Probing ‘exotic’ nuclei via laser spectroscopy in an MR-ToF device

Simon Lechner
CERN

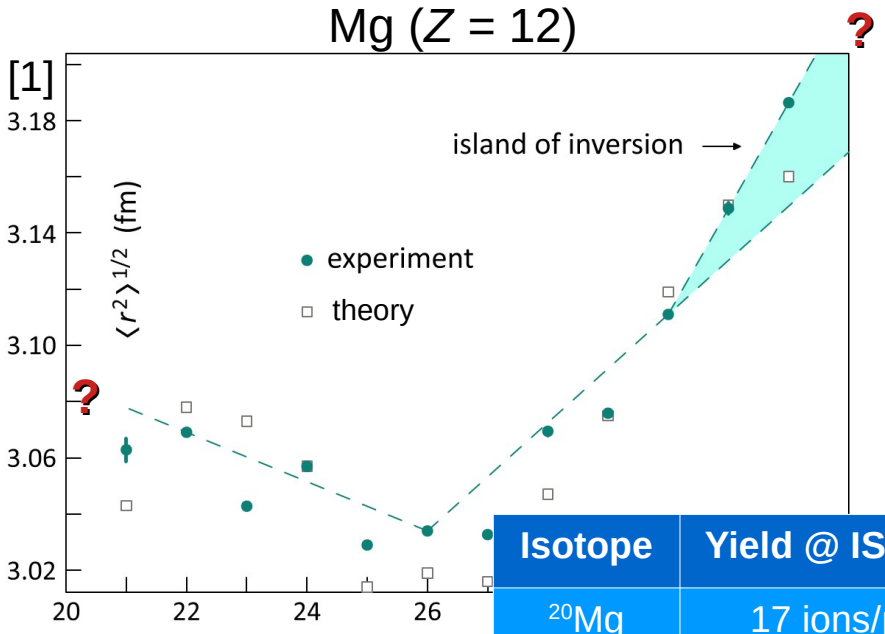
Outline

- Why we need more sensitive techniques
- MIRACLS principle

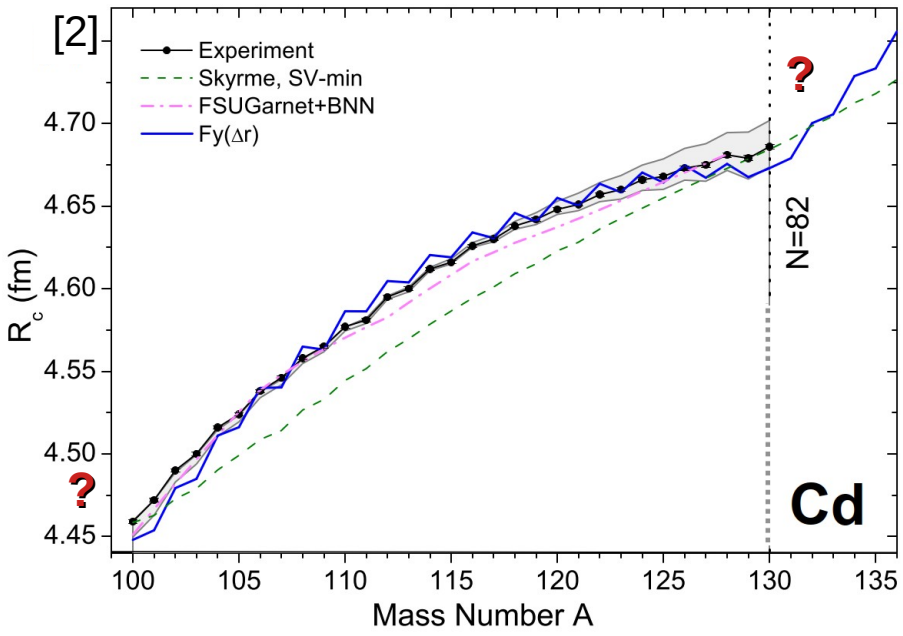
  Multi-Ion-Reflection-Apparatus for Collinear Laser Spectroscopy

- Previous studies
- Current status of experiment

Charge radii of Mg and Cd



Isotope	Yield @ ISOLDE
^{20}Mg	17 ions/μC*
^{34}Mg	140 ions/μC
^{98}Cd	10 ions/μC
^{132}Cd	5 ions/s*



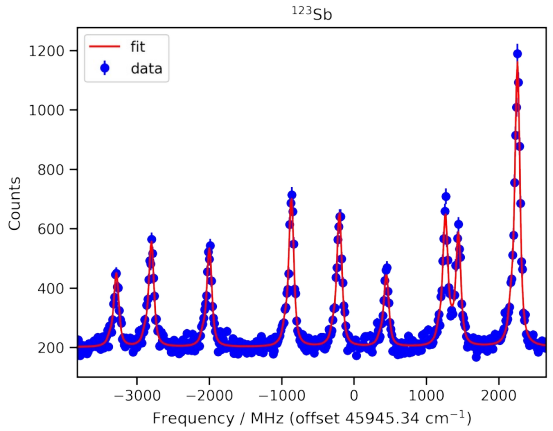
More sensitive techniques needed

[1] D. T. Yordanov, *et al.*, Phys. Rev. Lett., 108:042504, 2012
[2] M. Hammen, *et al.*, Phys. Rev. Lett., 121:102501, 2018

*estimated

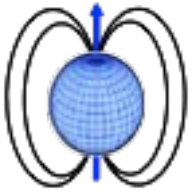
Collinear Laser Spectroscopy (CLS)

- Interaction between nucleus and electrons in atoms cause hyperfine structure **F = I + J**
- Probing the atom reveals information about the nucleus



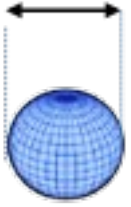
spin I

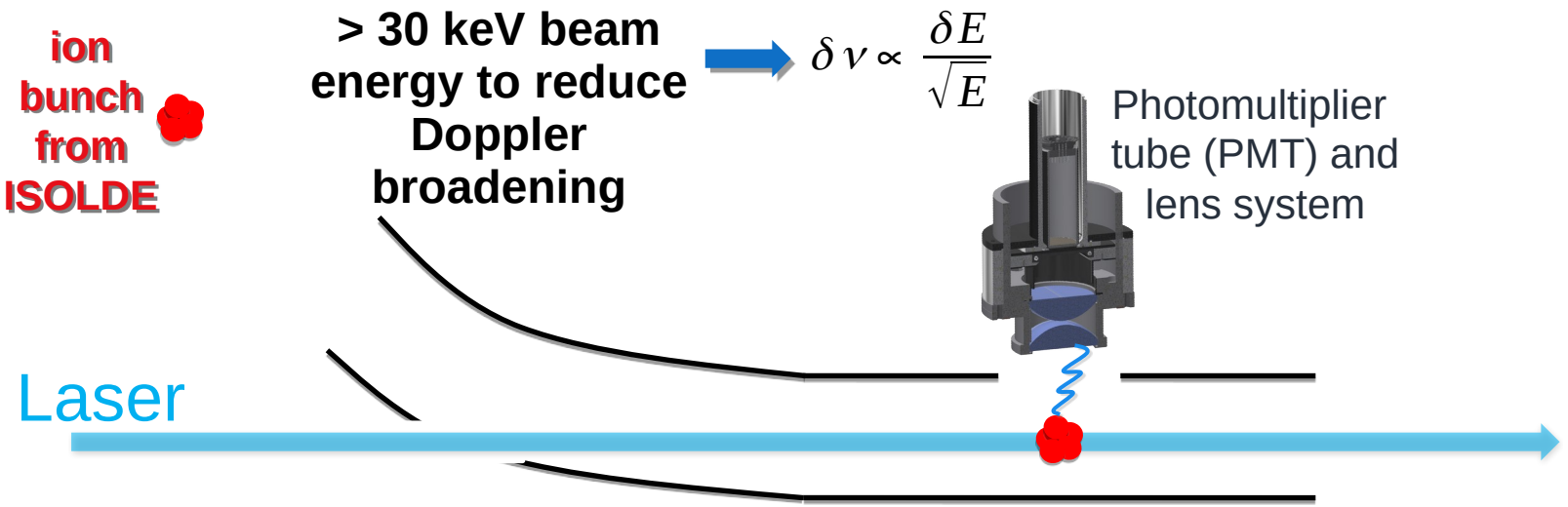
magnetic moment



quadrupole moment Q_s

charge radius





$T_{1/2}$ of accessible radionuclides:

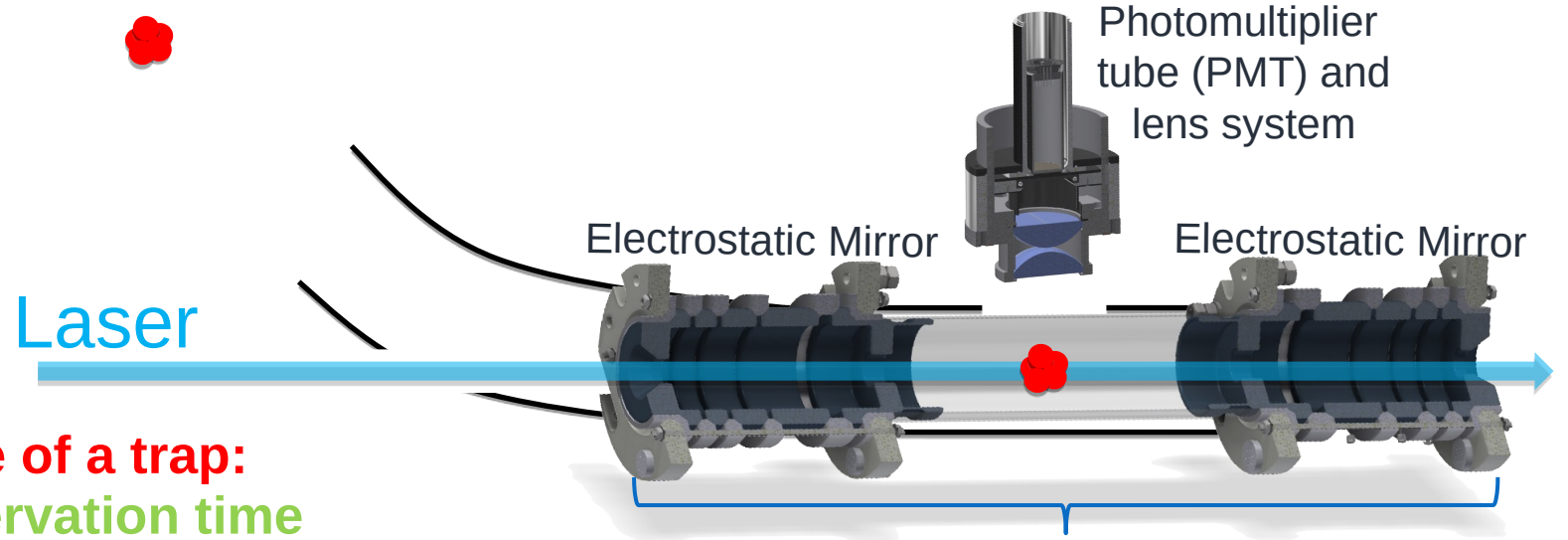
> 5 ms

Effective use for CLS

up to a few µs

? Can one use exotic nuclides even more efficiently ?

MIRACLS - Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy



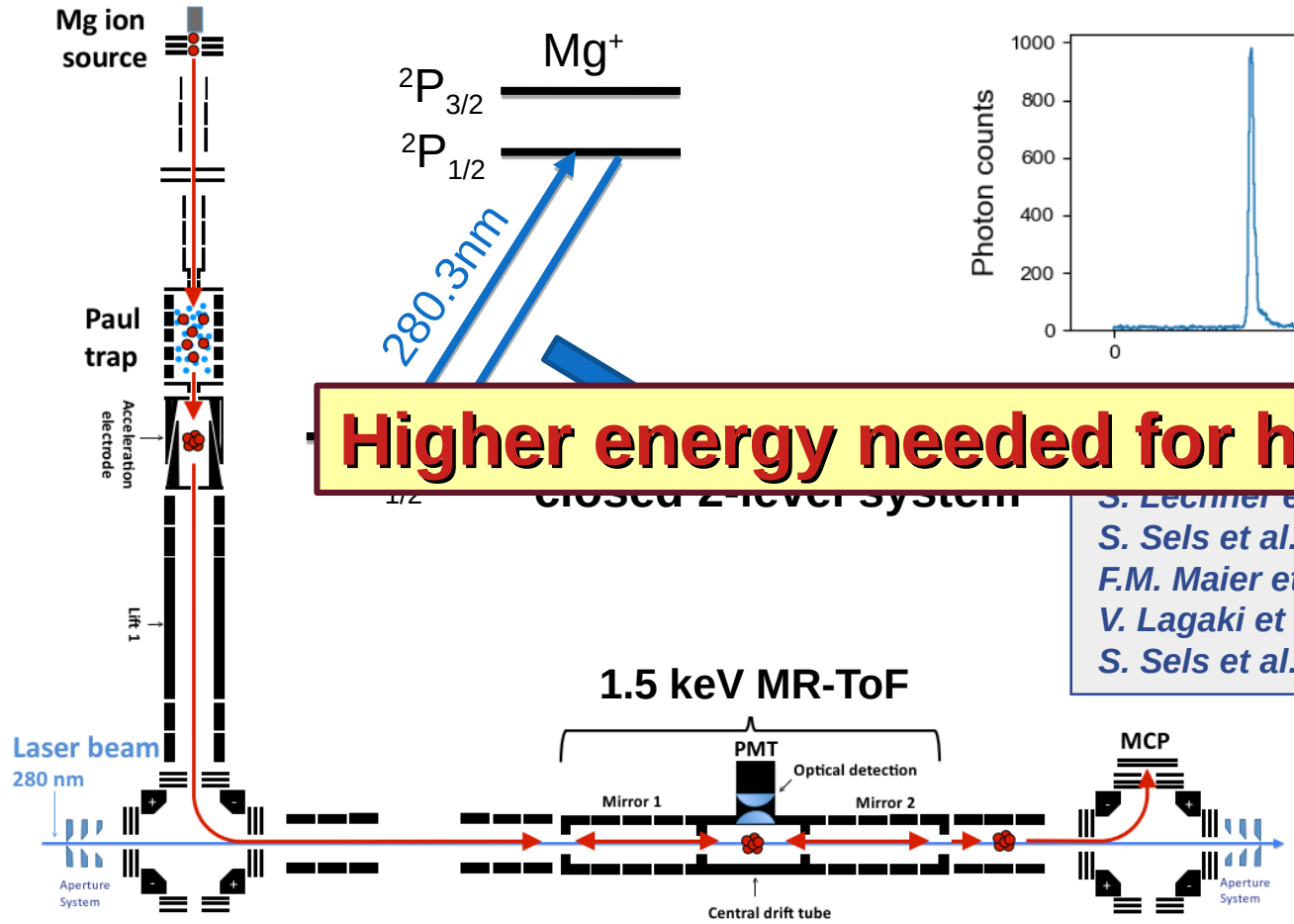
Multi Reflection Time-of-Flight (MR-ToF) device

