Applications of Mössbauer Spectroscopy

at

WITS and ISOLDE/CERN

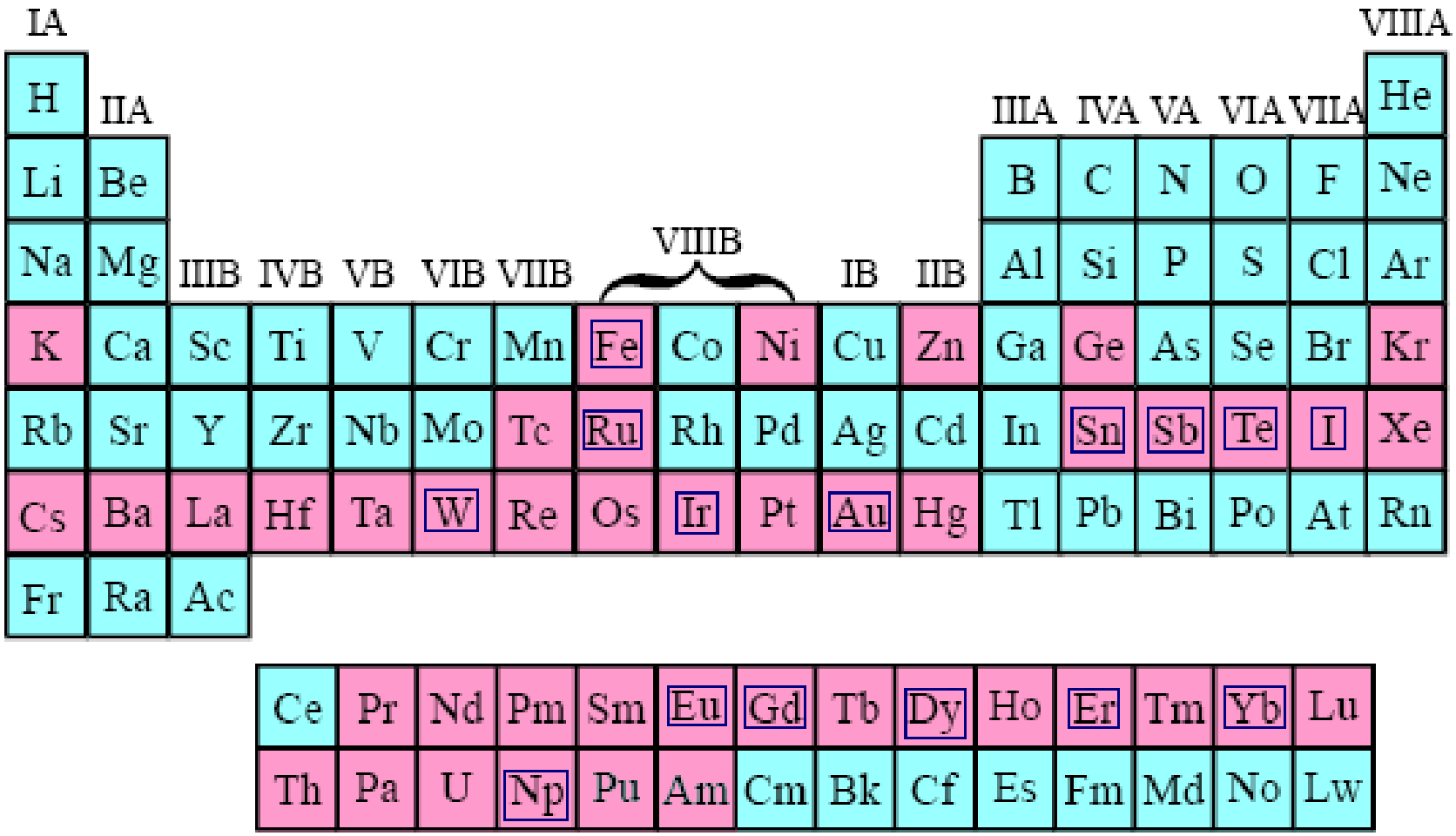
by

Professor Deena Naidoo

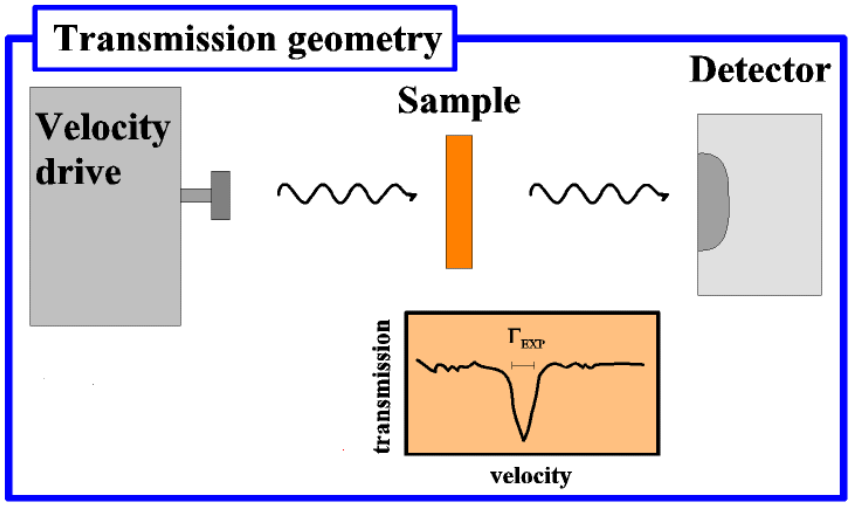
Outline of Presentation

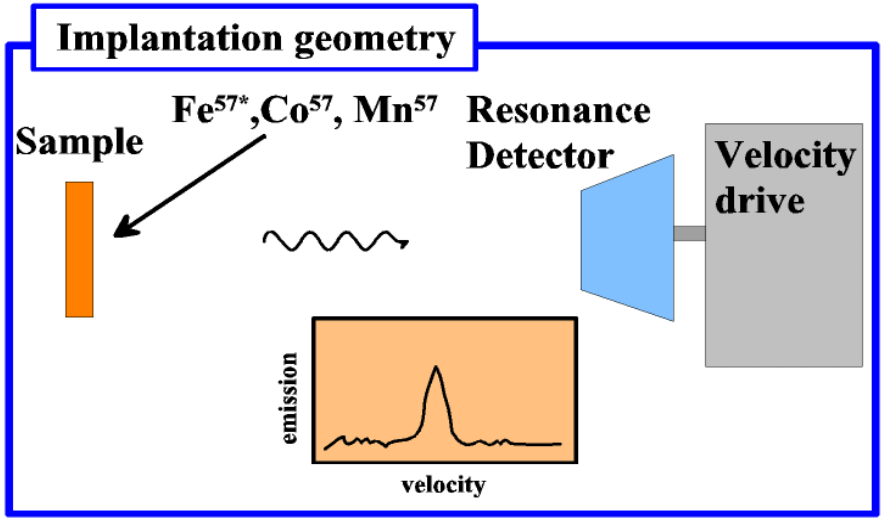
- Mössbauer Isotopes/Approaches
- Measurables
- WITS Mössbauer Facility and applications
- Mössbauer at ISOLDE and applications
- Local and International Collaborations

