# Energy resolved nuclear resonant scattering of synchrotron radiation applied to an $Fe_3Al$-foil

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**APS**

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# Overview

- Motivation
  - Comparative study of three Mössbauer techniques
  - Why $Fe_3Al$?
- Experimental details
  - Sample preparation
  - Mössbauer spectroscopy
  - Time Resolved NRS
  - Energy Resolved NRS
- Discussion
- Conclusion

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# Motivation

**Techniques**

Mössbauer spectroscopy (1966)

Time resolved nuclear resonant scattering of synchrotron radiation (1985)

Energy resolved nuclear resonant scattering of synchrotron radiation (2004)

R. Callens et al., Phys. Rev. B 72 (2005) 081402(R)

**Materials**

Materials with an increasing degree of complexity and reduced dimensions

# Motivation

**Techniques**

Mössbauer spectroscopy (1966)

Time resolved nuclear resonant scattering of synchrotron radiation (1985)

Energy resolved nuclear resonant scattering of synchrotron radiation (2004)

R. Callens et al., Phys. Rev. B 72 (2005) 081402(R)

**Materials**

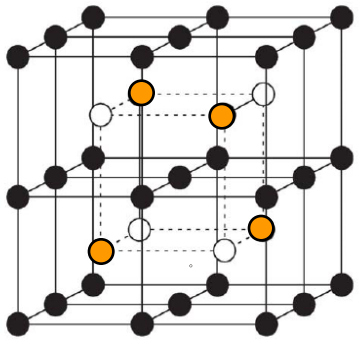
Materials with an increasing degree of complexity and reduced dimensions

Comparative study of the three techniques by extracting the magnetic structure of an $Fe_3Al$ foil from a MS spectrum, a time resolved NRS and an energy resolved NRS spectrum

# Why $Fe_3Al$?

* $Fe_3Al$ has a cubic $DO_3$ structure with two possible Fe environments:

Fe(bcc): 2.492 μB/ atom, Bhf = 31 T
Fe(fcc): 1.939 μB/ atom, Bhf = 24 T




→ **complex magnetic structure**

* The Fe(fcc) atoms could exhibit metamagnetism under high pressure (32 GPa)

J.Y.Rhee and B.N. Harmon, PRB 70, 094411 (2004)

→ **low-dimensional system**

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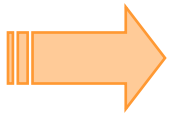
# Sample preparation

## 3 micron thick $^{57}Fe_3Al$-foil

melting of $^{57}Fe$ and Al
grinding to a foil of 10 micron
cold rolling to a foil of 3 micron (± 1 micron!)



**disordered alloy**

# Sample preparation

## 3 micron thick $^{57}Fe_3Al$-foil

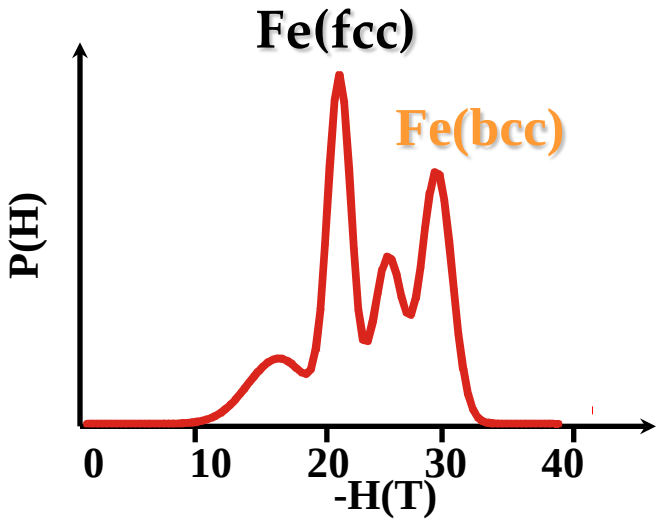
melting of $^{57}$Fe and Al
grinding to a foil of 10 micron
cold rolling to a foil of 3 micron (± 1 micron!)

⇒ disordered alloy

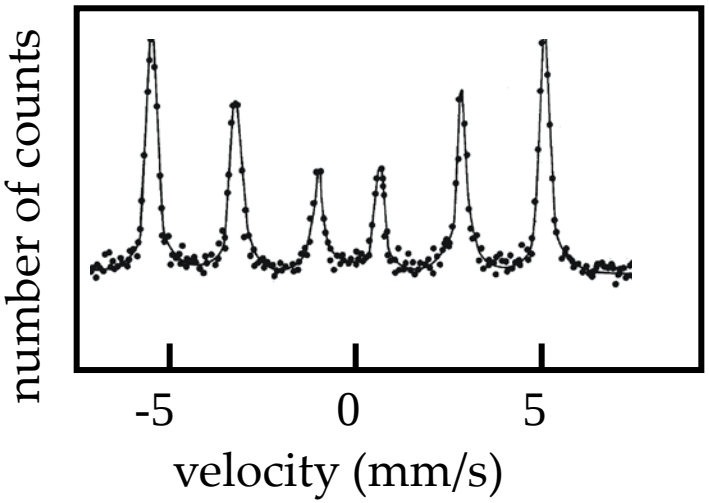
annealing for 4 h at 773 K
annealing for 32 h at 723 K

