BETA SPECTRUM SHAPE MEASUREMENTS at WISArD

ISOL FRANCE
04/04/2025

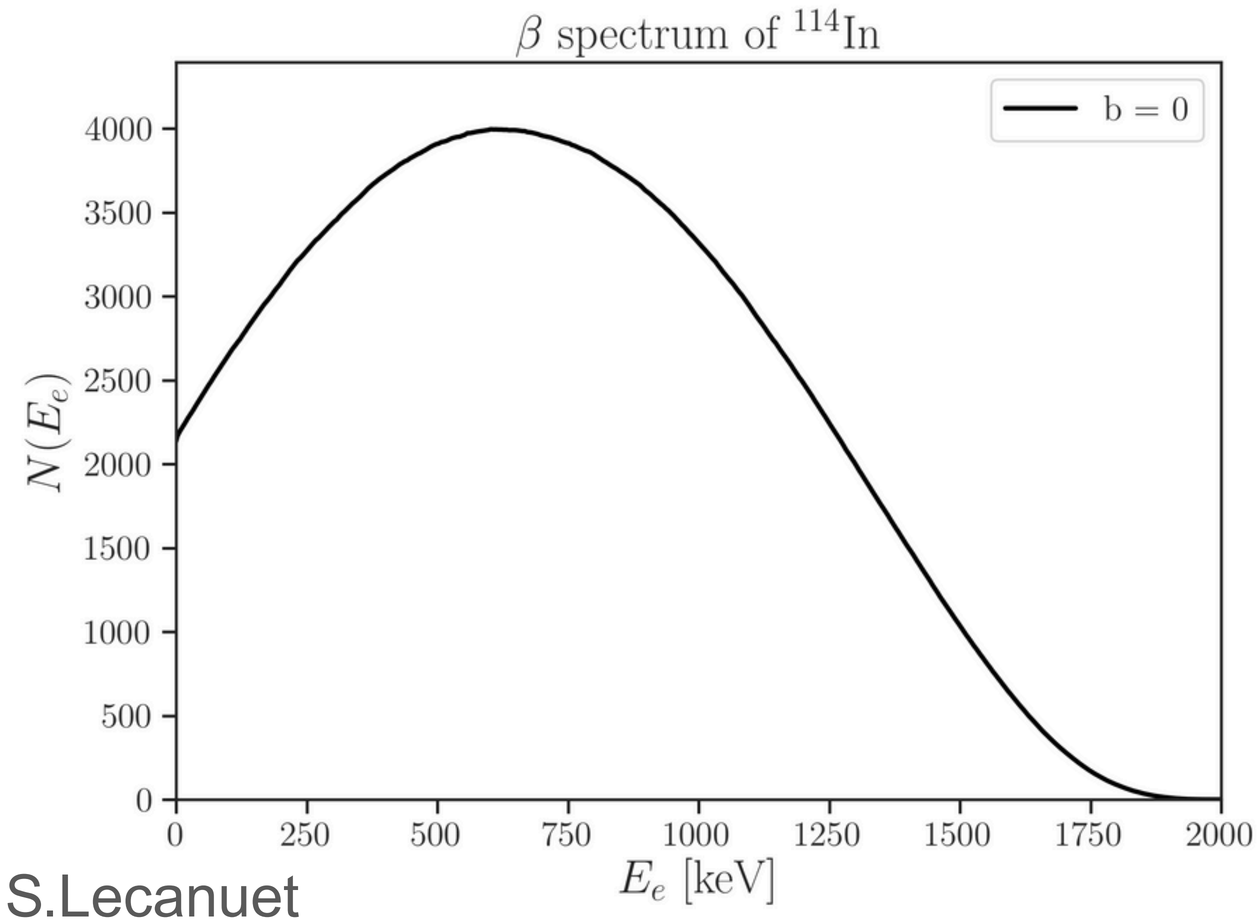
Lépine Anaïs
1st year PhD student
LP2iB

The study of β-shape

The energy distribution of emitted electrons for a Gamow-Teller decay:

$$N(E_e) \propto F(\pm Z, E_e)\, p_e E_e (E_0 - E_e)^2 \xi$$

Fermi function — Phase space — Nuclear matrix



Courtesy of S.Lecanuet

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The energy distribution of emitted electrons for a Gamow-Teller decay:

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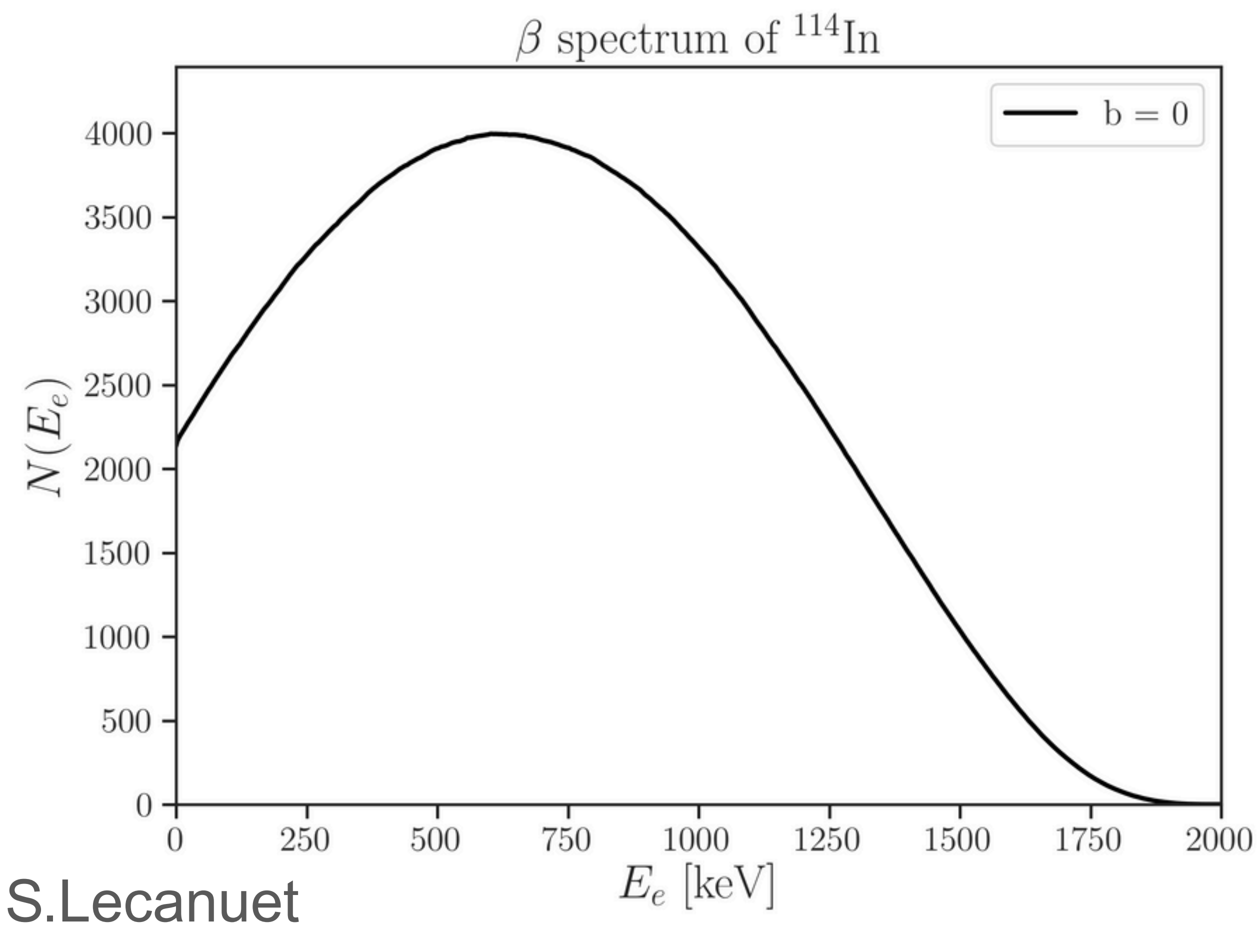
Fermi function Phase space Nuclear matrix

For a high level of precision:



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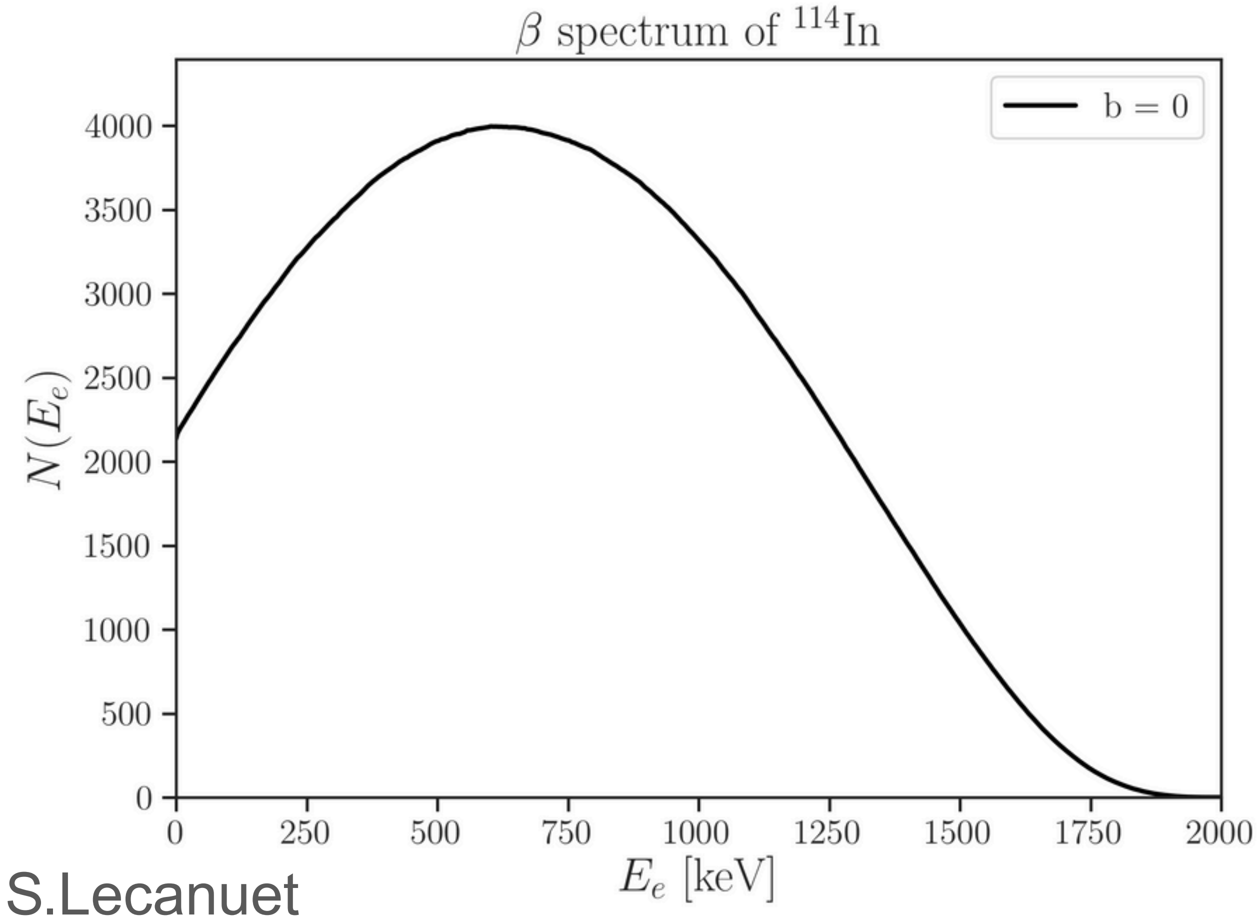

Courtesy of S.Lecanuet

For a high level of precision:

- b_{WM} : weak magnetism, **SM term,** induced by strong interaction
- $b_{Fierz} = \frac{C_T + C_T'}{C_A}$ $C_{T,A}$ coupling constants for Tensor or Axial-vector current

Fierz interference, **BSM term,** zero in SM

The study of β-shape

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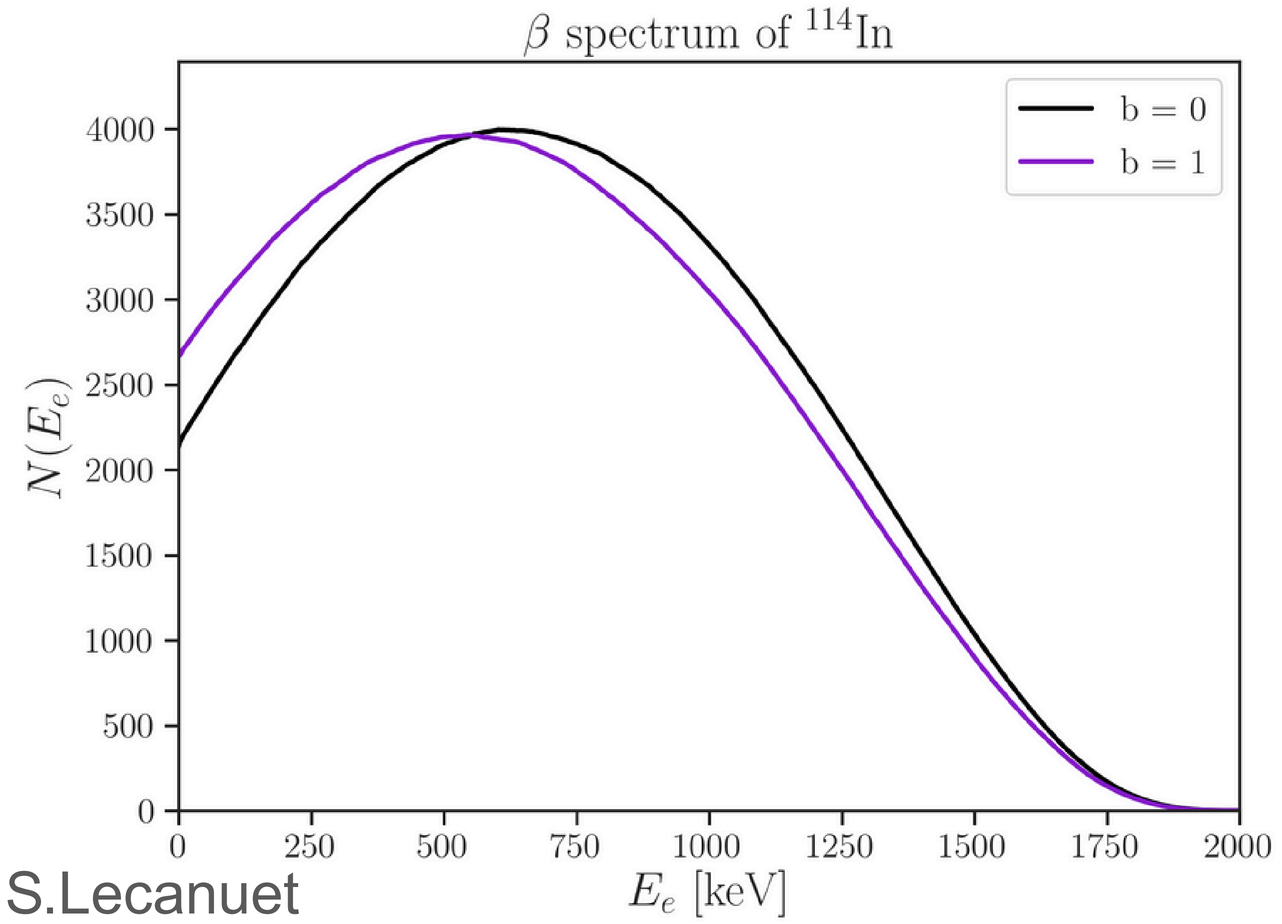
Fermi function   Phase space   Nuclear matrix

Both terms have influence on β-shape → For a high level of precision:



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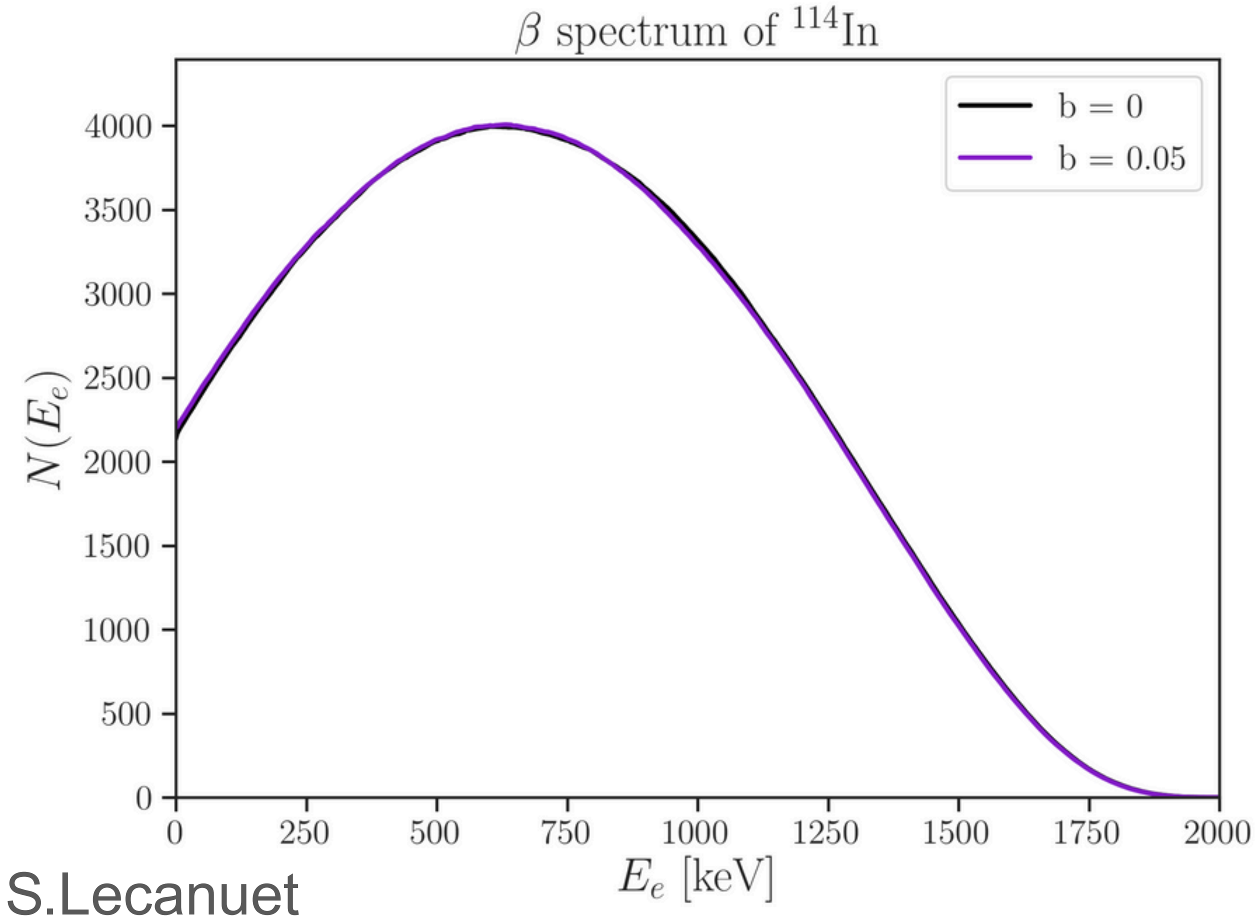
Fermi function — Phase space — Nuclear matrix

