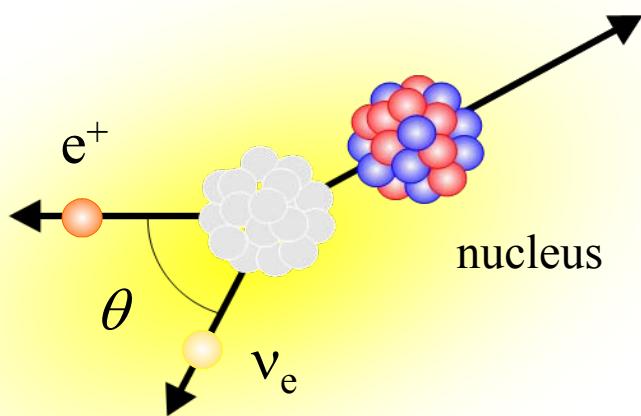


New method to determine the β asymmetry parameter for nuclei in search for a tensor type weak interaction



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1. Physics motivation

Beta decay hamiltonian:

- Most general case $\rightarrow H_\beta = H_V(C_V, C'_V) + H_S(C_S, C'_S) + H_A(C_A, C'_A) + H_T(C_T, C'_T)$

- In the SM $\rightarrow H_\beta(C_V, C'_V, C_A, C'_A)$

$$C_{V,A}/C'_{V,A} = 1, |C_A/C_V| \cong 1.26, \text{Im}(C_{V,A}) = 0$$

V-A theory of the weak interaction

$$(C_S = C'_S = C_T = C'_T = 0)$$

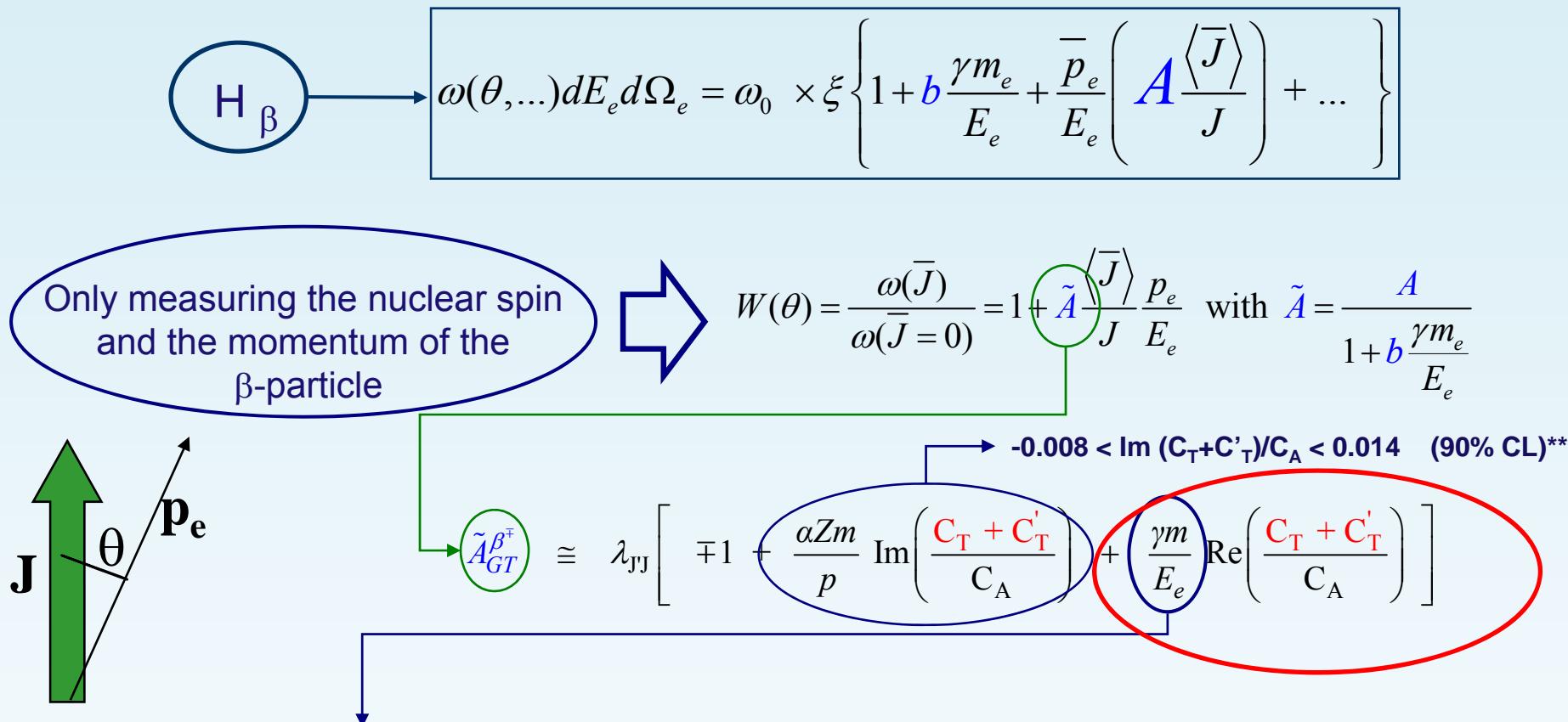
$$|C_S/C_V| < 0.070 \quad |C'_S/C_V| < 0.067$$

