Air Bearing Monochromator at APS 13-ID-E (GSECARS)

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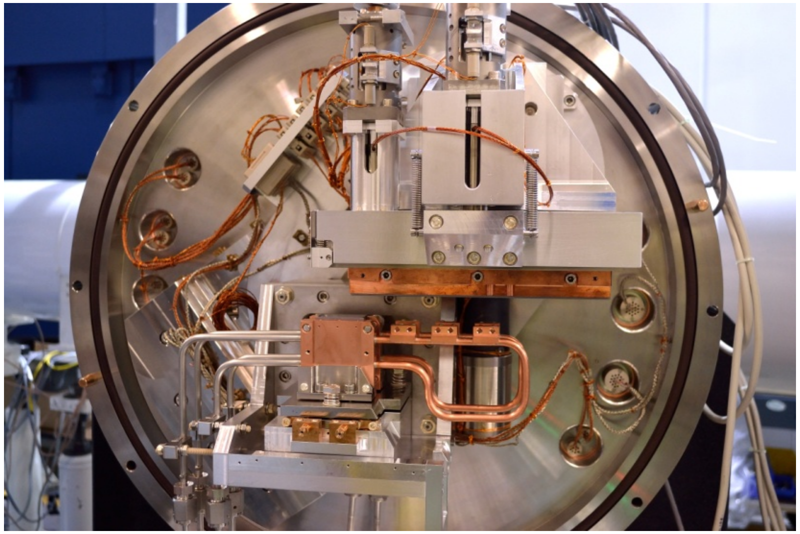


Upgraded Canted Beamline at GSECARS

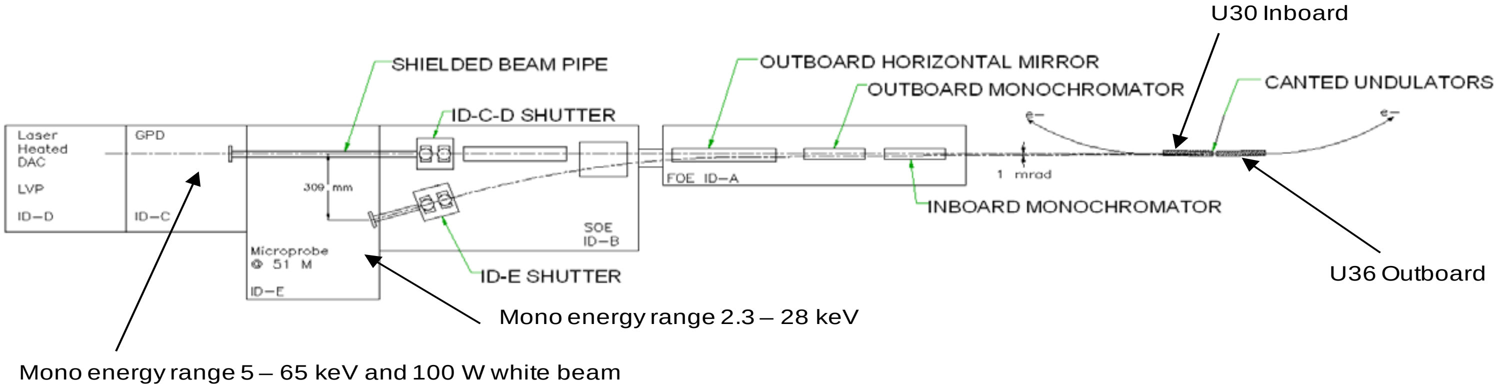
Air-bearing monochromator

Performance and Stability results

Fast Scanning / Quick XAFS

13-ID Canted Beamlines / Hard X-Ray Microprobe

APS Canted undulator upgrade: 2 IDs (2.1m) in a straight section, 1 mrad angle between them

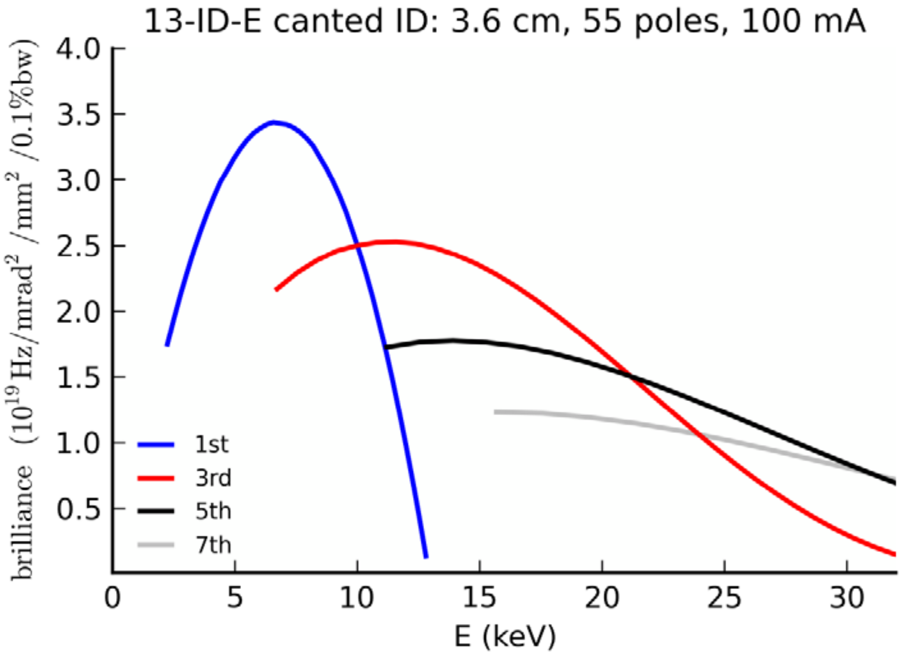


X-ray mirrors at ~31 m and set to 3 mrad separate canted branches by ~310 mm at 50m.
But the mirrors filter out energies > 30 keV, which are needed for most high-pressure work.

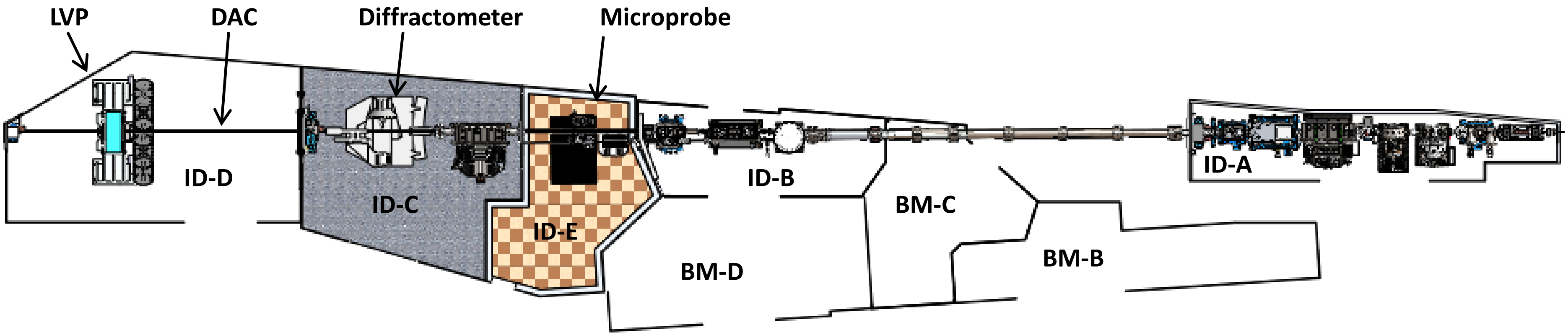
We use the deflected branch for an X-ray microprobe, and pushed to lower energy.

APS provided a 3.6 cm ID letting us reach the K edges of S, Cl, and Ca K edges for micro-XRF and micro-EXAFS spectroscopy.

This required a next-generation scanning monochromator for EXAFS scanning with an energy range from 2.4 to 28 keV.


