

ENGINEERING SPECIFICATION DOCUMENT (ESD)	Doc. No. SP-391-001-31 R0	LUSI SUB-SYSTEM XCS Detector Mover
<h2>LUSI XCS Large Angle Detector Mover Engineering Specification</h2>		
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## 1. Scope:

This document defines the engineering requirements for a Large Angle Detector Mover System (LADM) to precisely support, translate, and rotate the LUSI X-Ray Correlation Spectroscopy (XCS) main detector.

## 2. Glossary / Definitions:

**Accuracy:** The absolute error in the ability to establish a specified location and angle with respect to the origin of a fixed coordinate system.

**XCS Detector:** Pixilated x-ray detector.

**Detector Precision Mover:** Positions the detector relative to the Large Angle Detector Mover.

**ESD:** Engineering Specification Document

**FEH:** Far Experimental Hall

**Diffraction System:** Precision positioning device which provides angular and spatial sample motion.

**Center of Rotation (CoR):** Diffraction System center of rotation.

**PRD:** Physics Requirement Document.

**Range:** The total available motion with respect to a fixed coordinate system origin.

**Repeatability:** the absolute error in the ability to successively reestablish a specified location/angle, with respect to the origin of a fixed coordinate system.

**Resolution:** The uncertainty of the measurement of location/angle with respect to the origin of a fixed coordinate system.

**Stability:** The amplitude of motion over a specified time.

## 3. Documents, Specifications and Codes:

### 3.1. SLAC Documents:

GP- 391-750-60	HUTCH4 LAOUT II ASSY
MR-391-750-00	MASTER BEAM LINE
LO- 391-750-41	H4 XCS STAY-CLEARs

### 3.2. SLAC Specifications:

AP-391-000-59	Engineering Review Guidelines
DS-391-000-36	Design Standards Supplement
SLAC-I-720-0A24E-002	Specification for Seismic Design at the SLAC
SP-391-001-33	XCS large Angle Detector Mover system Physics Requirements
SP-391-001-35	XCS Instrument Physics Requirements
SP-391-001-29	XCS Instrument Engineering Specification

### 3.3. Industry Specifications and Codes:

NEC, NFPA 70:	National Electric Code
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NEC, NFPA 70E:  
CBC 2007:

Electrical safety in the Workplace  
California Building Code, 2007

#### **4. Large Angle Detector Mover System Summary:**

The XCS Large Angle Detector Mover (LADM) is used to precisely position a pixilated detector at the location of the scattered x-ray signal of interest. The various features of the device are :

- The overall motion that the LADM allows placing the XCS detector about a truncated sphere of approx. 8m maximum radius (with also the possibility of a shorter (i.e approx. 4m sample-detector distance) with the center coincident with the experimental interaction point.
- The LADM should have the capability of changing its Center or Rotation (horizontally and vertically), in order to properly adjust for any change in the experimental interaction point.
- The mover must rotate in the horizontal plane and cover scattering angles [2 $\theta$ ] ranging from +55° to -1°.
- The mover must also provide the capability to tilt in the vertical plane over a limited range of angles [ $\gamma$ ].
- At all positions, the detector mover must provide a stable and reproducible position and angular orientation of the XCS detector for the duration of an experiment.

The device will allow performing Small Angle, Wide Angle and Grazing Incidence x-ray scattering experiments.

The detector mover system is comprised of various subsystems:

- The main mover carriage.
- An adjustable (i.e. sliding/railed) end module consisting of the following capabilities :
  - A beam-stop module with an exit window.
  - A detector precision positioning stage.
  - A local diode detector, to aid its alignment.
- A modular (compatible with the previous item) vacuum system to prevent air scattering

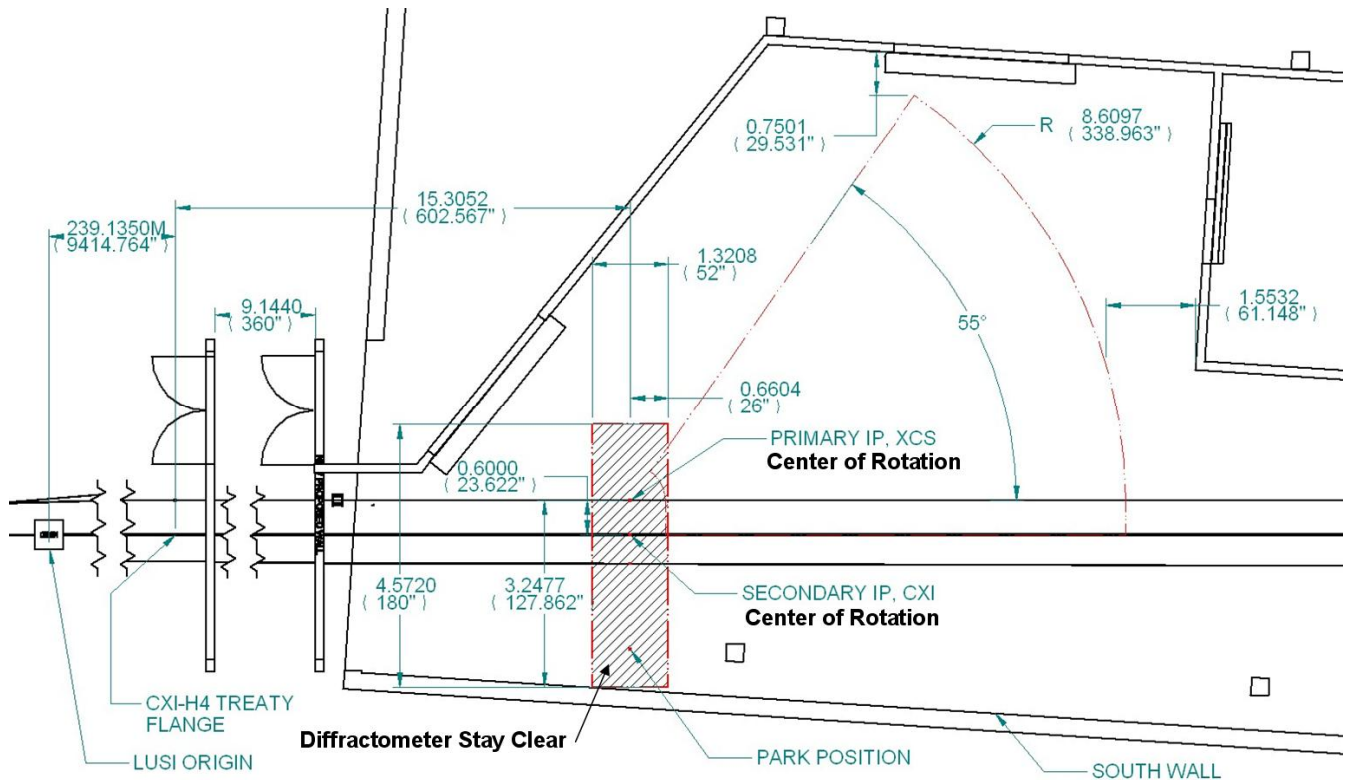
The subsystems may be procured separately or as a complete system.