$$|C_T/C_A| < 0.090 \quad |C'_T/C_A| < 0.089$$

(95.5 % C.L)**

** N. Severijns et. al. , Rev. Mod. Phys., 78 , 991 (2006)

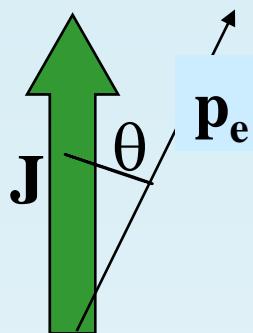
2. Beta asymmetry parameter A



Sensitivity factor → Low β -endpoint

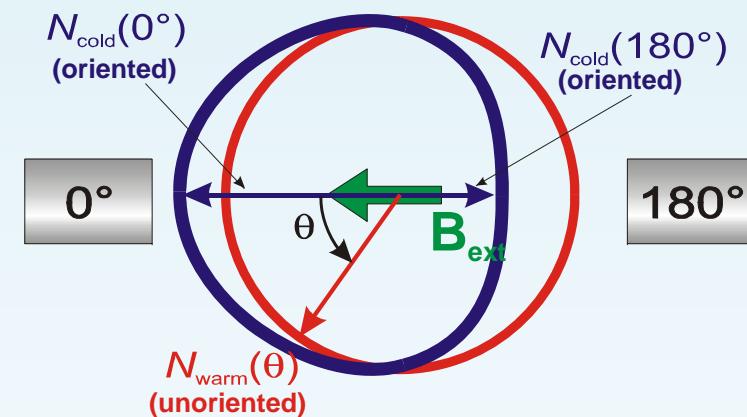
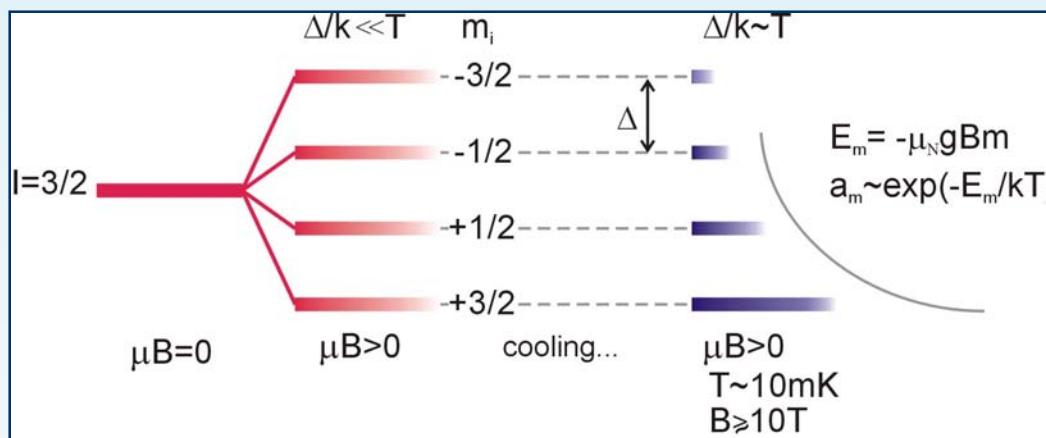
e.g. $\Delta A = 0.01 \rightarrow \operatorname{Re} [(C_T + C'_T) / C_A] < 0.033$
(for $\gamma m/E_e \approx 0.5$; 90% CL)

3. Experimental technique : Low temperature nuclear orientation



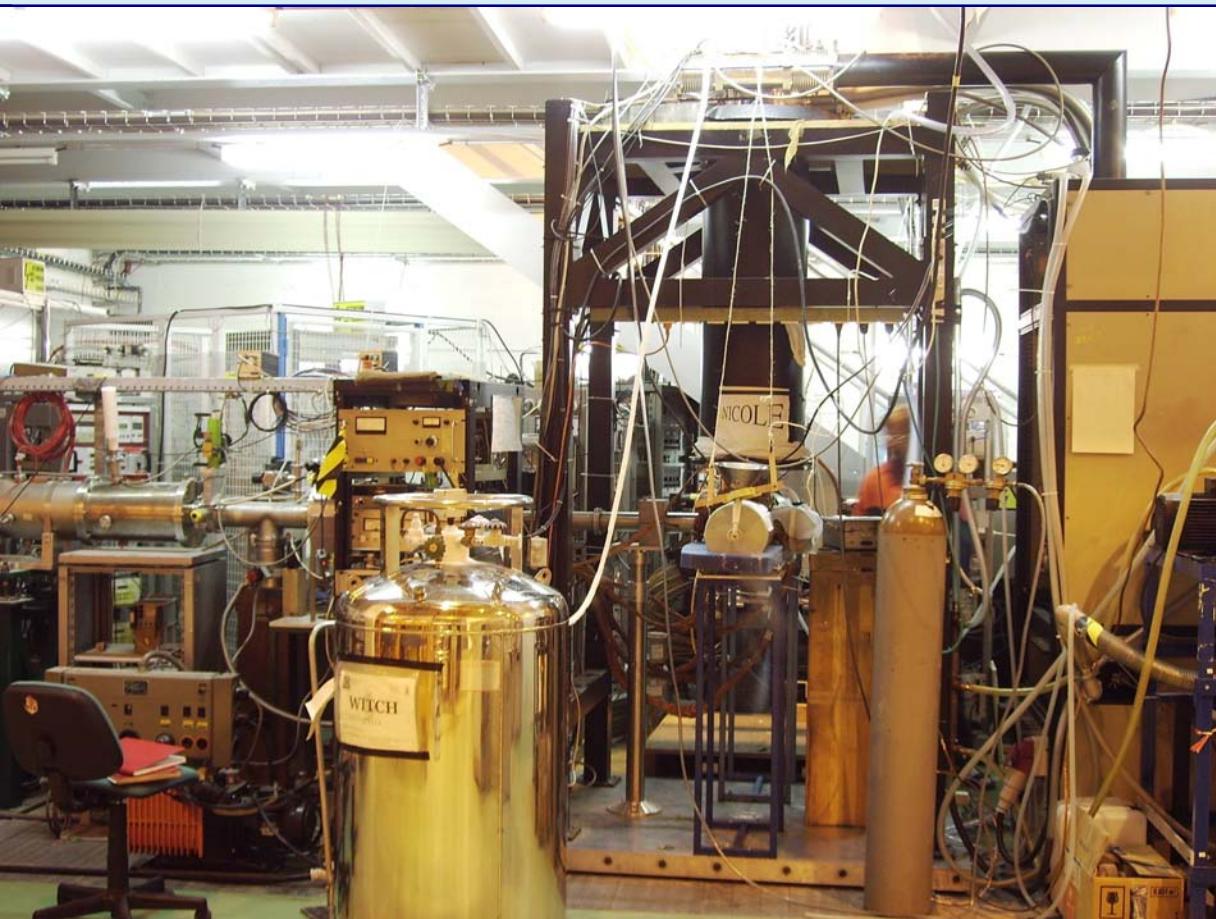
$$H = -\bar{\mu} \cdot \bar{B}_{mag}$$

Create an oriented ensemble of nuclei with LTNO



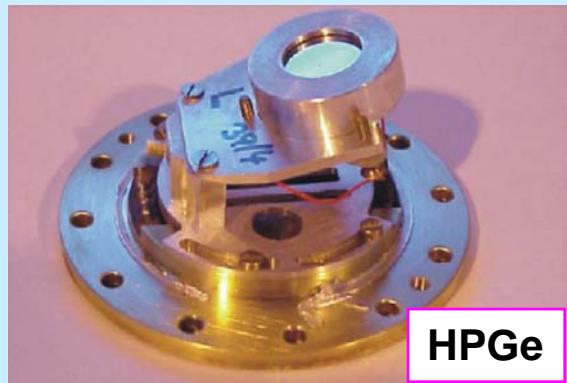


High-field setup (Leuven)

