An STJ Spectrometer for High-Resolution Soft X-ray Spectroscopy at the Synchrotron

Matthew H. Carpenter
STAR Cryoelectronics, UC Davis

Stephan Friedrich
Lawrence Livermore National Laboratory

J. Ad Hall, Robin Cantor
STAR Cryoelectronics

Overview

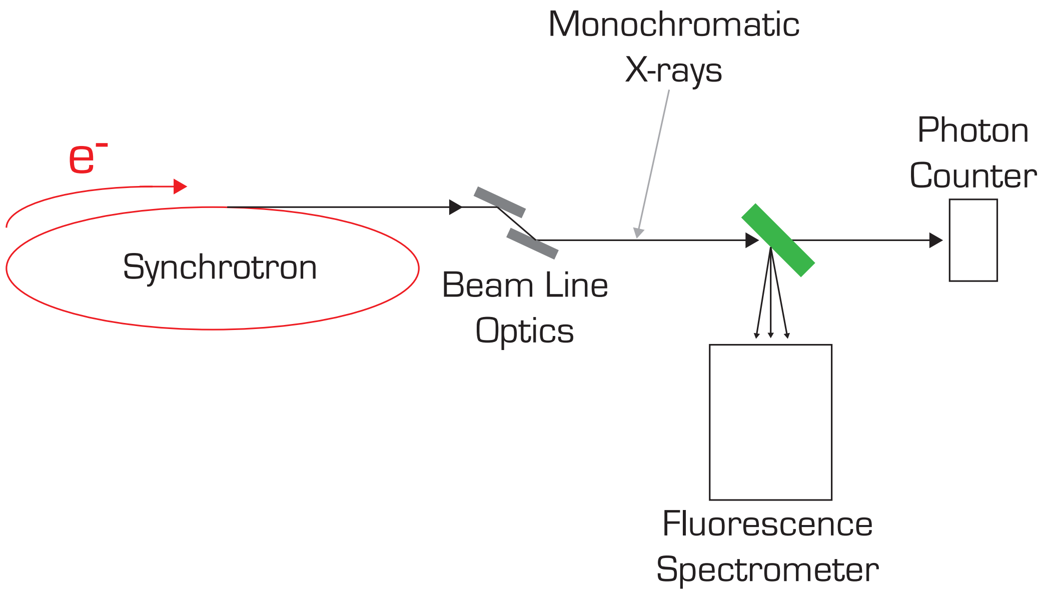
GOAL: High-resolution, user-friendly commercial detector for Synchrotron XAS

X-ray Absorption Spectroscopy
- Synchrotron Radiation, Measurement Techniques
- Partial Fluorescence Yield (PFY)
- Enhanced PFY with High-Resolution Detectors

STJ Detectors
- Operating principle
- Ta device design
- Device characterization
- Array spectra

Spectrometer System for Synchrotron XAS
- Requirements
- Cryogen-free cryostat design

X-ray Absorption Spectroscopy (XAS)



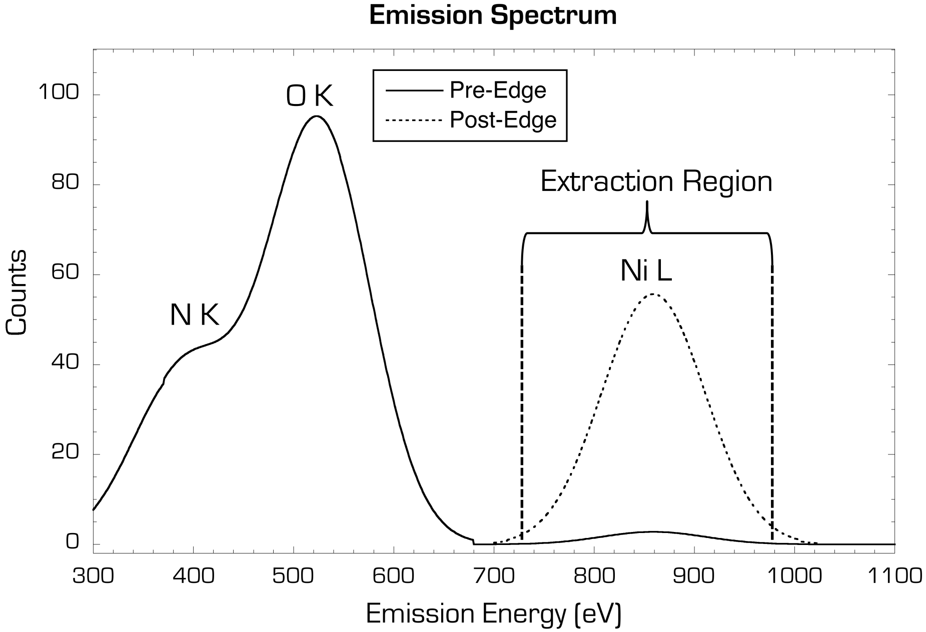
Measure Absorbance (A) of sample as function of energy across element absorption edge