Mössbauer Isotopes



^{57}Fe Mössbauer Spectroscopy





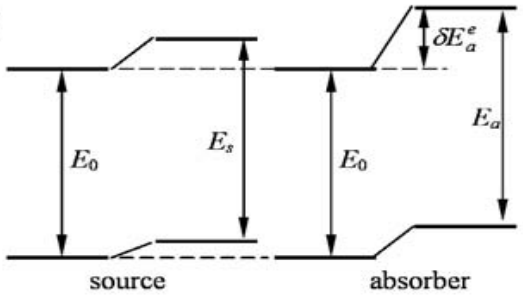
Mössbauer Approaches

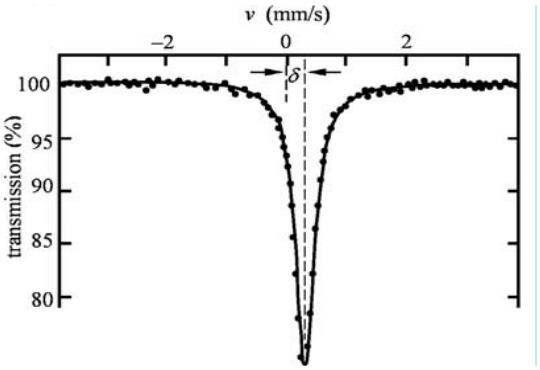
Stable ^{57}Fe (transmission)	^{57*}Fe	^{57}Co	^{57}Mn*
Accessible	Direct implantation behaviour	Accessible	Annealing, recoil
•High doses -> interacting Fe atoms. •Overlapping damage cascades.	•Needs large facilities. •Low intensity. •Spectra masked by implantation damage.	•Long lifetime. •Surface diffusion.	•Needs large facilities. •Competitive proposals.

Hyperfine Interactions and Measurables

Electric Monopole Interaction

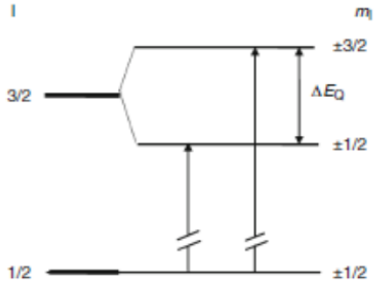
Valence/spin state => Position of resonance lines.

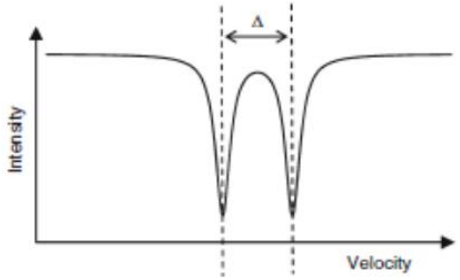




Electric Quadrupole Interaction

Site symmetry => Splitting of lines.

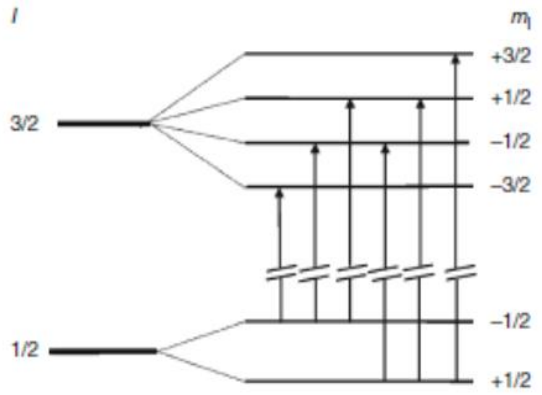


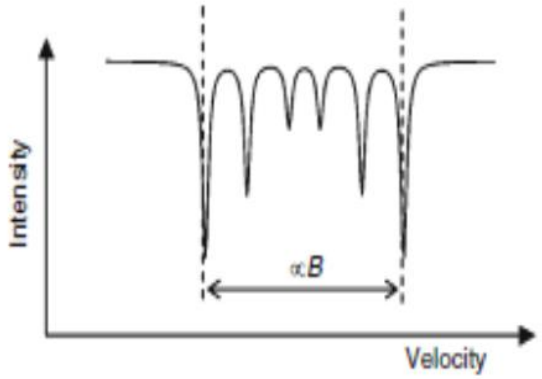


Hyperfine Interactions and Measurables

Magnetic interactions

Zeeman splitting into 6-line pattern.





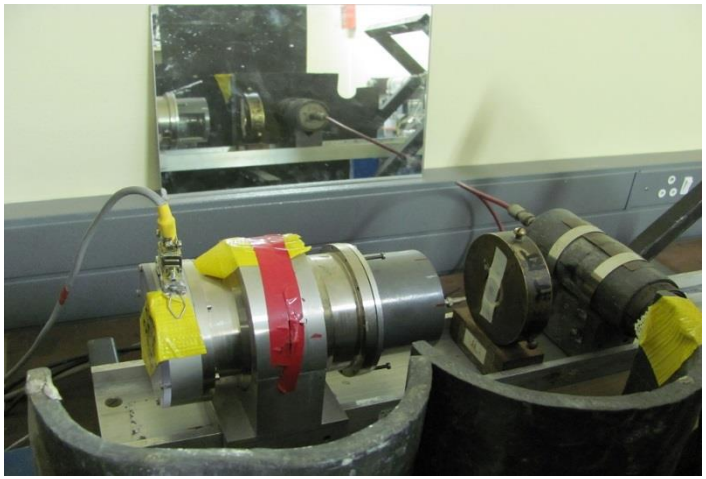
Other Measurables

- Spin relaxation rates (sextet broadening).
- Diffusion on a atomic scale (line broadening).
- Interaction with defects (implantation damage/lattice sites).
- Debye temperature (resonance area/intensity).