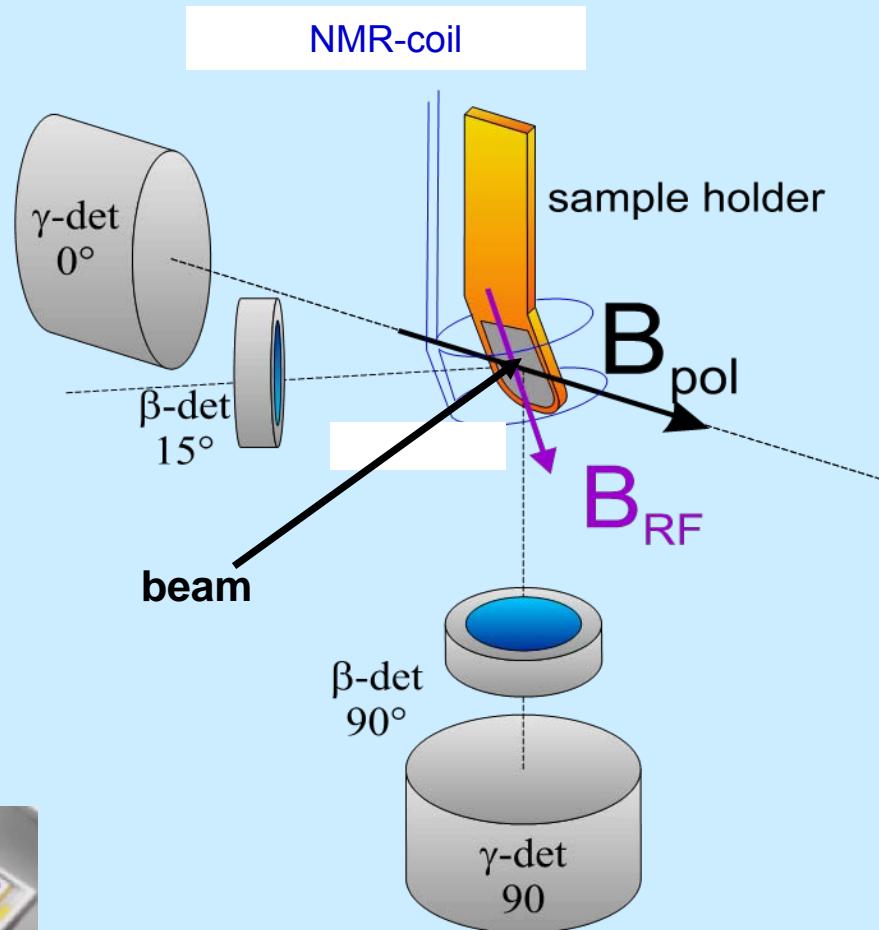
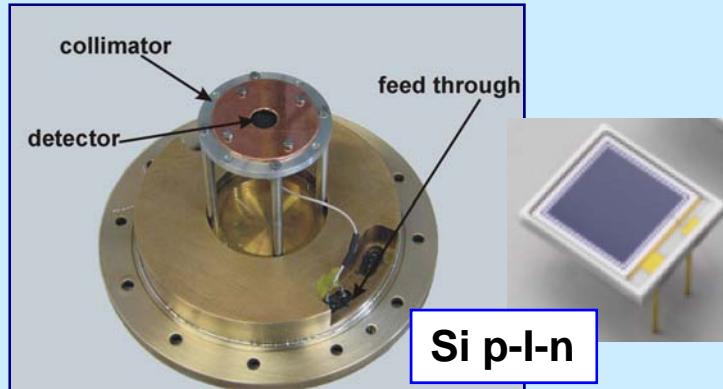


On-line NICOLE set-up, ISOLDE/CERN

Detection of β particles



operating inside refrigerator at $T \sim 10$ K



4. Parametrization of the experimentally measured β anisotropy

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

% atoms at good lattice sites, coming from a calibration measurement

Degree of polarization, function of $\mu B/T$

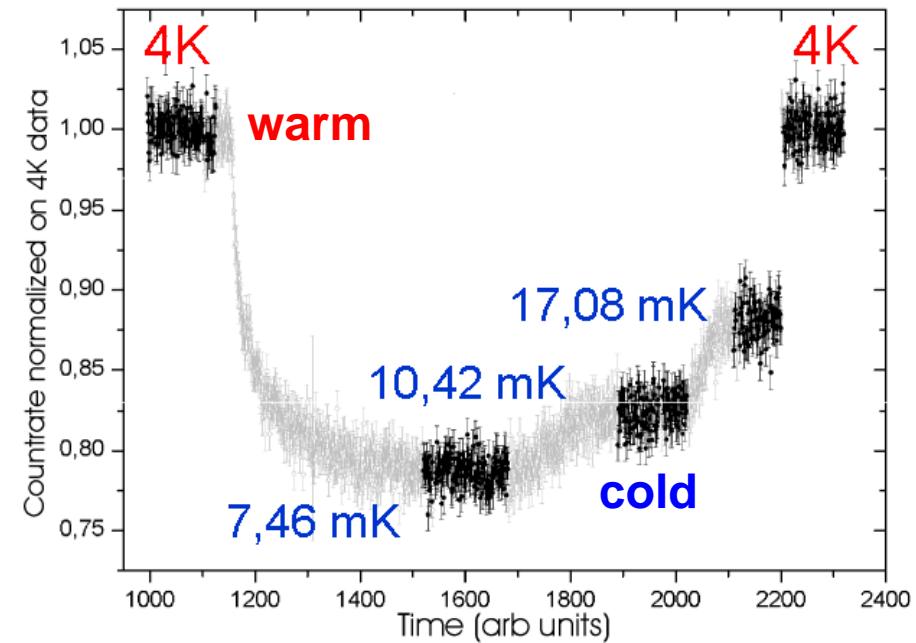
Initial energy / solid angle / scattering / magnetic field effects / ...