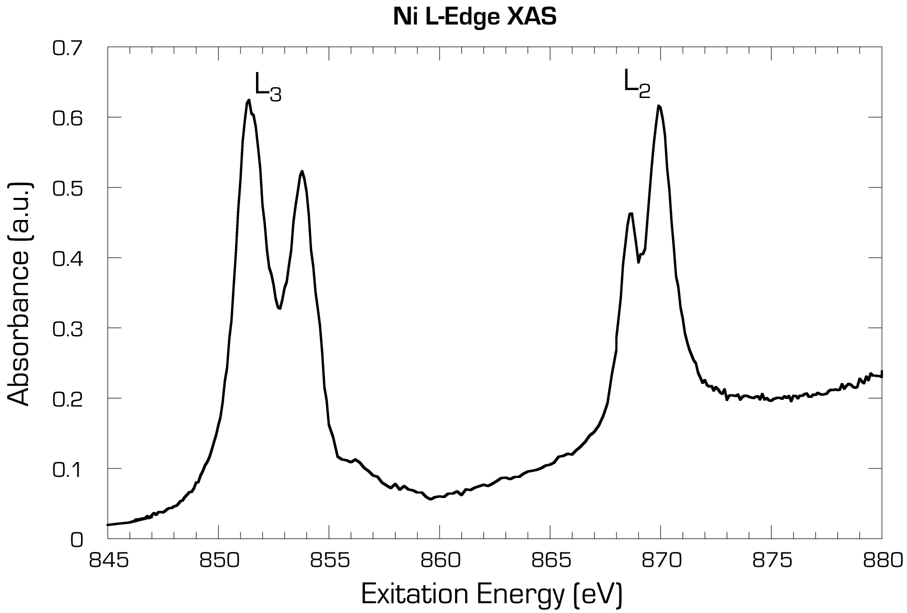
Measurement Methods:

1) Transmission
2) Electron Yield (EY)
3) Fluorescence Yield (FY)

- Information about oxidation state, spin state, chemical coordination, bond characteristics
- Very Soft XAS (100 – 2000 eV) => Transition metal L-edges and organic K-edges
- Very short attenuation lengths of O(1μm) rule out transmission for many samples
- Both EY and FY rely on assumption that Absorbance proportional to Emission

