β-asymmetry measurements : A probe for non standard model physics (status of the project)

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Overview

- Physics motivation : Correlation measurements
- Experimental techique : Low Temperature Nuclear Orientation (LTNO)
- Simulate the experiment : GEANT4
- Experiments: ^{60}Co, ^{114}In and ^{67}Cu
- Conclusions and outlook

Physics motivation : Correlation measurements to probe the weak interaction Hamiltonian

Hamiltonian β-decay : $H_\beta = H_V(C_V, C'_V) + H_A(C_A, C'_A)$

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

→ V-A theory of the weak interaction

Most general case :

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

Experimental observable ?

⇩

Correlation coefficients

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

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

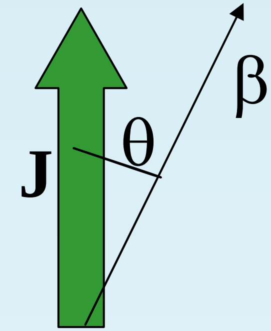
(95.5 % C.L)*

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

Physics motivation : Correlation measurements to probe the weak interaction Hamiltonian

H_β

$$W(\theta)=\frac{\omega(\bar{J})}{\omega(\bar{J}=0)}=1+\tilde{A}\frac{\langle\bar{J}\rangle}{J}\frac{p_e}{E_e}\quad \text{with}\quad \tilde{A}=\frac{A}{1+b\frac{\gamma m_e}{E_e}}$$ *



Pure GT Transition

$$\tilde{A}_{GT}^{\beta^{\mp}}\cong\lambda_{J'J}\left[\mp 1+\frac{\alpha Z m}{p}\,\mathrm{Im}\left(\frac{C_T+C_T'}{C_A}\right)+\frac{\gamma m}{E_e}\,\mathrm{Re}\left(\frac{C_T+C_T'}{C_A}\right)\right]$$

$-0.008 < \mathrm{Im}\,(C_T+C'_T)/C_A < 0.014$ (90% CL)**

* J.D. Jackson et al. , Nucle. Phys. 4 (1957) 206

R. Huber et. al. , PRL , **90 , 202301 (2003)

Physics motivation : Correlation measurements to probe the weak interaction Hamiltonian

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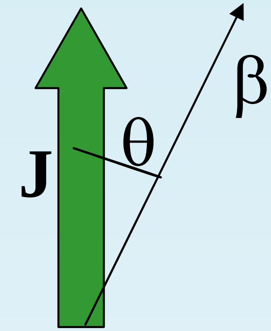

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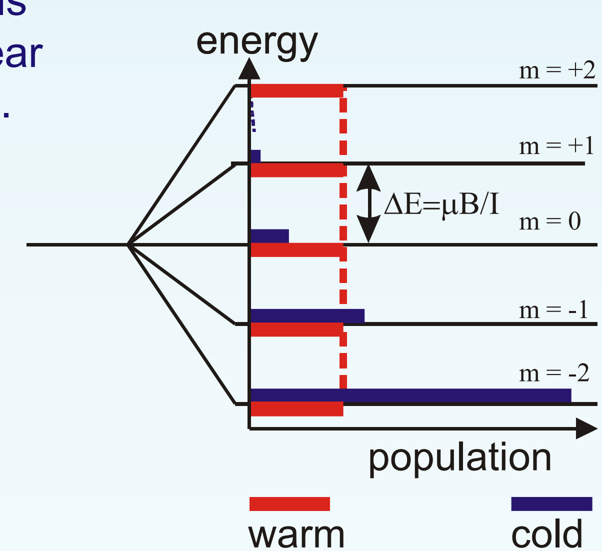
The angle between the impuls of the β-particle and the nuclear spin has to be under control.

⇓

Create an ensemble of oriented nuclei with Low Temperature Nuclear Orientation (LTNO).



