Laser Spectroscopy at CARIBU

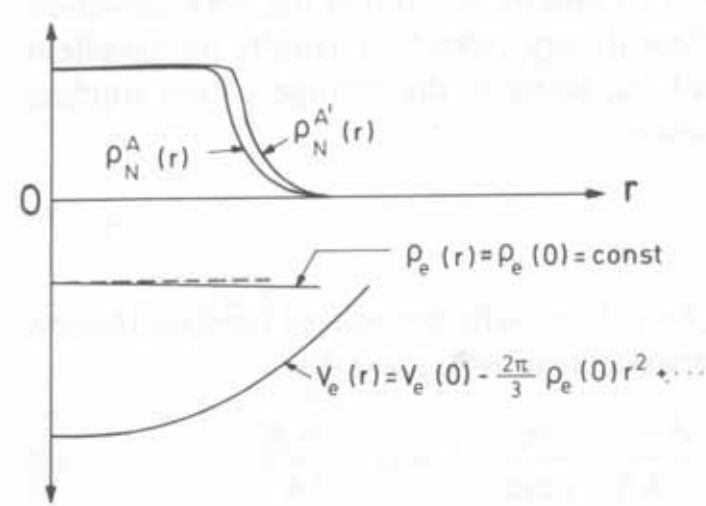
Peter Mueller

Isotope Shift and Nuclear Charge Radii

$$dn_A - n_{A'} = dn_{MS} + dn_{FS}$$

Mass shift

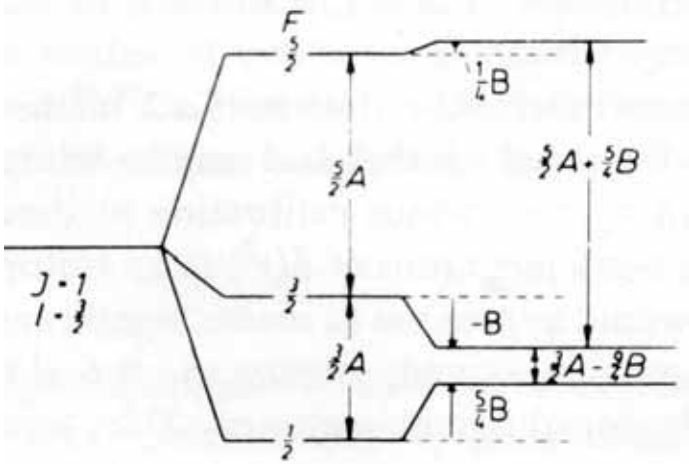
$$\delta\nu_{MS} = \left(\frac{m_e}{m_u}\nu^A + C_{SMS}\right)\frac{A - A'}{AA'}$$



Field (volume) shift

$$\delta\nu_{FS} = -\frac{2\pi}{3}Ze^2 \cdot \Delta\left|\Psi(0)\right|^2 \cdot \delta\left\langle r^2\right\rangle^{AA'}$$

