Early onset of deformation in the neutron-deficient polonium isotopes identified by in-source resonant ionization laser spectroscopy

T.E. Cocolios, W. Dexters, M.D. Seliverstov, A.N. Andreyev, S. Antalic, A.E. Barzakh, B. Bastin, J. Büscher, I.G. Darby, D.V. Fedorov, V.N. Fedosseyev, K.T. Flanagan, S. Franchoo, S. Fritzsche, G. Huber, M. Huyse, M. Keupers, U. Köster, Yu. Kudryavtsev, E. Mané, B.A. Marsh, P.L. Molkanov, R.D. Page, A.M. Sjoedin, I. Stefan, J. Van de Walle, P. Van Duppen, M. Venhart, S.G. Zemlyanoy, M. Bender, P.-H. Heenen

Outline I

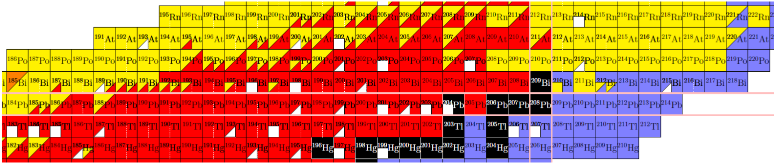
1. In-Source Spectroscopy at CERN's Isotope Separator On-Line DEvice

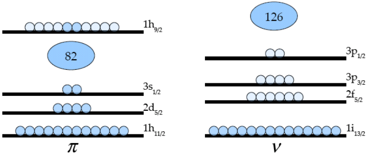
2. Shape coexistence in the neutron-deficient $_{84}$Po isotopes

3. Conclusions & Outlooks

Chart of the nuclides

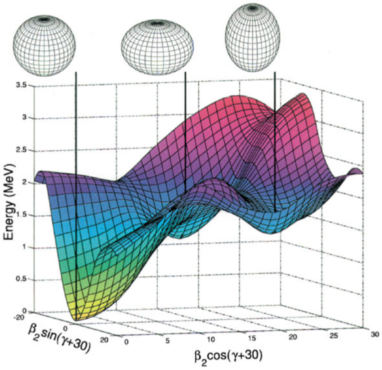
A large world to explore





Shape coexistence

around $_{82}$Pb isotopes



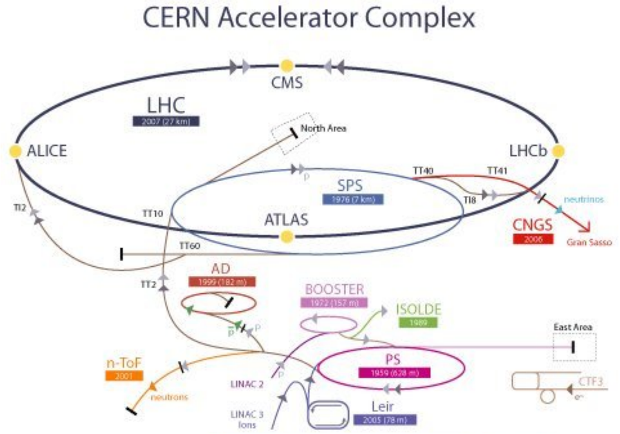
A.N. Andreyev et al., Nature 405(2000)430

- Shape coexistence = proximity of spherical and/or deformed shapes(s) at low energy ($E <$ few MeV)
- ^{186}Pb: most dramatic examples where the three lowest lying states are 0^+ states of three different shapes within less than 700 keV.
- More information in D. Jenkins presentation.

