q Draft Resolutions

Nuclear science in the US boasts a vibrant portfolio of experimental and theoretical research that aims to understand the implications of the Standard Model of electroweak interactions in nuclear phenomena and search for physics beyond the Standard Model (BSM). This research sheds light on a number of important open questions, such as: Why is there more matter than antimatter in the present universe? Are neutrinos their own antiparticles? How do neutrinos get masses and what are their values? Are there new forces in nature, weaker than the weak force? What is the nature of dark matter? The ``targeted program of fundamental symmetries and neutrino research'' established in previous LRPs has generated world-leading results and created a number of compelling opportunities for future discovery. In order to maintain the world-class program and expand U.S. leadership, the FSNN community has identified the following priorities:

1) **We recommend the timely construction of ton-scale neutrinoless double beta decay experiments using different isotopes, as prioritized in the 2015 Long Range Plan.**

The 2021 portfolio review affirmed the readiness of CUPID, LEGEND, and nEXO experiments to proceed to construction with the goal of measuring neutrinoless double beta decay to a discovery sensitivity below the inverted hierarchy. This will enable a US-led program of discovery science that could elucidate the nature of neutrinos and fundamentally alter our understanding of the origin of mass and matter in the Universe. Full realization of this program will require a US - International partnership.

Sensitivity beyond the inverted mass ordering will require next-generation R&D to explore multiple promising isotopes and new technologies. Next-generation experiments could provide further insight into the neutrinoless double beta decay mechanism in the case of a discovery by the ton-scale experiments or sensitivity to the normal hierarchy. A robust program in theory is integral to the success of the program.

2) **We recommend a suite of targeted experiments aimed at challenging the Standard Model and uncovering new phenomena. Unique opportunities in nuclear physics include searching for electric dipole moments, probing the fundamental structure of the electroweak interaction, and understanding neutrino properties. The success of this program demands robust research support commensurate with the tremendous discovery potential.**

Realizing these compelling scientific opportunities requires:

a. Capitalize on larger scale investments made to date by expeditiously completing high-impact experimental campaigns: nEDM@SNS, the world's most ambitious search for the neutron electric dipole moment (EDM); and MOLLER@JLab, soon to be the most precise low energy measurement of a purely leptonic weak neutral current interaction.

b. Support the small and mid-scale university and laboratory programs that address questions surrounding CKM unitarity through neutron and nuclear beta decay, substantially improve the sensitivity to CP violation through EDM searches, and extend the precision frontier's capability to discover BSM physics.

c. Pursue emerging opportunities with compelling scientific cases. These include the next generation measurements of the absolute neutrino mass (Project 8), lepton flavor universality in the weak interactions (PIONEER), search for new neutral current interactions (SoLID), as well as EDM searches enabled by FRIB.

FSNN is broad and diverse, with unique needs. The community strongly leverages facilities managed by other programs, offering an exceptional return on investment. Without a central managing facility, however, we must take greater measures to protect our level of research support and resources such as beamtime. Erosion of research support delays science, which threatens US leadership, and reduces our ability both to respond to new ideas and to develop the capabilities (such as brighter UCN sources and isotope harvesting at FRIB) needed to push the precision frontier beyond this Long Range Plan.

3) **We recommend new investments aimed at enlarging and supporting the nuclear theory efforts in FSNN.**

Addressing FSNN physics requires theoretical expertise in phenomenology, effective field theory, lattice QCD, and nuclear structure. An enhanced theoretical research program is essential for taking full advantage of the exciting physics opportunities and the broad scope of the FSNN experimental program.

Key elements of this program are:

> a. Increased support of collaborative efforts such as Theory Hubs, Topical Collaborations, and Physics Frontier Centers, to tackle the multi-scale problems relevant to FSNN discovery science.
>
> b. The creation of a faculty bridge program to grow the FSNN theoretical workforce with procedures and best practices that develop and sustain a diverse, equitable, welcoming, and inclusive workforce and culture.

4) **We recommend enhanced investment in the growth and development of a diverse workforce that will maximize our opportunities for scientific discovery.**

It has been shown that strong teams are diverse teams. The nuclear-physics research program serves an important role in developing a diverse STEM workforce for the critical needs of the nation. FSNN is a particularly strong training ground, allowing students to take part in all aspects of their experiment.

Creating and maintaining an inclusive, equitable, productive working environment for all members of the community is a necessary part of this development.

- Recruiting and maintaining a diverse workforce requires treating all community members with respect and dignity. Supporting the recent initiatives by the APS and DNP to develop community-wide standards of conduct, we recommend that experimental and theoretical collaborations establish enforceable conduct standards. The enforcement of such standards is the combined responsibility of all laboratories, theoretical and experimental collaborations, conference organizers, and individual investigators supported by the nuclear physics research program.

- We recommend increased resources for training programs and consultants to prepare and advise the community.

- We recommend development and expansion of programs that enable participation in research by students from under-represented communities at National Labs and/or Research Universities, including extended support for researchers from minority-serving and non-PhD granting institutions. These programs should be funded at a level that accounts for the financial needs of the students, especially those from disadvantaged backgrounds.

- We recommend development and expansion of programs to recruit and retain diverse junior faculty and staff at universities and national laboratories through bridge positions, fellowships, traineeships, and other incentives.

- In order to monitor progress in this area, we recommend increased resources for collecting data. The data will include the membership in our community and the career trajectories of our students and postdocs. With this data we can monitor progress and attract a more diverse group of young researchers, e.g. by promoting our field as a bridge to industry positions.

