A Strategic Plan for the Argonne Tandem Linac Accelerator System

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Introduction

This strategic plan is developed jointly by the ATLAS user community and the Physics Division at Argonne National Laboratory. This plan is a public document, hence available to the entire ATLAS user community, and is updated as the need arises. In practice, the community discusses this plan at regular ATLAS Users Workshops, the most recent of which was held on August 8-9, 2009. The users' executive committee and ATLAS management then work together to incorporate the outcome of these workshops into the strategic plan.

This plan provides the scientific and strategic vision for ATLAS, the goals for its future capabilities and the expected path forward in light of existing budget constraints.

Strategic Plan

Mission: **The mission for the ATLAS facility at Argonne is to enable research of the highest quality by its users and staff, especially probing the properties of atomic nuclei, through utilizing the capabilities of the accelerator and research equipment in a safe and efficient manner, with the associated responsibility of research and development in accelerator science and in the techniques that are required to accomplish its scientific goals.**

This mission requires identifying the highest priority scientific goals, and allocating resources to optimize the research output of the facility. The current scientific goals are fully consistent with those defined in the NSAC 2007 Long Range Plan (http://www.sc.doe.gov/production/henp/np/nsac/docs/Nuclear-Science.Low-Res.pdf) and the Performance Measures developed by NSAC for nuclear physics as updated in 2008 (http://www.sc.doe.gov/production/henp/np/nsac/docs/PerfMeasEvalFinal.pdf).

The optimization of the research involves the following elements:

1. Effective long-term operation of the accelerator.
2. Development of new accelerator capabilities to enable new high priority research opportunities.
3. Effective support of the experimental program.
4. Development of new experimental capabilities to pursue new high-priority research opportunities.
5. Nurturing the scientific and technical base of the low-energy research community and helping to develop the high-quality workforce for future initiatives.

This last element is not discussed explicitly below, but is a major factor in the delivery of the entire research program, including the need for young researchers to be involved in equipment development and new research initiatives.

The optimization of the strategic plan takes the following elements into account:

- FRIB is a major priority for the nuclear science community, the ATLAS users and Argonne management. The highest priority for low-energy nuclear science is to bring this facility on line. At the same time the science and the community must be carefully nurtured through the optimized use of the steadily upgraded existing facilities.

- ATLAS is the only low-energy national user facility focusing on experiments with stable beams. The user community and ATLAS management acknowledge the inherent responsibility to make stable beams available to the national community.

- The priorities expressed in the NSAC Long Range Plan, the performance measures as well as the scientific goals given below, make it imperative that opportunities with unique radioactive beams at ATLAS continue to be pursued with high priority when identified as being important science by the community and endorsed by the Program Advisory Committee.

- ATLAS has a future beyond the FRIB turn on, both as the stable beam facility for the nuclear physics community and as a complement to FRIB in specific areas of rare isotope science.

- It is the view of the user community and of the management of the Physics Division that a balance between the effective operation of ATLAS and the development of new accelerator capabilities and new instrumentation remains an essential consideration of the strategic plan. This approach helps realize the potential of the science for the low-energy community by continuously developing the long term future of research at ATLAS.

Major Scientific Goals

The major scientific goals below have been identified for the ATLAS research program. In each case, the anticipated experimental program for the next five years is based on the ideas of the user community. Further elaboration of these ideas can be found in a document summarizing the outcome of the August 8-9 Users Workshop which is available at http://www.phy.anl.gov/atlas/workshop09/Reports_on_Workshop.pdf.

I. Understanding the stability and structure of nuclei as many-body systems built of protons and neutrons bound by the strong force;

The following scientific issues have been identified as most urgent by the ATLAS users:

- comparisons of the properties of light nuclei (A<20) with *ab-initio* calculations (Greens function Monte Carlo (GFMC), no-core shell model) and other approaches,
- the study of nuclear structure near the proton drip-line, especially in N=Z nuclei in the 50<A<100 region, and in the direct vicinity of doubly-magic ^{100}Sn,
- the impact of weak binding on the structural properties of nuclei at the proton drip line and beyond such as shell structure, deformation, and the characteristics of proton radioactivity,
- the delineation of the structural properties of nuclei with Z>100 as a challenging test of theories describing the structural properties of the heaviest nuclei ,
- the exploration of the properties of neutron-rich nuclei (changes in shell structure, pairing, single-particle strength, new types of collective excitations, and other effects associated with a large neutron excess),
- the identification of new collective modes and the search for their characteristic spectral signatures throughout the periodic table,
- the study of the properties of the nuclei at the highest spins and excitation energies. This includes the exploration of the interplay between collective and single particle degrees of freedom, the search for new nuclear shapes (hyperdeformation) and the study of the dependence of level densities on angular momentum and temperature.

