# Collinear resonance ionization spectroscopy of neutron-deficient Sb (Z=51) isotopes, towards the proton drip line

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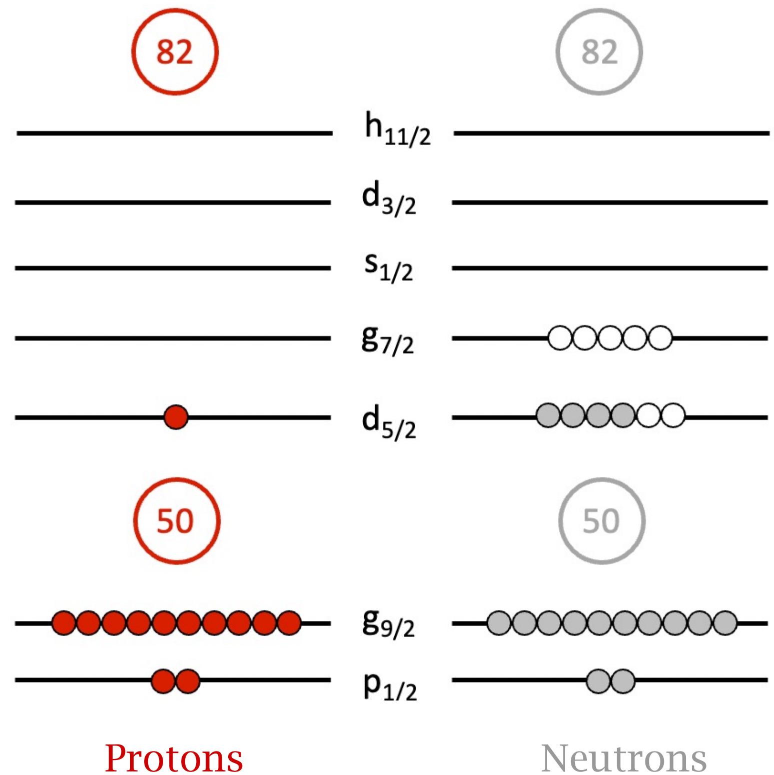
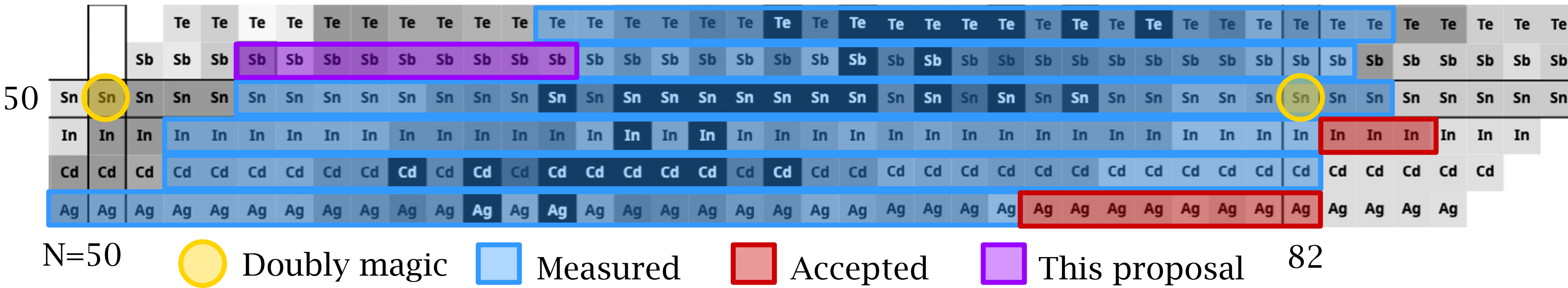
# Motivation: One proton outside Z=50


- Sb (Z=51) has one proton outside magic Z=50 shell closure
- Simple test of single-particle behaviour predicted by shell model
- In collaboration with nuclear theorists to understand evolution of nuclear structure using:
  - Density Functional Theory
  - *Ab-initio* VS-IMSRG calculations




