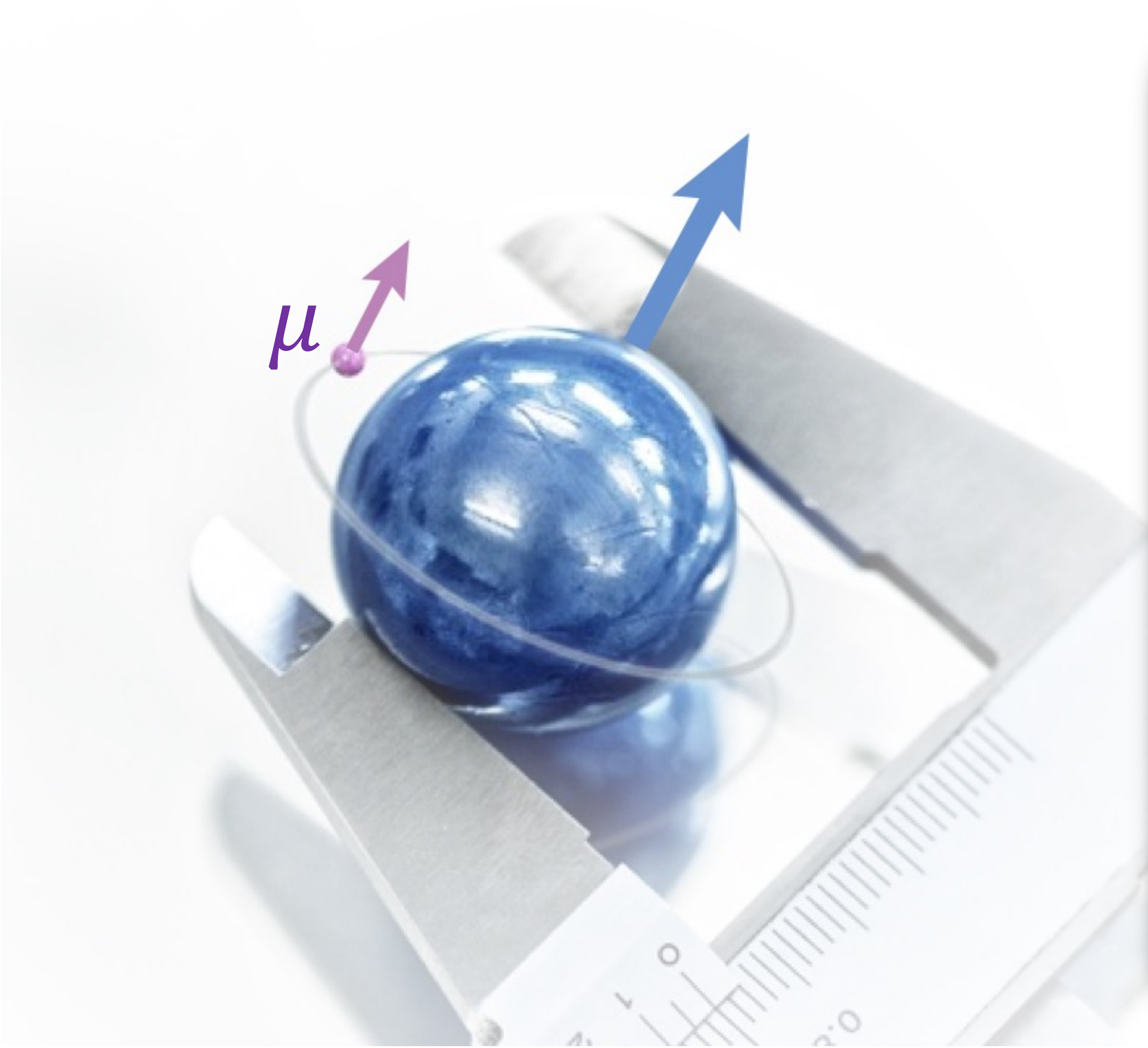
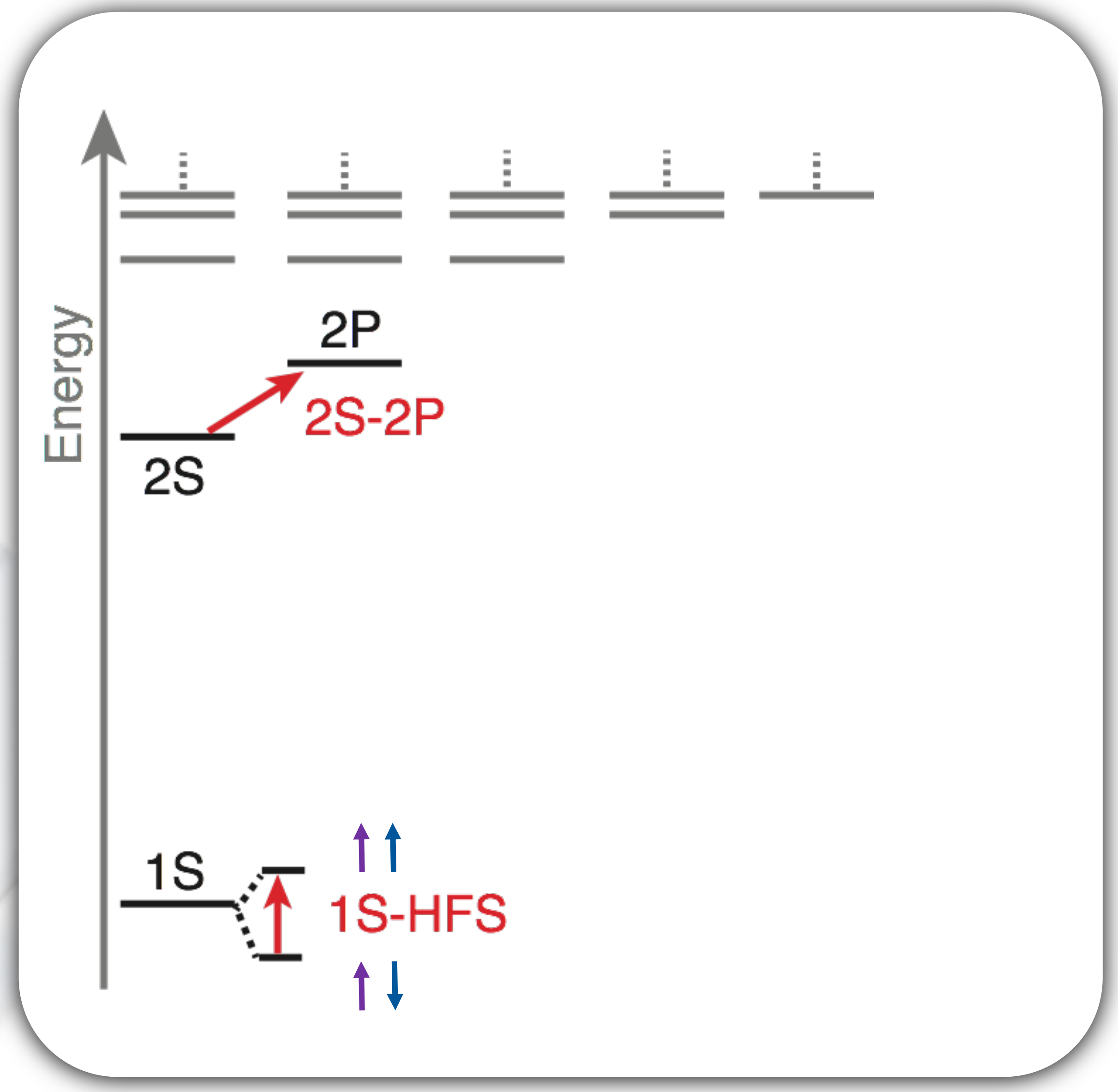
Hyperfine Splitting in Muonic Hydrogen



