β-decay spectroscopy with laser-polarised beams of neutron-rich potassium isotopes

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Spokespersons: M. Madurga, M. Piersa-Siłkowska

Contact person: M. Piersa-Siłkowska

INTC-P-662: 15 shifts with ^{47,49,51}K beams

72nd Meeting of the INTC, 8 February 2023

β decay of spin-polarised nuclei

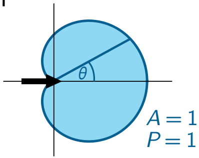
- β-decay angular distribution:

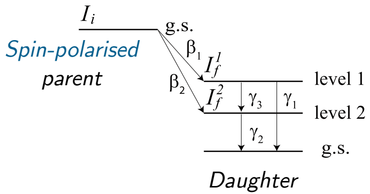
  $W(\theta) \simeq 1 + A\,P\cos\theta$ (allowed transitions)

  A – asymmetry parameter,

  $A = A(I_i, I_f)$ (discrete values)

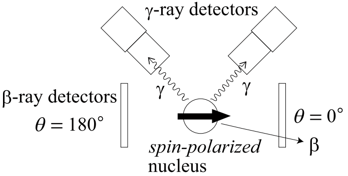
  P – polarisation





$$A = \begin{cases} -1 & (I_f = I_i - 1), \\ \dfrac{-1/(I_i+1) - 2\tau\sqrt{I_i/(I_i+1)}}{1+\tau^2} & (I_f = I_i), \\ \dfrac{I_i}{I_i+1} & (I_f = I_i + 1). \end{cases}$$

$$\tau = C_{\mathrm{V}}\langle 1\rangle / (C_{\mathrm{A}}\langle\sigma\rangle)$$



H. Nishibata *et al.*, PRC 99, 024322 (2019).

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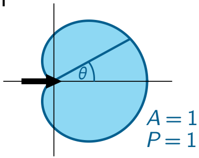
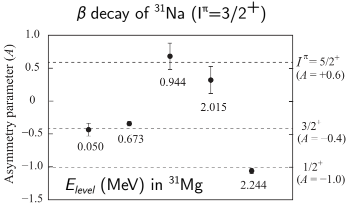
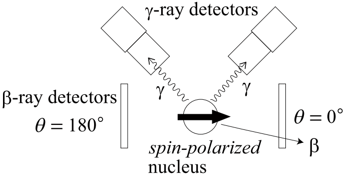


- Osaka method:
  - ✓ Spin-polarised parent nucleus
  - ✓ β-γ/n coincidences
  - ➤ Spin-parity of states identified

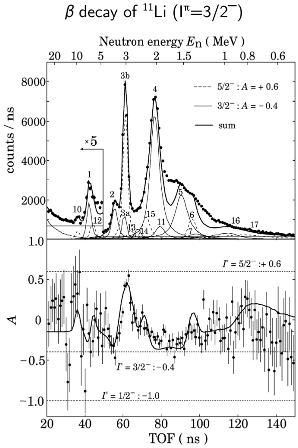
β-γ coincidences



H. Nishibata *et al.*, PRC 99, 024322 (2019).



β-n coincidences



Y. Hirayama *et al.*, PRC 91, 024328 (2015).

β decay of spin-polarised nuclei

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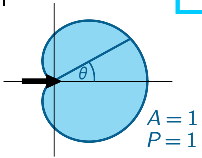

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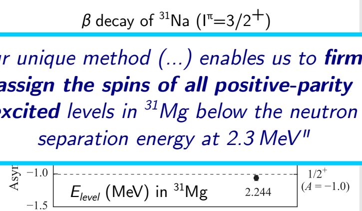
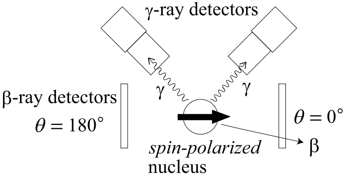
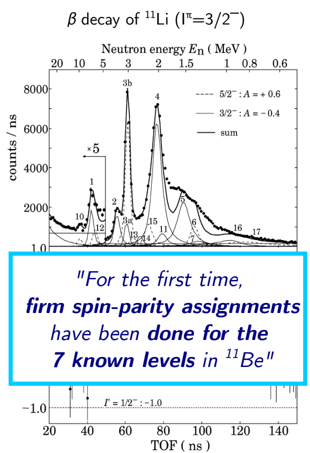


