Precision measurements of the beta-asymmetry parameter in nuclear beta decay as a probe for tensor-type weak currents

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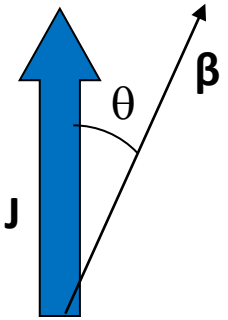
β anisotropies and tensor currents



Experimental observable

⇩

β-asymmetry parameter

Determination of GT/F mixing ratio for the T=1/2 →T=1/2 decays to get V_{ud}

O. Naviliat-Cuncic and N. Severijns , PRL 102 (2009) 142302

Neutron decay (λ)

e.g. UCNA and PERKEOII

Spin assignement of nuclear levels

Y. Hirayama et al., Phys. Lett. B 611 (2005) 239

Isospin mixing in ΔJ=0 GT transitions

N. Severijns et al., Phys. Rev. C 71 (2005) 064310

$$W(\theta) = \frac{\omega(< \mathbf{J} >)}{\omega(< \mathbf{J} >= 0)} = 1 + \widetilde{A}\,\frac{\mathbf{p_e}}{E} \cdot \frac{< \mathbf{J} >}{J}$$

Possible tensor-type weak currents

$$\widetilde{A}_{GT}^{\beta-} \cong A_{SM} + \frac{\gamma m}{E_e} Re\left(\frac{C_T + C_T'}{C_A}\right)$$

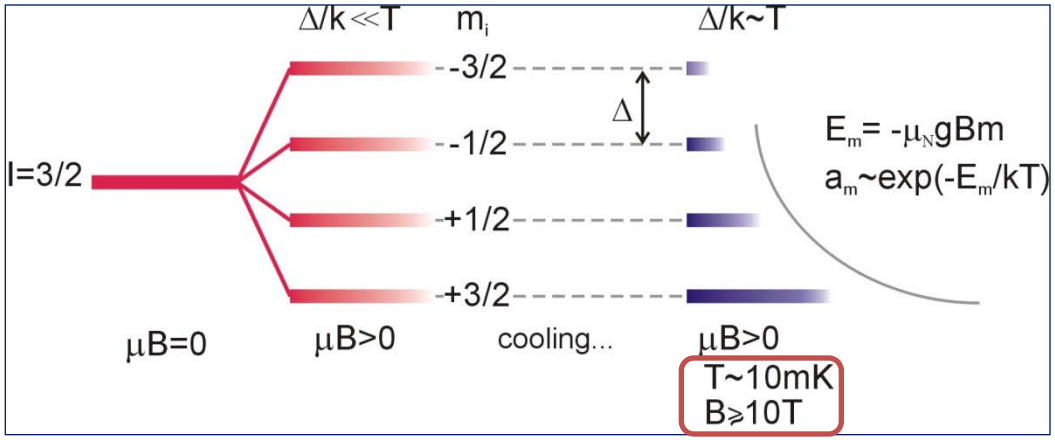
Low-energy β partciles

Overview

- Polarized nuclei with LTNO
- β asymmetries of ^{60}Co and ^{114}In
- Limits on tensor currents
- Future measurements and how to do better

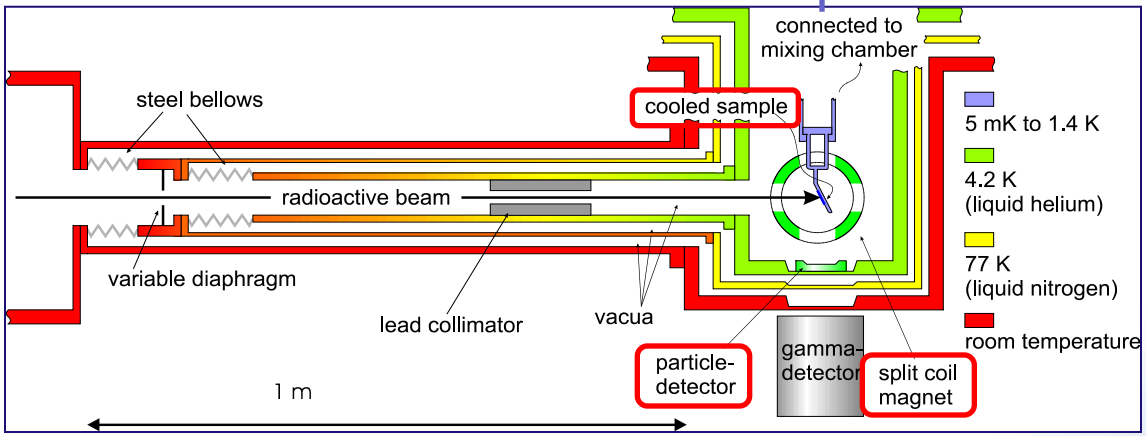
Polarized nuclei with LTNO

Low temprature nuclear orientation principle



Stable temperatures
~5mK

^{3}He/^{4}He dilution refrigerator



+ high, stable, and well-controled degree of polarization
  → γ anisotropies
+ wide variety of isotopes
  → $t_{1/2}$ > relaxation time (~10 s)
- solid sample foil
  → e^- scattering

