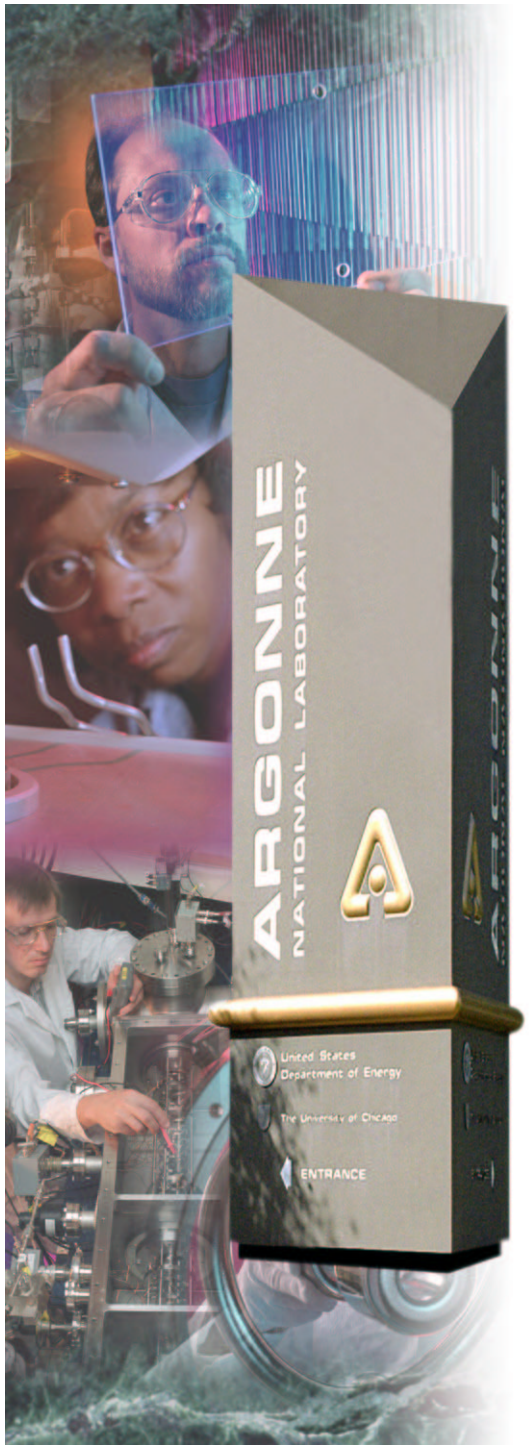


Inelastic X-ray Scattering with meV Resolution

Harald Sinn

Advanced Photon Source

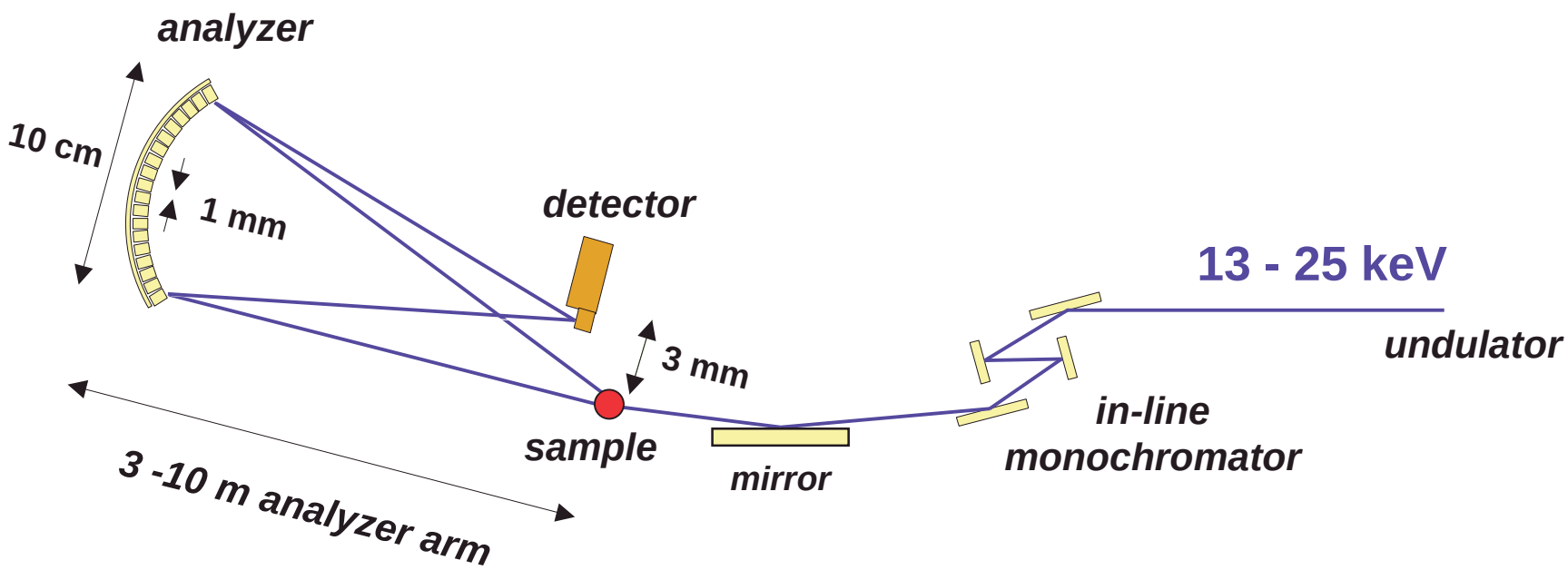
- ***Current meV Spectrometers***
- ***meV – IXS at NSLS II***

Argonne National Laboratory

Office of Science
U.S. Department of Energy

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Spectrometers for Inelastic X-ray Scattering