This program requires:

Effective operation of ATLAS,
Increased ATLAS beam intensities and energies,
Development of unique new radioactive beam capabilities, especially for neutron-rich beams with a reach as far as possible from the valley of stability with CARIBU, and intense neutron-deficient beams of higher energy and purity produced with the in-flight technique,

Continued effective operation and improvement of Gammasphere,
Targeted campaigns of research with GRETINA
Continued development of the HELIOS spectrometer,
Improvement of the transmission efficiency and the focal plane instrumentation of the FMA,
Development of a high-efficiency gas filled spectrometer for the detection of evaporation residues and products from more complex reactions,
Development of dedicated instrumentation for studies in CARIBU non-accelerated beam area (beta decay, g factors, laser spectroscopy, etc.).

II. Exploring the origin of the chemical elements and their role in shaping the reactions that occur in the high-temperature and explosive events of the cosmos;

The following scientific issues have been identified as most urgent by the ATLAS users:

- cross section measurements for reactions within the extended CNO cycle,
- the competition between (α,p) and (p,γ) reactions along the rp-process path,
- the measurement of reaction cross sections between heavy ions at energies relevant for star burning,
- the identification of waiting point nuclei along the rp-process path,
- the determination of the end-point of the rp-process path near A~100,
- the measurement of the mass and decay properties of neutron-rich nuclei close to the r-process path, especially around the N=82 and N=126 waiting points,
- the development of the surrogate reaction technique for the determination of reaction yields along the s- and r-process paths.

This program requires:

Effective operation of ATLAS and CARIBU,
Increased ATLAS beam energies and intensities,
Development of new rare isotope beam capabilities with the in-flight method combining higher intensities, higher energies (in some cases) with improved beam purity through a new, high-acceptance separator,
Access to neutron-rich beams as far from the valley of stability as possible,
Continued development of the HELIOS spectrometer,
Continued effective operation and improvement of Gammasphere,
High-precision mass measurements with ATLAS beams (i.e, in area III),
Development of dedicated instrumentation for studies in CARIBU non-accelerated beam area (beta decay, neutron detection, etc.).

III. Understanding the dynamics governing interactions between nuclei at energies in the vicinity of the Coulomb barrier;

The following scientific issues have been identified as most urgent by the ATLAS users:

- the study of the hindrance of fusion at extreme sub-barrier energies, especially in systems of relevance for nuclear astrophysics,
- the impact of nuclear structure (deformation, shell structure, diffuseness) on fusion, especially for reactions leading to Z>100 nuclei,
- the impact of neutron excess on nuclear reactions in the vicinity of the Coulomb barrier,
- the determination of the proton-neutron asymmetry dependence of the surface and volume terms of the nuclear level density.

This program requires:

Effective operation of ATLAS,
Increased ATLAS beam energies and intensities,
Higher intensity, higher purity rare isotope beams produced with the in-flight method,
Access to neutron-rich beams with the highest achievable intensities,
Development of a high-efficiency gas-filled spectrometer for the detection of evaporation residues and products from more complex reactions .

IV. Testing with high accuracy the fundamental symmetries of nature by taking advantage of nuclei with specific properties;

The following scientific issues have been identified as most urgent by the ATLAS users:

- tests of the conserved vector current (CVC) hypothesis and the unitarity of the first row of the Cabibbo-Kobayashi-Maskawa (CKM) matrix from studies of superallowed beta decays,
- searches for possible extensions of the Standard Model by improving by one order of magnitude or more limits on scalar, tensor and right-handed components to the electro-weak interaction.
- Tests of the nuclear structure inputs leading to large enhancements in EDM sensitivity in octupole-deformed heavy nuclei and critical to the nuclear structure dependent corrections in the determination of G_{uv} from nuclear decays

This program requires:

Effective operation of ATLAS,
Increased ATLAS beam intensities.

Smaller scale, complementary efforts exploit the exceptional and often unique capabilities of ATLAS: for example, accelerator research experiments, the irradiation of samples for materials research, or developing accelerator mass spectrometry techniques for applications in environmental studies, oceanography, astrophysics, fundamental interactions, and any other area of basic science where they apply. These efforts address important physics issues and, in some instances, such programs help focus improvements in overall performance of the facility. However, they do not set the priorities for new developments of ATLAS and the associated instrumentation.

