Laser spectroscopy and beta-NMR
for nuclear physics and applications

- Laser spectroscopy setups at ISOLDE
- Example – COLLAPS setup: laser and beta-NMR spectroscopy
- Results: nuclear structure and towards applications

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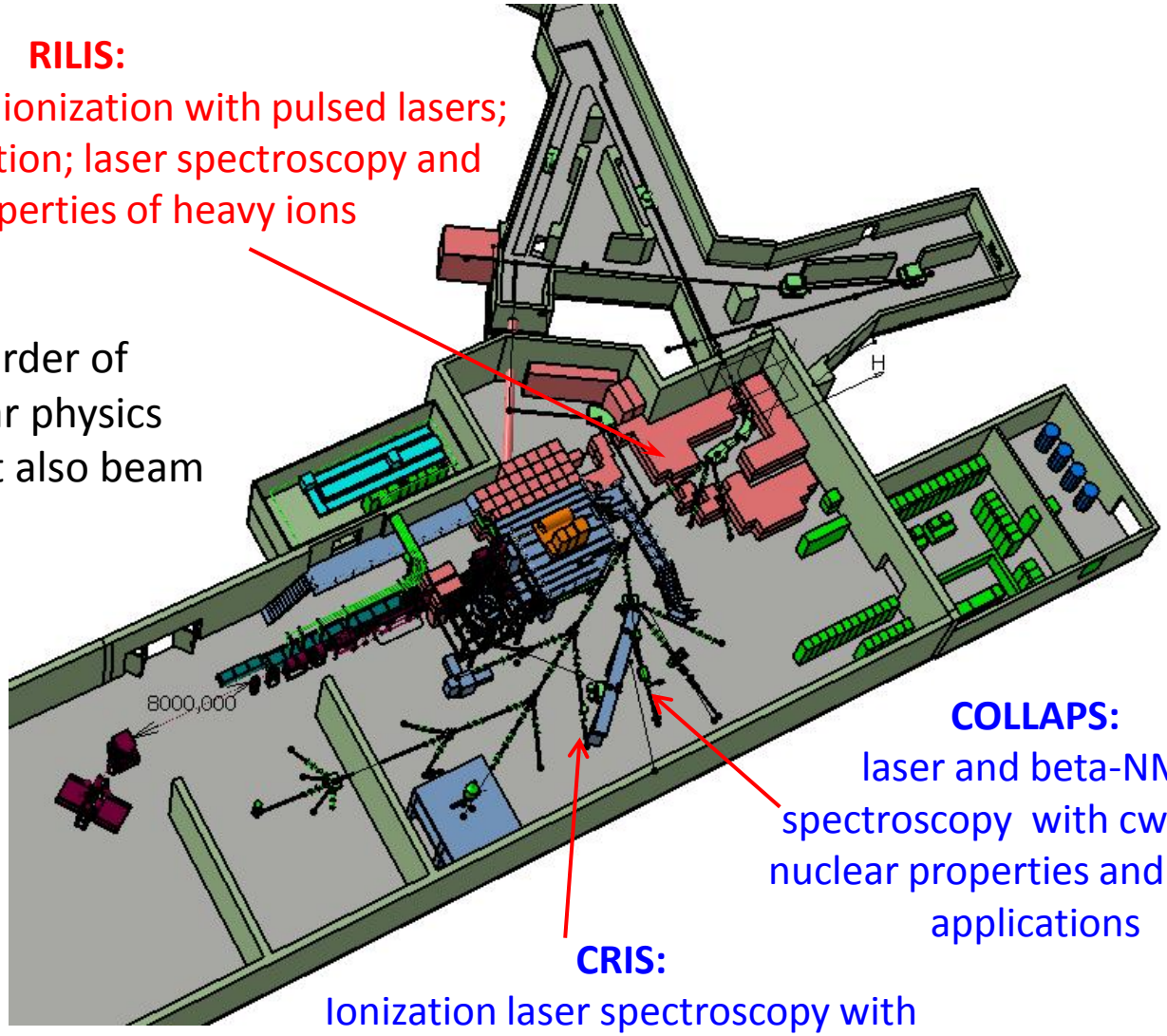
Laser spectroscopy

RILIS:
part of facility; laser ionization with pulsed lasers; ISOLDE ion production; laser spectroscopy and nuclear properties of heavy ions

- Studies at the border of atomic and nuclear physics
- Experiments, but also beam preparation



COLLAPS:
laser and beta-NMR spectroscopy with cw lasers; nuclear properties and biology applications

CRIS:
Ionization laser spectroscopy with pulsed beam and lasers; nuclear properties and beam purification

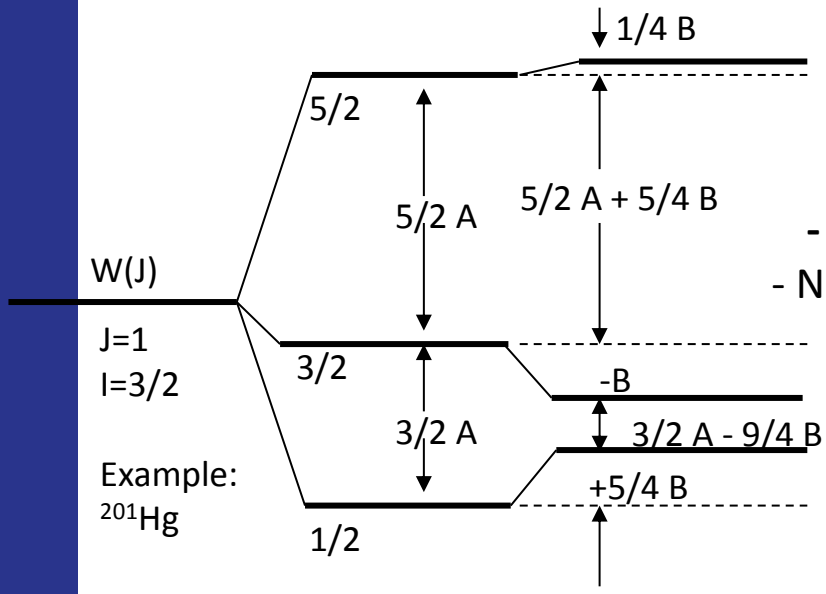
Laser spectroscopy and nuclear physics

Hyperfine structure: splitting of a single electronic level for nuclei with I>0

$$\Delta E_{HFS} = \frac{A}{2}K + B\frac{\frac{3}{4}K(K+1) - I(I+1)J(J+1)}{2(2I-1)(2J-1)I\cdot J}$$

