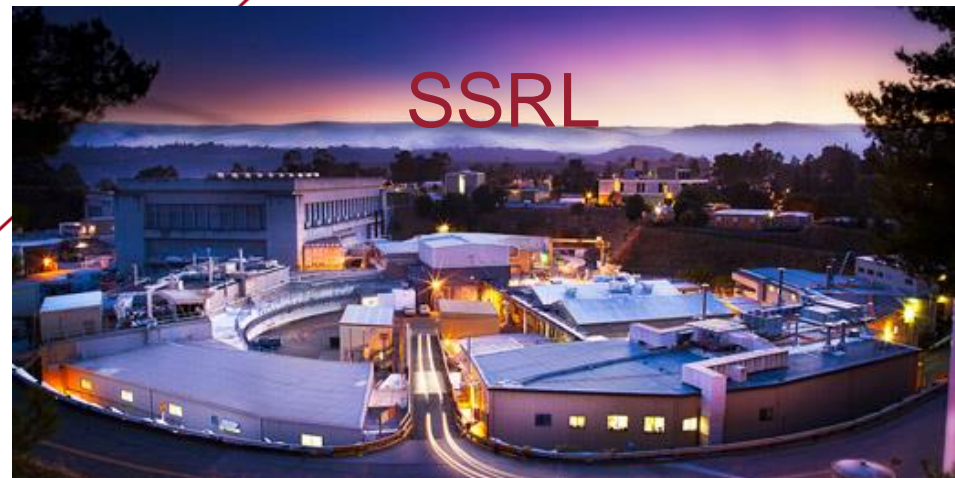


The first two years of TES spectrometer at SSRL

Developing the TES spectrometer for cutting-edge science

Sang Jun Lee

SLAC National Accelerator Laboratory



Acknowledgement

SLAC/Stanford

Mike Baker
Hsiao-Mei (Sherry) Cho
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Dale Li
Donghui Lu
Ron Marks
Dennis Nordlund
Dimosthenis Sokaras
Charles James Titus
Tsu-Chien Weng
Christopher Williams
Betty Young

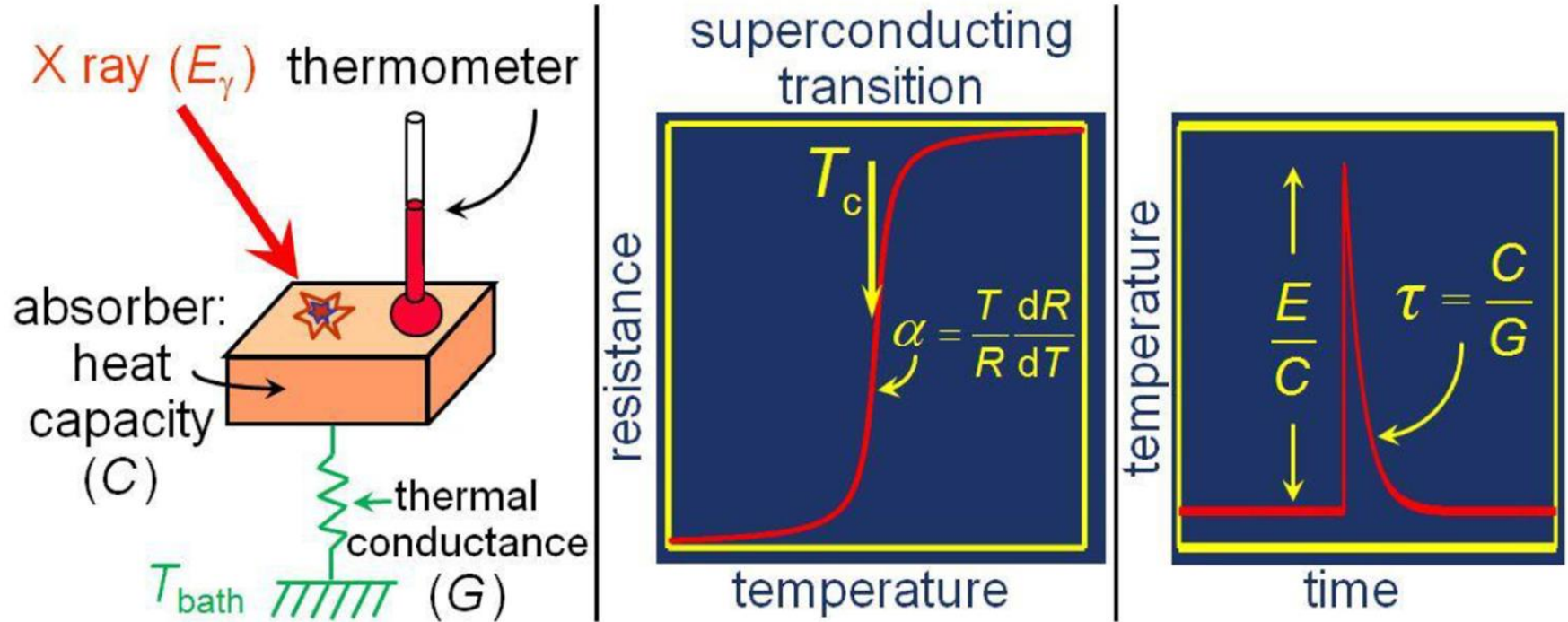
NIST

Randy Doriese
Joe Fowler
John Gard
Gene Hilton
Young Il Joe
Kelsey Morgan
Galen O'Neil
Carl Reintsema
Dan Schmidt
Daniel Swetz
Joel Ullom

- What is a TES?
- Two TES spectrometers at SSRL/SLAC
- TES @ BL 10-1 (HTXS)
 - Science highlights
- TES @ BL 13-3 (RSXS)
 - Motivation
- Prospects

- What is a TES? Thanks to Doug..
- Two TES spectrometers at SSRL/SLAC
- TES @ BL 10-1 (HTXS)
 - Science highlights
- TES @ BL 13-3 (RSXS)
 - Motivation
- Prospects

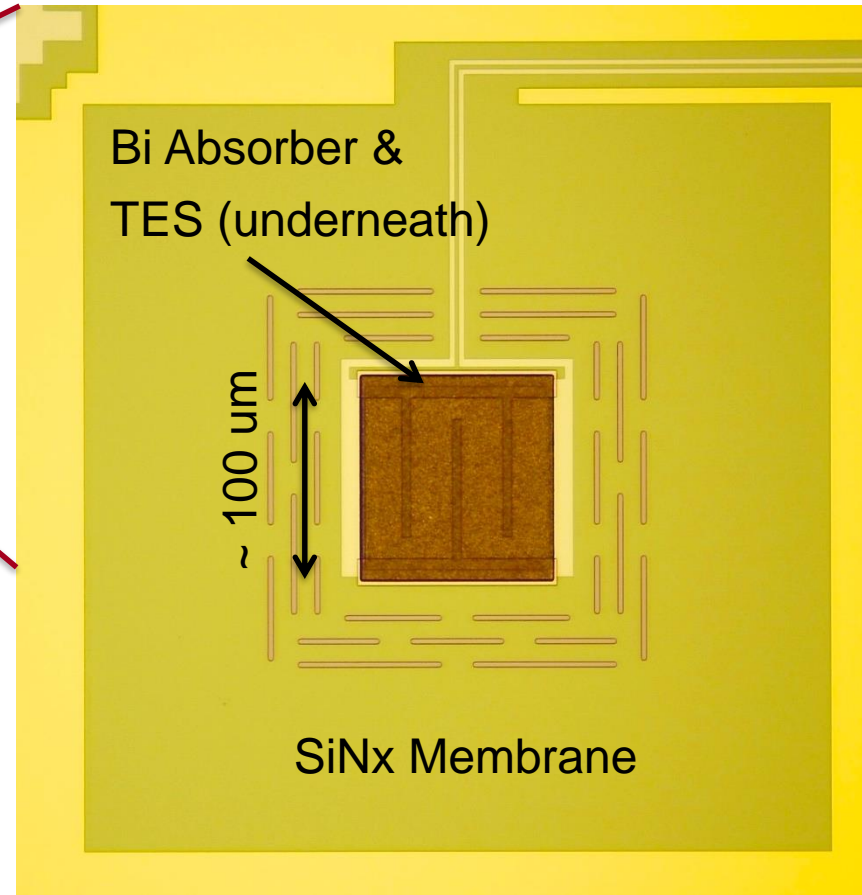
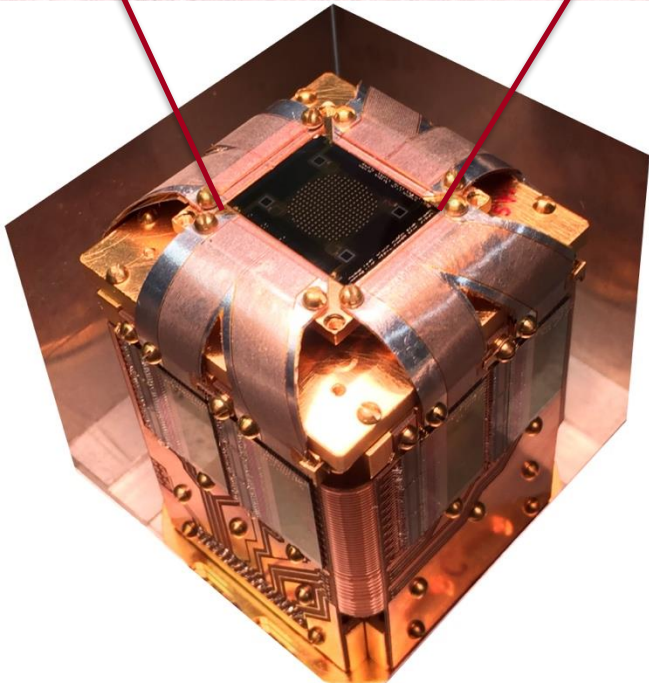
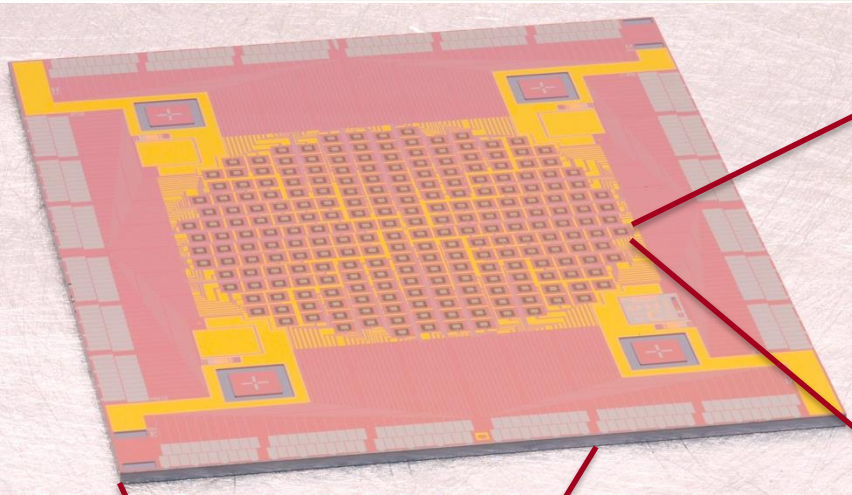
Superconducting Transition-Edge Sensor (TES)