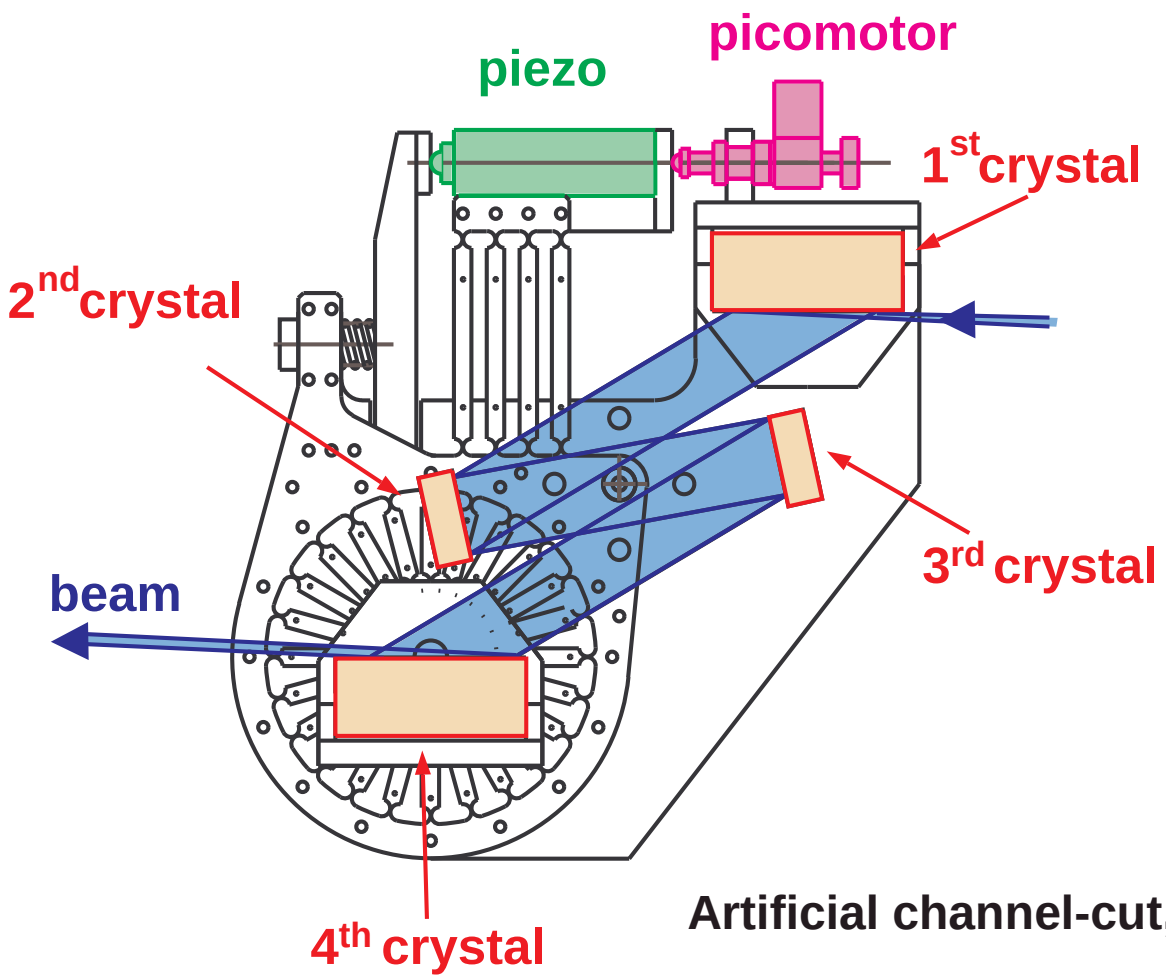


Energy resolution: 10 - 1 meV

$\delta E \sim 1/E^4$!

backscattering monochromator (ESRF, Sp8)

IXS-Monochromator



Resolution: 1.3 meV

Flux: 10^9 phts/sec

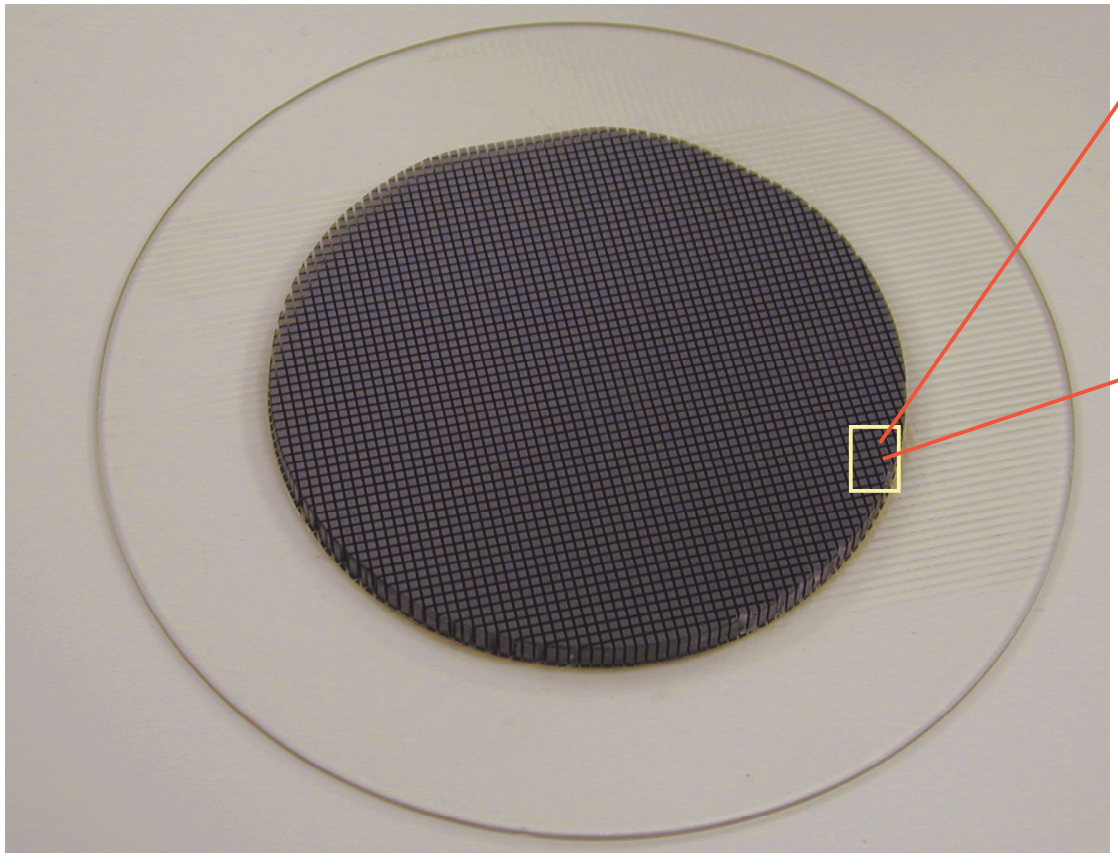
Tunable: 21.5-21.7 keV

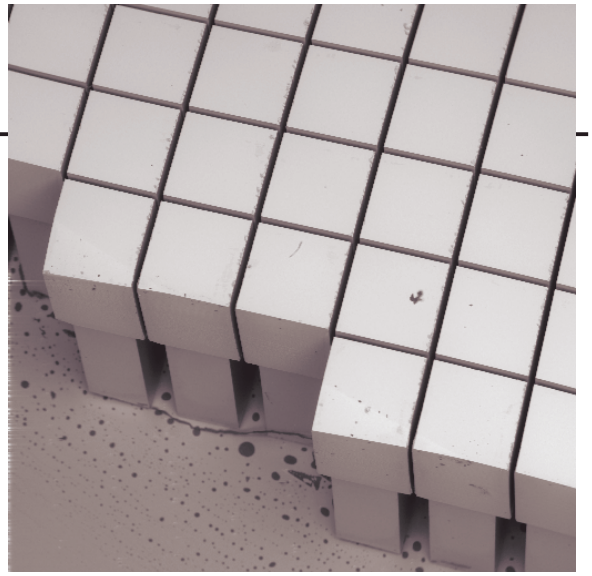
Similar monochromator for 0.9 meV @ 9 keV!

