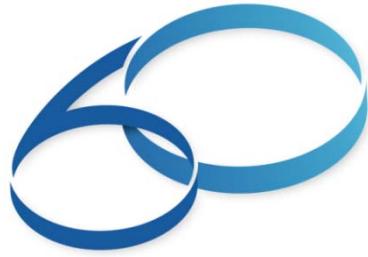


Application of radioactive isotopes for solid state physics and biophysics

Karl Johnston



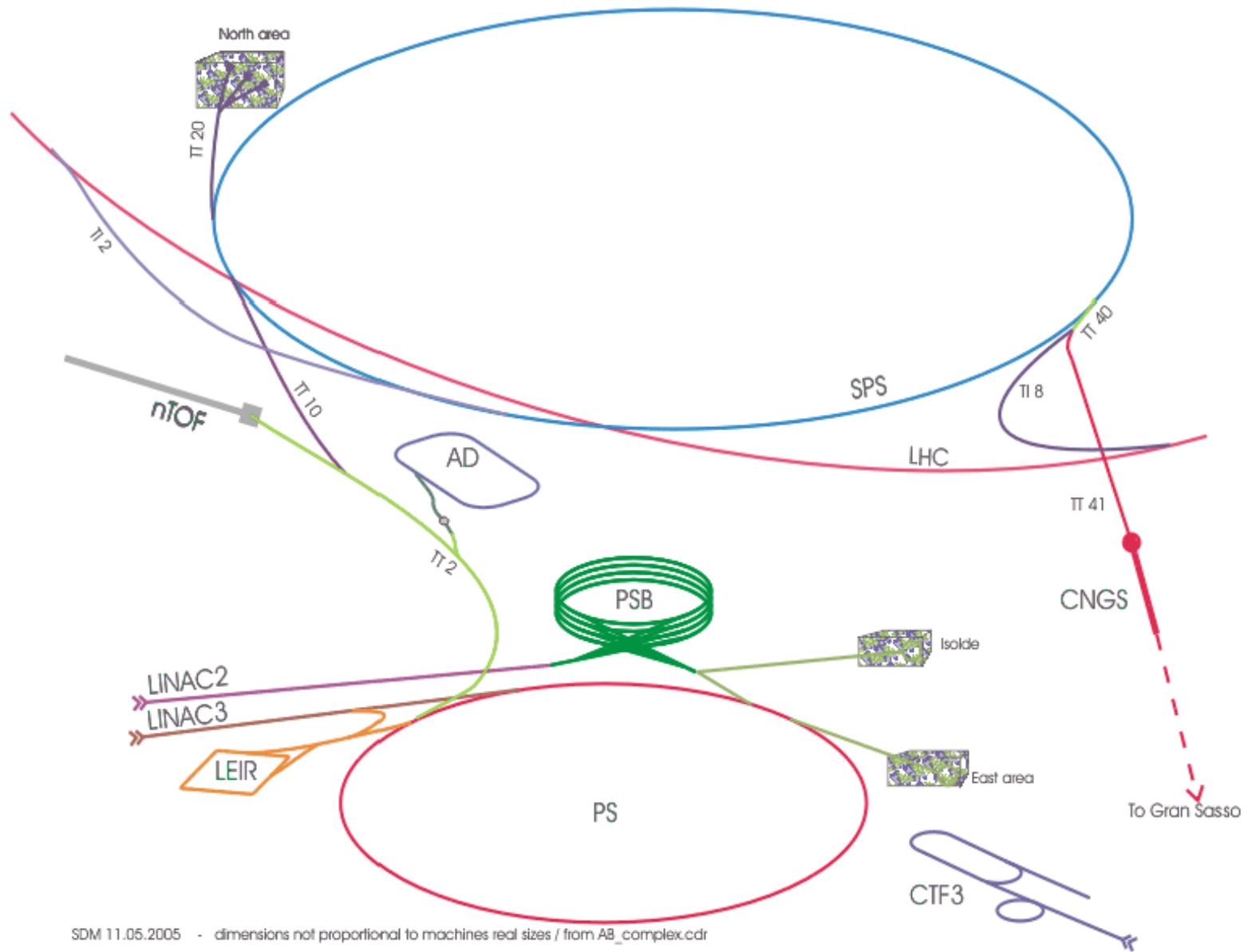
YEARS/ANS CERN

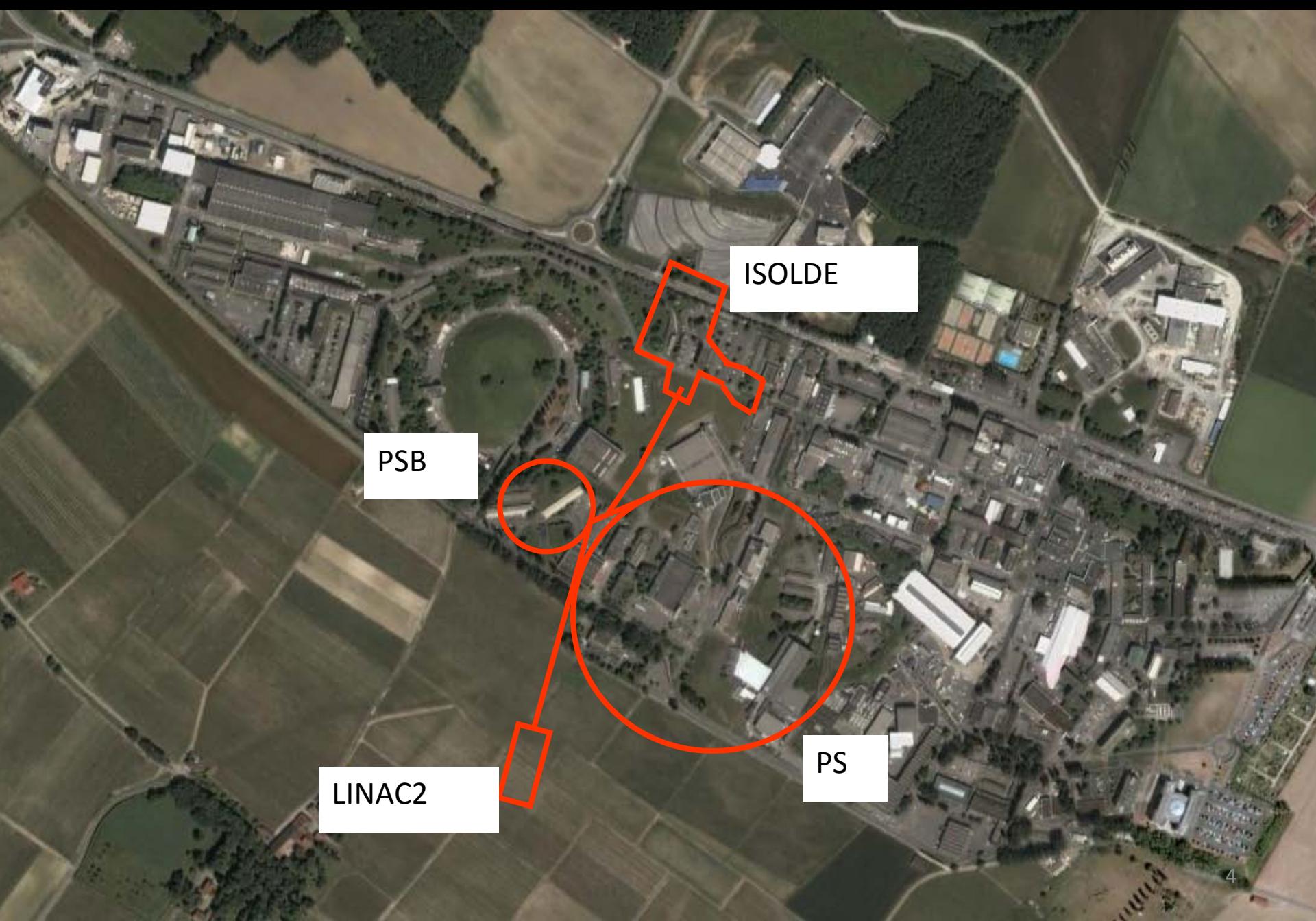


Overview

- (Very brief) Introduction to ISOLDE...
- (even shorter) “flash” of some recent nuclear physics highlights.
- “Applied” programme at ISOLDE: Solid state physics, biophysics.
- Techniques and materials:
 - Radiotracer Diffusion
 - Optical studies in semiconductors
 - Emission Channelling
 - Mossbauer spectroscopy using $^{57}\text{Mn}/^{57}\text{Fe}$
 - Perturbed angular correlation and β -NMR for biophysics
 - MEDICIS

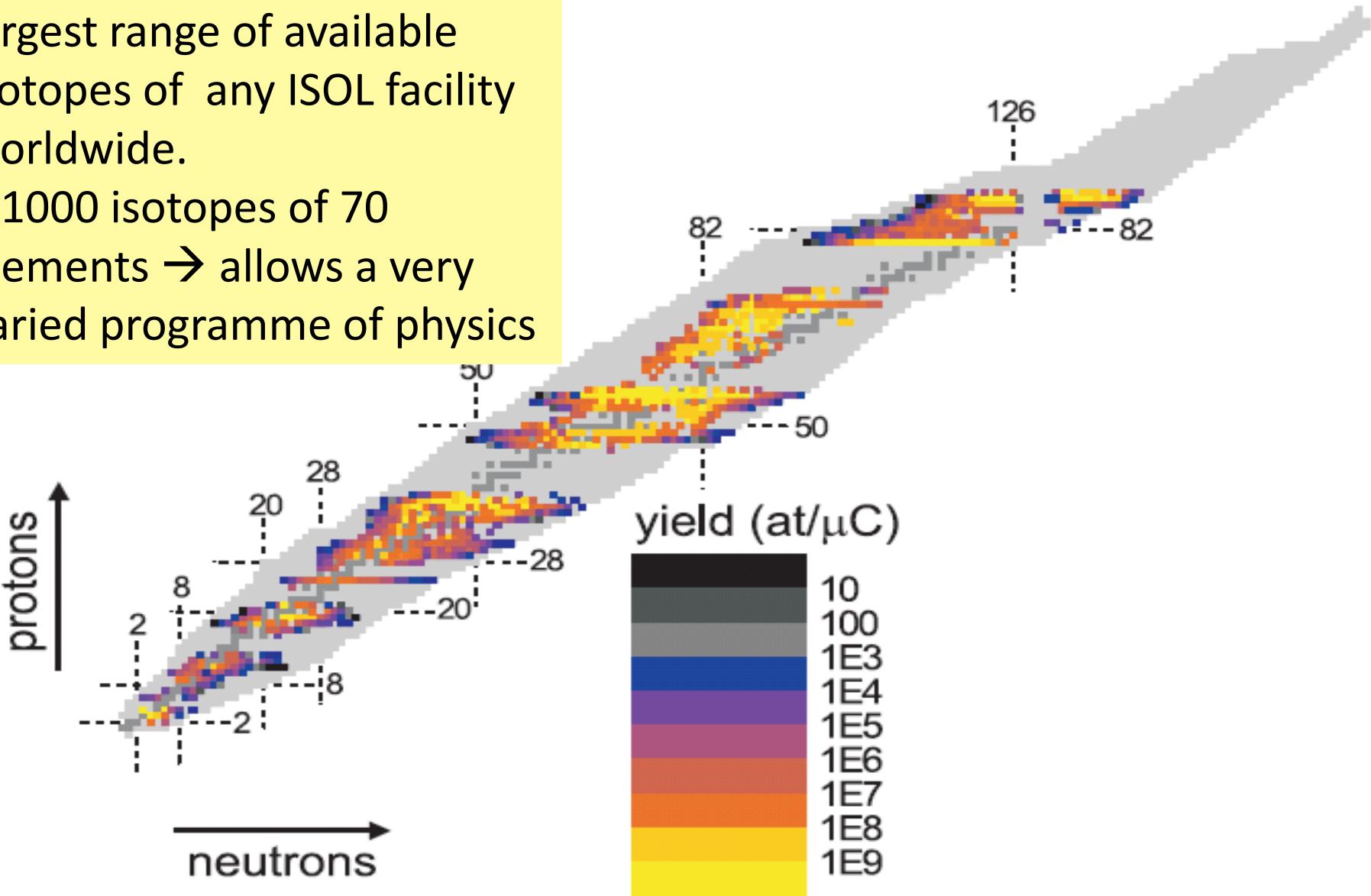
Accelerators at CERN



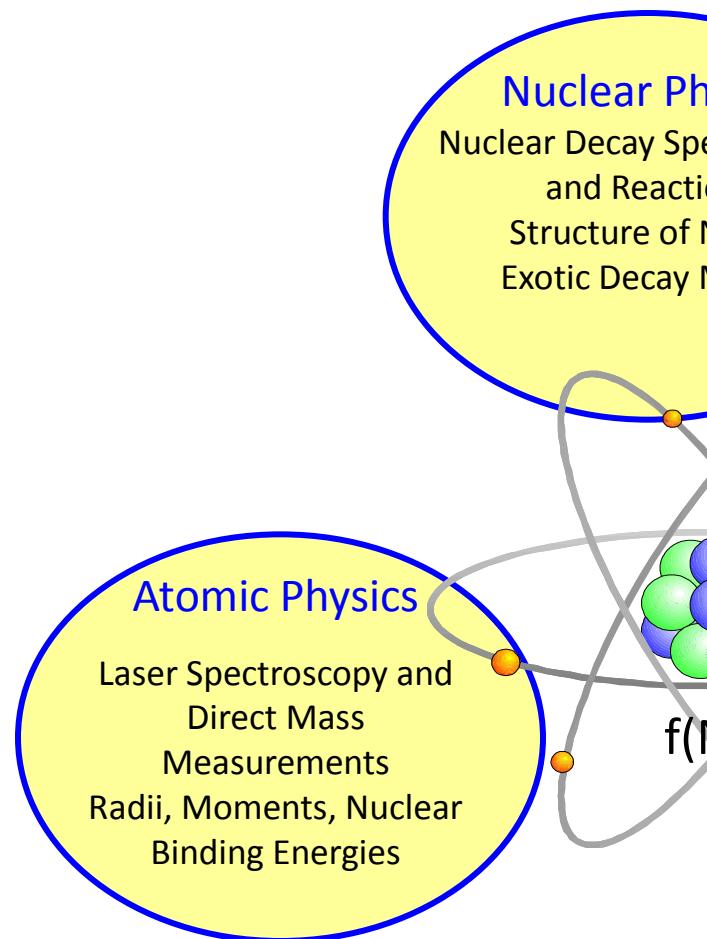


ISOLDE / 50 y Experience

ISOLDE today offers the largest range of available isotopes of any ISOL facility worldwide.
> 1000 isotopes of 70 elements → allows a very varied programme of physics



ISOLDE physics



ARTICLE



doi:10.1038/nature12073

Studies of pear-shaped nuclei using accelerated radioactive beams

L. P. Gaffney¹, P. A. Butler¹, M. Scheck^{1,2}, A. B. Hayes³, F. Wenander⁴, M. Albers⁵, B. Bastin⁶, C. Bauer², A. Blazhev⁵, S. Bönig², N. Bree⁷, J. Cederkäll⁸, T. Chupp⁹, D. Cline³, T. E. Cocolios⁴, T. Davinson¹⁰, H. De Witte⁷, J. Diriken^{7,11}, T. Grahn¹², A. Herzan¹², M. Huyse⁷, D. G. Jenkins¹³, D. T. Joss¹, N. Kesteloot^{7,11}, J. Konki¹², M. Kowalczyk¹⁴, Th. Kröll², E. Kwan¹⁵, R. Lutter¹⁶, K. Moschner⁵,

LETTER

doi:10.1038/nature12226

Masses of exotic calcium isotopes pin down nuclear forces

F. Wienholtz¹, D. Beck², K. Blaum³, Ch. Borgmann³, M. Breitenfeldt⁴, R. B. Cakirli^{3,5}, S. George¹, F. Herfurth², J. D. Holt^{6,7}, M. Kowalska⁸, S. Kreim^{3,8}, D. Lunney⁹, V. Manea⁹, J. Menéndez^{6,7}, D. Neidherr², M. Rosenbusch¹, L. Schweikhard¹, A. Schwenk^{7,6}, J. Simonis^{6,7}, J. Stanja¹⁰, R. N. Wolf¹ & K. Zuber¹⁰



ARTICLE

Received 21 Aug 2012 | Accepted 27 Mar 2013 | Published 14 May 2013

DOI: 10.1038/ncomms2819

OPEN

Measurement of the first ionization potential of astatine by laser ionization spectroscopy

Radioactive isotopes for solid state physics? Why & How??

Radiation: very easy to detect.....

The radioactive isotopes (“probes”) act as “spies” transmitting information with **atomic** resolution via their decay.