"our unique method (...) enables us to ***firmly assign the spins of all positive-parity excited*** *levels in ^{31}Mg below the neutron separation energy at 2.3 MeV*"

H. Nishibata *et al.*, PRC 99, 024322 (2019).



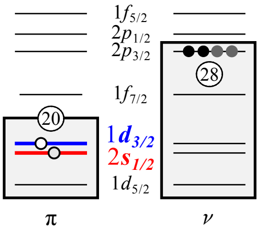
β-n coincidences



"*For the first time,* ***firm spin-parity assignments*** *have been* ***done for the 7 known levels*** *in ^{11}Be*"

Y. Hirayama *et al.*, PRC 91, 024328 (2015).

Neutron-rich potassium isotopes: ^{47,49,51}K ($Z=19$)



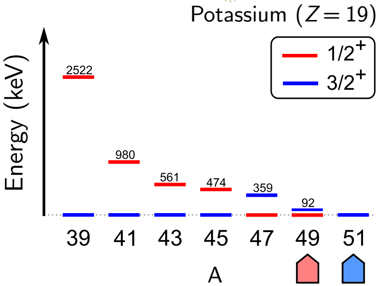
- Ground-state spins and magnetic moments measured at COLLAPS

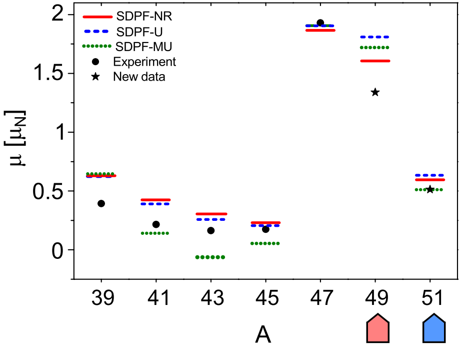
  ^{49}K: $I^{\pi} = \mathbf{1/2}^{+}$ $(\pi 2s_{1/2}^{-1})$

  ^{51}K: $I^{\pi} = \mathbf{3/2}^{+}$ $(\pi 1d_{3/2}^{-1})$

- ∼25% mixing with the $\pi 1d_{3/2}^{-1}$ components in the g.s. wave function of ^{49}K ($I^{\pi} = \mathbf{1/2}^{+}$)

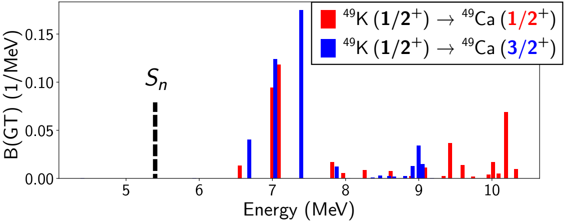
COLLAPS

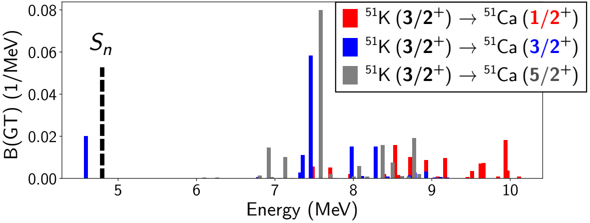




J. Papuga *et al.*, PRL 110, 172503 (2013); PRC 90, 034321 (2014).

^{49,51}K β-decay strength distribution using SDPF-MU



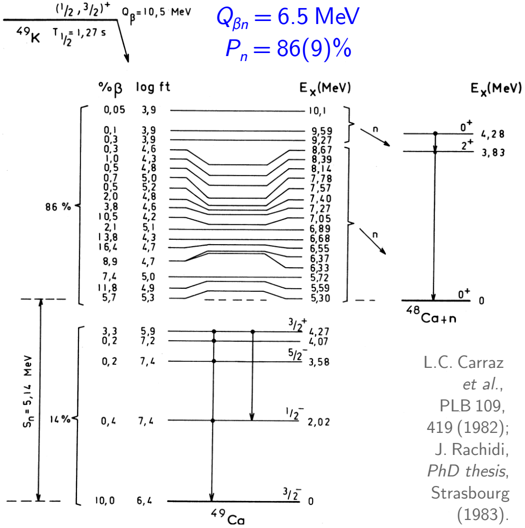


- Largest $1/2^+$ strength: largest contribution of $\nu s_{1/2}^{-1}$
- Intensity proportional to the depletion fraction of $\nu s_{1/2}^{-1}$
- $3/2^+$ states in ^{49}Ca: dominated by $\nu d_{3/2}^{-1}$
- Large $3/2^+$ feeding is only possible due to the substantial fraction (18%) of $\pi d_{3/2}^{-1}$ in the ^{49}K g.s.

