

The 12 GeV JLab Upgrade Project

Elton S. Smith *

Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606 USA

Abstract

The upgrade of the CEBAF Accelerator at Jefferson Lab to 12 GeV will deliver high luminosity and high quality beams, which will open unique opportunities for studies of the quark and gluon structure of hadrons in the valence region. Such physics will be made accessible by substantial additions to the experimental equipment in combination with the increased energy reach of the upgraded machine. The emphasis of the talk will be on the program in a new experimental Hall D designed to search for gluonic excitations.

Key words: JLab 12 GeV Upgrade, electromagnetic interactions, gluonic excitations, hybrid mesons, hadron structure

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1. Overview of the project

The 12 GeV Upgrade presents a unique opportunity for the nuclear physics community to expand its reaches into unknown scientific areas and allow researchers to probe the quark and gluon structure of strongly interacting systems. We first review the scope of the project. Then, due to limited space, we only feature two physics programs (study of gluonic excitations and study of Generalized Parton Distributions) and conclude with the current status of project construction. The description of the full experimental program using the upgraded machine can be found in Ref. [1].

The scope of the JLab 12 GeV Upgrade Project includes doubling the present energy of the accelerator, major enhancements to the equipment in the existing experimental areas, and the construction of a new experimental area (Hall D) with a new detector. In order to support these additional facilities, the project also covers the civil construction of the buildings and infrastructure associated with the Hall D complex and a major

* E-mail address: elton@jlab.org.

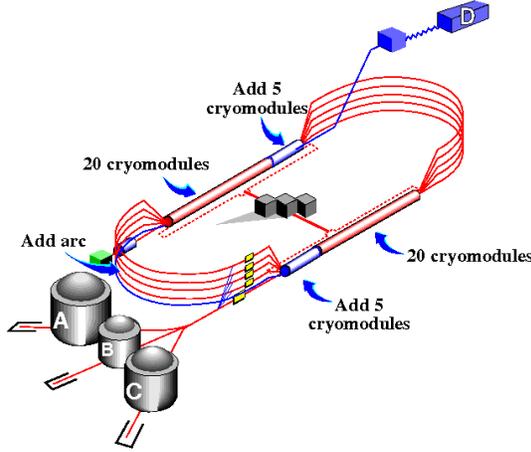


Fig. 1. Layout of the Jefferson Lab CEBAF accelerator indicating additions needed for the 12 GeV Upgrade Project.

addition to the Central Helium Liquefier (CHL) to double the cryogenic capacity for the accelerator upgrade.

The present CEBAF accelerator (Fig. 1) recirculates electrons through two superconducting linacs between one and five times delivering simultaneous independent beams to the current three experimental areas (A, B and C). The maximum gain per pass is 1.2 GeV. The typical beam energies on the experimental targets range from 0.8 to 5.7 GeV with 100% duty cycle, maximum total current of $200 \mu\text{A}$, and 75% polarization. Fortunately, the present footprint of the machine allows for growth. The 1.4 km race-track tunnel is large enough for the magnetic arcs to be able to accommodate a 12-GeV electron beam, and 20% of the linac sections are empty allowing additional accelerating cavities to be installed. The new cryomodule design aims to exceed the original CEBAF specification by a factor of five. The upgrade configuration will result in a maximum energy gain per pass of 2.2 GeV, providing the existing Halls A, B and C with up to 11 GeV. The maximum energy to Hall D will be 12 GeV, which will be achieved by adding a tenth arc and recirculating the beam 5.5 times before delivery. Three independent polarized beams can be delivered to the experimental areas with a current of up to $90 \mu\text{A}$ at the maximum beam energy.