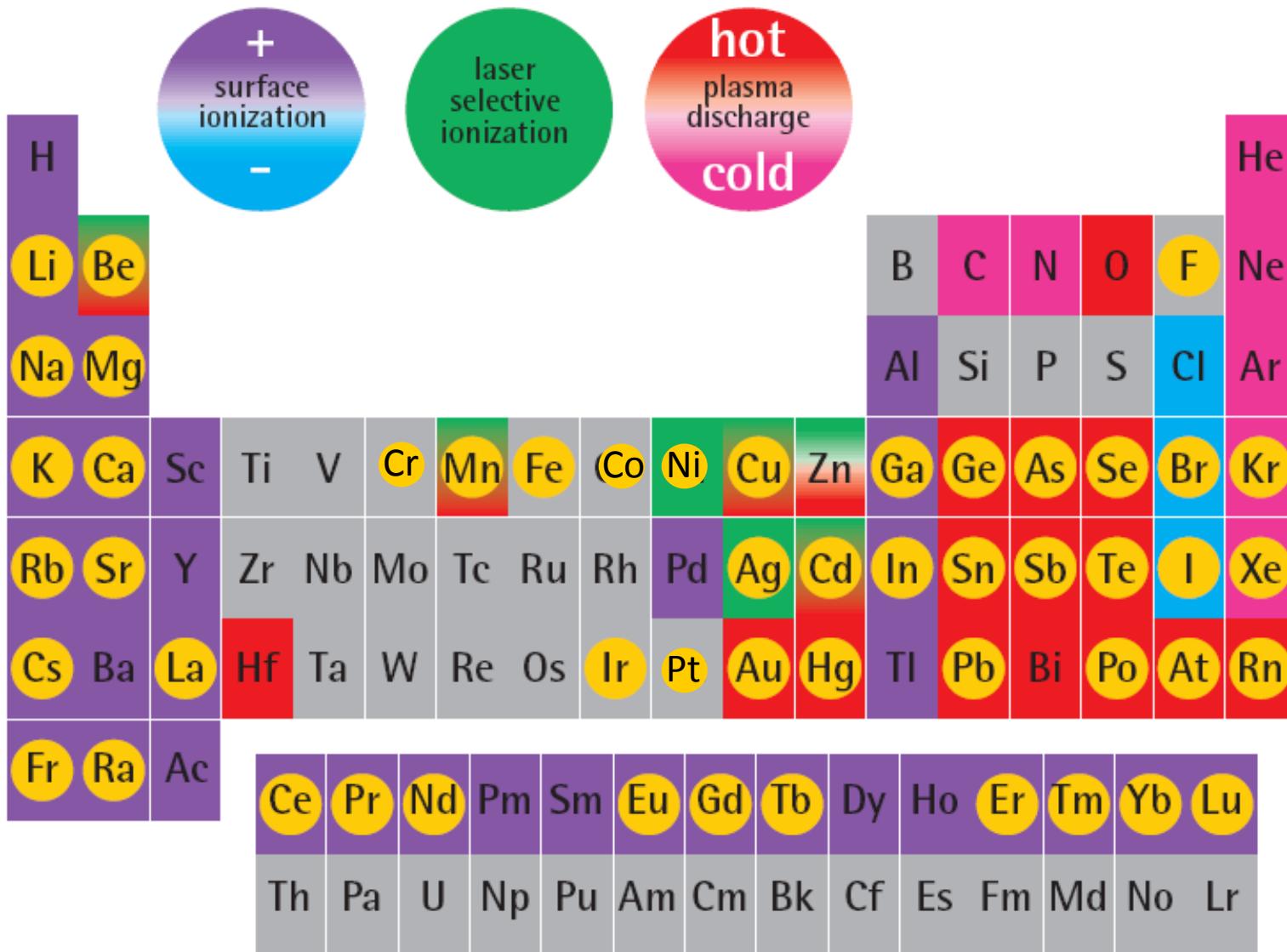
- What information do you get?????
 - Adds extra dimension to “normal spectroscopies” e.g. optical / electrical characterisation of semiconductors
 - Provides extremely **local probe** which can be applied to variety of systems

You need

A facility providing a large variety of radioactive isotope (if possible, isotopically clean)



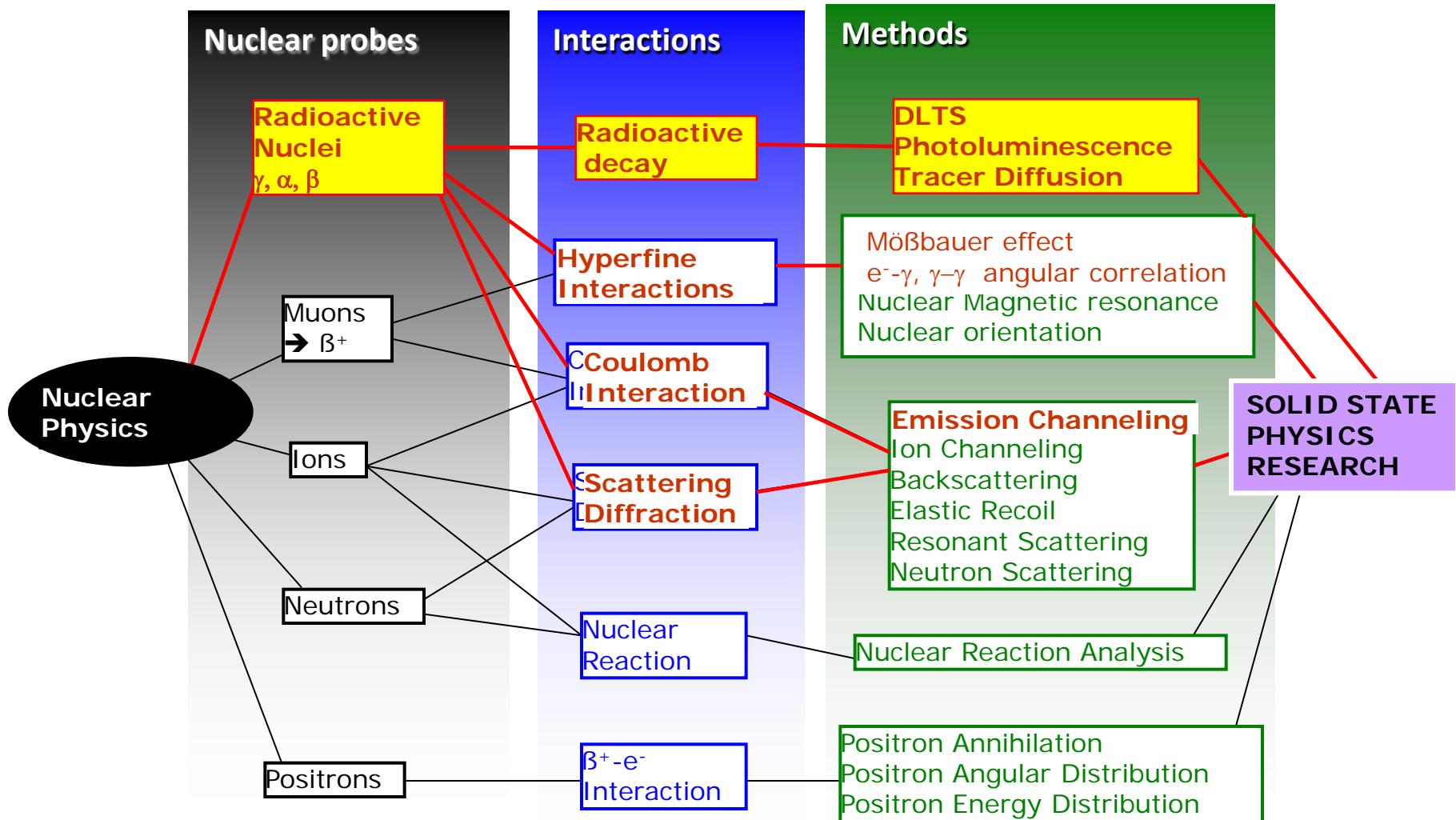
ISOLDE table of elements



Isotopes of
this element

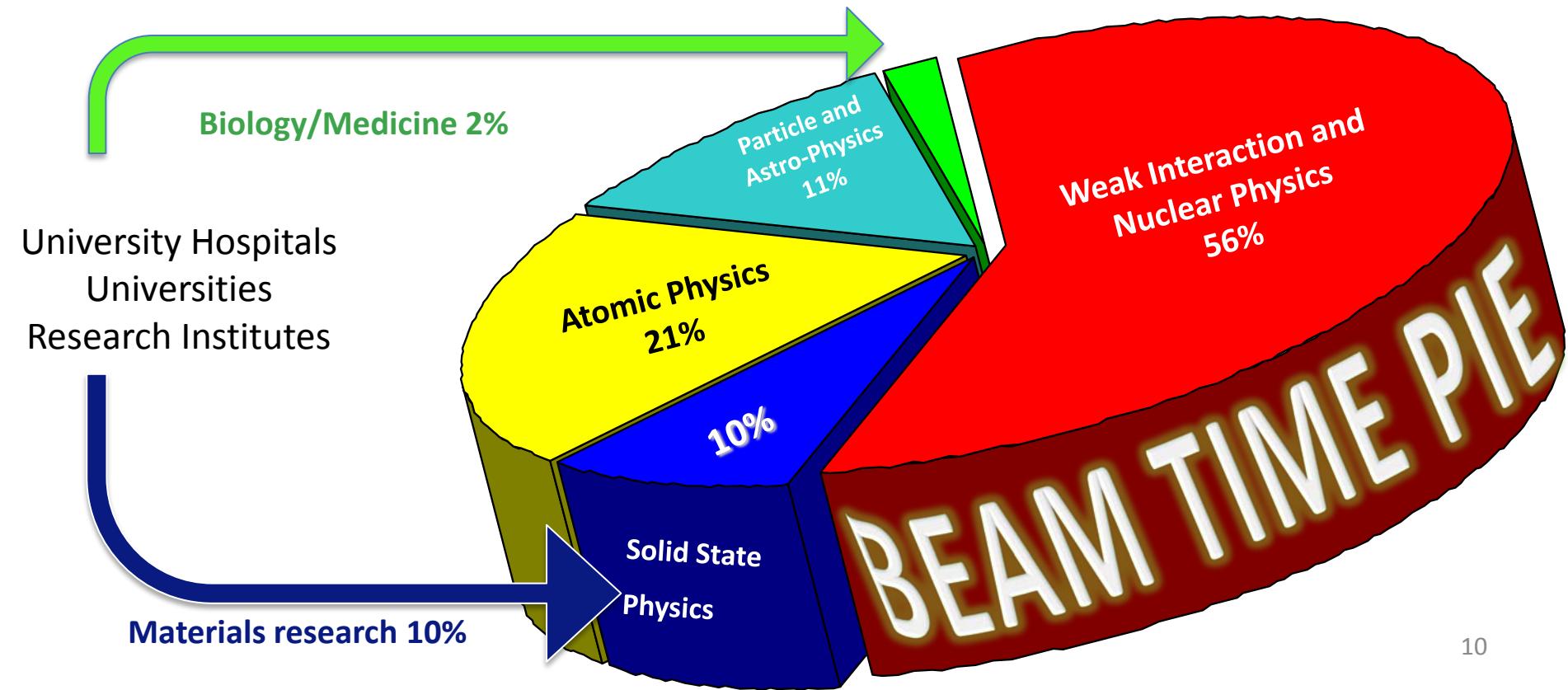
- yellow circle used for solid state physics or life science

Applying radioactivity to solid state physics



“APPLICATIONS”

- Intense beams
- Clean beams
- Ability to share time with more exotic nuclear physics: running in parallel

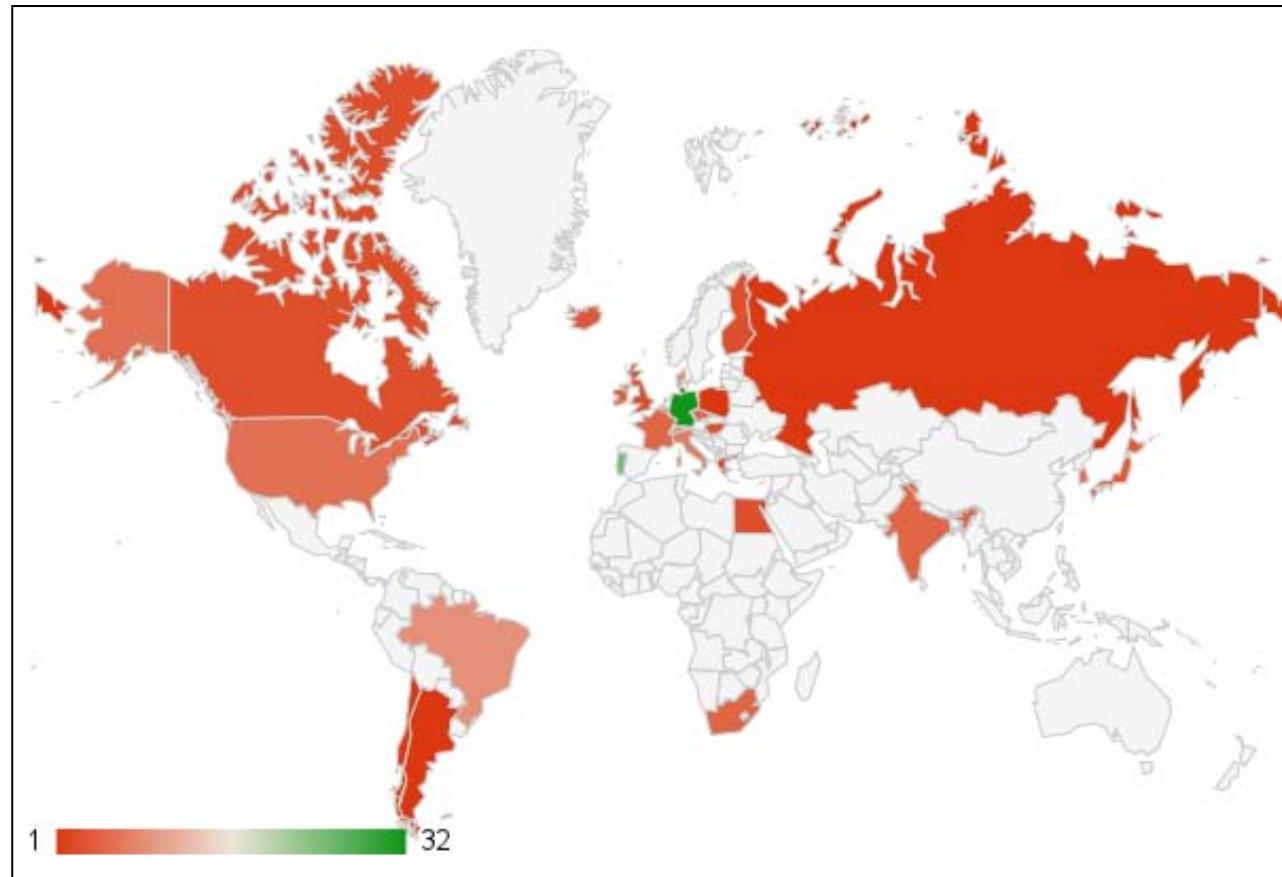


Solid state physics @ ISOLDE: Diverse community

Solid State physics:
Semiconductors,
Metals

Materials scientists:
High T_c
Superconductors,
Multiferroic materials

Biophysics:
structural properties &
role of heavy metals in
proteins, DNA.

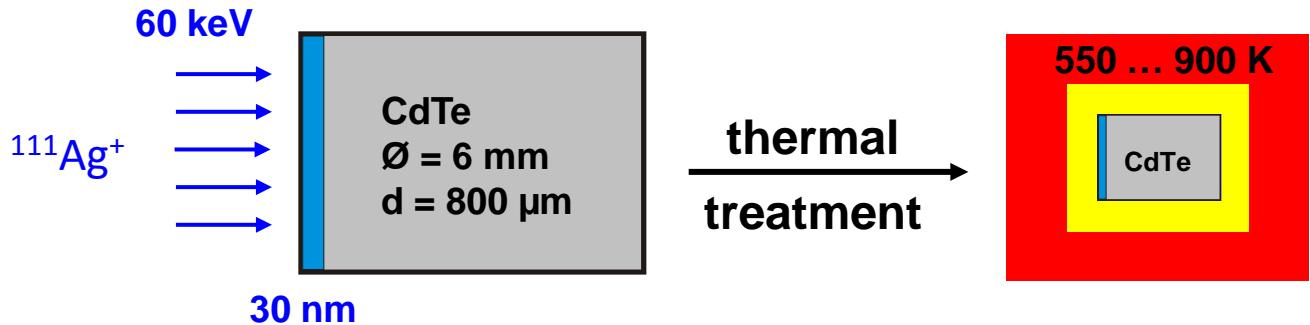
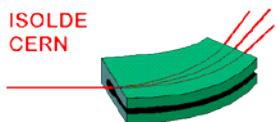


SSP collaborations

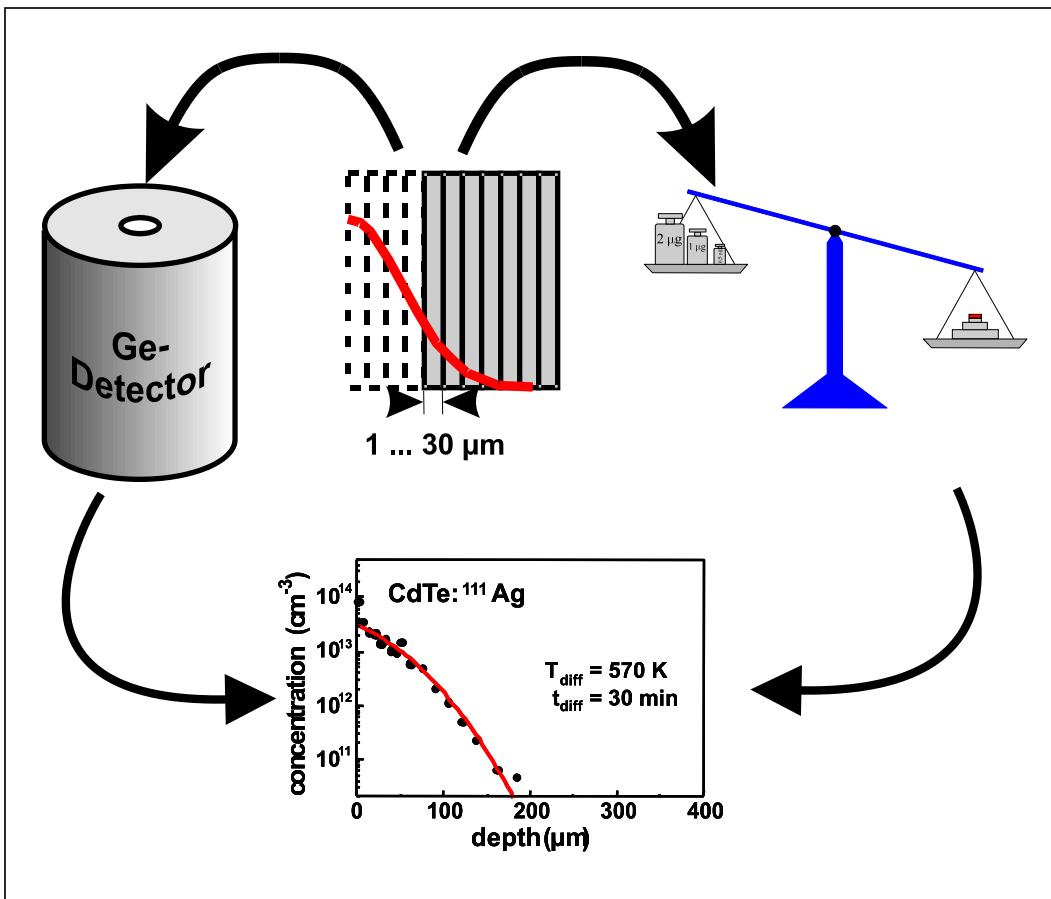
Running experiments/letters of intent	24
Participating countries	26
Scientists	160

Radiotracer technique

Implantation



Mechanical sectioning

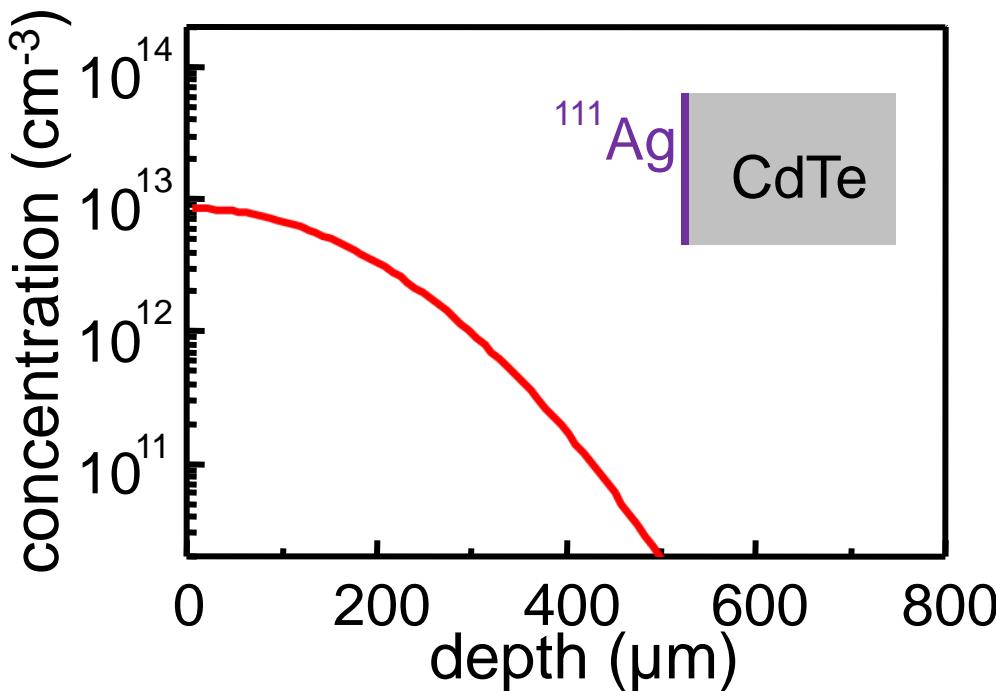


- Resolution > 1 µm
- $T_{1/2} > 1 \text{ h}$

Diffusion in solids

$$J(X) = -D_X \frac{\partial[X]}{\partial x}$$

$$\frac{\partial[X]}{\partial t} = -\frac{\partial}{\partial x} J(X)$$

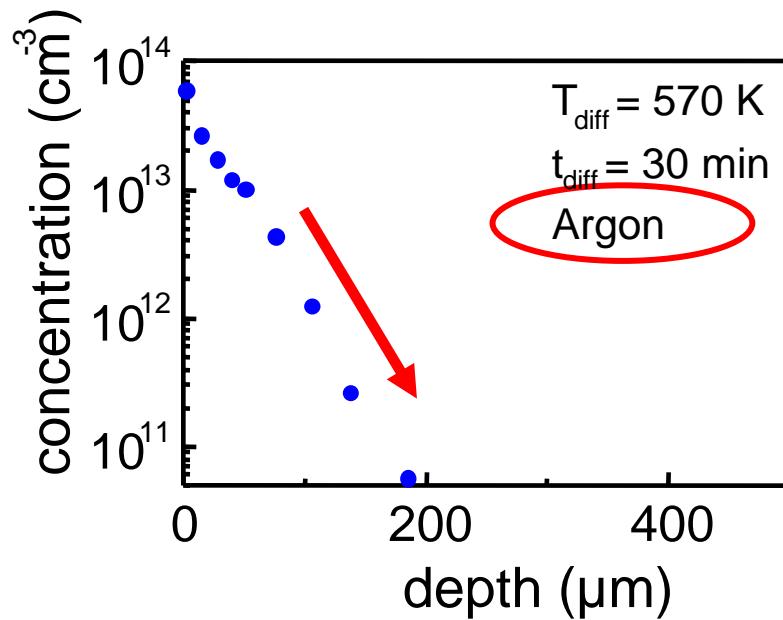


for $C(x, t = 0) = N \cdot \delta(x)$

$$C(x, t) = \frac{N}{\sqrt{2\pi \cdot D t}} \cdot e^{-\frac{x^2}{4Dt}}$$

Monotonously decreasing profiles

Diffusion of ^{111}Ag in CdTe



Monotonously
decreasing profile

Uphill diffusion profile

(H. Wolf et al., Phys. Rev. Lett. 94 (2005) 125901)