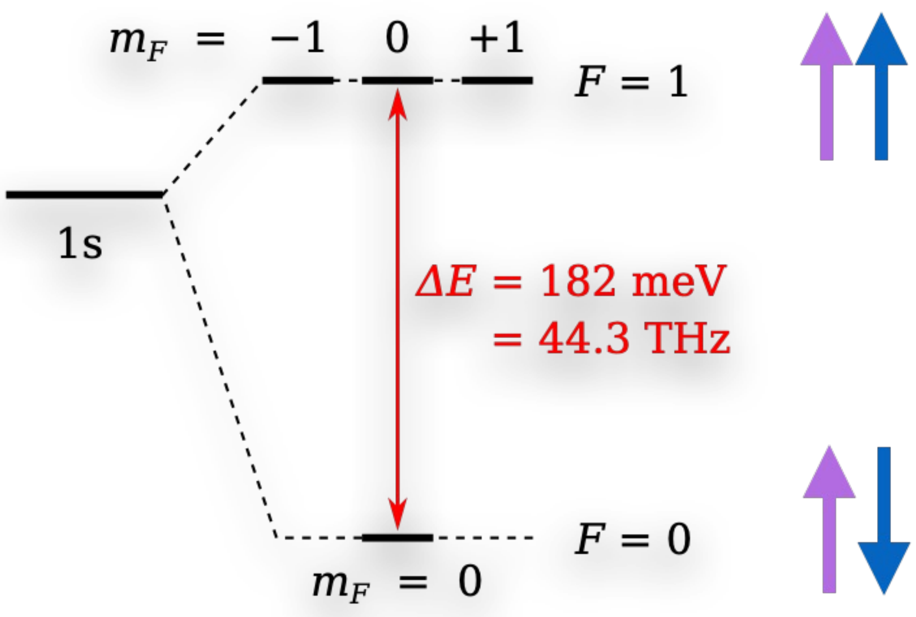


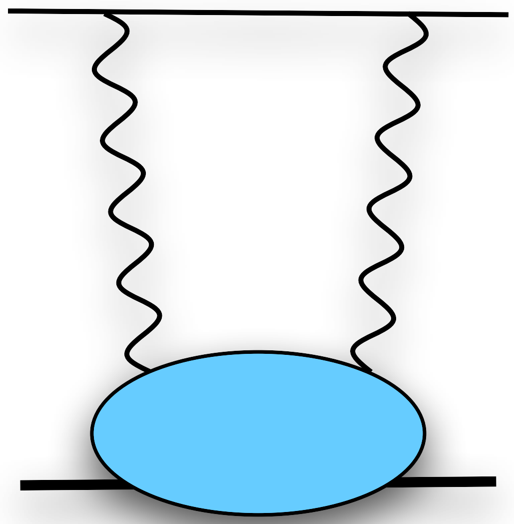
Measure the 1s-HFS in μp with a relative accuracy $\delta \approx 10^{-6}$

1S Hyperfine Splitting in muonic hydrogen

$$E_{1S\text{-HFS}}(\mu H) = [\underbrace{182.443}_{E_F} \underbrace{+1.350(7)}_{\text{QED+weak}} \underbrace{+0.004}_{\text{hVP}} \underbrace{-1.30653(17)\left(\frac{r_{Zp}}{\text{fm}}\right) + E_F(1.01656(4)\Delta_{\text{recoil}} + 1.00402\Delta_{\text{pol}})}_{2\gamma \text{ incl. radiative corr.}}]\text{meV}$$

