A Strategic Plan for the ATLAS Accelerator Facility

Physics Division
Argonne National Laboratory
Argonne, IL

June 2014

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 May 15-16, 2014. 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, in applications of nuclear 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 (science.energy.gov/~/media/np/nsac//pdf/docs/NuclearScienceHighRes.pdf), the 2013 report to NSAC on Implementing the 2007 Long Range Plan (science.energy.gov/~/media/np/nsac/pdf/20130201/2013_NSAC_Implementing_the_2007_Long_Range_Plan.pdf), and the Performance Measures developed by NSAC for nuclear physics as updated in 2008 (science.energy.gov/~/media/np/nsac/pdf/docs/perfmeasevalfinal.pdf).

The optimization of the research program involves the following elements:

1. Effective long-term operation of the accelerator.
2. Effective support of the experimental program.
3. Development of new accelerator capabilities to enable new high-priority research opportunities.
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 low-energy national user facility focusing on experiments with stable beams. The user community and ATLAS management acknowledge the inherent responsibility to make stable ion 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.

- Beyond the commissioning phase of FRIB, ATLAS will address the needs of the low-energy community both as the only stable beam user facility 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 the presentations to the May 15-16 2014 ATLAS Users Workshop and the documents summarizing the various sessions which are available at http://www.phy.anl.gov/atlas/workshop14/index.html .

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;
- study of the evolution of single-particle structure from light to medium mass 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 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 with particular emphasis on N=Z nuclei in the 50<A<100 region, and in the direct vicinity of doubly-magic ^{100}Sn;
- the study of the structure of nuclei with Z>100 as a challenging test of theories describing the properties of the heaviest nuclei;
- the study of the properties of the nuclei at the highest spins and excitation energies. This includes (i) exploring of the interplay between collective and single-particle degrees of freedom, (ii) searching for novel collective modes and for their spectral signatures throughout the periodic table, and (iii) studying of the dependence of level densities on angular momentum and temperature.

This program requires:

- Effective operation of ATLAS,
- Increased ATLAS beam intensities and energies,
- Increased availability of beam time through the proposed ATLAS multi-user upgrade,
- Development of unique new radioactive beam capabilities, especially of neutron-rich beams with a reach as far as possible from the valley of stability with CARIBU and with the planned N=126 factory, and of intense exotic

beams of higher energy and purity produced with the in-flight technique at the new AIRIS high-acceptance spectrometer,
- Continued effective operation and improvement of Digital Gammasphere and its ancillary equipment,
- Targeted campaigns of research with GRETINA/GRETA,
- Continued development of the HELIOS spectrometer and of its ancillary equipment,
- Continued improvement of the focal plane instrumentation of the FMA,
- Development of the AGFA spectrometer for the detection of evaporation residues and products from more complex reactions,
- Continued development of instrumentation for studies with CARIBU non-accelerated beams in an expanded experimental area.

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 through measurements of the relevant cross sections;
- the measurement of reaction cross sections between heavy ions at energies relevant for star burning;
- the study of the reactions responsible for the p-process nuclei through dedicated techniques such as Accelerator Mass Spectrometry;
- 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-, rp- and r-process paths.

This program requires:

- Effective operation of ATLAS and CARIBU,
- Increased ATLAS and CARIBU beam intensities,
- Increased availability of beam time through the proposed ATLAS multi-user upgrade,
- Development of new rare isotope beam capabilities with the in-flight method combining higher intensities and higher energies (in some cases) with improved beam purity through the new AIRIS high-acceptance spectrometer,

- Access to neutron-rich nuclei in the region responsible for the formation of the last r-process abundance peak through the proposed N=126 factory,
- Continued development of the HELIOS spectrometer and of its ancillary equipment,
- Continued effective operation and improvement of Digital Gammasphere and GRETINA/GRETA,
- Continued development of instrumentation for studies with CARIBU non-accelerated beams in an expanded experimental area.

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, dissipation, etc.) 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.

This program requires:

- Effective operation of ATLAS and CARIBU,
- Increased ATLAS intensities and increased availability of beam time through the proposed ATLAS multi-user upgrade,
- Higher-intensity, higher-purity rare isotope beams produced with the in-flight method using the new AIRIS high-acceptance spectrometer,
- Access to neutron-rich beams with the highest achievable intensities,
- Development of the AGFA 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:

- 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 conserved vector current (CVC) hypothesis and the unitarity of the first row of the Cabibbo-Kobayashi-Maskawa (CKM) matrix from studies of beta decay;
- studies of the antineutrino spectra in abundant fission products to determine the origin of the apparent reactor antineutrino anomaly observed in neutrino oscillation experiments.

This program requires:

- Effective operation of ATLAS and increased availability of beam time through the proposed ATLAS multi-user upgrade,
- Increased ATLAS beam intensities,
- Expanded low-energy experimental area at CARIBU.

V. Nuclear physics applications at ATLAS and CARIBU;

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

- the study via Accelerator Mass Spectrometry (AMS) of neutron-capture cross sections on various isotopes of interest for reactor physics and nuclear astrophysics;
- the study of the decay properties of neutron-rich isotopes (gamma, beta, beta-delayed neutrons) of importance for accurate modeling of kinetics and decay heat in novel nuclear fuel cycles and for stockpile stewardship;
- studies via heavy-ion bombardment of damage in irradiated reactor materials and of modifications to superconducting materials;
- the development of new production techniques for specific isotopes for medical and stockpile-stewardship applications.