Model

- Deviation from stoichiometry

$$[\Delta C] = [Cd_i] - [V_{Cd}]$$

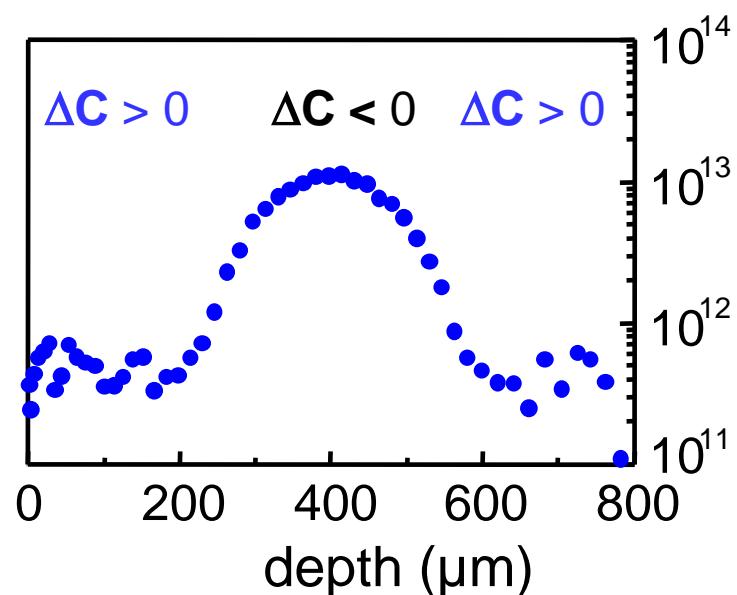
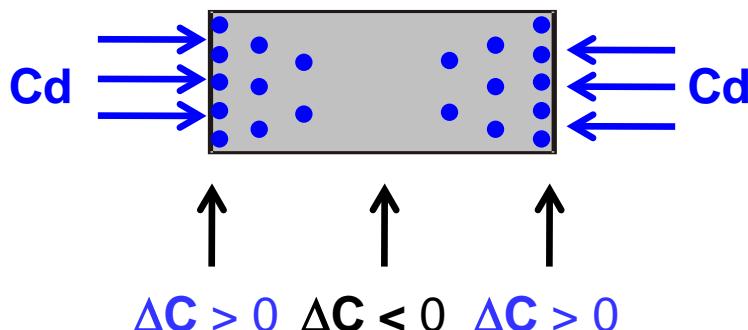
- Initial state of the crystal Te rich

$$\Delta C < 0$$

- Highly mobile Cd interstitials

- Highly mobile Ag dopant (interstitial)

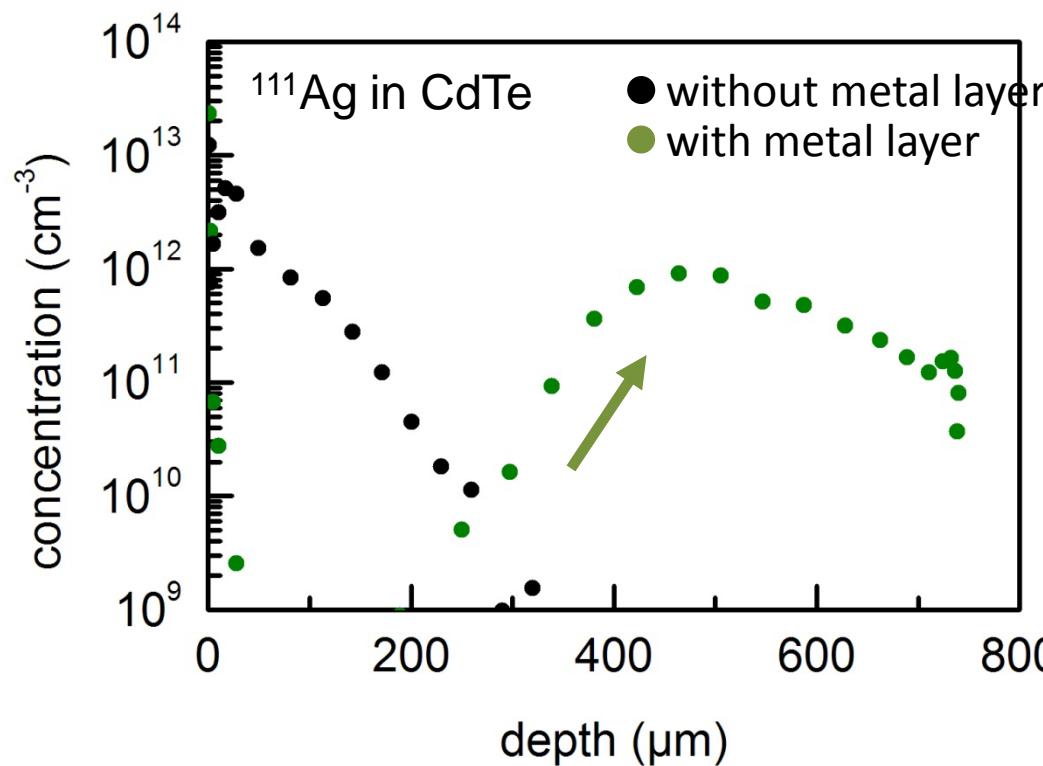
- Source of Cd interstitials during diffusion



- Ag dopants images the profile of the intrinsic defects

Also seen from metal layers (Cu)

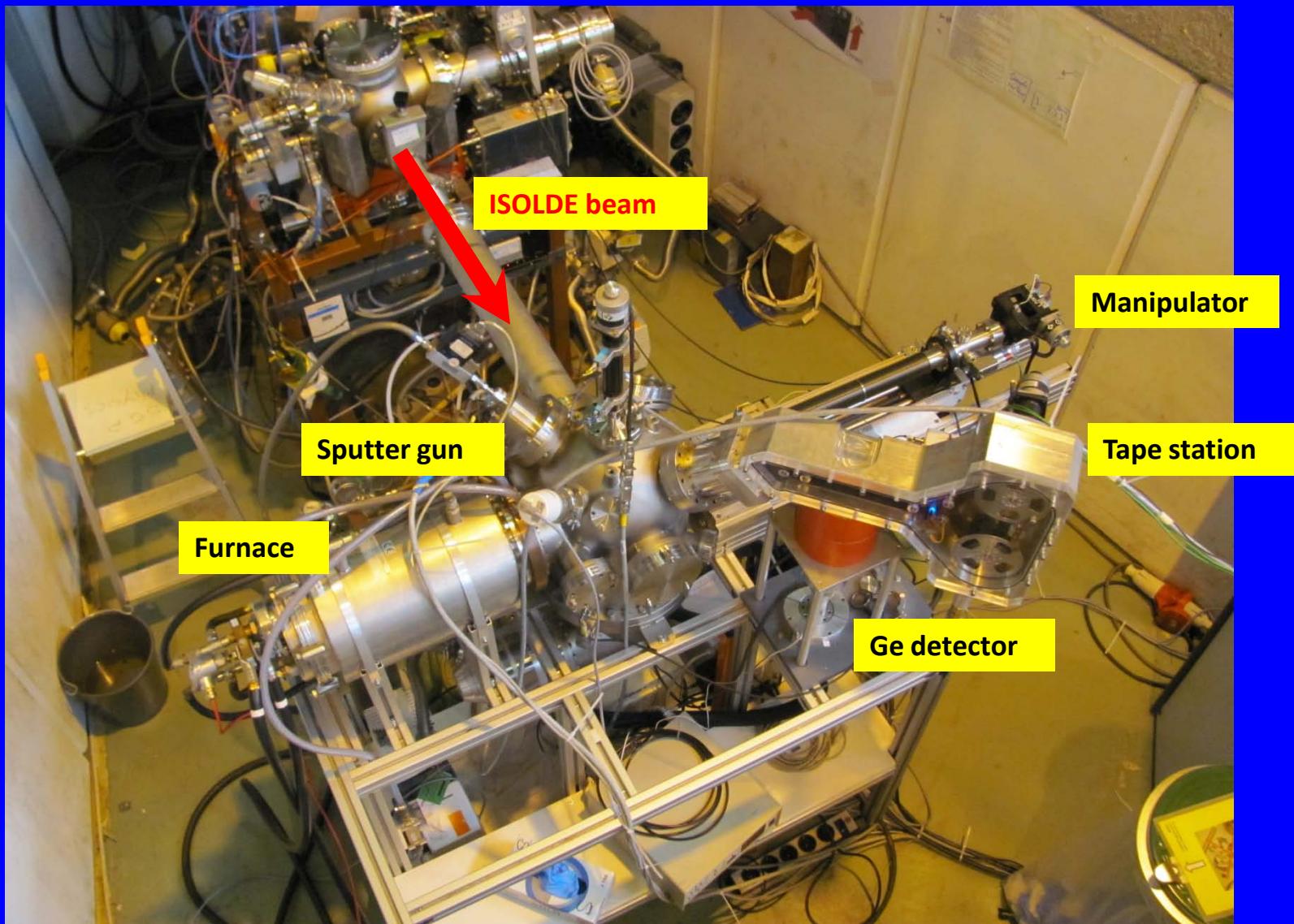
Diffusion without Cu layer at 500 K



Metal layers can initialize uphill diffusion

On-line diffusion chamber at ISOLDE

2012

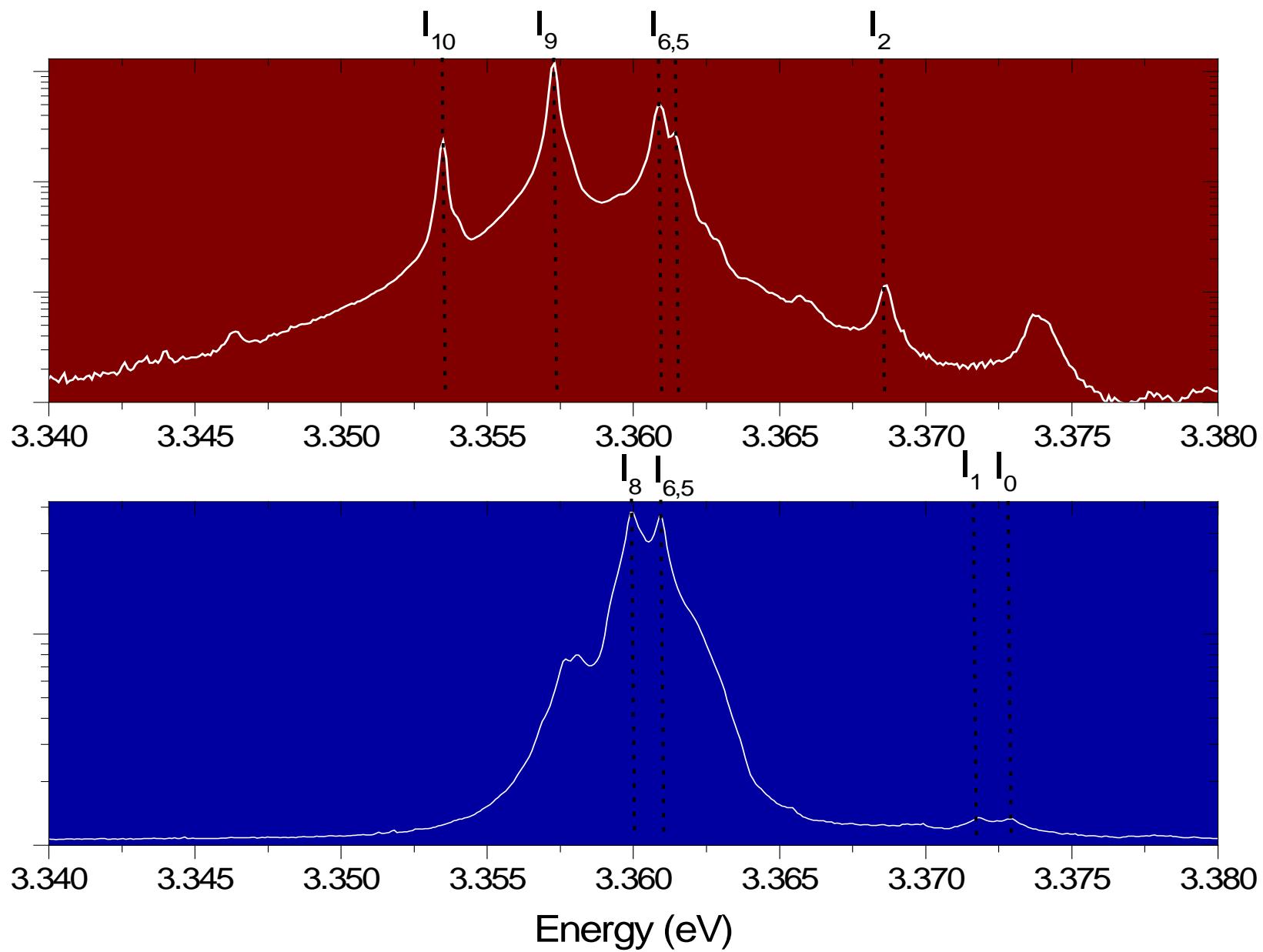


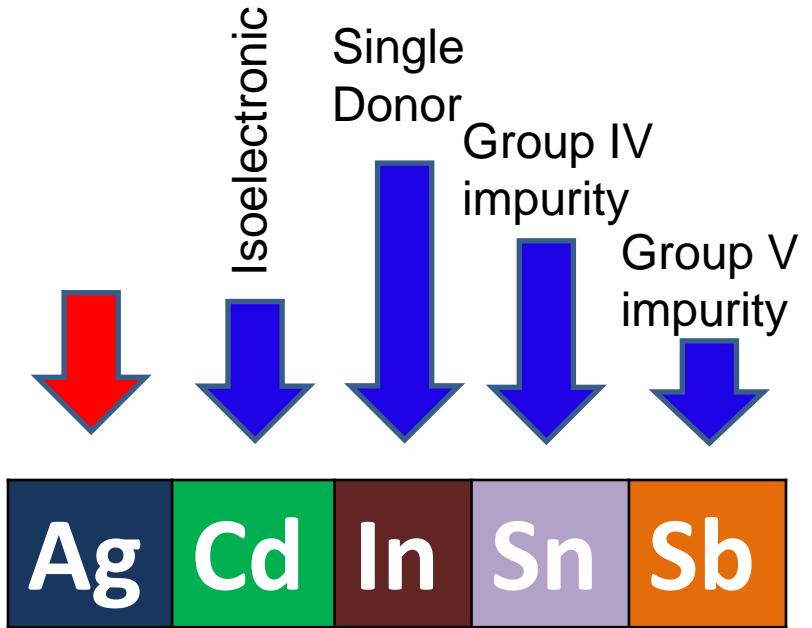
Photoluminescence Characterisation of Semiconductors

- ✓ One of the principal techniques in semiconductor research.
- ✓ High Spectral resolution
- ✓ Non-destructive
- ✓ No need for contacts
- ✓ Very sensitive (can probe ppb)
- ✓ Relatively flexible and straightforward
- ✓ Can be extended to include external perturbations.