Δ_{struc} In μp enhanced by a factor $\sim m_r$



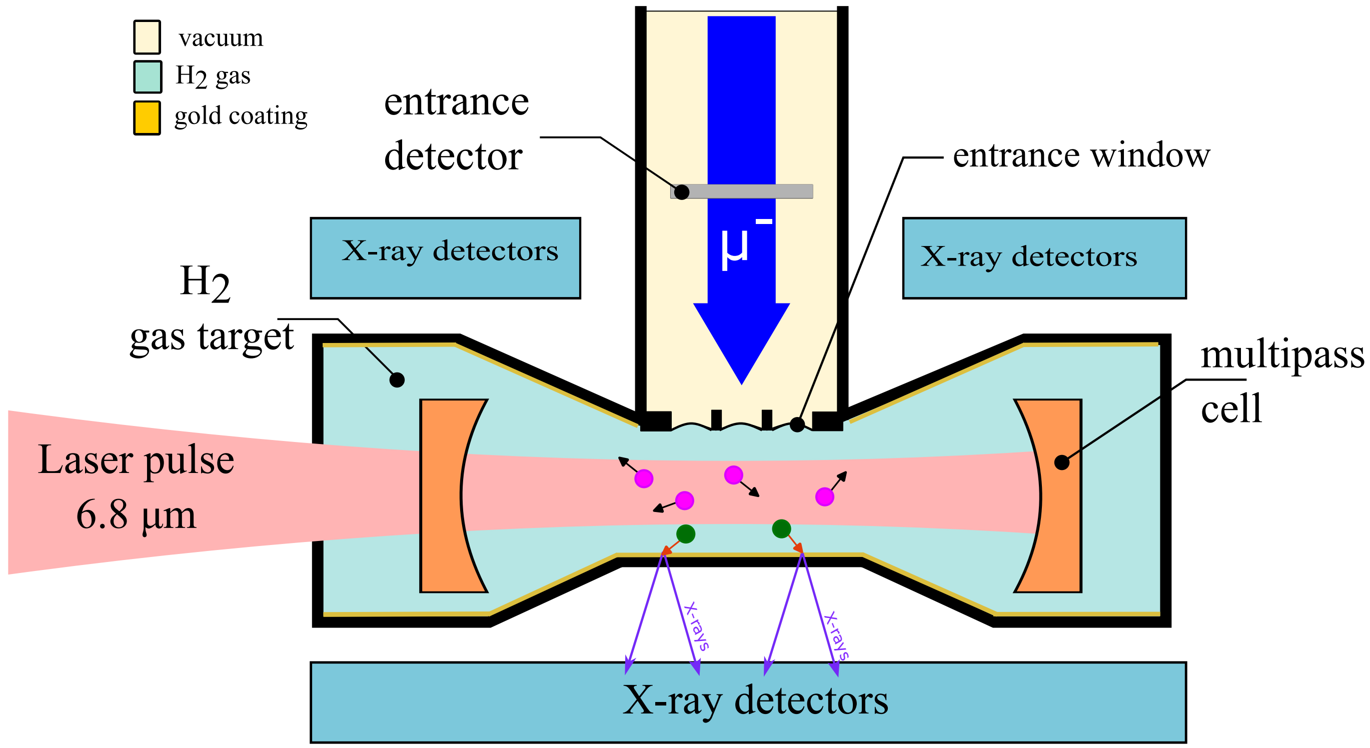


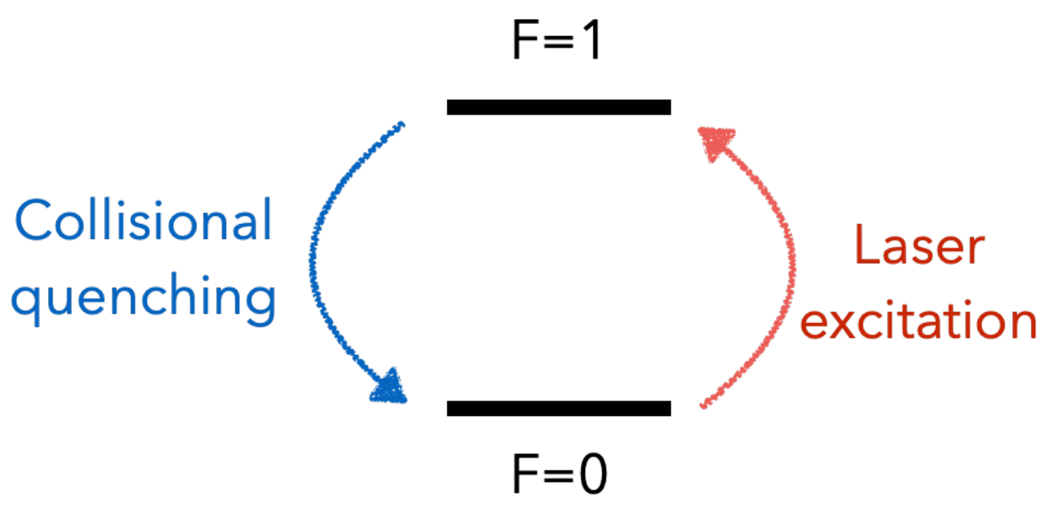
Two photon exchange

- Extract the 2γ-contribution with relative accuracy of $\approx 10^{-4}$

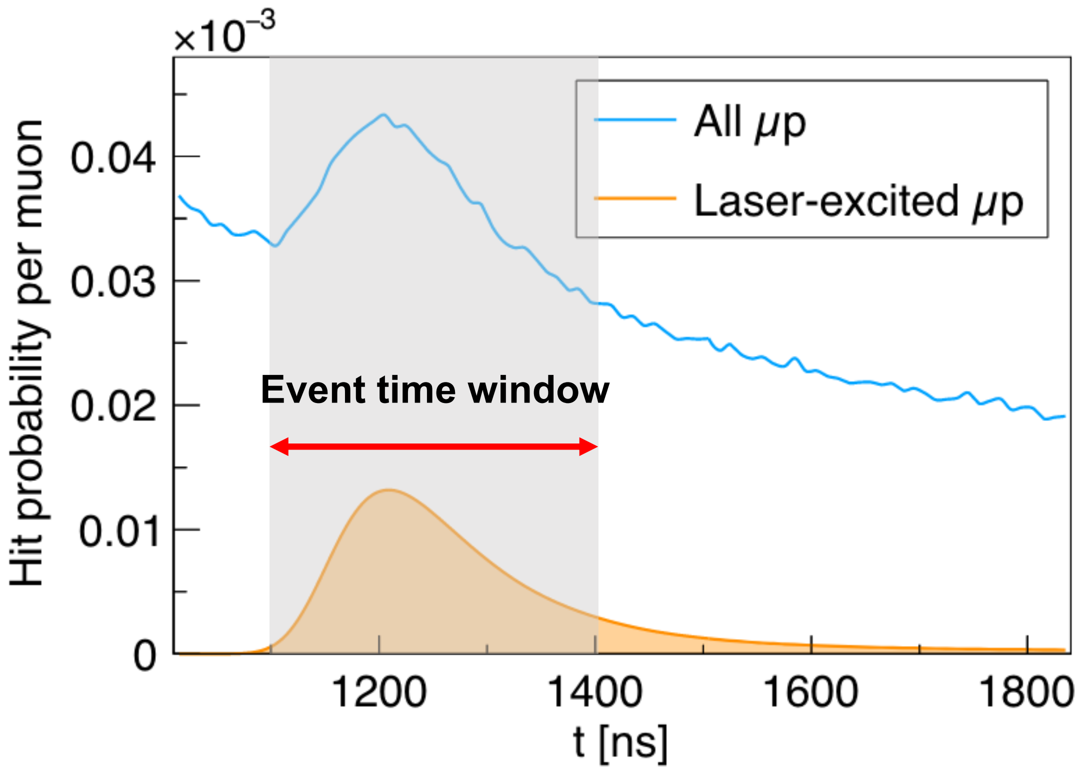
Antognini, Hagelstein, Pascalutsa, Annual reviews 389, 418 (2022)

