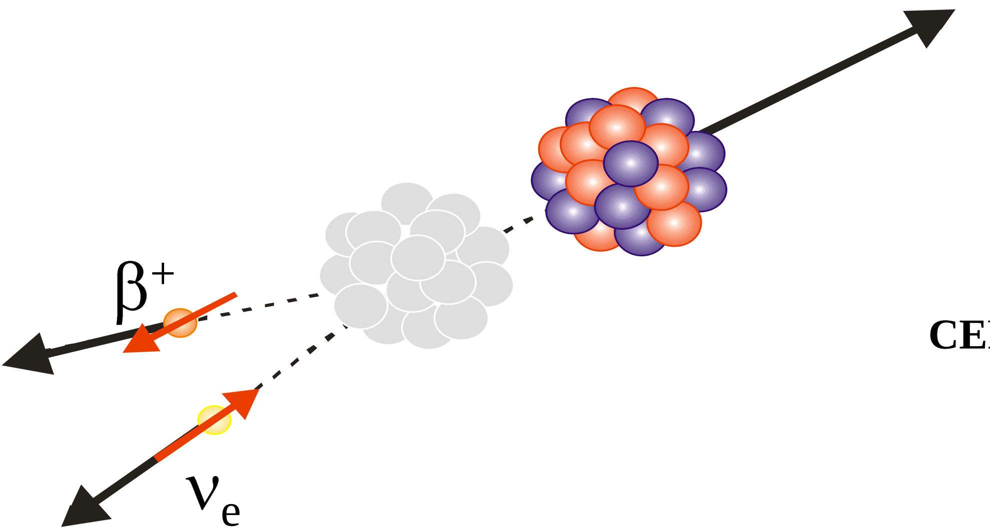
Recent progress with Low Temperature Nuclear Orientation and NMR/ON



HFI 2010

CERN, September 12-17, 20100

Nathal Severijns

Kath. University Leuven, Belgium

1. Low Temperature Nuclear Orientation

Weak interaction studies

- parity violation - ^{180m}Hf
- weak tensor currents - ^{60}Co, ^{114}In, ^{67}Cu

2. Nuclear Magnetic Resonance on Oriented Nuclei

Nuclear magnetic moments

- Cu isotopes
- Ag isotopes
- Sc isotopes
- Hf isotopes

Hyperfine anomaly

- Sc isotopes

Hyperfine fields

- Rb in Fe host

3. New NO-facility: Polarex (Orsay)

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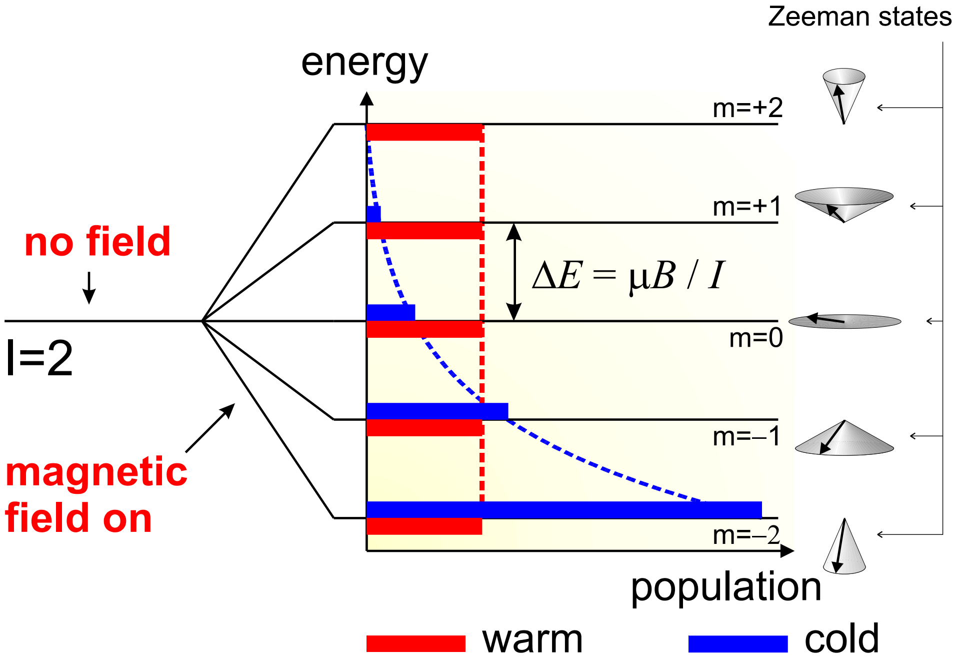
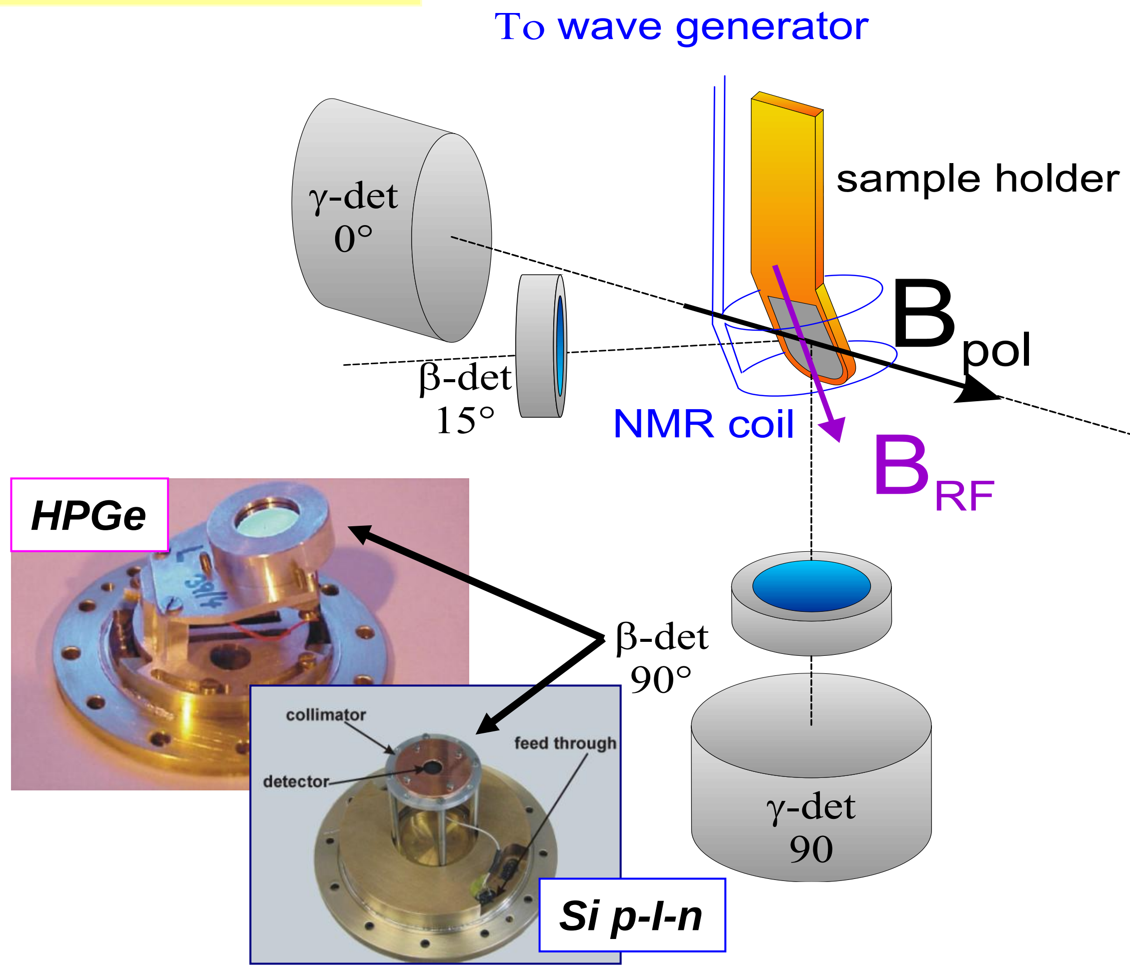
principle :





angular distribution :

$$W(\theta) = \frac{N(\theta)_{cold}}{N(\theta)_{warm}}$$

$$= 1 + f \sum_{k=2,4} A_k \; U_k \; B_k(\mu B, I, T) \; Q_k \; P_k(\cos\theta)$$