$\mu B \approx kT$

Millikelvin temperatures
→ $^3He/^4He$ refridgerators

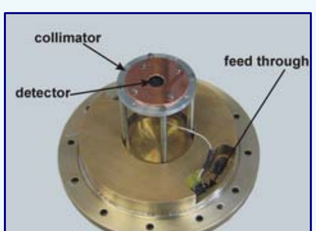
Magnetic field of 10 T or more
→ Hyperfine interactions or strong extrernal magnets

* J.D. Jackson et al. , Nucle. Phys. 4 (1957) 206

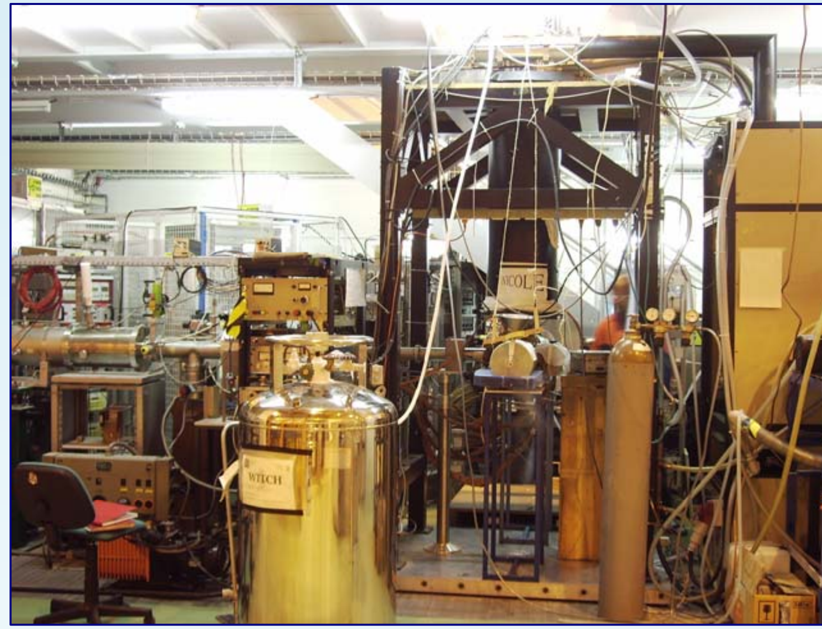
Low Temperature Nuclear Orientation :Using $^{3}He/^{4}He$ dillution refridgerators to orient nuclei

Hight Field setup (Leuven)

- Off-line
- 17 T magnet
- place for 1 γ-detector and 1 particle detector



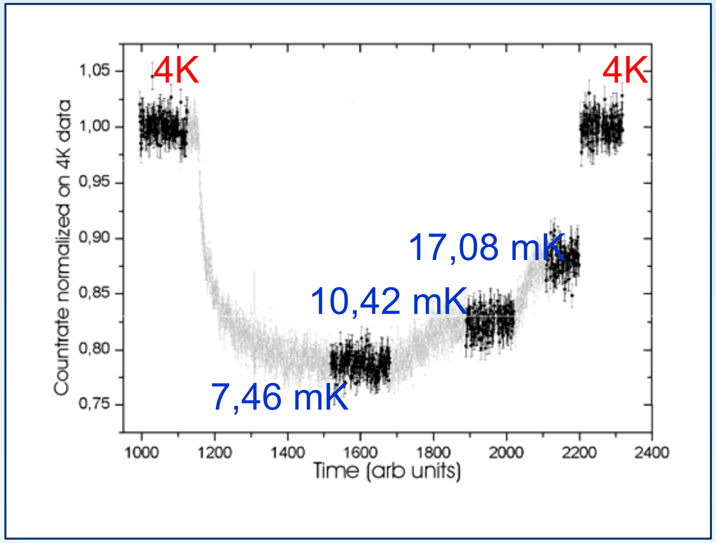
Online setup (ISOLDE/CERN)

