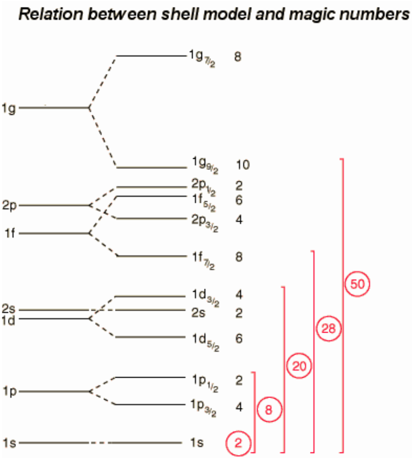
Laser Spectroscopy of $^{24-34}$Mg in an MR-ToF Device

Anthony Roitman

McGill University, CERN

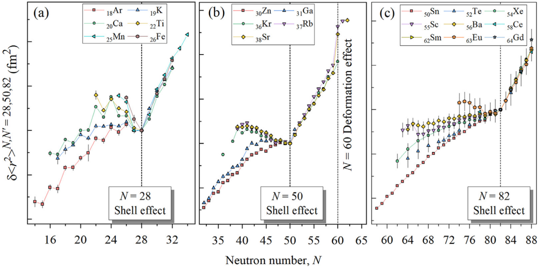
Nuclear Shell Model

- Major area of research at ISOLDE: stability at shell closures
  - Reflected in many observables, such as binding energy or charge radius



Nuclear Shell Model

kink in charge radii at shell closures



X. Yang et al., Progress in Particle and Nuclear Physics 129, 104005 (2023)

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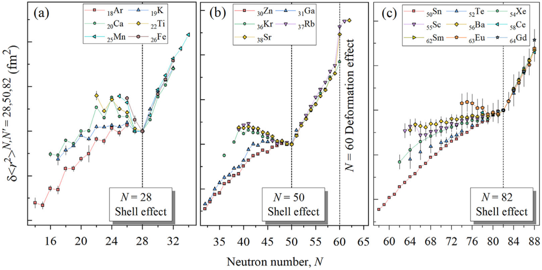
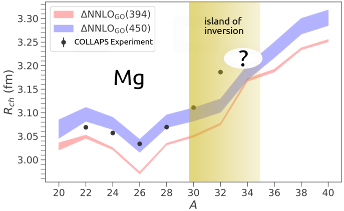


disappearance of shell closure at N=20: island of inversion



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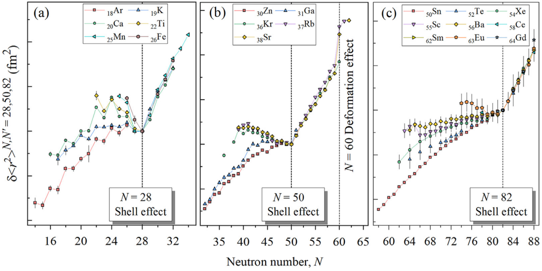

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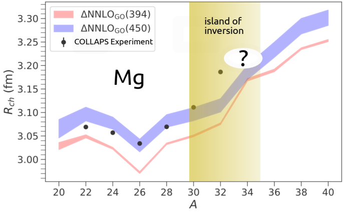

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- $N = 20$ shell closure disappears for magnesium: charge radii for ^{33,34}Mg would provide a powerful benchmark for nuclear theory

- Challenge: yields down to 100 ions / μC and half lives down to 40 ms

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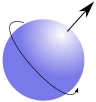
- Need highly sensitive laser spectroscopy techniques to probe charge radii of exotic nuclei

