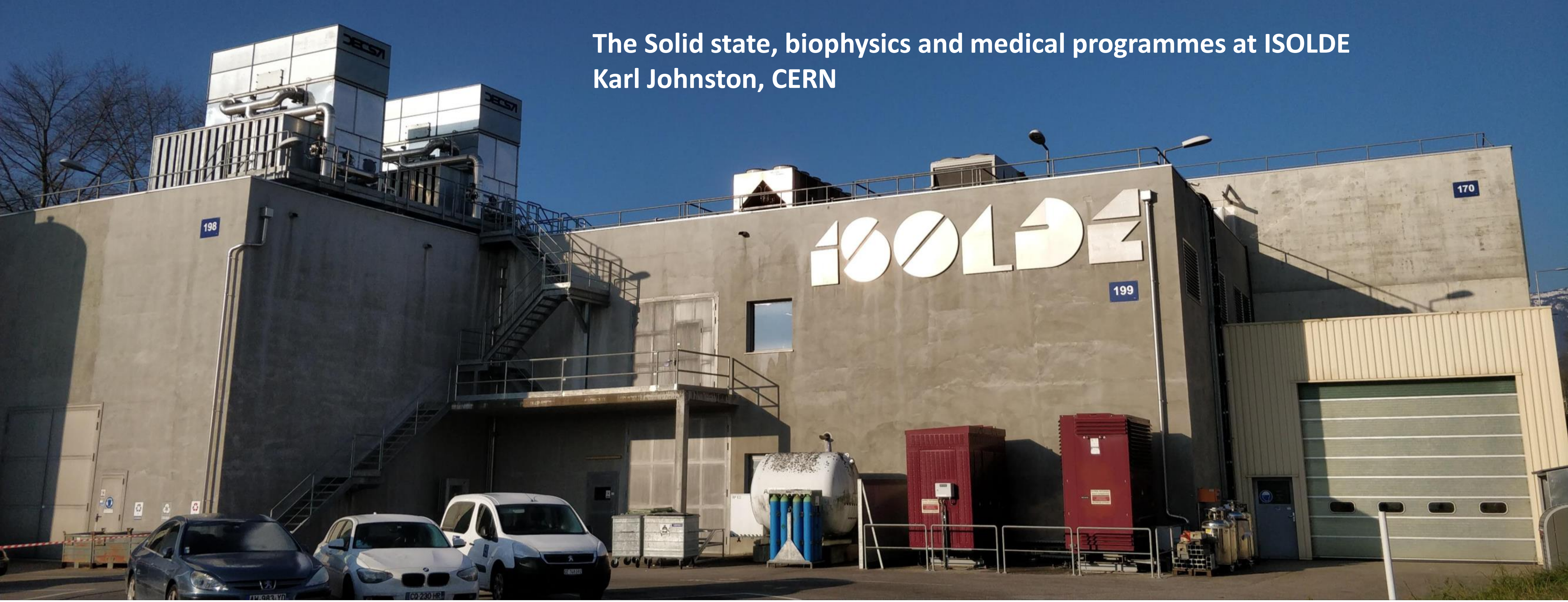
The Solid state, biophysics and medical programmes at ISOLDE

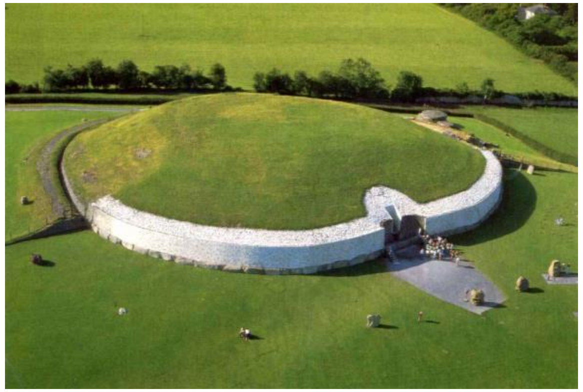
Karl Johnston, CERN



- ISOLDE facility and «applications» e.g. solid state physics, biophysics and medicine
- Why use radioactive isotopes?
- Examples of common techniques for nuclear solid state physics (and a bit of biology)
- Isotopes for medicine: where ISOLDE can play a role in developing «standard» diagnostic and treatment isotopes for the future.

Journey of a solid state physicist to a radioactive ion beam facility…

Born in Ireland



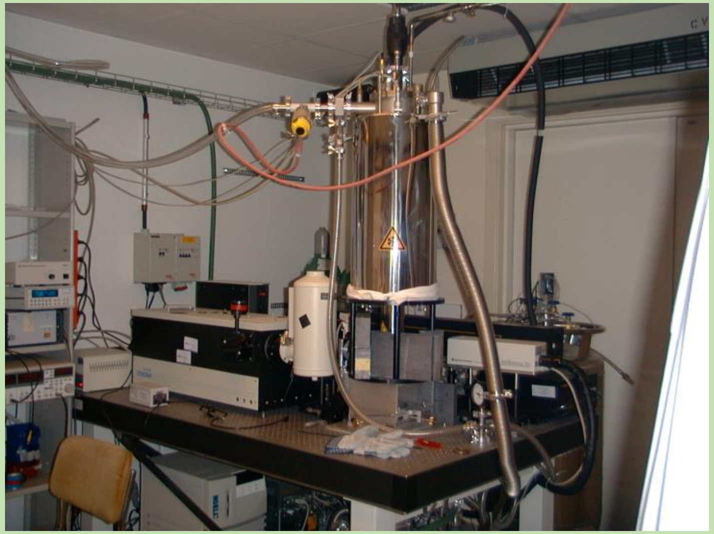
BSc in Dublin (Dublin City University) (1996)

PhD (2000) + postdoc (2002) in London (King’s College London)

Thesis on properties of metal-N complexes in diamond

Finally….some radioactive isotopes!

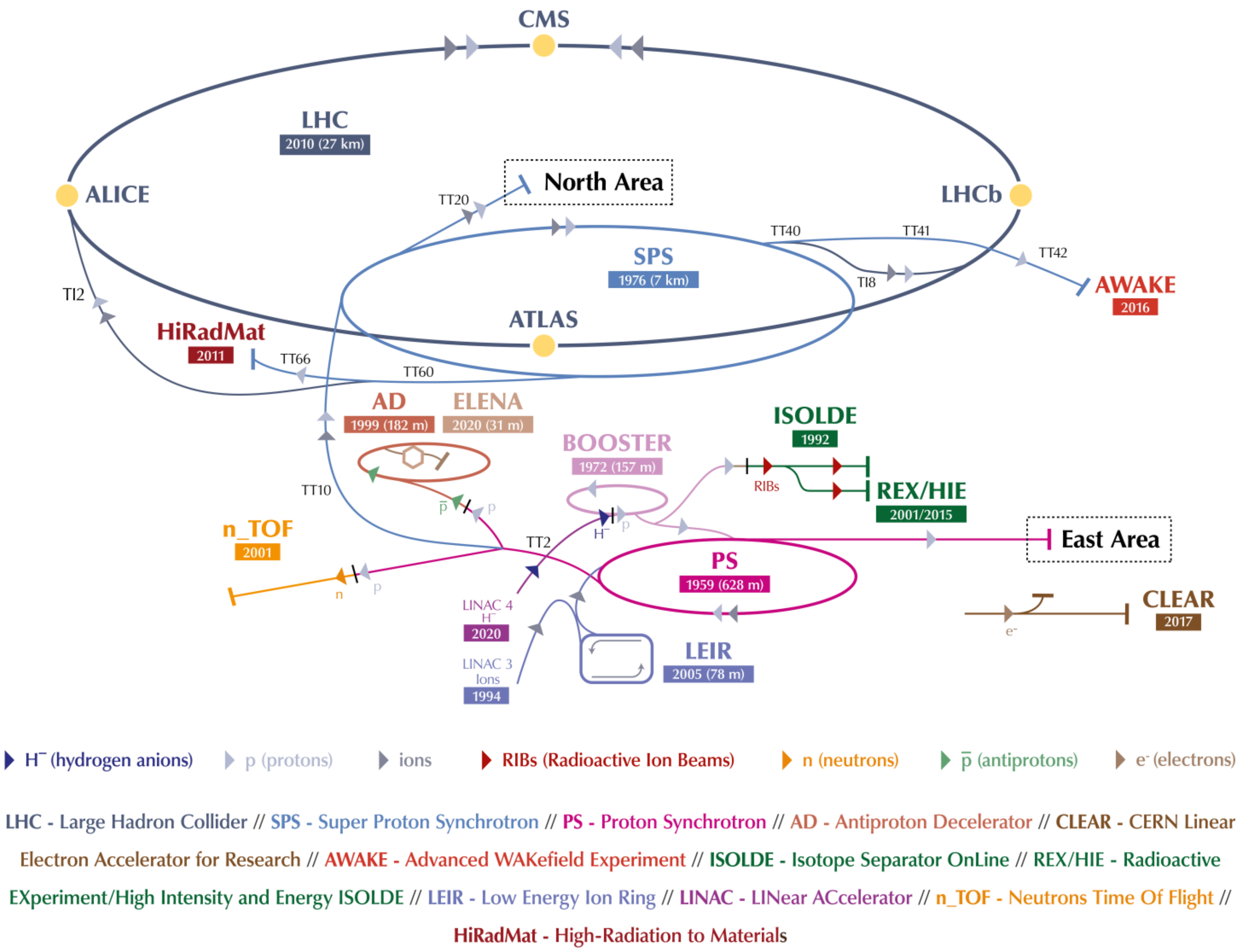
(2003) First experiments at ISOLDE
Built radiotracer PL laboratory at ISOLDE and studied semiconductors such as ZnO implanted with radioactive isotopes.



(2005) Brief interlude in Prague to work on nanodiamonds

Since 2005 first solid state, now physics coordinator at ISOLDE, CERN

The CERN accelerator complex
Complexe des accélérateurs du CERN



AD: Antiproton Decelerator for antimatter studies

AWAKE: proton-induced plasma wakefield acceleration

CAST, OSQAR: axions

CLOUD: impact of cosmic rays on aeorosols and clouds → implications on climate

COMPASS: hadron structure and spectroscopy

ISOLDE: radioactive nuclei facility

NA61/Shine: heavy ions and neutrino targets

NA62: rare kaon decays

NA63: radiation processes in strong EM fields

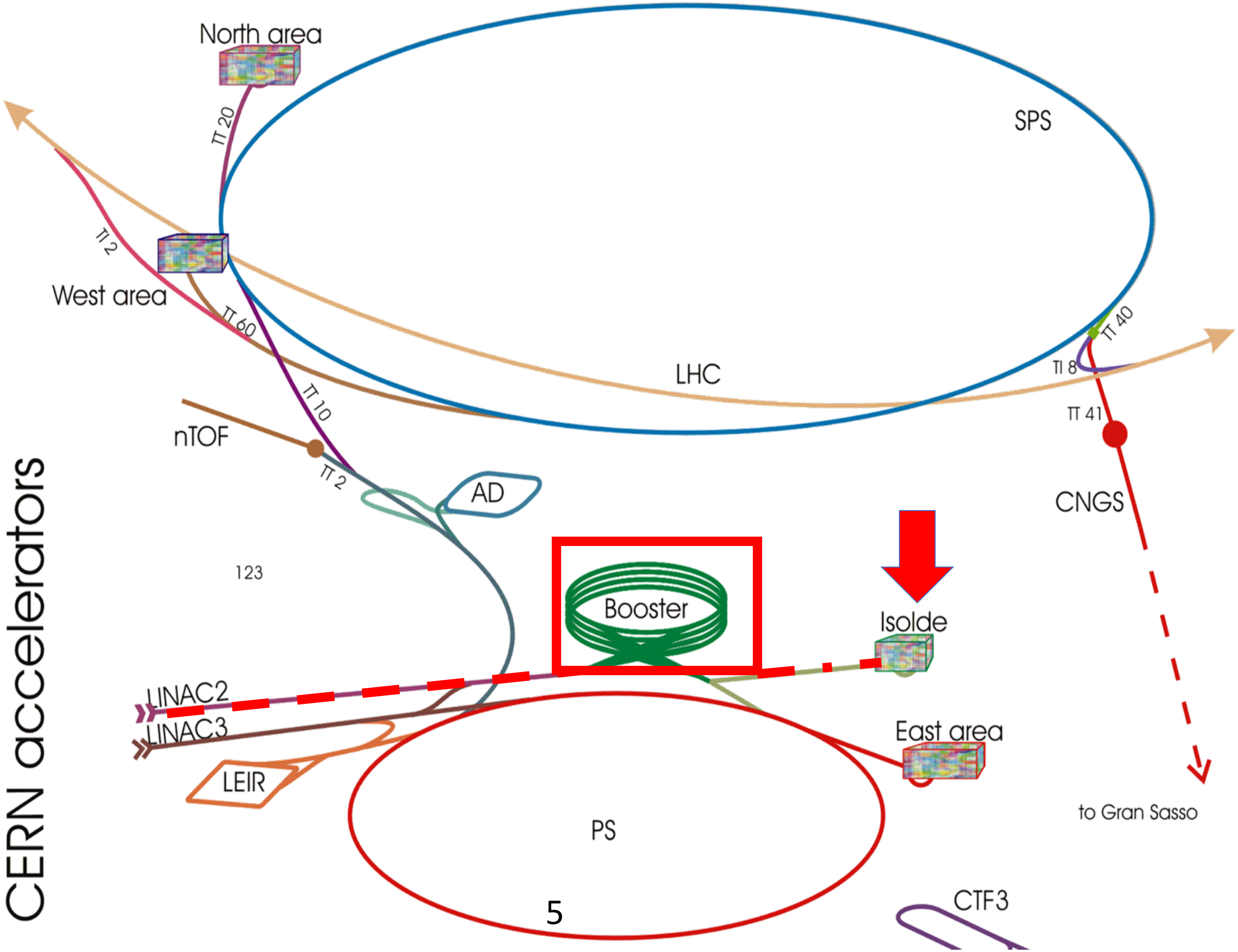
NA64: search for dark photons

Neutrino Platform: ν detectors R&D for experiments in US, Japan

n-TOF: n-induced cross-sections

UA9: crystal collimation

ISOLDE = **Isotope Separator On Line**



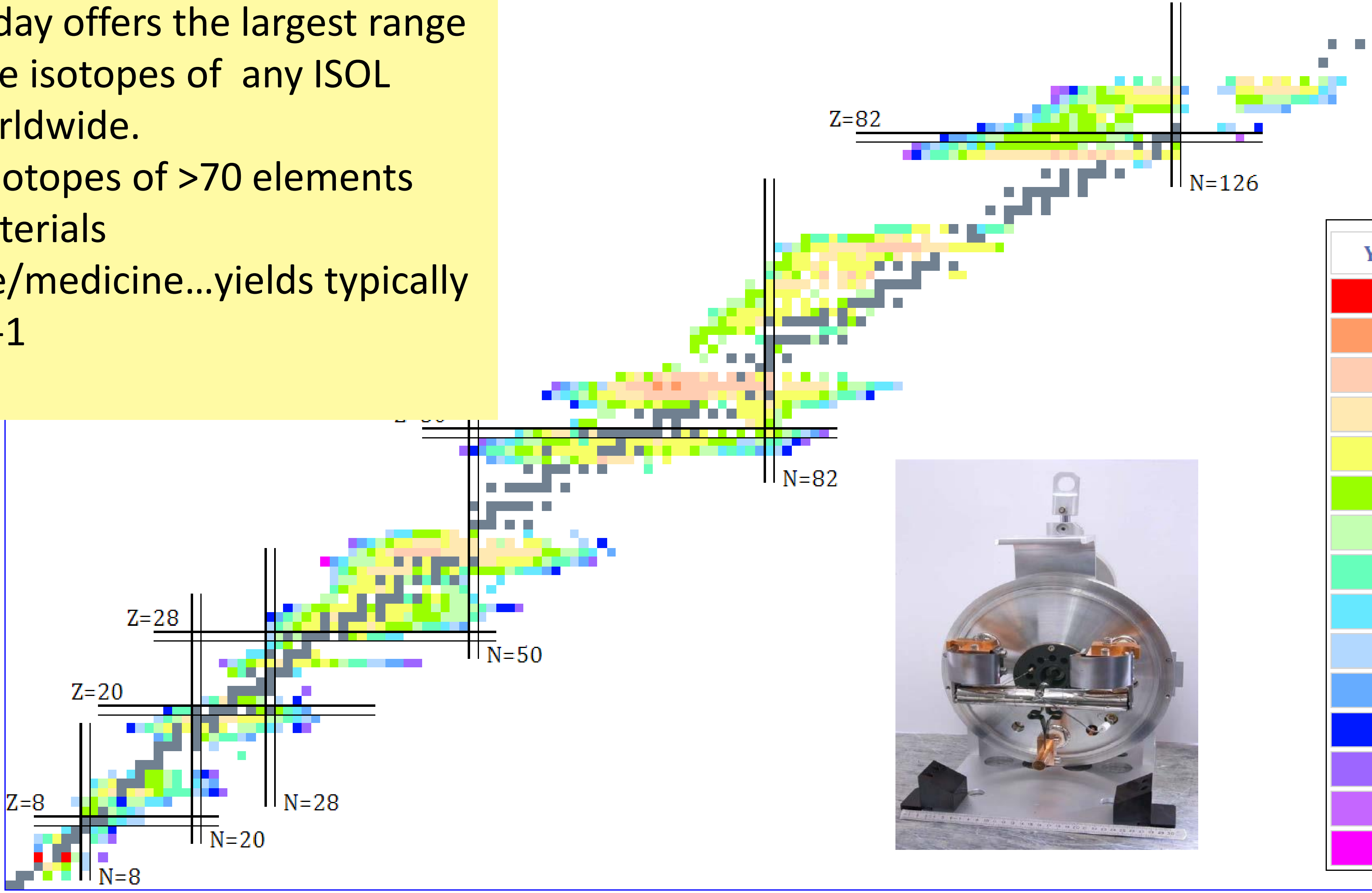
ATLAS
CMS
ALICE
LHCb

ISOLDE uses about 65% of CERN's protons....

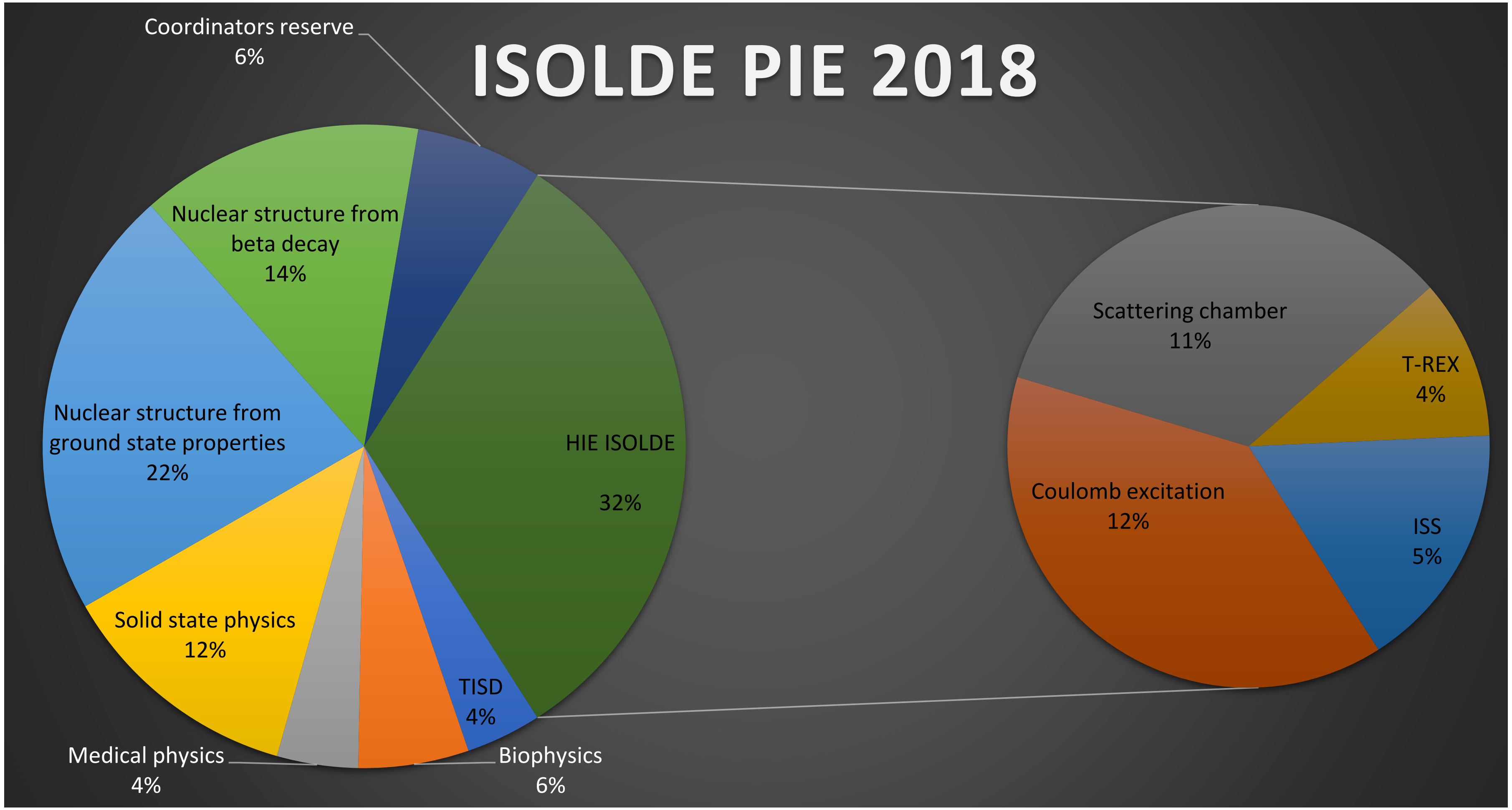
Nuclear chart for ISOLDE

ISOLDE today offers the largest range of available isotopes of any ISOL facility worldwide.

- 1000 isotopes of >70 elements
- For materials science/medicine…yields typically >1e7 s-1

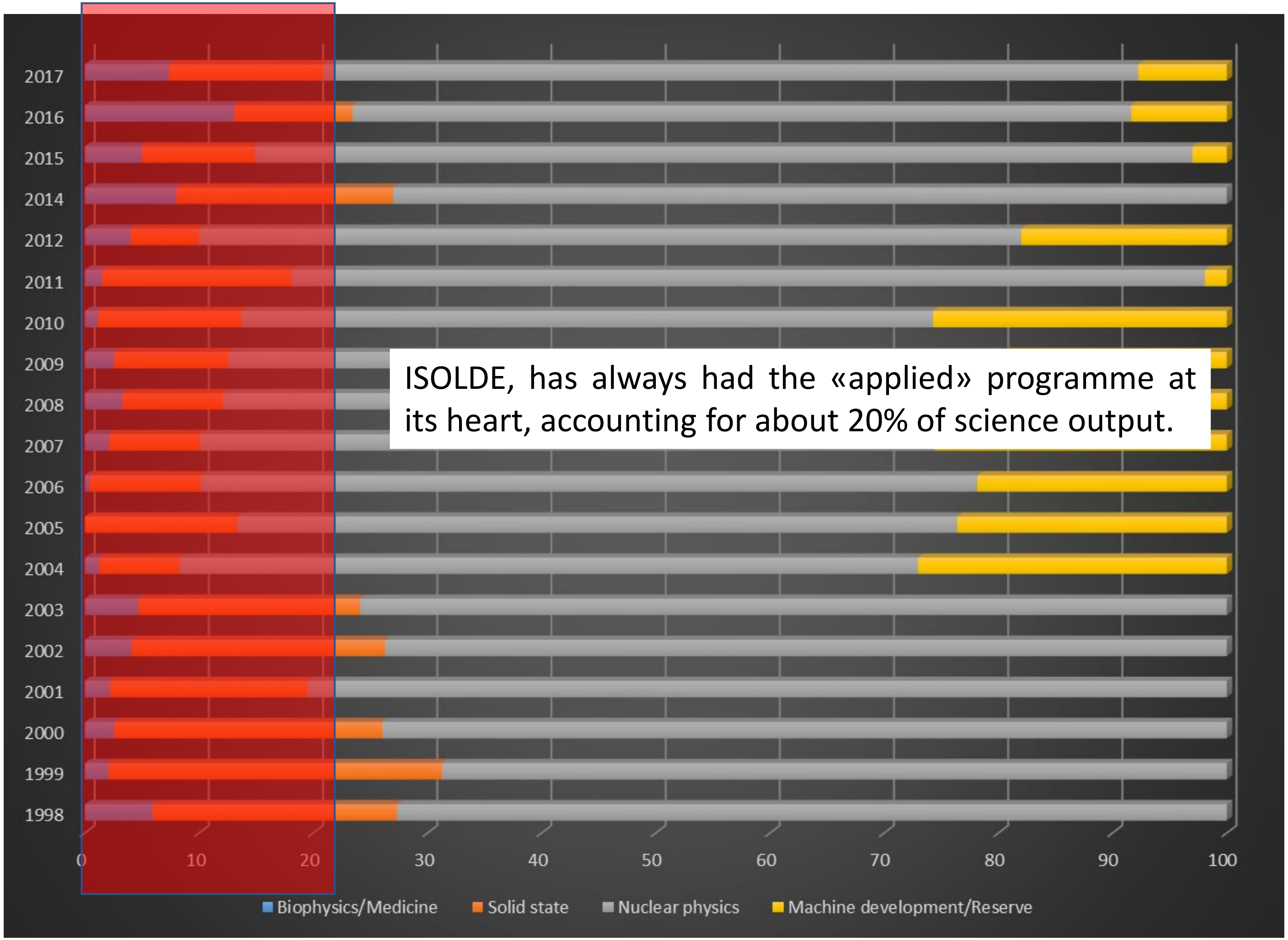


Yield (ions/μC)			
	10^{13}	-	10^{12}
	10^{12}	-	10^{11}
	10^{11}	-	10^{10}
	10^{10}	-	10^{9}
	10^{9}	-	10^{8}
	10^{8}	-	10^{7}
	10^{7}	-	10^{6}
	10^{6}	-	10^{5}
	10^{5}	-	10^{4}
	10^{4}	-	10^{3}
	10^{3}	-	10^{2}
	10^{2}	-	10^{1}
	10^{1}	-	10^{0}
	10^{0}	-	10^{-1}
	10^{-1}	-	10^{-2}



Étiquettes de lignes	Nombre de Delivered 2018
Biophysics	4
COLLAPS	3
CRIS	4
Gandalph	1
HIE	12
IDS	5
ISOLTRAP	2
la1	1
MEDICAL	2
REX	1
Special	1
SSP	13
Windmill; ISOLTRAP	1
WITCH	1
Total général	51

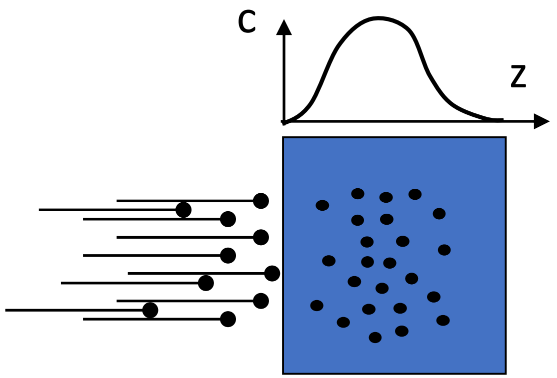
Applications: Solid state and biophysics/medicine long at the core of the ISOLDE programme

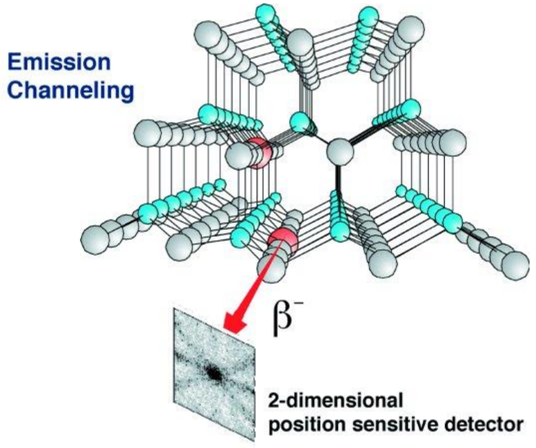


ISOLDE, has always had the «applied» programme at its heart, accounting for about 20% of science output.