GEANT4 Monte Carlo simulations

$$P = f(p_m) = f(I_i, \mu, B, T)$$

v = velocity of β particle

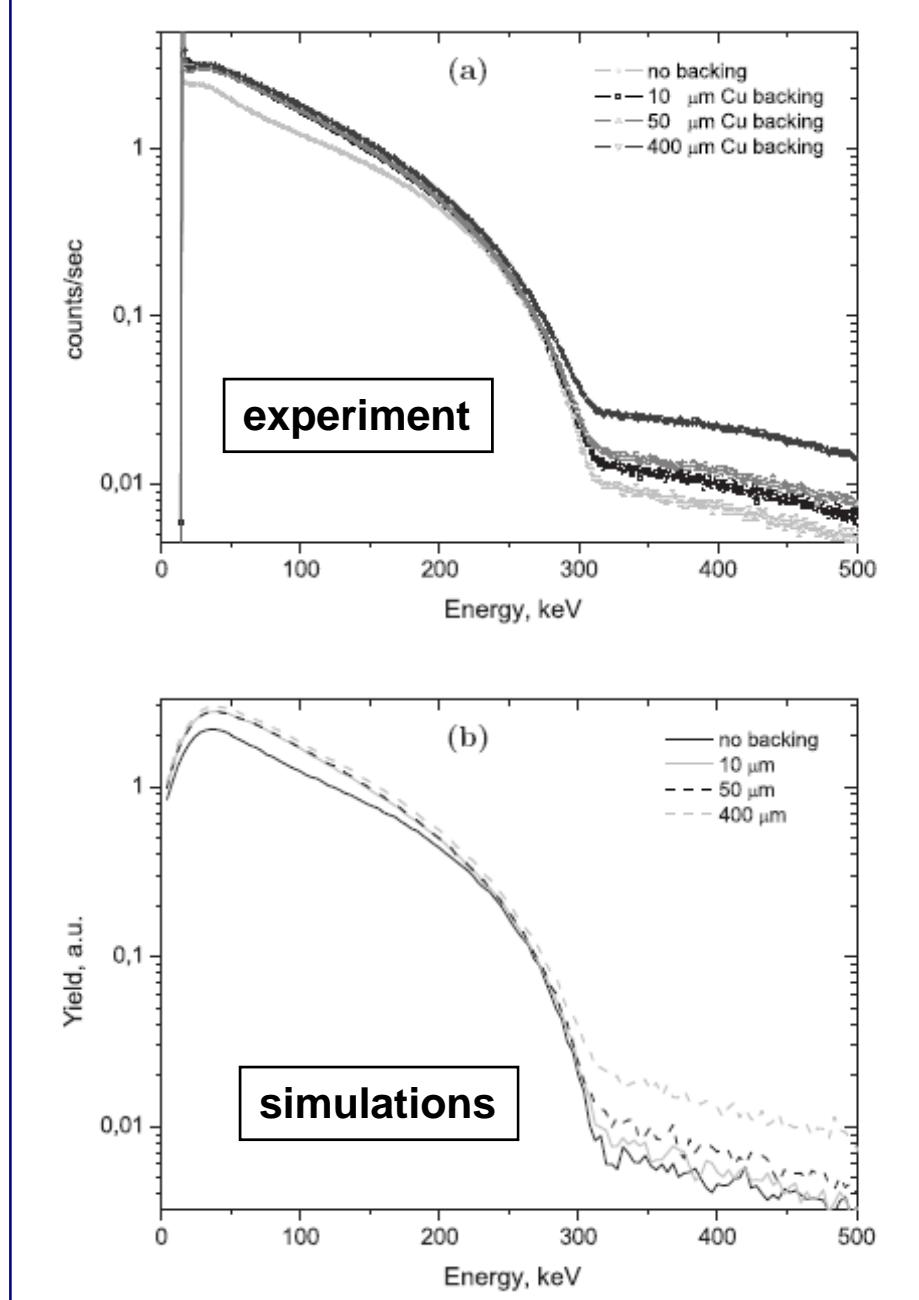
Q = solid angle

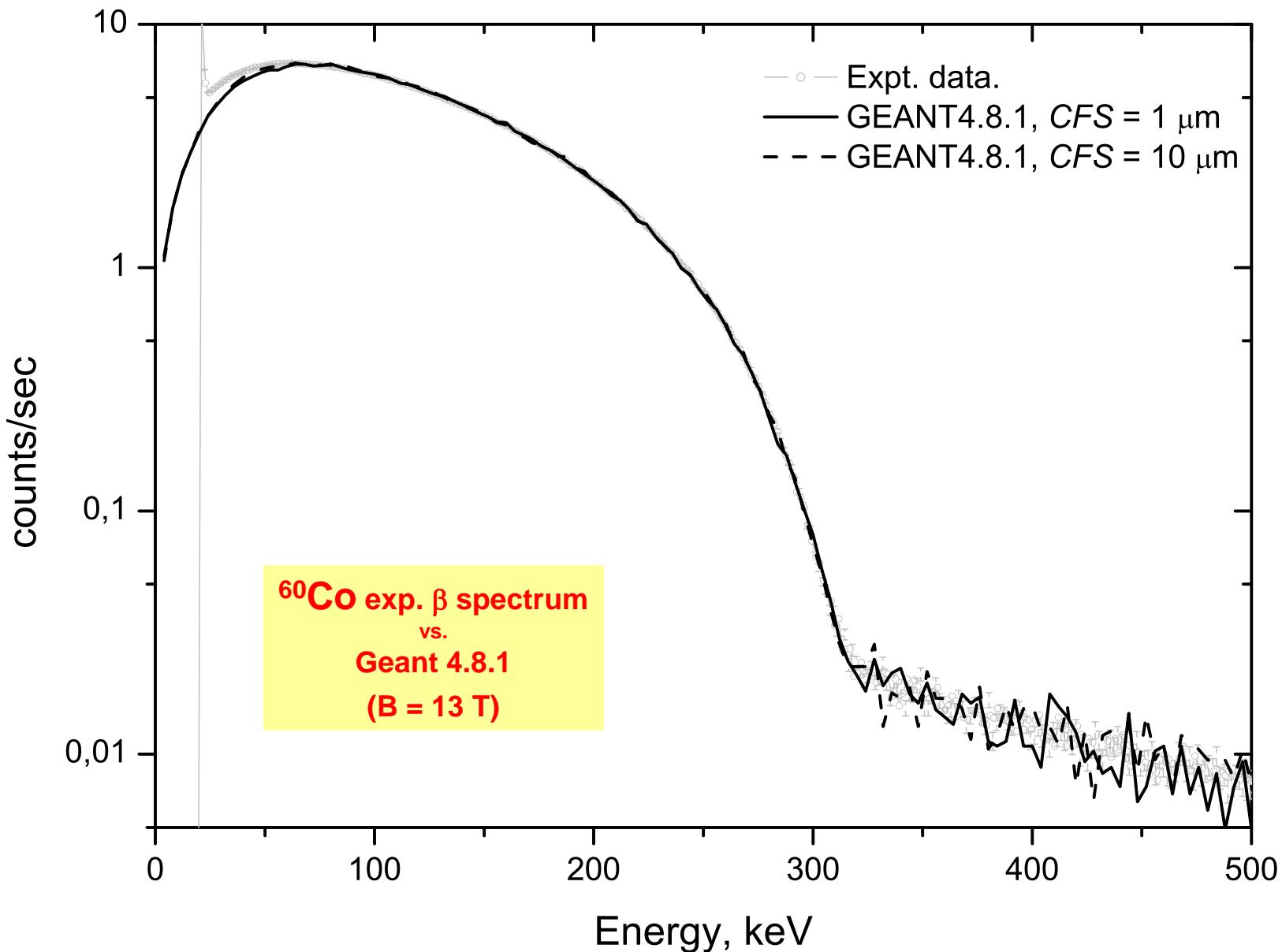


5. Geant 4 based simulation code

GEANT4 has to take care of :

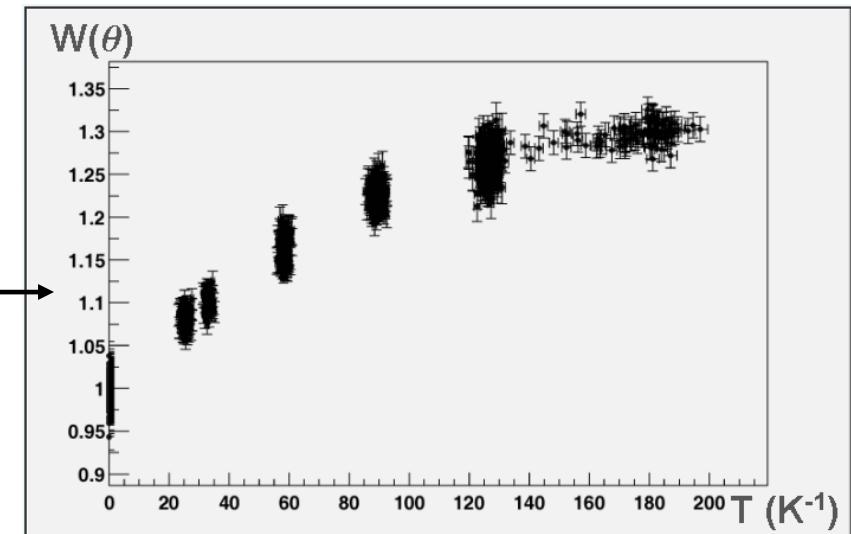
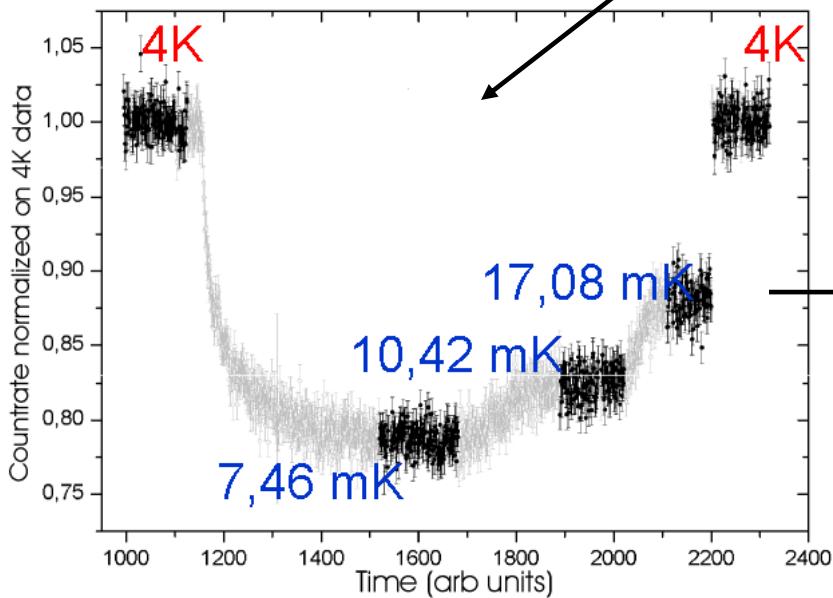