13-ID-E canted ID: 3.6 cm, 55 poles, 100 mA

APS 13-ID: Canted Undulator Beamline



LVP

DAC

Diffractometer

Microprobe

ID-D

ID-C

ID-E

ID-B

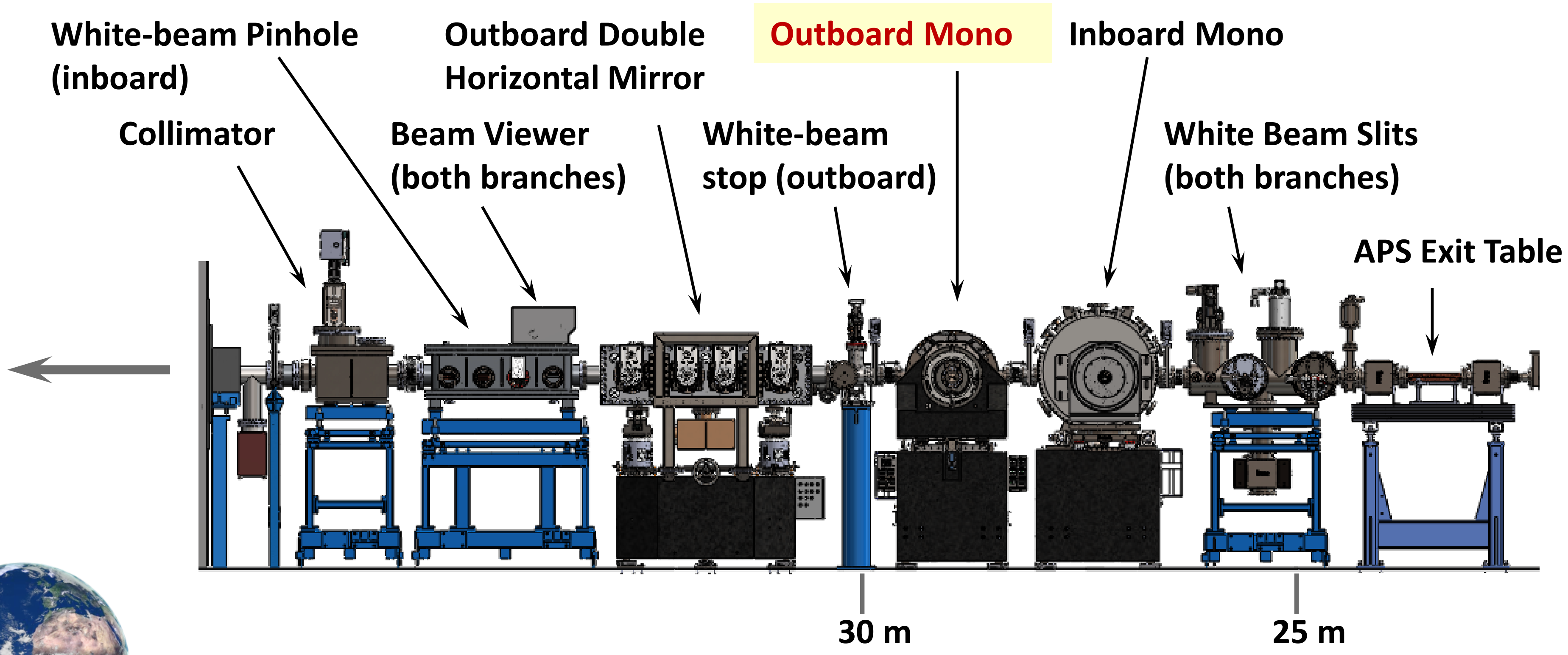
ID-A

BM-C

BM-D

BM-B

First Optics Enclosure



White-beam Pinhole (inboard)

Outboard Double Horizontal Mirror

Outboard Mono

Inboard Mono

Collimator

Beam Viewer (both branches)

White-beam stop (outboard)

White Beam Slits (both branches)

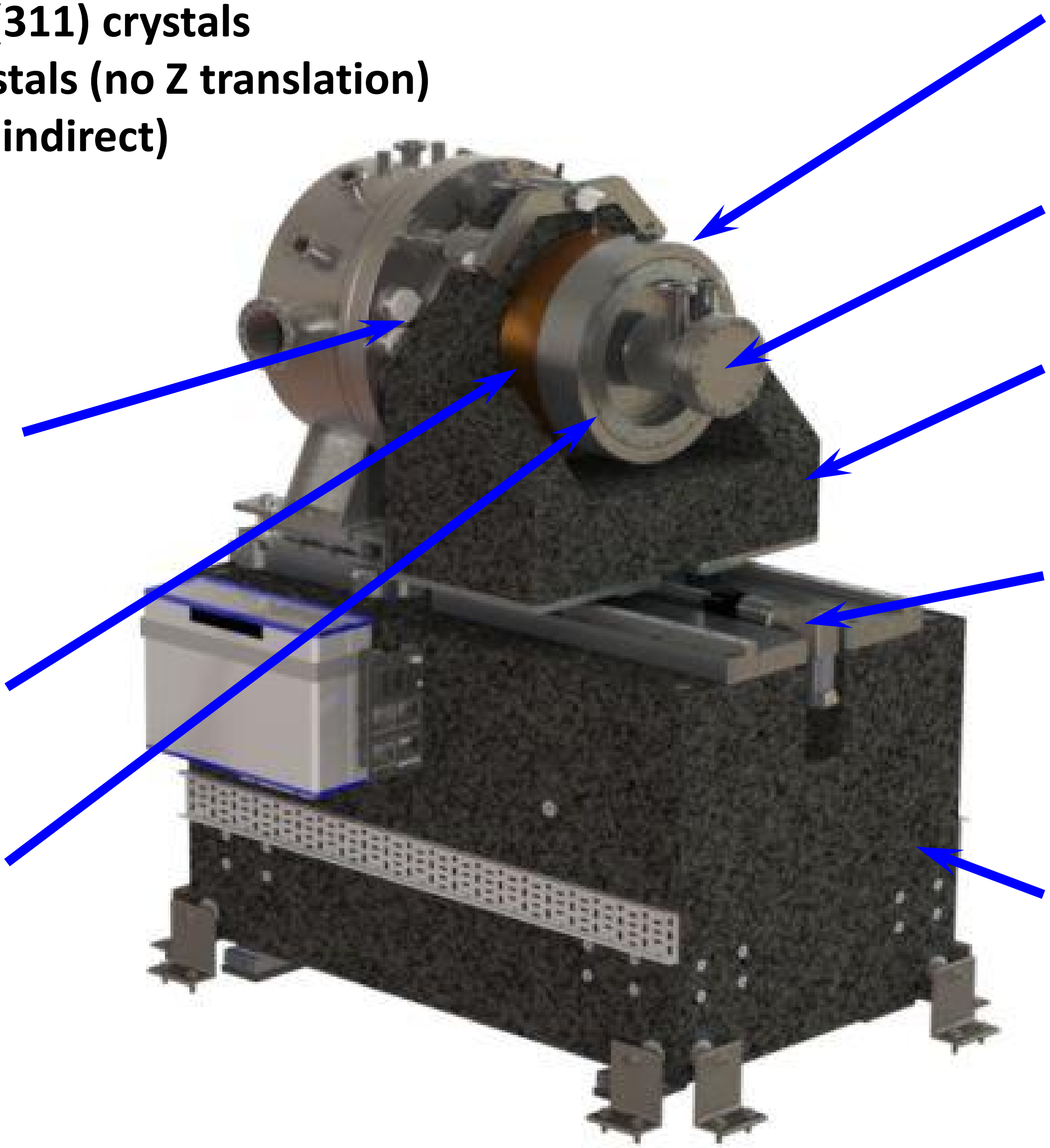
APS Exit Table

30 m

25 m

Monochromator for 13-ID outboard branch (ID-E)

Energy Range: 2.4 to 28 keV (max angle 57°)
Si(111) and (311) crystals
Long 2nd crystals (no Z translation)
LN_2 cooling (indirect)



direct drive 3-Phase 66 pole brushless DC motor

Cryo-cooling lines fed through rotation axis

granite “tombstone” supports main rotation axis

lateral translation of “tombstone” (but not vacuum vessel for changing crystal sets.

granite support block, vibration isolation.