Hyperfine Structure and Nuclear Moments



$$F = |I - J| \ldots I + J$$

$$\Delta E_{HFS} = \frac{A}{2} C_1(I,J,F) + \frac{B}{4} C_2(I,J,F) + \ldots$$

Magnetic dipole

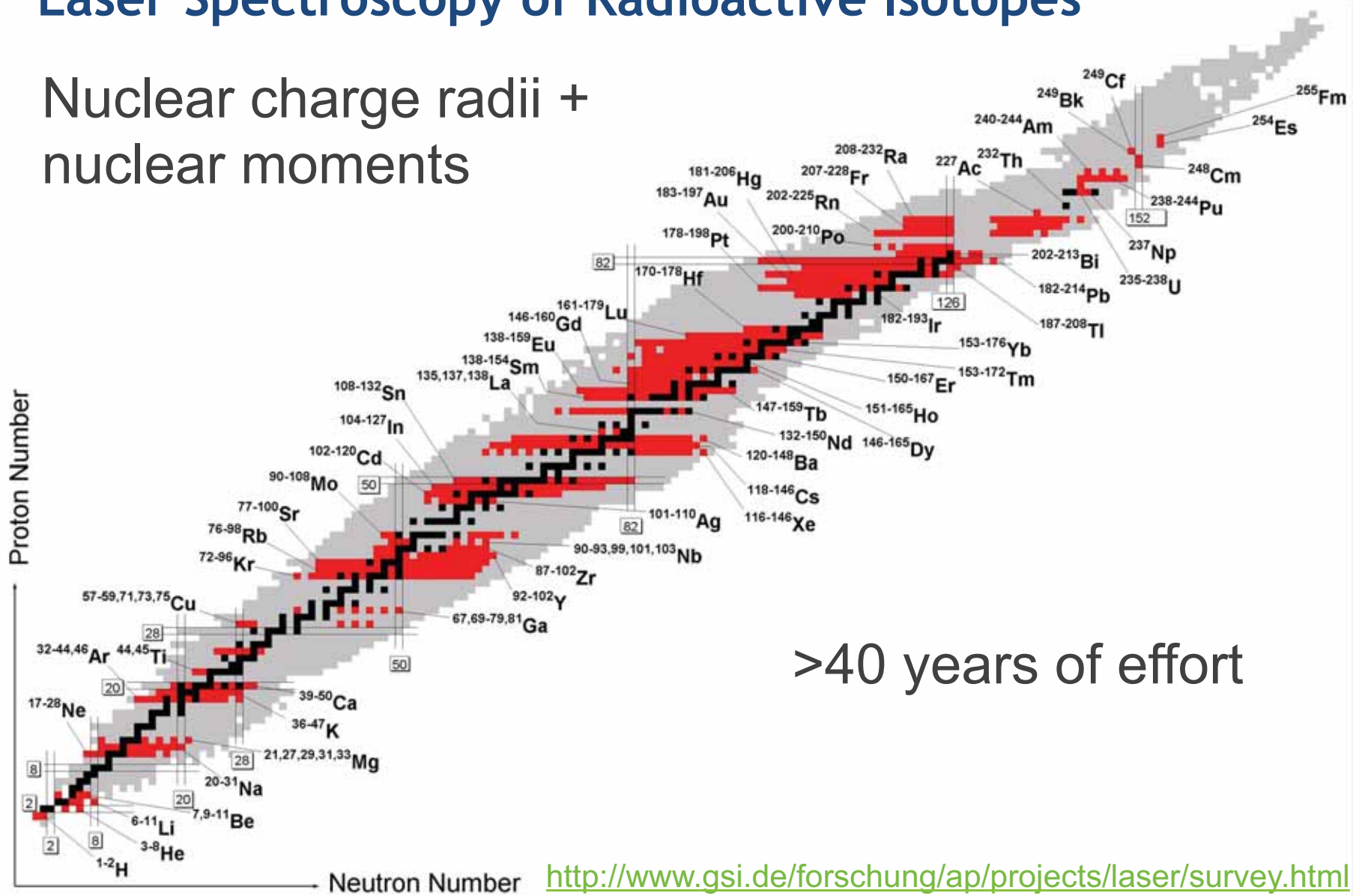
$$A = \frac{\mu_I H_e(0)}{I \cdot J} \qquad \mu_I' = \frac{A' I'}{AI} \mu_I (1 + \Delta)$$

Electric quadrupole

$$B = eQ_s \left\langle \frac{\partial^2 V_e}{\partial z^2} \right\rangle \qquad Q_s' = \frac{B'}{B} Q_S$$