The physics requirements of the Large Angle Detector Mover are described in SP-391-001-32, XCS Large Angle Detector Mover Physics Requirements.

#### **5. Detector Mover Use and Location:**

The Large Angle Detector Mover is located in the LCLS Far Experimental Hall in Hutch 4, the XCS experimental hutch.

The XCS instrument is a multipurpose instrument and must accommodate a wide variety of samples and sample environments. The region in the hutch occupied by the diffractometer indicated in **Figure 1** is reserved for sample environments and manipulation and may not be used for the detector mover motion.



**Figure 1 Large Angle Detector Mover location with exclusion zone (“stay clear”) for the diffractometer**

The purpose of the XCS LADM is to provide the capability to precisely position an x-ray detector while providing a large sample-detector distance. The LADM together with the Diffractometer System behaves as 4-circle nearly horizontal scattering diffractometer. Therefore the LADM should accommodate the changes of center of rotation of the diffractometer system which coincides with the interaction point of each experiment.

The LADM must therefore rotate about the Interaction Point (IP) where the incident X-Ray beam intercepts the sample. The primary IP is 1.4 m above the hutch floor. An alternate IP which the detector mover must also be capable of rotating about is located 60 cm aside (south) of the primary IP. The detector mover system must also allow clearance to a third beam-line located 50 cm further aside (south) of the secondary IP.

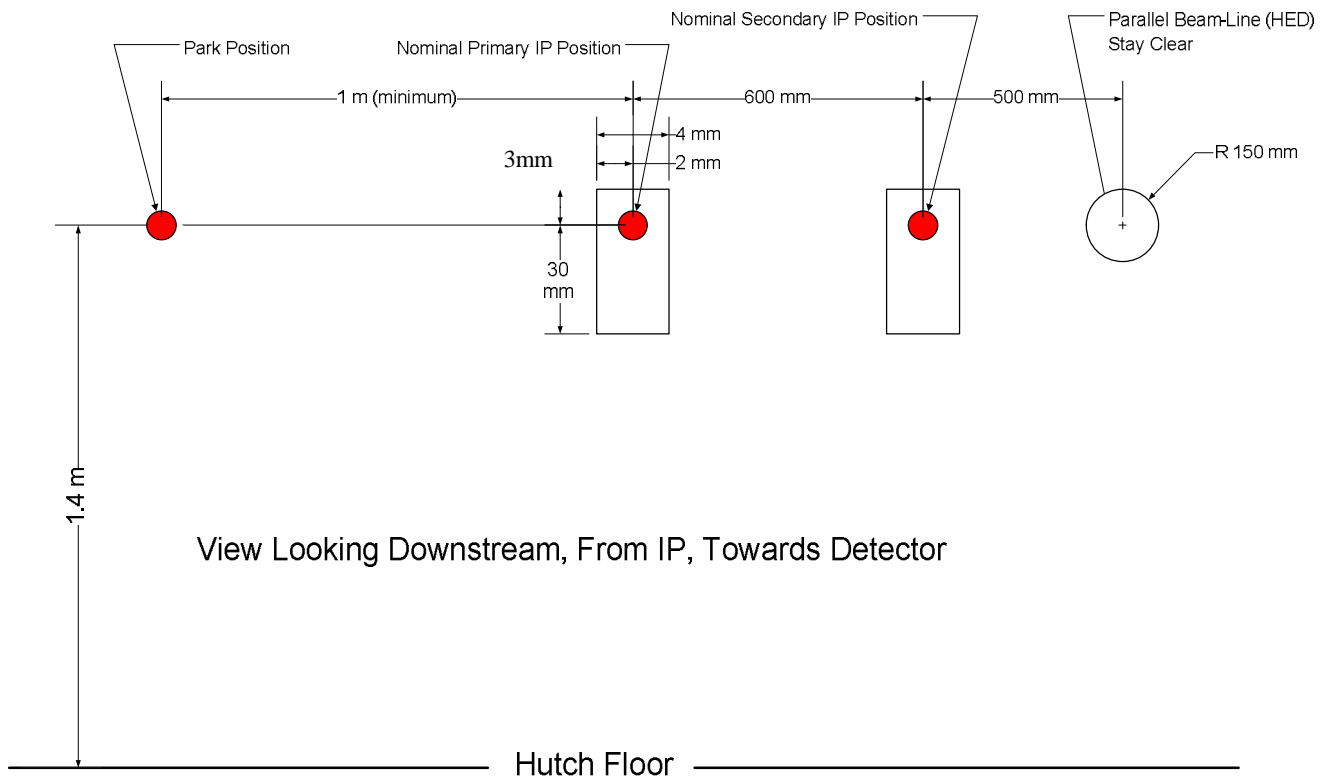
The detector mover system must also be capable of moving to a park position parallel to the primary beam-line at 1 meter to the top (north) of the primary beam line (center-line to center-line.)

In each position, the detector mover system ( including all its subcomponents) must be safely constrained against earthquake forces.

