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Title: SLAC National Accelerator Laboratory FACET & TEST  
BEAM FACILITIES PROPOSAL

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Intended for: proposal submission to FACET facility  
Report

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# SLAC National Accelerator Laboratory

## FACET & TEST BEAM FACILITIES PROPOSAL

Date: 6/17/13

### A. EXPERIMENT TITLE:

**Development of Electron Radiography for Material Science**

### B. PROPOSERS & REQUESTED FACILITY:

Principal Investigator:	Dr. Frank E. Merrill
Institution:	Los Alamos National Laboratory
Contact Information:	Phone: 505-665-6416      Email: fmerrill@lanl.gov
Experiment Members:	Konstantin Borozdin, Robert Garnett, Fesseha Mariam, Christopher Morris, Alexander Saunders, Peter Walstrom
Collaborating Institutions:	Los Alamos National Laboratory
Funding Source (optional)	
Facility/Facilities Requested:	FACET /
Approximate Duration:	~2 weeks

### C. EXPERIMENT:

#### 1. Science justification

The material science community is presently limited by diagnostics in both the fabrication of materials and measuring the resulting materials characteristics of these new fabrication techniques. Because of this limitation the community is forced into an empirical mode of material fabrication, where expert judgment is used to guide manufacturing processes and the resulting materials are inspected and tested for the desired characteristics. This development approach can be time consuming and costly. The solution to this problem is to improve our fundamental understanding of materials, which requires the development of new diagnostics capable of measurement at the micron length scale, during both processing and during testing. These new measurements will enable a fundamental understanding of material characteristics allowing the development of predictive models, which will in turn enable material engineering by design rather than today's empirical approach. Solving this problem has become a grand challenge for the materials science community. Los Alamos plans to address this challenge through the development of new diagnostics capable of measurements at the smallest length scales through the Multi-Probe Diagnostic Hall (MPDH) at the planned MaRIE (Material and Radiation In Extremes) Facility. One of the probes will be a coherent photon beam generated by an FEL driven by a multi-GeV electron beam. The photons will be used for diffraction measurements as well as radiography of

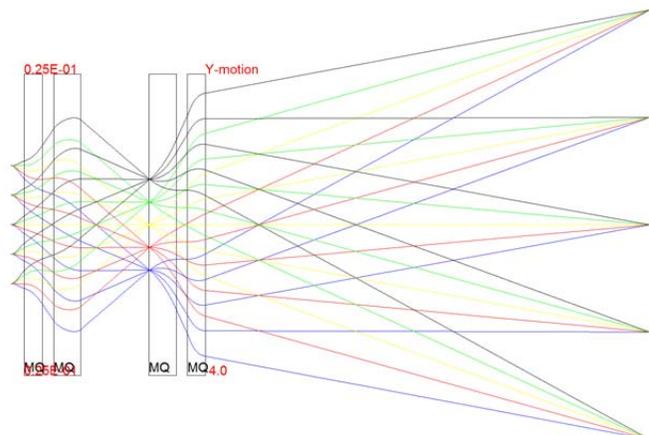
relatively thin samples (nearly single grains). The same multi-GeV electron beam can be used to directly radiograph thicker systems (many grains or “bulk” material), providing high resolution measurements of the density distribution of materials during both fabrication and dynamic testing. This technique, electron radiography or eRad, that has been identified by LANL as one of the probes required to meet this grand challenge has never been demonstrated with high energy electrons. We propose to begin development of this technique with the electron beam available at FACET.

## 2. Experimental Goals

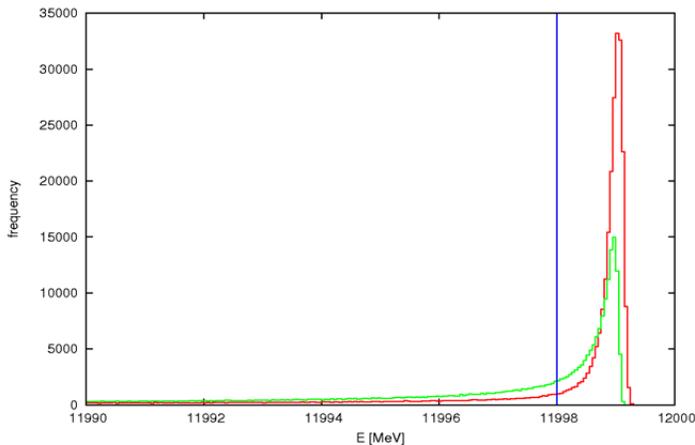
There are two primary experimental goals. First, we plan to design, install and commission an electron radiography imaging system. Once commissioned, we plan to radiograph a suite of radiographic test objects that will be used to measure the performance characteristics of the imaging system. These measurements will be used to validate our models of the radiography processes. Agreement with our predictions will serve as validation of our models for future calculations, while disagreement will identify areas where the physical process are not correctly implemented in the models or identify new physics which must be understood and implemented.

An electron radiography system includes a matching system composed of quadruplets and drifts to expand the illuminating beam to the desired size (typically 1-10 mm), a sample chamber, a magnetic lens, and an imaging detector. The magnetic lens provides point-to-point focusing from the object to the detector. A minimal magnetic lens consists of four quadrupoles with short drifts between them and a longer final drift from the last quadrupole to the detector that allows magnification of the radiographic image. This magnification reduces the impact of the detector resolution so that the electron beam characteristics and interactions in the object dominate the radiographic performance. Figure 1 shows a schematic of the layout required for a 12-GeV quadruplet imaging lens. We have chosen 12 GeV for these tests because the present MaRIE design will provide 12 GeV electrons for radiography applications. This figure shows the point-to-point nature of the imaging lens as well as demonstrating the Fourier plane at the entrance to the third quad. At this location the scattering angle introduced at the object is mapped to radial position, and therefore provides the ideal location for a collimator to set the angular acceptance of the imaging system.