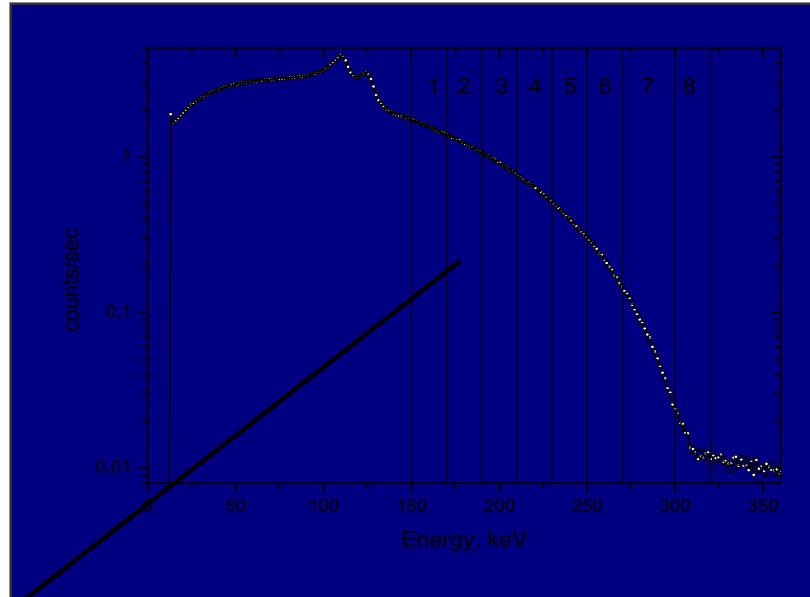
- scattering effects
- energy loss
- magnetic field effects
- ...
- use low energy packages
- tuned GEANT4 parameters to get optimal performance for β particles
- compare GEANT4 with well controlled experimental data for :
 - different scattering conditions
 - different magnetic fields
 - detectors used (Si p-i-n / HPGe)