Mössbauer Facility @ WITS

Some Electronics

Transmission MS

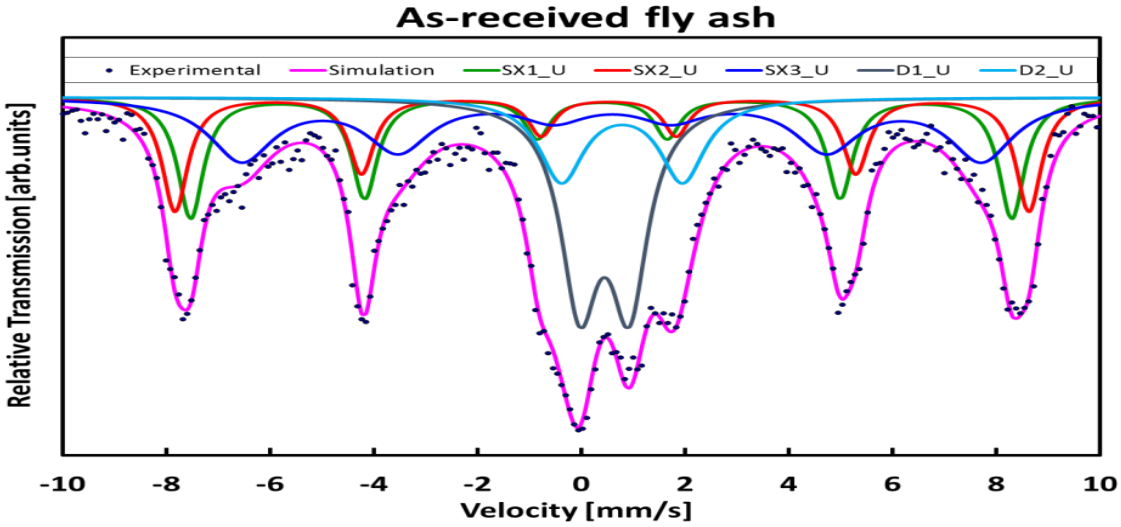


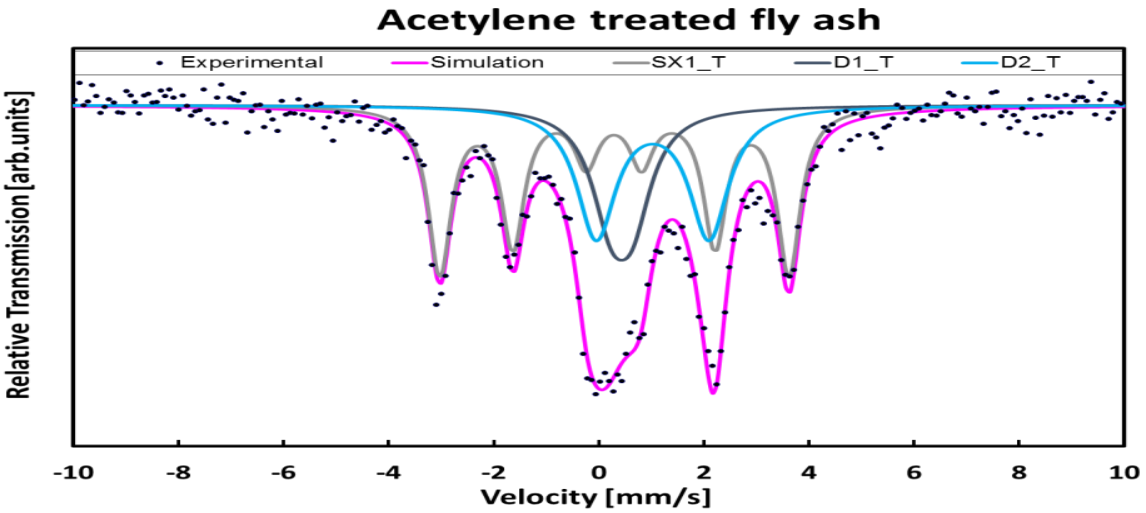
CEMS

Some Research Samples

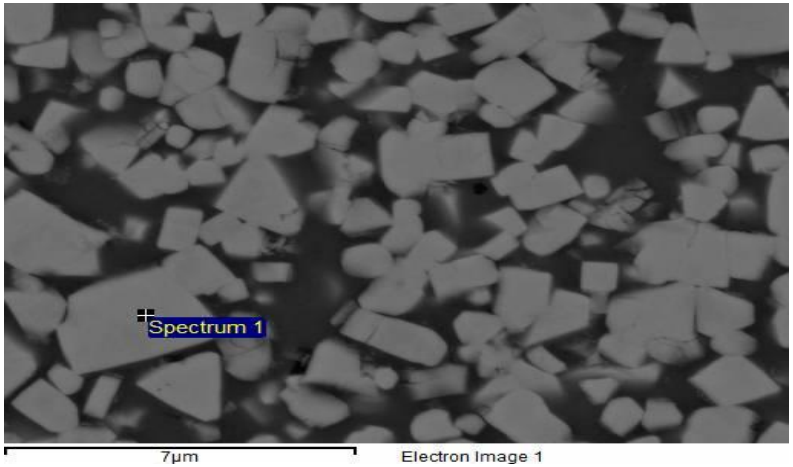
- Fly-ash
- Multiferroics
- Milled carbides with binders
- Cemented carbides
- Catalysts
- Carbon nanomaterials
- Rock bearing samples