$^{105-112}$Sb

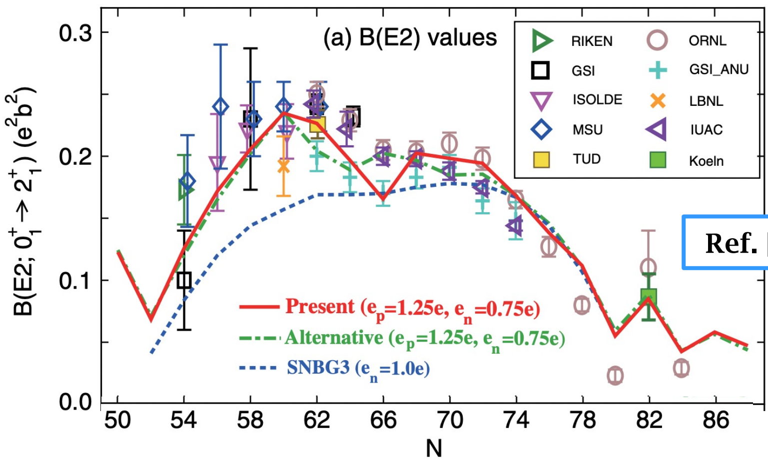
# Motivation: the $^{100}$Sn region

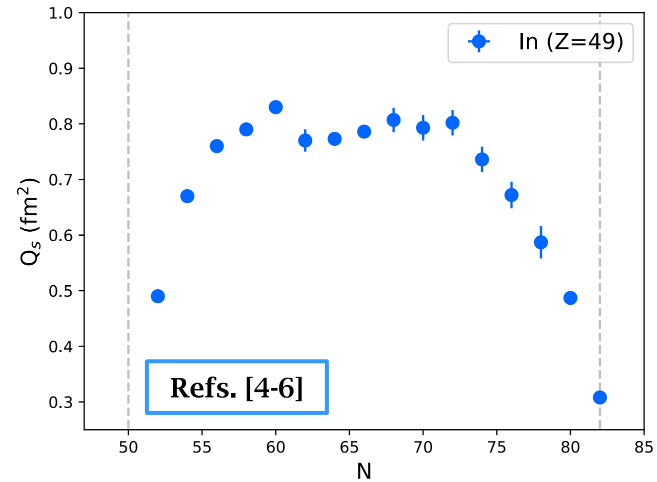



- Enthusiastic experimental effort in recent years around $^{100}$Sn and $^{132}$Sn
  - Motivated by advances in *ab-initio* nuclear theory and computational power
  - Measure spins, magnetic and quadrupole moments and charge radii
  - Understand evolution of structure in this region of the nuclear chart

- $^{100}$Sn (Z,N=50) is the heaviest self-conjugate doubly-magic nucleus
  - Neighbouring nuclei allow us to test understanding and theoretical description of nuclear properties
  - Extent to which $^{100}$Sn is a good shell closure
  - Extent to which the single-particle picture is correct

# Motivation: the magicity of $^{100}$Sn



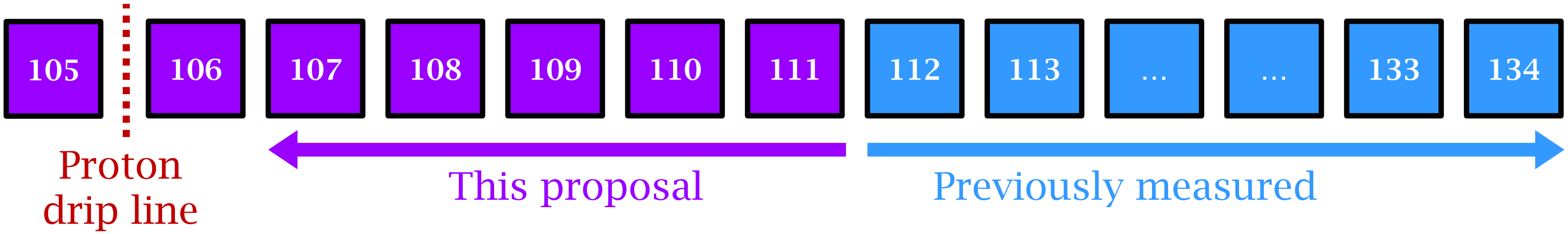




- Large B(E2) values suggest collective picture of neutron-deficient Sn isotopes
  - Recent Monte Carlo shell-model calculations suggest breaking of Z=50 core [1]
  - Charge radii for $^{104,106}$Sn suggest rapid reduction in collectivity towards $^{100}$Sn [2]

