Preliminary QIKR Motion Design Review Engineering Overview

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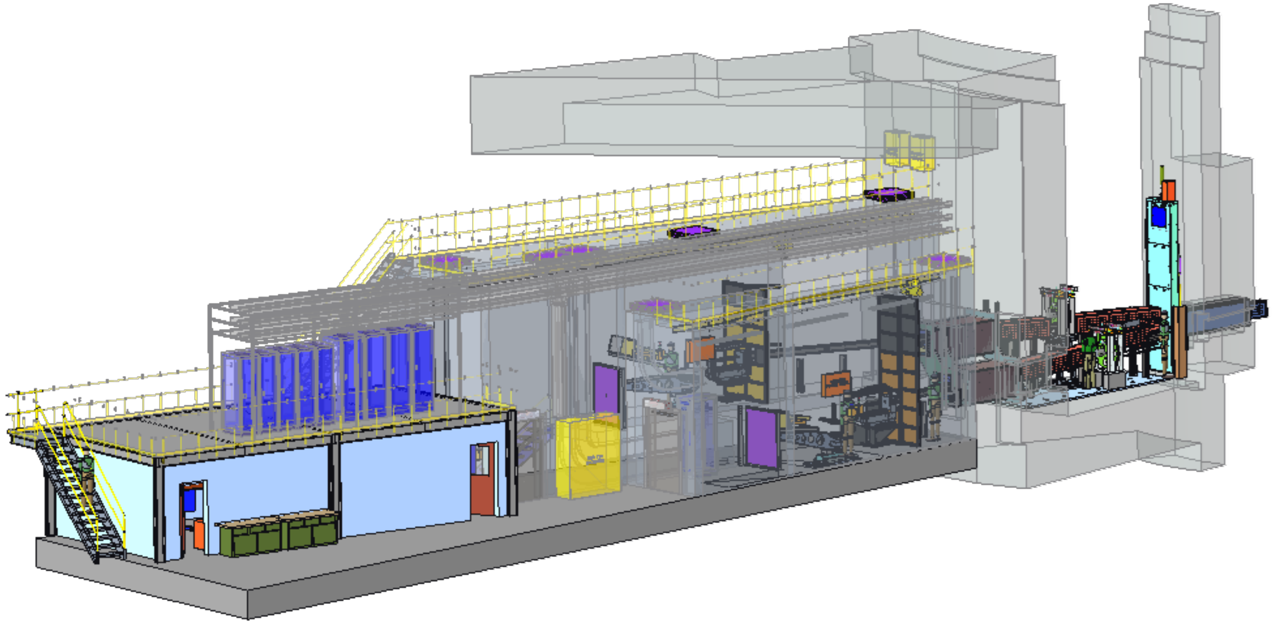
November 06, 2024

Outline

- Science Needs (John Ankner)
- Scope & Definition
- QIKR Overview
  - Documentation
  - QIKR & Motion Overview
  - Installation of Components in Cave
  - Pits and Cable Routing
- Discussion of Components
  - Maintenance Shield & Shutter
  - Incident Table (with Slits and Frame Overlap Mirror)
  - Detector/ Sample Table (with Hexapod and Sample Handler)
- Summary



Scope & Definition

Review Scope

Included

- QIKR Maintenance Shield overview
- QIKR Shutter (excluding safety aspects)
- Attenuator
- Slits overview
- Sample Changer overview
- Frame Overlap Mirror overview
- Incident Table
- Sample & Detector Table Assembly

Not Included

- Maintenance Shield operation, fabrication, and installation details (covered in Bunker PDR)
- Shutter operation safety details (covered in Bunker PDR)
- Slit operation details (QIKR is currently using a COTS version, not an original design)
- Sample Changer details (using the same assembly as is being used for BL4B)
- Frame Overlap Mirror details (QIKR currently uses a motion scheme similar to what is used on BL4B)

QIKR Overview

- Documentation
- QIKR & Motion Overview
- Installation of Components in Cave
- Pits and Cable Routing

Requirements, CQLD, Interface Documents

- **Requirements Documents**:
  - QIKR Motion System requirements: **S04080600-SRD10000-R00** (released)
  - QIKR Instrument Requirements: **S04080100-SRD10000-R02** (not released)
    - The latest revision (R02) has not been released yet, awaiting optics alignment updates
- **CQLD**:
  - Quality Level 2, Configuration Level 3: **S04080600-QAI10000-R00** (released)
    - Quality Level 2 is primarily because of the importance of motion component failures on QIKR and because some components may be difficult to source from multiple vendors
- **Interface Documents**:
  - Interface to CF (pits in the cave): **S04010100-C8U-8800-A10000** (released)
  - Interface to ICS (motion): **S01020500-IST10118-R00** (released)
    - Design is compatible with motion interface requirements

Link to more interface document details

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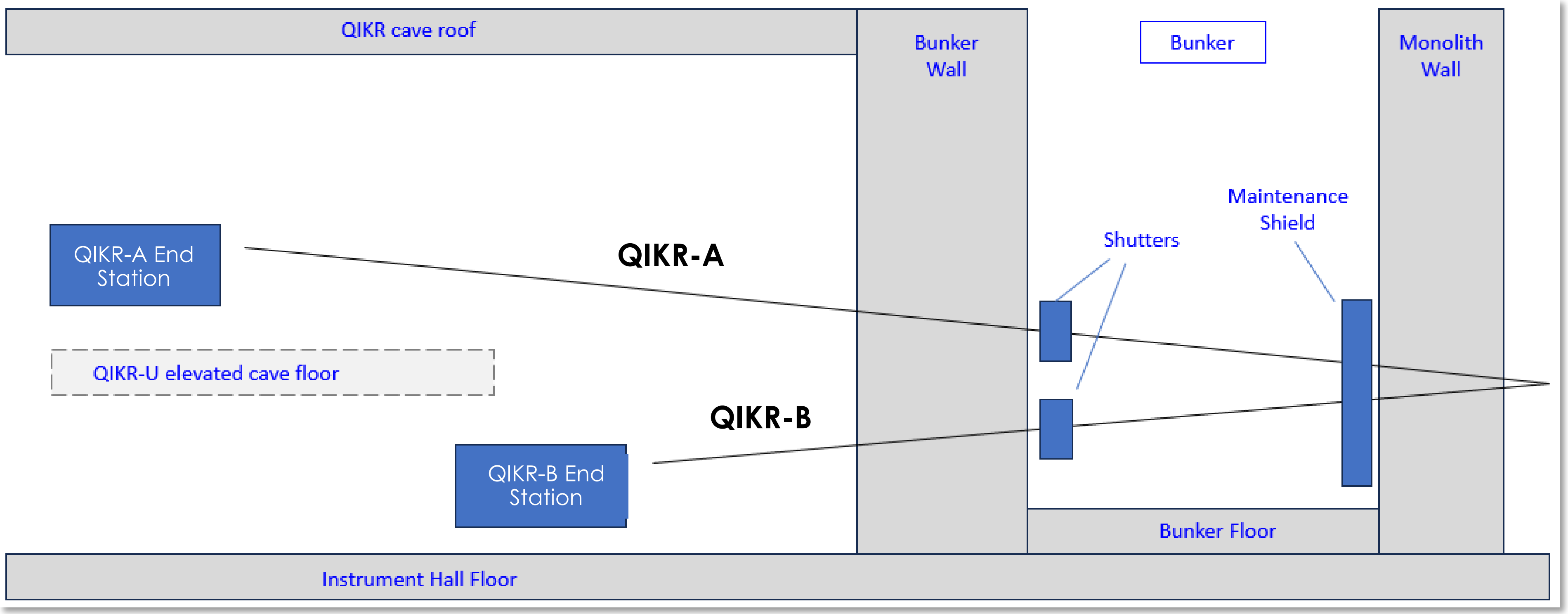
Additional Reference Documents

- **Seismic Design**:
  - Design guidelines for STS Instruments: **S04010000-TDO10000-R02** (released)
    - Gives guidance on performing seismic restraint calculations

- **ICS Reference**:
  - Motion Design Guidelines: **107030201-DCD10000-R00** (released)
    - Gives guidelines on types of components to use (stepper motors, roller switches), recommended limits on motor current & voltage, etc.
    - Written for SNS & HFIR, but applies to STS as well

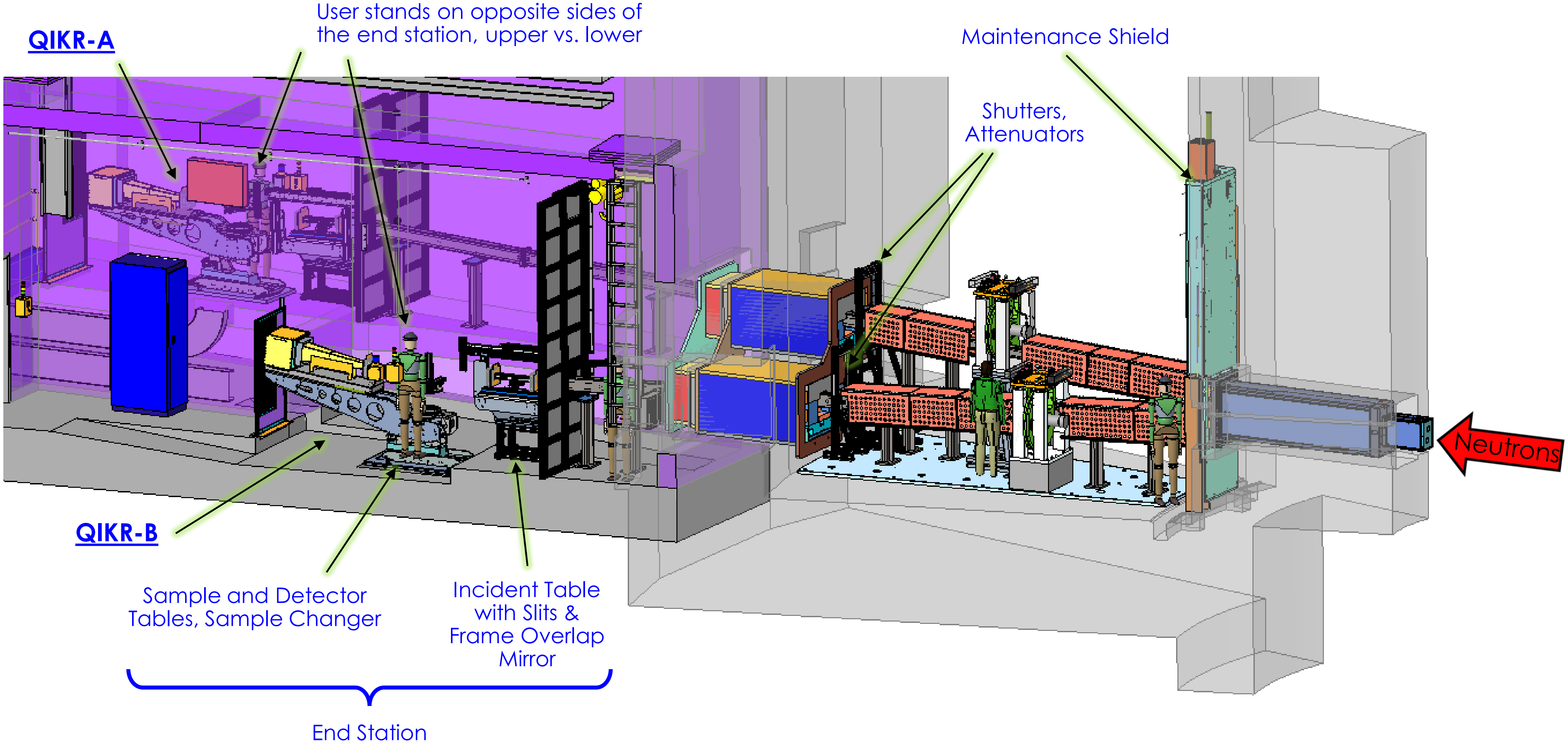
- **FMEA document**:
  - **STS FMEA_QIKR Motion Components_Oct-25-2024**.xlsx (not released)
    - Created by D.Wilson, R.Thermer, J.Ankner, M.Pearson
    - Contains 32 line items, 6 items of concern (discussed in the following slides)

QIKR – Schematic View

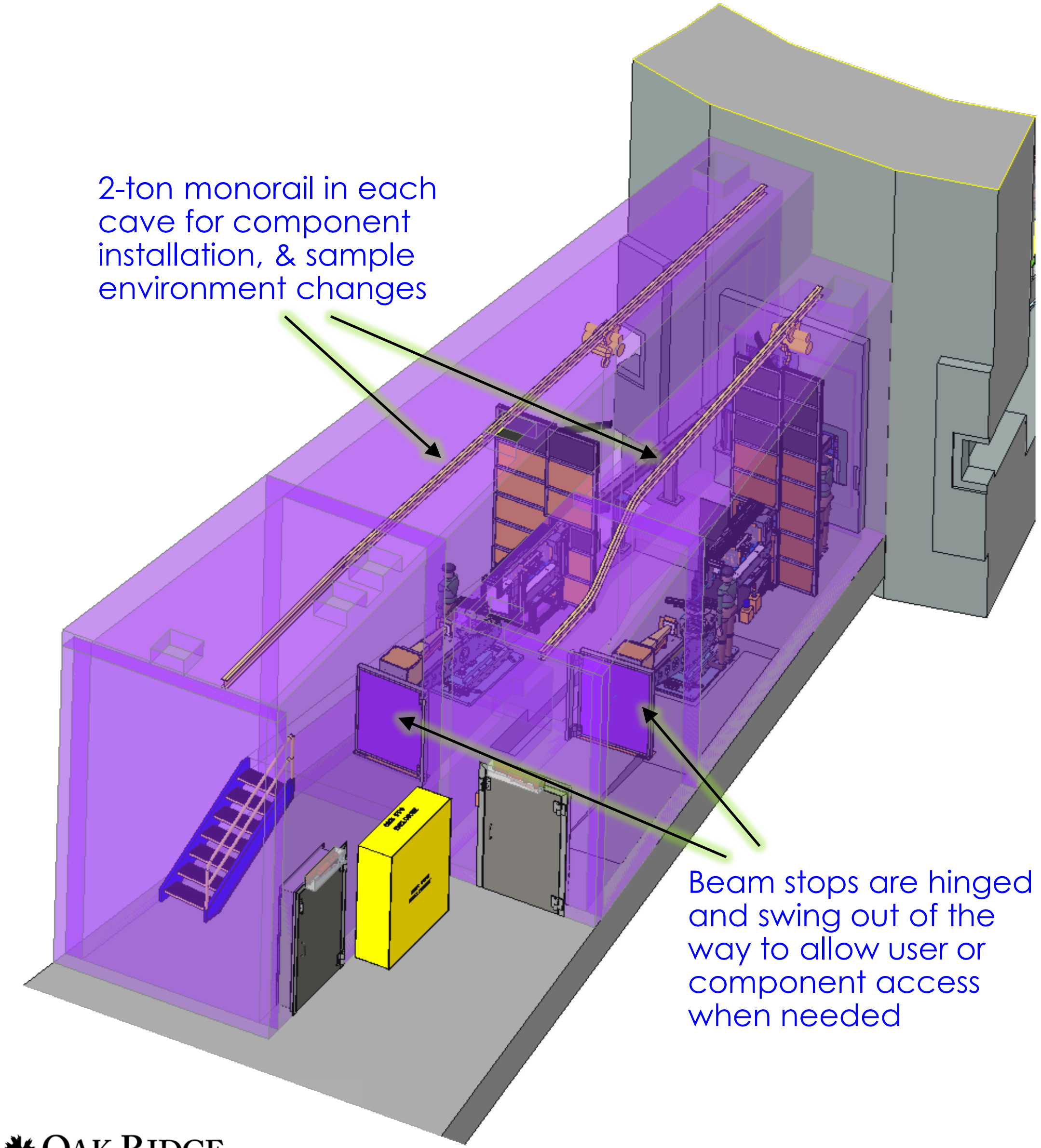


- The shutters also contain the attenuators
- The End Station consists of the Incident Table with Slits and Frame Overlap Mirror, the Sample Table, the Detector Table, and the Sample Changer

QIKR –3D Model View

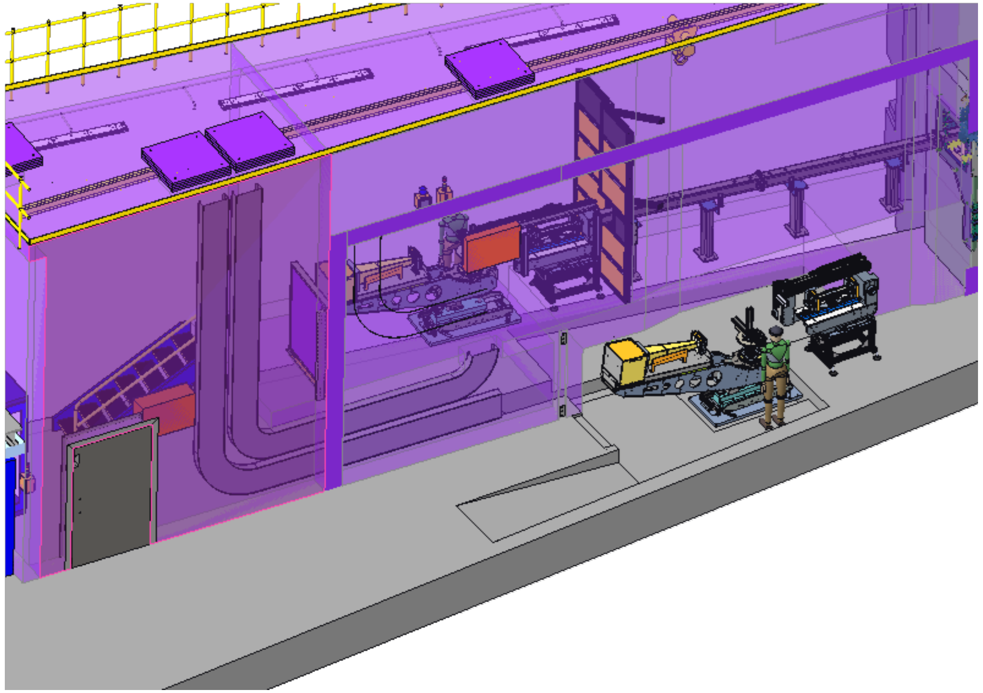


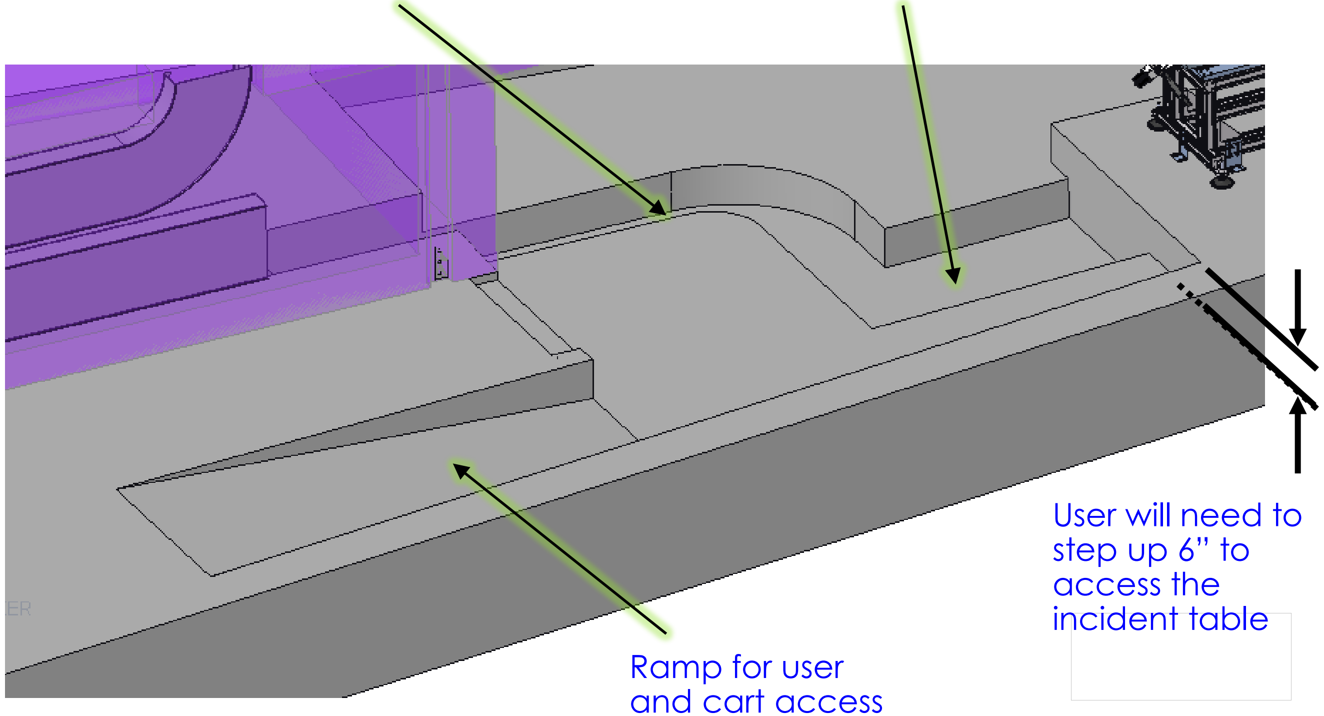
Installation of Components



- All QIKR in-bunker components will be installed by removing the bunker roof panels and using the 50-ton high bay gantry crane
- Most QIKR in-cave components will be installed by bringing the components into each cave on a cart, then carrying them to their final location with a 2-ton monorail hoist
- The monorail will also be used during operations to swap sample environments and to service end station components

