of astronomical surveys searching for kilonovae, we are nearing a watershed moment when we may directly observe r-process nuclei at their production sites. The LBNL theoretical work is providing the diagnostics needed to guide experiments and unravel the uncertain origin of the heavy elements.

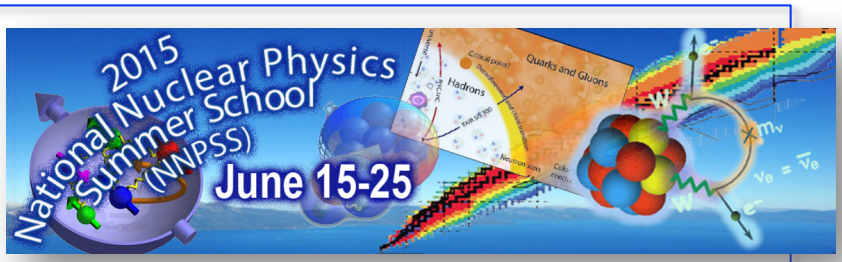
Fragments

NSD's Kai Vetter has been awarded an American Nuclear Society's Presidential Citation at their annual meeting in San Antonio, TX, for his work on radiation monitoring with RadWatch and Kelpwatch. Vetter was cited for ""his exceptional commitment and dedication to advancing nuclear science and technology, and outreach to the community to analyze and explain the impact of nuclear on the environment. His role in both RadWatch and KelpWatch, monitoring North America's west coast for potential impacts from the accident at Fukushima, are exemplary efforts to advance public awareness and understanding. Dr. Vetter's initiative in establishing and promoting the Institute for Resilient Communities to use science and technology to understand and minimize the impact associated with sudden or long-term changes induced by human actions or nature further exemplifies his commitment to advance the use of nuclear science and technology for the benefit of humanity."

NSD director Barbara Jacak has been induced into the Achievement Rewards for College Scientists (ARCS) program hall of fame, which honors distinguished ARCS alumni. She was honored for her role in discovering the quark gluon plasma, most notably including her service as PHENIX spokesperson. She is a member of the National Academy of Sciences; a Fellow of the American Association for the Advancement of Science; a Fellow of the American Physical Society.

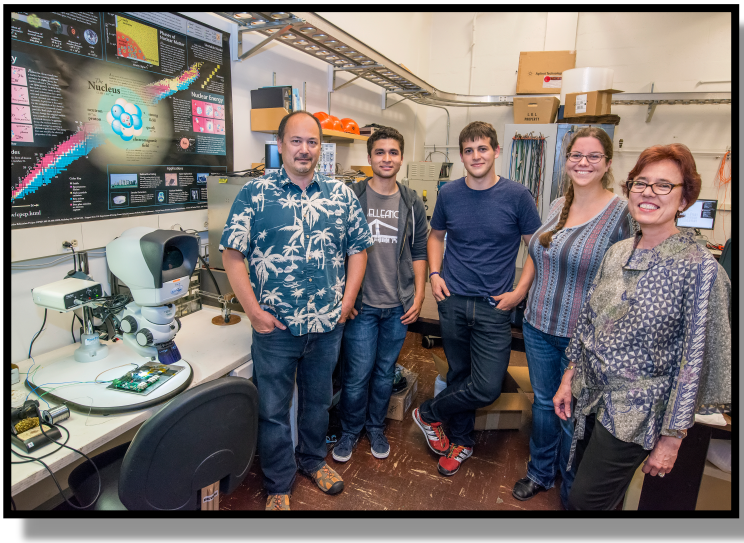
Alexander Donoghue has joined the 88-inch Cyclotron, where he has responsibility for the BASE (Berkeley Accelerator Space Effects) program. BASE serves a large user base of researchers who visit the 88-inch Cyclotron to study the effects of ionizing radiation in space on their electronics or other devices.

Jinlong Zhang has joined the RNC group, where he is working with Alex Schmah and Peter Jacobs on jet reconstruction in the STAR 62.4 GeV gold-on-gold data. He is also working on R & D for the STAR event plane detector.



This year's National Nuclear Physics Summer School, held for two weeks at Lake Tahoe in late June, featured a number of NSD lecturers speaking to about 60 graduate students and new postdocs: Heather Crawford (nuclear structure experiment), Barbara Jacak (heavy ion experiment), Augusto Macchiavelli (on gamma-ray tracking) and Feng Yuan (hadron structure theory). LBNL Physics Division's Dan Dwyer also lectured, on fundamental symmetries.

Summer has again brought an influx of undergraduate interns, many supported by the DOE Science Undergraduate Laboratory Internships SULI program. Fernando Torales Acosta, Elad Michal, and Joanna Szornel are working with Leo Greiner and Barbara Jacak, studying the latchup characteristics in the ALICE ITS upgrade, using ion beams at the 88-inch Cyclotron BASE facility. Kevin Nuckolls and Brianna Grado-White are working with Gabriel Orebi Gann on projects related to SNO+.



L-R: Leo Greiner, Fernando Torales-Acosta, Elad Michael, Joanna Szornel, Barbara Jacak.

Newsletter Notes

Please send any comments, including story suggestions to Spencer Klein at srklein@lbl.gov. Previous issues of the newsletter are available at:

https://commons.lbl.gov/display/nsd/NSD+Newsletter

Newsletter layout of current and previous issues by Sandra Ritterbusch.