Nuclear Physics Comparative Research Review
for the U. S. Department of Energy

October 31, 2013

1. Introduction

From the middle of May through the end of June of 2013, the Nuclear Physics (NP) Comparative Research Review (CRR) was carried out under the initiative of the U. S. Department of Energy (DOE). The research efforts of 170 university groups and 30 national laboratory groups were assessed on the basis of equally-weighted evaluation criteria. The DOE funding supports approximately 92% of the research in the field of nuclear physics in the U.S., whereas the remainder is mostly supported by the National Science Foundation (NSF). As of today, nuclear physics research, which is our main review topic, receives approximately $162M in support, whereas the total amount of DOE funds, including operation budgets for the facilities for nuclear physics, is approximately $519M.

The DOE is responsible for the strategic planning of the nuclear physics programs in the U.S. which are DOE-supported. It has to identify scientific opportunities for discoveries and advancements, and it also has to build and operate forefront facilities to allow for these opportunities. In addition, it has to develop and support a research community that produces a significant outcome. The results of the NP CRR will help optimize the research portfolio and enable the DOE to work with other agencies to optimize usage of U.S. resources.

The mission of the review panels was to assess the following for each research group:

1. Significance and merit of the group's research, in the context of present and emerging research directions within nuclear physics;
2. Future prospects for achieving scientific excellence based on the group's past achievements and the vigor and focus of the group members;
3. Scientific productivity of each group, including any specific strengths and weaknesses;
4. Impact of the group's scientific research effort nationally and internationally;
5. Effectiveness of the group in training the next generation of scientists; and
6. Particular strengths of each group, such as scientific leadership, technical leadership,

development of innovative concepts or instruments, maintenance of unusual skills, or crucial inputs into collaborative efforts.

During the review the panel identified (i) new insights and/or advancements in the fields of basic science; (ii) new and accumulated knowledge; (iii) well-developed and fore-front technology; and (iv) a very talented and well-trained workforce who would contribute to the DOE's mission and the U.S. nuclear science-related endeavors.

The review was carried out by five panels, each one consisting of about 10 panel members. The Chair of the review (Shoji Nagamiya of RIKEN/KEK) worked with members throughout all sessions. Names of the panel members are listed in Appendix I. The panel members had access to the submitted written material of the research groups and were present for all oral presentations by the research groups. Each research group gave a presentation of its work followed by a question and answer session. Since the panel members were mostly from outside the U.S., various topics on the U.S. nuclear physics programs were discussed from an international perspective, in addition to general scientific and diversity issues.

2. Premises

The DOE started planning the Comparative Research Review in the fall of 2012. The review took place during five weeks from May 20 through the end of June of 2013 with a week's break in between.

The exercise was a retrospective review of the quality and scientific impact of NP-supported research efforts for the time period January 1, 2010 – April 30, 2013. The review panels did not consider the relative priorities of the different scientific subfields within the NP portfolio in its assessment, only the relative competitiveness of research groups within a given subfield. While technical contributions were a relevant component of the quality and impact of a group's supported research, management of major projects and facilities operations were outside the scope of this review. Research efforts that were not included in this review included the Accelerator R&D Program, the Isotope Program, and the Nuclear Data Program. However, laboratory research funded through SciDAC and theoretical topical collaborations were included.

The panel members were carefully selected. First of all, all the panel members were well recognized in that field and represent an appropriate diversity in expertise. Both experimentalists and theorists were mixed in the same panel, with a larger number of theorists present in the nuclear theory panel and a larger number of experimentalists present in the other panels that reviewed experimental groups. Also, in each panel there was at least one expert in each individual topical field considered in that panel.

In order to avoid conflicts of interest, most of the panel members were selected from abroad, together with an admixture of U.S. physicists who do not receive DOE funding, typically NSF-funded scientists. Nevertheless, it was unavoidable that in a few cases there were conflicts of interest (COI). In such a case, e.g. if a panel member had a direct involvement with a research effort being judged, or for any reason believed that he/she could not objectively judge one or more efforts in comparison to the others, then the member identified himself/herself to the Chair of the Review who discussed it with the DOE Office to determine the extent of the possible COI and what, if any, actions might be appropriate.

Before the review, all individual research groups were asked to submit briefing packages summarizing the research group's activities during the period January 1, 2010 – April 30, 2013. Because of the large number of groups being reviewed, it was necessary to set strict limits on the material to be submitted. The material described

- Current laboratory permanent staff and other members of the group supported by NP research funding;
- Scientific areas being addressed;
- Funding level for the group during the last three fiscal years;
- Narrative description of the scientific motivation underlying the group's research activities;
- Progress during the period under review;
- Plans for the continued progress in the coming 1-2 years;
- Summary table of the research effort in fractional full-time-equivalents (ftes) of each member of the group devoted to various research categories;
- Graduate student tracking information;
- Post-doc tracking information of the group;
- The group bibliography by highlighting prominent papers published in refereed journals and invited talks, for which group members had made a direct and essential leading contribution; and
- Biographical sketch of each Ph.D.-level member of the group excluding post-docs.

Prior to the actual meeting, all submitted briefing packages were uploaded to a website called PeerNet hosted by the Oak Ridge Institute for Science and Education (ORISE) and made available to the panel members. The actual presentation files were distributed to the panel members on site when the presentations were conducted. Before each of the five panel meetings, a telephone conference was held among the panel members, together with staff of the NP Office, to explain and clarify the mission of the panel members and the review.

3. Procedures

The different subfield panels were assigned the following meeting dates:

Nuclear Structure/Nuclear Astrophysics (NSNA): 5/20 – 5/24, 2013
Heavy Ions (HI): 5/28 – 5/31, 2013
Medium Energy (ME): 6/10 – 6/14, 2013
Nuclear Theory (NT): 6/17 – 6/24, 2013
Fundamental Symmetries (FS): 6/25 – 6/28, 2013.

Each panel had about 30-60 groups to evaluate. The evaluation took place in the Washington D.C. area. The programs of all reviews are listed in Appendix II. The allotted times for presentations were: 30 minutes (20 + 10) for groups with 1–2 faculty members, 45 minutes (30 + 15) for groups with 3 faculty members, 60 minutes (40 + 20) for groups with 4 or more faculty members and 75 minutes (50 + 25) for national laboratories.

The Chair's mission was to ensure that a common standard was used by all panels, and that the assessments of the panels were consistent and fair. Yet, this CRR is based on individual scores provided by each panel member.

Each panel had one Co-Chair, who had the responsibility for the technical conduct of the panel session: for keeping the time and ensuring fairness, for leading the discussion periods and ensuring that the discussion was focused on the criteria of the review. For efficiency, the Chair and Co-Chair also assigned discussion leaders for various packages to ensure that discussions were not missing points. All panel members actively participated in the review and read carefully all the packages that were submitted.

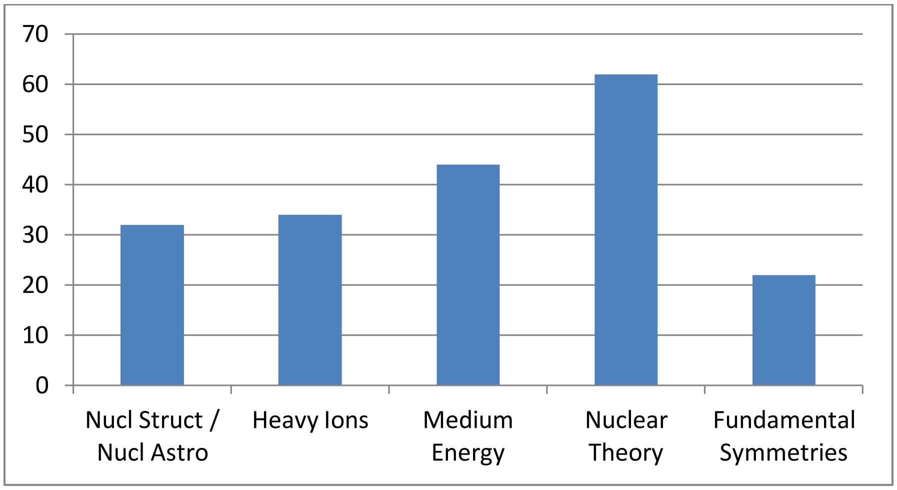


Figure 1: The number of reviewed groups in each subfield panel.

At the end of each day, a summary discussion regarding the reviews of individual presentations was conducted. In order to dynamically assess the progress of the review, daily feedback concerning the scoring was given to the panel members, which helped the discussion and lead to the desired differentiation between groups based on the criteria for the review.

The number of reviewed groups in each subfield panel is shown in Figure 1. The largest subfield was the NT program which contained 62 university and national laboratory groups.