Need for a QIKR-B Pit

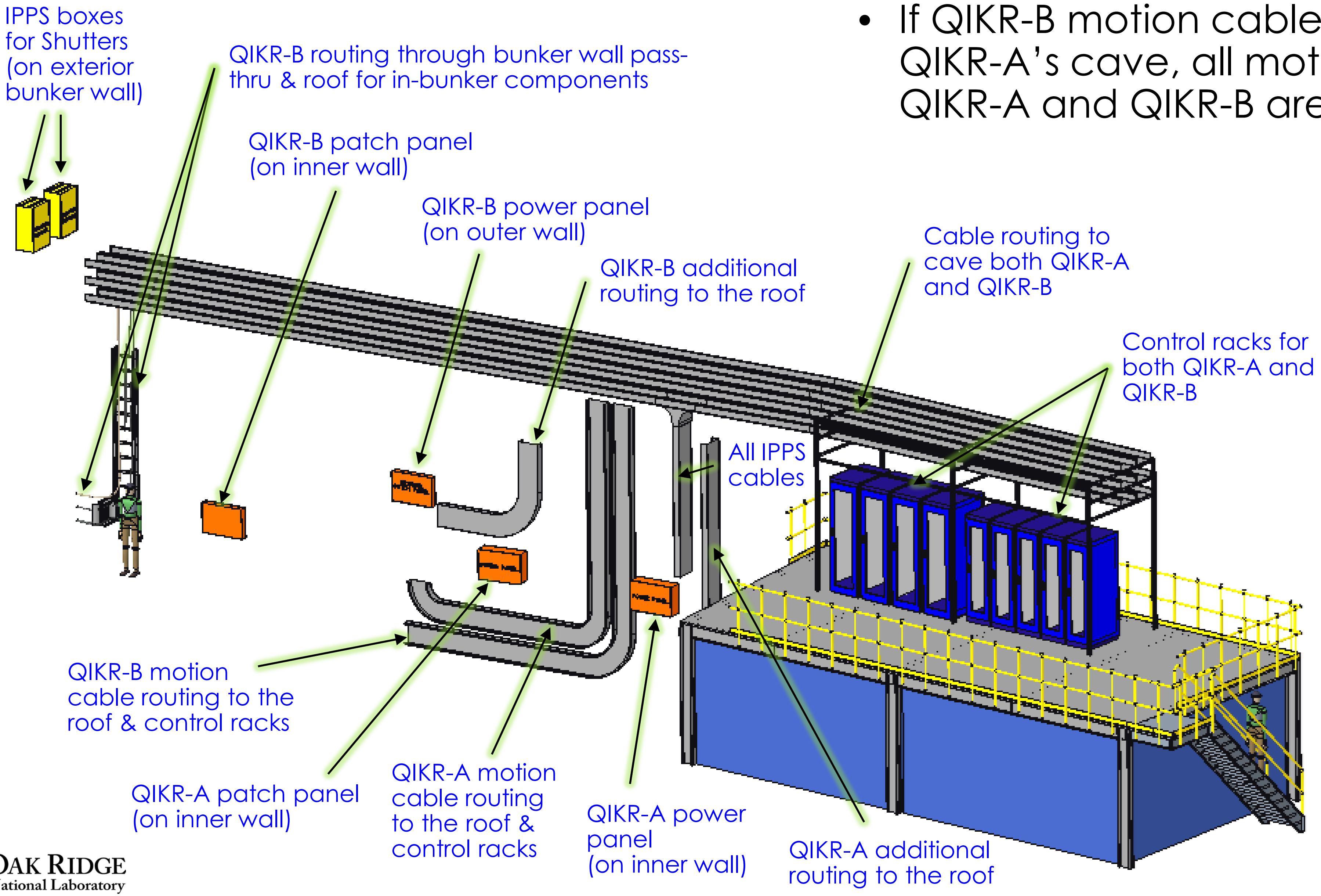




- QIKR-B requires a pit for the end station because of the downward sloping beam
- The pit is two-level to allow a reasonable height for the user to stand & to wheel in equipment carts
- The end station pit is combined with a cable channel to route motion cables into the upper cave (QIKR-A), then out to the control racks through the QIKR-A roof

Cable Routing

- If QIKR-B motion cables are routed through QIKR-A's cave, all motion cables for both QIKR-A and QIKR-B are under 30m in length



Discussion of Components

Maintenance Shield and Shutter

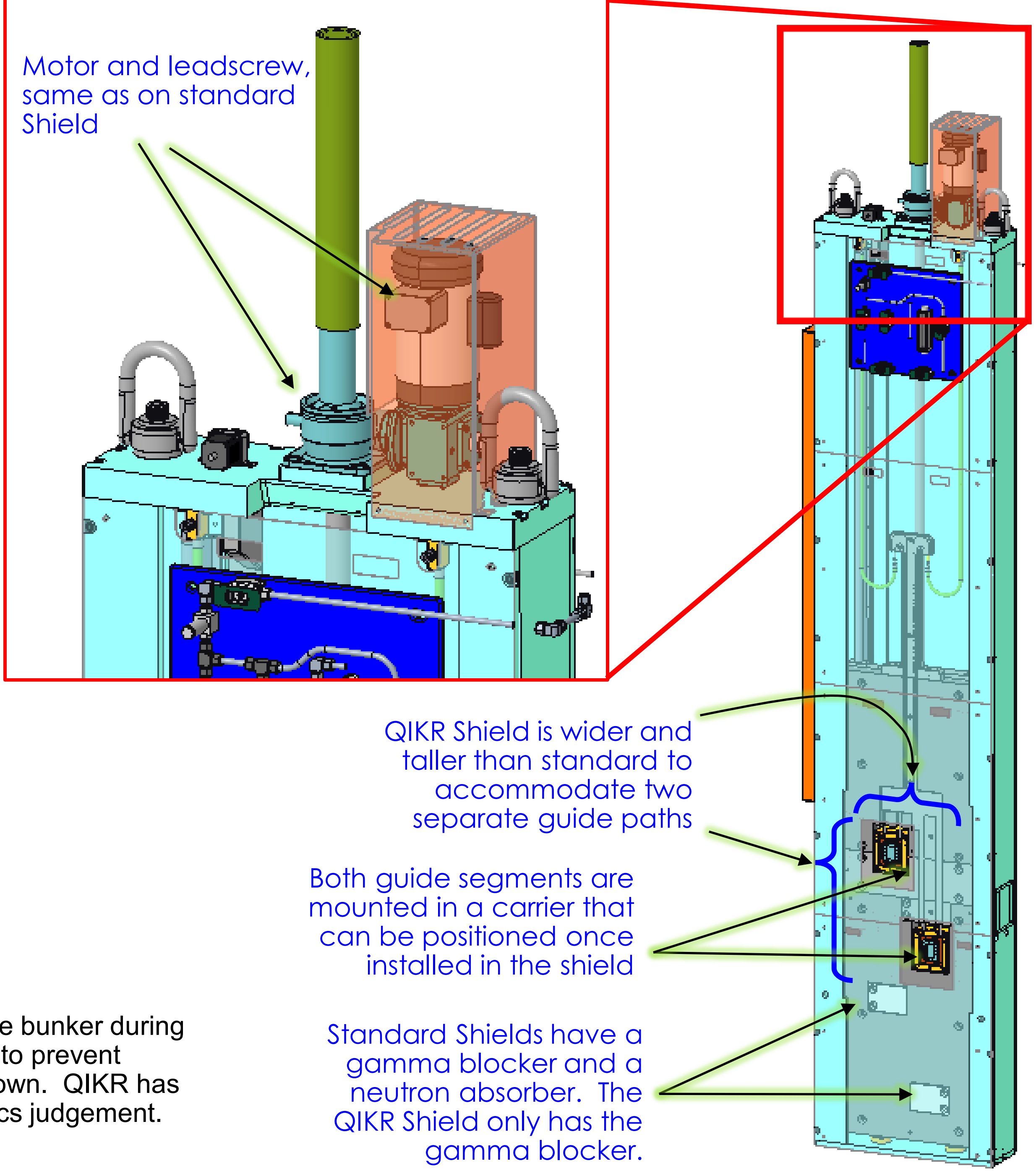
Maintenance Shield – Overview

- The Maintenance Shield at STS is different from the SNS Primary Shutter
  - The Shield is **not** used as a shutter to allow access to the cave
- The standard Maintenance Shield does one of three things:
  1. Allows beam to pass from the moderator out of the monolith wall and into the instrument guide system
  2. Blocks gamma radiation from the monolith area when the proton beam is off to allow safe personnel access to the bunker
  3. Blocks neutrons when the proton beam is on to prevent excessive activation of a failed bunker component
- Each instrument must have a Maintenance Shield and must also have a Shutter… the Shutter blocks neutrons to a degree that allows personnel access to the instrument caves during beam operation

Maintenance Shield

- The QIKR Maintenance Shield follows the standard design developed by Bunker (same motor, hard stops, PPS and control switches)
- The overall height and width of the Shield is different for QIKR
  - QIKR Shield must accommodate two guide paths
- The QIKR shield only has two positions versus the standard three positions*
  - QIKR does not have a neutron absorber, only a gamma blocker, so the Shield only has to move between "gamma blocker" and "open" positions

*__NOTE__: The gamma blocker is used to allow safe personnel access to the bunker during proton beam shutdown. The neutron absorber blocks the neutron beam to prevent excessive activation of a failed component prior to the next beam shut down. QIKR has no components that would experience excessive activation, per neutronics judgement.



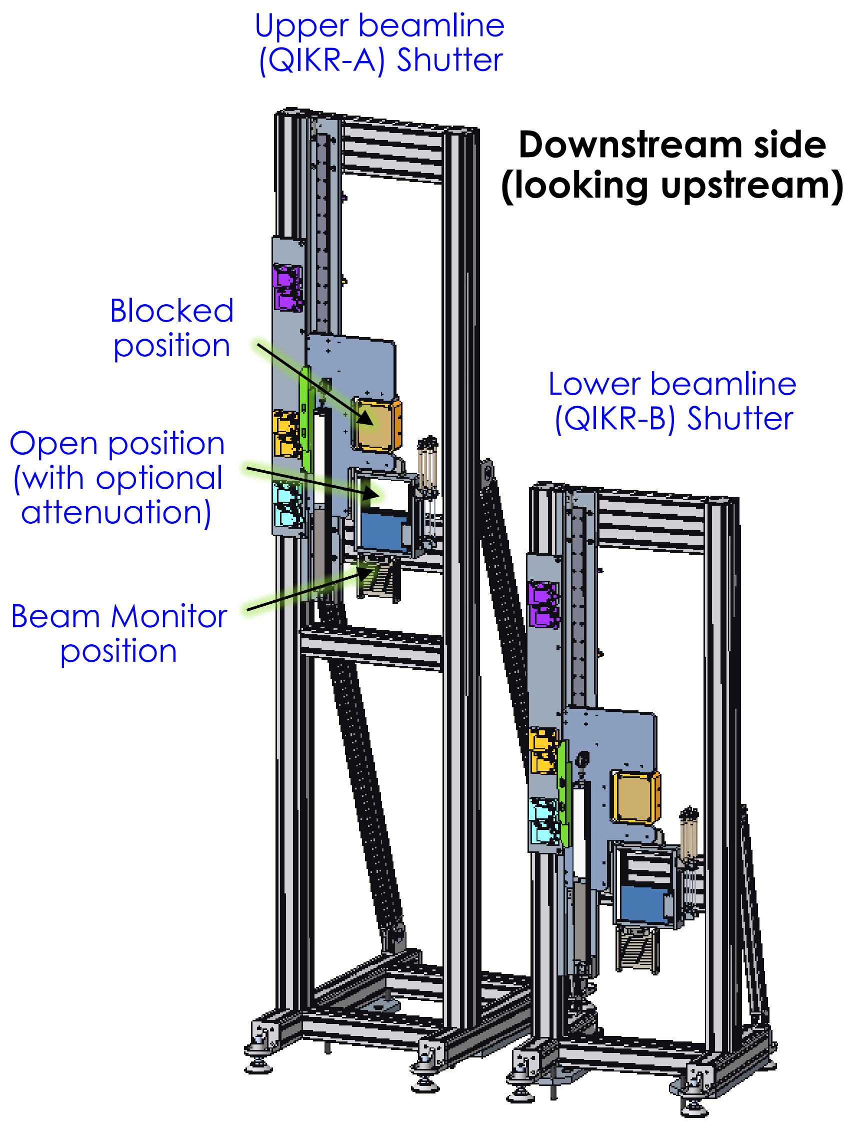
Maintenance Shield Requirements

From **S04080600-SRD10000-R00**

- S.04.08.06-R142 – The maintenance shield must follow standard shield design for general function and safety (see the maintenance shield requirement document listed in the reference table) with one exception: the neutron absorber may be omitted.
  - The QIKR maintenance shield does follow the standard shield design for general function and safety
- S.04.08.06-R143 – The maintenance shield must provide the ability to manually align two guide segments within the shield.
  - The QIKR maintenance shield does provide the ability to align two guide segments within the shield, though they currently cannot be adjusted independently when they are installed… can only be adjusted as a pair

NOTE: S.04.08.06-R142 will be further addressed in the Bunker Shutter PDR… maintenance shield operational details are not in the scope of this review. Installation, acquisition & manufacturing strategy, and costs will be addressed at the bunker PDR as well.

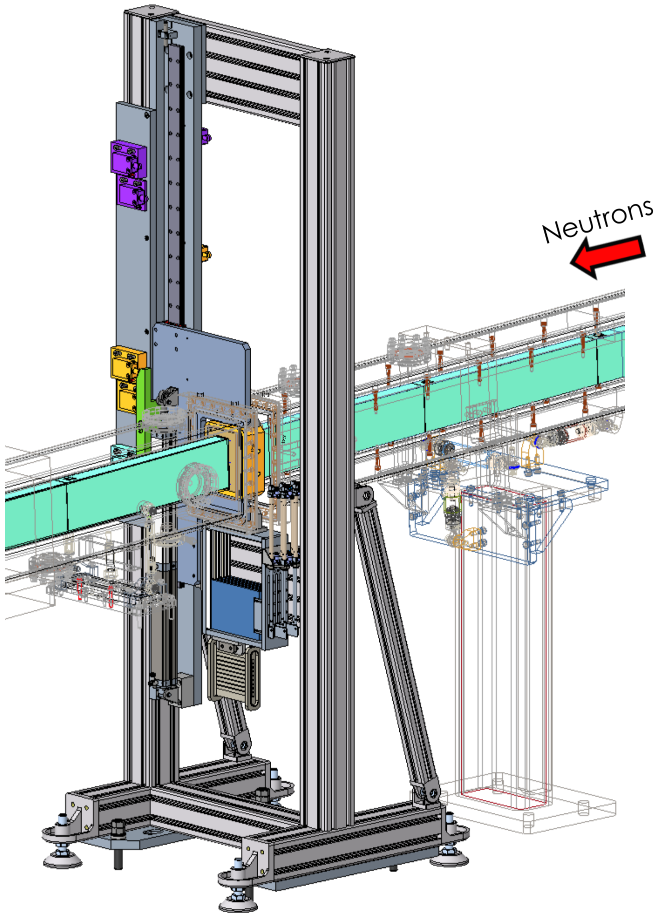
Shutter



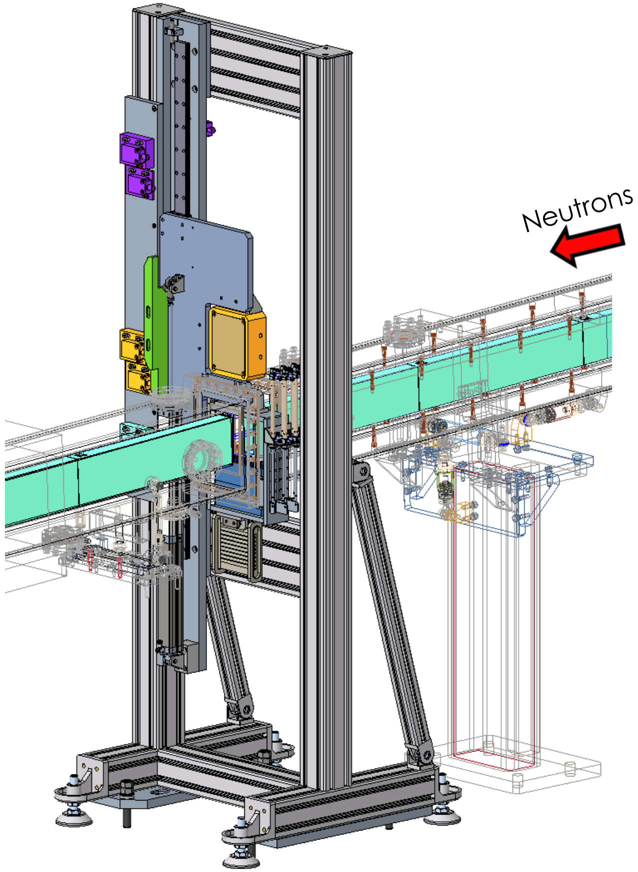
- The Shutter blocks the neutron beam to allow personnel access to the cave… there is one shutter per beamline (two total)
- The QIKR shutter follows the standard design for failsafe operation, support structure, and control & PPS switches
- The QIKR Shutter operation is different from standard in two ways:
  1. The "open" position also contains the attenuators
  2. There is a third Shutter position for a beam monitor
- The need to minimize guide gaps and windows drives the multi-functionality of the shutter

