LCLS Engineering Specifications Document # 1.6-103 X-ray End Stations Revision 0

AMO Ion Spectrometers

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Brief Summary:

Ion spectrometers will be used to measure the charge state and momenta of ions created when the LCLS x-ray FEL beam interacts with atoms, molecules or clusters in the AMO experimental apparatus. Three different types of ion spectrometer will be constructed, one to measure the charge state of the ions, a second to measure the momenta of the ions in two dimensions and a third that can measure the three dimensional momentum of the ions. Only one of the spectrometers can be mounted on the chamber at a time.

Change History Log

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<th>Rev Number</th>
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<th>Sections Affected</th>
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<td>000</td>
<td>11/23/2007</td>
<td>All</td>
<td>Initial Version</td>
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1. **INTRODUCTION:**

Atoms, molecules or clusters illuminated with the intense x-ray free-electron laser beam from the LCLS will undergo multiple ionization. One of the simplest imaginable experiments is to simply measure the resulting charge state of the ions. Recent calculations indicate that at the intensities expected from the LCLS it should be possible to remove all of the electrons from a Ne atom, resulting in a Ne$^{10+}$ ion (Rohringer and Santra 2007). Other recent experiments at FLASH have observed charge states of up to 22+ upon irradiation of Xe atoms with the FEL beam depending upon the size of the focused beam and hence the resulting power density (Sorokin, Bobashev et al. 2007).

Depending on the sample, whether atoms, molecules of clusters, ions of different charge states and initial kinetic energy are expected. Atomic samples will yield ions with the lowest kinetic energies. Molecules will yield ionic fragments with kinetic energies of 10's to 100's of eV due to Coulomb explosion of the molecular ion following charge stripping by multiple ionization. Clusters are expected to yield ions with the highest kinetic energies. Ions with 100's and even 1000's of eV kinetic energy have been observed in laser photoionization of rare gas clusters (Symes, Hohenberger et al. 2007).

With a pulsed source of ionizing radiation, time-of-flight (TOF) mass spectrometry is the preferred method for measuring the charge state of the resulting ions. In its simplest form the spectrometer involves a few accelerating grids, a field-free flight tube and a detector. More complex applications of the technique, such as ion-imaging and momentum-resolving ion spectrometry use position and time-position sensitive detectors respectively to measure the position and time plus position of the impact of the ion on the detector to determine its momentum in two or three dimensions. Three complete ion spectrometers are being designed for the AMO High Field Physics Chamber, 1) an ion TOF spectrometer, 2) an ion imaging spectrometer and 3) a momentum resolving ion spectrometer. Each of the three is being designed to be supported off of a flange that fits onto a port on the chamber, where only one of the three spectrometers can be attached at one time. The port is oriented vertically (downwards in this case) to allow direct observation of polarization dependencies in the ion imaging signal. When not in use in the chamber, the spectrometers will be stored in an evacuated off-line chamber to preserve the hygroscopic microchannel plates in the detectors. Each of the three spectrometers is described in greater detail below.

2. **CONNECTION to the CHAMBER:**

The three different types of ion spectrometer should be interchangeable on the experimental chamber, although that change-over would require venting the chamber, removing one spectrometer through a flange and replacing it with anther before pumping down the chamber.

2.1. Ideally the spectrometers will each mount off of a single interchangeable flange, including all of the electrical feed-throughs to facilitate spectrometer changes.

2.2. The flange and spool will need to be large enough to accommodate a 120mm hex-anode Roentdek detector for a momentum resolving ion spectrometer.
2.3. The baseline design of the ion spectrometers should accommodate simultaneous installation of the ion and electron spectrometers maintaining sufficient clearance and clear flight paths for the electrons to the electron detectors.

2.4. The length of the flight-tube (defined below) may be changed in different versions of the spectrometer. The design should accommodate different lengths of flight tube while maintaining the alignment of the spectrometer to the fixed interaction point. Different length spools can be used to accomplish this, along with extensions and stand-offs to vary the position of the detector relative to the flange.

2.5. The spectrometer will be pumped by the main chamber pumping. Sufficient conductance must be maintained in the design to ensure adequate pumping speed at the detector to maintain pressures < 10⁻⁸ Torr.

2.6. Magnetic shielding in the chamber will need to be extended down the ion spectrometer spool to minimize field penetration into the interaction region. See the AMO Mechanical and Vacuum requirements ESD for further information.

2.7. When not used in the main chamber, spectrometers will be stored in an evacuated chamber to keep them clean and dry and to preserve the hygroscopic microchannel plates.

3. ORIENTATION:

The ion spectrometers should mount in the vertical direction, either from above or below the beam axis. The x-ray FEL beam will be linearly polarized in the horizontal plane. Ions ejected in a particular direction relative to the polarization axis and projected onto a 2D detector will therefore should the greatest spatial contrast when viewed from above or below the polarization-propagation plane. Temporal contrast of ions directed forward-backward along the polarization axis will be lost in this case, but this will only affect the Wiley-McLaren spectrometer significantly as the other two utilize position sensitive detectors.

