SELECTION OF ENERGY CALIBRATION SOURCES FOR Be^9

Quartet – Technion – Ofir Eizenberg

MAIN IDEA

Required energy precision to improve radius

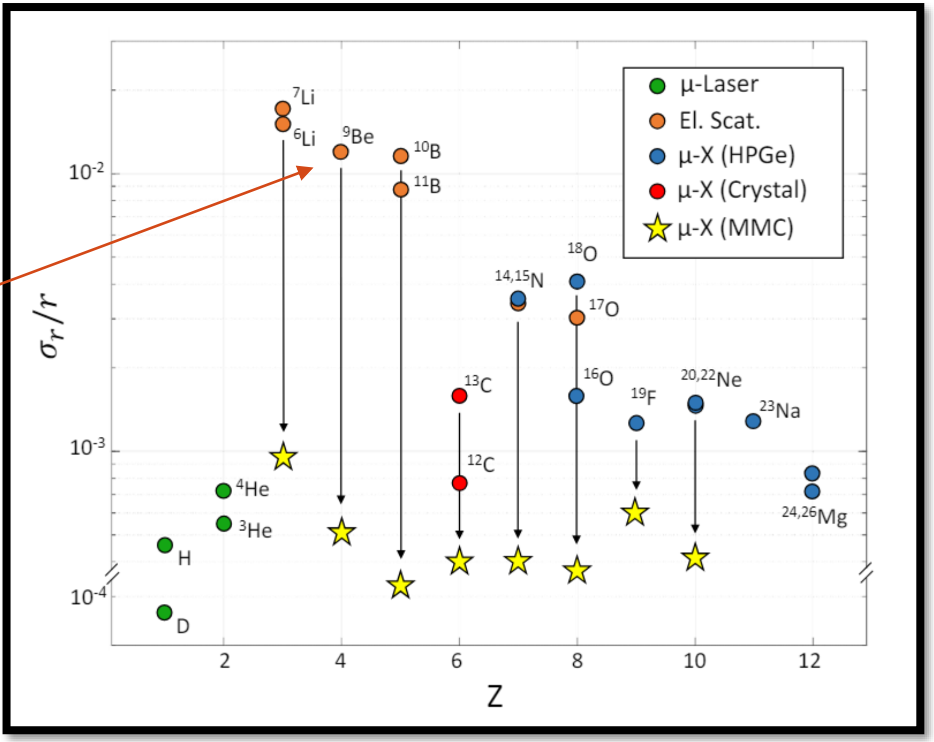
Needed statistics to achieve energy precision

Considering available sources

NEEDED ENERGY PRECISION

- Current status of radius uncertainty:

$$\frac{\sigma_r}{r} \sim 10^{-2}$$



Taken from [2] Quartet FFK 2023

- Using Mu-Dirac to calculate muonic Be x-ray spectra
- Mu-Dirac results for 2P-1S with Uehling :

$$E_{sphere} = E_{fermi} = 33393\ eV \quad ; E_{point} = 33478\ eV$$

$$\Delta\left(E_{sphere} - E_{point}\right) = 85\ eV = F \cdot r^2$$

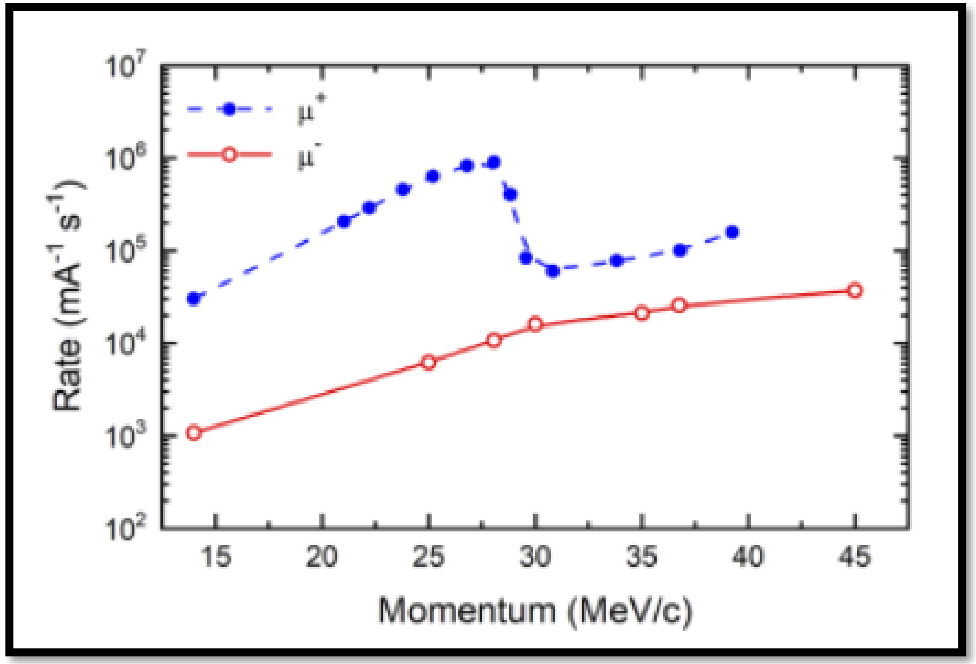
$$\downarrow$$

Uncertainty in energy from radius: $\sigma_E = 2 \cdot F \cdot r^2 \cdot \frac{\sigma_r}{r} = \mathbf{1.7\ eV}$

- We can reach better accuracy using statistics and calibration.