Initiatives

Based on the requirements to reach these goals, the following initiatives have been identified to carry out this research program:

- Improve the ability of ATLAS to deliver higher-intensity stable and rare isotope beams by modifying the first stages of acceleration of the system in order to make the process more efficient and intrinsically able to sustain higher beam intensities,
- Improve the ability of ATLAS to deliver high-intensity, high-purity rare isotope beams produced by the in-flight technique by developing suitable production targets and by adding a high-acceptance separator,
- Expand the range of unstable, neutron-rich beams available from ATLAS with the CARIBU upgrade by increasing the efficiency for charge breeding,
- Extend the energy range of ATLAS for high-intensity, stable beams,
- Complete the full instrumentation of HELIOS,
- Maintain and upgrade Gammasphere focusing in particular on digital pulse processing to accommodate higher count rates,
- Prepare for the siting of GRETINA at ATLAS
- Maintain and improve the other instruments present at ATLAS (FMA, ion and atom traps, magnetic spectrometers) to maintain their state-of-the-art status,
- Develop high-efficiency detection systems for the stopped beam area of CARIBU, i.e., instrumentation for beta decay studies, laser spectroscopy, etc.
- Develop a high-efficiency gas-filled spectrometer for the detection of reaction products from fusion-evaporation and from complex reactions.
- Maintain an infrastructure capable of developing or adapting other detectors designed by the community for use at ATLAS, and subsequently at FRIB.

Approach:

(a) Accelerator:

What is being planned is a two-stage ATLAS efficiency and intensity upgrade.
The *first stage* of the upgrade will replace the front end of the ATLAS Positive Ion Injector linac (PII) by a new bunching system, a Radio-Frequency Quadrupole (RFQ) and a new cryostat of resonators. These modifications will improve the transport efficiency throughout the ATLAS system, while limiting the emittance growth for high-intensity beams so that roughly a factor of 10 higher current can be accelerated to Coulomb barrier energies. Thus, this initial phase will provide an order of magnitude gain in intensity for the stable beam and in-flight rare isotope beam experiments that can use this intensity. It will also double the CARIBU re-accelerated beam intensities because the RFQ and associated bunching systems will capture more of the ions for subsequent acceleration. Accommodating these changes also requires a reconfiguration and refurbishment of the liquid helium distribution system. This first stage of the upgrade is funded through resources made available through the American Recovery and Reinvestment Act (ARRA) for a total of $9.8M and should be completed by mid-2013.

The *second stage* of the upgrade includes (1) the replacement of the CARIBU ECR charge-state booster by an EBIS breeder, (2) the removal of the tandem to gain critical space for experiments, (3) a reconfiguration of the main ATLAS cryostats, including the addition of two new cryostats with high-performance resonators developed recently at ANL as prototypes for FRIB, (4) improvements to the ECR sources, and (5) the installation of a large recoil separator for the in-flight radioactive beam program resulting in a better separation of the desired rare isotope beam from the primary production beam.

The completed upgrade will yield roughly an order of magnitude higher intensity of re-accelerated CARIBU beams, extending the range of isotopes accessible to experiment towards more neutron-rich species. It will provide stable heavy ions over the full energy range available at ATLAS with 10-100 pμA intensities, limited solely by ion source performance. It will result in a two orders of magnitude increase in the intensity of the in-flight rare isotope beams and, the availability of higher energies also augments the range of rare ions that can be produced with this technique.

(b) Instrumentation:

A number of on-going instrumentation projects, initiated by the user community and the ATLAS scientific staff, need to be completed in order to take full advantage of the present and forthcoming upgrades to the accelerator. These include:

- Completion of the instrumentation for HELIOS by (i) installing optimized light-ion detectors in both the forward and backward hemispheres, (ii) adding heavy-recoil detection capability,
- Instrumentation of Gammasphere with digital pulse processing capability,

- Completion of the X-array and addition of digital pulse processing capability for the focal plane Si detectors,
- Improvement of the FMA acceptance by replacement of the entrance quadrupole, and the addition of an external Faraday cup outside the tank containing the first electric dipole,
- Improvements to the CPT and associated equipment and other equipment at ATLAS as needed to maintain their state-of-the-art status.

In addition, a number of new initiatives have the full support of the ATLAS user community. These include:

- Development of a high-efficiency beta-decay station for the CARIBU stopped beam area,
- Development of a high-efficiency, gas-filled spectrometer for products of fusion-evaporation and complex reactions.
- Development of a laser spectroscopy capability for the CARIBU stopped beam area,
- Site preparation for GRETINA ,
- Site preparation for a move of the CPT to Area III,

It is the view of the user community and of the management of the Physics Division that the development of new instrumentation should be viewed in the context of the development of FRIB. ATLAS is the accelerator of choice for the low-energy nuclear physics community to test new concepts and ideas in preparation of the FRIB experimental program with low-energy and reaccelerated beams. Furthermore, future sharing of experimental equipment between FRIB and ATLAS is viewed as a strong possibility. Hence, the list above is likely to change and evolve as a result of future equipment-related workshops for FRIB.