CEBAF Commissioning and Future Plans

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I. INTRODUCTION

With first beam on target in July 1994 , the Continuous Electron Beam Accelerator Facility (CEBAF) in Newport News, Virginia began capitalizing on years of planning and work to create a laboratory devoted to the exploration of matter that interacts through the strong force, which holds the quarks inside the proton and binds protons and neutrons into the nucleus. This event is made more remarkable in that the accelerator is available to physicists on schedule and within cost. The success of the project is due largely to a reasoned approach to its planning and the extraordinary work of scores of talented and motivated individuals.

A. Why CEBAF Now?

Just as Quantum Mechanics and Coulomb's Law explained atoms as bound states of electrons and nuclei, and molecules as bound states of atoms, it is CEBAF's scientific goal to use the theory of Quantum Chromodynamics (QCD) to describe nucleons as bound states of quarks and gluons and nuclei as bound states of nucleons. This machine and its capabilities will enable us to fill in what are some of the most glaring gaps in our understanding of nature. In the "molecular physics" of nuclei it is our goal to understand the physical mechanisms and novel features in terms of known basic theory, to answer questions such as "Why do we have nucleons instead of a quark-gluon soup?", "What is the origin of the NN force", and "What are the short distance nuclear degrees of freedom?" In the atomic physics of quarks and gluons we seek to understand quark confinement, discover gluonic degrees of freedom; and understand why we only see quarks in qqq and $q\overline{q}$ configurations?

What makes the time right for a facility such as CEBAF? Key ingredients have come together including the theory of Quantum Chromodynamics, superconducting accelerator technology, advances in detector technology, and new capabilities for rapid data acquisition to make it possible for us to answer these questions.

When D. Allan Bromley and his committee met in 1983, they specified what the parameters of the beam for such a machine should be based on the Barnes Panel. They called for a machine with an energy of 4 GeV that could be upgraded to 6 GeV, a current of 200 μA, and energy spread of $\Delta E/E \leq 10^{-4}$, emittance of 2×10^{-8} (geometric at 45 MeV), and a duty factor of 100%, creating a continuous wave accelerator. When paired with the appropriate experimental instrumentation, such a machine provides a tool for the world physics community of unmatched capability.

In a recent popular movie "Field of Dreams", the main character hears a voice that tells him "If you build it, they will come." Though in that movie the voice referred to a baseball field, it could have applied to CEBAF as well. The physics community has responded with enthusiasm. Currently, CEBAF's user group has about 1100 members. Five hundred thirteen users from 114 institutions in 24 countries are collaborators on approved experiments. CEBAF's Program Advisory Committees have already approved 3 years of experimentation in each of the three halls with the following profile.

Table 1

Totals of Approved Experiments by Physics Topic

Topic	Number
Nucleon and Meson Form Factors and Sum Rules	11
Properties of Nuclei	28
N* and Meson Properties	24
Strange Quarks	12
TOTAL	75

CEBAF offers its user community three experimental halls which can run experiments simultaneously, with complementary capabilities and equipment. Hall C, the first to come on-line, is equipped with a High Momentum Spectrometer (HMS) which has a large solid angle, a moderate resolution (10^{-3}) and a maximum acceptance of 7 GeV/c. It also has a Short Orbit Spectrometer (SOS) with a large momentum acceptance and a very short (7.4m) optical path for use in detecting particles having a short lifetime, such as low momentum π's and K's. The HMS has already achieved its design specifications and the SOS spectrometer will begin operation shortly. The initial experimental program will include an investigation of the validity of the quark counting rules in the photodisintegration of the deuteron, measurements of the neutron electric form factor, and studies of kaon electroproduction. Hall C is also the area envisioned for the installation of specialized detectors designed to investigate specific problems such as hypernuclear physics and the strange quark content of the proton (via parity-violating $e\vec{p}$ scattering).

Hall A, scheduled to begin operation in early 1996, is equipped with two optically identical high resolution (10^{-4}) magnetic spectrometers (HRS) having a relatively large solid

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angle and a maximum momentum of 4 GeV/c. The detector packages have been optimized differently: one for detecting electrons and one for detecting hadrons. The Hall A experimental program will conduct detailed investigations of the structure of nuclei, and look at the elastic, inelastic, and weak structure of the nucleon. Such measurements will provide stringent tests for microscopic models of the nucleon, including the strange quark contributions to their charge and magnetization distributions.

Hall B, scheduled to begin operation in late 1996, is equipped with a large acceptance detector (CEBAF Large Acceptance Spectrometer, or CLAS), designed to carry out experiments which require the detection of several only loosely correlated particles in the hadronic final state, and measurements at limited luminosity. A major focus of the research program in Hall B is the investigation of the quark-gluon structure of the nucleon. The CLAS detector will also be used in a variety of other investigations requiring data on multiparticle final states.

