MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Spins, Moments and Sizes of $^{100-130}$Cd by Laser Spectroscopy

D. T. Yordanov[1], D. L. Balabanski[2], M. L. Bissell[3], K. Blaum[1], B. Cheal[4], K. T. Flanagan[4], N. Frömmgen[5], G. Georgiev[6], C. Geppert[5,9], M. Hammen[5], M. Kowalska[7], K. Kreim[1], A. Krieger[5], R. Neugart[5], G. Neyens[3], W. Nörtershäuser[5,8], J. Papuga[3], M. M. Rajabali[3], R. Sánchez[8]

[1]Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany
[2]INRNE, Bulgarian Academy of Science, BG-1784 Sofia, Bulgaria
[3]Instituut voor Kern- en Stralingsfysica, KU Leuven, B-3001 Leuven, Belgium
[4]School of Physics and Astronomy, The University of Manchester, Manchester M13 9PL, UK
[5]Institut für Kernchemie, Universität Mainz, D-55099 Mainz, Germany
[6]CSNSM-IN2P3-CNRS, Université de Paris Sud, F-91405 Orsay, France
[7]Organisation Européenne pour la Recherche Nucléaire, CH-1211 Geneva 23, Switzerland
[8]Helmholtzzentrum für Schwerionenforschung GmbH, D-64291 Darmstadt, Germany
[9]Helmholtz Institute Mainz, D-55099 Mainz, Germany

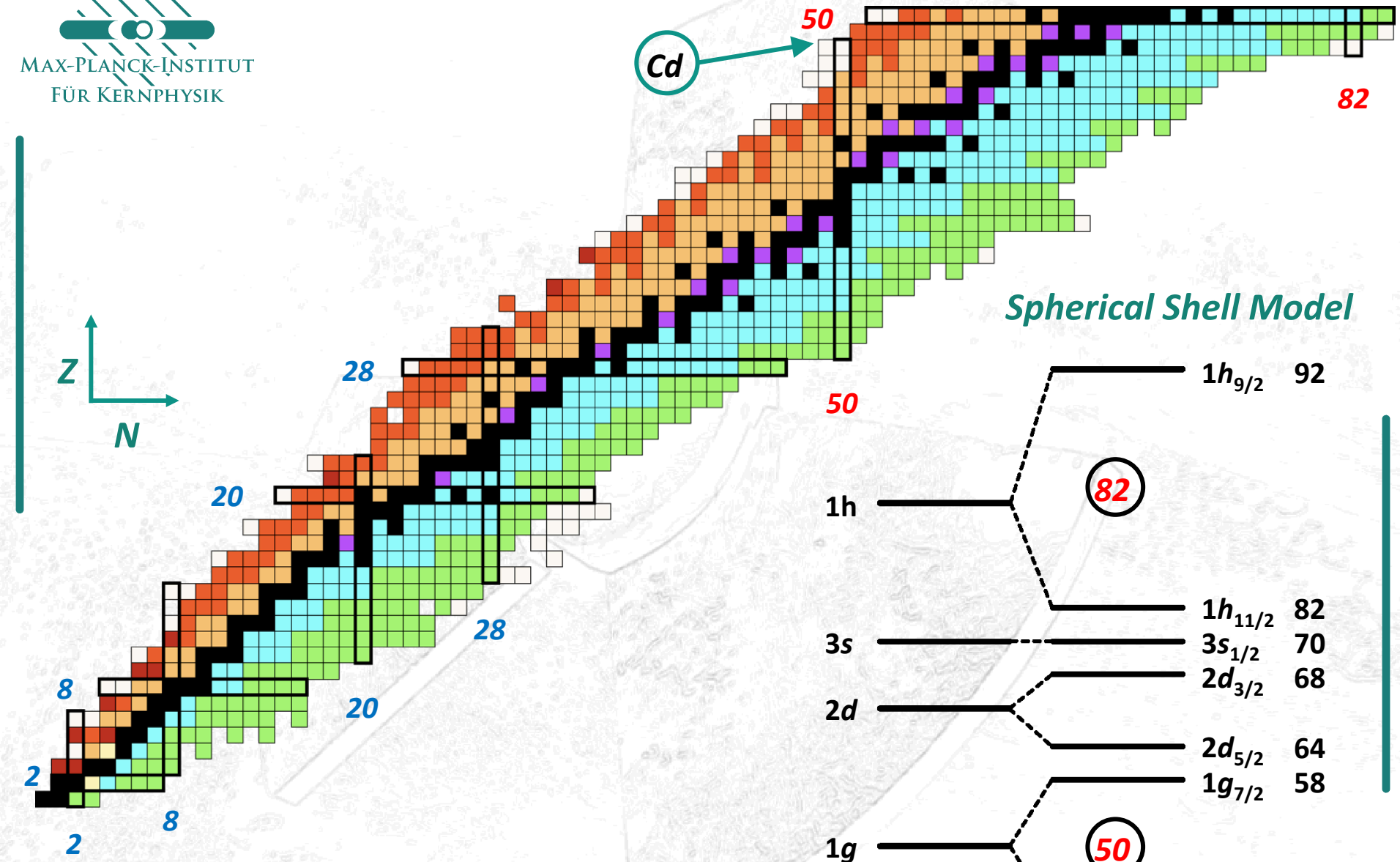
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Outline:

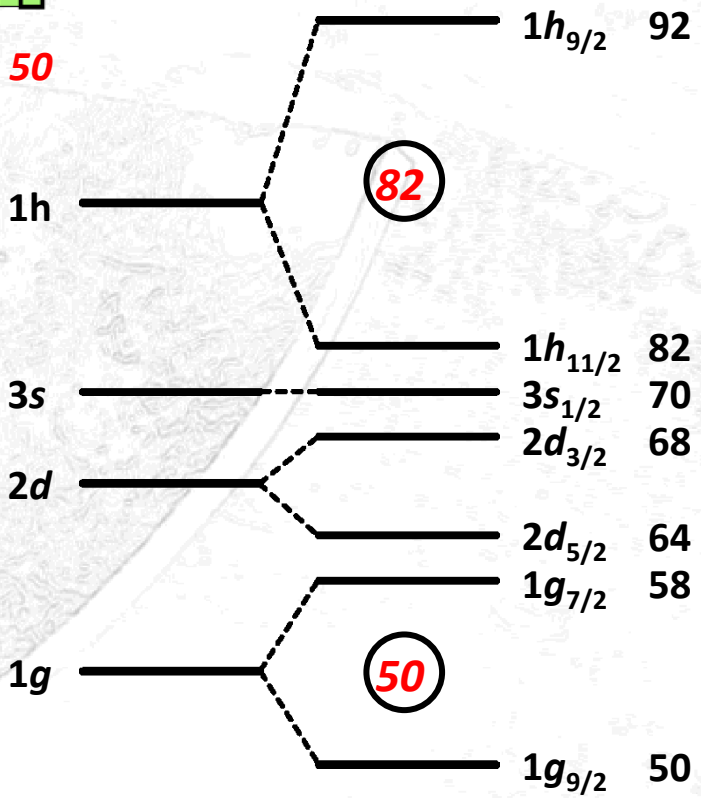
- Physics interest in the isotopes of cadmium
- Experimental procedures and results
- Systematics of μ and Q moments
- Charge radii - g.s. vs. isomers

MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK

Nuclear Chart

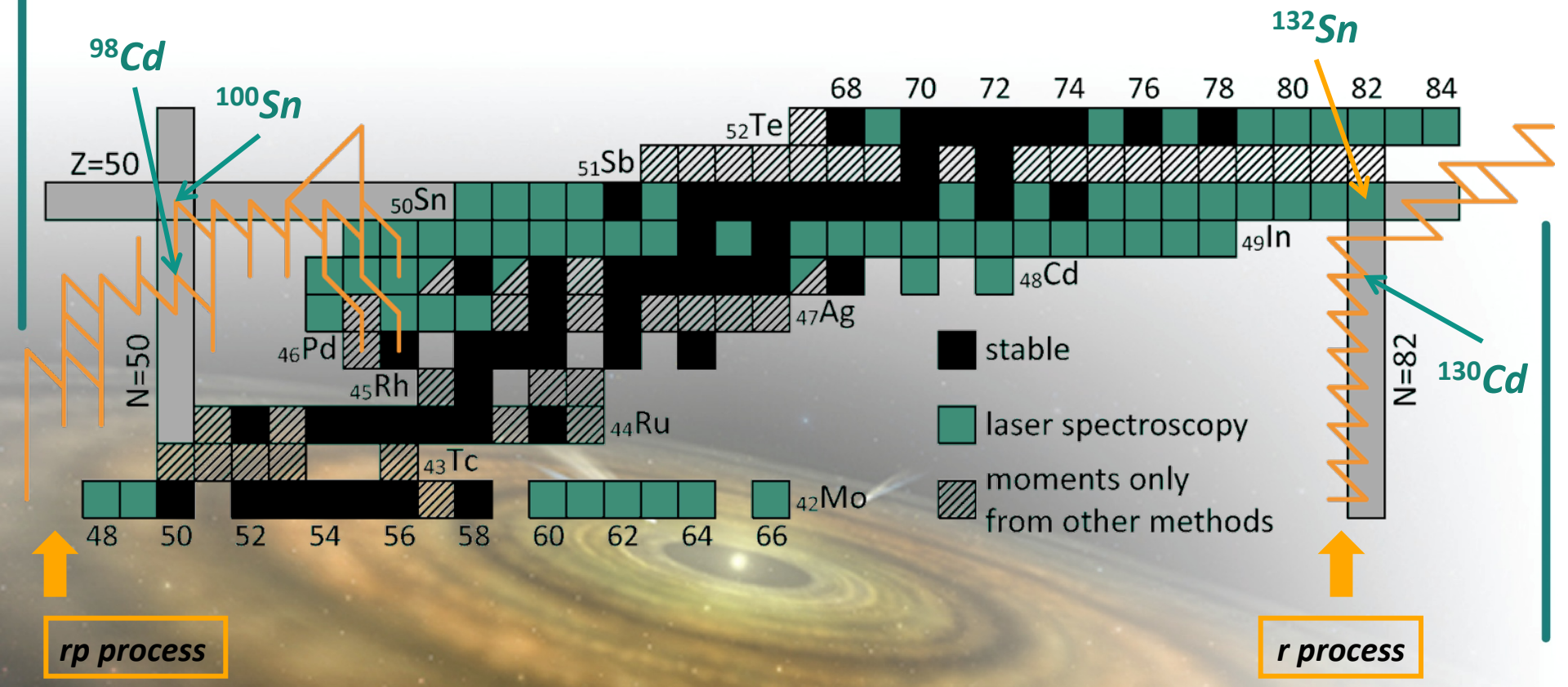


Spherical Shell Model



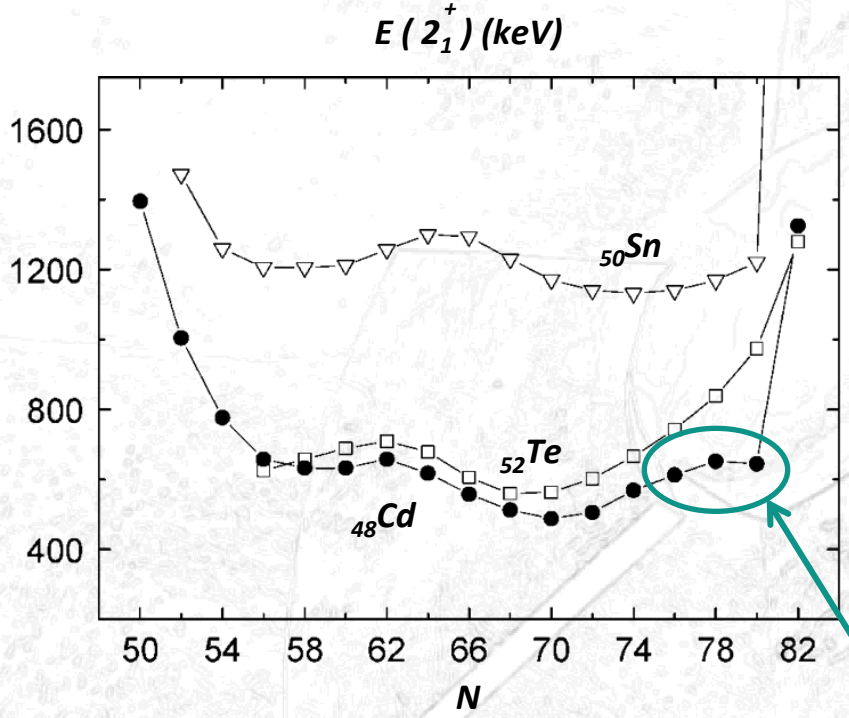
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

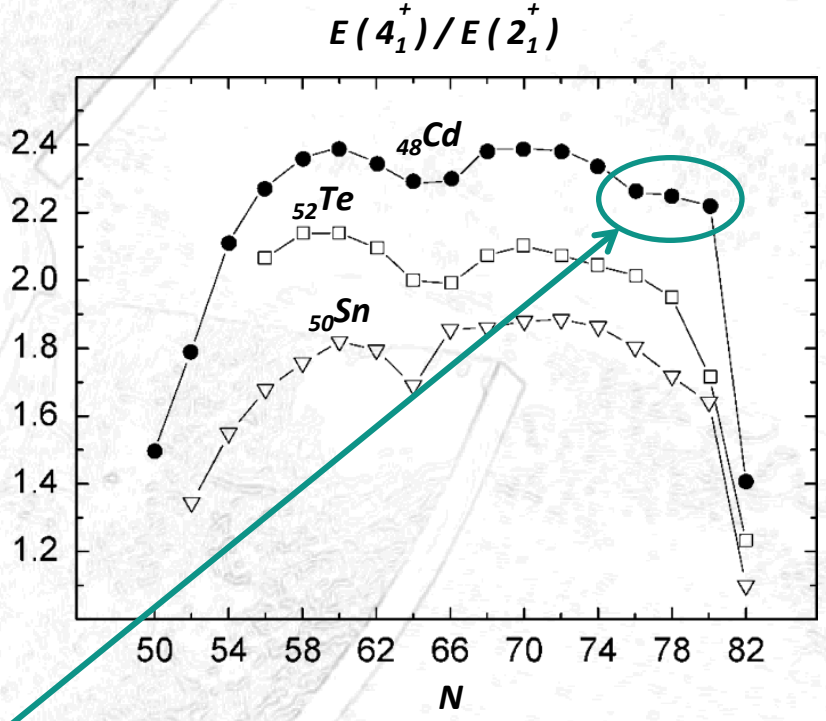
Survey of nuclear moments in the Z ≈ 50 region and astrophysical aspects



MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Indication for collectivity in the even - even isotopes



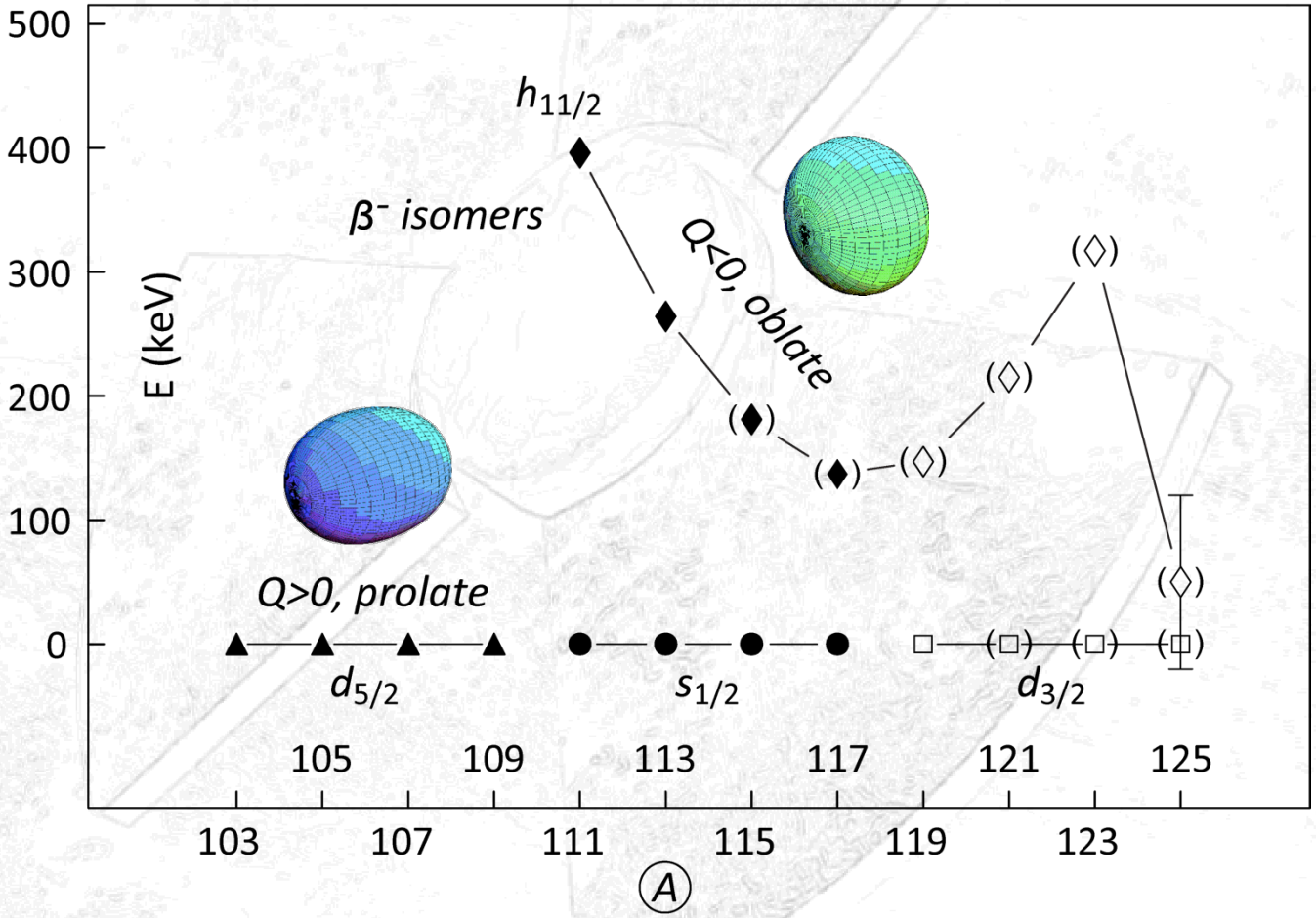


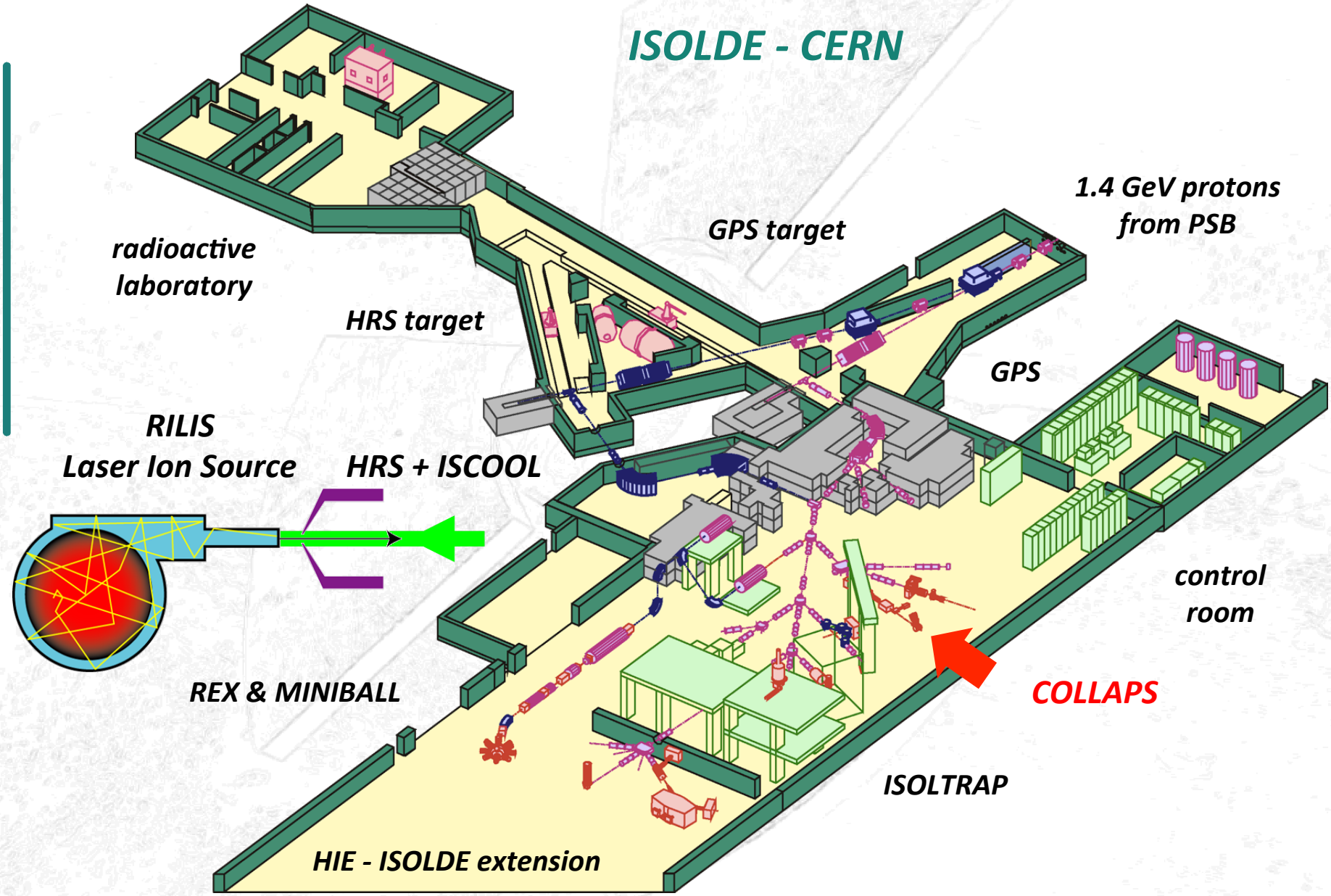
Anomaly in the energy levels of $^{126, 128}$Cd

