**Memorandum of Understanding**

**between**

**Jefferson Science Associates, LLC.,**
**Thomas Jefferson National Accelerator Facility**

**and**

**The Experimental Nuclear Physics Group at the University of Connecticut**

**pursuant to the**

**12 GeV Upgrade Project**
**WBS 1.5.5.1.2**
**The Hall D Tagger Hodoscope**
**and**
**WBS 1.5.5.3**
**The Hall D Photon Beamline Components**

**1 July 2011**

Jefferson Science Associates, LLC / Thomas Jefferson National Accelerator Facility (JSA/Jefferson Lab), acting under its management and operating contract with the U.S. Department of Energy, located at 12000 Jefferson Avenue, Newport News, Virginia 23606, and the University of Connecticut (UConn), located in Storrs, Connecticut 06269, execute this Memorandum of Understanding (MOU) in order to facilitate their joint interest in collaboration on nuclear physics research using the 12 GeV Upgrade facility.

1. **BACKGROUND AND PURPOSE**

   This memorandum outlines the terms and conditions by which JSA/Jefferson Lab agrees to collaborate with the University of Connecticut (UConn) in areas of common interest to promote scientific understanding of the fundamental building blocks of nature. Specifically, JSA/Jefferson Lab and UConn agree to collaborate on scientific research using the facilities to be built as part of the 12 GeV Upgrade project with an interest in the construction of the Hall D/GlueX high-resolution photon tagging hodoscope (microscope), diamond crystal radiators for the bremsstrahlung target (diamond targets), and the photon beam position monitor (active collimator). The UConn group has been a member of the Hall D/GlueX collaboration since its inception with strong participation in the development of both the scientific program and the design of the experimental equipment. The group possesses an intimate and unique knowledge of the capabilities of the polarized photon source and its relations to the needs of the GlueX experiment.

   Thomas Jefferson National Accelerator Facility (Jefferson Lab), located in Newport News, VA, is owned by the U.S. Department of Energy (DOE) and operated by Jefferson Science

Associates, LLC (JSA) under the Department of Energy Contract No. DE-AC05-06OR23177. JSA is a Southeastern Universities Research Association/Computer Sciences Corporation limited liability company created specifically to manage and operate Jefferson Lab. The DOE Office of Nuclear Physics (NP) within the Office of Science (SC) operates the Continuous Electron Beam Accelerator Facility (CEBAF) as a National User Facility at Jefferson Lab.

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab is a world-leading facility in the experimental study of hadronic matter. The 12 GeV CEBAF Upgrade directly addresses a major scientific opportunity identified in both the 2002 and the 2007 Long Range Plans in which the Nuclear Science Advisory Committee (NSAC) recommends the 12 GeV CEBAF Upgrade as its highest priority construction project for the Nuclear Physics program. The project was identified as a high priority initiative in the DOE Office of Science's plan, "Facilities for the Future of Science: A Twenty Year Plan".

The 12 GeV CEBAF Upgrade will enable CEBAF's world-wide user community to expand its research horizons, and will allow breakthrough programs to be launched in three key areas:

- The experimental verification of the powerful force fields ("flux tubes") believed to be responsible for quark confinement; understanding confinement is essential for understanding the structure of nuclear matter;
- The measurement of the quark and gluon structure of the proton, the neutron, and other nuclear building blocks at the most basic quantum level; and
- New research domains in key areas already under investigation.

The full scope of the 12 GeV CEBAF Upgrade project includes upgrading the electron energy of the main accelerator from 6 GeV (billion electron volts) to 12 GeV, constructing a new experimental area (Hall D) and the experimental equipment in Hall D (GlueX), and enhancing the capabilities in the existing experimental halls to support the most compelling nuclear physics research. All efforts include design, construction, installation, and testing and commissioning. Construction began in 2008 and commissioning in Hall D is foreseen to start in 2014.

