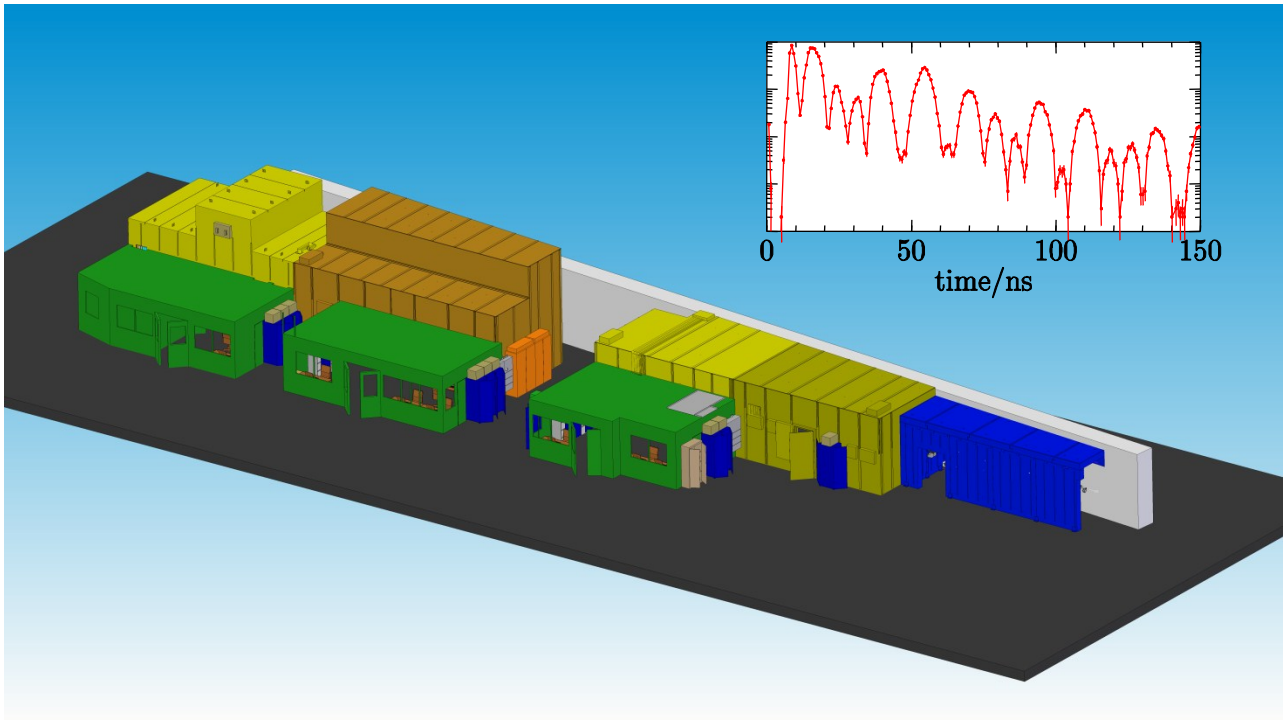
Timing experiments at the Dynamics beamline P01 of PETRA III .

Why bunch purity is important for Nuclear Resonant Scattering



Hans-Christian Wille

Beschleuniger-Betriebsseminar March 20 2013

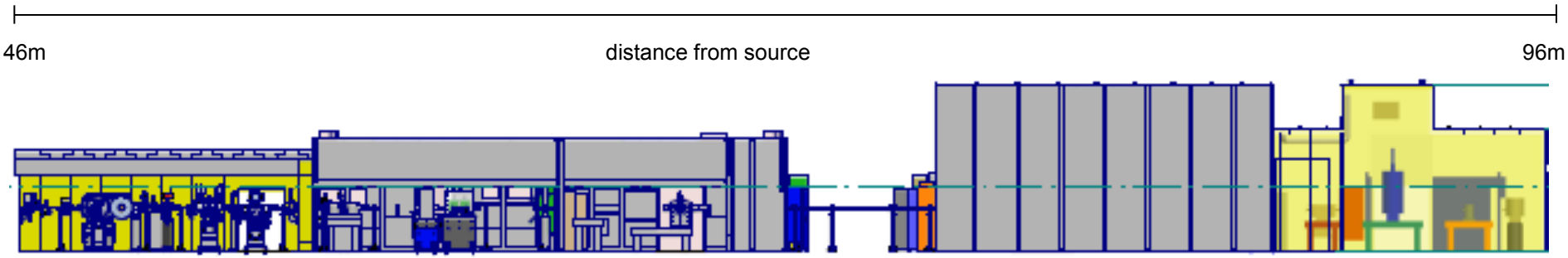
HELMHOLTZ GEMEINSCHAFT

DESY

Outline

- Beamline layout of P01
- Nuclear Resonant Scattering
- Some examples bunch purity / impurity
- Summary

P01 Beamline layout



	OH1	OH2	EH1	EH2	EH3
L:	9.6m	8.0m	7.5m	11.0m	9.0m

OH1: High heat load optics (HHLM, mirrors, Be lenses)

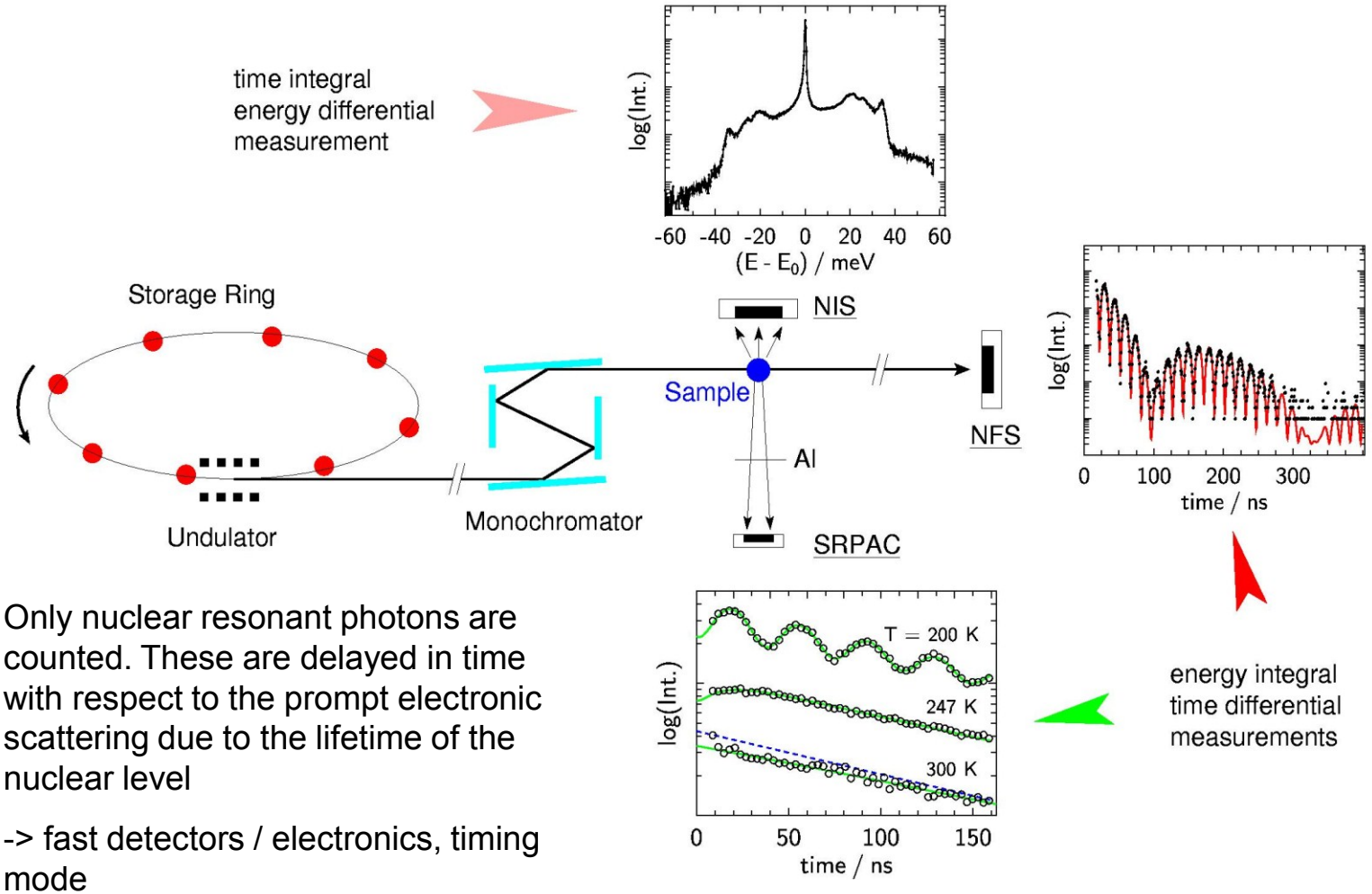
OH2: High resolution optics (HRMs)

EH1: Nuclear Resonant Scattering (raw focus, simple sample environment, θ-2θ-setup)

EH2: IXS spectrometers (focused beam 1 x 2 μm^2, electronic excitations, RIXS ?)

EH3: Nuclear Resonant Scattering (focused beam, UHV NFS / GISAXS in-situ)

Nuclear Resonant Scattering Techniques



Only nuclear resonant photons are counted. These are delayed in time with respect to the prompt electronic scattering due to the lifetime of the nuclear level

-> fast detectors / electronics, timing mode

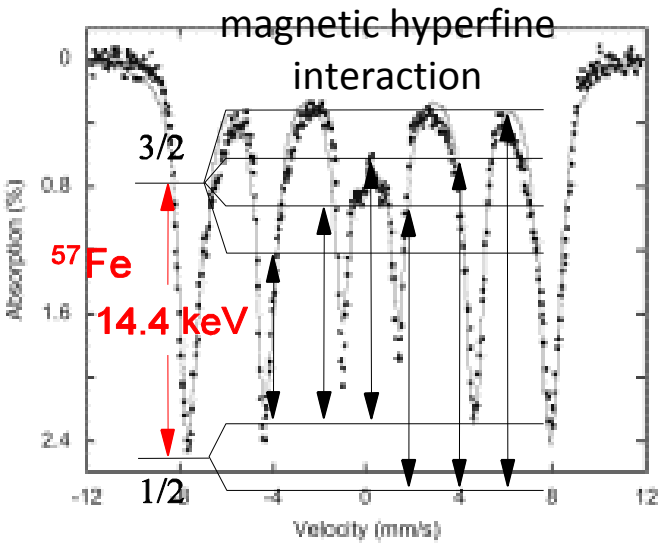
Nuclear Forward Scattering (Mössbauer effect)

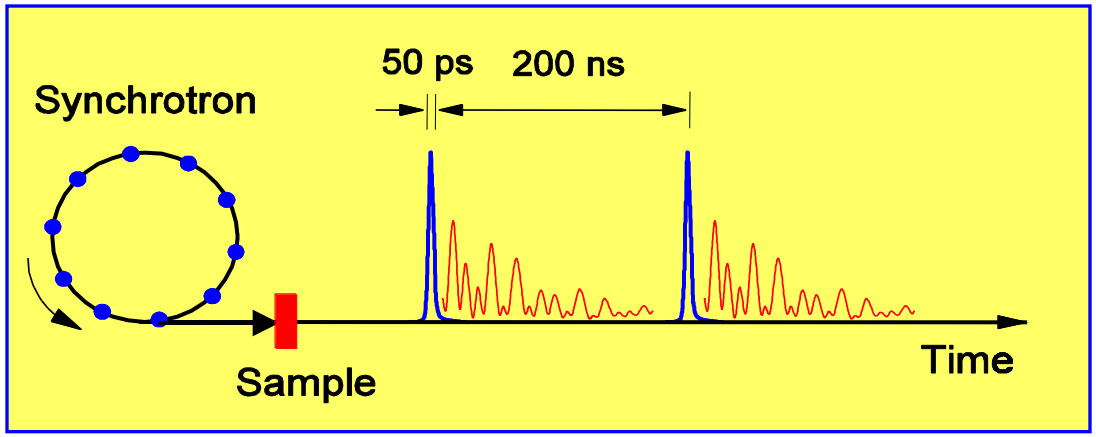
The Mössbauer effect:

Recoilless absorption and emission of photons

→ In the energy domain: Mössbauer spectroscopy

→ In the time domain : Nuclear forward scattering of synchrotron radiation





The 14.4 keV nuclear resonance of ^{57}Fe

τ_0 = 141 ns, Γ_0 = 4.7 neV

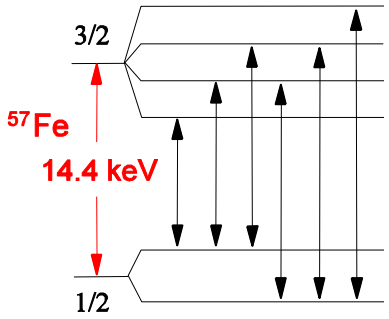
$\Delta E/E = 3.3 \times 10^{-13}$

Magnetic splitting: directon and value of ***B*** at the nucleus, magnetic moments

Quadrupole splitting: electronic state, e.g. valence state

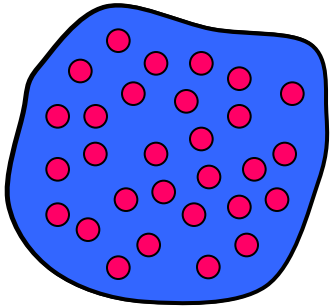
Nuclear Resonant Forward Scattering of Synchrotron Radiation

