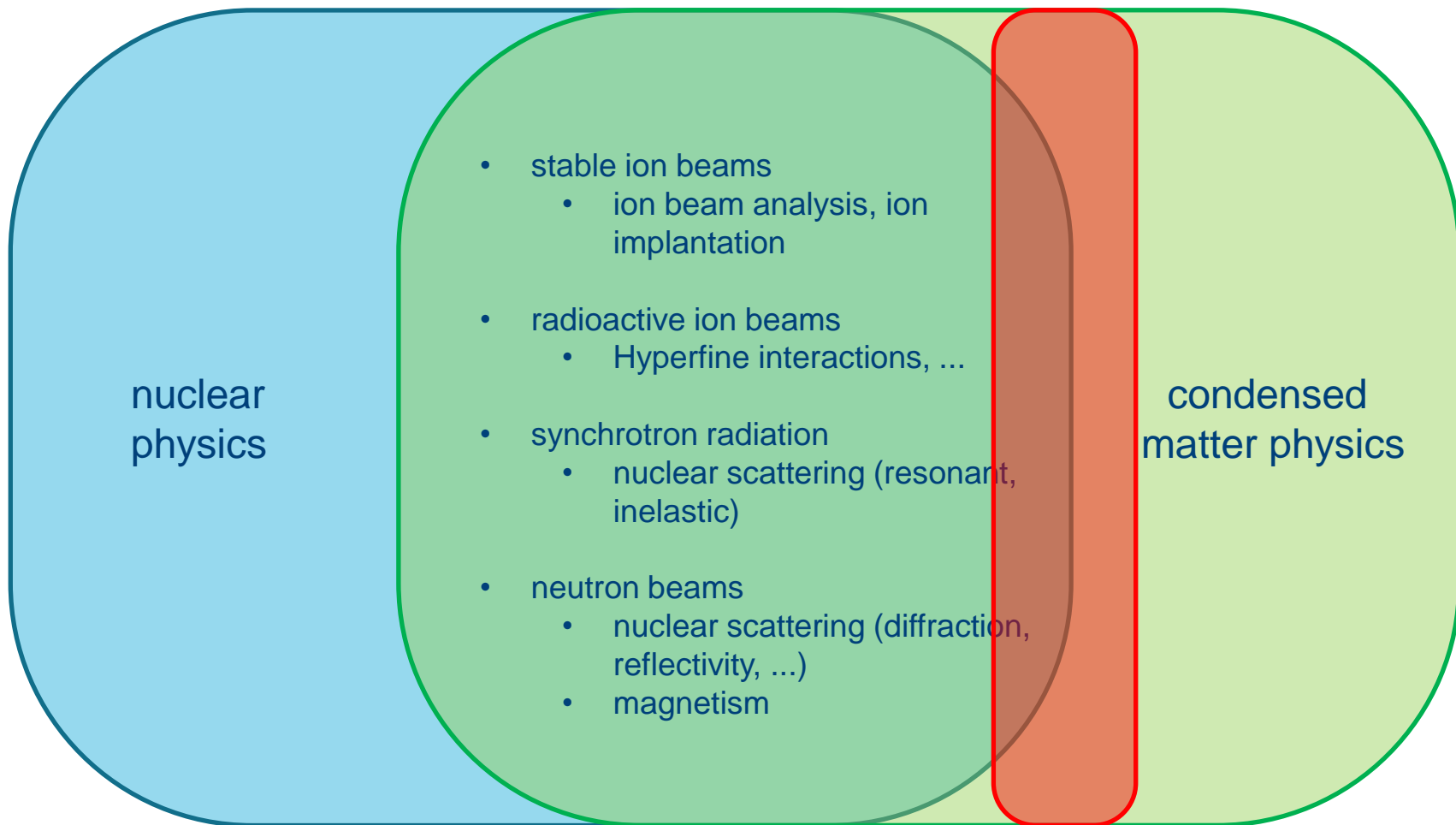




# Condensed matter research using nuclear physics techniques

Lino Pereira, A. Vantomme,  
K. Temst, W. Vandervorst

KU Leuven  
Instituut voor Kern- en Stralingsfysica



# stable ion beams (@ KU Leuven)

- Ion implantation (semiconductor doping, surface modification...)
- Ion beam analysis (RBS, channeling, PIXE, NRA)