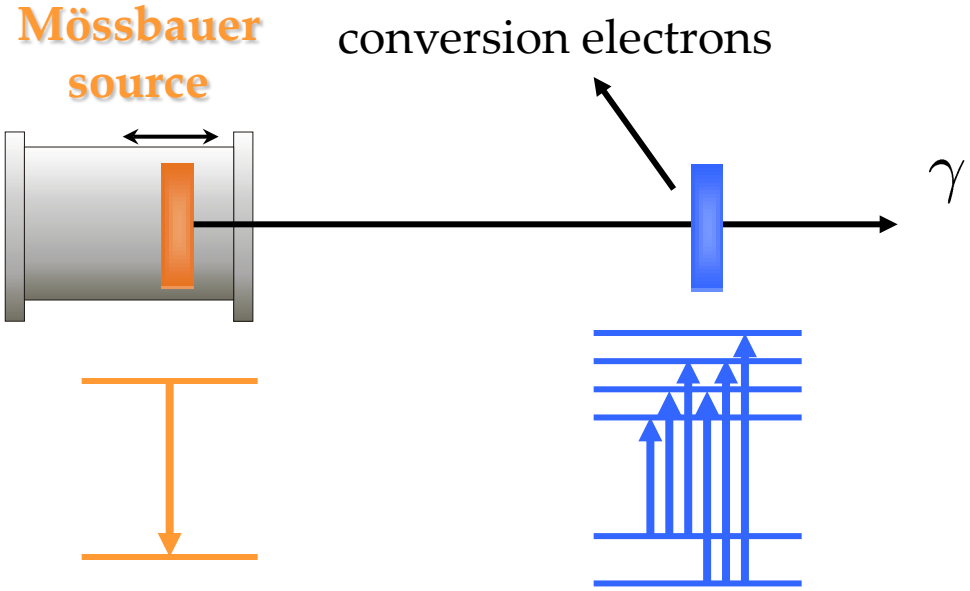
⇒ ordered alloy

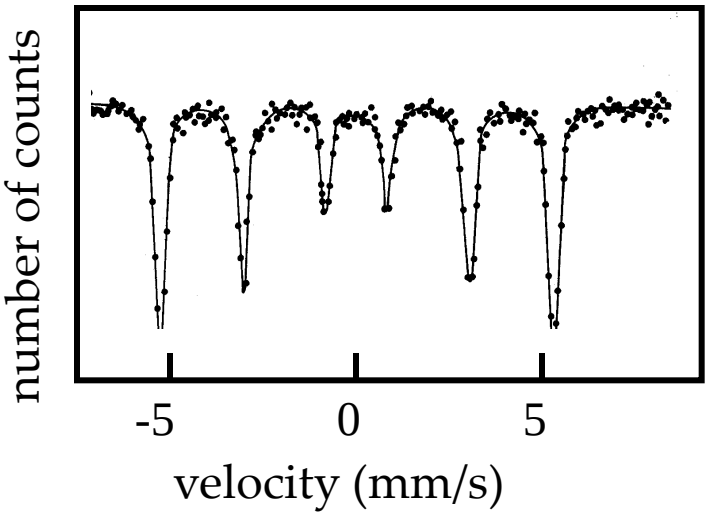
B. Fultz *et al.*, PRL 80 (1998) 3304



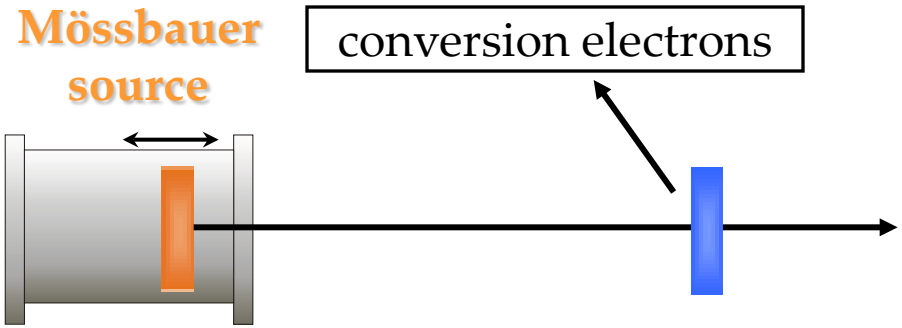
# Mössbauer spectroscopy



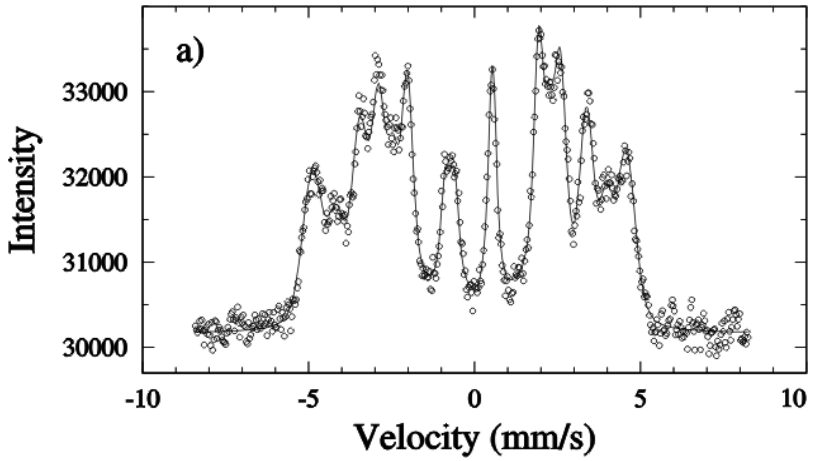



# Mössbauer spectroscopy



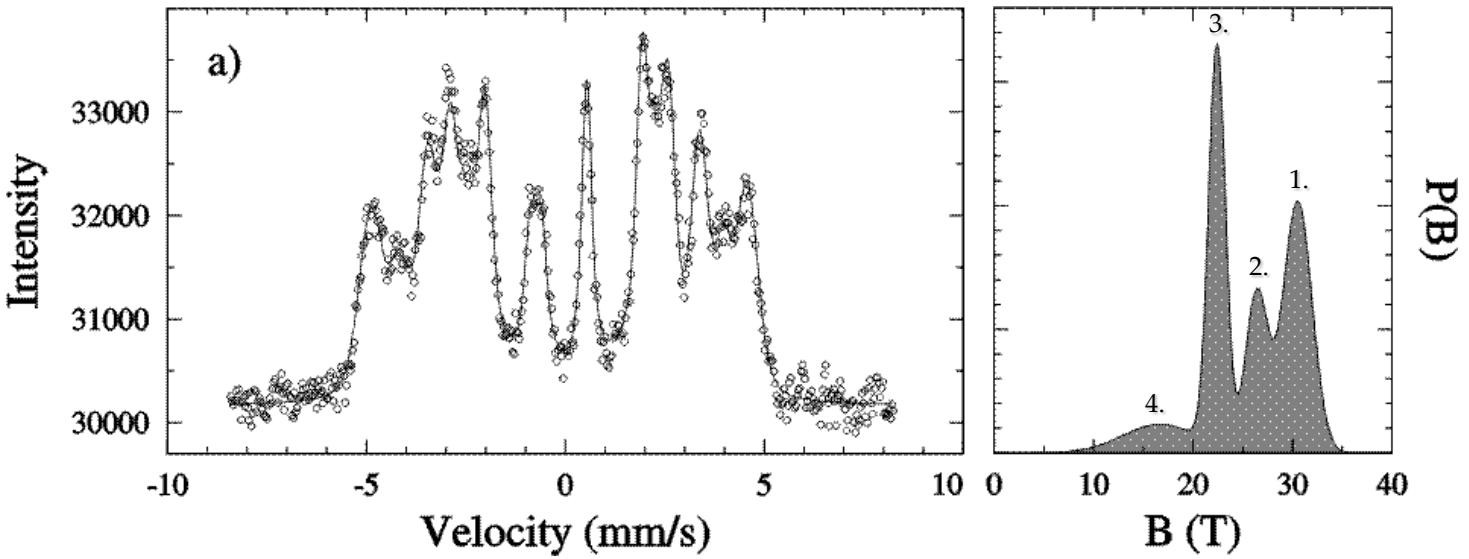

$^{57}$Co in a Rh matrix source

$^{57}Fe_3Al$ foil
$B_{ext}$= 0 T



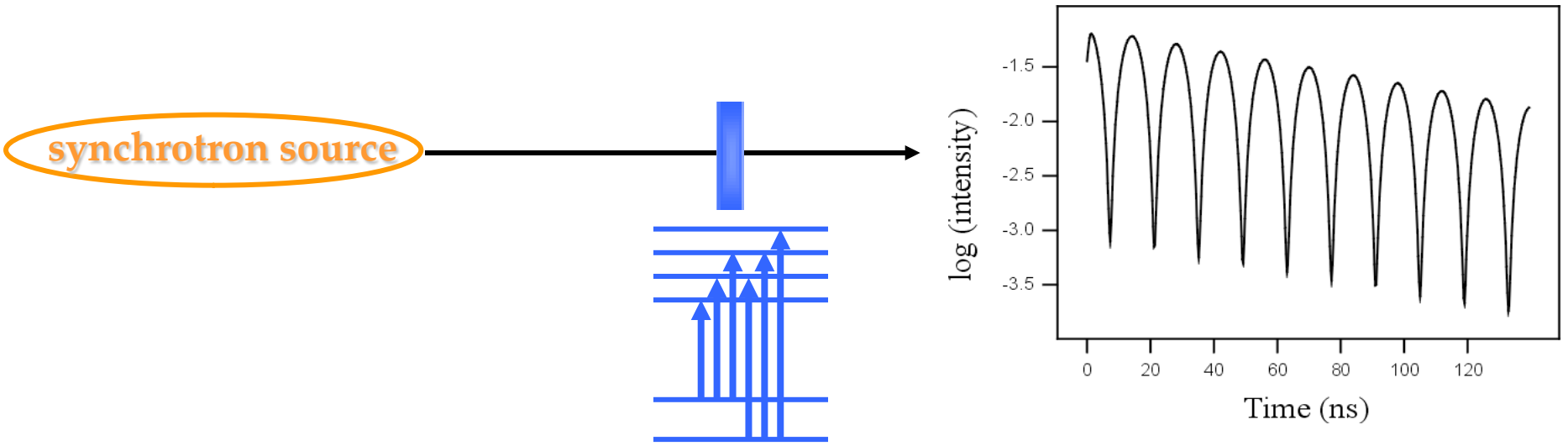
# Mössbauer spectroscopy

**Measured spectrum = incoherent addition of sextets of peaks**




* Four magnetic sites, Gaussian distribution included for each hyperfine field
* Site 1 and 3: ordered $DO_3$ stoichiometric $Fe_3Al$