Artificial channel-cut, T. Toellner, D. Shu, APS

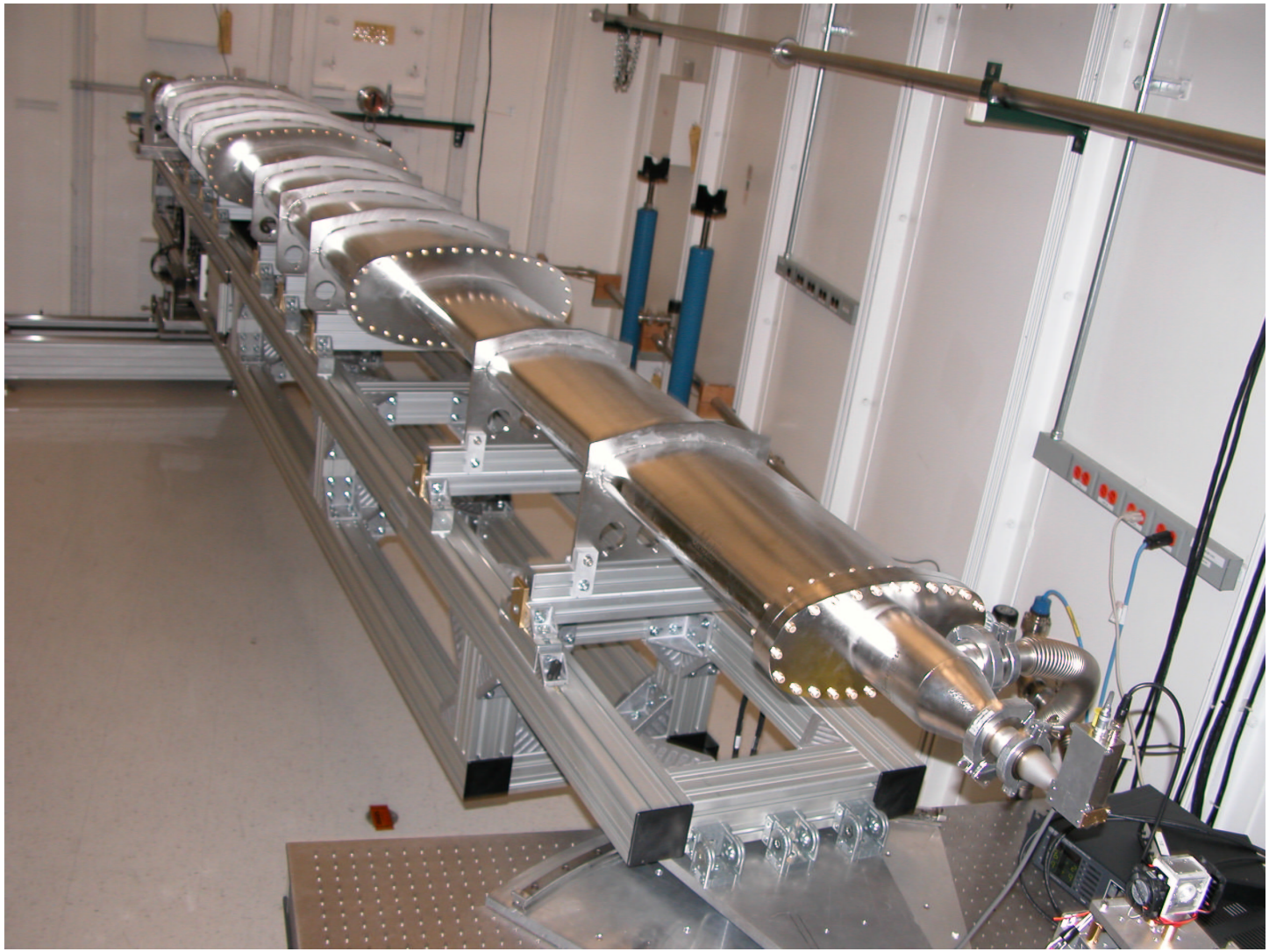
Analyzer disk

Diced and dynamically bent silicon substrate

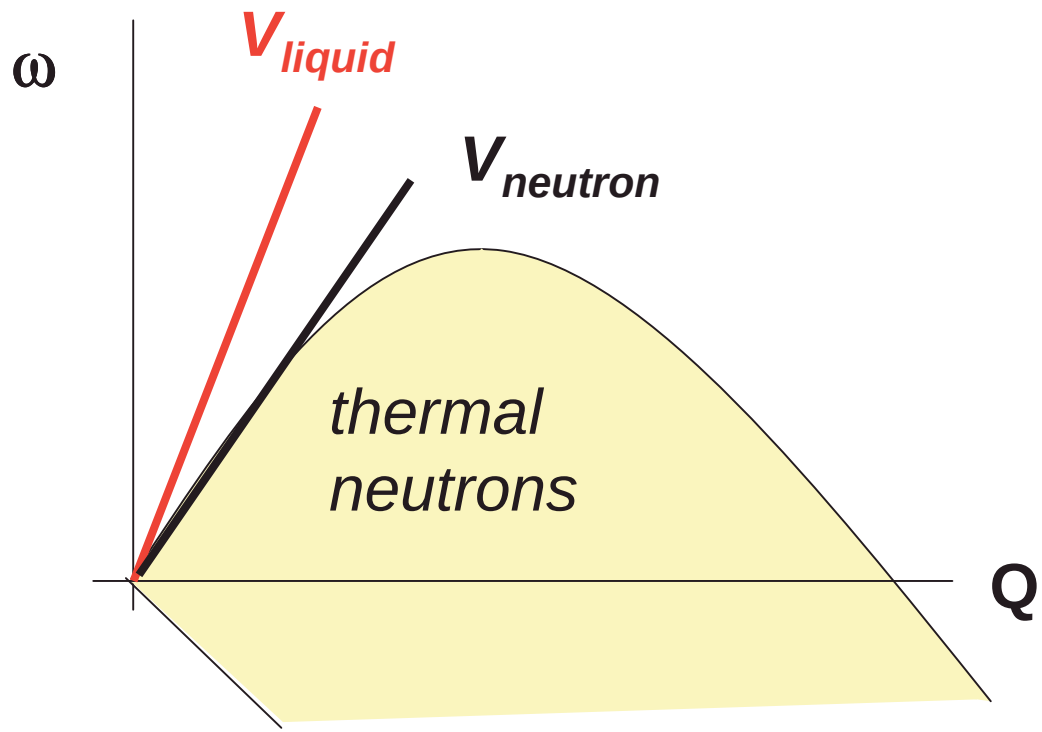




Inelastic spectrometer at APS, 3 IDC-C



Strengths of meV- IXS



- *small beam*
- *purely coherent*
- *high speed !*

Science with meV- IXS

Equivalence of sound velocity in water and ice at mesoscopic wavelength, Ruocco et al., Nature 1996.

Dynamics of glass and glass forming liquids: Sette et al., Science 1998.

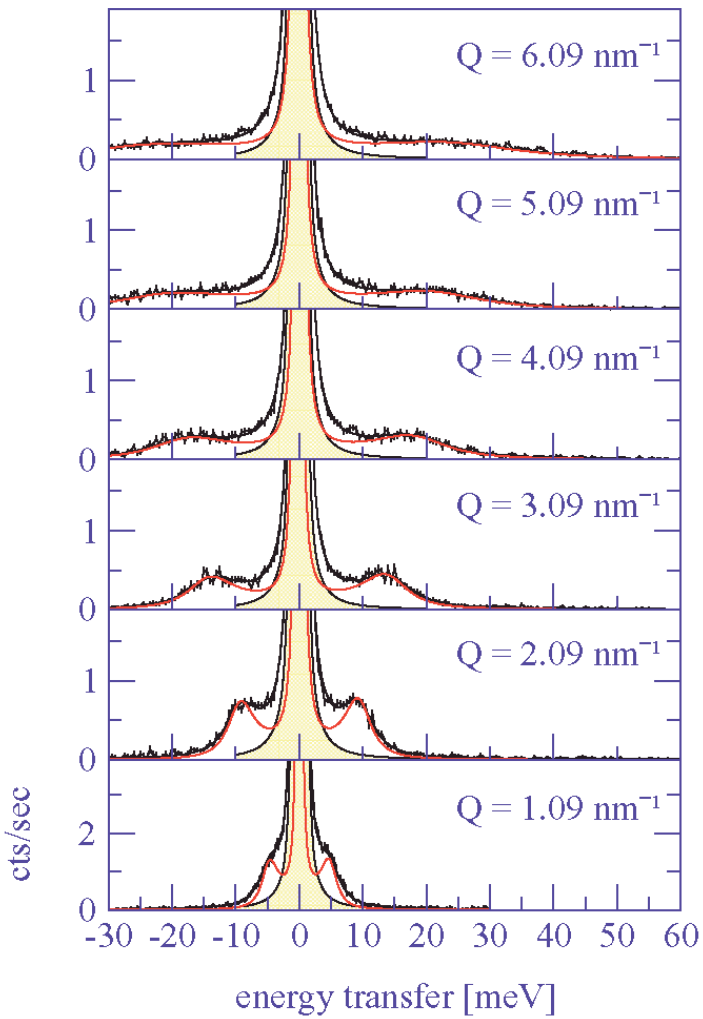
Sound velocities in Iron to 110 Gigapascals: Fiquet et al., Science 2001.

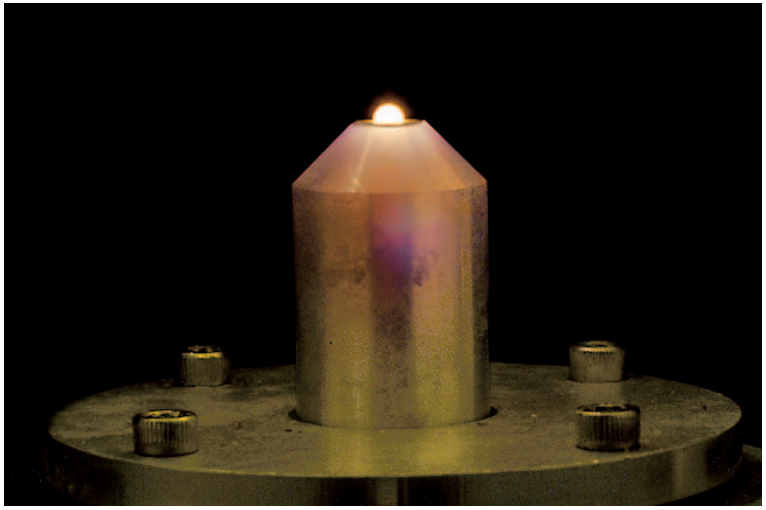
Microscopic Dynamics of Liquid Aluminum Oxide: Sinn et al., Science 2003.

