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A 1-D Imaging RIXS Spectrometer for Ultra-fast Phenomena and NonLinear Science at European XFEL

Joseph Nordgren
Dept. of Physics and Astronomy, Uppsala University, Sweden

Outline

- RIXS tutorial and scientific opportunities
- Experimental considerations
- The proposed instrument

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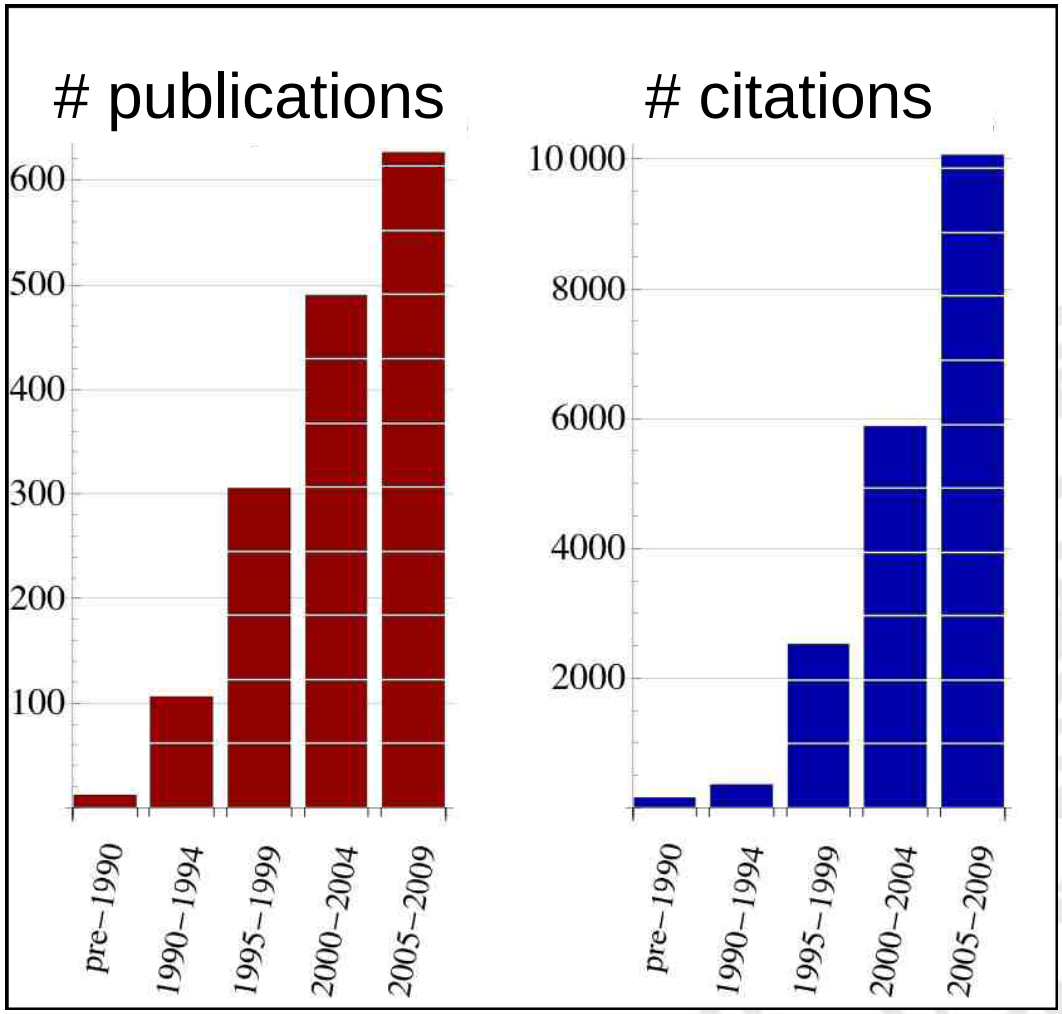
RIXS publication rates



L.J.P Ament, *et al*, arXiv:1009.3630v2

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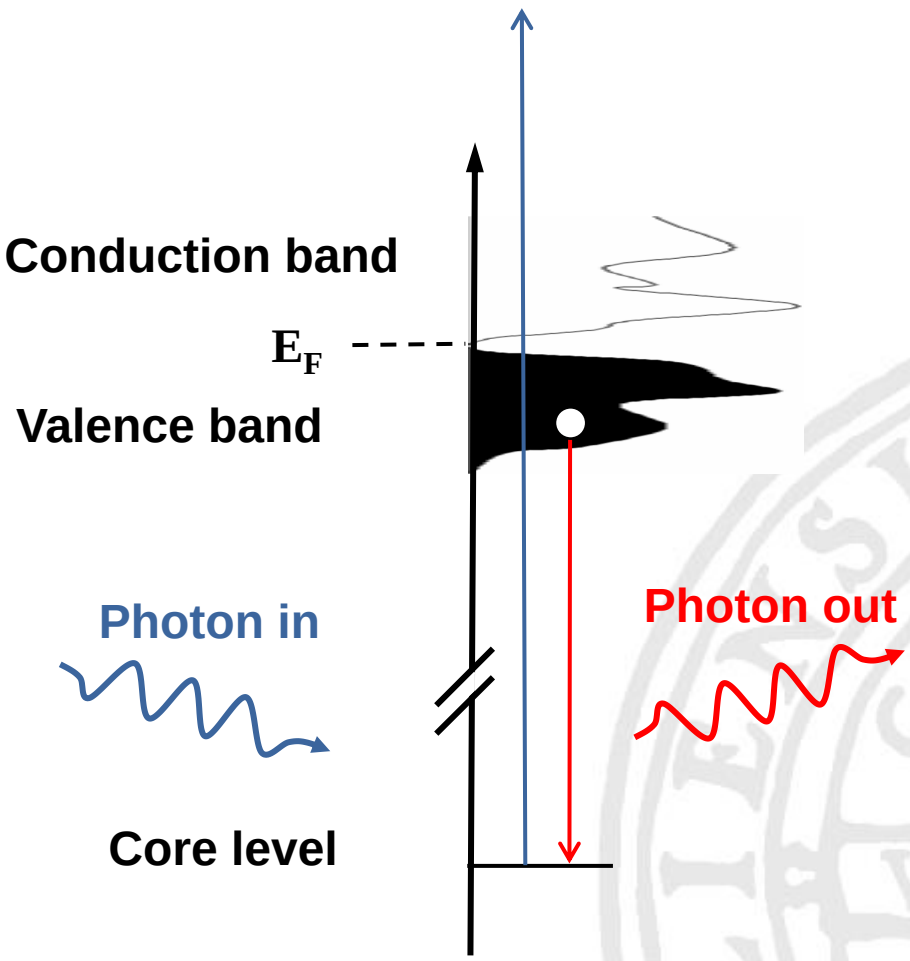
Valence-Core X-ray Spectroscopy



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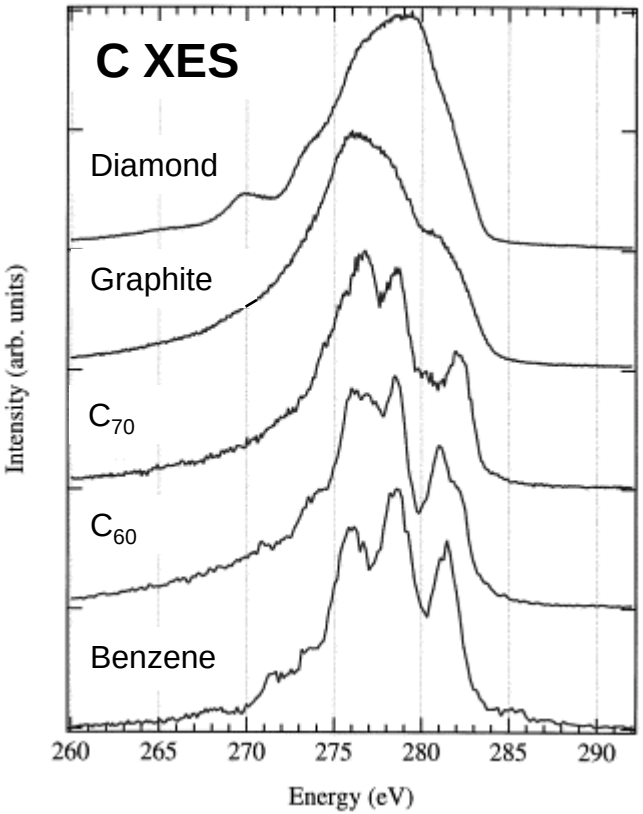
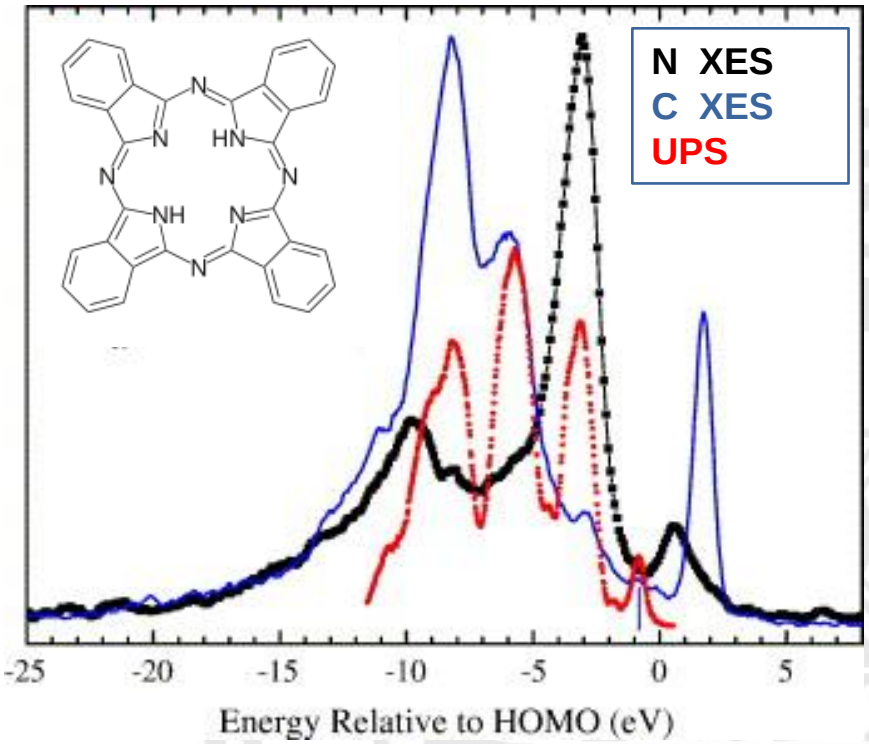
Examples
Valence-Core X-ray Emission