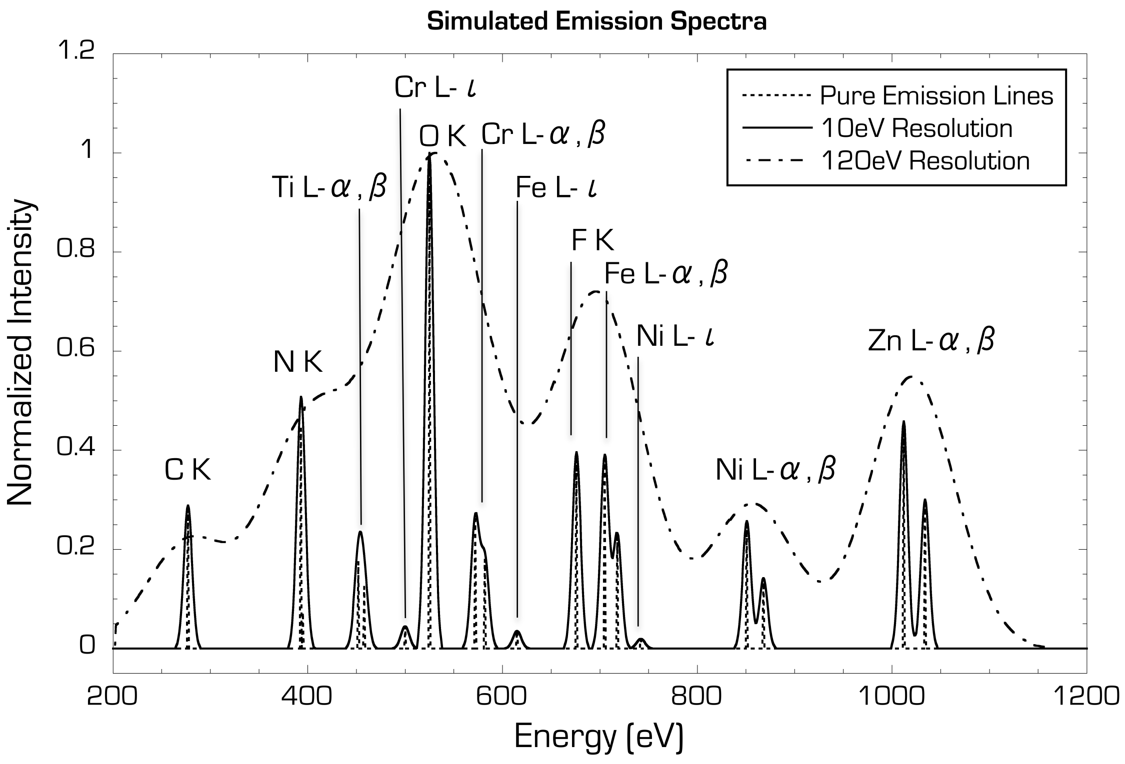
Partial Fluorescence Yield XAS





- Background rejection => High sensitivity=> Dilute/trace samples (to PPB)
- Large number of emission spectra needed (one for each XAS point)
- Dilute samples => Large solid angle coverage to acquire signal from species of interest

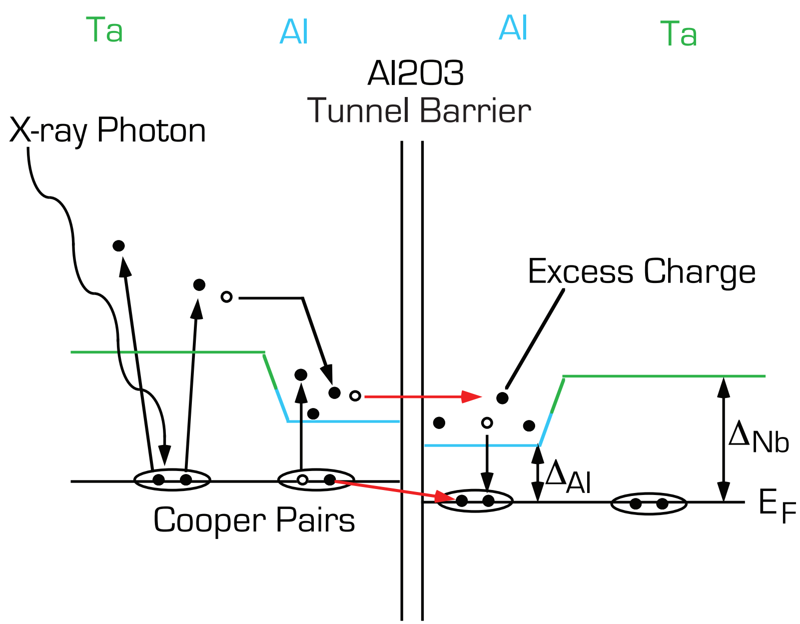
STJs for XAS



- High resolution, high efficiency fluorescence detector allows greater sensitivity, background rejection

- Need to be FAST to keep up with high flux (>1000 cts/sec/pixel)