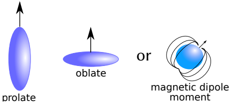
Laser Spectroscopy in Nuclear Physics

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

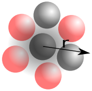
- nuclear spin



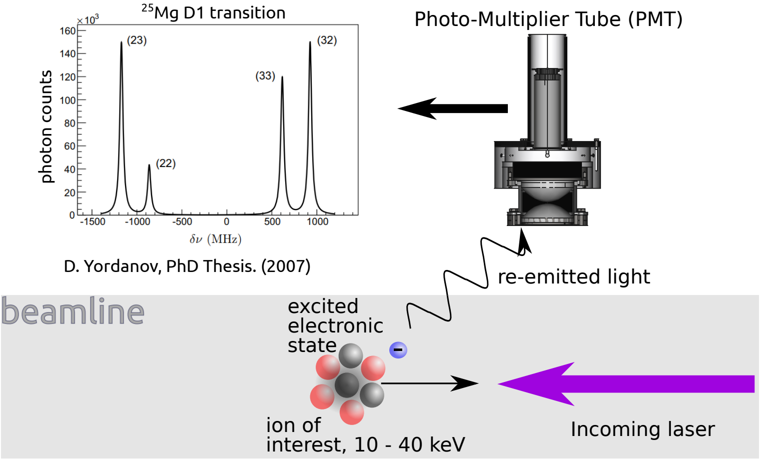
- electromagnetic moments



- charge radii



Collinear Laser Spectroscopy (CLS)



D. Yordanov, PhD Thesis. (2007)

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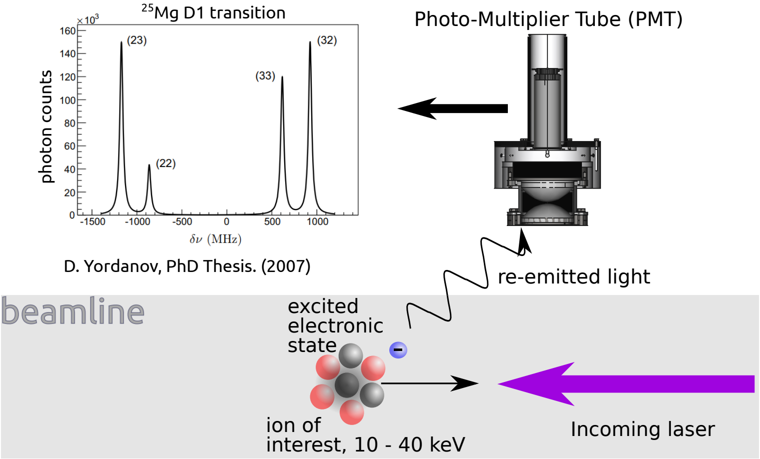

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- Collinear geometry minimizes Doppler broadening:

$$\delta\nu \propto \frac{\delta E}{\sqrt{E}}$$

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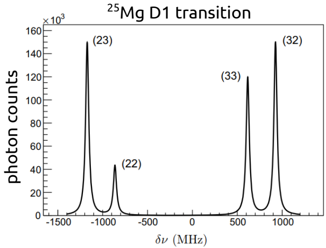

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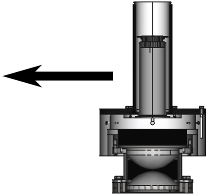
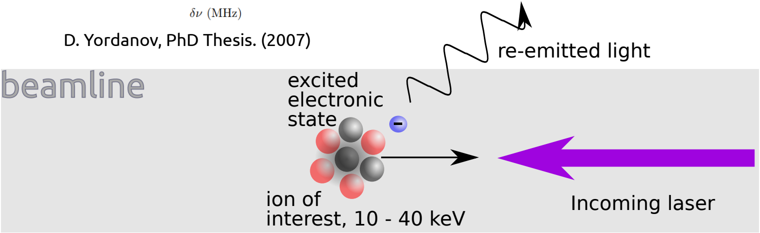
Photo-Multiplier Tube (PMT)





- Limitation: Measurement time $\boxed{\sim 5\ \mu s}$, but $\boxed{T_{1/2} > 10\text{ ms}}$

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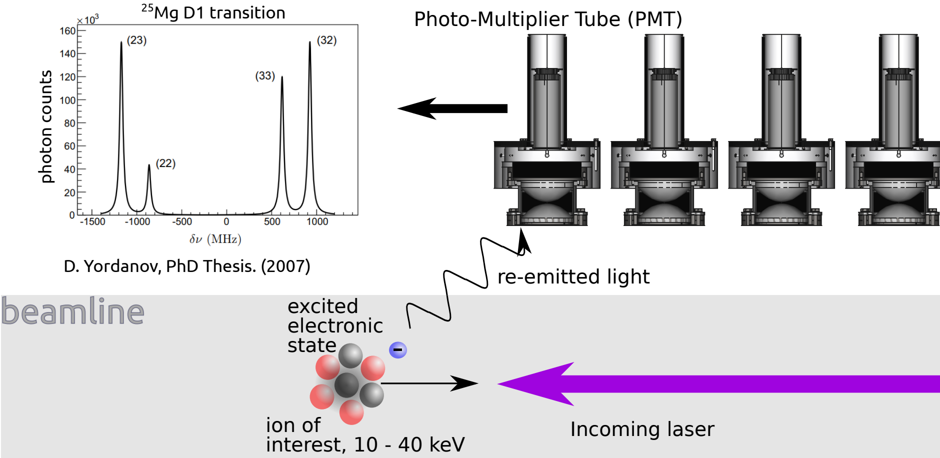