- *Evidence in the rms charge radii?*
- *Evidence in the Q moments of the neighboring odd isotopes?*

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

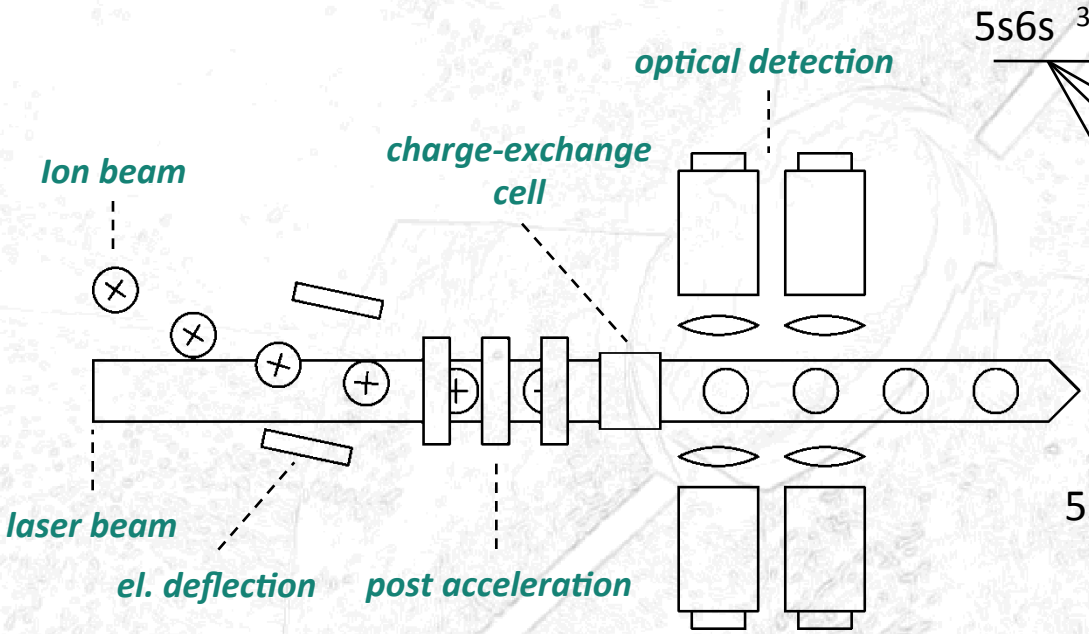
Spins, moments, shapes and isomers in the odd - A isotopes

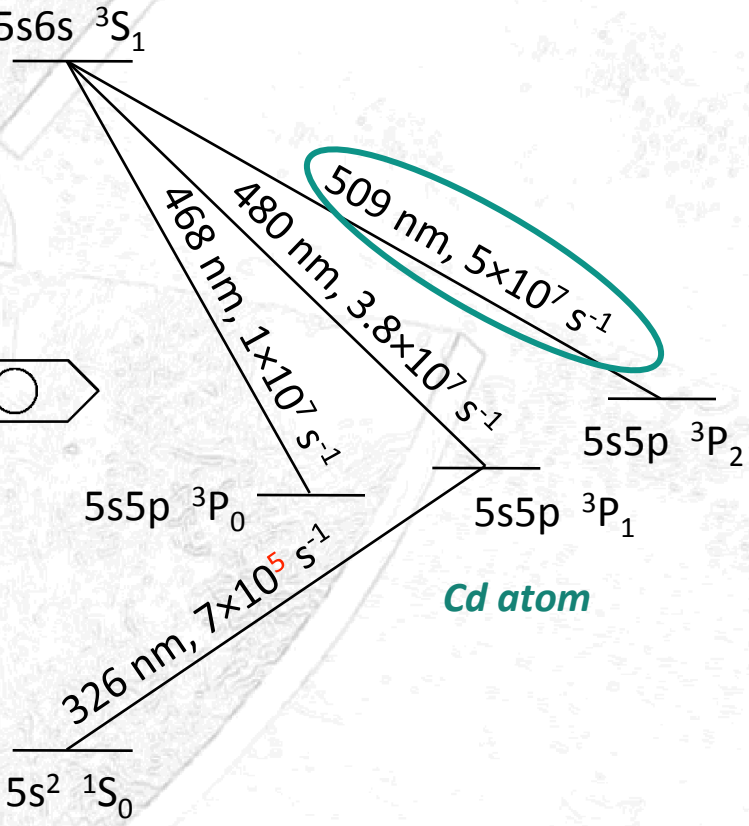



ISOLDE - CERN
radioactive laboratory
HRS target
GPS target
1.4 GeV protons from PSB
GPS
RILIS Laser Ion Source
HRS + ISCOOL
control room
REX & MINIBALL
COLLAPS
ISOLTRAP
HIE - ISOLDE extension

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

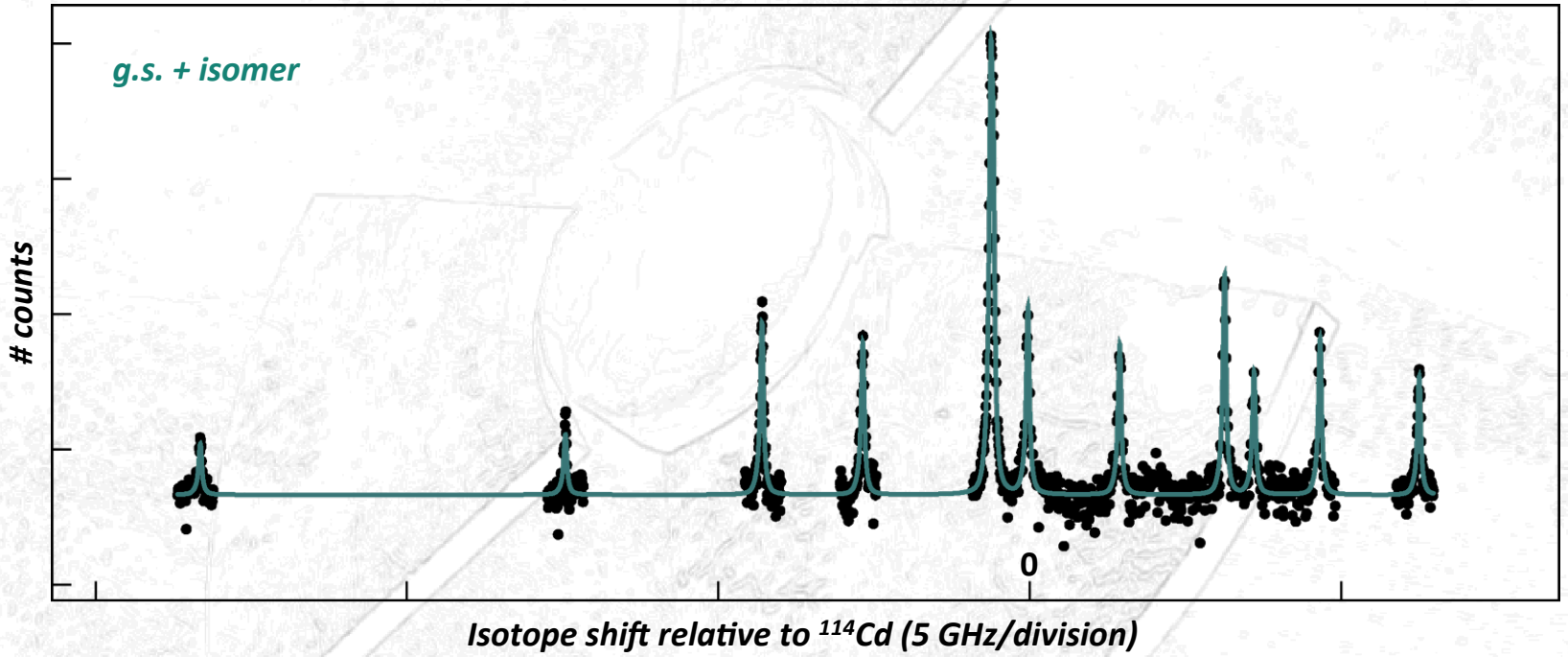
Continuous fast-beam fluorescence on $^{107\text{-}124,\ 126}$Cd





