Research Perspectives at Jefferson Lab: 12 GeV and Beyond

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Abstract. The plans for upgrading the CEBAF accelerator at Jefferson Lab to 12 GeV are presented. The research program supporting that upgrade are illustrated with a few selected examples. The instrumentation under design to carry out that research program is discussed. Finally, a conceptual design of a future upgrade which combines a 25 GeV fixed-target facility and an electron-ion collider facility at a luminosity of up to 10^{35} cm^{-2}s^{-1} and a CM energy of over 40 GeV.

1. INTRODUCTION

The design parameters of the Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility (JLab) were defined nearly two decades ago. In that period our understanding of the behaviour of strongly interacting matter has evolved significantly, providing important classes of experimental questions which can be optimally adressed by a CEBAF-type accelerator at higher energy. The original design of the facility, coupled to developments in superconducting RF technology, makes it feasible to triple the initial design value of CEBAF's beam energy to 12 GeV in a cost-effective manner (at about 15% of the cost of the initial facility).

The research program with the 12 GeV upgrade will provide breakthroughs in two key areas: (1) the experimental confirmation of the origin of quark confinement by QCD flux tubes and (2) the detailed mapping of the quark and gluon wavefunctions. In addition, the upgrade will provide important advances in areas already under study. A detailed overview of the upgrade research program is given in the recent White Paper[1].

2. ACCELERATOR

CEBAF was originally designed to accelerate electrons to 4 GeV by recirculating the beam four times through two superconducting linacs, each producing an energy gain of 400 MeV per pass. The beam can be split arbitrarily between three interleaved 499 MHz bunch trains. One such bunch train can be peeled off to any one of the Halls after each linac pass using RF separators and septa, while all Halls can simultaneously receive the maximum energy beam.

Each linac tunnel provides sufficient space to install five additional newly designed cryomodules. The new cryomodules will each provide over 100 MV (compared to the 28 MV from the existing ones), by increasing the gradient to 20 MV/m and the number

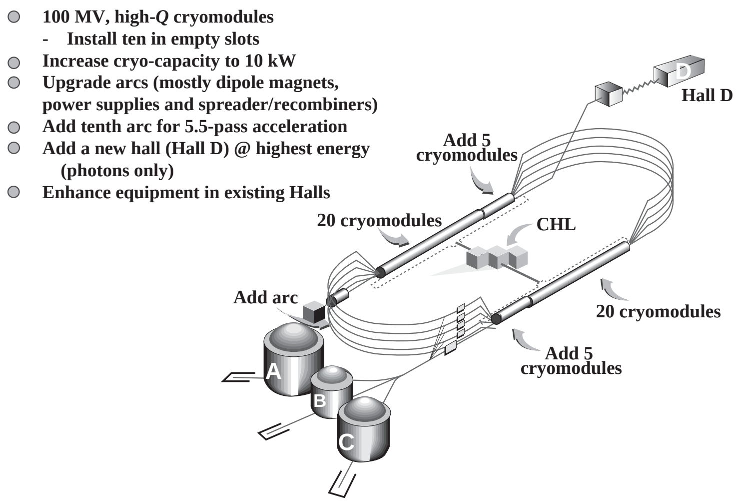

FIGURE 1. Overview of the accelerator upgrade to 12 GeV.

of cavity cells from five to seven. This will result in a maximum energy gain per pass of 2.2 GeV, providing a maximum beam energy to Halls A, B and C of 11 GeV. Hall D will be provided with the desired maximum energy of 12 GeV by adding a tenth arc and recirculating the beam a fifth time through one linac. A total of 90 μA of CW beam can be provided at the maximum beam energy. Further modifications required are changing the dipoles in the arcs from C-type to H-type magnets, replacing a large number of power supplies and doubling the central helium liquifier capacity to 10 kW. An overview of the upgrade of the accelerator is shown in Fig. 1.

3. HALL A

The present base instrumentation in Hall A has been used with great success for experiments which require high luminosity and high resolution in momentum and/or angle of at least one of the reaction products. The central elements are the two High Resolution Spectrometers (HRS). Both of these devices provide a momentum resolution of better than 2×10^{-4} and an angular resolution of better than 1 mrad with a design maximum central momentum of 4 GeV/c.