detection set-up

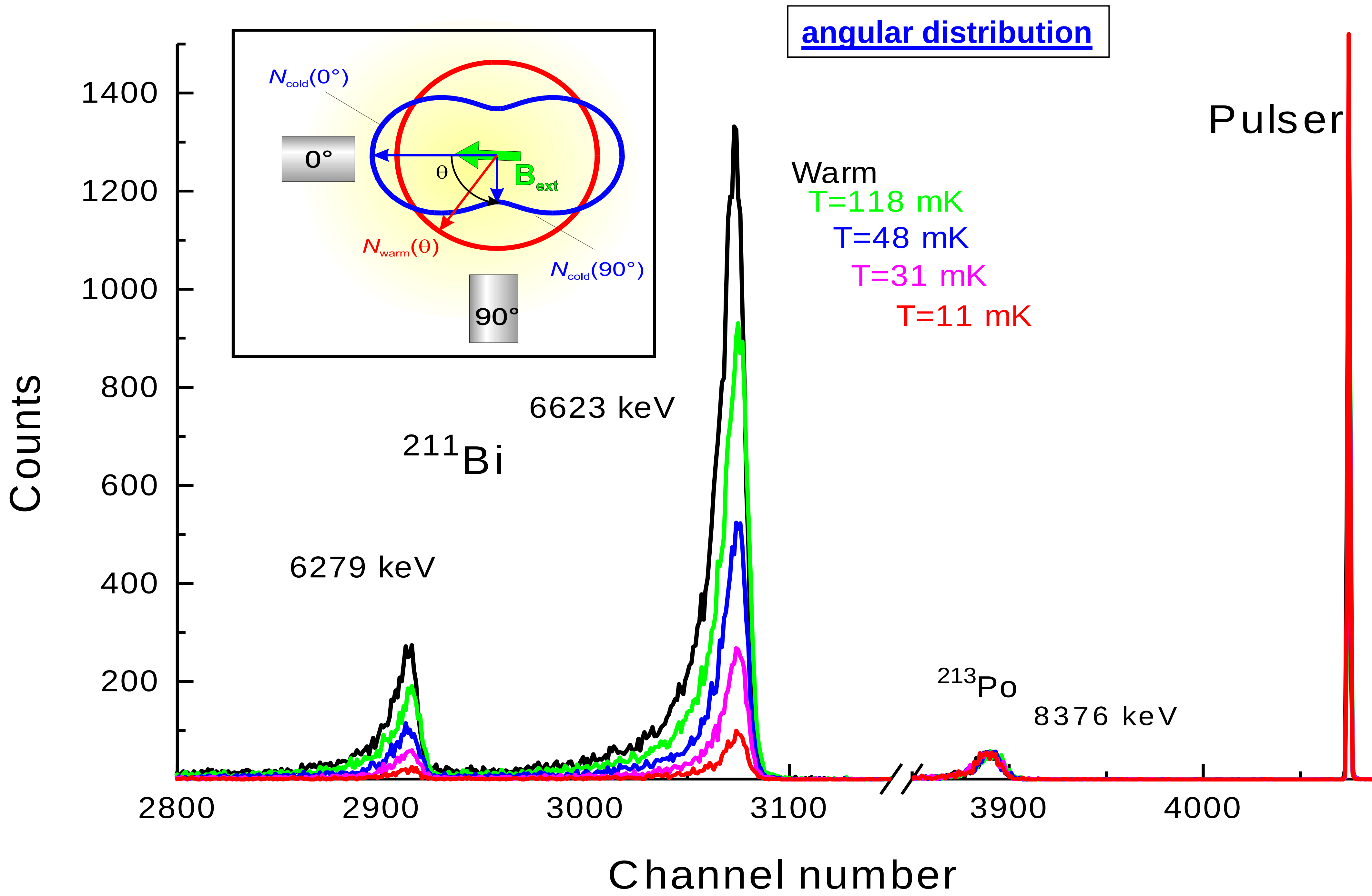
γ detectors: large volume HPGe

α, β detectors: Si p-i-n, HPGe, scintillators

D. Venos et al., NIM A 454 (2000) 403

D. Zákoucký, et al., NIM A 520 (2004) 80

F. Wauters et al., NIM A 604 (2009) 563


angular distribution
Counts
Channel number
Pulser
Warm
T=118 mK
T=48 mK
T=31 mK
T=11 mK
6623 keV
211Bi
6279 keV
213Po
8376 keV
Ncold(0°)
Ncold(90°)
Nwarm(θ)
Bext
θ
0°
90°
1400
1200
1000
800
600
400
200
2800
2900
3000
3100
3900
4000

Parity non-conservation in nuclei: ^{180m}Hf revisited (IS 429)

Oxford Univ., K.U.Leuven, Weizmann Institute, …

Hamiltonian for nuclear system: $H = H_0 + H_{PNC}$

H_0 : regular strong nucleon-nucleon Hamiltonian

H_{PNC} : PNC weak Hamiltonian

$H_{PNC} \cong 10^{-7} H_0$ → PNC part only visible if e.g. regular (γ-)transition hindered

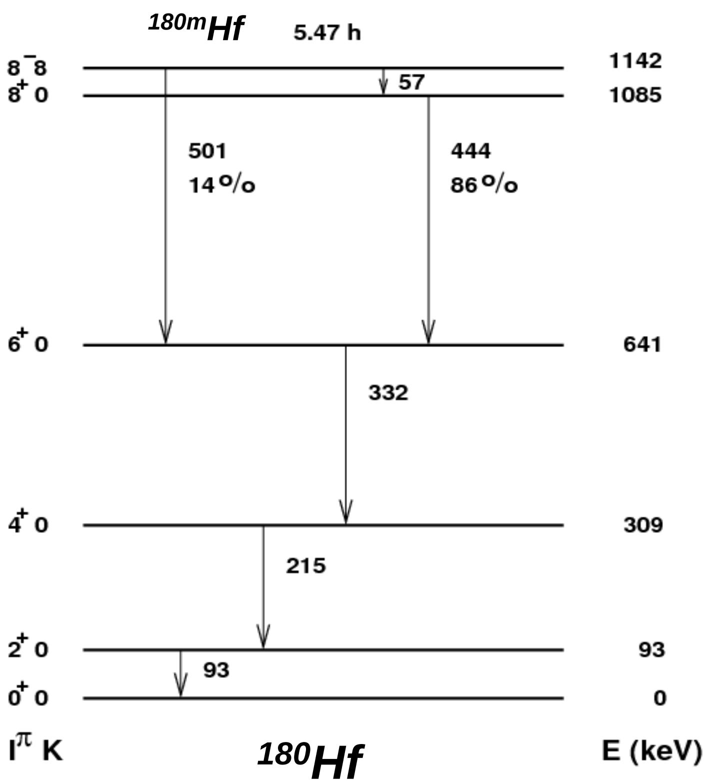
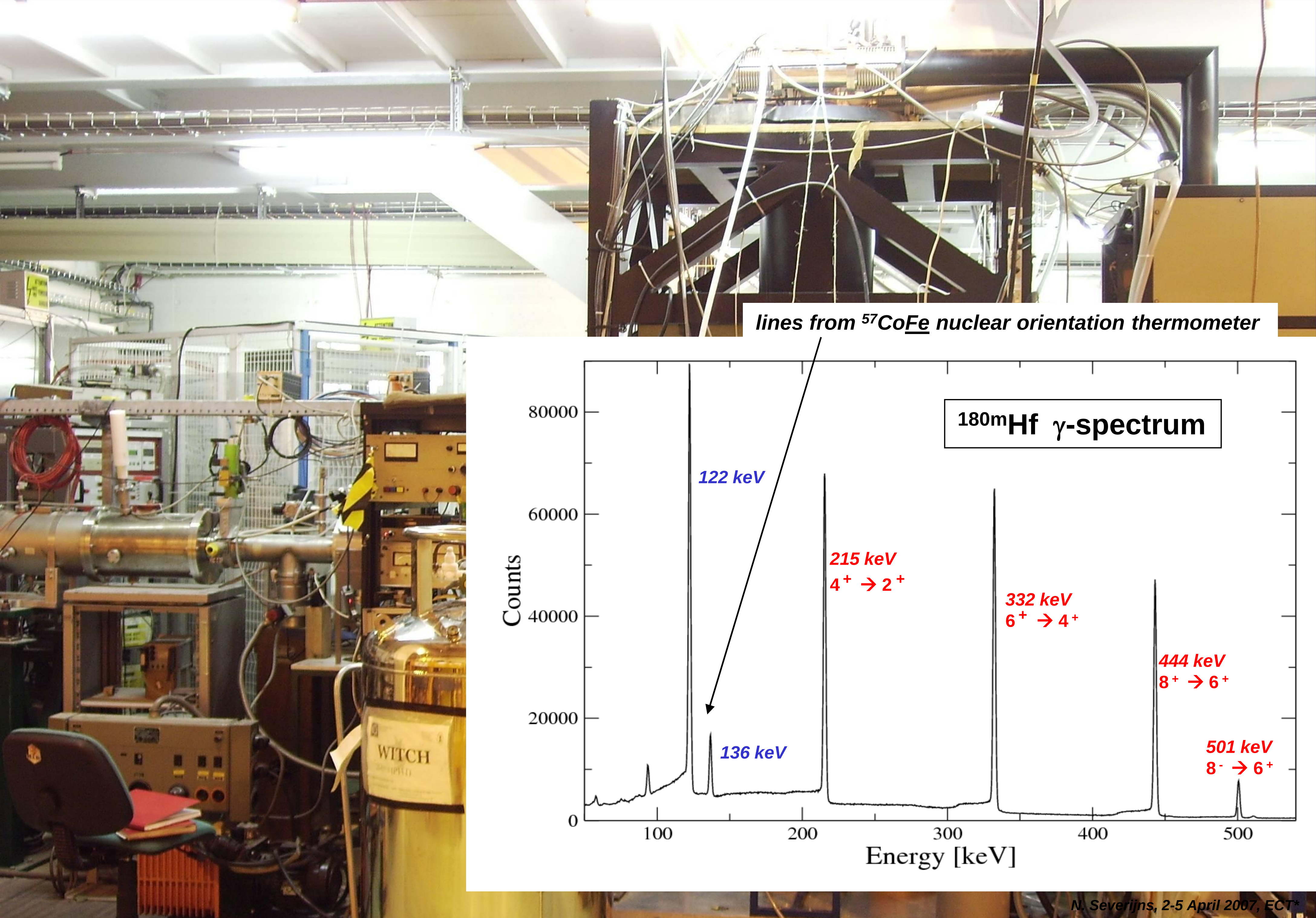


FIG. 1: Decay of the 5.47 h ^{180}Hf^{m}

J.R. Stone et al., PR C 76 (2007) 025502

case of ^{180m}Hf

- mixture of 8^- ($K = 8$) and 8^+ ($K = 0$) states (ΔE =57 keV)
- regular transition strongly suppressed by $K = 8$ difference
- detect mixing by non-zero E2 component in M2/E3 mixed 501 keV γ-ray

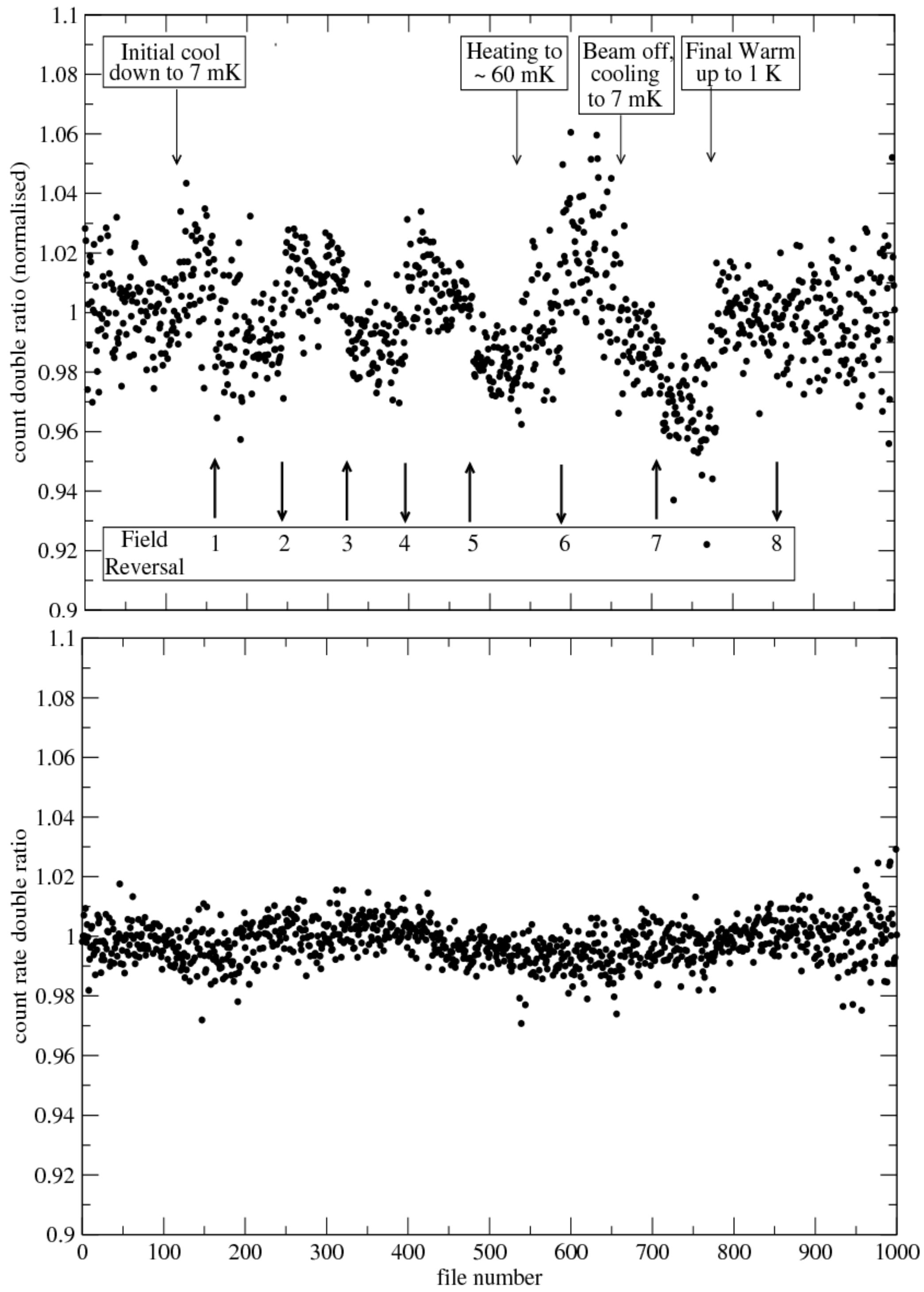

lines from 57CoFe nuclear orientation thermometer
180mHf γ-spectrum
122 keV
136 keV
215 keV
4+ → 2+
332 keV
6+ → 4+
444 keV
8+ → 6+
501 keV
8- → 6+
Counts
80000
60000
40000
20000
0
100
200
300
400
500
Energy [keV]
WITCH