Design credit: Rudy Thermer

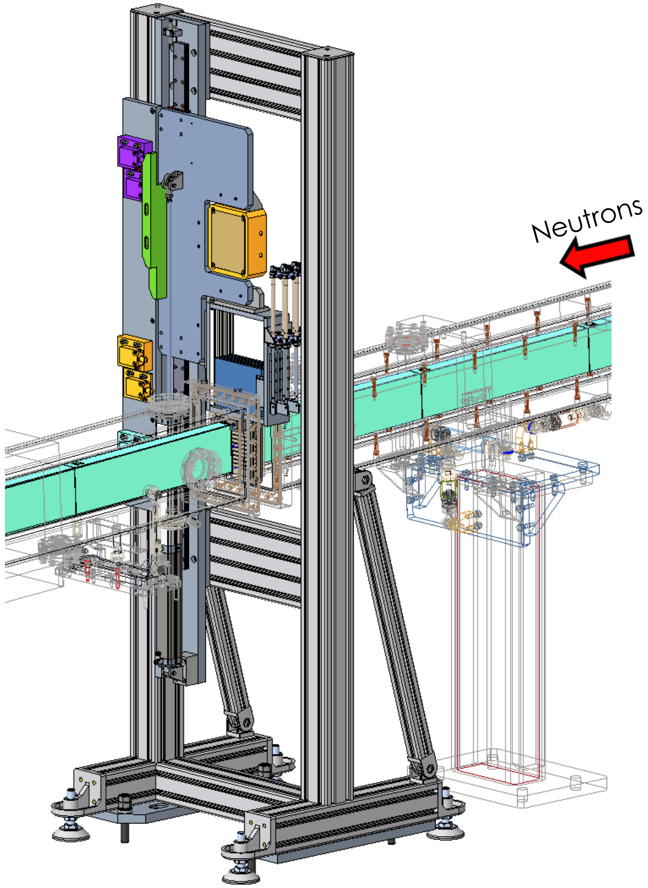
Shutter Positions



A) Beam blocker in position



B) Attenuator module in position



C) Multitube monitor in position

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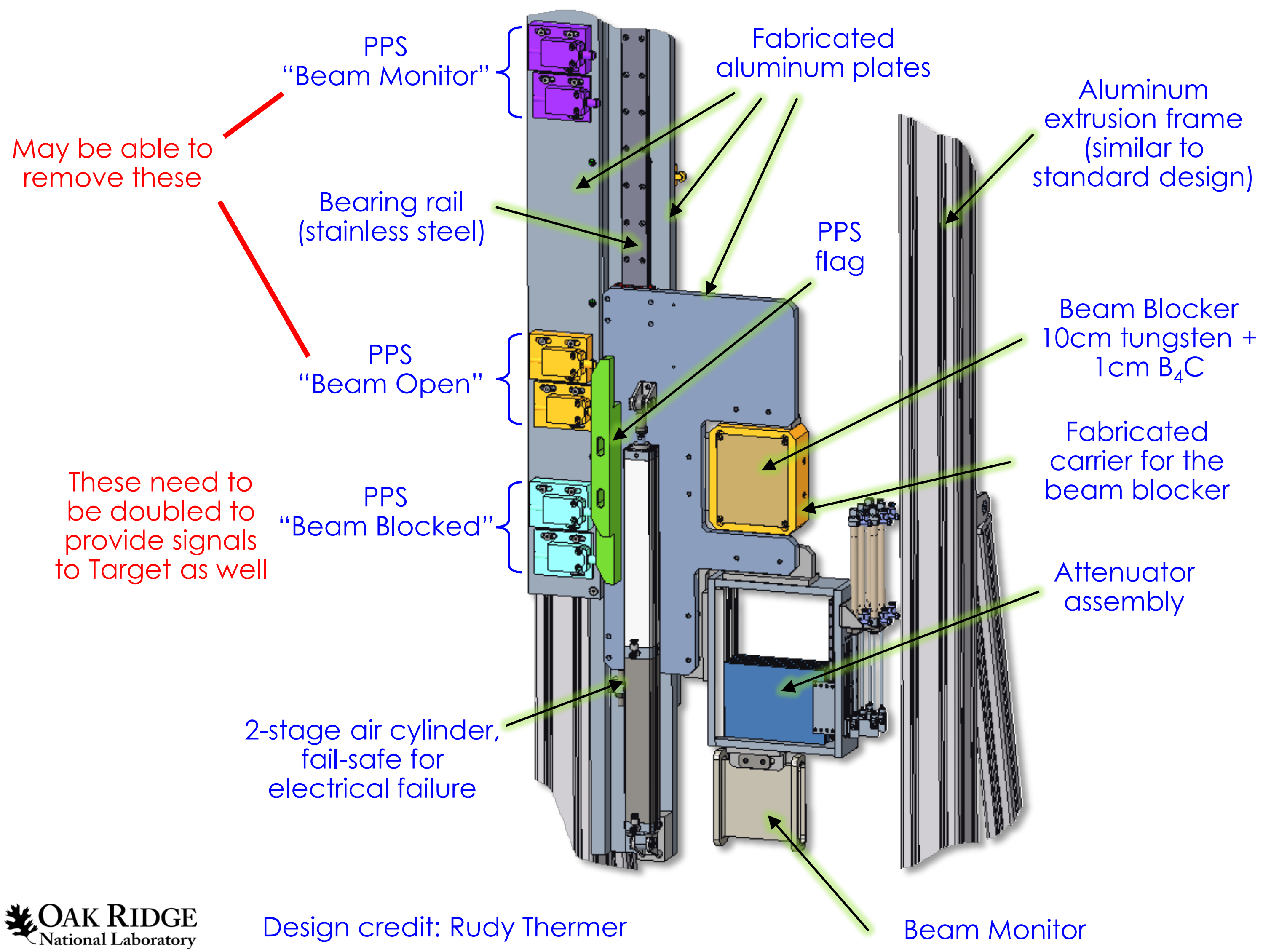
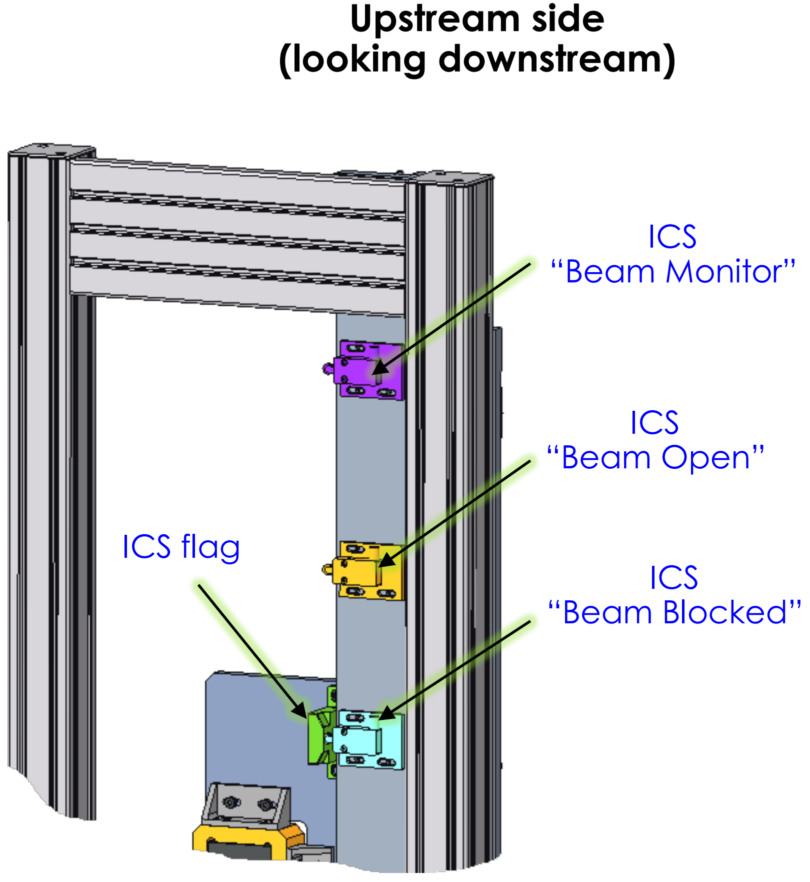
Design credit: Rudy Thermer

Shutter Components

Downstream side (looking upstream)



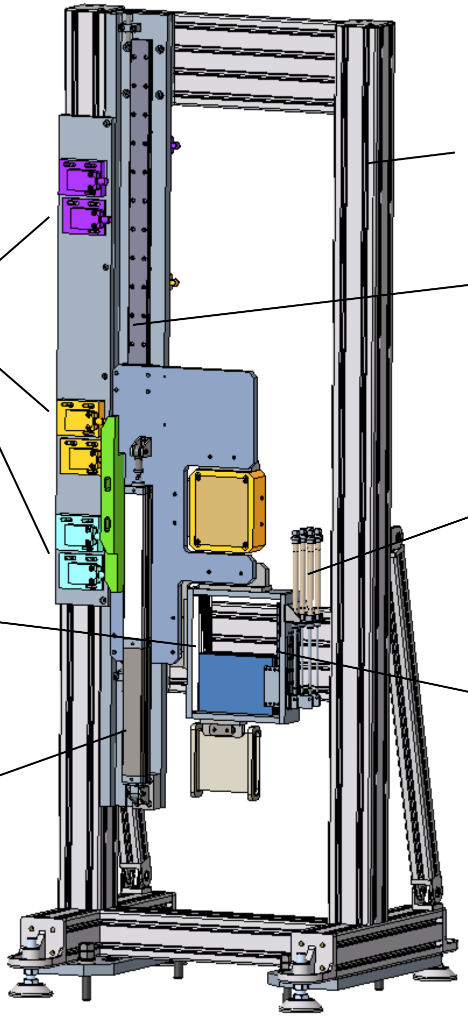
Upstream side (looking downstream)



Design credit: Rudy Thermer

Shutter COTS Component Details

- All components are from well-established companies which are sold through distributors in the US.
- Multiple vendors exist as alternates for the HIWIN, ITEM, FESTO, and Baumer products but not for the safety relevant Rockwell switches.



FESTO automation
https://www.festo.com/us/en/e/about-festo/company-id_3688/

HIWIN, precision motion control and system technology.
https://hiwin.com/

Rockwell automation and digital transformation technologies.
https://www.rockwellautomation.com/en-us.html

Baumer Group, Sensor Technologies.
https://www.baumer.com/us/en/company/a/Company

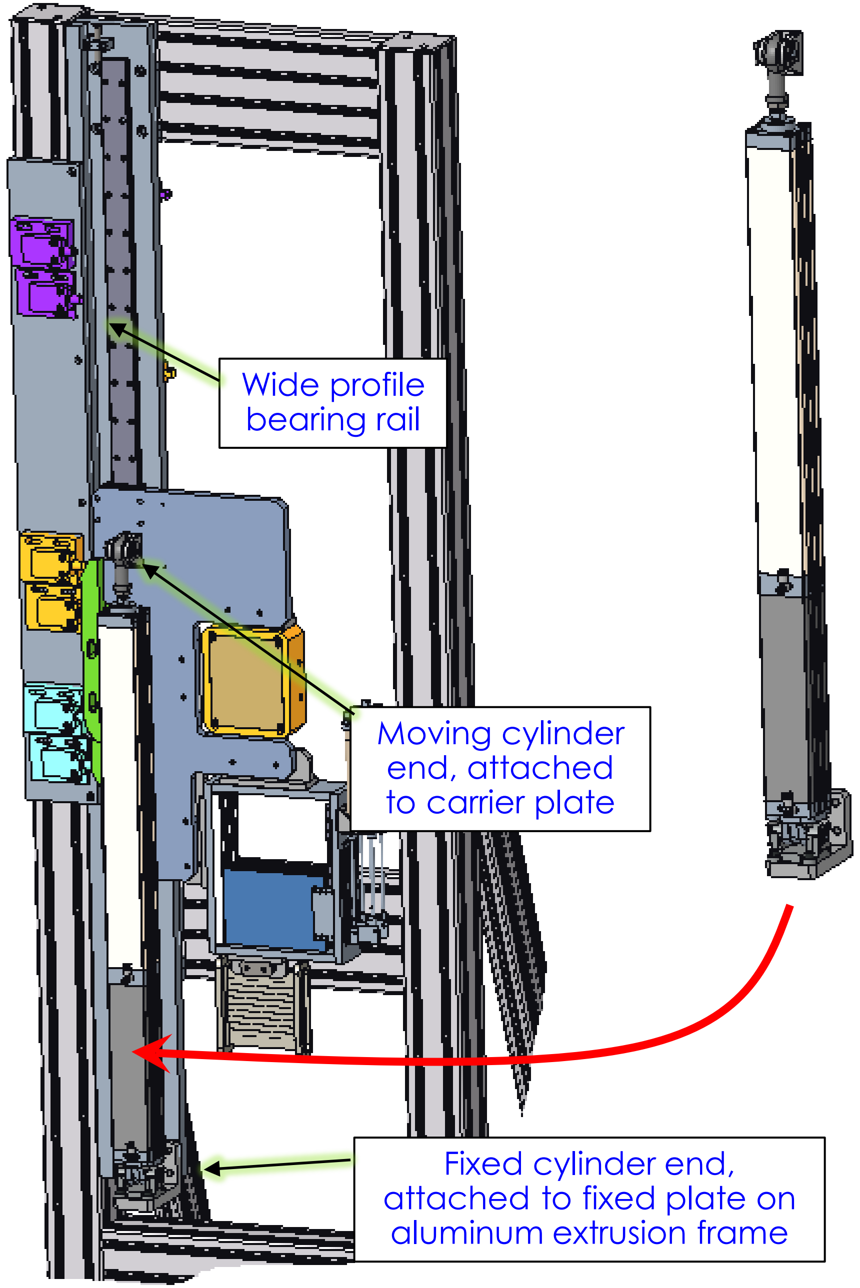
ITEM Ind. Technology GmbH, machinery and equipment construction.
https://www.item24us.shop/contact/

Note: There will be ICS and PPS switch junction boxes and solenoid valves that are not shown.

Design credit: Rudy Thermer

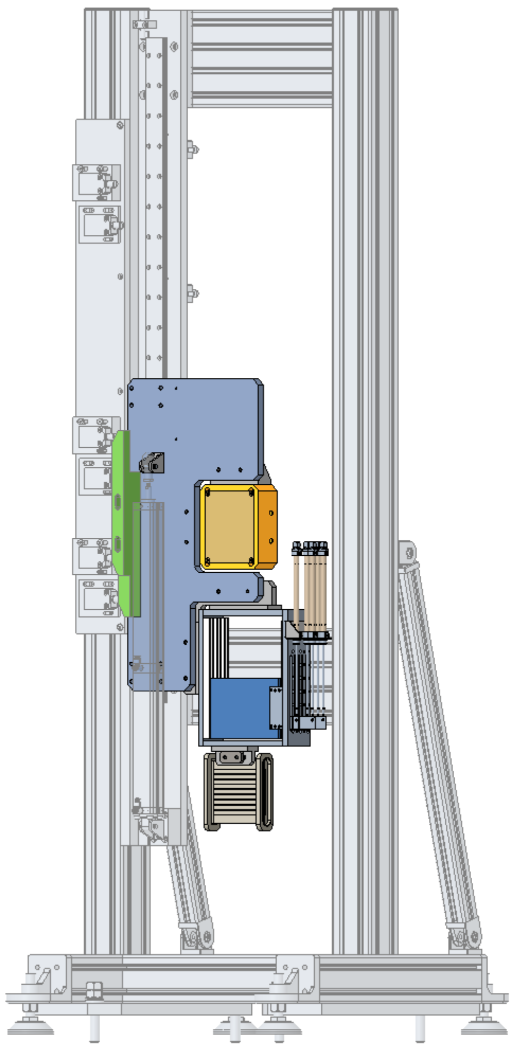
Shutter – Air Cylinder

- Air cylinder attachment to frame & carrier plate
  - The cylinder is mounted vertically and works against gravity. The blocker is in the beam when the cylinder is depressurized & fully retracted.
  - The use of a two-stage cylinder with suitable stroke lengths (first stage travel ~200mm, second stage ~240mm) enables the positioning of the blocker, attenuator and multitube monitor with sufficient accuracy in the beam.
  - A solenoid valve control system (not shown) ensures safe beam shut-down (cylinder vents to atmosphere) in the event of a power loss, but can maintain position if only air is lost (depends on valve configuration).
- Bearing rail
  - The use of a wide profile rail guide helps to absorb unwanted forces for the pneumatic cylinder and ensures sufficient positioning accuracy.
  - The low bearing friction helps ensures a gravity driven beam shutdown. The valves can be configured to provide pressure to assist cylinder retract motion.

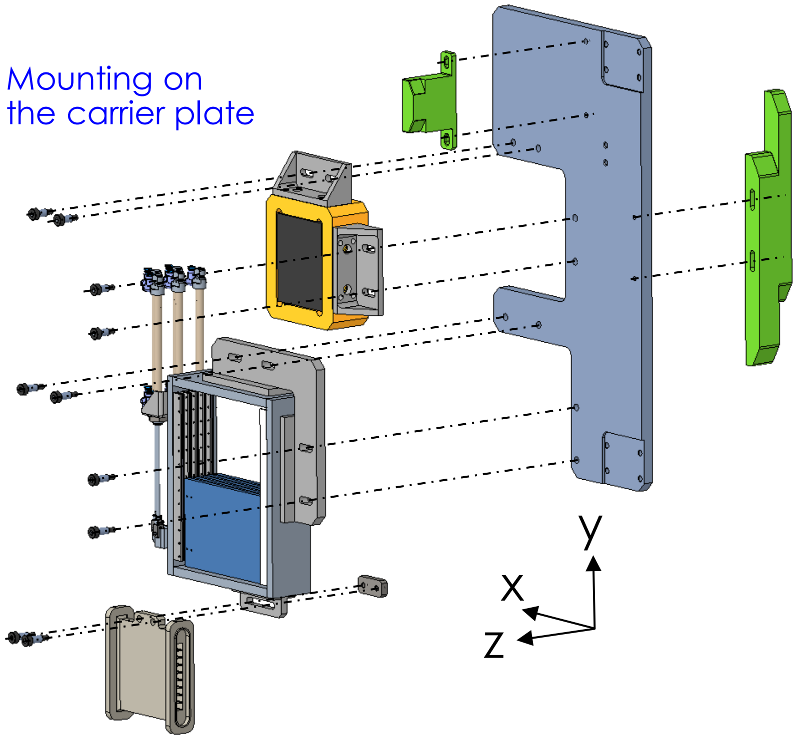


Design credit: Rudy Thermer

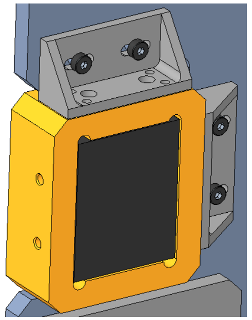
Shutter – Component Attachment to Carrier Plate



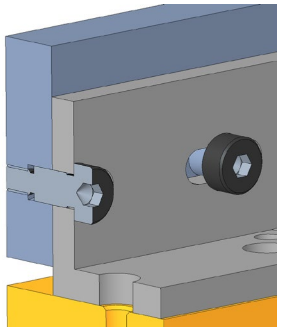
Mounting on the carrier plate



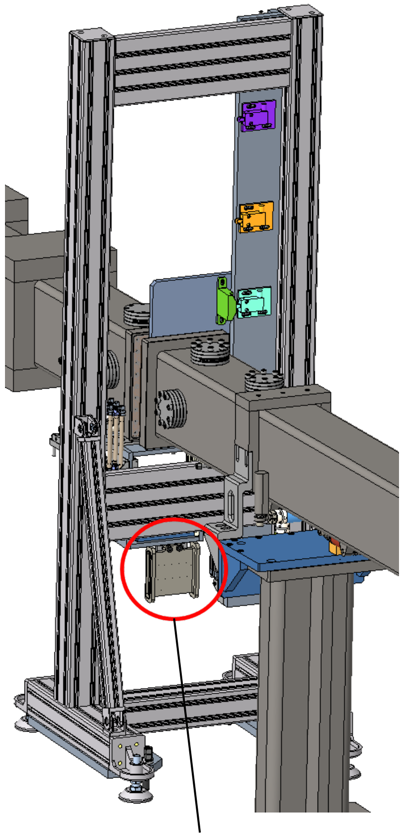
Elongated holes allow adjustment in x-direction



Nested shoulder fitting screw acts as a guide pin

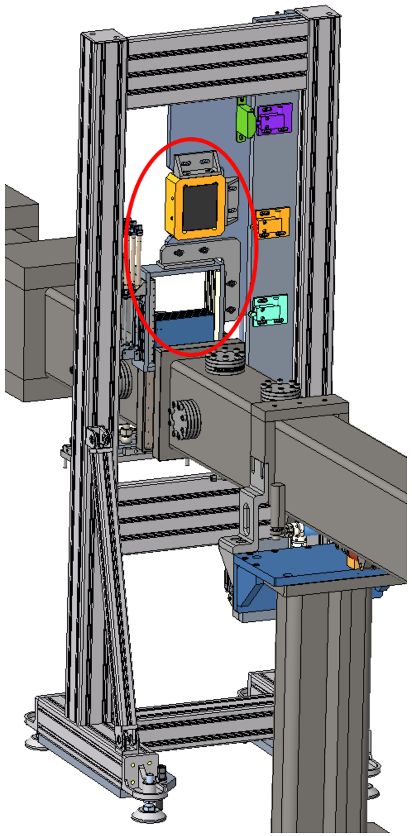


Accessibility for assembly and disassembly



Multitube monitor: accessible from below.

Multitube monitor & Attenuator: accessible from above the guide



Design credit: Rudy Thermer

Shutter Requirements

From S04080600-SRD10000-R00

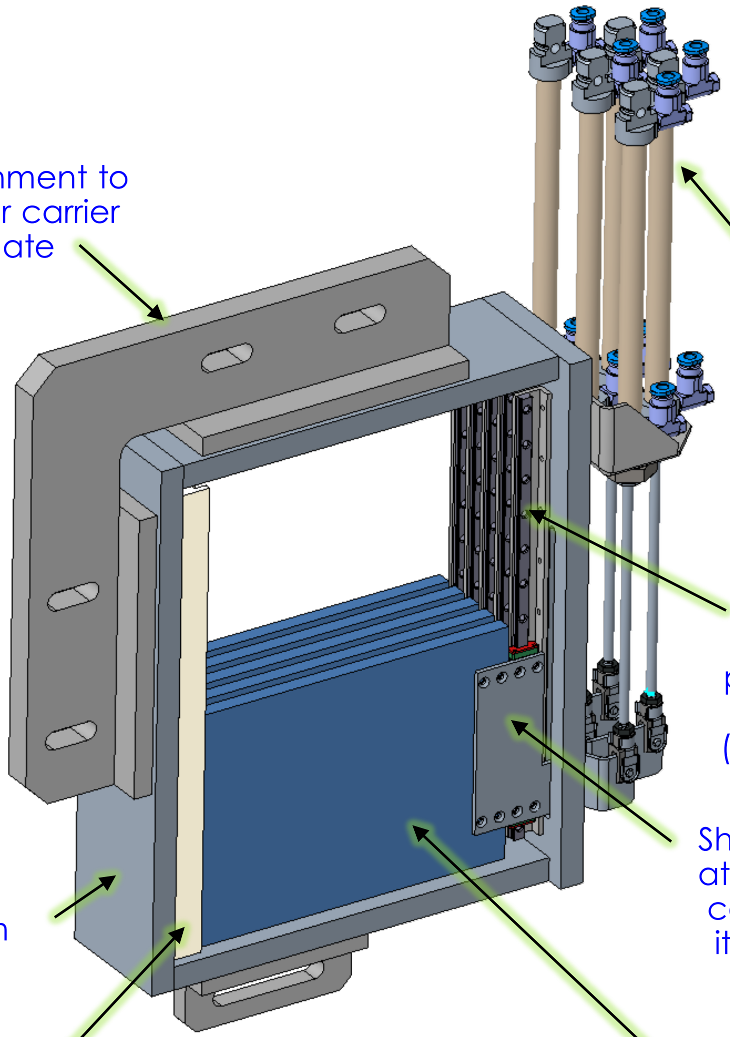
- S.04.08.06-R140 – The shutter must follow standard shutter design for general function and safety (see the shutter requirements documents listed in the reference table). Geometry may deviate as needed to accommodate the needs of each beamline at the chosen shutter location.
- S.04.08.06-R143 –The shutter must accommodate the z direction (direction along the beamline) thickness of beam stop material specified by neutronics.