- Lowest energy transition: $\nu d_{3/2} \rightarrow \pi d_{3/2}$
- Small strength to $1/2^+$ states:
  indicative of the ^{51}K g.s. little mixing with $\pi s_{1/2}^{-1}$
- Substantial strength to $5/2^+$ states:
  corresponding to $\nu 1f_{7/2} \rightarrow \pi 1f_{7/2}$

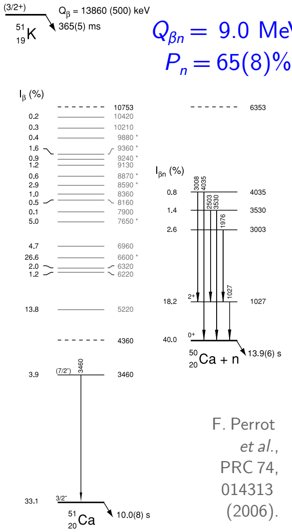
Identification of each spin-parity channel crucial to study these hypotheses!

^{49,51}K – previous β-decay studies



$Q_{\beta n} = 6.5$ MeV
$P_n = 86(9)\%$

L.C. Carraz *et al.*, PLB 109, 419 (1982);
J. Rachidi, *PhD thesis*, Strasbourg (1983).



$Q_{\beta n} = 9.0$ MeV
$P_n = 65(8)\%$

F. Perrot *et al.*, PRC 74, 014313 (2006).

Strong βn emitters

(but not well understood)

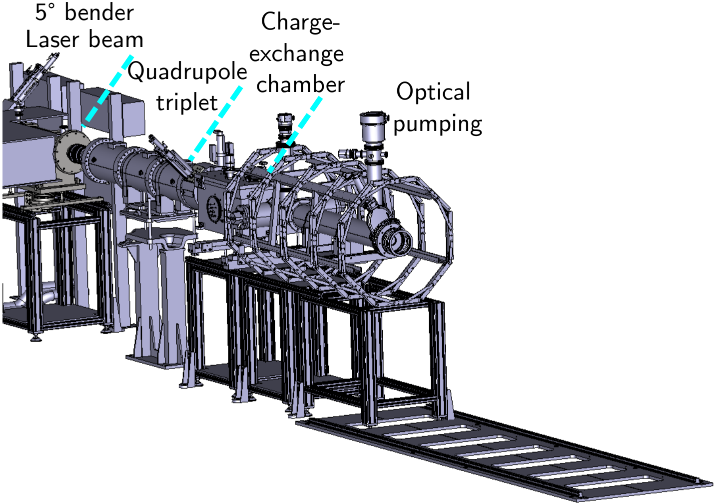
P_n (%)	^{49}K	^{51}K	
M. Birch *et al.*, NDS 128, 131 (2015).	**86(9)**	**65(8)**	*Exp*
P. Möller *et al.*, PRC 67, 055802 (2003).	21	62	*Theory*
T. Marketin *et al.*, PRC 93, 025805 (2016).	14	77	
P. Möller *et al.*, ADND 125, 1 (2019).	29	59	

