Limits on tensor-type weak currents obtained with β-asymmetry measurements in nuclear decays

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What we measure

Isospin mixing in ΔJ=0 GT transitions
N. Severijns et al., Phys. Rev. C 71 (2005) 064310

Experimental observable

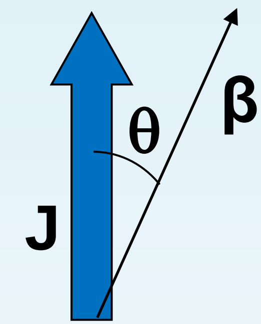
⇓

β-asymmetry parameter ⇒

Determination of GT/F mixing ratio for the $T=1/2 \rightarrow T=1/2$ decays to get V_{ud}
O. Naviliat-Cuncic and N. Severijns , PRL 102 (2009) 142302

Spin assignement of nuclear levels
Y. Hirayama et al., Phys. Lett. B 611 (2005) 239

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



Possible tensor-type weak currents

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

Low-energy β partciles

What follows

- **Polarized nuclei with LTNO**
- **Analysing the β asymmetries**
- **Ã of ^{60}Co and ^{114}In**
- **Limits on tensor currents**
- **Whats next?**

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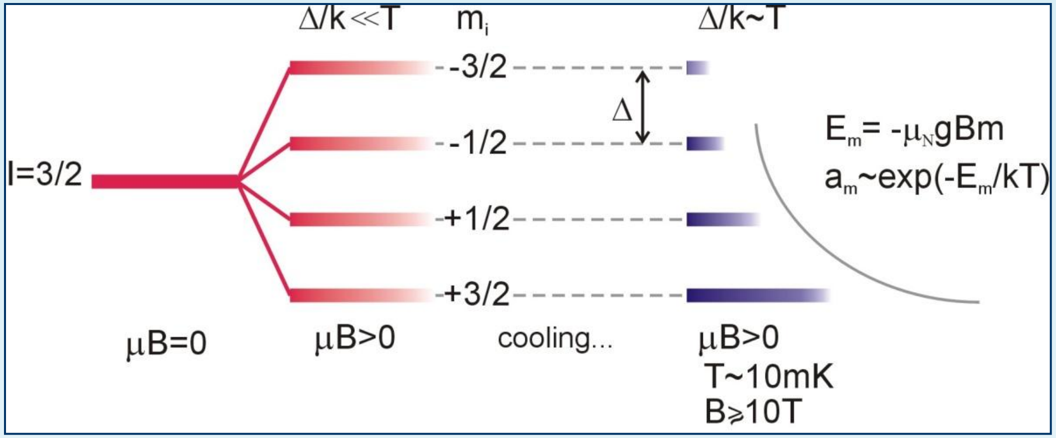
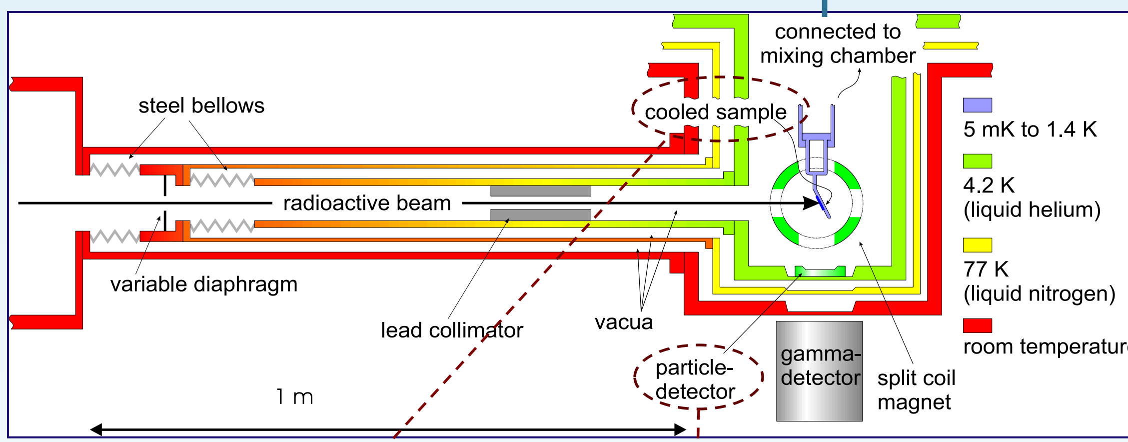
Polarized nuclei with LTNO





- \+ 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

↕

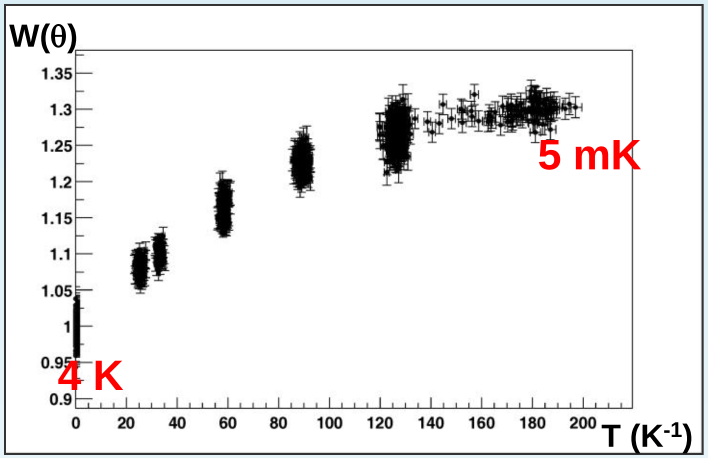
In-beam or in-trap polarization

3 operational setup: two off-line in Leuven (high and low field) and one at ISOLDE