Pulsed broadband excitation of all hyperfine-split nuclear levels simultaneously



The 14.4 keV nuclear resonance of ^{57}Fe

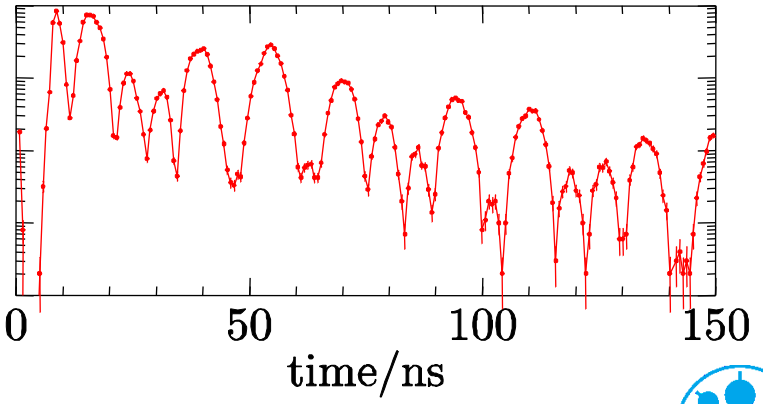
τ_0 = 141 ns, Γ_0 = 4.7 neV



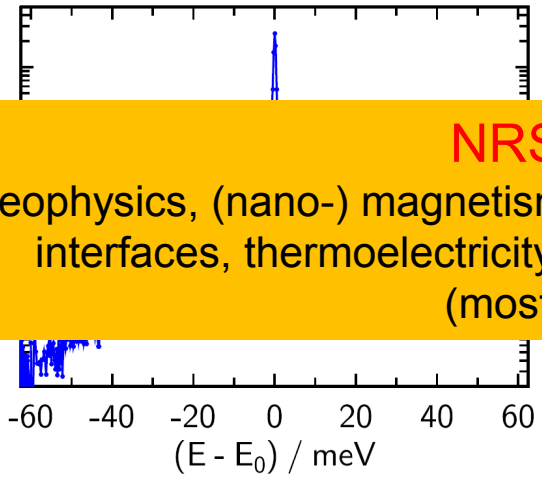
All levels are excited simultaneously and give rise to an interference beat pattern in time

The beat pattern is a fingerprint of the magnetic structure of the sample.

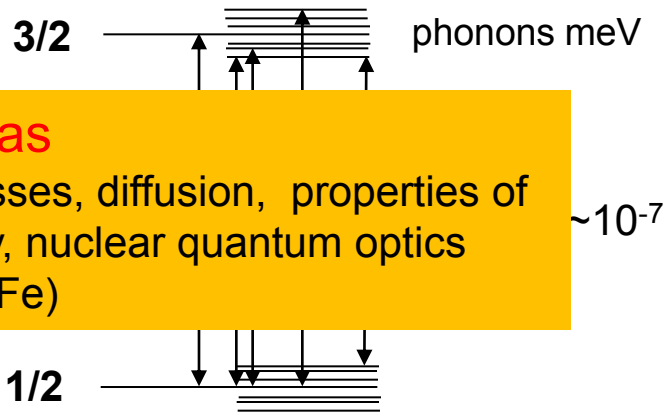
Temporal beats



Nuclear Inelastic Scattering (NIS)



NIS spectrum of Fe at ambient T



NRS Research areas

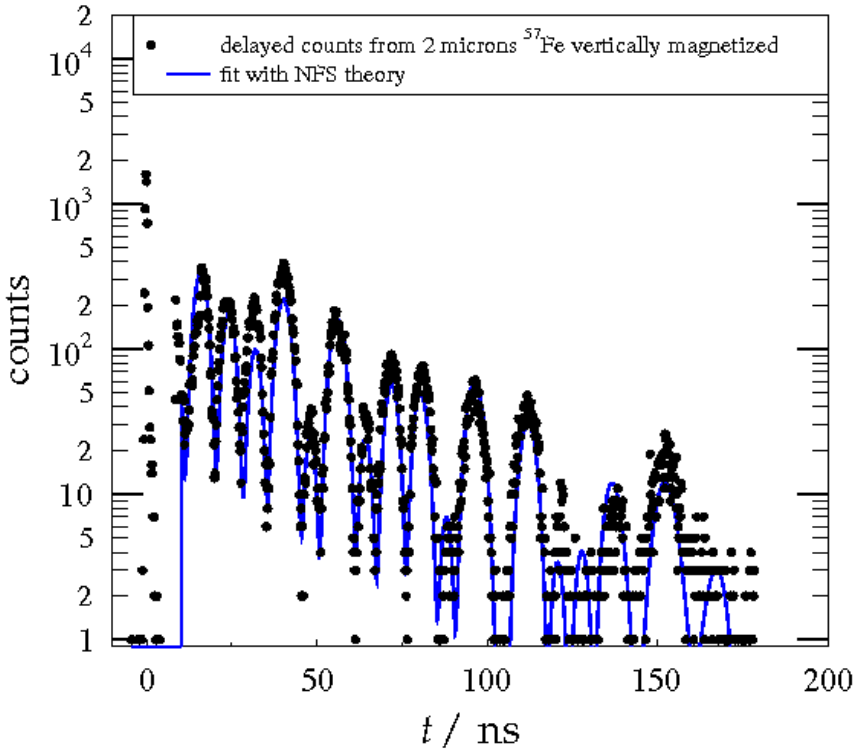
geophysics, (nano-) magnetism, dynamics in glasses, diffusion, properties of interfaces, thermoelectricity, molecular biology, nuclear quantum optics (most of it covered by ^{57}Fe)

Nuclear inelastic scattering is a tool to study vibrational dynamics.

Accomplishes other techniques like inelastic neutron scattering and is unique:

- Direct extraction of element specific VDOS (no background, no models)
- Element specific dynamics in complex systems, probe atoms, probe layers…
- Small sample size, nano structured materials

Nuclear Forward Scattering of enriched iron ^{57}Fe



2 microns ^{57}Fe, 40 bunch mode 192 ns bunch spacing, 2m U23 undulator

Can be done in a few ms today…

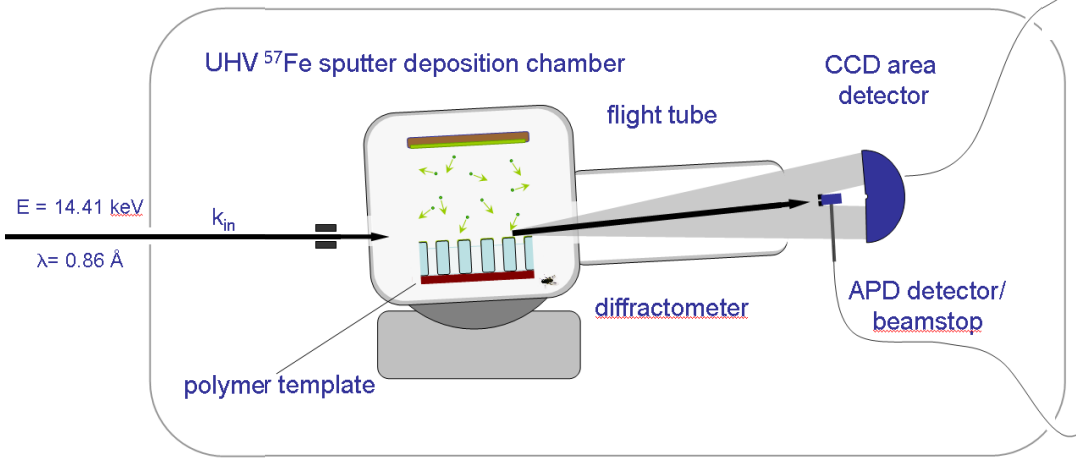
In-situ Synchrotron Radiation 3D Microscopy

By courtesy of Kai Schlage:

CCD for diffuse scattered x-rays: GISAXS

structural correlations (vertical and lateral),

particle geometry



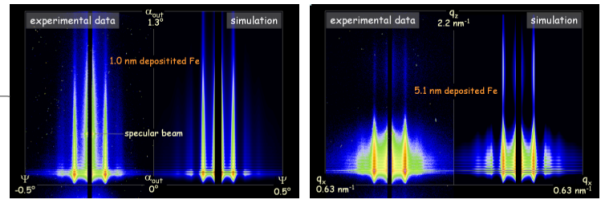
APD for specular reflection: NFS, NRXR

chemical and magnetic sensitivity to ^{57}Fe,

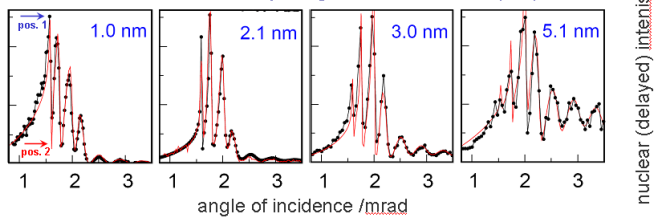
magnetization dynamics up to/close to GHz regime,

high resolution iron depth-profile

Grazing incidence small angle scattering – surface morphology

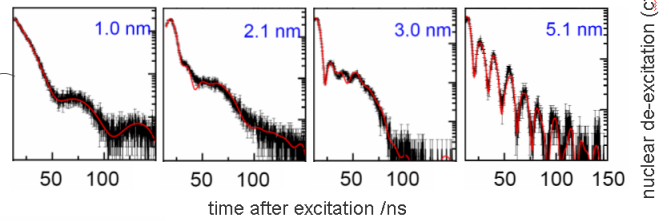


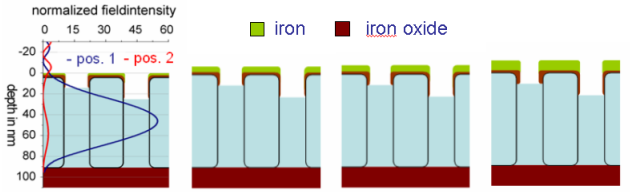
Nuclear resonant reflectometry – high resolution iron depth profile



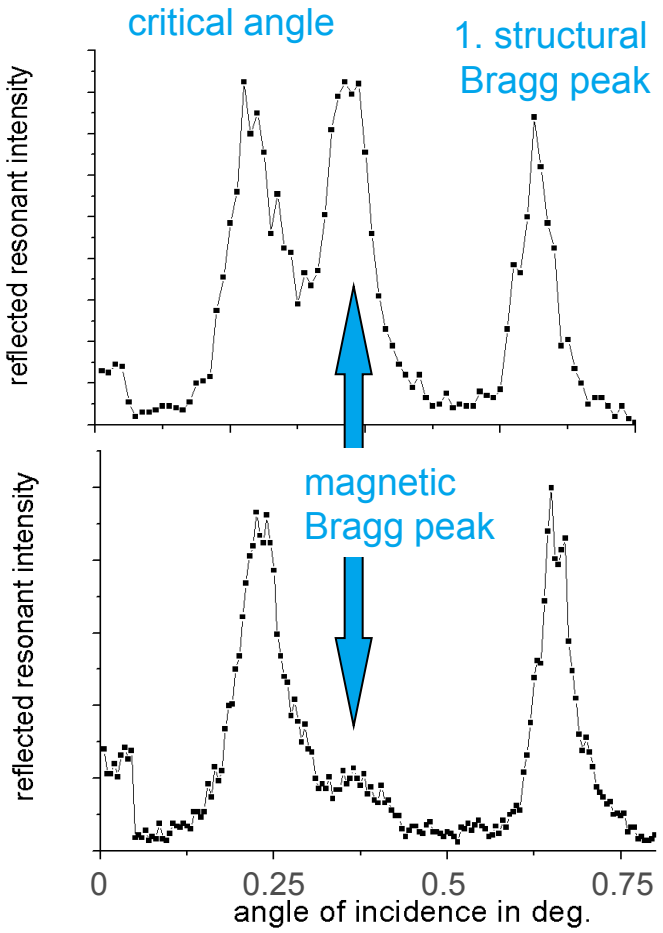
stepwise iron sputter deposition

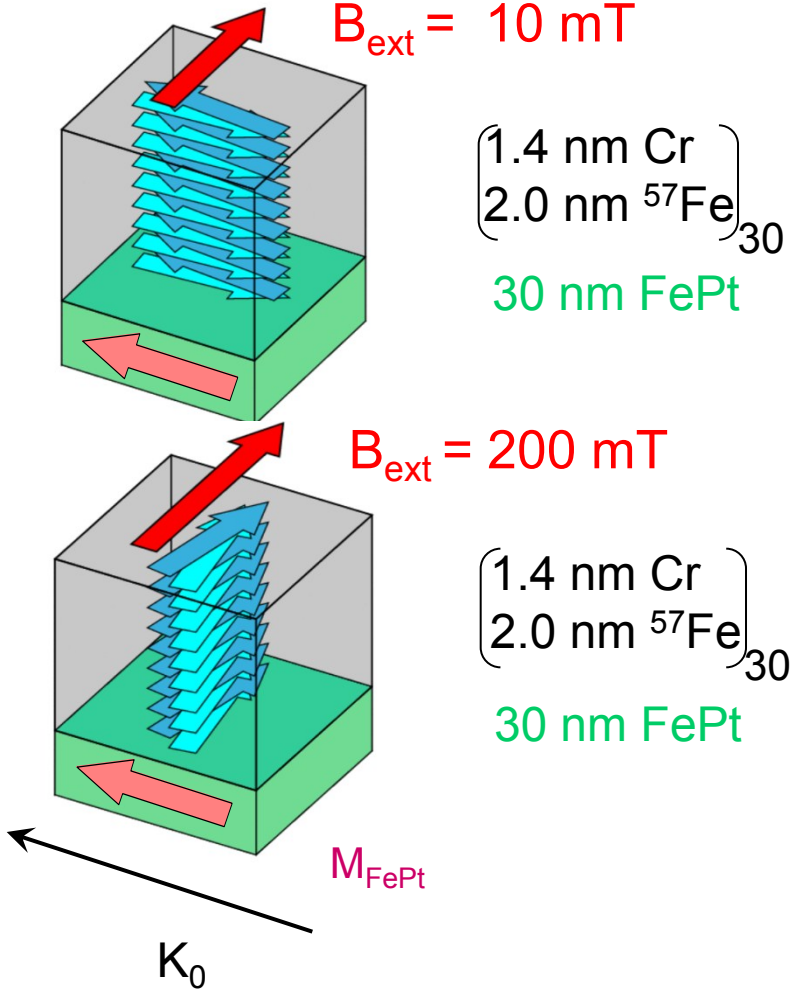
Nuclear time dependent scattering – chemical, magnetic state of iron