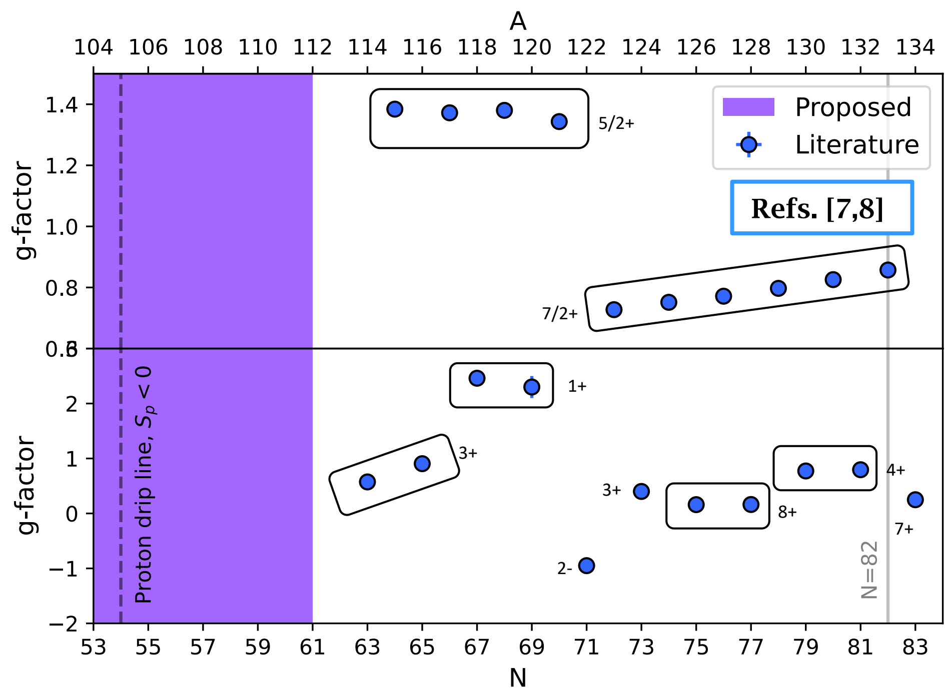
- Doubly-magic nature of $^{100}$Sn evidenced by:
  - Extremely large Gamow-Teller strength for beta-decay of $^{100}$Sn [3]
  - Reduction in quadrupole moments and differential charge radii of neutron-deficient In (Z=49) isotopes [4-6]


[1] T. Togashi et al. PRL **121** 062501 (2018)
[2] F.P. Gustafsson, Ph.D. thesis, KUL, (2021)
[3] C.B. Hinke et al., Nature **486** 341 (2012)
[4] C. Ricketts, Ph.D. thesis, UoM (2021)
[5] A. Vernon, Ph.D. thesis, UoM (2021)
[6] J. Karthein et al. (2023) in preparation

# Aims: Neutron-deficient Sb



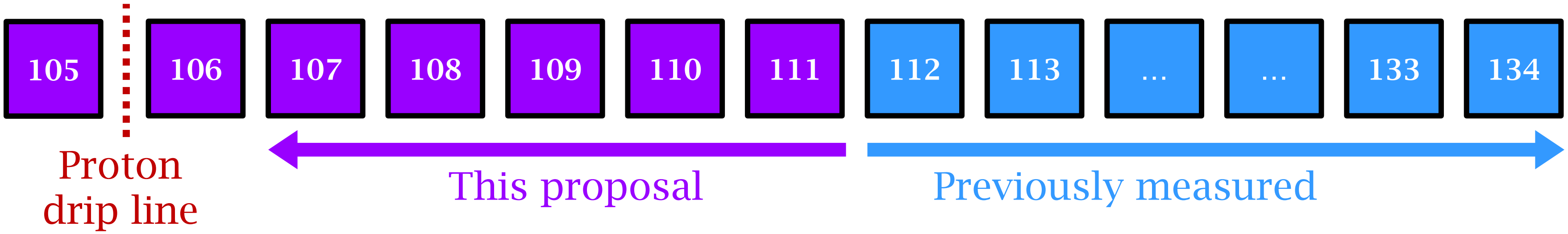

- Valence-proton analogue to In (Z=49)
  - Test the robustness of the closed Sn core from above the shell closure
- Recent COLLAPS measurements from $^{112-134}$Sb [7]
- Magnetic moments sensitive to structural changes
  - Probe behaviour of shell model orbitals
  - Probe purity of nuclear configurations
- Quadrupole moments provides insight into collectivity away from N=50



