The Jefferson Lab program: from 6 GeV operations to 12 GeV upgrade

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Abstract

The Thomas Jefferson National Laboratory and the CEBAF accelerator operated for more than a decade running a comprehensive scientific program that improved our understanding of the strong interaction. The facility is now moving toward an upgrade of the machine, from 6 GeV to 12 GeV, a new experimental hall will be added and the equipment of the three existing halls will be enhanced. In this contribution some selected results from the rich physics program run at JLab, as well as the prospective for the near future will be presented.

1 JLab scientific mission

QCD is the theory of strong interaction but, so far, many different aspects of hadron dynamic are not completely understood within this theory. There are still many questions that need an answer: understand how hadrons are constructed from quarks and gluons, understand the QCD basis for the nucleon-nucleon force, explore the limits of our understanding of nuclear structure. To make progress in this areas some critical issues have to be addressed: what is the mechanism of confinement? Where does the dynamics of the $q-q$ interaction make a transition from the strong (confinement) to the perturbative (QED-like) regime? How does Chiral symmetry breaking occur? JLab is carrying out a comprehensive experimental program to map out the transition from a picture based on nucleon and meson to a more fundamental view that makes use of the correct degrees of freedom of the QCD, i.e. quark and gluons. Beside the traditional *nuclear physics*, parity violation experiments were run to probe potential new physics trough high precision tests of the Standard Model. Many results were obtained in more than ten years of operations and many progresses in our understanding of fundamental interaction has been reached but the JLab mission does not run out and an upgrade of the accelerator to higher energy is now preparing another decade of great achievements.

2 Present status and progress on the 12 GeV upgrade

CEBAF (Continuous Electron Beam Accelerator Facility) is the heart of Jefferson Lab. It is an electron machine designed to deliver up to 6 GeV maximum energy electron beam to three experimental halls (Hall-A, -B and -C). Figure 1 shows the CEBAF sketch. Electrons are injected at 45 MeV and accelerated by superconducting RF cavities in two 0.4 GeV linac sections. Recirculation arcs keep the

