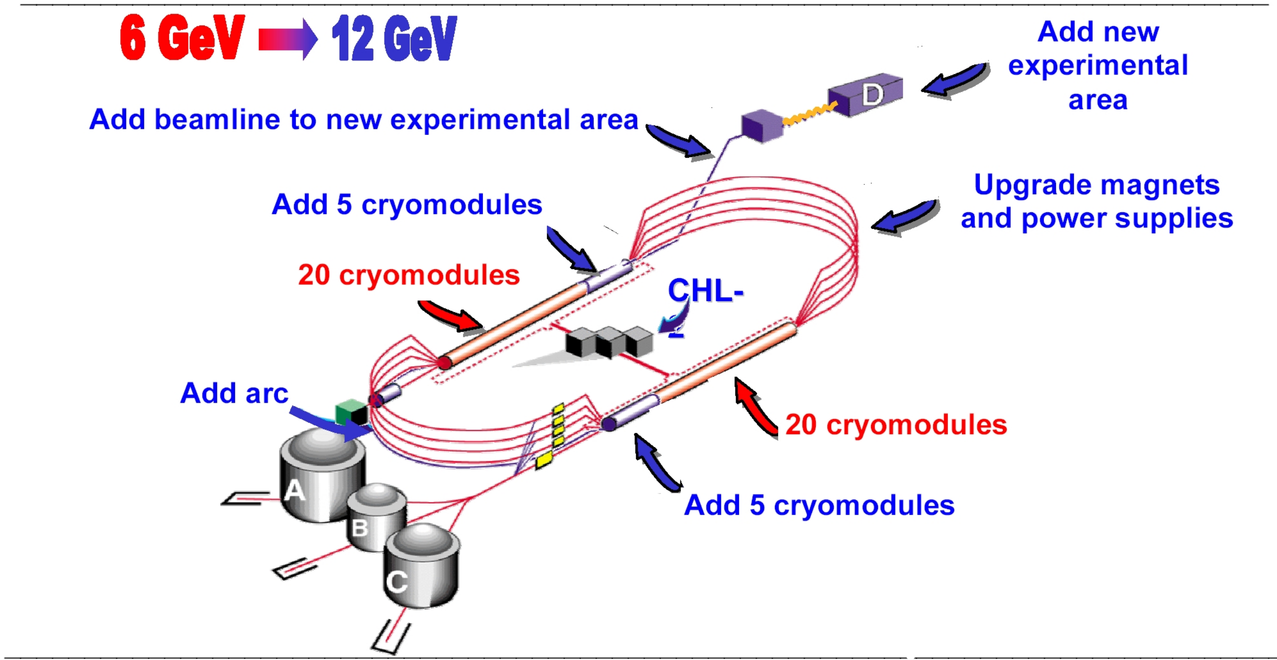
UPGRADING CEBAF TO 12 GEV*

Leigh Harwood [1] (for the JLab 12 GeV developmental team)
TJNAF, Newport News, VA 23606 USA



Abstract

As originally constructed, the Continuous Electron Beam Accelerator Facility (CEBAF) was a 4 GeV cw 5-pass recirculating linac. It has subsequently been enhanced to 5.7 GeV. Developments in lattice QCD have indicated that an extending CEBAF to 12 GeV would provide a unique opportunity to understand quark confinement. Jefferson Lab plans to reach 12 GeV by adding ten new 100 MV cryomodules and supporting rf systems to the present machine configuration. The 2K helium plant will be doubled. The beam transport system's capability will be doubled to 12 GeV with minimal replacement of components and with minimal saturation in the magnets. A new experimental hall, devoted to the quark confinement investigation, will be placed so that the beam transits one of the linacs 6 times (vs 5 times for the other linac). Beam emittances are degraded by synchrotron radiation such that the horizontal emittance of 1 nm-rad at 6 GeV increases to 7 nm-rad at 12 GeV. This paper discusses the issues listed above plus requirements for all systems and developmental opportunities presented by the project.

1 OVERVIEW

1.1 Motivation

The US National Academy of Science has identified understanding quark confinement as one of the ten most significant questions to be answered in physics in the 21st century. Lattice QCD calculations indicate that the explanation for confinement may lie in flux-tubes of gluons between quark pairs and also show that the flux-tubes' degrees of freedom yield exotic meson states. It appears possible to excite these exotic states with a beam of polarized 9 GeV photons and, most importantly, distinguish them from the other states. A high-quality, cw beam of 12 GeV electrons is the ideal way to produce the photons [1]. CEBAF presently has a high-quality cw beam of ~6 GeV and is thus an ideal platform upon which to base a facility.

1.2 Base requirements

6 MV of acceleration must be added. A new experimental area (for the exotic meson program) must be added to the present three. It will be on the opposite end of the accelerator from the existing ones; thus the beam that reaches the new end-station will transit one linac one more time than for any of the other end-stations.

