2023 DOE/NSF Nuclear Science Advisory Committee Facilities Charge

In response to Dr. Berhe's December 2023 Facilities Charge, Nuclear Physics is providing the following list of projects for consideration by the subcommittee.

Electron-Ion Collider (EIC)

Total Project Cost (TPC) range: $1.7B to $2.8B

The EIC will be located at Brookhaven National Laboratory, which will lead its construction in partnership with Thomas Jefferson National Accelerator Facility (TJNAF). ANL, LBNL, ORNL and LANL will also contribute to its construction, notionally envisioned to complete in the first part of the next decade. The EIC will provide unprecedented ability to "x-ray" the proton and discover how the mass of everyday objects is dynamically generated by the interaction of quark and gluon fields inside protons and neutrons. The EIC accomplishes this by colliding highly polarized electrons with a variety of ion species at high center-of-mass energy, and with high luminosity. Understanding how the macroscopic properties of the spin and mass of protons and neutrons are generated is key to addressing an outstanding grand challenge problem of modern physics: how quantum chromodynamics, the theory of the strong force, explains all strongly interacting matter in terms of points like quarks interacting via the exchange of gluons. The EIC is envisioned to be international in character. The EIC User Group actively working to develop concepts for the EIC detector, ePIC, comprises 1400 users from 277 institutions in 36 countries.

Current status: CD-1 achieved June 2021.

High-Rigidity Spectrometer (HRS)

Total Project Cost (TPC) range: $85M to $111M

The HRS will allow experiments at FRIB using beams of rare isotopes to be carried out at the maximum fragmentation or in-flight fission beam intensities, providing critical isotopes not available otherwise. The existing spectrometer available at FRIB has a limited bending capability, which limits the fluences achievable in experiments with fast rare isotope beams. The HRS removes this limitation by doubling the bending capability and matching the rigidities at which the most neutron-rich rare isotopes produced at FRIB—those of greatest interest for understanding nucleosynthesis in the cosmos— will have the highest production rate. This gain in rare isotope production rate increases the scientific potential of state-of-the-art detector instrumentation which the research community places high priority on, such as the Gamma-Ray Tracking Array (GRETA), to be used in conjunction with the HRS.

Current status: CD-1 achieved September 2020.

Ton-Scale Neutrinoless Double-beta Decay (TS-NLDBD)

Total Project Cost (TPC) range: $350M to $500M

Projects planned under a TS-NLDBD experiment program will instrument a large volume of a specially selected isotope to detect neutrinoless double beta decay ($0\nu\beta\beta$). The observation of NLDBD would demonstrate that the neutrino is its own antiparticle and elucidate the mechanism, completely unknown at present, by which the mass of the neutrino is generated. The observation would have major implications for the present-day matter/anti-matter asymmetry which has perplexed modern physics for decades and could reveal unknown particle states such as a conjectured heavy, right-handed neutrino.

The goal of a next generation ton-scale experiment is to reach a lifetime limit of a few counts in 10^{28} years. Three technologies (Large Enriched Germanium Experiment for Neutrinoless Double Beta Decay (LEGEND-1000), Next Enriched Xenon Observatory (nEXO), and Cryogenic Underground Observatory for Rare Events with Particle Identification (CUPID)) employing different isotopes to ensure a definitive outcome as a result of this scientific campaign are poised to reach this limit withing a 10-year measurement period. Working with the international community to deploy multiple experiments is important for contemporaneous verification as the best chance for unambiguous discovery. To be viable, the offshore international community will need to undertake at least a 50% share of the resources needed for this campaign.

Current status: CD-0 achieved November 2018.

Project 8

Total Project Cost (TPC): TBD

Project 8 will measure the absolute value of the neutrino mass by precisely measuring the energies of beta-decay electrons in the high-energy tail of the spectrum of tritium beta decays. Knowing the highest possible beta-decay energy determines the lower limit on the neutrino mass by simple conservation of momentum and energy in a three-body decay. The excitement is that Project 8 is using a new method of electron spectroscopy developed by PNNL and the University of Washington, Cyclotron Radiation Emission Spectroscopy, which measures the frequency of the cyclotron motion of electrons in a constant magnetic field to achieve a precise measurement of the energy. The ultimate science goal of Project 8 will be the use atomic tritium to measure the neutrino mass down to a limit of approximately 40 meV, about 20 times better than the current world limit.

Current status: Not an ongoing project, science review held July 2023.

Facility for Rare Isotope Beams Energy Upgrade (FRIB400)

Total Project Cost (TPC): TBD

The FRIB400 will extend the tremendous discovery potential of FRIB by realizing significant gains in isotope yields, nearly doubling the scientific reach of FRIB along the neutron dripline and bringing access to more nuclei relevant for the r process and neutron-star crust processes thought to be prime drivers of heavy element production in the cosmos. FRIB400 is an energy upgrade of the FRIB linear accelerator from 200 MeV/nucleon to 400 MeV/nucleon for uranium and to higher energies for lighter ions. Space was provided in the conceptual design of the FRIB tunnel for the proposed energy upgrade, which can be implemented with minimal interruption of the FRIB science program. The unlocked science potential includes creating dense nuclear matter at up to twice normal nuclear density, which is critical for multi-messenger astrophysics.

Current status: Not an ongoing project, white paper updated February 2023.

Solenoid Large Intensity Device (SoLID)

Total Project Cost (TPC): TBD

The SoLID detector will exploit the full potential of the CEBAF 12 GeV upgrade, enabling measurements in quantum chromodynamics and electroweak physics. SoLID is a large acceptance forward scattering spectrometer with full azimuthal angular coverage capable of handling high luminosities with a variety of polarized and unpolarized targets. The detector's science programs will focus on the three-dimensional imaging of the nucleon in a kinematic region complementary to the EIC, beyond standard-model searches for new physics, and exploration of gluonic forces.

Current status: Not an ongoing project, science review held March 2021.

Electron-Ion Collider (EIC) Detector II

Total Project Cost (TPC): TBD

The EIC project currently includes one large-acceptance detector, ePIC, that will capture most of the particles scattering from collisions of electrons and ions in all directions and at a wide range of energies. Detector II for the EIC will be complementary to the ePIC project detector, will focus its capabilities on full exploration of phenomena discovered in the first phase of ePIC research, and will capitalize on the possibility of a secondary focus. Multiple detectors will expand scientific opportunities building on the discoveries already made with the ePIC detector, drawing a more vivid and complete picture of the science, providing an independent confirmation for discovery measurements, and adding critical statistics to systematics-limited measurements the EIC expects to perform.

Current status: Not an ongoing project, first international workshop held May 2023.