* Site 2 and 4 : residual disorder, …
* Isomer shift of *all* sites relative to Mössbauer reference
* Linear dependende of I onto H: I = AH+B

# Time Resolved NRS

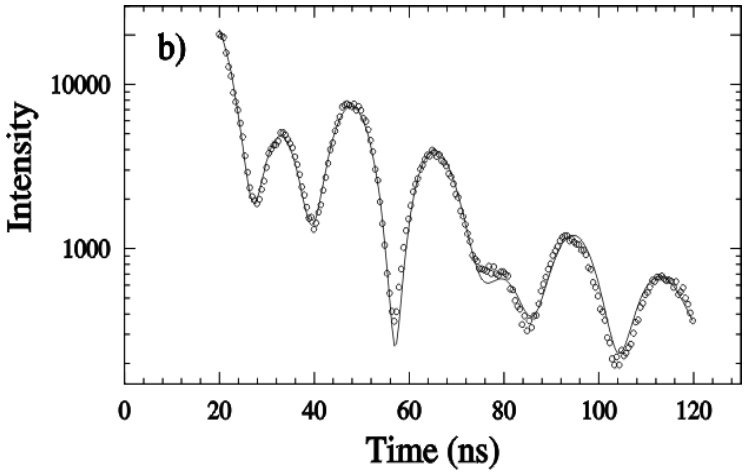


# Time Resolved NRS

synchrotron source

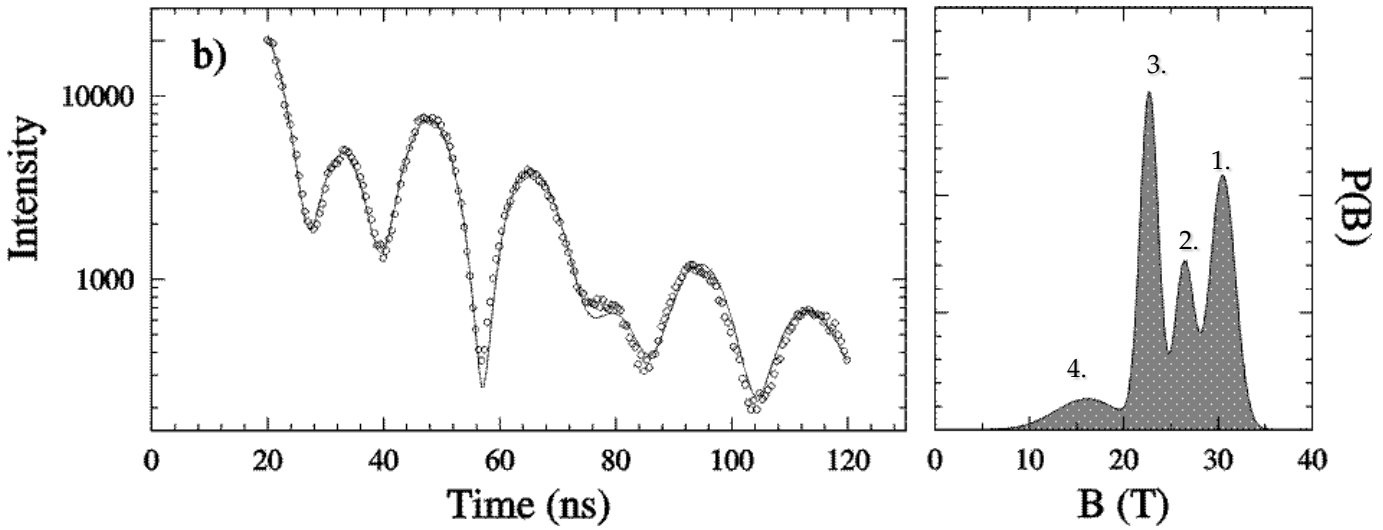
APS XOR-3-ID
14.413 keV
15 µm (v) x 10 µm (h)

$^{57}Fe_3Al$ foil
$B_{ext}$ = 2.50 T



# Time resolved NRS

**Measured spectrum = interference pattern**




* Four magnetic sites, Gaussian distribution included for each hyperfine field
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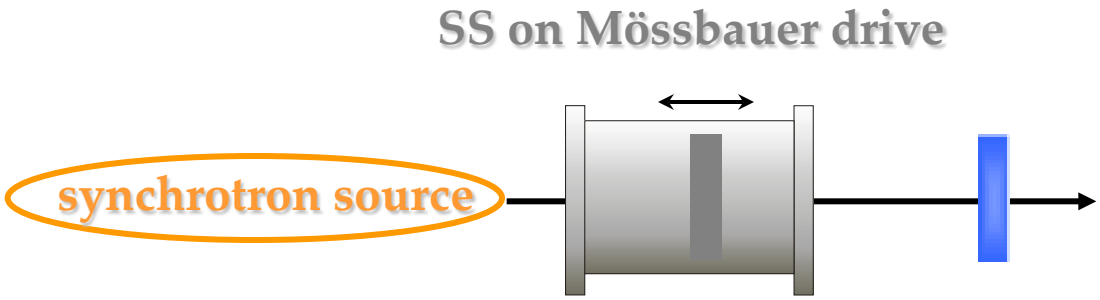
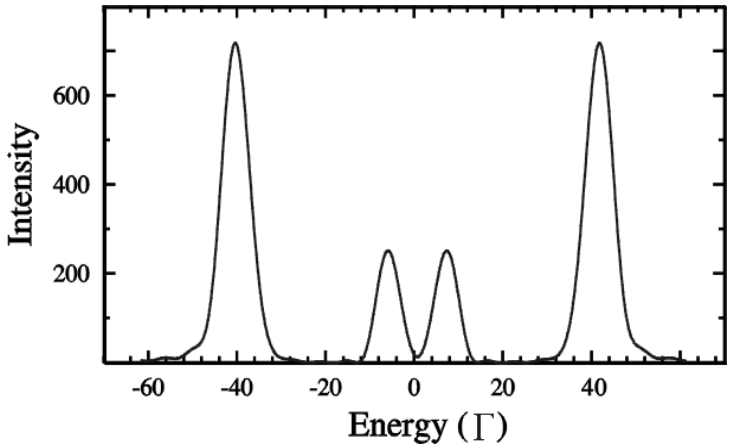
# Energy Resolved NRS