↕

In-beam or in-trap polarization

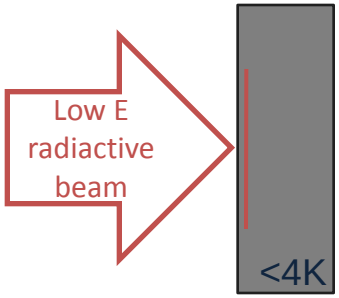
Polarized nuclei with LTNO

Technical challenges

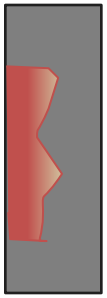
implanted | diffused | n activated

Sample foil

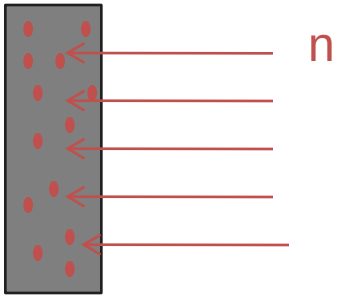
Needs to be a metal



~20 nm



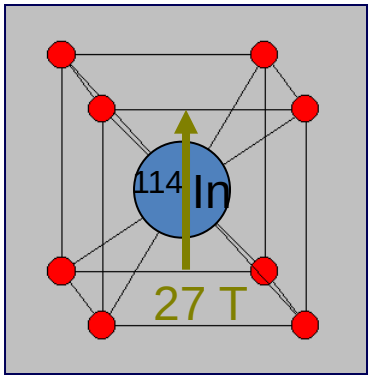
~2 µm



uniform

Magnetic field

Low magnetic field (0.1T)
+ hyperfine interactions
(high quality ferromagnetic sample)