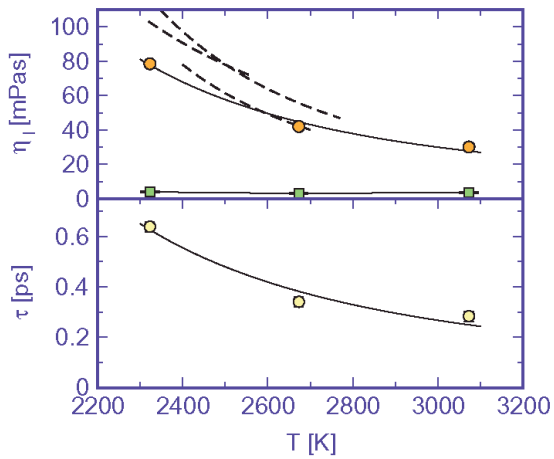
Phonon dispersion of fcc δ-Plutonium-Gallium by Inelastic X-ray Scattering, Wong et al. Science 2003.

Is the fragility of a Liquid Embedded in the Properties of its Glass? Scopignio et al., Science 2003.

Levitated Liquid Al_2O_3 @ 2050°C







H. Sinn, B. Glorieux, L. Hennet, A. Alatas, M. Hu, E. Alp, F. Bermejo, D. Price, M. Saboungi: Science, 299: 2047, 2003

1.8 meV, 21.6 keV

Phonons in MgB2

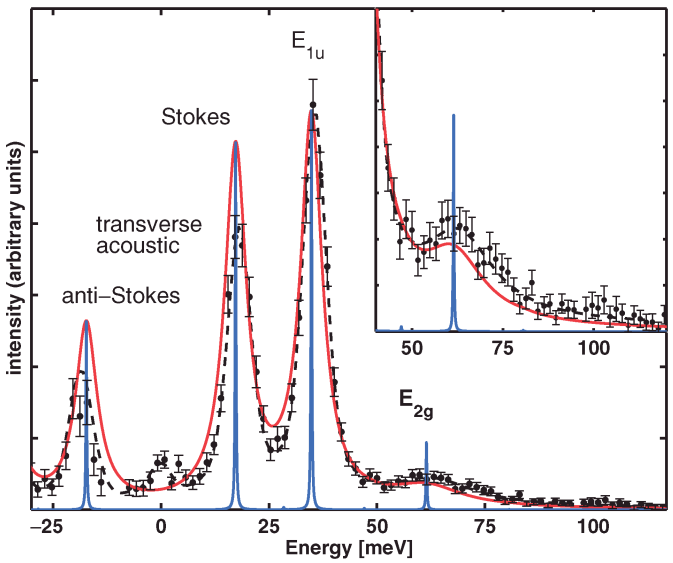
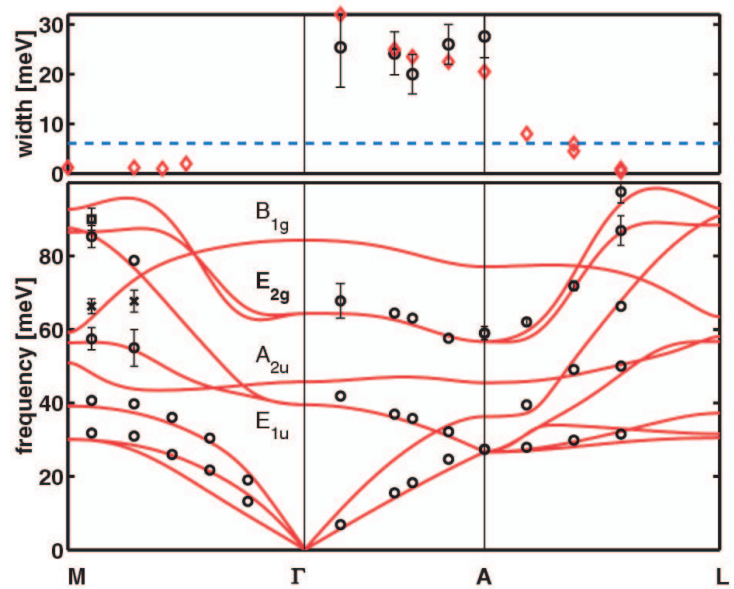


FIG. 1 (color online). Energy loss scan in almost transverse geometry measured at $\mathbf{Q} = (1\ 2\ 0.3)$ corresponding to 0.6 Γ-A. The data, normalized to the incident flux, are shown with the least-squares fit (dashed line) and the *ab initio* spectrum with and without broadening due to experiment and electron phonon coupling (solid lines). The broad peak corresponds to the damped E_{2g} mode and is shown in greater detail in the inset. The peak at zero is due to diffuse scattering.

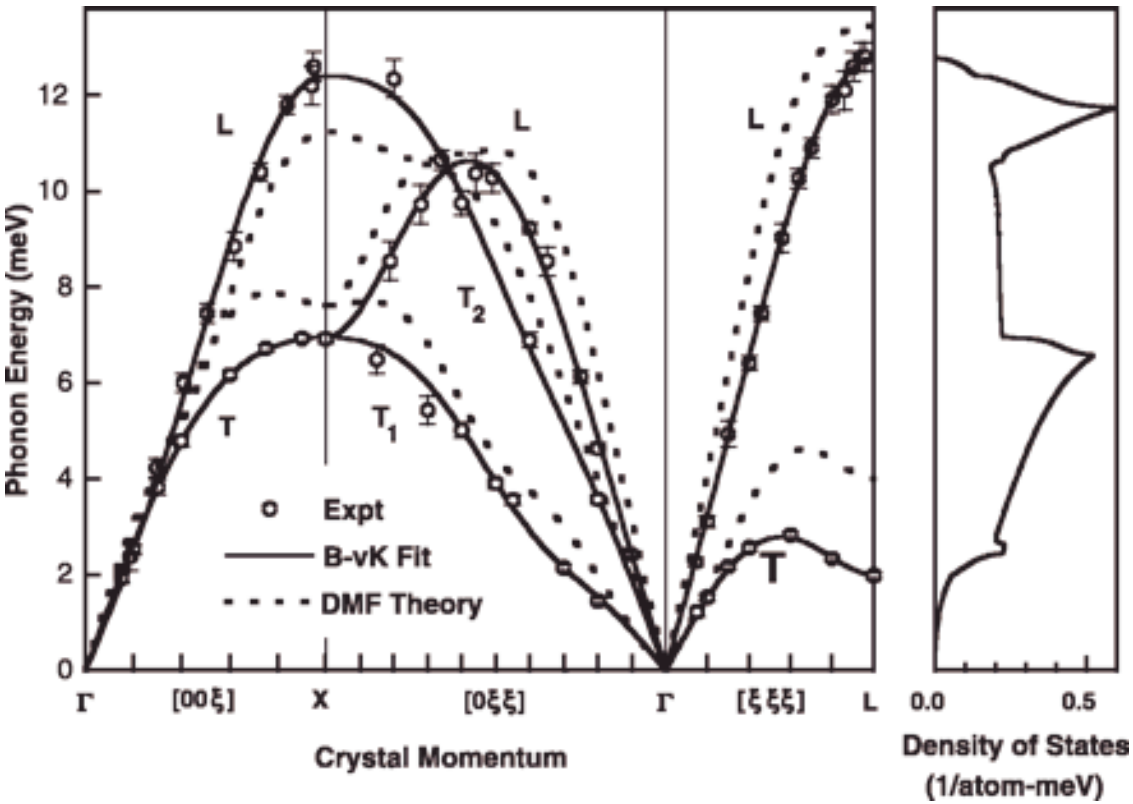


Crystal 400 x 400 x 40 µm

Energy resolution: 6 meV, 15.8 keV

A. Shukla et al., PRL 90, 095506 (2003)

Phonons in δ-Plutonium-Gallium



Polycrystalline foil

Grain size: 90 x 90 x 10 μm

Energy resolution: 1.8 meV

Energy: 21.7 keV

J. Wong et al., Science 301:1078 (2003)

meV-Spectrometers

Running	***ESRF:***	***2 spectrometers 1.5 – 10 meV***
	APS:	***1 spectrometer 2 meV***
	Spring8:	***1 spectrometer 2-6 meV***

Under construction:

APS IXS-CDT: 0.9 – 2 meV

Conceptual phase:

PETRA III: 0.5 – 3 meV

Diamond (?)