Integrated Infrastructure Initiative (I3)

Support of Public and Industrial  
Research using Ion beam  
Technology

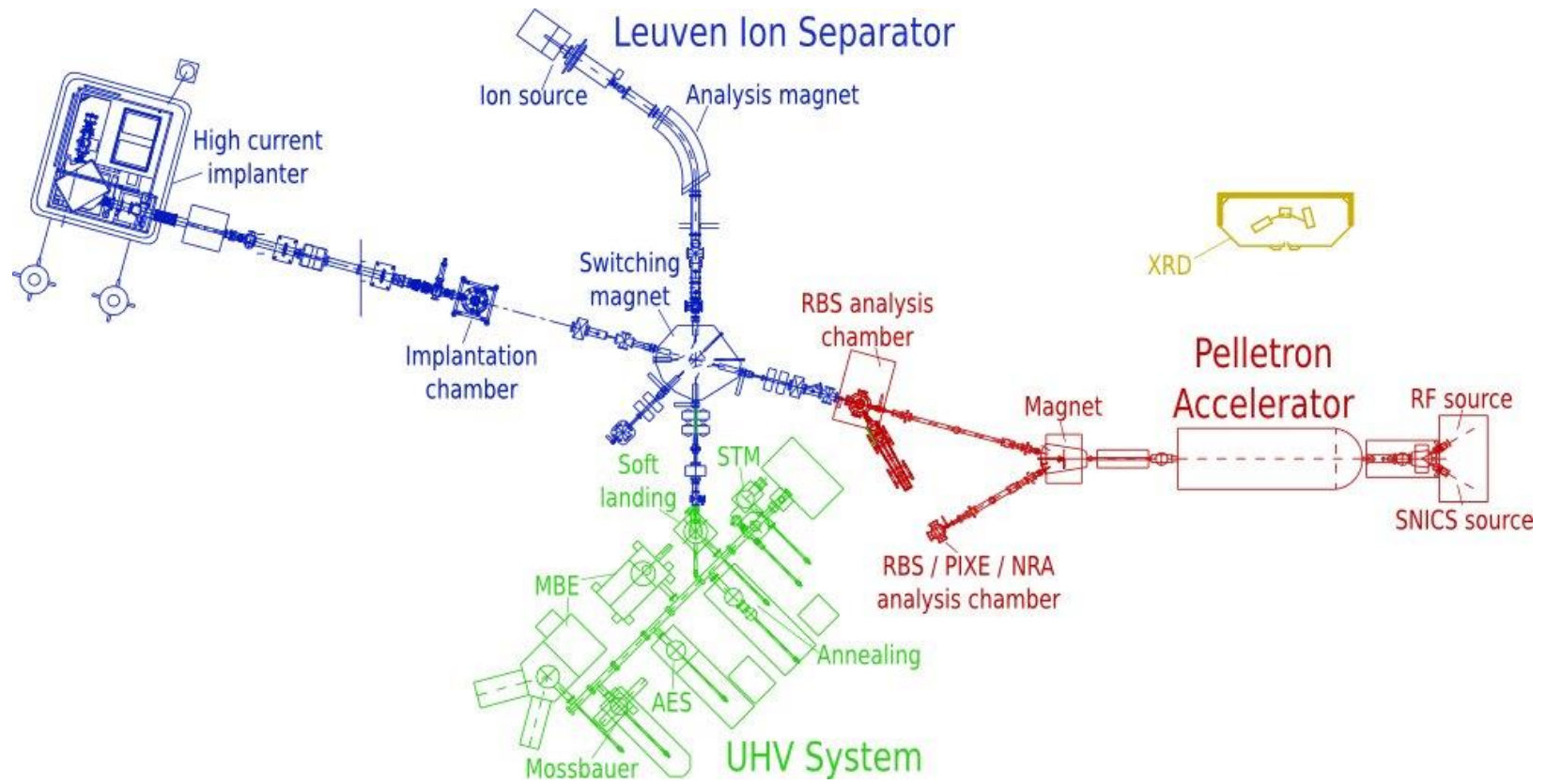


Initial Training Network (ITN)