Two TES spectrometers at SSRL/SLAC

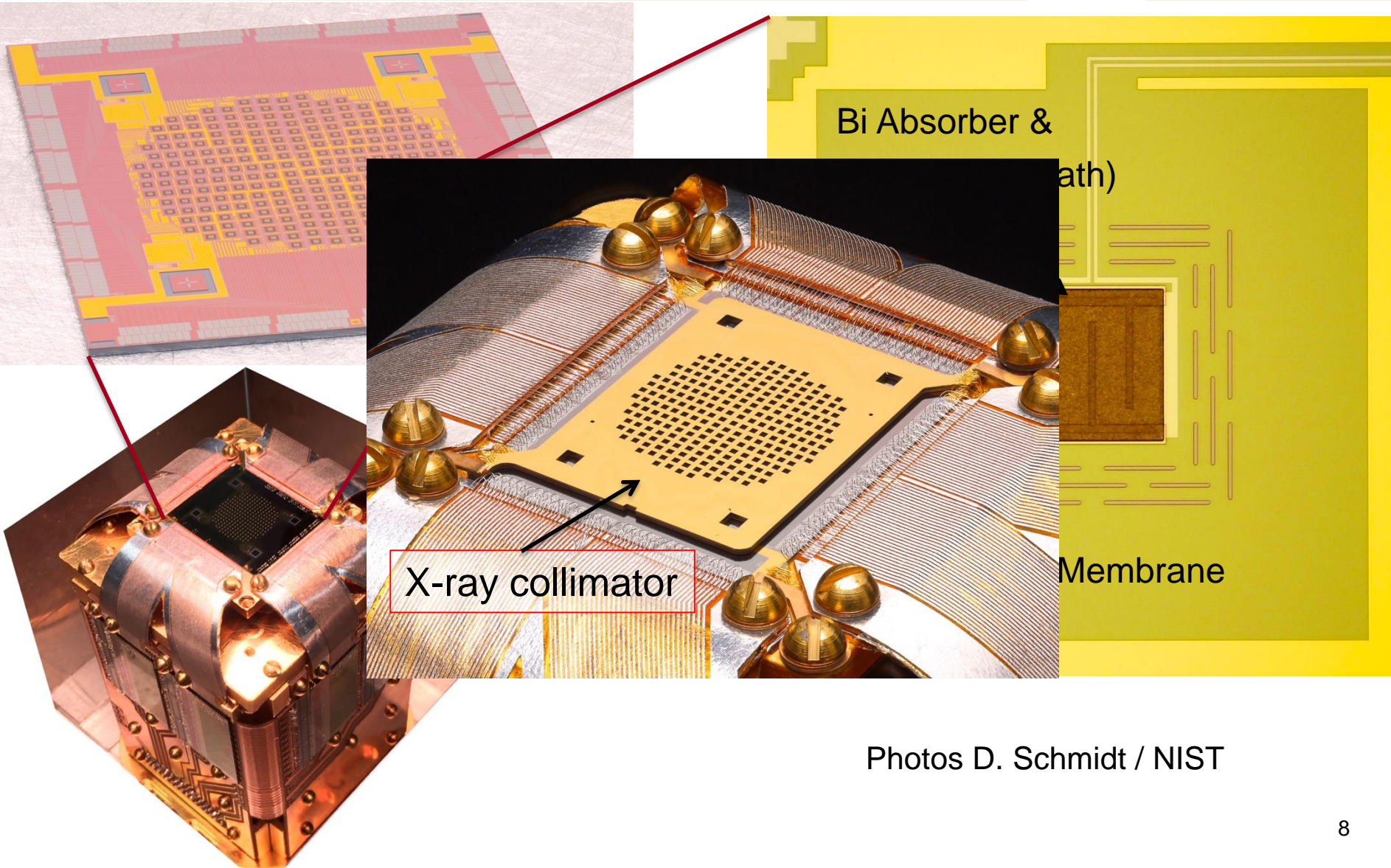
	BL 10-1	BL 13-3
TES Commissioning	April 2016	April 2018 (planned)
X-ray Energy	Soft (< 1.3 keV)	Soft (< 1.8 keV)
Synchrotron Radiation	Wiggler	Undulator
Main Technique	HTXS (spectroscopy)	RSXS (scattering)
Main Science	Bio., Chem., Mat. Sci.	Condensed Mat. Phys.
Non-TES Detectors	SC, PD, Channeltron, XPS	SC, PD, Channeltron, CCD
TES Array & Readout	240 pixels, TDM	240 pixels, TDM
TES Cryostat Hold-time	30 hours @ 60 mK	15 hours @ 70 mK

240 pixel TES array



Photos D. Schmidt / NIST

240 pixel TES array



Bi Absorber &

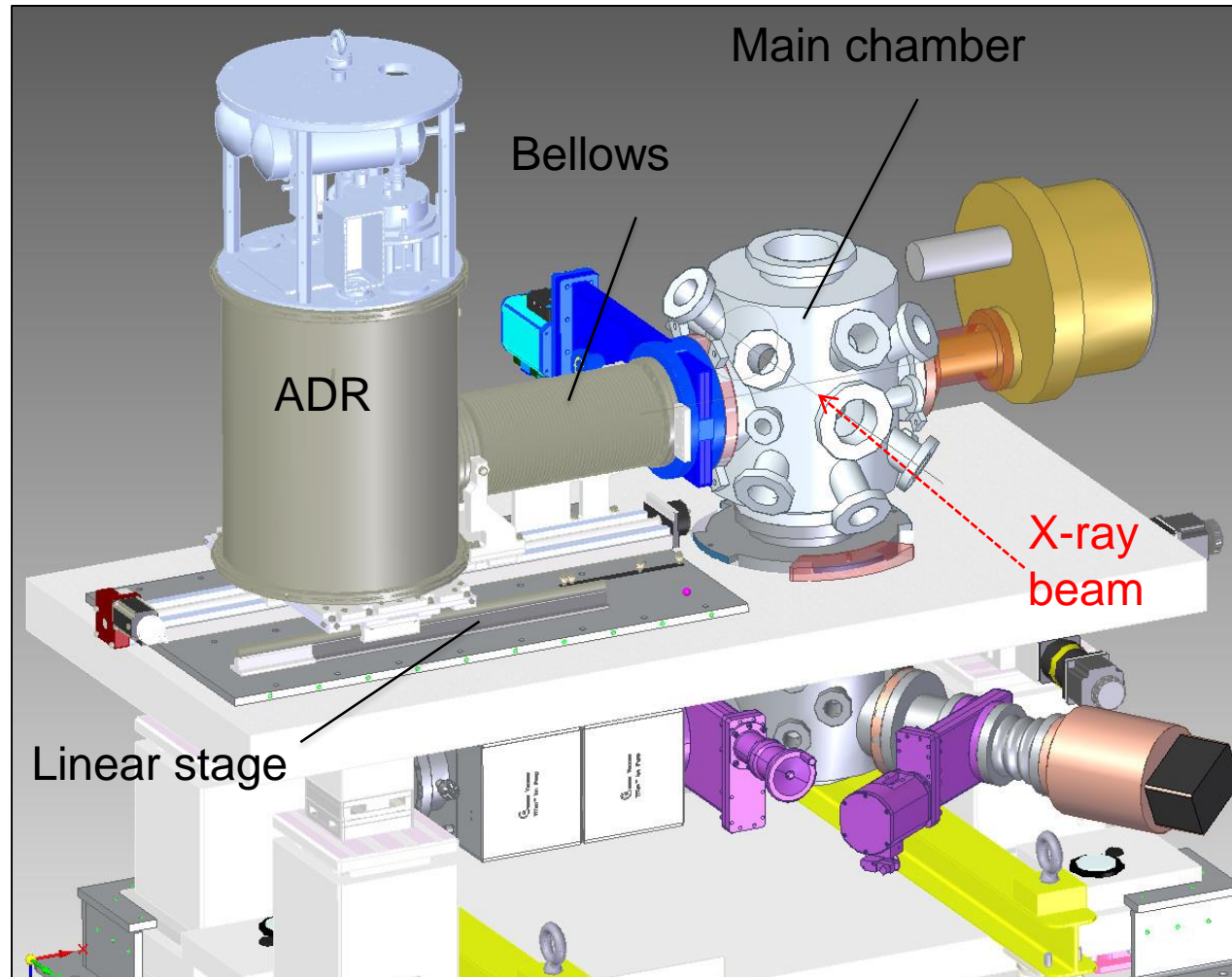
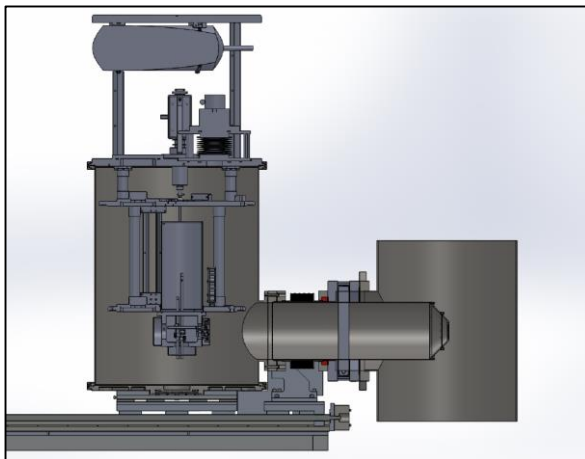
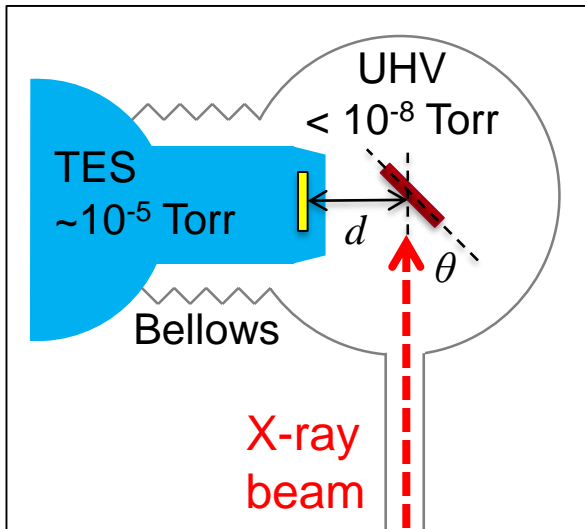
(ath)