Particle detectors (HPGe, Si PIN diode, PIPS) operating at ~10K and 1T

β anisotropies

The data :



We have set up a GEANT4-based code for our needs

Parametrization of the experimental measured β-anisotropy :

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

% atoms at good lattice sites
→ calibration measurement

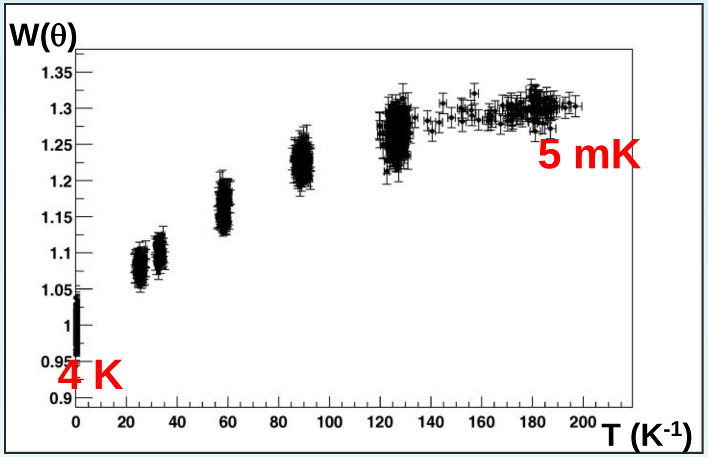
Degree of polarization, function of μB/T
→ γ-anisotropy of e.g. ^{57}Co

Initial energy / solid angle / scattering / magnetic field effects / ...

Monte Carlo simulations

Analysing the β anisotropies

The data :



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

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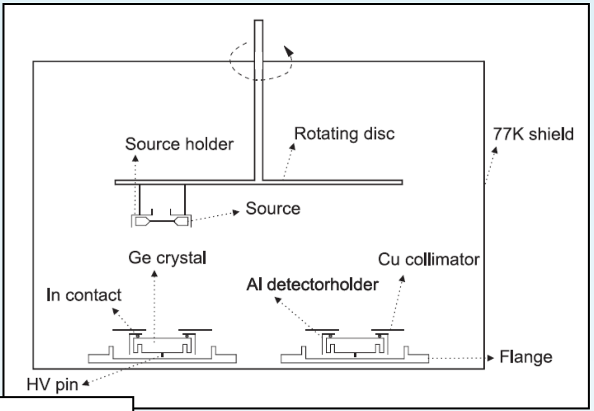
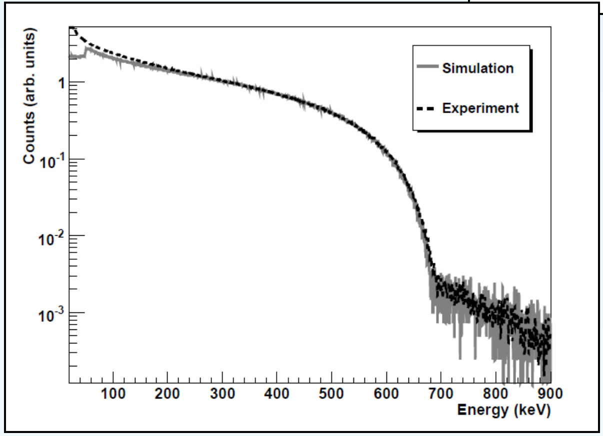
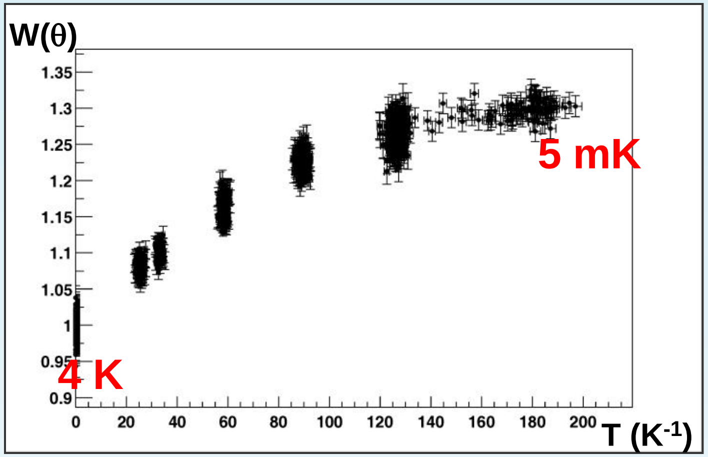




Analysing the β anisotropies

The data :