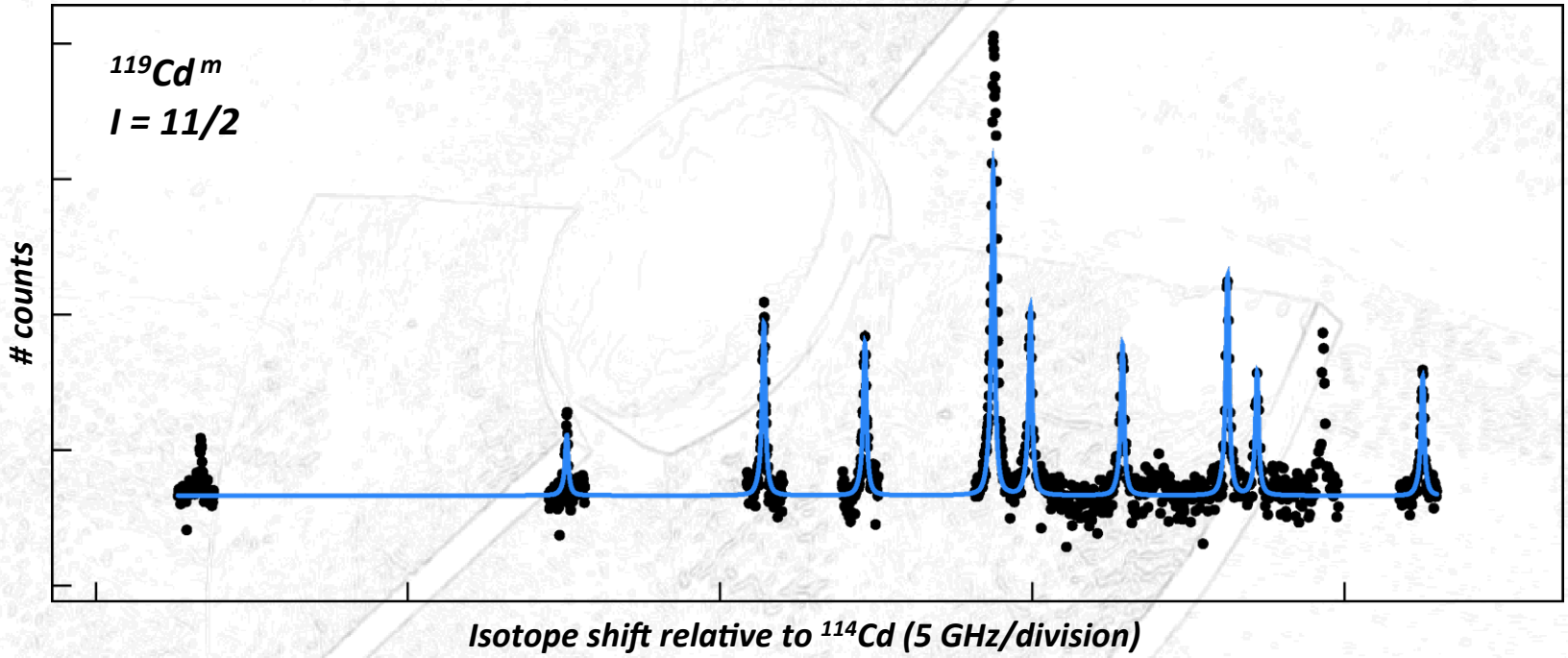
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

^{119}Cd



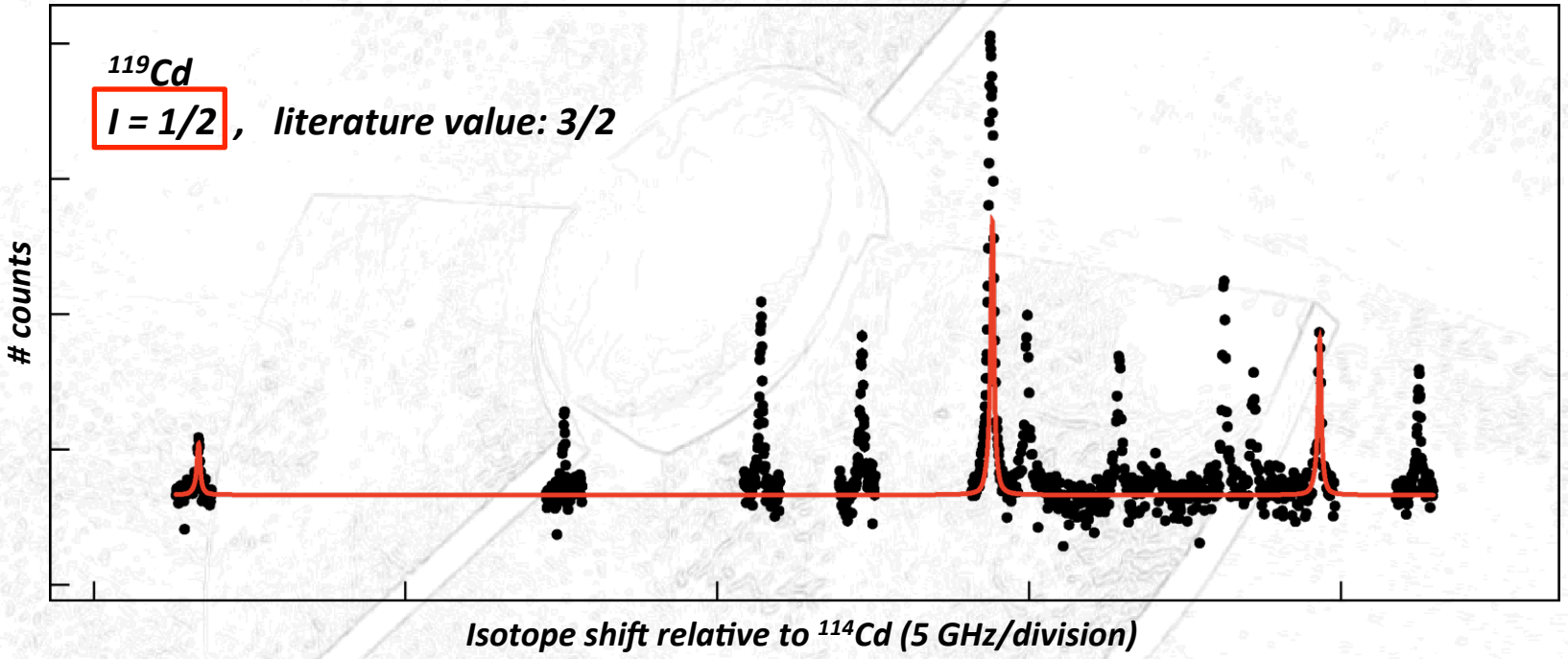
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

^{119}Cd



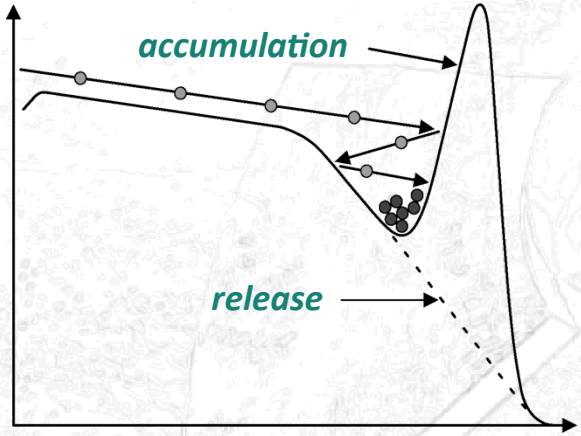
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

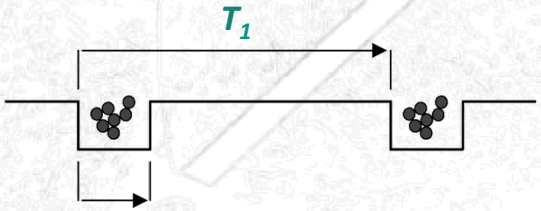
^{119}Cd

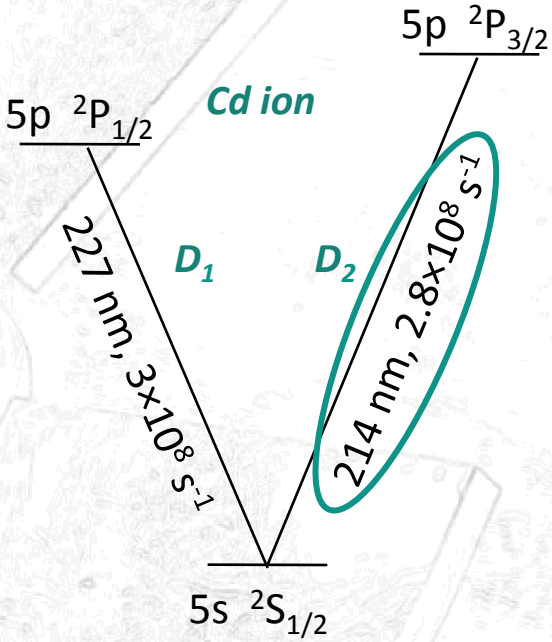


MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

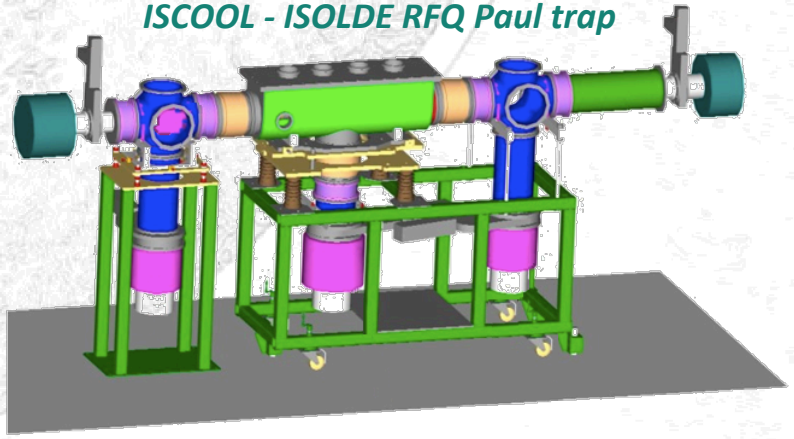
Bunched-beam fluorescence of $^{100\text{-}130}$Cd