$$R = \frac{\dfrac{N(501,L)}{N(444,L)}}{\dfrac{N(501,R)}{N(444,R)}}$$

0º/180º effect for 501 keV transition →
normalized to 444 keV

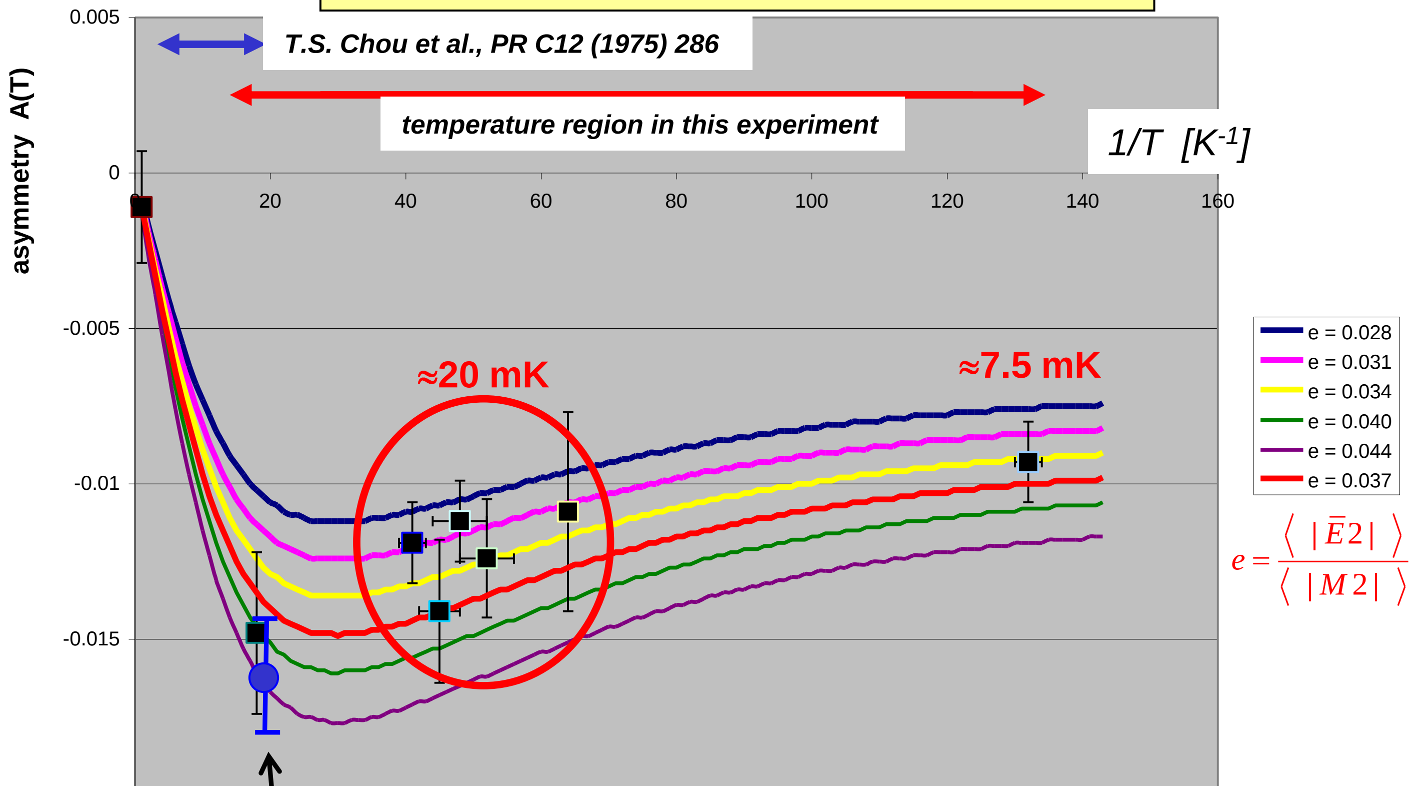
$$R = \frac{\dfrac{N(332,L)}{N(444,L)}}{\dfrac{N(332,R)}{N(444,R)}}$$

0º/180º effect for 332 keV transition →
normalized to 444 keV



$$\mathcal{A}(T) = 2\frac{W(0^o,T) - W(180^o,T)}{W(0^o,T) + W(180^o,T)} = \frac{2\sum_{\lambda odd} fB_\lambda(T)U_\lambda A_\lambda Q_\lambda P_\lambda(cos\theta)}{1 + \sum_{\lambda even} fB_\lambda(T)U_\lambda A_\lambda Q_\lambda P_\lambda(cos\theta)} \propto \frac{\langle\ |H_{PNC}|\ \rangle^2}{\langle\ |H_0|\ \rangle^2}$$

Asymmetry of 501 keV transition in ^{180m}Hf



$$e = \frac{\langle\ |\bar{E}2|\ \rangle}{\langle\ |M2|\ \rangle}$$

A (≈ 50 mK) = -1.66 (18) %

T.S. Chou et al., PR C12 (1975) 286

Our result:

A (≈20 mK) = -1.21(8) %

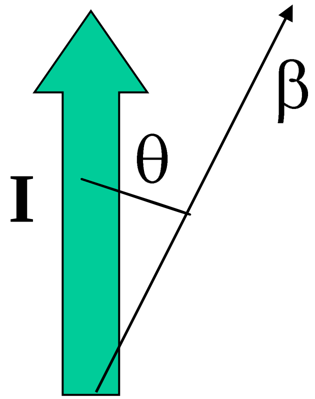
→ <H_{PNC}> = 0.73(5) μeV

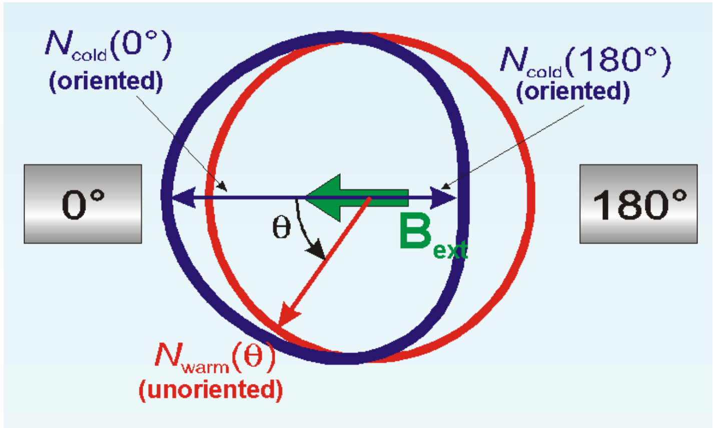
(most precise result to date !!)

Transition	A
122 keV (^{57}Co)	-0.08(9)
136 keV (^{57}Co)	-0.74(74)
215 keV (^{180m}Hf)	-0.04(7)
332 keV (^{180m}Hf)	-0.03(8)
444keV (^{180m}Hf)	-0.07(5)

Search for weak tensor currents: β asymmetry parameter (IS 431)