Brute force,
external field
of ~10 T

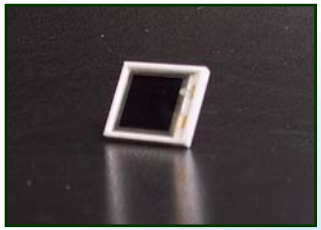
Detectors

Operate at ~10K
and in ~0.5T

4 mm HPGe detectors

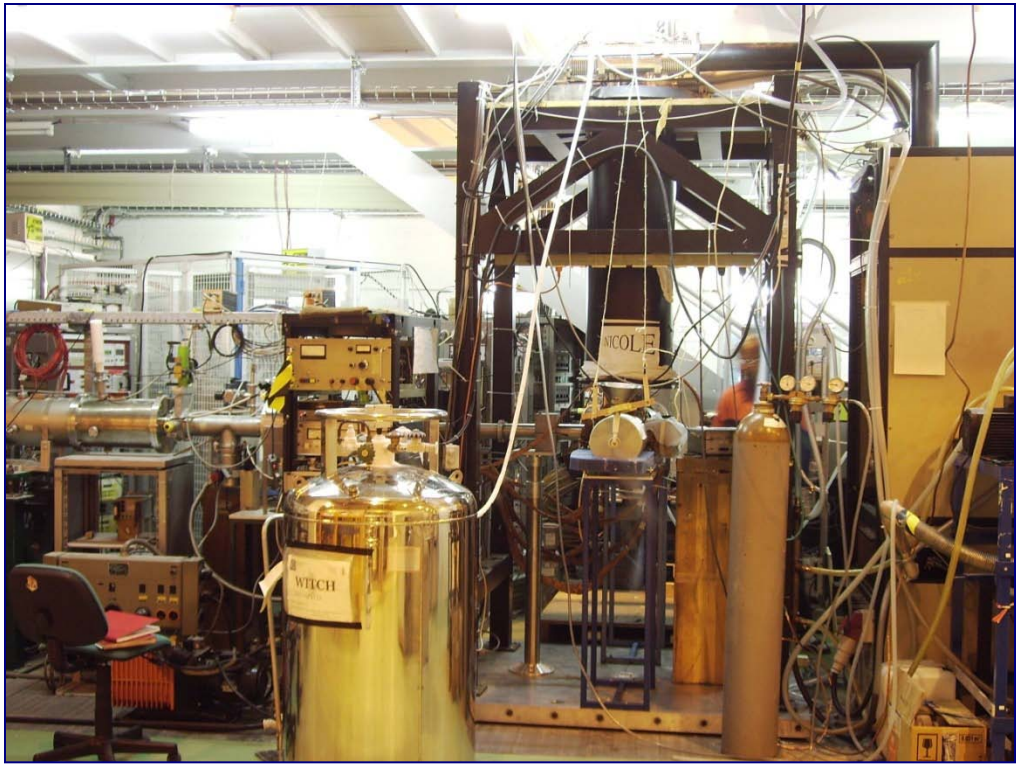
1.5 mm Si detectors

500 µm Si PIN diodes



Energy

Polarized nuclei with LTNO



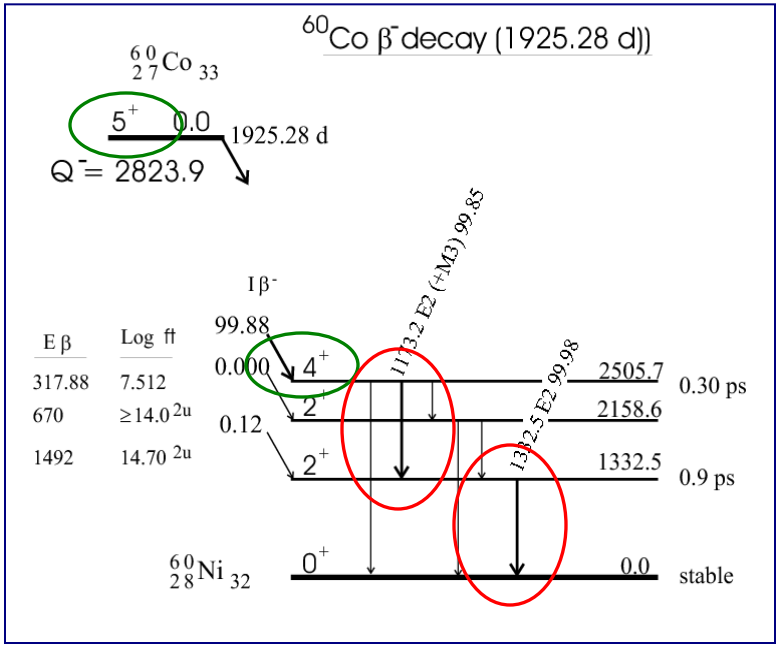
3 operational setups

- **On-line, low field in ISOLDE/CERN**
- **Off-line, low field in Leuven**
- **Off-line, high field (17T) in Leuven**

β asymmetries of ^{60}Co and ^{114}In

^{60}Co

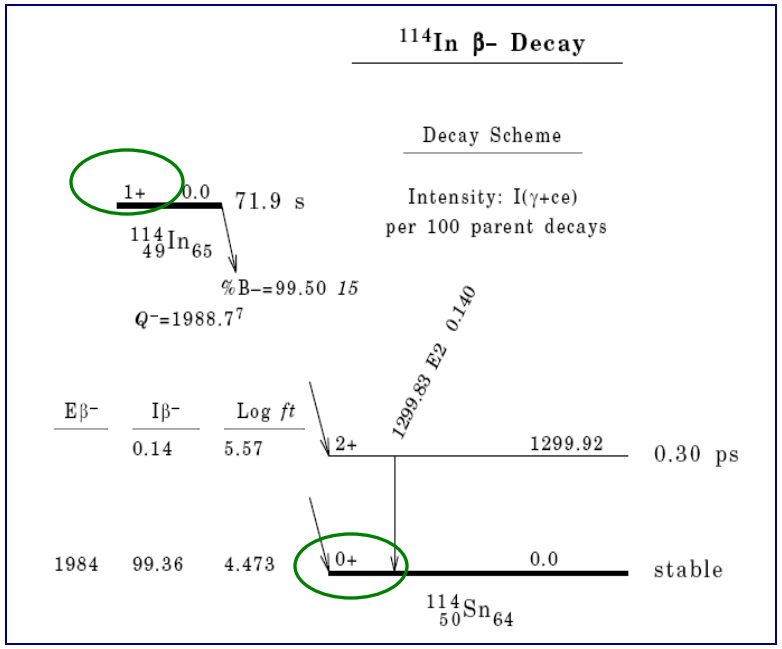
+ Low end-point → high γm/E (sensitive to C_T)
- High Log ft → Recoil corrections



- $^{57/60}$Co diffused in Cu
- **High external orienting field of 13 T**
- Si PIN diode detector

^{114}In

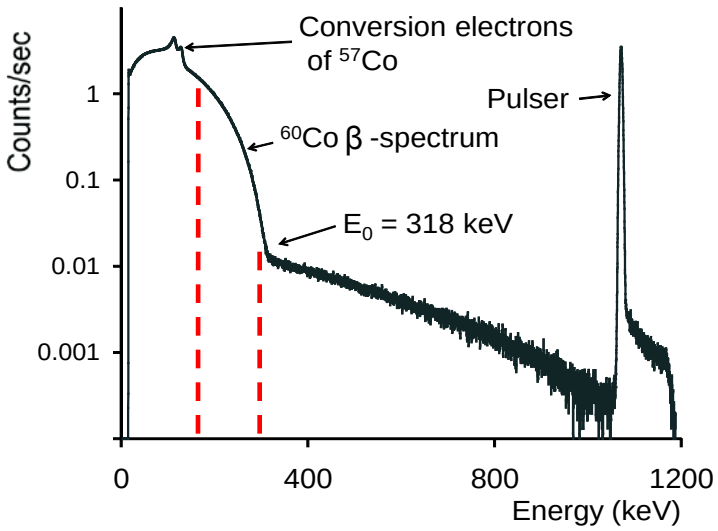
+ Low Log ft → fast clean transition
- High end-point → less sensitive to C_T