With the upgrade a large kinematic domain becomes available for studies of deep inelastic scattering. The combination of high luminosity and high polarization of beam and targets offers a unique opportunity to make significant contributions to the understanding of nucleon and nuclear structure and of the strong interaction in the high-x region. For example, the spin structure functions g_1 and A_1 of the neutron will be measured accurately by using a polarized ^{3}He target, establishing unambiguously the trend of A_1^n when x goes to 1, which will provide a benchmark test of pQCD and constituent quark models. Measurements of the g_2^n spin structure function and its moments will provide a clean measure of a higher twist effect (twist 3), which is related to quark-gluon correlations.

Two instrumentation upgrades are proposed to allow an optimal study of the intended experiments: a magnetic spectrometer, dubbed MAD (Medium Acceptance Detector), and an electro-magnetic calorimeter.

The proposed MAD device is a magnetic spectrometer built from two combined-function (quadrupole and dipole) superconducting magnets. The design provides a momentum acceptance (resolution) of ± 15 (0.2)% and an angular acceptance (resolution) of 30 msr (2 mrad). The maximum central momentum is 6 GeV/c at a total bend angle of 20°. The basic detector package for the MAD spectrometer, covering the full momentum and angular acceptance, includes: fast high-resolution tracking chambers, a hydrogen-gas Čerenkov counter, trigger scintillator counters and a lead-glass hadron rejector. For the detection of hadrons a variable-pressure gas Čerenkov counter, two diffuse-reflective aerogel counters, a Ring Imaging Čerenkov counter and a Focal Plane Polarimeter will also be available.

4. HALL B

The CEBAF Large Acceptance Spectrometer (CLAS) in Hall B is used for experiments that require the detection of several, loosely correlated particles in the hadronic final state at a limited luminosity. CLAS is a magnetic toroidal multi-gap spectrometer. Its magnetic field is generated by six superconducting coils. The detection system consists of drift chambers to determine the track of a charged particle, gas Čerenkov counters for particle identification, scintillation counters for the trigger and for measuring time-of-flight and electromagnetic calorimeters to detect showering particles like electrons and photons. CLAS presently operates at a luminosity of 10^{34} cm^{-2}s^{-1}.

With the 12 GeV upgrade the CLAS research program will focus on Generalized Parton Distributions (GPD) through the study of exclusive processes at large momentum transfer. The GPD's can be considered as overlap integrals between different components of the hadronic wave function[2], governed by the selection of the final state. Measurements of these GPD's will thus make it possible to map out quark and gluon wave functions. One way to access the quark orbital angular momentum contribution to the nucleon spin is through GPD's. Factorization is an essential ingredient in the extraction of GPD's. For Deeply Virtual Compton Scattering (DVCS) scaling will have been achieved at 11 GeV, but this has to be established experimentally for other processes.

The CLAS upgrade incorporates two major improvements: (1) increasing the luminosity by an order of magnitude to account for the lower cross section values, (2) provide more complete detection of the hadronic final state. The use of major components (torus magnet, scintillators, Cerenkov counters and EM calorimeters) will be retained. The tracking chambers will be replaced and a new central detector added.

5. HALL C

The Hall C facility has generally been used for experiments which require high luminosity at moderate resolution. The core spectrometers are the High Momentum Spectrometer HMS and the Short Orbit Spectrometer (SOS). These two devices have been used flexibly as either electron or hadron arms, at times in coincidence with each other, at times in coincidence with a third experiment-specific arm. The HMS has a maximum momentum of 7.6 GeV/c, the SOS a value limited to only 1.7 GeV/c.

The Hall C research program after the 12 GeV upgrade will be focused on electron-hadron coincidence experiments at large $z \equiv E_h/\nu$, where E_h and ν are the hadron energy and the energy loss, respectively. Examples of such experiments are measurements of the pion form factor at large Q^2 and a study of quark-hadron duality. This research program requires particle detection at a high luminosity, a small minimum scattering angle and a high maximum momentum. These conditions will be met by the so-called Super High Momentum Spectrometer (SHMS) which will replace the SOS spectrometer. The SHMS design consists of two superconducting quadrupoles and one combined-function magnet. It will have a maximum momentum of 11 GeV/c, a minimum scattering angle of 5.5°, a momentum acceptance (resolution) of ± 10 (0.2)% and an angular acceptance (resolution) of 2 msr (2 mrad). The basic configuration of the detector stack would consist of DC tracking chambers, trigger scintillator hodoscopes and a lead glass calorimeter.