Carbon allotropes



J. Guo and J.Nordgren, *J. Electr. Spectr*. 110–111, 105-134 (2000)

Phthalocyanines



Y. Zhang *et al.,Thin Solid Films*, **515**, 394–400 (2006)

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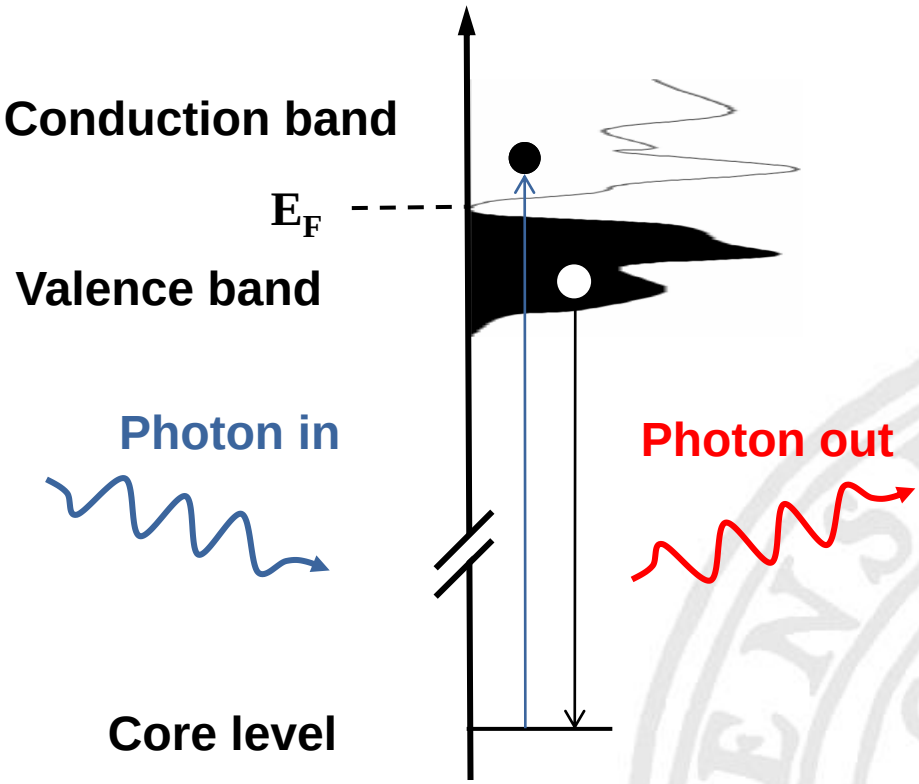
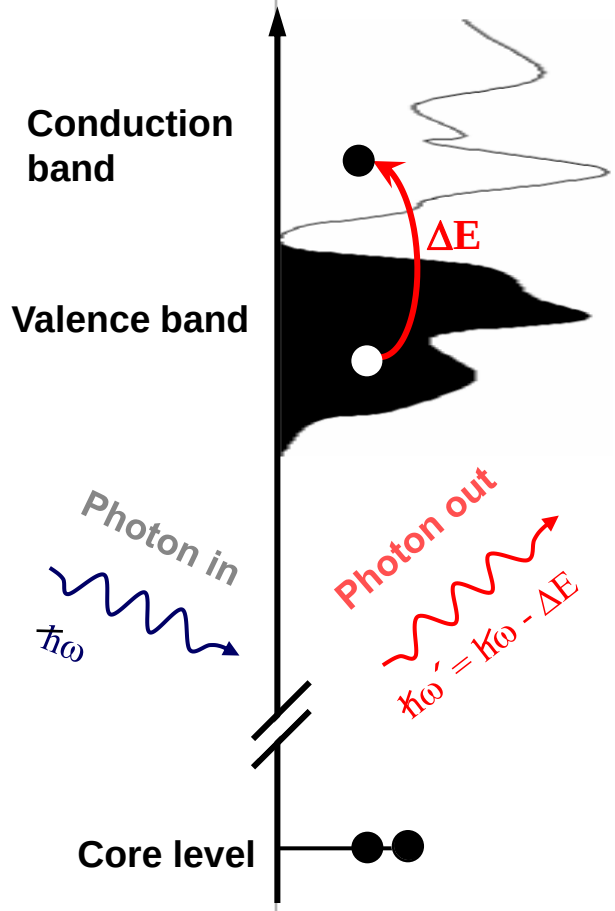
Resonant X-ray emission



Resonant Inelastic X-ray Scattering (RIXS)



Inelastic scattering cross section (*Kramers-Heisenberg* formula)**:**

$$F(\omega,\omega') = \sum_f \left| \sum_m \frac{\langle f|D|m\rangle\langle m|D|g\rangle}{E_g + \hbar\omega - E_m - i\Gamma_m} \right|^2 \delta(E_g + \hbar\omega - E_f - \hbar\omega')$$

Features of RIXS spectra:

- **Site selectivity**
- **Symmetry selectivity**
- **Probing of low-energy excitations**
- **Sub-natural width spectra**
- **Ultra-fast dynamics**
- **Bulk and buried structures**
- **Band dispersion**

Review: J. Nordgren *et al*., in *Handbook of Solid State Spectroscopy*, Springer 2006, Ed. W.R. Wij

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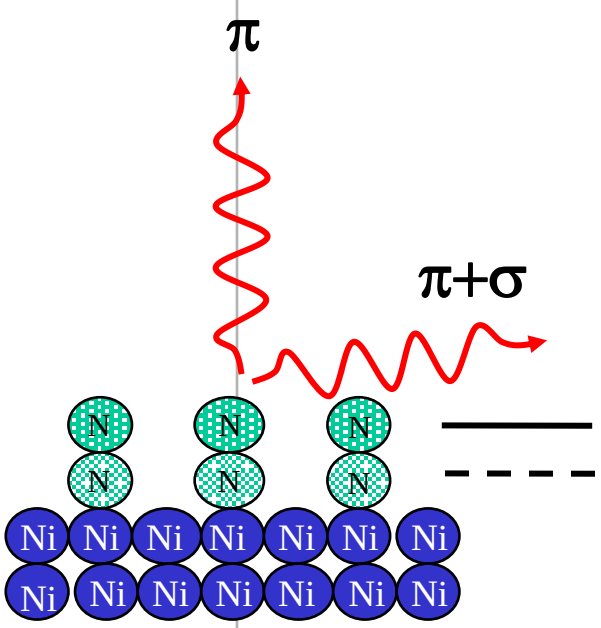
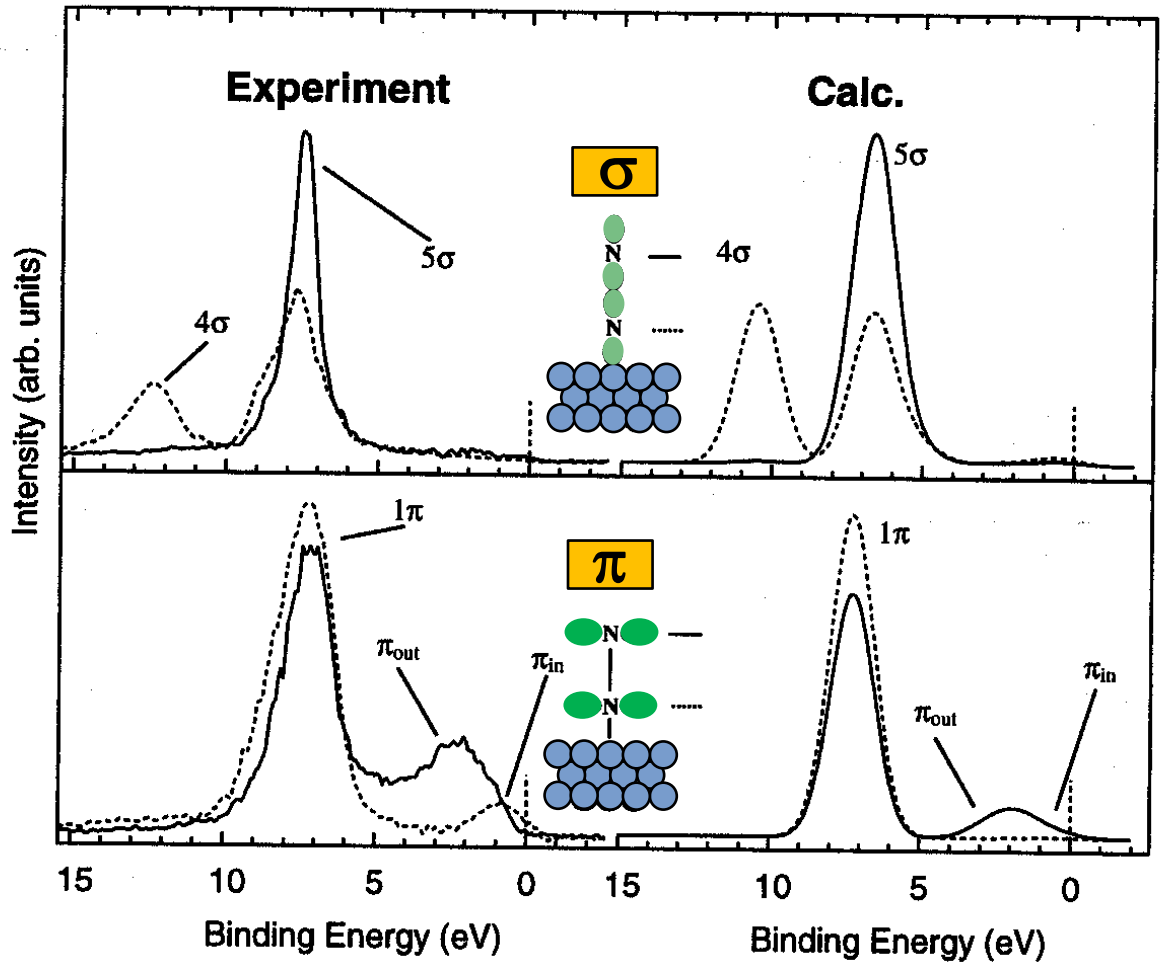
Site and Symmetry Selectivity in Resonant X-ray emission





A. Nilsson, *et al*, *Surf. Sci. Rep.*, **55**, 49 (2004)

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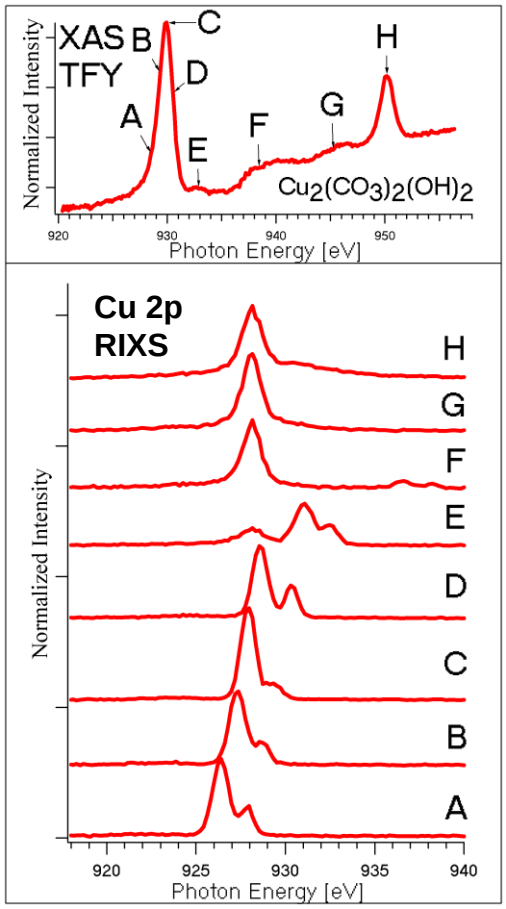
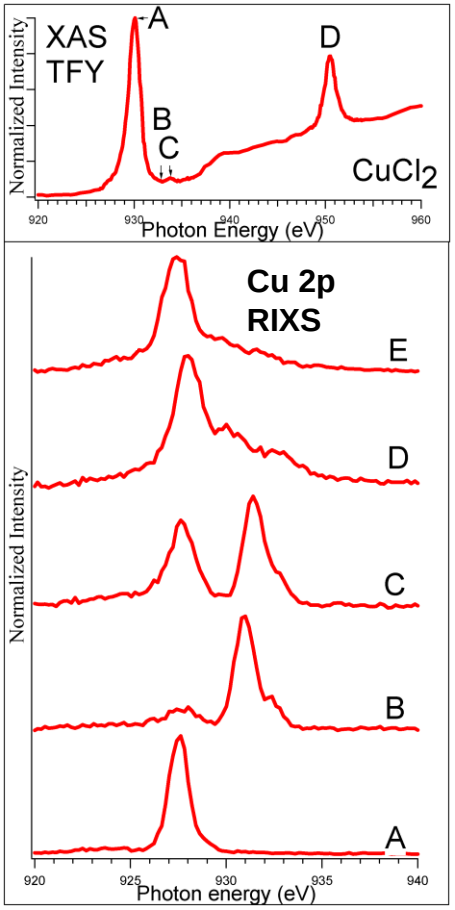
Analysis Capability of RIXS for Cu compounds

