Perturbed Angular Correlations at ISOLDE: A 40 years young technique

Ipek Efe, Rahman Rano Summer students 2017

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ISOLDE Workshop and Users meeting 2017

UNIVERSITÄT DUISBURG ESSEN

CERN

“new-is-small”

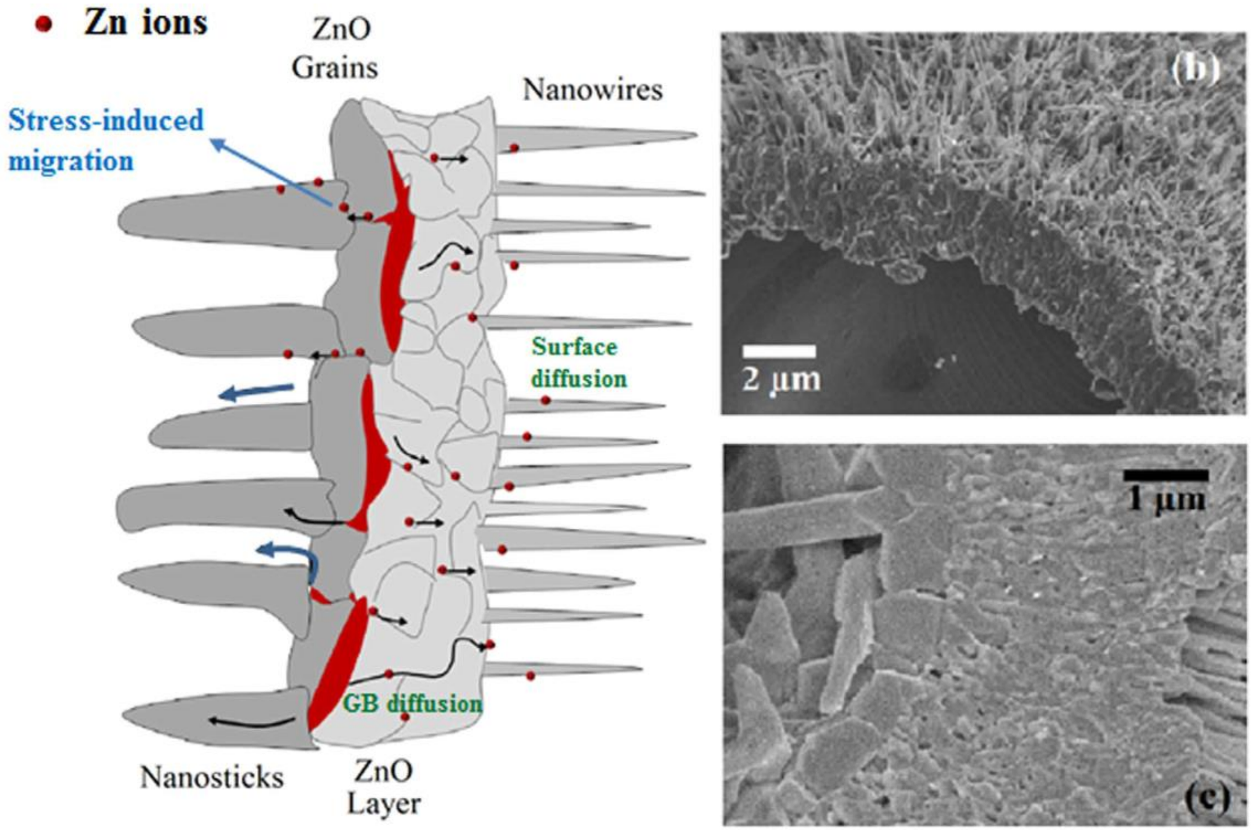
Source: https://www.computerhope.com/jargon/i/ibm5100.htm
Scientific America 1975

1975
First recognized portable computer
Released in September 1975 **IBM 5100**, weighed **55 pounds** and had a **five inch** CRT **display**

2017
Macbook air
“The Intel Core i5 and i7
…incredibly fast, whether you are editing photos or surfing the Web. The whole power is in a only **1.7 cm** thin unibody design, which weighs just **1.35 Kg**.”
Source: apple.com

Source: http://www.mobilegeeks.com
Macbook air fingers

How to make the "new" and the "small", understandable, applicable, and reliable?

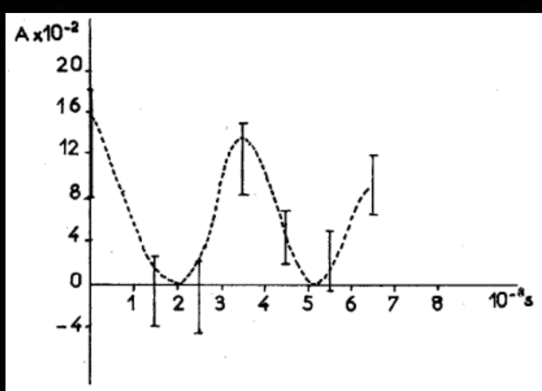


Source: DOi: 10.1038/srep15128 "This figure was drawn by the first author Cynthia M. Rivaldo-Gómez) Sketch of different regions observed in the ZnO microtubes illustrating the growth mechanism of the internal and external nanostructures of the microtubes. The metallic regions in red between layers are detected by PAC. (b) SEM image of a microtube in an intermediate stage showing a thin layer of Zn metal covering the inner surface. (c) Transversal section of ZnO microtube showing the presence of a chain of ZnO grains and a continuous ZnO layer."