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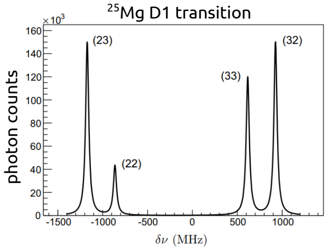
- Solution?

Collinear Laser Spectroscopy (CLS)



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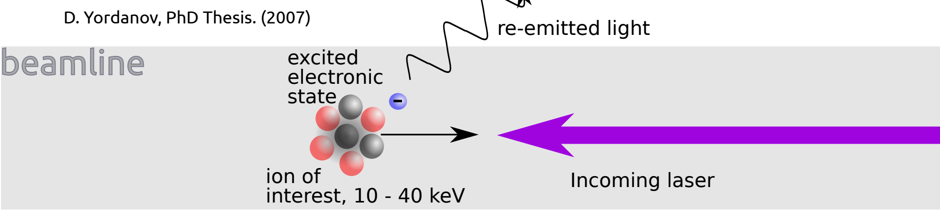
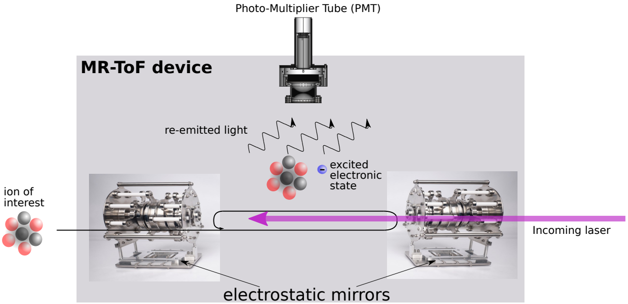


- Solution?

Our Solution: MIRACLS

Multi-Reflection Time-of-Flight (MR-ToF) device increases effective beampath to "recycle" ions



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

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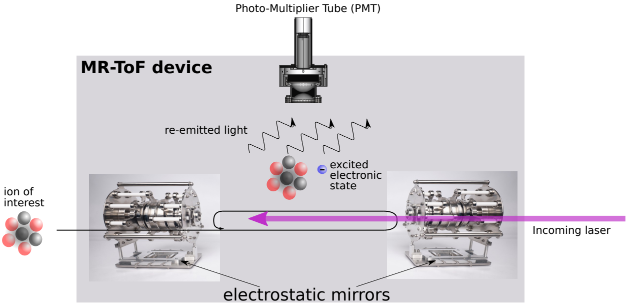
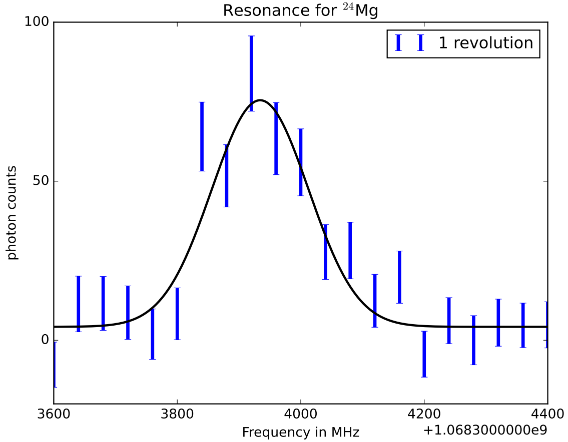


- signal-to-noise ratio improvement: $\frac{S}{N} = \frac{S_0}{N_0}\sqrt{r}$
- More exotic radionuclides with low production yields can be probed

