Grupo de Física Nuclear Experimental

Deformation of the N=Z nucleus ^{72}Kr via beta decay

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for the IS370 collaboration

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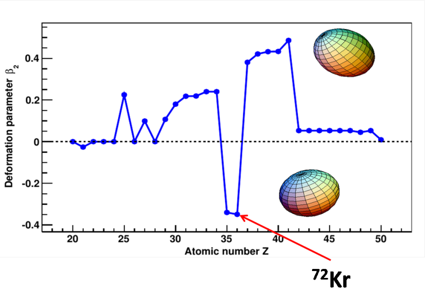
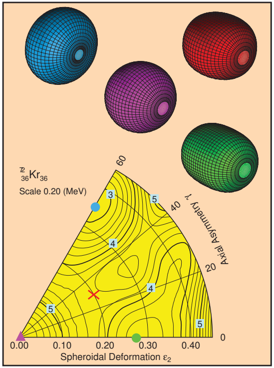
Motivation: Why $^{72}_{36}Kr_{36}$?

Only ^{70}Br and ^{72}Kr predicted oblate deformed in the N=Z line from A=40 up to A=100.

Predictions of **shape coexistence** in ^{72}Kr: *"the poster child of nuclear shape isomers"*

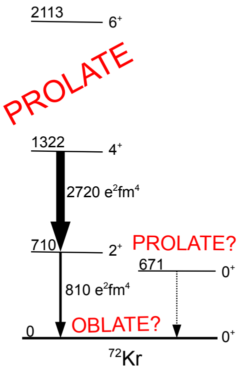




P. Möller et al., At. Data and Nucl. Data Tables 59, 185 (1995)

P. Möller et al., Phys. Rev. Lett. 103, 212501 (2009)

Motivation: Why $^{72}_{36}\mathrm{Kr}_{36}$?



- ^{72}**Kr ground state predicted oblate** deformed [Naz85,Mol95].
- **High spin states** interpreted as a **prolate** band [DeA97]
- **First excited 0^+ state**: shape isomer **head of the prolate band** [Bou03]. Mixing λ=0.1 with the 0^+ oblate gs (two-level calculation).
- B(E2;$0_1^+ \rightarrow 2_1^+$) = 4997(647) e^2fm^4 [Gad05] $\rightarrow$ $|\beta_2|$**=0.330(21)**.

  $\searrow$ B(E2;$2_1^+ \rightarrow 0_1^+$) = 999(129) e^2fm^4
- IS478 experiment (spokeperson B.S. Nara Singh, Univ. York) at ISOLDE (CERN) of ^{72}Kr Coulex whose **preliminary** results indicate **2_1^+ state is prolate** deformed.
- Recent results already shown today in H. Iwasaki talk [Iwa14]:

  B(E2, $4_1^+ \rightarrow 2_1^+$) = 2720(550) e^2fm^4 $\rightarrow$ **2_1^+ Prolate**;

  B(E2, $2_1^+ \rightarrow 0_1^+$) = 810(150) e^2fm^4 $\rightarrow$ Small overlap between 0^+ and 2^+ w.f.

  $\frac{\mathbf{B(E2;4_1^+ \rightarrow 2_1^+)}}{\mathbf{B(E2;2_1^+ \rightarrow 0_1^+)}}$**=3.4**; 1.43 (rotor) and 2.0 (vibrator).

However, **no evidence on the sign of the ground state deformation** (prolate or oblate).

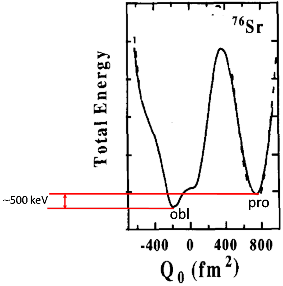
[Naz85] W. Nazarewicz *et al.*, Nucl. Phys. **A435**, 397 (1985)
[Mol95] P. Möller *et al.*, At. Data Nucl. Data Tables **59**, 185 (1995)
[DeA97] G. de Angelis *et al.*, Phys. Lett. B **415**, 217 (1997)
[Bou03] E. Bouchez *et al.*, Phys. Rev. Lett. **90**, 082502 (2003)
[Gad05] A. Gade *et al.*, Phys. Rev. Lett. **95**, 022502 (2005)
[Iwa14] H. Iwasaki *et al.*, Phys. Rev. Lett. **112**, 142502 (2014)

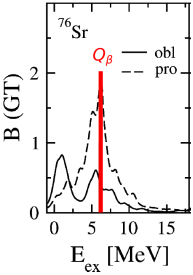
Determination of nuclear shape via B(GT) distributions

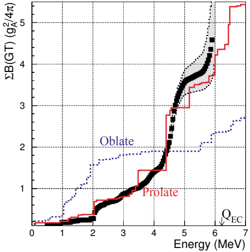
GT strength distributions found to **depend sensitively on the nuclear shape** (quadrupole deformation) for ^{80}Zr, ^{76}Sr and ^{72}Kr [Ham95].