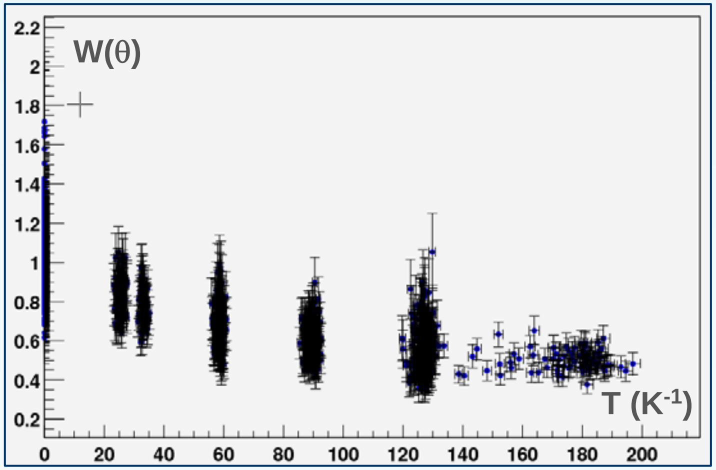


- On-line
- 2 T magnet
- place for 3 γ-detectors and 3 particle detectors

Low Temperature Nuclear Orientation :Using $^3He/^4He$ dillution refridgerators to orient nuclei

The data :





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

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

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

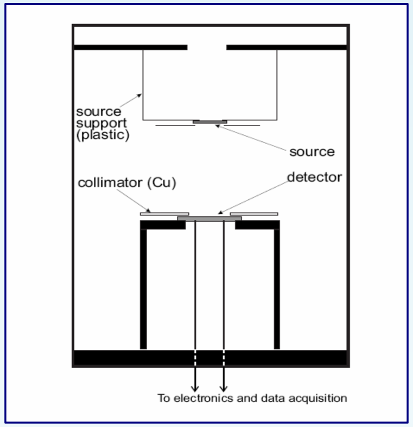
Initial energy / solid angle / scattering / magnetic field effects / ...

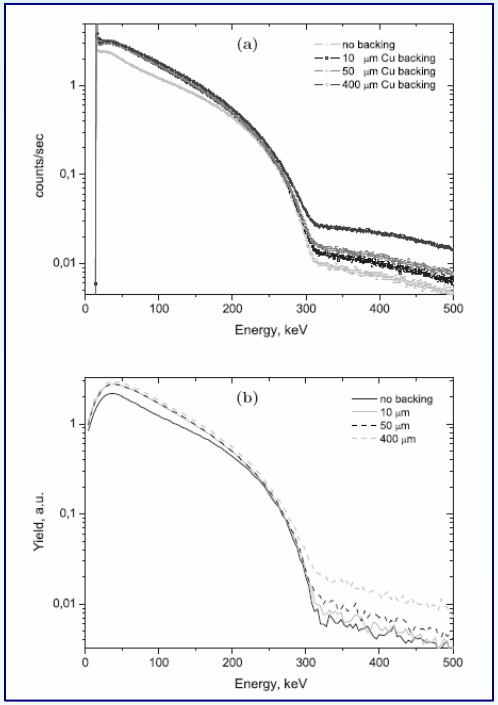
GEANT4 monte-carlo simulations

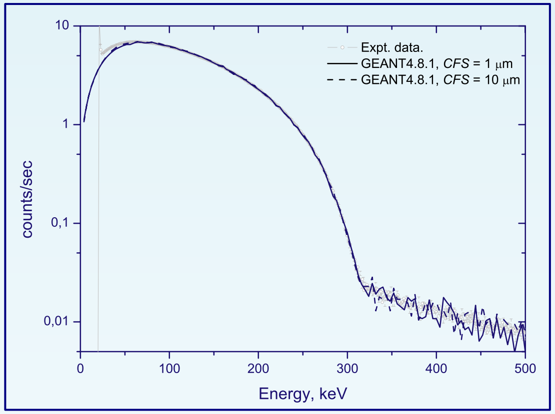
Simulating the experiment :Using GEANT4 to get control on systematic effects

GEANT4 has to take care of scattering effects, energy loss, magnetic field effects, ...