5a) **Endorsements: Computational Nuclear Physics**

Accurate theoretical calculations, with uncertainties reliably quantified, are essential to the planning of, and the interpretation of the results of, the FSNN experimental program, especially its flagship program in searches for a neutrinoless double-beta decay. Such calculations are enabled by adequate high-performance computing resources. Additionally, the success of many experimental programs recommended here also depends upon the prompt and reliable processing of experimental data, with corresponding simulation campaigns and enhancement with AI tools. This is often achievable only through the use of advanced high performance computing facilities. Therefore, to meet both the theoretical and experimental needs of this research program, we endorse the Computational NP workshop resolutions:

> COMPUTATIONAL WORKSHOP RESOLUTIONS
> High-performance computing is essential to advance nuclear physics on the experimental and theory frontiers. Increased investments in computational nuclear physics will facilitate discoveries and capitalize on previous progress. Thus, we recommend a targeted program to ensure that the utilization of ever-evolving HPC hardware via software and algorithmic development, which includes taking advantage of novel capabilities offered by AI/ML.
> The key elements of this programs are:
> 1. Strengthen and expand programs to support immediate needs in HPC and AI/ML, and also to target development of emerging technologies, such as quantum computing, and other opportunities.
> 2. Take full advantage of exciting possibilities offered by new hardware and software and AI/ML within the nuclear physics community through educational and training activities.
> 3. Establish programs to support cutting-edge developments of a multi-disciplinary workforce and cross- disciplinary collaborations in high-performance computing and AI/ML.
> 4. Expand access to computational hardware through dedicated and high-performance computing resources.

We add that dedicated software- and algorithm-development programs, such as successful DOE SciDAC programs, and concerted community efforts, following e.g., the USQCD model, for acquiring and maintaining access to leadership-class facility resources will be critical to meet the FSNN experimental-program’s needs in a timely manner.

5b) **Endorsements: Nuclear data.**

Nuclear data play an essential role in all facets of nuclear science. Access to reliable, complete and up-to-date recommended nuclear data is crucial for the fundamental nuclear physics research enterprise, as well as for the successes of applied missions in the areas of defense and security, nuclear energy, space exploration, isotope production, and nuclear medicine diagnostics and treatments. It is imperative to maintain an effective US role in the stewardship of nuclear data.

- We endorse support for identifying and prioritizing opportunities to advance and enhance the stewardship of nuclear data and efforts to build a diverse, equitable and inclusive workforce that maintains the currency and reliability of the nuclear databases.
- We recommend prioritizing opportunities that enhance the currency and quality of recommended nuclear data and its utility for propelling scientific progress in fundamental symmetry, neutrino and neutron projects and the broader nuclear science program.
- We endorse identifying interagency-supported crosscutting opportunities for nuclear data with other programs that enrich the utility of nuclear data in both science and society.

5c) **Endorsements: Quantum Information Science and Technology in Nuclear Physics**

Nuclear physics has much to gain from, and contribute to, quantum information science (QIS) and quantum sensing. Following the recommendations of an NSAC Subcommittee on QIS in 2019:

We recommend increased investment to capitalize on the rapid worldwide development of quantum sensor technology and its timely implementation in NP.

> *Advances made over the past two decades in material sciences and cryogenic infrastructure have accelerated the development of quantum sensors and quantum integrated systems, and in some cases provide revolutionary approaches to historically inaccessible problems. Quantum sensors are already in use in: neutrinoless double-beta decay, neutrino mass measurements, sterile neutrino searches, precision tests of fundamental symmetries, permanent electric dipole moment searches, and as probes to rare and exotic processes. Their targeted use in NP continues to grow and expanding R&D in this area, including through investments in national and university facilities, is essential.*

We recommend investment in exploratory research directions that aim to develop, integrate, and apply quantum-based simulation and computation techniques in NP.

> *Forefront research in NP involves accurate simulations of hadronic and nuclear phenomena. Despite their advanced state and crucial impact, classical computations are inadequate in simulating real-time dynamics of matter created in heavy-ion collisions or after the Big Bang, coherent neutrino oscillations in astrophysical environments, and of relevance to the FSNN program, a wealth of dynamical response functions, e.g., for neutrino-nucleus scattering, accurate rate of nuclear-reaction processes, and more. Quantum simulation has great potential to revolutionize our simulation capabilities in these problems. Furthermore, quantum information tools can guide the design of more efficient classical NP simulations, and quantum entanglement can serve as a new principle to enhance our understanding of NP phenomena and the underlying theory. The community needs to engage in the co-design of quantum-simulating devices dedicated to the NP program and be provided sustained access to quantum hardware. Programs and partnerships that enable collaborations across NP in QIS would be valuable.*

We recommend strengthening the QIS expertise in NP training to create a diverse, quantum-ready, nuclear-capable workforce.

A diverse, quantum-ready workforce is a necessity for both communities. QIS can attract young talent from a variety of backgrounds to our programs, and empower them with skills in emerging quantum technology and computing trends. Increased investment in recruiting and training these young researchers will accelerate the development and integration of QIS technology in NP, and will improve sustainability of the field.

We recommend further development of interdisciplinary, cross-cutting research between QIS and NP to leverage the knowledge base of different research communities.

The nuclear community's knowledge of the interactions between particles and matter serves as a valuable asset in the development of a future quantum computer and a robust quantum workforce. For example, the expertise developed by nuclear physicists in shielding against cosmic rays, and in the development of radio-pure materials for rare event searches, can play an important role in increasing the coherence times of next-generation qubits for a range of computing and sensing applications. We encourage support of these cross-disciplinary efforts that can potentially strengthen collaboration between the two communities.