Resonant Reflectometry of Antiferromagnetic Multilayers





Intensity of the magnetic Bragg peak as tool for characterization of magnetic reorientation phenomena

T. Guryeva, K. Schlage

Raw estimate of count rates

Natural line width $5*10^{-9}$ eV

We get 10^{10} photons per second in 1 meV

10^{13} photons / s / eV * $5*10^{-9}$ eV

= $5*10^{4}$ photons / s

In the conditon 1 photon per nucleus

*6 by the number of transitions and other factors < 1 like the Lamb Mössbauer factor, Natural abundance of ^{57}Fe (~2%)

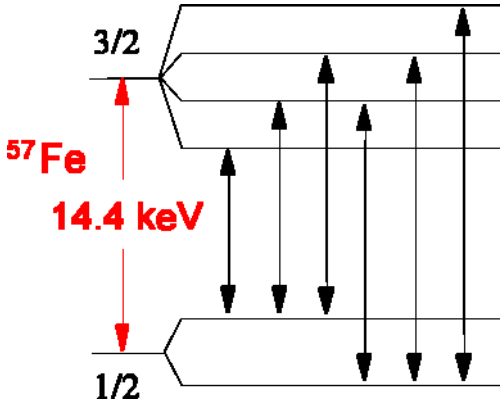
The most reducing factors is small cross section due to the sample size / thickness (nano science) and the sample environment (high P, low T, Fe embedded in optical thick material etc.)

Typical count rates are 0.1 to 100 Hz
One strength ot the method: it is (usually) background free @ bunch purity of 10^{-10}

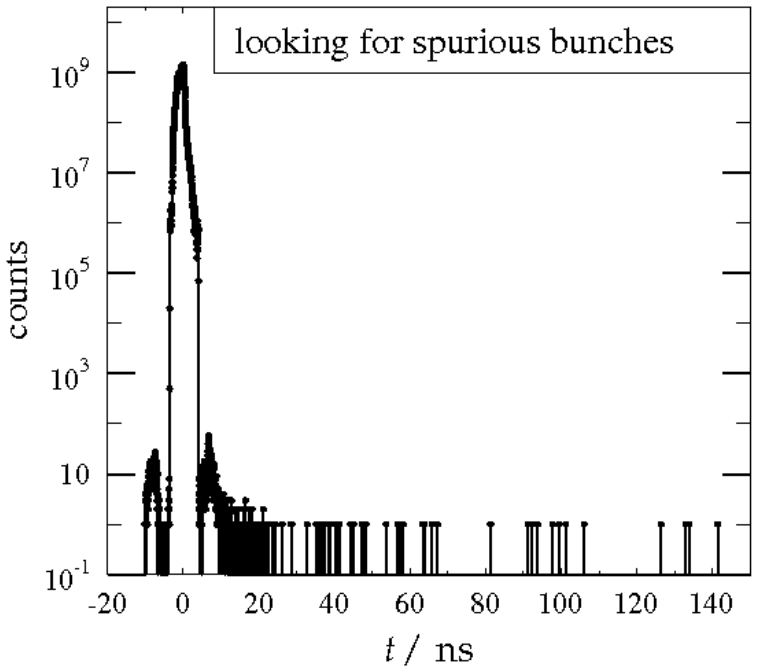
The 14.4 keV nuclear resonance of ^{57}Fe

τ_0 = 141 ns, Γ_0 = 4.7 neV

$\Delta E/E = 3.3x10^{-13}$



PETRA III bunch purity in 40 bunch mode (60 mA with top up 2011)

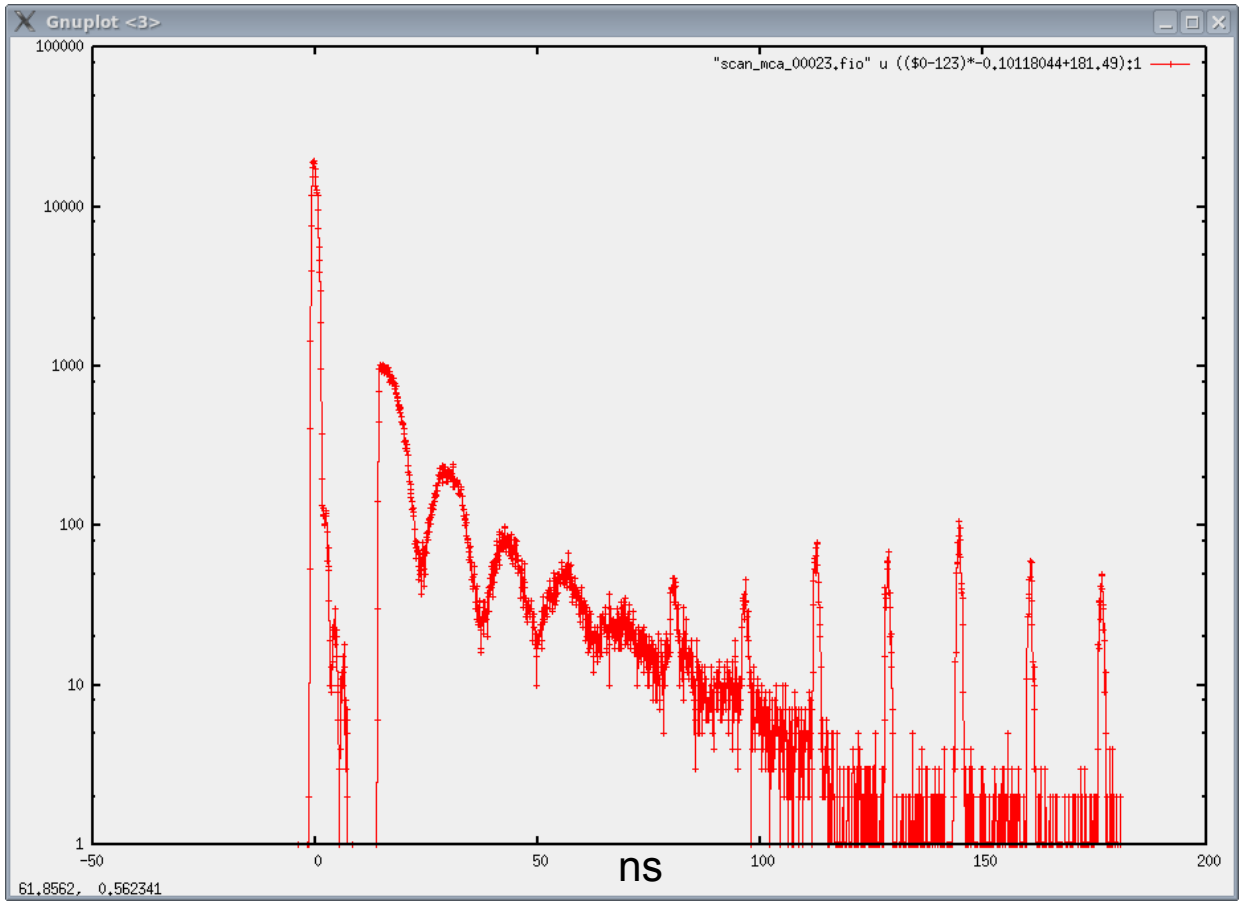


Spurious bunches at +- 8ns with 10^{-7} intensity

APD noise up to 20ns ?