## 6. Local Coordinate System and Interaction Point

The local Hutch 4 coordinate system as defined in DS-391-000-36 “Design Standards Supplement” and located in MR-391-750-00 “MASTER BEAM LINE”, is a right hand Cartesian system with Z+ axis in the direction of X-Ray propagation, parallel to the floor, the X+ axis parallel to the floor and Y+ vertical up.

The detector mover coordinate system is a right hand Cartesian with origin at the center of rotation of the Diffractometer System, Y+ axis vertical up, +Z axis along centerline, and +X parallel to the floor. During an experiment, the detector mover coordinate system must be aligned with the interaction point of the X-Ray beam and the sample, nominally 1.4 meters above the hutch floor. As described in SP-391-001-32, due to the requirements of specific experiments, the actual interaction point may vary as shown in **Figure 2**.



**Figure 2 Interaction Points range of motion and description of the "park" position**

## 7. Large Angle Detector Mover System:

The detector mover system is comprised of various subsystems:

- The main mover carriage : a “table or support” capable of describing the expected motion
- An adjustable (i.e. sliding/railed) end module consisting of the following capabilities :
  - A beam-stop module (to protect the detector) with an exit window
  - A detector precision positioning stage.
  - A local detector, to aid its alignment.
- A vacuum system to prevent air scattering along the path from the sample to the detector

This section describes each of the above mentioned features and associated design requirements.

### 7.1. Main Carrier mover

#### 7.1.1. Horizontal Motion : Rotation and Translation

The Large Angle Detector mover is required to rotate in the horizontal plane about an interaction point (i.e coinciding with the center of rotation of the diffractometer system) and to translate the center of rotation to either the primary interaction point of the secondary interaction point.

##### 7.1.1.1. Horizontal Motion Design Concept

The concept of LADM satisfying the required motion was investigated and compared to existing devices (with similar requirements) operated on 3<sup>rd</sup> generation storage rings (European Synchrotron Radiation Facility, Spring-8, and Advanced Photon Source).

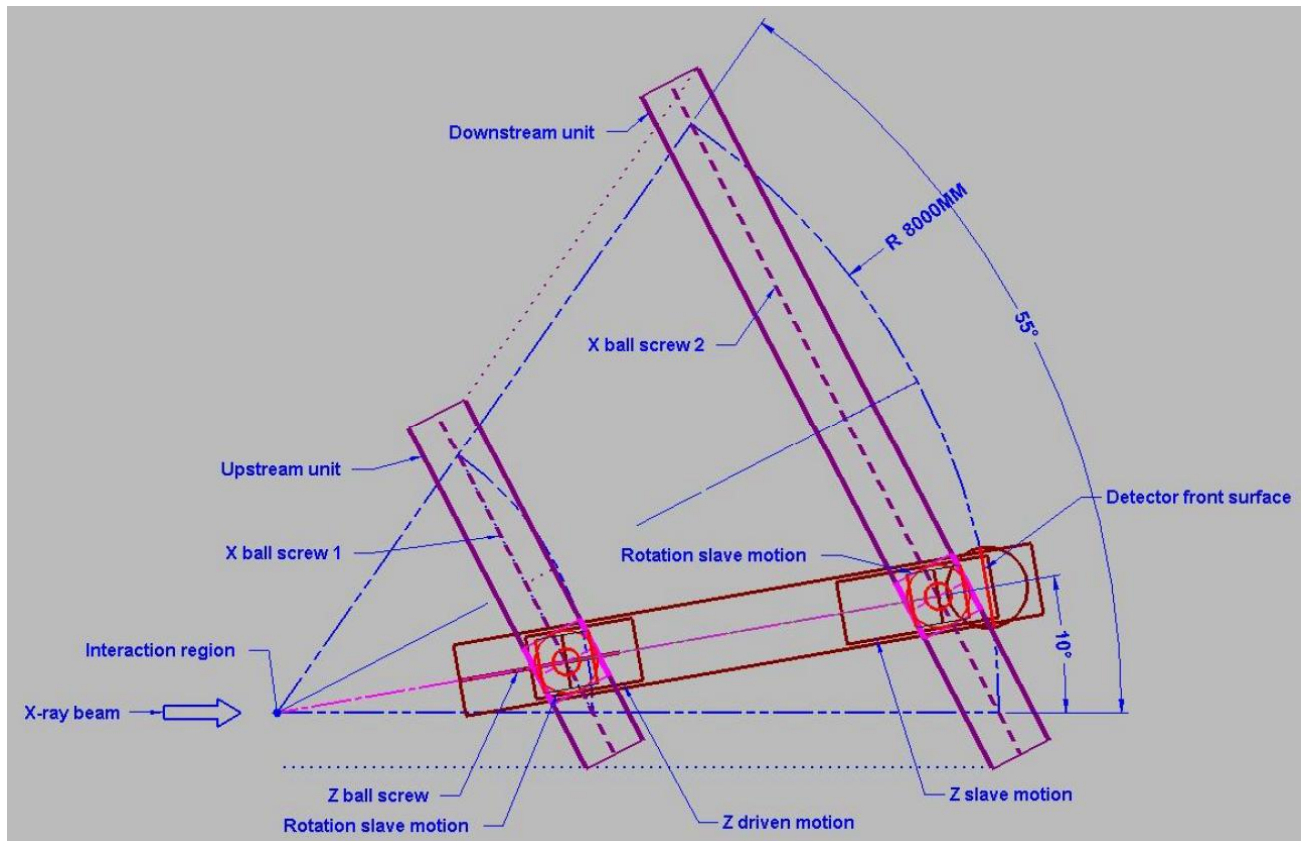
The Inelastic X-ray Scattering instruments at these facilities have devices with very similar requirements. There is however an instrument’s positioning device which fulfills all of the design issues for the XCS LADM in terms of independence regarding the Diffractometer System: The HERIX spectrometer at the Advanced Photon Source.

As for the XCS instrument, the space under the sample location is dedicated to the Diffractometer system and is not available for the LADM. Thus the rotation in the horizontal plane can’t be performed by pivoting around the sample axis but rather by coordinated linear motions in the X and Z directions and rotations at the intersections of linear motion stages.