K.U.Leuven, NPI-Rez (Prague), …

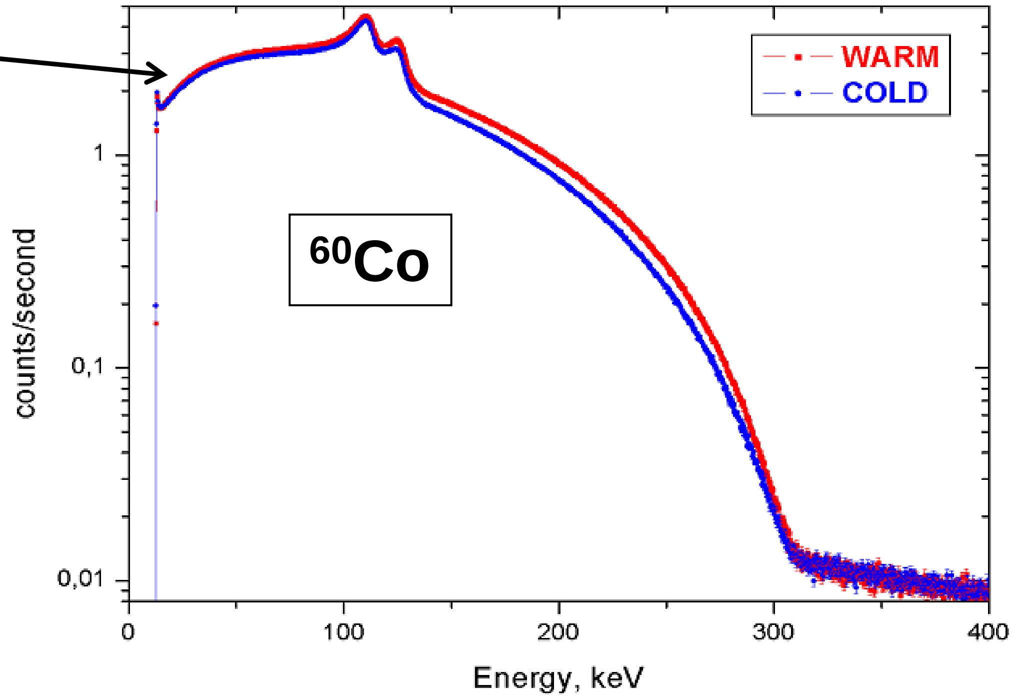




Leuven: ^{60}Co<u>Cu</u> , B_{ext} = 13 T

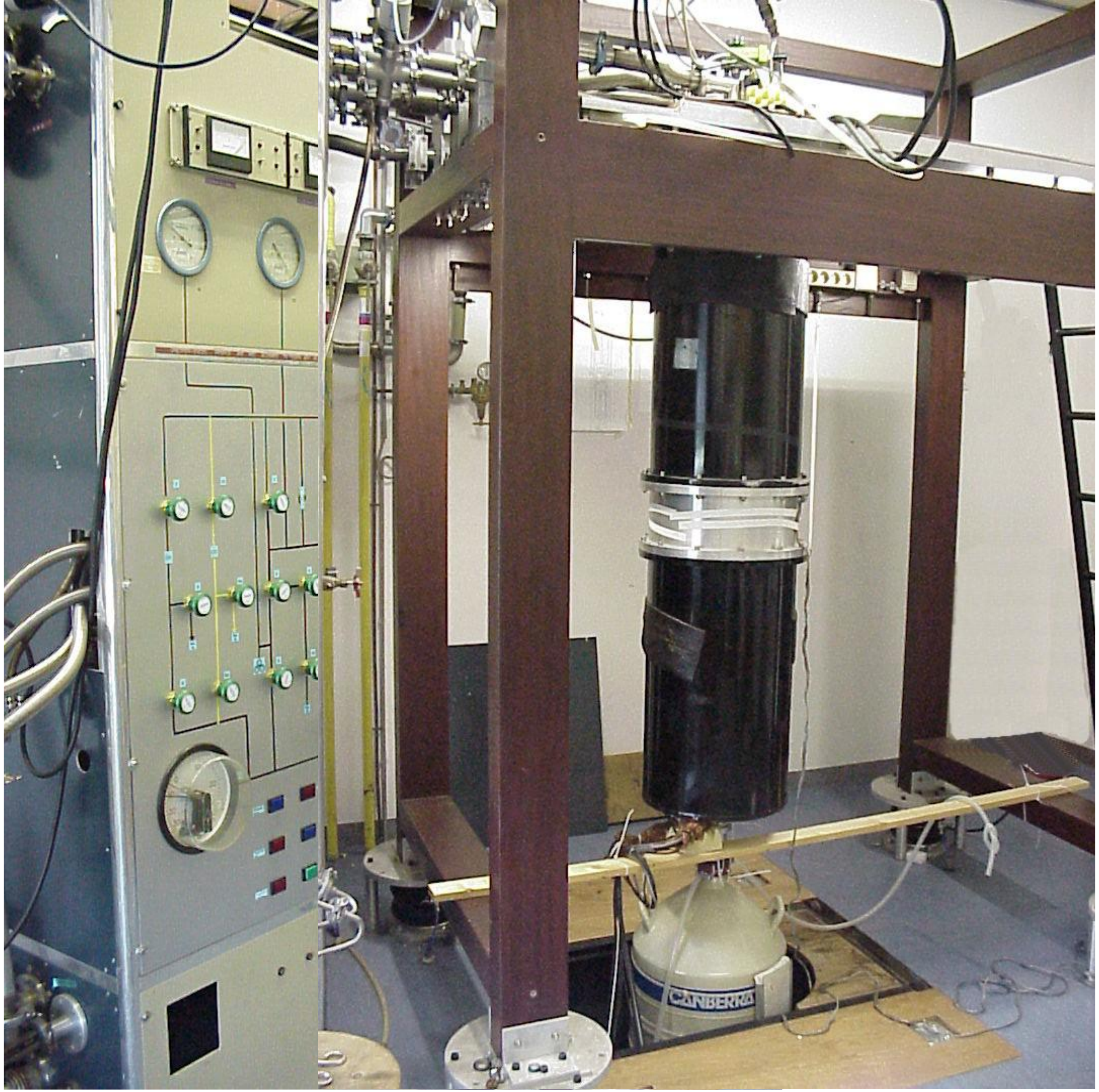
Leuven: ^{114}In<u>Fe</u> , B_{hf} = 45 T

ISOLDE: ^{67}Cu<u>Fe</u> , B_{hf} = 22 T



used GEANT4 code to account for :

- **detection geometry**
- **magnetic field effects**
- **scattering**
- **energy loss**
- **…**



15 T magnet

Leuven ^{3}He - ^{4}He dilution refrigerator setup

I.S. Kraev et al., NIM A 555 (2005) 420

Geant 4 simulation code

GEANT4 has to take care of :

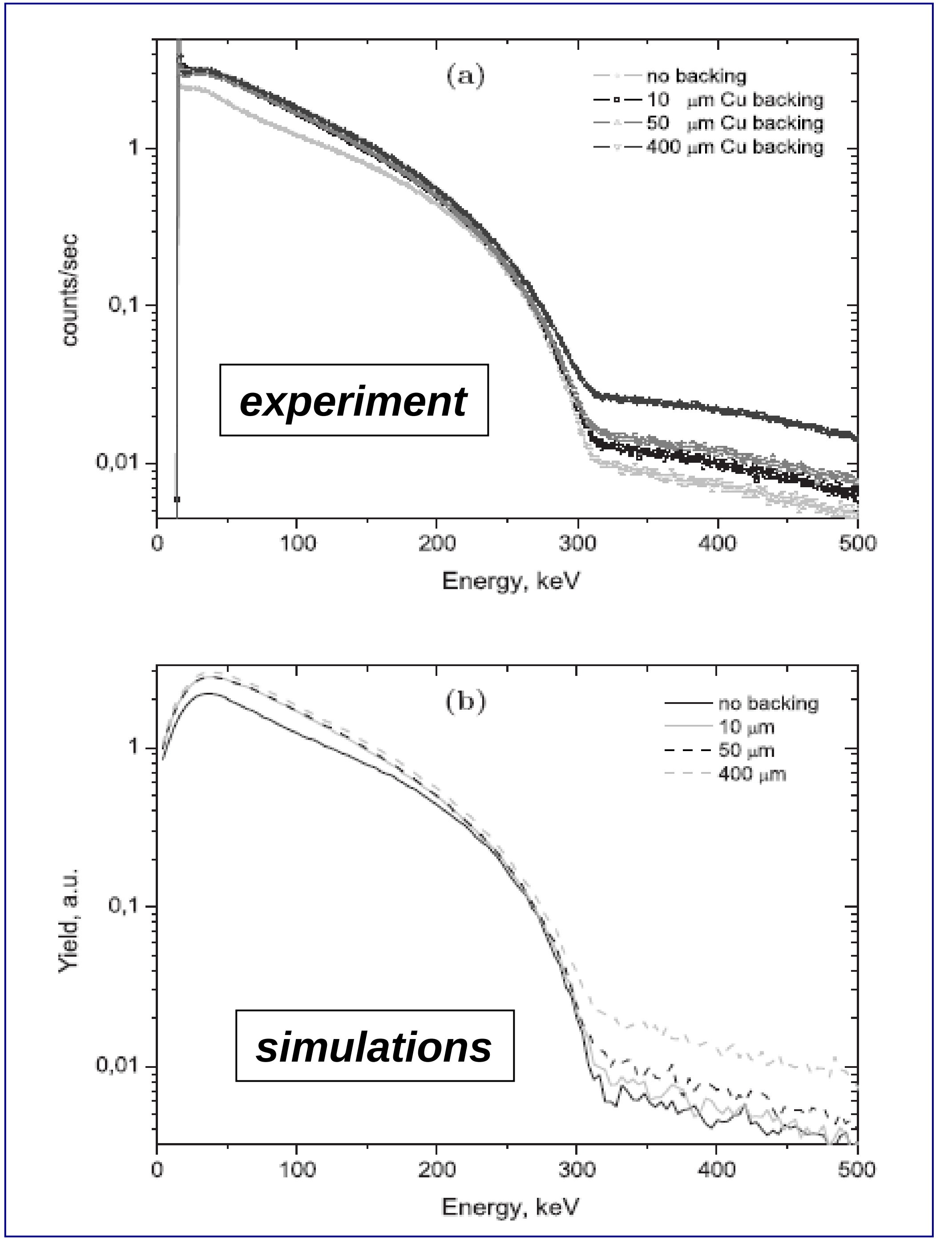
- *scattering effects*
- *energy loss*
- *magnetic field effects*
- *...*

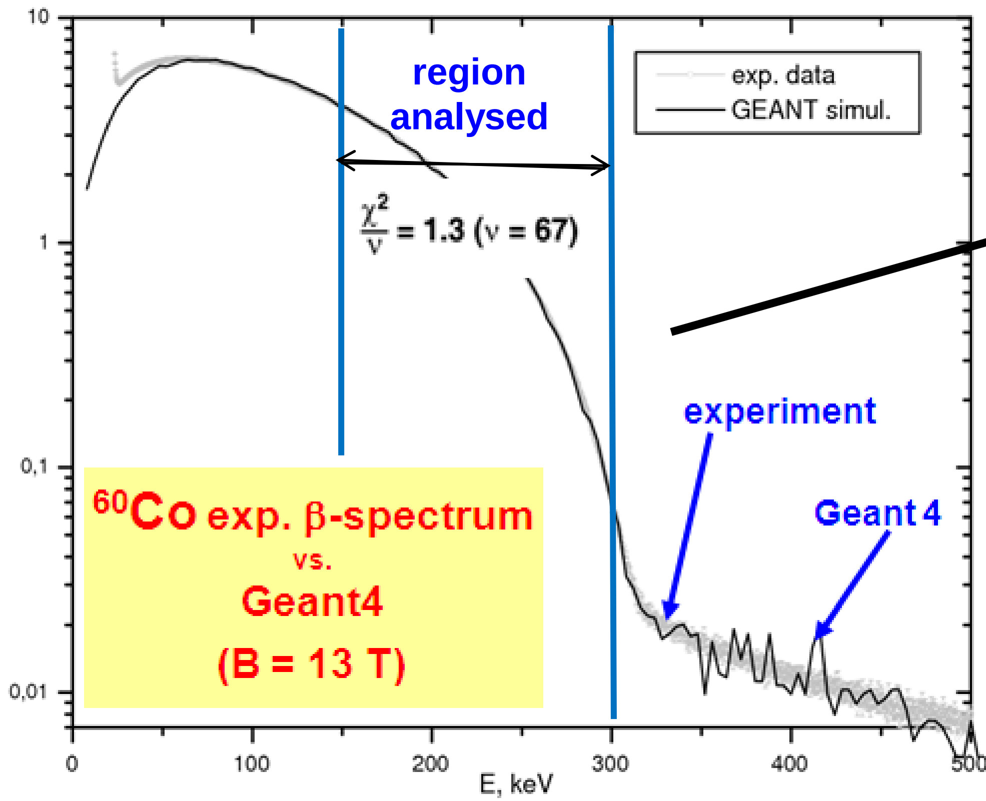
- *use low energy packages*
- *tune GEANT4 parameters to get optimal performance for β particles*

→ *compare GEANT4 with well controlled experimental data for :*

→ *different scattering conditions*
→ *different magnetic fields*
→ *detectors used (Si p-I-n / HPGe)*