Unique features of radioactive probe atoms for SSP/biology applications

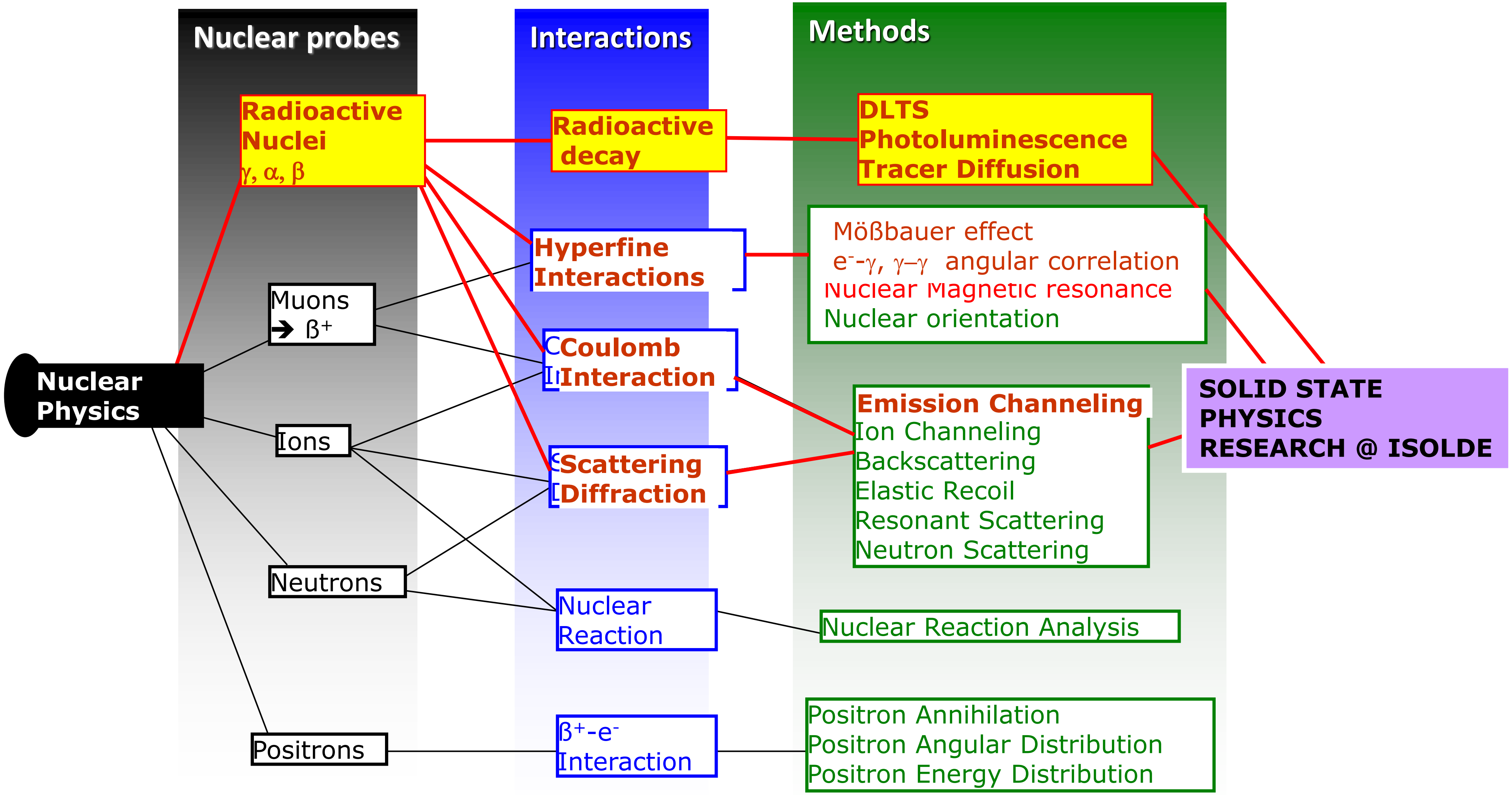
- **Chemically selective and isotope specific**
- **Extremely good detection limit**
  - among the most sensitive methods, no reaction cross section limitation
    - 10^{15} - 10^{18} probes/cm^3
    - 10^{11} - 10^{12} probe atoms
- **Depth distribution and concentration control**
  - Ion energy and ion fluence control
  - Circumventing solubility and diffusion limits
- **Highly local Information**
  - Nucleus-size sensors for **local** magnetic and electric fields
    Electric Field Gradient ~ r^{-3}
    Emission channeling: ~ 0.02 nm position resolution



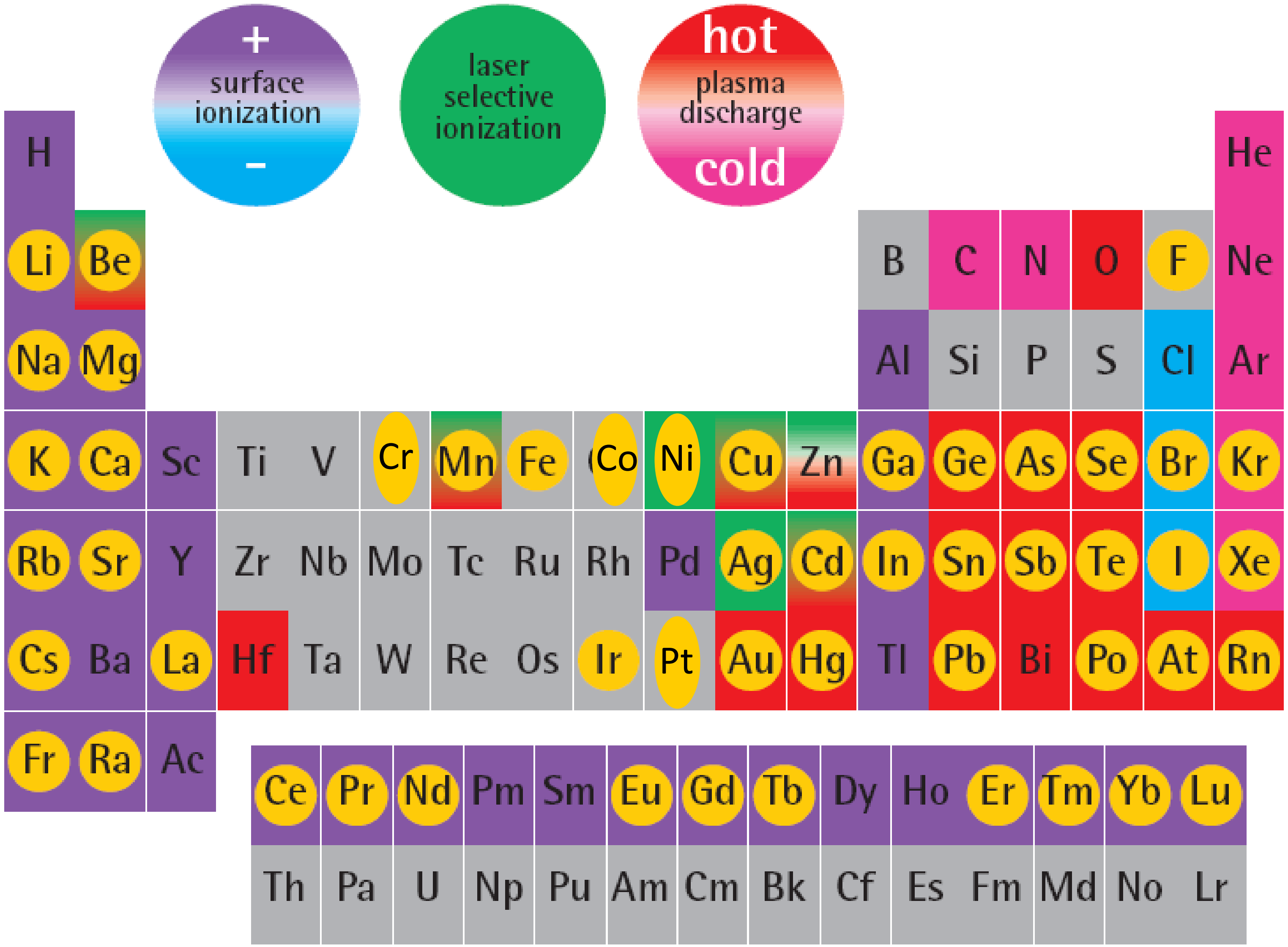


Why radioactive probes ? Sensitive – Selective - Controllable – Local
Often relatively easy isotopes for RIB facilities to produce (not always a good thing…)

Applying radioactivity to solid state physics



ISOLDE table of elements



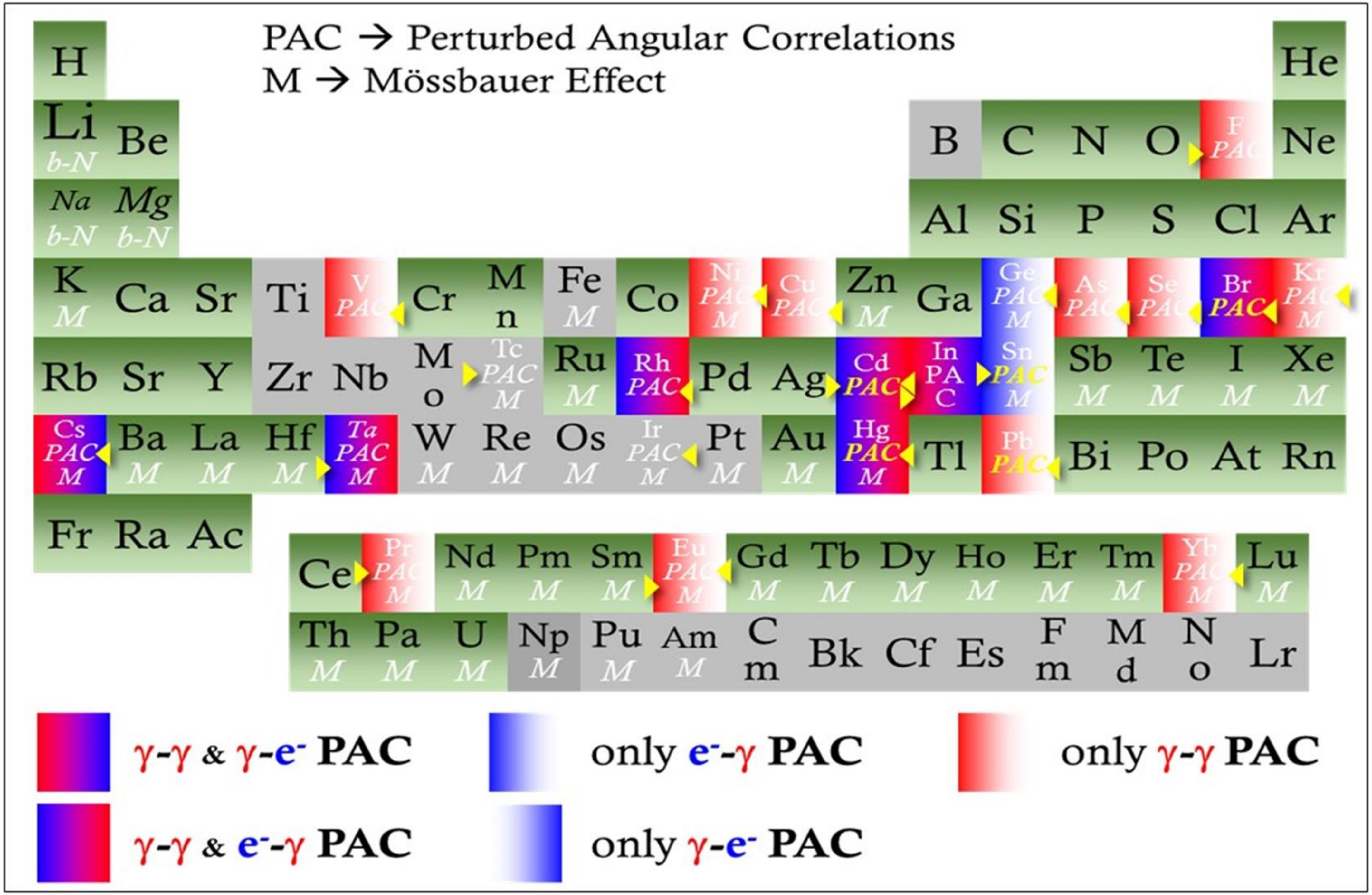
Workhorse probes:

^{111}Cd, ^{199}Hg, ^{117}Cd, ^{57}Mn, ^{73}As

New promising probes:

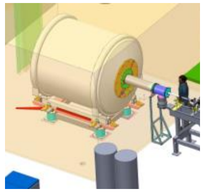
^{68}Cu, ^{149}Gd, ^{172}Lu, ^{151}Gd, ^{197}Hg

Isotopes of this element used for solid state physics or life science


PAC → Perturbed Angular Correlations
M → Mössbauer Effect
H
He
Li b-N
Be
B
C
N
O
F PAC
Ne
Na b-N
Mg b-N
Al
Si
P
S
Cl
Ar
K M
Ca
Sr
Ti
V PAC
Cr
Mn
Fe M
Co
Ni PAC M
Cu PAC
Zn M
Ga
Ge PAC M
As PAC
Se PAC
Br PAC
Kr PAC M
Rb
Sr
Y
Zr
Nb
Mo
Tc PAC M
Ru M
Rh PAC
Pd
Ag
Cd PAC
In PAC
Sn PAC M
Sb M
Te M
I M
Xe M
Cs PAC M
Ba M
La M
Hf M
Ta PAC M
W M
Re M
Os M
Ir PAC M
Pt M
Au M
Hg PAC M
Tl
Pb PAC
Bi
Po
At
Rn
Fr
Ra
Ac
Ce
Pr PAC M
Nd M
Pm M
Sm M
Eu PAC M
Gd M
Tb M
Dy M
Ho M
Er M
Tm M
Yb PAC M
Lu M
Th M
Pa M
U M
Np M
Pu M
Am M
Cm
Bk
Cf
Es
Fm
Md
No
Lr
γ-γ & γ-e⁻ PAC
only e⁻-γ PAC
only γ-γ PAC
γ-γ & e⁻-γ PAC
only γ-e⁻ PAC

Poland

MINIBALL



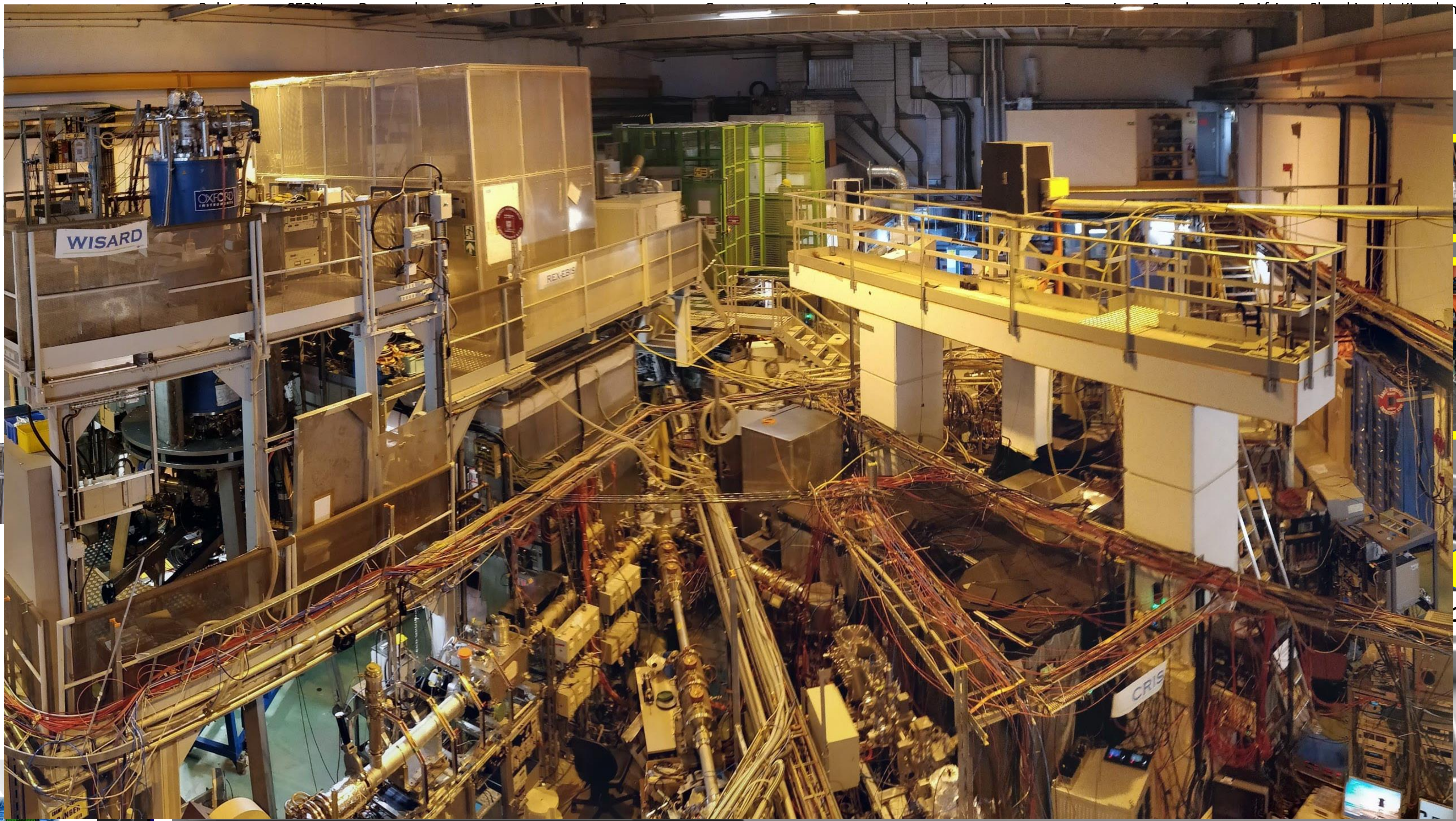
ISS

ISOLTRAP

IDS

SSP

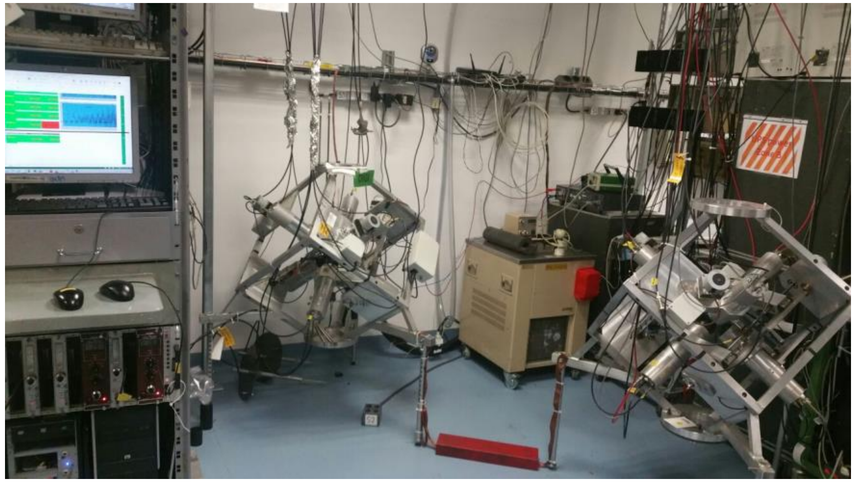
MEDICAL ISOTOPES



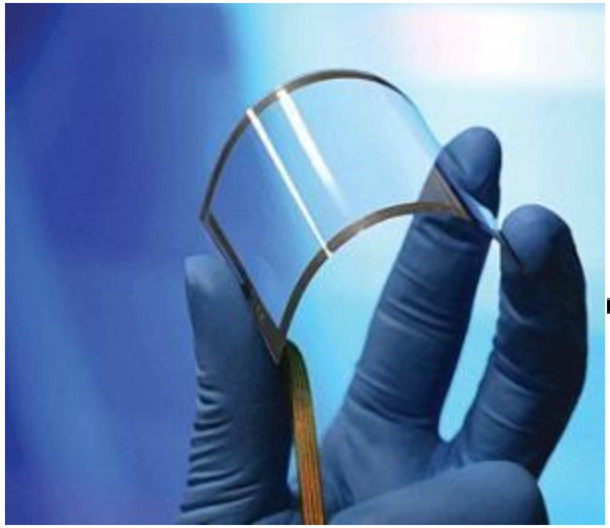
IS

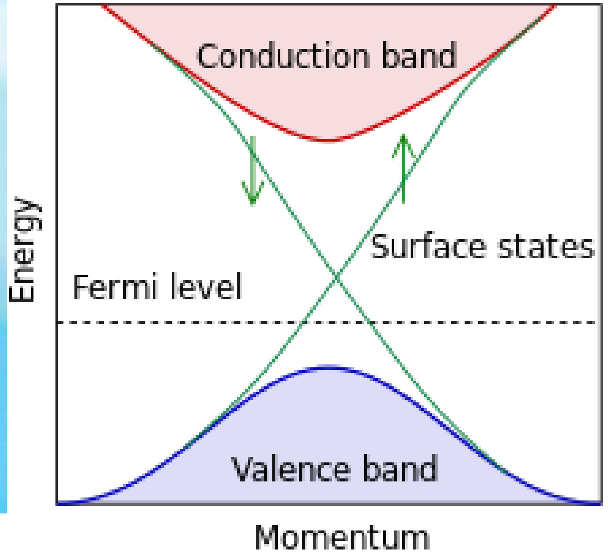
1.4 GeV

Offline labs at ISOLDE: B. 508

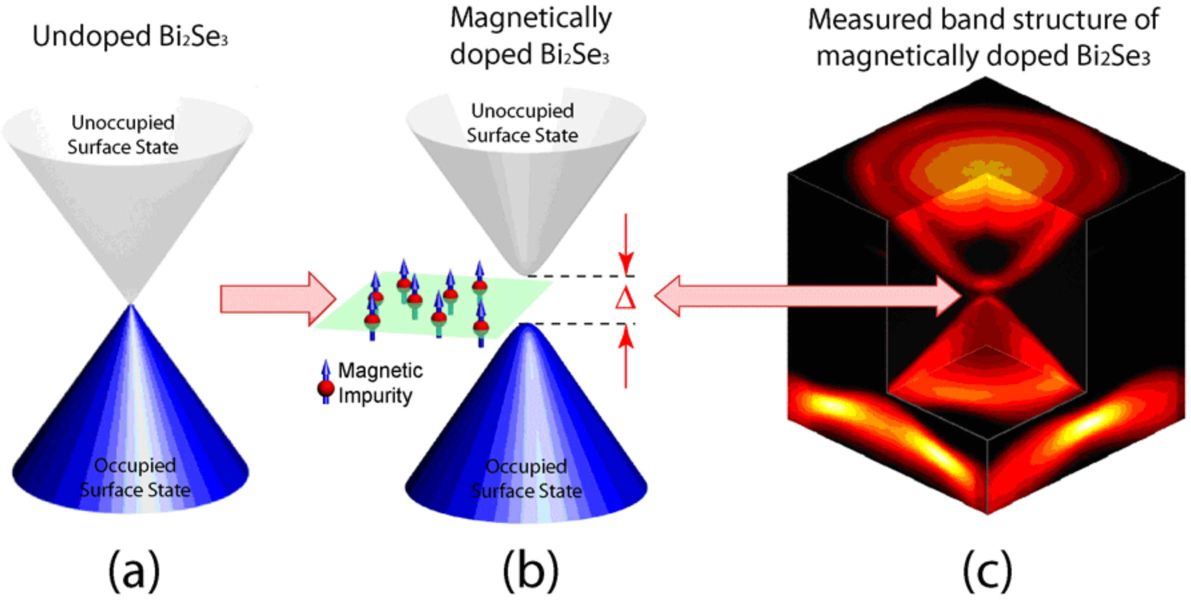


Staying relevant: Materials studied at ISOLDE

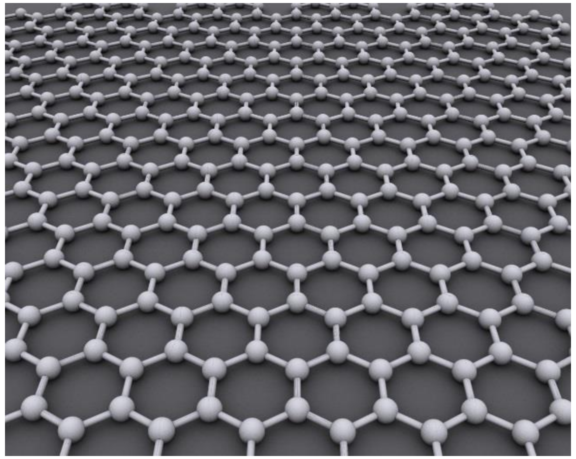




graphene



Topological Insulators



IOP Publishing Journal of Phy

J. Phys. D: Appl. Phys. **50** (2017) 393002 (26pp) https://doi.org/10.

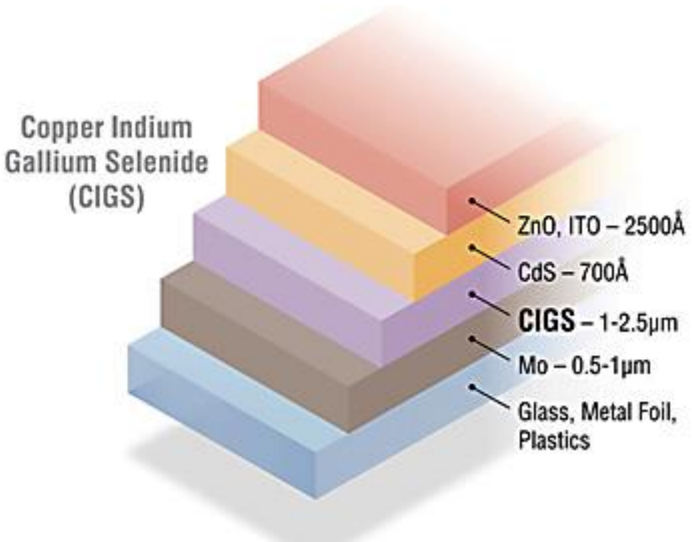
Topical Review

Experimentally evaluating the origin of dilute magnetism in nanomaterials

L M C Pereira

KU Leuven, Instituut voor Kern- en Stralingsfysica, 3001 Leuven, Belgium

Hyperfine techniques are particularly successful in unravelling subtle magnetic behaviour in materials


Copper Indium
Gallium Selenide
(CIGS)
ZnO, ITO – 2500Å
CdS – 700Å
CIGS – 1-2.5μm
Mo – 0.5-1μm
Glass, Metal Foil,
Plastics

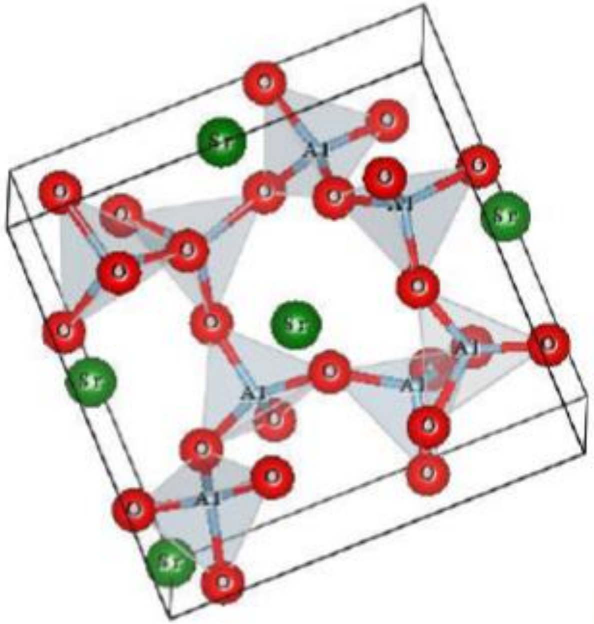
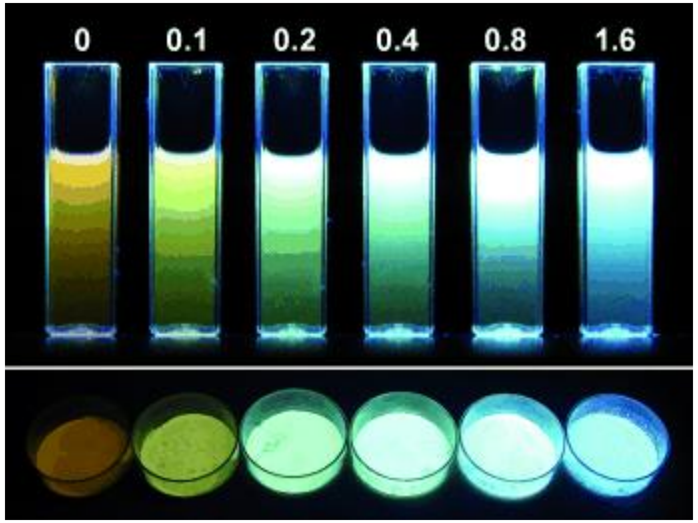