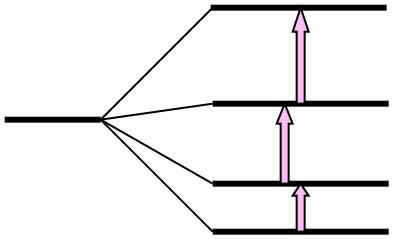
where $K = F(F+1) - I(I+1) - J(J+1)$

$$A = \frac{\mu_I H_e(0)}{I\cdot J} \qquad B = eQV_{zz}(0)$$



Nuclear Magnetic Resonance – NMR
(Zeeman splitting of nuclear levels)

$$\Delta E_{mag} = |g_I|\cdot\mu_N\cdot B + \frac{1}{2}Q\cdot V_{zz}$$



$B = 0$ $\qquad$ $B \neq 0$

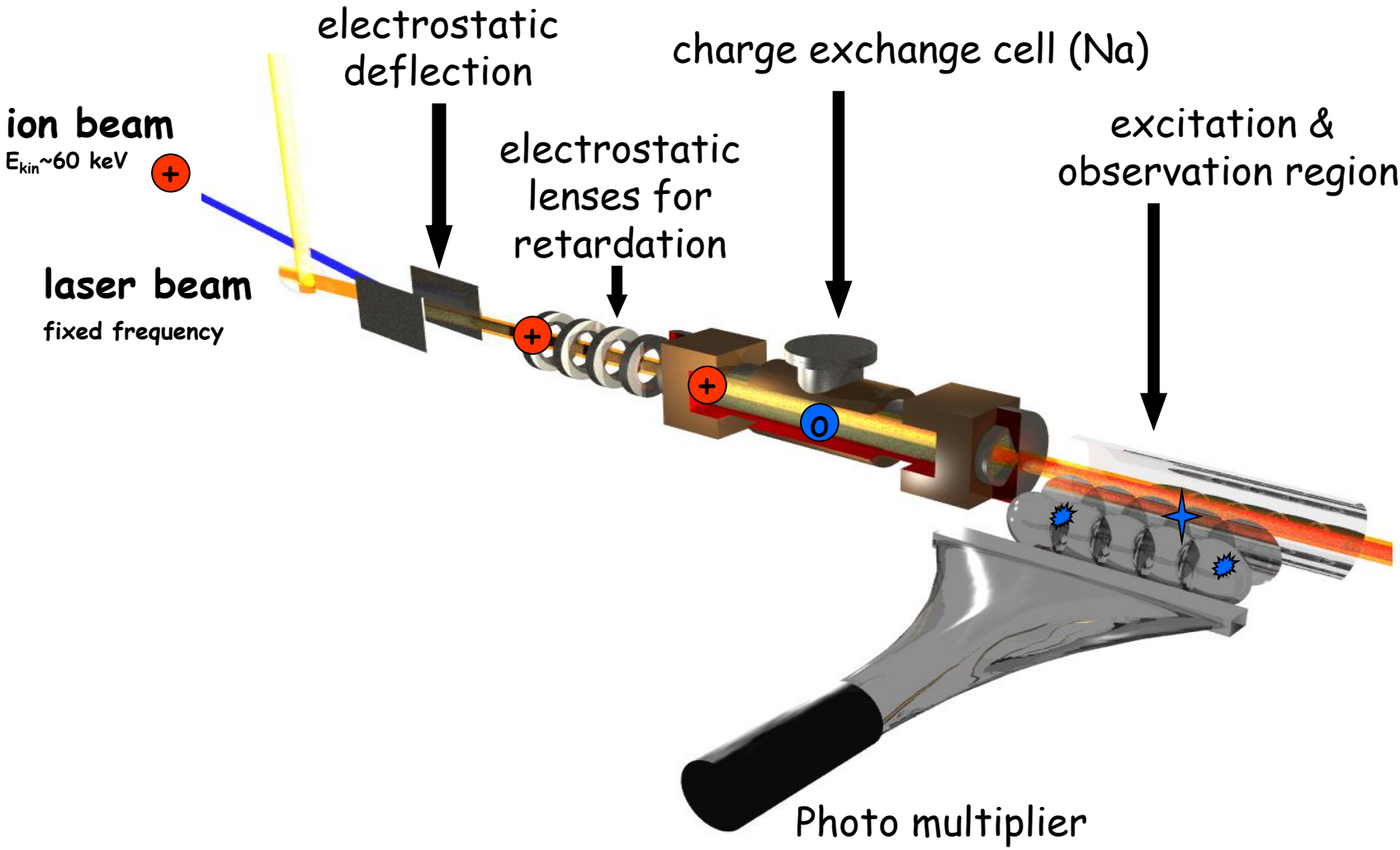
Derived properties of nuclei:

- **Spin** (orbital+intrinsic angular momentum), **parity** (I^{π})
- Nuclear ***g*-factor** and **magnetic** dipole **moment** (g_I and μ_I)
- Electric quadrupole moment (Q)
- **Charge radius** ($\langle r^2 \rangle$)

Give information on:

- Configuration of neutrons and protons in nucleus
- Size and form of nucleus

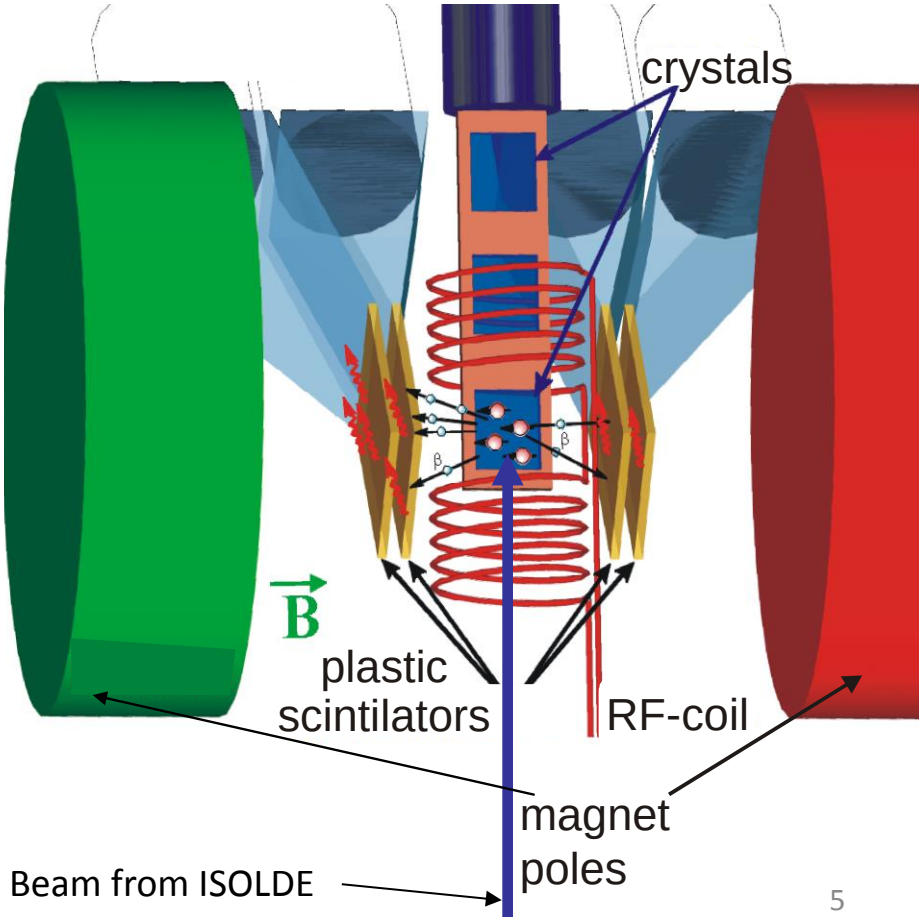
COLLAPS – laser spectroscopy



COLLAPS – beta-NMR

Beta- Nuclear Magnetic Resonance:

Beta particles (e-,e+) can be used as a detection tool, instead of rf absorption
(beams down to 1000 ions/s can be studied)
- Nuclear spins are polarized with laser light – asymmetry in beta emission