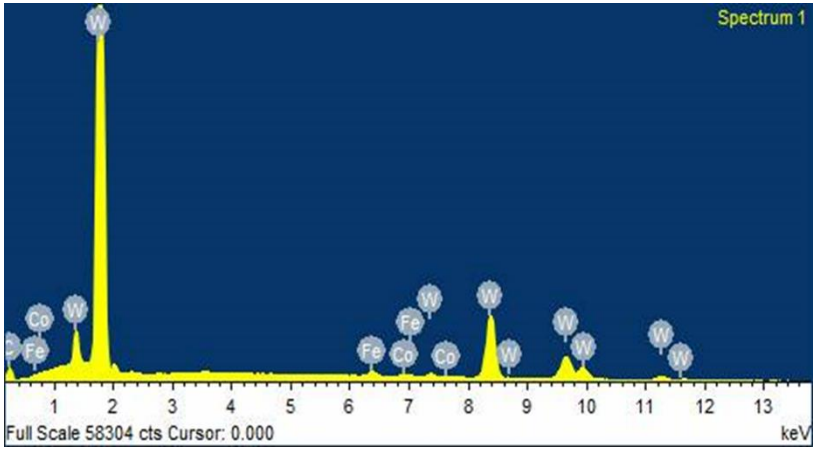
Apllications: WITS – Fly Ash

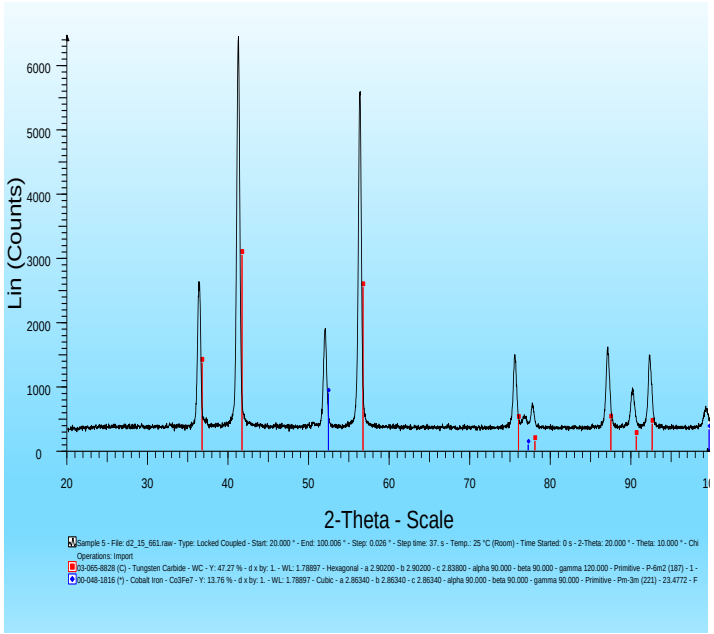


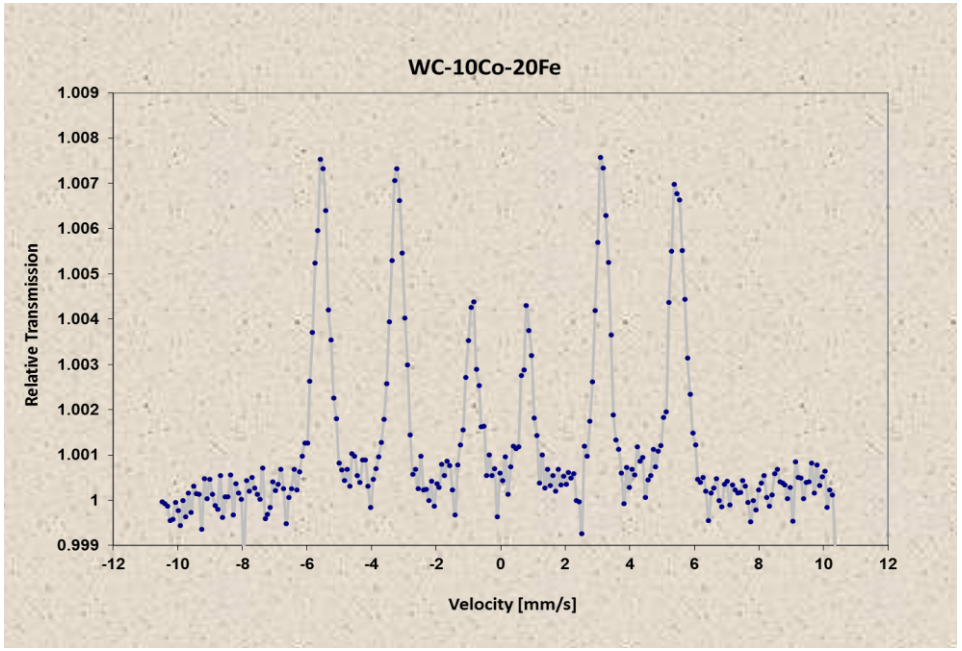


Applications: WITS – Cemented Carbides

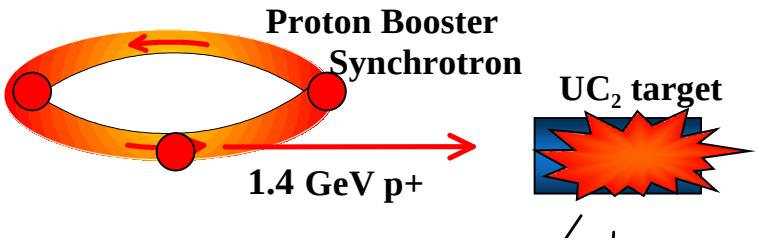








ISOLDE: Beam Production



- Proton induced fission in UC_2 target → Neutron rich isotopes

On-line emission Mössbauer spectroscopy

^{57}Mn decay to the ^{57}Fe probe:

Ion-implantation of dilute dopants into sample

^{57}Mn ($T_{½}$ = 85.4 sec.)

β-

$p \rightarrow n + e^- + \bar{\nu}_e$

^{57*}Fe (τ = 140 ns)