Supporting Postgraduate Research  
with Internships in industry and  
Training Excellence

- Other players in Belgium: IMEC, U. Namur, (IBA)

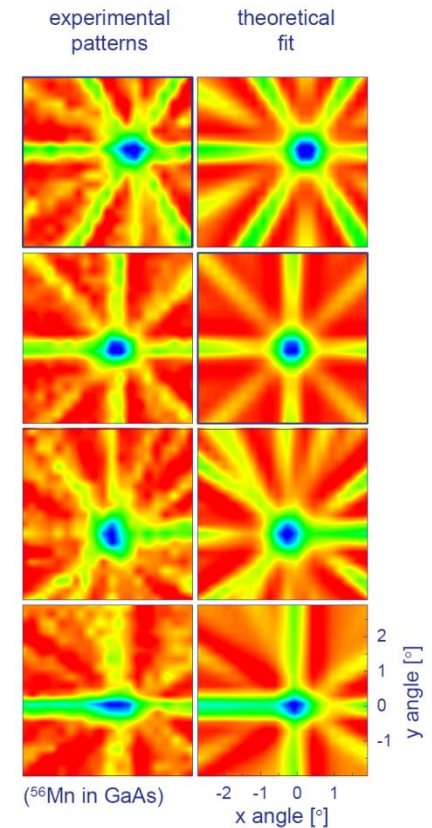
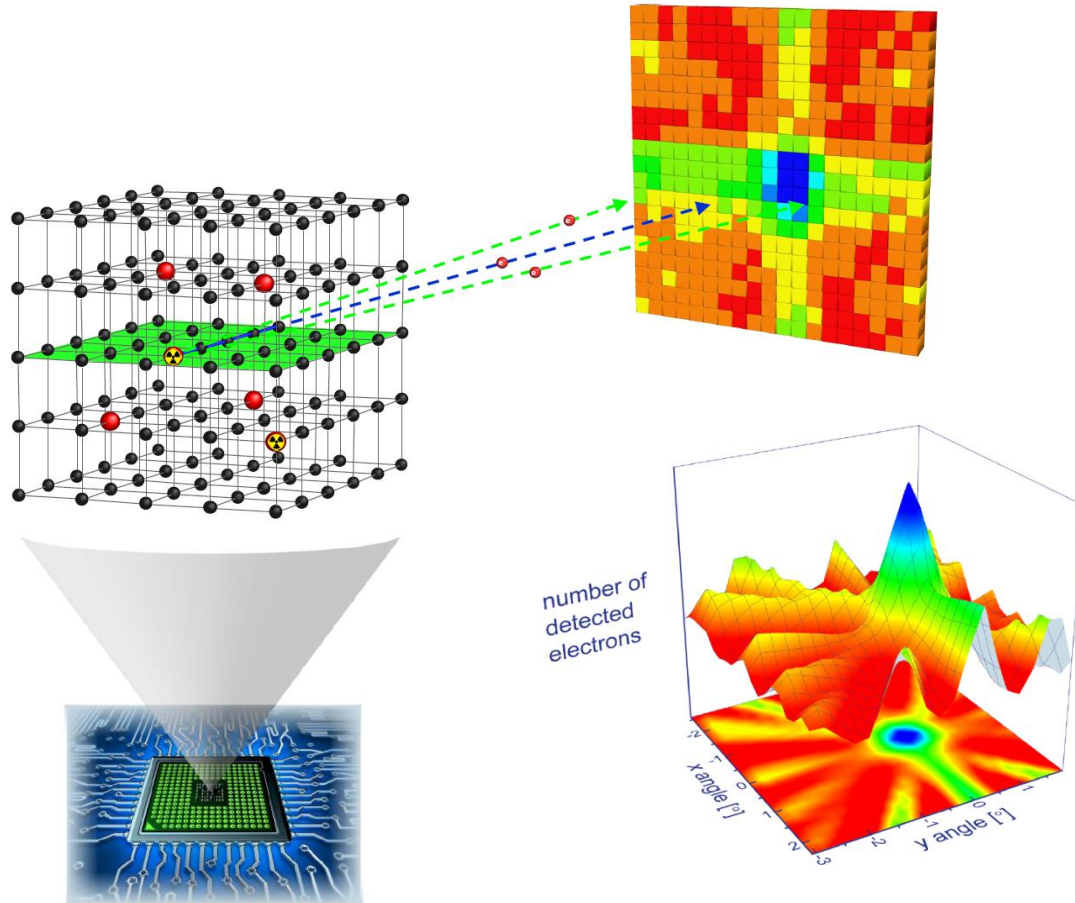
# IMBL @ KU Leuven (ground floor)