4. Ion TOF spectrometer:

The ion TOF spectrometer is being designed for high collection efficiency of ions created in the interaction region with relatively high mass-to-charge, \( m/q \), resolution. The design is based on the work of Wiley and McLaren who were the first to implement a two-stage acceleration stage to minimize effects of source spatial and kinetic energy variations. It basically consists of a series of accelerating grids, a field free flight tube and a large area integrating detector. A sketch of the spectrometer is shown below in Figure 1.

4.1. The entire spectrometer will be in that vacuum volume of the main chamber and vacuum flange mounting the ion TOF to the vacuum chamber will lie to the right of the anode in the figure. Only vacuum compatible materials with appropriately vented fasteners should be used.

4.2. Each of the elements shown in the figure will be at a different potential, with typical values given in the accompanying table, and thus need to be electrically isolated with a SHV electrical feedthrough provided for each voltage (three in total for the electrostatic elements).

4.3. Insulators used to isolate each part should be shielded from the ion and electron paths to the greatest extent possible to prevent charging of the surface that might affect the charged particle trajectories.
4.4. Grids should cover both ends of the flight tube and held at the same potential as the flight tube to maintain a volume at constant potential. They can be mounted independently but there should not be a gap between the grid and the flight tube.

4.5. The extractor grid and grids used at either end of the flight tube should be high transmission electroformed meshes of gold as available from Precision eForming (http://www.precisioneforming.com/products/mesh.htm) – previously known as Buckbee Mears. These thin meshes will require a supporting structure that will mount to the stand-off's holding them in place.

4.6. The design should accommodate future changes in the diameters of the meshes, the distances between them and the length of the flight tube through changes in the mounting hardware as necessary. The lenses will initially be smaller than the diameter of the flight tube to accommodate mounting both the ion TOF spectrometer and the electron spectrometers simultaneously.

4.7. The Repeller electrode can be either a grid or solid electrode and should have clearance holes to allow electrons to pass through it towards the three electron spectrometers that view the interaction region through it (see the electron spectrometer ESD for further information).

4.8. The detector (indicated as MCP’s and Anode on the figure) will be purchased as an assembly from Burle, part number APD 3120MA 32/25/8 D EDR 60:1, and requires four SHV feed throughs for the grid, input, output and anode connections.

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**Figure 1:** Sketch of the ion TOF spectrometer indicating the principle components and dimensions. The grids, flight tube and detector all have circular cross-section. Labels s, d and D refer to the lengths of the extraction, acceleration and field-free flight stages respectively while $E_s$, $E_d$ and $E=0$ refer to the electric fields in those stages.

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<tr>
<th>Element</th>
<th>Distance to interaction region or length</th>
<th>Voltage (approx)</th>
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<tr>
<td>Repeller</td>
<td>-5mm</td>
<td>+800</td>
</tr>
<tr>
<td>Extractor</td>
<td>5mm</td>
<td>-800</td>
</tr>
<tr>
<td>Acceleration grid</td>
<td>15mm</td>
<td>-2000</td>
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5. **Ion Imaging Spectrometer**

The Ion Imaging Spectrometer is similar to the ion TOF spectrometer in that it uses electrostatic fields to direct the ions created in the interaction region towards the detector. Differences in the specifics of the ion optics and detection scheme make this a unique spectrometer, however. Since the goal is to project the momentum of the ions transverse to the central axis of the spectrometer onto a position sensitive detector, grids are not used. In their place, open aperture lenses are used to accelerate and focus the ion beam. An image of the position of impact of the ions on the detector is formed by amplifying the ion impact on a set of channel plates to a phosphor screen that is imaged with a video camera. A sketch of the spectrometer is shown in Figure 2.

5.1. The entire spectrometer will be in that vacuum volume of the main chamber and vacuum flange mounting the ion TOF to the vacuum chamber will lie to the right of the anode in the figure. Only vacuum compatible materials with appropriately vented fasteners should be used.

5.2. Each of the elements shown in the figure will be at a different potential, with typical values given in the accompanying table, and thus need to be electrically isolated with a SHV electrical feedthrough provided for each voltage (three in total for the electrostatic elements).

5.3. Insulators used to isolate each part should be shielded from the ion and electron paths to the greatest extent possible to prevent charging of the surface that might affect the charged particle trajectories.

5.4. The design should accommodate future changes in the diameters of the lenses, the distances between them and the length of the flight tube through changes in

5.5. The detector (indicated as MCP’s and Phosphor on the figure) will be purchased as an assembly from Burle, part number APD 3120PA 32/25/8 I 60:1 P20, and requires three SHV feed throughs for the input, output and anode connections.

5.6. The conflat flange that the spectrometer is mounted to must include a viewport with clearance to view the entire 120mm detector. A mount for a camera with a light shield also needs to be included. Different lenses may need to be used when the position of the phosphor screen changes due to changes in the length of the flight tube.