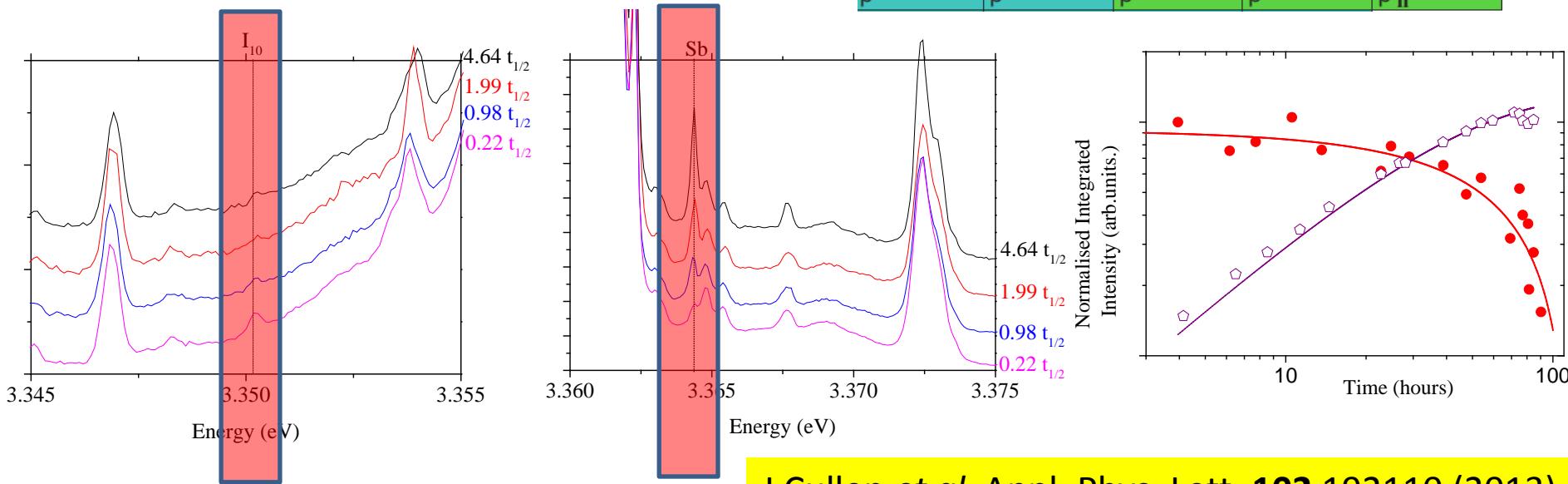
- X Not quantitative
- X Low concentrations may be more optically efficient
- X Lack of chemical information (except for some rare cases where isotope shifts are observed)

Optical Spectroscopy of Semiconductors: ZnO

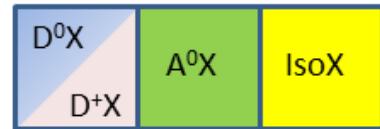




Sb121	Sb122 2.70 d	Sb123	Sb124 60.20 d	Sb125 2.7582 y
5/2+ * 57.36	2- * EC, β^-	7/2+ 42.64	3- * β^-	7/2+ * β^-
Sn120 0+ * 32.59	Sn121 27.06 h 3/2+ *	Sn122 0+ * 4.63	Sn123 129.2 d 11/2- *	Sn124 0+ * 5.79
β^-	β^-	β^-	β^-	β^-
In119 2.4 m 9/2+	In120 3.08 s 1+	In121 23.1 s 9/2+	In122 1.5 s 1+	In123 5.98 s 9/2+
* β^-	* β^-	* β^-	* β^-	* β^-
Cd118 50.3 m 0+	Cd119 2.69 m 3/2+ *	Cd120 50.80 s 0+	Cd121 13.5 s (3/2+) *	Cd122 5.24 s 0+
β^-	β^-	β^-	β^-	β^-
Ag117 72.8 s (1/2-) *	Ag118 3.76 s (1-) *	Ag119 2.1 s (7/2+) *	Ag120 1.23 s *	Ag121 0.78 s (7/2+) β^-n
β^-	β^-	β^-	β^-	β^-n



Radiotracer PL has allowed for the full classification of the dominant impurities in ZnO



Tentative D⁰X/A⁰X



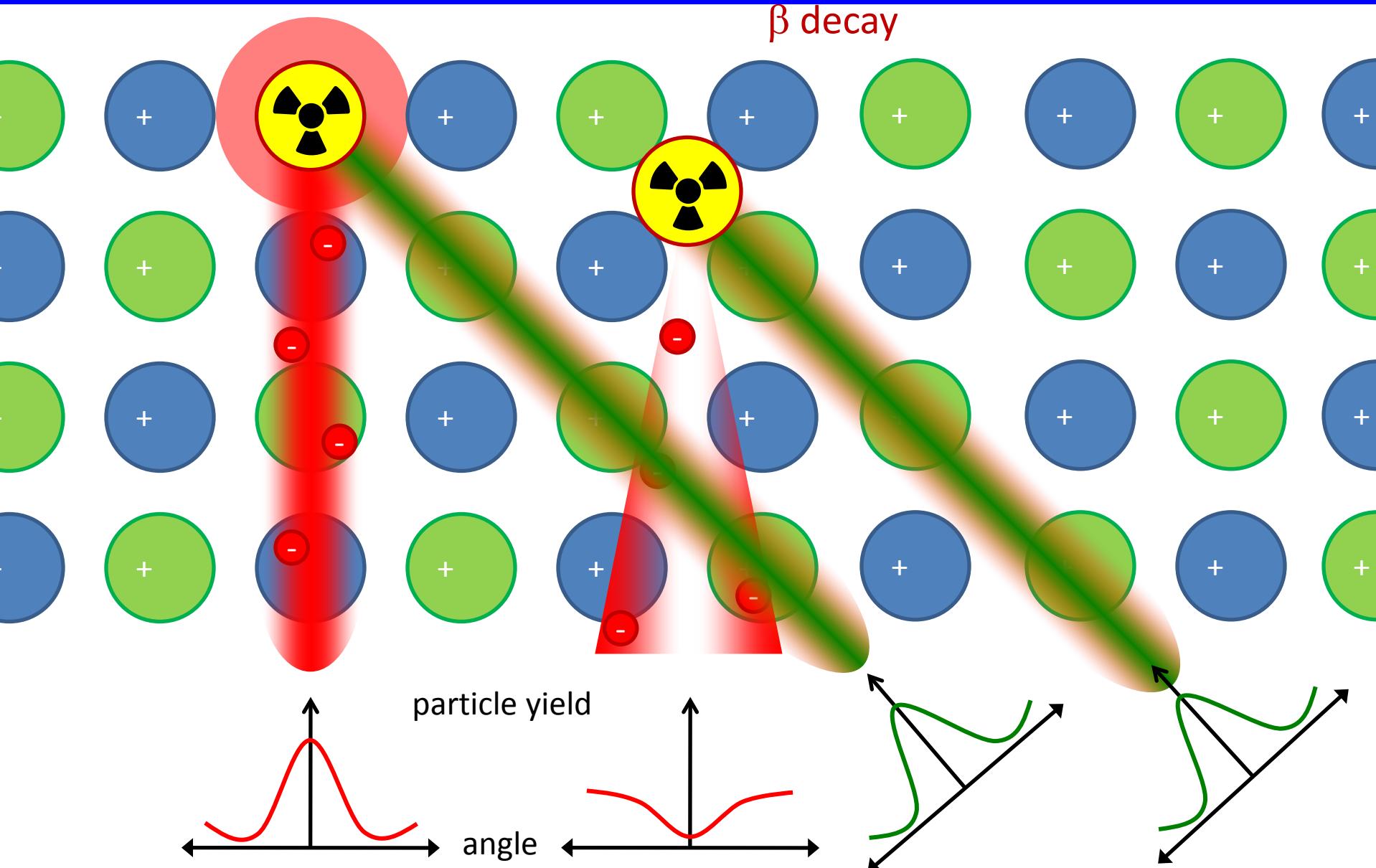
Defect complex?

	B	C	N
	I _{6a} Al I ₀ ?	Si	P
Cu	Zn I ₈ Ga I ₁	Ge	As X
Ag	Cd X I ₉ In I ₂ ?	Sn I ₁₀	Sb ✓
Au	Hg ✓	Tl	Pb Bi

- Radio PL allows for the subtle chemical identification of luminescence through different decay chains.
- Has allowed for the identification of neutral and ionised donors [1, 2], complexed impurities [3], “double donor” centres [2, 4], and isoelectronic centres [5].

1. K. Johnston *et al* Phys Rev B **73** 165212 (2006).
2. K. Johnston *et al* Phys Rev B **83** 125205 (2011).
3. J Cullen *et al* Appl. Phys. Lett. **102** 192110 (2013)
4. J. Cullen et al Phys Rev B **87** 165202 (2013)
5. J. Cullen et al J. Appl Phys (2013)

Emission Channeling of decay particles, on single crystals $(\beta^-$, β^+ , c.e., α)...lattice location of impurities in crystals



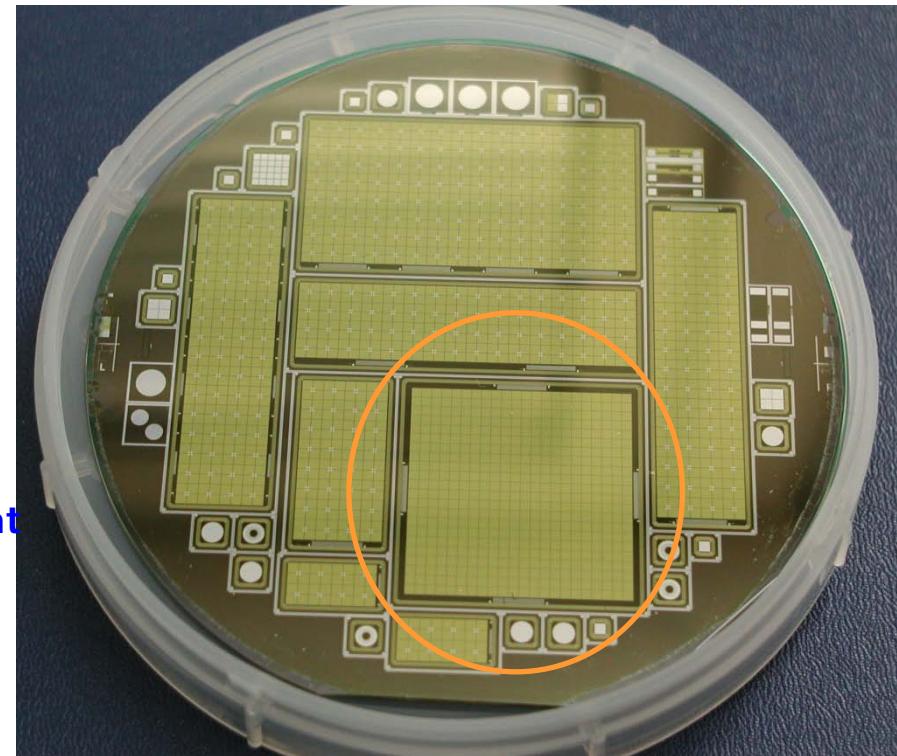
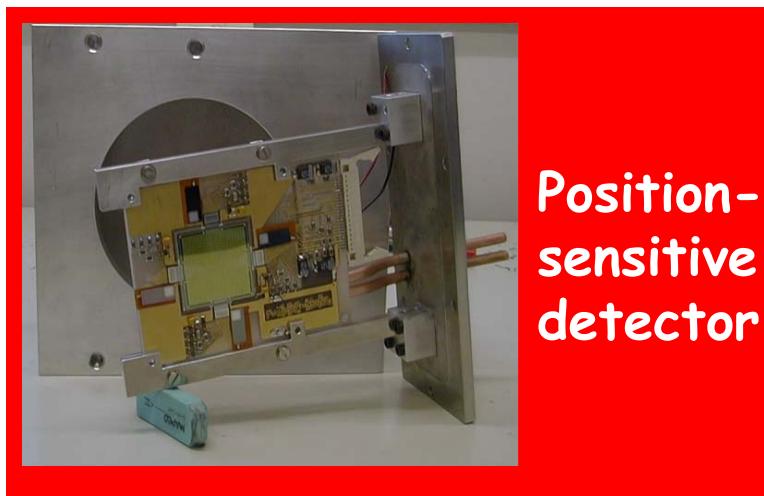
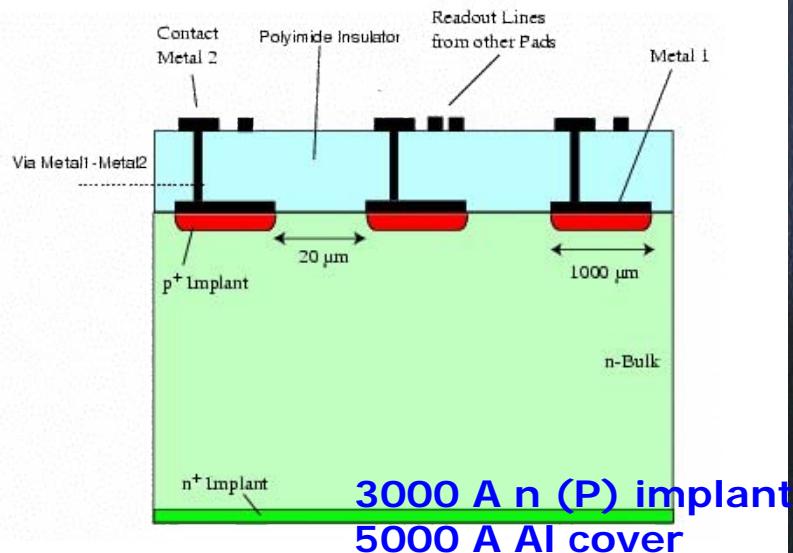
What do you need to do Emission Channeling

Si PAD electron detectors

5 μ m kapton

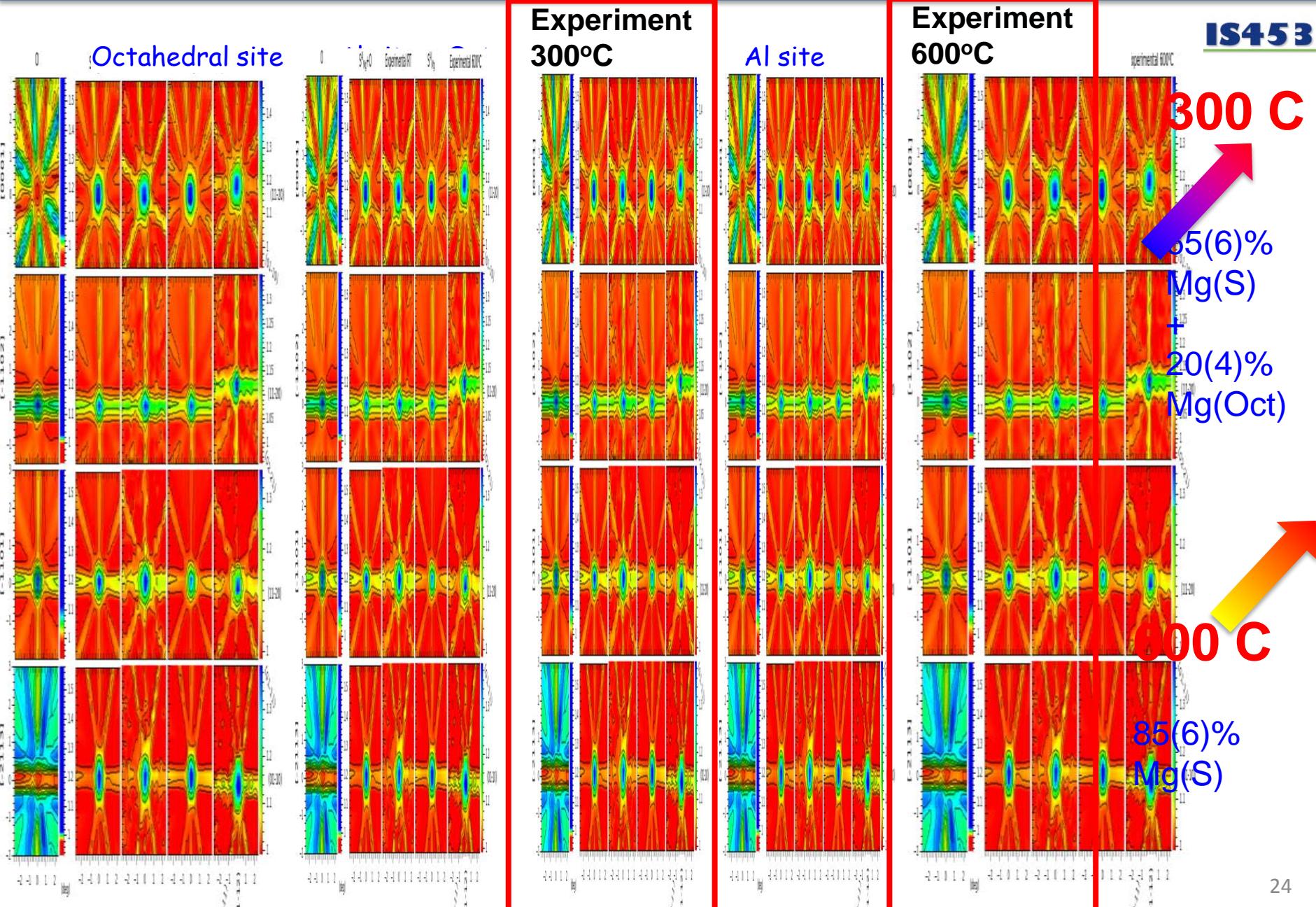
2 μ m SiO₂

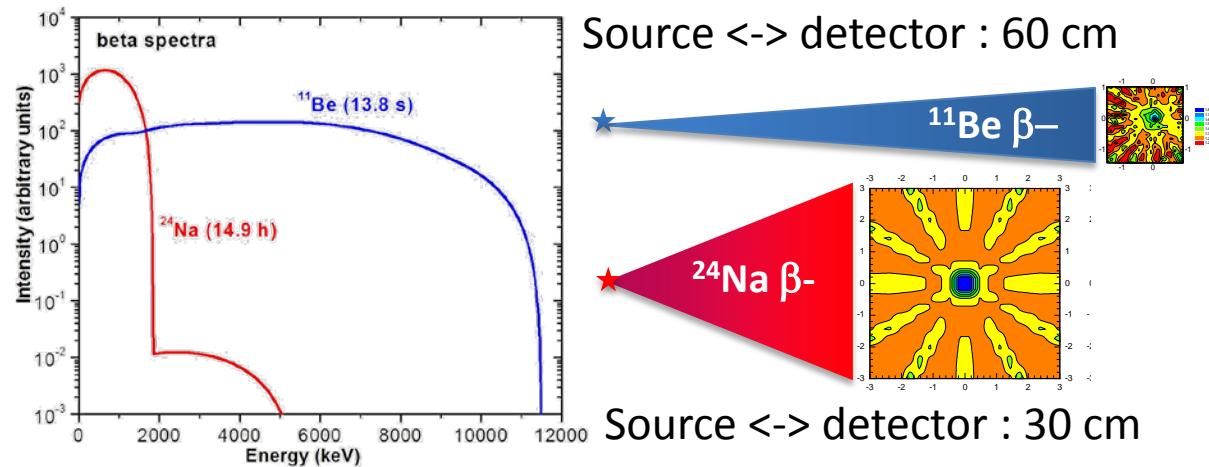
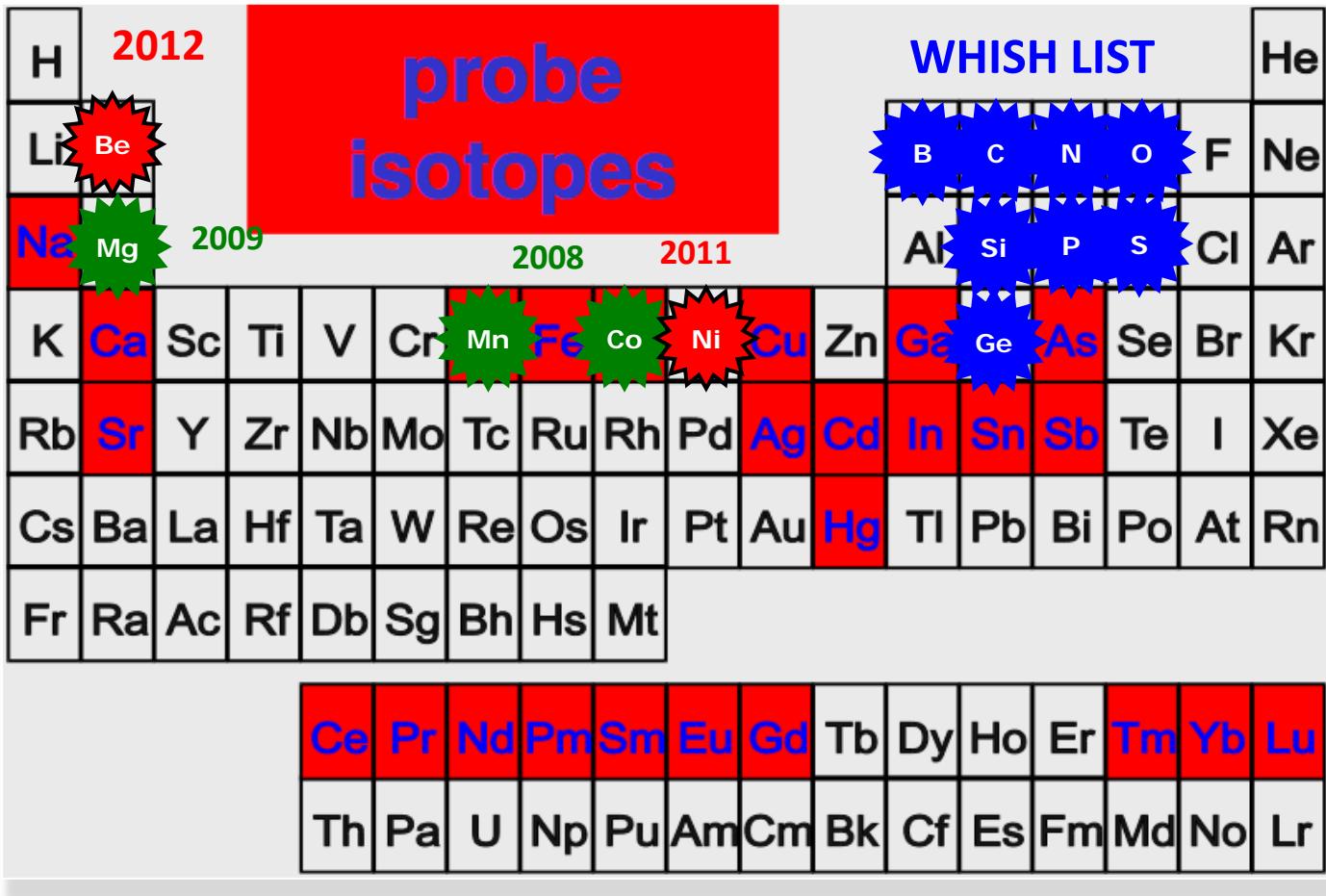
0.3mm p (B) implant