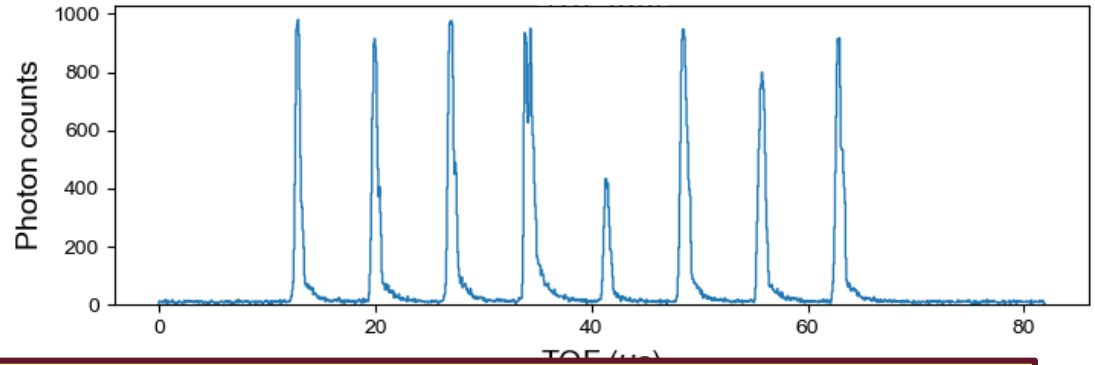
Advantage of a trap:
Long observation time
⇩
Higher sensitivity
⇩
More exotic nuclides accessible with low production yield (few ions/s)

$$\frac{Signal}{Noise} \propto \sqrt{Revolution}$$

improvement factor

Proof-of-Principle Experiment



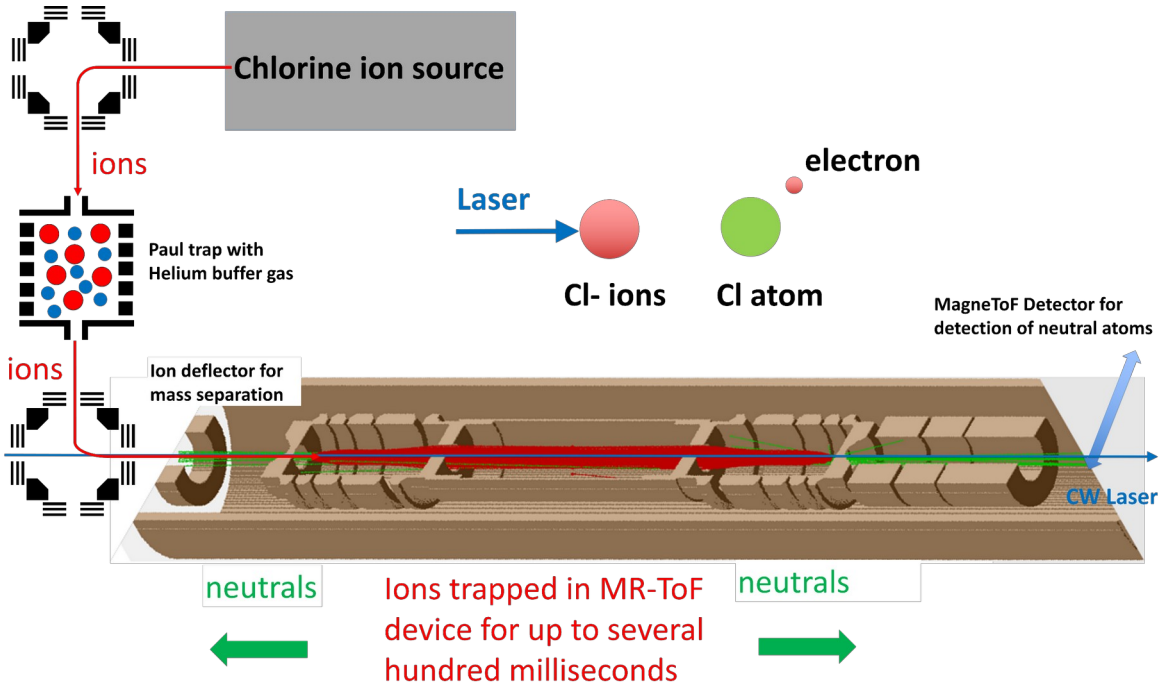


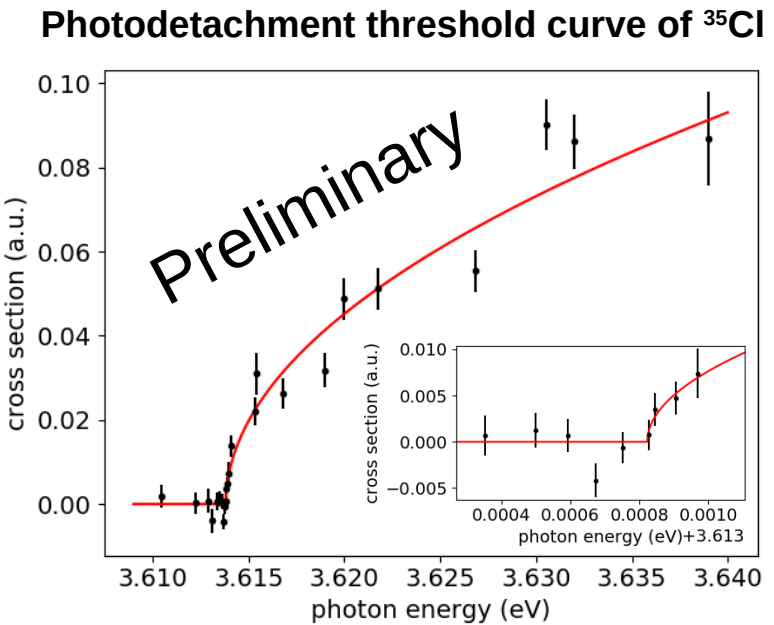
Higher energy needed for high-resolution CLS

S. Lechner et al., Hyperfine Interact. 240: 95 (2019)
S. Sels et al., Nucl. Instr. Meth. B, 463, 310-314 (2019)
F.M. Maier et al., Hyperfine Interact. 240: 54 (2019)
V. Lagaki et al., Nucl. Instr. Meth. A, Vol 1014, 165663 (2021)
S. Sels et al., Phys. Rev. Research 4, 033229, (2022)