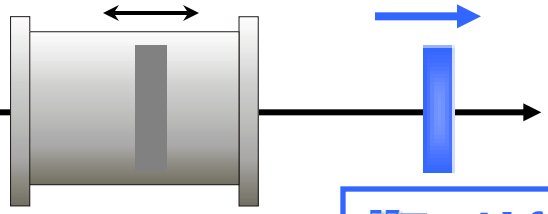




R. Callens et al., Phys. Rev. B 72 (2005) 081402(R)

# Energy Resolved NRS

SS on Mössbauer drive

synchrotron source



APS XOR-3-ID

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15 µm (v) x 10 µm (h)

$^{57}Fe_3Al$ foil

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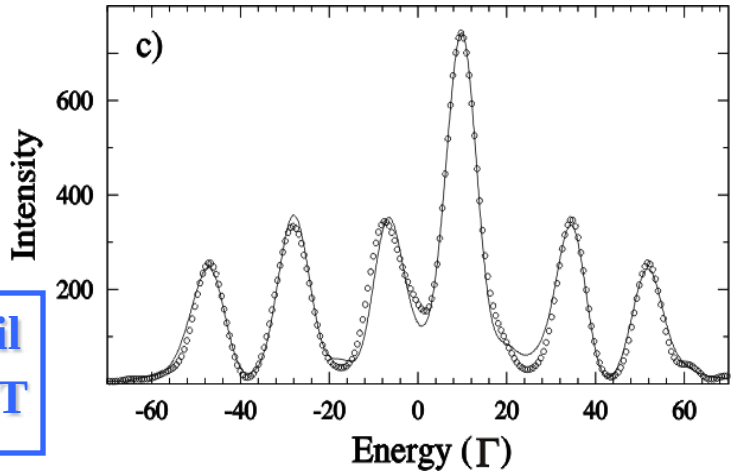



SS310 foil (0.93 µm thick)