Perturbed Angular Correlations "Childhood memories"

1955

P. Lehmann and J. Miller
Compt. Rend. Acad. Sc. 1955
vol. 240, pages 298 -299
„Interaction quadrupolaire dans ^{111}Cd"



1976
1977

ISOLDE Solid State Physics

H. Haas
The first TDPAC measurements at ISOLDE were carried out between 1976 and 1977.

1982

ISOLDE Solid State Physics

H. Haas
H. Haas, Proposal to ISOLDE on "Perturbed Angular Correlation Experiments" PSCC/82-11, PSCC/M99 IS30.

Possibilities

Trapping defects
Different valencies

Dynamic
Electronic properties

ASPIC
Versatile system to study surfaces and interfaces

Excitation
LASER

Temperature
from 10 to 1500 K

...and much more!
Flexible sample morphology

Fields
EFG and BHF
(also applied external)

Charge Symmetry
Lattice location

PAC: a method to probe hyperfine interaction in matter

Strengths

- Sample's morphology is very flexible: Solids, liquids, molecules...
- Efficiency is almost independent of temperature
- Its a differential time measurement ranging from ns to µs

Weaknesses

Needs radioactive nuclei with:

- suitable decay cascades, nuclear moments, half-lives
- *"complicated"* analyzing software
- interpretation is not direct

Opportunities

- Facilities like ISOLDE provide many "new" PAC probes
- Synchrotron radiation can make available more probe elements
- New DFT and Cluster models offer great progresses on interpretation
- New detection methods offer greater efficiency and handling of data (LaBr3 detectors, digital)
- **e-gamma, gamma-gamma and beta-gamma should be exploited TOGETHER providing new data and exciting new physics**

Threats

- Access to large scale facilities depends on appropriate funding
- Training and know-how (in applied nuclear physics) is vanishing from educational programs

How to insert isotopes?

Chemical lab
Collaboration ISOLDE, BMBF, FCT, COPENHAGEN, KU-Leuven
Sol Gel Method, Diffusion, Implantation on ice

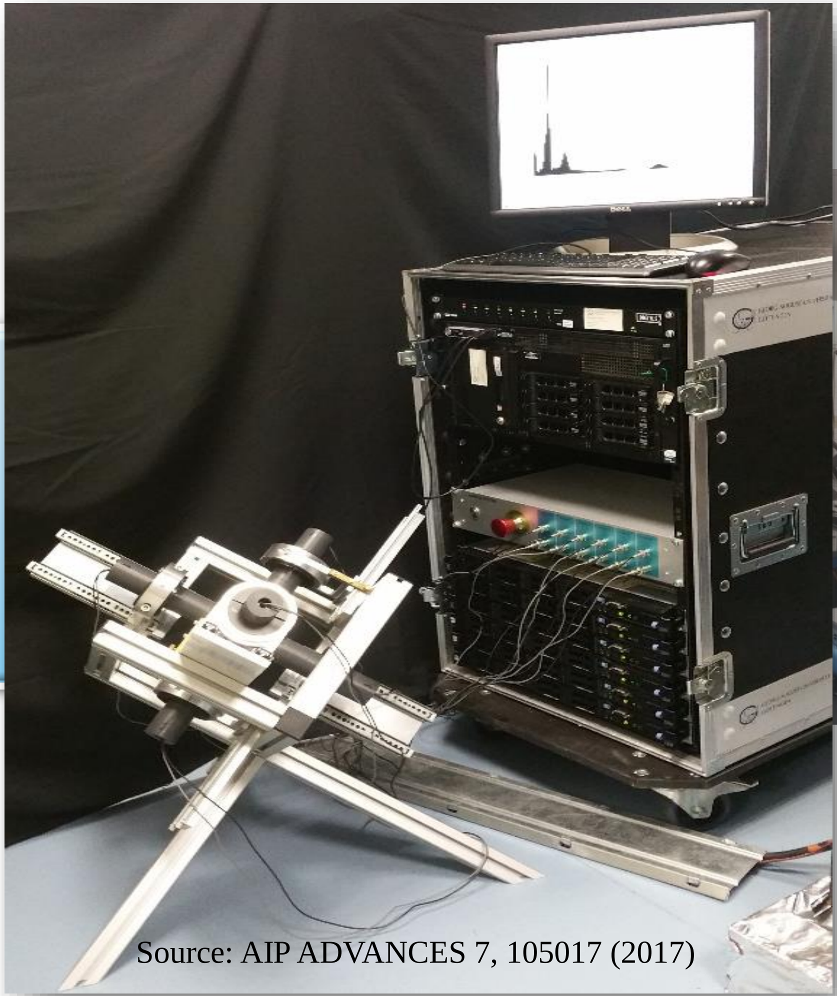
Evaporator
BMBF

How to recover implantation damage?

