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Towards High-Resolution X-Ray Spectroscopy of Muonic Lithium using Metallic Magnetic Microcalorimeters

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1 Nuclear Charge Radii

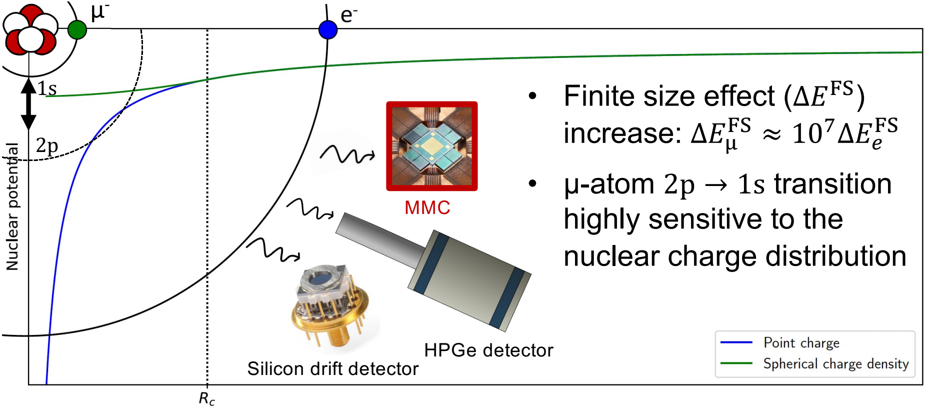
Precise absolute nuclear charge radii provide important benchmarks and inputs for modern nuclear structure theory and precision experiments. [1,2]

$$R_c = \sqrt{\langle r^2 \rangle} = \sqrt{\frac{1}{Ze} \int r^2 \rho(r)\, \mathrm{d}\tau}$$

nuclear charge density distribution

Muonic atom spectroscopy is an ideal tool to obtain precise absolute nuclear charge radii. However, the range of $2 < Z < 11$, is poorly studied, due to a lack of high-resolution, broadband x-ray detectors. At the Paul Scherrer Institute, we aim to overcome this technological gap using metallic magnetic microcalorimeters (MMC) for μ-atom spectroscopy.

2 Muonic Atom Spectroscopy

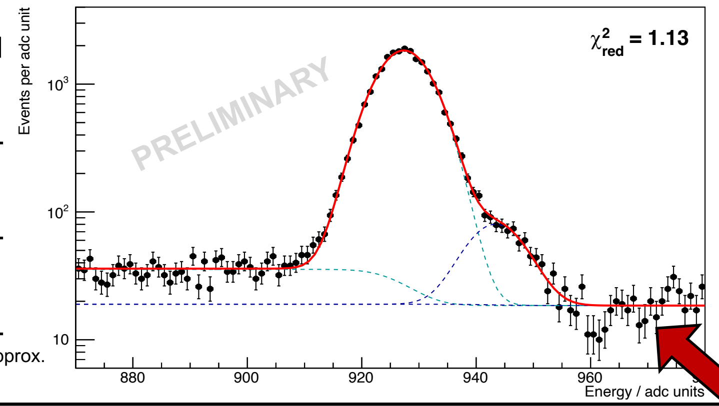


- Finite size effect (ΔE^{FS}) increase: $\Delta E^{\mathrm{FS}}_{\mu} \approx 10^7 \Delta E^{\mathrm{FS}}_{e}$
- μ-atom $2\mathrm{p} \rightarrow 1s$ transition highly sensitive to the nuclear charge distribution

3 μLi Spectroscopy using Silicon Drift Detectors

μLi $2\mathrm{p} \rightarrow 1s$ energy measurement and calculation based on charge radii $R_c(^6\mathrm{Li}) = 2.589(39)$ fm and $R_c(^7\mathrm{Li}) = 2.444(42)$ fm, extracted from electron scattering experiments [6]:

	E_{exp} / keV [5]	E_{calc} / keV	
	$2\mathrm{p} \rightarrow 1\mathrm{s}$	$2\mathrm{p}_{1/2} \rightarrow 1\mathrm{s}$	$2\mathrm{p}_{3/2} \rightarrow 1\mathrm{s}$
^{6}Li	18.64(7)	18.6709(8)	18.6716(8)
^{7}Li	18.69(6)	18.7235(9)	18.7245(9)



New data from May 2023 with a fit (right) of μ^{6}Li $2\mathrm{p} \rightarrow 1\mathrm{s}$ transition at approx. 18.7 keV. The higher energy shoulder is due to the close μC $4 \rightarrow 2$ line.