# Radioactive ion beams (ISOLDE, CERN)

- Electron emission channeling
  - crystal structure (dopant lattice location)
- Hyperfine interactions
  - (emission) Mössbauer spectroscopy
  - Perturbed angular correlations (PAC) spectroscopy
    - crystal structure
    - electrical/electronic properties
    - Magnetism
- Radiotracer techniques (diffusion and self-diffusion)
- ...

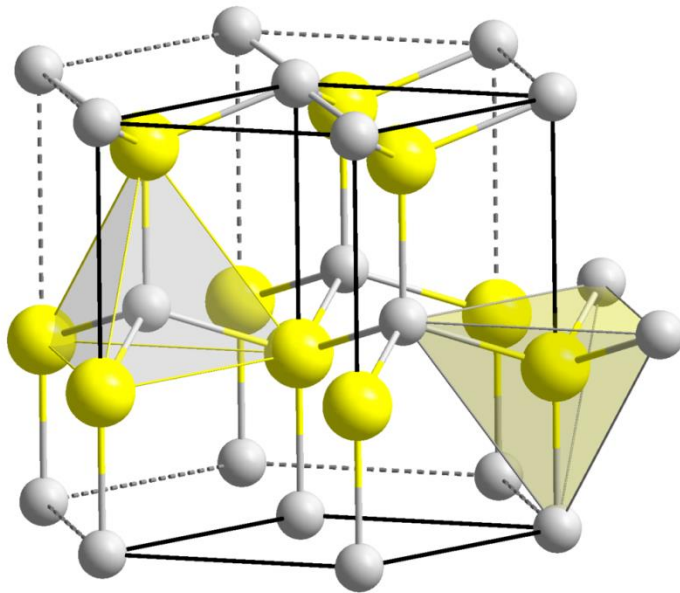
# Electron emission channeling (ISOLDE)



# Electron emission channeling (ISOLDE)

- Direct Evidence for As as a Zn-Site Impurity in ZnO

*Phys. Rev. Lett.* **95**, 215503 (2005)



Fe in Si

*Phys. Rev. B* **72**, 155204 (2005)

Sn in Ge

*Phys. Rev. B* **81**, 155204 (2011)

Mn and Co in ZnO

*Phys. Rev. B* **84**, 125204 (2011)

Mn in GaN

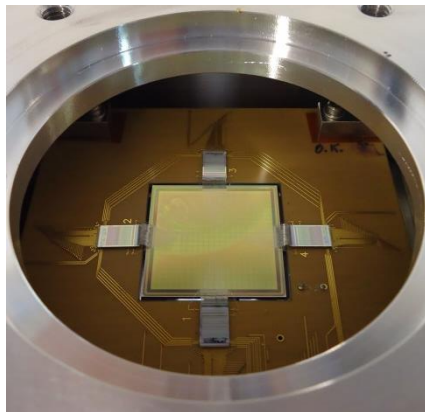
*Phys. Rev. B* **86**, 195202 (2012)

Mn in GaAs

*Phys. Rev. B* **86**, 125206 (2012)

# Electron emission channeling (ISOLDE)

- Present developments:
  - Timepix detectors (Medipix collaboration)
    - Higher spatial (angular) resolution