Annealing room
Collaboration ISOLDE, BMBF, FCT, KU-Leuven

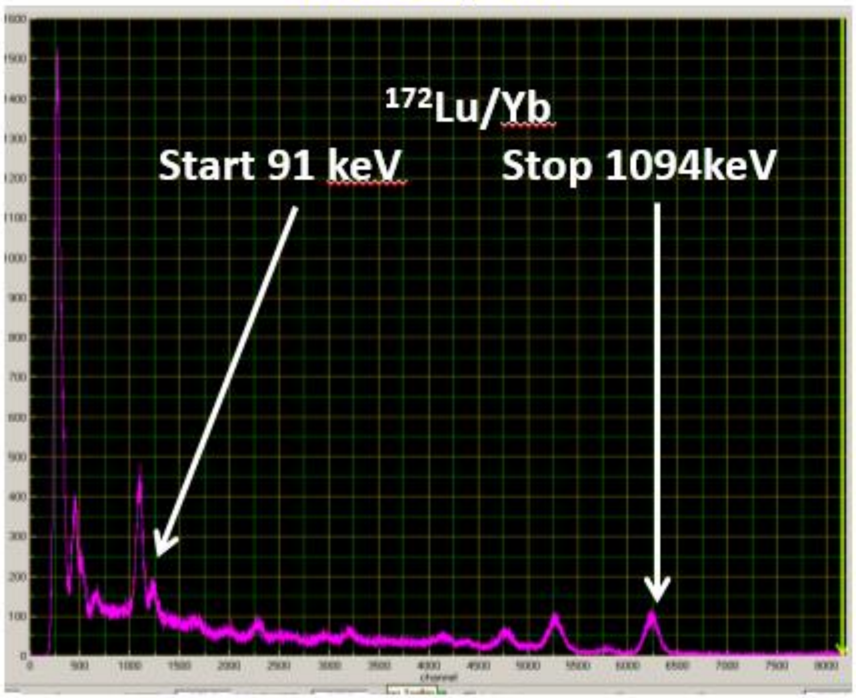
Equipment at ISOLDE

Digital PAC
Collaboration ISOLDE,

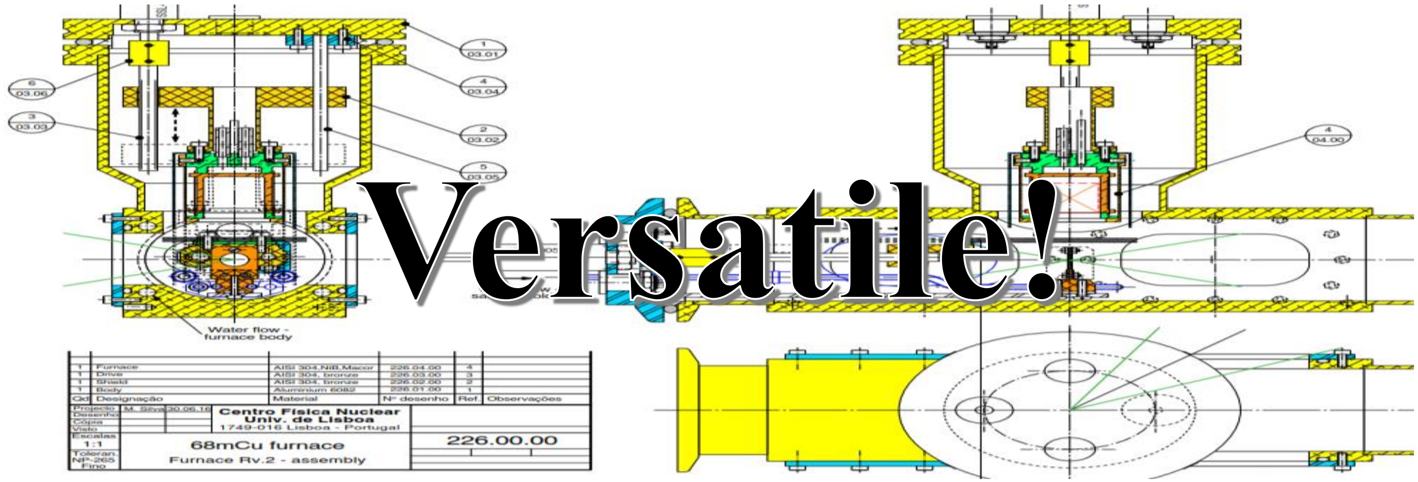


SSP infraestructure

$LaBr_3$: 3.2% versus BaF_2: 15.5%

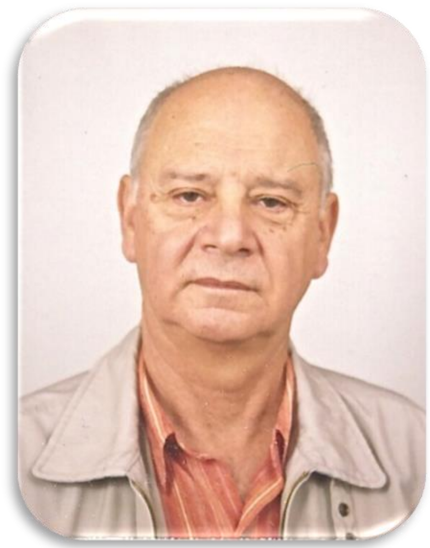


PAC-SLI... Short-lived isotopes!



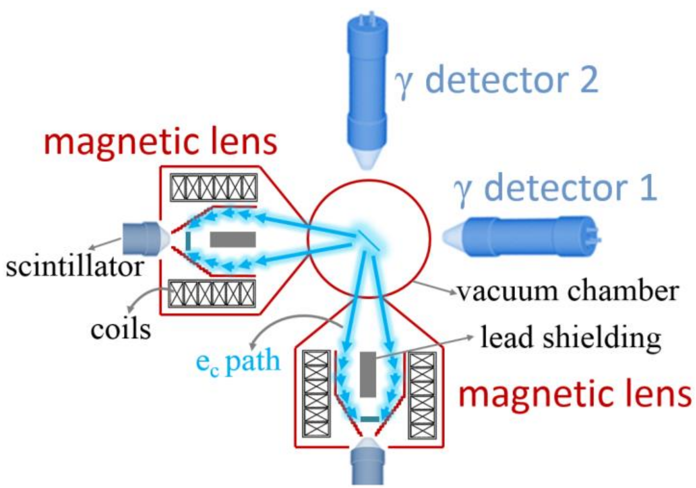
Perturbed Angular Correlations with Short-Lived Isotopes, the PAC-SLI setup

