Final Design Report

Partner Beamline NYX
19-ID

NYSBC Microdiffraction Beamline

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1. Executive Summary

The NYX Microdiffraction Beamline aims to provide scientists from the New York Structural Biology Center (NYSBC), and also General Users, with convenient access to x-rays from NSLS-II for macromolecular crystallography. This beamline has the scientific objective of providing a state-of-the-art source for a wide spectrum of crystallographic experiments and a cutting-edge source for optimized anomalous diffraction experiments.

NYSBC has led a Participating Research Team (PRT) at the National Synchrotron Light Source (NSLS) for many years, maintaining, upgrading and operating beamlines X4A and X4C. The X4 beamlines were developed originally with support from the Howard Hughes Medical Institute (HHMI). That project began in 1987, and X4A began operations in 1991. NYSBC took over in 2003 and completed major upgrades of X4A and X4C in 2004.

In anticipation of its continued presence in macromolecular crystallography at NSLS-II, NYSBC submitted a Type-II Beamline Development Proposal (BDP) for the NYSBC Microdiffraction Beamline NYX, with Wayne Hendrickson as spokesperson, and this proposal was approved in 2010. NYX features exceptional energy resolution for the optimization of anomalous signals from resonance features. Subsequently, the NYSBC team also submitted a BDP in 2011 for the Low-energy Anomalous X-ray Diffraction Beamline LAX, and this was approved in 2013 and an update LAX proposal is under consideration. Low-β straight section 19-ID has been allocated for the NYX beamline. Funding for NYX is in place from the National Science Foundation, including matching funds from NYSBC and the New York State Office of Science, Technology and Academic Research (NYSTAR), and from the Army Research Office (ARO) of the Department of Defense (DoD). The LAX beamline is not yet funded, but it is anticipated that it will share the 19-ID straight with beams from the NYX and LAX undulators separated by canting magnets. Thus, the designs for NYX are taking into account the eventual accommodation of LAX.

NYX features several innovations giving it best-in-class performance. These include a novel monochromator design for providing exceptional energy resolution in order to assure maximal anomalous scattering signals from sharp resonant features. The ultimate NYX undulator will be an adaptation of a Segmented Adaptive Gap Undulator (SAGU) proposed by Oleg Tchoubar of NSLS-II; however, the undulator formerly used at NSLS X25 will be adopted as the initial source. NYX also includes a novel pixel array detector, co-developed by the Area Detector Systems Corporation and NYSBC, to match performance requirements for detector speed and dynamic range. The beamline is designed throughout to be a stable and versatile resource for macromolecular crystallography.

2. Scientific Objective

2.1 Scientific Background

Knowledge of biological structure at the atomic level has informed, indeed formed, modern biology since the discovery of the double helical structure of DNA. Nearly all enzymology is now structural enzymology; how transcription factors recognize their DNA targets is understood in the detail of atomic interactions; and fundamental processes of replication, transcription and translation are now all richly founded in atomic-level descriptions of polymerases, ribosomes and cofactors. There are structures for impressively large and often pathogenic viruses; structure often leads the way in the study of protein kinases and other signaling molecules; several ribozymes are structurally characterized, and the new biology of micro RNAs has quickly succumbed to structural analysis. Structure is well integrated into drug development; degradative systems, molecular chaperones, and other homeostatic mechanisms now have structural underpinnings; and ion channels and membrane receptors are increasingly amenable to structural analysis. These developments derive predominantly from x-ray crystallography (89% of > 115,000 current PDB entries). This science is vibrant; half of all known structures were determined in the past six years, and increasing numbers of these more recent structures are challenging subjects – mammalian proteins, large multi-component complexes, and integral membrane proteins. Synchrotron radiation plays a huge part now (88.0 % of crystal structures recorded into the PDB in the last five years), and we anticipate that enhancements at NSLS-II will provide new advantages for structural analyses in increasing numbers and at ever increasing complexity.

At its beginning, all macromolecular crystal structures (then only proteins) were determined by the method of multiple isomorphous replacement (MIR) using heavy-atom derivatives for the needed phase evaluation. Subsequently, the method of multiwavelength anomalous diffraction (MAD) provided an effective alternative for solving novel macromolecular crystal structures, and the method of molecular replacement (MR) grew into predominance as the repertoire of structural homologs provided templates for this approach. Truly new information about biological structure continued to depend on *de novo* structure determination, such as from MIR and MAD. The innovation of selenomethionine as a particularly efficient and effective agent for MAD phasing provided an important impetus to the MAD method, but so too did the introduction of beamlines specialized for MAD phasing, most notably the X4 beamlines at NSLS. Ultimately, advances in methods for density modification effected an efficient resolution of phase ambiguities, which then spurred adoption of the method of single-wavelength anomalous diffraction (SAD). At present, over 70% of all *de novo* crystal structures are determined by SAD phasing (Hendrickson, *Quart. Rev. Biophys*. **47**, 49-93, 2014).

The X4 beamlines at NSLS, developed initially by HHMI and taken over in 2003 by NYSBC, led the way in advances for optimized anomalous diffraction experiments. Beamline X4A was particularly instrumental, but effective tunability with maintenance of energy resolution was also demonstrated with a single-crystal monochromator at X4C (Lidestri & Hendrickson, *Nucl. Instr. Meth. A*. **599**, 289-300, 2009; Moore & Hendrickson, *Structure* **20**, 729-741, 2012), and this development is the basis for the NYX monchromator.

In relatively recent experiments at X4A and also at LCLS, we have demonstrated the special effectiveness of lower than usual x-ray energies for SAD phasing based on elements intrinsic to virtually all biological macromolecules, notably sulfur and phosphorous (Liu *et al*., *Science* **336**, 1033-1037, 2012; Liu *et al., Acta Crystallogr. D* **69**, 1314-1332, 2013; Liu *et al*., *Acta Crystallogr. D* **70**, 2544-2557, 2014). These developments affect our plans for beamline development. In particular, NYX is being developed with its undulator canted such that in sector 19-ID will accommodate a second undulator to serve a partner beamline for Low-energy Anomalous X-ray Diffraction (LAX)

2.2 Scientific Aims

The primary scientific aim for NYX is focused on the needs of users from the nine member institutions of the New York Structural Biology Center (NYSBC) and also those of its DoD sponsor, but the beamline must also meet needs of NSLS-II General Users. Investigators from the NYSBC community include many pre-eminent structural biologists working on challenging problems at the forefront of the field. Challenges come from the size and complexity of systems under study. Moreover, as technological advances make it possible to deal with new challenges, such as those that come from very small samples, demand grows for the technical capability to meet these challenges. Micron-sized x-ray beams are readily feasible at NSLS-II, and we expect substantial demand for this capability. Micron-sized crystals are commonplace for many problems, and they are intrinsic to the lipidic cubic phase (LCP) methods from crystallization of membrane proteins. To achieve the desired brilliant x-ray microbeams, it is essential to take advantage of the enhancements that come best from undulator sources at a low-emittance synchrotron such as NSLS-II.

A second major emphasis for NYSBC beamlines, and a significant focus of research for NYSBC scientists, concerns the optimization for anomalous diffraction experiments. NYX is an intellectual successor to NSLS beamline X4A, which was designed in part for the testing of multiwavelength anomalous diffraction (MAD). While moving to incorporate microbeams, we also want to preserve the versatility of optimized anomalous scattering experiments across a broad spectrum of atomic resonances from different elements and we propose to capitalize on the intrinsic brightness of NSLS-II to optimize anomalous signals by improving energy resolution. In light of the overwhelming success of SAD phasing, such optimization has two aspects: one concerns the maximization of on-resonance anomalous scattering at the absorption edges, and the other concerns the off-resonance optimization of anomalous scattering signals in light of complications for diffraction experiments at low energy (long wavelengths).

Recognizing that many problems may not require *de novo* phase evaluation, we would not want to compromise generic performance of NYX to optimize anomalous diffraction experiments. With these considerations in mind, we focus for NYX on the kind of science that will benefit from three attributes that have motivated our proposed beamline design: (1) we aim to provide stable, high brightness beams at the level of cross sections from 50-micron down to 5-micron; (2) we aim to preserve the inherent spectral flux from a monochromator crystal (typically Si 111) within a bandpass down to energy resolution of $\Delta E/E = 5 \times 10^{-5}$; and (3) we aim to support efficient diffraction experiments in the range of x-ray energies from 5 to 17.5 keV. The NYX energy range covers all conventional phasing elements from the uranium L_{III} edge (17.17 keV) down to the cesium L_{III} edge (5.01 keV) with expected emphasis on the Se K edge (12.66 keV). Because low energy experiments encounter several special technical requirements, we have decided to limit the lower reach of NYX to approximately 5 keV, which includes transition metals through the manganese K edge (Z= 25, 6.54 keV) and accomodates demostrably effective sulfur SAD experiments, and to develop LAX as a separate beamline dedicated to experiments at energies that can reach the potent uranium M_V edge (3.49 keV) and the biologically prevalent phosphorous and sulfur K edges (2.15 and 2.47 keV).

2.3 Beamline Performance Requirements

To meet the Scientific Objective that we have set, NYX will need to provide reliable operation for macromolecuar crystallography experiments, including those without the need for a specific x-ray energy and those that require tuning to the energy of a specific resonance feature. This operation will also need to address crystallographic challenges of small crystals, large unit cells, radiation damage effects and sundry crystal pathologies. To be effective, it must also be designed to take full advantage of the high photon fluxes that the optics will be able to deliver.

The following are among the most salient of beamline characteristics needed to address the Scientific Objective and its specific aims:

- Accommodation of LAX as a companion beamline from a second canted undulator in the same straight section.
- Accommodation of the SAGU as the eventual NYX undulator, which will produce a greater heat load for the optics.
- Precision energy tuning (within 0.1 eV) over the range of energies from 5 keV to 17.5 keV.
- X-ray energy resolution to the level of $\Delta E/E = 5x10^{-5}$ at the Se K-edge.
- X-ray beam focusing with uniform intensity across the illuminated spot for beam from 5 μm to 50 μm with differential control horizontally and vertically.
- Beam position control to deliver the beam stably centered on the target position (wihin 1 μm).
- Visualization optics and raster scanning options for sample orientation and positional control.
- Sample control to maintain crystal centering (within 1 μm) and reliable rotations at high scanning speeds (>600 deg/sec).
- Sample exchange robotics to acccomodate current sample delivery systems, anticipating that new procedures may develop.
- X-ray detector designed to cope with anticipated fluxes and lattices with Bragg spacings as great as 2000 Å.

3. Beamline Overview

The x-ray source for NYX will be an undulator in the low-β straight section of NSLS-II sector 19, which will be laid out to accommodate two insertion devices (IDs), an upstream (U1) in the electron beam as the source for NYX and, ultimately, a second downstream undulator (U2) as the source for LAX (Figure 3-1). The ID source for the NYX beamline has two options, starting with the repurposed 1-meter X25 IVU and then ugraded to a 2-meter SAGU undulator. The X25 device is provided as a temporary option until the SAGU option can be produced. The straight section will incorporate appropriate canting magnets from the outset so that both the NYX and LAX beamlines can be accomodated without any future displacements. The 19-ID Front End is designed to handle the radiation from both undulators.

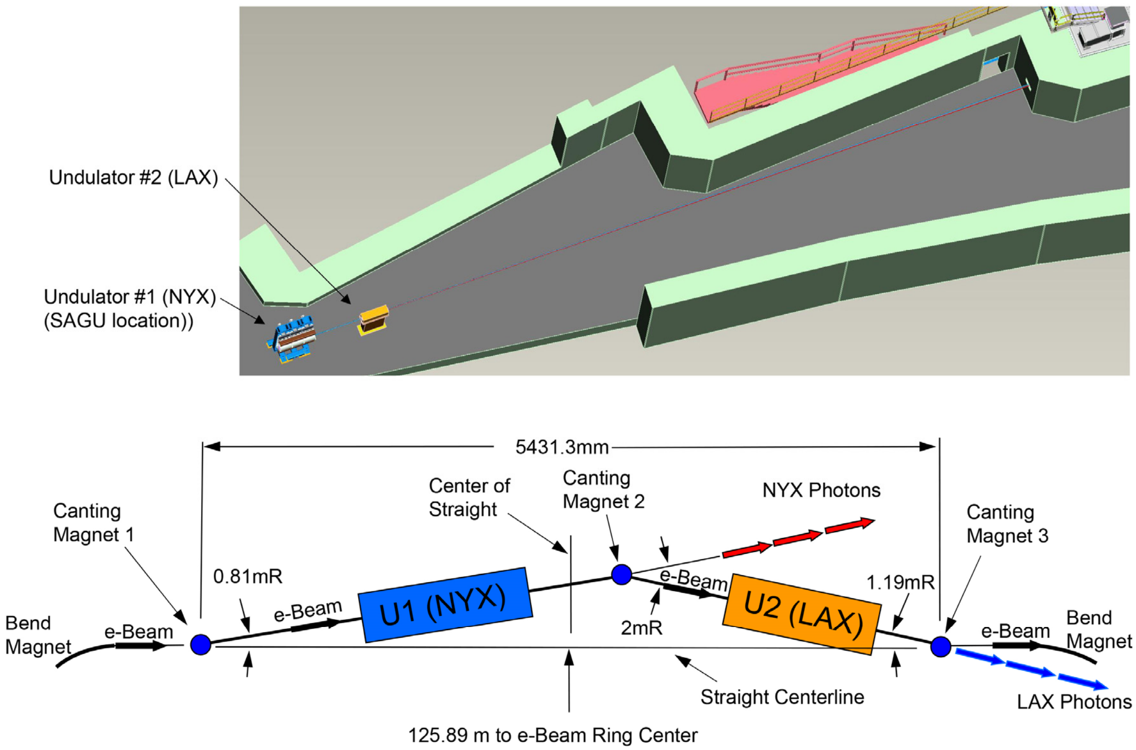


Figure 3-1. Straight-section geometry. Two undulators will be placed as shown without accelerator components in the 19-ID straight section (above), and as shown schematically to detail the separation of beampaths by canting-magnet deviations (below).

The NYX beam will be delivered through the front end components into a radiation and vacuum containment system as shown in Figure 3-2. Radiation enclosure hutch A, which abuts directly to the shield wall, will include the future LAX monochromator (Mo1). The NYX monochormator (Mo2) and vertical focusing mirror (VFM) will be enclosed in white-beam hutch C, which is contiguous with the NYX endstation hutch D. Hutch B is reserved for the eventual endstation radiation enclosure for LAX. A shielded white beam transport will pass the NYX beam from hutch A to hutch C. The entire NYX beam will be in vacuum through to its delivery into the environment at the sample crystal position (Xtl).

A fully developed CAD layout of the beamline has been generated that includes accurate 3D representation of all synchrotron beam apertures, bremsstrahlung collimators, vertically adjustable beam slits, beam filters, beam position monitors and beam optics compnents. The NYX beam optics components include the double crystal monochromator (DCM), and a Vertical Focusing Mirror (VFM) that deliver a focused monochromatic beam to the sample positioning point of the end station. The end station consists of a sample postioning goniometer, robotic sample handler, a sample dewar and x-ray detector system. The first optical element in the white beam is the DCM, which is designed to accommodate the full strength from the SAGU without sacrifice of energy-resolution performance. The overall beamline and the experimental floor beamline component layout is shown in Figure 3-3.

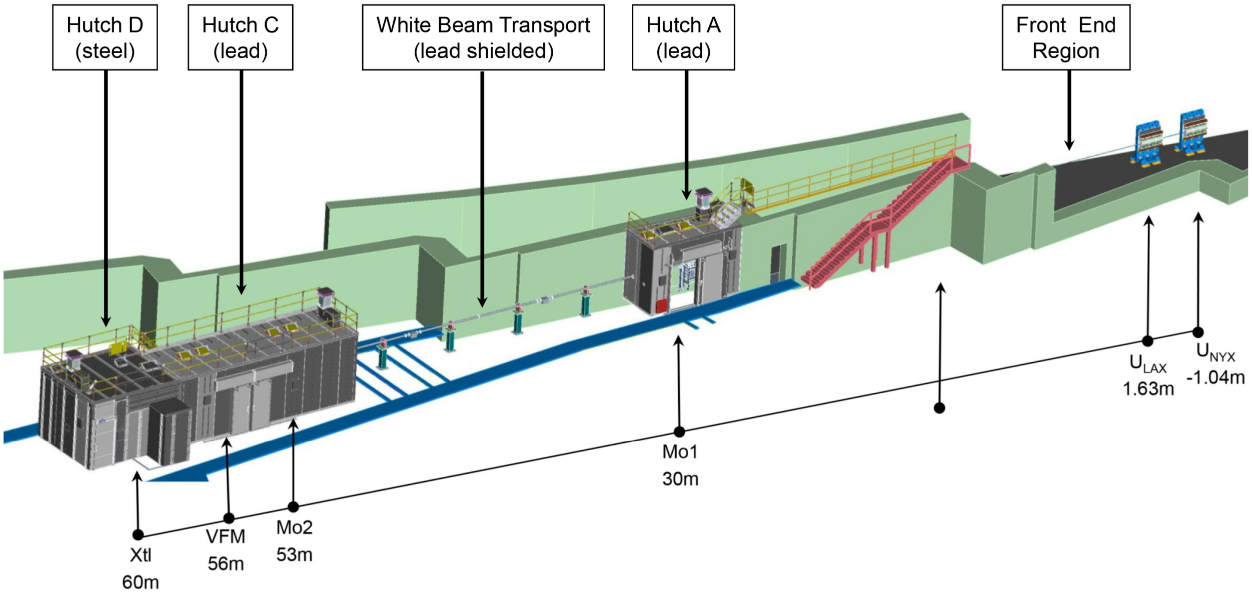


Figure 3-2. Isometric view of the radiation and vacuum containment system of the NYX beamline. This view is from outside shieldwall and toward the accelerator ring, opposite to that in Fig. 3-1.

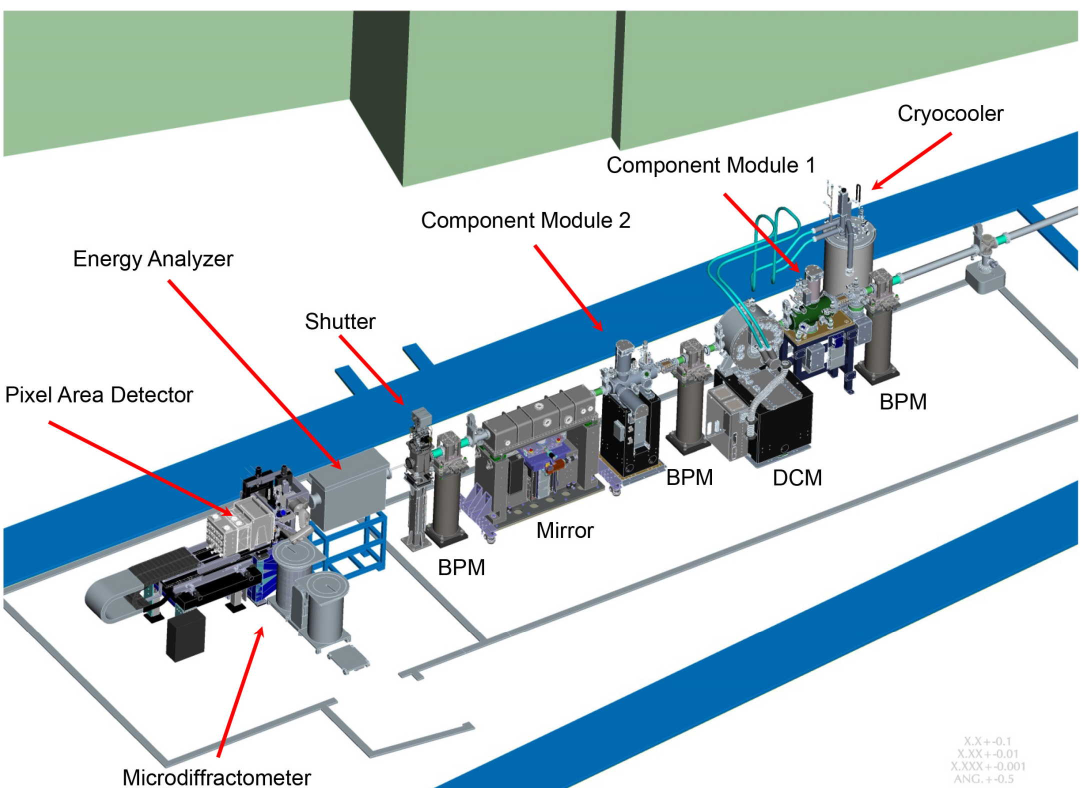


Figure 3-3. Layout of photon delivery system (C hutch) and endstation (D hutch) components of the NYX beamline. Floor footprints of the C and D hutch walls are shown in gray.

4. Straight Section and Insertion Device

4.1 19-ID Straight Section of Accelerator

4.1.1 General Description

The canting magnets in the 19-ID short straight are to be located so that a future 2 m undulator may be installed in the upstream section and a 1 m device in the downstream section. The upstream section will be used for the NYX source and will utilize a refurbished 1 m undulator acquired from NSLS X25. The 1 m X25 IVU will be placed with its downstream magnet location to coincide with the downstream magnet location of the future 2 m IVU as shown in Figure 4-1.

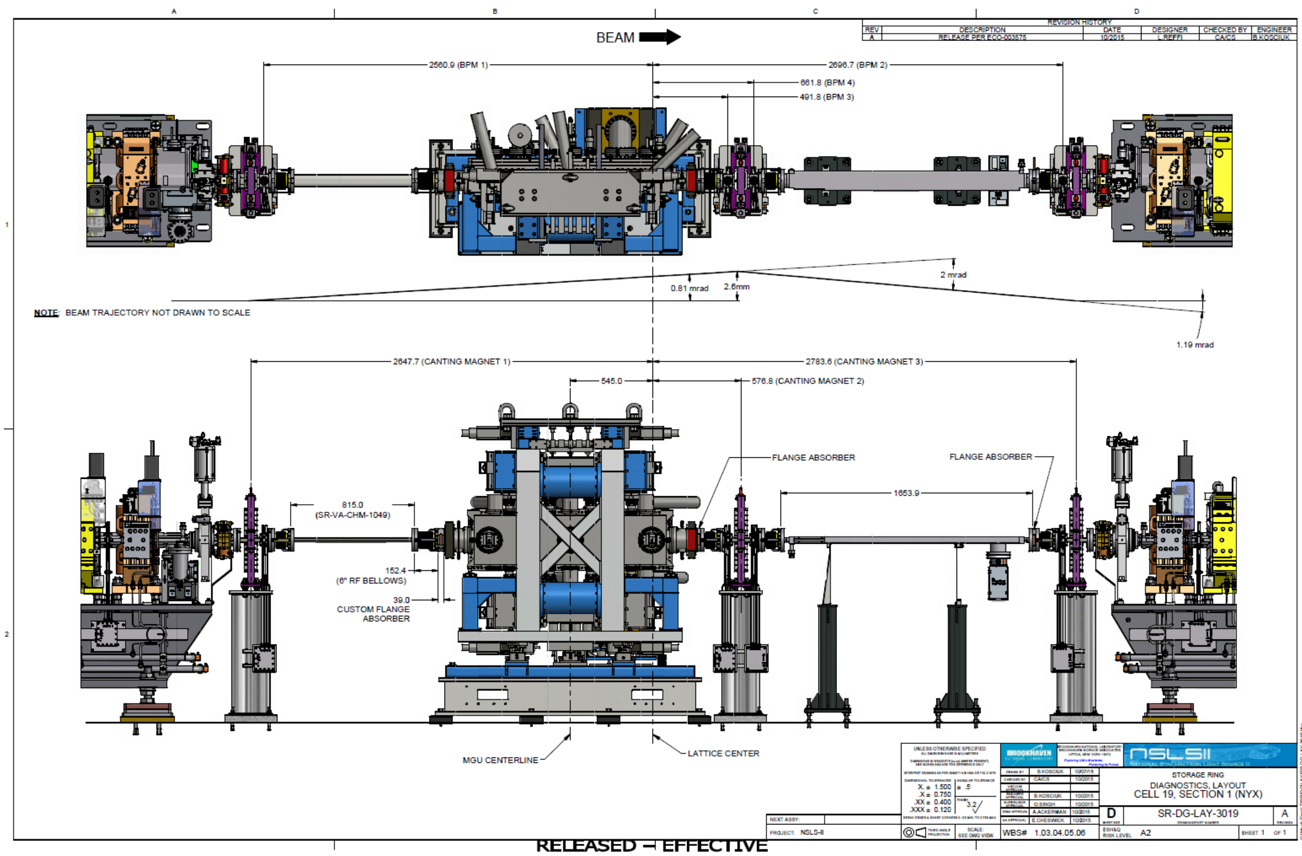


Figure 4-1. Straight section19 ID layout with 1 m X25 IVU and asymmetric canting.

4.1.2 Requisition, Specification and Interface (RSI)

The following table sumarizes the ID options for 19-ID beamlines NYX and LAX. There are two options for NYX: the IVU X25 repurposed from NSLS and the Segmented Adaptive Gap Undulator (SAGU), quoted in paretheses.

Table 4.1: Insertion devices for 19-ID beamlines.

Beamline	NYX	LAX
Type	X25 IVU (SAGU) *4	IVU
Length	1.0 (2.07) m *5	~1 m
Usable photon energy range	6.5 (1.4) – ~20 keV	~3 – 7 keV
Canted	Y (asymmetric)	
Canting angle	2.0 mrad NYX: ~0.79 mrad outwards ring LAX: ~1.21 mrad towards ring	
Period	18 (17.7 – 21.9) mm	~25 mm, TBD
Minimum magnetic gap *1	5.6 (3.5 – 6.3) mm	~6.6 mm
Peak magnetic field	0.95 (~0.98 – 1.43) T	~0.94 T
K_{eff} *2	1.55 (~1.90 – 2.23)	~2.2
Power total	2.43 (~7.6) kW	~2.5 kW
On-axis power density	22.6 (~55) kW/mr²	~16.3 kW/mr²
Straight section type	Short (low beta)	
Lowered horiz. beta desired	N/A	N/A
Device center	U/S 0.5 (~1.04) m	D/S ~1.63 m
Fan angle *3 (mrad H)	0.75/1.36 (0.91/1.50)	~0.97/~1.57
Fan angle *3 (mrad V)	0.80/1.26 (0.82/1.30)	~0.83/~1.32
Gap scanning and other requirements	Gap scanning speed 30 eV/sec or greater, over usable photon energy range.(?)	

Note 1: Vertical stay-clear aperture for in-vacuum devices (e.g. IVU, SAGU)

Note 2: In the general case of an ellipsoidal insertion device with non-sinusoidal periodic magnetic field:

$$K_{eff} = \frac{e\lambda_u}{2\pi mc}\left(\sum_{n=1}^{\infty}\frac{B_{hn}^2+B_{vn}^2}{n^2}\right)^{1/2} = 0.0934\ \lambda_u[mm]\left(\sum_{n=1}^{\infty}\frac{B_{hn}^2+B_{vn}^2}{n^2}\right)^{1/2}[T]$$

where e and m are charge and mass of electron, λ_u is period, $B_{h\,n}$ and $B_{v\,n}$ are amplitudes of n-th harmonics of the horizontal and vertical magnetic field components. In cases where detailed magnetic design of an insertion device has not yet been performed, only fundamental harmonics of the vertical and/or (where applicable) horizontal magnetic field components were used to estimate emission characteristics.

Note 3: Fan angles of the radiation quoted here are as seen at 16 m from ID center, and take into account the effect of ID length. The two values quoted for each case correspond to the points where the power density falls to values that are **1%** and **0.1%** of the central value. These values are accurate to within 5%. Designs of the XBPM and fixed mask entrance shall take into account these fringe power loads.

Note 4: Two options of the NYX undulator: X25 IVU (from NSLS) and a Segmented Adaptive Gap Undulator (SAGU), are considered.

Note 5: Prior to finalizing the designs of these insertion devices, the length specification may vary by up to ±15%.

For 2 mrad canting, the ID positions should assume a ~1.0 m gap along the beam direction to allow for the canting magnets and beam position monitors, etc.

4.2 Refurbishment of X25 IVU

4.2.1 Assessment of X25 IVU

The X25 IVU (950 mm, 53 periods of 18 mm) was procured from ADC and delivered to the NSLS on January 10, 2005 (Figure 4-2)and removed from the NSLS accelerator tunnel on February 15, 2015. (Figure 4-3).

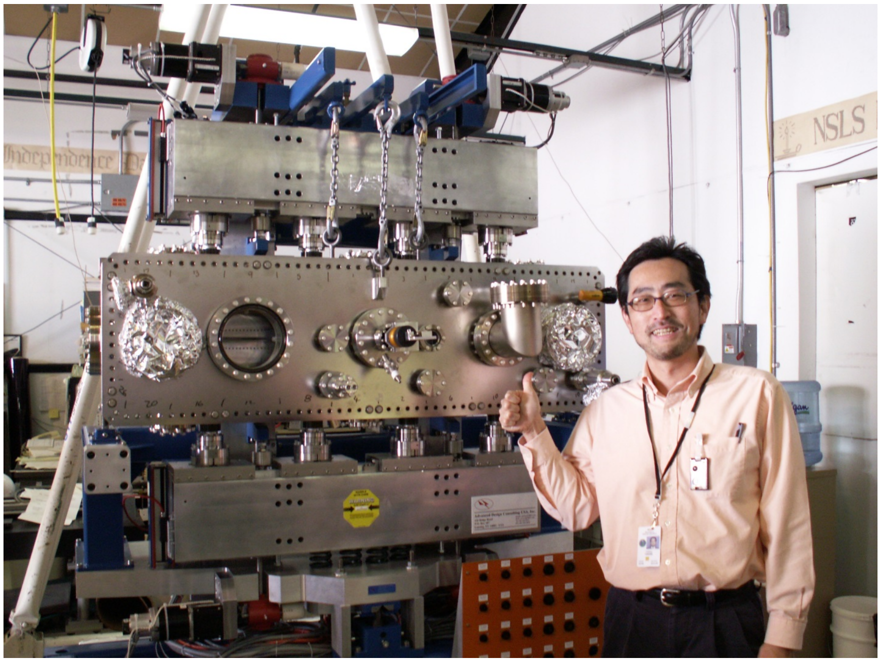


Figure 4-2. Arrival of the X25 IVU at NSLS from ADC on January 10, 2005

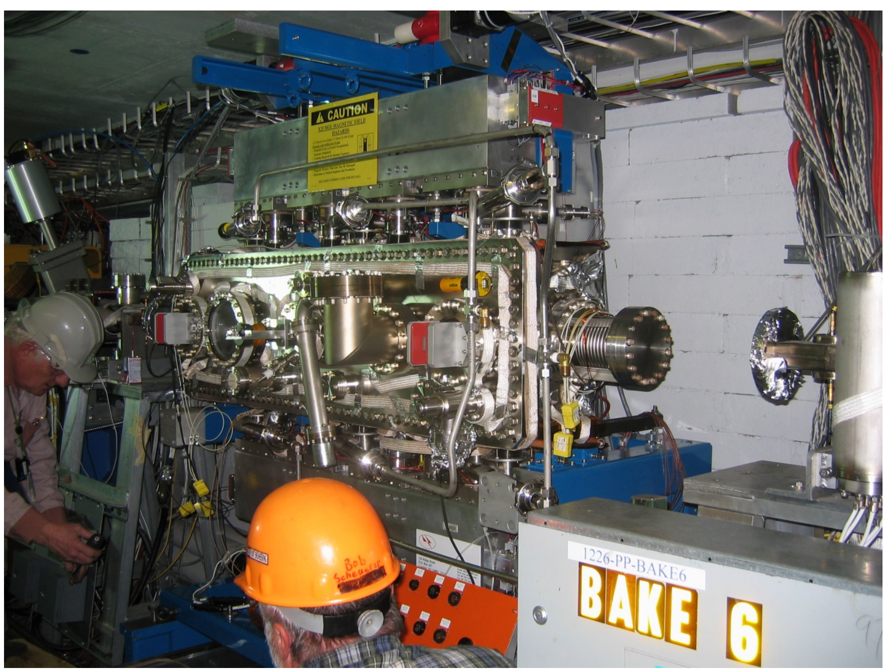


Figure 4-3. Removal of the X25 IVU from the NSLS accelerator tunnel on February 15, 2015

Magnetic field mapping of the X25 IVU was performed in November 2015 and calculations of Undulator Radiation (UR) spectral flux per unit surface and through a fixed collection aperture were made, using SRW code, for the recent X25 IVU magnetic measurements data provided by the ID group. Three different types of calculations were performed for 50.7 m observation distance (i.e. for the longitudinal position of first optical elements of the NYX beamline), for the real measured magnetic field of X25 IVU and for the corresponding "error-free" (ideal) periodic magnetic field. The calculations were performed for 6 mm IVU gap (the value for which one of the Hall probe measurements was performed), for 5th UR harmonic that peaks at ~11.85 keV photon energy Figure 4-4.

First, the on-axis spectral flux per unit surface for a filament electron beam (i.e. beam with zero transverse emittance and energy spread) was calculated for the two magnetic field cases (measured and error-free). This calculation showed only ~10% reduction of the flux per unit surface in the case of the measured magnetic field as compared to the error-free field case. Next, the on-axis spectral flux per unit surface was calculated taking into account the NSLS-II electron beam emittance and energy spread. This calculation showed only ~7% reduction of the spectral flux per unit surface in the case of the measured magnetic field compared to the error-free field case. Finally, the spectral flux of UR was calculated taking into account the electron beam emittance, energy spread, and a finite collection aperture (~6 mm (h) x 4 mm (v) at 50.7 m) that may be used at the NYX beamline. That calculation demonstrated <~4% reduction of the flux in the measured magnetic field case compared to the error-free case.

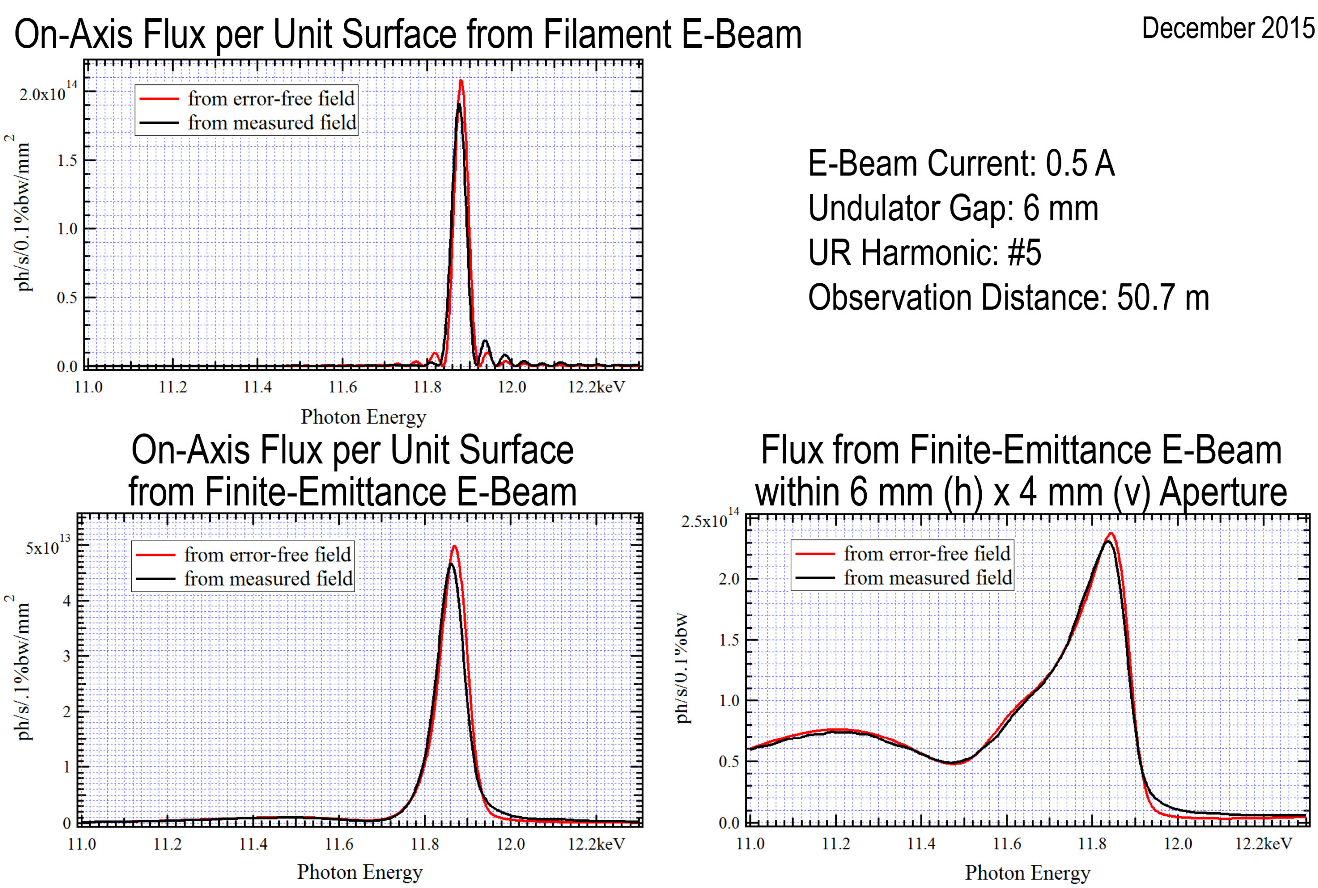


Figure 4-4. X25 undulator radiation spectra calculated from measured magnetic field compared to error-free field.

