CEBAF UPGRADE AT JEFFERSON LABORATORY

A.V. Glamazdin
National Science Center "Kharkov Institute of Physics and Technology", Kharkov, Ukraine
E-mail: glamazdi@jlab.org

Upgrade to CEBAF accelerator and all experimental halls to increase the maximal beam energy from 6 up to 12.1 GeV is in progress at Jefferson Laboratory. Schedule, plans and present status of the upgrade are presented in the article.

PACS: 29.20.Ej;29.27.Eg;29.27.Aj;29.30.Aj

INTRODUCTION

Accelerator facility CEBAF of the Thomas Jefferson National Accelerator Facility (Jefferson Lab) is in operation since 1997. It includes superconducting electron accelerator CEBAF, three experimental halls A, B and C and free electron laser.

"Racetrack" type accelerator CEBAF consist of an injector, two superconducting linacs ("North" and "South"), two sets of arcs ("East" set has five arcs, "West" set has four arcs) and systems of an electron beam extraction from the accelerator and beam separation between the halls.

Maximal beam energy after one linac is 0.6 GeV and after one pass is 1.2 GeV. It corresponds to the maximal beam energy 6.0 GeV after five passes.

CEBAF injector can provide polarized and unpolarized electron beams with different currents and energies for all three experimental halls simultaneously. The injector provides quasi-continuous electron beam with bunches frequency 499 MHz per each hall and accelerator frequency is 1497 MHz.

After 15 years of successful operation ones was decided to upgrade CEBAF to increase the accelerator energy and to improve parameters of experimental halls.

1. ACCELERATOR UPGRADE PROJECT

CEBAF accelerator upgrade project [1, 2] includes (Fig. 1):

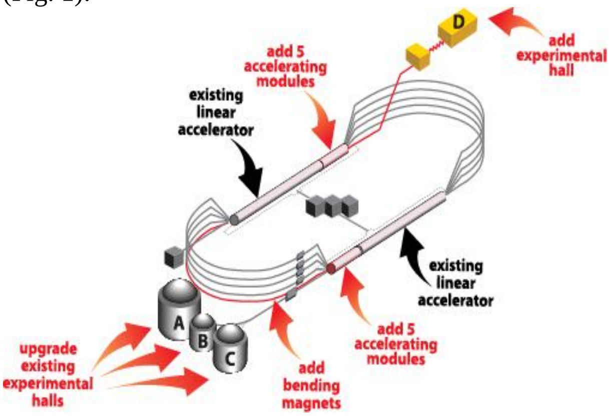

Fig. 1. CEBAF 12 GeV upgrade project

– Add ten new higher-voltage accelerating modules C100, five per each linac, to increase the maximal beam energy per linac from 0.6 GeV up to 1.1 GeV;

– New extraction line from "North" linac to new experimental hall D;

– Add new 10-th arc in the "West" arcs set to increase maximal number of passes in the accelerator from five to five and a half and provide maximal beam energy 12.1 GeV in the hall D;

– Upgrade of the existing arcs;

– Upgrade of the injector;

– New central helium liquefier CHL-2 to increase production of liquid helium.

Comparison of CEBAF parameters before and after upgrade are presented in Table. 1.

Table 1

Comparison of CEBAF parameters before and after upgrade [2]

Parameter	Before	After
Maximal number of passes in accelerator	5	5.5
Maximal beam energy, GeV	6	12.1*
Maximal beam energy per pass, GeV	1.2	2.2
Maximal beam current, μA	185	85**
Max. beam power, MW	1	1
Emittance ε_x, nm-rad	<1	10
Emittance ε_y, nm-rad	<1	5
Energy spread (%RMS)	0.003	0.05
Number of experimental halls	3	4

* – *in Hall D after five and a half turns;*
** – *maximal beam current in accelerator at maximal beam energy.*

1.1. CEBAF INJECTOR UPGRADE

The injector upgrade includes [3]:

– Increase of the gun voltage from 130 kV to 200 kV;

– Upgrade of the Wien filter;

– New booster with new SRF design;

– Integration of Capture into the booster;

– Upgrade of the Cryo-modules to increase the injector energy from 45 MeV to 123 MeV.