In order to capitalize on the physics opportunities offered by the increased kinematic reach and quality of beams of the upgraded accelerator, the experimental equipment in each of the halls will have significant improvements. The CEBAF Large Acceptance Spectrometer (CLAS) will be upgraded to the CLAS12 detector (Fig. 2) to meet the requirements of the study of the structure of nucleons and nuclei. Its main features include operating at a luminosity of $10^{35} \text{cm}^{-2} \text{s}^{-1}$, a ten-fold increase over the current CLAS operating conditions, and detection capabilities and particle identification for forward-going high momentum charged and neutral particles. The Hall C facility will use the existing High Momentum Spectrometer (HMS) together with a new Super High Momentum Spectrometer (SHMS), powerful enough to analyze charged particles approaching the beam momentum. The SHMS will cover a solid angle up to 4 msr with sensitivity down to 5.5° using a small horizontal-bend magnet. The beamline into Hall A will be

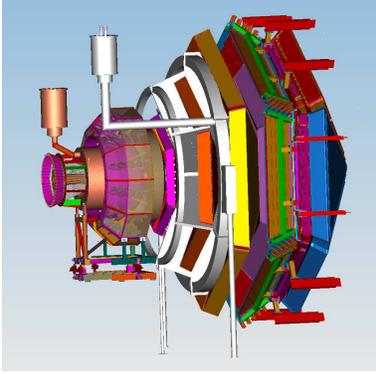


Fig. 2. CLAS12 detector in Hall B.

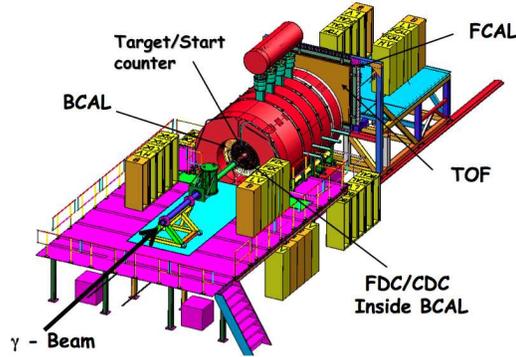


Fig. 3. Layout of the Hall D detector and electronics.

upgraded to transport the full 11 GeV beam into the experimental area for experiments using the existing spectrometers, and for installation of major specialized experiments. The Hall D facility (Fig. 4) will use the 12 GeV electron beam to produce a coherent bremsstrahlung beam. This photon beam, which peaks in the energy range between 8.4 and 9.0 GeV, is 40% linearly polarized and will be used to carry out a program in gluonic spectroscopy with the new Hall D detector (Fig. 3).

2. Gluonic excitations

The observation, nearly four decades ago, that mesons are grouped in nonets, each characterized by unique values of J^{PC} – spin (J), parity (P) and charge conjugation (C) quantum numbers – led to the development of the quark model. Within this picture, mesons are bound states of a quark (q) and antiquark (\bar{q}). The three light-quark flavors (*up*, *down* and *strange*) suffice to explain the spectroscopy of most – but not all – of the lighter-mass mesons (below $3 \text{ GeV}/c^2$). Early observations yielded only those J^{PC} quantum numbers consistent with a fermion-antifermion bound state. Other J^{PC} combinations, such as 0^{--} , 0^{+-} , 1^{-+} and 2^{+-} , require additional degrees of freedom and are called *exotic* in this context.

Our understanding of how quarks form mesons has evolved within quantum chromodynamics (QCD) and we expect a rich spectrum of mesons that takes into account not only the quark degrees of freedom, but also the gluonic degrees of freedom. Excitations of the gluonic field binding the quarks can give rise to so-called *hybrid* mesons. (For a review see Ref. [2]). A picture of these hybrid mesons is one where these particles are excitations of a gluonic flux tube that forms between the quark and antiquark. Particularly interesting is that many of these hybrid mesons are expected to have exotic J^{PC} quantum numbers, which simplifies the spectroscopy because they do not mix with conventional $q\bar{q}$ states. The level splitting between the ground state flux tube and the first excited transverse modes is expected to be about $1 \text{ GeV}/c^2$, and lattice QCD calculations [3] indicate the lightest exotic hybrid (the $J^{PC} = 1^{-+}$) has a mass of about $1.9 \text{ GeV}/c^2$. The GLUEX experimental search in Hall D has a mass reach up to about $2.8 \text{ GeV}/c^2$ to observe mesons with masses up to $2.5 \text{ GeV}/c^2$.