Both terms have influence on β-shape → Study of β-shape =

- **Constraints on SM with weak magnetism**
- **Search for new physics with extraction of fierz term**



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The study of β-shape

The energy distribution of emitted electrons for a Gamow-Teller decay:

$$N(E_e) \propto F(\pm Z, E_e)\, p_e E_e (E_0 - E_e)^2 \xi \left[1 + \frac{m_e}{E_e} b_{\text{Fierz}} + k E_e b_{\text{WM}}\right] (1+\eta)$$

Fermi function Phase space Nuclear matrix

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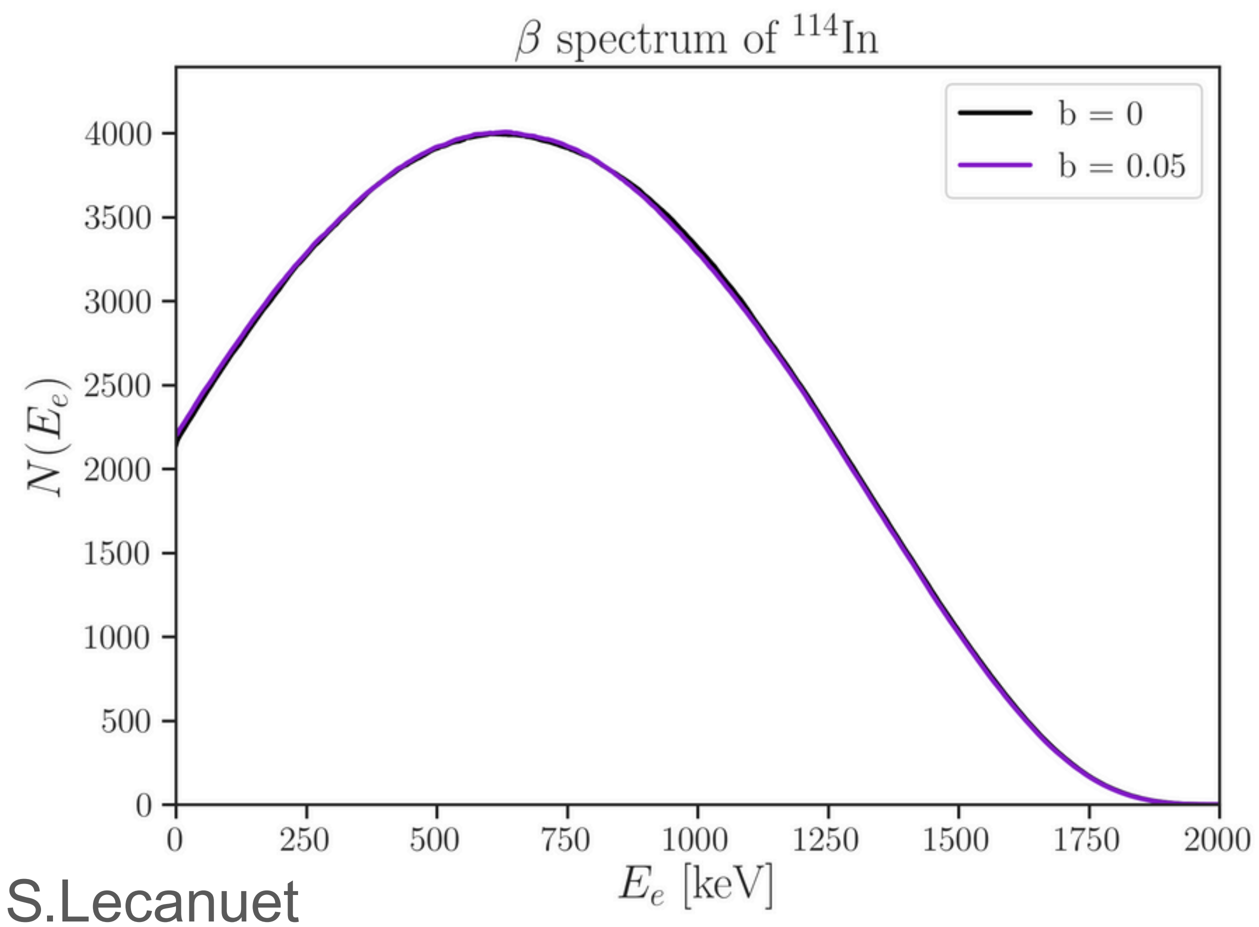
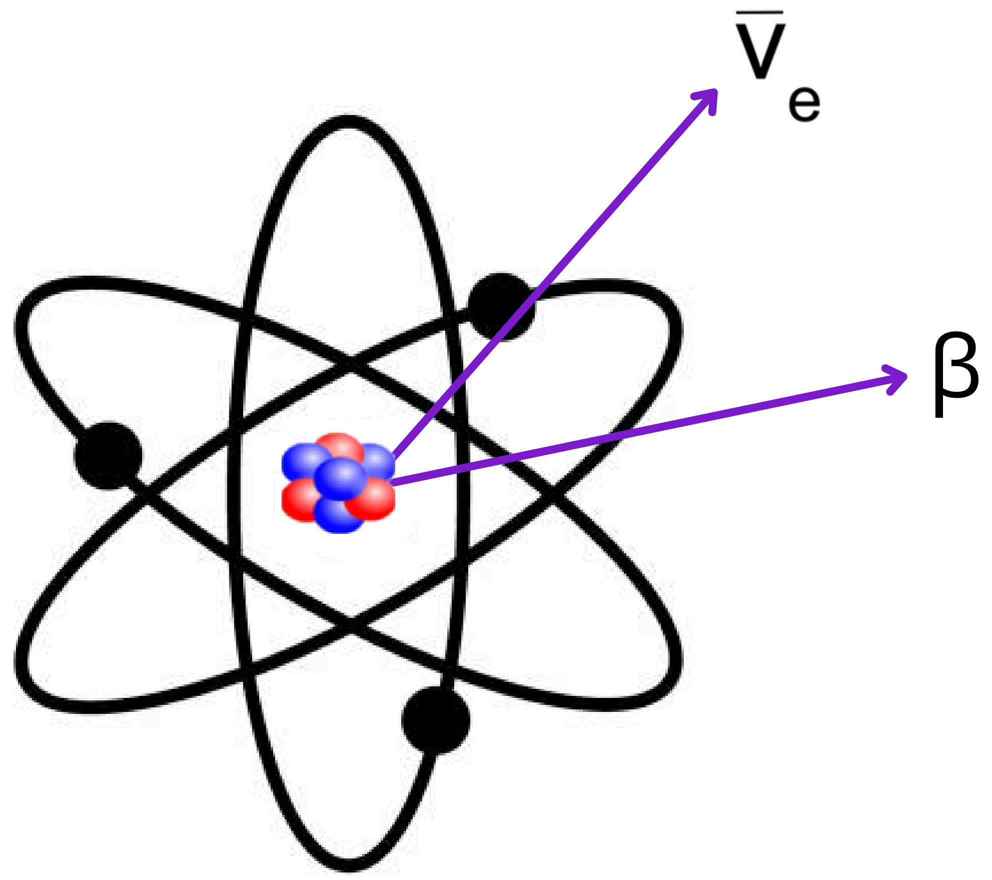


Courtesy of S.Lecanuet

At this level of precision, there are theoretical corrections to take into account!

Theoretical corrections



$$(1+\eta)$$

- Kinematics
- Electrostatics

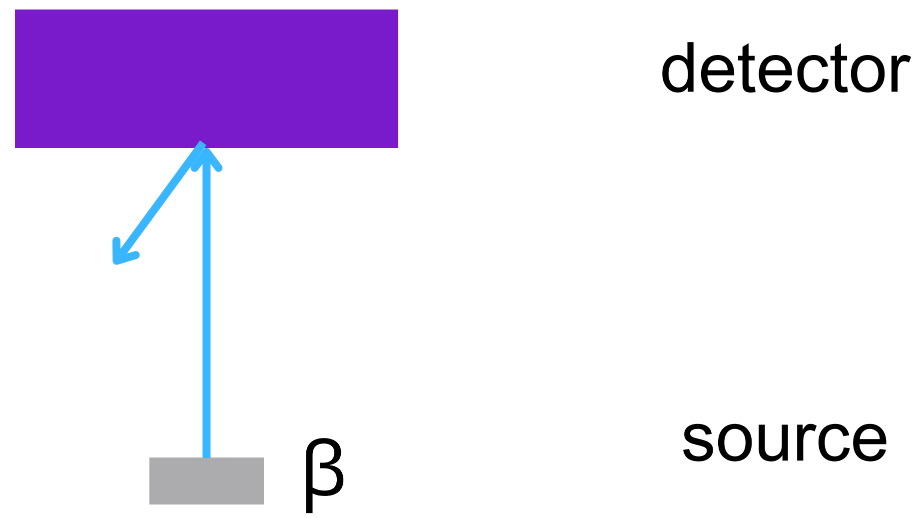
- Radiative corrections
- Atomic and molecular effects
- Recoil-order corrections

Beta Spectrum Generator (BSG):
High precision allowed spectrum shape generator
with all theoretical corrections included

L.Hayen, N.Severijns and al, RMP, 2018

How to study β-shape: experimental challenges

Goal: Measure the β-decay energy distribution with 10^{-3} precision



β-energy loss in:

- Detector dead layer
- Source
- Bremsstrahlung escape

- Backscattering → Adapted 4π geometry needed, several solutions proposed: bSTILED, spectrometer..

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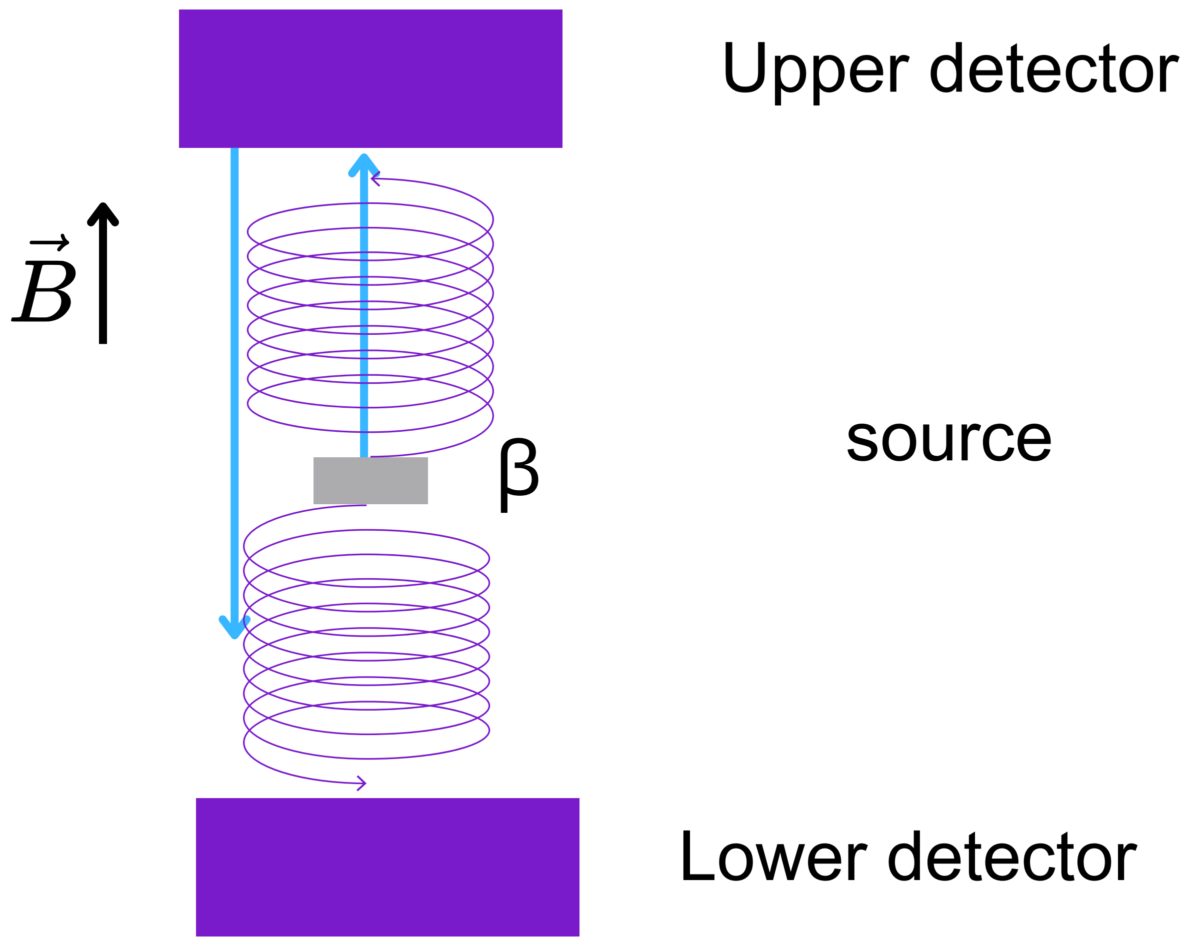

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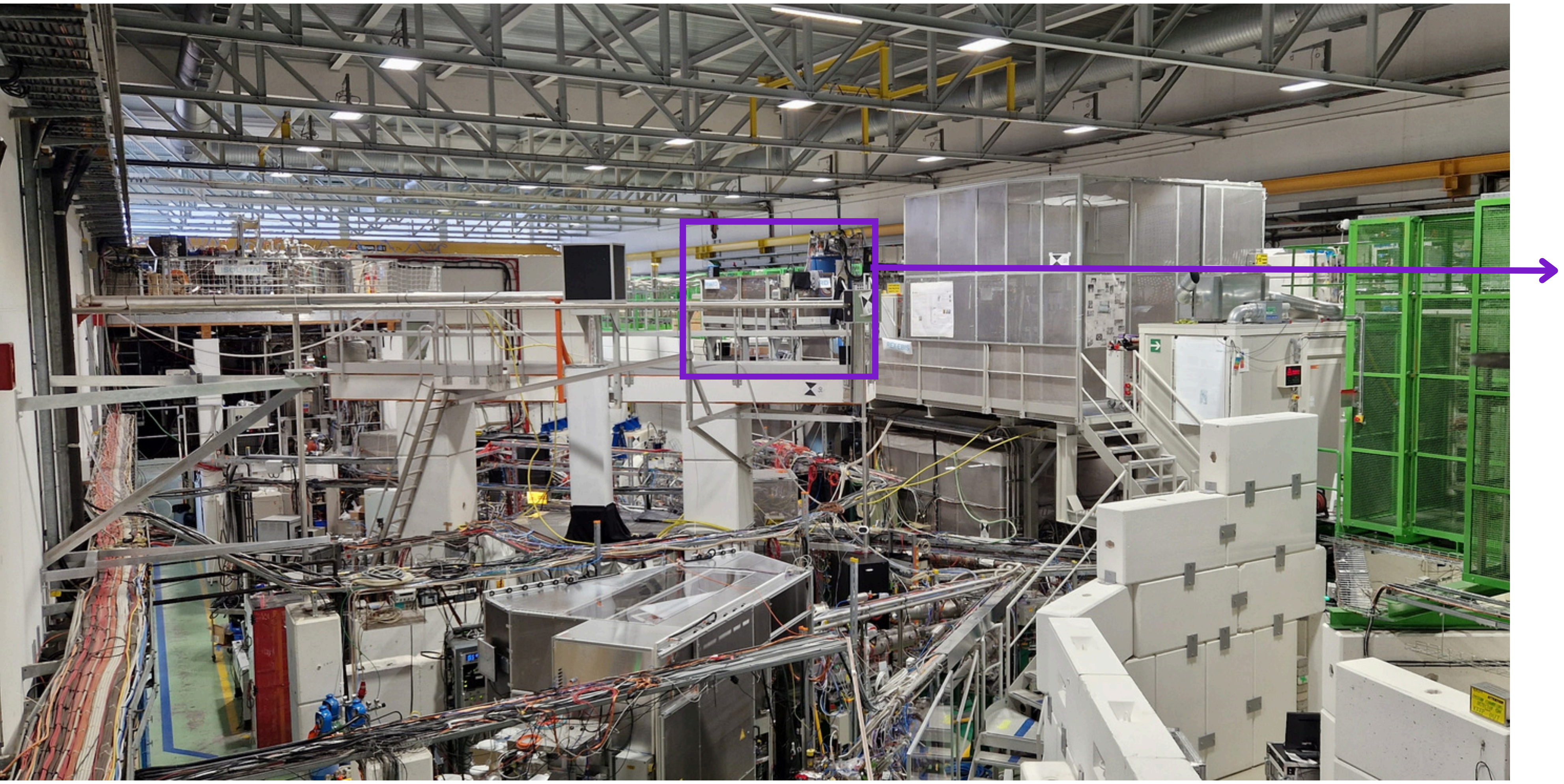
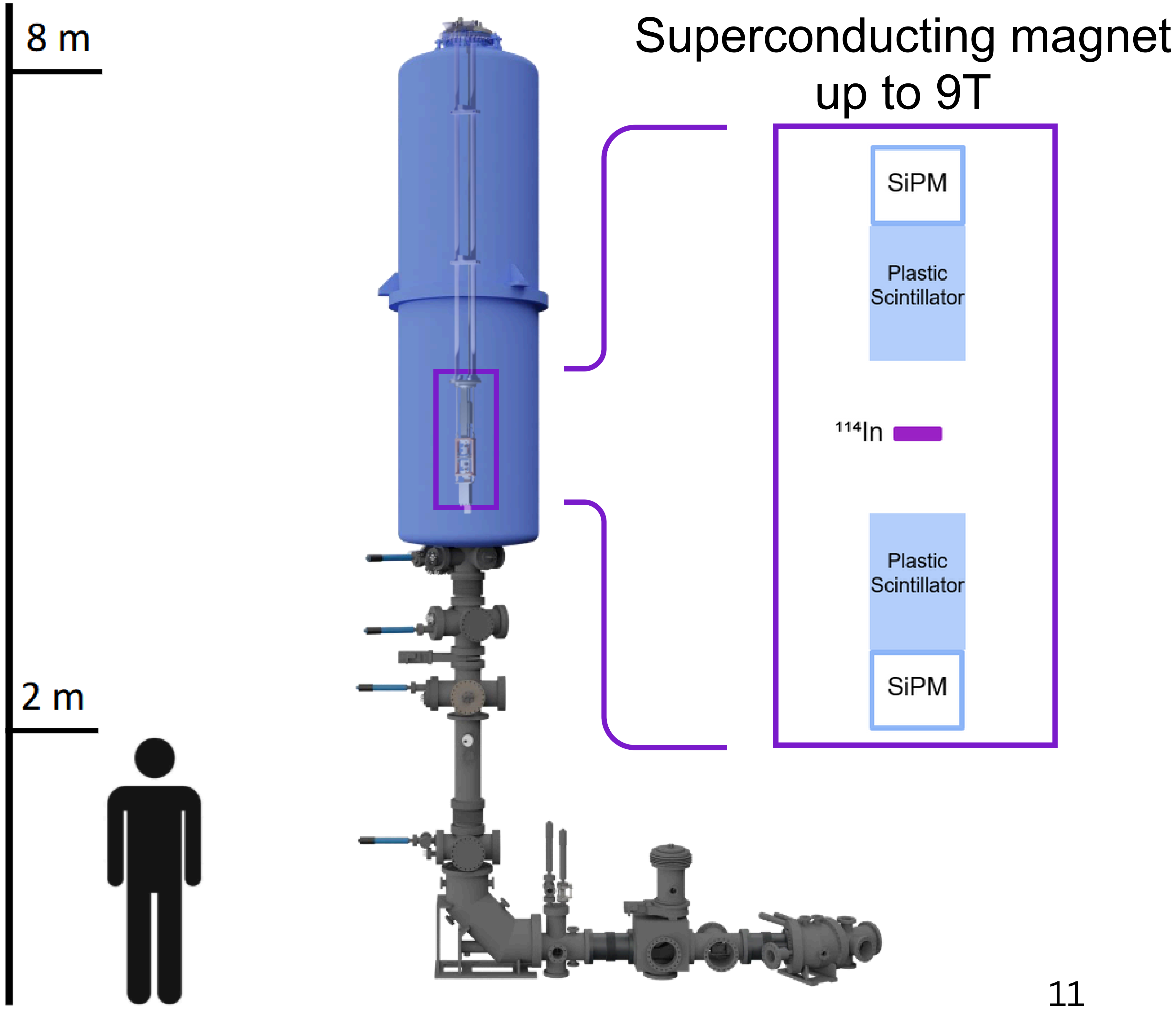
How to study β-shape: WISArD