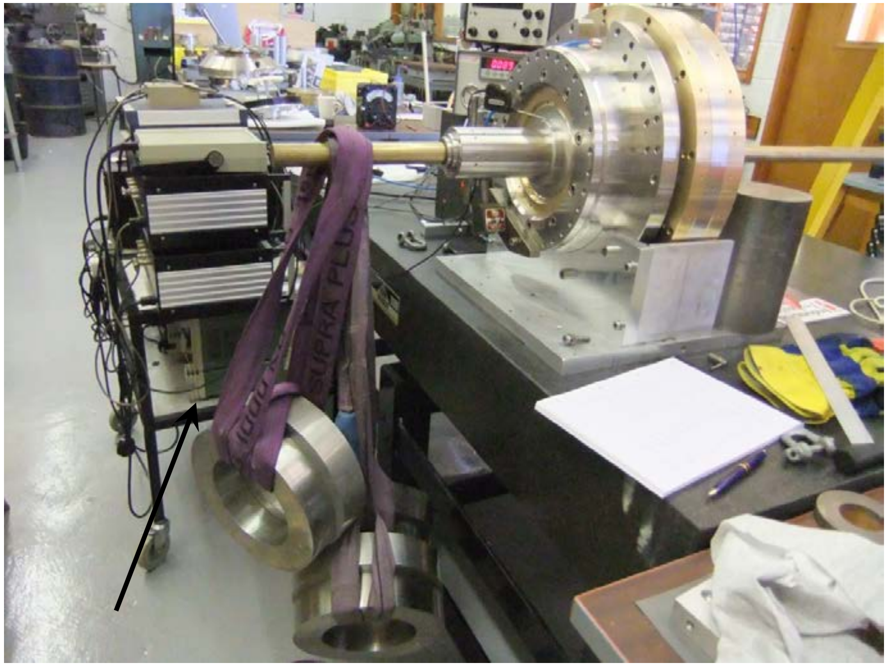
ferrofluid vacuum seal

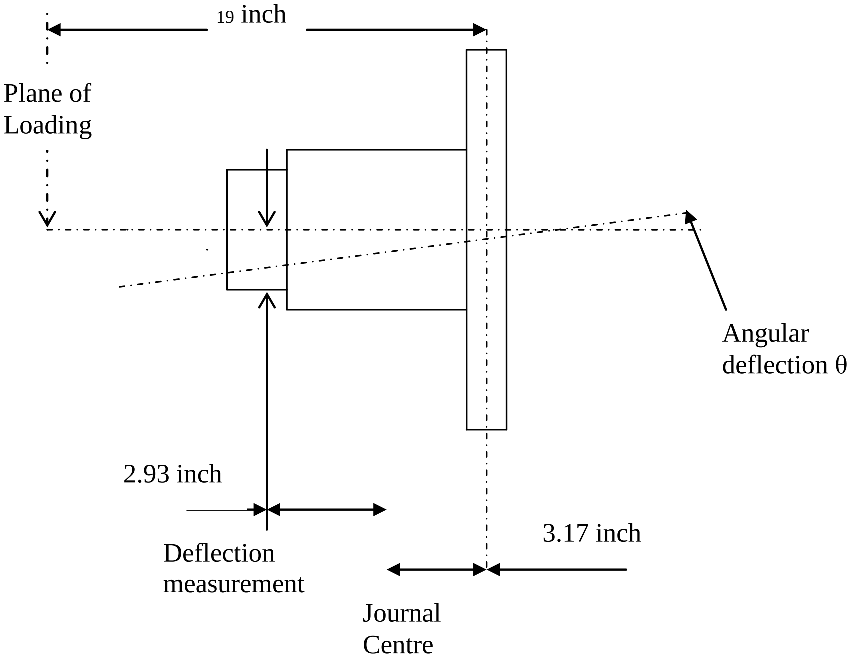
air bearing

angular encoder

Air-bearing Strength and Safety

102 kg Test Load (actual crystal cage assembly ~ 25 kg)

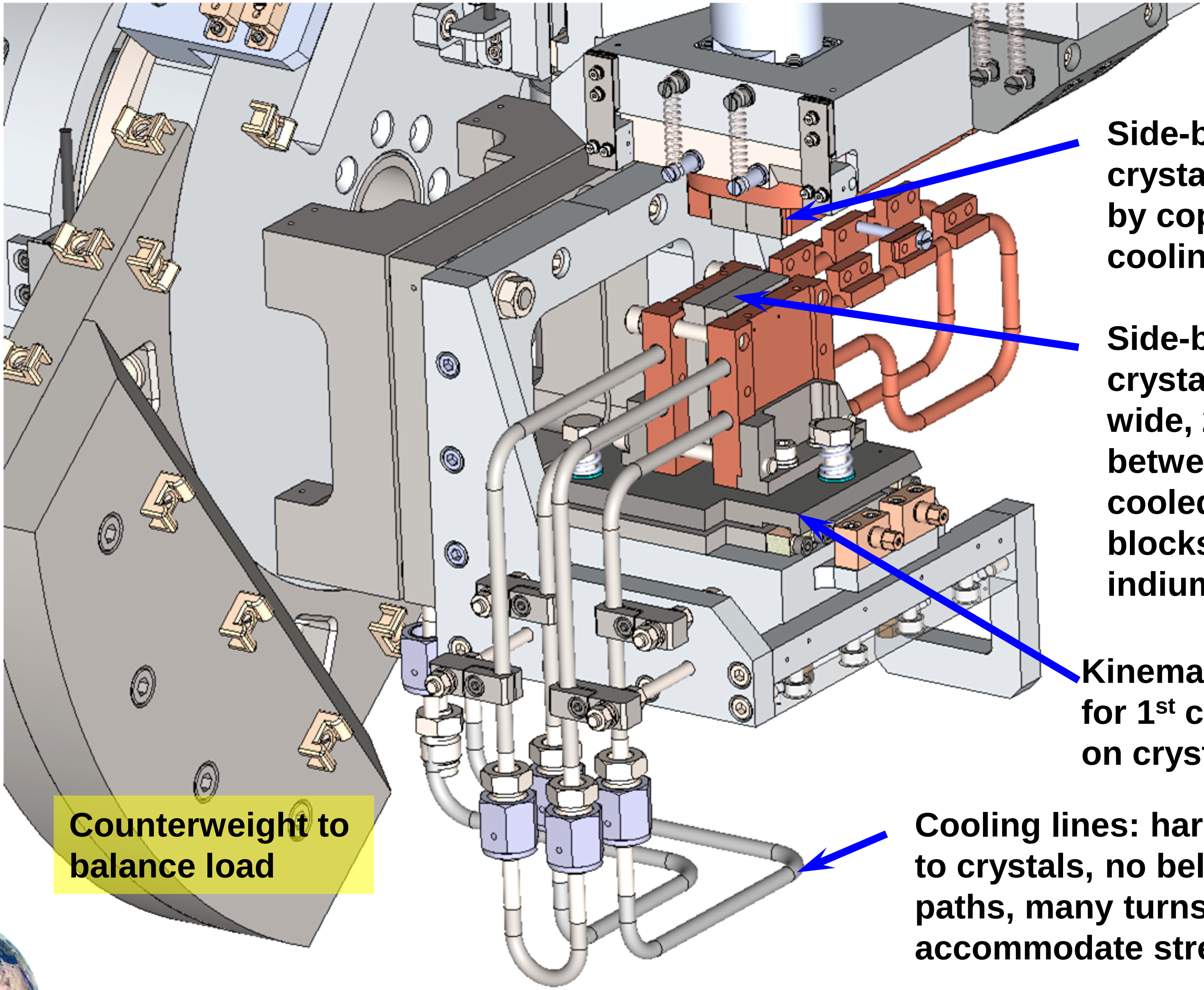




Air Pressure (PSIG)	deflection (μrad)
60	21.7
70	17.0
80	14.6

Dual air pressure sensors kill power to controller when pressure < 70 psig

Monochromator Crystal Cage: Si(111) and Si(311)