- (Screening effect, self-energy, Kallen-Sabri, and Nuclear polarization are sub-eV corrections)

STATISTICS OF MUONS



Taken from [4] L. Gerchow

- Muon rate at "Default momentum" of 28 MeV/c: $10^4 \cdot Hz$
- Efficiency + Solid angle few 10^{-4} : $\frac{10^4}{10^4} \sim few\ Hz$
- Max total rate on detector: 0.4 photons/double-pixel=12 Hz
- With 10 eV resolution, can significantly improve radius with few 100 events, **a few minutes**
- Can go to lower energy if needed (GEANT4 simulation in progress)

CALIBRATION

- Integration time calculation for Cs^{137} for example:
  - Energy uncertainty goal - $\sigma_E = 0.5\ eV$
  - Number of samples required - $N = \left(\frac{16}{0.5}\right)^2 = 10^3$ samples
  - Assume source load on detector is 10 Hz.
  - Integration time required given 4% intensity - $40\ [minutes]$

X-rays from ^{137}Cs (30.07 y 3)

E (keV)	I (%)	Assignment
31.452	0.000263 *8*	Ba $K_{\alpha 3}$
31.817	2.04 *5*	Ba $K_{\alpha 2}$
32.194	3.76 *8*	Ba $K_{\alpha 1}$
36.304	0.352 *8*	Ba $K_{\beta 3}$
36.378	0.680 *15*	Ba $K_{\beta 1}$
36.652	0.0079 *3*	Ba $K_{\beta 5}$
37.255	0.215 *5*	Ba $K_{\beta 2}$
37.349	0.0481 *20*	Ba $K_{\beta 4}$

- Assumed $16\ [eV]$ FWHM linewidth and $9[Hz]$ of x-ray rate.

Source	Closest Energy Line $[eV]$	Energy Uncertainty $[eV]$	Intensity $[\%]$	Other Lines $[eV]$	Amount of Samples $[\#]$	Time Needed $[Hours]$
Cs^{137} (Ba x-rays)	32193	0.07	3.76	31816.61(6)	1000	0.6
				36303.3(1)		
				36377.45(8)		

POTENTIAL SOURCES

Source	Closest Energy Line $[eV]$	Energy Uncertainty $[eV]$	Abundance $[\%]$	Other Lines $[eV]$	Amount of Samples $[\#]$	Time Needed $[Hours]$
Cs^{137} (Ba x-rays)	32193	0.07	4	31816.61(6)	1000	0.7
				36303.3(1)		
				36377.45(8)		
Ba^{133} (Cs x-rays)	34919.7	0.6	6	306254.4(4)	1000	0.5
				30973.1(4)		
	34987.3	1.0	12	35821.7(3)		
				35988.0(1)		

* Taking into account $10\ [eV]$ FWHM resolution and $9[Hz]$ of x-ray rate.

POTENTIAL SOURCES

Source	Closest Energy Line $[eV]$	Energy Uncertainty $[eV]$	Abundance $[\%]$	Other Lines $[eV]$	Amount of Samples $[\#]$	Time Needed $[Hours]$
Ce^{139} (La x-rays) Not in PSI…	33442	0.3	24	37720.6(6)	1000	0.1
				37801.4(5)		
	33034	0.3	44	38071.4(5)		
				38730.3(1)		
Am^{241} (gamma line)	33196	0.3	0.12	26344.6(2)	400	9
				59540.9(1)		

* Taking into account $10\ [eV]$ FWHM resolution and $9[Hz]$ of x-ray rate.

SUMMARY

- ***chosen material*****

BIBLIOGRAPHY

- [1] Sturniolo, S, Hillier, A. , ''Mudirac: A Dirac equation solver for elemental analysis with muonic X-rays. '' X-Ray Spectrom. **2020**; 1– 17. https://doi.org/10.1002/xrs.3212
- [2] Quartet FFK 2023 (Still in progress)
- [3] W. Nortershauser, "Nuclear Charge Radii of $^{7,9,10}Be$ and the one-neutron halo nucleus ^{11}Be" https://arxiv.org/pdf/0809.2607.pdf
- [4] L. Gerchow, "Germanium array for non-destructive testing (GIANT) setup for muon-induced x-ray emission (MIXE) at the Paul Scherrer Institute." ,Rev Sci Instrum 1 April 2023; 94 (4): 045106.
- [5]