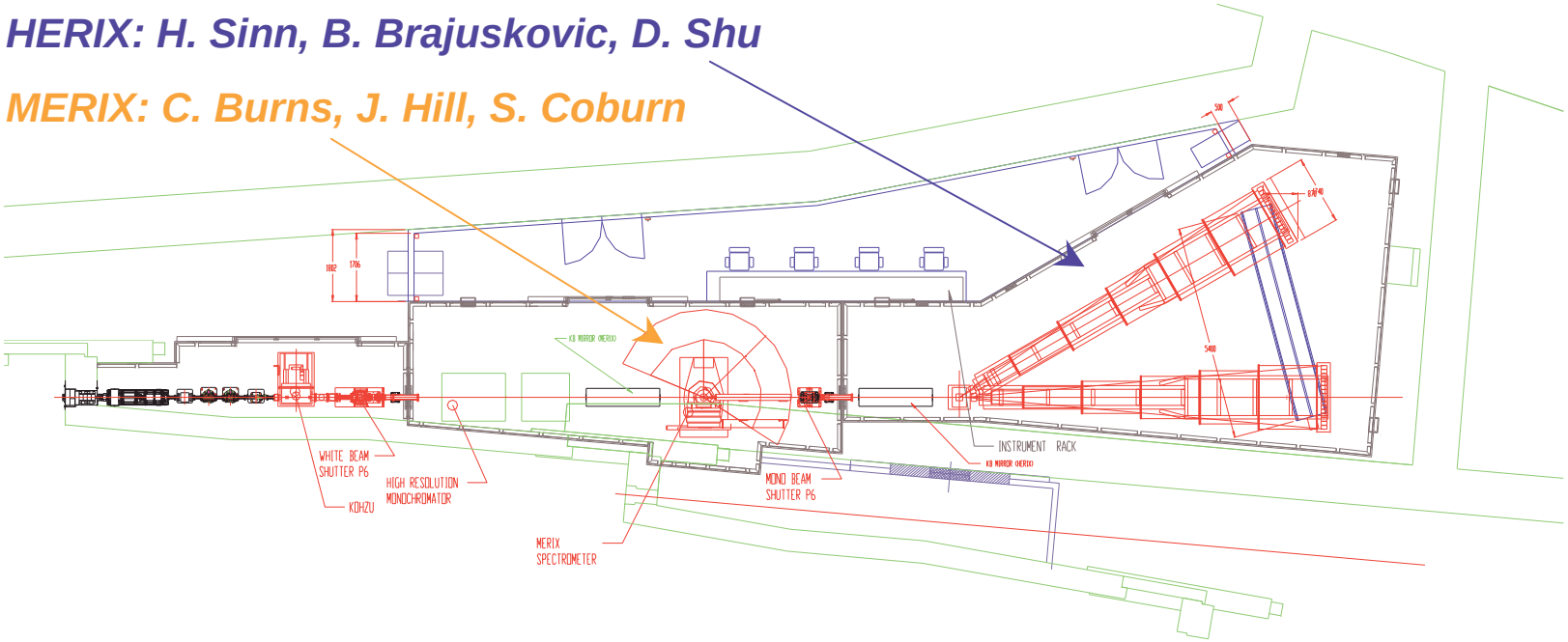
IXS- CDT: APS, Sector 30

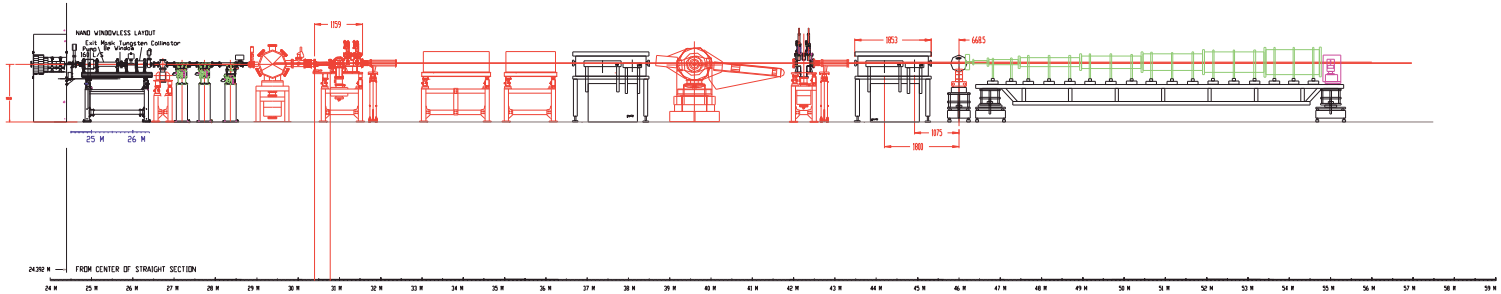
CDT directors: J. Hill (BNL), E. Alp (APS)