Clean from 20 ns up

Spurious bunch problem 2013

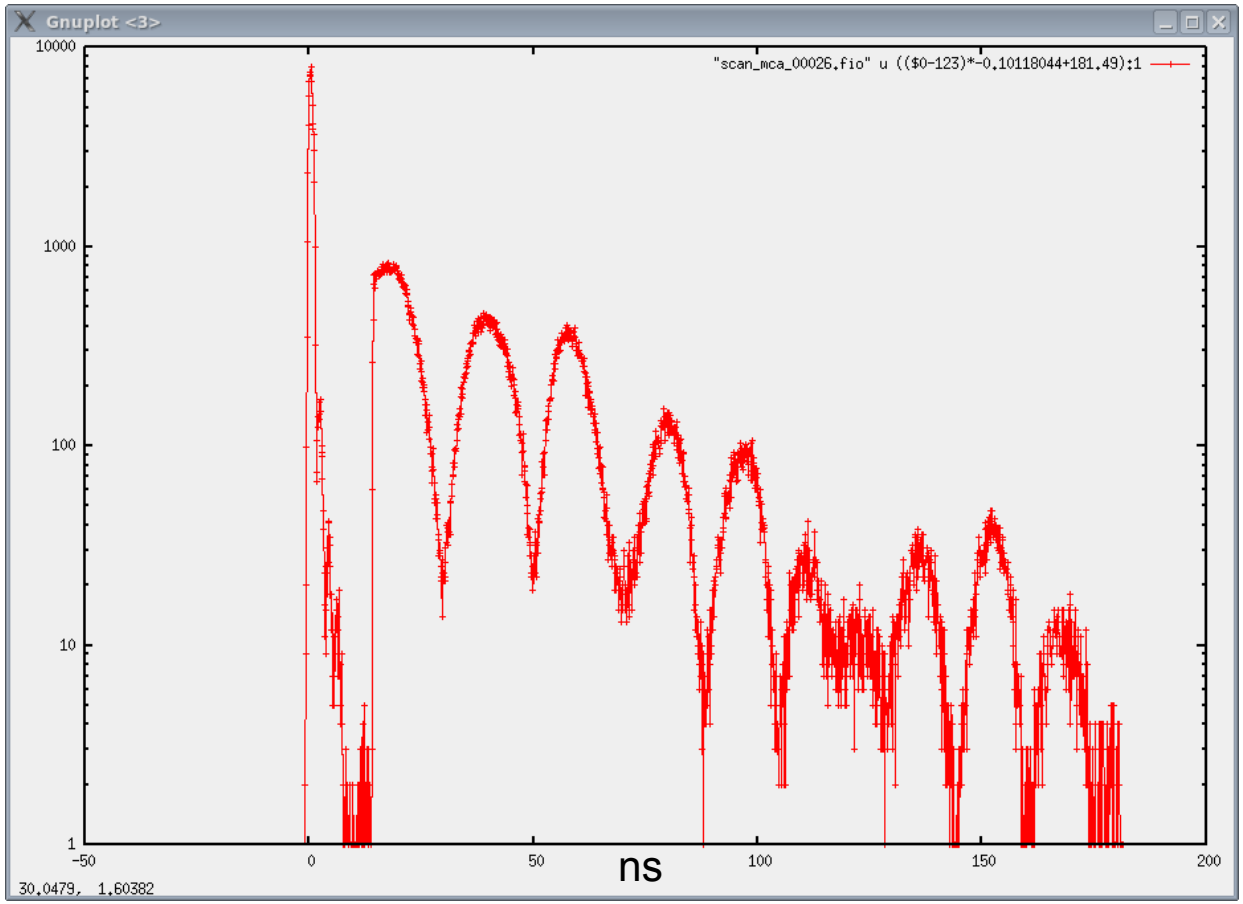


2 h sample time, sp. bunch rate < 5 Hz, regular with 16ns distance

prompt at t = 0 ns measured only for fraction of a second

detector noise < 0.1 Hz

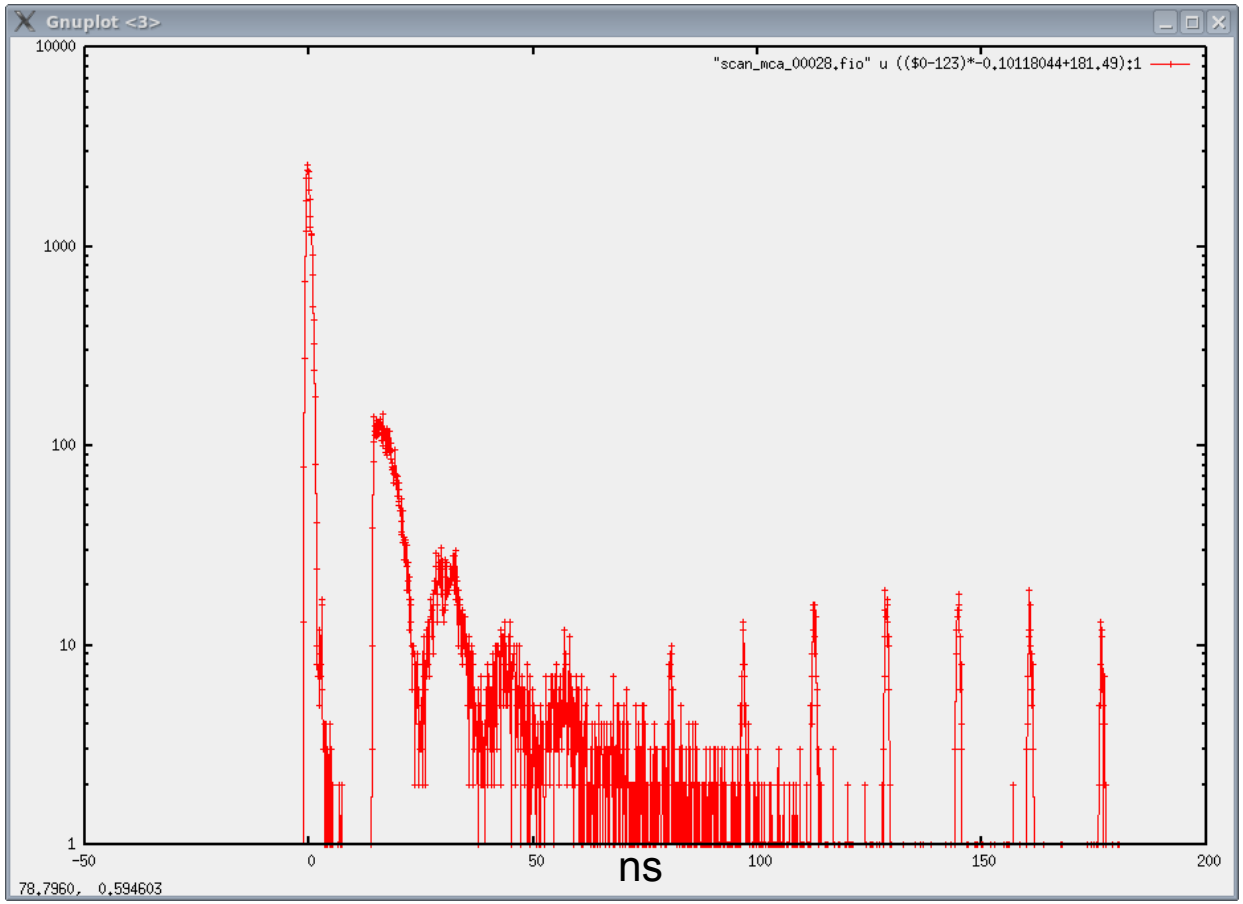
Spurious bunch problem



600 s sample time, sp. bunch rate < 5 Hz

detector noise < 0.1 Hz

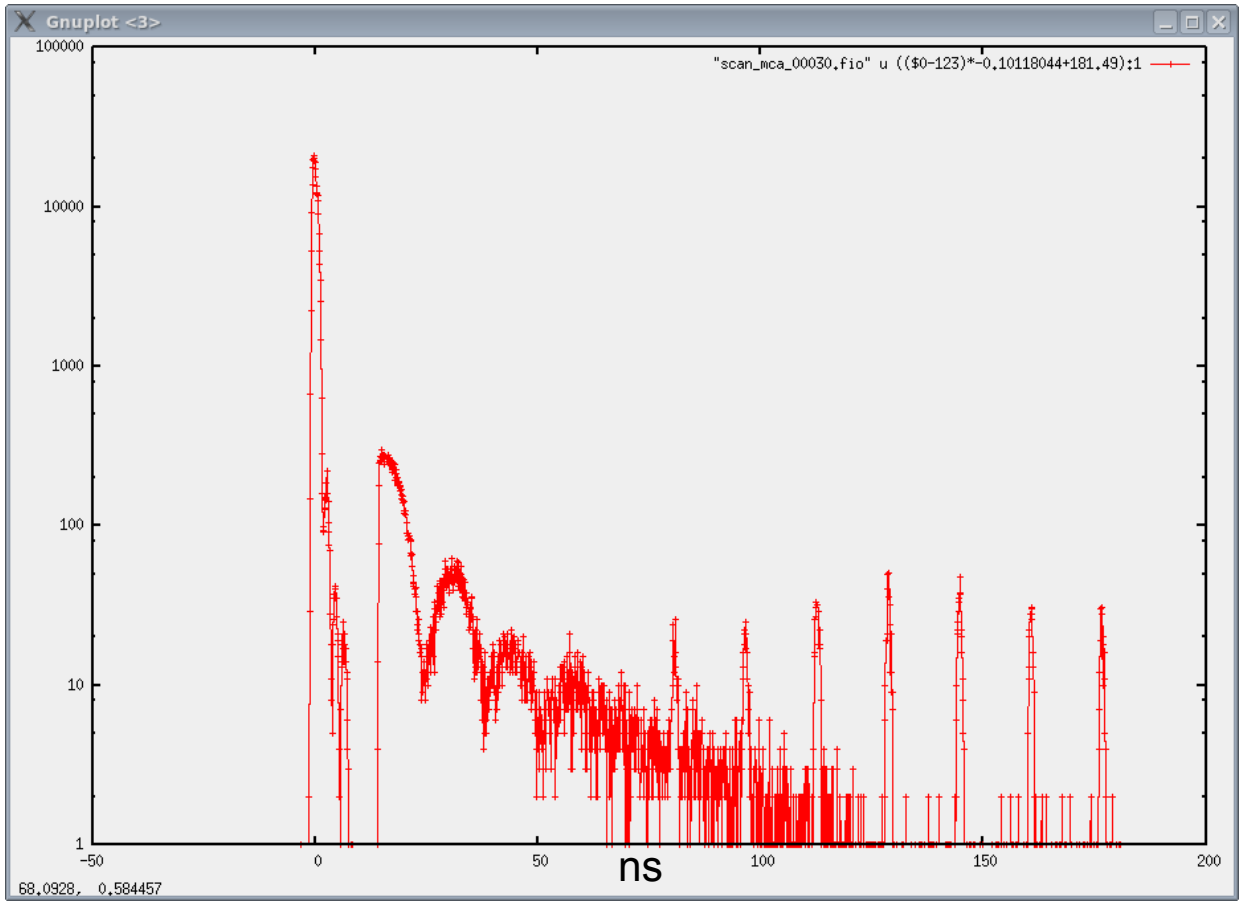
Spurious bunch problem



1000s sample time, sp. bunch rate < 5 Hz

detector noise < 0.1 Hz

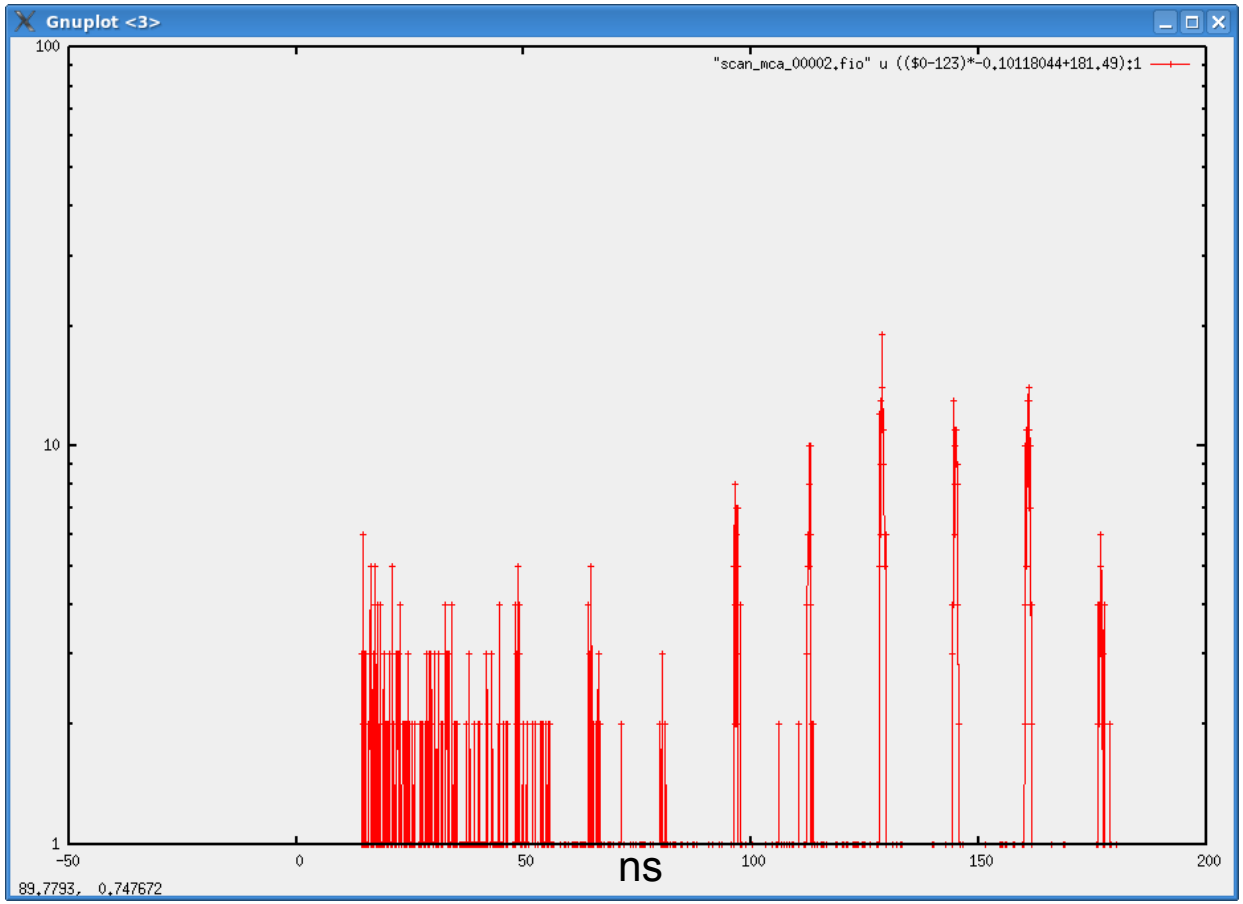
Spurious bunch problem



2700 s sample time, sp. bunch rate < 5 Hz

detector noise < 0.1 Hz

Spurious bunch problem

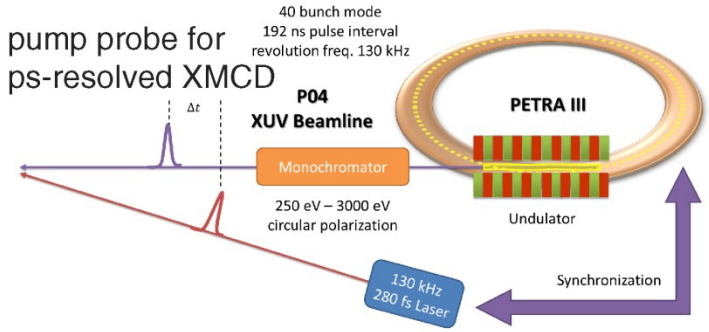


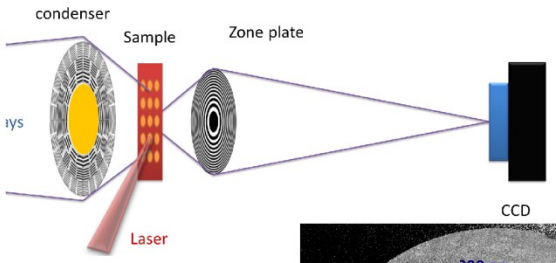
1000 s sample time, sp. bunch rate < 5 Hz

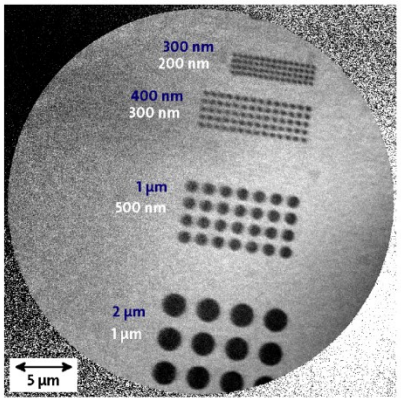
detector noise < 0.1 Hz

Timing Experiments at the XUV Beamline P04

> Time resolved XMCD-Imaging



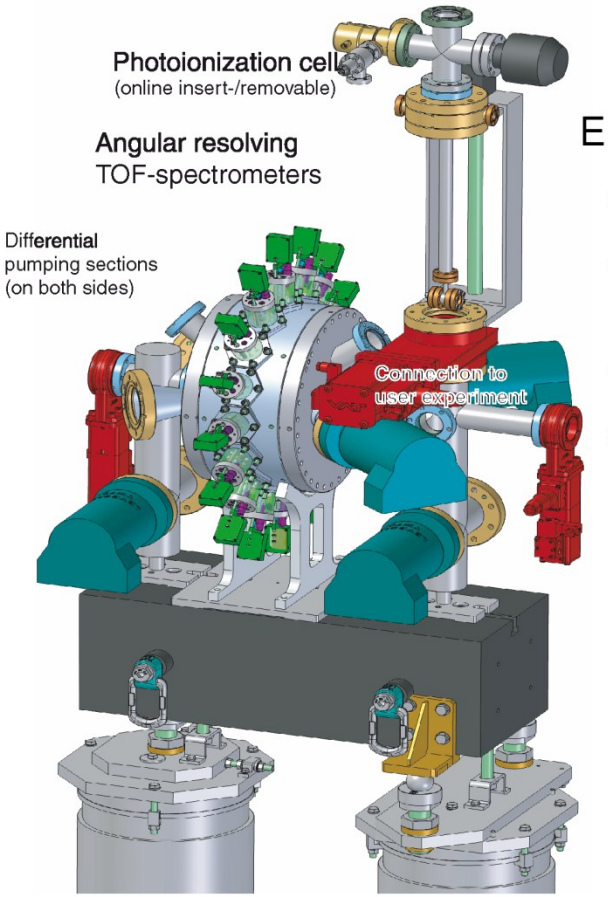




Flatfield corrected TXM image of nanostructured Co/Pt ML-system

AGs Drescher/Wilhein

> P04 beamline diagnostics and in-house research



Electron time-of-flight system:

- Photon flux (accuracy ≤1% abs.)
- Beam position (accuracy ≤1 µm) calibration possible with "BPMs
- Photon energy (≤ΔE, ≤1/10,000)
- Degree of polarization (accuracy ≤1%) user warning if S_i below a user-defined threshold.

