LT-C-XFD-STD-BL-COORD-001

Beamline Coordinate System Standards

Revision 2

April 2012

This page intentionally blank.

Version History

Version	Date	Author(s)	Description
1	05 May 2011	Wayne Lewis	First version ready for release
2	4 April 2012	Wayne Lewis	Updates include: Change definition of positive direction at motion controller. Make axis labelling identical across coordinate systems. Move component definitions to Appendix. Clarify rotation sign conventions.

Concurrence and Approval Signatures

		Date
Beamline Engineering	**Andrew Broadbent**, NSLS-II Beamlines & Interfaces Manager	5/9/2012
	Daron Chabot, NSLS-II Beamline Controls Engineer	4/20/12
	Wayne Lewis, NSLS-II Beamline Controls Engineer	4/26/12
	Kaz Gofron, NSLS-II Beamline Controls Engineer	4/20/12
	Bob Dalesio, NSLS-II Controls Group Leader	5/3/2012
	Mary Carlucci-Dayton, NSLS-II Beamline Engineering Group Leader	4/25/12
Scientific Staff	**Andrei Fluerasu**, CHX Beamline Group Leader	4/25/2012
	Yong Chu, HXN Beamline Group Leader	5/2/2012
	Yong Cai, IXS Beamline Group Leader	5/1/2012
	Juergen Thieme, SRX Beamline Group Leader	4/26/2012

[signature] 5/14/12

Eric Dooryhee, XPD Beamline Group Leader

N/A

Cecilia Sanchez Hanke, CSX Beamline Group Leader

[signature] 5/9/12

Division Head **Qun Shen**, NSLS-II Experimental Facilities Division Director

Contents

Acronyms

DCM	Double Crystal Monochromator
NSLS	National Synchrotron Light Source
NSLS-II	National Synchrotron Light Source II
PV	Process Variable

1 INTRODUCTION

A consistent coordinate system convention is required for NSLS-II beamline design and operation. This document identifies the coordinate systems that need to be defined for an experimental beamline and provides a definition for each coordinate system.

This document provides coordinate system definitions both for low level instrumentation such as motion controls and for end-user applications.

This document attempts to maintain consistency with existing coordinate system definitions as far as possible. In most cases, the movements of the beamline components only have relevance in a local coordinate system.

The relevant and appropriate coordinate systems should be used in each specific application.

1.1 Applicable Documents

Document Number	Document Title
LT-MECH-ENG-0001	NSLS-II Mechanical Design Office Standards Manual
LT-C-XFD-SPC-CO-IIS-001	Beamline Systems Instrumentation Interfacing Standard

2 OVERVIEW

This section provides a brief summary of the coordinate systems defined for the beamlines. Figure 1 shows this graphically.