1.2. ACCELERATING CRYOMODULE C-100

New accelerating cryogenic module C-100 was developed at Jefferson Lab for the 12 GeV upgrade project. The 12 GeV cavities have been supplied by Research Instruments. Cryomodule consists of eight cavities with seven halfway cells per cavity (Fig. 2).

Fig. 2. Cavity of new Cryomodule C-100

A design gradient for the new cryomodule C-100 is 19.2 MV/m (108 MV for 5.6 m of cryomodule length). An operational limit is 25 MV/m. It is limited by the klystron RF power and possibly field emission. When testing on stand, all new cryomodules show performance exceeding the specifications. Particularly, C100-5 were found to quench at ~33.5 MV/m [4].

All ten cryomodules C-100 were manufactured, tested and installed on the accelerator CEBAF (Fig. 3). Two of the ten C100 were installed on the accelerator in 2011 and were successfully operated since November 2011 through May 2012.

Fig. 3. New Cryomodule C-100 with Waveguide installed in South Linac

1.3. CEBAF ARCS UPGRADE

A combination of old and new elements will be used in arcs upgrade to reduce the 12 GeV upgrade project cost. Precision field mapping will be done for all old and new magnets in the arcs.

Old elements will be used in the arcs after upgrade:

– 357 dipole magnets (1…3 m length);

– 730 quadruple magnets (30×30×30 cm);

– More than 2000 power supplies;

– More than 700 elements of the beam diagnostics;

More than 5 km of the beam lines.

News elements will be used to build a new 10-th arc and to upgrade existing arcs:

– 32 dipole magnets (4 m length);

– 40 quadruple magnets (35×30×30 cm);

– 82 power supplies;

– 32 elements of the beam diagnostics;

– 0.3 km of the beam lines.

Due to delay with delivery of power supplies for magnets in arcs 7…10 CEBAF accelerator will be operated with maximal beam energy 6.6 GeV (three passes) through summer 2014.

1.4. CENTRAL HELIUM LIQUEFIER

The helium liquefier CHL currently working at CEBAF uses a 4.8 kW 2 K helium refrigerator for cooling the superconducting accelerator and physical facilities. Doubling the maximum energy of the accelerator beam, and the reconstruction of the physical equipment in the halls and the creation of a new hall D require an increase in productivity of helium. To achieve this goal, in addition to the existing liquefier CHL, a new liquefier CHL-2 was build. With two liquefiers, the total capacity of production of helium at a temperature of 2 K is 10.2 kW.

2. EXPERIMENTAL HALLS

Running a program of experimental research on CEBAF accelerator beam with an energy of 12 GeV requires a diverse set of physical hardware. After the reconstruction, CEBAF will include three old experimental Halls: A, B and C, and a new Hall D.

A new experimental Hall D will be equipped with the tagged photon detector and a detector based on large superconducting solenoid magnet (see Ch.2.4).

Beam lines in experimental Halls A, B and C will be upgraded in accordance with the higher energy electron beam. This upgrade includes reconstruction of the beam transport system to the Hall, the Moller and the Compton polarimeters, the beam raster system, etc.

12 GeV upgrade in Hall A is minimal. The Hall A space will be used as a platform for building new detectors for specific experiments (see Ch.2.1). In Hall B, as a replacement of the existing CLAS spectrometer, a new spectrometer of the same type, CLAS12, will be built (see Ch.2.2). In Hall C, as a replacement of the existing spectrometer SOS, a new spectrometer SHMS will be developed (see Ch.2.2).

Finally, a new set of equipment in all four halls will allow to conduct experiments in the whole energy range of the accelerator CEBAF (1…12 GeV) with photon or electron beams with high luminosity and high resolution.

2.1. EXPERIMENTAL HALL A

Due to limited funds, upgrade in Hall A is reduced to the reconstruction of the beam line elements, upgrade of the Moller and the Compton polarimeters to allow them to work with a maximum beam energy of the accelerator CEBAF in the Hall (11.0 GeV). The magnets of the ARC energy measurement system will be refurbished and remapped at the larger acceptance to provide the beam energy measurement accuracy $\Delta E/E=\pm 5\times 10^{-4}$.