Experiment in ISOLDE hall



Courtesy of S.Lecanuet

β-shape at WISArD 2020 setup

First measurement at WISArD of the beta shape of ^{114}In

S. Vanlangendonck, The effect of weak magnetism on the shape of the ^{114}In beta energy, PhD thesis, KU Leuven (2023).

β-shape at WISArD 2020 setup

First measurement at WISArD of the beta shape of ^{114}In

- Weak magnetism for A>70
- Pure Gamow Teller decay
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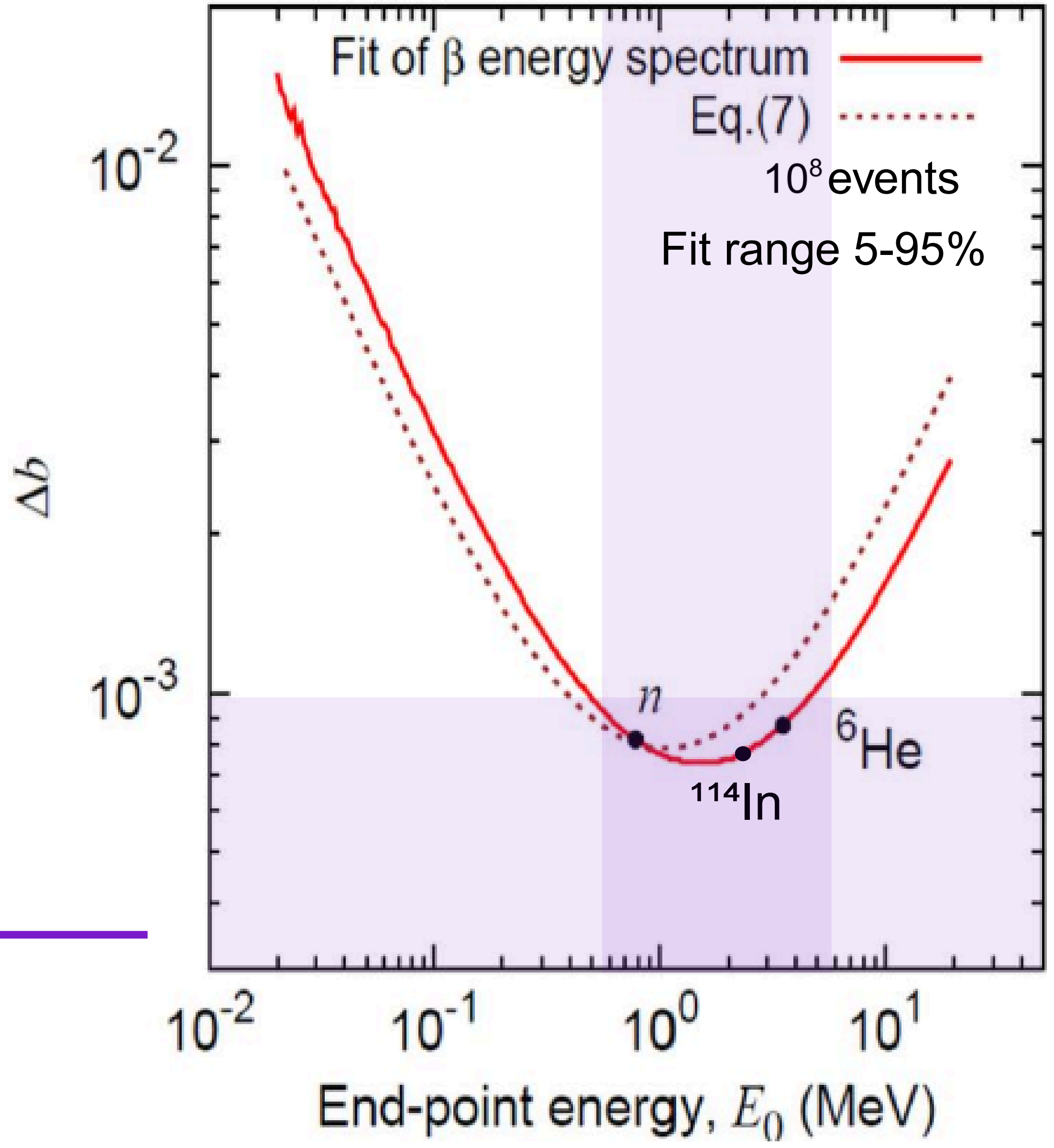
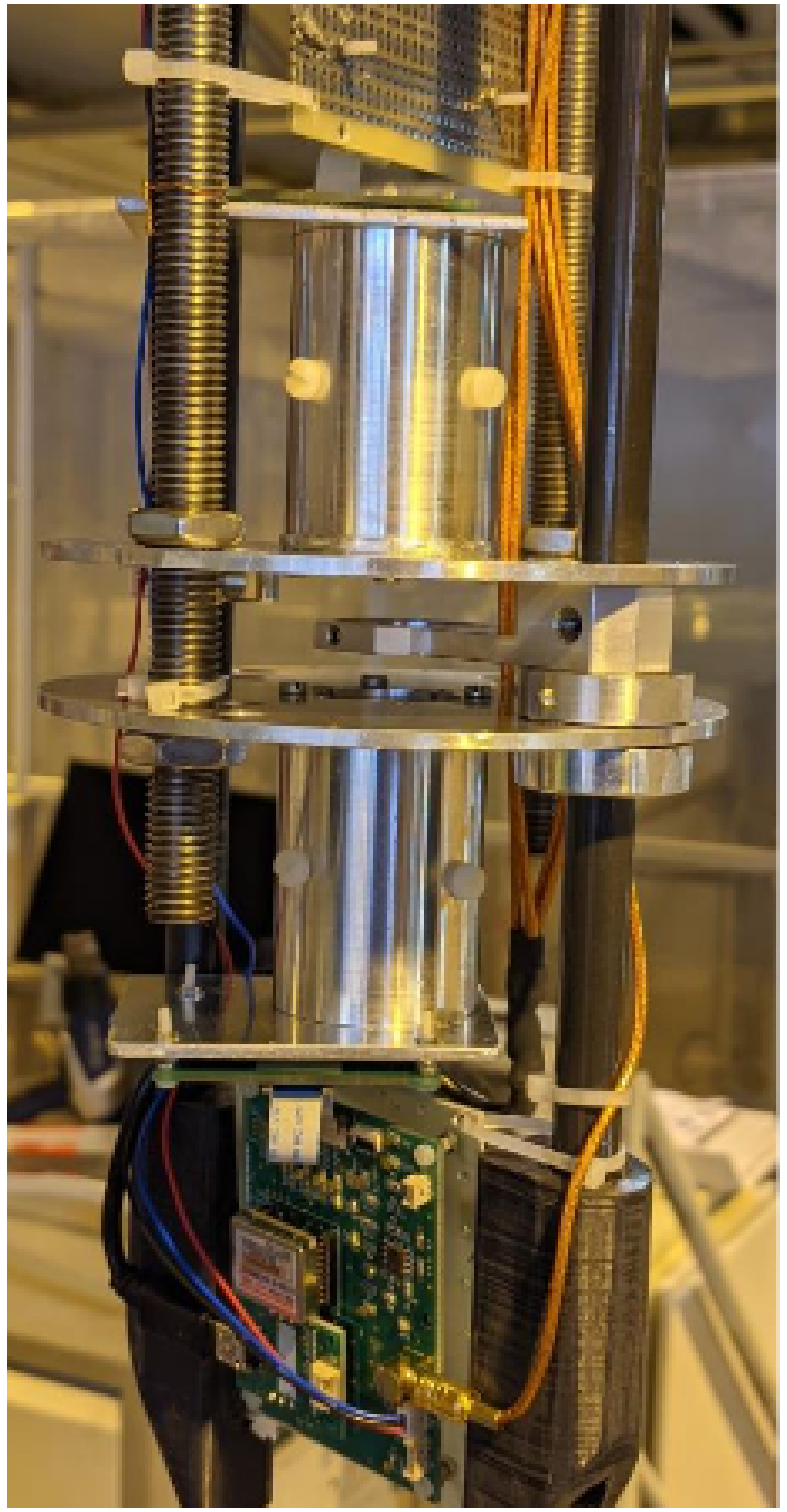


M. González-Alonso et al, PRC, 2016.

β-shape at WISArD 2020 setup



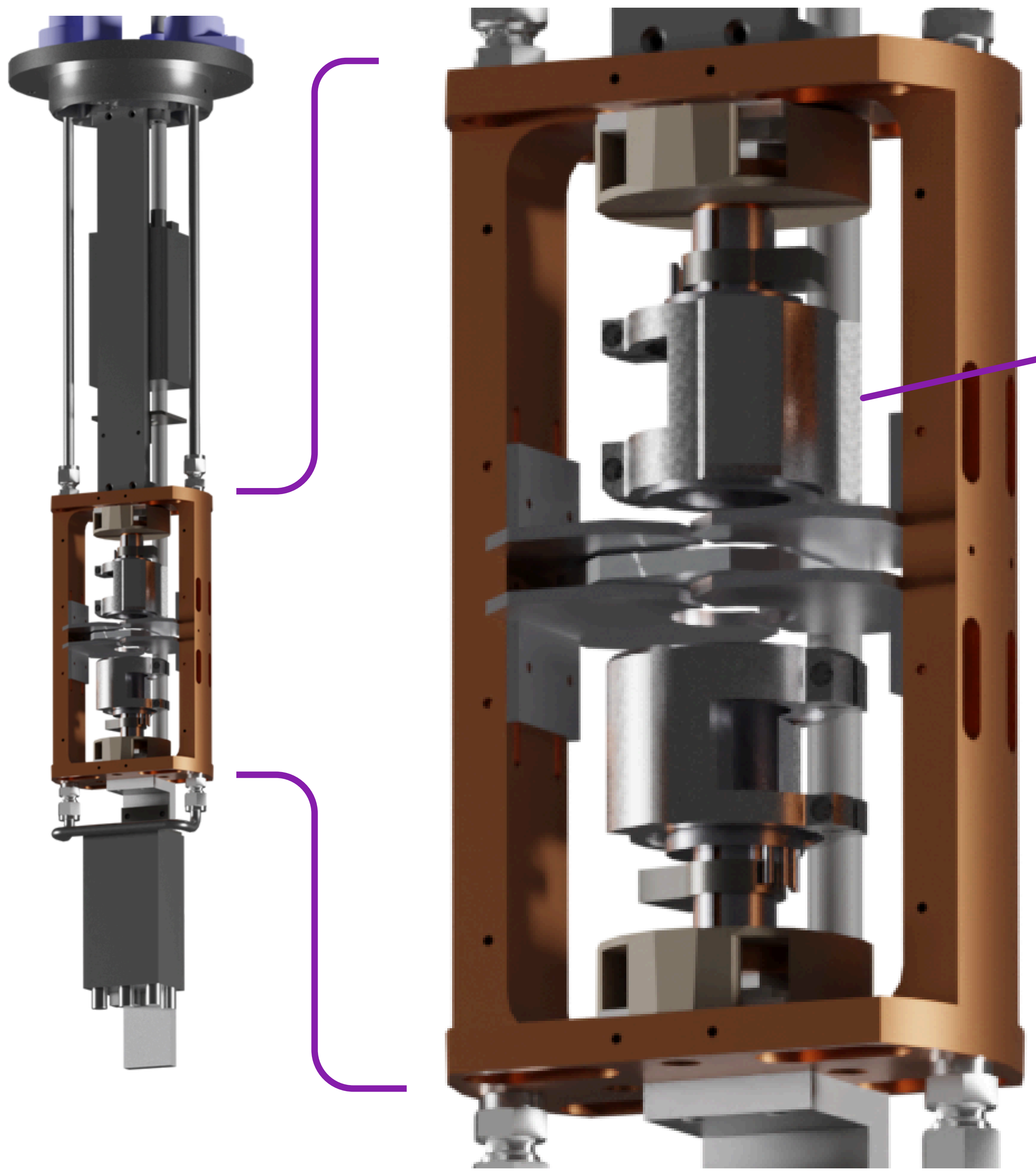
First measurement at WISArD of the beta shape of ^{114}In

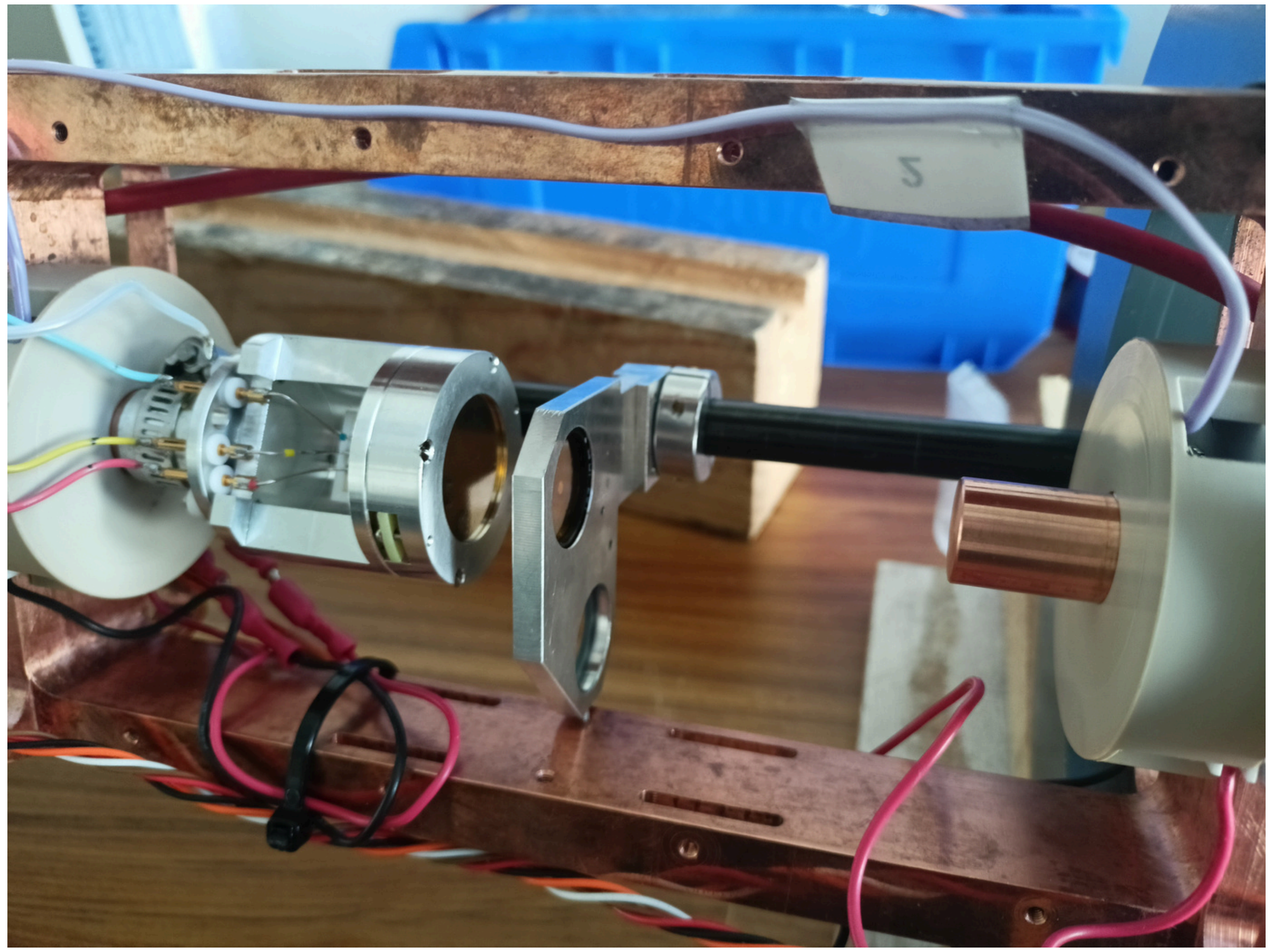
Necessary improvements:

- Source position
- Thinner sources
- Detectors
    - Lower threshold
    - Good linearity in energy (calibration, resolution)

S. Vanlangendonck, The effect of weak magnetism on the shape of the ^{114}In beta energy, PhD thesis, KU Leuven (2023).

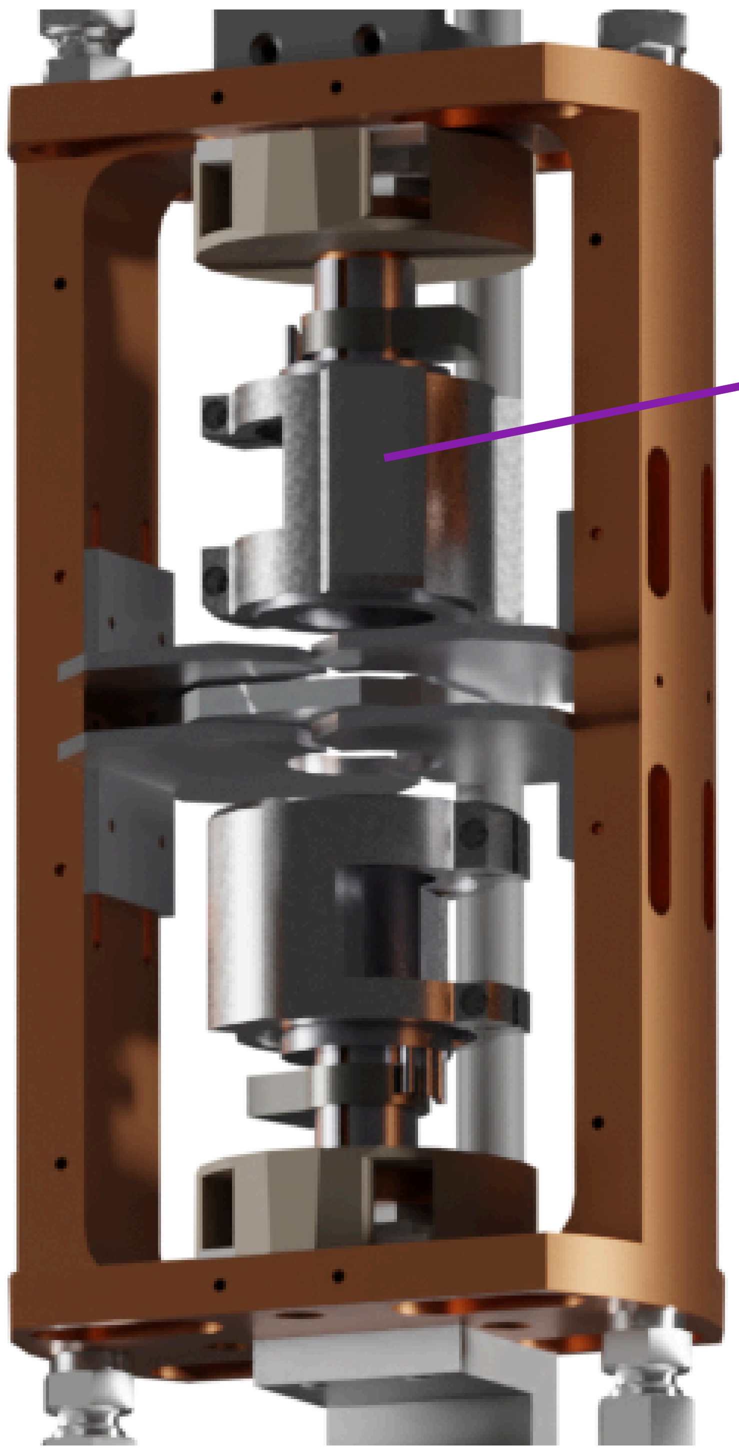
β-shape at WISArD 2025 setup

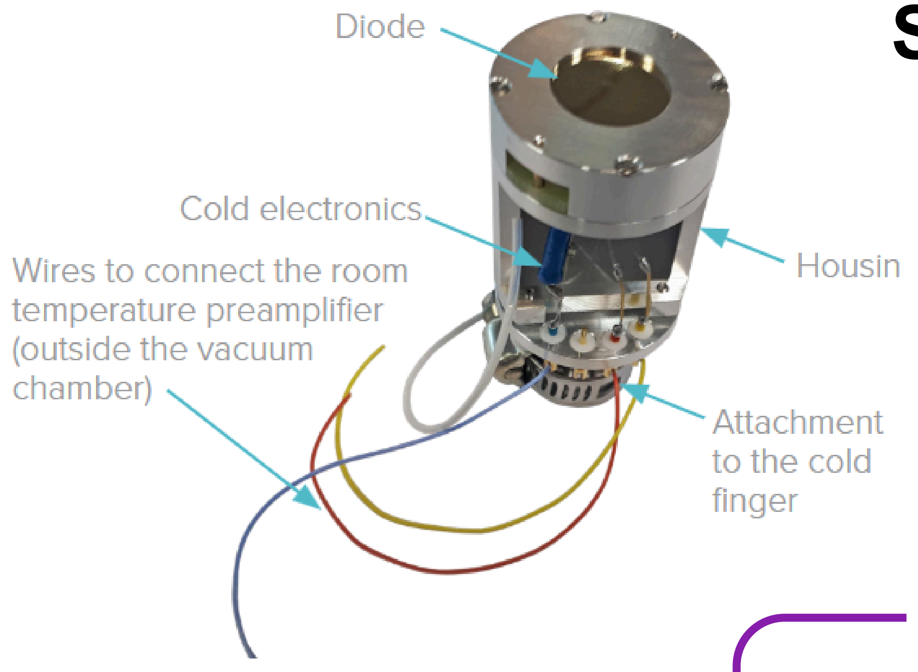




- Thinner sources from 2 μm to 500 nm
- Calibration source
- Aluminum garage
- Tungsten disk to shield detector from 207Bi

β-shape at WISArD 2025 setup



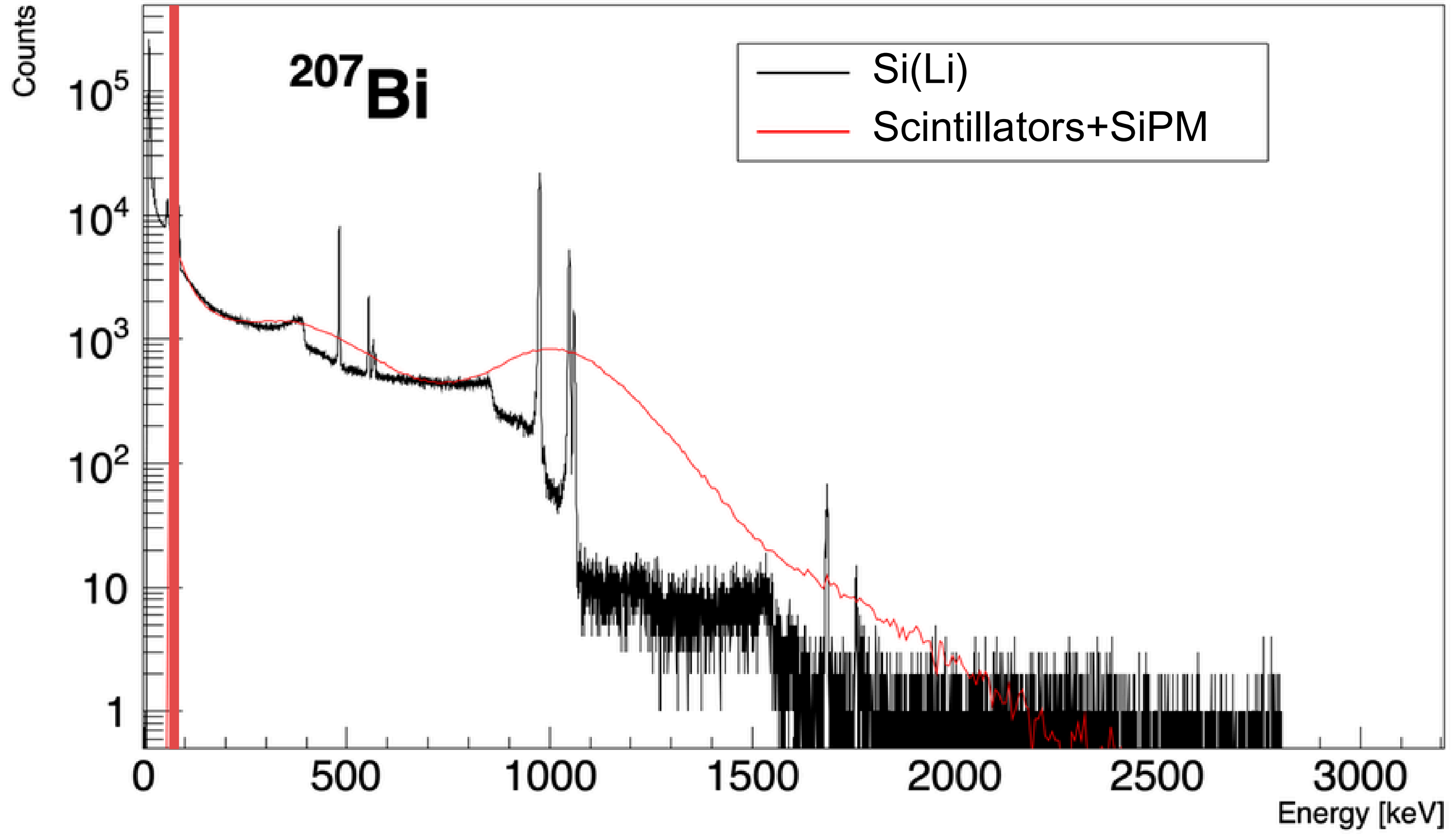


Scintillator+SiPM

↓

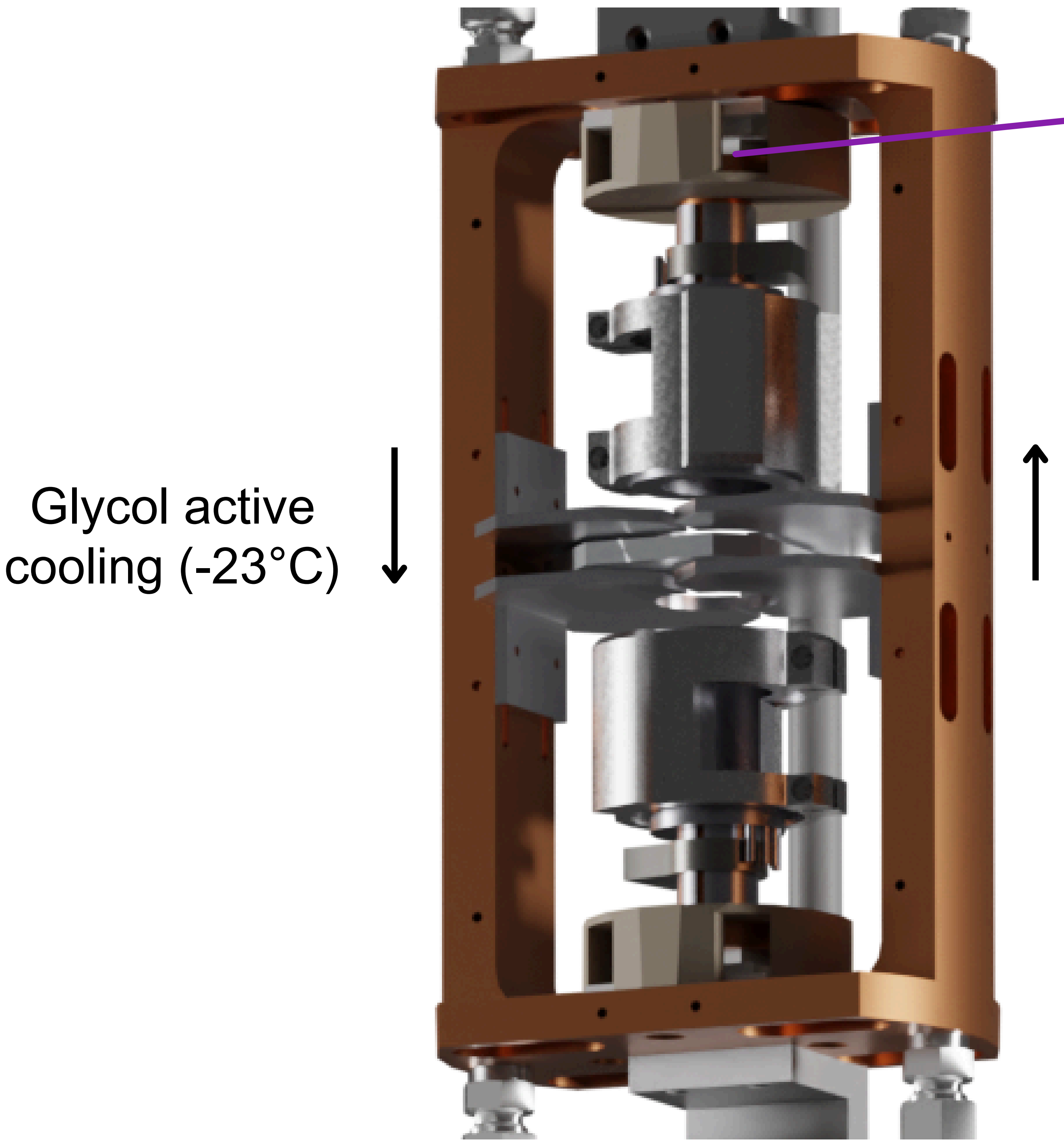
Si(Li)