Side-by-side 2nd crystals, cooled by copper foils to cooling lines

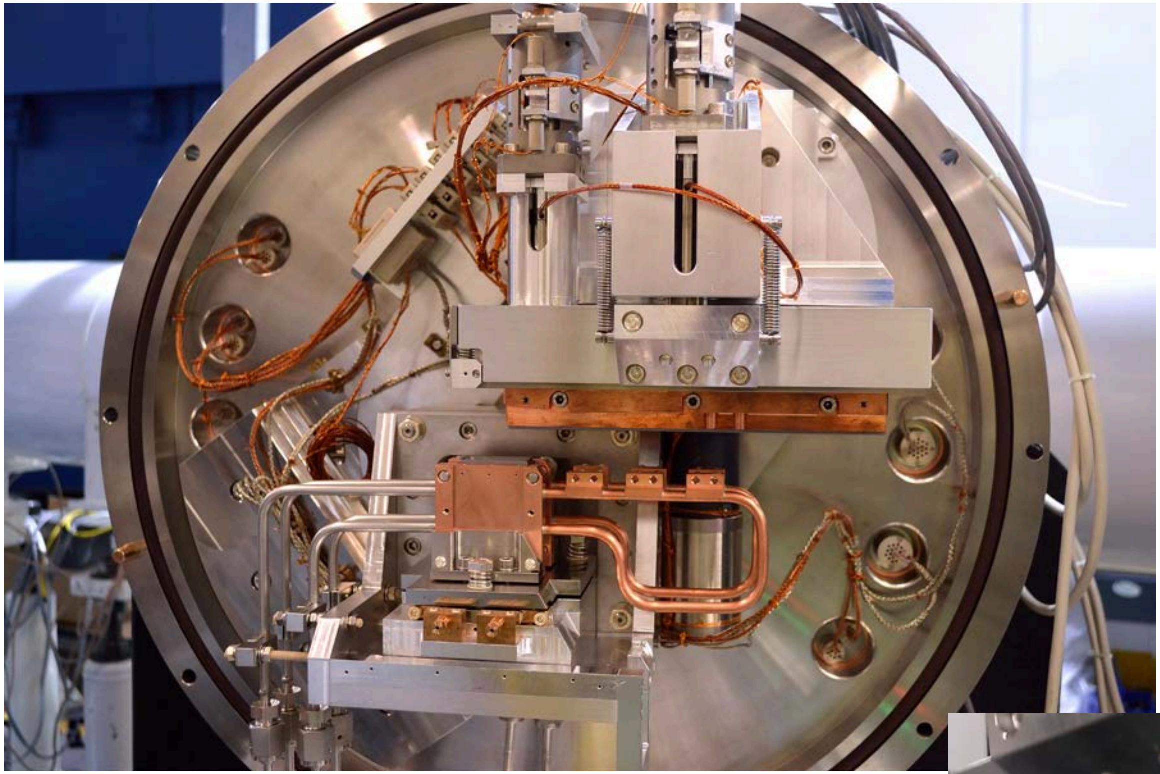
Side-by-side 1st crystals (5mm wide, 20mm long), between cryo-cooled copper blocks (with indium foil).

Kinematic mount for 1st crystal block on crystal cage

Cooling lines: hard plumbed to crystals, no bellows, long paths, many turns to accommodate stress

Counterweight to balance load

Monochromator Crystal Cage: Si(111) and Si(311)



Crystal specified to near mirror quality:

Property	Value
flatness (rms)	5 μrad
roughness (rms)	< 1 nm
Miscut tolerance	0.35 mrad

2nd crystals (200mm long) are cooled with many thin copper foils to LN2 tubes downstream of 1st crystal blocks. 2nd Crystal Temperatures ~105 +/-10 K.

no Compton shielding.

Monochromator Operating Conditions

The mono is at ~28 m from source, and runs at fixed offset of 25mm

2nd Crystal Travel Ranges:

axis	Range (mm)
Height	12
Pitch	4
Roll	4

In-line piezos (low-backlash) for pitch/roll:

50 microns (~300 μrad)

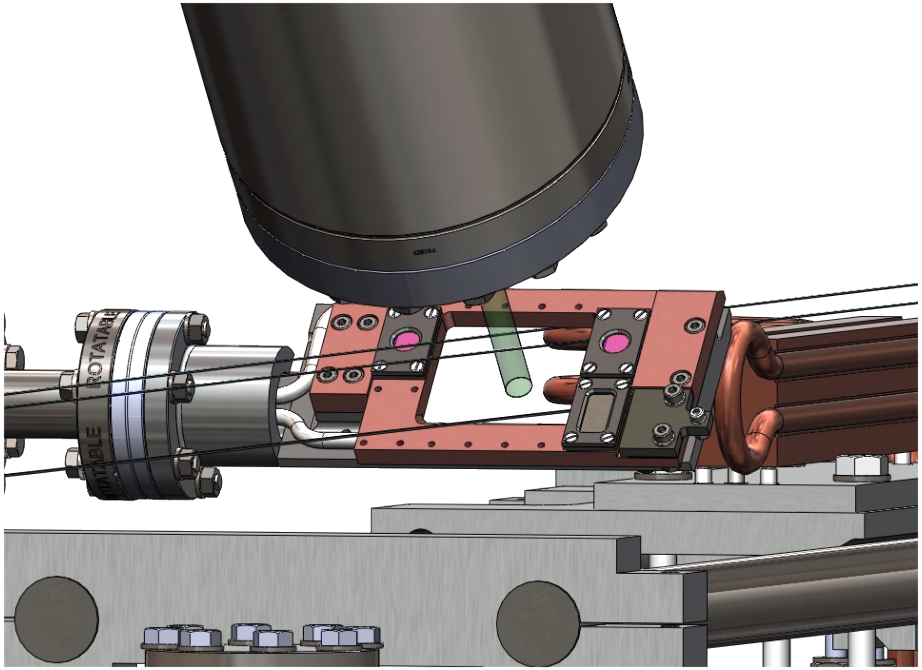
After initial alignment, we normally move the pitch/roll motors only when changing crystal sets, and use only piezos for adjustment over full energy range.

We steer the beam horizontally to be centered on **~0.3 mm x 0.1mm (V x H)** secondary source aperture (SSA, ~42 m) with ~5μrad steps of horizontal mirror.

At E < 3 keV, we feedback roll piezo with horizontal position at SSA.

Front End White Beam Slits (~25 m from source), are set to **0.3 x 1.0 mm (V x H)**

Limits power on mono to < 100 W



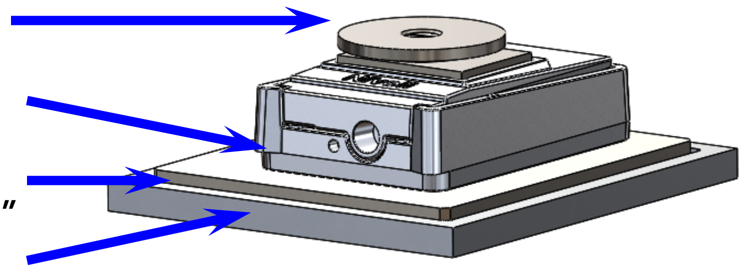
A phosphor view-screen with digital camera downstream of mono (and mirrors) allows us to align undulator beam on slits/mono, set true roll=0, measure mono beam offset, and calibrate mirror pitch. **Vital to operation!**

Monochromator Vibration Isolation

LN_2 flows through mono blocks a ~2 l / min with a cryo pump (Oxford) operating at 40 Hz.

We initially saw a fair amount of beam shaking in the downstream stations, and suspected the cryo-lines and floor vibrations. Turning on/off cryo-pump had little effect.

Adding a stack of vibration isolation materials to below the 3 mounting feet (granite block to floor) helped considerably.



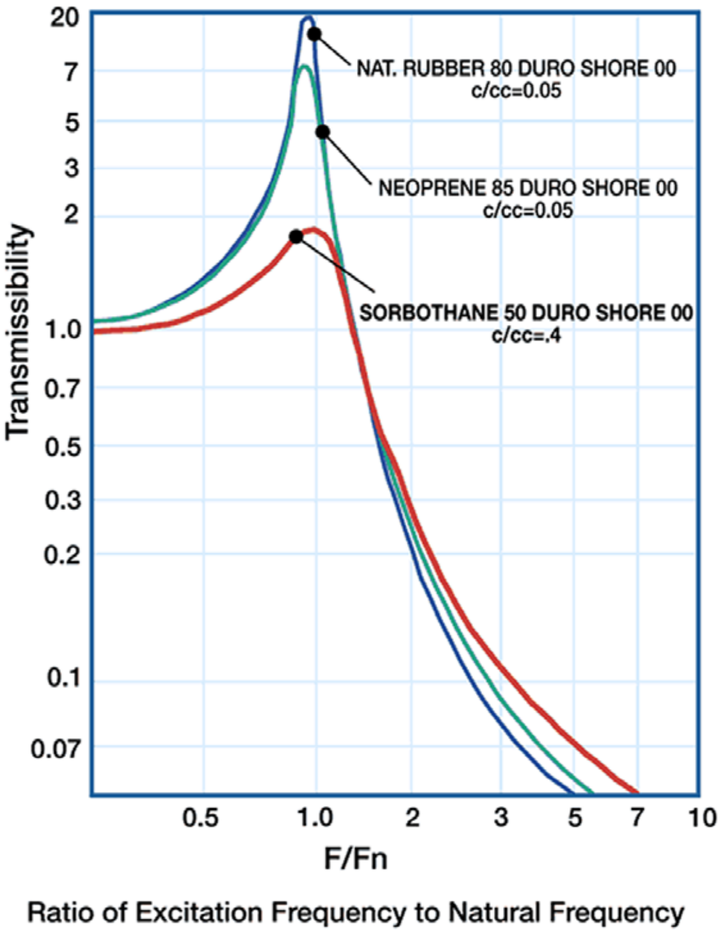
Leveling Foot
to granite block

Ground Steel Plate

Sorbothane:
70 Duro, 6 x 7 x 3/8”

Aluminum Pan

This is working much better for us, but probably needs more thorough study.