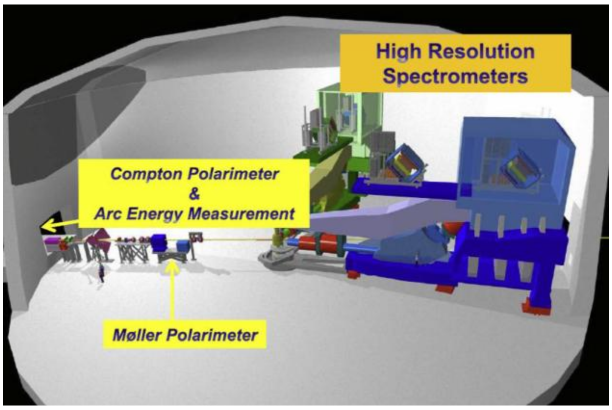

Fig. 4. Layout of Hall A showing the existing pair of High Resolution Spectrometers and polarimeters being upgraded

Hall A will continue to use two existing high-resolution spectrometers HRS (High Resolution Spectrometer) with a maximum momentum of 4 GeV/c (Fig. 4), as well as a set of the existing equipment: neutron detector NeutronArm, a large acceptance spectrometer BigBite, Hadron calorimeter Big-Cal and the detector DVCS [5].

The minimal reconstruction in Hall A will allow it to become the first experimental hall to begin physical experiments on the accelerator CEBAF after the 12 GeV upgrade.

In the future, large one-of-a-kind facilities for specialized experiments will be created in Hall A.

One of such facilities is SBS (**S**uper **B**ig Bite **S**pectrometer). SBS is a spectrometer designed to perform series of experiments of measurements of the nucleon form factor, down to the smallest distance scales accessible at Jefferson Lab [6]. SBS scheme is represented in Fig. 5.

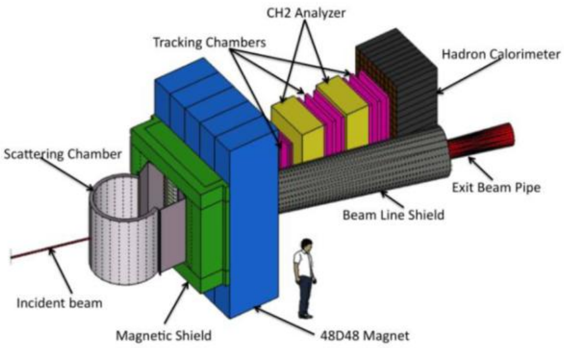

Fig. 5. Layout of new spectrometer SBS (Super Big Bite) in Hall A

SBS spectrometer consists of a large acceptance dipole magnet with the possibility to capture particles at small forward angles, a set of 64 tracking chambers of GEM-type (Gas Electron Multiplier), a carbon analyzer and a hadron calorimeter.

MOLLER experiment is an extension of the experiment E-158 "Measuring the effects of parity violation in Moller scattering", which was done at SLAC. The MOLLER experiment has to measure a parity-violating asymmetry in fixed electron scattering with unprecedented precision.

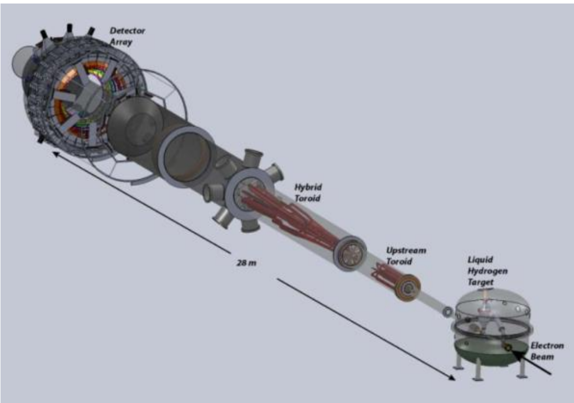

Fig. 6. Layout of MOLLER experiment equipment in Hall A

Layout of the experiment MOLLER [7] is shown on Fig. 6. The following instruments will be built for the experiment: a new liquid hydrogen target with a length of 1.5 m and a capacity of 5 kW, two room- temperature toroidal magnets, a dipole magnet downstream of the target to remove background, specialized very forward angle detector, reconstructed beam line in Hall A.

According to the plans, the MOLLER experiment will be running for about 3 years, and will become the longest-running experiments in the history of Hall A.

