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Appendix F

The NSAC Long Range Plan

The DOE/NSF Nuclear Science Advisory Committee (NSAC) of the Department of Energy and the National Science Foundation is charged with providing advice on a continuing basis regarding the management of the national basic nuclear science research program. In July 2000, the Committee was asked to study the opportunities and priorities for U.S. nuclear physics research, and to develop a long-range plan that will serve as a frame-work for the coordinated advancement of the field for the next decade.

The NSAC Long-Range Plan Working Group was formed to determine the overall priorities for the field and met in Santa Fe, NM during the week of March 25 , 2001. During this meeting, the scientific opportunities and priorities were discussed in depth and consensus was reached on the prioritized recommendations contained in the final report. This group looked at the output from the town meetings held during the previous six months, as well as many white papers and reports that were written. The outcome of this meeting was a list of four recommendations as well as a larger list of opportunities for the Nuclear Science community. During the next 10 months, the report which is submitted to both DOE and NSF was written and edited. The final report became available in April of 2002: **Opportunities in Nuclear Science, A Long-Range Plan for the next Decade** [1]. The following excerpts, which are particularly relevant to the GlueX project, are taken directly from this final report .

The Four NSAC Recommendations

1. *Recent investments by the United States in new and upgraded facilities have positioned the nation to continue its world leadership role in nu-*

clear science. The highest priority of the nuclear science community is to exploit the extraordinary opportunities for scientific discoveries made possible by these investments.

Specifically, it is imperative to

- *Increase support for facility operations – especially our unique new facilities, RHIC, CEBAF and NSCL – which will greatly enhance the impact of the nations nuclear science program.*
- *Increase investment in university research and infrastructure, which will both enhance scientific output and educate additional young scientists vital to meeting national needs.*
- *Significantly increase funding for nuclear theory, which is essential for developing the full potential of the scientific program.*

2. *The Rare Isotope Accelerator (RIA) is our highest priority for major new construction..... RIA will require significant funding above the nuclear physics base. This is essential so that our international leadership positions at CEBAF and at RHIC be maintained.*

3. *We strongly recommend the immediate construction of the world's deepest underground science laboratory....*

4. *We strongly recommend the upgrade of CEBAF at Jefferson Laboratory to 12 GeV as soon as possible.*

The 12-GeV upgrade of the unique CEBAF facility is critical for our continued leadership in the experimental study of hadronic matter. This upgrade will provide new insights into the structure of the nucleon, the transition between hadronic and quark/gluon descriptions of matter, and the nature of quark confinement.

Elaboration in the Overview and Recommendations

Favorable technical developments, coupled with foresight in the design of the original facility, make it feasible to triple CEBAF's beam energy from the initial design value of 4 GeV to 12 GeV (thus doubling the "achieved" energy of 6 GeV) in a very cost-effective manner. The timely completion of the upgrade will allow Jefferson Lab to maintain its world leadership position, as well as to expand that leadership into new areas. The upgrade will provide an exceptional opportunity to study a family of "exotic mesons" long predicted by theory, but whose existence has only recently been hinted at experimentally. Equally important, the higher energy will open the door to the exploration, through fully exclusive reactions, of regions of high momentum and high energy transfer where electron scattering is known to be governed by elementary interactions with quarks and gluons.

Various Budget Scenarios

In discussing budget scenarios, the worst case considered was a constant dollar budget. There the report stated:

We should emphasize that smaller initiatives – even medium-sized initiatives such as the Jefferson Lab Upgrade – should be accommodated within a constant budget effort. However, the lost opportunity to build a major new facility, and the much slower pace of new initiatives, would be costly for the field.

There are also specific recommendations that the funding of the construction of RIA should not impact existing programs.

Resources. The long-range plan that we are proposing will require increased funding, first to exploit the facilities we have built, and then to invest in the new initiatives we have identified.