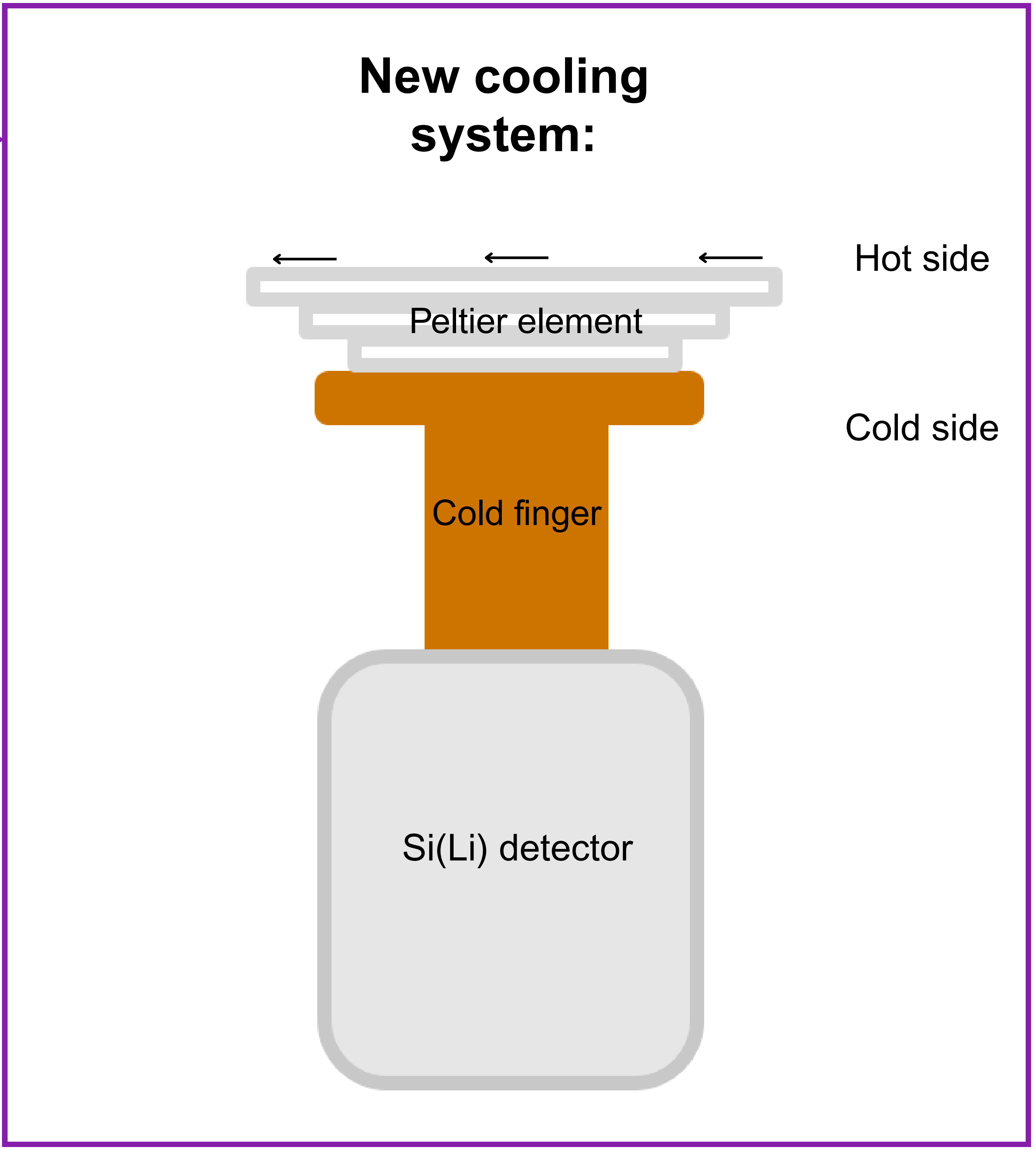
HV	-800V
T	-196°C
Cooling	LN2



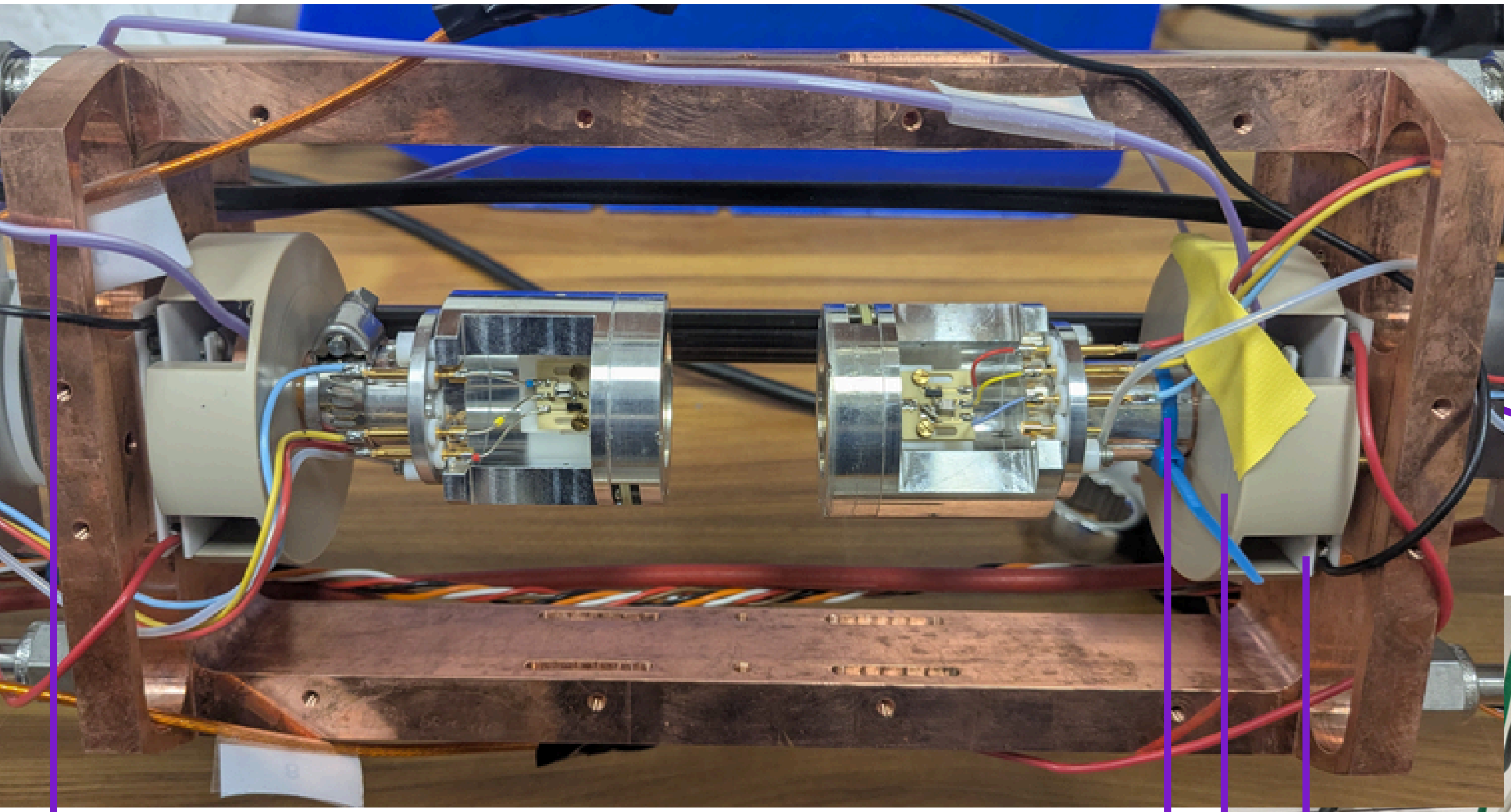
C.Knapen, Characterisation of Si(Li) Detectors for β Spectrum Shape Measurements, Master thesis, KU Leuven (2023)

β-shape at WISArD 2025 setup

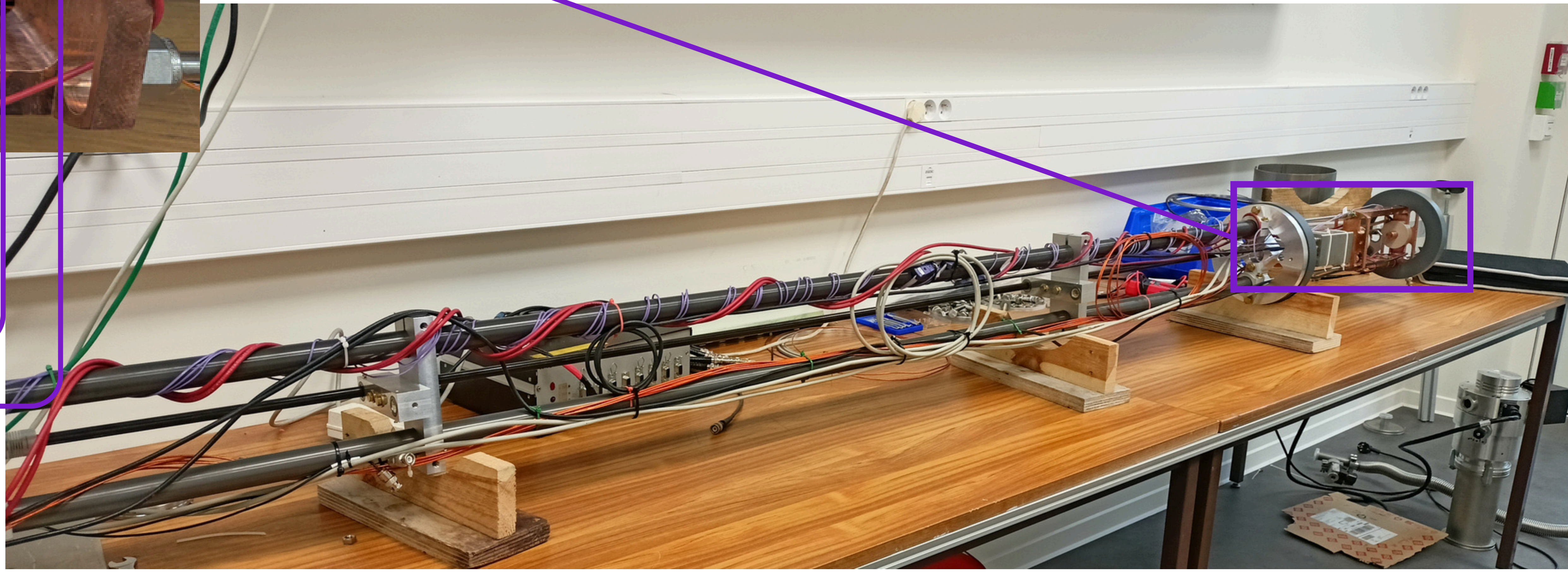




Work in progress between Leuven and Bordeaux



- Thermocouple
- Cold finger
- Support for Peltier
- Peltier element



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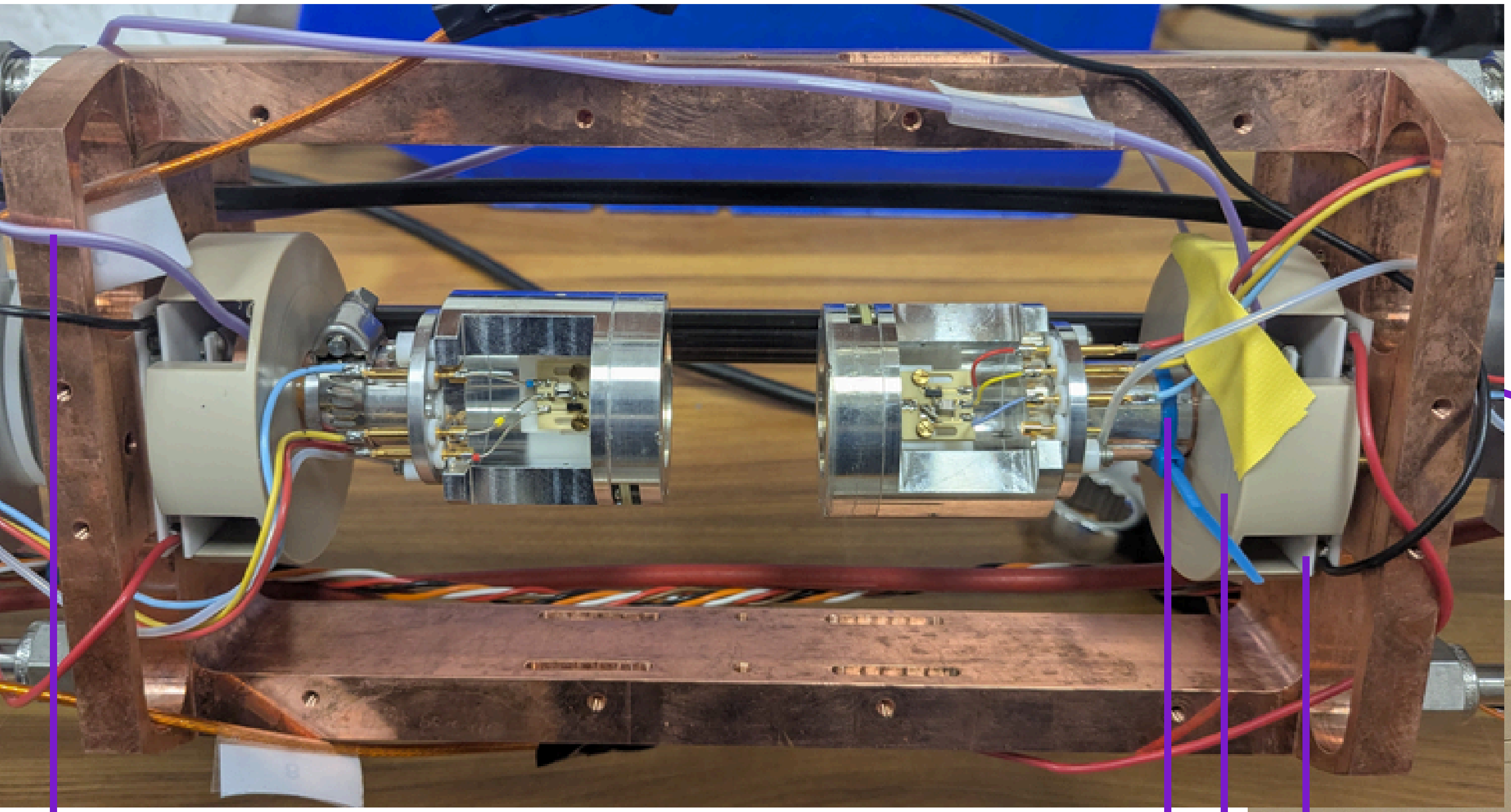

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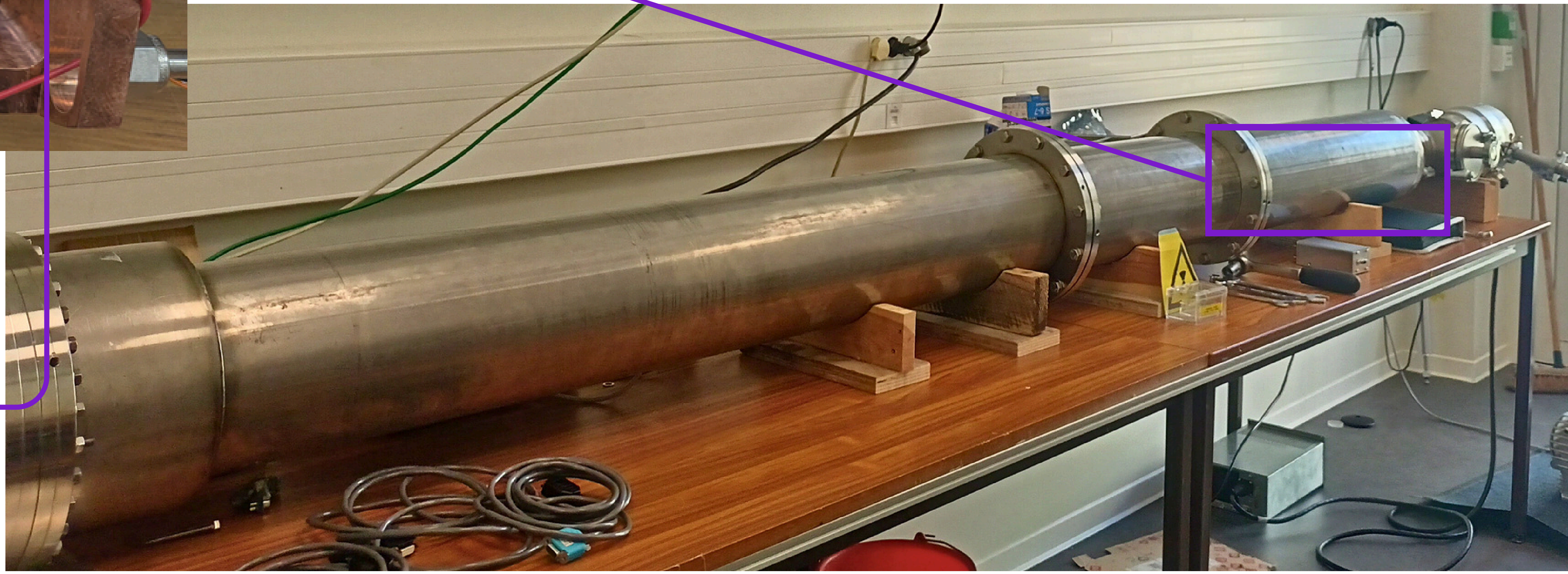

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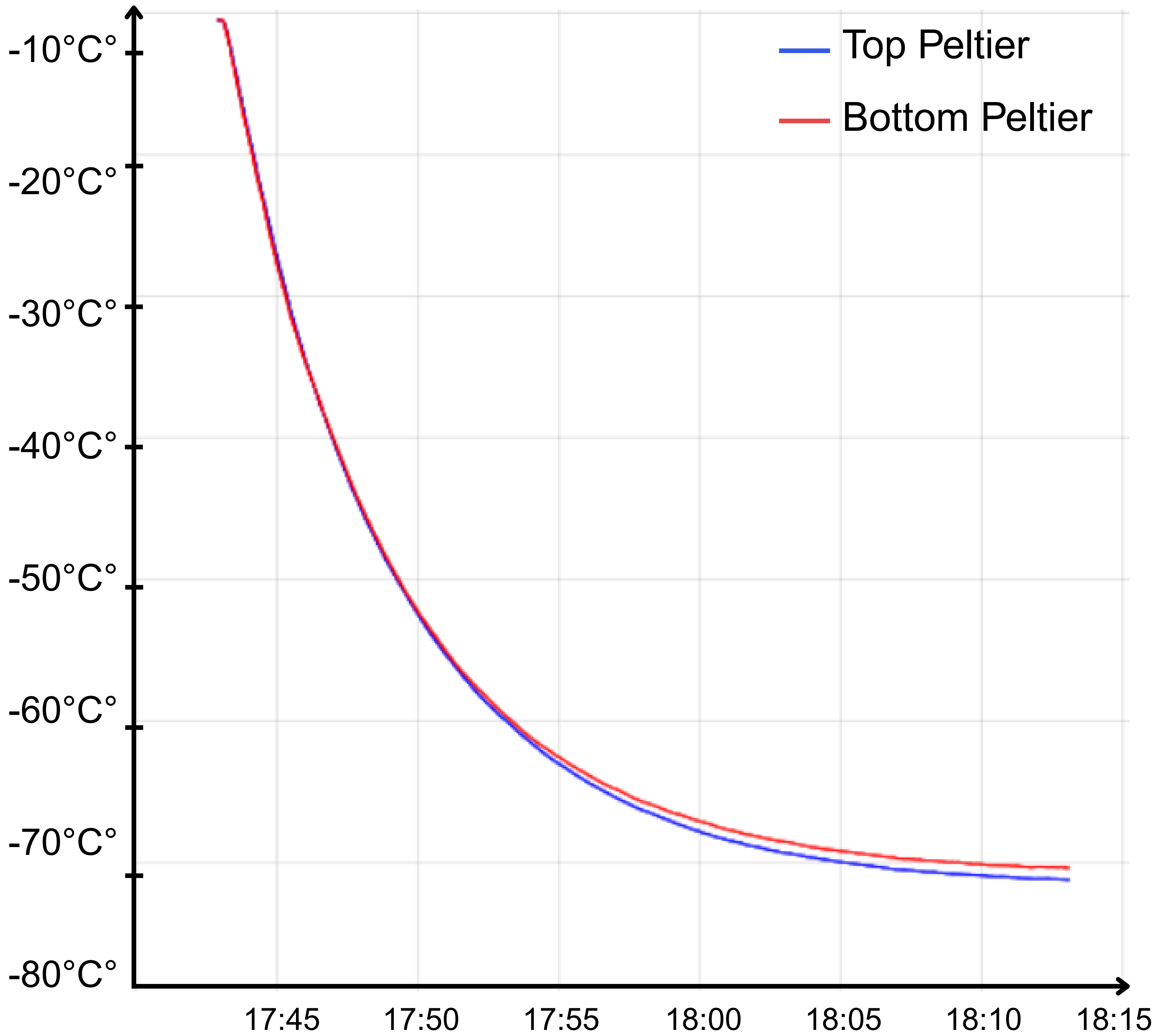
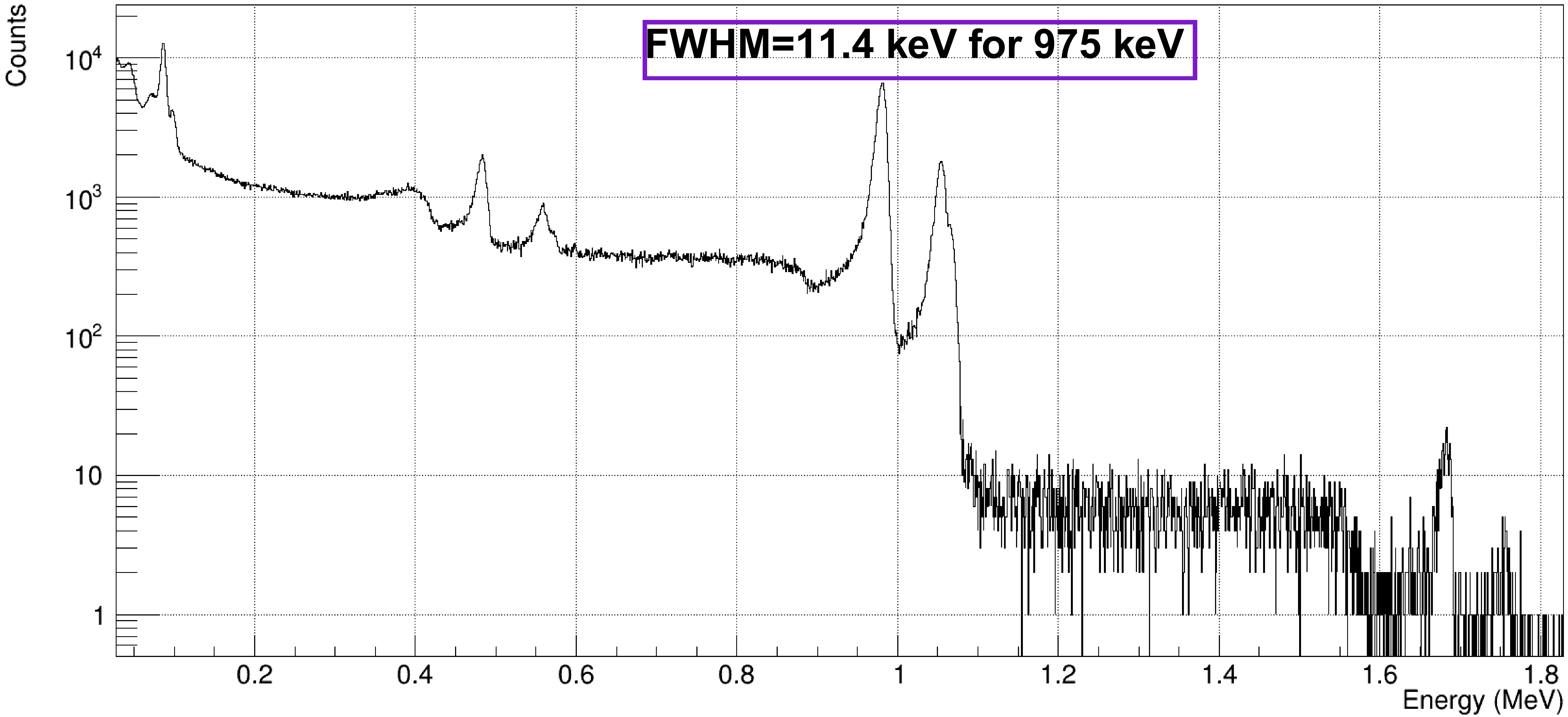


Cooling test performed to see if we were able to reach -70°C, at which current and the time necessary.