I = 3/2

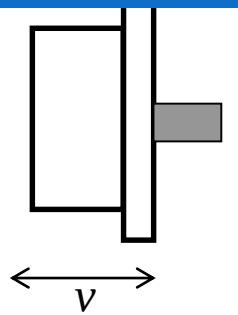
14.4 keV Mössbauer transition

γ

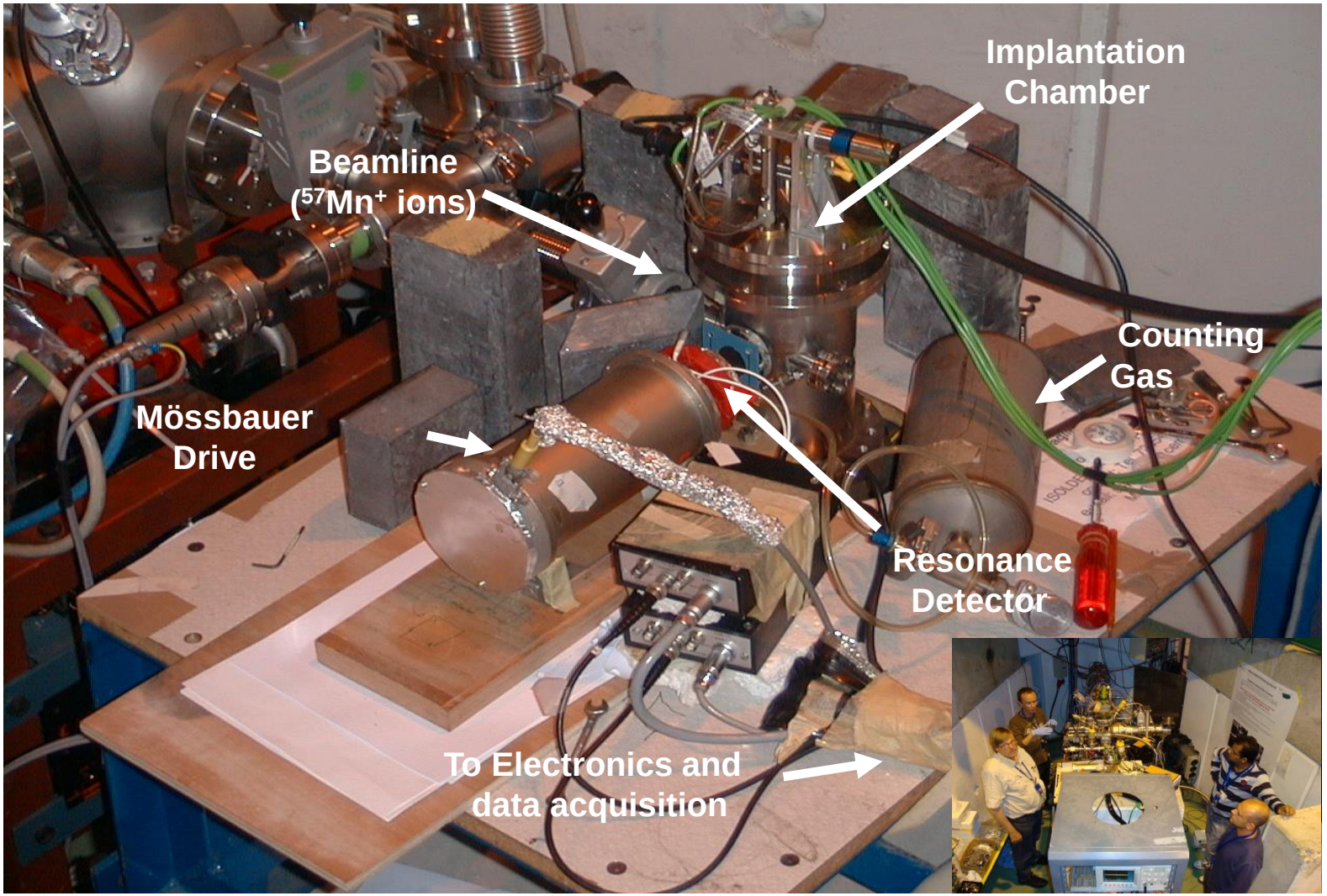
I = 1/2

^{57}Fe

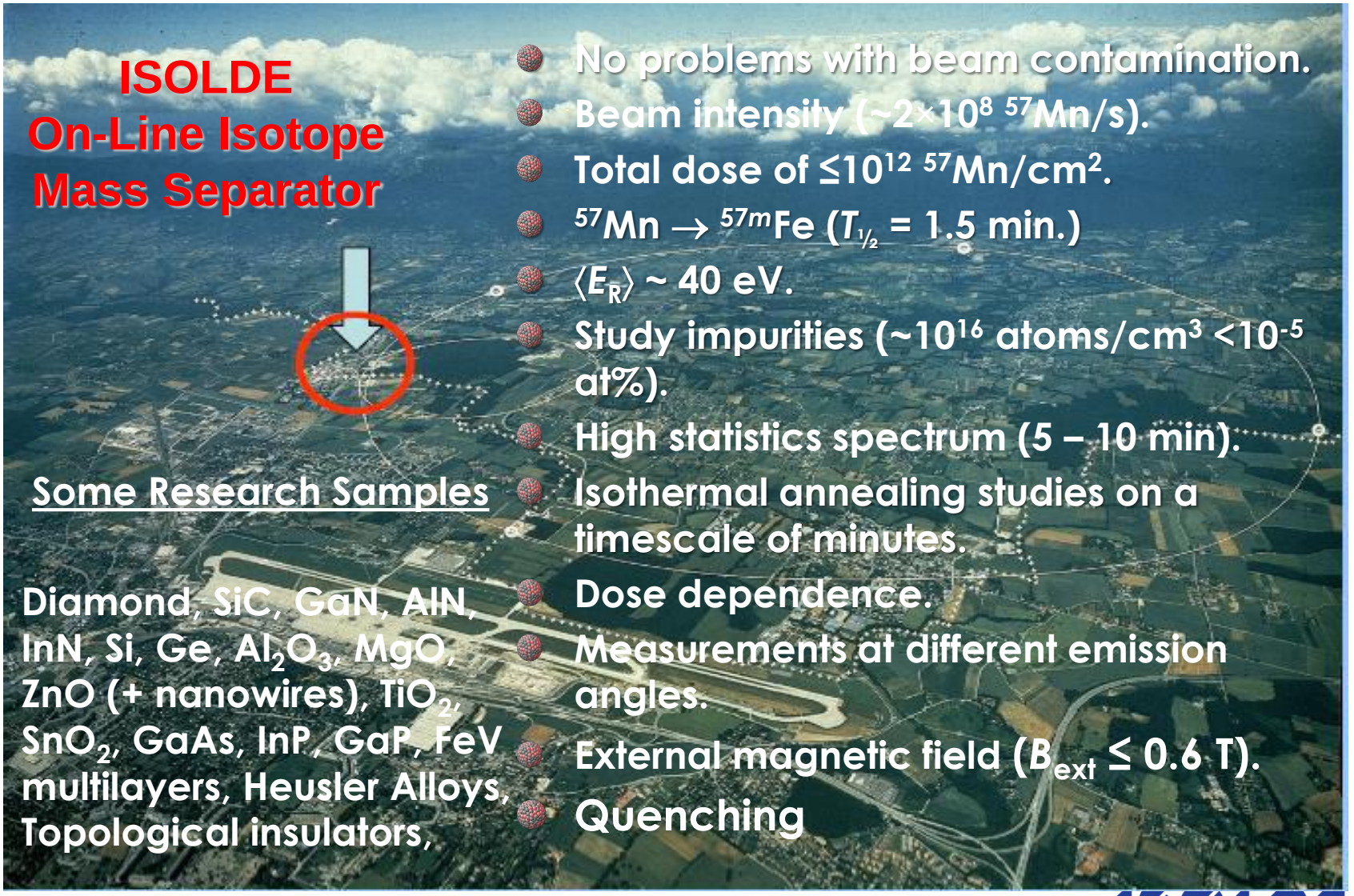
Resonance detector



Mössbauer @ ISOLDE, CERN