- Testing GEANT4 under different experimental conditions
- Tuning parameters / optimizing the code
- Simulating the whole experiment to extract the β-asymmetry parameter from the data

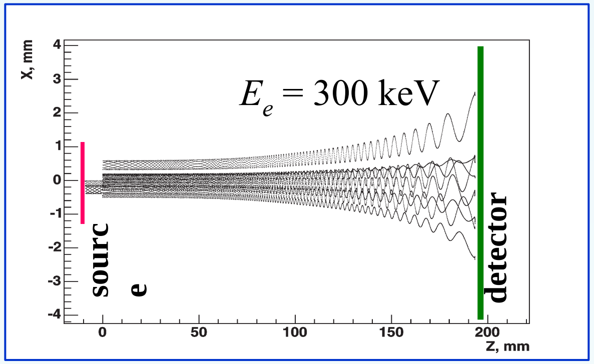






Backscattering of e^- on Si

CFS, µm	f_r		
	0.2	0.02	0.002
10	8.7	13.2	13.2
5	9.1	12.6	13.5
1	10.9	12.5	14.3



Experiments : ^{60}Co

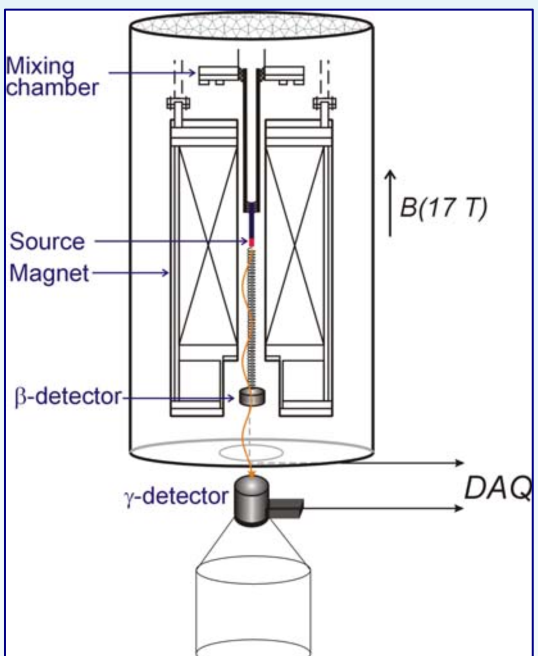
^{60}Co

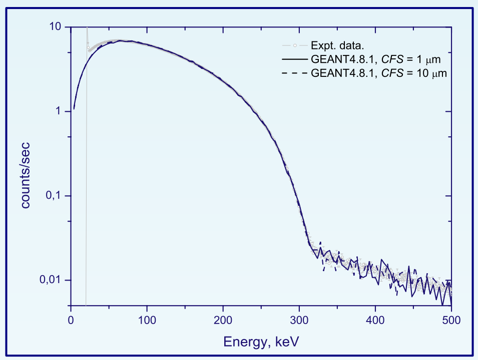
- $T_{1/2}$ = 5,3 y
- $5^+ \rightarrow 4^+$
- 99,88 % br
- 318 keV end point

Proof of principle experiment for our methods.

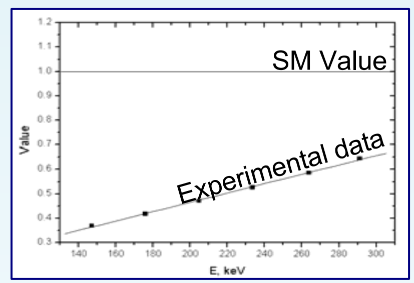
Try to improve the best experimental value for the β-asymmetry parameter measured with ^{60}Co.
(A = -1.01(2)Chirovsky et al., 1984)

Performing the experiment and simulate is with GEANT4

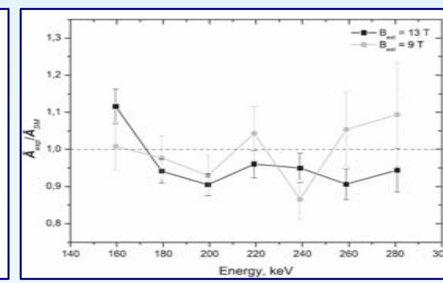




Without GEANT



With GEANT



$$\tilde{A}_{exp} = -0.953(22) \quad (\tilde{A}_{SM} = -1)$$

Preliminary

PHD thesis
Ilya Kraev
(KULeuven)