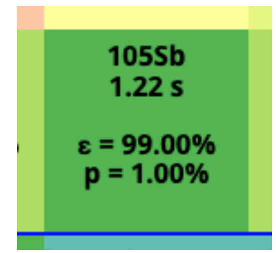

[7] S. Lechner et al. PRC **104** 014302 (2021)]

[8] N. Stone, ADNDT **90**, 75 (2005)

# Aims: Towards the proton drip line

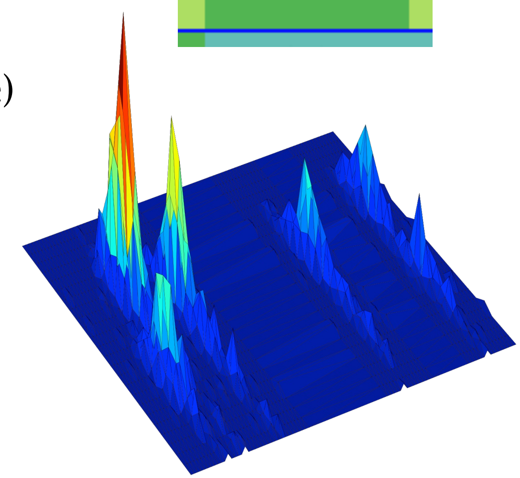



- Measure across proton drip line at $^{105}$Sb
  - Measure the change in deformation that occurs when the protons are no longer bound in the nucleus by the nuclear force
  - Lightest place to cross the proton drip line in relatively simple region




- Investigate simultaneously:
  - the role of the valence proton (above the Sn (Z=50) core)
  - the role of the unbound proton (as we cross the proton drip line)

- Request 0.5 shifts to measure yield of $^{106,105}$Sb to explore possibility of:
  - Measuring hyperfine structure of proton-unbound $^{105}$Sb
  - Studying proton decay of ‘proton-emitting’ $^{105}$Sb with DSS