## 1.1. The Hall D Tagging Microscope

The purpose of the Tagging Spectrometer is to measure the energy of post-bremsstrahlung electrons downstream of the photon radiator, and to identify the accelerator beam pulse in which each occurs. Subtraction of the energy measured in the tagger from the beam energy coming from the accelerator "tags" the energy of the photon produced by electron bremsstrahlung in the radiator. Events in the GlueX detector are associated with tagged electrons by requiring both to come from the same beam pulse. This places an effective upper limit on the rate of photons in the tagged beam to be less than the accelerator beam pulse frequency of 500 MHz. The Hall D tagger microscope has been designed to run with better than 95% efficiency at rates up to 250 MHz within the range 8.4 – 9.0 GeV in photon energy, with a RMS time resolution of 200 ps and energy bins of 8 MeV full width. Besides the microscope, the tagger is also instrumented with a more coarse-grained array of scintillation counters called the "fixed array" spanning the energy range from 3.0 – 11.7 GeV. The microscope consists of a packed rectangular array of 2x2 $mm^2$ scintillating fibers whose axes are aligned with the post-bremsstrahlung electron trajectories. Each energy bin is subtended by a column of 5 fibers, each connected through a clear light guide to an individual photon sensor. Amplified signals from each of

the sensors in the column are summed and fed to a discriminator to produce the tagging signal for that bin. Individual fibers in each column can be included or excluded from the sum, in order to optimize the tagging ratio in the collimated photon beam.

### 1.2. The Hall D Diamond Targets

The bremsstrahlung radiator used to produce the photon beam for the GlueX experiment is a thin sheet of monocrystalline diamond. By precisely aligning the diamond crystal axes with respect to the axis of the electron beam, and then collimating the bremsstrahlung photon beam that exits the crystal, the experiment can achieve a photon beam with 40% plane polarization, at intensities that are only limited by the requirements of tagging. Optimum collimation requires that the electron beam emittance not be degraded by multiple-scattering inside the bremsstrahlung target. The optimum radiator target thickness for GlueX has been determined to be 20 microns. Besides electron beam emittance, diamond crystal quality is the other factor limiting the ability to enhance the photon beam properties using collimation. A comparison between these two limiting effects is made by comparing the divergence of the 12 GeV electron beam (10 μr RMS nominal, horizontal plane) with the rocking curve width of the diamond crystal. The very best diamond monocrystals have rocking curve widths less than 10 μr RMS (ideal crystal is 6 μr FWHM for 220 lattice vector), as measured using a highly-collimated X-ray facility. The requirement for the rocking curve width of a GlueX radiator diamond is 20 μr or better at the 220 lattice vector. Synthetic diamond monocrystals of the required quality and size are available from industry, but thinning them down to 20 microns and mounting them without distorting their shape requires special expertise.

### 1.3. The Hall D Active Collimator

Achieving 40% photon beam linear polarization at 9 GeV with a 12 GeV electron beam requires collimation of the photon beam with an opening angle of 22 μr. The collimator consists of a circular aperture of radius 1.7 mm in a tungsten block located 76 m downstream of the radiator. Optimum collimation is only achieved if the center of the photon beam intensity profile is centered on the axis of the collimator aperture with a tolerance of 200 microns. A segmented pre-collimator called the ``active collimator'' placed just upstream of the primary collimator is instrumented to provide a continuous monitor of the center of gravity of the photon beam incident on the collimator. The active collimator has an aperture somewhat larger than the primary collimator, and only interacts with the parts of the photon beam that must be collimated away. It senses the photon beam intensity integrated over each of 4 quadrants arranged around the central axis. Proper photon beam alignment is achieved by steering the electron beam upstream of the radiator such that the intensities in all four quadrants of the active collimator are equalized. The elements of the active collimator are blocks of tungsten with a special geometry designed to maximize the current from knock-on electrons produced in the early stages of an electromagnetic shower. Operating without any electron multiplication or high voltage, the device is highly linear and radiation-hard, well suited to operation in the high-radiation environment near the collimator.

## 2. RESPONSIBILITIES OF THE PARTIES

In accordance with the purpose of this MOU:

2.1. The Experimental Nuclear Physics Group at UConn hereby agrees to:

- participate in Jefferson Lab research as a member of the Hall D/GlueX Collaboration,

- participate in the construction effort of the Hall D/GlueX experimental equipment, specifically the fabrication of the tagger microscope; production, quality control, and mounting of diamond radiators; and construction of the active collimator, including some work done on-site at Jefferson Lab, at the level summarized in Section 3 below,
- provide regular updates on progress and schedule to the Hall D 12 GeV Control Account Manager,
- participate as necessary in related 12 GeV Upgrade project reviews, and
- participate in the installation and hardware checkout of the Hall D tagged photon beamline.

