Shape effects along the Z=82 line: study of the beta decay of $^{186,188}$Pb


Addendum to ISOLDE Experimental Proposal IS440 CERN-INTC-2011-004, INTC-P-199-ADD-1
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General Motivations
(IS440 + Addendum)

• Neutron deficient Pb isotopes have been the subject of intensive exp. and theoretical work (shape coexistence, see for example $^{186,188}$Pb)

• Theoretical calculations by P. Sarriguren et al. show that the GT strength distributions show clearly different patterns depending on the deformation of the parent nucleus (PRC 72 (2005) 054317, PRC 73 (2006) 054317)

• Based on similar theoretical results for the A≈80 region, we have been able to determine the deformation of $^{74}$Kr and $^{76,78}$Sr by means of the TOTAL ABSORPTION TECHNIQUE (TAS)

• Preliminary results of the IS440 show the potential of the technique in this region
Theoretical Background of the Shape Coexistence Phenomenon (quick overview)

- In the shell model picture: intruder $0^+$ states are interpreted as two- and four-quasiparticle configurations.

- Phenomenological mean field models and Strutinsky method predict the existence of several competing minima in the deformation surface of these nuclei.

- Self-consistent mean field calculations and calculations including correlations beyond the mean field with Skyrme and Gogny forces confirm these results.

- The problem has also been studied in the framework of the IBM.
Hartree-Fock calculations: $^{184-194}$Pb
(P. Sarriguren et al. PRC 72 (2005) 054317)

- Hartree-Fock mean field calculations using an effective two-body Skyrme interaction and including pairing correlations in the BCS approximation. In this framework single part. energies, wave functions and occupation probabilities are generated from the mean field.

- Two forces were considered: Sk3 and SG2

- Different profiles depending on the shape

- One important result: the profiles of the B(GT) distributions for the different deformations are not dependent on the forces and on the pairing interactions used $\Rightarrow$ the B(GT) profile is characteristic of the shape

(O. Moreno et al., PRC 73 (2006) 054317) used SLy4, res. sim.)
How to measure the $B(GT)$

\[ B(GT) = \frac{1}{2j_i+1} K \phi_i \left[ \sum \sigma_{\ell} e^{-\gamma_{\ell}} \phi_{\ell} \right]^2 = (\alpha \tau)^2 \]

Theoretical quantity

Strength function

Beta feeding

Half life of parent

Fermi function

Relationship
Total absorption spectroscopy

Ideal case: beta minus decay, and no contamination. There is need for a 100% efficient summing device.

\[ d = R(B)f \]
Total Absorption Spectroscopy

Real case: two processes in the beta plus/EC case.
We need to distinguish between them.
Total absorption spectroscopy

Solution: use of coincidences with ancillary detectors

After an ideal deconvolution and sum

\[ E_2 \]

\[ I_\beta \]
Lucrecia, Total Absorption Gamma Spectrometer at CERN

- A large NaI cylindrical crystal 38 cm Ø, 38cm length
- An X-ray detector (Ge)
- A β detector
- Collection point inside the crystal
Lucrecia, the TAS at ISOLDE

Analysis is difficult

d = R(B).f

Method of analysis developed by the Valencia group

NIM A 571, 710 (2007)
NIM A 571, 728 (2007)
Very prolate  \( N=Z \) nucleus

Mixture of prolate and oblate

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Ground state of 76Sr prolate \((\beta_2 > 0.4)\) as indicated in Lister et al., PRC 42 (1990) R1191

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Ground state of 74Kr: \((60\pm8)\%\) oblate, in agreement with other exp results and with theoretical calculations (A. Petrovici et al.)
Experimental Motivations

• New insight into the problem of shape coexistence in the region. “Independent way” to study the problem since it does not depend on assumptions made in other nuclei except for the gs. It is also complementary to other studies (isotope shift, charge radii).

• Our measurements can validate the application of this method in this region. Future studies of Pt, Hg, Po cases.

• Proper measurements of the B(GT) offer means to test further nuclear models in this region.

• Exploit the availability of more pure beams (RILIS)
Objective: Pb-s are expected to be spherical. Our idea was to confirm the viability of the method in the region for later extending it to other cases of interest (Hg, Pt, Po cases)
Summary of IS440

15 shifts were requested to study the beta decay of $^{188,190,192}\text{Pb}$.

7 shifts were approved to show the viability of the study.

6 (5 according to my counting) shifts were used to measure $^{188,190,192}\text{Pb}$ using the TAS in coincidence with X-rays of the Tl daughter isotopes (EC component). 1 shift was not used (2?).

Analysis of $^{190,192}\text{Pb}$ is practically finished. The analysis of $^{188}\text{Pb}$ requires a better knowledge of the level scheme from high resolution. These analyses are part of the thesis of E. Estevez, that should be finished this year.
IS440 preliminary results: $^{190,192}$Pb

Preliminary results consistent with spherical picture, less impressive than in the $A \approx 80$ region. Calculations may require fine-tuning.