These spectral calculations confirm the good quality of the X25 IVU magnetic field (that even exceeds that of some of the recently-purchased IVU), which makes it possible to use this IVU at the NYX beamline without extra “spectral shimming”. It should be noted, however, that some “multipole shimming” of the X25 IVU may still need to be done using the “magic finger” technique, to minimize its potential effect on the electron beam at NSLS-II (especially at a small gap).

4.2.1 X25 IVU Installation Design at NYX

The X25 IVU is integrated into the NSLS accelerator with the standard bellows, custom absorber and custom taper transition, as shown in Figure 4-5.

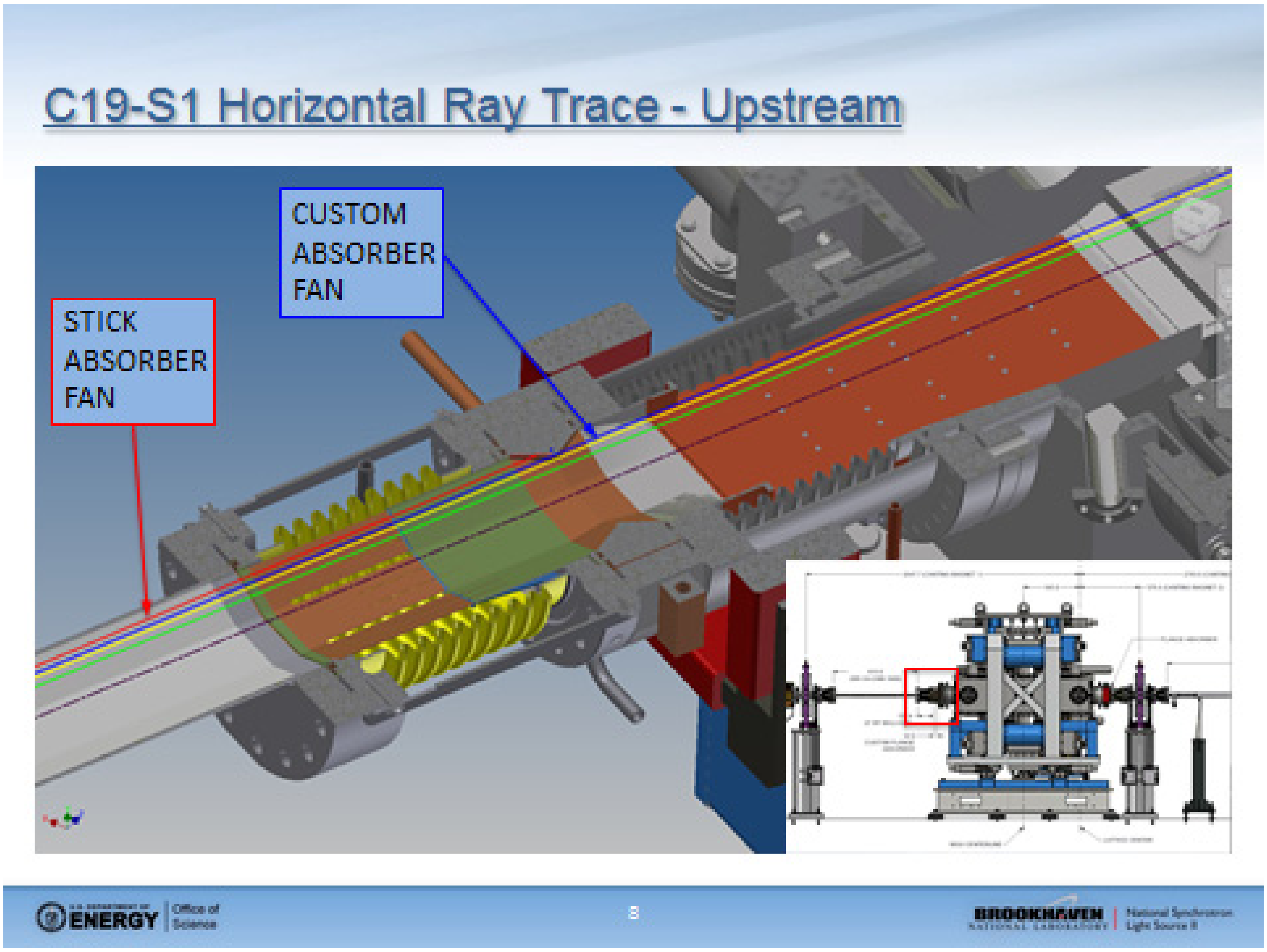


Figure 4-5. Upstream bellows, absorber and transition for the X25 installation into the NSLS-II accelerator at NYX.

Cooling for the taper transition (which must flex to accommodate the 5.6 mm to 20 mm magnet gap)will be provided by thermal straps to avoid a water leak in the accellerator if water cooling had been used (Figure 4-6).

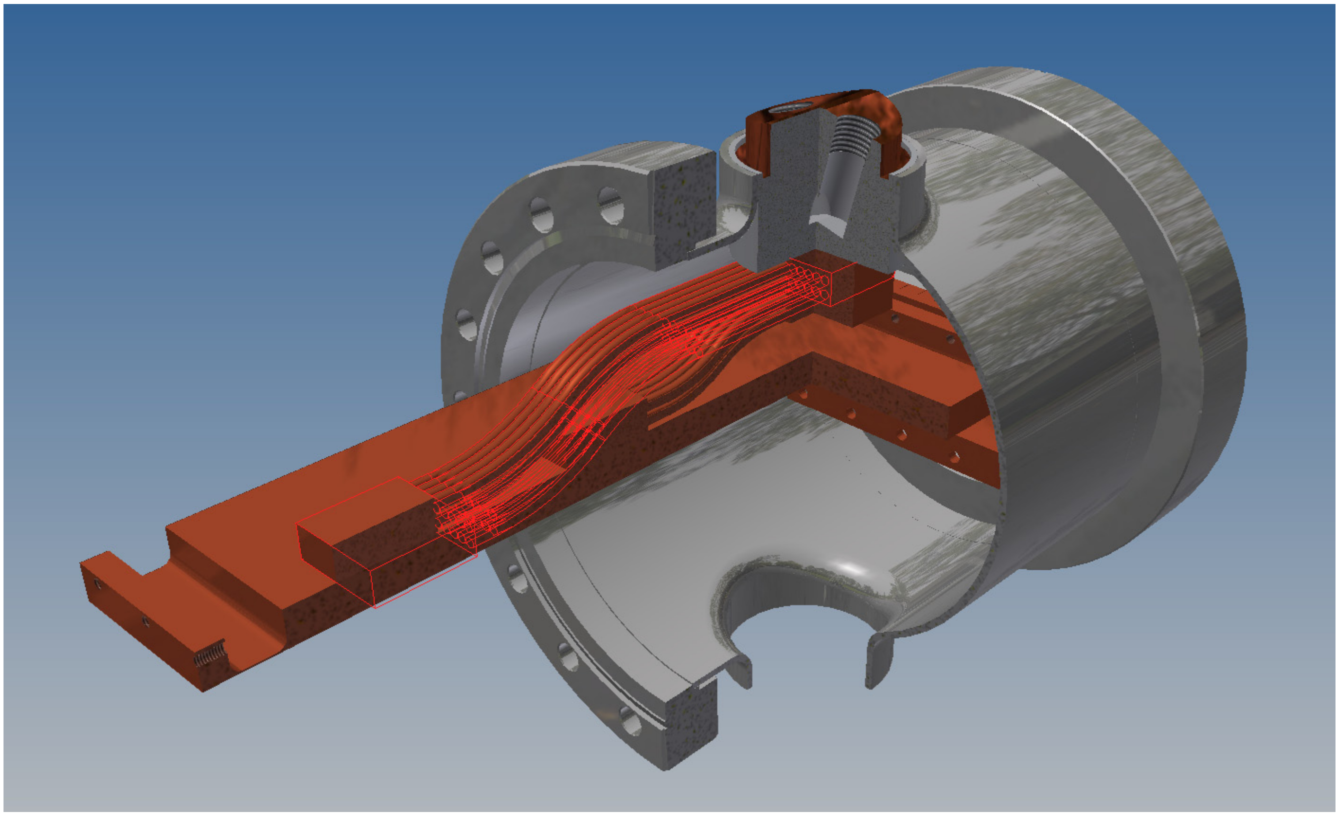


Figure 4-6. Thermal straps for cooling of the taper transition.

4.3 Segmented Adaptable Gap Undulator (SAGU) Option

4.3.1 General Description

The SAGU utilizes different gaps and magnetic periods in short segments to produce high flux and brightness hard X-rays that cannot be obtained with a standard IVU of similar length. The original concept (S.C. Gottschalk *et al*., *AIP Conf. Proc.* **521**, 348, 2000) would have had many rather short segments; however, calculations demonstrate excellent performance from with longer segments (O. Chubar *et al*., Spectral Performance of Segmented Adaptive-Gap In-Vacuum Undulators for Storage Rings", *Proc. of IPAC2012*, MOPPP090, 765-767, 2012), and the design for implementation at NYX was reported at SRI 2015 (T. Shea *et al.* Mechanical Systems for Segmented Adaptive-Gap In-Vacuum Undultator, Proceedings of the 12th International Conference on Synchrotron Radiation 2015)

Our SAGU implementation will have a total magnetic length of 2.07m in three independet segments each 660mm long. Vertical gaps in each segment are adjusted to satisfy “Stay-Clear” and impedance constraints and all segments are tuned to the same resonant photon energy by varying the magnet period. Undulator period will vary from segment to segment, however constant within each segment. Figure 4-7 below shows the conceptual design of the SAGU. A concept was created that only needs two motors, one for gap and one for vertical offset – taper would be provided manually. This was the preferred approach because it reduces the perceived complexity for three segments. Each segment will be mounted on a robust base plate. The below figure shows the three-segment concept for the SAGU. This is based on a two-motor design where one motor controls the gap and another motor controls the vertical offset. A double set of vertical rails is used to accomplish the gap and vertical offset. The inner rails mounted to the strong back that carries a plate which is moved vertically by the offset motor. Rails mounted to this plate support the outer girders which are driven by a single left/right hand threaded ball screw to produce the gap motion.

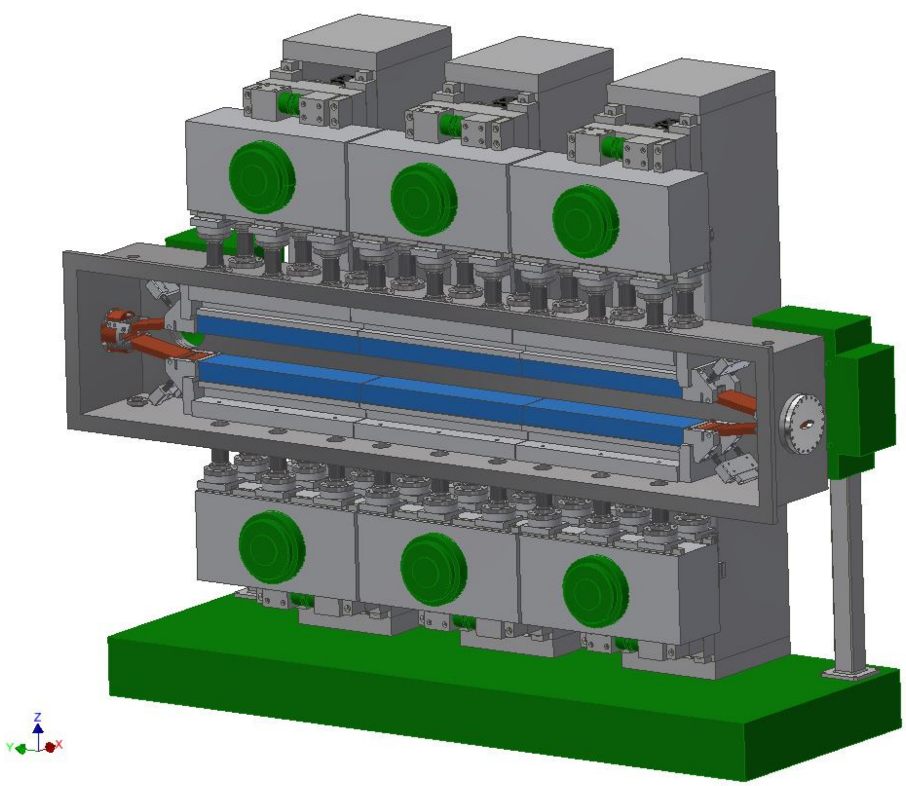


Figure 4-7. Conceptual design of the SAGU for NYX

4.3.2 Power Density Distributions for NYX IVU Options

Figure 4-8 shows the power density distributions at 56m, which will be the location of the NYX monochromator. The total power ranges from 4.9kW - 7.6 kW depending on the IVU option. This range of power is well below the power limits of the front end components (at 16m) . The details of the power limiting aperture upstream of the monochromator will be discussed in the photon delivery section of this report.

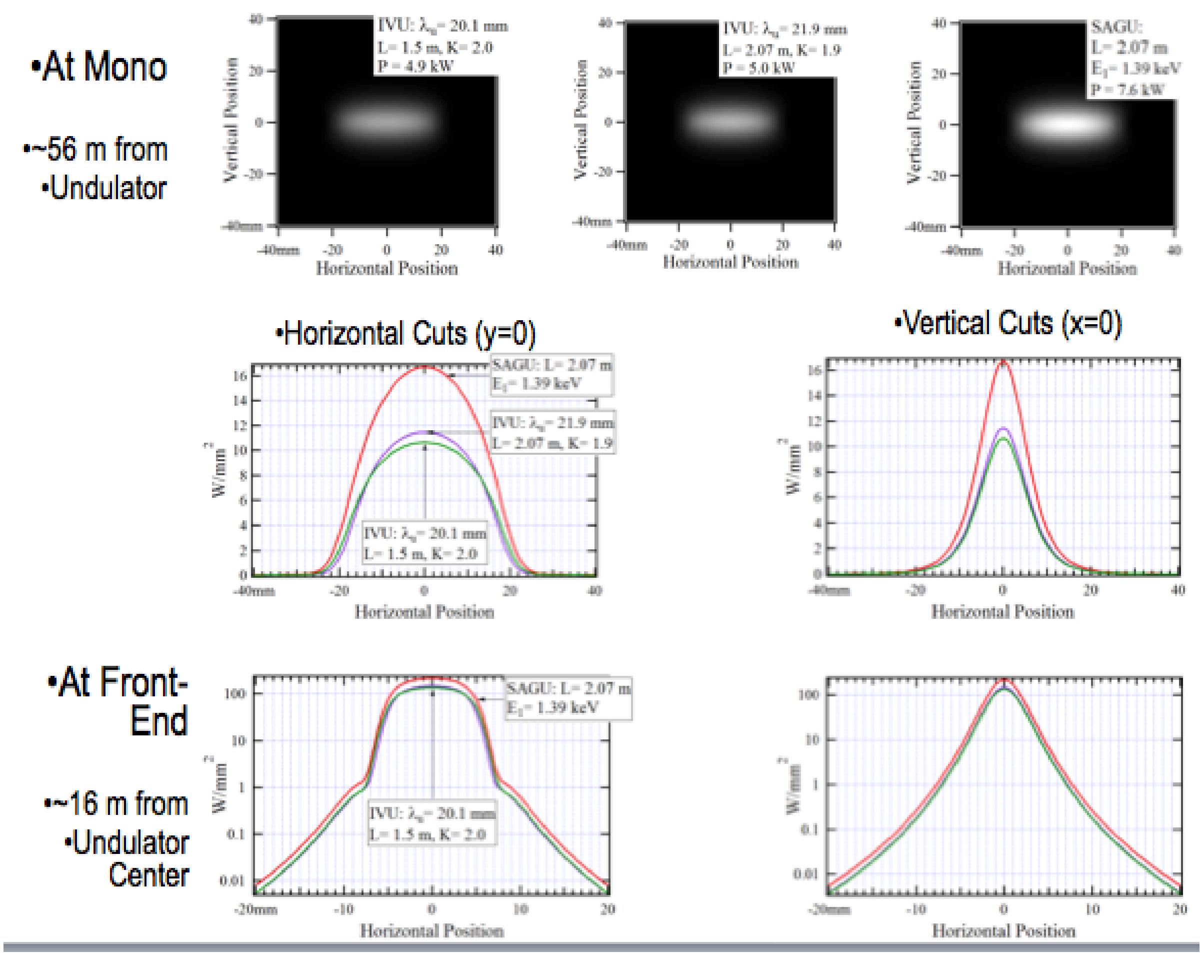


Figure 4-8. Power density distributions.

4.3.3 Tapered Transition

A tapered transition from the liner foil of an in-vacuum undulator (IVU) to the beam pipe in the NSLS-II synchrotron storage ring has been developed to provide a continuous conduction path for the image current induced by the passing electron bunches. Figure 4-9 shows a tapered transition concept developed by NYSBC, ADC & AES, which was intended as a common design for both the X25 and SAGU.

The criteria for the above tapered transition design were defined by Alexei Blednykh of BNL from longitudinal wake-potential calculations. Figure 4-10 shows an example wakepotenial calculation that determines a maximum allowable step of 0.5mm in the transition.

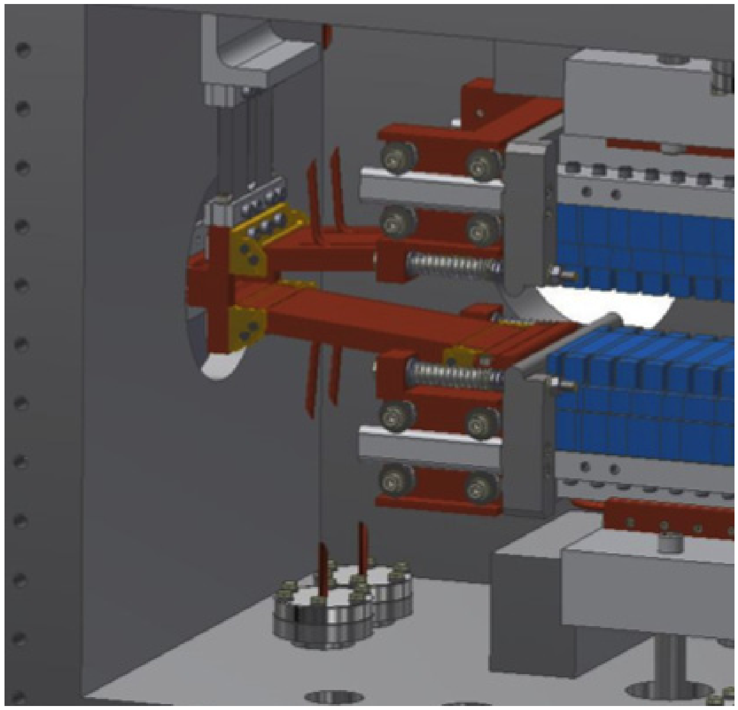


Figure 4-9. Tapered transition concept.

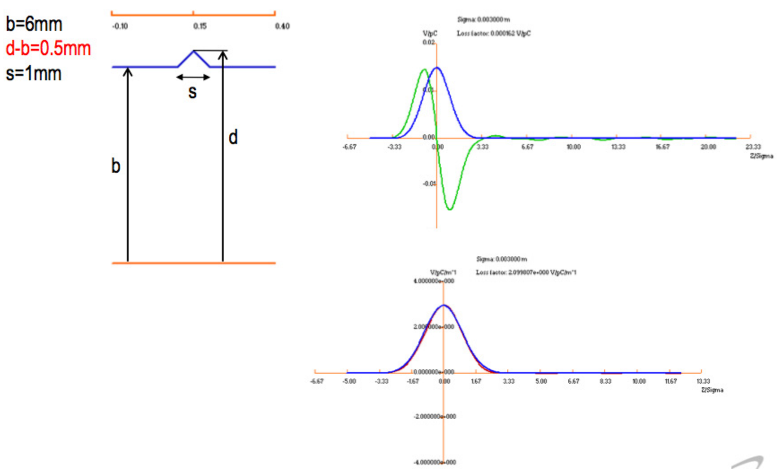


Figure 4-10. Example wake-potential calculation.

Current Density Estimates. The RF tapered transition design shown in Figure 4-8 takes advantage of beryllium copper flexures to provide good current contact and shield the RF wake fields generated by the high frequency electron bunch. Beryllium copper (BeCu), also known as copper beryllium (CuBe), beryllium bronze and spring copper, is a copper with 0.5—3 beryllium and is an industry standard for creating RF-tight electronic seals due to its excellent electrical conductivity and ability to be cold-formed before tempering into spring copper. Given the SAGU gap range of 3.5 -40mm it is important that the flexure operate within the elastic range well before plastic deformation occurs therefore CuBe spring copper is superior to many other metals. Also given the electrical resistivity of 7.8E-6 ohm-cm for BeCu an simple transient anaylsis can be done to estimate the maximum current density at the BeCu contact. First, given the actual risetime of the passing electron bunch at NSLS-II the RF skin depth can be calculated assuming a bunch frequency of 33GHz. The estimated skin depth at this frequency and resistivity is 0.774μm. The lateral extent of the image current can be estimated as a current filament over a plane where most of the current is within 6mm; therefore the resulting current density is estimated to be 108A/mm^2 given a maximum synchrotron current of 500mA. The RF tapered transition developed for the SAGU is well suited for the small emittances of NSLS-II and has the following advantages:

1. A pivoting rigid bridge design with BeCu shields provides durability and simplicity over flexing bridge tapered transitions.
2. Modularity allows the bridge alone to be incorporated into an IVU, or allows the axial compliance assembly or liner foil tensioner to be used with the bridge.
3. The taper transition cooling lines are simplified by the use of a rigid bridge.
4. Adapter plates can be made to connect the tapered transition with any IVU girders (X25 or SAGU).
5. Axial compliance section can be adapted to various chambers and beam pipes.
6. The number of sliding contacts is minimized and all steps or valleys are kept to 0.5 mm or less to minimize wake potential.
7. UHV compatible materials used throughout: C10100 Copper, 6061 Aluminum, 304 or 316 Stainless Steel.

4.3.4 Controls for Insertion Device

A complete and comprehensive definition of the control system requirement for the SAGU is provided in document ID: CSL-RSP-15-115440. Cosylab generated this document under contract to NYSBC by aggregating the BNL guidelines and criteria defined in 15 separate references listed in CSL-RSP-15-115440.

The simplified controls architecture (Figure 4-11) will be in compliance with the platform defined by NSLS-II. The motion controllers will be based on the NSLS-II preferred Delta-Tau Geobrick-LV. This will consist of two motors per segment, for gap and vertical offset, and five encoders per segment.

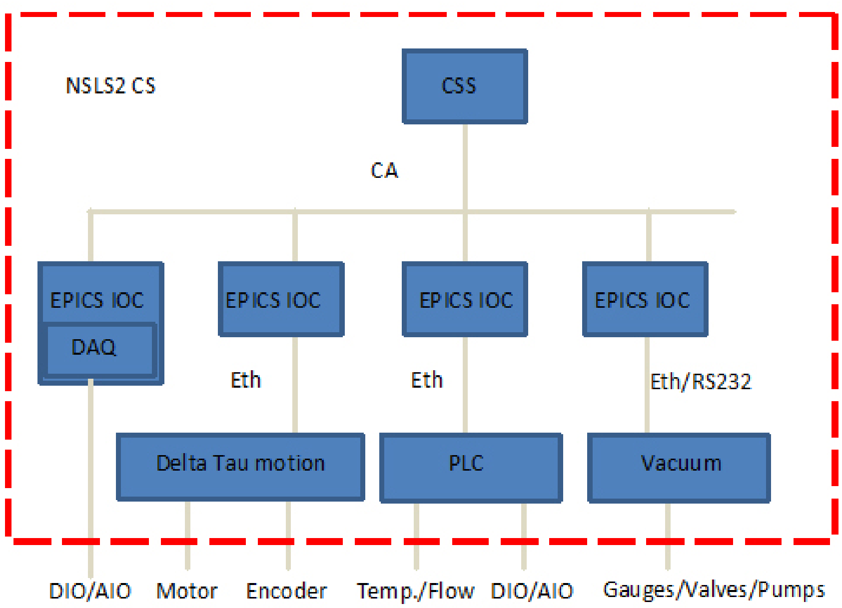


Figure 4-11. SAGU controls architecture.

4.4 Spectral Flux Comparisons

Figure 4-12 shows the calculated flux for the X25 IVU at the short straight NSLS II 19-ID (odd harmonics only) compared to SAGU options for the future upgrade to a 2 m device for NYX.

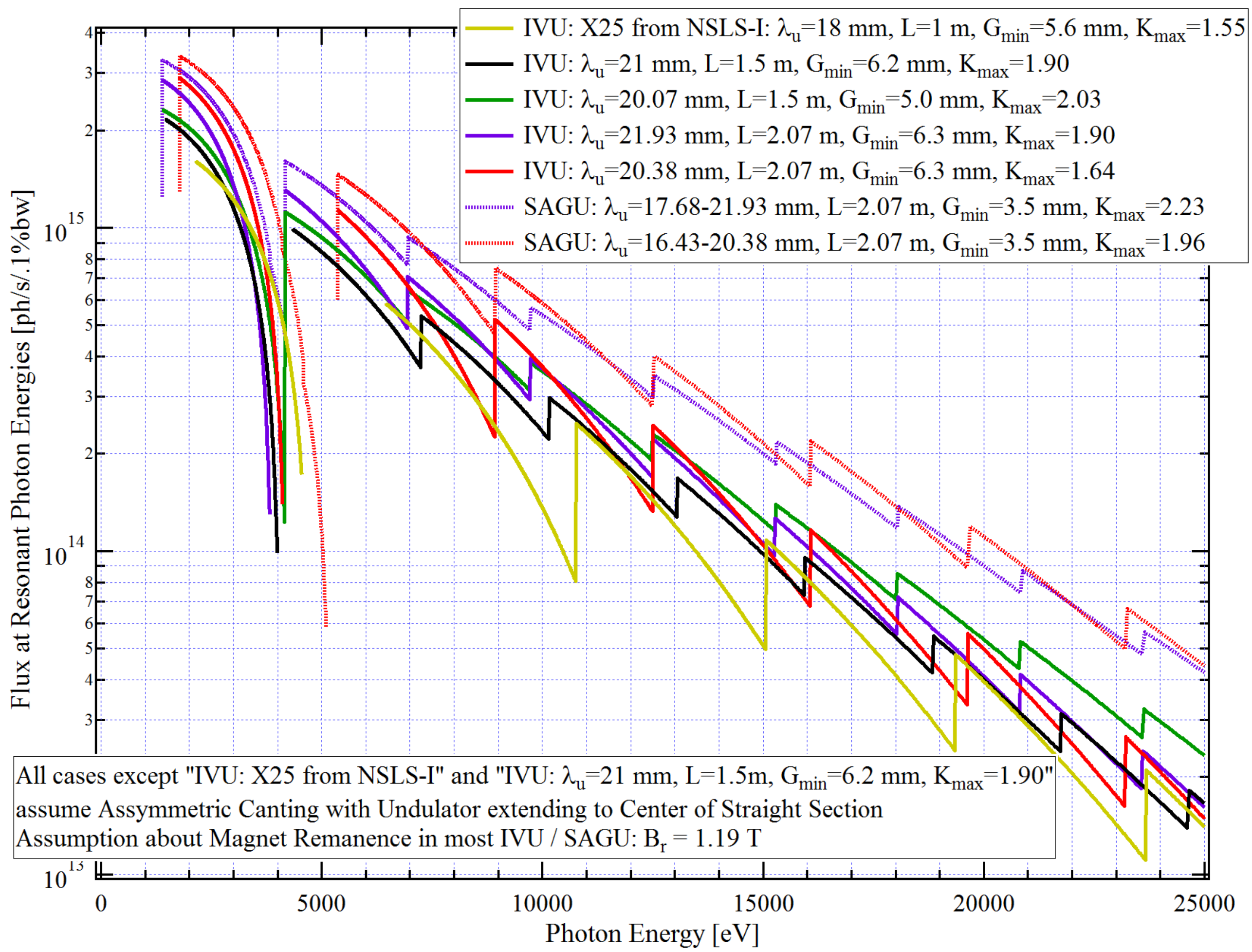


Figure 4-12. Spectral flux for odd harmonics for IVU devices at the NYX section of canted sector 19-ID at NSLS II.

5. FRONT END

Contents

Acronyms

BMPS	Bending Magnet Photon Shutter/Absorber
CO1, CO2	Lead Collimators 1 and 2
FEA	Finite Element Analysis
FGV	Fast Gate Valve
MSK	Fixed Aperture Mask
PLC	Programmable Logic Controller
PSH	Photon Shutter
RCO	Ratchet Wall Collimator
SGV	Slow Gate Valve
SR	Storage Ring
SS	Safety Shutter

Figures

Tables

5.1 General Layout of the NYX Front End (FE)

Layouts of the standard NSLS-II undulator beamline front ends (non-canted and canted) are shown in Figures 5-1. Constituent subassemblies include: Bending Magnet Photon Shutter/Absorber (BMPS), Slow Gate Valve (SGV), Fixed Aperture Mask (MSK), Lead Collimator (CO1), Fast Gate Valve (FGV); Photon Shutter (PSS), Lead Collimator (CO2), Safety Shutters (SSH), and Ratchet Wall Collimator (RCO, burn through device omitted for NY4.

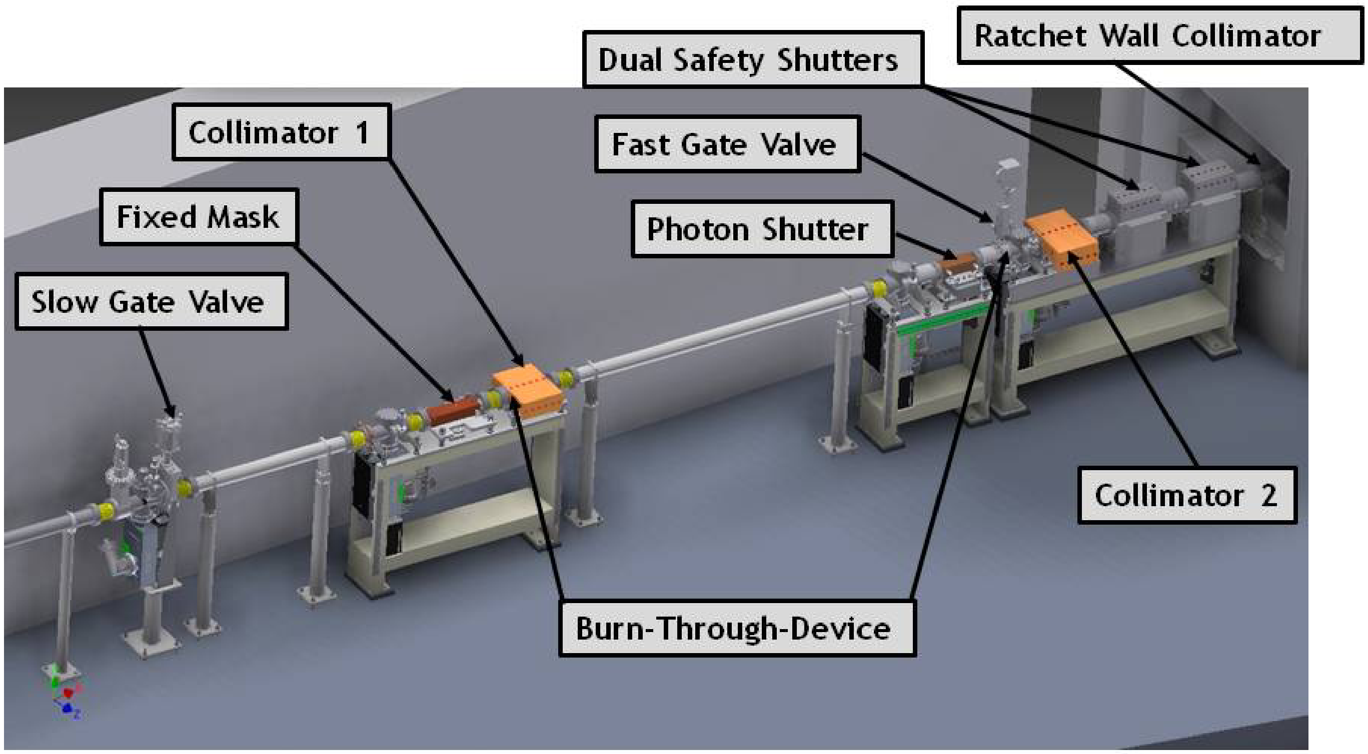


Figure 5-1. Typical front end configuration at NSLS-II, canted.

5.2 Brief Description of the Major Components of the Front End

5.2.1 Photon Shutter (BMPS) and Absorber

An absorber capable of trimming the sides of the insertion device beam will be mounted on the outlet of the bending magnet vacuum chamber immediately upstream of the front end. This absorber is required, to trim the beam in order to allow it to pass the sextupole and quadrupole magnets at the upstream end of the storage ring section four girder assembly. A maximum drift pipe size of 1.875 in. OD centered on the beam axis is allowable in this area.

The absorber is cantilevered from the upstream flange to allow thermal expansion during bakeout. A formed bellows will be mounted on the downstream flange of the absorber to allow for alignment and thermal movement during bakeout.

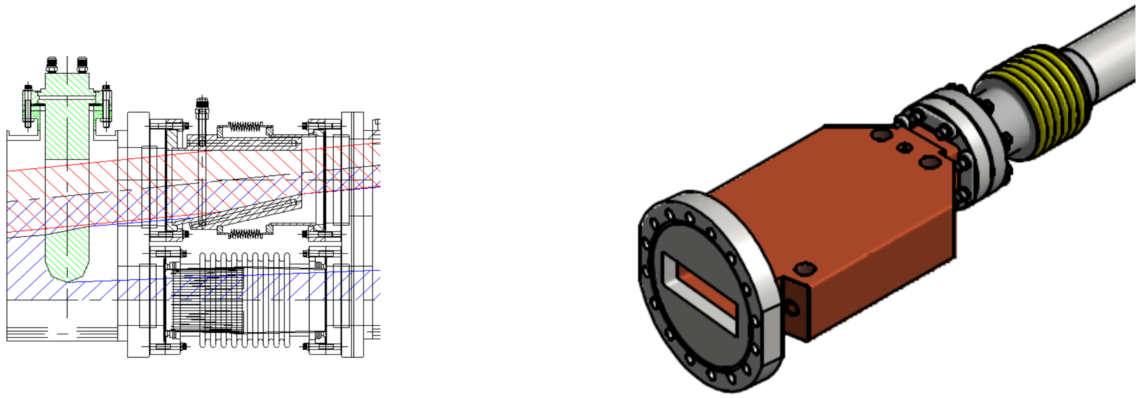


Figure 5-2. Principle of the Glidcop absorber.

The BMPS will be used to protect the SGV from bending magnet radiation if the completed front end needs to be isolated from the machine. If the SGV is required to close during machine operation, the ID power will first be reduced, followed by closing the BMPS and then the SGV.

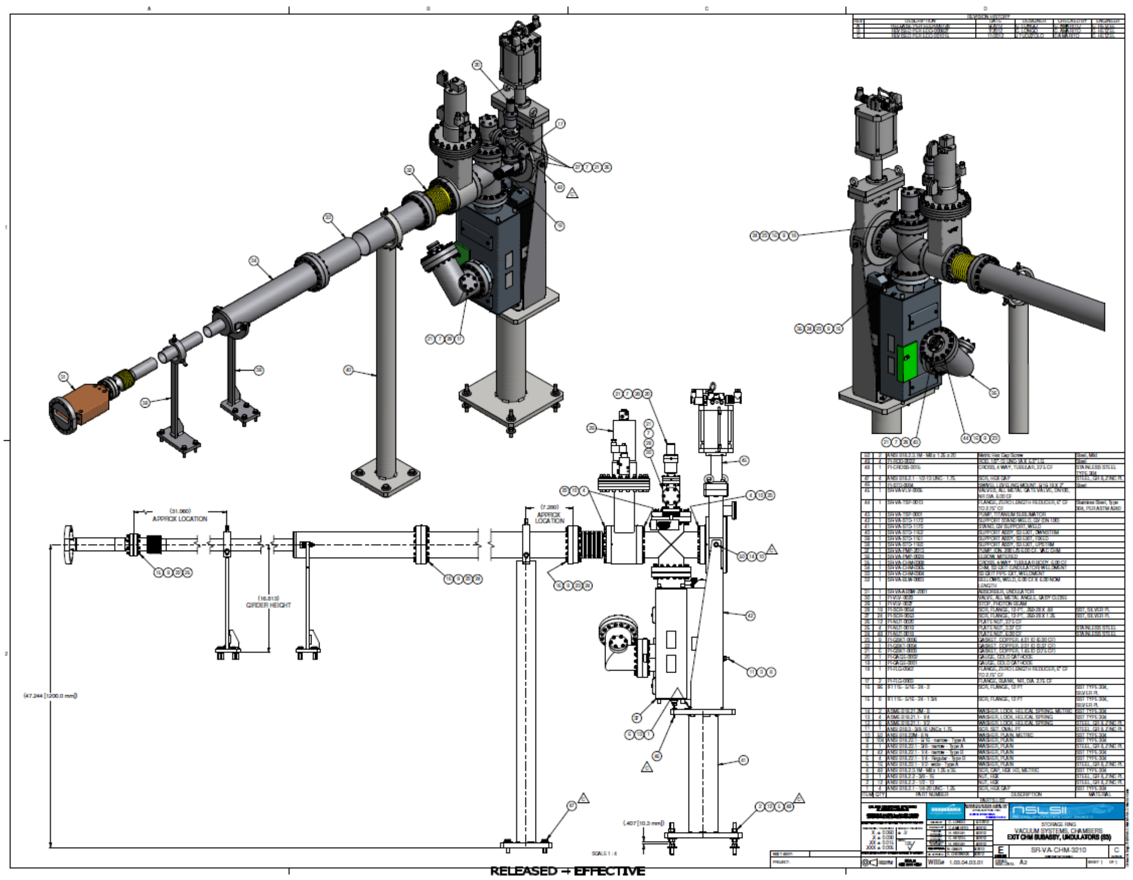


Figure 5-3. Design for the bending magnet photon shutter.