Project managers: Mohan Ramanahan, Yeldez Amer

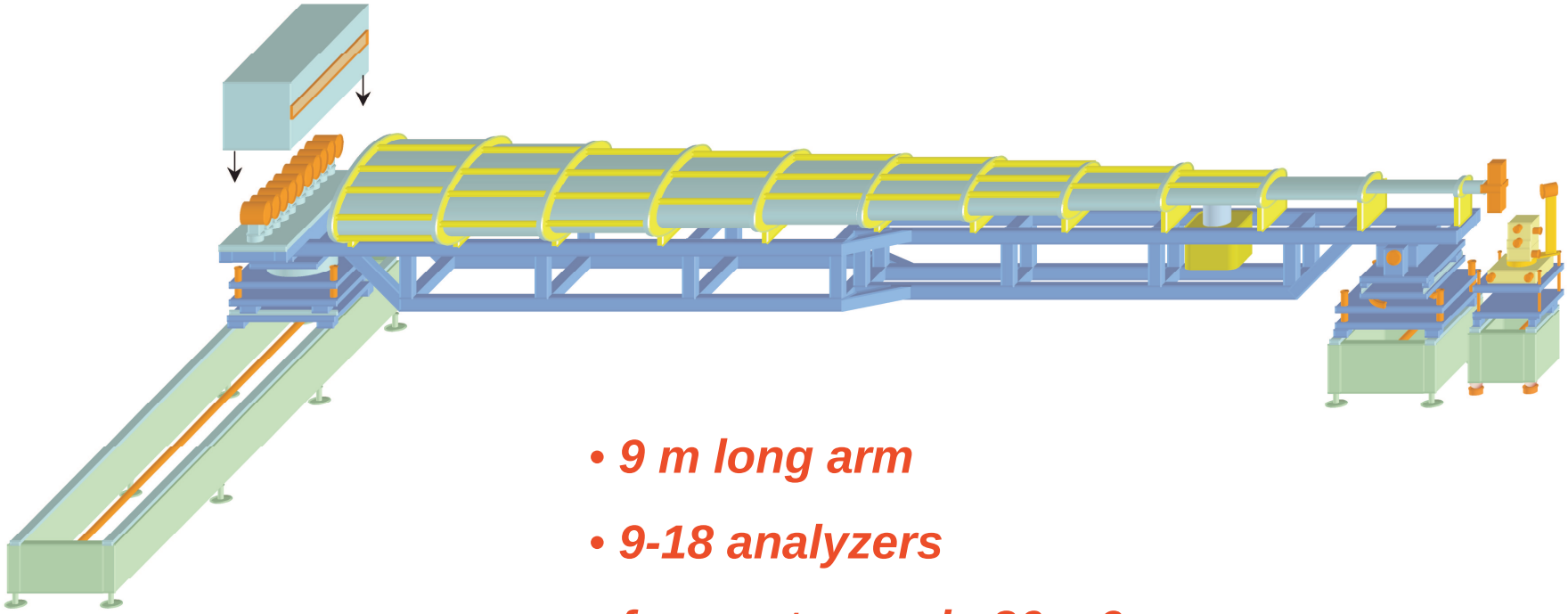
HERIX: H. Sinn, B. Brajuskovic, D. Shu

MERIX: C. Burns, J. Hill, S. Coburn





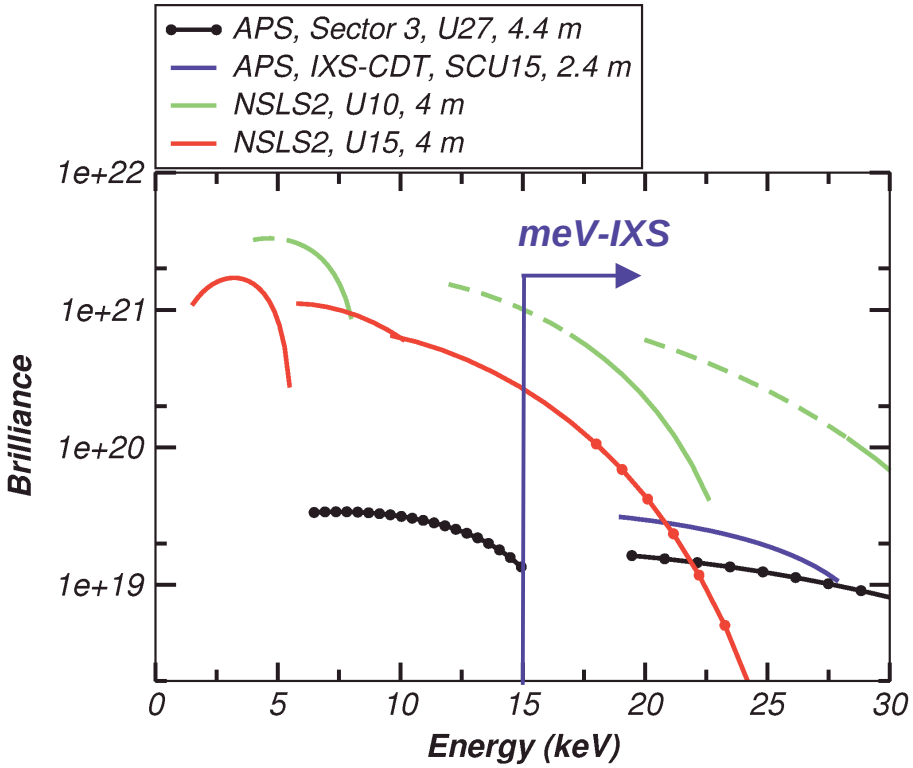
HERIX spectrometer: 0.9 meV

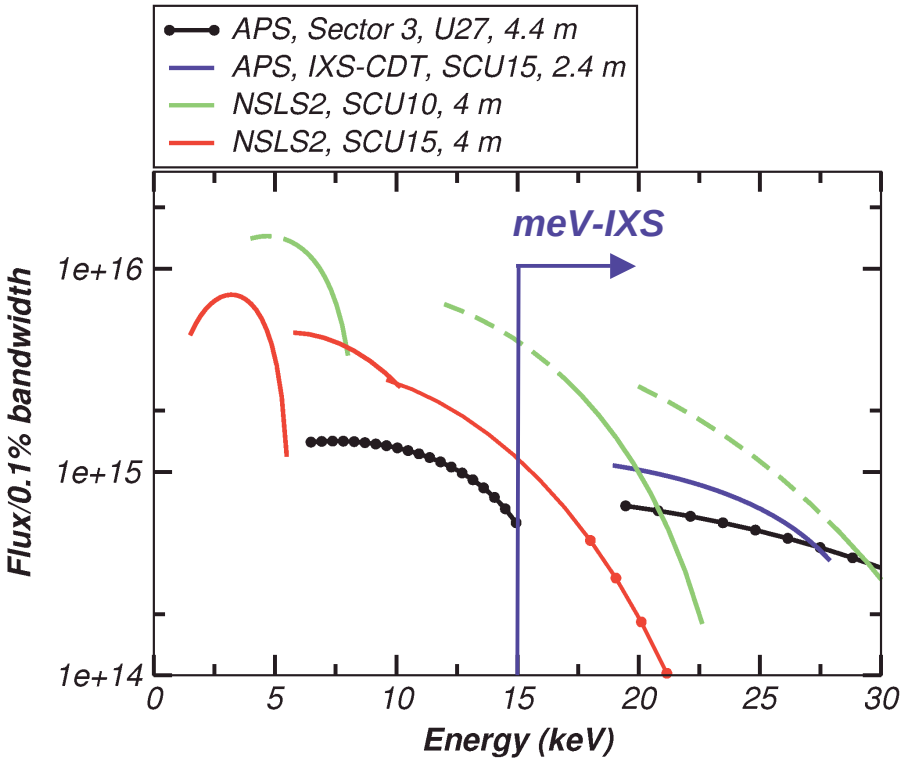


- *9 m long arm*
- *9-18 analyzers*
- *focus at sample 30 x 6 μm*
- *moved weight 6 tons*