Dr. Manuel Silva

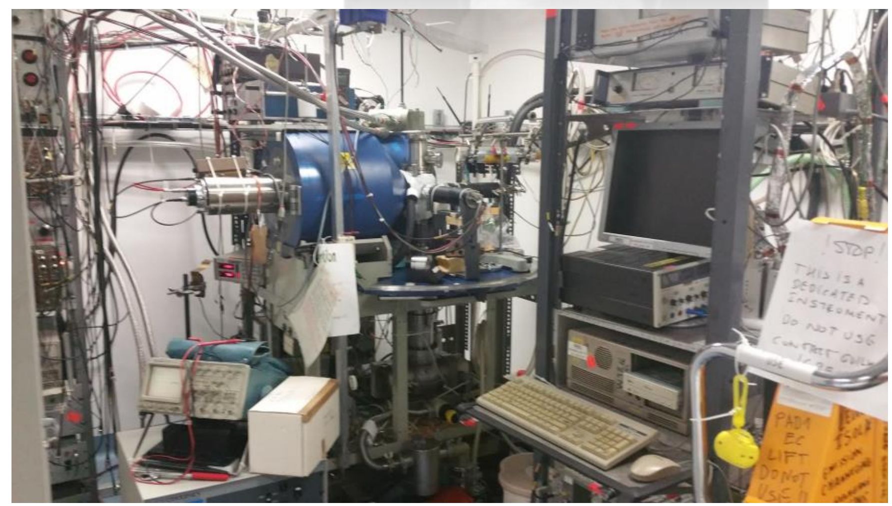


Electron-gamma:
A favourable complement to the γ-γ TDPAC method

e-g PAC
Collaboration ISOLDE, BMBF, FCT
Dr. J. G. Martins Correia

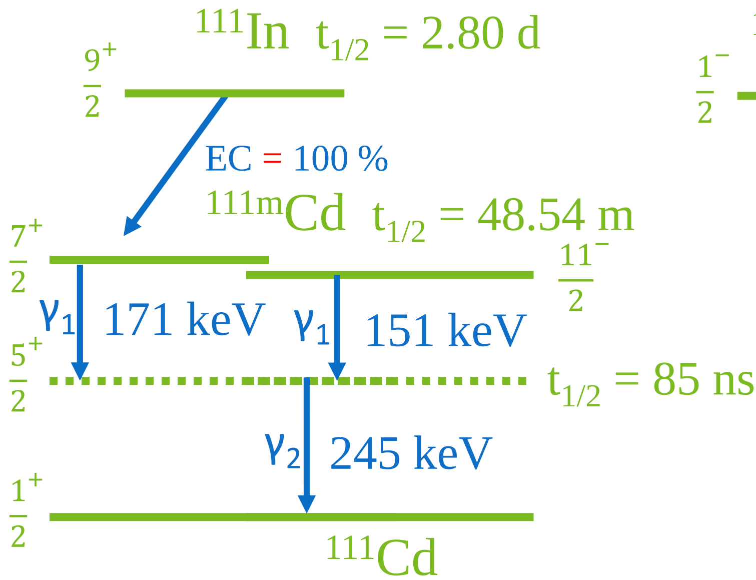


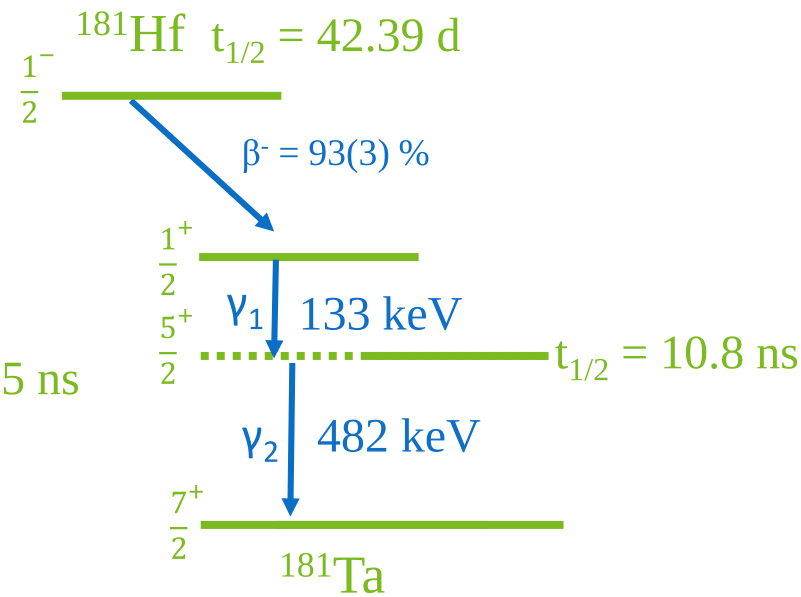
Source: AIP ADVANCES 7, 105017 (2017)



The footsteps of a stranger…

Footsteps of strangers…





	Q (b)	μ (μ_N)	A_{22}	I
^{111m}Cd	+0.765(15) (*)	-0.766(3)	0.1786	$5/2^+$
^{181}Hf (**)	+2.35(6)	+3.29(3)	-0.3185(11)	$5/2^+$
	+2.16(37)	+0.669(16)	-0.392(8)	2^+

(*)**Haas, H.** and **Correia J. G.**, Hyp. Int. 198, 133-137, 2010.
(**)**Singh, B.,** Nuclear Data Sheets, 199 **& Tuli J.K.**, Academic Press Inc., 1995.

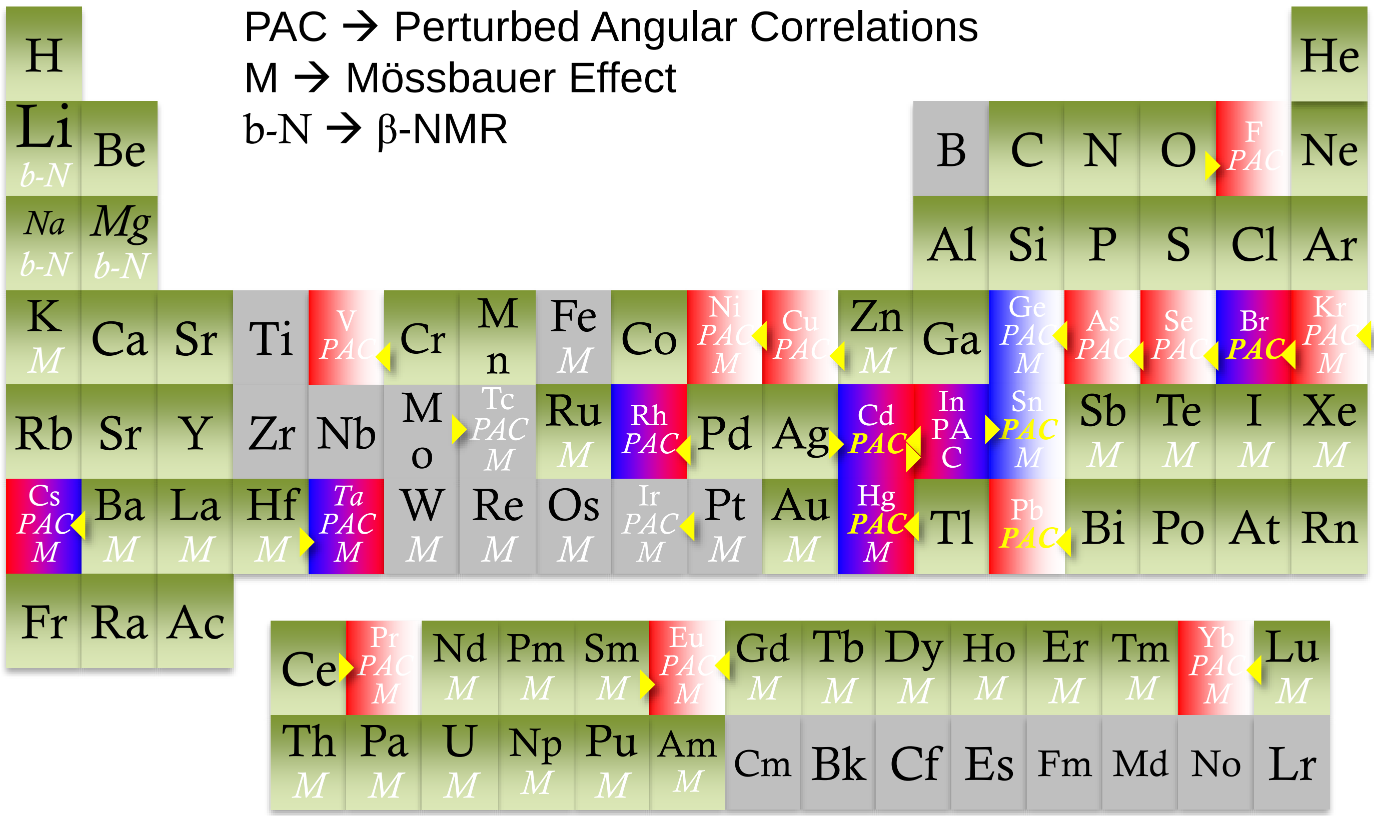
Why only conventional PAC ISOTOPES?