Theory from PRC 72, 054317 (2005)
Experimental Details (Addendum)

We propose to use the Laser Ion Source RILIS to clean the nuclear species of interest and UCx/graph target with Ta ionizer.

TAS technique in combination with ancillary detectors, new feature: the addition of a particle telescope (dE-E)

Analysis of the EC component (coincidence with X-rays) with the programs and algorithms developed by the Valencia Group

High resolution measurements are required (separate experiment), to provide data for the TAS analysis and they are interesting in itself.
Beam request for the addendum

6 shifts are required for the TAS measurement of the $^{186}$Pb isotope (estimated to reach 400000 counts in the EC spectrum with a 3% Pb purity of the beam using RILIS).

2 shifts are required for the measurement of the daughter activities of $^{186}$Pb (TAS) and background.

2 shifts are required for the TAS measurement of the $^{188}$Pb isotope (beta delayed p- emission in combination with the TAS).

1 shift is required for the on-line calibration using the $^{24}$Na (TAS)

2 shifts are required for the $^{188}$Pb high-resolution measurement.

6 shifts are required for the $^{186}$Pb high-resolution measurement.
<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half life</th>
<th>EC branch (%)</th>
<th>Sp (keV)</th>
<th>$Q_{EC}$ (keV)</th>
<th>Status</th>
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<td>4.82(3) s</td>
<td>60(8)</td>
<td>1303(185)</td>
<td>5509(185)</td>
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<td>25.1(1) s</td>
<td>90.7(8)</td>
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<td>99.6(4)</td>
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<td>$^{192}$Pb</td>
<td>3.5(1) min</td>
<td>99.9941(7)</td>
<td>2570(40)</td>
<td>3320(30)</td>
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</table>
Thank you
Spare Slides
Mixing prediction
Fossion et al. PRC 73 (2006) 054317, within IBM

<table>
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<tr>
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<th>Configurations</th>
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<td>$0_{2}^{+}$</td>
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<td>71</td>
<td>57</td>
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The B(GT) Profiles I

$^{190}\text{Pb}$

$^{188}\text{Pb}$

spherical

oblate

$Q_{EC}$
The B(GT) Profiles II

$^{192}\text{Pb}$

spherical

oblate

$Q_{EC}$
## Experimental details IS440

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Beamtime Requirements (IS440)

- **Target**: UCx/graphite target with a Nb surface ionization ion source (U. Köster et al. NIM B 204 (2003) 347)

- RILIS is required

- 9 shifts are required for the $^{188-192}$Pb isotopes (TAS, TAS & β-delayed particles)

- 3 shifts are required for measuring the daughter activities

- 2 shifts are required for the $^{188}$Pb high resolution measurement

- 1 shift is required for the on-line calibration ($^{24}$Na source)
Theoretical calculations predict different B(GT) distributions for oblate, prolate and spherical shape of the ground state.


Followed up by Sarriguren and collaborators and Petrovici and collaborators
Preliminary results: $^{190}\text{Pb}$

Preliminary results: $^{192}\text{Pb}$

Theory from PRC 72, 054317 (2005)
Preliminary results consistent with spherical picture.
Calculations may require fine-tuning
In order to properly analyse Ta's data, one needs some high resolution data. And the electron conversion information.

\[ ^{78}\text{Sr} \] needed a larger effort due to the lack of experimental information.

Clearly prolate

\[ ^{78}\text{Sr} \]

Similarly, \[ ^{72}\text{Kr} \] analysis needed complementary information and the analysis is still in progress.

A. Pérez
Ph. D thesis Valencia (almost finished)

J.A. Briz
Ph.D thesis Madrid
The decay of $^{188}\text{Pb}$: what is presently known

**Decay Scheme**

Intensities: $I(\gamma + ce)$ per 100 parent decays

$^{188}_{82}\text{Pb}_{106} \rightarrow 0^+ 0.0 25.1 \text{ s}$

$\%e^+\%B^+=90.78$

$Q^+=4420^{140}$

<table>
<thead>
<tr>
<th>$I\beta^+$</th>
<th>$I\epsilon$</th>
<th>Log $ft$</th>
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<td>27</td>
<td>4.6</td>
</tr>
<tr>
<td>17</td>
<td>40</td>
<td>4.6</td>
</tr>
</tbody>
</table>

$^{188}_{81}\text{Tl}_{107}$
Intruder 0+ states in $^{186}$Pb

A. N. Andreyev et al.
Nature 405 (2000) 430
A=186: what is presently known
A=185: what is presently known
Very preliminary results: $^{188}\text{Pb}$

Theory from PRC 72, 054317 (2005)
Preliminary results consistent with spherical picture.
Calculations may require fine-tuning.
The first two proposals IS370 and IS398, were focused in deducing the deformation of the Ground state of neutron deficient Sr (Z=38) and Kr (Z=36) isotopes from the B(GT) distribution of their $\beta^+$ decay. Strong oblate-prolate competition and rapid shape changes.

To extract information on the sign of the deformation is not easy.