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

- Simulate the complete experiment

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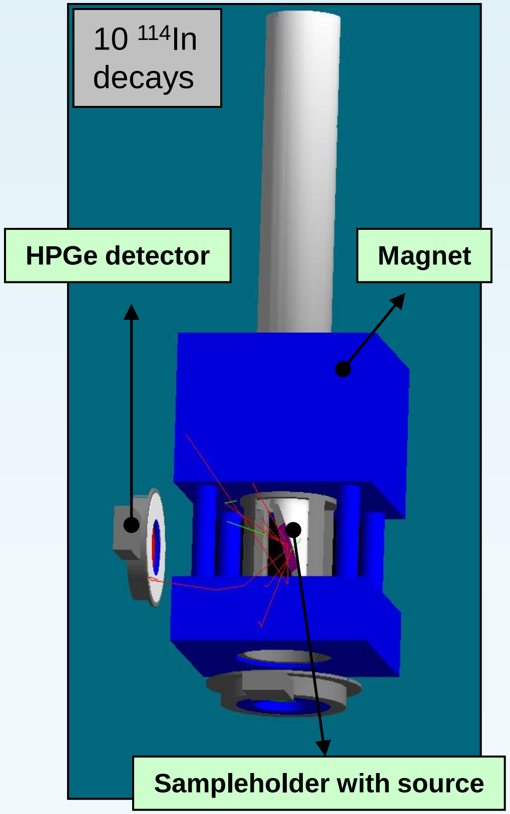
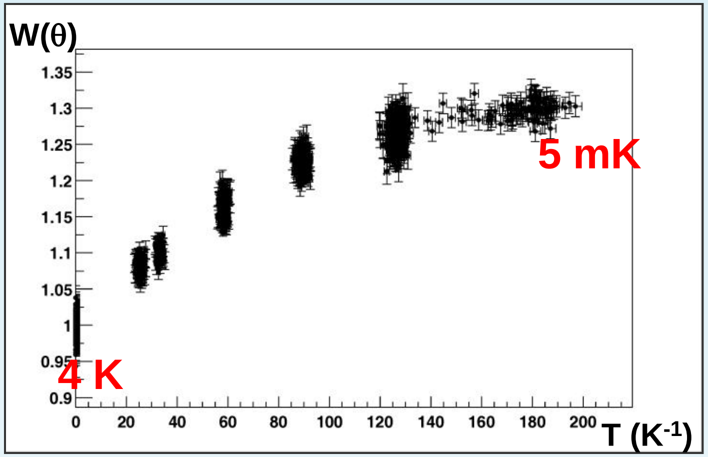


Analysing the β anisotropies

The data :



We have set up a GEANT4-based code for our needs

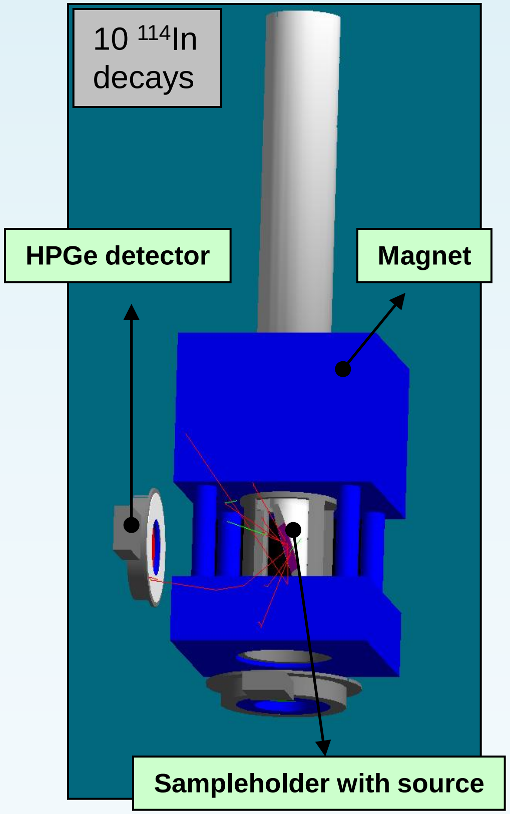
- Tuned and validated the code

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

- Simulate the complete experiment
- Quantify systematic effects

Parametrization of the experimental measured β-anisotropy :

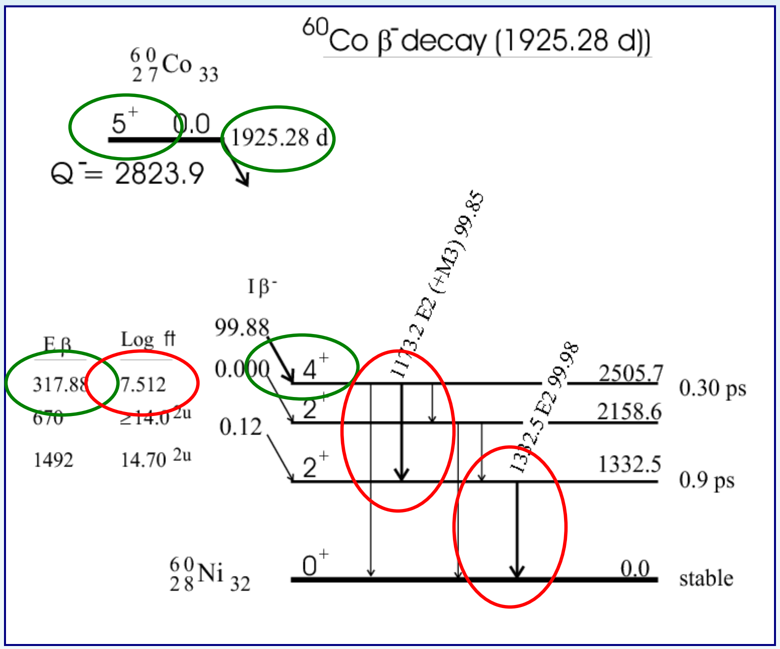
$$W(\theta) = \frac{N(\theta)_{cold}}{N(\theta)_{warm}} = 1 + f\ \tilde{A}\ P\ \frac{v}{c}\ Q\cos\theta$$