**Only the carriage mover design concept is similar to the HERIX spectrometer. All the other components have a different design and will require to be designed in order to fulfill the requirements of the XCS instrument.**

The suggested design for the motion of the LADM in the horizontal plane is a combination of 3 linear stages and 2 rotary stages; resulting in the rotation of carriage mover around a virtual axis in the interaction region. These stages are combined in two different units as illustrated in **Figure 3.**





**Figure 3 Description of the motion consisting of 2 units to perform the requested rotation motion**

The carriage is supported by two units, combining the following motions:

- The upstream unit consists of :
  - 1 X driven motion
  - 1 Z driven linear motion
  - 1 slaved rotation motion
- The downstream unit consists of :
  - 1 X driven motion
  - 1 Z slaved linear motion
  - 1 slaved rotation motion

The advantage of this solution is that it provides the potential to vary the position of the rotation axis by software. It also provides the capability to remove the whole diffractometer from the x-ray beam path without interfering with the LADM.



### 7.1.1.2. Horizontal Motion Requirements

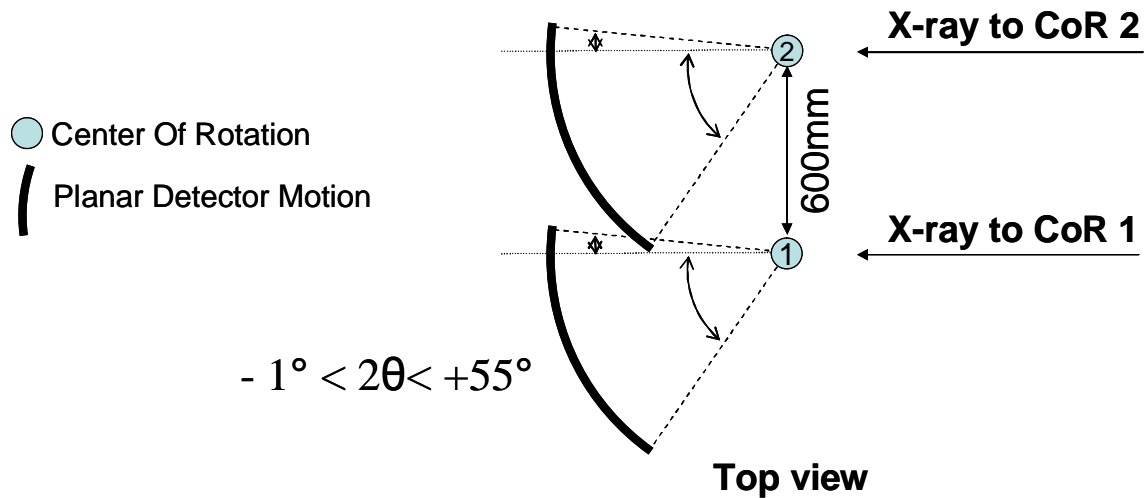


Figure 4 Description of the horizontal motion requirements

The Large Angle Detector Mover should meet the following requirements:

- Move in the horizontal plane covering scattering angles  $[2\theta]$  ranging from **-1 up to 55 degrees**.
- The desired resolution is **1mDeg**.
- It should accommodate a Center of rotation change compatible with the Diffractometer System CoR changes, as described in [Figure 4](#). Namely an horizontal offset of 600mm in the horizontal plane.
- In satisfying the above motion requirements, the LADM should have the possibility to translate in the horizontal plane parallel to the beam-line axis up to a distance a 1 meter. This would thus clear up the beam path completely from the LADM structures and associated subsystems.

### 7.1.2. Vertical Motion : Rotation and Translation

The Large Angle Detector Mover is required to rotate in the vertical plane for any scattering angle position  $[\gamma]$  The LADM must also be able to translate vertically to match the actual IP position of any experiment.

#### 7.1.2.1. Vertical Motion Description

The vertical motion will be of two types (as described in [Figure 5](#)):

- A vertical translation of the entire carriage,  $[\Delta Y]$ .
- An angular tilt of the whole carriage in the vertical plane, referred to as  $[\gamma]$ .

This motion can be, for example, achieved by placing on each unit performing the horizontal motion described in Sec. 7.1.1.1, an assembly of a motorized machine screw jacks and pivoting units. For simplicity the two vertical motion stages located on the downstream and upstream units should be identical.

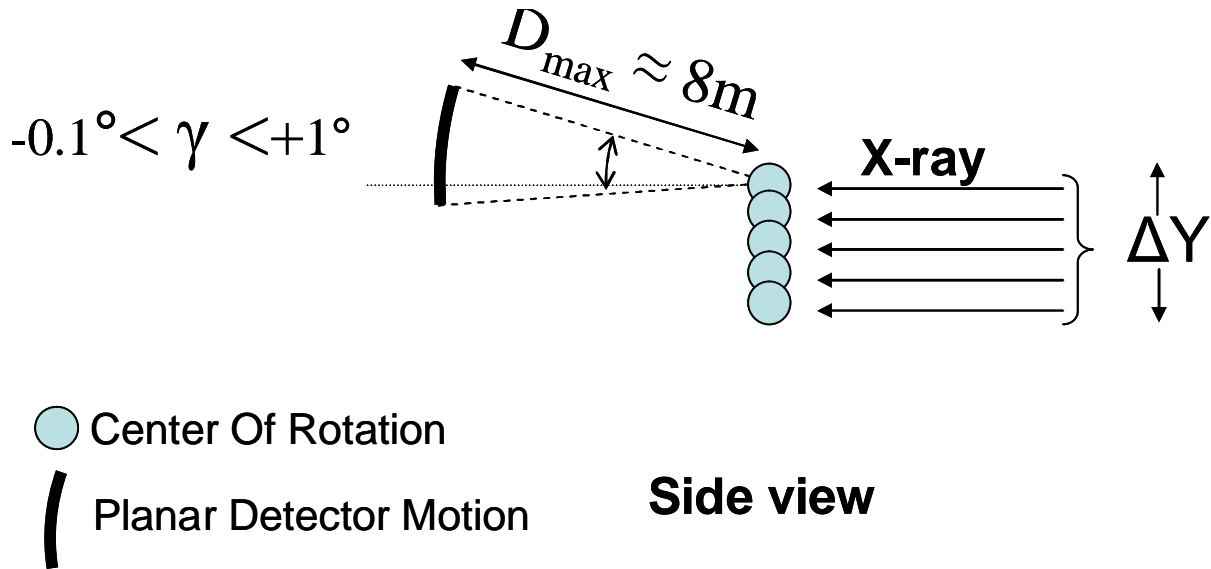


Figure 5 Description of the vertical motion requirements

### 7.1.2.2. Vertical Motion Requirements

The Large Angle Detector Mover vertical motion should meet the following requirements:

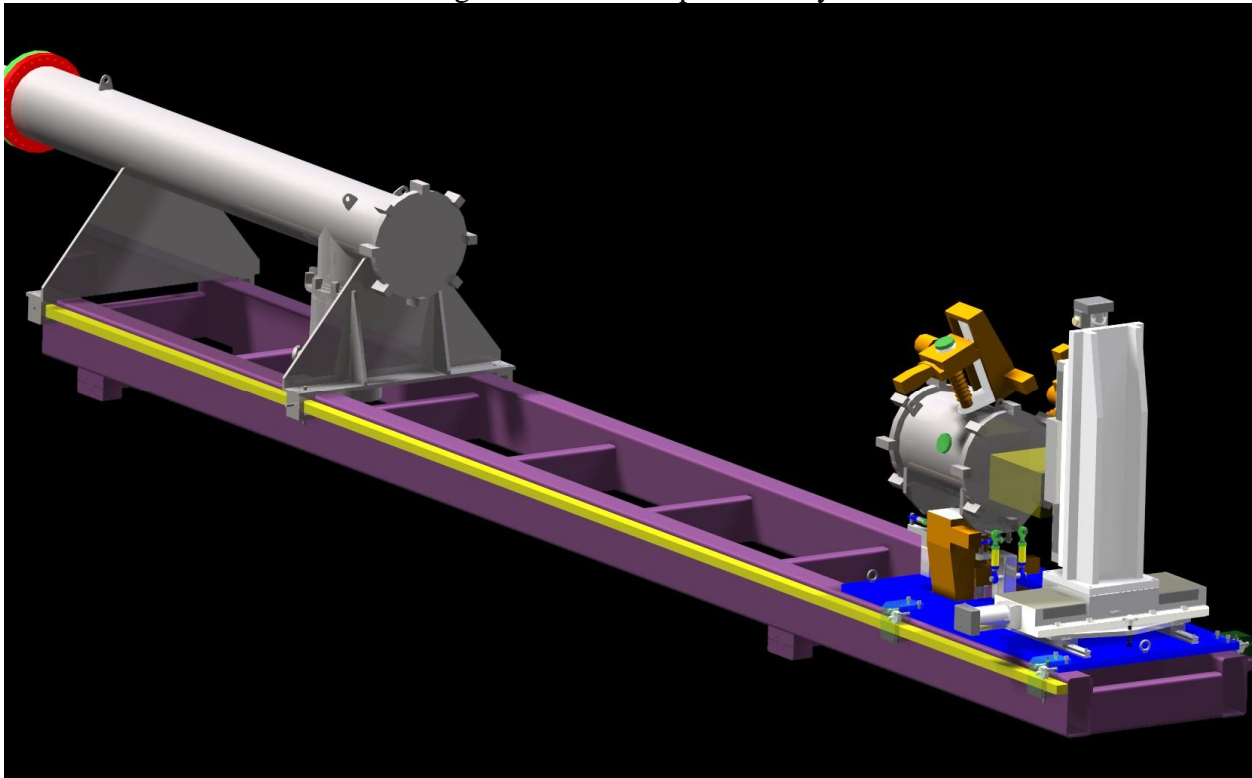
- Rotation in the vertical plane covering scattering angles  $[\gamma]$  with a range of  **$-0.1^\circ$  to  $+1^\circ$  degrees.**
- The desired resolution is **1m Deg.**
- Translation in the vertical plane  $[\Delta Y]$  with a range of  **$-30$  mm to  $+3$  mm.**
- **Since the tilt motion is performed using a combination of linear translations and pivoting units, the overall range of vertical translation at the downstream unit is at a minimum  $-45$  mm to  $+145$  mm. The Z slaved linear motion device on the downstream unit of the horizontal motion assembly must accommodate the change in projected Z length due to tilt in the vertical plane.**

### 7.1.3. Specific Requirements for the Carriage Mover

The design of the carriage mover, which horizontal and vertical motions are described in Sec. 7.1.1 and 7.1.2 respectively, should also satisfy the following requirements.

- When the vacuum chamber is centered on the nominal beam height 1.4 meter from the floor), the top of the carriage mover should not exceed 892mm.
- Minimum load capacity of carriage mover: 4000 lbs
- Maximum width of the upper carriage: 30 inch.

- The interface of the carriage mover to the equipment mounted on top of the carriage will be to an inverted “V” and flat rails permanently mounted to the side of the carriage.(Cf. design concept in **Figure 6**)
- The design of the carriage must provide the described motion without violating any indicated stay-clear.
- Motion control of the carriage mover will be provided by SLAC.

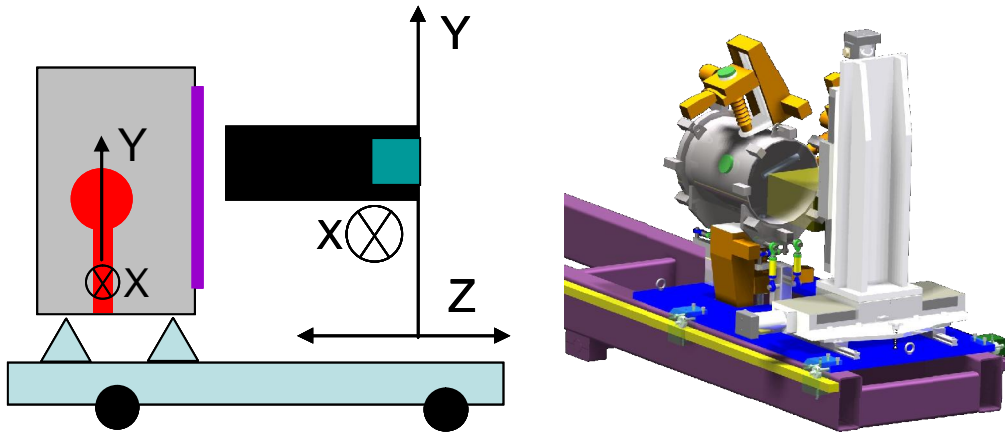


**Figure 6** Design concept presenting the carriage mover (purple structure) with the rail system on the side (yellow). The end-module can translate along the rail as all its subcomponents are mounted on the blue plate.