NOTE: Both of these requirements will be addressed in the Bunker Shutter PDR… they are safety-related and are therefore not in the scope of this review

Attenuator – Overview

Design credit: Rudy Thermer

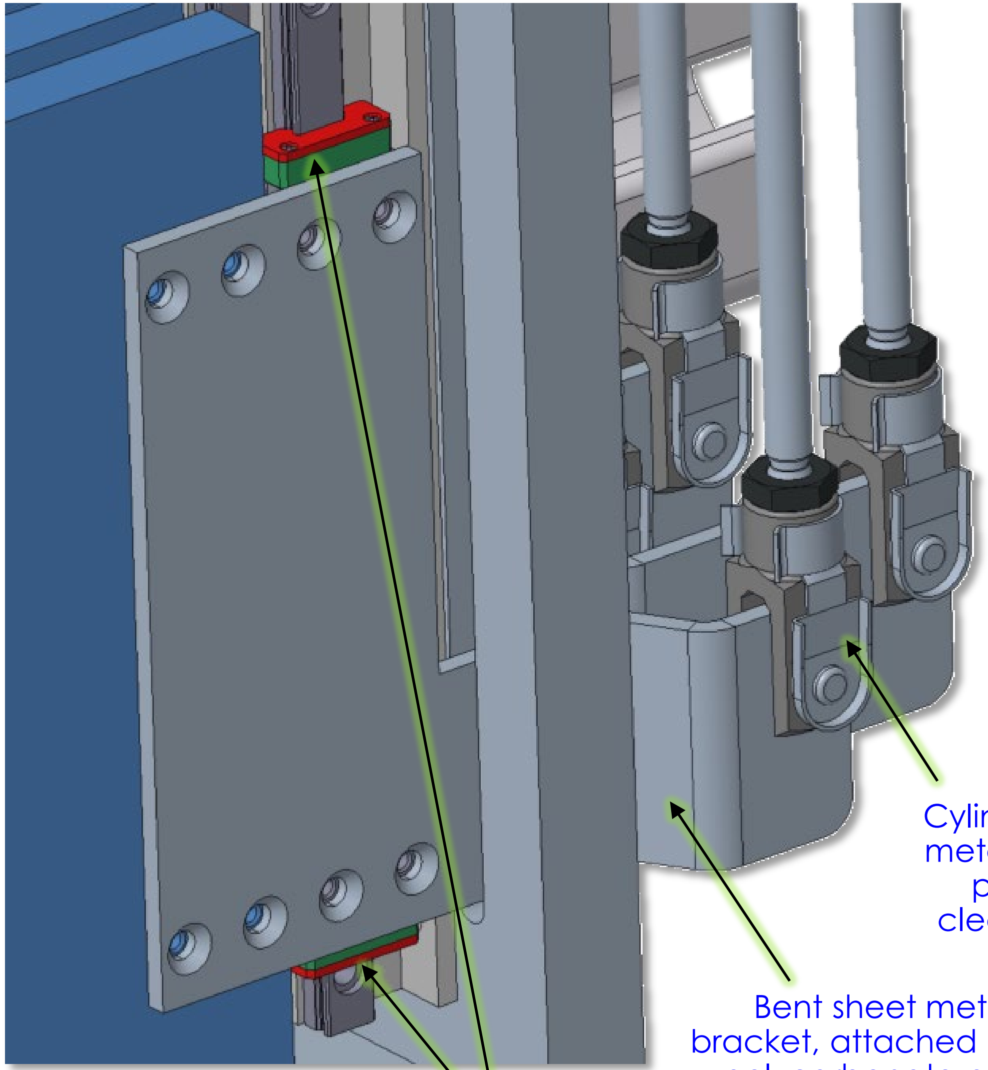
- The QIKR attenuator currently has 5 equal-thickness (t = 6.35mm) polycarbonate plates that are intended to be actuated separately to achieve 5 attenuation levels
  - Final design may use 3 plates of varying thicknesses (t, 2t, 4t), that can be combined to provide 7 attenuation levels
- Each plate is attached via a bracket to its own pneumatic cylinder, each plate's motion is guided by a linear bearing rail to reduce friction and prevent binding

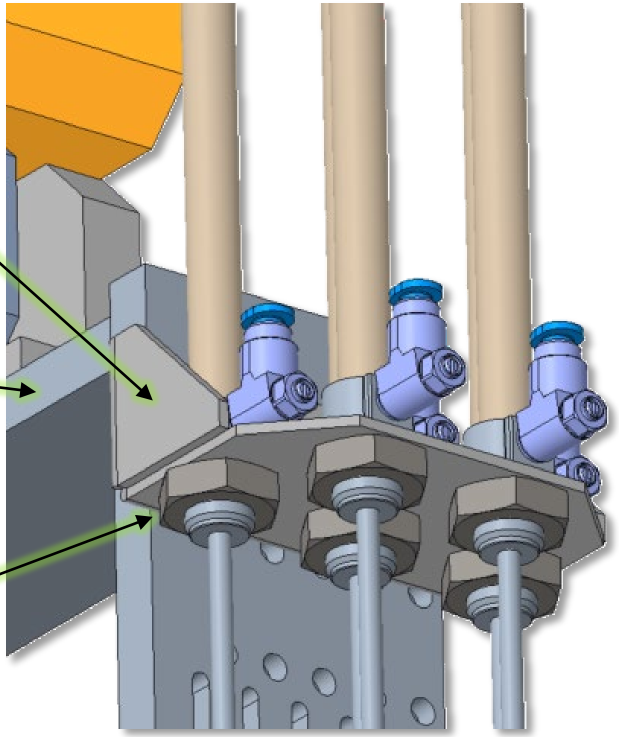


All components are screw-attached (screws not shown)

Attenuator – Cylinder Attachment

Cylinder Rod Attachment, Lower End





Cylinder Attachment, Upper End

Attenuator Requirements

From S04080600-SRD10000-R00

- S.04.08.06-R133 – The attenuator must provide a means of remotely selecting between 5 levels of attenuation plus an open position with no attenuation.
  - Air cylinders with independent solenoid control currently provide 5 levels of attenuation or no attenuation at all, as desired.
- S.04.08.06-R134 – The attenuator material must move completely out of the beam when no attenuation is required, and completely cover the full beam cross-section otherwise. No particular motion range or accuracy is required beyond that.
  - The attenuator plate geometry, plate travel range, and overall location on the shutter (placed by the two-stage shutter air cylinder) meet this requirement
- S.04.08.06-R135 – The attenuator must provide confirmation it has arrived at its desired position.
  - Either built-in sensors in the air cylinders may be used (preferred), or separate switches used to sense the plate positions
- S.04.08.06-R136 – Attenuator motion components must be designed to work in the radiation environment of the attenuator's chosen location. *Note: This may mean local shielding is required around the attenuator components. The radiation environment is determined by neutronic analysis.*
  - It is unknown at this point whether the motion components will work for an acceptable length of time within the radiation environment of the bunker. It is possible that shielding may need to be designed if component life cannot be determined. See next slide.

Shutter & Attenuator Concerns from FMEA

- Elastomer seals in the air cylinder and solenoid valves may fail in the radiation environment of the bunker
- Built-in air cylinder limit sensors may fail due to radiation
- Possible actions:
  - Specify EPDM (or radiation-resistant) seals, if possible
  - Design radiation shielding for the air cylinder and solenoid valves
  - Test cylinders & valves with standard seal materials in a radiation environment to investigate failure rate
  - Use alternate radiation-hardy limit switches

Acquisition strategy

- The parts will be a combination of COTS, customized COTS (ITEM or 80/20 frame pieces), or fabricated from domestic company
- Competitive bid possible on most parts
  - An alternative to Festo's 2-stage cylinder would have to be identified
- All COTS parts are available from US distributors
- No expected supplier constraints
- No exotic or hard-to-obtain materials

Manufacturing strategy

- The fabricated parts will be build-to-print
- All assembly will be done in-house
  - Shutter will be fully assembled prior to being installed in the bunker
  - Pneumatics and switches should be tested for basic functionality at this point

Installation Plan

- SAM team to identify correct placement along beamline
- Riggers to place assembly into the bunker with the 50-ton overhead high bay crane (through the bunker roof)
  - Installation should occur after the bunker wall and monolith guide sections are installed, but before the remaining in-bunker guide sections are installed
- SNS technicians & engineers to do final adjustments, connect pneumatics & electronics (switches, solenoids), test component function while connected to bunker air & instrument power, PPS, ICS

Shutter Costs & Labor Hours (Includes Attenuator)

Costs

COTS parts only*

Shutter	COTS Mat'l Cost	Labor Cost	Labor Hours
P6	$92,862	$22,961	144
Current Design	$85,994	$57,134	416
Delta	**-$6,868**	+$34,173	+272

Labor Hours

P6 vs. Current	Labor Type	Procure/Asm	Install
P6	scientist		16
	engineer	20	60
	designer		20
	technician		40
	Davis-Bacon		16
Current Design	scientist	20	80
	engineer	80	160
	technician		40
	Davis-Bacon		16

ICS has additional hours for install, not funded from the Instrument budget

*fabricated part data only exists for all the motion components combined, shown on slide 69

Discussion of Components

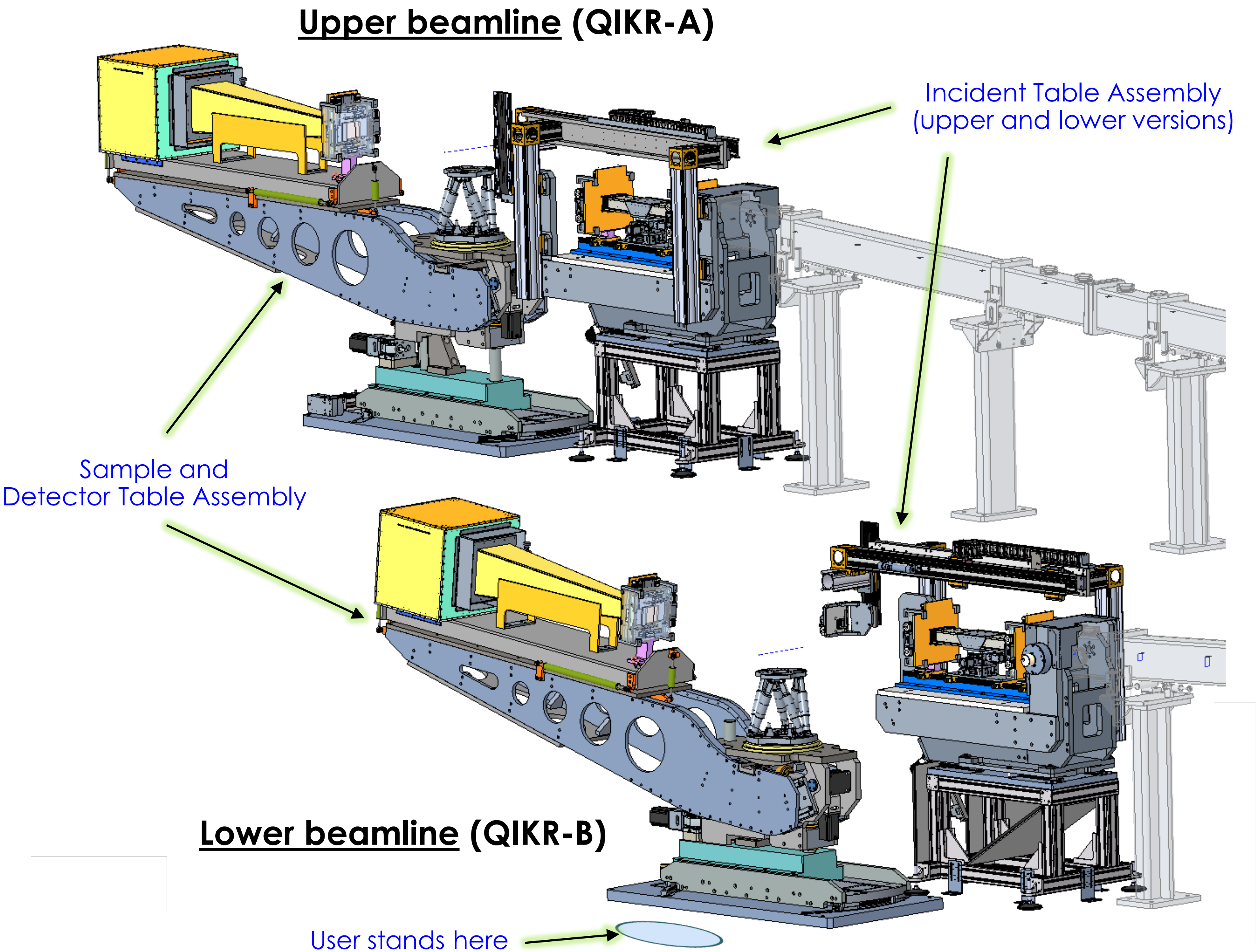
Incident Table
(End Station)

- Also Includes:
  - Slits
  - Frame Overlap Mirror (FOM)

End Station – Overview

Design credit: Rudy Thermer

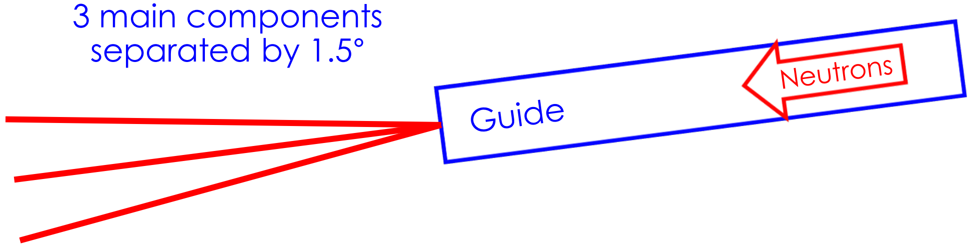
- End station components:
  - Incident Table
  - Sample/Detector Table
  - Beam Conditioning Slits
  - Frame overlap mirror (FOM)
  - Hexapod
  - Sample Changer
  - Detector & Shielding
- The user stands on the opposite side of the upper end station vs. the lower one
  - Some features on the incident table must be mirrored
  - The upper end station must rotate about "Y" in the opposite direction from the lower station

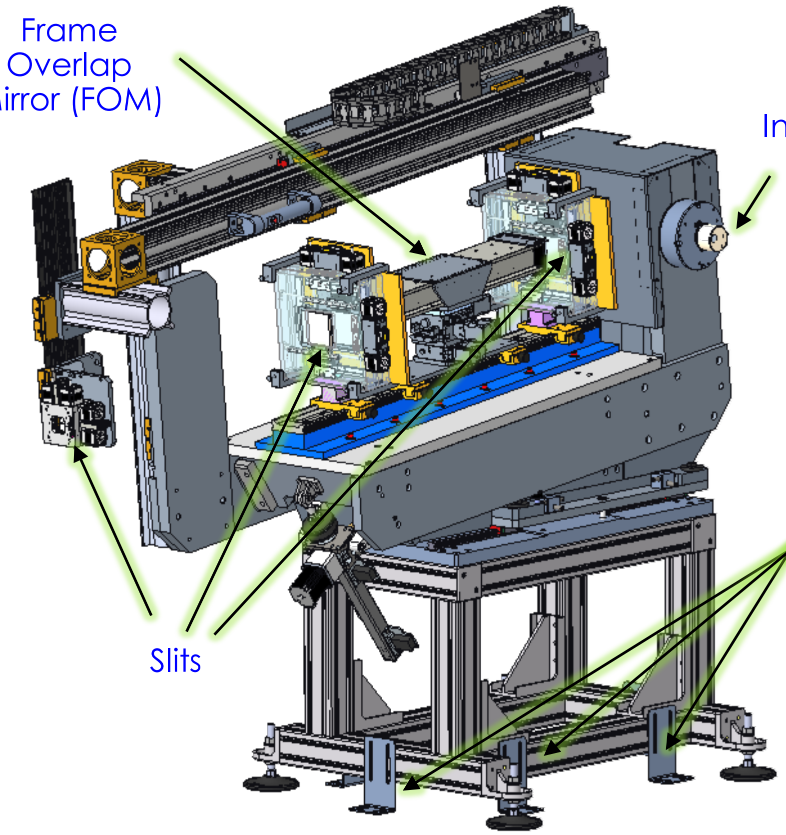


Incident Table – Operation Overview

Design credit: Rudy Thermer

- The incident table's purpose is to select one of the 3 main neutron beams exiting the guide
- A beam is selected by moving the slits and Frame Overlap Mirror (FOM) as a unit to be in line with the desired beam
  - The slits allowed the selected beam to pass through while blocking the others





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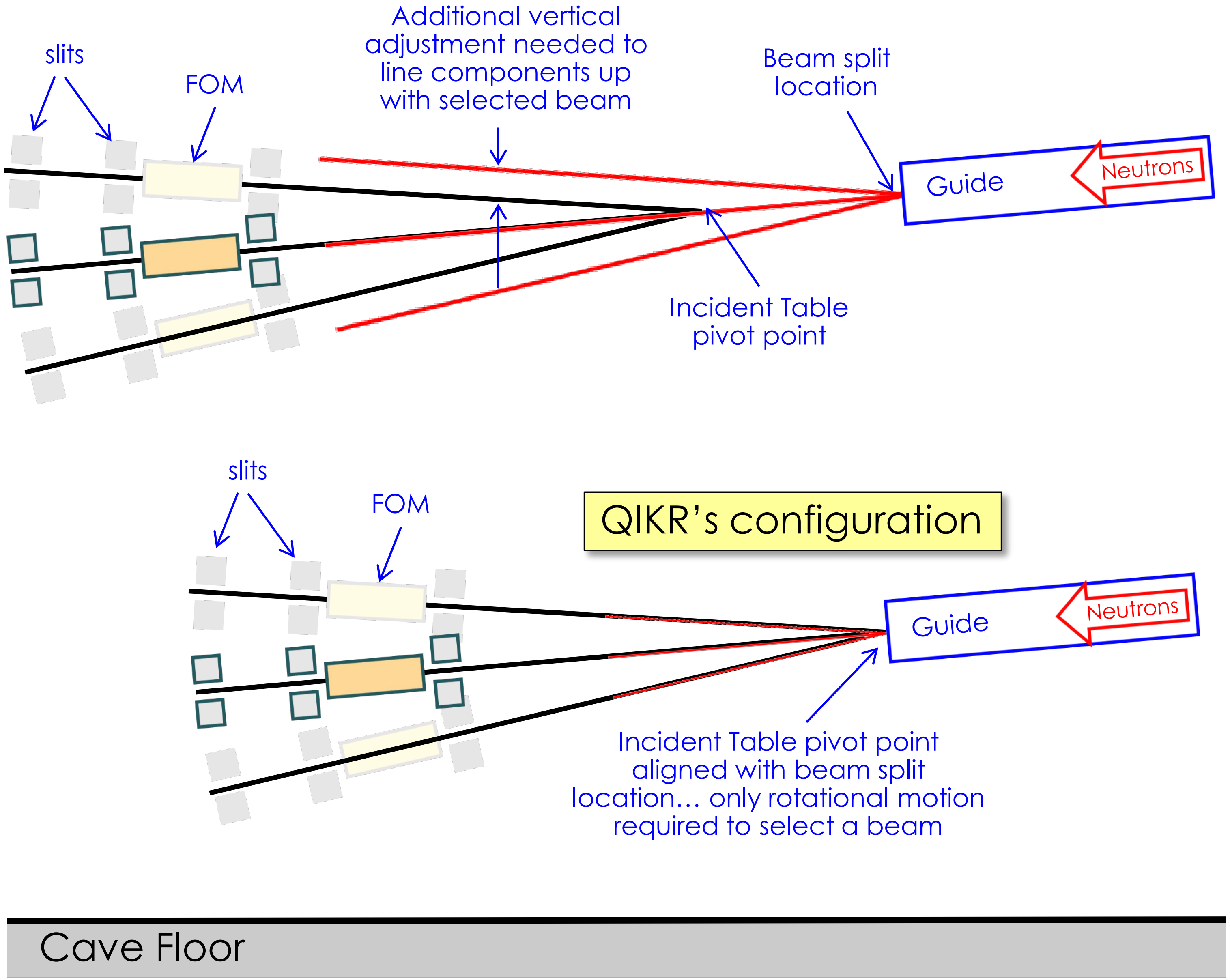
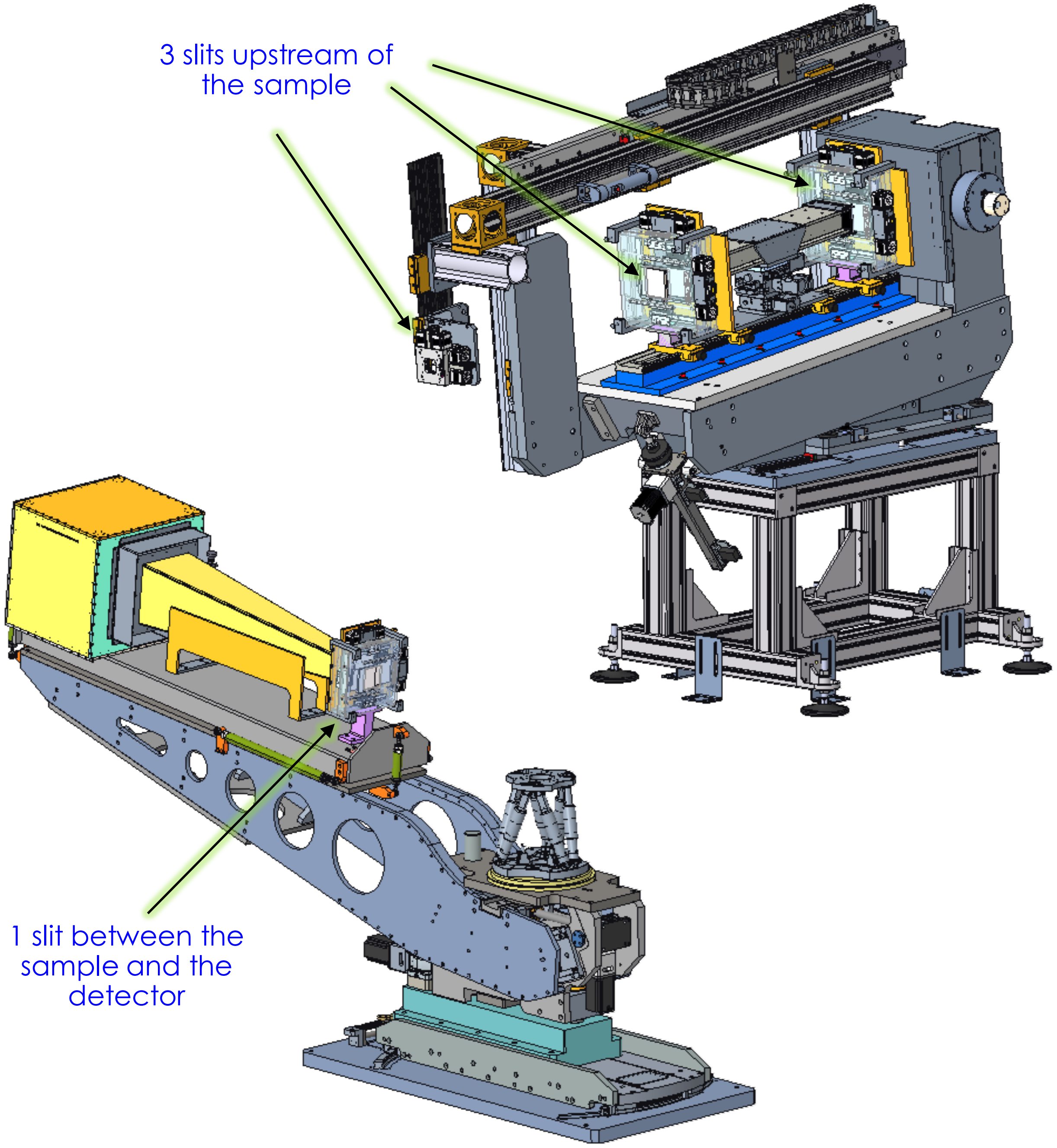
Incident Table – Selection of Pivot Point Location