Fig. 1



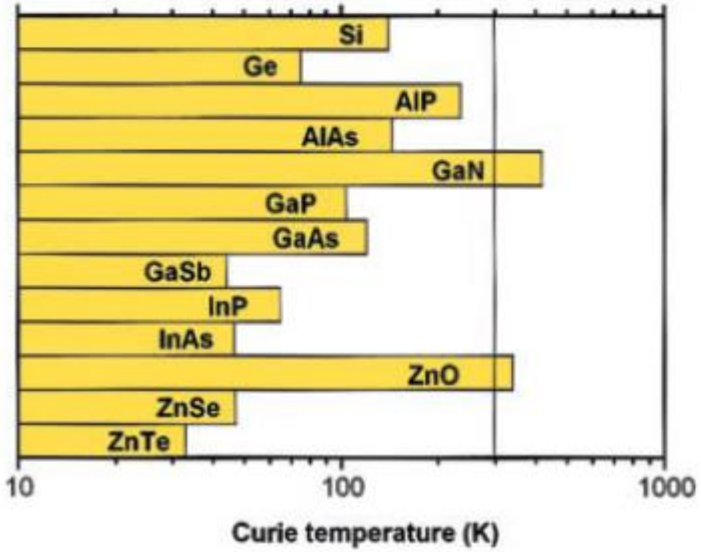


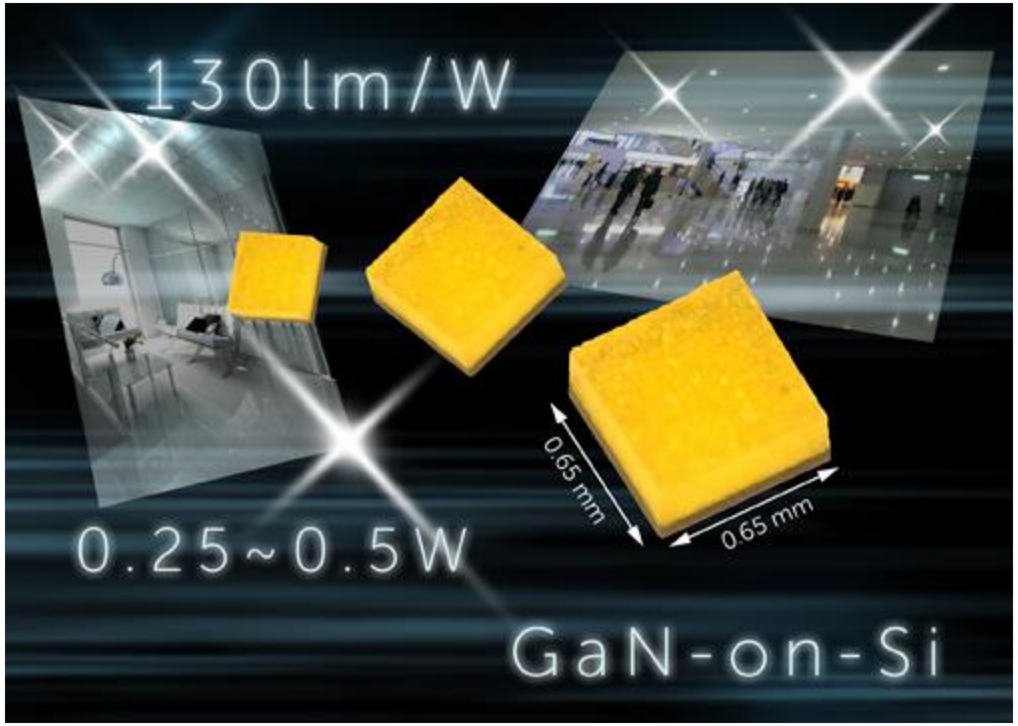
Fig. 3. Computed values of the Curie temperature T_C for various p-type semiconductors containing 5% of Mn and 3.5×10^{20} holes cm^3.

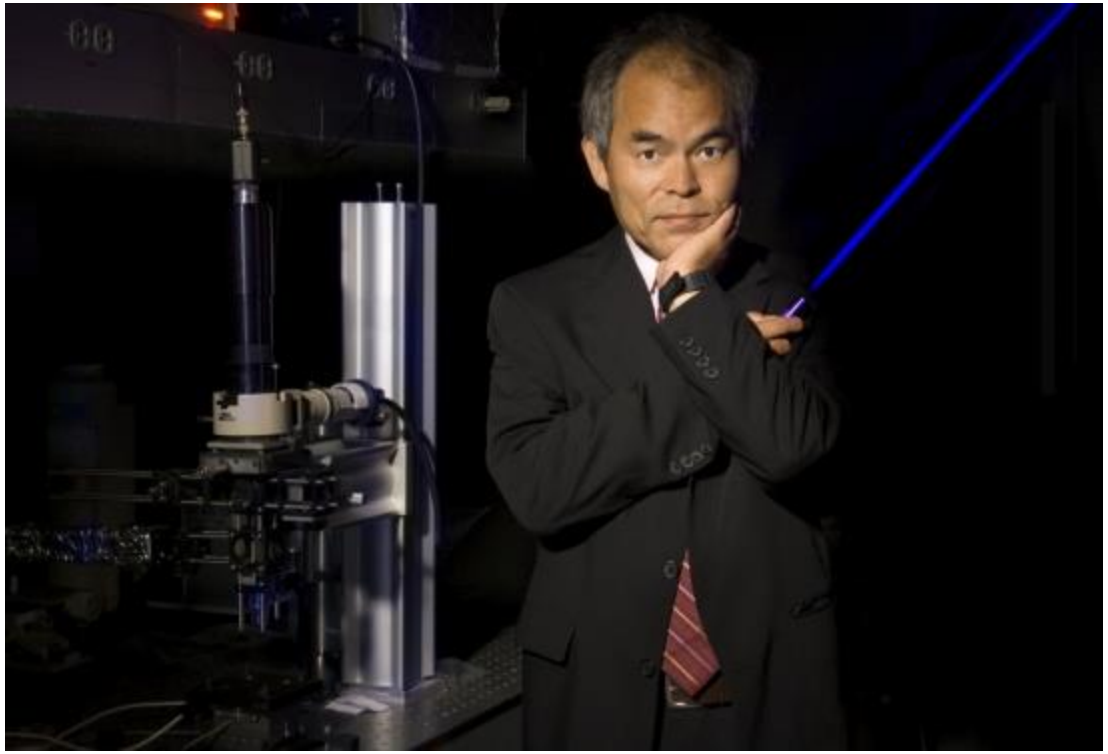
Dietl *et al*, *Science* 287 (2000) 1

Is it possible to create magnetic semiconductors that work at room temperature?

Such devices have been demonstrated at low temperatures but not yet in a range warm enough for spintronics applications.

Next generation semiconductors : doping



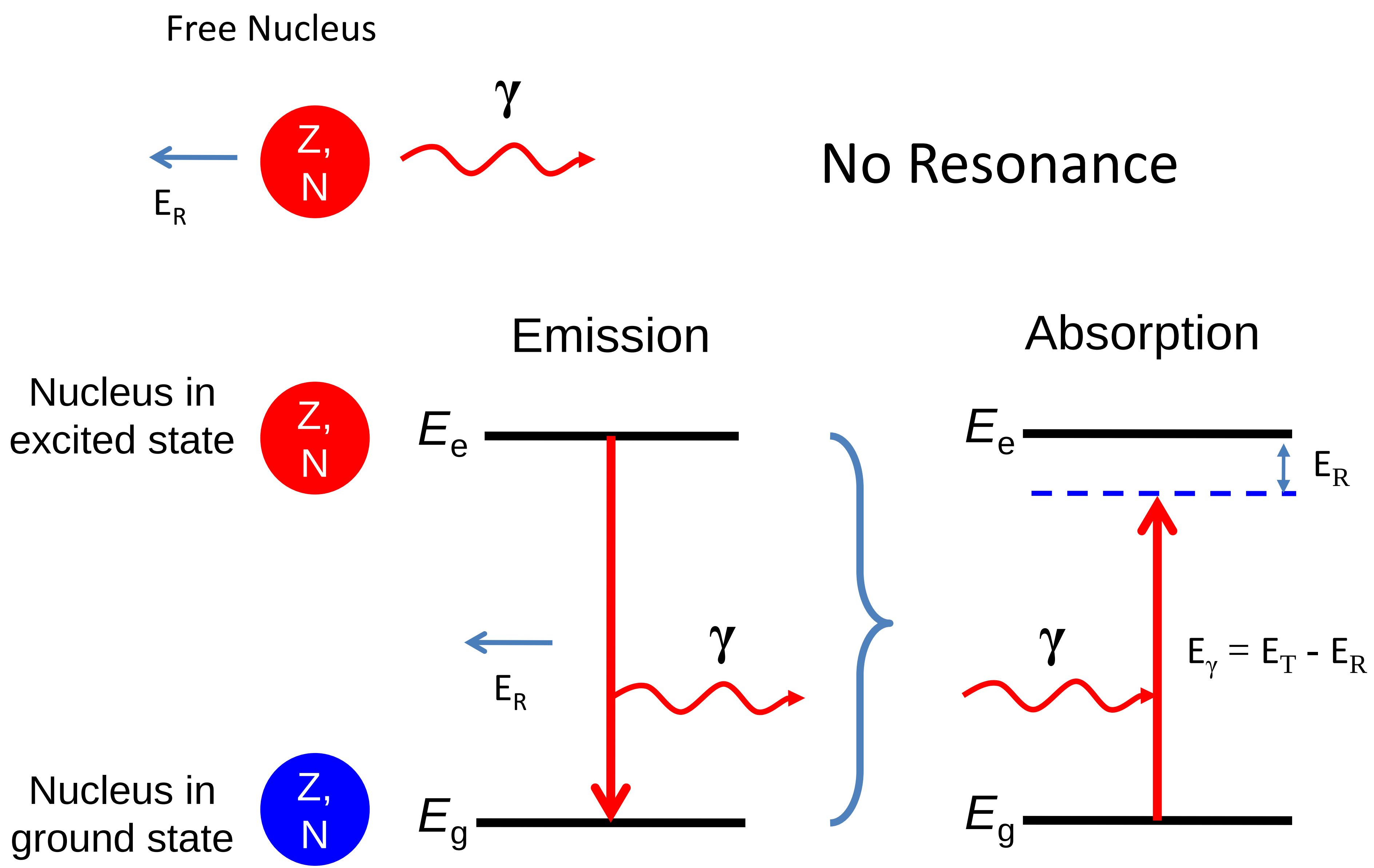


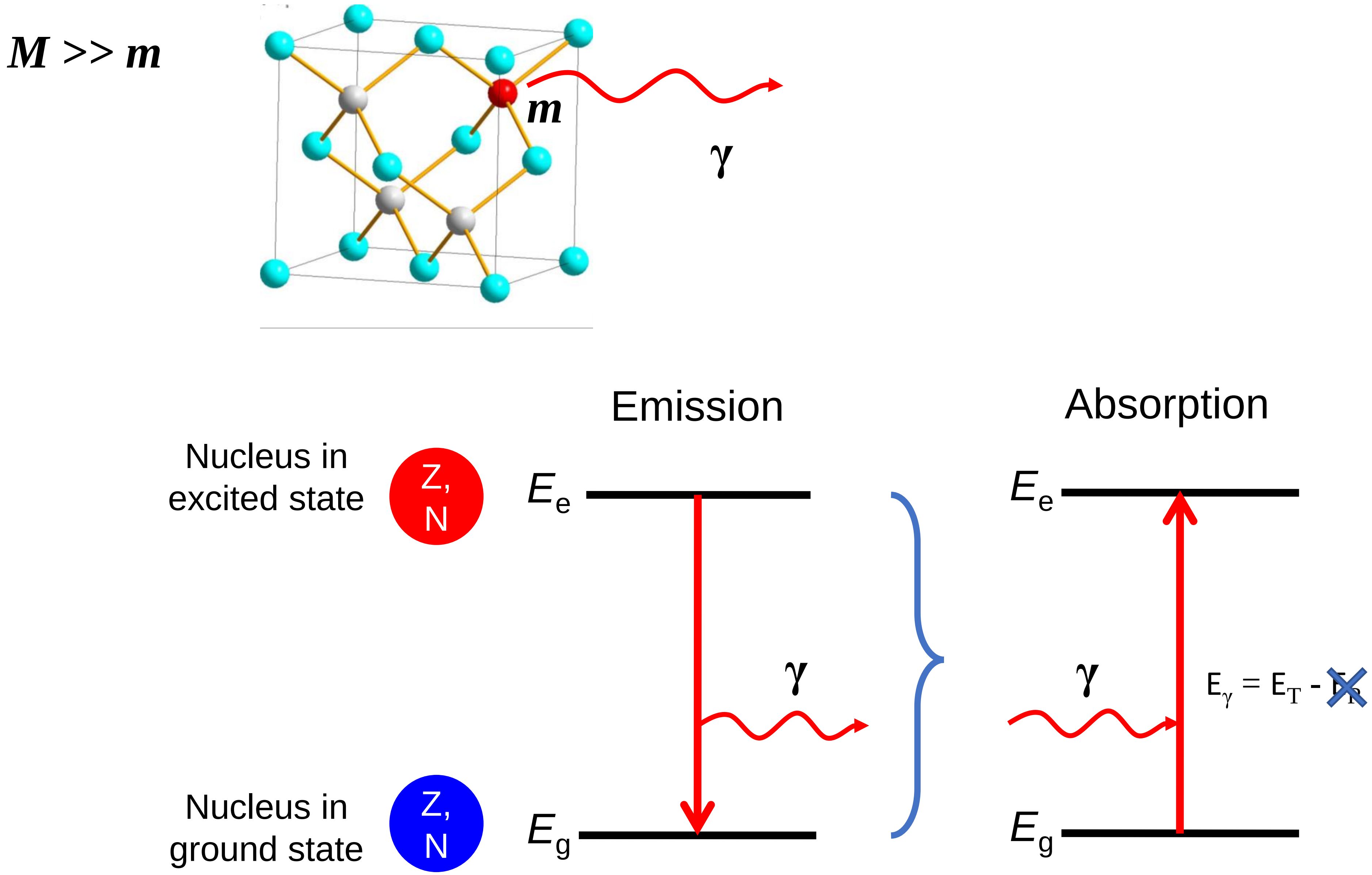
^{129}Ir

Rudolf L. Mössbauer

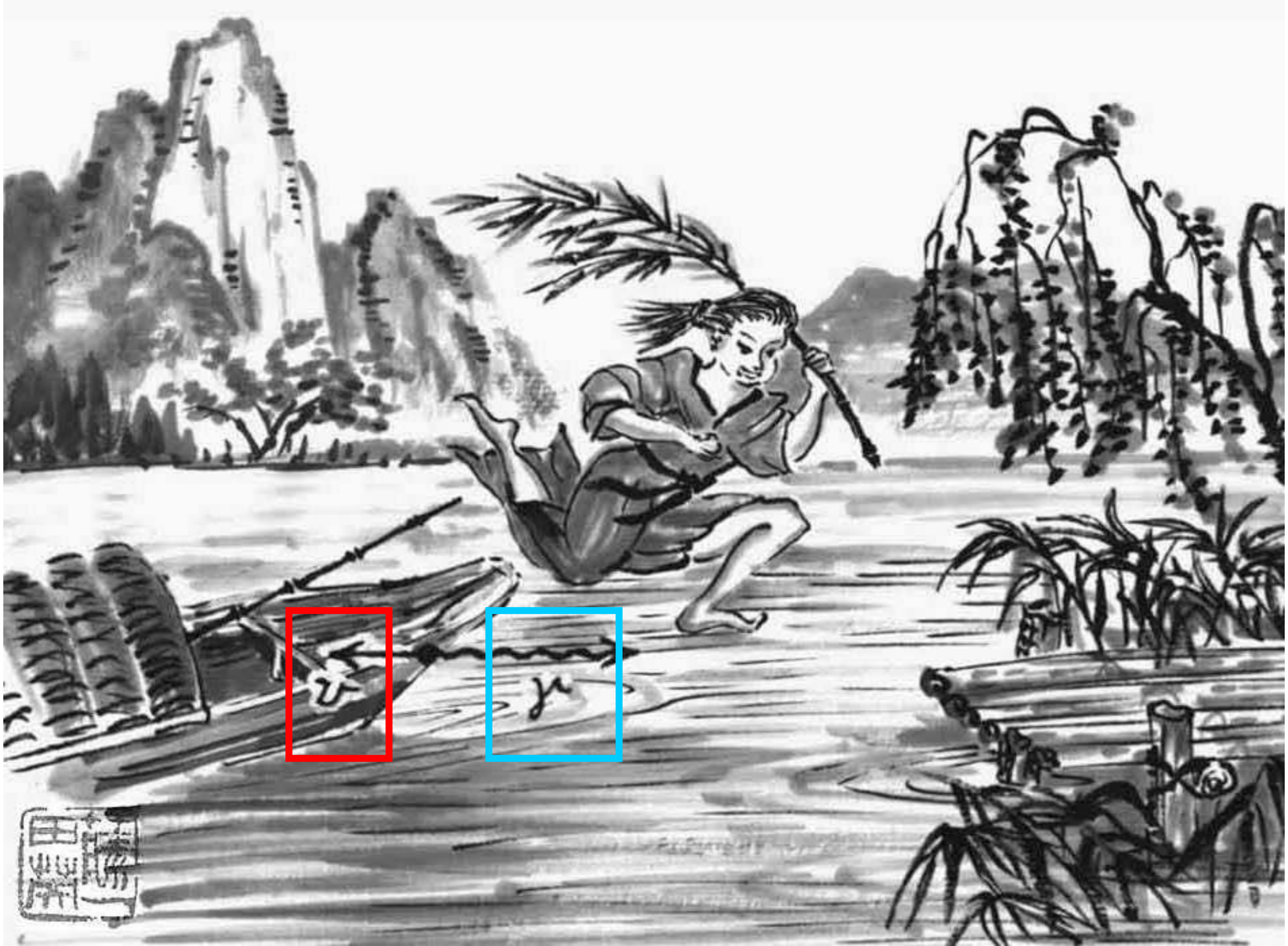
Nobel Prize in Physics in 1961
for his 1957 discovery of the
Mössbauer effect

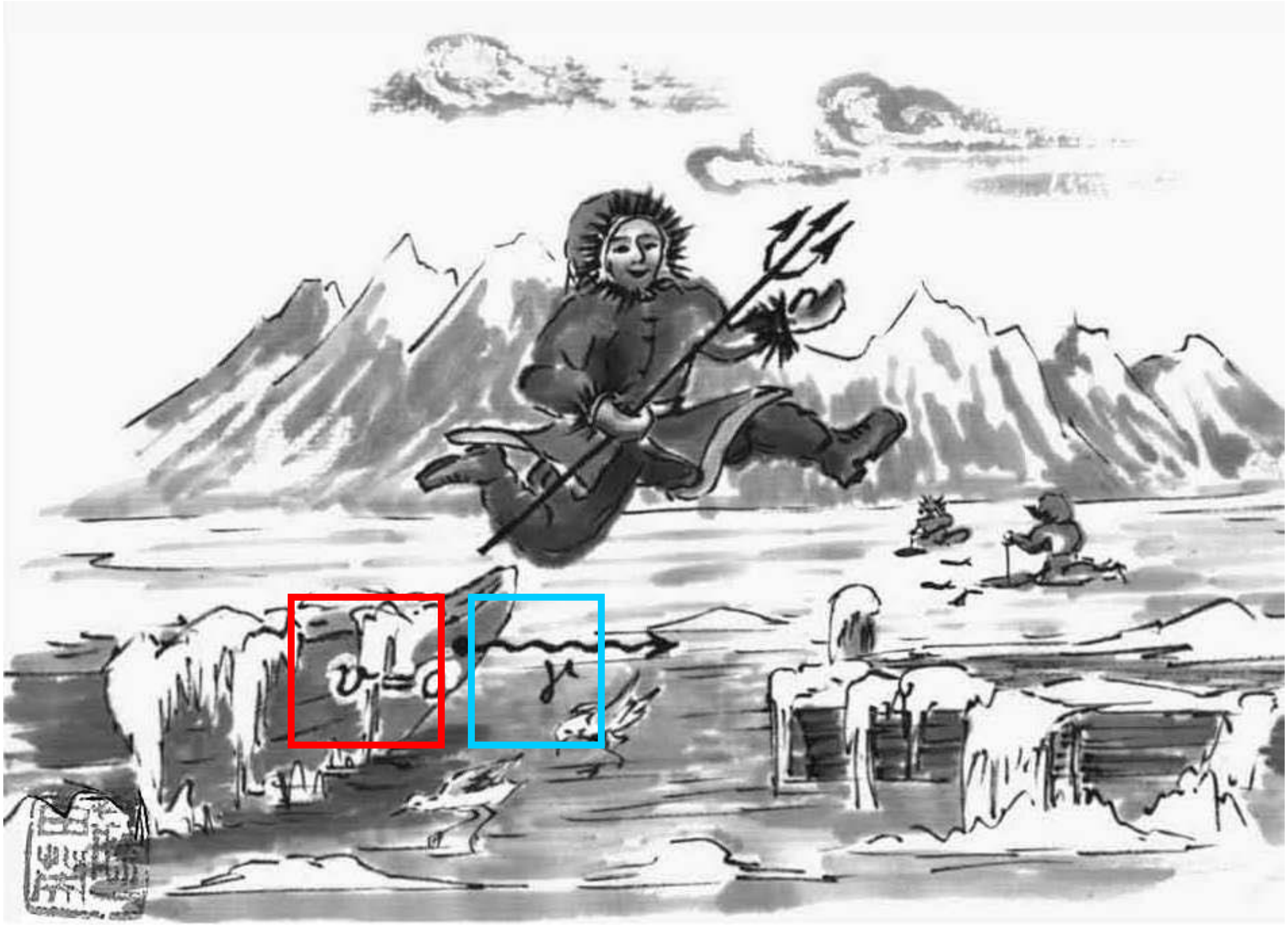
1929 – 2011


Free Nucleus
γ
Z,
N
E_R
No Resonance
Emission
Absorption
Nucleus in
excited state
Z,
N
E_e
E_e
E_R
γ
γ
E_γ = E_T - E_R
E_R
Nucleus in
ground state
Z,
N
E_g
E_g

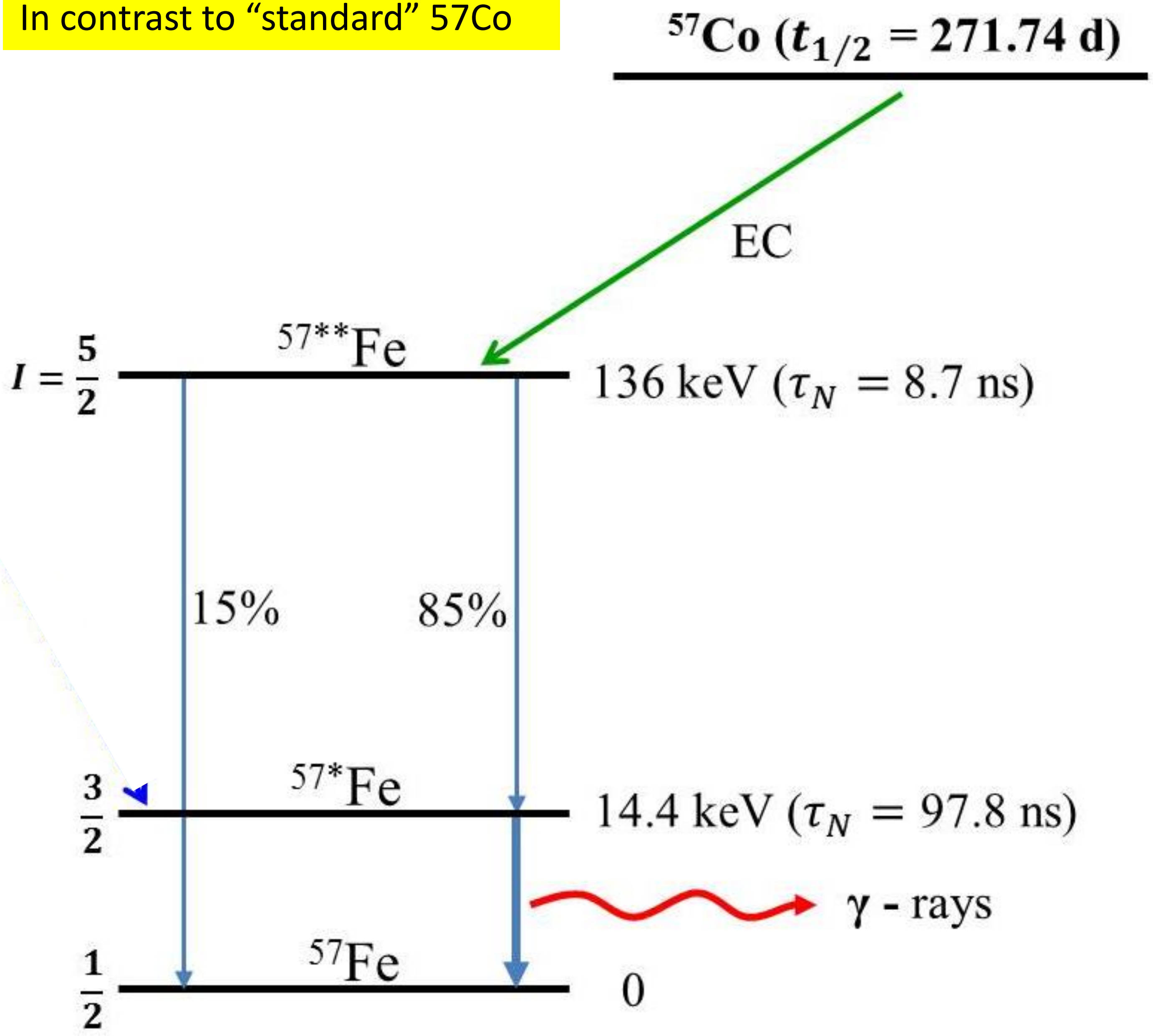


M >> m
m
γ
Emission
Absorption
Nucleus in excited state
Z, N
Nucleus in ground state
Z, N
E_e
E_g
γ
E_e
E_g
γ
$E_\gamma = E_T - E_R$

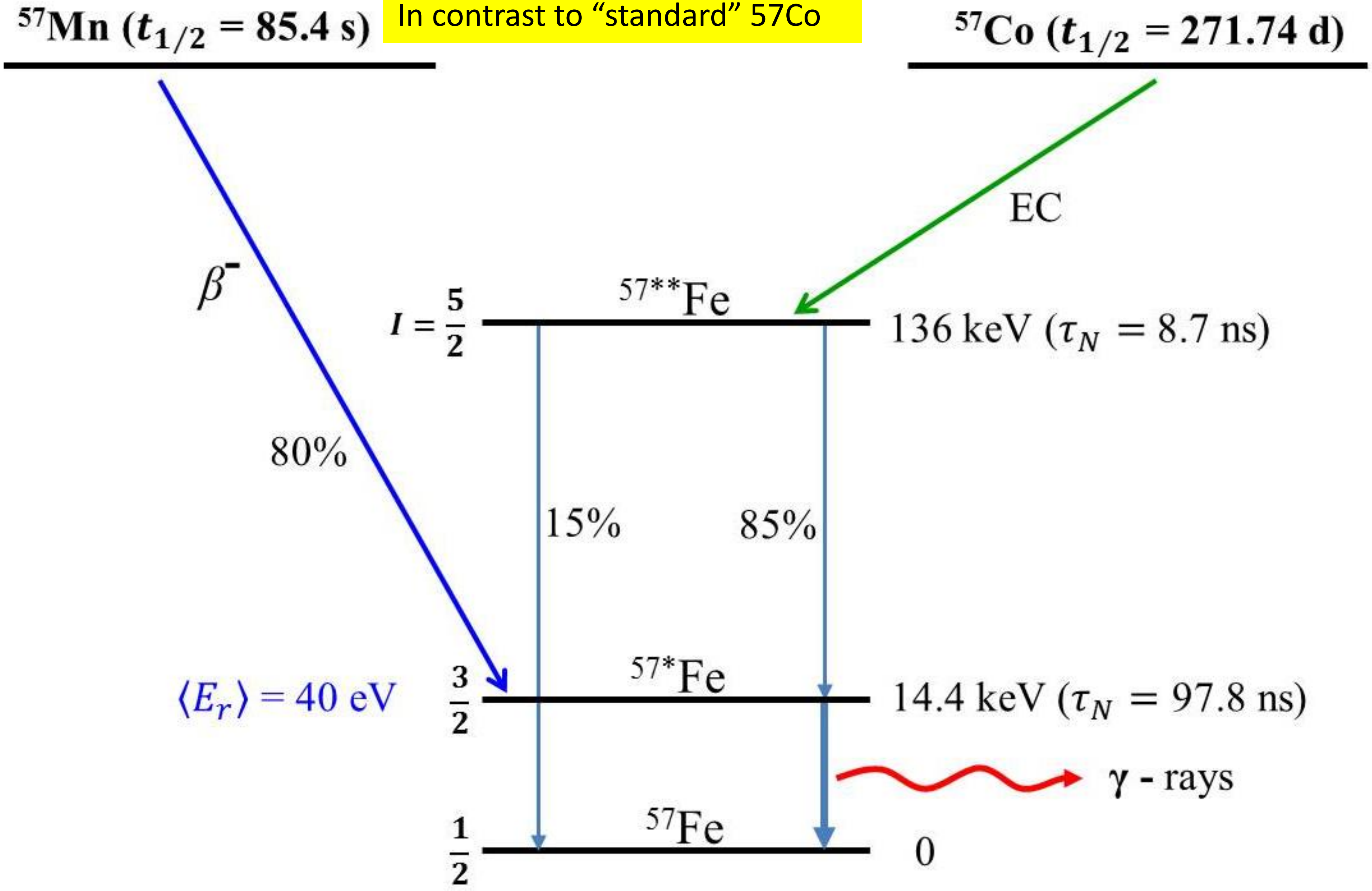




Mossbauer state 57Fe via 57Mn
In contrast to “standard” 57Co

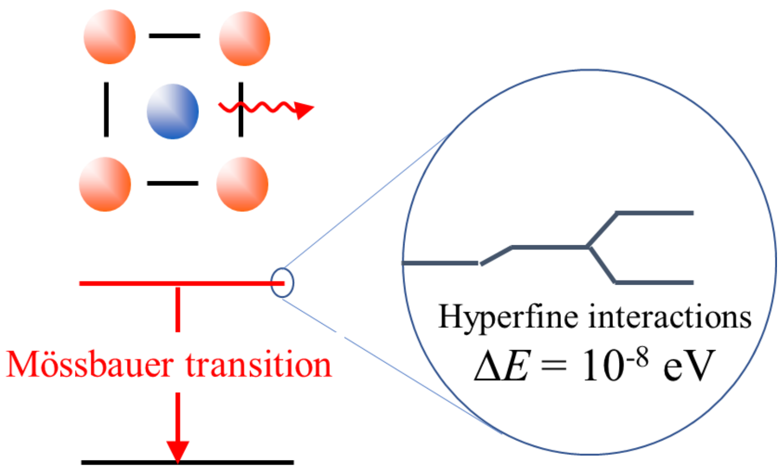


Mossbauer state 57Fe via 57Mn
In contrast to “standard” 57Co



Local information….