Probe elements

Available at ISOLDE

NOT available at ISOLDE

PAC → Perturbed Angular Correlations
M → Mössbauer Effect
b-N → β-NMR



γ-γ & γ -e⁻ **PAC**

only e⁻-γ **PAC**

only γ-γ **PAC**

γ-γ & e⁻-γ **PAC**

only γ-e⁻ **PAC**

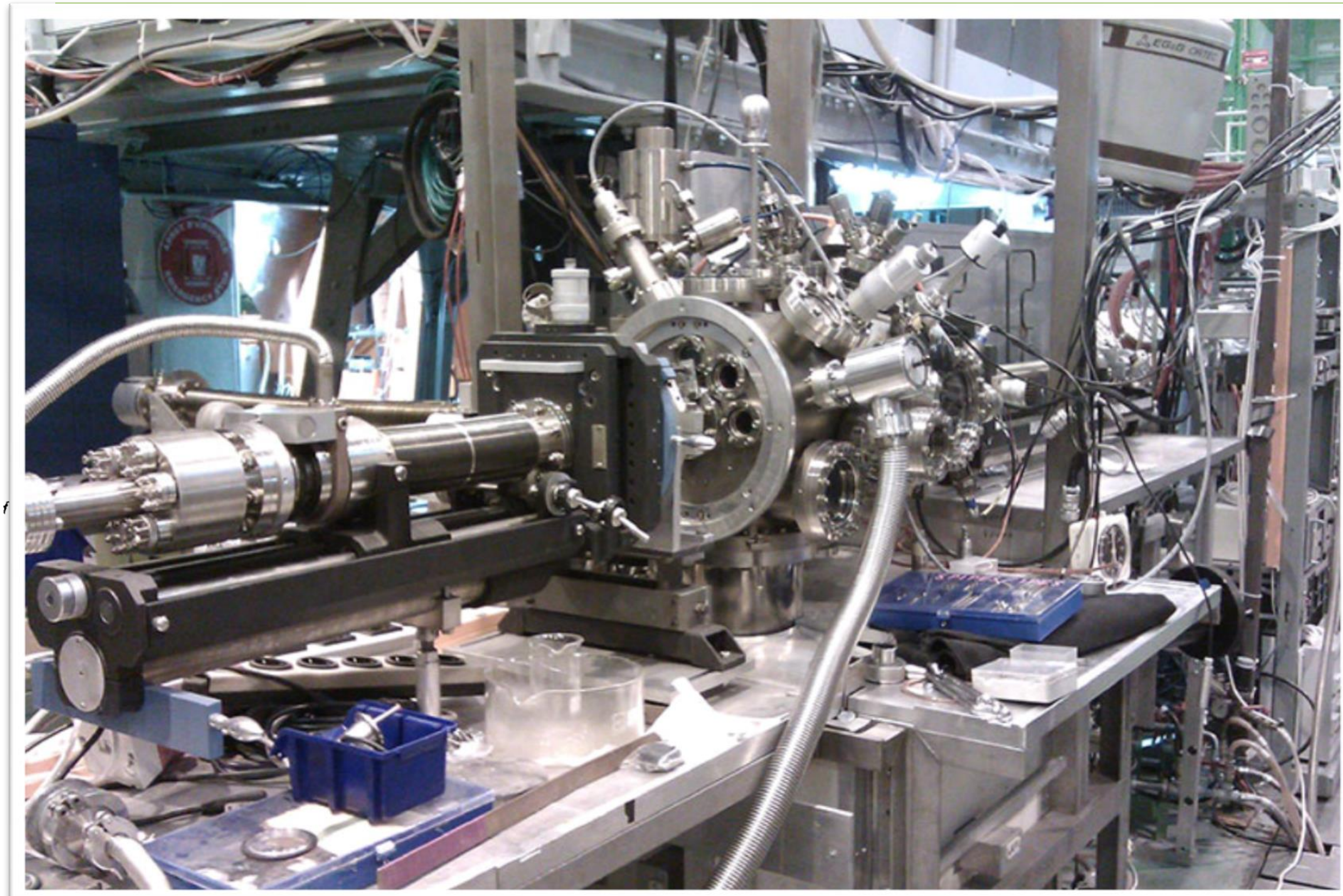
Apparatus for surface Physics at ISOLDE CERN (1991)

Apparatus for Surface Physics and Interfaces at CERN (2003)

(ASPIC)