Experiments : ^{114}In

^{114}In

- $t_{1/2}$ 50d ^{114m}In
- $t_{1/2}$ 71s ^{114m}In
- $1^+ \rightarrow 0^+$
- 99,36 % br
- 1988 keV end point
- Low Logft

• Using the hyperfinefield of In in Fe to orient the In nuclei

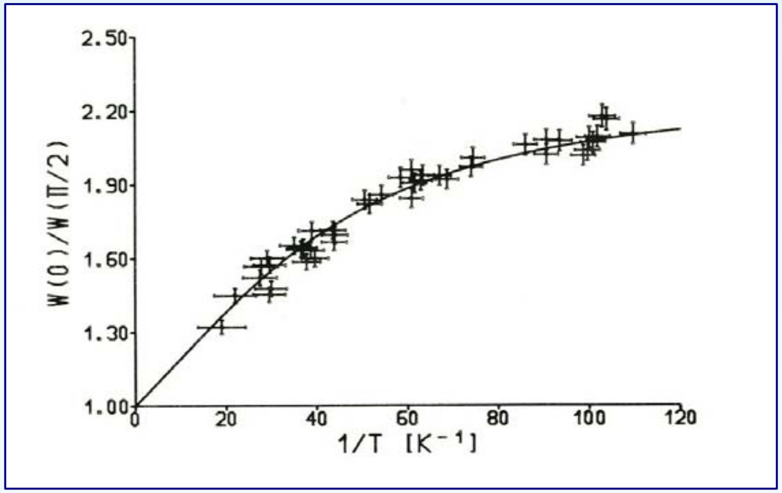
• 3 measurements in 3 different external fields (46 mT, 93mT and 186 mT)

Calculating the factor $v/c*Q_1*\cos(\theta)$ with GEANT4

	45 mT	93 mT	186 mT
Ã	1.007(41)	0.986(32)	0.985(35)

$$\tilde{A} = -0.991(19) \ (\tilde{A}_{SM} = -1)$$

Preliminary



Most precise result of the β-asymmetry parameter for a fast pure GT transition

Experiments : ^{67}Cu

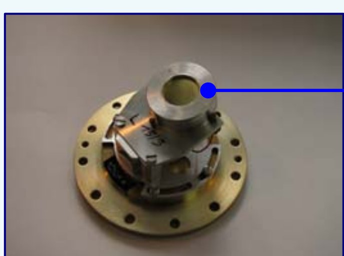
^{67}Cu

- $t_{1/2}$ 62h
- $3/2^- \rightarrow 5/2^-$
- 20 % br
- 562 keV end point

- 60 keV implantation at 4K
- B_{hf} Cu(Fe) = -21,81(1) T
- 0,1 T external field
- ^{57}Co for temperature determination and ^{68}Cu for callibration

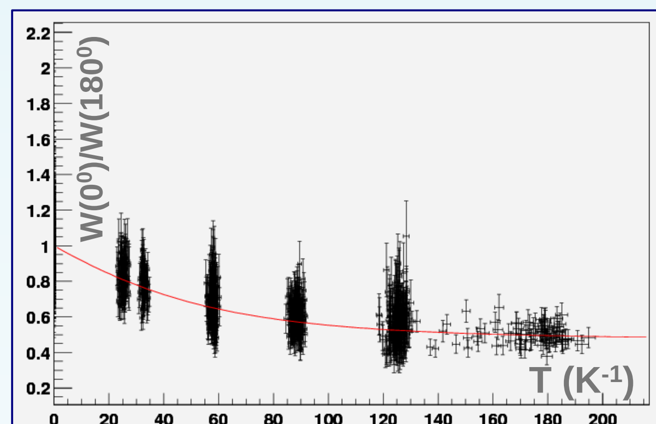
Two run's on ^{67}Cu : 2006 & 2007

- Good quality data
- Low statistics due to low Cu yields
  → -0.427(6) (SM = 0.447)
  (with estimated systematic effects!)



