Laser Spectroscopy of radioactive isotopes in an MR-ToF Device

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July 2, 2024

Outline - In two parts

1. Intro to MIRACLS
   - Motivation
   - the MIRACLS technique
2. The latest beamtime results

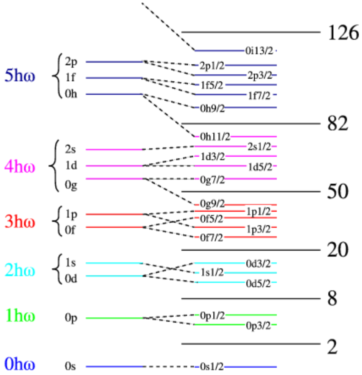
Motivation

In a nutshell

- Search for more sensitive methods to benchmark nuclear theory.

Nuclear Shell Model

- Nucleons are organized into shells, with increased stability at shell closures corresponding to magic numbers.



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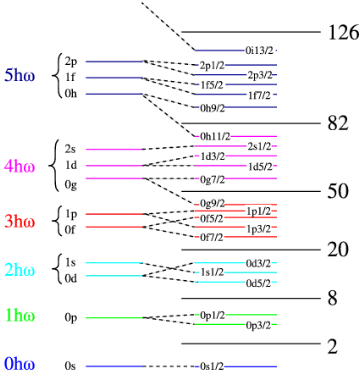

Nuclear Shell Model

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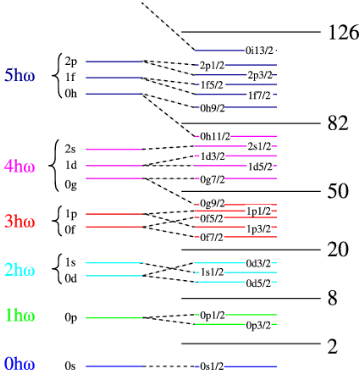
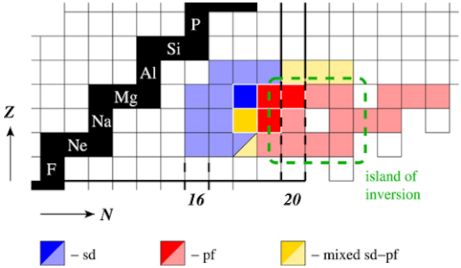
- Reflected in many observables, such as binding energy, or charge radius.
- Highly effective at describing stable isotopes



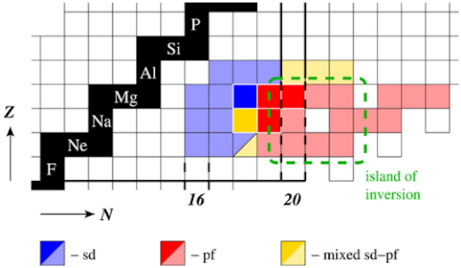
Islands of Inversion

- $N = 20$ shell closure disappears, and isotopes have decreased stability due to "intruder states"



Islands of Inversion

- $N = 20$ shell closure disappears, and isotopes have decreased stability due to "intruder states"
- highly interesting for nuclear theory.



Islands of Inversion - Magnesium

- $N = 20$ island of inversion is observed in charge radii of Mg isotopes.

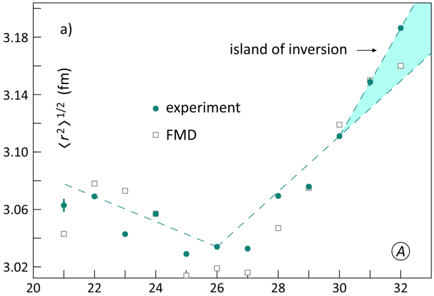
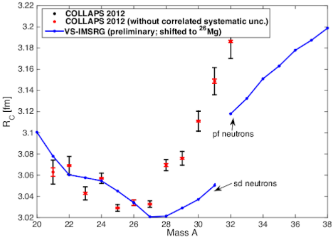


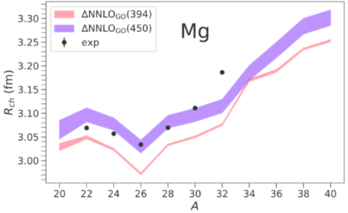
Figure: D. T. Yordanov, et al., Phys. Rev. Lett., 108:042504, (2012)

Ab-initio method

- Ab-initio methods – progress in modeling Mg charge radius.



(a) VS-IMSRG model.
T. Miyagi, et al., Phys. Rev. C 102, 034320, (2020)



(b) Coupled Cluster model.
S. J. Novario, et al., Phys. Rev. C 102, 051303(R), (2020)

- ^{20}Mg has a different predicted charge radius in the two models above.