4.2.2 Slow Gate Valve (SGV)

The Slow Gate valve is part of the storage ring vacuum system and is included to isolate the machine and FE, but will not withstand white beam from IDs, or BM radiation. The SGV is controlled and monitored by storage ring vacuum PLC using a voting scheme with inputs from vacuum sensors at both sides of the valves and position of BMPS.

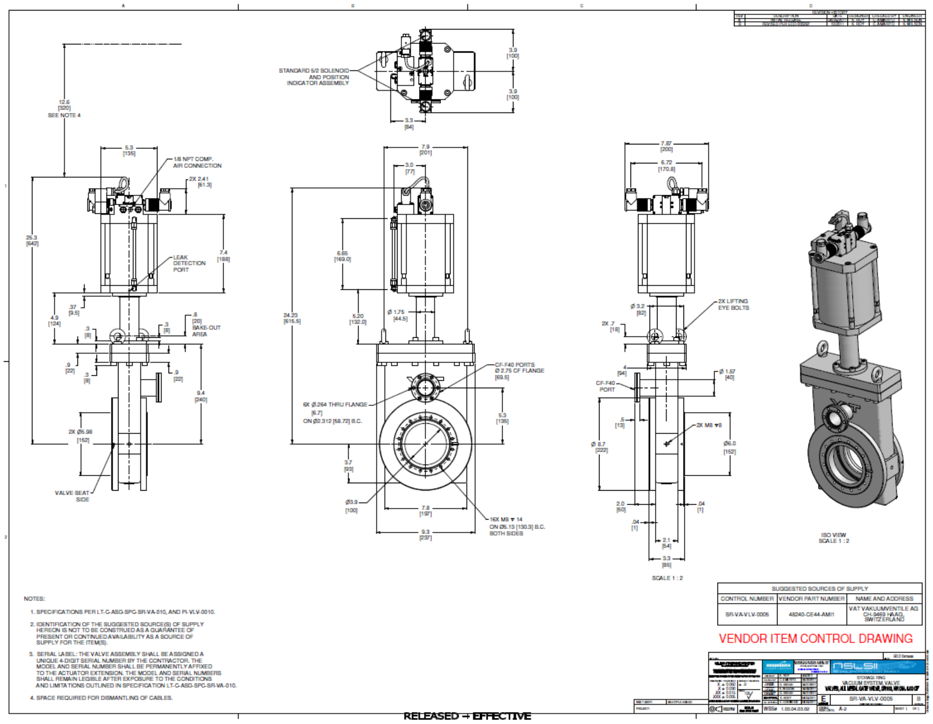


Figure 5-4.

5.2.3 Beam Position Monitor 1 (XBPM1)

The NYX Front End design has omitted the XBPM1.

5.2.4 Beam Position Monitor 2 (XBPM2)

The NYX Front End design has omitted the XBPM2.

5.3.5 Fixed Aperture Mask (FAPM)

The fixed aperture mask shall provide radiation fans to the FOE. No tolerance shall be added to the mask for mis-positioning; however, a manufacturing tolerance of ±0.2 mm for the aperture (at the downstream end of the mask) shall be included in the downstream fan definition.

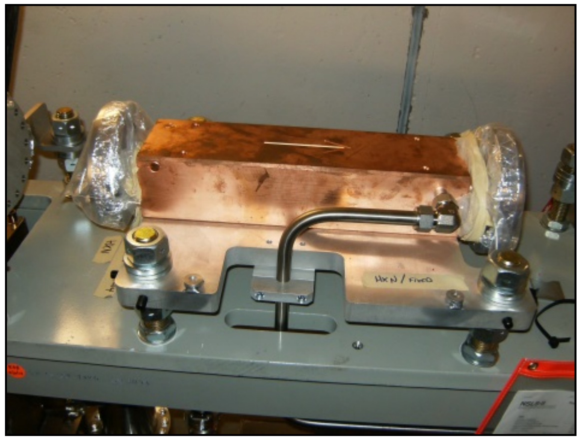


Figure 5-5. Fixed-aperture mask.

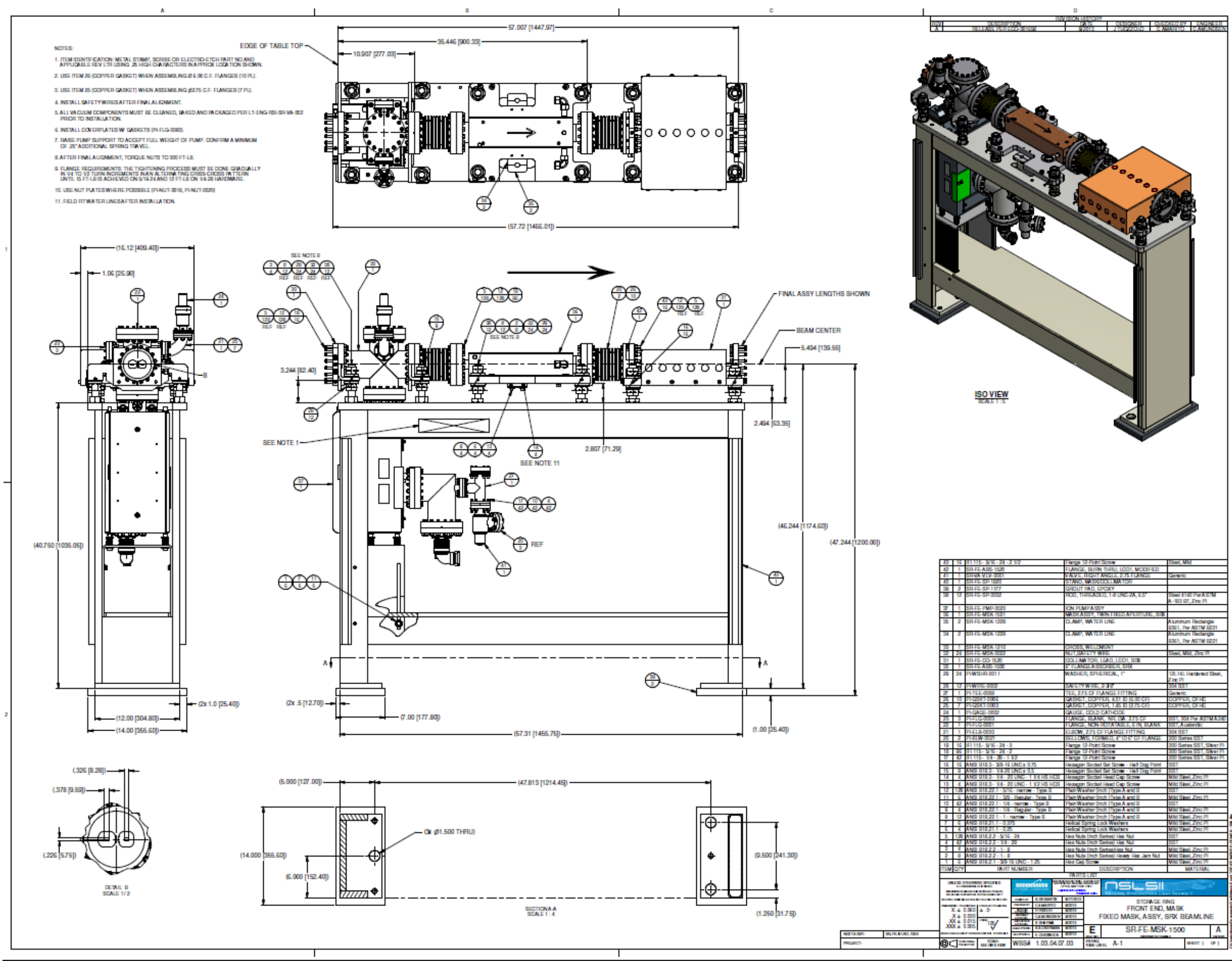


Figure 5-6. Fixed Aperture Mask Assembly

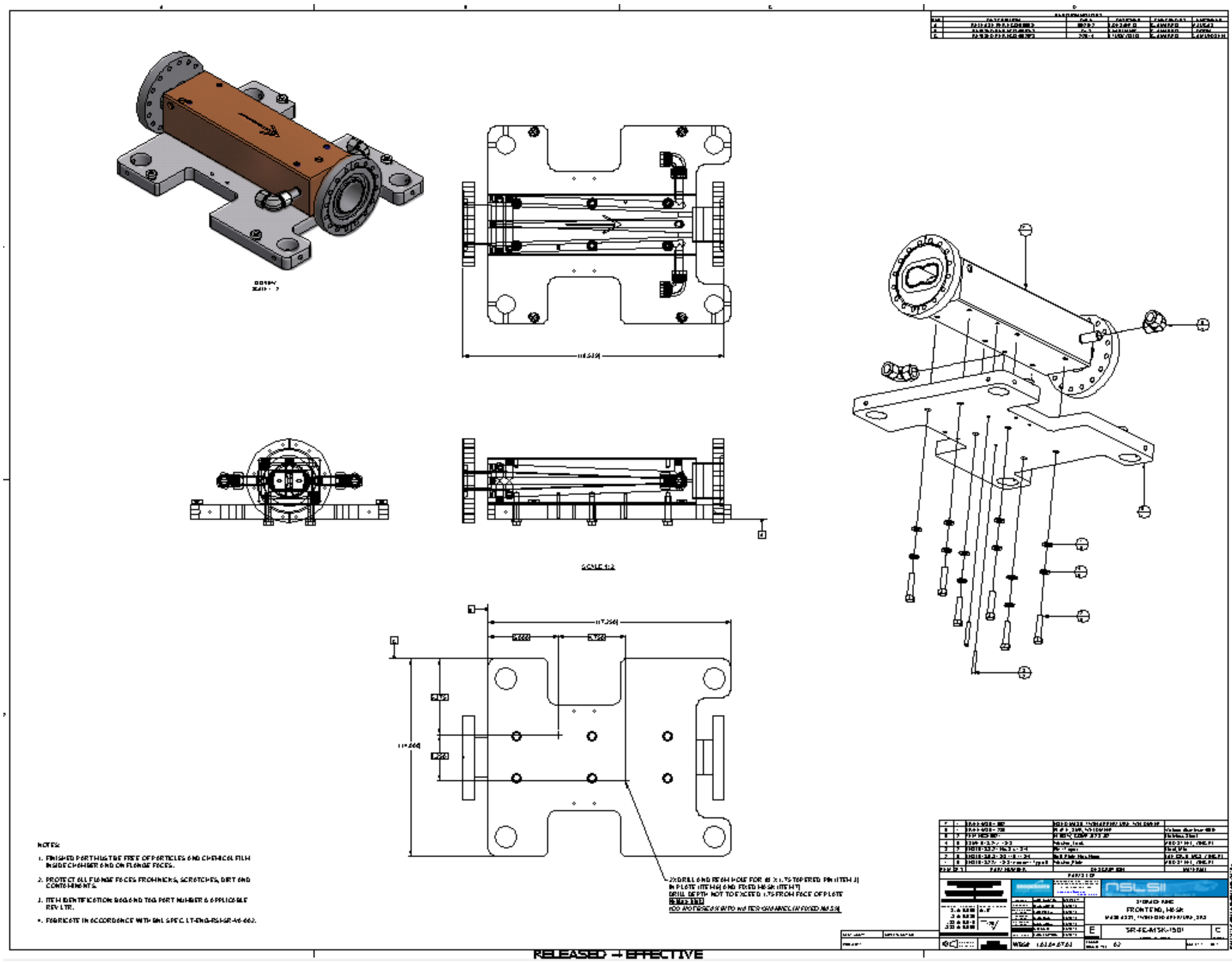


Figure 5-7. Storage ring front end mask.

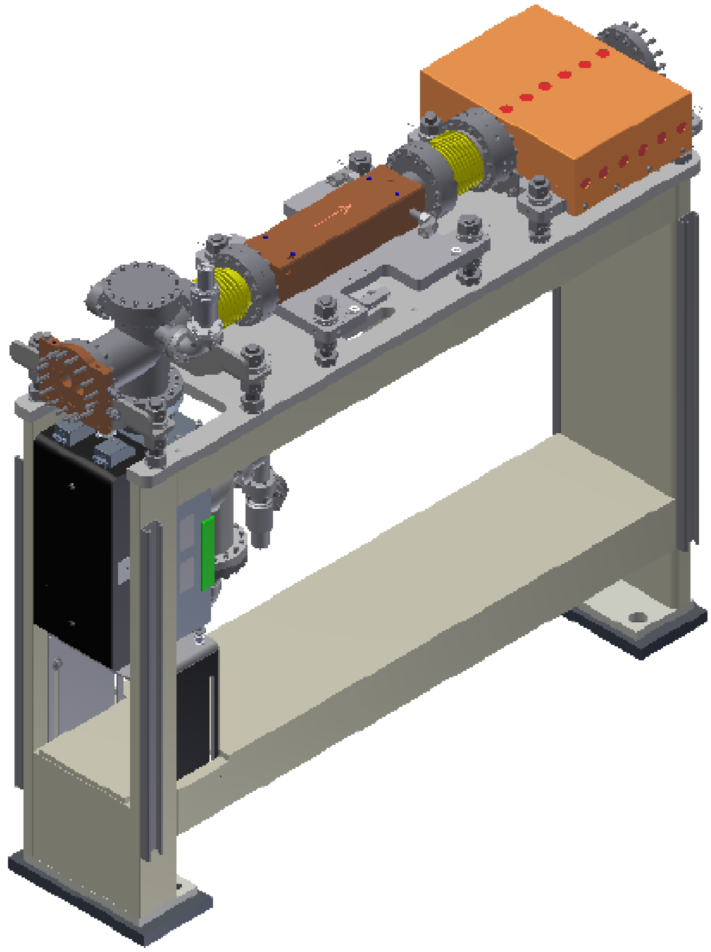


Figure 5-8. Mask mounted in the assembly.

5.2.6 Bremsstrahlung Collimator (CO1) and "Burn Through" Device

The bremsstrahlung collimator restricts the bremsstrahlung radiation fan exiting the shield wall. This should be as tight to the beam as is reasonable without undue mechanical tolerances or alignment difficulty.

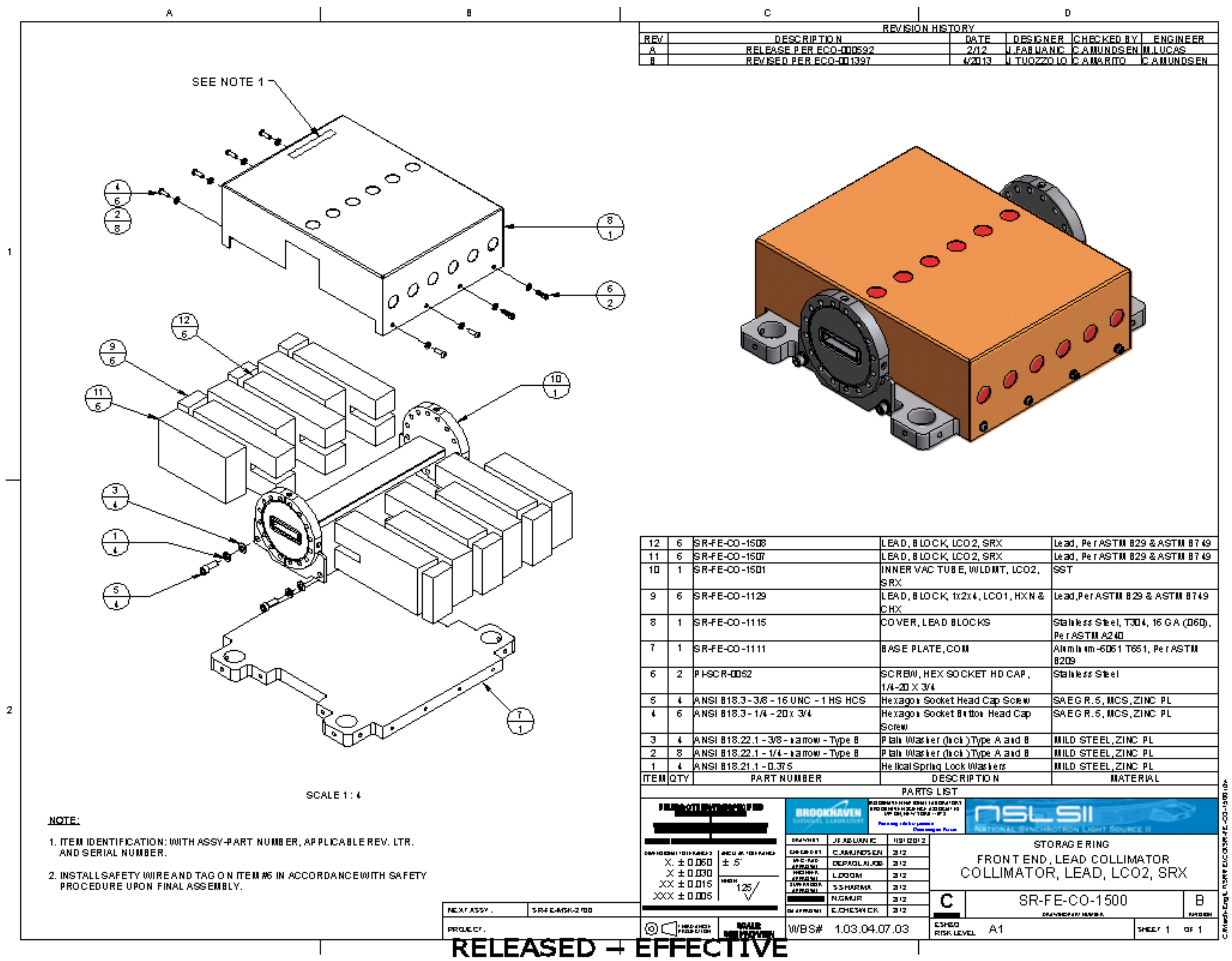


Figure 5-9. Front end lead collimator.

A Front End Personnel Protection System Task Force was assembled to review and make recommendations regarding the risks of stored electron beam excursions beyond the Active Interlock Envelops. The Task Force recommendation being implemented is to add Burn Through Devices upstream of the lead collimators to protect the lead from melting in the case of an Equipment Protection System failure. The Burn Through Devices are designed to have apertures outboard of the maximum synchrotron fan defined by the Active Interlock Envelope. The Burn Through device will shadow the downstream lead collimator in case of beam excursions outboard of the Active Interlock Envelope or a Fixed Mask Failure. If the Burn Through Device intercepts Insertion device synchrotron beam it will vent the storage ring.

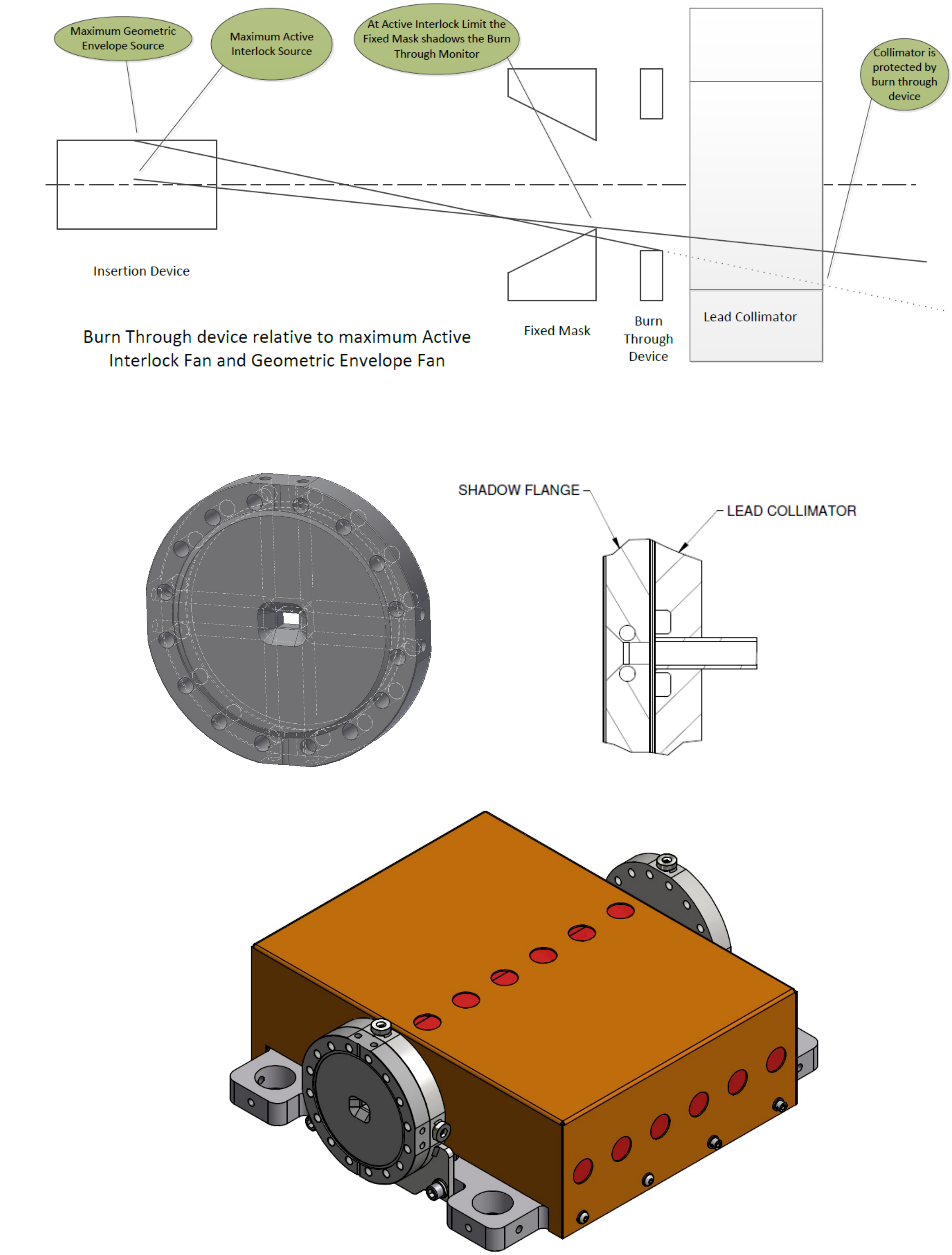


Figure 5-10. Burn Through Device Ray Tracing, Burn Through Device, Burn Through Device mounted on Lead Collimator

5.2.7 4-Y Slits

White-beam 4-Y slits usually located immediately downstream of the first lead have been omitted from the NYX Front End design, however, this space has been retained for future needs.

5.2.8 Photon Shutter (PSH)

The photon shutter is required to stop full white beam. For IDs this is a water-cooled Glidcop assembly with a grazing incidence angle.

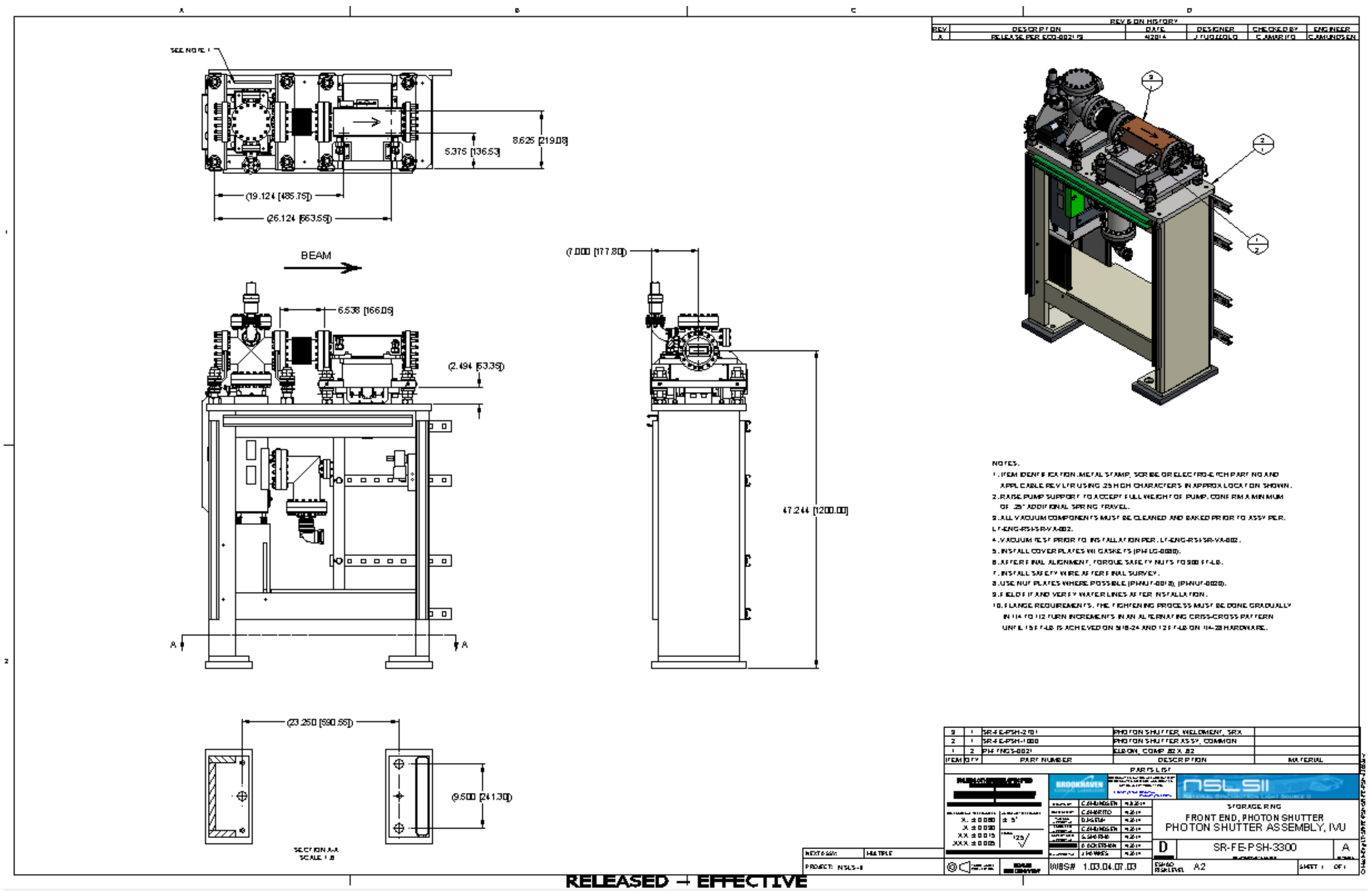


Figure 5-11. Photon Shutter Assembly

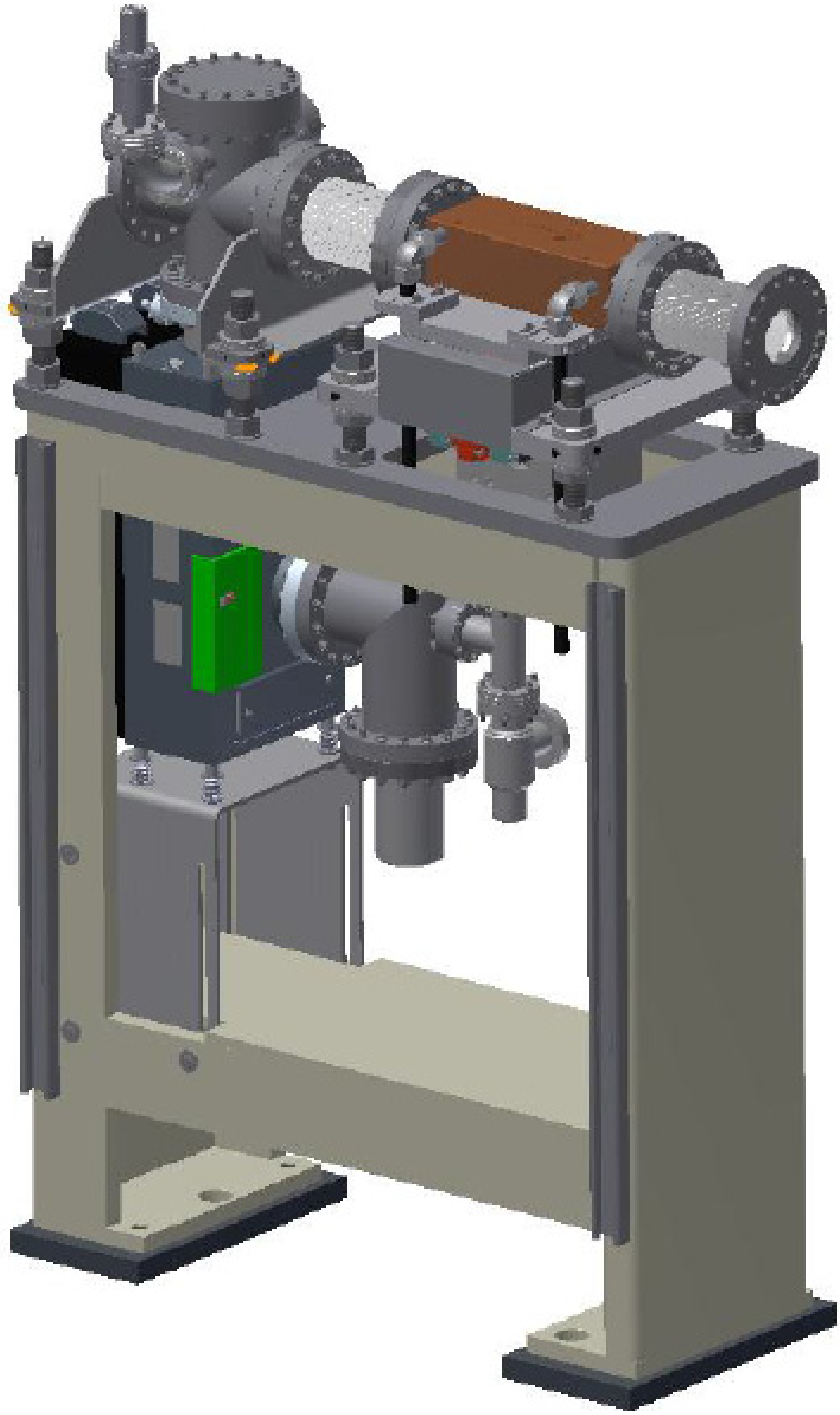


Figure 5-12. Closer view of the photon shutter.

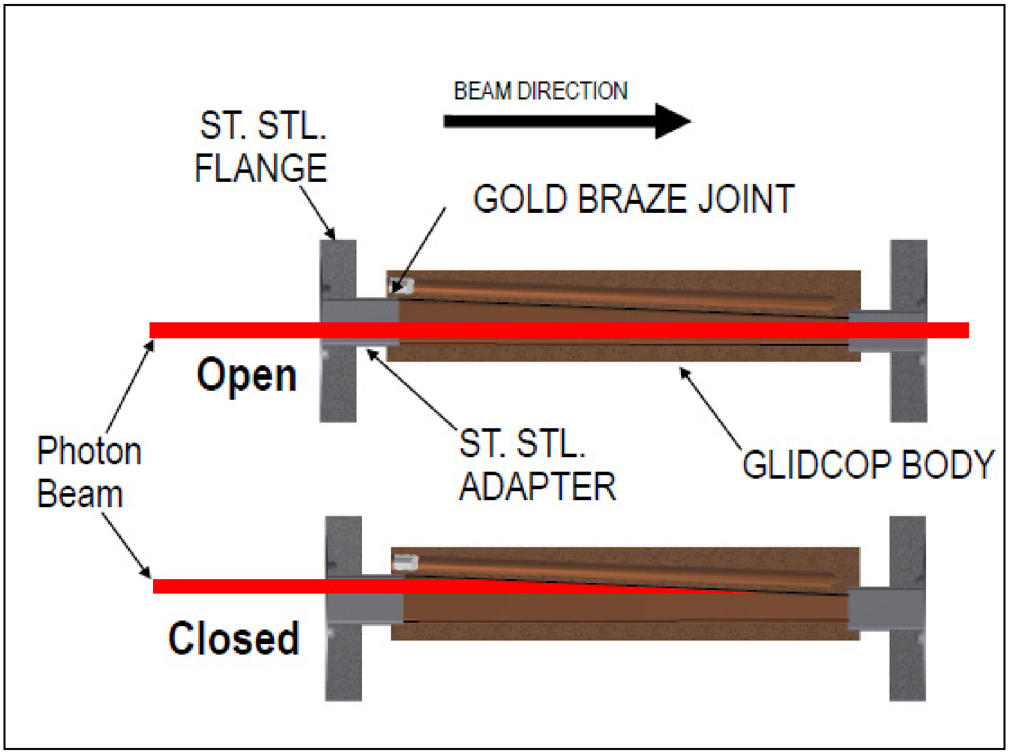


Figure 5-13.

5.2.9 Fast Gate Valve (FGV)

The fast gate valve is to shut within 12 milliseconds, once triggered by FGV sensors located in the FE and beamline whenever there is a sudden increase of pressure of a few decades. The stored beam has to be dumped prior to the FGV closing, and the cause then investigated and mitigated.

5.2.10 Bremsstrahlung Collimator (CO2).

Bremsstrahlung collimators 1 and 2 are of similar design.

5.2.11 Safety Shutter (SSH)

The safety shutter is actually a pair of shutters, required for redundancy, air actuated with independent redundant and diverse position sensing. An external lead design is being used, as shown below.