www-nds.iaea.org/relnsd/delayedn

Experimental details

Experimental details: the VITO beamline

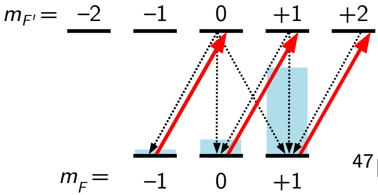
- VITO beamline



CAD model: N. Azaryan

Experimental details: the VITO beamline

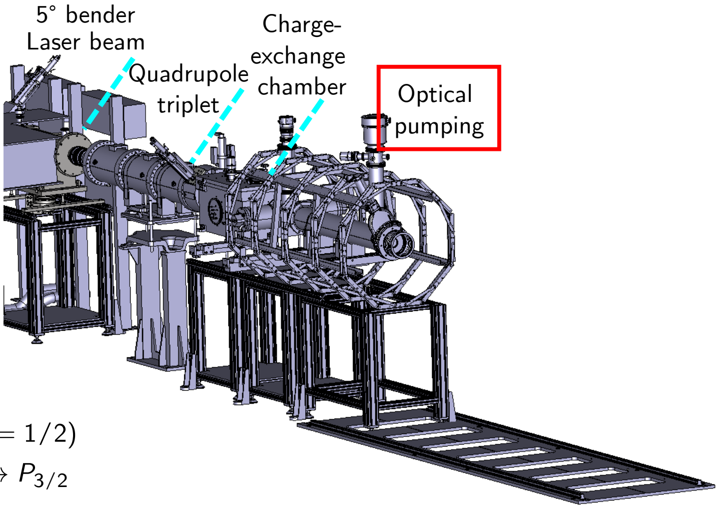
- VITO beamline
- K atoms: D2 line at 766.49 nm
- ^{47,49}K polarisation established (βNMR campaigns, IS666, 2022)



σ^+: $\Delta m_F = +1$

^{47}K ($I = 1/2$)

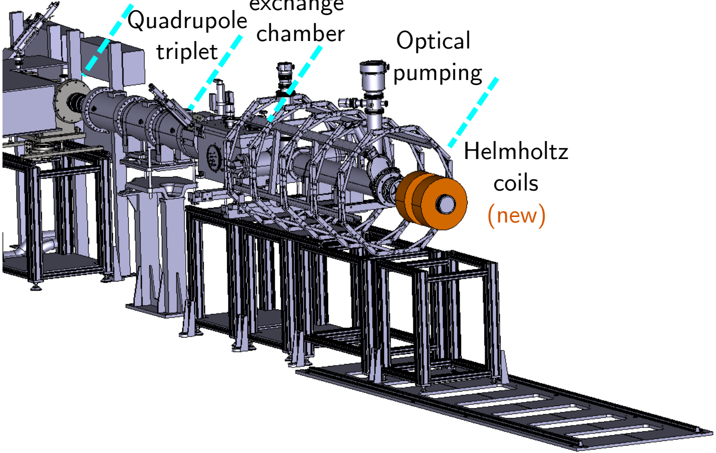
$S_{1/2} \rightarrow P_{3/2}$



CAD model: N. Azaryan

Experimental details: new detection station at VITO

- Helmholtz coils: 800-1200 Gauss



Experimental details: new detection station at VITO

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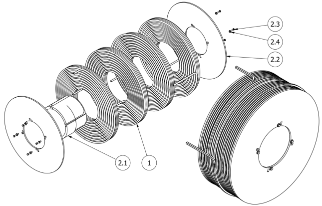
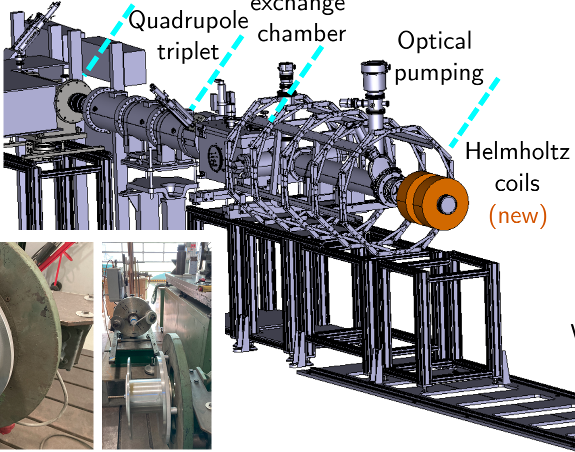
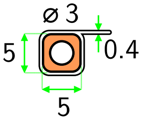