Improvement Factor

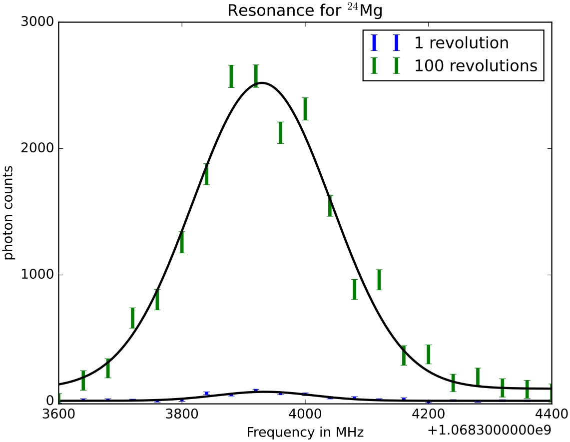
- Single-passage mode (experimental data):



Preliminary

Improvement Factor

- Multi-reflection improvement (experimental data):



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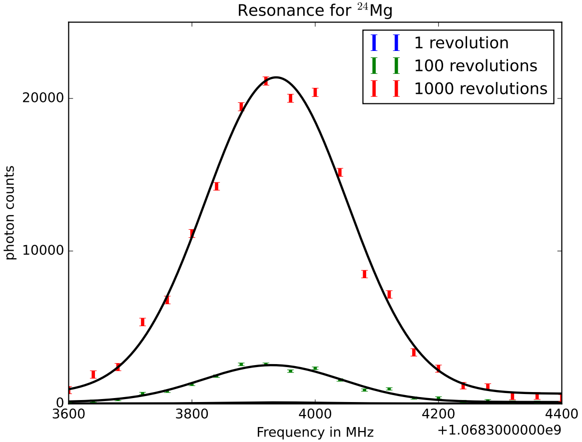

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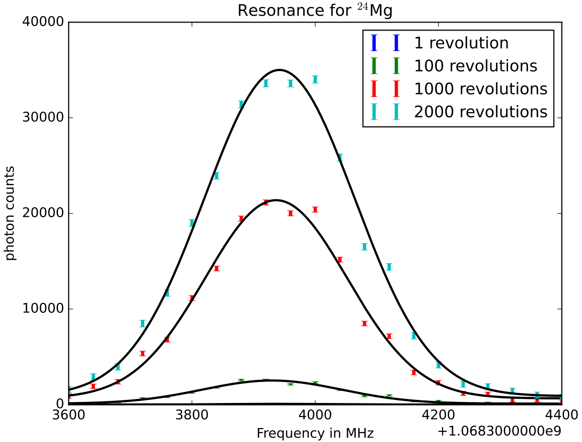
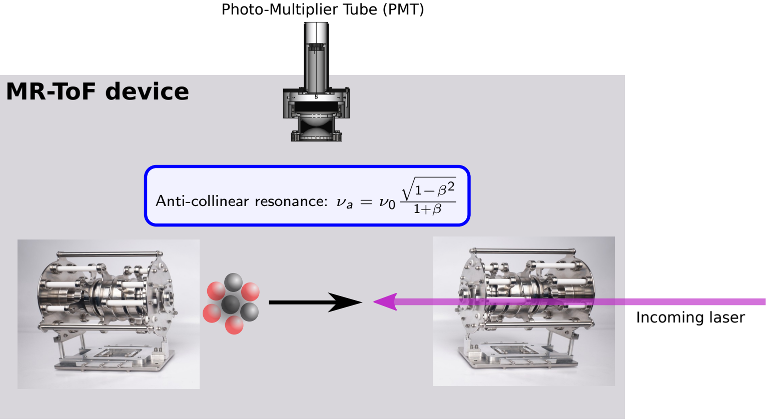


Preliminary

Collinear-Anticollinear measurements at MIRACLS

Beam energy: large source of uncertainty in CLS



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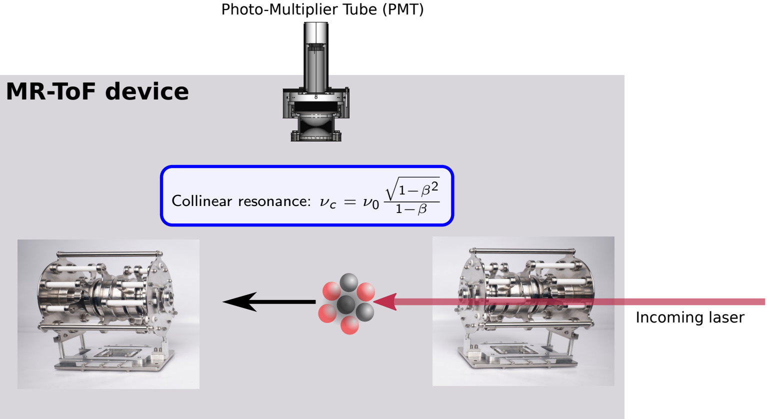