HPGe partcile detectos

Anisotropycurve of ^{67}Cu (2006)



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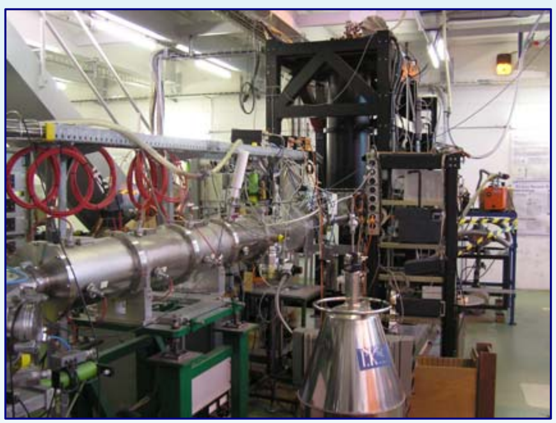
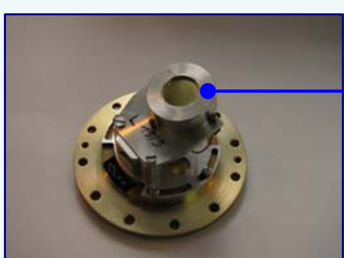
Two run's on ^{67}Cu : 2006 & 2007

2006:
- Good quality data
- Low statistics due to low Cu yields
  → -0.427(6) (SM = 0.447)
  (with estimated systematic effects!)

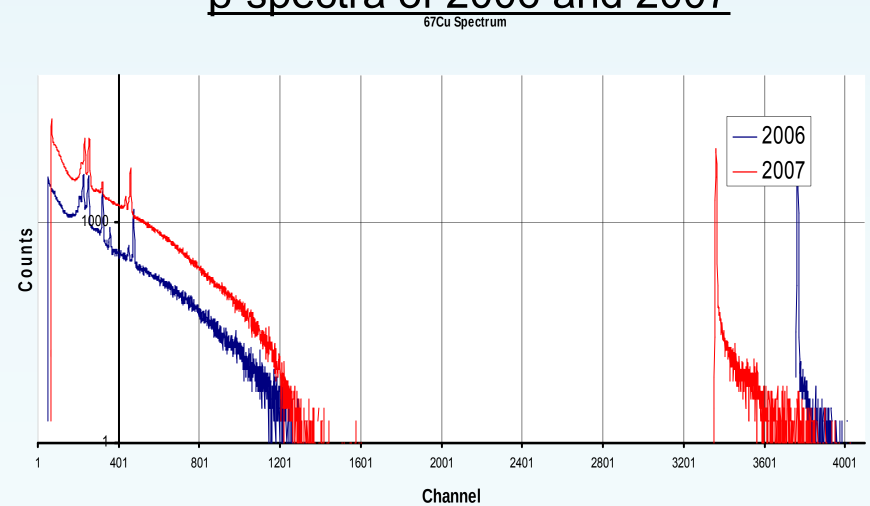
2007:
- 4 to 5 times better statistics
- better callibration measurement with ^{68}Cu





HPGe partcile detectos

β-spectra of 2006 and 2007



Conclusions and outlook

- Our 2% precision on the β-asymmetry parameter is a compatible result
- Approaching the 1% precision we need to get good weak interaction physics

  → 1% precision (1σ) on Ã gives

$$\mathrm{Re}\left(\frac{C_T + C_T^{'}}{C_A}\right) \leq 0{,}04 \qquad \text{current limits} \left|\frac{C_T}{C_A}\right| \leq 0{,}09 \;\; \& \left|\frac{C_T^{'}}{C_A}\right| \leq 0{,}089$$