Fabrication: F. Garnier (CERN) + Uni. Warsaw

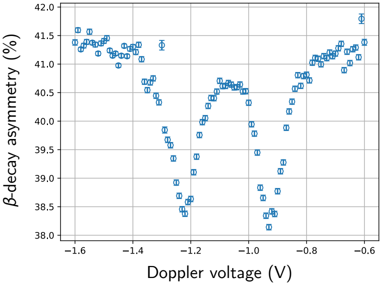


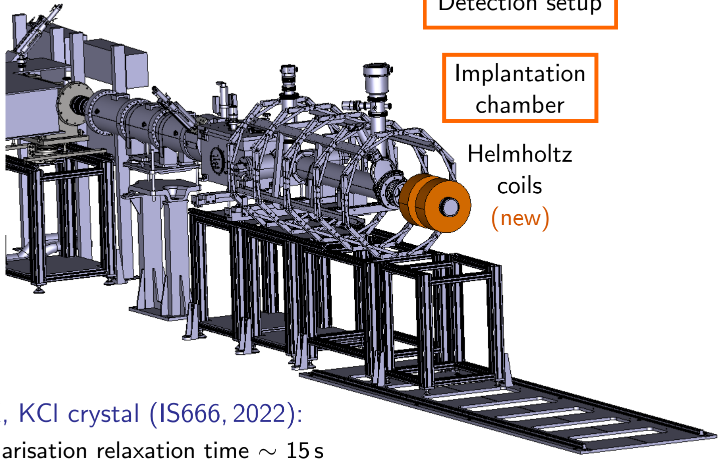


Design and simulations: F. Saeidi (ILSF)

Experimental details: new detection station at VITO

- Helmholtz coils: 800-1200 Gauss (fabricated at CERN, Jan 2023)
- Implantation host: KCl crystal





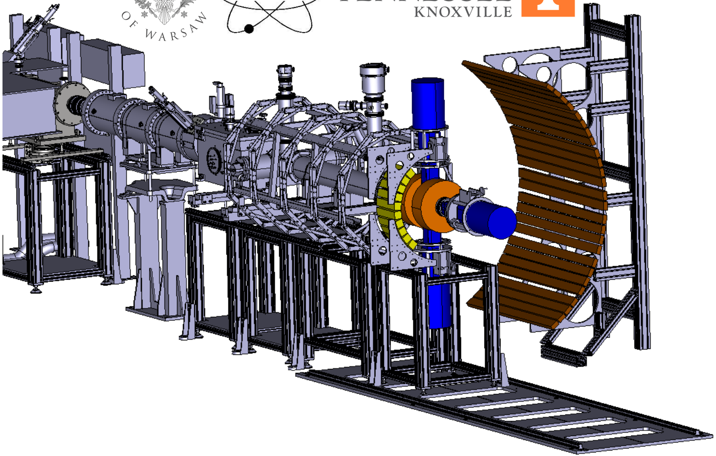
^{47}K, KCl crystal (IS666, 2022):

Polarisation relaxation time $\sim$ 15 s

Analysis: M. Jankowski (CERN)

Experimental details: new detection station at VITO

- Helmholtz coils: 800-1200 Gauss (fabricated at CERN, Jan 2023)
- **β-decay spectroscopy station**:
  - γ-ray detectors (**IFIN-HH Clovers**)
  - neutron TOF arrays (**INDiE** and **NEXT**)
  - β-particle detectors (plastic scintillator + SiPMs)
  - DAQ: XIA PIXIE-16



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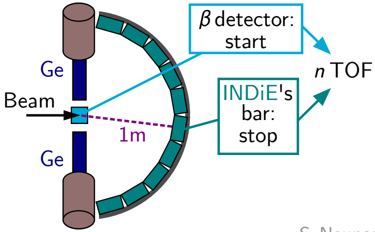

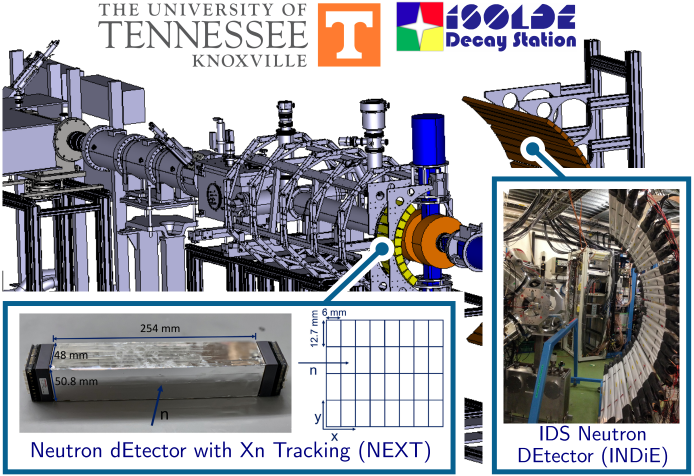

R. Grzywacz *et al.*, IS662 (INTC-P554), IS705 (INTC-P614); S. Neupane, J. Heideman, R. Grzywacz *et al.*, NIM A 1020, 165881 (2021); PRC 106, 044320 (2022).