Laser Photodetachment of negative ions in an MR-ToF device

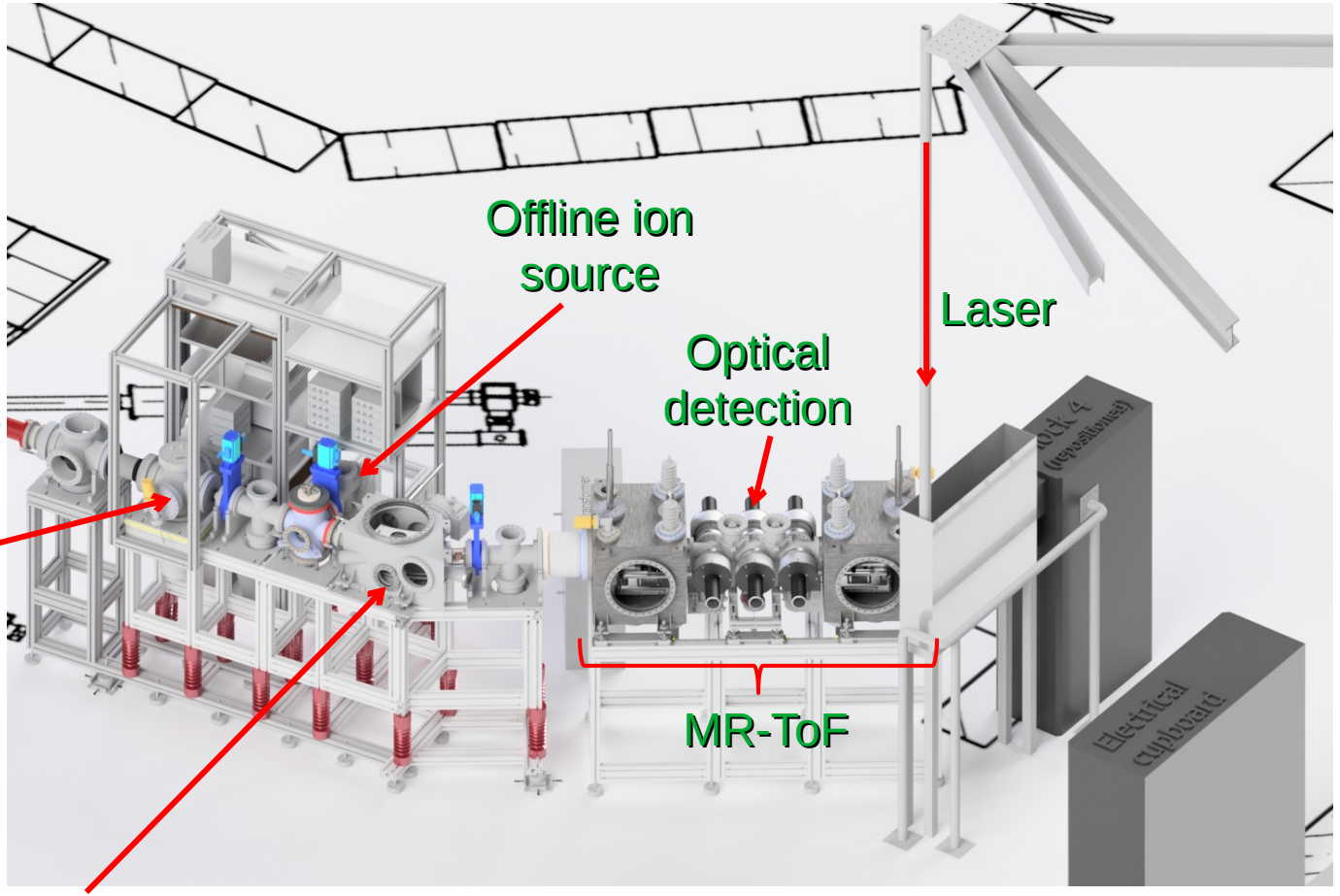
See talk of Erich Leistenschneider Fr 12:00