X-ray collimator

Membrane

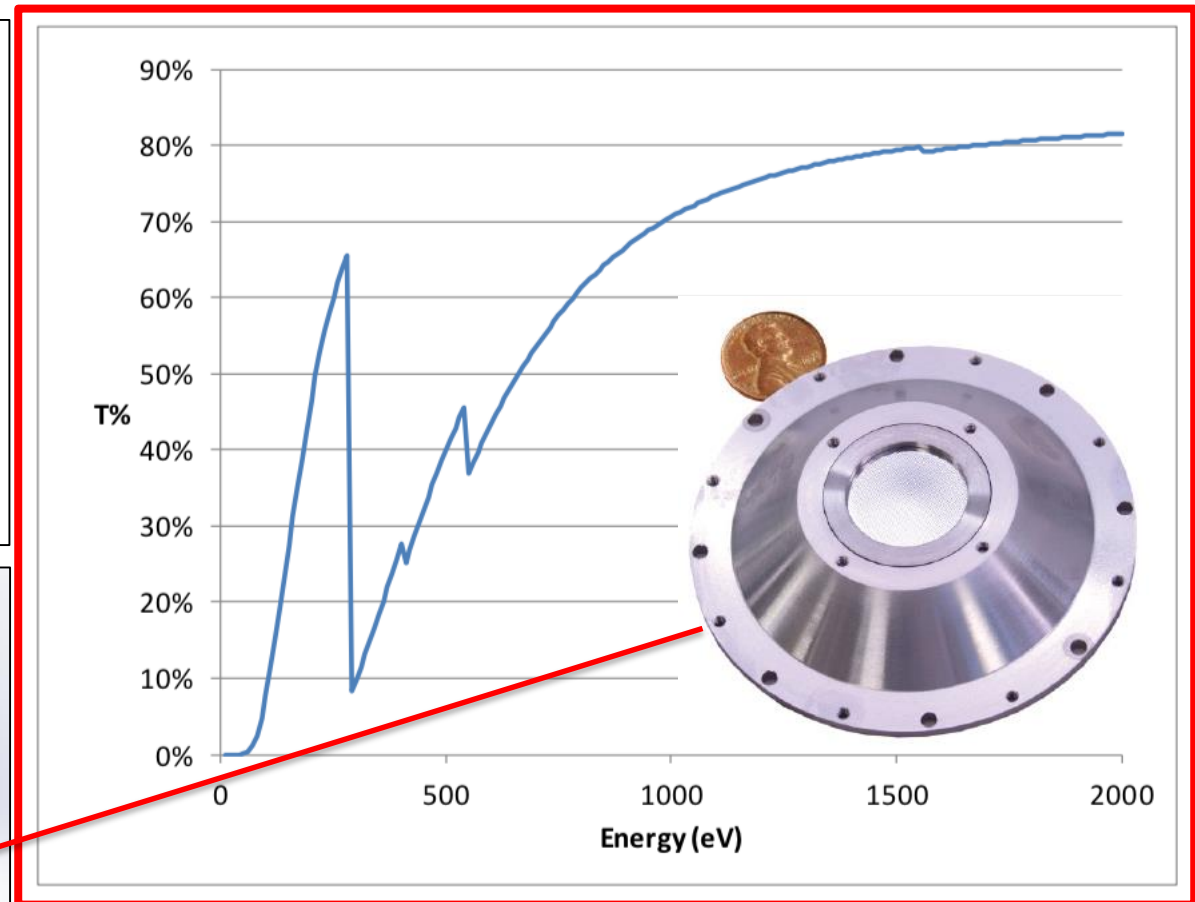
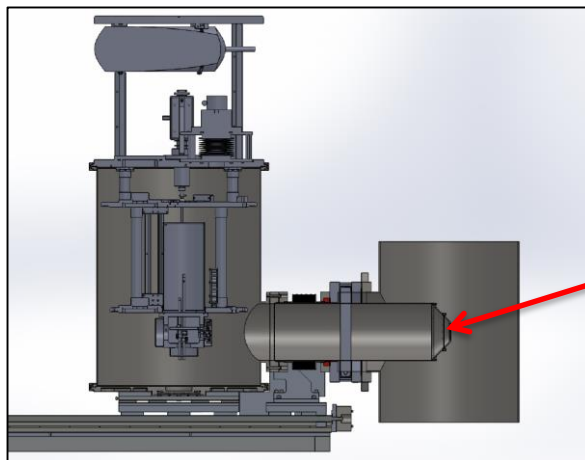
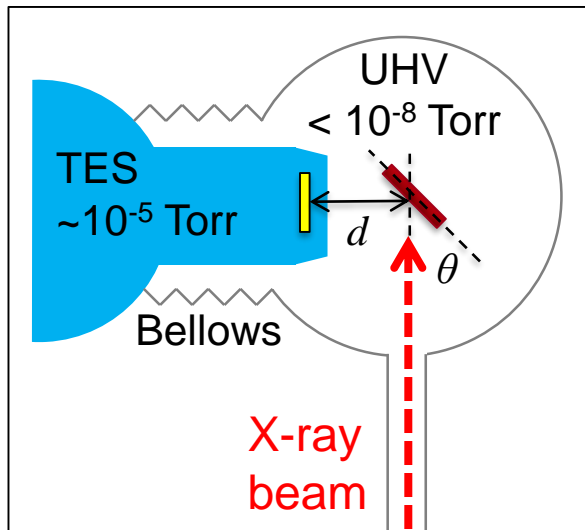
Photos D. Schmidt / NIST

TES spectrometer at BL 10-1

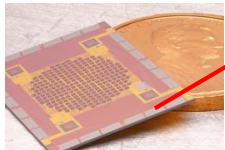


TES spectrometer at BL 10-1

SLAC



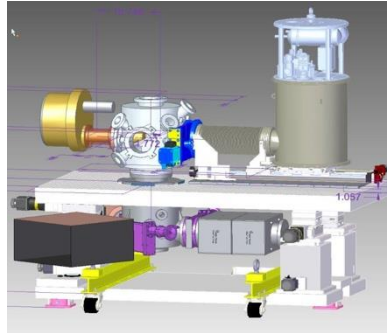
TES project at BL 10-1



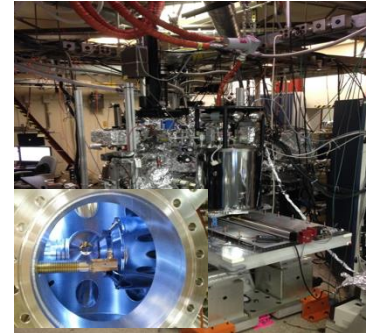
240-pixel TES
TDM readout



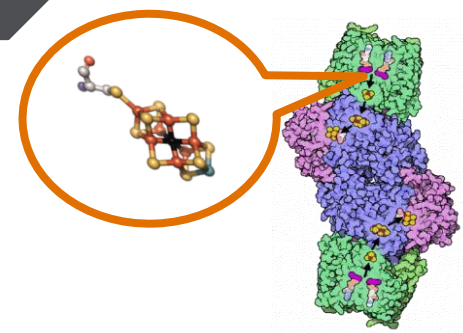
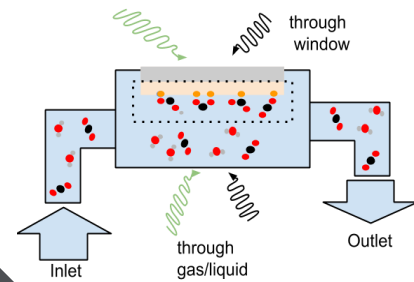
Conceptual Design



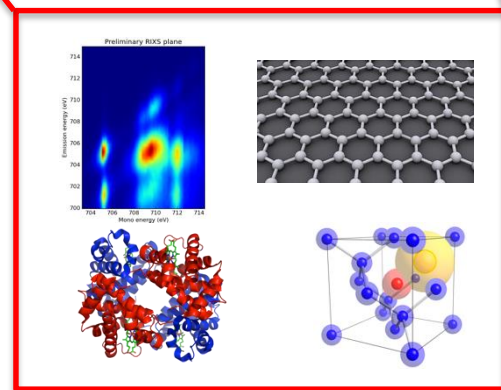
Final Design



First Beam



TES Assembled and Tested at NIST



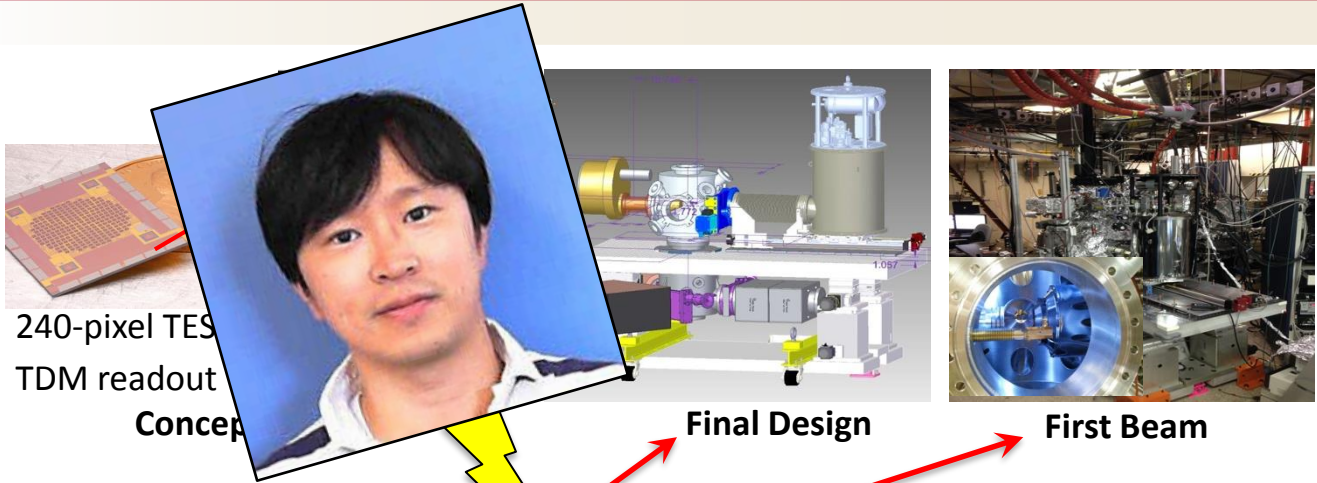
SLAC



NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

LDRD funded

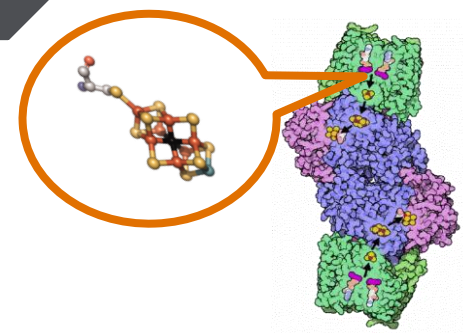
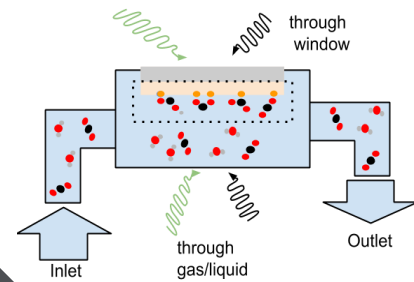
TES project at BL 10-1



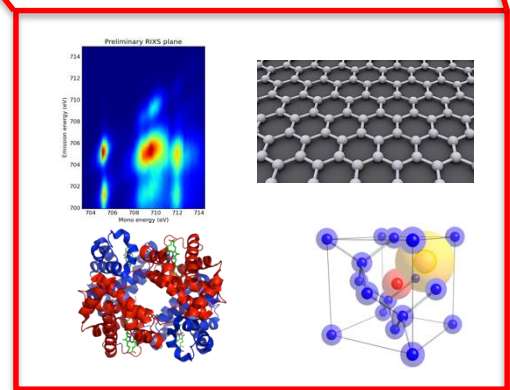
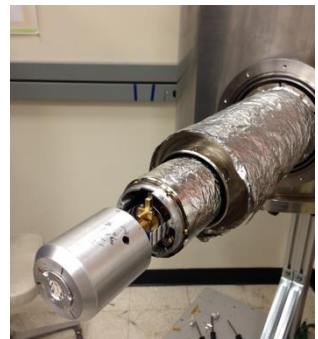
240-pixel TES
TDM readout
Concept

Final Design

First Beam



TES Assembled and Tested at NIST



LDRD funded

Motivation for BL 10-1 TES

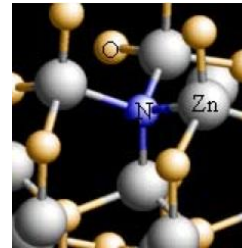
Defects/Dopants ~ 10^{19} - $10^{20}/\text{cm}^3$

Surface Sensitivity ~ 1-10% ML

Solute Sensitivity ~ 10-100 mM

(Spot Size ~ 10-100 μm)

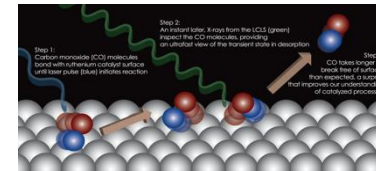
N in ZnO



NREL

**Dopants
high conc.**

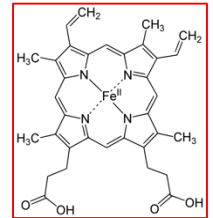
CO/Ru desorption



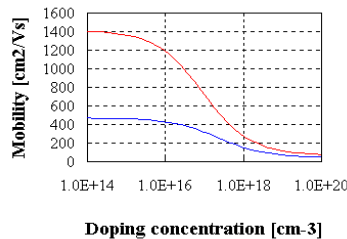
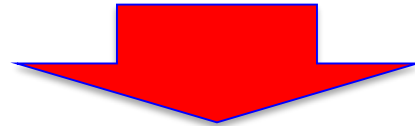
Ogasawara