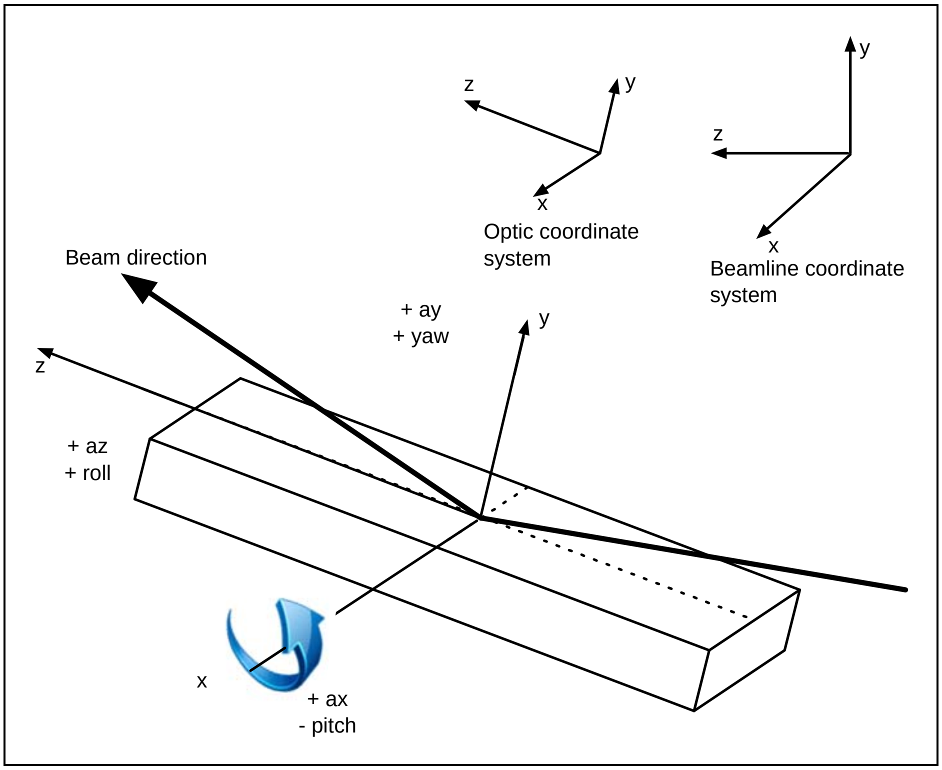

Figure 1: Summary of beamline coordinate systems using vertical bounce-up mirror example

2.1 Cartesian axes

The general definition of the cartesian axes is the z-axis in the direction of the beam and positive in the direction of the beam propagation, the x-axis parallel to the floor and positive in the outboard direction, and the y-axis perpendicular to the floor and positive upwards.

A number of specific cartesian axis sets are defined, including one that is constant for the beamline, one that rotates/is deflected to follow the beam path and one that is aligned with each optical element. All cartesian axis sets are a right-handed orthogonal set of axes.

2.2 Rotation axes

One set of rotation axes is defined as rotation about each of the cartesian axes. The designation is (ax, ay, az), meaning “angle about x,” etc. The sign of these rotations is strictly right-handed.

A second set of rotation axes are the named rotations (e.g., pitch, theta, Bragg, etc.) depending on the requirements of the beamline and the component. The signs generally follow the definition above, but pitch can be inverted to provide an intuitive value. The relationship between pitch, roll and yaw, and ax, ay, and az varies depending on the orientation of the optical element.

2.3 Zero offsets

Each translation and rotation axis has an associated offset in the control system to allow the zero point for that axis to be set at a meaningful position.

2.4 Exceptions

There will be exceptions to the definitions in this document, where applications require a coordinate system different from those described in this document. These exceptions will be documented with the system or application that requires the alternative coordinate system.

3 BEAMLINE COORDINATE SYSTEM DEFINITIONS

3.1 Definitions

3.1.1 Reflection plane

The reflection plane contains both the incoming and outgoing beam.

3.2 Existing coordinate systems

A summary of the existing coordinate systems is provided in Appendix D.

3.3 Cartesian coordinate system

Figure 1 shows a vertically upwards reflecting optic and the relationship between the beamline, beam and optic reference frames.

3.3.1 Beamline reference frame

Each beamline has a fixed reference frame, using the definition in 2.1. The z-axis is parallel to the photon beam as it passes through the ratchet wall and the x-axis is perpendicular to the photon beam.

Beamlines using canted undulators as their source may have a beamline reference frame for each undulator source.

3.3.2 Component reference frame

The axis definitions for the component reference frame vary depending on the orientation of the component (i.e. vertical deflecting, horizontal deflecting, transmission). The intent of this reference frame is to provide a set of axes that are aligned with the optic, and have axis designations that are similar (although rotated) to those of the beamline reference frame.

3.3.2.1 Component types and orientation

The definitions for all components are in Appendix A.

3.3.3 Sample reference frame

A sample reference frame will be defined. This definition will take into account any effect of sample rotation through the use of a diffractometer.

3.3.4 Others

Other reference frames will be defined as required.

3.3.5 Axis designations

All of the above coordinate systems have the cartesian axes labelled x, y, and z

3.3.6 Axis definition

All cartesian coordinate systems for the beamlines obey the right-hand rule.

3.3.7 Zero definition

Zero position for each axis will be defined in the control system by setting an appropriate offset. This will be defined based on the operational requirements and the optical and mechanical design.

3.4 Rotation coordinate system

3.4.1 Definitions

The first level of rotations is defined by rotations around each of the cartesian axes. These are designated ax, ay and az.