## 7.2. Adjustable End-Module

This section describes the various components and corresponding requirements for the adjustable end-module. The end-module consists of the following components as described in **Figure 7**:

- A detector precision positioning system
- A beam stop module right before an exit window
- A local detector feature

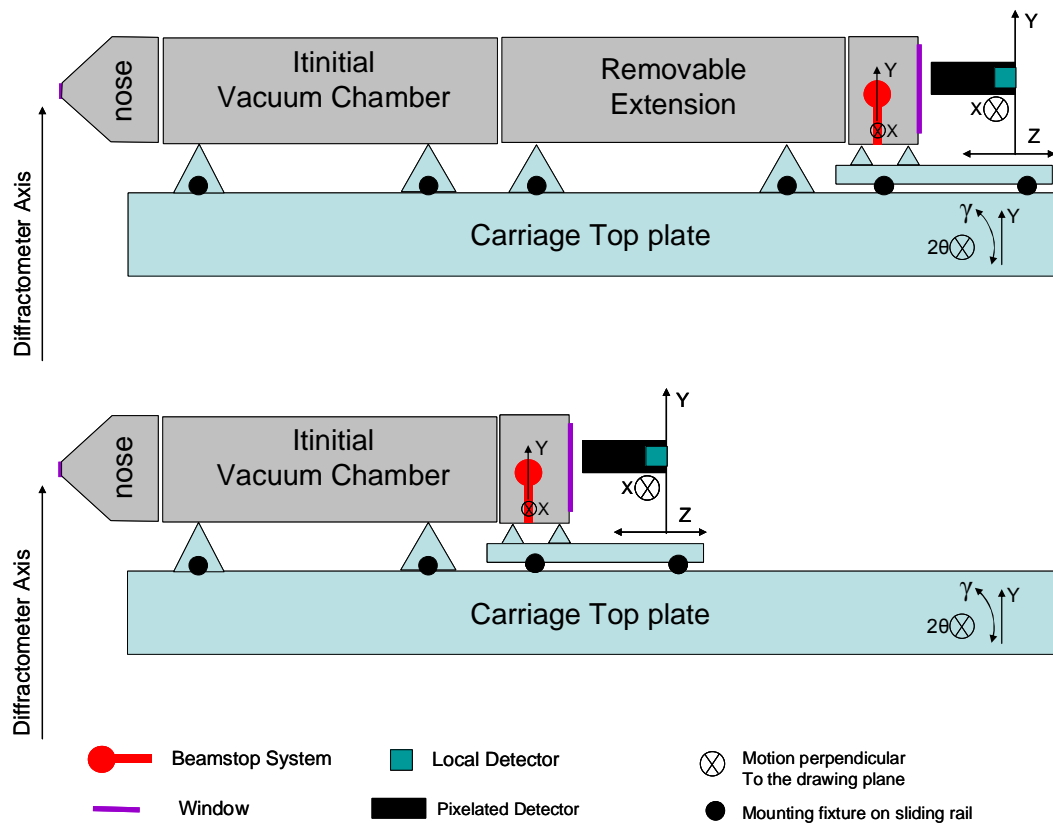


**Figure 7**Left :Description of the end-module subcomponents (cf. [Figure 8](#) for legend). Right : Engineering concept for the end-module.

The end module components are required to have the capability to move as a single unit along the carriage. This should be achieved by mounting all of the End-Module components on a single support and to provide the capability to the support to slide (using guiding rails) along the sides of the carriage mover (as described in [Figure 8](#)).

**The longitudinal motion of the end-module is not required to be motorized.**

The whole module will be connected to the “adjustable” vacuum system described later in this document. This provides the capability to change the sample-detector distance easily without having to adjust the location of each of these components independently. The following schematic illustrate the overall requested design concept:



**Figure 8** Description of the various components to be installed on the mover carriage. This also illustrate the motion and the provided modularity of the end module.

The mounts and supports for the all the components to be installed on the Carriage mover must use the rail system described briefly in section [7.1.3](#).

## 7.2.1. Detector Precision Positioner

### 7.2.1.1. Description

The purpose of the LADM is to precisely position, at a large distance from the sample, an x-ray pixelated detector in the vicinity of the horizontal scattering plane. Therefore a detector precision position stage is required. The detector positioner stage orients the detector relative to the carriage mover coordinate system in a range where the detector can cover the entire downstream window.

The positioning stage provides the capability to position the detector both in the longitudinal [**Z**] and transverse directions [**X,Y**] relative to the carriage mover. Besides the capability to cover the entire exit window, the transverse motion must have a range of motion sufficient to move the detector outside of the window aperture. The longitudinal motion of the positioning stage [**Z**] allows placement of any detector as close as possible to the exit window and allows movement of the detector away from the exit window for window maintenance. The positioner must also provide a mount for a local detector to aid in positioning the Beamstop. The local detector consists of a diode and a pair of precision slits.

The detector precision positioner is part of the end-module and will therefore be installed on the end-module base plate.

### 7.2.1.2. Requirement

The detector positioner may be comprised of commercial linear translation slides. **All motions (except the longitudinal [Z] translation) must be motorized with position read-back.** When set at a location, the positioner assembly must provide a stable platform for the detector for the duration of an experiment. The motions required are summarized in [Table 1](#).