4. Review Criteria

After reviewing the briefing packages, and hearing and discussing presentations, the panel members were asked to score each individual research effort on a scale of 1 (lowest) to 10 (highest) for the following 6 criteria:

1. Significance and merit of the group's research, in the context of present and emerging research directions within nuclear physics.
2. Future prospects for achieving scientific excellence based on the group's past achievements and the vigor and focus of the group members.
3. Scientific productivity of each group, including any specific strengths and weaknesses.
4. Impact of the group's scientific research effort nationally and internationally.
5. Effectiveness of the group in training the next generation of scientists.
6. Particular strengths of each group, such as scientific leadership, technical leadership, development of innovative concepts or instruments, maintenance of unusual skills, or crucial inputs into collaborative efforts.

The panel members were asked to use the full dynamic scoring range available to differentiate between the various groups. In assessing productivity and impact, the panel was also encouraged to roughly normalize according to the resources provided to each group. Thus the "figure of merit" for such metrics should be "d(Physics)/d(dollar)" integrated over the above time period.

In addition, it was highly encouraged by DOE to add written comments, even short ones, to justify or help the NP Office understand why individual panel members scored certain numbers.

Finally, for the purpose of providing an overall score, a three-tranche scheme was employed as part of the assessment. In this scheme, at most 20% of the groups should be rated as “High competitive” and at least 10% should be rated “Low competitive”. The number of groups ending-up in the middle “Mid-range” tranche varied depending on the numbers assigned to the “High” and “Low” tranches. At the end of each panel session all the panel members reviewed whether the subfield portfolio warranted more than 10% of the groups being placed in the “Low” tranche and less than 20% being placed in the “High” tranche. This guidance was, in fact, followed approximately for all the panels.

In addition, panel members were strongly encouraged to complete their assessment by the end of the review week, but were allowed access to PeerNet for an additional period of two weeks following the review, in case further refinements were needed.

5. General Observations

Broad Coverage and Strong Leadership in U.S. Nuclear Physics

The scope of the U.S. nuclear physics program is much broader than in any other country. As stated in the 2007 Nuclear Science Advisory Committee (NSAC) Nuclear Physics Long Range Plan, the program encompasses research on the existence and properties of nuclear matter under extreme conditions, including that which existed at the beginning of the universe, exotic and excited bound states of quarks and gluons, including new tests of the Standard Model, the ultimate limits of existence of bound systems of protons and neutrons, nuclear processes that power astrophysical objects and are of relevance for the origin of the elements in the Universe, the nature and fundamental properties of neutrinos and neutrons and their role in the matter-antimatter asymmetry of the universe. In all of these topics, U.S. nuclear scientists are at the forefront of research worldwide and often define the decisive scientific milestones. This leadership of U.S. nuclear science, as well as the breadth of its research program, has been visible during the entire review process.

Strengths of the Individual Sub-Fields

The field of nuclear structure and nuclear astrophysics has undergone a renaissance since the last review. Experimentally this has been driven by research at radioactive ion (RI) beam facilities like the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU), the Argonne Tandem Linac Accelerator Facility (ATLAS) at Argonne National Laboratory (ANL), the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory (ORNL), and other facilities, and exploiting major new instrumentations such as GRETINA and HELIOS. Utilizing these facilities, this subfield produces world-leading results, in particular expanding the knowledge about nuclei and their properties at the limit of existence.

Research with ultra-relativistic heavy-ion collisions is led by the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) in the U.S. Program. The discovery of the strongly interacting Quark Gluon Plasma behaving as an almost perfect liquid is an outstanding achievement, together with the discovery of jet quenching, the unexpected large suppression of heavy quarks, etc. With the Large Hadron Collider (LHC) now in operation, many groups have distributed their interest to both the LHC (ALICE, ATLAS, CMS) and RHIC programs. RHIC produces significant results and plays a leading role in the entire field.

The Medium Energy program focuses on the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF), supplemented by the RHIC Spin program, some smaller FNAL experiments, and some participation in other facilities outside the U.S. As major achievements in this subfield in recent years, U.S. scientists significantly advanced the knowledge on the quark and gluon structure of the nucleon (and the nucleus) and the origin of its spin.

The theoretical activities in the U.S. are remarkably broad, rich and strong. We observed significant progress in the understanding of nuclei and nuclear matter made possible by formal developments and modeling, supported by significant computational advances both in hardware and software and guided by experimental results. This encompasses the entire field of nuclear physics, ranging from fundamental studies of hadron structure and dynamics, to ab-initio and QCD-inspired descriptions of light nuclei, to novel approaches to nuclear structure and reactions globally applicable to the entire nuclear chart and often of important astrophysical relevance.

Finally, an important aim in the field of fundamental symmetries, such as neutrino-less double beta decay, neutron EDM, Project 8, etc., is precision measurements of quantities probing physics beyond the current Standard Model. Some of these topics still require time to obtain results, and all of them attract a large number of students.

International Usage of Facilities

The radioactive-ion beam facilities of the ATLAS at ANL and the NSCL at MSU, together with the RHIC at BNL, and the CEBAF at TJNAF, provide world-class facilities for the U.S. nuclear physics program. Based on these and planned next generation facilities like Facility for Rare Isotope Beams (FRIB), and the complementary university-based cyclotron laboratories, the U.S. nuclear physics community supports a forefront research program.

Several new facilities outside the U.S. have recently become operational or are under construction. Among these are the RIKEN RI Beam Facility and J-PARC in Asia, FAIR, HIE-ISOLDE, SPIRAL-2, ESS in Europe and the new accelerators at TRIUMF. Furthermore, the relativistic heavy-ion program at the CERN experiments (ALICE, ATLAS, and CMS) will further benefit from the LHC energy increase and the planned upgrade program.

International usages of these facilities will have to be considered to optimize the U.S. nuclear science program.

Strength of National Labs and Synergy Effects

Several panel members were impressed by the strength of research efforts at the national laboratories (ANL, BNL, TJNAF, Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), Lawrence Berkeley National Laboratory (LBNL), ORNL). Even those laboratories without a large accelerator play a major role for the nuclear physics community by providing computer resources, major detector laboratories, technical staff or other relevant infrastructures. The strong involvement of university groups, in particular at top institutions, is mandatory to attract bright students into the field and to provide well-trained students. The panel also notes close collaborations of scientists at national laboratories and universities in research, as well as detector design and construction, computer simulations, preparation of materials. This very positive synergy effect between groups at the national laboratories and universities strongly contributes to the success of nuclear science in the U.S.

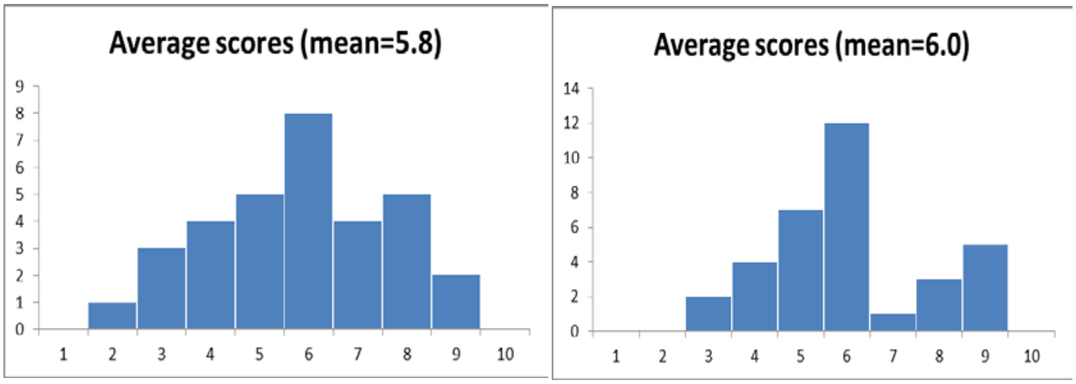
Joint Positions and Positions at the Top-Level Universities

The panel observed that the research strength in the U.S. is leveraged by the joint appointment system between national labs and universities. A typical example is TJNAF, which provides positions at many surrounding universities to support their faculties and students. In this way, both the neighboring universities and the laboratory benefit from the leveraged research efforts. The RIKEN-BNL Research Center is another strong example, serving as a doorway for junior researchers that obtained later high-level positions at universities all over the world.

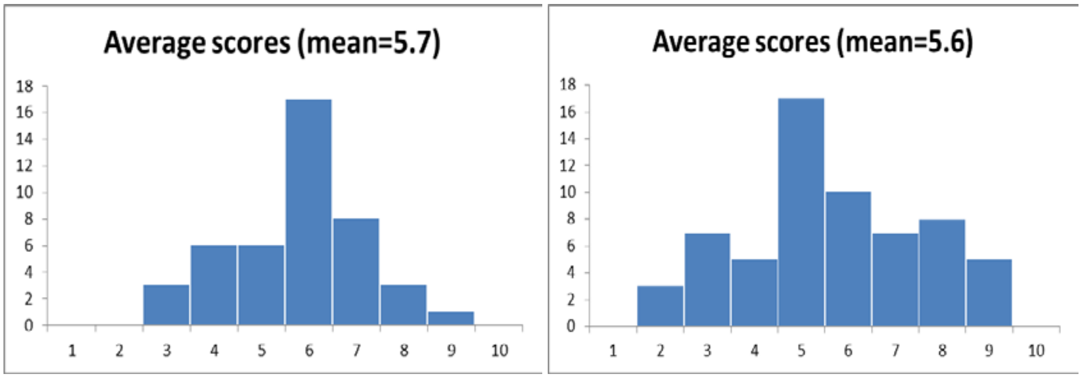
While this joint appointment system is a success, the panel also noted that top-level universities are gradually losing nuclear physics faculty positions. Some panel members expressed strong concerns on this point.

