Recommendations

- **We recommend the completion of the 12 GeV Upgrade at Jefferson Lab. The Upgrade will enable new insights into the structure of the nucleon, the transition between the hadronic and quark/gluon descriptions of nuclei, and the nature of confinement.**
- **We recommend the construction of the Facility for Rare Isotope Beams, FRIB, a world-leading facility for the study of nuclear structure, reactions and astrophysics. Experiments with the new isotopes produced at FRIB will lead to a comprehensive description of nuclei, elucidate the origin of the elements in the cosmos, provide an understanding of matter in the crust of neutron stars, and establish the scientific foundation for innovative applications of nuclear science to society.**
- **We recommend a targeted program of experiments to investigate neutrino properties and fundamental symmetries. These experiments aim to discover the nature of the neutrino, yet unseen violations of time-reversal symmetry, and other key ingredients of the new standard model of fundamental interactions. Construction of a Deep Underground Science and Engineering Laboratory is vital to US leadership in core aspects of this initiative.**
- **The experiments at the Relativistic Heavy Ion Collider have discovered a new state of matter at extreme temperature and density—a quark-gluon plasma that exhibits unexpected, almost perfect liquid dynamical behavior. We recommend implementation of the RHIC II luminosity upgrade, together with detector improvements, to determine the properties of this new state of matter.**

Recommendation 1

We recommend the completion of the 12 GeV Upgrade at Jefferson Lab. The Upgrade will enable new insights into the structure of the nucleon, the transition between the hadronic and quark/gluon descriptions of nuclei, and the nature of confinement.

A fundamental challenge for modern nuclear physics is to understand the structure and interactions of nucleons and nuclei in terms of quantum chromodynamics. Jefferson Lab's unique electron microscope has given the US leadership in addressing this challenge. Its first decade of research has already provided key insights into the structure of nucleons and the dynamics of finite nuclei.

Doubling the energy of this microscope will enable three-dimensional imaging of the nucleon, revealing hidden aspects of its internal dynamics. It will complete our understanding of the transition between the hadronic and quark/gluon descriptions of nuclei, and test definitively the existence of exotic hadrons, long-predicted by QCD as arising from quark confinement. Through the use of parity violation, it will provide low-energy probes of physics beyond the Standard Model complementing anticipated measurements at the highest accessible energy scales.

Recommendation 2

We recommend the construction of the Facility for Rare Isotope Beams, FRIB, a world-leading facility for the study of nuclear structure, reactions and astrophysics. Experiments with the new isotopes produced at FRIB will lead to a comprehensive description of nuclei, elucidate the origin of the elements in the cosmos, provide an understanding of matter in the crust of neutron stars, and establish the scientific foundation for innovative applications of nuclear science to society.

A roadmap has been delineated to achieve the goal of a comprehensive and unified description of nuclei. New data on exotic isotopes, that only FRIB will provide, are an essential ingredient of this approach as they will allow us to understand the nature of the forces that hold the nucleus together, to assess the validity of the theoretical approximations, and to delineate the path towards integrating nuclear structure with nuclear reactions. The study of rare isotopes is essential to explain the chemical history of the universe and the synthesis of elements in stellar explosions. Advances in Astrophysics and astronomy are driving the need for new and improved nuclear data on isotopes at the very limits of nuclear stability which will be available for the first time with suitable rates at FRIB. Rare isotopes also play a role in testing the fundamental symmetries of nature, and are essential for the many cross-disciplinary contributions they enable in basic sciences, national security, and societal applications. To launch the field into this new era requires effective exploitation of current User facilities, NSCL, HRIBF and ATLAS, and the immediate construction of FRIB with its ability to produce ground breaking research.

Recommendation 3

We recommend a targeted program of experiments to investigate neutrino properties and fundamental symmetries. These experiments aim to discover the nature of the neutrino, yet unseen violations of time-reversal symmetry, and other key ingredients of the new standard model of fundamental interactions. Construction of a Deep Underground Science and Engineering Laboratory is vital to US leadership in core aspects of this initiative.

The discovery of flavor oscillations in solar, reactor, and atmospheric neutrino experiments – together with unexplained cosmological phenomena such as the dominance of matter over anti-matter in the Universe – call for a new standard model of fundamental interactions. Nuclear physicists are poised to discover the symmetries of the new standard model through searches for neutrinoless double beta decay and electric dipole moments, determination of neutrino properties and interactions, and precise measurements of electroweak phenomena.

The Deep Underground Science and Engineering Laboratory will provide the capability needed for ultra-low background measurements in this discovery-oriented program. Experiments also will exploit new capabilities at existing and planned nuclear physics facilities. Assembling the new standard model using the breadth of new experimental results will require enhanced theoretical efforts.

Recommendation 4

The experiments at the Relativistic Heavy Ion Collider have discovered a new state of matter at extreme temperature and density—a quark-gluon plasma that exhibits unexpected, almost perfect liquid dynamical behavior. We recommend implementation of the RHIC II luminosity upgrade, together with detector improvements, to determine the properties of this new state of matter.

The striking discoveries of the first five years at RHIC compel us to carry out a broad, quantitative study of the fundamental properties of the quark-gluon plasma. This can be accomplished through significant increases in collider luminosity, detector upgrades, and advances in theory, which also create further discovery potential.

The RHIC II luminosity upgrade, using electron cooling, provides a ten-fold increase in collision rate, which enables measurements using uniquely sensitive probes of the plasma such as energetic jets and rare bound states of heavy quarks. The detector upgrades make important new types of measurements possible and extend significantly the physics reach of the experiments. Achieving a quantitative understanding of the quark-gluon plasma also requires new investments in modeling of heavy ion collisions, in analytic approaches, and in large scale computing.