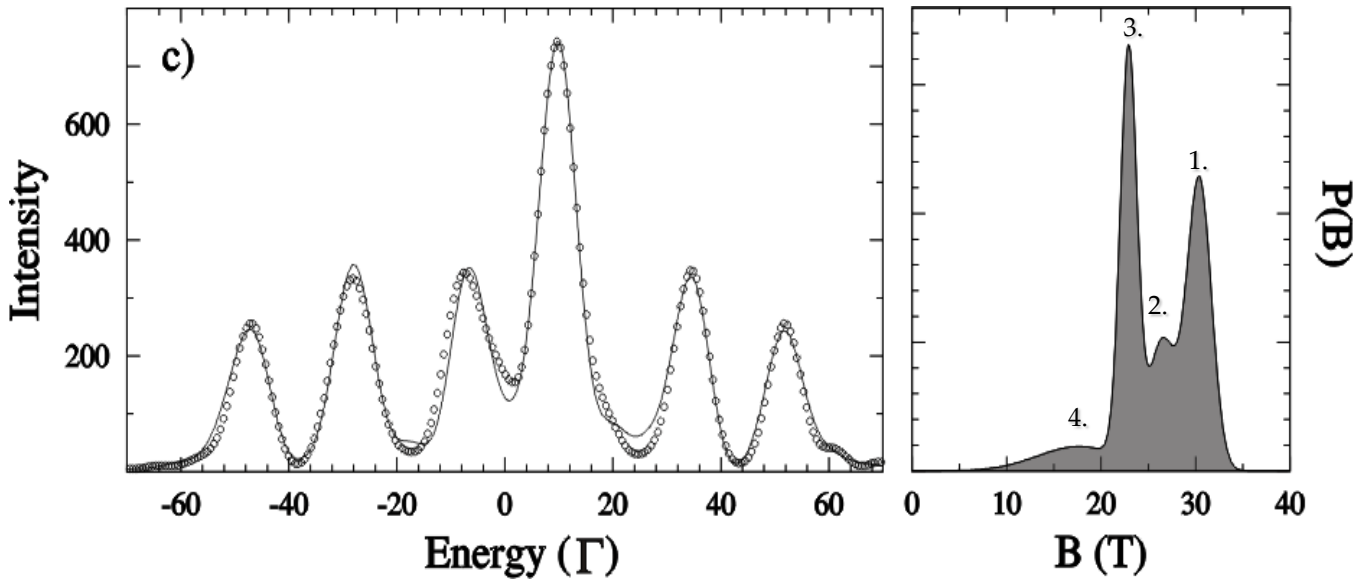
95% $^{57}Fe$ enriched

velocity drive in sinusoidal mode

$v_{max}$=16.7 mm $s^{-1}$

# Energy Resolved NRS

**Measured spectrum = coherent addition of quartets of peaks**

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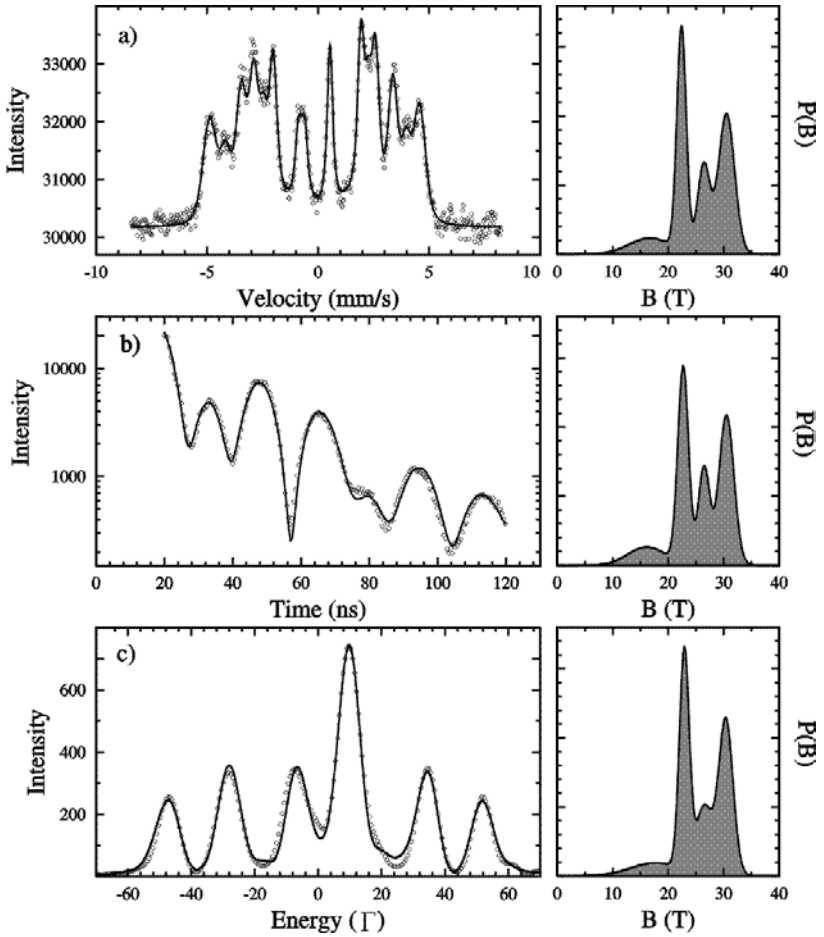
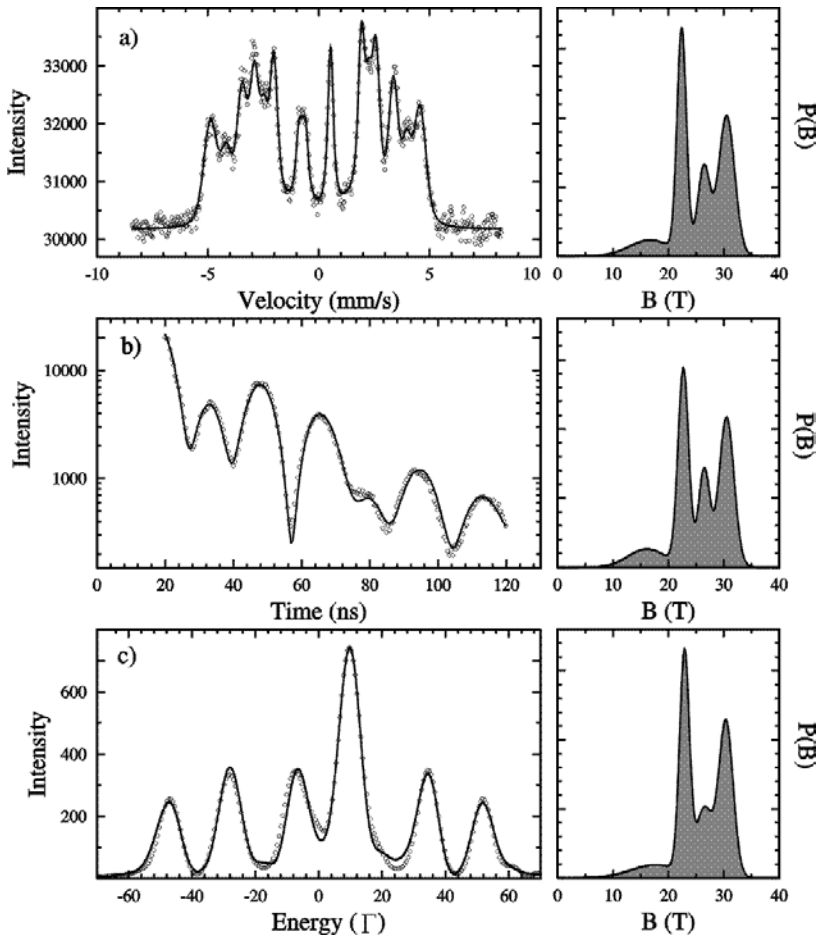
# Comparison of the spectra

* The three spectra can be analyzed with nearly the same model



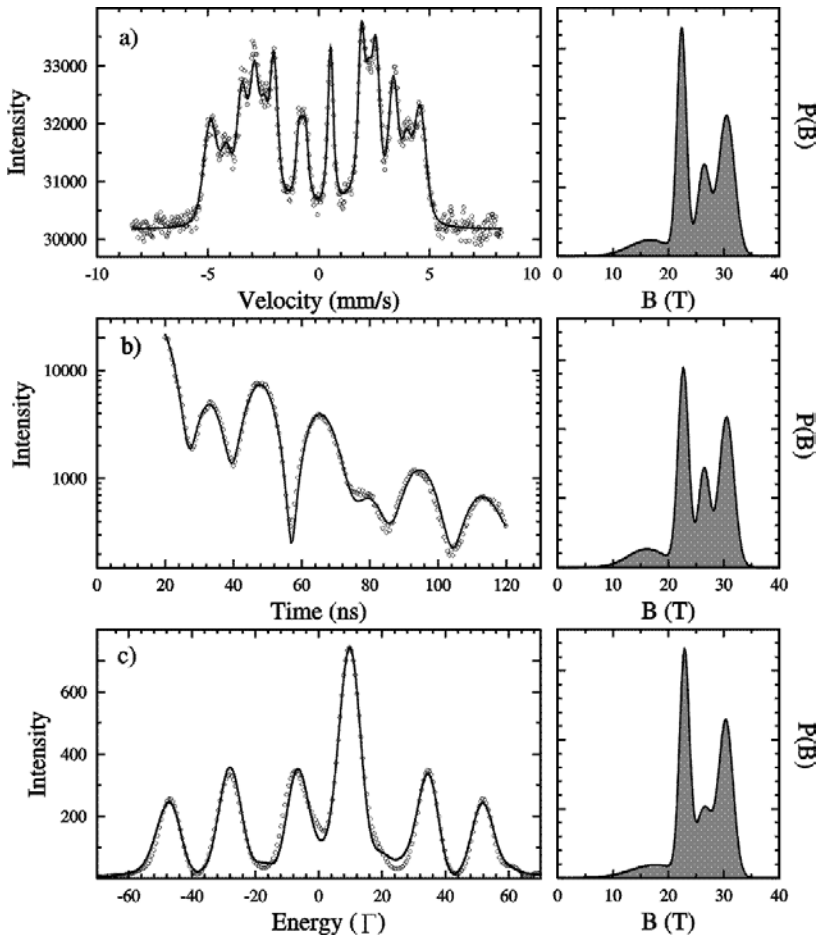

* Small discrepancies between the hyperfine field distributions can be assigned to different parts of the sample that are probed with the different techniques