Malachite



$CuCl_2$



K. Kvashnina, *et al*, J. Phys. Cond. Mat. 19, No. 226002 (2007)

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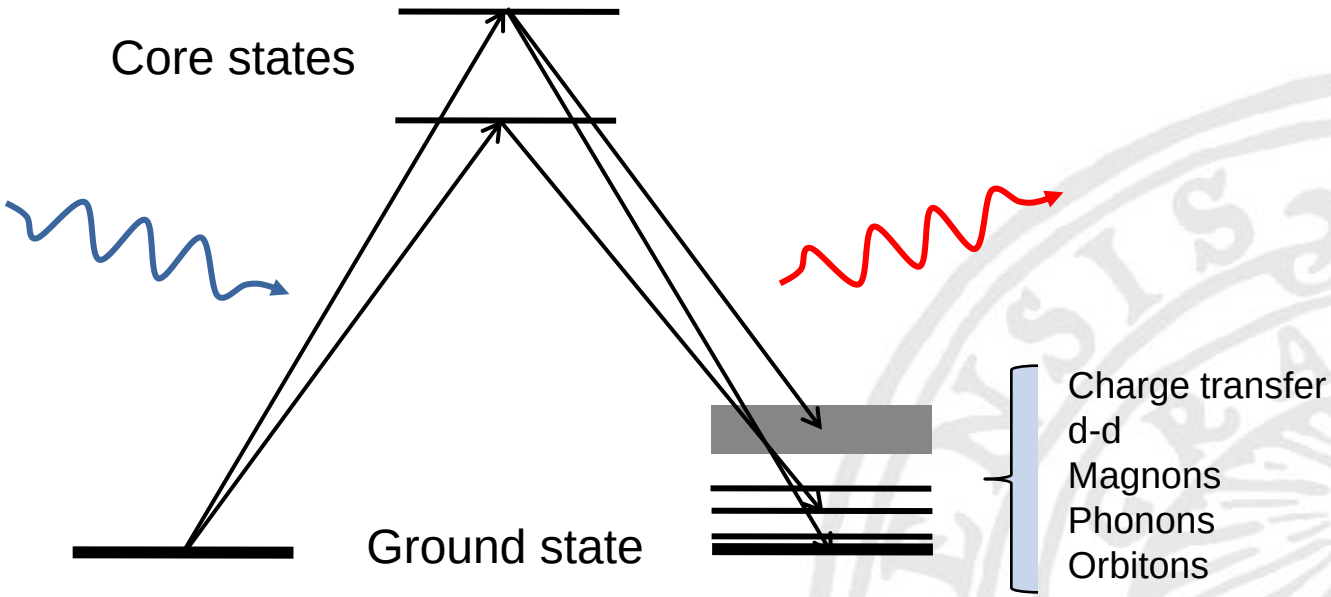
Elementary Excitations in Strongly Correlated Materials

$$F(\omega,\omega') = \sum_f \left| \sum_m \frac{\langle f|D|m\rangle\langle m|D|g\rangle}{E_g + \hbar\omega - E_m - i\Gamma_m} \right|^2 \delta(E_g + \hbar\omega - E_f - \hbar\omega')$$



For original work, see e.g., S. Butorin, *et al.*, *Phys. Rev. Lett.*, **77**, 574 (1996)
For excellent review, see L.J.P. Ament, *et al.*, *Rev.M od..Phys.*, **83**, No.2 (2011)

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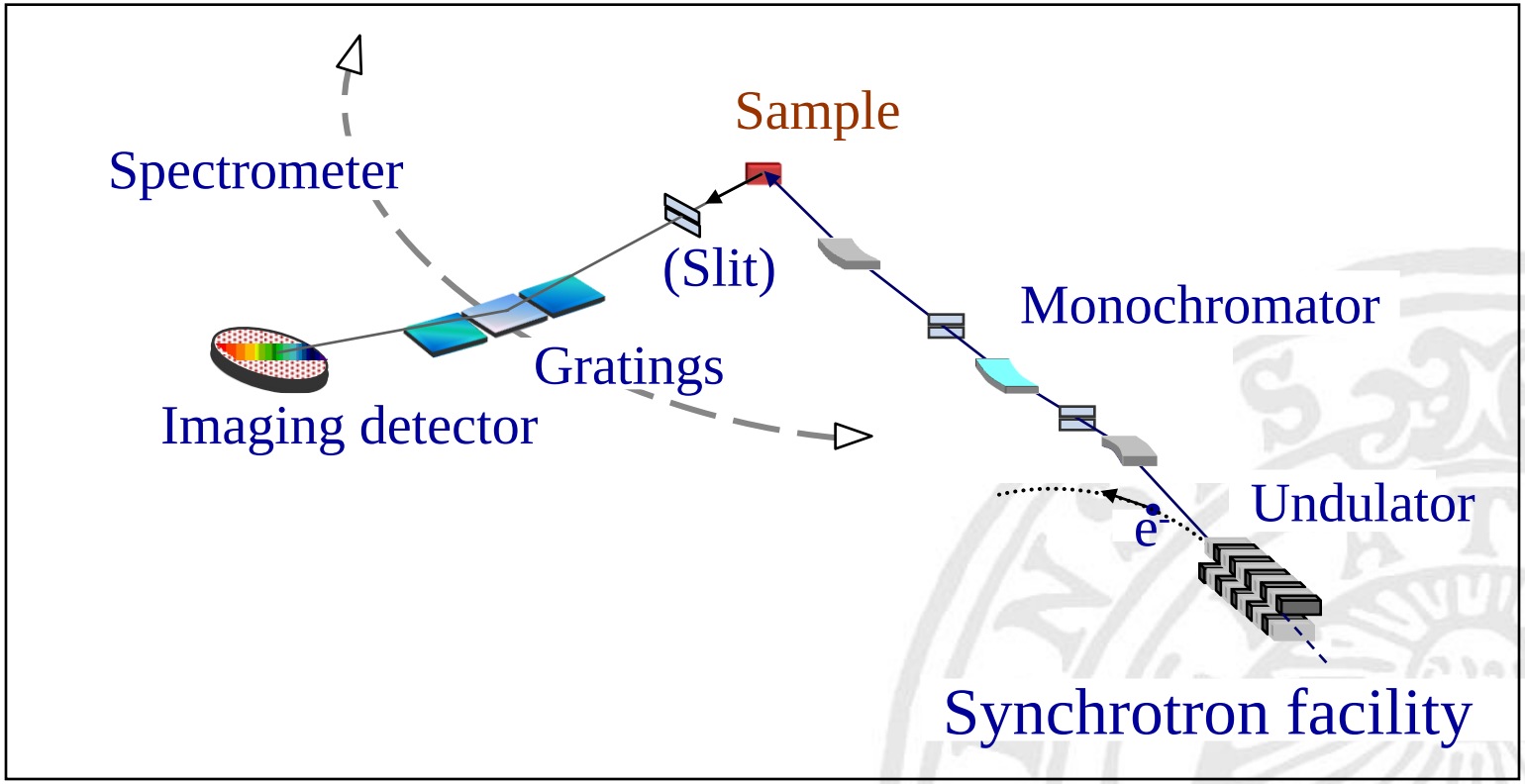
Experimental setup for RIXS



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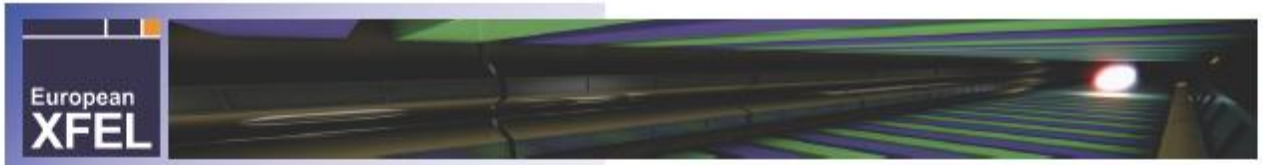
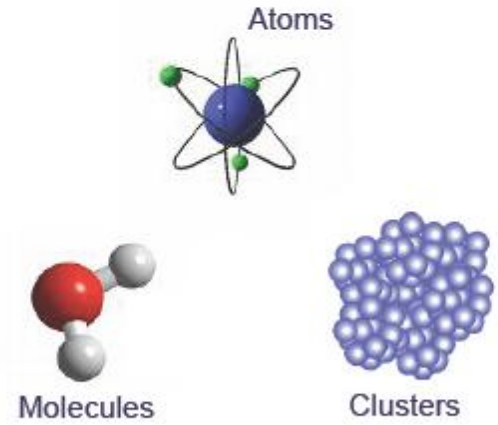


The SQS - Scientific Instrument at the European XFEL

M. Meyer, European XFEL GmbH

"Small Quantum Systems"



Joint Instrumentation Seminar, November 11, 2011

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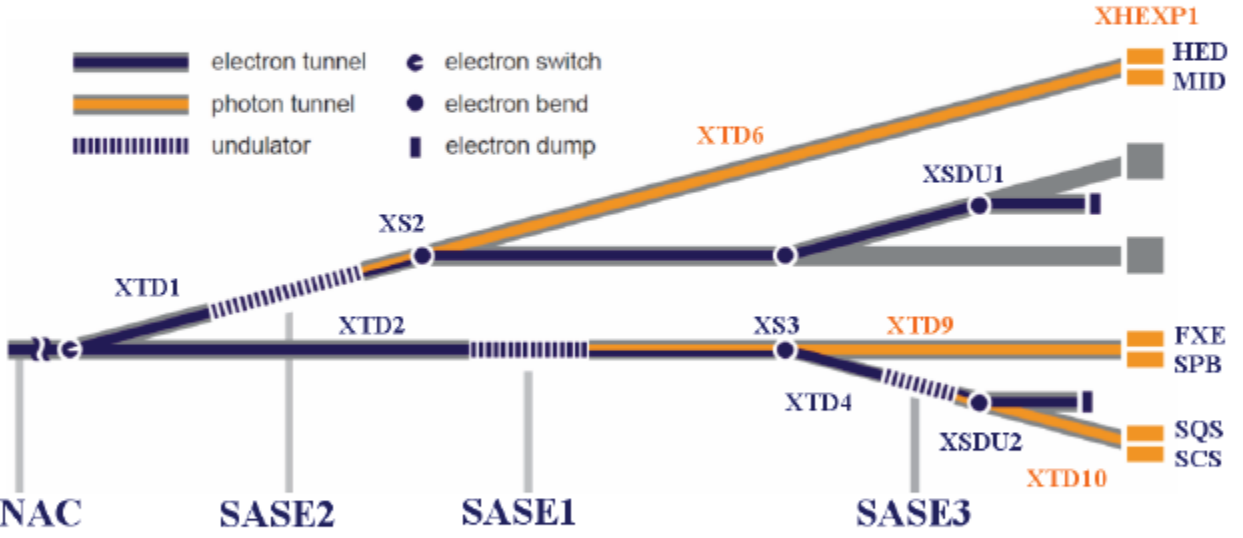
SQS Scientific Instrument

European XFEL

Photon beam transport systems



SQS – Small Quantum Systems –

Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena

High intensities: $>10^{15}$ W/cm^2	⇨	**Non-linear phenomena, multi-photon**
Short pulses: 2 - 100 fs	⇨	**Ultra-fast dynamics, pump-probe**
High flux $> 10^{12}$ photons / pulse $> 10^{15}$ photons / sec	⇨	**Extremely dilute targets,** **Processes with small cross section**
Spatial coherence	⇨	**Coherent Diffraction Imaging**
Soft X-Ray photon energies	⇨	**Threshold phenomena** C(1s)=290 eV, N(1s)=410eV, O(1s)=560eV