Outline

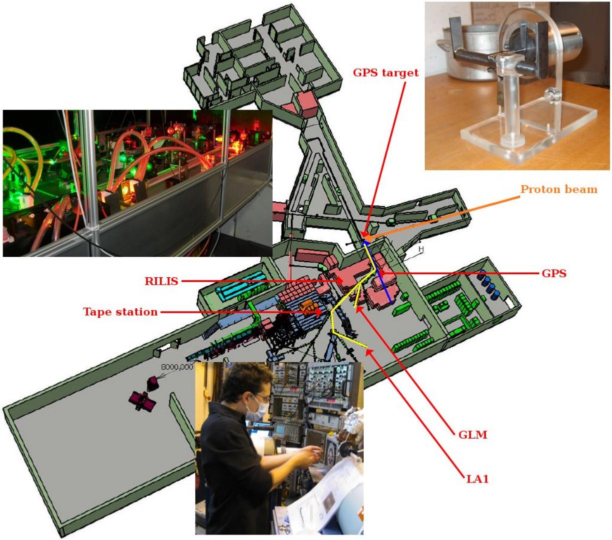
CERN ISOLDE

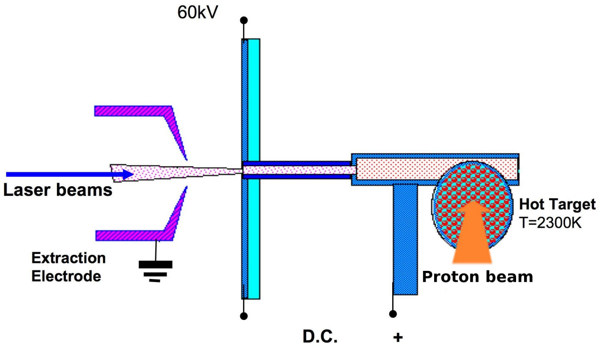
Isotope Separator On-Line DEvice



CERN ISOLDE

Isotope Separator On-Line DEvice

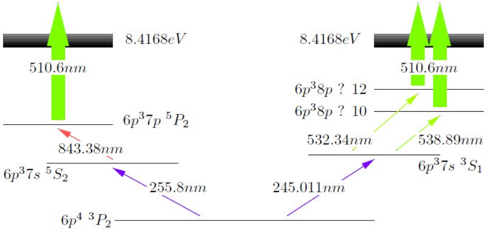




60kV
Laser beams
Extraction Electrode
Hot Target
T=2300K
Proton beam
D.C.
+

Laser ionisation of polonium

essential to all the polonium campaigns at ISOLDE



T.E. Cocolios, B.A. Marsh et al., NIMB 266(2008)4403

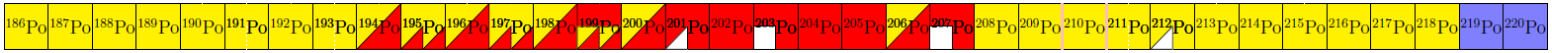
Challenges of a radioactive element

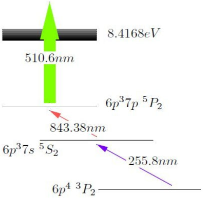
- No stable isotope ⇒ no off-live developments possible;
- 3 laser ionization schemes were successfully developed;
- *s*-electron has the necessary overlap with the nucleus.

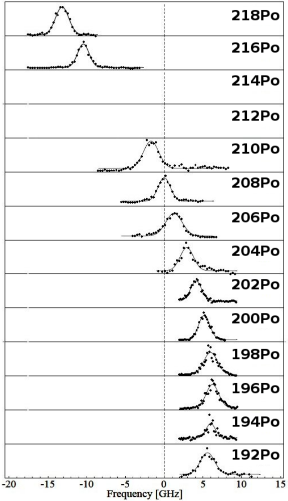
Outline

1. In-Source Spectroscopy at CERN's Isotope Separator On-Line DEvice
2. Shape coexistence in the neutron-deficient $_{84}$Po isotopes
3. Conclusions & Outlooks

In-source laser spectroscopy of Po
even-A isotopes



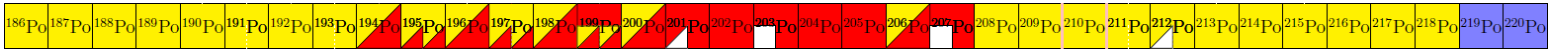


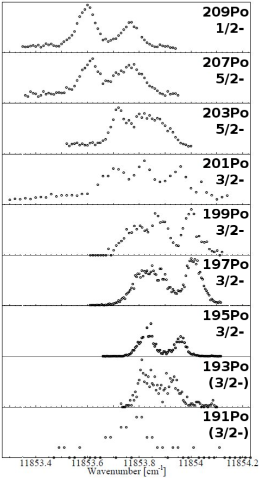


- from $A = 192$ up to $A = 218$;
- from $T_{1/2} = 33$ ms up to $T_{1/2} = 3$ yr;
- from 0.3 ion·s^{-1} to over 10^7 ion·s^{-1};
- using α, β, γ and ion (FC) counting.