IXS-CDT 2003

meV-IXS at NSLS-II





Permanent magnet

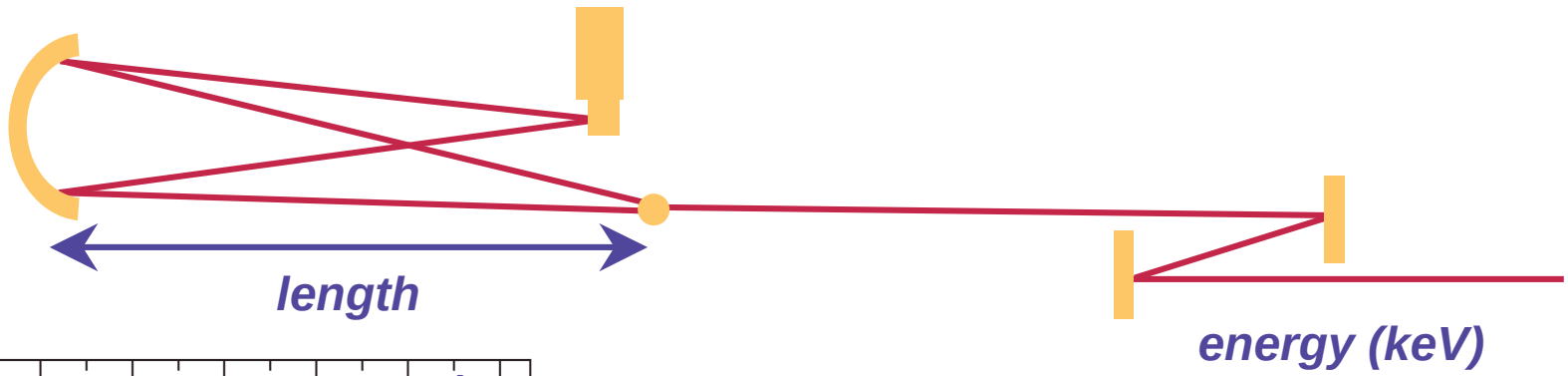
S.C. Undulator NbTi/Cu

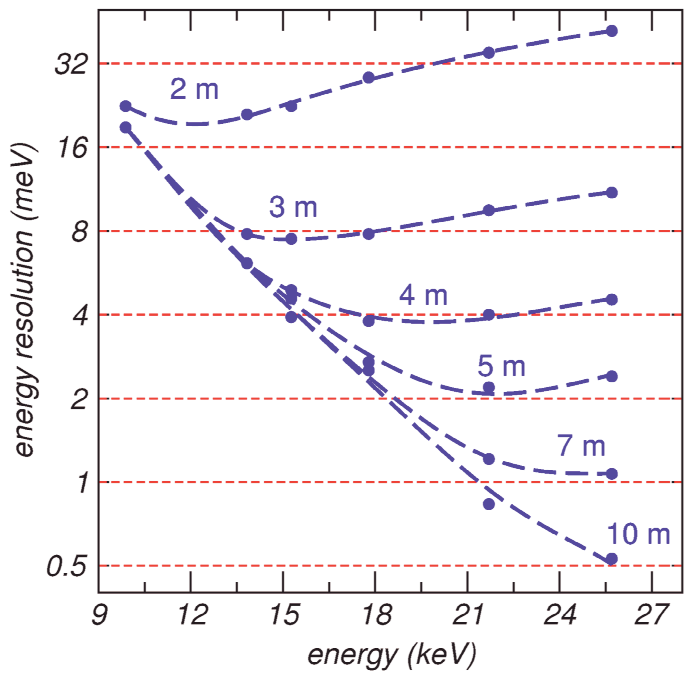
S.C. Undulator Nb_3Sn

APS: 7 GeV, 100 mA, 8mm gap

NSLS-2: 3 GeV, 500 mA, 5 mm gap

Energy resolution for different arm lengths



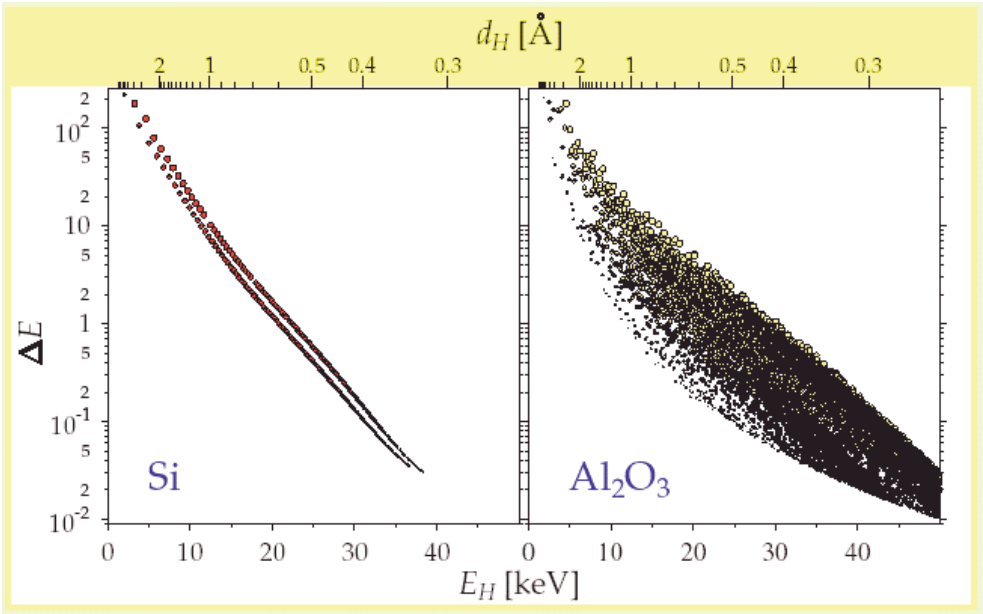


For E ≤ 20 keV:

5 m analyzer arm!

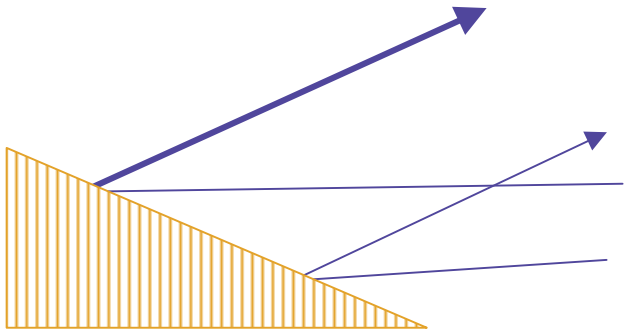
Analyzers with 1-2 meV @ 10 keV?

1. Sapphire



Courtesy: Y. Shvydko, Univ. Hamburg + E.E. Alp, H. Yavas, APS

2. Asymmetric silicon

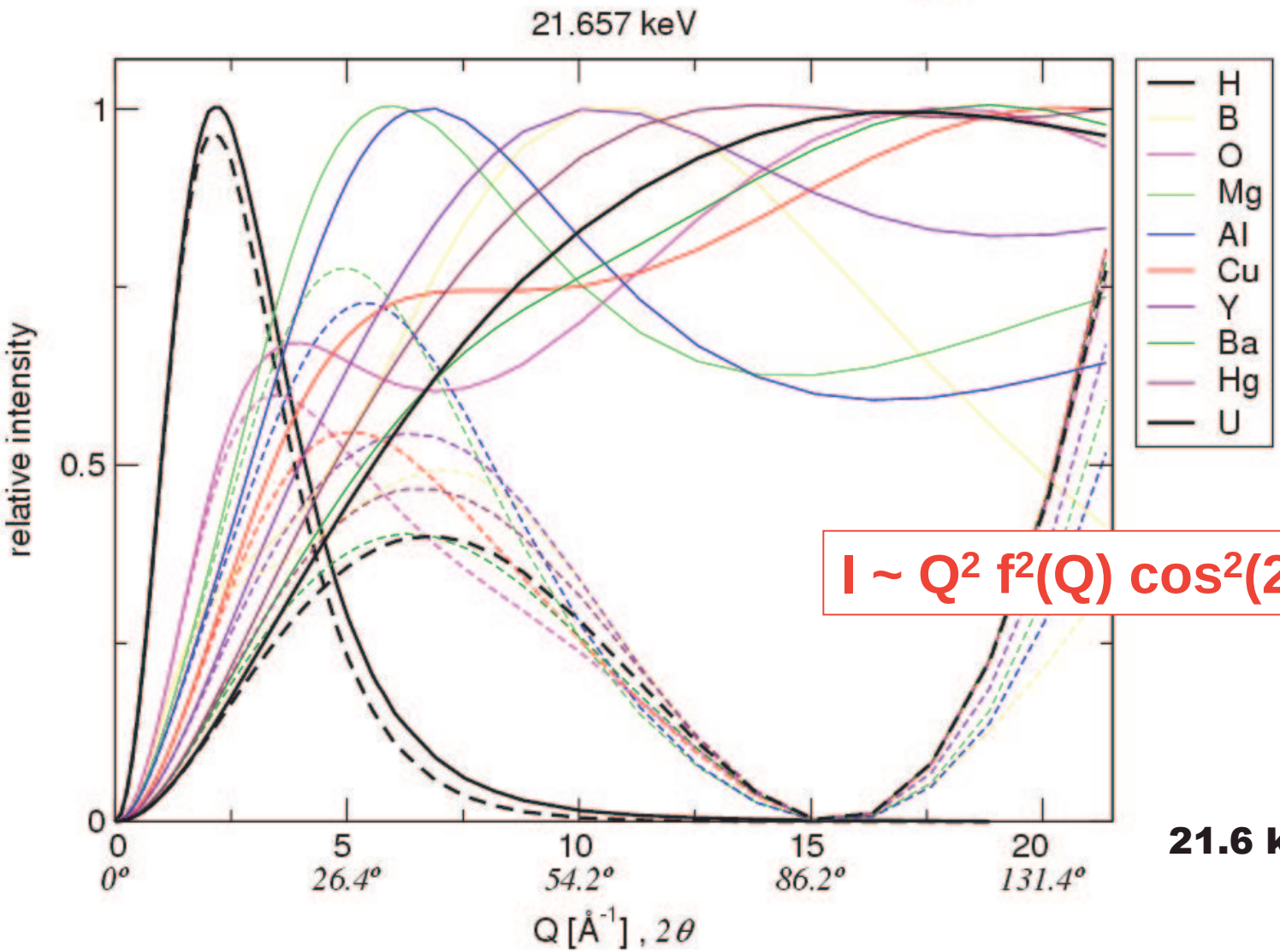


Y. Shvydko

Conclusions

- *NSLS-II very competitive in flux and superior in brilliance for E $\leq$20 keV.*
- *IXS spectrometer could be built with $\delta E \geq 2$ meV (maybe even better).*
- *Instead of glasses and liquids, phonons in micro-crystals!*
- *Instead of multiple analyzers, vertical scattering geometry with one (big) analyzers.*