↓

Characterization of the detector with different values of HV and temperature

First spectrum in Bordeaux



- 1 Si(Li) detector
- ^{207}**Bi**
- Acquisition with FASTER for one hour

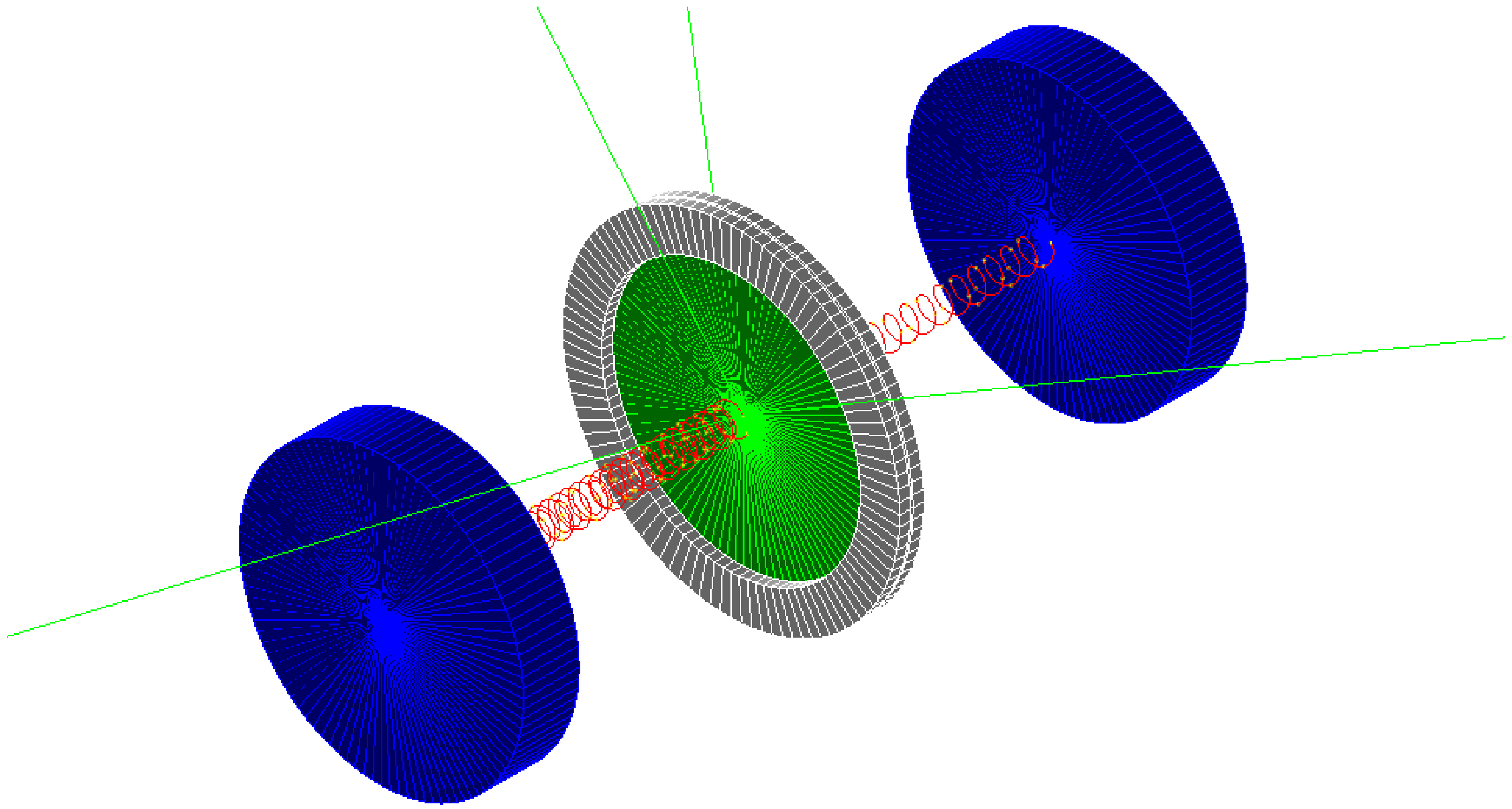
PRELIMINARY

	Bordeaux	Leuven
HV	-50V	-800V
T	-70°C	-196°C
Cooling	Glycol+Peltier	LN2

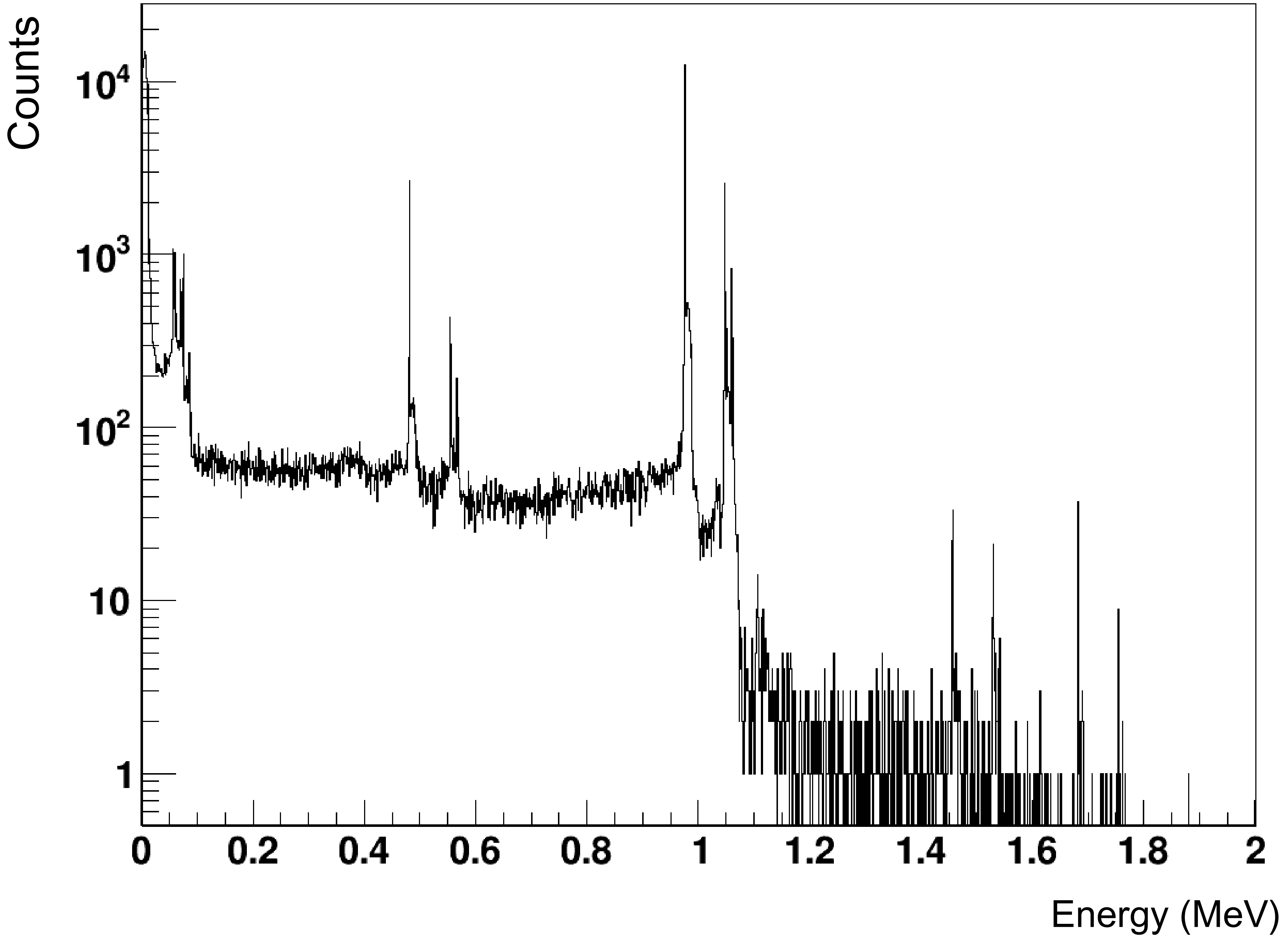
FWHM=1.5 keV

Simulation toolkit GEANT4

Simulated setup
- 2 Si(Li) detectors
- Magnetic field
- Source in the mylar disk



Deposited energy spectrum of ^{207}Bi for the upper Si(Li)

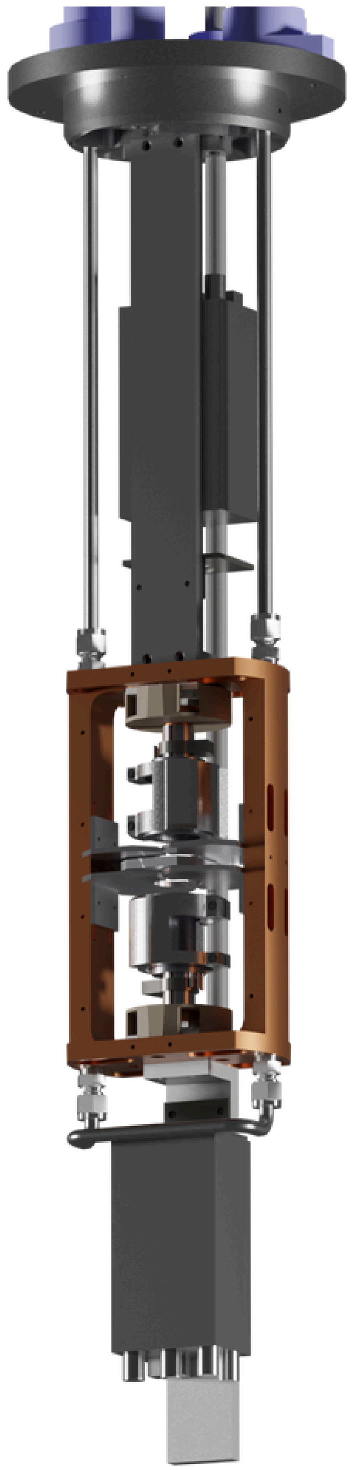


PRELIMINARY

Summary and perspectives

Improvements from previous setup:

- New cooling system glycol+Peltier elements
- Scintillator + SiPM $\rightarrow$ Si(Li)
- Garage + disk of tungsten
- Sources are thinner



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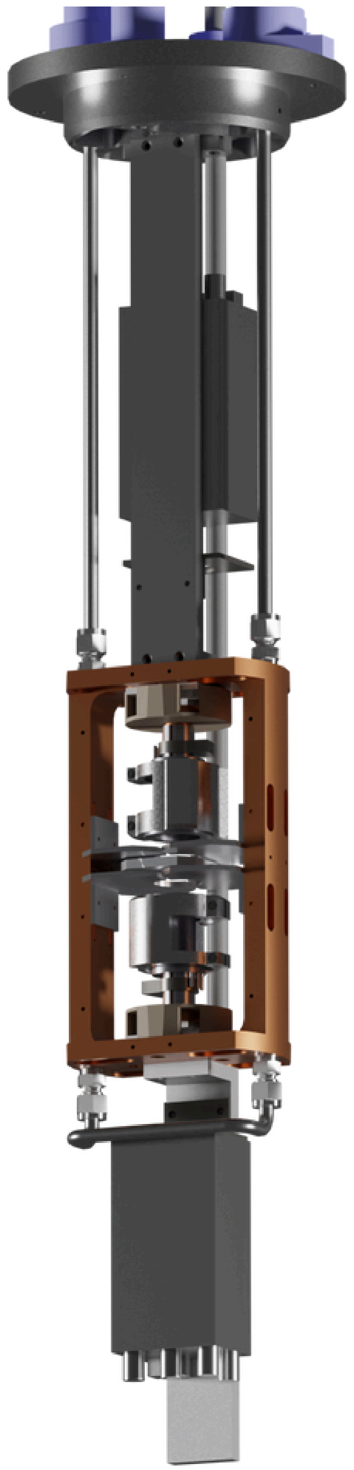


Next steps:

- Test full setup with both detectors at Bordeaux
- Geant4 simulation ongoing
- Data taking at ISOLDE for beginning of 2026

Thank you for your attention!

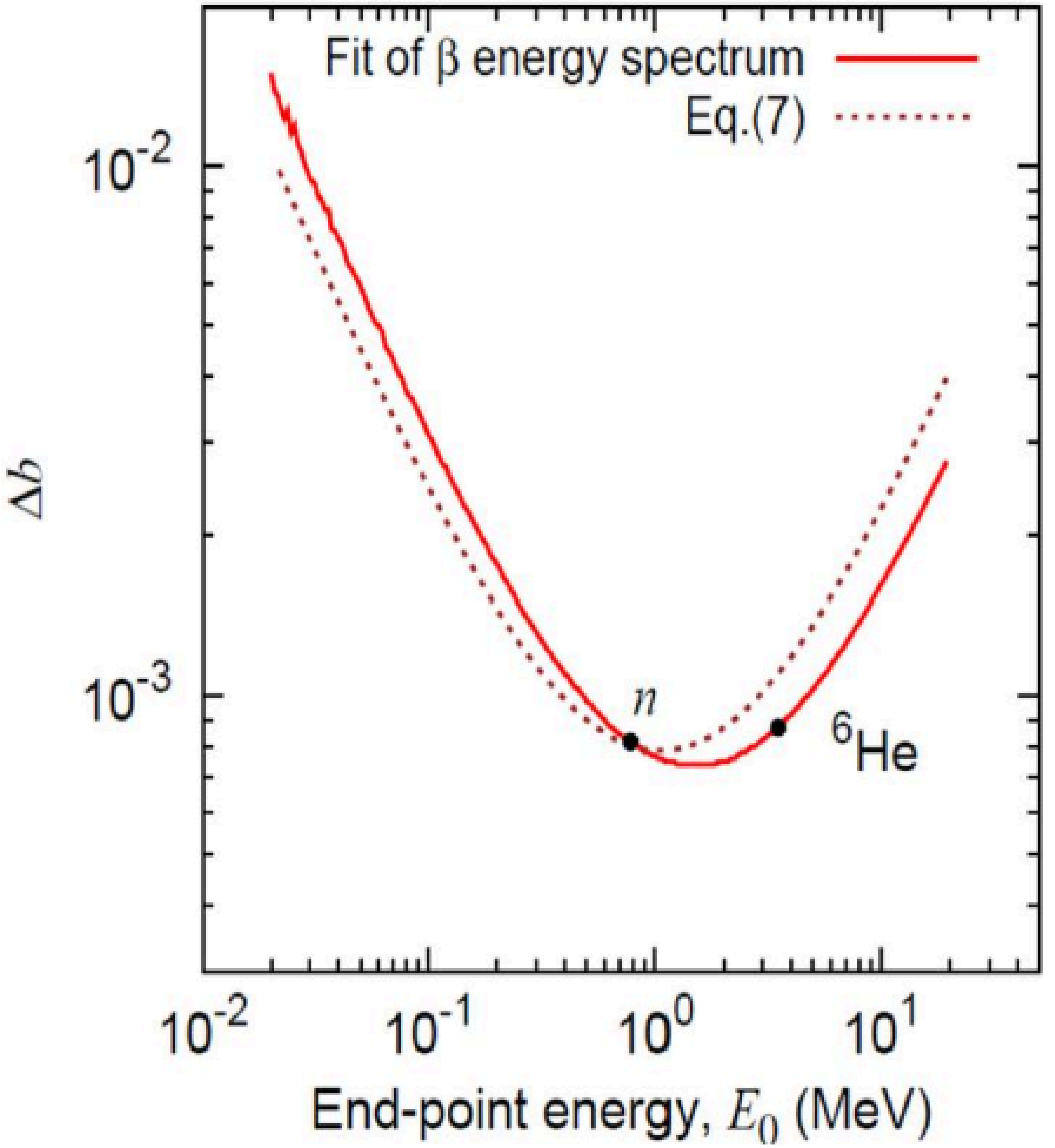
P. Alfaurt, P. Ascher, D. Atanasov, B. Blank, L. Daudin, X. Fléchard, G.Frémont,M.Gerbaux,J. Giovinazzo, S.Grévy

J. Ha, C. Knapen, S.Lecanuet, R.Lica, M. Pomorski, M.Roche, N.Severijns, S. Vanlangendonck, M. Versteegen, D. Zakoucky

Isotopes candidates

- ^{114}In: favorable endpoint for BSM, pure GT + already measured in 2021 so useful to show improvement of the setup
- ^{32}P: favorable endpoint, allowed transition with large ft value
- ^{22}Na: β+ emitter, measurement to study BR of ^{14}O

Calibration sources: ^{207}Bi, ^{137}Cs,..