Measure hyperfine interactions

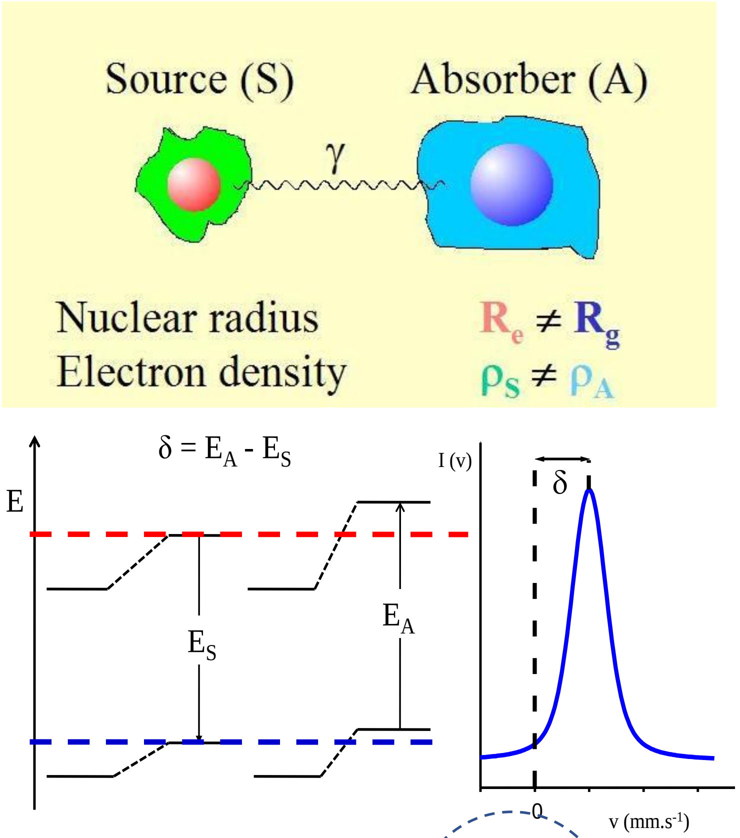


Dilute Probe:

Below 10^{-3} at.%

1×10^{18} atoms/cm^3

Isomer Shift

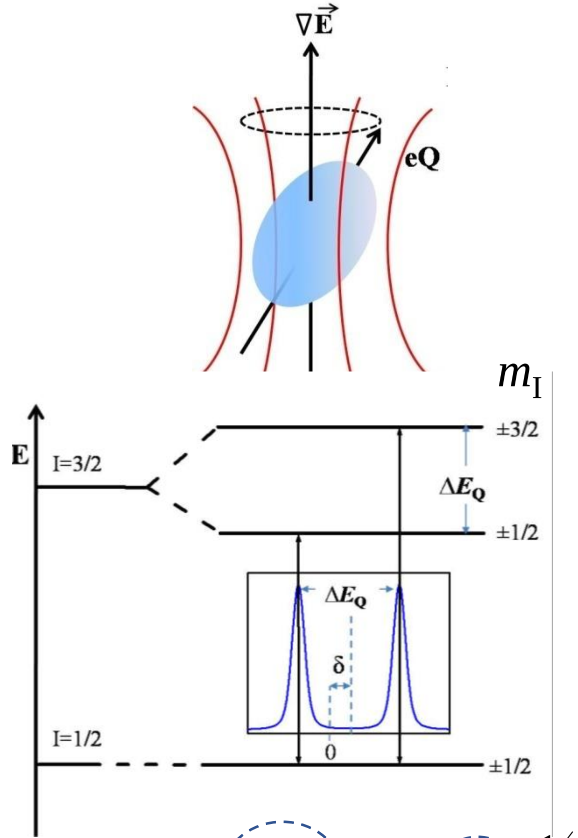


$$\delta_{IS} = \alpha\left[\rho_a(0) - \rho_s(0)\right]$$

Chemical bonding

Charge states

Quadrupole Splitting

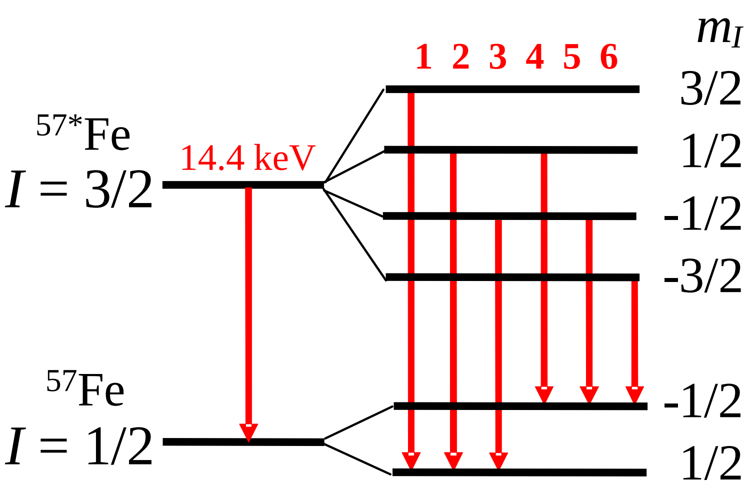


$$\Delta E_Q = \pm \frac{eQV_{ZZ}}{2}\left(1+\frac{\eta^2}{3}\right)^{1/2}$$

Lattice asymmetry

Clustering of atoms

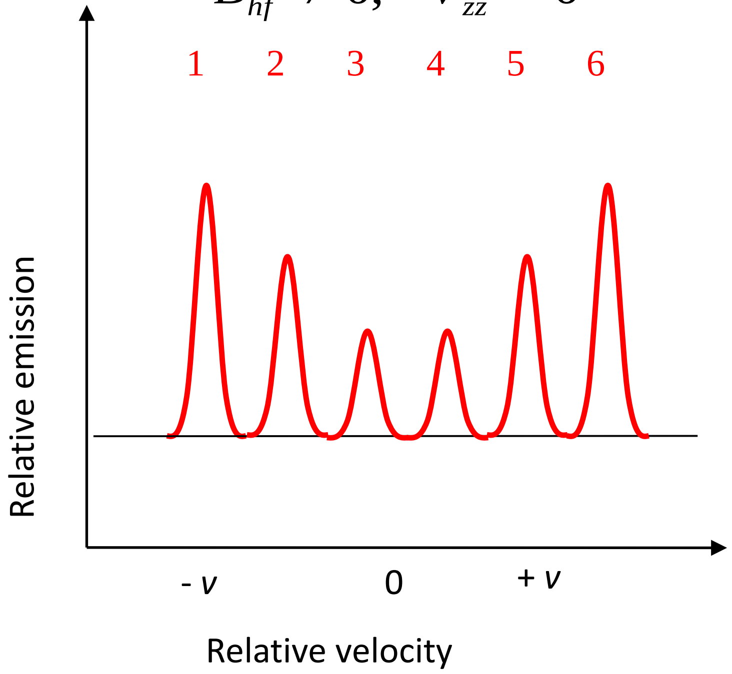
Magnetic hf. splitting of ^{57}Fe: Sextet



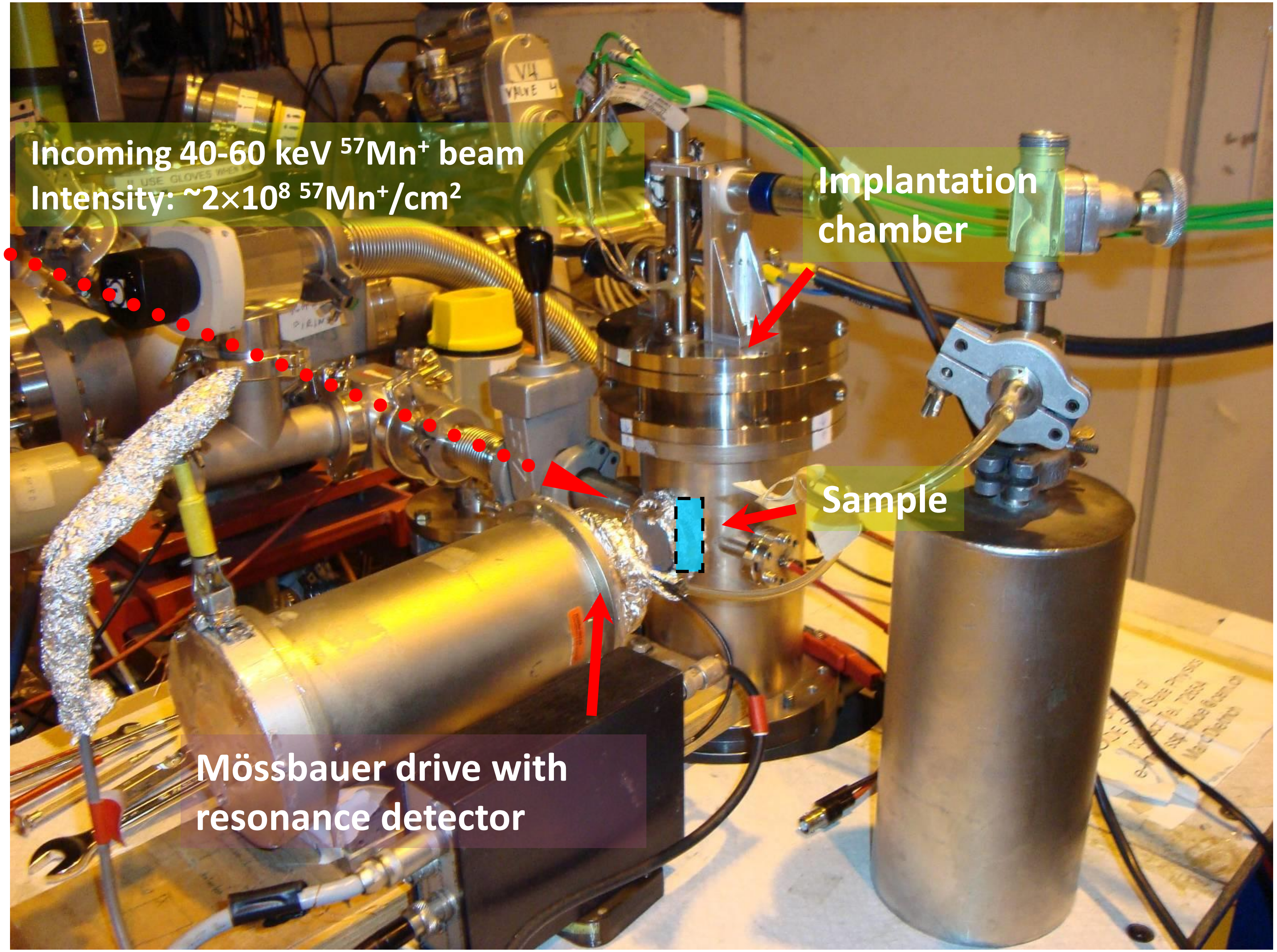
Source/sample:
Mn/Fe implanted MgO

$$B_{\mathrm{hf}} \propto \left|\psi_s^{\downarrow}\right|^2 - \left|\psi_s^{\uparrow}\right|^2$$

$$B_{hf} \neq 0, \quad V_{zz} = 0$$



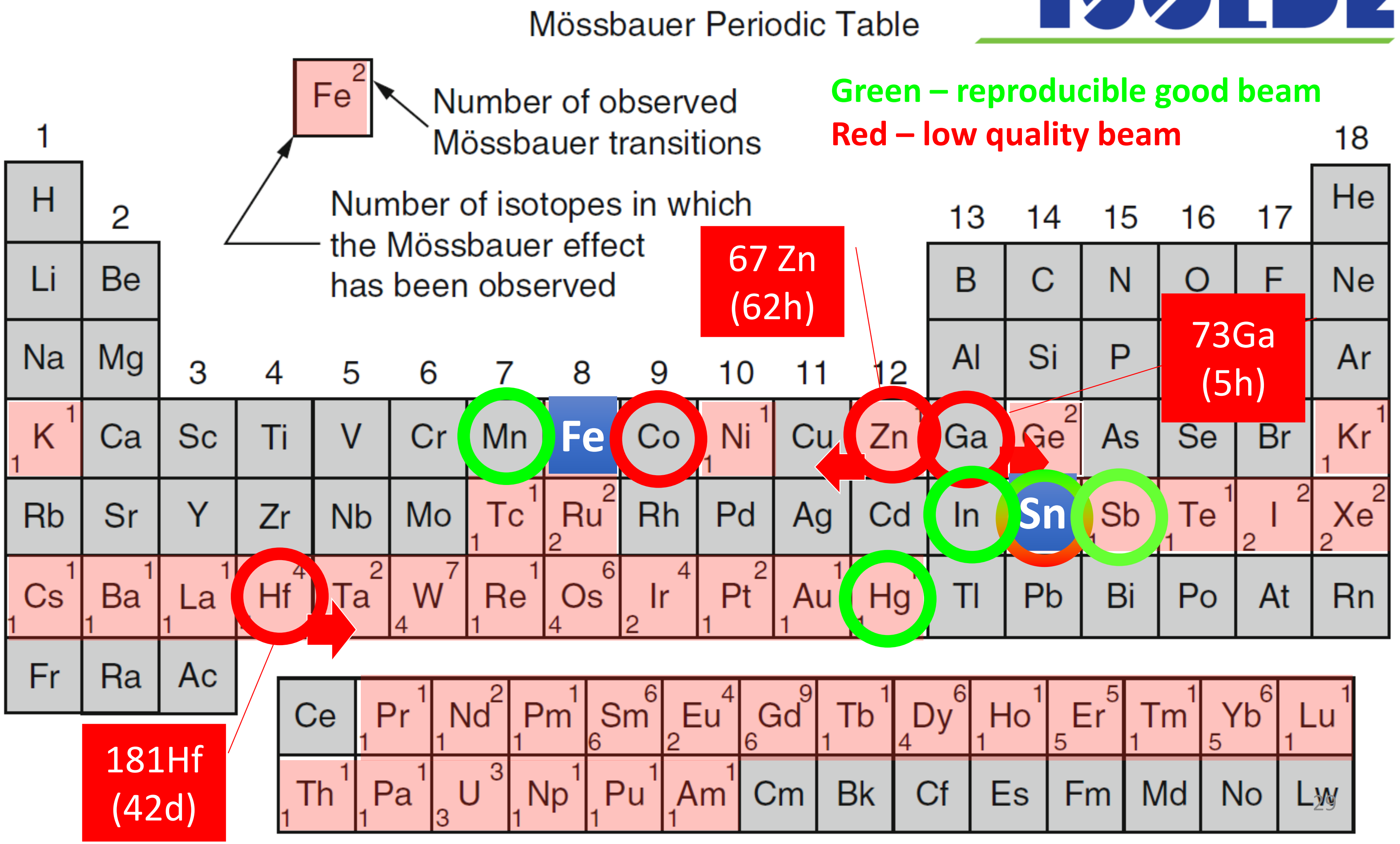
Hyperfine Interactions with Mossbauer spectroscopy



Laser Ionised **^{57}Mn** beam : a new era for Mossbauer experiments at ISOLDE. 20th anniversary in 2016

- Very clean, intense beam of ^{57}Mn **(>3x10^{8} ions sec^{-1})**
- **Allows collection of single Mossbauer spectrum in ~ 3 mins.**
- **Able to collect many hundreds over course of a 3 day run.**
- **Allows low concentrations of probe atoms to be used (~10^{-4}At%)**

Mössbauer periodic table



Fe: ZnO a ferromagnetic semiconductor? (no!)

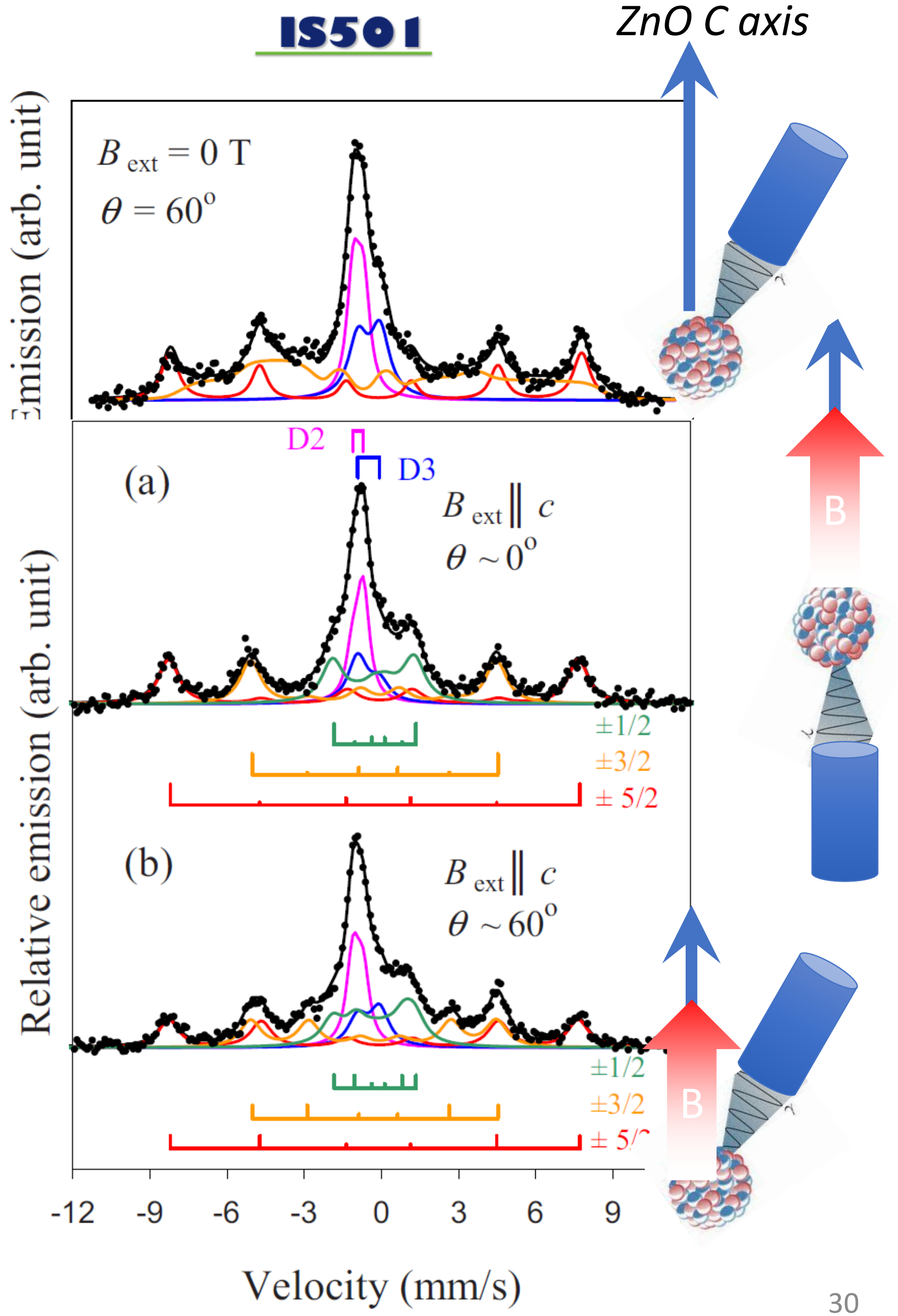
6 fold spectrum: characteristic of magnetic structure (at room temperature!!!).

Results in an external magnetic field show that the spectrum shown to be a **slowly relaxing paramagnetic system** .

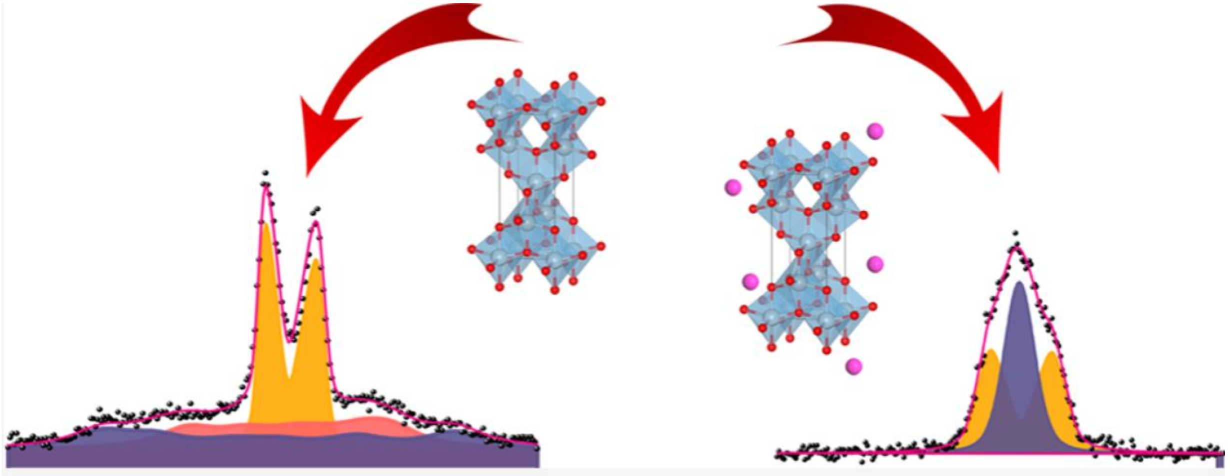
Gunnlaugsson *et al* (APL **97** 142501 2010)

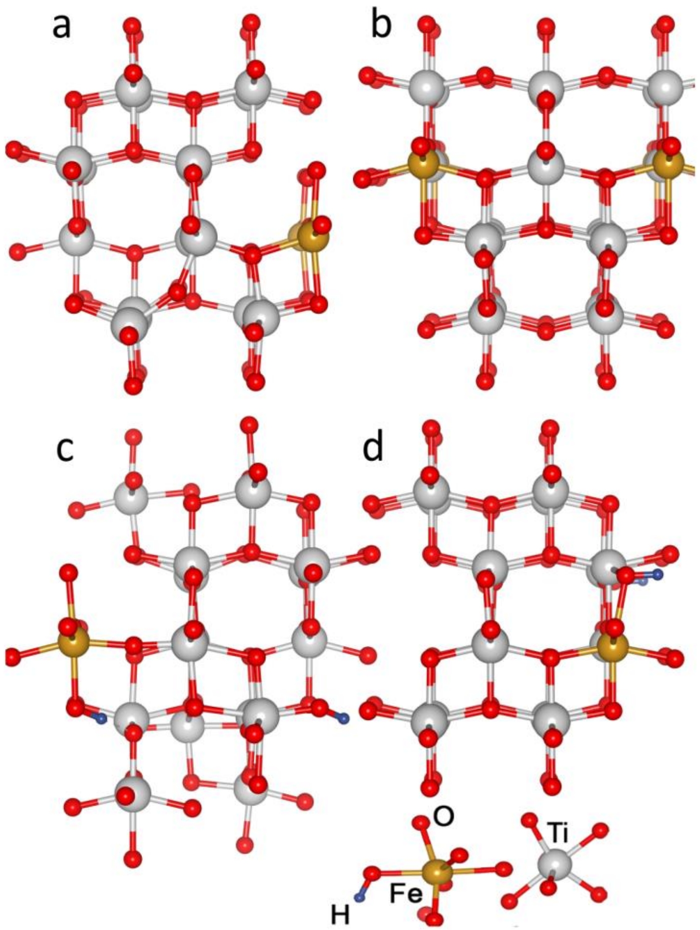
After high-dose implantations, precipitates of Fe-III are formed. These form ***clusters*** *yielding misleading information about the nature of magnetism in ZnO (as reported by many groups over the last number of years).*

Gunnlaugsson *et al* APL **100** 042109 **(**2012)



Experimental and Theoretical Study of Electronic and Hyperfine Properties of Hydrogenated Anatase (TiO_2): Defect Interplay and Thermal Stability