2.2. JSA/Jefferson Lab hereby agrees to:

- provide an appropriate on-site work environment including space, computer access, necessary training etc. as required for all User scientists,
- provide a sufficiently detailed Statement of Work describing the goals and expectations,
- keep key University personnel informed of overall project status and requirements for the joint scope of work, and
- develop and provide the forum for regular progress updates by the UConn personnel.

## 3. KEY PERSONNEL

3.1. The principal investigator for the GlueX participants of the Experimental Nuclear Physics Group at the University of Connecticut is Professor Richard Jones. The salary and benefits for the contributed UConn labor will be supplied from the University and ongoing grants. Estimates of contributed personnel in the table below are based on current funding levels, and are subject to the ongoing availability of funds. It is anticipated that the total effort contributed to the construction project in FY11 through FY13 will include 0.3 FTEs at the professor level, 0.1 FTEs at the professional staff level, 2 FTEs at the PhD student level, and 0.5 FTE at the undergraduate student level. All manpower numbers are quoted per year. Note: The assumed maximum FTE fraction available for research for a professor is 0.33, for professional staff it is 1.00, by a research postdoctoral associate it is 1.00, by a graduate student it is 1.00, and by undergraduates it is 0.25. The time commitment of members of the Experimental Nuclear Physics Group at the University of Connecticut contributed to the 12 GeV construction efforts described in this MOU, including faculty, students, and technical personnel, is as follows:

| NAME | POSITION | FTE PER YEAR | | | |
|---|---|---|---|---|---|
| | | 2011 | 2012 | 2013 | 2014 |
| Richard Jones | Assoc. Professor | 0.3 | 0.3 | 0.3 | 0.1 |
| Alan Chasse | Machinist | 0.1 | 0.1 | 0.1 | 0 |
| Igor Senderovich | Graduate student | 1.0 | 0 | 0 | 0 |
| Brendan Pratt | Graduate student | 0.5 | 1.0 | 1.0 | 0.2 |

| | | | | | |
|---|---|---|---|---|---|
| James McIntyre | Graduate student | 0.5 | 1.0 | 1.0 | 0.2 |
| (new) | Undergrad students | 0.5 | 0.5 | 0.5 | 0.1 |
| Total FTE | Contributed Manpower | 2.9 | 2.9 | 2.9 | 0.6 |

Note: "FTE" in the above table refers to the fraction of a full-time equivalent person, which will be contributed to the 12 GeV construction project scope of work covered by this MOU.

3.2. Dr. Alexander Somov, a member of the Jefferson Lab 12 GeV Project Team, will act as the liaison and primary point of contact for the collaboration on Hall D experimental equipment construction between Jefferson Lab and the Experimental Nuclear Physics Group at UConn.

## 4. TERMS

4.1. Each party enters into this collaborative agreement on a best effort basis without guarantees of quality or completion of the collaboration.

4.2. Neither party shall have any liability to the other for any consequential, indirect, or incidental damages from any cause whatsoever.

4.3. It is understood by both parties that the scope and execution of this MOU is governed by JSA's prime contract with the United States Department of Energy and that the terms and conditions of that prime contract supersede any express or implied agreements between JSA and UConn as stated within this MOU.

## 5. GENERAL AGREEMENT FOR EQUIPMENT AND SERVICES IN THE CASE OF A JSA CONTRACT AWARD DURING THE 12 GeV CONSTRUCTION PHASE

### 5.1. The University of Connecticut:

5.1.1. The UConn group will undertake the responsibility of constructing the tagger microscope detector and detector-mounted electronics for its readout.

5.1.2. The UConn group will produce the construction drawing package for the tagger microscope consistent with the specifications provided by JLab.

5.1.3. The UConn group will produce the design and layout package for all of the detector-mounted electronics it builds for the microscope.

5.1.4. Sufficient lab space of at least 200 square feet will be provided at UConn for the assembly of the microscope detector, as well as for storage and testing. The UConn group will have access to their machine shop in the Physics Department that will be used for construction of the microscope.