M. González-Alonso et al, PRC, 2016.

Theoretical corrections

Category	Effect	Formula	Magnitude
Phase space		$pW(W_0 - W)^2$	Unity or larger
Electrostatic	Fermi function	F_0	
	Finite size nucleus	L_0	
Radiative corr.		R	
Recoil-order	Shape factor	C	
	Isovector correction	C_I	
Atomic	Atomic exchange	X	$10^{-1} - 10^{-2}$
	Atomic mismatch	r	
	Atomic screening	S	
	Shake-up & Shake-off	included in r	
Higher order	Diffuse nucl. surface	U	
	Nuclear deformation	D_{FS} & D_C	
	Recoil Coulomb corr.	Q	$10^{-3} - 10^{-4}$
	Recoiling nucleus	R_N	
	Molecular screening	ΔS_{Mol}	
	Molecular decay	Case by case	
	Bound state β decay	Γ_b/Γ_c	$< 1 \times 10^{-4}$
	Neutrino mass	negligible	

L.Hayen, N.Severijns and al. High precision analytical description of the allowed β spectrum shape. (2018)

Theoretical corrections

Category	**Description**
Kinematics	Accounts for the relativistic motion of beta particles.
Electrostatics	Corrects for Coulomb interaction between the emitted electron and the nucleus.
Radiative Corrections	Includes photon emission and loop-level quantum electrodynamics (QED) effects.
Atomic & Molecular Effects	Considers the influence of the atomic structure on beta decay.

L.Hayen, N.Severijns and al. High precision analytical description of the allowed β spectrum shape. (2018)

Lagrangian weak interaction

$$\mathcal{L}_{Lee-Yang} = +\bar{p}\gamma^{\mu}n\,\bar{e}\gamma_{\mu}\left(C_V + C'_V\gamma_5\right)\nu$$ Vector current

$$-\bar{p}\gamma^{\mu}\gamma_5 n\,\bar{e}\gamma_{\mu}\left(C_A\gamma_5 + C'_A\right)\nu$$ Axial-vector current

$$+\bar{p}n\,\bar{e}\left(C_S + C'_S\gamma_5\right)\nu$$ Scalar current

$$+\frac{1}{2}\bar{p}\sigma^{\mu\nu}n\,\bar{e}\sigma_{\mu\nu}\left(C_T + C'_T\gamma_5\right)\nu$$ Tensor current

$$-\bar{p}\gamma_5 n\,\bar{e}\left(C_P\gamma_5 + C'_P\right)\nu$$ Pseudo-scalar current

$$+h.\,c.$$

$$C_V = 1 = C'_V, C_{A=}1.27 = C'_A, C_S = 0, C_T = 0$$

Systematic uncertainties on WM and 2020 results

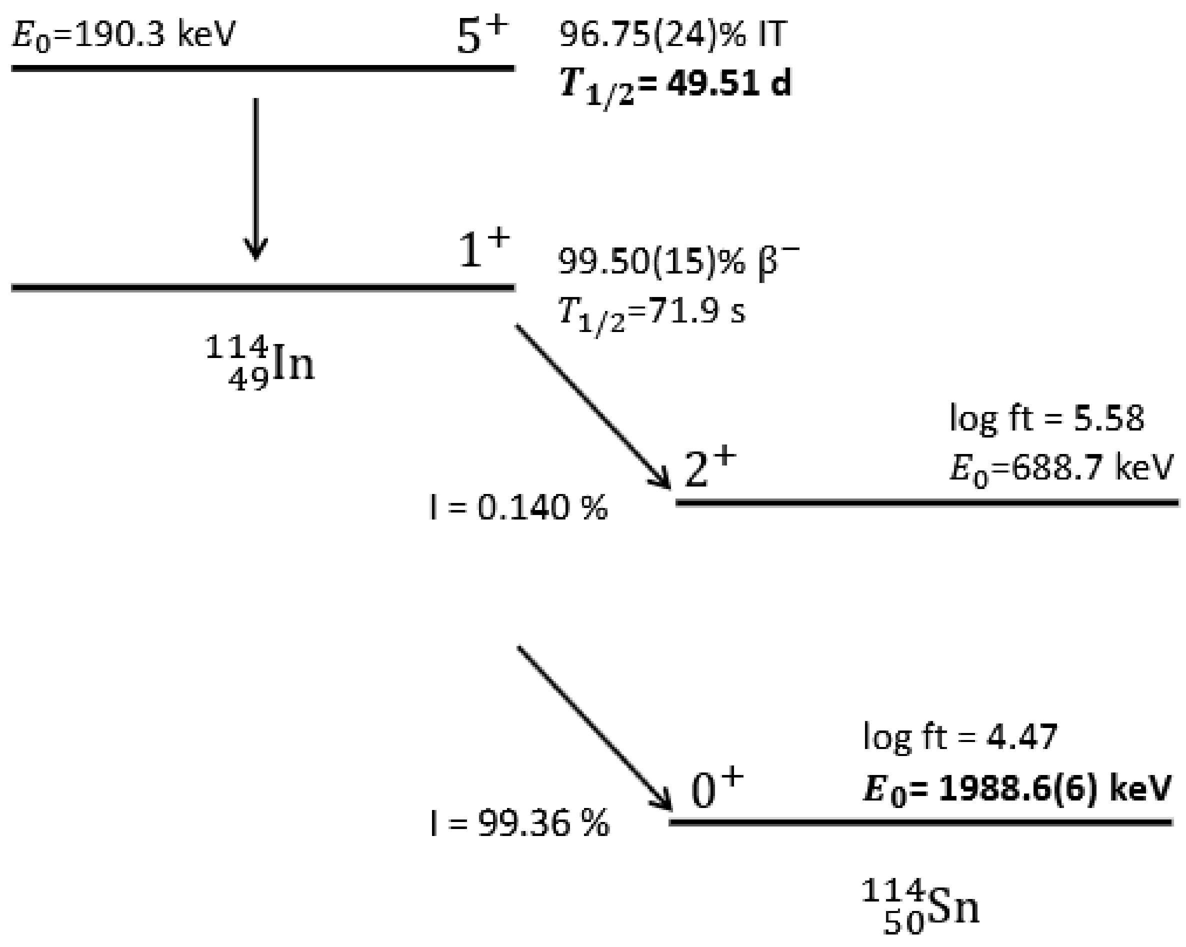
$$\frac{b}{A_c} = 17.0(23)_{stat}(18)_{sys}$$

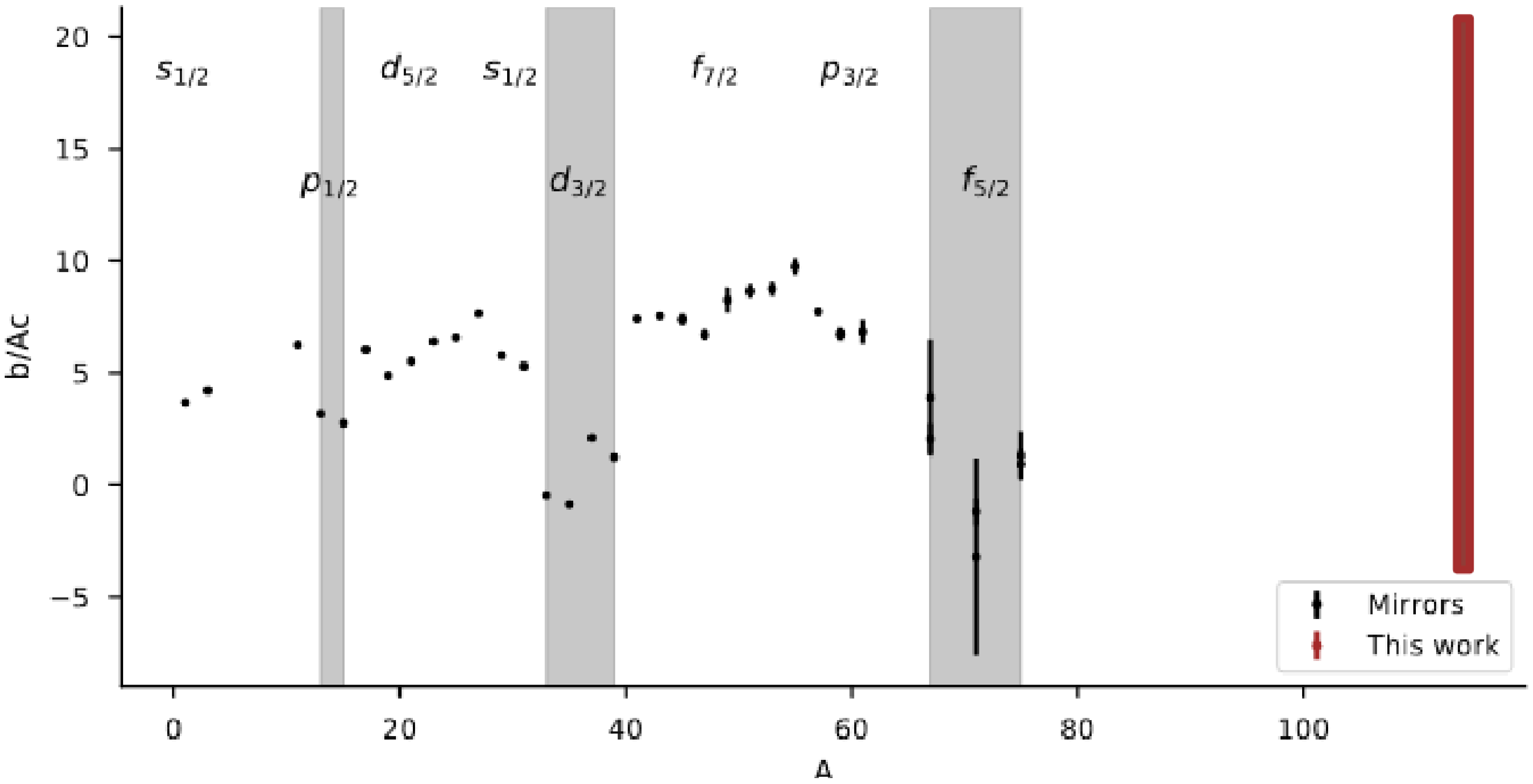
	Effect	Uncertainty	Δb_{WM}
Theory	Endpoint energy	0.3 keV	0.1
	ρ, R and d/Ac		None
Geant4	Detector threshold	3.75 keV	1.2
	Source position		
	Rotation	1°	0.1
	Source diameter	1 mm	0.3
	QDC time window	50 ns	None
	Foil thickness	±10%	None
Energy resolution	σ_1	σ_{fit}	< 0.1
	σ_2	σ_{fit}	< 0.1
SiPM non-linearity	E/pixel	0.16 keV	1.1
	$P_{crosstalk}$	Unknown	
(Auto-)calibration	a_0	σ_{fit}	< 0.1
	a_1	σ_{fit}	0.3
Total			1.7

PRELIMINARY

S. Vanlangendonck, The effect of weak magnetism on the shape of the ^{114}In beta energy, PhD thesis, KU Leuven (2023).

114In

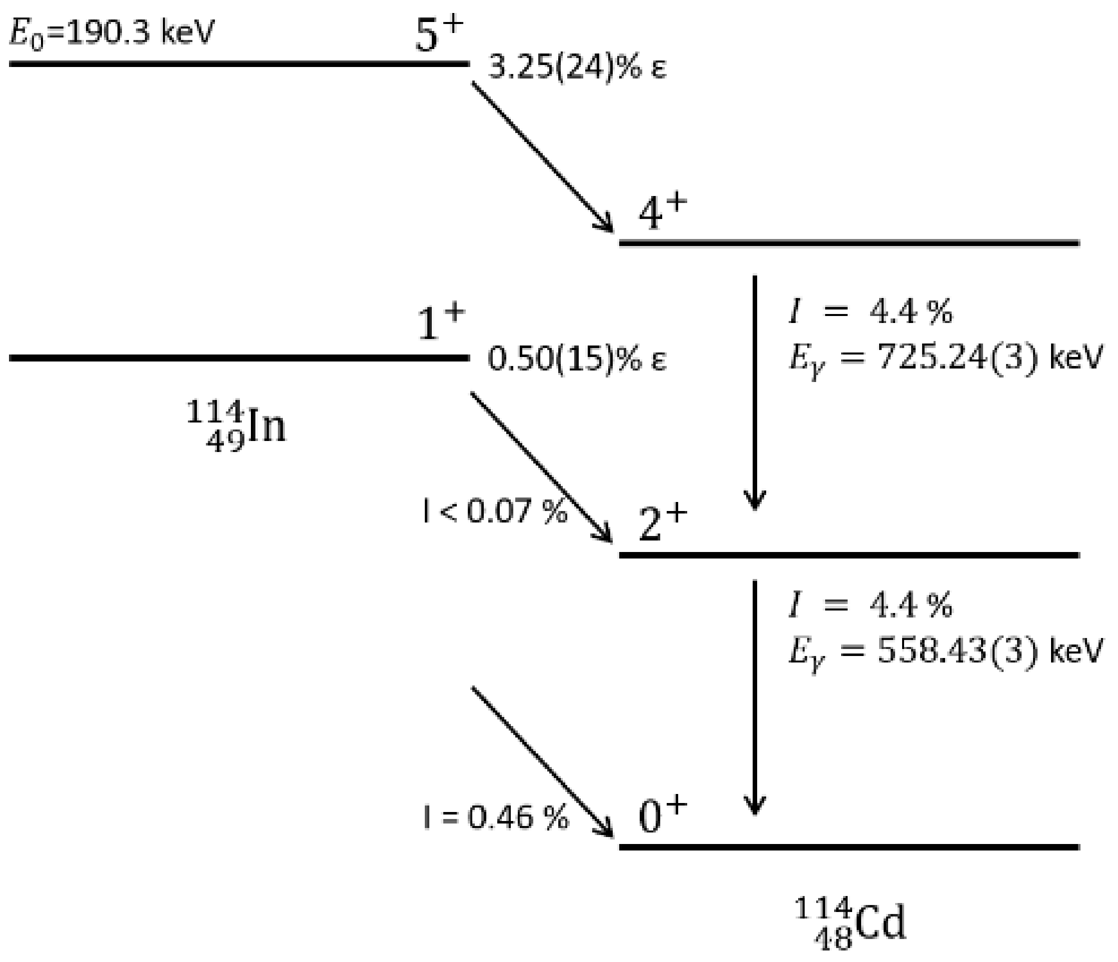




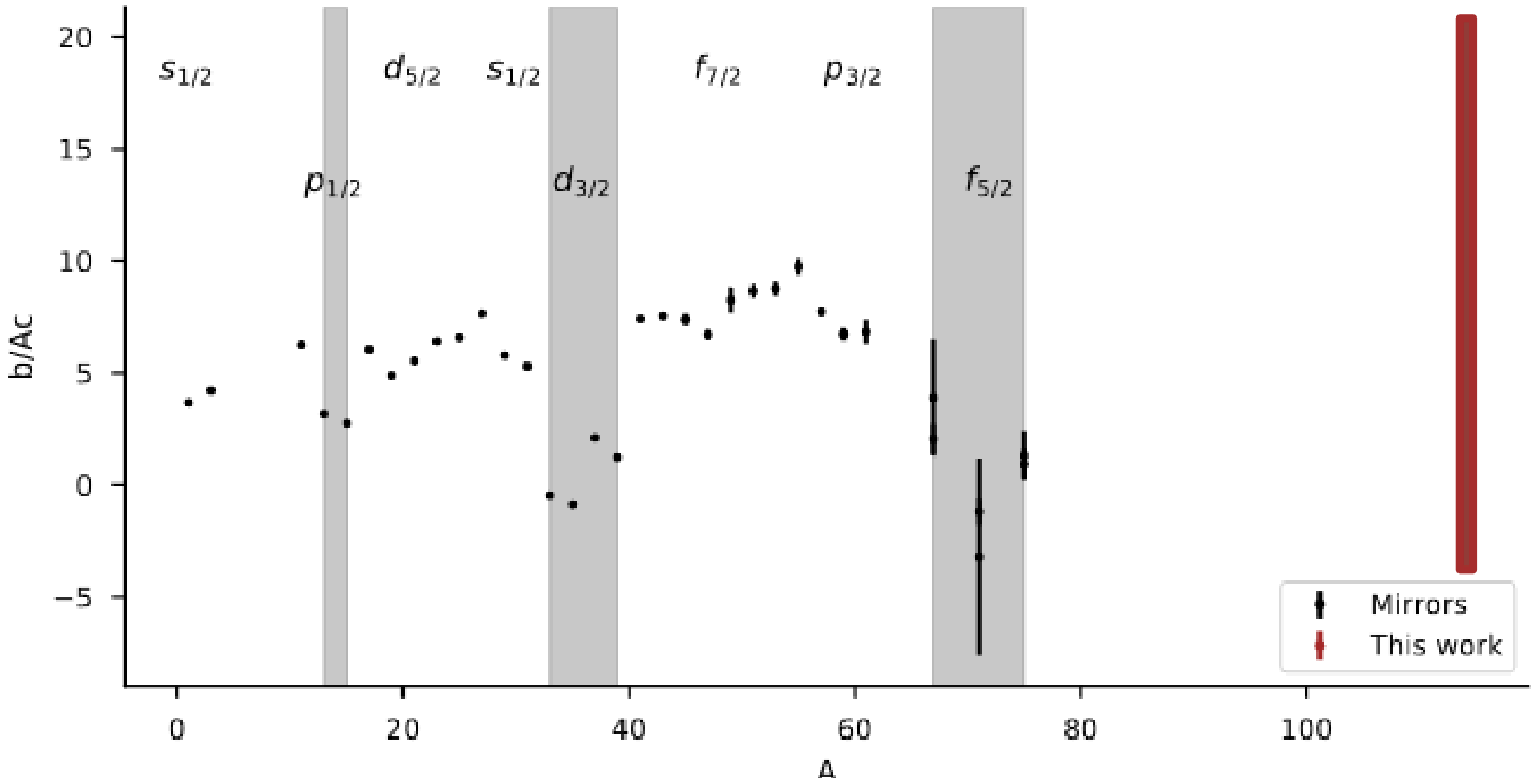
The decay scheme of
114In towards 114Sn with the small contribution towards the excited state and the main decay branch of interest.

S. Vanlangendonck, The effect of weak magnetism on the shape of the ^{114}In beta energy, PhD thesis, KU Leuven (2023).

114In



The decay scheme of 114In towards 114Cd due to electron capture.