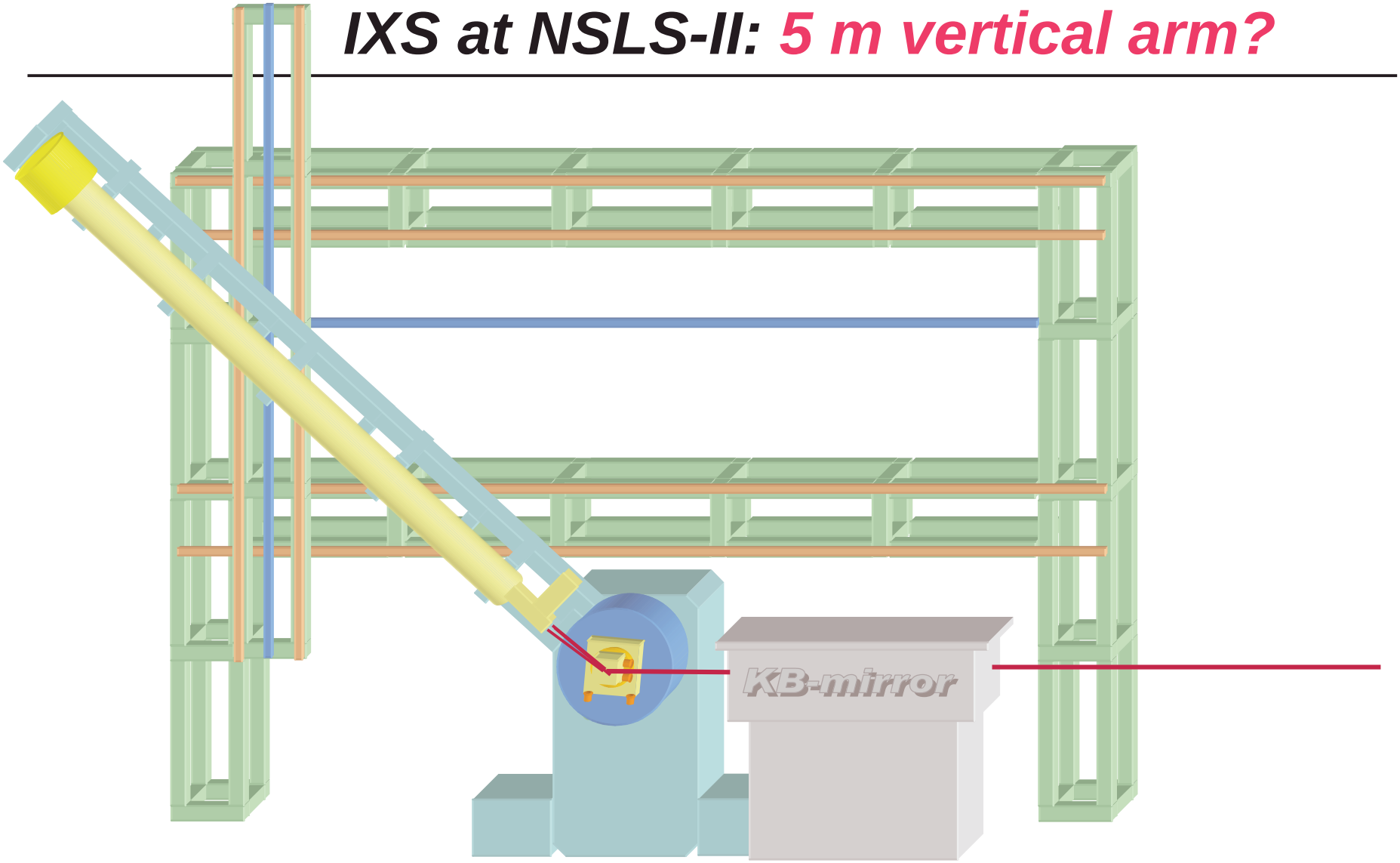
Vertical versus horizontal scattering plane



$$I \sim Q^2 f^2(Q) \cos^2(2\theta)$$

21.6 keV

IXS at NSLS-II: 5 m vertical arm?

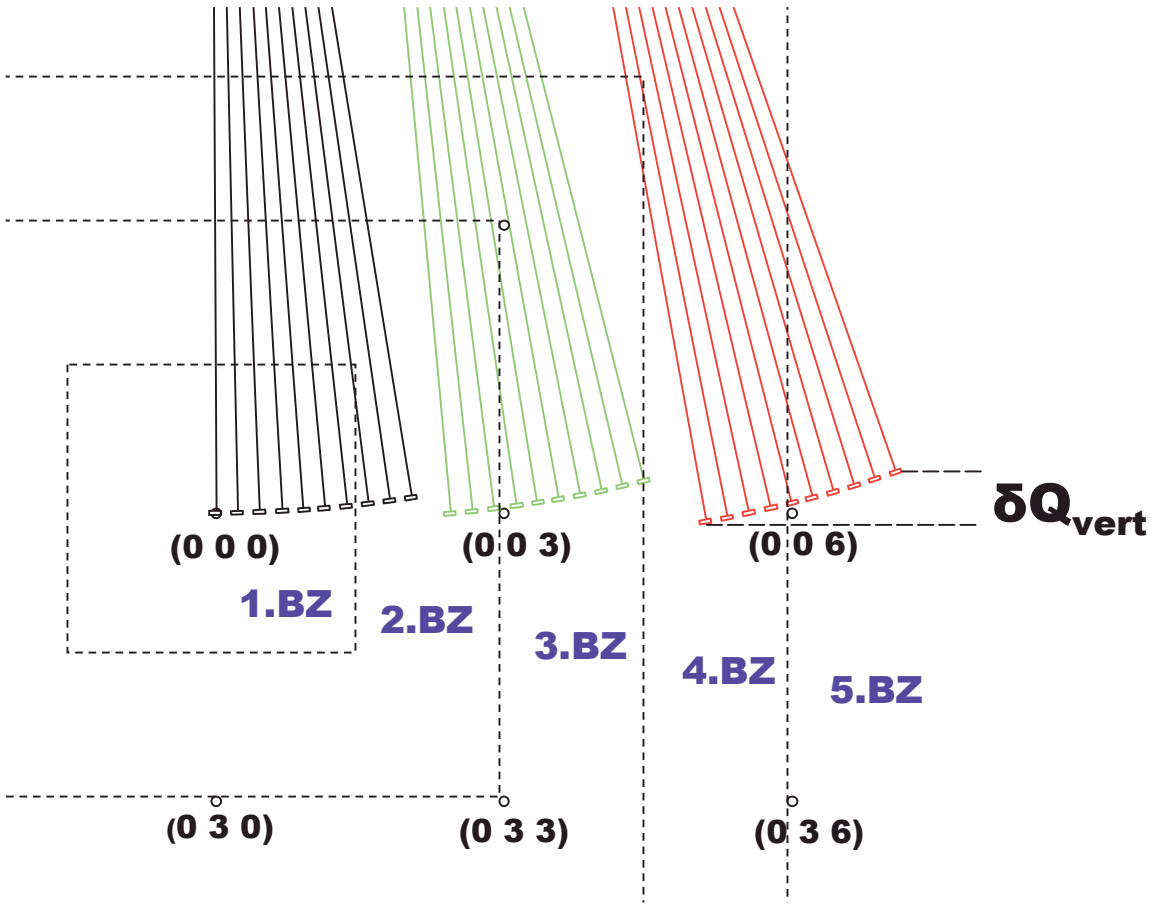


Multiple analyzers for single crystals?

1 analyzer:

$\delta Q = 0.13$ Å^{-1}

10 analyzers:

$\delta Q_{vert} = 0.16$ Å^{-1}

... 0.9 Å^{-1}