> One third of P04 users requests timing mode

> Beamlines using timing mode: P01, P02, P04, P06, P08, P10, P11, (P24)

Summary

About half of the PETRA III beamlines are performing timing experiments

For most of them a decent bunch purity of 10^{-5} is sufficient

NRS experiments rely on a purity of at least 10^{-9}

(This is not new and had been established until summer 2012… lets go for it again !!)

MANY THANKS TO…

Hasan Yavas
Alessandro Kropmanns

Kai Schlage
Alexander Scholl

Frank-Uwe Dill
Yilmaz ‚Jimmy' Bican

Hermann Franz
Tatyana Guryeva
Olof Gutowski

Ralf Röhlsberger
Denise Erb
Anita Ehnes

Wolfgang Caliebe
Balaram Sahoo
Daniel Schumacher

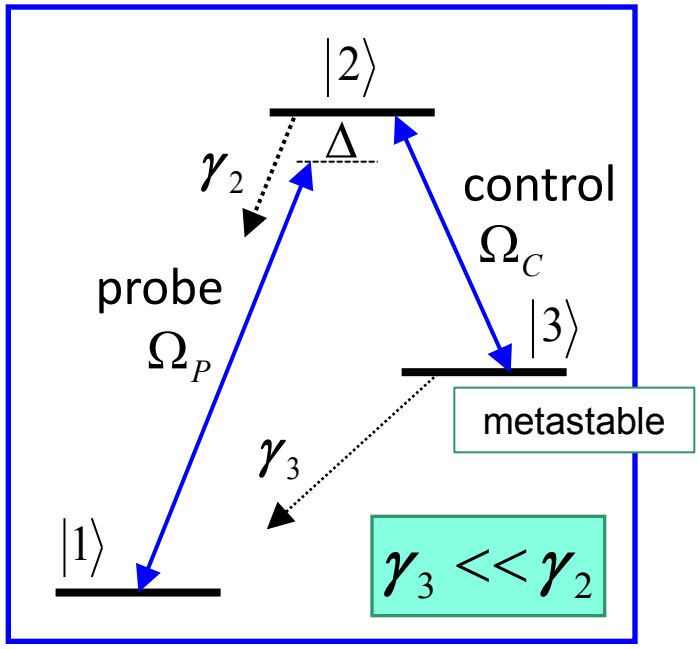
Hanns-Peter Liermann + P02 team
Michael Sprung + P10 team

FS-BT FS-EC FS-TI Safety + Machine Group

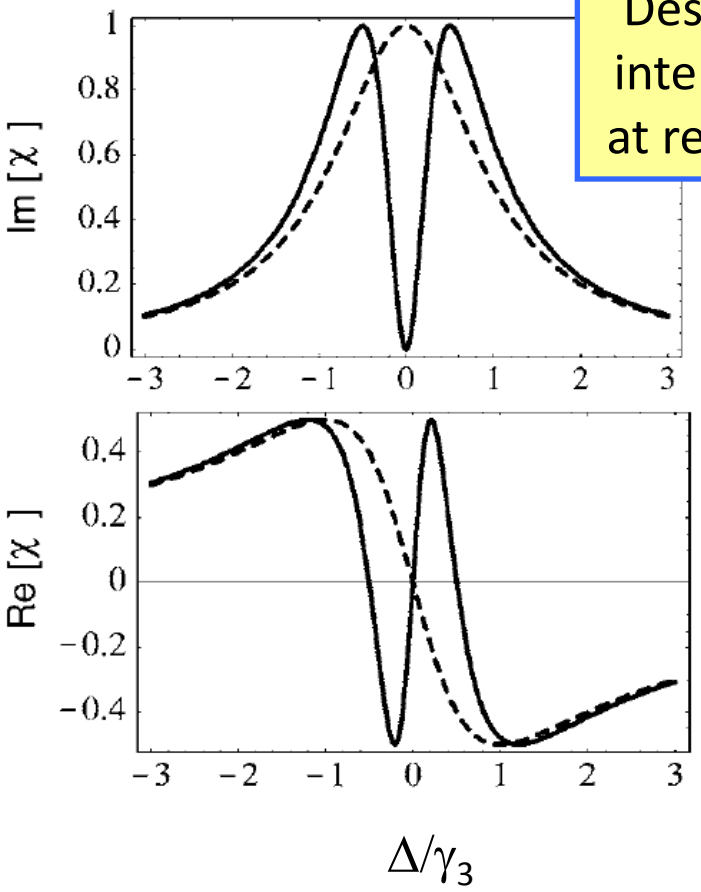
…

!! THANK YOU FOR YOUR ATTENTION !!

Electromagnetically Induced Transparency (EIT)



Destructive interference at resonance



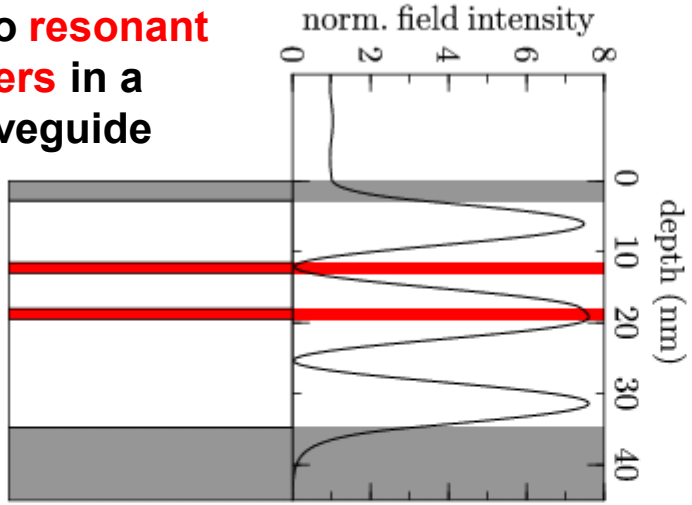
1st - order susceptibility

$$\chi(\Delta) = \frac{iP_{12}(i\Delta + \gamma_3)}{(i\Delta + \gamma_3)(i\Delta + \gamma_2) + |\Omega_C|^2}$$

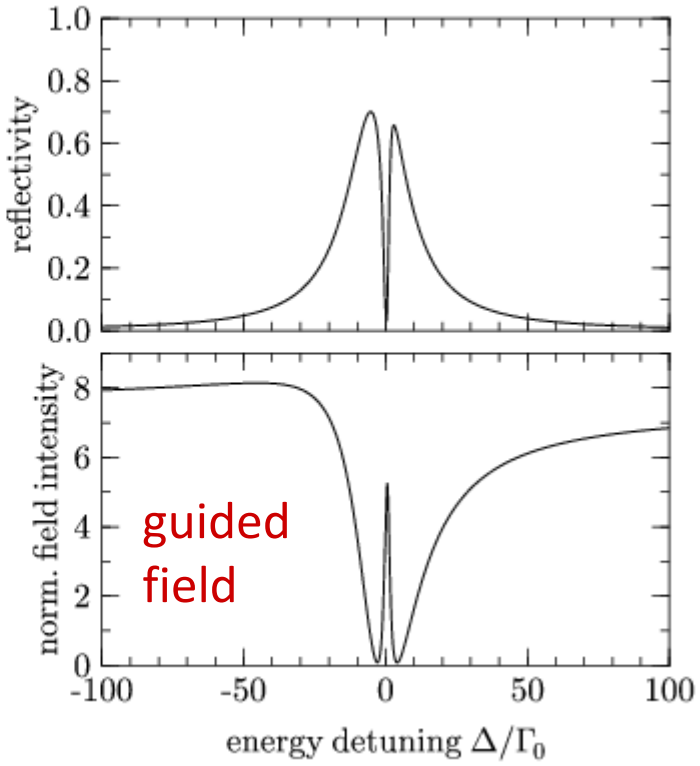
M. Fleischhauer, A. Imamoglu, J. P. Marangos, Rev. Mod. Phys. 77, 633 (2005)

Electromagnetically Induced Transparency

Two resonant layers in a waveguide



reflectivity



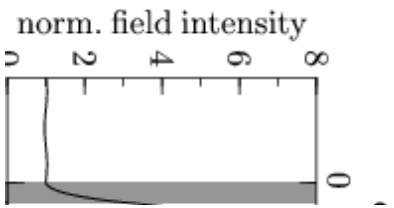
The ^{57}Fe layers occupy node (natural decay, metastable) and antinode (superradiant, fast) of the field

Electromagnetically Induced Transparency (EIT)

O. Kocharovskaya, Ya. I. Khanin, Sov. Phys. JETP 63, 945 (1986)

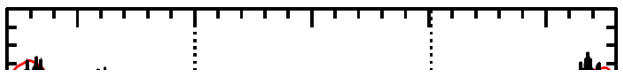
K. J. Boller, A. Imamoglu, S. E. Harris, Phys. Rev. Lett 66, 2593 (1991).

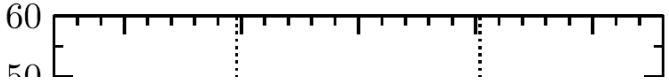
Nuclear Resonant EIT in a Cavity: Experiment



Experiment at P01 (R. Röhlsberger et al., May 2011)

(Four lines of nuclear resonance due to magnetic hyperfine splitting)



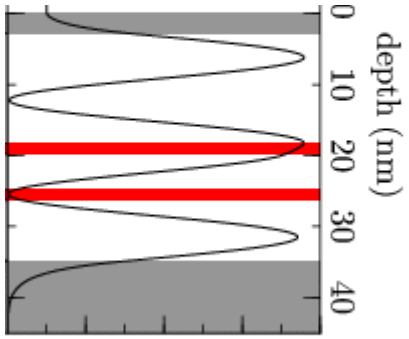


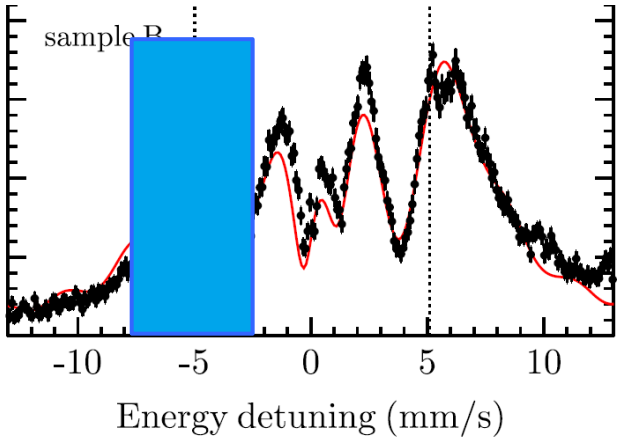
LETTER

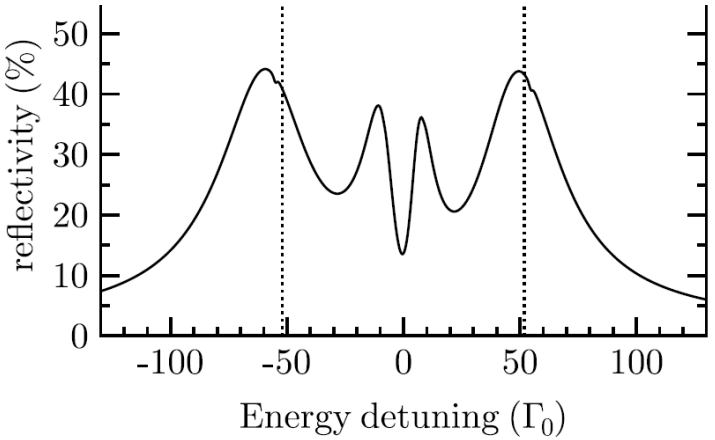
doi:10.1038/nature10741

Electromagnetically induced transparency with resonant nuclei in a cavity

Ralf Röhlsberger[1], Hans-Christian Wille[1], Kai Schlage[1] & Balaram Sahoo[1]