**Surface
Chemistry
(idealized)**

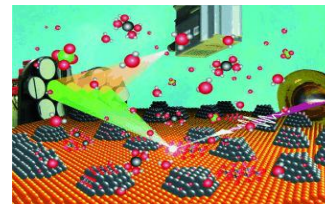
Fe in Heme a



**Bio-
inorganic
model sys**

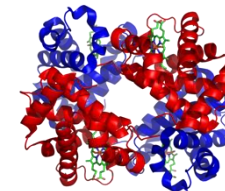


**Doping
Common Levels
< $10^{18}/\text{cm}^3$**



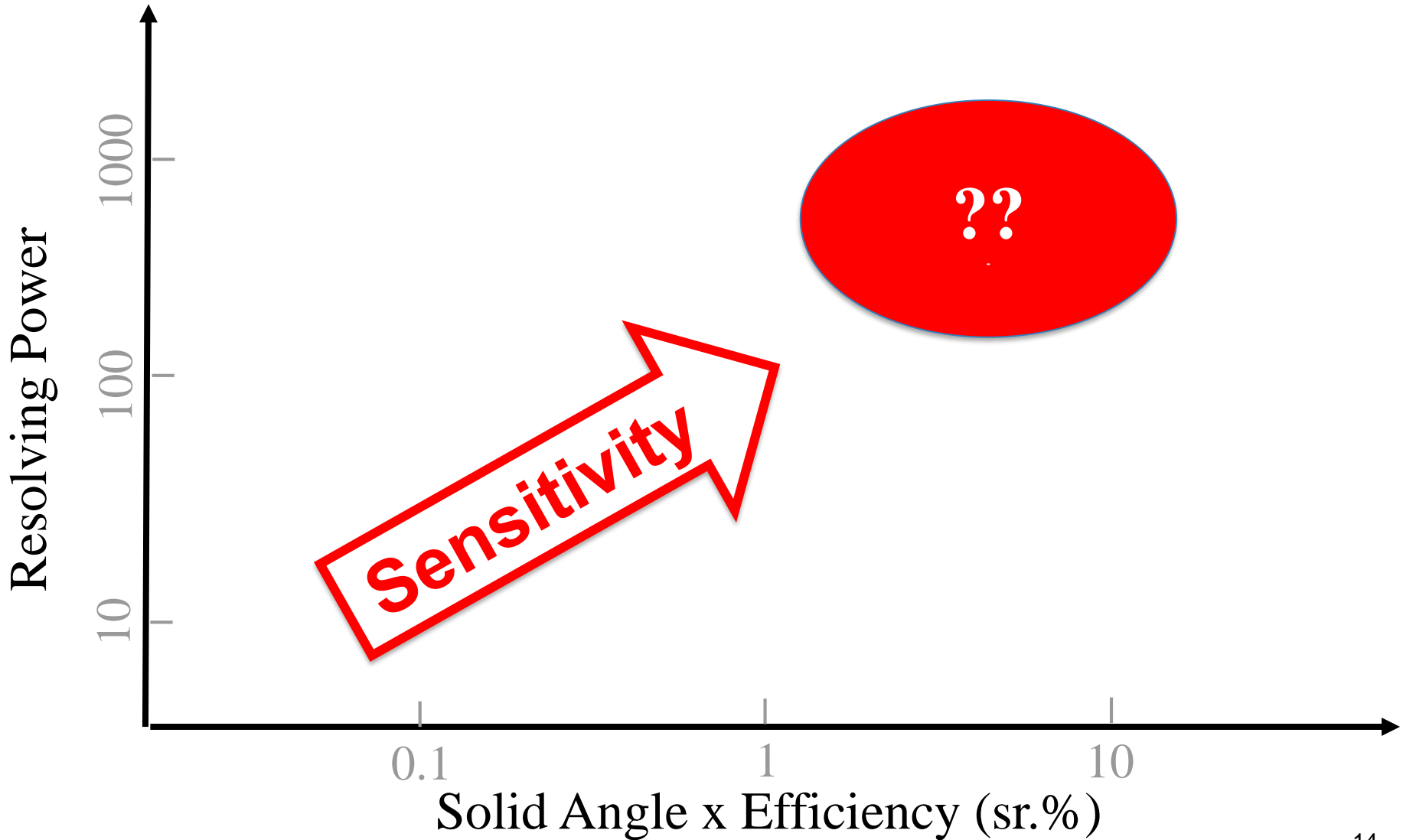
Friebel

**Surface
Chemistry
(realistic!)**

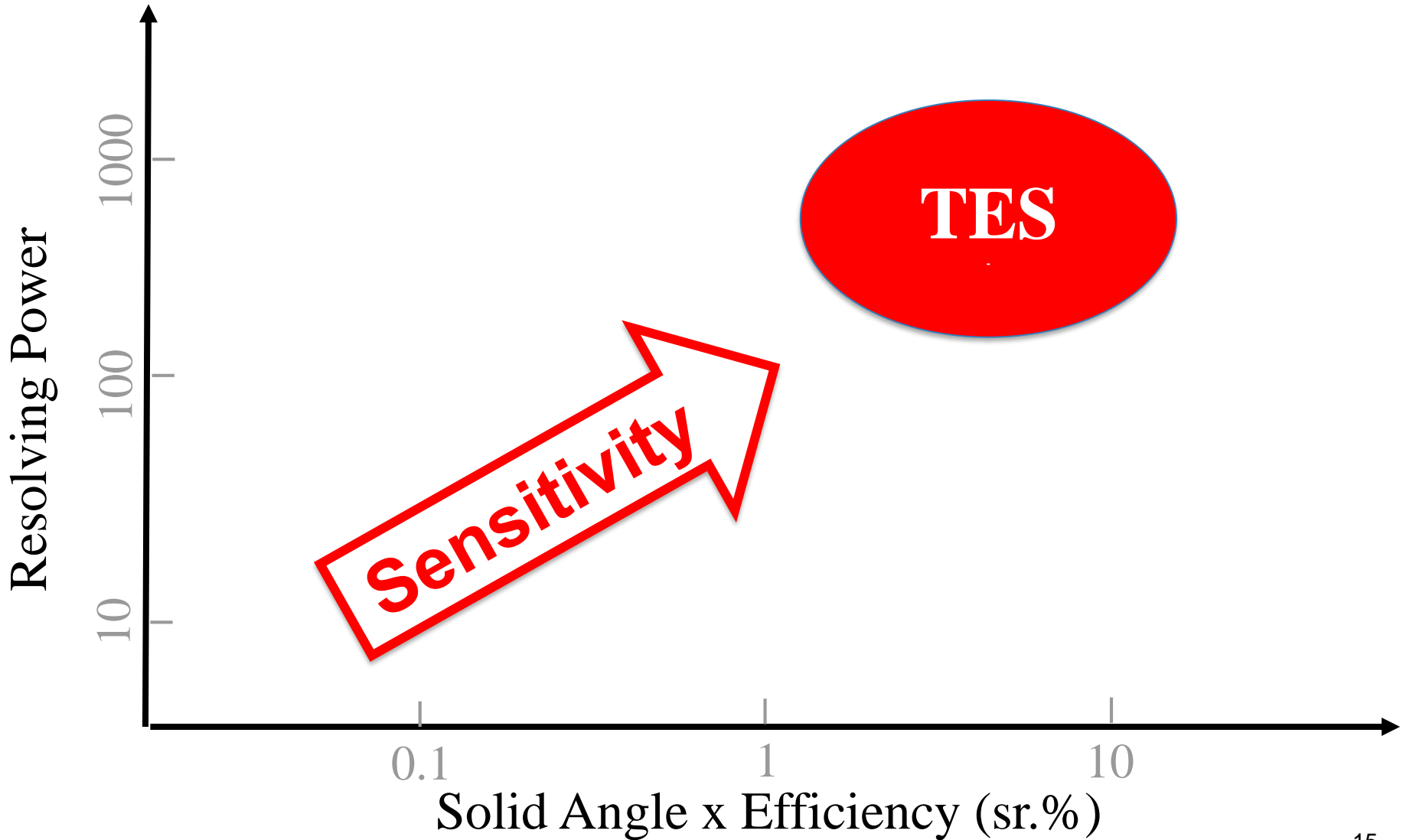


**100s of
metallo-
protein**

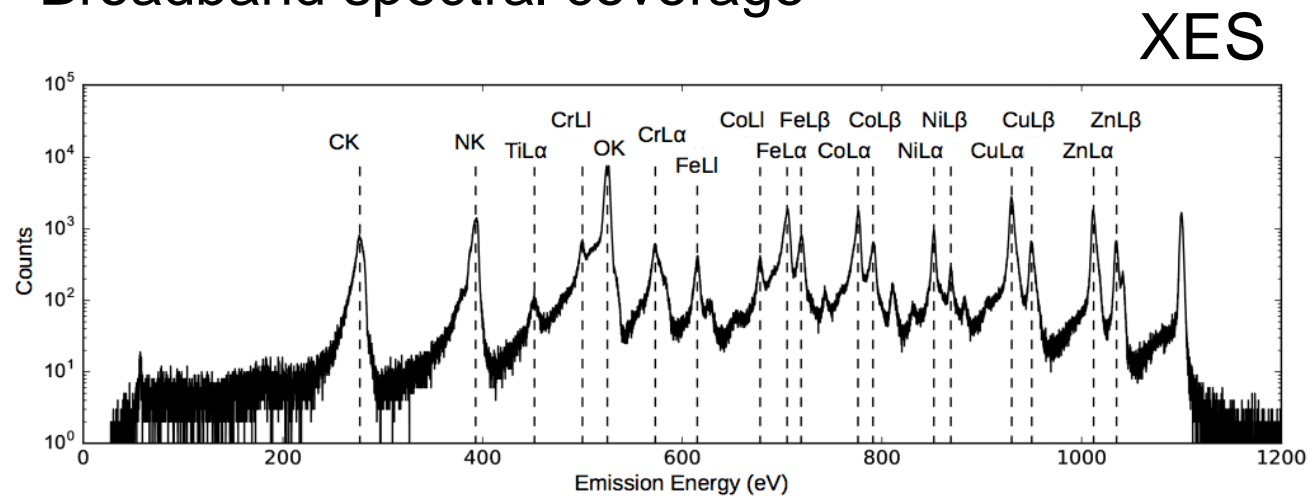
High resolution & high efficiency



High resolution & high efficiency

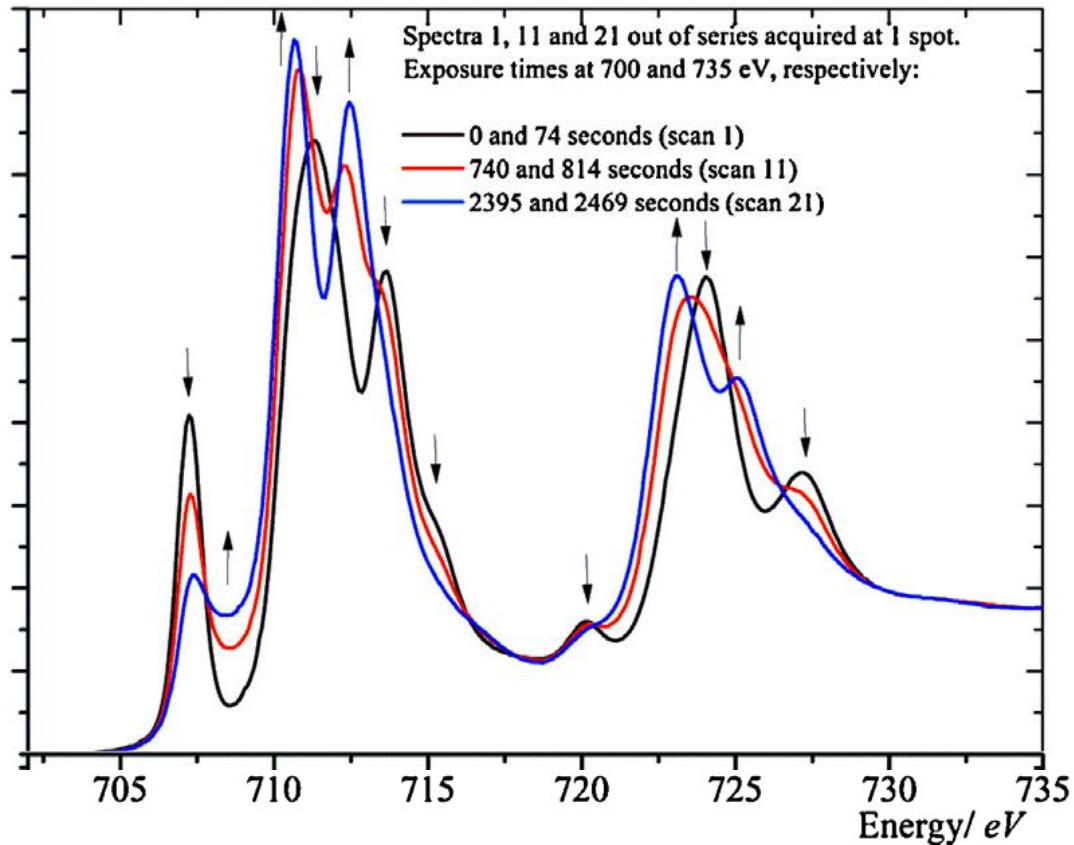


- Unique combination of:
 - Moderate spectral resolution of 1–1.5 eV
 - High efficiency
 - Broadband spectral coverage