Pitch, roll, and yaw are defined in a way that is relevant for each component. Pitch changes the angle of incidence between the optic and the incoming beam, yaw rotates about the axis normal to the optical face and roll is the remaining rotation.

The sign of pitch can change to allow intuitive values (e.g. increasing pitch increases the incidence angle of the beam on the optic), while roll and yaw remain right handed. The relationship between the pitch, roll, and yaw and the “rotation about a cartesian axis” values changes depending on the orientation of the optic. Examples of this definition are provided in Appendix B for a range of optic types.

Appendix C has a figure showing an optic in third angle projection and the associated axis definitions.

3.4.2 Sign of rotations

When the rotations are described about a cartesian axis (ax, ay, az), the positive direction is always defined using the right-hand rule: When the thumb of the right hand is pointing in the positive direction of the axis, the fingers curl in the sense of the positive rotation.

When the rotations are referred to as pitch, roll, and yaw, the right-hand rule applies to roll and yaw.

Pitch can also be defined this way, or it can be defined to be positive in the direction that increases the angle of incidence of the beam on the optical element. This changes the sign of the pitch, depending on whether the optical element is deflecting the beam up, down, inboard, or outboard. This allows pitch to be defined as positive in an intuitive manner for the specific application.

3.4.3 Zero definition

The x and y rotations are zero when the z-axis of the optical element is parallel to the beamline coordinate system z-axis. The z and y rotations are defined as zero when the x-axis of the optical element is parallel to the X-axis of the beamline coordinate system.

Pitch, roll, and yaw can be defined as having an offset from the axis rotations values. This allows these values to be set to a meaningful zero position from the perspective of each optical component. For example, Bragg rotation should be zero when it is parallel to the incoming beam, which may not be parallel to the beamline Z-axis if there is a mirror prior to the monochromator.

4 CONTROL SYSTEM

4.1 Motion controller

4.1.1 Permanently installed motion axes

Where the motion axis has a clear and permanent alignment with the beamline or component coordinate system, a positive motion in the motion controller shall result in a positive motion with respect to the relevant coordinate system. All rotations shall strictly follow the right-hand rule (ax, ay, az).

Where the motion axis does not have a clear and permanent alignment with the beamline or component coordinate system (e.g., translation stage mounted on top of a rotary stage with > 45˚ range), the axis designation and positive direction should be defined when all rotary stages are in their nominal zero position.

4.1.2 Non-permanently installed motion axes

If the motion stage has an permanently mounted scale that defines a positive direction, the motion controller should be consistent with this.

For linear stages that are not permanently installed and do not have a permanently mounted scale, a positive motion in the motion controller should result in movement away from the motor or motor connector.

For rotary stages that are not permanently installed and do not have a permanently mounted scale, a positive motion in the motion controller should result in a counter-clockwise rotation of the stage when viewed looking at the stage from the sample mounting side. This is consistent with the right-hand rotation rule.

4.1.3 Other motion axes

If none of the above definitions apply, a positive motion from the motion controller should result in a clockwise rotation of the motor shaft when viewed from the rear of the motor.

4.2 EPICS

The EPICS layer will provide the capability of inverting the sign of the motion direction to align it with the requirements of the end user. This may be done in the motor record that interfaces directly to the motion controller, or in additional records that sit above the motor record.

The EPICS layer will implement the offset required to define an appropriate zero position.

5 ENDSTATION COORDINATE SYSTEMS

Endstations have a range of systems that can provide different translations and rotations. Also, user communities may have specific requirements of the coordinate systems.

5.1 Three-circle diffractometer

A diffractometer that has three concentric circles has the sample mounted on the inner circle, and the detectors on the middle and outer circles (e.g. a typical powder diffraction setup). The inner circle is designated a theta axis, and the two outer circles are two-theta axes.

5.2 Four/five/six circle diffractometers

This is yet to be defined. One option is to use the Spec definitions. This section will be updated prior to specification of the first four circle diffractometer. Using the Spec axis definitions would end up changing the definitions of x,y, and z, with y being positive from the sample towards the beam source, x positive upwards, and z positive inboard .