Laser Spectroscopy of Radioactive Isotopes

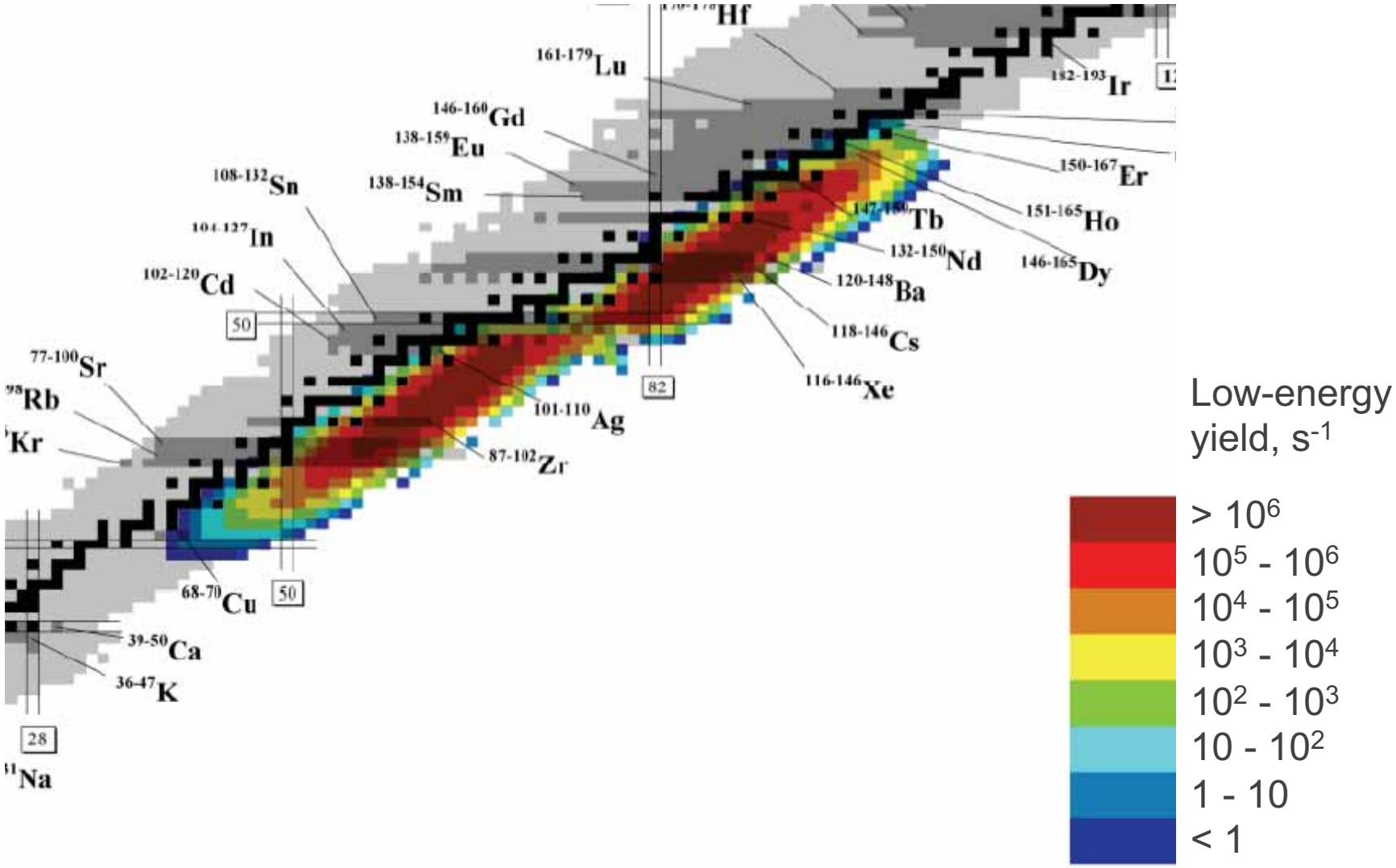
Nuclear charge radii +
nuclear moments



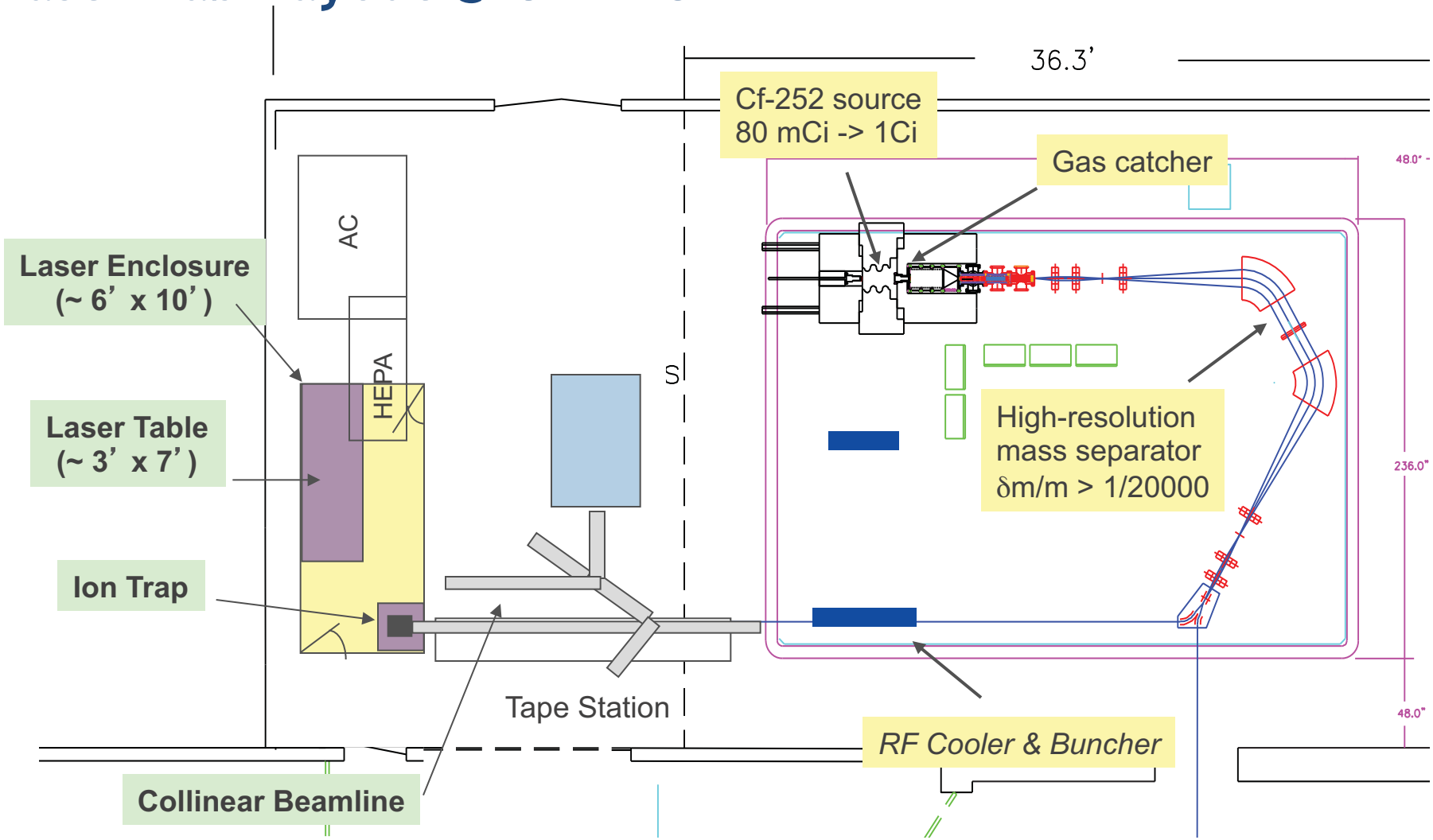
>40 years of effort

http://www.gsi.de/forschung/ap/projects/laser/survey.html