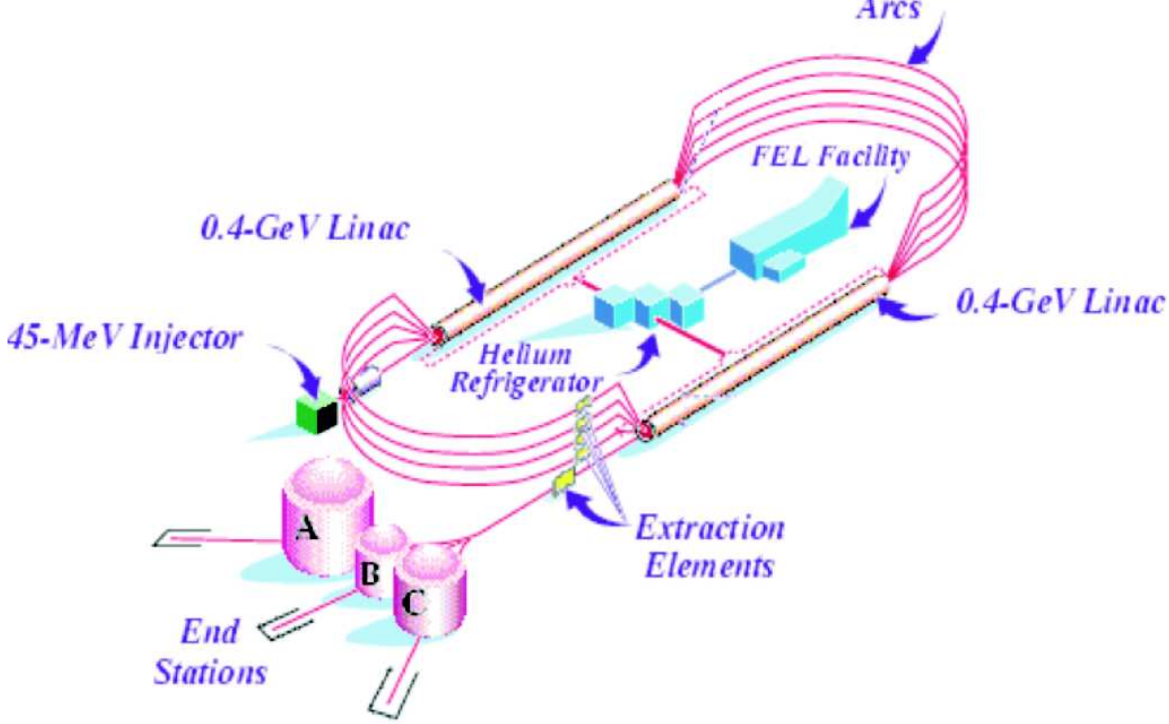

Figure 1: The CEBAF accelerator, the heart of JLab.

electron trajectory for multi-pass acceleration up to the desired extraction energy. The corresponding electron wavelength, ranging from 0.1 fm to 10 fm, is perfectly matched to explore the transition regime from quarks to nucleons. The main characteristic of CEBAF is the capability of deliverying an almost continuous-beam with 100% duty factor that is necessary to study exclusive reactions with detection of multi-particle final states. In addition the electron beam polarization of 80% extends the capability of studying the nucleon spin degrees of freedom and run precision weak neutral current experiments. With a luminosity that is about 6 order of magnitudes higher than the luminosity available at SLAC at the time of the original DIS experiments, CEBAF is the most advanced and highest performance electron machine ever built to explore this energy region. Experiments run simultaneously in three experimental halls. Beam intensity (from 100 pA to 100 μA) and energy (from 0.4 to 6 GeV) is independently varied allowing ones to run complementary physics programs in the three end stations. Hall-A is equipped with a pair of High Resolution Spectrometers ($\delta p/p \sim 10^{-4}$) that cover a large momentum range (0.3-4.3 GeV/c and 0.-3.3 GeV/c). The high luminosity (up to $10^{38}\text{cm}^{-2}\text{s}^{-1}$) and the presence of a proton polarimeter allowed to run precision experiment as the precise determination of the elastic proton form factors. Other detectors recently installed, such as the BigBite spectrometer or the DVCS calorimeter, extended the Hall-A capabilities. Hall-B hosts the CLAS (CEBAF Large Acceptance Spectrometer) detector, a 4π magnetic spectrometer based on six-coil toroidal field with a large kinematic coverage and the capability of running high luminosity experiments (up to $10^{34}\text{cm}^{-2}\text{s}^{-1}$). CLAS is well suited for simultaneous measurement of multi particle final states of exclusive reactions and a central field-free region allows to operate polarized targets for a complete extraction of reaction amplitudes. Hall-C is equipped with a pair of magnetic spectrometers: the High Momentum Spectrometer, maximum momentum up 7.5 GeV/c and resolution down to $\delta p/p \sim 10^{-3}$, and the Short Orbit Spectrometer, with 40% momentum acceptance. Hall-C has been used for dedicated experiment requiring large installations such as G_0 (parity violation) or Q_{weak} (measurement of the weak charge). The complementarity of the

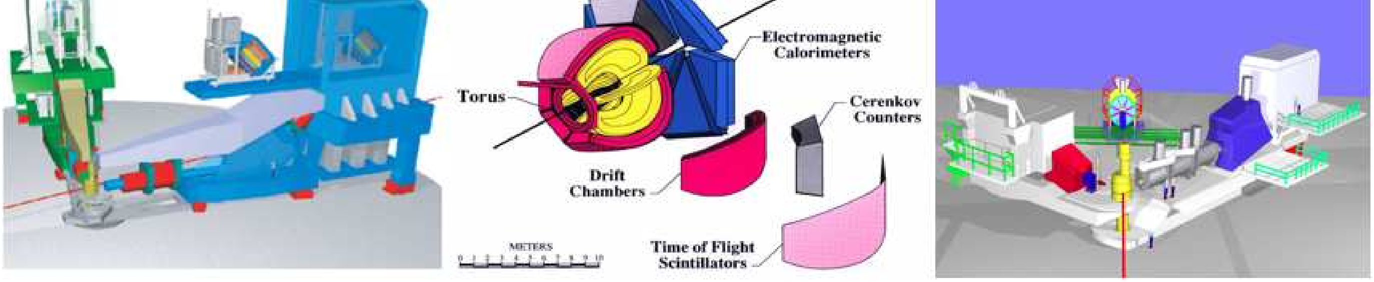

Figure 2: Detectors in the three experimental halls.