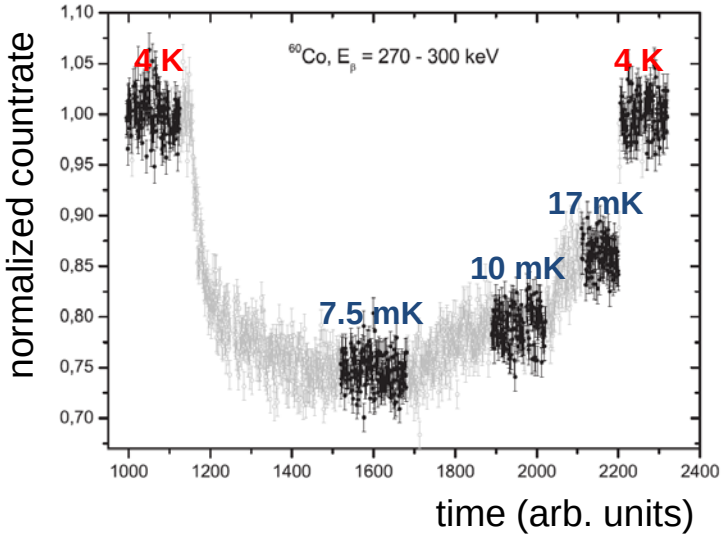


- ^{114m}In implanted in Fe
- **Low external field (~0.1T)**
  + internal hyperfine field of 27 T
- HPGe detector

β asymmetries of ^{60}Co and ^{114}In

^{60}Co

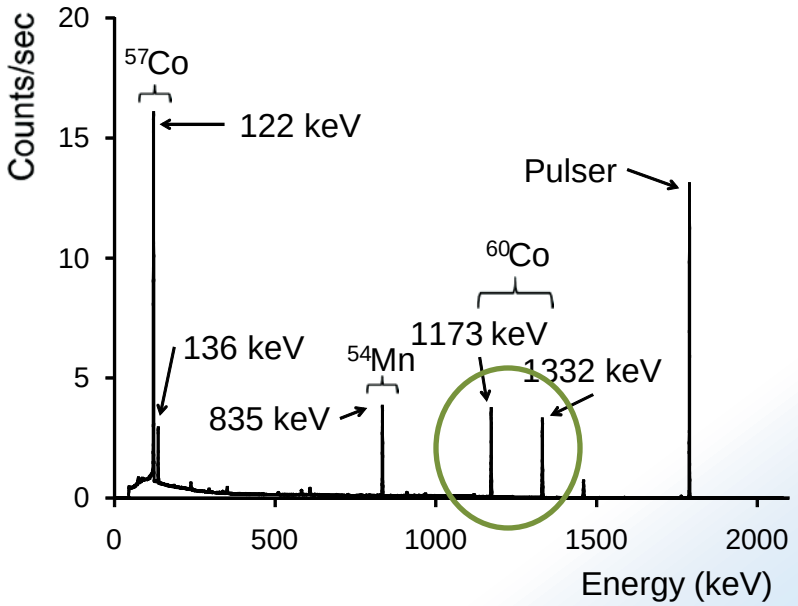




Understanding the observed β anisotropy:

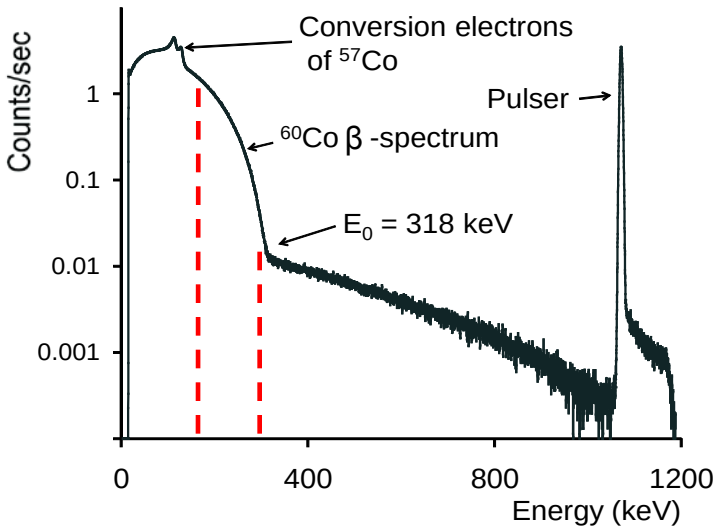
$$W(\theta) = \frac{N(\theta)_{cold}}{N(\theta)_{warm}} = 1 + f\,\tilde{A}\,P\,\frac{v}{c}\,Q\cos\theta$$

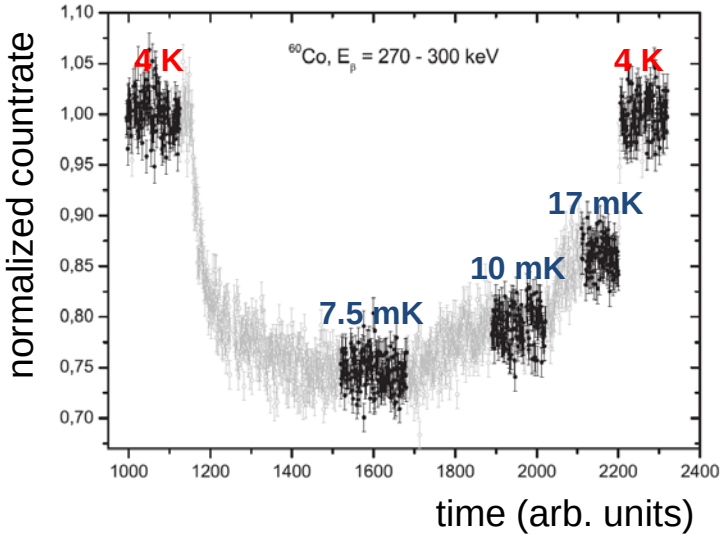
- Overall attenuation of the anisotropy
- Due to lattice sites, demagnetisation, ...
- Calibration measurement using γ anisotropies