F. Wauters et al., NIM A 609 (2009) 156





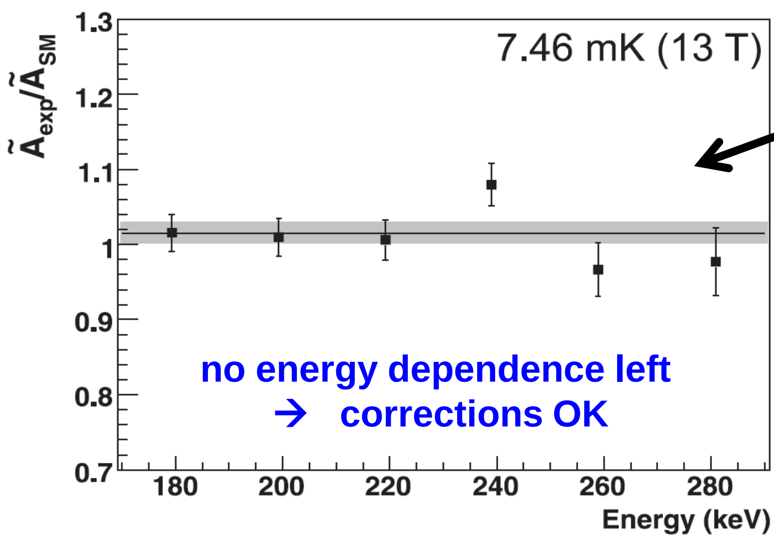
$$W(\theta) = \frac{N(\theta)_{pol}}{N(\theta)_{unpol}} = 1 + \tilde{A}\ \ P\ \frac{v}{c}\ Q\cos\theta$$

(P from anisotropy of γ-rays)

Geant 4

Analysis of measured and simulated spectra:

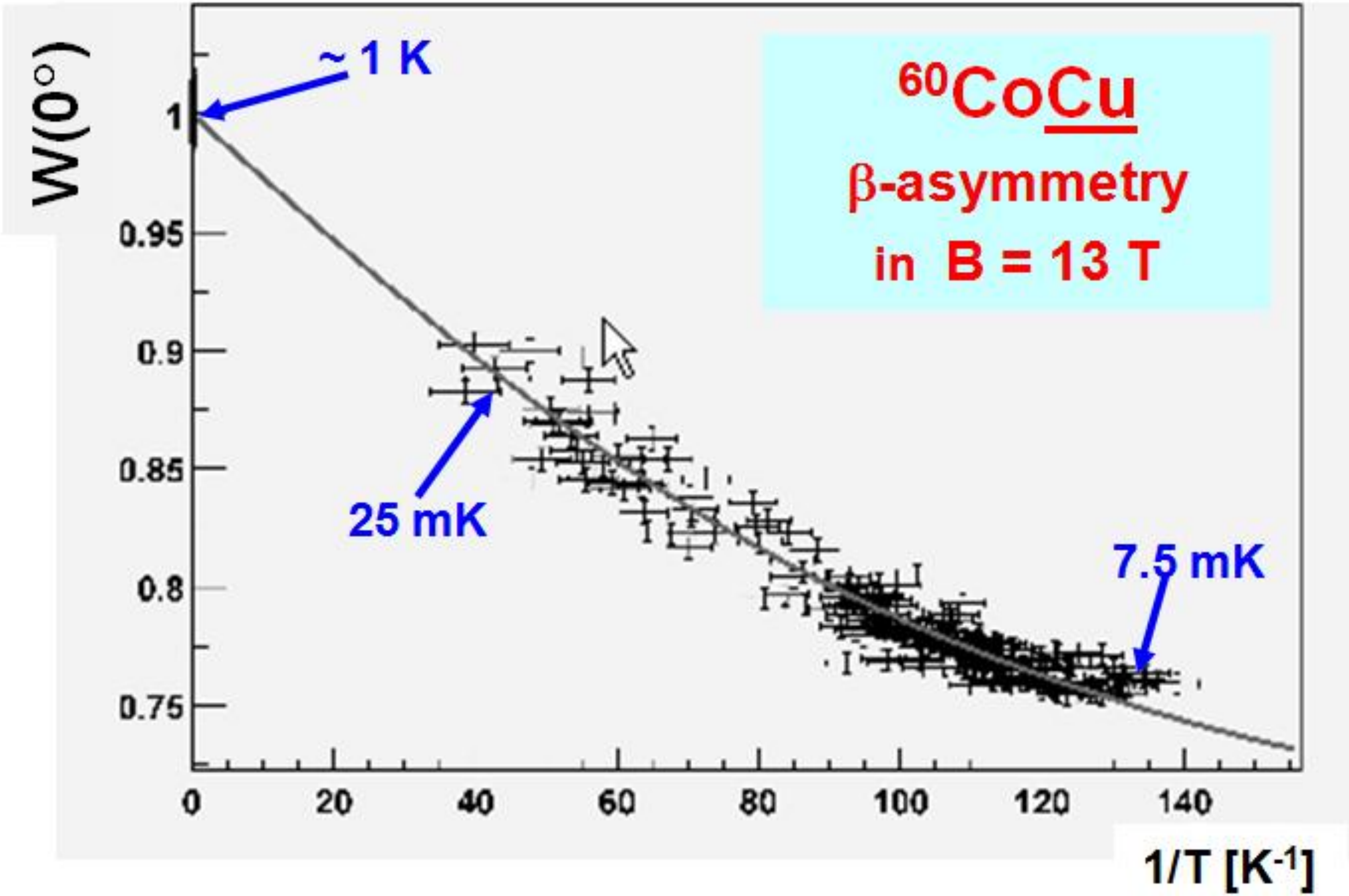
$$\frac{\left[W(\theta)-1\right]_{exp}}{\left[W(\theta)-1\right]_{Geant}} = \frac{\left[\tilde{A}_{exp}\ P\ \frac{v}{c}\ Q\ \cos\theta\right]_{exp}}{\left[\tilde{A}_{SM}\ P\ \frac{v}{c}\ Q\cos\theta\right]_{Geant}}$$



$A_{exp}\ ({}^{60}Co)\ =\ -1.014\ (12)_{stat}\ (16)_{syst}$

$(\ A_{SM} = -0.987(9)\ )$

F. Wauters et al., submitted


~1 K
^{60}CoCu
β-asymmetry
in B = 13 T
25 mK
7.5 mK
W(0°)
1
0.95
0.9
0.85
0.8
0.75
0
20
40
60
80
100
120
140
1/T [K^{-1}]

A_{exp} (^{114}In) = - 0.994 (10)$_{stat}$ (10)$_{syst}$

(A_{SM} = -1.000)

(most precise result for $A_{nuclear}$ ever !)

F. Wauters et al., PR C 80 (2009) 062501(R)

(^{67}Cu in progress - IS431)

major systematic errors:

- performance of GEANT code (scattering)
- determination of nuclear polarization

(M)LRS-models

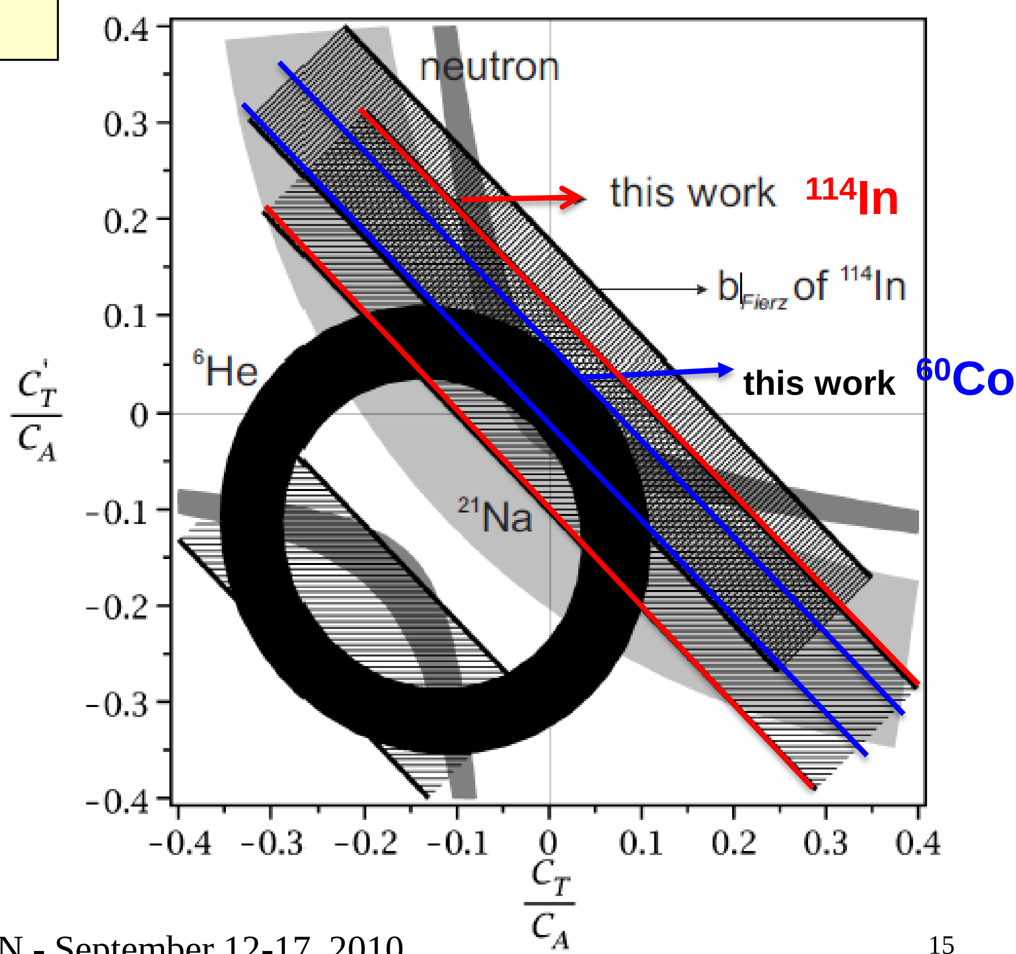
$W_1 = W_L \cos\zeta - W_R \sin\zeta$

$W_2 = W_L \sin\zeta + W_R \cos\zeta$

$\delta = m_1^2 / m_2^2$

^{114}In : $M(W_2)$ > 230 GeV/c^2 (90% C.L.)

^{60}Co : $M(W_2)$ > 245 GeV/c^2 (90% C.L.)