Mean field calculations [Sar99] and [Sar01] predict **different B(GT) distributions for different deformations of the ground state of the parent nucleus**.

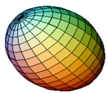
^{76}Sr (next N=Z even-even nucleus)







Prolate



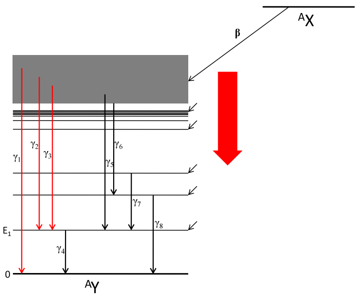
[Ham95] I. Hamamoto et al., Z. Phys. A353, 145 (1995)

[Sarr99] P. Sarriguren et al., Nucl. Phys. A658, 13 (1999)

[Sarr01] P. Sarriguren et al., Nucl. Phys. A691 631 (2001)

[Nac04] E. Nácher et al., PRL 92 232501 (2004)

Determination of the beta feeding distribution



C.L. Duke *et al.*, Nuclear Physics **A151**, 609 (1970)
B. Rubio *et al.*, J. Phys. G 31, S1477 (2005)

- **High density of levels** for high excitation energies causing **very fragmented feeding distribution and de-excitation pattern**
- **Low photopeak efficiency** for high energy gammas with HPGe detectors
- Apparent strength is located at lower energies
- **As a result**: overestimated strength at low excitation energies and underestimated for high excitation energies

Pandemonium effect
J.C. Hardy *et al.*, Phys. Lett. 71B, 307 (1977)

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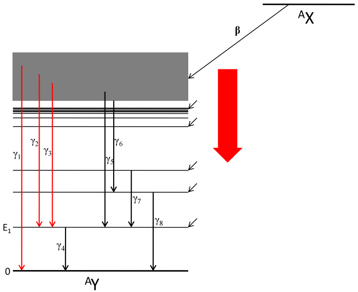

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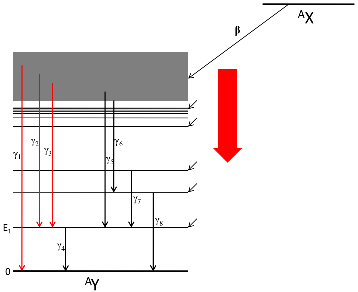

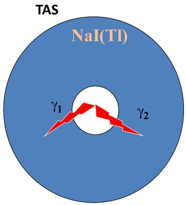

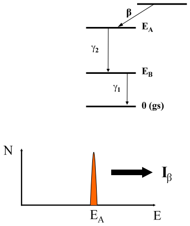

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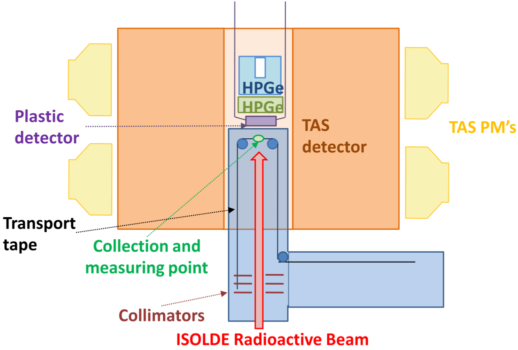
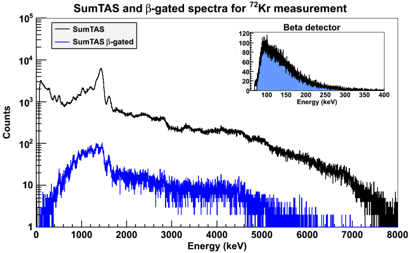
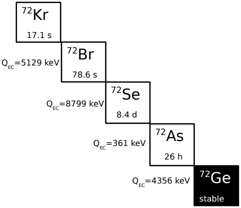
TAS experimental setup







Reduced statistics in β-gated spectrum due to:

- **Geometric efficiency of beta detector**: $\approx 16\ \%$
- **Room background** suppressed by shielding components and coincidence condition.