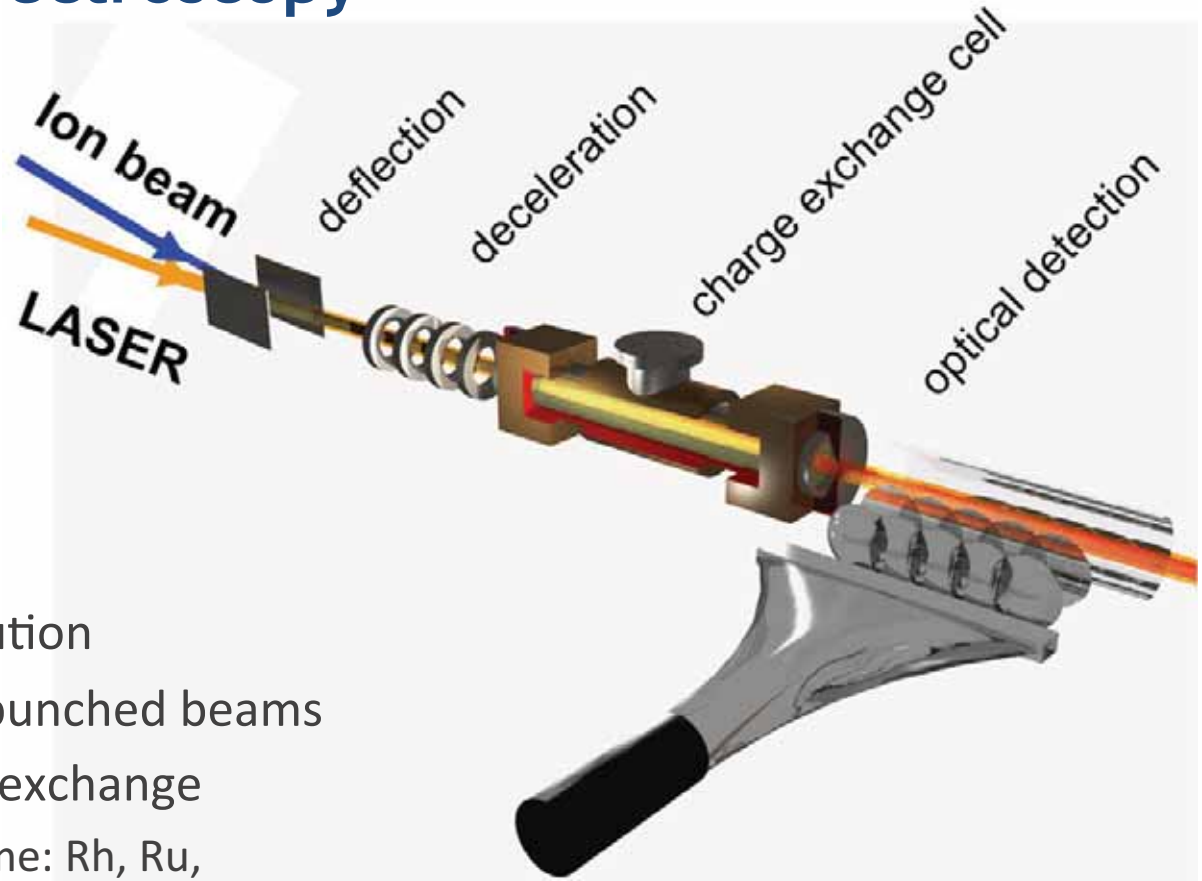
Isotopic Menu for Laser Spectroscopy



Laser Lab Layout @ CARIBU



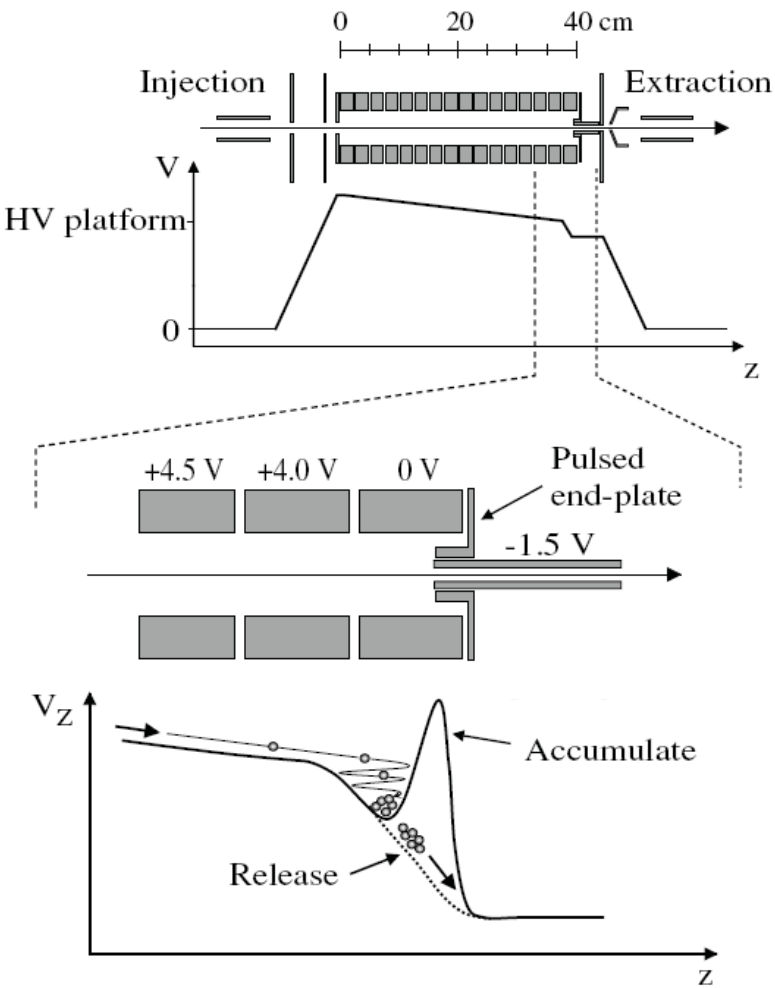
Collinear Laser Spectroscopy