Ã of ^{60}Co and ^{114}In

^{60}Co

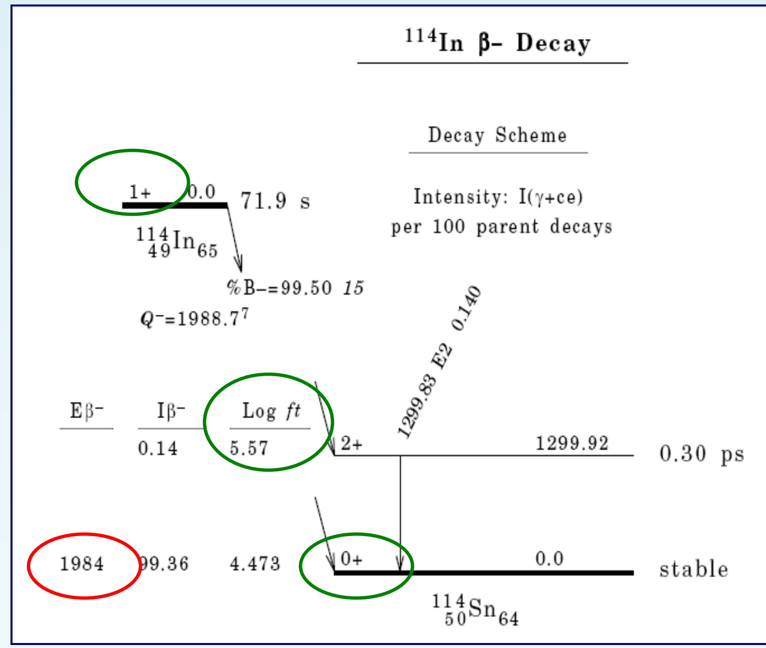
+ Low end-point → high γm/E (sensitive to C_T)
- High Log ft → Recoil corrections



- $^{57/60}$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 -28.7 T
- HPGe detector

$\tilde{A}$ of ^{60}Co and ^{114}In

^{60}Co

top 3 systematic errors

^{114}In

- **Quality of the Monte Carlo simulations → 1.0 %**
- **Source profile → 0.9 %**
- **Fraction *f* determination → 0.4 %**

- **Quality of the Monte-Carlo simulations → 0.6 %**
- **Geometry→ 0.3 %**
- **Fracrion *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

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

Recoil corrections

Limits on tensor currents

Recoil corrections

Ã in terms of induced form factors

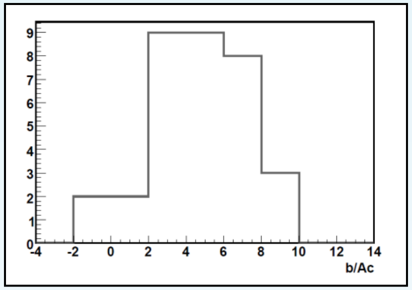
weak magnetism ← b

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

B.R. Holstein, Rev. Mod. Phys. **46** (1974) 789

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

CVC values



V. De Leebeeck et al., to be published

→ A_{SM} = -0.996(3)