TAS data analysis

- **Experimental data (d)** is the result of the convolution of **Response function (R)** of TAS detector and the **feeding at a certain level (f)**:

$$d(i) = \sum_j R(i,j) \otimes f(j) + contam.$$

- Solve the **Inverse problem** with the *Expectation-Maximization Algorithm [Dem77]*:

$$f^s(j) = \frac{1}{\sum_i R(i,j)} \sum_i \frac{R(i,j) f^{s-1}(j) d(i)}{\sum_j R(i,j) f^{s-1}(j) + contam.}$$

  f^0 is chosen as an uniform feeding distribution.
  The application of this algorithm to the TAS problem is explained in detail in [Tai07]
  Relative gamma transition intensities measured with the HPGe detector are included in *d(i)*.

  Through this methodology we try to **reproduce both**:

  - the **TAS experimental spectrum** and
  - the **relative gamma transition intensities**.

[Dem77] A. P. Dempster *et al.* J. R. Statist. Soc. B 39 (1977) 1
[Tai07] J. L. Taín, D. Cano-Ott Nucl. Inst. and Meth. A 571, (2007) 719 and 728

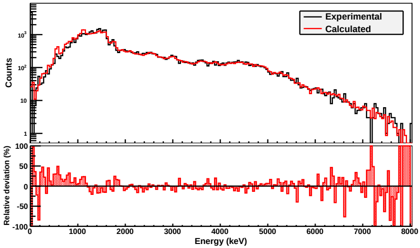
- **RESPONSE MATRIX (R)** is obtained from Monte Carlo simulations (GEANT4) and decay scheme information (High Resolution information available+Statistical Models).

Beta gated analysis: Check of goodness

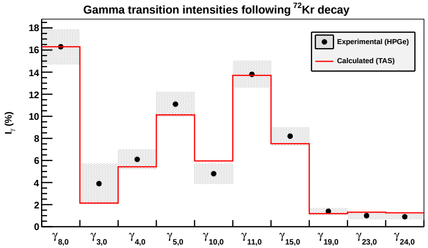
Check of results:

Reproduction of experimental TAS spectrum:

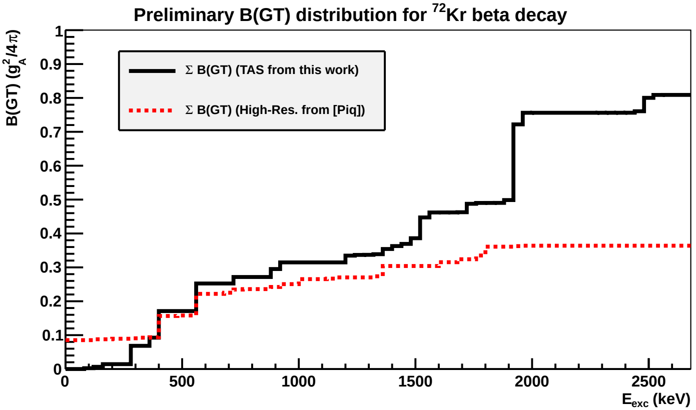
$$\mathbf{d(i)} = \sum_j R(i,j) \otimes f(j) + contam.$$



Reproduction of gamma transition intensities measured with HPGe detector (10 most intense lines reaching the ground state).



Result from first set of data

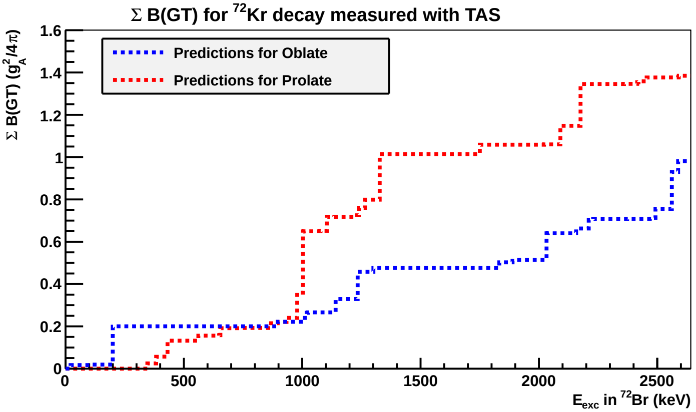


Result from the analysis of only a set of data, not full statistics.

Evidence of "Pandemonium effect"

[Piq] I. Piqueras *et al.*, Eur. Phys. J. A **16**, 313-329 (2003)

Comparison with theoretical predictions (QRPA)



QRPA approach using the SLy4 Skyrme-type force for the oblate and prolate minima in the ^{72}Kr potential energy surface. An standard quenching factor of 0.77 is used [Sar09].