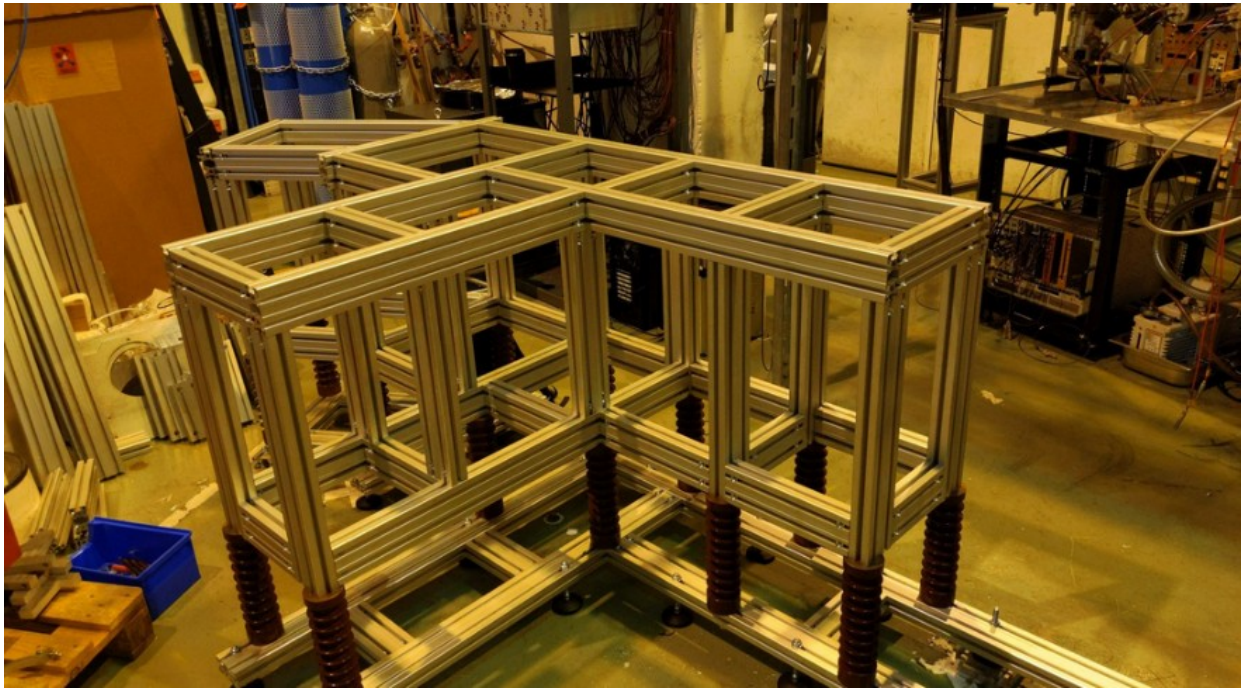
High-Resolution Experimental Setup

Radioactive ion beam from ISOLDE

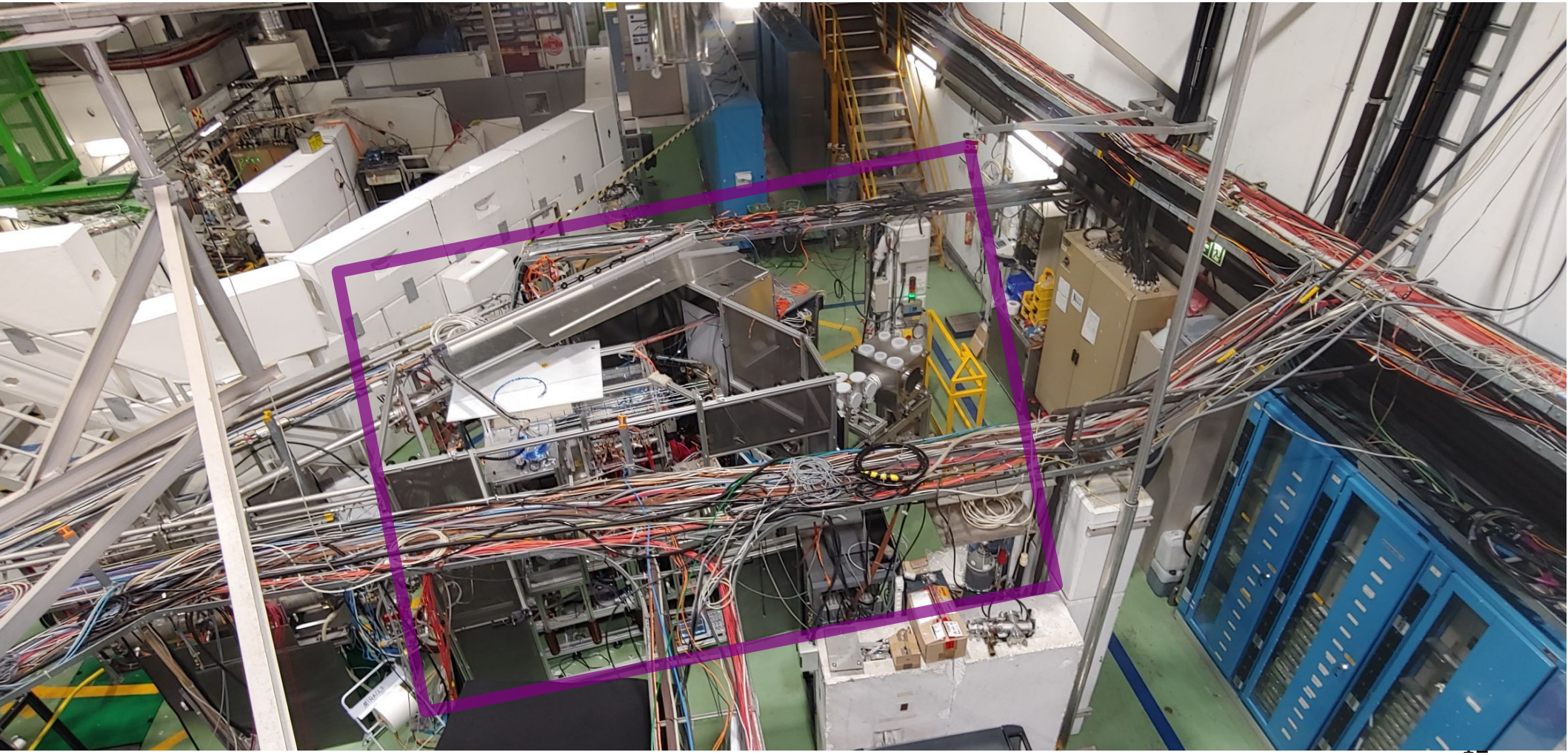


First MR-ToF designed for beam energies of 30 keV

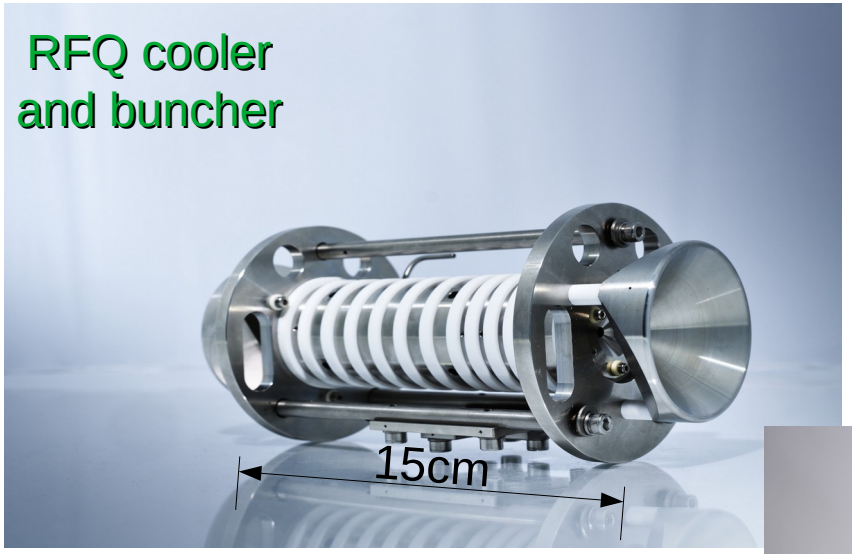
January 2022



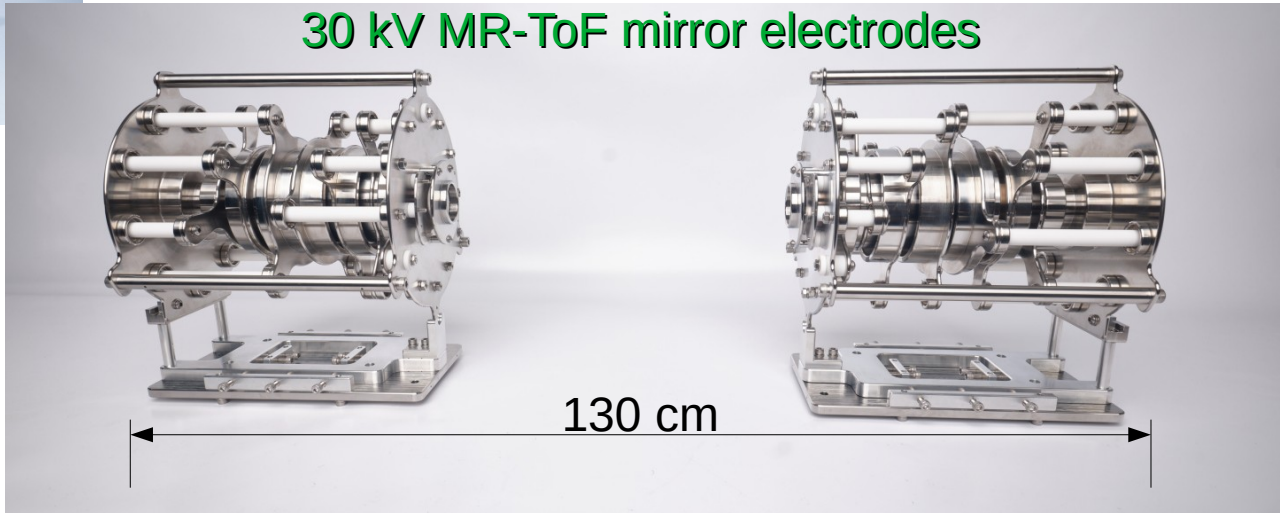
November 2022



Real pictures
(no photoshop)