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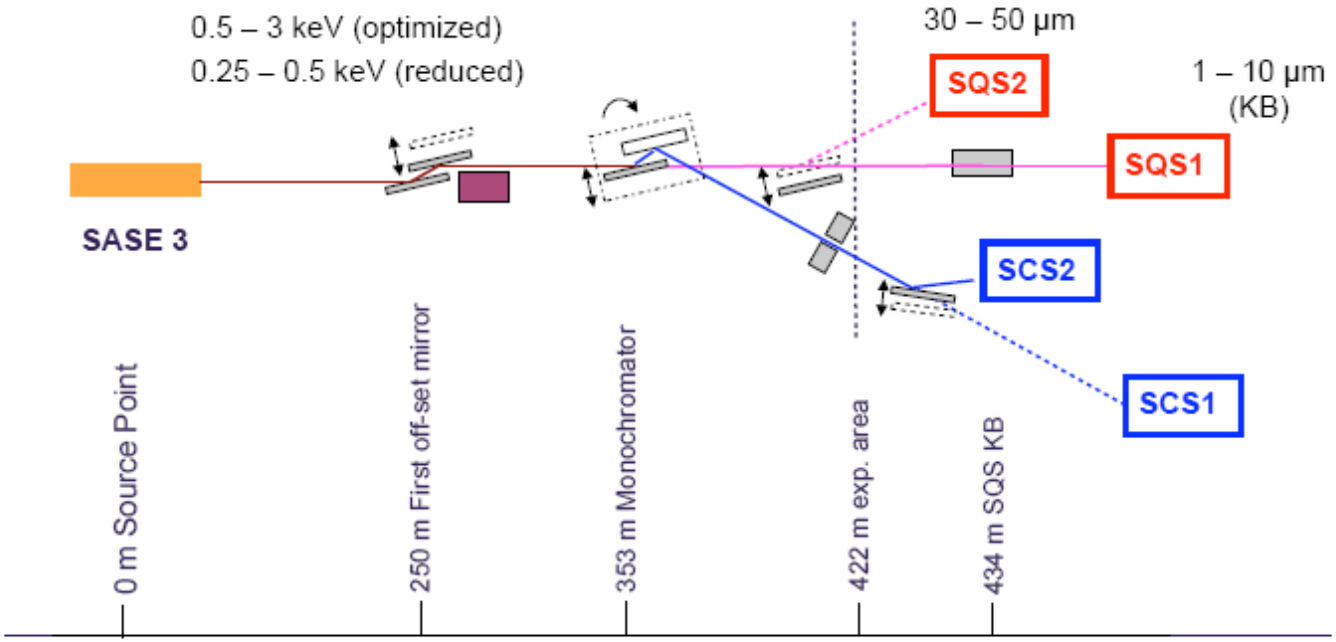
SQS Scientific Instrument

European XFEL

Optical layout of the beam transport system (H. Sinn)

- direct beam → Small Quantum System (SQS)
- monochromatized → Spectroscopy @ Coherent Scattering (SCS)



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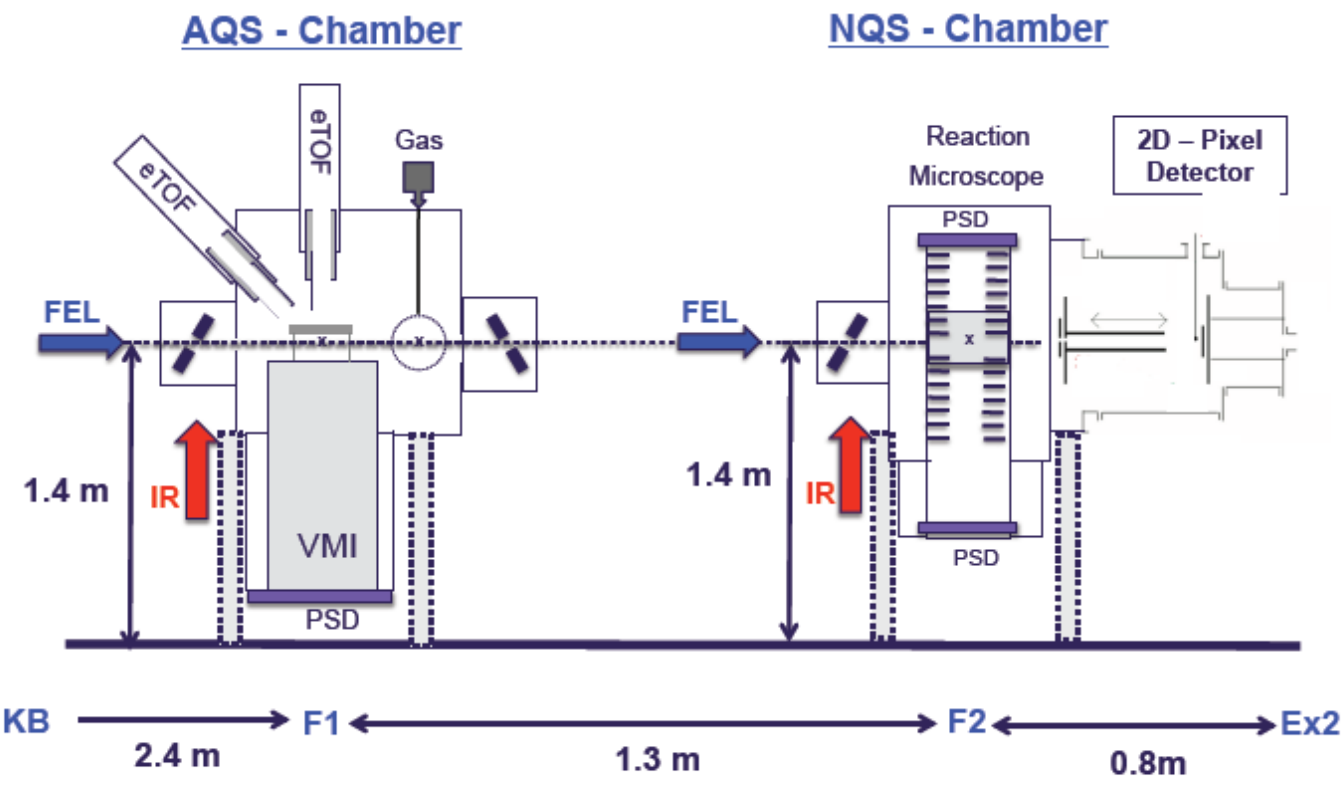
SQS Scientific Instrument

European XFEL

SQS end-station



M. Meyer, Joint Instrumentation Seminar, November 11, 2011

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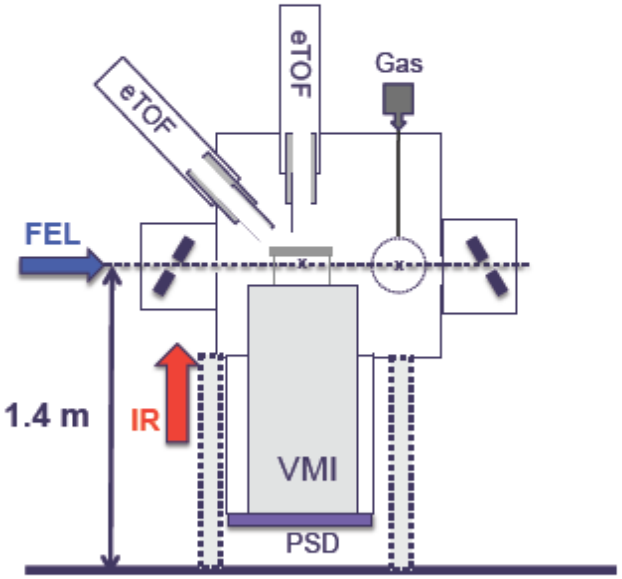
European XFEL

SQS Scientific Instrument

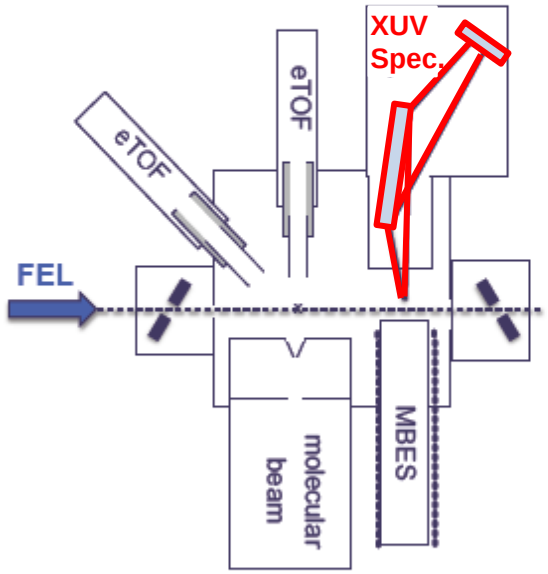
SQS end-station

AQS - Chamber

(side view)



(top view)



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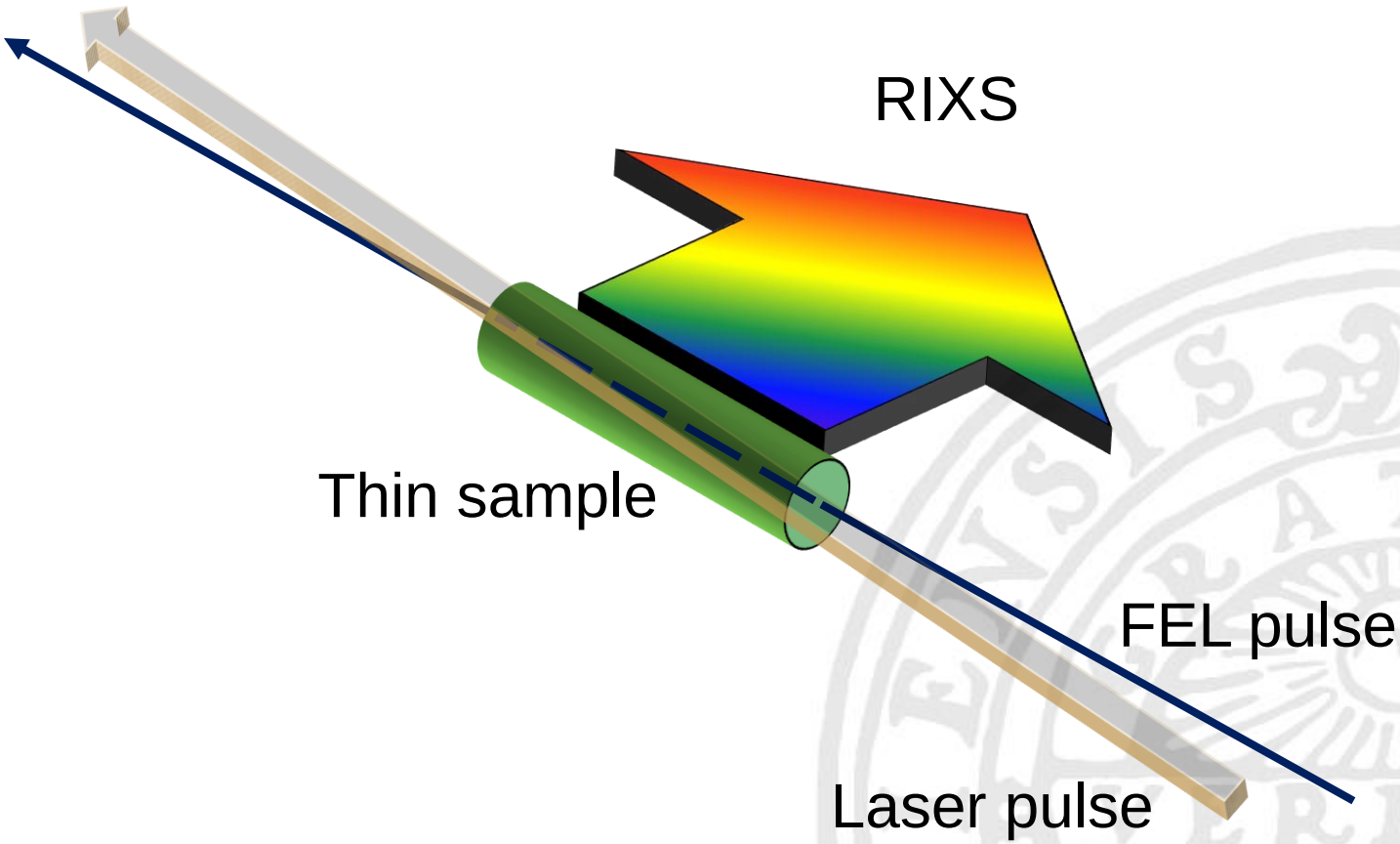
Pump-probe experiments with RIXS