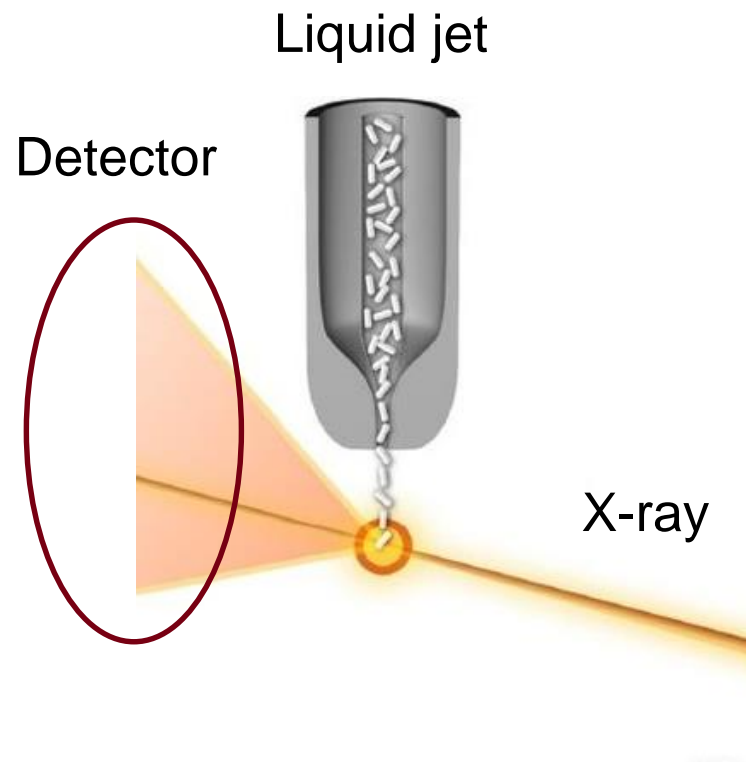


- Capabilities multiply with array size

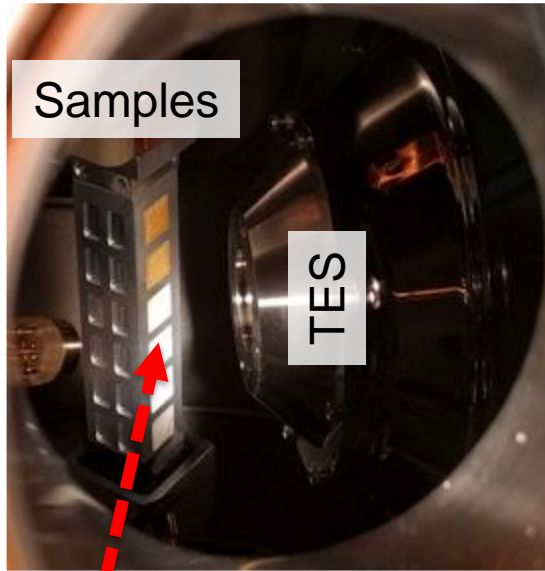
Why not use more intense X-ray?



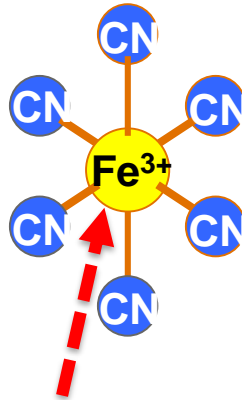
van Schooneveld & S. DeBeer, JESRP 198 (2015) 31-56



RIXS of dilute samples

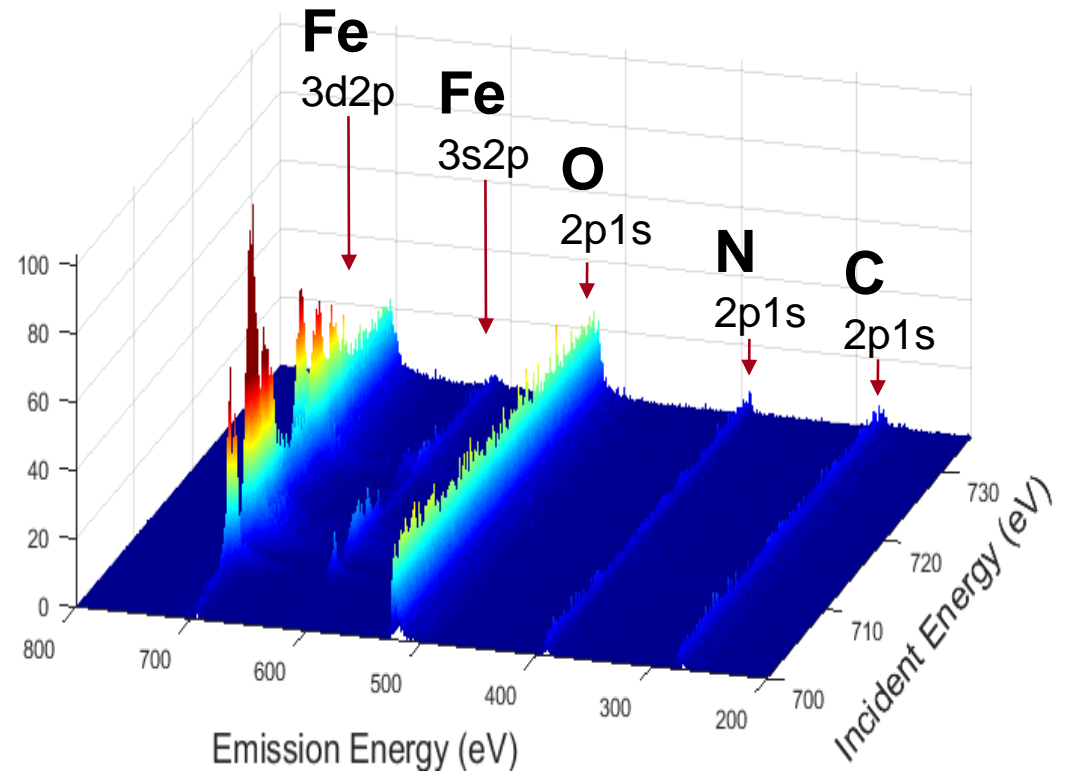


Incident X-rays



Incident X-rays

Frozen $\text{Fe}^{3+}(\text{CN})_6$ solution



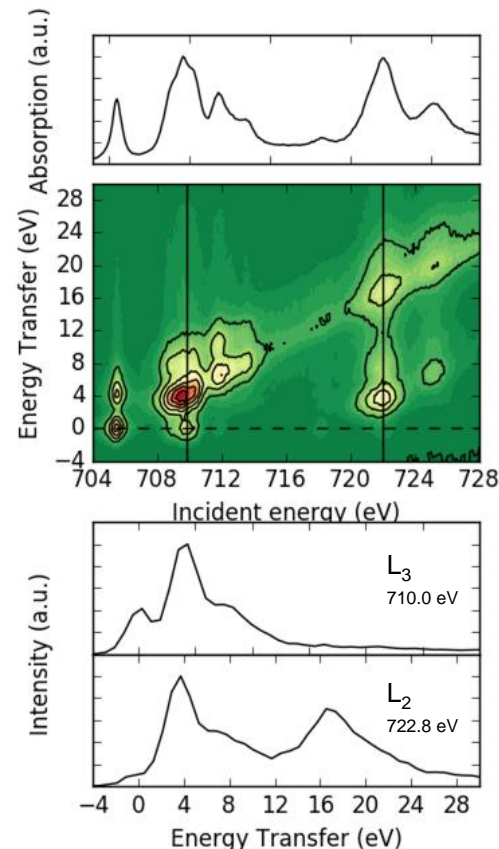
High efficiency enables bioinorganic chemistry

TES vs Grating

- Same acquisition time
- TES uses 10x more dilute sample
- TES can use frozen sample with large spot size (also can use liquid jet)
- Grating can only use liquid jet (sample damage)
- Also demonstrated down to 0.5 mM.

SSRL BL10-1 TES

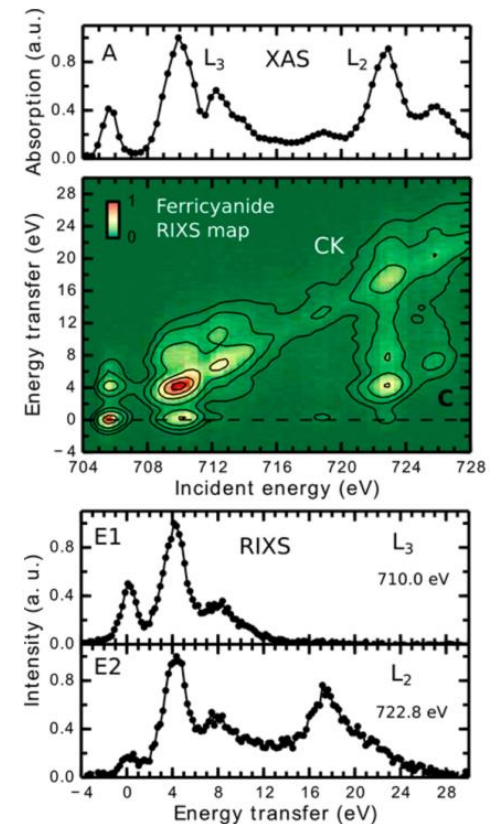
- 50 mM
- Frozen sample



Titus et al., JCP (2017)