6. HALL D

The Hall D research program will be focused on a definitive measurement of the spectrum of exotic hybrid mesons, which are expected in a mass range from 1 to 2.5 GeV/c^2. Lattice QCD calculations have convincingly illustrated[3] the linear quark-quark potential necessary for confinement. However, very little is still known about the direct excitation of the flux tube. The observation of such direct manifestations of gluonic degrees of freedom will provide understanding of confinement[4]. The quantum numbers of the flux tube, added to those of a $q\bar{q}$ meson, can produce exotic hybrids with unique J^{PC} quantum numbers. These excitations can be probed far more effectively with photons than with π- or K-mesons, because the quark spins are aligned in the virtual vector-

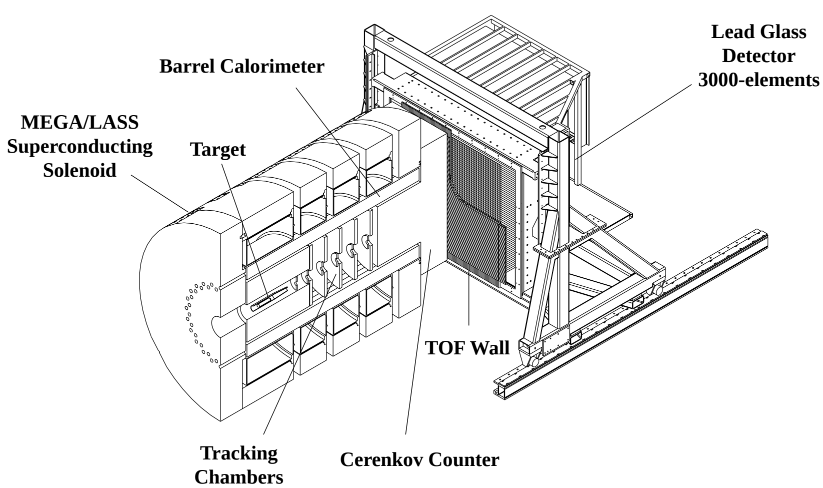

FIGURE 2. Schematic view of the detector in Hall D.

meson component of the photon. For a full partial-wave analysis of such excitations linearly polarized photons are a requisite.

The optimum photon energy for production of exotic hybrids in its expected mass range is between 8 and 9 GeV. Linearly polarized photons in this energy range are optimally produced by coherent bremsstrahlung with 12 GeV electrons. The Hall D detector provides a nearly hermetic acceptance for both charged and neutral particles and includes several particle identification systems. Figure 2 is a schematic representation of the proposed detector. Momentum analysis of charged particles is achieved with a superconducting solenoid and tracking chambers. The final planned photon flux is 10^8 photons/s. At this flux the experiment will acumulate in one year of running a factor of 100 more meson data than are presently available even from pion production.

7. ELECTRON-ION COLLIDER

A conceptual design has been initiated for a high-luminosity asymmetric (5 GeV on 250 GeV) electron-ion collider at Jefferson Lab. The ELIC (Electron Light-Ion Collider) proposal[5] is based on the following concepts. A “figure 8" booster and storage ring is added for final acceleration to a maximum of 250 GeV, spin preservation and flexible manipulation of ^{1}H, ^{2}H and ^{3}He ions. All of the remaining 20 MV cryo-modules in CEBAF are replaced by new 100 MV modules, so that electrons can be accelerated to 5 GeV in a single pass. After circulating for appr. 100 turns, the electrons are re-injected into CEBAF for deceleration and energy recovery. This design results in a maximum CM energy of over 40 GeV. A luminosity of 10^{35} cm^{-2}s^{-1} appears feasible through the use of electron cooling and crab crossings. This design will also provide a 25 GeV beam in fixed-target mode.

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