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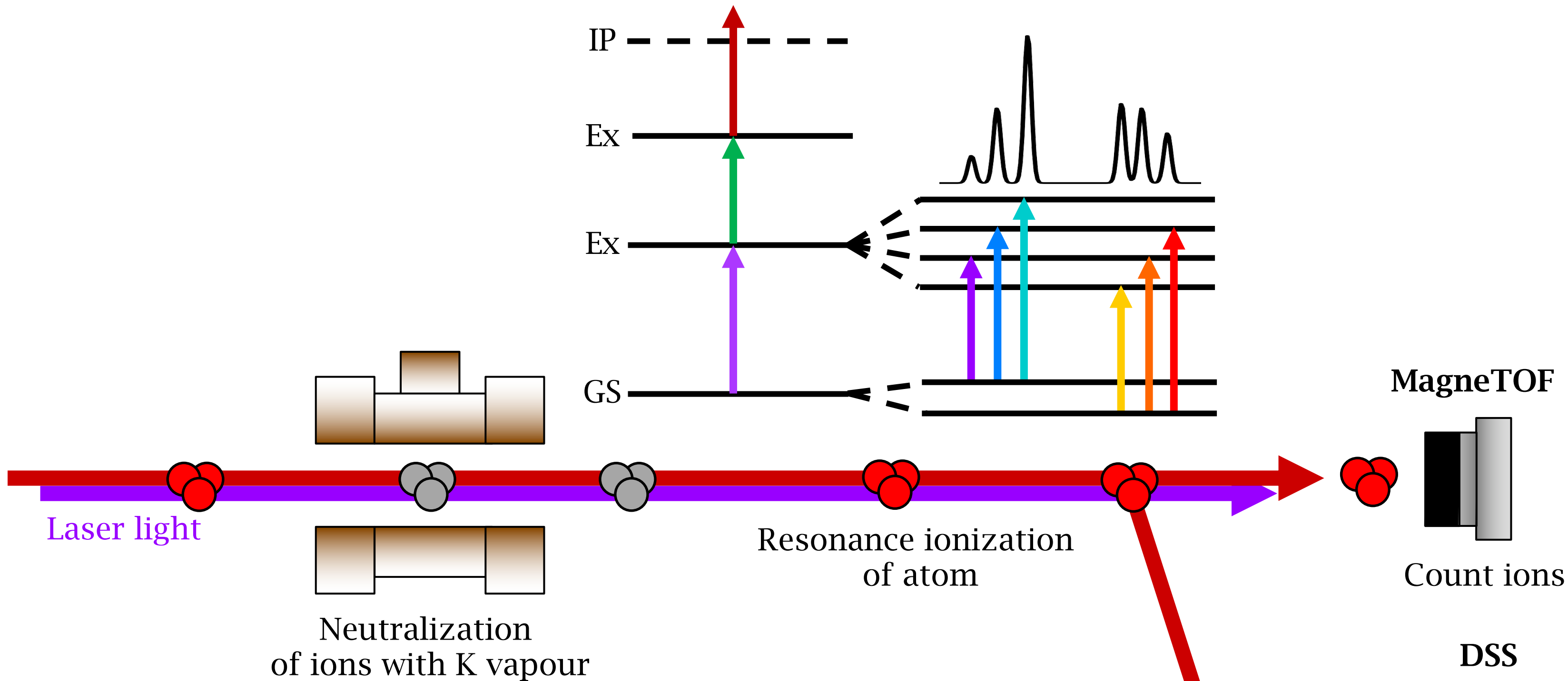
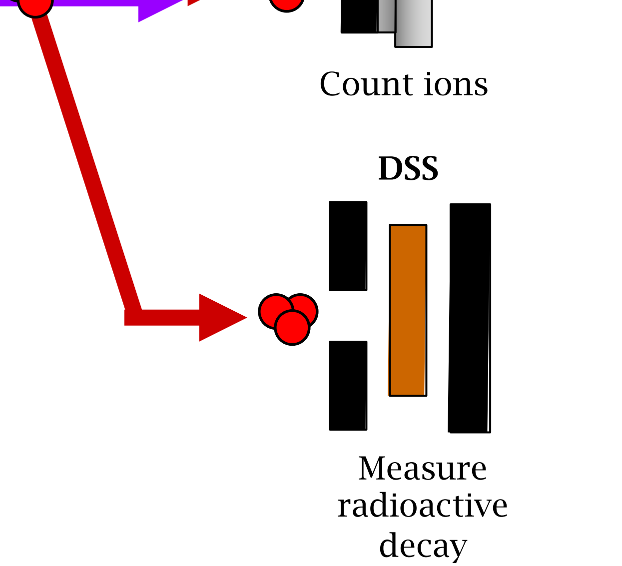
# Collinear resonance ionization spectroscopy