6. Data analysis

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



Extraction of result

$$W(\theta)_{\text{exp}} = \left[\frac{N(\theta)_{\text{pol}}}{N(\theta)_{\text{unpol}}} \right]_{\text{exp}} = 1 + \tilde{A}_{\text{exp}} P - \frac{v}{c} Q \cos \theta$$

Geant 4

from anisotropy of γ rays

&

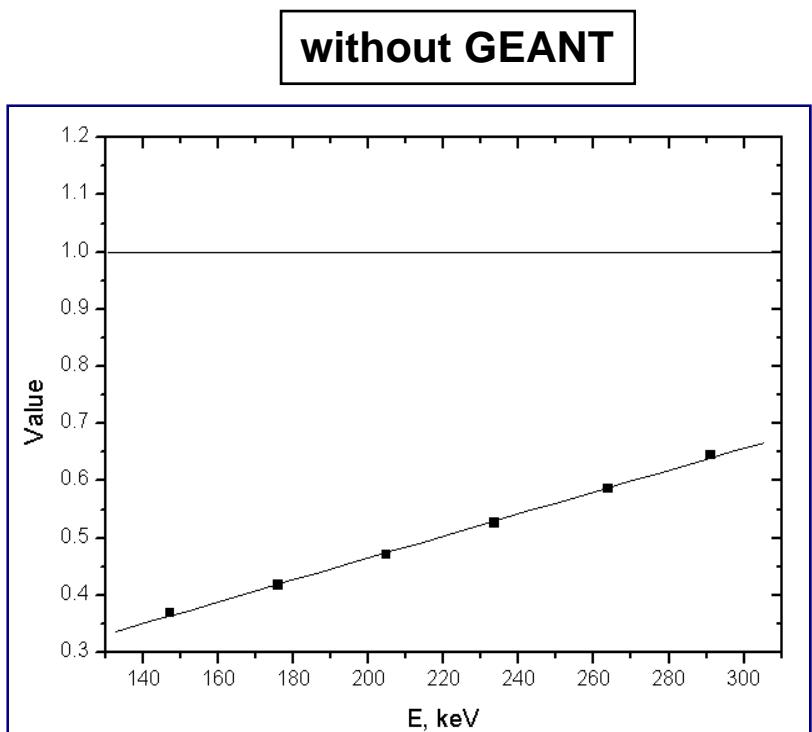
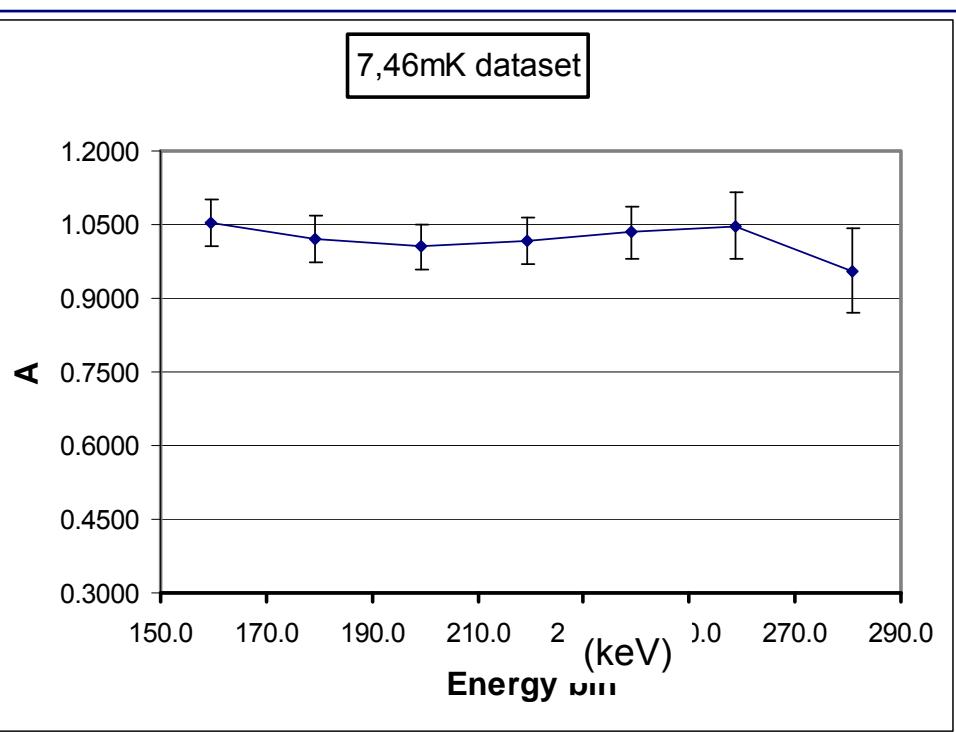
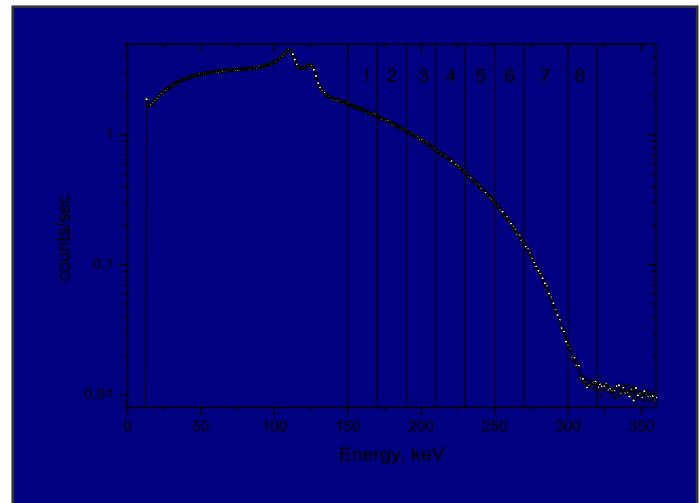
$$W(\theta)_{\text{sim}} = \left[\frac{N(\theta)_{\text{pol}}}{N(\theta)_{\text{unpol}}} \right]_{\text{sim}} = 1 + \tilde{A}_{\text{SM}} P(T_{\text{exp}}) - \frac{v}{c} Q \cos \theta$$