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

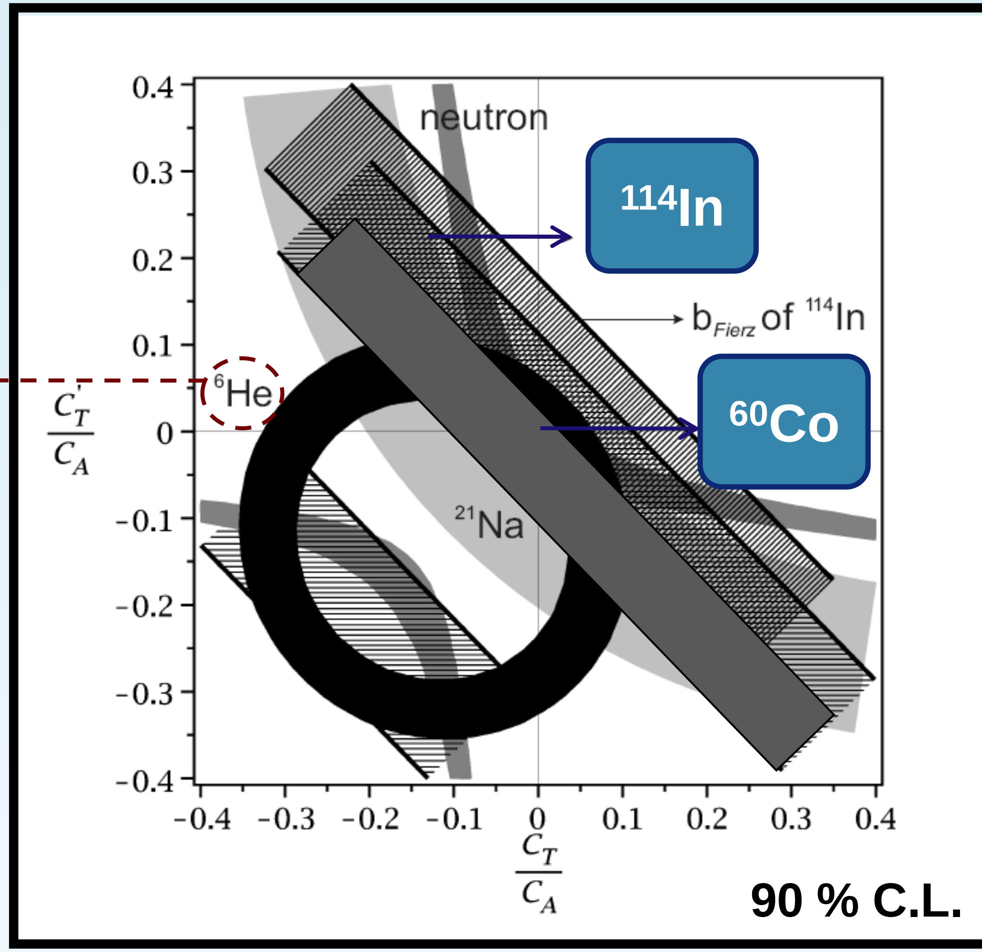
I. S. Towner, private communications

Limits on tensor currents

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

β-ν correlation

C. H. Johnson et al. Phys Rev. 132 (963) 1149
X. Fléchard et. Al., PRL 101 (2008) 212504



(Limits of n and ^{21}Na with $C^{(')}_S$ set to zero)

Concluding

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

Whats next?

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^{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
- 1.5 mm Si detectors operating close to 4K