three Hall's equipment allowed to run a rich physics program, the distinctive character of Jefferson Lab. We are now in the phase of upgrading CEBAF from 6 GeV to 12 GeV operation. The design of CEBAF and the outstanding performance of the machine, make easy the energy upgrade. CEBAF RF cavities exceeded the designed specification by a 50% allowing to run the 6 GeV after few years from the beginning of the operations. The original accelerator design was so well devised, that it is now easy to expand it without major civil construction and big investments, e.g. arcs can accomodate an electron beam of energy up to 24 GeV. The end stations will be upgraded as well: Hall-A will be equipped with a new multipurpose, high resolution spectrometer to study short range correlations in nuclei, to extend the knowledge of elastic form factors at large Q^2 and, is ready to host new dedicated detectors such as SOLID, MOELLER or SBS. In Hall-B, CLAS12, a large acceptance detector for high luminosity measurement will be used to study the nucleon structure via GPDs and run a meson spectroscopy program. A super high momentum spectrometer in Hall-C will be used for precise determination of valence quark properties in nucleons and nuclei. A new experimental hall will be added, Hall-D, equipped with a 4π detector, GLUEx, entirely devoted and optimized to explore the origin of confinement by studying hybrid mesons by mean of photoproduction experiments. The upgrade of the CEBAF accelerator to 12 GeV and the upgrade of the whole laboratory, stated as the highest priority project of the 2007 NSAC Long Range Plan, is now well underway. The upgrade is *on cost and on schedule* and over half complete as of today. Initial beam operation are expected to begin in Hall-A in October 2014 and full operations are expected by June 2015.

3 JLab physics today and the 12 GeV era: the nucleon elastic form factors

The broad physics program carried out at JLab so far will be extended to the new 12 GeV era. It can be summarized in four different areas: nucleon structure, quark electro-weak coupling, physics of confinement and the quark structure of nuclei. A detailed report on the results obtained and the projects for the future in each area is beyond the scope of these proceedings. I will briefly illustrate, as an example, the achievemnt in understanding the nucleon structure obtained by measuring the electromagnetic elastic form factors. Protons and neutrons are the *hydrogen atom* of QCD and therefore a clear picture of the dynamic governing their properties is the first step towards a full understanding of strong forces. Electromagnetic interaction is the ideal tool to study nucleons: the well know QED and the possibility of varying spacial resolution allow us to map the nucleon constituents at different scales: for distances greater than 1 fm, the nucleon appears as a whole, a spin 1/2 and electric charge 0/1 particle. Reducing the wavelength from 0.1 to 1 fm, degrees of freedom of constituent quarks can be accessed, while for size smaller than 0.1 fm all the richness and complexity of QCD with *bare* quarks and