This program requires:

- Effective operation of ATLAS, including improved control techniques for accurate configuration scaling and reproduction of previous accelerator configurations,
- Increased ATLAS beam intensities and energies,
- Increased availability of beam time through the proposed ATLAS multi-user upgrade,
- Higher intensity, higher purity neutron-rich beams from CARIBU,
- Expanded, dedicated experimental area for low-energy CARIBU experiments,
- Availability of dedicated experimental stations at ATLAS.

Initiatives

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

- Move forward with the development and implementation of the ATLAS multi-user upgrade to allow ATLAS to address the present large oversubscription of the facility by providing a larger fraction of the number of research hours requested by its user community;
- Improve the ability of ATLAS to deliver high-intensity, high-purity rare isotope beams produced by the in-flight technique by developing both the AIRIS high-acceptance separator and the production targets able to tolerate the highest primary beam intensities;
- Construct in a timely manner the AGFA high-efficiency gas-filled spectrometer for the detection of reaction products from fusion-evaporation and from complex reactions;
- Expand the range of unstable, neutron-rich beams available from ATLAS with the CARIBU upgrade by increasing the efficiency for charge breeding and the purity of the reaccelerated beams by implementing the EBIS charge breeder;
- Extend the energy range of ATLAS for high-intensity, stable beams primarily for in-flight production of exotic beams with AIRIS;
- Provide first access to the region of the chart of nuclei east of ^{208}Pb through the construction of the proposed N=126 factory;
- Complete the full instrumentation of HELIOS, and develop ancillary detectors;
- Maintain and improve the instruments present at ATLAS (Digital Gammasphere, FMA, ion and atom traps, magnetic spectrometers) to increase count rate capabilities and maintain their state-of-the-art status;
- Expand the size of the area available for experimentation with low-energy CARIBU beams;
- Develop high-efficiency detection systems for the low-energy area of CARIBU, i.e., instrumentation for beta-decay studies, laser spectroscopy, etc.;
- 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:

A staged multi-user upgrade of the facility is being proposed, building on the recently completed Intensity and Efficiency upgrade of ATLAS which enables the high-efficiency acceleration of stable beams to much higher intensity (> 10 pμA). Additional improvements of ATLAS currently being completed include the replacement of the CARIBU ECR charge-state booster by an EBIS breeder and the removal of the tandem injector. The latter initiative will provide critical space for low-energy CARIBU experiments. The shift to the EBIS charge breeder will result in a significant change in the delivery of reaccelerated CARIBU beams as the full radioactive beam intensity will be compressed into short buckets taking up less than 1% of the total time available for acceleration. In other words, the linac will be essentially empty for the remaining 99% of the time. When completed, the ATLAS multi-user upgrade will enable the simultaneous acceleration of a CARIBU beam and one or two independent stable beams by fully exploiting the availability of the linac during the remaining 99% of the total time.

The initial stage of this upgrade involves a rearrangement of the injection lines into ATLAS so that two independent beams can be injected simultaneously: a stable beam from the ECR-II ion source and a charge-bred CARIBU beam from the EBIS charge breeder. The addition of fast beam switching capability behind the booster section of the linac then allows one beam to be directed to experimental area II, while the second can be sent to any other ATLAS experimental area with an energy that can be further adjusted in the ATLAS section of the linac. The wide choice in charge-state selection for acceleration through ATLAS, combined with the demonstrated flexibility of operation of the facility, then provides a relatively independent two-user operation. A possible next stage for this upgrade would involve the addition of two new cryostats replacing part of the existing linac and of achromatic transport systems in the 40-degree bend region and at the switchyards leading to the experimental areas. This phase of the upgrade would generalize the two-user operation to all experimental areas and, in some cases, would lead to the capability of simultaneous three-user operation.

These upgrades would result in close to a doubling in the total number of experimental hours the facility can deliver to experiments. In so doing, this initiative addresses the large current oversubscription of ATLAS while also enabling the running of the experiments of longer duration required for studies with small cross sections or with low-intensity radioactive beams.

(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 AGFA high-efficiency gas-filled spectrometer for products of fusion-evaporation and complex reactions;
- Development of the AIRIS large acceptance spectrometer to increase the intensity and purity of in-flight radioactive beams produced at ATLAS;
- Completion of the instrumentation for HELIOS with the addition of an optimized light-ion detector for higher coverage in both the forward and backward hemispheres and continued development of ancillary detectors and target systems as required for approved experiments;
- Continuous improvements to Digital Gammasphere, the FMA, the CPT/BPT, the X-array and other permanent instruments 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 the N=126 factory to provide access to the exotic nuclei east of ^{208}Pb on the nuclear chart;
- Development of a laser spectroscopy capability for the CARIBU low-energy beam area;
- Expansion of the CARIBU low-energy experimental area into the tandem vault;
- Installation of the MR-TOF spectrometer in order to improve the purity of the available CARIBU beams.

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.

The user community continues to express its concerns about the availability of target fabrication capabilities sufficient, not only for the ATLAS program, but also for research at other national and university-based facilities. It strongly supports the establishment of the Center for Accelerator Target Science (CATS) proposed by the Physics Division and urges the timely and full consideration of the CATS proposal submitted to the U. S. Department of Energy in October 2013.