- Further test GEANT4 for our applications
- New experiments …

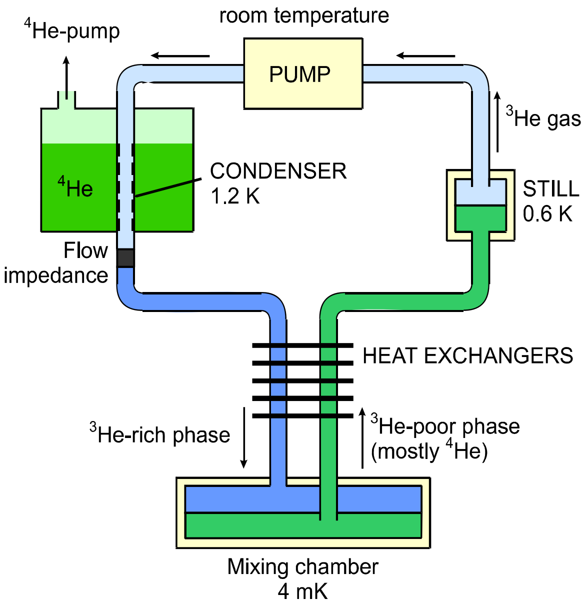
Experimental technique

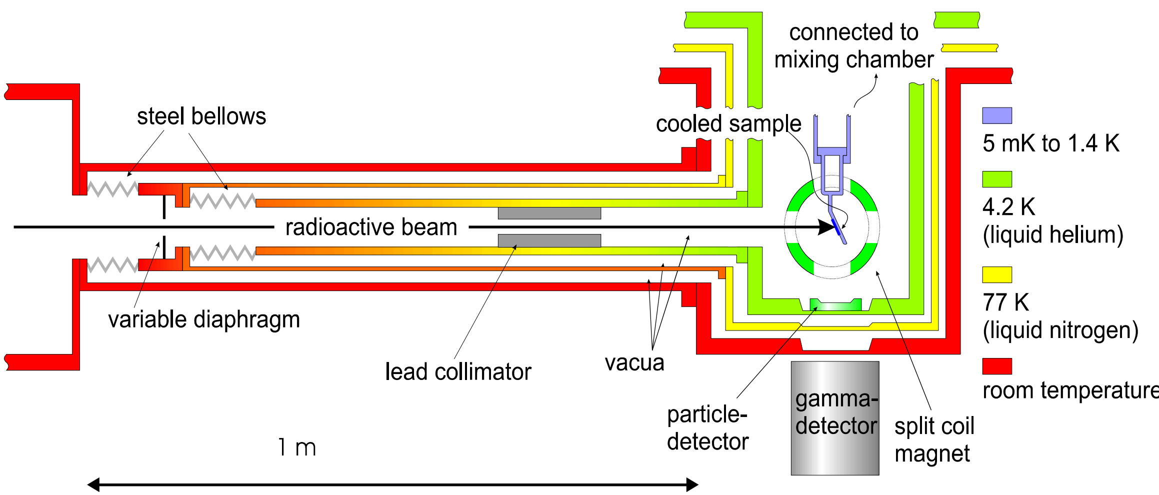
Millikelvin temperatures

- ^3He-^4He dilution refrigerators

High fields

- Hyperfine field in a magnetised Fe/Ni/... Foil
- Strong external field





Experiments

^{67}Cu

Determining the implantation quality with ^{68}Cu

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

$$= 1 + f\ A_1\ B_1\ \frac{v}{c}\ Q\cos\theta$$

$$(A_1 = \sqrt{\frac{I_0+1}{3I_0}}\tilde{A})$$

Half life 31.1 s → measured on-line

~~Function of the Boltzmann distribution based on the interaction μB and the lattice temperature T_L~~

⇓

$$B_1(eff) = \rho_1(I, \frac{T_i}{T_L}, \frac{\tau T_i}{C_k}) B_1(\frac{\mu B}{T_L})$$

Estimated relaxation time T_1 = 5 s

↕

$T_{1/2}$ = 31.1 s

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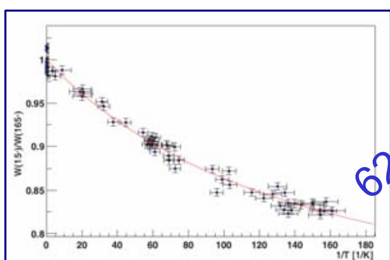
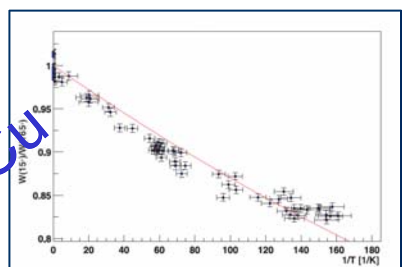
Two parameter fit on f and C_k