STJ Operating Principle



Signal = Current Pulse

$$\Delta E_{tot} = \sqrt{\Delta E_{stat}^2 + \Delta E_{tun}^2 + \Delta E_{elec}^2 + \Delta E_{geom}^2}$$

$$\Delta E_{stat} = 2.355\sqrt{F\epsilon E} \quad \epsilon = 1.7\Delta$$

$$\Delta E_{tun} = \sqrt{\epsilon E(\langle n\rangle + 1)/\langle n\rangle}$$

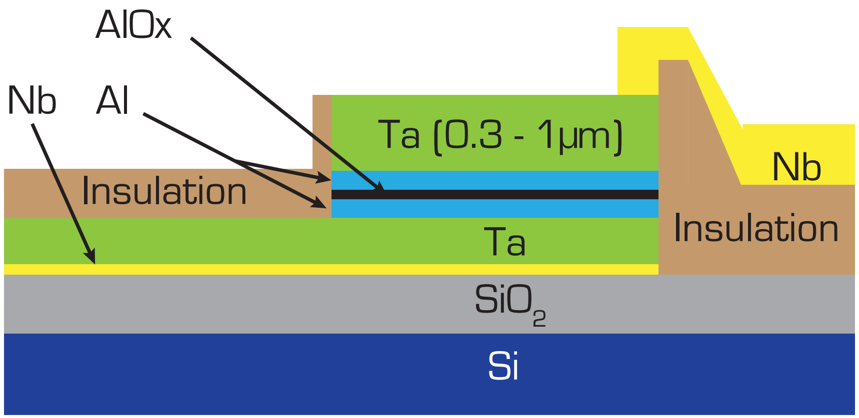
- Very Linear response vs. Energy
- No temperature control needed (below cutoff T ~300mK)

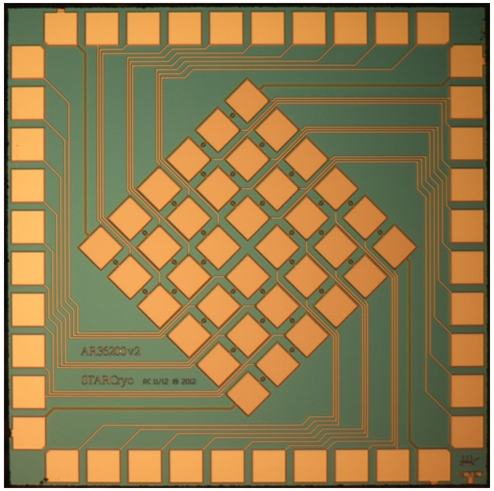
High-resolution operation requires:
- Low-noise charge-sensitive preamplifier
- Stable biasing at operating point
- Ability to apply magnetic field to suppress DC Josephson current

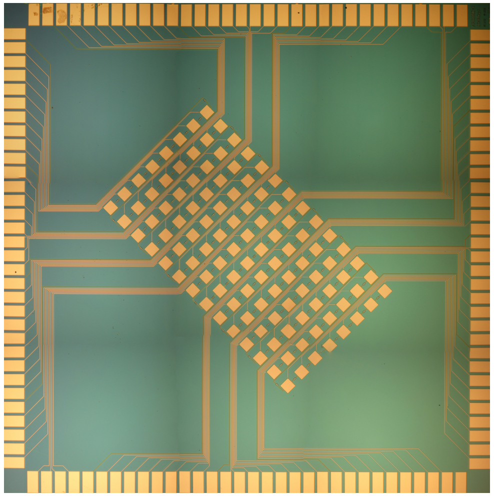
Segall, K. et al. (2000). Noise mechanisms in superconducting tunnel-junction detectors. Applied Physics Letters, 76(26), 3998-4000.

STJ Device Design

Photolithographic Process: generate large arrays on single chip







Parameters:

36- and 112-pixel arrays

Pixel size: 208μm X 208μm

Base electrode thickness: 265nm

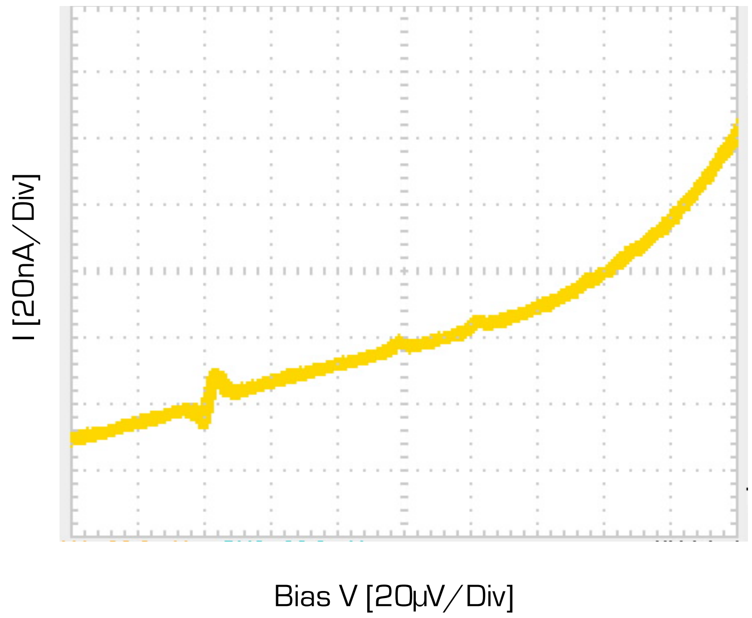
Top electrode thickness: 300 - 1000nm

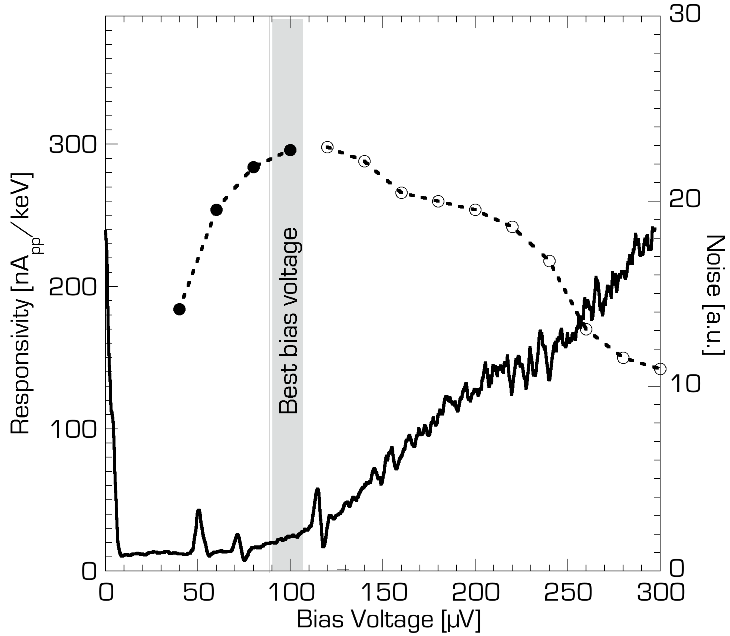
Shared ground between 8 or 9 pixels

Device Characterization

Desired Characteristics:

1) Low leakage current
2) Separation of Fiske modes to provide stable bias points
3) Uniformity across array with shared grounds