- If the incident table's pivot point is not coincident with the point at which the neutron beam splits, additional vertical motion is required to line the beam up with the table components
- On QIKR, the incident table pivot **<u>is</u>** coincident with the beam split location, which means **only rotational motion is required**… saves cost and complexity



Slits – Overview

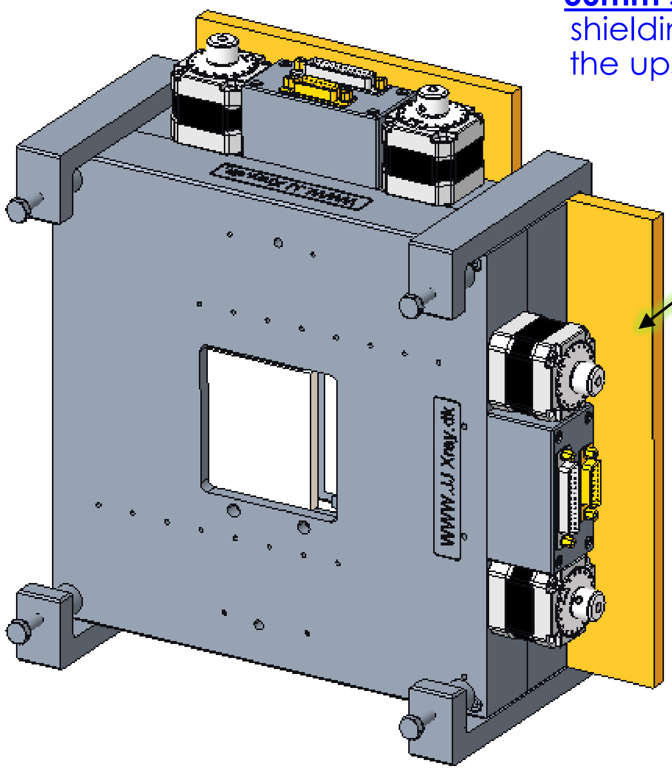
- There are 3 slits upstream of the sample, 1 slit downstream between the sample & detector
  - The 3 upstream slits select & define the shape of the beam
  - The 1 downstream slit helps shield & reduce noise on the detector
- The three upstream slits must be movable along the beam direction, but only the 3rd slit will be moved routinely
  - Beam direction motion is not required to be motorized
  - 3rd slit must be positioned as close as possible to the sample
- All slit aperture openings must be motorized



Slits – Details

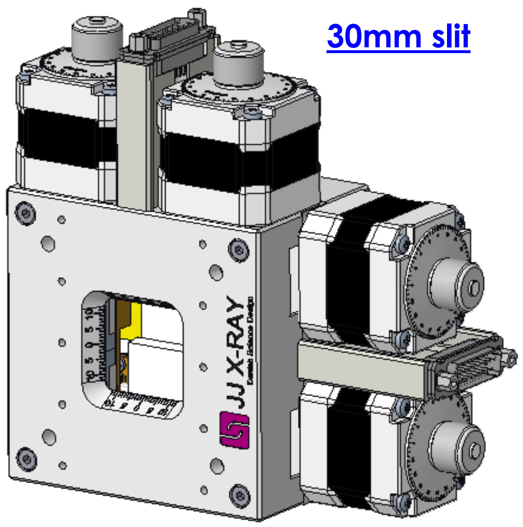
- Slits are COTS from JJ Xray
  - Three large slits with 50mm x 50mm max openings, 1 small slit with 30mm x 30mm max opening
  - All slits can overlap by their full width when closed
- Position of the slit blades is motorized
  - 4 stepper motors per slit, limit switches on all, encoders on the large slits
  - Motion accuracy = ±5μm (50mm), ±2μm (30mm)
  - Motion resolution = 1μm / full step

50mm slit with B4C shielding plate on the upstream side



Shield plate

30mm slit



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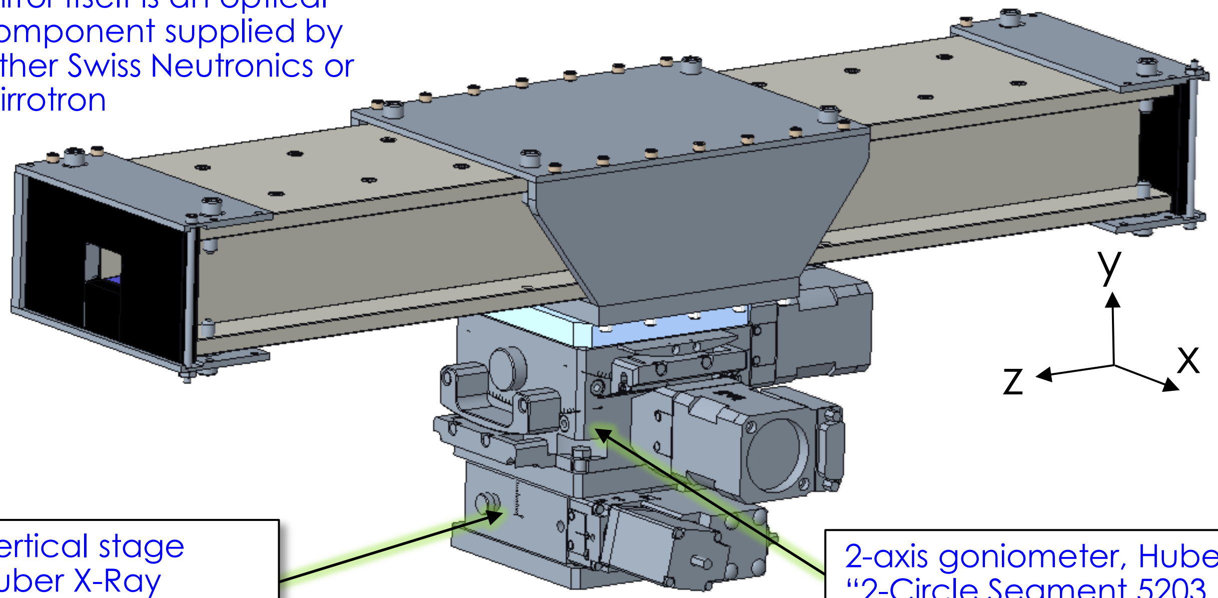
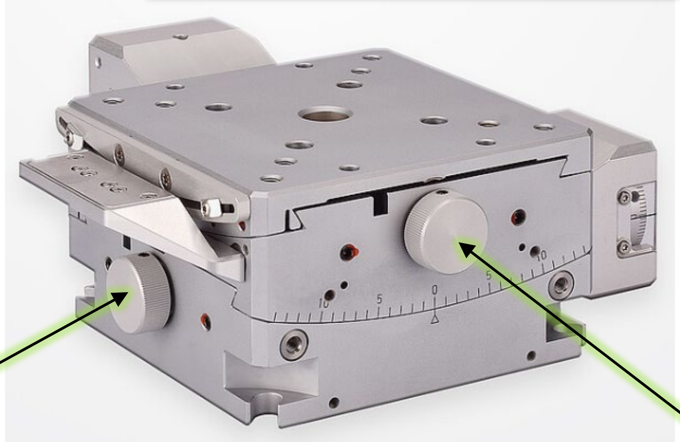
Frame Overlap Mirror – Motion

Mirror itself is an optical component supplied by either Swiss Neutronics or Mirrotron



Vertical stage Huber X-Ray "Z-Stage 5103.A10"

2-axis goniometer, Huber X-Ray "2-Circle Segment 5203.10-150"



Leave as manual thumb wheels

Replace with stepper motor (available option)

- The frame overlap mirror rejects unwanted low energy neutrons & must be positioned accurately about the x-axis
- On BL4B, a vertical stage + 2-axis goniometer was used to provide the positioning capability… QIKR is currently using the same setup, but will not install motors except on one rotation axis
- Huber X-Ray 5103.A10 (vertical stage)
  - Motion range: 15mm
  - Motion accuracy: 7µm
  - Motion resolution: 0.05µm
- Huber X-Ray 5203.10-510 (goniometer)
  - Motion range: ±11° (lower) ±13 ° (upper)
  - Motion accuracy: ±30" (arcsec)
  - Motion resolution: .001°

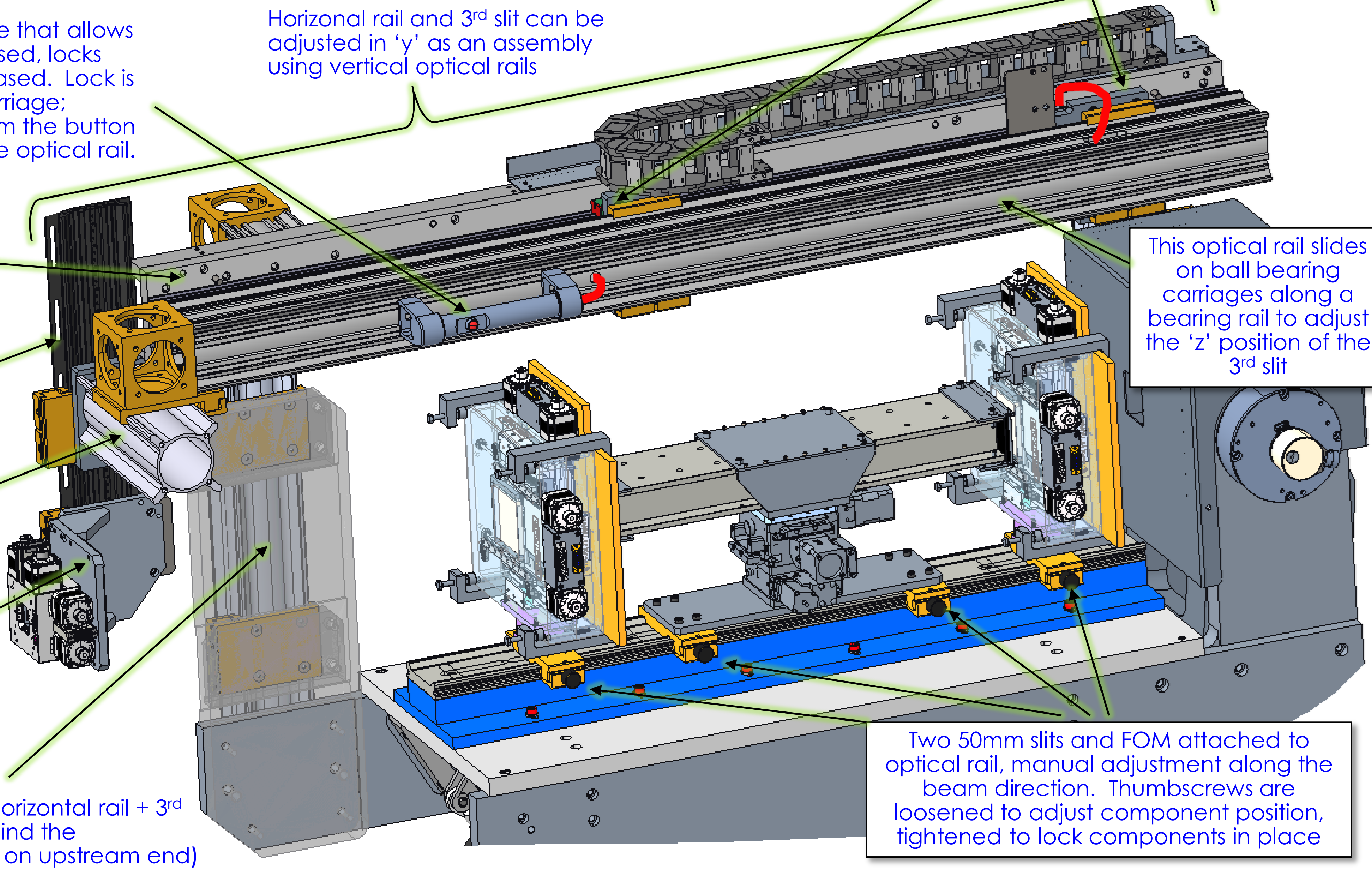
Slit and FOM Positioning Along the Beamline

Pneumatically actuated handle that allows motion when the button is pressed, locks motion when the button is released. Lock is located at the rear bearing carriage; pneumatic tubing (red line) from the button to the lock is routed through the optical rail.

Horizonal rail and 3rd slit can be adjusted in 'y' as an assembly using vertical optical rails

Bearing carriage locations

There will be a scale etched or printed on this plate (stationary) in millimeter increments to provide an indication of the 3rd slit location



3rd slit vertical adjustment (optical rail)

3rd slit horizontal adjustment (optical rail)

3rd slit mounting bracket, backed by B_4C or cadmium shielding. Has additional vertical adjustment (if needed) on the vertical optical rail

This optical rail slides on ball bearing carriages along a bearing rail to adjust the 'z' position of the 3rd slit

Vertical adjustment for the horizontal rail + 3rd slit assembly (optical rail behind the transparent plate, repeated on upstream end)

Two 50mm slits and FOM attached to optical rail, manual adjustment along the beam direction. Thumbscrews are loosened to adjust component position, tightened to lock components in place

Incident Table, Slits, and FOM Requirements

From S04080600-SRD10000-R00

- S.04.08.06-R100 – End station assemblies in contact with the cave floor must be tied to the floor to prevent accidental shifting of assemblies after initial alignment.
  - Done
- S.04.08.06-R101 – End Station components weighing more than 181.4kg (400lbs) or having a center of gravity greater than 1.2m (4ft) must be secured against motion during a seismic event per S04010000-TDO10000.
  - Tiedowns will be designed for seismic restraint at FD (total table weight is estimated to be ~500lbs)
- S.04.08.06.R102 – End station assemblies and components must not be permanently located within the sample environment keep-out zone around the nominal sample position.
  - The third slit is designed to move into and out of this zone. All other components are permanently located outside of it.
- S.04.08.06-R103 – Incident table must be placed between the guide end and the sample location.
  - Done

Incident Table, Slits, and FOM Requirements

From S04080600-SRD10000-R00

- S.04.08.06-R104 – Incident table must have a footprint in the x-dir of $\leq$ 765 mm.
  - Table is 720mm wide
- S.04.08.06-R105 – Incident table must support $\geq$90.7kg (200lbs) in addition to its own weight.
  - Table can safely support 1000N (100kg) of extra weight in addition to the existing components (slits, FOM, etc.)
- S.04.08.06-R106 – Incident table must accommodate optical components in this upstream-to-downstream order: 1st slit, frame overlap mirror, 2nd slit, 3rd slit.
  - Done
- S.04.08.06-R107 – The first slit must be located $\leq$120 mm of the guide end along the z direction. *Note: Closer spacing is preferrable, z motion is not required to be motorized.*
  - Currently can be as close as 107mm
- S.04.08.06-R108 – The second slit must be located within $\leq$50 mm of the downstream end of the frame overlap mirror along the z direction. *Note: Closer spacing is preferrable, z motion is not required to be motorized.*
  - Currently can be as close as 0mm

Incident Table, Slits, and FOM Requirements

From S04080600-SRD10000-R00

- S.04.08.06-R109 – The first and second slits must have remotely adjustable vertical openings to within a range of -5mm to ≥40mm, an accuracy of ±0.01mm, and a resolution of +.001mm. *Note: Negative numbers indicate amount of slit blade overlap.*
  - The vertical motion accuracy for each slit blade is ±5µm with a resolution of 1µm per full step. Slit blades can fully overlap each other. Largest opening is 50mm.
- S.04.08.06-R110 – The third slit must be movable along the z direction to within a range of ≤10mm and ≥500mm from the nominal sample center, motion resolution of ≤0.5mm
  - Currently can only move 342mm away from sample center. Solution has been identified for FD.
    Motion is manual, a scale in millimeters printed on the third slits sliding arm will provide position information to within ±0.5mm
- S.04.08.06-R111 – The third slit must have a remotely adjustable vertical opening to within a range of -5mm to ≥20mm, an accuracy of ±0.01mm, and a resolution of +.001mm. *Note: Negative numbers indicate amount of slit blade overlap.*
  - The vertical motion accuracy for each slit blade is ±2µm with a resolution of 1µm per full step. Slit blades can fully overlap each other. Largest opening is 30mm.

Incident Table, Slits, and FOM Requirements

From S04080600-SRD10000-R00

- S.04.08.06-R112 – Each slit must have remotely adjustable horizontal openings to within a range of -5mm to ≥20mm, an accuracy of ±0.01mm, and a resolution of +.001mm. *Note: Negative numbers indicate amount of slit blade overlap.*
  - The horizontal motion accuracy for each slit blade is ±5µm (50mm slit) and ±2µm (30mm slit) with a resolution of 1µm per full step. Slit blades can fully overlap each other. Largest opening is 50mm (50mm slits) or 30mm (30mm slit).
- S.04.08.06-R113 – Each slit must have a gap that can be centered on the nominal 'z' axis (through the guide end center) to within a vertical range of ±0.01mm and a horizontal range of ±0.1mm
  - Each blade is independently adjustable with ≥10mm (±5mm) of additional travel beyond what is required.
- S.04.08.06-R114 – The incident table must remotely and collectively rotate all slits and the frame overlap mirror about an x axis drawn through the center of the guide glass end to within a range of ±5° and with a resolution of 0.0005°. *Note: angle measured from horizontal.*
  - Motion range is ±6° from horizontal, motion resolution is 6.5 $(10)^{-5}$ degrees.

Incident Table, Slits, and FOM Requirements

From S04080600-SRD10000-R00

- S.04.08.06-R144 – The frame overlap mirror mounting features must support 30kg (66lbs)
  - The current Huber vertical and rotational stages can support 300N (67.4lbs) and 500N (112.4lbs) respectively.
- S.04.08.06-R145 – The frame overlap mirror must allow manual vertical adjustment in the ‘y’ direction within a range of ≤ -1.25cm and ≥ 1.25cm of nominal placement and a resolution of ≤0.05mm
  - The standard Huber vertical stage has ±7.5mm. Nominal starting height can be changed by adding shims… the stage will likely not be adjusted again after initial setup. This stage has an optional stepper motor that will not be needed.
- S.04.08.06-R146 – The frame overlap mirror must allow manual horizontal adjustment in the ‘x’ direction within a range of ≤ -1.25cm and ≥ 1.25cm of nominal placement and a resolution of ≤0.05mm. *Note: There is no need for special z’ direction adjustment ranges or resolutions*
  - NOTE: Resolution should be ≤1mm. Did not catch this one prior to document release.
  - The mounting plate to the optical rail will allow manual shifting within this range via slots around the attachment screws… not implemented yet.
- S.04.08.06-R147 – The frame overlap mirror must allow a manual angular adjustment about the ‘z’ axis within a range of ≤ -2° and ≥ 2°, and a resolution of ≤0.1°. *Note: Only coarse adjustment is needed here.*
  - The Huber Xray rotational stage has an axis to provide this motion with a range of ±11°. The resolution can be achieved using the stage’s visual scale. This axis has an optional stepper motor that will not be needed.

Incident Table, Slits, and FOM Requirements

From S04080600-SRD10000-R00

- S.04.08.06-R148 – The frame overlap mirror must allow motorized angular adjustment about the 'x' axis with a range of ≤-5° and ≥5°, an accuracy of ≥.005° and a resolution of ≤0.001°. *Note: Angle measured from the 'z' axis. This is the mirror's most critical adjustment, followed by coarse adjustments about the 'z' axis. There is no need for finer positioning about the 'y'-axis beyond what normal machining tolerances of the mirror support components will provide.*
  - NOTE: Accuracy should be ≥.05° and resolution should be ≤.01°. Did not catch this one prior to document release.
  - The Huber Xray rotational stage has an axis to provide this motion. It has an optional stepper motor that will be included. Its motion range, accuracy, and resolution are ±11°, ±30" (30/3600 = 0.008°), and 0.001° respectively.

Incident Table & Slit Concerns from FMEA

- Slit blades jam and cannot be actuated
  - This has happened on JJ Xray slits on BL4B. JJ Xray claims they are aware of the previous problems, and the current design has changes to correct it:
    - Original brass nut plates and threads (soft material) have been replaced with AMPCOLOY 972, precipitation hardened copper alloy with high wear resistance
    - Leadscrews now have a larger diameter and are connected to the motor with a pinion screw rather than (previously) with glue
  - Could use SNS in-house designed slits; there is an 80mm version that has been used successfully for several years, and a 50mm version that has yet to be installed.
    - Disadvantage is size… larger than we need, particularly for the 3rd slit
    - Another disadvantage is cost… the SNS 80mm slit cost $12k when last purchased in 2018, the 50mm version is expected to cost ~$25k. By comparison, the 50mm and 30mm JJ Xray slits was quoted (respectively) at $8,473 and $8,758 per slit on August 12, 2024. The 50mm JJ Xray slit includes a $1,330 discount for buying quantity 3x.