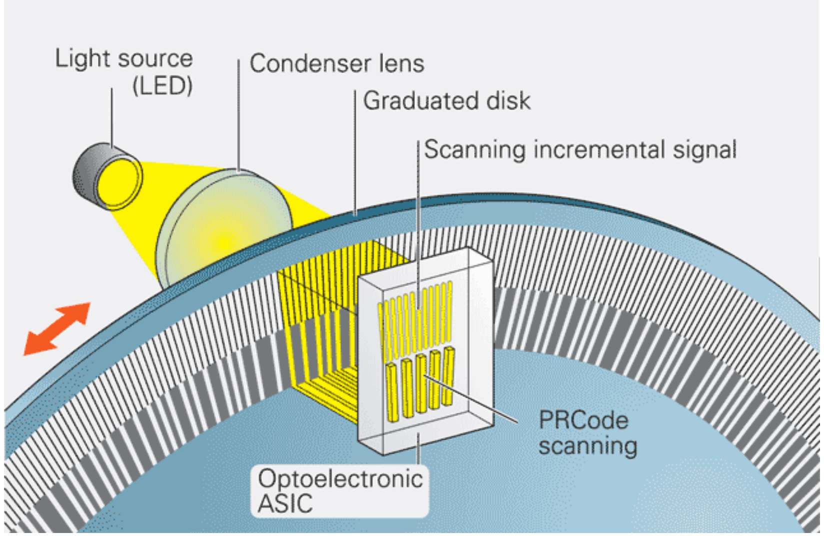
Monochromator Control and Angle Readout

A smart motor controller is needed to control DC motor, read encoder positions, continually feedback position, and coordinate motions.

We are using the Newport XPS system, though many similar controllers (Delta Tau, Aerotech, ...) should work as well.

This includes several safety features:

- kill power to DC motor on following error
- kill power to motor on loss of air pressure.



Angle measured with two on-axis angular encoder each with 47,200,000 lines:

131,111.1 lines / degree

Encoder Precision	0.133 μrad
APS vertical source divergence	6.6 μrad
Typical Darwin Widths:	3 to 30 μrad

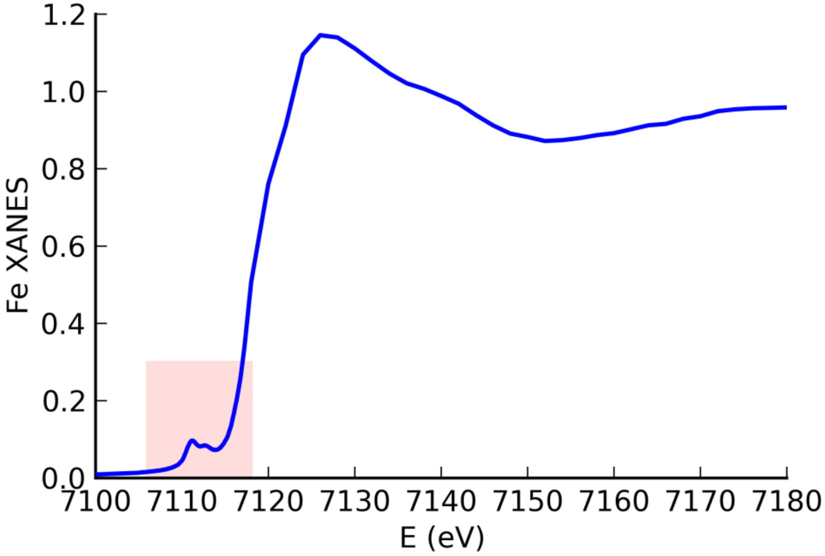
Encoder and read-out electronics need to be very well shielded!

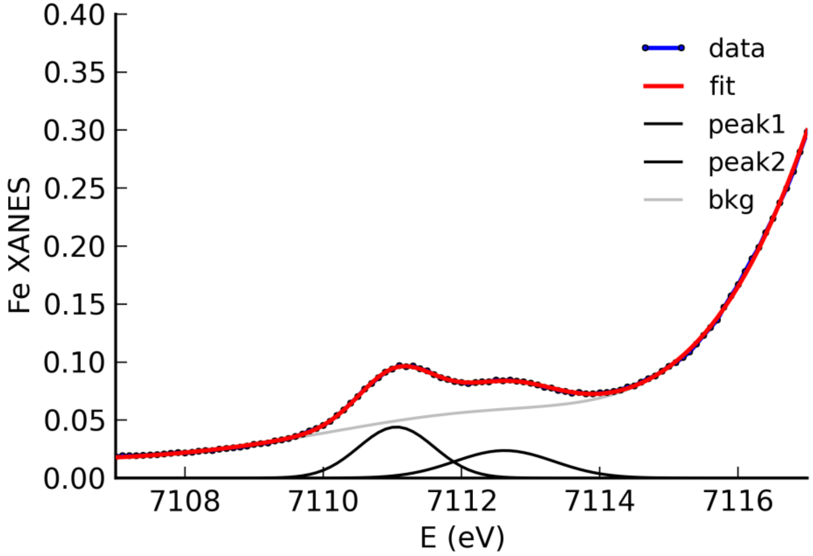
Energy Reproducibility Tests

How reproducible is the energy calibration over time?

Test: repeat Fe XANES on a stable sample with Si(311) crystal over ~2 days.

Sample: synthetic, reduced (Fe^{2+}) basaltic glass, used as a redox standard.
sample from Liz Cottrell, Smithsonian Institute





Fit the pre-edge peaks with Gaussian peaks (typical σ ~ 0.5 eV), and watch variation of centroid of first peak over time – 34 spectra over 46 hours.

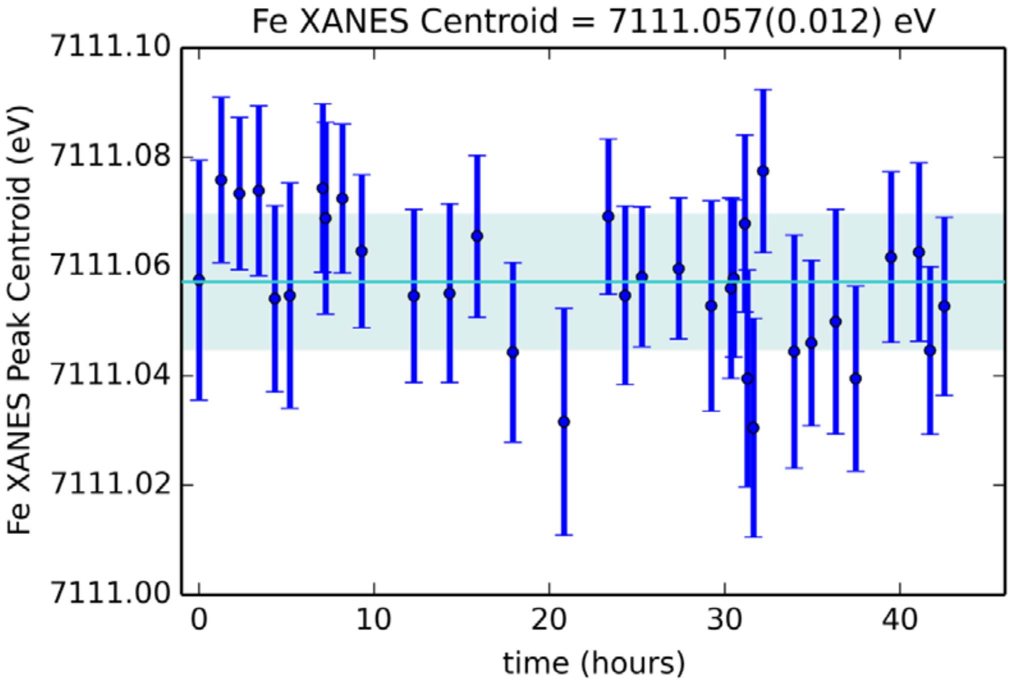
Bonus: APS was in non-top mode - test stability under varying heat-load!