5.7. An optional fast photodiode might be included to allow measurement of ion time-of-flight spectra using the intensity of the light pulse as a measure of the ion intensity. A mount for the diode should be included that allows it a full view of the phosphor screen.

5.8. Similar voltages to those used in the ion TOF spectrometer will be used here.
Figure 2: Sketch of the Ion Imaging spectrometer.
6. **Momentum Resolving Ion Spectrometer**

A third type of ion spectrometer that can be mounted to the AMO chamber is a momentum resolving ion spectrometer. It utilizes a delay-line anode to measure both the time and position of the impact of the ion on the detector, combining the capabilities of the other two ion spectrometers. The ion time-of-flight together with position on the detector allows the three momentum components of the ion to be determined and provides the ultimate ion detector. The delay line anode is limited in its ability to measure simultaneous impacts, however, restricting its use to situations where only a few ions are created per FEL pulse, necessitating very low background pressures in the experimental chamber to prevent ionization of background gases by the intense FEL pulse. A sketch of the electrostatic elements of the spectrometer is shown in Figure 3.

6.1. The entire spectrometer will be in that vacuum volume of the main chamber and the vacuum flange mounting the spectrometer to the vacuum chamber will lie to the right of the anode in the figure. Ultrahigh vacuum (UHV) conditions are required in the path of the FEL beam to maintain a low background count rate. Only vacuum compatible materials with appropriately vented fasteners should be used.

6.2. Each of the elements shown in the figure will be at a different potential, with typical values given in the accompanying table, and thus need to be electrically isolated with a SHV electrical feedthrough provided for each voltage (three in total for the electrostatic elements).

6.3. Insulators used to isolate each part should be shielded from the ion and electron paths to the greatest extent possible to prevent charging of the surface that might affect the charged particle trajectories.

6.4. The design should accommodate future changes in the diameters of the lenses, the distances between them and the length of the flight tube through changes in

6.5. The detector (indicated as MCP’s and Delay line anode on the figure) will be purchased as an assembly from Roentdek (http://www.roentdek.com), model number HEX120. The outer diameter of the detector assembly is 246mm with a depth of 30mm per the web site specification. The detector requires 16 electrical vacuum feedthroughs, 12 for the anode signals and four for the MCP and holder. The company sells feedthroughs with the required pins and characteristics.
Figure 3: Sketch of the momentum resolving ion spectrometer.
7. Controls:

The three different ion spectrometers have similar control requirements as all three are controlled strictly with electrostatic potentials on the lenses, flight tubes and detectors, although the details of the quantity and magnitude of the voltages are all slightly different.

7.1. The repeller electrode will always be at a positive potential to repel the ions towards the detector.

7.2. Separate negative power supplies are required for the lens(es) and acceleration potentials.

7.3. The flight tube is at the potential of the acceleration grid.

7.4. A grid in front of the channelplates will be held at a slightly more negative potential than the flight tube to accelerate the ions towards the detector.

7.5. The front of the channelplates will be at a slightly more negative potential than the grid to attract the ions from the grid.

7.6. The voltages across the channelplates increase towards more positive values across each plate (usually two plates per detector) by about 750-1000V. Increasingly positive voltages are used because the channelplate amplifies the signal from the ion’s impact on the surface of the plate as electrons.

7.7. The anode is maintained at a higher positive potential to further attract the electrons towards the detector.

7.8. A fast pulsed power supply with a few ns rise time will be used for the two electrodes surrounding the interaction region when electron and ion spectra are to be measured on the same shot.

8. Data acquisition:

Data from the ion TOF is read as a waveform on the detector anode. A fast digitizer will be required to measure the amplitude of the signal as a function of time over a period of up to 1 μs with a resolution of 1 ns. The amplitude of the signal can be changed by increasing or decreasing the gain of the channelplates or by introducing a pre-amplifier immediately after the anode. Each waveform should be saved along with the appropriate shot identifying information for later binning with data from similar shots and processing to extract the intensity and mass-to-charge ratio information of interest.

The ion imaging spectrometer’s signal is measured as an image on the phosphor screen using a CCD camera. The image should be sampled for each LCLS shot and digitally binned according to the properties of the LCLS shot at a later time. Each image will require additional processing to extract the desired information. The data acquisition system should therefore be capable of obtaining and storing raw images at the repetition rate of the LCLS source.

Data from the delay line anode of the momentum resolving spectrometer will be either timestamp data from seven time-to-digital channels or waveforms from seven fast digitizers. Seven channels of fast time determination are required to measure the arrival time of the ion at the detector (1 channel) and three sets of time values for the signal at the ends of the three delay line wires. Differences in the arrival times of the signals at the ends of the wires or known lengths yield the position of the signal along the wire. Three wires are used to provide redundant information about the position of
the impact of the ion on the detector in order to be able to detect up to four or five ions from the same ionization event.

9. References:

