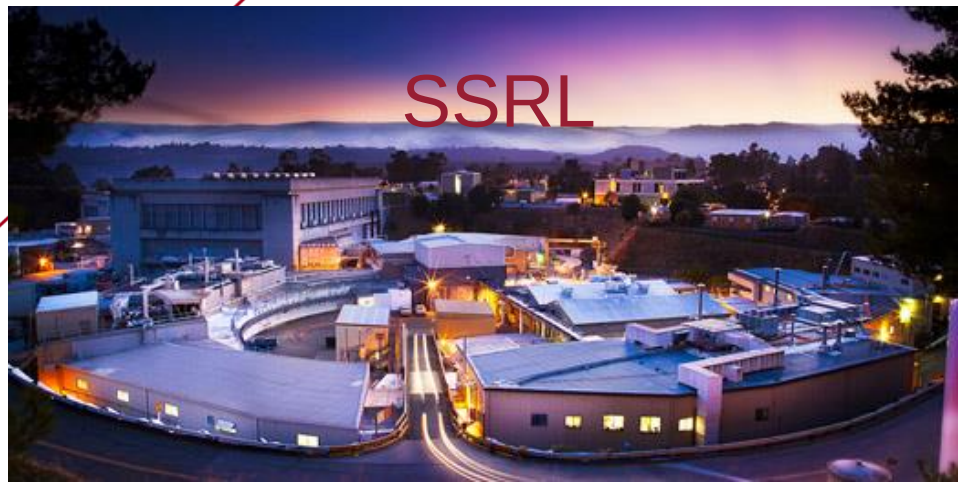
The first two years of TES spectrometer at SSRL

Developing the TES spectrometer for cutting-edge science

Sang Jun Lee

SLAC National Accelerator Laboratory



U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

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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

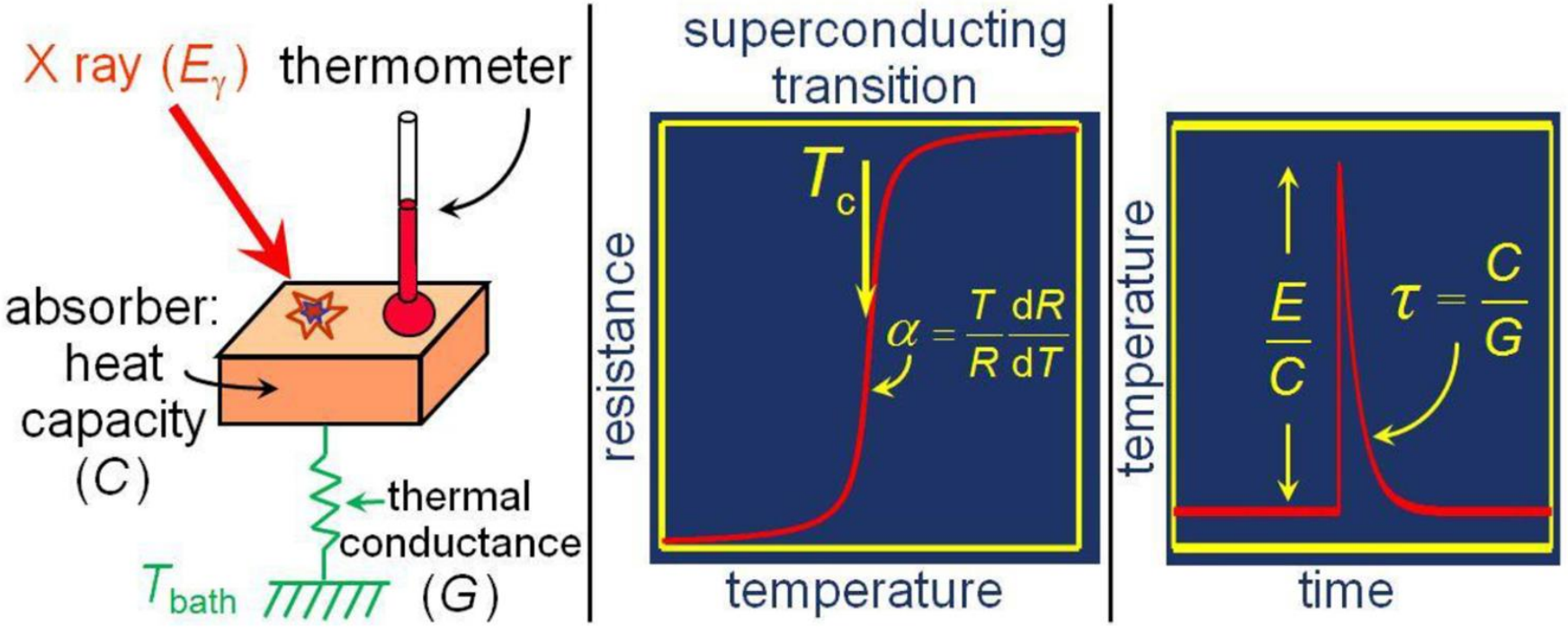
Outline

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

Outline

- 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

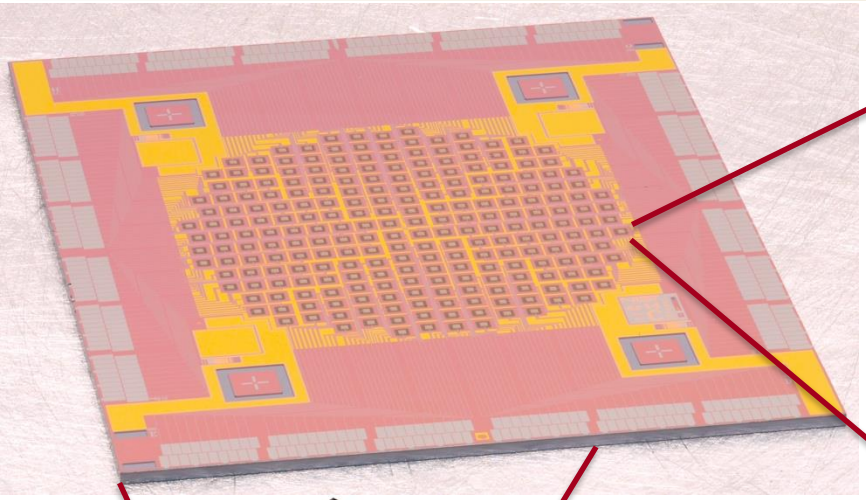
Superconducting Transition-Edge Sensor (TES)

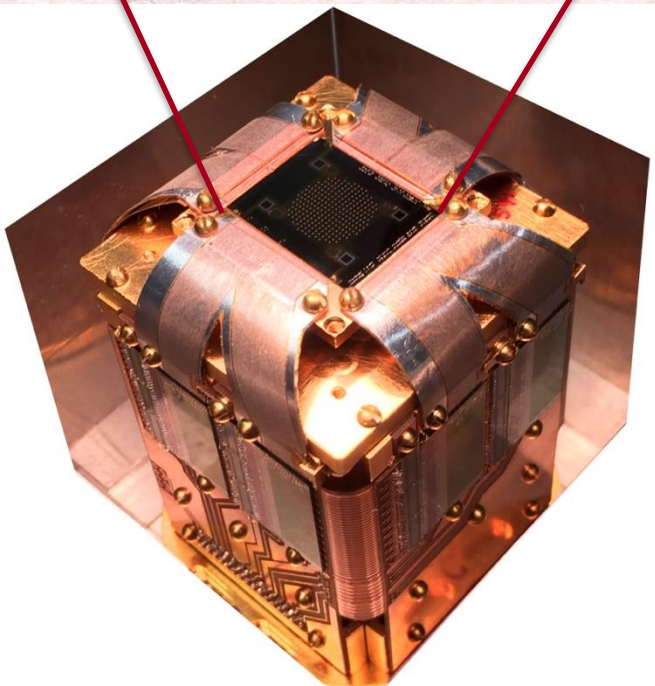


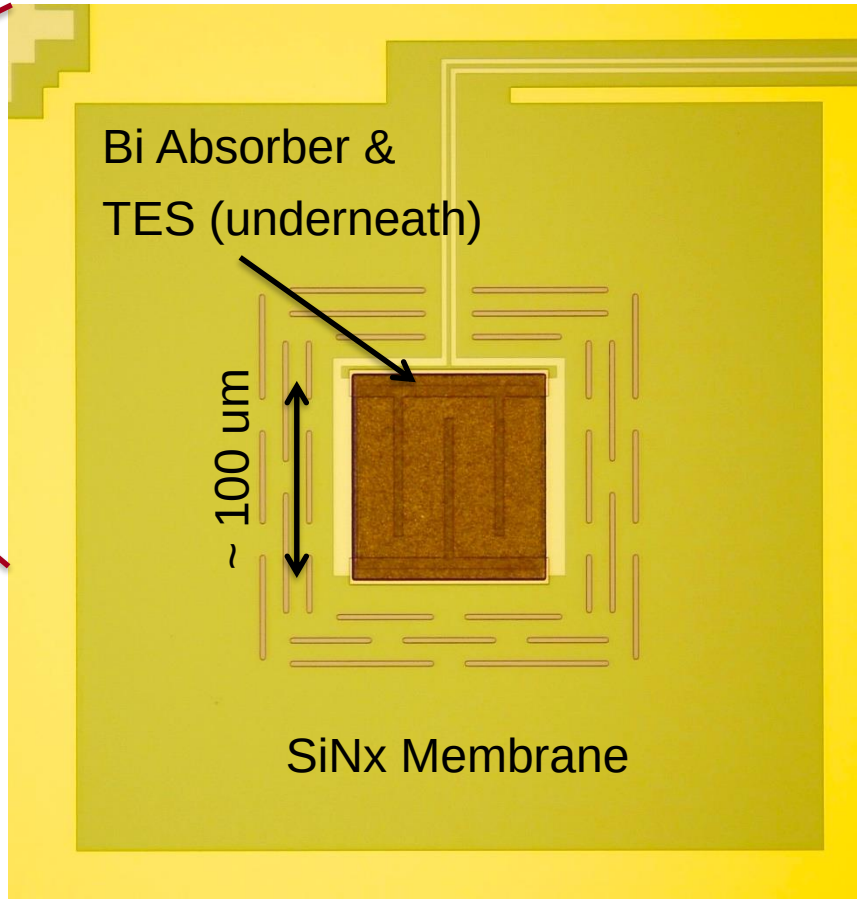
Two TES spectrometers at SSRL/SLAC

	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

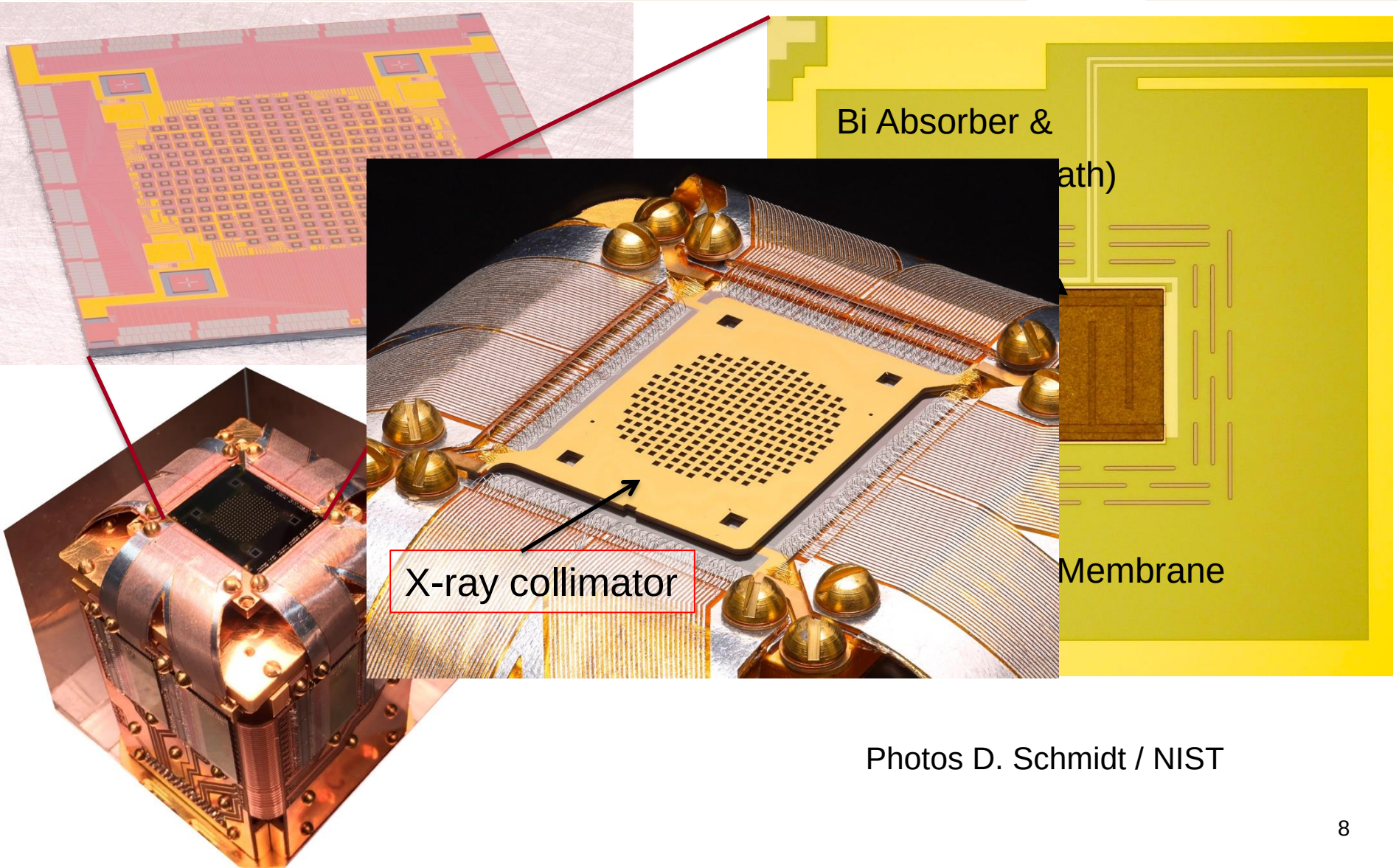






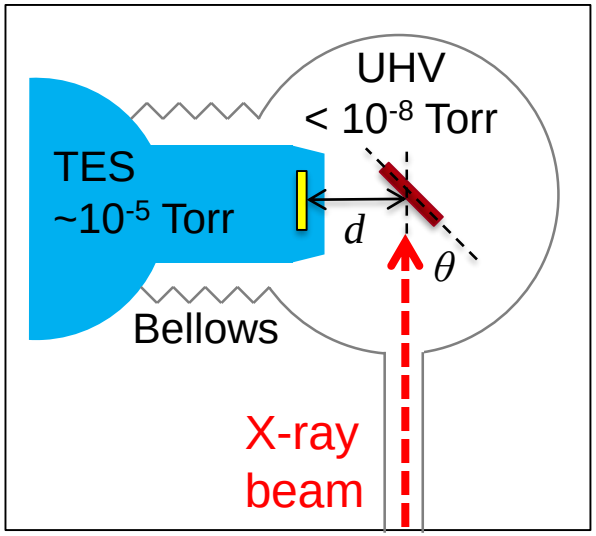
Photos D. Schmidt / NIST

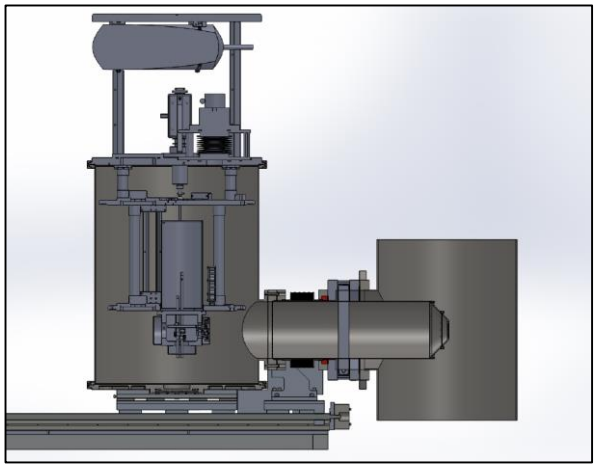
240 pixel TES array

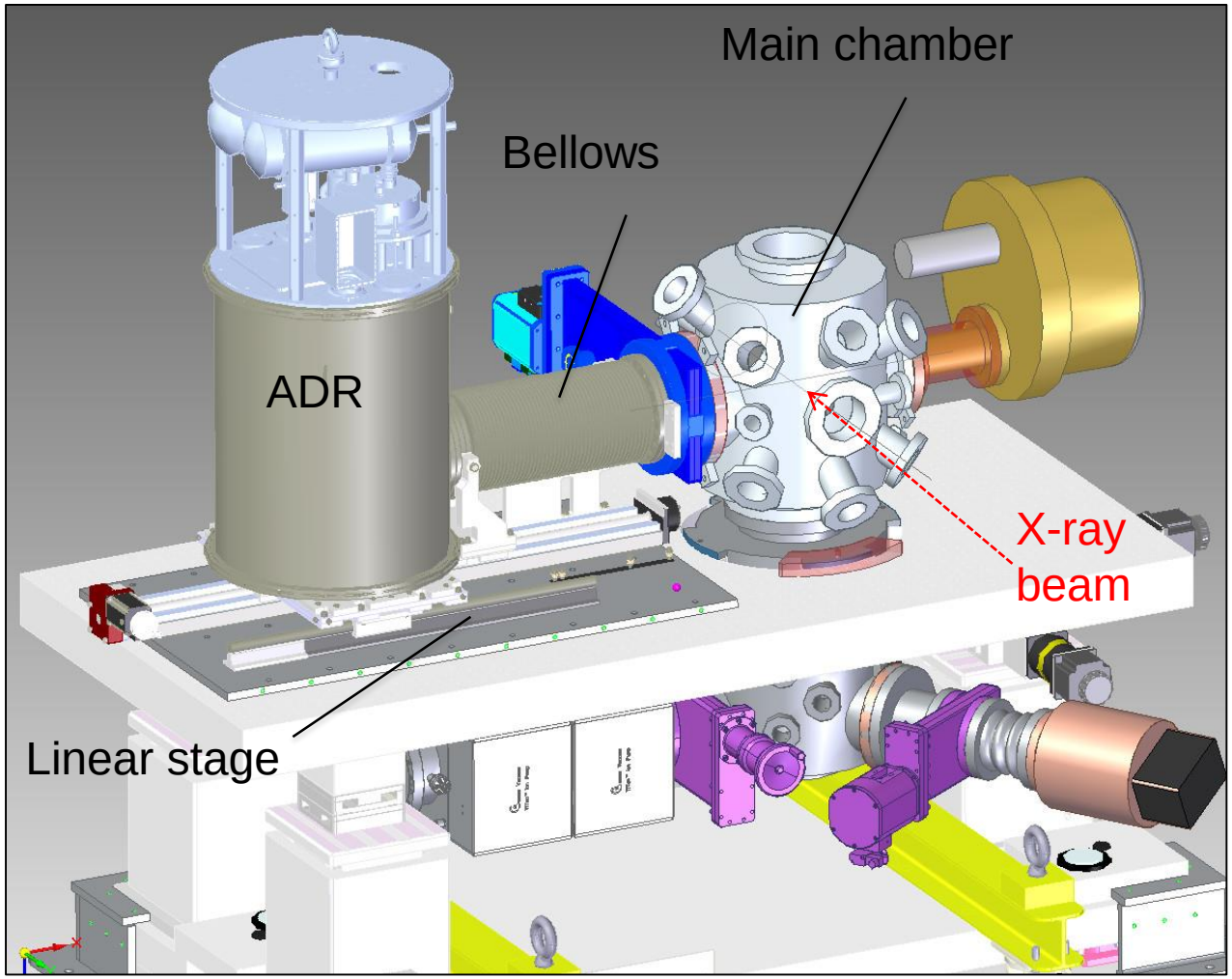


Photos D. Schmidt / NIST

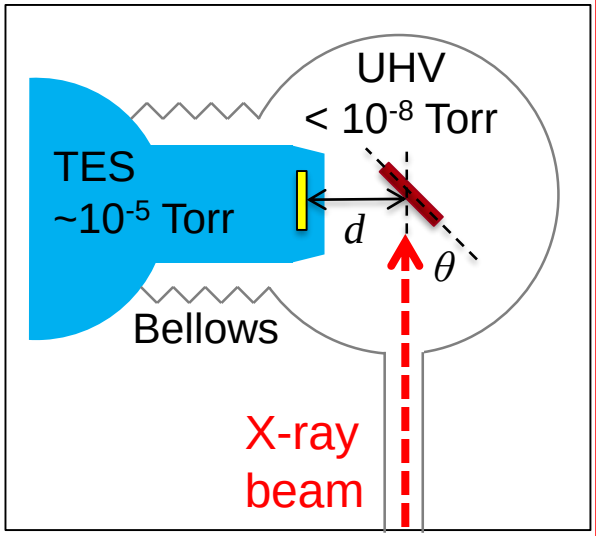
TES spectrometer at BL 10-1

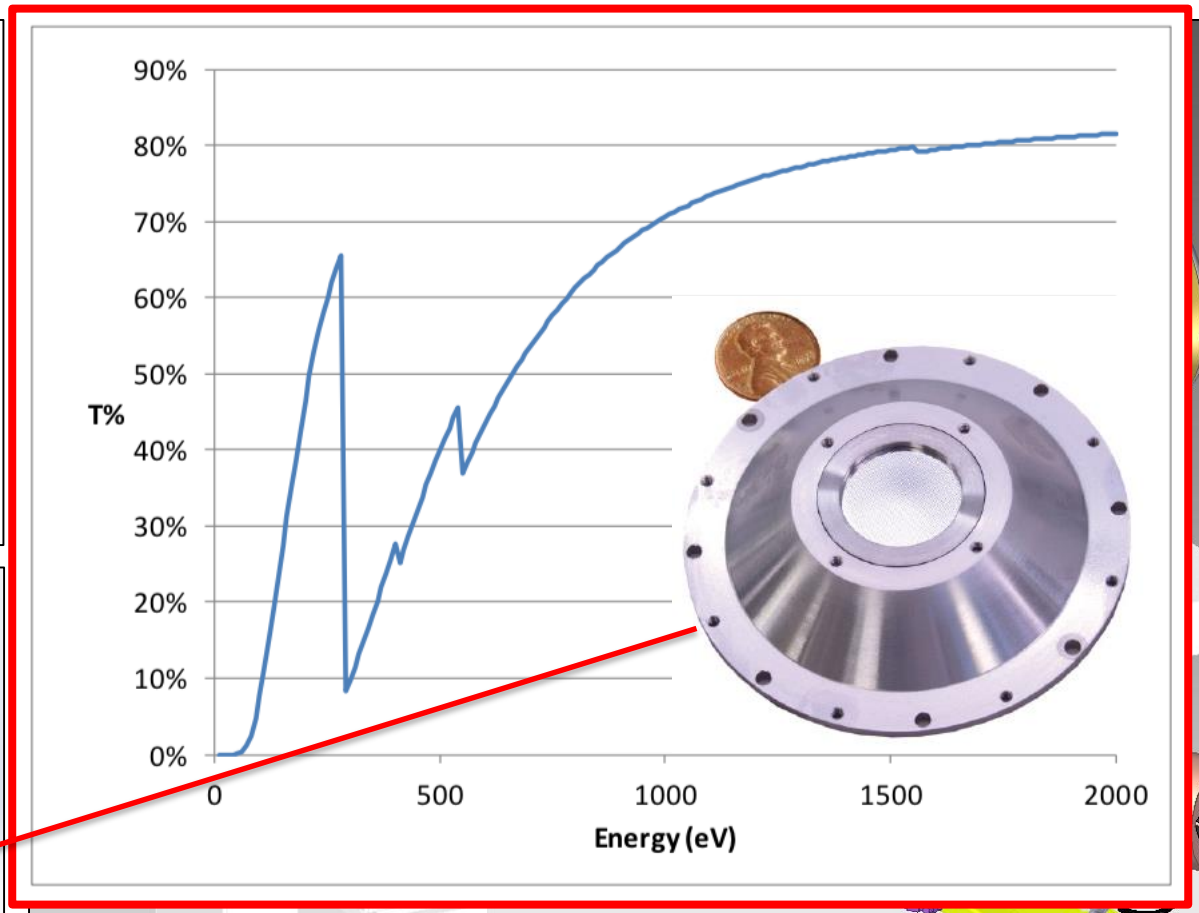


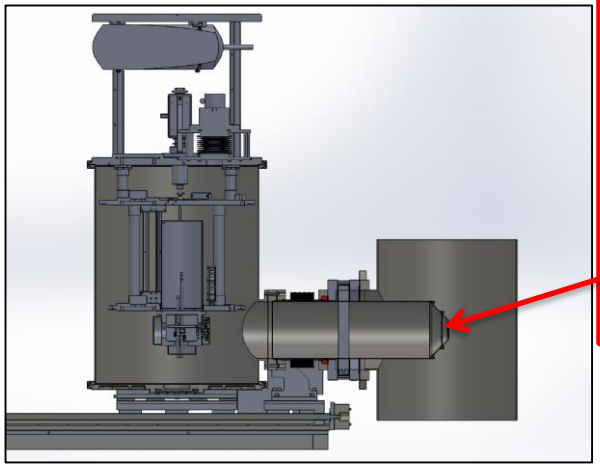




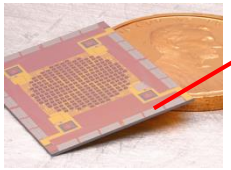
TES spectrometer at BL 10-1







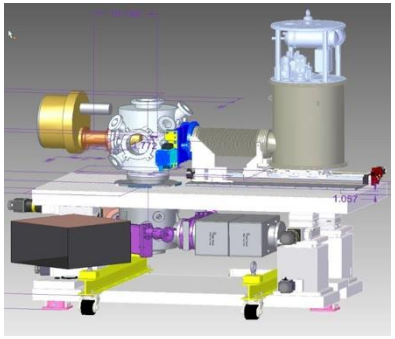
TES project at BL 10-1



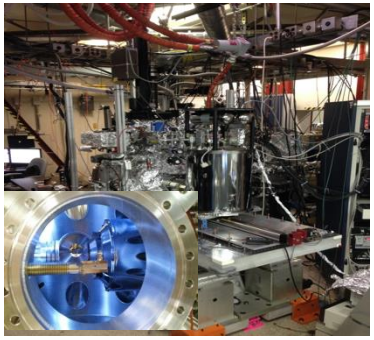
240-pixel TES

TDM readout

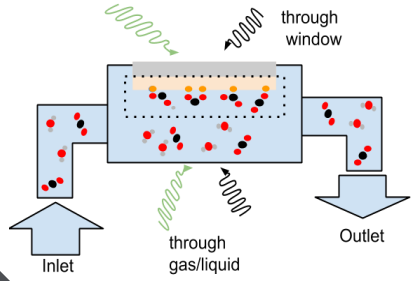
Conceptual Design



Final Design



First Beam



2014 2015 2016 2017 2018

SLAC

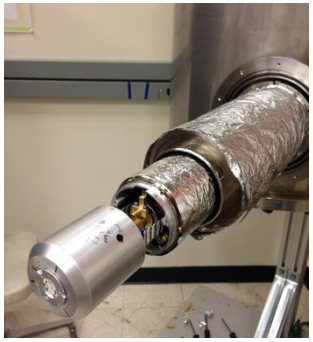
SSRL

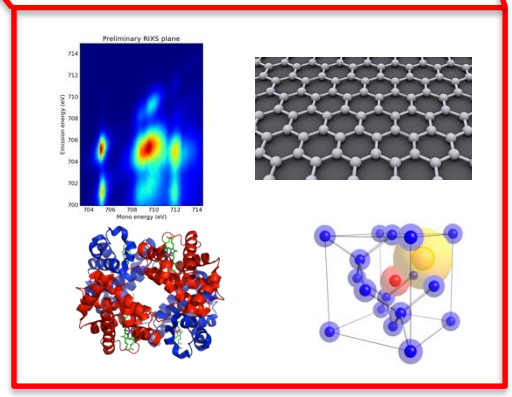
Leland Stanford Junior University

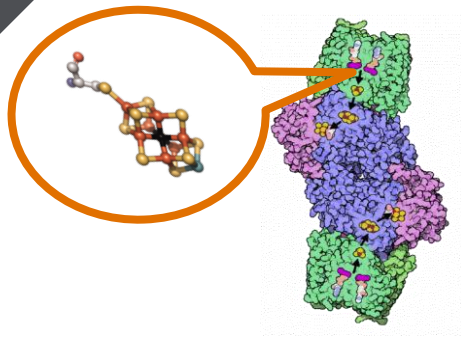
NIST National Institute of Standards and Technology U.S. Department of Commerce

LDRD funded

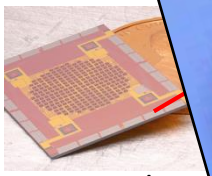
TES Assembled and Tested at NIST







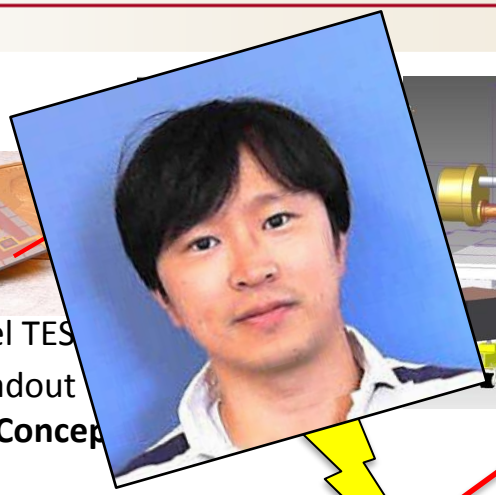
TES project at BL 10-1

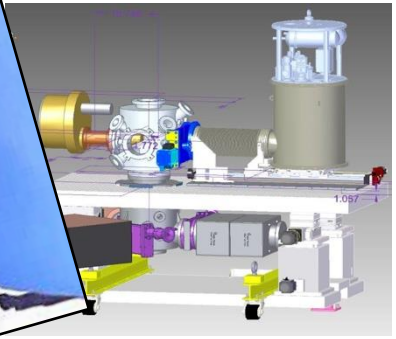


240-pixel TES

TDM readout

Concep





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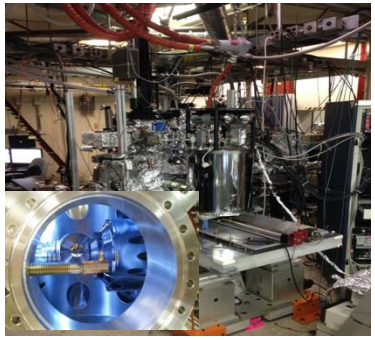

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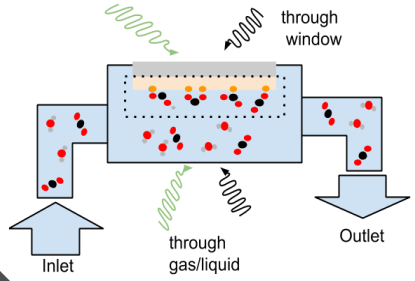

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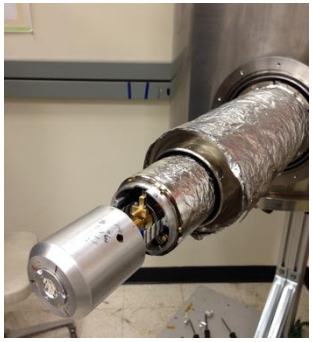
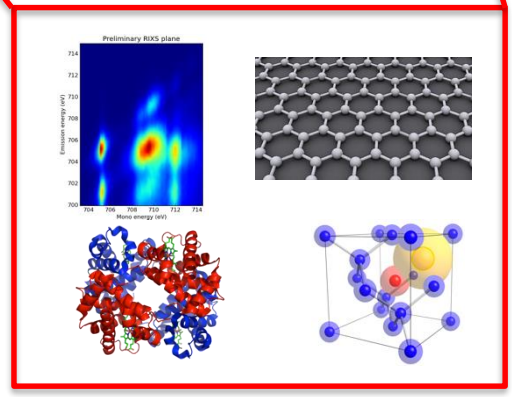
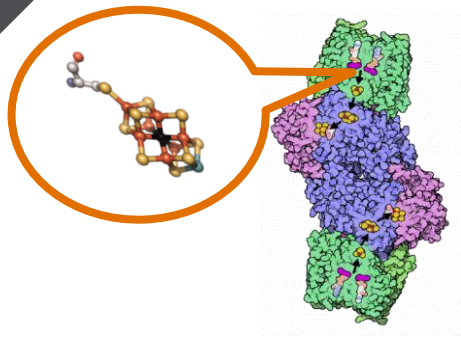


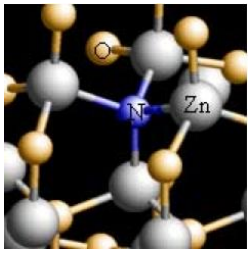




Motivation for BL 10-1 TES

Defects/Dopants	**~ 10^{19}-10^{20}/cm^3**
Surface Sensitivity	**~ 1-10% ML**
Solute Sensitivity	**~ 10-100 mM**
(Spot Size	**~ 10-100 um)**

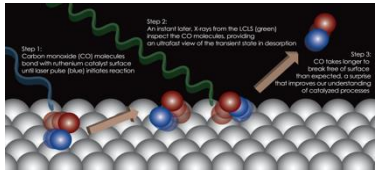
N in ZnO



NREL

Dopants high conc.

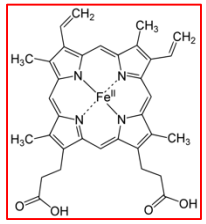
CO/Ru desorption



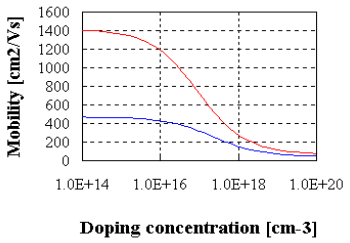
Ogasawara

Surface Chemistry (idealized)

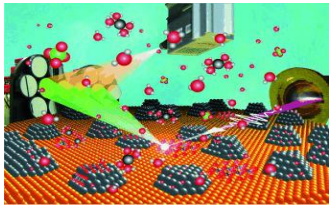
Fe in Heme a



Bio-inorganic model sys

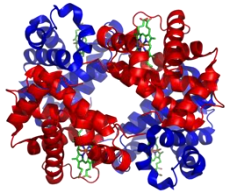


Doping Common Levels < 10^{18}/cm^3



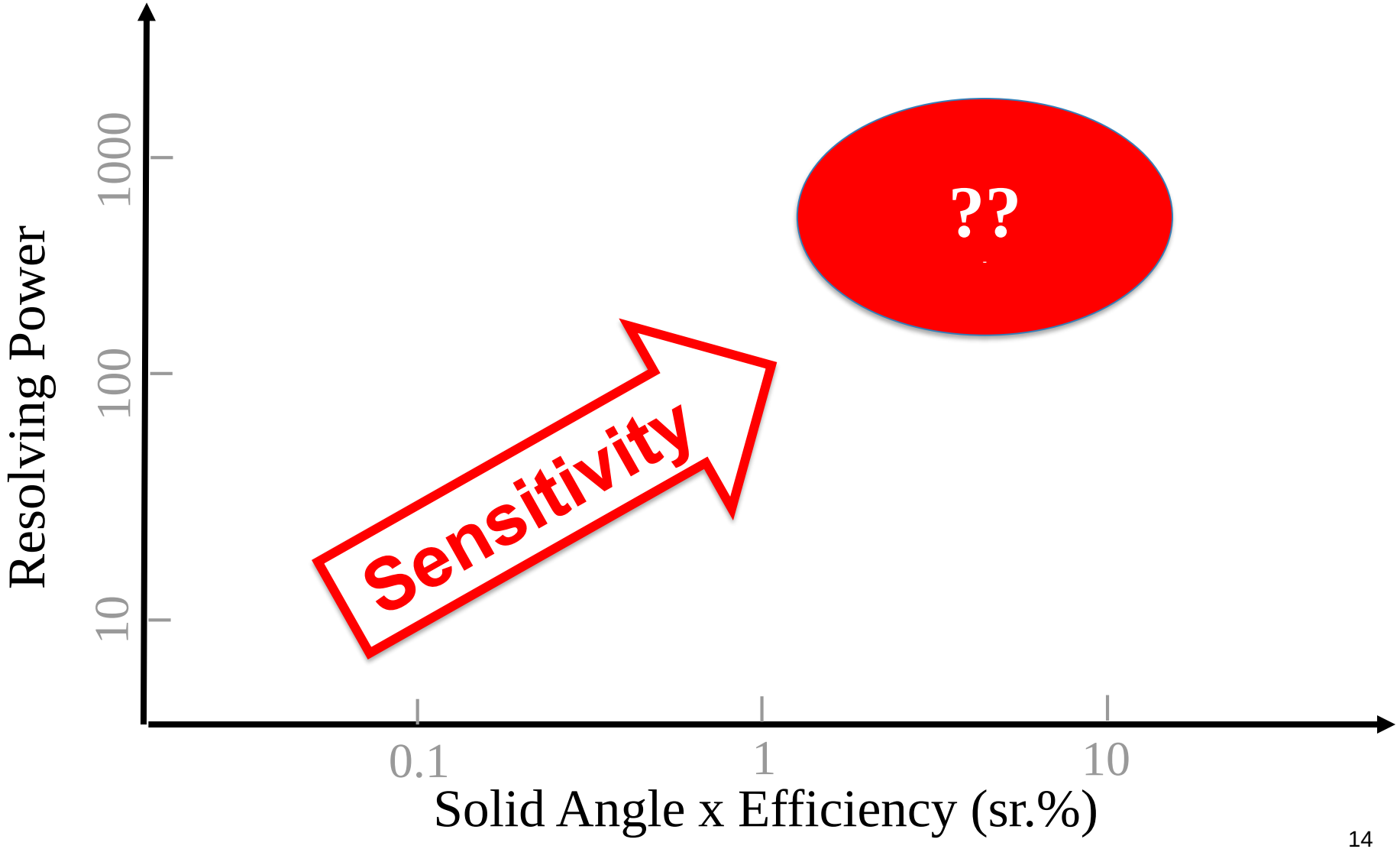
Friebel

Surface Chemistry (realistic!)

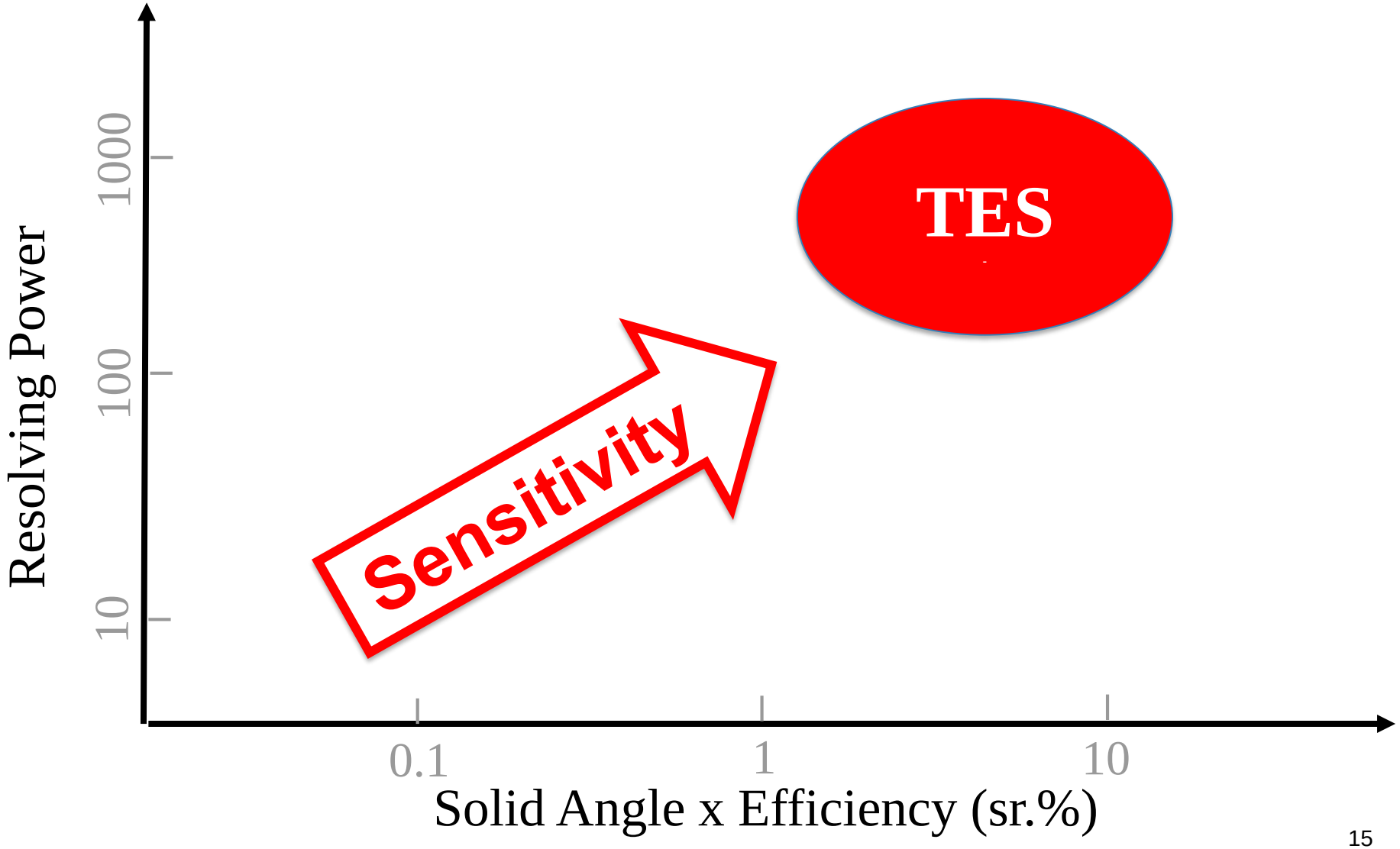


100s of metallo-protein

High resolution & high efficiency



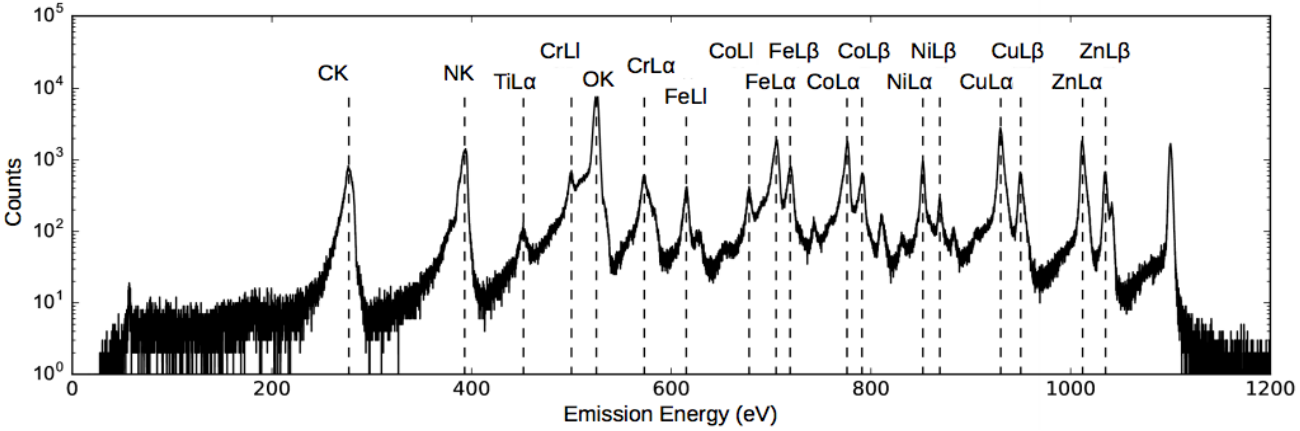
High resolution & high efficiency



TES capabilities

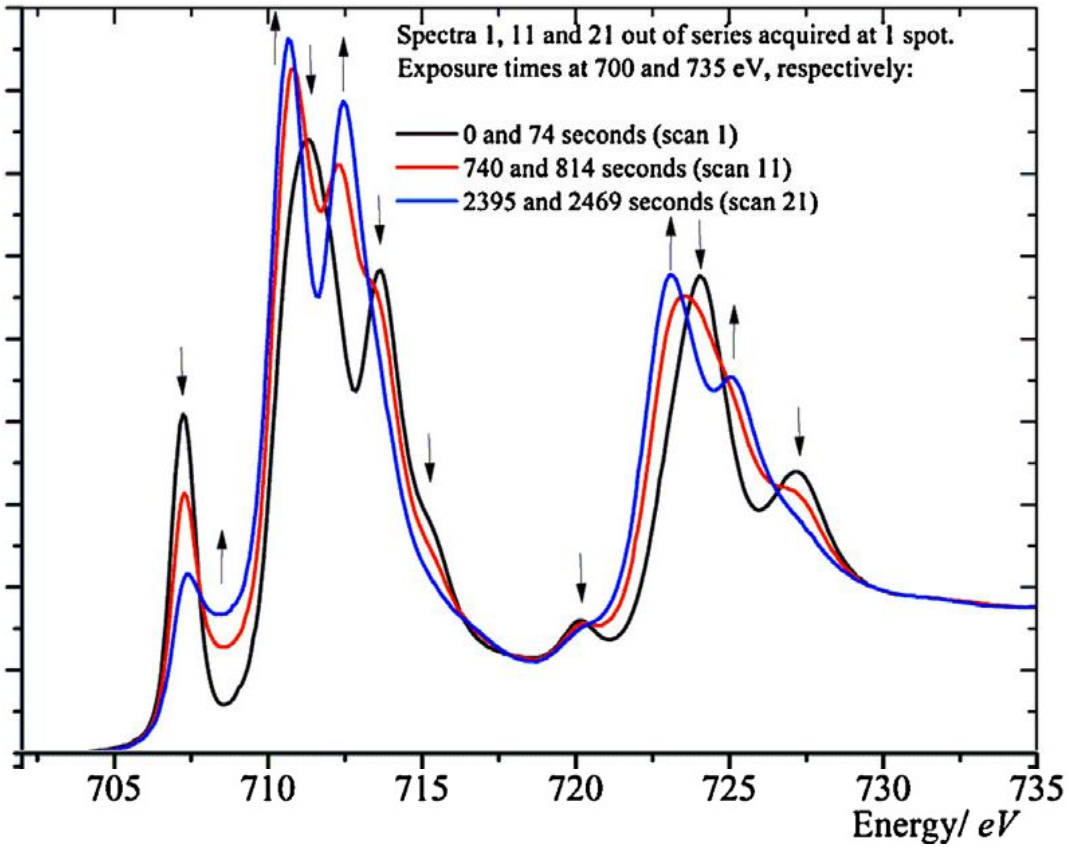
- Unique combination of:
  - Moderate spectral resolution of 1–1.5 eV
  - High efficiency
  - Broadband spectral coverage

XES



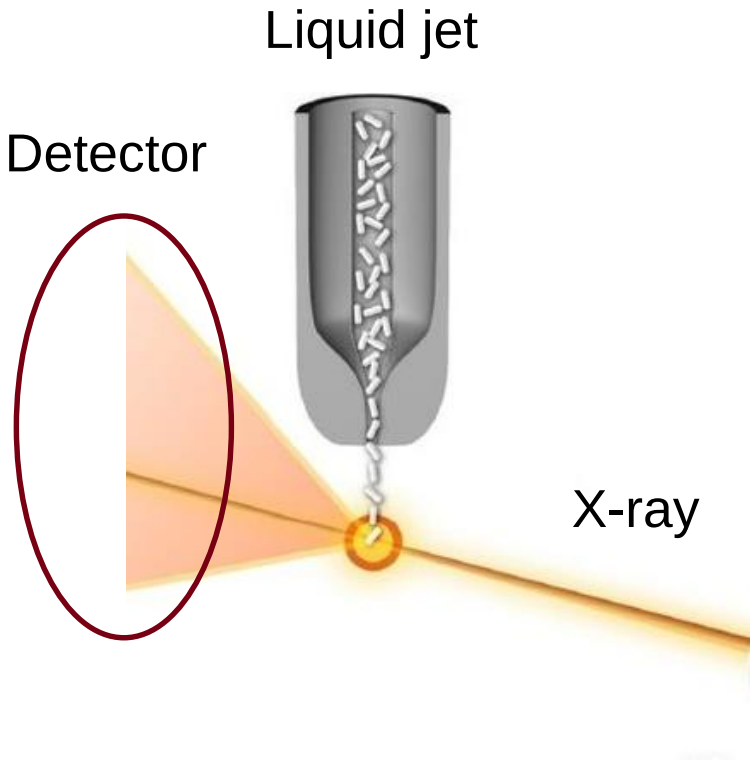
- Capabilities multiply with array size

Why not use more intense X-ray?

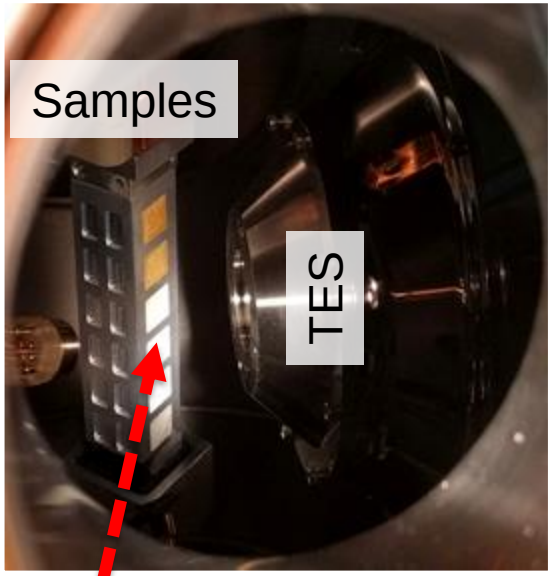


van Schooneveld & S. DeBeer, JESRP 198 (2015) 31-56

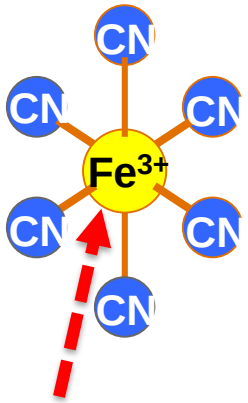
Liquid jet



RIXS of dilute samples

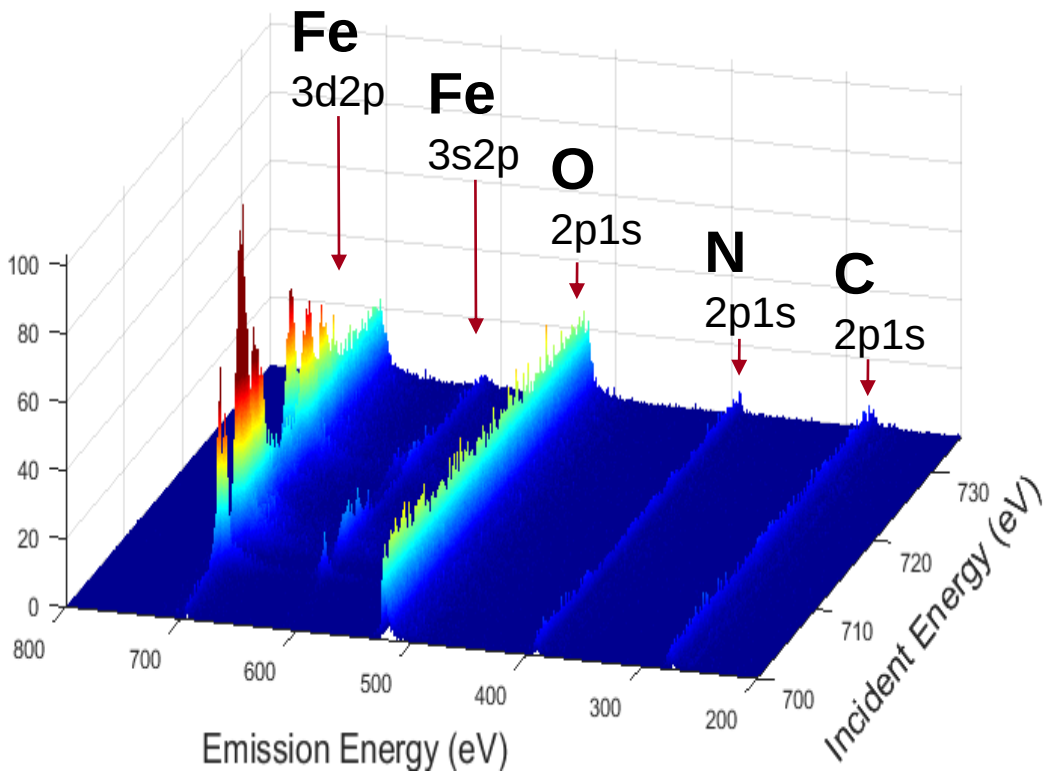


Incident X-rays



Incident X-rays

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



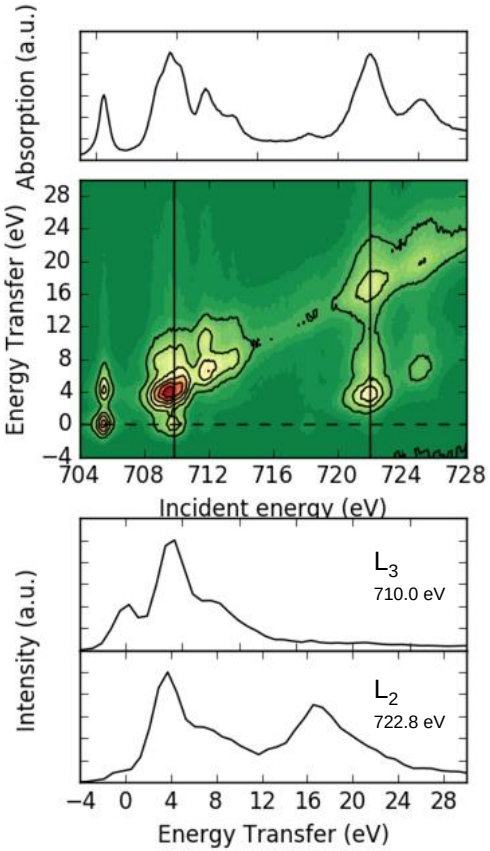
High efficiency enables bioinorganic chemistry

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

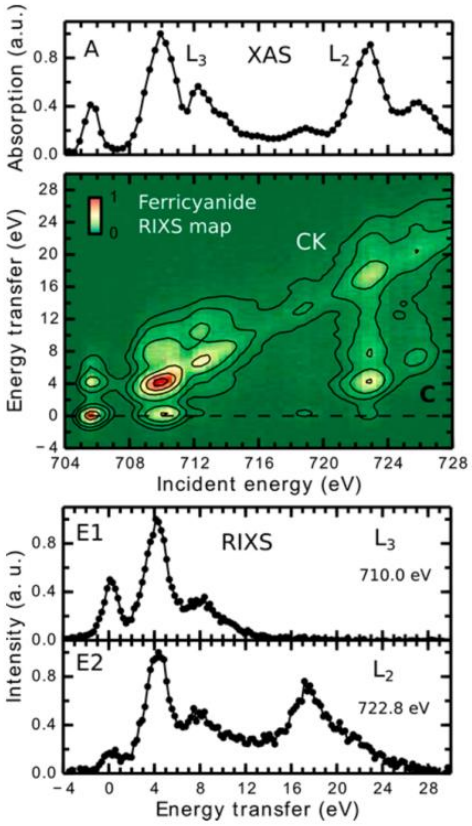
- 50 mM
- Frozen sample



Titus et al., JCP (2017)

BESSY-II Grating

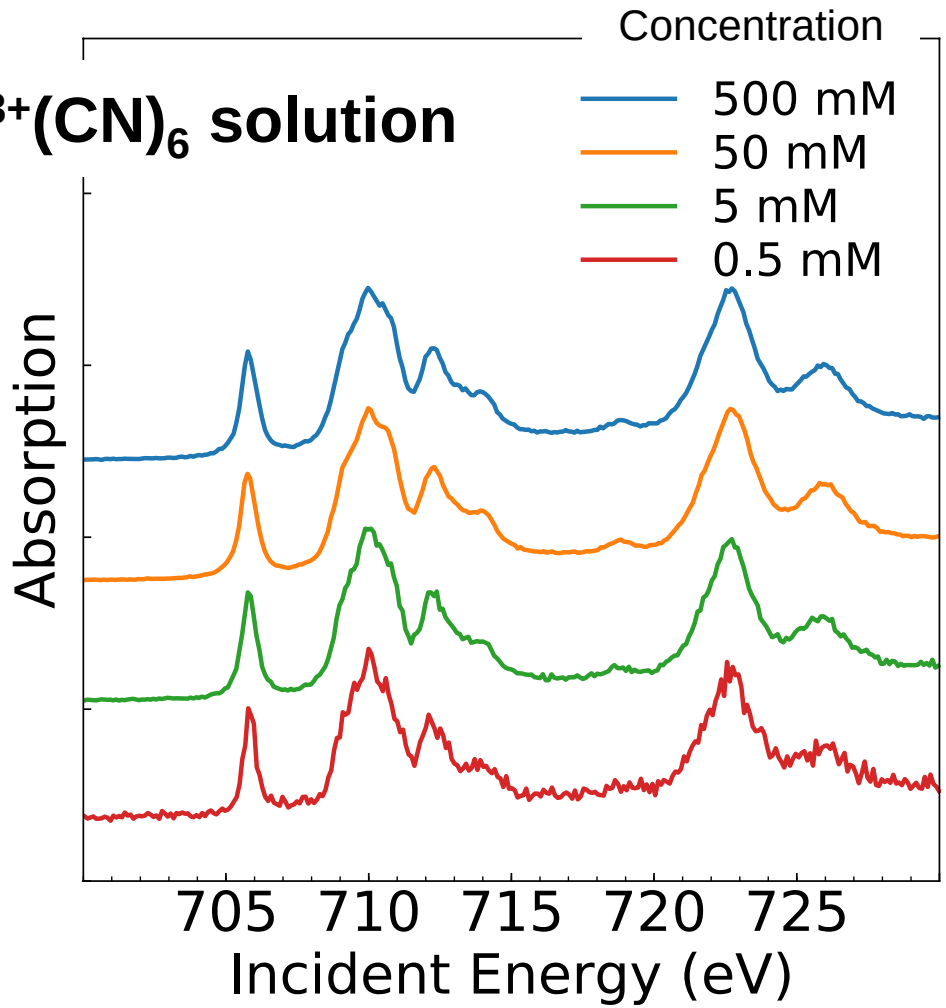
- 500 mM
- Liquid jet



Kunnus et al., JPC B (2016)

