XFELO Retreat, SLAC, 28 June – 1 July 2016

Nuclear Resonant Scattering with an XFELO
- Session Summary -

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Applications in Physics and Materials Science

Scientific fields

- **Dynamics of mesoscopically structured materials – understanding energy dissipation in technologically relevant materials**
- **Non-equilibrium vibrational dynamics – resonant nuclei as spectators of phonon population with very high spatial and temporal resolution**
- **High – resolution hyperfine spectroscopy understanding electronic structure of complex materials**

Applications in biology

High brilliance and small bandwidth makes XFELO-Mössbauer spectroscopy applicable to all iron containing proteins without tedious ^{57}Fe enrichment. This will boost the interest of biological communities and generate a wealth of applications, e.g.:

- **Exploring iron trafficking in cells**
- **Time dependent NRS (NFS;NIS): frozen samples (high-throughput)**
- **Extension of SRPAC to non-frozen biological samples**
- **Iron cofactor –protein assembly in cells**
- **Nucleation and Growth of iron containing nanophases in iron storage proteins (ferritin)**
- **Pathologic iron in human cell tissue (substantia nigra, cancer cells)**

Applications in chemistry

XFELO NRS with nuclear probes will allow to look more deeper into complex chemical systems:

- **Exploring iron in catalysts (De-NOx, fuel cells, Fischer-Tropsch, Haber-Bosch) under working conditions will allow to contribute to important issues for society (air pollution, energy)**

- **Exploring nucleation and growth of single iron containing nanoparticles**

NRS with an XFELO allows one to gain unique insight in condensed matter physics, biophysics and chemistry that surpasses existing methods

- **Enormous gain in energy and time resolution to follow dynamical processes**
- **stable source required !! Fluctuations of the source must not superimpose the dynamics and fluctuation of the system under study**
- **Stable source like XFELO → stimulate development of new techniques**

XFELO will make a difference !

Two directions:

Current experiments

more resonant photons per second → *photon hungry*

more resonant photons per pulse → *"qualitatively new" (nonlinear, coherent, quantum)*

"More than one excitation"
(will be routinely available)

- Quantum effects (2-photon entanglement, correlations)
- Correlation spectroscopy ($G^{(n)}$, dynamics of host material)
- Nonlinear light-matter interaction
- multidimensional spectroscopy

"Full inversion"
(will remain challenging)

- Control fields for x-ray quantum optics
- Excited state / out-of-equilibrium dynamics
- Nonlinear spectroscopy
- Population transfer (nuclear structure, batteries, sample preparation)

Key question: What can be done with few excitations, but not with one?

Nuclear Physics and Nuclear Quantum Optics

Driving nuclear transitions...

can be done much more efficiently with XFELO e.g. Rabi flopping

Possible applications borrowed from atomic systems...

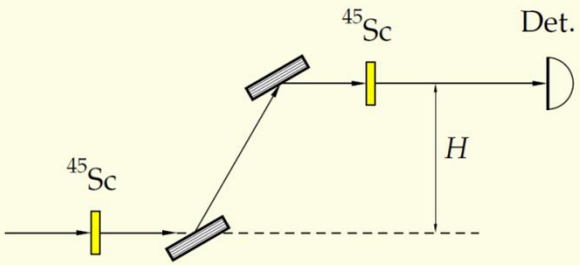
nuclear coherent population transfer, pump-probe experiments, 4-wave mixing

Closer to nuclear physics...

exploit efficiency of XFELO to probe for the first time nuclear reactions starting from excited nuclear states

Needed:
most importantly, tunability for addressing nuclear resonances!
Intensity, repetition rate, BW depending on the envisaged application
Average vs. peak brilliance an issue depending on whether excitation after one pulse or excitation after 1 s is of interest.

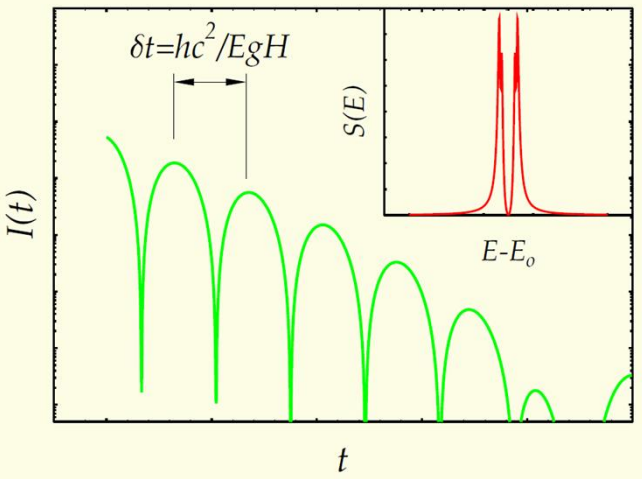
Exploring extremely narrow nuclear resonances using XFELO radiation.



$\Delta E/E = 1.1*10^{-19}$

$g = 9.81\ m\ s^{-2} = 1.1*10^{-16}\ c^2\ m^{-1}$

Red shift in 1mm up in the earth gravitational field = a linewidth



Isotope	E_0 [keV]	Γ_0 [eV]	ΔE/E	τ [s]	a [%]	f [%] 300K / 0K		α $\sigma_0 \sim \alpha^{-1}$
^{45}Sc	12.4	$1.4*10^{-15}$	$1.1*10^{-19}$	0.45	100	77	93	427
^{229m}Th	0.0076	$\approx 7.6*10^{-20}$	$\approx 10^{-20}$	600 ?	0	no	IC	

Fundamental physics, extreme metrology

HELMHOLTZ GEMEINSCHAFT

DESY