The principle of the experiment

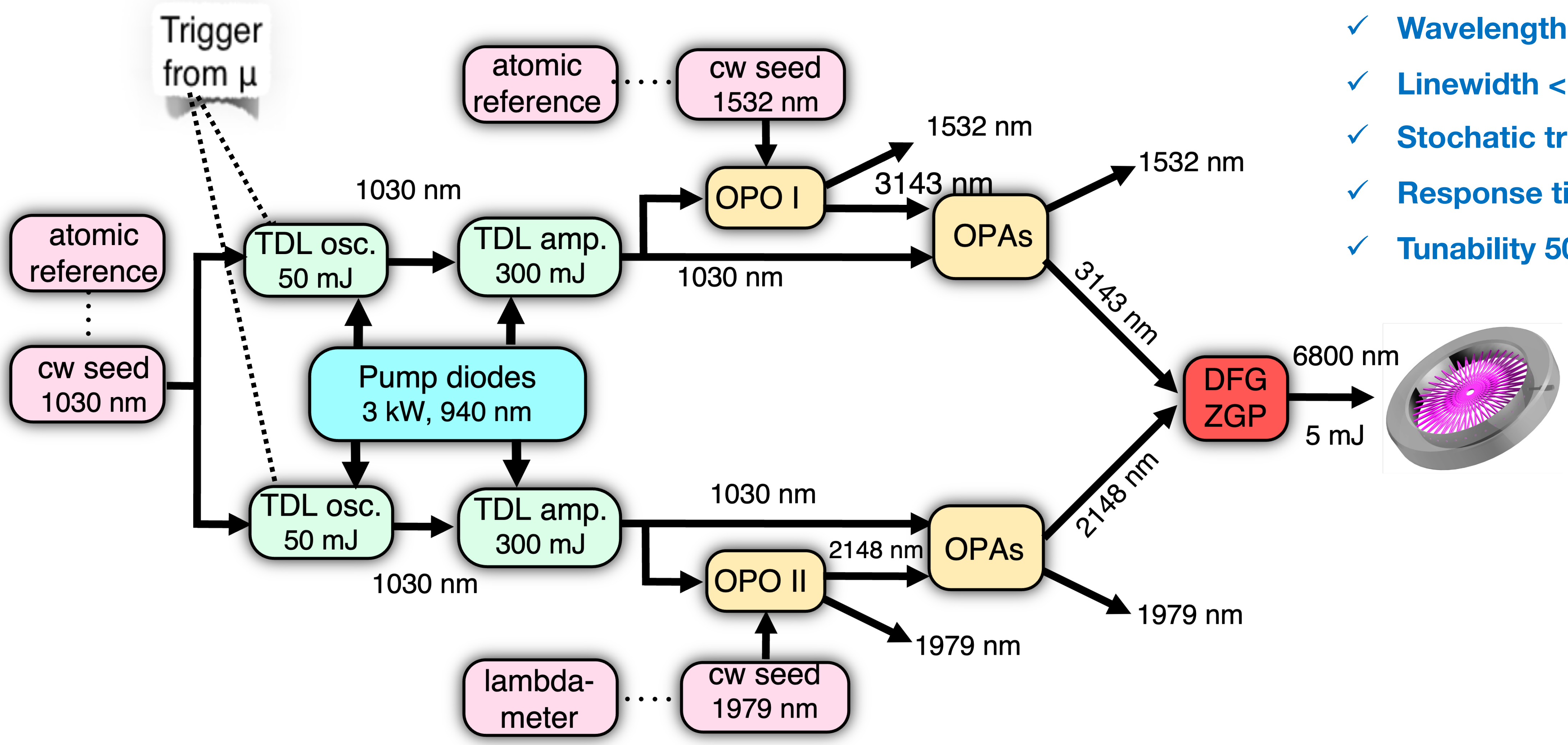




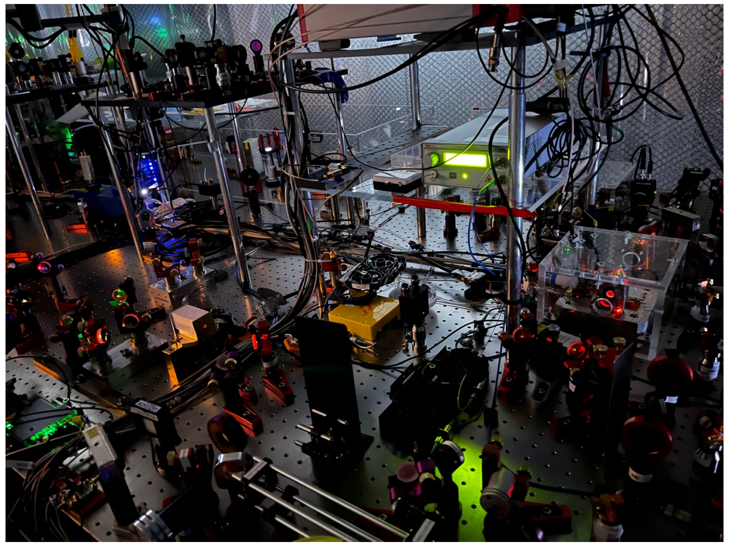
- Stop muon beam in 1 mm H_2 gas target at 22 K, 0.5 bar
- Wait until μp atoms de-excite and thermalize
- Laser pulse: μp(F=0) + γ → μp(F=1)
- De-excitation: μp(F=1) + H_2→μp(F=0) + H_2 + E_{kin}
- Diffusion: μp diffuses to Au-coated target walls