Incident Table & Slit Concerns from FMEA

- Foreign object accidentally placed in the beam cannot currently be detected (caused high radiation in the adjacent cave, QIKR-A or QIKR-B)
  - Protective padlocked cover added to prevent accidental placement of foreign objects, but…
  - …Could consider adding radiation monitor in the adjacent cave to detect spikes
- Third slit pneumatic lock fails
  - May be able to overcome the lock with a tool (key)… needs checking
- Sample environment could hit the third slit during sample setup with beam on
  - Currently no way to detect a collision or to detect that a collision is imminent
  - Possible solutions… need investigation:
    - Use a compliant mount for the 3rd slit
    - Place sensors that can detect an impending collision (or, less preferred, when a collision has occurred)
    - Place SE-specific limits on hexapod motion
    - Use an in-cave camera to remotely monitor position of SE relative to the 3rd slit

Acquisition strategy

- The parts will be a combination of COTS, customized COTS (ITEM or 80/20 frame pieces), or fabricated from domestic company
- Competitive bid possible on fabricated parts
  - Possible to find alternatives to most COTS parts, but would prefer to use the ones currently specified
- Most COTS parts are available from US distributors, some are sourced internationally (JJ Xray slits, Huber stages)
- No expected supplier constraints
  - Will need to check on expected lead times for slits & stages
- No exotic or hard-to-obtain materials

Manufacturing strategy

- The fabricated parts will be build-to-print
- All assembly will be done in-house
  - When parts are initially received, several sub-assemblies will be created (for the Incident Table), some of which may be sent out again for further machining to obtain desired feature tolerances
  - Sub-assemblies will be combined into the final Incident Table assembly during installation in the beamline

Installation Plan

- SAM team to identify correct placement along beamline for the incident table frame
- Riggers or ORNL technicians to place sub-assemblies & COTS parts onto the frame either manually (if component weight allows) or with the 2-ton overhead monorail hoist
  - This will be done after the cave guide sections have been fully installed an aligned
  - Sub-assemblies can each be individually aligned for correct placement… SAM may need to be involved at this stage also
- SNS technicians & engineers to do final adjustments, connect pneumatics & electronics (motors, encoder, limit switches), test component function & set up motor controls

Incident Table Costs & Labor Hours (Includes Slits & FOM)

Costs

COTS parts only*

Shutter	COTS Mat'l Cost	Labor Cost	Labor Hours
P6	$92,862	$22,961	144
Current Design	$85,994	$57,134	416
Delta	**-$6,868**	+$34,173	+272

Doesn't yet include the cost of FOM motor stages

Labor Hours

P6 vs. Current	Labor Type	Procure/Asm	Install
P6	scientist		8
	engineer	40	20
	designer	8	
	technician		20
	Davis-Bacon		48
Current Design	scientist		8
	engineer	40	80
	technician	160	80
	Davis-Bacon		48

ICS has additional hours for install, not funded from the Instrument budget

*fabricated part data only exists for all the motion components combined, shown on slide 69

Discussion of Components

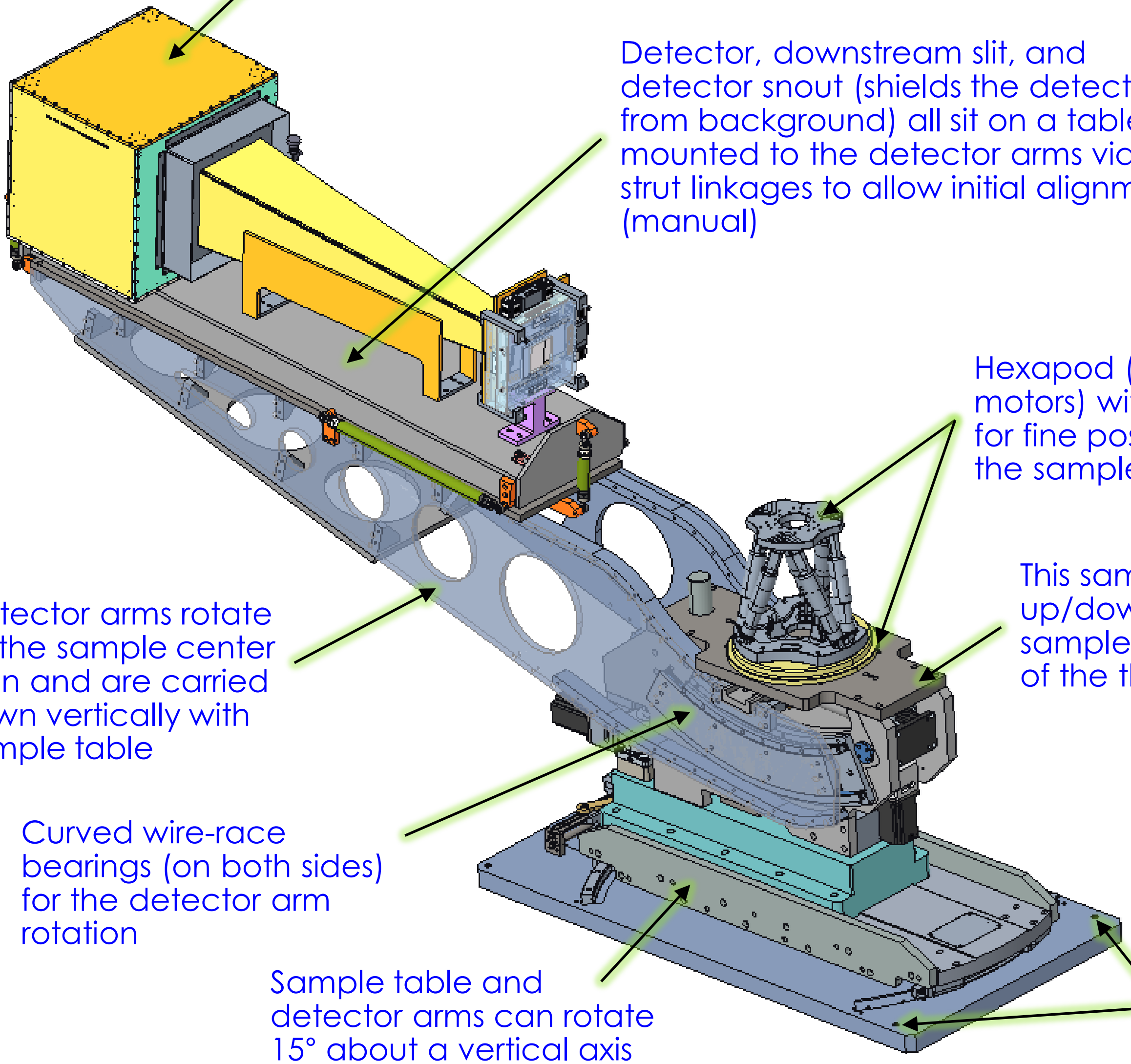
Sample/Detector Table (End Station)

- Also Includes:
  - Hexapod
  - Sample Handler

Sample/Detector Table

Design credit: Rudy Thermer

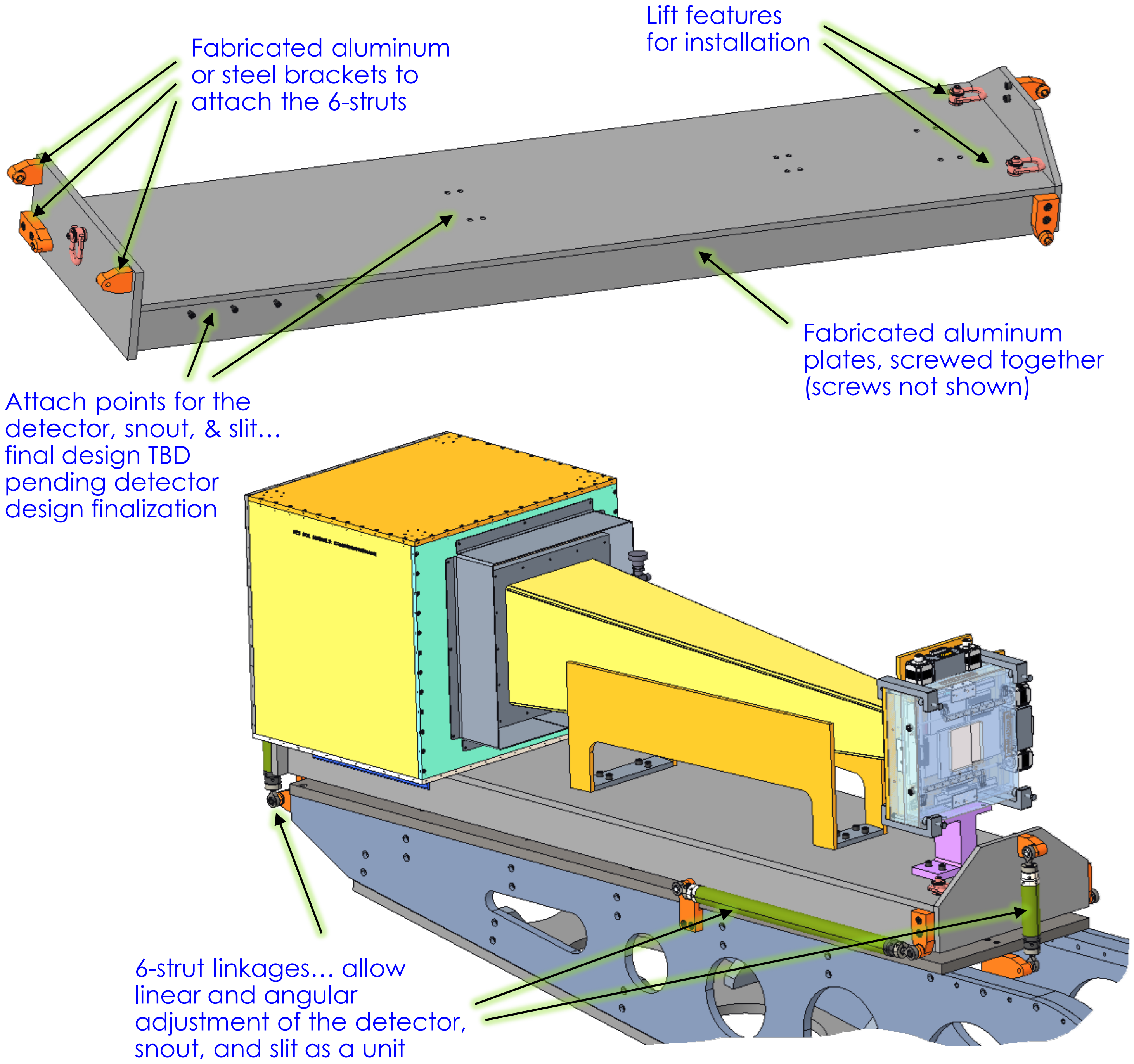
- The detector and sample table move vertically together (motorized)… there is no separate vertical motion for those components
  - Reduces axes & cost
- The detector and sample table also rotate together (motorized) about a vertical axis through the sample nominal center
- Fine sample positioning is handled by an electric motor hexapod sitting on a stack of shims
  - The shims provide larger height adjustments for tall vs. short sample environments
- The detector rotates about an x-axis (motorized) through the sample center using curved guide rails
  - The detector is always looking at the sample center, even if the sample table changes height



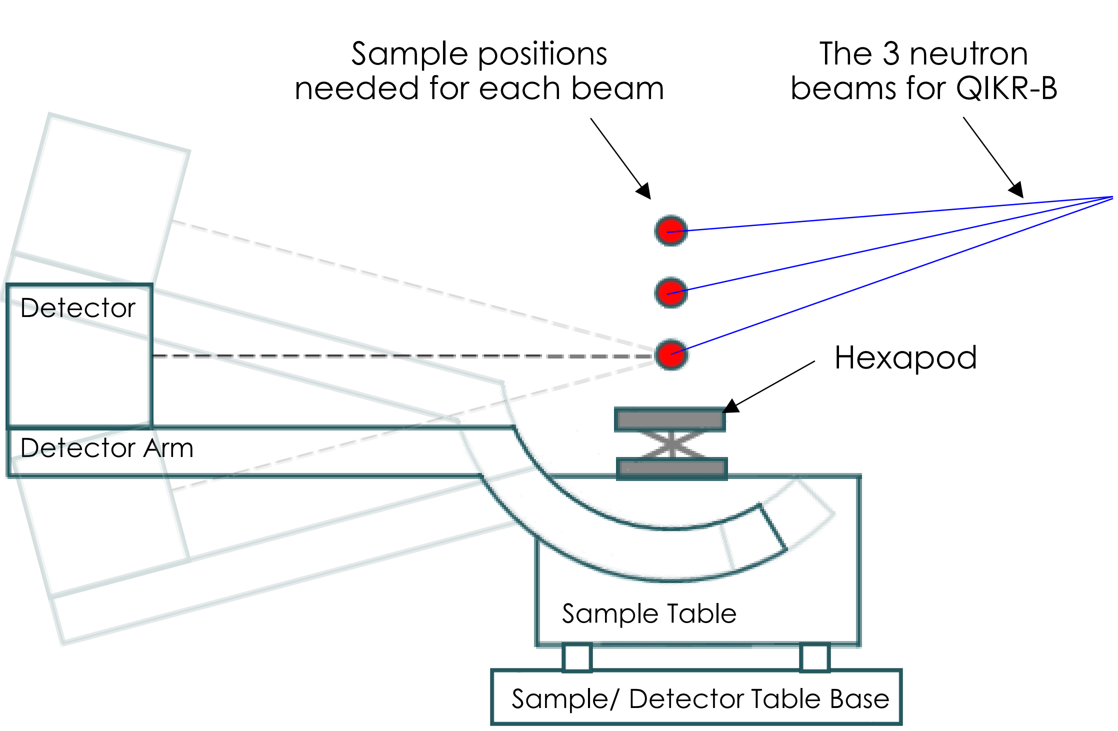
Detector Platform

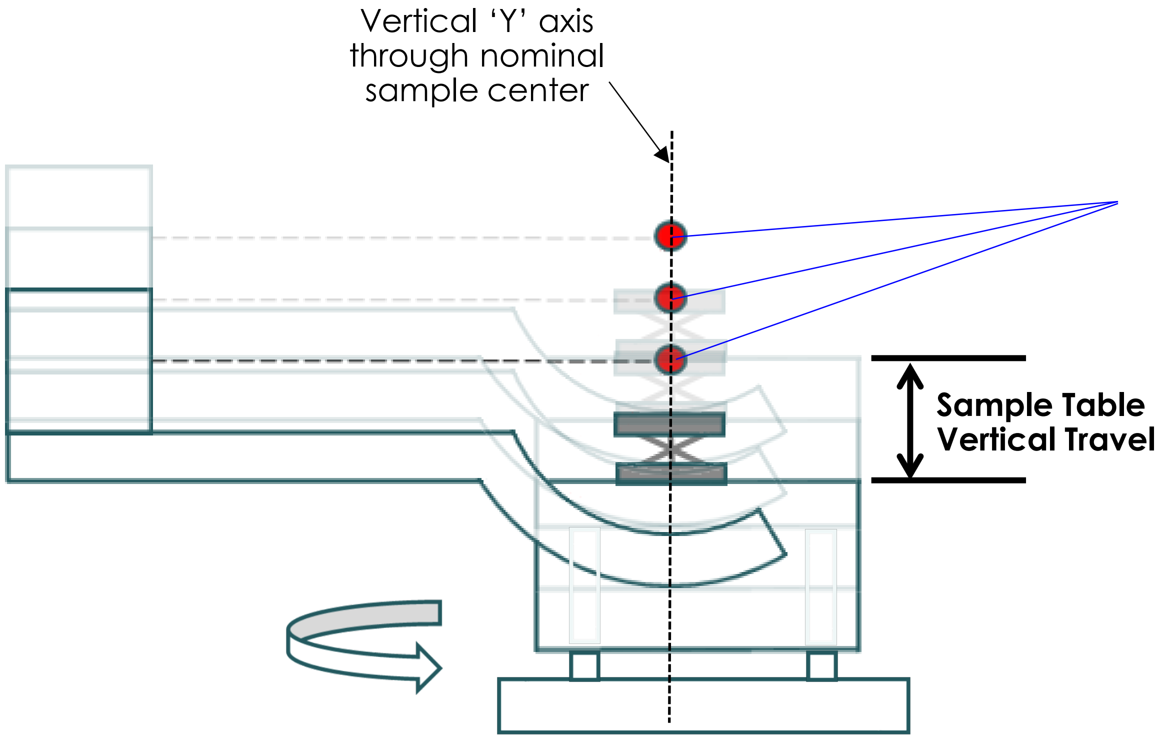
Design credit: Art Diaz

- The detector platform is attached to the detector arm via 6-strut linkages… 6 turnbuckles that fully constrain and allow position adjustment of all DOF’s
  - Struts allow ~25mm (1”) of linear adjustment
- The detector platform has lift features for installation via the overhead monorail crane
- Design is a placeholder at the moment… will be completed with the detector and snout design is finished (still in WIP status)
- There will be mounting features for the detector, the snout, and the slit that allow some relative position adjustment between the 3 components



Motions of Detector Arm and Sample Table





- Detector Arm rotates about a horizontal 'X' axis drawn through the nominal sample center

- Sample Table moves vertically to place the Detector Arm's center of rotation on the desired sample position
- Sample Table also rotates toward the user about a vertical 'Y' axis drawn through the nominal sample center

Detector Table Requirements

From S04080600-SRD10000-R00

- S.04.08.06-R125 – The detector table must place the center of the detector sensing surface at a fixed radial distance 2m $\pm$ 1mm from the nominal sample location.
  - The detector face of the current placeholder model is located a nominal distance of 2m from the sample center location, and can be adjusted within a range of 25mm (1") to within 50µm. When the final design of the detector is known, the nominal distance will be corrected as needed.
- S.04.08.06-R126 – The detector table must have a footprint in X of $\leq$765 mm.
  - The detector & sample table are 475.8mm wide. The detector arms are 375.1mm wide.
- S.04.08.06-R127 – The detector table must be able to support at least $\geq$227 kg ($\geq$500 lbs) in addition to its own weight.
  - The detector table can support 306kg (674lbs) applied at the downstream edge of the table.
- S.04.08.06-R128 – The detector table must provide means to manually adjust the detector sensor surface angle to be perpendicular to a radial line drawn from the sample position to within 2°.
  - The detector platform and six-strut linkages allow ~0.5" of linear motion in all directions, 2° of rotation about 'X' and 5° of rotation about 'Y' and 'Z'. Position accuracy of 6-strut linkages are ~0.05mm per Survey and Alignment. Assuming the resolution is ~0.10x the accuracy, the angular resolution of the detector platform is .0002° about 'X' and .0007° about 'Y' and 'Z'.

Detector Table Requirements

From S04080600-SRD10000-R00

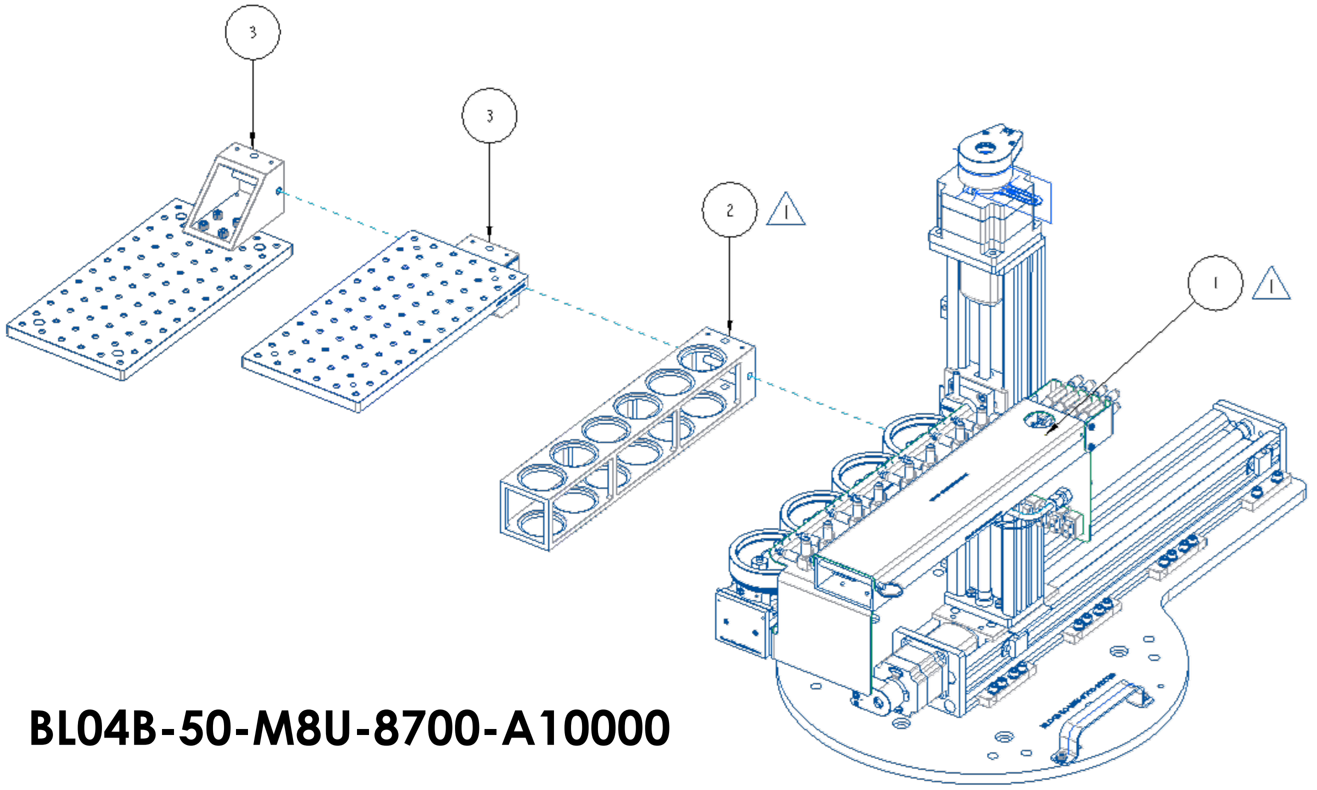
- S.04.08.06-R129 – The detector table must provide means to manually adjust the detector sensor center to within ±5mm of its nominal position from the nominal sample location.
  - The 6-strut linkages allow ±12mm of adjustment.
- S.04.08.06-R130 – The detector table must provide ±17.5° of remote rotation about the X-axis with motion resolution of .002°. *Note: Angle measured from horizontal. This angle range provides at least +15° of rotation about the QIKR-A and QIKR-B beam inclinations of 2.5° and -2.5° respectively.*
  - The detector arms rotate through a range of ±17° measured from horizontal with a resolution of $1.1(10)^{-4}$ degrees/ full step.
- S.04.08.06-R131 – The detector table must provide ≥15° degrees of remote rotation toward the user about the Y-axis with motion resolution of ±.002°.
  - The detector provides 17° of rotation about the Y-axis through the sample center with a resolution of $6.8(10)^{-4}$ degrees/ full step.
- S.04.08.06-R132 – The detector table must allow installation of additional optics components in the space between the nominal detector and sample locations. *Note: It is expected that there will be a slit and a radiation shield in this space.*
  - The detector table allows the installation of a snout and a slit in the space between the detector and the sample.

