Collaboration report NUSTAR progress in 2013

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Since several decades, the year 2013 was the first year without beamtimes at GSI. Various NUSTAR detectors and sub-systems for FAIR are already in operation and the collaboration looks forward to their implementation and use at FAIR. The lack of beamtime induced a serious change of the daily scientific work and hampered the beam-related preparations of FAIR experiments, component tests and R&D-work, including pilot experiments for FAIR.

NUSTAR collaboration

The NUSTAR collaboration is fully operational. All bodies and gremia are established and work continuously since several years.

Like in previous years, NUSTAR has held its two major collaboration meetings: in spring 2013 the NUSTAR Annual Meeting took place as usual at GSI, and in fall the NUSTAR Week, which is traveling to the major NUSTAR partner countries and institutes, took place in Helsinki (Finland). These meetings focus on the scientific achievements, on technical developments and they are important meeting platforms for the various groups and boards of the collaboration; they also give opportunity to present status and progress of the NUSTAR common working groups to the whole collaboration. Besides these meetings, the NUSTAR News Letter appears regularly several times per year and keeps all collaboration members and other people up-to-date on all relevant collaboration activities. For the missing LEB building, a task force was established to firmly promote the realization of the LEB hall. The Super-FRS experimental program was established as comprising part of NUSTAR, and a scientific high-level program has been identified, which is characteristic for the high-energy accelerator capabilities at FAIR. With few, dedicated ancillary detectors, a NUSTAR science program extended in scope and quality, competitive on the world scale, will become possible by the time when FAIR operation will start.

The NUSTAR groups at GSI and FAIR fulfil important integrating activities and play a vital role for the whole scientific collaboration. They are an essential prerequisite for the exploitation of existing instruments at UNILAC and SIS-ESR of GSI and the future facilities of FAIR. They are a melting pot of all relevant scientific activities and provide organizational support and coordination. Together with the scientific-technical infrastructure departments and the collaboration, they perform cross-sectional developments, for instance data acquisition, electronics, data analysis, quality assurance etc., and integrate and coordinate the collaborative efforts for operating, maintaining and upgrading the experimental instruments and laboratories.

Project developments

NUSTAR builds on a continuous transition from GSI towards FAIR. The central device of the NUSTAR collaboration at FAIR will be the superconducting fragment separator (Super-FRS), which is in preparation. The separator itself and its three exit branches will be equipped with complex detectors for forefront experiments. These detector systems are mostly built modularly and allow for a stepwise setup and integration. Already today, all of them have reached the status of a basic “start version” for experiments.

Also the procurement of Super-FRS components is well underway. The collaborative work with FAIR members and in-kind partners is in full swing. Also the fruitful scientific-technical collaboration with KVI continues with work packages like the cryogenic ion catcher for the Low-Energy Branch of the Super-FRS or the slit system for the separator itself. The layout of the energy buncher spectrometer at the Low-Energy Branch of the Super-FRS was finalized. The new layout has many experimental advantages and will solve several technical challenges. It builds mostly on standard Super-FRS components and reduces R&D efforts and costs. Target and material tests, R&D work of detectors, new ion-optical modes and separation schemes are carried out as a concentrated effort of the whole NUSTAR collaboration with a large degree of synergy and cross-fertilization among the various NUSTAR sub-collaborations and the GSI NUSTAR groups.

Scientific achievements

The NUSTAR groups at GSI made several important scientific achievements. The year prompted many publications and conference contributions, and awards for several group members. They are described in this annual report, and the most important ones are briefly mentioned here.

In the theory groups the main focus of last year’s activities was on astrophysical applications of nuclear physics. The inclusion of charged-current interactions for muon neutrinos in supernova calculations showed a significant change in opacities that will have consequences for the neutrino spectra emitted from a proto neutron star. In studies of nuclear matter at low densities the relativistic density functional approach was extended with an explicit treatment of clusters of light nuclei and nucleon-nucleon correlations. These additional degrees of freedom are nec-

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essary to obtain a correct low-density limit as provided by the virial equation of state.

Calculations within an extended Hartree-Fock-Bogoljubov (HFB) approach with multiphonon excitations provided an improved description of M1 strength distributions and neutron-capture cross sections at low energies. Microscopic calculations for resonances and continuum states with the fermionic molecular dynamics (FMD) approach were extended with an explicit treatment of coupled channels, and used to investigate the structure of the continuum states in ^{12}C. Realistic nucleon-nucleon interactions have a non-trivial momentum dependence. A phase-space representation was developed to provide a better visualization of interaction properties.

The activities of the superheavy element research groups concentrated on the analysis of previously measured data, technical developments for their experimental setups and FAIR injectors, and participation in experiments elsewhere.

Together with the partners at the University of Mainz, the Helmholtz Institute in Mainz, and several foreign groups, the chemistry group performed two experiments at the RIKEN facility in Japan. The goal was the synthesis and chemical characterization of a compound class, which would be new for superheavy elements: seaborgium hexacarbonyl (element 106). The physics group performed in collaboration with the superheavy element group of RIKEN an experiment at the GARIS separator: in reactions ^{48}Ca + ^{248}Cm → ^{296}116* several decay chains of Z=116 isotopes were observed, whose decay pattern were previously measured at SHIP. This experiment was a starting point for the future experiments with 248Cm targets at RIKEN. Further, the physics group participated in transfer and fusion-fission reaction experiments at JINR in Dubna and contributed a diamond dE-E-TOF telescope as a new asset to the CORSET set-up for studies at the Coulomb barrier. These activities help to maintain the experimental expertise and develop practical skills for working towards the future FAIR facility.