Energy Reproducibility Tests

Si(311) at Fe K-edge:

1st ID harmonic (21 mm gap), modest heat load (1/4 max).

Feature	Angle (mrad)	Energy (eV)
Si(311) Bragg Angle	561.455 6	7112.000
Fe 1s Level Width	0.115 8	1.31
Si(311) Darwin Width	0.017 1	0.192
Mono Encoder Step	0.000 13	0.0015



Step Size in Energy Scan: **0.100 eV**
Variation of centroid: 0.012 eV
Typical σ for each fit: 0.020 eV

0.1 eV:

- ~Darwin Width/2
- ~9 μrad
- ~70 encoder steps

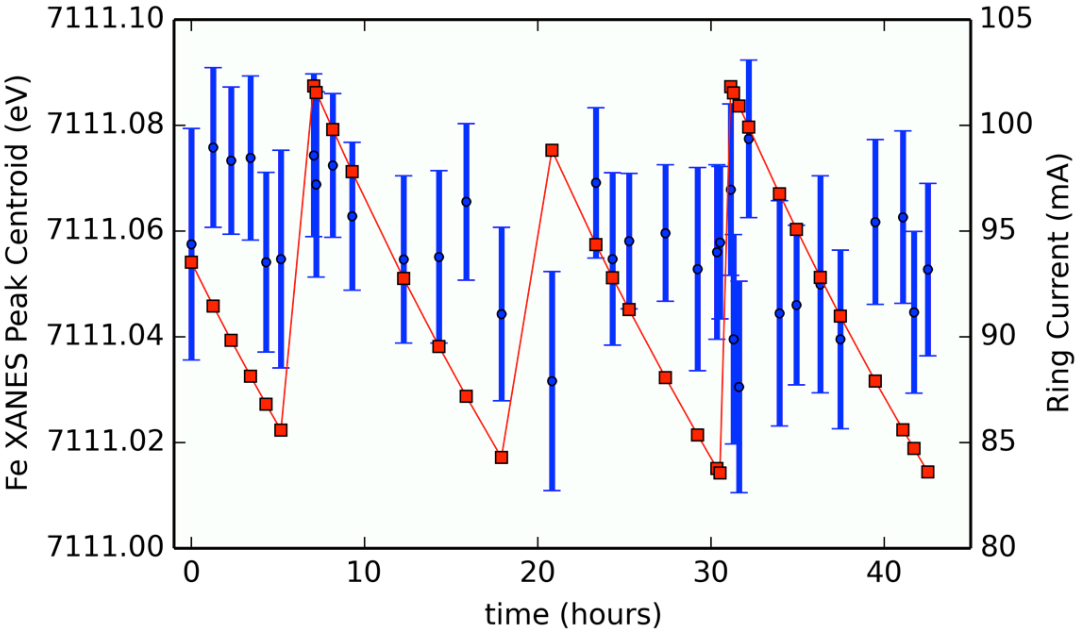
0.012 eV:

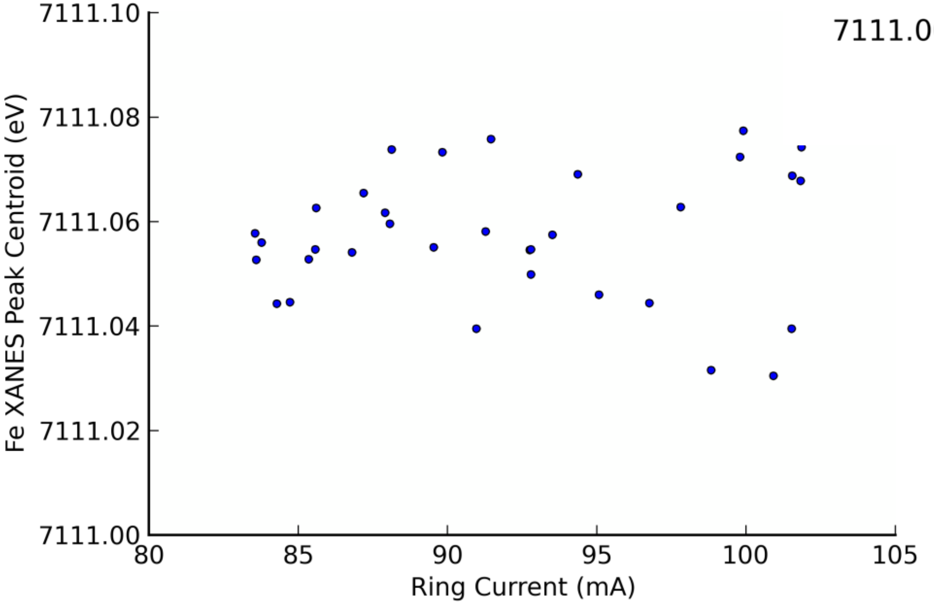
- ~Darwin Width/16
- ~1 μrad
- ~8 encoder steps

Energy Reproducibility Tests: Effect of Decaying Ring Current

Could the decaying ring current and changing heat-load might cause some energy shifts?

At first look, there seem to be small jumps on fills.





But: the centroid energy and ring current are very poorly correlated (R=0.056, 75% chance of having R=0).

Changing ring current in non-top-up mode has **no measured effect** on energy stability.

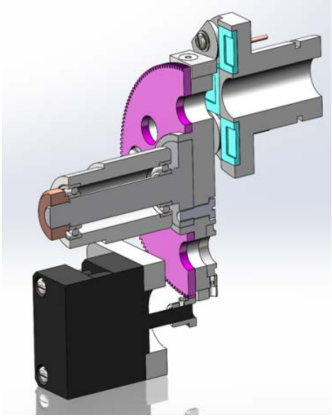
May need to revisit with finer energy steps to get a better measure of this.

Angular Stability of Monochromatic X-ray beam

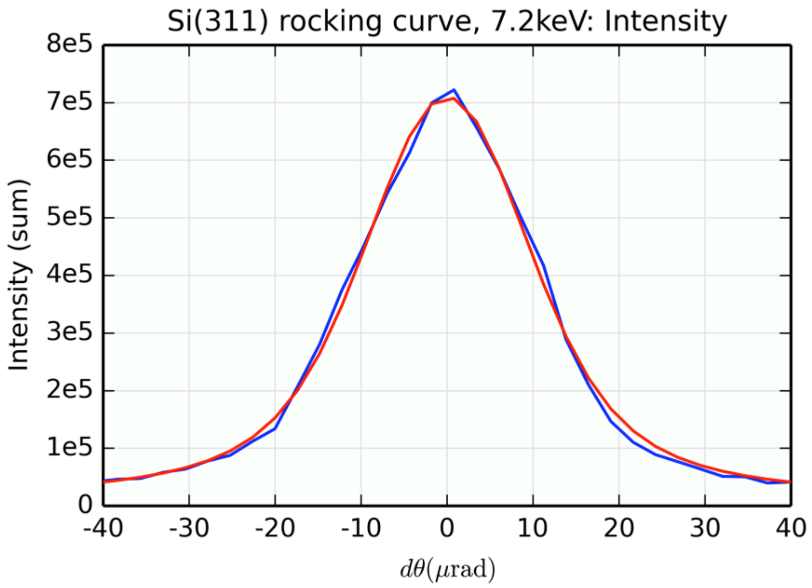
How much does the beam shake (after sorbothane)?

Test: Use Beam Position Monitor (~42 m) to measure fluoresced signal onto top and bottom diodes to determine X-ray beam position far from source.