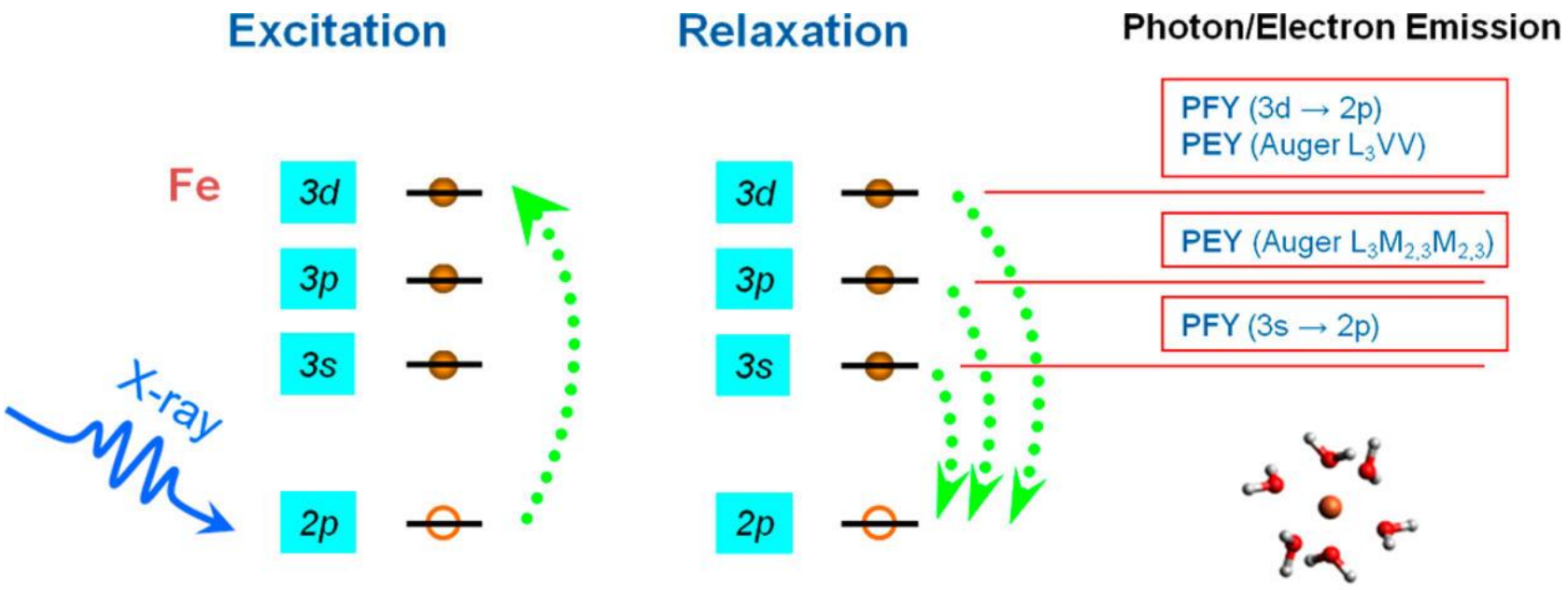
TES at BL10-1: unprecedented sensitivity

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

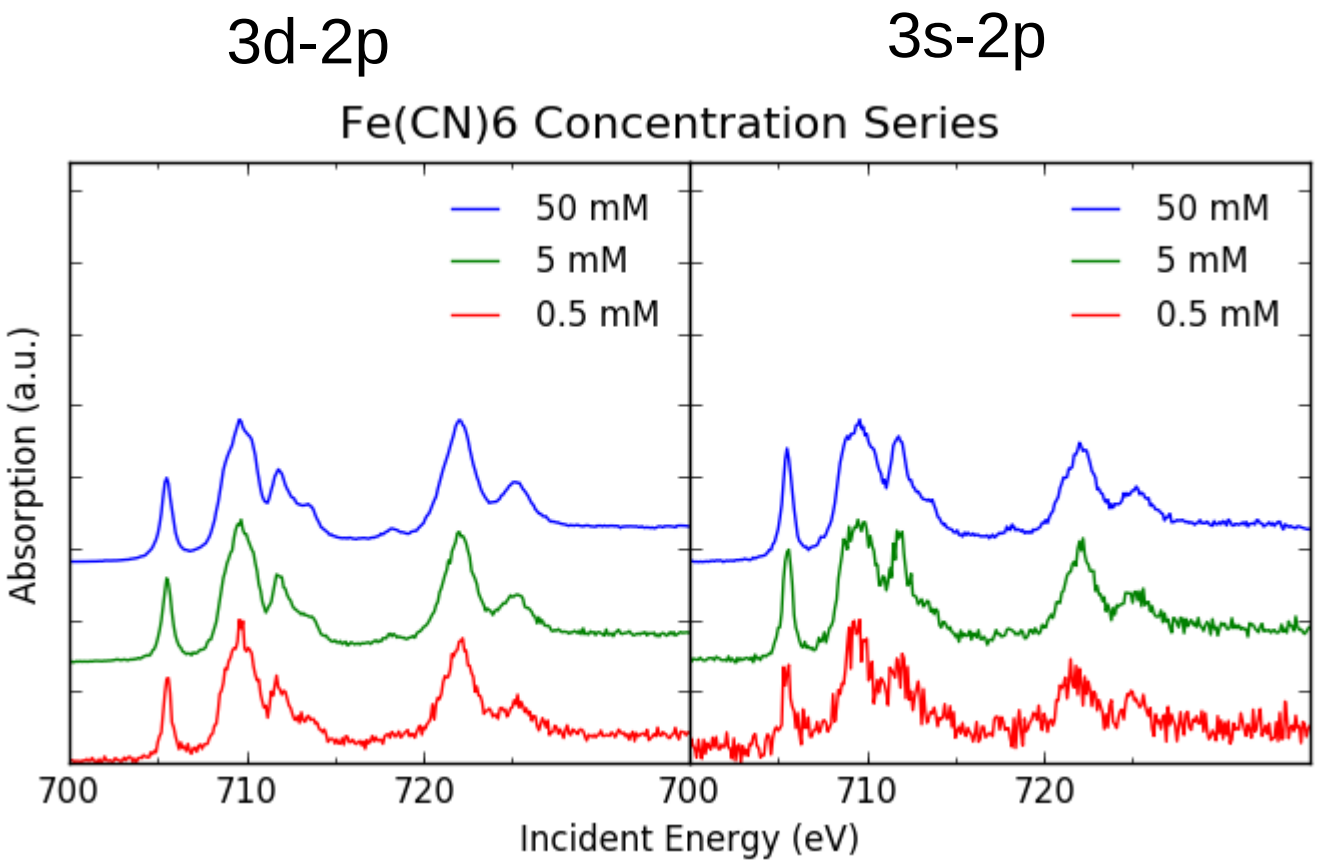


Integration Time
5 hours
5 hours
5 hours
15 hours

3s-2p core-to-core decay



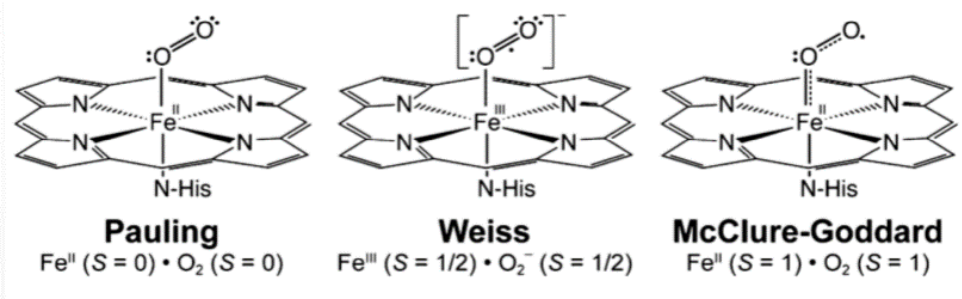
New capabilities



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

Hemoglobin

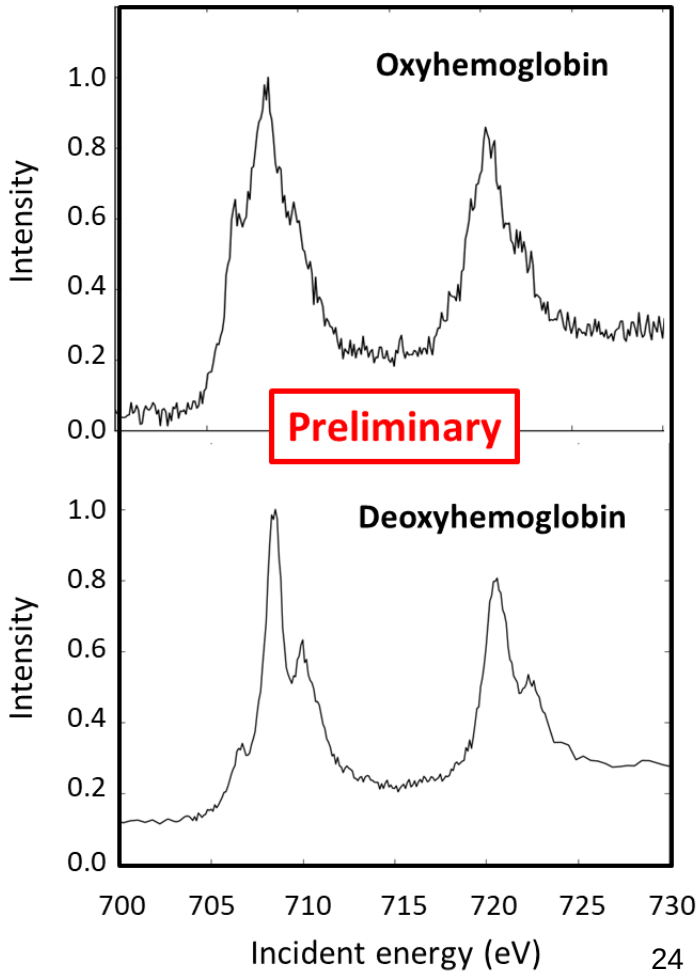
Three limiting cases for Fe-O_2 bonding in Oxyhemoglobin



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.

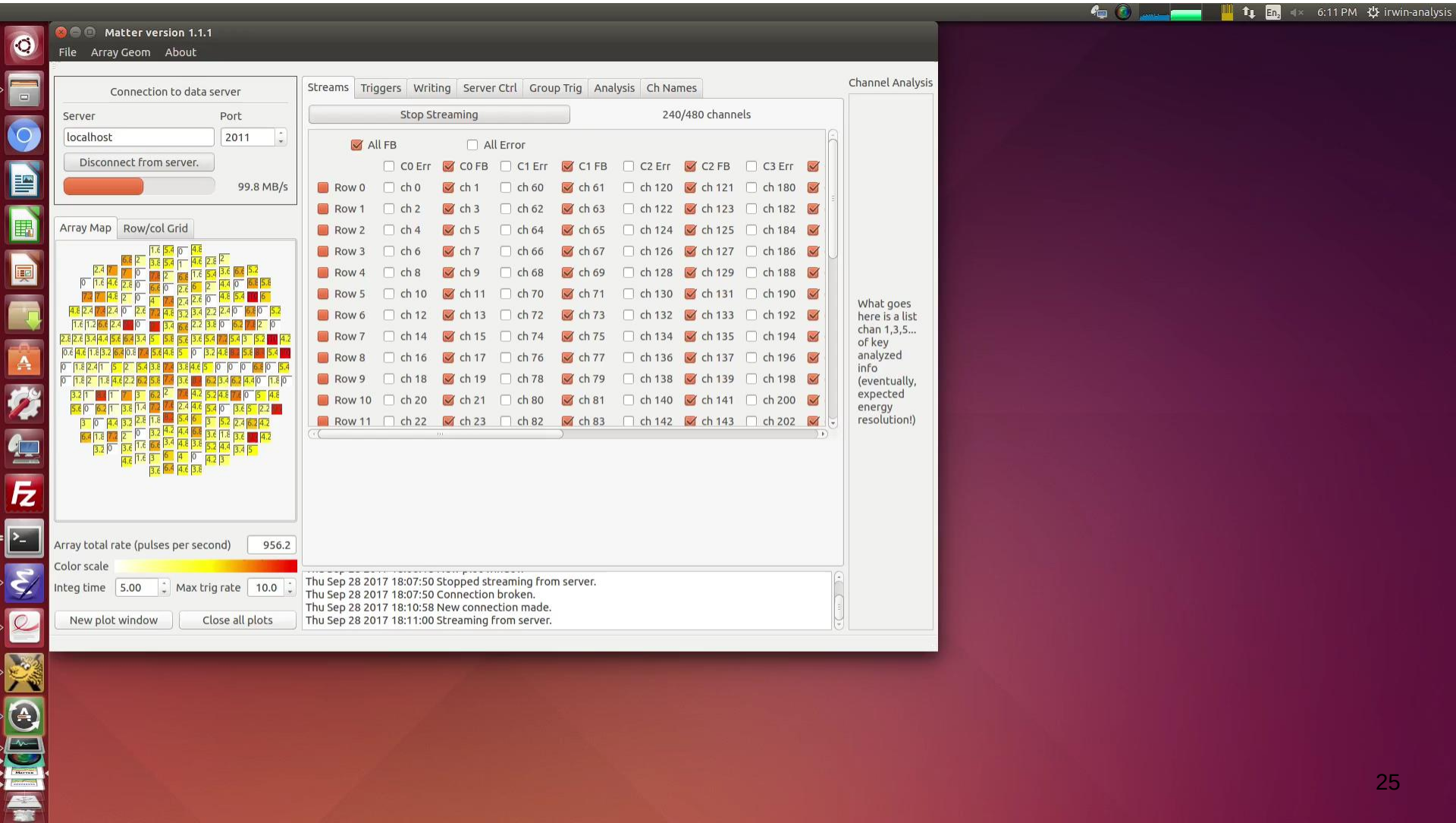
- For the first time, efficiency for Fe L-Edge PFY-XAS of radiation-sensitive samples
- Potential to resolve 80-year-long controversy
- Extensive modeling required for science result
- Collaboration with Ed Solomon's group at Stanford

Fe L-Edge PFY-XAS



Work in progress

- Real time analysis



Work in progress

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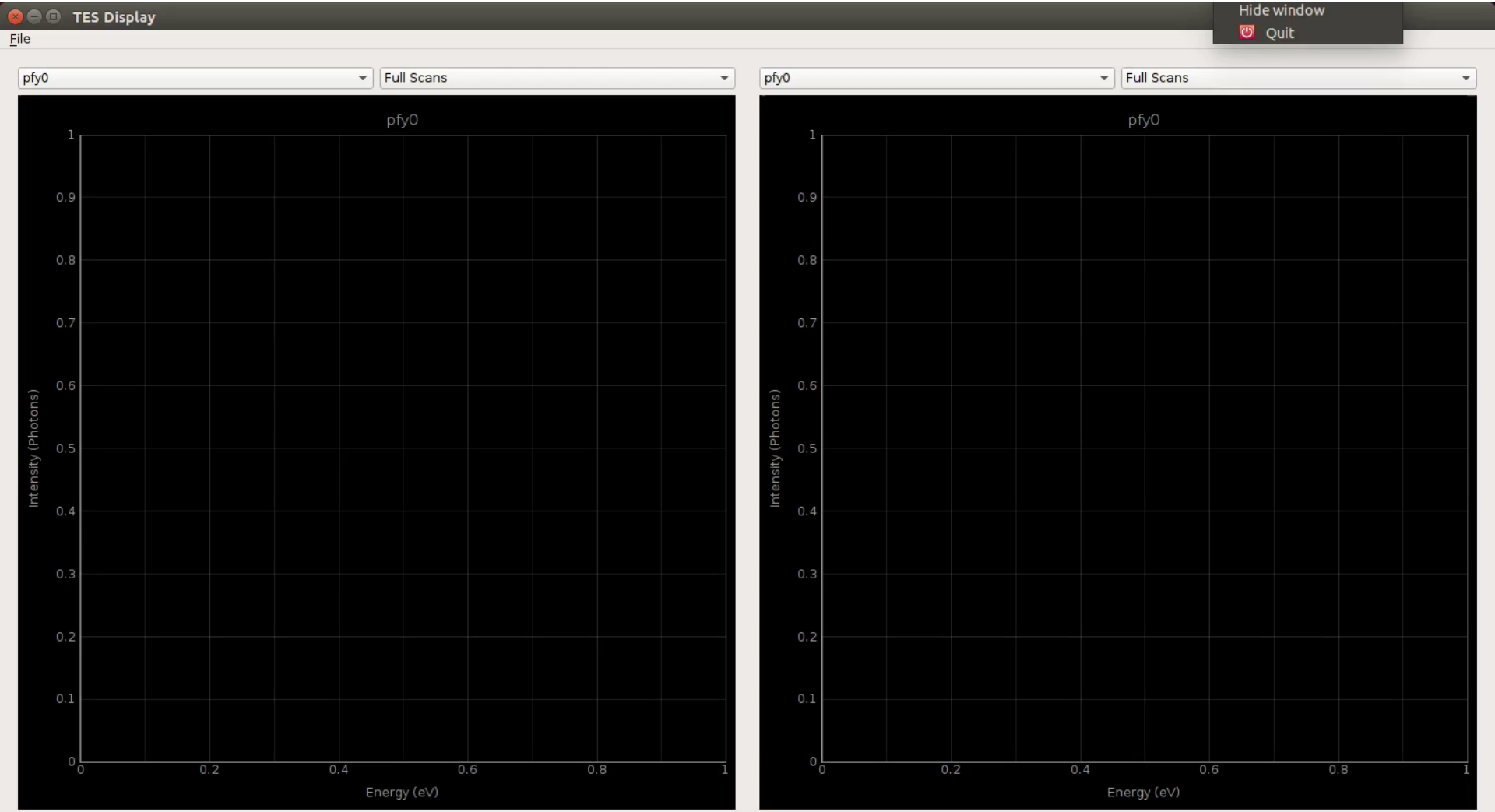
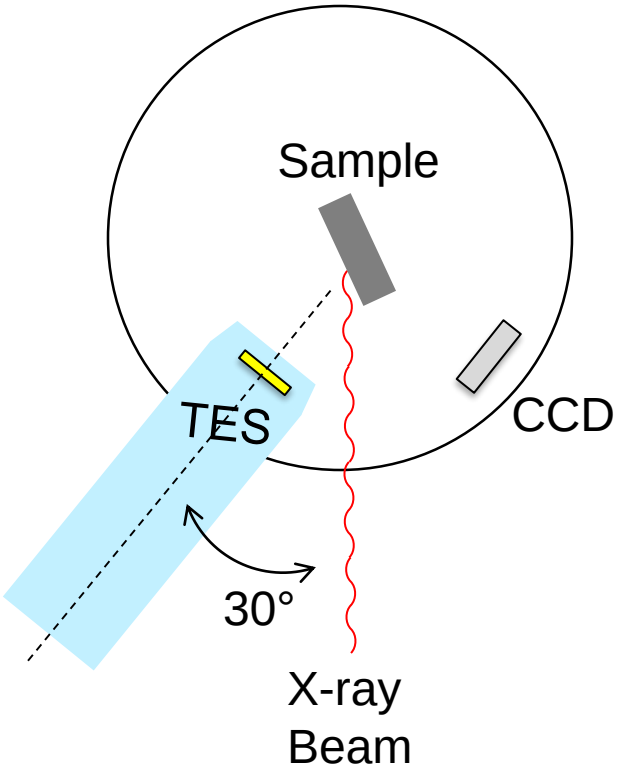
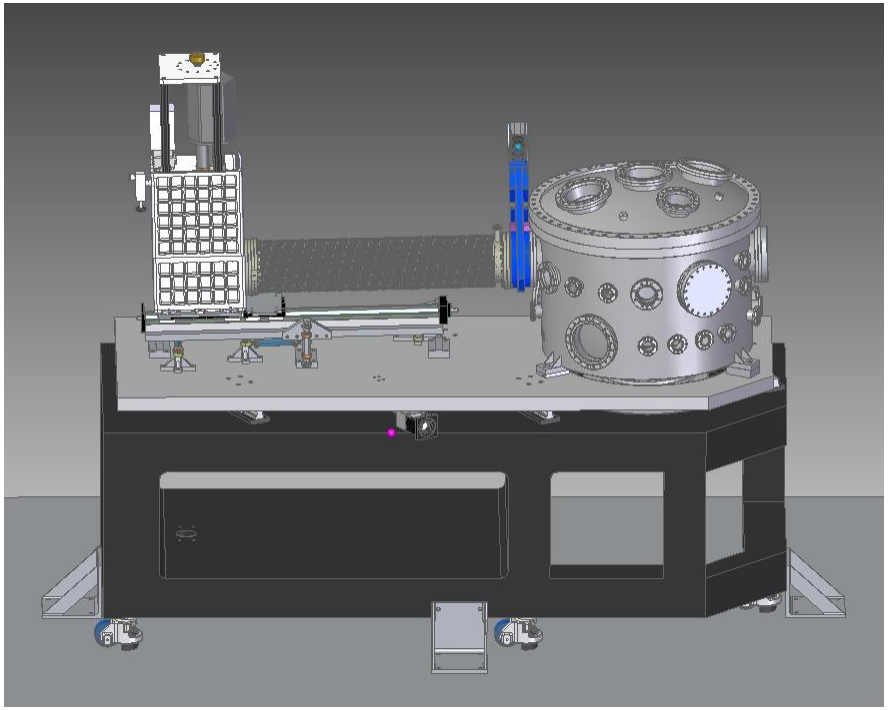
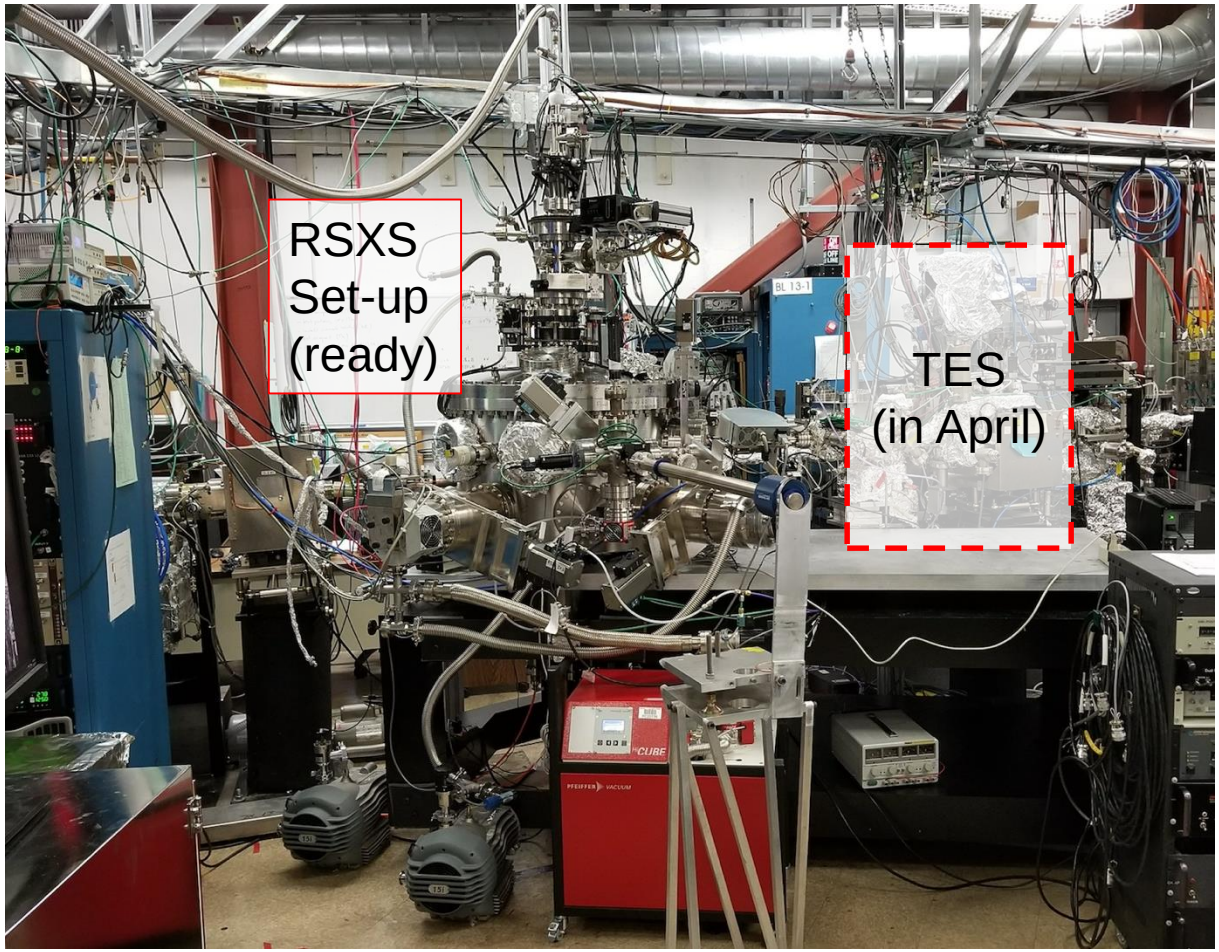