Theta, chi, phi, and two-theta are standard definitions for diffractometers. Two-theta is the rotation that changes the angle between the sample and the detector, theta is the outermost circle with the same rotation axis as the two-theta circle. The chi circle is mounted on the theta circle, with its axis of rotation perpendicular to the theta circle. The phi circle is mounted on the chi circle with its axis of rotation in the plane of the chi circle. Two-theta can rotate independently of the other circles. The detector is mounted on the two-theta circle, and the sample mounted on the phi circle and positioned in the center of rotation of the theta, chi, and phi circles.

5.3 Sample coordinates

Samples are often be mounted on translation stages that can be capable of up to three orthogonal movements. These axes are referred to as x, y, and z, with the axis definitions lining up with the beamline reference frame axes when the diffractometer theta, chi, and phi are all at zero.

If fewer than three axes are provided for the sample, then the axis designations match those axes of the beamline reference frame that the sample stage axes align with.

5.4 Protein crystallography

For protein crystallography, omega and kappa are defined. Omega is the outermost rotation of the goniometer, and is typically analagous to theta (or rotation about the x-axis) in the standard rotational axis definition. Kappa is a rotation stage with the rotation axis at a non-90 degree angle to the omega rotation axis. A phi rotation stage is then mounted on the kappa stage. The sample is mounted on the phi stage, usually with some translation capabilities.

5.5 Others

Other experimental endstations and experimental techniques that require specific coordinate system definitions will be added as they are identified.

A COMPONENT REFERENCE FRAME DEFINITIONS

A.1 Vertical reflecting/diffracting optic

The y-axis is in the reflection plane, normal to the optical surface, and positive in the upward direction.

The z-axis is in the reflection plane, parallel to the optical surface, and positive in the beam propagation direction.

The x-axis is normal to the reflection plane, parallel to the optical surface and positive in the direction away from the storage ring.

Where the optic is curved, the axes are parallel or normal to the optical surface at the nominal center of that surface.

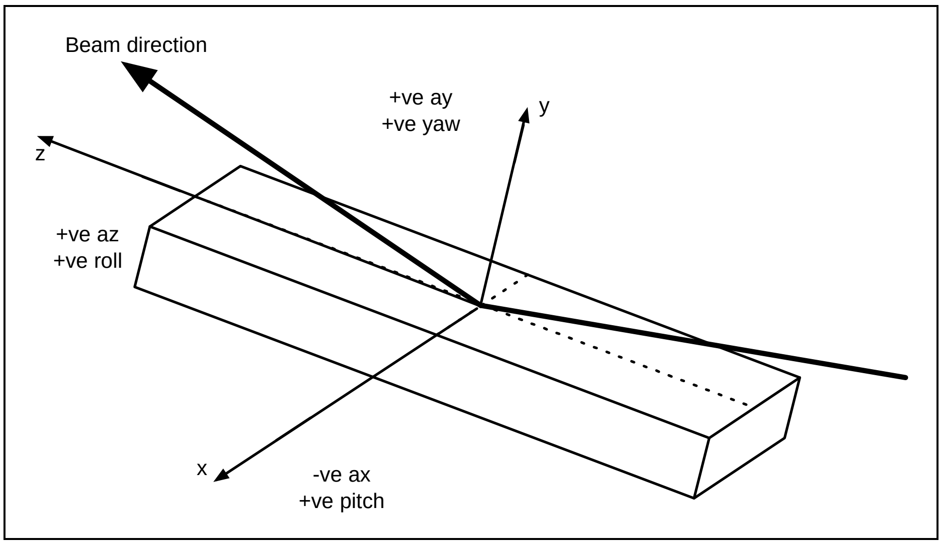

Figure 2: Axis definition for vertically deflecting optic

A.2 Horizontal deflecting optic

The y-axis is normal to the reflection plane, parallel to the optical surface, and positive in the upwards direction.

The z-axis is in the reflection plane, parallel to the optical surface, and positive in the beam propagation direction.

The x-axis is in the reflection plane, normal to the optical surface and positive in the direction away from the storage ring.