Physics interpretation:
- better control recoil order formfactors

Other experiments/futher future
- βν-correlation ^{6}He
- In-trap polarization

J. A. Behr and G. Gwinner, J. Phys. G. 23 (2009) 033101

Extras

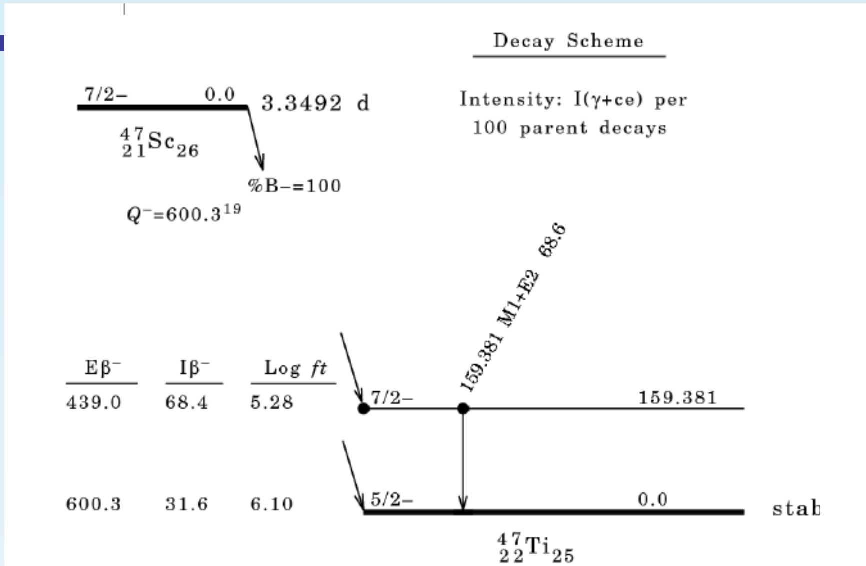
^{114}In

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

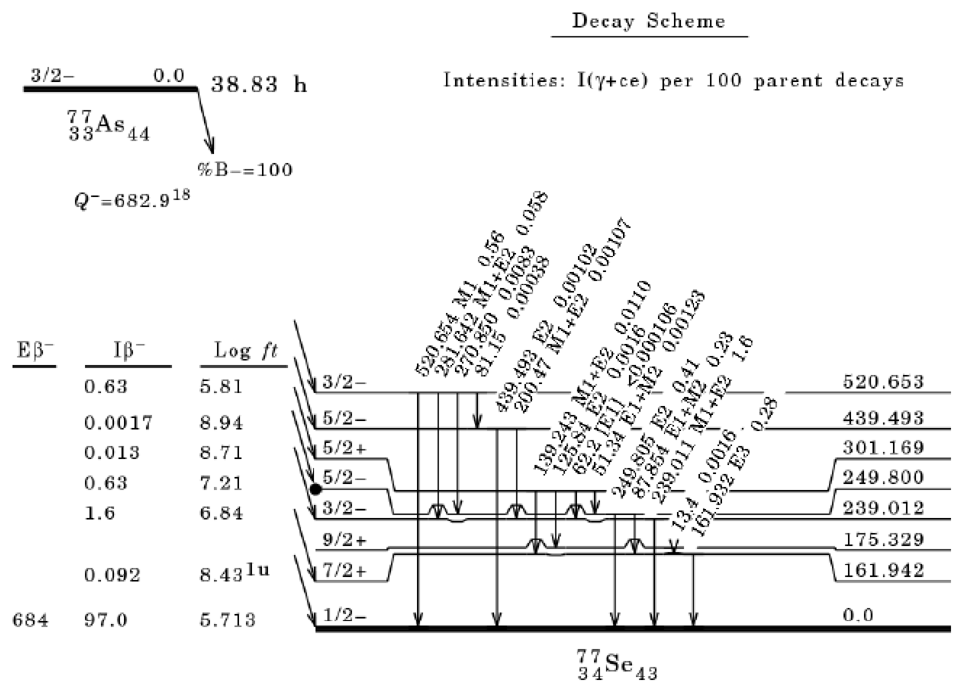
^{60}Co

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

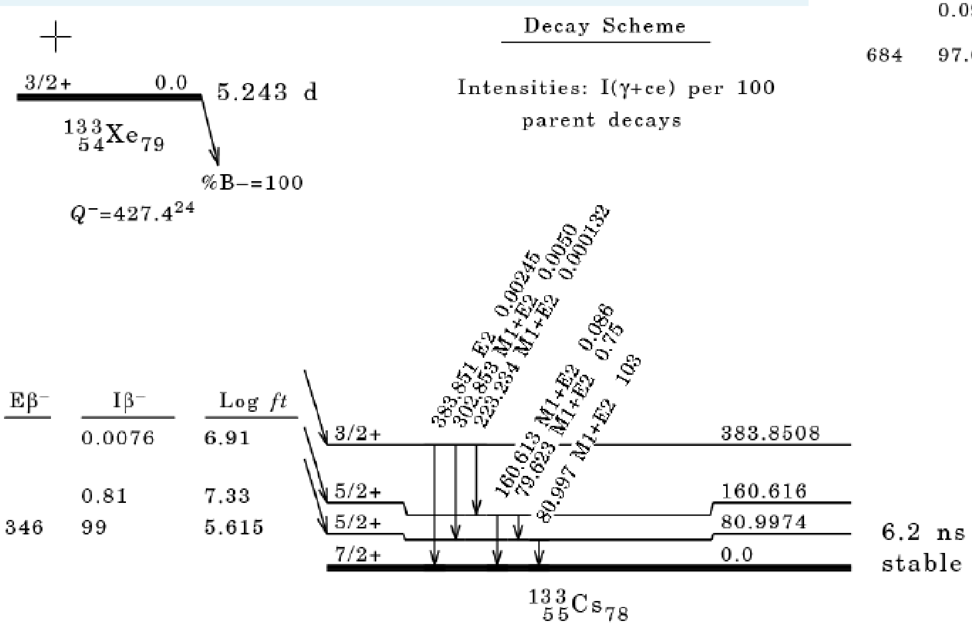
Extras



Decay Scheme
Intensity: I(γ+ce) per 100 parent decays
7/2− 0.0 3.3492 d
47 21 Sc 26
%B−=100
Q−=600.3 19
Eβ− Iβ− Log ft
439.0 68.4 5.28
600.3 31.6 6.10
7/2− 159.381
5/2− 0.0
159.381 M1+E2 68.6
stab
47 22 Ti 25

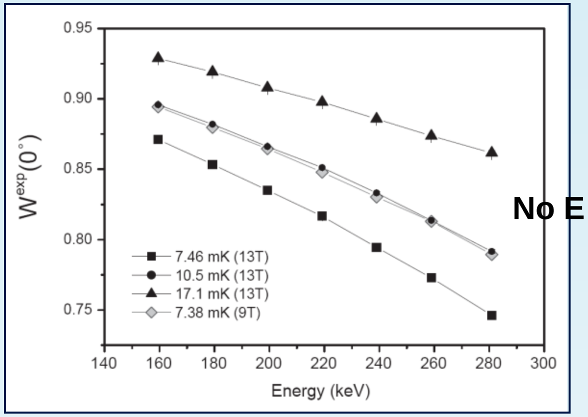


Decay Scheme
Intensities: I(γ+ce) per 100 parent decays
3/2− 0.0 38.83 h
77 33 As 44
%B−=100
Q−=682.9 18
Eβ− Iβ− Log ft
0.63 5.81 3/2− 520.653
0.0017 8.94 5/2− 439.493
0.013 8.71 5/2+ 301.169
0.63 7.21 5/2− 249.800
1.6 6.84 3/2− 239.012
9/2+ 175.329
0.092 8.43 1u 7/2+ 161.942
684 97.0 5.713 1/2− 0.0
77 34 Se 43

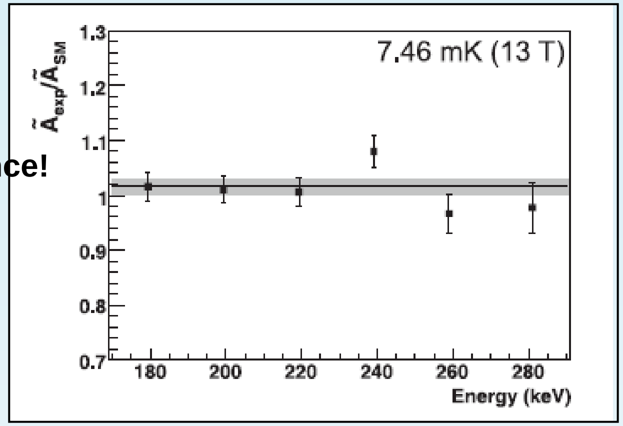


Decay Scheme
Intensities: I(γ+ce) per 100 parent decays
3/2+ 0.0 5.243 d
133 54 Xe 79
%B−=100
Q−=427.4 24
Eβ− Iβ− Log ft
0.0076 6.91 3/2+ 383.8508
0.81 7.33 5/2+ 160.616
346 99 5.615 5/2+ 80.9974
7/2+ 0.0
383.851 E2 0.00245
302.853 M1+E2 0.0050
223.234 M1+E2 0.000132
160.613 M1+E2 0.086
79.623 M1+E2 0.75
80.997 M1+E2 103
6.2 ns
stable
133 55 Cs 78