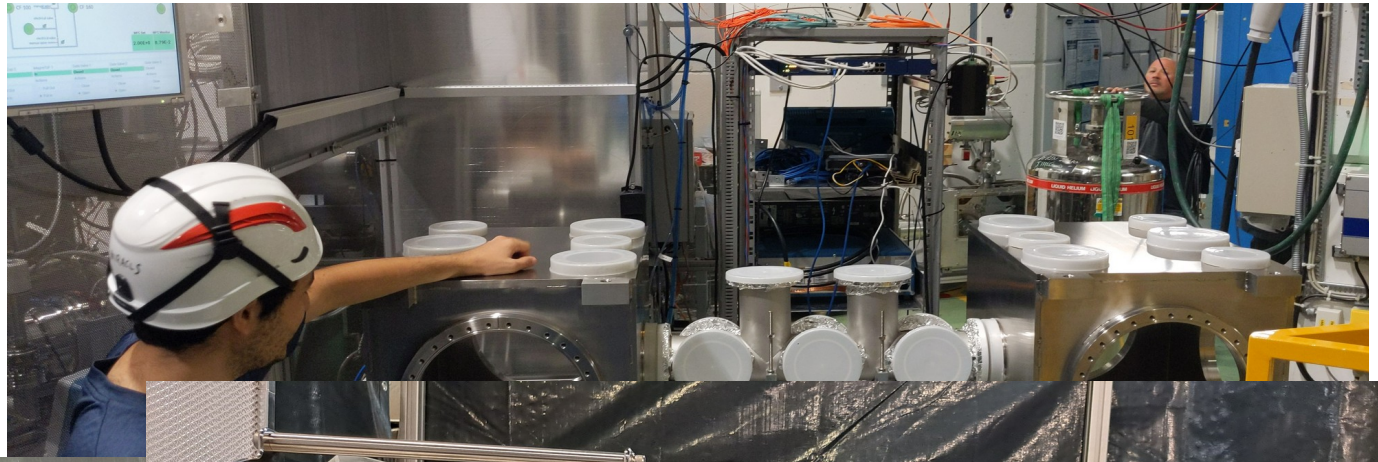


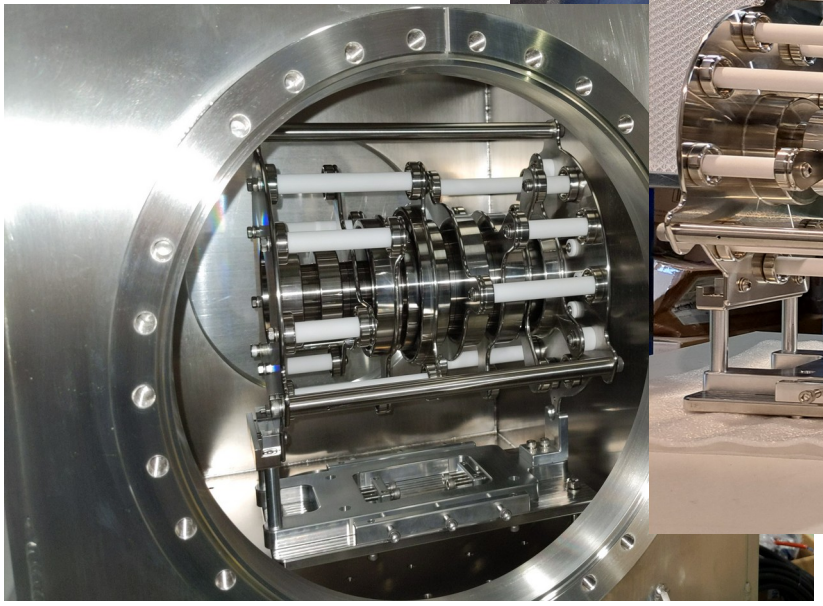
Our design copied for PUMA,
MIT, Greifswald and Beijing



ΔV up to 60 kV

MR-ToF





EPICS based control system

GUI

Sets the values of channel PVs using the PV object's put() method

ISEG EPICS IOC

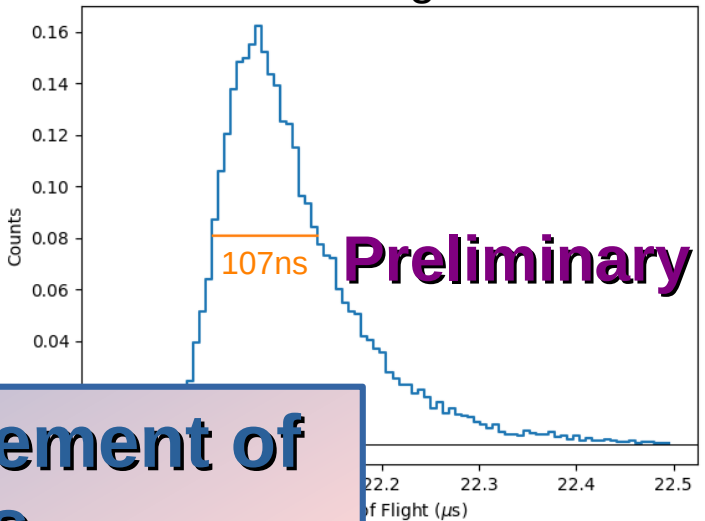
Separate EPICS server hosted on the ISEG power supply module. Able to control settings for each ISEG channel.

Gets values of channel PVs using the PV object's get() method

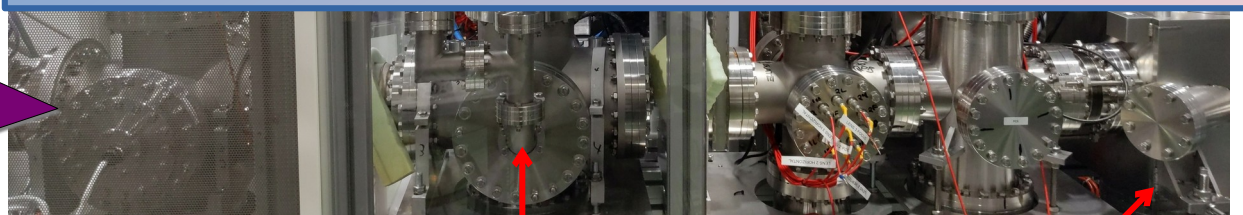
See poster of Anthony Roitman

Ion source

^{24,25,26}Mg



Stay tuned for first CLS measurement of short-lived radionuclides



Radioactive ion beam from ISOLDE

RFQ cooler and buncher

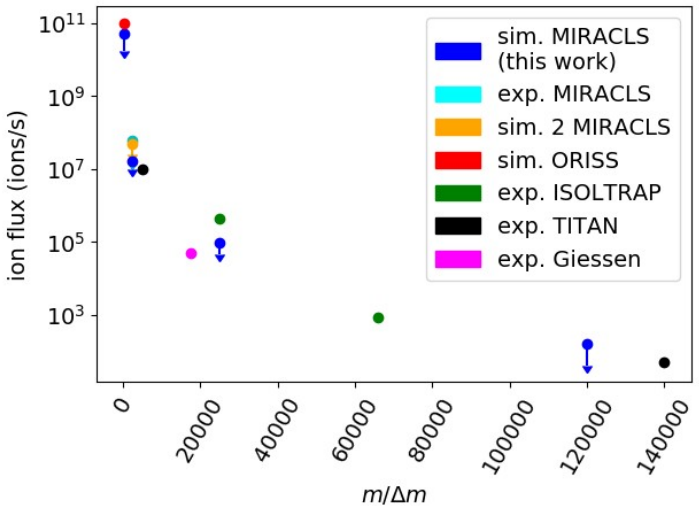
30 deg deflector

See poster of Fabian Hummer

Towards a Highly Selective and High Flux MR-ToF Mass Separator for ISOLDE

- MIRACLS RFQ and MR-ToF for ISOLDE mass separator
  - Needed for PUMA
- High-energy MR-ToF allows higher ion throughput

See poster of Franziska Maier



> 50 increase in flux for 30 keV MR-ToF compared to 1.5 keV

Summary & Outlook

- MIRACLS → new highly sensitive laser spectroscopy technique to measure nuclear structure of exotic nuclei
- Experimental setup currently under construction → first measurements soon
- MIRACLS technique applicable also for photodetachement studies of negative ions
- RFQ cooler and buncher and MR-ToF will be used as ISOLDE high-resolution mass separator in future

ERNST MORITZ ARNDT UNIVERSITÄT GREIFSWALD

TECHNISCHE UNIVERSITÄT DARMSTADT

ISOLDE

McGill

TRIUMF

European Research Council
Established by the European Commission

MIRACLS

CERN

Simon Lechner, F. Buchinger, L. Croquette, P. Fischer, F. Hummer, E. Leistenschneider, F. Maier, W. Nörtershäuser, P. Plattner, A. Roitman, M. Vilen, F. Wienholtz, L. Schweikhard, S. Malbrunot-Ettenauer