Collinear resonance: $\nu_c = \nu_0 \frac{\sqrt{1-\beta^2}}{1-\beta}$

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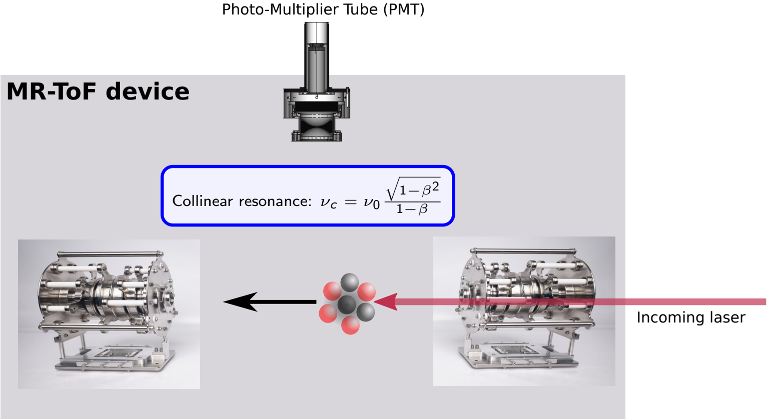

$\Rightarrow \nu_0 = \sqrt{\nu_c \cdot \nu_a}$, independent of beam energy!

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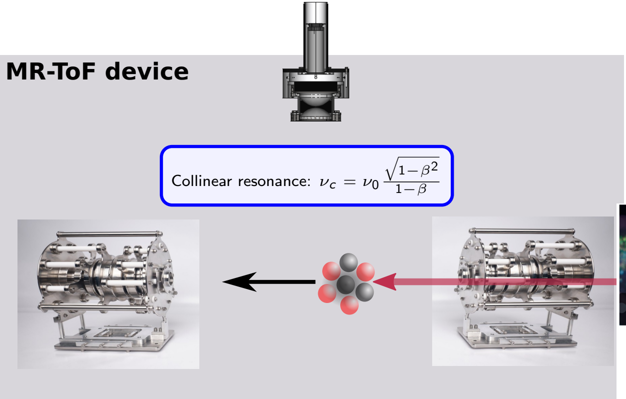

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Nuclear Charge Radii of ^{7,9,10}Be and the One-Neutron Halo Nucleus ^{11}Be

W. Nörtershäuser[1,2], D. Tiedemann[2], M. Žáková[2], Z. Andjelkovic[2], K. Blaum[3], M. L. Bissell[4], R. Cazan[2], G. W. F. Drake[5], and Ch. Geppert[1,6] *et al.*

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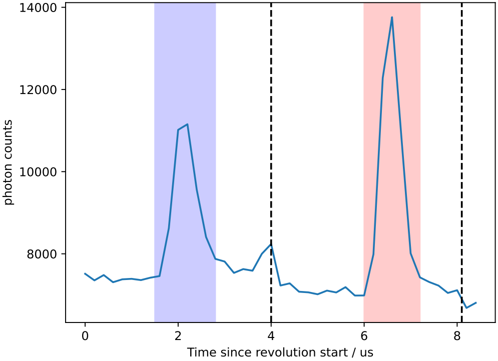
- Implementation: Acousto-optic modulator (AOM) as a laser switch



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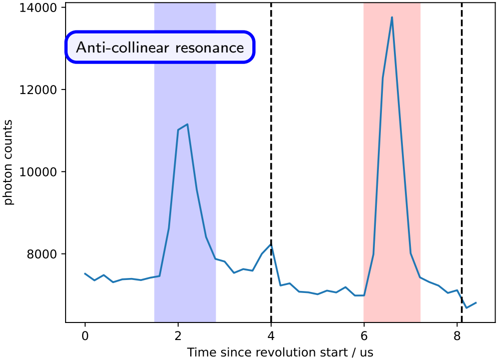