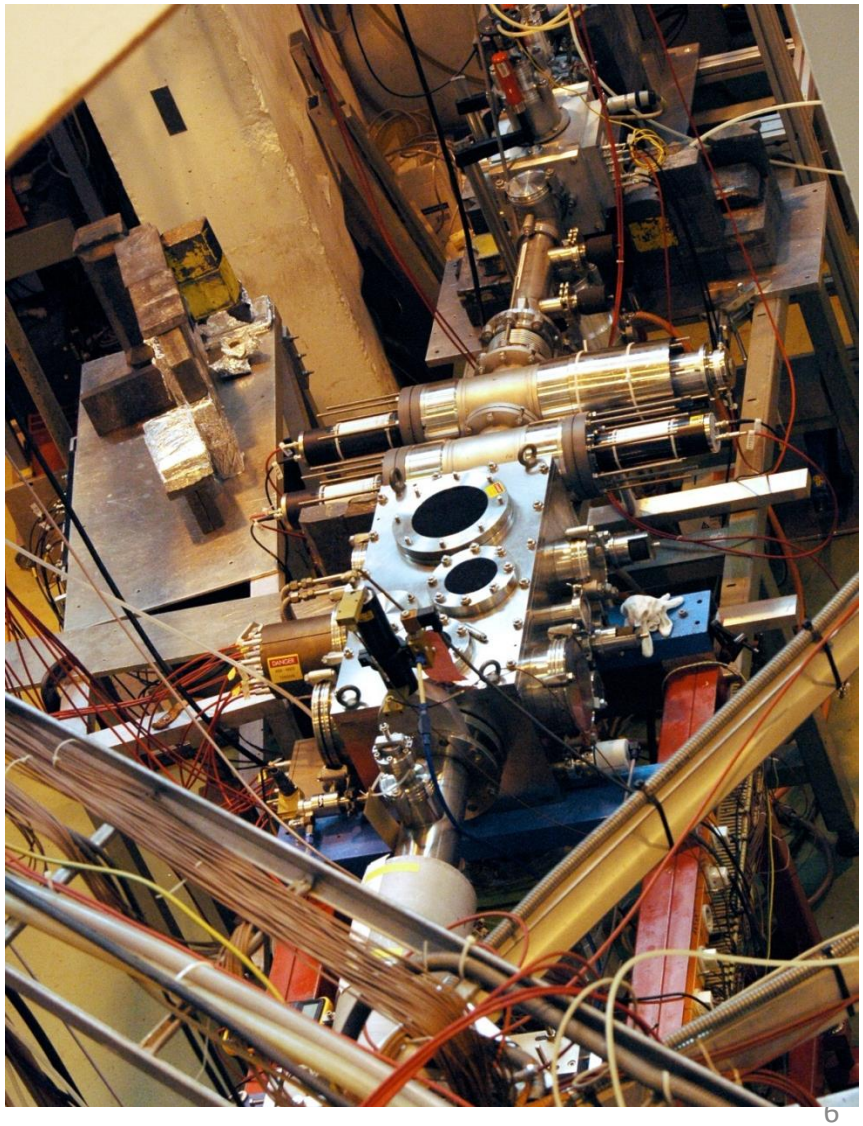


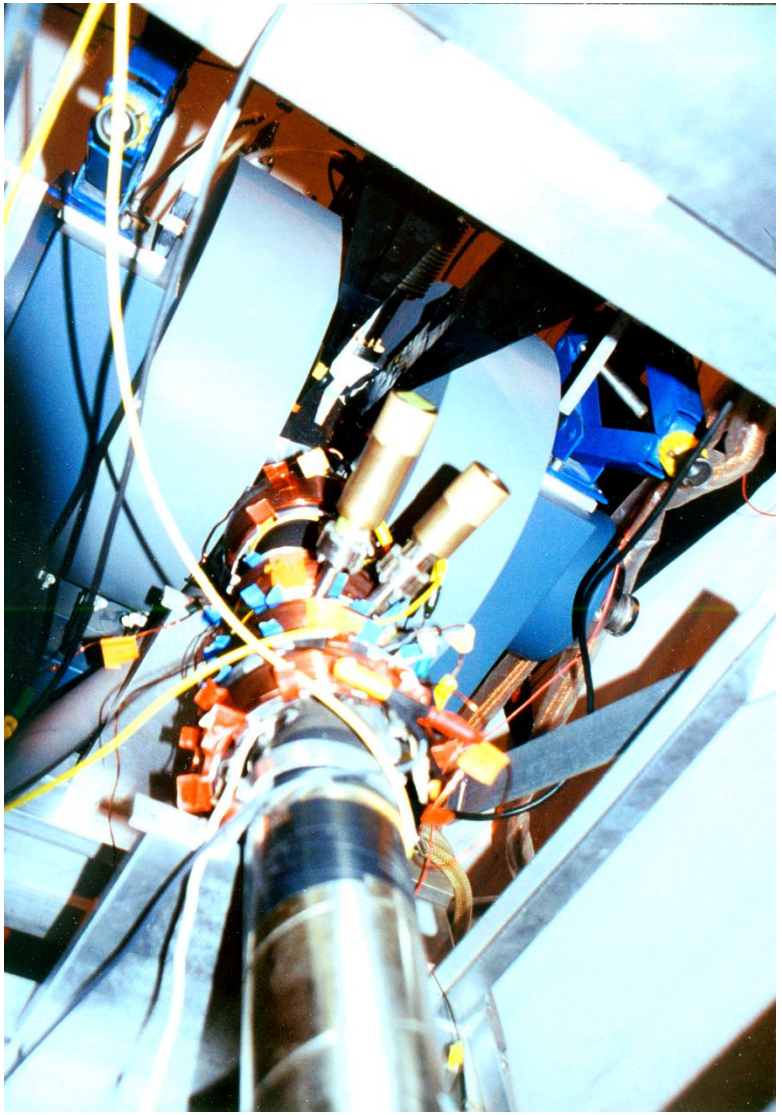
Measured decay asymmetry:

$$A = \frac{N(0°) - N(180°)}{N(0°) + N(180°)}$$

Results: Larmor frequency
Magnetic and electric moments of nuclei
(position of last nucleons, shapes)