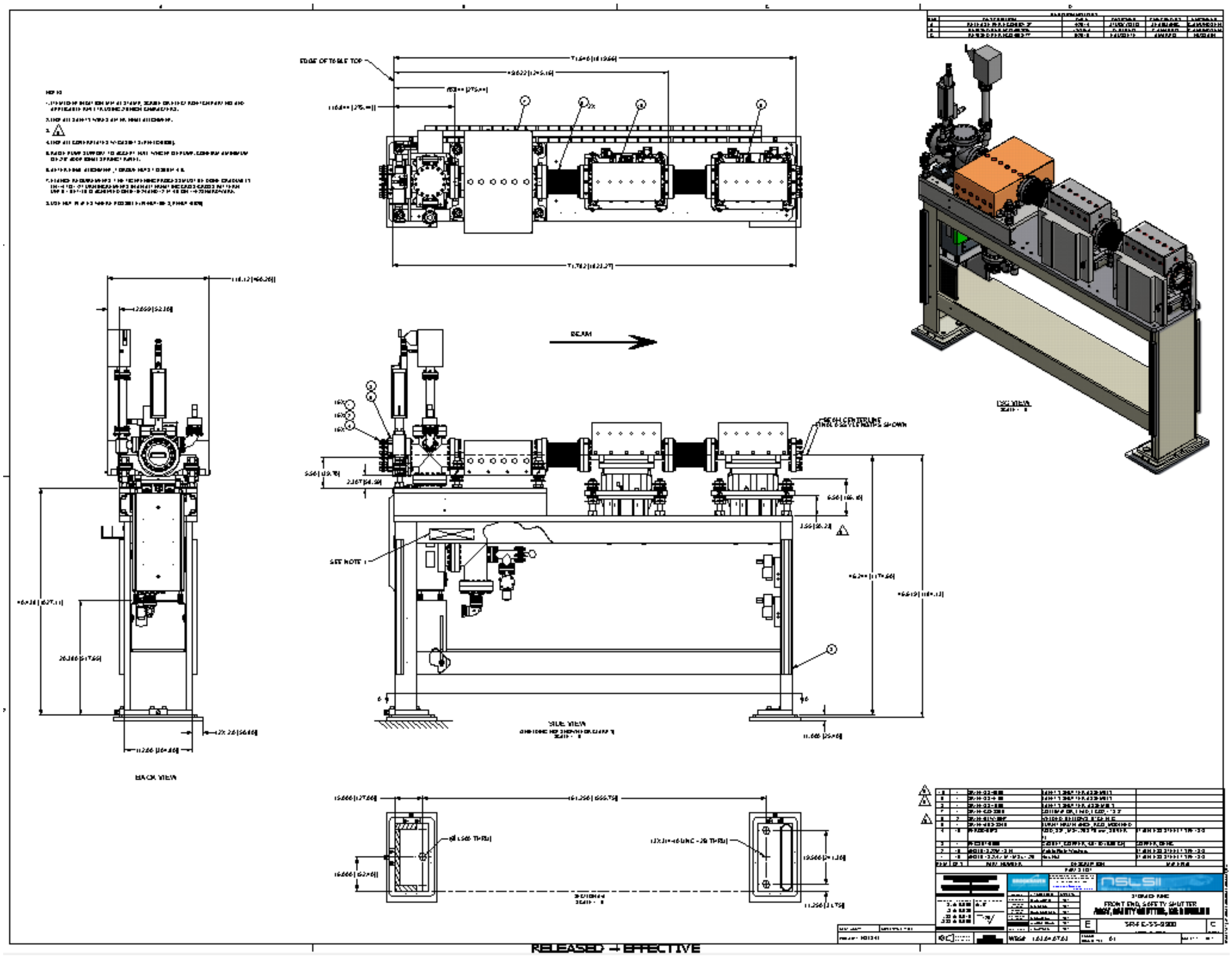
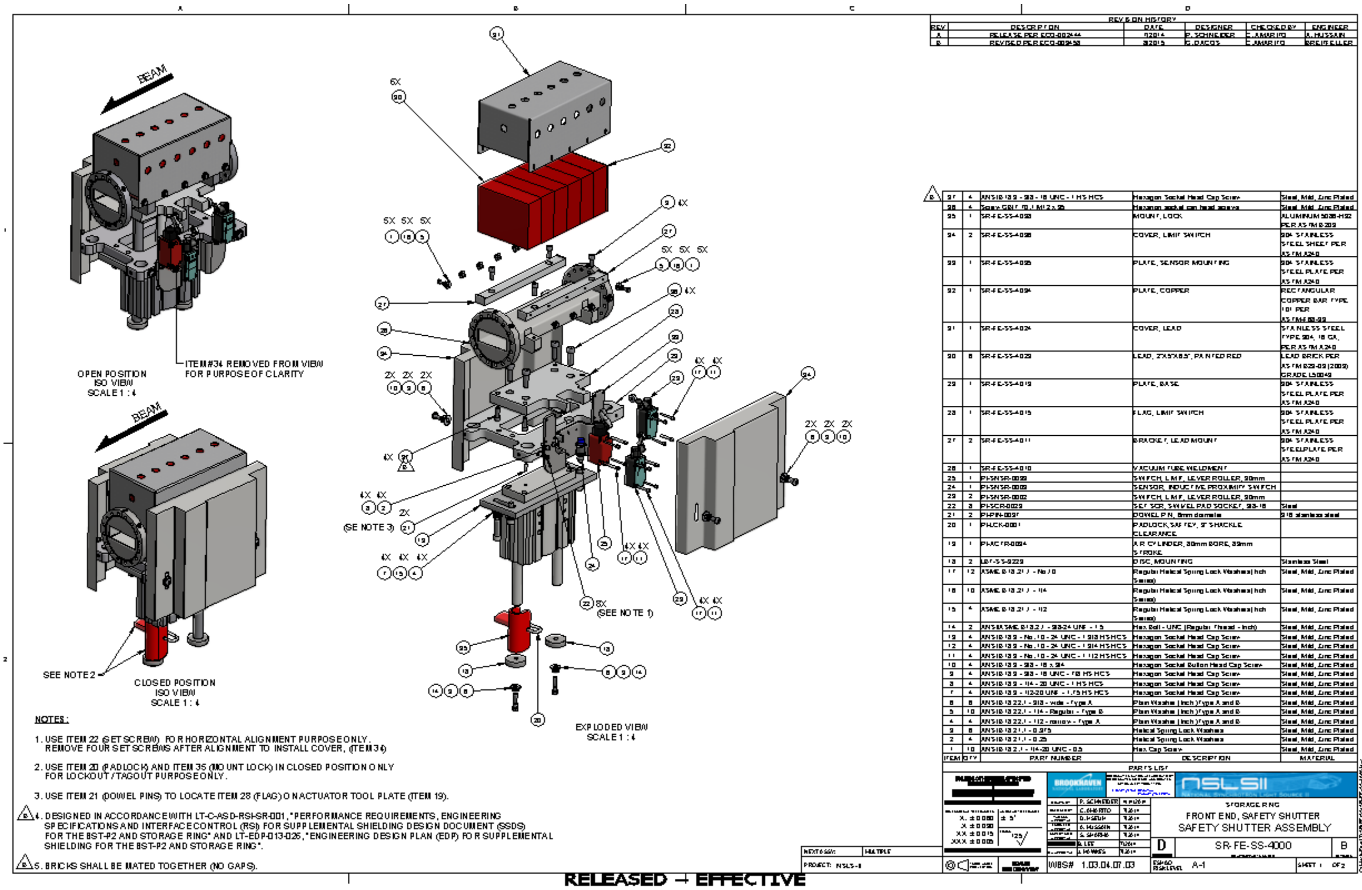


Figure 5-14. Design for the safety shutter.



RELEASED → EFFECTIVE

Figure 5-15. Safety Shutter

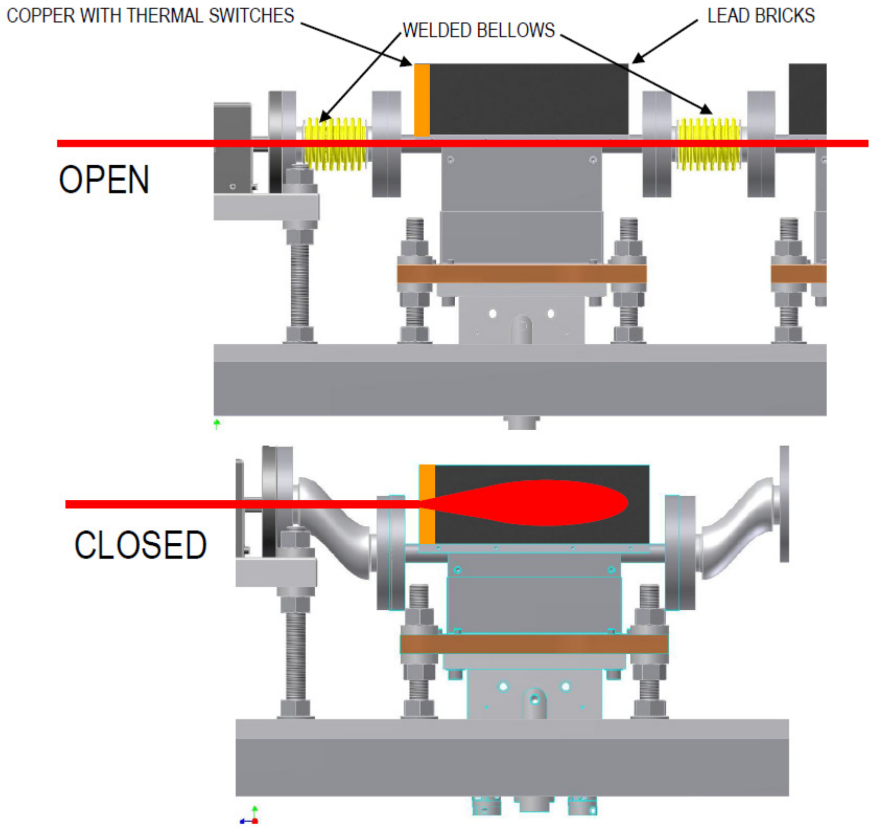


Figure 5-16. Safety Shutter Bellows Test Apparatus

5.2.12 Ratchet Wall Collimator

The design of the ratchet wall collimator is shown below. The upstream end of the collimator assembly includes 12” of lead and 6” of high density polyethylene surrounding the upstream beam pipe. The downs stream beam pipe and lead provide the final Bremstrahlung collimation. The slow gate valve is mounted on the downstream flange of the beam pipe and includes a cold cathode gauge as well as a thermocouple gauge.

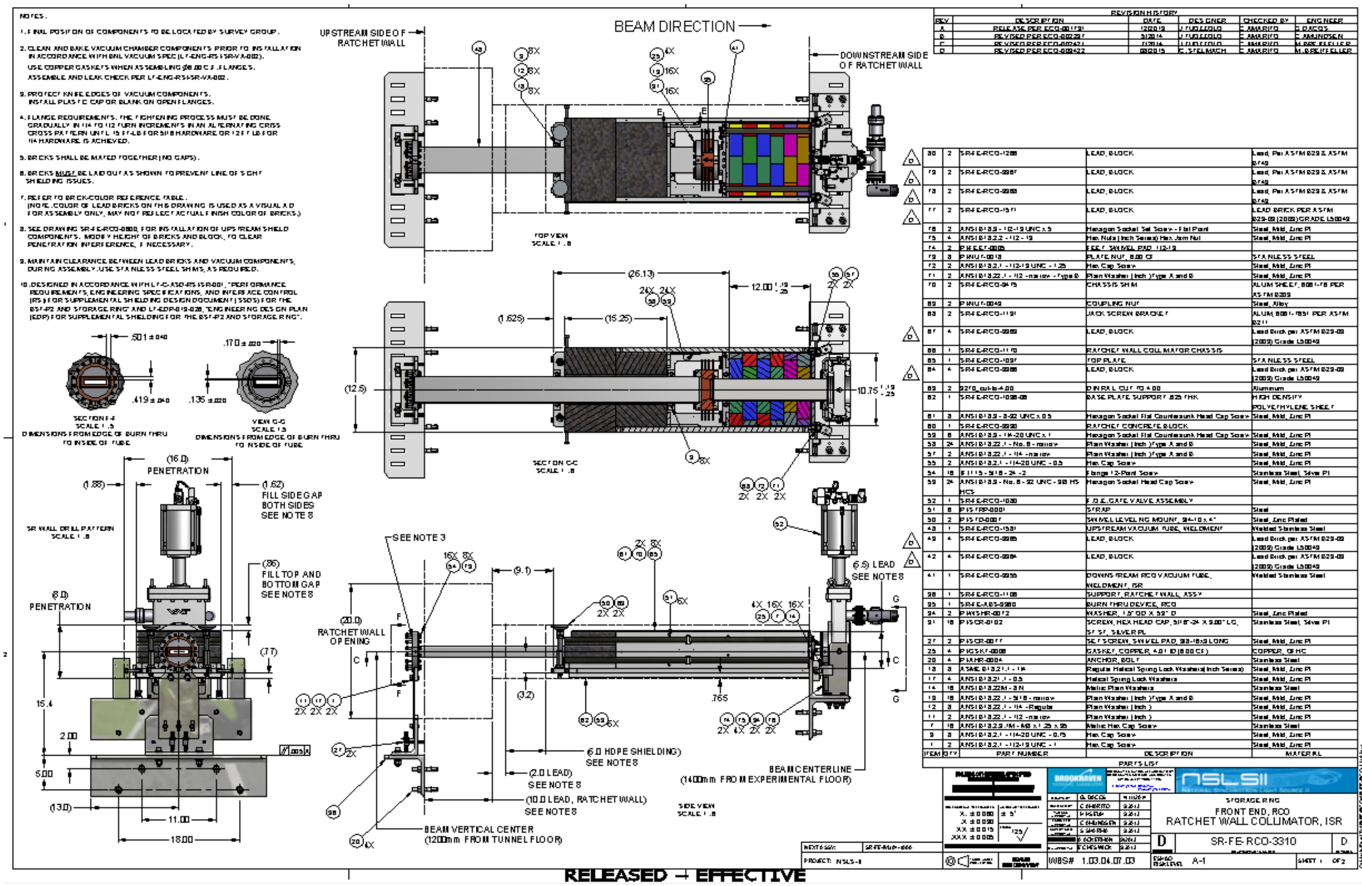
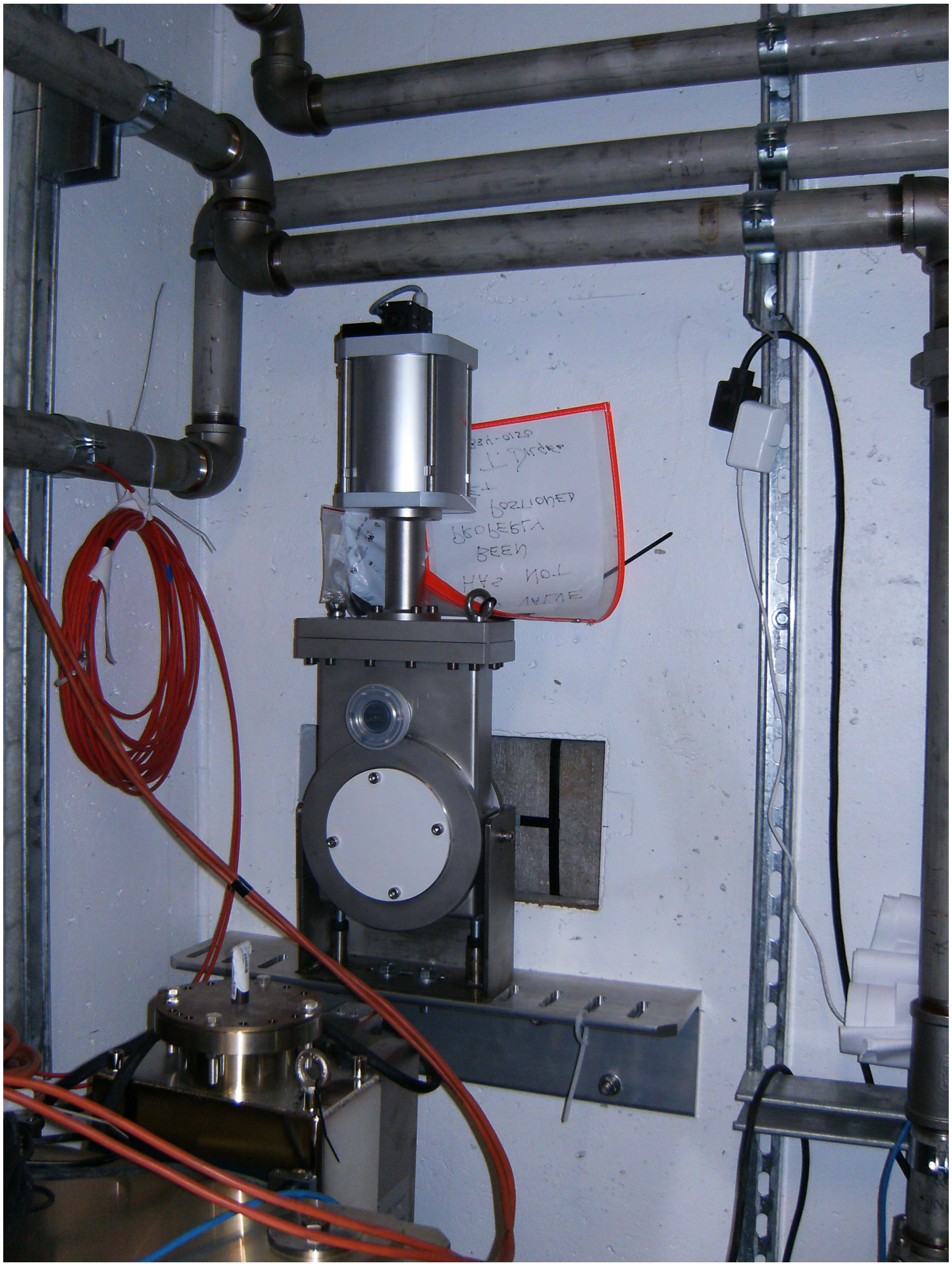


Figure 5-17. Ratchet wall collimator.

Burn-Through-Device will be moved upstream of the ratchet wall for increased reliability.

5.2.13 Gate valve downstream of Ratchet Wall

This slow gate valve, pneumatically actuated, and with position sensing switches, will be monitored and controlled by the SR vacuum PLC using vacuum sensors in the FE and beamlines.



Note-1: This valve cannot be removed after commissioning.

Note-2: This gate valve must be protected from any exposure to beam.

Figure 5-18. Slow Gate Valve in cell 28 (XPD).

5.3 Front End ray Tracings

The NYX front end ray trace has been performed by the NSLS II accelerator group, approved by the NSLS II Radiation Safety Committee and deposited in the NSLS II drawing vault as drawing SR-FE-IVU19-1001. The pdf version of the NYX front end ray trace is available from the NYX FDR web site.

5.3.1 General Guidelines for Ray Tracings

- The origin for the dimensional convention is at the center of the straight section for the ID beamlines.
- The direction of the beam is taken as +Z direction. Beam direction is from left (upstream) to right (downstream).
- X is the direction transverse to the beam, with (+X) towards the outboard direction with respect to the storage ring, and (-X) towards the inboard direction.
- Y is the vertical direction with (+Y) as up and (-Y) as down.
- The typical scale used for synchrotron ray tracings is X:Z = 1:200 and Y:Z = 1:200.
- The typical scale used for bremsstrahlung ray tracings is X:Z = 1:50 and Y:Z = 1:50.
- All components shall be labeled with unique identifying names.
- The stopped external bremsstrahlung ray should not be closer than 3 Moliere Radii (3R) from the lateral edge of the collimator or stop. (Moliere Radius for lead is 12.5 m and for tungsten is 8 mm.)
- Lead thickness of >30 cm and tungsten thickness of >20 cm is required as stops/shutters/collimators at NSLS-II beamlines.
- Bremsstrahlung source locations for the ID beamlines (long straight) is +4 meters; for the ID beamline (short straight) is +2.5 meters.

References: NSLS-II Technical Note No. 00014 and 00020.

5.4 Finite Element Analysis for the Front End

Table 5-1 Finite Element Analysis for the Front End

ID	EPU49 (CSX)	IVU22 (IXS)	DW100 (XPD)
Total power (kW)	10	9.4	60
Peak angular power density (kW/mrad^2)	33.4	89.8	55.5

Components	Fixed mask	Photon shutter	Fixed mask	Photon shutter	Fixed mask	Photon shutter
Location (m)	18.93	21.63	20.19	22.88	20.19	22.88
Fixed mask exit aperture (mrad)	0.6(h) x 0.6(v)		0.5(h)x0.3(v)		1.1(h) x 0.15(v)	
P_Absorbed (W)	5	5	2.4	7	52	8
Peak power density (W/mm^2))	93	73	220	172	136	107
Horizontal taper angle (°)	4.5		3		4	
Vertical taper angle (°)	4.5	7	.2.7	3.5	2	3
Peak temperature (°C)	344	258	265	257	331	268
Peak von Misses Stress (MPa)		352		425		424

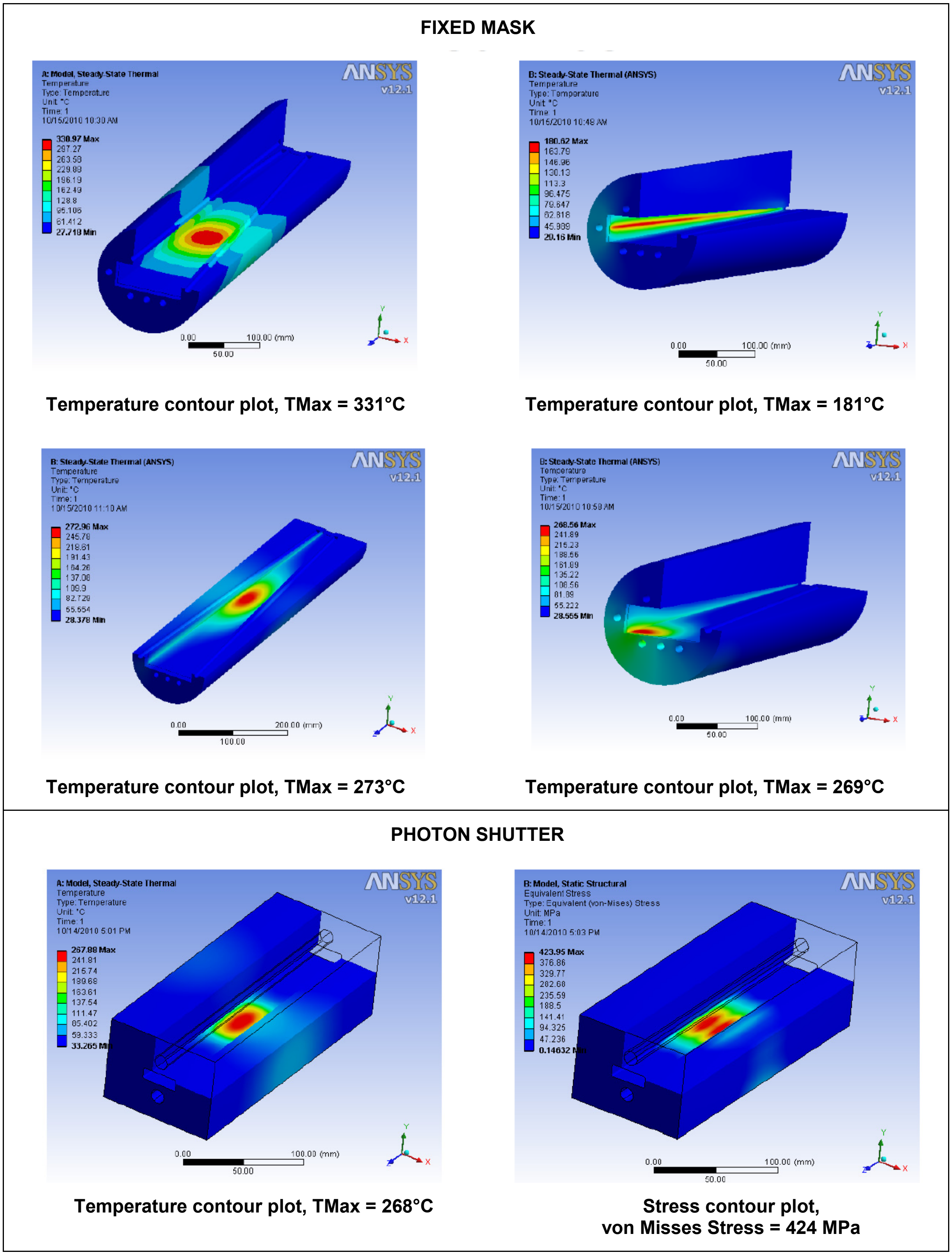


Figure 5-19. Thermal calculations on the Glidcop mask and photon shutter.
(Courtesy of V. Ravindranath)

6. Radiation and Vacuum Containment

Conventional vacuum tubulation, pumping and gauging will contain the beam path from the front end through the optical elements and into the experimental end station. This vacuum beam path passes through three radiation containment enclosures that contain all beamline components (Figure 6-1).

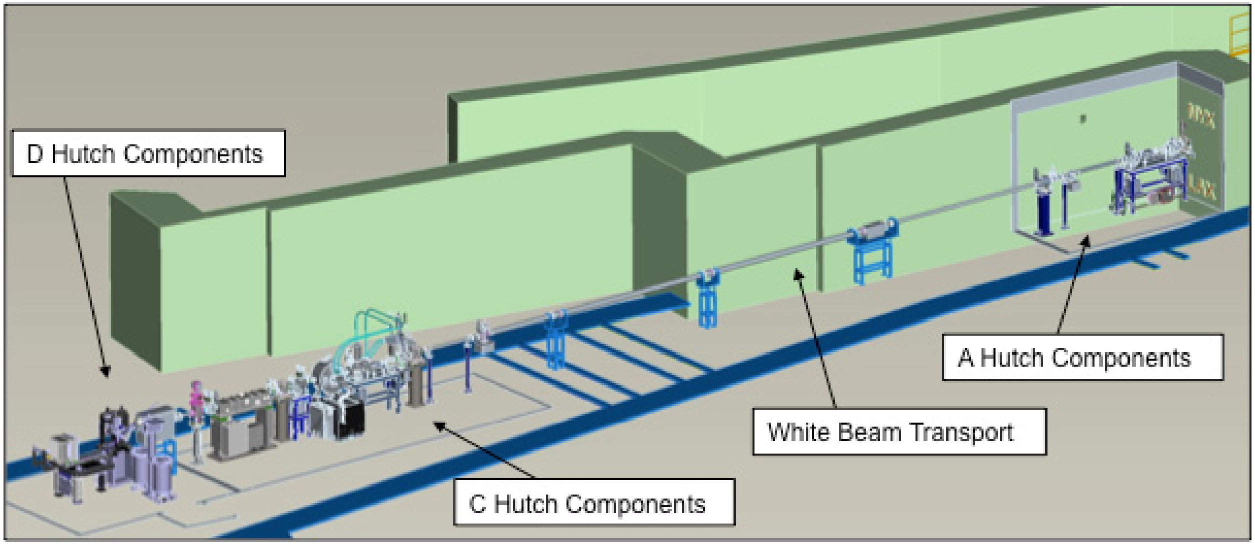


Figure 6-1. Beamline layout in radiation containment elements

6.1 Beampath Component Packages

The NYX beamline components are organized into two major groups, which contain either optical elements or non-optical elements. Details of the optical elements, such as diffracting and reflecting elements, will be described in Section 7 of this document on the photon delivery system. The non-optical elements, which are described in this section, have the primary purpose of passing the useful synchrotron radiation to the Photon Delivery System while restricting the undesirable portion of the synchrotron radiation as well as restricting the passage of bremsstrahlung radiation. These components primarily condition the beam for the downstream NYX beamline. The various elements are grouped into "Component Modules" that are described in this section: "LAX Hutch Components", "White Beam Transport", "Diagnostic Module 1" and "Diagnostic Module 2". "Diagnostic Module 1" intercepts the white beam upstream of the monochromator and "Diagnostic Module 2" intercepts the vertically offset monochromatic beam downstream from the monochromator. The "LAX Hutch Components" are located in Hutch A. Both "Diagnostic Module 1" and "Diagnostic Module 2" are located in Hutch C. The component packages "LAX Hutch Components", "Diagnostic Module 1" and "Diagnostic Module 2" contain water-cooled masks, apertures and collimators that are designed to manage the expected heat load from the 2-meter long IVU described Section 4 above. These three component packages will be manufactured by FMB-Oxford, who have produced the detailed Finite Element Anaylysis (FEA) that is reported in **Appendix 6-1**.

6.1.1 LAX Hutch Components

The "LAX Hutch Components" (Figure 6-2) are designed to accept the incoming canted undulator beams, separated by 2mrad, provide a space for a future, large-offset monochromator off the inboard beam and allow the outboard beam to pass downstream to the NYX hutch.

Ports are provided for mounting diagnostic elements, however the diagnostic elements themselves are not included.

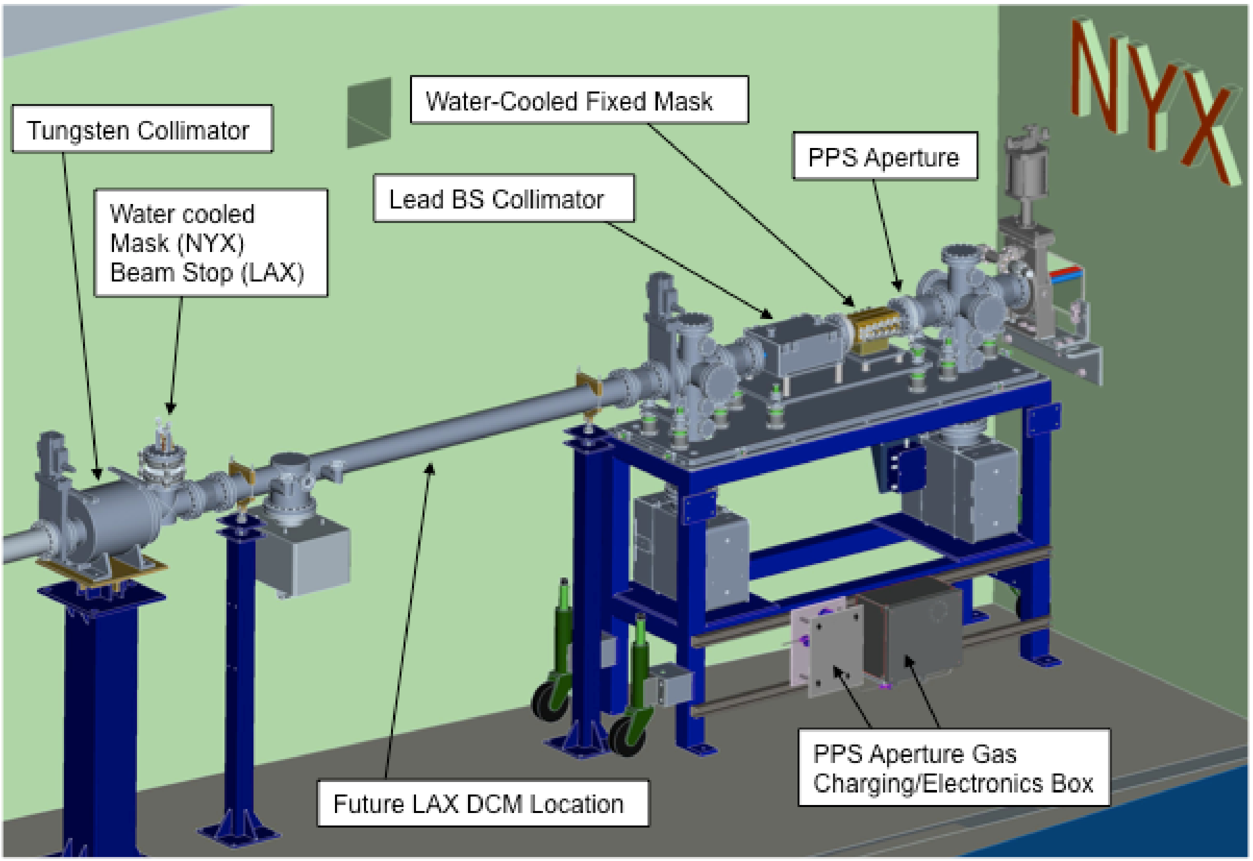


Figure 6-2. LAX hutch components. The LAX hutch is also known as Hutch A.

6.1.2 Beamline Component Module 1

Beamline Component Module 1 is located immediately upstream of the DCM and includes a single aperture mask, BS collimator, cooled filter unit and a cooled Fluorescent Screen (complete with camera) on a mild steel support frame.

White Beam Filter Assembly. The filter materials are mounted on a water-cooled OFHC copper filter holder. Each filter holder has provision to mount 4 filters up to 2mm thick. The unit also accommodates an out of beam position. The filter material is clamped against a lapped copper surface using a sprung loaded clamping plate.

The filter system is based on FMB's proven filter mechanism which is already installed at various facilities on undulator beamlines including NSLS II, ANKA and Soleil. The filter system comprises two independently actuated filter holders (Figure 6-3) mounted on the same DN200CF flange. The filters can be actuated to allow for any combination of two filters.

The filter holders move along external and in-vacuum guides to ensure that they remain parallel to each other. A stepper motor and gearbox driven precision actuator moves each filter holder. The actuator operates through a bellows assembly mounted on the flange.

Each actuator has two limit switches at each end of the travel. These switches are to stop the motor driving the actuator into the end stops. The limit switch actuators are adjustable to set the end of travel position. The first switch acts as a soft limit while the second acts as a “kill switch” which actuates if the system travels through the soft limit

Each independent filter holder is directly encoded by attachment of a Renishaw TONIC encoding system, which allows for repeatable positioning for different filter combinations.

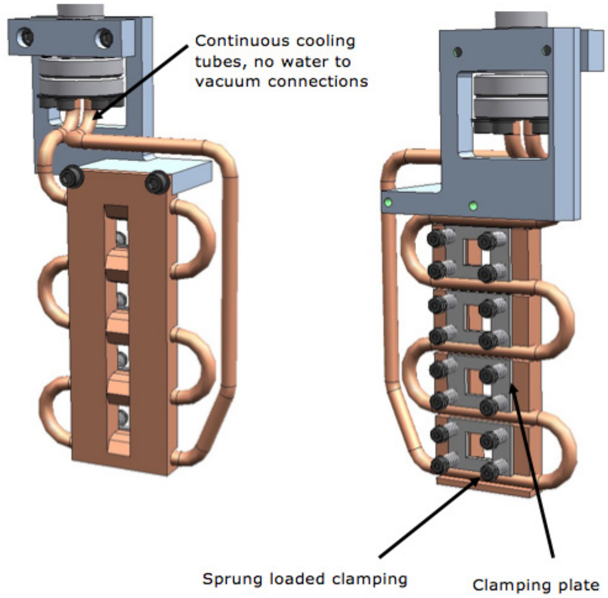


Figure 6-3. Front and rear views of the filter holder

Fluorescent Screens. The white-beam screen, FS1, uses a doped CVD diamond foil mounted on a water-cooled copper absorber block to image the beam (Figure 6-4).

The monochromatic beam screens, FS2 and FS3, use YAG crystals to image the beam.

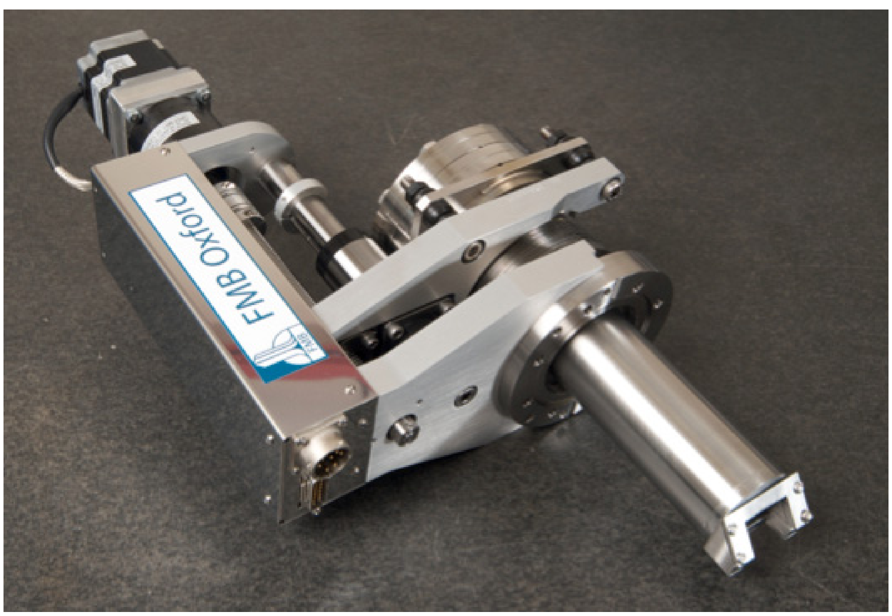


Figure 6-4. YAG Fluorescent Screen Assembly. The white-beam water-cooling block is not shown.

Fluorescent Screen Actuation. The pneumatically-actuated fluorescent screen is mounted onto a Conflat and the camera/lens unit is mounted to the viewport to image the beam.

The Actuator consists of two fixed Conflats joined via edge welded bellows. A hollow shaft is welded to the top Conflat and travels through the inside of the bellows. Attached to each Conflat of the bellows are the actuator plates. The top plate is where the slide rods are fixed. Roller switches are attached to each end of travel to give 2 end of travel feedback.

Cameras. Prosilica CCD cameras in accordance with NSLS-II specifications are fitted to each fluorescent screen (Figure 6-5).

A CCD camera is mounted on a viewport so that it has a clear view of the CVD diamond foil. The CCD camera allows positional and spatial information about the X- ray beam to be viewed remotely.

The camera mount is designed to clamp onto a DN63 4 1⁄2“CF. The mount provides adjustment to help in the setup of the system.

EPICS drivers for the cameras produced by FMB-Oxford will be delivered to NYX.

Figure 6-5. GC-Series Camera

6.1.3 Beamline Component Module 2

Beamline Component Module 2 (Figure 6-6) is located immediately downstream of the DCM and includes a white beamstop, BS stop and Fluorescent Screen FS2 (complete with camera) on a mild steel support frame.

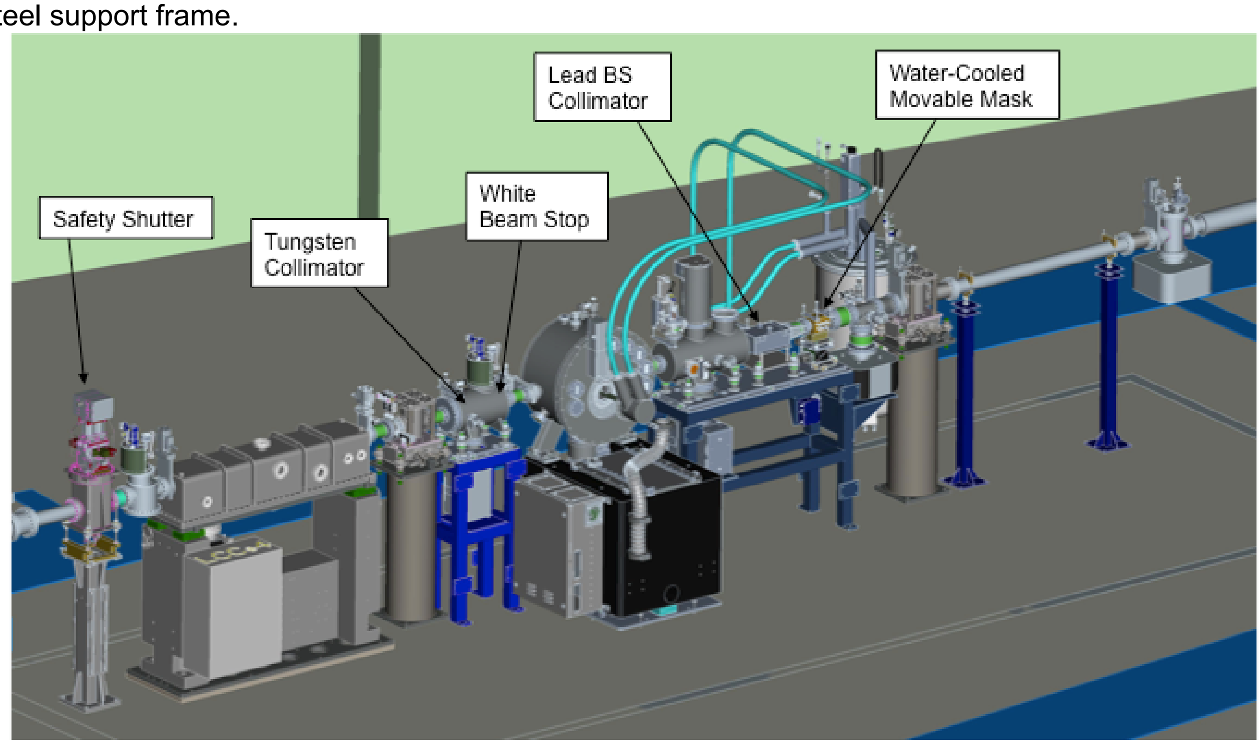


Figure 6-6. Beamline Component Module 2

6.1.4 4-Jaw Slits

A set of 4-jaw slits is located on the exit port of the 2nd diagnostic stand and is used to aperture the beam entering the Vertically Focussing Mirror.