β asymmetries of ^{60}Co and ^{114}In

^{60}Co

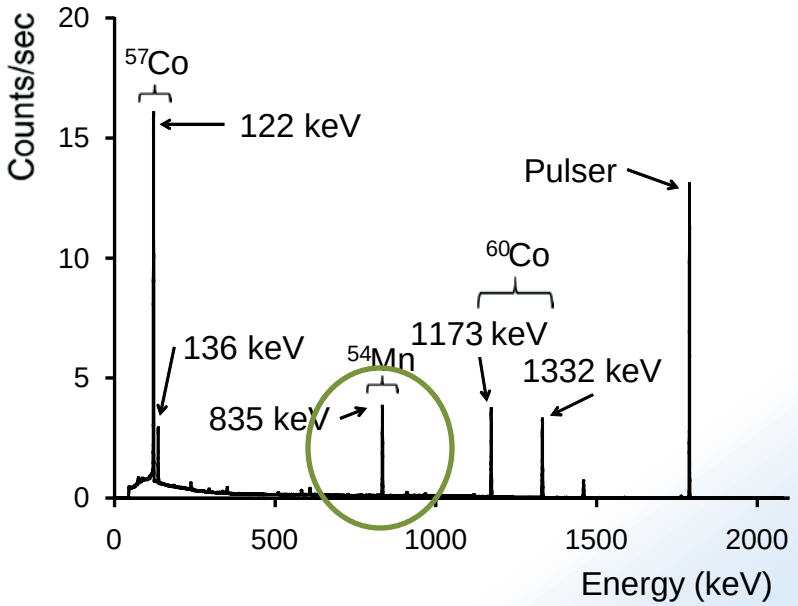




Understanding the observed β anisotropy:

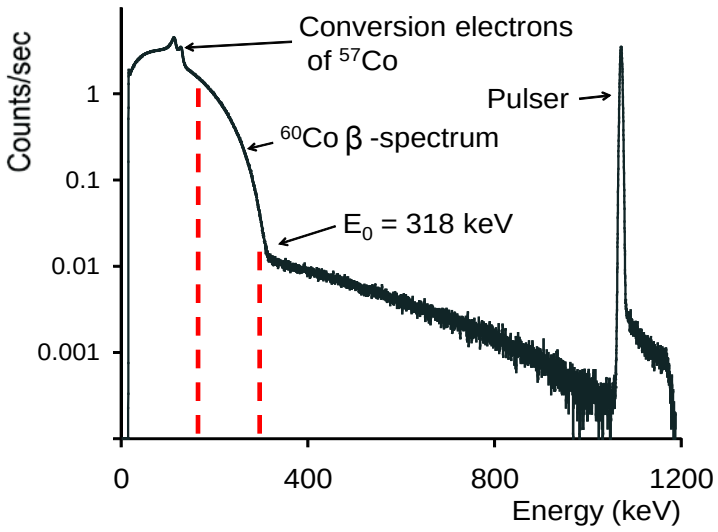
$$W(\theta) = \frac{N(\theta)_{cold}}{N(\theta)_{warm}} = 1 + f\ \tilde{A}\ P\ \frac{v}{c}\ Q\ \cos\theta$$

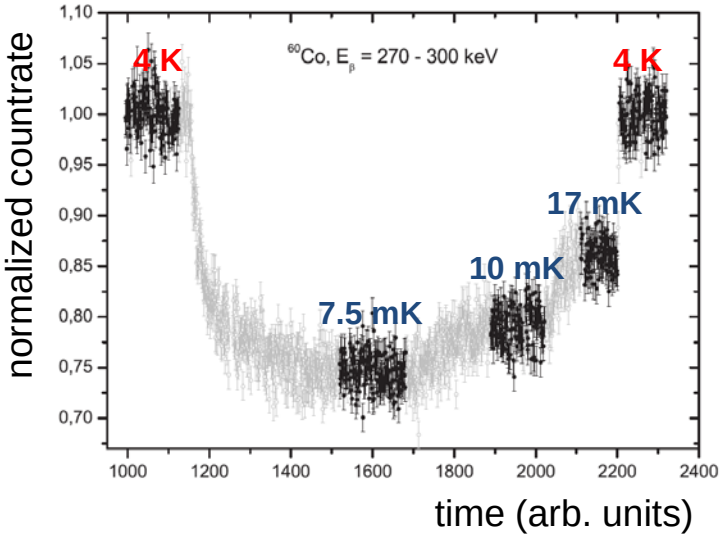
- Degree of orientation depends on temperature and hyperfine interaction μB
- Temperature from nuclear thermometer
- B_{ext} = 13T and 9T