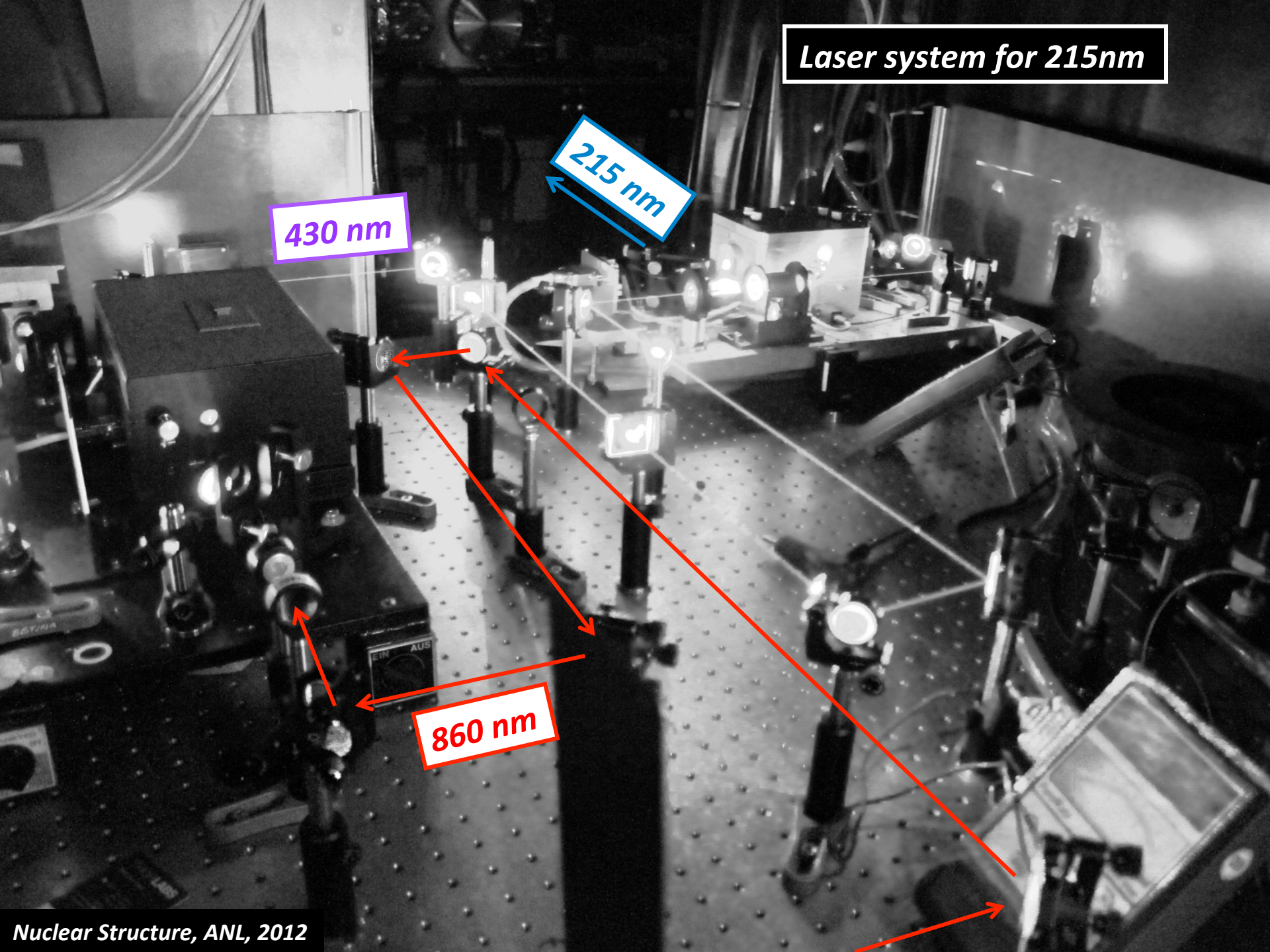






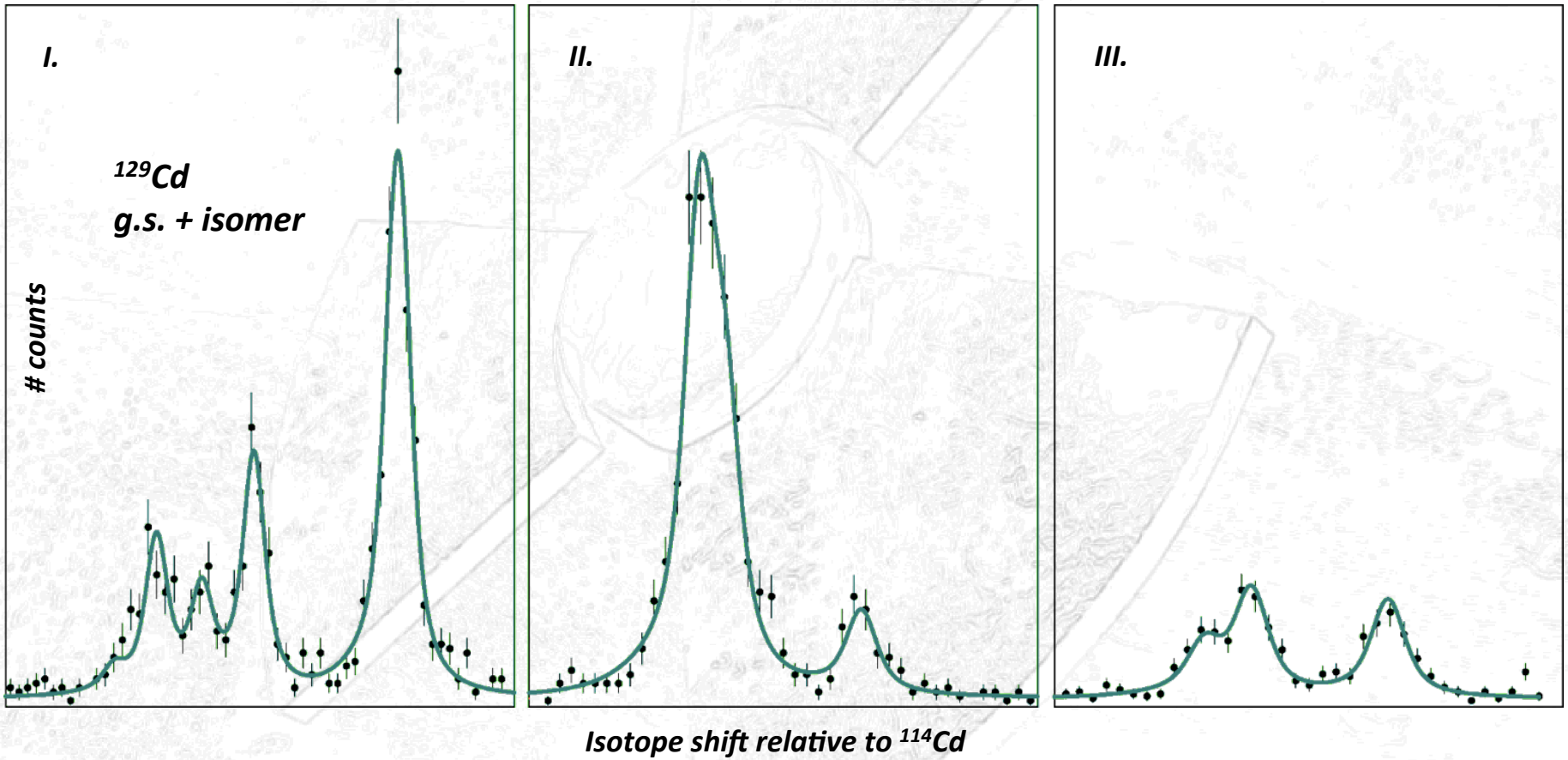
ISCOOL - ISOLDE RFQ Paul trap




Laser system for 215nm
215 nm
430 nm
860 nm

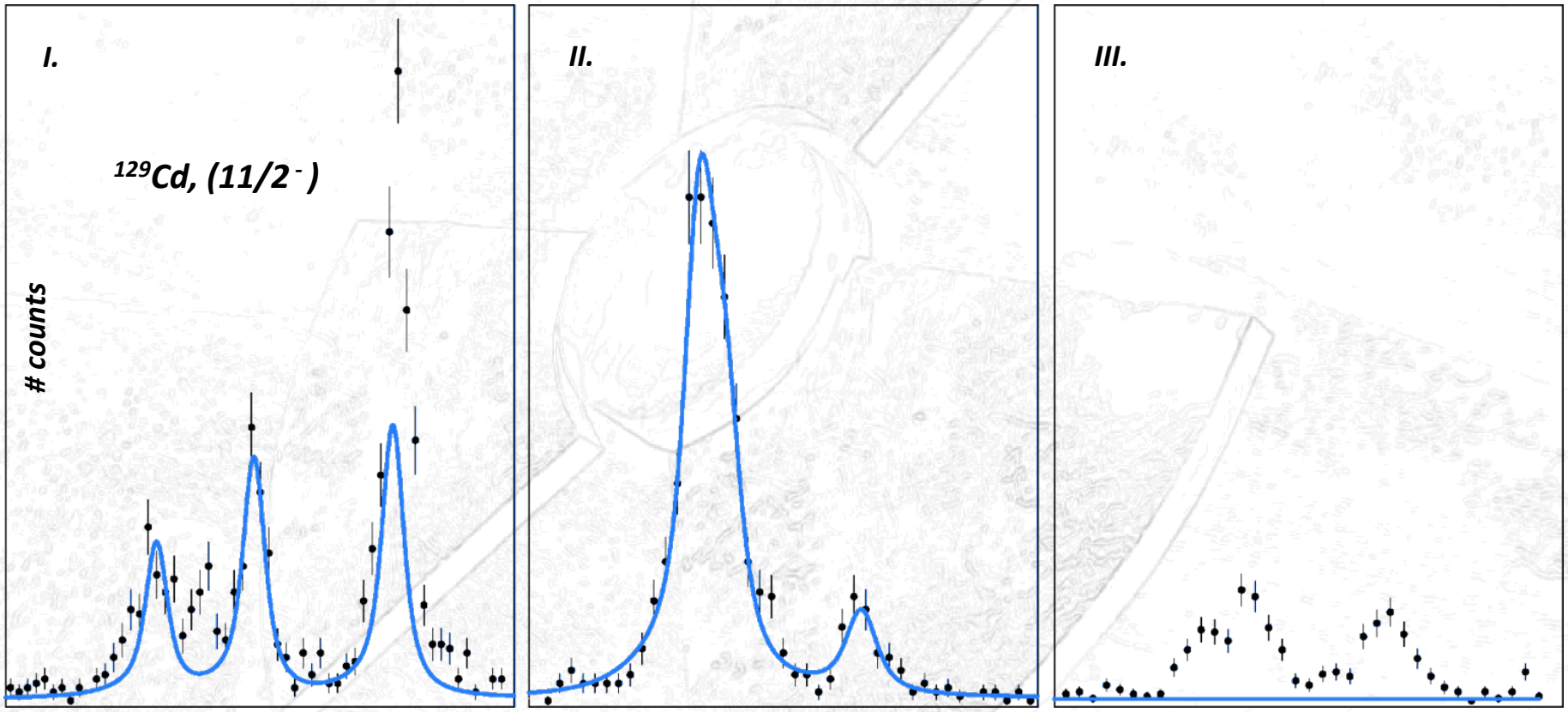
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Discovery of a long-lived isomeric state in ^{129}Cd