In-source laser spectroscopy of Po

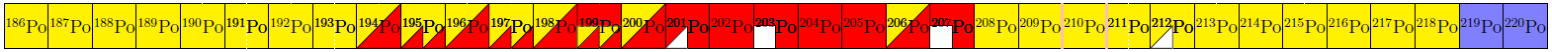
odd-*A* isotopes

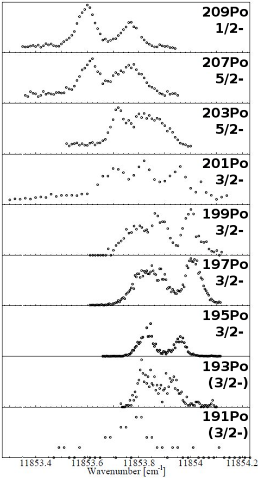


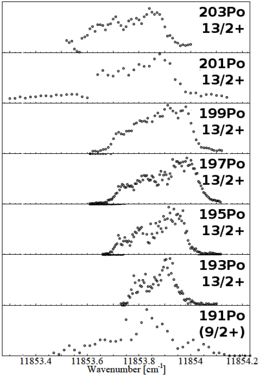


- $A = 191$ to $A = 211$;
- $T_{1/2} = 22$ ms to $T_{1/2} = 102$ years;
- 0.01 to over 10^7 ion$\cdot$s^{-1};
- long-lived high-spin $\left(\frac{13}{2}^+\right)$ isomers.

In-source laser spectroscopy of Po
odd-*A* isotopes

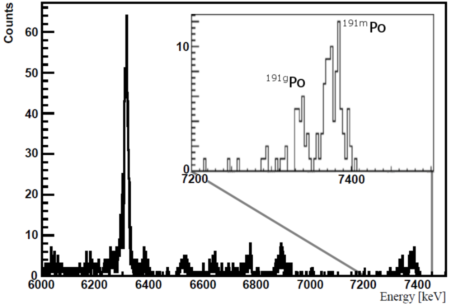






^{191}Po

Pushing the limits of the technique

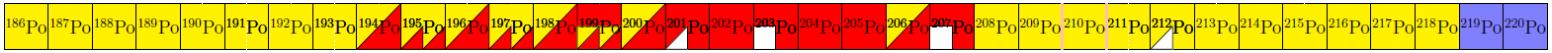


^{191}Po with only 0.01 ion·s^{-1}

- very limited production rates due to limited cross section and short half lives;
- sufficient resolution for clean identification via α decay;

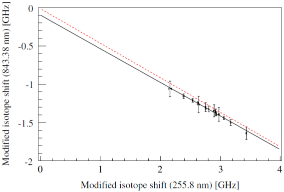
Extracting charge radii

King at play



$$\delta\nu^{AA'} = \frac{A'-A}{AA'} \cdot (m_e\nu + K_{SMS}) + 0.932 \cdot F \cdot \delta\langle r^2\rangle$$

$$\mu\delta\nu_2^{AA'} = \frac{F_2}{F_1} \cdot \mu\delta\nu_1^{AA'} + \frac{A'_{ref} - A_{ref}}{A_{ref}A'_{ref}} \cdot \left(K_{SMS2} - \frac{F_2}{F_1} \cdot K_{SMS1}\right)$$



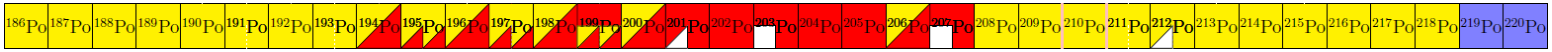
T.E. Cocolios, W. Dexters, M.D. Seliverstov et al., PRL 106(2011)052503

Large-scale atomic calculation by S. Fritzsche (GSI)

- F and K_{SMS} have been calculated;
- if the y intercept is left free, $\chi^2_\nu \sim 1$ can be reached

$\Rightarrow$ good $\frac{F_2}{F_1}$ but systematic uncertainty on K_{SMS}.