Sensitivity of Mossbauer to local interactions + *ab initio* modelling

Hydrogenated TiO2

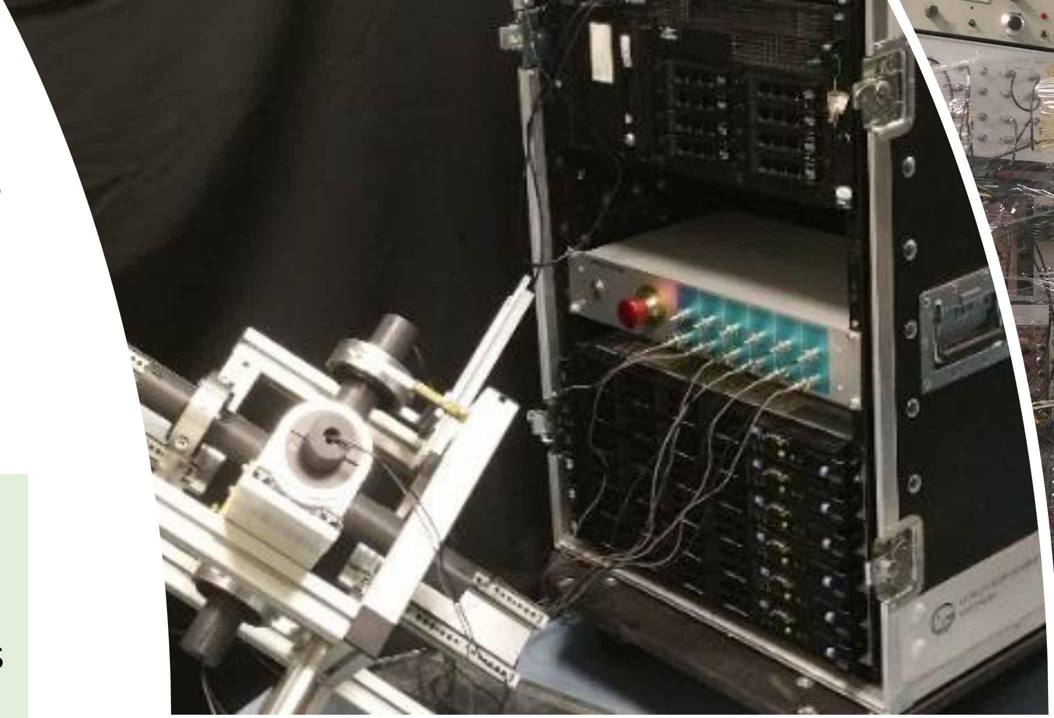
J. Phys. Chem. C 2020, 124, 7511–7522

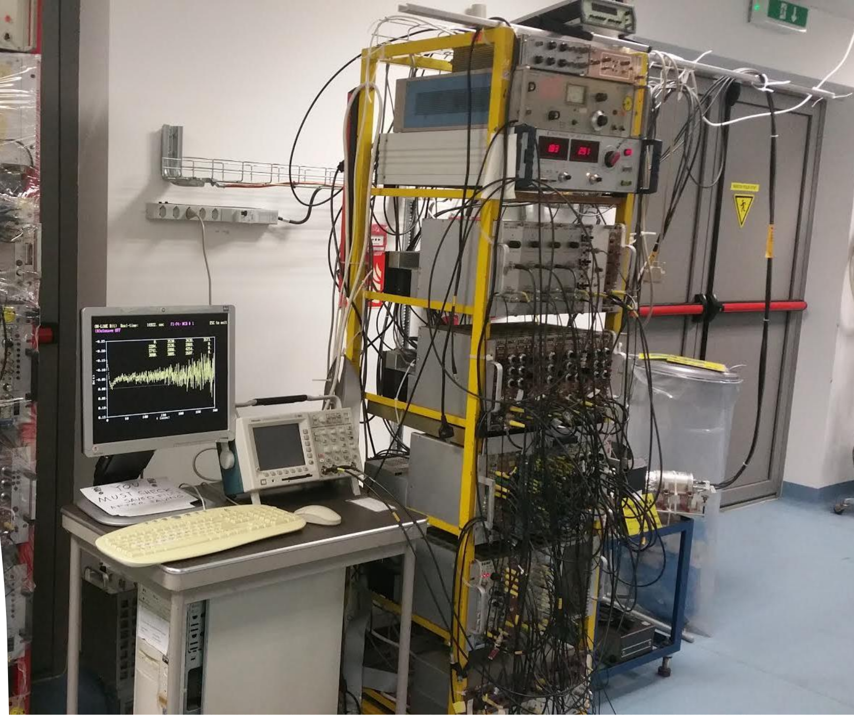
Perturbed angular correlation @ ISOLDE

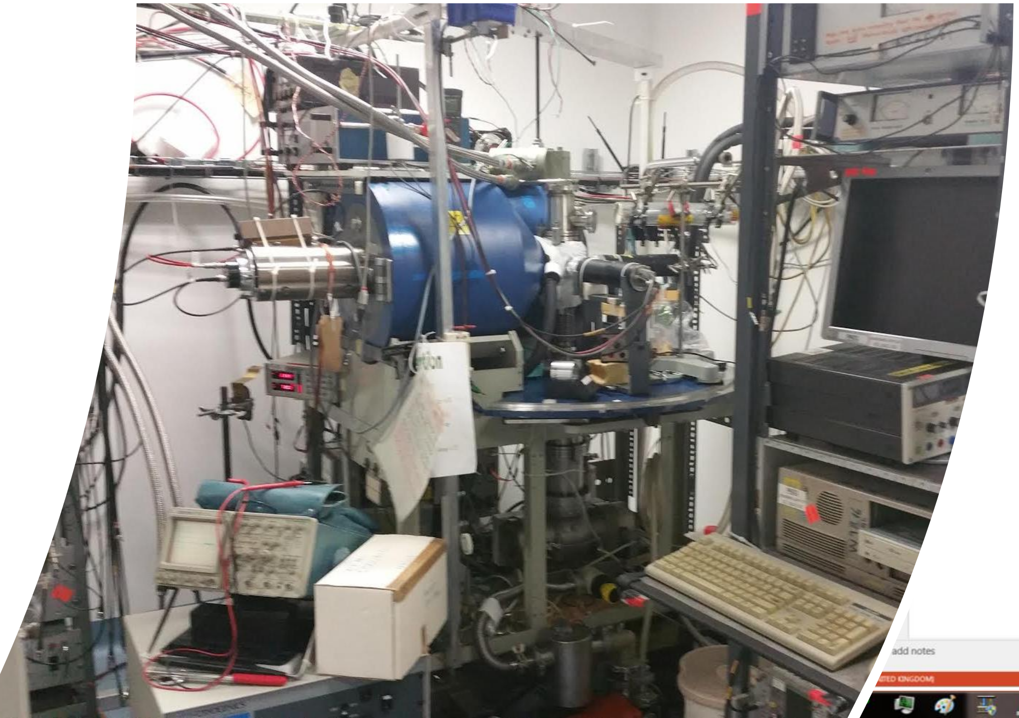
- Most established technique at ISOLDE: benefitting from upgrade of spectrometers in recent years and improved relation to theory.

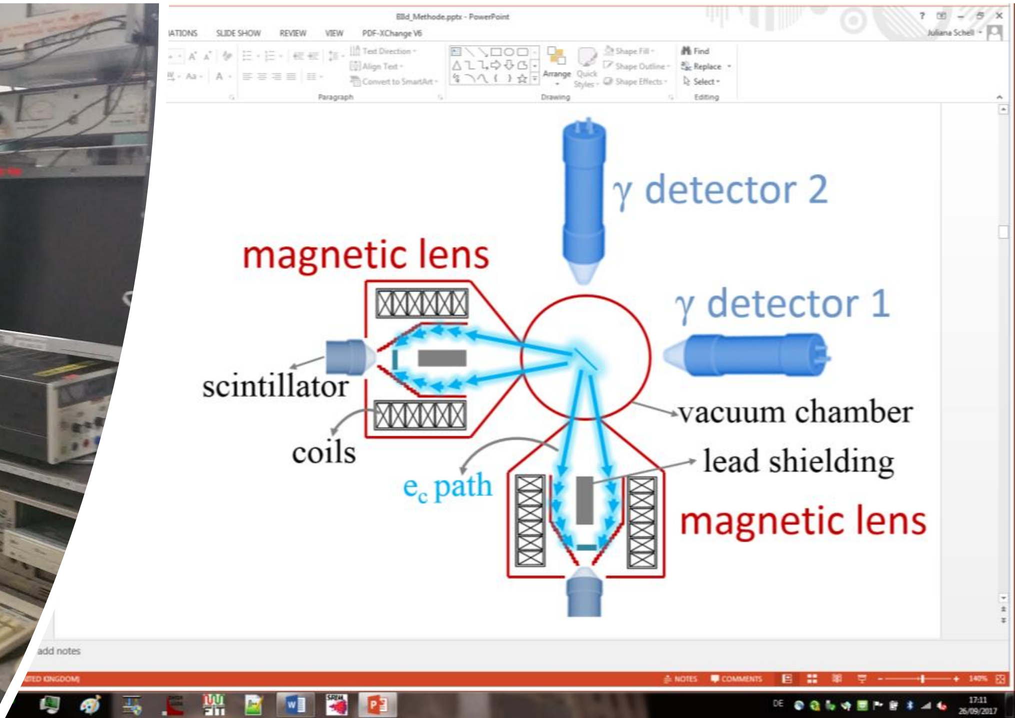
- Electron gamma unique to ISOLDE.

- Range of novel isotopes also only useable at ISOLDE: allows for varied programme in materials physics, biophysics and beyond

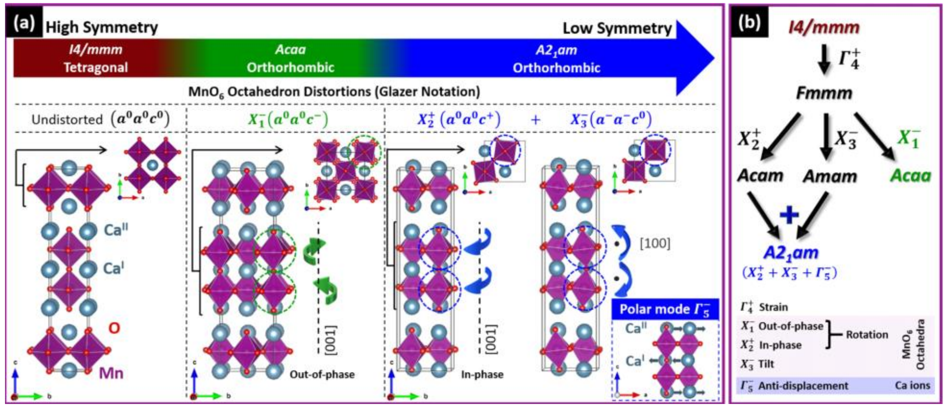




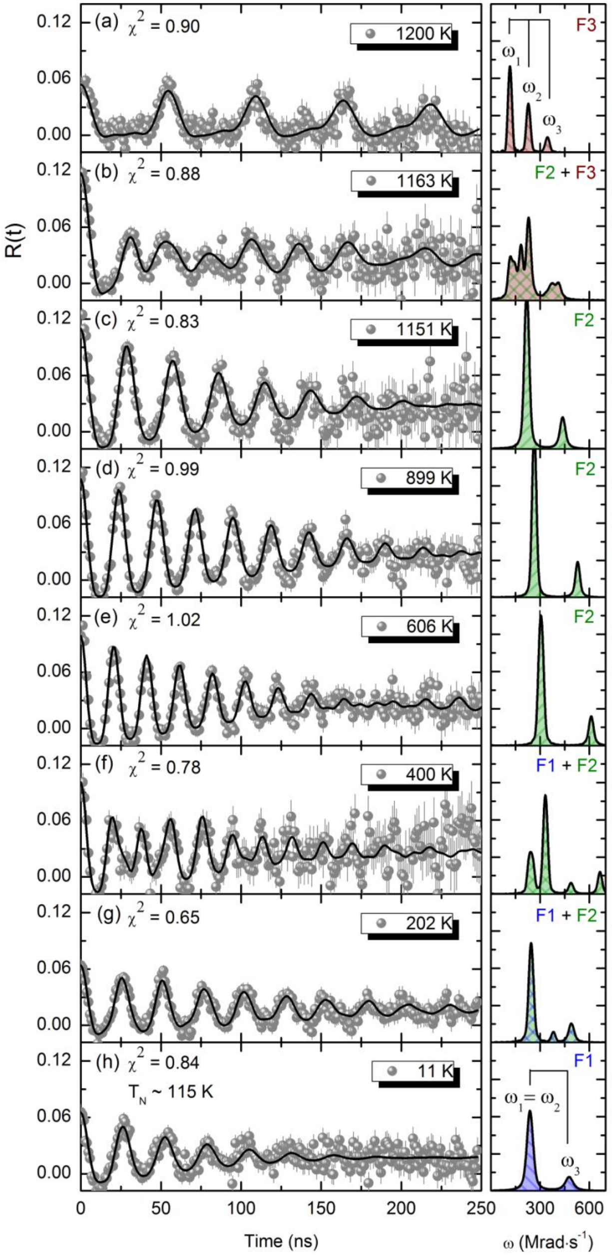




$Ca_3Mn_2O_7$ structural path unraveled by atomic-scale properties: A combined experimental and *ab initio* study



Probing multiferroic materials with PAC on the atomic scale: revealing the atomic changes behind the transitions from polar to ferroelectric behaviour



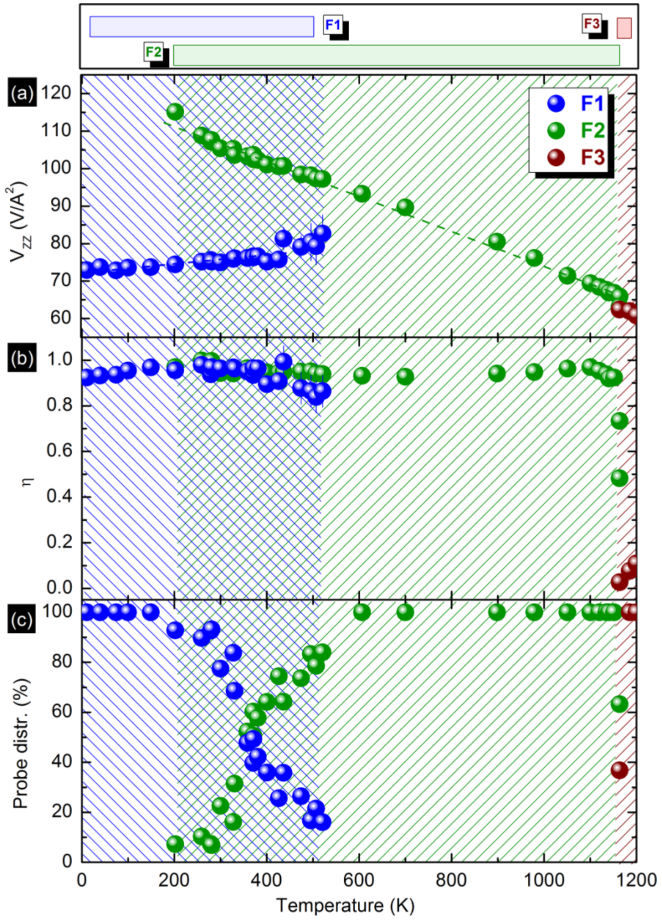
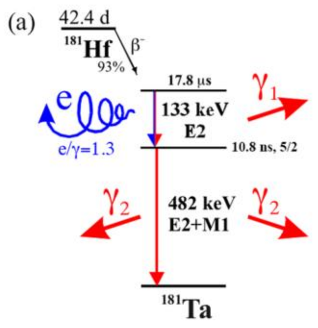
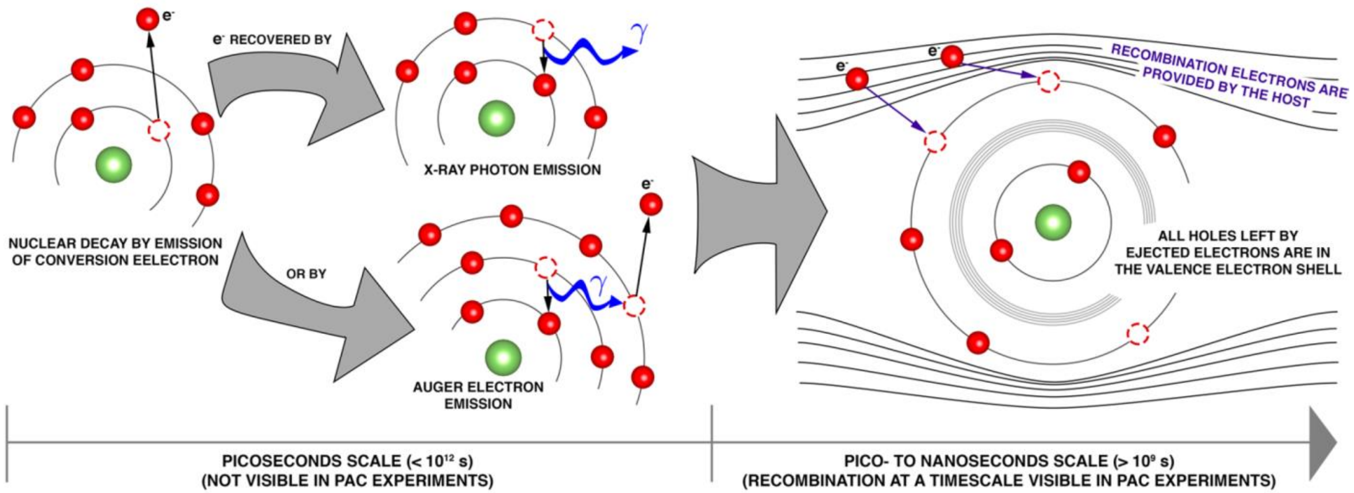


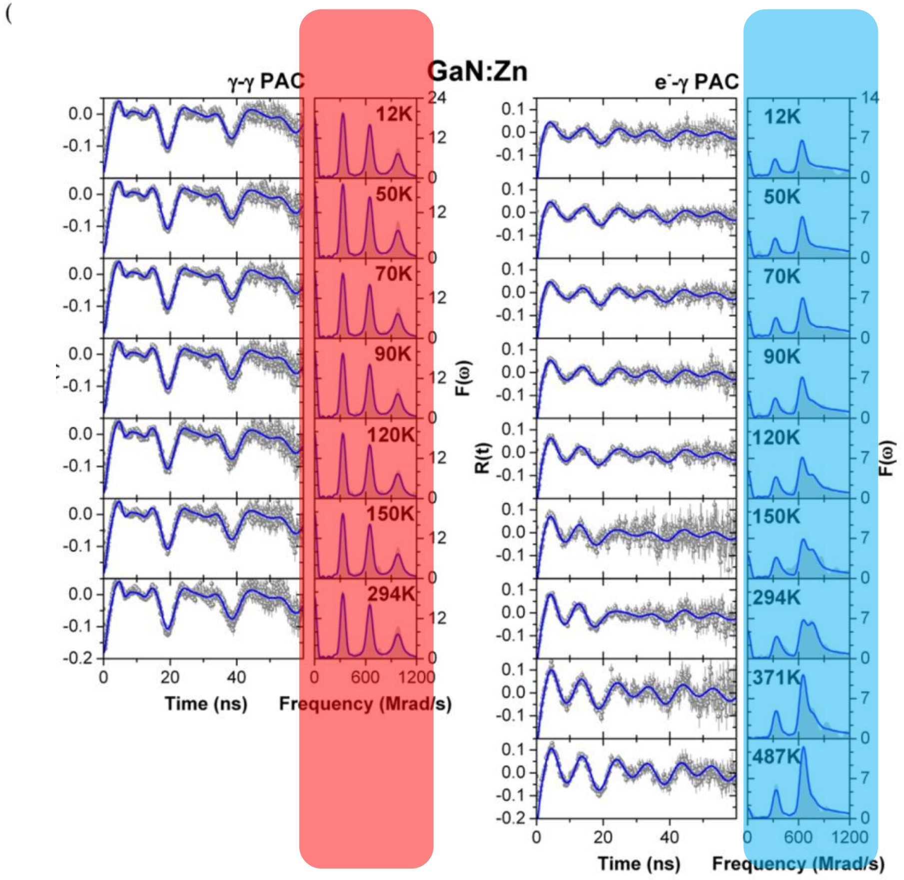
FIG. 3. Experimental EFG tensor at ^{111}Cd probe for the $Ca_3Mn_2O_7$ sample. (a) Principal component $|V_{zz}|$; (b) asymmetry parameter η; (c) probe distribution. The dashed lines are a guide for the eyes.

PHYSICAL REVIEW B **101**, 064103 (2020)

Studying electronic properties in GaN without electrical contacts using γ-γ vs e^{-}-γ Perturbed Angular Correlations







PAC revealing bulk properties of Si and Zn-doped Ga using γ-γ and e- - γ PAC

SCIENTIFIC REPORTS | *(2019) 9:15734*

Biophysics: PAC of ^{111m}Cd, ^{111}Ag and ^{199m}Hg at protein metal sites

Impact factor: 21

ACCOUNTS of chemical research

Article

pubs.acs.org/accounts

Nanosecond Dynamics at Protein Metal Sites: An Application of Perturbed Angular Correlation (PAC) of γ-Rays Spectroscopy

Saumen Chakraborty,[†] Stavroula Pallada,[‡,§] Jeppe T. Pedersen,[§] Attila Jancso,[∥] Joao G. Correia,[‡,⊥] and Lars Hemmingsen[*,§]

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[‡]ISOLDE/CERN, PH Div, CH-1211 Geneve 23, Switzerland
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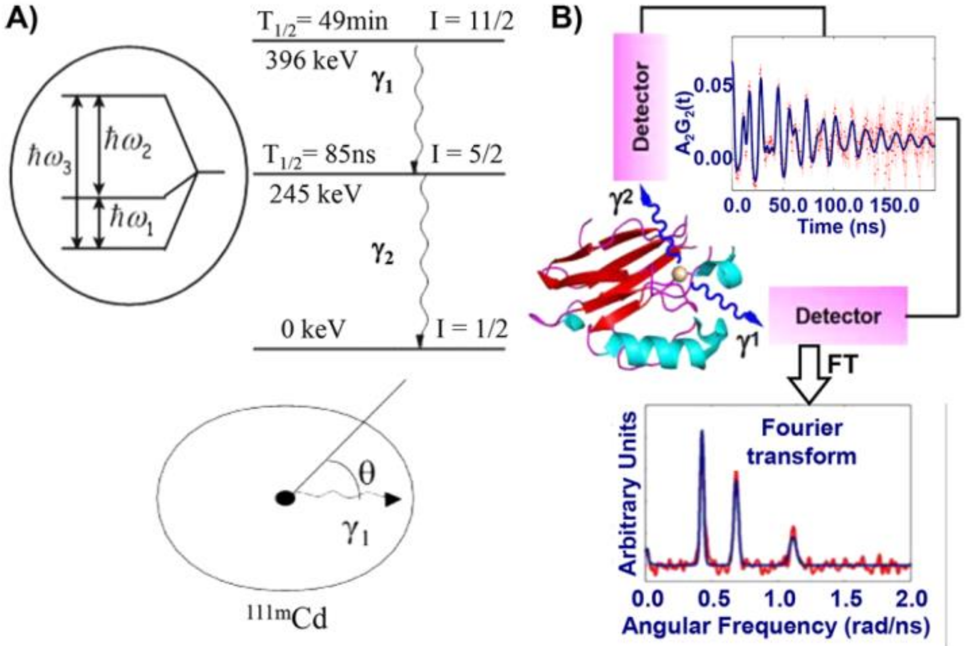
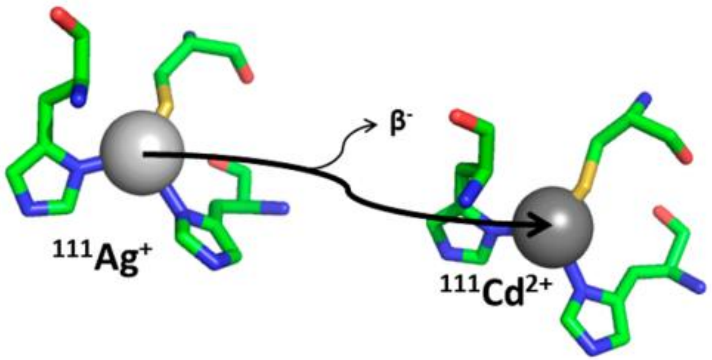
[⊥]Centro de Ciências e Tecnologias Nucleares, Instituto Superior Técnico, Universidade de Lisboa, 2695-066 Bobadela, Portugal



Metalloproteins are essential to numerous reactions in nature, and constitute approximately one-third of all known proteins. Their reactivity in aqueous solution depends on the exchange of water molecules. By means of PAC with several metal ion nuclear probes the dynamics of structural changes at the metal site of the proteins on the ns time scale was clearly revealed.



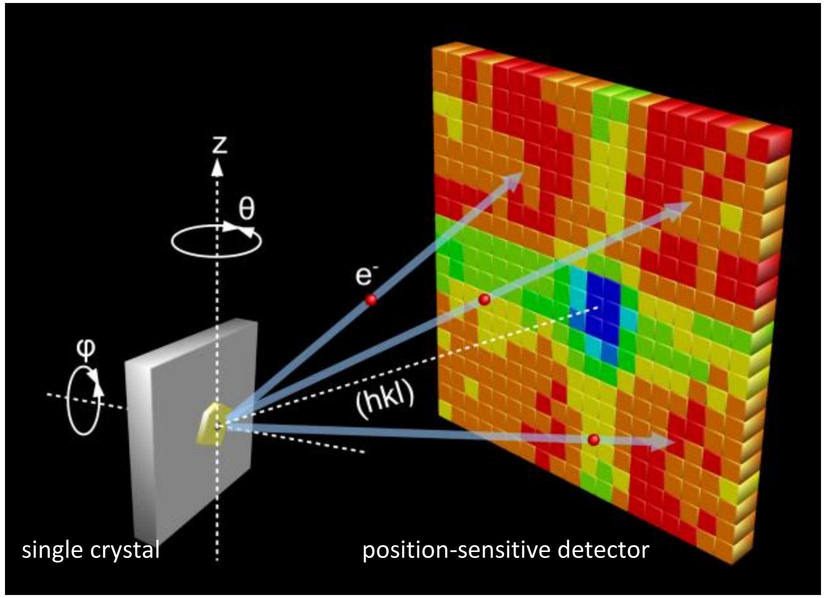
- **S. Chakraborty *et al*, Acc. Chem. Res. 50 (2017) 2225**

Emission Channeling method

Radioactive isotopes are implanted into a single crystal.

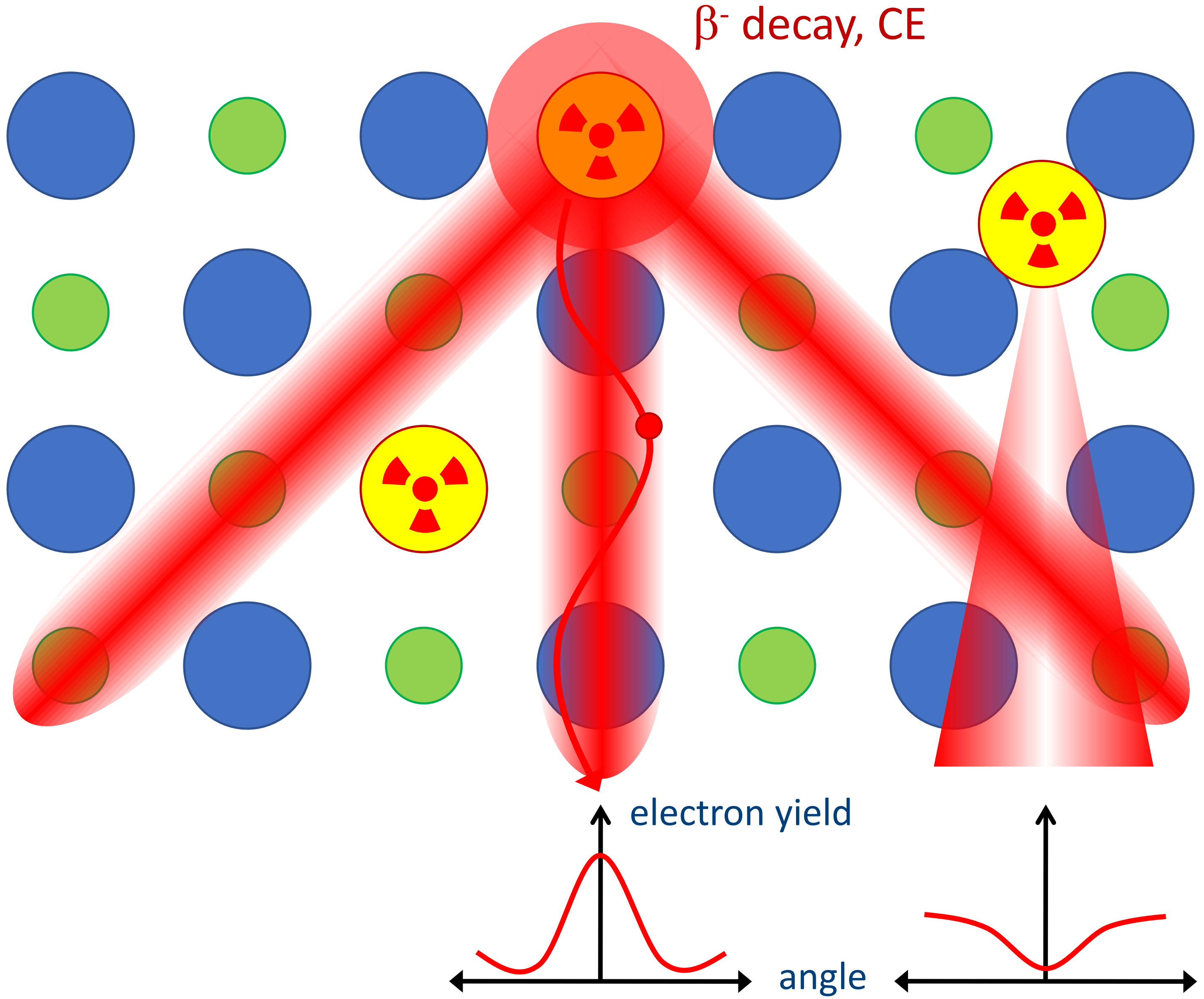
On their way out of the crystal, β^- particles emitted during probe decay experience channeling or blocking effects along major crystallographic directions.