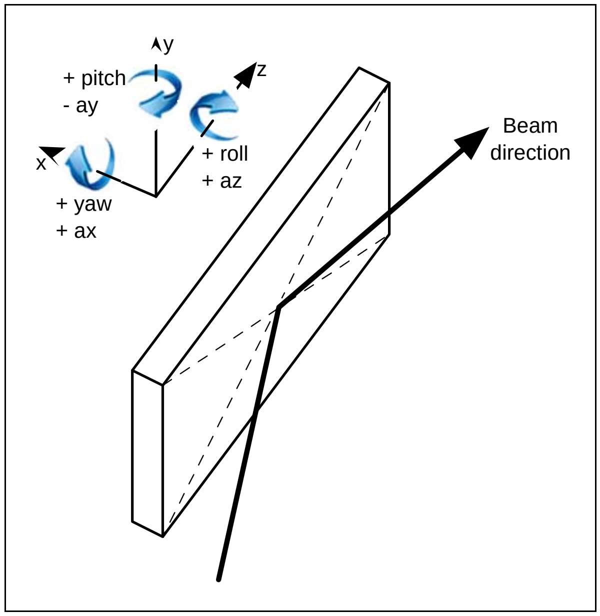

Figure 3: Axis definition for horizontal inboard deflecting optic

A.3 Vertical deflecting transmission optic

The y-axis is in the reflection plane, parallel to the optical surface, and positive in the upwards direction.

The z-axis is in the reflection plane, normal to the optical surface, and positive in the beam propagation direction.

The x-axis is normal to the reflection plane, parallel to the optical surface and positive in the direction away from the storage ring.

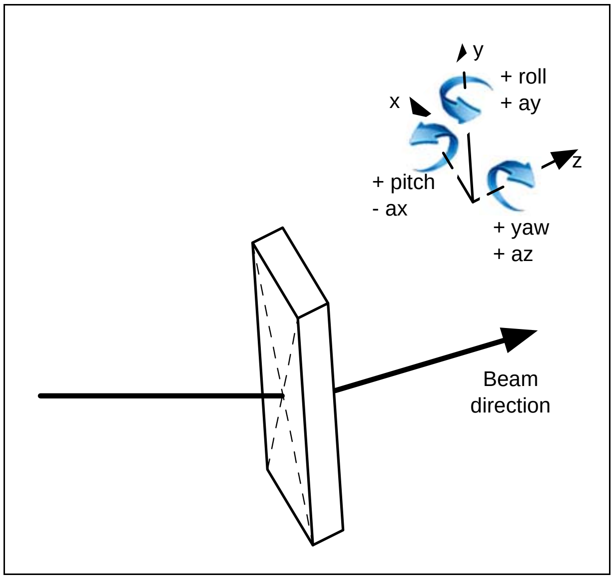

Figure 4: Axis definition for vertical upward deflecting transmission optic

A.4 Horizontal deflecting transmission optic

The y-axis is normal to the reflection plane, parallel to the optical surface, and positive in the upwards direction.

The z-axis is in the reflection plane, normal to the optical surface, and positive in the beam propagation direction.

The x-axis is in the reflection plane, parallel to the optical surface and positive in the direction away from the storage ring.

A.5 Monochromators

Monochromators will generally use the definitions above, depending on the type and orientation.

Monochromator crystal translations

One crystal of a monochromator may have a parallel and perpendicular translation in order to maintain a fixed exit position of the beam. The crystals are rotated from the beamline reference frame by the Bragg rotation of the monochromator. These translations are defined relative to the optic reference frame for the second crystal, so are referred to as z for the parallel translation and y (for vertical bounce) or x (for horizontal bounce) for the perpendicular translation.