Sample Table Requirements

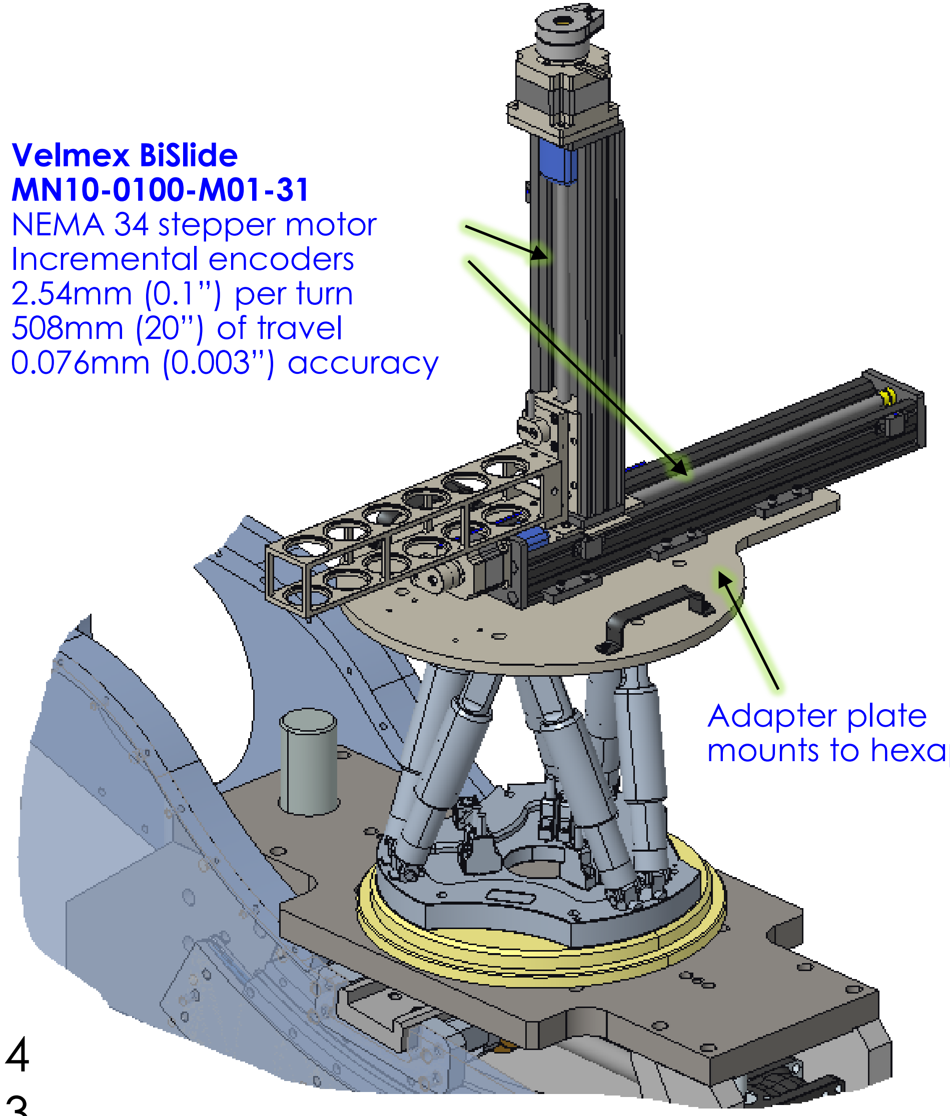
From S04080600-SRD10000-R00

- S.04.08.06-R115 – The sample table must place the sample 2m±5mm from the end of the guide in the z' direction.
  - The sample table provides a nominal position for the sample of 2m from the guide end. The sample position can be adjusted with the hexapod by at least 5mm in any linear direction.
- S.04.08.06-R116 – The sample table must have a footprint in X of ≤765 mm.
  - The detector & sample table are 475.8mm wide.
- S.04.08.06-R117 – The sample table must be able to support at least ≥455 kg (≥1000 lbs) in addition to its own weight. *Note: Sample environments are expected to weight under 500lbs.*
  - The sample table can support 510kg (1,124lbs) applied at the downstream edge of the table.
- S.04.08.06-R118 – The sample table must provide coarse positioning of the sample to one of three nominal Y locations to within ±.1mm. The Y locations correspond to the height of the three beam components of interest at the nominal sample Z distance from the guide end.
  - The sample table has a vertical motion range of 150mm to cover a distance of 105mm between lowest and highest sample positions. Currently, when the sample table sits at its lowest position, its surface sits below the lowest sample position by 560mm. Motion resolution is $1.25(10)^{-3}$mm/ full motor step.

Sample Handler – Same as BL04B



BL04B-50-M8U-8700-A10000



DESCRIPTION	PART NUMBER	
LIQUID SOLID CELL SAMPLE CARTRIDGE	BL04B-50-M8U-8700-A10013	4
BREADBOARD CARTRIDGE ASSEMBLY	BL04B-50-M8U-8700-A10008	3
SOLID SAMPLE CARTRIDGE 6X2	BL04B-50-M8U-8700-A10006	2
BL4B SAMPLE BASE ASSEMBLY	BL04B-50-M8U-8700-A10001	1

Sample Handler Requirements

From S04080600-SRD10000-R00

- S.04.08.06-R137 – The sample changer must remotely move at least 12 samples into and out of the beam.
  - Using BL04-50-M8U-8700-A10006, 12 solid samples can be moved into and out of the beam.
- S.04.08.06-R138 – The sample changer must position each sample in the beam to within ±1mm of the nominal position.
  - The Velmex linear slides and motors provide motion of 0.0127mm per step (assuming 200 steps / revolution), and have 0.076mm accuracy over the length of travel.
- S.04.08.06-R139 – The sample changer must provide confirmation that the sample has moved into position. *Note: Motor encoders are sufficient for this purpose*
  - The Velmex stackup of linear stages use stepper motors with encoders (though they are currently relative encoders… the preference is for absolute encoders)

Hexapod

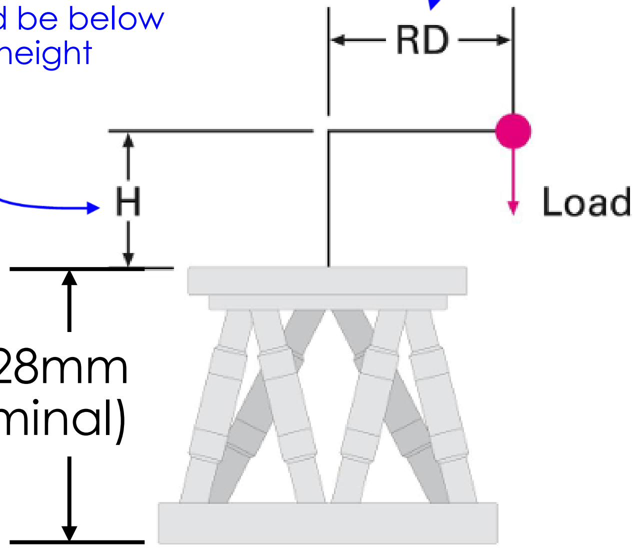
- Advantages:
  - Infinitely variable pivot point
  - Can move in all six DOF with much better path accuracy & repeatability, **much more compact** & stiff compared to stacked systems
  - Provides both fine sample positioning and coarse positioning (within ~±14mm)
  - High load capacity
- Disadvantages
  - Expensive (~$110,000)
  - Does not use stepper motors
  - Requires its own controller & cabling (additional cost)
  - Maxing out the motion range in one DOF means no motion range is available in other DOF's

- PI H-850.H2 A hexapod chosen for fine adjustments of samples
  - Max load capacity of 250kg (551 lbs), max holding force of 2000kg (4409 lbs) when oriented as shown at left (horizontal), depending on height & lateral location of load CG
  - Uses **electric servo motors** with absolute encoders
  - Motion resolution:
    - 1 μm in 'x' and 'z', 0.5 μm in 'y'
    - 7.5 μrad about 'z' and 'x', 15 μrad about 'y'
  - Unidirectional repeatability:
    - ±0.5 μm in 'x' and 'z', ±0.2 μm in 'y'
    - ±3 μrad about 'z' and 'x', ±7.5 μrad about 'y'
  - Backlash:
    - 6 μm in 'x' and 'z', 1.5 μm in 'y'
    - 20 μrad about 'z' and 'x', 90 μrad about 'y'

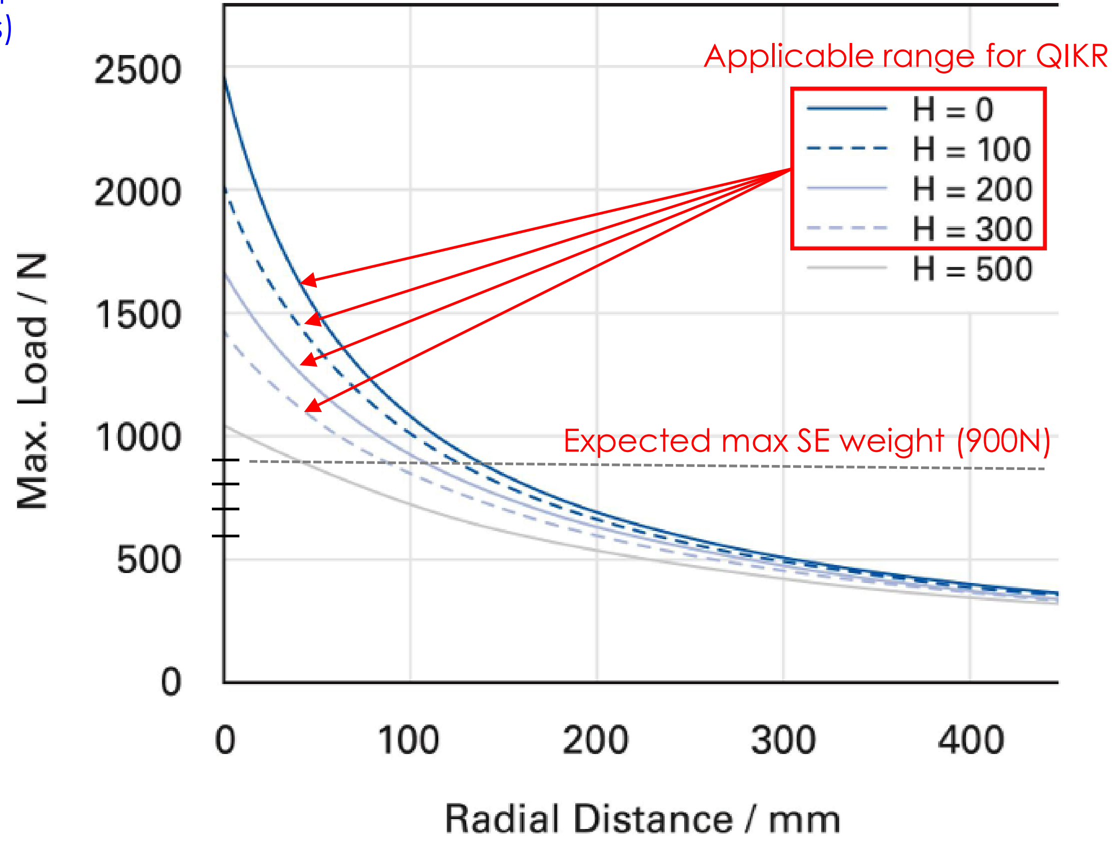
Hexapod

Sample Environments (SE's) will require a mounting plate for the hexapod… for those SE's with off-center CG's, a weighted mounting plate could be made to balance the CG. Expect maximum SE weight ≤900N (200 lbs)

Max H for QIKR sample location = 350mm… the sample environment CG would be below that height



H-850.H2 A



Maximum loads on the H-850.H2A when mounted horizontally

Fine Sample Positioning Requirements

From S04080600-SRD10000-R00

- S.04.08.06-R119 – The sample table must provide fine positioning of the sample about each nominal location in the Y-dir to within a range of $\pm$25mm and a resolution of $\pm$0.01mm
  - The hexapod is capable of this, but **only if** no motion is required of the other axes at the same time. If the other axes are all moved to their required limits, the hexapod can only guarantee +7.6mm and -14.5mm motion in 'Y'. Additional height adjustment is provided by placing/removing shims beneath the hexapod.
- S.04.08.06-R120 – The sample table must provide remote sample position adjustment in the X-dir about the nominal beam X-dir center to within a range of $\pm$5mm and a resolution of $\pm$0.1mm
  - The hexapod can achieve this as well as the other linear and rotational motions, **but cannot simultaneously provide the full required range in 'Y' on its own.**
- S.04.08.06-R121 – The sample table must provide remote sample position adjustment in the Z-dir about the nominal beam Z-dir center to within a range of $\pm$5mm and a resolution of $\pm$0.1mm
  - The hexapod can achieve this as well as the other linear and rotational motions, **but cannot simultaneously provide the full required range in 'Y' on its own.**
- S.04.08.06-R122 – The sample table must accommodate sample environments with a mounting surface $\leq$350 mm below the nominal sample position
  - Currently does not, but the detector and sample table can be modified without significant design change to achieve that at FD. The QIKR-B cave pit already accommodates the required change.

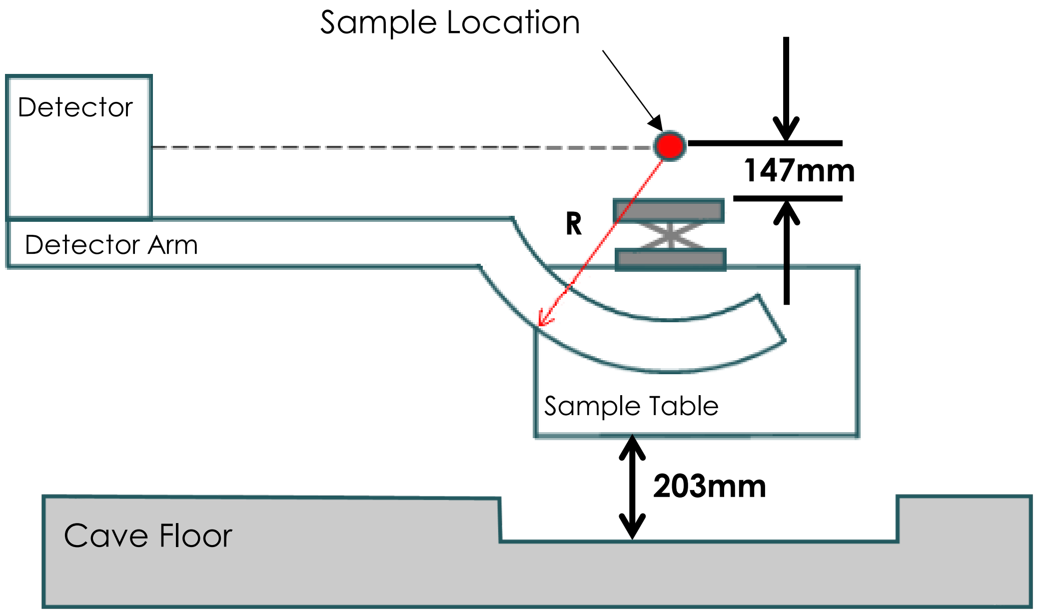
Sample Positioning Requirements

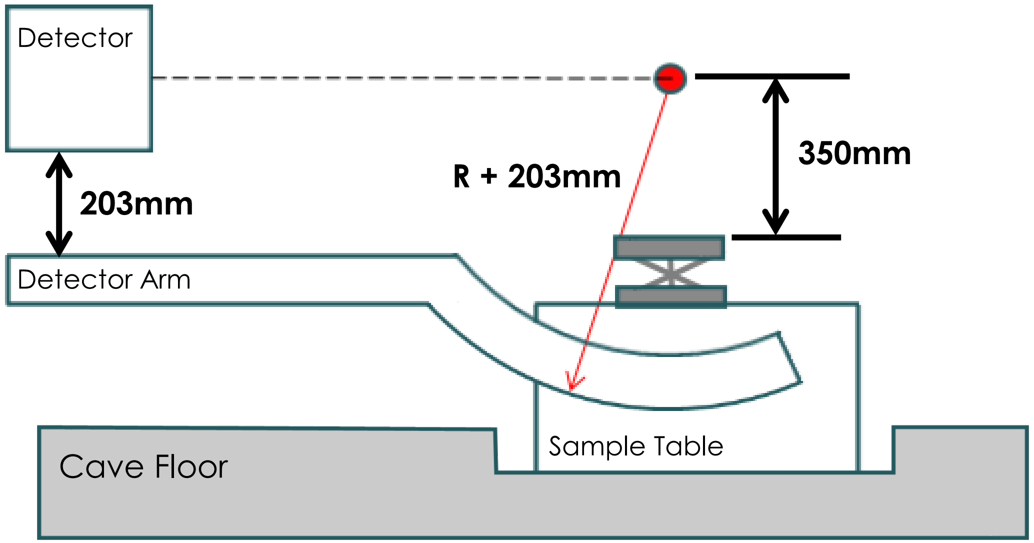
From S04080600-SRD10000-R00

- S.04.08.06-R123 – The sample table must be able to angle the sample $\geq$ |2°| about the X axis with a resolution of $\geq$ .002°
  - The hexapod can achieve this as well as the other linear and rotational motions, **but cannot simultaneously provide the full required range in 'Y' on its own.**

- S.04.08.06-R124 – The sample table must be able to angle the sample $\geq$ |5°| about the Z axis with a resolution of $\geq$ .2°
  - The hexapod can achieve this as well as the other linear and rotational motions, **but cannot simultaneously provide the full required range in 'Y' on its own.**

Changes Required at FD for Taller Sample Environments





- Current design only provides 147mm of space between the hexapod top surface (at the hexapod's nominal height) and the sample location
- It was determined that this spacing should be increased to 350mm

- Changes:
  - Detector Arm, Sample Table, and Hexapod shift down by 203mm
  - Detector Arm circular bearing radius increases by 203mm
- Detector does **not** move, detector support platform will be modified

Detector/Sample Table, Sample Handler Concerns from FMEA

- Curved rail guides for the detector arms may not be able to be fabricated to within the tolerances needed
  - Conversations with Franke, the wire-race bearing vendor, have indicated that tight tolerances are required, but not to an extreme degree that may challenge machining capabilities.

Acquisition strategy

- The parts will be a combination of COTS components and parts fabricated from domestic companies
- Competitive bid possible on fabricated parts
- Most COTS parts are available from US distributors, some are sourced internationally (Franke wire race bearings, Hexapod)
  - Possible to find alternatives to most COTS parts, but would prefer to use the ones currently specified
- No expected supplier constraints
  - Will need to check on expected lead times for hexapod (6 weeks for standard models, ≥12weeks for custom)
- No exotic or hard-to-obtain materials

Manufacturing strategy

- The fabricated parts will be build-to-print
- All assembly will be done in-house
  - When parts are initially received, several sub-assemblies will be created (for the Detector and Sample Tables), some of which may be sent out again for further machining to obtain desired feature tolerances
  - Sub-assemblies will combined into the final Sample/Detector Table assembly during installation in the beamline

Installation Plan

- SAM team to identify correct placement along beamline for the sample/ detector table grout plate, SAM will assist in levelling it.
- Riggers or ORNL technicians to place sub-assemblies & COTS parts either manually (if component weight allows) or with the 2-ton overhead monorail hoist
  - This will be done after the grout plate has been installed, and after the Incident Table has been fully installed and aligned
- SNS technicians & engineers to do final adjustments, connect electronics (motors, encoder, limit switches), test component function & set up motor controls

Detector/Sample Table + Hexapod Costs & Labor Hours

Costs

COTS parts only*

Shutter	COTS Mat'l Cost	Labor Cost	Labor Hours
P6	$464,310	$58,617	304
Current Design	$262,000	$116,438	816
Delta	**-$202,310**	+$57,821	+512

Doesn't yet include the cost of the Franke wire race bearings, or hexapod cables

The hexapod is $110,000 of this, hexapod controller is $11k

Labor Hours

P6 vs. Current	Labor Type	Procure/Asm	Install
P6	scientist		16
	engineer	120	80
	designer	8	
	technician		
	Davis-Bacon		80
Current Design	scientist		16
	engineer	120	80
	technician	320	200
	Davis-Bacon		80

ICS has additional hours for install, not funded from the Instrument budget

*fabricated part data only exists for all the motion components combined, shown on slide 69

Sample Handler Costs & Labor Hours

Costs

COTS parts only*

Shutter	COTS Mat'l Cost	Labor Cost	Labor Hours
P6	$278,586	$103,374	768
Current Design	$19,468	$14,896	78
Delta	**-$259,118**	**-$88,478**	**-690**

Labor Hours

P6 vs. Current	Labor Type	Procure/Asm	Install
P6	scientist		8
	engineer		40
	designer	120	
	technician		200
	Davis-Bacon		400
Current Design	scientist		8
	engineer	20	40
	technician		10
	Davis-Bacon		

ICS has additional hours for install, not funded from the Instrument budget

*fabricated part data only exists for all the motion components combined, shown on slide 69

Summary

Cost & Labor Hours Summary

- Original P6 costs (material + labor): $1,715,708
- Current design costs (COTS + labor): $1,355,759
- Fabricated parts cost estimate: $152,800
  (From a single vendor)

Delta: **-$207,149**

Still missing:
Franke wire races
Hexapod controller cables
FOM motion stages

- Original P6 labor hours (total): 1724
- Current design labor hours (total): 2068

Delta: **+344**

Links back to individual summaries:
Shutter & Attenuator
Incident Table, Slits, & FOM
Detector/Sample Table
Sample Handler

Acquisition strategy – Summary

- All parts will be a combination of COTS components and parts fabricated from domestic companies
- Competitive bid possible on fabricated parts
- Most COTS parts are available from US distributors, some are sourced internationally (Franke wire race bearings, Hexapod, JJ Xray slits, Huber stages)
- No expected supplier constraints
  - Will need to check on expected lead times for hexapod, slits & stages
- No exotic or hard-to-obtain materials

Manufacturing strategy

- The fabricated parts will be build-to-print
- All assembly will be done in-house
  - When parts are initially received, several sub-assemblies will be created (for the Detector and Sample Tables), some of which may be sent out again for further machining to obtain desired feature tolerances
  - Sub-assemblies will combined into the final assemblies during installation in the beamline

Installation Plan

- SAM team to assist in initial component placement, alignment, and levelling
- Riggers or ORNL technicians to place sub-assemblies & COTS parts either manually (if component weight allows) or with the 2-ton overhead monorail hoist
- SNS technicians & engineers to do final adjustments, connect electronics& pneumatics, test component function & set up motor controls

Overall Summary – Charge Questions

1. Have system requirements been defined, and are they complete and adequate to ensure acceptable system performance?
2. Can the proposed system designs meet their functional and performance requirements?
3. Are the cost estimate and acquisition strategy reasonable?
4. Are the proposed preliminary designs sufficiently mature to proceed to final design?