B. Machine configuration and design

In planning what CEBAF's accelerator would look like , there was thought given not only to what the physics community wanted now, but what they were likely to want in the future. What was needed was a continuous wave electron accelerator. However, that offered a number of challenges. The first was controlling the power cost for such a machine, a challenge that was best met by utilizing superconducting radiofrequency (SRF) cavities. Though other more mature technologies existed that would allow the necessary specifications, SRF would allow "growth" in the capabilities of the machine since it was a technology at a promising beginning, not a successful end. The next hurdle was limiting the capital expense of such a machine, which was done by using beam recirculation. The final challenge was leaving some room for upgradabilty of the machine. This was done through the design of arcs that could accommodate 20 GeV beam, with their limitation being synchrotron radiation and the resulting degraded beam quality. Thus the CEBAF accelerator was born.

The system itself is an impressive array of hardware and software. The accelerator system consists of 338 SRF cavities, each with its own klystron, in 42 1/4 cryomodules. The injector will consist of three independent electron sources to allow independent current, independent pulse sequence and independent polarization to meet the needs of the user community. Our helium liquifier is the largest 2 K˚ system in the world with 5000W at 2.1˚ K at 97% availability. It is a closed system with two temperatures, 50˚ K and 2˚ K. The instrumentation and control system consists of 100,000 i/o points. The system is currently operational running under the EPICS control system. The beam transport system in the arcs and the beam switchyard consists of 2,241 magnets (dipoles, quadrupoles, and correction magnets), 4.5 km of vacuum line and the necessary beam dumps and LCW system.

C. Commissioning and status

To bring such a collection of state of the art equipment together into a functioning system was not an easy task. There were a number of challenges along the way to make things interesting. With the SRF cavities themselves, we needed to achieve and maintain high gradient and high Q factor in a production environment. We have successfully met that challenge, producing, installing and commissioning the cavities with characteristics that are twice the CEBAF specifications for both these parameters. This experience and performance makes CEBAF the recognized world leader in SRF technology.

The machine control system offered its own challenges including a successful mid-construction migration to the EPICS control system. Currently the hardware upgrade is complete, and the RF, magnets and diagnostics have successfully been migrated to EPICS. The injector is now in the process of conversion, with plans to convert the gun control later in Spring and the Central Helium Liquifier in August.

The injector has also exceeded specifications, producing currents of 340 μA, as compared to the specified 200 μA. The injector will offer the capability to produce three independent interleaved beams, though this capability is not fully operational yet. It can start up from a cold state in about ten minutes.

Along with our challenges, the commissioning has offered its share of successes. On March 20, 1995, we achieved an energy of 3.2 GeV, the equivalent of 4-pass beam. We have also delivered continuous wave beam to allow the commissioning of coincidence capabilities in Hall C.

D. Looking toward the future

Even though CEBAF has just begun operations, we are already looking toward the future. Our highest priority over the next five years is to run the presently approved experimental program. However, we and our user community are looking toward increasing the science that is possible using the CEBAF accelerator. The existing capabilities of our SRF cavities have us aiming for gradually pushing the current machine's energy from 4 to 6 GeV. Our user community has also recommended, and NSAC has supported, an evolutionary upgrade of CEBAF to the 10 GeV range. This upgrade would be particularly cost effective, since it can be achieved by adding additional cavities in existing free spaces in the linacs and upgrading the performance of those cavities that have lesser gradients.

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CEBAF has also been active in partnership with industry to apply its SRF technology for an accelerator-driven free electron laser. There are industrial applications for cost-effective, high average power sources of coherent infrared and ultraviolet light. These include primarily materials processing that will enable new and value-added products. Industrial partners have identified SRF technology as the route to such a device for industrial processing, and thus an industry-driven alliance, the Laser Processing Consortium, was organized to develop, test and apply high average power FELs. The program plan has two phases; Phase 1, a UV and IR demonstration at a few (2-3) kw, and Phase 2, an industrial prototype of 10-100 kw. The conceptual design for Phase 1 is being reviewed by the Department of Energy, and funding opportunities are being explored.

As the nation's newest laboratory, CEBAF has worked hard to become a center of scientific and academic excellence that benefits not only the nation's scientific community but the nation's economic competitiveness as well. With continued sound planning, with the dedication of its excellent staff, and with the continued development of cutting edge technology, the phenomenal contributions that can come from such a facility will be realized.

Note added: On May 9, 1995, in the week immediately following the Conference, CEBAF attained its full design energy of 4 GeV.

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