**Figure 1:** Quadruplet lens configuration for 12-GeV electron radiography. The colored lines represent electron trajectories through the lens while the boxes represent the quadrupole magnets. This lens system is 14 m long and provides a factor of 4 magnification.



The important interaction processes are bremsstrahlung, multiple Coulomb scattering, ionization energy loss and straggling. The multiple Coulomb scattering and ionization energy loss and straggling processes in eRad are almost the same as the analogous processes in proton radiography (pRad), a well understood radiography technique used around the world for thick object imaging<sup>1-11</sup>. However, bremsstrahlung interactions are dominant in the formation of electron radiographs and thus are the primary focus of these studies. Electron radiography has been demonstrated with low energy sources<sup>12-13</sup>, but Monte Carlo simulations indicate that Bremsstrahlung interactions will be the limiting interaction for high-energy electron radiography. Figure 2 shows the energy spread resulting from the interaction of 12-GeV electrons with a 0.5-mm thick sample of uranium, which was chosen for its high Z and thus maximum Bremsstrahlung interactions. The long energy tail of the energy distribution could result in substantial radiographic blur through second-order chromatic aberrations in the quadruplet lens. However, if there is a strong correlation between energy loss and scattering angle, a small collimator at the Fourier plane could remove the majority of this tail and provide high resolution radiography. Our measurements will focus on characterizing the impact of this long energy tail on radiographic performance. These measurements will allow us to determine the maximum object thickness that is accessible to electron radiography at these high energies as well as determine density resolution for very thin objects.



**Figure 2:** High-energy end of energy distribution of a monochromatic 12 GeV beam that has passed through 0.5 mm of uranium. Red: Geant 4 simulation; green: simplified Monte Carlo code. Only 22% of the electrons of the incident beam are to the right of the blue line (red curve).

### 3. Beam parameters

In order to achieve the best available resolution, the smallest possible beam energy spread should be used. Bunch compression is not needed in a static eRAD demonstration experiment, or even in later dynamic experiments. According to the FACET website, the bunch length before compression is 5.5 mm, or 18 picoseconds. This time spread is small enough to limit motion blur to a fraction of a micron in almost all dynamic experiments that would be performed in an eRAD system. Also according to the FACET website, the linac beam before entering the bunch compression chicane has an energy spread of about 0.07%; after bunch compression, the energy spread increases to more than 1%. We wish to run the beam line without bunch compression and with the RF cavities set to minimize energy spread.

#### **D. EXPERIMENTAL APPARATUS AND LOGISTICS:**

These measurements require the installation of a sample chamber, quadruplet imaging lens, collimators and camera system. Ideally, the lens would be up to 20 m in length. However, these measurements can be made with shorter lenses and fit into a space as small as 6 m. We believe that we can use the existing FACET beam line to expand the beam to cover the radiographic field of view. In this proposal we have planned to use the last ~15 m downstream of the existing end-station for the imaging lens, but other longer, more desirable configurations may be possible with additional design work. This imaging lens will require the highest magnetic fields possible and therefore adequate cooling. The required field regulation is <1%. Typically the quadruplet lens will require two power supplies with the end magnets in series on one power supply while the inner magnets in series with the second power supply. Many details remain to be determined such as the design and installation of an imaging system that does not interfere with the existing experimental configuration. This will be the focus of future design efforts if approved for beam time. A camera-based imaging system will be required at the end of this lens system. The imaging system consists of a phosphor (CsI, LSO or plastic scintillator screen), a turning mirror, and camera. The camera is typically operated remotely through fiber optic connections. Therefore, we would need fiber optic connections from a control room down to the experimental area. Alternatively, a computer system can be run locally (if it can withstand the radiation environment) with a network connection to a remote computer for image acquisition.

We will also need to install many test objects, which need to be within the vacuum system of the imaging lens. Typically a series of objects are installed on a linear actuator allowing remote actuation. It is also likely that we will need to adjust collimation and these collimators will also need to be installed in the vacuum envelope. Therefore, we will need to be able to vacuum isolate the imaging system with a means to quickly pump down this section of the beam line.

## **USEFUL FACILITIES INFORMATION**

(do not include in proposal)

### **A. PROPOSAL SUBMISSION:**

Go to

for information on how to submit proposals and for contact information.

### **B. FACILITY BEAM PARAMETERS:**

	ASTA	ESTB	FACET	NLCTA	XTA
Beam Type	e <sup>-</sup>	e <sup>-</sup>	e <sup>-</sup>	e <sup>-</sup>	e <sup>-</sup>
Beam energy (MeV) (range)		2000-15,000	20,000	120 60, 80-120	80
Repetition Rate (Hz) (range)	60	5	10 1 - 30	10 1-10	10
Bunch Intensity (E8) (range)		20-250 or single particle	200 50-300	1.2 0.06-12	
Bunch Length ( $\sigma$ , $\mu\text{m}$ ) (range)		300	30 20-1000	60	
Beam Spot size ( $\sigma$ , $\mu\text{m}$ ) (range)		30	30 20-200	150 100-300	
Comments/Notes		(1)			

### **C: NOTES**

1). ESTB - The way secondary particles are produced at ESTB has the inherent risk that the full power beam might be delivered to your experiment. This can happen when the energies between LCLS and the A-line are matched and/or the production target is removed. So suddenly, instead of a single or a few particles it becomes possible that up to around  $10^9$  particles per bunch might be delivered. Please evaluate the consequences for your experimental apparatus and document them in the proposal.

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