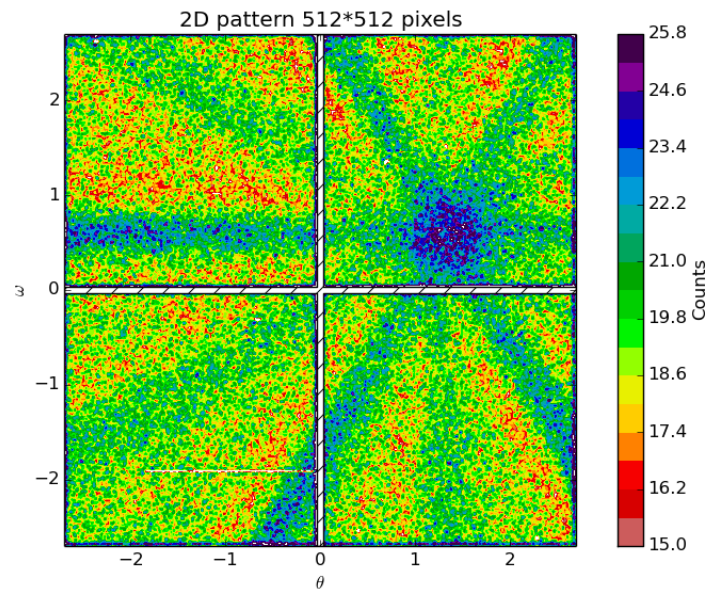
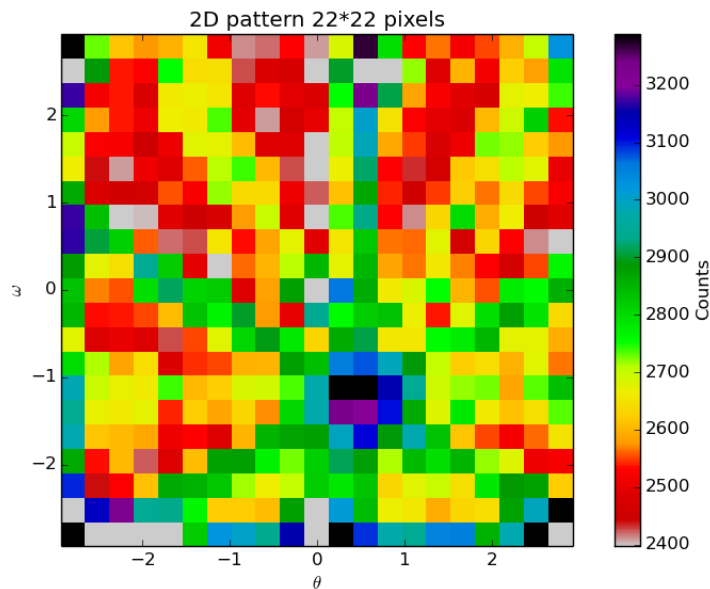
**2008-2015**  
**VATAGP7 PAD detector**  
22x22 pads 1.4 x 1.4 mm<sup>2</sup>  
(~10 kHz)



**2016 - ...**  
**TIMEPIX (Medipix2)**  
512 x 512 55mm pixels  
(~1 kHz?)

# Electron emission channeling (ISOLDE)

- Present developments:
  - Timepix detectors (Medipix collaboration @ CERN)
    - Higher spatial (angular) resolution