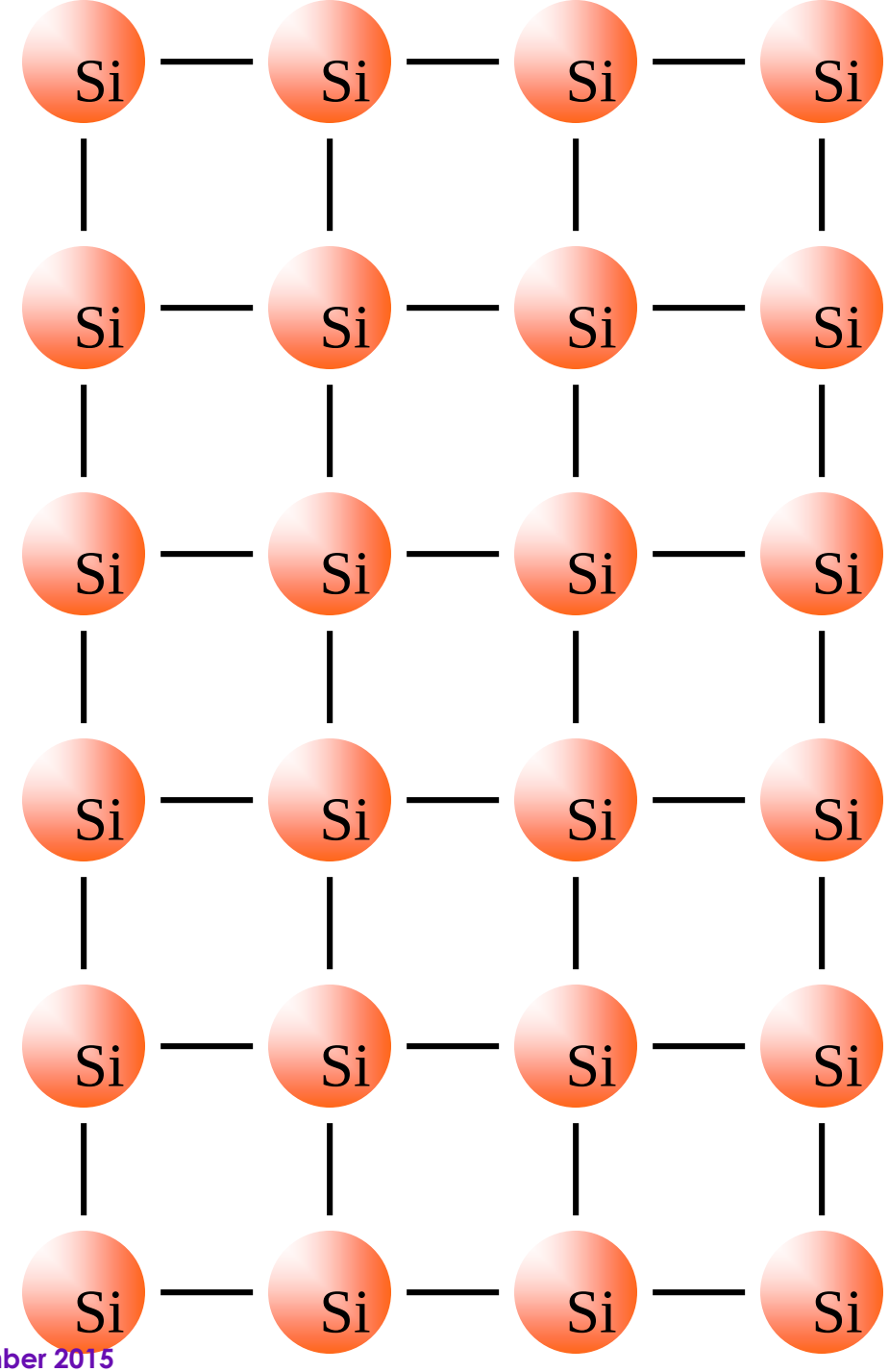
Why Radioactive Beams (RIB)?

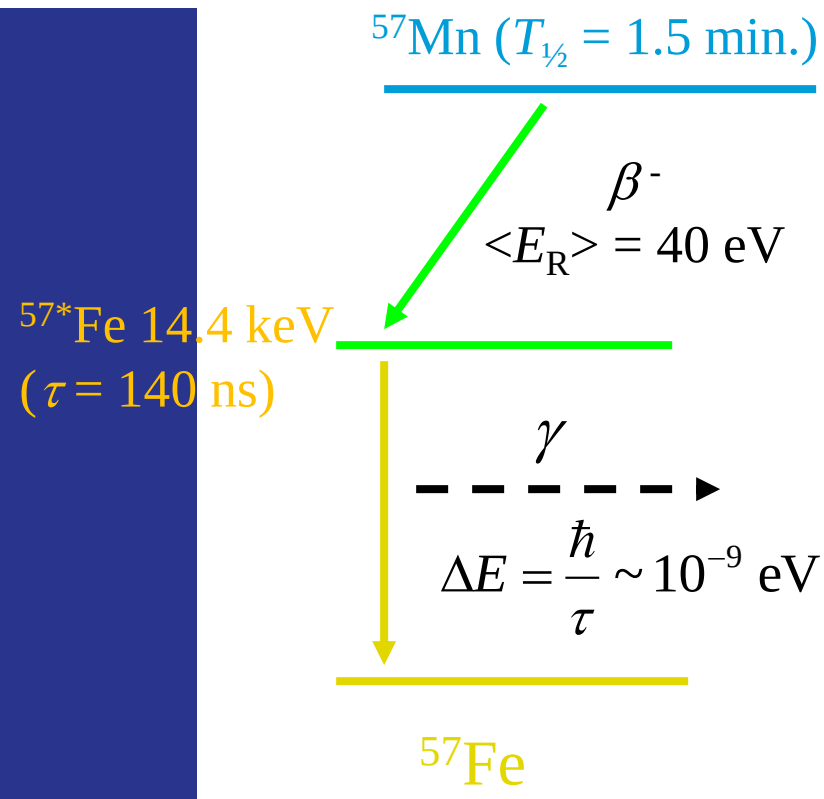


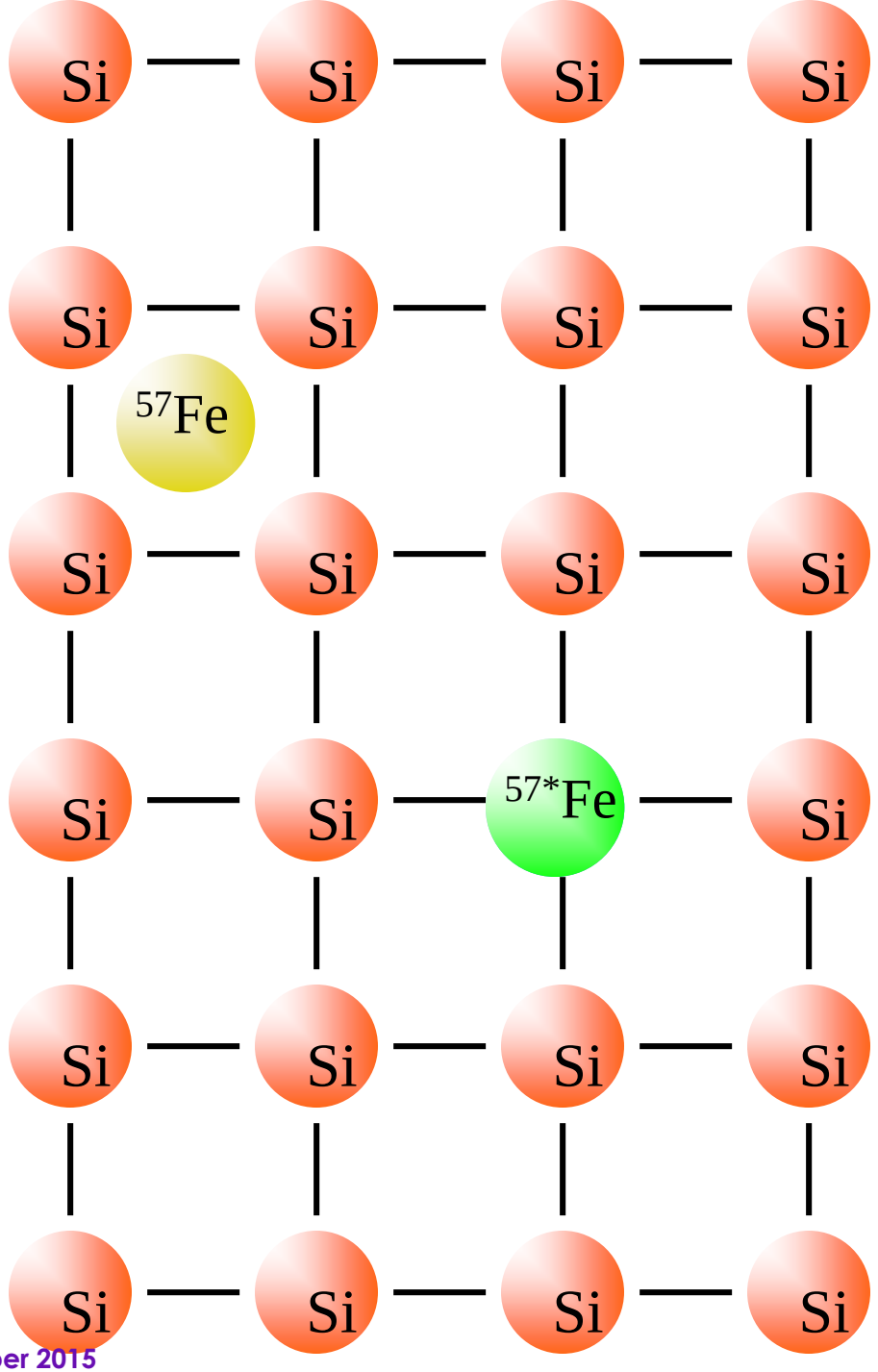
Upon annealing of implantation damage ($T > 450$ K, $t = 90$ sec)