Time stamps…what happened so far @ P01

17.05.2010 First beam from 2m U23 (P02) in OH1

11.06.2010 First ^{57}Fe resonant counts

27.06.2010 First time spectrum from 2 microns thick ^{57}Fe foil (6 meV HR Monochromator)

15.07.2010 2.4meV HRM installed

25.07.2010 First Nuclear Inelastic Scattering (NIS) spectrum

Shutdown from 25.07.2010 until 20.08.2010

20.08.2010 3 weeks of timing mode

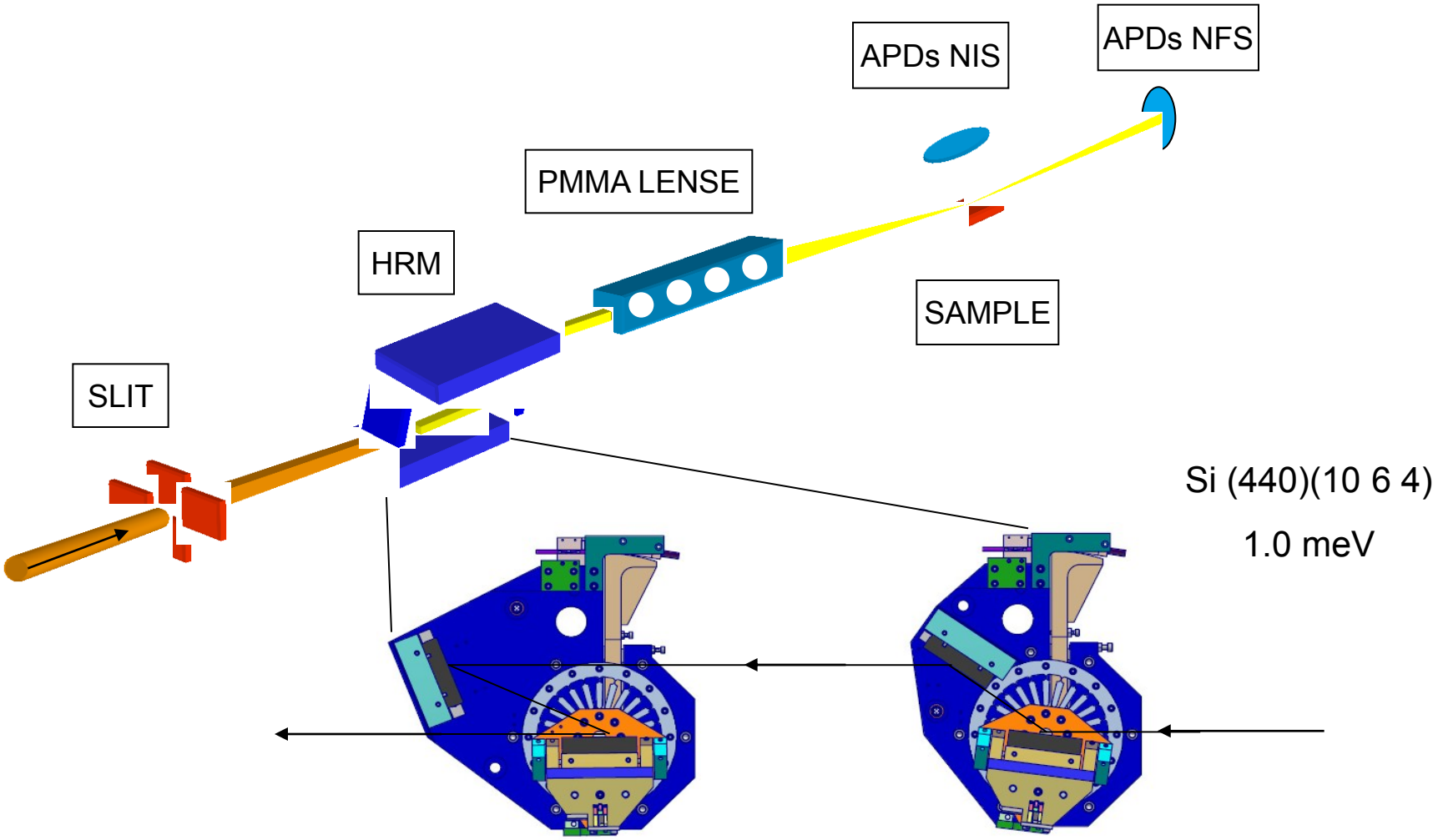
20.09. – no timing mode U23 back to P02

11.11.2010 Commissioning of the 5m U32

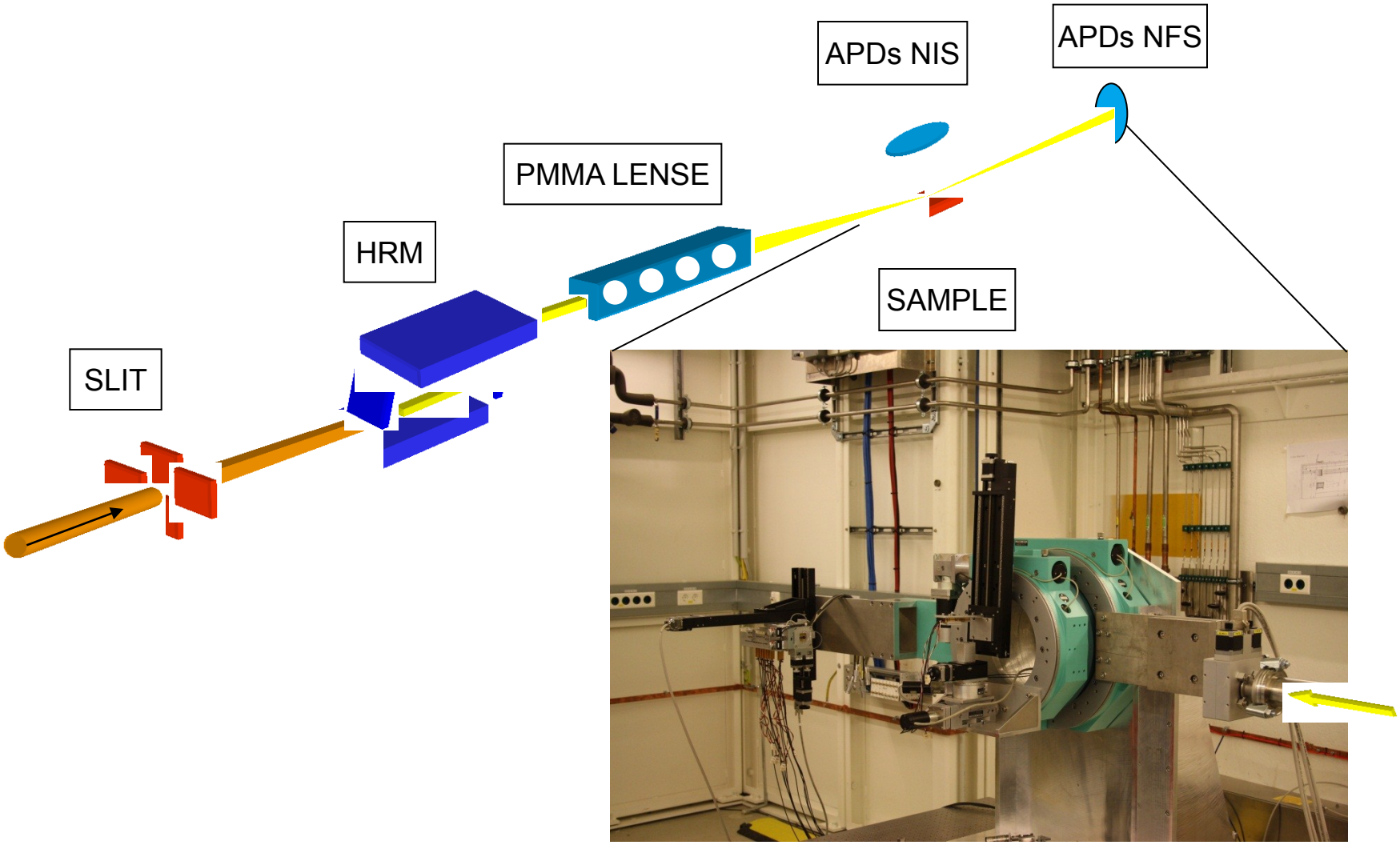
03.12.2010 3 weeks of timing mode

In total 6 weeks of timing mode beamtime since August 2010

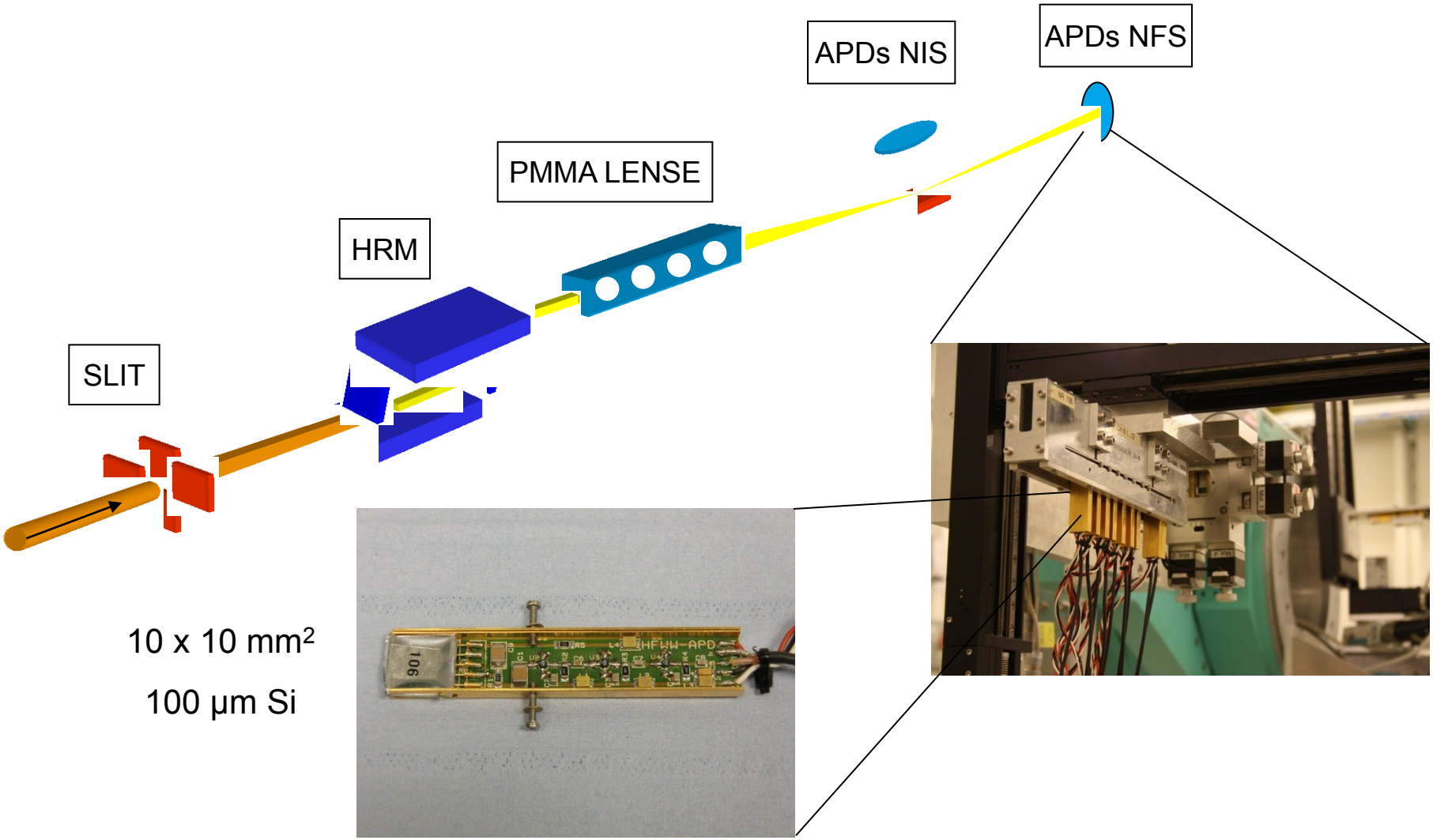
Setup θ-2θ with focused beam (EH1)



Setup θ-2θ with focused beam (EH1)



Setup θ-2θ with focused beam (EH1)

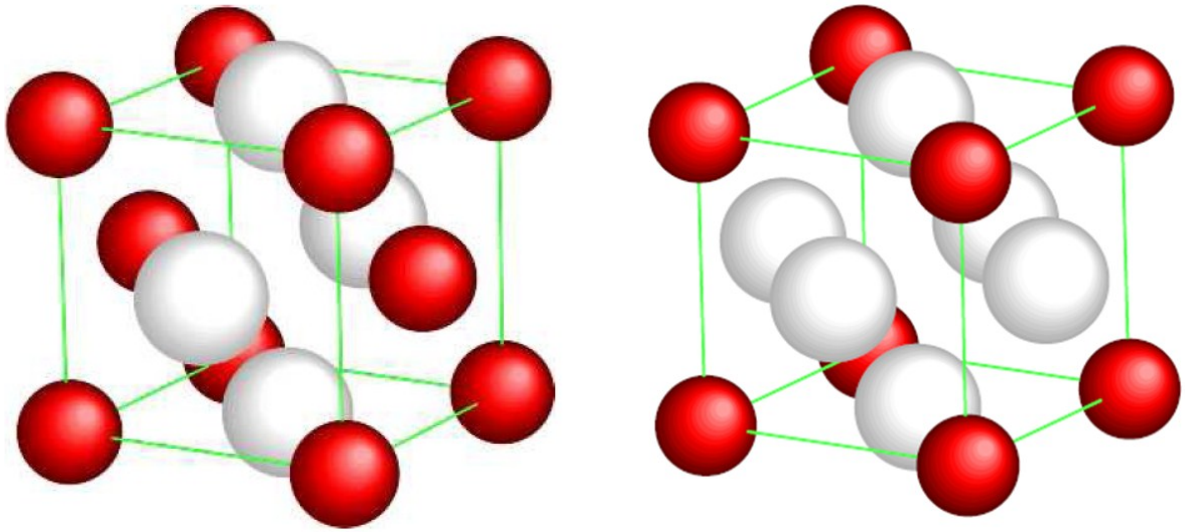


Site specific phonon density of states in $L1_x$ $FePt_x$ alloys (S. Couet)

FePt is a magnetic material with a huge magneto-crystalline anisotropy (good hard magnet)

$\Rightarrow$ This originates from the crystal anisotropy

$FePt$ $L1_0$



$FePt_3$ $L1_2$

Fe atoms in red

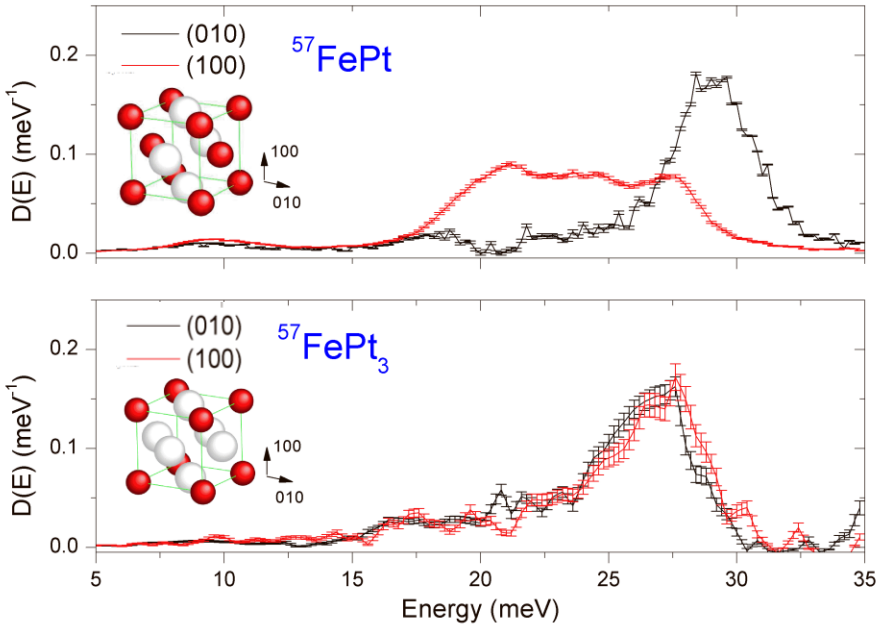
- How the anisotropy translate on the vibration spectrum?
- Which atoms contribute to which part of the PDOS (non equivalent atom position)?