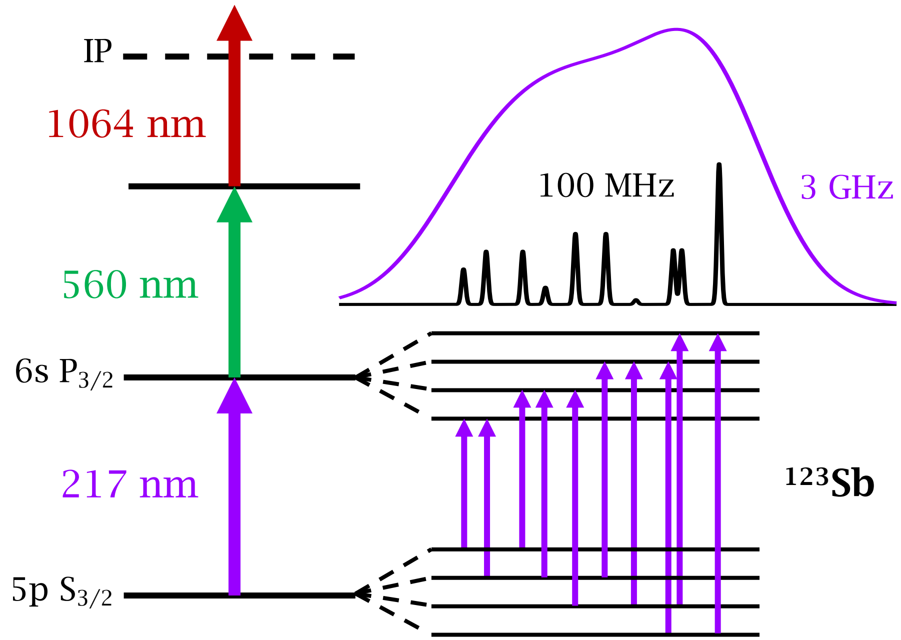

Nuclear spin $I$

Electric quadrupole moment $Q_S$

Magnetic dipole moment $\mu_I$

Change in mean-square charge radii $\delta\langle r^2\rangle^{A,A'}$

# Laser ionization scheme




- All laser light available with current CRIS laser systems
  - 217 nm light from frequency-quadrupled injection-seeded Ti:Sa laser (100 MHz) or grating Ti:Sa laser (3 GHz)
  - 560 nm light from pulsed dye laser or new broadly-tunable DPSS laser (405–2600 nm)
  - 1064 nm light from Nd:YAG laser

- 217 nm transition same as COLLAPS work for simple calibration

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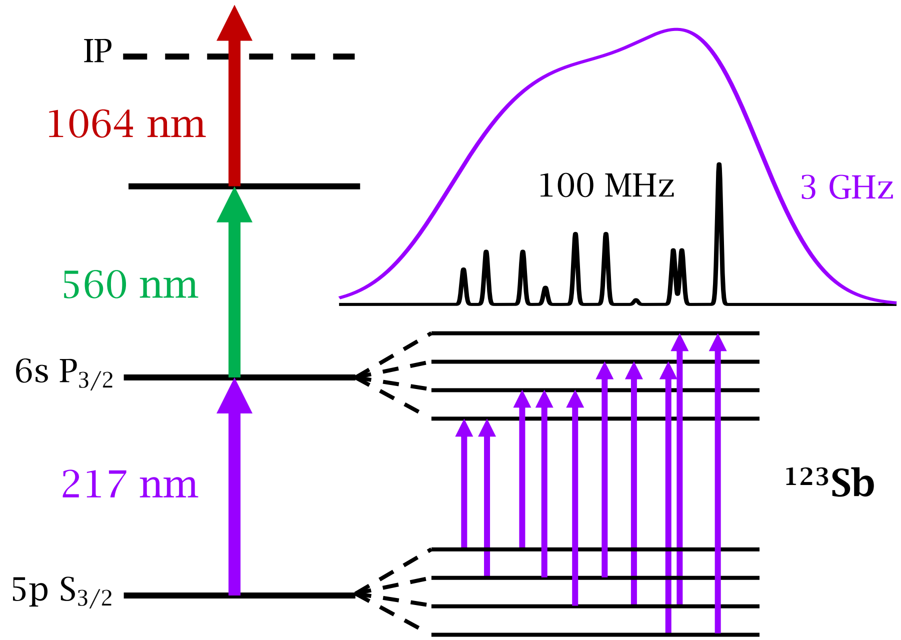
# Laser ionization scheme




- Each isotopes ($^{>108}$Sb):
  - Scan HFS with high-resolution 217 nm light (100 MHz)

- Low-yield isotopes ($^{107,108}$Sb):
  - Search for peaks with broadband 217 nm light (3 GHz)
  - Scan HFS with high-resolution 217 nm light (100 MHz)

# TAC comments

| Collinear resonance ionization spectroscopy of neutron-deficient antimony isotopes, towards the proton drip line | | | | | |
|---|---|---|---|---|---|
| **CDS#** | **Proposal #** | **IS #** | **Setup** | **Shifts** | **Isotopes** |
| CERN-INTC-2023-016 | INTC-P-657 | | CRIS | 19 | 105-123Sb |
| Beam intensity/purity, targets-ion sources | The isotopes would be produced using a LaC target and RILIS. In general, the yields in the proposal are realistic, but the discussion with the target team was based on isotopes /uC rather than ions/s. Therefore, the assumption for the yields in the proposal are based on a 1uA proton current.<br><br>It should be noted that 106 and 105Sb are on the limit of production and can be considered "bonus" cases which may be present, but there is a strong chance that they would not be measurable. | | | | |
| General implantation and setup | | | | | |
| General Comments | | | | | |
| Safety | Use of CRIS – Safety Clearance at EDMS 1807216.<br>CRIS is currently undergoing beamline modifications – an updated Safety Clearance is required. | | | | |
| TAC recommendation | **The TAC does not foresee any serious issues with the feasibility of this proposal. The lightest cases should be considered a bonus if present but can't be guaranteed. Note that the discussion on yields was based on a 1uA proton current.** | | | | |