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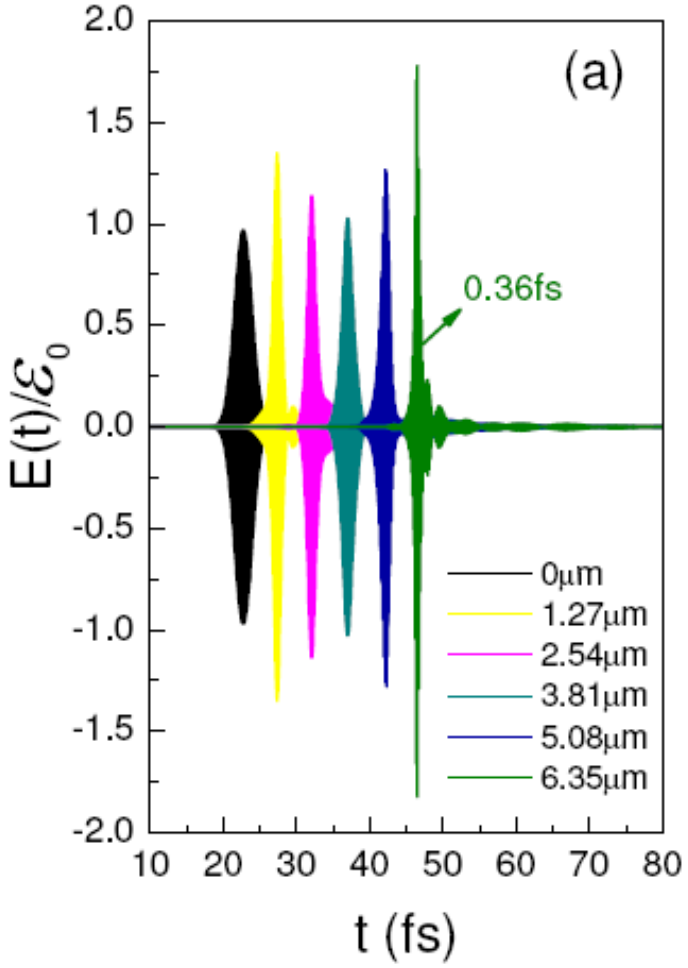
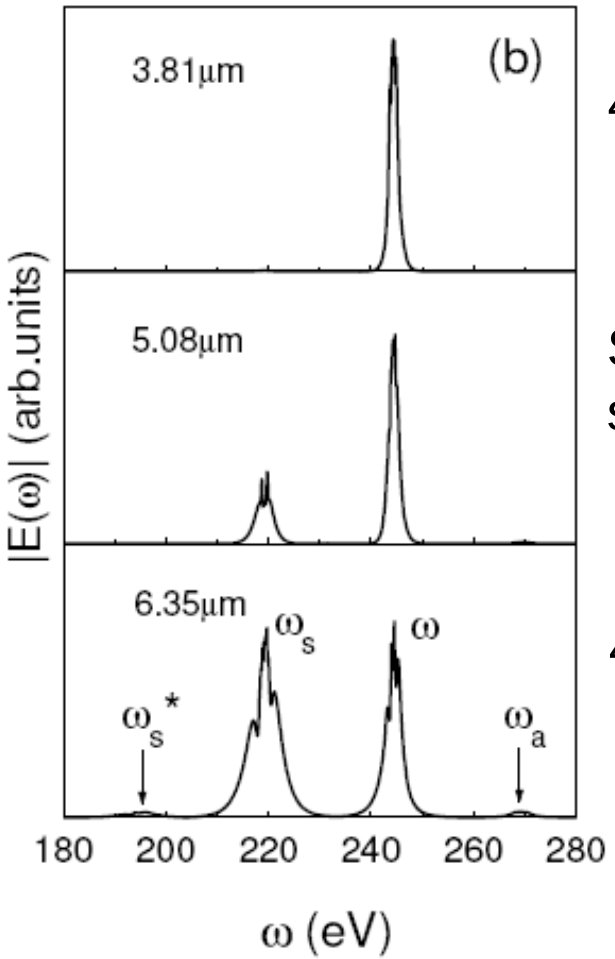
Non-linear processes in FEL beam interaction





4s-2p

Spectral broadening stimulates 3s-2p

4-wave mixing

Yu-Ping Sun, Faris Gelmukhanov PHYSICAL REVIEW A 81, 013812 (2010)

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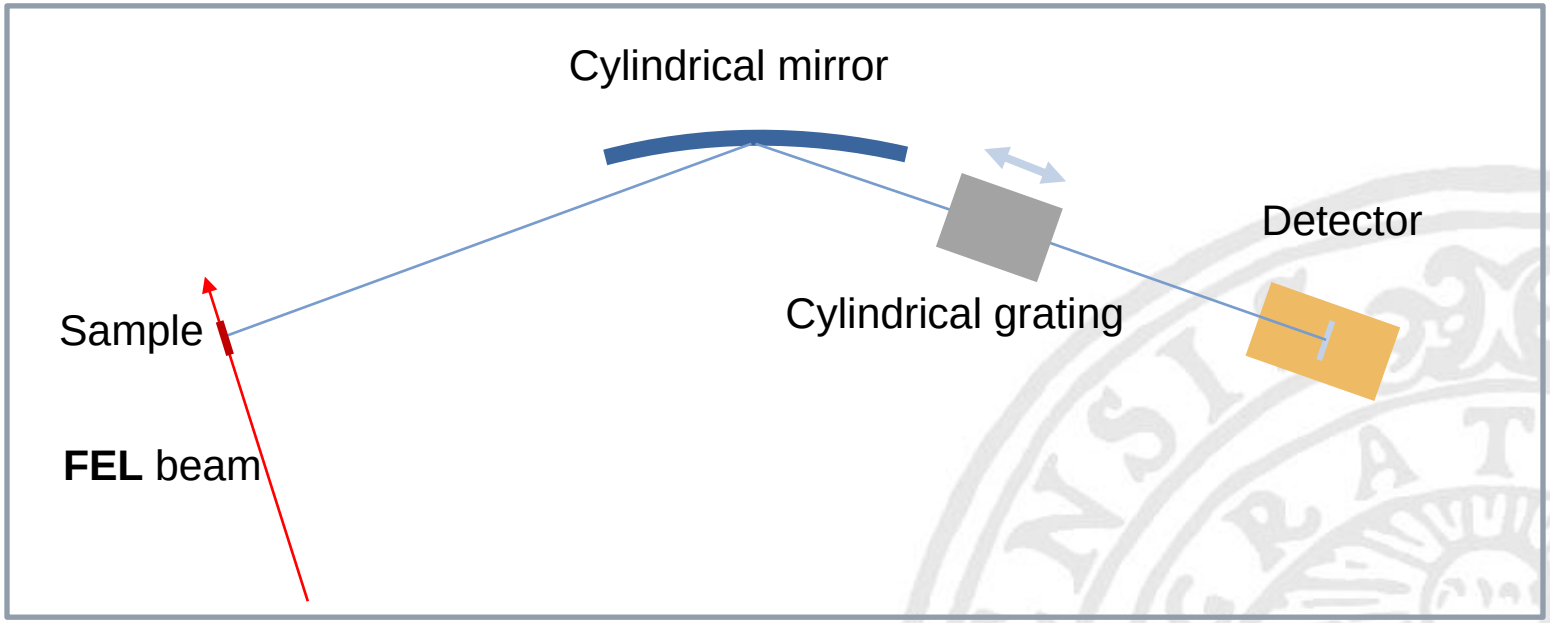
Cylindrical mirror imaging RIXS



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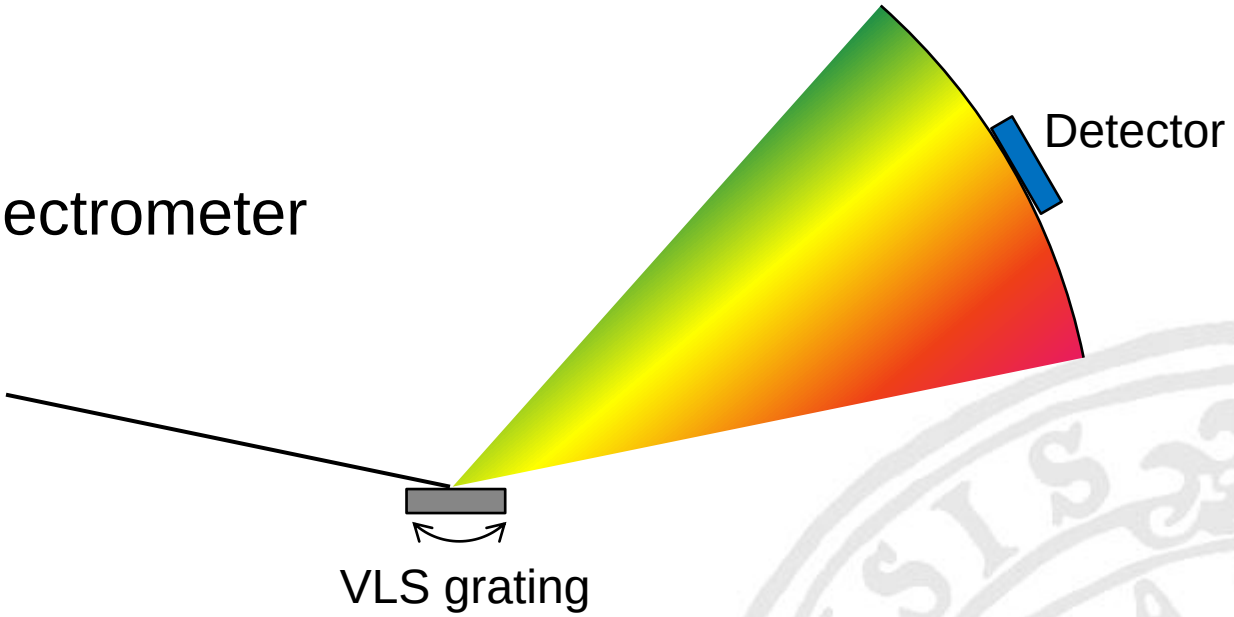
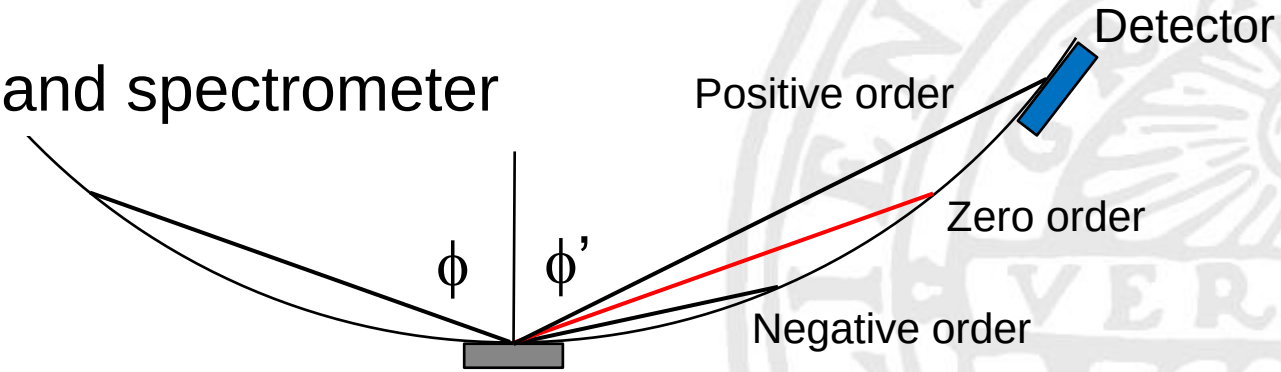
Soft X-ray grating spectrometers

