Electron Spectro Microscopy (ESM) Beamline

IRR Functional Description

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1 INTRODUCTION

Primary Research Capabilities

The ESM beamline, constructed as part of the NSLS-II Experimental Tools (NEXT) project funded by the Department of Energy (DOE), aims at providing material scientists with state of the art instruments to perform soft-X-ray photoemission spectro-microscopy measurements. The beamline serves two end stations, one at a time: the micro-ARPES end-station and the XPEEM end-station. The first is a high-resolution ARPES spectroscopy instrument with scanning microscopy capabilities; the second is a full field (photo)electron microscope with an emispherical energy filter. The XPEEM end station is provided via a PUP by BNL-CFN. The main techniques made available at ESM are:

μ-ARPES End Station:

1. *Spin and Angle Resolved Photoemission Spectroscopy (SP-ARPES)*: For complete mapping of the electronic structure of materials.
2. *Scanning Microfocused Spin and Angular Resolved Photoemission Spectroscopy (μ-SP-ARPES:* Mapping of the electronic structure of materials with 1 micron lateral resolution; scanning imaging capabilities (1 micron lateral resolution)
3. *High-Resolution Microfocused Angular Resolved Photoemission Spectroscopy (HR-SP-ARPES):* Low temperature, high resolution mapping of the electronic structure.
4. *Microfocused absorption and magnetic circular dichroism (μ-XAS, μ-XMCD):* Absorption spectroscopy and magnetic circular dichroism with scanning imaging capabilities (1 micron lateral resolution)

XPEEM End Station:

1. *Abberation Corrected X-ray Photomission Micrscopy:* Full-field photoelectron microscopy with lateral resolution of 10 nm and energy resolution of 100 mV.
2. *Low Energy Electron Microscopy:* Full-field electron microscopy micro-LEED

Having these focused research areas allows the beamline instrumentation to be specialized and optimized. The aim of the NEXT project is to complete the instrumentation that delivers the beam to the sample position. Operation grant will continue to support the full implementation of all experimental capabilities.

Beamline Staff

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2 BEAMLINE DESIGN AND COMPONENTS

2.1 Beamline Performance Goals

Table 1 summarizes the design performance of the ESM beamline. The beam size and the resolving power are based on the needs of the supported experiments. An optical layout of the beamline (described below) and the specifications for the individual components are then determined. The flux performance is estimated using ray-tracing simulations that have incorporated the specifications of the source and the optical components. The actual flux will depend on the configuration of the optical components called for by the experiment.

Table 1. Designed Performance of the ESM Beamline

Parameter	Specification/Description
Insertion Device:	EPU105 (2.8 m long) and EPU57 (1.4 m long), low-β straight section, *in-line* configuration.
Operating Energy Range:	15 – 1500 eV
Monochromator:	Plane Grating Monochromator (PGM). 4 Variable Line Spacing (VLS) gratings (300, 600, 800, 1200 l/mm, Au coated)
Beam size at sample (FWHM):	<1 μm at μ-ARPES; (KB refocusing optics) 40 μm at XPEEM (ellipsoidal refocusing optics)
Flux at sample at 500 mA storage ring current:	Up to 1 x 10^{11} (1 x 10^{12}) ph/sec for μ-ARPES (XPEEM)
Detector system	μ-ARPES: Scienta DA30 μ-ARPES XPEEM: ELMITEC AC-LEEMIII

2.2 Beamline Layout

The estimated performance above is based on the conceptual layout of the ESM beamline shown in Figure 1. The source for the ESM beamline is one of the two in-line elliptically polarized undulator (EPUs); EPU57 or EPU105. EPU57 is a 1.4 m long device with a magnet period of 57 mm, installed in the upstream section of the 21-ID low-β straight section; EPU105 is a 1.4 m long quasi periodic device with a magnet period of 105