12 GeV can be achieved by increasing the linac capabilities or increasing the number of passes. An analysis determined that it would be more cost effective to increase the linac capabilities than to reconfigure (rebuild) the beam transport system for additional passes. Therefore, the present 0.6 GV linacs will be upgraded to

---

*This work was supported by the U.S. Department of Energy Contract NumberDE-AC05-84-ER40150
[1] harwood@jlab.org

1.1 GV. The exotic meson studies need < 5 μA; the other programs need much larger beam currents. It was decided to retain the present beam power limit of 1 MW.

The present beam transport system supports 5-pass beam at 6 GeV to each of the existing end-stations. It must be modified to deliver 11 GeV beam to those halls and have added the requisite beam transport to deliver the full 12 GeV beam to the photon radiator target for the new end-station, including an additional recirculation arc.

2 BEAM PHYSICS

2.1 Beam breakup

Beam breakup (BBU) driven by high-order modes (HOM's) in the cavities must always be addressed when using srf cavities even if the beam current in the cavities, < 1 mA in this case, is not exceptional on the scale of storage rings. As was done for 4 GeV CEBAF, the code TDBBU [2] was used to evaluate the situation. A specification of $Q < 2x10^6$ (versus $1x10^5$ for 4 GeV CEBAF) for the HOM's came out of the study. Initial tests of the new cavities indicate that there should be no problem with BBU for the upgrade.

2.2 Emittance, energy spread, and depolarizaion

Emittance growth from synchrotron radiation of the electrons in dispersive sections of the beam transport did not present a limitation to meeting the 1 nm-rad specification for CEBAF at 4 GeV. For the Upgrade, cost containment drove a desire to forego extensive modifications to the existing optics. Retaining those optics leads to emittances at 11 GeV in the existing end-stations of ε_x=7 nm-rad and ε_y=1 nm-rad. The projected energy spread at 12 GeV is 0.02%, as compared to 0.01% at 6 GeV. The CEBAF User's Group Board of Directors reviewed these values and found they did not limit the proposed research programs. Estimates for modifying the beam transport in order to reduce the dilution of the emittance by synchrotron radiation effects were ~$5M; it was decided to retain the present optics. Potential depolarization of the beam was checked and found to be inconsequential.

3 ACCELERATION

Note: The details of the acceleration systems (cryo-modules, rf, and cryogenics) are described in detail in ref. [3]. The following is a summary of that information. It should be remembered that the existing systems will be used without modification.

3.1 SRF

The additional 0.5 GV/linac will be achieved by adding 5 new cryomodules (total of 10 needed for both linacs) each providing 100 MV. Each cryomodule will have eight 7-cell cavities. The cavities have a performance specification of $Q_0 = 8x10^9$ at 19.2 MV/m. While only 17.5 MV/m is required for the cryomodule to reach 100 MV, the specification was set at 19.2 MV/m to overcome the likelihood that some cavities might be off-line. The Q_0 specification was set by the requirement to fit within the projected cryogenics plant's capacity (see below). Key to meeting this performance is elimination of field emission. To accomplish this several steps will be taken: 1) changes in cryomodule design details aimed at excluding particulate-producing components [4,5], 2) changes in assembly procedures in order to better preclude contamination of cavities [6], and 3) utilization of in situ cavity processing to deal with any particulates. Electropolishing may be used. In addition a new cavity shape [7] will be used which has higher R/Q than the original CEBAF shape.

In addition, the tuner resolution has been improved versus that of the existing cryomodules, this being motivated by a desire to minimize the rf power required for keeping detuned cavities on-phase.

Prototype 7-cell cavities have exceeded the performance specification both with and without electropolishing. The first cryomodule with 7-cell cavities has been completed using many of the new procedures and design details; it achieved 82 MV. A second will be completed in 2003. New cell-shape options will be prototyped in 2003. The prototype 100 MV cryomodule is expected to completed in 2004.

3.2 Cryogenics

The present 2K helium plant is now operating at its full capacity. In anticipation of the Upgrade project, JLab acquired the former MFTF-B helium plant from LLNL, which has a capacity of >10 kW at 4K. We also have a redundant ("hot spare") 2K coldbox. With a reconditioned MFTF-B plant, the potential addition of an 80K exchanger, and utilization of the "spare" 2K coldbox, we will have a 2K plant with maximum capacity of ~5 kW at 2K. After allowance for system control headroom, there would be ~300W available for each of the new cryomodules, 250W of which would be available for dynamic load. At 19.2 MV/m, 250W translates to the $Q_0 = 8x10^9$ mentioned earlier.

3.3 RF

Each cavity will be energized by its own klystron. The required saturated output power for the klystrons is based on the following criteria: 1) ≤450 μA of beam transiting the cavity (limited by 1MW total beam power limit), 2) Q_{ext} is off-optimum by ≤ 30%, 3) maximum detuning ≤ 25 Hz of which 4 Hz is 2x the tuner resolution and 21 Hz is 6x the σ of the measured microphonics spectrum on existing cavities [8], 4) some cavities will be able to operate at 21 MV/m (10% above the mean of the population) and stay within the cryogenic limits, and 5) add 10% so that the klystron will still have gain. The result of the calculation was 12.5 kW. 13 kW has been chosen as the design specification to add headroom.