# Limitations of the techniques



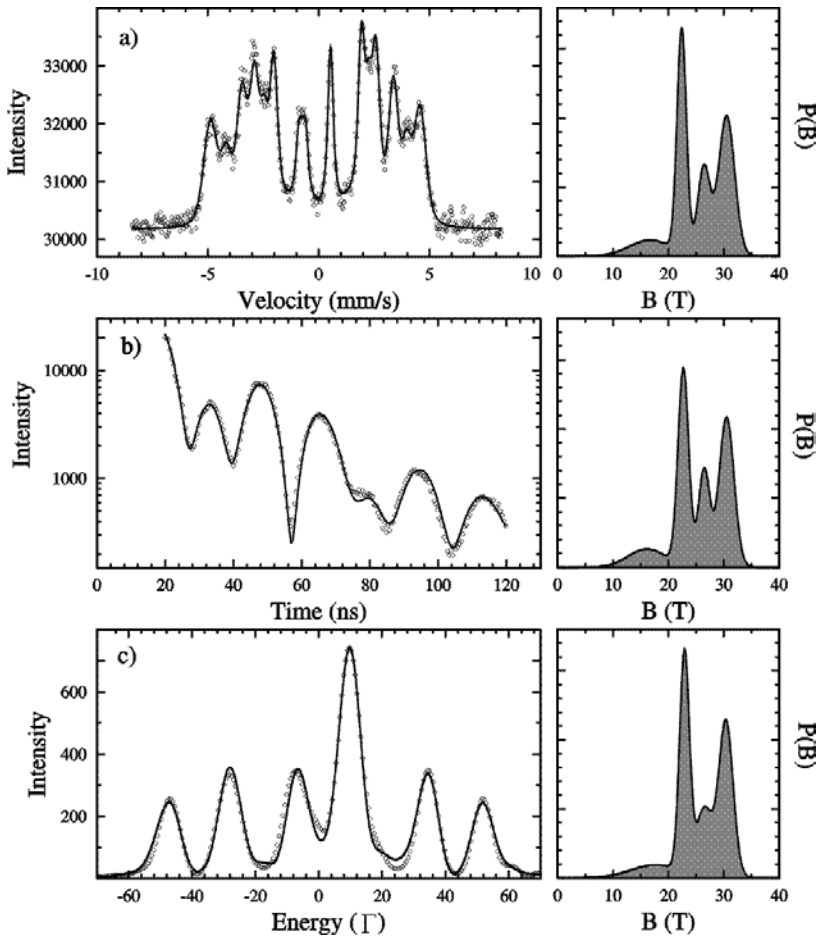

**Mössbauer spectroscopy: limited to samples containing enough nulcear resonant material**

# Limitations of the techniques




**Time resolved NRS: complex systems acquire additional Mössbauer measurements**

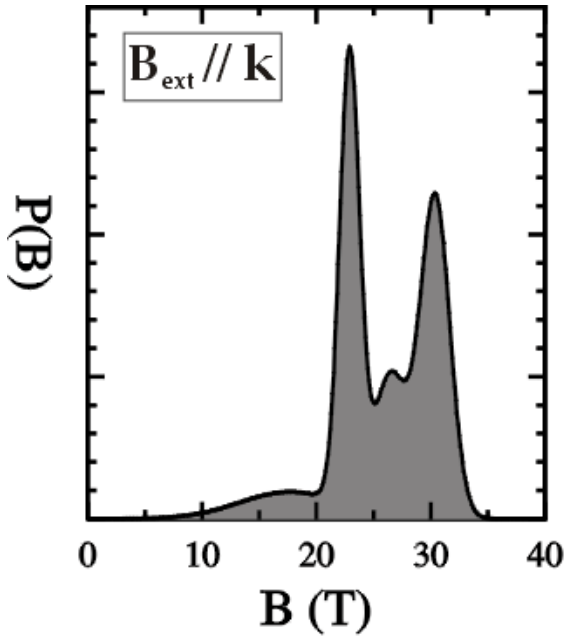
# Limitations of the techniques

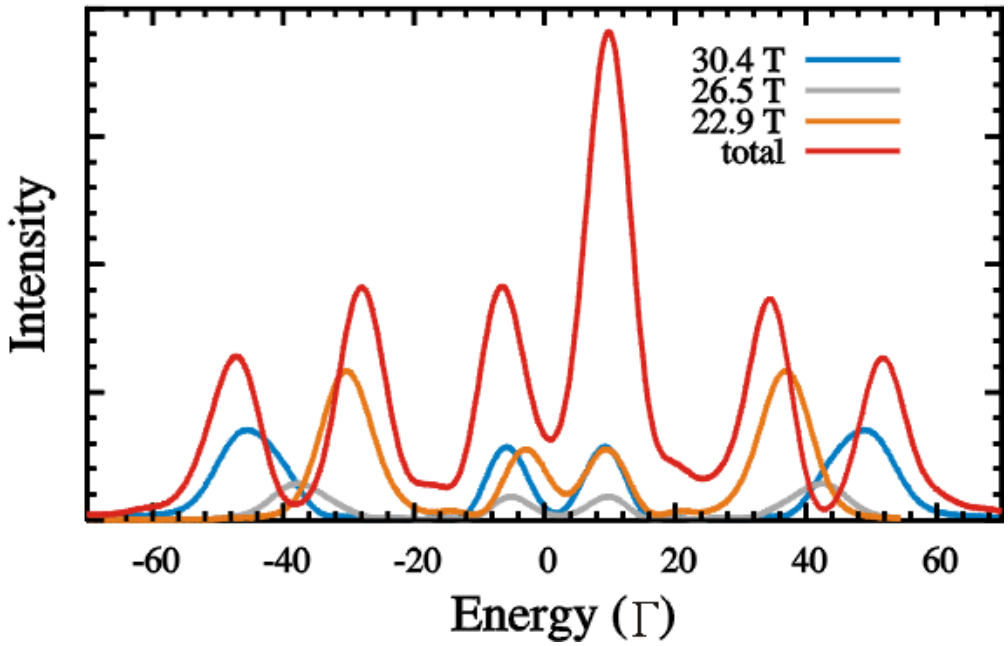



**Energy resolved NRS: only simple Fe-structures were investigated up till now.**

**Analysis??**

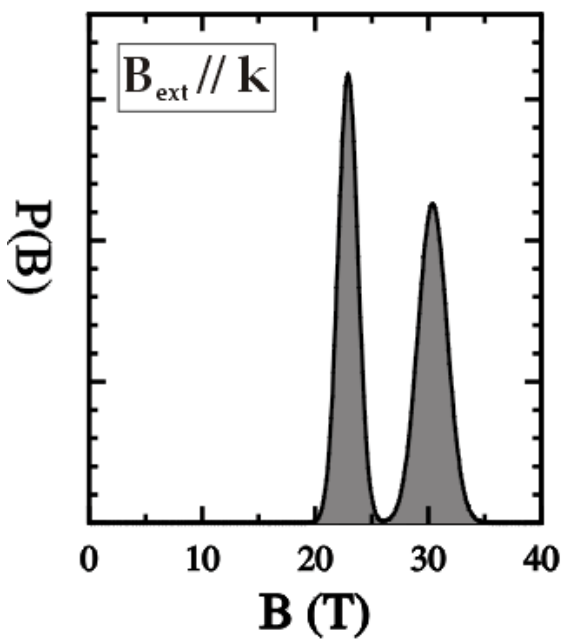
# Analysis of the energy resolved spectrum

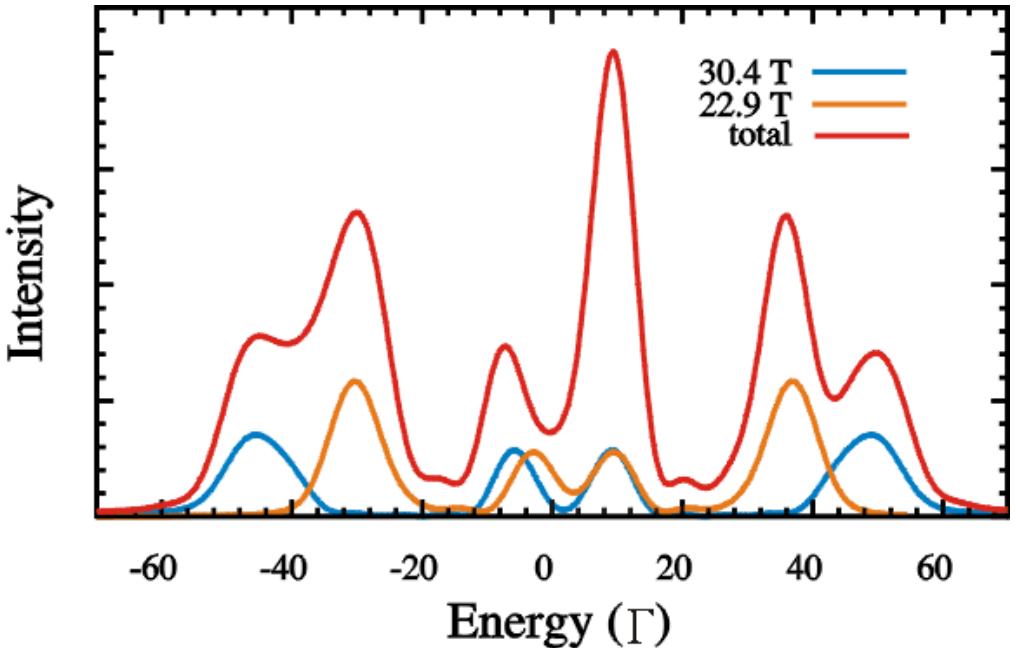



* The spectrum is a coherent addition of the different subspectra
* Due to the coherence effect, the original positions of the resonance lines are affected
* No direct extraction of the different hyperfine fields from the spectrum is possible