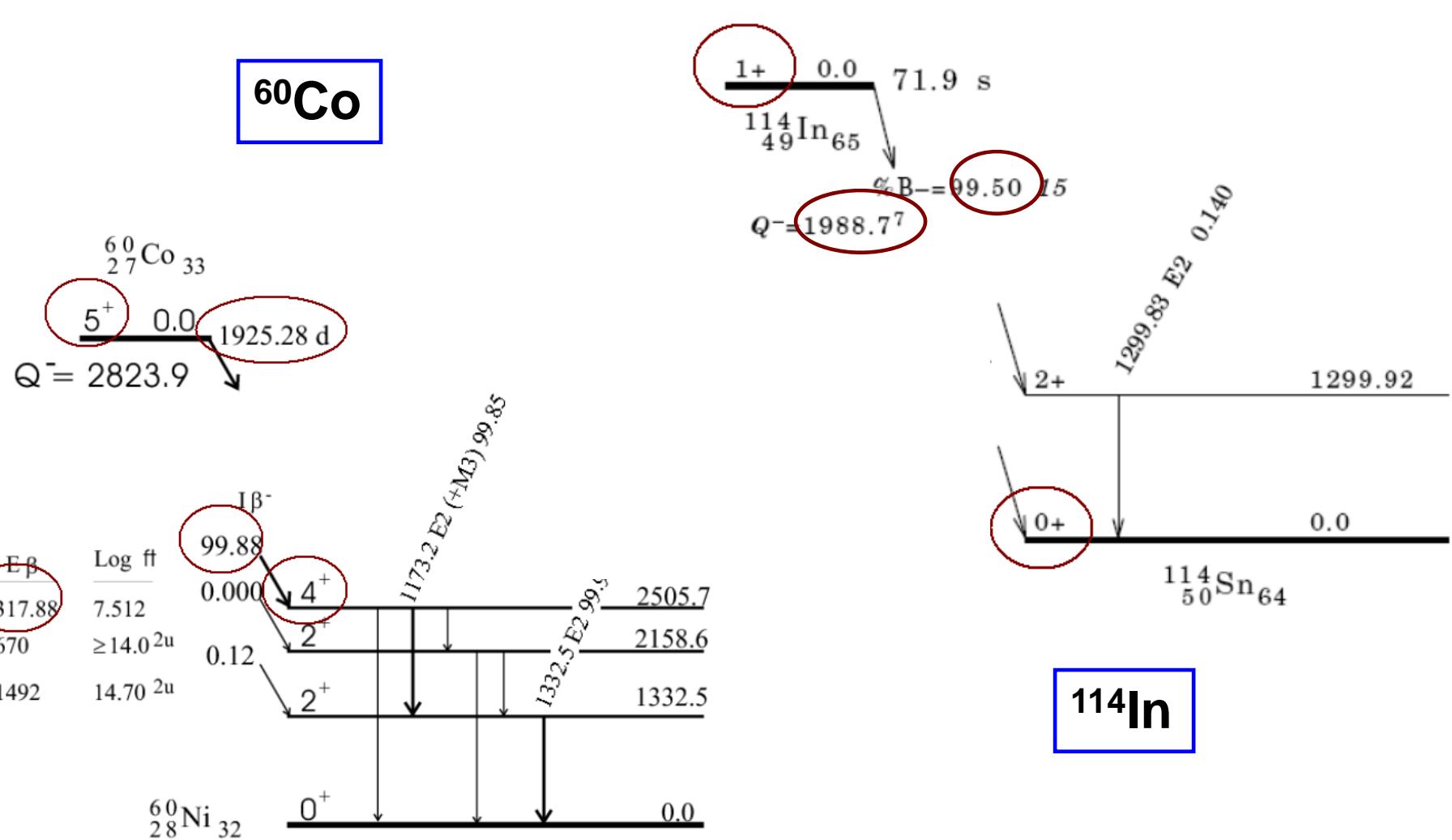
$$\frac{[1 - W(\theta)]_{\text{exp}}}{[1 - W(\theta)]_{\text{sim}}} = \frac{\left[\tilde{A}_{\text{exp}} P - \frac{v}{c} Q \cos \theta \right]_{\text{exp}}}{\left[\tilde{A}_{\text{SM}} P - \frac{v}{c} Q \cos \theta \right]_{\text{sim}}} = \frac{\tilde{A}_{\text{exp}}}{\tilde{A}_{\text{SM}}}$$

e.g. case of ^{60}Co

with GEANT



7. First results with ^{60}Co and ^{114}In



60Co

	13 T , 7.5mK	13 T , 10.4mK	13 T , 17.1mK	9T , 7,4mK
\tilde{A}_{exp}	-1.024(20)	-1.027(42)	-1.06(40)	-0.964(25)

(preliminary)



$$\tilde{A}_{\text{exp}} = -1.013(18) \quad (\tilde{A}_{\text{SM}} = -1)$$

114In

B_{ext} [T]	fraction f	\tilde{A}
0.046	0.734(5)	-1.003(9)
0.093	0.803(8)	-0.987(13)
0.186	0.874(7)	-0.972(11)
weighted average		-0.990(11)



$$\tilde{A}_{\text{exp}} = -0.990 \pm 0.011(\text{stat}) \pm 0.009(\text{syst})$$

$$\rightarrow \tilde{A}_{\text{exp}} = -0.990(14) \quad (\tilde{A}_{\text{SM}} = -1)$$

$$\rightarrow -0.05 \leq \text{Re} \left(\frac{C_T + C'_T}{C_A} \right) \leq 0.17 \quad (90\% \text{ C.L.})$$

8. Summary and outlook

$$\tilde{A}_{GT}^{\beta^-} \approx \lambda_{JJ} \left[-1 + \frac{\gamma m}{E_e} \text{Re} \left(\frac{C_T + C'_T}{C_A} \right) \right] \text{Re } T$$

New method to determine asymmetry parameter in nuclear β decays, combining LTNO and Geant simulations

most
precise
results
to date !!