A new rf control module must also be developed. We anticipate using digital technology [9]. Preconceptual work is presently underway in collaboration with Cornell, and DESY. Important control issues that must be addressed are:

- The cavities' will have multi-valued resonance detuning curves resulting from the high field and its accompanying large optimum external Q. A self-excited loop may be used to alleviate the problem.
- ~1/3 of the rf power is reserved for the effects of microphonics-induced detuning of the cavity. A potential solution is a new control algorithm [10] that uses a field modulation to damp the microphonics. The algorithm must be validated with a real cavity.

4 BEAM TRANSPORT

4.1 Upgrading existing beamlines

The existing beam transport system consists of ~400 dipoles (B*L≥0.2T-m) and ~700 quads. Simply replacing their power supplies is not viable because saturation in the return iron would require excessively large power supplies and installation of a large refrigerated cooling-water system. Replacing the magnets is also cost prohibitive. Another alternative was has been indentified.

For the majority of the dipoles, i.e. those in the nine 180° arcs and in the beamlines to the existing end-stations, the present "C" shape will be changed to "H" profiles by augmenting the magnets with bolted-on iron. Modeling and prototyping have shown that the saturation is only a few percent with the additional iron, while it would exceed 50% if the iron were not added.

The dipoles in the spreaders and recombiners (S/R), i.e. the sections of the beam transport system which separate the co-linear beams after they exit the linacs or combine them before re-injection into the linacs, are so closely spaced that the bolt-on iron option is often not viable. A combination of three approaches will be used: 1) reshape the poles to reduce the flux, and thus the saturation, 2) add coil packs and accept the saturation, and 3) add iron, but in lesser amounts than in the 180° arcs. For some magnets, no combination of the three options will work; those magnets will be replaced.

The quadrupole fields required for the Upgrade exceed the original design specifications of the present magnets for only ~10% of the population. Tests were performed that showed satisfactory field quality if the units were pushed to the required field levels. The plan now is to replace the power supplies on that 10% and run them well in excess of their original design specification; the remainder will be left "as is".

The dipole strings are energized by 32 power supplies varying in size up to 750 kW. All but nine will be reused for the upgrade. Those nine will be replaced with larger units that are anticipated to use one or more of a common power unit feeding a current regulating unit.

4.2 New beamlines

A new recirculation arc is needed so that the beam re-enters the north linac for its final acceleration before going to Hall D. Both Arc 10 and the beamline to Hall D must be built using new components. Thirty-two 4 m "H-style" dipoles will be used for Arc 10 and four of the same magnets will be used for the Hall D beamline. ~40 new quadrupoles will be built using a new design that is matched to the needs of these two beamlines.

4.3 Diagnostics

We presently anticipate no need to develop any new beam diagnostic instrumentation for this project. For the existing beamlines, no changes whatsoever are planned. New units of existing designs will be used for Arc 10 and for the beamline to Hall D. We need not add electronics for the beam position monitors in Arc 10 since they can be multiplexed onto the same electronics that presently monitor the existing arcs on that end of the accelerator.

5 PROJECT STATUS

The 12 GeV Upgrade received the endorsement of the US Nuclear Science Advisory Committee (NSAC) in its 2002 Long Range Plan. More recently, NSAC rated it's science as "absolutely central" and the project as "ready to start construction". With this endorsement, JLab is confident that the 12 GeV Upgrade will be a near-term priority project in the soon-to-be-released US Department of Energy Office of Science's 20-year Strategic Facilities Plan and will shortly thereafter receive approval from the US Department of Energy to proceed with the project.

6 SUMMARY

Lattice QCD calculations have indicated that the nature of quark confinement can be investigated with the availability of a 12 GeV cw electron beam. JLab has developed a cost-effective plan that builds on its existing infrastructure to deliver the 12 GeV beam and, furthermore, extend srf and rf control technologies. The project is under review by the US Department of Energy.

7 REFERENCES

[1] http://www.jlab.org/div_dept/physics_division/GeV.html
[2] B. Yunn, JLab internal report TN-01-028
[3] L. Harwood and C. Reece, "CEBAF at 12 and 25 GeV," SRF2001, Tsukuba, October 2001.
[4] Wilson, et al, RPAB064, this conference.
[5] Daly, et al, TPAB077, this conference.
[6] Mammosser, et al, RPAB062, this conference.
[7] Sekutowicz, et al, TPAB085, this conference.
[8] Delayen, et al, MPPB081, this conference.
[9] Hovater, et al, FPAB047, this conference.
[10] Delayen, "Electronic Damping of Microphonics in Superconducting Cavities", PAC-2001,