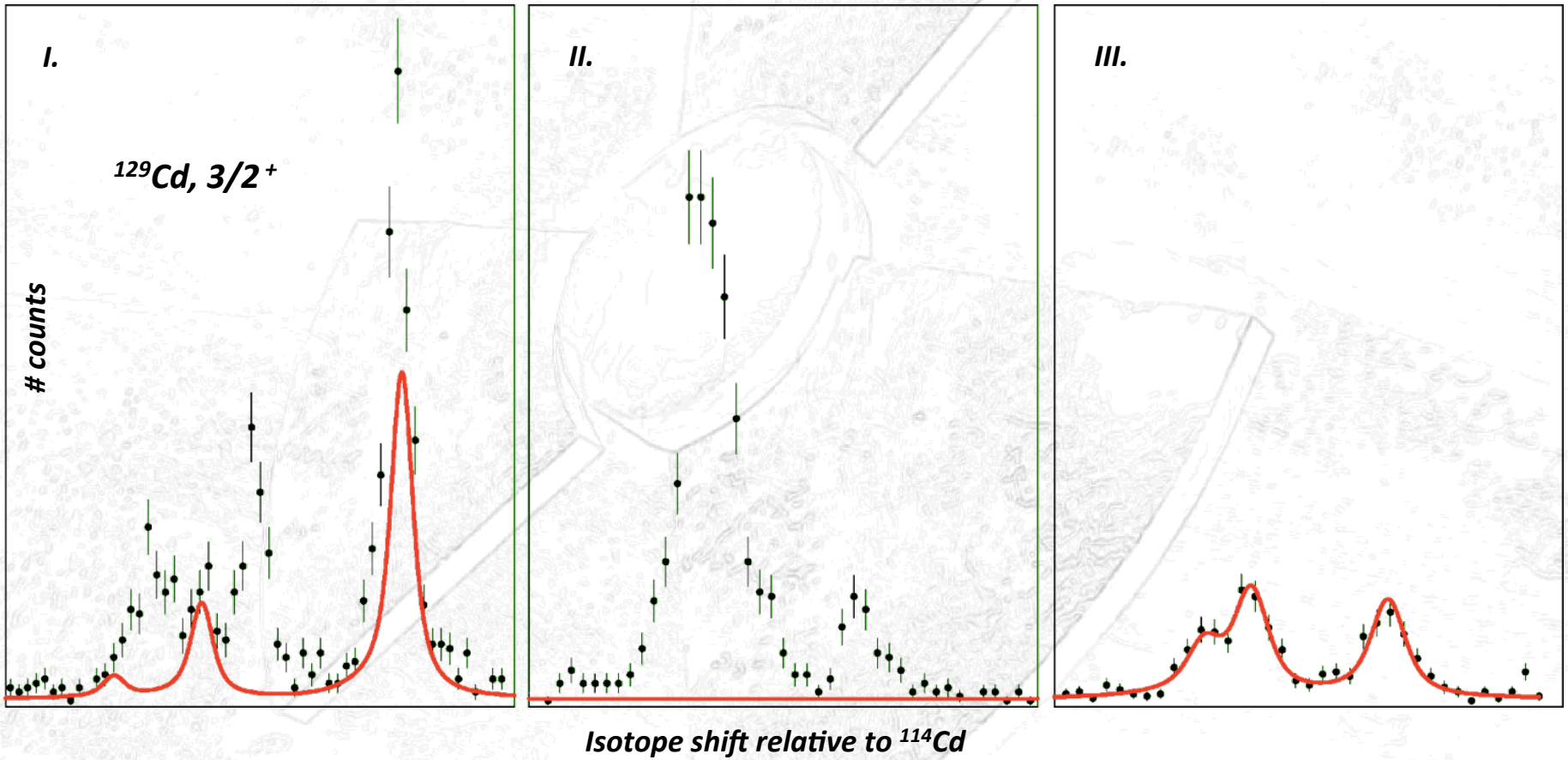
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Discovery of a long-lived isomeric state in ^{129}Cd



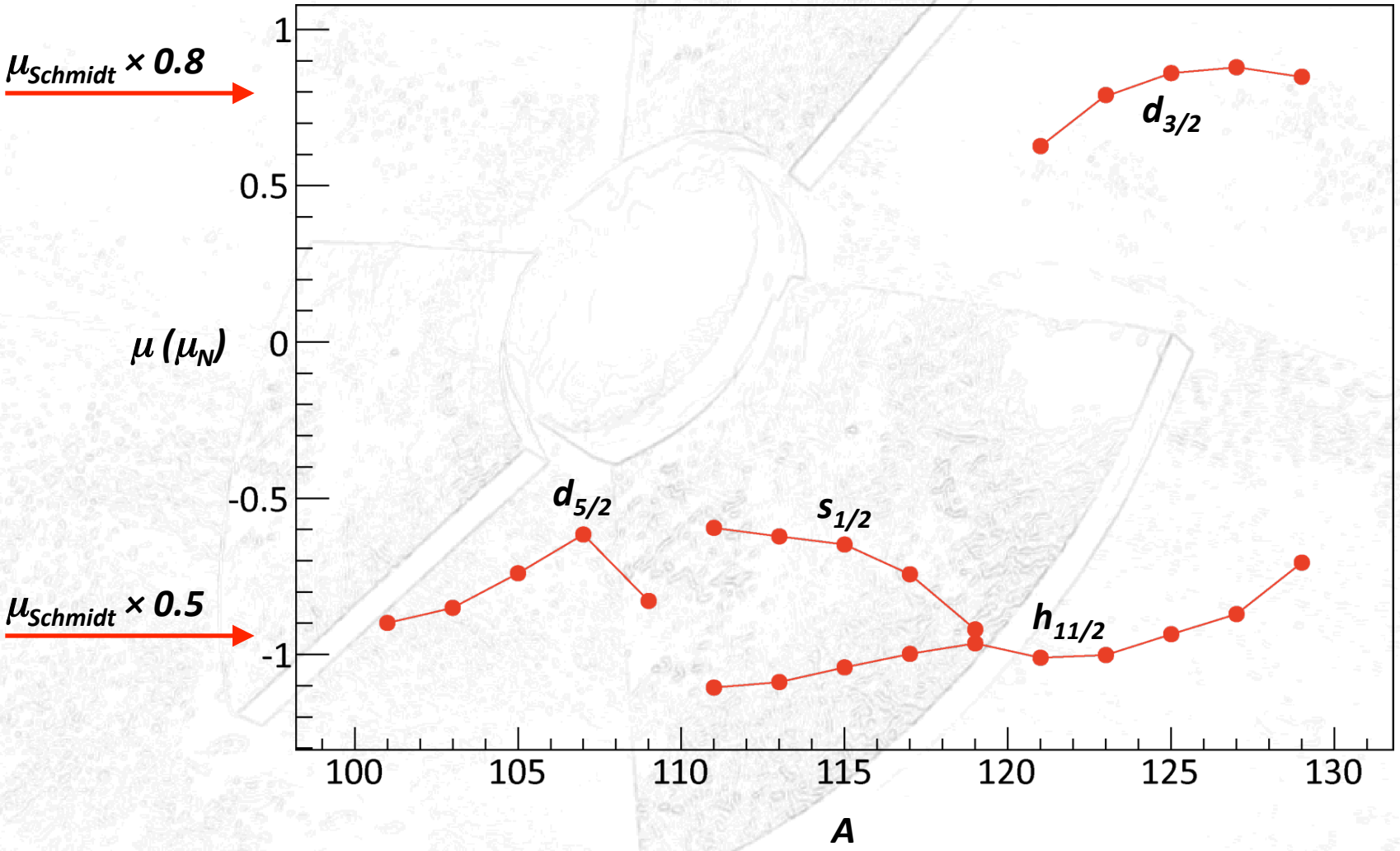
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Discovery of a long-lived isomeric state in ^{129}Cd



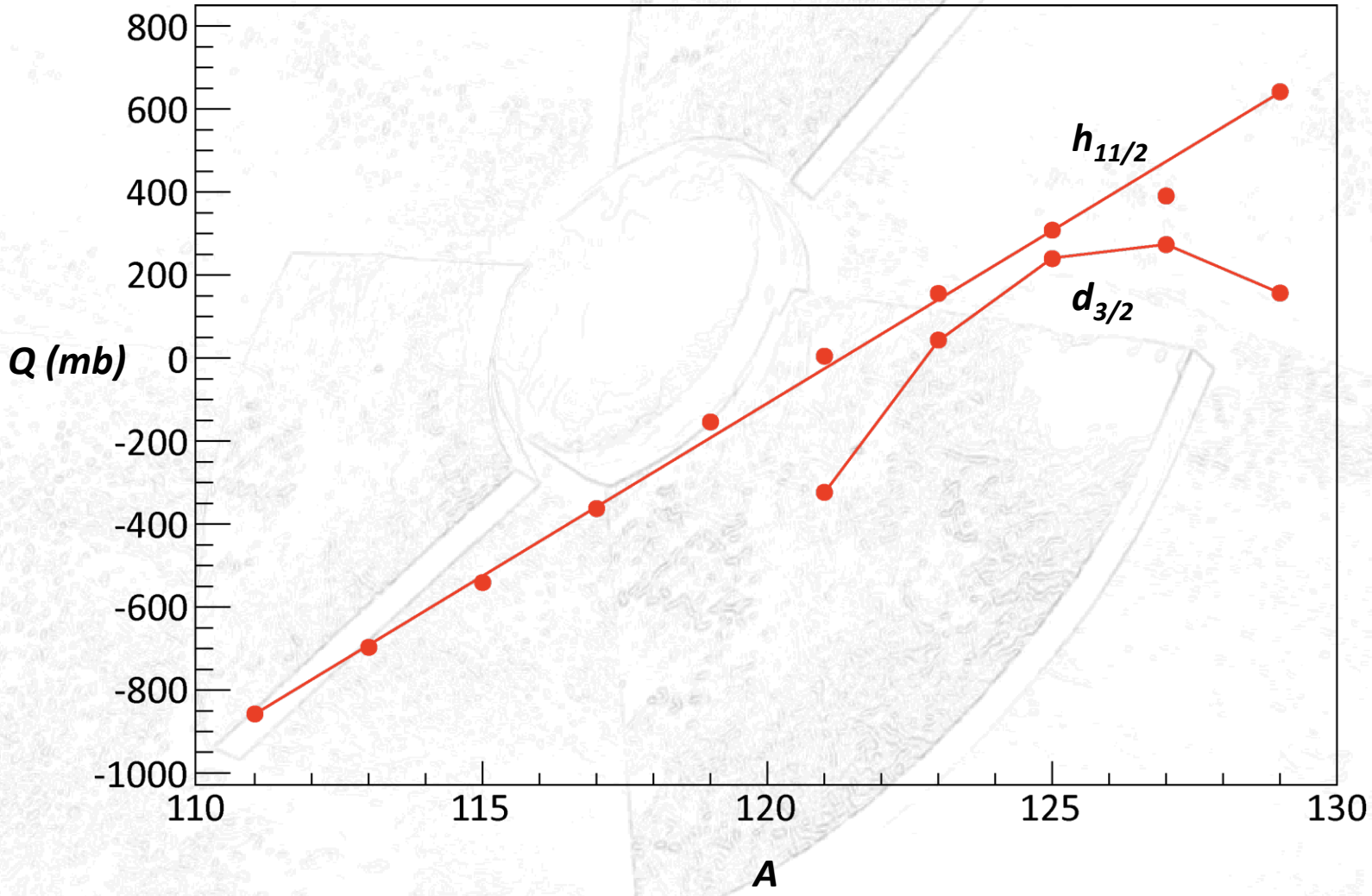
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Magnetic - moment systematics