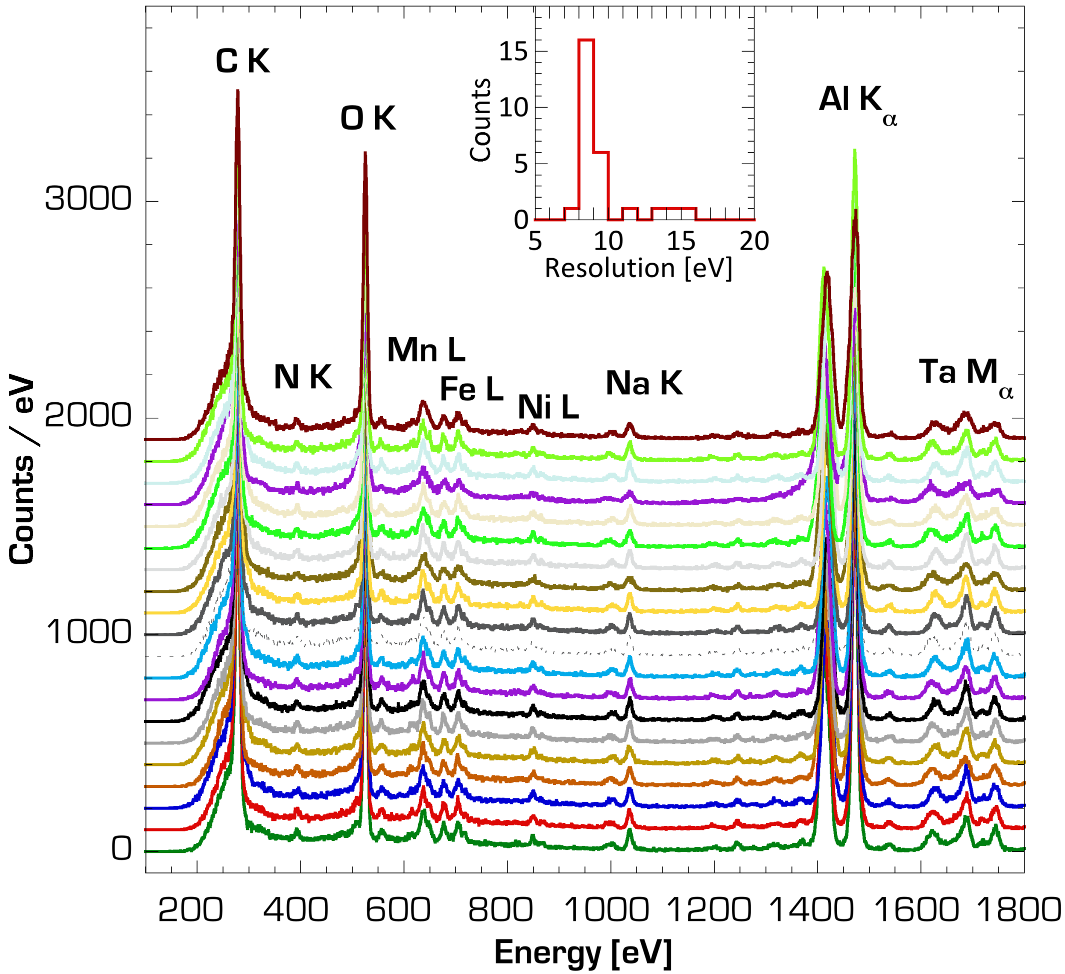




Spectroscopy with Arrays

Larger arrays => Greater solid angle coverage => More dilute samples

- 36-pixel array
- Simultaneous readout with XIA automated preamplifiers
- No cross-talk across shared grounds