**Table 1 Requirements for the Detector precision positioner motion**

Direction	Range (in)	Accuracy (micron)	Repeatability (micron)	Resolution (micron)	Stability (micron / hour)
X	+12/-6	<20.0	<10.0	<20	<1.0
Y	>+/- 15	<20.0	<10.0	<20	<1.0
Z	>25	n.a	n.a	n.a	<1.0

**The Detector Precision Positioner must have a load capacity of 50lbs.**

### 7.2.2. Beam-stop System and exit window

The Beamstop sub-assembly must protect the XCS detector from illumination by the transmitted or strongly Bragg reflected x-ray beam. A local detector (consisting of an x-ray diode and pair of slits in front of it) will be used behind the detector mover, to adjust the beamstop position. The local detector will be located on the chamber centerline. As for any state of the heart beamstop system, it should be on the vacuum side of the exit window.

#### 7.2.2.1. Beam-stop System

The beamstop consists of a piece of highly x-ray absorbing material (typically Tantalum) and can have various shapes required by the experiment scattering geometry. Whatever the details of the beamstop shape and dimension, it however needs to meet the following requirements:

- It should be located in vacuum, namely on the vacuum side of the exit window
- It should be located as close as possible from the exit window.
- It should move along the diameter of the vacuum system pipe (i.e radial motion).
- It should also be adjustable perpendicular to the radial motion (tangential motion).
- Both motions should be motorized
- The radial motion should offer the capability to remove completely the beamstop from the exit window aperture

The design phase should investigate the possibility to provide multiple beamstop system simultaneously in order to offer a large flexibility of use to the experimentalist. Some preliminary design investigations indicate that 3 different beamstops could be implemented simultaneously.

**Table 2 Radial and tangential motion requirements for a single beamstop**

<b>Direction</b>	<b>Range (in)</b>	<b>Accuracy (micron)</b>	<b>Repeatability (micron)</b>	<b>Resolution (micron)</b>	<b>Stability (micron / hour)</b>
Radial	>6	<20.0	<10.0	<20	<1.0
Tangential	>+/-0.25	<20.0	<10.0	<20	<1.0

### **7.2.2.2. Exit window**

The exit window system is located right after the in-vacuum beamstop. It will consist of a thin foil of Kapton, which dimension and shape will be defined by the experimental needs. Whereas the area of the window will be maximized, the details of its shape and dimension are not known yet.

However the window will be in any case consisting of a flange which dimension is compatible with the dimension of the vacuum system. Several of these flanges will be available with various window configurations.

## **7.3. Vacuum System : Evacuated Flight Path**

In order to reduce air absorption and air scattering from the scattered signal between the sample and the detector an evacuated flight path must be provided.

### **7.3.1. Description**

The evacuated flight path is achieved by including a vacuum chamber with a window on the upstream end and connection to the end module described in section 7.2. The end module provides the downstream window of the vacuum system as described in Sec 7.2.2. The vacuum system must accommodate the following requirements:

- Adjustable sample detector distance, i.e. modularity.
- Adjustable nose system to adapt to any sample environment.
- An entrance window as large as possible.
- Compatibility to a large exit window (included in the end module).
- Be as light as possible for convenience of reconfigurations



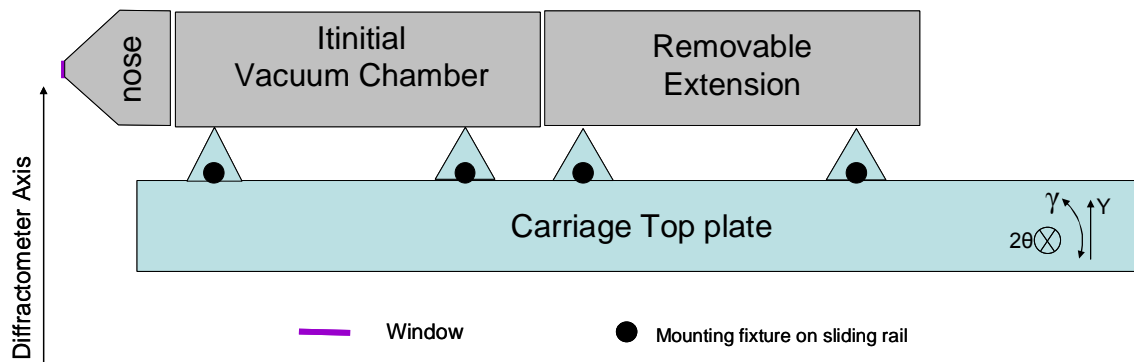


Figure 9 Vacuum System schematic

### 7.3.2. Requirement

This section describes the requirements for the overall vacuum system:

- The vacuum system must be capable of achieving  $5 \times 10^{-4}$  Torr minimum. Therefore the use of turbo pumps is sufficient.
- The use of o-rings is recommended for sealing each section to another.
- The system must be able to be vented and pumped in a minimum of time.
- All vacuum components required to pump the system must be permanently attached to the mover carriage.
- The system only needs to be vented to room air.
- Maximum pipe size diameter is 12"
- A system to monitor the vacuum pressure should be provided

Nose side of the vacuum system requirements:

- The entrance window must offer the capability to accommodate a CVD Diamond window of diameter 40mm. It could also be replaced with Kapton.
- The flanges on which the window is mounted should be easily exchangeable.
- It should also offer the possibility to connect the flypath directly to the sample environment and operate windowless.
- Provide a large modularity in terms of closest distance from the center of the diffractometer.

The vacuum chamber must accommodate a diamond window mounted to a 2-3/4 inch flange on the sample end. The chamber must increase in diameter along the length to transmit a maximum of the signal's solid angle. The chamber diameter at the detector end should be of 12 inch OD tube. The vacuum chamber must be configurable to place the detector at 8 m or 4 m from the sample. Therefore, the pumping (if sufficient with a single turbo-pump) must be attached only to the upstream end of the chamber

The tapering of the chamber may be accomplished in cylindrical steps rather than in conical sections. The upstream end of the tapering must be done in several sections to provide variation

in the distance of the diamond window to the IP, allowing for various sample environment dimensions.

The attachment of the vacuum system to the mover carriage should employ the same attachment method as the Beamstop and Detector Positioner.