β asymmetries of ^{60}Co and ^{114}In

^{60}Co





Understanding the observed β anisotropy:

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

MC simulation based analysis

Requires the knowlage of:

- Knowledge of initial speed of the β particles
- Effective solid angle of the detector
- Scattering of the β particle
- Deviation of their trajectories by the magnetic field

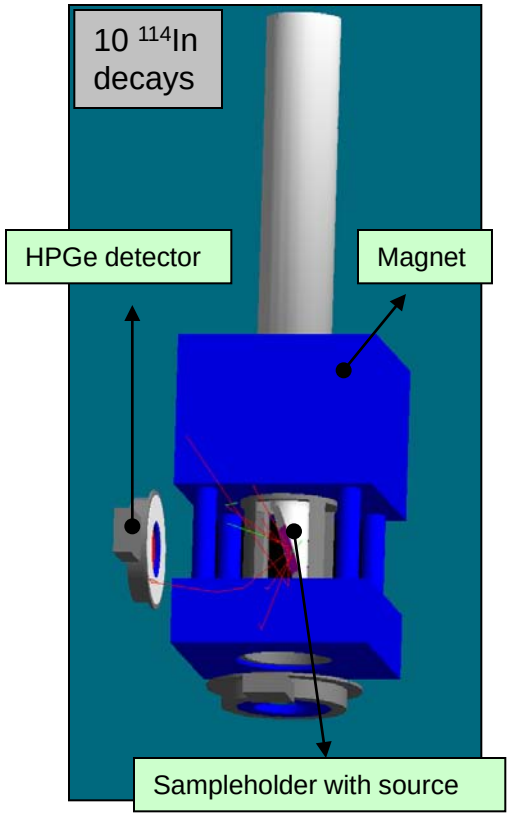
Geant 4

β asymmetries of ^{60}Co and ^{114}In

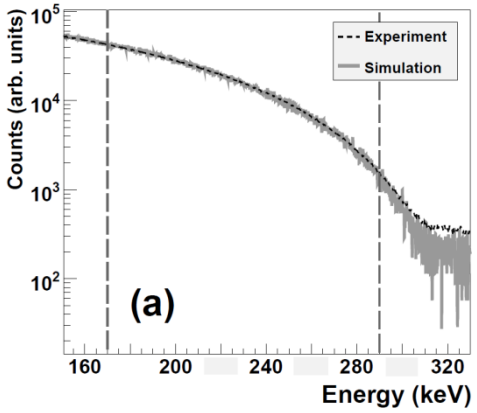
Development and validation of our GEANT4-based simulation code*

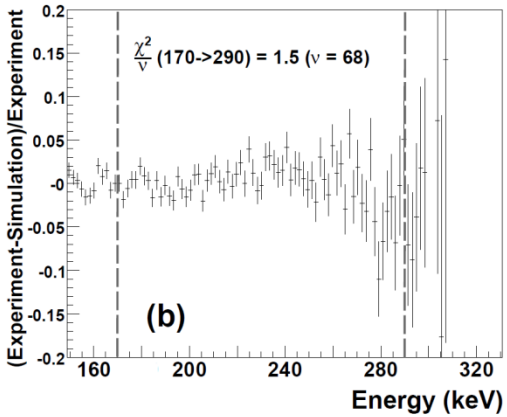
⇨ Poster: GEANT4 simulation used in the search for tensor type weak currents, Gergelj Soti

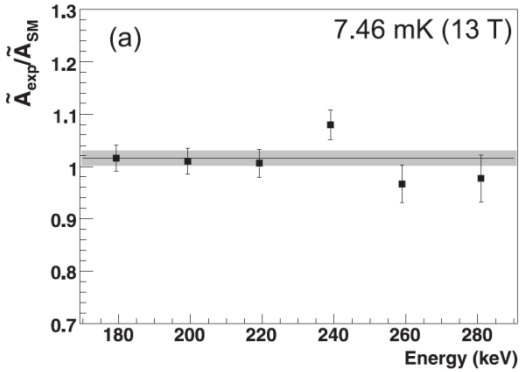
Philosophy: Simulate the complete experiment and compare to the experiment



^{60}Co







B_{ext} (T)	T (mK)	$\tilde{A}$	χ^2_ν	Stat. error
13	7.46	−1.015	0.6	0.015
13	10.42	−0.999	3.9	0.045
13	17.08	−1.050	1.4	0.032
9	7.38	−0.984	1.7	0.032
Weighted average				−1.014(12)

+ systematic effect study

* F. Wauters et al. NIMA 604 (2009) 563

β asymmetries of ^{60}Co and ^{114}In

^{60}Co

top 3 systematic errors

^{114}In

^{60}Co	
• Quality of the Monte Carlo simulations	1.0 %
• Source profile	0.9 %
• Fraction *f* determination	0.4 %

^{114}In	
• Quality of the Monte-Carlo simulations	0.6 %
• Geometry	0.3 %
• Fraction *f* determination	0.4 %