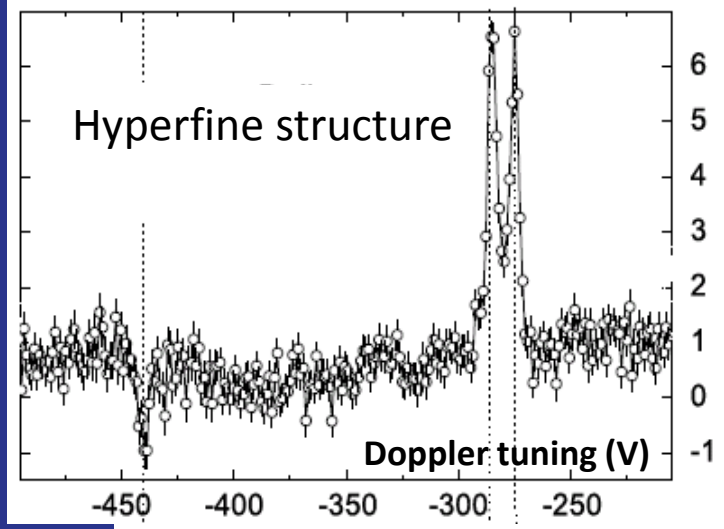
Collinear and beta-NMR spectroscopy

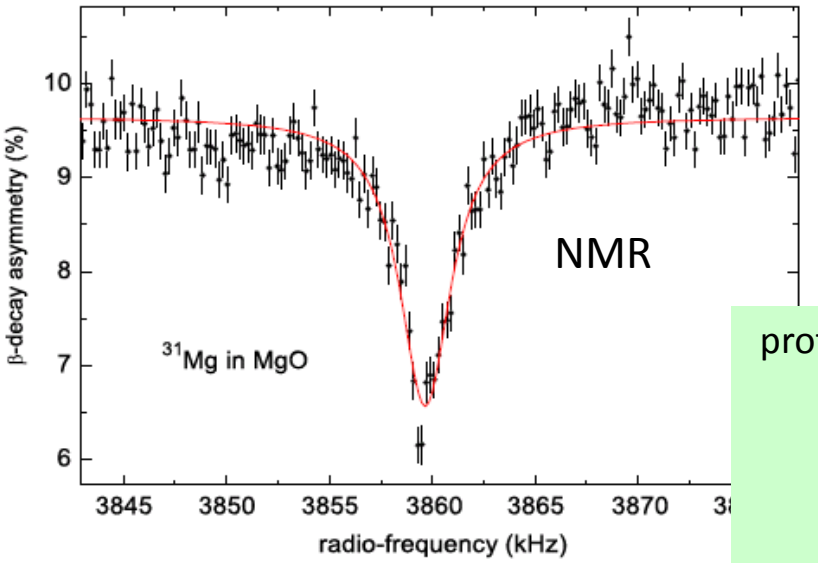


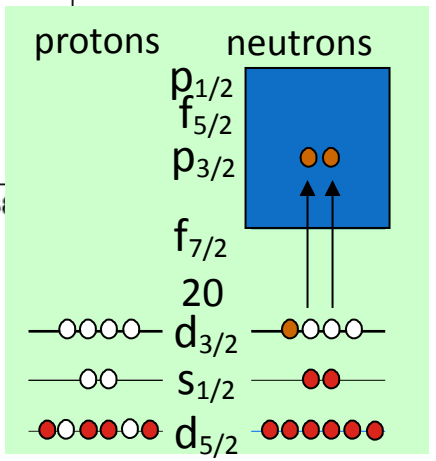


Example: properties of 31Mg

- 12 protons and 19 neutrons
- in "island of inversion" region, where neutron shell 20 is not closed -> why?
- Our results:
  - Unexpected spin of ground state = 1/2
  - Magnetic moment consistent with positive parity and 2 neutrons in next shell
- Now this region and inversion mechanism better understood theoretically







G. Neyens , M. Kowalska et al, Phys. Rev. Lett. 94, 022501 (2005)

D. Yordanov, M. Kowalska et al, Phys. Rev. Lett. 99 (2007) 212501

M. Kowalska , D. Yordanov et al Phys. Rev. C77 (2008) 034307

Towards Beta-NMR in biology

Interest

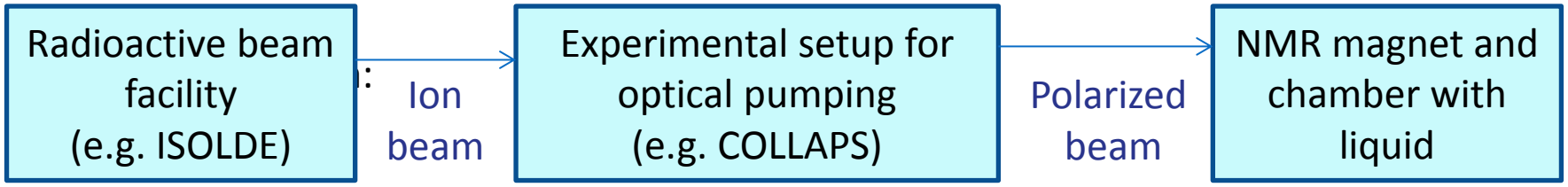
- Metal ion interaction with biomolecules
- For many ions: no convenient physical and spectroscopic properties to study ligand environment
- **Zn(II), Cu(I), Mg(II):** among most abundant cations in living organisms; essential for proper regulation of cell bioenergetics, protein synthesis and enzymatic chemistry:

Challenge: closed electron shells, thus invisible in many methods; in NMR: almost invisible signals due to small abundance, nuclear spin >1/2, and small sensitivity (due to small magnetic moment)

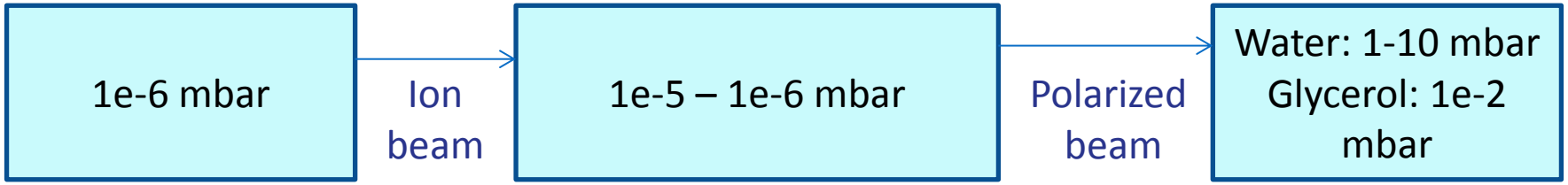
Proposed solution: NMR – increase many-fold method's sensitivity =>
try for first time beta-NMR in liquids (10 orders of magnitude higher sensitivity)

Beta-NMR on liquids

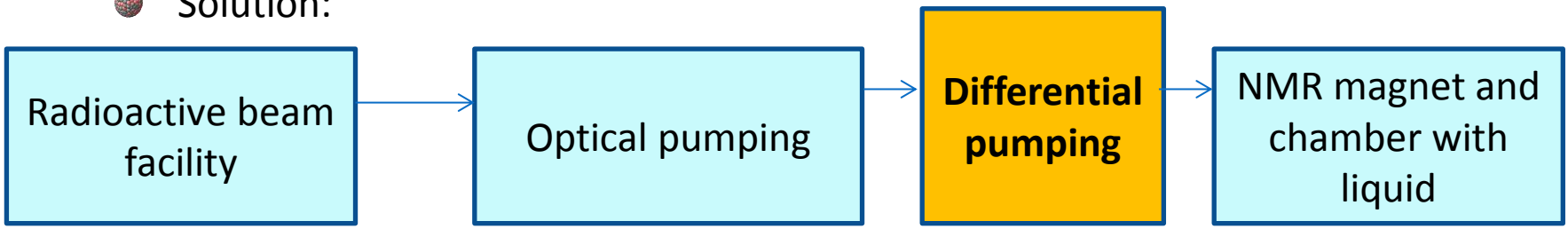
Letter of Intent to INTC (ISOLDE and nTOF Committee, CERN-INTC-2010-015 / INTC-I-088



- Big problem: radioactive beams like high vacuum; most liquids – don't



- Solution:



Beta-NMR on liquids: proof-of-principle

Experiment performed in August 2012:

- Liquid maintained due to 6 orders of magnitude vacuum difference
- Test beam: 31Mg studied earlier by COLLAPS:
  - Good beam intensity
  - Large beta asymmetry
  - Short half-life – small influence of relaxation
  - Spin 1/2 – no additional interactions which broaden signals
- First-ever beta-NMR signal in a liquid

M. Stachura, A. Gottberg, M. Kowalska, et al, in preparation

Publicity …

- CERN Bulletin liked our experiments and made us a cover story:

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The Bulletin

Issue No. 37-38/2012 - Monday 10 September 2012
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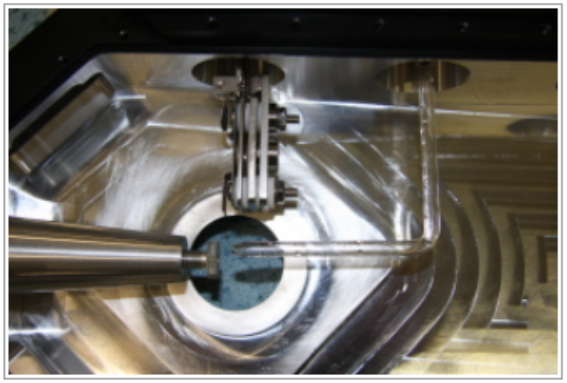
That's one small drop for Mankind...