BESSY-II Grating

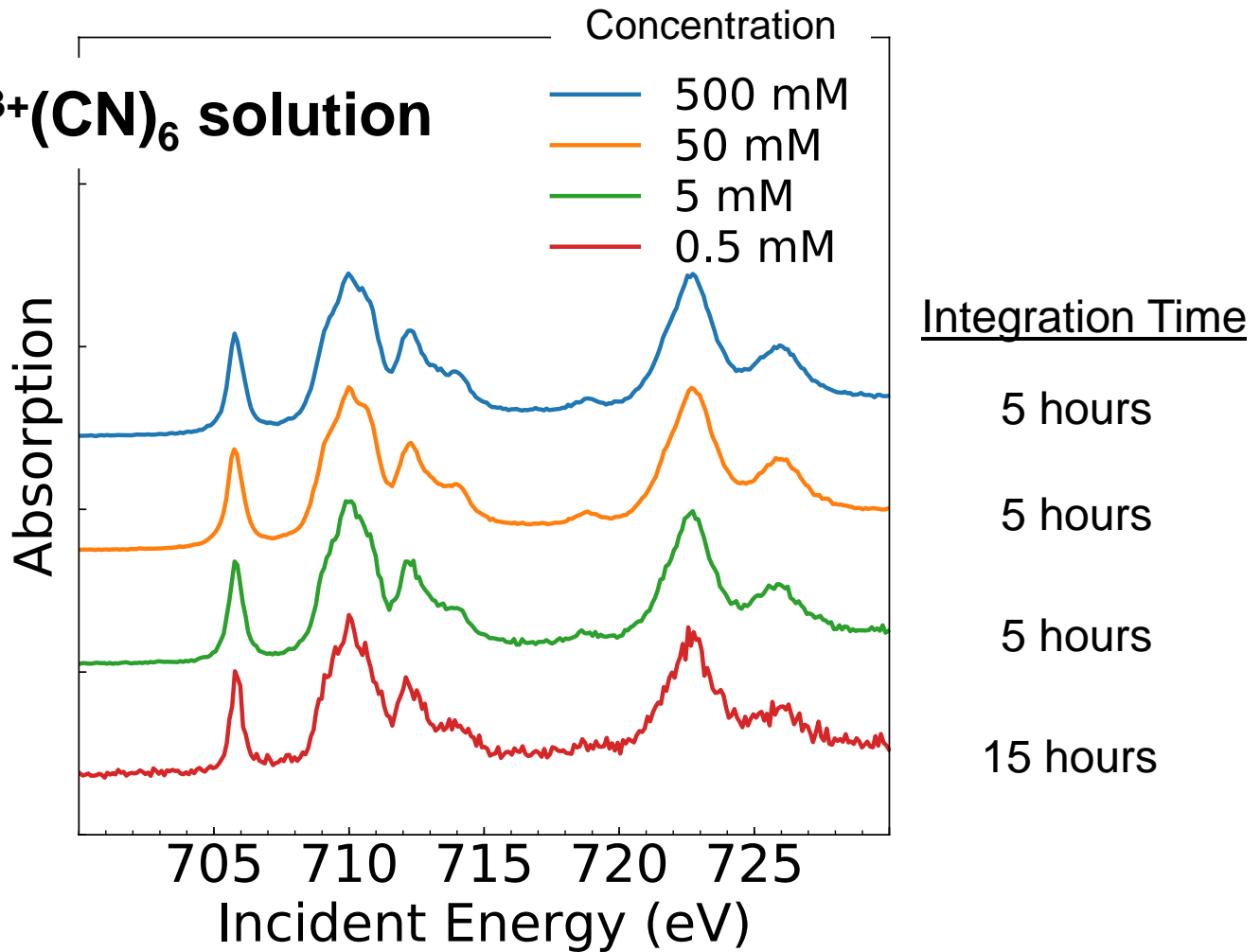
- 500 mM
- Liquid jet



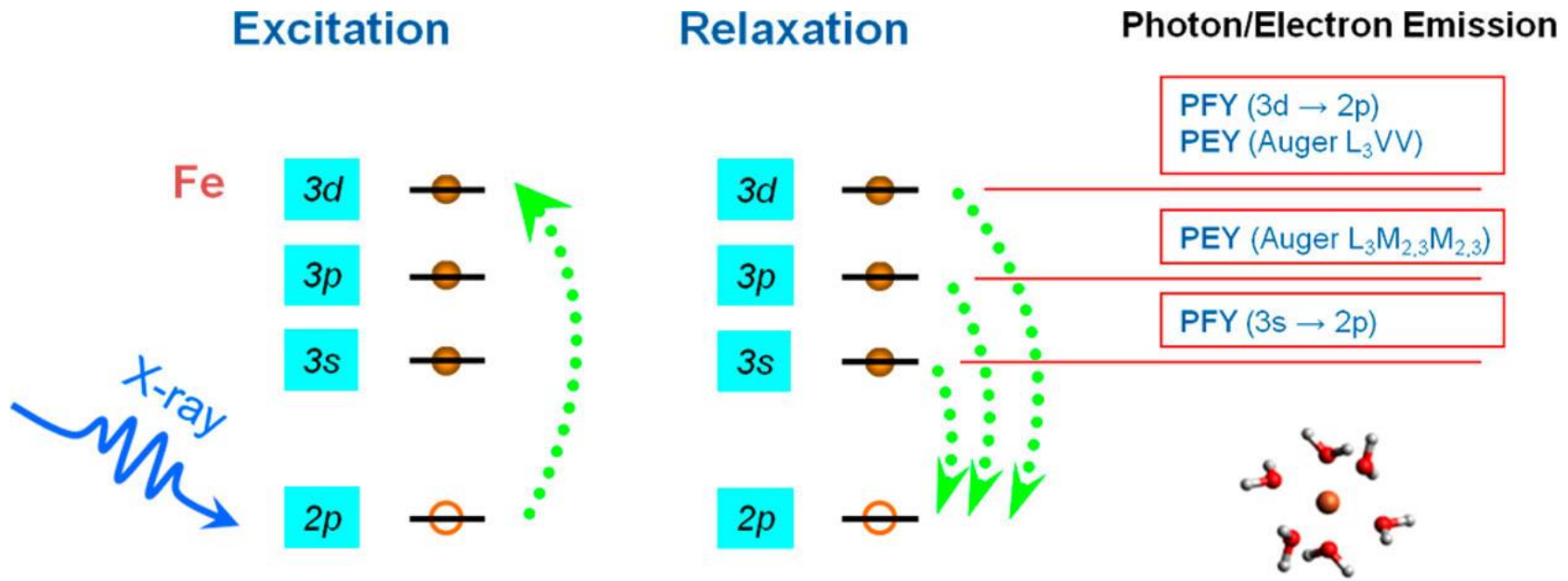
Kunnus et al., JPC B (2016)

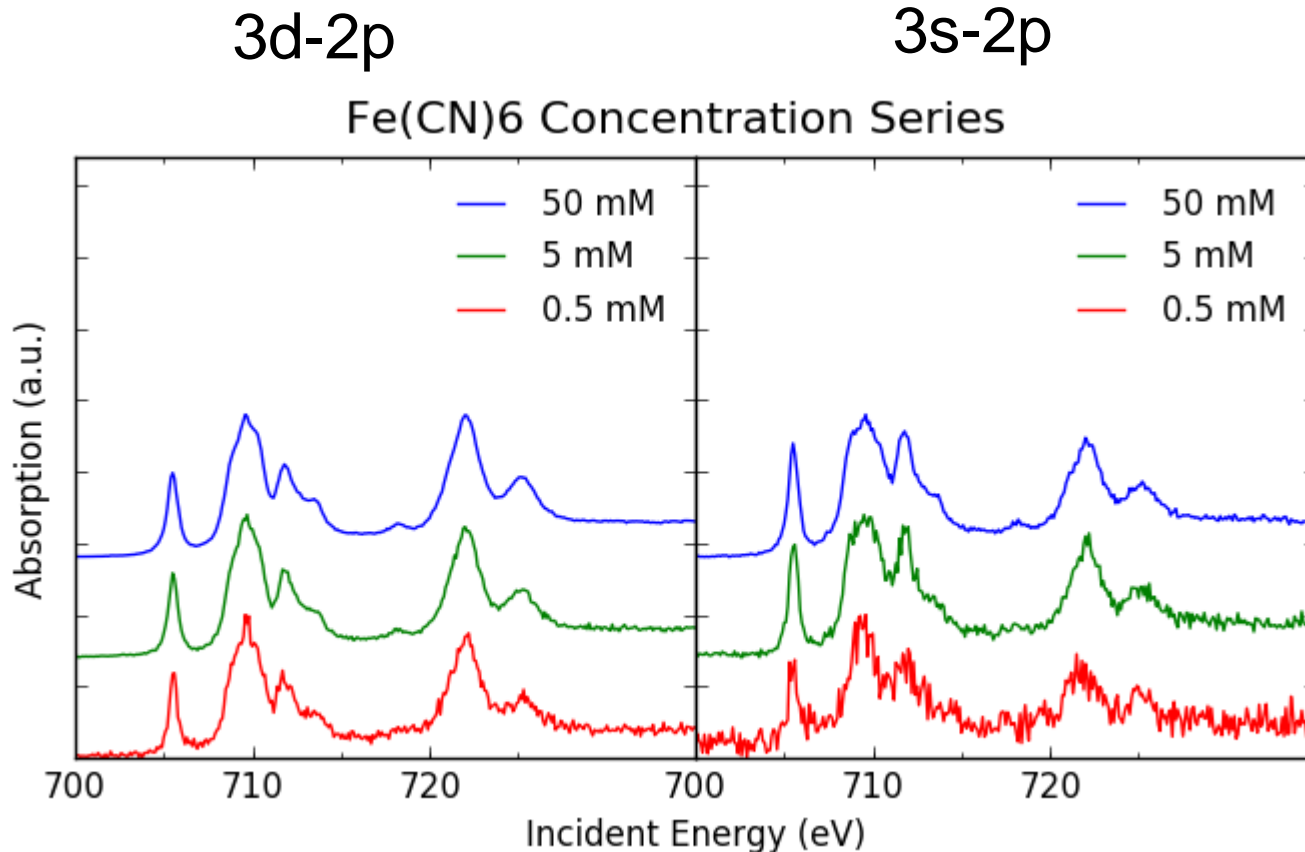
TES at BL10-1: unprecedented sensitivity

Frozen $\text{Fe}^{3+}(\text{CN})_6$ solution



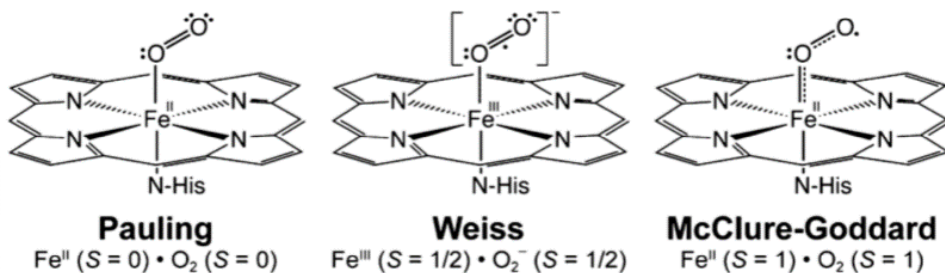
3s-2p core-to-core decay





- Probing both 3d2p and 3s2p – new complementary information
- 3s2p (previously unused) maps better to electron-yield spectra

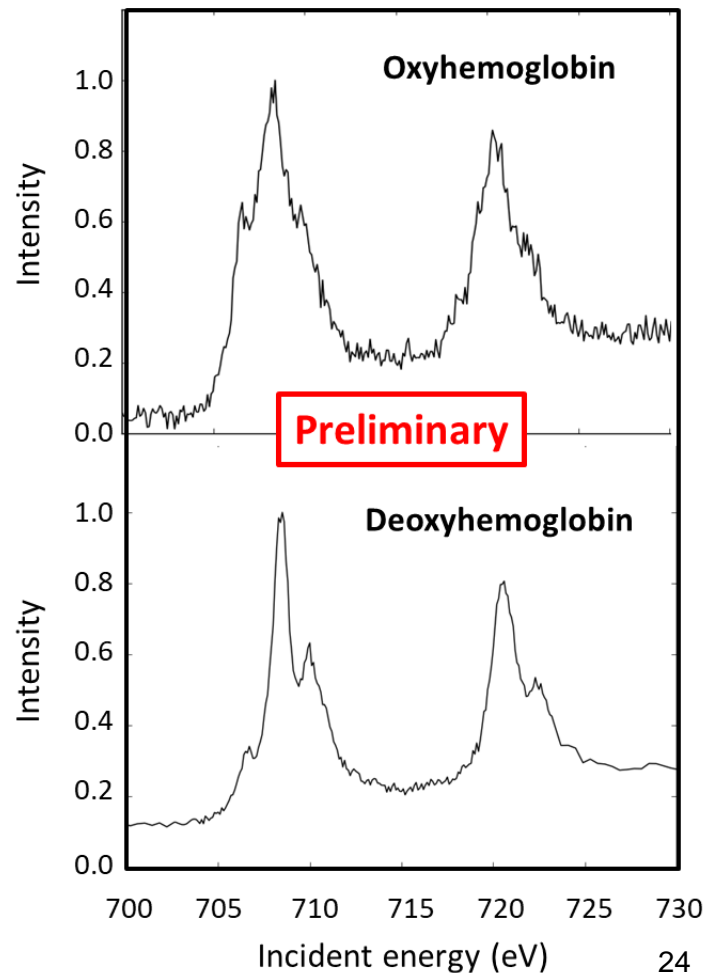
Three limiting cases for Fe-O₂ bonding in Oxyhemoglobin



Pauling, L. et. al, *PNAS* **1936**, 22, 210.
 Weiss, J. J., et. al., *Nature* **1964**, 202, 83.
 McClure, D. S., *Rad. Research Sup.*, **1960**, 2, 218.
 Harcourt, R. D., et. al., *Int. Jour. Quant. Chem.*, **1971**, 5, 479.