Experimental details: new detection station at VITO

- Helmholtz coils: 800-1200 Gauss (fabricated at CERN, Jan 2023)
- ***β*-decay spectroscopy station**:
  - γ-ray detectors (**IFIN-HH Clovers**)
    $\epsilon = 0.8\%$ / Clover (1 MeV, 5 cm)
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    $\epsilon = 6\%$ for 1 MeV (INDiE, 26 bars)
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    $\epsilon = 20\text{-}25\%$ / det.
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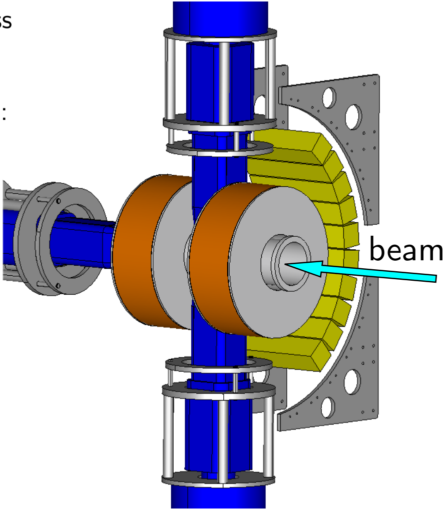

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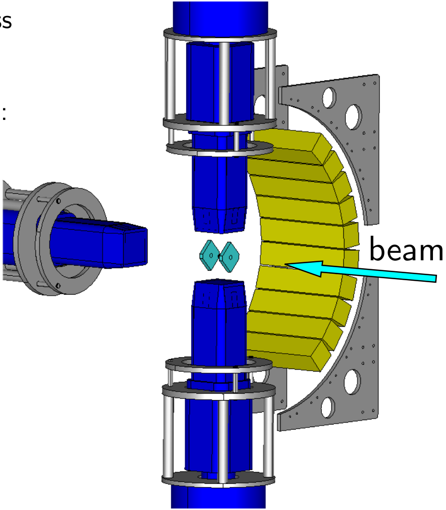

Coincidences:

- $\beta - \gamma$
- $\beta - n$
- $\beta - \gamma - n$

Asymmetry measurements

- ✓ β particles: plastic at 0° and 180°
- ✓ γ rays: HPGe at 90° and 180°
- ✓ neutrons: NEXT at 90° and VANDLE at 180°

Beam time request

Goal: measure β-decay asymmetries with a precision that enables to distinguish between different discrete asymmetry values (depending on the spin change)

[+ investigate γ-ray and neutron emission asymmetries]

Isotope	Half-life (s)	P_n (%)*	Yield (ions/μC)	Requested shifts
^{47}K	17.50(24)	–	1×10^7	• 2 shifts for establishing laser polarisation and optimising laser-atom overlap; • 0.5 shift with laser polarisation; • 0.5 shift without laser polarisation;
^{49}K	1.263(50)	86(9)	1×10^5	• 0.5 shift for optimising laser polarisation • 2 shifts with laser polarisation; • 0.5 shift without laser polarisation
^{51}K	0.365(5)	65(8)	4.5×10^3	• 0.5 shift for optimising laser polarisation • 8 shifts with laser polarisation • 0.5 shift without laser polarisation

* M. Birch *et al.*, Nucl. Data Sheets 128, 131 (2015).

"Technical advisory committee does not foresee any technical issues with this proposal."

Summary

Neutron-rich potassium isotopes for commissioning the β-decay spectroscopy experiment at VITO using laser-polarised beams

✓ ^{47,49}K were already polarised at VITO (2022)

✓ Known (and appropriate) properties of the emitted radiation from ^{47,49,51}K

➤ Perfect cases to demonstrate the capability to measure β-decay asymmetry in coincidence with delayed radiation and, thus, to determine spins and parities of excited states

➤ High selectivity of the β decay + B(GT) distributions for individual spins

➤ Experimental information about pure/mixed nature of the g.s. wave functions and particle-hole excitations of the ^{48}Ca core

➤ Robust experimental dataset to test βn emission models (neutron angular momenta)

Beam time request: **15 shifts** with UC$_x$ target, surface ionisation, and potassium mass marker.

This project has received funding from the European's Union Horizon 2020 Research and Innovation Programme under grant agreement number 101032999, project "BeLaPEx"