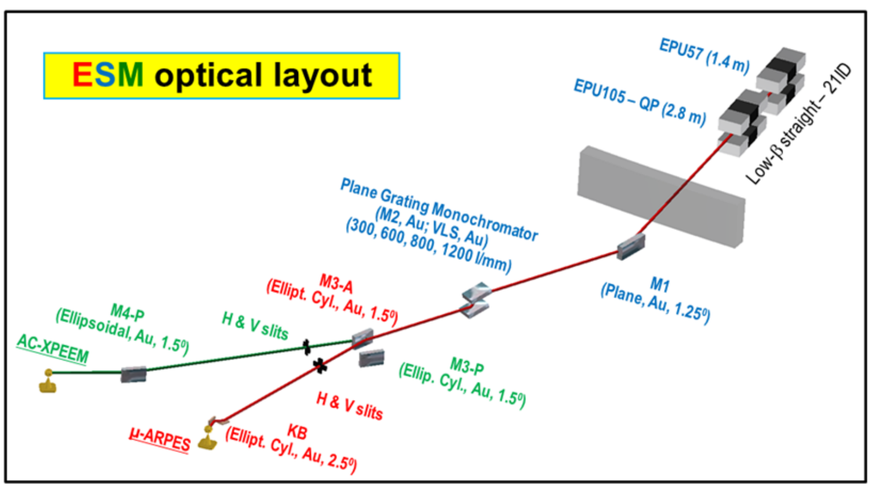

Figure 1. The conceptual layout of the ESM beamline.

mm, installed in the downstream section of the 21-ID low-β straight section. The undulator parameters (Table 2) are optimized to provide continuous coverage in the energy range 15 – 1500 eV.

Table 2. Main characteristics of the EPU57 and EPU105 undulator sources for ESM

Device Name	EPU57	EPU105
Device Type	Ellipt. Pol. Undulator	Ellipt. Pol. Undulator
Period [mm]	57	105
Length [m]	1.4m	2.8
Number of periods	24	26
Minimum Gap @ Low-β Straight [mm]	16	16
Maximum K	4.45 (140 eV)	11.2 (15 eV)

In order to achieve the wide energy range and high resolving power needed for photoemission experiments, we have adopted a plane grating monochromator design. The ESM mono is equipped with 4 gratings covering the entire energy range as detailed in Table 3 below.

Table 3. Main characteristics of the ESM Monochromator

Device Name	Energy Range (eV)	Sample Flux (ph/s)
Low Energy Grating (LEG – 800 l/mm)	15 – 100	10^{9}- 10^{10}
Medium Energy Grating (MEG – 600 l/mm)	50 – 350	10^{11}
High Energy Grating (HEG – 1200 l/mm)	200 – 1500	10^{10}
High Intensity Grating (HIG – 300 l/mm)	50 – 350	10^{12}

After the monochromator, the beam can be intercepted by either of the two M3 mirrors. M3-A deflects the beam outboard toward the ARPES end-station; M3-P deflects the beam inboard toward the XPEEM endstation. Optically the two branch adopt different refocusing schemes. In the ARPES branch, a pair of elliptical cylinders are arranged in the KB configuration to focus the beam down to 1 micron. The focusing in the XPEEM branch is obtained with a single ellipsoidal mirror.

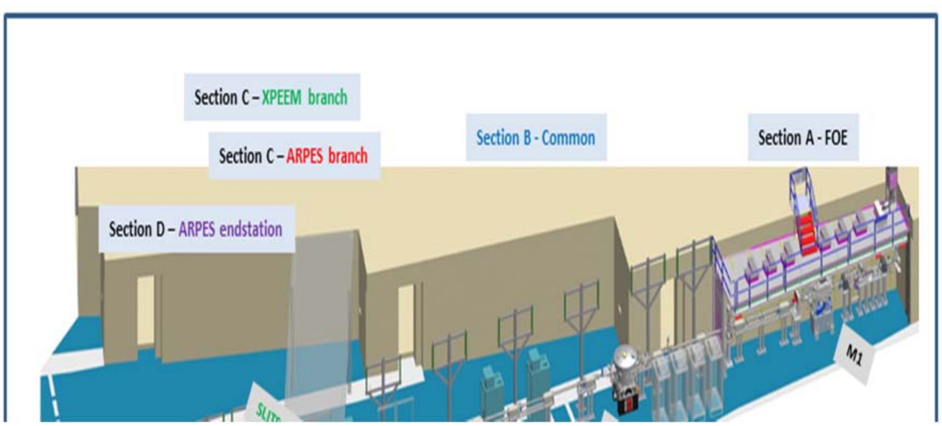

Figure 2. An overview of the beamline components at the ESM beamline

The actual layout of the beamline components is shown in Figure 2. Light emitted by the EPUs, enters the the first optical enclosure (FOE) at a height of 1400 mm. The only optical element contained in the FOE is the deflecting mirror, M1. This is a directly water cooled plane mirror whose principal function is to reduce the power of the beam sent to the monochromator. The M1 also deflect the beam inboard 2.5°. Following the M1 mirror, a few meters downstream in the FOE, is the VLS-PGM. The PGM contains a directly water cooled plane mirror (M2) and 4 gratings. The M2 mirrors deflects the light upward and the gratings redirect the light horizontally. The height of the beam after the monochromator is therefore 1440 mm. The next optical elements are the two sets of slits; one for the ARPES branch and one for the XPEEM branch. These slits are located in the focus of the beam (vertically due to VLS gratings and horizontally due to mirrors M3) and serve as secondary sources for the final refocusing optics. In the ARPES branch the refocusing scheme is based on a KB pair of elliptical cylinders. A single ellipsoidal mirror is adopted for the XPEEM branch.