$\tilde{A} = -1.014(12)_{stat}(16)_{syst}$

F. Wauters et al., arXiv:1005.5034

$\tilde{A} = -0.990(10)_{stat}(10)_{syst}$

F. Wauters et al., PRC 80 (2009) 062501

$A_{SM}(J,J') \neq -1$

Recoil corrections

β asymmetries of ^{60}Co and ^{114}In

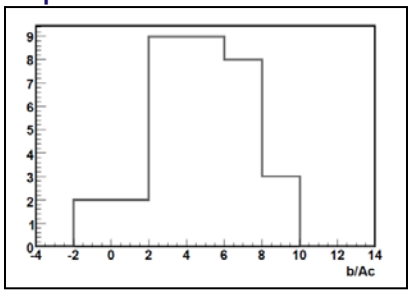
Recoil correction ⇨ Poster: A study of recoil terms for beta transitions in mirror and triplet nuclei, Veronique De Leebeeck

weak magnetism

$$A^{\beta^{\mp}}_{SM,GT} = \mp\frac{\gamma_{JJ'}}{J+1}\Big[1+\frac{1}{A}\Big[\frac{E+2m_e^2/E}{3M_n}\Big] \pm \frac{b}{Ac_1}\Big[\frac{E+2m_e^2/E}{3M_n}\Big] + \frac{d}{Ac_1}\Big[\frac{-E+m_e^2/E}{3M_n}\Big] \pm \frac{f}{Ac_1}\Big[\frac{\lambda_{JJ'}}{\gamma_{JJ'}}\frac{5E}{M_n}\Big]\Big]$$

^{114}In → fast transition 1+→0+ transition →

Spread of known values



→ A_{SM} = -0.996(3)

V. De Leebeeck et al., to be published

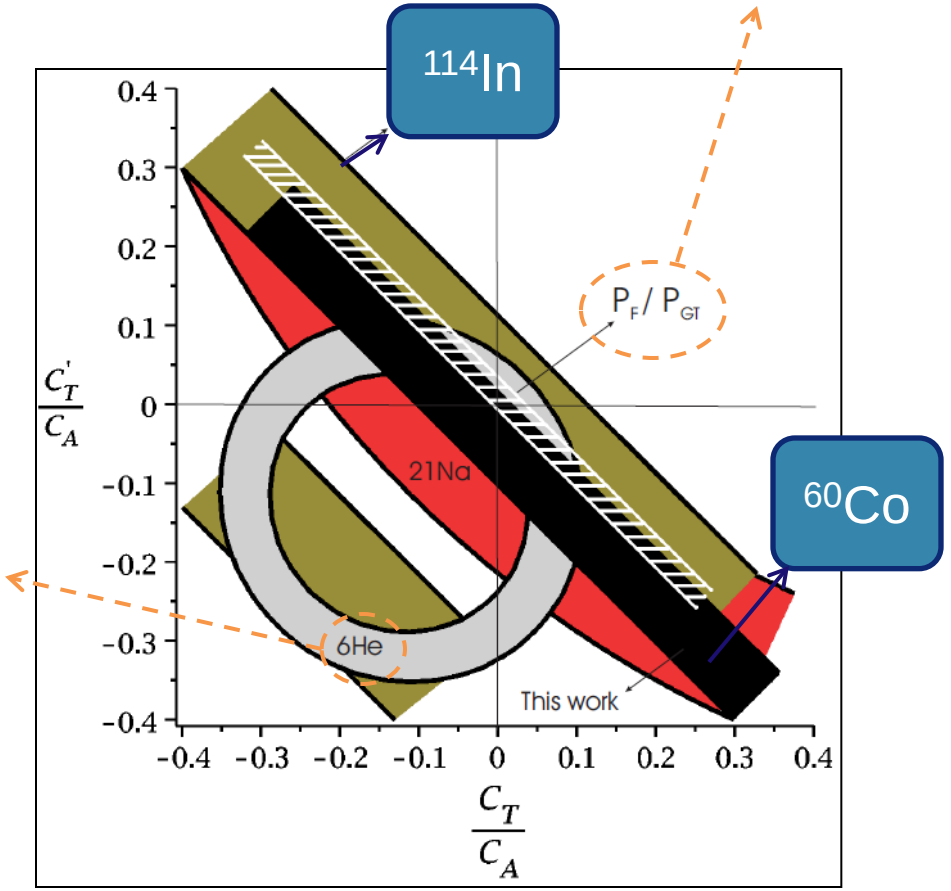
^{60}Co → Shell model calculation of all induced formfactors → A_{SM} = -0.987(9)

I. S. Towner, private communications

β asymmetries of ^{60}Co and ^{114}In

A. S. Carnoy et al. Phys Rev. C 43 (1991) 2825

$$\widetilde{A}_{GT}^{\beta-} \cong A_{SM} + \frac{\gamma m}{E_e} Re\left(\frac{C_T + C_T'}{C_A}\right)$$