As noted in the detailed recommendation, construction of RIA will require significant funding above the nuclear physics base. Most of the current base funding in nuclear physics from the DOE supports researchers at universities, national laboratories, together with the operation of our two flagship facilities, CEBAF and RHIC. Redirection of funds away from areas where we are reading the scientific benefits of recent investments would be inconsistent with our first recommendation.

Looking to the Future: The CEBAF 12 GeV Upgrade

Almost two decades have passed since the parameters of CEBAF were defined. During that period, the picture of how strongly interacting matter behaves has evolved dramatically, thus posing whole new classes of experimental questions best addressed by a CEBAF-class machine operating at higher energy. Fortunately, favorable technical developments, coupled with foresight in the design of the facility, make it feasible to triple CEBAFs beam energy from the initial design value of 4 GeV to 12 GeV (thus doubling the *achieved* energy of 6 GeV) in a very cost-effective manner. The cost of the upgrade is about 15% of the cost of the initial facility. Doubling the energy of the accelerator has three major motivations, the first two of which are "breakthrough" opportunities to launch programs in completely new areas of research.

First, the higher beam energy will allow us to cross the thresholds for the production of states that are not currently accessible with CW beams. A prime example is the spectroscopy of "exotic mesons," which will provide the data needed to determine whether the origin of quark confinement lies in the formation of QCD flux tubes. Not only general considerations and flux tube models, but also first-principles lattice QCD calculations require that these states exist in the accessible mass regime and demonstrate that the levels and their orderings will provide experimental information on the mechanism that produces the flux tube. Tantalizing experimental evidence has appeared over the past several years for both exotic hybrids and gluonic excitations with no quarks (glueballs). Through simple spin arguments, photon beams acting as virtual vector mesons are expected to be particularly favorable for the production of exotic hybrids. A definitive experiment to map out the spectrum of these new states required by the confinement mechanism of QCD will be possible at 12 GeV. These programs will be carried out in a new "photons only" experimental area, Hall D.

Equally important, the higher energy (coupled with the CW beam and appropriate detectors) will open the door to the exploration, by fully exclusive reactions, of regions of high momentum and high energy transfer where electron scattering is known to be governed by elementary interactions with quarks and gluons, not with hadrons. The original CEBAF energy did not allow full access to this critical regime, whereas at 12 GeV, researchers will have access to the entire "valence quark region." This will be the first experimental facility that can measure the deep exclusive scattering (DES) cross sections in the kinematical regime where the three basic ("valence") quarks of the proton and neutron dominate the wave function. The valence quarks play a big role over a large part of the nucleon, but it is only in this newly accessible regime that there are no significant contributions from more complicated components to the nucleon wave functions. With the energy upgrade, it will be possible to map out the quark distribution functions in the entire valence quark regime with high precision, which will have a profound impact on our understanding of the structure of the proton and the neutron. However, these structure functions are probabilities, not wave functions, and until recently the attempt to determine the quark-gluon wave functions of the nucleons has been seriously handicapped by the lack of a rigorous framework for making a connection between experimental measurements and these wave functions. The theoretical discovery of generalized parton distributions (GPDs) and their connection to certain totally exclusive cross sections have made it possible in principle to rigorously map out the complete nucleon wave functions themselves. The 12-GeV upgrade will make it possible to explore this new DES domain. This will allow exploration of the complete quark and gluon wave functions of the nucleons through measurements of quark momentum distributions, as well as through the novel framework of GPDs.

Finally, in addition to these qualitative changes in the physics reach of CEBAF, 12 GeV will also allow important new research thrusts in Jefferson Labs existing research campaigns, generally involving the extension of measurements to substantially higher momentum transfers (and thus to correspondingly smaller distance scales). An example of this is the measurement of the pion elastic form factor, one of the simplest quark systems. With the larger momentum transfers available, it should be possible to observe the transition from the strong QCD of confinement to perturbative QCD. Another example is the ability to probe the limits of the nucleonic picture of short-range correlations (SRCs), whose kinematics were first reachable at CEBAF at 4-6 GeV. The upgrade provides unique opportunities for measuring quark distributions over an even broader range of x and Q^2, thus investigating the parton structure of bound nucleons. At this upgraded energy, we also cross the threshold for charmed-quark production. Another benefit is that most experiments that are approved to run at a currently accessible momentum transfer can be run more efficiently at higher energy.