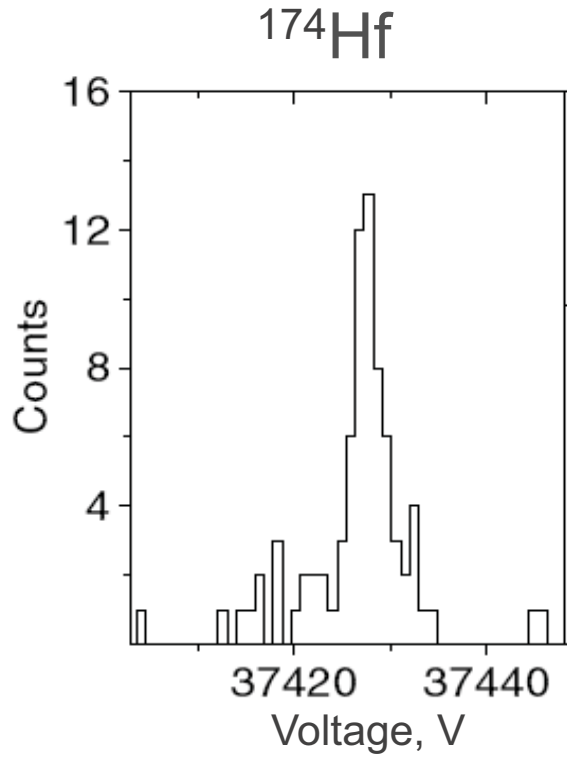


- High spectroscopic resolution
- High sensitivity through bunched beams
- Neutral atoms w/charge-exchange
  - Measure for the first time: Rh, Ru,
  - Extend isotopic chains on: Mo, Nb, …

Collinear Spectroscopy with Cold & Bunched Beams

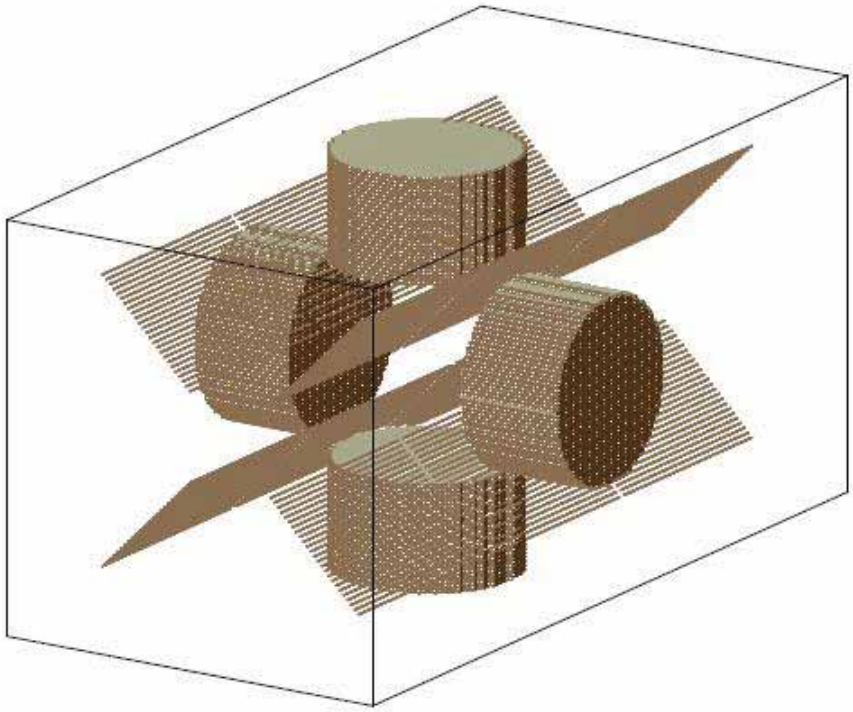
A. Nieminen *et al., PRL 88, 094801 (2002)*

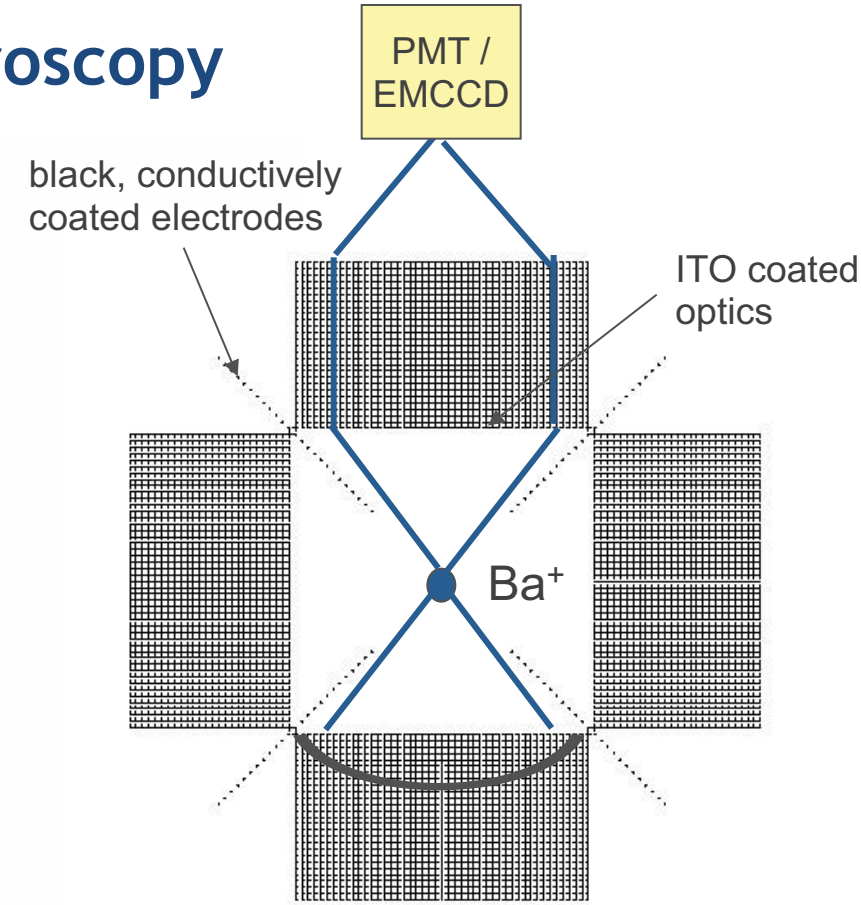




- gate on ion bunch
- reduce ion energy spread
- increase S/N by ~ 10^2
- deal with 100 ions/s