6. Statistics

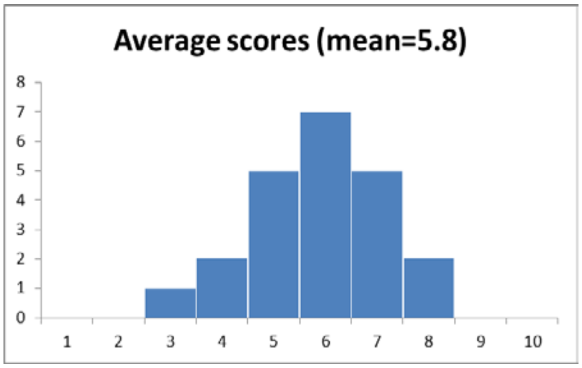
The scoring was performed based on the process described under Section 4 above. Every day after the session the panels examined the scoring for each of the review criteria. Also, the panels examined and discussed the strength and weakness of individual groups on a daily basis. In the morning of the next day, the panel examined the scoring distributions and



Nuclear Structure/Nuclear Astrophysics Heavy Ions



Medium Energy Nuclear Theory



Fundamental Symmetries

Figure 2: Score distributions for the five different panels.

discussed any large deviations. This ensured that the entire score distributions was balanced and well justified. The scoring scale ranged from 1 (lowest) to 10 (highest). Below are the score distributions for each panel. The average is 5.6 - 6.0 and the distribution is slightly narrower for “Medium Energy” and “Fundamental Symmetries”. For “Heavy Ions” the distribution has two peak structures. Nevertheless, the average score is very similar for all panels.

7. Individual Panel Summaries

Each panel summary statements resulted from the activities developed in each separate panel.

Nuclear Structure and Nuclear Astrophysics

Overview

In the last two decades, the field of nuclear structure and nuclear astrophysics has undergone a renaissance, thanks to the availability of radioactive ion beams (RIB). Nuclear structure can now be probed at the extremes of the N-Z plane, enabling precision studies of phenomena such as halo nuclei, appearance of new magic numbers, shape-coexistence, isospin dependence of the nuclear force, etc. Nuclear astrophysics has also immensely benefitted from the new era of RI beams. The nuclear reactions that take place in novae as well as in the primordial universe immediately after the Big Bang can now be studied at the relevant energies. As mentioned in Section 5, many U.S. groups have been in the vanguard of this effort, exploiting the complementary facilities NSCL at MSU, ATLAS at ANL, and HRIBF at ORNL, and exploiting major advances in instrumentation such as GRETINA and HELIOS.

The provision of stable beams has also enabled many important discoveries at the ATLAS at ANL and 88" Cyclotron at LBNL and, thanks to the world-leading gamma-ray spectrometer GAMMASPHERE and the recoil separators FMA and BGS. These instruments have proved crucial for studies of high-spin phenomena and exotic and super-heavy nuclear systems. The Centers of Excellence at Texas A&M University (TAMU), Triangle University Nuclear Laboratory (TUNL) and A. W. Wright Nuclear Structure Laboratory (WNSL) at Yale University have provided outstanding opportunities in nuclear structure and nuclear astrophysics research, while training a large number of graduate and undergraduate students.

The panel was impressed by the high quality of many of the groups. This includes the national laboratories as well as university-based groups, where the latter sometimes consists of only one or two staff persons. Many of the university and laboratory groups have recently hired excellent junior new faculty and staff members, respectively. It was especially encouraging that several of these new faculties gave outstanding presentations to the panel.

Nuclear structure and nuclear astrophysics are experiment-based sciences that have made major advances because of the strong synergy between experiment and theory: the panel observed many cases where experiments were performed in order to test nuclear theory. The panel also noted that the experimental program is providing excellent hands-on experience for the future generation of scientists. In this respect, most groups are able to play this very important role in preparing the next generation of nuclear scientists, although the number of students, relative to staff, was surprisingly variable.

Highlights

- The low-energy community has developed a suite of state-of-the-art instrumentation to best address important questions about nuclear structure and the production of nuclei in stellar environments. The panel noted a number of areas where DOE-supported groups have made outstanding contributions:
- Studies of neutron-rich nuclei in order to probe the nucleon-nucleon interaction, using HELIOS (unique world-wide) and GRETINA;
- Precision measurements of electromagnetic transition rates in light nuclei that provide stringent tests of ab-initio theory, thanks to the strong collaboration with theorists;
- Measurements of single-particle structure near the exotic doubly-magic nuclei ^{100}Sn and ^{132}Sn, using α-decay with stable beams and direct transfer reactions with RIB respectively;
- Discovery of a new region of collectivity around $N{\sim}40$ and $Z \leq 26$;
- Measurement of the 2^+ Hoyle state in ^{12}C that plays a central role in understanding the cluster structure of the 0^+ Hoyle state;
- Advances in making measurements of the astrophysically important $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ reaction, by applying bubble chamber techniques in inverse kinematics;
- Advances in the application of indirect methods to measure key reaction rates in nuclear astrophysics. Most of the nuclear reactions relevant for nova nucleosynthesis are now based on experimental information. We are beginning to achieve a similar result for models of X-ray bursts and core-collapse supernova;
- Precision measurements of nuclear masses for most of the nuclei relevant for the rp-process. Such measurements are starting to approach the r-process nuclei in the region around $N \sim 82$.

Opportunities

The opportunities to realize new discoveries in the fields of nuclear structure and astrophysics will greatly expand with the decision to build the next generation radioactive beam facility, the Facility for Rare Isotope Beams (FRIB). On the path to FRIB, major opportunities are presented by the planned and proposed upgrades to the ATLAS facility for stable-beam and in-flight RIB physics, and the new post-accelerated facilities after CARIBU and at ReA3, that should come fully online during the next years. The CARIBU facility at ATLAS has already shown its potential in the provision of extremely neutron-rich fission fragments for mass measurements. At NSCL, the NSF-supported ReA3 will provide a wide range of radionuclides produced by fragmentation, giving opportunities for nuclear structure studies using Coulomb excitation and transfer reactions, and allowing studies of key astrophysical reactions near stellar energies. Both these post-accelerators use advanced gas-stopping techniques that remove some of the disadvantages of the traditional ISOL method. Other radioactive beam facilities are also being constructed for niche applications at TAMU and the NSF-supported Florida State University (FSU).

The planned upgrades to both LENA and the HIγS photon facility at TUNL will ensure that the U.S. has competitive, if not leading capabilities, for studies of certain classes of astrophysical reactions. The former will allow hydrostatic reactions of very small cross sections to be probed with very high-intensity low energy stable beams, while the latter provides an innovative photon probe for understanding thermonuclear reactions and the impact of three-body forces in the structure of light nuclei.

Concerns

The recent closings of the WNSL at Yale University and the HRIBF nuclear structure facilities at ORNL will have consequences for the field. In particular, the closure of the ISOL facility HRIBF means that unique opportunities for nuclear structure and nuclear astrophysics studies have been lost. While CARIBU and ReA3 will eventually recover some of this loss, these facilities will take some years to reach their design performance.

The panel observed, however, the dynamics of the affected groups in effectively re-orienting their research programs, including the cutting-edge detector technologies that they have developed, towards activities in other laboratories in the U.S. and elsewhere. The panel noted that there are only a few groups not prepared for the near- and longer-term opportunities offered by the emerging facilities. It has particular concern for those groups led by senior scientists in institutions that have no apparent plans to appoint replacement staff, especially where the group has specialized skills that may not be handed down to the next generation.

International Perspectives

The U.S. program in nuclear structure and nuclear astrophysics is very competitive world-wide, and in some areas world-leading. The new RIB facilities CARIBU and ReA3 have a window of opportunity before HIE-ISOLDE becomes operational in ~ 2015 and ARIEL and SPIRAL-2 later in this decade. ReA3 and CARIBU will be unrivalled for the provision of refractory element beams of spectroscopic quality. GAMMASPHERE will remain the γ-ray spectrometer of choice for many applications, world-wide. The high-resolution tracking spectrometers GRETINA and the early-implementation of AGATA have similar capabilities to each other. However, the solid-angle coverage of both of these tracking arrays means that they perhaps can only be fully exploited at in-flight facilities. The U.S. groups have made and will make good use of the fast radioactive beams at NSCL, and are preparing to exploit the facility at RIBF (RIKEN); competition from FAIR is planned to come at the end of this decade, at the earliest. In the area of nuclear astrophysics, the LENA and HIγS facilities will remain highly competitive. The U.S. groups also have well-established collaborations with ISAC (TRIUMF).