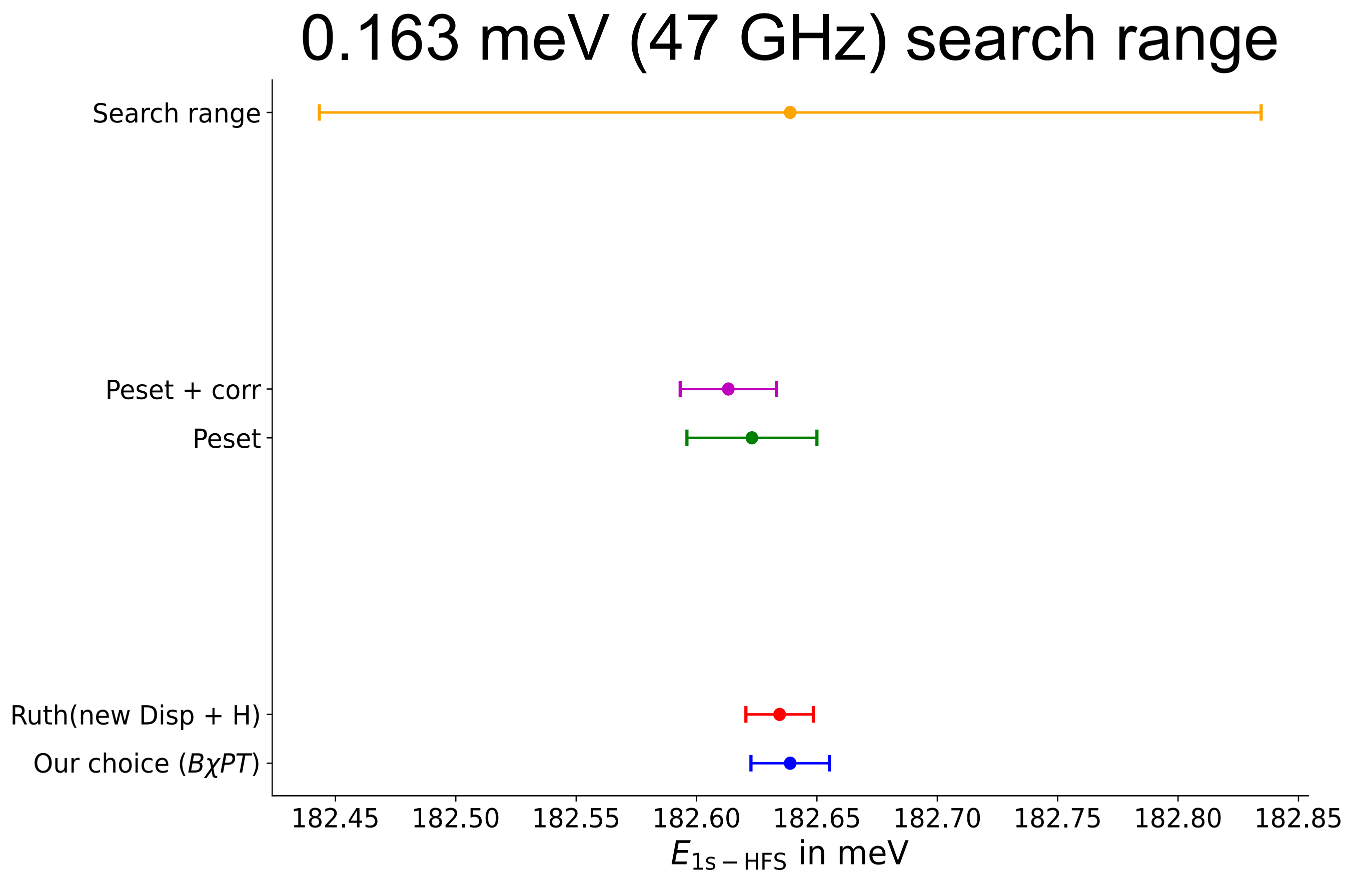
The laser system



- ❑ Pulse Energy 5mJ
- ✓ Wavelength 6.8 μm
- ✓ Linewidth < 100 MHz
- ✓ Stochatic trigger (detected muon)
- ✓ Response time 1 μs
- ✓ Tunability 50 GHz



Search for the resonance



- **Steps to search for resonance**
- Measure 1.4 h at fixed wavelength to expose a 4 σ effect over background
- 1 h to change the laser frequency in steps of 100 MHz