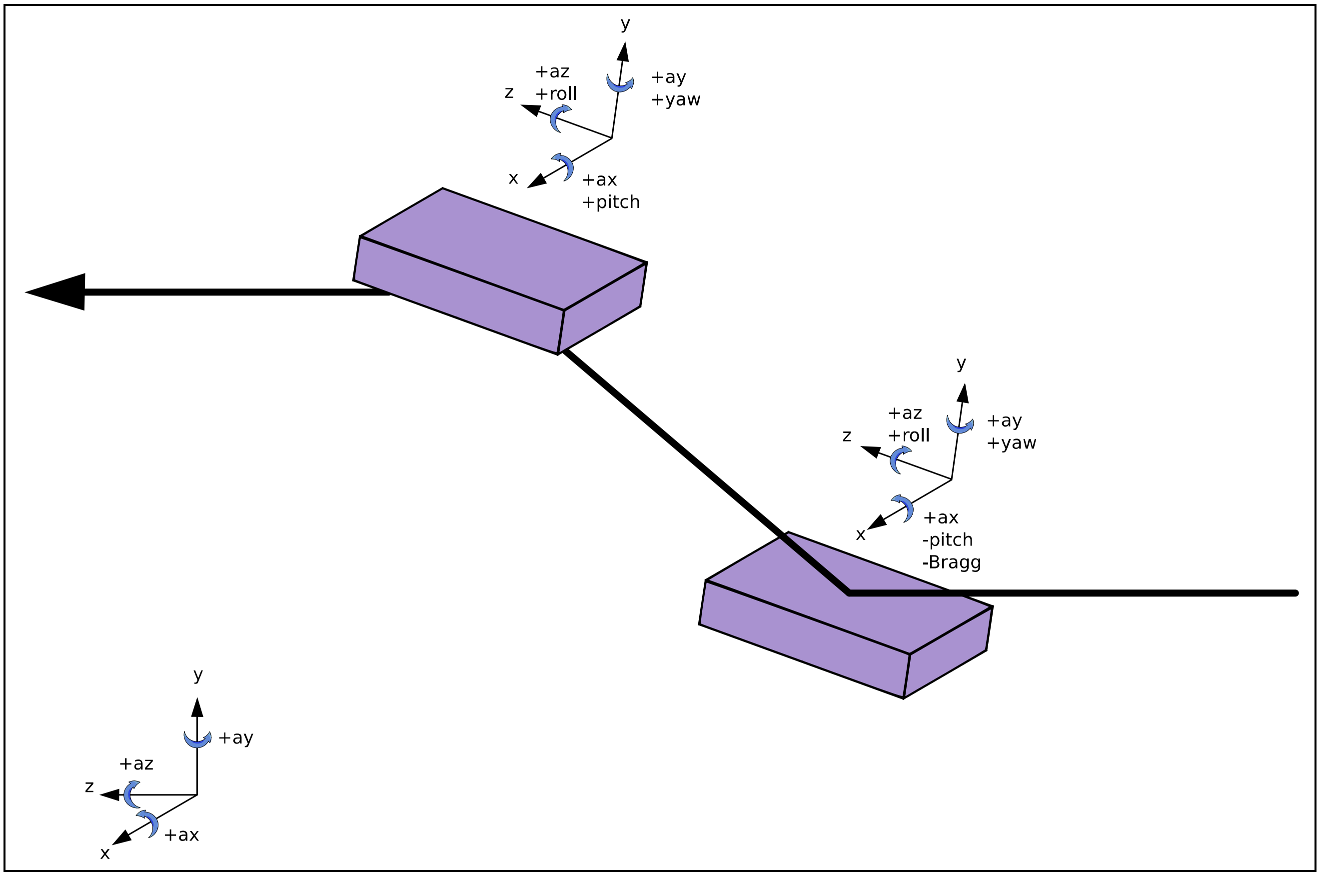

Figure 5: Monochromator coordinate system

A.6 Slits

The end-user definition for slits motion is that positive movement results in an opening of the slit aperture. In other words, a positive movement of the blade is away from the nominal slit center position.

B ROTATION DEFINITIONS

Cartesian axis	Rotation	Bounce up	Bounce down	Bounce in	Bounce out
z	ax	– Pitch	Pitch	Yaw	Yaw
y	ay	Yaw	Yaw	– Pitch	Pitch
z	az	Roll	Roll	Roll	Roll

Table 1: Mirror rotation axis definitions

Cartesian axis	Rotation	Vertical 1st crystal	Vertical 2nd crystal	Horizontal 1st crystal	Horizontal 2nd crystal
x	ax	+/– Bragg[1]	–/+ Pitch[1]	Yaw	Yaw
y	ay	Yaw	Yaw	+/– Bragg[1]	–/+ Pitch[1]
z	az	Roll	Roll	Roll	Roll

Table 2: Monochromator rotations

Cartesian axis	Rotation	Vertical deflecting	Horizontal deflecting
x	ax	+/–Pitch[1]	Roll
y	ay	Roll	+/–Pitch[1]
z	az	Yaw	Yaw

Table 3: Transmission optic rotations

[1] The sign depends on whether the optic is scattering in the upward, downward, inboard or outboard direction. The sign should reflect the end user requirements of each optic. Typically, the second optic in a pair (as in a double crystal monochromator) will have the opposite sign to the first optic.