Relativistic Heavy Ions

Overview

After the discovery phase at RHIC, the field of relativistic heavy-ion (HI) collisions is now focusing on precision measurements to characterize the properties of the strongly interacting Quark Gluon Plasma (sQGP). The field benefits from the unprecedented opportunities offered by five large experiments operating at two outstanding facilities and copiously producing high quality results (the PHENIX and STAR experiments at RHIC and the ALICE, ATLAS and CMS experiments at the LHC). The complementarity of these two facilities, combining the flexibility of RHIC with the energy frontier of the LHC, and the precision measurements foreseen in the near term, ensure productive and exciting research in the next decade with profound insights into the properties of the sQGP.

The U.S. groups involved in HI collisions play a leading role in forging the research program in this area. During the period of this review, the productivity and vitality of the U.S. groups, measured in terms of publications, PhD theses and new faculty positions, are outstanding. Given the short-term perspectives and opportunities there is every reason to believe that these high standards will be maintained in the next few years.

Highlights

- In the decade preceding the period of this review, experiments carried out at RHIC made significant discoveries that brought profound paradigm changes in our concept of the Quark Gluon Plasma (QGP). Instead of the expected gas of free quarks and gluons, the QGP was found to be strongly interacting, behaving as an almost perfect liquid with the lowest shear viscosity to entropy density ratio (η/s) ever measured and approaching the conjectured quantum limit derived in the framework of AdS/CFT. This synergy between experimental HI physics and string theory is one of the totally unexpected and remarkable developments of the RHIC program.
- Among the prominent results obtained at RHIC in that period are the large elliptic flow of particles with values close the ideal hydrodynamic limit, the jet quenching, (first discovered in the suppression of high p_T particles, further studied in two-particle correlations and being precisely characterized now using fully reconstructed jets) and the unexpected large suppression of heavy quarks.
- The study of cold nuclear matter effects, using d+Au and p+Pb collisions at RHIC and LHC, respectively, necessary for a quantitative understanding of the nucleus-nucleus collisions, is becoming a topic of great interest in its own right. Surprising results were recently reported raising the question of whether p,d+A are the proper reference to study cold nuclear matter effects.
- The period of the review coincides with the beginning of QGP exploration at the new energy frontier opened with the start of LHC operations in 2010. In two one-month long runs in 2010 and 2011, ALICE, ATLAS and CMS produced an unprecedented wealth of high quality results, confirming the main paradigms established at RHIC and substantially increasing the research scope in terms of p_T reach and new observables.
- At the same time, RHIC continued to produce outstanding results: first insights into the plasma temperature derived from the measurements of direct photons, first measurements of low-mass dileptons, first hints of Color Glass Condensate as doorway state toward the formation of the QGP in AA collisions, first results from the BES (Beam Energy Scan) in the quest for a possible critical point in the phase diagram of nuclear matter.
- The current emphasis in heavy ion physics is on precise measurements to characterize the properties of the sQGP. Sometimes, it is necessary to perform the same measurement at the energy regimes of the two facilities to answer specific questions or to scrutinize or constraint theoretical models. For example, is the fluid perfection the same at RHIC and LHC? Or in other words is the η/s ratio (that characterizes the sQGP as a perfect fluid) the same at RHIC and LHC? Initial conditions are presently limiting the accuracy in the determination of this quantity. Combining the elliptic flow results with the higher order flow harmonics is expected to provide tighter constraints in the determination of η/s.
- Another example is the determination of the Debye screening length through the measurement of J/ψ suppression that remains elusive due to competing mechanisms. It is only the systematic study of charmonia and bottomonia states over a large energy range

and several collision species that will allow one to disentangle the melting of the resonances in the plasma from recombination, cold nuclear matter, or other competing effects.

Opportunities

The field benefits from the flexibility of RHIC (with its unique capabilities of accelerating practically all species, from p up to U, including asymmetric systems like Cu+Au, over a broad energy range from the top energy of $\sqrt{s_{NN}}$ = 200 GeV down to 7 GeV). In addition, the LHC opened new horizons with new observables that became easily accessible with the 14-fold increase in energy. This complementarity of RHIC and LHC creates unique circumstances and offer unprecedented opportunities of progress in the next decade.

During the period of this review, the productivity and vitality of the U.S. groups, measured in terms of publications, PhD theses and new faculty positions, are outstanding. STAR and PHENIX have published a total of 75 papers in the refereed literature, including 20 papers published in PRL. ALICE, ATLAS and CMS have similar numbers, a total of 78 HI related papers including 24 published in PRL. In the vast majority of these papers there is a leading or very strong contribution from U.S. groups. A total of 56 students completed their PhD thesis and about a dozen of junior scientists got a tenured position, within the HI program at U.S. Universities or national labs during the period of this review.

The panel was impressed by the quality of the 28 university groups and 6 national lab groups that were reviewed. The panel identified 8 groups of outstanding quality with clear scientific leadership and in most cases also with exceptionally strong infrastructure and hardware capabilities. Their scores do not follow the regular distribution as a tail above the average score but rather they form a separate cluster, giving rise to the two peak structure seen in the score distribution. The two groups at BNL have a unique and special role. They take the bulk responsibility to ensure smooth operation and maintenance of the PHENIX and STAR detectors. They have been very successful in these tasks in addition to a strong participation in data analyses.

Since the beginning of the RHIC program, a series of upgrades of both the PHENIX and STAR detectors, mostly aimed at answering questions raised by the ongoing research, together with machine upgrades to attain higher luminosities, have been essential in achieving progress. A similar pattern of detector and machine upgrades has now started at the LHC. Given the scientific questions to be answered, together with the ongoing and proposed upgrades of the detectors, there is every reason to believe that the present level of productivity and impact will be maintained or even increased in the next years.

Concerns

A premature cessation of RHIC operations, that could be imposed, not on scientific grounds, but as a result of the U.S. economic climate, is by far the main concern and will have irreversible devastating consequences for the entire field.

International perspectives

The U.S. university groups and national labs involved in HI physics played and are playing, a leading role in shaping the HI research program worldwide, both at RHIC and the LHC. They have a very strong standing in the HI international community providing scientific and intellectual leadership. They are leading not only the PHENIX and STAR experiments, but also the ATLAS and CMS HI programs. In ALICE, U.S. groups have had a very significant impact on the first data analyses and are among the leading groups in the experiment.

Medium Energy

Overview

Physics has been very successful in identifying the fundamental building blocks of nature. At the first level of complexity, when these building blocks join to form real-world particles, our understanding already falters. After the Higgs confirmation at CERN, the non-perturbative sector of QCD is the last fundamental puzzle of the Standard Model. The study of particles composed of quarks and antiquarks and their governing properties and forces are at the core of the medium energy physics program. Experimental strategies addressing this rely world-wide on six major facilities, CEBAF/TJNAF, BNL/RHIC, BES, J-PARC, KEK and, in the intermediate future, FAIR. To achieve an understanding and a quantitative description here is the big challenge for physics in the years to come.

The basic underlying interaction between quarks can be described successfully in the perturbative regime by the field theory Quantum Chromodynamics (QCD), but this description starts to fail when the distance among quarks becomes comparable to the size of the nucleon, the characteristic dimension of our microscopic world. In the evolution of the universe, some microseconds after the Big Bang, a coalescence of quarks to hadrons occurred which was associated with the generation of mass. The elementary light quarks, the so-called up and down quarks that make up the nucleon, have very small masses that amount to only a few percent of the total mass of the nucleon. Most of the nucleon mass, and therefore of the visible universe, comes from the QCD interaction itself. This generation of mass is associated with the confinement of quarks and the spontaneous breaking of chiral symmetry, one of the fundamental symmetries of QCD in the limit of massless quarks. The composition of nucleons from quarks and gluons has been a puzzle for the past several decades and tremendous efforts world-wide have been made to try to solve it.

While high-energy physics tries to understand the fundamental aspects of nature by pushing the energy frontier, medium energy nuclear physics concentrates on the precision frontier. The experimental research programs cover a broad field, ranging from the search for exotic forms of matter, such as glueballs or hybrids, to studies of the quark and gluon structure functions obtained in polarized deep inelastic scattering; from meson and baryon spectroscopy to short-range correlations in nuclei to tests of the electro-weak Standard Model. Progress in understanding the strong interaction will have an impact on astrophysical questions, e.g. the physics of neutron stars. The detector technology developed for hadron research paves the way for research beyond the Standard Model, for example the new approaches to the electric dipole moment of the nucleon or dark matter searches.