Apparatus for Surface Physics and Interfaces at CERN

f



a Cu

only)

ven

experiments

CERN-ISC-91-10

Examples

Examples: Local symmetry lowering in $CdMn_2O_4$ spinel

J. Appl. Phys. 116, 223907 (2014)

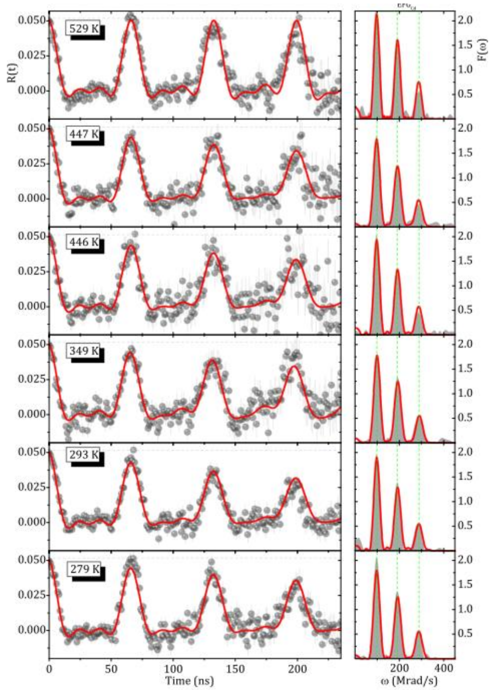


FIG. 2. a: Representative R(t) functions, corresponding fits, and respective Fourier transforms taken at different temperatures using the ^{111m}Cd parent probe.

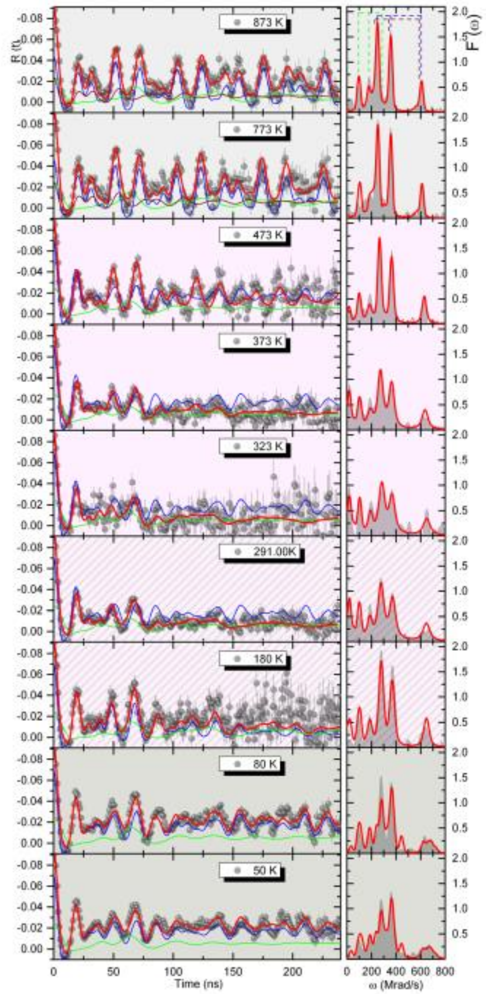


FIG. 3. (a) Representative R(t) functions, corresponding fits (partial fits, corresponding to each individual EFG, are represented in blue and green and some in red) and respective Fourier transform taken at different temperatures using the ^{111}Cd probe.

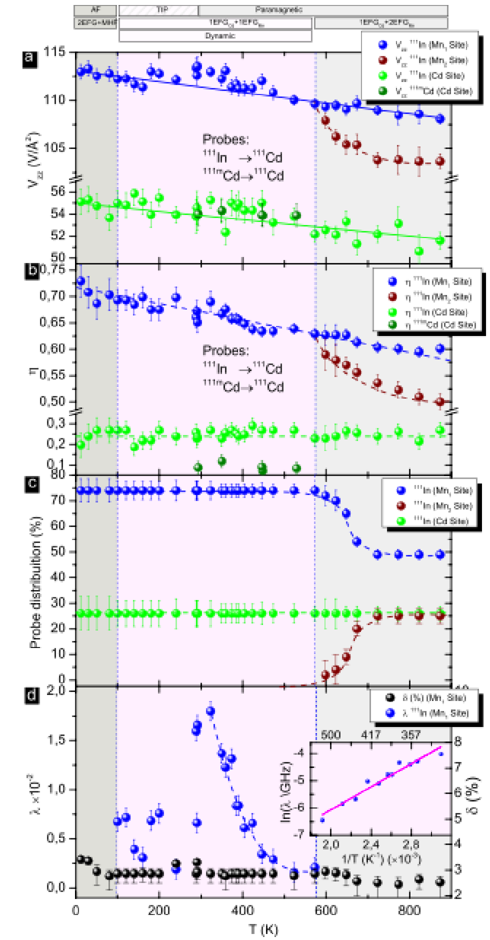
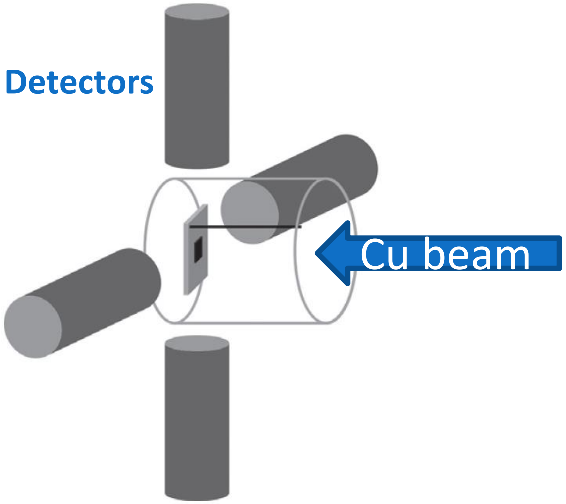
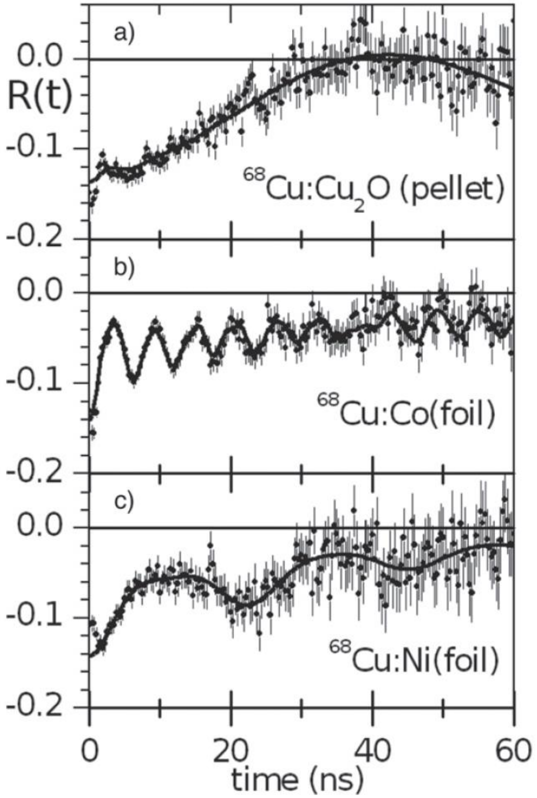