(a) with C_K

^{62}Cu



(b) without C_K

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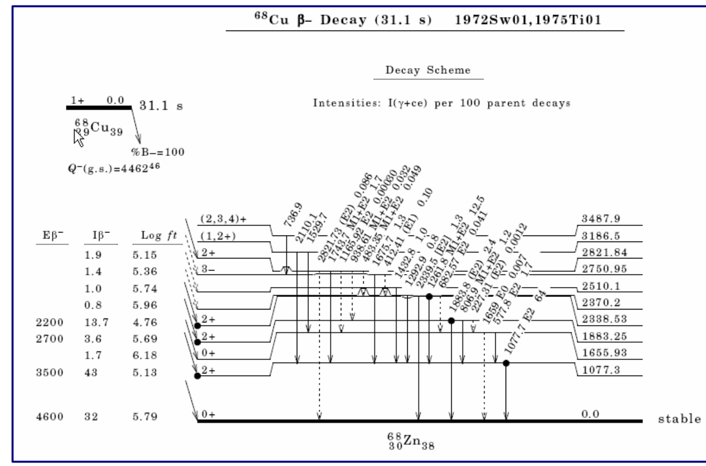
$$\left(A_1 = \sqrt{\frac{I_0+1}{3I_0}}\,\tilde{A}\right)$$

Get the fraction (=implantation quality) of ^{67}Cu from the anisotropy of the β's from ^{68}Cu.

→ Presume SM Value for A_1 for ^{68}Cu



For the endpoint:

- $\gamma m/E_e = 0.479$ (^{67}Cu)
- $\gamma m/E_e = 0.115$(^{68}Cu)

→ Still sensitive to tensor currents

Experiments

^{67}Cu

Determining the implantation quality with ^{68}Cu

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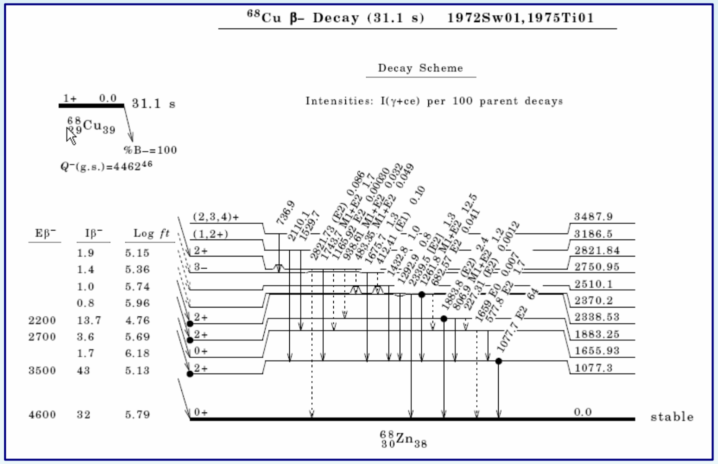

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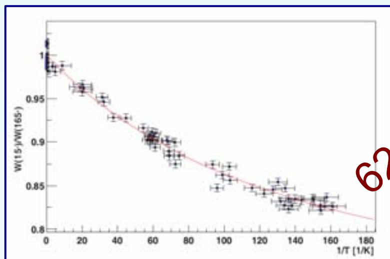
Two parameter fit on f and C_k



(a) with C_K

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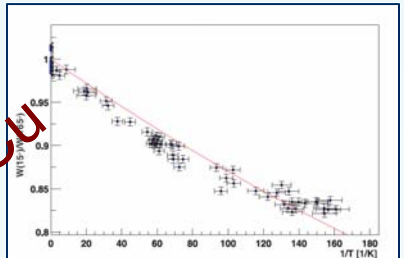

(b) without C_K