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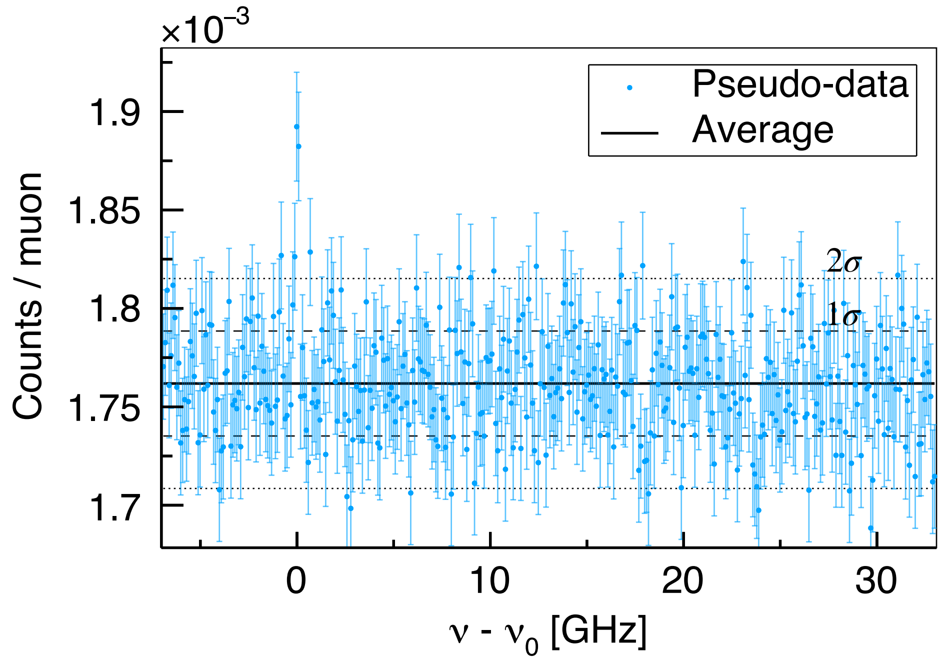
- **10 Weeks of beam time**

- ***Simulation of the search for resonance***



Charge radii from muonic X-rays

•Radii of Z=1,2 by with laser spectroscopy

•Z>10 Measured with semiconductor x-ray detectors, limited by nuclear theory and charge distribution input: https://arxiv.org/abs/2409.08193

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Z<10 limited by experimental resolution
(electron scattering or semiconductor x-ray detectors)
→ statistical variance of number of number of electron-hole pairs created

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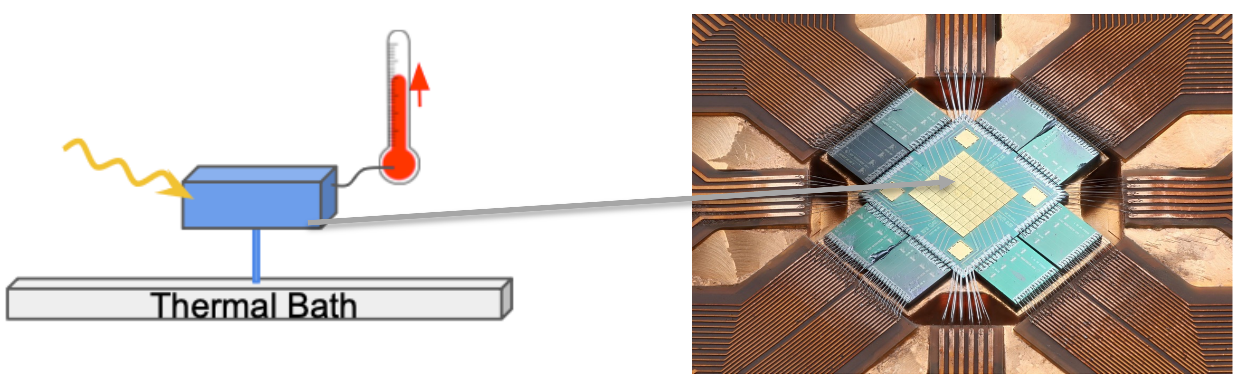
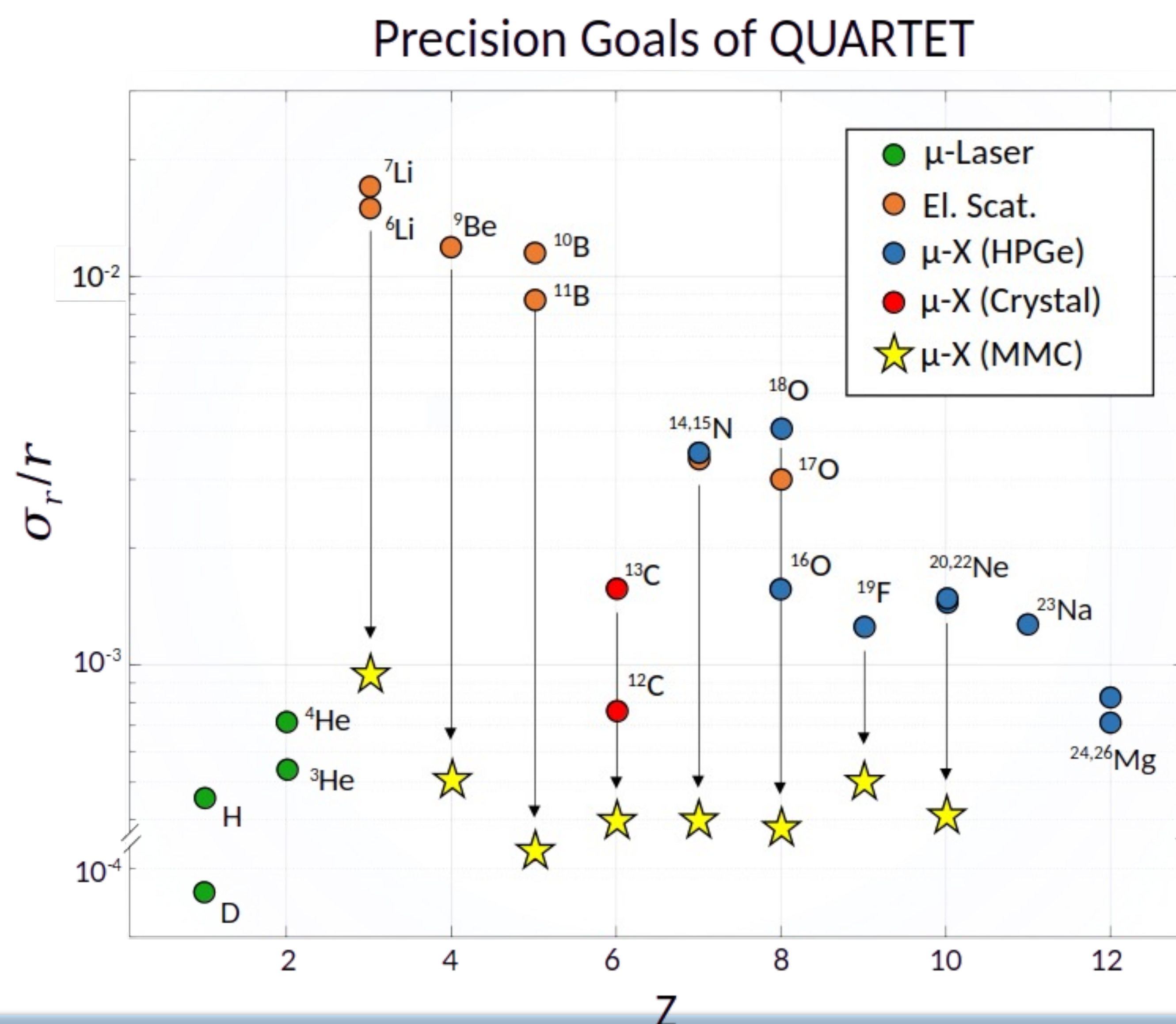
Unit of heat ≪ Unit of Ionization:

- •$\Delta T \cong E_{deposited} / C_{tot}$
- •$\Delta T / T$ large → operate < 0.1 K
- •A very good temperature sensor

Use Novel Metallic Magnetic Calorimeter (MMC) detectors



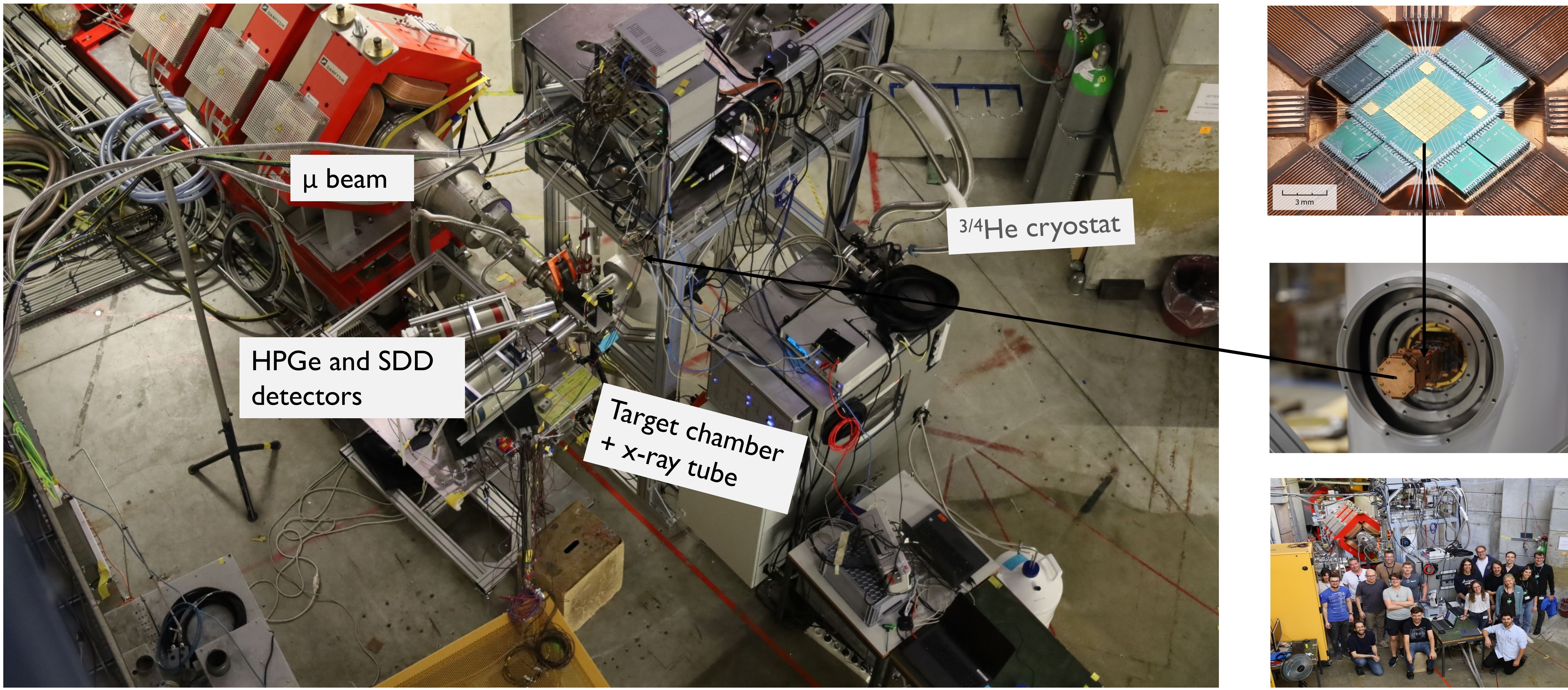
Experimental goal with MMC



Spectroscopy with MMC

Quartet: First measurements ongoing for Li, Be, and B isotopes
Unprecedented resolution for muonic x-ray spectroscopy
Approved experiment at PSI