Initial vacuum chamber requirement requirements:

- 12” diameter tube at downstream end minimum.
- As light as possible (the use of aluminum is recommended instead of steel).
- Features compatible with a crane-lifting for installation.
- O-ring sealed to the beam-stop system on the end module.
- The support of the beam-pipe should use the rail installed on the mover carriage.
- The support of the beam-pipe should be removable.

Removable extension requirements:

- 12” diameter tube.
- As light as possible (the use of aluminum is recommended instead of steel).
- Features compatible with a crane-lifting.
- O-ring sealed to the beam-stop system on the end module.
- The support of the beam-pipe should use the rail installed on the mover carriage.
- The support of the beam-pipe should be removable.

## 8. Local Obstruction Avoidance

Specific care has to be taken regarding the interaction between the motion of the overall assembly and possible nearby obstacles such as the CXI beam-line located 600mm south from the XCS beam-line line and the HED beam-line located 500 mm south of the CXI beam-line. This could be performed by software; however, interference studies must be conducted during the design phase.

## 9. Motion Control Requirement:

### 9.1. Motor Specifications and Requirements:

**Motors shall be Intelligent Motion Systems, Inc. MDrive™ motion control version (MDI3CRL-XXX) “smart motors” using MDrive Plus™ and Expanded PLUS2™ Control.**

The number of motors required is 5 for the carriage motion and 2 for the detector positioning stage (in addition of 2 for a single beamstop).

### 9.2. Encoder Specifications and Requirements:

Translations and rotation axes requiring external encoding shall use hardware compatible with the requirements specified for closed loop-external connection for the Intelligent Motion

Systems, Inc. MDrive™ motion control version (MDI3CRL-XXX) “smart motors” using MDrive Plus™ and Expanded PLUS2™ Control.

Translations and rotation axes not compatible with external encoding shall employ closed loop internal encoding specified for the Intelligent Motion Systems, Inc. MDrive™ motion control version (MDI3CRL-XXX) “smart motors” using MDrive Plus™ and Expanded PLUS2™ Control or open loop control.

### **9.3. Limit Switches:**

All translation and rotation elements shall be provided with adjustable limit switches. Adjustability shall be provided such that the limit switch can be positioned to change state at the point of contact with the hard stop.

## **10. Cable Management:**

All cabling shall be located, configured and labeled to provide rapid and intuitive reconfiguration of the detector mover system.

All power and data cabling shall be routed and strain relieved in a manner such that all translation directions and rotation axis can achieve full range capability, plus 10% of full range, without load on cable, connector or diffractometer hardware.

**Industry standard approved flexible cable carriers shall be mounted on the upstream carriage unit of the main carrier mover.** Three flexible cable carriers must be employed, one for the X-travel, one for Z-travel and one for rotation. The location of the flexible cable carriers should be on the side of the motion stages away from the IP and away from the adjacent beam-lines.

A cable tray must be installed along the side of the upper motion carriage to distribute control cables to the stopper, detector positioner, detector, local detector and vacuum components.

Each motor must have a nearby disconnect for motor replacement. The disconnects, must be mil-spec metal shell multi-pin connectors which mate to a fixed receptacles mounted on a DIN rail connector block. The “pig-tail” from the motor to the DIN rail connector must not be more than 1 m long.

DIN rail connector blocks for the detector precision positioner motors must be duplicated for the two positions of the End Module. The two sets of detector precision positioner motors connector receptacles must be wired in series for this purpose.

## **11. Power and Data Cable Requirements / Interface:**

### **11.1. Power Cabling Requirement / Interface:**

Power cable gauge size shall be the maximum size applicable to the given motor frame. Power cabling shall be of sufficient length to terminate at DIN block.

## **11.2. Control Cabling Requirement / Interface:**

Control cabling shall be consistent with the requirements and specifications of Intelligent Motion Systems, Inc. MDrive™ motion control version (MDI3CRL-XXX) “smart motors” using MDrive Plus™ and Expanded PLUS2™ Control.

Motor controller to serial port server shall use RS-422/485 protocol. Communications port connector at motor shall be 10-pin friction lock wire crimp (style RL)

All control communications cabling shall be of sufficient length to terminate at DIN blocks.

## **12. Reviews**

All systems hardware will be subject to SLAC review and approval. Reviews will be conducted in accordance with SLAC document number AP-391-000-59: “Engineering Review Guidelines”. SLAC reserves to right to employ an internal (SLAC direct), external-independent, or mixed source review panel.

Particular review attention will be devoted to:

- Personnel access restriction methodology
- Emergency stop methodology / mechanisms
- Power failure provision – fault modes
- Electrical Safety including Lock-Out / Tag-Out
- Training mode functionality
- Maintenance mode functionality.

All electrical hardware must meet SLAC electrical safety standards.

## **13. Environmental Safety and Health Requirements**

### **13.1. General Seismic Considerations**

SLAC is situated in an active seismic zone. All hardware exceeding a weight of 300 Lbs. and / or mounted greater than 4 feet above the floor will be reviewed by a SLAC “citizen safety committee” for seismic loading resistance. Applicable loads and structural behavior will be evaluated for compliance to the 1997 version of the uniform building code and SLAC publication SLAC-I-720-0A24E-002: “Specification for Seismic Design of Buildings, Structures, Equipment, and Systems at the Stanford Linear Accelerator”.

## **14. Supplemental System Requirements:**

Requirements, including the following topics, will be addressed in detail in subsequent procurement specifications and contracts.

- i. Inspection, testing and acceptance
- ii. Installation support services
- iii. Training support services
- iv. Maintenance procedures, schedules and assistance
- v. Repair and overhaul services

### **14.1. Materials**

All parts and materials for the device shall be new and compatible with the performance requirements of this specification. No part interfaces should result in galvanic corrosion for the life of the system.

No system, sub-system or part shall be reconditioned or remanufactured.

All applicable material safety data sheets (MSDS) shall be provided and stored in an accessible location.

### **14.2. Paint Color**

**All painted surfaces are to be painted purple, defined as federal standard 17100.**