- No issues foreseen with feasibility
- $^{106,105}$Sb at limit of production and should be considered a bonus if present
  - Important to do yield measurements to check feasibility of HFS measurements
- Yield estimate in proposal based on 1 μA proton current, not 2 μA
- Updated Safety Clearance required due to current beamline upgrade

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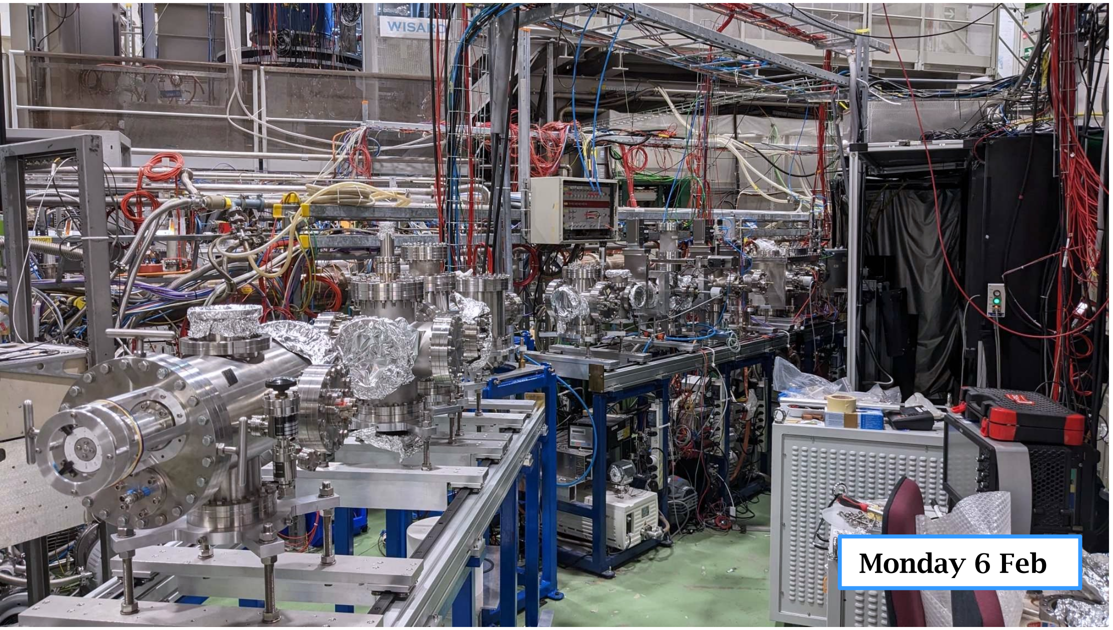
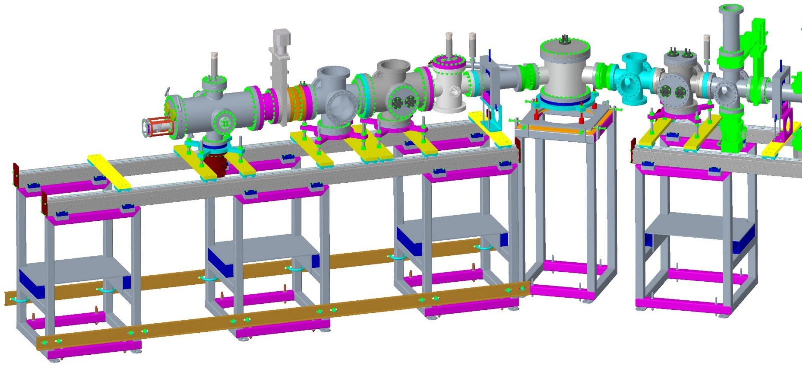
# Status of CRIS upgrade