$\Rightarrow$ Compare the PDOS of FePt and $FePt_3$

Site specific phonon density of states in $L1_x$ $FePt_x$ alloys

Measurement carried out on epitaxial FePt and $FePt_3$ thin films (30 nm) grown on MgO(100) and MgO(110) substrates

Measurement on ^{57}FePt carried out at ID18, ESRF[1]



- FePt(010) PDOS close to $FePt_3$
- Peak shift induced by different strain in the two layers
- No major modes belonging to the “face-centered” Fe atom?

[1]S. Couet et al., Phys. Rev. B 82, 094109 (2010)

Size dependent PDOS of ^{57}Fe islands on MgO (S. Couet)

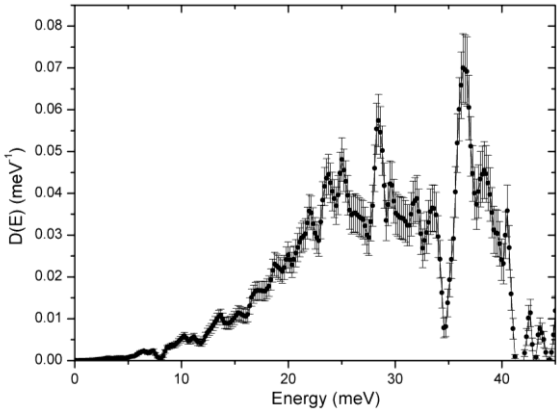
Tuning of the island size by control of the nominal thickness of Fe deposited at 700°C

5 nm

2 nm

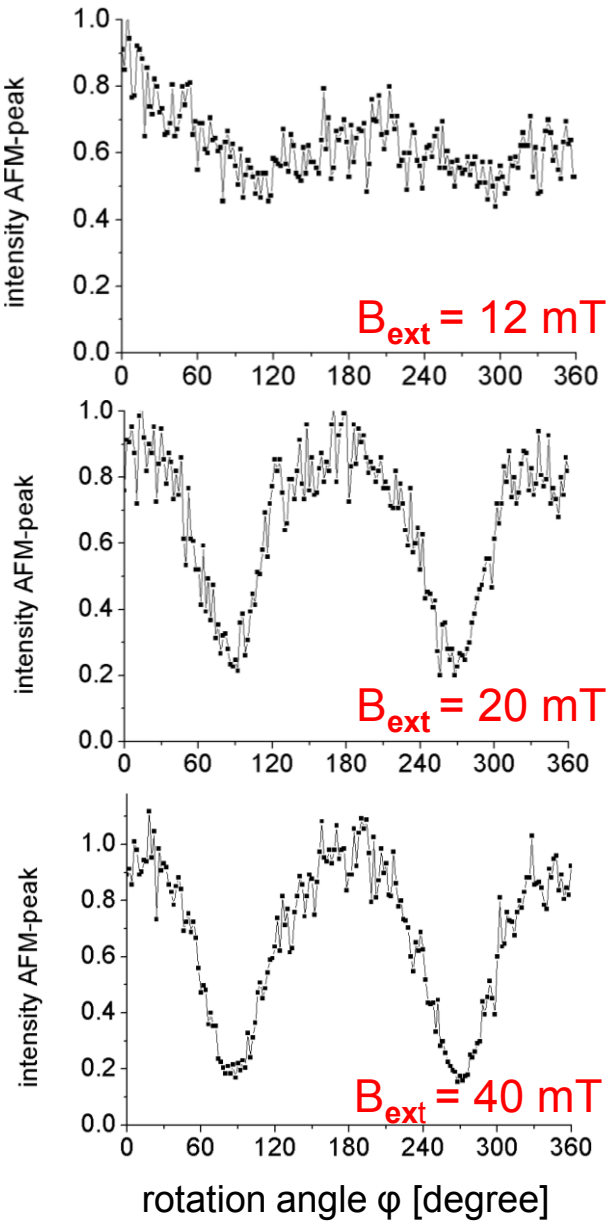
1 nm

⇒ Search for phonon confinment/quantum effects in nanostructures

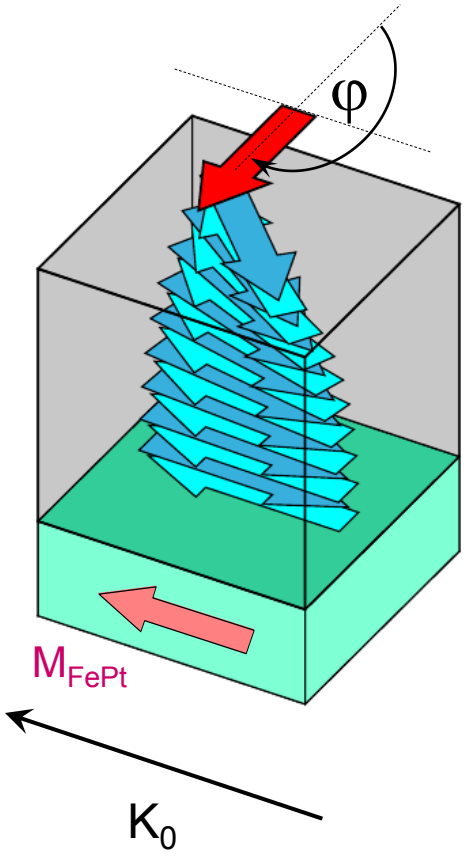


Still to be measured

Resonant Reflectometry on Magnetically Coupled Thin Films

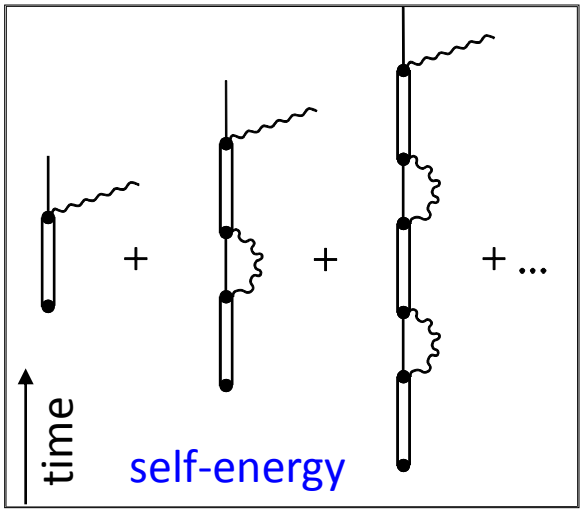


azimuthal rotation of the external field:

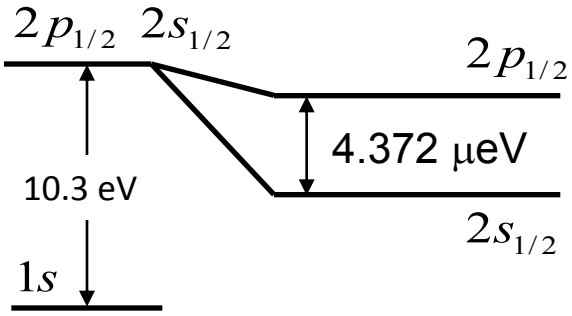


The Collective Lamb Shift

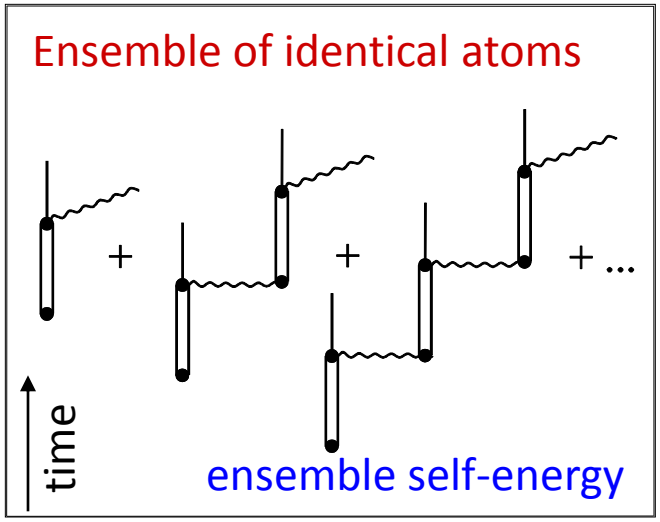
Single-atom Lamb shift



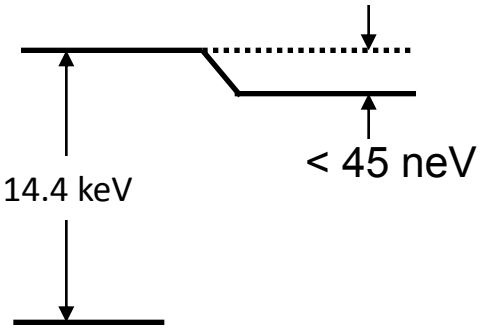
Hydrogen energy levels

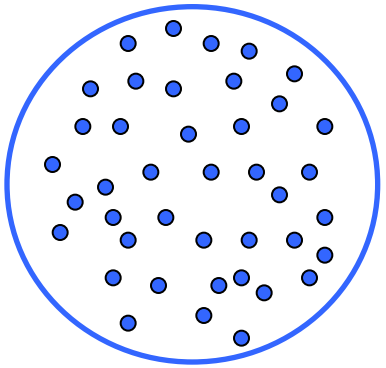


Collective Lamb shift



^{57}Fe nuclear resonance



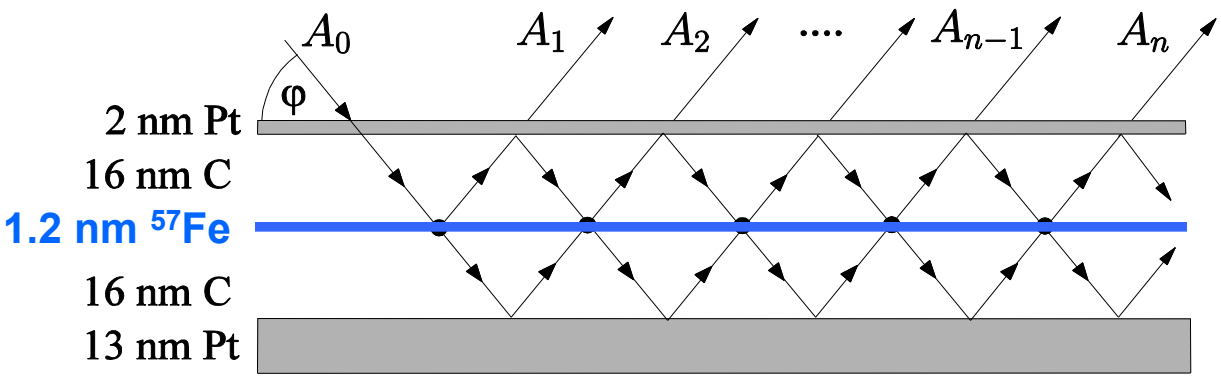


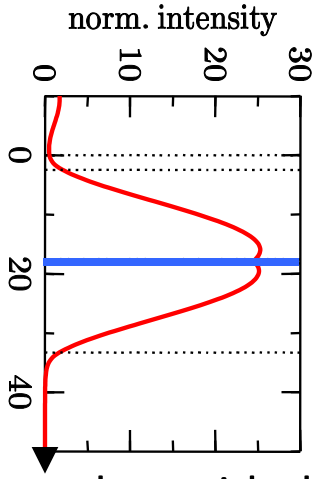
Cloud of N identical atoms acting as a giant atom