Extras



No E dependence!



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

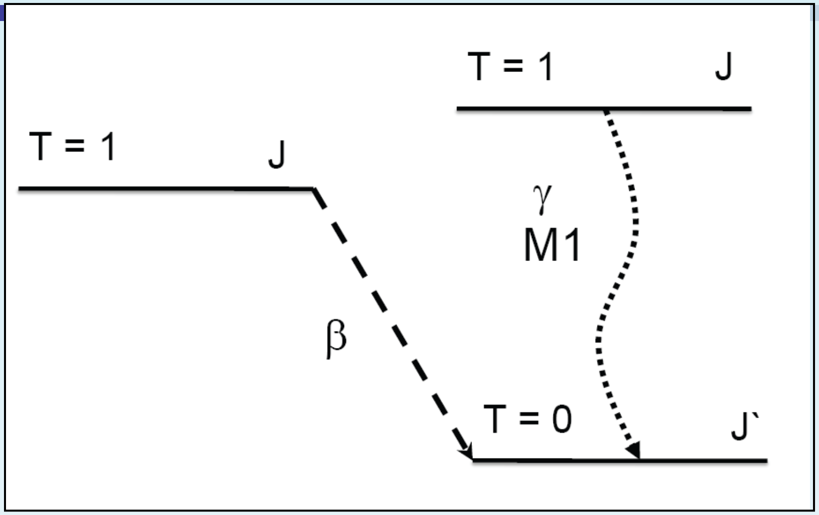
	KB3	FPMI3	GXPF1A
M_{GT}	-0.022	0.024	-0.002
$M_{\sigma r^2}$	-0.441	0.455	-0.046
M_L	0.169	-0.158	-0.153
$M_{\sigma L}$	-0.060	0.047	-0.059
M_Q	4.230	-4.246	-2.654
M_{1y}	1.973	-2.187	2.077
M_{2y}	-6.725	6.937	4.521

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

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

B_{ext} [T]	T (mK)	$\tilde{A}$	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)