VLS spectrometer



Rowland spectrometer



$\sin \phi - \sin \phi' = n\lambda/d$

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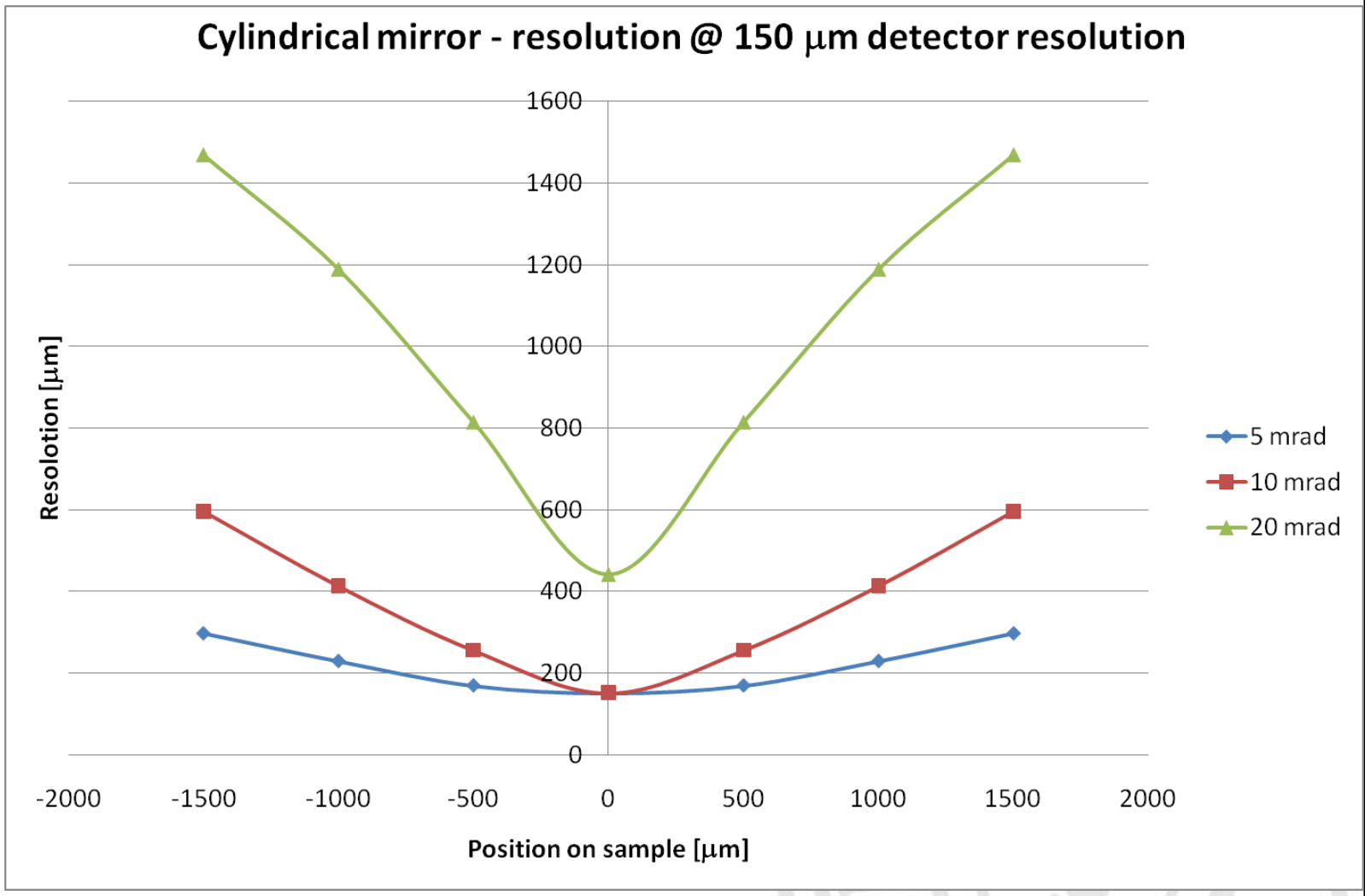
Spatial resolution for cylindrical mirror



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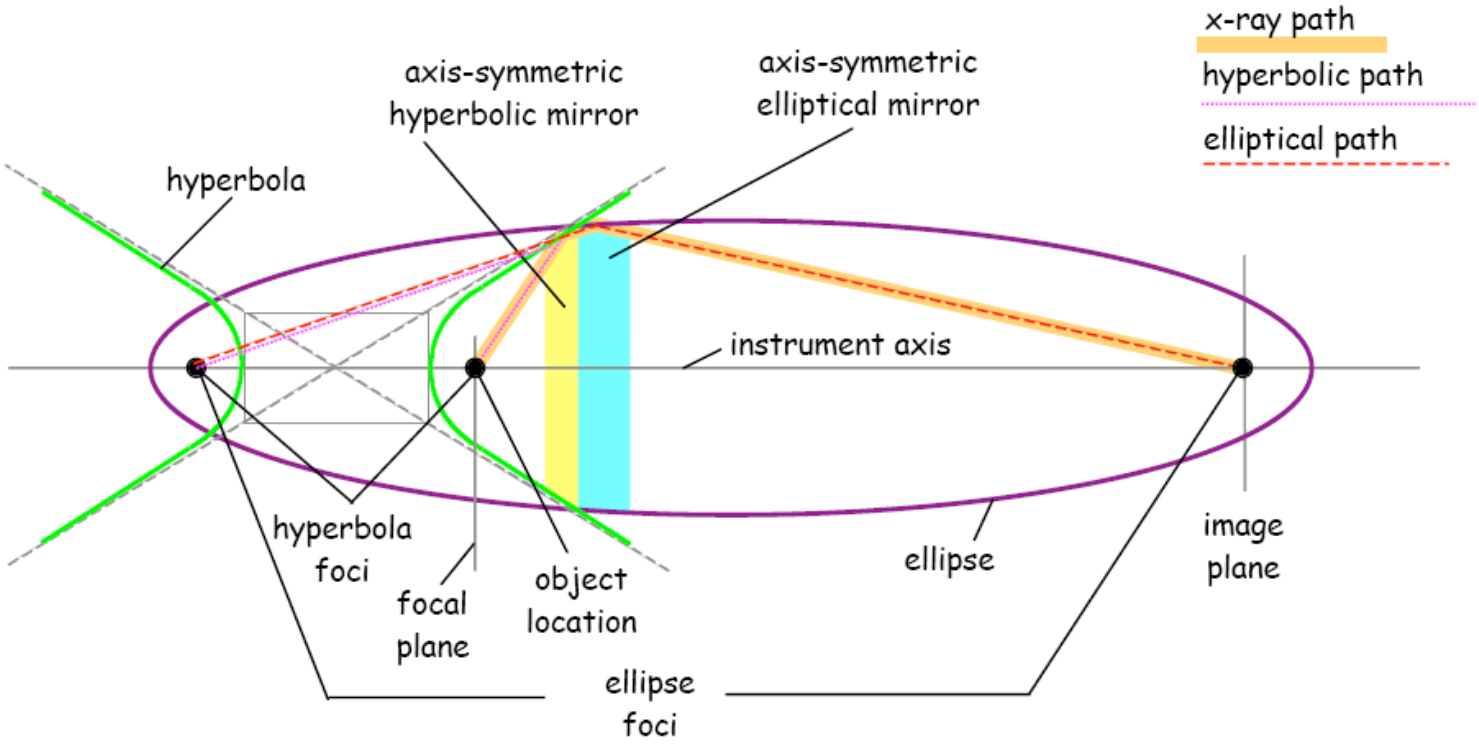
Principle of Wolter Microscope

Wolter, H. 1952, Annalen der Physik (6. Folge) 10, 94



J.A. Jackson, LLNL report UCRL-TR-220019 (2006)

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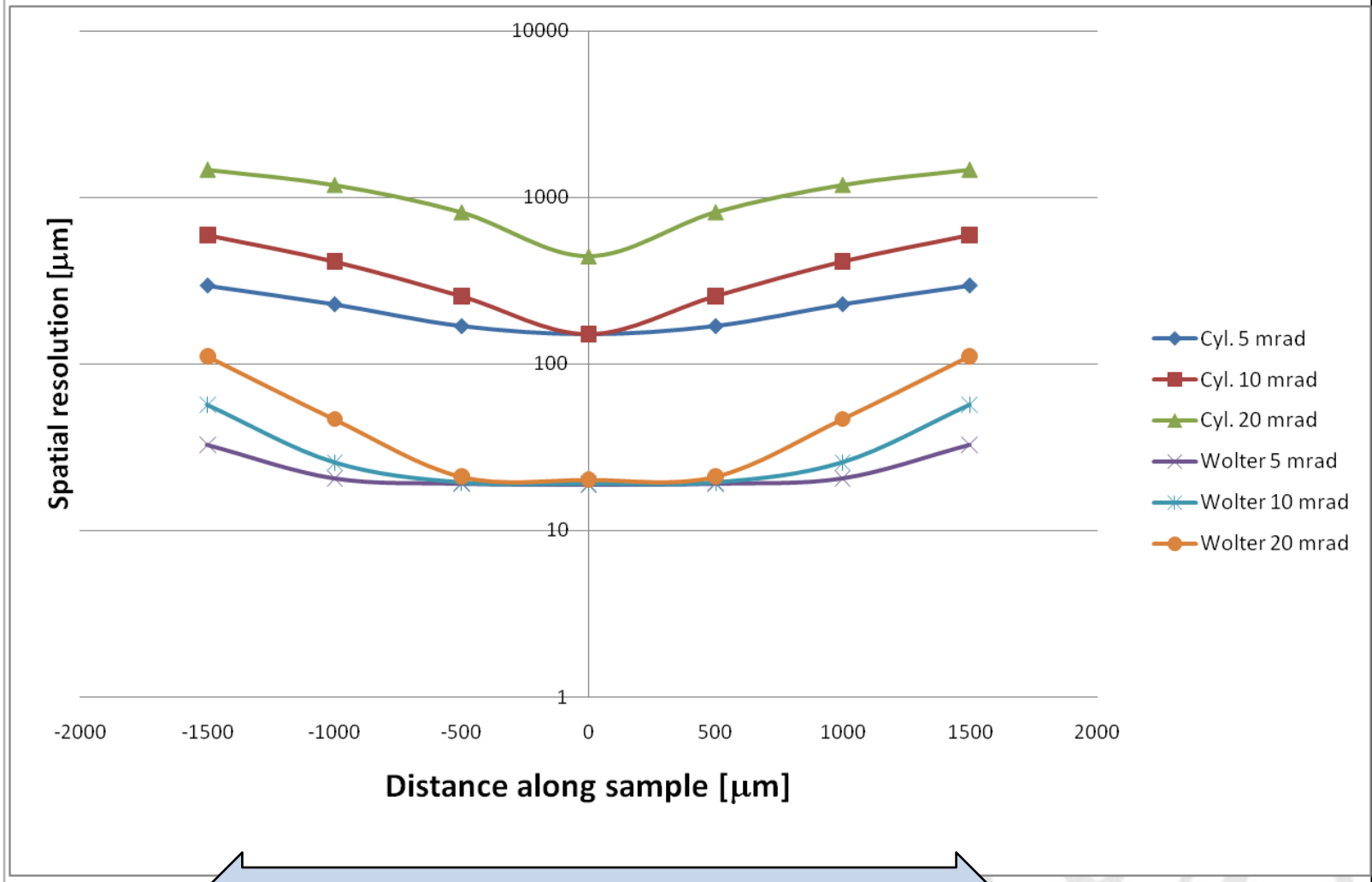
Comparison Cylindrical mirror – Wolter pair @ 150 μm detector resolution



10 ps (for c_{vacuum})