There are tantalizing suggestions, mainly from experiments using beams of π mesons,

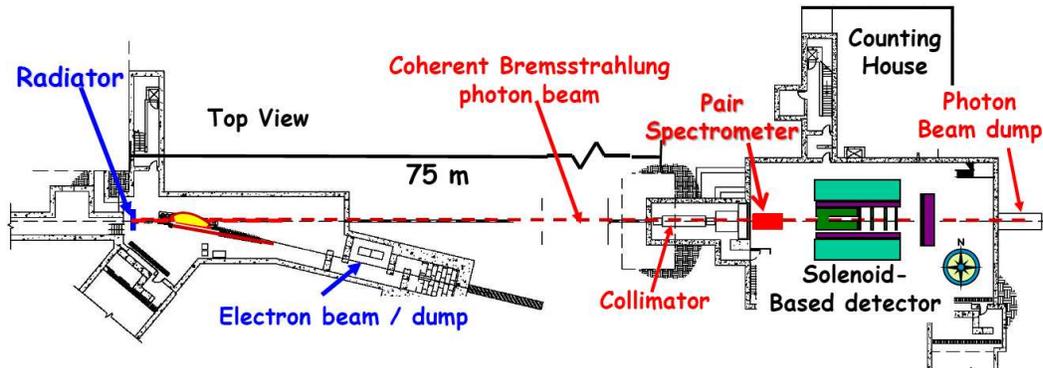


Fig. 4. Layout of the Hall D photon beamline.

that exotic hybrid mesons do exist. The evidence is by no means clear cut, owing in part, to the apparently small production rates for these states in the decay channels examined. It is safe to conclude that the extensive data collected to date with π probes have not uncovered the hybrid meson spectrum. Based on models, such as the flux-tube model, we expect the production of hybrid mesons in photon induced reactions to be comparable to the production of normal mesons.

Photoproduction of mesons using an ≈ 9 GeV, linearly polarized photon beam provides a unique opportunity to search for exotic hybrids. Existing data is extremely limited for charged final states, and no data exist for multi-neutral final states. To carry out such a search, GLUEX will need to look at many different final states involving both charged particles and photons, but particular emphasis will be placed on those reactions that have 3 or more pions in the final state. The discovery potential for GLUEX comes first from the very high statistics based on 10^7 tagged γ 's on target, which will exceed existing photoproduction data by 4 to 5 orders of magnitude. Second, GLUEX has the ability to

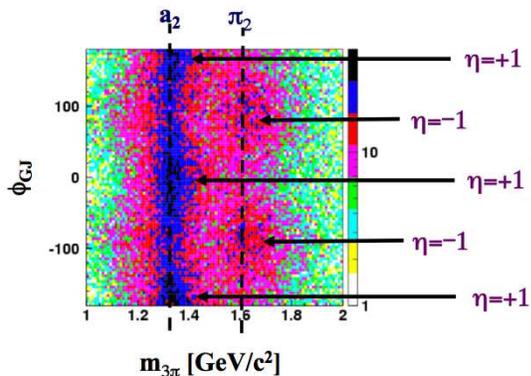


Fig. 5. Correlations between the angular decay distributions and the mass of the parent system decaying to three pions. The major particles in the spectrum are indicated as well as nodes in the decay spectrum, highlighting the wealth of information in decay correlations when the incident photon is polarized.

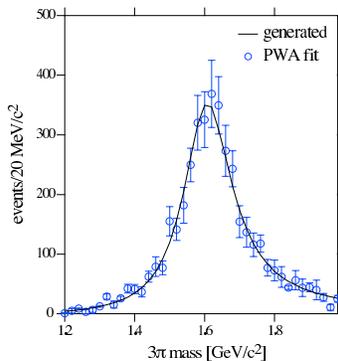


Fig. 6. Expected precision for extracting an exotic wave representing 2.5% level of the total sample consisting of six non-exotic waves.

study many different final states in the same detector. These two capabilities will identify hybrids, if they exist at the few percent level, and also map out their decay properties.