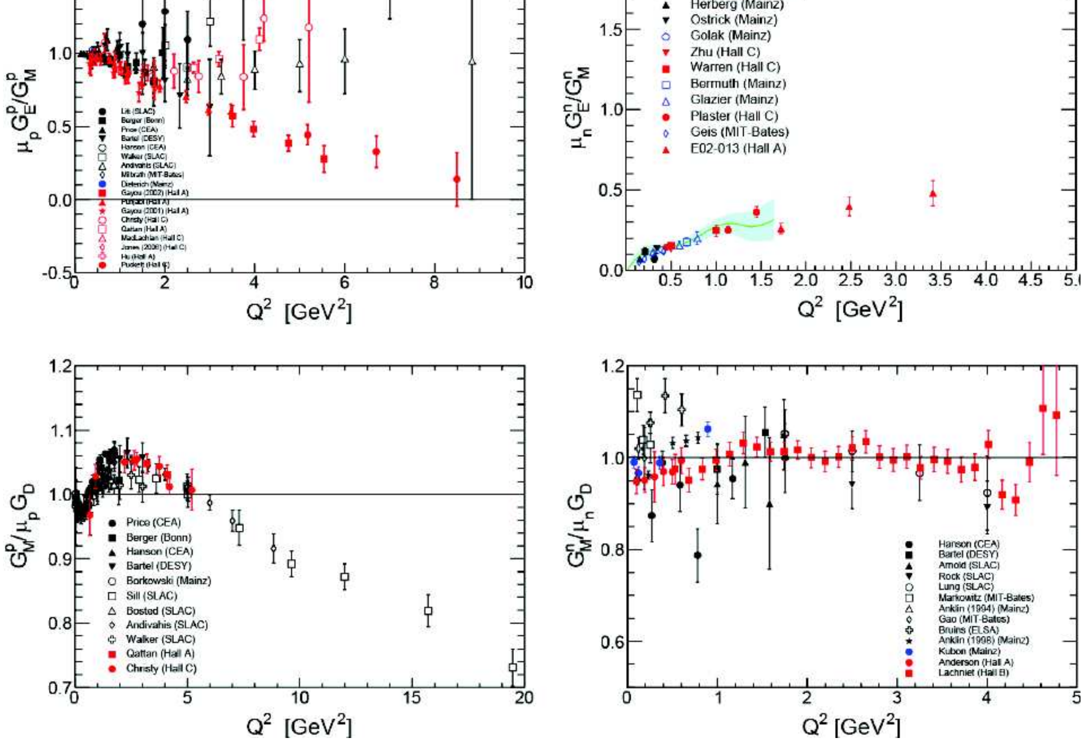

Figure 3: Nucleon elastic electric and magnetic form factors before and after JLab measurements (reported in red) as a function of the momentum transfer Q^2. Proton is shown on the left while neutron on the right.

gluons shows up. Nucleon structure is mapped out by running different electron scattering experiments: elastic electron scattering probes transverse quark distribution in coordinate space providing charge and current densities; Deep Inelastic Scattering provides information about the longitudinal quark distribution in momentum space; deep exclusive scattering combines the two providing fully-correlated distribution in both coordinate and momentum space via Generalized Parton Distributions. As an example, Fig. 3 shows the elastic electromagnetic form factors for proton and neutron. The extended kinematic coverage and the G_E^p new results [1] obtained with the polarization transfer technique, in disagreement with old data points obtained using the Rosenbluth separation, provides a testing ground for theories constructing nucleons from quarks and glue. The inequality of G_E and μG_M was a surprise. The reconciliation of the two methods is still debated: a more precise treatment of radiative corrections or the Two-Photon-Exchange contribution, usually neglected in the electro-scattering description, may explain the discrepancy. From the new data we learned that relativity is essential and a proper treatment of quark angular momentum is important as well as the contribution of the pion cloud surrounding the nucleon core. For the 12 GeV upgrade, many experiments are planned to extend our knowledge of such fundamental quantity in a wider Q^2 range: the Super BigBite Spectrometer in Hall-A will measure G_E^p up to 15 $\mathrm{GeV^2/c^2}$ [2] and CLAS12 in Hall-B will extend G_M^n measurement up to 13 $\mathrm{GeV^2/c^2}$ [3].

4 Conclusions

CEBAF at Jefferson Lab is fulfilling its scientific mission to understand how hadrons are constructed from QCD quarks and gluons, to understand the QCD basis for the nucleon-nucleon force, to explore the limits of our understanding of nuclear structure. With more than 10 years of high precision experiments, uses quark and gluons, we progressed our understanding of strong interaction. We are now moving to a new era with improved detector, higher energy and a comprehensive experimental program for the next 10 years. The 12 GeV upgrade will greatly enhance the scientific reach of the facility supporting an exciting program of fundamental research.

References

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