Report of working group on Single-Particle Structure and Reactions

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This session focused on the new insights into single-particle properties of nuclei and reaction dynamics that can be gained in the context of the current and anticipated capabilities of ATLAS and the associated suite of instruments—both those available in-house and those from other institutions. The discussions were motivated by nine contributed talks, two in absentia:

- Walter Loveland, Heavy Element Synthesis Reactions
- Kathrin Wimmer, Physics Opportunities with AIRIS
- Steven Pain, A = 100 and A = 132 Physics with GODDESS
- Alan Wuosmaa, Physics Opportunities with HELIOS (+AIRIS)
- Tan Ahn, Physics Opportunities with the Prototype AT-TPC at ATLAS
- Mitch Allmond, Heavy-ion Induced Transfer with Exotic Beams
- Stanley Paulauskas, VANDLE Reaction Studies
- Augusto Macchiavelli, Studies of Neutron-Proton Pairing with AIRIS and HELIOS
- Vandana Tripathi, Reactions Around the Barrier with AIRIS Beams

Several general themes emerged from the discussions. These broadly align with the current and anticipated capabilities of ATLAS and are presented in this context below.

High intensity stable beams.—The high-intensity upgrade makes stable beams available up to 10 pμA. Such high-intensity beams open up many new opportunities for the exploration of reaction dynamics, heavy-element synthesis, and access to new regions of the nuclear chart. Among the reactions of interest are hot- and cold-fusion reactions to probe fusion and survival probabilities. There is renewed interest in multi-nucleon transfer reactions to make new neutron-rich heavy nuclei, for which high intensities are key. Reactions such as ^{136}Xe + ^{208}Pb at E_{cm} = 450 MeV could be used to probe the ^{208}Pb, N = 126 region, allowing the reaction mechanism, spectroscopy of reaction products, and *r*-process related physics to be probed. New actinide nuclei could be probed through, e.g., the ^{238}U + ^{248}Cm reaction, and perhaps multi-nucleon transfer induced by the more intense of the neutron-rich CARIBU beams. Key instruments for spectroscopy studies are Gammasphere coupled to AGFA as well as 'non-standard' equipment. In this latter case, Area II, the natural space for high-intensity stable beams when running ATLAS in multi-user mode (see below), will be ideal. The broad range of projectiles and energies and heavy-element targets are key assets to this program.

Multi-user capabilities.—The proposed multi-user upgrade, following the installation of the EBIS, will allow reaccelerated CARIBU beams to run in parallel with stable beams without any loss of intensity to either. This has major implications for enabling experiments which require long beam times, including long measurements with intense stable beams for studies of heavy nuclei, along with transfer-reaction studies with CARIBU beams, either to HELIOS, Gammasphere or GODDESS.

AIRIS beams.—The AIRIS upgrade expands the in-flight-beam capabilities of ATLAS, and importantly will allow in-flight beams to be delivered to all target areas. The high-intensity stable beams coupled with the new production target and new separator is anticipated to provide an increase in beam intensity by up to two orders of magnitude. The discussions, in a large part, explored the many physics opportunities with these beams, from the neutron-rich He isotopes to neutron-deficient Zn. Of particular importance is the broad range of beam energies that can be attained, nominally a few to 20 MeV/u, significantly enhancing the physics scope of the program. Transfer reactions such as (d,p), (p,d), (d,^{3}He), (^{3}He,d) are seen as important probes into single-particle structure, enabling detailed spectroscopy where hitherto only limited structure information is available. Neutron-pair transfer through the (t,p) reaction was also mentioned numerous times. Examples included tracking structural changes across the chains of isotopes such as $^{6\text{-}8}$He(d,p) and (t,p) and $^{10\text{-}16}$C(d,^{3}He) (A. Wuosmaa), and the evolution of the N = 20 and 28 closures with both neutron and proton number through transfer reactions with Si, S, Ar, Ca, and Ti beams (K. Wimmer, C. Hoffman, S. Freeman). Probing *np* correlations with *np*-transfer to explore the role of T = 0 and T = 1 pairing through (p,^{3}He), (^{3}He,p), and (d,α) reactions with, e.g.,