[Sar09] P. Sarriguren, Phys. Rev. C **79**, 044315 (2009)

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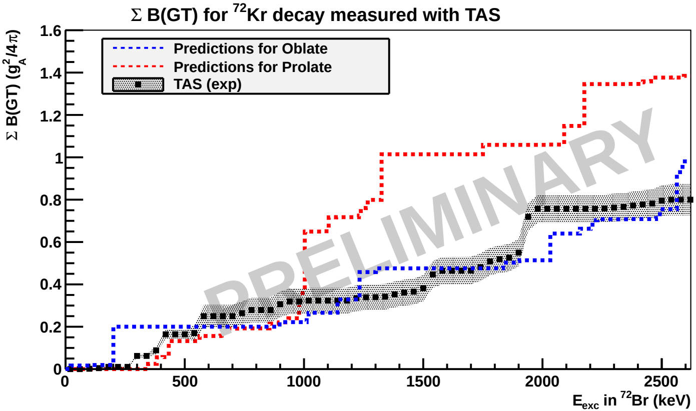

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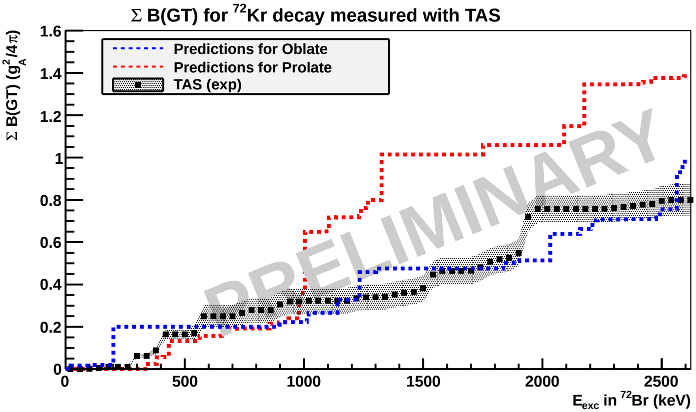

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Preliminary results suggest:
First experimental evidence of the negative sign of quadrupole moment of ^{72}Kr gs $\rightarrow \beta_2 < 0$.
First time an oblate deformed gs has been inferred from the B(GT) distribution of its β decay.

Oblate minimum corresponds to $\beta_2 \approx -0.176$ (th.)

[Sar09] P. Sarriguren, Phys. Rev. C **79**, 044315 (2009)

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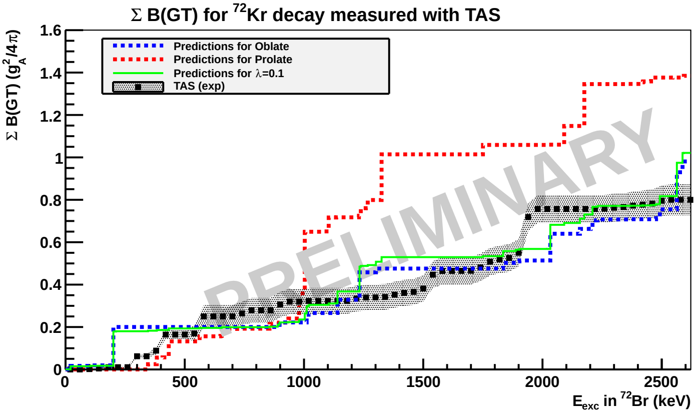


Preliminary results are compatible with 10 % mixing[1] [Bou03] with the prolate 0^+ excited state but no improvement is observed.

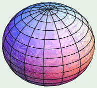
[Sar09] P. Sarriguren, Phys. Rev. C **79**, 044315 (2009)

[Bou03] E. Bouchez et al., Phys. Rev. Lett. **90**, 082502 (2003)

[1] The distribution for 10 % mixing ratio is a rough estimation to guide the eye (0.1 times the value of B(GT) for prolate minimum plus 0.9 times the value for the oblate minimum) and not strictly an appropriate calculation.

Conclusions

1. The preliminary results from our study suggest a **dominantly oblate deformation of the ^{72}Kr in the ground state**.



2. Preliminary, we conclude that it is the **first** time an **oblate deformed gs** has been **inferred from the B(GT) distribution** of its β decay. **First experimental evidence of the sign of the deformation** (and the intrinsic quadrupole moment) of the ^{72}**Kr** ground state.

3. The preliminary experimental B(GT) distribution **does not exclude a certain prolate mixing** for the dominantly oblate ground state but it does not improve the experiment-theory agreement.

Acknowledgements

Thanks to the IS370 collaboration:

J. A. Briz[1], M. J. G. Borge[1], O. Tengblad[1],
A. Algora[2], E. Nácher[1,2], B. Rubio[2], J.L. Taín[2]
S.Courtin[3], Ph. Dessagne[3], F. Maréchal[3], Ch. Miehé[3],
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[4] Universidad Complutense, E-28040 Madrid, Spain
[5] University of Surrey, Guildford, GU2 7XH, Surrey, UK
[6] ISOLDE, CERN, CH-1211 Geneva 23, Switzerland.