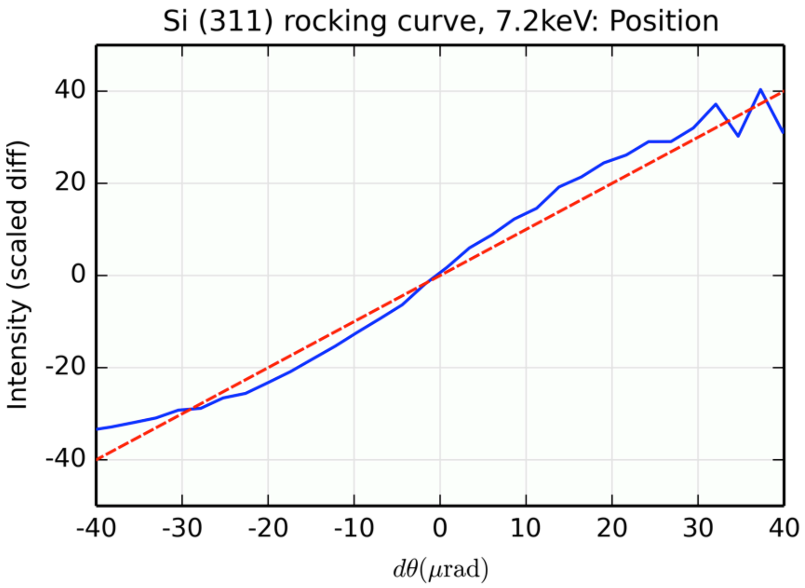
Calibration Check: Use BPM currents to check calibration by measuring rocking curve for Si(311) at 7.2 keV



X-ray BPM with Foil Wheel and diodes



Si(311) rocking curve, 7.2keV: Intensity



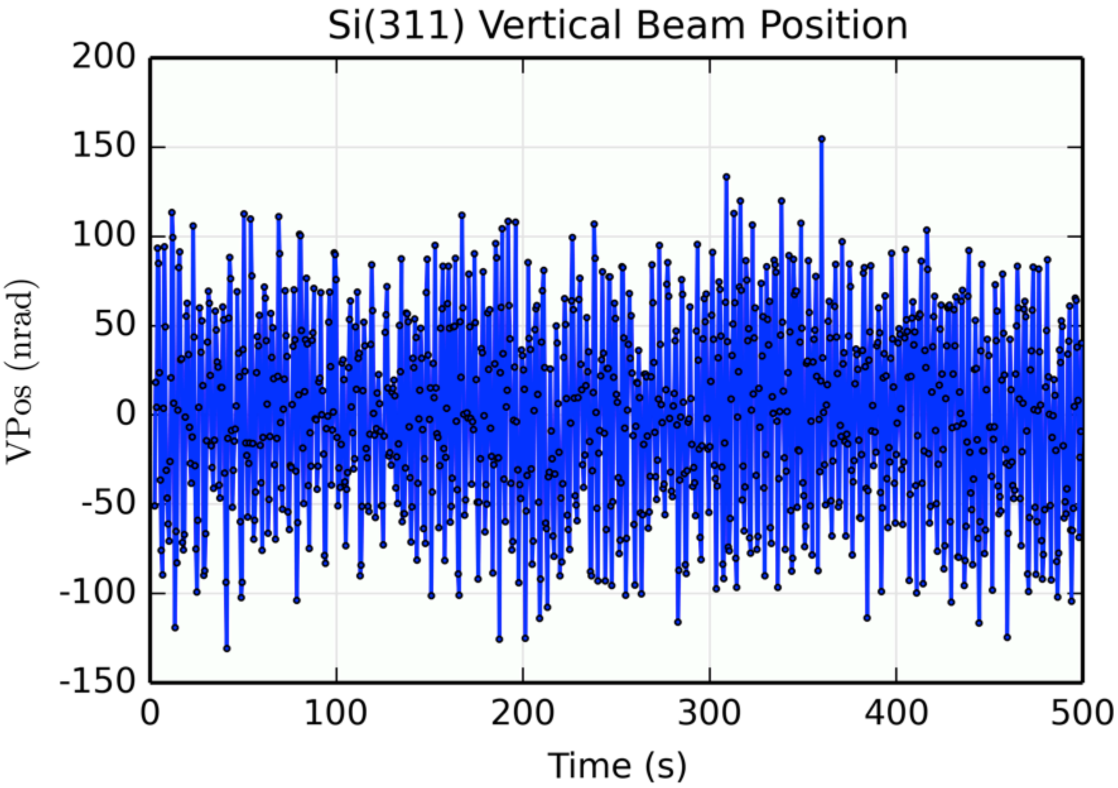
Si (311) rocking curve, 7.2keV: Position

Fit rocking curve with Voigt Function gives FWHM = 24 μrad, slightly bigger than theoretical value (~17 μrad). This verifies calibration of BPM Position with angle.

Angular Stability of Monochromatic X-ray beam

We can record BPM vertical position (top-bottom)/(top+bottom), convert to angle, and watch the beam shake (mono vibrations from cryo lines + source motion).

Beam energy at 7.2 keV, no active feedback, sampling position every 0.5 sec for 500 sec.



These measurements can be made any time without interfering with data collection most of the time – it is simply capturing BPM currents.

Could include spectral analysis.

Identifying a source of motion at this level would be challenging .

At 15 m from mono

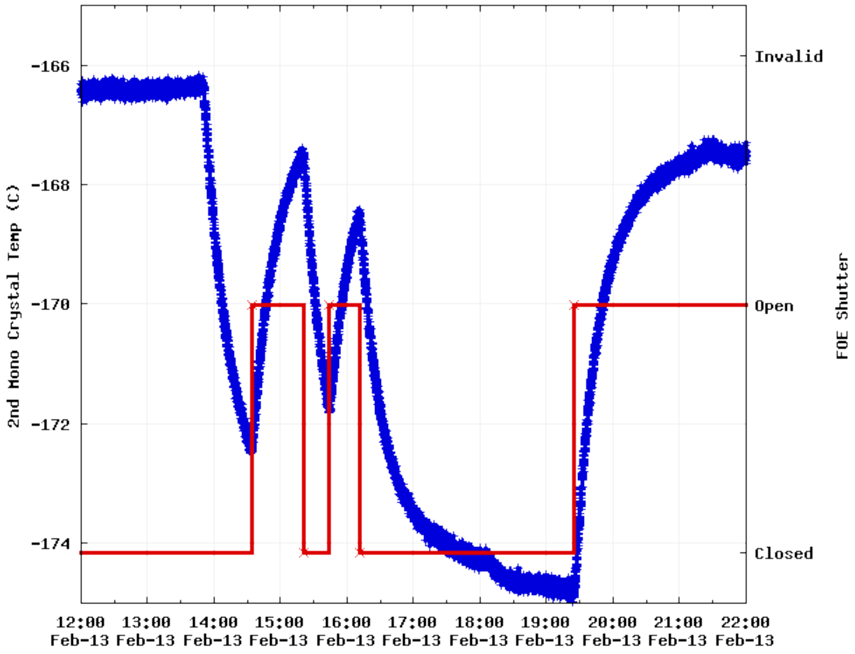
54 nrad X 14 m	0.76 μm
beam size	~400 μm

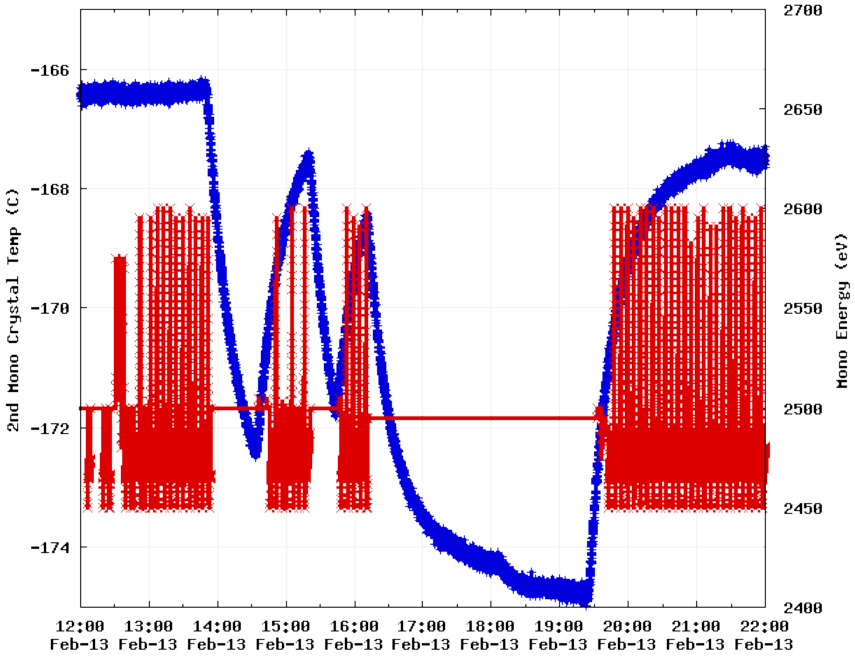
Standard deviation of beam angle: 54 nrad (1 encoder step = 133 nrad)

Thermal Stability

How does the mono react to changing thermal loads?