- For the first time, efficiency for Fe L-Edge PFY-XAS of radiation-sensitive samples
- Potential to resolve 80-year-long controversy
- Extensive modeling required for science result
- Collaboration with Ed Solomon's group at Stanford

Fe L-Edge PFY-XAS



Work in progress

- Real time analysis

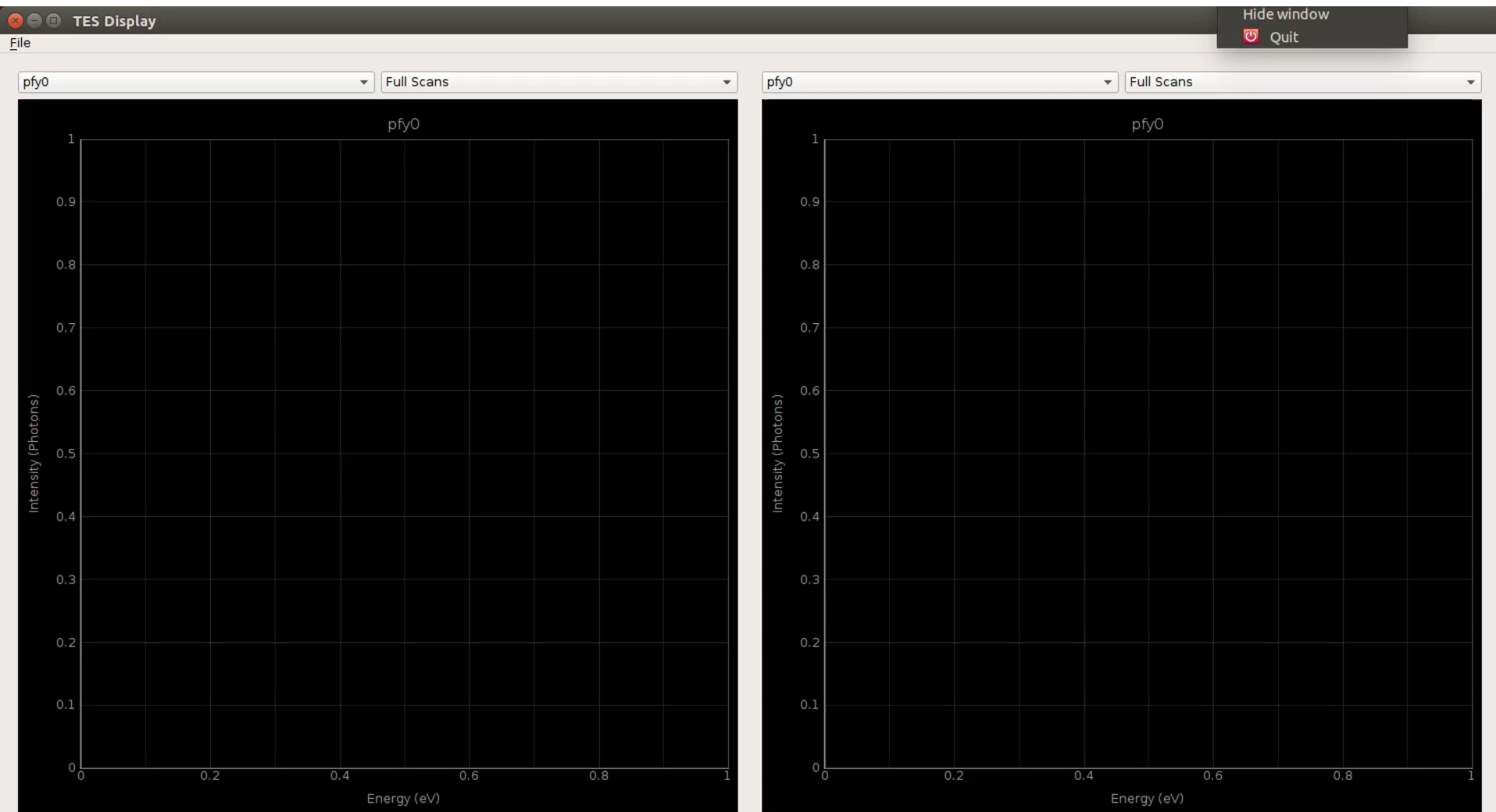
The screenshot displays the Matter software interface (version 1.1.1) running on a Linux desktop. The interface is divided into several sections:

- Connection to data server:** Shows the server as 'localhost' on port '2011'. A 'Disconnect from server.' button is present, and the connection speed is indicated as '99.8 MB/s'.
- Array Map:** A 'Row/col Grid' showing a 12x12 array of channels. Each cell contains a numerical value representing the channel's status or data.
- Streams:** A 'Stop Streaming' button and a label '240/480 channels'. Below this is a control panel with checkboxes for 'All FB' (checked) and 'All Error' (unchecked). A grid of checkboxes allows selecting specific channels for analysis, with labels like 'C0 Err', 'C0 FB', 'C1 Err', 'C1 FB', etc.
- Channel Analysis:** A text box on the right side of the interface that reads: 'What goes here is a list of key analyzed info (eventually, expected energy resolution!)'.
- Log/Status:** A bottom section showing system messages: 'Thu Sep 28 2017 18:07:50 Stopped streaming from server.', 'Thu Sep 28 2017 18:07:50 Connection broken.', 'Thu Sep 28 2017 18:10:58 New connection made.', and 'Thu Sep 28 2017 18:11:00 Streaming from server.'

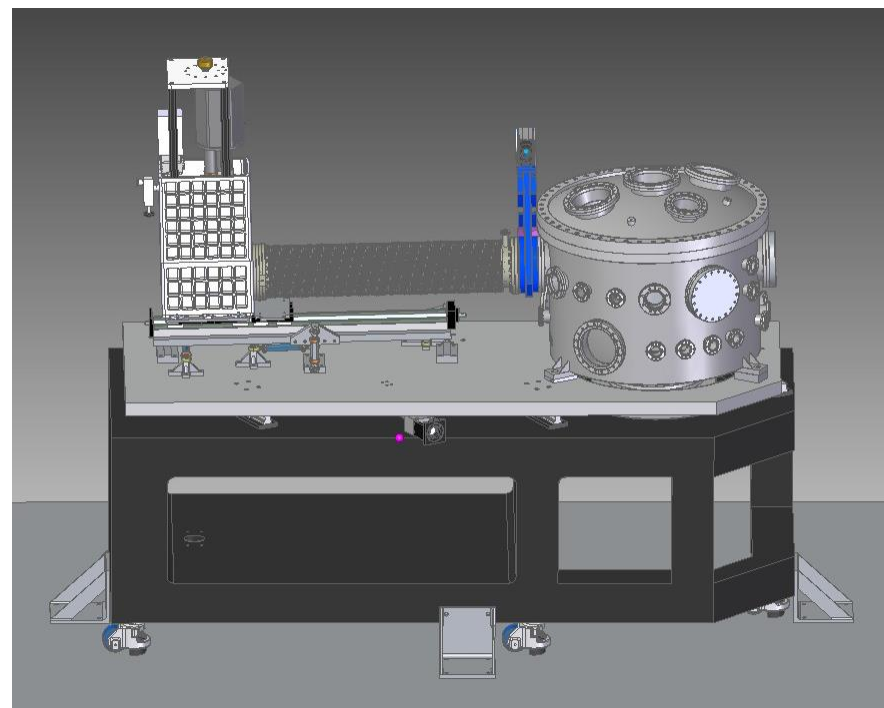
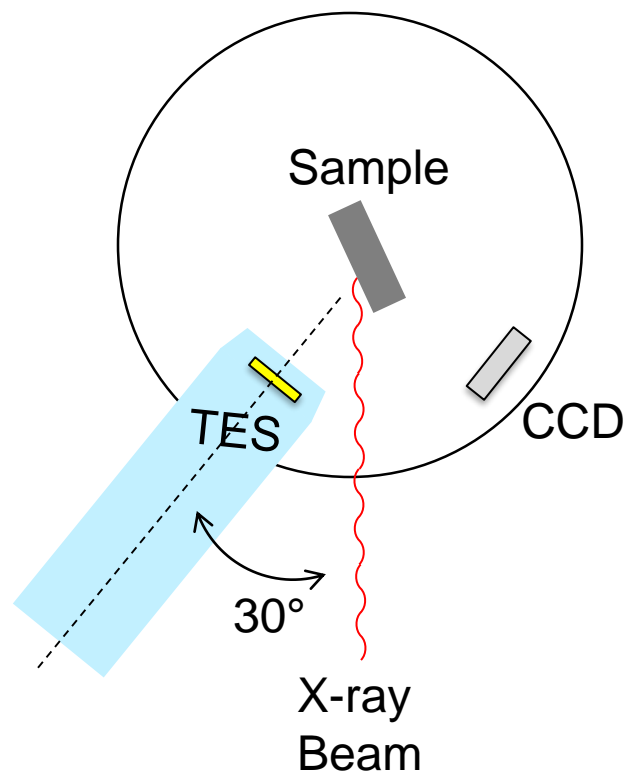
The desktop environment includes a taskbar on the left with various application icons and a system tray on the top right showing the time as 6:11 PM and the user 'irwin-analysis'.