S. Vanlangendonck, The effect of weak magnetism on the shape of the ^{114}In beta energy, PhD thesis, KU Leuven (2023).

^{114}In corrections

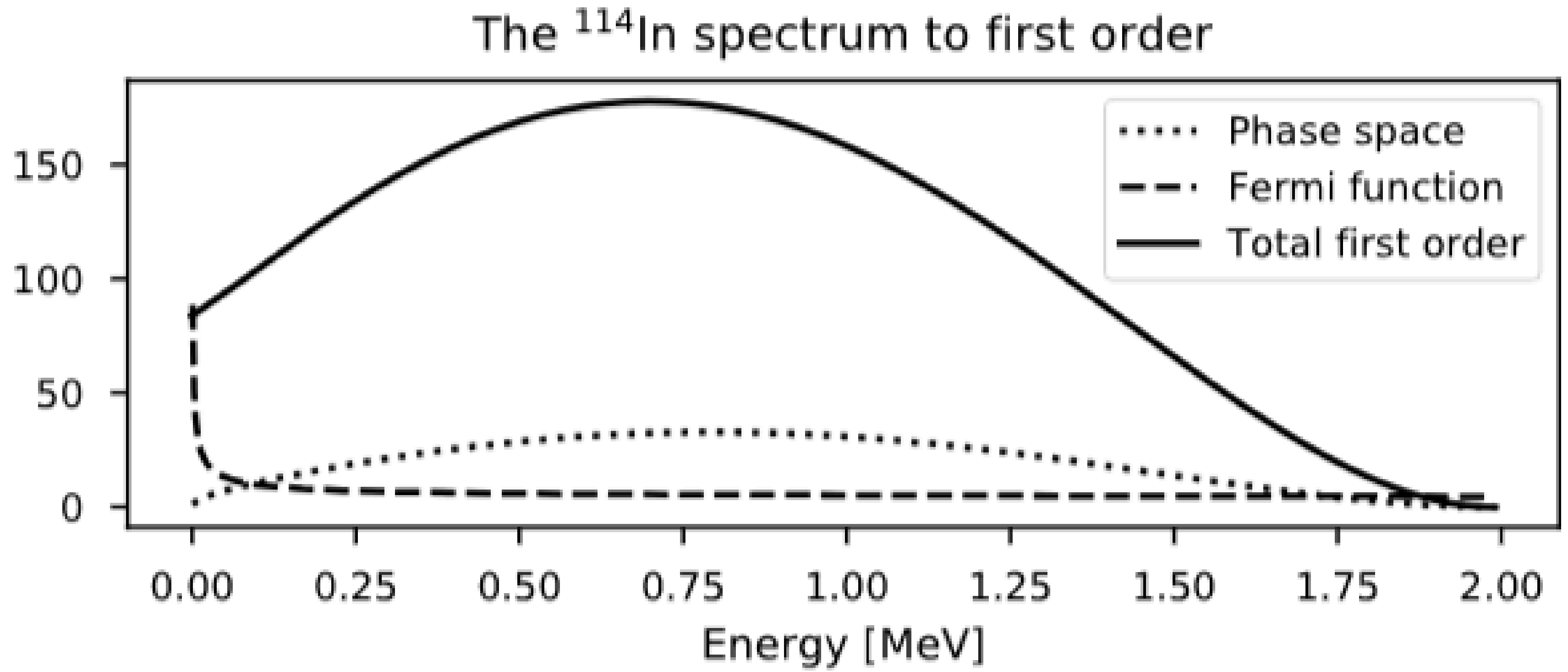


Figure 4.4: The first order description of the beta decay spectrum for the isotope of interest, ^{114}In. The total first-order spectrum shape is the product of the phase space factor and the Fermi function.

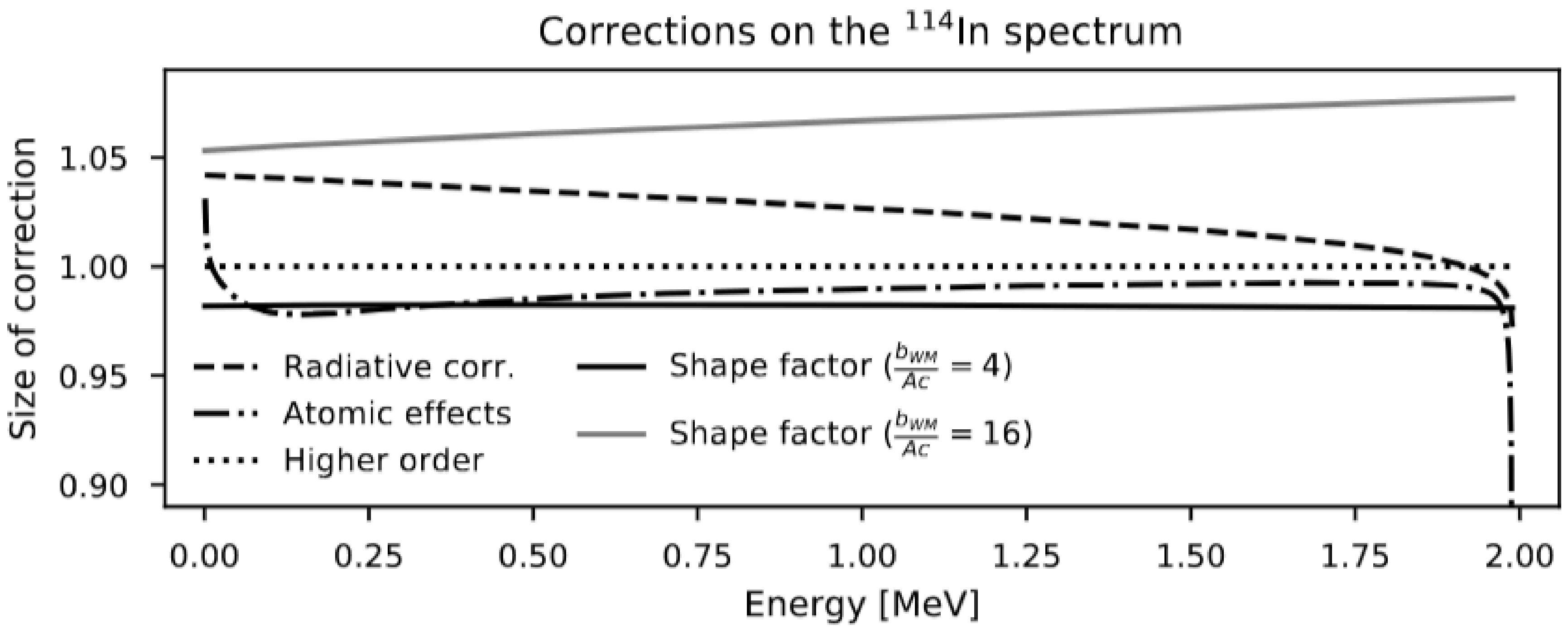


Figure 4.5: The correction factors, as calculated using the BSG code [102], with which the beta spectrum has to be multiplied to take in account the different corrections described in Sec. 4.1 for the isotope of interest ^{114}In.

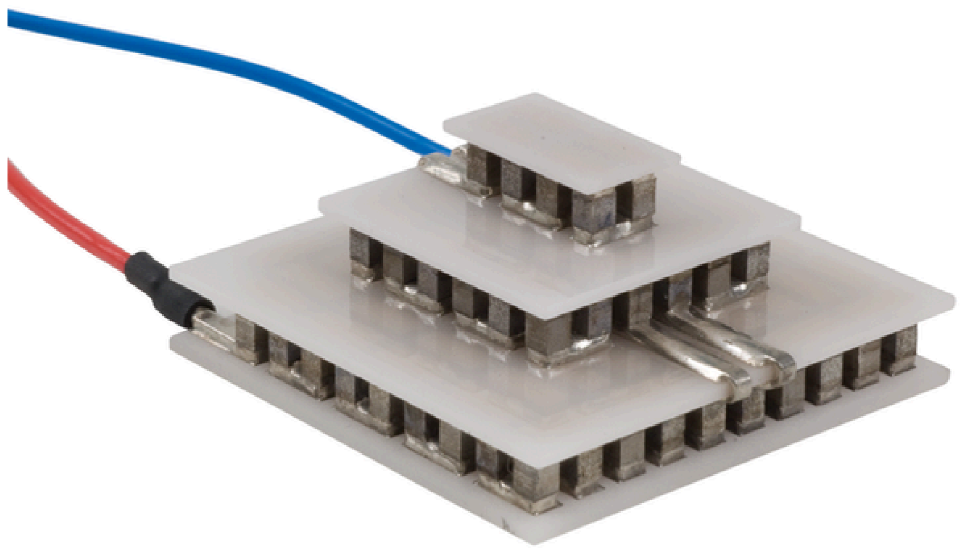
S. Vanlangendonck, The effect of weak magnetism on the shape of the ^{114}In beta energy, PhD thesis, KU Leuven (2023).

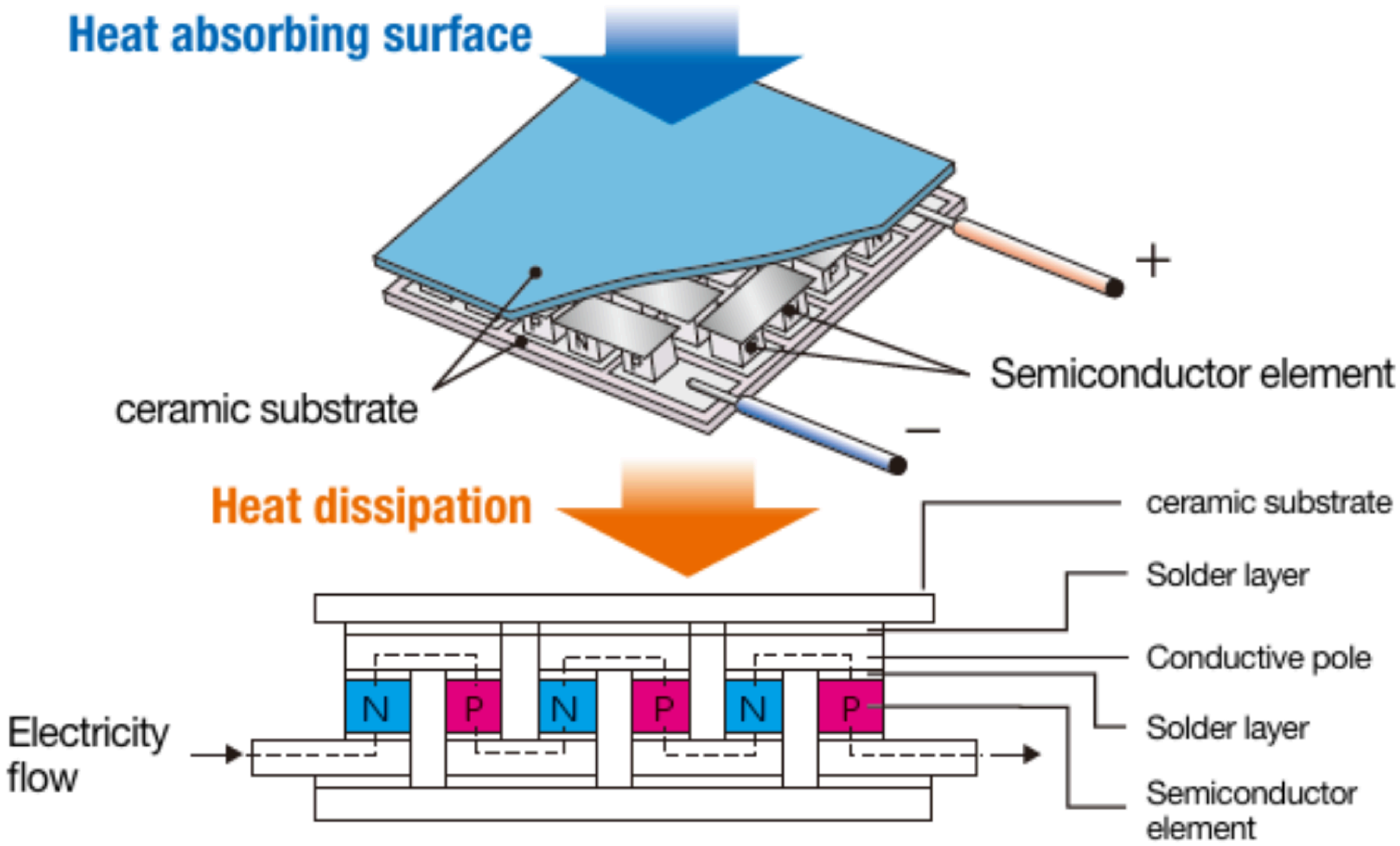
207Bi

Decay Mode: EC, β^+		Half-Life: (11523 ± 1) d					[1]
Radiation Type		Energy (keV)			Intensity (%)		Ref.
Auger-L		5.2	-	15.7	53.8	14	[5]
Auger-K		56.0	-	88.0	2.8	3	[5]
ec-K-1		481.7			1.52	2	[5]
ec-L-1		553.8	-	557.7	0.440	6	[5]
ec-M-1		565.8	-	567.2	0.15	2	[5]
ec-K-2		809.8			0.003	1	[5]
ec-K-3		975.7			7.03	13	[5]
ec-L-3		1047	-	1051	1.84	5	[5]
ec-M-3		1059	-	1061	0.54	7	[5]
ec-K-4		1682			0.02	1	[5]
β+max		806.5			0.012	2	[5]
β+av		383.4					[5]
X-ray L	Σ	9.18	-	15.8	33.2	14	[5]
X-ray Kα	Σ	74.2			58.19	24	[5]
X-ray Kβ	Σ	84.4	-	87.6	16.22	25	[5]
γ		328.11			0.00076	8	[5]
γ	Annih	511.0			0.0024	4	[5]
γ		569.70			97.76	3	[5]
γ		897.8			0.131	6	[5]
γ		1063.7			74.58	49	[5]
γ		1442.2			0.131	2	[5]
γ		1770.2			6.87	3	[5]

Peltier elements

A current flow applied to semiconductors arranged in a certain sequence creates a temperature gradient





Function of the peltier-technology. Dr. Neumann Peltier-Technik GmbH. (2021, March 10)

The study of β-shape

When taking both the Beyond Standard Model Fierz term and the Standard Model WM term into account, the β spectrum shape for an allowed Gamow-Teller decay can be written as:

$$W(E_e)dE_e = \frac{F(\pm Z, E_e)}{2\pi^3} p_e E_e (E_0 - E_e)^2 dE_e \, \xi \left(1 + b_{\text{Fierz}} \frac{m_e}{E_e} \pm \frac{4}{3} \frac{E_e}{M_n} \frac{b_{\text{WM}}}{Ac}\right), \quad (1)$$

$$b_{wm} = \frac{1}{g_a}\left(g_m + g_v \frac{M_L}{M_{GT}}\right)$$

L.Hayen, N.Severijns and al. High precision analytical description of the allowed β spectrum shape. (2018)

Shape factor

$$^{A}C(Z,W) \approx 1 + {}^{A}C_0 + {}^{A}C_1 W + {}^{A}C_{-1}/W + {}^{A}C_2 W^2$$

$$\begin{aligned} ^{A}C_0 = & -\frac{1}{5}(W_0 R)^2 + \frac{4}{9}R^2\left(1 - \frac{1}{10}\Lambda\right) \\ & + \frac{1}{3}\frac{W_0}{M_N}\left(\mp 2\frac{b}{Ac_1} + \frac{d}{Ac_1}\right) \pm \frac{\alpha Z}{M_N R}\left(\pm 2\frac{b}{Ac_1} + \frac{d}{Ac_1}\right) \\ & + \frac{2}{35}\alpha Z W_0 R(1 - \Lambda) - \frac{233}{630}(\alpha Z)^2, \end{aligned} \tag{4.3}$$

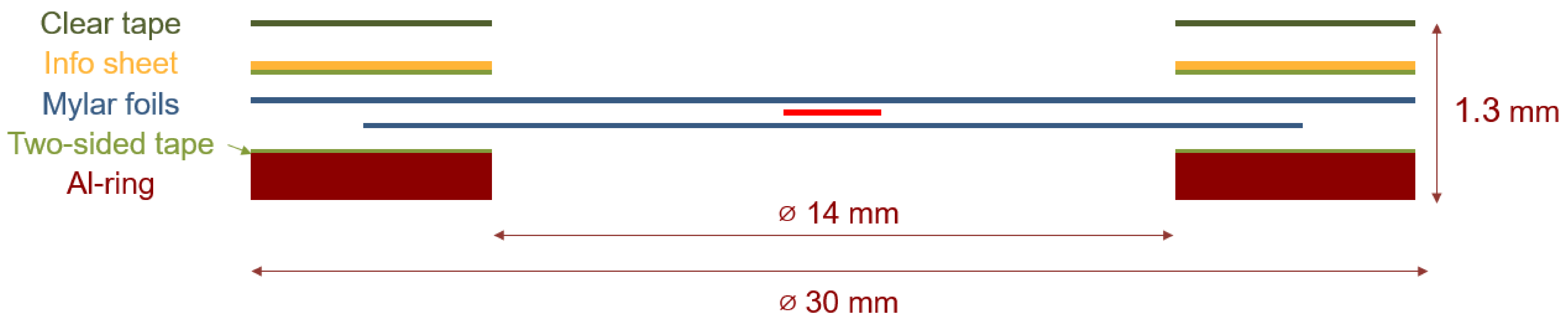
$$^{A}C_1 = \pm\frac{4}{3M_N}\frac{b}{Ac_1} + \frac{4}{9}W_0 R^2\left(1 - \frac{1}{10}\Lambda\right) \mp \frac{3}{5}\alpha Z R\left(1 - \frac{2}{21}\Lambda\right), \tag{4.4}$$

$$^{A}C_{-1} = -\frac{1}{3M_N}\left(\pm 2\frac{b}{Ac_1} + \frac{d}{Ac_1}\right) - \frac{2}{45}W_0 R^2(1 - \Lambda) \mp \frac{\alpha Z R}{70}, \tag{4.5}$$

$$^{A}C_2 = -\frac{4}{9}R^2\left(1 - \frac{1}{10}\Lambda\right) \tag{4.6}$$

S. Vanlangendonck, The effect of weak magnetism on the shape of the ^{114}In beta energy, PhD thesis, KU Leuven (2023).

Source


Clear tape
Info sheet
Mylar foils
Two-sided tape
Al-ring
1.3 mm
⌀ 14 mm
⌀ 30 mm