Highlights

- Important constraints on Δg (the gluon contribution to the nuclear spin) from inclusive polarized pp scattering have been achieved at RHIC.
- The completely unexpected drop of the proton's electric form factor (GEP) with increasing momentum transfer as observed in recoil polarization measurements at TJNAF. This result has started a "cottage industry" of experiments to test the contribution of two-photon exchange radiative corrections to the previous Rosenbluth extractions of GEP which did not show this trend. This discovery contradicts assertions which have been in the textbooks for almost 50 years.
- New data on the anti-quark contribution to the proton spin (Δu-bar, Δd-bar) have arisen from W production in polarized pp scattering at RHIC.
- Precision measurement of the neutral pion decay rate in the PRIMEX experiment at TJNAF, confirming the validity of the chiral anomaly.
- An intriguing similarity has emerged from the comparison of deep inelastic scattering from nuclei (the so-called EMC effect) with ratios of high Bjorken x nuclear structure functions at TJNAF. These data appears to highlight the importance of the local density of nuclei in defining their short-distance structure.
- Important constraints have emerged on the possible contributions from strange quarks to the nucleon's electromagnetic structure through parity violating electron scattering at TJNAF.
- At TRIUMF, achievement of an order of magnitude reduction in the uncertainties for the Michel parameters in muon decay, which play a key role in determining the structure of the Electroweak currents.

Opportunities

The plans for future activity presented by the groups are most impressive and should produce results of comparable importance to what has been achieved in the past 5 years. Particularly noteworthy are the following:

- Major expected improvements in our knowledge of the gluon and sea quark polarizations.
- Expected improvements in our knowledge of the spectra of excited hadrons, leading eventually to tests of non-perturbative QCD which underpins lattice calculations of the spectra.
- Measurement of the nucleon polarized structure functions g_1 and g_2 over an enlarged range of Bjorken x, allowing tests of both chiral perturbation theory and perturbative QCD.
- Improvements in our knowledge of the generalized parton distributions, allowing tests of the angular momentum sum rules.
- Participation in the Fermilab Sea Quest experiment and possibly in the development of a polarized beam at Fermilab, with the potential to test crucial predictions in QCD concerning Drell-Yan reactions.
- The search for an electric dipole moment of the neutron and the proton points to physics beyond the Standard Model. Many theories have not survived the improved upper limits for the EDM that have been achieved in the last decades.
- Possible future experiments at TJNAF on parity violating deep inelastic scattering and Moeller scatter which could provide key constraints on physics beyond the electroweak Standard Model.
- Finally, there are important investigations such as DARKLIGHT or Qweak that make full use of the existing facilities and might hint at physics beyond the Standard Model.

Some more general remarks on the interaction between university research groups and the national laboratories: The national labs play an essential role in the success of medium physics (MEP) in the U.S. TJNAF and BNL MEP research groups provide a critical interface with the university user groups. In addition to providing important technical resources (e.g. maintaining the spectrometers at TJNAF and measuring the proton beam polarization at RHIC), these groups are also intellectual leaders on many of the experiments. Those national labs that are not directly associated with a facility provide major infrastructure resources to guide large experiments from construction to completion. The second key factor in this successful program is the university groups. Many of the larger universities also provide important infrastructure in terms of key detectors and components. It is the DOE support not only to these groups, but also sometimes to smaller groups, which often fosters new important developments that play a crucial role in future experiments. The university groups have a major influence in the planning and running of experiments and in providing scientific leadership and spokespersons for the experiments. It is the universities that provide the "new blood" in the form of graduate and undergraduate students. Some institutions only have undergraduate programs, often for minority students. It is important that these groups can participate in fore-front research by being supported by DOE grants.

Concerns

The groups reviewed are highly professional and focused on research at domestic facilities. Given the complexity of the field, the groups should consider increased international collaboration abroad as a means to optimize the U.S. program.

International Perspectives

Medium energy physics has become a center of focus across Asia and Europe, where major investments in facilities have been done recently or are underway. The U.S. medium energy community currently, and in near future, have excellent national labs allowing groups to do world-class forefront research. Also, BNL and TJNAF attract international researchers from other countries to participate in attractive experimental programs.

Nuclear Theory

Overview

During the last two decades there has been impressive progress in nuclear theory due to novel and refined models and to computational advances both in hardware and software, with key guidance from experimental findings. This progress encompasses the entire field of nuclear physics, ranging from fundamental studies of hadron structure and dynamics, to ab-initio and QCD-inspired descriptions of light nuclei, to novel approaches to nuclear structure and reactions globally applicable to the entire nuclear chart, to deep insight into the behavior of dense and hot nuclear matter produced in ultra-relativistic heavy-ion collisions and into the origin of the elements in the Universe in a combined effort of nuclear and astrophysics. With strong support by DOE, the U.S. nuclear theory community has contributed significantly and often decisively to these advances. It impresses by its broad scientific scope as well as by the high quality of most of its individual groups.

Nuclear theory research is intimately related to the experimental efforts and programs at the current and future U.S. flagship facilities TJNAF, RHIC and NSCL/FRIB. The progress achieved in all facets of nuclear physics reflects the close and intertwining relation between experiment and theory and is made possible by strong theoretical efforts in groups at the ANL, BNL, TJNAF, LANL, LBNL, and ORNL national laboratories and at many universities. The involvement of strong university groups, in particular at top institutions, is mandatory to attract bright students to nuclear topics. The panel emphasizes that a prerequisite for the success in the field is the education of well- trained students at the universities. They are the basis for the next generation of nuclear scientists who can help address important U.S. societal concerns.

Many advances in nuclear theory and its applications require the availability of large-scale computational resources. Here the SciDAC initiative has played a crucial and innovative role by stimulating close collaborations between nuclear researchers, computational scientists and applied mathematicians. This has enabled the optimal use of high-performance computing and has been the basis of much of the achieved progress, not only in nuclear theory, but in related fields such as nuclear astrophysics.

The panel has been broadly impressed not only by the overall strength and quality of DOE-supported nuclear theory, but also by the fact that some of these efforts come from small university groups where the scientific output per dollar invested is often maximized.

Highlights

As noted above, the U.S. nuclear theory community has achieved significant progress in all facets of the field, often leading the world-wide efforts. The panel has noted in particular the following highlights:

- **Dramatic advances in lattice QCD (LQCD) physics, including improved actions and algorithms.** This has allowed ab-initio investigations of many nucleon properties, such as the origin of the nucleon's spin. More recently, the first calculations are being made of multi-baryon interactions on the lattice. The LQCD efforts have also led to improved understanding of the QCD phase boundary in the search for measures of criticality.
- **Descriptions of the structure of hadrons in terms of QCD degrees of freedom as probed in high energy scattering processes.** Understandings of geometrical aspects of partonic structure and flavor dependence of electromagnetic form factors, for a large variety of high energy scattering processes have developed considerably. This has been driven by developments in LQCD, continuum QCD models, and their interaction.
- **Derivation of nucleon-nucleon (2N) and three-nucleon (3N) interactions respecting QCD symmetries, together with the development and application of microscopic many-body models to nuclear structure and reactions**. Green's Function Monte Carlo studies have demonstrated the importance of 3N interactions for the accurate description of structure and transition strengths in light nuclei up to mass 12. Exploiting 2N and 3N interactions, consistently and systematically derived within Effective Field Theory, ab-

initio calculations performed within the coupled-cluster and no-core shell model approaches have become possible for medium-mass nuclei. Promising attempts are being made to derive a Density Functional that is inspired by QCD symmetries and is applicable across the entire nuclear chart.

- **Studies of the dynamics and associated nucleosynthesis of astrophysical objects, consistently combining realistic multi-dimensional simulations with state-of-the-art nuclear microphysics.** Tremendously increased computational resources enabled multi-dimensional codes to simulate core-collapse and thermonuclear supernovae, novae and x-ray bursters. Improved nuclear physics input proved important in supernovae simulations. The theoretical understanding of the rp-process has benefited from crucial experimental input and improved simulations. Such improved simulations for the astrophysical r-process have pointed to deficiencies of the suggested astrophysical sites, and decisive progress is expected once the next-generation RIB facilities such as FRIB allow many nuclei on the r-process path to be produced and their properties measured.
- **Exploration of the QCD phase diagram at finite temperature and/or baryon density.** Important insights into the properties of the Quark Gluon Plasma (QGP) have been obtained by developing novel models to investigate the structure of the initial state of the nuclear collision via analysis of final-state flow fluctuations. This is similar to progress in understanding the structure of the early universe via correlation analysis of the Cosmic Microwave Background radiation. Important new results were also obtained for understanding the energy loss of (heavy) quarks in a hot QGP and for how the rapid thermalization observed in experiment can be understood theoretically. Finally, impressive progress has been made in the simultaneous understanding of transport properties in the hottest and coldest strongly correlated matter: the QGP and cold atomic gases, respectively, studied in the laboratory.
- **Promising progress in describing the structure and properties of neutron stars.** Constraints of dense nuclear matter from laboratory experiments together with astronomical observations on the cooling of neutron stars and the discovery of neutron stars with masses in excess of 2 solar masses has led to an improved understanding and stringent constraints on these compact objects, including their mass-radius relation, the nuclear Equation of State at high densities and neutron superfluidity.
- **Refined computations with relevance to fundamental symmetries in nature and neutrino properties.** Calculations have been performed for a precision estimate of the muon g-factor, including improved treatment of the pion polarizabilty. Studies of nuclear theory at the interfaces to high-energy physics and cosmology aim at the understanding of electroweak baryo-genesis and the matter-antimatter asymmetry in the Universe.