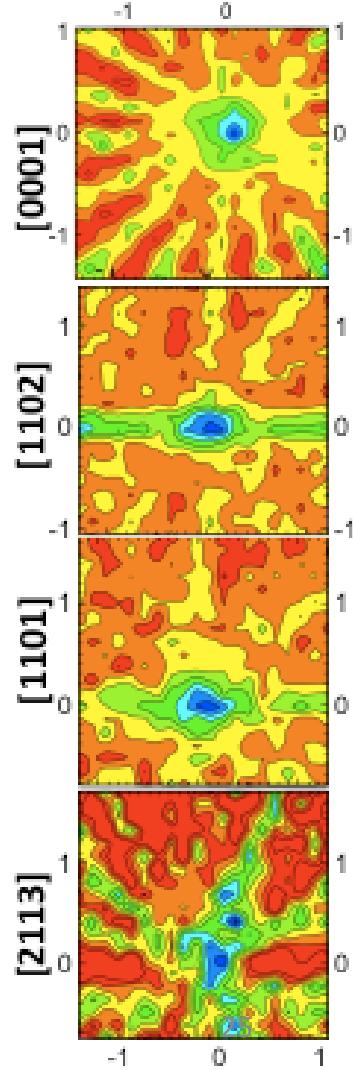
Good energy resolution ~3 keV
Large pad – 1.4x1.4 mm²
Dead / unbonded channels
Leakage current limiting depletion
 $15\text{keV} \ll E(e^-) \ll 300\text{ keV}$
Readout → 200Hz ... 5 kHz

Lattice location study of implanted ^{27}Mg (13min) : AlN





IS453
first ever done β^-
EC patterns
using $^{11}\text{Be}(14\text{ s})$
in GaN



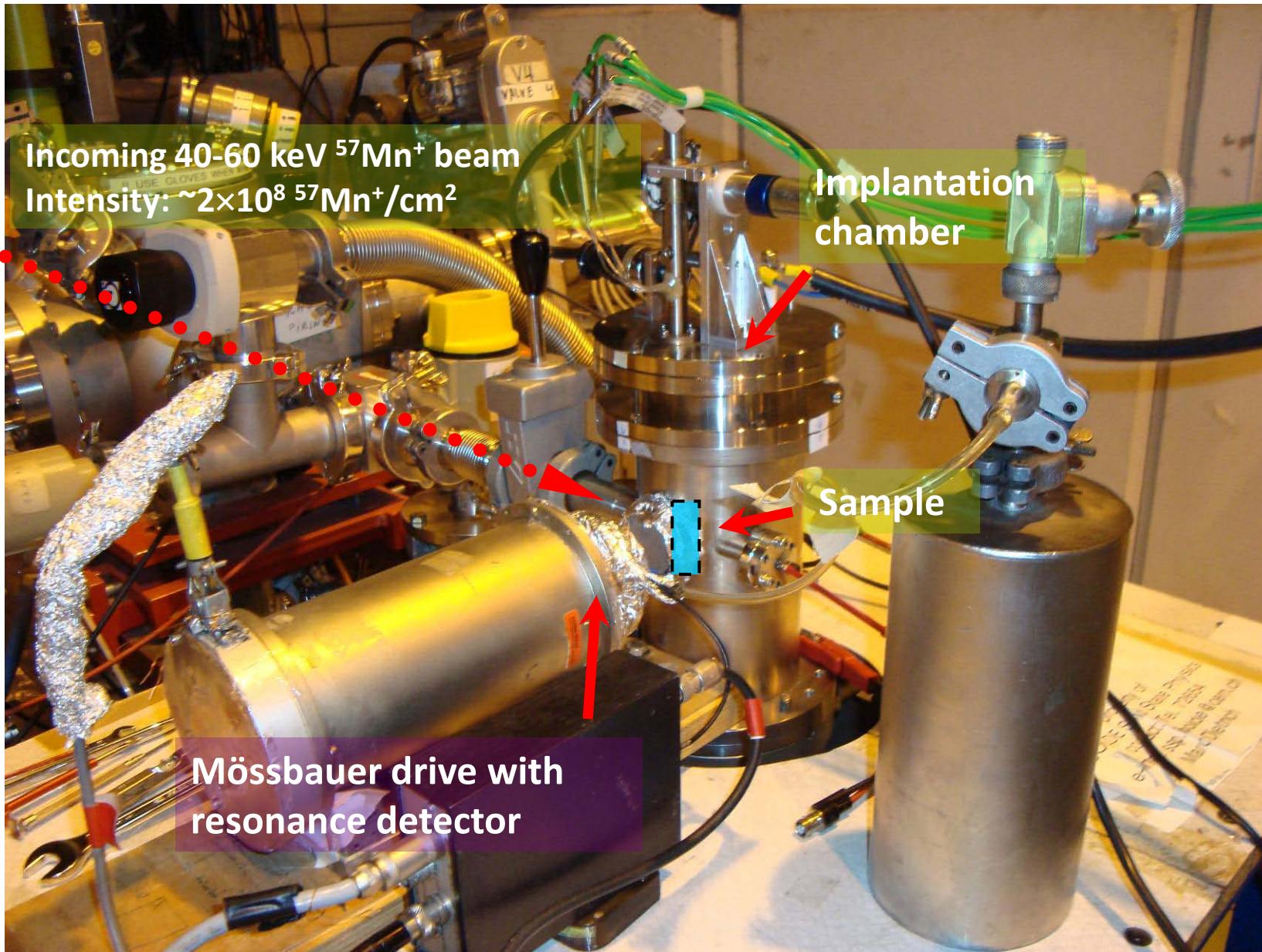
....and good for publicity

The screenshot shows the official CERN website. The header includes the CERN logo, navigation links for "About CERN", "Students & Educators", "Scientists", and "CERN people", and language options "English" and "Français". A central feature is a large, abstract graphic composed of concentric, multi-colored rings (blue, green, yellow, orange, red) set against a background of wavy, organic shapes in the same color palette. Below this graphic, a news item is displayed: "MAGNESIUM IMPURITIES IN A CRYSTAL LATTICE OF GALLIUM NITRIDE ISOLDE, 1 Sep 2009, 14.29". A brief description follows: "Intensity of beta particles emitted by radioactive Mg-27 nuclei reveal the position of the Mg impurity inside a GaN crystal". To the right, a white sidebar titled "CERN updates" lists recent news items:

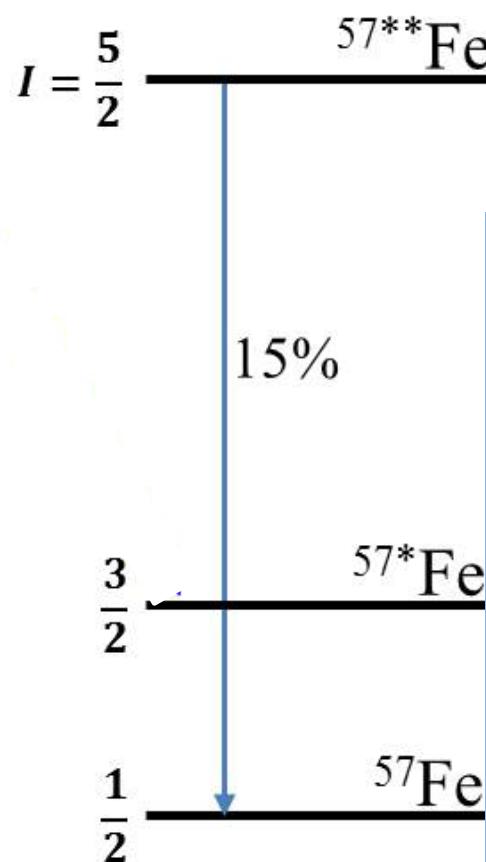
- Still making tracks: Eighty Years of the Positron
15 March
- New results indicate that new particle is a Higgs boson
14 March
- ATLAS releases animated particle plots
12 March
- LHCb studies particle tipping the matter-antimatter scales
12 March

A link "Past updates →" is also present. At the bottom right of the sidebar is a search bar with the placeholder "Search this site" and a blue "Search" button.

Hyperfine Interactions with Mossbauer spectroscopy



^{57}Co ($t_{1/2} = 271.74$ d)

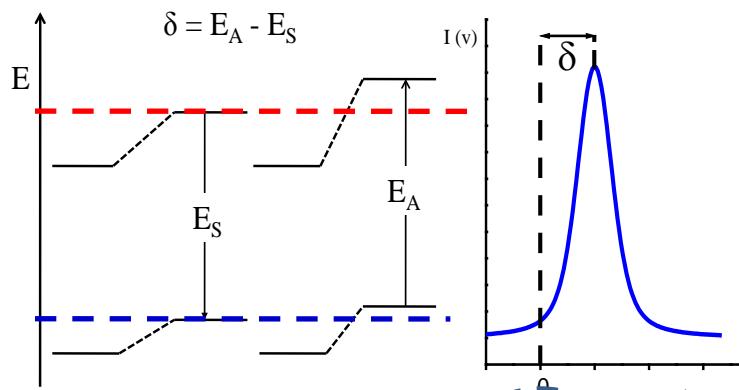
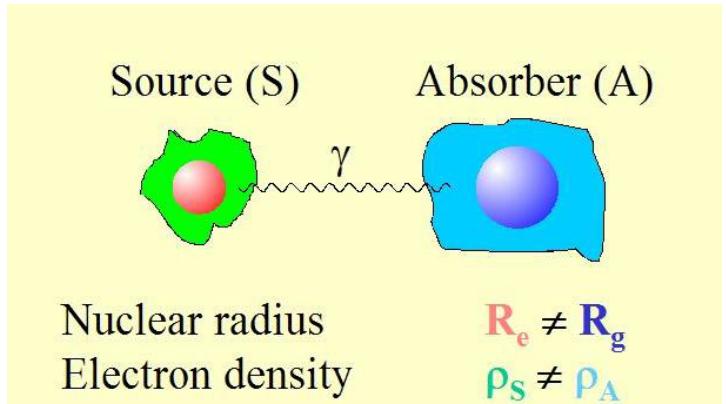


Laser ionised ^{57}Mn beam : a new era for Mossbauer experiments at ISOLDE.

- Very clean, intense beam of ^{57}Mn ($>3 \times 10^8$ 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 ($\sim 10^{-4}$ At%)

Local information....

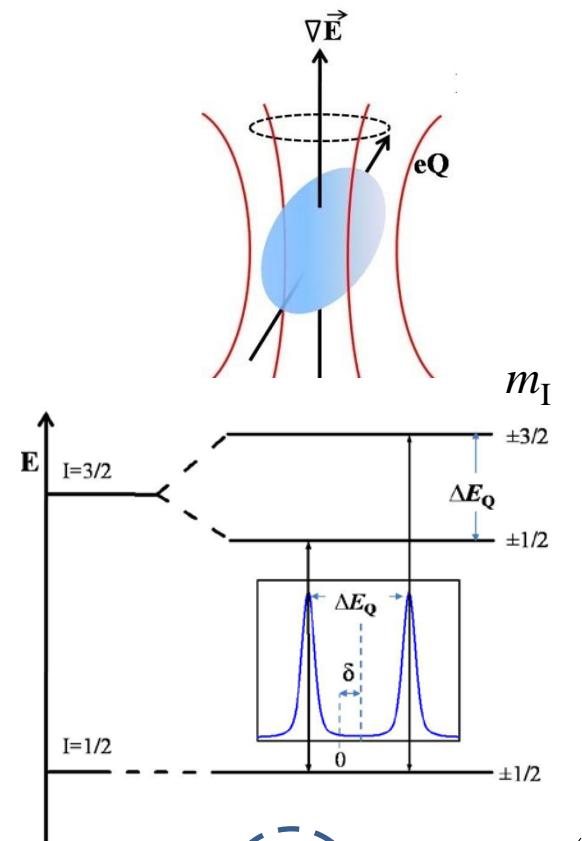
Isomer Shift



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

Chemical bonding
Charge states

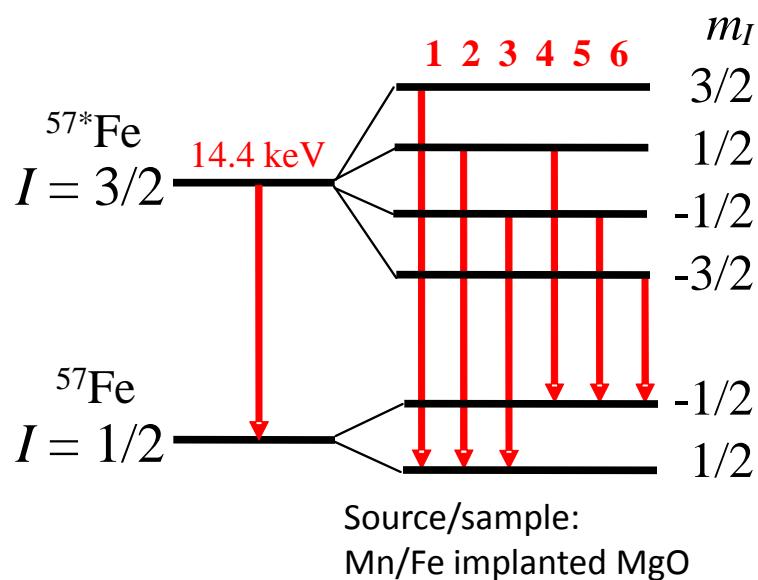
Quadrupole Splitting



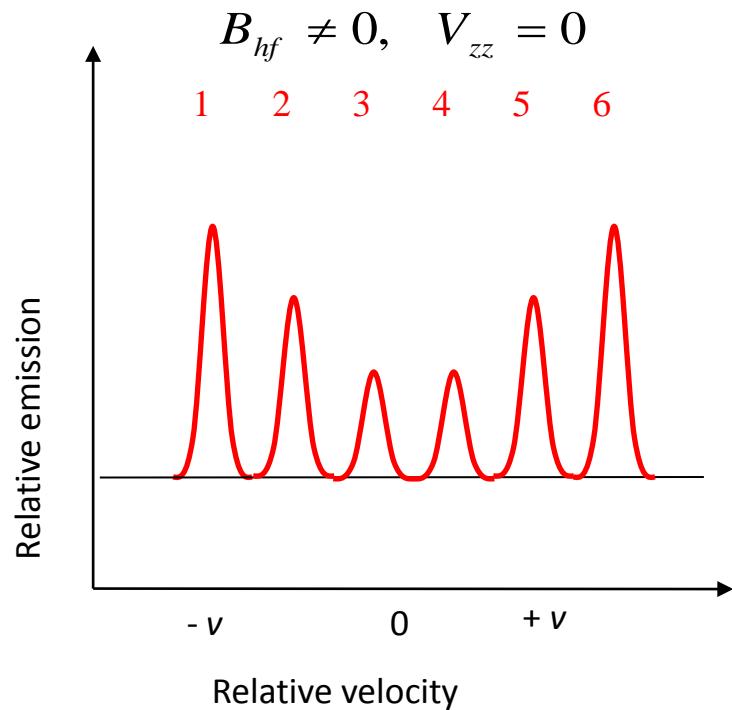
$$\Delta E_Q = \pm \frac{eQV_{ZZ}}{2} \left(1 + \frac{\eta^2}{3} \right)^{1/2}$$

Lattice asymmetry
Clustering of atoms

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



$$B_{\text{hf}} \propto |\psi_s^\downarrow|^2 - |\psi_s^\uparrow|^2$$



Motivation

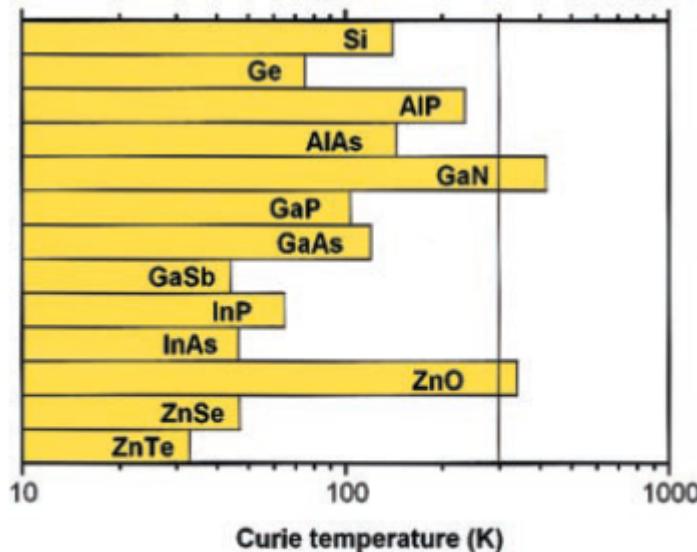


Fig. 3. Computed values of the Curie temperature T_c for various p-type semiconductors containing 5% of Mn and 3.5×10^{20} holes per cm^3 .

Dietl *et al*, *Science* 287 (2000) 1019

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.

Fe: ZnO a ferromagnetic semiconductor? (no!)