5.1.5. The UConn group will be responsible for arranging the transportation for the constructed detector elements to Jefferson Lab and will work with JLab personnel to install it in the tagger hall part of the Hall D complex.

5.1.6. The UConn group will be responsible for obtaining diamond crystals of sufficient quality and thickness for use as radiators.

5.1.7. The UConn group will take responsibility for quality assurance of diamonds for use as radiators in Hall D, including conducting rocking curve measurements at the CHESS synchrotron light source at Cornell U, and analyzing the results.

5.1.8. The UConn group will be responsible for mounting the diamond radiators within the Hall D goniometer, in a way that assures the specified baseline performance of the photon source.

5.1.9. The UConn group will be responsible for the construction and instrumentation of the active collimator for the Hall D photon beam line.

**5.2. JSA/Jefferson Lab:**

5.2.1. Jefferson Lab will provide specifications for the tagger microscope and the detector-mounted electronics.

5.2.2. Jefferson Lab will provide the specifications and performance parameters for the diamond radiators.

5.2.3. Jefferson Lab will be responsible for the design of the support table and mounting fixtures that will be used to attach the microscope to the tagger magnet support.

5.2.4. Jefferson Lab will be responsible for the tagger magnet alignment and survey which determines the location of the focal plane of the tagger, and where along the focal plane the microscope should be mounted.

5.2.5. Jefferson Lab will be responsible for constructing a radiation-shielded enclosure to hold the chassis containing the microscope readout electronics.

5.2.6. Jefferson Lab will be responsible for the PLC controller and any associated software needed to control the microscope remote control alignment mechanism.

5.2.7. Jefferson Lab will be responsible for designing and building a remote control radiator target ladder that holds the mounted diamond inside the goniometer mount and enables selection between various radiator options during photon beam line commissioning.

5.2.8. Jefferson Lab will provide a mechanism to mount the active collimator in front of the primary tungsten collimator, and a shielded housing to contain the readout preamps and protect them from radiation damage.

5.2.9. Jefferson Lab will provide a means so that photon beam position information can be fed back to correctors in the electron beam line upstream of the radiator, and define the interface to the active collimator readout system.

5.2.10. Jefferson Lab will approve all construction drawing prior to fabrication.

5.2.11. Jefferson Lab will be responsible for the overall Hall D project management.

## 5.3. FUNDING

5.3.1. Funding for the Experimental Nuclear Physics Group at UConn is provided by the NSF under grant NSF-PHYS 0901016. Estimates of contributed personnel in the above table are based on current funding levels and are subject to the ongoing availability of funds.

5.3.2. Each institution will be responsible for any necessary travel costs of their employees. Travel for UConn participants will be funded out of their ongoing NSF grant.

5.3.3. Funding for all manpower in the 12 GeV Upgrade baseline project plans that is needed for the tagger microscope, the diamond radiators, and the active collimator, that is not identified as contributed UConn manpower, is funded out of 12 GeV project funds.

5.3.4. Jefferson Lab will provide all parts for the construction of the tagger microscope, the diamond radiators, and the active collimator, or fund them through 12 GeV project funds.

5.3.5. Jefferson Lab will provide funds for transportation of items covered under this MOU between UConn and Jefferson Lab.

5.3.6. JSA/Jefferson Lab's performance under this MOU is subject to the availability of funds and nothing required herein commits the U.S. Department of Energy to appropriate funds hereto.

5.3.7. Further, this MOU shall not be used to obligate or commit funds or as the basis for the transfer of funds from one party to another. If a commitment, obligation, or transfer of funds is required, a specific contractual agreement, or other reimbursable arrangement shall be developed between JSA/Jefferson Lab and UConn to provide specific funding, obligation, and billing data.

## 5.4. BUSINESS TERMS

The University of Connecticut considers the tagger microscope construction as an equipment fabrication project which is thus not subject to overhead charges. Fringe, benefits, and overhead will be charged on hired labor and expenses as appropriate at rates consistent with the UConn policy at the time of the construction contract. As the work entails a mix of work performed on the UConn campus and work performed away from campus, overhead on labor performed under the terms of this MOU will be assessed at the intermediate rate of 32%.