The four blade in flange slit unit comprises of two pairs of horizontal and vertical beam slits. Each slit unit consists of two slit blades and defines either the horizontal or vertical dimension of the beam. The slits are able to close in both directions. The slit blades move along in-vacuum guides to ensure that they remain parallel to each other. Each slit blade is moved by a stepper motor with two limit switches and encoder.

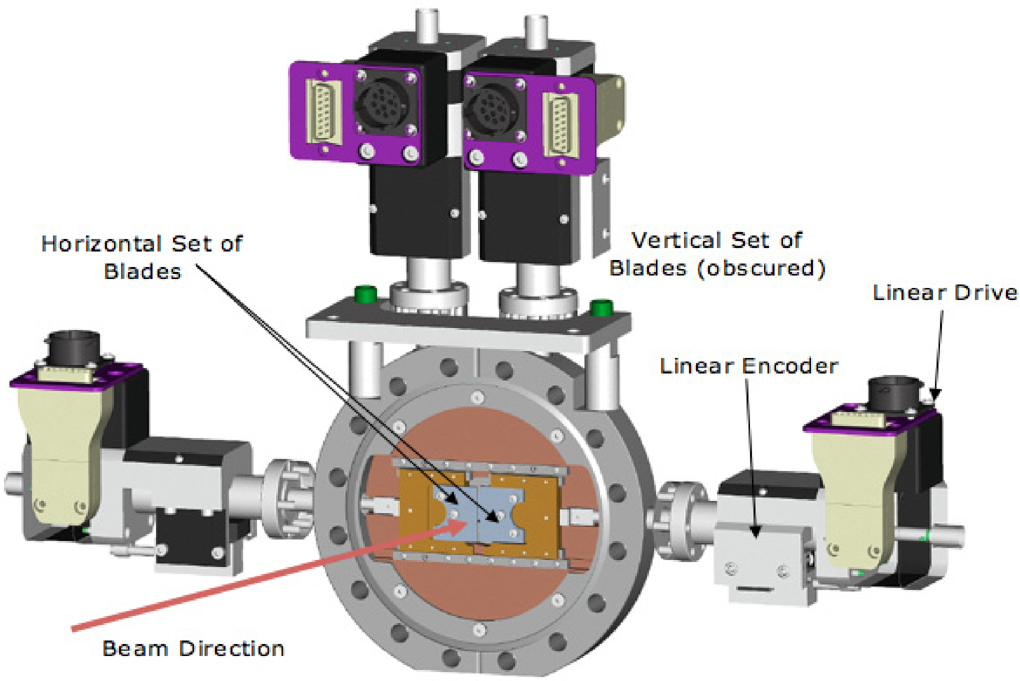


Figure 6-7. 4-Jaw Slit

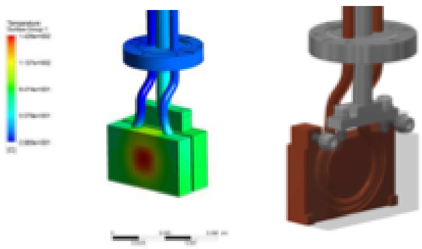
6.1.5 Fluorescent Screen 3 (FS3)

A third motorized, uncooled Fluorescent Screen is mounted onto a flange of the Diagnostic Stand downstream of the VFM to image the beam exiting either the VFM or directly from the DCM. Details of the FS are contained in the relevant previous section.

6.2 Beampath Photon Shutter

Johnsen Ultravac has successfully developed a dual-shutter style photon shutter for various beamlines operating in state of the art synchrotron facilities, some of the advantages of our photon shutter are listed below:

1. The beamline photon shutter assembly (see right) consists of an Ultra-High Vacuum (UHV) vessel with two aperture blocks and two water-cooled shutters that are controlled by two independent actuators.



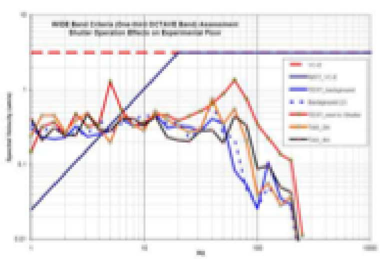
2. The overall shutter block provides sufficient thermal protection: The photon shutter blocks are designed and fabricated for a minimum of 1.15KW of heat energy incident upon either shutter block applied over an area of 25mm x 25mm centered vertically and horizontally on the shutter block face with a maximum heat density of 2.7W/mm^2. One formed 5/16" OD x 0.035" wall OFHC copper tubing is vacuum brazed into the groove of Glidcop block to eliminate the direct water-to-vacuum joints. The maximum temperature on Glidcop block is under 150^{o}C with 2.52L/min water flow rate (see left).

3. Tungsten alloy ≥95% W, for radiation protection, detailed specifications are: Shutter Block: 80 W x 50 H x 19.05 T (mm); Aperture Plate: 125 W x 150 H x 19.05 T (mm) with a 40 W x 25 H (mm) aperture in the center. The thickness of tungsten shutter can be increased upon customer's request.

4. Two identical actuators with 2.5" bore and 2" stroke are used to independently move each shutter block. The actuators are designed to be fail-safe; the shutters are fully closed upon loss of actuator supply power (e.g., loss of air pressure and/or electrical power). When the shutter is commanded to close or when a loss of actuator power/ air pressure occurs, both shutter blocks will fully close with sufficient overlap – 10mm and keep the minimum gap (less than 1.0mm) between the aperture plates at all times, so that no radiation leakage downstream of the shutter occurs.

5. The all-metal CF flange structure allows repeated bake-out of all in-vacuum components at 200C max.

6. Our compact design, with 300mm overall length from upstream to downstream, provide maximum space for other beamline components which may be located on either end.



7. The overall structure of the photon shutter is designed & manufactured to minimize shock and vibration transfer to the supporting beamline as well as the experimental floor resulting from opening or closing of the shutter blocks. The First Item Tests were performed and the vibration levels transmitted to the experimental floor were much lower than the VC-E curve criteria (see left) The provisions of shock/vibration in actuator, chamber support and stand are optional features.

8. Competitive both on pricing and delivery due to the proficient design, excellent QA system, outstanding workmanship and zero failure rate of our products.

9. The redundant PPS interlock, provisions for safety and tamper-resistance will satisfy all synchrotron facility requirements globally. All materials, coating and finishes are capable of withstanding prolonged exposure to x-ray radiation.

6.3 White-beam Transport and Shielding Validation

6.3.1 White-beam Transport

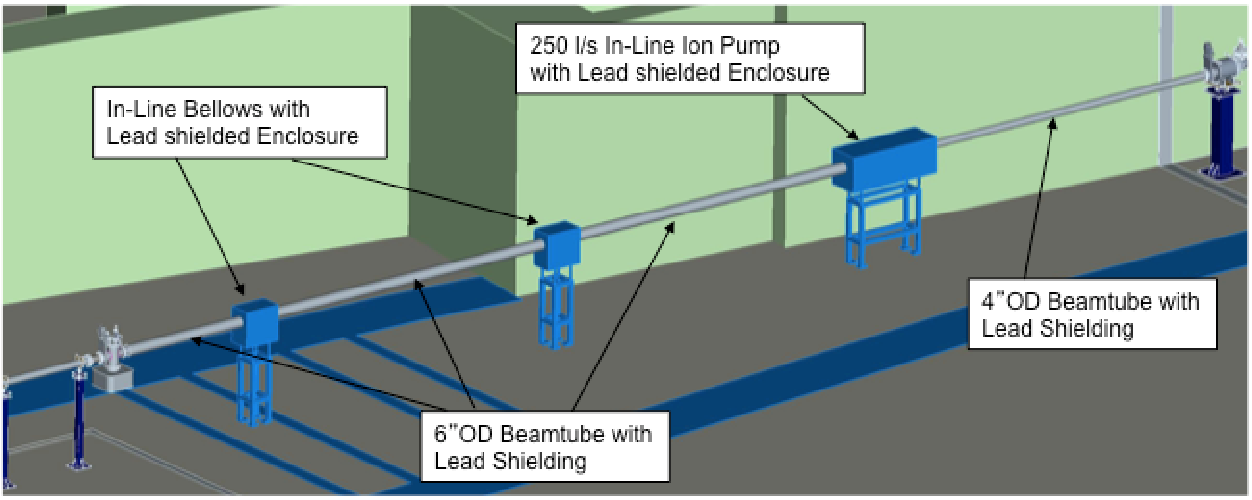


Figure 6-8. White-beam transport vacuum and radiation containment components.

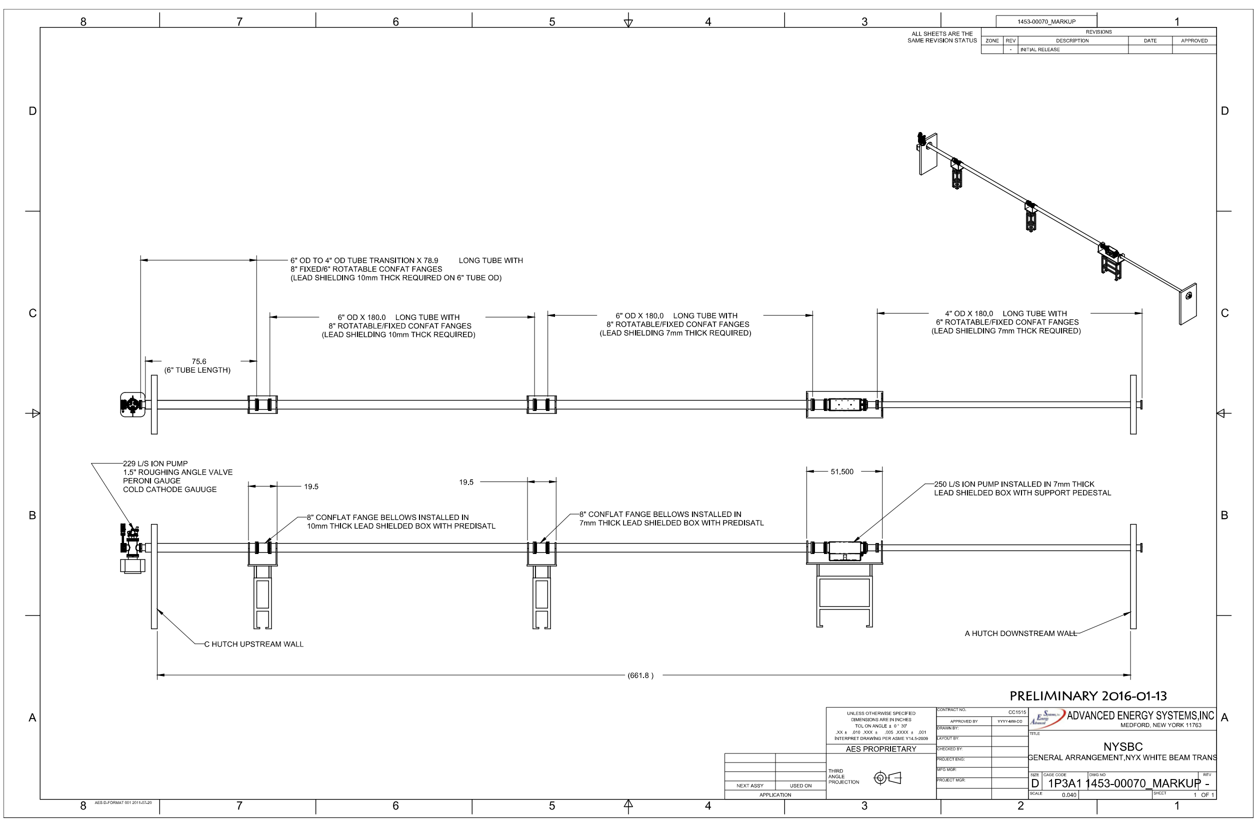


Figure 6-9. White-beam transport vacuum layout.

6.3.2 Shielding validation.

The 19-ID hutches and white-beam transport have been designed following the *"Guidelines for Beamline Radiation Shielding Design at the National Synchrotron Light Source II"* however shielding validation is required to insure that proper radiation protection has been provided in full compliance with NSLS-II standards. Radiological risks need to be analyzed in the following specific areas:

1) The stay-clear region of gas-Bremsstrahlung in the last section of the white-beam transport.
2) Shielding required to reduce the dose from secondary radiation (electromagnetic shower and photoneutrons) produced by the gas-Bremsstrahlung encountering the transition from 6" to 4" dia. tube at the downstream end of hutch 19-ID-C.
3) Shielding required to reduce the dose from secondary radiation (electromagnetic shower and photoneutrons) produced by the gas-Bremsstrahlung encountering the high-Z material in the slits upstream of the monochromator.
4) Shielding required to reduce the dose from secondary radiation (electromagnetic shower and photoneutrons) produced by the gas-Bremsstrahlung encountering the 1st crystal of the monochromator.
5) Shielding required to reduce the dose from secondary radiation (electromagnetic shower and photoneutrons) produced by the gas-Bremsstrahlung encountering the high-Z material of the white-beam stop at the exit of the monochromator.

The NYX beamline design includes accommodations for additional shielding as described in the above NSLS-II guideline; however, further validation is required before actual shielding can be implemented.

6.4 Radiation Enclosures

6.4.1 General Description

NYX has three radiation enclosures (Figure 6-10): Hutch A, which will also serve as the first optical enclosure for the eventual LAX beamline and Hutch B, which is the first optical enclosure for NYX are lead shielded. Hutch C encloses the end station is shielded with steel. Hutches C and D are contiguous. The eventual enclosure for LAX will be called Hutch B.

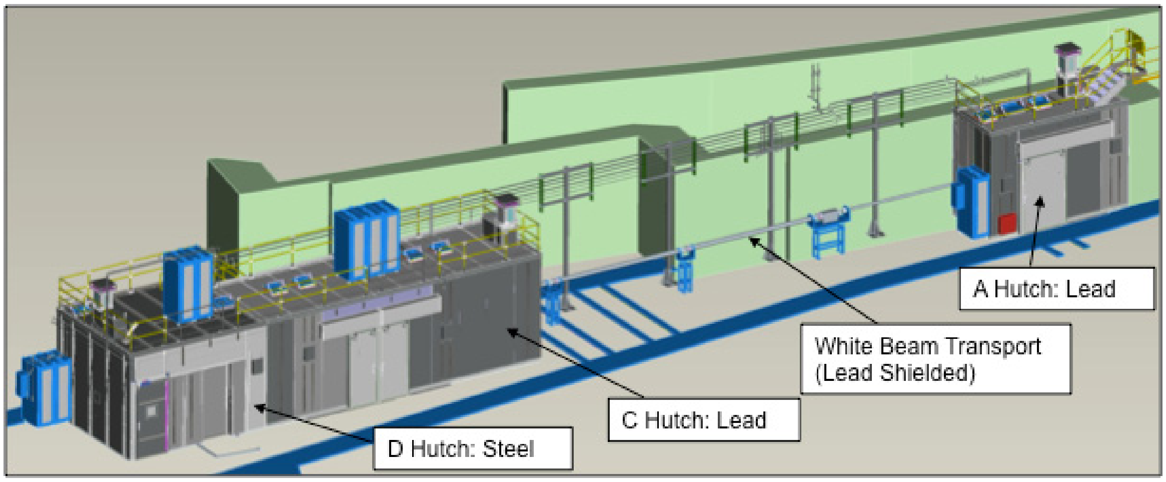


Figure 6-10. Bealine layout the hutch identifications

Beamline hutches for NYX are being implemented throughout the beamlines' WBS areas; the technical aspects of the hutches are described in this section. The hutches have been contracted with GPS by NYSBC and installation is complete at NSLS II with final acceptance expected by the end of January 2016.

The beamline hutches are provided to contain all harmful x-ray radiation and prevent personnel exposure during operation. The First and Secondary Optics Enclosures (FOE, SOE), constructed from thick lead panels of a standard 1 m width and calculated thickness, to contain not only the white x-ray beam, but also the very-high-energy bremsstrahlung x-ray radiation. Experimental stations for monochromatic beam will be constructed from steel (typically, ¼-in. thick). The NYX FOE during utilities installation is shown in Figure 6-11.

Figure 6-11. View of an FOE hutch (18 mm lead sidewall thickness) after completion.

Calculations have been performed on the lead thickness requirements for sidewalls, roofs, and downstream walls of FOE, SOE, white beam transport between the FOE and SOE the and experimental station for an IVU source; these are documented in “Guidelines for NSLS-II Beamlines and Front End Radiation Shielding Design,” LT-ESHDES-08-003-Rev 001, and summarized in Table 6-1, below.

Table 6-1. First Optics Enclosure (FOE) and Experimental End Station shielding thickness requirements, in mm. The first dimension is for sidewalls, then roof, then downstream wall.

Source	FOE Shielding*	End Station Shielding*
IVU	18/6/50 Pb	6/3/6 Fe

- Shielding given is for sidewalls/roof/downstream wall, in mm.

6.4.2 Hutch Labyrinths

All hutches will be provided with labyrinths for allowing passage through the shielding walls of the following services:

- Control cabling
- Mains electricity
- PPS cabling
- Liquid nitrogen
- Ventilation air (in and out)
- Exhaust gas (from hoods ,etc. to the facility extraction system)
- Chilled water

Note that Low Conductivity Water and compressed air will enter the FOE through the concrete ratchet wall from the accelerator tunnel.

Labyrinths will be fitted with Personnel Protection System (PPS) locks and/or safety switches, as needed, to inhibit beamline operation when a labyrinth is not closed and secured.

A typical labyrinth is shown in Figures 6-12.

Figure 6-12. Typical NYX roof labyrinths.

Figure 6-13. NYX endstation hutch and SOE, hutches C and D.

Hutches will be fitted with standard doors, either swinging single door or sliding single/door as needed (Figure 6-13). One door per hutch will be pneumatically actuated. These will be fitted with PPS magnetic locks, switches, etc. Generally, windows are discouraged on FOEs due to the extreme thickness of lead glass needed. Experimental station windows are more reasonable in thickness and will be used where desirable. The image below (Figure 6-14) shows the typical lead lined floor groove cross section.

Figure 6-14. Typical hutch floor showing groove, steel insert, and the lead shielding.

6.4.3 Hutch Electrical Equipment

The hutch will be fitted with standard ventilation fans and lights within the hutch contract. Wiring to this equipment (and all other electrical wiring) will be performed under the beamline utilities scope.

6.4.4 Hutch Roof Access

The hutches are all designed for roof access (except in the case of any small “doghouse type” hutches); features include load ratings compatible with human loads, as well as equipment and utilities, handrails and kick-plates, and swing gates to restrict access to hutch roofs from the mezzanine floor (storage ring tunnel roof) to just beamline staff and other authorized staff (Figure 6-15).

Figure 6-15. Personnel access gate and railing for the 19-ID-C&D hutches.

Table 6-2. Specification Sheet for Enclosure 19-ID-A

Specification Sheet for Enclosure 19-ID-A

Enclosure designation		19-ID-A
Enclosure type		IVU (LAX)
Enclosure description		LAX White Beam Optics Enclosure
Shielding material		Lead
AES Drawing reference		1453-00100
Dimensions (m)	Height max	3.5 m
	Width max	2.3 m
	Length max	5 m
Shielding	Side (lateral) panels	18 mm lead
	Roof panels	10 mm lead
	Downstream wall panels	50 mm lead
	Guillotine	2 required, Single aperture-downstream, One supplied with lead shielding plug
	Beam pipe penetration door	(alignment window): Not required
Entry 1	Position	Outboard side
	Size (m)	2.4 H x 1.2 W (minimum)
	Type	Sliding single door, Manual operation
	Floor groove	yes
	PPS Interfaces	Mounting plates for magnetic lock and dual position switches.
	Window	Not required
	Strip Curtain (internal)	No
Hoist		Not Required
Labyrinths		Positioned as on drawing, sealed with anti-tamper screws except where locks/interlocks specified.
	Fluids labyrinth	(on roof): Qty 1
	Electrical labyrinth	(on roof): Qty 1
	Air inlet labyrinth, with fan and filter	(on roof): Qty 1
	Air outlet labyrinth	(base of sidewall): Qty 1
	Exhaust labyrinth	(on roof): N/A
	User access labyrinth	(on sidewall): Qty 1, with interlock switch provisions
	Liquid nitrogen labyrinth	(on roof): Qty 1
Bridges		Not required
Lighting		Fluorescent
Other		Attachment points for adjacent enclosures: Not required
Drawings		Number of full sized prints required of all drawings: Qty 3
Manuals		Number of copies required of all manuals: Qty 3

Table 6-3. Specification Sheet for Enclosure 19-ID-C

Specification Sheet for Enclosure 19-ID-C

Enclosure designation		19-ID-C
Enclosure type		IVU (NYX)
Enclosure description		NYX White Beam Optics Enclosure
Shielding material		Lead
AES Drawing reference		1453-00101
Dimensions (m)	Height max	3.5 m
	Width max	3.25 m
	Length max	10.0 m
Shielding	Side (lateral) panels	18 mm lead
	Roof panels	10 mm lead
	Upstream panels	18 mm lead
	Downstream wall panels	50 mm lead
	Guillotine	2 required, Single aperture- upstream and downstream
	Beam pipe penetration door	(alignment window): Not required
Entry 1	Position	Outboard side
	Size (m)	2.4 H x 2.0 W
	Type	Sliding double, Manual Operation
	Floor groove	Yes
	PPS Interfaces	Mounting plates for magnetic lock and dual position switches.
	Window	Not required
	Strip Curtain (internal)	No
Hoist		Not Required
Labyrinths		Positioned as on drawing, sealed with anti-tamper screws except where locks/interlocks specified.
	Fluids labyrinth	(on roof): Qty 2
	Electrical labyrinth	(on roof): Qty 2
	Air inlet labyrinth, with fan and filter	(on roof): Qty 1
	Air outlet labyrinth	(base of sidewall): Qty 1
	Exhaust labyrinth	(on roof): N/A
	User access labyrinth	(on sidewall): Qty 2, (Qty 1 with interlock switch provisions, Qty 1 with padlock provisions for PPS)
	Liquid nitrogen labyrinth	(on sidewall): Qty 1
Bridges		Not Required
Lighting		Fluorescent
Other		Attachment points for adjacent enclosures: Required for attachment to 19-ID-C (see AES drawing 1453-00103)
Drawings		Number of full sized prints required of all drawings: Qty 3
Manuals		Number of copies required of all manuals: Qty 3

Table 6-4. Specification Sheet for Enclosure 19-ID-D

Specification Sheet for Enclosure 19-ID-D

Enclosure designation		19-ID-D
Enclosure type		IVU (NYX)
Enclosure description		NYX Endstation 1
Shielding material		Steel
AES Drawing reference		1453-00102
Dimensions (m)	Height max	3.5 m
	Width max	4.25 m
	Length max	5.0 m
Shielding	Side (lateral) panels	6 mm steel
	Roof panels	3 mm steel
	Upstream wall panels	6 mm steel on 1.1m wide segment, Open area attaches to downstream wall of Enclosure 19-ID-B
	Downstream wall panels	6 mm steel
	Guillotine	None Required
	Beam pipe penetration door	(alignment window): Not required
Entry 1 & 2	Position	Entry #1 Inboard side, Entry #2 Outboard side
	Size (m)	2.4 H x 1.0 W
	Type	Entry #1 Sliding Single, Entry #2 Hinged Single, Both Manual Operation
	Floor groove	Entry #1 Yes, Entry #2 No
	PPS Interfaces	Mounting plates for magnetic lock and dual position switches.
	Window	Not required
	Strip Curtain (internal)	No
Hoist		N/A
Labyrinths		Positioned as on drawing, sealed with anti-tamper screws except where locks/interlocks specified.
	Fluids labyrinth	(on roof): Qty 1
	Electrical labyrinth	(on roof): Qty 1
	Air inlet labyrinth, with fan and filter	(on roof): Qty 1
	Air outlet labyrinth	(base of sidewall): Qty 1
	Exhaust labyrinth	(on roof): Qty 1
	User access labyrinth	(on sidewall): Qty 2 (Qty 1 with interlock switch provisions, Qty 1 with padlock provisions for PPS)
	Liquid nitrogen labyrinth	(on sidewall): Qty 1
Bridges		Not Required
Lighting		Fluorescent
Other		Attachment points for adjacent enclosures: Required for attachment to 19-ID-B (see AES drawing 1453-00103). Required for attachment to future load lock vestibule around perimeter of Entry #1
Drawings		Number of full sized prints required of all drawings: Qty 3
Manuals		Number of copies required of all manuals: Qty 3

6.5 Beamline Ray Tracing

The latest revision of the NYX Beamline Ray Trace drawing, dated 12-23-2015, has been tentatively approved by the BNL Radiation Safety Committee (RCS). This ray trace drawing specifies the synchrotron beam water cooled mask aperture geometry and synchrotron beam stops, the high energy bremsstrahlung collimator geometry and bremsstrahlung beam stops as well as the white beam transport beam tube shielding. The axial location of all components and aperture geometry is accurately represented in this layout. Aperture geometry is sized to assure delivery of the total synchrotron beam fan angle that can be captured and focused by the tangencially bent first crystal and sagittally bent second crystal set planned for the Double Crystal Monochromator (DCM). Table 6-5 below outlines the beamline aperture and collimator location and sizes. Figures 6-16 through 6-19 below depict the four-sheets of the Ray Trace drawing submitted for review by the RSC on 12-23-2015.

Table 6-5. NYX Beamline Apertures/Collimators

Position	Beamline Component	from X25 center	from SAGU center	Aperture Horz	Aperture Vert	Aperture Diag	Fan Angle µrad H (from SAGU)	Fan Angle µrad V (from SAGU)	Fan Angle µrad Diag (from SAGU)	from Cant Mag #1	Transvers offset from center of straight to NYX
-1035	Center of Source IVU (SAGU)	-490	0							1612.70	
-545	Center of Source IVU (X25)	0	490							2102.70	
0	Center of Straight	545	1035							2647.70	
17892.75	Fixed Mask-Front End (water cooled)	18438	18928	9.4	5.4	10.8	496.6	285.3	572.7	20540.45	16.638
26224	Fixed Mask (water cooled)	26769	27259	4.3	2.2	4.8	157.7	80.7	177.2	28871.60	23.386
26224	Rev 12 Fixed Mask (water cooled)	26769	27259	4.0	2.0	4.5	146.7	73.4	164.1	28871.60	23.386
26424	(aperture exit location)									29071.60	23.548
26540	Lead Collimator	27085	27575	round	round	9.0			326.4	29187.70	23.642
26540	Rev 12 Lead Collimator	27085	27575	round	round	5.0			181.3	29187.70	23.642
26840	(aperture exit location)									29487.70	23.885
29670	White Beam Mask (NYX) & Beamstop (LAX)	30215	30705	5.0	3.0	5.8	162.8	97.7	189.9	32318.18	26.178
29670	Rev 12 White Beam Mask (NYX) & Beamstop (LAX	30215	30705	5.0	3.0	5.8	162.8	97.7	189.9	32318.18	26.178
29710	(aperture exit location)									32358.18	26.210
29850	Rev 12 BS Collimator (tungsten)	30395	30885	8.2	5.8	10.0	265.5	187.8	325.2	32497.70	26.323
30050	(aperture exit location)									32697.70	26.485
50655	Single Aperture White Beam Mask (water cooled)	51200	51690	8.0	4.0	8.9	154.8	77.4	173.0	53302.70	43.175
50855	(aperture exit location)									53502.70	43.337
51000	BS Collimator (Lead)	51545	52035	round	round	17.0			326.7	53647.70	43.455
51300	(aperture exit location)									53947.70	43.698
52697	DCM	53242	53732							55344.70	44.829
53477	White Beam Stop (water cooled)	54022	54512							56124.70	45.461
53594	Tungsten Collimator	54139	54629							56241.70	45.556
53794	(aperture exit location)									56441.70	45.718
55400	VFM	55945	56435							58047.70	47.019
56833	Photon Shutter	57378	57868							59480.70	48.179
59400	Microdiffractometer (goniometer)	59945	60435							62047.70	50.259
62245	Beam Stop - Downstream Wall	62790	63280							64892.70	52.563

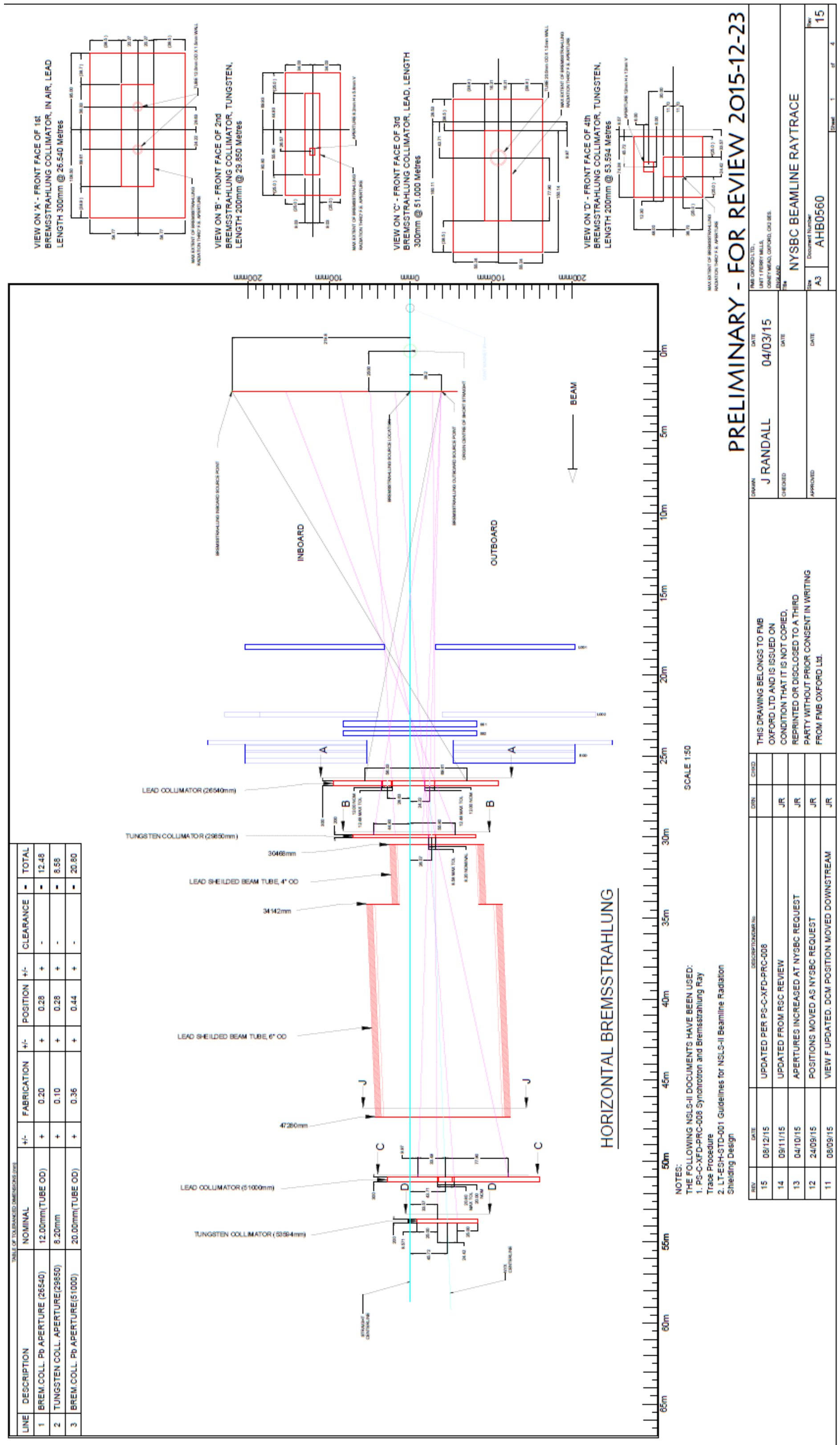


Figure 6-16. Horizontal Bremsstrahlung Ray Trace (Sheet 1)

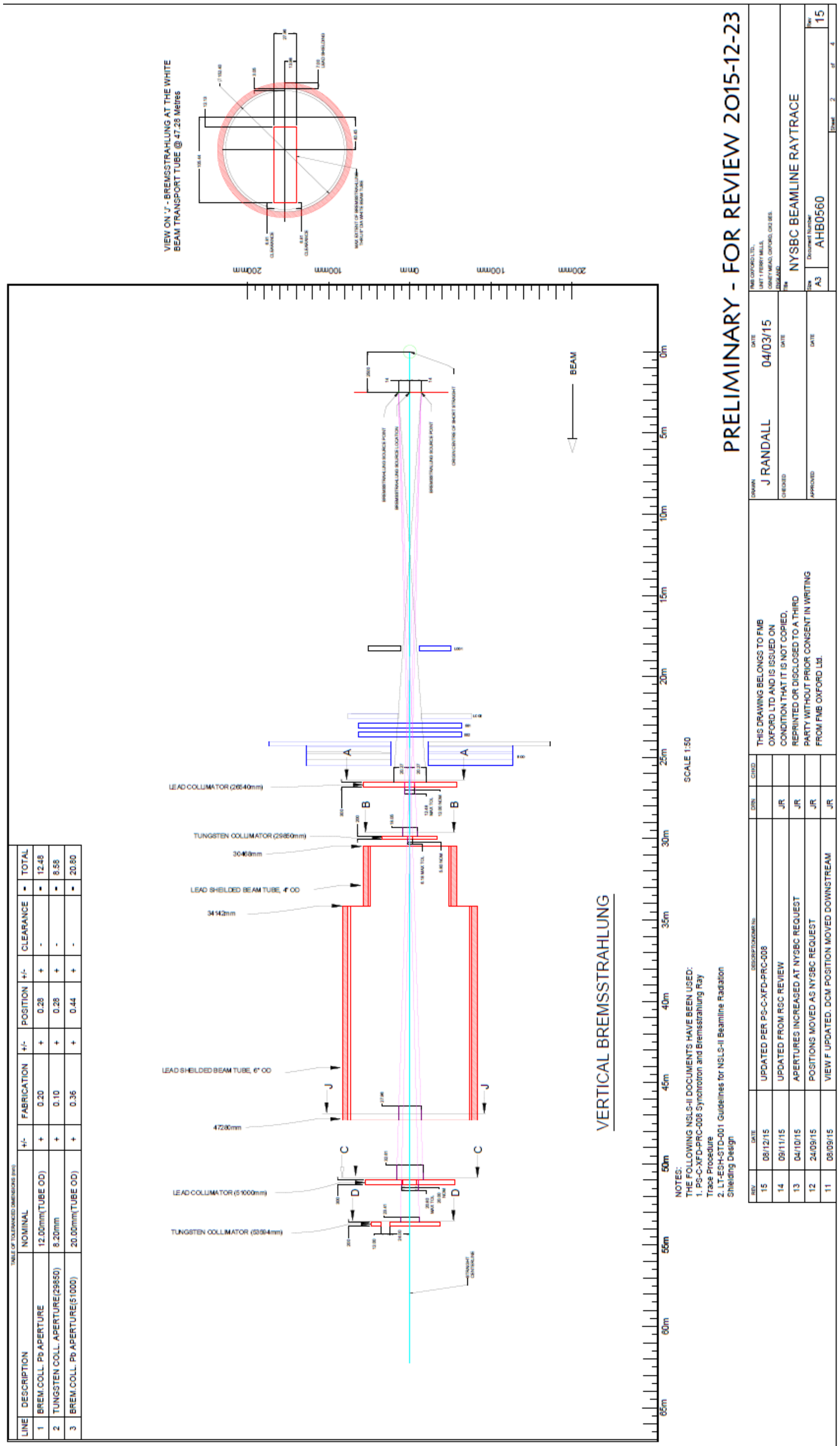


Figure 6-17. Vertical Bremsstrahlung Ray Trace (Sheet 2)