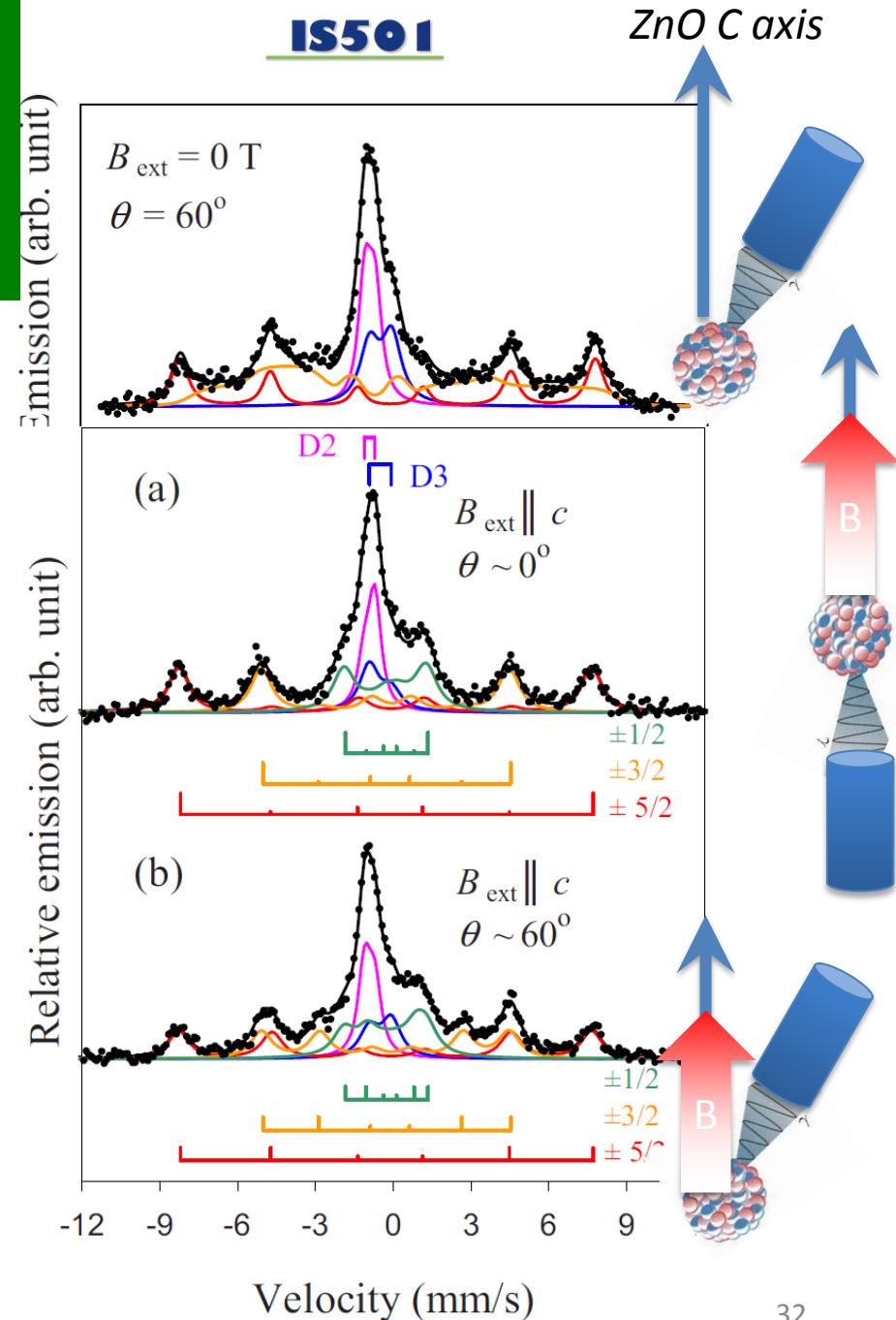
6 fold spectrum: characteristic of magnetic structure (at room temperature!!!).

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

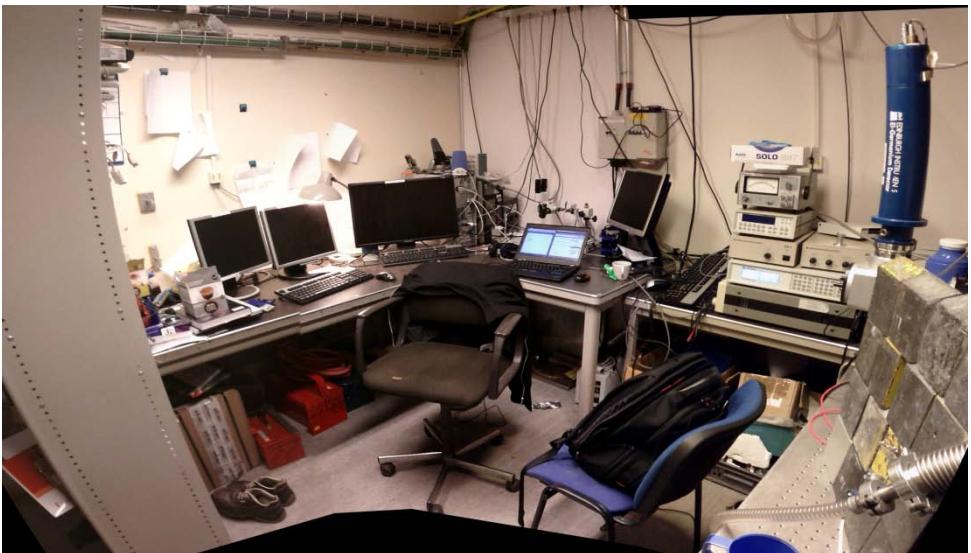
Gunnlaugsson *et al* (APL **97** 142501 2010)

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)



Also....Infrastructure



Time for a change...



New 120m² lab...completion ~ sometime ...2014













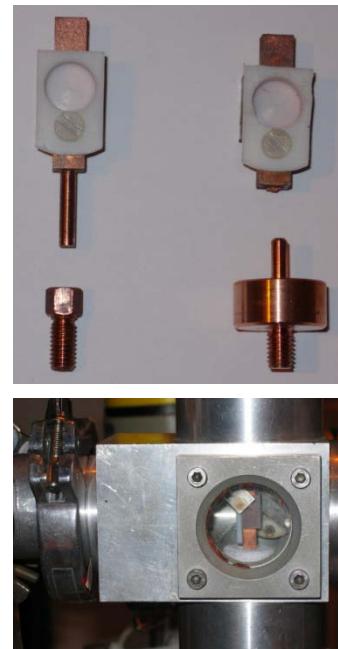


Biophysics at ISOLDE: Radioisotopes for Probing Biomolecular Functionality in Living Matter

PAC isotopes used for biophysics at ISOLDE:

parent	half-life	decay	isomer	half-life (ns)
 ⁶² Zn	9.186(13) h	EC/ β^+	⁶² Cu	4.57(18)
 ⁹⁹ Mo	65.94(1) h	β^-	⁹⁹ Tc	3.61(7)
 ^{111m} Cd	48.54(5) min	IT	¹¹¹ Cd	85.0(7)
 ¹¹¹ In	2.8049(1) days	EC	¹¹¹ Cd	85.0(7)
 ¹¹¹ Ag	7.45(1) days	β^-	¹¹¹ Cd	85.0(7)
¹³³ Ba	10.52(13) years	EC	¹³³ Cs	6.27(2)
 ¹⁶⁰ Tb	72.3(2) days	β^-	¹⁶⁰ Dy	2.02(1)
 ¹⁸¹ Hf	42.39(6) days	β^-	¹⁸¹ Ta	10.8(1)
 ^{199m} Hg	42.6(2) min	IT	¹⁹⁹ Hg	2.45(2)
 ^{204m} Pb	67.2(3) min	IT	²⁰⁴ Pb	265(10)
isotopes that have only been used for the sum-p				
¹⁴⁷ Nd	10.98(1) days	β^-	¹⁴⁷ Pm	2.50(5)
¹⁵² Eu	13.542(10) years	EC	¹⁵² Sm	1.428(7)

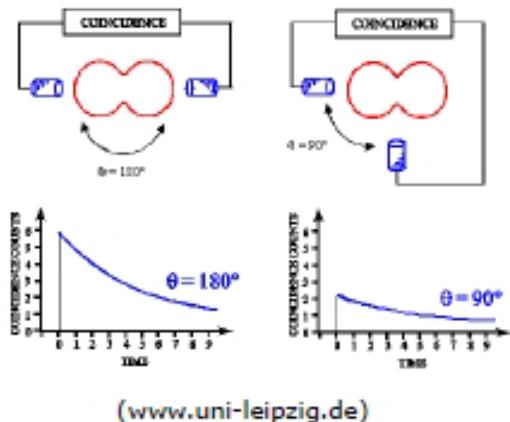
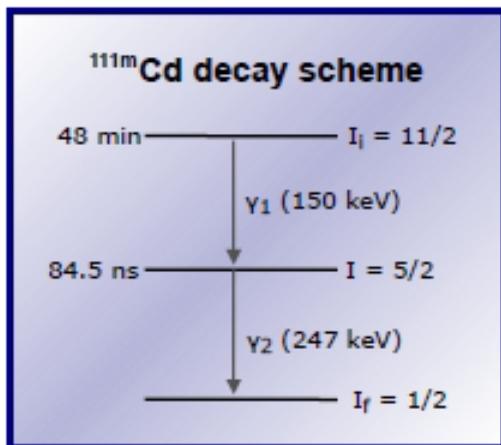
Hemmingsen et al. *Chem. Rev.*, 2004, 104: 4027



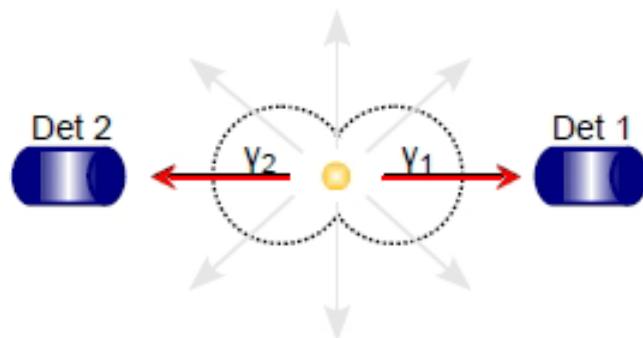
Suitable isotopes exist for probing toxicology in bio-systems: Pb, Cd and Hg

No implantations: collect activity in ice → chemistry

PAC Spectroscopy

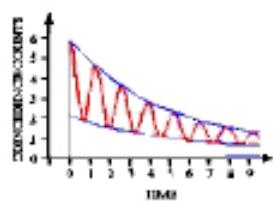
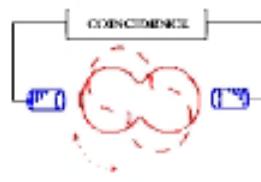
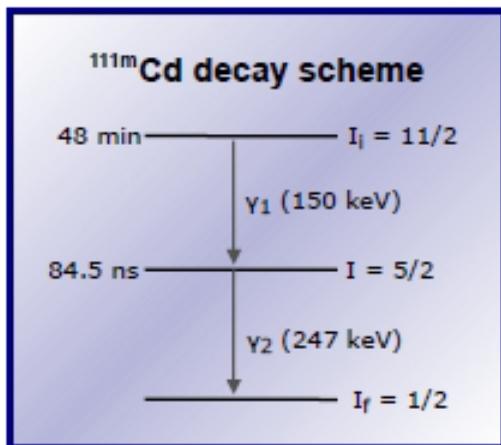


Angular correlation of γ -rays



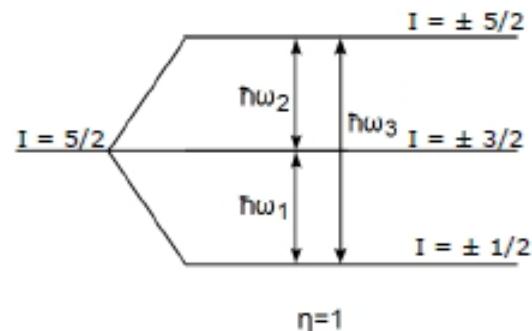
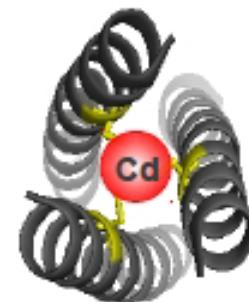
- Angular correlation of γ -rays is a property of the nuclear decay
- The distance from the center to the curve gives the probability of emission of γ_2 in that direction
- Coincidence count rate depends on the angle between detectors

PAC Spectroscopy



(www.uni-leipzig.de)

Perturbed angular correlation of γ -rays:
the influence of extra-nuclear fields



HFI causes precession of the nuclear spin
↓
Rotation of the angular correlation
↓
Information about ω_1 , ω_2 and ω_3
(the finger print of the local charge distribution)

Metal Ion Binding Site Structure: Fast inter-conversion between species

B

111^mCd-PAC

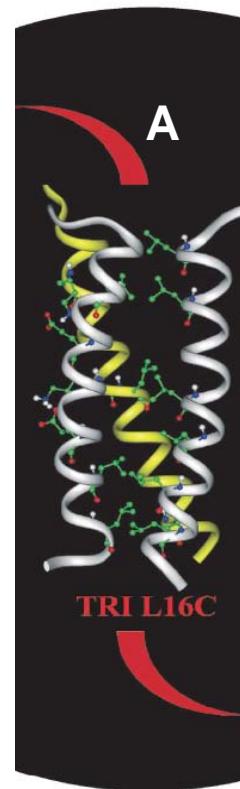
C

B

113Cd-NMR

C

Chemical shift / ppm



Matzapetakis *et al.* J. Am. Chem. Soc. **2002**, 124: 8042; Lee *et al.* Angew. Chem., **2006**, 45: 2864; Peacock *et al.* Proc. Nat. Acad. Sci. **2008**, 105: 16566

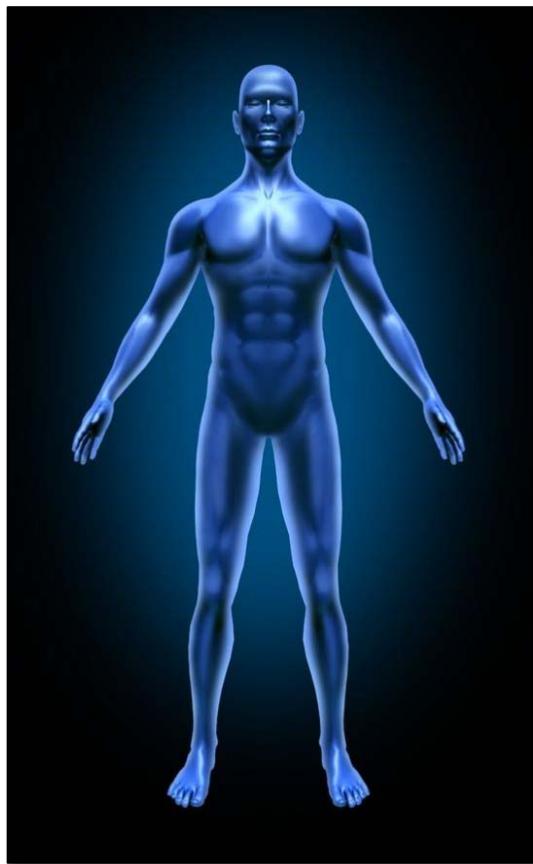
Elements in Human Body



Human body:

- $6.7 \cdot 10^{27}$ atoms
- 99% 4 major elements:
O (43kg), C (16kg), H (7kg), N (1.8kg)
- 1% 21 other elements:
(Ca:1kg, Mg:19g, Fe:3-5g, Zn:3g,
Cu: 300mg)

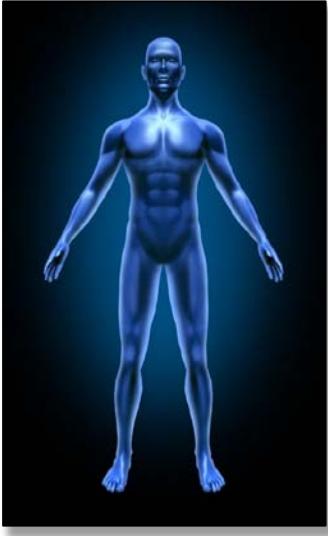
Elements in Human Body



1A	H 1.00794	2A	He 4.002602
3 Li 6.941	4 Be 9.012182		
11 Na 22.989769	12 Mg 24.3050		
19 K 39.09893	20 Ca 40.078	21 Sc 44.955912	22 Ti 47.867
			V 50.9415
			24 Cr 51.9961
			25 Mn 54.938045
			26 Fe 55.845
			27 Co 58.935195
			28 Ni 58.6934
			29 Cu 63.546
			30 Zn 65.38
			31 Ga 69.725
			32 Ge 72.64
			33 As 74.92160
			34 Se 78.956
			35 Br 79.904
			36 Kr 83.798
37 Rb 85.4678	38 Sr 87.62	39 Y 88.90585	40 Zr 91.224
			41 Nb 92.90638
			42 Mo 95.96
			43 Tc [98]
			44 Ru 101.07
			45 Rh 102.0550
			46 Pd 106.42
			47 Ag 107.8692
			48 Cd 112.4111
			49 In 114.818
			50 Sn 118.710
			51 Sb 121.760
			52 Te 127.60
			53 I 120.90447
			54 Xe 131.293
55 Cs 132.9054519	56 Ba 137.327	57-71 Lanthanides	72 Hf 178.49
			73 Ta 180.94788
			74 W 183.84
			75 Re 186.207
			76 Os 190.23
			77 Ir 192.217
			78 Pt 195.084
			79 Au 196.966569
			80 Hg 200.59
			81 Tl 204.3833
			82 Pb 207.2
			83 Bi 208.98040
			84 Po [209]
			85 At [210]
			86 Rn [222]
87 Fr [223]	88 Ra [226]	89-103 Actinides	104 Rf [267]
			105 Db [268]
			106 Sg [271]
			107 Bh [272]
			108 Hs [270]
			109 Mt [278]
			110 Ds [281]
			111 Rg [280]
			112 Cn [285]
			113 Uut [284]
			114 Uuo [289]
			115 Uup [288]
			116 Uuh [293]
			117 Uus [294]
			118 Uuo [294]
Lanthanides			
57 La 138.90547	58 Ce 140.116	59 Pr 140.90765	60 Nd 144.242
			61 Pm [145]
			62 Sm 150.36
			63 Eu 151.984
			64 Gd 157.25
			65 Tb 158.92535
			66 Dy 162.500
			67 Ho 164.93032
			68 Er 167.259
			69 Tm 168.93421
			70 Yb 173.054
			71 Lu 174.9668
Actinides			
89 Ac [227]	90 Th 232.03806	91 Pa 231.03588	92 U 238.02891
		93 Np [237]	94 Pu [244]
			95 Am [243]
			96 Cm [247]
			97 Bk [247]
			98 Cf [251]
			99 Es [252]
			100 Fm [257]
			101 Md [258]
			102 No [259]
			103 Lr [262]

Natural elements

Elements in Human Body

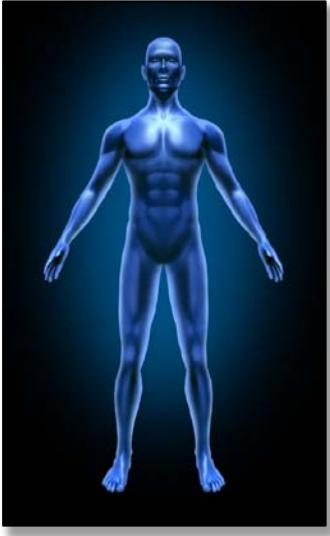


1A	H 1.00794													2A												
3 Li 6.941	4 Be 9.012162																									
11 Na 22.989769	12 Mg 24.3050																									
19 K 39.0983	20 Ca 40.078	21 Sc 44.955912	22 Ti 47.867	23 V 50.95845	24 Cr 51.9961	25 Mn 54.938045	26 Fe 55.845	27 Co 56.938195	28 Ni 58.9354	29 Cu 63.946	30 Zn 65.406	31 Ga 69.723	32 Ge 72.64	33 As 74.92160	34 Se 74.96	35 Br 79.904	36 Kr 83.798									
37 Rb 85.4678	38 Sr 87.62	39 Y 88.90585	40 Zr 91.224	41 Nb 92.90638	42 Mo 95.96	43 Tc [98]	44 Ru 101.07	45 Rh 102.90550	46 Pd 106.42	47 Ag 107.8692	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.90447	54 Xe 131.293									
55 Cs 132.9054510	56 Ba 137.327	57-71 Hf Lanthanides 178.49	72 Ta 180.94785	73 W 183.84	74 Re 188.207	75 Os 190.23	76 Ir 192.217	77 Pt 195.084	78 Au 196.96659	79 Hg 200.59	80 Tl 204.3833	81 Pb 207.2	82 Bi 208.96040	83 Po [209]	84 At [210]	85 Rn [222]										
87 Fr [223]	88 Ra [226]	89-103 Rf Actinides [267]	104 Db [268]	105 Sg [271]	106 Bh [272]	107 Hs [270]	108 Mt [278]	109 Ds [281]	110 Rg [280]	111 Cn [285]	112 Uut [284]	113 Uup [288]	114 Uuh [293]	115 Uus [294]	116 Uuo [294]	117 Uus [294]	118 Uuo [294]									
Lanthanides		57 La 138.90547	58 Ce 140.116	59 Pr 140.96765	60 Nd 144.242	61 Pm [145]	62 Sm 150.38	63 Eu 151.964	64 Gd 157.25	65 Tb 158.92535	66 Dy 162.500	67 Ho 164.93032	68 Er 167.259	69 Tm 169.93421	70 Yb 173.054	71 Lu 174.9668										
		89 Ac [227]	90 Th 232.03806	91 Pa 231.03560	92 U 239.02891	93 Np [237]	94 Pu [244]	95 Cm [243]	96 Cm [247]	97 Bk [247]	98 Cf [251]	99 Es [252]	100 Fm [257]	101 Md [258]	102 No [259]	103 Lr [262]										