C ROTATION PROJECTION DRAWING

The following figure shows projections of a rotated mirror which give definitions of pitch, roll, and yaw, as well as showing the different orientations of the beam and optic axes.

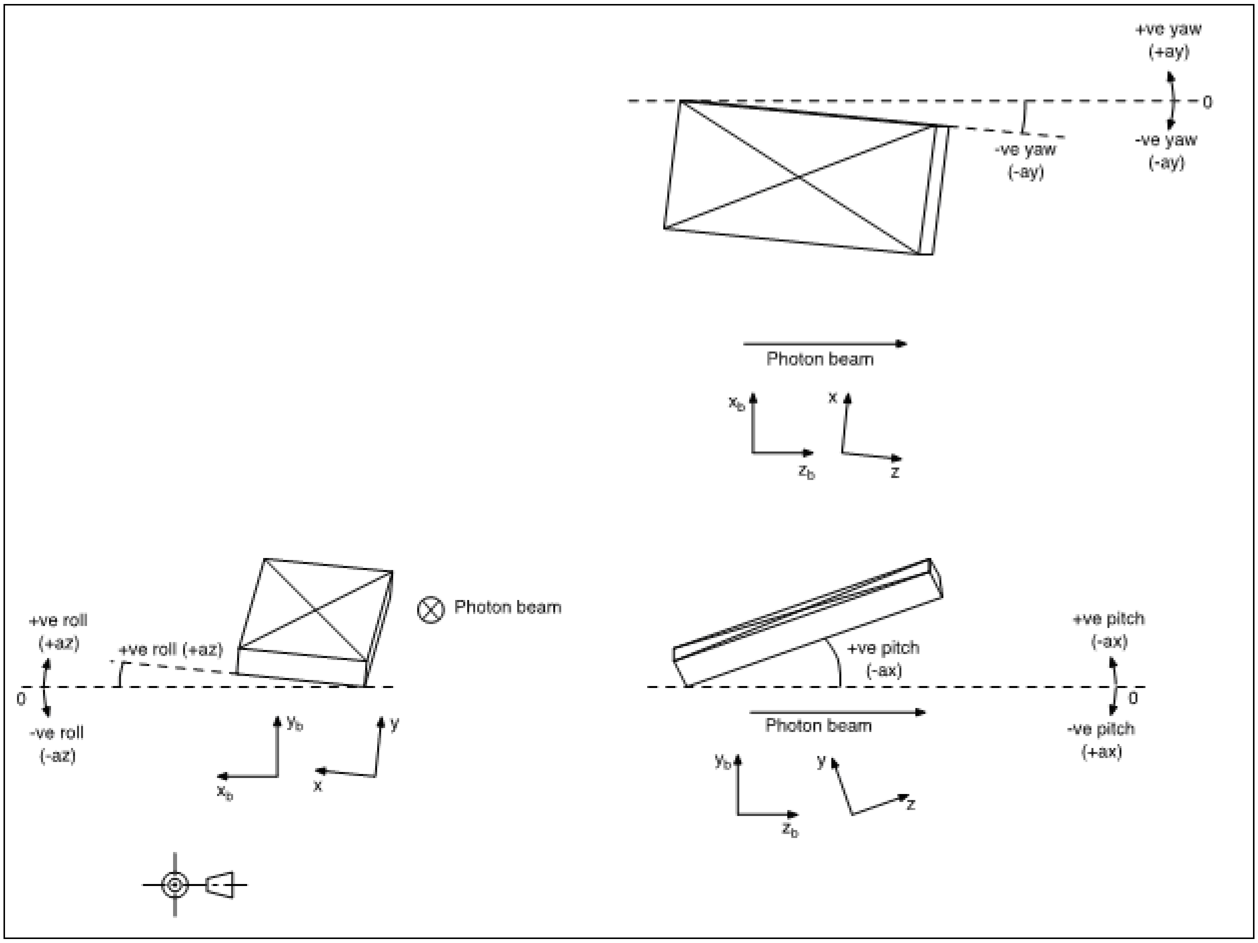

Figure 6: Third angle projection of mirror showing orientation of axes

D EXISTING COORDINATE SYSTEMS

D.1 Survey and alignment

A coordinate system exists which allows the position of each component in the facility to be defined relative to each other and a fixed origin.

D.2 Accelerator

The accelerator has adopted a right-handed coordinate system, with the z-axis positive in the direction of the electron beam, the y-axis positive vertically upwards and the the x-axis positive in the outboard (away from the center of the storage ring) direction. The accelerator also defines an s position, which is the distance around the ideal electron beam orbit.

D.3 Insertion devices

The insertion devices have adopted a left-handed coordinate system. The y- and z-axis definitions are the same as in **Error! Reference source not found.**, but the x-axis is defined as positive in the inboard direction (toward the center of the storage ring).

D.4 NSLS

Many beamlines at NSLS define y to be the beam direction, z to be vertically upwards, and x to be horizontal, perpendicular to the beam. The axis definitions proposed in this document differ from this existing standard.

D.5 NSLS Mechanical Design Office Standards

The NSLS-II Mechanical Design Office Standards Manual, LT-MECH-ENG-0001, defines a cartesian coordinate system with axis definitions consistent with the accelerator and beamline coordinate systems.

D.6 Design software

The Shadow ray-tracing software defines the z-axis as normal to the optical surface of the optic, the y-axis as parallel to optic surface in the direction of beam propagation, and the x-axis as parallel to the optic surface and normal to the reflection plane.

E ENDSTATION COORDINATE SYSTEMS

Endstations have a range of systems that can provide different translations and rotations. Also, user communities may have specific requirements of the coordinate systems.

E.1 Three-circle diffractometer

A diffractometer that has three concentric circles has the sample mounted on the inner circle, and the detectors on the middle and outer circles (e.g. a typical powder diffraction setup). The inner circle is designated a theta axis, and the two outer circles are two-theta axes.