FIG. 4. (a) Experimental electric field gradient principal component (dots). The continuous lines represent a least-squares fit of the function $V_{zz}(T) = V_{zz}(0)[1 + \alpha T^{\alpha}]$ to the data points. (b) Asymmetry parameter. (c) Local probe distribution in the lattice sites. (d) Dynamic (left scale) and static (right scale) attenuation parameters of EFG^{1}_{Mn}. (Inset) Natural logarithm of the dynamic attenuation parameter of EFG^{1}_{Mn}. Continuous lines are fits to the data and dashed lines are guides for the eye.

Examples: The $^{68m}Cu/^{68}Cu$ isotope as a new probe for hyperfine studies: The nuclear moments

A. Fenta et al. EPL 115 (2016) 62002





IS640: PAC studies of isolated small Cd and Hg molecules

H. Haas, J. Schell, J.G. Correia, A.E. Silva-Fenta, R. Vianden, J.Roeder,
L. Hemmingsen, S.P.A. Sauer, V. Amaral, D.C. Lupascu

What we wanted to do:

Measure the quadrupole interaction in some free Hg and Cd molecules by PAC

Basic idea: In a linear molecule the EFG (V_{zz}^{mol}) is along the molecular axis

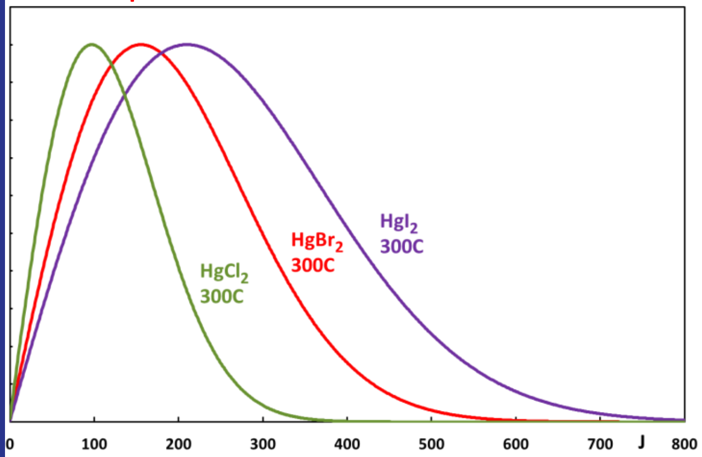
The rotation axis J is always perpendicular to the molecular axis

The EFG along J is then, independent of J: $V_{zz}^{rot} = -1/2\ V_{zz}^{mol}$

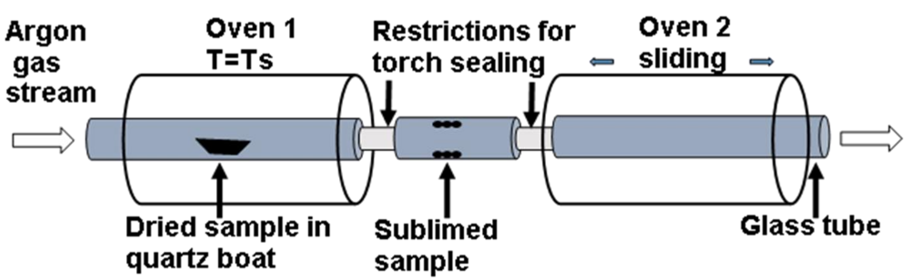
For large J the splitting frequency should be independent of J!

