Towards precision beta-decay measurements with laser-cooled argon-35

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Motivation

Testing fundamental physics

$$\underbrace{\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}}_{\text{weak-interaction eigenstates}} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{\text{quark-mixing CKM matrix}} \cdot \underbrace{\begin{pmatrix} d \\ s \\ b \end{pmatrix}}_{\text{quark-mass eigenstates}}$$

Unitarity under scrutiny

Is the CKM matrix unitary, as the Standard Model claims it is?

$$\sum_{q=d,s,b} |V_{uq}|^2 \overset{?}{=} 1 \xrightarrow{\text{experiments [1]}} \sum_{q=d,s,b} |V_{uq}|^2 = 1.00008 \pm 0.00056.$$

A promising candidate [2]

$${}^{35}_{18}\mathrm{Ar}_{17} \downarrow {}^{35}_{17}\mathrm{Cl}_{18} + e^+ + \nu_e$$

Nuclear $T = 1/2$ mirror transition

Providing the β-asymmetry parameter A_β is determined with a precision of **0.5 %**:

ΔV_{ud}	$(\Delta V_{ud})^{\text{limit}}$	factor $\Delta\mathcal{F}t$
0.0007	0.0004	4.8

0.0004 ≈ twice the uncertainty obtained from the set of superallowed Fermi decays.

Key objectives

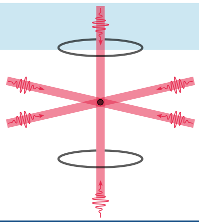
- ☐ Produce a sample of **polarized** nuclei/atoms and measure its polarization with **high precision**.
- ☐ Achieve high **counting statistics**.

Toolbox

Atoms are best served **cold**.

Laser cooling & trapping techniques provide backing-free, cold, localized sources of atoms:

ideal for **precision tests**.



A tale of two isotopes

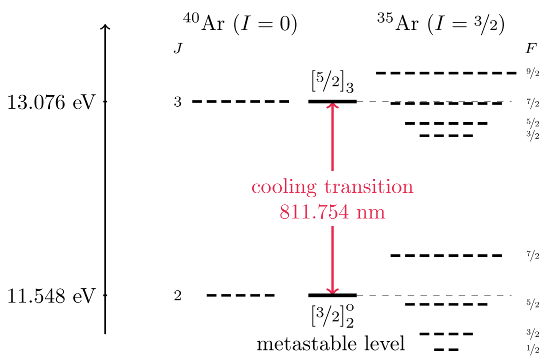
^{40}Ar: development of an offline magneto-optical trap (MOT) setup

⇒ crucial to developing **optimized** apparatus & techniques for future experimental work with ^{35}Ar.

^{35}Ar: theoretical & numerical investigation of methods for **spin-polarizing** an atomic sample & for measuring its resulting degree of polarization

⇒ preliminary to future experimental work with ^{35}Ar,

⇒ of general interest for studying interactions between multilevel atoms & multiple laser beams.



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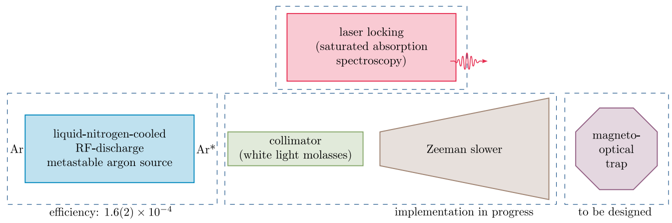
Development of a MOT system for trapping ^{40}Ar

Overview of the experimental scheme



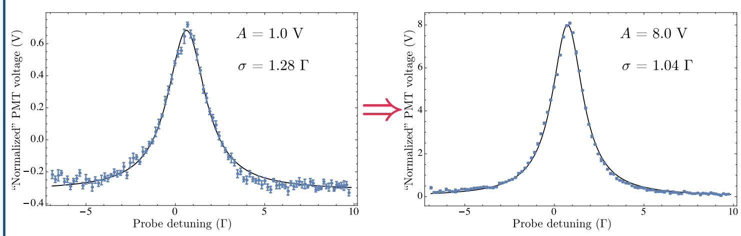
High precision measurements demand **high counting statistics** which demand **high-flux atomic beams** which demand **high system efficiencies**

⇒ the setup needs to be **optimized at every stage**.

Characterizing & optimizing the atomic beam

Transverse fluorescence spectroscopy of the atomic beam

⇒ investigating the influence of a standard (i.e., not spectrally broadened) optical molasses:



Ongoing:

setup of the **white-light** version of the optical molasses [3].

feasibility study of "optically enhanced" production of metastables [4] –in order to mitigate the low efficiency of the source.

Efficient polarization of ^{35}Ar

The ingredients

A 48-level density operator following the Liouville equation

$$\frac{d\hat{\rho}(t)}{dt} = \underbrace{-\frac{i}{\hbar}\left[\hat{H}_A + \hat{H}_I(t), \hat{\rho}(t)\right]}_{\text{conservative part}} \underbrace{-\frac{1}{2}\left\{\hat{\Gamma}, \hat{\rho}(t)\right\} + \mathrm{Tr}\left[\hat{\mathcal{F}}\hat{\rho}(t)\right]}_{\text{dissipative part}}$$

where $\hat{H}_A$ is the atomic Hamiltonian, $\hat{H}_I(t)$ is the interaction Hamiltonian, $\hat{\Gamma}$ is the relaxation matrix, and $\hat{\mathcal{F}}$ is the spontaneous emission operator.

The menu

We aim at **polarizing** an atomic system

= populating the Zeeman sublevel such that $m_F = \pm F$ (stretched state),

= minimizing the entropy of the system.

How to increase the degree of polarization $\mathcal{P}$?

Coherent processes ⇒ reversible ⇒ cannot increase $\mathcal{P}$ [5].

Relaxation processes ⇒ irreversible ⇒ can increase $\mathcal{P}$.

⇒ Typical method: **optical pumping**.

We also aim at **minimizing** both **population loss** and the **number of spontaneous emission events** involved in optical pumping

⇒ repump laser beam + static magnetic field,

⇒ exploration of methods beyond conventional optical pumping [5].

Also under study: **coherent population trapping** (CPT) effect

⇒ may cause false polarization signal [6].

We thank the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office (BriX network P7/12) for financial support.