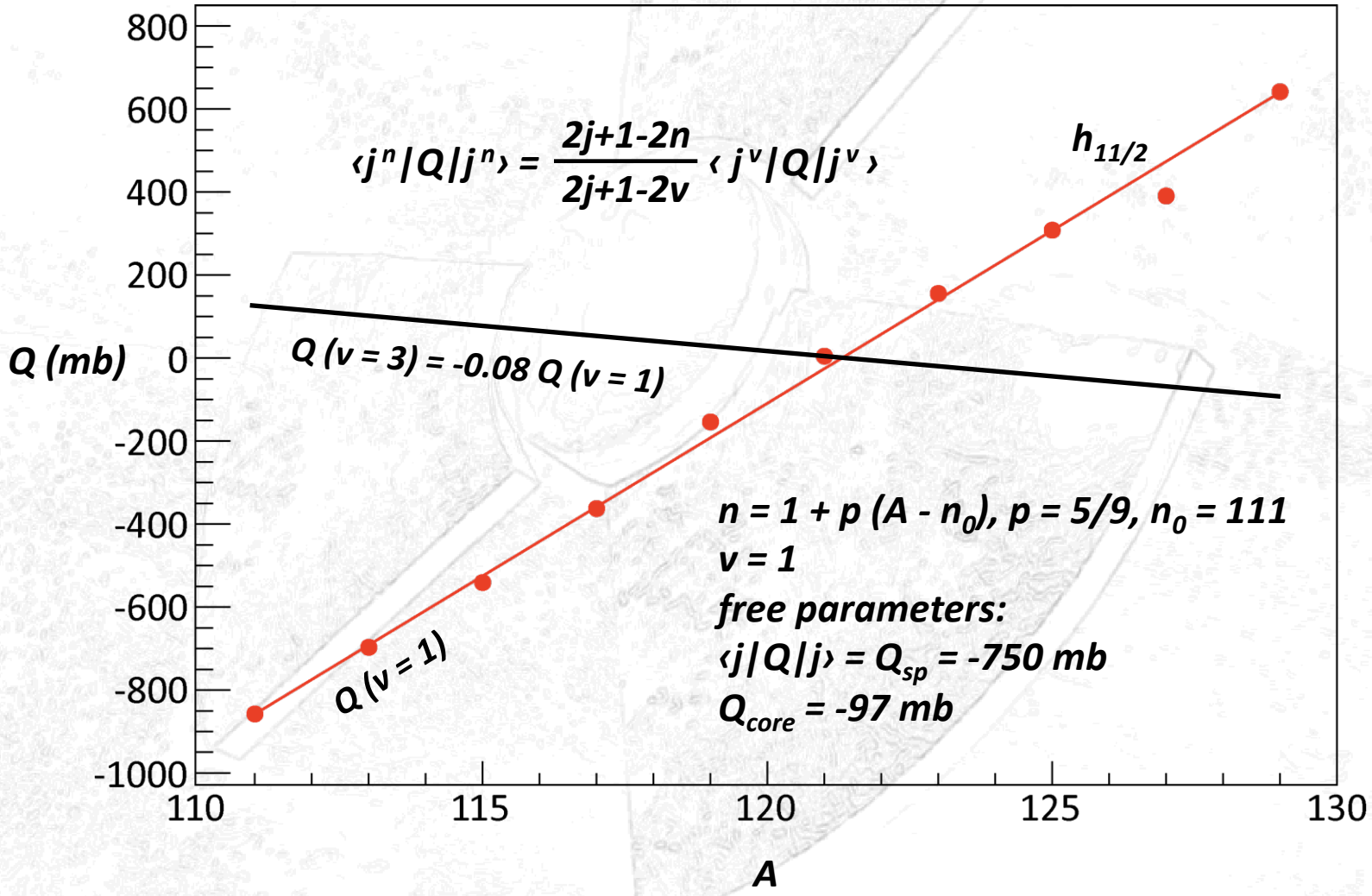
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Q - moment systematics



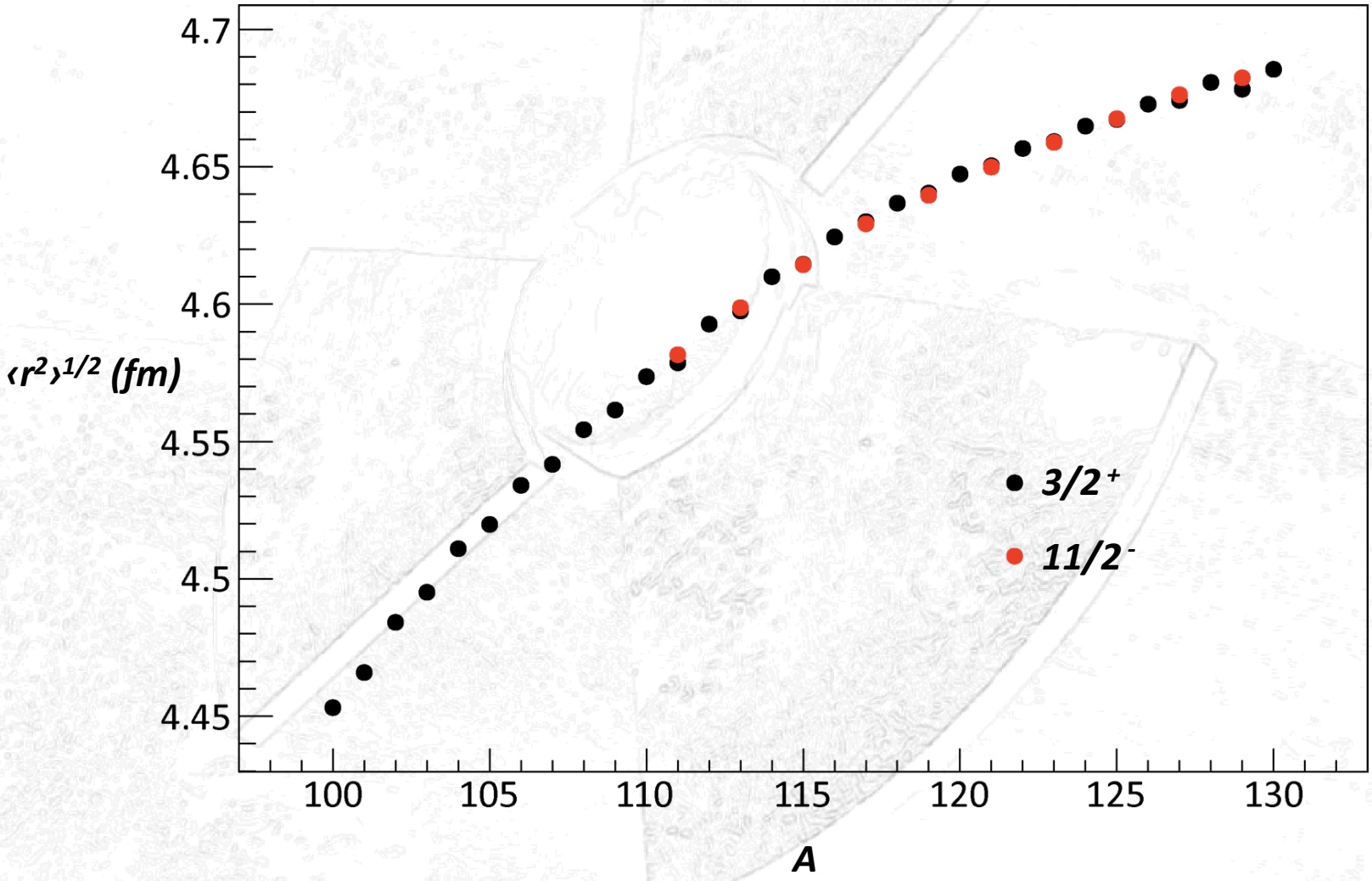
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Seniority scheme