Whether channeling or blocking is observed, depends on the lattice sites of the emitter atoms.

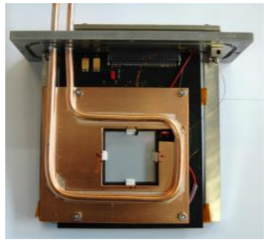


A position-sensitive detector at 30 cm from the sample is used to record the angular dependence of β^- emission patterns.

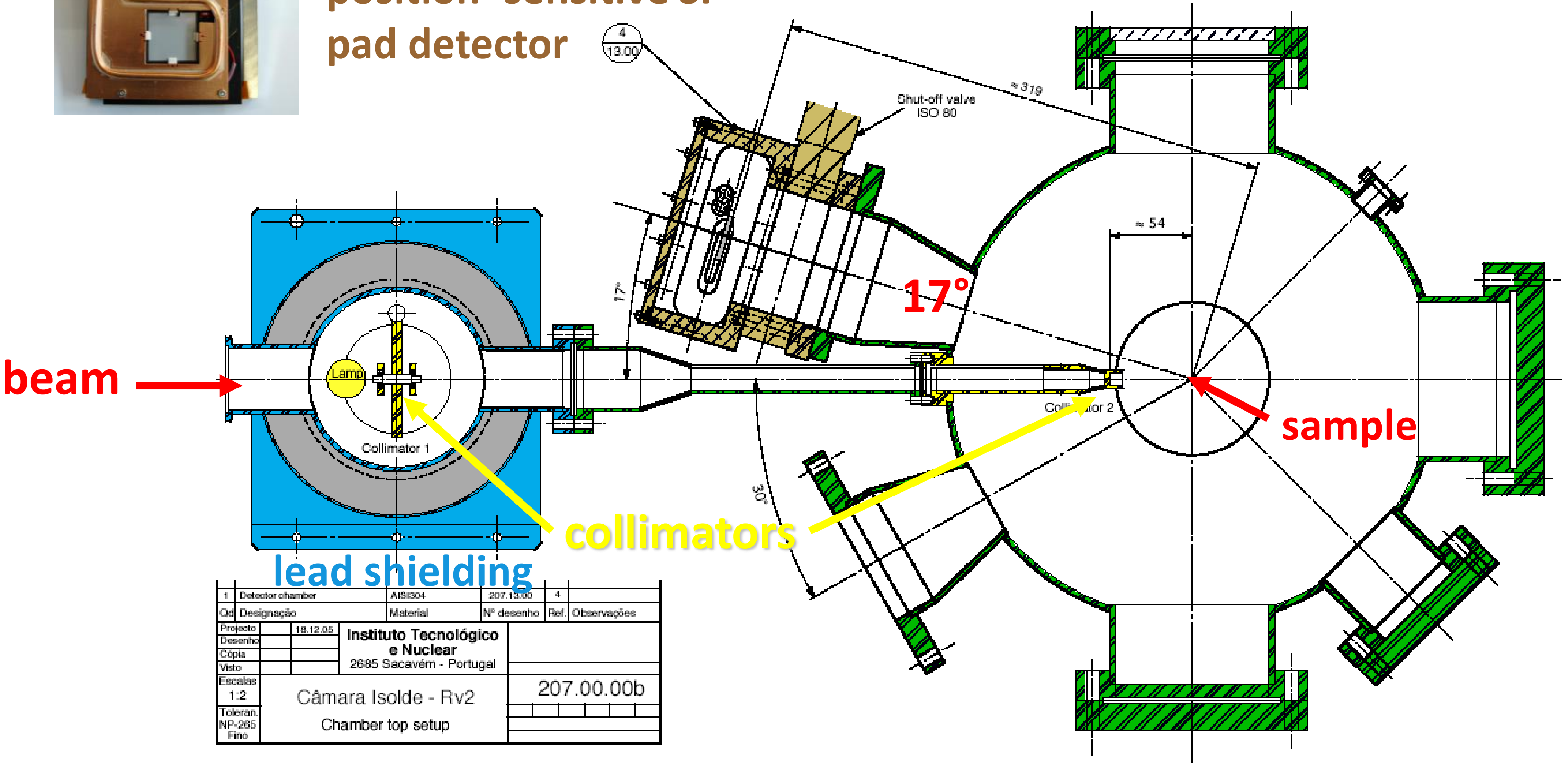
Emission channeling lattice location inside the crystal: **(β^-, β^+, c.e., α)**



Emission channeling setup



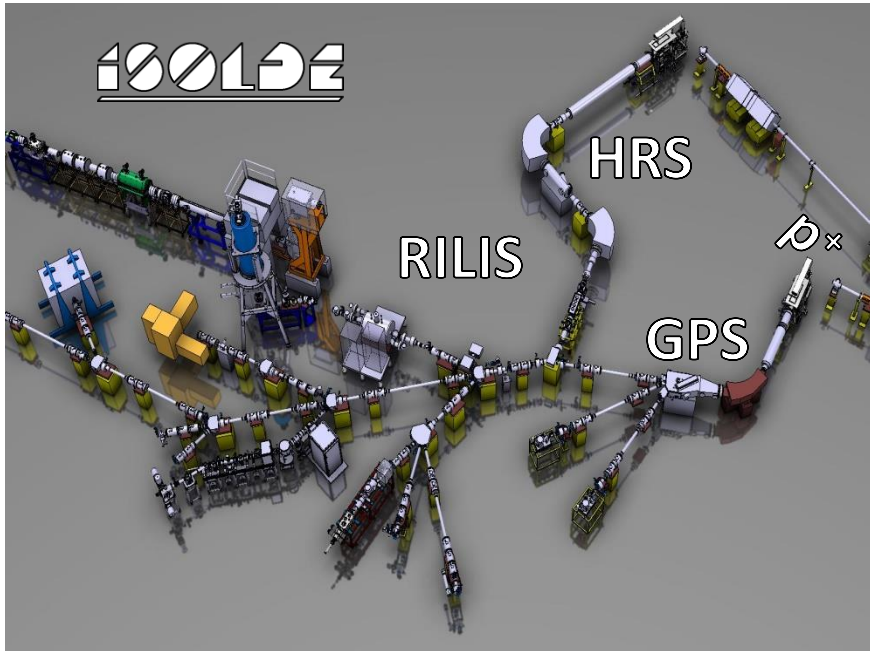
3×3 cm² cooled position- sensitive Si pad detector



- beam collimated on sample by two apertures (last one ∅ 1mm)
- detector at 17° backward geometry for simultaneous implantation and measurement
- 22×22 pixels of 1.3 mm position-sensitive Si pad detector, water cooled

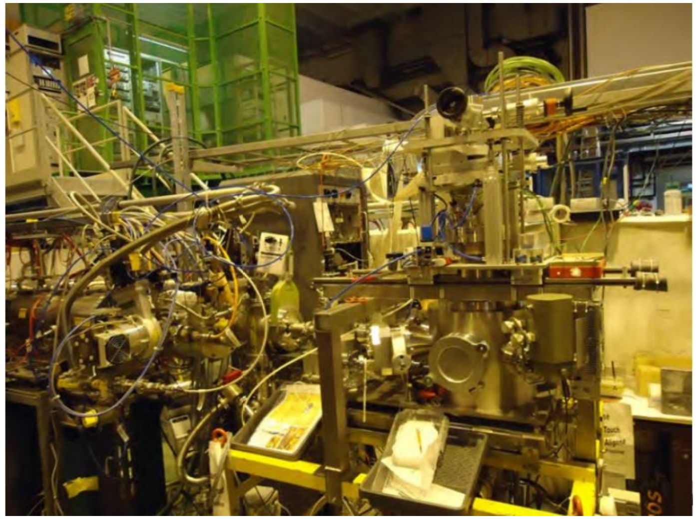
M.R. Da Silva et al , Rev. Sci. Instr. 84 (2013) 073506

Emission channeling at ISOLDE

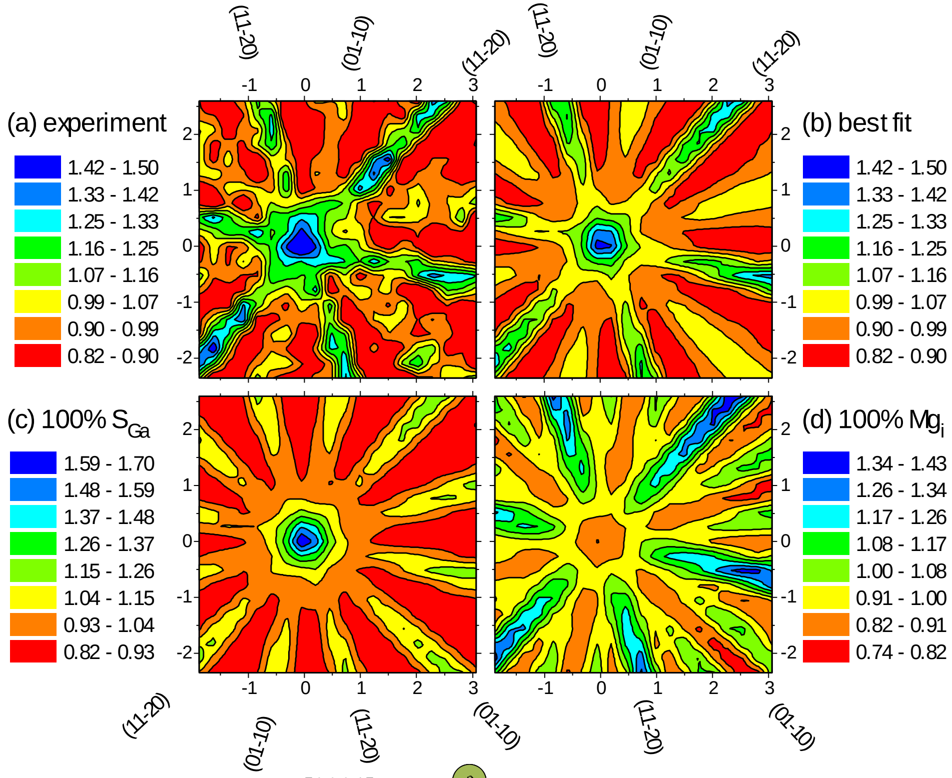


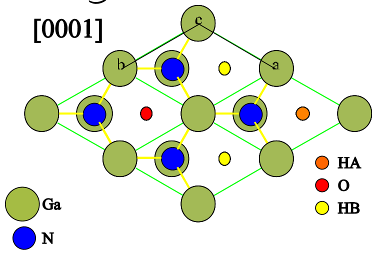
On-line setup for
Emission Channeling lattice location
with Short-Lived Isotopes (EC-SLI)
at ISOLDE GHM beam line

GHM

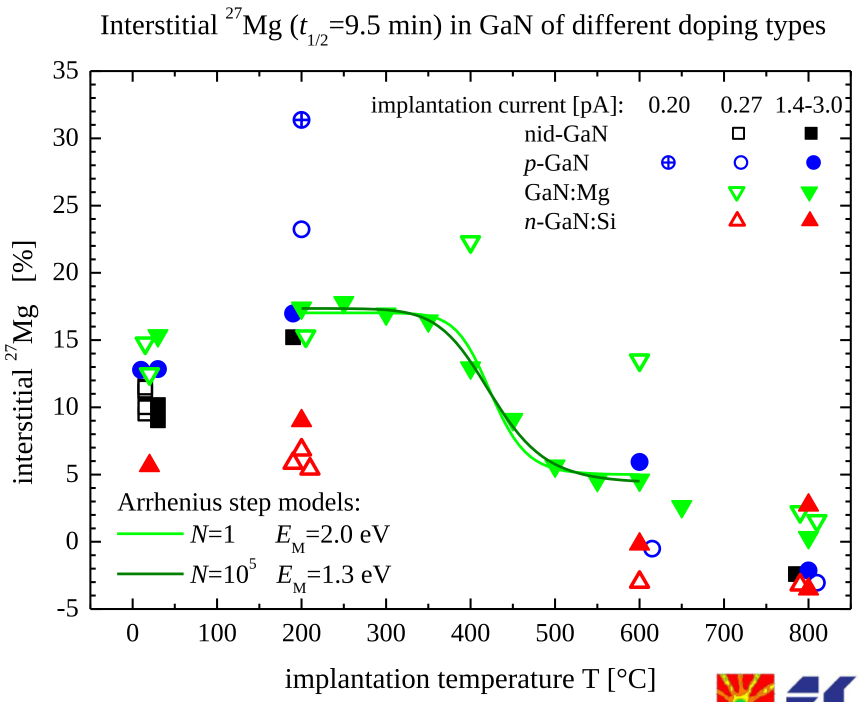


Lattice sites of ^{27}Mg in different pre-doped GaN





- Electron emission channeling patterns show mix of substitutional + interstitial ^{27}Mg



- Interstitial Mg fraction highest in *p*-GaN:Mg
- Lowest in *n*-GaN:Si

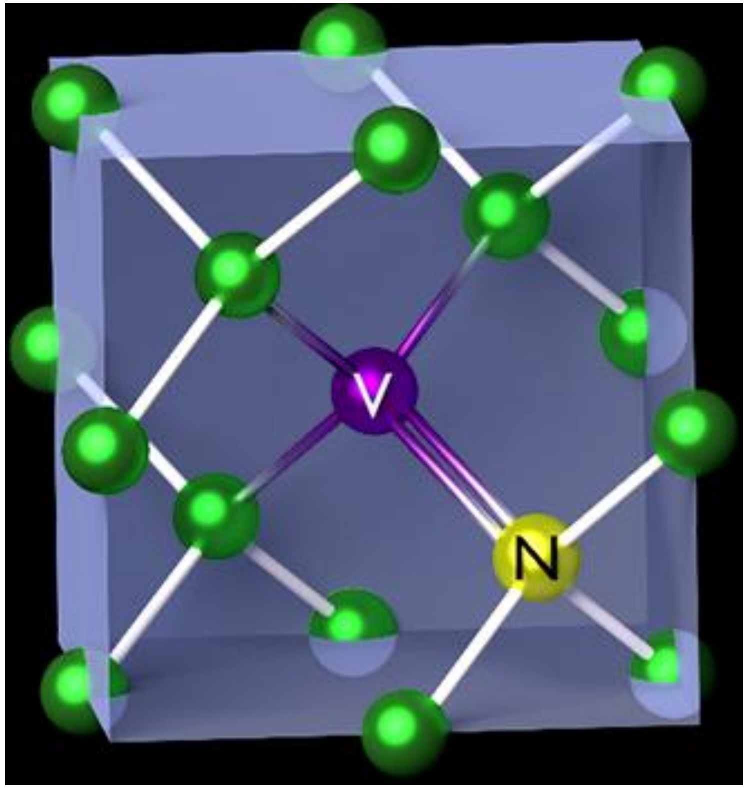
⇒ Direct evidence for amphoteric character of Mg that is coupled to the doping type

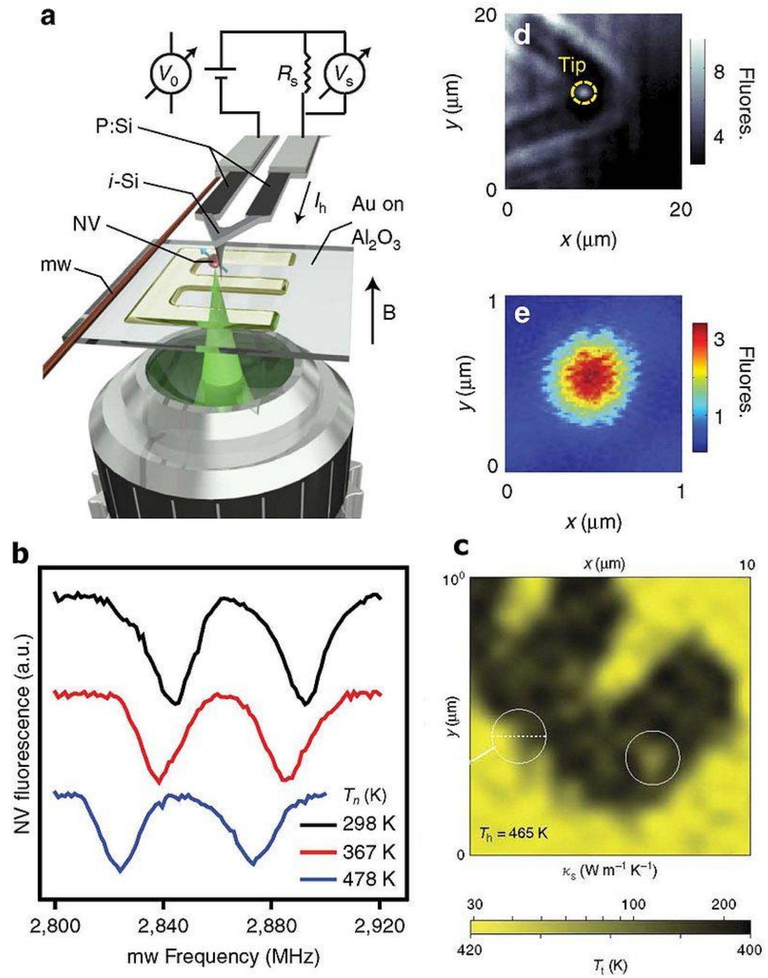
- Site change interstitial - substitutional Mg_{Ga}

⇒ Activation energy for migration of interstitial Mg: E_M » 1.3 - 2.0 eV

Phys. Rev. Lett. **118**, 095501(2017)

N-V centres in diamond: towards quantum bits….

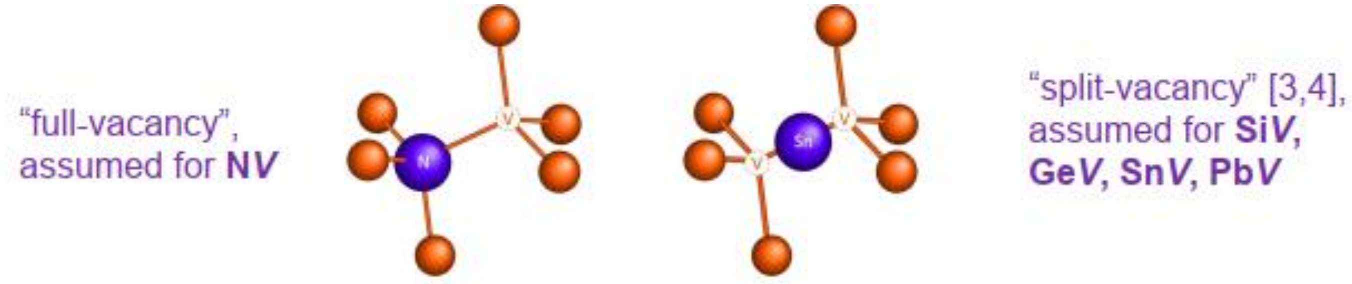




NV centre, extensively studied in the past 10 years. Has a long coherence time but low efficiency for photonic applications…already being used for metrology and sensor applications…

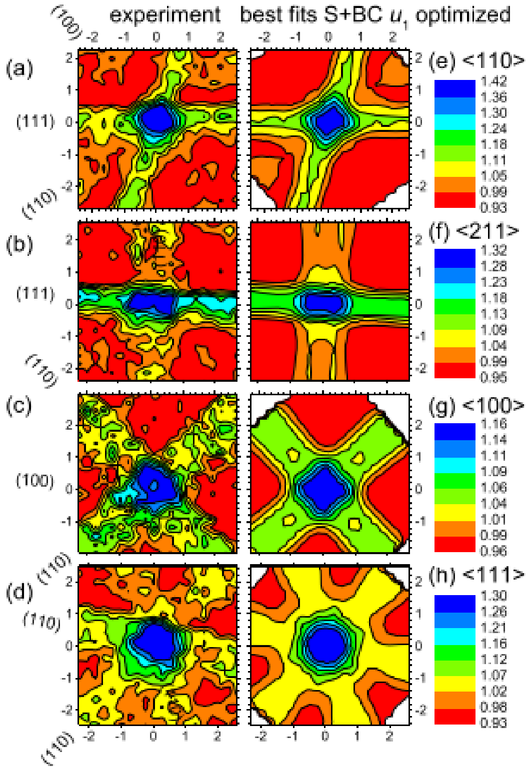
Alternative centres to N-V…

PHYSICAL REVIEW LETTERS **125,** 045301 (2020)

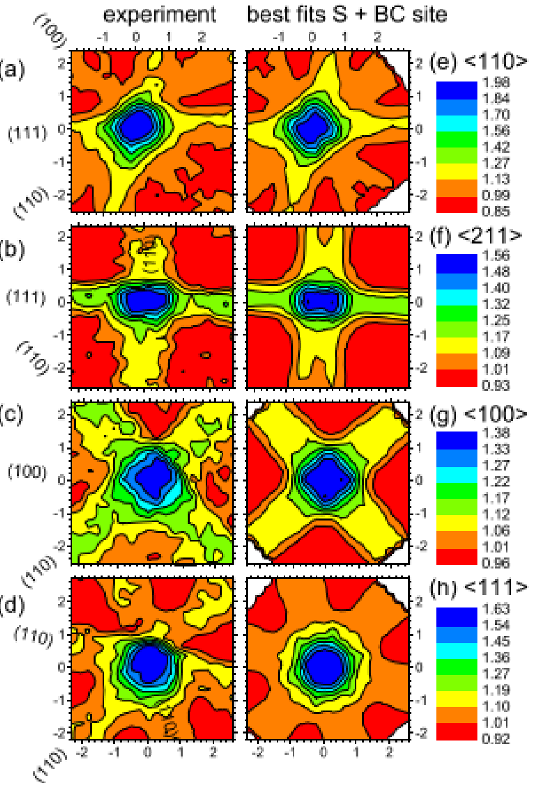


Direct Structural Identification and Quantification of the Split-Vacancy Configuration for Implanted Sn in Diamond

U. Wahl,[1,2,*] *et al*

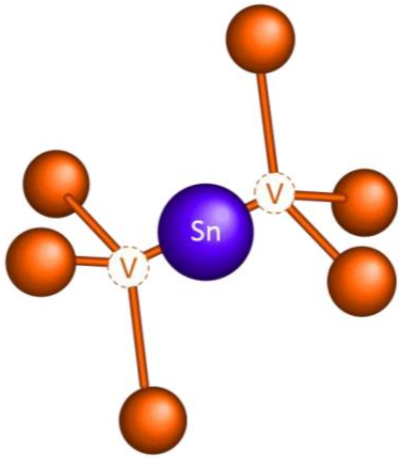


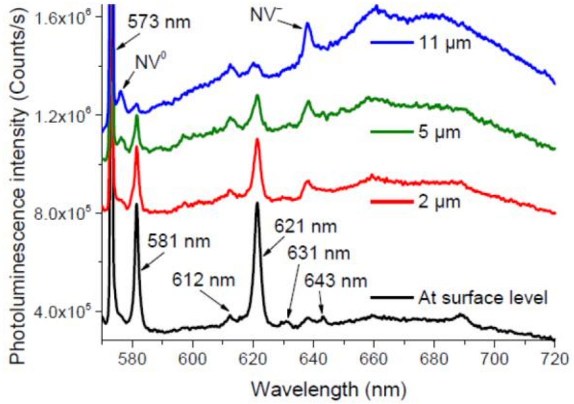
As implanted



Annealed at 920C

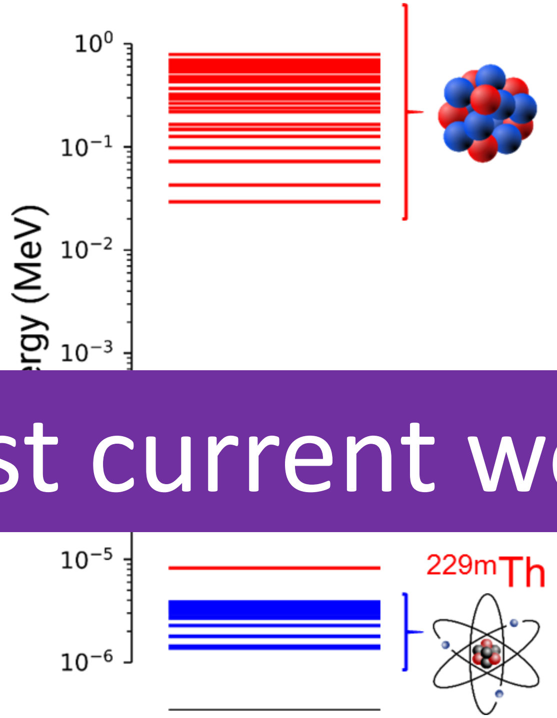
^{121}SnV

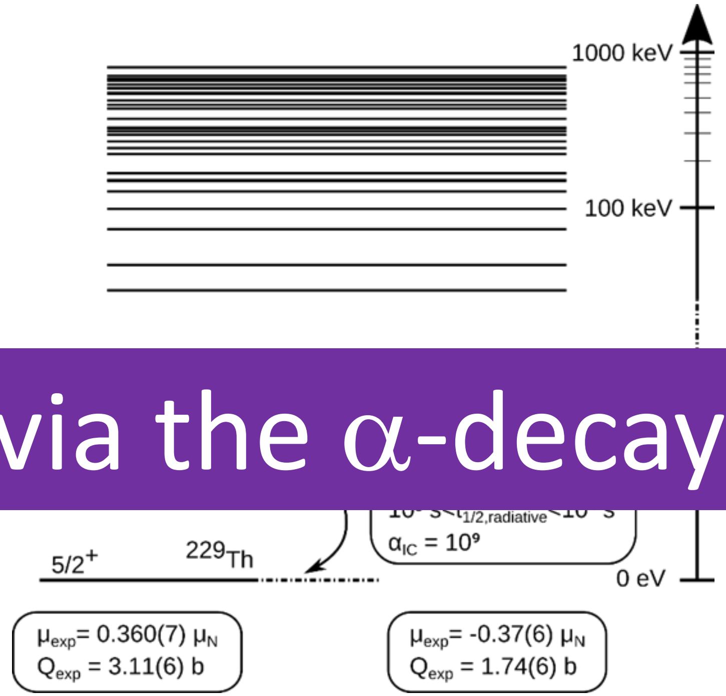




Observation of sharp line possibly related to SnV in PL …

Slight tangent: characterization of the the low lying isomer in ^{229}Th: a nuclear clock?