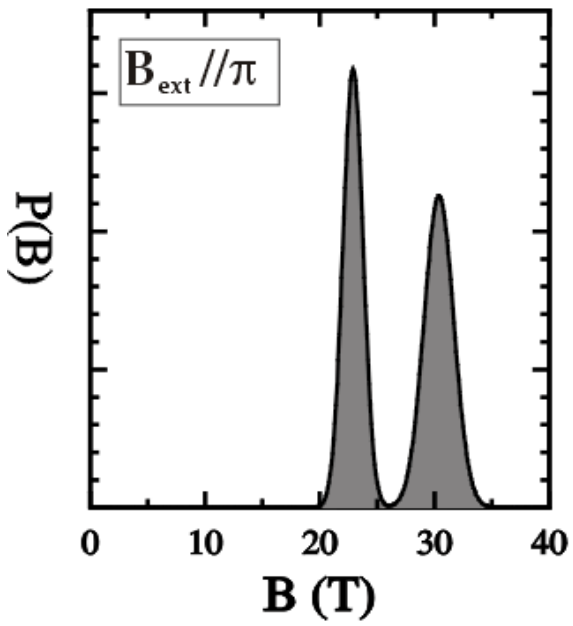
# Analysis of the energy resolved spectrum

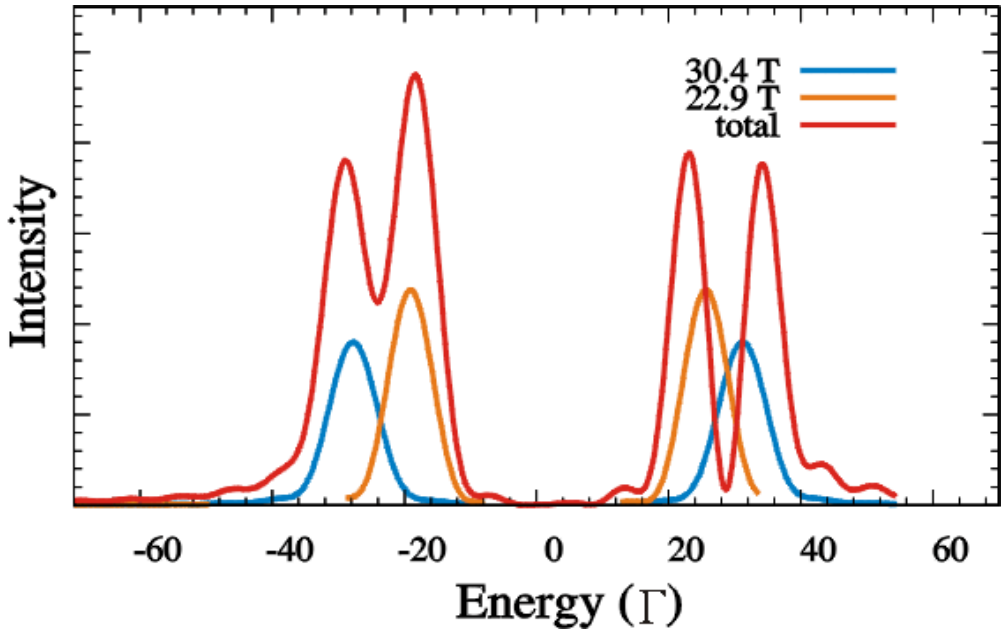



For samples with a less complex hyperfine field distribution, a direct extraction of the different magnetic components from the spectrum should be possible.

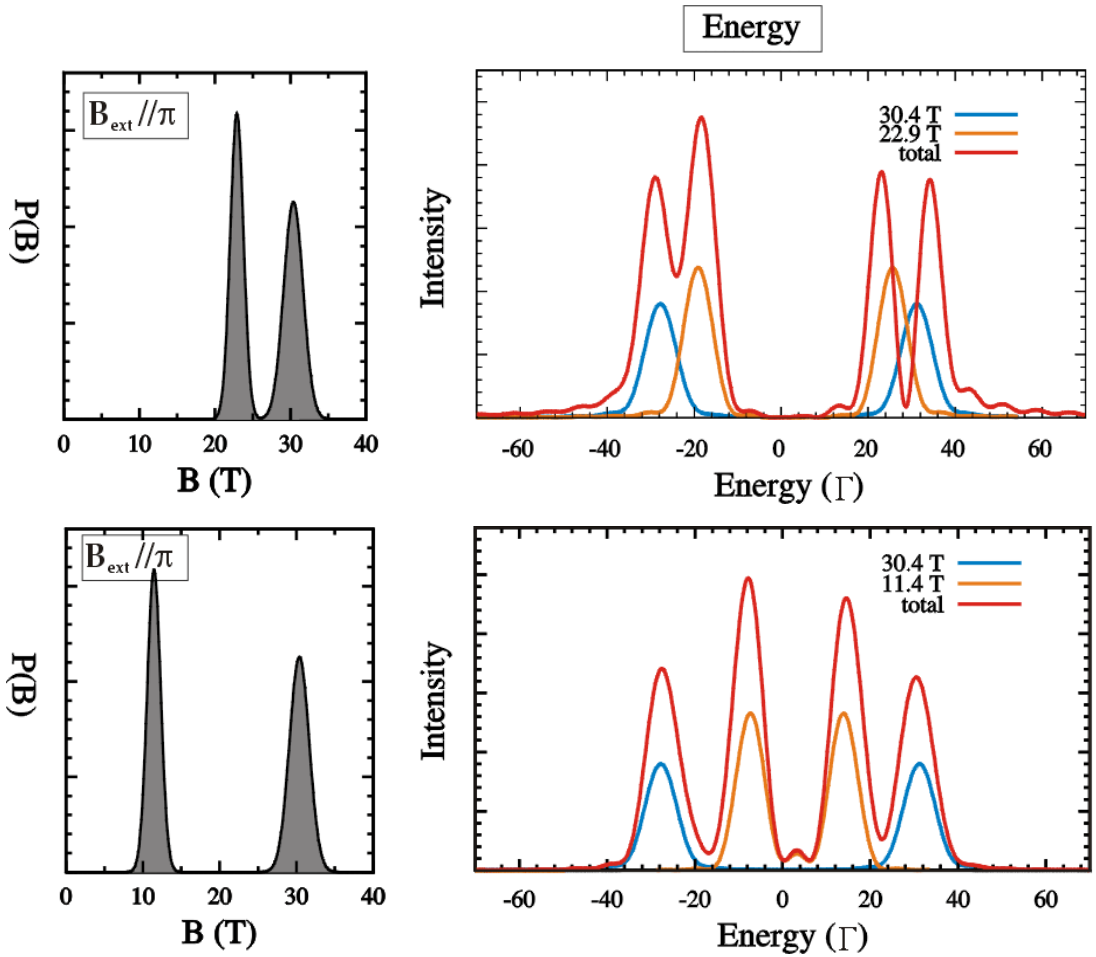
# Analysis of the energy resolved spectrum