SoLID spectrometer (**So**lenoidal **L**arge **I**ntensity **D**evice) [8, 9] is designed for three series of experiments:

– Measuring of parity violating deep inelastic scattering (PVDIS);

– Measuring of semi inclusive deep inelastic scattering;

– Measuring of cross-section of electro-production of J/Ψ mesons near threshold.

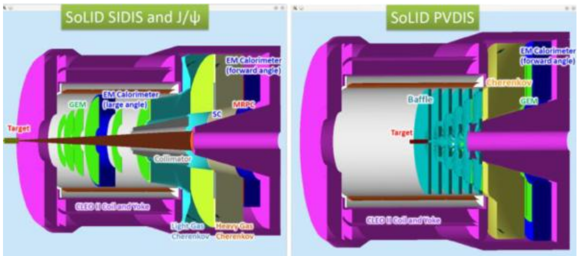

Fig. 7. Scheme of the two detector configurations SoLID for experiments SIDIS and PVDIS in Hall A

The SoLID (Fig. 7) is a versatile apparatus based on a large superconducting solenoidal magnet formerly used for experiments CLEO in CESR. The magnet will serve as a mounting platform for two different configurations of detectors, which consist of tracking, chambers GEM-type, two (forward and backward) electromagnetic calorimeters, a set of baffles, and a set of gas Cherenkov counters with different fillings.

2.2. EXPERIMENTAL HALL B

After the 12 GeV upgrade, Hall B will be equipped with a large acceptance spectrometer CLAS12 (**C**EBAF **L**arge **A**cceptance **S**pectrometer) (Fig. 8). Magnetic Spectrometer CLAS12 [10] consists of two superconducting magnets: a six-sector torus with maximum field 2.3 T, and a ~1 m long solenoid with a maximum field 5 T.

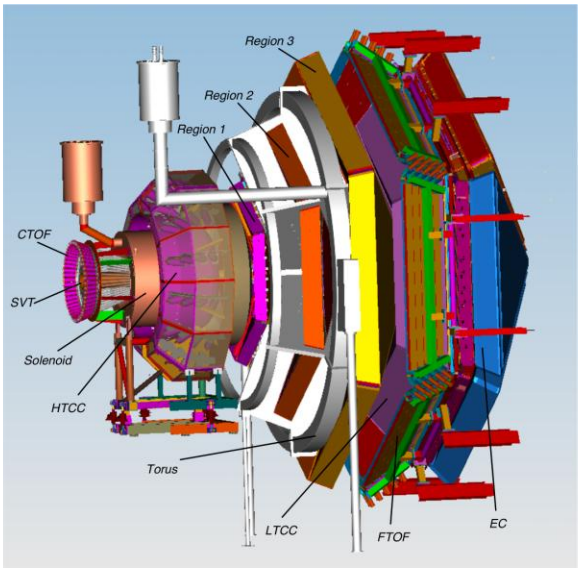

Fig. 8. Schematic of CLAS12 – a new spectrometer in Hall B

The new detector will use some parts from the existing detector CLAS, such as a front time-of-flight (TOF) detector, an electromagnetic calorimeter (EC), the restored and reconstructed Cherenkov counter. The structure of the detector CLAS12 will include new instruments: a central time-of-flight detector, a drift chamber, a four-layer silicon-strip vertex tracker (SVT), a high-threshold Cherenkov counter (HTCC) and a pre-shower calorimeter. In the future, CLAS12 will be equipped with a RICH detector to improve the identification of kaons.

CLAS12 detector will be able to register particles with energies within the entire range of accelerator CEBAF (up to 11 GeV) and will have a 10 times higher luminosity than the CLAS.

2.3. EXPERIMENTAL HALL C

In the Hall C, the existing spectrometer SOS (**S**hort **O**rbit **S**pectrometer) will be replaced with a new spectrometer SHMS (**S**uper **H**igh **M**omentum **S**pectrometer). The existing spectrometer HMS (**H**igh **M**omentum **S**pectrometer) will be used as a complement to the SHMS spectrometer (Fig. 9) [11]. Comparison of the parameters of the existing HMS spectrometer and the new spectrometer SHMS is given in Table 2. This pair of heavily shielded magnetic spectrometers allows for high-precision measurements of neutrino-like cross sections to map valence quarks in nucleons and nuclei.