# Electron emission channeling (ISOLDE)

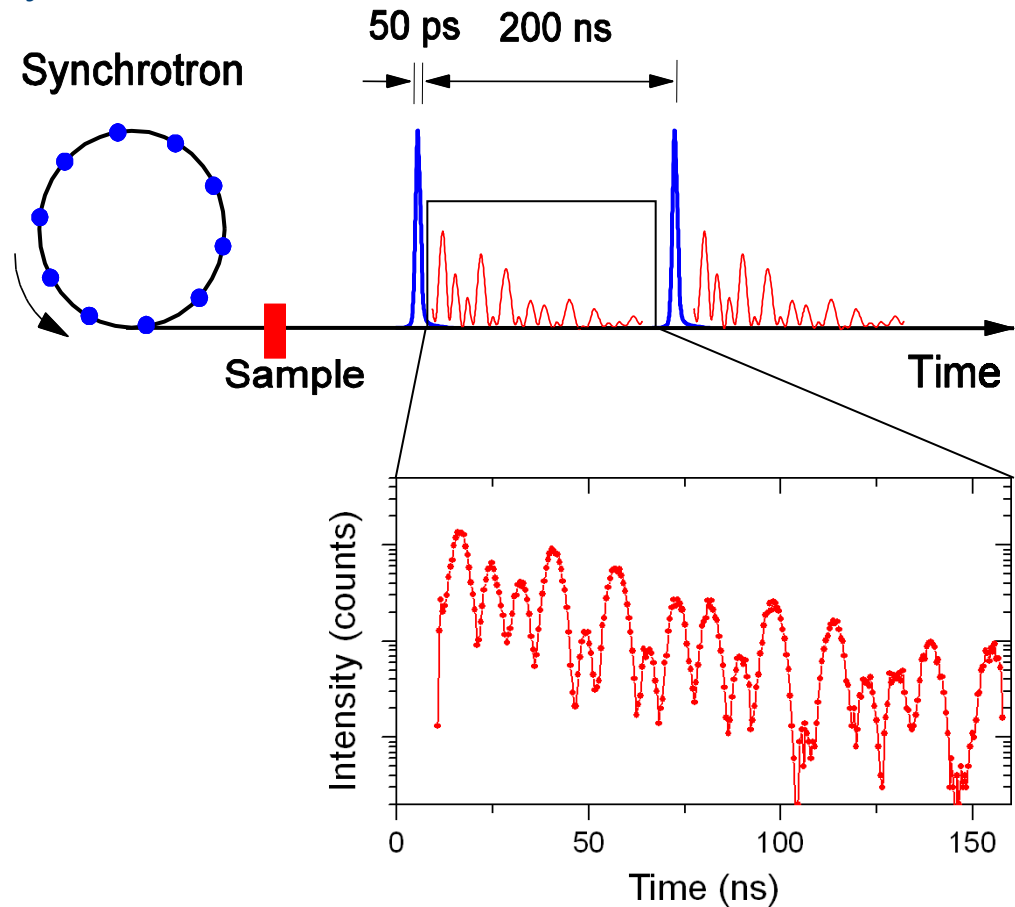
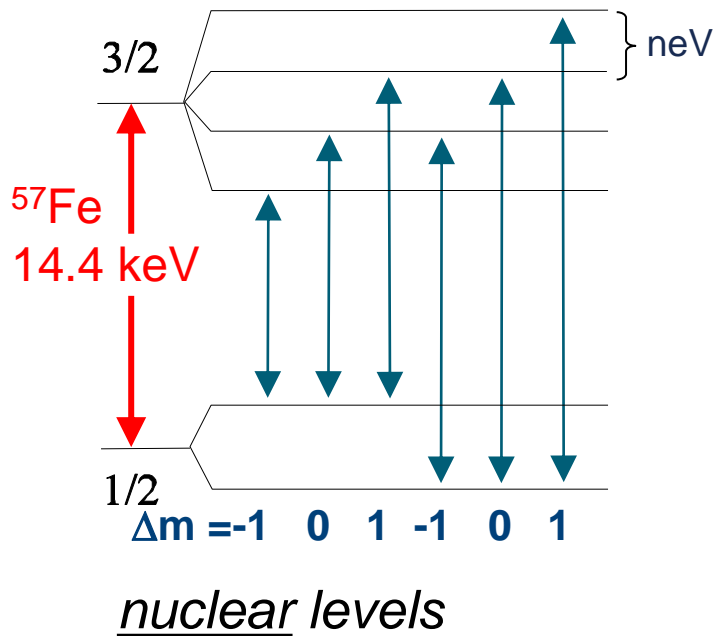
- Present developments:
  - Timepix detectors (Medipix collaboration)
    - Higher spatial (angular) resolution
    - But lower countrate than previous VATAGP7 (~1 kHz?)
- Future:
  - Medipix3
    - For emission channeling (@ISOLDE):
      - high spatial (angular) resolution + high countrate
    - For conversion electron emission channeling (@synchrotron)
      - Timing (prompt X-rays)