- We want to measure the charge radii of exotic magnesium isotopes, such as ^{34}Mg, ^{33}Mg and ^{20}Mg.

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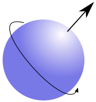
- These are very rare and short-lived isotopes – need techniques such as laser spectroscopy to probe them.

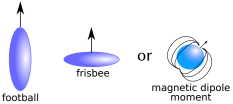
What is Collinear Laser Spectroscopy?

By probing an atom's electronic structure, we can determine the properties of its nucleus, such as:

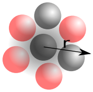
- nuclear spin



- electromagnetic moments

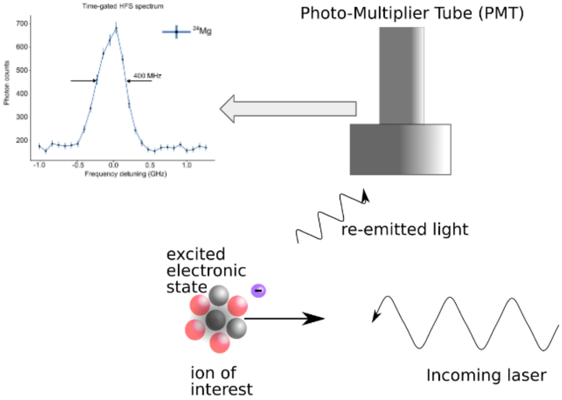


- charge radii

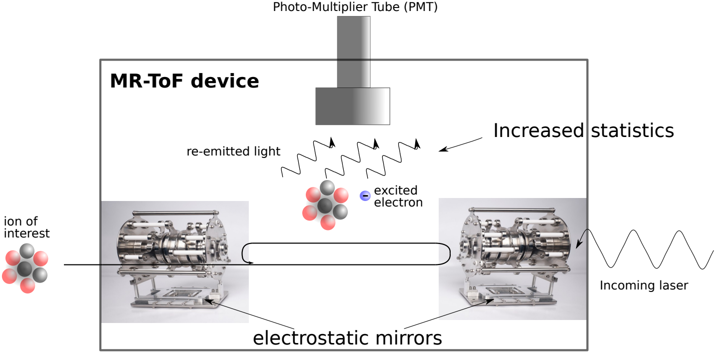


Many observables become accessible with only one measurement!

Conventional fluorescence-based CLS



Our method: MIRACLS



- signal-to-noise ratio improvement: $\frac{S}{N} = \frac{S_0}{N_0}\sqrt{r}$.

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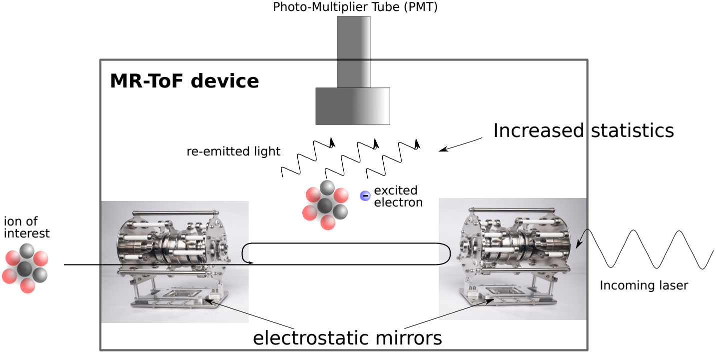


- signal-to-noise ratio improvement: $\frac{S}{N} = \frac{S_0}{N_0}\sqrt{r}$.
- More exotic radionuclides with low production yields can be probed.

MIRACLS method

Paul Trap injection: (show animation)

MIRACLS method

Paul Trap extraction: (show animation)

MIRACLS method

CLS in MR-ToF Device: (show animation)

Improvement Factor

- Single-passage mode:

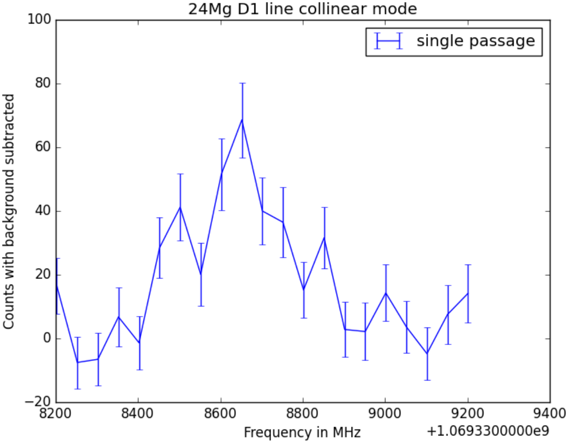
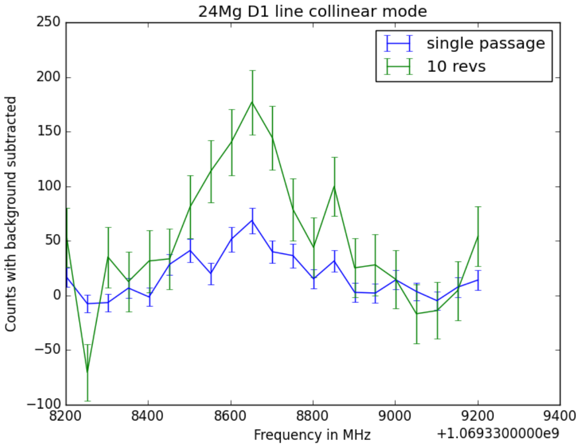