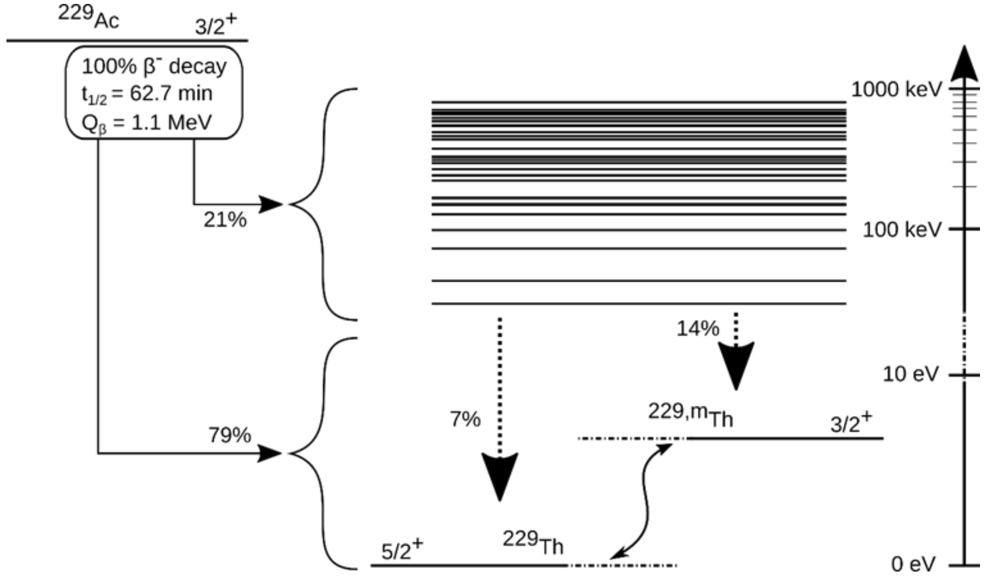
Most current work is via the α-decay of ^{233}U

Low lying isomer in ^{229}Th is within reach of laser excitation….if addressable could result in a highly accurate and stable clock… however, isomer level position still not accurately known…

Current status – ^{229m}Th

- Energy is poorly-defined
- Radiative decay not yet observed
- Internal conversion ($^{229}Th^0$): $T_{1/2,IC} = 7(1)10^{-6}\ s$ (5,6)
- Radiative decay ([$^{229}Th^{1+}$], $^{229}Th^{2+}$,..): $T_{1/2,rad} \sim 10^3 - 10^4 s$

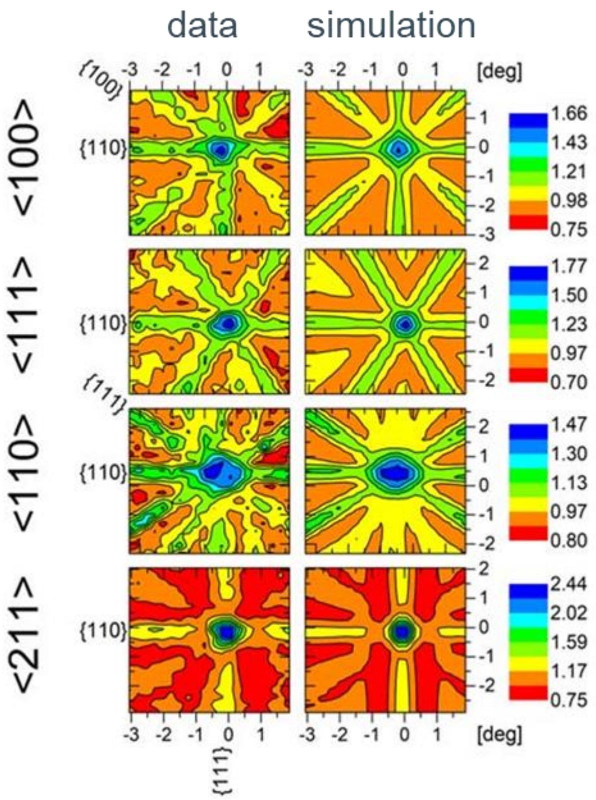
Novel probe of the isomer using ^{229}Ac beams at ISOLDE: combining nuclear decay spectroscopy and emission channelling



How to observe radiative emission?

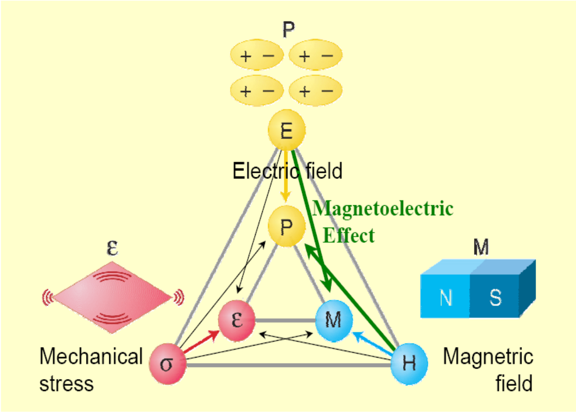
Implant into wide band material e.g. CaF which blocks internal transition…

If on substitutional position can clearly study the decay properties…

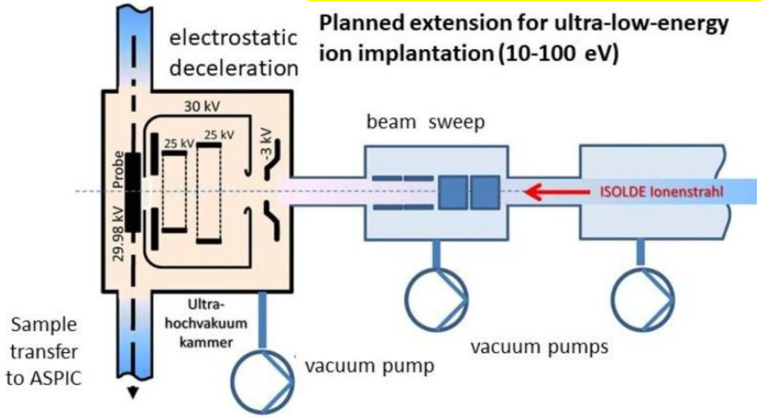


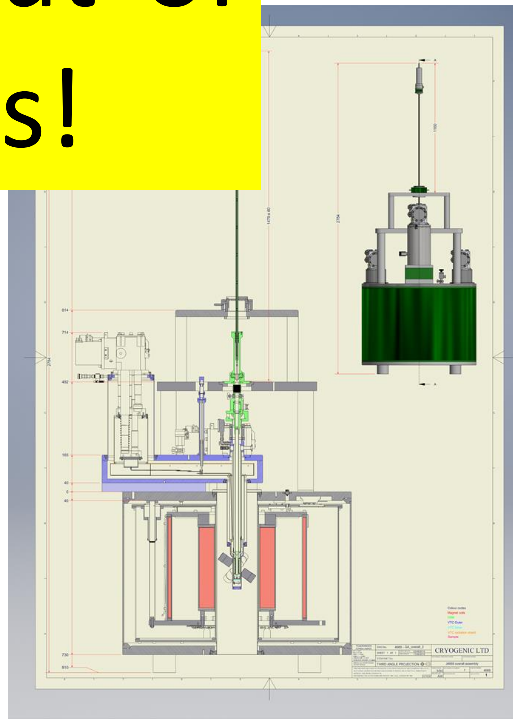
Preliminary data shows 90% on sub site….to be continued next year…further studies required to control the annealing and bring isotopes to substitutional posiition…

Future plans

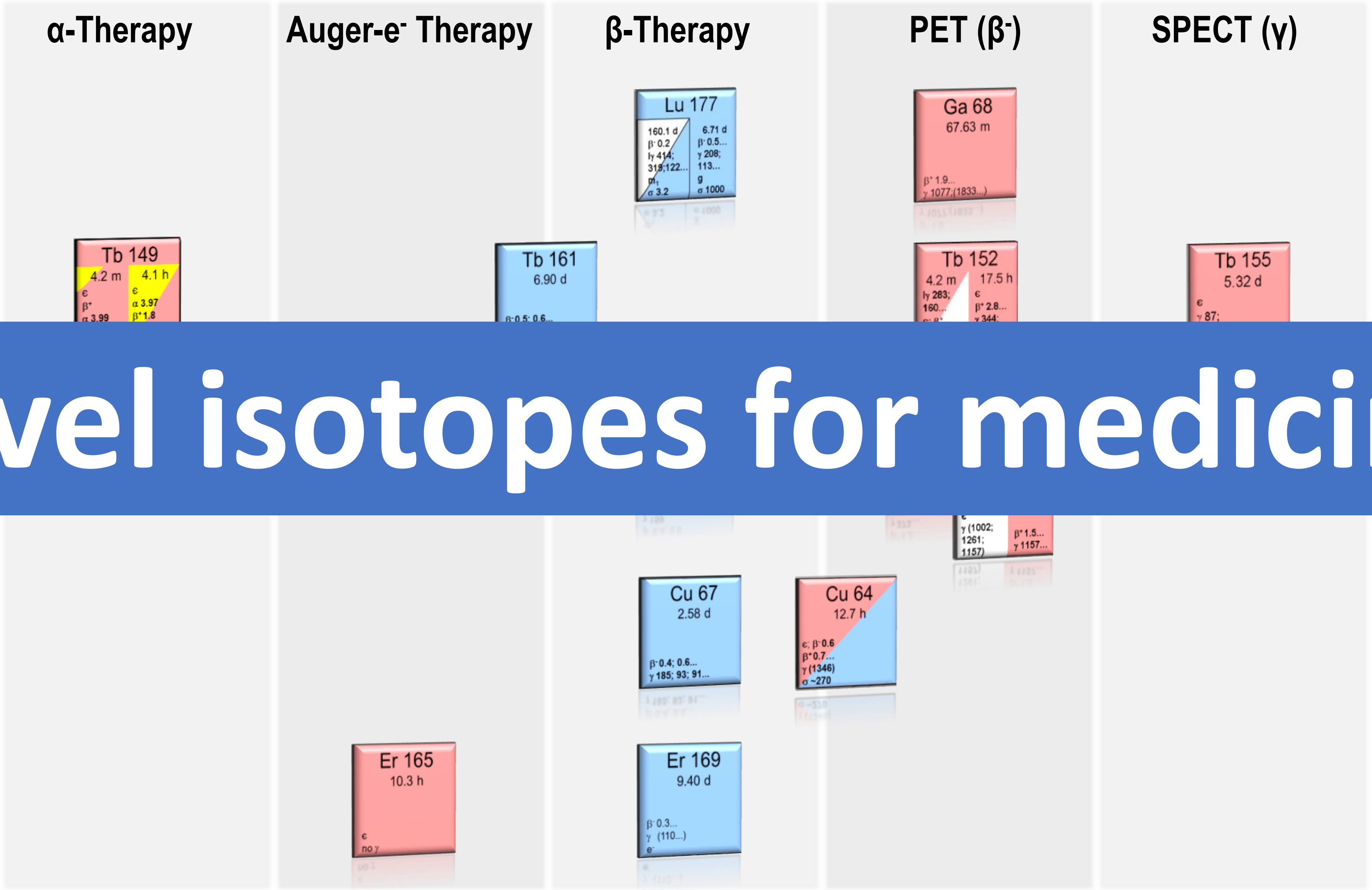


But we are beginning to run out of space for all the proposed setups!



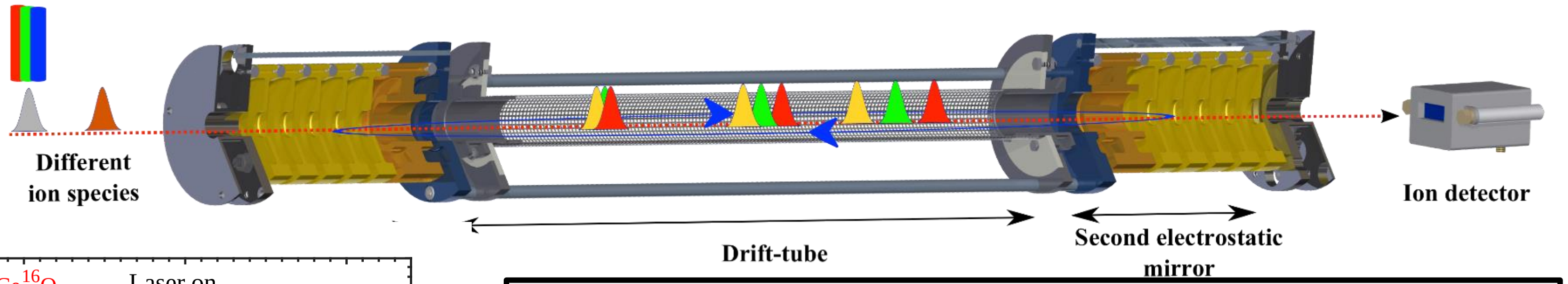


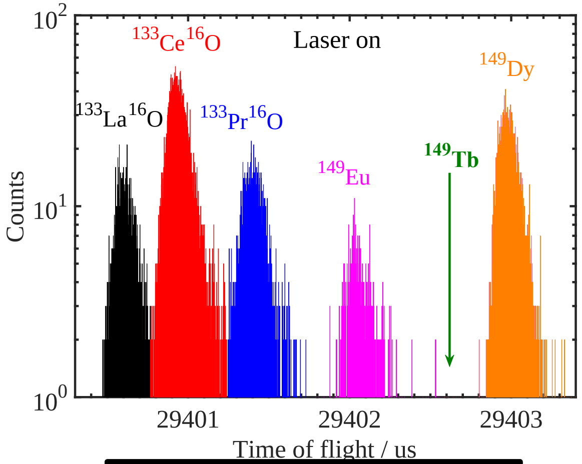
"Matched Pairs" of Radionuclides for Theragnostics



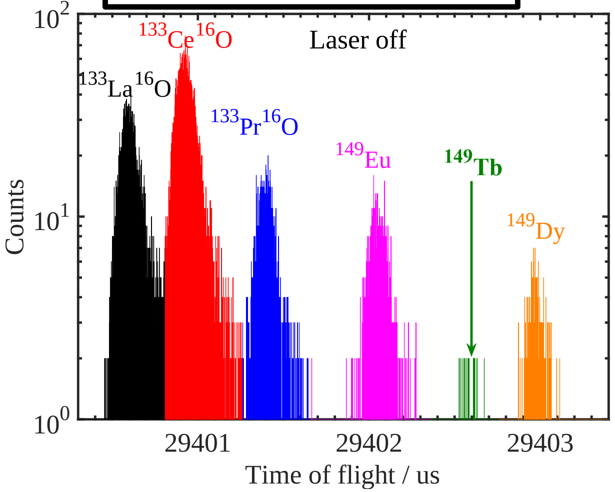
Novel isotopes for medicine

Beam optimization with ISOLTRAPs MR-ToF for Dy/Tb collections

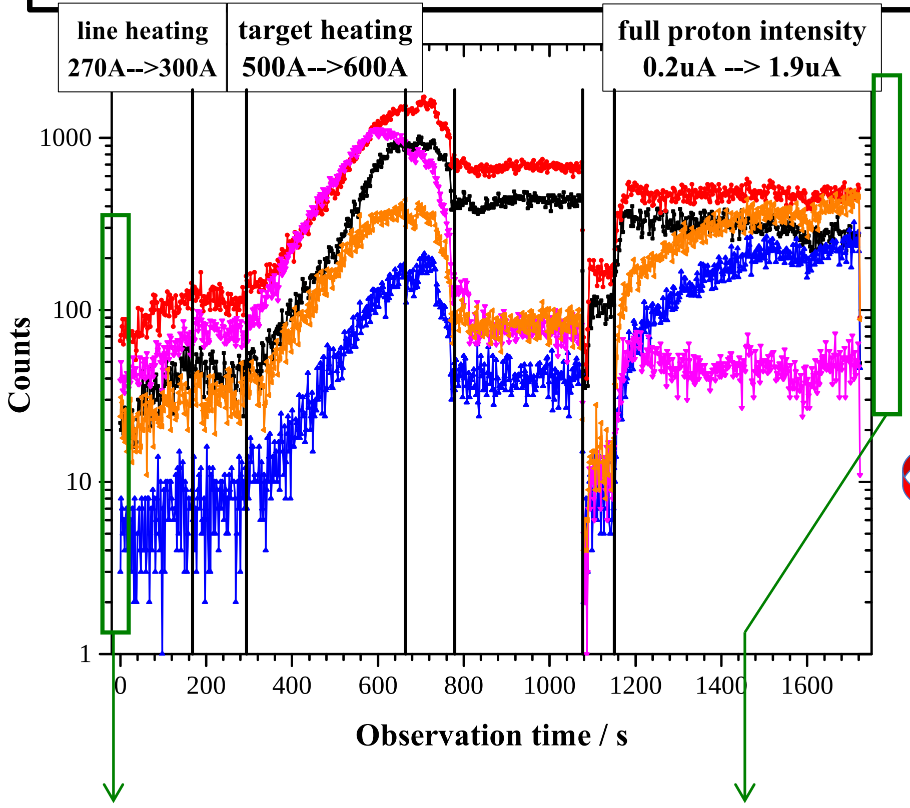




Laser on/off ratio = 10/1



Distinct observation of all involved species at the same time



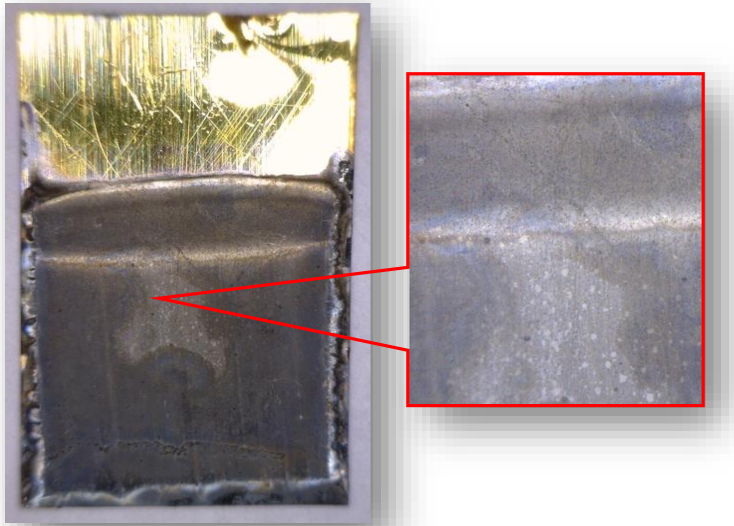
Isotope	Half life
^{133}La	3.912h
^{133}Ce	97m
^{133}Pr	6.5m
^{149}Eu	93.1d
^{149}Dy	4.2m
^{149}Tb	4.118h

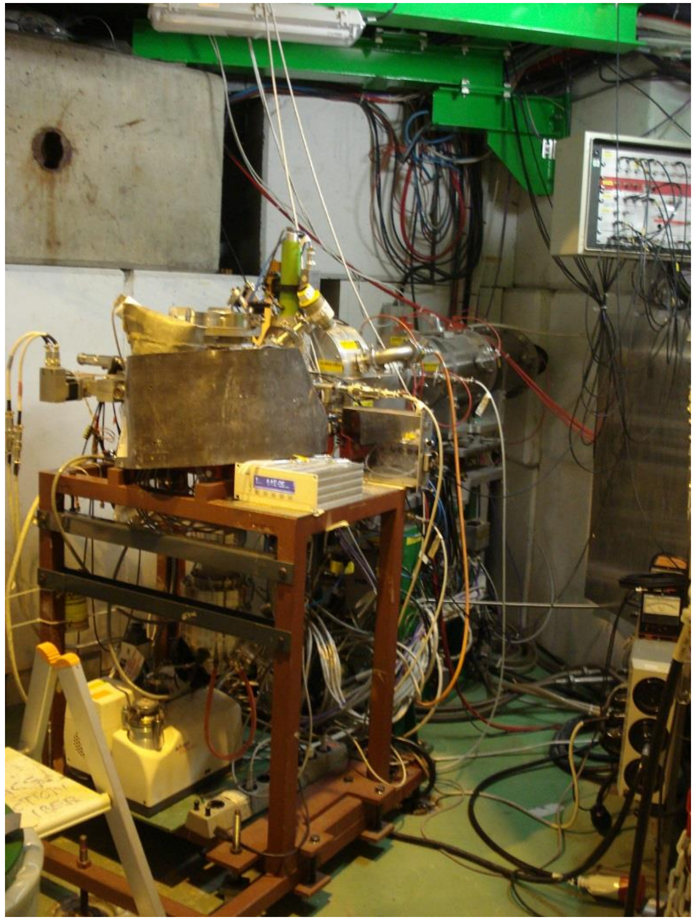
Before optimization: 6.3/1 After optimization: 2.3/1

contaminants / ^{149}Dy → almost factor 3 improvement!

Implantation Foils

The Old Way

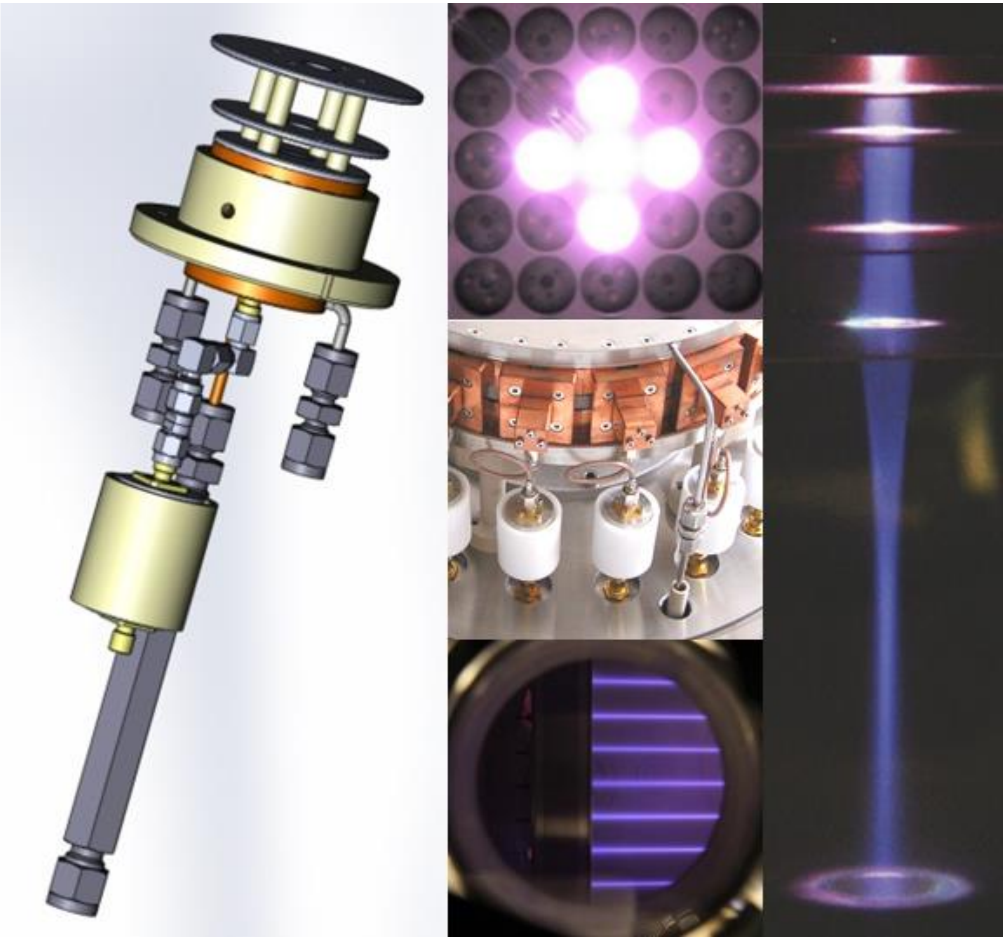


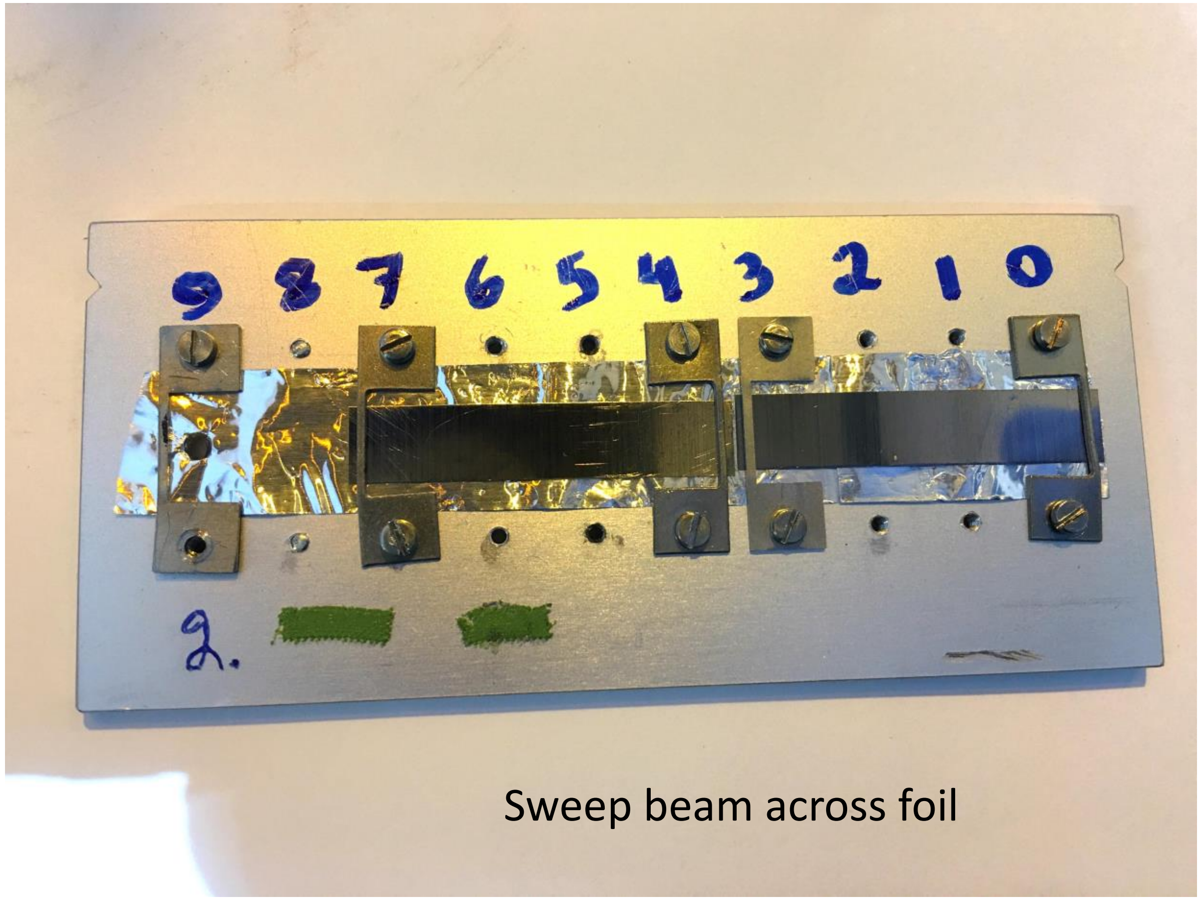


Sputtering of foils due to intense beam: implanted in Au!