Mn enters predominantly substitutional sites or near-substitutional sites

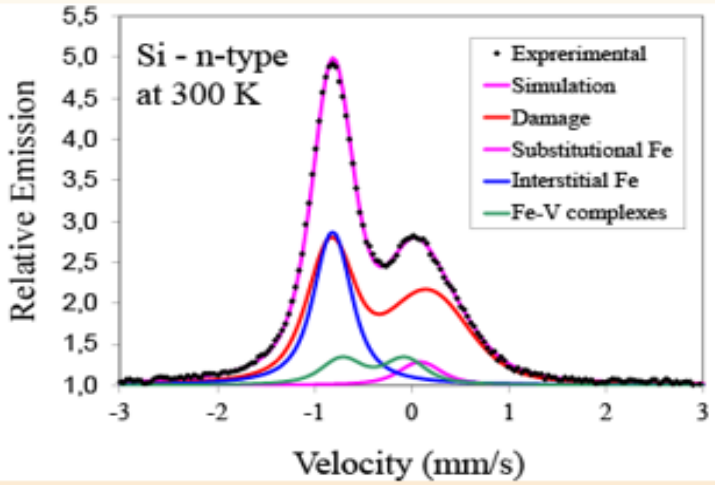
Mn

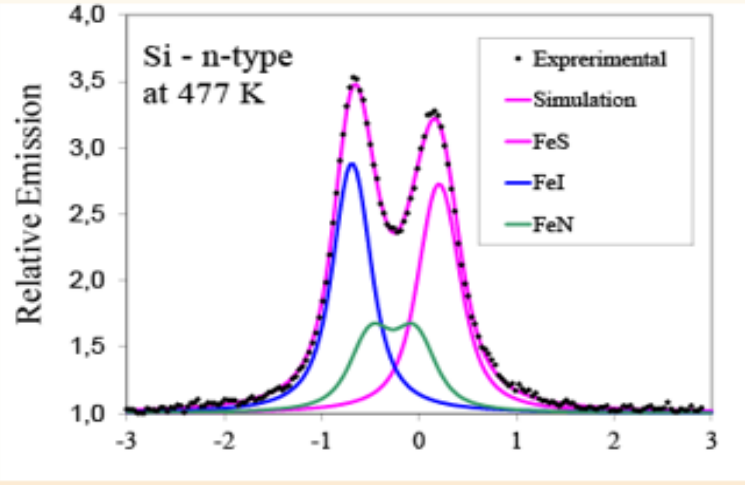



^{57}Mn ($T_{½}$ = 1.5 min.)
β^-
<E_R> = 40 eV
^{57*}Fe 14.4 keV
(τ = 140 ns)
γ
$\Delta E = \frac{\hbar}{\tau} \sim 10^{-9}$ eV
^{57}Fe


Si
^{57}Fe
^{57*}Fe

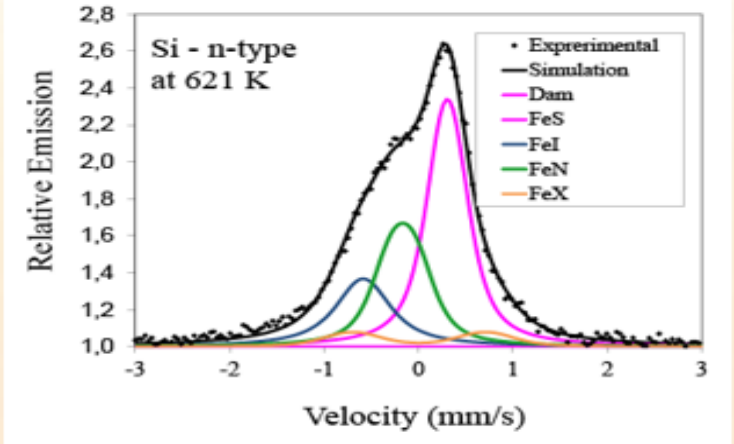
Applications: ISOLDE - Silicon

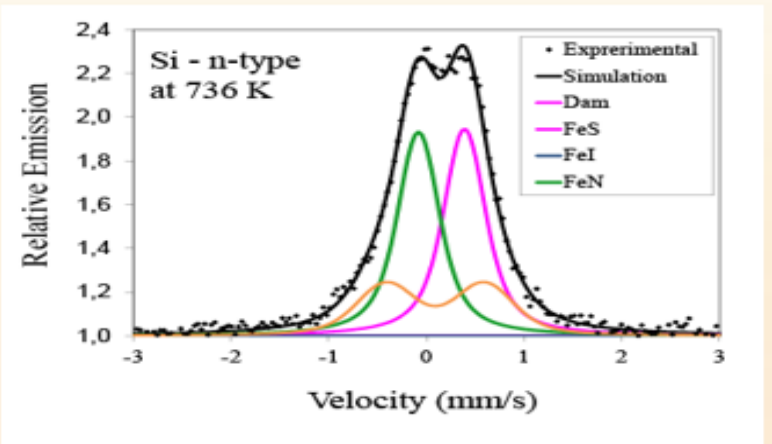




At low T:

At intermediate T:

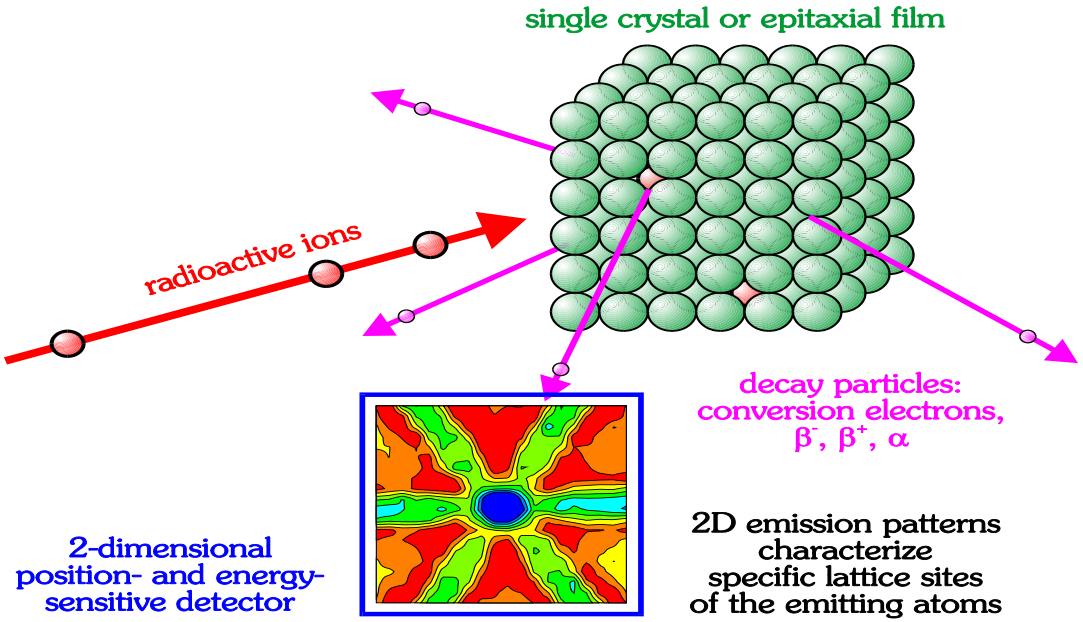




At higher T:

At the highest T:

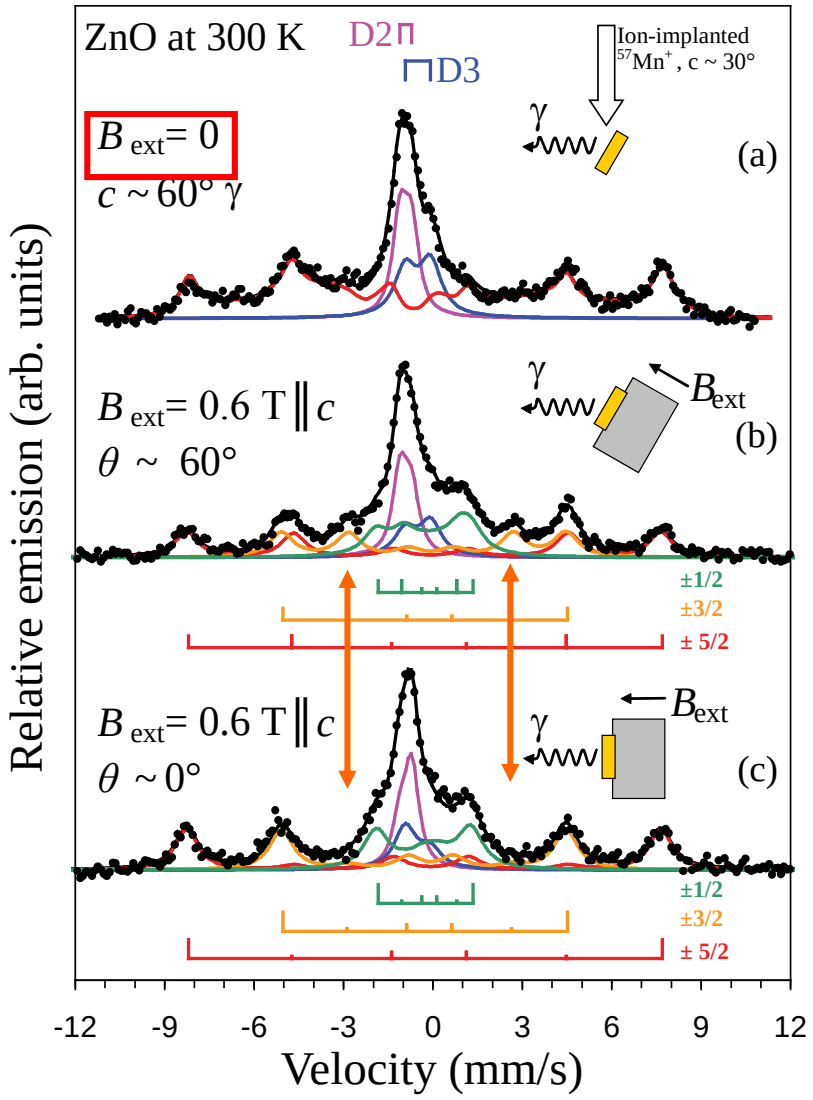
Emission Channeling in Si @ ISOLDE



Four fractions:

- Random fraction (R) => disordered environment.
- Ideal substitutional site (S)
- Near substitutional site (near-S)
- Near interstitial site (near-T)

Applications: ISOLDE - ZnO



B_{ext} = 0 T: Complex magnetic sextet structure.

Magnetic structure originate from Kramers doublets.

- **NO ordered magnetism.**
- **Slow Relaxing Paramagnetism.**

Some Collaborators at CERN

South Africa: *D. Naidoo, K. Bharuth-Ram, H. Masenda and M. Ncube* **acknowledges support from South African National Research Foundation and the Department of Science and Technology.**

***Denmark**: H.P. Gunnlaugsson, G. Weyer and M.B. Madsen.*

Italy: *R. Mantovan and M. Fanciulli* **acknowledges support from MIUR through the FIRB Project RBAP115AYN "Oxides at the nanoscale: multifunctionality and applications".**

Iceland: *T.E. Mølholt, S. Ólafsson and H. P. Gíslason* **acknowledges support from the Icelandic Research Fund.**

CERN-ISOLDE: *K. Johnston*

Belgium: *G. Langouche*

Germany: *R. Sielemann*

Local Collaboration

- Professor D. Naidoo (Group Leader)
- Dr H. Masenda
- Undergraduate Students (Physics Majors III and Materials Science III)
- Postgraduate Students (Honours, MSc and PhD)
- School of Physics: MPRI Members
- Modelling Group DST/NRF CoE in Strong Materials
- School of Chemistry
- School of Geosciences
- University of Johannesburg
- Durban University of Technology (DUT)
- MINTEK/ANGLO/CSIR/SASOL/ELEMENT 6
- NECSA – future?