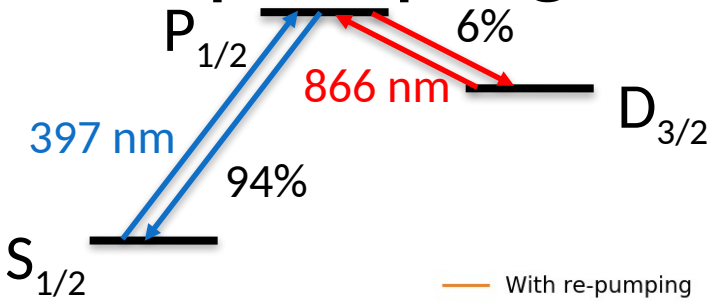
Open positions

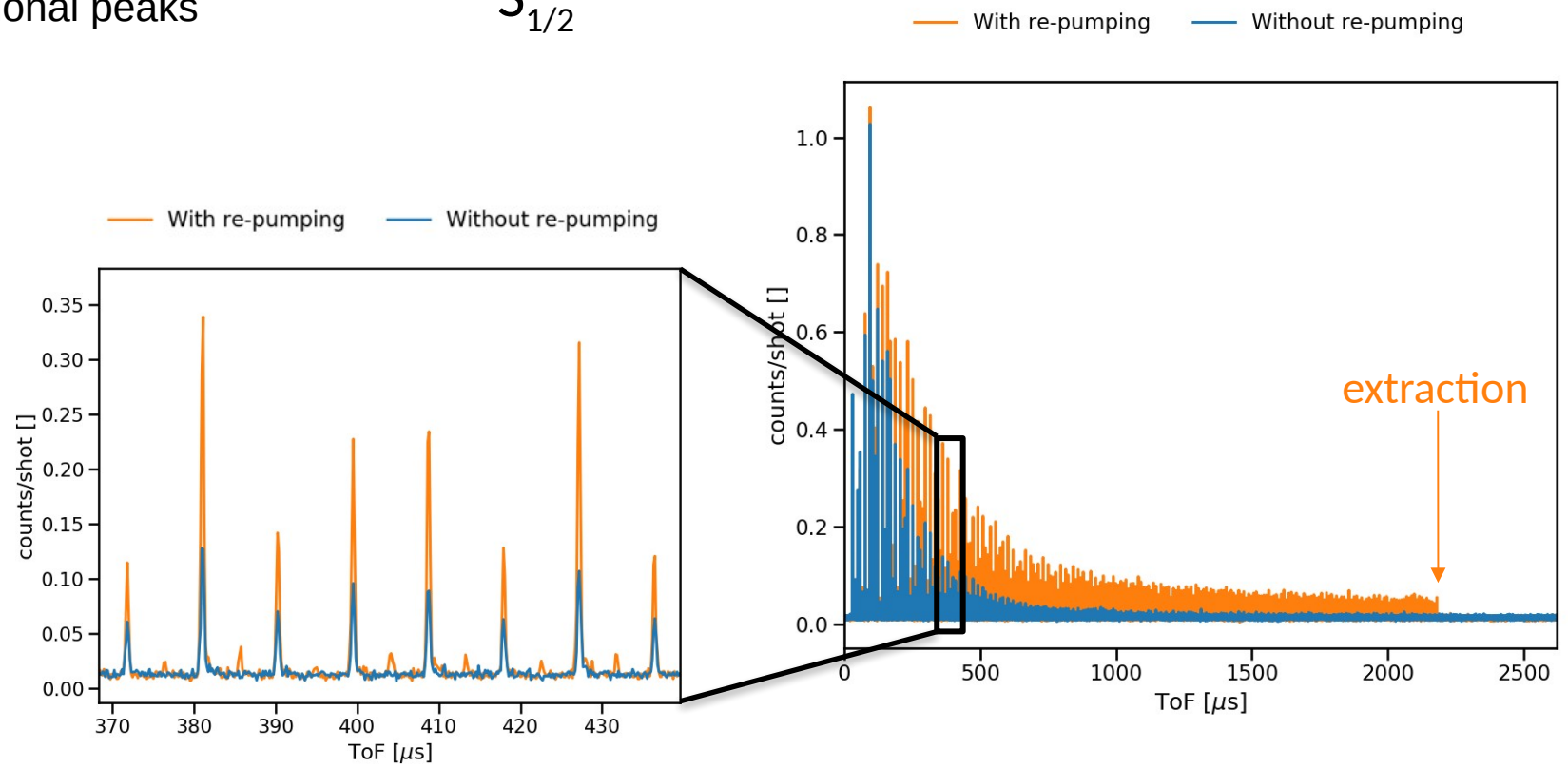
simon.lechner@cern.ch
stephan.ettenauer@cern.ch

Back-up

Optical re-pumping of $^{40}Ca^{+}$

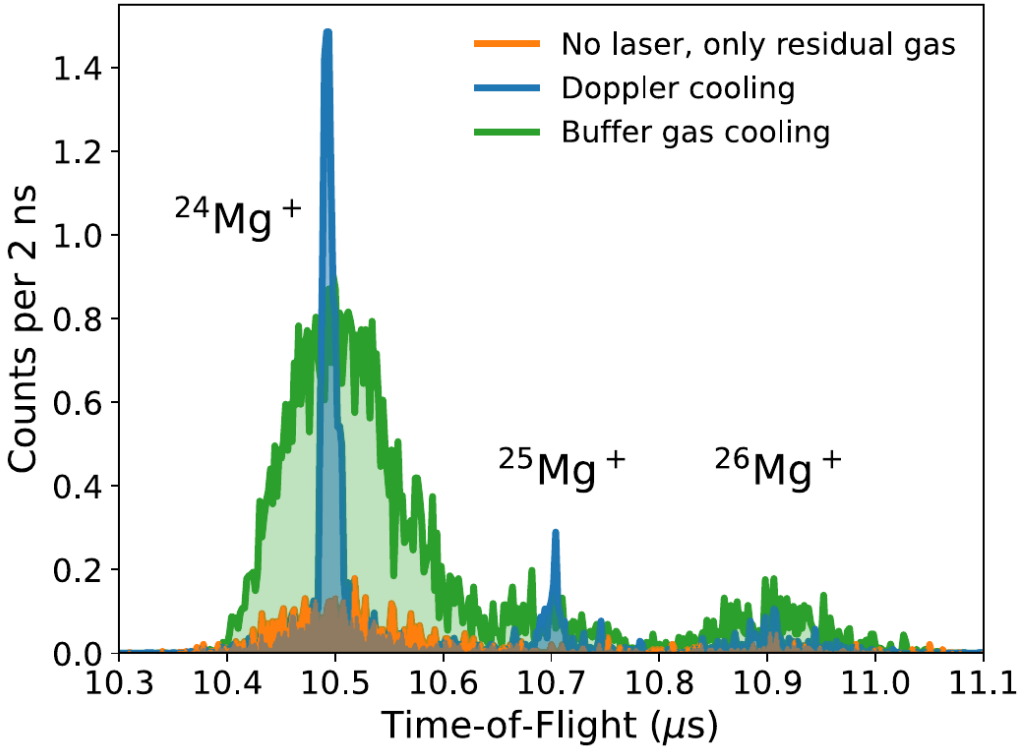
Problem: using only 397 nm laser
→ pumping into dark state D3/2
Add second laser at 866 nm for re-pumping in anti-collinear direction
→ additional peaks





