Mössbauer Spectroscopic Methods at the SwissFEL

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SwissFEL

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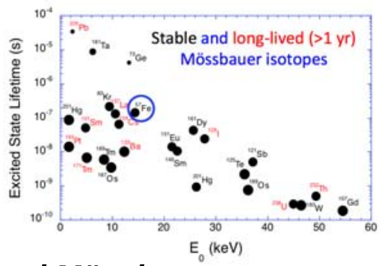
Introduction

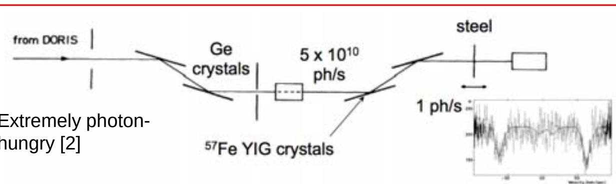
So-called "Mössbauer nuclei" have a low-lying, long-lived excited state
- narrow resonance: $\Gamma = \hbar / \tau \,;\, \hbar = 0.66 \text{ eV fs}$
- recoil-less absorption (entire sample carries recoil momentum)
- inelastic spectroscopy (sensitive to magnetism via hyperfine splitting)
- resonant forward scattering (quantum beats)

Mössbauer nuclei [1]

^{57}Fe:
E_0 = 14.4125 keV
τ = 141 ns
Γ = 5 neV

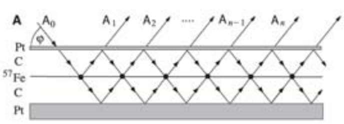


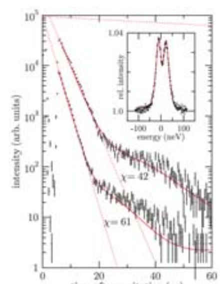
1. Synchrotron-based Mössbauer spectroscopy



Extremely photon-hungry [2]

Highlight: super-radiant Dicke state





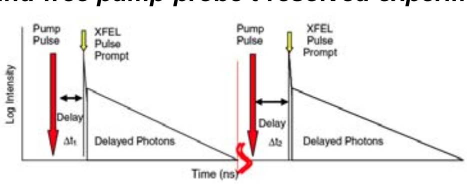
^{57}Fe nuclei in a resonant cavity are coherently excited with SR: the super-radiant decay is accelerated by a factor 40-60 [3].

2. Advantages of an XFEL

High resonant flux [4] at 14.4 keV

	synchrotron	SASE XFEL	seeded XFEL
average flux ph/s/Γ	2 x 10⁴	3 x 10⁷	3 x 10⁹
pulse length	80 ps	100 fs	20 fs
repetition rate	5 MHz	100 Hz	100 Hz
fluence ph/pulse/Γ	4 x 10⁻³	3 x 10⁵	3 x 10⁷

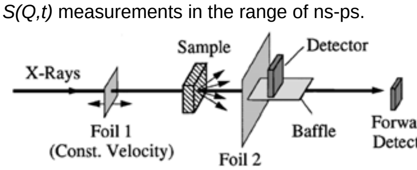
Background-free pump-probe t-resolved experiments [4]



3. XFEL Mössbauer ideas

A) Coherent "filter-foil" spectroscopy [5]

Perform XFEL $S(Q,t)$ measurements in the range of ns-ps.

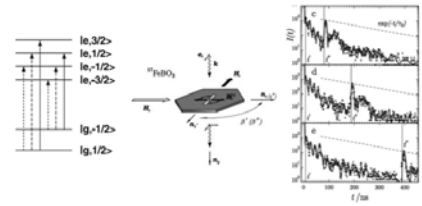


$$I(t) = \left\langle \left| \rho(Q,0) g(t) + g(t) \rho(Q,t) \right|^2 \right\rangle = A + B \left\langle \rho(Q,0) \rho(Q,t) \right\rangle$$

sample(0) foil$_2$(t) — foil$_1$(t) sample(t) — intermediate scattering function S(Q,t)

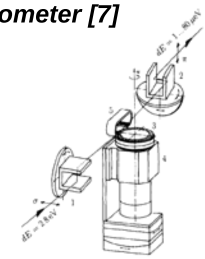
B) Active modification of quantum beats [6]

Fast magnetic switching pulse alters hyperfine levels and hence the Mössbauer decay.

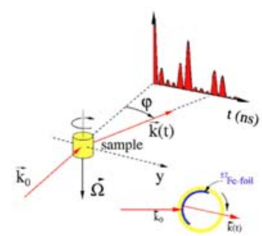


C) Ultra-high resolution inelastic spectrometer [7]

Polarization filters and rotating Doppler ^{57}Fe scatterer allow μeV resolution.



D) Nuclear Lighthouse Effect [8]

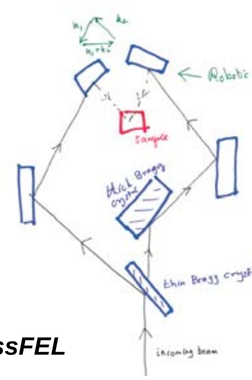


Sample rotation maps time evolution into angle.

4. SwissFEL possibilities

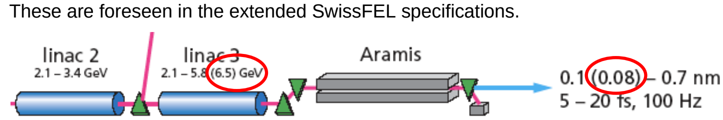
A) 2-photon excitation of ^{57}Fe [9]

Phase-matching of two 7.2 keV beams in Bragg diffraction allows accurate mapping of ^{57}Fe in the crystal unit cell.

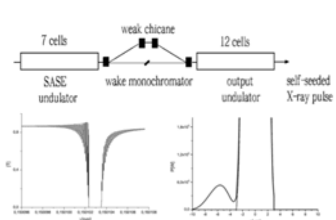


B) 14.4 keV photons from the SwissFEL

These are foreseen in the extended SwissFEL specifications.



C) self-seeding seeding at 14.4 keV [10]



The "stop-band" resonance of a single diamond-crystal monochromator produces a delayed X-ray pulse which can seed a second undulator section.

References

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[2] E Gerdau, *et al*, PRL **54**, 835, (1985)
[3] R Röhlsberger, *et al*, Science **328**, 1248 (2010)
[4] GK Shenoy and R Röhlsberger, Hyp Int **182**, 157 (2008)
[5] AQR Baron, *et al*, PRL **79**, 2823 (1997)
[6] YV Shvyd'ko, *et al*, PRL **77**, 3232 (1996)
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[8] R Röhlsberger, *et al*, PRL **84**, 1007 (2000)
[9] S Doniach, *private communication* (2009)
[10] G Geloni, *et al*, arXiv:1006.2045v1 (2010)