$$^{114}\text{In} : \tilde{A} = -0.990(14)$$

$$\gamma m/E = 0.21 \rightarrow |\text{Re } T| < 0.11$$

$$^{60}\text{Co} : \tilde{A} = -1.013(18)$$

$$\gamma m/E = 0.70 \rightarrow |\text{Re } T| < 0.04$$

$$^{67}\text{Cu} : \tilde{A} \sim -0.42$$

$$\gamma m/E = 0.45 \rightarrow |\text{Re } T| < 0.05$$

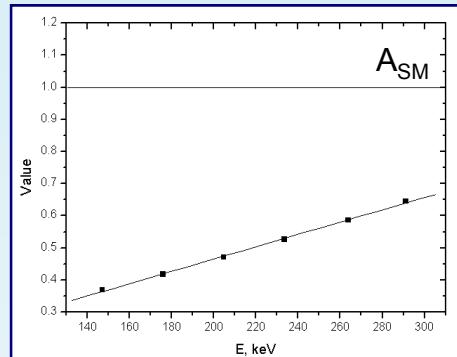
(under analysis)

for $\Delta A=0.015$

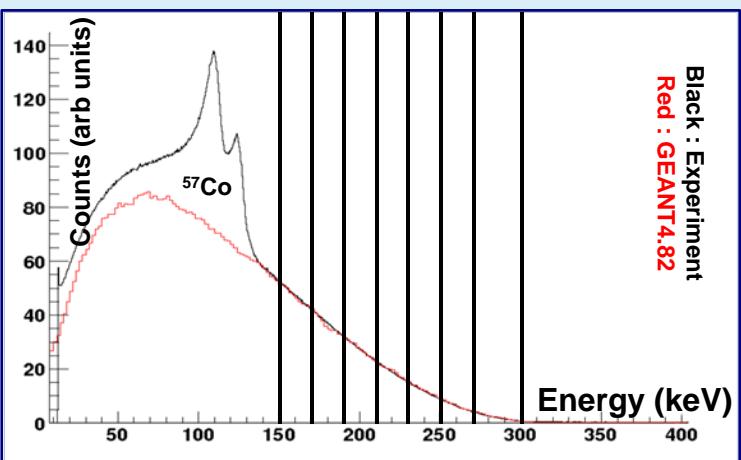
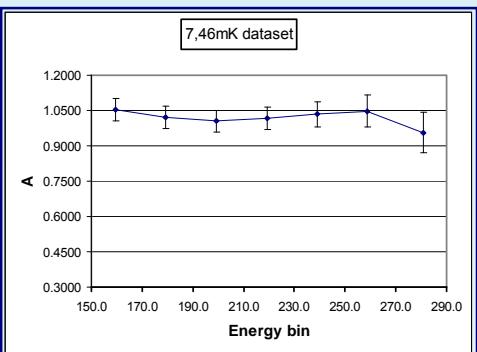
Next : towards even higher precision

Experimental results : the β -asymmetry parameter of ^{60}Co

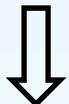
Without GEANT



With GEANT



	13 T , 7.5mK	13 T , 10.4mK	13 T , 17.1mK	9T , 7.4mK
\tilde{A}_{exp}	-1.024(20)	-1.027(42)	-1.06(40)	-0.964(25)



$$\tilde{A}_{\text{exp}} = \mathbf{-1.013(18)} \quad (\tilde{A}_{\text{SM}} = -1)$$

Error bar contribution

- statistics $\rightarrow 1\%$
- calibration with γ 's $\rightarrow 0.5\%$
- quality simulations $\rightarrow 1.2\%$
- other effects $\rightarrow 0.7\%$

Experimental results : the β -asymmetry parameter of ^{114}In

B_{ext} [T]	fraction f	\tilde{A}
0.046	0.734(5)	-1.003(9)
0.093	0.803(8)	-0.987(13)
0.186	0.874(7)	-0.972(11)
weighted average		-0.990(11)

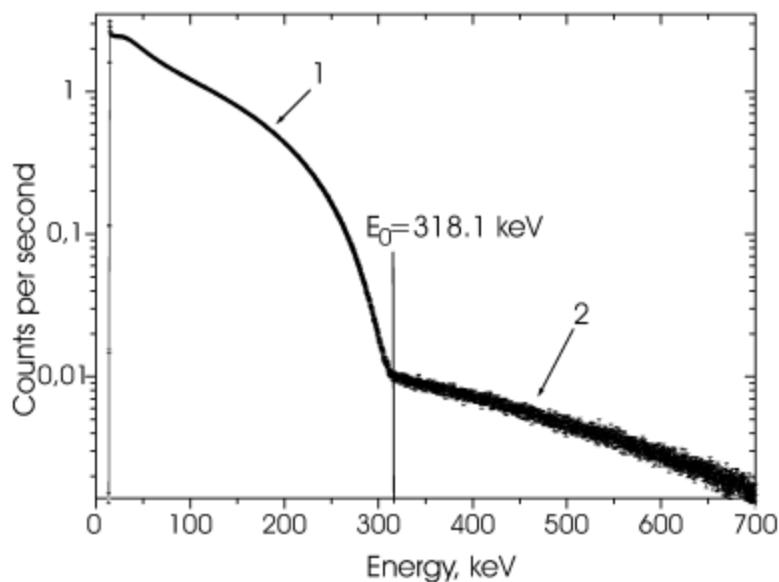


Effect	Correction [%]	Error [%]
Statistics (see Table I)		1.1
Geometry of the set-up		0.3
Magnetic field map		0.4
Accuracy in setting magnetic field		0.001
Simulations of β asymmetry ($Q \cos \theta$)		0.60
Solid angle corrections for γ dets. (fraction)		0.13
Effect of uncertainty on μB on values of fraction f (0.15 %) and \tilde{A} (0.16 %)		0.31
Incomplete relaxation of ^{114}In and polarization inherited from ^{114m}In		0.3
Induced from factors b/Ac and d/Ac	+0.28	0.24
Sum	+0.28	1.4

$$\begin{aligned} \bar{A} &= -0.990 \pm 0.011(\text{stat}) \pm 0.009(\text{syst}) \\ &= -0.990(14) \quad \text{SM-Value} = -1 \\ \rightarrow & -0.05 \leq \text{Re} \left(\frac{C_T + C'_T}{C_A} \right) \leq 0.17 \quad (90\% \text{ C.L.}) \end{aligned}$$

GEANT4 simulations – Compton counts

^{60}Co spectrum,
“scattering free” source



^{60}Co spectrum,
“scattering free” source,
detector covered by 1 mm Cu