$\delta\langle r^2\rangle$
even-A isotopes



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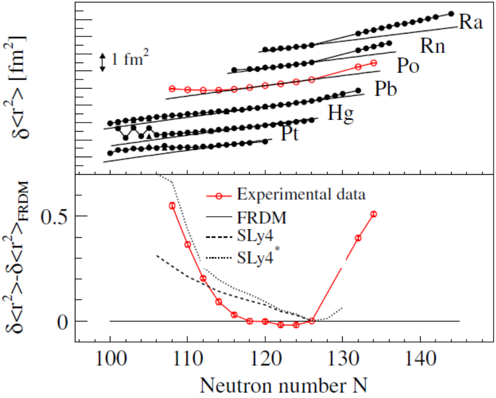
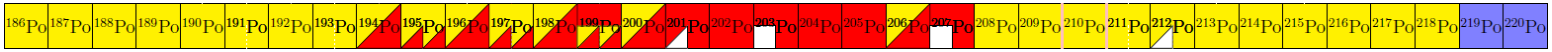
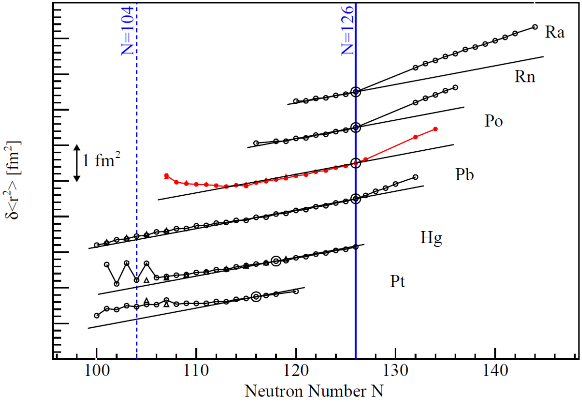