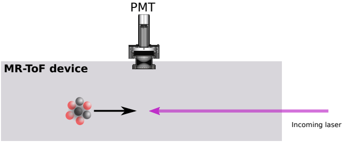

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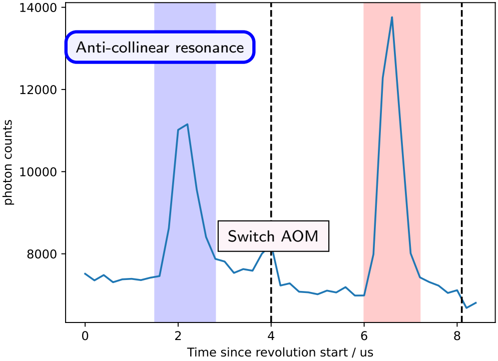

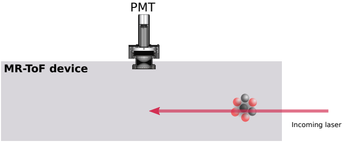

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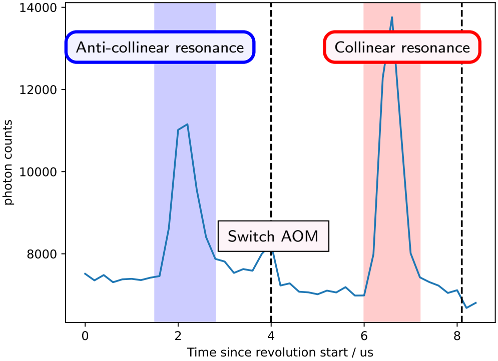

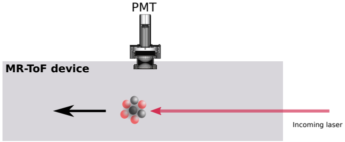

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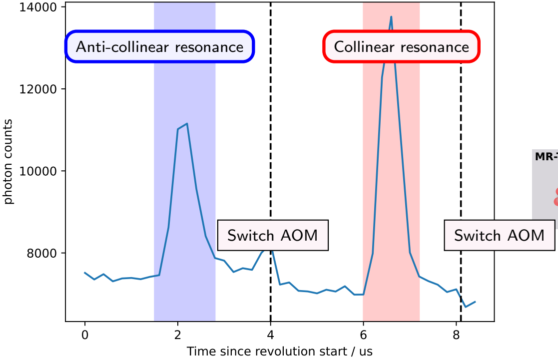
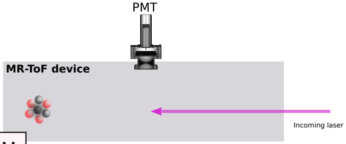
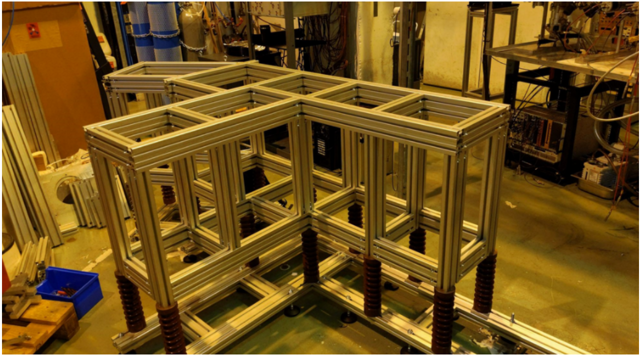




Online Apparatus Progress:

Status January 2022



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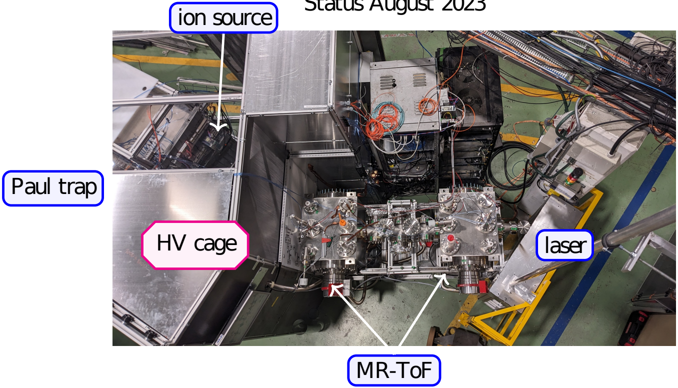