^{48}Cr and ^{56}Ni beams was discussed (A. Macchiavelli). HELIOS, including auxiliary devices such as the APOLLO (LANL) array for coincident gamma-ray detection, the gas target and ionization chamber (LSU), the potential use of a tritium target, and the GODDESS setup are seen as the key instruments / infrastructure for such studies. The use of heavy-ion transfer reactions such as (^{9,10}Be,2α) with these lighter beams was also discussed owing to their unique selectivity (K. Wimmer). The possibility of using the prototype AT-TPC with neutron-rich Be and C beams to study clustering in these nuclei was suggested (T. Ahn). There is also a natural overlap of these studies with those of interest for astrophysical processes (discussed in the astrophysics session) such as using the (^{3}He,*d*) reactions to study (*p*,γ) channels in astrophysical processes. The possibility of using the VANDLE spectrometer for reaction studies was also discussed, possibly coupling it with the split-pole spectrograph for studying reactions such as (*d*,*n*). Most of these reaction studies discussed are well above the Coulomb barrier. There was also discussion of using AIRIS beams for studies around the barrier such as fusion and the influence of Q values, by using different combinations of AIRIS beams, e.g., $^{28\text{-}34}Si + ^{58}Ni$, where the Q value changes by over 18 MeV. Such studies have not been possible to date (V. Tripathi). The prospect of using neutron-rich ^{15}C, a very intense AIRIS beam, for fusion-evaporation studies was also discussed using Gammasphere (GRETINA) and Microball.

CARIBU beams.—A broad physics program is anticipated with CARIBU beams, primarily in transfer-reaction studies both with HELIOS and the GODDESS setup, with the focus moving away from just (*d*,*p*) reactions, towards more 'complete' studies with both proton and neutron transfer, and reactions with better momentum matching for high-*j* states, particularly around the ^{132}Sn region. The latest progress with GODDESS was reported. The large angular acceptance will allow for the simultaneous measurements of many reactions such as (*d*,*p*), (*d*,*t*), (*d*,^{3}He), with complementary gamma-ray data from Gammasphere, offering an efficient — in the sense of information gained — way to study weak beams. The use of heavy-ion transfer through e.g., (^{9}Be, 2α), (^{13}C,^{12}C), and (^{7}Li,^{6}He), inelastic scattering, and Coulex were also discussed (S. Pain, M. Allmond). Some of these reactions could be studied with Gammasphere and the Phoswich Wall. The use of HELIOS for key reactions around the Z = 50, N = 82 region remains a key focus, particularly with Te, Sb, and Sn beams. The use of the prototype AT-TPC to study isobaric analog states around ^{132}Sn with very low intensity beams is an exciting prospect (T. Ahn). A possible avenue for exploration is the use of inelastic scattering such as the (*d*,*d*') reaction to probe collective states away from N = 82, around Z = 56, N = 90, and extract $B(E2)$ and $B(E3)$ values from the cross sections. An advantage here is the efficiency of the HELIOS device.

General comments.—There was a general consensus that the flexibility of ATLAS and the instrument halls is a great asset to the facility and that every effort should be made to preserve this. There were several issues raised that are in need of consideration. A common concern for reaction studies with radioactive ion beams is recoil detection on, or close to, the beam axis. These detectors, e.g., the LSU ionization chamber for HELIOS and the ionization chamber for GODDESS, are rate limited at the $\sim10^5$ Hz level and, particularly for heavy CARIBU beams, must 'swallow' the unreacted beam. It is essential that the contaminants form only a fraction of the total beam incident on the target—stable contaminants in these weak radioactive beams can prohibit measurements. There is strong support for the EBIS which should alleviate some of these problems. For operation of the prototype AT-TPC, isobaric contamination must be negligible (T. Ahn). There was some concern over what the time structure of the beam would be with the EBIS source, and whether this would result in higher instantaneous rates—a potential issue for recoil detection with CARIBU beams and for the AT-TPC. It is encouraged that the structure of the EBIS spills be developed to mitigate this issue. In discussion following the session, it was commented on that the Users need better access to information on the available beams either via the website or with the PAC announcements. This includes information on current in-flight capabilities (not just beams that have been accelerated, but those that can be with reasonable confidence), AIRIS (though it was appreciated this was a new development), CARIBU, and revised floor plans showing the mult-iuser layout. A general comment, echoed in several sessions, was the need to develop reliable targets for use with high-intensity beams.