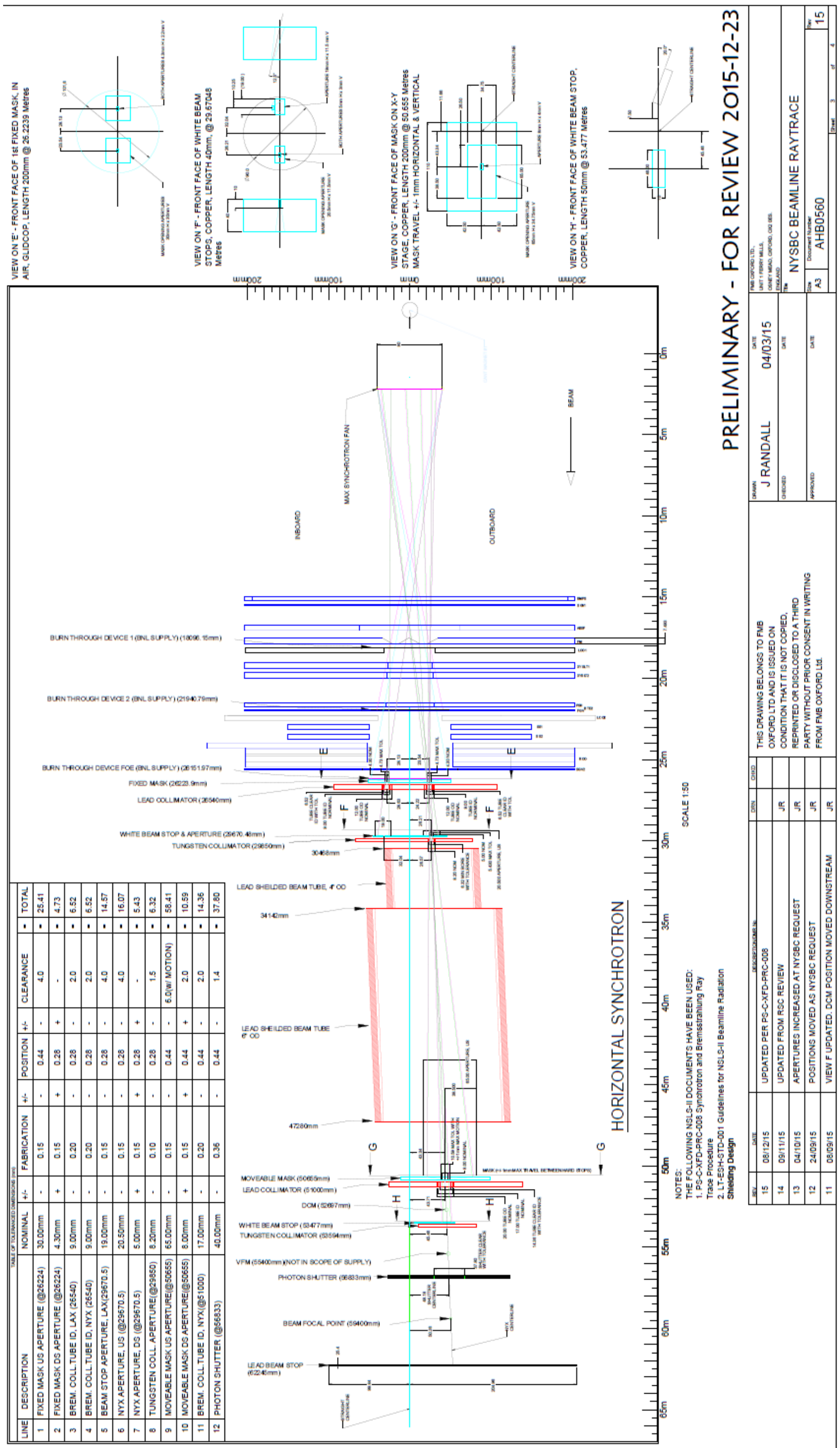


Figure 6-18. Horizontal Synchrotron Ray Trace (Sheet 3)

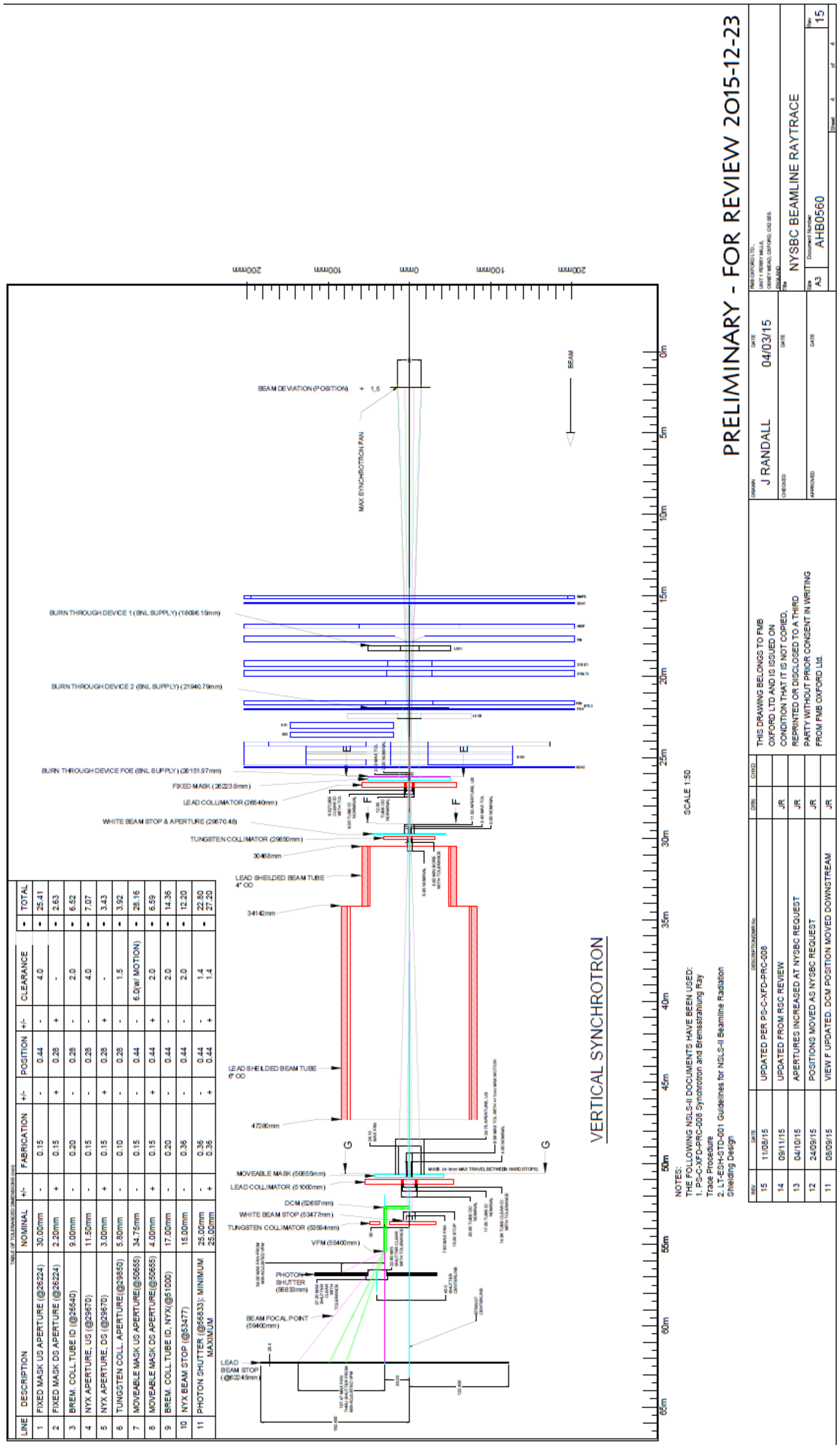


Figure 6-19. Vertical Synchrotron Ray Trace (Sheet 4)

6.6 Vacuum System

NYX vacuum system was developed following the guidelines in “Standard Technical Specifications for NSLS-II Beamline Components” and involved acquiring new equipment along with repurposing viable equipment from our prier beam line efforts on NSLS.

The Beamline will be UHV (NSLS-II ring vacuum) from the front end isolation valve located at the ratchet wall to the beginning of the end station hutch were a Beryllium window will Isolate the vacuum system for the remainder of the photon transport. This vacuum system includes nine VAT series 10 and series 48 gate valves, sizes DN63 and DN100, along the beamline transport resulting in nine individual vacuum sections that can be independently isolated. The beamline is serviced by thirteen ion pumps ranging in size from 30 l//s to 500 l/s making up a mix of conventional and differential style pumps. Seven Gamma Vacuum Digital MPC’s are used for Ion Pump control and monitoring. Vacuum instrumentation includes ten convection enhanced Pirani series 317 gauges for pressure reading from atmospheric pressure down to 1x10^-3 Torr and seven cold cathode series 422 gauges for pressure measurements from 10^-3 Torr to <10^-10 Torr. MKS series 937b gage controllers are used to display and transmit vacuum status. Beamline vacuum integrity will be verified with the Hiden Residual Gas Analyzer model HAL101. A total of six MDC 420035 burst disks are included for incorporation in all vacuum sections housing water and or LN2 cooled components to mitigate over pressure scenarios due to possible coolant-to-beamline vacuum leaks. All metal 1.5“ right angle valves are incorporated in each vacuum section between gate valves for rough vacuum pumping of the isolated sections in preparation for the start of ion pump operation. Table 6-6 summarizes the assortment of ion pumps and VAT valves used throughout the beamline.

Table 6-6. Ion Pump and Gate Valve List

Ion Pumps			Vat Gate Valves		
Qty.	Size	Type	Qty.	Size	Type
2	30 l/s	differential	1	DN 63	series 10
1	120 l/s	differential	2	DN 63	series 48
1	150 l/s	conventional	5	DN 100	series 10
3	220 l/s	differential	1*	DN 100	series 48
1	250 l/s	conventional			
3	300 l/s	conventional			
2	500 l/s	conventional	*Ratchet Wall Valve		

The vacuum system components described in this section are distributed throughout the beamline in the A hutch, white beam transport section and C hutch component systems. The first two vacuum sections reside in the A hutch, illustrated in the following Figure 6-20. The very first vacuum section includes a Residual Gas Analyzer as well as the more standard Pirani and Cold Cathode vacuum gauges to verify vacuum integrity prior to opening the beamline ratchet wall gate valve to the NSLS-II ring vacuum. The white beam transport section is next, extending into the C hutch as shown in Figure 6-21.

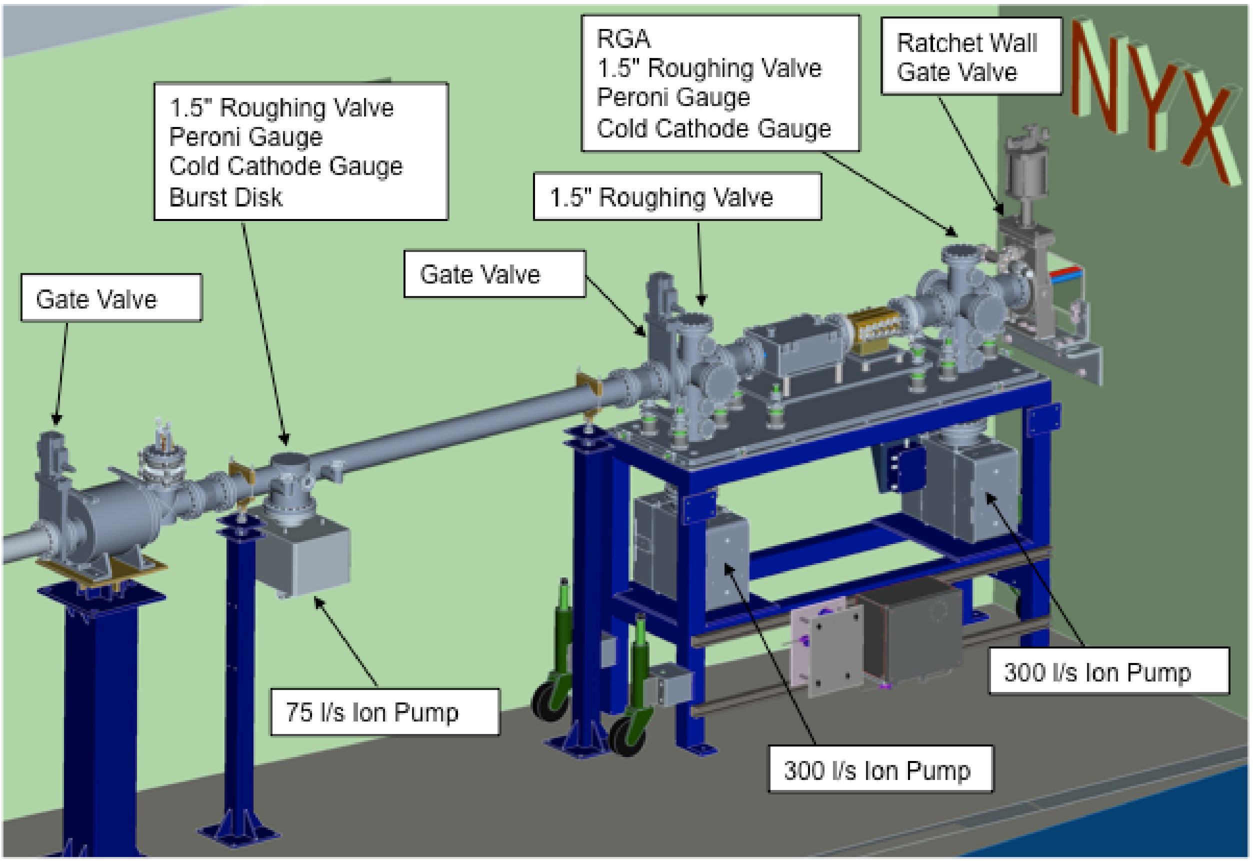


Figure 6-20. A Hutch vacuum components

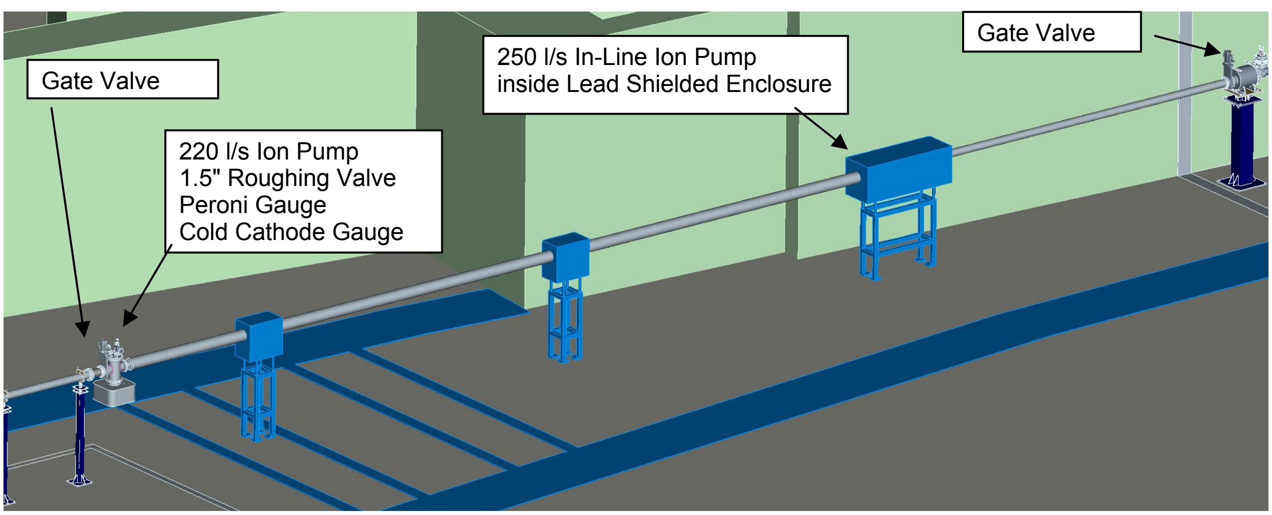


Figure 6-21. White-beam transport vacuum components

The remaining six vacuum sections serviced by the components outlined in this section reside in the C hutch. As indicated in Figure 6-22, the components are distributed throughout the sections enabling the isolation, venting and pumping of each section independently.

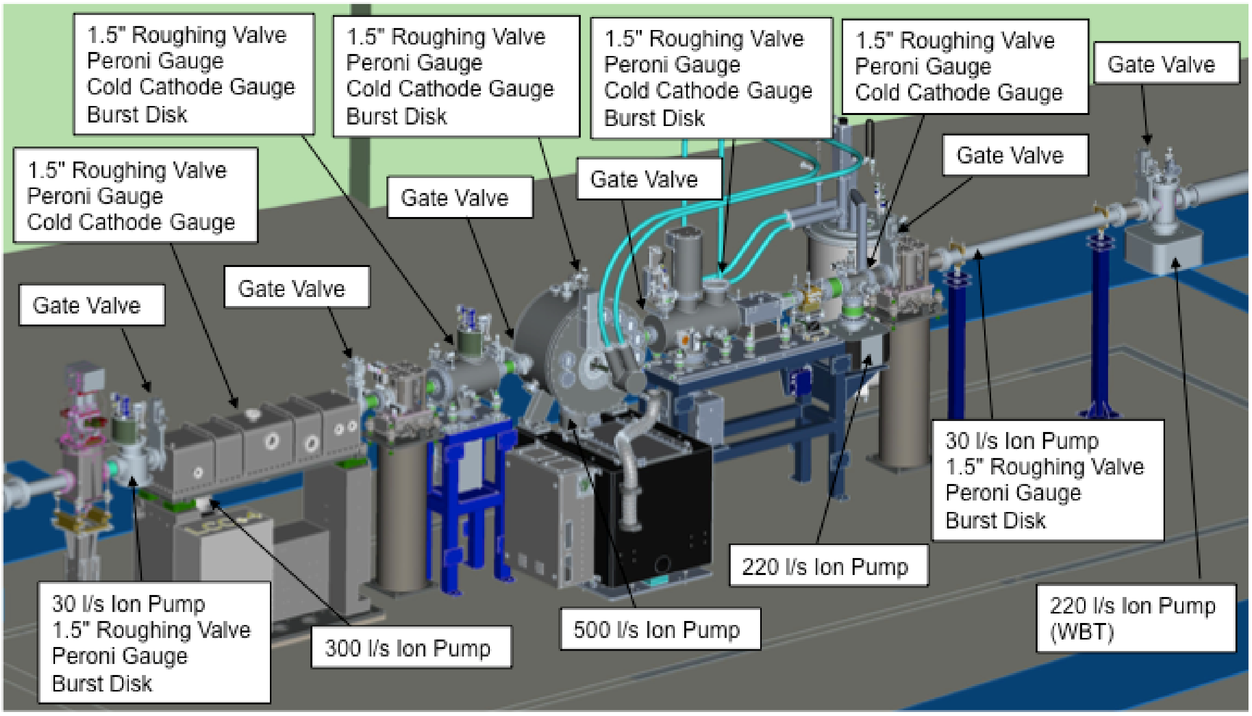


Figure 6-22. C Hutch Vacuum Components

7. Photon Delivery System

8. End Station Instrumentation

9. Beamline Controls

9.1 General Description

9.1.1 Hardware Configuration

NYX uses Galil DMC-4080 advanced motion controllers to control NYX the beamline photon delivery system and the experimental station. It takes care of all the motion controls, most I/Os, temperature monitoring and analog input. The Galil motor amplifiers are built into the controller. We embedded the Galil controllers in custom-built control cabinets located near each of the major beamline and endstation components. The advantage of such a configuration is that it eliminates long motor and encoder cables to the motor amplifier and controllers. The main control PC communicates to the Galil controller through ethernet.

9.1.2 Software Plan

Blu-Ice is a graphical interface to a Distributed Control System (DCS) for crystallographic data collection at synchrotrons. It was designed and developed by SSRL, and it is used at crystallography beamlines worldwide. It is proven and has the reputation of being elegant and user friendly.

NYSBC used Blu-Ice at NSLS beamline X4 in the last five years of its operation. It controlled all major components of the X4 endstation. Our experience with Blu-Ice can be summarized as follows:

1. User friendly. Blu-Ice is easy to use. The GUI is self-explanatory. The user can master beamline control and data collection in a very short time. Our users love it.
2. Central control. All the beamline control and data collection is under one GUI, unlike much beamline software, where the user needs to open multiple windows. It's less confusing.
3. Multi-user. It controls or monitors the data collection both locally and remotely. Blu-Ice can be accessed by many users at the same time to monitor their experiments. Users are able to view all processes of the experiments, but only one user is allowed to control the experiments.
4. Security. The authentication server takes care of the user login security. Each user can have their own user name and password to access the software and collect their data securely.
5. Reliability. We have had very smooth operating experience since using Blu-Ice, and there is rarely a need to reboot or restart, unlike with our previous control softwares.
6. Efficiency. The experimental processes are standardized. The user can simply use data collection number tabs to setup multiple data collections and run them continuously.
7. Many experimental procedures and scripts have already been developed for beamline control; we can easily use them or modifiy them. This saves us a lot of time in development.
8. Easy to expand and upgrade. New hardware can be easily added into the system. SSRL provides many useful templates. We also have full access to the Blu-Ice repository so that we can upgrade to the newer version of the Blu-Ice whenever it's available.
9. Excellent support from SSRL. The people in the SSRL control group have been extremely supportive over the last five years, making themselves available for us if we need help.

Blu-Ice References

[1] T.M. McPhillips, S.E. McPhillips, H.-J. Chiu, A.E. Cohen, A.M. Deacon, P.J. Ellis, E. Garman, A. Gonzalez, N.K. Sauter, R. P. Phizackerley, S.M. Soltis and P. Kuhn Blu-Ice and the Distributed Control System: software for data acquisition and instrument control at macromolecular crystallography beamlines. J. Synchr. Rad., 2002. *J. Appl. Cryst.* **9**, 401-406 (2002).

[2] A. González, P. Moorhead, S.E. McPhillips, J. Song, K. Sharp, J. R. Taylor, P.D. Adams, N.K. Sauter and S.M. Soltis. *Web-Ice*: integrated data collection and analysis for macromolecular crystallography. *J. Appl. Cryst.* **41**, 176-184 (2008).

[3] Y. Tsai, S.E. McPhillips, A. Gonzalez, T.M. McPhillips, D. Zinn, A.E. Cohen, M.D. Feese, D. Bushnell, T. Tiefenbrunn, C. D. Stout, B. Ludaescher, B. Hedman, K.O. Hodgson and S.M. Soltis. AutoDrug: fully automated macromolecular crystallography workflows for fragment-based drug discovery. *Acta Cryst. D* **69**, 796–803 (2013).

9.2 Major Hardware Components

9.2.1 Components and Controlling Connections

End Station	Vendor
• Diffractometer	Crystal Logic
• Auto Mounter Robot	Crystal Logic
• Dual Mode detector	ADSC
• Camera Server	Axis
• BPM System	BNL/Libera
Optics	
• Monochromator	Oxford FMB
• Mirror	Irelec
Insertion Device	
• Undulator	X25-NSLS
Control Computer	
• Intel based PC	

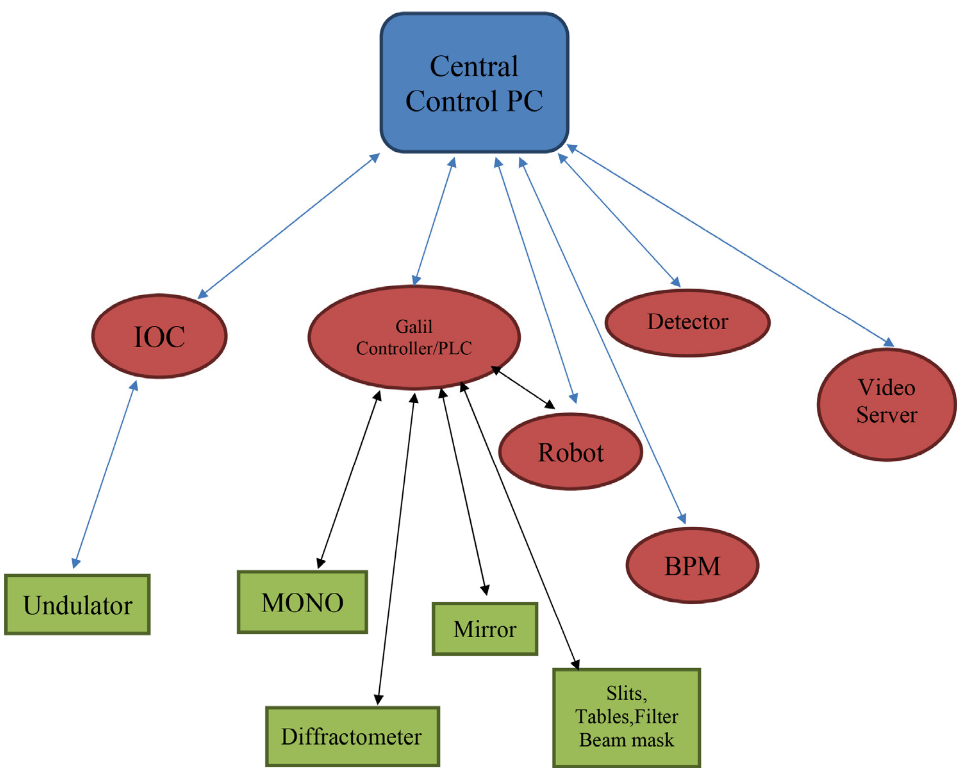


Figure 9-1. Connection schematics

9.2.2 Device and Interface List

Device Name	Function	Specification	controlled by	Interface	Protocol Name
GUI PC	User interface to control experiment	Intel Processor base PC	-	-	-
Galil Motor Controller	Control motors and encoders		GUI PC	eth	proprietary
Galil Pocket PLC	Analog Input Timer and Counter		GUI PC	eth	proprietary
Mean Well	Power Supply	24V-48V		eth	
Galil SCB 48316	K thermal card for reading motor temperature sensor	Galil	Galil	eth	analog
Renishaw	Encoder		Galil		quadrature
MicroE Mercury2000-MV	Encoder		Galil		quadrature
Phtron	Vacumm Motors		Galil		
PM170	McLennan servo driver		Galil	-	-
M543E	Mclennan Servo Motor for Phi		Galil		
Stogra SM56.2.18.J3	Steppers for Mirror		Galil		
VEXTA PK266M-03A	NSLS2 Stage		Galil		
Nanotec 2 phase	Stepper for 4 Jaw slits		Galil		
NEMA 17-4018	Stepper for Beam mask		Galil		
HaydonKerk 57H4A 3.25	Steppers for Crystal logic		Galil		

050 ENG 0716	diffractometer				
Oriental Motor AR66MA-N10-3	Stepper for Crystal logic table		Galil		
Lin WO-211-18-02D	Steppers for camera and sample stage		Galil		
FaulhaberAM15A0046	Steppers for Slits		Galil		
McLennan 23HSX206	Stepper for filter		Galil		
LS	Limit switches for motion	-	Galil	5v DIO	TRUE/FALSE
Physik Instrument P-841-30	Stain gauge for Mono Benders		Galil	0-10V	
PI E-500 Modular Piezo controller	Control Piezo		Galil	0-10V	
Infinity Strain Meter	Mirror bending force reader		Galil	0-10V	
IOC	Hosts PVs, integrates connected devices	NSLS2 compliant	GUI PC	eth	CA
PLC	Read temperature, implement Interlock logic	Allen Bradley Compact Logix	IOC	eth	EtherIP
GB	DeltaTau Geobrick IMS 2 Motion controller	BNL compliant	IOC	eth	DeltaTau proprietary

9.3 NYX Beamline Control System

The NYX control system has three components: the general user interface (GUI), the distributed control system server (DCSS) and the the distributed hardware server (DHS).

Blu-Ice provides the GUI for NYX beamline controls and it thereby interfaces with the DCSS and on to hardware elements through the DHS/EPICS Gateway (Figure 9-2).

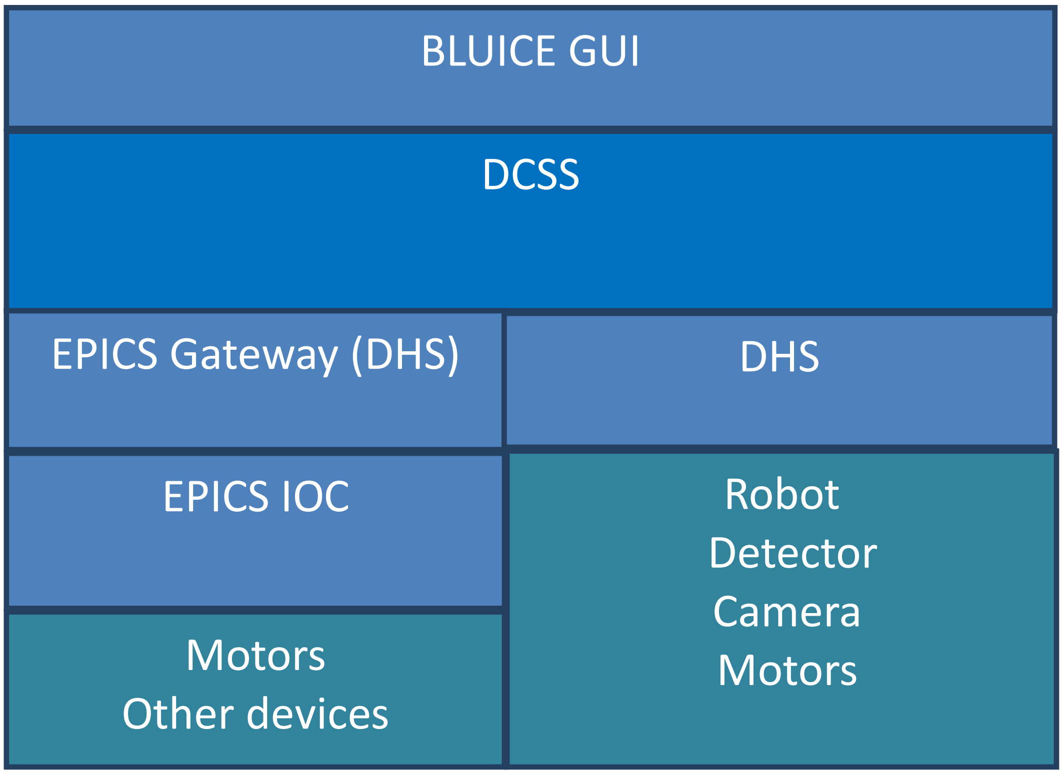


Figure 9-2. Blu-Ice Control Block Diagram

9.3.1 DCSS

Distributed Control System Server (DCSS) is a centralized sever. It handles the communications between GUI and DHS. It has two basic functions:

1. **Message handler:**

   It delivers messages from Blu-ice GUI to DHS to control the devices and broadcast messages from DHS to all the GUI

   GUI ←→ DCSS ←→ DHS ←→ Device

2. **Script Engine:**

   It also is a special Client called “self” for both DCSS and Blu-Ice GUI. It can receive all the messages from DHS and access all the DHS. It can execute the user defined scripts which controls devices.

   The DCSS is running in the Central Control PC.

9.3.2 DHS

Distributed Hardware Server is a program which talks directly to devices. It accept DCS messages and controls a piece of hardware directly. It reports the status of the device to the DCS.

9.3.3 Blu-Ice DCS Framework

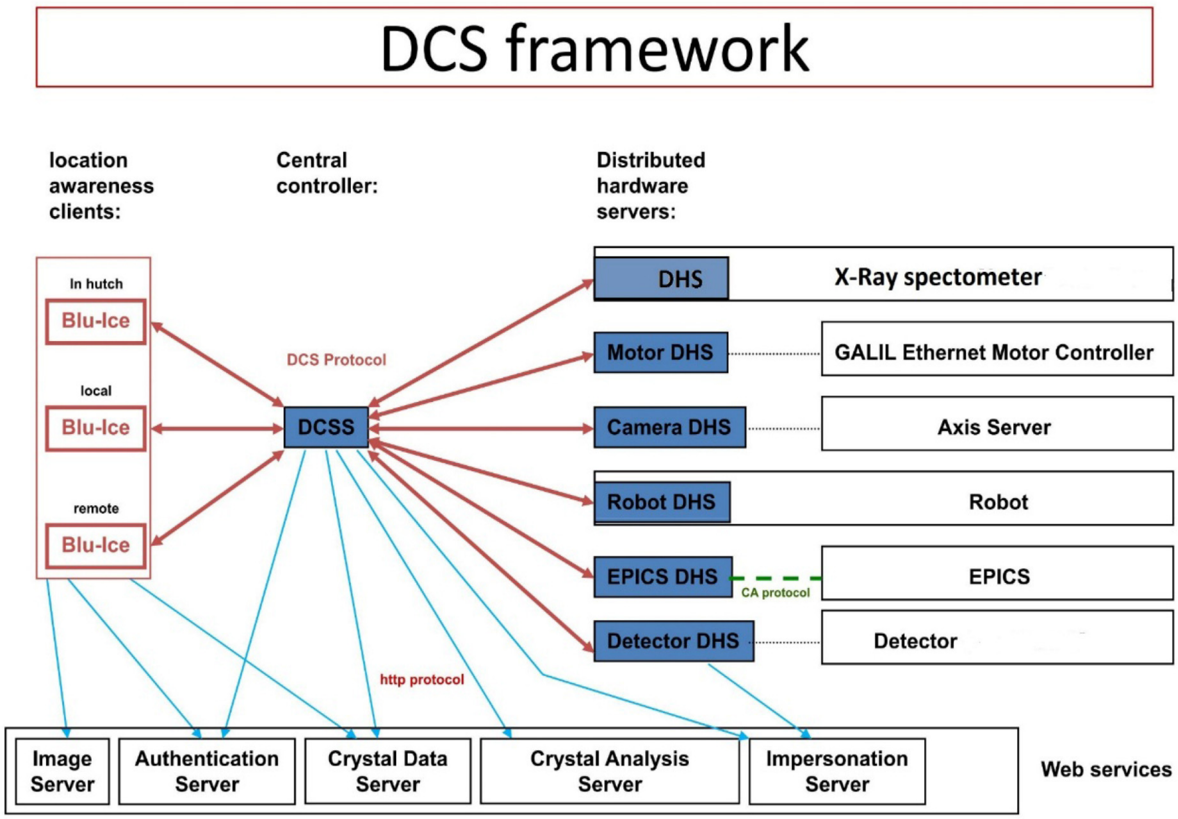


Figure 9-3. DCS Framework. This figure is courtesy of SSRL

Features of the framework include the following:

- **Central Control**
- **Security**
    - **Authentication Server**
    - **Impersonation Server**
- **Web-Ice service** [Reference 2]
    - **Crystal Information Server**
    - **Crystal Analyze Server**

9.3.4 Blu-Ice GUI

9.3.4.1 Hutch Tab

The **Hutch Tab** (Figure 9-4) allows the users to adjust various parameters for data collection.

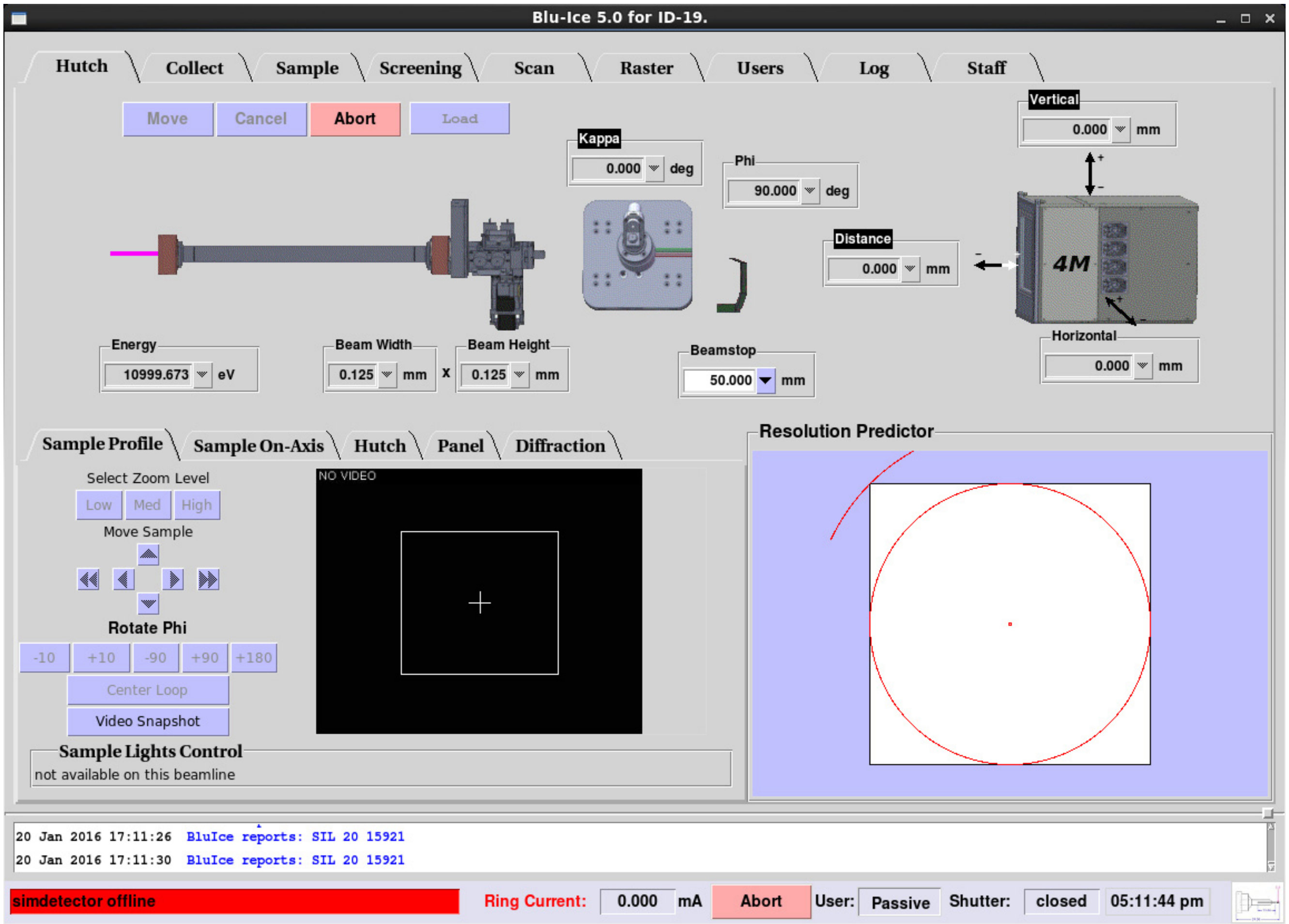


Figure 9-4. Hutch Tab

9.3.4.2 Data Collection Tab

The **Collect Tab** (Figure 9-5) is used for collecting test images and complete monochromatic, SAD and MAD data sets. Multiple run windows can be set up by creating additional Run Tabs.