Extras



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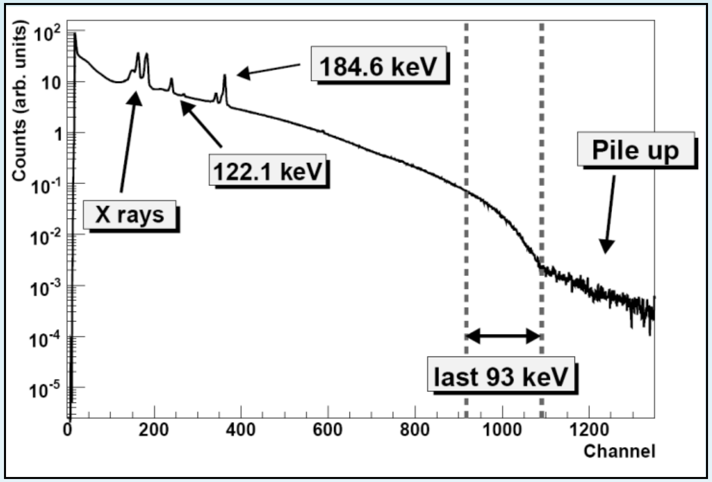
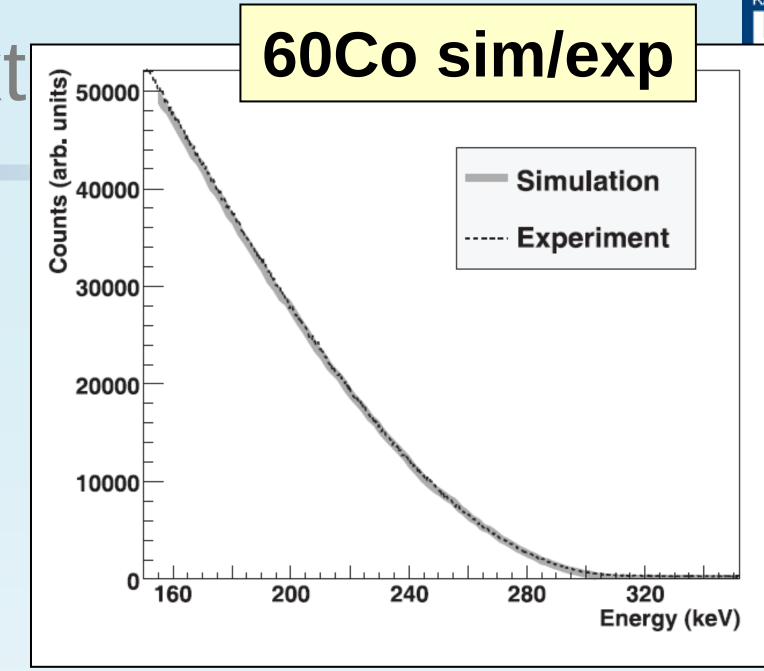
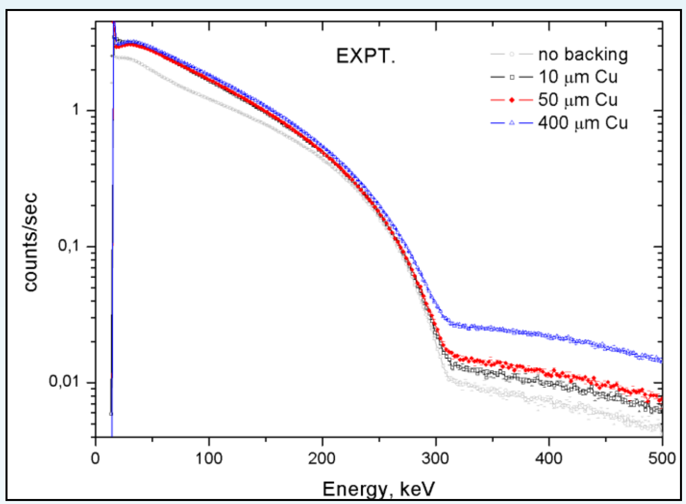
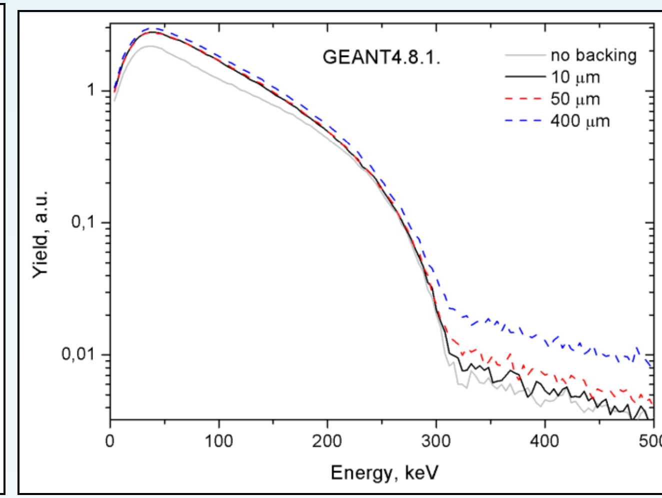
Ext



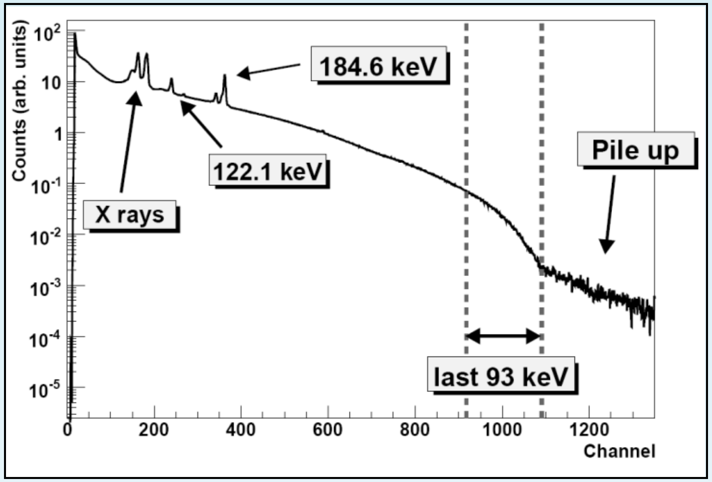




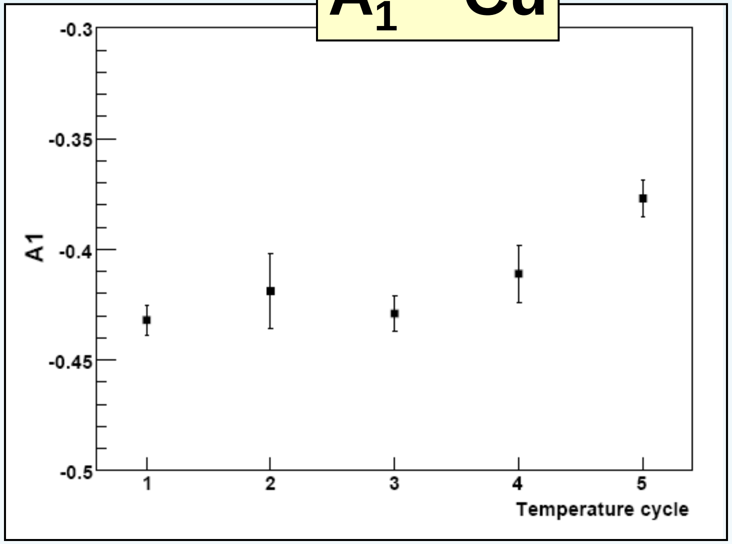


Extras

60Co sim/exp



A_1 ^{67}Cu



Extras

Extras

TRINAT