The microscope and its readout electronics will be constructed out of a large number of individual parts. These parts will need to be purchased, inspected and ultimately assembled into the final detector. While the procurement documents which specify the parts will be written jointly between UConn and Jefferson Lab, it is recognized that each party may have advantages and disadvantages in purchasing of specific items

for construction. As such, individual parts will be purchased in a manner that will minimize the overall cost, while utilizing the appropriate expertise in the most efficient manner. Because of expertise and availability of local vendors, the following items will likely be purchased by Jefferson Lab:

1. Silicon photomultiplier devices for the microscope readout.
2. Scintillating fiber and clear light guides for the microscope.
3. Diamond crystals for the initial Hall D radiator inventory.
4. Tungsten wedges for the active collimator.
5. The frontend preamplifiers for the active collimator.
6. Controller or PC to read out the active collimator.

### 5.5. PERSONAL PROPERTY / EQUIPMENT

Any transfer or loan of equipment will be implemented under a separate agreement.

### 5.6. MILESTONE SCHEDULE

The schedule for construction shall be in accordance with the 12 GeV baseline project plan as captured in the P6 resource-loaded schedule, and tracking of that schedule will be conducted according to the certified JSA/Jefferson Lab Earned Value management System (EVMS). The major project milestones are listed in table below. The UConn group will provide a detailed construction plan at the start of construction, to be approved by Jefferson Lab, which will include project milestones and serve as a basis for operations.

| Activity | Date |
|---|---|
| Fabrication of microscope counters | May 2013 |
| Shipment of microscope detector to JLab | December 2013 |
| Procurement and testing of diamond crystals | September 2012 |
| Mounting and testing of diamond radiators | March 2013 |
| Assembly and test of active collimator | April 2013 |

## 6. INTELLECTUAL PROPERTY RIGHTS

(a) If a subject invention is developed solely by an employee(s) of JSA/Jefferson Lab, then all rights to such intellectual property shall belong to JSA/Jefferson Lab.

(b) If a subject invention is developed solely by an employee(s) of UConn, then all rights to such intellectual property shall belong to UConn.

(c) If a subject invention is jointly developed by the Parties, then all rights to such subject invention shall jointly belong to the developing Parties. The Parties shall negotiate, under a separate agreement, who will pay for the preparation

and filling of patent applications covering jointly developed inventions in one or more countries, who will prosecute such applications, who will maintain such applications during prosecution, and who will maintain any resulting patents. Patent applications covering jointly developed intellectual property that include a JSA/Jefferson Lab inventor shall contain the following statement:

"This invention was made with Government support under Contract DE-AC05-060R23177 awarded by the United States Department of Energy. The Government has certain rights in the invention."

Specifically, the United States Federal Government shall have a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States the joint inventions developed under the JSA/Jefferson Lab contract with the U.S. Department of Energy.

**7. PUBLICATIONS**

Papers and publications may result from this collaboration. All institutions will be acknowledged in such publications and in the manner customary for scholarly publication. All publications (to include presentations) developed under this MOU are subject to the review procedures of each institution prior to publication.

**8. EXPORT CONTROL**

Each party will be responsible for fulfillment of their own obligations under applicable U.S. Export Control Laws and regulations.

**9. TERM OF AGREEMENT**

The MOU shall remain in effect for a term of 5 years from the latest date upon which all Parties have executed same, unless extended or terminated pursuant to Paragraph 10 below.

**10. MODIFICATION AND TERMINATION**

This MOU sets forth the entire and complete agreement between the Parties and may be modified only by written mutual agreement. This MOU may be terminated prior to its expiration by any of the Parties upon written notice to the other Party communicated not less than sixty (60) days in advance.

**11. EFFECTIVE DATE**

This MOU will be effective when fully executed on behalf of both parties.

**Concurrences:**

**Jefferson Lab**

Dr. Hugh Montgomery Date
Director

Claus Rode Date
12 GeV Upgrade Project Manager

Rolf Ent Date
Associate Director for Physics

Glenn Young Date
12 GeV Associate Project Manager for Physics

Eugene Chudakov Date
Hall D Group Leader and Control Account Manager

Alexander Somov Date
Hall D Staff Scientist

**University of Connecticut**

8/3/11
Suman Singha Date
Vice President for Research, UConn

7/26/11
Doug Hamilton Date
Head, UConn Physics Department

7/26/11
Richard T. Jones Date
UConn contact person, grant PI