Proof-of-Principle experiment

- Doppler and sympathetic cooling for very cool ion beams



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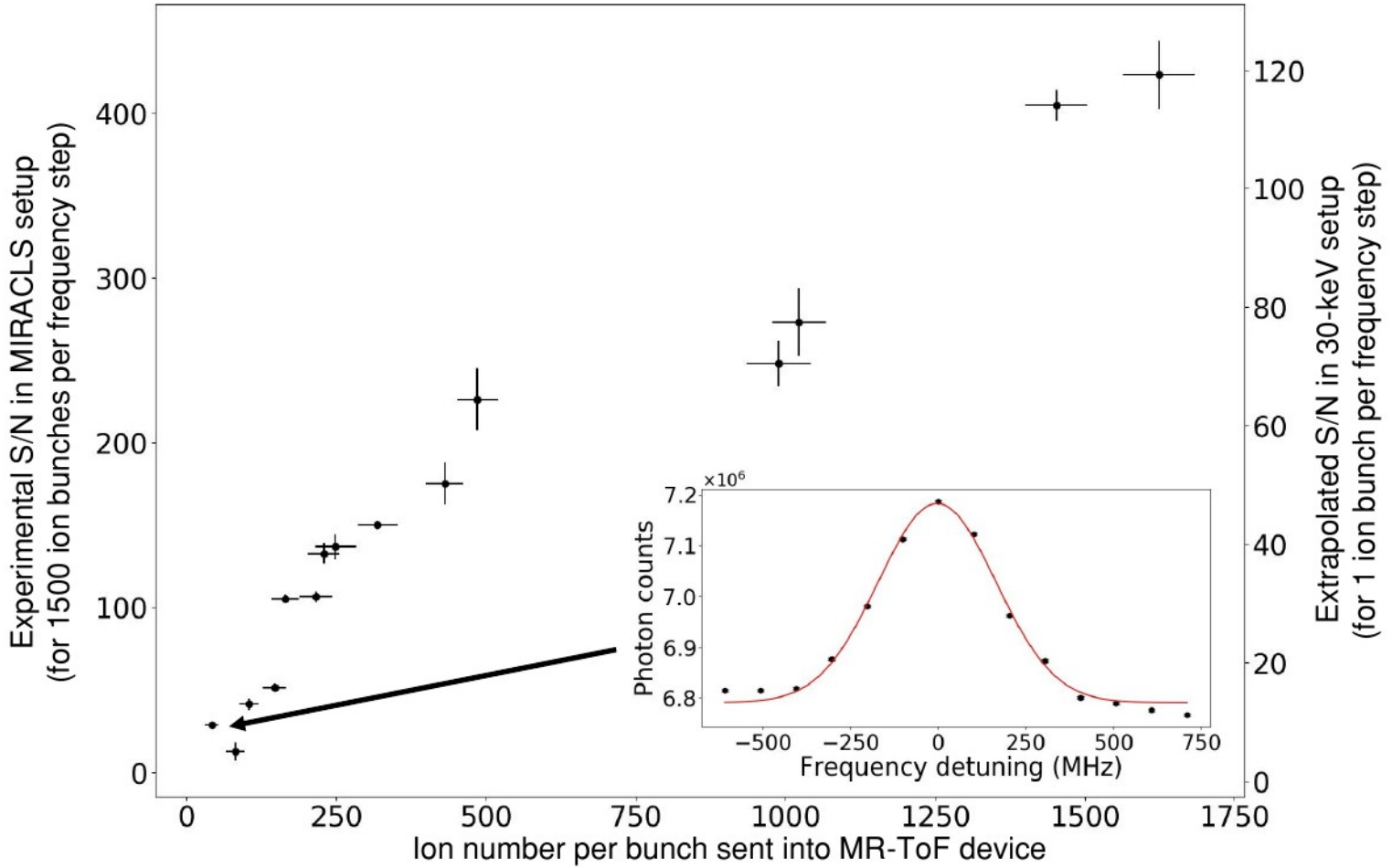
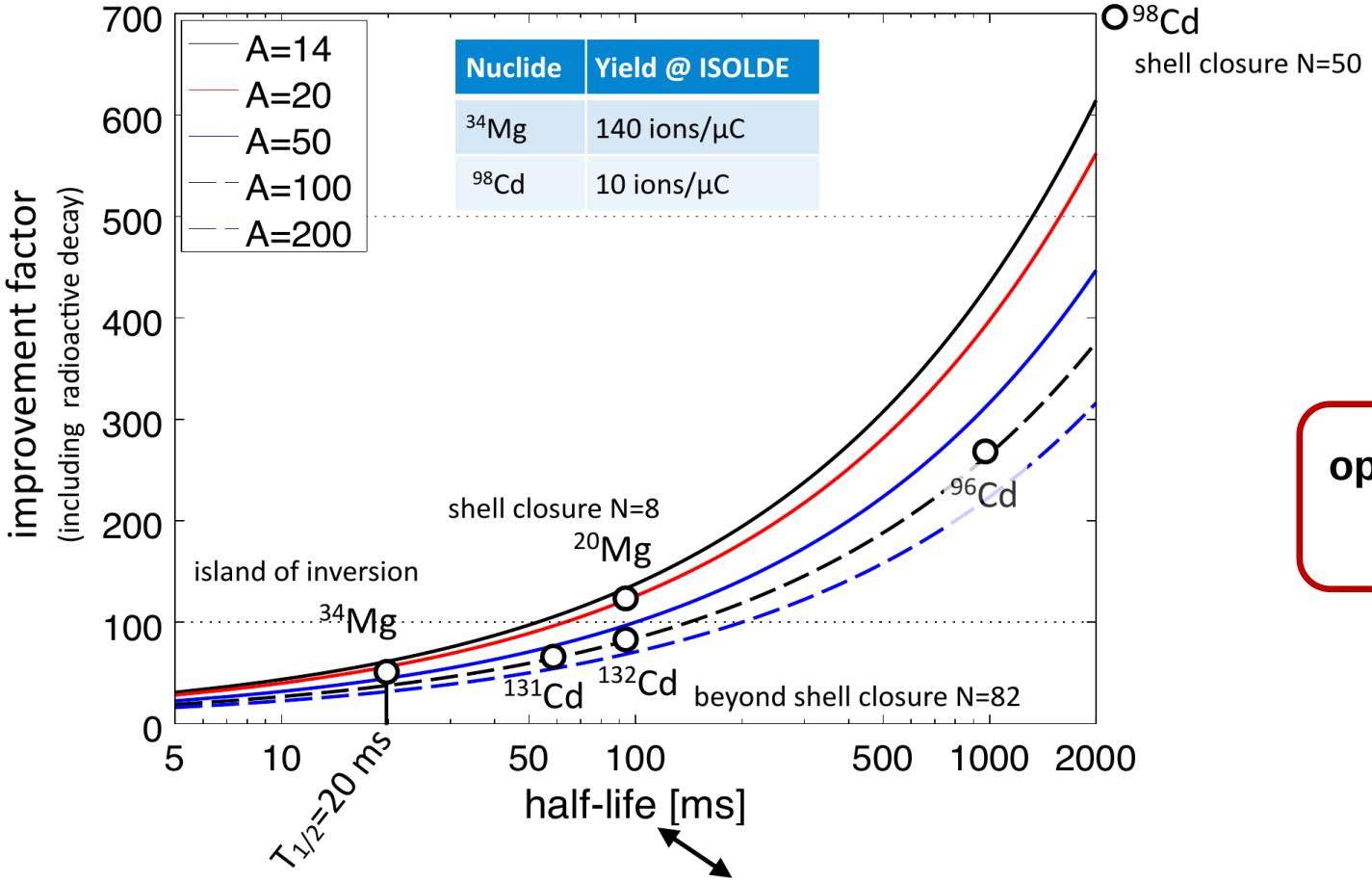


V. Lagaki et al., Nucl. Instr. Meth. A, Vol 1014, 165663 (2021)

Improvement Factor & 1st Science Cases



optimal trapping time

$$t = 1.8\, T_{1/2}$$