Opportunities

The basis of progress in nuclear science is a close collaboration between experiment and theory, and DOE has optimized the output from forefront large-scale experimental facilities by establishing leading theory efforts at the facility and at nearby universities. RHIC has been an outstanding example. In parallel with the construction of the Relativistic Heavy Ion Collider, world-leading theory groups have been established at BNL and other national laboratories, at the RIKEN/BNL Center (with Japanese funding), and at universities such as Columbia, Duke, MIT, Ohio State, Stony Brook and others. This DOE strategy paid off in the numerous discoveries and new insights into the behavior of dense and hot nuclear matter drawn from RHIC, and more recently, LHC experiments. The same strategy has been applied to TJNAF and will help guarantee that experimental results made possible by the 12 GeV CEBAF Upgrade will be optimally exploited. Recently most national laboratories have added very talented junior researchers to their staff, which the panel views as an important step to secure the theory strength in the U.S.

The decision to build the next generation radioactive beam facility, FRIB, offers many new opportunities in nuclear structure and reaction physics, nuclear astrophysics, and nuclear applications. These opportunities could be maximized, following the RHIC example, by establishing an associated world-leading theory effort. These measures can build on the exciting low-energy nuclear theory renaissance the panel witnessed in the contributions of several theory groups from national laboratories and universities.

Theory research in fundamental symmetries and neutrino physics involves much less workforce, but is of high quality and considerable potential. This field is expected to gain further importance and momentum once the Amherst Center for Fundamental Interactions is established and fully operational.

Concerns

Currently DOE support guarantees successful and leading theory efforts in all four pillars of nuclear science. The panel views it as decisive that this overall strength has to be kept. However, there is concern how the future of RHIC might affect this balance. The DOE support for the theory efforts in hot and dense matter physics are the backbones of the entire field worldwide. Specifically in the unwise case of downscaled activities at RHIC, potential impact on the related theoretical effort must be avoided by all means. The panel has expressed concern that efforts in nuclear reaction theory at energies relevant for FRIB are not optimized and should be strengthened. To optimize the large DOE investment in lattice QCD, less competitive small-scale efforts may need to be curtailed within the LQCD collaboration.

During the review panel some concern was raised regarding the future perspectives of the theory effort at some top universities in the case that no recruitment of junior faculty members occurs soon.

International Perspectives

The theory activities are overall of high quality in all 4 pillars of the DOE-supported nuclear sciences. In all areas they are competitive world-wide, and often they are world-leading. It is conceivable that the international competition will grow as several next-generation experimental infrastructures have recently become operational outside of the U.S. or are in the construction phase. These include the ultra-relativistic heavy-ion program at the Large Hadron Collider at CERN, the hadron physics activities at J-PARC in Japan, at BESIII in China, and the nuclear structure opportunities at the radioactive ion-beam facility RIBF at RIKEN in Japan. In the midterm future, FAIR, the Facility for Antiproton and Ion Research, which is currently under construction in Germany, will allow a cutting edge physics program in nuclear structure and astrophysics, hadron physics, compressed baryonic matter, atomic and plasma physics and applications in material sciences and biophysics. New RIB facilities are under construction in Canada, France, and Asia. With the wider spread of world-leading experimental facilities, international networking will become more important in the future. As a first step, DOE has created exchange programs for nuclear theorists with selected countries. These programs should be expanded and include joint graduate education with international partners.

Fundamental Symmetries

Fundamental Symmetries (FS) research covered in this review includes topics that are characterized by important discoveries in the recent past, the foremost being the discovery of neutrino mass and mixing through oscillation experiments on solar and reactor neutrinos (SNO, KamLAND, the high energy physics (HEP) experiment - Daya Bay).

The DOE Fundamental Symmetries program is world-class research that has the potential for additional discoveries of far reaching consequence. The non-zero neutrino mass motivates experimental searches for neutrinoless double beta decay, a topic well represented among the research groups reviewed here. Neutrinoless double beta decay is the only viable window to lepton number violation; its discovery would provide a needed ingredient for Leptogenesis, a leading candidate explanation for the matter-antimatter asymmetry of the universe.

With new facilities and methods, experiments on the neutron and nuclear electric dipole moment (EDM) are poised to achieve major breakthroughs in sensitivity to CP violation. The Standard Model predicts very small CP-violating EDM’s. With the existence of non-baryonic dark matter and other evidence for physics beyond the Standard Model, the EDM experiments could reveal a new source of CP violation. A number of theories suggest that an observation may be close at hand. Discovery of a new CP violation would be a window to new physics and more direct baryogenesis.

Observation of neutrino-less double beta decay or a non-zero EDM would be fundamental discoveries of transformational importance. The FS program focuses on a deeper understanding of neutrinos and fundamental interactions that govern our universe. Measurements include a new probe of neutrino mass in ^{3}H beta decay with KATRIN, searches for sterile neutrinos, measurements of the neutron lifetime, and angular correlations in neutron and nuclear beta decay that probe new interactions at the TeV mass scale, and parity violation in nuclei.

Overview

Overall, the FS research activities are diverse, yet well directed toward the priorities of the Nuclear Physics program. All groups in the comparison are excellent and perform admirably. The balance of large to small groups and of national labs to universities is good. The program has attracted excellent faculty, postdocs, and students; junior scientists have excellent career opportunities and relatively good job prospects in a growing field with exciting opportunities. The emphasis placed on training the next generation of scientists is commendable, with junior researchers exposed to a broad variety of methodologies, analyses, and interdisciplinary experimental techniques. The number of women may be lower than the overall average in the field of nuclear physics. The excellence of all the groups, in combination with the very diverse nature of the portfolio, made ranking them very challenging. Although the panel was charged for the scores to span the full range it felt strongly that all groups have been effective in producing important science and are worthy of future support.

Comments on Specific Research Topics

1. Neutrino physics

The FS program supports major projects that address the most pressing questions in neutrino physics: What is the absolute scale of neutrino mass? Are the neutrinos Dirac or Majorana? Do sterile neutrinos exist? While other subfields such as HEP are also engaged in neutrino physics, NP is the steward within the Office of Science for neutrinoless double beta decay.

Within the subfield of neutrino physics, the NP portfolio is nearly entirely focused on long-term projects (Majorana, CUORE, SNO+, Katrin, Project-8). There are a few past experiments with limited data sets (SNO, KamLAND and MiniBooNE), and the HEP-supported EXO is the only currently running experiment. The lack of running experiments poses a serious problem for physics productivity that can lead to a real issue as junior scientists come up for tenure. If possible, it would be desirable to avoid “dry spells” like this in the future by staggering projects.

Neutrinoless Double Beta Decay: Recent progress made by the double beta decay experiments is impressive. In the coming decade we can expect limits (or measurements) at the sub-100 meV mass level using 3 different isotopes: ^{76}Ge (Majorana Demonstrator), ^{130}Te (CUORE, SNO+), and ^{136}Xe (EXO-200, KamLAND-Zen). The sensitivity of the first phase of these on-going experiments is adequate to test the validity of the evidence for neutrinoless double beta decay in ^{76}Ge claimed by the Klapdor-Kleingrothaus collaboration. The GERDA collaboration recently published their Phase I data on ^{76}Ge that show no evidence for neutrinoless double beta decay; the limits strongly disfavor the claim of Klapdor-Kleingrothaus. These experiments will also test low-background methods necessary for future ton-scale experiments that aim to probe the inverted hierarchy 15-50 meV mass scale. The relatively large number of experiments reflects innovative approaches. However, the challenging background requirements and the high cost of future detectors make it mandatory to continue to review and maintain a measured long-range plan that will lead to success.