In August, the members of an ISOLDE project called LOI88 successfully employed a new technique to study the interaction of metal ions in a liquid. It's the first time that specific ions have been studied in a liquid medium - a technical achievement that opens promising doors for biochemistry.

>>

Inspiring a generation

The motto of the 2012 Olympic and Paralympic Games is 'Inspire a generation' so it was particularly pleasing to see science, the LHC and Higgs bosons featuring so strongly in

What's New

There are no new articles for the moment

What's on today

14:00 Particle and Astro-Particle Physics Seminars
On loop corrections in thermal particle production, Laine, Mikko
CERN TH common room

11:00 Academic Training Lecture Regular Programme
Electroweak Symmetry Breaking (3/3), Contino, Roberto
CERN Main Auditorium

09:30 Science, Technology and Industry Seminar
Greek Industry Visit, Barone, Michele
CERN 500-1-61C

>> Seminars of the week

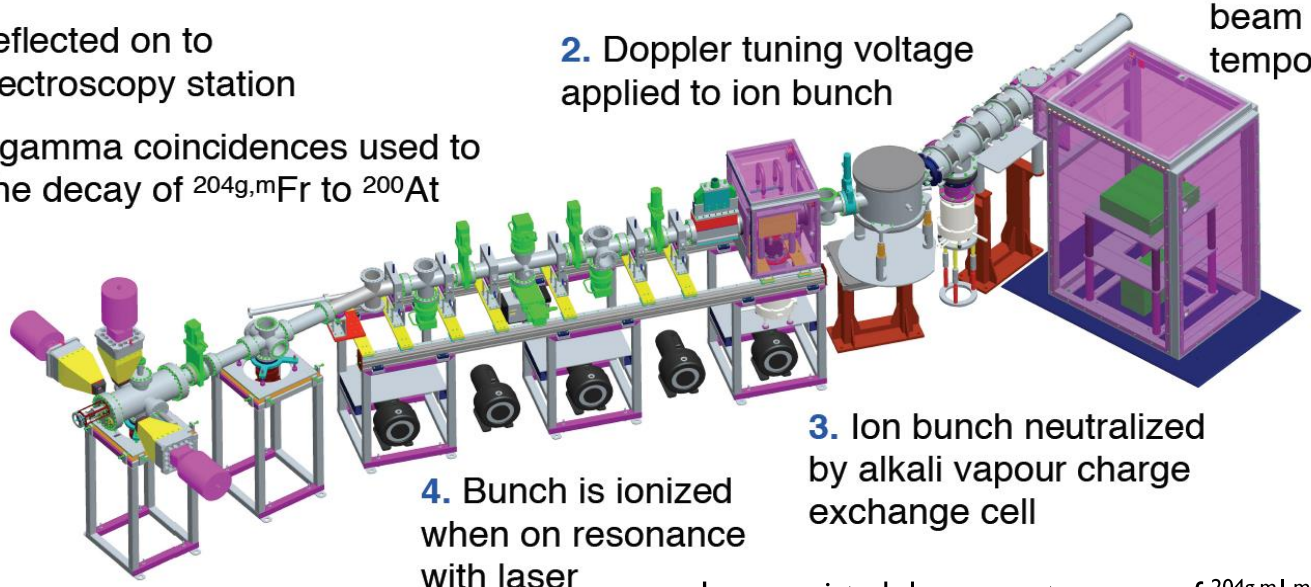
Under the CERN sky

Summary and outlook

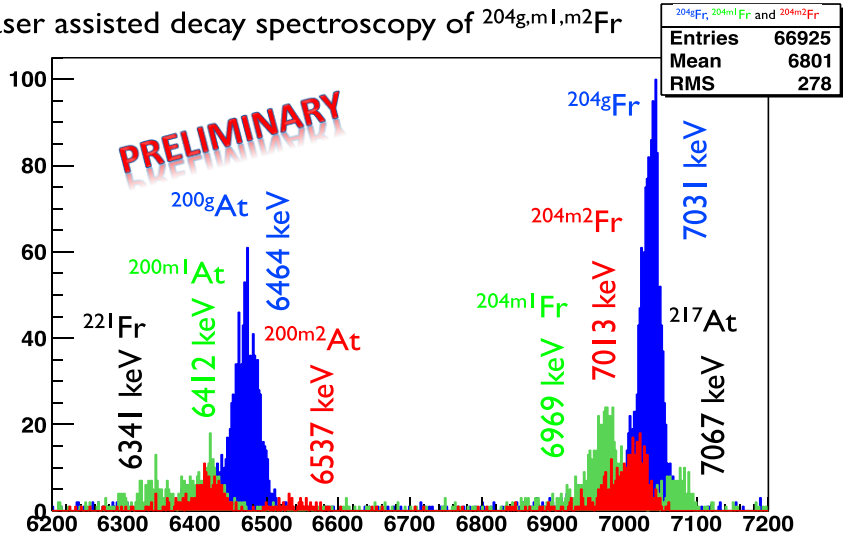
- Laser spectroscopy on radionuclides:
  - At the border of atomic and nuclear physics
  - Used to study properties of nuclei and to prepare RIB beams
- Example - COLLAPS setup:
  - Laser and beta-NMR spectroscopy
  - Valuable nuclear structure results
- Towards beta-NMR on liquids:
  - Promising to study metal-biomolecule interaction
  - Successful proof-of-principle experiment
  - Towards dedicated liquid beta-NMR beamline

CRIS

- Collinear Resonant Ionisation Spectroscopy
- High sensitivity, lower resolution -> perfect for heavy ions