- New end of the beamline being installed and aligned by CERN survey team
  - Increase efficiency of ion detection and transmission to DSS
  - Installation of field-ionization unit to increase sensitivity

- This proposal can be performed with current CRIS setup
- If $^{106,105}$Sb yield measurements look promising
  - Submit addendum to measure $^{106,106}$Sb with field ionization

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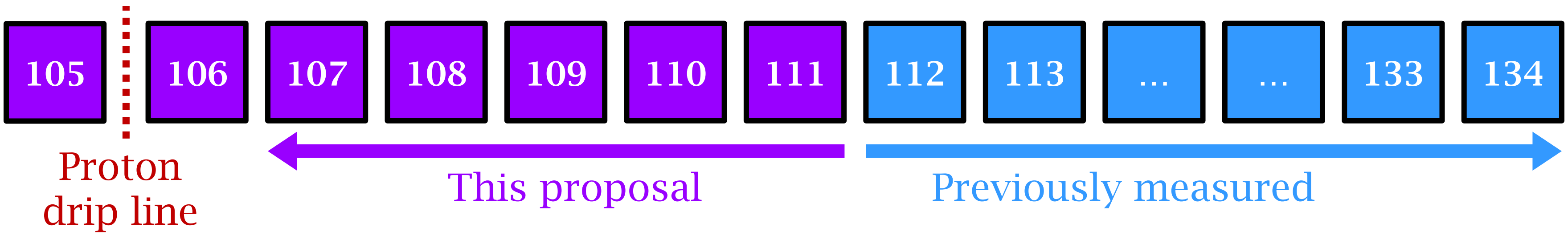
# Shift request

| Isotope | Half-life | Predicted yield (/μC) | Shifts requested | New results |
|---|---|---|---|---|
| $^{123}$Sb | Stable | $3.0\times10^{6}$ | 3 (without protons) | - |
| $^{112-121}$Sb | >53.5 s | >$7.0\times10^{5}$ | 5 | - |
| $^{111}$Sb | 75 s | $5.1\times10^{5}$ | 0.5 | $\mu$, $Q_s$, $\delta\langle r^2\rangle$ |
| $^{110}$Sb | 23 s | $2.7\times10^{4}$ | 1 | $I$, $\mu$, $Q_s$, $\delta\langle r^2\rangle$ |
| $^{109}$Sb | 17 s | $4.1\times10^{3}$ | 2 | $\mu$, $Q_s$, $\delta\langle r^2\rangle$ |
| $^{108}$Sb | 7.4 s | $1.9\times10^{2}$ | 4 | $\mu$, $Q_s$, $\delta\langle r^2\rangle$ |
| $^{107}$Sb | 4.0 s | $1.7\times10^{1}$ | 6 | $\mu$, $Q_s$, $\delta\langle r^2\rangle$ |
| $^{106,105}$Sb | 0.6 s, 1.22 s | $1.3\times10^{-1}$ | 0.5 | $\mu$, $Q_s$, $\delta\langle r^2\rangle$ |

- Request a LaCx target with RILIS

- 18.5 shifts requested for laser spectroscopy of neutron-deficient Sb
  - Scans of $^{112\text{-}121}$Sb necessary throughout run to properly calibrate new data
  - Shift estimate for $^{107}$Sb based on $^{78}$Cu measurement (20 ions/s)
- 0.5 shifts requested for yield/background measurements of $^{106,105}$Sb
  - Investigate possibility of measuring Sb at proton drip line
- 3 (offline) shifts requested for experimental setup before experiment

# Summary




- We propose to measure neutron-deficient Sb (Z=51) isotopes down to $^{107}$Sb at N=56, towards the proton drip line at $^{105}$Sb
- Test the robustness of the closed Sn core from above the shell closure
- Understand the evolution of nuclear structure away from N=50
- Provide final piece of the puzzle for studies around $^{100}$Sn
- Yield measurements of $^{106,105}$Sb will explore feasibility of measuring Sb at the proton drip line

# Acknowledgements

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[1]The University of Manchester, [2]KU Leuven, [3]CERN, [4]Peking University, [5]Photon Science Institute, [6]Universite Paris-Saclay, [7]Massachusetts Institute of Technology, [8]GANIL, [9]University of Gothenburg, [10]CERN, [11]SCK · CEN