We were doing S K edge (~53 degrees, 2.5 keV, closed undulator gap ~12mm) during beam some recurring dumps (Feb 2014). Here's how the 2nd crystal temperature responded:





2nd crystal temperature changed by ~10 C on beam dumps.

We continued S K edge scans ~15 minutes after the beam returned. A piezo sweep of beam position at SSA of 0.35 mm x 0.08 mm (V x H), and locked in on position.

Quick XAFS Tests

Can XAFS be collected in continuous scan mode? How fast?

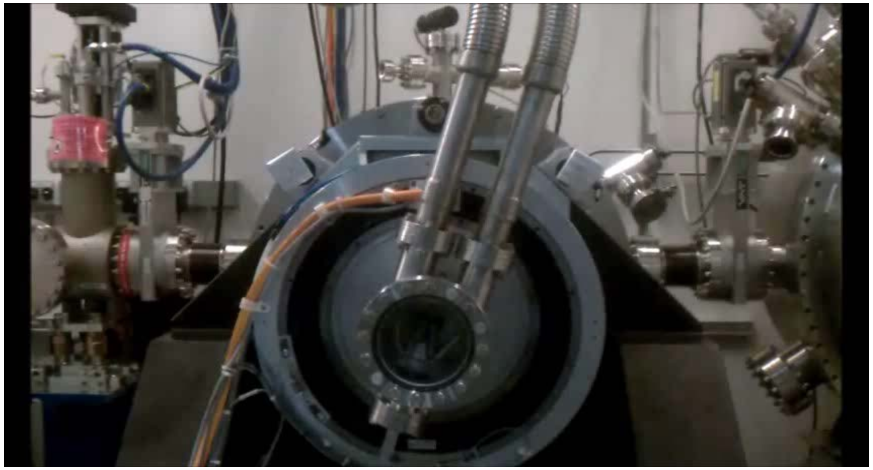
Many Quick XAFS beamlines have a dedicated mono that uses a cam to oscillate back and forth over a selected energy range.

With the Newport XPS, we can scan the mono continuously up to 10 deg / sec, and simulate a sinusoidal trajectory at any energy in software.

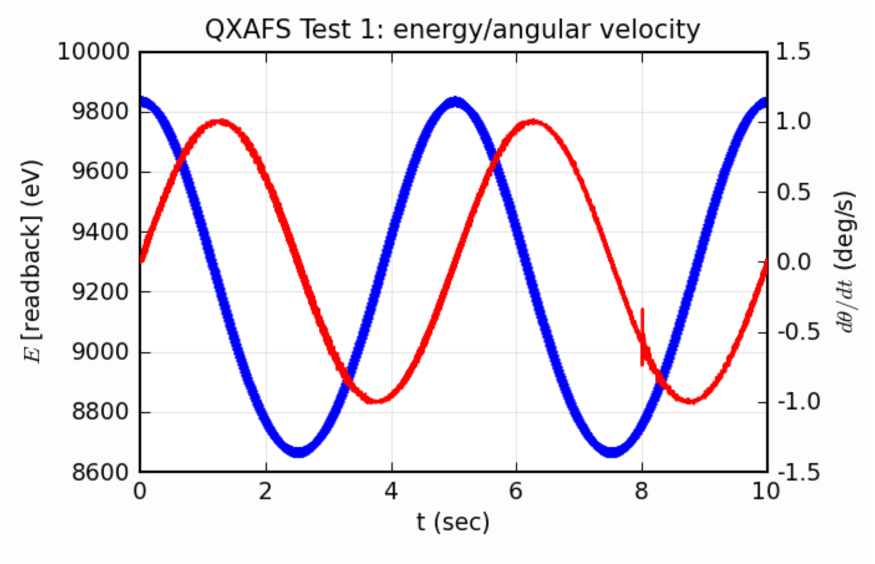
With an energy range of ~1 keV, 2 full oscillations were run in 10 seconds.

Pulses from the mono θ axis triggered the SIS3820 MCS reading ion chambers.

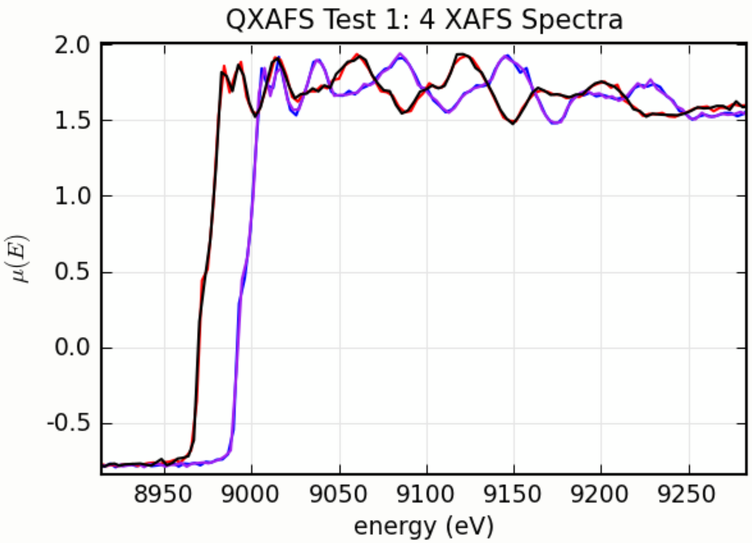
The undulator was tapered -- did not try to synchronize ID and mono, initially.

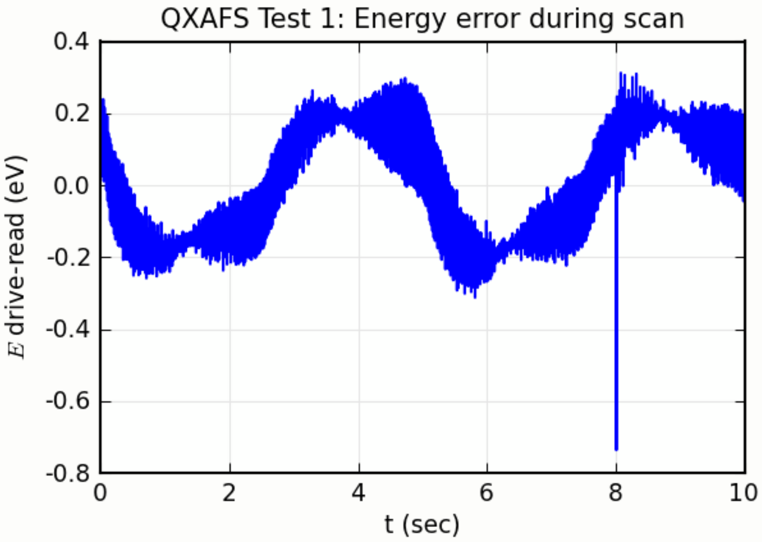


Sinusoidal trajectory, 1 deg/sec



Quick XAFS Tests





We can do 4 XAFS Spectra in 10 seconds!

The apparent energy shift (forward v backward) is due to the capacitance of the ion chamber – a well-known effect in Quick-XAFS.

The XAFS is decent quality. The counting chain is not optimized for fast acquisition (standard ion chambers, amplifiers, 100 kpulses/Volt V2F).

The mono mechanics are not challenged: the following error for energy is very small. And the mono can go 10x faster.

Attempts to synchronize with ID were mixed:

- It is possible to give a Gap Profile move.
- Hardware synchronization is not yet possible.
- there is a ~1 sec accel and decel time for the gap to get to speed.
- Cannot simulate sinusoidal gap profile.

Conclusions

- Air bearing + high torque motor + high precision encoder + smart motor controller can make for an excellent monochromator.
- Air bearing + ferrofluid seal gives an ideal drive – near-zero friction, and a purely linear damping term. It requires carefully balanced load, including cryo-lines, and careful set up and tuning.
- To match angular stability on modern sources, mono crystals need to have flatness and roughness typically specified for mirrors.
- A single monochromator that can do Quick-XAFS in software (and no-wear direct-drive motor) is very attractive for many beamlines.
- Thermal and vibrational stability involves integration of whole beamline (including source and building), not just a single X-ray component.
- Every X-ray spectroscopy beamline needs a mono this good.
- Hopefully this mono will not be the state-of-the-art in 5 or 10 years.