T.E. Cocolios, W. Dexters, M.D. Seliverstov et al., PRL 106(2011)052503

$\delta\langle r^2\rangle$
all isotopes

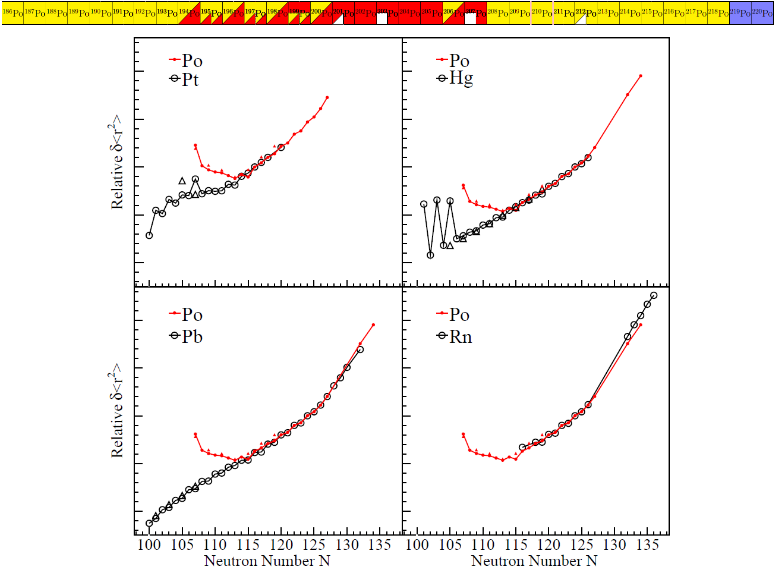




M.D. Seliverstov, T.E. Cocolios et al., in preparation

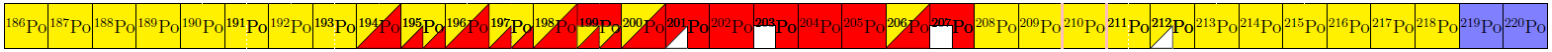
$\delta\langle r^2 \rangle$

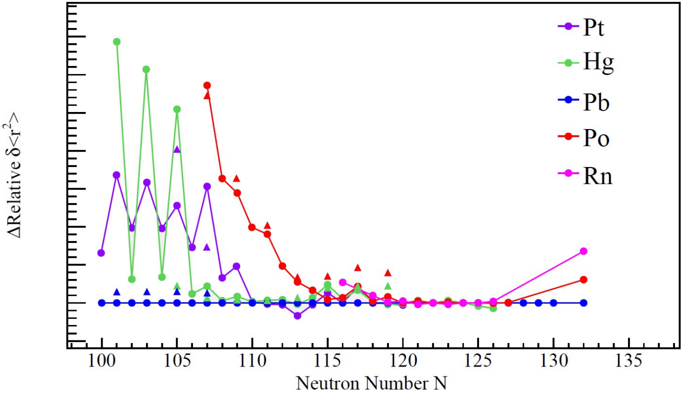
...compared to the neighbouring nuclei



$\delta\langle r^2\rangle$

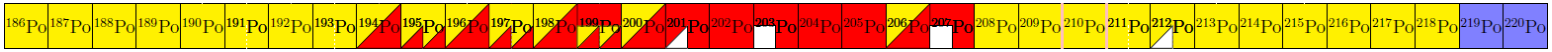
. . . compared to the neighbouring nuclei

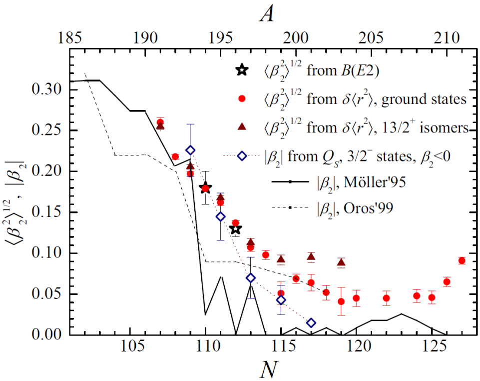




Deformation

Consistency check in the β_2 parameter





Outline

Conclusions I

from the in-source laser spectroscopy work

- clean beams of polonium are available (less than 1% contamination in beams of ^{200}Po);
- $\delta\langle r^2\rangle$ deviate early and strongly from the spherical droplet model;

$\Rightarrow$ large mixing between the ground and intruder configurations;

- some uncertainties on the spins challenge the previous nuclear spectroscopic conclusions.

Conclusions II

concerning shape coexistence around $Z = 82$

- $\surd$ low-energy excited 0^+ state in *even-even nuclei*;
- $\surd$ low-energy excited structure issued from coupling to those states in *odd-A nuclei*;
- $\surd$ shape of the ground state;
- ? excitability of the structure and excited levels quadrupole moments $\Rightarrow$ *Coulomb excitation*;
- ? single-particle strength in the different energy levels $\Rightarrow$ *transfer reactions*.

Outlooks

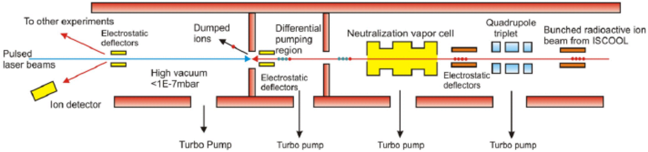
Things to look forwards to. . .

Shape coexistence in Po

- determine the spins of the most neutron-deficient isotopes with a higher resolution technique (CRIS);
- Coulomb excitation of ^{196,198,200,202}Po at REX-ISOLDE with MiniBall to determine $E2$ matrix elements and quadrupole moments (N. Kesteloot and B. Bastin);
- HIE-ISOLDE opens new opportunities for transfer reactions on those nuclei.

CRIS

Collinear Resonant Ionization Spectroscopy

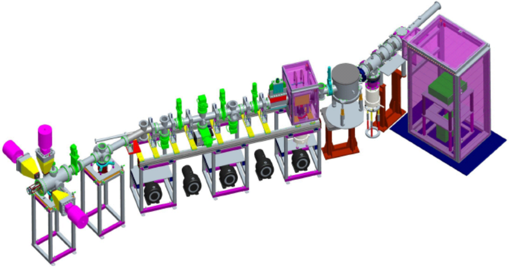


CRIS concepts

- Collinear ⇒ Doppler compression of the velocity distribution for *resolution*.
- Resonant Ionisation ⇒ efficient selection of the beam of interest for *sensitivity*.

CRIS

Collinear Resonant Ionization Spectroscopy



Achievements

- CRIS is being developped and tested at CERN ISOLDE.
- vacuum of $\sim 10^{-9}$ mbar achieved at the interaction region.
  $\Rightarrow$ non-resonant background suppressed by 1:50 000 on-line.
- Further suppression can be achieved if ionising ions to a X^{++} state.

Collaboration

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