Various types of diagnostic units are available to monitor the quality of the X-ray beam. In the FOE there is a visible reflector and the DiagOn optic. The visible reflector is a mirror polifshed, directly water cooled, glidcop piece, which can be positioned in the beam path to reflect the visible light from the bending magnet outside the vacuum pipe. To image the soft X-ray radiation from the EPUs, a DiagOn optic is used. This consists of two sets of multilayers deposited on Si wafers and mounted on two water cooled holders (also made of glidcop); one enetering the beam horizontally and the other vertically. These multilayers, when introduced along the beam path, reflect the light producing polarization selective images of the incoming beam.

Additionally, each optic chamber is preceeded and followed by vertical and horizontal buffle slits to define the shape of the beam incident on the optics and to trim the edges of the outcoming beam. The blades of these slits are electrically isolated and can be used as beam position monitors. Furthermore, diagnostics units – consisting of a XUV diode, a Au mesh and a YAG crystals - are mounted at strategic locations along the beamline. Finally gas-chambers for energy resolution characterization are located after each of the two secondary sorces.

The ARPES end station terminated the ARPES branch. This end station consists of three main units:

1. Main Chamber: Hosting the electron energy analyzer, the cryocooled sample microscanning stage, a sample transfer system from the horizontal manipulator and the microscanning stage.
2. Preparation Chamber: Hosting a cryo-cooled horizontal sample manipulator and surface science equipment for the preparation and characterization of single crytal surface.
3. Sample Transfer System: Consisting of a load-lock chamber for fast in-vacuum insertion of samples and a sample transfer system toward the horizontal manipulator of the preparation chamber.

A layout diagram that contains more details on the beamline components is included in the appendix.

3 BEAMLINE SAFETY

3.1 Radiation Shielding

The design of all radiation shielding (hutches and radiation safety components) follows guidelines to reduce radiation levels external to the beamline enclosures during normal operation to < 0.05 mrem/hr and as low as reasonably achievable. The shielding wall thicknesses follow released shielding guidelines:[1]

Hutch A (FOE, white beam hutch):

- Lateral wall: 18 mm lead
- Downstream wall: 50 mm lead
- Roof: 10 mm lead

A beam shutter of the standard NSLS-II design is installed at the downstream end of the 21-ID-A hutch. Two additional NSLS-II standard beam shutters are located just downstream of the M3 chamber, one serving the ARPES branch and one serving the XPEEM branch.

3.2 Radiation Safety Components

These are the components that help contain the synchrotron radiation from the undulator source and the gas Bremsstrahlung radiation from the storage ring. The major components are shown in Figure 3 and described in detail below. The location and dimensions of these components are determined based on the ray-tracing analysis and documented in the ray-tracing drawing. Radiation safety components also include devices such as labyrinths and guillotines. A full list of components are identified in the 21-ID radiation safety components checklist (PS-R-XFD-CHK-011).

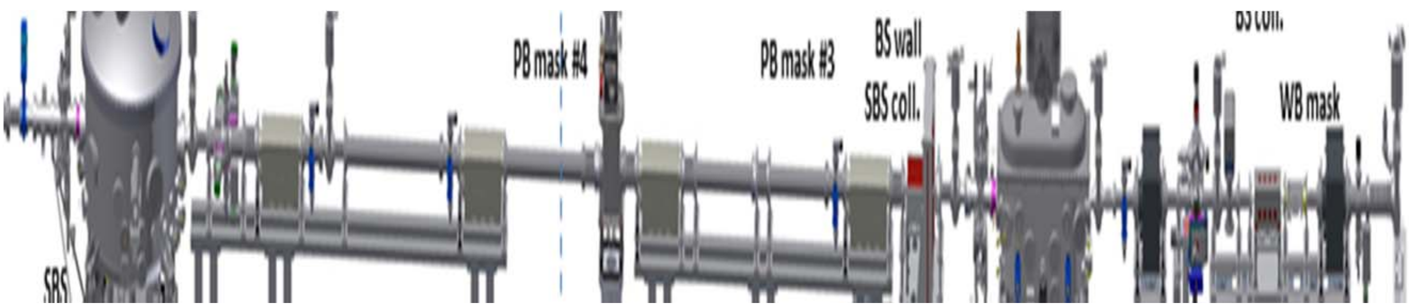

Figure 3. Radiation safety components located in the FOE and the monochromator chamber. Details are given in the text.