64 pixel MMC array



Spectroscopy with MMC

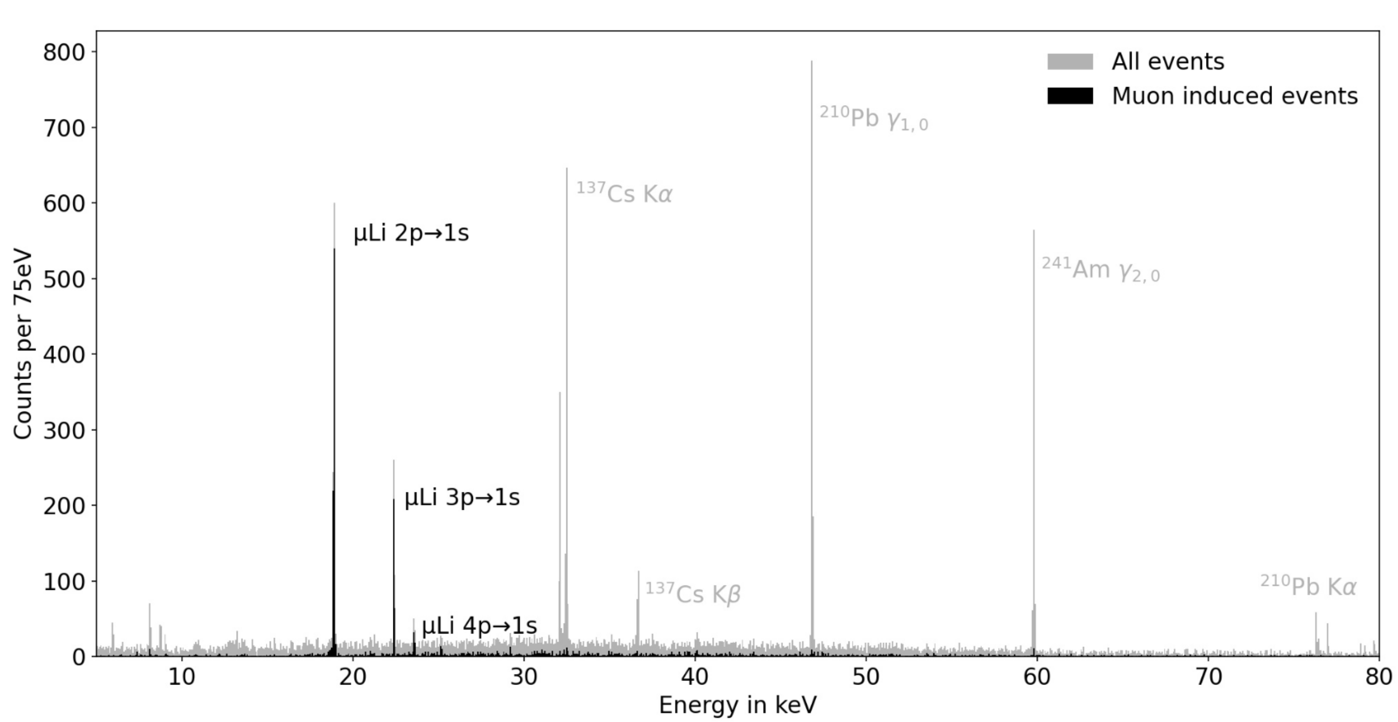
Quartet: MMC from the *basement* to an online experimental environment

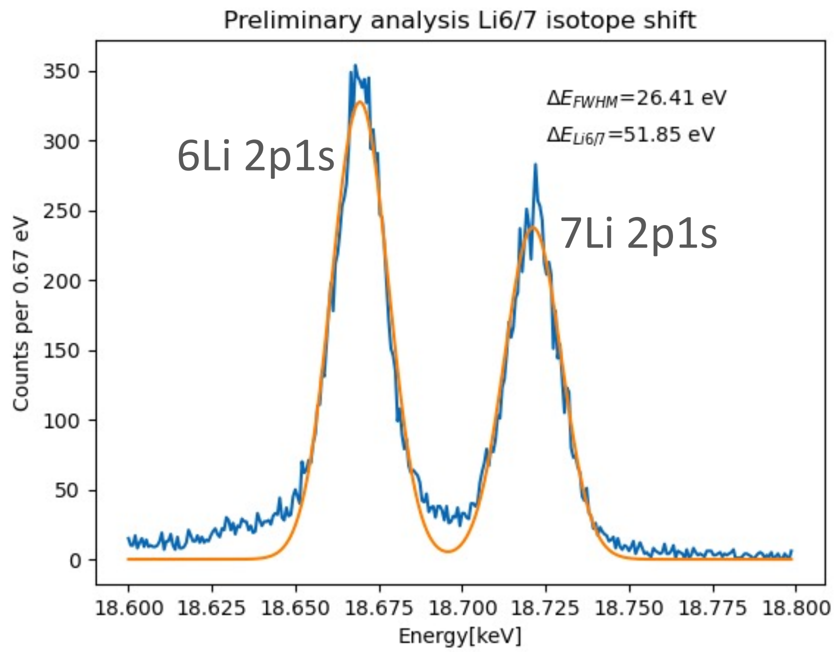
→ 2023 test beam at PSI with Li/B/Be

→ Applying a new technology: it's not that simple

→ 2024 upgrades

- ~~New 18-bit digitizers~~
- ~~New detector with fast thermalization~~
- Measure ADC properties and T stabilize Vref
- Tuned calibration sources
- Long & stable measurements





Aligned on Li7 line and disregarded 7 pixels with bad energy resolution