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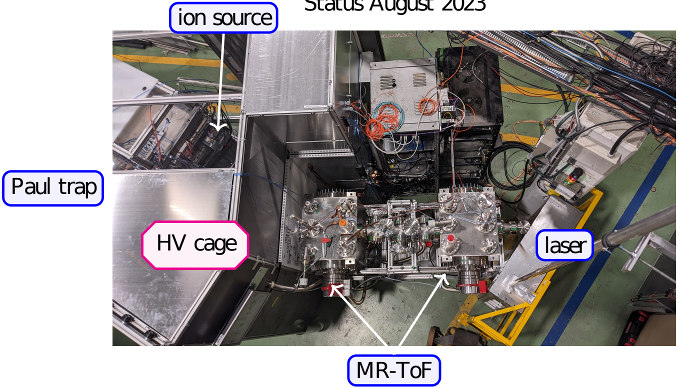
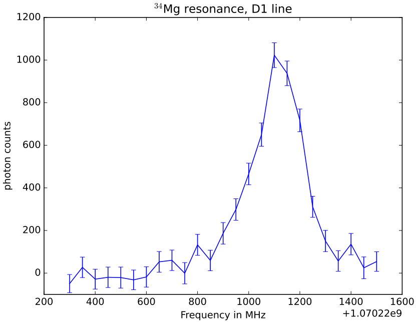


Highest energy MR-ToF device every built! (> 10 kV)

November 2024: Beamtime (11 days ago!)

Measured our first physics case: ^{34}Mg

Preliminary



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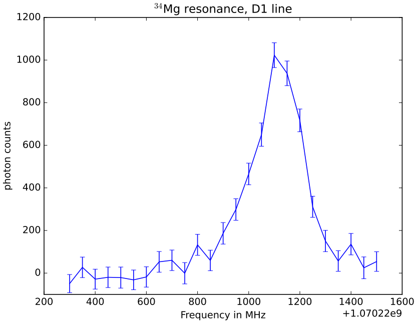

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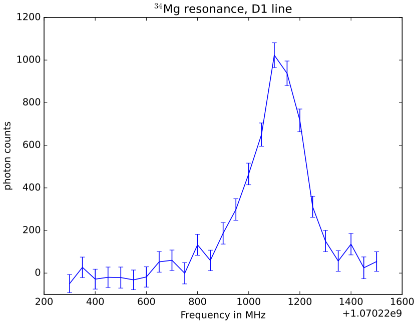

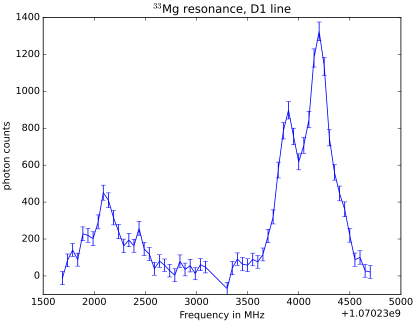

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Outlook

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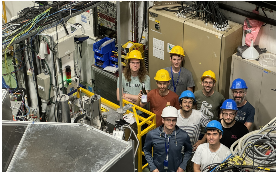
- Isotope shifts measured for even-even isotopes $^{24-34}$Mg, and odd-even ^{33}Mg
- Opens a door to other exciting physics cases

Acknowledgements



Collaboration:

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MIRACLS Collaboration:

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Thanks again to all Beamtime Participants:

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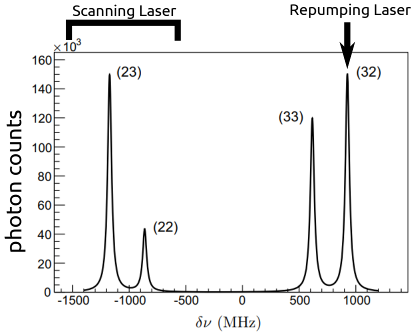
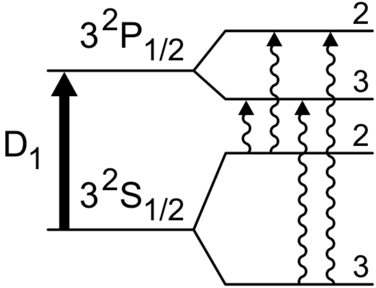
Odd-even scheme

- Repurposing Lasers: One for repumping, one for scanning





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