Laser assisted decay spectroscopy of ^{204g,m1,m2}Fr



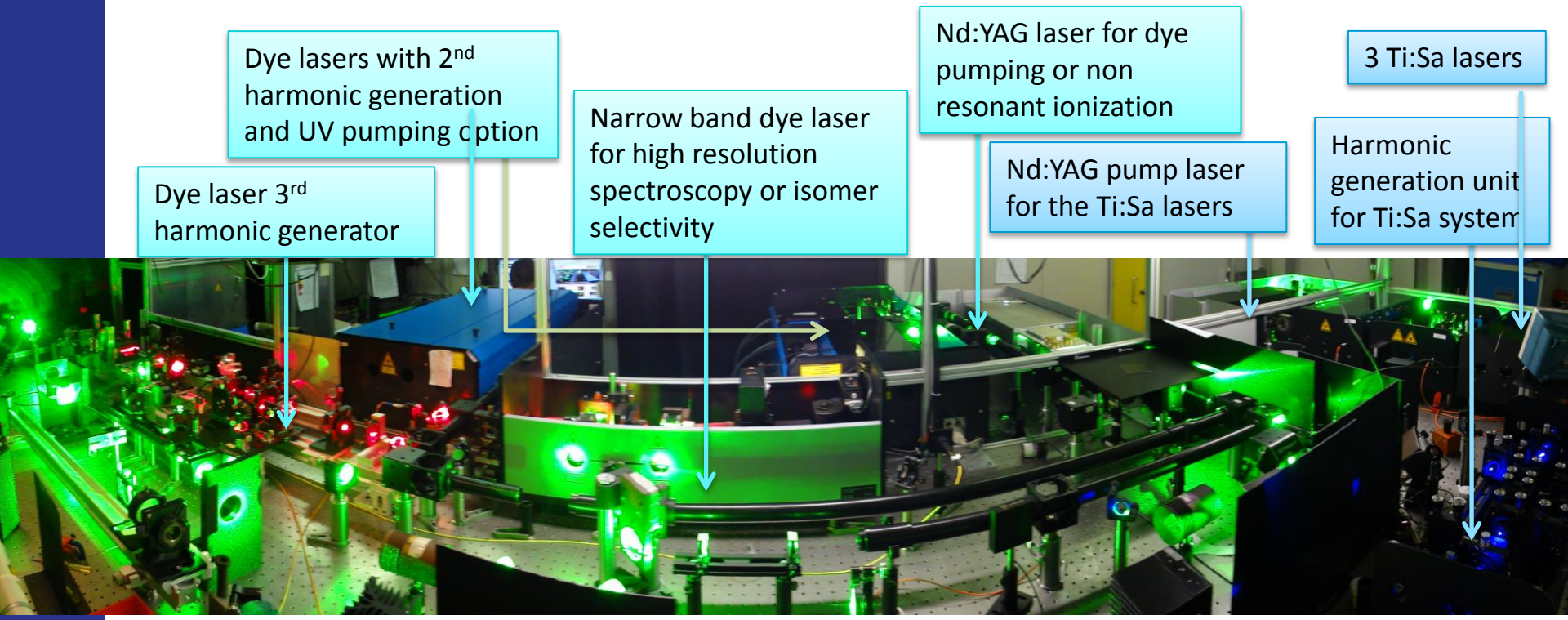
Open projects:

IS471: Collinear resonant ionization laser spectroscopy of rare francium isotopes

IS531: Collinear resonant ionization spectroscopy for neutron rich copper isotopes

RILIS

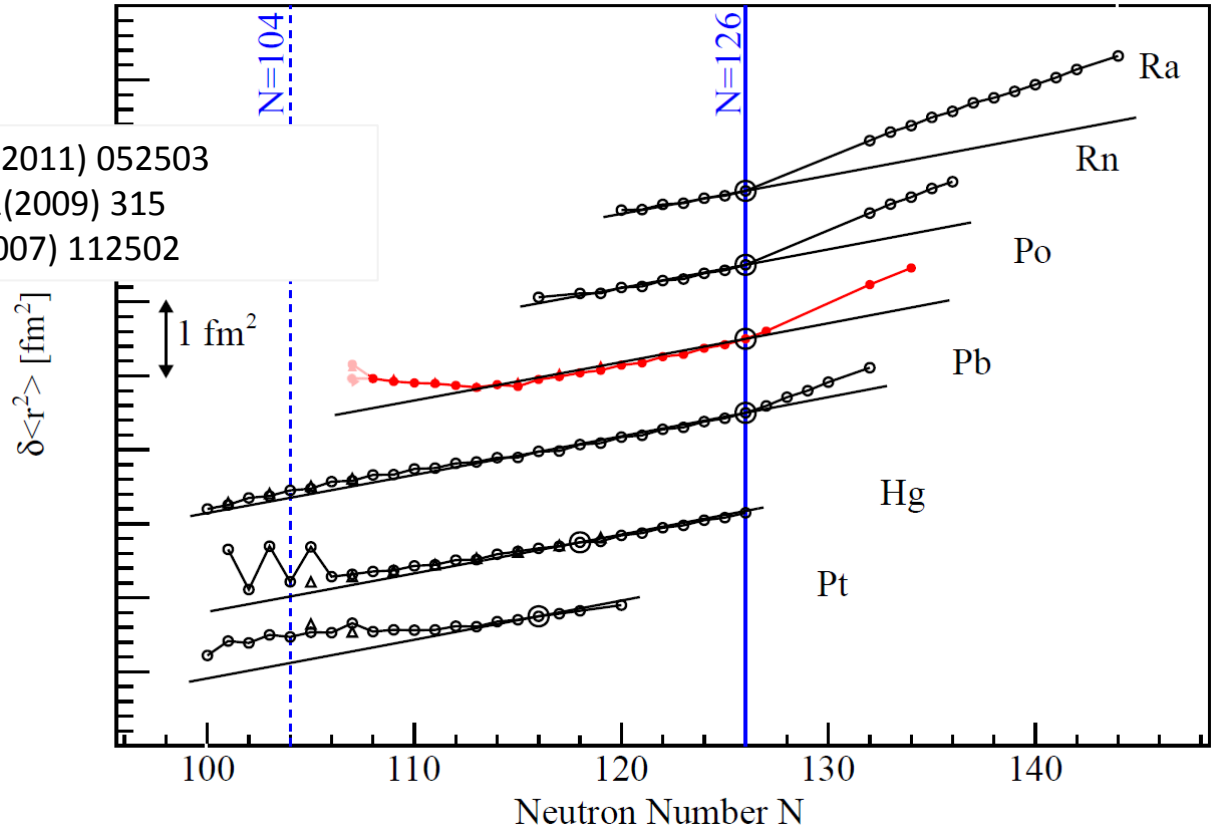
- **Resonant Ionisation Laser Ion Source**; one way to ionise produced atoms
- Nd: YAG pumping dye or Ti:Sa lasers, with possibility of doubling to quadrupling
- Atomic physics: Used to determine ionisation schemes and ionising potential of chemical elements with no stable isotopes (e.g. polonium, astatine)
- Nuclear physics: laser spectroscopy -> electromagnetic ground state properties



RILIS – nuclear structure

Changes in charge radii of heavy nuclei

T.E. Cocolios et al., PRL 106 (2011) 052503
M. Seliverstov et al., EPJ A41(2009) 315
H. De Witte et al., PRL 98 (2007) 112502



Open projects:

IS456: Study of polonium isotopes gs properties by simultaneous atomic- and nuclear-spectroscopy

IS466: Identification and systematical studies of the electron-capture delayed fission (ECDF) in the lead region - Part I: ECDF of 178,180Tl and 200,202Fr isotopes

IS511: Shape coexistence in the lightest Tl isotopes studied by laser spectroscopy

IS534: Beta-delayed fission, laser spectroscopy and shape-coexistence studies with radioactive At beams