Linear Paul Trap for Spectroscopy

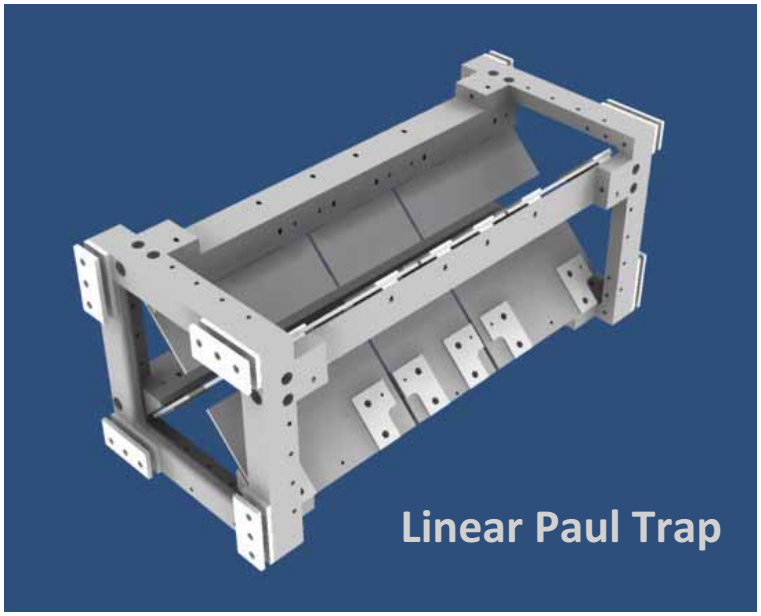


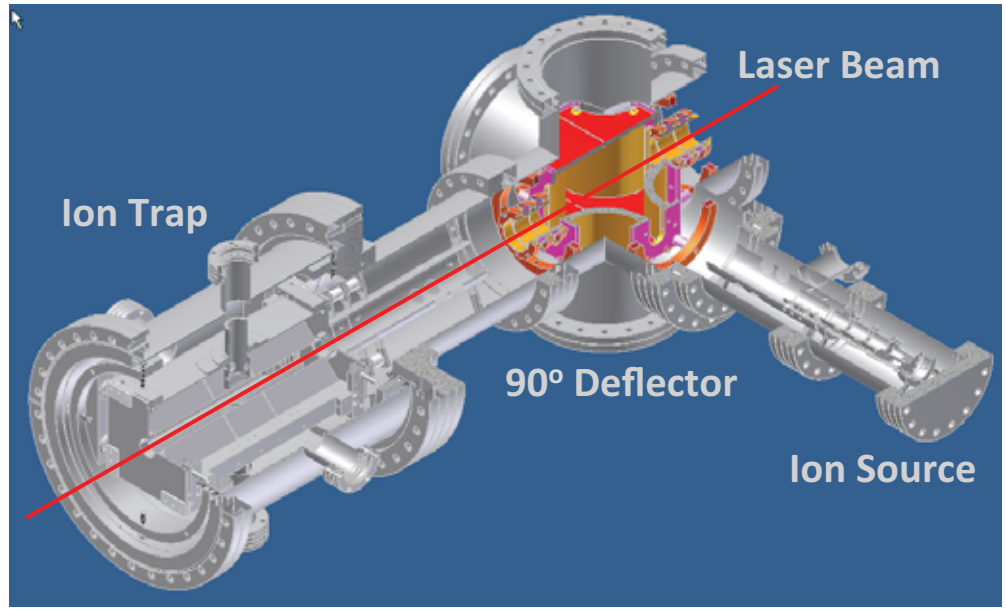


- open geometry, linear Paul trap -> large light collection efficiency
- buffer gas w. LN_2 cooling, -> good spectroscopic resolution, quenching of dark states

-> single ion detection sensitivity

In-trap spectroscopy





Matt Sternberg
Alexandra Carlson
Luis Brennan

- open geometry, LN_2 cooled linear Paul trap
  - buffer gas cooling
  - large light collection efficiency
  - few to single ion detection sensitivity

In-Trap Spectroscopy at CARIBU

Linear Paul trap for spectroscopy

- Initially with neutron-rich Ba^+
- Isotope shift + moments (HFS)
- Use RF cooler / buncher & transfer line

To investigate:

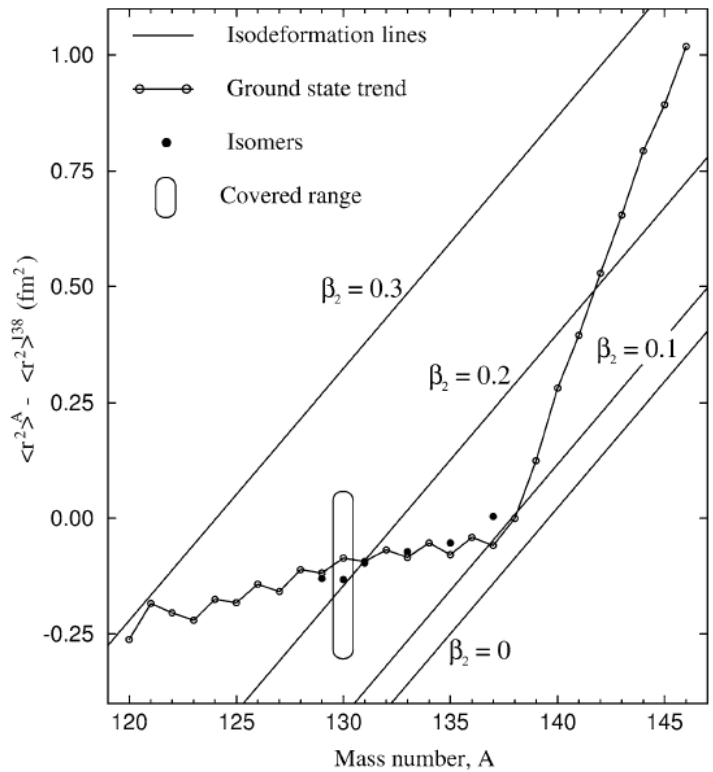
- optimized trap geometry and detection system
- Buffer gas cooling + quenching (with H_2)
- Cooling of trap with LN_2