2. Electric Dipole Moments

The question of fundamental particle electric dipole moments is amongst the most compelling in all of physics. New experiments on the neutron and on Hg, Ra, Rn could achieve improved sensitivity by factors of 100 over the next decade. In particular, a measurement with sensitivity at the anticipated reach of the US nEDM experiment ($\sim 4 \times 10^{-28}$ e-cm) would have a profound impact on nuclear physics, particle physics and cosmology, even in the event of a negative result.

nEDM: The nEDM experiment would take advantage of the intense source of neutrons that will be available at the NP Fundamental Neutron Physics Beamline (FNPB) of the SNS facility in the Oak Ridge National Laboratory. With innovative techniques to control systematic effects, including the use of polarized ^{3}He as a co-magnetometer, the experiment aims to achieve a sensitivity that is 60 times better than the present limit. The experiment is currently in a pre-R&D phase to demonstrate the feasibility of meeting outstanding technical challenges. A Technical Review Panel regularly monitors progress and recently noted “impressive progress on the technical hurtles.” Nevertheless, our panel was concerned that the technical challenges and the relative high cost may stretch out the schedule, making it difficult to be competitive with other groups. A small-scale version of the experiment aimed at demonstrating integrated technical readiness of all parts of detector could avoid major problems and delays

Nuclear EDM: The ^{199}Hg EDM experiment provides one of the most stringent bounds on new sources of CP violation. The next data runs are aimed at improving the current upper limit of 3.1 x 10^{-29} e-cm by factor of 3-5. Proposed experiments on ^{225}Ra and ^{221,223}Rn will exploit nuclear enhancements that arise from the existence of nearby opposite parity states, owing to nuclear octupole deformation. The enhancement of ^{225}Ra is expected to be of the order of 100-1000 relative to ^{199}Hg. Laser trapping of radium atoms has been demonstrated, and the first phase of the ^{225}Ra EDM experiment is expected to reach a sensitivity of 10^{-26} e-cm, comparable to ^{199}Hg, after allowing for enhancement. A second phase could achieve ~ 30 times higher sensitivity. Similar parity doublet enhancement is expected in the radon isotopes, and on-going nuclear structure experiments are making progress towards quantifying it.

3. Beta Decay

Neutron Beta Decay: The study of neutron decay provides important constraints on the couplings of weak currents to the nucleon. Precise measurements are important to astrophysics, where uncertainties on the axial-vector coupling G_A influence predictions of the pp solar neutrino flux, and to searches for physics beyond the Standard Model. In particular, recent theoretical publications show that at a precision of 0.1%, angular correlation measurements are sensitive to a broad range of extensions of the Standard Model, including sensitivity to 4-Fermi scalar and tensor interactions complementary to the LHC. Ambitious neutron and nuclear beta decay experiments such as Nab, currently being fabricated for operations at the FNPB, can approach this accuracy if systematic errors can be controlled, as planned. The Nab experiment could also determine $\lambda = G_A/G_V$ to unprecedented precision providing a measurement complementary to that of UCNA.

Over the years the National Institute of Standards and Technology (NIST) beam experiment has produced neutron lifetime values that are significantly higher than the most recent UCN in-trap method. The current disagreement between neutron lifetimes using beam and in-trap methods is important to clarify. The in-beam program deserves strong support for a measurement of the lifetime with uncertainty well below 1 sec. Detecting new physics beyond the Standard Model motivates an uncertainty of 0.1 sec. The UCN lifetime project at LANL is well underway with a design that utilizes a 700-liter trap. In the first test run this year the measured UCN storage time was consistent with the beta decay lifetime, indicating that wall losses that plagued previous experiments are quite small. This bodes well for a 0.1 s measurement with improved statistics.

Nuclear Beta Decay: The program of superallowed beta decay FT values at Texas A&M is an extraordinary success in determining the value of V_{ud}, inspiring the remeasurement of V_{us}, establishing CKM matrix unitarity, and testing for new physics beyond the Standard Model. Further improvement in V_{ud} is important, but requires studies of model dependent nuclear isospin mixing corrections. Alternatively, those corrections can be avoided by combined precision measurements of the neutron lifetime and angular decay correlations.

Highlights of New Facilities that Enable Scientific Opportunities

Neutrons: The neutron physics program at the FNPB of the SNS at ORNL is now producing world-class results (npdgamma) and is preparing to mount the next generation neutron decay correlation experiment (Nab). The U.S. neutron program has previously lagged behind Europe. The new FNPB facility gives the U.S. program a major boost.

Atom and Ion Traps: The development of atom and ion traps is enabling a new generation of experiments on nuclear electric dipole moments and nuclear beta decay angular correlations. The recent invention by of the Atomic Trap Trace Analysis method at ANL for measuring noble gas isotope ratios in water is a revolutionary breakthrough for geoscience, and a perfect example of the broad benefits of nuclear science to technology and society.

Underground Facilities: Low-background underground facilities are essential for experiments on neutrinoless double beta decay. The Majorana Demonstrator experiment is housed in the Sanford Underground Research Facility (SURF) in South Dakota, while detector studies for Majorana are carried out in the Kimballaton Underground Research Facility (KURF) in Virginia. CUORE is based in the LNGS laboratory in Italy, and EXO is operating in the WIPP facility in New Mexico.

Appendices

Appendix I: Panel Members

Shoji Nagamiya	Science Advisor, RIKEN / Professor, KEK	Chair

Panel 1: Nuclear Structure and Nuclear Astrophysics

Peter Butler	Professor, University of Liverpool	Co-Chair
Brian Fulton	Professor, University of York	
Shigeru Kubono	Visiting senior scientist, RIKEN Nishina Center / Professor, University of Tokyo	
Paul Mantica	Professor, Michigan State University	
Gabriel Martinez-Pinedo	Professor, Professor, TU Darmstadt	
Petr Navratil	Professor, TRIUMF	
Karsten Riisager	Professor, Aarhus University	
Berta Rubio	Professor, IFIC-Instituto de Física Corpuscular	
Michael Thoennessen	Professor, Michigan State University	

Panel 2: Heavy Ions

Itzhak Tserruya	Professor, Weizmann Institute	Co-Chair
Joerg Aichelin	Professor, Subatech/University of Nantes	
Federico Antinori	Dr., INFN Padova and CERN	
Jana Bielcikova	Professor, Czech Academy of Sciences	
William Brooks	Professor, Universidad Tėcnica Federico, Santa Maria	
Raphael Granier de Cassagnac	Professor, IN2P3-CNRS	
Juergen Schukraft	Dr., CERN	
Urs Wiedemann	Dr., CERN	

Panel 3: Medium Energy

Ulrich Wiedner	Professor, Bochum University	Co-Chair
William Brooks	Professor, Universidad Tėcnica Federico, Santa Maria	
Suh-Urk Chung	Dr., CERN, TU/Munich (Germany) and PNU/Busan (Korea)	
Brad Filippone	Professor, California Institute of Technology	
Siegfried Krewald	Professor, Forschungszentrum Jülich	
Elliot Leader	Professor, Imperial College London	
Jean-Marc Richard	Professor, Universite Lyon 1	

Panel 4: Nuclear Theory

Karlheinz Langanke	Professor, GSI Darmstadt	Co-Chair
Peter Braun-Munzinger	Professor, GSI Darmstadt	
Zoltan Fodor	Professor, Universitaet Wuppertal	
Richard Furnstahl	Professor, Ohio State University	

John Timothy Londergan	Professor, Indiana University	
Sandra Padula	Professor, Universidade Estadual Paulista	
Achim Richter	Professor, TU Darmstadt	
Peter Tandy	Professor, Kent State University	

Panel 5: Neutrons, Neutrinos and Fundamental Symmetries

Frank Calaprice	Professor, Princeton University	Co-Chair
Hartmut Abele	Professor, Technische Universitat Wien	
John Behr	Professor, TRIUMF	
Janet Conrad	Professor, Massachusetts Institute of Technology	
Andre de Gouvea	Professor, Northwestern University	
Karol Lang	Professor, University of Texas	
William Marciano	Dr., Brookhaven National Laboratory	
Michael Romalis	Professor, Princeton University	
Fred Wietfeldt	Professor, Tulane University	

Appendix II: Presentations of All Panels (Listed in order presented)

Nuclear Structure and Nuclear Astrophysics Presentations

Western Michigan University	Professor Alan Wuosmaa
Argonne National Laboratory	Dr. Robert Janssens
University of Massachusetts Lowell	Professor Partha Chowdhury
Washington University	Professor Demetrios Sarantites
Yale University	Professor Keith Baker
Mississippi State University	Professor Wenchao Ma
Washington University	Professor Lee Sobotka
Indiana University Bloomington	Professor Romaldo de Souza
University of Rochester	Professor Udo Schroeder
Texas A&M University	Professor Robert Tribble
Florida State University	Professor Ingo Wiedenhoever
University of Maryland	Professor William Walters
Michigan State University	Professor Alexander Gade
Mississippi State University	Professor Jeff Winger
Oak Ridge National Laboratory	Dr. David Dean
University of Tennessee Knoxville	Professor Robert Grzywacz
Louisiana State University	Professor Jeff Blackmon
Ohio University	Professor Carl Brune
Tennessee Technological University	Professor Raymond Kozub
Colorado School of Mines	Professor Fred Sarazin
Oak Ridge Institute for Science & Education	Dr. Ken Carter
Lawrence Berkeley National Laboratory	Dr. James Symons
Oregon State University	Professor Walter Loveland
University of Richmond	Professor Cornelius Beausang
Lawrence Livermore National Laboratory	Dr. Dennis McNabb
Vanderbilt University	Professor Joseph Hamilton
University of Tennessee Knoxville	Professor Kathryn Jones
Duke University	Professor Calvin Howell
University of North Carolina	Professor John Wilkerson
North Carolina Central University	Professor Benjamin Crowe
University of Connecticut	Professor Moshe Gai
North Georgia College	Professor Mark Spraker