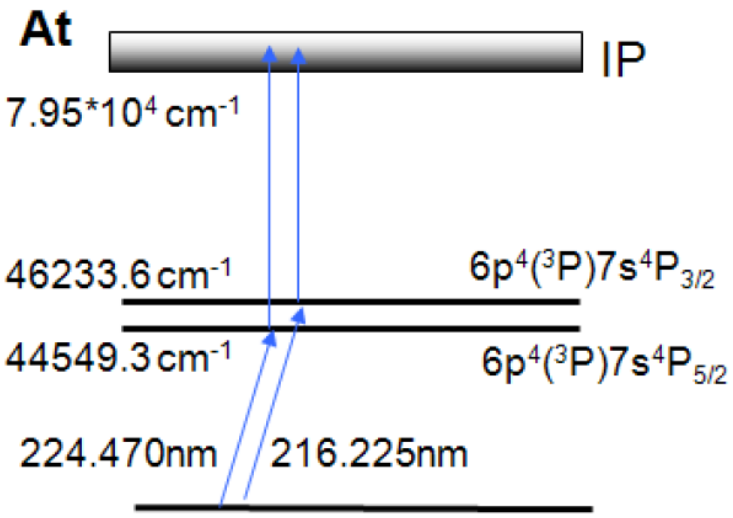
RILIS – atomic structure

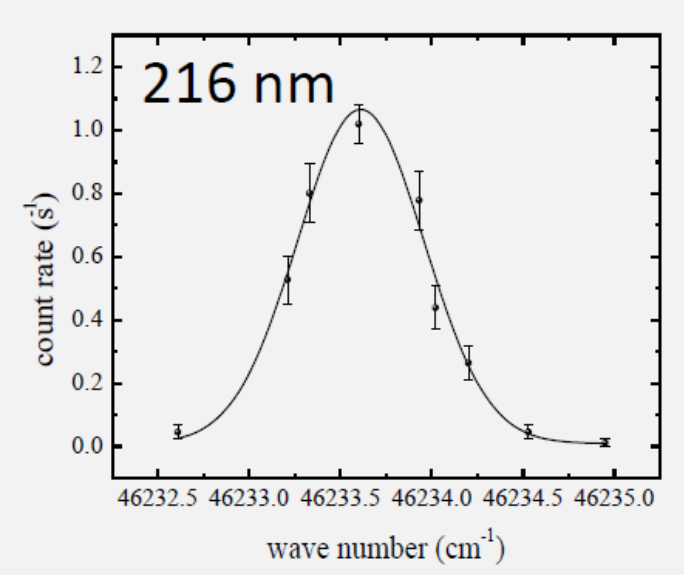
Astatine beams:

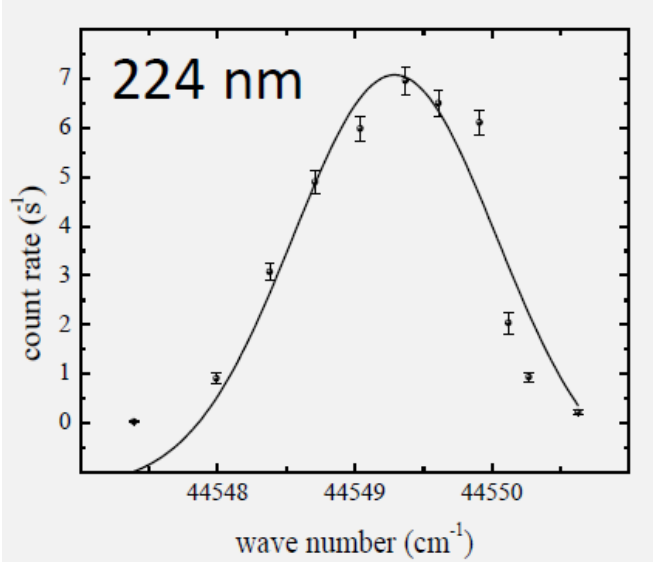
Determination of ionising potential

Identification of new atomic transitions

Comparison with atomic theory







Recent projects:

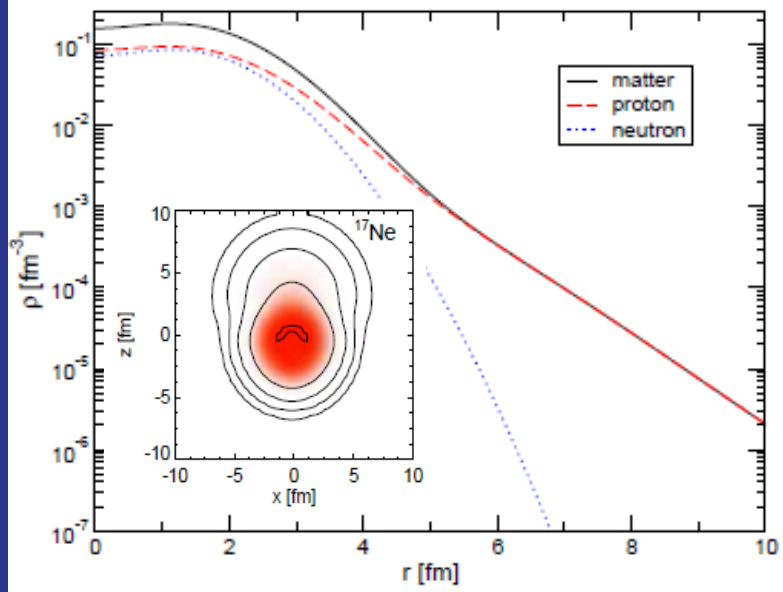
Polonium

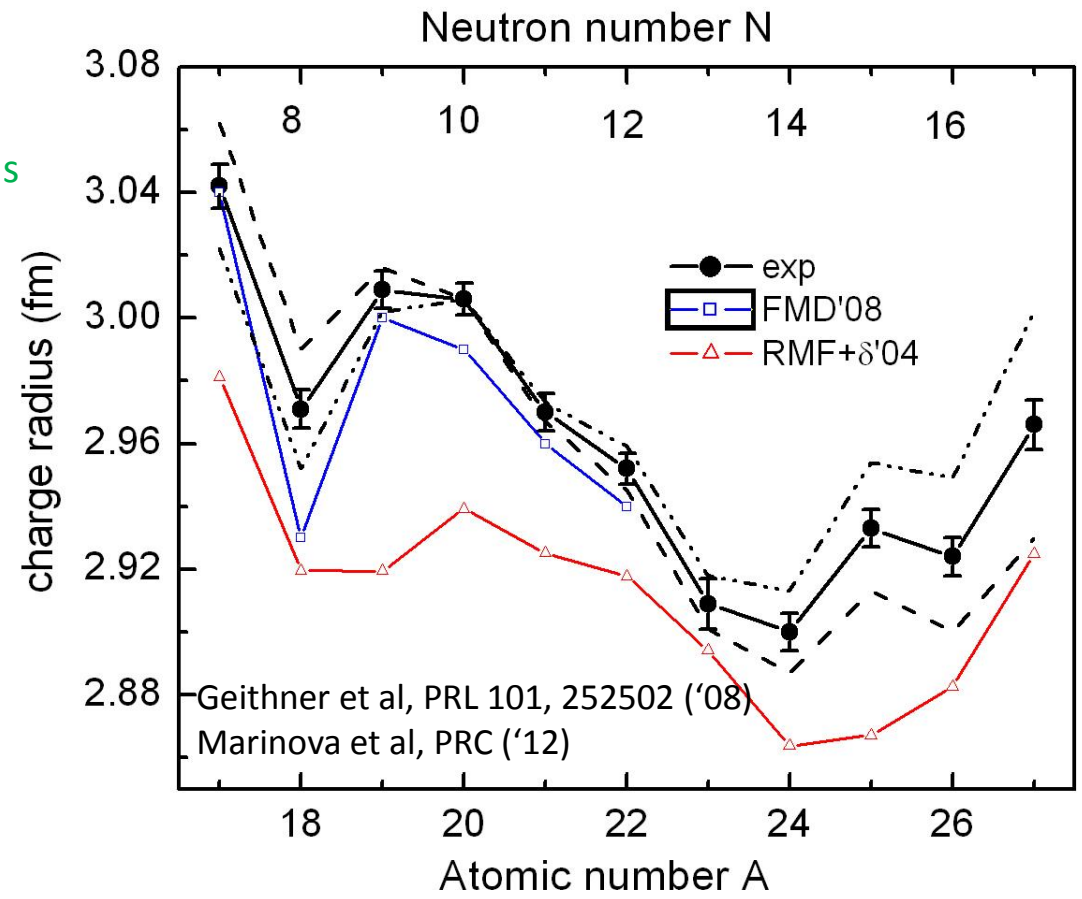
Astatine

COLLAPS – Ne charge radii

Laser spectroscopy

Intrinsic density distributions of dominant proton FMD configurations





Open projects:

IS484: Ground-state properties of K-isotopes from laser and β-NMR spectroscopy

IS497: Laser Spectroscopy of Cadmium Isotopes: Probing the Nuclear Structure Between the Neutron 50 and 82 Shell Closures

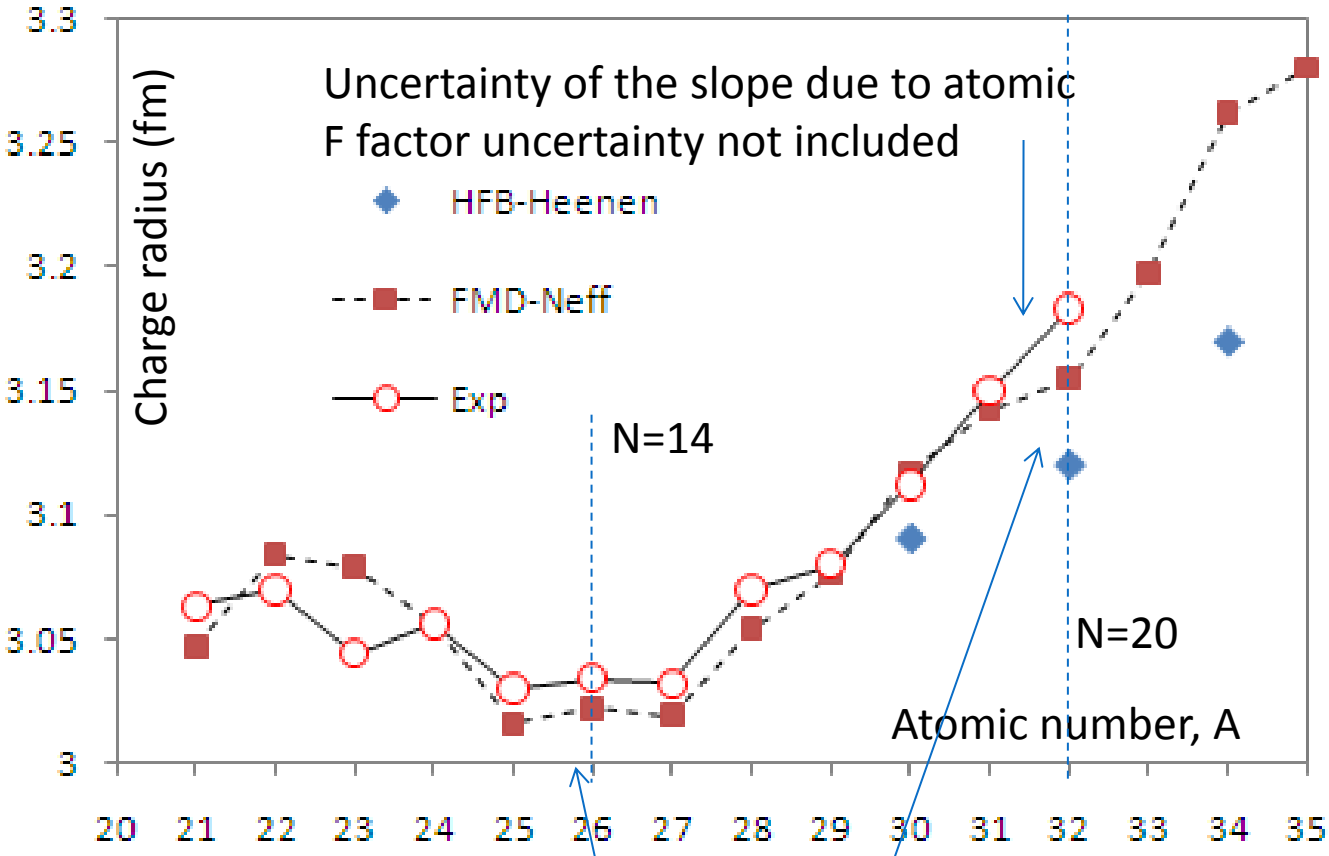
IS517: Determination of the Magnetic Moment of 140-Pr

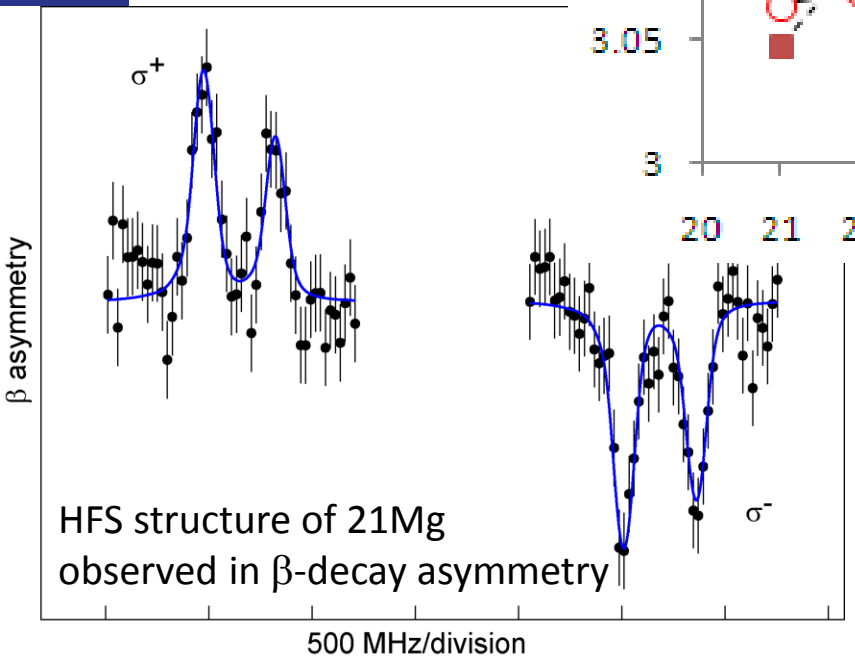
IS519: Shell structure and level migrations in zinc studied using collinear laser spectroscopy

IS529: Spins, Moments and Charge Radii Beyond 48Ca

Properties of Mg isotopes

Laser spectroscopy with COLLAPS





HFS structure of 21Mg observed in β-decay asymmetry

Smallest radius at N=14, not N=20: Migration of the shell closure

D. Yordanov et al, PRL 2012