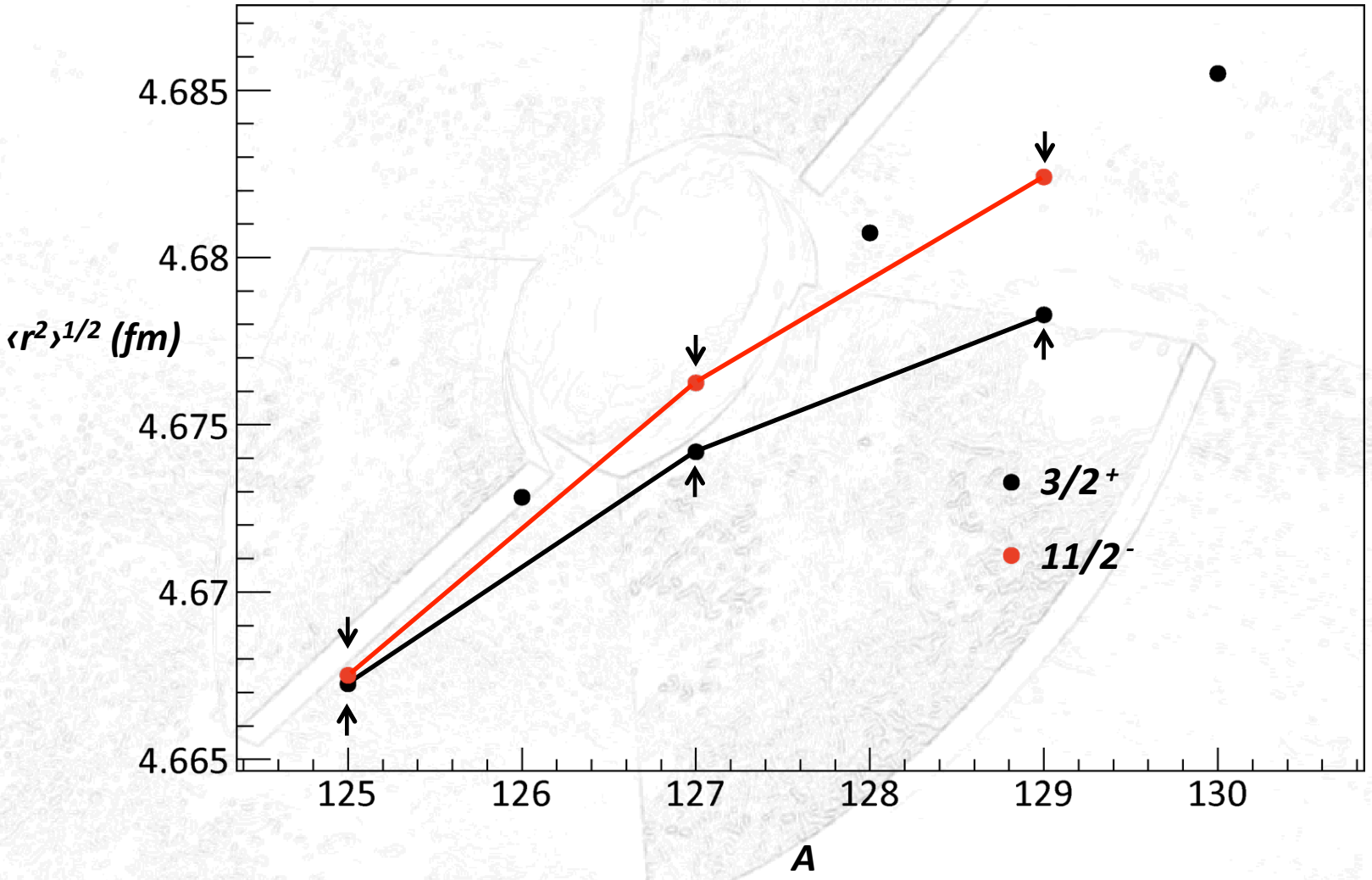
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Charge - radius systematics



MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Isomer shifts of ^{125,127,129}Cd



MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

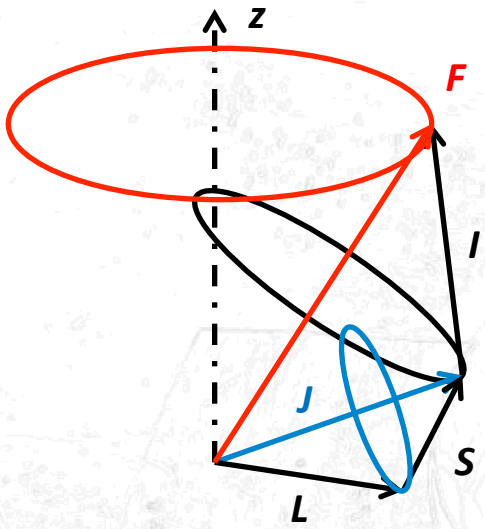
Summary

- Measured model independent I, μ, Q and $\langle r^2 \rangle$ of $^{100\text{-}130}$Cd
- First direct observation of long-lived isomers in $^{127, 129}$Cd
- Unique parity orbital - linear behavior of the $h_{11/2}$ Q moments
- g.s. - isomer size change towards N = 82

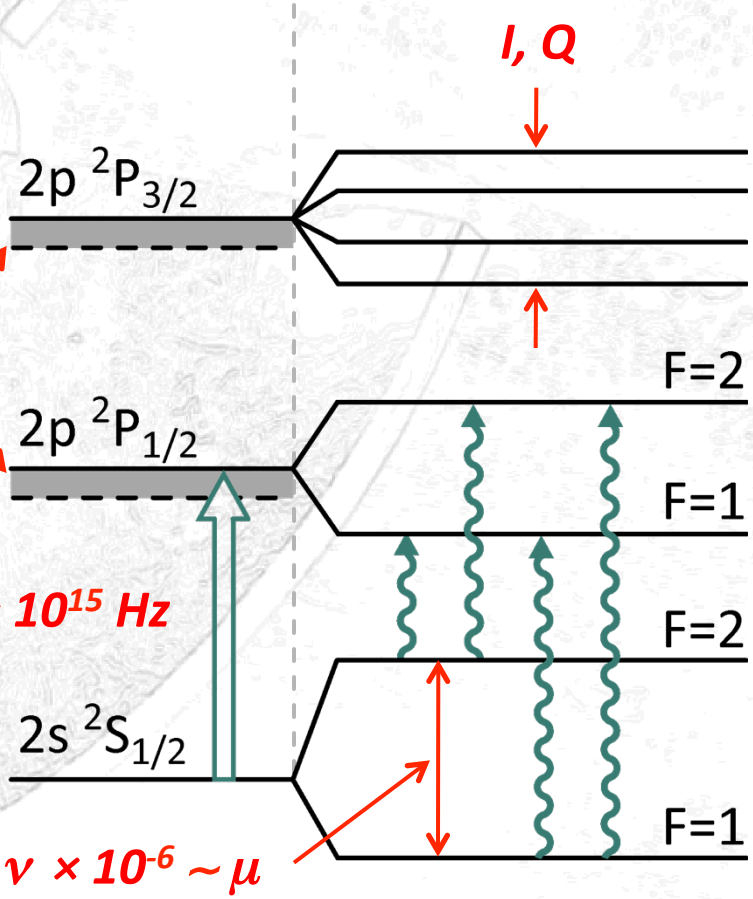
MAX-PLANCK-GESELLSCHAFT
Federal Ministry of Education and Research
ENSAR
Carl Zeiss Stiftung
IAP

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Hyperfine structure (HFS) → Laser Spectroscopy → Model Independent: I, μ, Q, $\langle r^2 \rangle$



$FS \rightarrow \vec{F} = \vec{I} + \vec{J} \rightarrow HFS$



$\delta\nu \approx \nu \times 10^{-6} \sim \langle r^2 \rangle$

$\nu \approx 10^{15}$ Hz

$\Delta E \approx \nu \times 10^{-6} \sim \mu$

Hyperfine parameters:

$A = g\mu_N\langle B(0)\rangle/J \qquad B = eQ\langle V_{JJ}(0)\rangle$

$g_1/g_2 = A_1/A_2 \qquad Q_1/Q_2 = B_1/B_2$

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Electromagnetic moments of the nucleus

General definition:

$$\mathscr{M}_{\lambda\mu=0} = \langle I, M = I | \sum_{k=1}^{A} \hat{T}_{\lambda\mu=0}(k) | I, M = I \rangle$$

Wigner-Eckart theorem:

$$\langle IM | \hat{T}_{\lambda\mu} | IM \rangle = (-1)^{I-M} \begin{pmatrix} I & \lambda & I \\ -M & \mu & M \end{pmatrix} \langle I || \hat{T}_{\lambda} || I \rangle \qquad 0 \le \lambda \le 2\,I$$

Magnetic-moment operator ($\lambda = 1$, $I \ge 1/2$):

$$\boldsymbol{\mu} = \mu_N \left(g_l^{t_z} \boldsymbol{l} + g_s^{t_z} \boldsymbol{s} \right) / \hbar$$

$$g_l^{\pi} = 1 \qquad g_s^{\pi} = 5.586$$

$$g_l^{\nu} = 0 \qquad g_s^{\nu} = -3.826$$

Quadrupole-moment operator ($\lambda = 2$, $I \ge 1$):

$$e\,Q_{zz} = e^{t_z} e \left(3z^2 - r^2 \right) = e^{t_z} e \sqrt{\frac{16\pi}{5}} r^2 Y_{20}(\boldsymbol{r})$$

Single-particle magnetic moments (Schmidt values):

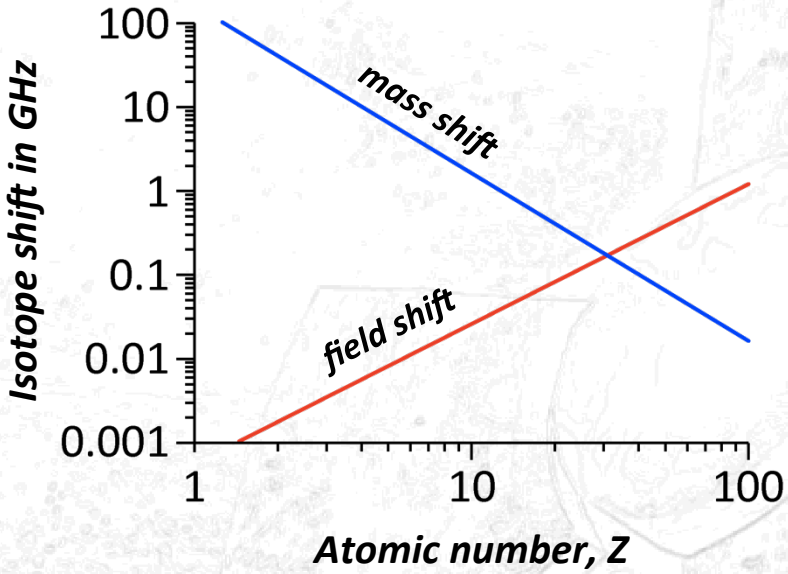
$$\mu = j \left(g_l^{t_z} \pm \frac{g_s^{t_z} - g_l^{t_z}}{2l+1} \right) \mu_N, \; j = l \pm \frac{1}{2}$$

Single-particle quadrupole moment:

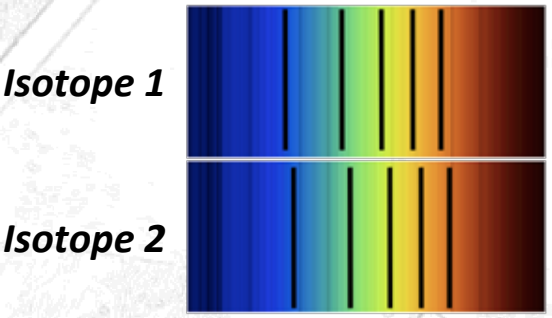
$$eQ = \mp \frac{2j-1}{2j+2} \langle r^2 \rangle \, e^{t_z} e$$

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Isotope shifts and nuclear rms charge radii



Absorption lines:



Field shift:
Finite nuclear size

Isotope shift: $$\delta\nu^{AA'} = K\,\frac{m_A - m_{A'}}{m_A\, m_{A'}} + F\;\delta\left\langle r^2\right\rangle^{AA'}$$

Mass shift:
Center of mass motion of the nucleus