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- **Ag isotopes**
- **Sc isotopes**
- **Hf isotopes**

Hyperfine anomaly

- **Sc isotopes**

Hyperfine fields

- **Rb in Fe host**

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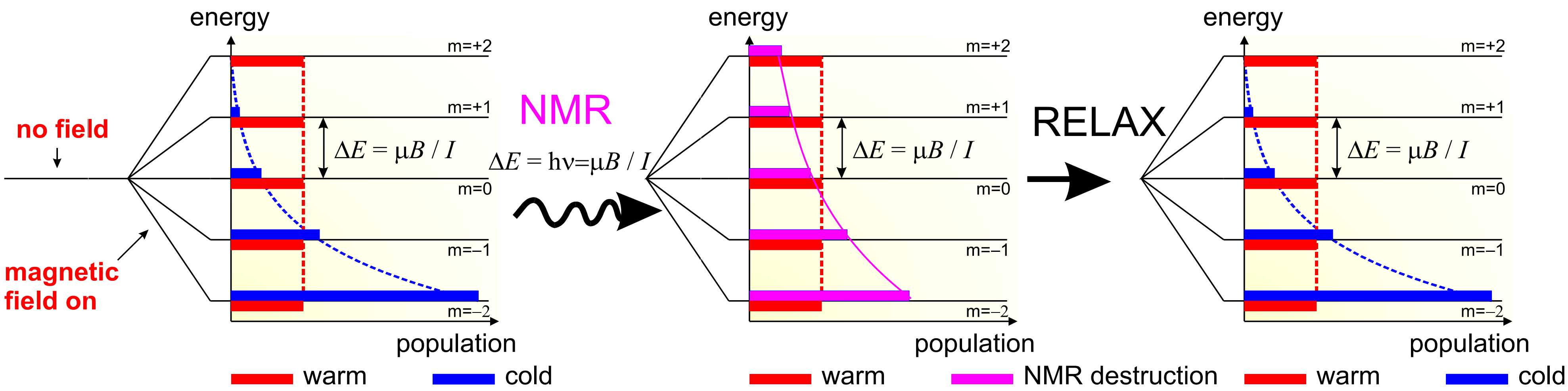
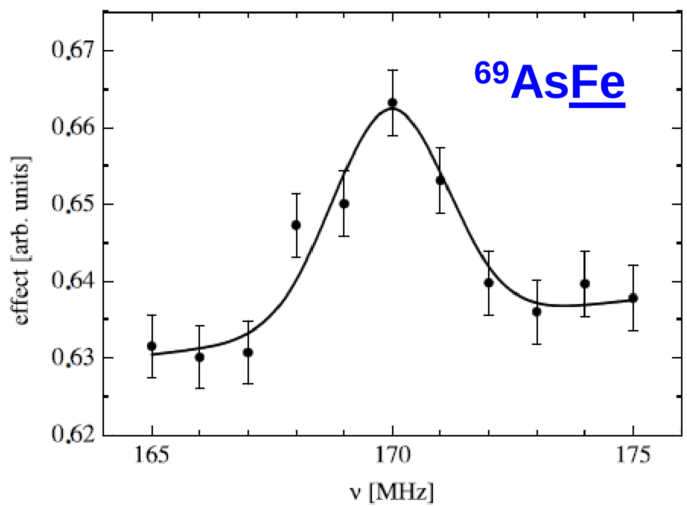
2. Nuclear Magnetic Resonance on Oriented Nuclei - NMR/ON

principle :

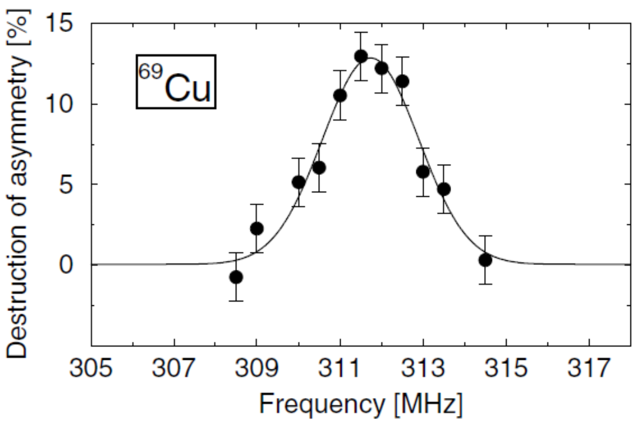




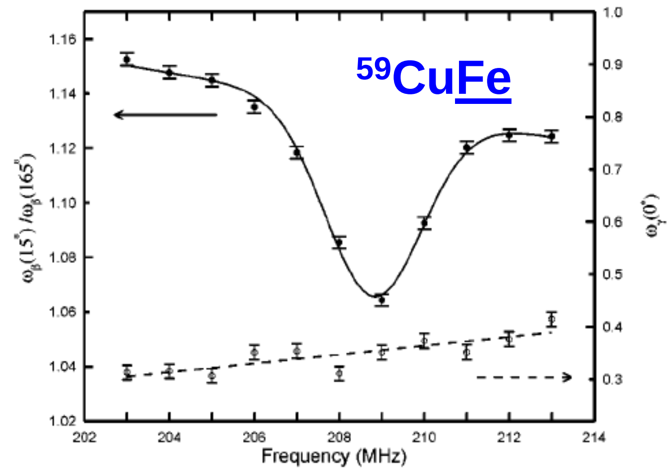
V.V. Golovko et al, PR C72 (2005) 064316

Magnetic moments: Cu isotopes (IS358, IS381)

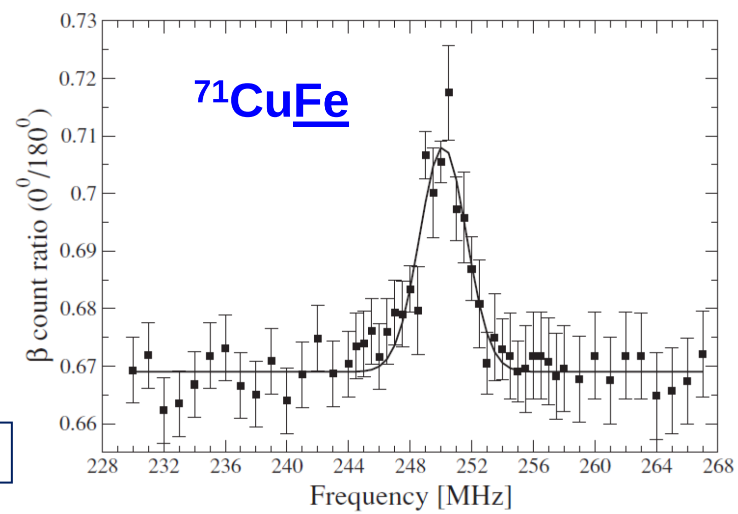
Oxford Univ., Maryland Univ., … and K.U.Leuven, NPI-Rez (Prague), Univ. Bonn, …



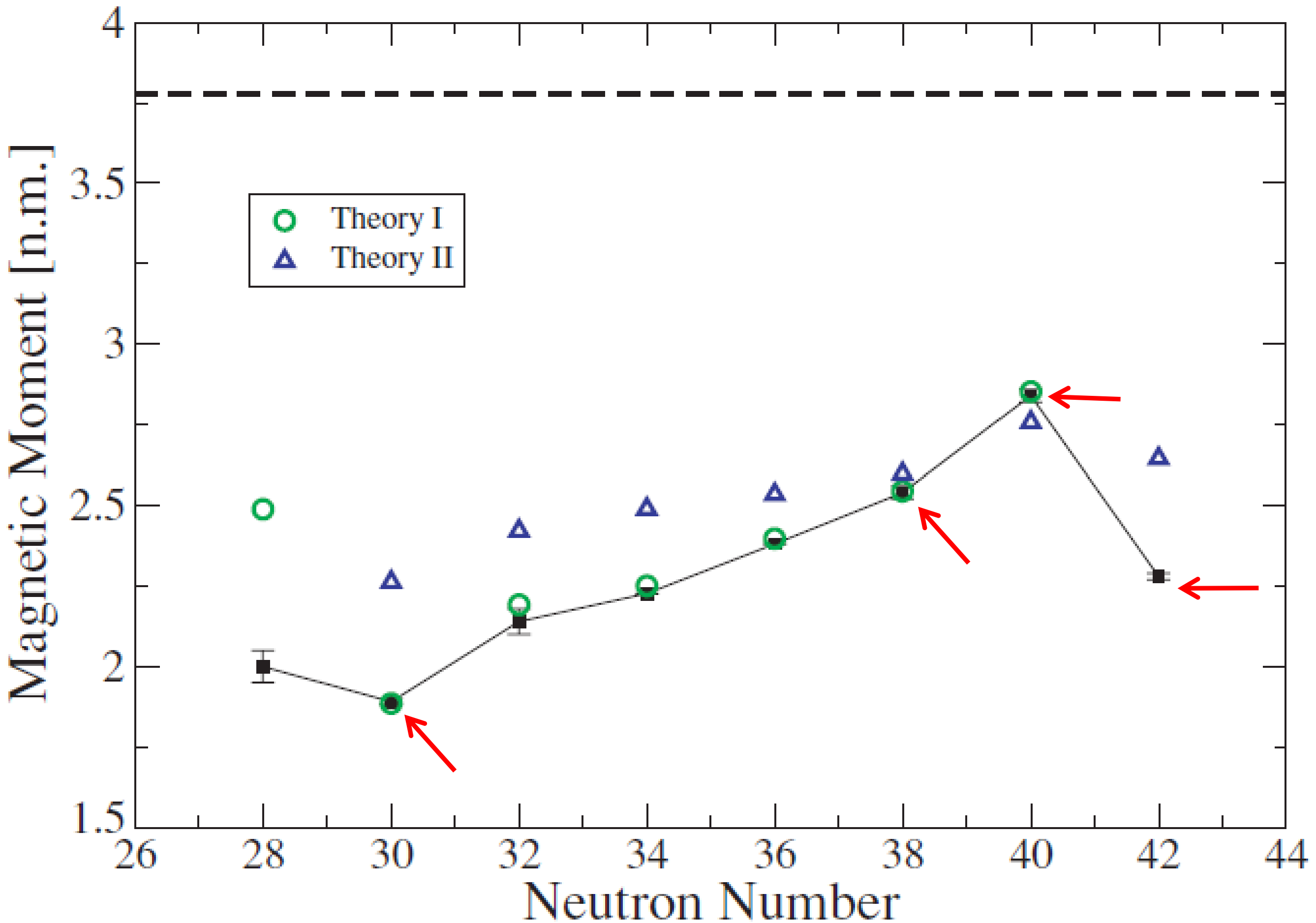
J. Rikovska et al., PRL 85 (2000) 1392



V.V. Golovko et al., PR C70 (2004) 014312



N.J. Stone et al., PR C77 (2008) 014315



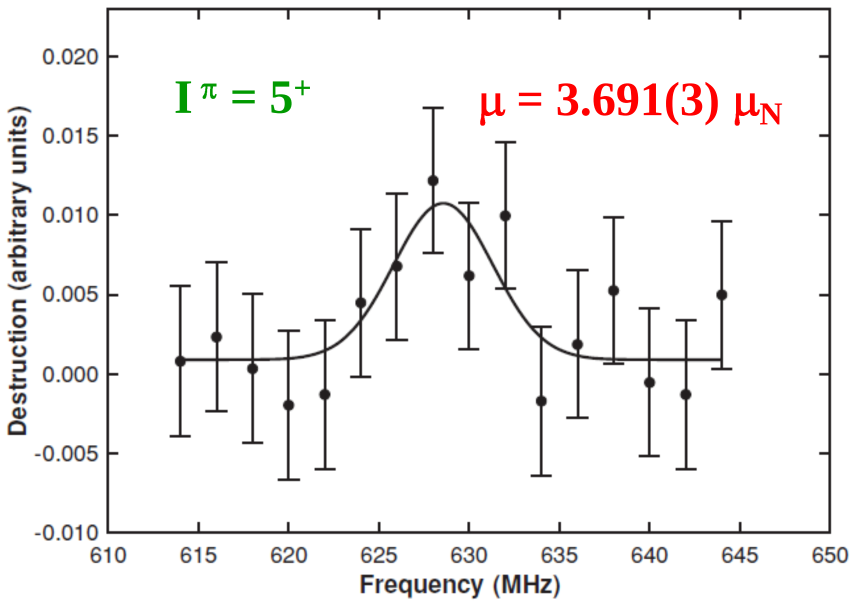
N.J. Stone et al., PR C77 (2008) 014315

Magnetic moments: Ag isotopes (IS381)