# Synchrotron radiation

- Nuclear X-ray scattering (Mössbauer effect)
  - Resonant (NRS)
    - Energy domain (synchrotron Mössbauer source - SMS)
    - Time domain (nuclear forward scattering – NFS)
    - Determine hyperfine parameters  
→ crystal structure, electrical/electronic properties, magnetism
  - Inelastic (NIS)
    - “Non-Mössbauer”
    - Lattice dynamics (phonon density of states)
- Synchrotrons (high energy, high flux):
  - ESRF (Grenoble), APS (USA), SPRING8 (Japan)

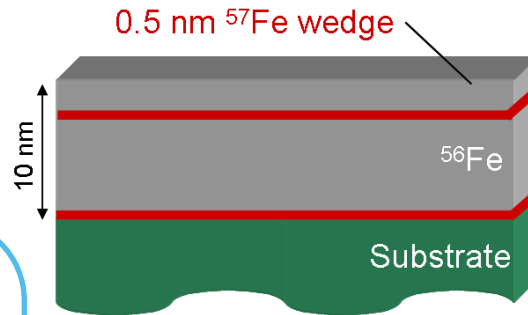
# Nuclear resonant scattering (time domain)

- X-ray pulse (50 ps), broadband (1 meV)
- coherently excites the nuclei  $\rightarrow$  decay
- different spectral components  
 $\rightarrow$  interference (*quantum beats*)

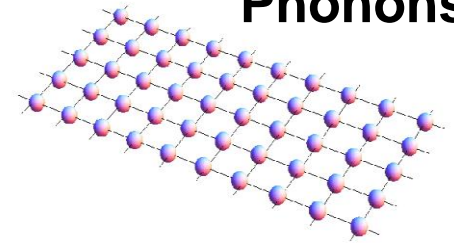


# Nuclear X-ray scattering

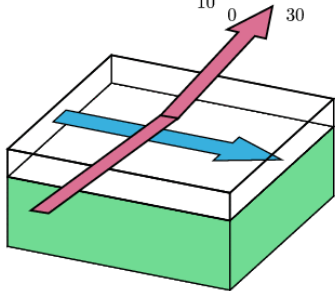
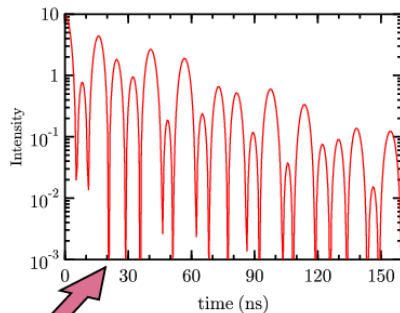
**Isotope sensitivity:**  
Interface selective



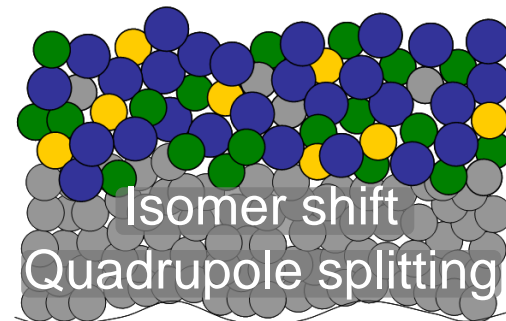
**Phonons**



**Hyperfine magnetic field:**  
Local magnetic moment  
+ orientation



**Hyperfine parameters:**  
Quantitative interface chemistry



● Fe ● O ●  $\text{Fe}^{2+}$  ●  $\text{Fe}^{3+}$

# Neutron scattering

- nuclear scattering (diffraction, reflectometry...)
  - spatial distribution of composition (light elements)...
- magnetic scattering (diffraction, reflectometry...)
  - magnetic structure, coupling...
- inelastic scattering
  - phonons...
- neutron sources
  - reactor: ILL (Grenoble) ...
  - spallation: ISIS (UK), SNS (USA), ESS (Sweden) ...

- Overlap between (experimental) nuclear and condensed matter
  - methodology, infrastructure...
- It enables condensed matter physicists
  - Sensitivity, atomic scale, dynamics...

- How to further stimulate?
- How to make it benefit nuclear physics?





# Condensed matter research using nuclear physics techniques

Lino Pereira, A. Vantomme, K. Temst, W.  
Vandervorst

KU Leuven  
Instituut voor Kern- en Stralingsfysica