Determining the quantum numbers of mesons produced in the GLUEX experiment will require an amplitude analysis based on measuring the energy and momentum of their decay products. An example of the rich information content in the decay angular distributions is shown in Fig. 5, which is exploited in the amplitude analysis. In a partial-wave analysis exercise on Monte Carlo data, exotic waves of order a few percent of the total sample could be extracted reliably as shown in Fig. 6. In summary, the GLUEX detector has been designed to carry out a broad program to study gluonic excitations and provide extensive data to search for exotic mesons in the essentially unexplored territory of photoproduction reactions.

3. 3D view of the nucleon

Historically, electron scattering experiments have focussed either on the measurements of form factors, using exclusive processes, or on measurements of inclusive processes to extract deep inelastic structure functions. Elastic processes measure the momentum transfer dependence of the form factors, while the latter ones probe the quark's longitudinal momentum and helicity distributions in the infinite momentum frame. Form factors and deep inelastic structure functions measure two different slices of the proton structure. While it is clear that the two pictures must be connected, a common framework for the interpretation of these data has only recently been developed using Generalized Parton Distribution (GPD) functions. Mapping out the GPD's will allow, for the first time, to obtain a 3-dimensional picture of the nucleon. For reviews of this subject, see e.g. Refs. [4,5].

Unravelling the information about GPDs from the data is not a simple task. It requires an extensive experimental program and detailed analysis with controlled theoretical cor-

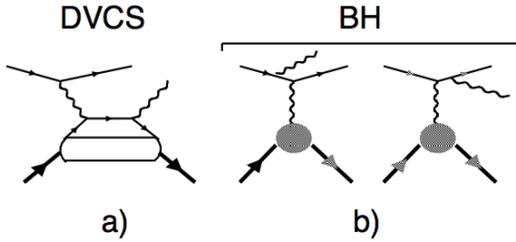


Fig. 7. Schematic handbag diagrams for deeply virtual Compton scattering (left) and Betler-Heitler process (right).

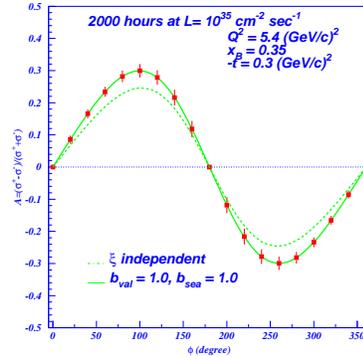


Fig. 8. Expected precision in the measurement of a DVCS asymmetry as a function of the azimuthal angle ϕ for a specific kinematic point specified by Q^2, x_B and $-t$. The curves show typical predicted model dependencies of the asymmetry.

reactions. Measurements of cross sections on the proton and neutron, as well as beam spin asymmetry measurements, will be needed to disentangle the GPDs. The reaction $ep \rightarrow ep\gamma$ (Fig. 7) includes the physically interesting amplitude for Deeply virtual Compton scattering (DVCS). This process is the cleanest tool for constraining GPDs from the data, because it is in the most advanced stage of theoretical studies. Therefore we use DVCS to illustrate the wealth of data which will be accessible using CLAS12. The reaction is dominated by the Bethe-Heitler (BH) amplitudes, but the interference term between DVCS and BH can be probed using polarized electron beams via the single beam spin asymmetry, which is dominated by the $\sin\phi_{\gamma\gamma^*}$ moment. In this case, the small DVCS amplitude which depends on the GPD's, is amplified by the larger but well-known BH amplitude.

The large coverage for photons by the CLAS12 detector will allow clean identification of the DVCS events, and with the large acceptance, cross sections and spin asymmetries will be measured in a large number of kinematic bins simultaneously. From the more than one thousand kinematic bins measured, we show one example of the beam spin asymmetry in Fig. 8. The expected experimental precision is sufficient to be sensitive to different model calculations which are also shown on the figure.

4. Status of the project and summary

The approval for construction of the project, known as Critical Decision 3, was received in September 2008. Construction funding has begun, with commissioning planned to start in 2013. Contracts for civil construction are in progress and orders for major components for the accelerator and experimental equipment are being placed. We have presented two examples of the exciting physics program envisioned for this facility, demonstrating some of its unique features that will extend our understanding of the strong interactions.

5. Acknowledgments

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