An old idea, but early experiments (Berkeley, Bonn) in the 1970s have failed

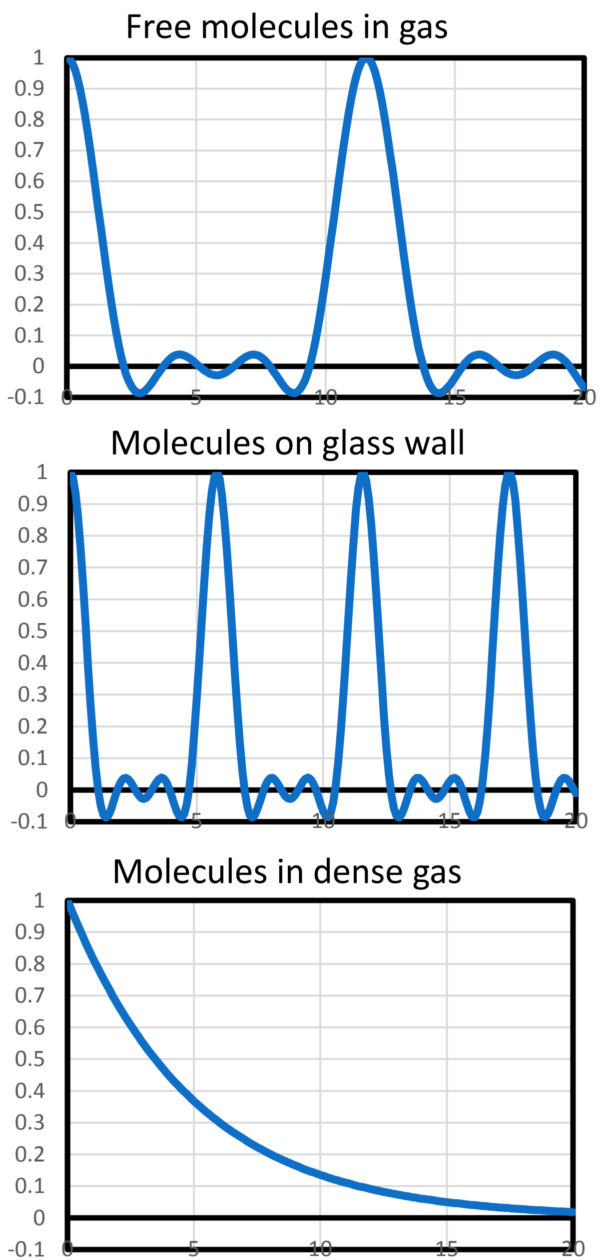
Population of J states



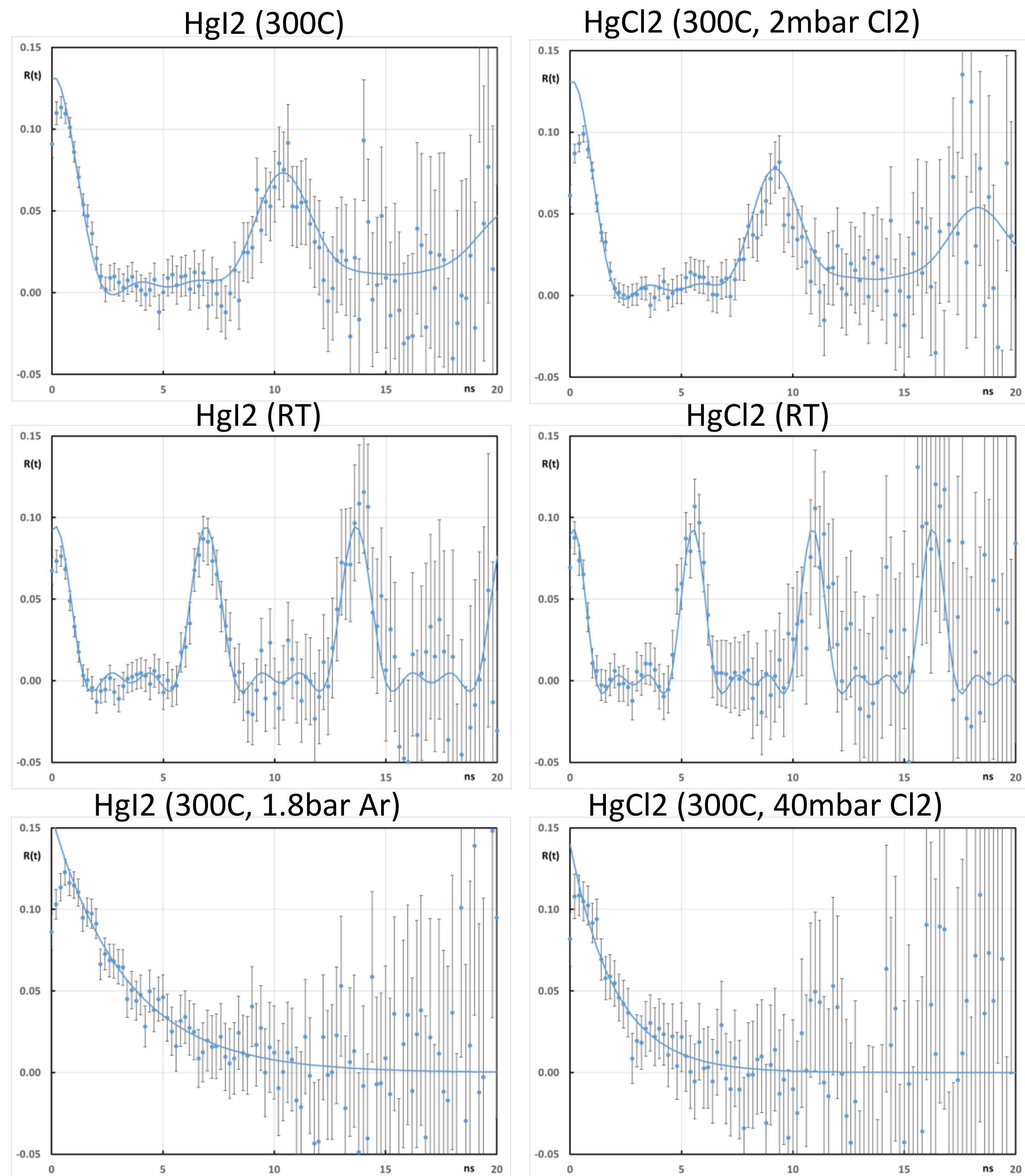
The Technique



What R(t) could we expect ?



What R(t) did we see ?



IS640 Status

- We have made the first (successful) PAC experiments on free molecules
- We have seen a considerable difference between the EFG in the free molecules and the molecular solids
- Still to do: Final determination of experimental spectra with reduced energy windows
- To do: Final fitting including centrifugal stretching, vibrational excitation, quantum effects, (nuclear recoil)
- Goal: Compare the results to the quantum chemistry calculations for Hg halides
- Final goal: A precision value of Q for the $5/2^+$ state in ^{111}Cd from similar experiments with the Cd halides

Additional information?

AIP ADVANCES **7**, 105017 (2017)

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The idea that "new-is-small" is a paradigm propelling industries and research: new materials for new applications and new technologies. Precise and efficient characterization techniques are, therefore, required to make the "new" and the "small", understandable, applicable, and reliable. Within this concept, Time Differential Perturbed Angular Correlations, TDPAC, appears as one of the most exotic and efficient techniques to characterize materials and is celebrating 40 years at ISOLDE, CERN. In this overview we explore the TDPAC measurement possibilities at ISOLDE-CERN for solid state physics research with a rich potential due to the wide number of available radioactive probe elements, delivered with great purity and high yield. https://doi.org/10.1063/1.4994249

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40 years young technique!


If you can't say
anything nice
you obviously
haven't had your
coffee yet