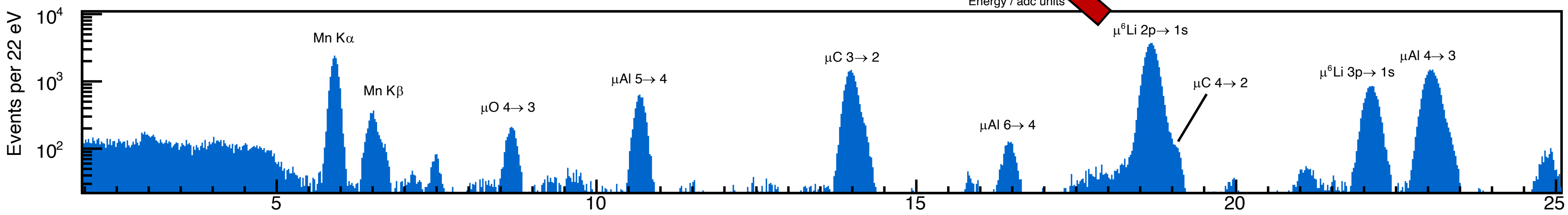
Preliminary result of this work for

μ^{6}Li $2\mathrm{p} \rightarrow 1\mathrm{s}$:

$$E_{\mathrm{exp}} = 18.670 \pm 0.008(\mathrm{stat + calib})\ \mathrm{keV}$$

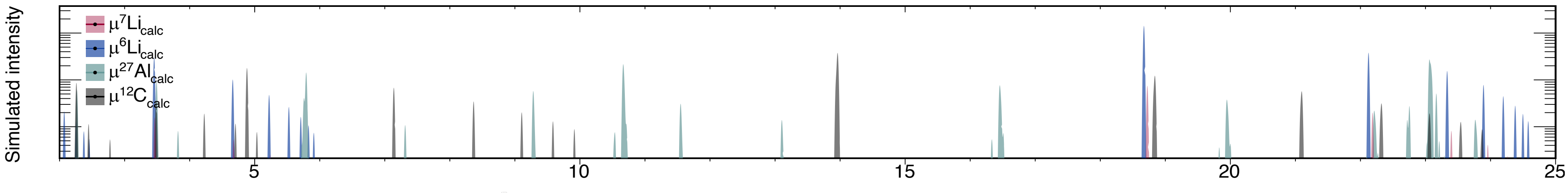
Resolution is a limiting factor for

- Precision of calibration lines
- Contaminations in μLi $2\mathrm{p} \rightarrow 1s$ peak (Isotope impurity, μC transition)



Muonic x-ray spectrum of a ^{6}Li target obtained during an ~8h measurement with a silicon drift detector in May 2023.

4 Metallic Magnetic Microcalorimeters

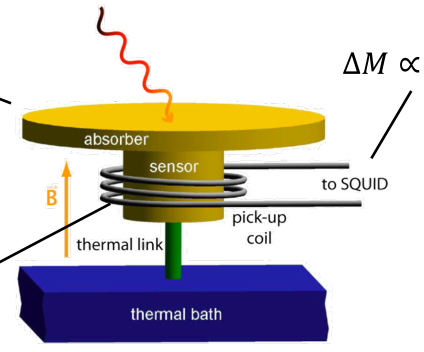


- X-ray energy deposited in Au absorber
  - → good thermal contact to paramagnetic (e.g. Ag:Er) sensor
- Temperature change leads to change of sensor magnetization
  - → detected via SQUID

$$\Delta T = \frac{E_\gamma}{C_{\mathrm{tot}}}$$

$$\Delta M = \frac{\partial M}{\partial T} \Delta T$$

$$\Delta M \propto \frac{E_\gamma}{C_{\mathrm{tot}}}$$



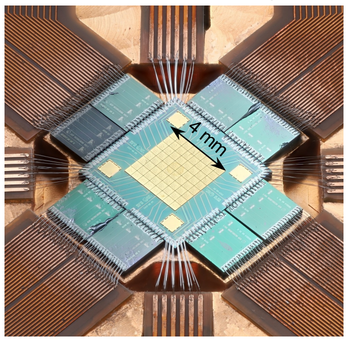
Schematic drawing of the MMC working principle. [4]

Energy resolution:

- $\Delta E \propto T\sqrt{C_{\mathrm{abs}}}$
- Const., depends on total energy range (smaller range ⇒ smaller ΔE)
- Typically: $T \sim 20$ mK and ΔE_{FWHM} @ 20 keV < 10 eV

⇒ stat. precision (in < 1 day):

~ 0.1 eV



Microfabricated maXs-30 MMC detector array. [3]

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