Table 2

Comparison of parameters
of the Hall C spectrometers HMS and SHMS

Parameter	HMS	SHMS
Scheme	QQQD	DQQQD
Maximal momenta, GeV/c	7.5	11.0
Energy resolution, ΔP/P	0.5×10^{-3}	0.5×10^{-3}
Angular acceptance, msr	6.5	5.0
Momentum acceptance ΔP, %	18	30
Angles range, deg	10.5…90°	5.5…40°

All five of the spectrometer magnets SHMS are superconducting. A SHMS spectrometer detector package consists of a Cherenkov detector (filled with Ar or Ne), a set of two coordinate (x-y) drift chambers, two two-axis (x-y) scintillation hodoscopes, a Cerenkov detector (filled with C4F8O), two two-axis (x-y) scintillation trigger hodoscopes, and the electromagnetic calorimeter consisting of pre-shower and shower detectors, both built of lead glass blocks.

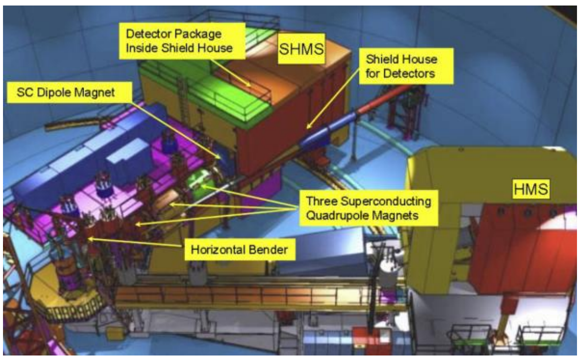

Fig. 9. Layout of Hall C after reconstruction. The existing HMS detector and a new detector SHMS are shown

Some space in the detector is reserved for future detectors, such as an aerogel-based Cherenkov counter. In addition, it is possible to remove some of the detectors and insert a proton polarimeter.

2.4. EXPERIMENTAL HALL D

A new Hall D is designed to conduct experiments on the photon beam and for the study of new exotic states. Hall D equipment includes a diamond target for photon beam production, a system of photon tagging and photon detector GlueX (Fig. 10), which is named in honor of the main experiment in program of physics research in Hall D [12].

The linearly polarized photon beam is produced by scattering of the electron beam on the diamond crystal which is located 75 m from the detector GlueX. Photon beam is separated from electronic components in the tagger magnet and hits the target. The maximum energy of the electron beam in Hall D is 12.1 GeV. It corresponds to the photon energy 9 GeV.

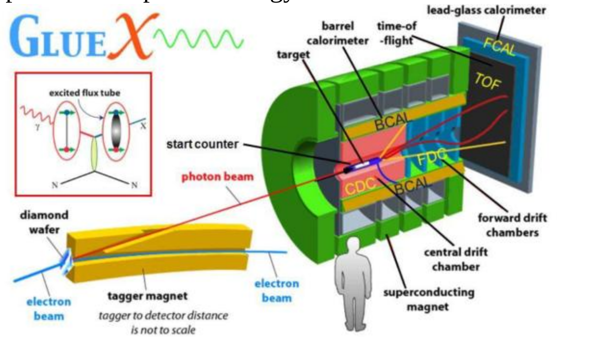

Fig. 10. Layout of detector Glue-X in new hall D

GlueX spectrometer is based on a superconducting solenoid with the 2 m diameter and 4m length, and with a maximum field 2 T.

GlueX detector consists of two parts placed inside and after the solenoid. The part of GlueX detector located inside the solenoid consists of a starter counter, central and forward drift chambers and a barrel electromagnetic calorimeter. The part located after the solenoid consists of a lead-glass calorimeter and a time-of-flight detector.