Natural elements

Ions accessible in established techniques

Elements in Human Body



Mg²⁺																	
1A H [1s1]	2A Li [2s1]	3B Sc [2s1 2p2]	4B Ti [2s1 2p1 3s2]	5B V [2s1 2p1 3d1 4s2]	6B Cr [2s1 2p1 3d5 4s1]	7B Mn [2s1 2p1 3d5 4s2 4p6]	8B Fe [2s1 2p1 3d6 4s2]	9B Co [2s1 2p1 3d7 4s2]	10B Ni [2s1 2p1 3d8 4s2]	11B Cu [2s1 2p1 3d10 4s1]	12B Zn [2s1 2p1 3d10 4s2]	13B Ga [2s1 2p1 3d10 4s2 4p1]	14B Ge [2s1 2p1 3d10 4s2 4p2]	15B As [2s1 2p1 3d10 4s2 4p3]	16B Se [2s1 2p1 3d10 4s2 4p4]	17B Br [2s1 2p1 3d10 4s2 4p5]	18B Kr [2s1 2p1 3d10 4s2 4p6]
37 Rb [95.4678] 87.62	38 Sr [88.90565] 87.62	39 Y [91.224]	40 Zr [92.90630]	41 Nb [93.90]	42 Mo [95.96]	43 Tc [96.07]	44 Ru [96.90550]	45 Rh [96.42]	46 Pd [97.6992]	47 Ag [98.411]	48 Cd [98.618]	49 In [98.730]	50 Sn [98.730]	51 Sb [98.730]	52 Te [98.730]	53 I [131.293]	54 Xe [131.293]
55 Cs [132.904515] 157.327	56 Ba [132.904515]	57-71 Lanthanides [178.49]	72 Hf [180.94769]	73 Ta [183.84]	74 W [186.207]	75 Re [190.25]	76 Os [192.217]	77 Ir [195.084]	78 Pt [196.99569]	79 Au [199.59]	80 Hg [204.3833]	81 Tl [207.2]	82 Pb [209.9940]	83 Bi [209.9940]	84 Po [210.0]	85 At [222]	86 Rn [222]
87 Fr [223]	88 Ra [226]	89-103 Actinides [267]	104 Rf [269]	105 Db [271]	106 Sg [272]	107 Bh [276]	108 Hs [281]	109 Mt [286]	110 Ds [289]	111 Rg [291]	112 Cn [295]	113 Uut [294]	114 Uuq [298]	115 Uup [298]	116 Uuh [293]	117 Uus [294]	118 Uuo [294]
Lanthanides		57 La [130.90547]	58 Ce [140.116]	59 Pr [140.97075]	60 Nd [144.242]	61 Pm [145]	62 Sm [150.38]	63 Eu [151.964]	64 Gd [157.25]	65 Tb [168.9255]	66 Dy [162.500]	67 Ho [164.93032]	68 Er [167.259]	69 Tm [169.93421]	70 Yb [173.954]	71 Lu [174.9556]	
Actinides		89 Ac [227]	90 Th [232.03809]	91 Pa [231.05595]	92 U [238.02901]	93 Np [237]	94 Pu [244]	95 Am [243]	96 Cm [247]	97 Bk [247]	98 Cf [251]	99 Es [252]	100 Fm [251]	101 Md [259]	102 No [259]	103 Lr [262]	

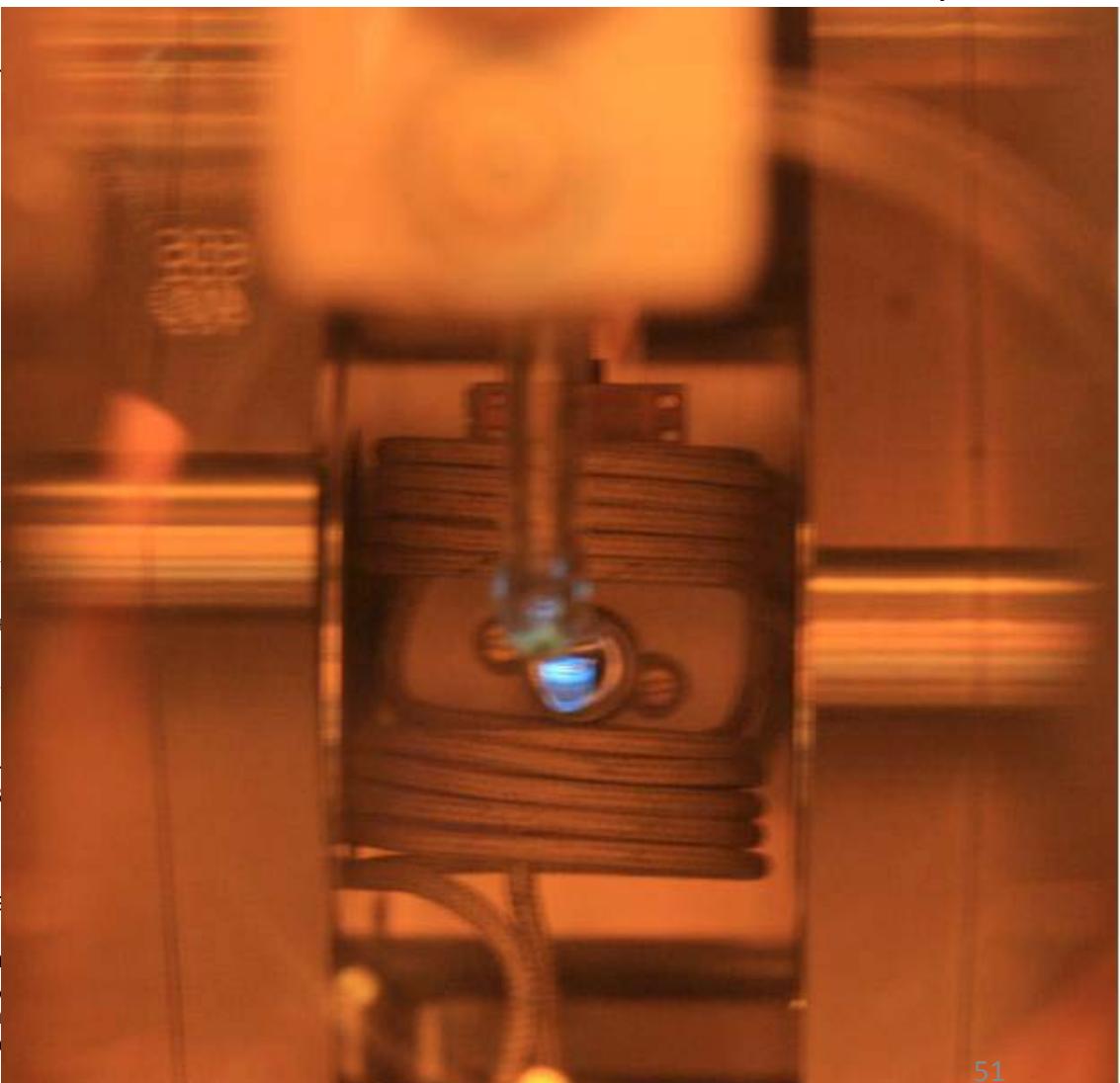
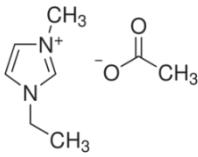
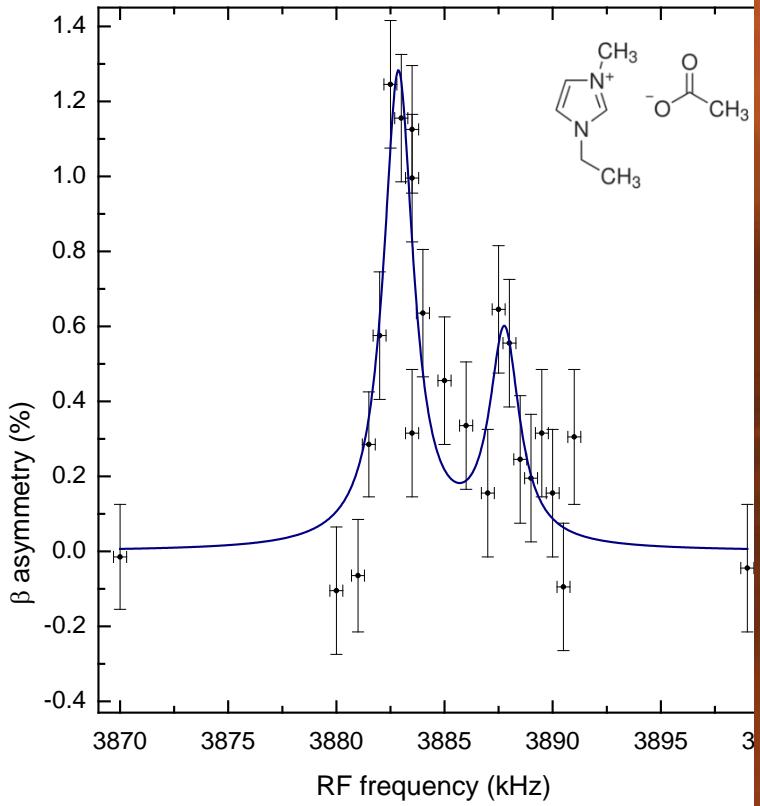
Mg(II), Cu(I), Zn(II)

- Most abundant ions in human body
 - Closed shell ions → silent in most spectroscopic techniques

2012 – first (and successful) $^{31}\text{Mg}^+$ β -NMR experiment applied to soft condensed matter

$^{31}\text{Mg}^+$ implanted into an ionic liquid (EMIM-Ac):

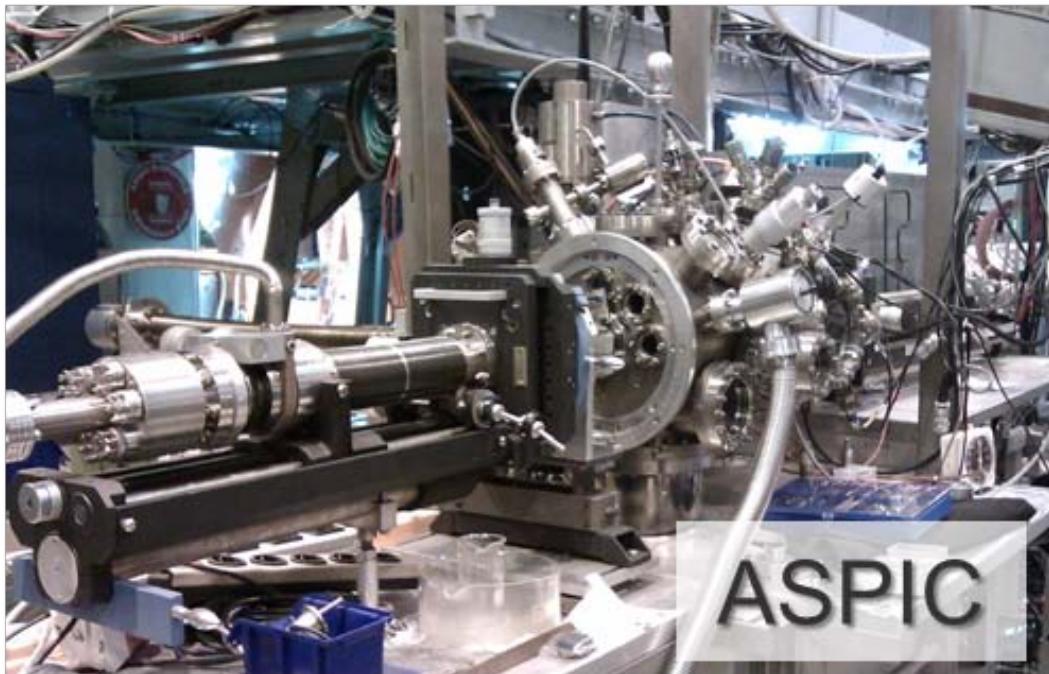
Differential pumping and drop
Mounted @ COLLAPS experiment



Monika Stachura, University of Copenhagen; Magdalena Kowalewska, CERN, Geneva; Alexander Gottberg, CSIC, Madrid; Klaus Blaum, Max Planck Institute for Nuclear Physics, Heidelberg; Gerda Neyen, Leuven University, (Leuven); Rainer Neugart, Mainz University (Mainz); Deyan Yordanov, Max Planck Institute for Nuclear Physics, Heidelberg; Mark Bissell, Leuven University, (Leuven); Kim Krämer, Max Planck Institute for Nuclear Physics, Heidelberg

The VITO project

(Versatile Ion-polarized Techniques Online)



Cern.ch/vito

ASPIC → ViTO Upgrade

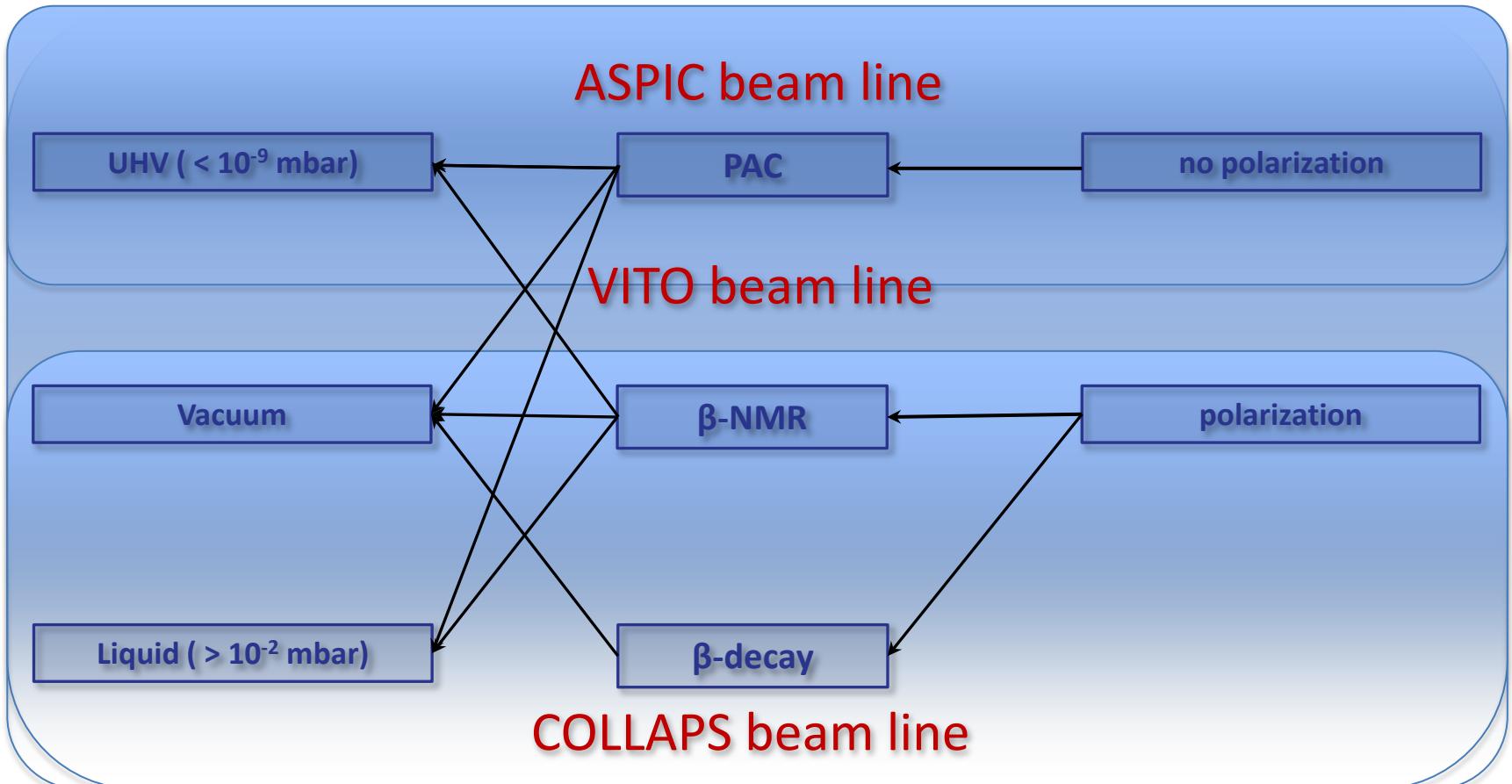
ASPIC



ViTO



Physics at ViTO



Radioisotopes for targeted alpha therapy

Radio-nuclide	Half-life (h)	Advantage	Problem
Tb-149	4.12	Known (bio)chemistry	Availability
Pb-212	10.6	Availability (recycled from U-fuel ^{228}Th)	Release of daughter?
Bi-212	1.01	Known (bio)chemistry Availability	Short half-life
Bi-213	0.76	Known (bio)chemistry	Short half-life Availability
At-211	7.22	Half-life	Challenging (bio)chemistry
Ra-223	274	Half-life Availability	Only for bone metastases (similar chemistry to Ca)
Ac-225	240	Half-life Known (bio)chemistry	Release of daughters? Availability