Work in progress

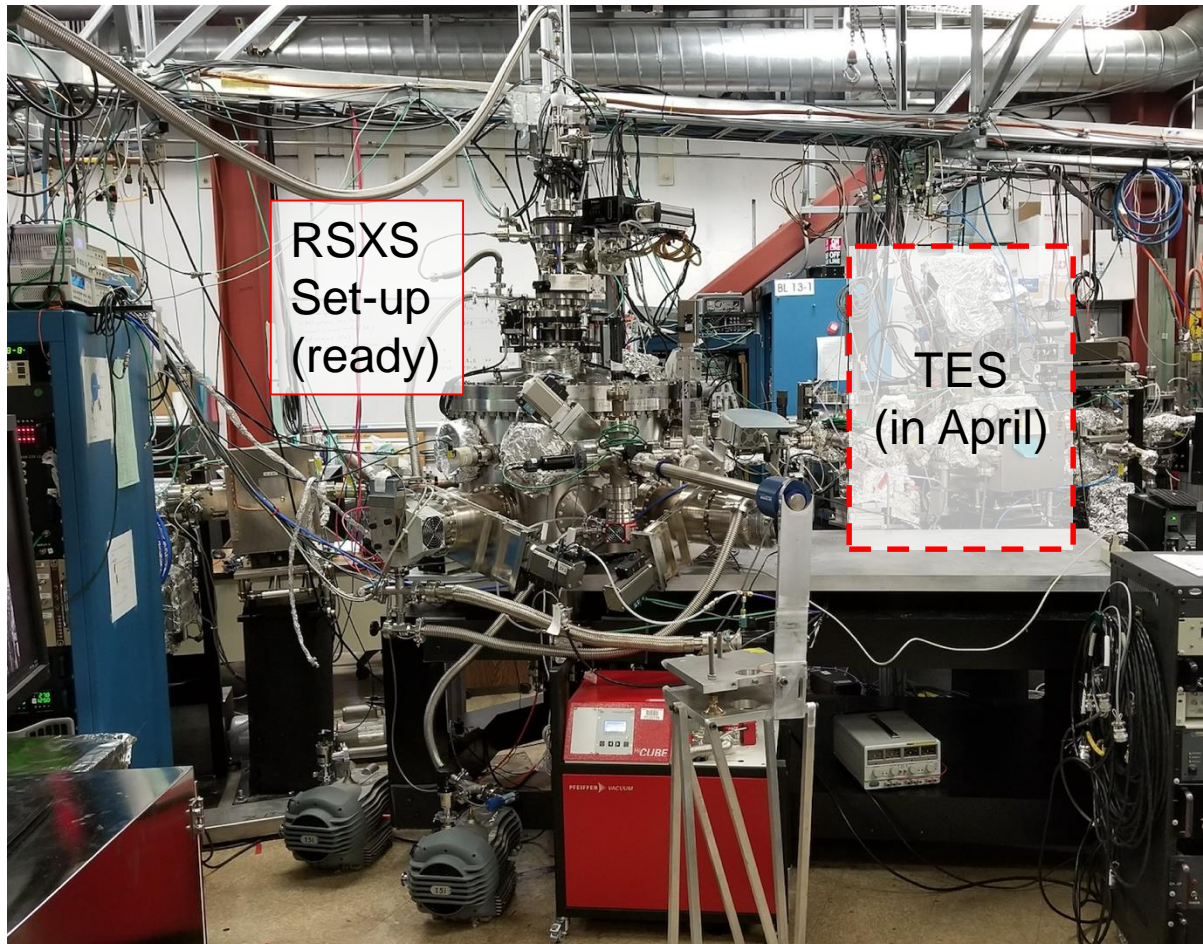
- Real time analysis



TES-RSXS set-up at BL 13-3



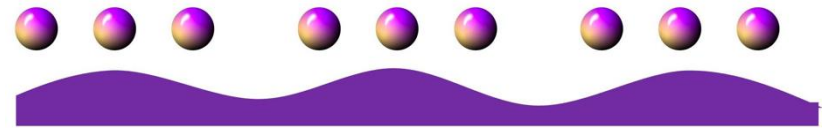
Current status of TES-RSXS



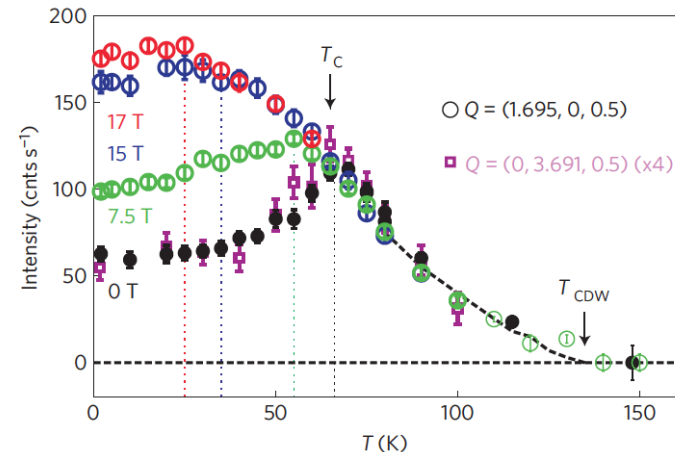
- Unconventional high T_c superconductor
 - Mechanism unknown => fundamental physics problem
 - Plenty of applications => applied physics problem

- Charge Density Wave?

- Modulated electron density
- Universally found in cuprates

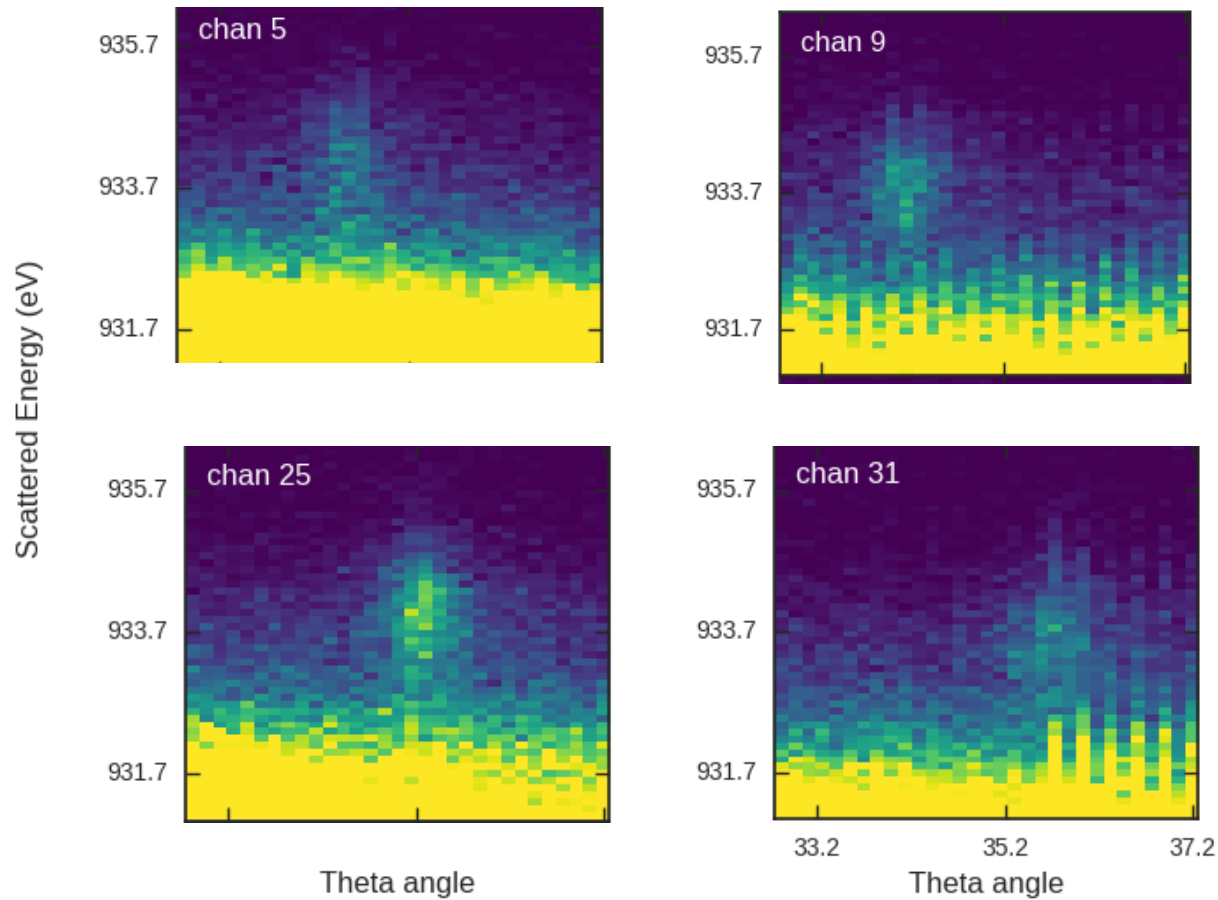


- CDW and SC intertwined



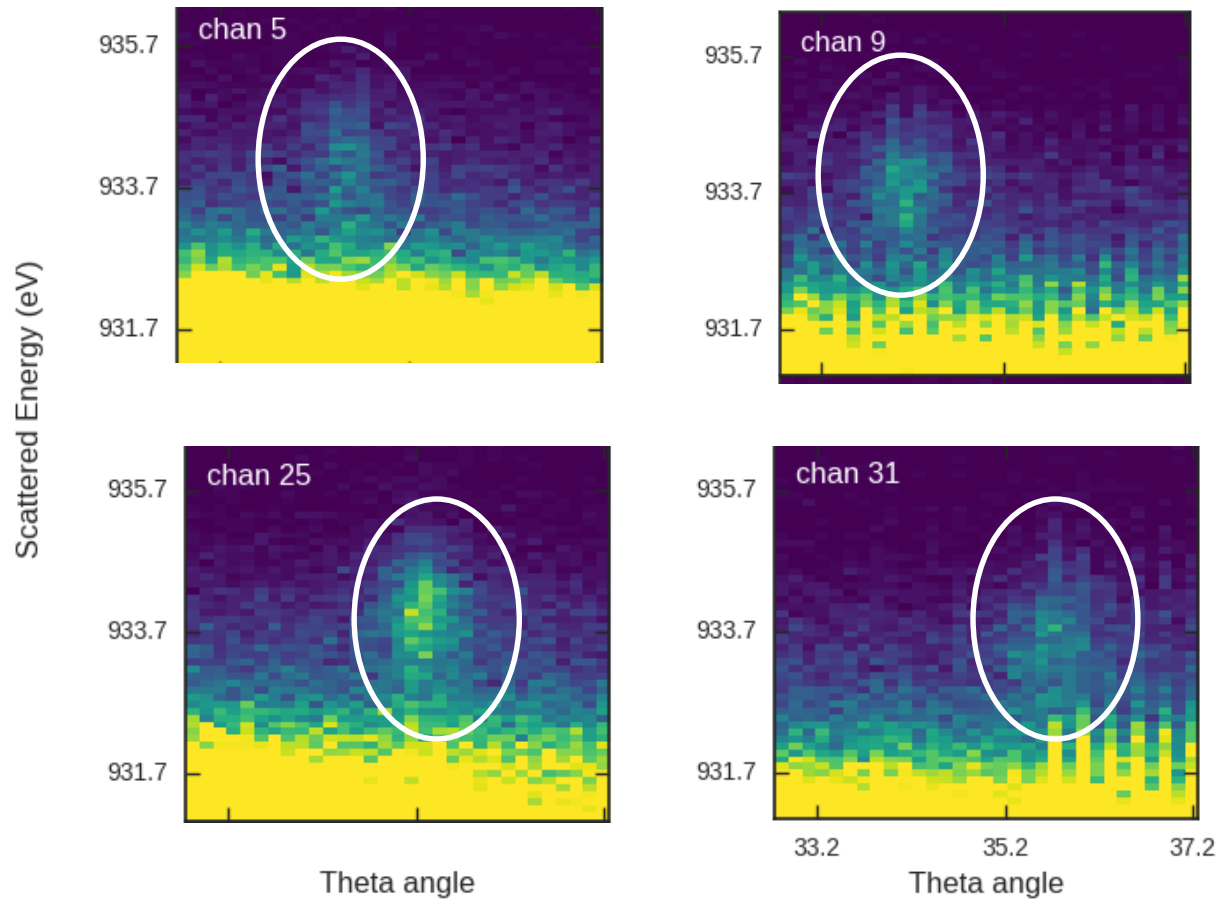
J. Chang et al.
Nature Physics
(2012)

Demonstration @ APS IEX: YBCO CDW



Yizhi et al. L30.00010, APS March Meeting 2018

Demonstration @ APS IEX: YBCO CDW



Yizhi et al. L30.00010, APS March Meeting 2018

Summary

- First TES works smoothly, needs more user friendliness
- Second TES coming soon
- Will explore new capabilities, will unravel mysteries
- R&D test bed for LCLS-II. Successful effort at BL 10-1 made possible the next SLAC investigation into TES