Figure: Preliminary

Improvement Factor

- Multi-Reflection improvement:



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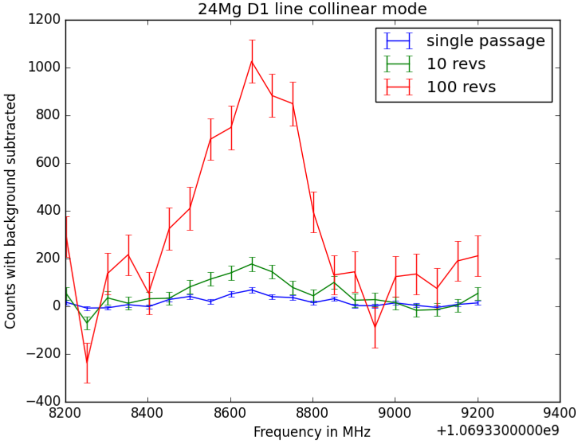

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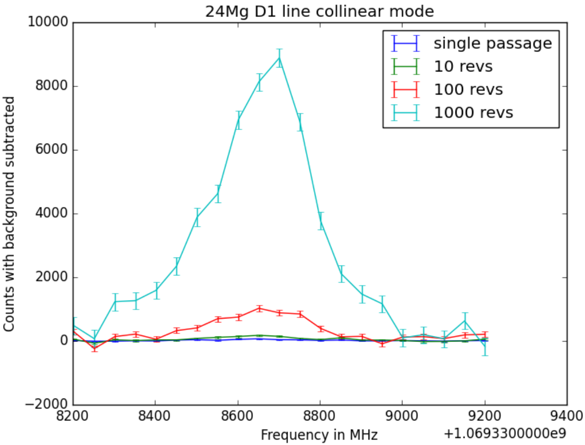

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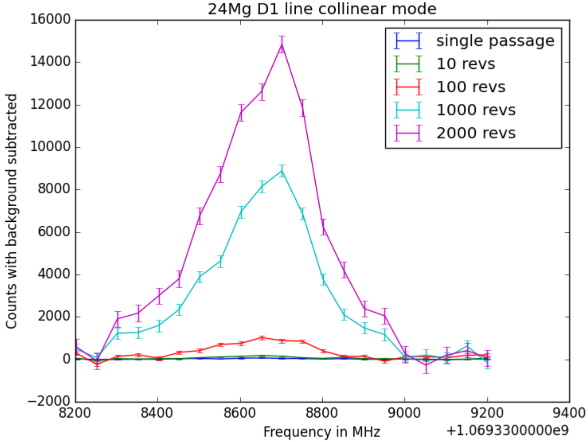

Figure: Preliminary

Collinear-Anticollinear measurements

- Collinear:

$$\nu_0 = \nu_c \frac{1-\beta}{\sqrt{1-\beta^2}}$$

- Anticollinear:

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- Removes the need for knowing beam energy for the determination of ν_0

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- For higher energies:
  - number of ions stored can increase because of reduced space charge effects.
  - bunches with smaller time spread can be accepted into MR-ToF $\Rightarrow$ shorter separation time.

Mass separation capabilities of MIRACLS

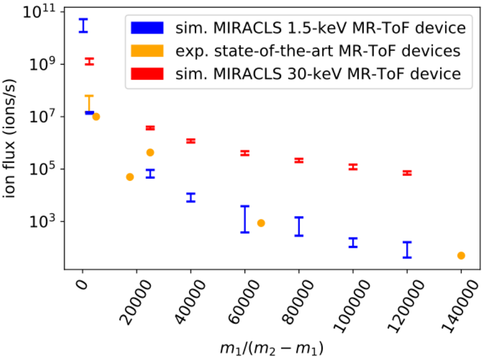

Figure: F.M. Maier, NIM A, 1056, 168545, (2023)

- 10^5 ions/s with mass resolving power $R = 10^5$ at 30 keV beam energy.