3.2.1 Heat Load Management (white and pink beams)

The maximum incident total power from the undulator is expected to be 10.1 kW (EPU105 operated at 16 mm gap). This heat load is limited by the front end water-cooled fixed mask, with aperture size of 0.7 mrad, limiting the maximum power to ~2.5 kW. The white beam mask with aperture size of 0.4 mrad reduces the power downto 1.2 kW Further reduction of the incident power can be achieved by adjusting the frontend slits. The Au coated, directly water cooled M1 mirror then serves as a low-pass filter and reduces the maximum power in the reflected pink beam to below 162W. The directly water cooled M2 mirror further reduces the pink beam power down to < 5 W incident on the indirectly water cooled gratings.

[1] W.-K Lee et.al., *Guidelines for the NSLS-II Beamline Shielding Design*, (LT-C-ESH-STD-001).

To stop mis-steered white beam from the front end, a set of 3 white beam radiation safety componenets is provided: a white beam mask, the M1 entrance mask and white beam stop. To stop mis-steered pink beam from M1, a set of pink beam radiation safety componenets is provided: M1 exit mask, 4 pink beam masks, PGM entrance mask, pink beam stop.

All the high heat load components are cooled with the same DI water circuits interlocked in the personnel protection system (PPS).

3.2.2 Primary Bremsstrahlung Radiation Management

There are two components for primary Bremsstrahlung shielding:. The Primary Bremsstrahlung collimator and the Primary Bremsstrahlung stop. Primary Bremsstrahlung collimator is located immediately downstream of the white beam mask; the Primary Bremsstrahlung stop is located just downstream of the M1 tank.

3.2.3 Secondary (Scattered) Bremsstrahlung Radiation Management

Secondary Bremsstrahlung radiation arises from scattering of primary Bremsstrahlung radiation off the white beam mask, the M1 mirror and the white beam stop. Based on NSLS-II guidelines, a Secondary Gas Bremsstrahlung collimator (SGBC shielding wall in Figure 3) has been installed. FLUKA simulations[2] were carried out to verify that the dose rate outside the FOE is below the limit of 0.05 mrem/hr at 500 mA operation current. Furthermore in the PGM tank a Secondary Gas Bremsstrahlung stop (SGBS Tungsten block) has been installed. Additionally pink beam vacuum sections outside the FOE as well as end stations are equipped with a pair of vacuum switches to prevent generation of Secondary Bremsstrahlung due to vacuum failure.

3.2.4 Configuration control

All radiation safety components are under configuration control, in accordance with the NSLS-II Radiation Safety Component Configuration Management procedure (PS-C-ASD-PRC-055). Examples are given in Figure 4.