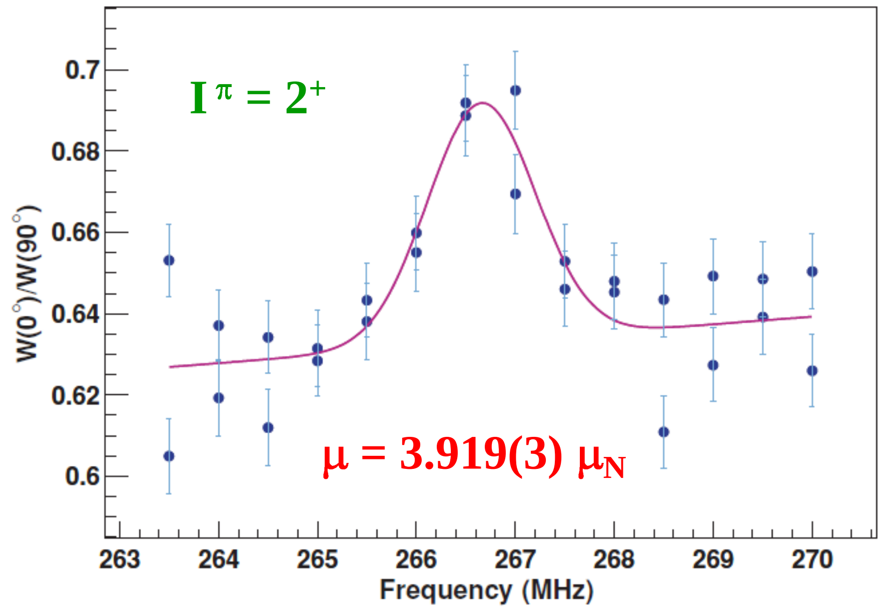
K.U.Leuven, NPI-Rez (Prague), Univ. Bonn, …

V.V. Golovko et al., PR C 81 (2010) 054323

β-NMR/ON ^{104m}Ag Fe



γ-NMR/ON ^{104m}Ag Fe



provided info on mixing of the $(\pi g_{9/2})^{-3}_{7/2^+}$ and $(\pi g_{9/2})^{-3}_{9/2^+}$ **proton hole groups**

each coupled to the $(\nu d_{5/2} \nu g_{7/2})^{n}_{5/2^+}$ **neutron configuration**

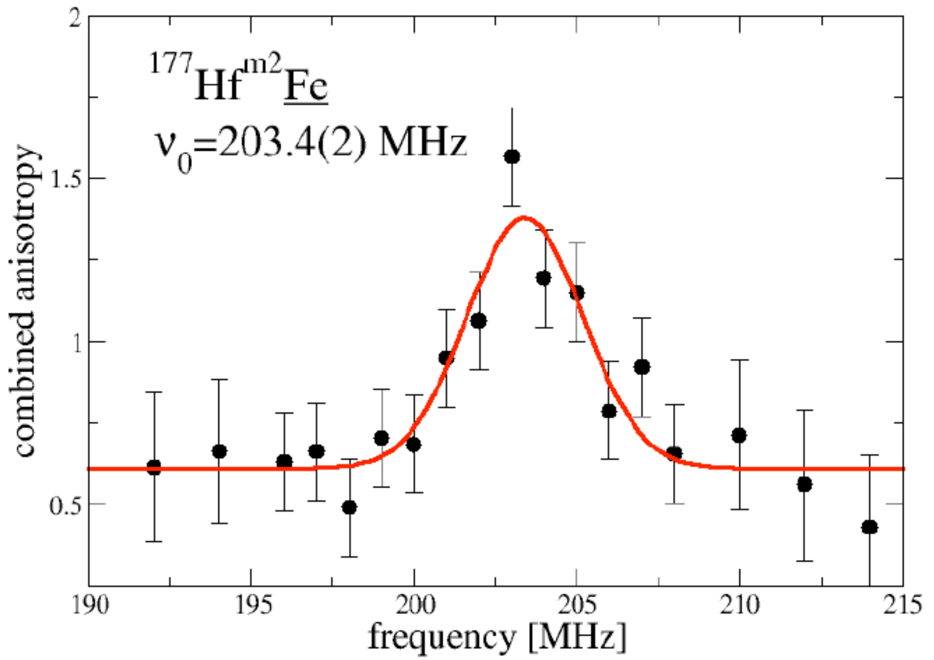
Magnetic moments: Hf isotopes (IS460)

Oxford Univ., Maryland Univ., CSNSM-Orsay, ILL-LPSC Grenoble, Niigata Univ., …

measurement of magnetic dipole moments of high-K isomers in Hf isotopes

(^{177m1}Hf, ^{177m2}Hf, ^{179m1}Hf, ^{180m1}Hf, ^{182m1}Hf)

HfF_3 beam at ISOLDE



N.J. Stone et al., INTC - P-229 - ADD-1

μ(^{177m2}Hf; 37/2$^-$ at 2740 keV) = 7.33(7) μ_N

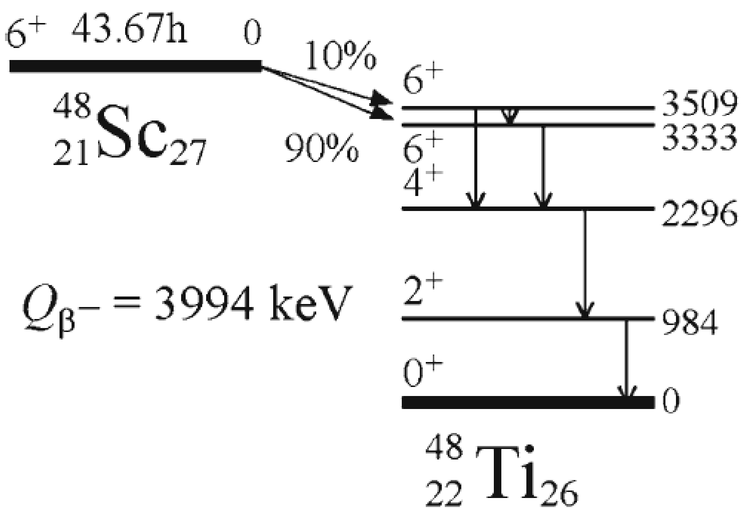
→ **collective g_R factor of band built on this state: g_R = 0.22(3)**

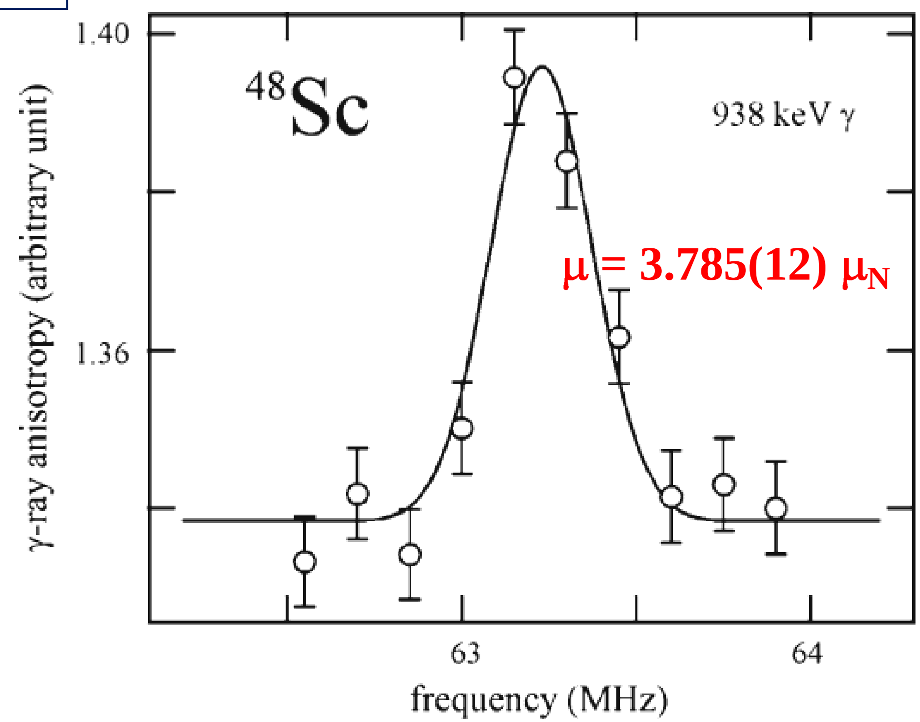
(preliminary)

Magnetic moments: Sc isotopes

Niigata Univ., Toyama Univ., KEK, …

T. Ohtsubo et al., Hyp. Int. 180 (2007) 79





^{48}Sc : doubly-closed shell ^{48}Ca plus one particle in $\pi(f_{7/2})$ orbital and one hole in $\nu(f_{7/2})$ orbital

- **theoretical moment values (3.36 – 3.51 μ_N; Honma 2004, van der Merwe 1994) systematically too low;**
- **comparison of experimental and theoretical moment values for ^{47}Ca and ^{47}Sc shows that the quenching of magnetic moments for the $\pi(f_{7/2})$ configuration around the ^{48}Ca core is overestimated in the calculations → more theoretical work needed**

Hyperfine anomalies: Sc isotopes

Niigata Univ., Toyama Univ., KEK, Tohoku Univ.