Heavy Ion Presentations

Kent State University	Professor Declan Keane
University of California Riverside	Professor Richard Seto
Massachusetts Institute of Technology	Professor Gunther Roland
Vanderbilt University	Professor Charles Maguire
Wayne State University	Professor Thomas Cormier
Purdue University	Professor Ralph Scharenberg
University of Tennessee Knoxville	Professor Soren Sorensen
Oak Ridge National Laboratory	Dr. David Dean
University of Houston	Professor Rene Bellwied
Brookhaven National Laboratory - PHENIX	Dr. Berndt Mueller
Brookhaven National Laboratory - STAR	Dr. Berndt Mueller
University of California Los Angeles	Professor Huan Huang
University of Texas Austin	Professor Gerald Hoffmann
University of Texas Austin	Professor Christina Markert
University of California Berkeley	Professor Ken Crawford
University of Illinois Chicago	Professor David Hofman
Creighton University	Professor Michael Cherney
Naval Academy	Dr. Richard Witt
University of Maryland	Professor Alice Mignerey
Texas A&M University	Professor Saskia Mioduszewski
Georgia State University	Professor Xiaochum He
Baruch College	Professor Stefan Bathe
Los Alamos National Laboratory	Dr. Scott Wilburn
Columbia University	Professor William Zajc
Stony Brook University	Professor Barbara Jacak
Yale University	Professor John Harris
Lawrence Berkeley National Laboratory	Dr. James Symons
Lawrence Livermore National Laboratory	Dr. Dennis McNabb
Michigan State University	Professor Gary Westfall
University of Kansas	Professor Stephen Sanders
Stony Brook University	Professor Roy Lacey
Iowa State University	Professor John Hill
Rice University	Professor Frank Geurts
University of Colorado	Professor Jamie Nagle

Medium Energy Presentations

Florida State University	Professor Paul Eugenio
Massachusetts Institute of Technology	Professor Richard Milner
Duke University	Professor Haiyan Gao

Texas A&M University	Professor Carl Gagliardi
Old Dominion University	Professor Charles Hyde
Carnegie Mellow University	Professor Gregg Franklin
George Washington University	Professor William Brisco
University of New Mexico	Professor Bernd Bassalleck
University of Virginia	Professor Donald Day
University of New Hampshire	Professor Maurik Holtrop
Brookhaven National Laboratory	Dr. Berndt Mueller
Stony Brook University	Professor Abhay Deshpande
University of Massachusetts Amherst	Professor Krishna Kumar
University of Virginia	Professor Blaine Norum
Norfolk State University	Professor Vina Punjabi
Florida International University	Professor Joerg Reinhold
College of William & Mary	Professor Keith Griffioen
Thomas Jefferson National Accelerator Facility	Dr. Hugh Montgomery
University of Virginia	Professor Gordon Cates
George Washington University	Professor Gerald Feldman
Syracuse University	Professor Paul Souder
Argonne National Laboratory	Dr. Robert Janssens
Temple University	Professor Zein-Eddine Meziani
New Mexico State University	Professor Stephan Pate
University of Connecticut	Professor Richard Jones
Indiana University Bloomington	Professor Matthew Shepherd
Hampton University	Professor Michael Kohl
University of Kentucky	Professor Wolfgang Korsch
University of Virginia	Professor Kent Paschke
Los Alamos National Laboratory	Dr. Scott Wilburn
Lawrence Berkeley National Laboratory	Dr. James Symons
Abilene Christian University	Professor Donald Isenhower
University of Richmond	Professor Jerry Gilfoyle
Hampton University	Professor Liguang Tang
Northwestern University	Professor Kamal Seth
Kent State University	Professor Mark Manley
Iowa State University	Professor John Lajoie
University of Virginia	Professor Nilanga Liyanage
Valparaiso University	Professor Shirvel Stanislaus
University of California Riverside	Professor Kenneth Barish
Mississippi State University	Professor Dipangkar Dutta
Argonne National Laboratory	Dr. Hal Spinka
University of Virginia	Professor Xiaochao Zheng

Nuclear Theory Presentations

Indiana University	Professor Charles Horowitz
Baruch College	Professor Jamal Jalilan-Marian
Argonne National Laboratory	Dr. Robert Janssens
University of Maryland	Professor Thomas Cohen
University of Notre Dame	Professor Grant Mathews
University of Texas El Paso	Professor Vivian Incera
University of North Carolina	Professor Jonathan Engel
University of Arizona	Professor Bira van Kolck
Purdue University	Professor Denes Molnar
Pennsylvania State University	Professor Anna Stasto
Stony Brook University	Professor James Lattimer
Lawrence Berkeley National Laboratory	Dr. James Symons
Massachusetts Institute of Technology	Professor Edward Farhi
Iowa State University	Professor James Vary
Ohio State University	Professor Ulrich Heinz
Union College	Professor Rebecca Surman
Stony Brook University	Professor Derek Teaney
Stony Brook University	Professor Michael Zingale
University of Kentucky	Professor K. F. Liu
Florida State University	Professor Winston Roberts
Lawrence Livermore National Laboratory	Dr. Dennis McNabb
Stony Brook University	Professor Edward Shuryak
Ohio University	Professor Charlotte Elster
Florida International University	Professor Misak Sargsian
University of Kentucky	Professor Susan Gardner
San Diego State University	Professor Calvin Johnson
University of Virginia	Professor Simonetta Liuti
Los Alamos National Laboratory	Dr. Scott Wilburn
University of Wisconsin	Professor Michael Ramsey-Musolf
Vanderbilt University	Professor Sait Umar
Washington University	Professor Mark Alford
University of Minnesota	Professor Joseph Kapusta
Tennessee Technological University	Professor Sakir Ayik
Pennsylvania State University	Professor Mark Strikman
University of South Carolina	Professor Vladimir Gudkov
Duke University	Professor Berndt Mueller
Brookhaven National Laboratory	Dr. Raju Venogupalan
University of Washington	Professor Gerald Miller
Florida State University	Professor Jorge Piekarewicz
University of Arizona	Professor Johann Rafelski
Pennsylvania State University	Professor Leonard Gamberg
Mississippi State University	Professor Anatoli Afanasjev

University of Idaho	Professor Francesca Sammarruca
New Mexico State University	Professor Mathias Burkardt
University of Washington Institute of Nuclear Theory	Professor David Kaplan
Old Dominion University	Professor Anatoly Radyushkin
North Carolina State University	Professor Gail McLaughlin
Michigan State University	Professor Scott Pratt
University of Pittsburgh	Professor Eric Swanson
College of William & Mary	Professor Konstantinos Orginos
University of Tennessee Knoxville	Professor Witek Nazarewicz
University of Illinois Urbana-Champagne	Professor Mikhail Stephanov
University of Iowa	Professor Wayne Polyzou
Oak Ridge National Laboratory	Dr. David Dean
North Carolina State University	Professor Thomas Schaefer
George Washington University	Professor Frank Lee
Yale University	Professor Francesco Iachello
Texas A&M University Commerce	Professor Carlos Bertulani
Columbia University	Professor Miklos Gyulassy
University of California Berkeley	Professor Wick Haxton
Thomas Jefferson National Accelerator Facility	Dr. Hugh Montgomery
Duke University	Professor Roxanne Springer

Neutrons, Neutrinos and Fundamental Symmetries Presentations

nEDM Overview	Professor Brad Filippone
MJD Overview	Professor John Wilkerson
CUORE Overview	Professor Yury Kolomensky
Texas A&M University	Professor Robert Tribble
University of Washington - CENPA	Professor Hamish Robertson
University of California Santa Barbara	Professor Benjamin Monreal
University of Michigan	Professor Timothy Chupp
Los Alamos National Laboratory	Dr. Scott Wilburn
Oak Ridge National Laboratory	Dr. David Dean
University of Tennessee Knoxville	Professor Geoffrey Greene
University of North Carolina	Professor John Wilkerson
North Carolina State University	Professor Paul Huffman
University of Kentucky	Professor Brad Plaster
University of California/Berkeley	Professor Yury Kolomensky
University of Wisconsin	Professor Karsten Heeger
Lawrence Berkeley National Laboratory	Dr. James Symons
Pacific Northwestern National Laboratory	Dr. Richard Kouzes

University of Tennessee Knoxville	Professor Yuri Efremenko
University of South Dakota	Professor Vince Guiseppe
University of Alabama	Professor Andreas Piepke
University of Pennsylvania	Professor Joshua Klein
Brookhaven National Laboratory	Dr. Berndt Mueller
Argonne National Laboratory	Dr. Robert Janssen
Lawrence Livermore National Laboratory	Dr. Dennis McNabb
Massachusetts Institute of Technology	Professor J. Formaggio