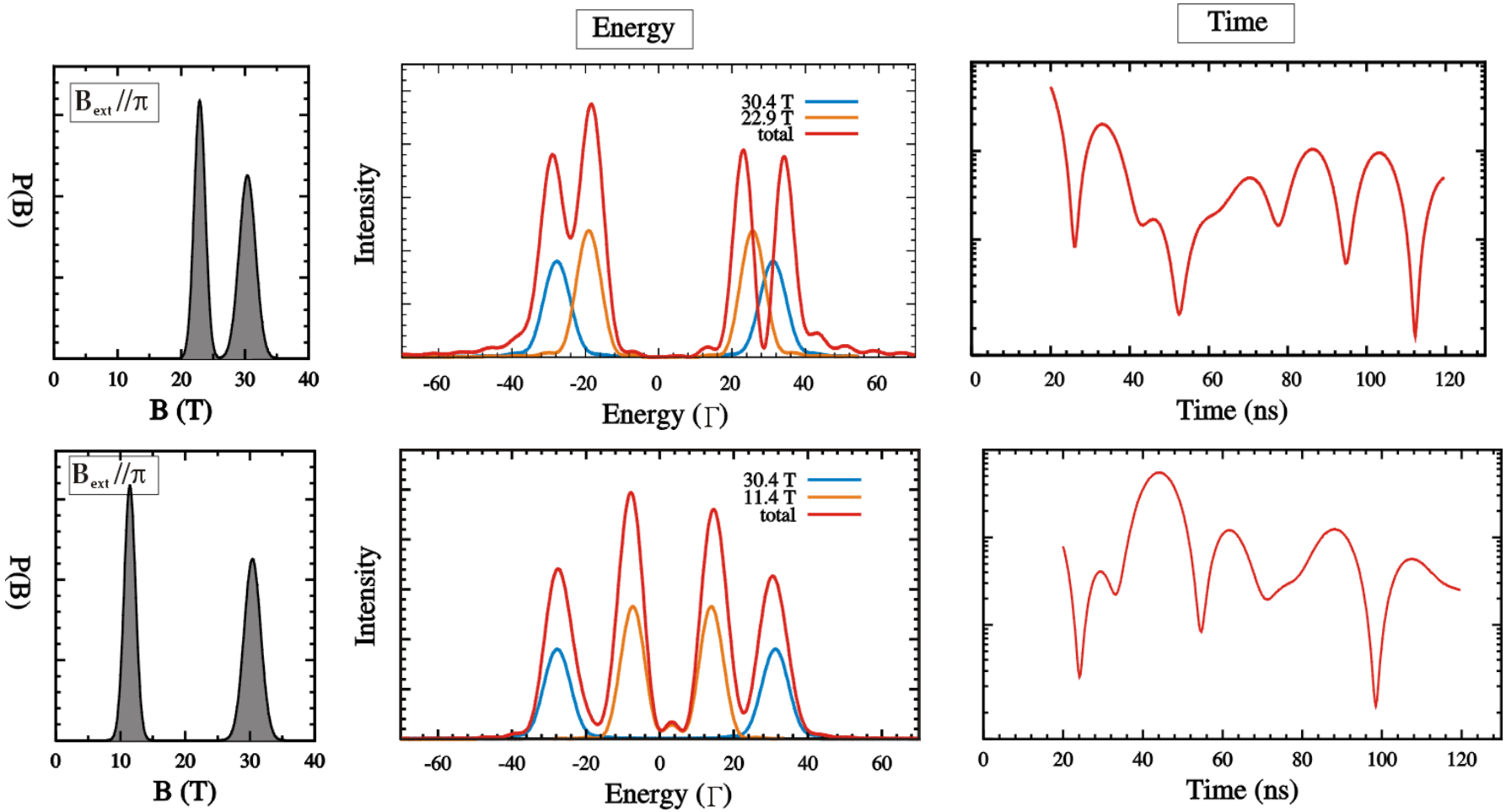

Applying the external field perpendicular to the synchrotron plane, results in an even easier to interpret energy resolved spectrum.

# Analysis of the energy resolved spectrum




What happens to the spectrum if a phase transition occurs?

# Analysis of the energy resolved spectrum




The phase transition can be followed in energy domain, but not in time domain!

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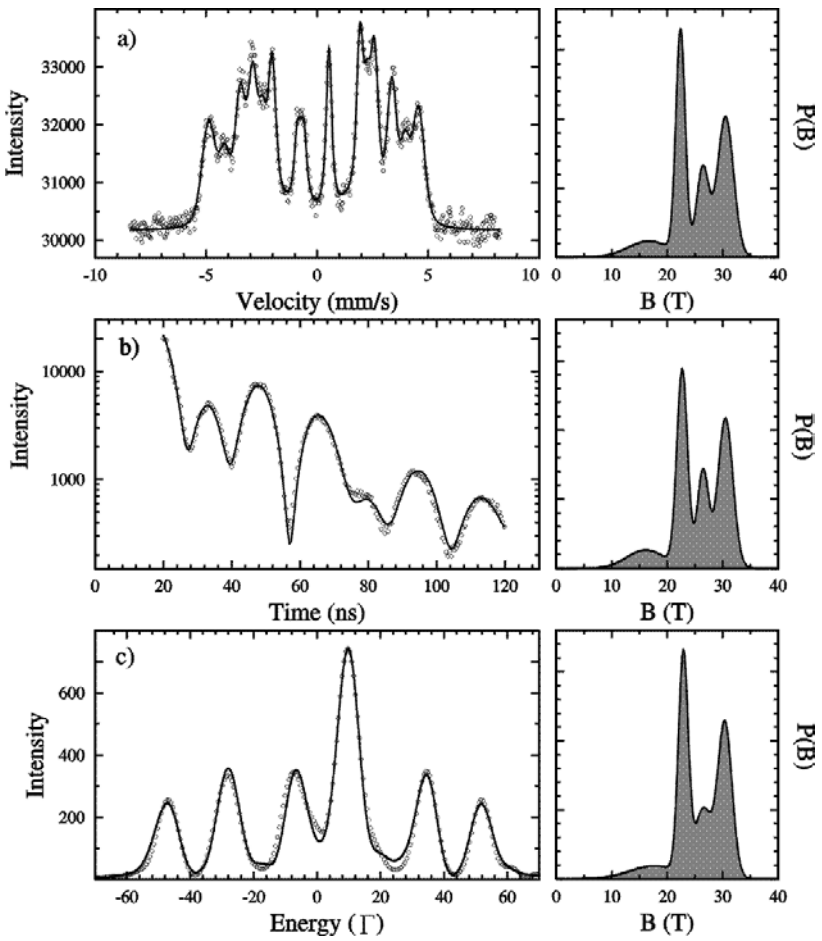
# Conclusion




* We measured a Mössbauer spectrum, a time and an energy resolved NRS spectrum onto the same $Fe_3Al$-foil.

* Comparison of the hyperfine field distributions indicates that the three spectra can be analyzed with nearly the same model.

* Both the time and energy resolved NRS technique lend themselves to the study of samples with reduced sizes.

* In most cases, the analysis of the energy resolved spectrum is more straightforward than the time resolved spectrum and allows one for an on-line analysis.