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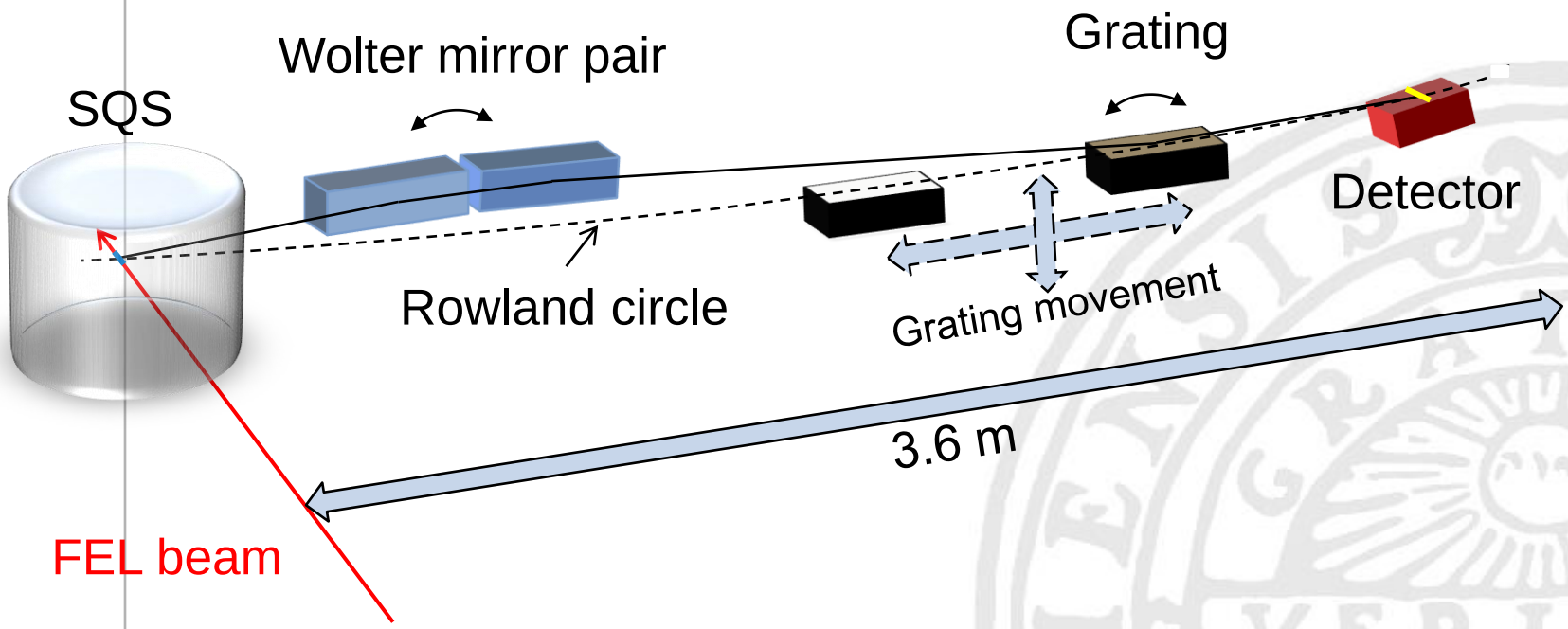
Outline of 1-D Imaing RIXS Spectrometer



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Imaging detectors for Soft X-rays

Issues:
Resolution - < 50 μm
Sensitivity at various incidence angles
Speed – 220 ns pulse separation

Back thinned CCD
MCP with various read-outs
Pixelled silicon devices with on-board memory

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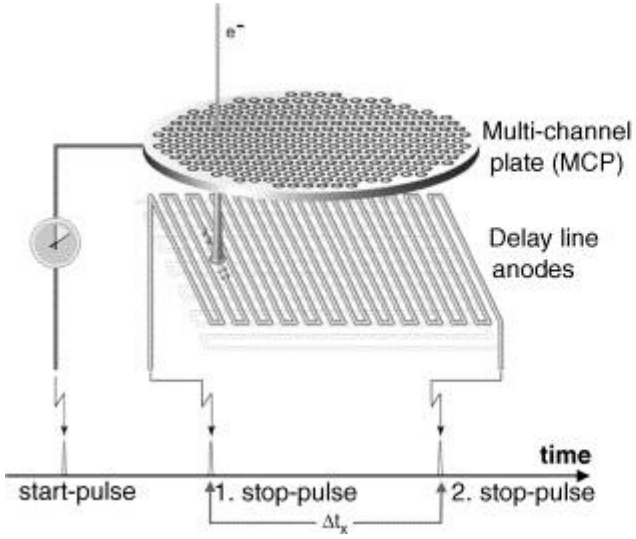
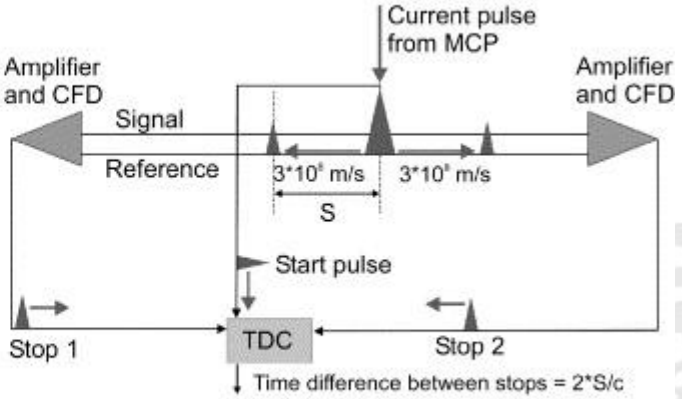
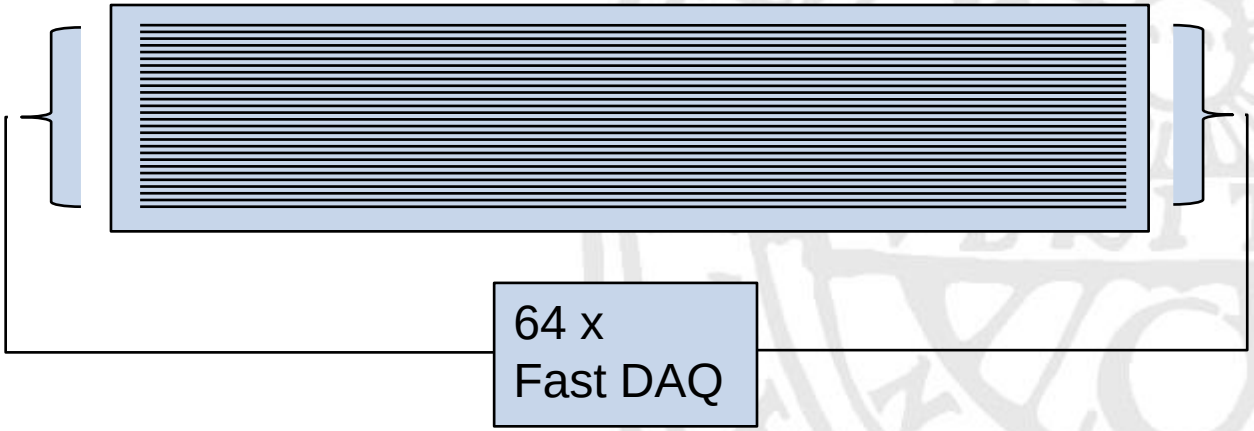
Striped Time Delay Detector





Surface Concept Company



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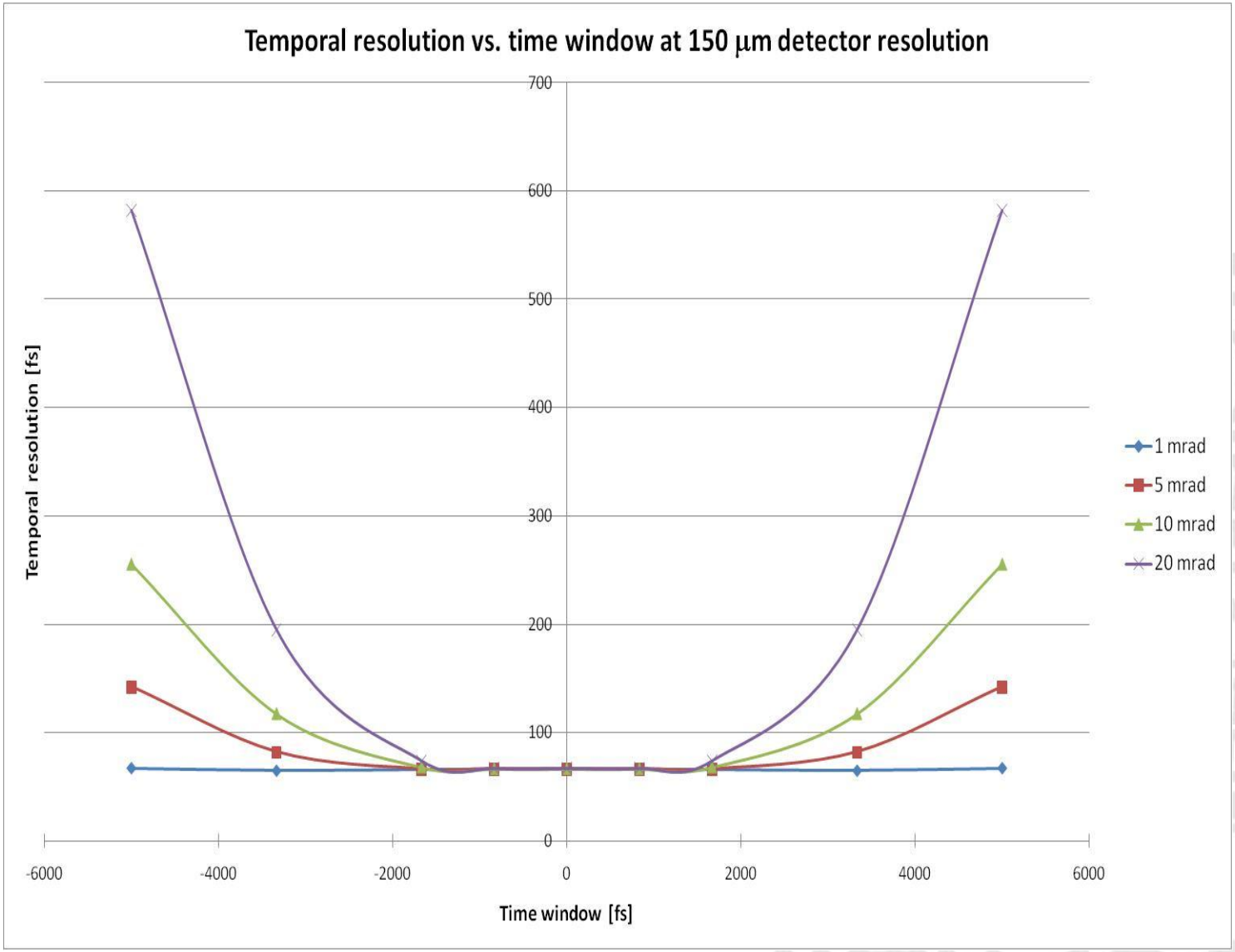
Temporal resolution - Wolter optics @ 150 μm detector resolution



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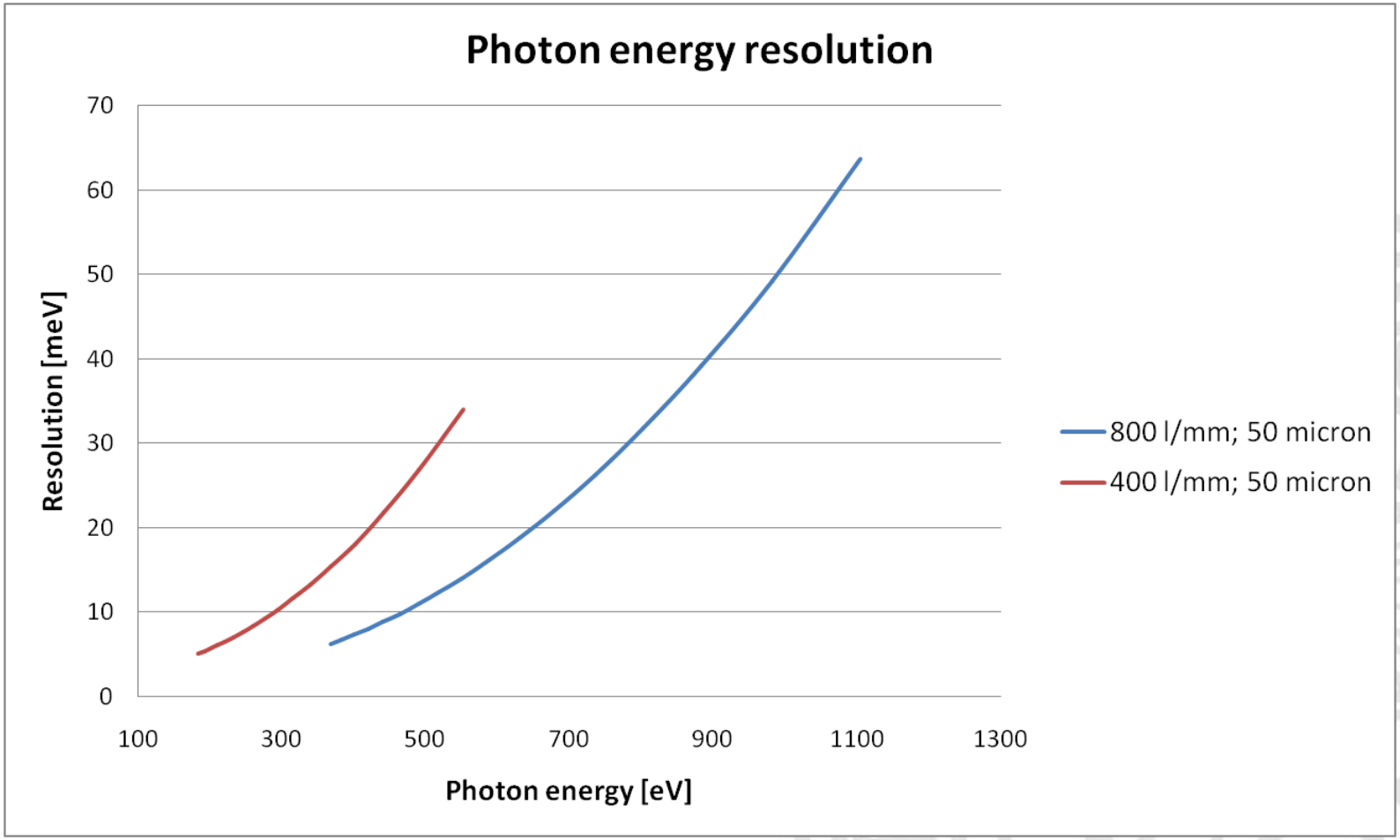
Photon Energy Resolution