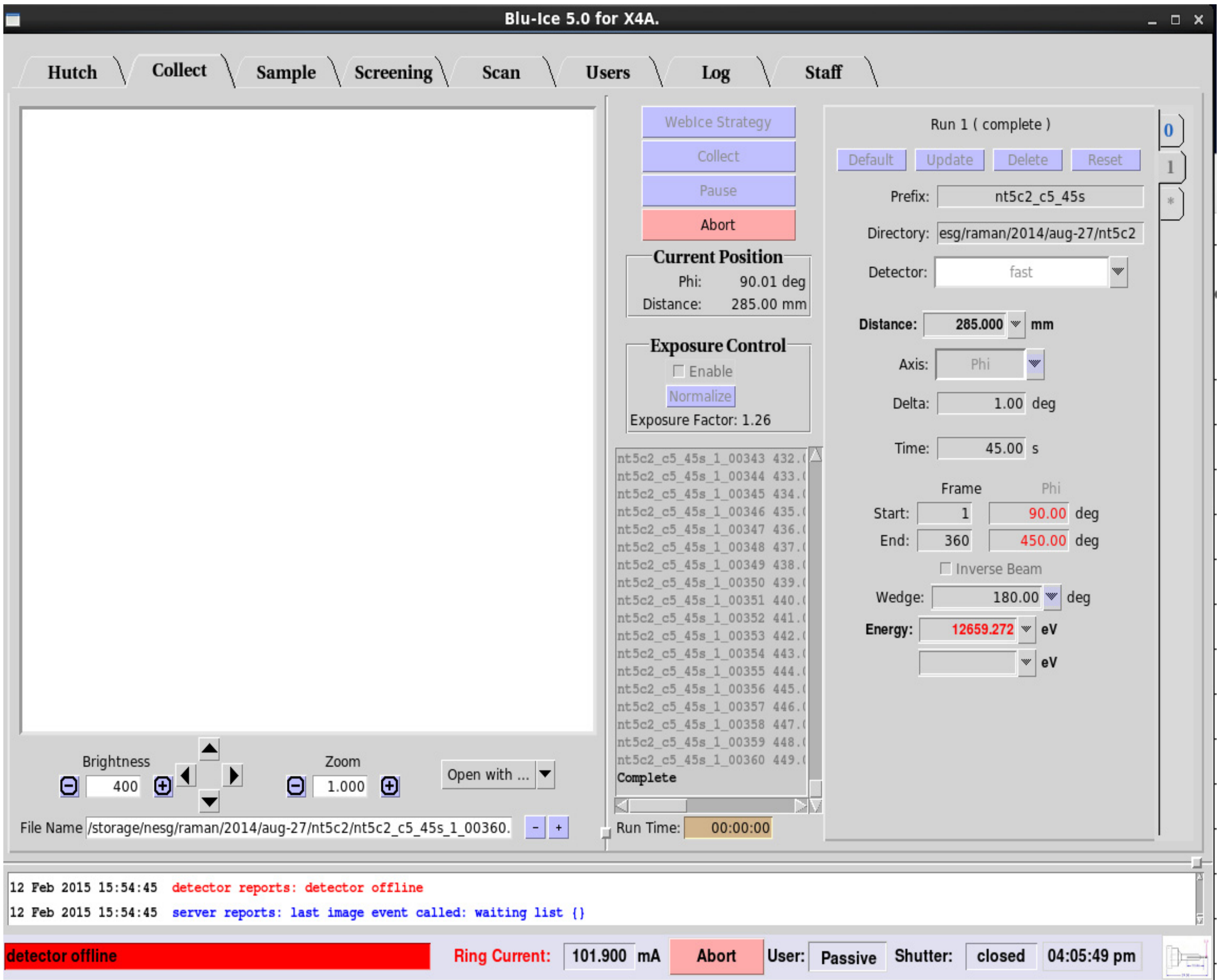


Figure 9-5. Data Collect Tab

9.3.4.3 Sample Tab

The **Sample Tab** (Figure 9-6) allows the user to prepare the sample for data collection: The user can change the sample camera zoom and adjust the sample position, change the beam size, mount and dismount additional samples with the robot, remove ice, and anneal the crystal.

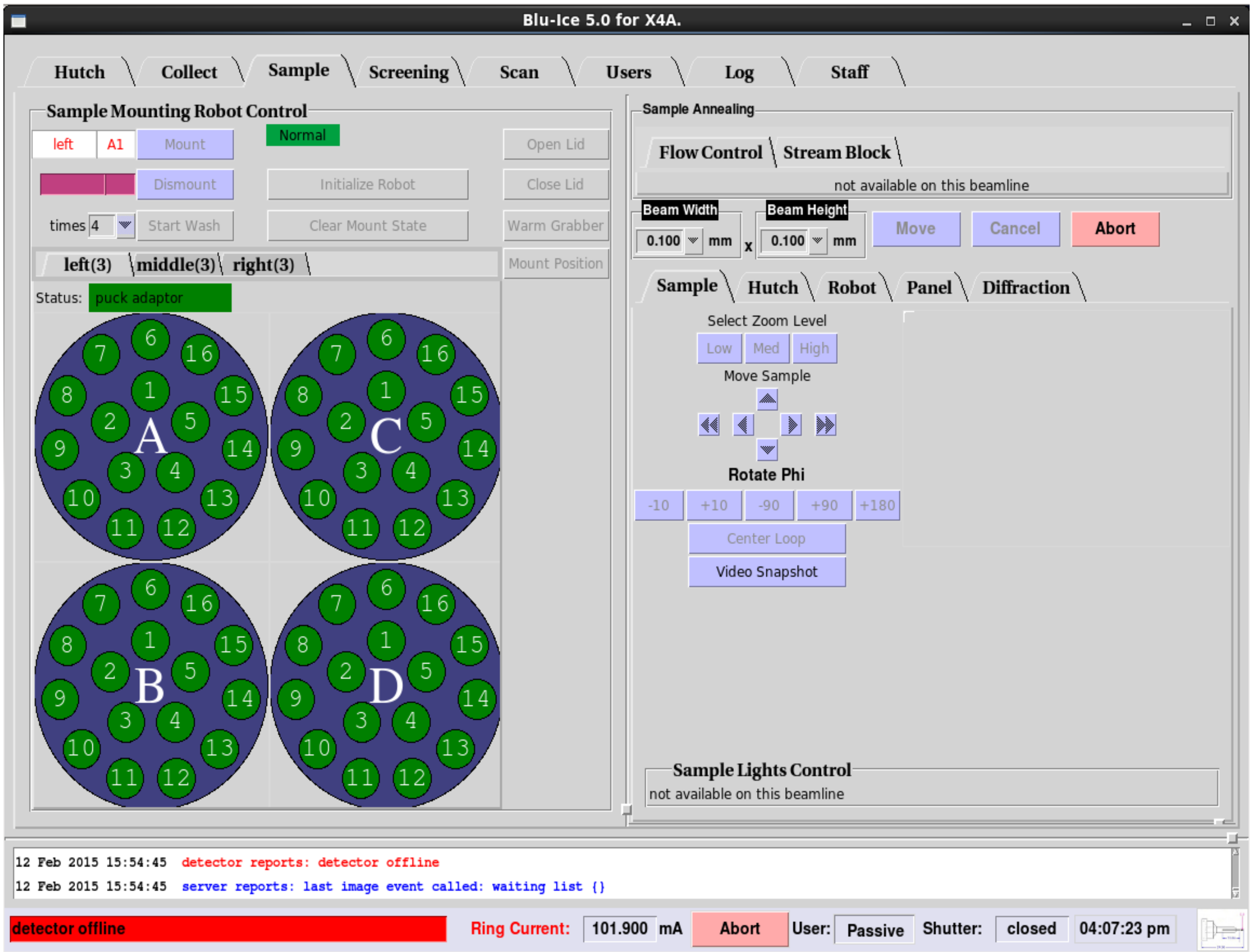


Figure 9-6. Sample Tab

9.3.4.4 Screening Tab

The **Screening Tab** (Figure 9-7) provides an interface for automatically screening samples. With this interface, the user selects multiple samples of interest from an embedded spreadsheet and defines the actions to be performed on each sample. Once started, the interface can run with minimal supervision until all of the samples have been screened identically.

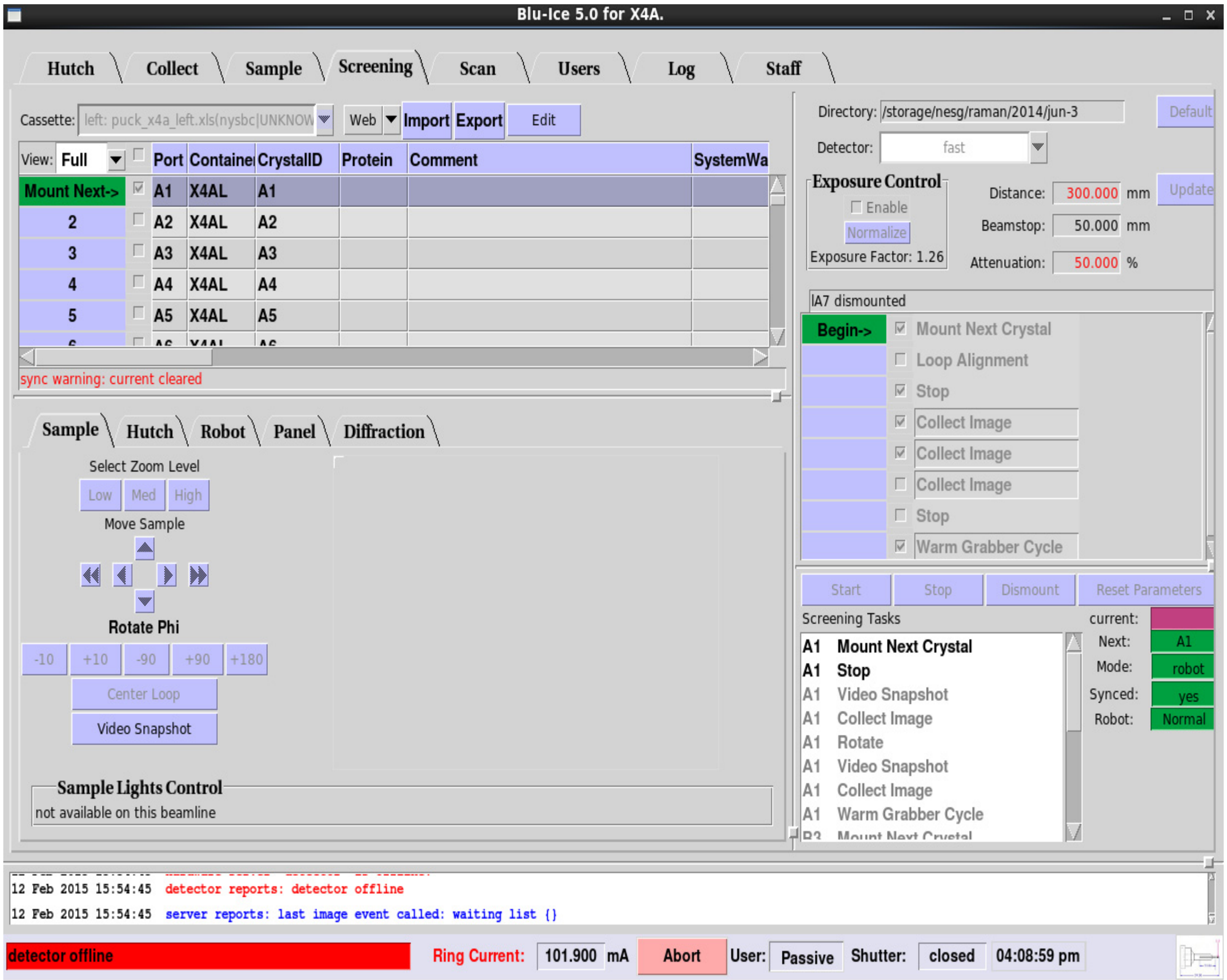


Figure 9-7. Screening Tab

9.3.4.5 Scan Tab

The **Scan Tab** (Figure 9-8) is used for energy and excitation scans. The energy (MAD) scans are used to select the appropriate wavelengths for anomalous dispersion experiments (optimized SAD and MAD). The excitation scan is useful to identify and verify the presence of anomalous scatterers in the sample.

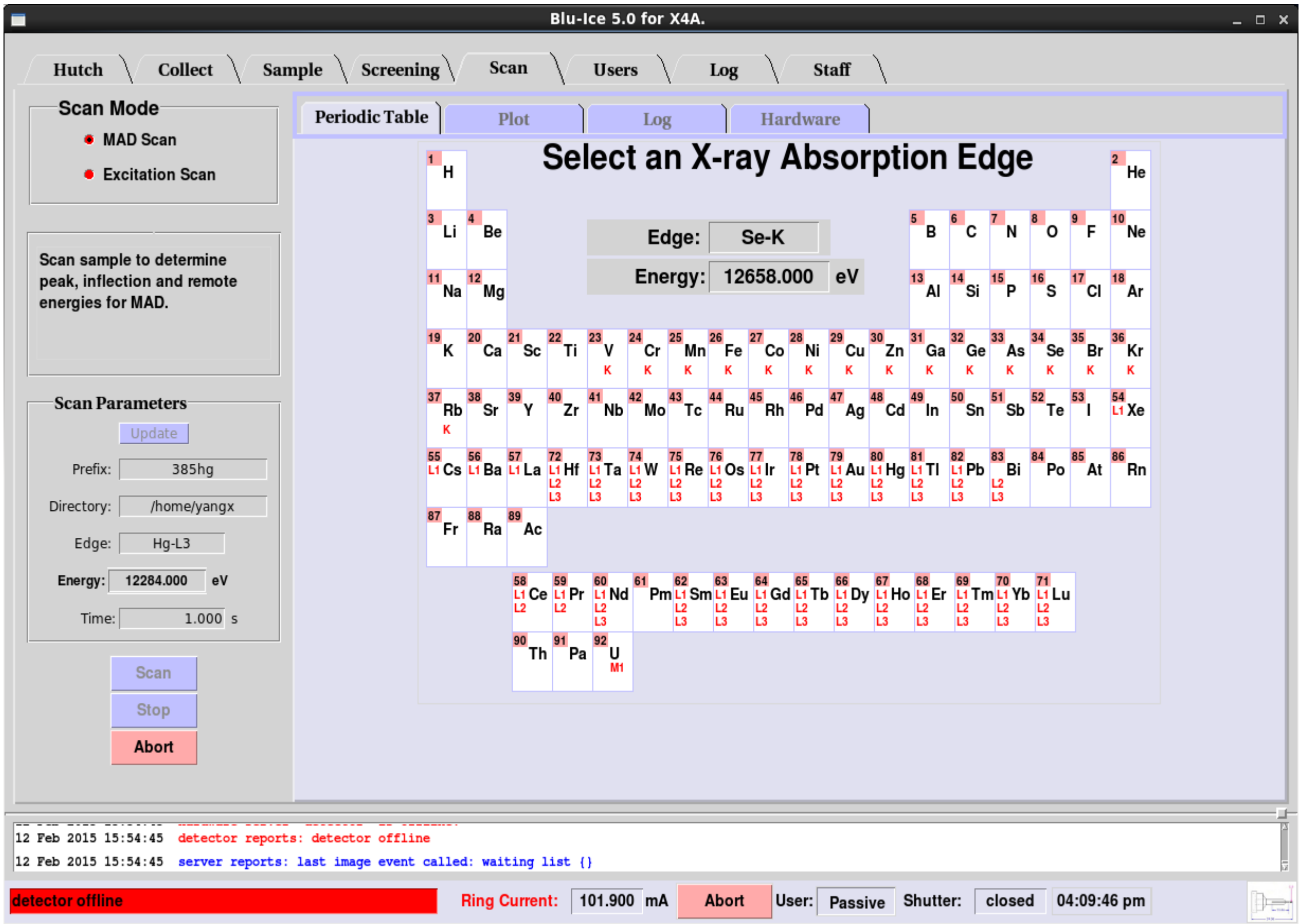


Figure 9-8. Scan Tab

9.3.4.6 Raster Tab

The **Raster Tab** (Figure 9-9) allows the user to search for and align crystals based on low level diffraction. This is carried out by defining a 3-dimensional raster, recording low level diffraction images, and then processing them with "Spotfinder" using a specialized input file tailored for weak low resolution spots and detector characteristics.

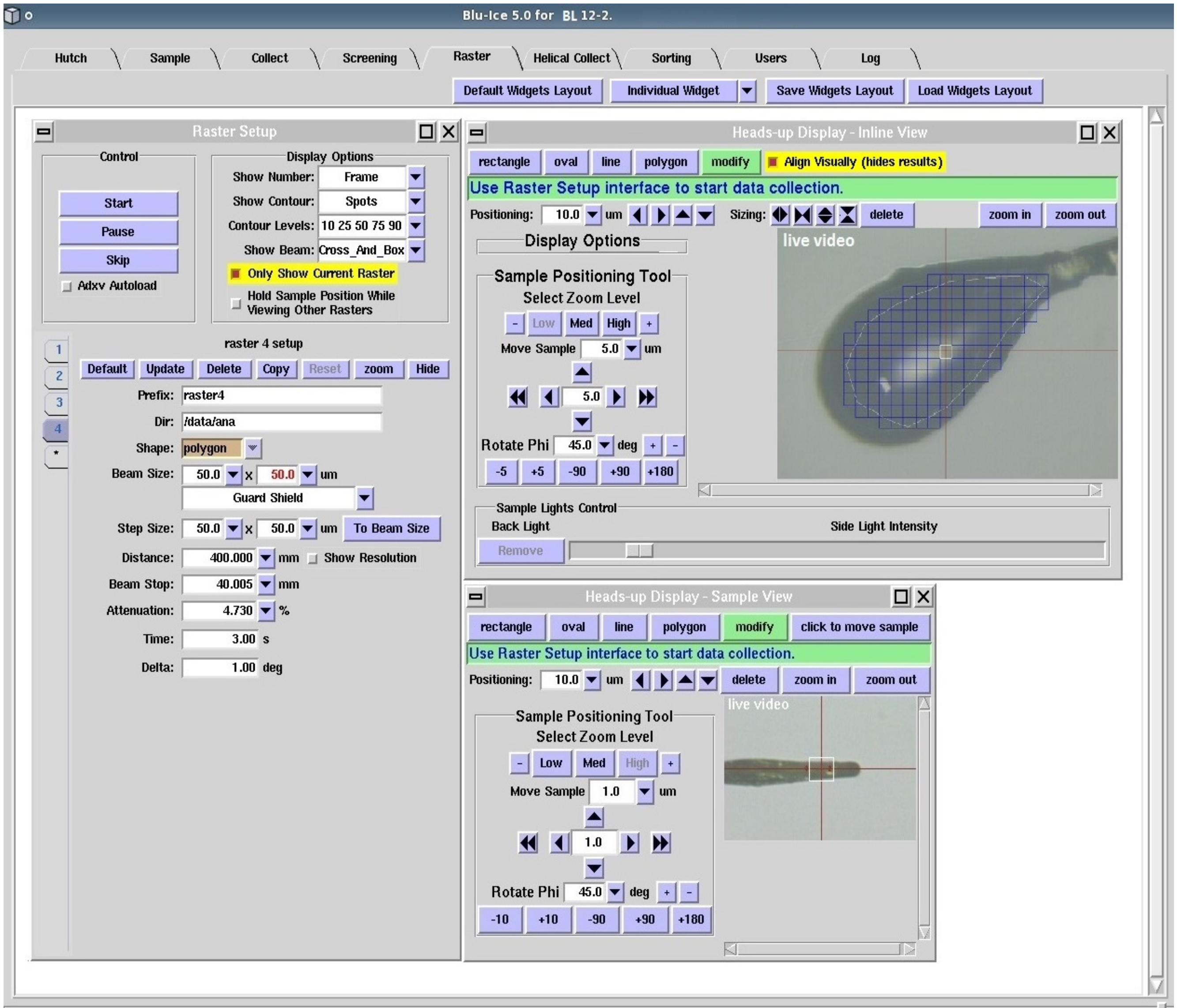


Figure 9-9. Raster Tab. This figure is courtesy of SSRL

9.3.4.7 Helical Collection Tab

The **Helical Tab** (Figure 9-10) allows collection of oscillation data while translating the crystal along the spindle axis: The software collects one oscillation image before moving the crystal to a new position and collecting a new image, with the new oscillation starting where the previous one ended.

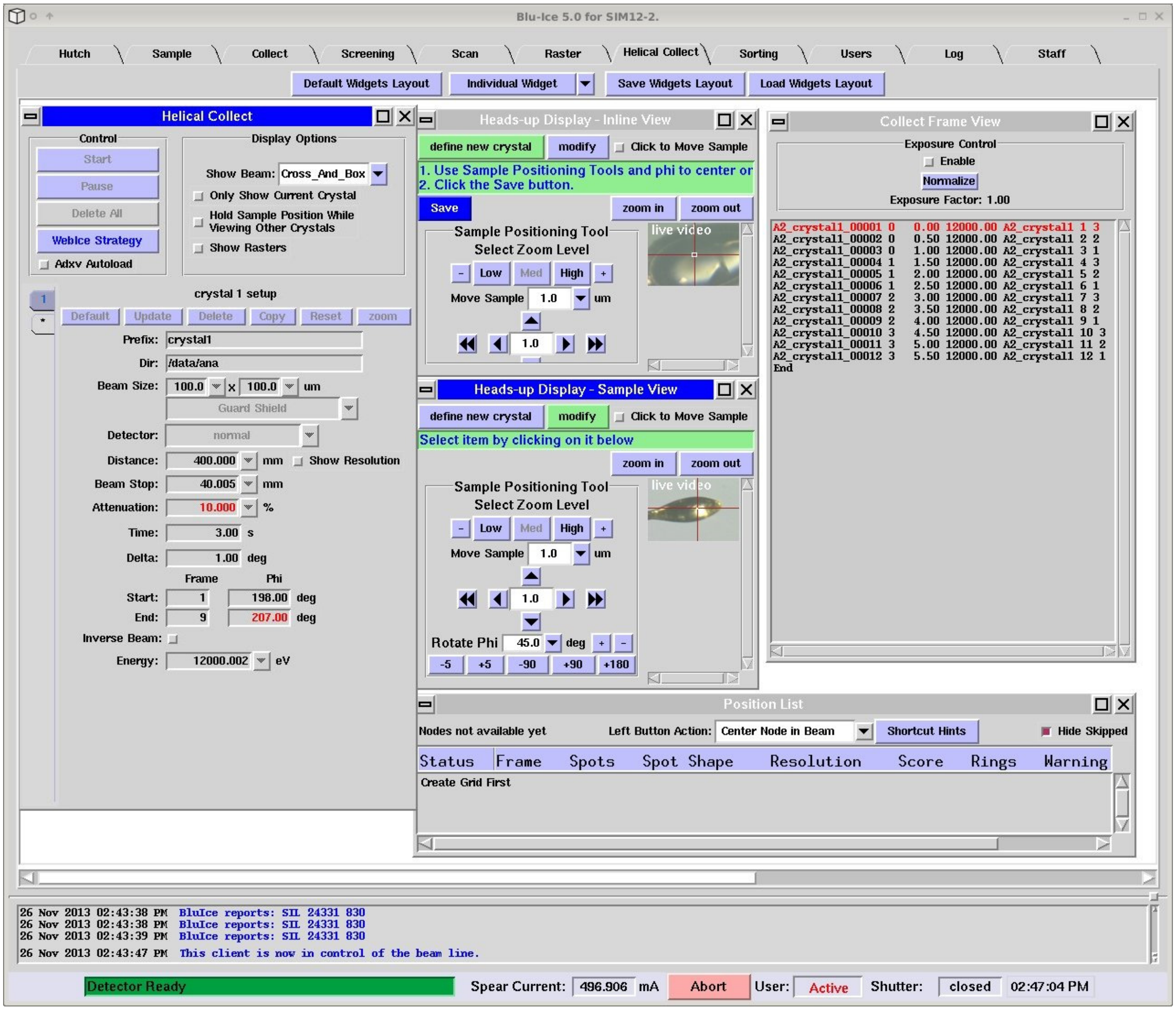


Figure 9-10. Helical Collection Tab. This figure is courtesy of SSRL

9.3.4 Summary on Blu-Ice

- Least risk (transition from X4 to NYX); Easy to manage for a small group with limited resource.
- Minimal development work required.
- Good support from SSRL.
- Takes advantages of other software associated with Blu-Ice like Web-Ice [Reference 2] and Autodrug [Reference 3].

9.4 Local Control Cabinets

There are four local control cabinets designated for the NYX beamline. There is an additional local control cabinet for the LAX line.

Each local control cabinet, as shown in Figure 9-11, contains motor controllers with drivers and ancillary components for up to 12 motions. Each cabinet will be mounted near the motors it drives, so motor and encoder cables will be kept short, as well as any other cables such as thermocouple. Each cabinet has its own internal DC power supplies, so the cabinet will need only a single AC cord for power, and an ethernet line for communications.

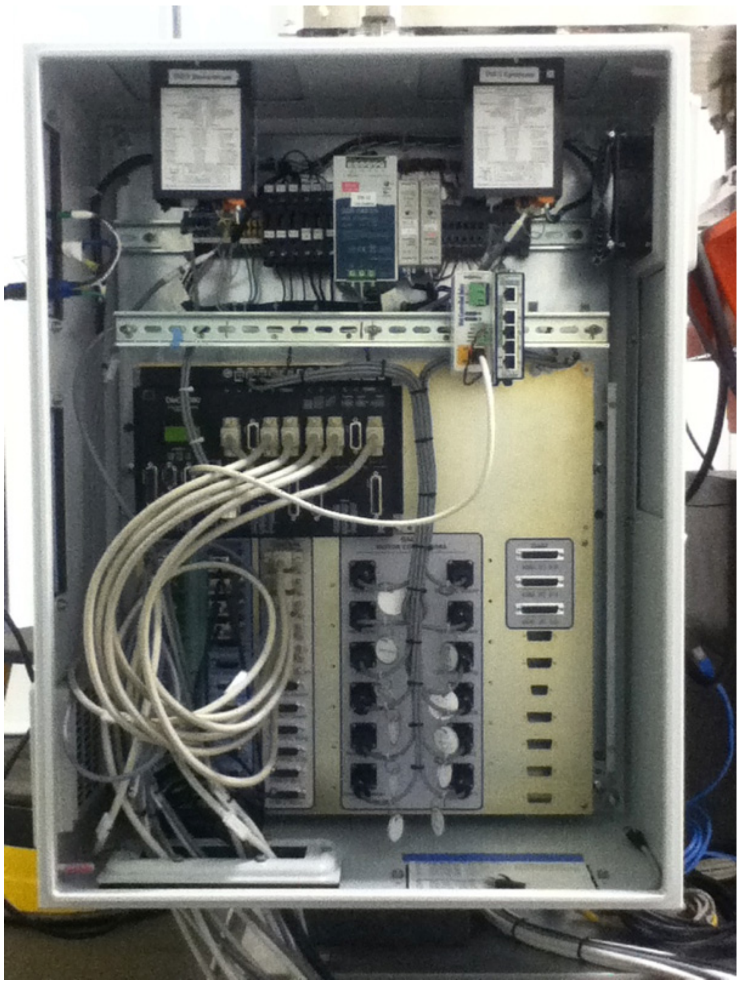


Figure 9-11. An NYX Local Control Cabinet

Locations:

For the NYX line, there are four designated cabinets: LCC2, LCC3, LCC4, and LCC5.

LCC2 will be mounted on the upstream C-hutch wall and will control beam position monitor 1, an aperture, and filters.

LCC3 will be mounted in the C-hutch on the monochromator plinth and control the monochromator motions as well as beam position monitor 2.

LCC4 will be mounted in the C-hutch on the mirror plinth, and will control the motions of the mirror as well as the 4-jaw slits and beam position monitor 3.

LCC5 will be mounted in the D-hutch on the pathway stand, and will control the four motions of the pathway.

The control cabinets are 600mm x 800mm x 300mm, and are manufactured by Hoffman. They are sealed with high-density foam gasketing on all removable panels and the door, and use Roxtec glands for cable entry. There is a fan and a passive vent.

The contents of each cabinet are arranged around a large aluminum patch panel, which serves to mount the Galil motor drivers, as well as all the connectors needed to interface the Galils with the motors. In addition, each cabinet has two DIN rails to mount DIN components.

The large aluminum panel on which the Galil drivers are mounted acts as an additional heat sink. Then, forced air cooling removes the heat from the cabinet. There is a passive vent on the lower right of the cabinet, and a five inch fan blowing air out on the upper right of the cabinet, drawing air across the Galils.

The electronic components common to every LCC are:

Galil DCM-4080 – 8-motion controller/driver

Galil DCM-4040 – 8-motion controller/driver

Meanwell SDR-240-24 - 10amp 24vdc power supply – for Galil and motor power

(2) Meanwell MDR-20-24 - 1 amp 24vdc power supplies – for Netswitch and Web-relay

Stride Netswitch SE-SW5U-WT - to distribute ethernet within the cabinet

Xytronix WebRelay X-WR-1R12-1I5-I to enable a remote shutdown function

Location-specific components:

Also, there are a few location-specific components, such as the readouts for the strain gauges on the mirror (LCC4), and the crystal heater with its power supply for the monochromator (LCC3).

Components specific to the monochromator cabinet, LCC3, are:

Jumo Ctron crystal heater and power supply

Components specific to the mirror cabinet, LCC4, are:

(2) Rockport INFS strain gauge readouts for the mirror bender

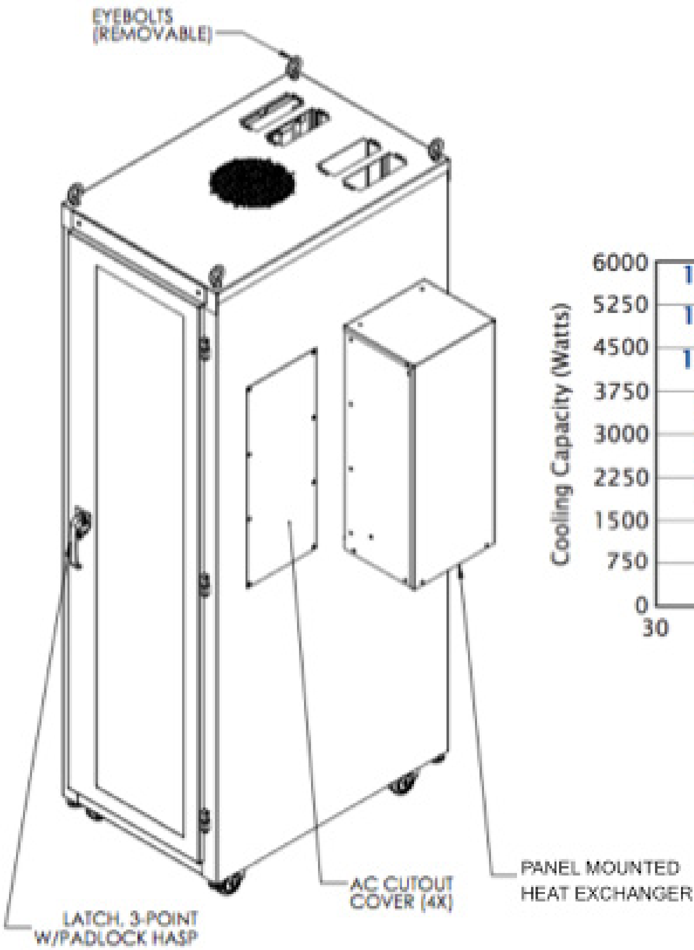
In each cabinet there is a power distribution harness for AC and DC which uses DIN terminal blocks and fuses. The cabinet has a main fuse, and each AC powered device within the cabinet has its own fuse, this includes the DC power supplies as well as the fan. In addition, each DC powered item has its own fuse, this includes each Galil drivers as well as the DIN components such as the Netswitch.

The patch panel:

In brief, the Galil groups its motor output on one connector (per motion), and its limit and encoder together on a second connector, whereas we need a different grouping: we use the motor and limit signals grouped together on one connector (per motion), and the encoder on a second connector. So, the panel’s main patch function is to provide this regrouping for twelve motions.

9.5 Equipment Racks

There are eight equipment racks distributed along the NYX beamlines. The configuration adopted by NYX consist of commercially available NEMA-12 racks integrated with industry standard pannel mounted heat exchangers (Figure 9-12). This configuration is similar to what was implemented by the NSLS-II accelerator group for more than 800 racks used to enclose accelerator power supplies and instruments. The panel mounted heat exchangers are attached to the side of each group of racks avoiding over head water connections and eliminating equipment damage due to water leaks. Conforming to NEMA-12 restricts air infiltration which provides automatic fire saftey by oxygen starvation in the event of equipment failure. To manage the loss of the cooling supply water while the equipment contained in the racks are actively rejecting heat, the electrical power will be latched with power relays activaed by passive temperture alarm in each heat exchanger. The following is the distrubution of rack on NYX. One is near the A-hutch and reserved for the LAX beamline. The remaining seven are dedicated to the NYX beamline. All the racks are identical and connected in groups of two and three. Each rack has both UPS power and unconditioned power.



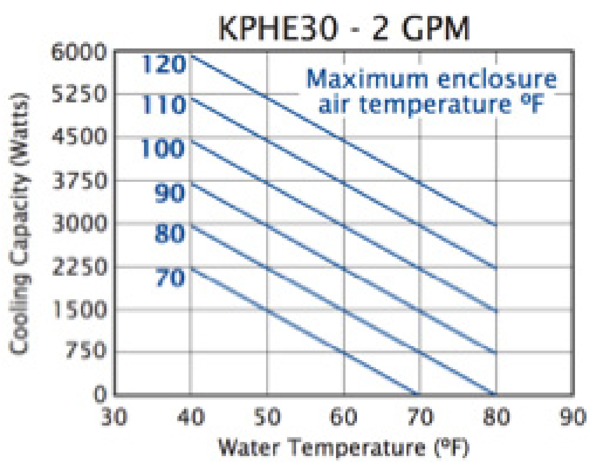


Figure 9-12. NYX Equipment Rack

NYX Rack Locations:

The racks will be distributed along the NYX beamline as shown in Figure 9-13.

There is a group of two racks on the outside end of the D-hutch that will be used for control and data collection systems and computers.

There is group of two racks on the roof of the D-hutch that will be used for Ion pump controllers, gauging controllers, and any diamond detector equipment which cannot fit inside the D-hutch.

There is a group of three racks on top of the C-hutch that will be used for Ion pump controllers, gauging controllers, and any other support equipment for the C-hutch.

There will be space available in all racks for EPS units, so they can be placed where needed.

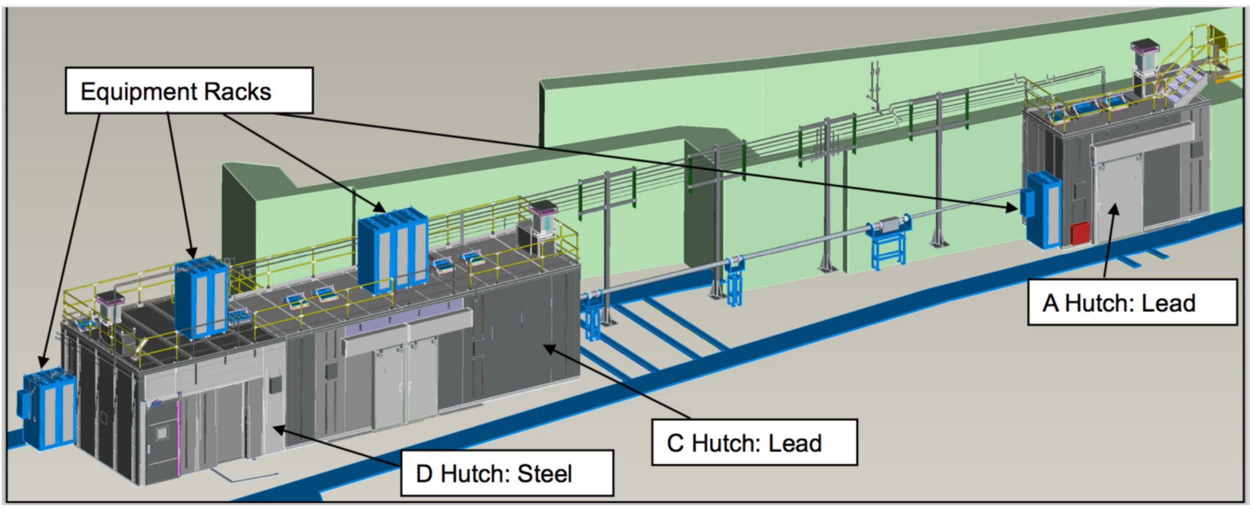


Figure 9-13. Distribution of NYX Equipment Racks

9.6 Cables and Interconnectivity

Most of the electronic control system cabling, motor, limit, and encoder, will be provided by the vendors who supply the connected equipment: Irelec for the Mirror, and Oxford for the Monochromator, Slits, Filters, and Apertures. These cables will run directly from the respective unit to the assigned local control cabinet, and will not run in cable trays.

We will be making the motor, limit, and encoder cables for the Beam Position Monitors, and for the D-hutch pathway. Cables will be constructed of PVC multi-conductor cable, with motor/limit cables being terminated at the motor side with 12 pin metal Trim-Trio connectors, and at the control cabinet/patch panel side with fifteen-pin D-sub connectors.