R. Friedberg et al., Phys. Rep. C 7, 101 (1973)
M. O. Scully, Phys. Rev. Lett. 102, 143601 (2009)

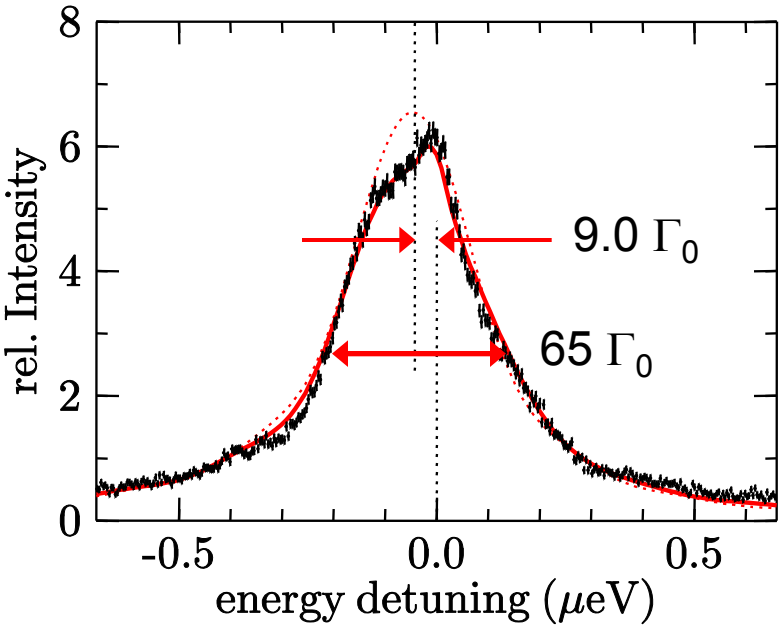
DESY

Experimental results (ID18 ESRF): The collective Lamb shift



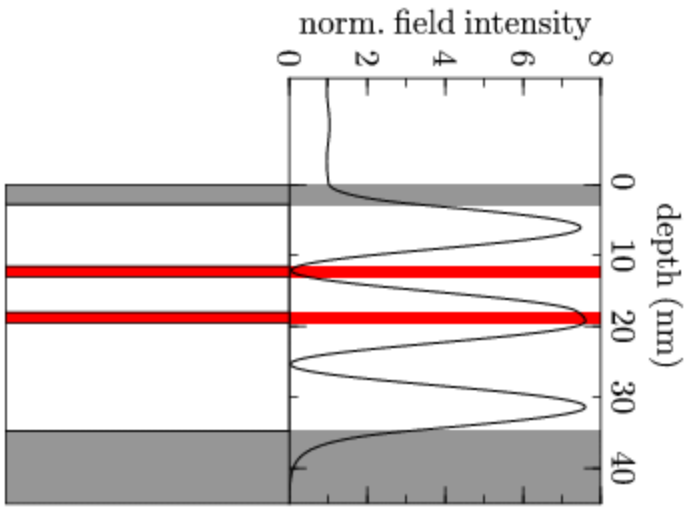


first-order guided mode

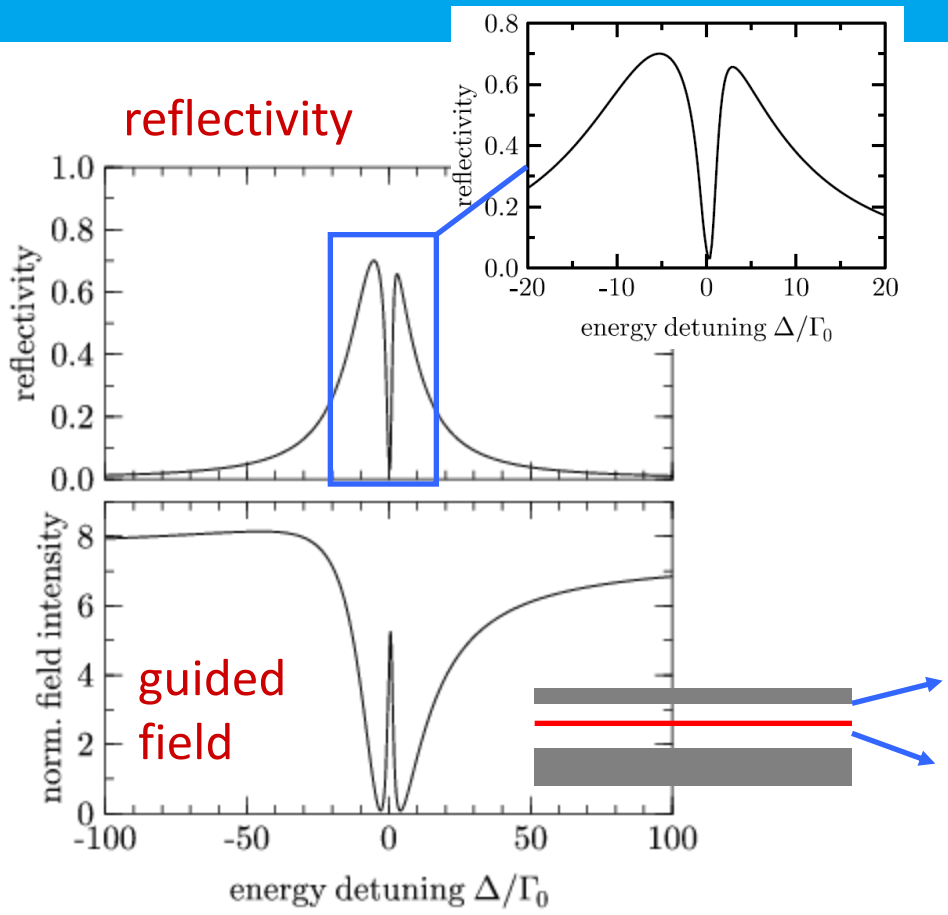


R. Röhlsberger, K. Schlage, B. Sahoo, S. Couet, R. Rüffer, *Science* 328, 1248 (2010)

Two resonant layers in a cavity



The layers occupy node and antinode of the cavityfield



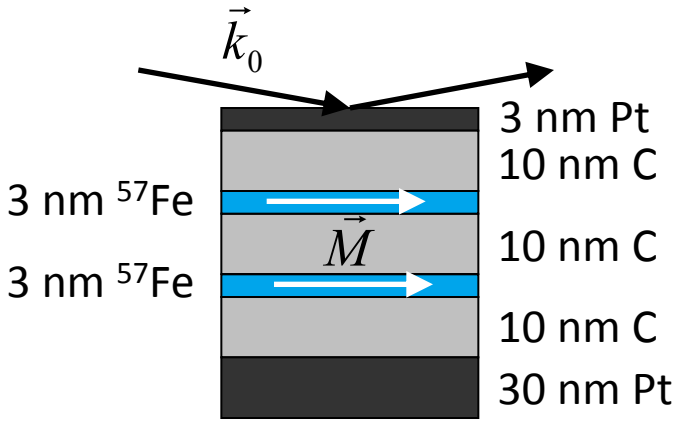
Electromagnetically induced transparency

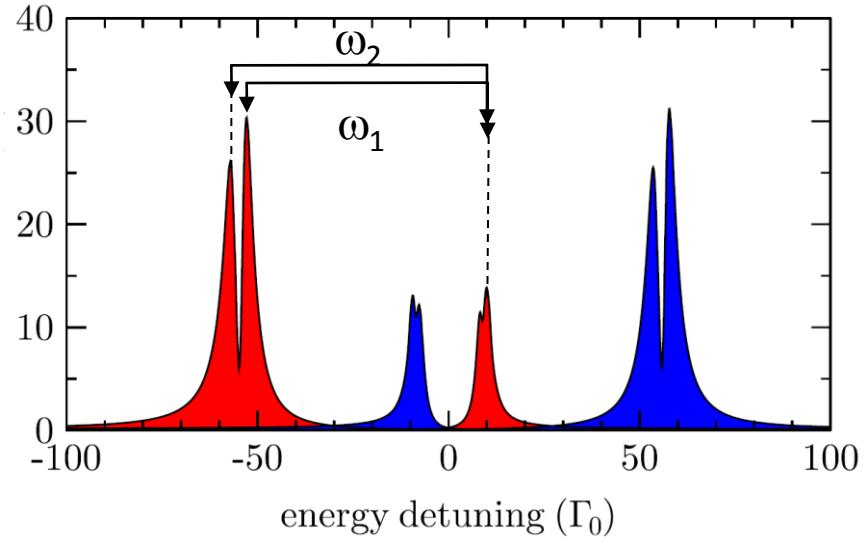
O. Kocharovskaya, Ya. I. Khanin, Sov. Phys. JETP 63, 945 (1986)

K. J. Boller, A. Imamoglu, S. E. Harris, Phys. Rev. Lett 66, 2593 (1991).

Electromagnetically induced transparency

Possible evidence seen at P01





DATA NOT YET PUBLISHED AND NOT SHOWN IN THIS VERSION

Flux compared to ESRF

	P01	ID18 (4.8m U23)
Now (5m U32):		
Flux after HHLM (in 2eV)	$2.6*10^{13}$	$5.0*10^{13}$
Flux after 2.4 meV HRM	$6.0*10^{8}$	$1.2*10^{10}$
Efficiency of HRM	2% (channel cut)	20%
June 2011 (2x5m U32):		
Flux after HHLM (in 2eV)	$5.2*10^{13}$	$5.0*10^{13}$
Flux after 1.0 meV HRM	$7.5*10^{9}$	$5.7*10^{9}$
Efficiency	30%	23%
2012 / 2013 (2x5m U32 + 2x5m U21):		
Flux after HHLM (in 2eV)	$1.5*10^{14}$	$5.0*10^{13}$
Flux after 1.0 (0.7) meV HRM	$2.2*10^{10}$	$5.7*10^{9}$

In the end a factor of 4 more flux at P01 All values for 100 mA ring current

Summary

First nuclear forward and nuclear inelastic measurements have been performed

Theoretical flux from 5m U32 undulator confirmed, new HRM setup and 10m optimized undulators strongly desired

Even with raw focussing and low flux enriched nano structured samples can be studied

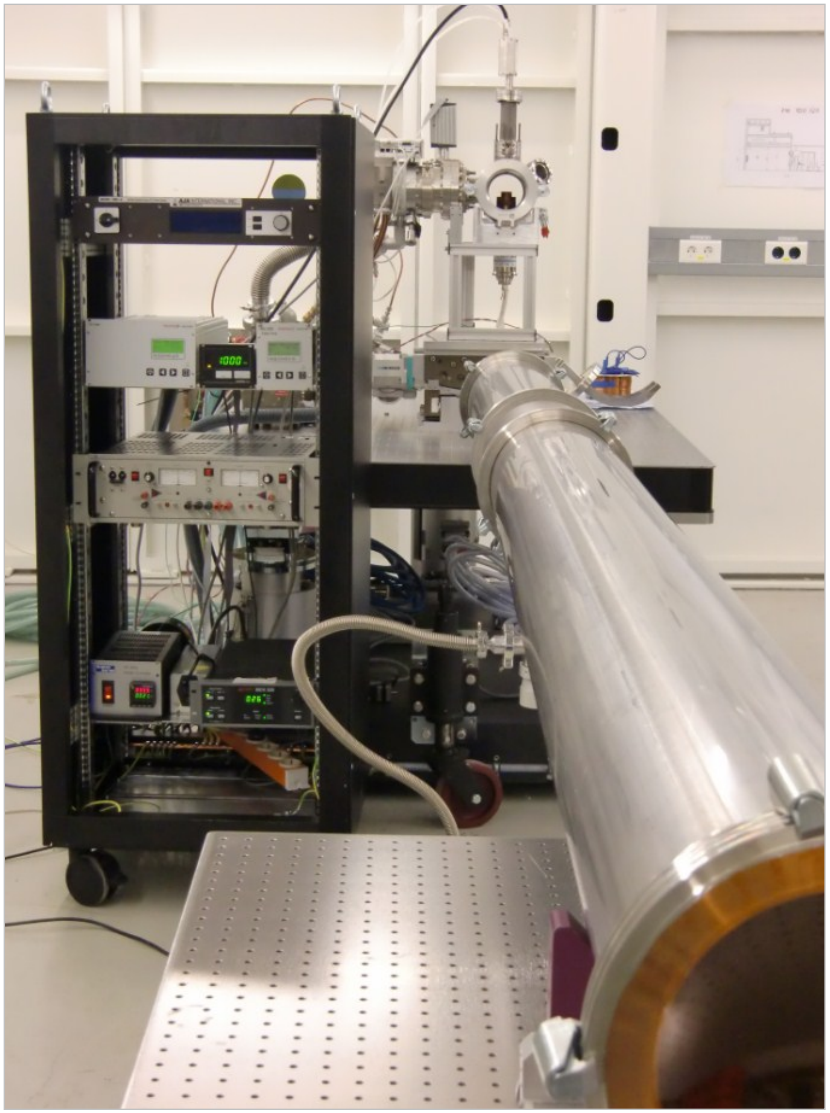
First experiments on vibrational dynamics in nano systems and on magnetic nano layer systems have been performed succesfully

Due to its outstanding brilliance and focusing options P01 will offer unique possibilities for NRS and IXS in nano - and extreme condition science

First official user experiments in November 2011

Application deadline for first round is 1st of March 2011

Outlook: Combined In-Situ NFS-GISAX Setup



- sputter deposition chamber
- flexible flight tube setup (1 m to 6 m)
- guard slits + beam stops
- 2D-PMMA x-ray lenses
- x-ray area detector
- APD stage for nuclear line scans

What´s coming next @ P01?

April	2011	TÜV check of EH2 and EH3
May	2011	Installation of the 2nd 5m U32 undulator
June	2011	Installation of the 1 meV HRM
October	2011	Installation of the first KB mirror
		1 Tesla magnet, He flux (^{3}He) and He displex
November	2011	First official user experiments on NRS
2012		Reflecting focusing mirrors for IXS installed in OH1
		IXS diffractometers installed in EH2
		Backscattering HRM 1meV for isotopes with E_0 > 20 keV in EH3
201x		Installation of 2 x 5m U21

!! Proposals are accepted now 1st deadline is March 01 2011 !!