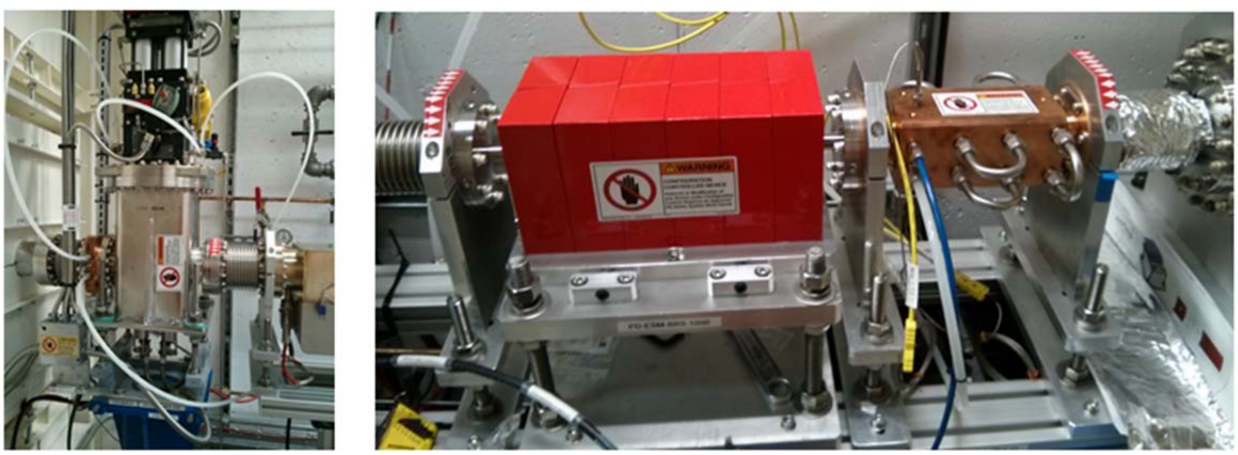

Figure 4. Examples of configuration control on radiation safety components. Left: the photon shutter in the FOE; right: the primary GBS collimator and the white beam stop, both located in the FOE.

[2] V.J. Ghosh, *21-ID ESM Beamline Radiation Shielding Analysis,* NSLS-II Technical Note Number 217, June 2016

3.3 Area Radiation Monitor (ARM)

Radiation levels in the area are actively monitored through an area radiation monitor (ARM) installed on the outboard wall at the downstream end of the FOE (Figure 5). The monitor has been certified in accordance with the procedure PS-C-ASD-PRC-008, *NSLS-II Area Radiation Monitor PPS Test.*

Figure 5. Area Radiation Monitor (ARM) installed on the ESM beamline

3.5 Personnel Protection System (PPS)

The PPS controls access to the hutches through an interlock system and search and secure procedure, to ensure personnel safety during normal operation of the beamline. The FOE hutch is equipped with a PPS-interlocked user labyrinth to facilitate temporary equipment access during user experiments.

The PPS also monitors critical DI water flow to the beam mask and beam stops to ensure the safe operation of the radiation safety components. In the event that water flow is lost, the PPS system will close the front end photon shutter to shut off the beam.

The PPS also monitors 5 pair of vacuum switches in the pink sections outside the FOE (3 pair) and at the end stations (2 pairs).

3.6 Hazard Identification and Mitigation

Overall, the ESM beamline is similar to other beamlines that are already in operation at NSLS-II. A USI evaluation has been conducted and it was determined that the anticipated activities at the beamline do not violate the existing SAD and ASE. All relevant NSLS-II procedures and safety practices are followed during the design and construction of the beamline to mitigate the hazards identified in these document.

4 INSTRUMENT READINESS

4.1 Survey and alignment

The beamline components are installed according to the specifications and the respective final designs. Installation of the components are verified and documented by the NSLS-II Survey group working closely with the beamline staff.

4.2 Utilities

The following services/capabilities are deployed at the beamline:

- Electrical power distribution: to all electrical power outlets, light fixtures, fans, etc. in the enclosures and along the beamline
- Distribution of deionized water for high heat-load components
- Distribution of process chilled water, water-cooled racks
- Compressed air: for pneumatic valves
- Dry nitrogen gas
- Network connectivity
- Cabling and piping support structures, for all utilities including EPS and PPS.

4.3 Vacuum System and Pressure Safety

The vacuum pressure for all beamline components is expected to be in the 10^{-10} mbar range. There is no physical barrier between the beamline vacuum and front end vacuum. Instead, two ion pumps are installed upstream and downstream of the white beam mask to provide differential pumping. The effectiveness of these pumps has been confirmed using calculations and will be verified by testing. A fast gate valve sensor is installed just downsream the front end interface gate valve to protect the storage ring in case of vacuum failure in the beamline vacuum system.

All vacuum vessels are installed with a pressure relief valve to avoid over pressure when the vessel is vented using dry nitrogen. Pink beam vacuum sections outside the FOE, as well as end stations, are equipped with a pair of vacuum switches, which belong to the PPS system.

4.4 Controls

All motorized components have been tested by the Controls Group and documented in the travelers. Controls System Studio (CSS) screens have been prepared to access the motors on the components. The individual motors are also accessible using standard EPICS Extensible Display Manager (EDM) screens.

4.5 Equipment Protection System (EPS)

The EPS at the ESM beamline performs the following functions:

1. Vacuum pressure monitoring and interlock for all the vacuum sections of the beamline.
2. Temperature monitoring and interlock for all non-safety related components, including components exposed to heat load in the white beam mirror system and monochromator.
3. Water flow monitoring and interlock for the cooling of the M1 white beam mirror, M2 and gratings.
4. EPICS interface for components that require I/Os installed on the EPS PLC, including the readout of LVDTs and control of venting and evacuation valves in the experimental station.

APPENDIX: LAYOUT OF THE ESM BEAMLINE COMPONENTS