The local control cabinets are connected to the beamline control computer by ethernet cables. These cables will run through hutch walls and in cable trays, so will have to be LSZH.

10. Beamline Safety Systems

ACRONYMS

APPS Accelerator Personnel Protection System
EPS Equipment Protection System
ESD Emergency Shutdown
FOE First Optics Enclosure
HMI Human Interface
LAN Local Access Network
PLC Programmable Logic Controller
PPS Personnel Protection System

CONTENTS

FIGURES

10.1 Personnel Protection System (PPS)

10.1.1 Beamline Area PPS

NSLS-II will produce intense light from IR, UV, and hard x-rays. Beamlines are designed to use either the bending magnet radiation or the radiation from insertion devices located in the straight sections of the storage ring. Beamlines may have more than one station along the beamline. These stations are expected to work in parallel or sequentially. The PPS is an engineered system that provides a means to ensure that personnel are not exposed to the radiation in the beamline. At NSLS-II, the role of the PPS is specifically to protect personnel from radiation that is present only when there are stored electrons in the storage ring. The PPS is expected to monitor the various devices installed in the beamline for personnel safety and to provide emergency shutdown in case of any breach of the interlock. The PPS system, along with the required shielding in the beamlines, is expected to provide complete personnel safety during routine operation of the facility and provide protection during abnormal conditions. The following figure shows a typical system configuration, in this case for an FOE and two experimental stations, although this is designed to be easily configured to the required number of stations and beamline operating modes.

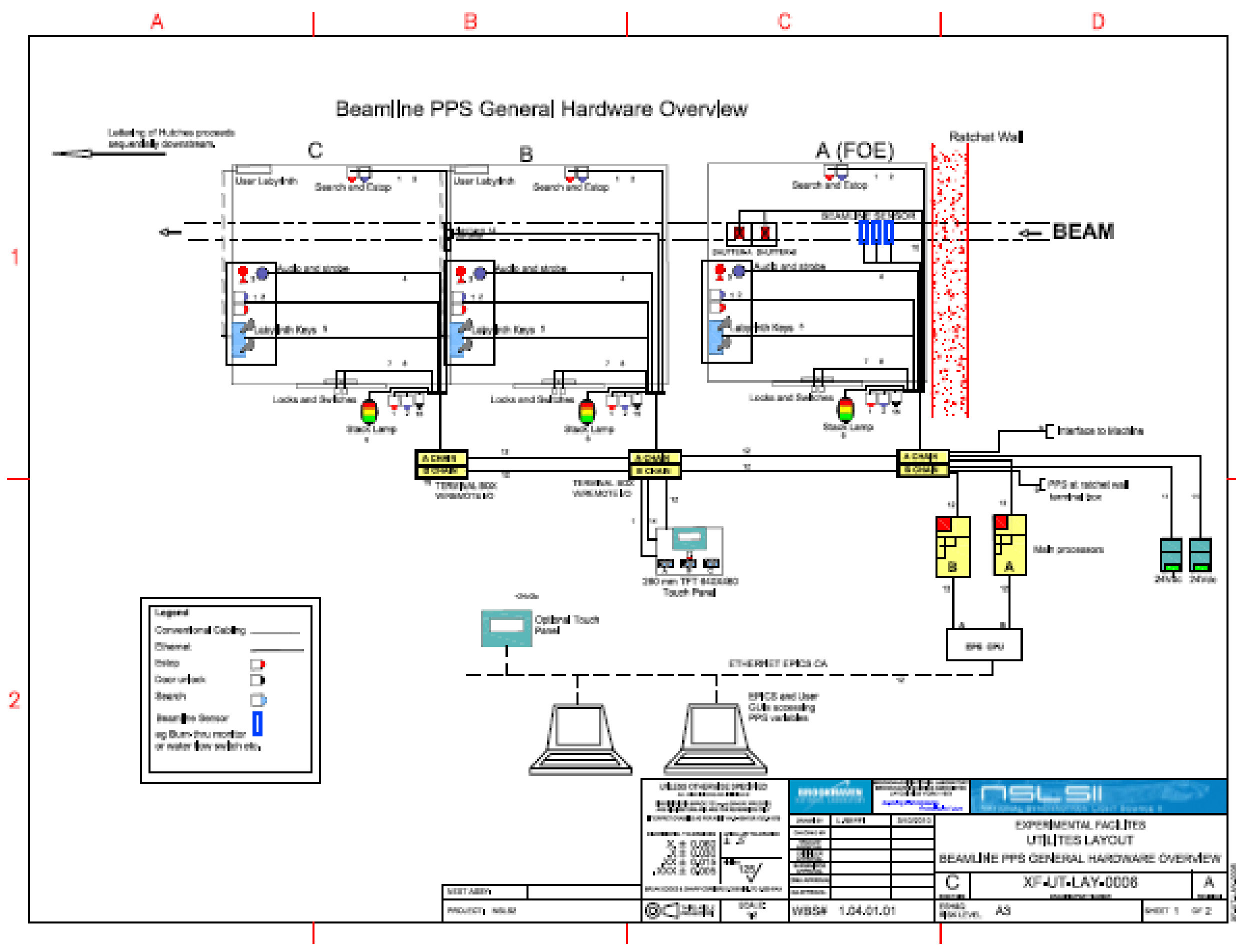


Figure 10-1X. Typical system configuration for an FOE and two experimental stations.

10.1.2 Functionality

Beamlines will consist of stations where synchrotron radiation is expected to be admitted. The beamline stations are expected to be made of lead-lined walls and roof, as appropriate for the particular radiation characteristics. These stations will house beamline optical components or beamline experimental equipment. The stations are expected to be large enough for personnel to work with the equipment inside. The beamlines will have one or more shutters based on the particular layout, which is expected to vary from beamline to beamline. However, the functionality of the shutters, from the PPS perspective, is expected to be the same and they will be monitored by the PPS. All x-ray beamlines will have shutters in the front-end area inside the storage ring shield wall. The bremsstrahlung radiation emitted by the synchrotron can only be stopped by heavy metal elements such as tungsten or lead. The heavy metal device that stops the bremsstrahlung radiation is referred to as the safety shutter. This is a dual shutter for redundancy. The synchrotron radiation beam, consisting of very high total power and power density, will be stopped by a device that is water cooled, made of copper or alloys of copper, and referred to as the photon shutter. These three devices, the two safety shutters and the photon shutter, will form a shutter cluster; their states (open, closed, or undefined) are monitored by the PPS. Along the beamline are beamline optical elements that will condition the beam, including, for example, monochromators and mirrors. These devices change the characteristics of the synchrotron radiation. The radiation passing through the monochromator will, in most cases, be displaced in either the vertical plane or the horizontal plane from the incident radiation and only a small fraction of the incident radiation with a band pass (of about 0.01% or less) will be passed, with little or no power. In such cases the shutters, located downstream of the monochromator, are known as monochromatic shutters. They will be made of heavy metal and will be much shorter than the safety shutters. Once again, these monochromatic shutters are fully redundant for safety and will be monitored by the PPS.

A major role for the PPS will be to provide a means of ensuring that no personnel are inside beamline stations when the station is opened to synchrotron radiation. Prior to admitting the synchrotron radiation inside these stations, a search of the area has to be performed by a person. It is expected that the station search will be performed by one person only. There will be PPS devices called "search boxes" inside the station which must be visited as part of the search. Search boxes are strategically placed to ensure that during the search all parts of the station are either visible or visited by the search personnel and no person is left behind inside the station. The search is completed when the station door is closed. The PPS will then lock the door. Once the search process is started the PPS will start a beacon and audio signal inside the station, warning all personnel to exit. This signal is expected to last for some time, on the order about 20 to 30 seconds after the station door is closed. The function of the beacon and audio signal is to warn any personnel overlooked by the search person of impending danger. There will be very distinct emergency shutdown buttons placed inside the station which, when pressed, will instantly remove the presence of the prompt synchrotron radiation hazard. In addition, there will be also emergency egress buttons inside the station to unlock and open the door.

10.1.3 Design Specifications

The PPS will be designed to be robust and provide the emergency shutdown functionality to provide personnel safety from prompt radiation. Like the EPS, the PPS is expected to be based on programmable logic controllers. PLCs have numerous advantages over the relay logic scheme of interlocks. They can be reprogrammed to reflect changes in configurations and also have numerous diagnostics. The use of PLCs in safety systems is now very common. All devices attached to the PPS are expected to be designed to be fail-safe—that is, in case of failure the device will fail in such a manner as to either remove the hazard or remove the permit to generate or maintain the hazard. Every beamline PPS will be designed under the same guidelines. The PPS will consist of two PLCs, referred to as chains A and B. The two PLCs will provide redundancy and will independently monitor all the devices. All shutters will have two switches, one for chain A and one for chain B. There will be switches to monitor the closed and open positions. Similarly, all station doors will be monitored with two switches, one each for chains A and B. At beamlines, there will be circumstances when a device such as a mask or photon beam stop is provided to absorb the power of the beam, while the radiation safety is provided by lead shielding in the form of collimators or radiation stops. In such cases, the integrity of the masks and beam stops cannot be compromised, as they, in turn, protect the lead shielding which provides the personnel safety. In these cases, the mask or beam stop will be monitored by the PPS to ensure that it is not compromised. In most cases, a burn-though monitor will be fitted and the water flow to these components will be monitored independently by chains A and B of the PPS. All PPS equipment will be clearly identified, and secured in locked cabinets. Cabling for the PPS equipment to field devices will be on separate closed conduits, which will be used exclusively for the PPS. All power to the PPS will be provided by uninterruptible power supplies, which will be backed up by generators.

10.1.4 Interface

The PPS must interface with numerous systems. The primary functionality of the PPS is to monitor and provide emergency shutdown. To provide emergency shutdown, the PPS interfaces to the Accelerator Personnel Protection System (APPS). The PPS will remove a permit to the APPS to operate the storage ring. In the event of the removal of the permit by the PPS, it is the responsibility of the APPS to remove the hazard by dropping the dipole power supply and the RF to the storage ring systems. The APPS will monitor the positions of the front-end shutters located inside the storage ring shield wall. The APPS will fan-out the status of the shutters to the PPS. There will be a provision in the APPS to remove the PPS interactions for a specific beamline. This is expected to be in the form of a Kirk Key in an interface box between the PPS and APPS for each beamline. The APPS will monitor the closed positions of the front end shutters when the PPS is not available and will remove the storage ring permit if it experiences any “not closed” activity. When the PPS is available, the APPS will ignore the status of the shutters. This scheme will allow installation, maintenance, and validation of the PPS to take place while the machine is in operation. All PPS functions will be monitored and data archived using the control system at NSLS-II. It is expected that EPICS will interface to the PPS PLCs to monitor their functionality. The EPICS interface will be read-only; there will be no writing to PLCs from the EPICS interface. Changes to the PLC operating codes will be possible from the field devices or when the PLC software is downloaded to the PLCs during routine validation of the system. All command and control functionality for the PPS will reside with the Equipment Protection System (EPS) for the beamlines and front ends. The EPS will interface to the PPS and will receive signals from the PPS prior to operation of the shutter. In the event the EPS malfunctions, the emergency shutdown (ESD) procedure of the PPS will activate and will remove the permit for the machine to operate. The PPS will only provide the ESD functionality; hence it is expected to be simple and easy to maintain and validate.

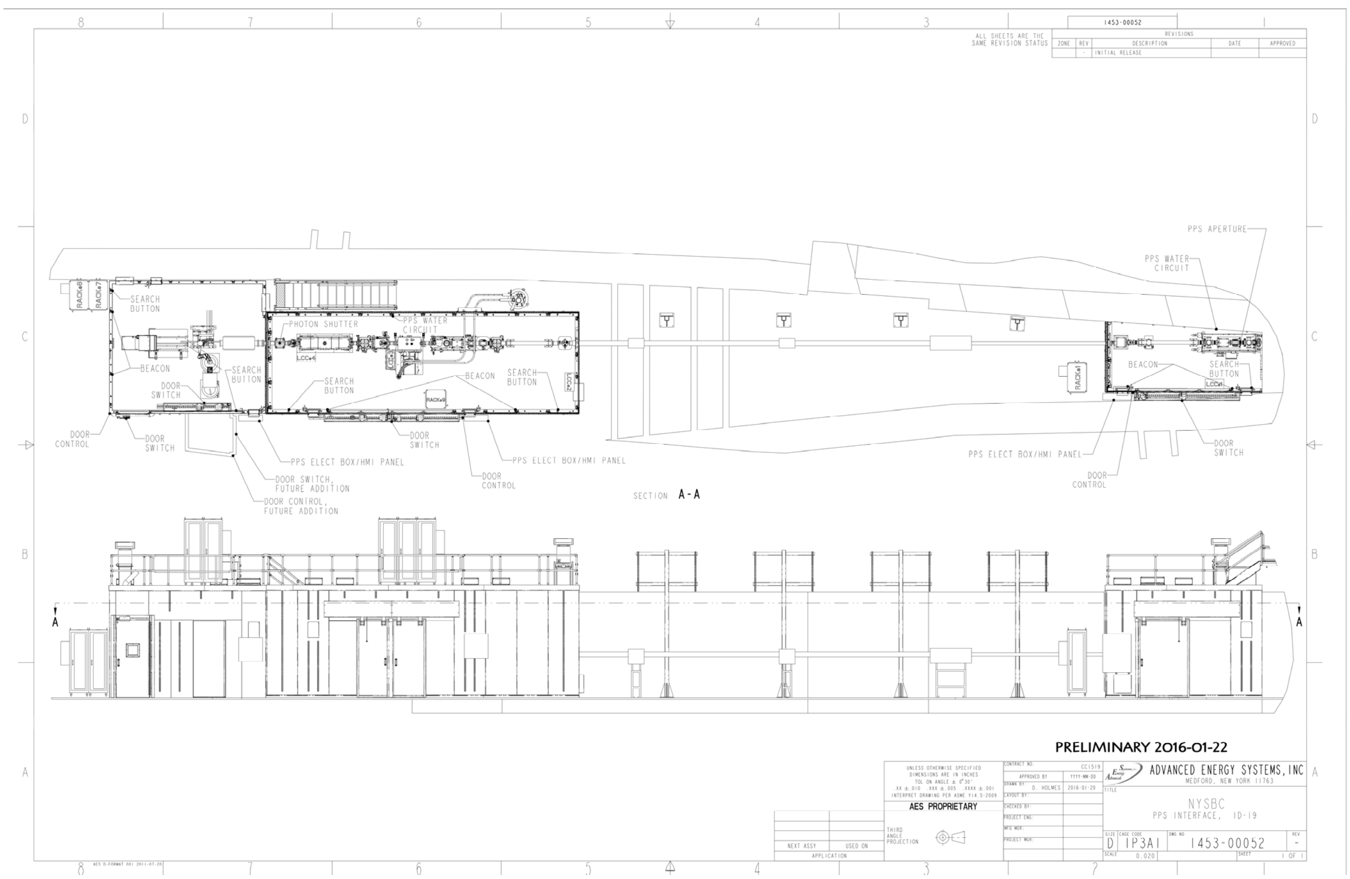


Figure 10-2. NYX PPS Interface

10.2 Equipment Protection System (EPS)

The beamlines at NSLS-II are expected to handle x-ray beams with very high power and power densities. Therefore, care must be taken to design the beamline with components that can handle these power loads. Any component that will handle these high levels of power must be monitored. The beamline Equipment Protection System provides a means of monitoring the components which, when jeopardized, can cause component failure. The EPS has the responsibility to act on alarm conditions by mitigating the situation that has caused the alarms.

10.2.1 Functionality

Every beamline EPS will monitor and interlock the devices in the front end and the beamline. All front ends at NSLS-II are expected to have two safety shutters, one photon shutter, and a few masks. In addition, the front end will also have vacuum inline valves to provide vacuum isolation. The front end is also expected to have a fast valve to provide a conductance limitation during a vacuum accident. Some beamlines will also have an x-ray exit window as part of the front end. These x-ray windows will provide a vacuum isolation but will transmit the x-ray beam. Certain beamlines, such as the soft x-ray beamlines, are expected to share the storage ring vacuum with the front end providing the interface. In such cases, the fast valve, along with the rest of the inline vacuum valves, provides the isolation needed in case of accidents. Due to the large power loads, all components in the front end that intercept the beam will have water cooling. These components are typically the fixed mask, photon shutter, and exit windows. The water flow will be monitored by flow meters and the signals will be fed to the EPS. All vacuum valves will be pneumatically operated. All vacuum valves will be operated by the EPS and have their positions monitored. Most beamlines are expected to have some beam conditioning optics upstream of their monochromator. The beam conditioning optics will see the large power of the beam and as such will be interlocked by the EPS. Beamlines are also expected to have vacuum valves, which will also be controlled by the EPS. The beamline portion of the EPS system will be customized to suit the condition of the specific beamlines.

10.2.2 Design Specification

The design of the EPS is expected to be robust. The system will be based on programmable logic controllers (PLCs), which provide excellent customization capability and also extensive diagnostics. The hardware used will be the same as used in the beamline PPS and the APPS. Each beamline will have its own EPS system, with the sole function being to provide protection from damage of equipment due to synchrotron radiation. As such, the EPS will consist of only one PLC per beamline. The EPS system will consist of three parts: front-end EPS, beamline-specific EPS, and command/control of PPS components such as shutters and station doors. The front-end portion of the EPS is expected to be similar on most beamlines, while the beamline portion of the EPS will be customized to each beamline. Similarly, for the command/control of PPS components, the front-end shutters will be identical in all beamlines; however, additional shutters on the beamline will be beamline specific. All front-end components that intercept the synchrotron beam will have water cooling of the components. The water flow of the components will be monitored by the EPS via flow meters. The EPS will be in alarm state if the flow drops below a specified set point for more than a defined short duration. Depending on the location of the component an EPS monitors, it will command the photon shutter to close and—for cases where the flow is upstream of the photon shutter—it will request the stored beam to be dumped. All vacuum valves in the front end will also be controlled by the EPS. Set points from vacuum controllers that are provided to the EPS will be used to determine when it is permissible to allow opening of the valves. The EPS will determine when it is necessary to close a valve, and will do so if it senses a vacuum alarm, based on the vacuum set-point of the system.

For specific beamlines, the EPS will be customized based on the user requirements for that beamline. Besides monitoring the water flow and controlling the vacuum valves, the EPS system may be used on beamlines to monitor other variables, such as temperature, position, and so forth. The EPS will be used to control the actuation of the shutters. It will monitor the status of the PPS for each shutter and, when a permit is available, it will accept requests to open the shutters. The EPS will be responsible for sequencing the shutters in cases that involve a combination of photon shutters and safety shutters. Any station doors that are automated (none are planned at this stage) will also be operated by the EPS.

(Insert EPS interface design drawing)

10.2.3 Interface

The EPS will have human interfaces (HMI) located at the main location of the hardware, which is expected to be directly above the front end on top of the storage ring tunnel. In addition, there will be a minimum of one HMI per beamline at the beamline stations. The EPS provides the command and control functionality for the beamline PPS. It receives the status information of the PPS and, based on that, can operate the shutters. The PPS, in addition, can request the shutter to close and the EPS will then command the shutter to close. In the event the shutter does not close within a specified time, as determined by the PPS, the PPS will initiate an emergency shutdown (ESD) situation. The EPS will have an EPICS interface to the control system. The EPICS interface will provide both the main control room and the beamlines a complete overview of the status of each beamline. The data from the EPICS interface will also be logged and archived by the central computing systems. The EPICS interface to the EPS will be both read and write. The write functionality will be controlled by the EPICS Channel Access Security. This is essential, to isolate the possibility of accidental control of the wrong beamline EPS via the control system.

11. Utilities

The utility systems for NSLS-II beamlines comprise the following services in a standardized (but tailored) "utility pack":

- Mains electrical distribution: 30 kVA total, with separate UPS circuits where needed.
- Chilled water for electrical racks and user equipment
- De-ionized (DI) water for beamline optical components
- Compressed air, experimental gases, gaseous nitrogen, and liquid nitrogen
- PPS wiring and conduits

11.1 Mechanical Utilities

The design approach includes the supply of air and water in modules (stainless steel for water, copper for air) utilizing purchased standard manifolds, these modules may be added or subtracted as needed by a specific beamline. Flow measuring or flow alarms will be used on the water return circuits where required.

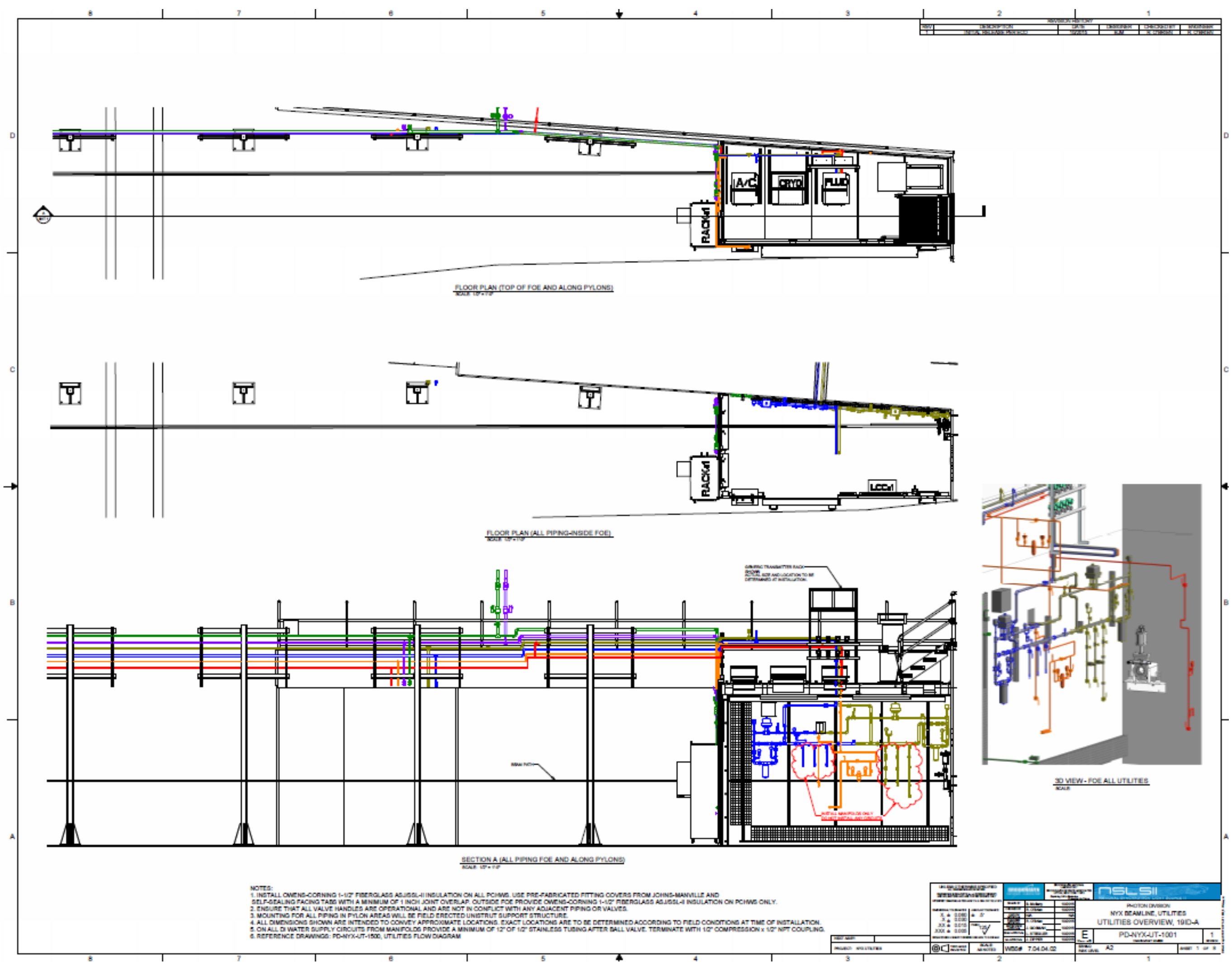


Figure 11-1. Mechanical Utilities Requirements installation for NYX FOE (19-ID-A)

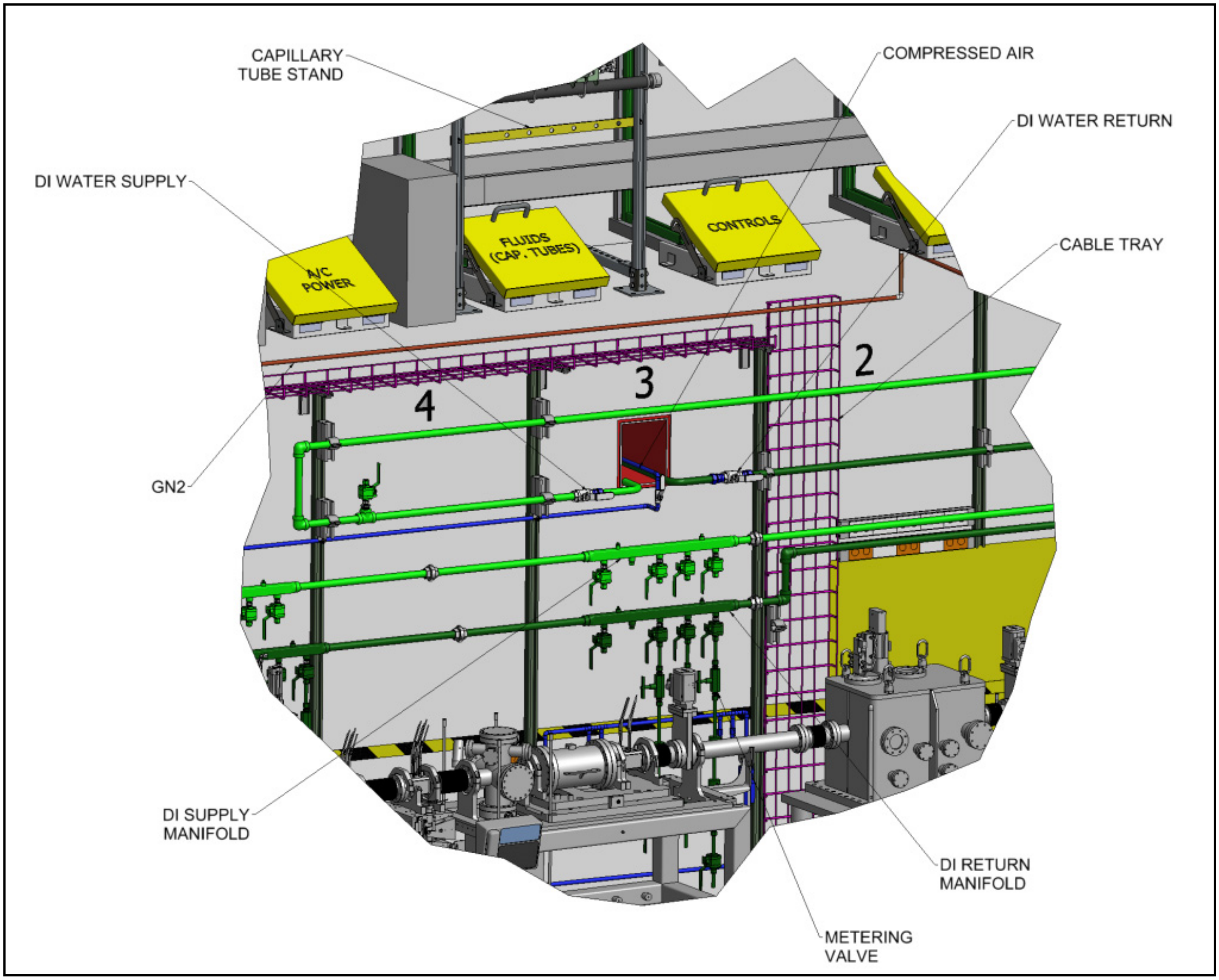


Figure 11-3. Utility layout showing the DI water and compressed air passing through the ratchet wall into the FOE, and the pipework distribution, along with labyrinth designations.

11.2 Electrical Utilities

The AC power sockets and the water connections will be located in alternating 1 m “bays” for improved electrical safety. The two supply transformers provide power for sensitive and non-sensitive applications. Outlets inside the enclosure are supported within a Wiremold product designed for such applications.

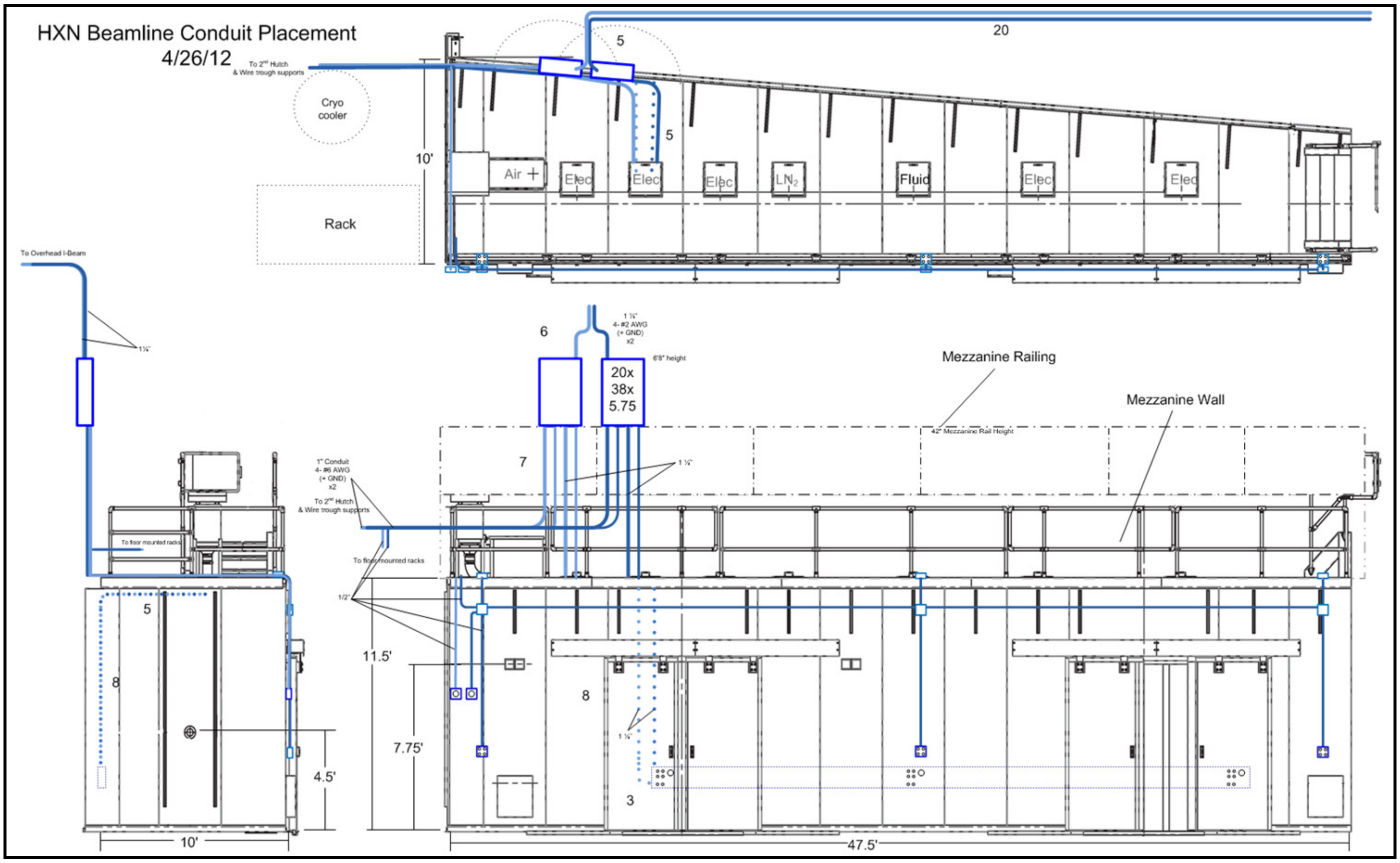


Figure 11-4. A typical provisional layout for the electrical mains distribution.

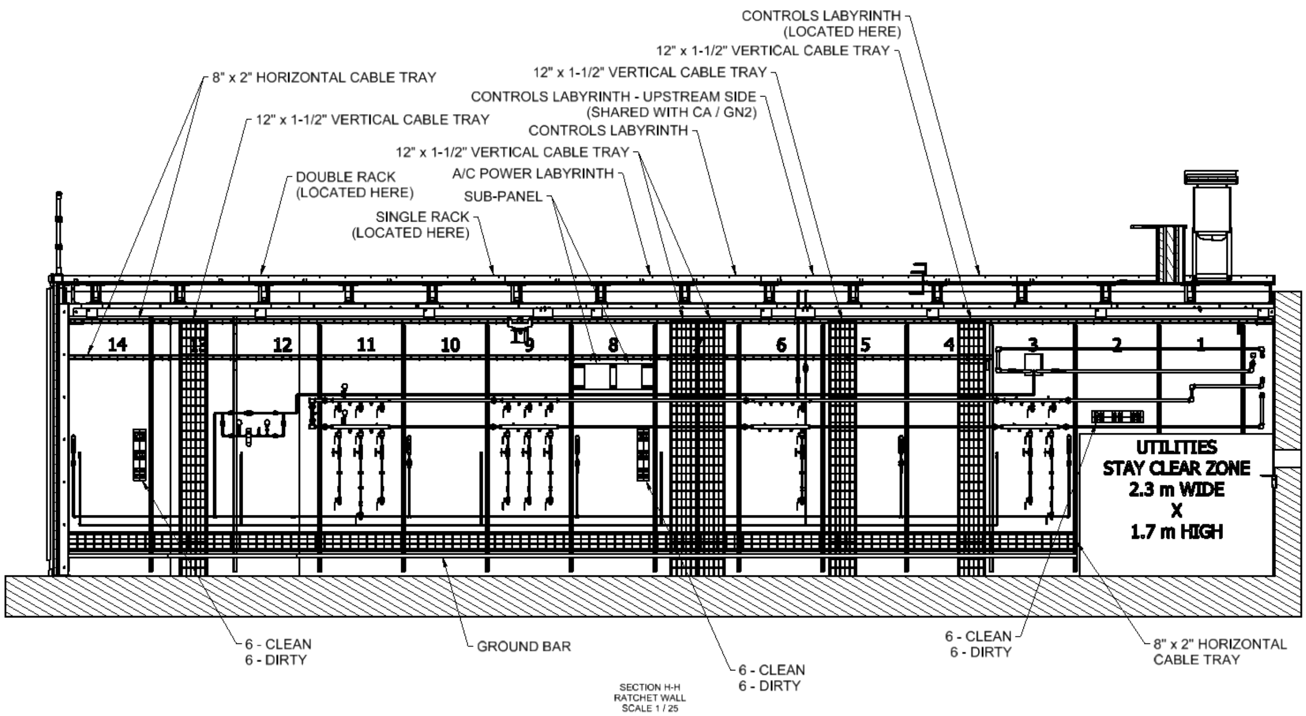


Figure 11-5. A typical preliminary layout for the electrical distribution within an FOE

(insert NYX one line drawing)

Figure 11-6. Preliminary One-Line Diagram for Electrical Distribution to LIX Beamline.

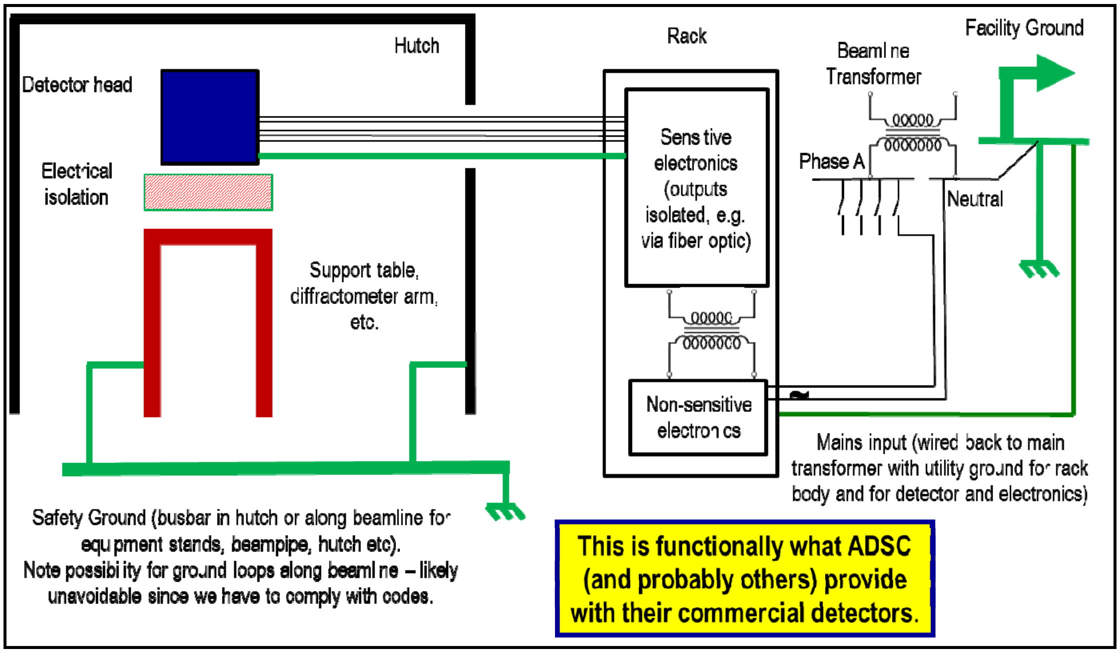


Figure 11-7. Schematic for the mains grounding, commensurate with both low-noise detectors AND a high level of electrical safety.