E.2 Four/five/six circle diffractometers

This is yet to be defined. One option is to use the Spec definitions. This section will be updated prior to specification of the first four circle diffractometer. Using the Spec axis definitions would end up changing the definitions of x,y, and z, with y being positive from the sample towards the beam source, x positive upwards, and z positive inboard .

Theta, chi, phi, and two-theta are standard definitions for diffractometers. Two-theta is the rotation that changes the angle between the sample and the detector, theta is the outermost circle with the same rotation axis as the two-theta circle. The chi circle is mounted on the theta circle, with its axis of rotation perpendicular to the theta circle. The phi circle is mounted on the chi circle with its axis of rotation in the plane of the chi circle. Two-theta can rotate independently of the other circles. The detector is mounted on the two-theta circle, and the sample mounted on the phi circle and positioned in the center of rotation of the theta, chi, and phi circles.

E.3 Sample coordinates

Samples are often be mounted on translation stages that can be capable of up to three orthogonal movements. These axes are referred to as x, y, and z, with the axis definitions lining up with the beamline reference frame axes when the diffractometer theta, chi, and phi are all at zero.

If fewer than three axes are provided for the sample, then the axis designations match those axes of the beamline reference frame that the sample stage axes align with.

E.4 Protein crystallography

For protein crystallography, omega and kappa are defined. Omega is the outermost rotation of the goniometer, and is typically analagous to theta (or rotation about the x-axis) in the standard rotational axis definition. Kappa is a rotation stage with the rotation axis at a non-90 degree angle to the omega rotation axis. A phi rotation stage is then mounted on the kappa stage. The sample is mounted on the phi stage, usually with some translation capabilities.

E.5 Others

Other experimental endstations and experimental techniques that require specific coordinate system definitions will be added as they are identified.