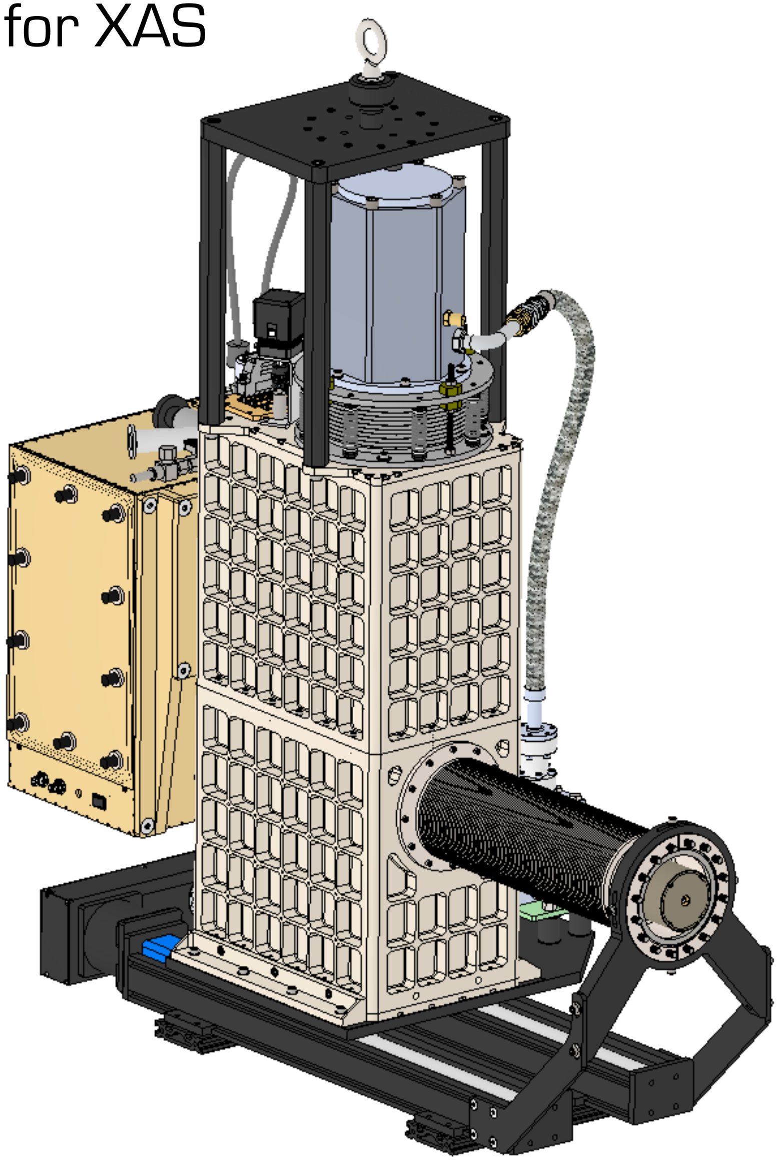
Cryostat Design for XAS

Requirements for Device Operation:

1) Sustained operation <300mK
2) Magnetic shielding during transition through T_C to prevent flux trapping
3) Ability to apply magnetic field to suppress DC Josephson current

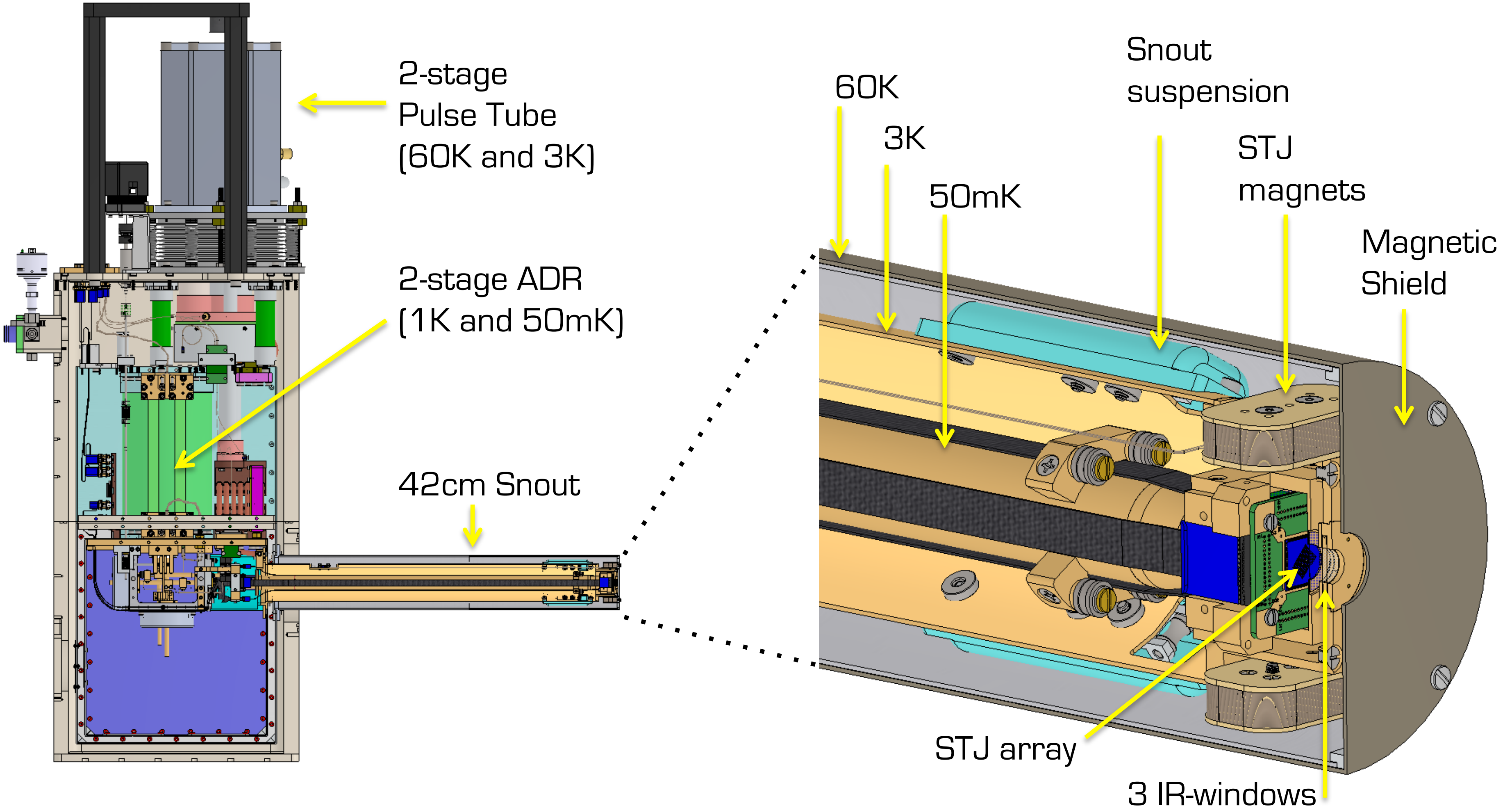
Requirements for soft XAS:

1) Shares vacuum with sample chamber
2) Minimal IR-blocking windows
3) Ability to insert into chamber close to sample to maximize solid angle

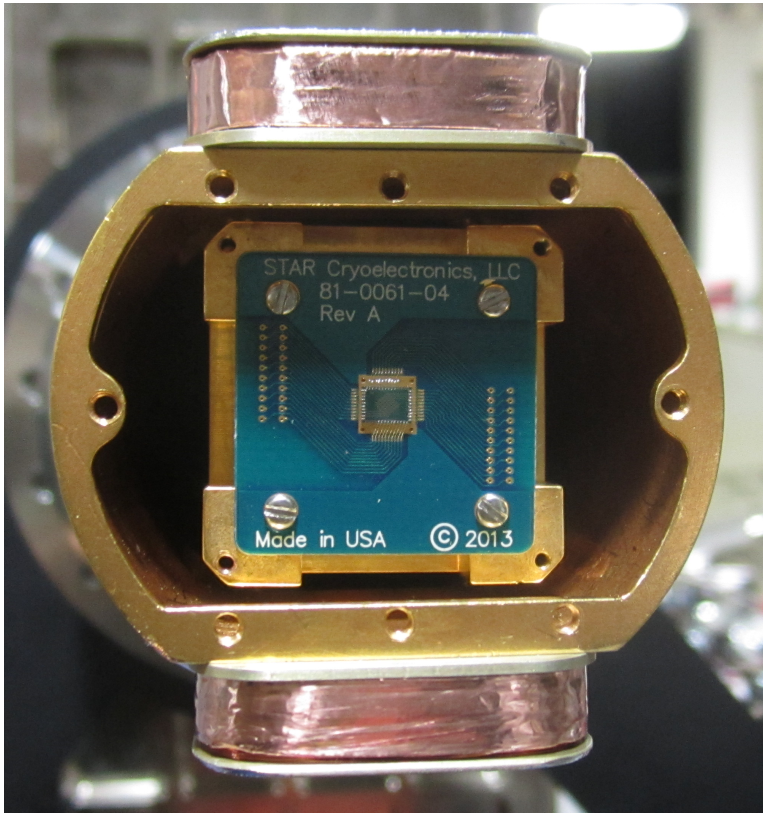


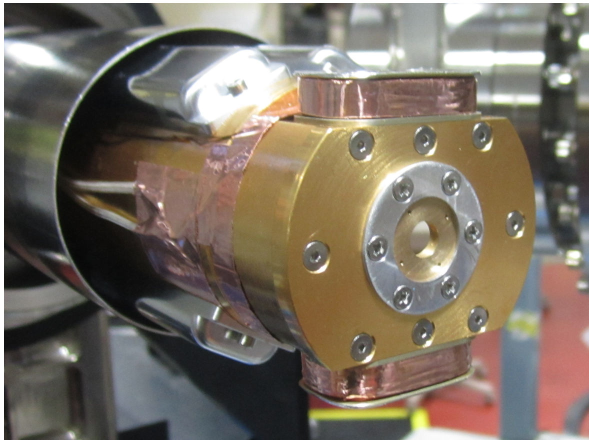
Cryostat Design for XAS

Automated cool-down and operation, cryogen-free cryostat based on STAR Cryo DRC-100



Commissioning and Testing





Summary

- STJ Detectors allow increased sensitivity and high speed for soft XAS
- Ta STJs have higher efficiency and resolution than previous Nb-based STJs
- We have fabricated and tested arrays with <10eV resolution below 1 keV
- Design and assembly of cryostat system is complete, testing is underway
- First beam time at LBNL Advanced Light Source in September 2013

Thank you!