Other main activities included performing the data analyses from the long experiments in 2011/12 on the search for the new elements 119 and 120 as well as the synthesis of element 117, which were partially completed, and the preparations for experiments foreseen for 2014 at GSI, including experimental and theoretical studies of chemical properties of superheavy elements. Analysis of spin distributions for compound nuclei from compound nuclei from Ni-64 + Mo-100 reactions at energies around the Coulomb barrier measured previously at INFN Legnaro was performed, decay properties of neutron deficient Fr- and Ra-isotopes were studied, nuclear shell strengths towards N = 162 was analyzed.

Construction and purchase for the new focal plane detector system for SHIP was sustained, first off-line tests were started. Improved detection for trapped ions using the 'phase imaging ion cyclotron resonance' (gaining more than one order of magnitude higher mass resolution) was successfully applied in off-line measurements. The RADRIS method for laser spectroscopy of superheavy elements was further optimized on the basis of results from test experiment in late 2012 and is now ready for laser spectroscopy experiments on 254No. As a new activity an upgrade program to optimize the operation of the UNILAC gas stripper with respect to the requirements of FAIR was started.

The first determination of radii of proton distributions of $^{12-17}$B nuclides from charge changing cross section (σcc) measurements at the FRS has been reported. The radii are deduced from a finite-range Glauber model analysis of the σcc and show an increase from ^{13}B to ^{17}B. The measurements show the existence of a thick neutron surface with a neutron-proton radius difference of 0.51(0.11) fm in 17B.

The in-flight decay measurement of the short-lived proton-drip-line nuclide ^{31}Ar has been analysed. The experiment setup was similar to the previously successfully measured two-proton emitter ^{19}Mg.

The FRS group worked also intensively on the ion-optical layout of the LEB of the Super-FRS and its experimental performance in different scenarios with the ion-catcher in combination with the Multiple- Reflexion Time-of-Flight Mass Spectrometer (MR-ToF-MS). High-resolution Super-FRS spectrometer experiments can be performed with the dispersion-matched energy buncher combined with the main Separator. The extraction efficiency of the stopping cell has been significantly improved to about 60% by higher gas purity and lower temperatures of 70-100 K. The average extraction time for uranium fragments was 24 ms. Broad band mass spectra have demonstrated the cleanliness of the gas-filled stopping cell. The performance of the MR-ToF-MS has been investigated experimentally at the FRS with isobars of A=211 produced with 1000 MeV/u ^{238}U projectiles in a Be target. The achieved accuracy and resolution of the MR-ToF-MS has not yet reached the off-line results but with the performed technical changes it will be possible. However, the presently achieved online resolving power (R > 2·105) is already sufficient to unambiguously identify the nuclides of hot fusion products in the range of Z>113. This identification was not possible in the past.

The analysis of the data obtained from two different isochronous mass measurements with the correlation matrix has made a lot of progress.

The analysis of data obtained at the R^{3}B-LAND setup yielded several highlights concerning the spectroscopy of nuclear systems beyond the drip lines. On the proton-rich side, the ground state of the unbound nucleus ^{15}Ne could be identified for the first time. Several cases beyond the neutron drip line have been studied, including the neutron-unbound systems ^{25,26}O, which are presently the heaviest nuclei beyond the neutron drip line which can be reached experimentally. The structure of the unbound ^{13}Be nucleus has been investigated in detail on the basis of high-quality data from knockout reactions measured at the R^{3}B-LAND setup in conjunction with results from

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previously published data. A consistent description of the ^{13}Be excited states was obtained resolving previous discrepancies in the interpretation. For the nucleus ^{14}Be, the second 2+ excited state was identified and its structure and decay mechanism was investigated for the first time.

The program concerning the investigation of collective dipole excitations, in particular low-lying Pygmy strength in neutron-rich nuclei has been continued. The analysis of the data on electromagnetic excitation of ^{68}Ni has been finalized and published. The dipole polarizability has been measured for the first time for a short-lived nucleus from which a neutron-skin thickness for 68Ni of 0.17(2) fm has been extracted, which provides constraints on the density dependence of the symmetry energy. The Pygmy dipole resonance (PDR) was observed at 9.6 MeV exhausting 2.8(5)% of the energy-weighted sum rule. In addition, a gamma decay branch for the PDR of 7(2)% could be extracted by combining our result with a previous measurement.

The activities of the nuclear spectroscopy group was dominated by the preparations of the PRESPEC experiments using the AGATA-detector. The set-up was further optimized, based on the experience gained in the beamtimes in 2012, and the data analysis of the 2012 runs was continued and data integrity confirmed. A new concept for the DESPEC DEGAS array, backed by simulations, has been worked out. A new segmented scintillator detector (finger detector) for very high beam particle rates has been realized. As spin-off a novel position sensitive gamma-detector for industrial applications has been developed and successfully tested. A conceptually new data analysis software suite has been developed and implemented, allowing to analyse data from FRS, PRESPEC and other detection systems in an easy and versatile manner.

Awards

- Michael Block was awarded the Flerov Preis 2013 of the JINR Dubna
- Timo Dickel received the GENCO Young-Scientist Award 2013 of the GSI Exotic Nuclei Community
- Sophie Heinz has been named by Elsevier for excellence in reviewing as “one of the most valued reviewers of 2013”
- Sigurd Hofmann became member of the “Polish Academy of Arts and Sciences”

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