The success of the original CEBAF design is one of the key features that make a cost-effective upgrade possible. First, the installed five-cell superconducting RF cavities have exceeded their design acceleration gradient of 5 MV/m by more than 2 MV/m and their design Q-value by a similar factor. Furthermore, seven-cell cavities have now been designed that are significantly more powerful than the original design. Accordingly, 12 GeV can be reached by adding ten new modules in space available in the linac tunnels. However, this technological advance would not be so readily applied if it were not for the fact that the “footprint” of the CEBAF accelerator was, with considerable foresight, designed so that the recirculation arcs could accommodate an electron beam of up to 24 GeV. The basic elements of the CEBAF upgrade can thus be seen in Figure F.1. The upgrade utilizes the existing tunnel and does not change the basic layout of the accelerator. There are four main changes:

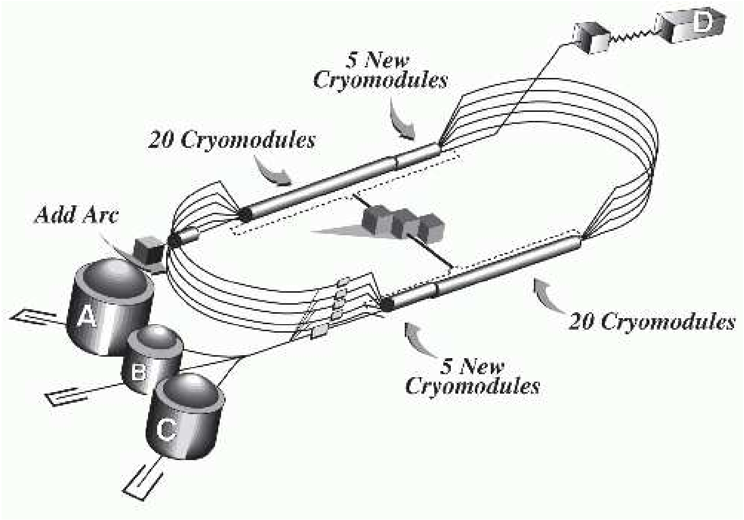

Figure F.1: Elements of the CEBAF upgrade. Increasing the beam energy at CEBAF from 6 to 12 GeV requires upgrades in four areas: (i) additional accelerating power, (ii) stronger magnets in the recirculation arcs, (iii) an upgraded cryoplant, and (iv) one additional recirculation arc. The higher-energy electrons can be directed to a new experimental area, Hall D.

(i) additional acceleration in the linacs, as outlined above; (ii) stronger magnets in the recirculation arcs; (iii) an upgraded cryoplant; and (iv) the addition of a tenth recirculation arc, permitting an additional "half pass" through the accelerator (to reach the required 12-GeV beam energy), followed by transport to the new hall that will be added to support the meson spectroscopy initiative.

The timely completion of the CEBAF upgrade will allow Jefferson Lab to maintain its world leadership position, as well as to expand that leadership into new areas. The program of exotic mesons in Hall D is viewed by many as the definitive search for these states, and Jefferson Labs polarized photon beam will be the unique instrument to carry it out. The complete mapping of the nucleon wave functions is both interesting and of significant importance in other branches of nuclear physics, where these wave functions are important input to understanding higher-energy phenomena.

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Bibliography

[1] James Symons, *et al.* Opportunities in Nuclear Science, A Long-Range Plan for the Next Decade, April 2002. Available at `http://www.nscl.msu.edu/future/lrp2002.html`.