Terbium: a unique element for nuclear medicine

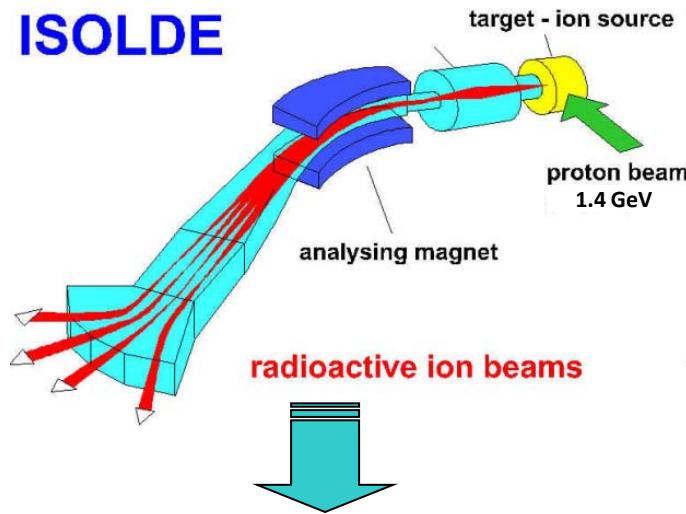


Dy 150 7.2 m $\epsilon: \beta^+$ $\alpha: 4.23$ $\gamma: 397$	Dy 151 17 m $\epsilon: \alpha 4.07$ $\gamma: 386; 49;$ $548; 176...$ $\sigma: 1.1$	Dy 152 2.4 h $\epsilon: \beta^+$ $\alpha: 3.63$ $\gamma: 257$	Dy 153 6.29 h $\epsilon: \beta^+$ $\alpha: 3.46$ $\gamma: 81; 214;$ $100; 264...$ $\sigma: 2.87$	Dy 154 $3.0 \cdot 10^6$ a $\epsilon: \beta^+$ $\alpha: 0.98$ $\gamma: 227...$ $\sigma: 0.33$	Dy 155 10.0 h $\epsilon: \beta^+$ $\alpha: 0.98; 1.1...$ $\gamma: 33$ $\sigma: < 0.0009$	Dy 156 0.056 $\epsilon: \beta^+$ $\alpha: 0.98; 1.1...$ $\gamma: 33$ $\sigma: < 0.0009$	Dy 157 8.1 h $\epsilon: \beta^+$ $\alpha: 0.98; 1.1...$ $\gamma: 326...$ $\sigma: < 0.0008$	Dy 158 0.095 $\epsilon: \beta^+$ $\alpha: 0.98; 1.1...$ $\gamma: 58; \sigma^-$ $\sigma: 8000$	Dy 159 144.4 d $\epsilon: \beta^+$ $\alpha: 0.98; 1.1...$ $\gamma: 58; \sigma^-$ $\sigma: 8000$	Dy 160 2.329 $\epsilon: \beta^+$ $\alpha: 0.98; 1.1...$ $\gamma: 600$ $\sigma: 600$	Dy 161 18.889 $\epsilon: \beta^+$ $\alpha: 0.98; 1.1...$ $\gamma: 120$ $\sigma: 120$	Dy 162 25.475 $\epsilon: \beta^+$ $\alpha: 0.98; 1.1...$ $\gamma: 120$ $\sigma: 120$
Tb 149 4.2 m $\epsilon: \beta^+$ $\alpha: 3.93$ $\gamma: 188$ $\sigma: 1.1$	Tb 150 5.8 m $\epsilon: \beta^+$ $\alpha: 3.87$ $\gamma: 188$ $\sigma: 1.1$	Tb 151 25 s $\epsilon: \beta^+$ $\alpha: 3.7$ $\gamma: 23$ $\sigma: 1.1$	Tb 152 17.6 h $\epsilon: \beta^+$ $\alpha: 3.41$ $\gamma: 100$ $\sigma: 1.1$	Tb 153 42 m 17.5 h $\epsilon: \beta^+$ $\alpha: 3.28$ $\gamma: 232$ $\sigma: 1.1$	Tb 154 2.34 d $\epsilon: \beta^+$ $\alpha: 3.07$ $\gamma: 232$ $\sigma: 1.1$	Tb 155 23 h 5.32 d $\epsilon: \beta^+$ $\alpha: 2.88$ $\gamma: 248$ $\sigma: 1.1$	Tb 156 5.32 d $\epsilon: \beta^+$ $\alpha: 2.71$ $\gamma: 248$ $\sigma: 1.1$	Tb 157 4 h? 99 a $\epsilon: \beta^+$ $\alpha: 2.54$ $\gamma: 87; 105;$ $\sigma: 1.1$	Tb 158 99 a $\epsilon: \beta^+$ $\alpha: 2.54$ $\gamma: 87; 105;$ $\sigma: 1.1$	Tb 159 100 $\epsilon: \beta^+$ $\alpha: 2.54$ $\gamma: 10.5$ $\sigma: 1.1$	Tb 160 72.3 d $\epsilon: \beta^+$ $\alpha: 0.6; 1.7...$ $\gamma: 879; 299;$ $966...$ $\sigma: 570$	Tb 161 6.90 d $\epsilon: \beta^+$ $\alpha: 0.6; 0.6...$ $\gamma: 26; 49; 75...$ $\sigma: 1.5$
Gd 148 74.6 a $\epsilon: \alpha 3.183$ $\sigma: 14000$	Gd 149 9.28 d $\epsilon: \alpha 3.016$ $\gamma: 150; 299;$ $347...$	Gd 150 $1.8 \cdot 10^8$ a $\epsilon: \alpha 2.60$ $\gamma: 154; 243;$ $175...$	Gd 151 120 d $\epsilon: \alpha 2.14$ $\gamma: 700$ $\sigma: \alpha < 0.007$	Gd 152 0.20 $\epsilon: 1.1 \cdot 10^{14}$ a $\sigma: 0.20$	Gd 153 239.47 d $\epsilon: \alpha 0.97$ $\gamma: 97; 103; 70...$ $\sigma: 20000$	Gd 154 2.18 $\epsilon: \alpha 0.97$ $\gamma: 97; 103; 70...$ $\sigma: 60$	Gd 155 14.80 $\epsilon: \alpha 0.97$ $\gamma: 97; 103; 70...$ $\sigma: 60$	Gd 156 20.47 $\epsilon: \alpha 0.97$ $\gamma: 97; 103; 70...$ $\sigma: 60$	Gd 157 15.65 $\epsilon: \alpha 0.97$ $\gamma: 97; 103; 70...$ $\sigma: 2.0$	Gd 158 24.84 $\epsilon: \alpha 0.97$ $\gamma: 97; 103; 70...$ $\sigma: 2.0$	Gd 159 18.48 h $\epsilon: \alpha 0.97$ $\gamma: 97; 103; 70...$ $\sigma: 2.3$	Gd 160 21.86 $\epsilon: \alpha 0.97$ $\gamma: 97; 103; 70...$ $\sigma: 1.5$

In practice (at the moment)

i. Collection at ISOLDE

ISOLDE

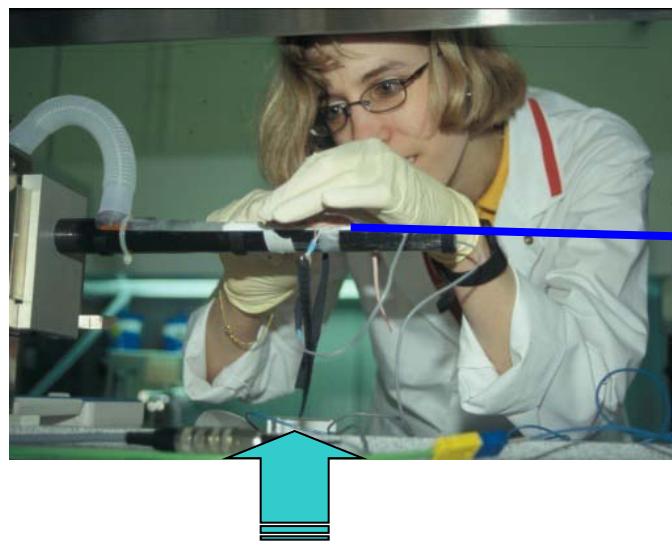


ii. Shipping to PSI

PSI



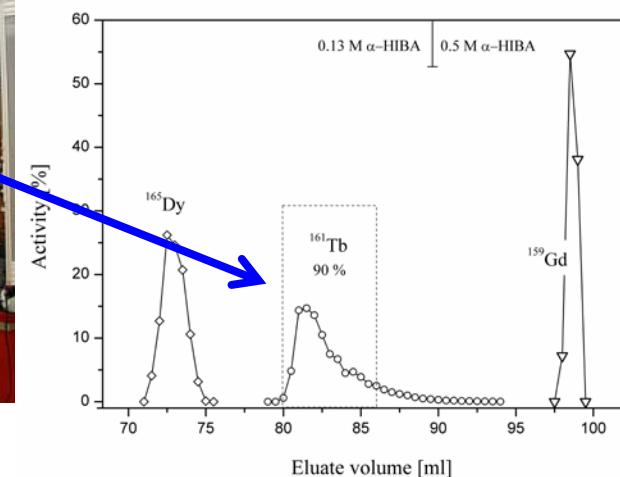
iv. Injection into mouse



v. PET/SPECT imaging and tumor treatment



iii. Radiochemical purification and labeling



Imaging Studies Using PET and SPECT

PET

A

SPECT

B

SPECT

C

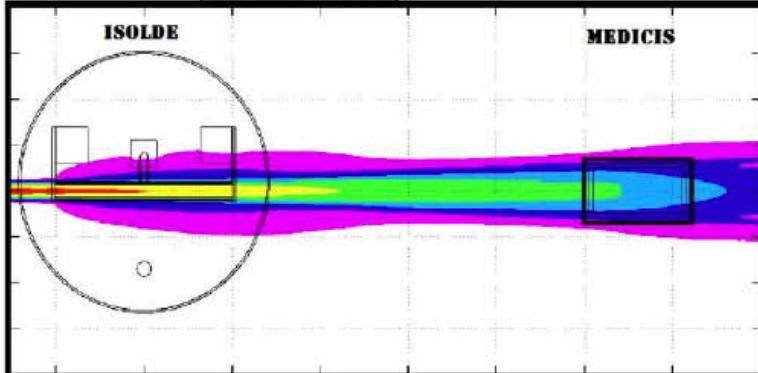
All very nice, but: how to have a more regular source of beam for these kinds of experiments? (once a year not enough)



C. Müller et al., J. Nucl. Med. 53 (2012) 1951

IS528 collaboration: supported by ENSAR, Swiss National Science Foundation and Swiss South African Joint Research Program.

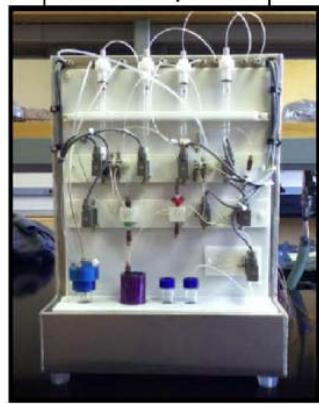
Irradiation



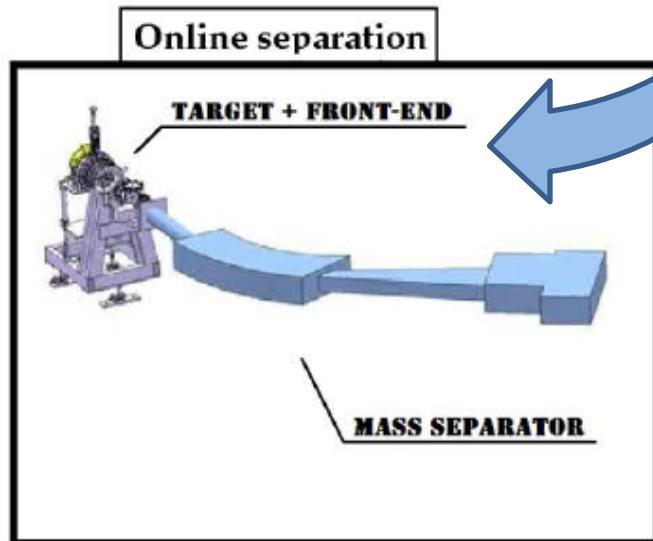
Preparation



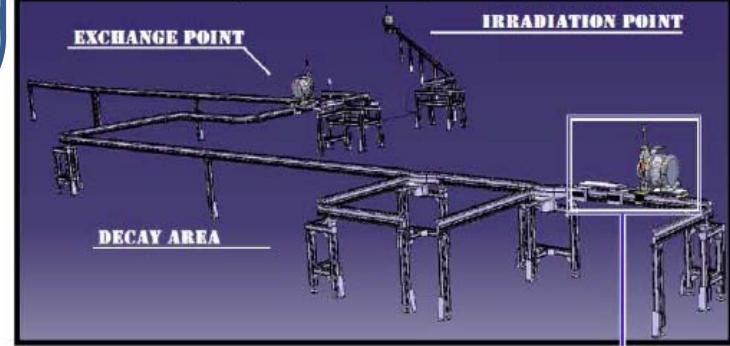
Chemical separation



Online separation



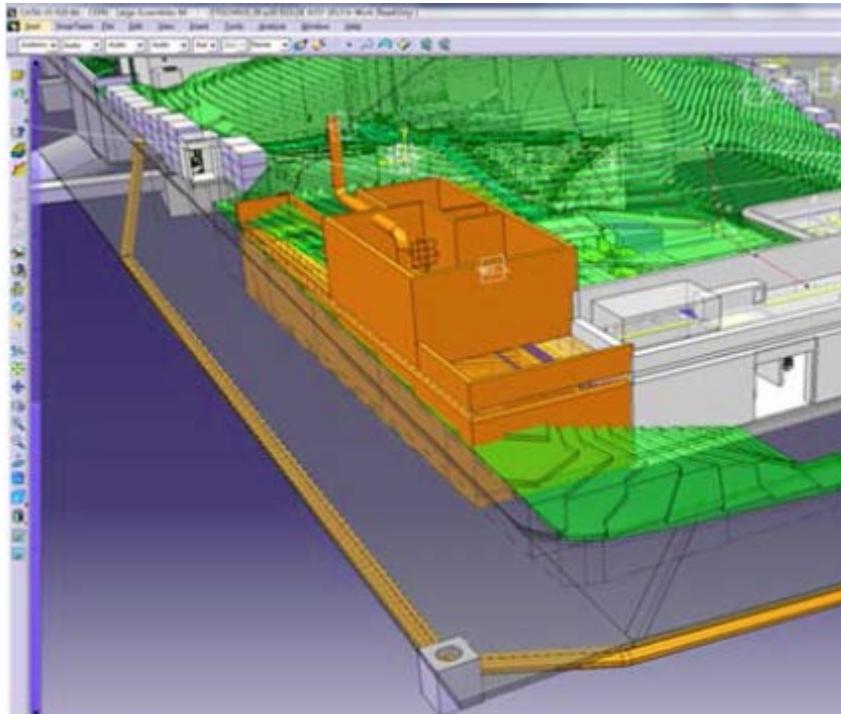
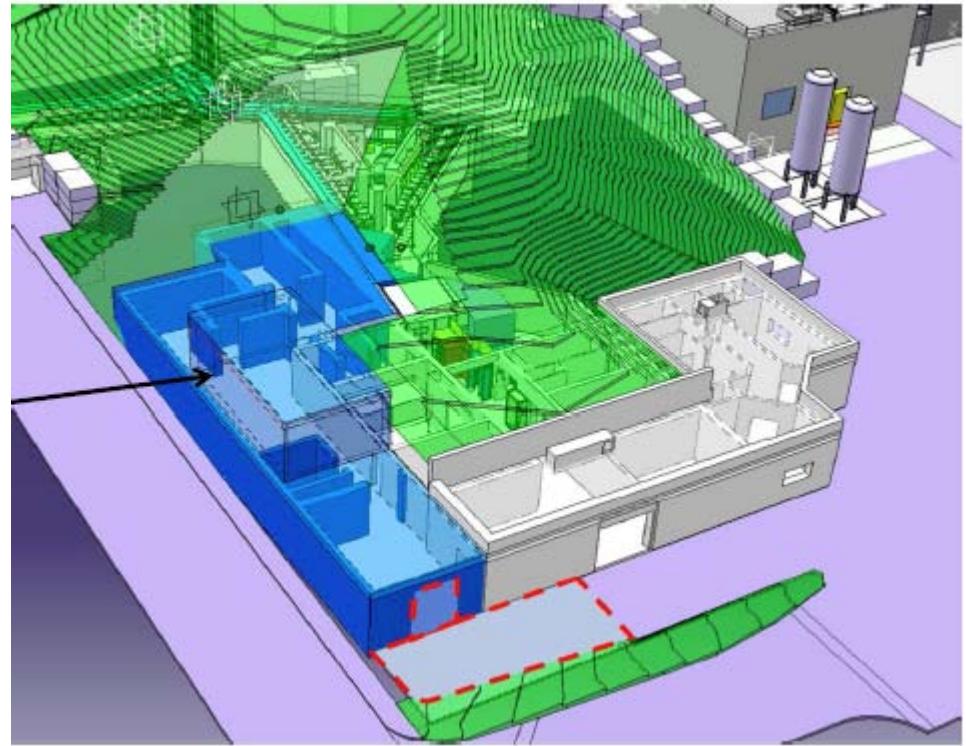
Transfer



Shuttle System

Ground breaking Sept 4th 2013









INNOVATIVE ISOTOPES

A new office for biomedical applications at CERN

Field of Application	Radiation	Chemical elements	Half lives
PET	β^+	Alkaline earth	10's min.
SPECT	γ	Halogen	Hours
TAT	α	Lanthanide	Days
Beta therapy	β^-	Transition metals	Months
Auger therapy	e^-	...	

Interview with Steve Myers

Oct

20

2013

Medical applications play an important role at CERN and recently the DG has decided to structure them under a common umbrella. Steve Myers, CERN's Director of Accelerators and Technology has been appointed as the first Head of CERN's Office for Medical Applications. We have decided to dedicate October's issue of the PH Newsletter to this interesting field and asked Steve Myers for an interview. Following his long-standing career on accelerators and his experience from LEP and the LHC, Steve discusses about his future ambitions and the challenges of his new role.



What do you think about your new role and what is your greatest ambition?

This is the first time that CERN has put (into its medium-term) a budget line for medical applications. It is a small budget line but can be the seed for important projects. Over the last years, many medical activities have been going on at CERN; however these efforts were not focused. There are several activities related to CERN's technologies including the design of specialized accelerators for cancer therapy, the conversion of the Low Energy Ion Ring (LEIR) into a biomedical facility, radio-isotope production using ISOLDE, medical imaging and applications to improve dosimetry for patients and finally large scale computing applications. The DG thought that the time had come to put these projects under one umbrella and asked me to be the coordinator.

I want to set a common goal and try to coordinate these

Summary

- **Unique** information – be it chemical or local – which is only achievable using radioactive implantations/probes.
- Ability to profit from the large range of beams available at ISOLDE (especially now with online *and* offline setups)....imagination (and sometimes money) the only limitation.
- Can go beyond the “standard” isotopes used ... e.g. ^{111}In , ^{57}Co .
- Many new developments underway e.g. β -NMR for biophysics and new dedicated offline labs.

Funding and Acknowledgements

- Manfred Deicher, Herbert Wolf, University of Saarlandes, Germany
- Guilherme Correia, Uli Wahl ITN, Lisbon, Portugal
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- Martin Henry, Dublin City university, Ireland
- **Monika Stachura**, CERN
- Peter Butler, University of Liverpool, UK
- Bruce Marsh, Sebastian Rothe, Valentin Fedesseov, CERN
- Palle Gunnlaugsson, University of Arhus, Denmark
- Thierry Stora, CERN
- Frank Wienholtz, CERN

Portuguese Foundation for Science and Technology



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Bundesministerium
für Bildung
und Forschung



Danish Agency for Science
Technology and Innovation
Ministry of Science
Technology and Innovation



Advantages and Limitations of PAC Spectroscopy for biophysics

Advantages:

- Characterisation of structure and dynamics at the PAC probe site (including rotational correlation times)
- High sensitivity to **structural changes**
- Small amount of PAC probe needed (in principle about **1 pmol**)
- **Different physical states** (crystals, surfaces, solutions, *in vivo*...)
- Mechanically stable, allowing for stirring, flow, ...

Limitations:

- Suitable PAC isotopes do not exist for all elements
- PAC isotope **must bind strongly** to the molecule of interest
- Spectral parameters do not uniquely determine structure
- After effects can cause problems (in particular for EC). (**¹¹¹In**)
- Production of PAC-isotopes