3. TIMING OF THE 12 GeV UPGRADE PROJECT

The 12 GeV CEBAF upgrade project consists of several stages [2]:

1. May 2011 - November 2011: two new cryomodules C100 were installed on the accelerator (one per each linac) for testing with electron beam and operation since November 2011 through May 2012;

2. June 2012 - October 2013: complete upgrade of the accelerator CEBAF;

3. November 2013 - January 2014: running CEBAF accelerator with energy 2.2 GeV (one pass). Complete Hall A upgrade;

4. January - May 2014: run the accelerator with the beam energy 6.6 GeV. Beam delivery to Hall A for testing of the systems of beam extraction and separation, Hall A beam line and Hall A equipment;

5. September 2014 - May 2015: the energy of the beam up to 9 GeV. The beam delivery to Hall D. Testing of the equipment and early experiments in Hall A;

6. September 2015 - May 2016: 12 GeV beam energy. The beam delivery to halls B and C;

7. March 2017: the end of 12 GeV of CEBAF upgrade project.

After the 12 GeV upgrade any three of the four experimental halls will be able to work simultaneously. The accelerator will work about 30 weeks a year with breaks for the Christmas holidays and for three summer months. The duration of the autumn session will be 13…14 weeks, and duration of the spring session will be 16…17 weeks.

CONCLUSIONS

As of July 2013, the overall rate of completion of the project is about 92%. Among them: construction – 92%, accelerator – 91%, physics – 62% [13]. Completion of the 12 GeV CEBAF upgrade project is scheduled for March 2017. The total project cost of the 12 GeV CEBAF upgrade is $338M.

This work was supported by DOE contract DE-AC05-06OR23177, under which Jefferson Science Associates, LLC, operates the Thomas Jefferson National Accelerator Facility.

REFERENCES

1. http://www.jlab.org/12GeV/
2. A. Freyberger. 12 GeV CEBAF Status and Plans // *Hall A Collaboration meeting*, 14 June 2013, Jefferson Lab, Newport News.
3. R. Kazimi. Injector Upgrade for 12 GeV CEBAF and Accelerator Technology Laboratory // *MOLLER Collaboration meeting*, 20 June 2013, Jefferson Lab, Newport News.
4. F. Marhauser, W. Clemens, M.A. Drury, D. Forehand, J. Henry, S. Manning, R. Overton, S. Williams. Results of Cavity Series Fabrication at Jefferson Laboratory for the Cryomodule R100 // *Conf. Proc. C110904*. 2011, p. 343-345.
5. J. Dudek, R. Ent, R. Essig, K. Kumar, C. Meyer, R. McKeown, Z. Meziani, G.A. Miller, M. Pennington, D. Richards, L. Weinstein, G. Young. Physics Opportunities with the 12 GeV Upgrade at Jefferson Lab \\ arXiv: 1208. 1244 [hep-ex]. 2012, 64 pp.
6. http://hallaweb.jlab.org/12GeV/SuperBigBite/
7. http://hallaweb.jlab.org/parity/PR-09-005-moller.pdf
8. http://www.lepp.cornell.edu/Research/EPP/CLEO/
9. https://hallaweb.jlab.org/wiki/index.php/SoLID
10. http://www.jlab.org/Hall-B/clas12-web/
11. http://www.jlab.org/Hall-C/upgrade/
12. http://www.jlab.org/Hall-D/
13. H. Montgomery. Jefferson Lab 12 GeV Upgrade Project // *Hall A Collaboration meeting*, 14 June 2013, Jefferson Lab, Newport News.

Article received 07.10.2013

РЕКОНСТРУКЦИЯ НАУЧНО-ИССЛЕДОВАТЕЛЬСКОГО КОМПЛЕКСА CEBAF ЛАБОРАТОРИИ ДЖЕФФЕРСОНА

А.В. Гламаздин

В настоящее время в лаборатории Джефферсона проводится реконструкция научно-исследовательского комплекса CEBAF с целью увеличения максимальной энергии пучка электронов с 6 до 12,1 ГэВ и расширения возможностей по проведению физических исследований в экспериментальных залах. Представлены планы реконструкции и современное состояние ускорителя и экспериментальных залов.

РЕКОНСТРУКЦІЯ НАУКОВО-ДОСЛІДНИЦЬКОГО КОМПЛЕКСУ CEBAF ЛАБОРАТОРІЇ ДЖЕФФЕРСОНА

О.В. Гламаздін

У теперішній час у лабораторії Джефферсона відбувається комплексна реконструкція науково-дослідницького комплексу CEBAF з метою підвищення максимальної енергії пучка електронів з 6 до 12,1 ГеВ та покращення можливостей з проведення фізичних досліджень в експериментальних залах. Подані плани реконструкції та теперішній стан прискорювача та експериментальних залів.