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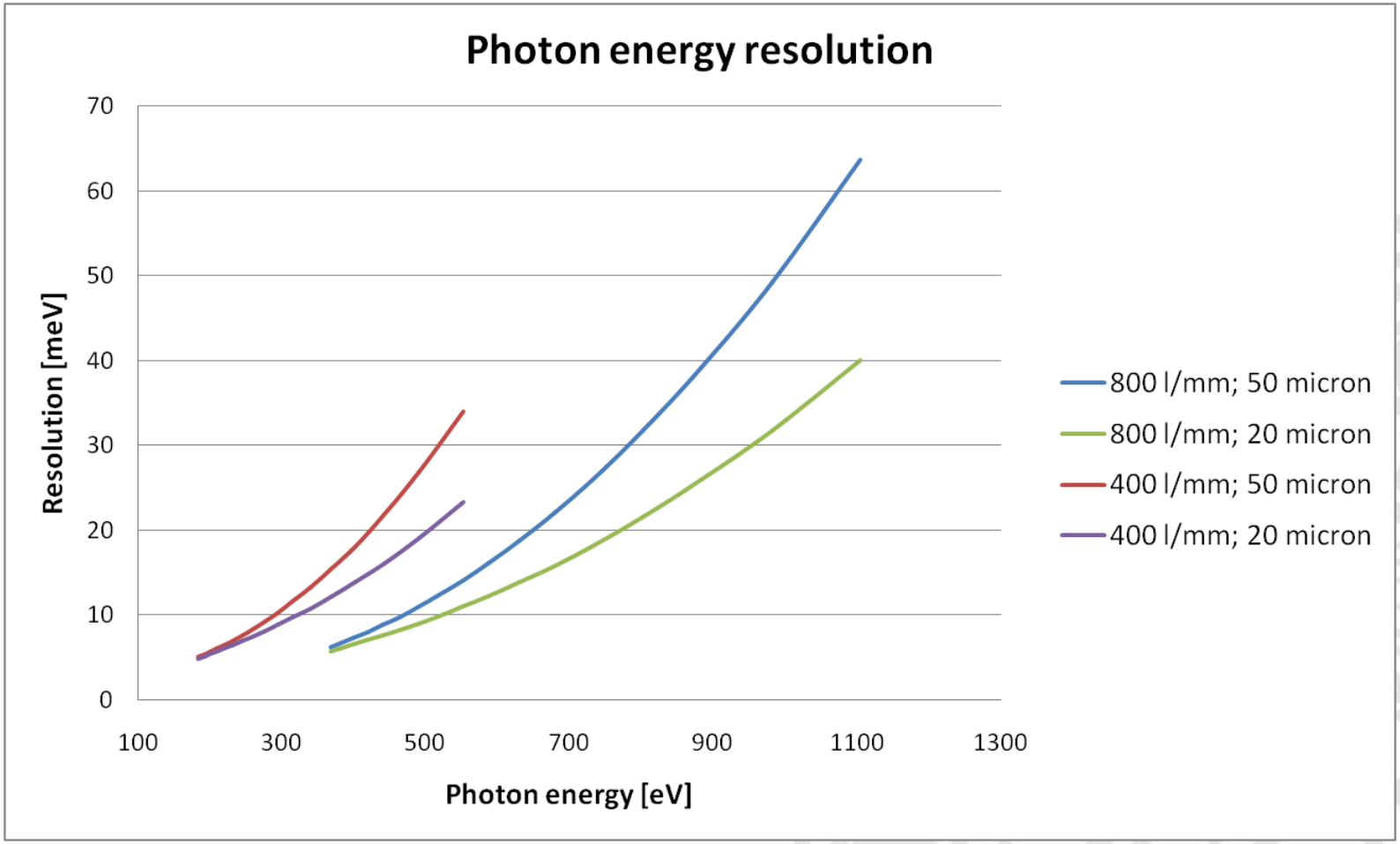
Photon Energy Resolution



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Other Applications of 1-D Imaging RIXS

- Spectroscopic imaging
  - Non-homogeneous samples
  - Graded sample composition
- RIXS maps

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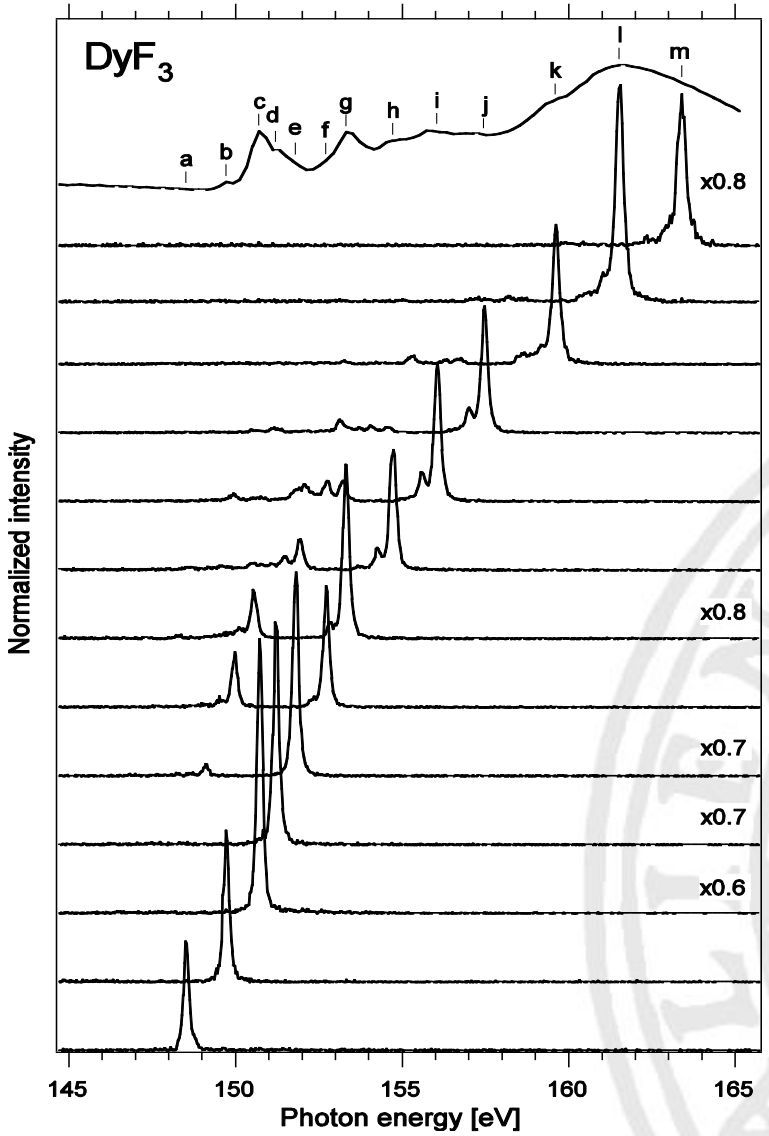
RIXS Maps



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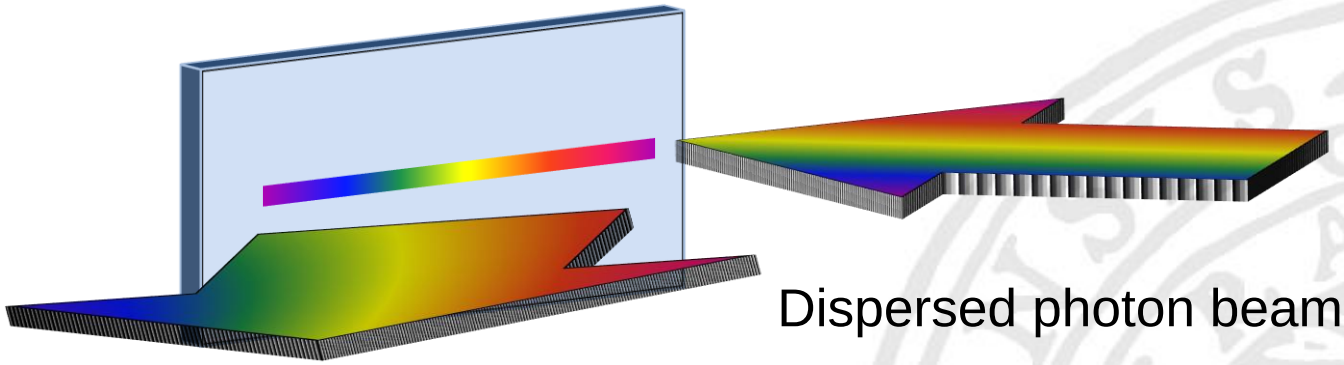
RIXS Map Recordning by 1-D Imaging Spectrometer

Homogeneous sample



Dispersed photon beam

Position coded RIXS

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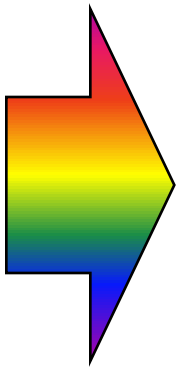
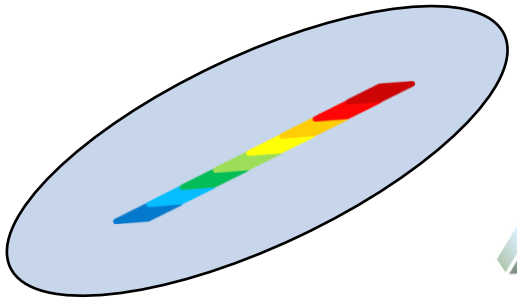
Vertical to horizontal dispersion

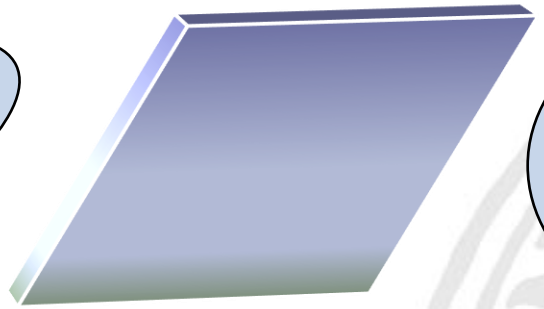
From mono



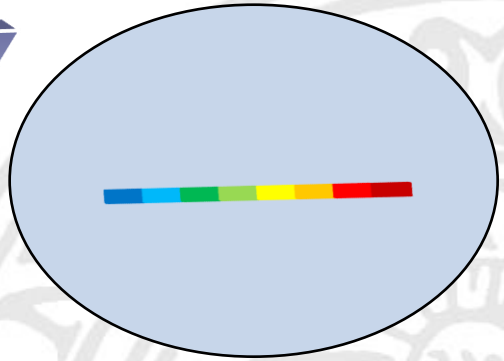
Vertical dispersion



Grazing inc. mirror
at ~45 deg. slant



Horizontal dispersion



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- Jan-Erik Rubensson
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- Monica Turcato
- Markus Kuster