Overall Summary

1. Have system requirements been defined, and are they complete and adequate to ensure acceptable system performance?
    - Each system in the Motion WBS has requirements defined for footprint, load support, location, motion type (motorized vs. manual), motion range, accuracy, and resolution where applicable
    - The Shutter and Shield safety requirements are driven by the standard designs and are not listed separately in the QIKR Motion WBS requirements
2. Can the proposed system designs meet their functional and performance requirements?
    - DAC's show that the incident table and sample/detector table are very capable of meeting their requirements
    - The designs largely use COTS components that are common and can be sourced from multiple vendors… lowers the risk and cost of the design. Also lowers the risk of long downtimes & high repair costs if replacement parts are needed during operations.
    - Fabricated parts are fairly simple; tight tolerances required only in certain places, not across the board
    - There are some concerns about performance of some of the components in a radiation environment, which will need investigating & may generate some additional radiation shielding requirements

Overall Summary

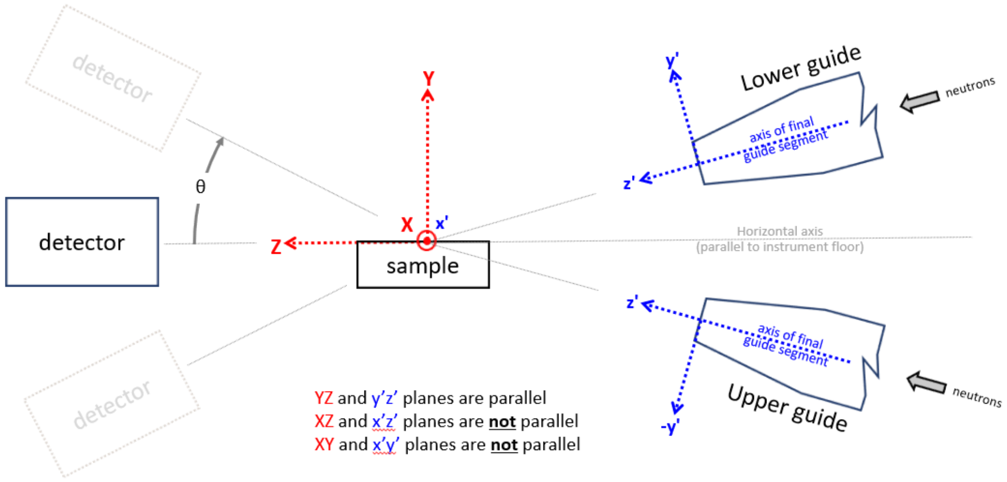
3. Are the cost estimate and acquisition strategy reasonable?
   - The parts are a combination of COTS components and fabricated (largely aluminum & steel) parts
   - There are some components like Franke wire bearing races & hexapods that have limited vendor sourcing options, and may require sole sourcing. Both PI and Franke are well-established successful vendors, though, which lowers the risk of having no suitable replacement parts in the event of a failure.
   - The fabricated parts do not require special processing techniques and do not use exotic materials. They can be sent out for competitive bid.
   - Cost estimates shown here include:
     -- Budgetary estimate from one vendor on the fabricated parts (seems unreasonably high, though)
     -- All COTS part costs except: FOM stages, hexapod controller and cables, Franke wire races
     -- All labor costs (including conservative estimates of assembly labor hours)
     -- Cost result: **Current design costs $218,149 less than P6 estimate**

4. Are the proposed preliminary designs sufficiently mature to proceed to final design?
   - The design is essentially complete except for components awaiting designs from other WBS's (detector)
   - DAC's have been performed to confirm performance and robustness of motors & components
   - Motors, limit switches, and encoders have been selected, hard stops added, cable routing started
   - Still need some investigation of in-bunker component robustness (may need local radiation shielding), need to perform seismic calculations & revisit tie-down design, need to adjust end station to accommodate taller sample environments

Backup slides

Axes Definitions (used in Requirements Document)

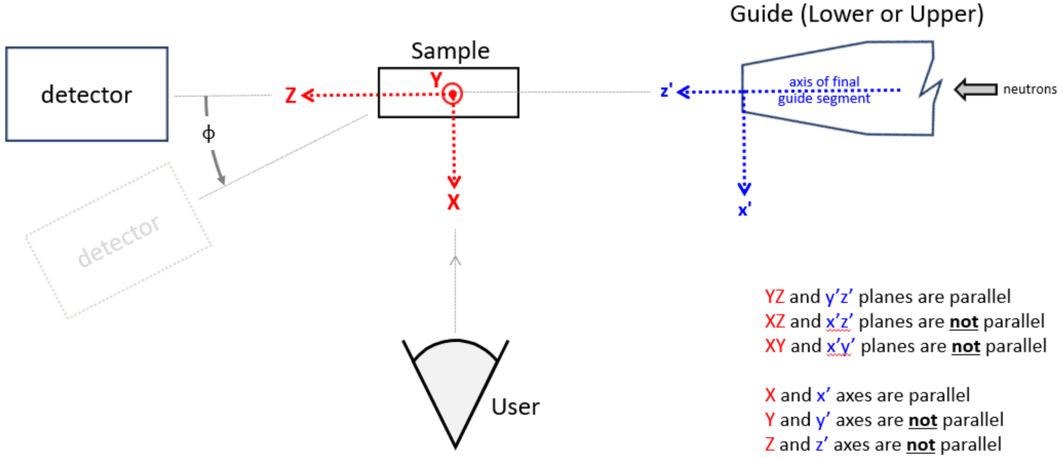
Axes Definition, User (elevation) view



YZ and y'z' planes are parallel
XZ and x'z' planes are **not** parallel
XY and x'y' planes are **not** parallel

X and x' axes are parallel
Y and y' axes are **not** parallel
Z and z' axes are **not** parallel

Axes Definition, Top (plan) view

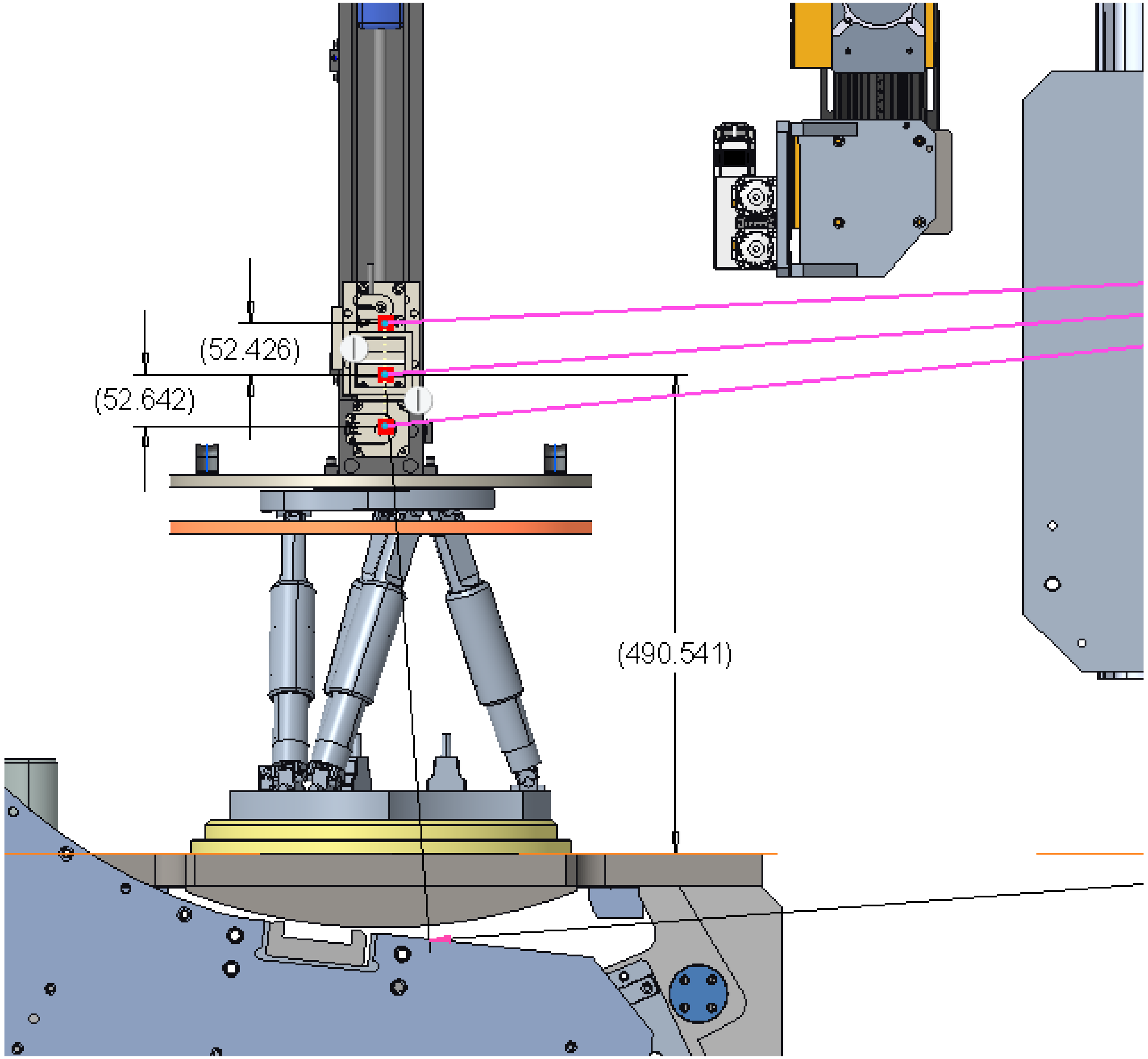


YZ and y'z' planes are parallel
XZ and x'z' planes are **not** parallel
XY and x'y' planes are **not** parallel

X and x' axes are parallel
Y and y' axes are **not** parallel
Z and z' axes are **not** parallel

Sample Locations, 2m from the Guide End

Dimensions are in mm



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Interfaces – ICS to Instrument Motion Components

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STS S01020500-IST10118-R00

SECOND TARGET STATION (STS) PROJECT

Interface Sheet for Instrument Motion Systems and Integrated Control Systems Process Controls

Matthew Pearson
Rudy Thermer

1st March 2023

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

1. PURPOSE

This document defines the interface between Instrument Systems motion systems and Integrated Control Systems (ICS) process controls. The interface will provide inputs to the design of the motion systems and the process control systems. Requirements that may be derived from this document will be included in the requirements documents for Instrument Systems and ICS. This interface will be applicable to all motion systems across the STS Instruments and Bunker.

2. SCOPE

The scope of this document is the complete interface definition between Instrument Systems motion systems and the process controls that will be part of the ICS. The interface points are summarized in the parent Interface Control Document [1] between Work Breakdown Structure (WBS) S.04 Instrument Systems and WBS S.06 Integrated Control Systems. The interface points are expected to include:

- Electrical interfaces for general purpose motion systems
- Cabinet or rack space needs
- Equipment protection & interlock logic
- Communication interfaces for specialized motion systems

As the motion systems and process controls preliminary design progresses, additional interface points may become apparent and will be captured in this document. Cable tray needs, power panel and grounding interfaces will be handled in separate interface sheets between ICS and Conventional Facilities (CF) and between Instrument Systems and CF.

The Instrument Systems motion systems include all motorized assemblies, such as:

- Shutters (maintenance and operation)
- Steerable optics systems
- Chopper translation stages (but not chopper rotations)
- Slits, apertures, and attenuators
- Guide translations and mirror translations
- Detector motions
- Sample motions

A motorized assembly means a combination of a translation or rotation stage, gear reduction, electric motor, switches, and position encoding devices.

Interfaces – CF to Instrument Systems (QIKR-B Cave Pit)

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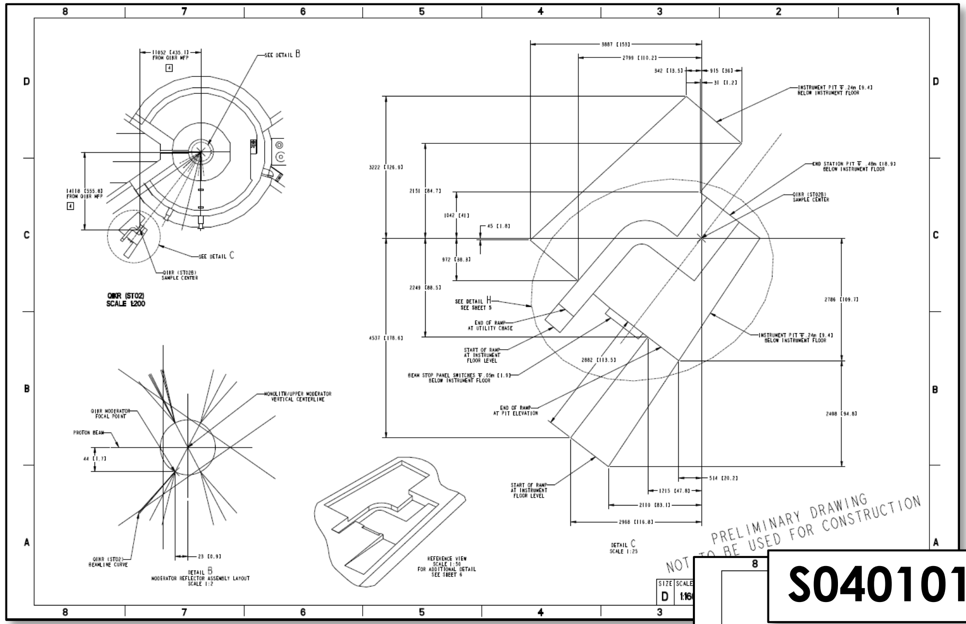

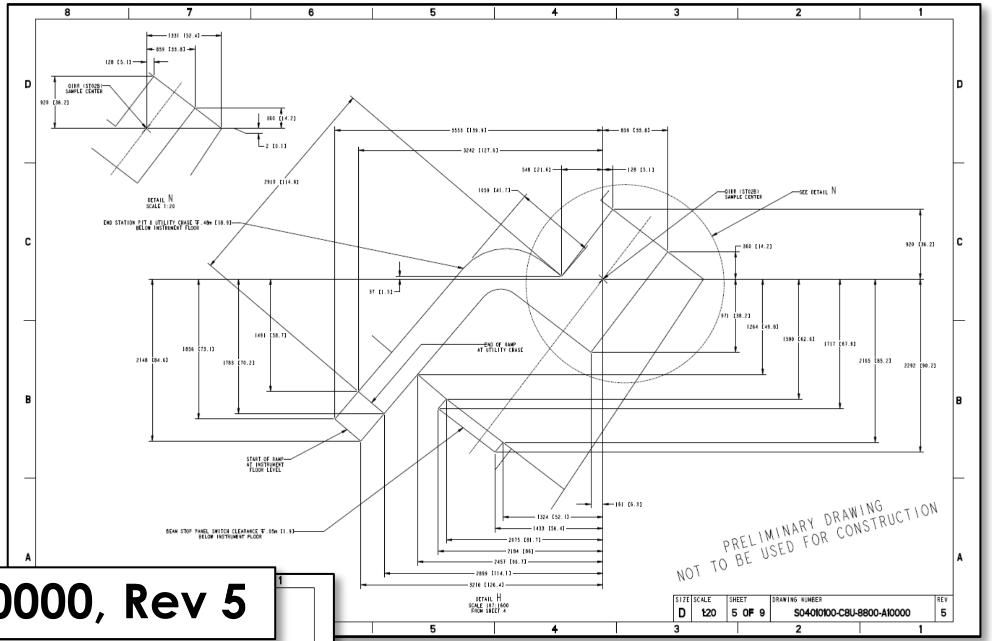

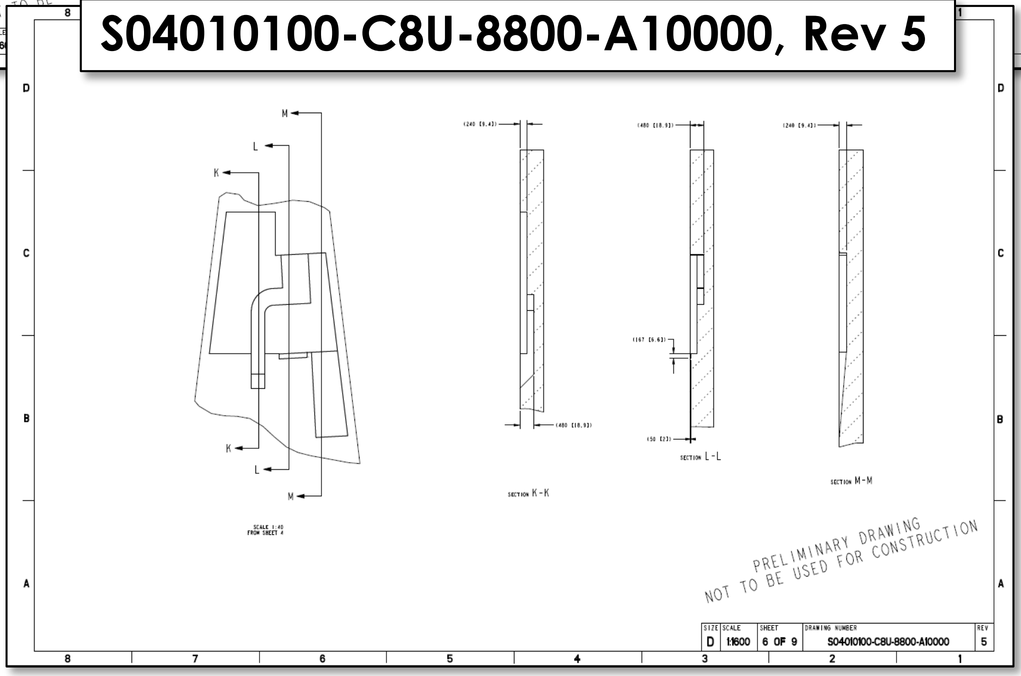

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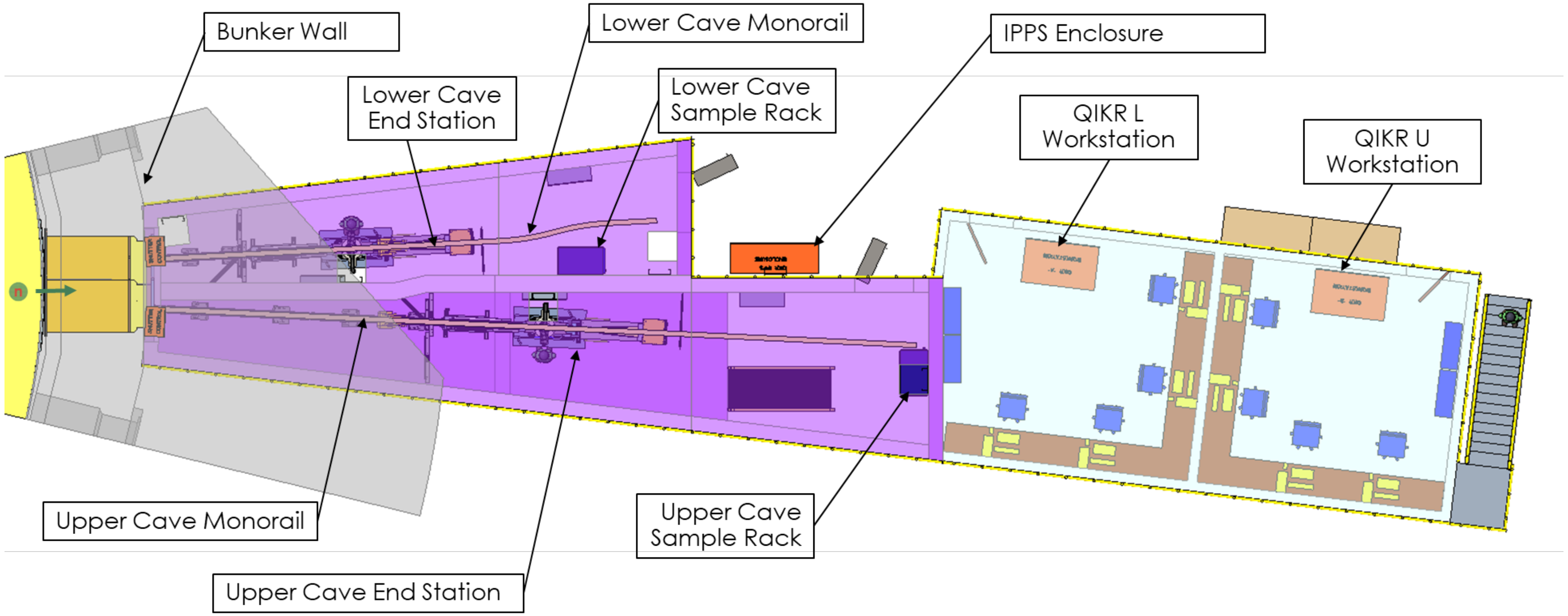
Top View of QIKR – Cables and Control Racks Hidden



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