Future:

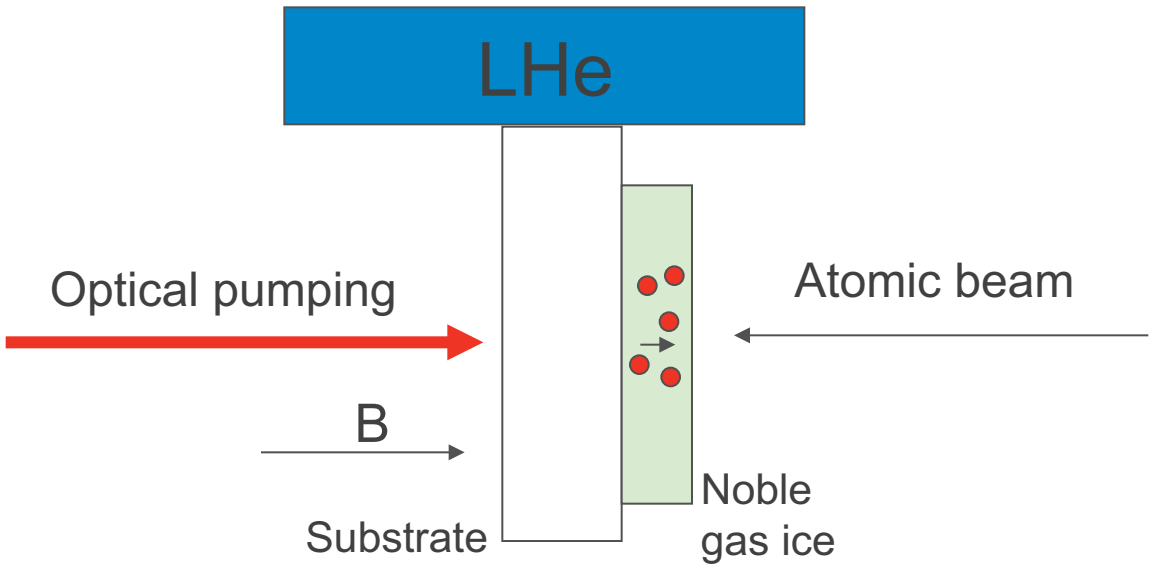
- other CARIBU beams
  - High mass: Pr, Nd, Eu, …
  - Low mass: Y, Zr, Nb, Sr, …
- Yb^+ -> No^+ with ATLAS Upgrade

Ba Isotopes

A		t_1/2	yield, 1/s
139	1.45E-01	1.396h	3.22E+05
140	5.16E-01	12.75d	1.15E+06
141	1.11E+00	18.3 m	2.46E+06
142	2.70E+00	10.7 m	5.99E+06
143	4.40E+00	14.3 s	9.77E+06
144	3.37E+00	11.4 s	7.48E+06
145	2.06E+00	4.0 s	4.57E+06
146	9.81E-01	2.20 s	2.18E+06
147	2.50E-01	0.892s	5.55E+05
148	4.80E-02	0.64 s	1.07E+05
149	4.04E-03	0.36 s	8.97E+03
150	3.27E-04	0.962s	7.26E+02
152	3.77E-07	0.420s	8.37E-01



Nuclear Spin Polarization in Solid Noble-Gas Matrix



Chen-Yu Xu
Jaideep Singh
Shuiming Hu

- Capture atoms in solid noble-gas matrix (Ne … Xe)
- Optical pumping in situ
- Spin precession detection with SQUIDs (stable isotopes) or decay asymmetry (radioactive isotopes)
- Started feasibility studies for
  - Optical pumping / nuclear polarization (initial tests with Yb)
  - Measurements of nuclear magnetic moments (other rare earth, …)

Some concluding thoughts

- Limitations on isotopic yields for laser spectroscopy
  - Molecular fraction
  - Charge state distribution (2+/1+)
  - Charge exchange in cooler/buncher or in-beam
  - Population of metastable atomic states

- Limitations in number of elements that can be done
  - Not "universal technique"; each element different
  - Not all elements are technically feasible

- Tight space limitations in CARIBU LE-beam area
  - Need to wait until CPT moves out
  - Possible extension of LE beams into tandem hall

- Combination with decay spectroscopy ?
  - Laser excitation provides high selectivity, i.e., isobaric & isomeric
  - Resonance ionization to produce pure beams
  - Laser polarization (in-matrix or in-beam)