Implantation Foils

The New Way



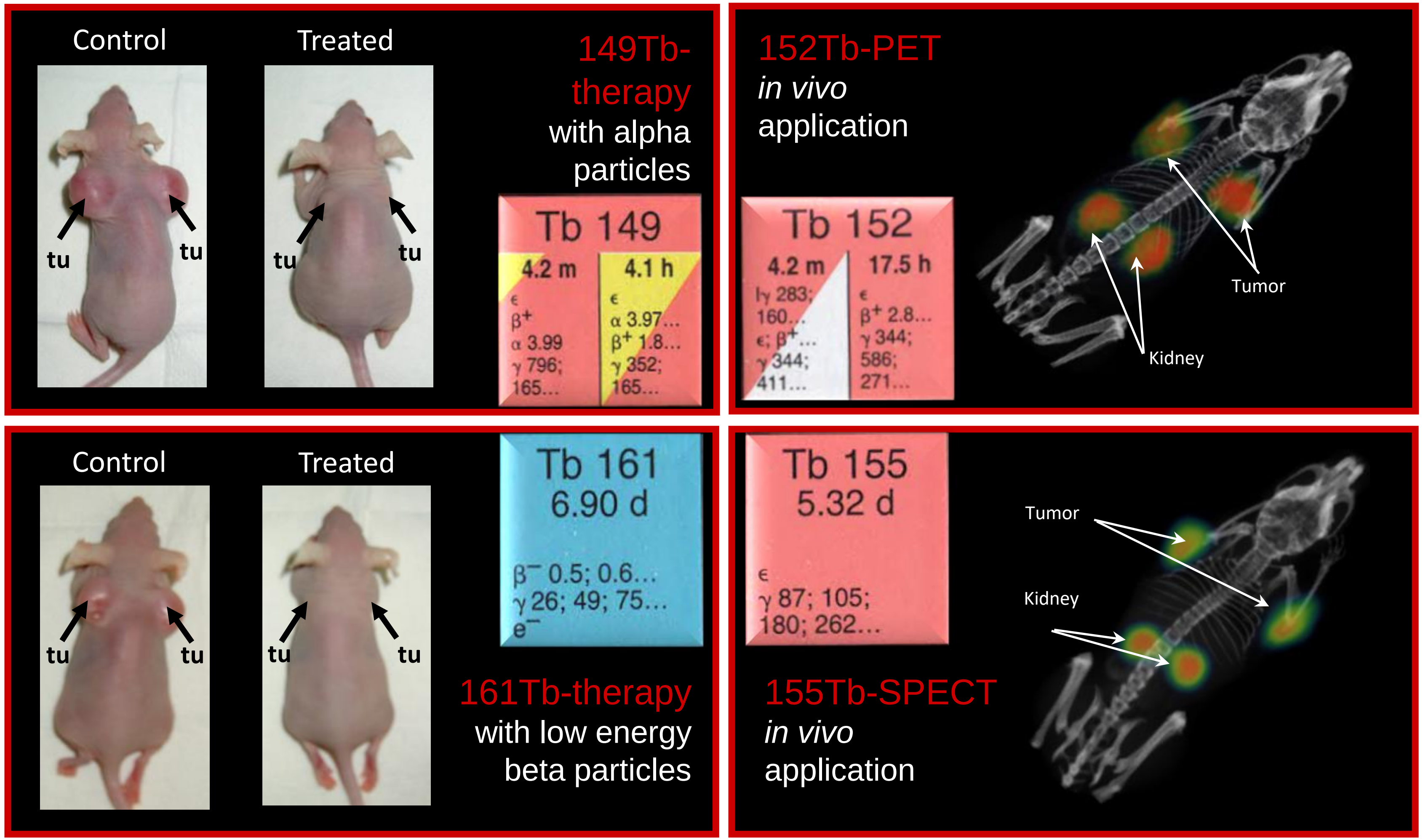


Sweep beam across foil

Separation Method Used to Obtain ^{152}Tb and ^{149}Tb

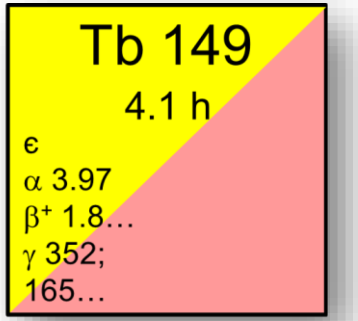
- Foil contents dissolved at 80 ˚C using 2x 0.5 mL dil. HNO_3/NH_4NO_3.
- Dissolved radionuclides loaded onto cation exchange resin.
- Column was eluted in gradients: 0.07 M to 0.13 M α-HIBA to remove Tb radionuclide.
- >100 MBq ^{149}Tb, >600 MBq ^{152}Tb was obtained in 2015
- Product labelled DOTA-compounds up to 10 MBq/nmol.

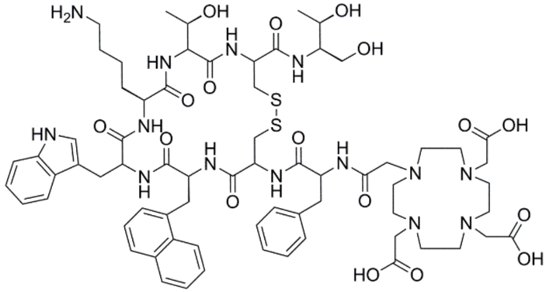
Applications of Tb-nuclides

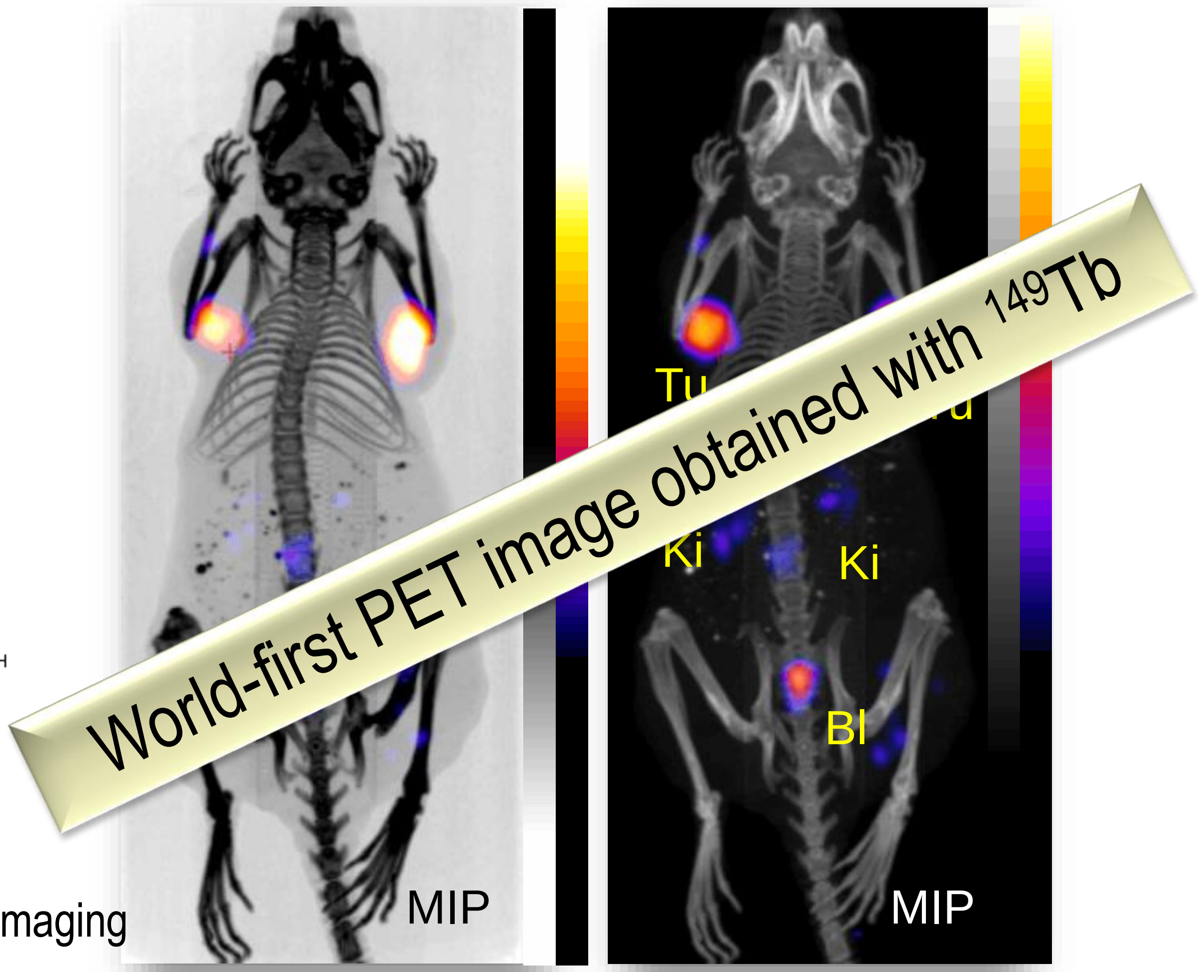


Müller et al. *J. Nucl Med* (2012) 53:1951-1959.

^{149}Tb: A Part Of The Future of ISOL







Useful for α-Therapy and PET Imaging

PET/CT scan of a AR42J tumor-bearing mouse performed 2 h after injection of ^{149}Tb-DOTANOC

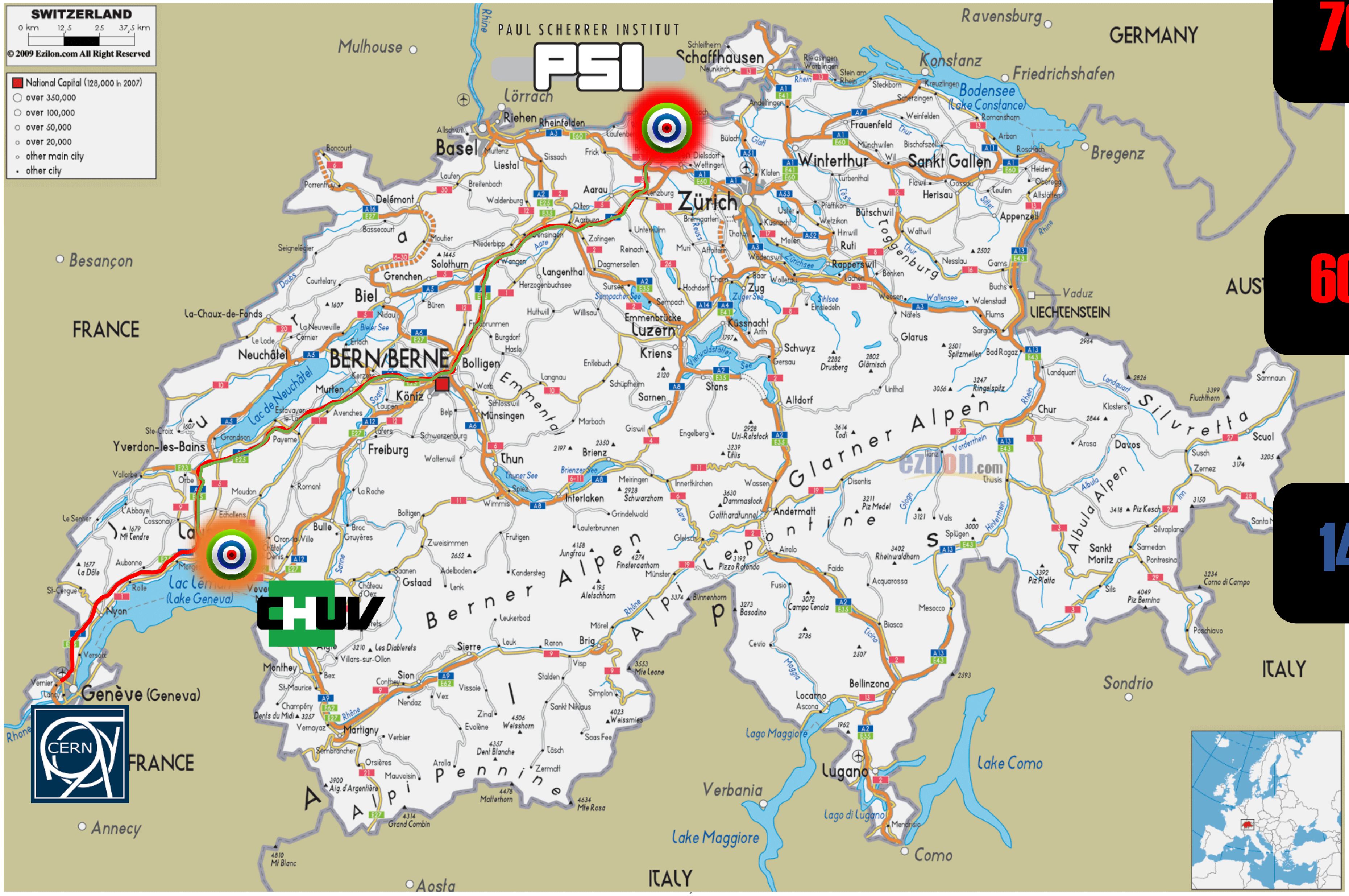
Muller et al., *EJNMMI Radiopharmacy and Chemistry*, (2016) 1:5.

Logistics: The Travel Challenge : ^{149}Tb

200 MBq

110 MBq

The Travel Challenge : ^{152}Tb: very indirectly to Lausanne



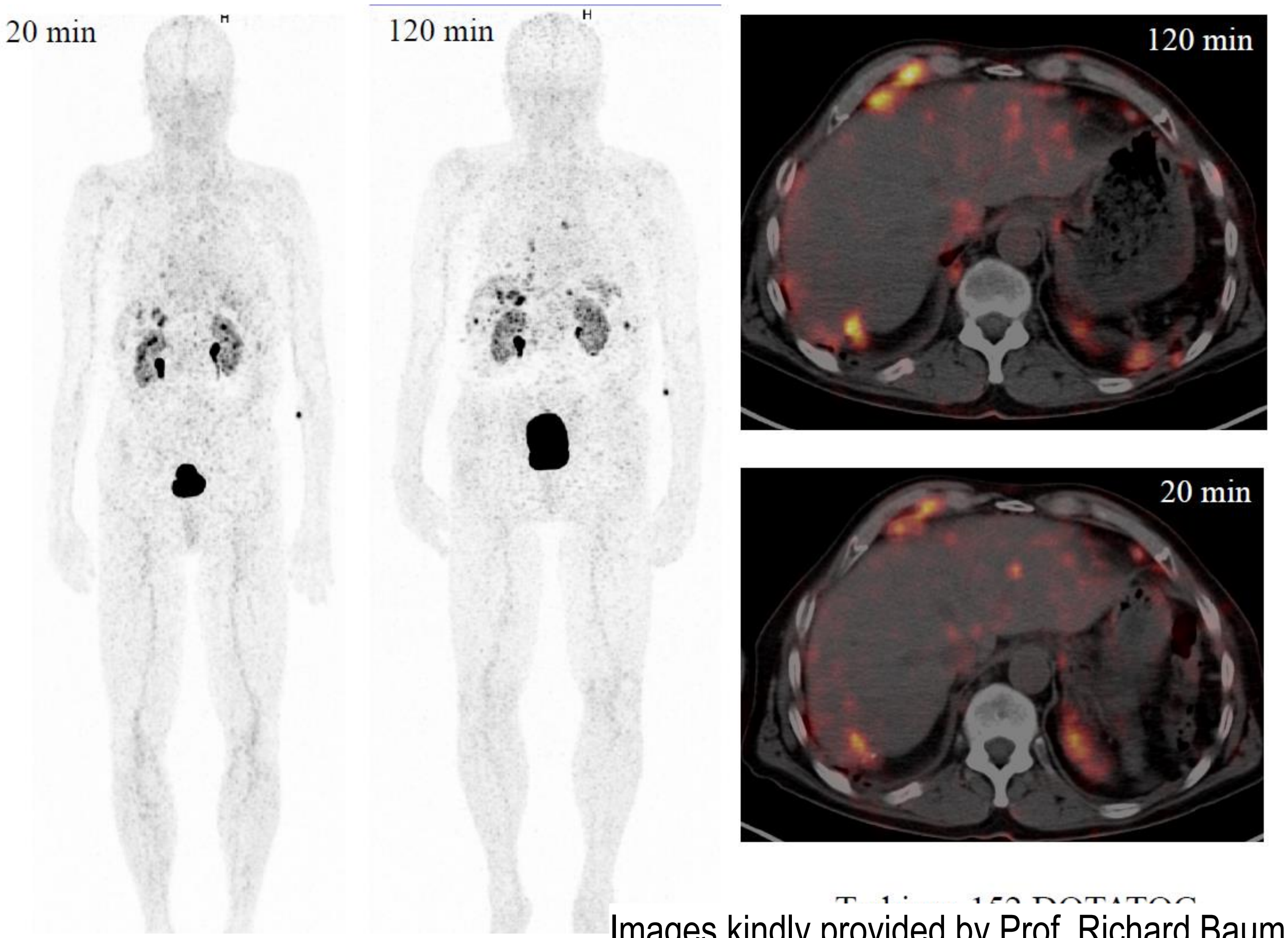
700 MBq

600 MBq

140 MBq

^{152}Tb-DOTATOC: First Clinical Study

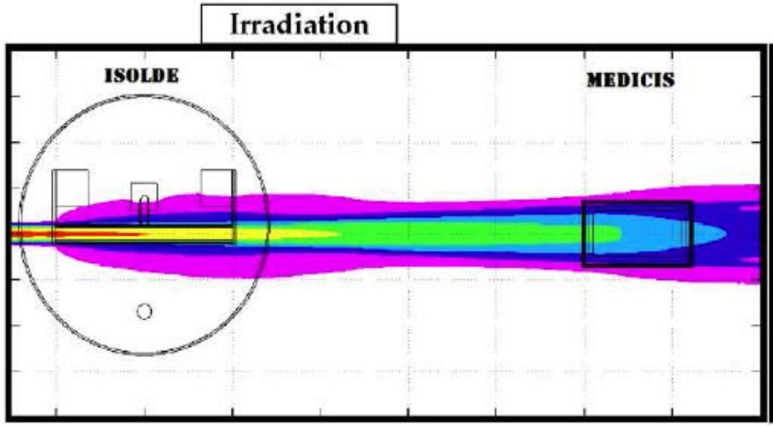
First ^{152}Tb-based PET Scan of a Patient – Performed at Zentralklinik Bad Berka, Germany (Prof. Richard Baum)

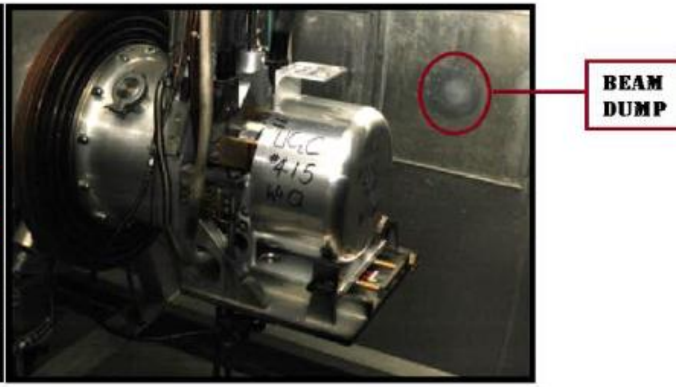


Images kindly provided by Prof. Richard Baum

Dalton Transactions (2017) DOI: 10.1039/c7dt01936j

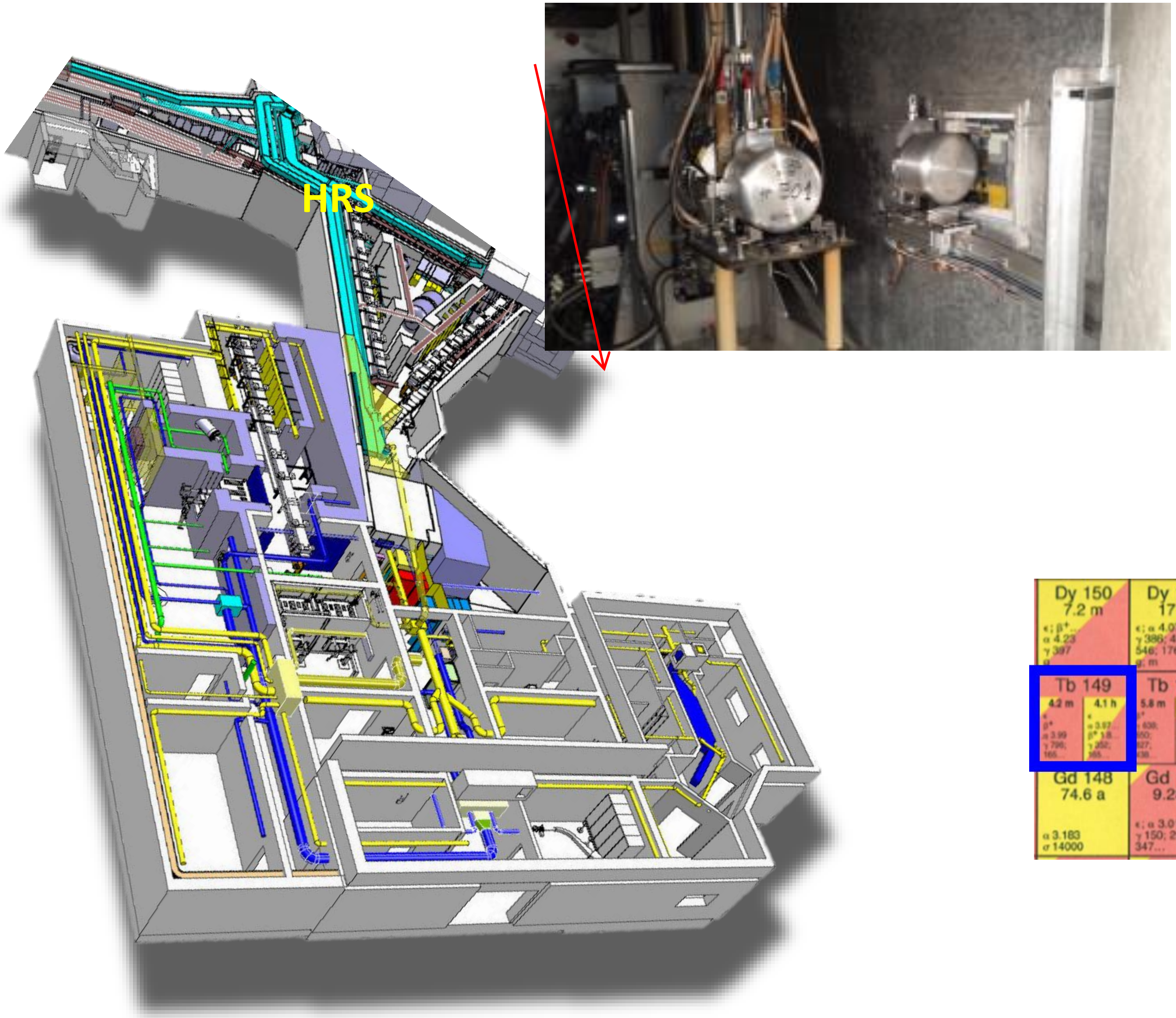
MEDICIS: a dedicated facility for production of isotopes for medicine

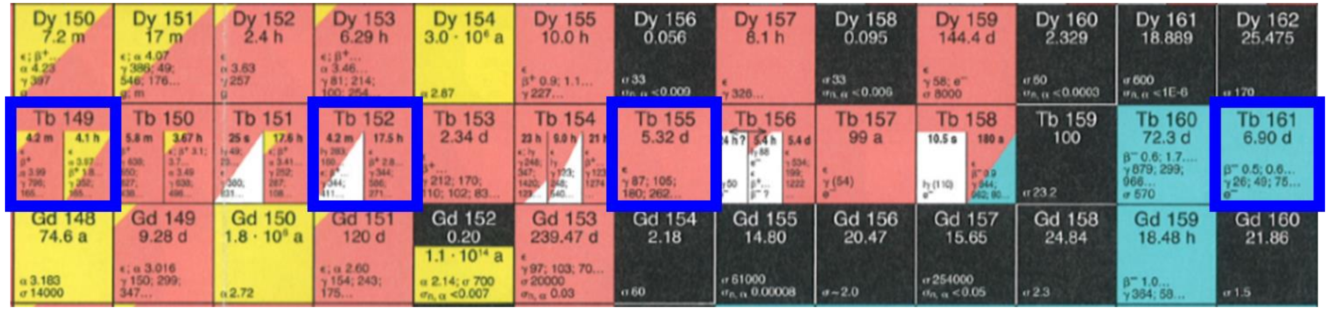




90% of protons are going to the dump: We can recycle them !

CERN-MEDICIS: new Facility for medical isotopes (and solid state/materials?)





CERN Courier October 2016

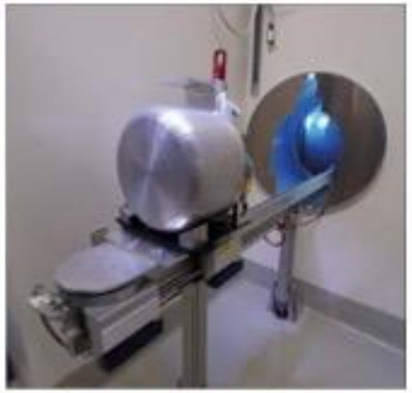
CERN MEDICIS

CERN to produce radioisotopes for health

A new project called CERN MEDICIS aims to produce novel isotopes as diagnostic agents and treatments for brain and pancreatic cancers, explain **Leo Buehler**, **Thomas Cocolios**, **John Prior** and **Thierry Stora**.

Accelerators and their related technologies have long been developed at CERN to undertake fundamental research in nuclear physics, probe the high-energy frontier or explore the properties of antimatter. Some of the spin-offs of this activity have become key to society. A famous example is the World Wide Web, while another is medical applications such as positron emission tomography (PET) scanner prototypes and image reconstruction algorithms developed in collaboration between CERN and Geneva University Hospitals in the early 1990s. Today, as accelerator physicists develop the next-generation radioactive beam facilities to address new questions in nuclear structure – in particular HIE-ISOLDE at CERN, SPIRAL 2 at GANIL in France, ISOL@Myrrha at SCK•CEN in Belgium and SPES at INFN in Italy – medical doctors are devising new approaches to diagnose and treat diseases such as neurodegenerative disorders and cancers.

The bridge between the radioactive-beam and medical communities dates back to the late 1970s, when radioisotopes collected from a secondary beam at CERN's Isotope mass Separator On-Line facility (ISOLDE) were used to synthesise an injectable radiopharmaceutical in a patient suffering from cancer. ^{167}Tm-citrate, a radiolanthanide associated to a chelating chemical, was used to perform a PET image of a lymphoma, which revealed the spread-out cancerous tumours. While PET became a reference protocol to provide quantitative imaging information, several other pre-



Clockwise from top left: Storage shelves for ISOLDE and CERN-MEDICIS targets after their operation, showing the robot for remote handling. A "fresh" target unit stands on the CERN-MEDICIS supply point, ready for the robot pick-up and transportation to the irradiation point. A rail conveyor system end-station for target transportation, showing the inspection camera and two modern target units. The MEDICIS building at CERN, next to ISOLDE. (Image credits: Yury Gavrikov.)

cells, killing them with minimal damage to healthy tissue.

CERN-MEDICIS aims to further advance this area of medicine. New isotopes with specific types of emission, tissue penetration and half-life will be produced and purified based on expertise acquired during the past 50 years in producing beams of radioisotope ions for ISOLDE's experimental programme. Diagnosis by single photon emission computed tomography (SPECT), a form of scintigraphy, covers the vast majority of worldwide isotope consumption based on the gamma-emitting ^{99m}Tc, which is used for functional probing of the brain and various other organs. PET protocols are increasingly used based on the positron emitter ^{18}F and, more recently, a ^{68}Ga compound. Therapy, on the other hand, is mostly carried out with beta emitters such as ^{131}I, more recently with ^{177}Lu, or with ^{223}Ra for the new application of targeted alpha therapy (see p35). Other isotopes also offer clear benefits, such as ^{149}Tb, which is the lightest alpha-emitting radiolanthanide and also combines positron-emitting properties.

Driven by ISOLDE

With 17 Member States and an ever-growing number of users, ISOLDE is a dynamic facility that has provided beams for around 300 experiments at CERN in its 50 year history. It allows researchers to explore the structure of the atomic nucleus, study particle physics at low energies, and provides radioactive probes for solid-state and biophysics. Through 50 years of collaboration between the technical teams and the users, a deep bond has formed, and the facility evolves hand-in-hand with new technologies and research topics.

CERN MEDICIS is the next step in this adventure, and the user community is joining in efforts to push the development of the machine in a new direction. The project was initiated six years ago by a relatively small collaboration involving CERN, KU Leuven, EPFL and two local University Hospitals (CHUV in Lausanne and HUG in Geneva). One year later, in 2011, CERN decided to

Summary

- Nuclear solid state physics allows for unique experiments to be performed which can reliably and unambiguously study at the local level electrical, magnetic and structural properties of materials.
- ISOLDE with the largest number of beams available in the world has had so-called “applications” at its core since the early 1970s.
- These techniques have now also been extended towards biological systems.
- Also core to the science programme at ISOLDE is the development of novel isotopes for medicine. ISOLDE develops the isotopes and MEDICIS will then allow such isotopes to be used for systematic trials.
- Although pressure for beamtime is intense, the current generation of RIB facilities emphasise the science case for nuclear applications and the field is growing.
- ISOLDE is now exploring the concept of a new experimental hall to allow for more experimental campaigns in these areas to realise the field’s ultimate potential.

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The solid state physics programme at ISOLDE: recent developments and perspectives

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