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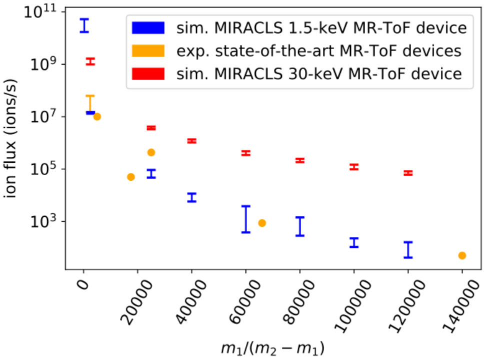

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- 10^5 ions/s with mass resolving power $R = 10^5$ at 30 keV beam energy.
- Plans for a general purpose mass sepator at ISOLDE.
  - Needs to be upgraded with shorter drift tube (currently $R = 10^4$)

Beamtime conducted on June 30th, (2 days ago)

Beamtime: Isotope shift measurements

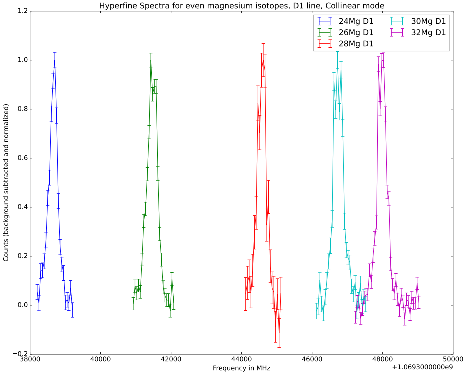


Figure: Preliminary

- Measured the collinear and anticollinear D1 and D2 transitions for even magnesium isotopes $^{24-32}$Mg.

Beamtime: Isotope shift measurements

isotope shift for D1 line (Already measured in 2013 at COLLAPS)

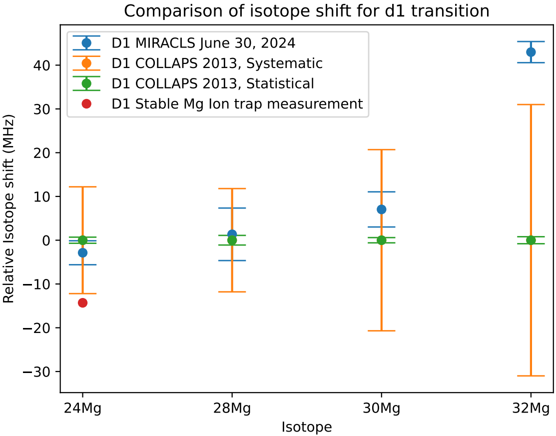
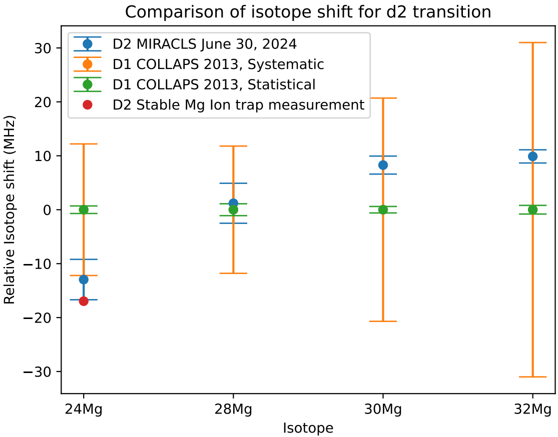


Figure: Preliminary.

COLLAPS: D. T. Yordanov, et al., Phys. Rev. Lett., 108:042504, (2012)
Stable Mg: V. Batteiger, et al., Phys. Rev. A, 80:022503, (2009)

Beamtime: Isotope shift measurements

isotope shift for D2 line (New measurement!)



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Sensitivity limit: 28 ions / cycle

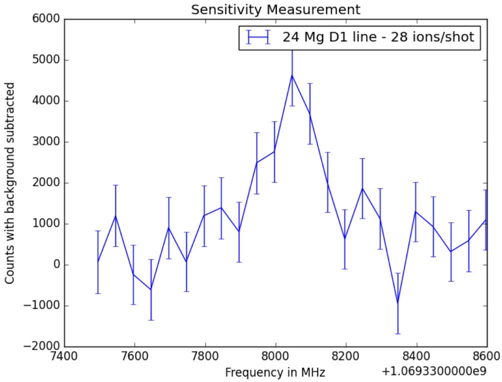

Figure: Preliminary

- A measurement taken with equivalent of 12 hours with ISOLDE beam.
- ^{34}Mg achievable next beamtime (150 ions / μC)

Plans for next beamtime

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- Add another laser for easier swap between anti-collinear and collinear geometries.

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- ^{34}Mg measurement within sights for beamtime later this year.

Questions?