TES-RSXS set-up at BL 13-3





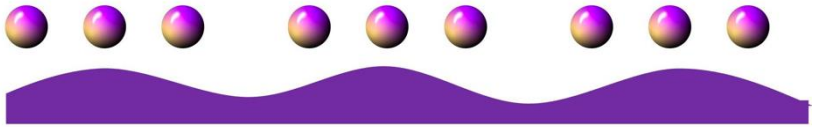
Current status of TES-RSXS



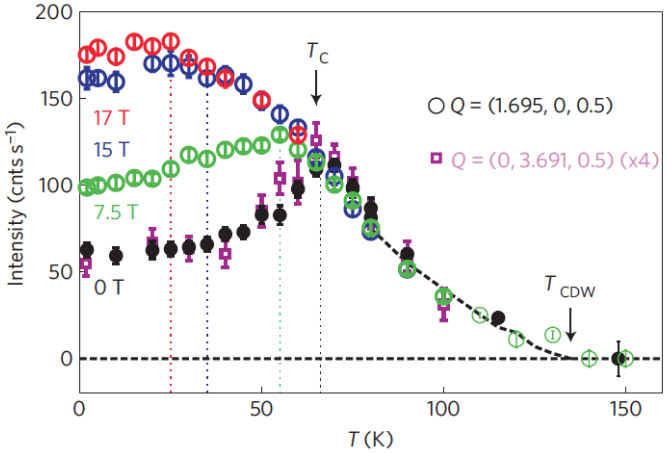
Cuprate and CDW

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

- Charge Density Wave?
  - Modulated electron density
  - Universally found in cuprates

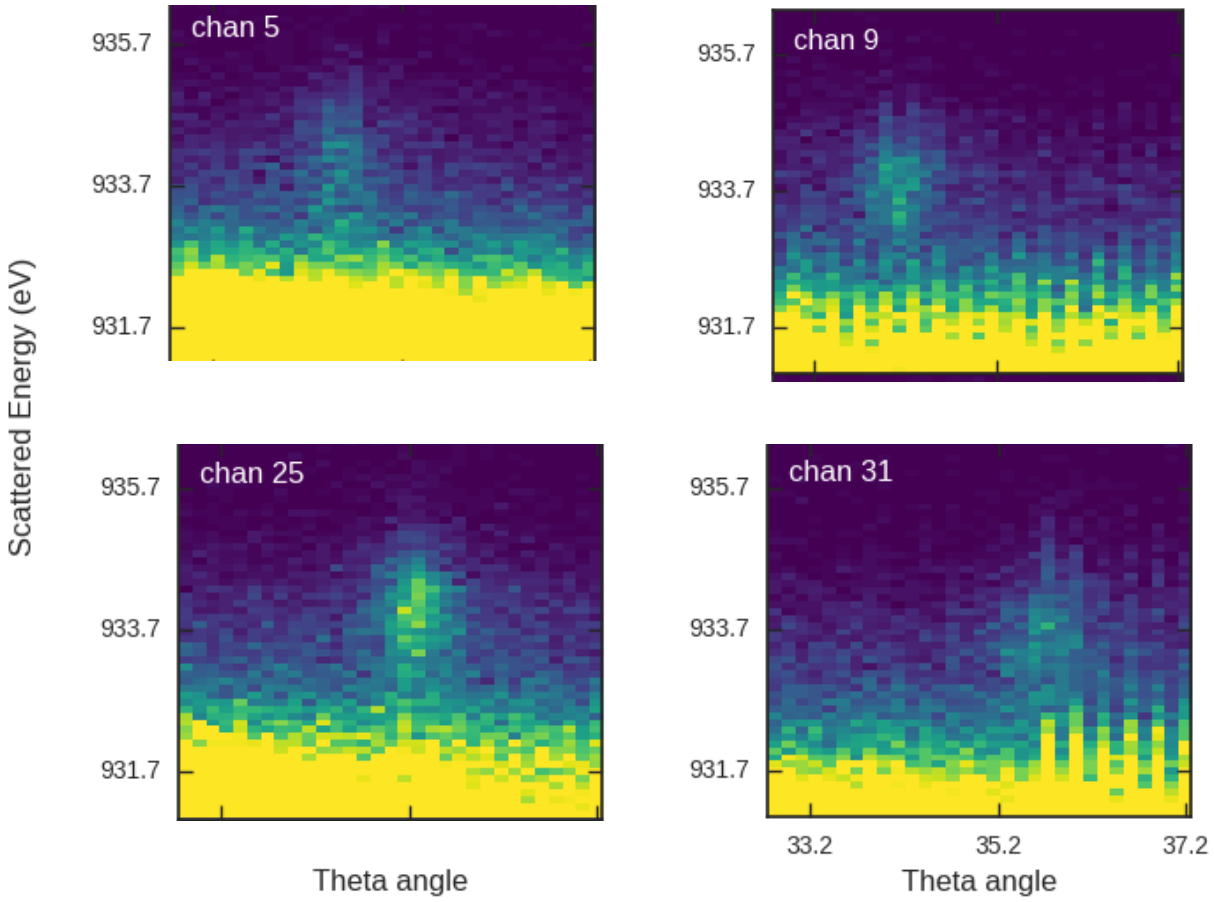


- CDW and SC intertwined



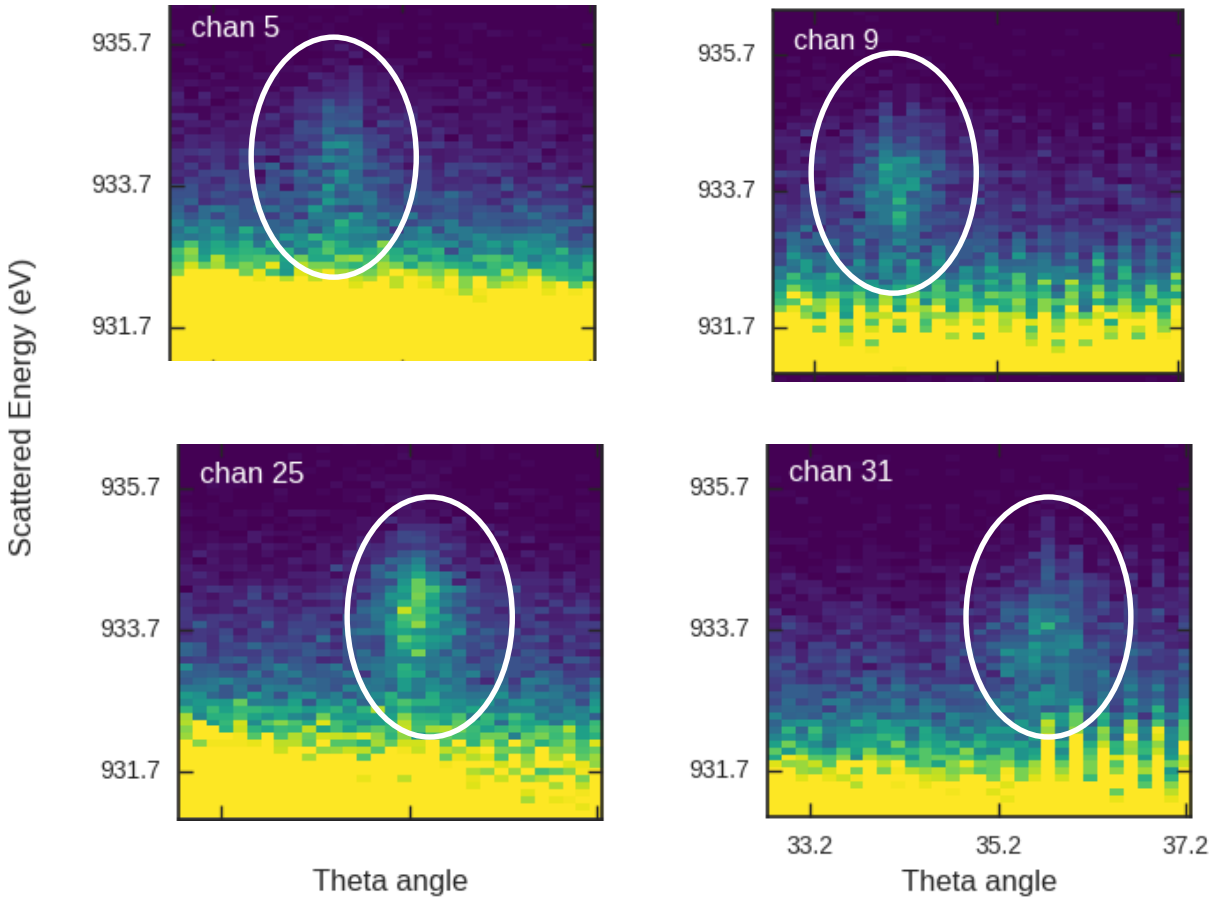
J. Chang et al. Nature Physics (2012)

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