S. Ohya et al., Hyp. Int. 180 (2007) 55

arises from hf interaction of :

radially distributed nuclear magnetization over finite nuclear volume

and hyperfine field due to Fermi contact interaction

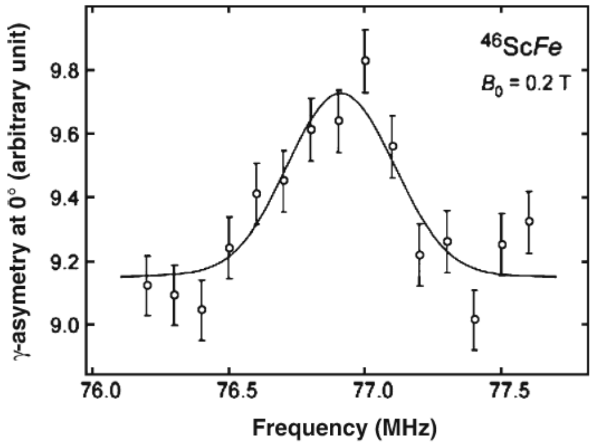
for single isotope defined as :

$$B_{hf} = B_0 (1 + \varepsilon_i)$$

difference for two isotopes:

$$^1\Delta^2 = \varepsilon_1 - \varepsilon_2$$

comparison with theory indicates many-configuration mixing



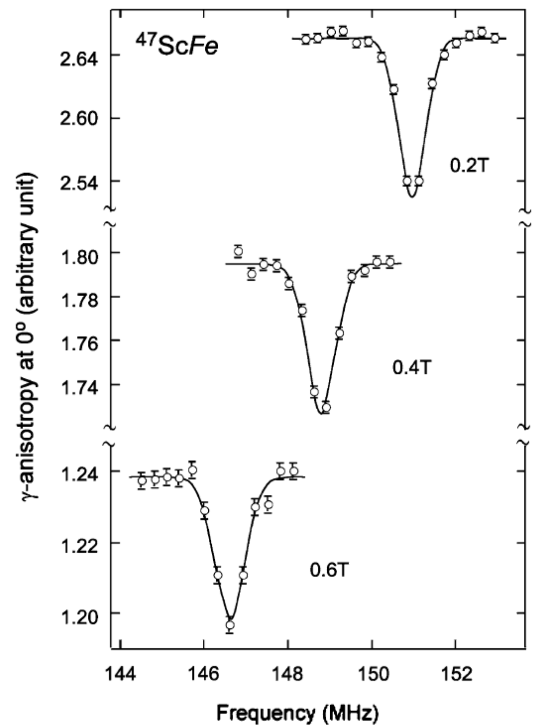


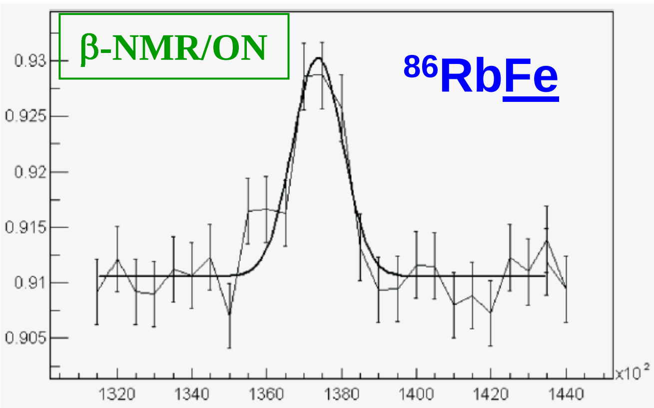
Table 1 Magnetic hyperfine fields of Sc isotopes in iron and the hyperfine anomalies

Isotope (A)	I^π	$\mu_{exp}(\mu_N)$ (Ref. [1])	B_{hf} (T)	$^A\Delta^{47}$(%)
^{47}Sc	7/2$^-$	+5.34 (2)	−13.17 (5)	
^{44}Sc	2$^+$	+2.56 (3)	−13.17 (15)	0.0 (12)
^{44m}Sc	6$^+$	+3.88 (1)	−13.33 (4)	1.2 (4)
^{46}Sc	4$^+$	+3.03 (2)	−13.52 (9)	2.7 (8)

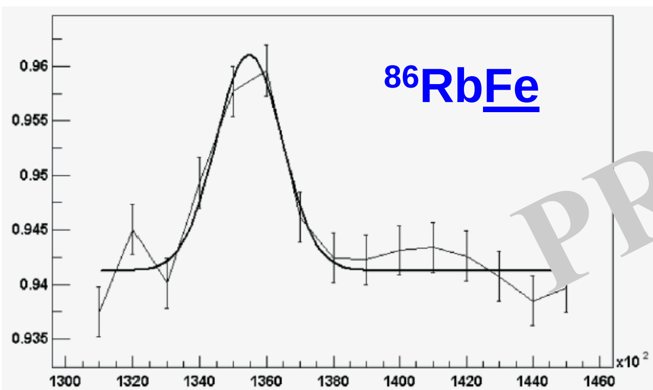
Hyperfine fields: Rb in Fe host (IS 431)

K.U.Leuven, NPI-Rez (Prague), Niigata Univ., …

F. Wauters et al.



B_{app} = 0.1 T → ν = 137.4 MHz

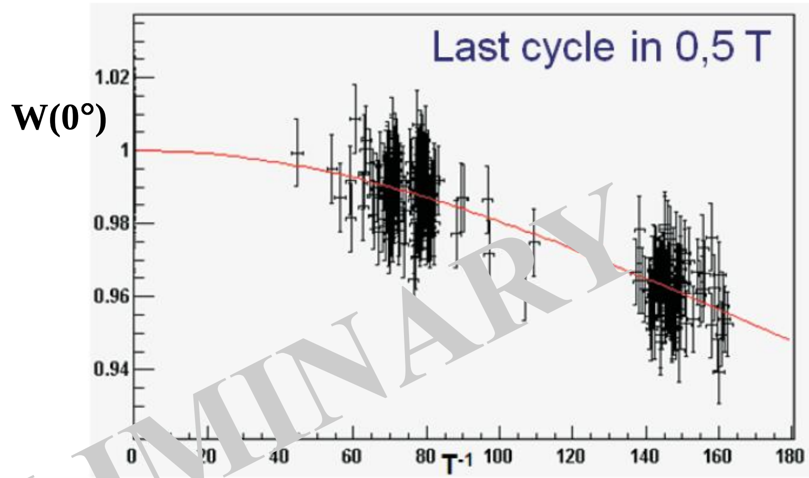


B_{app} = 0.4 T → ν = 135.4 MHz

also γ-NMR/ON on ^{83}Rb<u>Fe</u>

→ B_{hf} (Rb<u>Fe</u>) ≅ -21 T

BF-NO in B_{app} = 0.5 T and 13 T



$\underline{B_{app}}$	<u>W(0°)</u>
0.5 T	0.96
13 T	0.92

→ B_{hf} ≅ +14 T

<u>Note</u>: previously also two hyperfine field values observed for Cs and Fr isotopes

→ being investigated in more detail with ab-initio hf-field calculations (coll. S. Cottenier)

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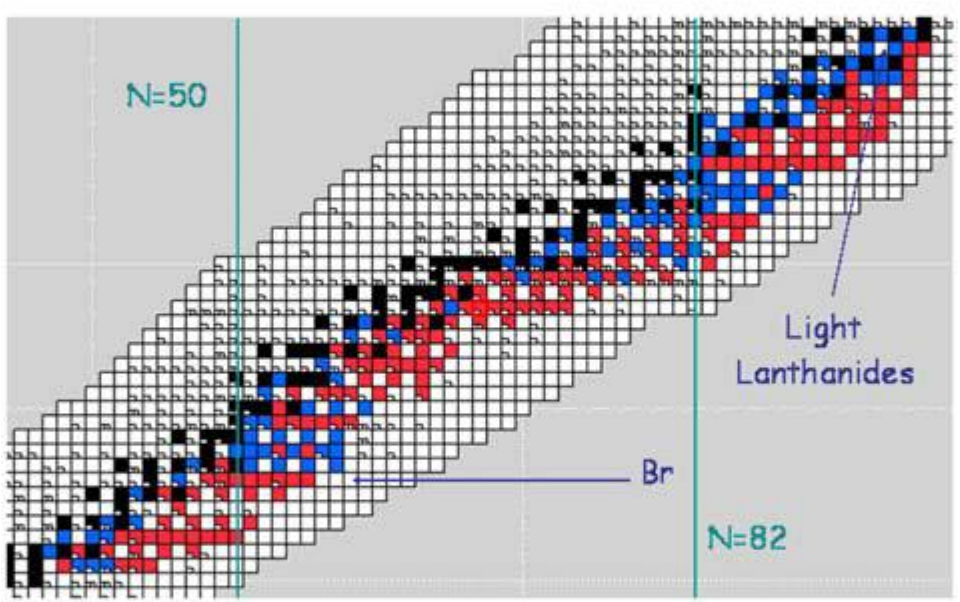
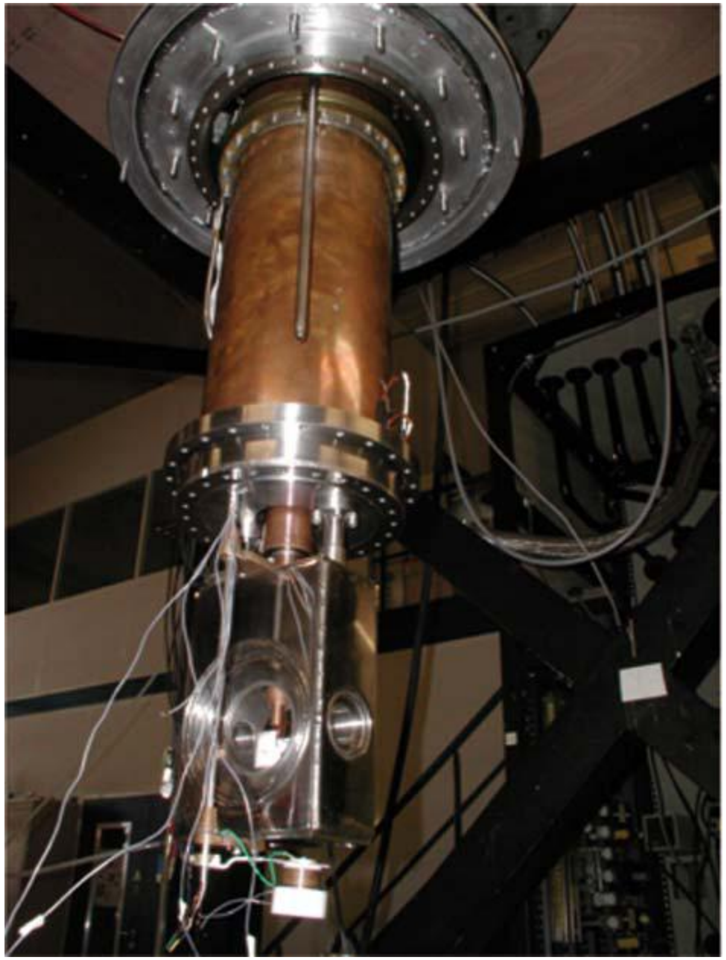
Polarex nuclear orientation facility

CSNSM-Orsay, Oxford Univ., Maryland Univ., …

L. Risegari et al., Eur. Phys. J. A 42 (2009) 307

- **new on-line NO setup at ALTO facility in Orsay to study properties of fission isotopes**
- **will focus mainly on nuclear magnetic moments**
- **first cases: $^{83-86}$Br isotopes and heavier Pm isotopes**





status: assembled at CSNSM-Orsay
commissioning (cf. poster)

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