β-ν correlation

C. H. Johnson et al. Phys Rev. 132 (1963) 1149
X. Fléchard et al., PRL 101 (2008) 212504
A. Knecht : Poster PSI2010

(Limits of $P_F(^{14}O)/P_{GT}(^{10}C)$ and ^{21}Na with $C^{(\prime)}_S$ set to zero)

Concluding

- **Most accurate** β-asymmetry parameters in nuclear decays
- Competing limits on C'_T

⇔ n decay ... π decay ... μ decay

β asymmetries of ^{60}Co and ^{114}In

^{60}Co

(Diffused) source profile and 13T external field major source of σ_{syst}

New low-field measurement with an implanted or **neutron** activated source

First on-line β-asymmetry measurements, performed at ISOLDE/CERN (under analysis)

^{67}Cu

^{133}Xe ^{47}Sc ^{77}As

Most promising candidates for a *near future* LTNO measurement with a ~1% precision or better

<1 % precision on Ã

Technical:
- Digital detector electronics
- Cooled pre-amplifiers
- 1.5 mm Si detectors operating close to 4K

Physics interpretation:
- Better control recoil order formfactors

Poster: Development of a backscatter-free β spectrometer for determination of weak magnetism recoil terms in allowed transitions, Emil Traykov

^{114}In

$$-0.082 < (C_T + C'_T)/C_A < 0.139\ (90\ \%\text{C.L.})$$

^{60}Co

$-0.088 < (C_T + C'_T)/C_A < 0.014$ (90% C.L.)

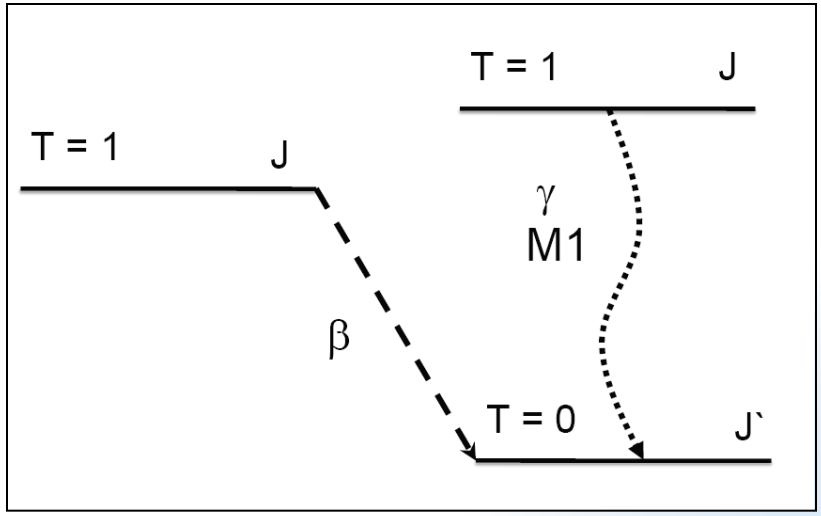
Table II: Values for $\widetilde{A}$'s for each of the four measurements with their statistical error bars.

B_{ext} [T]	T (mK)	$\widetilde{A}$	stat. error
13	7.46	-1.015	15
13	10.42	-0.999	45
13	17.08	-1.050	32
9	7.38	-0.984	32
		weighted average	-1.014(12)

Shell model calculation of nuclear matrix elements with three different interactions*

	KB3	FPMI3	GXPF1A
M_{GT}	-0.022	0.024	-0.002
$M_{\sigma r^2}$	-0.441	0.455	-0.046
M_L	0.169	-0.158	-0.153
$M_{\sigma L}$	-0.060	0.047	-0.059
M_Q	4.230	-4.246	-2.654
M_{1y}	1.973	-2.187	2.077
M_{2y}	-6.725	6.937	4.521

form factor	effect on A_{SM} (%)
b	+0.23
d	-0.15
f and g	+1.17
h	0.00
j_2	-0.22
c_2	0.00



Effect	Error (%)
Choice of region for analysis	0.4
Pile-up correction	0.3
Background subtraction*	0.25
Mismatch between simulation and experiment*	0.3
Choice of GEANT4 physics parameters*	0.5
Distribution of Co activity in Cu foil	0.9
μB of ^{60}Co(Cu) **	0.2
μB of ^{60}Co(Cu) and ^{57}Co(Cu) via the fraction f_{Co}**	0.32
Fraction f_{Co} determination of Co(Cu)	0.43
Temperature determination with ^{54}Mn	0.32
Geometry of the setup	0.02
Total	1.6

Table III: Total error account

Systematic effect	Correction [%]	Error [%]
Energy calibration		0.005
Simulations of the β asymmetry ($Qcos\theta$)		0.60
Geometry of the β detection setup		0.3
Magnetic field map		0.4
Apparent magnetic field dependence		0.4
Accuracy in setting the magnetic field		0.001
Geometry of the γ detection setup (f)		0.13
Effect of error on μB on the values of f (0.15 %) and $f\widetilde{A}$ (0.16 %)		0.31
Possible incomplete relaxation of ^{114}In and polarization inherited from ^{114m}In		0.3
Induced form factors b/Ac and d/Ac	-0.41	0.30
Systematics total	-0.41	1.0
Statistics (see Table II)		1.0
Sum	-0.41	1.4